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**The Circumstellar Environments of
Intermediate Mass Main Sequence Stars**

**A FINAL REPORT
NAS5-32059**

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FINAL REPORT for NAS5-32059

Analysis of archival IRAS and IUE data has resulted in identification of accreting gas toward a 2.8 Myr post-Herbig Be star in the R CrA star formation region, and identification of accreting gas toward HD 93563, previously identified as a classical Be star. Accreting gas has also been detected toward two B[e] stars of previously controversial evolutionary state, resulting in identification of these systems as pre-Main Sequence Herbig Be stars viewed edge-on to their circumstellar disks. In parallel with this effort, accreting gas has now been detected toward the Herbig Ae star HR 5999, resulting in development of identification criteria for edge-on PMS proto-planetary disk systems. The work on individual stars is described below:

HD176386: Analysis of recent and archival IUE observations of the post-Herbig Be star HD 176386 reveal the presence of accreting gas with velocities as high as +300 km/s in C IV and Si IV. Detection of these species in the spectrum of a B9 star is consistent with collisional ionization of the accreting gas to temperatures well in excess of the stellar effective temperature. The IUE data also provide evidence for discrete absorption components similar to those seen in β Pic. The accreting gas column densities and velocities are intermediate between those characteristic of bona-fide PMS Herbig Be stars and field, (presumably older) systems such as 51 Oph and β Pic. These data suggest a gradual transition from the optically thick continuum high mass accretion rates seen in the systems younger than 1 Myr to the optically thin accretion typical of stars like beta Pic. Given the age estimates for HD 176386, the timescale for the transition appears to be 1.5 to 2.8 Myr at B9. A paper detailing this study has been accepted for publication in *Astronomy and Astrophysics* and is in press for July 1993. A galley proof is included.

Comparison of the IR data for HD 176386 and 51 Oph reveals a pronounced lack of a near IR thermal excess of the kind reported for 51 Oph by Waters et al. (1988). Given the location of HD 176386 in the R CrA star formation region, it is entirely possible that the far IR excess represents confusion with nearby, but not intimately associated dust clouds. In this case, the detection of accreting gas toward HD 176386 suggests that the parent grain population must be sufficiently large that it does not radiate efficiently in the IR. Follow up far IR observations with future S/C such as ISO will be needed to test this hypothesis. We note that the recent claim of a dust disk around 68 Oph, which also lacks a pronounced IR excess, suggests that HD 176386 may not be unique in this regard. If supported by additional observations, the HD 176386 data suggest that planetesimal formation may have occurred in this system. A poster paper on this topic was presented at the *Planetary Systems: Formation, Evolution, Detection* Meeting held in Pasadena in December 1992, and an extended, refereed paper will appear in the conference proceedings from that meeting.

HR 5999: As the result of a serendipitous IUE high dispersion spectrum of this bright, 0.5 Myr PMS A5 star which showed an anomalous Mg II emission profile, we report the detection of high velocity, accreting gas with velocities as high as 300 km/s. Together with large amplitude photometric variability, and a limited set of polarimetric observations, the available data suggest that HR 5999 has a circumstellar dust/gas accretion disk which we view edge-on. This system is particularly important since it enables us to effectively look back in time and study a young β Pic system. A paper has been accepted for publication in *Astronomy and Astrophysics*, and is scheduled for publication in July 1993.

HD 45677: An *ApJ Letter* on the detection of high velocity, accreting gas toward this peculiar B[e] star with a circumstellar dust disk has been accepted. Detection of accreting gas rules out identification of HD 45677 as a post-AGB object, and instead suggests that we have found one of the missing disk-edge-on Herbig Be stars (same orientation as for β Pic).

Work was begun (and is continuing under LTSA contract NASW-4756) on the HUT observations of HD 45677 (with R. Buss, T. Brown, and A. Davidsen of JHU). We confirm the detection of grey extinction (particle sizes in the disk typically $>1.6 \mu\text{m}$) for the dense cloud responsible for the deep optical minimum noted by Sitko et al. (1993), and confirm the flux excess in the deep optical minimum data obtained with IUE relative to the attenuated bright state light. Similar behavior is seen in UX Ori (A1-3e) and has been interpreted as evidence for the detection of light scattered into the line of sight by small grains associated with the bipolar flow detected in IUE spectra at optical minimum. The HUT and IUE data provide convincing evidence for variability in the H I column density, and suggest a non-detection of molecular hydrogen in the circumstellar disk (and hence the non-detection in IUE data of OH and CO). The variation in $N(\text{H I})$ is correlated with changes in A_v and is consistent with a gas-to-dust ratio in the line of sight typical of the ISM. If this object, as the accreting gas suggests, is a PMS star with $t < 10^5$ years, preferential stripping of the volatile gases has not yet begun. A paper to be submitted to *ApJ (Letters)* is in preparation with Brown as the first author.

HD 50138: A number of authors have commented on the similarity of the optical spectrum of this object to HD 45677. Inspection of IUE archival spectra have revealed the presence of high velocity, accreting gas profiles extending to 250 km/s, as well as continuum light variations (most pronounced at the epoch of the ANS observations) similar to HD 45677. The IR excess of this object is very similar to HD 45677. The $10 \mu\text{m}$ emission feature is also very pronounced (see Olton et al. 1987), and anomalously broad compared to the diffuse ISM or evolved stars. Similar, broad profiles are seen in HD 45677 and have been studied in detail in β Pic and 51 Oph (Knacke et al. 1993; Fajardo-Acosta et al. 1993). These studies indicate that the breadth of the feature is a signature of thermally processed silicates which have crystallized (seen in Solar

System comets). Work on this star will continue under NASA contract NASW-4756 with a paper to be submitted to the *ApJ* envisioned for completion late in 1993.

HD 93563: In the process of looking for a good, high $v \sin i$ comparison B8 star for HD 50138, IUE archival data for this object were retrieved and inspected. The IUE data demonstrate the presence of accreting gas with velocities as high as +150 km/s in species such as Al III, Fe III, Mg II, and some velocity extension in Si II and Fe II. C IV and Si IV look more typical of classical Be stars, which is why this system was not identified previously. IRAS data for this object in Oudmaijer et al. (1992) suggest an excess closer in temperature to Vega than to 51 Oph. Analysis of this object is continuing under NASW-4756. Detection of this system means that accreting gas has now been observed in 4 late-type B stars and 2 A stars.

Refereed Publications Resulting from this Contract:

1. Grady, C.A., Pérez, M.R., and Thé, P.S. 1993, **A&A (in press)**, "*The Accreting Circumstellar Gas Envelope of HD 176386, a young star in the R Coronae Australis star formation region*", to appear July 1993.
2. Grady, C.A., Bjorkman, K.S., Shepherd, D., Schulte-Ladbeck, R.E., Pérez, M.R., de Winter, D., and Thé, P.S. 1993, **ApJ (Letters) in press**, "*Detection of Accreting Gas Toward HD 45677: A Newly Recognized, Herbig Be Proto-Planetary System*".
3. Grady, C.A., Pérez, M.R., and Thé, P.S. 1993, "*Detection of Accreting Circumstellar Gas Around Weak Emission-Line Herbig Ae/Be Stars*", to appear in "Planetary Systems: Formation, Evolution, Detection", J. Rahe, N. Nickle, E. Roettger (eds.), (Dordrecht: Kluwer).
4. Pérez, M.R., Grady, C.A., and Thé, P.S. 1993, "*The Evidence for Clumpy Accretion in the Herbig Ae Star HR 5999*", to appear in "Planetary Systems: Formation, Evolution, Detection", J. Rahe, N. Nickle, E. Roettger (eds.), (Dordrecht: Kluwer).
5. Pérez, M.R., Grady, C.A., and Thé, P.S. 1993, **A&A (in press)**, "*UV Spectral Variability in the Herbig Ae Star HR 5999: XI. The accretion hypothesis*", to appear July 1993.