STUDIES OF CIRCUMSTELLAR DISK EVOLUTION

Grant NAG5-13210

Annual Report No. 2

For the period 1 April 2004 through 31 March 2005

Principal Investigator

Dr. Lee W. Hartmann

January 2005

Prepared for

National Aeronautics and Space Administration
Goddard Space Flight Center, Greenbelt, MD

Smithsonian Institution
Astrophysical Observatory
Cambridge, Massachusetts 02138

Annual Report for NAG5-13210

Studies of Circumstellar Disk Evolution

L. Hartmann, PI

Introduction

The aim of this project is to develop a comprehensive global picture of the physical conditions in, and evolutionary timescales of, pre-main sequence accretion disks. The results of this work will help constrain the initial conditions for planet formation.

To this end we are developing much larger samples of 3-10 Myr-old stars to provide better empirical constraints on protoplanetary disk evolution; measuring disk accretion rates in these systems; and constructing detailed model disk structures consistent with observations to infer physical conditions such as grain growth in protoplanetary disks.

1. Past year

i. Cluster survey

We are completing our observational program to identify star clusters with ages of 3-10 Myr which are sufficiently populous to provide good statistical information on disk properties as a function of stellar mass and age. We have identified two such clusters, Tr 37 and NGC 7160, which lie in the Cep OB2 association at a distance of approximately 900 pc.

The first paper reporting optical and near-infrared results for these clusters has been published (Sicilia-Aguilar *et al.* 2004), and the second, final paper has been submitted (Sicilia-Aguilar *et al.* 2005b). We now have a reasonably robust set of members identified from these data, which lean heavily on results from the new Hectospec multiobject spectrograph on the MMT on Mt. Hopkins, taken in June 2004.

We have completed our *Spitzer Space Telescope* survey of infrared excesses in these two clusters, and a paper on these results is nearing completion (Sicilia-Aguilar *et al.* 2005c). The fundamental results from this survey are: first, the disk frequencies seen of 0.4 at 3-4 Myr and 0.1 at 10 Myr are quite consistent with other investigations; second, the 3-4 Myr-old objects in Tr 37 show disk excesses lower than in younger (Taurus) systems at wavelengths of 3-8 microns, but closer to Taurus systems at 24 microns; this seems to indicate that disk evolution is much more rapid at radii $\lesssim 10$ AU than at larger radii, as might be expected for the onset of planet formation in the inner disk. We also find very little evidence that the massive (O6) star in the center of Tr 37 has had much effect in evaporating disks in this cluster.

This work completes the thesis of Aurora Sicilia Aguilar, to be defended in summer 2005.

ii. Other Spitzer *results*

Several initial papers have been published on results from the *Spitzer Space Telescope* characterizing disk emission seen with the IRAC and MIPS instruments (Allen et al. 2004;

Megeath et al. 2004; Muzerolle et al. 2004; Reach et al. 2004). A survey of Taurus stars with IRAC has been submitted to the Astrophysical Journal (Hartmann et al. 2005) and is in the refereeing stage. These papers, particularly the Taurus results, establish the typical colors of stars with disks and stars with envelopes (protostars) which will be of use in interpreting results from more distant, less well-studied regions.

iii. Molecular cloud and star formation

Two papers were published which mark steps along our path of trying to understand star formation as an initial condition problem. In Bergin et al. (2004) we examined the formation of molecular gas behind a shock front in the diffuse interstellar medium and showed that the chemical evolution could in principle be sufficiently rapid to explain the observational result that few molecular clouds show no star formation.

In Burkert & Hartmann (2004), we presented two-dimensional simulations of finite, self-gravitating gaseous sheets. Unlike the case of infinite sheets, such configurations do not constitute equilibrium states but instead are subject to global collapse unless countered by pressure forces or rotation. The initial effect of finite geometry is to promote concentrations of material at the edges of the sheet. If the sheet is not perfectly circular, gravitational focusing results in enhanced concentrations of mass. In the second-most simple geometry, that of an elliptical outer boundary, the general result is collapse to a filamentary structure with the densest concentrations of mass at the ends of the filament. We suggest that these simple calculations have interesting implications for the gravitational evolution of overall molecular cloud structure, envisioning that such clouds might originate as roughly sheetlike sections of gas accumulated as a result of large-scale flows in the local interstellar medium. We show some examples of local clouds with overall filamentary shape and denser concentrations of mass and star clusters near the ends of the overall extended structure, suggestive of our simple ellipse collapse calculations. We suggest that cluster-forming gas is often concentrated as a result of gravity acting on irregular boundaries; this mechanism can result in very rapid infall of gas, which may be of importance to the formation of massive stars. This picture suggests that much of the supersonic "turbulence" observed in molecular clouds might be gravitationally generated. Our results may provide impetus for further theoretical explorations of global gravitational effects in molecular clouds and their implications for generating the substructure needed for fragmentation into stars and clusters.

iv. Accretion and Kinematics in the Orion Nebula Cluster

In a recently published paper (Sicilia-Aguilar et al. 2005a), we presented results from high-resolution spectra of stars in the Orion Nebula cluster using the new Hectochelle instrument on the MMT. Using the high spectral resolution newly available, we were able to distinguish stellar accretion and wind ejection from Halpha profiles with greater accuracy than previously possible. We identified 15 new members based on emission and Li absorption. Finally, we presented an initial result on the radial velocity disperion of the brighter stars in the cluster. The very small velocity dispersion derived, ≤ 1.8 km/s, is in good agreement with estimates from proper motions. This work is an initial result of a longer-term program we are just starting to determine the kinematics of young clusters with the goal of trying to understand how clusters are formed.

Papers supported by this grant last year

Allen, L.E. et al. 2004, ApJS, 154, 363

Bergin, E. A., Hartmann, L. W., Raymond, J. C., & Ballesteros-Paredes, J. 2004, ApJ, 612, 921

Burkert, A., & Hartmann, L. 2004, ApJ, 616, 288

Hartmann, L., et al. 2005, ApJ, in refereeing

Megeath, S.T. et al. 2004, ApJS, 154, 367

Muzerolle, J. et al. 2004, ApJS, 154, 379

Reach, W.T. et al. 2004, ApJS, 154, 385

Sicilia-Aguilar, A., Hartmann, L., Briceno, C., Muzerolle, J., & Calvet, N. 2004, AJ, 128, 805

Sicilia-Aguilar, A. et al., 2005a, AJ, 129, 363

Sicilia-Aguilar, A. et al., 2005b, ApJ, submitted

Sicilia-Aguilar, A. et al., 2005c, in preparation