PROTOTARS AND DISKS

GRANT NAGW-3121

Final Report

For the Period 1 September 1992 through 31 August 1996

Principal Investigator

Dr. Paul Ho

May 1997

Prepared for

National Aeronautics and Space Administration
Washington, D.C.

Smithsonian Institution
Astrophysical Observatory
Cambridge, Massachusetts 02138
During the support period, we have made great progress on our studies of protostars and disks. Attached is a list of our publications and submitted papers while supported by our grant. Our goal was to concentrate on high angular resolution (arc-second scale) studies of molecular cloud cores associated with very young star formation. We also explored new ways to study disks and protoplanetary systems. We summarize and describe our findings here in this report.

**Molecular Cloud Studies.** Using a number of interferometers, including the VLA, BIMA, OVRO, and NMA, we continue our program to study the molecular cloud cores in a number of star forming regions. These include studies of Cepheus A (Publ. 2, 7), NGC2024 (Publ. 5), GM24 (Publ. 6), CTB80 (Publ. 10), Herbig-Haro 1 (Publ. 11, 15), Herbig-Haro 34 (Publ. 17), G5.48-0.24 (Publ. 23), Orion (Publ. 32), Herbig-Haro 25-26 (Publ. 35), GSS 30 (Publ. 38), and L723 (Publ 40). What we have found in these studies are the readily detectable signatures of the underlying physical processes. For example, localized heating and enhanced linewidths are good indicators of an embedded exciting source. Interactions between outflows and the local environment suggest that outflow morphology can be strongly influenced by interactions.

**Gravitational Contraction.** We have also continued to study the kinematical signatures of contractions. Specific cases which we examined include G10.6-0.4 (Publ. 13), Herbig-Haro 1 (Publ. 15), G45.47+0.05 (Publ. 27), L1551-IRS5 (Publ. 31), W51 (Publ. 34, 41, 43), IRAS04368+2557 (Publ. 37), IRAS04169+2702 and IRAS04365+2535 (Publ. 39). In the cases where a strong continuum emission source is available, contraction can be identified by the red-shifted absorption seen projected against the continuum source. In the low mass cases, where continuum emission is not available, rotation and contraction can be distinguished by resolving the velocity field and modeling.

**Jets, Winds, and Outflows.** It is now well known that outflows and winds are extremely prevalent in the early stages of star formation. We have also studied the relation of outflows to the presence of disk-like structures. The sources which were studied include HL Tau (Publ. 14), W51 (Publ. 20), L1157 (Publ. 21), Serpens FIRS 1 (Publ. 24), W33A (Publ. 28), and W75N (Publ. 42). We find that the large scale outflows are often driven by an underlying radio jet which is collimated at the AU scale. A circumstellar disk is probably associated with the radio jet and can be traced sometimes by the presence of H$_2$O masers. The large scale outflows can be traced in increasing number of molecules which has allowed the study of shock chemistry.
Circumstellar Disks. The goal of studying molecular cloud cores, especially in the context of the NASA Origins Program, is to try to discover the disks which may be the precursors of protoplanetary systems. Here, we pursued a few systems which reveal structures at the 100 AU scale. These are Cepheus A (Publ. 7, 26), HL Tau (Publ. 9, 14, 33), L1551-IRS5 (Publ. 9, 31), and W75N (Publ. 42). Dust continuum emission, molecular line emission and H$_2$O masers may be the best tracers of such compact disks.

Extrasolar Planetary Systems. To push to even smaller scales, we have been investigating direct detection of planets. Our first efforts are toward detecting brown dwarfs. Here we are employing differential methane band imaging at 2 microns in order to detect brown dwarf candidates. Only brown dwarfs have atmospheres that are cool enough to sustain methane while at the same time have enough luminosity to serve as a background. Hence methane band absorption can be seen toward a brown dwarf but not against the primary star. Differential imaging was successful in detecting GL229B (Publ. 36), and we are continuing to search for other candidates.

Support of Students. This grant also supported in part graduate students Jennifer Wiseman (Ph.D. Harvard 1995), Qizhou Zhang (Ph.D. Harvard 1997), Jose Girart (Ph.D. Barcelona 1997), and also postdoctoral fellow Hua Chen (1996).
Published 1992-1997

Paul T. P. Ho


