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Final Report for NASW 4756

"Observational Studies of the Clearing Phase in Proto-Planetary Disk Systems"

Abstract: A detailed study of circumstellar gas associated with young, intermediate-mass stars has demonstrated that, far from being unique or an infrequently occurring phenomenon, beta Pic-like infall activity is routinely observed in stars younger than 10-50 Myr when the observer's line of sight lies within 15 degrees of the disk mid-plane. Detailed studies of 2 Herbig Ae/Be stars, AB Aur and HD 163296 demonstrate that enhanced infall episodes last 20-60 hours, comparable to the duration of similar episodes in beta Pictoris. The infall activity is consistent with detection of the comae of swarms of star-grazing bodies of asteroidal to cometary composition. Episodic fluctuations in the infall activity are clearly present by ~6 Myr, and may indicate the presence of massive planets within the disk. This study has therefore, directly contributed to NASA's Origins of Planetary Systems theme by identifying under what conditions extra-solar planetesimals can be remotely sensed, indicating that such bodies appear to be routinely detectable among young stars in the 1-10 Myr range, and suggesting that temporal studies of spectroscopic variability may provide a means of identifying those systems harboring massive planets. This study has resulted in 2 refereed review papers, 13 other refereed papers, and 17 conference papers.

Keywords: circumstellar dust and gas, protoplanetary disks, planetesimals, cometesimals, extra-solar comets

February 20, 1998

Dr. Guenter Riegler
LTSA Technical Officer
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NASA Headquarters
300 E St., S.W.
Washington, DC 20546

Dear Dr. Riegler,

Enclosed please find my final report for the LTSA program entitled "Observational Studies of the Clearing Phase in Proto-Planetary Disks Surrounding Intermediate-Mass Stars", which is supported under NASA Contract NASW 4756 to Eureka Scientific, for the period through March 18, 1999. Work during the final quarter of the study has involved final revisions (copy editing) to the *Protostars and Planets IV* review paper, and participation in the La Palma International Time observing run from January 28-31, 1999. Grady supported the run at the William Herschel Telescope using the Utrech Echelle Spectrograph. Data reduction for this project is in progress under separate funding, with presentation of initial results at a team science workshop scheduled for June 1999.

Highlights of the Study:

At the outset of this study, β Pictoris-like infall activity, manifesting in the form of redshifted absorption features in a wide range of atomic ions had been detected toward β Pic, and a few stars with at most Vega-like IR excesses. The lack of detections had lead to speculation that β Pictoris was at best an extremely unusual object, if not "pathological". An immediate goal of this study, therefore, was to test the hypothesis that systems younger than β Pic might exhibit infall activity, rather than the general population of field A stars.

- Data mining of the extensive IUE moderate resolution spectroscopic holdings for pre-Main Sequence A and B stars, the Herbig Ae/Be stars, yielded identification of β Pic-like infall in 14 Herbig Ae/Be stars, and an additional 9 A-shell stars. This number has been expanded with optical spectra, and it is now possible to state that all known Herbig Ae/Be stars viewed within 15 degrees of their disk mid-planes exhibit similar activity at some epoch.

- The IUE data have also indicated that the infall activity is consistent with detection of material sublimated from swarms of star-grazing planetesimals. Compositional studies of one Herbig Be star with

infall activity, HD 100546, indicate that, in that 10 Myr-old system, the infalling material is consistent with the gaseous comae of star-grazing bodies resembling material in the Solar System's outer asteroid belt. The UV data, in particular, complement the emerging view of the dust composition provided by ISO, and which is likely to be expanded greatly by SIRTF and SOFIA.

- This study has also explored the temporal frequency of infall events. Detailed studies of 2 Herbig Ae stars with dense UV spectral time series, AB Aur and HD 163296, indicate that high infall episodes last 20-60 hours, comparable to similar episodes in β Pic. Episodic variation in the infall frequency toward HD 100546, and the slightly younger HD 163296 system (t=4-8 Myr) may point to the presence of massive planets within the disk. Episodic bombardment of the star may also be a source of the chain of HH objects associated with HD 163296 , which were imaged by STIS in September 1998 (Grady et al. 1998, AAS193, 73.04). If correct, the UV data constrain the time needed to produce Jupiter-mass planets, and to have them sufficiently modify their surroundings to be macroscopically observable, to no more than ≈6 Myr, substantially shorter than predicted by current models for the production of Jupiter and other gas giant planets.

Far from highlighting the uniqueness of β Pic, these data strongly imply that β Pic and its circumstellar disk are typical of young (t=10-50 Myr) planetary systems. The spectroscopic data analyzed in this study also point to circumstellar disks associated with stars in the 1-10 Myr range as harboring forming planetary systems. More detailed study of these systems is thus directly relevant to NASA's Origins goals of studying the formation, evolution,and diversity of planetary systems. The ease of detection of infall signatures among the Herbig Ae/Be stars also indicates that assembly of material into sizes typical of cometary nuclei occurs rather routinely, and thus that the prospects for planet detections around stars with masses less than 10 solar masses are more favorable than had previously been considered. The signatures of planetary activity may also be present in systems with appreciable amounts of both distant, and near-stellar dust, which has implications for the design of upcoming NASA missions such as SIM and TPF.

This study has resulted in 2 refereed review articles, 13 other refereed papers, including a survey of infall activity in UV spectra of HAeBe stars, and 17 conference papers.

Publications To Date:

A. Refereed:

1. Grady, C.A., Bjorkman, K.S., Shepherd, D., Shulte-Ladbeck, R.E., Pérez, M.R., de Winter, D., and Thé, P.-S. 1993, "Detection of Accreting Gas Toward HD 45677: A Newly Recognized, Herbig Be Proto-Planetary System", ApJ (Letters), 415, L39.

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13. Sitko, M.L., Grady, C.A., Lynch, D.K., Russell, R.W., and Hanner, M.S. 1999, "Cometary Dust in the Debris Disks of HD 31648 and HD 163296: Two "Baby" β Pics", ApJ 510, 408.

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1. Grady, C.A., Pérez, M.R., Thé, P.-S., de Winter, D., Yusef-Zadeh, F., Johnson, S.D. 1993, "Detection of a Bipolar Flow Associated with UX Ori: An Intermediate Mass Pre-Main Sequence Star", ApSS 187, 559.

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If you have any questions, I can be reached at (301) 490-6853, or via e-mail at cgrady@mtolympus.ari.net.

Regards,

Carl Anne Grady

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