

RESEARCH STUDIES WITH THE  
INTERNATIONAL ULTRAVIOLET EXPLORER

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CONTRACT NAS5-28749

RELEASE BY  
PRIOR DATA

FINAL REPORT

prepared for  
Goddard Space Flight Center

prepared by  
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## PREFACE

This volume contains the Final Report for the International Ultraviolet Explorer (IUE) Research Studies contract NAS5-28749. The report summarizes the work performed over the time period June 19, 1985 through May 2, 1991.

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## SECTION 1 - SCOPE OF WORK

The IUE Research Studies contract NAS5-28749 comprises 118 separate research programs involving observations, data analysis, and research conducted with the Guest Observer program of the International Ultraviolet Explorer (IUE) satellite and the NASA Astrophysics Data Program (ADP). Included are 92 programs for which a CSC astronomer was the Principal Investigator (PI) and 26 programs for which a CSC astronomer was a Co-Investigator (Co-I).

The original contract period of 12 months, covering research programs from the seventh IUE observing episode, was extended through May 2, 1991 with a series of contract modifications to include research programs from the eighth through eleventh IUE episodes and the first and second years of the NASA Astrophysics Data Program (ADP, formerly SADAP).

The original contract stated that "the contractor shall provide the personnel, materials, and facilities necessary to obtain observational data on a variety of astronomical sources and to furnish the items specified" in the contract. Included in the original contract is a statement of work (SOW) for each program. Subsequent contract modifications included a SOW for each additional program.

For each research program there is a title, program ID, name of the investigator, statement of work, summary of results, and list of publications. In some cases, a publication contains data from more than one program, and is therefore listed under each applicable program. For those programs that are a continuation of an earlier study, the program ID is listed along with the ID for the original program, and the statement of work, summary of results, and list of publications is given only once.

## SECTION 2 - LIST OF PUBLICATIONS

This section lists all of the astronomical research publications published as a result of the work performed under this contract. The publications are listed alphabetically by author.

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Wu, C.-C., Crenshaw, D.M., Blackwell, J.H., Jr., Wilson-Diaz, D., Schiffer, F.H., III,

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- Wu, C.-C., Reichert, G.A., Ake, T.B., Boggess, A., Holm, A.V., Imhoff, C.L., Kondo, Y., Mead, J.M., and Shore, S.N., "IUE Ultraviolet Spectral Atlas of Selected Astronomical Objects", in press (1991).
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### SECTION 3 - SUMMARY OF RESULTS FOR INDIVIDUAL PROGRAMS

This section summarizes the results for the various individual research programs; each program is listed on a separate page. The program title, program identification (if applicable), investigator, specific Statement of Work, summary of scientific results, and titles of published papers are presented. The programs are arranged alphabetically by investigator. For each investigator, the programs are arranged chronologically.

**Title:** Giants and Supergiants with Hot Companions

**Program ID:** HCGTA     **PI:** T. B. Ake

**Statement of Work:**

IUE observations will be obtained for middle- and late-type giant and supergiant stars for which TD-1 and ANS flux data indicate the presence of hot companions. Ultraviolet spectra of the companions may be used to derive more accurate luminosities than previously for individual giant and supergiant stars. Evidence for enhanced mass loss for the secondaries or warm circumstellar gas, as seen in some systems of this kind, will be examined.

**Results:**

Seventeen middle- and late-type giant and supergiant stars whose TD-1 or ANS fluxes indicated the presence of a hot companion were observed. Some of the secondaries are seen weakly in optical spectra but could not be classified accurately, while others were UV discoveries. A total of 11 LW low-dispersion, 20 SW low-dispersion and 1 LW high-dispersion spectra were obtained. UV spectral types were assigned based on the IUE spectra. The IUE spectra were combined with optical broad-band photometry, and fits were made to the entire energy distribution of the systems using standard colors for the multiple components. Magnitude differences and reddenings were derived, which yielded more accurate luminosities for the giant and supergiant primaries.

**Publications:**

- Ake, T.B., "Composite Stars and Binaries: The Need for New Spectrophotometry", in *New Directions in Spectrophotometry*, eds. A.G.D. Philip et al. (Schenectady: L. Davis Press), 27 (1988).
- Parsons, S.B., and Ake, T.B., "Late-Type Supergiant Absolute Magnitudes from UV Binaries", *B.A.A.S.*, 19, 708 (1987).
- Ake, T.B., and Parsons, S.B., "HR 2554 - A Possible New Zeta Aur System", *I.B.V.S.*, No. 3002 (1987)
- Ake, T.B., Barksdale, W.S., Fried, R.E., Hopkins, J.L., Fekel, F.C., Jr., Hall, D.S., Landis, H.J., and Louth, H., "Discovery of an Atmospheric Eclipse of Tau Per", *I.B.V.S.*, No. 2847 (1986).

**Title:** The Interacting S Star Binary HD 35155

**Program ID:** IBGTA    **PI:** T. B. Ake

**Statement of Work:**

New IUE observations of HD 35155, the first S star known to have an interacting companion, will be obtained in order to distinguish between the possible models for the system. The few previous IUE spectra show ultraviolet variations of nearly a factor of 2 in the emission lines and continuum, suggesting that the secondary is either highly variable on a weekly time scale, with an outburst occurring in late 1982, or that an eclipse occurred early in 1983.

**Results:**

Further observations of HD 35155, the first S star known to have an interacting binary, were obtained. This system was discovered by the PI and collaborators during an earlier survey of chromospheric activity in S stars. The UV source is highly variable in the IUE region even though Eggen (*Ap.J.*, 177, 489) found it to be photometrically constant at optical wavelengths. Subtraction of the observed flux of a similar, single S star (HR 8714) from the ultraviolet spectrum yielded a curve of excess emission which was close to a simple  $f_{\lambda} \sim \lambda^{-1}$  power law instead of a blackbody curve, pointing to its probable production by a cloud radiated by a hot source. The integrated excess flux at minimum light amounts to a luminosity of  $0.2 L_{\odot}$  at the prescribed position of the source - far too much for a white dwarf - which confirms that the excess ultraviolet light originates in a source other than the photosphere of the companion. Measurement of the emission lines indicated that they are formed in different regions of the system, with permitted lines, such as C IV, coming from a rapidly rotating accretion disk and semi-forbidden lines, such as Si III] and C III], from a nebular cloud. Of particular interest is the absence of He II  $\lambda 1640$ , indicating the lack of a hot boundary layer of the disk. The Mg II lines have a blue cutoff indicating mass outflow. Several considerations place the hot gas in the matter thrown off by the S star. Consequences for the evolution of the S star are unclear, but there is a strong presumption that the chemical peculiarities of the red giant are due to mass transfer from a WD companion when the companion itself was an AGB star. Six other S stars were observed as part of a quick survey for other interacting systems. A total of 11 LW and 13 SW low-dispersion, and 3 LW and 1 SW high-dispersion spectra were taken as part of this program.

**Publications:**

Ake, T.B., Johnson, H.R., and Ameen, M.M., "An Interactive Companion to the S Star HD 35155", *Ap. J.*, in press (1991).

Johnson, H.R., Ake, T.B., Ameen, M.M., and Brown, J.A., "Continuing Search for Companions to PRG Stars", in *From Miras to Planetary Nebulae, Which Course for Stellar Evolution?* (Montpellier Conference, 4-7 Sept. 1989).

**Title:** Egress observations of Epsilon Aurigae

**Program ID:** VVGTA     **PI:** T. B. Ake

**Statement of Work:**

Further IUE observations of the unique stellar system Epsilon Aurigae will be made in order to address several issues. The timing and amplitude of the Cepheid variations, which are best observed outside of eclipse, will be defined to determine the shape of the ultraviolet eclipse light curve. This will yield information on the size and opacity of the occulting material. A UV brightening, akin to that which occurred just prior to first contact, will be searched for at fourth contact. High quality SWP exposures will be compared with available spectra at totality to determine the origin of the far-ultraviolet spectrum.

**Results:**

Epsilon Aurigae is a single-line spectroscopic binary which undergoes eclipse once every 27.1 years, the eclipse lasting nearly two years. The 1982-84 eclipse was followed with high and low-resolution IUE observations as well as with extensive optical and infrared photometry, spectrophotometry and spectroscopy. During the seventh IUE episode, fourth contact of the eclipse occurred. Twenty LW low-dispersion, 24 SW low-dispersion, and 18 LW high-dispersion spectra were obtained to address several issues. The timing and amplitude of the Cepheid variations, which were best observed outside of eclipse, were defined to determine the shape of the UV eclipse light curve. The UV brightening that occurred just prior to first contact was not seen on egress, nor was there evidence of the UV eclipse extending beyond the geometrical end of eclipse, which is usually seen in zeta Aurigae systems. High quality SWP exposures were obtained to compare the totality spectra and a model was produced to explain the observed flux excess below 1400 Å as arising from warmer gas at the primary star's poles.

**Publications:**

Kemp, J.C., Henson, Kraus, D.J., Beardsley, I.S., Carroll, L.C., Ake, T.B., Simon, T., and Collins, G.W., "Epsilon Aurigae: Polarization, Light Curves, and Geometry of the 1982-84 Eclipse", *Ap.J. (Letters)*, 300, L11 (1986).

Ake, T.B., "IUE Observations of the 1982-84 Eclipse of Epsilon Aurigae", *NASA SP-2384*, 37 (1985).

**Title:** Further Observations of S Stars

**Program ID:** OD73K    **PI:** T. B. Ake

**Statement of Work:**

IUE observations of the S star AA Cyg will be obtained. These will be used to examine the feasibility of studying the chromosphere and the effectiveness of molecular cooling in the outer atmosphere.

**Results:**

This program entailed one 438 min. LWP exposure of the S star AA Cyg. This observation was requested to demonstrate the feasibility of observing faint S stars of intermediate abundance type after the IUE eight episode peer review committee rejected the proposal to observe these objects based on feasibility concerns. The Mg II emission lines and a faint continuum were successfully detected, and the information was used to resubmit the proposal the following year.

**Publications:** None



**Title:** Winds in Supergiant Binaries

**Program ID:** SBITA    **PI:** T. B. Ake

**Statement of Work:**

A comparative study of wind structures and shock fronts in G-type binaries will be performed. IUE observations will be obtained of three short-period binary systems with B spectral type secondaries at various orbital positions. By using the hot stars as probes, the spatial distribution of the outer winds of the primaries and the shock waves that form in the supersonic flow passing the secondaries can be studied.

**Results:**

A comparative study of the wind structures and shock fronts in G-type supergiant binaries was made by observing several short period systems that had B-type secondaries. A total of 2 LW and 4 SW low-dispersion and 10 LW and 10 SW high-dispersion spectra were taken of five objects at various orbital positions. For the three primary systems,  $\mu$  Per, HR 2554 and 22 Vul, several differences were found. For  $\mu$  Per, the G0 Ib star has a moderate velocity wind that appears to be tightly concentrated to the star; HR 2554 (G6 II) has low velocity material surrounding the entire system; 22 Vul (G3 Ib-II) has a large, high velocity cloud in which both components are embedded. One of the systems, HR 2554, was also found to undergo partial eclipses.

**Publications:**

- Ake, T.B., "Composite Stars and Binaries: The Need for New Spectrophotometry", in *New Directions in Spectrophotometry*, eds. A.G.D. Philip et al (Schenectady: L. Davis Press), 27. (1988).
- Ake, T.B., and Parsons, S.B., "HR 2554 - A Possible New Zeta Aur System", *I.B.V.S.*, No. 3002 (1987).
- Ake, T.B., and Parsons, S.B., "The November 1987 Eclipse of the Zeta-Aur System HR 2554", in *A Decade of UV Astronomy with the IUE Satellite*, ed. E.J. Rolfe, ESA SP-281, 213 (1988).
- Parsons, S.B., and Ake, T.B., "Late-Type Supergiant Absolute Magnitudes from UV Binaries", *B.A.A.S.*, 19, 708 (1987).

Title: The Atmospheric Eclipsing Binary HR 2554

Program ID: CBJTA      PI: T. B. Ake

#### Statement of Work:

New IUE observations will be made of the binary Zeta Aur-like eclipsing system HR 2554. The ultraviolet data will be acquired at various times near eclipse to map out the extent and homogeneity of the absorbing material in the system. A ground-based campaign will also be organized to support IUE observations for the next eclipse.

#### Results:

HR 2554 (G6 II + A0 V) was the second zeta Aurigae system, after 22 Vul, discovered by the PI and collaborators using IUE. Eleven LW and 11 SW low-dispersion and 8 LW and 4 SW high-dispersion spectra were obtained around the time of and during the November 1987 eclipse of the system to map out the homogeneity of the extended atmosphere of the primary star. Observations indicated that the eclipse was not total and lasted about 4 days. Absorption lines from the outer atmosphere of the G star were seen a day before and after eclipse, but are missing two days from first and fourth contact. Thus the outer envelope of the primary extends to less than 1 stellar radius beyond the photosphere, a much smaller value than we found for 22 Vul. HR 2554 appears to be a more moderate case of mass flow, which implies there is reduced interaction of the secondary within the wind from the primary as is seen in other zeta-Aurigae systems.

#### Publications:

- Ake, T.B., "Composite Stars and Binaries: The Need for New Spectrophotometry", in *New Directions in Spectrophotometry*, eds. A.G.D. Philip et al (Schenectady: L. Davis Press), 27 (1988).
- Ake, T.B., and Parsons, S.B., "HR 2554 - A Possible New Zeta Aur System", *I.B.V.S.*, No. 3002 (1987).
- Ake, T.B., and Parsons, S.B., "The November 1987 Eclipse of the Zeta-Aur System HR 2554", Parsons, in *A Decade of UV Astronomy with the IUE Satellite*, ed. E.J. Rolfe, ESA SP-281, 213 (1988).
- Parsons, S.B., and Ake, T.B., "Late-Type Supergiant Absolute Magnitudes from UV Binaries", *B.A.A.S.*, 19, 708 (1987).

**Title:** Hot Companions to S and MS Stars

**Program ID:** HCJTA    **PI:** T. B. Ake

**Statement of Work:**

IUE observations will be obtained of a group of MS and S type stars. The data will be used to determine if their peculiar abundances are due to their binarity. The IUE spectra will be examined for evidence of white dwarf companions and mass transfer as indicated by the presence of high temperature ultraviolet emission lines.

**Results:**

Eight LW and 13 SW low-dispersion IUE spectra were obtained to search for white dwarf companions to 7 S and MS stars. S and MS stars are descendents of K and M giants which have been enriched in s-process and CNO elements. Generally they would be considered to lie above the asymptotic giant branch and would have begun the third dredge-up on their way to becoming carbon stars. The stars in this program, however, were considered on various grounds to be possible candidates of binary stars where the spectral peculiarity of the primary was due to mass transfer from the secondary star. A suspected companion was found for the spectroscopic binary HR 363 and ER Del was found to be a symbiotic-like system. Some M giants with incipient S-type characteristics were observed, but the presence of a degenerate companions was difficult to determine due to the level of chromospheric flux.

**Publications:**

Ake, T.B., Johnson, H.R., and Peery, B.F., Jr., "Companions to Peculiar Red Giants: HR 363 and HR 1105", in *A Decade of UV Astronomy with the IUE Satellite*, ed. E.J. Rolfe, ESA SP-281, 245 (1988).

Johnson, H.R., and Ake, T.B., "Discovery of a White Dwarf Companion to the MS Star 4o1 Ori", in *New Insights in Astrophysics: 8 Years of UV Observations with IUE*, ed. E.J. Rolfe, ESA SP-263, 395 (1986).

Johnson, H.R., and Ake, T.B., "ER Del: A True Symbiotic Star?", in *Evolution of Peculiar Red Giant Stars*, ed. H.R. Johnson and B. Zuckerman (Cambridge: Cambridge University Press), 371 (1989) .

Johnson, H.R., Ake, T.B., Ameen, M.M., and Brown, J.A., "A Continuing Search for Companions to PRG Stars", in *From Miras to Planetary Nebulae, Which Course for Stellar Evolution?* (Montpellier Conference, 4-7 Sept. 1989).

**Title:** Atmospheric Eclipsing Binaries: Tau Per

**Program ID:** EBKTA      **PI:** T. B. Ake

**Statement of Work:**

Follow-up observations of the binary system Tau Per will be performed. Ultraviolet observations at various times near eclipse will be used to map out the extent and homogeneity of the material surrounding the late-type giant and to investigate the wavelength dependent nature of the eclipse.

**Results:**

Follow-up observations were performed for the 4-year binary system tau Per (G5 III + A2 V), which was found to be another zeta-Aurigae like eclipsing system. This is the third such system discovered with IUE, after 22 Vul (G3 Ib-II + B9 V) and HR 2554 (G6 II + A0 V). Nine LW and 14 SW low-dispersion and 13 LW and 11 SW high-dispersion spectra were obtained around the January 1989 eclipse. In addition, extreme care was made to obtain accurate FES measurements of tau Per and nearby photometric check stars to tie the IUE observations with coordinated ground based optical observations. As with HR 2554, tau Per exhibits only a partial eclipse, and shows little atmospheric eclipse effects except at geometrical eclipse phases. Determination of a UV light curve has been hampered by the lack of an adequate LWP high-dispersion calibration after new ITFs were used in processing the data. Engineering telemetry, including gyro and FES data, was requested to examine the effects of spacecraft jitter on the FES measures and to refine the FES light curve. The FES light curve after mid-eclipse but before last contact shows variations not seen on the other side, consistent with optical observations.

**Publications:**

Ake, T.B., "Composite Stars and Binaries: The Need for New Spectrophotometry", in *New Directions in Spectrophotometry*, eds. A.G.D. Philip et al (Schenectady: L. Davis Press), 27 (1988).

Parsons, S.B., and Ake, T.B., "Late-Type Supergiant Absolute Magnitudes from UV Binaries" *B.A.A.S.*, 19, 708 (1987).

**Title:** WD Companions to Tc-Deficient Peculiar Red Giants

**Program ID:** HCKTA     **PI:** T. B. Ake

**Statement of Work:**

Ultraviolet spectra of a number of peculiar red giants possessing no technetium will be obtained to determine if they have white dwarf companions. This information will be used to determine which of these stars owe their peculiar abundances to their binarity.

**Results:**

Two LW and six SW low-dispersion IUE spectra were obtained to search for white dwarf companions to six Peculiar Red Giants (PRGs). The PRGs include the S, MS and C stars and are descendents of K and M giants which have been enriched in s-process and CNO elements. Generally they would be considered to lie above the asymptotic giant branch and would have begun the third dredge-up of processed material. One subgroup of these, the objects possessing no technetium, appear to be more closely related to Ba II stars than to K-M giants and may have been mass-transfer binaries in the past. Six such objects were observed to locate the highly evolved, degenerate companion that should remain. The two carbon stars observed did not have companions; two MS stars did not have companions, but later optical work by others concluded that these did not display abnormal abundances and thus were normal M giants; the two S stars observed had WD companions. It appears that the Tc-deficient S and MS stars are binary and owe their peculiarity to the time period when the current degenerate companions were themselves PRG stars.

**Publications:**

- Ake, T.B., and Johnson, H.R., "A White Dwarf Companion to the MS Star 4o1 Ori and the Binary Hypothesis for the Origin of Peculiar Red Giants", *Ap.J.*, 327, 214 (1988).
- Ake, T.B., Johnson, H.R., and Peery, B.F., Jr., "Companions to Peculiar Red Giants: HR 363 and HR 1105", in *A Decade of UV Astronomy with the IUE Satellite*, ed. E.J. Rolfe, ESA SP-281, 245 (1988).
- Johnson, H.R., and Ake, T.B., "ER Del: A True Symbiotic Star?", in *Evolution of Peculiar Red Giant Stars*, ed. H.R. Johnson and B. Zuckerman (Cambridge: Cambridge University Press), 371 (1989).
- Johnson, H.R., Ake, T.B., Ameen, M.M., and Brown, J.A., "A Continuing Search for Companions to PRG Stars", in *From Miras to Planetary Nebulae, Which Course for Stellar Evolution?* (Montpellier Conference, 4-7 Sept. 1989).

**Title:** Observations of Broad-Line Radio Galaxies

**Program ID:** RGIDC      **PI:** D. M. Crenshaw

**Statement of Work:**

Simultaneous ultraviolet and optical observations of five broad-line radio galaxies will be obtained. Methods developed for studies of optical line profiles will be used to deconvolve the two components of the Lyman-alpha profiles for five broad-line radio galaxies. The results for these galaxies will be compared to those obtained for Seyfert I galaxies and narrow-line radio galaxies.

**Results:**

Near-simultaneous ultraviolet and optical spectra of three broad-line radio galaxies (3C 382, 3C 445, and PKS 2349-014) have been obtained, and the emission lines of  $L\alpha$ ,  $H\beta$ , and  $H\alpha$  have been deconvolved into narrow and broad components. Although the broad  $L\alpha/H\beta$  ratios in these objects cover a large range (1.2 - 22.3), there is no evidence that these ratios are intrinsically different from those of Seyfert 1 galaxies or quasars. Thus, in general, the higher  $H\alpha/H\beta$  ratios in these broad-line radio galaxies cannot entirely be due to additional reddening of the broad-line region. However in the specific case of 3C 445, there is evidence that the nonstellar continuum and broad-line region are highly reddened.

**Publications:**

Crenshaw, D.M., Peterson, B.M., and Wagner, R.M., "Ultraviolet and Optical Spectra of Broad-Line Radio Galaxies", *A.J.*, 96, 1208 (1988).

**Title:** Narrow-Line Seyfert 1 Galaxies

**Program ID:** SYJDC    **PI:** D. M. Crenshaw

**Statement of Work:**

Ultraviolet and optical spectra, will be obtained of narrow-line Seyfert 1 galaxies. The relative line intensities of the weak emission lines in the narrow-line Seyfert 1 galaxies will be used to (1) estimate the reddening of the broad-line region, (2) investigate the origin of the broad emission feature at 1909 Å, (3) estimate the C:N:O abundances, and (4) identify and measure as many weak emission lines as possible.

**Results:**

Test exposures of three high-ionization Seyfert galaxies with narrow emission lines were obtained. These Seyfert galaxies have most of the properties of Seyfert 1 galaxies (high-ionization lines, strong nonstellar continua), but have permitted lines that are relatively narrow, like Seyfert 2 galaxies. Although the test exposures, which were only two hours or less in duration, resulted in low signal-to-noise spectra, they were useful in calculating the correct exposure times (12 to 14 hours each) for targets in the program AGKDC.

**Publications:** None

**Title:** Narrow-line Seyfert Galaxies

**Program ID:** AGKDC     **PI:** D. M. Crenshaw

**Statement of Work:**

Simultaneous ultraviolet and optical spectra of three Seyfert galaxies that resemble normal Seyfert 1 galaxies, except for their unusually narrow lines, will be obtained. The spectra will be used to study weak features that are blended together in normal Seyfert 1 galaxies.

**Results:**

Ultraviolet and optical spectra are presented for three unusual Seyfert galaxies (Mrk 1239, Mrk 42, and Mrk 493) that resemble Seyfert 1 galaxies in that they have strong high-ionization lines and strong nonstellar continua, but resemble Seyfert 2 galaxies in that the widths of their permitted lines are as narrow as the widths of their forbidden lines. The He II  $\lambda 1640$  and He II  $\lambda 4686$  lines are used to determine an upper limit to the reddening experienced by the emission lines. Published optical data show that these particular high-ionization narrow-line (HINL) Seyferts have low  $[\text{O III}]\lambda 5007/\text{H}\beta$  ratios and strong Fe II emission, which suggest the presence of high-density regions. The low  $L\alpha/\text{H}\beta$  ratios in these objects indicate that high-density clouds are indeed present, and, like the broad-line region clouds in Seyfert 1 galaxies, these clouds have large optical depths with partially-ionized zones. Overall, the line ratios and continuum fluxes of these particular HINL Seyferts are indistinguishable from those of broad-lined Seyfert 1 galaxies.

**Publications:**

Crenshaw, D.M., Peterson, B.M., Korista, K.T., Aufdenburg, J.P., Wagner, R.M., "Ultraviolet and Optical Spectra of High-Ionization Seyfert Galaxies with Narrow Lines", *A.J.*, 101, in press (1991).



**Title:** Frequency of Multiple Systems Among Cepheid Binaries

**Program ID:** CBGNE     **PI:** N. R. Evans

**Statement of Work:**

A sample of binary Cepheids will be tested for multiplicity by searching for short-period radial velocity variations of their hot companions. With this sample, the fraction of binaries which are multiple will be determined. In addition, a lower limit to the mass ratio of the Cepheid to the spectroscopic binary will be derived, yielding basic data about the fragmentation process.

**Results:**

Velocities from IUE high-dispersion spectra of binary Cepheids have been measured. The low-dispersion spectrum of S Sge has been analyzed and an A7V-FOV companion has been detected. This result, combined with the mass function from the ground-based orbit, shows that the companion must itself be a close binary.

**Publications:**

Slovak, M. H., Barnes, T. G. III, Evans, N.R., Welch, D. L., and Moffett, T. J., "The Orbit and Companion of the Binary Cepheid S Sge", *A.J.*, in press (1991).

**Title:** Mass of the High Luminosity Cepheid T Monocerotis

**Program ID:** DCGNE    **PI:** N. R. Evans

**Statement of Work:**

IUE observations will be used to determine whether the companion of the Cepheid T Mon is itself a binary. For this purpose two suitably spaced high dispersion spectra of T Mon will be obtained in order to search for velocity variations of the companion. These spectra will be used to analyze the possible combinations of masses for the Cepheid and its companion.

**Results:**

IUE high and low dispersion spectra and ground-based velocities have been obtained. Density sensitive emission lines, which have not previously been detected in Cepheids, have been detected in T. Mon. Techniques and software for analyzing this Cepheid and (probably) giant companion have been developed for more normal systems, and can now be applied to this system with a more unusual evolved companion.

**Publications:**

Evans, N. R. "Fixed Pattern Noise in High-Dispersion Spectra", *NASA IUE Newsletter*, **34**, 84 (1988).

**Title:** New Calibrators for the Cepheid Period-Luminosity Relation

**Program ID:** PLHNE      **PI:** N. R. Evans

**Statement of Work:**

IUE LWP and SWP spectra will be used to derive the parameters needed to obtain an absolute magnitude for a Cepheid from the absolute magnitude of the blue companion. These are the magnitude difference between the two stars, the temperature of the companion, the luminosity of the companion, and the reddening of the system.

**Results:**

IUE low-dispersion spectra of known Cepheid binary stars have been obtained. From the short wavelength spectra, the spectral type of the companions can be obtained, and hence, an absolute magnitude for the companion can be inferred. The luminosity of the Cepheid can either be obtained directly from the SWP spectrum of the companion, or by matching the long and short wavelength spectra to comparable spectra of standard stars to obtain the magnitude difference between them. In some cases, additional information is also obtained. The companion of AW Per is probably a magnetic chemically peculiar star, and is also likely to be a member of a short period binary itself. A companion of spectral type approximately F V has been detected for FF Agl. The luminosity determined from the companion of SV Cas requires Cepheid pulsation in the first overtone mode. This makes SV Cas the only Cepheid with independent luminosity confirmation that it is pulsating in a mode other than the fundamental.

**Publications:**

- Evans, N. R., "The Binary Companion of the Classical Cepheid AW Per", *A.J.*, **97**, 1737 (1987).
- Evans, N. R., "The Orbit and Colors of the Cepheid 3 Mus", *P.A.S.P.*, in press (1991).
- Evans, N. R., Welch, D. L., and Scarfe, C. D., "Orbit and Companions of the Classical Cepheid FF Agl", *J.R.A.S.C.*, **83**, 309 (1989).
- Evans, N. R. and Arellano-Ferro, A., "The Luminosity of the Binary Cepheids SU Cyg, SU Cas, and W Sgr", *Rev. Mexicana Astron. Astrof.*, **14**, 435 (1987)

**Title:** The Reddening and Temperature Scales for Cepheids

**Program ID:** DCHNE     **PI:** N. R. Evans

**Statement of Work:**

Low-dispersion LWP spectra of a number of Cepheids with both high and low reddenings, and both long and short periods, will be carefully compared with nonvariable supergiants and Kurucz models. This comparison will be made over a 20,000 Å baseline, using recent B, V, R, I and J, H, K photometry and IUE fluxes for extensive coverage of the energy distribution. Improved reddening and temperature scales will be derived.

**Results:**

Spectra have been obtained of cluster Cepheids, field Cepheids with high and low reddening, and as hot and cool phases, and nonvariable supergiants. Comparisons are made with Kurucz atmospheres. Differences between Cepheids and nonvariable supergiants in the ultraviolet have been identified.

**Publications:**

Evans, N. R., Welch, D. L., Scarfe, C. D., and Teays, T. J. "The Orbit and Companions of the Classical Cepheid FF Agl", *A.J.*, in press (1991).

**Title:** Long Period and Overtone Cepheids

**Program ID:** DCINE      **PI:** N. R. Evans

**Statement of Work:**

IUE spectra of an 18-day Cepheid, YZ Car, and a double mode Cepheid, Y Car, will be obtained to search for companions of these binary Cepheids. Absolute magnitudes for the main sequence companions will be determined from their temperatures, and hence the distances of the Cepheids can be calibrated.

**Results:**

IUE low-dispersion observations of a double-mode Cepheid have demonstrated that it has a hot companion. Analysis is as discussed in PLHNE and CBBINE.

**Publications:** None

**Title:** The Mass of the Classical Cepheid SU Cygni

**Program ID:** CCINE    **PI:** N. R. Evans

**Statement of Work:**

IUE high-dispersion spectra will be obtained at the velocity extrema of SU Cygni's orbit. These spectra will be searched for the velocity signal from the third star in the system, a hot blue star. The velocity of the third star, if it can be determined, will be used to set the relative masses of the three stars so that the Cepheid mass can be more accurately estimated.

**Results:**

IUE long and short wavelength high-dispersion spectra have been measured to determine the velocity of the hot companion of the classical Cepheid SU Cyg as well as the velocity amplitude of the companion system in the long period orbit have been derived. The lower limit to the Cepheid is  $5.9 \pm 0.4$  solar masses. This is in good agreement with the evolutionary mass for the Cepheid, and places constraints on convective overshoot in evolutionary phases near the main sequence.

**Publications:**

Evans, N.R. and Bolton, C. T., "The Mass of the Classical Cepheid SU Cygni", *Ap.J.*, in press (1991).

Evans, N. R., Bohm-Vitense, E., and Bolton, C. T., "Ultraviolet Observations of the System Containing the Cepheid SU Cygni", *B.A.A.S.*, 17, 559 (1985).

Evans, N. R. and Bolton, C. T., "The Mass of the Classical Cepheid SU Cygni", in *Eight Years of UV Astronomy with IUE*, ESA SP-263, 405 (1986).

**Title:** Cepheid Binarity and Star Formation

**Program ID:** CBINE    **PI:** N. R. Evans

**Statement of Work:**

IUE spectra of the fifty brightest classical Cepheids in our galaxy will be used to search for blue companions. Statistics on the percentage of Cepheid binaries with companions more massive than two solar masses will be derived, based on the results. Improved calibrations of temperature, reddening, and luminosity will be determined, where possible.

**Results:**

A magnitude limited survey of Cepheids has been carried out with IUE. Detection of hot main sequence companions results from the comparison of long wavelength spectra with nonvariable supergiants. Several new binary companions have been found, which are potential luminosity calibrators. Approximately 20% of Cepheids which have hot companions. In addition, it has been possible to determine mass ratios from spectra types for  $M(1)/M(2)$  larger than three. This is a powerful tool in studying binary systems.

**Publications:**

Evans, N. R., "A Search for the Binary Companion Of Polaris", *P.A.S.P.*, **100**, 724 (1988).

Evans, N. R., "Cepheid Binaries with Large Mass Ratios", *J.R.A.S.C.*, **82**, 281 (1988).

Evans, N. R. and Udalskam J., "Search for Binary Companions of Cepheids Using IUE", *J.R.A.S.C.*, **83**, 308 (1989).

Evans, N. R., Szabados, L., and Udalska, J., "Cepheid Companions? FM Agl, FN Agl, RX Aur, Y Lac, and RS Ori", *J.R.A.S.C.*, **83**, 308 (1989).

Evans, N. R., Szabados, L., and Udalska, J., "Cepheid Companions? FM Agl, FN Agl, RX Aur, Y Lac, and RS Ori", *P.A.S.P.*, in press (1990).

Evans, N. R., "Cepheid Binaries with Large Mass Ratios  $M(1)/M(2)$ ", in *A Decade of UV Astronomy with the IUE Satellite*, ESA SP-281, Vol. 1, 237 (1988).

**Title:** Fluxes, Temperatures, and Radii of Stars Defining the ZAMS

**Program ID:** MSINE      **PI:** N. R. Evans

**Statement of Work:**

Ultraviolet flux distributions for Pleiades stars in the A and B spectral range will be obtained using IUE spectra. With these ultraviolet data and available visual observations, improved individual bolometric corrections may be derived. This is possible since the ultraviolet and visual data cover the wavelength range where most the flux is radiated.

**Results:**

IUE observations of stars defining the ZAMS in the Pleiades, the Alpha Per cluster, and NGC 2244 have been reduced. Preliminary discussions of the ultraviolet observations of ZAMS stars has been included in work for PLHNE.

**Publications:** None



**Title:** Ultraviolet Continua of B and Be Stars

**Program ID:** HSGCG    **PI:** C. A. Grady

**Statement of Work:**

IUE observations will be used to provide low-dispersion far-ultraviolet continuum flux distributions for a group of rapidly rotating, lightly reddened B and Be stars in the Sco-Cen association. This data set will be used to study any systematic differences between rotating B and Be stars at similar  $v \sin i$  and spectral type. The data will be compared against model flux distributions for rapidly rotating B stars.

**Results:**

IUE observations were obtained to provide low-dispersion far-ultraviolet continuum flux distributions for a group of rapidly rotating, lightly reddened B and Be stars in the Sco-Cen association as a probe of systematic differences between rotating B and Be stars at similar  $v \sin i$  and spectral type. The program stars were chosen to lie in the Gould belt and to have interstellar extinction  $E(B-V) < 0.03$  magnitudes, so that any interstellar contribution to the UV selective extinction could be neglected. No evidence for systematic differences in the UV flux distributions between the B and Be stars was found, ruling out critical rotation in the Be stars or the presence of UV selective extinction in these stars.

**Publications:** None

**Title:** Circumstellar Shells in B and Be Stars

**Program ID:** CMGTS      **Co-I:** C. A. Grady

**Statement of Work:**

Existing IUE high-resolution far-ultraviolet spectra of B and Be stars will be used to obtain column densities for circumstellar shell material around these stars. Any correlation between shell strength and stellar parameters will be explored from this large sample of stars. The relation between the shell features and the Be phenomenon will be examined.

**Results:**

Analysis of more than 800 IUE high-dispersion spectra of 100 bright Be stars and 45 comparison B stars has shown that detections of cool circumstellar plasma, as inferred from the density-sensitive (electron density  $>1,000 \text{ cm}^{-3}$ ) excited state transition of Si II multiplet UV 2 at  $1533.4 \text{ \AA}$ , tend to be more common in the cooler Be stars. When circumstellar shell absorption is seen in the B0.5-B5e stars, the wind absorption tends to be weaker than is typical of Be stars at that spectral type and luminosity class. Most of the wind absorption tends to be concentrated to low velocities (outflow) and emission is sometimes observed at the line center or longward of line center. Emission in the UV resonance lines of N V, C IV, or Si IV is not typical of the majority of Be stars.

Grady and collaborators found that 36 percent of their sample of lightly veiled B6-B9.5e stars showed shell features. With the exception of one star (HD 23630), shell features were observed in this sample only for stars with  $v \sin i > 200 \text{ km s}^{-1}$ , which is consistent with a similar threshold observed for the presence of hot plasma. The strength of the Si II absorption is not correlated with the strength of the C IV absorption. Inspection of the archival spectra of omicron And, which has been monitored by IUE during and since a strong shell episode, showed weaker C IV absorption during the period of heavy line blanketing. Similar results have been noted by Doazan and collaborators (private communication) for Pleione. These suggest that the effect noted by Grady, Bjorkman, and Snow (1987) extend to later spectral types.

**Publications:**

Grady, C.A., Bjorkman, K.S., and Snow, T.P. 1987, "Highly Ionized Stellar Winds in Be Stars: The Evidence for Aspect Dependence", *Ap.J.*, **320**, 376 (1987).

Grady, C.A., Bjorkman, K.S., and Snow, T.P., Sonneborn, G., Shore, S.N., and Barker, P.K., 1989, "Highly Ionized Stellar Winds in Be Stars: II. Winds in B6-B9.5e Stars", *Ap.J.* **339**, 403 (1989).

**Title:** Late-Type Be Stellar Winds

**Program ID:** DEHCG     **PI:** C. A. Grady

**Statement of Work:**

Bright late-type Be stars will be studied using available archival spectra and supplemented by IUE SWP and LWP high-dispersion spectra as required to reasonably sample Be stars from B5 to B9.5 and 0-350 km s<sup>-1</sup> in  $v \sin i$ . These data will be used to (1) further study the frequency and distribution in radial velocity of narrow absorption components as a function of projected rotational velocity and spectral type, (2) compare B and Be stellar wind profiles, mass loss rates, and wind ionization balances as a function of  $v \sin i$  and spectral  $T_{\text{eff}}$ , (3) compare B and Be star photospheric line profiles as a function of  $v \sin i$  at each spectral type, and where possible, (4) study Be star wind properties as a function of metallicity.

**Results:**

In this program the stellar winds in 40 B6-B9.5e stars covering luminosity classes V-III were studied in an extension of the B0.5-B5e survey (Grady, Bjorkman, and Snow 1987). An extension of the  $v \sin i$  threshold was found for the detection of C IV, with C IV detected only in luminosity class V stars with  $v \sin i > 200 \text{ km s}^{-1}$ , and in luminosity class IV-III stars if  $v \sin i > 140 \text{ km s}^{-1}$ . Comparison of the UV data with published infrared color excesses, optical polarization data, and optical line profile atlases shows that these datasets have similar thresholds in the vicinity of 150-200 km s<sup>-1</sup>, indicating that the Be phenomenon in B6-B9.5e stars is similar to that observed in hotter and more luminous stars. The C IV absorption in 9 of the program stars is produced in one or more shortward-shifted narrow absorption components, similar to those seen in B0.5-B5e stars. Three of the program stars show unambiguous variability in C IV in the course of IUE monitoring, suggesting that the highly ionized material is produced in a stellar wind.

**Publications:**

Grady, C.A., Bjorkman, K.S., and Snow, T.P., Sonneborn, G., Shore, S.N., and Barker, P.K., "Highly Ionized Stellar Winds in Be Stars: II. Winds in B6-B9.5e Stars", *Ap.J.*, **339**, 403 (1989).

Title: Survey of Stellar Winds in Be Stars

Program ID: HSICG     PI: C. A. Grady

### Statement of Work:

An examination of stellar winds in B and Be stars will be pursued using highdispersion IUE spectra. Spectra of 22 Be stars not previously examined will be used to-examine the correlation of Be wind properties and projected rotational velocity.

### Results:

Data from this program was used to supplement archival observations of B0.5-B5e stars. A total of 62 Be and 43 normal B stars covering spectral types B0.5-B5e and luminosity classes V-III, accounting for approximately 600 IUE high-dispersion spectra were evaluated for the presence and nature of any absorption in the resonance lines, primarily those of C IV, which would indicate the presence of a strong, highly-ionized stellar wind. It was found that wind absorption in the Be stars is frequently due to blended absorption from multiple shortward-shifted discrete absorption components, which were detected in 65 components are visible only in the stars with higher values of  $v \sin i$ , the projected rotational velocity. Discrete absorption components were observed only if  $v \sin i > 150 \text{ km s}^{-1}$ . Comparison of the C IV data with published infrared excesses, continuum polarization data, and optical line profile atlases shows that these datasets have similar thresholds in the vicinity of  $v \sin i = 150 \text{ km s}^{-1}$ . The recent discovery that many, if not all, Be stars appear to be non-radial pulsators with characteristic pulsation modes, and the observation that the pulsational characteristics of these stars change at  $v \sin i = 150 \text{ km s}^{-1}$  suggests that non-radial pulsation may be important in generating the Be phenomenon.

### Publications:

Grady, C.A., Bjorkman, K.S., and Snow, T.P., "Highly Ionized Stellar Winds in Be Stars: The Evidence for Aspect Dependence", *Ap.J.*, **320**, 376 (1987).

Title: Strong Wind Episodes and Non-Radial Pulsation Changes in Be Stars

Program ID: PRJCG, PRKCG      PI: C. A. Grady

#### Statement of Work:

An IUE synoptic observing program will be conducted to study the long term wind changes in Be stars. The IUE observations will be coordinated with a program of optical non-radial pulsation monitoring, optical photometry, spectrophotometry and polarimetry as well as Voyager far-UV monitoring of selected stars. IUE observations will be obtained for the second year of a two-year monitoring program. Be stars will be observed monthly to test the hypothesis that the Be phenomenon, including the highly-ionized winds, are caused by a combination of rapid rotation and pulsation.

#### Results:

On the basis of the suggestion that non-radial pulsational activity might be responsible for episodic enhancements of highly ionized stellar winds in Be stars, a group of 12 Be stars were monitored for 2 years. One of the program stars, HD 58978, shows recurrent shell episodes, together with complex variability in the resonance line profiles of N V, C IV, Si IV, Si III, Al III, and C II. While the spectrum of this star resembles those of known Be-binary systems, no convincing periodicity has been observed in the IUE data. Previous UV studies of Be Stars have demonstrated that variation in the strength of the stellar wind absorption is characteristic of high  $v \sin i$  Be stars. The mechanism responsible for the variation is not understood. Some proposed mechanisms are temperature or luminosity changes, potentially associated with non-radial pulsations, which would cause the UV continuum fluxes in these stars to vary. UV continuum flux data obtained simultaneously with observations of the wind can be used to determine whether variability in the wind is correlated with continuum light changes. The IUE high-dispersion spectra are potentially one dataset which can be used to search for such correlations. Full utilization of the IUE data requires correction for the slow loss of sensitivity of the IUE SWP camera as a function of time. Such a correction was derived from IUE standard star spectra and applied to three Be stars: Lambda Eri, HD 58978, and Pi Aqr. Lambda Eri exhibits pronounced continuum light variations on a 16 hour interval which have been clearly linked to non-radial pulsation activity. No correlation of wind state with the short-term continuum light variations is observed. This star also exhibits a, currently unexplained, long-term decrease in continuum light beginning in 1986, which is uncorrelated with strong wind episodes.

#### Publications:

- Grady, C.A., et al. 1988 "Recurrent Shell Infall Events in a B0.5e Star: HD 58978 1979-1988", in *A Decade of UV Astronomy with the IUE Satellite*, ESA SP-281, Vol. 1, 257.
- Silvis, J.M.S. and Grady, C.A. 1990, "Long Term UV Continuum Light Variations in Two Be Stars: Lambda Eri and HD 58978", *B.A.A.S.*, 22, 1202.

**Title:** Protoplanetary Disks and Circumstellar Shells in A Stars

**Program ID:** CMKCG     **PI:** C. A. Grady

**Statement of Work:**

IUE high-dispersion spectra of A shell stars will be obtained to determine whether the inner portions of the circumstellar disks or shells in these objects are depleted in refractory elements such as Fe with respect to cosmic abundances, and to establish column densities, temperatures, and ionization characteristics of the inner portions of the circumstellar material. IUE low-dispersion spectra will be used to confirm the optical spectral types, and to measure the selective extinction in the line of sight through the circumstellar envelope.

**Results:**

Bruhweiler, Grady, and Chiu (1989) have surveyed 40 ostensibly normal late-type B and early-type A stars for the presence of C IV, Si IV, and signatures of cool circumstellar plasma. Four of the 40 stars showed sharp absorption cores in Si II 1533.4 Å. The Si II features in two of these stars were variable, providing evidence for an unambiguously circumstellar origin for these features. All of the objects with high density cool plasma also showed C IV absorption in at least one spectrum, suggesting that they are previously unidentified Be/Ae shell stars.

**Publications:**

- Bruhweiler, F.C., Grady, C.A., and Chiu, W.A., "Highly Ionized Species and Circumstellar Shells in B8-A1 Stars", *Ap.J.* 340, 1038 (1989).
- Chiu, W.A., Bruhweiler, F.C., and Grady, C.A. 1988, "C IV and Si IV in IUE Spectra of Normal B8-A0 Stars: UV Identified Be/Ae Stars?", in *A Decade of UV Astronomy with the IUE Satellite*, ESA SP-281, Vol. 1, 397 (1988).
- Cheng, K.-P., Grady, C.A., Bruhweiler, F.C., and Kondo, Y., "The Search for Beta Pictoris Analogs", in *Evolution in Astrophysics: IUE Astronomy in the Era of New Space Missions*, Y. Kondo, and W. Wamsteker editors, ESA SP-310, 227 (1990).
- Grady, C.A., Bruhweiler, F.C., K.-P. Cheng, Chiu, W.A., and Kondo, Y., "The Circumstellar Disks of Beta Pictoris Analogs", *Ap.J.* 367, 296 (1991).

**Title:** The Dwarf Nova SS Cygni

**Program ID:** CVGRP      **Co-I:** A. V. Holm

**Statement of Work:**

When possible, simultaneous IUE and Voyager observations of SS Cygni will be obtained during one or more outbursts. The combined data will help provide the most complete spectral coverage to date of a dwarf nova in outburst. This information will be used to form flux distribution sequences and to explore the evolution of the accretion disk from the initial stages of the outburst, through maximum, to quiescence. Existing models for accretion disks will be employed in the analysis.

**Results:**

IUE spectra of the dwarf nova SS Cygni were obtained during the summer and fall of 1984 as required for the program. Thanks to cooperation from the AAVSO and to the rapid response from IUE operations, it was possible to observe the very early phases of several outbursts of SS Cygni. Other observations were at the peak of the outburst, during the decline back to quiescence, and at quiescence. In all, four outbursts were observed.

Preliminary reports of the observations were presented at the 165th meeting of the AAS in Tucson, Arizona. Two interesting aspects of the behavior of SS Cygni were discussed at that time. First, the observations of the early phases of outburst showed that the ultraviolet outburst lagged behind the visual outburst by approximately half a day. During the decline to quiescence, however, there were no major changes in the visual-to-ultraviolet slope. Second, the strength of the emission lines measured during quiescence appeared to have decreased steadily from the time of the earliest IUE observations in 1978 until 1984. There was no corresponding change in the continuum flux.

**Publications:**

- Polidan, R.S., Holberg, J.B., Holm, A.V., and Carone, T.E. "The Evolution of the UV Line Spectrum in the Dwarf Nova SS Cyg Through Outburst", *B.A.A.S.* 16, 884 (1984).
- Polidan, R.S., Holberg, J.B., Holm, A.V., Mattei, J.A., and Carone, T.E. "Simultaneous Voyager, IUE, and Ground Based Observations of SS Cyg", *B.A.A.S.*, 16, 898 (1984).
- Holm, A.V., and Polidan, R.S., "SS Cygni in Quiescence", in *A Decade of UV Astronomy with the IUE Satellite*, ESA SP-281, Vol. 1, 179 (1988).

**Title:** Simultaneous IUE and Voyager Observations of the Dwarf Nova Z Camelopardis

**Program ID:** CVHRP      **Co-I:** A. V. Holm

**Statement of Work:**

IUE low-resolution spectra of the dwarf nova Z Cam will be obtained simultaneously with Voyager observations. The combined data will be used to form composite 500 to 3200 Å flux distribution sequences to explore the evolution of the disk from the initial stages of an outburst, through maximum, to quiescence .

**Results:**

IUE spectra of the dwarf nova Z Cam were obtained during 5 occasions during an outburst in the fall of 1985 and once during quiescence in the spring of 1986, as required for the program. Many of these observations were affected adversely by high particle radiation levels. In addition, analysis of the low-dispersion IUE spectra of SS Cygni was conducted to search for the spectral signature of the white dwarf primary. Archival spectra of WZ Sge, another dwarf nova system, also were analyzed for the same purpose. In both cases, features indicative of a white dwarf were found and interpreted, but in neither case could the features be claimed to prove uniquely that the white dwarf had been found. Research papers describing this work were presented at the IUE Tenth Year Symposium.

**Publications:**

Holm, A.V., "Searching for the White Dwarf in WZ Sagittae", in *A Decade of UV Astronomy with the IUE Satellite*, ESA SP-281, Vol. 1, 229 (1988).

Holm, A.V., and Polidan, R.S., "SS Cygni in Quiescence", in *A Decade of UV Astronomy with the IUE Satellite*, ESA SP-281, Vol. 1, 179 (1988).



**Title:** The Strength of Ultraviolet Spectral Features

**Program ID:** STHAH      **Co-I:** A. V. Holm

**Statement of Work:**

The variation of the strength of spectral features with spectral classification will be studied using the uniform set of low-resolution spectra collected in the IUE ultraviolet spectral atlas and using selected echelle spectra of the same sources. This study will be used to place ultraviolet spectral classification on a quantitative basis, and to provide a data base for comparison with hot stars having luminous red companions, for comparison with unusual and variable stars, for use in determining ultraviolet extinction curves, and for use in population synthesis studies.

**Results:**

Software for correcting SWP low-dispersion spectra for the change in sensitivity reported by Bohlin and Grillmair (*NASA IUE Newsletter*, 33, 28) was installed and debugged. Archival data used for the IUE Spectral Atlas (Wu et al., *NASA IUE Newsletter*, 22, 1) was obtained and re-reduced to provide spectral files for analysis. The re-reduction included screening out defective spectra, correcting for changes in instrumental sensitivity, applying calibration curves, and merging multiple observations of individual stars into a single spectrum. Seventeen features for which spectral indices might be meaningful were selected and software was written to generate those indices from the database of spectra. Further analysis to refine the bandpasses for the extraction and to categorize the effects of changes of the indices with spectra class and with luminosity type is needed.

**Publications:** None

**Title:** Emission Line Spectrum of R CrB Variables

**Program ID:** RCIAH    **PI:** A. V. Holm

**Statement of Work:**

The emission-line spectrum of R CrB will be studied during minimum. Low-dispersion IUE spectra will be obtained when the star is faint, so that the emission from the stellar atmosphere is not obscured by the surrounding gas shell. The emission-line spectrum may then be removed from previous continuum observations in order to derive a more accurate extinction curve. The emission lines will be used to obtain a better understanding of the conditions in the extended stellar atmosphere.

**Results:**

Software for correcting low-dispersion spectra for grating-scattered light (Basri, *NASA IUE Newsletter*, 28, 58) was implemented. Software for removal of the geocoronal component of Lyman-alpha from the line-by-line file of low-dispersion spectra as described by Ponz at a 1981 Three-Agency meeting also was implemented. It was found that the Ponz model of Lyman-alpha does not fit the modern spectral extraction methods; development of Lyman-alpha models to match line-by-line files having higher spatial and wavelength resolution than available to Ponz was started but has not yet been completed. All existing high-dispersion spectra of R CrB at maximum were co-added to search for possible emission lines of C III at 1909 angstroms and C II at 2325 angstroms. It was determined that the noise in the data overwhelms any flux from these lines.

**Publications:** None

**Title:** Helium Pulsational Variables

**Program ID:** RCKAH    **PI:** A. V. Holm

**Statement of Work:**

IUE spectra of the hydrogen-deficient carbon stars R CrB and RY Sgr will be used to determine how the process of dust formation is related to the amplitude and timescale of the photospheric variations of these Stars.

**Results:**

Synoptic observations of R CrB were carried out on over a 60-day interval. The project was intended to measure the pulsational characteristics during a normal low-amplitude pulsation to contrast with the large-amplitude pulsation observed by Holm and Doherty (*Ap.J.*, 328, 726). This goal could not be achieved because the star began a major decline during the IUE run, falling to visual magnitude 11.2 by the last shift. Three LWP echelle spectra were obtained during the observing run. These data confirmed the dramatic spectral changes at the start of an R CrB minimum reported by Holm et al. (*P.A.S.P.* 99, 497). The three echelle spectra were underexposed and affected by high-backgrounds, but nonetheless do show emission lines in partial confirmation of the hypothesis advanced by Holm et al.

**Publications:** None

Title: Young Stars Relevant to the Earth's Early Atmosphere

Program ID: CSGCI PI: C. L. Imhoff

#### Statement of Work:

IUE spectra of young solar-type stars will be employed to simulate the evolution of the young Sun's ultraviolet spectrum at a few epochs from about 100 million to one billion years. Archival data for several young G stars will be analyzed to provide flux distributions for use in atmospheric models. Additional IUE observations of the stars will be obtained in order to fill in the gaps in the available spectral coverage.

#### Results:

IUE observations were obtained of eight stars which are similar to the Sun in mass and surface temperature, but much younger. The observations consisted of 26 IUE low-dispersion spectra, of which 8 were obtained with the LWP camera, 6 with the LWR, and 12 with the SWP. Analysis of the ultraviolet spectra was performed to describe the variation in flux with age of a solar-mass star. The results indicate that the Sun's ultraviolet flux decreased dramatically with time. This is likely to have affected the evolution of the early Earth's atmosphere and the origin of life.

#### Publications:

Canuto, V. M., Levine, J. S., Imhoff, C. L., Goldman, I., Augustsson, T. R., and Hubickyi, O. "The Young Sun, The Early Earth, and the Photochemistry of, Oxygen, Ozone, and Formaldehyde in the Early Atmosphere" in *Chemical Events in the Atmosphere and Their Impact on the Environment* ed. G. B. Marini-Bettiol (Pontifical Academy of Sciences, Rome), 51 (1984).

**Title:** Survey of T Tauri Chromospheres

**Program ID:** CCGCI    **PI:** C. L. Imhoff

**Statement of Work:**

Archival IUE data on the T Tauri stars will be used to extend the sample of stars for which surface fluxes and chromospheric diagnostics have been derived. Some early erroneous line identifications and fluxes will be corrected. Questions raised by previous research will be reexamined, concerning such issues as the apparent weakening of the high temperature lines, the association of HeII emission with coronal X-rays, and correlations between lower chromospheric and transition-region diagnostics.

**Results:**

All the available archival IUE data of T Tauri stars were obtained and analyzed. Careful identification of emission lines was performed, and line fluxes measured. Surface fluxes were computed from the estimated stellar radii and distances. The ultraviolet spectra were found to strongly resemble those seen in late-type stars with very active chromospheres. However some T Tauri stars exceed any other cool stars in their surface activity. There is some indication that the hottest outer regions, such as the corona, might be inhibited by the formation of strong winds in the atmospheres of the most extreme T Tauri stars.

**Publications:**

Imhoff, C. L., and Appenzeller, I. "Pre-Main Sequence Stars", in *Exploring the Universe with the IUE Satellite*, ed. Y. Kondo (Reidel), 295 (1987).

Imhoff, C. L., Basri, G., and Giampapa, M. S. , "A Catalog of Mg II Emission Line Fluxes for T Tauri Stars", *B.A.A.S.*, 19, 728 (1987).

Giampapa, M. S., and Imhoff, C. L., "Simultaneous Observations of the H-alpha and Mg II Resonance Line Profiles in the T Tauri Star SU Aurigae" *B.A.A.S.*, 19, 1026 (1987).

**Title:** UV Extinction in the Taurus Dark Clouds

**Program ID:** IMHCI    **PI:** C. L. Imhoff

**Statement of Work:**

IUE observations will be used to study the ultraviolet extinction due to the grains in the Taurus dark clouds, a site of low-mass star formation. Additional early-type stars with significant visual extinction will be observed in order to improve the accuracy and generality of the Taurus extinction law results. The extinction curve will be extended to the full available wavelength range of 1200 Å to 3.4 microns, by using visual and infrared results for these stars.

**Results:**

Two early-type stars embedded in the Taurus-Auriga dark clouds were observed with IUE in order to measure the extinction of their light by grains in the clouds. Eight IUE spectra were obtained, consisting of 6 LWP low-dispersion and 2 SWP low-dispersion spectra. Some of the LWP spectra were overexposed so that the shorter-wavelength regions of the spectrum would be well exposed. An analysis of the spectra obtained under this program, plus existing archival data, indicated that some of the stars exhibit unusual extinction curves. For the most heavily reddened stars, the 2200 Å feature is significantly weakened.

**Publications:** None

Title: Atmospheric Structures in High and Low Mass T Tauri Stars

Program ID: PMHGB Co-I: C. L. Imhoff

**Statement of Work:**

High-dispersion observations of selected T Tauri stars will be obtained. Profiles for MgII and some other lines will be used to construct physically meaningful atmospheric models for those stars. An assessment will be made of the mass loss rates, structure and acceleration of the wind, and relative importance of the chromospheric versus wind region contributions of emission spectra.

**Results:**

The IUE satellite was used to obtain six LWP high-dispersion spectra of a few bright T Tauri stars. Mg II line profiles were obtained for the stars BP Tau, DF Tau, DG Tau, GM Aur, GW Ori, and CO Ori. These spectra, plus archival spectra of the same and additional T Tauri stars, have been carefully and uniformly reduced. The lines are very broad, indicating significant winds in the atmospheres of the stars. There is generally a deep absorption feature superimposed on a broad emission feature, but somewhat blueshifted. In general variability is seen in the overall flux of the line and in the strength of the absorption on the blue wing of the line, but not in the red side of the line. This indicates that the variability is largely due to the wind absorption component, not in the underlying emission.

**Publications:**

Imhoff, C. L., and Appenzeller, I. "Pre-Main Sequence Stars", in *Exploring the Universe with the IUE Satellite*, ed. Y. Kondo (Reidel), 295 (1987).

Imhoff, C. L., Basri, G., and Giampapa, M. S., "A Catalog of Mg II Emission Line Fluxes for T Tauri Stars", *B.A.A.S.*, 19, 728 (1987).

Title: Chromospheric Activity in Solar Mass Pre-Main Sequence Stars

Program ID: TTHGB      Co-I: C. L. Imhoff

**Statement of Work:**

Low-dispersion IUE observations will be obtained for several solar-mass pre-main sequence stars. The MGII and UV emission will be measured concurrently with optical observations at similar resolution. The data will be used to analyze the atmospheres of these stars which are most representative of the early evolution of stellar chromospheres.

**Results:**

A total of 15 LWP low-dispersion spectra were obtained for several classical and weak emission T Tauri stars. Eight stars were observed, including V410 Tau, DN Tau, DS Tau, GG Tau, UX Tau A, 0430+24, 0429+18, and HD 283572. The Mg II emission line fluxes are comparable to other late-type stars with high levels of surface activity. This distinguishes them from the more extreme T Tauri stars, for which surface activity appears to be inadequate to explain all their characteristics.

**Publications:**

- Imhoff, C. L., and Appenzeller, I. "Pre-Main Sequence Stars", in *Exploring the Universe with the IUE Satellite*, ed. Y. Kondo (Reidel), 295 (1987).
- Imhoff, C. L., Basri, G., and Giampapa, M. S., "A Catalog of Mg II Emission Line Fluxes for T Tauri Stars", *B.A.A.S.*, 19, 728 (1987).



**Title:** Differential Activity Analysis Along the Pre-Main Sequence

**Program ID:** PMIGB      **Co-I:** C. L. Imhoff

**Statement of Work:**

IUE observations will be obtained, to be combined with existing ground-based data, for several low-mass T Tauri stars in the Lupus and Chameleon dark clouds. Fluxes for the Mg II and Ca II emission lines will be used to examine the characteristics of the atmospheric emission regions which give rise to the lines. These results for lower mass stars will be compared to previous results for stars in other dark clouds and with higher masses.

**Results:**

The IUE satellite was used to obtain spectra of 8 T Tauri stars in the Chamaeleon dark clouds. The stars are identified by their Schwartz catalog numbers as Sz 6, 19, 65, 68, 77, 82, and 98. Eleven LWP and one SWP low-dispersion spectra were obtained. The spectra were reduced and the Mg II emission lines fluxes were derived. The stars were found to follow similar behavior to that already seen in the T Tauri stars in the Taurus- Auriga dark clouds.

**Publications:**

Imhoff, C. L., and Appenzeller, I. "Pre-Main Sequence Stars", in *Exploring the Universe with the IUE Satellite*, ed. Y. Kondo (Reidel), 295 (1987).

Imhoff, C. L., Basri, G., and Giampapa, M. S., "A Catalog of Mg II Emission Line Fluxes for T Tauri Stars", *B.A.A.S.*, 19, 728 (1987).

**Title:** Ultraviolet Spectral Survey of Bright Stars

**Program ID:** USSBS      **PI:** C. L. Imhoff

**Statement of Work:**

IUE high-dispersion spectra will be obtained on a time-available basis for several bright stars never observed before with the satellite. The spectra will be examined to look for unusual characteristics that might be deserving of further observations.

**Results:**

Spectra were obtained on a contingency basis with the IUE satellite over a period of two years. During the first year, 16 LWP and 16 SWP high-dispersion spectra were obtained for 18 bright stars. In the second year, 37 LWP and 38 SWP high-dispersion spectra, plus 2 LWP low-dispersion spectra, were obtained for 40 different bright stars. The bright stars which were observed had not previously been well observed in high-dispersion by IUE. Most of the stars were A, B, G, and K stars. Many are spectral and spectrophotometric standards of various kinds. These observations made good use of available satellite time that might otherwise been lost.

Spectra were obtained on a contingency basis with the IUE satellite over an additional period of two years, for a total of four years. During the first year, 33 LWP and 18 SWP high-dispersion spectra were obtained for 33 bright stars. In the second year, 41 LWP and 30 SWP high-dispersion spectra and 7 LWP and 3 SWP low-dispersion spectra were obtained for 42 different bright stars. The bright stars which were observed had not previously been well observed in high-dispersion by IUE. Most of the stars were A, B, G, and K stars. Many are spectral and spectrophotometric standards of various kinds. These observations made good use of available satellite time that might otherwise been lost. No publication was required for this program.

**Publications:** None

**Title:** Extended Atmospheres of Herbig Ae/Be Stars

**Program ID:** U095-87      **PI:** C. L. Imhoff

**Statement of Work:**

Existing IUE and IRAS data will be used to pursue a systematic study of the stellar winds, chromospheres, and circumstellar environments of a group of Herbig Ae/Be stars. The IUE data will be used to survey wind and chromospheric characteristics and compare them to normal Be stars. The IRAS data will be used to search for extended dust emission and faint nebulosity.

**Results:**

Analysis was performed of all available archival IUE spectra of the Herbig Ae/Be stars. The Mg II line profiles were derived from the available long-wavelength, high-dispersion data. For some of the stars, high-resolution SWP data were available. An examination of the far-ultraviolet line profiles for two of the hotter Herbig Ae/Be stars shows evidence for a stratified wind, similar to that seen in some unusual Be stars. None of the current proposed mechanisms for producing winds in hot stars is adequate to explain the winds seen in these stars.

**Publications:**

Grady, C. A., Imhoff, C. L., and Bjorkman, K., "Stellar Winds in Two Massive Herbig Be Stars", in *A Decade of UV Astronomy with the IUE Satellite*, ESA SP-281, 109 (1988).

**Title:** The Extended Atmospheres of Herbig Ae/Be Stars

**Program ID:** AEKCI     **PI:** C. L. Imhoff

**Statement of Work:**

IUE observations of Herbig Ae and Be stars, along with IUE archival data, will be analyzed to determine whether winds from these objects exhibit departures from spherical symmetry. The data will also be used to constrain wind acceleration mechanisms for these stars. Chromospheric emission fluxes or upper limits will be derived for the Ae stars.

**Results:**

IUE spectra were obtained for four Herbig Ae/Be stars to complement the available archival data analyzed in an earlier program. The new data included three LWP high-dispersion spectra, one SWP high-dispersion spectrum, and one SWP low-dispersion spectrum. The high-dispersion, long-wavelength data were used to examine the Mg II h and K resonance lines in a number of stars. It was found that the Mg II lines fall into three categories for these pre-main sequence stars. First, the Mg II line may show a pronounced P Cygni line profile, clearly indicating that the star is not a normal hot star. Second, the Mg II line shows a broad emission with an absorption feature superimposed. The line resembles that seen in the T Tauri stars and generally is seen in the cooler Herbig Ae/Be stars. The third type of Mg II line is a simple absorption feature resembling an interstellar feature. This case is likely to correspond to stars which are not truly pre-main sequence.

**Publications:**

Imhoff, C. L., Grady, C. A., and Bjorkman, K., "Mg II Profiles in the Herbig Ae/Be Stars", *B.A.A.S.*, **20**, 1091 (1988).

**Title:** Chromospheric Variability and Atmospheric Inhomogeneity of T Tauri Stars

**Program ID:** TTKAB      **Co-I:** C.L. Imhoff

**Statement of Work:**

IUE observations of T Tauri stars will be obtained and compared to contemporaneous optical and infrared observations. Low-dispersion spectra will be obtained over a ten to twelve day period to monitor the atmospheric variability of T Tauri stars.

**Results:**

Observing support was provided for a portion of a large monitoring program involving a number of investigators, some of which were supported under other grants and contracts. The IUE satellite was used to obtain 58 LWP low-dispersion spectra, 11 LWP high-dispersion spectra, and 9 SWP low-dispersion spectra of 6 T Tauri stars. Excellent data were obtained for V410 Tau, HD 283571, DF Tau, DN Tau, and DR Tau in order to monitor the variability of these stars.

**Publications:** None

**Title:** Disks in T Tauri Stars

**Program ID:** TTKGB    **PI:** C. L. Imhoff

**Statement of Work:**

IUE spectra will be obtained and compared to contemporaneous optical and infrared photometric data. The observations will be used to study the relation between accretion and spectral peculiarities of T Tauri stars.

**Results:**

Observations of several T Tauri stars were obtained at two epochs during the observing year in order to monitor the ultraviolet variability of the stars. A total of 27 LWP low-dispersion spectra and one SWP low-dispersion spectrum was obtained for 14 T Tauri stars in the Taurus-Auriga dark clouds. The LWP spectra were exposed longer than normal in order to obtain good fluxes for the ultraviolet continuum, which may originate in an accretion disk around the star. Some stars are found to have strong and variable ultraviolet continua, which provides significant evidence of a disk.

**Publications:**

Kenyon, S. J., Hartmann, L., Imhoff, C. L., and Cassatella, A., "Ultraviolet Spectroscopy of Pre-Main Sequence Accretion Disks", *Ap. J.*, 344, 925 (1988).

Title: High-Velocity Interstellar Gas toward HD 50896

Program ID: IGGJH     PI: J. Nichols-Bohlin

### Statement of Work:

High-dispersion spectra will be obtained for selected stars located at various angular distances from and behind the high-velocity gas structure associated with the binary Wolf-Rayet star HD 50896. These observations will be used to examine the structure's extent, distance, and potential connection with the star.

### Results:

A large, high-velocity interstellar shell has been discovered in the direction of the Wolf-Rayet star HD 50896. Two distinct high velocity interstellar components at approximately  $-80$  and  $-125 \text{ km s}^{-1}$  were detected in the low-ionization resonance lines of IUE spectra for HD 50896 and 11 neighboring field stars, precluding the possibility that this high-velocity gas is related to S308, the prominent ring nebula surrounding HD 50896. The data collected for HD 50896, at a distance of 1.5 kpc, and for 19 field stars located up to  $4''$  from HD 50896 with distances ranging from 0.6 to 2.9 kpc, indicate that the high-velocity interstellar gas lies at a distance of  $1.0 \pm 0.2$  kpc, has a diameter in excess of 90 pc, and is probably physically associated with the cluster Cr 121. We conclude that this high-velocity expanding interstellar shell represents a previously unidentified, well-evolved supernova remnant. Abundance estimates for this gas indicate relatively low depletion consistent with shock processing of interstellar grains. Furthermore, faint diffuse optical [O III] emission detected in this direction appears well correlated with the location and extent of the observed high-velocity components, and thus may represent weak optical shock emission.

### Publications:

Nichols-Bohlin, J., and Fesen, R.A., "High Velocity Interstellar Gas in the Line-of-Sight to the W-R Star HD 50896", *A.J.*, 92, 642 (1986).

Title: O-Star Ultraviolet Spectral Atlas

Program ID: OBGNW      Co-I: J. Nichols-Bohlin

### Statement of Work:

A sample of uniform, high-quality spectra provided by the IUE archives will be used to provide a comprehensive overview of the behavior of both photospheric and stellar-wind spectral features in the 1200-1900 ang region among the O stars. These ultraviolet spectra will be used to explore systematic trends with spectral type among the normal stars and anomalies in the peculiar objects. An atlas illustrating the full spectral range for numerous representative objects will be prepared.

### Results:

An atlas of high-dispersion IUE spectra covering the 1200-1900Å region has been generated. The atlas includes 101 spectra of 98 stars, together with optical spectral classifications. The primary purpose of the atlas is to investigate systematic trends in the ultraviolet lines of O stars, including the prominent stellar wind features, and the degree to which they correlate with the optical spectral classifications. Another objective is to identify ultraviolet features which may prove useful as classification criteria.

### Publications:

Walborn, N.R., Nichols-Bohlin, J., and Panek, R.J., "International Ultraviolet Explorer Atlas of O-Type Spectra from 1200 to 1900Å ", *NASA RP-1155*, 1 (1986).

Walborn, N.R., and Nichols-Bohlin, J., "Ultraviolet Morphology of the O Stars. IV. The OB Supergiant Sequence", *P.A.S.P.*, 99, 40 (1986).



**Title:** Evolutionary Status of the Peculiar B3Ia Supergiant HD 157038

**Program ID:** SGIJN     **PI:** J. Nichols-Bohlin

**Statement of Work:**

IUE observations of HD 157038 will be obtained to confirm that nitrogen enrichment of the stellar atmosphere has occurred. This would indicate that the products of interior nuclear reactions have contaminated the surface of the star. In addition, the current mass loss rate for the star will be derived, if possible, from the ultraviolet spectrum.

**Results:**

One SWP high-dispersion spectrum of HD 157038 was obtained with IUE. HD 157038 is a peculiar hot supergiant whose optical spectrum shows evidence of contamination by the products of interior nuclear reactions. In particular, nitrogen enrichment of the stellar atmosphere appears to have occurred. Analysis of the IUE data did in fact confirm the nitrogen enrichment in the spectrum of this star.

**Publications:** None

**Title:** Investigation of High-Velocity Interstellar Gas in the Line-of-Sight to Two Wolf-Rayet Stars

**Program ID:** IGIJN      **PI:** J. Nichols-Bohlin

**Statement of Work:**

IUE observations will be obtained for several stars in the line-of-sight to the two Wolf-Rayet stars HD 97152 and HD 96548. The ultraviolet spectra will be used to determine the distances, spatial extents, and abundances for the high-velocity structures detected. This information will be used to ascertain whether these structures are old, previously undetected supernova remnants.

**Results:**

High-dispersion spectra of 7 stars in the regions around the Wolf-Rayet stars HD 97152 and HD 96548 were obtained with IUE. The spectra obtained were analyzed for the presence or absence of high-velocity components to the interstellar lines, which, if present, are indicative of an expanding shell of gas in the line of sight. Equivalent widths and velocity displacements of each detected high-velocity component were calculated. The data for the stars in the line of sight to HD 97152 clearly indicated the presence of a huge, expanding shell of gas in this line of sight. However, the size of the structure could not be determined with the limited sample of stars obtained with this program. The data for the stars in the line of sight to HD 96548 were inconclusive.

**Publications:** None

Title: Investigation of High-Velocity Interstellar Gas in the Lines-of-Sight to the WR Stars HD 96548 and HD 97152

Program ID: ISJJN      PI: J. Nichols-Bohlin

### Statement of Work:

The region near the field WR star HD 96548 will be investigated to study the distance, spatial extent and abundances of the high-velocity gas. IUE observations will be used to probe the interstellar medium and to determine if the high-velocity gas in the direction of HD 96548 can be interpreted as an evolved supernovae remnant. More complete spatial information will also be obtained for the structure in the direction of HD 97152.

### Results:

High-dispersion spectra of 7 stars in the regions around the Wolf-Rayet stars HD 97152 and HD 96548 were obtained with IUE. In addition, 4 spectra of previously observed field stars in these two regions were obtained from the IUE archives. The spectra obtained were analyzed for the presence or absence of high velocity components to the interstellar lines. Equivalent widths and velocity displacements of each detected high velocity component were calculated. The survey of 13 early-type stars located over a 1.5 degree area toward HD 97152 revealed shifted high- and low-ionization absorption components in the spectra of five stars with component velocities between -50 and -150 km/sec. The presence of high-velocity gas in the spectra of these early-type stars, together with an analysis of optical and IRAS image data for this region, suggested that the detected expanding interstellar gas structure consists of two OB cluster supershells. The presence of high-velocity absorption components in one out of five field star spectra in the direction toward the more isolated Wolf-Rayet star HD 96548 suggested that this expanding gas does not originate from the optical ring nebula, RCW 58, surrounding HD 96548, as previously believed, but instead indicated the detection of a previously unknown expanding interstellar shell with dimensions 100-150 pc (assuming  $d=2.1$  kpc) which is nearly centered on HD 96548 and which is spatially consistent with the UV-detected high-velocity gas. The expanding interstellar shell detected both in the UV and in the infrared is proposed to be a highly evolved supernova remnant associated with the suspected compact companion of HD 96548.

### Publications:

Nichols-Bohlin, J., and Fesen, R.A., "Expanding Shells of Interstellar Gas in the Lines of Sight to Wolf-Rayet Stars", in *A Decade of UV Astronomy with the IUE Satellite*, ESA SP-281, 243 (1988).

Nichols-Bohlin, J., and Fesen, R.A., "High-Velocity Interstellar Gas in the Lines-of-Sight to the Wolf-Rayet Stars HD 96548 and HD 97152", *Ap.J.*, 353, 281 (1990).

**Title:** Search for High-Velocity Gas in the Lines-of-Sight to Wolf-Rayet Stars

**Program ID:** U094-87      **PI:** J. Nichols-Bohlin

**Statement of Work:**

Existing IUE and IRAS data will be used to investigate a few large scale expanding shells of high-velocity interstellar gas associated with Wolf-Rayet stars. IUE spectra of Wolf-Rayet stars will be examined to search for new cases of high-velocity gas components. The spatial extent and structure of the expanding interstellar gas shells will be investigated using the dust emission evident from the IRAS All-Sky Image data set.

**Results:**

IUE spectra of all Wolf-Rayet stars observed at high-dispersion with IUE (34 in number) were analyzed for the presence or absence of high-velocity components to the interstellar lines. The survey suggests that despite the powerful stellar winds exhibited by WR stars in general, few non-cluster WR stars show high-velocity, shifted components in their UV spectra. Thus, the phenomenon of high-velocity gas in the line of sight to WR stars is probably not correlated with stellar winds alone. This phenomenon is, however, correlated with a WR subclassification of WN5-8, the presence of a suspected compact companion, and the presence of a WR ring nebula.

The IRAS data in the regions of all known galactic WR stars was examined for evidence of expanding gas shells centered on the WR stars. Numerous structures were cataloged, including at least one highly evolved supernova remnant around HD 96548, and at least five previously unidentified ring nebulae.

**Publications:**

Nichols-Bohlin, J., and Fesen, R.A., "Wolf-Rayet Stars and Highly Evolved Supernova Remnants. A Missing Evolutionary Link?", *B.A.A.S.*, 20, (1988).

**Title:** High-Resolution Observations of the Early-Type Halo Star PHL1580

**Program ID:** HSKJN     **PI:** J. Nichols-Bohlin

**Statement of Work:**

An SWP high-dispersion spectrum of PHL1580 will be obtained. Mass loss rates will be estimated by fitting the P Cygni emission lines to determine if the star is a lowmass subluminoous object or a normal, massive Population I star.

**Results:**

One high-dispersion SWP image of PHL 1580 was obtained as a collaborative exposure using a VILSPA and US1 shift. An analysis of high-resolution optical data had indicated that this star was not a low mass, subluminoous object as currently thought, but a normal, massive Population I star. Analysis of the IUE data, however, showed that PHL 1580 is in fact a relatively nearby AGB star. This conclusion was reached by determining the stellar mass from P-Cygni profiles in the IUE data.

**Publications:** None

**Title:** High-Velocity Gas in the Lines-of-Sight to Wolf-Rayet Stars

**Program ID:** IGKJN     **PI:** J. Nichols-Bohlin

**Statement of Work:**

High-dispersion ultraviolet spectra of background stars near the Wolf-Rayet stars HD 192163 and HD 96548 will be obtained to determine spatial and abundance information on the expanding shells of interstellar gas in these regions. An analysis of this data will be used to determine expansion velocities, element depletions, and kinetic energies.

**Results:**

High-dispersion spectra of three stars in the line of sight to the WR star HD 192163 were obtained with IUE. In addition, 21 archival spectra of field stars in this line of sight were analyzed. The spectra obtained were analyzed for the presence or absence of high velocity components to the interstellar lines. Equivalent widths and velocity displacements of each detected high velocity component were calculated. These data showed that high-velocity components to UV interstellar absorption lines are present in both high and low ionization lines in 20 of the 24 stars studied. Thus, there is a pervasive presence in this direction of gas expanding at a velocities of 60-80 km/sec, not uniquely associated with any known optical or infrared structure. This expanding shell of gas is probably a multi-association superbubble associated with Cyg OB1, Cyg OB3, and possibly Cyg OB9. Based on the distance estimates of these associations, the superbubble must be at least 190x125 pc in size.

**Publications:** None

**Title:** Stellar Wind Variability of O Stars

**Program ID:** MLKJN      **PI:** J. Nichols-Bohlin

**Statement of Work:**

IUE spectra will be used to investigate the quasi-periodic behavior of the "discrete absorption components" in UV resonance lines in a few well-selected O stars. A possible link with non-radial pulsation behavior using simultaneous optical information will be studied.

**Results:**

Simultaneous IUE and optical spectra were obtained over a period of five days for three stars. Approximately 80 spectra of these three objects were obtained with IUE during this campaign. These data were examined for a possible link between the UV variability and the well-established photospheric activity of the three stars. Two types of UV variability have been identified: 1) discrete absorption components which appear episodically at low velocity and accelerate through the profile, and 2) changes (up to 10% of the steep blue edge of the saturated lines (C IV and N V). The data from this campaign strongly suggested a very significant coincidence between the behavior in the UV resonance lines and sudden changes in the He II 4868 line. These results imply that the origin of the stellar wind is connected with the behavior of the subsonic atmosphere of the star, not an intrinsic property of the supersonic wind flow. However, poor weather conditions limited the optical coverage to 2 nights. Future campaigns will include more optical sites and longer coordinated coverage to insure useful data from all instruments.

**Publications:**

Henrichs, H. Nichols-Bohlin, et al., "Correlated Near-Photospheric and Stellar-Wind Variability in the O Supergiant Lambda Cep", in *Evolution in Astrophysics, IUE Astronomy in the Era of New Space Missions*, ESA SP-310, 401 (1990).

Title: Image Processing Enhancements

Program ID: None      PI: J. Nichols-Bohlin

### Statement of Work:

Analysis of various image processing methods to improve the signal-to-noise ratio in IUE data will be performed. Improvements to be investigated include improved alignment of the ITFs, removal of two-dimensional fixed pattern noise, improved geometric correction, and optimized extraction techniques.

### Results:

Various methods of improved photometric correction and data reduction for IUE two-dimensional data were investigated. In particular, a method of cross-correlating the two-dimensional science data with the ITF for proper alignment was developed for general use with all IUE images. A method for removing the instrument-induced distortions analytically was explored. This method proved unsuccessful. A sophisticated algorithm for resampling two-dimensional data from an irregular grid was developed and tested. This algorithm has the advantage of preserving flux in the resulting resampled data to within 1% in high-dispersion images was identified.

### Publications:

- Nichols-Bohlin, J., "IUE Final Archive", in *Evolution in Astrophysics, IUE Astronomy in the Era of New Space Missions*, ESA SP-310, 207 (1990).
- De La Pena, M.D., Shaw, R.A., Linde, P., and Dravins, D., "The archival reprocessing of IUE data: I. An accurate registration technique for distorted images", in *Evolution in Astrophysics, IUE Astronomy in the Era of New Space Missions*, ESA SP-310, 617 (1990).
- Shaw, R.A., "The archival reprocessing of IUE data: II. A new photometric correction technique for the IUE Final Archive", in *Evolution in Astrophysics, IUE Astronomy in the Era of New Space Missions*, ESA SP-310, 621 (1990).
- Nichols-Bohlin, J., De La Pena, M.D., and Shaw, R.A., "The archival reprocessing of IUE data: III. Results of the new processing method for IUE data", in *Evolution in Astrophysics, IUE Astronomy in the Era of New Space Missions*, ESA SP-310, 623 (1990).
- Smith, M.A., "The archival reprocessing of IUE data: V. A new approach to remove interorder background in High-Dispersion IUE images", in *Evolution in Astrophysics, IUE Astronomy in the Era of New Space Missions*, ESA SP-310, 631 (1990).
- Taylor, M.A., and Shaw, R.A., "Electro-Optical Distortions in IUE Cameras", *NASA IUE Newsletter*, 42, 75 (1990).



**Title:** Geometric Structure of EG And and AX Per

**Program ID:** ZAGNO    **PI:** N. A. Oliverson

**Statement of Work:**

Ultraviolet spectra will be obtained at critical phases for the symbiotic star, EG And and AX Per, which are believed to be binary stars. These spectra will be used to study the interaction features such as streams, accretion disks, and winds from either the hot or cool components. The mass ratio of the components of EG And will be estimated by comparison with previous spectra.

**Results:**

Observations of opposite quadratures of the interacting symbiotic binary EG and (HD 4174, Period - 470<sup>d</sup>) were obtained. After correcting for absolute motion at the system, it appears, surprisingly, that many of the nebular lines arise from material that moves with the red giant star. This fact was used to interpret the observed complex line profiles of C IV and He II in the object.

**Publications:**

Pesce, J.E., Stencel, R.E., and Oliverson, N.A., "The Search for the Elusive Companion of EG Andromedae", *P.A.S.P.*, 99, 1178 (1987).

**Title:** Atlas of IUE Spectrograms of Planetary Nebulae

**Program ID:** NAGWF      **Co-I:** N. A. Oliverson

**Statement of Work:**

An atlas of low- and high-dispersion spectra of planetary nebulae based on the accumulated IUE archival material on about 160 objects will be generated. In addition to plots of flux versus wavelength, the atlas will contain information on exposure times, coordinates, morphology, line identifications, and line fluxes for a few selected objects.

**Results:**

Nine years of observations with the *International Ultraviolet Explorer (IUE)* satellite have resulted in a data bank of approximately 180 objects in the category of planetary nebulae, their central stars, and related objects. Most of these objects have been observed in the low-dispersion mode with both the short wavelength (SWP) and long wavelength (LWR or LWP) cameras. Although numerous papers have appeared in the recent literature based on these observations, the published data represent various aspects selected for specific purposes and are often processed by widely varying methods. Thus, until now, there has not been available a comprehensive atlas of ultraviolet spectrograms of these objects.

The overwhelming majority of the spectra in this reference atlas were taken through the large (10" x 20") entrance aperture, thus resulting in spectra that contain information on the nebular spectrum, as well as that of the central star. The low-dispersion IUE spectra also provide spatial information along the long axis of the large aperture, which is perpendicular to the direction of dispersion, and can therefore be used for a line-by-line analysis. Approximately 40 objects are of large angular diameter relative to the IUE entrance apertures and low nebular intensity so that the central stars were observed without nebular contamination. For about 15 nebulae of sufficient brightness and angular extent, the large or small aperture was purposely offset from the central star so as to obtain a nebular spectrum uncontaminated by the central star. One of the surprising results of these studies has been the realization that no two planetary nebulae have identical spectra in the ultraviolet region, even if their optical spectra are very similar.

**Publications:**

Feibelman, W.A., Oliverson, N.A., and Garhart, M.P., "IUE Spectral Atlas of Planetary Nebulae, Central Stars, and Related Objects", *NASA Reference Publication*, 1203, 1.

**Title:** Giants in Globular Clusters

**Program ID:** GCGAD      **Co-I:** N. A. Oliverson

**Statement of Work:**

The MgII emission in red giant stars in globular clusters will be measured to define the radiative energy loss and structure of the chromosphere in a population of stars with known ages and specific metallicity. Simultaneous high-resolution spectroscopy at H-alpha, if available, will be used to correlate mass flow with chromospheric emission levels.

**Results:**

This program was approved to observe only one target. Unfortunately, there was an error in the setup of the collaborative high-dispersion LWP exposure, and no useful data were obtained.

**Publications:** None

**Title:** Nova-Like Outbursts in Z And and other Symbiotic Stars

**Program ID:** ZAHNO     **PI:** N. A. Oliverson

**Statement of Work:**

IUE observations of a nova-like event in a symbiotic star such as Z And will be obtained. These spectra will be used to constrain models of the outburst mechanism to study the hot component and to study the velocity structure in the outflowing wind.

**Results:**

Z Andromedae, often considered as the prototype of symbiotic stars, experienced, after several years of quiescence, a small outburst in March-April 1984, followed by a larger one in September-October 1985. The behavior of Z And in the ultraviolet during the recent activity phases can be summarized as follows. The regular variations of the UV continuum and emission line fluxes observed during quiescence continue during activity but are superimposed on variations having the time scale of the V light curve. In addition, the hot stellar continuum almost disappears from the the UV energy distribution. Finally, a general broadening of the emission lines is seen in the high-resolution IUE spectra during the high activity phase in 1985-1986.

**Publications:**

Cassatell, A., Fernandez-Castro, T., and Oliverson, N., "Z Andromedae: Quiescence and Activity", in *The Symbiotic Phenomenon*, J. Mikolajewska et. al (editors), 181.

**Title:** Masses and Nebular Velocity Structure of Symbiotic Stars

**Program ID:** COHNO    **PI:** N. A. Oliverson

**Statement of Work:**

High-dispersion archival IUE spectra will be analyzed to find radial velocity variations in selected symbiotic stars. Such variations are expected due to the high probability that the stars are close binaries. The data will be used to estimate the mass ratios and velocity structure of several selected symbiotic stars.

**Results:**

The symbiotic star AG Peg shows periodic variations in the central radial velocity and total flux of several emission lines. Seventeen high-dispersion archival SWP spectra covering the time period from 1978.6 to 1986.9 were examined. Gaussian profiles were fit to each of the narrow emission lines of O III], N III], O IV], Si IV, C III], and Si III]. Radial velocity curves with an amplitude of 15-20 km/sec were measured for the N III] 1748.6Å , 1749.7Å lines, the O III] 1660.8Å , 1666.2Å lines, and the C III] 1908.7Å line. The O IV] and Si IV lines were generally too weakly exposed to derive reliable velocity curves, while the Si III] line was often overexposed. The N III], O III], and C III] line fluxes are correlated with phase. These line flux and velocity changes are consistent with formation of the lines near the red giant.

**Publications:**

Oliverson, N.A., Evans, N.R., and Anderson, C.M., "The Nebular Velocity Structure of AG Pegasi", in *A Decade of UV Astronomy with the IUE Satellite*, ESA SP-281, 183 (1988).

**Title:** Nova-Like Outbursts of Z Andromeda and Other Symbiotic Stars

**Program ID:** ZAINO     **PI:** N. A. Oliverson

**Statement of Work:**

IUE observations of Z And will be obtained during the active phase following its recent outburst. The ultraviolet spectra will be used to study the velocity structure in the wind and to constrain the models involving accretion onto a hot main-sequence star.

**Results:**

An analysis of ultraviolet and optical spectroscopy for the symbiotic binary CI Cyg was performed. This system contains an M5 II asymptotic branch giant transferring material into a large accretion disk surrounding a main-sequence star. A boundary layer at the inner edge of the disk photoionizes a small nebulae approximately confined to the Roche volume of the accreting star. An extended, more highly ionized region forms when material ejected from the disk interacts with the red giant wind.

**Publications:**

Kenyon, S.J., Oliverson, N.A., Mikolajewska, J., Mikolajewska, M., Stencel, R.E., Garcia, M.R., and Anderson, C.M., "On the Nature of the Symbiotic Star CI Cygni", *A.J.*, 101, 637 (1991).

**Title:** Astrometric Binaries: White Dwarfs?

**Program ID:** WDJNO    **PI:** N. A. Oliverson

**Statement of Work:**

A selection of astrometric or spectroscopic-astrometric binaries nearer than 20 pc will be observed with IUE to search for the presence of white dwarf companions. These data will be used to provide complete statistical information about the nearest stars and provide information about the masses of white dwarfs.

**Results:**

A total of 3 SWP and 3 LWP low-dispersion exposures were obtained for the targets on this program. None of the observations showed any evidence that targets had previously unknown white-dwarf companions.

**Publications:** None

**Title:** TZ Eri

**Program ID:** OD48Y    **PI:** E. A. Park

**Statement of Work:**

Test exposures of the eclipsing Algol-type binary TZ Eri will be obtained. The exposures will form the basis of a new proposal to observe this binary.

**Results:**

Test exposures obtained by IUE of TZ Eri include a 15 minute LWP out of eclipse, a 60 minute SWP in eclipse, and a 50 minute LWP in eclipse. The two LWP spectra were well exposed, with Mg II clearly in absorption out of eclipse and in emission during totality. The SWP, however, was very underexposed. A subsequent proposal to obtain better exposures over a range of phases was not accepted.

**Publications:** None



**Title:** Eclipse Coverage of the G Supergiant 22 Vul

**Program ID:** VVGSP    **PI:** S. Parsons

**Statement of Work:**

Ultraviolet observations will be obtained at various times near eclipse for the G supergiant binary system 22 Vul. These spectra will be used to map out the extent and homogeneity of the gas in the system, to study its physical properties, to look for effects of interaction between it and the hot star, and to relate it to the more complex situations seen in strongly interacting binary systems.

**Results:**

A total of 19 SW and 20 LW spectra was obtained for the target 22 Vul on 10 dates in the orbital phase range 0.93 to 0.08. These data allowed study of the eclipse effects of the G supergiant atmosphere on the light from the B companion. The spectra show a combination of line and continuous opacity effects, and suggest inhomogeneity in a very extensive outer atmosphere. This program also served to augment the data bank for future analysis of time-dependent effects in the systems.

**Publications:**

Parsons, S.B., and Ake, T.B., "Results from the August 1984 Eclipse of 22 Vulpeculae," *B.A.A.S.*, **16**, 913 (1984).

Parsons, S.B., Ake, T.B., and Hopkins, J.L., "The August 1984 Eclipse of 22 Vulpeculae," *P.A.S.P.*, **97**, 725 (1985).

**Title:** Eclipse Coverage of the G Supergiant 22 Vul

**Program ID:** VVHSP      **PI:** S. Parsons

**Statement of Work:**

New IUE observations will be obtained of the binary system 22 Vul, discovered with IUE to be an eclipsing system. UV observations will be obtained at various times near eclipse to map out the extent and homogeneity of the plasma, to study its physical properties, to look for similarities with the better-studied zeta Aurigae systems, and to relate it to the more complex situations of strongly interacting binary systems.

**Results:**

A total of 32 SW and 39 LW spectra was obtained for the target 22 Vul on 15 dates in the orbital phase range 0.87 to 0.13. These data, taken at carefully selected phases to augment previous observations, allowed more complete study of the eclipse effects of the G supergiant atmosphere on the light from the B companion during both ingress and egress. The spectra aided in the precise determination of total eclipse duration and timing. The UV opacity effects demonstrate some inhomogeneity and show that the supergiant's outer atmosphere extends to 3-4 stellar radii. The changes in profile of the C IV resonance doublet confirms the picture of a bow shock and accretion cone as the B star moves through the wind from the G supergiant.

Exploratory exposures, 1 SW and 1 LW, on an additional target V777 Sgr were taken to see if this 936-day system might be related to the Zeta Aurigae binaries. Its spectra do imply substantial atmospheric eclipse effects in the UV; however, the exposure times needed for an adequate follow-up program were found not to be feasible.

**Publications:**

Parsons, S.B., and Ake, T.B., "Early Results from the May 1985 Eclipse of 22 Vulpeculae," *B.A.A.S.* 17, 753 (1985).

**Title:** Interacting F and Be Binaries

**Program ID:** IBGBB    **Co-I:** S. Parsons

**Statement of Work:**

Several binary star systems containing an F giant and a Be star component will be examined at middle- or far-ultraviolet wavelengths at several orbital phases each. These systems will be compared to the W Serpentis binary systems containing hot plasma. High-resolution spectra will be used to give insight into the probable location of the plasma and the evolutionary status of these systems.

**Results:**

A total of 17 SW and 22 LW spectra was obtained for 6 targets on 4 dates. This program was a continuation of program IBFSP to sample more epochs of four seemingly related systems which have anomalous UV spectra and variability. The observations served to demonstrate that the variability is not predictable and to confirm that two other binaries show related anomalies. This program also served to augment the data bank for future analysis of time-dependent effects in the systems (see report for program IBJBB).

**Publications:**

Parsons, S.B., and Bopp, B.W., "Far-Ultraviolet Variability of HD 207739", *B.A.A.S.*, 18, 682 (1986).

Parsons, S.B., Dempsey, R.C., and Bopp, B.W. (1988). "HD 207739 and Other F + Be Variables", in *A Decade of UV Astronomy with the IUE Satellite*, ESA SP-281, 225 (1988).

**Title:** Interacting F and Be Binaries

**Program ID:** HCHBB    **Co-I:** S. Parsons

**Statement of Work:**

Several binary star systems containing an F giant or bright giant and a Be component, all showing strong hydrogen emission, will be observed at several orbital phases. High-resolution UV spectroscopy will be obtained if possible and will be used to give insight into the probable location of the plasma (envelope or accretion disc around the hot star, gas streams, and/or extended atmosphere of the cool star) and evolutionary status of these systems and related objects.

**Results:** A total of 12 SW and 13 LW spectra was obtained for 5 targets on 5 dates. This program was a continuation of program IBFSP to sample more epochs of seemingly related systems which have anomalous UV spectra and variability. The observations continued to demonstrate that the variability is not predictable and that these binaries show related spectral anomalies. This program also served to augment the data bank for future analysis of time-dependent effects in the systems (see report for program IBJBB).

**Publications:**

Parsons, S.B., and Bopp, B.W., "Far-Ultraviolet Variability of HD 207739", *B.A.A.S.*, **18**, 682 (1986).

Parsons, S.B., Dempsey, R.C., and Bopp, B.W. (1988). "HD 207739 and Other F + Be Variables", in *A Decade of UV Astronomy with the IUE Satellite*, ESA SP-281, 225 (1988).

Dempsey, R.C., Parsons, S.B., and Bopp, B.W., "The Long-Period K + Be Binary HR 2577 (MWC 827)", *P.A.S.P.*, **100**, 481 (1988).

Dempsey, R.C., Parsons, S.B., Bopp, B.W., and Fekel, F.C., "HD 43246 and HD 127208: Two Unusual F-G + B Binary Systems", *P.A.S.P.*, **102**, 312 (1990).

Bopp, B.W., Parsons, S.B., and Dempsey, R.D., "Optical and Ultraviolet Spectroscopy of Three F + B Binary Stars", *P.A.S.P.*, **103**, in press (1991).

**Title:** Interacting F and Be Binaries

**Program ID:** IBJBB     **PI:** S. Parsons

**Statement of Work:**

IUE observations of several binary stars involving F and Be stars will be obtained. The new data will be used to determine the phase-related changes in the ultraviolet spectra, using the newly determined orbital parameters. The data will be analyzed and used to investigate the evolutionary status of the binaries.

**Results:**

A total of 9 SW and 9 LW spectra was obtained for 5 targets on 2 dates. This program was a continuation of program IBFSP to sample more epochs of seemingly related systems which have anomalous UV spectra and variability. The observations continued to demonstrate that the variability is not predictable and that these binaries show related spectral anomalies. Two systems with tidally distorted cool giant primaries, HD 43246 and HD 127208, show variable hot wind absorption features against otherwise normal late B type far-UV spectra. Three systems containing more luminous late-type primaries - HD 59771, HDE 242257, and CoD -30 5135 - have been demonstrated to belong to a class of strongly interacting binary systems typified by HD 207739, in which the hot main sequence component is partially obscured by gas streams or a disk. Most of the binaries observed in this program exhibit mid-UV flux excesses, which imply radiation from a disk at about 10,000K. This program also served to augment the data bank for future analysis of time-dependent effects in the HD 207739 system, which will be found to have a much shorter periodicity than the orbital cycle in its UV variations.

**Publications:**

- Parsons, S.B., Dempsey, R.C., and Bopp, B.W. (1988). "HD 207739 and Other F + Be Variables", in *A Decade of UV Astronomy with the IUE Satellite*, ESA SP-281, 225 (1988).
- Dempsey, R.C., Parsons, S.B., Bopp, B.W., and Fekel, F.C., "HD 43246 and HD 127208: Two Unusual F-G + B Binary Systems", *P.A.S.P.*, 102, 312 (1990).
- Bopp, B.W., Parsons, S.B., and Dempsey, R.D., "Optical and Ultraviolet Spectroscopy of Three F + B Binary Stars", *P.A.S.P.*, 103, in press (1991).
- Parsons, S.B., Bopp, B.W., and Dempsey, R.C., "Pulsational Mass Dumping in the cF + B Binary HD 207739", *B.A.A.S.*, 23, in press (1991).

**Title:** Fluxes, Temperatures, and Radii of Stars Defining the ZAMS

**Program ID:** MSJRP      **PI:** R. E. Pitts

**Statement of Work:**

Flux distributions will be obtained for O, B and A type main sequence stars in the open clusters Alpha Per and NGC 2244. These observations, combined with existing observations of the Pleiades, will be used to set up a sequence of IUE observations defining the upper zero age main sequence (ZAMS). Various radii measurements will be combined with distances and observed fluxes to provide a consistency test of the model atmospheres employed.

**Results:**

This program, a continuation of program MSINE (Dr. N. Evans, PI), obtained LWP and SWP for 18 stars during the 10th episode. Galactic and extra-galactic distance scales often use the distance of open clusters such as the Pleiades and Alpha Persei as one of their primary calibration steps. The spectral types, luminosities, etc. of these stars have thus been well studied in the past using ground data. However, the majority of the energy output of these stars is in the ultraviolet. The program consists of obtaining low-dispersion spectra of these stars so that the IUE absolute fluxes may be obtained. By comparing the results to stellar models, the luminosities, effective temperatures, etc of these stars can be obtained and compared with the ground results assumed for distance determinations. This then provides an effective check on distance scale calibrations. To do the comparisons with models require the most accurate flux measurements possible. The IUE project is currently getting ready to begin final IUE reprocessing of the data archives. A calibration effort using white dwarf stars to possibly recalibrate the blue end of the SWP camera is also underway. Further, the results to date of program STJRP (see above) indicate it may be possible to calibrate the LWP camera to beyond 3300 Å and directly tie the UV to ground data measurements for at least some of these stars. Once these efforts are further along, it should be possible to decide if the expected changes in this recalibration effort are sufficiently large as to be important to this program.

**Publications:** None

**Title:** Ultraviolet Spectra of Spectrophotometric Standard Stars

**Program ID:** STHRP, STJRP      **PI:** R. E. Pitts

**Statement of Work:**

Low-dispersion LWP exposures will be obtained for a number of the spectrophotometric standards in order to obtain absolute flux measurements on the IUE system. These will be used to verify consistency with ground-based spectrophotometry and, if needed, revise the absolute flux scales used in the important overlap region near the atmospheric cutoff. Trailed Spectra of Bright Spectrophotometric Standard Stars

IUE observations will be obtained of four of the brightest ground-based spectrophotometric standard stars using new observing techniques. Trailed and point-source spectra will be combined to provide ultraviolet flux distributions from 1200-3200 Å. A comparison will be made of Alpha Lyr and 109 Vir with the nearby star Alpha CMa A, which has a well determined distance and measured radius.

**Results:**

The IUE calibration is used by the Hubble Space Telescope as a source for part of its calibrations. The object of this program is then to compare the results of ground based data on some of these standard photometric stars with the results obtained on the IUE absolute flux scale. Since these are A stars, most of their flux is actually in the ultraviolet. As a second goal, an investigation has been made as to whether the LWP camera's calibration can be extended beyond its nominal reliable cutoff of 3200 Å. If it can be extended another 100 angstroms, it would be possible to compare IUE data directly with ground data measurements. During the 8th and 10th episodes, reliable data was obtained for 8 standard stars including the fundamental stars of Vega and 109 Vir. An investigation into extending the calibration of the LWP camera to longer wavelengths is nearly complete. It indicates that it is possible to do this. However, the inherent noise in the camera rapidly reduces the sensitivity of the camera so only strong signals are measureable and there are indications of scattered light being a significant part of the signal longward of about 3300 angstroms. The eventual goal is a final determination of the absolute calibration of the LWP longward of 3200 Å.

**Publications:** None

**Title:** Low-Dispersion Observations of Bright Stars

**Program ID:** HSJEF      **Co-I:** R. E. Pitts

**Statement of Work:**

Low-dispersion SWP and LWP spectra will be obtained of a group of bright nearby early-type stars. The new fast-trailing technique will be used to obtain optimally exposed spectra of stars that previously were too bright to observe with IUE. The data will be used to repeat and improve previous determinations of the effective temperatures and bolometric corrections of these stars based on previous ultraviolet missions.

**Results:** With the development of the "Fast Trail" technique, it became possible to obtain low-dispersion spectra of early bright B-stars. Since the absolute calibration is defined in terms of low-dispersion spectra, fast trailing allows the direct determination of absolute UV fluxes on the IUE scale of bright B-stars. These results can in turn be fed into stellar models and, combined with other data, yield accurate effective temperatures and luminosities. Accurate UV data is especially important in early B stars where the peak of the stellar flux is in the wavelength region of the SWP camera.

During the tenth episode, complete data was obtained for 3 out of the 10 program stars. Partial data was obtained for several other stars. Preliminary reduction of the data was performed at GSFC and the data was then forwarded to Dr. E. Fitzpatrick, the P.I. In this type of work, very accurate fluxes are crucial in obtaining accurate effective temperatures and luminosities. As a result, the P.I. is currently awaiting the final IUE archive reprocessing of the tenth episode data before proceeding with the model fitting and determination of final parameters.

**Publications:** None



**Title:** Simultaneous UV and EUV Observations of Active Galaxies

**Program ID:** AGHGR, AGIGR    **PI:** G. A. Reichert

**Statement of Work:**

IUE observations of several nearby AGN will be performed concurrently with observations using the Voyager 2 UVS, in order to extend spectral coverage down to rest wavelengths  $\leq 900$  Å. The spectra will be analyzed with the following goals: (1) to develop a self-consistent model of the nuclear region of NGC 1068, (2) to examine the decompositions of the ultraviolet spectra of NGC 4151 and 3C 273, and (3) to derive more sensitive bounds to the temperatures of any thermal emission which may be present in NGC 4151, Fairall 9, and 3C 273.

**Results:**

All of the IUE data obtained for this program was reduced and compared to the Voyager observations. The quasar 3C 273 was detected at many sigma during the first Voyager observation, but no significant emission was detected during the second observation. Results for the first observation are reported under programs AGJGR and AGKGR. NGC 4151 and Fairall 9 were not detected by Voyager.

**Publications:** None

**Title:** Search for Rapid UV Variability in the Seyfert 1 NGC 4593

**Program ID:** SYJGR     **PI:** G. A. Reichert

**Statement of Work:**

Very rapid variations on time scales between 3 and 16 hours will be searched for in the short wavelength ultraviolet continuum of the Seyfert 1 galaxy NGC 4593. These data will be used to determine whether the UV continuum in Seyfert 1 galaxies has a non-thermal origin or whether it arises via thermal emission from geometrically thin, optically thick accretion disk around a massive compact object.

**Results:**

A number of low-dispersion IUE exposures were obtained. There is no evidence that the Seyfert galaxy NGC 4593 varied on time scales less than a day.

**Publications:** None

**Title:** Simultaneous UV and EUV Observations of Active Galaxies

**Program ID:** AGJGR    **PI:** G. A. Reichert

**Statement of Work:**

IUE observations of three nearby Active Galactic Nuclei will be performed concurrently with Voyager 2 far-ultraviolet observations. The data will be used to (1) probe the intrinsic extreme ultraviolet continuum of AGN, (2) test models for the spectral decomposition of the continuum, (3) search for a Lyman cutoff in the spectra of 3C 273 and Fairall 9 and (4) measure the strengths of the O IV 1035 emission lines.

**Results:**

Near-simultaneous IUE and Voyager ultraviolet spectrometer (UVS) observations were obtained of 3C 273 during the period of late July-early August 1985. The UVS data show a significant drop in flux for observed wavelengths below 1060Å . This is interpreted as Lyman continuum absorption in the rest frame of 3C 273. The depth of the edge indicated column densities of neutral hydrogen in the range  $N_H \sim 0.4-2.0 \cdot 10^{17} \text{ cm}^{-2}$  (at 90% confidence). The presence of such a strong edge is surprising since previous high-dispersion IUE observations show no corresponding Lyman  $\alpha$  absorption with equivalent width about 0.15Å . Implications concerning the physical characteristics and possible location of the absorbing medium have been investigated.

**Publications:**

Reichert, G.A., Polidan, R.S., Wu, C.-C., and Carone, T.E., "Detection of Possible Lyman Continuum Absorption in 3C 373", *B.A.A.S.*, 18, 996 (1986).

**Title:** Optical and Ultraviolet Emission Line Variability in the Seyfert Galaxy NGC 5548

**Program ID:** U092-87     **PI:** G. A. Reichert

**Statement of Work:**

Existing IUE spectra of NGC 5548 will be analyzed and compared to concurrent optical data. The ultraviolet and visual fluxes will be used to compare the fluxes and profiles of various spectral lines, and to obtain physical diagnostics of the conditions in the emitting gas.

**Results:**

The structure of the broad-line region in NGC 5548 was investigated by analysis of the integrated flux and profile variations observed in optical and ultraviolet emission lines. The observations do not appear to be consistent with models which identify the variable part of the emission lines with a simple rotating disk structure. The variable continuum and integrated emission-line fluxes are highly correlated and suggest a small broad-line region ( $\sim 18$  light days  $\approx 5 \times 10^{16}$  cm), although the size of the line-emitting region is not well-determined. At least some of the broad emission arises in a component which at times appears very prominently and distinctly in difference spectra. This emission component appears to arise in a region which is physically distinct from the rest of the broad-line region. Although the integrated fluxes in the various optical and ultraviolet emission lines seem to vary together, there clearly are differences between the profiles of various lines, which suggests that there is at least some ionization stratification within the broad-line region.

**Publications:**

Peterson, B.M., Reichert, G.A., Korista, K.T., and Wagner, R.M., "Ultraviolet and Optical Spectroscopy of NGC 5548 and the Nature of the Broad-Line Region", *Ap.J.*, 352, 68 (1990).

**Title:** Simultaneous UV and EUV Observations of Active Galaxies

**Program ID:** AGKGR    **PI:** G. A. Reichert

**Statement of Work:**

Simultaneous IUE and Voyager 2 UVS observations of nearby active galaxies will be used to relate the extreme ultraviolet and ultraviolet continua, and thereby test models for the spectra decomposition of active galaxy continua. The spectra will be analyzed for the presence of rest frame Lyman continuum absorption and O VI emission lines.

**Results:**

Near-simultaneous IUE and *Voyager* ultraviolet spectrometer (UVS) observations of 3C 273 were made during the period of 1985 late July-early August. The data cover a total combined wavelength range 500-3200Å (observed frame). This is the first time that observations shortward of 1200Å have been obtained for any extragalactic object. The source was significantly detected for all observed wavelengths above 912Å, at a level (for  $\lambda_{obs} > 1060\text{Å}$ ) consistent with previous optical and IUE observations. The UVS data show a significant drop in flux for observed wavelengths below 1060Å. This may be due to Lyman continuum absorption in the rest frame of 3C 273. If so, then the lack of associated Lyman  $\alpha$  absorption severely constrains the properties of the absorbing medium. The most plausible explanation may therefore be that the edge is due to absorption in an accretion disk within the nucleus of 3C 273. Alternatively, models in which the drop in flux is due to a turnover in the underlying continuum cannot be excluded; this interpretation raises serious questions concerning the total energy budget in the broad-line regions. In either case, there can be *no* reddening of the source on continuum emission other than that due to our own Galaxy.

**Publications:**

Reichert, G.A., Polidan, R.S., Wu, C.-C, and Carone, T.E., "Voyager and IUE Observations of 3C 273: Detection of Possible Lyman Continuum Absorption in a Nearby ( $z = 0.158$ ) Quasar", *Ap.J.*, 325, 671 (1988).

**Title:** UV and Optical Observations of Liners

**Program ID:** EGKGR    **PI:** G. A. Reichert

**Statement of Work:**

New IUE observations of four Liners will be obtained to separate the nuclear ultraviolet emission from the more extended emission arising from-integrated starlight. The data will be used to establish whether the observed ultraviolet continua within the nuclei have sufficient ionizing flux to ionize the gas that produces the emission lines.

**Results:**

IUE observations of the Liner NGC 3998 were obtained. Spatial structure in the long wavelength emission is apparent; the spatial profiles from the LWP line-by-line images show a two-component structure, with an unresolved central component superimposed on extended underlying emission. New software was used to separate the LWP emission into component spectra. The unresolved component spectrum is considerably flatter than the extended component spectrum, which is dominated by fairly late type stars (late F to early G). The unresolved component also shows strong CII] 2326Å and broad MgII 2800Å emission. The width of the MgII emission is ~8600 km/s, and its profile agrees quite well with the broad wings of the H $\alpha$  emission. These results further support the idea that NGC 3998 may contain a "dwarf" Seyfert nucleus.

**Publications:**

Reichert, G.A., Wu, C.-C., and Filippenko, A.V., "Spatially Resolved Ultraviolet Spectroscopy of the Liner NGC 3998", in *A Decade of UV Astronomy with the IUE Satellite*, ESA SP-281, 307 (1988).

**Title:** Structure of the Broad-Line Region in NGC 5548

**Program ID:** AGKMM      **Co-I:** G. A. Reichert

**Statement of Work:**

The first complete set of regular spectroscopic observations of a variable Seyfert 1 galaxy, NGC 5548, will be obtained. IUE observations obtained every few days will be combined with observations at other wavelengths to determine the size and structure of the broad-line region in NGC 5548.

**Results:**

Emission-line and ultraviolet continuum observations of a type I Seyfert galaxy were made; the time resolution is adequate for describing the character of variability. Using the IUE satellite, the nucleus of NGC 5548 was observed every 4 days for a period of 8 months. Its mean properties—continuum shape, line ratios—are not unusual for type I Seyfert galaxies, but it was found to be strongly variable. The ultraviolet continuum flux and broad emission line fluxes varied significantly, going through three large maxima and three deep minima. The ratio of maximum flux is  $\approx 4.5$  for the continuum at  $1350\text{\AA}$ , and the continuum was significantly bluer when it was brighter. The high-ionization emission lines showed the strongest variations, with N v  $\lambda 1240$  and He II  $\lambda 1640$  exhibiting maximum to minimum flux ratios as high as those of the continuum. Intermediate-ionization lines, including Ly $\alpha$   $\lambda 1216$ , C IV  $\lambda 1549$ , and C III]  $\lambda 1909$ , had maximum to minimum amplitudes of  $\sim 2$ , and Mg II  $\lambda 2798$ , the lowest ionization line, exhibited the smallest amplitude fluctuations,  $\sim 1.3$ . The great majority of all variations correlate extremely well with those of the  $1350\text{\AA}$  continuum if allowance is made for a systematic delay, lending qualitative support to the view that photoionization by the nuclear continuum is responsible for driving the emission lines. The delay of a given line seems to depend on the degree of ionization of its species. The He II  $\lambda 1640$  and N v  $\lambda 1240$  features exhibit the shortest delay,  $\Delta t \sim 4\text{--}10$  days, while the Ly $\alpha$   $\lambda 1216$  and C IV  $\lambda 1549$  lines yield  $8\text{--}10$  days. The Si IV + O IV]  $\lambda 1402$  feature and the C III]  $\lambda 1909$  line exhibit significantly larger delays, between  $12$  and  $34$  days. In the case of Mg II  $\lambda 2798$ , the cross-correlation is broad and shallow, so that the delay is only loosely constrained,  $\Delta t \sim 34\text{--}72$  days.

**Publications:**

Clavel, J., Reichert, G.A., Alloin, E., Crenshaw, D.M., Kriss, G., Krolik, J.H., Malkan, M.A., Netzer, H., Peterson, B.M., Wamsteker, W., *et al.*, "Steps Toward Determination of the Size and Structure of the Broad-Line Region in Active Galactic Nuclei. (I) An Eight Month Monitoring Campaign of NGC 5548 with IUE", *Ap.J.*, **336**, 64 (1991).

**Title:** Spatially Resolved Ultraviolet Spectroscopy of Starburst Galaxies

**Program ID:** U070-88     **PI:** G. A. Reichert

**Statement of Work:**

IUE archival observations of blue compact dwarf galaxies will be used to study the spatial extent of the activity region in the ultraviolet, and to determine the stellar population responsible for the heating of the grains observed in the far-infrared. Ideas concerning triggering mechanisms and propagation mechanisms for star formation will be tested.

**Results:**

IUE observations were made of NGC 3998 and NGC 404. In both objects, the spatial profile of the long wavelength emission (i.e., perpendicular to the dispersion direction) shows a two-component structure, consisting of an unresolved (size less than 1 arc-sec) core superimposed on broader underlying emission. Similar spatial structure is not apparent in the SWP images, probably due to the lower signal-to-noise ratios. Recently developed software was applied, using the known spatial responses of the IUE cameras, to separate the LWP images into core and extended component spectra. In both cases, the core component spectra are much flatter than the extended component spectra, which are dominated by fairly late type (late F to early G) stars. In NGC 3998, the core component also shows strong MgII  $\lambda 2800$  and CII]2326 emission lines; the Mg II emission is broad (FWZI  $\sim 8600$  km/s) and its profile matches that of the broad component seen in H $\alpha$ . One of the LWP spectra also shows possible extranuclear MgII line emission. Since NGC 3998 is similar to M81 in other respects, it may be another likely case for photoionization by a nonstellar continuum. There are broad peaks at both 1500 and 1800Å in the SWP spectra for NGC 404, and there is possible absorption at the wavelengths expected for redshifted SiIII]  $\lambda 1300$ , SiIV  $\lambda 1400$ , and CIV  $\lambda 1550$ , indicating the possible presence of hot (O and B) stars. Hence these data may provide evidence for the presence of two distinct stellar populations.

**Publications:**

Reichert, G.A., Wu, C.-C., and Filippenko, A.V., "IUE Observations of NGC 3998 and NGC 404: Spatially Resolved Ultraviolet Spectroscopy of the Central Regions", *B.A.A.S.*, 20, 970 (1988).



**Title:** Study of the CIII] Line in Active Galaxies

**Program ID:** U051-88      **Co-I:** G. A. Reichert

**Statement of Work:**

IUE archival observations of the CIII] line in a number of active galaxies will be compared to optical observations of narrow forbidden lines. The data will be used to search for correlations between the critical density of a line and its velocity dispersion, which may help to discriminate between various models of the emission line clouds.

**Results:**

IUE archive spectra have been retrieved for a number of active galaxies. The GEX routine has been used to re-extract the merged spectra from the line-by-line files, resulting in spectra with significantly better signal-to-noise ratios than the standard SIPS spectra. The data have been forwarded to the PI for detailed comparisons with optical observations.

**Publications:** None

**Title:** Metal-Poor Extragalactic H II Regions

**Program ID:** NEGRD      **Co-I:** F. S. Schiffer

**Statement of Work:**

IUE observations will be obtained of several of the brightest HII regions in the Magellanic Clouds and in other nearby late-type galaxies known to be metal-poor. The spectra will be used to derive carbon abundances, silicon abundances, electron densities, and the ionization structure in several HII regions.

**Results:**

High-dispersion spectra have been obtained of N81 and N66A in the SMC, the 30 Doradus Nebula in the LMC, NGC 2363 in the SBm galaxy NGC 2366, NGC 5471 in M101, and NGC 604 in M33, that are superior in quality to low-dispersion spectra in the statistical accuracy and resolution of the nebular emission lines of ions such as C III], Si III], N III], and O III]. These data were combined with ground-based spectroscopy to diagnose physical conditions (temperatures, densities, and ionization) and abundances in over twenty extragalactic H II regions.

**Publications:**

Dufour, R.J., Schiffer, F.H. III, and Shields, G.A., "IUE Spectroscopy of Extragalactic H II Regions", in *Eight Years of UV Astronomy with IUE*, ESA SP-263, 111 (1986).

**Title:** Rotational Broadening of Photospheric Lines in Later-Type B Stars

**Program ID:** OBGGS    **PI:** G. Sonneborn

**Statement of Work:**

IUE observations of late-type B stars will be used to derive UV line widths. These results will be compared to those previously obtained for the early-type B stars. In these stars, discrepancies in spectral line widths between UV and visual wavelength regions occurs in some stars with large  $v \sin i$ . The data will be used to determine the variations in UV photospheric line widths as a function of  $v \sin i$  and spectral type and to provide a homogeneous set of UV line profiles for comparison with high-resolution visual spectra for the same stars.

**Results:**

High-dispersion images of 49 B stars were analyzed. The wavelength, FWHM, and equivalent width of photospheric C II, Si III, Si II, and Al III absorption lines were measured for each star. The UV line widths were compared to model line profiles and visual line measurements for each star to derive a UV  $v \sin i$  calibration.

**Publications:**

Carpenter, K. Slettebak, A., and Sonneborn, G., "Rotational Velocities of Later B-type and A-type Stars as Determined from Ultraviolet vs. Visual Line Profiles", *Ap. J.*, **286**, 741 (1984).

**Title:** UV Spectral Classification of B Stars

**Program ID:** HSGGS    **PI:** G. Sonneborn

**Statement of Work:**

A new study of ultraviolet spectral classification of B stars using high-dispersion IUE archival data will be performed. High-dispersion SWP spectra of MK standards and other B stars will be retrieved from the IUE archives and compacted to a uniform resolution on the order of 0.5 Å. The spectra will then be examined in order to set up a two-dimensional classification matrix, following the method used to create the MK classification system for visual spectra. An atlas of standard spectra that will enable other IUE observations to classify spectra on this system will be produced.

**Results:**

Some 39 SWP high-dispersion images of B stars (luminosity classes V, IV, and III) were reprocessed. These images and 75 others were analyzed in order to facilitate the eventual creation of a comprehensive two-dimensional classification scheme.

**Publications:** None

**Title:** Time-Resolved Spectroscopy of Superhumps in Eclipsing SU UMa Systems,

**Program ID:** CVHGS     **PI:** G. Sonneborn

**Statement of Work:**

OY Car will be observed during superoutburst when the red component eclipses the accretion disk and the spot is at a maximum. These observations will be used to examine the applicability of the spot model and, if correct, analyze the physical characteristics of the spot.

**Results:**

Ultraviolet IUE and X-Ray EXOSAT observations were obtained of the eclipsing dwarf nova OY Carinae during the superoutburst of 1985 May. From the lack of X-ray eclipse and UV behavior it is deduced that the X-ray flux originates in an optically thin corona comparable in size to the Roche lobe, and not directly from the white dwarf or boundary layer. The asymmetric UV line emission originates partly in the accretion disc and partly in a wind. There is a strong modulation of the UV continuum flux that is possibly caused by extended vertical disc structure shadowing the inner regions.

**Publications:**

Harlaftis, E., Hassall, B.J.M., Sonneborn, G. Taylor, T., and Charles, P.A., "IUE Observations of the 1987 Superoutburst of the Dwarf Nova Z Cha", in *A Decade of UV Astronomy with the IUE Satellite*, ed. E.J. Rolfe, ESA SP-281, 187 (1988).

**Title:** Phase-Resolved Spectroscopy of the Ap Si Star 56 Arietis

**Program ID:** APHGS     **PI:** G. Sonneborn

**Statement of Work:**

Existing SWP high-dispersion images of 56 Ari will be analyzed to provide phase-resolved spectroscopy of an Ap Si star, 56 Ari. These will be used to examine the complex flux redistribution mechanism due to silicon absorption as a function of phase and wavelength.

**Results:**

Detailed light curves from 1150 to 8000Å have been derived for 56 Ari from new IUE UV spectrophotometry and optical data from the literature. This is made possible by the great stability of 56 Ari's variability and the accuracy of the measured ephemeris. The wavelength dependence of the amplitude of the variations shows a sharp break at 1315Å, which is identified with photoionization of Si II  $3s3p^2 \ ^2D$ , and a broad band at 1400Å which has been identified with Si II photoionization. The synchrony of the variation of the strength of the 1315Å edge, the 1400Å band, and a band at 1550Å with optical spectral lines confirm the identification of these features with Si II. The factor of 2 variation in flux below 1315Å, in only one quarter of a stellar rotation, indicates that a region filling about half of a hemisphere must be so rich in silicon as to be nearly perfectly black below the Si II photoionization edge at 1306Å. Model atmosphere calculations allow an empirical estimate for the Si II  $3s3p^2 \ ^2D$  cross-section of about  $1 \times 10^{-16} \text{ cm}^{-2}$ ; theoretical confirmation is needed. The photometric variation above and below 1600Å is roughly anti-phased. The observations confirm earlier suspicions that the variation of the strong UV features of Si II drives the photometric variability of 56 Ari, and presumably other Ap Si stars as well, through the action of flux redistribution. The light curves at the various wavelengths show remarkable differences in exact phase and shape which indicate that the mechanism of flux redistribution is complex.

**Publications:**

Sonneborn, and G., Panek, R.J., "Ultraviolet Variability and Flux Redistribution in the Ap Si star 56 Arietis", *B.A.A.S.*, 16, 893 (1984).

Shore, S.N., Brown, D.N., Sonneborn, G., and Gibson, D.M., "The Rapidly Rotating AP Stars as a Test of Stellar Chromospheric Heating Mechanisms", *Astr. Ap.*, 182, 285 (1987).

**Title:** UV Flux Distributions in Later-Type B and Be Stars

**Program ID:** HSHGS    **PI:** G. Sonneborn

**Statement of Work:**

IUE observations of stars of spectral types B5-B9 will be used to determine the flux distributions of a group of rapidly rotating B and Be stars with very low interstellar reddening. The data will be examined for systematic differences between rotating and non-rotating B stars and between B and Be stars with similar  $v \sin i$  and spectral type, as well as for evidence of circumstellar extinction in the Be stars. The spectra will also be compared against model flux distributions for rapidly rotating B stars.

**Results:**

Coordinated ultraviolet and visual observations of the B2 IIIe star  $\omega$  Ori made during 1982-1983 reveal the Si IV and C IV ultraviolet resonance line profile variability to be uncorrelated with the visual continuum polarization state of the star. The IUE spectra and visual data cover periods of both high and low linear polarization and have been supplemented by archival IUE spectra from 1978-1984. Variations in visual colors and continuum fluxes are correlated with the amount of the linear polarization.  $H\alpha$  emission-strength variations are at best weakly correlated with the polarization activity. The lack of correlation between the highly ionized stellar wind and the continuum polarization and flux variations is interpreted as evidence for the spatial separation of the wind-acceleration zone and the inner portion of the envelope. Similarly, the lack of correlation between the  $H\alpha$  fluxes and continuum changes is interpreted as indicating that the  $H\alpha$  line-formation zone is much more extended than the regions of the envelope where the stellar wind lines and the polarization are formed.

**Publications:**

Sonneborn, G., Grady, C.A., Wu, C.-C., Hayes, D.P., Guinan, E.F., Barker, P.K., and Henrichs, H.F., "Mass Loss in a B2 IIIe Star: Omega Orionis 1978-1984", *Ap.J.*, 325, 784 (1988).

**Title:** Superoutburst Development in Eclipsing SU UMa Systems

**Program ID:** CVIGS     **PI:** G. Sonneborn

**Statement of Work:**

IUE observations of two eclipsing SU UMa systems will be obtained during superoutburst on a target of opportunity basis. A determination will be made of how the line and continuum emissions vary with orbital phase at times when the superhump maximum is well outside of the eclipse. This information will be used to probe the structure of the line and continuum emitting regions.

**Results:**

Low-resolution IUE observations were made of the dwarf nova Z Cha during superoutburst. These cover most of the development of the outburst and have sufficient time resolution to probe continuum and line behavior on orbital phase. The observed modulation on these phase is very similar to that observed in the related object OY Car. The results imply the presence of a "cool" spot on the edge of the edge of the accretion disk, which periodically occults the brighter inner disk. Details of the line behavior suggest that the lines originate in an extended wind-emitting region. In contrast to archive spectra obtained in normal outburst, the continuum is fainter and redder, indicating that the entire superoutburst disk may be geometrically thicker than during a normal outburst.

**Publications:**

Taylor, T., Bath, G.T., Charles, P.A., Hassall, B.J.M., Sonneborn, G., van der Woerd, H., and van Paradijs, J., "The 1985 May Superoutburst of the Dwarf Nova OY Carinae - II. IUE and EXOSAT Observations", *M.N.R.A.S.*, **231**, 237 (1988).



**Title:** Lyman Alpha Spectra of Three Standard Candles

**Program ID:** SDITS      **Co-I:** G. Sonneborn

**Statement of Work:**

Small-aperture IUE spectra will be obtained of the hot dwarf or subdwarf companions of three binary stars, AY Ceti, 29 Draconis, and HD 185510. These special observations will reduce the contamination of geocoronal emission from the stellar Lyman-alpha line profiles. The higher quality of these spectra will permit the derivation of effective temperatures and surface gravities of the hot stars as well as the refinement of the masses, radii, and other parameters of the binary stars.

**Results:**

AY Cet is a single-line binary comprised of a spotted G5 III primary and a white dwarf secondary. A series of UV spectra were obtained with the IUE satellite on five different dates covering a substantial part of the optical cycle of the primary star. No evidence was found that the continuum or the Ly $\alpha$  absorption line of the secondary star varied. There were significant changes in the strengths of the UV emission lines, but the variations were only weakly correlated with either the orbital phase of the binary or the rotational phase of the primary. The UV emission lines were especially strong near maximum visual brightness at a time when the starspot(s) on the primary was least visible. The enhanced line emission is attributed to a flare event on the primary, most likely at a high-latitude site close to the pole of this star. The UV radiative losses of this flare were comparable with those of flares previously observed on the RS CVn variables  $\lambda$  And and HR 1099.

**Publications:**

Simon, T., and Sonneborn, G., "The Ultraviolet Variability of AY Ceti", *A.J.*, **94**, 1657 (1987).

**Title:** Small-Scale Structure of the ISM in Orion OB1

**Program ID:** ISJGS    **PI:** G. Sonneborn

**Statement of Work:**

The small-scale structure of the expanding shell of high-velocity gas surrounding the Orion OB1 association will be mapped out using IUE data. The primary goals of the program are to (1) map the variation in column density, abundances and ionization structure of the shell centered on Orion OB1, (2) probe the shock structure near the edge of the shell toward Barnard's loop and (3) look for sub-parsec structure in the high velocity gas along selected sight lines. The observations will be used to test current models of interstellar shocks and the role OB associations play in the overall dynamics of the interstellar gas in the galaxy.

**Results:**

Results have been obtained for a study of the small scale dynamics and structure of the interstellar medium of the Orion OB1<sub>b,c</sub> Association using new and reprocessed archival high dispersion SWP and LWR/LWP spectra. The area surveyed centers on the Belt and encompasses the Orion Cloak. The dynamics and abundances of the ionized and warm neutral gas surrounding the central parts of the association were determined using about 35 B stars. A comparison of these results with the picture of the Orion interstellar medium gained using Copernicus, especially for the structure and dynamics of the Orion Cloak, has been made.

**Publications:**

Sonneborn, G., Shore, S.N., and Brown, D.N., "The Small Scale Structure of the Interstellar Medium in the Orion Association: The Flotsam of Star Formation", in *A Decade of UV Astronomy with the IUE Satellite*, ed. E.J. Rolfe, ESA SP-281, 231 (1988).

**Title:** Alpha Orionis

**Program ID:** LSJAD      **Co-I:** G. Sonneborn

**Statement of Work:**

IUE observations of the M supergiant Alpha Ori will be obtained over a two year period, in conjunction with coordinated ground-based observations. Ultraviolet spectra will be obtained over a portion of the 5.8 year period to follow the decay of the chromospheric activity and the radial velocity variations.

**Results:**

Ultraviolet spectroscopy and optical photometry of Alpha Orionis (M2 Iab) have been obtained at approximately two-week intervals from January 1984 through April 1986. The ultraviolet (2950Å - 3050Å ) and optical continua are found to vary in phase with each other. The Mg II h and k total emission flux is similarly modulated, but lags the optical light curve by about 0.25 years. However, the h and K lines fluxes vary by different amounts and in a manner which suggests a periodicity of about one year. These and other spectral variations may be causally linked to atmospheric disturbances, possibly related to a close stellar companion.

**Publications:**

Sonneborn, G., Baliunas, S.L., Dupree, A.K., Guinan, E.F., and Hartmann, L., "Long-Term Spectroscopic Monitoring of Alpha Orionis", in *New Insights in Astrophysics: 8 Years of UV Observations with IUE*, ed. E.J. Rolfe, ESA SP-263, 221 (1986).

**Title:** SN 1987A

**Program ID:** None     **PI:** G. Sonneborn

**Statement of Work:** Supernova 1987a in the Large Magellanic Cloud

IUE spectra of the bright supernova in the Large Magellanic Cloud will be obtained and analyzed. The ultraviolet spectra will be deconvolved to yield the individual spectra of Star 2, Star 3, and the Supernova. The changes in the ultraviolet flux levels will be monitored carefully, to be used not only in analysis of the development of the supernova but in planning subsequent observations of the supernova by IUE and by other experiments.

**Results:**

Ultraviolet observations of the supernova in the Large Magellanic Cloud, SN 1987A, were carried out with the *International Ultraviolet Observer* satellite. The first observations were obtained at 1987 February 24.80, 14 hr after the discovery. The earliest data show that the UV flux from the supernova was already declining while the optical flux was still rising. The UV spectrum at these epochs consists of broad features associated with the supernova atmosphere punctuated by sharp interstellar absorptions. The long-wavelength ultraviolet resembles the spectrum of a SN I, which is attributed to the absence of a circumstellar envelope and the presence of line absorption, perhaps due to Co II and Fe II. The rapid decline of the supernova in the short-wavelength ultraviolet allows a glimpse of the stars which remain. One of these is star 2, a neighbor of Sanduleak -69°202, the other appears to be star 3, a fainter close neighbor of the Sanduleak star. If this is correct, then the star which exploded is Sanduleak -69°.

**Publications:**

- Crenshaw, D.M., Sonneborn, G., and Kirshner, R.P., "IUE Low-Dispersion Spectra of Supernova 1987A", *B.A.A.S.*, **19**, 752 (1987).
- Dupree, A.K., Kirshner, R.P., Nassiopoulos, G.E., Raymond, J.C., and Sonneborn, G., "The Interstellar Medium Towards SN 1987A", *Ap.J.*, **320**, 597 (1987).
- Kirshner, R.P., Sonneborn, G., Crenshaw, D.M., and Nassiopoulos, G.E., "Ultraviolet Observations of SN 1987A", *Ap.J.*, **320**, 602 (1987).
- Sonneborn, G., Altner, B., and Kirshner, R.P., "The Progenitor of SN 1987A: Spatially Resolved Ultraviolet Spectroscopy of the Supernova Field", *Ap.J.*, **323**, L35 (1987).

**Title:** The Unusual Pulsating Variable XZ Ceti

**Program ID:** CAKTT    **PI:** T. Teays

**Statement of Work:**

IUE and optical spectra of the pulsating variable XZ Ceti will be used to determine its relation to other types of pulsating variables. The UV and optical continua will be used to determine the star's temperature and effective gravity. The behavior of possible Mg II emission as a function of pulsation phase will also be studied.

**Results:**

The unique pulsating variable star XZ Ceti has been proposed as a possible Anomalous Cepheid by Teays and Simon (*Ap. J.*, 290, 683), which, if it turns out to be the case, would be only the second one discovered in our galaxy. This program was aimed at searching for an early-type companion to XZ Cet, which might be expected to be present if some of the theoretical scenarios were correct. Low-dispersion IUE spectra were obtained, using both cameras. There is no evidence of a hot companion in these spectra. The continuum slope was compared to Kurucz model atmospheres and archival white dwarf spectra. The UV energy spectra could be well matched to a Kurucz model with a temperature of 6500K and surface gravity of  $\log g = 2.5$ . This confirms the conclusions drawn based on the PI's earlier energy distributions obtained at Cerro Tololo Inter-American Observatory, in the visual wavelengths. If the standard theory is assumed to be correct, then this (originally binary) star appears to have already coalesced.

**Publications:** None

**Title:** Emission in TU Cas at Maximum Brightness

**Program ID:** BCKTT     **PI:** T. Teays

**Statement of Work:**

IUE spectra of the beat Cepheid TU Cas will be obtained when the variable star's light curve is at "super maximum". Emission features will be used to determine whether the chromospheres in Cepheids are driven by pulsation or by convection.

**Results:**

This program's purpose was to obtain UV spectra of the beat Cepheid, TU Cas, when it was experiencing the largest amplitude variation seen in its complicated pulsation cycle. Simultaneous ground-based spectroscopy and photometry were scheduled at observatories in Hungary, Canada, and Mexico. Unfortunately, the last two sights were unable to obtain good spectra due to poor weather and equipment failure. The two IUE spectra (LWP) did not show any evidence of emission in the line core of the Mg II resonance doublet, in spite of previous suggestions of its presence during rising light in H alpha. The IUE data have been reduced and analyzed, and the results sent to L. Szabados, in Budapest, who is integrating them with the ground-based data.

**Publications:** None

**Title:** Chromospheres of Delta Scuti Stars

**Program ID:** CCKTT    **PI:** T. Teays

**Statement of Work:**

A study of the chromospheres of dwarf Cepheids with IUE will be continued. The observations will follow the variation of the emission throughout several consecutive pulsational cycles. The goal is to gain insight into both the excitation of chromospheres by pulsation and the details of the pulsation itself.

**Results:**

This was a collaborative program with several Italian colleagues to study the ultraviolet characteristics of delta Scuti stars. In previous programs the stars Rho Pup and Beta Cas were studied. In program CCKTT, omicron (1) Eri and tau Cyg were examined. Altogether, 27 high-dispersion LWP spectra were obtained of omicron (1) Eri, thoroughly covering more than two pulsation cycles. No emission is seen in the line core of the Mg II lines in any of these spectra. Simultaneous ground-based CCD photometry was obtained by E. G. Schmidt at Behlen Observatory. All of the data reduction and analyses for this program have been completed. Preliminary reports have been presented at meetings, and publications in refereed journals are in press or being prepared. For the suspected delta Scuti variable, tau Cyg the coverage is less extensive, but there appears to be emission in the Mg II line core in all seven of the spectra. This emission does not appear to vary with pulsation cycle, as was seen in beta Cas and rho Pup, but is generally stronger than in those two stars.

**Publications:**

Fracassini, M., Pasinetti Fracassini, L. E., Pastori, L., Schmidt, E. G., and Teays, T. J., "Chromospheric Activity in Delta Scuti Stars: The Suspected Variable Tau Cyg", *Astr. Ap.*, in press (1991).

Teays, T. J., Pasinetti Fracassini, L. E., and Schmidt, E. G., "Phase Dependent Mg II Emission in Delta Scuti Stars", *B.A.A.S.*, 21, 789 (1989).

Pasinetti Fracassini, L. E., Pastori, L., Schmidt, E. G., and Teays, T. J., "Search for Possible Chromospheric Activity in the Delta Scuti Star Omicron (1) Eri", in *The Confrontation between Stellar Pulsation and Evolution*, ed., C. Cacciari and G. Clementini (San Francisco: A.S.P.), 230 (1990).

Pasinetti Fracassini, L. E., Pastori, L., Schmidt, E. G., and Teays, T. J., "Possible Evidence of Mass Loss in the Population I Instability Strip" in *The Confrontation between Stellar Pulsation and Evolution*, ed., C. Cacciari and G. Clementini (San Francisco: A.S.P.) (1990).

**Title:** Cepheid Temperatures: Delta Cephei

**Program ID:** DCKTT    **PI:** T. Teays

**Statement of Work:**

A homogeneous set of SWP and LWP observations of Delta Cep will be obtained, which will span its temperature range. The IUE observations will be combined with optical and infrared data to map the flux distribution of Delta Cep over its temperature range.

**Results:**

This program was aimed at improving our understanding of the temperatures of Cepheid variable stars, a matter of some controversy over the years. Pairs of low-resolution LWP and SWP spectra were obtained of delta Cep at selected phases during the descending branch of the light curve, which covered the temperature range of the pulsation cycle. All of the observations for this program were successfully completed. The spectra were corrected for reddening and binned to form UV colors, which were then compared to archival spectra of non-variable supergiants. The Cepheid colors on the descending branch of the light curve form a tight sequence, as a function of unreddened (B-V), but one which is systematically offset from the non-variable supergiants. These preliminary results led to a follow-on program for IUE's 13th episode. All of these results have been sent to the Lead Investigator, N. R. Evans. These Cepheid spectra also played a role as template spectra for studying the binary Cepheid FF Aql.

**Publications:**

Evans, N.R., Welch, D.L., Scarfe, C.D., and Teays, T.J., "The Orbit and Companions of the Classical Cepheid FF Aql", *A.J.*, **99**, 1598 (1990).



**Title:** Target of Opportunity Observations of Novae and X-ray Novae

**Program ID:** CVGCW     **PI:** C.-C. Wu

**Statement of Work:**

If a suitable nova occurs, spectra at visual maximum, during the post-maximum decay, and if possible during the premaximum rise will be obtained. Low-dispersion spectra will be used to follow the evolution of the continuum and line spectrum and to derive the interstellar extinction and distance of the nova. The time sequence of spectra will be used to derive information on the evolution of effective temperature, luminosity, physical conditions, and abundances of the nova.

**Results:**

GK Per was observed in 1981 with the IUE, during its rise, maximum, and subsequent return to minimum. In outburst, GK Per is luminous but much redder than dwarf novae or standard model accretion disks. The observed spectrum can be explained qualitatively with the Ghosh and Lamb model for the interaction of an accretion disk with the magnetic field of the accreting white dwarf. N V and He II are enhanced relative to other emission lines during outburst. This can be understood with photoionization by very soft X-rays having a luminosity comparable to that of the hard X-rays.

**Publications:**

- Wu, C.-C., Holm, A.V., Raymond, J.C., Hartmann, L.W., and Swank, J.H., "The 1981 Outburst of the Old Nova GK Persei", in *A Decade of UV Astronomy with IUE*, ESA SP-281, Vol. 1, 155 (1988).
- Wu, C.-C., Panek, R.J., Holm, A.V., Raymond, J.C., Hartmann, L.W., and Swank, J.H., "Ultraviolet Spectrophotometry and Optical and Infrared Photometry of the Old Nova GK Persei", *Ap.J.*, **339**, 443 (1989).
- Starrfield, S., Stryker, L. L., Sonneborn, G., Sparks, W.M., Ferland, G., Wagner, R.M., Williams, R.E., Gehrz, R.D., Ney, E.P., Kenyon, S., Wade, R., Truran, J.W., and Wu, C.-C., "Observations of Classical Novae in Outburst", in *A Decade of Astronomy with IUE*, ESA SP-281, Vol. 1, 159 (1988).
- Starrfield, S., Sonneborn, G., Stryker, L.L., Sparks, W.M., Truran, J.W., Ferland, G., Wagner, R.M., Gallagher, F.S., Wade, R., Williams, R.E., Gehrz, R.D., Ney, E.P., Kenyon, S., Wade, R., Shaviv, G., and Wu, C.-C., "Observations and Simulations of Nova Vul 1984 No. 2: a Nova with Ejecta Rich in Oxygen, Neon, and Magnesium", in *A Decade of Astronomy with IUE*, ESA SP-281, Vol. 1, 163 (1988).

**Title: Short Time Variations in the Mass-Loss Rate of Early-Type Stars**

**Program ID: MLGCW    PI: C.-C. Wu**

**Statement of Work:**

Frequent monitoring will be carried out with IUE of a few Be and O stars which are known to be currently active. High time-resolution observations will be obtained to follow the behavior of UV shell lines or enhanced low velocity absorption lines, if these occur. The data will be used to examine models which attempt to explain the lack of intermediate velocity shell lines, to derive the velocity law for the stellar wind, to examine the ionization structure of the gaseous envelope, to study the brief shell phase of the Be stars, and to determine the time scales for this phenomenon.

**Results:**

Twenty-five high-resolution SWP images of  $\xi$  Per (07.5 III  $v \sin i \sim 200$  km/s) obtained with the IUE satellite over a 2.5 day period in October 1984 showed dramatic changes in the Si IV P Cygni profiles. (The C IV and N V profiles are saturated and indicate a terminal velocity of  $\sim -2600$  km/s.) Superposed on the emission-type P Cygni profile are very broad irregularly shaped variable absorption at velocities between -600 and -2000 km/s, in addition to a discrete narrow absorption feature at  $\sim -2000$  km/s which also varies, similar to previous observations. Our new high time resolution data show that the strength of the broad absorption varies from totally absent up to an equivalent width of  $\sim 6\text{\AA}$  (combined doublet). The broad feature seems to set in at -800 km/s, increases in strength, narrows and consequently decreases. Because of the irregular structure a particular velocity cannot be assigned to the broad feature (complicating the derivation of a velocity law, apart from possible ionization affects), but it is very clear that its weighted mean velocity increases with time and that the acceleration stops at the velocity of the narrow feature. In other words, the (always present) narrow high-velocity components are the remnants of the broad low-velocity features. These data, combined with earlier obtained spectra, seem to suggest a quasi-periodic behavior in the appearance and development of the broad feature. The recurrence period is about 1.4 d, which might be related to the stellar rotation period of about 2.8 d. Not enough data exist to establish whether the cycle is really periodic like in  $\beta$  Cep. Such behavior is not known for any other star. The observed behavior may be explained in terms of an expanding, strongly shocked region in the stellar wind, although quantitative support for this view is difficult to provide and alternative explanations may exist.

**Publications:**

"Quasi-Periodic Modulation in the Stellar Wind of Xi Per", Henrichs, H.V., Prinja, R.K., Howarth, I.D., Wu, C.-C., Sonneborn, G., and Grady, C.A., *B.A.A.S.*, 17, 513 (1985).

**Title:** Variations in the Mass-Loss Rate and Linear Polarization of Be Stars

**Program ID:** MLHCW    **PI:** C.-C. Wu

**Statement of Work:**

Coordinated IUE and optical polarimetric observations of a few stars which are shown to be currently active will be obtained. High time-resolution observations both of the UV resonance line profiles and optical linear polarization in the wavelength range 4000-7000 Å will be made. These data will be used to determine whether the episodes of enhanced linear polarization are associated with episodes of enhanced mass loss observed in the UV, and to pin down the geometry and timescales for formation, development, and disappearance of episodes of enhanced mass loss from OB stars near the main sequence.

**Results:**

High-dispersion ultraviolet spectra obtained with the IUE of the B2 IV-Ve star 66 Oph have revealed that the conspicuous changes in the profiles of C IV, Si IV, Si III, and Al III are associated with recurrent, episodic variation in the number, distribution in radial velocity, and strength of multiple shortward-shifted discrete absorption components. Forty spectra obtained between 1982 April and 1985 June indicate that the stellar wind in 66 Oph went through at least two and probably three episodes of weak-wind absorption. At wind minimum, the resonance profiles and equivalent widths of C IV, Si IV, Si III, and Al III are similar to those observed in normal B stars of comparable luminosity, effective temperature and  $v \sin i$ . The strong-wind absorption profiles show one or more shortward-shifted discrete components superposed upon the weak-wind absorption profiles. Significant profile variations are seen on time scales spanning over 2 orders of magnitude, ranging from small-amplitude changes detected on time scales of hours to the transitions from wind minimum to wind maximum, which take months. The study period included one transition from wind maximum to wind minimum in 1982. During this event the high velocity ( $v < -250 \text{ km s}^{-1}$ ) absorption vanished first, followed by a gradual decay in the low-velocity ( $-200 \text{ km s}^{-1}$ ) feature over the next 2 to 3 weeks. The mass-loss episodes observed in 1982-1985 were remarkably regular, but observations obtained from 1985 to 1987 indicate that the episodes are not periodic. Comparison of the available IUE archival data obtained in 1982 with linear polarimetry reported by Hayes suggests that little correlation exists between linear polarimetric episodes and wind variability.

**Publications:**

Grady, C.A., Sonneborn, G., Wu, C.-C., and Henrichs, H.F., "Recurrent Episodic Mass Loss in a B2e Star: 66 Ophiuchi 1982-1985", *Ap.J. Suppl.*, 65, 673 (1987).

**Title:** Photometric Standards for Space Telescope Instruments

**Program ID:** HSGCW    **PI:** C.-C. Wu

**Statement of Work:**

High quality IUE spectra for stars which can be used to calibrate and serve as photometric standards for the Space Telescope instruments will be obtained. These data will be used to provide the best possible absolute UV energy distributions for stars which can be observed by the ST instrumentation.

**Results:**

A joint European/US program of IUE observations has provided accurate, absolutely calibrated spectrophotometric data for a set of selected stars covering a wide range of brightness to facilitate calibration of the *HST* and other future UV astronomy missions. The faint ( $V = 14-15.5$ ) White Dwarf stars are particularly crucial for the calibration of most of the sensitive HST instruments.

**Publications:**

Harris, A.W., Gry, C., Bohlin, R.C., Blades, J.C., and Holm, A.V., "The IUE Data-Base of Faint UV Standard Stars for Calibration of the Hubble Space Telescope", in *A Decade of Astronomy with IUE*, ESA SP-281, Vol. 2, 365 (1988).

**Title:** UV Observations of Seyfert Galaxies

**Program ID:** QSGAB    **Co-I:** C.-C. Wu

**Statement of Work:**

High quality, broadened spectra for several Seyfert galaxies will be obtained with IUE. The spectra will be used to perform detailed fitting of line profiles for the investigation of the kinematics, dynamics, and stratification of the emitting regions. They will also be used to provide better measurements of weak spectral features, to estimate the covering factor of the broad line region, and to provide additional information on the galactic halo. X-ray fluxes may be combined with the UV continua to estimate the amounts of ionizing radiation.

**Results:**

The exceptionally narrow-lines Seyfert 1 galaxy Mrk 359 is ideally suited for determining reddening via the He II  $\lambda 1640/\lambda 4686$  emission-line ratio. The validity of He II lines as a reddening indicator for quasars and Seyfert galaxies is reexamined and confirmed in the context of the most complete photoionization models available. In addition,  $\lambda 1640$  equivalent width measurements are shown to support previous contentions of substantial differences between observed and intrinsic quasar far-ultraviolet continua. The IUE satellite and ground-based spectral data show the surprising result that both the  $\lambda 1640/\lambda 4686$  and  $\text{Ly}\alpha/\text{H}\beta$  ratios do not differ greatly from case B recombination values in Mrk 359. This object is only slightly reddened, and it shows no evidence for extended, high-optical-depth,  $\text{H}^+/\text{H}^0$  transition regions in the line-emitting gas. The very narrow lines and lack of deep transition regions and/or reddening may be related. In addition, Mrk 359 has low luminosity compared with most other Seyfert 1 galaxies, measured emission lines suggest an unusually high ionization parameter, and there is a hint of low nitrogen abundance. Further work is needed to examine possible relationships among all these peculiar properties.

**Publications:**

MacAlpine, G.M., Davidson, K., Gull, T.R., and Wu, C.-C., "He II 1640/4686 and Ly Alpha/H Beta Ratios in the Extraordinary Seyfert Galaxy Mrk 359", *Ap. J.*, 294, 147 (1985).

**Title:** UV Observations of Seyfert Galaxies

**Program ID:** AGHAB    **Co-I:** C.-C. Wu

**Statement of Work:**

High-quality, broadened spectra for several Seyfert galaxies will be obtained with the IUE. These spectra will provide better line profiles for modelling, more accurate measurements of weak-emission features, and better information on the broad features seen at several wavelengths. X-ray fluxes will be combined with the UV continua to estimate the amounts of available ionizing radiation.

**Results:**

The full widths at 10% intensity level were compared for the prominent emission lines: Lyman  $\alpha$ , C IV  $\lambda 1550$ , C III]  $\lambda 1909$ , Mg II  $\lambda 2800$ , H $\beta$ , H $\alpha$ . The widths of the ultraviolet lines are measured from the low-dispersion spectra obtained by the International Ultraviolet Explorer (IUE). The widths of optical lines are mostly those published by Osterbrock and Shuder. In Seyfert galaxies, C IV  $\lambda 1550$  is significantly broader than the other emission lines. This indicates that ions of higher ionization potential produce broader emission lines. This phenomenon is not common in high redshift and high luminosity quasars. Wu, Boggess and Gull and Mushotsky argued earlier that lower luminosity active galaxies have higher covering factor. The higher covering factor in Seyfert galaxies may cause significant shadowing effect in the Broad Line Region and this leads to more pronounced stratification of the BLR according to the available ionizing radiation. The centroid velocity of the UV lines were also compared with published redshifts based on the optical emission lines. The C IV line is found to have lower redshift.

**Publications:**

Wu, C.-C., Grady, C.A., and Boggess, A., "Comparison of the Widths of Broad Emission Lines in Seyfert Galaxies and Quasars", *B.A.A.S.*, 16, 987 (1984).

**Title:** UV and Optical Observations of Liners

**Program ID:** AGHCW    **PI:** C.-C. Wu

**Statement of Work:**

New IUE observations of 4 Liners will be obtained and combined with IUE archival images of 3 Liners and optical observations carried out at groundbased telescopes. The spectra will be analyzed for several purposes: (1) to establish whether the observed ultraviolet continua indicate sufficient ionizing flux to photoionize the gas and produce the emission lines, (2) to determine from stellar population synthesis whether the ionizing continua can be explained by stars alone, and (3) to search for systematic differences in the ultraviolet spectra of Liners whose emission-line properties differ in some respects.

**Results:**

Recent IUE observations have been made of two LINERs, NGC 3998 and NGC 404. In both objects, the spatial profile of the long wavelength emission (i.e., perpendicular to the dispersion direction) shows a two-component structure, consisting of an unresolved (size less than 1 arcsec) core superimposed on broader underlying emission. Similar spatial structure is not apparent in the SWP images, probably due to the lower signal-to-noise ratios. Recently developed software, has been applied, using the known spatial responses of the IUE cameras to separate the LWP images into core and extended component spectra. In both cases, the core component spectra are much flatter than the extended component spectra, which are dominated by fairly late type (late F to early G) stars. In NGC 3998, the core component also shows strong MgII  $\lambda$ 2800 and CII]  $\lambda$ 2326 emission lines; the MgII emission is broad (FWZI  $\sim$ 8600 km/s) and its profile matches that of the broad component seen in H $\alpha$ . One of the LWP spectra also shows possible extranuclear MgII line emission. Since NGC 3998 is similar to M81 in other respects, it may be another likely case for photoionization by a nonstellar continuum. There are broad peaks at both 1500 and 1800Å in the SWP spectra for NGC 404, and there is possible absorption at the wavelengths expected for redshifted SiIII]  $\lambda$ 1300, SiIV  $\lambda$ 1400, and CIV  $\lambda$ 1550, indicating the possible presence of hot (O and B) stars. Hence, these data may provide evidence for the presence of two distinct stellar populations.

**Publications:**

Reichert, G.A., Wu, C.-C., and Filippenko, A.V., "Spatially Resolved Ultraviolet Spectroscopy of the Liner NGC 3998", in *A Decade of Astronomy with IUE*, ESA SP-281, Vol. 2, 307 (1988).

Reichert, G.A., Wu, C.-C., and Filippenko, A.V., "IUE Observations of NGC 3998 and NGC 404: Spatially Resolved Ultraviolet Spectroscopy of the Central Regions", *B.A.A.S.*, 20, 970 (1988).

**Title:** UV Observations of Low Redshift Quasars

**Program ID:** QSHCW    **PI:** C.-C. Wu

**Statement of Work:**

High signal-to-noise pseudo-trailed IUE spectra will be obtained for low redshift quasars in order to perform detailed comparisons with existing spectra of similar high quality for Seyfert 1 galaxies. The morphological distinction of "Seyferts" and "quasars" will be examined in respect to the physical properties indicated from their IUE spectra. The phenomena observed for active galaxies will be studied to see whether they can be explained by a limited number of parameters, e.g., evolutionary stage, luminosity, radio properties or Fe II emission strength.

**Results:** Near-simultaneous IUE and Voyager ultraviolet spectrometer (UVS) observations were made of 3C 273, obtained during the period of 1985 late July-early August. The data cover a total combined wavelength range 500-3200Å (observed frame). This is the first time that observations shortward of 1200Å have been obtained for any extragalactic object. The source was significantly detected for all observed wavelengths above 912Å, at a level (for  $\lambda_{obs} > 1060\text{Å}$ ) consistent with previous optical and IUE observations. The UVS data show a significant drop in flux for observed wavelengths below 1060Å. This may be due to Lyman continuum absorption in the rest frame of 3C 273. If so, then the lack of associated Lyman  $\alpha$  absorption severely constrains the properties of the absorbing medium. The most plausible explanation may therefore be that the edge is due to absorption in an accretion disk within the nucleus of 3C 273. Alternatively, models in which the drop in flux is due to a turnover in the underlying continuum cannot be excluded; this interpretation raises serious questions concerning the total energy budget in the broad-line regions. In either case, there can be *no* reddening of the source of continuum emission other than that due to our own Galaxy.

**Publications:**

Reichert, G.A., Polidan, R.S., Wu, C.-C., and Carone, T.E., "Voyager and IUE Observations of 3C 273: Detection of Possible Lyman Continuum Absorption in a Nearby ( $Z=0.158$ ) Quasar", *Ap. J.*, **325**, 671 (1988).



**Title:** K Giant Spectra for Stellar Population Models

**Program ID:** CSHDB      **Co-I:** C.-C. Wu

**Statement of Work:**

A library of IUE spectra of old stellar populations will be established, concentrating on late-type giant stars. These will be compiled for use in analyzing composite galaxy spectra for temperature, metallicity, and gravity of the stellar population.

**Results:**

Low-resolution IUE spectroscopy of the  $\lambda$  2800 Mg II *h* and *k* lines is shown to provide a useful means for documenting chromospheric activity among relatively young dwarf stars. An index  $I(\text{Mg II})$  has been defined which measures the integrated flux in the region  $\lambda\lambda$  2784–2814 relative to the flux interpolated from nearby comparison regions. Values of this index have been derived from low-resolution IUE spectra for a sample of field dwarfs for which Ca II H and K line indices have been published as part of the Mount Wilson HK program. The large range in chromospheric activity among field dwarfs that is exhibited by the Mount Wilson Ca II S index is found to also be reflected by the lower resolution  $I(\text{Mg II})$  index. Using an age calibration of Ca II emission line strengths derived by Barry, it is found that the value of  $I(\text{Mg II})$  can be used to distinguish between dwarfs younger and older than  $\sim 3$  Gyr. The low-resolution nature of the  $I(\text{Mg II})$  index means that it holds potential for use as an age diagnostic for stellar population studies. Among dwarfs of age greater than 3 Gyr there is some evidence that this Mg II index is affected by line blanketing.

**Publications:**

Smith, G.H., Burstein, D., Fanelli, M.N., O'Connell, R.W., and Wu, C.-C., "Low-Resolution IUE Spectroscopy of the 2800 Å Mg II Lines: A Possible Age Diagnostic for Stellar Populations", *A.J.*, 101, 655 (1991).

**Title:** UV Observations of the Blue Star Behind the Young Type I SNR of AD 1006

**Program ID:** SNHRF      **PI:** C.-C. Wu

**Statement of Work:**

Ultraviolet spectra of an sd OB star situated behind the young galactic supernova remnant of AD1006 will be obtained. The new spectra will allow (1) confirmation of the high velocity redshifted Si lines, (2) more accurate Fe+ line profile and equivalent widths providing a better iron mass estimate, and (3) investigation of Co and Ni lines hinted at by the earlier spectra.

**Results:**

New low-dispersion IUE spectra of a faint sdOB star (the "Schweizer-Middleditch" star) located in a direction near the center of the SN 1006 remnant were obtained. Analysis of UV spectra of this star covering the wavelength region 1200–3000Å, which include a reanalysis of earlier IUE spectra (Wu *et al* 1983), indicate the presence of several strong and definitely nonstellar absorption lines in this star's UV spectrum. Broad absorption features at 2370Å and 2600Å are identified as resonance Fe II lines at 2343, 2382, and 2599Å and estimate an Fe II mass within the remnant of  $\approx 0.015 M_{\odot}$  with a radial velocity dispersion of approximately  $\pm 5000 \text{ km s}^{-1}$ . Although this is only a small fraction of the remnant's predicted unshocked iron, the observed shape of the Fe II density profile agrees with that predicted by models of carbon-deflagrated white dwarf explosions. Strong absorption features at 1281, 1331, and 1420Å are interpreted as redshifted absorption lines of Si II 1260 and Si IV 1394, 1403 at a velocity of  $5200 \pm 400 \text{ km s}^{-1}$ , S II 1251, 1254, 1259 at a velocity of  $6000 \pm 1000 \text{ km s}^{-1}$ , and O I 1302 at  $6500 \pm 300 \text{ km s}^{-1}$ . A freely expanding, iron-rich core and high-velocity clumps rich in intermediate-mass elements (O, Si, S) support both a Type Ia classification of SN 1006 and deflagration white dwarf models of Type Ia supernovae.

**Publications:**

Fesen, R.A., Wu, C.-C., and Leventhal, M., "Confirmation of High-Velocity UV Fe and Si Absorption Lines from the Remnant of SN 1006", *B.A.A.S.*, 18, 949 (1986).

Fesen, R.A., Wu, C.-C., Leventhal, M., and Hamilton, A.J.S., "High-Velocity Ultraviolet Iron, Silicon, Oxygen, and Sulfur Absorption Features Associated with the Remnant of SN 1006", *Ap.J.*, 327, 164 (1988).

**Title:** IUE Atlas of Selected Stellar and Extragalactic Objects

**Program ID:** None     **PI:** C.-C. Wu

**Statement of Work:**

Archived IUE spectra will be used to produce a reference atlas of spectra of a variety of astronomical objects. Included in the atlas will be spectra of premain sequence stars, solar system objects, Wolf-Rayet stars, peculiar A and B stars, R CrB stars, RS CVn stars, flare stars, supernova remnants, planetary nebulae, subluminous stars, supernovae, novae, cataclysmic binaries, globular clusters, BL Lac objects, QSOs, and various types of galaxies, including spiral, elliptical, irregular, Seyfert, and radio galaxies.

**Results:**

The "IUE Ultraviolet Spectral Atlas of Selected Astronomical Objects" is intended to serve as a quick reference for the ultraviolet spectra of many categories of astronomical objects. While the 1983 "IUE Ultraviolet Spectral Atlas" emphasizes the photosphere of normal, single, and non-variable stars which are on the main sequence or have evolved to be subgiants, giants, bright giants, and supergiants, the atlas generated under this program attempts to fill in other areas in the Hertzsprung-Russell diagram. In addition, the atlas presents the ultraviolet spectra of many other types of galactic and extragalactic objects. Plots that show the merged short and long wavelength IUE spectra of these objects are presented. Tables that give the final merged fluxes in 5Å bins are also included.

**Publications:**

Wu, C.-C., Reichert, G.A., Ake, T.B., Boggess, A., Holm, A.V., Imhoff, C.L., Kondo, Y., Mead, J.M., and Shore, S.N., "IUE Ultraviolet Spectral Atlas of Selected Astronomical Objects", in press (1991).

**Title:** UV and Optical Observations of Liners

**Program ID:** AGICW    **PI:** C.-C. Wu

**Statement of Work:**

Ultraviolet data will be obtained of a sample of bright Liners using the IUE satellite: The data will be used to establish whether the ultraviolet continua are sufficient to photoionize the gas, whether the ionizing continua can be explained by hot stars alone, and whether there are systematic differences in the ultraviolet spectra of Liners with different emission line properties.

**Results:**

IUE observations have been obtained of the LINER galaxy NGC 3998. Spatial structure in the long wavelength emission is apparent; the spatial profiles in the LWP images show a two-component structure, with an unresolved central component superimposed on extended underlying emission. New software, which exploits knowledge of LWP point spread function and its variation with wavelength, was used to model the spatial profiles and to separate the LWP emission into component spectra. The extended emission is symmetric about the center of the galaxy, and if characterized by a Gaussian, has a sigma of  $\sim 4.5$  arcsec. The centers of the unresolved and extended emission coincide to within 0.22 arcsec. The unresolved component spectrum is considerably flatter than the spectrum of the extended component, which is dominated by fairly late-type stars (late F to early G). The unresolved component also shows strong C II]  $\lambda 2326$  and broad MgII  $\lambda 2800$  emission. The width of the Mg II emission is  $\sim 8000$  km s<sup>-1</sup>, and its profile agrees quite well with the broad wings of the H $\alpha$  emission. The prominence of Mg II relative to C II] indicates that the broad-line emitting gas must be dense ( $n_e \approx 10^8$  cm<sup>-3</sup>). Finally, the spectrum of the unresolved component is also dominated by starlight, but allows a photoionizing power law continuum of sufficient flux to account for the emission-line fluxes if the emission-line spectrum is similar to that seen in M81. These results strengthen the resemblance between NGC 3998 and M81, and further support the idea that NGC 3998 may contain a 'dwarf' Seyfert nucleus.

**Publications:**

Reichert, G.A., Branduardi-Raymont, G., Filippenko, A.V., Mason, K.O., Puchnarewicz, E.M., and Wu, C.-C., "Spatially Resolved Ultraviolet Spectroscopy of the LINER Galaxy NGC 3998", *Ap.J.*, in press (1991).

**Title:** Wind and Polarization Variability in Be Stars

**Program ID:** MLICW     **PI:** C.-C. Wu

**Statement of Work:**

IUE observations will be obtained on short time scales of Be stars suspected to have regular wind variations. Spectrophotometric observations will also be performed in the optical. The data will be used to determine whether short-term variations in mass flux are a general property of Be stellar winds and whether the changes in wind characteristics are associated with changes in the optical linear polarization.

**Results:**

Coordinated ultraviolet and visual observations of the B2 IIIe star  $\omega$  Ori made during 1982-1983 reveal the Si IV and C IV ultraviolet resonance line profile variability to be uncorrelated with the visual continuum polarization state of the star. The IUE spectra and visual data cover periods of both high and low linear polarization and have been supplemented by archival IUE spectra from 1978-1984. Variations in visual colors and continuum fluxes are correlated with the amount of the linear polarization.  $H\alpha$  emission-strength variations are at best weakly correlated with the polarization activity. The lack of correlation between the highly ionized stellar wind and the continuum polarization and flux variations is interpreted as evidence for the spatial separation of the wind-acceleration zone and the inner portion of the envelope. Similarly, the lack of correlation between the  $H\alpha$  fluxes and continuum changes is interpreted as indicating that the  $H\alpha$  line-formation zone is much more extended than the regions of the envelope where the stellar wind lines and the polarization are formed. Comparison of  $\omega$  Ori's wind with those observed in other similar Be stars shows that the wind absorption strength in  $\omega$  Ori is comparable to that reported for other early Be stars during periods of moderately strong to strong wind absorption. The major idiosyncrasy of  $\omega$  Ori's wind from 1978 to 1984 is the absence of any period of B-normal wind characteristics. Significantly, the data demonstrate  $\omega$  Ori's wind on time scales spanning over two orders of magnitude. The shortest observed variation in the highly ionized stellar wind is  $\sim 1.5$  hr, comparable to the expected flow time through the wind acceleration zone. Changes on time scales of months are also seen, both in the wind characteristics and in the presence of polarization episodes. As shown by the data, monitoring short time intervals in either the optical or the ultraviolet alone can lead to misleading interpretations of the overall behavior of this stellar envelope.

**Publications:**

Sonneborn, G., Grady, C.A., Wu, C.-C., Hayes, D.P., Guinan, E.F., Barker, P.K., and Henrichs, H.F., "Mass Loss in a B2 IIIe Star: Omega Orionis 1978-1984", *Ap.J.*, 325, 784 (1988).

**Title:** Galactic Absorption from Low-Dispersion Spectra of Active Galaxies

**Program ID:** GHICW    **PI:** C.-C. Wu

**Statement of Work:**

IUE low-dispersion spectra for selected active galaxies will be combined to improve the signal-to-noise ratio for the data. Absorption lines from the galaxy's disk and halo will be measured and compared to those seen in the spectra of high redshift QSOs. The distribution of line strengths in different directions will be used to give the geometric structure of the galactic halo.

**Results:**

Spectra of two Seyfert galaxies, Mrk 509 and Akn 120, show galactic interstellar absorption lines of S II, Si II, and Fe II, while Si IV is seen in the quasar 3C 273. The lines probably lie within 3 kpc of the galactic disk. Extragalactic absorption lines are found in the spectrum of Mrk 509, with two redshift systems at  $z=0.033$  and  $0.034$  identified to have  $L\alpha$  and both members of the C IV doublet.

**Publications:**

York, D.G., Ratcliff, S., Blades, J.C., Cowie, L.L., Morton, D.C., and Wu, C.-C., "Interstellar Lines in Spectra of Extragalactic Sources. III. Markarian 509, Arakelian 120, 3C 273", *Ap.J.*, 276, 92 (1984).

**Title:** FGK Dwarf Spectra for Stellar Population Models

**Program ID:** LDIDB      **Co-I:** C.-C. Wu

**Statement of Work:**

IUE observations of F, G, and K dwarf stars will be obtained. The new long-wavelength low-dispersion spectra, combined with available spectra in the archives, will be used to create a library of spectra for spectral synthesis and interpretation of composite spectra of old stellar populations.

**Results:**

The far-UV ( $\lambda\lambda$  1230-1900) stellar library has been extended to the mid-UV wavelength range ( $\lambda\lambda$  1900-3200) using low-resolution spectra obtained from the IUE Spectral Atlas and new cool (FGK) star spectra. A set of spectral energy distributions of common stellar types ranging from O3 to M0 is derived for this entire wavelength range. The usefulness of various spectral diagnostics in the mid-UV such as Mg I  $\lambda$ 2852, Mg II  $\lambda$ 2798, and the Fe II blend near  $\lambda$ 2400 was explored. This library will be used to examine the population components in a variety of stellar systems. In particular, it will extend the analysis of the stellar populations in actively star-forming galaxies to cooler (A-F) spectral types, thereby probing the intermediate age (1-5 Gyr) stellar content in these galaxies. The library will also be useful for synthesis of the mid-UV spectra of old stellar populations.

**Publications:**

Fanelli, M.N., O'Connell, R.W., Thuan, T.X., Burstein, D., and Wu, C.-C., "A Mid-UV Stellar Library for Population Synthesis", in *A Decade of Astronomy with IUE*, ESA SP-281, Vol. 2, 377 (1988).

**Title:** UV Observations of Seyfert Galaxies

**Program ID:** AGIAB    **Co-I:** C.-C. Wu

**Statement of Work:**

High quality, broadened spectra of several Seyfert galaxies will be obtained using IUE. These high signal-to-noise spectra will be used to determine accurately the strengths of several weak spectral features needed to provide various diagnostics of the state of the gas and reddening. The IUE data will be combined with existing X-ray data to estimate the amount of ionizing radiation present in the galaxies and to test various models.

**Results:**

IUE observations were obtained of the broad line radio galaxies 3C 120, 3C 383, and 3C 390.3. The observations were obtained from the IUE archives and cover the period from late 1978 to mid-1984. All three objects show variability in their emission line and continuum fluxes by factors of up to  $\sim 2$  and  $\sim 4$  over timescales of  $\sim 2$  weeks to four months. No phase lag between emission line and continuum variations is apparent in these data, so that any such lag must be less than a few months. Variations in the line profiles are also seen, but the nature of the variability differs for each object. In 3C 390.3, the lines can be decomposed into broad components which vary strongly and narrow components which are constant to within 25%. In 3C 120, the line profiles are smooth and cannot be resolved into narrow and broad components. Broadening in the lines seems to occur throughout the line profiles. In 3C 382, the lines show complicated and variable structure, with possibly variable self-absorption in Lyman  $\alpha$ . Finally, there has been a general increase in the ratio of broad Lyman  $\alpha$  to C IV flux in 3C 390.3 as the continuum has dimmed, indicating a possible change in the ionization parameter for the broad lines region. In contrast, the ratios of Lyman  $\alpha$  to C IV flux changed by less than  $\pm 40\%$  for 3C 120.

**Publications:**

Reichert, G.A., Wu, C.-C., Boggess, A., and Oke, J.B., "Ultraviolet Emission Line and Continuum Variability in the Broad Line Radio Galaxies 3C 120, 3C 382, and 3C 390.3", *B.A.A.S.*, 17, 578 (1985).



**Title:** Augmentation of the IUE Ultraviolet Spectral Atlas

**Program ID:** SAJCW, SAKCW    **PI:** C.-C. Wu

**Statement of Work:**

Observations will be obtained to augment the IUE Ultraviolet Spectral Atlas published in 1983. The additional observations will provide a more complete coverage of spectral type and luminosity class and will provide more than one star per spectral type-luminosity class combination to guard against variability and peculiarity.

**Results:**

The first edition of *The IUE Ultraviolet Spectral Atlas* was published by Wu *et al.* (1983) in printed and magnetic tape versions and it has been widely used by the astronomical community for research and teaching purposes. It was recognized then that numerous spectral type-luminosity class combinations were not available in the atlas, but the authors decided that it was important to provide the atlas to the community early, and to attempt a more complete spectral type-luminosity class coverage at a later date. During the period between May 1985 and February 1989, high quality trailed and pseudo-trailed spectra were obtained for the first addendum to the original atlas. The addendum contains spectra for 142 stars from O5 to M5. Stars earlier than F0 have both SWP and LWP data, while only LWP spectra were taken for stars later than F0.

**Publications:**

Wu, C.-C., Crenshaw, D.M., Blackwell, J.H., Jr., Wilson-Diaz, D., Schiffer, F.H., III, Burstein, D., Fanelli, M.N., and O'Connell, R.W. 1991, "The IUE Ultraviolet Spectral Atlas. Addendum I.", *NASA IUE Newsletter*, 43, 1 (1991).

**Title:** Dwarf Star Spectra for Stellar Population Models

**Program ID:** LDJDB     **PI:** C.-C. Wu

**Statement of Work:**

A library of ultraviolet spectra will be compiled of standard stars for which temperature, metallicity and gravity are well established. The spectra will be available for modelling of the composite spectra of old stellar populations and will be essential in the interpretation of galaxy spectra for HST and the Astro missions.

**Results:**

A dataset of 225 IUE spectra covering most the the HR diagram was used to examine the morphology and mid-ultraviolet,  $\lambda\lambda 1900-3200$ , spectra with respect to basic physical properties. Several line and continuum indices were defined and their usefulness as temperature, luminosity, and metallicity discriminants were investigated. Features include (2600-V), (3000-V), Fe II 2402+2609, Fe I 3000, Mg II 2800, and Mg I 2852. The mid-UV provides excellent temperature discrimination: ultraviolet spectral indices have large amplitudes and there is a tight correlation of line indices with (V-K). There is little luminosity discrimination among dwarfs, subgiants, and giants, but supergiants form a separate relation in most of the mid-UV indices. A differential magnesium diagram, Mg II 2800 - Mg I 2852, provides the most promising luminosity discriminant.

**Publications:**

Fanelli, M.N., O'Connell, R.W., Burstein, D. and Wu, C.-C., "Ultraviolet Spectral Synthesis: The Spectral Morphology of Normal Stars in the Mid-Ultraviolet", *B.A.A.S.*, 21, 1113 (1989).

**Title:** UV Observations of Seyfert Galaxies

**Program ID:** AGJAB    **Co-I:** C.-C. Wu

**Statement of Work:**

High quality, widened IUE spectra will be obtained of several recently discovered Seyfert galaxies. The widened spectra will be used to compare the optical and ultraviolet line profiles and for fitting the line profiles with models in order to investigate the kinematics, dynamics, and stratification of the emitting regions. These spectra will also be used to accurately measure weak spectral features. X-ray fluxes will be combined with the ultraviolet data to estimate the amounts of available ionizing radiation.

**Results:**

Near-simultaneous IUE and Voyager ultraviolet spectrometer (UVS) observations were obtained of 3C 273, during the period of late July - early August 1985. The UVS data show a significant drop in flux for observed wavelength below 1060 Å . This is interpreted as Lyman continuum absorption in the rest frame of 3C 273. The depth of the edge indicates column densities of neutral hydrogen in the range  $N_H \sim 0.4-2.0 \times 10^{17} \text{ cm}^{-2}$  (at 90% confidence). The presence of such a strong edge is surprising, since previous high-dispersion IUE observations show no corresponding Lyman  $\alpha$  absorption with equivalent width above 0.15Å .

**Publications:**

Reichert, G.A., Polidan, R.S., Wu, C.-C., and Carone, T.E., "Detection of Possible Lyman Continuum Absorption in 3C 373", *B.A.A.S.*, 18, 996 (1986).

**Title:** An Investigation of Galactic Absorption Lines from the Low Dispersion Spectra of Active Galaxies

**Program ID:** U090-87, U046-88      **PI:** C.-C. Wu

### **Statement of Work:**

Existing IUE spectra of selected Seyfert galaxies, radio galaxies, and BL Lac objects will be merged to produce better signal-to-noise spectra for analysis. The merged spectra will be used to search for and measure galactic absorption lines in various lines of sight through the galactic disk and halo. The IUE archival spectra of selected Seyfert galaxies, radio galaxies, and BL Lac objects will be used to measure the UV Fe II emission and the Galactic absorption lines. The Fe II emission provides an important diagnostic tool to investigate the physical conditions in the broad line clouds. The Galactic absorption lines will be compared to those seen in the spectra of high redshift QSOs.

### **Results:**

Measurements of interstellar absorption line strengths in the Galactic halo have been made in spectra of eight active galactic nuclei. The main purpose is to empirically explore the validity of the idea that galactic halos of normal galaxies are the source of QSO absorption lines at redshifts below the emission line redshifts. For our sampling of the Galactic halo, resonance line strengths for  $C^{+3}$  and  $Si^{+3}$  are  $< 0.5 \text{ \AA}$ , while the resonance line strengths for  $C^{+}$ ,  $Si^{+}$  and  $Fe^{+}$  range from less than  $0.4 \text{ \AA}$  to  $1 \text{ \AA}$ . Lines of  $Mg^{+}$  ( $\lambda\lambda 2795, 2802$ , combined) are greater than  $1 \text{ \AA}$  in equivalent width, reaching  $3.5 \text{ \AA}$  along sight-lines to high velocity clouds. Less than 10% of QSO absorption lines are dominated by first ions to the degree found in our halo sample, which includes some disk gas and a high fraction of high velocity clouds. In the relevant sub-sample of QSO absorption systems with  $W_{\lambda}(C \text{ II})/W_{\lambda}(C \text{ IV}) > 2$ , the average line strengths of all species match those measured in our Galaxy. However, C IV is no stronger through the entire halo than through the near halo sampled by O-B stars. Evidently, the halo of our Galaxy forms a poor analogy to most of the entities producing QSO absorption line systems, but may be a useful analogy for a small subset of absorbers. The high velocity clouds in our halo appear to contain large amounts of C II, traces of Si IV, and little, if any, C IV. The measured line strengths are smaller than those seen in the low resolution spectra of low redshift, gas rich dwarf galaxies (SMC, LMC, NGC 4449, NGC 1705, etc.) which are blended with Galactic halo lines. Thus, most of the absorption in those gas rich dwarfs arises in the galaxies themselves, not in our Galactic halo.

### **Publications:**

Wu, C.-C., Caulet, A., York, D.G., Blades, J.C., Boggess, A., and Morton, D.C., "Galactic Interstellar Absorption Over Long Sightlines at High Latitude", *Ap.J.*, in press (1991).

Title: Dwarf Star Spectra for Stellar Population Models

Program ID: LDKDB      Co-I: C.-C. Wu

**Statement of Work:**

Ultraviolet spectra of late-type field dwarf stars will be obtained and combined with optical and infrared spectra to establish a library of standard star spectra for which temperature, metallicity, and gravity are well determined. These observations will be essential in the interpretation of galaxy spectra over a large range in redshift.

**Results:**

Analysis of 225 IUE spectra indicates that mid-UV stellar continua are markedly affected by abundance; The ultraviolet excess  $\delta(2600-V)$ , analogous to  $\delta(U-B)$ , is a factor of 10 more sensitive for an equivalent range in  $[Fe/H]$ . Mid-UV photometry opens new horizons on the investigation of metal-poor stellar populations. Conversely, the relative strength of spectral lines in the mid-UV is less affected by abundance; variations in line strength appear to be diluted by corresponding variations in the blanketing of the adjacent continuum. The result is that mid-UV spectra will be more sensitive to the temperature of the stellar population than either metallicity or the dwarf/giant ratio. Mg II 2800 exhibits unexpected behavior, displaying no sensitivity to abundance for cool stars and a *reversed* sensitivity in FG dwarfs such that metal-poor stars have stronger Mg II strengths at the same temperature than more metal-rich stars. This is attributed to chromospheric emission; the result indicates that Mg II emission depends significantly on metallicity (or age).

**Publications:**

Fanelli, M.N., O'Connell, R.W., Burstein, D., and Wu, C.-C., "Spectral Synthesis in the Ultraviolet. III. The Spectral Morphology of Normal Stars in the Mid-Ultraviolet", *Ap.J.*, 364, 272 (1990).