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The following report covers the Department activities from July 2000 through June 2001.

1. PERSONNEL

At the University of Cincinnati, research in astrophysics can be broadly characterized as the investigation of young stellar systems and their environment, primarily at infrared wavelengths. The astrophysics faculty consists of Margaret Hanson, whose major research interest centers primarily around near-IR studies of young, massive stars and their circumstellar and nebular environment, and Michael Sitko, who works largely in the field of dusty disks surrounding young intermediate-mass and low-mass stars. Dr. Matthew Kenworthy joined the group in November 2001, hired under the auspices of Hanson's recent NSF CAREER award. Kenworthy's expertise is in adaptive optics, infrared photometry, and astronomical software and hardware.

During the past year Hanson has supervised research by graduate student Uswatte Hemamala, who completed her master's thesis in the Summer of 2000 and is now pursuing a PhD at the University of Missouri, Kansas City. Graduate student Ryan Culler, who was also active in the astrophysics group, completed his master's degree in June 2001 and is now teaching astronomy as an adjunct professor at The College of Wooster. This year Sriyani Jayatilleke began graduate research work with Hanson, studying the young, massive galactic clusters, W51 and W49 using near-infrared spectra. She is also helping Prof. Hanson with a project to develop near-infrared quantitative analysis of early-B supergiants. Soon she will begin a study of the surface chemical abundances of early-B stars throughout our galaxy (Prof. Kim Venn, of Macalester College, MN, is a co-advisor on this project).

A number of undergraduate students are also actively involved in research at the University of Cincinnati. Amanda Bauer spent time investigating the photometric characteristics of an SBIG ST-8 CCD camera that has been shipped to the Perth Observatory in Australia. She is also reducing BRI photometry from this camera of selected Herbig Ae/Be stars and T Tauri stars observed simultaneously with the Space Telescope Imaging Spectrograph on the Hubble Telescope in a program headed by Carol Grady [STIS Instrument group, NOAO/Goddard Space Flight Center]. She has spent the past two summers working on spectral classification for the Sloan Digital Sky Survey at Fermilab [supervised by Dan Vanden Berk].

Lara Mercurio is working with Hanson on near-infrared spectra of CI Cam. She will be looking at how the emission lines in CI Cam have evolved since a high energy outburst occurred 2 years ago, and investigate if in studying the changing conditions of CI Cam, she can discern the nature of the compact object.

In the summer of 2001, Carolyn Eglet and Melodie Fickenscher joined Hanson's massive stars group. Melodie is

analyzing some recently obtained spectra of SS 433, while Carolyn has begun a project studying the young star forming region M17 in red-optical spectra.

2. RESEARCH

2.1 Young Stars and their Environments

Hanson's long awaited near-infrared survey of ultra-compact HII regions, in collaboration with K. Luhman (Harvard, CfA) and G. Rieke (Steward Observatory) was finally completed in Spring 2001, and was accepted for publication in *The Astrophysical Journal*, Supplements, January 2002. This survey of 63 radio selected regions is the first of its kind to have studied a significant number of sources in a systematic way to make statistical claims about the detection limit of such sources, and the utility of developing near-infrared nebular analysis for such sources. Approximately half of the radio-selected sources were detected in Br γ emission, and of those, nearly half were detected in He I, allowing the temperature of the central ionizing object to be estimated. In three sources, the central ionizing source was directly revealed using follow up high-resolution near-infrared spectroscopy at the Multiple Mirror Telescope.

Hanson is finishing up a 2-year collaboration with T. Wilson, director of the Sub-Millimeter Telescope Observatory, to study the extensive molecular cloud associated with the young star forming region, M17. In this study, Hanson and Wilson have mapped a $13' \times 23'$ region adjacent to the central OB cluster of M17, in C¹⁸O J=2-1 and CS J=3-2 and J=5-4. The study concentrated on two large molecular clouds, Cloud A to the north, and Cloud B to the southwest. Over 40 cloud cores have been identified. Most have never been previously cataloged. The effect of the local OB cluster is heating and strongly compressing Cloud B, reflected in the large number of very young massive stars being formed within. Cloud A, while less effected, may have some associated star formation.

As part of a program supported by a grant from NASA's Origins of Solar Systems program, Sitko is collaborating with D. Lynch and R. Russell [The Aerospace Corporation], and C. Grady [STIS Instrument Group, NOAO/Goddard Space Flight Center] in a survey of the mid-IR (3-14 μ m) spectral characteristics of dusty protostellar disks. The spectral features observed provide valuable clues about the chemical composition and thermal history of the dust grains in these disks. Because of their generally higher brightness levels, the project has focused mainly on Herbig Ae stars (intermediate-mass PMS stars), and is only just beginning to push to the fainter IR flux densities typical of the T Tauri stars (lower-mass PMS stars). Observations are being obtained using the Aerospace Corporation's Broad-band Array Spectrograph System (BASS) on NASA's Infrared Telescope Facility (IRTF). Although the survey is not yet complete, some of the data has already been analyzed and published.

Most recently, mid-IR spectra of three members of the TW Hydrae Association, the nearest known PMS star grouping, were obtained. Included in this study were HR 4796A, HD 98800, and TW Hya itself. In spite of the fact that all three stars have the same age and were formed in the same molecular cloud, their spectral characteristics are quite different. TW Hya possesses a strong silicate band, HD 98800 a somewhat weaker one, while HR 4796A has only a slight excess at these wavelengths. None has significant disk emission at wavelengths shorter than $8 \mu\text{m}$, indicating that the inner regions of the disks are cleared of dusty material. Detailed modeling of the entire spectral energy distribution (SED) of TW Hya has been done in collaboration with a team led by N. Calvet [Harvard-Smithsonian Center for Astrophysics]. The SED indicates that an optically thick disk extends to at least 140 AU from the star, and the dust within it must have grown to sizes on the order of 1 cm. Inside 4 AU, the disk is optically thin, and this region must contain a sufficient population of grains on the order of $1 \mu\text{m}$ in size in order to produce the observed $10 \mu\text{m}$ silicate emission band.

2.2 Solar System

In order to place the mid-IR spectra of the dusty disks surrounding young stars within the context of the formation of the best-studied solar system (our own), Sitko is collaborating with D. Lynch and R. Russell [The Aerospace Corporation] in their long-term program of observing solar system comets at mid-IR ($3\text{--}14 \mu\text{m}$) wavelengths. Because comets represent the most primitive and least processed remnants of the formation of the solar system, the study of their composition is most directly relevant to the early stages of formation on both our own solar system and the first few million years of young protostellar disks. In January 2001, they observed Comet C/1999 T1 (McNaught-Hartley) using BASS on NASA's IRTF. This comet exhibited a silicate emission band in the $10 \mu\text{m}$ region about 15 percent above the continuum level. The general shape of the silicate band was trapezoidal, similar to that seen in many other solar system comets, and included the $11.2 \mu\text{m}$ feature due to crystalline olivine.

Sitko is collaborating with J. Bradley [MVA, Inc.] in a project to study the spectroscopic properties of interplanetary dust particles (IDPs) of presumed cometary origin. Laboratory studies of these particles provide a degree of "ground truth" in our understanding of the chemical composition of the protosolar nebula, and by inference, young protostellar disks. X-ray spectroscopy of the particles provides an inventory of the atomic species present in the IDPs, from which the grain mineralogy can be deduced. IR spectra are then obtained in order to connect the mineralogy to a spectral signature. Most recently, the bright narrow beam of the synchrotron light facility at the Brookhaven National Laboratory was used to collect IR spectra on these IDPs. The spectra are found to be quite complex, and can vary from place to place within a single IDP. For some IDPs, the net spectrum of the entire grain resembles that of young protostellar disks. In other cases it does not. By comparing data on a large number of particles of varying composition with protostellar disks, it

may be possible to place constraints on the chemical composition of the disks.

Laboratory studies can also provide important information about the thermal processing history of the grains in these disks. Sitko is working with J. Nuth [Goddard Space Flight Center] and J. Bradley [MVA, Inc.] on a project to study the change in spectral characteristics of silicate condensates as they anneal at high temperatures. One of the most puzzling aspects of the study of cometary dust is the presence of the crystalline olivine feature at $11.2 \mu\text{m}$. It is seen in comets, yet is absent in the spectra of interstellar dust, the raw material from which the solar system formed. Where did it come from? In simulations using silicate condensates, temperatures above about 800 K are generally needed to allow amorphous silicate material to anneal into a crystalline form. Yet the gaseous composition of comets indicates that they were never warmer than a few tens of Kelvins. In order to place grains heated to 800 K into material that has remained very cold would suggest that material in the warm innermost parts of the protosolar disk must have been transported outward and redeposited in the comet-forming region. The details are unclear, but a disk wind may be implicated.

2.3 Stellar Astrophysics

Sitko worked with D. Lynch and R. Russell [The Aerospace Corporation] in their project of obtaining and analyzing BASS spectra of Nova V455 Pup. The spectrum revealed only a smooth, featureless continuum that decreased monotonically with increasing wavelengths between 3 and $13.6 \mu\text{m}$. Its slope was much shallower than the Rayleigh-Jeans tail of a black body. The spectrum was consistent with thermal emission from gray (constant)-emissivity dust whose temperatures ranged from around 280 K to upwards of 1300 K. The presence of such strong IR continuum emission so early after the nova's outburst may suggest that this object has undergone previous outbursts.

Hanson has begun a five-year collaboration with Joachim Puls (University of Munich) to develop a method for quantitative spectral analysis for massive stars which depends solely on near-infrared spectra. The motivation for this program, which is sponsored by an NSF CAREER award, is to allow them to quantitatively study massive stars through out the entire Galaxy, with extinction as high as tens of magnitudes in the optical. Puls is extending his highly sophisticated, non-LTE, unified model atmospheres developed for the UV and optical to the near-infrared. Hanson has been obtaining very high-resolution, near-infrared spectra of well-known, optically visible stars, to use as the first standards and to calibrate the method. Data for this purpose has been obtained at the 8.2-m VLT2 using the ISAAC spectrometer, and will soon be obtained using the 8-m Subaru telescope using IRCS.

2.4 X-ray Binaries and Variable Stars

Hanson has continued her studies of variable stars and binaries in the past year, most recently completing an analysis of G79.29+0.46 star, and obtaining new high resolution near-infrared spectra of two new sources: CI Cam and SS

433. M. Krauss (Harvard-Smithsonian, CfA) and Hanson completed a comparative near-infrared analysis of the newly identified central blue star found at the center of the spherical radio remnant, G79.29+0.46. The nature of this star has been difficult to surmise because of the high line of sight extinction, $A_V \approx 14$. The nebular morphology of G79.29+0.46 suggests it was cast off by the central star, suggesting it to be a Luminous Blue Variable (LBV). They obtained high-resolution $H-$ and $K-$ band spectra of G79.29+0.46 star, along with identical spectra of the prototypical spherical winded LBV, P Cygni, and the non-spherical, flat-winded emission line object, MWC 349. Spectral similarities of G79.29+0.46 star were found with both P Cygni and MWC 349, as well as the LBV HR Car. While spectral similarities are not appropriate for use in identifying LBV stars, G79.29+0.46 star appears to be one of this very unique class.

Hanson has recently completed a multi-year observational campaign to observe the slow variation of spectral and continuum features of the outburst star, CI Cam, also known as XTE J0421+560. This transient X-ray source was first detected by RXTE on 1998 March 31, and it was soon confirmed that the B[e] star CI Cam is the optical counterpart, probably the mass donor for a compact object. High-resolution near-infrared spectra obtained in October 1999 and October 2000 found the strong spectral lines seen at outburst to have been entirely engulfed in excess infrared emission. Also seen is a clear steepening of the near-infrared continuum through the $H-$ and $K-$ band. It appears that the entire binary system has now become enshrouded in an expanding dust shell.

Hanson and R. Fender (U. Amsterdam) recently completed a near-infrared spectroscopic study of the very well known X-ray binary system, SS 433. They obtained unprecedented observations in June 2000: high-resolution, near-infrared spectroscopy of SS 433 for a continuous 13 nights at the University of Arizona's Bok telescope. This covered the entire orbital period of the binary system. While the analysis has only begun, working with M. Stills (GSFC/NASA), they find strong evidence of sinusoidal motion in the trailed spectra, indicating they may be detecting the orbital motion of the binary system.

2.5 Extragalactic

Working with a team led by D. Hines, Sitko continued his (now infrequent) research activities in extragalactic astronomy with a spectropolarimetric study of the two IRAS-selected QSOs, IRAS 13349+2438 and the BALQSO IRAS 14026+4341. These two objects were observed using the HST Faint Object Spectrograph in the polarimetric mode at ultraviolet wavelengths, complemented at longer wavelengths with ground-based spectropolarimetry. The polarization of both objects rises rapidly toward the blue, peaks near 3000 Angstroms in the rest frame, and remains nearly constant for shorter wavelengths. The rest frame optical polarized flux density spectra also increase rapidly toward the blue, but then decrease dramatically below 3000 Angstroms. This distinctive wavelength dependence of polarized flux shows that the polarization is produced by dust scattering. The lower polarization of the [O III] $\lambda\lambda 4959, 5007$ lines in

IRAS 13349+2438 compared to the continuum suggests that the scattering grains are interior to, or mixed with, the narrow line gas.

PUBLICATIONS

The publication list includes all papers published or submitted between July 2000 and June 2001 by the permanent staff.

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