

THE STAR FORMATION NEWSLETTER

An electronic publication dedicated to early stellar evolution and molecular clouds

No. 18 — 3 Feb 1994

Editor: Bo Reipurth (reipurth@eso.org)

Abstracts of recently accepted papers

SHARP images of the pre-main sequence star V536 Aquilae: a highly polarized binary

N. Ageorges^{1,2}, F. Ménard¹, J.-L. Monin¹, A. Eckart²

¹ Laboratoire d'Astrophysique, Observatoire de Grenoble, BP 53X, 38041 Grenoble Cedex, France

² MPE, Giessenbachstrasse, D-85748 Garching bei München, Germany

V536 Aql is a classical T Tauri star that has been known for a long time to exhibit a large optical linear polarization (6%-8%), a fact that suggested the presence of extended and asymmetrically distributed material around the star. We present infrared JHK images of V536 Aql, obtained with the SHARP infrared camera attached to the ESO-NTT telescope. These high-angular resolution observations allow, for the first time, to resolve V536 Aql as a binary system with a projected separation of 0.52 arcsec at a position angle $\sim 17^\circ$ and to give evidence for extended nebulosity associated with the star.

A simple model gives photospheric temperatures of 4000K for the primary and 3000K for the secondary. Luminosities are $2.4L_\odot$ and $0.5L_\odot$, respectively. These estimations assume an extinction of $A_V = 3.6$ for both components and are in agreement with the total bolometric luminosity $L = 3.1L_\odot$ derived by Cohen and Kuhn 1979 (CK), assuming that the distance of V536 Aql is 200 pc. The location of the pair in the H-R diagram of CK suggests that the components are coeval. All our images in J, H and K show evidence for extended circumstellar medium around V536 Aquilae so that it appears that the previously unexplained large polarization can be explained, at least qualitatively, by invoking the same mechanism as for all the other highly polarized pre-main sequence stars, namely scattering by dust grains.

Accepted by Astronomy & Astrophysics Letters

Near-IR imaging photometry of NGC1333. I. The embedded PMS stellar population

C. Aspin¹, G. Sandell¹ and A.P.G. Russell²

¹ Joint Astronomy Centre, 660 N. A'Ohoku Pl., University Park, Hilo, HI 96720 U.S.A.

² Royal Observatory, Blackford Hill, Edinburgh, EH10 3HJ, Scotland, United Kingdom

We present near-IR (NIR) J, H and K mosaic images of the active star forming region associated with the optical reflection nebula NGC1333. These observations cover an area of $10'' \times 10''$ and are centered on the energetic outflow source SSV13. From these data, we have obtained NIR photometry of 134 objects down to a 5σ limiting K magnitude of $m_K=16.2$ and a conservative survey completeness limit of $m_K=16.0$. With the addition of new optical R and I band CCD photometry, and both (sub)mm line and continuum maps, we analyse and discuss the region's morphology and spatial source distribution with additional reference to existing multi-wavelength data.

Within the survey field, NGC1333-S, we find a significant population of young, PMS stars. Specifically, we consider 55 sources or $\sim 41\%$ of the total stellar population are in a PMS evolutionary state. These sources exhibiting clustering in the vicinity of SSV13 although SSV13 is not at the cluster centre. The implied stellar PMS population has a range of M_K of 0-9 magnitudes and J-K colours of $\sim 1-5$. We interpret the data as evidence that i) that the embedded population is dominated by relatively low-mass stars i.e. $< 0.3M_\odot$ ($\sim 55\%$), and ii) there exists a smaller population of objects consistent with standard young star classes namely, classical T Tauri stars ($\sim 25\%$), Herbig Ae/Be stars ($< 10\%$) and Class I sources ($< 10\%$). We demonstrate that an apparent turn-over in the m_K luminosity function for all sources in the survey field can be modelled by the combined effect of the survey detection limit and spatially

variable extinction over the survey region. This suggests that a combination of a de-reddened sample of PMS star, and a detection limit several magnitudes below the expected faintest m_K for those sources is required before inferences can be drawn on the luminosity/mass function.

We additionally present the discovery of several new compact nebulous features in the region. Two such objects are possibly associated with SSV13 and HH7–11. Almost all of these features are associated with blue-shifted CO in the outflows from IRAS sources in the region.

We consider in some detail the usage of NIR photometry and colours in a region of significant extinction, e.g. within the boundaries of molecular clouds, to both determine the evolutionary state of an observed sample of stars and subsequently to characterize them into mass, luminosity, activity and age classes. We discuss and apply several methods to separate a population of embedded young pre-main sequence (PMS) stars from the generally larger population of reddened background galactic sources.

Accepted by Astron. Astrophys.

The remarkable pre-main sequence object V1318 Cygni

C.Aspin¹, G.Sandell¹ and D.A.Weintraub²

¹ Joint Astronomy Centre, 660 N. A'Ohoku Pl., University Park, Hilo, HI 96720 U.S.A.

² Department of Physics and Astronomy, Vanderbilt University, Nashville, TN 37235 U.S.A.

We present optical, near-IR, and sub-mm observations of the young pre-main sequence (PMS) star V1318 Cygni. Together with the Herbig Ae/Be stars BD+40 4124 and V1686 Cygni, these objects form a small cluster of young emission line stars. The optically brightest member is BD+40 4124. At wavelengths $\geq 5\mu\text{m}$ however, V1318 Cygni is the dominant source. In the optical and near-IR, V1318 Cygni resolves into three distinct components orientated north–south with a total separation of $5''$. The northern (N) and southern (S) sources appear stellar. Both are photometrically variable. The middle (M) source appears to be a nebulous knot in the optical while at $2\mu\text{m}$, its morphology suggests it may be a nebulous bridge or stream joining N and S. We suggest that V1318 Cygni is a young, PMS binary, possibly interacting, with a projected separation of ~ 5000 A.U. The southern object is likely of intermediate-mass and probably a very young HAEBE stars. The northern object is possibly a young, low-mass star.

Accepted by Astron. Astrophys. Letters

Successive ejection events in the L1551 molecular outflow

R.Bachiller¹, M.Tafalla^{2,3,1}, J.Cernicharo¹

¹Centro Astronómico de Yebes (IGN). Apartado 148, E-19080 Guadalajara, Spain

²Astronomy Department, University of California at Berkeley, 601 Campbell Hall, Berkeley, CA 94720, USA

³Harvard-Smithsonian Center for Astrophysics, MS42, 60 Graden Street, Cambridge, MA 02138, USA

We report CO 2-1 strip maps along the axis and across the lobes of the L1551 molecular outflow. The overall structure of the outflow is more complicated than previously believed. In particular, we find at least 4 successive high-velocity features along the axis of the blueshifted lobe which are very suggestive of different ejection episodes. The well-known “shell structure” is restricted to the feature closest to the exciting source, indicating that a simple hollow-shell model is inappropriate to explain the overall outflow structure. In contrast, our data are more consistent with recent jet-driven models for bipolar outflows. The presence of different high-velocity features strongly suggest that the entraining jet could be of intermittent nature.

We have also carried out high-sensitivity observations of ^{13}CO toward selected positions in the outflow, and we infer from them that self-absorption effects in the CO wing profiles are unimportant.

Accepted by Astrophys. J. Letters

A Sub-Arcsecond Scale Spectroscopic Study of the Complex Mass Outflows in the Vicinity of T Tauri

K.-H. Böhm¹ and J. Solf²

¹ Astronomy Department, FM-20, University of Washington, Seattle, WA 98195, USA

² Max-Planck-Institut für Astronomie Königstuhl 17, D-69117 Heidelberg, Germany

High-resolution long-slit spectra in the 6250 – 6800 Å range, obtained at various position angles from the emission nebulosities around T Tau, are presented. Using a method recently developed by Solf, we have eliminated the contribution of the stellar continuum spectrum to the detected emission lines and determined position-velocity diagrams of the [O I], [N II], and [S II] lines in the immediate vicinity of the star. We identify at least five individual components (A, B, C, D, E) in the complex emission line structure which are distinguished by their spatial distribution and their related kinematic properties. Each line component can be attributed to a separate nebular condensation in the mass outflows associated with the T Tau system. Two line components (A and B) are analogues to those observed in other T Tauri stars and seem to be due to a slow disk wind (A) and a fast stellar wind (B). Component A presents a centroid velocity of ~ -9 km s⁻¹ with respect to the stellar velocity and is offset towards NW from the optical stellar component T Tau N by $\sim 1.''1$ and $\sim 0.''1$ in [S II] and [O I], respectively. Component B presents a centroid velocity of ~ -120 km s⁻¹ and maximum velocities up to ~ -175 km s⁻¹ at $\sim 3''$ W of the star. Most likely, B represents the approaching part of a bipolar jet emanating from T Tau N and pointing towards W, whose receding counterpart is obscured by a circumstellar disk. The jet is already highly collimated at only $\sim 0.''3$ (~ 50 AU) from the star and ultimately leads to the formation of the Herbig-Haro object in NGC 1555. The other three line components have no analogues in other T Tauri star systems. Two of them (C and D) form a second bipolar outflow system of moderate collimation. The orientation of its flow axis is near the N-S direction and hence significantly different from that of the jet seen in B. The centroids of the northern lobe (C) and southern lobe (D) are separated from T Tau N by $0.''9$ and $1.''3$, respectively; the magnitudes of their centroid velocities with respect to the stellar velocity are approximately the same (~ 43 km s⁻¹). In both lobes, the radial velocity drops to about zero at a distance of $\sim 4''$ from the star. Arguments are presented suggesting that the star-like infrared source T Tau S may be the origin of the bipolar outflow C-D. Component E represents an extended structure with an Herbig-Haro spectrum and has been attributed to "Burnham's nebula" S of T Tau. In component E the derived mean relative radial velocity of ~ -5 km s⁻¹ and the velocity dispersion of ~ 25 km s⁻¹ (FWHM) seem to indicate a rather low shock velocity, although the observed line ratios suggest shock-excited gas with a shock velocity of typically 90 km s⁻¹. In this sense, the structure of Burnham's nebula is enigmatic. Our data seem to indicate that there exists a kinematical and physical connection between the southern lobe (D) of the bipolar outflow C-D and component E. This would imply that a significant deceleration of the outflowing gas occurs in the region where Burnham's nebula is formed.

Accepted by the Astrophysical Journal

The W3 IRS 5 Cluster: Radio Continuum and Water Maser Observations

M. J. Claussen¹, R. A. Gaume², K. J. Johnston², and T. L. Wilson³

¹ National Radio Astronomy Observatory, P.O. Box O, Socorro, NM 87801 USA

² Naval Research Laboratory, Washington, DC 20375 USA

³ Max Planck Institut für Radioastronomie, Auf dem Hügel 69 D-53121 Bonn, Germany

E-mail: mclauss@nrao.edu (internet)

High-sensitivity and angular resolution observations of the radio continuum toward W3 IRS 5, along with observations of strong water masers, have been made with the VLA. At least seven distinct radio continuum sources have been discovered, which are most likely a cluster of B0.5 - B0 stars with ionized stellar winds. This is in contrast to previous interpretations of observational data, which suggested that IRS 5 is a single massive protostar with bolometric luminosity of $2 \times 10^5 L_{\odot}$. The spatial distribution of the water masers roughly follows that of the radio sources; and these masers show a gradient in radial velocity similar to that found in a larger-scale molecular outflow. We suggest that previously observed, multi-component absorption in CO infrared transitions traces outflows from the several stellar wind sources, rather than episodic outbursts from a single source.

Accepted by Astrophysical Journal Letters

The formation of stellar systems by gravitational instability in the Cygnus Superbubble

F. Comerón¹, J. Torra¹

¹ Departament d’Astronomia i Meteorologia, Universitat de Barcelona, Av. Diagonal 647, E-08028 Barcelona, Spain

We have developed an analytical model of the onset of gravitational instabilities in the dense shell surrounding an expanding superbubble, in order to account for the origin of Cygnus OB1-OB9 and the anomalous motions of the stars in that region as reported in a previous paper. Expressions for the masses, sizes and ages for the resulting unstable complexes are derived, the observed peculiar velocity in Cygnus OB1-OB9 being used as an input parameter. It is shown that the mechanical luminosity injected into the Superbubble by stellar winds in the active association Cygnus OB2 is consistent with the observational characteristics of Cygnus OB1-OB9 if Cygnus OB2 was originally immersed in a ISM dominated by giant molecular complexes

Accepted by The Astrophysical Journal

Direct determination of stellar and orbital parameters of the spectroscopic binary TY CrA

P. Corporon, A.M. Lagrange and J. Bouvier

Laboratoire d’Astrophysique de Grenoble, Université J. Fourier, BP 53X, F-38041 Grenoble Cédex, France

We present high resolution spectra of the Herbig star TY CrA in the Na I doublet region. The spectroscopic binary nature SB2 of this star, known to be the member of a close eclipsing binary system, which was tentatively proposed in a previous paper is here confirmed. The radial velocity curves of both components of the system are built as the function of phase. This allows us to derive directly for the first time the masses for the primary and the secondary, $2.8 \pm 0.2 M_{\odot}$ and $1.5 \pm 0.1 M_{\odot}$ respectively. Other parameters (R_{\star} , L_{\star} , T_{\star}) of both objects are derived. All these data are discussed, as well as the measured rotational velocity of the secondary ($v \sin i = 100 \text{ km s}^{-1}$).

Accepted by Astron. & Astrophys. (Letters)

Structure and Evolution of Magnetically Supported Molecular Clouds: Evidence for Ambipolar Diffusion in the Barnard 1 Cloud

R. M. Crutcher¹, Telemachos Ch. Mouschovias^{1,2}, T.H. Troland³, and Glenn E. Ciolek²

¹ Department of Astronomy, University of Illinois, Urbana, IL 61801, USA

² Department of Physics, University of Illinois, Urbana, IL 61801, USA

³ Physics and Astronomy Department, University of Kentucky, Lexington, KY 40506, USA

Axisymmetric simulations have demonstrated that ambipolar diffusion initiates the formation and contraction of protostellar cores in predominantly magnetically supported, self-gravitating, isothermal molecular model clouds. New, fully implicit, multifluid, adaptive-grid codes have reliably followed both the early, quasistatic, ambipolar-diffusion controlled phase of core formation as well as the later, dynamic contraction phase of thermally and magnetically supercritical cores. In this paper we apply these results and present the first evolutionary, dynamical model of any one specific molecular cloud. Using observational input on the structure of the B1 cloud, we first show that the “internal envelope” of B1 (mass $\leq 600 M_{\odot}$ within $r \leq 2.9 \text{ pc}$, implying a mean density $\simeq 2 \times 10^3 \text{ cm}^{-3}$; and mean magnetic field along the line of sight $= 16 \pm 3 \mu\text{G}$) can be represented very well by a model in exact magnetohydrostatic equilibrium. An evolutionary calculation then follows the ambipolar-diffusion induced formation and collapse of a supercritical protostellar core, whose predicted physical properties, including mass ($13.4 M_{\odot}$), size (0.13 pc), mean density ($1.3 \times 10^5 \text{ cm}^{-3}$), and mean magnetic field strength along the line of sight ($29.1 \mu\text{G}$) are in excellent agreement with observed values for the NH_3 core ($M_{\text{core}} = 13 M_{\odot}$, $R_{\text{core}} = 0.15 \text{ pc}$, $n_{\text{n,core}} > 8 \times 10^4 \text{ cm}^{-3}$, and $B_{\text{los}} = 30 \pm 4 \mu\text{G}$). Moreover, the calculated spatial profiles of the number density, column density, and magnetic field strength (hence, Alfvén speed) compare well with observations. The model makes further predictions concerning the structure of the protostellar core of B1 that can be tested by higher spatial resolution observations.

Accepted by The Astrophysical Journal

Images of the GG Tau Rotating Ring

A. Dutrey¹, S. Guilloteau¹ and M. Simon²

¹ Institut de Radio Astronomie Millimétrique, 300 Rue de la Piscine, F-38406 Saint Martin d'Hères, Grenoble, France

² Astronomy Program, State Univ. of New-York, Stony Brook, NY 11794 U.S.A.

Interferometric ^{13}CO $J = 1 \rightarrow 0$ observations performed with the IRAM interferometer reveal unambiguously a fully resolved rotating thin disk around the young close binary system GG Tau. The rotation curve and geometrical aspect are in perfect agreement with a Keplerian disk orbiting a binary system with total mass $\simeq 1.2 M_{\odot}$, consistent with the luminosities of the central stars, and inclined $\sim 43^{\circ}$ to the line of sight. Images of the dust continuum emission show that the disk has a large inner cavity, of radius ~ 180 AU. The disk extends at least to an outer radius ~ 800 AU. The continuum dust emission and ^{13}CO and C^{18}O line fluxes taken together imply that the CO abundance in the disk is lower than that typical of the ISM by at least a factor of ~ 20 . Tidal forces induced by the binary are probably responsible for the inner hole in the dust and gas distribution. The size of the inner cavity is most simply explained if the orbit of the binary is eccentric. In such a case, the dust ring is located near an orbital resonance of the disk with the binary period. Effective angular momentum transfer from the binary to the disk is expected to increase the orbital eccentricity, and to stop further accretion onto the stars, thereby increasing the lifetime of the circumbinary disk.

Accepted by A&A

A Q Condition for Long-Range Propagating Star Formation

B.G. Elmegreen

IBM Research Division, T.J. Watson Research Center P.O. Box 218, Yorktown Heights, NY 10598, USA

Collapse conditions for large expanding shells and rings in a disk galaxy are derived and shown to lead to a condition for star formation that is similar to the condition $Q < 1$ for spontaneous instabilities. This result implies that both spontaneous and stimulated star formation are sensitive to Q , and that the observation of a critical surface density for star formation that is based on Q does not necessarily imply that all star formation results from large scale quiescent instabilities. The results also suggest that in regions with high gas densities and high rotation rates, such as starburst galaxy nuclei, the normal balance between stimulated and spontaneous star formation mechanisms could shift to give a higher proportion of stars forming in shells and other swept-up debris, and less in giant cloud complexes containing the local Jeans mass.

Accepted by Astrophysical J.

Emission Line Studies of Young Stars: IV. The Optical Forbidden Lines

F. Hamann^{1,2}

¹ Department of Astronomy, The Ohio State University

² Now at The Center for Astrophysics and Space Sciences, University of California - San Diego, Mail Code 0111, La Jolla, CA 92093-0111, USA; Internet: hamann@cass157.ucsd.edu

Optical forbidden line strengths and profiles are discussed for a sample of 30 T Tauri stars and 12 Herbig Ae/Be stars. Transitions of [C I], [N II], [O I], [O II], [S II], [Ca II], [Cr II], [Fe II], and [Ni II] are detected. Profile variability occurred in DG Tau and probably other sources. The ensemble profiles can be divided into four generic components that may represent distinct emitting regions; (1) narrow rest velocity lines, (2) "low" velocity lines (peaking at less than about ± 50 km·s⁻¹), (3) "high" velocity (usually greater than about ± 100 km·s⁻¹) blueshifted peaks or wings, and (4) "high" velocity redshifted peaks. Among T Tauri stars, the rest velocity lines appear most often in sources with weak and narrow permitted lines, e.g. the Ca II triplet. The "low" and "high" velocity blueshifted components usually appear together in sources with strong and broad Ca II triplet lines.

If the velocity shifted lines form in jets, the smallest (full) opening angles required by the profiles are less than about 20° for the narrow, blueshifted [Ca II] lines of DG and HL Tau. Other lines in DG Tau are much broader, implying larger opening angles or greater velocity dispersions in their emitting regions. The variability in DG Tau also implies significant changes in the collimation or velocity coherence on timescales of a few years. RW Aur and AS 353A have blue and redshifted line peaks that could form in oppositely directed jets. The strong [S II] $\lambda 6716$ and $\lambda 6731$ lines in

RW Aur are exclusively redshifted and require opening angles less than about 60° .

Measurements of different profiles in the same spectrum show that the physical conditions change with the line-of-sight velocities. The most persistent trends are for more [N II] and [O II] and less [O I] $\lambda 5577$ flux at “high” velocities. Constraints on the physical conditions are derived by modeling the emission lines via multi-level ions in “coronal ionization equilibrium.” A single temperature and density cannot fully describe the line spectra in any velocity interval. Temperatures in the [O I] region are $9000 \lesssim T_e < 14000$ K and the ionization fraction (of H) is $< 35\%$. The densities derived from [O I] include $n_e \lesssim 5 \times 10^5$ to $\sim 10^7$ pcc, but $n_e \gtrsim 10^6$ pcc obtains only at “low” velocities. In the [S II] regions the densities are lower, $10^3 \lesssim n_e \lesssim 7 \times 10^4$ pcc, and the temperatures are probably higher, $T_e \gtrsim 13000$ K. At “high” velocities (only) there is additional hot gas that produces [N II] and [O II], possibly most of the [S II], and little [O I]. This region is characterized by $T_e \gtrsim 15000$ K, $n_e \lesssim 10^5$ pcc, and an ionization fraction $\gtrsim 50\%$. When combined with the spatially segregated emitting regions observed by others by spectral imaging, these results suggest decreasing n_e and increasing T_e away from the star in at least the “high” velocity gas.

Accepted by The Astrophysical Journal Supplements

Magnetospheric Accretion Models for T Tauri Stars. I. Balmer Line Profiles without Rotation

Lee Hartmann¹, Robert Hewett¹ and Nuria Calvet²

¹ Harvard-Smithsonian Center for Astrophysics, 60 Garden St., Cambridge, MA 02138, USA

² Centro de Investigaciones de Astronomia, Ap. Postal 264, Merida 5101-A, Venezuela

We argue that the strong emission lines of T Tauri stars are generally produced in infalling envelopes. Simple models of infall constrained to a dipolar magnetic field geometry explain many peculiarities of observed line profiles that are difficult, if not impossible, to reproduce with wind models. Radiative transfer effects explain why certain lines can appear quite symmetric while other lines simultaneously exhibit inverse P Cygni profiles, without recourse to complicated velocity fields. The success of the infall models in accounting for qualitative features of observed line profiles supports the proposal that stellar magnetospheres disrupt disk accretion in T Tauri stars, that true boundary layers are not usually present in T Tauri stars, and that the observed “blue veiling” emission arises from the base of the magnetospheric accretion column.

Accepted by Ap. J., May 10 issue

Multi-wavelength study of NGC 281 A

Th. Henning¹, K. Martin¹, H.-G. Reimann², R. Launhardt¹, D. Leisawitz³ & H. Zinnecker⁴

¹ Max-Planck-Gesellschaft, AG “Staub in Sternentstehungsgebieten”, Schillergäßchen 2-3, D-07745 Jena, Germany

² Astrophysikalisches Institut und Universitäts-Sternwarte, Schillergäßchen 2, D-07740 Jena, Germany

³ NASA/Goddard Space Flight Center, Code 631, Greenbelt, MD 20771, USA

⁴ Institut für Astronomie und Astrophysik, Universität Würzburg, Am Hubland, D-97074 Würzburg, Germany

We present a study of the molecular cloud NGC 281 A and the associated compact and young star cluster NGC 281 (AS 179).

Optical photometry leads to a new distance of 3500 pc for the star cluster which is in good agreement with the kinematical distance of the adjacent molecular cloud NGC 281 A. The exciting star HD 5005 of the optical nebulosity is a Trapezium system with O6 III as photometric spectral type for the component HD 5005 AB. For the age of the star cluster we estimated a value of about $3 \cdot 10^6$ yr.

The $^{12}\text{CO}(2 \rightarrow 1)$, $^{13}\text{CO}(2 \rightarrow 1)$, and $^{12}\text{CO}(3 \rightarrow 2)$ emission shows that the molecular cloud NGC 281 A consists of two cloud fragments. The western fragment is more compact and massive than the eastern fragment and contains an NH_3 core. This core is associated with the IRAS source 00494+5617, an H_2O maser, and 1.3 millimetre dust continuum radiation.

Both cloud fragments contain altogether 22 IRAS point sources which mostly share the properties of young stellar objects. They have luminosities between 150 and $8800 L_\odot$. The maxima of the 60 and $100 \mu\text{m}$ HIREs maps correspond to the maxima of the $^{12}\text{CO}(3 \rightarrow 2)$ emission.

The NGC 281 A region shares many properties with the Orion Trapezium-BN/KL region the main differences being a larger separation between the cluster centroid and the new site of star formation as well as a lower mass and luminosity of the molecular cloud and the infrared cluster.

Accepted by Astronomy and Astrophysics

Jet flows and disk winds from T Tauri stars: the case of CW Tau

Gerhard A. Hirth, Reinhard Mundt and Josef Solf

Max-Planck-Institut für Astronomie, Königstuhl 17, D-69117 Heidelberg, Germany

We have carried out long-slit spectroscopy of the forbidden emission line region of the T Tauri star CW Tau with both medium (FWHM $\approx 50 \text{ km s}^{-1}$) and high spectral resolution (FWHM $\approx 20 \text{ km s}^{-1}$), and with a typical spatial resolution of $1.4''$ – $1.8''$. From the spectra obtained at various slit positions we found that CW Tau has a bipolar outflow which can be traced over $4''$ – $6''$ along both outflow directions. The blueshifted flow is orientated at a position angle of about 160° . The deduced high-resolution position-velocity diagrams of the [OI] $\lambda\lambda$ 6300, 6363, [NII] λ 6583 and the [SII] $\lambda\lambda$ 6716, 6731 lines show two velocity components which differ strongly in their spatial and spectroscopic properties (e.g. spatial extent along the outflow direction, degree of excitation and electron density). These results and similar ones from other T Tauri stars support the model of Kwan and Tademaru (1988) in which the two velocity components observed in the forbidden emission lines of T Tauri stars originate in two different flow components, namely in a jet and in a disk wind (and/or disk corona) in the case of the high-velocity and low-velocity component, respectively. All other models for the formation of the forbidden emission lines in T Tauri stars proposed so far encounter severe difficulties in explaining the observations. The model of Kwan and Tademaru can also explain qualitatively various new data on the low-velocity component, in particular its relatively large line width and high-velocity red wing. We suggest that rotation in the disk atmosphere or disk magnetosphere may explain these line profile data. Furthermore we show that the differences in the kinematical properties of the low-velocity component in various forbidden lines having different critical densities (e.g. [OI] $\lambda\lambda$ 6300, 6363, [SII] $\lambda\lambda$ 6716, 6731) might be due to acceleration effects in the presumed disk wind. We also briefly discuss whether the hypothesis of Kwan and Tademaru might be adopted to explain recently obtained [OI] $\lambda\lambda$ 6300, 6363 line profile data of Herbig Ae/Be stars.

Accepted by Astron. and Astrophys.

A Near Infrared Study of the Monoceros R2 Star Formation Region

Eric M. Howard¹, Judith L. Pipher¹ and William J. Forrest¹

¹ University of Rochester, Department of Physics and Astronomy, Rochester, NY 14627-0171, USA

We present H ($1.65\mu\text{m}$), K ($2.23\mu\text{m}$), and L' ($3.81\mu\text{m}$) broadband images as well as Br γ ($n = 7 \rightarrow 4$, $2.166\mu\text{m}$) and Br α ($n = 5 \rightarrow 4$, $4.052\mu\text{m}$) hydrogen recombination line images, and $3.29\mu\text{m}$, and $3.4\mu\text{m}$ unidentified feature emission images of the Monoceros R2 star formation region at a plate scale of $\sim 0.9 \text{ arcsec/pixel}$. The Brackett line images are combined with 5GHz data to map the line of sight dust extinction to the compact HII region on a small spatial scale. This extinction map is then used to de-redden regions of the H and K images interior to the HII region. IRS1_{SW}, the ionizing source, is found to be consistent with a B0 star. Comparison of de-reddened H and K images with the Brackett images and recent high resolution HCO⁺ measurements leads to the development of a torus model for the dense molecular gas surrounding the HII region. The $3.29\mu\text{m}$ emission is found to be coincident with the ring of scattered light at $2.2\mu\text{m}$ and just outside the Br α and Br γ emission. The $3.4\mu\text{m}$ image is of too low S/N to determine if any variation in the 3.29 to $3.4\mu\text{m}$ emission ratio with distance from the ionizing source is seen, however $3.4\mu\text{m}$ emission is detected in a ring coincident with the $3.29\mu\text{m}$ emission.

Accepted by ApJ

Observations of methanol masers at 95 GHz

S.V. Kalenskii¹, T. Liljeström², I.E. Valts¹, V.I. Vasilkov¹, V.I. Slysh¹ and S. Urpo³

¹ Astro Space Center of Lebedev Physical Institute, Profsovnaya 84/32, 117810 Moscow, Russia

² Helsinki University Observatory, P.O. Box 14, SF-00014 University of Helsinki, Finland

³ Metsähovi Radio Research Station, Helsinki University of Technology, Otakaari 5 A, SF-02150 Espoo, Finland

The Metsähovi 13.7-m radio telescope was used to search for emission in the 95 GHz $8_0 - 7_1A^+$ transition of methanol towards a number of star-forming regions. Eleven known 44 GHz ($7_0 - 6_1A^+$ transition) methanol masers were observed; 95 GHz emission was found towards nine sources, five of which are new detections. For two sources, S 140 and R 146, only upper limits were obtained. Most likely the 95 GHz line is masing in all cases with detected emission, except for W51 e1/e2 toward which a broad thermal line is observed. The integrated flux density is higher at 95 GHz than at 44 GHz. It is suggested that the 95 GHz methanol masers are as widespread as the 44 GHz masers.

Accepted by Astron. Astrophys.

Dust Extinction and Molecular Gas in the Dark Cloud IC 5146

Charles J. Lada¹, Elizabeth A. Lada^{1,2} Dan P. Clemens³, and John Bally⁴

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

² Present Address: Astronomy Program, University of Maryland, College Park, MD 20742, USA

³ Astronomy Department, Boston University, 725 Commonwealth Ave., Boston MA 02215, USA

⁴ Astronomy Department, University of Colorado, Boulder CO 80309, USA

In this paper we describe a powerful method for mapping the distribution of dust through a molecular cloud using data obtained in large scale, multi-wavelength, infrared imaging surveys. This method combines direct measurements of near-infrared color excess and certain techniques of star counting to derive mean extinctions and map the dust column density distribution through a cloud at higher angular resolutions and greater optical depths than those achieved previously by optical star counting.

We report the initial results of the application of this method to a dark cloud complex near the cluster IC 5146 where we have performed coordinated, near-infrared, JHK imaging and ^{13}CO , C18O and CS millimeter-wave, molecular-line surveys of a large portion of the complex. More than 4000 stars were detected in our JHK survey of the cloud. Of these all but about a dozen appear to be field stars not associated with the cloud. Star count maps at J band show a striking and detailed anti-correlation between the surface density of J band sources and CO and CS molecular line emission. We used the (H-K) colors and positions of nearly 1300 sources to directly measure and map the extinction and thus trace the dust column density through the cloud at an effective angular resolution of 1.5 arc min. We report an interesting correlation between the measured dispersion in our extinction determinations and the extinction. Modelling this relation indicates that effects of small scale cloud structure dominate the uncertainties in our measurements. Moreover, we demonstrate that such observations can be used to place constraints on the nature of the spatial distribution of extinction on scales smaller than our resolution. In particular, we show that models in which the dust is distributed uniformly or in discrete high extinction clumps on scales smaller than 1.5 arc min are inconsistent with the observations.

We have derived extinctions at the same positions and at the same angular resolution (1.7 arc min) as our molecular-line observations. This enabled a direct comparison of ^{13}CO , C18O and CS integrated intensities and column densities with A_v for more than 500 positions in the cloud corresponding to a range in A_v between 0-32 magnitudes of extinction. We found the integrated intensities of ^{13}CO , C18O and CS to be roughly linearly correlated with extinction over different ranges of extinction. However, for all three molecules we find the scatter in the observed relations to be larger than can be accounted for by instrumental error, suggesting that there are large intrinsic variations in the abundances or excitation of the molecules through the cloud. Mean abundances for all the molecules relative to hydrogen were directly derived from the data. The ratio of ^{13}CO to C18O abundances was found to be significantly higher than the terrestrial ratio in regions where the extinction is less than 10 magnitudes. In the same region the dispersion in the abundance ratio is also found to be very large suggesting that the abundances of one or both molecules are very unstable even at relatively large cloud optical depths. Beyond 10 magnitudes of extinction the abundances of both species appear very stable with their ratio close to the terrestrial value. .

Accepted by The Astrophysical Journal

Dense Cores in Dark Clouds. X. NH₃ Emission in the Perseus Molecular Cloud Complex

E. F. Ladd¹, P. C. Myers² and A. A. Goodman²

¹ Institute for Astronomy, University of Hawaii, 2680 Woodlawn Drive, Honolulu, HI 96822, USA

² Harvard-Smithsonian Center for Astrophysics, Mail Stop 42, 60 Garden Street, Cambridge, MA 02138, USA

We present a survey for dense material around young IRAS sources in the Perseus molecular cloud complex in the NH₃ (J,K) = (1,1) line at 1.3 cm. NH₃ emission was detected in eight, and mapped in seven, out of ten positions chosen for study. The dense cores found typically have lower masses and narrower linewidths than cores previously studied in Perseus and are located near sources of lower luminosity. NH₃ cores are found throughout the Perseus complex; however, much of the detected dense gas is concentrated into two filamentary “ridges” located in the western part. As a group, NH₃ cores in Perseus have a mean linewidth of 0.6 km s⁻¹, mean radius of 0.12 pc, mean kinetic temperature of 13 K, and mean mass of 9 M_⊙. These mean values are larger than the mean values for NH₃ cores with associated stars in Taurus, but smaller than the mean values for cores associated with stars in Orion A. Some of the cores in Perseus are “thermally dominated,” with thermal and nonthermal linewidths similar to most Taurus cores, while others are “nonthermally dominated” and are more similar to the cores in Orion A. We conclude that the Perseus complex is intermediate in its star forming potential between the predominantly low-mass star-producing regions like Taurus and the regions capable of producing high-mass stars such as Orion A.

Accepted by Ap. J.

Submillimetre polarimetric mapping of DR21 and NGC7538-IRS11: tracing the circumstellar magnetic field

Nigel R. Minchin and Alexander G. Murray

Department of Physics, Queen Mary and Westfield College, University of London, Mile End Road, London E1 3NS, U.K.

We have detected 800μm polarization at the flux peak and positions around the outflow sources DR21 and NGC7538-IRS11. For both sources the direction of the polarization vectors is extremely uniform and the dispersion is small. This implies that, within the resolution of our observations, the magnetic field is both uniform in direction and strong. The direction of the magnetic field around DR21 does not appear to be aligned with either the direction of the outflow axis or the major axis of the submm circumstellar dust structure. For NGC7538-IRS11 the magnetic field is aligned with the outflow axis, implying that within the resolution of our observations (14 arcsec FWHM) the circumstellar magnetic field is poloidal. The direction of the molecular outflows, magnetic fields and dust ridges for both IRS11 and its neighbour IRS1 (60 arcsec/0.9 parsec to the north) are in identical directions. As IRS1 and IRS11 are linked by an arm of submm emission and form an elongated dust ridge that is orthogonal to the ambient magnetic field of the NGC7538 region, part of the cloud may have collapsed along the magnetic field lines to produce the core from which IRS1 and IRS11 have formed.

For both DR21 and NGC7538-IRS11 the percentage polarization at the position of the flux peak is low compared to the surrounding points. This has been noted for several other outflow sources and is commonly referred to as a polarization ‘hole’. The most plausible explanation is a change in the magnetic field alignment in the vicinity of the outflow source. There is a marked increase in the observed percentage polarization from DR21 at higher wavelengths. This implies the grain composition cannot be predominantly silicate, but instead is mainly graphite/metallic, and may require grains of different magnetic susceptibility or varying elongation to also be at different temperatures along the observed line of sight.

Accepted by Astron. Astrophys.

Spectroscopy and further imaging of *IRAS* sources near the Galactic Centre

A. Moneti,¹ I. S. Glass² and A.F.M. Moorwood³

¹ European Southern Observatory, Casilla 19001, Santiago 19, Chile

² South African Astronomical Observatory, PO Box 9, Observatory 7935, South Africa

³ European Southern Observatory, Karl-Schwarzschild-Str. 2, 85748 Garching, Germany

We present new infrared spectroscopic and imaging observations of *IRAS*-selected sources suspected of being deeply embedded young stellar objects within 40 pc of the Galactic Centre. These new results are combined with our earlier ones to elucidate further the nature of the sources, with the goal of determining whether star formation has occurred recently in the greater Galactic Centre region. We find that these objects do not form a homogeneous set but can be classified into three groups: (i) compact H II regions, (ii) pure continuum sources, and (iii) He I or Br γ emission-line stars. The latter are probably evolved massive stars. The nature of the pure continuum sources is not clear but their luminosities and their low temperatures, coupled with the fact that at least some of them lie in a tight cluster, suggest that they are very young objects and thus that some stars have been formed near the Centre comparatively recently. The fact that there are objects of different ages in the sample suggests that recent star formation in the Centre has not been in the form of a single burst.

Accepted by MNRAS

Spectropolarimetry of Five Objects toward the Galactic Center from 1.4 to 4.2 Microns

Tetsuya Nagata¹, Naoto Kobayashi¹ and Shuji Sato²

¹ Department of Physics, Kyoto University, Kitashirakawa, Kyoto 606, Japan

² Department of Astrophysics, Nagoya University, Chikusa-ku, Nagoya 464, Japan

Spectropolarimetric observations between 1.4 and 4.2 μm are presented for five infrared sources within 0.5° of the Galactic center. The observed polarization up to 2.5 μm can be represented very well by a power law $p(\lambda) \propto \lambda^{-2}$, but all the five objects have polarization well in excess of this power law in the whole 2.8 - 4.2 μm atmospheric window. This excess polarization might be caused by grains located in the general diffuse interstellar medium or grains specific to the inner Galaxy. In two objects enhanced polarization in the 3.0 μm absorption feature has been observed; both the peak wavelength and the ratio of the polarization increase to the optical depth $\Delta p/\tau_{3.0}$ are in the range observed for molecular cloud sources in the water-ice band. However, the shape of the polarization increase seems different from that of the molecular cloud sources. In one object marginal rotation of the position angle has been detected across the 3.0 μm feature. This might suggest that the carrier of the 3.0 μm feature is not distributed ubiquitously in the line of sight.

Accepted by Astrophysical Journal Letters

Photoionized Regions around Shocked Cloudlets

A. C. Raga¹ and L. Wang²

¹ Mathematics Department, UMIST, P.O. Box 88, Manchester M60 1QD, U.K.

² Beijing Astronomical Observatory, Beijing 100080, P. R. China

The compact condensations of Herbig-Haro objects can be interpreted in terms of the “shocked cloudlet” or the “interstellar bullet” scenario. In these models, a high density clump is assumed to have a high relative velocity with respect to the surrounding environment, leading to the formation of a radiative bowshock, which produces the observed emission. We show that for relative velocities > 100 km/s, a photoionized preionization region is formed. This H II region should be observed as a faint, diffuse emission around the compact condensations.

The really interesting property of the preionized H II region is that it will survive the eventual disruption of the dense clump (which occurs as a result of the clump/environment interaction), and should be observable as a “fossil H II region” for a timescale of ~ 1000 yrs (for parameters typical of HH objects). The emission line spectrum of this fossil H II region is formed in a partially ionized gas, so that it is qualitatively similar to the spectrum observed in HH objects. We speculate that at least some of the condensations of HH objects might correspond to such fossil H II regions.

Accepted by Monthly Not. R. A. S.

Atomic and Molecular Gas in Interstellar Cirrus Clouds

William T. Reach^{1,2}, Bon-Chul Koo^{2,3,4}, and Carl Heiles²

¹ NASA Goddard Space Flight Center, Code 685, Greenbelt, MD 20771, USA

² Astronomy Department, University of California, Berkeley, CA 94720, USA

³ Harvard-Smithsonian Center for Astrophysics, 60 Garden St., Cambridge, MA 02138, USA

⁴ Seoul National University, Astronomy Department, Seoul 151-742, Korea

The dust, atomic gas, and molecular gas content of a sample of 26 of isolated, degree-sized infrared clouds are compared. Half of the clouds have an infrared excess indicating the presence of H₂, and 14 contain compact CO-emitting regions. Complete, high-angular-resolution H I and CO maps of one cloud, G236+39, resolve the transition between atomic and molecular H, as well as the location of CO formation. Assuming the infrared emission traces the total column density, H₂ is inferred to be much more widely distributed than the CO. The CO rotational levels are subthermally excited, and the (2–1)/(1–0) line ratios suggest a density $n(\text{H}_2) \sim 200 \text{ cm}^{-3}$ where CO was detected. A model of H₂ formation on grain surfaces balanced by self-shielded photodissociation fits the variation of infrared brightness with H I column density. Assuming a temperature of 80 K, typical of diffuse H₂ (Savage *et al.* 1977), the H₂ chemistry requires an average density $n(\text{H} + 2\text{H}_2) \sim 50 \text{ cm}^{-3}$. For G236+39, if the distance is 100 pc, the H I and H₂ masses are estimated to be 90 and 70 M_\odot , respectively. High-resolution H I and infrared maps of a smaller cloud, G249.0+73.7, reveal no evidence for molecular gas, which is likely due to the low total column density through this cloud. These results suggest the H₂ and H I content are comparable for some interstellar cirrus clouds with column densities $N(\text{H I}) > 4 \times 10^{20} \text{ cm}^{-2}$, even where CO was not detected.

Accepted by Ap. J.

Mutually stimulated formation of interstellar clouds and star aggregates.

Vladimir Surdin

Sternberg Astronomical Institute, Universitetskii Prospect, 13, Moscow 119899, Russia; e-mail: surdin@sai.msk.su

A selfconsistent scenario of large scale ($\sim 1 \text{ kpc}$) star formation is considered. Young star aggregates (YSA) are created in giant molecular clouds (GMC), destroy them by their energy output, and create expanding interstellar bubbles. After a few 10^7 years dense elliptical supershells are formed in the differentially rotating galactic disk. Finally, the swept up matter accumulates at the tips of the banana shaped supershells, leading to GMC formation. An analytical theory of this scenario give a stable solution for GMC and YSA masses. In the Galactic molecular ring ($5 \text{ kpc} \leq R \leq 9 \text{ kpc}$) it gives $M_{\text{GMC}} = (5 \times 10^5 - 3 \times 10^6) M_\odot$ and $M_{\text{YSA}} = (6 \times 10^2 - 1 \times 10^4) M_\odot$. In the Galactic central molecular disk ($R \leq 1 \text{ kpc}$) it gives $M_{\text{GMC}} \sim 10^7 M_\odot$ and $M_{\text{YSA}} \sim 10^6 M_\odot$. But the interaction of galaxies can modify the maximum cloud and stellar aggregate mass up to ($\sim 10^8 M_\odot$), and lead to stimulated bursts of star formation.

Accepted by Astronomy Letters

The Preferential Formation of High-mass Stars in Shocked Interstellar Gas Layers

Anthony Whitworth, Amardeep Bhattal, Simon Chapman, Mike Disney and Jake Turner

Department of Physics and Astronomy, University of Wales, Cardiff CF2 3YB, Wales, UK.

Gravitationally unstable, shocked layers of interstellar gas are produced by cloud-cloud collisions and by expanding nebulae around massive stars. We show that the resulting fragments are likely to be of high mass ($\geq 7 M_\odot$), and initially well separated (*i.e.* weakly bound to one another, if at all).

This result may explain why dynamically active regions tend to have a high efficiency of massive star formation, and why they tend to relax quickly into a self-propagating mode which generates sequences of OB subgroups. These tendencies are manifest on many scales, from local star forming regions like Orion, through regions like 30 Doradus in the LMC, to the most IR-luminous starburst galaxies.

We also show that for a wide range of input parameters, gravitational fragmentation of a shocked layer occurs when the column-density of hydrogen nuclei through the accumulating layer reaches a value $\sim 6 \times 10^{21} \text{ cm}^{-2}$. This may be one reason for the mass-radius relation for molecular cloud clumps first noted by Larson (1981).

Accepted by MNRAS

Studies of dense molecular cores in regions of massive star formation. CS $J = 2 - 1$ and HCN $J = 1 - 0$ observations of 11 northern cores

I. Zinchenko^{1,2}, V. Forsström², A. Lapinov¹ and K. Mattila²

¹ Institute of Applied Physics of the Russian Academy of Sciences, Uljanov st. 46, 603600 Nizhny Novgorod, Russia

² Helsinki University Observatory, Tähtitorninmäki, P.O.Box 14, SF-00014 University of Helsinki, Finland

Eleven dense molecular clouds associated with Sharpless H II regions have been observed in the $J = 2 - 1$ CS and C³⁴S lines with the 13.7-m radio telescope in Metsähovi. In addition, we have observed a few clouds in the $J = 1 - 0$ HCN line. Almost all of the clouds represent sites of massive star formation and have been studied earlier in some other molecular lines. We have compared the spatial structure of the sources as seen in the different lines and discuss the possible reasons for the similarities and differences between them. The CS emitting regions have been modelled using LVG and Monte Carlo radiative transfer codes. We have found that the CS column densities derived in the framework of the uniform cloud models are too low, in some cases probably by an order of magnitude. The most plausible physical explanations involve small scale clumpiness in the clouds and/or the presence of low-density molecular envelopes which shield partly the emission from the core in the CS main isotope line. However the HCN data do not support the hypothesis of a scattering envelope. The masses derived from the CS data are close to the virial masses for most sources. The corresponding average densities along the line of sight are rather low, $n \sim 10^3 - 10^4 \text{ cm}^{-3}$. The densities found from the comparison with the CS $J = 7 - 6$ data are 2–3 orders of magnitude higher. This implies strong density inhomogeneities in the cores. There are size–linewidth and size–density correlations similar to those found earlier for CO and NH₃ emitting regions.

Accepted by Astron. Astrophys.

This issue and all past issues of the Star Formation Newsletter are available, each as an individual file in LaTeX format, by anonymous ftp from [ecf.hq.eso.org](ftp://ecf.hq.eso.org) (134.171.11.4) in directory /pub/star-formation. The contents of all issues are additionally free-text searchable using WAIS, a publicly available information retrieval package. A file in the above anonymous ftp directory, called WAIS-FAQ.txt, provides further details on WAIS. The procedure to follow is also described in a 'readme' file.

Meetings

Clouds, Cores, and Low Mass Stars

The Fourth Haystack Conference

May 18, 19, 20 1994

at Haystack Observatory, Westford, MA

Tentative list of Topics:

- I. CLOUD CORE FORMATION MECHANISMS
- II. CLOUD CORE PROPERTIES
- III. MODELS OF CORE EVOLUTION AND COLLAPSE
- IV. THE YOUNGEST STARS
- V. THE PROTOSTELLAR ENVIRONMENT
- VI. WINDS, JETS, AND OUTFLOWS

Special Student Oral Session:

- CLOUD CORE OBSERVATIONS
- COLLAPSE MODELS
- YOUNG STELLAR OBJECTS
- ENERGY GENERATION
- PROTOSTELLAR ENVIRONMENTS
- PROTOSTELLAR AND/OR YSO JETS

Invited speakers include:

- R. Pudritz, P. Myers, S. Stahler, N. Evans, A. Boss, Tch. Mouschovias
- M. Barsony, C. Masson

Contributions are solicited for a limited number of oral presentations, for the special student oral session, and for the extensive poster sessions

Registration Information or Questions:

Prof. Dan Clemens
Astronomy Department
Boston University
725 Commonwealth Ave
Boston, MA 02215
(617) 353 - 6140
clemens@buast1.bu.edu