THE STAR FORMATION NEWSLETTER

An electronic publication dedicated to early stellar evolution and molecular clouds

No. 36 — 3 Sept 1995 Editor: Bo Reipurth (reipurth@eso.org)

Abstracts of recently accepted papers

A study of the Chamaeleon star forming region from the ROSAT all-sky survey: I. X-ray observations and optical identifications

J.M. Alcalá[1,5], J. Krautter[2], J.H.M.M. Schmitt[1], E. Covino[3], R. Wichmann[2] and R. Mundt[4]

[1] Max-Planck-Institut für Extraterrestrische Physik, D-85740 Garching, Germany
[2] Landessternwarte-Königstuhl, D–69117 Heidelberg, Germany
[3] Osservatorio Astronomico di Capodimonte, Via Moiariello 16, I-80131 Napoli, Italy
[4] Max-Planck-Institut für Astronomie, Königstuhl D–69117 Heidelberg, Germany
[5] Instituto Nacional de Astrofísica, Optica y Electrónica,A.P. 51 y 216 C.P. 72000, Puebla, Pue. Mexico

E-mail contact: jmae@mpe-garching.mpg.de

We present the observations of the ROSAT all-sky survey (RASS) in the direction of the Chamaeleon cloud complex, as well as the spectroscopic identifications of the detected X-ray sources. The main purpose of this identification program was the search for low mass pre–main sequence stars. Sixteen previously known PMS stars were detected with high confidence by ROSAT. Eight are classical T Tauri stars and eight are weak–line T Tauri stars, Seventy-seven new weak-line T Tauri stars were identified on the basis of the presence of strong Li λ6707 absorption, spectral type later than F0 and chromospheric emission. We give coordinates and count rates of the X-ray sources, and present optical spectra and finding charts for the sources identified optically as new pre-main sequence stars. Optical UBV(RI)$_c$ and near–infrared JHKLM photometry for this sample of stars is also provided. In addition, 6 new dKe–dMe candidates are found among the RASS sources.

Accepted by Astron. & Astrophys. Suppl. Ser.

The dynamics of a jet in a supersonic sidewind

J. Cantó and A. C. Raga

Instituto de Astronomía, UNAM, Ap. 70-264, 04510 México, D. F., México

E-mail contact: raga@astroscu.unam.mx

We study the problem of a jet ejected from a source with a supersonic relative velocity with respect to the surrounding environment. We find that while the adiabatic problem (appropriate for extragalactic jets) has to be solved numerically, the isothermal problem (appropriate for Herbig-Haro jets) does have a complete analytic solution. Furthermore, we show that the adiabatic solutions (for any value of the specific heat ratio γ) converge to the isothermal solution in the region close to the stagnation point of the flow. Because of this, the analytic isothermal solution can be used for comparisons with observations of curved jets in both the isothermal and adiabatic regimes. Finally, we present a comparison of our model with observations of the curved Herbig-Haro flow HH 30.

Accepted by MNRAS

Dust Emission from L1641N: An Optically Thick Circumstellar Disk?

H. Chen[1], J.-H Zhao[1,2], and N. Ohashi[1]

[1] Center for Astrophysics, 60 Garden St. MS-42, Cambridge, MA 02138, USA
[2] Institute for Astronomy and Astrophysics, Academia Sinica, Taipei, Taiwan

We have obtained high angular resolution ($1'' - 3''$) continuum maps of the young stellar object L1641N (IRAS 05338-0624) at 2.0 mm, 7.0 mm, and 1.3 cm. The source positions at the three wavelengths coincide with a very red near-IR source detectable only at $\lambda > 4\mu$m. The source is unresolved at 1.3 cm with a $1''$ beam (or 250 AU in radius). When combined with flux densities at other wavelengths, we find that the spectral energy distribution at mm wavelengths can be well fit by a power-law with a spectral index of 2.1 ± 0.2, and that the distribution between 2.0 mm and 6 cm can be well fit by a combination of the dust emission and optically thin free-free emission. Among several possible interpretations of the observed continuum spectrum, we favor optically thick dust emission from within 250 AU of L1641N, and the most probable origin of such emission is a circumstellar disk around the young star. We also discuss the physical properties of the optically thick disk.

Accepted by ApJ Letters

Polarimetry of Young Stellar Objects I : Linear Polarization of GSS 30

Antonio Chrysostomou[1], Stuart G. Clark[1], J.H Hough[1], T.M Gledhill[1], Alan McCall[1], Motohide Tamura[2]

[1] Division of Physical Sciences, University of Hertfordshire, College Lane, Hatfield, Herts, AL10 9AB, UK
[2] National Astronomical Observatory, Osawa, Mitaka, Tokyo 181, Japan

E-mail contact: acc@star.herts.ac.uk

We present broad band near-infrared (JHK_n) imaging linear polarimetry of the young stellar object, GSS 30. The overall polarization pattern is centrosymmetric about the illuminating source, IRS 1. The model of Clark & McCall (1995) is used to model the wavelength dependence of the degrees of polarization of the scattered radiation in the nebula. The results suggest that the axis of the nebula is inclined at an angle of $\sim 25^o$ - 30^o to the plane of the sky, with the northern lobe towards us. The grain size distribution is best fitted by grains covering the range 0.005 to 0.35 μm. However, the model cannot reproduce the observed polarization pattern across the nebula, which is seen to decrease towards its edges.

A polarization disk, ie. a band of aligned polarization vectors, is seen close to the source. This pattern breaks down to the east of the source where the polarization pattern reverts back to a centrosymmetric one. We speculate that a binary system could disrupt the density gradient across the circumstellar disk such that photons can easily escape in this direction and are then scattered (singly) towards us. To the west of the source the pattern of the polarization disk remains intact. The degrees of polarization, both in the line of sight to the source and along the disk, are higher at J and H than they are at K_n. We propose that the wavelength dependence of the polarization here may be produced by a combination of scattering and dichroism, with the grains aligned by a magnetic field parallel to the plane of the disk.

Accepted by MNRAS

The Dense Core, Outflow, and "Jet" in L810: High-Resolution Haystack Observations at λ3mm

Dan P. Clemens[1], Michael Berkovitch[2], João Lin Yun[3], Nimesh Patel[4], and Taoling Xie[5]

[1] Astronomy Department, Boston University, 725 Commonwealth Avenue, Boston, MA 02215, USA
[2] Astronomy Department, University of California at Los Angeles, Los Angeles, CA 90024, USA
[3] Departamento de Física, Universidade de Lisboa, Campo Grande, Ed. C1, 1700 Lisboa, Portugal
[4] Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138, USA
[5] Astronomy Program, University of Maryland, College Park, MD 20742, USA

We have used the Haystack 37 meter radio telescope to obtain high angular resolution spectral line maps of the innermost region of the star forming Bok globule L810 (CB205). These maps cover the central 1×1 arcmin region

with a sampling interval of 8 - 10 arcsec. One map was obtained in the CO (J = 1-0) spectral line in order to identify the source(s) of the high velocity gas. A CS (J = 2-1) map was obtained in order to find the location and kinematics of dense gas in this cloud core. Finally, a jet-like feature seen in near-infrared images was examined in two lines each of SO and SO_2, to search for post-shock chemical abundance enhancements.

We find a bright 4 - 11 $M_\odot$ CS core associated with both the IRS near-infrared stellar source (identified by Yun et al 1993) and the *IRAS* 19433+2743 far-infrared point source. The red and blue CO outflow lobes do appear to originate from IRS/*IRAS* 19433+2743 and join with the larger scale CO lobes mapped by Xie & Goldsmith (1990). However, the outflow lobes are not symmetrically placed about the IRS source. Instead, the outflow lobes are both offset some 30″ westward of the IRS position, producing a "swept back" appearance. The abundance of SO is not enhanced in the region of the jet-like feature, although CS shows a local intensity maximum there. The apparent location of the near-infrared jet-like feature, in the middle of the newly resolved blue outflow lobe, may be due to either enhanced dust scattering from a preexisting cloud clump located within the outflow or it could signify the presence of a region influenced by a previous epoch of star formation within L810.

Accepted by Astrophysical Journal

Radial and Rotational Velocities of Young Stars in Chamaeleon and Lupus

P. Dubath[1], Bo Reipurth[2] and M. Mayor[3]

[1] UCO/Lick Observatory, University of California, Santa Cruz, CA 95064, USA
[2] European Southern Observatory, Casilla 19001, Santiago 19, Chile
[3] Observatoire de Genève, CH-1290 Sauverny, Switzerland

We present a kinematic study of 26 T Tauri stars in the Chamaeleon and Lupus molecular clouds, based on high resolution CASPEC spectra and CORAVEL radial velocity scanner observations. After discarding stars with high rotational velocities, noisy spectra or apparently variable velocities, we find a velocity dispersion of 0.9 ± 0.3 km/s for the remaining 10 stars of the Cha I T Tauri association. We also observe the J=1-0 line of ^{13}CO towards our target stars in Cha I, and find no significant gas motions to within 0.3 km/s, corresponding to the accuracy of the measurements. We derive a value of 0.5 ± 0.4 km/s for the difference between the mean stellar radial velocity and the mean gas velocity. The stars and the gas in Cha I are thus still closely linked kinematically. In the Lupus 3 clouds our sample of stars is smaller, and we merely note that the stars observed divide into two kinematically distinct subgroups, one of which belongs to the background Carina arm. Clearly a larger number of measurements would be desirable. We argue, however, that the accuracy of the stellar radial velocities may be difficult to improve because of the presence of undetected long-period spectroscopic binaries and large star spots. In addition, the determination of the gas motions is limited by complex line profiles due to cloud structure along the line-of-sight.

Accepted by Astron. Astrophys.

Clumpy Ultracompact H II Regions I: Fully supersonic wind-blown models

J.E. Dyson, R.J.R. Williams and M.P. Redman

Department of Physics and Astronomy, University of Manchester, Oxford Road, Manchester M13 9PL, UK

E-mail contact: mpr@ast.man.ac.uk

We propose that a significant fraction of the ultracompact H II regions found in massive star-forming clouds are the result of the interaction of the wind and ionizing radiation from a young massive star with the clumpy molecular cloud gas in its neighbourhood. Distributed mass loading in the flow allows the compact nebulae to be long-lived. In this paper, we discuss a particularly simple case, in which the flow in the H II region is everywhere supersonic. The line profiles predicted for this model are highly characteristic, for the case of uniform mass loading. We discuss briefly other observational diagnostics of these models.

Accepted by MNRAS, preprint available via http://axp2.ast.man.ac.uk:8000/preprints.html

An Ultraviolet and Optical Study of Accreting Pre-Main Sequence Stars: UXors

Nancy L. Eaton and William Herbst

Astronomy Department, Wesleyan University, Middletown, CT 06459

E-mail contact: neaton@wesleyan.edu

UX Ori stars (UXors) are pre-main sequence stars of both the Herbig Ae/Be and T Tauri type which show aperiodic eclipse-like minima. Their variations have been attributed to occultations by circumstellar material. We use archival IUE spectra and a catalog of UBVRI photometry to study the variations of 5 such objects, namely: RY Lup, RY Tau, CO Ori, BF Ori, and UX Ori. Relationships between UV spectral line fluxes and equivalent widths and V magnitude are found and displayed. Some shell features in UX Ori and BF Ori switch from absorption to emission during the minima. The equivalent widths of the emission features increase as the star fades. Spectral energy distributions (SEDs) covering the interval of 1200 to 8900 angstroms were constructed for several stars at different V magnitude light levels. A strong depression in the SED around 2400 angstroms, caused primarily by iron absorption lines (the "iron curtain") is quite noticeable in UX Ori and BF Ori when the stars are bright, but is diminished or absent when faint. The data are discussed in the context of the variable circumstellar obscuration hypothesis and provide some additional support for it.

Accepted by Astron. J.

Polarization of Astronomical Maser Radiation. III. Arbitrary Zeeman Splitting and Anisotropic Pumping

Moshe Elitzur

Dept. of Physics & Astronomy, University of Kentucky, Lexington, KY 40506, USA; moshe@pa.uky.edu

General solutions of the maser polarization problem are presented for arbitrary absorption coefficients. The results are used to calculate polarization for masers permeated by magnetic fields with arbitrary values of x_B, the ratio of Zeeman splitting to Doppler linewidth, and for anisotropic (m-dependent) pumping. In the case of magnetic fields, one solution describes the polarization for overlapping Zeeman components, $x_B < 1$. The $x_B \to 0$ limit of this solution reproduces the linear polarization derived in previous studies, which were always conducted at this unphysical limit. Terms of higher order in x_B have a negligible effect on the magnitude of q. However, these terms produce some major new results: (1) The solution is realized only when the Zeeman splitting is sufficiently large that $x_B > \sqrt{S_0/J_s}$, where S_0 is the source function and J_s is the saturation intensity (pumping schemes typically have $S_0/J_s \sim 10^{-5}$–10^{-8}). When this condition is met, the linear polarization requires $J/J_s \geq x_B$, where J is the angle-averaged intensity. This condition generally requires considerable amplification, but is met long before saturation ($J/J_s \geq 1$). (2) The linear polarization is accompanied by circular polarization, proportional to x_B. Because x_B is proportional to the transition wavelength, the circular polarization of SiO masers should decrease with rotation quantum number, as observed. In the absence of theory for $x_B < 1$, previous estimates of magnetic fields from detected maser circular polarization had to rely on conjectures in this case and generally need to be revised downward. The fields in SiO masers are $\sim$ 2–10 G and were overestimated by a factor of 8. The OH maser regions around supergiants have fields of $\sim$ 0.1–0.5 mG, which were overestimated by factors of 10–100. The fields were properly estimated for OH/IR masers ($\leq$ 0.1 mG) and H_2O masers in star-forming regions ($\sim$ 15–50 mG). (3) Spurious solutions that required stability analysis for their removal in all previous studies are never reproduced here; in particular, there are no stationary physical solutions for propagation at $\sin^2\theta < \frac{1}{3}$, where θ is the angle from the direction of the magnetic field, so such radiation is unpolarized. These spurious solutions can be identified as the $x_B = 0$ limits of non-physical solutions and they never arise at finite values of x_B, however small. (4) Allowed values of θ are limited by bounds that depend both on Zeeman splitting and frequency shift from line center. At $x_B \leq 10^{-3}$, the allowed phase space region encompasses essentially all frequencies and $\sin^2\theta > \frac{1}{3}$. As the field strength increases, the allowed angular region shrinks at a frequency-dependent rate, leading to contraction of the allowed spectral region. This can result in narrow maser features with linewidths smaller than the Doppler width and substantial circular polarization in sources with $x_B \geq 0.1$. When $x_B \geq 0.7$, all frequencies and directions are prohibited for the stationary solution and the radiation is unpolarized.

Another solution describes the polarization when the Zeeman components separate. This occurs at line center when $x_B > 1$ and at one Doppler width when $x_B > 2$. The solution is identical to that previously identified in the $x_B \to \infty$ limit, and applies to OH masers around HII regions. A significant new result involves the substantial differences

between the π- and σ-components for most propagation directions, differences that persist into the saturated domain. Overall, HII/OH regions should display a preponderance of σ-components. The absence of any π-components in W3(OH) finds a simple explanation as maser action in a magnetic field aligned within $\sin^2\theta < \frac{2}{3}$ to the line of sight.

Accepted by The Astrophysical Journal (January 20, 1996)

Shell Masers

Moshe Elitzur[1] and Valentín Bujarrabal[2]

[1]Dept. of Physics & Astronomy, University of Kentucky, Lexington, KY 40506, USA
[2] Centro Astronómico de Yebes (IGN), Apartado 148, 19080 Guadalajara, Spain

E-mail contact: moshe@pa.uky.edu

We present the analytical solution of a maser shaped like a spherical shell. We determine the general condition on the size of the central cavity at which a sphere becomes a shell maser, and derive the intensity, beaming angle and observed size of both unsaturated and saturated shells.

Accepted by Astronomy and Astrophysics

Continuum emission associated with 6.7-GHz methanol masers

S.P. Ellingsen[1], R.P. Norris[2] and P.M. McCulloch[1]

[1] Physics Department, Unversity of Tasmania, GPO Box 252C, Hobart, TAS 7001, Australia
[2] Australia Telescope National Facility, CSIRO, PO Box 76, Epping, NSW 2121, Australia

E-mail contact: Simon.Ellingsen@phys.utas.edu.au

We have used the Australia Telescope Compact Array (ATCA) to search for continuum emission toward three strong 6.7-GHz methanol maser sources. For two of the sources, G339.88-1.26 and NGC 6334F (G351.42+0.64), we detect continuum emission closely associated with the methanol masers. A further three clusters of masers showed no radio continuum emission above our sensitivity limit of 1-5 mJy. We find the position of the 6.7-GHz methanol masers in G339.88-1.26 to be consistent with the hypothesis that the masers lie in the circumstellar disc surrounding a massive star. We also argue that one of the clusters of methanol masers in NGC 6334F provides indirect observational support for the circumstellar disc hypothesis.

Accepted by Mon. Not. R. Astr. Soc.

Variability of classical T Tauri stars. Its relation to the accretion process

Matilde Fernández[1,2] and Carlos Eiroa[2]

[1] Instituto de Astronomía, UNAM, Apdo. 70-264, 04510 México D.F., México
[2] Dpto. Física Teórica, C-XI, Univ.Autónoma Madrid, Ciudad Univ. Cantoblanco, E-28049 Madrid, Spain

E-mail contact: matilde@astroscu.unam.mx

We present the analysis of a UBV(RI)$_c$ photometric monitoring program carried out from July 1988 to August 1992 on a sample of 13 classical T Tauri stars and 2 suspected classical T Tauri stars.

We detected optical irregular variability with an amplitude larger than 0.1 mag in the V band in 8 stars. For 5 of them most of the variability can be attributed to hot spots, for one, to cool spots and for two of them, there is no clear mechanism; nevertheless, other phenomena must explain the short term (hours – days) and long term (years) variations superimposed. For some objects an anomalous behaviour at the shorter wavelengths (U band) is detected.

From the comparison between the amplitude of the optical variability due to hot spots and the equivalent width of the H$_\alpha$ emission a correlation between them is suggested. Assuming that the H$_\alpha$ emission is related to the accretion process, this correlation supports the idea that we are observing the hot spots where the material from the accretion disks falls onto the star.

Accepted by Astron. Astrophys.

The Southern Coalsack – II. Analysis of the colour excess toward Selected 194

G.A.P. Franco

Departamento de Física – ICEx – UFMG – Belo Horizonte – MG, Brazil

E-mail contact: franco@fisica.ufmg.br

The distribution of the interstellar dust toward the northern part of the Coalsack, and its surrounding, is investigated on the base of the colour excess and distances estimated from Strömgren photometry for a sample of stars earlier than G0, and belonging to the Selected Area 194. The analysis indicates that the interstellar medium along the observed directions is composed by a low column density material up to distances of about 150 pc (average colour excess $E(b-y) \approx 0\overset{m}{.}014$). Beyond that distance, one notices the effect of a higher column density material on the observed colour excesses. Such effect may be due in part to dust in the Coalsack. The colour excess for stars within the distance interval 200 pc to 1100 pc shows a well defined minimum of $E(b-y) \approx 0\overset{m}{.}100$, while beyond that distance another minimum of $E(b-y) \approx 0\overset{m}{.}200$ is reached.

Accepted by Astron. & Astrophys. Suppl. Ser.

A precessing jet in the L 1157 molecular outflow

F. Gueth[1], S. Guilloteau[1] and R. Bachiller[2]

[1] Institut de Radio Astronomie Millimétrique, 300 rue de la Piscine, F-38406 Saint Martin d'Hères, France
[2] Centro Astronómico de Yebes, Apartado 148, E-19080 Guadalajara, Spain

E-mail contact: gueth@iram.fr

The blue-shifted lobe of the L 1157 molecular outflow has been imaged in the CO J=1 line, and in the λ 2.6 mm continuum, with angular resolution of 3.5 x 3 arcsec ($\sim$ 7 10^{-3} pc at the distance of L 1157, 440 pc) at the IRAM interferometer. The data consist of a mosaic of 10 partially overlapping fields, complemented with short spacing information from the IRAM 30-m telescope.

The images reveal the presence of at least two prominent limb-brightened cavities which have been likely created by the propagation of large bow-shocks due to episodic events in a precessing, highly-collimated jet. A simple spatio-kinematic model involving two different ejection events provides an accurate description of the observations. We find that the outflow is inclined by $\sim$80° to the line of sight, and that the axis of the underlying jet precesses on a cone of 6° opening angle, with a period of $\sim$4000 yr. We discuss the constraints derived from the present observations on several recent models for jet-driven molecular outflows. We conclude that, similarly to what happens in other outflows (e.g.: L1448), the large opening angle of the L 1157 CO outflow is originated by the large size of the propagating bow-shocks, since the precession in L 1157 happens in a narrow cone. However, the observed shape of the cavities evacuated by the bow-shock propagation are not well accounted for by current models of gas entrainment by bow-shocks.

Accepted by Astron. Astrophys.

Polarization Profiles of Scattered Emission Lines. III. Effects of Multiple Scattering and Non-Rayleigh Phase Functions

W. J. Henney[1] and D. J. Axon[2,3]

[1]Instituto de Astronomía, UNAM, Ap. 70-264, 04510 México, D. F., México
[2]Nuffield Radio Astronomy Laboratories, Univ. of Manchester, Jodrell Bank, Macclesfield, Cheshire, SK11 9DL, UK
[3]Affiliated to European Space Agency, Space Telescope Science Institute, Baltimore, USA

E-mail contact: will @ astroscu.unam.mx

The techniques of Henney (1994) for interpreting spectropolarimetric observations of emission line scattering are extended to cover moderately optically thick cases and cases in which the scatterers are dust particles with a size that is not negligible compared with the wavelength of the scattered light. Particular attention is paid to the problem of the scattering of the emission lines from a light source moving within a cloud of dust. It is found that in many cases it is possible to infer the three-dimensional relative velocity vector between the emitting source and the scattering cloud from observations of the scattered spectra from two different areas of the cloud. This method of spectropolarimetric tomography is largely insensitive to the scattering phase function of the dust and to the optical depth of the cloud,

showing that approaches based on the single scattering assumption have a surprisingly broad range of validity.

Accepted by ApJ (To be published Nov 20 1995)

Massive Star Formation in the Hot, Dense Cloud Core of G9.62+0.19

P. Hofner[1*], S. Kurtz[2], E. Churchwell[1], C.M. Walmsley[3*] and R. Cesaroni[4]

[1] Astronomy Department, Univ. of Wisconsin-Madison, 475 North Charter Street, Madison, Wisconsin 53706, U.S.A.
[2] Instituto de Astronomia, UNAM, Apdo. Postal 70-264, 04510 México, D.F., México
[3] Max-Planck-Institut für Radioastronomie, Auf dem Hügel 69, 53 Bonn 1, Germany
[4] Osservatorio Astrofisico di Arcetri, Largo E. Fermi 5, I-50125 Firenze, Italy
[*] present address: I. Physikalisches Institut der Universität zu Köln, Zülpicherstr. 77, D-50937 Köln, Germany

We present high resolution observations of CH_3CN(J=6–5), $C^{18}O$(J=1–0), and 2.7 mm continuum obtained with the Owens Valley mm-array, toward a region of massive star formation in the G9.62+0.19 HII region complex. Our observations reveal three embedded centers of massive star formation located along the major axis of an elongated molecular cloud core. Two of those (components D and F) are observed close to the maximum of $C^{18}O$ column density whereas component E is located at the edge of the molecular core. Based on the $C^{18}O$ observations, we derive cloud core dimensions of 0.6×0.3 pc, a total mass of $1000\,M_\odot$ and a mean hydrogen density of $2 \times 10^5\,cm^{-3}$ for an assumed temperature of 30 K. The cloud core has a systematic velocity gradient of $9\,km\,s^{-1}\,pc^{-1}$ along its major axis. The embedded centers of massive star formation are all detected in the 2.7 mm continuum and all three are bright, compact sources of CH_3CN(J=6–5) emission.

Component D is an UC HII region with an electron density of $1.8 \times 10^5\,cm^{-3}$, an electron temperature of 8000 K, a diameter ≤ 0.014 pc, and an ionizing star of type B0.5 ZAMS. For component E, the power-law spectrum of index 1.1 between 2 cm and 2.7 mm together with the small angular diameter suggest that the continuum emission is produced either by a partially ionized stellar wind or by an UC HII region of electron density $8.0 \times 10^5\,cm^{-3}$ and a diameter ≤ 0.0025 pc, ionized by a star of type B1 ZAMS, plus some excess dust emission. Our $C^{18}O$ and 2.7 mm continuum data indicate that the mass associated with component E is in the range $120 - 160\,M_\odot$. For component F, continuum emission is only detected at 2.7 mm. It is likely that most or all of this emission is produced by warm circumstellar dust. If so, then we estimate a total mass associated with component F of 55 to 160 $M_\odot$, depending on the temperature of the gas and dust which is not well determined for this object. Broad line wings in the $C^{18}O$ line are detected close to the position of component F; we interpret this is as being due to a bipolar molecular flow. Thus, component F is probably a premain sequence star which may be still in a rapid accretion phase, and we postulate that it is the youngest of the three centers of massive star formation in the G9.62+0.19 cloud core. In fact, it may be one of the youngest massive stars yet identified.

Each of the continuum components D, E, and F are enclosed in very compact, dense, warm molecular cocoons. Analysis of our CH_3CN and $C^{18}O$ data indicate gas temperatures in the range 50 K (component D) to possibly as high as 300 K (component F), but more likely about 100 K (components E and F). The optical depths in the lower K-transitions of CH_3CN(J=6-5) are > 1 toward all three sources. From our LVG analysis we obtain methyl cyanide column densities in the range $5 \times 10^{15}\,cm^{-2}$ (component D) to $1 \times 10^{17}\,cm^{-2}$ (component F); the methyl cyanide abundance is clearly enhanced at least in component F and probably also in components D and E. Hydrogen densities are in excess of $10^7\,cm^{-3}$ in components E and F.

The systematic increase in density, column density, and temperature in components D, E, and F, respectively, together with properties of the continuum emission at the three positions lead us to suggest that D to F probably represents an evolutionary sequence with D being the oldest and F being the youngest among the three centers of massive star formation.

Accepted by the Astrophysical Journal

Potential Protostars in Cloud Cores: H_2CO Observations of Serpens

Robert L. Hurt[1], Mary Barsony[1] and Alwyn Wootten[2]

[1] Department of Physics, University of California, Riverside Riverside, CA 92521, USA
[2] NRAO, 520 Edgemont Road, Charlottesville, VA 22903-2475, USA
E-mail contact: rhurt@fun.ucr.edu fun@nusun.ucr.edu or awootten@nrao.edu

The Serpens cloud contains a large number of heavily embedded protostellar cores. We present results of a formaldehyde survey of the strongest submillimeter continuum sources here in an attempt to determine the gas properties in these objects. The formaldehyde transitions we have measured trace exceptionally dense gas to which most other commonly-observed molecular species, or dust, are not sensitive. In the four sources observed in at least 3 H_2CO transitions we find higher gas kinetic temperatures than have been derived previously, ranging from 40-190 K. The gas densities in this region are also large, in the range of $n_{H_2} \sim 10^6$–$10^{6.5}$ cm^{-3}. Some of the objects exhibit strong self-reversal features which may indicate infall, and two of them possess exceptionally broad linewings which may be associated with molecular flows. Several of these sources may represent extremely young protostars that have not yet accreted the bulk of their mass from their surrounding circumstellar envelopes.

Preprint available via WWW at http://www.cv.nrao.edu/ awootten

Accepted by The Astrophysical Journal, appearing 10 Jan 96

The Connection between Submillimeter Continuum Flux and Binary Separation in Young Binaries: Evidence of Interaction between Stars and Disks

Eric L. N. Jensen[1], Robert D. Mathieu[1], and Gary A. Fuller[2]

[1] Department of Astronomy, University of Wisconsin-Madison, Madison, WI 53706, USA
[2] NRAO, Edgemont Road, Charlottesville, VA 22903, USA

E-mail contact: jensen@astro.wisc.edu

We present 800 μm continuum photometry of pre–main-sequence binary stars with projected separations $a_p < 150$ AU in the Scorpius-Ophiuchus star-forming region. Combining our observations with published 1300 μm continuum photometry from André & Montmerle (1994), we find that binaries in Sco-Oph with $1 < a_p < 50$–100 AU have lower submillimeter continuum fluxes than wider binaries or single stars, as previously found for Taurus-Auriga binaries. The wide binaries and single stars have indistinguishable submillimeter flux distributions. When the Sco-Oph and Tau-Aur samples are combined, this dependence of submillimeter flux on binary separation is detected with a confidence level of greater than 99%. Thus, binary companions with separations less than 50–100 AU significantly influence the nature of associated disks.

We have explored the hypothesis that the reduction in submillimeter flux is the result of gaps cleared in 100-AU disks by companions. Gap clearing produces the qualitative dependence of submillimeter flux on binary separation, and a simple model suggests that large gaps in disks with surface densities typical of wide-binary or single-star disks can reduce submillimeter fluxes to levels consistent with the observed limits. This model shows that the present submillimeter flux upper limits do not necessarily imply a large reduction in disk surface densities.

Two-thirds of the pre–main-sequence binaries were detected by IRAS at 60 μm, showing that most binaries have at least one circumstellar disk. We have used these fluxes to place lower limits of 10^{-5} $M_\odot$ on circumstellar disk masses. Similarly, the 60 μm fluxes indicate that the circumstellar disk surface densities are no more than two orders of magnitude smaller than those of typical disks around single stars.

Our upper limits on submillimeter fluxes place upper limits of 0.005 $M_\odot$ on circumbinary disk masses. Thus massive circumbinary disks (such as that found around GG Tau) are rare among binaries with projected separations between a few AU and 100 AU. Circumbinary disks are found around some binaries with separations less than a few AU.

Accepted by Ap. J. Scheduled for the Feb. 10, 1996 issue.

This paper is available via the World Wide Web at http://www.astro.wisc.edu/prints/prints.html

Limits on the Differential Rotation of T Tauri Stars

Christopher M. Johns-Krull

McDonald Observatory, The University of Teaxs at Austin, Austin, TX 78712-1083, USA

The hypothesis that strong differential rotation coupled with the preferential appearance of higher latitude hot spots on classical T Tauri stars (CTTS) and low latitude cool spots on naked T Tauri stars (NTTS) can account for the apparent difference in the rotation periods of the two groups of stars is tested. It is shown that the required level of differential rotation produces measurable changes in the profile shapes of the photospheric absorption lines. High

spectral resolution observations of 1 NTTS (HDE 283572 - $v\sin i \approx 110$ km s^{-1}) and 2 CTTS (SU Aur - $v\sin i \approx 66$ km s^{-1}; RY Tau - $v\sin i \approx 50$ km s^{-1}) are analyzed for the presence of differential rotation. It is shown that these stars are consistent with solid-body rotation and rule out the strong differential rotation required to explain the rotation period difference between CTTS and NTTS. This further supports the hypothesis that CTTS do in fact rotate slower than NTTS due to the interaction of stellar magnetic fields with the accretion disks which surround CTTS. In addition, a more accurate measure of $v\sin i \approx 80$ km s^{-1} for HDE 283572 is given.

Accepted by Astron. & Astrophys.

Far-Infrared Water Emission from Magnetohydrodynamic Shock Waves

Michael J. Kaufman[1,2] **and David A. Neufeld**[1]

[1] Department of Physics and Astronomy, The Johns Hopkins University, Baltimore, MD 21218 USA
[2] Present Address: MS 245-3, NASA/Ames Research Center, Moffett Field, CA 94035 USA

E-mail contact: kaufman@warped.arc.nasa.gov

Non–dissociative, magnetohydrodynamic, C-type shock waves are expected to be a prodigious source of far–infrared water emissions in dense interstellar regions. We have constructed a model to calculate the far-infrared H_2O line spectra that emerge from such shocks. Using the best estimates currently available for the radiative cooling rate and the degree of ion-neutral coupling within the shocked gas, we modeled the temperature structure of MHD shocks using standard methods in which the charged and neutral particles are treated separately as two weakly-coupled, interpenetrating fluids. We then solved the equations of statistical equilibrium to find the populations of the lowest 179 and 170 rotational states of ortho– and para–H_2O. We have completed an extensive parameter study to determine the emergent H_2O line luminosities as a function of preshock density in the range $n(H_2) = 10^4 - 10^{6.5}\,\mathrm{cm}^{-3}$ and shock velocity in the range $v_s = 5 - 40\,\mathrm{km\,s}^{-1}$. We find that numerous rotational transitions of water are potentially observable using the *Infrared Space Observatory* and the *Submillimeter Wave Astronomy Satellite*, and may be used as diagnostics of the shocked gas. We have also computed the rotational and rovibrational emissions expected from H_2, CO and OH, and we discuss how complementary observations of such emissions may be used to further constrain the shock conditions. In common with previous studies, we come close to matching the observed H_2 and high-J CO emissions from the Orion–KL star forming region on the basis of a single shock model. We present our predictions for the strengths of H_2O line emission from the Orion shock, and we show how our results may be scaled to other regions where molecular shocks are likely to be present.

Accepted by The Astrophysical Journal

Water Maser Emission from Magnetohydrodynamic Shock Waves

Michael J. Kaufman[1,2] **and David A. Neufeld**[2]

[1] Department of Physics and Astronomy, The Johns Hopkins University, Baltimore, MD 21218 USA
[2] Present Address: MS 245-3, NASA/Ames Research Center, Moffett Field, CA 94035 USA

E-mail contact: kaufman@warped.arc.nasa.gov

Slow, non-dissociative, magnetohydrodynamic shock waves that propagate in dense molecular gas are a probable source of water maser emission in regions of active star formation. We have constructed a model to compute the water maser emission expected from such shocks. We have integrated a set of one–dimensional hydrodynamics equations in which the neutral species and charged particles are treated separately as two interpenetrating but weakly-coupled fluids, and then solved the equations of statistical equilibrium to obtain the level populations of the lowest 179 and 170 rotational states of ortho– and para–H_2O. Our model includes radiative cooling due to rovibrational transitions of H_2O, CO, and H_2, and cooling due to dissociation of H_2 and due to gas–grain collisions. The fractional ionization is extremely low in the dense shocks considered here, and resides primarily on charged dust grains. We find that luminous H_2O maser emission is expected from dense non-dissociative MHD shocks: in particular, the warm molecular gas behind such shocks is ideal for pumping numerous low– and high–lying submillimeter maser transitions. Here we present results for shocks with initial H_2 densities of $10^7 - 10^{9.5}\,\mathrm{cm}^{-3}$ and velocities of propagation up to $\sim 45\,\mathrm{km\,s}^{-1}$. Over this entire parameter space, we have determined the efficiency with which shock energy is converted into maser luminosity for each of the water maser transitions that have so far been observed in interstellar gas, under conditions where the maser action is saturated, and we have considered the geometrical effects which determine whether or not a

given maser transition will be saturated. For the range of pre-shock densities that we considered,non-dissociative shocks give rise to individual masing regions with sizes of $\sim 10^{12}$ to a few times 10^{14} cm, and, given suitable geometries, can reproduce the high brightness temperatures characteristic of observed maser sources. Non-dissociative shock models are also successful in accounting for the magnetic field strengths that have been inferred from observations of Zeeman splitting. Maser line ratios are presented for use as potential probes of the conditions in the masing gas. These are compared with observational data, some of which cannot be explained on the basis of fast *dissociative* shock models.

Accepted by The Astrophysical Journal

Aperture Synthesis Imaging of the Circumstellar Dust Disk Around DO Tauri

D.W. Koerner[1], C.J. Chandler[2] and A.I. Sargent[3]

[1]169-506, Jet Propulsion Laboratory, CIT, 4800 Oak Grove Dr., Pasadena, CA 91109, USA
[2]National Radio Astronomy Observatory, P.O. Box 0, Socorro, NM 87801, USA
[3] Division of Physics, Mathematics and Astronomy, 105-24, CIT, Pasadena, CA 91125, USA

E-mail contact: davidk@coma.jpl.nasa.gov

We have detected the T Tauri star, DO Tauri, in a 0.6″-resolution VLA map of 43.3 GHz (λ = 7 mm) continuum emission. The 43 GHz flux density lies on the same power-law slope defined by 89 to 232 GHz measurements, $F_\nu \propto \nu^\alpha$ with index $\alpha = 2.39 \pm 0.23$, confirming that the 43.3 GHz emission is thermal radiation from circumstellar dust. Upper limits to the flux densities at 8.4 and 22.5 GHz constrain the contribution of free-free emission from a compact ionized wind to less than 49%. The dust emissivity index, β, is 0.39 ± 0.23, if the emission is optically thin. Fitting a model of a thin circumstellar disk to the observed spectral energy distribution gives $\beta = 0.6 \pm 0.3$, consistent with the power-law derivation. Both values are substantially lower than is generally accepted for the interstellar medium, suggesting grain growth. Given the youth of DO Tau and the early evolutionary state of its circumstellar disk, this result implies that mm-size grains have already formed by the early T-Tauri phase.

Accepted by Astrophysical Journal Letters

The HII Region Complex G5.48−0.24: Radio Continuum, H I, and CO Observations

Bon-Chul Koo[1], Kee-Tae Kim[1], Ho-Gyu Lee[1], Min-Su Yun[2] and Paul T. P. Ho[3]

[1] Department of Astronomy, Seoul National University, Seoul 151-742, Korea
[2] Astronomy Department, Caltech 105-24, Pasadena, CA 91125, USA
[3] Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138, USA

E-mail contact: koo@astrohi.snu.ac.kr

We have carried out VLA radio continuum (6 and 20 cm), VLA H I 21-cm line, and ^{13}CO J=1–0 line observations of the Galactic H II region G5.48−0.24. We present the continuum maps at 21 cm with $\sim 50''$ resolution and at 6 and 20 cm with $\sim 5''$ resolution. The radio continuum maps show that the H II region is composed of a bright component immersed in a diffuse emission of $\sim 6'$ (or 21 pc) radius. The bright component has a compact (0.7 pc) core surrounded by an extended (3.4 pc) halo. According to Wood & Churchwell (1989), the compact core has an ultracompact (0.04 pc) subcomponent. The rms electron density of the diffuse emission is 7 cm^{-3} and it increases roughly by a factor of 10 from one structure to the next small-scale structure. The observed radio continuum flux, half of which is contributed by the diffuse emission, requires an ionizing star of O5 ZAMS. If we consider the direct absorption of ionizing stellar photons by dust within H II regions, the bright component alone requires an O5 exciting star.

The brightness of the diffuse continuum emission decreases steeply along its western boundary and gradually at other directions. The VLA H I 21-cm line maps show that there is an H I cloud in contact with the steep western boundary. The ^{13}CO line observations show that there is a giant molecular cloud associated with the H II region. The bright component of the radio continuum emission coincides with the dense core of the molecular cloud. Therefore, G5.48−0.24 appears to be an H II region-molecular cloud complex where the formation of massive stars occurred recently. The radio continuum structures of largely different dynamical ages (e.g., 4×10^3–2×10^6 yr) may indicate that either the sequential star formation is proceeding, or G5.48−0.24 is a blister-type H II region.

Accepted by Astrophysical Journal

NGC 1333 IRAS 4: Further Multiplicity Revealed with the CSO–JCMT Interferometer

Oliver P. Lay[1], **John E. Carlstrom**[1] **and Richard E. Hills**[2]

[1] Division of Physics, Math. and Astronomy, California Institute of Technology, Pasadena, CA 91125, USA
[2] Mullard Radio Astronomy Observatory, Cavendish Laboratory, Madingley Road, Cambridge CB3 0HE, UK

E-mail contact: opl@astro.caltech.edu

Single dish submillimeter continuum observations showed that IRAS 4 in the NGC 1333 region of the L1450 molecular cloud is a $30''$-separation binary protostellar system. The components are designated as 4A and 4B, and are believed to be very young and deeply embedded. Our observations with the CSO–JCMT Interferometer at $\lambda = 0.84$ mm show that both 4A and 4B are multiple systems; the visibility curve for 4A is well fitted by a $1''.8$ binary whose components are consistent in size and flux with dusty accretion disks. IRAS 4B appears to show even higher multiplicity, since it is not fitted well by either single or binary models. We conclude that IRAS 4 is a hierarchical quadruple, or higher order, embedded protostellar system.

Accepted by Ap. J. (Letters)

A dense stellar cluster surrounding W3 IRS 5

S. T. Megeath[1], **T. Herter**[2], **C. Beichman**[3], **N. Gautier**[3], **J. J. Hester**[4], **J. Rayner**[5] **and D. Shupe**[6]

[1] Max Planck Institut für Radioastronomie, Auf dem Hügel 69, D-53121 Bonn 1, Germany
[2] Department of Astronomy, Cornell University, Ithaca, NY 14853, USA
[3] Infrared Processing and Analysis Center, 100-22, Pasadena, CA 91125, USA
[4] Department of Physics and Astronomy, Arizona State University, Tempe, AZ 85287, USA
[5] Institute for Astronomy, University of Hawaii, 2680 Woodlawn Dr. Honolulu, HI 96822, USA
[6] Department of Physics, California Institute of Technology, MS 320-47, Pasadena, CA 91125, USA

E-mail contact: v701tom@mpifr-bonn.mpg.de

We present J, H, and K–band mosaics of a $\sim 1.5 arcmin \times 1.5$ arcmin field in the W3 Main molecular core, a massive molecular core in the process of forming an OB association. Our mosaics include the HII regions W3 A and W3 B and a massive molecular clump surrounding W3 IRS 5. These data show a large, embedded population of intermediate to low mass stars co–existing with recently formed OB stars. The highest density of embedded stars is in a compact cluster surrounding IRS 5; to a limiting absolute magnitude of $M_K = 5.1$, we estimate a stellar density of 1200-4200 pc^{-3}. A comparison of the m_K vs. $H - K$ diagrams for the W3 population and for nearby YSOs shows that most of the stars have colors and magnitudes consistent with reddened T Tauri stars, i.e. low mass pre–main sequence stars. On the basis of the dereddened K–band magnitude we find that 60% of the stars detected in H and K have an upper mass limit of 2 M$_\odot$, supporting our claim that most of the embedded stars are low mass stars. The K–band luminosity function is consistent with the KLF of a 0.3 Myr cluster with a Miller–Scalo initial mass function (IMF); however, an older cluster with an IMF flatter than the Miller–Scalo IMF is not excluded. Comparing the results of radio surveys of the IRS 5 clump with our infrared data, we find evidence that the > 10 M$_\odot$ stars traced by the radio observations are more numerous than predicted by a Miller–Scalo IMF. We estimate a star formation efficiency in the molecular clump surrounding IRS 5 of 6–15%, suggesting that most of the molecular mass has not been converted into stars. We also report the detection of candidate exciting stars for the W3 B, W3 E and W3 F ultracompact HII regions.

Accepted by A. & A.

Giant Bow Shock Pairs Associated with Herbig-Haro Jets

Katsuo Ogura

Kokugakin University, Higashi, Shibuya-ku, Tokyo 150,Japan

E-mail contact: katsuo@tansei.cc.u-tokyo.ac.jp

Two pairs of giant (linear size ≈ 1 pc) bow shock structures have been discovered, each located symmetrically about HH 1/2 and HH 124. Their Herbig-Haro (HH) nature has been examined by narrow band CCD imaging on and off [SII] 6717/6731 and/or slit spectroscopy. Multiple bow shocks are known associated with a few HH objects such as HH 34, and are interpreted as evidence for recurrent outflow activity of the exciting sources. The giant bow shocks

associated with HH 1/2 or HH 124 provide further, beautiful examples of this phenomenon and, with dynamical ages of about 10,000 yr in the both pairs, extend the timescale of HH activity by an order of magnitude.

Accepted by Astrophys. J. Letters (Sep 1 1995)

CH_3CN towards G10.47+0.03 and G31.41+0.31

L. Olmi[1], R. Cesaroni[2] and C.M. Walmsley[3]

[1] Cornell University, NAIC, Arecibo Observatory, P.O. Box 995, Arecibo, P.R. 00613, USA
[2] Osservatorio Astrofisico di Arcetri, Largo E. Fermi 5, I-50125 Firenze, Italy
[3] Max-Planck-Institute für Radioastronomie, Auf dem Hügel 69, D-53121 Bonn, Germany

We have used the IRAM 30-m telescope to map, in the J=6–5, J=8–7, and J=12–11 rotational transitions of methyl cyanide (CH_3CN), the two ultracompact HII regions G10.47+0.03 and G31.41+0.31. We also detected transitions of vibrationally excited $v_8 = 1$ CH_3CN and of the isotopomer $^{13}CH_3CN$. These observations confirm the existence of hot and dense molecular clumps around the sources, as indicated by Olmi et al. (1993). We extend their work here, through the use of (i) mapping of the two sources, (ii) different techniques to analyse the data, and (iii) detection and description of a velocity shift across the core of G31.41+0.31, whose origin is unclear but it can be interpreted as being due to rotation. Therefore, the observations furnish an independent estimate of temperature and density to compare with those previously obtained from NH_3 and $C^{34}S$. Temperatures and column densities for the two sources were determined on the basis of the intensities of the optically *thin* lines, as well as employing the optically *thick* lines. We conclude that the temperature of the G10.47 and G31.41 cores, on a size scale of $1.5''$, is about 160 K and 140 K, respectively. We indirectly estimate the hot-cores angular size ($< 2''$), and can also infer the existence of an extended envelope ($\geq 10''$). The molecular abundance ratio $[CH_3CN]/[NH_3]$ is of order of 0.01 in both sources. We also infer a mass of roughly 10^3 $M_\odot$ inside a region of order 0.1 pc in the case of G31.41+0.31, and a rather similar situation is found for G10.47+0.03. From this information, it seems reasonable to speculate that we may be observing an early phase of the evolution of a galactic cluster.

Accepted by Astron. Astrophys.

Winds and Accretion Flows around T Tauri Stars

Gernot Paatz and Max Camenzind

Landessternwarte Königstuhl, D-69117 Heidelberg, Germany

E-mail contact: gpaatz@hp2.lsw.uni-heidelberg.de

Low-mass protostellar objects are often found to be surrounded by circumstellar disks. Due to a strong magnetization of the protostellar object and its accretion disk, accretion onto the central object occurs along magnetic surfaces. Similarly, winds are driven away by the magnetic properties of the underlying disk and star. We solve the stationary axisymmetric equations of motion for a polytropic flow in a given magnetosphere in a Newtonian approximation. Wind solutions are uniquely determined by the requirement that the flow successively passes through the slow magnetosonic, the Alfvén and the fast magnetosonic points. Accretion flows, on the other hand, can never reach super-Alfvénic speeds.

We consider several topologies for the acceleration of a wind: a magnetosphere which is built up by magnetic fields of the accretion disk only and a magnetosphere which results from the interaction of the stellar magnetic field with the surrounding accretion disk. In the latter case the wind can originate from the disk as well as from the star. The stellar magnetosphere is assumed to be of dipolar structure. In contrast to purely hydrodynamic winds, the form of the magnetic flux-tube is essential for the conversion of magnetic Poynting flux into kinetic energy of the wind. Initial conditions appropriate for T Tauri stars lead to outflow velocities of a few hundred kilometers per second, as observed in these systems. Winds driven by the magnetosphere of a disk are only slightly supermagnetosonic, while those driven away by a star-disk magnetosphere are found to be highly supermagnetosonic, provided the magnetic flux surfaces are collimated into a conical shape at a distance of a few thousand stellar radii.

Magnetized winds carry away angular momentum and in this way exert a torque on the star-disk system. This leads to a braking of the stellar rotation. The corresponding time scale depends on the position of the Alfvén point. Our results imply that rapid protostellar rotation can be spun down on a time-scale of a few million years. In this way, a protostar accreting from a circumstellar disk reaches an equilibrium rotation period at the level of about ten percent

of breakup, which agrees with observed rotation periods of T Tauri stars.

The strong stellar magnetisation leads to a gap between the star and the surrounding disk. For gaps of the order of a few stellar radii accretion achieves a sub-Alfvénic velocity of 300 km/s at the stellar surface. Flow topologies are discussed for parameters characteristic of T Tauri systems.

Accepted by Astron. & Astrophys.

Mid–Infrared images of young stellar objects with molecular outflows

P.Persi[1], M.Busso[2], L.Corcione[2], M.Ferrari–Toniolo[1] ānd A.R.Marenzi[1]

[1] Istituto Astrofisica Spaziale,CNR,C.P.67,00044 Frascati,Italy
[2] Osservatorio Astronomico di Torino, Pino Torinese,Italy
E-mail contact: persi@saturn.ias.fra.cnr.it

Images from 8.8 to 12.5 μm of the luminous young stellar objects (YSOs) W3–IRS5, and MonR2–IRS3, and of the Herbig AeBe stars Z CMa and LkHα 101, associated with molecular outflows, are presented. The images were obtained through the mid–IR camera TIRCAM with a pixel scale of 1.23 arcsec/pix, operating at the 1.5 m Italian Infrared Telescope (TIRGO). The observed point–spread function has a FWHM size of $\sim$3 arcsec. With deconvolution algorithms a spatial resolution of $\sim$1.8 arcsec can be achieved. At these scales, the two Herbig AeBe stars and the luminous YSO MonR2–IRS3 are unresolved, while W3–IRS5 shows an effective extended emission of elliptical shape, 2.3 arcsec wide along its major axis, similar to those seen in other outflow objects, and indicative of the possible presence of disk–like structure around a cluster of embedded B0.5–B0 stars.

Accepted by Astron.Astrophys.

A Survey of Near Infrared Emission in Visual Reflection Nebulae

K. Sellgren[1], M. W. Werner[2] and L. J. Allamandola[3]

[1] Department of Astronomy, Ohio State University, 174 West 18th Av., Columbus, OH 43210 USA
[2] M/S 169-327, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109 USA
[3] M/S 245-6, NASA Ames Research Center, Moffett Field, CA 94035 USA

E-mail contact: sellgren@payne.mps.ohio-state.edu

We present a survey for extended 2.2 μm emission in 20 new visual reflection nebulae, illuminated by stars with temperatures of 3,600−33,000 K. We detect extended 2.2 μm emission in 13 new nebulae, illuminated by stars with temperatures of 6,800−33,000 K. For most of these 13 nebulae we have measured $J-K$, $H-K$, and $K-L'$, as well as obtaining surface brightness measurements at the wavelength of the 3.3 μm emission feature. All of the reflection nebulae with extended near infrared emission in excess over scattered starlight have very similar near infrared colors and show the 3.3 μm feature in emission with similar feature-to-continuum ratios. The 3.3 μm feature-to-continuum ratio ranges from $\sim$3 to $\sim$9, both within individual nebulae and from nebula to nebula, which suggests that the 3.3 μm feature and its underlying continuum arise from different materials, or from different ranges of sizes within a size distribution of particles. No dependence on the temperature of the illuminating star is seen in the near infrared colors or 3.3 μm feature-to-continuum ratio, over a factor of two in stellar temperature. This is similar to our previous IRAS results, in which we found no dependence of the ratio of 12 μm to 100 μm surface brightnesses in reflection nebulae illuminated by stars with temperatures of 5,000−33,000 K.

Accepted by ApJS

High Velocity Molecular Gas from High-Mass Star Formation Regions

D.S. Shepherd and E. Churchwell

Department of Astronomy, University of Wisconsin – Madison, 475 N. Charter St., Madison, WI 53706, USA

E-mail contact: shepherd@madraf.astro.wisc.edu

We present results of a search for ^{12}CO(J=1-0) high velocity line wings toward 122 high-mass star formation regions using the NRAO 12 m telescope. Of the 94 sources for which we obtained data suitable for interpretation of low

intensity line wings, fully 90% are associated with high velocity (HV) gas in the beam. Ten percent have little or no high velocity gas (full width, FW < 15 km s^{-1} at the 1σ T_A^* level), 49% have FWs between 15 and 30 km s^{-1}, 30% have FWs between 30 and 45 km s^{-1} and 11% have FWs greater than 45 km s^{-1}. We find that the ^{12}CO(J=1-0) full widths are generally substantially larger than those seen toward low-mass stars. If the HV gas is due to bipolar outflows, then these results indicate that molecular outflows are a common property of newly formed massive stars; similar to that found for low-mass stars. Two high-mass star formation regions with strong ^{12}CO(J=1-0) line wings, G25.65+1.05 and G240.31+0.07, were identified during the survey and mapped with the NRAO 12 m telescope. Each field of view contains an ultracompact (UC) HII region located on or near the flow axis of a massive and energetic bipolar outflow. The molecular outflows associated with these sources, like those associated with other massive star formation regions, have several times more mass and momentum in their flows and about an order of magnitude greater energies and luminosities than those associated with low-mass stars.

Accepted by ApJ

T Tauri Variability in the Context of the Beat Frequency Model

Kester W. Smith, Geraint F. Lewis & Ian A. Bonnell

Institute of Astronomy, Madingley Road, Cambridge CB3 0HA, UK

E-mail contact: kester@ast.cam.ac.uk

We examine the implications of a beat frequency modulated model of T Tauri accretion. In particular we show that measurements of the variability of accretion generated lines can be used in conjunction with existing photometry to obtain a measurement of the underlying photospheric and disc flux. This provides an independent way of checking spectral energy distribution modelling. In addition, we show how spectroscopy of T Tauri stars can reveal the inclination angle between the magnetic axis and the plane of the disc.

Accepted by Monthly Notices

CCS Observations of The Protostellar Envelope of B335

T. Velusamy[1], T. B. H. Kuiper[2], W.D. Langer[1]

[1]Jet Propulsion Laboratory, California Institute of Technology, MS 169-506, Pasadena, CA 91109, USA
[2]Australia National Telescope Facility, CSIRO, PO Box 76, Epping, NSW 2121 Australia

We present single dish and interferometric spectral line observations of CCS at 22 GHz towards the core of B335, a classical example of a young protostellar region. We combined the VLA and DSN 70-m observations to produce high resolution ($6''$ and $12''$) channel maps at 0.04 km s^{-1} velocity intervals. These maps image for the first time the collapsing envelope around the protostar. These show that CCS emission arises primarily from the outer parts of the collapsing envelope down to half the infall radius and that CCS is clumpy throughout the core. LVG excitation analysis indicates that X(CCS) is $\sim 3\times10^{-9}$ in the outer envelope and $< 5\times10^{-11}$ in the center of the infall region. The absence of CCS in the interior could be due to time dependent chemical evolution. The velocity structure supports the evidence for inside-out collapse and the high velocity features are consistent with accretion onto a rotating central disk. The asymmetric clumpy distribution of CCS emission implies that the physical conditions are not spherically symmetric, and that the gas falling onto the circumstellar disk may be episodic.

Accepted by Astrophys. J (Letters).

The Deeply Embedded Source That Drives the Protostellar Outflow in AFGL 437: Evidence From Near-Infrared Polarimetric Imaging

David A. Weintraub[1] and Joel H. Kastner[2]

[1] Vanderbilt University, Department of Physics & Astronomy, Box 1807 Station B, Nashville, TN 37235, USA
david@ttau.phy.vanderbilt.edu
[2] MIT Center for Space Research, 37–667a, Cambridge, MA 02139, USA

Near-infrared polarimetric images of AFGL 437 reveal that this source, previously identified as a compact cluster of four infrared stars, is in fact an extensive reflection nebula containing more than two dozen and possibly more than five

dozen sources. Our near-infrared polarimetric maps of this nebulosity, reinforced with evidence from the nebular colors and the position of the associated water maser, provide strong evidence that WK 34 — a deeply embedded young stellar object — drives the molecular outflow known to emanate from AFGL 437. At 2.2 μm, this YSO illuminates a red bipolar reflection lobe that stretches to the north, curves toward the northeast, and is approximately parallel to the molecular outflow direction. WK 34 appears similar to the deeply embedded sources that illuminate near-infrared reflection nebulae and likely drive molecular outflows in L1287, NGC 7129 and OMC–1. As in the cases of L1287 and NGC 7129, the identification of an embedded YSO as the most likely source of the AFGL 437 outflow appears to eliminate more evolved, *optically* identified sources as active drivers of the outflow. Together, the infrared polarimetric imaging results of AFGL 437, L1287 and NGC 7129 indicate that in many, if not most, cases where an optically identified pre-main-sequence star lies near the apex of a bipolar outflow, upon closer inspection we are likely to find a younger, more deeply embedded source.

Accepted by ApJ

In Search of HL Tauri

David A. Weintraub[1], Joel H. Kastner[2] and Barbara A. Whitney[3]

[1] Vanderbilt University, Department of Physics & Astronomy, Box 1807 Station B, Nashville, TN 37235, USA
david@ttau.phy.vanderbilt.edu
[2] MIT Center for Space Research, 37–667a, Cambridge, MA 02139, USA
[3] Space Science and Engineering Center, Univ. of Wisconsin-Madison, 1221 W. Dayton St., Madison, WI 53706, USA

We present infrared polarimetric images that demonstrate that the T Tauri star HL Tau is not seen in direct light at $\lambda \leq 2.2$ μm. The position of the intensity centroid moves monotonically southwest from V (0.555 μm) through J (1.25 μm) and H (1.65 μm) to K (2.2 μm) wavebands. Furthermore, the mean position of the J, H and K polarimetric centroids — which marks the position of the illuminating source of extensive reflection nebulosity — is displaced $\sim 1''$ southwest of the position of the K band intensity peak. This offset is in the same direction as the offset between the K band intensity peak and the centroid of previously detected 3.6 cm emission. We conclude that, at optical and near-IR wavelengths, all of the observed radiation is scattered light from the circumstellar nebula. Our polarimetric images of HL Tau show a "polarization disk" at PA 134° and therefore support a model in which the projection of the equatorial plane of the protoplanetary disk is aligned at PA 134°. These results reinforce the contention that HL Tau is younger and more deeply embedded than typical T Tauri stars.

Accepted by ApJ Letters

An H_2O Maser Near Sgr A East: Evidence for Active Massive Star Formation

Farhad Yusef-Zadeh[1] & David M. Mehringer[2]

[1]Department of Physics and Astronomy, Northwestern University, IL 60208, USA
[2]Department of Astronomy, University of Illinois, USA

E-mail contact: dmehring@sirius.astro.uiuc.edu

We present the results of an H_2O maser search of six fields in the inner $5'$ of the Galactic center using the VLA in its DnC configuration. Four new H_2O masers are detected with typical luminosities of order 10^{-7} $L_\odot$. Three of the masers are associated with evolved stars and one with the Sgr A East H II region which is identified as the closest active star forming region to the Galactic center. This HII region and its associated H_2O maser lie at the boundary between the shell-type SNR source (Sgr A East) and an adjacent +50 km s^{-1} molecular cloud.

Evidence that the pressure wave of the Sgr A East supernova explosion has reached the HII region is given by presenting a radio continuum image of Sgr A East at λ20 cm and it is argued that the expanding SNR is inducing high-mass star formation. The possibility is considered that weak H_2O masers, like the 1720 MHz OH masers found at the boundary of the W28 SNR and an adjacent molecular cloud (Frail et al. 1994, ApJ, 424, L111), may also be used as a probe of massive star formation induced by the interaction of an expanding SNR and molecular clouds.

Accepted by ApJ (Letters)

SiO Emission in a Jet-like Molecular Outflow toward L1157

Q. Zhang[1], Paul T. P. Ho[1], M. C. H. Wright[2], D. J. Wilner[1]

[1] Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138, USA

[2] Astronomy Department and Radio Astronomy Laboratory, University of California at Berkeley, 601 Campbell Hall, Berkeley, CA 94720, USA

E-mail contact: qzhang@cfa.harvard.edu

We report interferometric observations of the SiO(2–1) and CO(1–0) lines toward the blue-shifted lobe of the L1157 bipolar outflow. These observations reveal clumpy SiO emission aligned with highly collimated CO emission. The SiO emission is enhanced in two prominent condensations, similar to those seen in VLA images of the NH_3(3,3) line. The SiO condensation closer to the outflow source peaks within $10''$ of a bright knot of the 2.1 μm H_2 line emission and shows blue-shifted emission extending more than 17 km s^{-1} from the cloud velocity. The close association between the SiO and H_2 emission suggests that the SiO emission is excited in the accelerated post-shock regions near the head of an underlying jet. The SiO condensation further downstream shows a smaller velocity extent and no apparent associated H_2 emission. We suggest that the two condensations result from separate interactions of an episodic jet with the surrounding cloud core. In this scenario, the emission region further downstream results from an older event. Both SiO condensations appear to lead the high velocity CO emission, consistent with the idea that SiO emission is excited close to the head of the jet and the CO accelerated in the oblique outer wings of the bow-shock.

To appear in ApJ Letters, Oct. 1, 1995

Dissertation Abstracts

Theoretical Study of OH Masers in Star-Forming Regions

Konstantinos G. Pavlakis

Thesis work conducted at: University of Crete, Greece

Current address: University Of Crete, Department of Physics, Leof. Knossou (P.O. Box 2208), 71409 Heraklion, Crete, Greece

Electronic mail: pavlakis@iesl.forth.gr

Ph.D dissertation directed by: Nikolaos D. Kylafis

Ph.D degree awarded: March 1995

A systematic study of OH masers in star-forming regions has been undertaken with the aim to invert, at least partially, the maser problem and from the observations to infer the physical conditions in star-forming regions. The pumping mechanisms investigated, one at a time, are: Collisions, local line overlap, non-local line overlap and external infrared radiation field. The present work is an improvement over the work of previous researchers in two main aspects. First, a formalism has been developed to treat radiation transport of spectral lines that overlap locally or non-locally. By using the Sobolev or Large Velocity Gradient approximation, the radiative transfer equation has been solved and analytic expressions have been derived for the first time for the intensity and the mean intensity of the radiation field. Second, the collision rates between OH and H_2 that are used distinguish for the first time between ortho-H_2 and para-H_2. All previous calculations considered para-H_2 only. As our calculations have shown, it makes a big difference in which form H_2 is in the interstellar medium. It is thus hoped that this work will help determine the abundance of ortho-H_2. Our model calculations have shown that a combination of a FIR field, collisions and line overlap are necessary to reproduce the general features of HII/OH masers. The general conclusions from our study are:

1) If the 4660 MHz line is seen, it means that $n_{\rm H_2} \sim 10^8$ cm^{-3}. If the 4751 MHz line is seen in the same spatial region, it confirms that $n_{\rm H_2} \sim 10^8$ cm^{-3}.
2) In the presence of a FIR radiation field, it is more likely to see the 1612 MHz line in the same spatial region with the 1665 MHz line than with the 1667 MHz one. When the 1612 MHz line is seen in the same spatial region with the 1665 MHz one, it means that $n_{\rm H_2} \sim 10^6$ cm^{-3}.
3) If both the 1665 MHz and the 1667 MHz lines are seen in the same spatial region, a FIR radiation field must be present and $n_{\rm H_2} \lesssim 10^6$ cm^{-3} there. The 1665 MHz line is typically the stronger of the two.
4) When the 1612 MHz line is observed, it means that $n_{\rm H_2} \gtrsim 10^6$ cm^{-3}.
5) Inversion of the 4766 MHz line means relatively small velocity gradients. We have found that this line is seen only for $V \lesssim 1$ km s^{-1} under all conditions we investigated.
6) The existence of the lines 1667 and 4766 MHz in the same spatial region, with the 1667 MHz one typically an order of magnitude brighter than the other, means $T_{\rm H_2} > 150$ K, $f_{\rm ortho-H_2} \gtrsim 0.5$ and relatively small velocities (typically $V < 1$ km s^{-1}).
7) In the presence of moderate velocity gradients ($V \sim 1$ km s^{-1}), if the 4766 MHz line is seen together with the 4751 MHz one in the same spatial region, then $f_{\rm ortho-H_2} \lesssim 0.5$. The 4766 MHz line is much stronger than the 4751 MHz one.
8) In the presence of moderate velocity gradients ($V \sim 1$ km s^{-1}), if the 4766 MHz line is observed together with the 1612 MHz one in the same spatial region, then $f_{\rm ortho-H_2} \gtrsim 0.5$.
9) In the presence of significant velocity gradients ($V \geq 2$ km s^{-1}), it is more likely to have the 1720 MHz line strongly inverted at $n_{\rm H_2} \sim$ few $\times 10^8$ cm^{-3} than at $n_{\rm H_2} \lesssim$ few $\times 10^7$ cm^{-3}.
10) As the FIR radiation field increases, the 1665 MHz line increases in intensity and is inverted in a larger range of densities.
11) Contrary to common belief, the dust temperature need not be high and the optical depth of the dust need not be a large ($p \geq 2$) power of frequency in order to have the 1665 MHz line stronger than the 1667 MHz one.

Meetings

FIRST ANNOUNCEMENT

Planetary Formation in the Binary Environment

The majority of stars in our Galaxy belong to multiple systems and these systems appear to be well established during the epoch of planet formation. The goal of this conference is to bring together the observationalists and theorists working in the areas star formation and planetary formation to discuss the implications of binary stars for planet formation.

The conference will be held at SUNY-Stony Brook, New York on June 16-18, 1996. It will include review papers and contributed poster papers. The conference is supported in part by the NASA Origins of Solar Systems Program.

Scientific Organizing Committee:

P. Bodenheimer (UCSD), A. Boss (CIW), R. Brown (STScI), C. Clarke (IoA, Cambridge), A. Ghez (Co-Chair, UCLA), S. Lubow (STScI), J. Lissauer (SUNY-SB), P. Nicholson (CU), C. Porco (UA), M. Simon (Co-Chair, SUNY-SB), S. Strom (UMass), H. Zinnecker (Würzburg)

For inquiries and to receive further announcements, contact:

origins@sbast1.ess.sunysb.edu

or,

msimon@sbast1.ess.sunysb.edu and *ghez@urania.astro.ucla.edu*

Short Announcements

Five College Astronomy Department, Tabular Data available on WWW

Karen M. Strom[1]

[1] Five College Astronomy Dept., University of Massachusetts, Amherst, MA 01003
kstrom@hanksville.phast.umass.edu

Tables of data published in papers from the Star Formation Group over the past several years have been converted to HTML and are now available on the World Wide Web at http://www-astro.phast.umass.edu/tables/ . Much of this data originates in the papers available in our online of preprints available at http://www-astro.phast.umass.edu/sfpreprints.html. However, we also collected other data tables from previous papers that were still available on disk and have made these available as well. Further data will be added as it becomes available.

These tables are all in HTML Table format as supported by Netscape 1.1 and to some extent Mosaic 2.5 and higher. For these tables to look as they should, Netscape 1.1 should be used, as Mosaic will not yet display the mathematical notation properly. Where available, Postscript and/or text tables are also offered, as well as links to the online preprint if it is available.

The latest versions of Netscape are listed on a page maintained by
Netscape at http://home.netscape.com/comprod/mirror/index.html.