THE STAR FORMATION NEWSLETTER

An electronic publication dedicated to early stellar evolution and molecular clouds

No. 20 — 5 April 1994 Editor: Bo Reipurth (reipurth@eso.org)

Abstracts of recently accepted papers

A Parsec Scale "Superjet" and Quasi-Periodic Structure in the HH 34 Outflow?

John Bally[1] **and David Devine**[1]

[1] Department of Astrophysical, Planetary, and Atmospheric Sciences and Center for Astrophysics and Space Astronomy Campus Box 389, University of Colorado, Boulder, CO 80309, USA bally@janos.colorado.edu

We report the detection of a new Herbig-Haro (HH) object, HH 173, near the young stellar object HH 34* in the L1641 molecular cloud in Orion. The new object appears to be part of a remarkable bipolar chain that includes known HH objects in this region and extends symmetrically about HH 34* for 1.5 pc. The chain terminates in the north at the position of HH 33 and includes HH 40, HH 85, HH 126, and HH 34N. Towards the south, the chain ends at the position of HH 88 and includes HH 87, HH 86, HH 173, HH 34X, HH 34, and the HH 34 jet. All HH objects in the chain that have recognizable bow shock morphologies point to a driving source in the HH 34* cloud core. We propose that this chain delineates a 3 pc long bipolar outflow from HH 34* with blueshifted gas in the south and redshifted gas in the north. The quasi-periodic spacing of the HH objects may be a consequence of episodic mass-loss events from HH 34* occurring roughly every $900/V_{300}$ years (for a flow velocity V_{300} measured in units of 300 km s^{-1}). The dynamic age of the most distant HH object from HH 34* is about 5000 years. The S-shaped symmetry of the HH objects about the central source may result from jet precession with a period of about 10^4 years.

Accepted by The Astrophysical Journal Letters

A New Binary Formation Mechanism

Ian Bonnell

Institute of Astronomy, Madingley Road, Cambridge, CB3 0HA, England (email:bonnell@mail.ast.cam.ac.uk)

A new mechanism for the formation of binary systems through the fragmentation of a protostellar disk is presented. This process requires a strongly rotationally unstable (to both $m = 2$ and $m = 1$ modes), central accreting object surrounded by a rotationally supported disk of gas which is subject to continuing infall. The central instability becomes off-centre due to the growth of the $m = 1$ mode. The interaction of the spiral arms thus driven into the disk, with the continued infall, give rise to the formation of a self-gravitating secondary body in orbit around the first.

For cores that form without disks, the core evolves as in past studies of rotational instabilities. In addition to the $m = 2$ bar mode, an $m = 1$ mode develops, allowing the protostar to convert some of its spin angular momentum into orbital angular momentum. Furthermore, the gravitational torques from the bar directly account for the outward transfer of angular momentum.

For cores that form with surrounding disks and with continuing infall, the spiral arms from the core move through the disk gathering matter together. The combination of the $m = 2$ mode and the displacement of the core from the $m = 1$ mode allow the spiral arms to gather sufficient matter together from the disk and the continuing infall to become gravitationally unstable. This matter then collapses to form a secondary. In cases where there is no continuing infall onto the disk, the spiral arms (from the $m = 1$ and $m = 2$ mode) are not able to gather sufficient material to form a Jeans unstable condensation.

Accepted by MNRAS

Flat Spectrum T Tauri Stars: The Case for Infall

Nuria Calvet[1], Lee Hartmann[2], Scott J. Kenyon[2], and Barbara A. Whitney[2]

[1] Centro de Investigaciones de Astronomia, Ap. Postal 264, Merida 5101-A, Venezuela
[2] Harvard-Smithsonian Center for Astrophysics, 60 Garden St., Cambridge, MA 02138, USA

We show that the mid- to far-infrared fluxes of "flat spectrum" T Tauri stars can be explained by radiative equilibrium emission from infalling dusty envelopes. Infall eliminates the need for accretion disks with non-standard temperature distributions. The simplicity and power of this explanation indicates that models employing "active" disks, in which the temperature distribution is a parameterized power law, should be invoked with caution. Infall also naturally explains the scattered light nebulae detected around many flat-spectrum sources. To match the observed spectra, material must fall onto a disk rather than the central star, as expected for collapse of a rotating molecular cloud. It may be necessary to invoke cavities in the envelopes to explain the strength of optical and near-infrared emission; these cavities could be produced by the powerful bipolar outflows commonly observed from young stars. If viewed along the cavity, a source may be lightly extincted at visual wavelengths, while still accreting substantial amounts of material from the envelope. Infall may also be needed to explain the infrared-bright companions of many optical T Tauri stars. This picture suggests that many of the flat spectrum sources are "protostars" - young stellar objects surrounded by dusty infalling envelopes of substantial mass.

Accepted by Ap. J.

Hot ammonia towards compact HII regions

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

[1] Osservatorio Astrofisico di Arcetri, Largo E. Fermi 5, I-50125 Firenze, Italy
[2] Washburn Observatory, University of Wisconsin-Madison, 475 North-Charter Street, Madison, WI 53706, USA
[3] Max-Planck-Institut für Radioastronomie, Auf dem Hügel 69, D-53121 Bonn, Germany
[4] Instituto de Astronomía, UNAM, Apdo. Postal 70-264, 04510 México, D.F., Mexico

We present VLA C- and D-array measurements of NH_3(4,4) towards a sample of four galactic ultracompact HII regions: G9.62+0.19, G10.47+0.03, G29.96−0.02, and G31.41+0.31. Our data shows that the ammonia emission originates from optically thick clumps with kinetic temperature of 50–200 K and size ~ 0.1 pc. The hot ammonia clumps are situated close to the compact HII regions seen in the radio continuum but in three out of four cases (G10.47+0.03 is the exception) are not absolutely coincident with them. Moreover, there is good positional coincidence between the water masers observed in these regions and the hot ammonia clumps. This suggests to us that the ultimate energy source responsible for the hot ammonia is not the ionizing star of the compact HII region but is a separate young massive star. We have made estimates of the luminosity required for such an embedded object and derive values of order 10^4 to 10^6 solar luminosities although with very large uncertainties. We have also made estimates of the masses of the hot ammonia clumps under the assumption that the virial theorem is applicable. In this way, we obtain masses of typically 100 $M_\odot$, densities of $\sim 10^7$ cm^{-3} and NH_3 abundances relative to H_2 of $\geq 10^{-6}$. Such high ammonia abundances are probably caused by evaporation of grain mantles due to the high temperature in these cores. The dynamical state of these ammonia clumps is not clear but we detect a blue-shifted absorption line towards the ultracompact HII region G10.47+0.03B which suggests that in this case, the predominant motion is expansion. We conclude in general that such clumps are likely to be the sites of massive star formation in an early evolutionary phase prior to the development of an ultracompact HII region.

Accepted by Astronomy & Astrophysics

Constraining Circumstellar Environments: Far-Infrared Observations of Herbig Ae/Be Stars

James Di Francesco[1], Neal J. Evans II[1], Paul M. Harvey[1], Lee G. Mundy[2], and Harold M. Butner[3]

[1] Dept. of Astronomy, R.L.M 15.308, The University of Texas at Austin, Austin, TX, U.S.A., 78712-1083
[2] Astronomy Program, University of Maryland, College Park, MD, U.S.A., 20742
[3] Dept. of Terrestrial Magnetism, Carnegie Inst. of Washington, 5241 Broad Branch Rd. N.W., Washington, D.C., U.S.A., 20015

We have observed 6 Herbig Ae/Be stars at 50 and 100 μm with the Kuiper Airborne Observatory. All were classified as Group I sources by Hillenbrand et al. (1992), signifying that their spectral energy distributions could be modeled with stars surrounded only by accretion disks. If the far-infrared emission is assumed to arise in a disk, it should be unresolved at 100 μm, regardless of the size of the disk. In contrast, we find that 5 out of 6 sources are clearly resolved at 100 μm. Three sources were also observed at 50 μm and at least 2 were resolved. Consequently the far-infrared emission must arise in another component, most plausibly a circumstellar envelope. This suggests that the Group I sources may be less distinct from the Group II sources than previously suggested. Since the presence of an envelope can affect both the actual temperature distribution in a disk and the temperature distribution derived from modeling the emission, more consistent models, including both disks and envelopes, are needed for these sources.

Accepted by The Astrophysical Journal

The Parker instability in disks with differential rotation

T. Foglizzo[1], M. Tagger[1]

[1] Service d'Astrophysique, CE-Saclay, 91191 Gif-sur-Yvette Cedex, France

We present a detailed study of the growth of the Parker instability in a differentially rotating disk embedded in an azimuthal equilibrium magnetic field, such as the interstellar gas or an accretion disk. Basic properties of the instability without shear are first recalled. Differential rotation is modeled in the shearing sheet approximation, classical in the theory of spiral density waves, and the linearized problem is transformed into a second order differential equation. The action of differential rotation is reduced to two different effects, (i) a linear time-dependence of the radial wavenumber, and (ii) a radial differential force. We present both exact numerical solutions, and approximate analytical ones based on the WKB approximation in the limit of weak differential rotation. This allows us to discuss the mathematical and physical nature of new behaviours obtained numerically in cases with realistic differential rotation. Most important are (i) a transient natural stabilization of the Parker mode due to the radial differential force (ii) the generation of magnetosonic waves (i.e. spiral density waves if we had included self-gravity) and Alfvenic ones, and (iii) in a certain parameter range a possible "turn-over" of the perturbation whereby, quite surprisingly, matter which had started being elevated by the instability may end up dropping towards the disk midplane. A simplified model shows the possible observable effects of this turn-over.

Accepted by Astronomy and Astrophysics

A Near-Infrared Survey for Pre-Main Sequence Stars in Taurus

Mercedes Gomez, Scott J. Kenyon, and Lee Hartmann

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

We present a near-infrared survey of ~ 2 deg^2 covering parts of L1537, L1538, and Heiles Cloud 2 in the Taurus-Auriga molecular cloud. Although this study is more sensitive than previous attempts to identify pre-main sequence stars in Taurus-Auriga, our survey regions contain only one new optically-visible young star. We did find several candidate embedded protostars; additional 10 μm photometry is necessary to verify the pre-main sequence nature of these sources.

Our results – combined with those of previous surveys – show that the L1537/L1538 clouds contain no pre-main sequence stars. These two clouds are less dense than the active star formation sites in the Taurus-Auriga, which suggests a cloud must achieve a threshold density to form stars.

Accepted by Astron. J. – May 1994

Polar accretion and light variability on T Tauri stars

E. Gullbring[1]

[1] Stockholm Observatory, S-133 36 Saltsjöbaden, Sweden

The proposition that some T Tauri stars are accreting material magnetically from a circumstellar disk is examined. The model developed by Ghosh and Lamb (1979a,b) is applied to the star-disk system, and the general features of the spectral energy distribution of the disk are discussed. It is found that accretion along magnetic field lines in a dipole stellar magnetic field affects the continuous spectra over a large wavelength range. The implications concerning light variability due to an inhomogeneous accretion flow are discussed. High speed photometric observations of BP Tauri, where a number of flare-like events have been recorded, are compared with the results from the model calculations. It is found that the changes in the black-body temperature of the excess emission during these events is in quantitative and qualitative agreement with these calculations. The emission from the plasma column of accreting material close to the stellar surface, where the kinetic energy is released, is analysed. It is found that soft X-ray radiation could emerge from the post-shock region in a bimodal way dependent on the optical depth in the accretion column.

Accepted by Astron. & Astrophys.

Mass Loss Rates, Ionization Fractions, Shock Velocities and Magnetic Fields of Stellar Jets

Patrick Hartigan[1], **Jon Morse**[2] **and John Raymond**[3]

[1] Five College Astronomy Department, University of Massachusetts, Amherst, MA 01003, USA
[2] Space Telescope Science Institute, Baltimore, MD 21218, USA
[3] Center for Astrophysics, Mail Stop 16, Cambridge, MA 02138, USA

In this paper we calculate emission line ratios from a series of planar radiative shock models that cover a wide range of shock velocities, preshock densities, and magnetic fields. The models cover the initial conditions relevant to stellar jets, and we show how to estimate the ionization fractions and shock velocities in jets directly from observations of the strong emission lines in these flows. The ionization fractions in the HH 34, HH 47, and HH 111 jets are $\sim 2\%$, considerably smaller than previous estimates, and the shock velocities are ~ 30 km s^{-1}. For each jet the ionization fractions were found from five different line ratios, and the estimates agree to within a factor of ~ 2. The scatter in the estimates of the shock velocities is also small (± 4 km s^{-1}).

The low ionization fractions of stellar jets imply that the observed electron densities are much lower than the total densities, so the mass loss rates in these flows are correspondingly higher ($\gtrsim 2 \times 10^{-7}$ M$_\odot$ yr^{-1}). The mass loss rates in jets are a significant fraction (1% – 10%) of the disk accretion rates onto young stellar objects that drive the outflows. The momentum and energy supplied by the visible portion of a typical stellar jet are sufficient to drive a weak molecular outflow. Magnetic fields in stellar jets are difficult to measure because the line ratios from a radiative shock with a magnetic field resemble those of a lower velocity shock without a field. The observed line fluxes can in principle indicate the strength of the field if the geometry of the shocks in the jet is well-known.

Accepted by the Astrophysical Journal

Thermal Infrared Imaging of Sub-arcsecond Structure in the Trapezium Nebula

T. L. Hayward, J. R. Houck, and J. W. Miles

Center for Radiophysics and Space Research, Cornell University, Ithaca, NY 14853, USA

We present 11.7 and 8.8 μm images of the central region of the Ney-Allen nebula in Orion which reveal mid-infrared counterparts to the ionized globules previously discovered by optical and radio observations. The $0.5''$ FWHM resolution images also reveal several arc-shaped structures which are associated with the compact sources. Each of the arcs points toward θ^1 Orionis C, providing further evidence for the strong effects of the intense radiation and wind from this star on the central Orion nebula. Low-resolution spectra of a few of these condensations and arcs are similar to spectra of the diffuse, optically thin silicate dust observed throughout the region. Photometry of one of the condensations, however, indicates that it is cooler than the others. Simple momentum-balance arguments indicate that dust in the arcs could originate in the outflow from the compact sources and flow outwards until stopped by the stellar wind and radiation pressure from θ^1C.

Accepted by Astrophys. J.

Asymmetries in Bipolar Jets from Young Stars

G.A. Hirth[1], R. Mundt[1], J. Solf[1] and T.P. Ray [2]

[1] Max-Planck-Institut für Astronomie, Königstuhl 17, D-69117 Heidelberg, Germany
[2] School of Cosmic Physics, Dublin Institute for Advanced Studies, 5 Merrion Square, Dublin 2, Ireland

While carrying out a survey of T Tauri stars (TTSs) in the Taurus-Auriga dark cloud for extended forbidden emission line regions by long-slit spectroscopy we have discovered relatively extended bipolar jets emanating from RW Aur, DO Tau and DP Tau. In the case of the bright TTS RW Aur the bipolar jet can be traced in Hα and [SII] for at least 20$''$ on either side of the source. For DO Tau and DP Tau the high-velocity jets extend up to approximately 4$''$ and 10$''$, respectively. In RW Aur and DO Tau, our radial velocity measurements indicate that the velocities of the blueshifted and redshifted parts of the outflow differ by about a factor of two. A search through the literature shows that this rather surprising behaviour is not unusual and that in about 50% of bipolar *optical* outflows the flow velocities of the blueshifted and redshifted parts differ by a factor 1.5 – 2.5. Possible explanations for these unusual results are briefly discussed and it seems that the source itself or its immediate environment is responsible for the observed behaviour.

Accepted by Astrophysical Journal Letters

A Connection Between Submillimeter Continuum Flux and Separation in Young Binaries

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

[1]University of Wisconsin-Madison, Dept. of Astronomy, 475 N. Charter St., Madison, WI 53706 USA
E-mail: jensen@madraf.astro.wisc.edu, mathieu@madraf.astro.wisc.edu
[2]NRAO, Edgemont Road, Charlottesville, VA 22903 USA. E-mail: gfuller@nrao.edu

We have made sensitive 800-μm continuum observations of low-mass, pre-main sequence (PMS) binary stars with projected separations less than 25 AU in Taurus-Auriga to study disks in the young binary environment. We did not detect any of the binaries, with typical 3σ upper limits of $\sim$ 30 mJy. Combining our observations with previous 1300-μm observations of PMS Taurus binaries by Beckwith et al. (1990) and others, we find that the submillimeter fluxes from binaries with projected separations a between 1 AU and 50 AU are significantly lower than fluxes from binaries with $a > 50$ AU. The submillimeter fluxes from the wider binaries are consistent with those of PMS single stars. This may indicate lower disk surface densities and masses in the close binaries. Alternatively, dynamical clearing of gaps by close binaries is marginally sufficient to lower their submillimeter fluxes to the observed levels, even without reduction of surface densities elsewhere in the disks.

Accepted by Astrophysical Journal Letters

The Hot Spot in DR Tauri

Scott J. Kenyon[1], Lee Hartmann[1], Robert Hewett[1], Luis Carrasco[2], Irene Cruz-Gonzalez[2], Else Recillas[2], Luis Salas[2], Alfonso Serrano[3], Karen M. Strom[4], Stephen E. Strom[4], and Geoff Newton[4]

[1] Harvard-Smithsonian Center for Astrophysics, 60 Garden St., Cambridge, MA 02138, USA
[2] Instituto de Astronomia, UNAM, Apartado Postal 70-264, 04510 Mexico, D.F., Mexico
[3] Instituto Nacional de Astrofisica Optica y Electronica Apartado Postal 51 y 216, 72000 Puebla, Pue., Mexico
[4] Dept. of Physics & Astronomy, Univ. of Mass., Amherst, MA 01003, USA

This paper presents BVRIJHKL light curves for DR Tauri, a pre-main sequence star in the Taurus-Auriga molecular cloud. We find phased optical and near-infrared brightness variations with time scales of roughly 5 or 10 days. The lack of a significant time lag indicates that the same phenomenon produces these changes. The observed color and flux changes suggest a two component model for the excess emission: a bright spot with T $\sim$ 10^4 K and a cool region with T $\sim$ 1700 K.

We develop a magnetic accretion model to explain the broadband spectral energy distribution and optical light curves of DR Tau. The magnetic field truncates the inner disk at a distance of five stellar radii from the central M0 star. This field channels the accretion flow into the bright spot, which we approximate as a narrow ring symmetric about the magnetic pole. Radiation from the inner edge of the disk produces the flat near-infrared excess in DR Tau; ring emission is responsible for the large optical veiling. Our results suggest that an accretion rate of $\dot{M} \sim 4\times10^{-7} M_{\odot}\,yr^{-1}$ provides a reasonable fit to the spectral energy distribution if the underlying M0 star has a radius of 2 $R_{\odot}$. This model can also account for broadband light variations observed in T Tauri stars if the magnetic axis is inclined relative to the stellar rotational axis. Our analysis suggests the sum of the observer's inclination to the rotational axis, i, and the angle between the magnetic and the rotational axes, β, is $i + \beta \sim 95^o$.

Accepted by Astron. J. – June 1994

Dust in protostellar cores and stellar disks

E. Krügel[1] and R. Siebenmorgen[2]

[1] Max-Planck-Institut für Radioastronomie, Auf dem Hügel 69, D–53121 Bonn, Federal Republic of Germany
[2] ISO Science Team, Astrophysics Division, Space Science Dept, ESTEC, Postbus 299, 2200AG Noordwijk, The Netherlands

We present the absorption and extinction cross section κ as a function of wavelength for dust that is thought to exist in cold dense clouds as well as in stellar disks. The grains are fluffy and composed of subparticles of astronomical silicate and amorphous carbon with an admixture of frozen ice. We assume a grain size distribution $n(a) \propto a^{-3.5}$ with fixed lower limit $a_- = 300Å$ and variable upper limit a_+. As long as the grains are smaller than $100\mu m$, which must apply to the cores of cold protostellar clouds, the absorption coefficient at $1.3mm$ is about $0.02\,cm^2$ per g of interstellar matter, an enhancement by a factor of eight relative to the diffuse interstellar medium; its variation with frequency is $\kappa \propto \nu^2$ in the submm/mm region. At $2.2\mu m$, the optical depth increases by a factor of 1.5 if the grains are small ($a_+ < 1\mu m$). Should coagulation have increased their size the outcome depends sensitively on the precise value of a_+.

Particular attention is given to the cross sections at $2.2\mu m$ and $1.3mm$, as these are the wavelengths for detecting embedded young stars and deriving masses from dust emission; we show in detail how variations in grain size, fluffiness and ice mantle affect the cross section and also the temperature that grains acquire in a far IR radiation field.

We also discuss the dust around Vega–type stars where the largest grains are known to be several millimeters big.

Accepted by Astronomy & Astrophysics

Near-infrared (J, H, K) Imaging of Herbig Ae/Be Stars

Wenbin Li[1], Neal J. Evans II Paul M. Harvey, and Cecilia Colomé

McDonald Observatory and Astronomy Department, the University of Texas, Austin, TX 78712, USA
E-mail: wenbin, nje, pmh, cc@astro.as.utexas.edu

Near-infrared (J, H, K) images were obtained for 16 Herbig Ae/Be stars. The primary goal was to determine the contributions by circumstellar nebulae and nearby sources to near-infrared photometry carried out with large beams. Quasi-simultaneous photometric results were obtained with small apertures. The emission toward five Herbig Ae/Be stars is extended, including all 4 Group II sources in our sample (Hillenbrand et al. 1992); thirteen objects have nearby sources (within $10''$ separation). However, the extended emission and nearby sources are too faint to affect previous photometry significantly. The surface brightness profiles of most of the nebulae can be explained by reflection nebulae which scatter the light from the central star/disk systems with single, isotropic scattering processes. The exception is Par 21, which may require emission from very small grains. The color-color diagram, making use of our new photometry, essentially agrees with the results of Lada & Adams (1992). The Group II objects in our sample tend to have extended emission more frequently than do Group I objects, supporting the suggestion of Hillenbrand et al. that Group II sources are more affected by circumstellar envelopes. However, most of the near-infrared emission comes from the central ($\leq 6''$) regions. This upper limit is still much larger than the expected size of accretion disks. Possible envelope effects could not be ruled out for most Herbig Ae/Be stars with unresolved emission. The images do not clearly favor very small, thermally-emitting grains as the origin of the near-infrared emission. The problem still exists of how to explain the observed peaks near 3 μm in the spectral energy distributions of Herbig Ae/Be stars. The possible effects of envelopes and companions are addressed.

Accepted by Ap.J. September 20 1994

Discovery of $^{14}NH_3$ (3,3) Maser Emission in the Interstellar Medium

Jeffrey G. Mangum[1] **and Alwyn Wootten**[2]

[1] Submillimeter Telescope Observatory, Steward Observatory, University of Arizona, Tucson, AZ 85721, USA
[2] National Radio Astronomy Observatory, 520 Edgemont Road, Charlottesville, VA 22903, USA

We report the discovery of $^{14}NH_3$ (3,3) maser emission toward the DR21(OH) star forming region. This maser emission is spatially and spectrally coincident with CH_3OH maser emission. Given the position of these $^{14}NH_3$ and CH_3OH masers relative to the observed outflow emission in DR21(OH), along with the recent observation that thermal $^{14}NH_3$ (3,3) emission traces outflows, we conclude that $^{14}NH_3$ and CH_3OH masers are produced within shocked molecular outflows. The sensitivity of the $^{14}NH_3$ (3,3) maser emission to the ortho-H_2/para-H_2 ratio has allowed us to derive an upper limit of 10^6 years to the age of the cloud which gives rise to the $^{14}NH_3$ (3,3) maser emission.

Accepted by Astrophysical Journal Letters

Entrainment by the Jet in HH47

John C. Raymond[1], Jon A. Morse[2], Patrick Hartigan[3], Salvador Curiel[1], and Steve Heathcote[4]

[1] Center for Astrophysics, 60 Garden St., Cambridge, MA 02138, USA
[2] Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218, USA
[3] Five College Astronomy Dept, University of Massachusetts, Amherst, MA 01003, USA
[4] Cerro Tololo Inter-American Observatory, Casilla 603, La Serena, Chile

Fabry-Perot images of the HH47 optical jet show that the velocity decreases from the center towards the edges which is interpreted as evidence for entrainment. Those images can be used to investigate the rate of entrainment required to account for the observed luminosity. Entrainment along the jet can account for only small fractions of the jet mass and the molecular outflow seen in CO. We compare the density, excitation and velocity structure of the jet with the predictions of viscous entrainment models and models of entrainment by expulsion of jet material by internal shocks, and find that either type of model can explain the general features of the observations.

Accepted by ApJ

New binary young stars in the Taurus and Ophiuchus star–forming regions

A. Richichi[1], **Ch. Leinert**[1], **R. Jameson**[2], **H. Zinnecker**[3]

[1] Max-Planck-Institut für Astronomie, Königstuhl 17, D-69117 Heidelberg, Federal Republic of Germany
[2] Astronomy Group, University of Leicester, University Road, Leicester Le1 7RH, England
[3] Institut für Astronomie und Astrophysik der Universität Würzburg, Am Hubland, D-97074 Würzburg, Germany

We have observed 30 lunar occultations (LO) in the near infrared of sources in the Taurus and Ophiuchus star–forming regions (SFRs) during three runs from September 1991 to January 1993. Twenty–six of the sources were proper young stellar objects (YSOs), the remaining four were field stars (or at least suspected to be). Our observations have led to the discovery of the following new binary systems: HK Tau/G2, IW Tau, HP Tau and HP Tau/G3 in Taurus, and GSS 35 and VSSG 14 in Ophiuchus. In the case of the known binary Haro 6–10 (Leinert & Haas 1989), our observation shows the presence of extended emission around the main component, while nothing can be said about the circumbinary disk suggested by Ménard et al. (1993). Additionally, FY Tau should be considered a suspected binary, and we find the field star VSS 35 to be double. We discuss the implications of these new findings: at least in the Taurus SFR, where most of our events were observed, the currently emerging view that most –if not all– stars begin their life as members of binary or multiple systems (Ghez et al. 1993, Leinert et al. 1993, Simon et al. 1994) appears strengthened; a statistical discussion of all LO observations obtained so far in the Taurus and Ophiuchus SFRs will be given by Simon et al. (1994).

Accepted by Astron. Astrophys.

Subarcsecond VLA Maps of the Disk and the Jet in HL Tau

L. F. Rodríguez[1,2], J. Cantó[3], J. M. Torrelles[4], J. F. Gómez[5,4], G. Anglada[6], and P. T. P. Ho[5]

[1] National Radio Astronomy Observatory, P. O. Box 0, Socorro, NM 87801, USA Email (Internet): lrodrigu@nrao.edu
[2] On sabbatical leave from Instituto de Astronomía, UNAM
[3] Instituto de Astronomía, UNAM, Apdo. Postal 70-264,04510 México, D. F., MEXICO
[4] Instituto de Astrofísica de Andalucía, CSIC, Apdo. Correos 3004, E-18080 Granada, Spain
[5] Harvard-Smithsonian CfA, 60 Garden St., Cambridge, MA 02138, USA
[6] Departament d'Astronomia i Meteorologia, UB, Av. Diagonal 647, E-08028 Barcelona, Spain, and Laboratori d'Astrofísica, Societat Catalana de Física, IEC

High-angular resolution ($\sim 0''.3 - 0''.4$) VLA observations of HL Tau at 3.6 and 1.3-cm show extended structures associated with this young star that are strikingly different at each wavelength. While the structure observed at 3.6-cm is elongated approximately in the east-west direction, the 1.3-cm structure is elongated approximately in the north-south direction. We interpret these results to imply that while the 3.6-cm emission is dominated by free-free radiation from an ionized outflow, the 1.3-cm emission traces dust emission from a perpendicular, collimating disk. If our interpretation is correct, these VLA images represent the first subarcsecond images of both jet and disk in a young star.

Accepted by The Astrophysical Journal (Letters)

A molecular jet and bow shock in the low mass protostellar binary system NGC1333-IRAS2

G. Sandell[1], L.B.G. Knee[2,3], C. Aspin[1], I.E. Robson[1], A.P.G. Russell[4]

[1] Joint Astronomy Centre, 660 North A'Ohoku Place, Hilo, HI 96720, U.S.A.
[2] Swedish-ESO Submillimetre Telescope, European Southern Observatory, Casilla 19001, Santiago 19, Chile
[3] Onsala Space Observatory, S-43992 Onsala, Sweden
[4] Royal Observatory, Blackford Hill, Edinburgh EH9 3HJ, U.K.

We present new molecular spectral line and (sub)millimetre continuum observations of the IRAS2 region of NGC1333. Our data locates the (sub)millimetre counterpart of the IRAS source. This source is located at the centre of symmetry of two bipolar molecular outflows. The older 'fossil' outflow extends approximately north–south while a younger, highly collimated, jet-like east–west outflow terminates in a well-defined molecular bow shock. Multi-transition methanol line data suggests that the molecular bow shock is very cold and that shock interactions have greatly enhanced the methanol abundance. This source provides a striking example of a molecular counterpart to the frequently observed optical Herbig-Haro type bow shock structures and provides a valuable specimen for detailed shock chemistry studies.

Accepted by Astronomy and Astrophysics, Letters

The 3.2 to 3.6 Micron Spectra of Mon R2/IRS-3 and Elias 16

K. Sellgren[1], R. G. Smith[2] and T. Y. Brooke[3]

[1] Department of Astronomy, Ohio State University, 174 West 18th Av., Columbus, OH 43210 USA
E-mail (internet): sellgren@payne.mps.ohio-state.edu
[2] Department of Physics, University College, University of New South Wales, Australian Defence Force Academy, 2600 Canberra, Australia
[3] Jet Propulsion Laboratory, M/S 169-237, 4800 Oak Grove Dr., Pasadena, CA 91109 USA

We have obtained 3.2–3.6 μm spectra, with a resolution $\lambda/\Delta\lambda \sim 750$, of the protostar Mon R2/IRS-3 and of Elias 16, a background K giant behind the Taurus molecular cloud. A feature at 3.482 μm (2872 cm^{-1}), with a full width at half maximum of 0.09 μm (76 cm^{-1}), is clearly seen in Mon R2/IRS-3. This feature is not detected in Elias 16. The 3.482 μm feature in Mon R2/IRS-3 is similar to a feature at 3.466–3.478 μm (2875–2885 cm^{-1}) detected by Allamandola et al. (1992) in four protostars and attributed by these authors to a CH stretch in hydrocarbons dominated by sp^3-bonded carbon. Neither Mon R2/IRS-3 nor Elias 16 shows absorption at 3.540 μm (2825 cm^{-1}), which has been detected in two of the four protostars observed by Allamandola et al. and attributed by them to CH_3OH ice. Our limit on CH_3OH ice toward Elias 16 is compared to models of gas-grain chemistry in dark clouds.

Our results confirm those of Allamandola et al. (1992, 1993) that at this resolution the 3.4 μm absorption due to dust in molecular clouds has very different spectral structure than that due to dust in the diffuse interstellar medium.

Accepted by Ap. J.

Strong evidence for a molecular jump shock in the HH 90/91 outflow

Michael D. Smith

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

The nature of shocks in star-forming clouds can be deduced from the infrared spectra of molecular hydrogen emission lines. The first clear evidence for a jump (J)-shock within dense molecular gas is found on analysing the published results for the bipolar outflow Herbig-Haro (HH) 90/91 (Gredel et al 1992). The rotational and vibrational lines of H_2 correspond to J-shocks with standard quiescent-cloud chemistry and any speed in the range $12 - 21$ km s^{-1}. No alternative shock physics can be applied with satisfaction.

The relatively high level of ionisation required to produce a J-shock (as opposed to a C-shock) is consistent with the dense gas being located near the edge of the cloud, thus being directly exposed to the UV of a nearby OB association. Limits to the near infrared Fe[II] emission lines are used as a further test. It is shown how to employ these line strengths to distinguish between shock types in HH objects.

Accepted by A&A

Numerical Simulations of Magnetic Accretion Disks

James M. Stone[1] and Michael L. Norman[2]

[1] Department of Astronomy, University of Maryland, College Park, MD 20742-2421, USA
[2] National Center for Supercomputing Applications, University of Illinois at Urbana-Champaign
5600 Beckman Institute, D-25, 405 North Mathews Avenue, Urbana, IL 61801, USA

The global evolution of magnetic accretion disks is studied by means of time-dependent numerical simulations. Ideal magnetohydrodynamics is used to compute the evolution; the simulations assume the disk is adiabatic, axisymmetric, and initially threaded by a purely axial magnetic field. These restrictions permit a large number of exploratory simulations to be performed. The evolution of both Keplerian and sub-Keplerian disks with a variety of magnetic field strengths is investigated. In the case of an initially sub-Keplerian disk, collapse of the disk is halted at the centrifugal barrier, and rapid wind-up of the magnetic field results in the production a strongly collimated, magnetic pressure driven wind. Although the evolution of the disk in this case is relatively independent of the magnetic field, the detailed properties of the wind are not. Surprisingly, in the case of an initially Keplerian disk, we also find collapse of the disk occurs on orbital timescales regardless of the initialfield strength. In the case of an initially strong field the collapse is driven by external torques (magnetic braking), while in the case of an initially weak magnetic field, the collapse is driven by internal torques (the Balbus-Hawley instability). These simulations indicate that magnetized accretion disks and any magnetically driven winds that are associated with them may be intrinsically unsteady.

Accepted by Ap. J.

Near-Infrared Imaging Survey of Young Stellar Objects in Bok Globules

João Lin Yun[1], and Dan P. Clemens[2]

[1] Departamento de Física, Universidade de Lisboa, Campo Grande, Ed. C1, 1700 Lisboa, Portugal
[2] Astronomy Department, Boston University, 725 Commonwealth Avenue, Boston, MA 02215, U.S.A.

We performed a near-infrared imaging survey toward 34 Bok globules containing IRAS point sources, which were young stellar objects (YSOs) candidates. We used state-of-the-art NICMOS 3 and SQIID cameras for this survey.

Visual examination of the images revealed that 20 globules showed evidence of nebular emission or very red stellar objects located at the position of the YSO-candidates. The IRAS 12/25 μm spectral indices of these 20 objects are distinctively different from those of the 14 globules which showed no nebulosity, in the sense that more than 50% of the 20 nebular or very red objects have negative IRAS 12/25 μm spectral indices, while only 20% of the 14 non-nebular objects show such red IRAS colors.

Analysis of the near-infrared nebulosities present in the images revealed that: 1) these nebulosities generally contain a stellar-like source surrounded by an extended component; 2) several possible binaries with separations of about 10″ were found to reside in common infrared nebulosity; 3) infrared reflection nebulae, seen at 2.2 μm, are good tracers of CO mass outflow morphology.

The group of objects displaying nebulosities, when ordered by their increasing 12/25 μm indices, seems to form an evolutionary sequence. Large negative 12/25 μm indices seem to indicate objects deeply embedded in their clouds (by showing nebulosities mostly in the K-band, having associated molecular outflows, and no optical counterparts). As these objects reach later stages of their pre-main sequence evolution (by showing nebulosity in the J-band only, no detected molecular outflow, and having optical counterparts or optical nebulae), their 12/25 μm indices increase and become positive.

Accepted by The Astronomical Journal

A $C^{18}O$ Survey of Dense Cores In The Taurus Molecular Cloud: Signatures Of Evolution And Protostellar Collapse

Shudong Zhou[1], Neal J. Evans II[2], Yangsheng Wang[2], Ruisheng Peng[1], and K.Y. Lo[1]

[1] Department of Astronomy, University of Illinois, Urbana, IL 61801, USA
[2] Department of Astronomy, University of Texas, Austin, TX 78712-1083, USA

We have mapped 11 dense cores in the Taurus molecular cloud in the $C^{18}O$ J = 2→1 line at a linear resolution of 0.02 pc. The core masses derived from $C^{18}O$ range from 0.06 to 5 $M_\odot$. Five of them have embedded infrared sources and six do not. Dense cores without infrared sources show multiple emission peaks. In contrast, dense cores with infrared sources have a single peak and smaller sizes. The cores with infrared sources have line widths that are 2-3 times the value expected from correlations found in previous surveys. This enhancement may be accounted for by models of gravitational collapse. The data are consistent with the idea that dense cores evolve first toward smaller sizes and smaller line width along the line width–size relation, and then toward larger line width and constant or smaller sizes as an infrared source becomes observable. A good collapse candidate, L1527, is identified based on the shapes of $C^{18}O$ and H_2CO lines.

Accepted by Astrophys. J.

X-ray and Optical Studies of Low–Mass Star Formation

J.M. Alcalá-E.

Thesis work conducted at: Landessternwarte, Königstuhl D–69117 Heidelberg, Germany

Current address: Landessternwarte Königstuhl, D–69117 Heidelberg, Germany

Electronic mail: bo7@vm.urz.uni-heidelberg.de

Ph. D. dissertation directed by: Joachim Krautter

Ph. D. degree awarded: February 1994

Weak–line T Tauri stars (WTTS) are low–mass pre–main sequence (PMS) stars which lack both the strong emission lines and the infra–red (IR) excesses typical of classical T Tauri stars (CTTS). Most of them have been discovered on the basis of their solar–like X–ray emission. In this work, X–ray data from the ROSAT all-sky survey in the Chamaeleon (Cha) and the Orion star forming regions (SFR's), and from one ROSAT pointed observation in the Cha I dark cloud, were used to determine the number of WTTS, to investigate their spatial distribution, and to study their physical properties and their X–ray emission.

The total number of X-ray sources detected in the ROSAT survey is 820 in Orion ($\sim$ 450 square degrees), and 181 in Chamaeleon ($\sim$ 200 square degrees). Fifty four X–ray sources were detected in the ROSAT pointed observation in Cha I. Cross correlation of the X-ray positions with those of catalogued objects in the Simbad database gives about 30% of coincidences in the two SFR's. These counterparts are mainly extragalactic objects, HD, HR or SAO stars, CTTS, and a few WTTS known from previous EINSTEIN observations. For the remaining sources, a programme of spectroscopic observations has been conducted. These observations led to the identification of 85 and 58 new WTTS in the Chamaeleon and Orion SFR's respectively. For the Chamaeleon SFR, the spectroscopic identification of the survey sources is complete, while for the Orion SFR there are about 470 sources still to be investigated. Eighty percent of the sources from the pointed observation in Cha I have been identified. In addition, optical and near IR photometric observations of a sub–sample of the new WTTS were carried out. The spectral energy distributions of these stars are very similar to those of normal stars of the same spectral type.

The effective temperature and the stellar luminosity were derived in order to place the sub–sample of WTTS in the H–R diagram. By comparison with the theoretical evolutionary tracks from D'Antona and Mazzitelli (1993), the sub–sample of WTTS in Chamaeleon are estimated to have masses in the range 0.3–2.5$M_\odot$, and ages in the range 10^5yr to 5×10^7yr, with about 70% of the stars having ages less than 3×10^6yr. On the other hand, the sub–sample of WTTS in Orion have masses in the range 1–3$M_\odot$, and ages in the range 10^5yr to 10^7yr.
A comparison of the bulk properties of WTTS and of CTTS gives the following results: i) the WTTS are distributed throughout the studied areas, while the CTTS are mainly concentrated in the cloud cores; ii) no substantial difference between the ages of WTTS and CTTS is found; iii) WTTS have, on average, earlier spectral types than CTTS; iv) on the basis of the survey data, the ratio of the number of WTTS to CTTS is $\geq$ 1.5 in the Chamaeleon complex. However, a larger ratio (up to 7) can not yet be ruled out. This ratio will be derived for the Orion complex when sufficient spectroscopic observations are complete.

The X–ray luminosity function (XLF) for the identified sources was derived. WTTS with very low levels of X–ray emission (logLx(erg/s)$\leq$28.7) were found. These stars are the main contribution to this XLF at lower X–ray luminosities.
A correlation between the bolometric luminosity and the X–ray luminosity of the new WTTS was found. This may indicate that a mass–X–ray luminosity relation exists for low–mass PMS stars.
A comparison of the strength of the Hα emission line of WTTS to that of other magnetically–active stars shows that the emission in WTTS represents the maximum level which can be attributed to stellar chromospheric emission.
No anticorrelation is found between the strength of the Hα emission line and the level of X–ray emission, as would

be expected for smothered coronae of T Tauri stars. However, a strong trend for the K − L index, a diagnostic of accretion activity, to increase when the level of X-ray emission decreases is found. High accretion rates in CTTS may produce high hydrogen column densities between the disk and the star. Matter at these densities efficiently absorbs the coronal X–ray photons, leading to a smothering of the coronal emission in CTTS.

First results of spectroscopic and photometric monitoring show that strong variability can be found among WTTS. Spectacular variability exhibited by the Hα line of the star T Chamaeleontis has been found. The line can change from absorption to strong emission on timescales of one day, and sometimes an inverse P Cygni profile is seen.
The analysis of the X–ray light curves of the ROSAT survey sources demonstrated that flare activity may enhance the X–ray emission in T Tauri stars, but this is not the main mechanism for the X-ray emission.

Finally, it is concluded that the initial physical conditions during the star formation process may determine the stellar characteristics, the evolution of angular momentum towards the main-sequence, and consequently the X–ray properties.