

THE STAR FORMATION NEWSLETTER

An electronic publication dedicated to early stellar evolution and molecular clouds

No. 72 — 22 September 1998

Editor: Bo Reipurth (reipurth@casa.colorado.edu)

Abstracts of recently accepted papers

Correlation Between Gas and Dust in Molecular Clouds: L977

João Alves¹, Charles Lada¹ and Elizabeth Lada²

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

² Astronomy Department, University of Florida, Gainesville, FL 32608, USA

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

We report observations of the $J = (1-0)$ C¹⁸O molecular emission line toward the L977 molecular cloud. To study the correlation between C¹⁸O emission and dust extinction we constructed a gaussian smoothed map of the infrared extinction measured by Alves et al. (1998) at the same angular resolution (50'') as our molecular-line observations. This enabled a direct comparison of C¹⁸O integrated intensities and column densities with dust extinction over a relatively large range of cloud depth ($2 < A_V < 30$ mag) at 240 positions inside L977. We find a good linear correlation between these two column density tracers for cloud depths corresponding to $A_V \leq 10$ magnitudes. For cloud depths above this threshold there is a notable break in the linear correlation. Although optically thick C¹⁸O emission could produce this departure from linearity, CO depletion in the denser, coldest regions of L977 may be the most likely cause of the break in the observed correlation. We directly derive the C¹⁸O abundance in this cloud over a broad range of cloud depths and find it to be virtually the same as that derived for IC 5146 from the data of Lada et al. (1994).

Our results suggest that the use of C¹⁸O as a column density tracer in molecular clouds can lead to a 10 to 30% underestimation of overall cloud mass. In regions of very high extinction ($A_V > 10$ mag), such as dense cores, our results suggest that C¹⁸O would be a very poor tracer of mass.

We estimate the minimum total column density required to shield C¹⁸O from the interstellar radiation field to be 1.6 ± 0.5 magnitudes of visual extinction.

Accepted by The Astrophysical Journal

<http://cfa-www.harvard.edu/~jalves>

Spectral Indices of Centimeter Continuum Sources in Star-Forming Regions: Implications on the Nature of the Outflow Exciting Sources

Guillem Anglada¹, Eva Villuendas², Robert Estalella^{2,3}, Maria T. Beltrán², Luis F. Rodríguez⁴, José M. Torrelles^{1,5}, Salvador Curiel⁴

¹ Instituto de Astrofísica de Andalucía, CSIC, Apdo. Correos 3004, E-18080 Granada, Spain

² Departament d'Astronomia i Meteorologia, Universitat de Barcelona, Av. Diagonal 647, E-08028 Barcelona, Spain

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

⁴ Instituto de Astronomía, UNAM, Apdo. Postal 70-264, 04510 México D.F., Mexico

⁵ Instituto Mediterráneo de Estudios Avanzados (CSIC-UIB), Universitat de les Illes Balears, Carretera de Valldemosa km 7.5, E-07071 Palma de Mallorca, Spain (visitor; present address)

E-mail contact: guillem@iaa.es

We present 6 cm VLA observations of nine regions with molecular or HH outflows, that appear to be driven by young stellar objects of low bolometric luminosity. Radio continuum emission at 3.6 cm had been previously detected toward the center of symmetry of 13 outflows in these regions. With the new 6 cm observations we have been able to estimate the spectral index in the 6 cm to 3.6 cm wavelength range for 11 of these outflow central (Class 0 and Class I) sources. All the spectral indices obtained for these central sources are positive, and consistent with partially thick thermal free-free emission. We discuss this result in relation to the current models for the origin of cm radio continuum emission in outflow sources. In particular, we find that the observed flux densities of these sources fit very well in the observational correlation between the radio continuum luminosity and the momentum rate of the outflow (e.g., Anglada 1996), and that the results are consistent with the central sources being thermal radio jets. Our data suggest that the ionized part of the jets begins at a distance $\lesssim 10$ AU from the star. In addition, we have derived a positive value for the spectral index of the Herbig-Haro object 32A, indicative of partially thick thermal emission. For the remaining sources detected in the nine fields observed, our results indicate that the emission is, in general, non-thermal as expected for background extragalactic sources. However, a few of these sources could be related to the star-forming regions studied.

Accepted by The Astronomical Journal (to appear December 1998 issue)

Preprint available at <http://www.astro.unam.mx/~luisfr/>
<http://www.am.ub.es/~robert/ISMPub.html>

ISO-SWS Observations of Herbig Ae/Be Stars: HI Recombination Lines in MWC1080 and CoD -42° 11721

M. Benedettini¹, B. Nisini¹, T. Giannini¹, D. Lorenzetti², E. Tommasi³, P. Saraceno¹ and H.A. Smith⁴

¹ CNR-Istituto di Fisica dello Spazio Interplanetario, Area di Ricerca di Tor Vergata, via del Fosso del Cavaliere, I-00133, Roma, Italy

² Osservatorio Astronomico di Roma, via Frascati 33, I-00040, Monte Porzio, Italy

³ ISO Science Operations Centre, Villafranca, P.O. Box 50727, E-28080 Madrid, Spain ⁴ Harvard - Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138, USA

E-mail contact: milena@sirius.ifs.rm.cnr.it

ISO-SWS grating spectra are obtained towards the two Herbig Ae/Be stars MWC1080 and CoD -42° 11721, showing hydrogen recombination lines of the Brackett, Pfund and Humphreys series. The observed line decrements in each spectral series are consistent with emission from ionized winds, as expected from these early-type stars. We compare the observed line emission with a wind model assuming a constant rate of mass flow from the star, which allows to consistently derive mass loss rate and distance of both stars. We also show that the observed decrements can only be explained by assuming a ionization bounded compact regions whose sizes are a few tens of the stellar radii.

Accepted by Astronomy and Astrophysics

The Ionization Fraction in Dense Molecular Gas II: Massive Cores

Edwin A. Bergin, René Plume, Jonathan P. Williams, and Philip C. Myers

Harvard-Smithsonian Center for Astrophysics MS-66, 60 Garden Street, Cambridge, MA 021 38-1596, USA

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

We present an observational and theoretical study of the ionization fraction in several massive cores located in regions that are currently forming stellar clusters. Maps of the emission from the $J = 1 \rightarrow 0$ transitions of $C^{18}O$, DCO^+ , N_2H^+ , and $H^{13}CO^+$, as well as the $J = 2 \rightarrow 1$ and $J = 3 \rightarrow 2$ transitions of CS, were obtained for each core. Core densities are determined via a large velocity gradient analysis with values typically $\sim 10^5$ cm^{-3} . With the use of observations to constrain variables in the chemical calculations we derive electron fractions for our overall sample of 5 cores directly associated with star formation and 2 apparently starless cores. The electron abundances are found to lie within a small range, $-6.9 < \log_{10}(x_e) < -7.3$, and are consistent with previous work. We find no difference in the amount of ionization fraction between cores with and without associated star formation activity, nor is any difference found in electron abundances between the edge and center of the emission region. Thus our models are in agreement with the standard picture of cosmic rays as the primary source of ionization for molecular ions. With the addition of

previously determined electron abundances for low mass cores, and even more massive cores associated with O and B clusters, we systematically examine the ionization fraction as a function of star formation activity. This analysis demonstrates that the most massive sources stand out as having the lowest electron abundances ($x_e < 10^{-8}$).

Accepted by the Astrophysical Journal

Preprints available at <http://cfa-www.harvard.edu/~ebergin/> or by request: ebergin@cfa.harvard.edu

Multi-lines analysis of the spectra of Herbig Ae/Be stars

Jean-Claude Bouret and Claude Catala

Laboratoire d'Astrophysique de Toulouse, CNRS UMR 5572, Observatoire Midi-Pyrénées, 14 avenue Edouard Belin, F-31400 Toulouse, France

E-mail contact: bouret@obs-mip.fr

We present the results of the study of four Herbig Ae/Be stars (AB Aur, BD+46°3471, HD250550, BD+61°154). For each of them, semi-empirical models of the structure of their winds have been constructed; we then calculated the $H\alpha$ line, the Balmer discontinuity, as well as the C IV 1548 Å and Mg II h or k resonance lines. Thanks to comparison with observational data, we have deduced constraints on the parameters of the models, which provide us with a rather good representation of the averaged structure of the winds. Despite of the time variability of these stars, we show that we can gather trustworthy informations on the values of the mass loss rates of these stars. It is also shown that models with departure from spherical symmetry are needed to account for the observed shapes of the lines. In addition, radiative losses due to several transitions (lines and continua) of hydrogen have been evaluated, in order to gain more insight in the energy sources that generate the observed activity of these stars.

Accepted by Astronomy & Astrophysics

Preprints available from <http://www.obs-mip.fr/omp/astro/people/bouret/publications.html>

The Structure and Emission of the Accretion Shock in T Tauri Stars

Nuria Calvet¹ and Erik Gullbring²

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

² Also Centro de Investigaciones de Astronomía, Mérida, Venezuela

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

We have examined one of the key predictions of the magnetospheric infall model for Classical T Tauri stars (CTTS), namely, the formation of a shock on the stellar surface. We find that accretion column emission can successfully reproduce the main observational properties of the excess continuum that veils the absorption features in CTTS. This success adds further support to the magnetospheric infall model for disk accretion. We have calculated the structure and the spectral energy distribution of the emergent continuum emission from a shock at the base of the magnetospheric accretion column. We find that the spectral shape of the excess can be understood as optically thick emission from the heated photosphere below the shock, appearing mostly on the Paschen and Brackett continua, and optically thin emission from the pre-shock and attenuated post-shock regions, dominating at wavelengths shorter than the Balmer threshold. The accretion luminosity and rate depend on two parameters: the energy flux of the accretion flow, $curf$, and the surface coverage of the column, f , with typical values $\log curf \sim 10.5 - 11.5$, of the order or up to a factor of 10 higher than the intrinsic stellar flux, and $f \sim 0.1 - 1\%$ of the surface area. The so-called “continuum stars” have accretion columns with similar energy fluxes than the less veiled, typical CTTS but with much larger surface emitting areas of $f \geq 10\%$. At near-infrared wavelengths, the predicted veiling from the accretion column for typical CTTS parameters is nearly constant and ≤ 0.1 . Only for the “continuum stars” are significant amounts of near-infrared veiling from the accretion column expected. For accretion columns with low values of $curf$, the Paschen continuum emission has spectral features, rendering the usual deveiling procedures uncertain. Magnetospheric flow Balmer emission may also contribute to the excess for stars with low- $curf$ columns. Finally, accretion column emission can successfully reproduce the observed correlation between the excess luminosity at the U This correlation does not depend on the characteristics (mass, spectral type) of the underlying star, at least in the range M3 – K5.

Accepted by Ap. J.

Detection of doubly deuterated formaldehyde towards the low-luminosity protostar IRAS 16293–2422

C.Ceccarelli¹, A.Castets¹, L.Loinard^{1,2}, E.Caux³ and A.G.G.M.Tielens⁴

¹Laboratoire d’Astrophysique, Observatoire de Grenoble - BP 53, F-38041 Grenoble cedex 09, France

²Institut de Radio Astronomie Millimétrique, 300 rue de la piscine, F-38406 St. Martin d’Hères, France

³CESR CNRS-UPS, BP 4346, 31028 - Toulouse cedex 04, France

⁴SRON, P.O. Box 800, NL-9700 AV Groningen, the Netherlands

E-mail contact: Cecilia.Ceccarelli@obs.ujf-grenoble.fr

We report the detection of the doubly deuterated form of formaldehyde towards IRAS 16293-2422, an extremely young protobinary system. This is the only detection of D₂CO in any astronomical source other than Orion (Turner 1990). The line searched was that corresponding to the 4_{2,2} – 3_{2,1} transition at $\nu_0 = 236.102$ GHz, and was detected at three positions, one centered on the source itself, and the other two 10'' West and 10'' East respectively. A survey of the literature revealed that two additional lines of D₂CO at 245.532 and 342.522 GHz were detected towards IRAS 16293-2422, but classified as “unidentified”. We failed to detect any signal towards the outflow (at offsets (-20'';0'') and (-30'';+10'')) where low-J CO emission lines are quite strong. The line profiles at the three positions show a dip at the zero rest velocity. We rule out the possibility that this dip may be due to a pure kinematic effect and show that it is actually due to *self absorption*. The gas responsible for the D₂CO emission is located at less than about 10'' ($\sim 2 \cdot 10^{16}$ cm) from the central source.

We used multi-transition H₂CO observations of van Dishoeck et al. (1995) to estimate the density ($n_{H_2} \sim 10^7$ cm⁻³) and temperature ($T \sim 100$ K) of the emitting gas. From those values, we can derive a lower limit to the column density required for the D₂CO line we observed to be self-absorbed : $N(D_2CO) \sim 10^{14}$ cm⁻². Combining the previous and present observations of H₂CO, HDCO and D₂CO we obtain the following upper limits to the abundance ratios of the three species: $[HDCO] / [H_2CO] \leq 0.25$ and $[D_2CO]/[HDCO] \leq 0.5$. If the abundance of H₂CO in IRAS16293-2422 is comparable to that observed towards the Hot Cores in Orion ($\sim 10^{-8}$; Blake et al. 1987) and if the D₂CO 4_{2,2} – 3_{2,1} line is only moderately thick, D₂CO is only 1/10 less abundant than H₂CO. We finally speculate that such a large amount of warm D₂CO can only be produced by evaporation of this molecule from the grain mantles, where it was presumably copiously formed during the long pre-collapse period.

Accepted by Astronomy & Astrophysics Letters

Distribution and Motion of the Water Masers near IRAS 05413-0104

Mark J Claussen¹, Kevin B. Marvel², Alwyn Wootten³, and Bruce A. Wilking⁴

¹ National Radio Astronomy Observatory, P.O. Box 0, Socorro, NM 87801 USA

² Owens Valley Radio Astronomy Observatory, 105-24, California Institute of Technology, Pasadena, CA 91125 USA

³ National Radio Astronomy Observatory, 520 Edgemont Road, Charlottesville, VA 22903 USA

⁴ Dept. of Physics and Astronomy, University of Missouri at St. Louis, 8001 Natural Bridge Road, St. Louis, MO 63121 USA

E-mail contact: mclausse@nrao.edu

We have used the NRAO Very Long Baseline Array to image water masers associated with the low-luminosity, young stellar object (YSO) IRAS 05413-0104 at four epochs over a period of ten weeks. The maser images show the detail of a symmetric, jet-like structure about 300 mas in extent. The $23^\circ \pm 2^\circ$ position angle of the maser spot distribution is in excellent agreement with measured position angles for the observed larger scale H₂ and SiO emission distributions; radial velocities are in agreement with SiO measurements showing redshifted gas to the southwest and blueshifted gas to the northeast. We have detected proper motions of numerous maser spots averaging 30 ± 12 mas yr⁻¹ implying space velocities of 64 ± 27 km s⁻¹ for a source distance of 450 pc. Some masers are located within a projected distance of 40 AU of the origin of expansion, the assumed position of the central source, suggesting that jet formation and acceleration takes place within this radius of the YSO. We compute an inclination of the outflow system to the plane of the sky of 4° , based on the relative magnitude of the proper motions and radial velocities of the masers. VLBI observations of water masers in YSOs are clearly demonstrated to be interesting and competitive probes of the

kinematics of the gas in YSO jets.

Accepted by *ApJ Letters*

Preprints available at: http://www.cv.nrao.edu/html/library/nrao_preprints.html

VLBI Observations of 6 GHz OH Masers in three ultra-compact HII regions

J.F. Desmurs^{1,2} & A. Baudry²

¹ JIVE / Observatorio Astronómico Nacional, Apartado 1143, 28800 Alcalá de Henares, Spain.

² Observatoire de l'Université de Bordeaux 1, BP 89, 33270 Floirac, France.

E-mail contact: desmurs@oan.es

Following our successful analysis of VLBI observations of the ${}^2\Pi_{\frac{3}{2}}, J = \frac{5}{2}, F = 3 - 3$ and $F = 2 - 2$ excited OH emission at 6035 and 6031 MHz in W3(OH), we have analyzed the same transitions in three other ultra-compact HII regions, M17, ON1, and W51. The restoring beams were in the range 6 to 30 milliarc sec. The $F = 3 - 3$ and $2 - 2$ hyperfine transitions of OH were both mapped in ON1. Seven 6035 MHz LCP or RCP maser components were identified in ON1. They are distributed over a region whose diameter is similar to that of the compact HII region, namely $\approx 0.4 - 0.5$ arc sec. In contrast with the $F = 3 - 3$ line emission, the $F = 2 - 2$ transition at 6031 MHz is nearly an order of magnitude weaker than the peak 6035 MHz emission. In M17, we observed fringes only in the 6035 MHz line. The detected OH components appear to be projected on to the compact HII region. We report also on weak VLBI detection of the 6035 MHz emission from W51. This emission seems to be located between two active ultra-compact HII regions in a complex area which deserves further investigation. The 5 cm OH minimum brightness temperatures range from about $3 \cdot 10^7$ K in W51 to $8 \cdot 10^9$ K in ON1. Variability of the 6035 or 6031 MHz emission is well established and suggests that the 5 cm OH masers are not fully saturated.

The high spectral and spatial resolutions achieved in this work allowed us to identify Zeeman pairs and hence to derive the magnetic field strength. In ON1 and W51 the field lies in the range 4 to 6 mG with a trend for higher field at 6031 MHz than at 6035 MHz in ON1. In M17 no Zeeman splitting was observed and the magnetic field appears to be weaker than 1 mG.

Accepted by A&A on September 16, 1998.

<http://www.observ.u-bordeaux.fr/public/radio/JFDesmurs/articles/VLBI5cm.3regions.p.s.gz>

CO Study of the GM Aurigae Keplerian Disk

A.Dutrey¹, S.Guilloteau¹, L.Prato², M.Simon², G.Duvert³, K.Schuster¹ & F.Ménard³

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

² Dept. of Physics and Astronomy, State Univ. of New York, Stony Brook, NY 11794-3800, U.S.A.

³ Laboratoire d'Astrophysique de Grenoble, B.P. 53, F-38041 Grenoble Cedex 9, France

E-mail contact: dutrey@iram.fr

We report new high resolution ($0.6 - 1.7''$) images of GM Aur in the ${}^{12}\text{CO}$ J=2-1 line and the 1.3 and 2.7 mm continuum. The dust disk, located at the center of the CO disk, is resolved by the $0.6''$ beam of the interferometer. We derive a minimum radius of ~ 200 AU, and a total mass (dust+gas) of about $\sim 0.025 M_{\odot}$. Our CO observations also resolve the Keplerian rotation of the gas disk. Since the CO emission is optically thick, the CO data does not allow a disk mass measurement but we can estimate the dynamical mass of the system, i.e. the *stellar mass*, $M_* = 0.84 \pm 0.05 \times (D/140 \text{ pc}) M_{\odot}$ although a solution with a more inclined disk and lower stellar mass ($\sim 0.6 M_{\odot}$) is also possible.

Accepted by A&A main Journal

Preprints are available at: <http://iram.fr/PP/papers.html>

The biconical cavity associated with HD 200775: The formation of a cometary nebula

A. Fuente¹, J. Martín-Pintado¹, A. Rodríguez-Franco^{1,2}, Moriarty-Schieven G.D.³

¹ Observatorio Astronómico Nacional (IGN), Campus Universitario, Apdo. 1143, E-28800 Alcalá de Henares (Madrid), Spain

² Escuela Universitaria de Óptica, Universidad Complutense de Madrid, Av. Arcos de Jalón s/n, E-28037 Madrid, Spain

³ Joint Astronomy Centre, 660 N. A'ohoku Place, Hilo, HI 96720

E-mail contact: fuente@oan.es

We have observed with high angular resolution ($10'' - 24''$) an area of $\approx 18' \times 15'$ around HD 200775 in the J=2 \rightarrow 1 line of ^{12}CO and the J=1 \rightarrow 0 lines of ^{13}CO and C^{18}O . An interferometric HI 21cm image with similar angular resolution ($14''$) is also presented. Molecular observations show that the star is located in a biconical cavity that has been very likely excavated by an energetic and bipolar outflow in an earlier evolutionary stage. The star is not located at the apex of this cavity but $\sim 50''$ towards the eastern lobe. At the present stage, there is no evidence for high velocity gas within the lobes of the cavity. However, the morphology of the HI emission, two filaments arranged in a “>” shape feature, and the bow shock located at the tip of one of these filaments, show that high velocity atomic gas is outflowing in a shell adjacent to the walls of the cavity in the eastern lobe. Since this high velocity atomic gas has not been detected in the western lobe, the outflow has a cometary shape. We propose that this outflow is formed when the atomic gas in the inner walls of the cavity is accelerated by the stellar wind. The cometary shape is due to the off-center position of the star. This cometary HI region constitutes the latest evolutionary stage of the bipolar outflow associated with HD 200775. Based on these results we propose a simple model to explain the formation of cometary nebulae in massive star forming regions.

Accepted by Astronomy and Astrophysics

preprints are available from: <http://www.oan.es/preprints/lista.html>

Physical parameters of the Keplerian protoplanetary disk of DM Tau

Stéphane Guilloteau & Anne Dutrey

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

E-mail contact: guillote@iram.fr

We present high sensitivity $3''$ aperture synthesis images of the DM Tau protoplanetary disk in the $^{12}\text{CO} \text{ J} = 1 \rightarrow 0$ line. The images unambiguously reveal that the disk is rotating around the central star. To model the observations in terms of a rotating disk in hydrostatic equilibrium, we have developed a χ^2 fitting procedure which allows derivation of the disk parameters and their errors. Dependencies among the disk parameters are discussed in detail. The disk is large, with an outer radius of 850 AU. We find that the rotation curve is essentially Keplerian, at least up to 600 AU. The stellar mass derived from the rotation curve is $0.50 \pm 0.06 M_{\odot} (D/150 \text{ pc})$. The intrinsic local velocity dispersion in the disk is found to be essentially thermal, with a turbulent component of less than 30 % of the thermal width. Parameters derived from this observation are used to confirm the molecular abundances and depletion factors estimated for several simple organic molecules by Dutrey et al (1997) for DM Tau.

Accepted by Astron. Astrophys.

<http://iram.fr/~guillote/PRE/ms7873.ps.gz>

Hubble Space Telescope FOS Optical and Ultraviolet Spectroscopy of the Bow Shock HH 47A

P. Hartigan¹, J. Morse², J. Tumlinson², J. Raymond³, and S. Heathcote⁴

¹ Space Physics & Astronomy Dept, Rice University, 6100 S. Main, Houston TX 77005-1892

² Center for Astrophysics and Space Astronomy, Campus Box 389, University of Colorado, Boulder, CO 80309, USA

³ Harvard-Smithsonian Center for Astrophysics, MS 16, 60 Garden St., Cambridge MA 02138

⁴ Cerro Tololo Inter-American Observatory, National Optical Astronomy Observatories, Casilla 603, La Serena, Chile

E-mail contact: hartigan@sparky.rice.edu

We present new spectra obtained with the Faint Object Spectrograph aboard the Hubble Space Telescope of the HH 47A bow shock and Mach disk that cover the entire spectral range between 2220Å and 6810Å. In addition to emission lines seen previously from HH objects, we uncover over a dozen weak Fe II transitions in the ultraviolet. The flux ratios between these permitted lines can only be understood if transitions to the ground state are resonantly scattered within HH 47A. The expected column density of Fe II within HH 47A suffices to scatter these lines, though the scattering optical depths imply that the Fe II line broadening must exceed that expected from thermal motions. Excitation of ultraviolet Fe II occurs locally within HH 47A, probably from collisions within the hot postshock gas, and not from UV pumping from some nearby O-stars. The data show no evidence for significant depletion of Fe within HH 47A.

The emission lines fluxes and ratios indicate that jet material currently enters the Mach disk with a density of $\sim 350 \text{ cm}^{-3}$ and a velocity of $\sim 40 \text{ km s}^{-1}$. The mass loss rate of the exciting star, as measured by the mass flux through the Mach disk, is $1.6 \times 10^{-8} M_{\odot} \text{ yr}^{-1}$. This mass loss rate is considerably lower than that closer to the star where the jet is brighter, probably because the density along the jet is highly nonuniform. A single shock velocity does not match the bow shock spectrum well. We propose that secondary shocks reheat the gas within the cooling zone of the HH 47A bow shock. Compression from the first shock will cause these secondary shocks to be strongly magnetized, and the secondary shocks should emit strongly in low-excitation lines such as Mg II, C II] and [S II]. The weak blue continua seen at optical wavelengths in spectra of the Mach disk and bow shock extend into the ultraviolet, and have spectral energy distributions and total fluxes consistent with those expected from 2-photon emission.

Accepted by Ap. J.

<http://sparky.rice.edu/~hartigan/pub.html>

Ammonia Absorption toward the Ultracompact HII Regions G45.12+0.13 and G45.47+0.05

Peter Hofner^{1,2}, Sarah Peterson³ and Riccardo Cesaroni⁴

¹ University of Puerto Rico, Rio Piedras Campus, Physics Department, P.O. Box 23343, San Juan, PR 00931

² Arecibo Observatory, NAIC/Cornell University, P.O. Box 995, Arecibo, PR 00614

³ Cornell University, Astronomy Department, REU Program 1997

⁴ Arcetri Observatory, Largo E. Fermi 5, 50125 Florence, Italy

E-mail contact: hofner@naic.edu

We present observations of the 1.3 cm continuum and NH₃(2,2) and (4,4) inversion lines toward the two ultracompact HII regions G45.12+0.13 and G45.47+0.05 with a resolution of about 3". In G45.12+0.13 we find that the continuum emission from the ultracompact core is embedded in a larger region with an extent of about 20" × 10". Compact absorption in the NH₃(2,2) and (4,4) lines is detected against the bright continuum core. The ammonia data indicate $T_{rot} = 78 \text{ K}$ and $N(\text{NH}_3) = 1.4 \times 10^{16} \text{ cm}^{-2}$. The molecular gas traced by the NH₃ absorption is blueshifted by about 5 km s⁻¹ with respect to the ionized gas and the bulk of the molecular gas in the region. Possibly the ammonia absorption traces the molecular gas at the base of an outflow which originates very close to the ultracompact HII region.

In the case of G45.47+0.05, we measure a deconvolved size of 1.5" × 0.8" for the region of 1.3 cm continuum emission. We detect extended emission in the NH₃(2,2) line in the vicinity of the ionized gas. Compact absorption is detected in both the (2,2) and (4,4) line against the 1.3 cm continuum. The absorption line data indicate $T_{rot} = 59 \text{ K}$ and $N(\text{NH}_3) = 1.8 \times 10^{17} \text{ cm}^{-2}$. The ammonia absorption occurs at a velocity redshifted by about 3.5 km s⁻¹ with respect to the emission. This supports the hypothesis of a remnant infalling molecular core onto the ultracompact HII region.

Accepted by the Astrophysical Journal

A Circumstellar Disk in a Pre-Main Sequence Binary Star

C.D. Koresko

Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA 91125, USA

E-mail contact: koresko@gps.caltech.edu

order

New high-resolution images of HK T Tauri B, the companion to the 10^6 yr old classical T Tauri star HK Tauri A (Cohen & Kuhl 1979; Beckwith et al. 1990) show it to be surrounded by an optically-thick, edge-on circumstellar disk which extends to a radius of at least 50 AU. The images were taken using a modified speckle technique to achieve a linear resolution of 8 AU. The disk is strikingly coherent, showing no evidence of any strong perturbation by the primary star. The disk is illuminated by the central star, and it hides the star from direct view. The small changes in vertical thickness with wavelength require a dust+gas mass $\gtrsim 10^{-3} M_{\odot}$. The relative position angles of the disk and the binary suggest that the disk probably does not lie in the plane of the binary orbit.

Accepted by ApJ Letters

Preprint available at <http://gulliver.gps.caltech.edu>

Relative intensities of semiforbidden lines in UV spectra of T Tauri stars

Sergei Lamzin¹ and Ana Ines Gómez de Castro²

¹ Sternberg Astronomical Institute, Moscow V-234, 119899 Russia

² S.D. Astronomía y Geodesia, Facultad de CC. Matemáticas, Universidad Complutense de Madrid, 28040-Madrid, Spain

E-mail contact: lamzin@sai.msu.ru

Relative intensities of the most strong resonant semiforbidden lines in 1200-2000 Å spectral band were calculated in the frame of the accretion shock model (Lamzin, 1998, Astron. Reports 42, 322). Theoretical spectra are compared in qualitative way with T Tauri stars spectra derived from IUE satellite in low resolution ($\simeq 6$ Å) mode. It follows from our analyses that some semiforbidden lines in addition to well known C III 1909 and Si III 1892 lines can be identified in HST spectra of TTs and used for *quantitative* comparison with predictions of the accretion shock theory.

Accepted by Astronomy Letters v.11, 1998

Preprints available through anonymous ftp: [infml.sai.msu.ru/pub/PEOPLE/lamzin](ftp://infml.sai.msu.ru/pub/PEOPLE/lamzin)

CS Emission from Bok Globules: Survey Results

R. Launhardt^{1,2}, N. J. Evans II³, Y. Wang^{3,4,5}, D. P. Clemens⁶, Th. Henning², and J. L. Yun⁷

¹ Max-Planck-Institut für Radioastronomie, Bonn, Germany

² Astrophysikalisches Institut und Universitäts-Sternwarte, Jena, Germany

³ Astronomy Department, The University of Texas, Austin, TX 78712

⁴ MRAO, University of Cambridge, Cambridge CB3 0HE, UK

⁵ Fidelity Management and Research, Fidelity Investment Systems Co., Irving, TX 75039

⁶ Astronomy Department, Boston University, Boston, MA 02215

⁷ Physics Department, The University of Lisbon, Portugal

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

We present the results of a survey for CS emission toward a sample of 47 Bok globules selected from the catalog of Clemens & Barvainis (1988). The globules were observed at the FCRAO 14 m, the SEST 15 m, and the IRAM 30 m telescopes in the CS J=2→1 transition. Additionally, higher spatial resolution ($11^{prime}prime-30^{prime}prime$) observations in the CS J=3→2 and 5→4 lines, as well as the C³⁴S J=2→1 and 3→2 lines, were carried out toward a subsample of 20 globules using the IRAM 30 m and the CSO 10 m telescopes. Two-thirds of the globules were detected in the CS J=2→1 line. The detection rate was higher in globules with IRAS sources (72%) than in globules without IRAS sources (44%). The detection rate was 100% for globules with embedded Class 0 and Class I infrared sources, dropping to 60% for Class II-D sources and to 40% for Class II sources. These results support the association of dense cores with IRAS point sources in Bok globules and indicate that the dense gas is most apparent in the early stages. We present CS maps of 12 globule cores and derive sizes for 9 CS cores. The results of the CS survey are compared with the results of surveys of other lines and of dust continuum emission. The integrated intensities of the CS lines correlate with those of C¹⁸O J=2→1, but the linewidths and FWHM sizes tend to be somewhat larger than those of C¹⁸O. The mean FWHM size of those sources with reasonable distance estimates is 0.41 ± 0.18 pc and the mean virial

mass is $60 \pm 52 M_{\odot}$. The mean size places them intermediate between cores in Taurus and cores associated with water masers and massive star formation.

Accepted by *Astrophys. J. Suppl. Ser.* (scheduled for Nov. 1998)

FU Orionis resolved by infrared long baseline interferometry at a 2-AU scale

F. Malbet¹, J.-P. Berger¹, M.M. Colavita², C.D. Koresko³, C. Beichman⁴, A.F. Boden², S.R. Kulkarni³, B.F. Lane³, D.W. Mobley², X.P. Pan³, M. Shao², G.T. Van Belle², & J.K. Wallace²

¹ Laboratoire d'Astrophysique, Observatoire de Grenoble, UMR UJF/CNRS 5571, BP 53, F-38041 Grenoble cedex 9, France

² Jet Propulsion Laboratory, California Institute for Technology, Pasadena, CA, USA

³ Palomar Observatory, California Institute for Technology, Pasadena, CA, USA

⁴ Infrared Processing and Analysis Center, California Institute for Technology, Pasadena, CA, USA

E-mail contact: malbet@obs.ujf-grenoble.fr

We present the first infrared interferometric observations of a young stellar object with a spatial projected resolution better than 2 AU. The observations were obtained with the *Palomar Testbed Interferometer*. FU Ori exhibits a visibility of $V^2 = 0.72 \pm 0.07$ for a 103 ± 5 m projected baseline at $\lambda = 2.2 \mu\text{m}$. The data are consistent on the spatial scale probed by PTI both with a binary system scenario (maximum magnitude difference of 2.7 ± 0.5 mag and smallest separation of 0.35 ± 0.05 AU) and a standard luminous accretion disk model ($\dot{M} \sim 6 \times 10^{-5} M_{\odot} \text{ yr}^{-1}$) where the thermal emission dominates the stellar scattering, and inconsistent with a single stellar photosphere.

Accepted by ApJL

Preprint available at <http://xxx.lanl.gov/abs/astro-ph/9808326>

The instability strip for pre-main-sequence stars

Marcella Marconi^{1,2} and Francesco Palla³

¹ Università degli Studi di Firenze, Dipartimento di Astronomia, L.go E. Fermi, 5, 50125 Firenze, Italy

² Osservatorio Astronomico di Capodimonte, Napoli, Italy

³ Osservatorio Astrofisico di Arcetri, Largo E. Fermi 5, 50125 Firenze, Italy

E-mail contact: marcella@cerere.na.astro.it, palla@arcetri.astro.it

We investigate the pulsational properties of Pre-Main-Sequence (PMS) stars by means of linear and nonlinear calculations. The equilibrium models were taken from models evolved from the protostellar birthline to the ZAMS for masses in the range 1 to 4 M_{\odot} . The nonlinear analysis allows us to define the instability strip of PMS stars in the HR diagram. These models are used to constrain the internal structure of young stars and to test evolutionary models. We compare our results with observations of the best case of a pulsating young star, HR 5999, and we also identify possible candidates for pulsational variability among known Herbig Ae/Be stars which are located within or close to the instability strip boundaries.

Accepted by *The Astrophysical Journal (Letters)*

Does “ $\tau \approx 1$ ” terminate the isothermal evolution of collapsing clouds?

H. Masunaga and S. Inutsuka

Division of Theoretical Astrophysics, National Astronomical Observatory, Mitaka, Tokyo 181-8588, Japan

E-mail contact: masunaga@milano.mtk.nao.ac.jp

We examine when gravitationally collapsing clouds terminate their isothermal evolution. According to our previous work, the condition with which isothermality is broken down is classified into three cases, i.e., when, (1) the compressional heating rate overtakes the thermal cooling rate, (2) the optical depth for thermal radiation reaches unity, or (3) the compressional heating rate becomes comparable to the energy transport rate due to radiative diffusion. In the present paper this classification is extended to more general values of the initial cloud temperature T_{init} and opacity κ , and we determine the critical densities with which these conditions are satisfied. For plausible values of T_{init} and

κ , we find that the isothermal evolution ceases when Case (1) or (3) is satisfied, and Case (2) has no significance. We emphasize that the condition of “ $\tau \approx 1$ ” never terminates isothermality but non-isothermal evolutions begin either earlier or later depending on the initial temperature and opacity. This result contrasts with the conventional idea that opaqueness breaks isothermality.

On the basis of the critical density discussed above, the minimum Jeans mass for fragmentation, M_F , is reconsidered. In contrast to the results by previous authors that M_F is insensitive to T_{init} and κ , we find that M_F can be substantially larger than the typical value of $\sim 10^{-2}M_{\odot}$ depending on T_{init} and κ . In particular, M_F increases with decreasing metallicity, $M_F \propto \kappa^{-1}$, for low-metal clouds. A cloud with $\kappa = 10^{-4}\text{cm}^2 \cdot \text{g}^{-1}$ and $T_{\text{init}} = 10\text{K}$ yields $M_F = 3.7M_{\odot}$. Finally, our critical densities would be helpful for hydrodynamic simulations which are intended to simply handle the hardening of the equation of state.

Accepted by the Astrophys. J.

Simultaneous Polarimetry and Photometry of the Young Stellar Object R Mon

M. Matsumura¹, M. Seki² and K. Kawabata^{2,3}

¹ Faculty of Education, Kagawa University, Saiwai-cho 1-1, Takamatsu 760-8522, Japan

² Astronomical Institute, Tohoku University, Sendai 980-8578, Japan

³ National Astronomical Observatory, Mitaka, Tokyo 181-8588, Japan

E-mail contact: matsu@ed.kagawa-u.ac.jp

Linear polarization and flux of the young stellar object R Mon were observed simultaneously at 7 bands in the optical wavelength from 0.36 to 0.76 μm in 1991-1997. During the observational period, the V magnitude of R Mon changed by about 0.7 mag in a diaphragm of $18''$. We have found a strong positive correlation between the degree of linear polarization p and the V magnitude, and that the coefficient of correlation is 0.92 for the data in 1993-1997. The values of p and V in 1991-1992 did not follow this correlation. The colors ($B - V$, $V - R_c$, and $R_c - I_c$) are also found to increase with the V magnitude in the whole observational period. However, in 1991 when the object was in the faintest phase, only the color $U - B$ decreased. These correlations are similar to those observed in other Herbig Ae/Be stars. The position angle θ of the linear polarization also shows significant variation with time, though the correlation between θ and other quantities is weak.

The observed correlations between magnitude, colors, and polarization degree can be explained by the combination of extinction by the clouds orbiting around R Mon and scattering by diffusely surrounding medium, as originally proposed by Grinin (1988) for Herbig Ae/Be stars. Since the time scale of variation is short (≈ 10 days), the orbiting clouds should be in the vicinity, i.e. $\lesssim 10$ AU, of the star. The extinction by those clouds less depends on wavelength than that observed in the diffuse interstellar medium. The size of grains in the clouds may be larger than those in the diffuse interstellar clouds. Our Mie calculations show that the radius of grains may be in the range from 0.08 to 0.50 μm . Alternatively, if the clouds are dense and opaque, 'gray' extinction may occur and explain the observation.

Accepted by Astron. J.

Preprints available through <http://133.92.54.34/matsu/manuscripts/paperE.html>

Herbig-Haro jet in the Haro 6-10 system

T.A. Movsessian and T.Yu. Magakian

Byurakan Astrophysical Observatory, 378433 Aragatsotn reg., Armenia

E-mail contact: tigmov@bao.sci.am; tigmag@sci.am

Results of the integral-field spectroscopy of the young binary Haro 6-10 show the presence of an emission Herbig-Haro jet, superposed on the bright reflection nebula. Length of the jet is only $5''$, its position angle is 195° , radial velocity changes from -30 to -80 km s^{-1} . On the base of these observations and of the existing polarimetric and infrared data the northern (infrared) component of the Haro 6-10 system is suggested as a probable source of the outflow.

Accepted by Astronomy and Astrophysics

A Br γ Probe of Disk Accretion in T Tauri Stars and Embedded Young Stellar Objects

James Muzerolle^{1,2}, Lee Hartmann¹ and Nuria Calvet^{1,3}

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

² also Five College Astronomy Department, University of Massachusetts, Amherst, MA 01003, USA

³ also Centro de Investigaciones de Astronomía, Mérida, Venezuela

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

We report on observations of Pa β and Br γ for a sample of classical T Tauri stars in Taurus, and find a tight correlation between the emission line luminosities and the accretion luminosity as measured from the hot continuum excess. We use the Br γ luminosity correlation to calculate accretion luminosities in highly-reddened young stars with existing line measurements. The distribution of accretion luminosities is similar in Taurus and Ophiuchus Class II sources. For the deeply embedded Class I objects, the accretion luminosities are in general less than the bolometric luminosities, which implies that the disk accretion rates are significantly lower than the envelope infall rates. We find that the central sources of many Class I objects are quite similar to their Class II counterparts.

Accepted by Astron. J.

<http://cfa-www.harvard.edu/cfa/youngstars>

Turbulent Cooling Flows in Molecular Clouds

P. C. Myers¹ and A. Lazarian²

¹ Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge MA 02139, USA

² Princeton University Observatory, Peyton Hall, Princeton, NJ 08544, USA

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

We propose that inward, subsonic flows arise from the local dissipation of turbulent motions in molecular clouds. Such “turbulent cooling flows” may account for recent observations of spatially extended inward motions toward dense cores. These pressure-driven flows may arise from various types of turbulence and dissipation mechanisms. For the example of MHD waves and turbulence damped by ion-neutral friction, sustained cooling flow requires that the outer gas be sufficiently turbulent, that the inner gas have marginal field-neutral coupling, and that this coupling decrease sufficiently rapidly with increasing density. These conditions are most likely met at the transition between outer regions ionized primarily by UV photons and inner regions ionized primarily by cosmic rays. If so, turbulent cooling flows can help form dense cores, with speeds faster than expected for ambipolar diffusion. Such motions could reduce the time needed for dense core formation, and could precede and enhance the motions of star-forming gravitational infall.

Accepted by Astrophysical Journal (Letters).

ROSAT X-ray Detection of a Young Brown Dwarf in the Chamaeleon I Dark Cloud

Ralph Neuhauser¹ and Fernando Comerón²

¹ Max-Planck-Institut für Extraterrestrische Physik, D-85740 Garching, Germany

² European Southern Observatory, D-85748 Garching, Germany

E-mail contact: rne@mpe.mpg.de

Photometry and spectroscopy of the object *Cha H α 1*, located in the Chamaeleon I star-forming cloud, show that it is a $\sim 10^6$ -year-old brown dwarf with spectral type M7.5 to M8 and 0.04 ± 0.01 solar masses. Quiescent x-ray emission was detected in a 36-kilosecond observation with 31.4 ± 7.7 x-ray photons, obtained with the Röntgen Satellite (ROSAT), with 9σ detection significance. This x-ray count rate corresponds to an x-ray luminosity of 2.57×10^{28} ergs per second and an x-ray to bolometric luminosity ratio of $10^{-3.44}$. These are typical values for late M-type stars. Because the interior of brown dwarfs may be similar to that of convective late-type stars, which are well-known x-ray sources, x-ray emission from brown dwarfs may indicate magnetic activity.

Accepted by Science

pre-prints by anonymous ftp from [hpth03.mpe-garching.mpg.de](ftp://hpth03.mpe-garching.mpg.de) in the directory [ftp/pub/zwerge](ftp://pub/zwerge)

CS observations of the hotspot at the S 155/Cepheus B interface

L. Olmi¹ and M. Felli²

¹ LMT Project and FCRAO, University of Massachusetts, 630 L.G.R.C., Amherst, MA 01003, U.S.A.

² Osservatorio Astrofisico di Arcetri, Largo E. Fermi 5, I-50125 Firenze, Italy

E-mail contact: olmi@fcrao1.phast.umass.edu, felli@arcetri.astro.it

We have used the IRAM 30-m telescope to map, in the $J=2-1$, $J=3-2$ and $J=5-4$ rotational transitions of CS, the molecular *hotspot* located south-east of the Cepheus OB3 association, at the interface that divides the S 155 diffuse HII region from the Cepheus B molecular cloud. We have also used the FCRAO 13.7-m telescope to map the larger scale CS(2-1) emission. The $\simeq 1' \times 1'$ segment that has been mapped at higher spatial resolution with the 30-m telescope covers four radio continuum sources, one of which (source A) is a blister-type HII region. By using the CS molecule we analyse: *i*) the molecular density at the interface region and *ii*) the kinematics of the molecular gas at the front. The observations confirm that the blister has created a cavity at the edge of the molecular *hotspot* and is bounded on its sharp side by a dense molecular front in pressure equilibrium with the ionized gas. The near-IR star at the centre of the blister (A-NIR) is responsible for its ionization and for the heating of the *hotspot*.

Accepted by Astron. Astrophys.

Deep near-infrared images and ISOCAM observations of Chamaeleon I

P.Persi¹, A.R.Marenzi¹, A.A.Kaas², G.Olofsson², L.Nordh², and M.Roth³

¹ Istituto Astrofisica Spaziale, Area di Ricerca Roma-Tor Vergata, Via del Fosso del Cavaliere 00133 Roma, Italy

² Stockholm Observatory, S-133 36 Saltsjobaden, Sweden

³ Las Campanas Observatory, Carnegie Inst. of Washington, Casilla 601, La Serena, Chile

E-mail contact: persi@saturn.ias.rm.cnr.it

We present the results of deep near-infrared imaging and ISOCAM observations of three selected regions localized in the northern part of the Chamaeleon I dark cloud, in order to search for the low-luminosity population. In an area of 3×3 square arcmin centered on the bipolar molecular outflow, which is the densest part of the cloud, we have discovered a new Class I source (here named ISOCAM-ChaIN a2) with a spectral index $\alpha=1.9$ and the 1-18 μm luminosity of $0.6 L_{\odot}$ that is most probably responsible for the observed CO outflow.

The comparison between the observed K- magnitude distribution for this region with that obtained for a region outside the outflow and adjacent to the star HD 97300, could indicate the presence of a very low luminosity young stellar population in the densest part of the cloud.

Accepted by Astron. J.

A 3-mode, variable velocity jet model for HH 34

A. Raga¹ and A. Noriega-Crespo²

¹ Instituto de Astronomía, UNAM, Ap. 70-264, 04510 México, D. F., México ² Infrared Processing and Analysis Center, CalTech-JPL, Pasadena, CA 91125, USA

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

Variable ejection velocity jet models can qualitatively explain the appearance of successive working surfaces in Herbig-Haro (HH) jets. This paper presents an attempt to explore which features of the HH 34 jet can indeed be reproduced by such a model. From previously published data on this object, we find evidence for the existence of a 3-mode ejection velocity variability, and then explore the implications of such a variability. From simple, analytic considerations it is possible to show that the longer period modes produce a modulation on the shorter period modes, resulting in the formation of “trains” of multiple knots. The knots observed close to the source of HH 34 could correspond to such a structure. Finally, a numerical simulation with the ejection velocity variability deduced from the HH 34 data is computed. This numerical simulation shows a quite remarkable resemblance with the observed properties of the HH 34 jet.

Accepted by Astron. J.

Excitation and Disruption of a Giant Molecular Cloud by the Supernova Remnant 3C 391

William T. Reach¹ and Jeonghee Rho^{2,3}

¹ Infrared Processing and Analysis Center, California Institute of Technology, Pasadena, CA 91125, USA

² Service d'Astrophysique, CEA, DSM, DAPNIA, Centre d'Etudes de Saclay, F-91191 Gif-sur-Yvette cedex, France

³ postal address: Physics Department, University of California, Santa Barbara, CA, USA

E-mail contact: reach@ipac.caltech.edu

Using the IRAM 30-m telescope, we observed the supernova remnant 3C 391 (G31.9+0.0) and its surroundings in the $^{12}\text{CO}(2 \rightarrow 1)$, $\text{HCO}^+(1 \rightarrow 0)$, $\text{CS}(2 \rightarrow 1)$, $\text{CS}(3 \rightarrow 2)$, and $\text{CS}(5 \rightarrow 4)$ lines. The ambient molecular gas at the distance (9 kpc) of the remnant comprises a giant molecular cloud whose edge is closely parallel to a ridge of bright non-thermal radio continuum, which evidently delineates the blast-wave into the cloud. We found that in a small (0.6 pc) portion of the radio shell, the molecular line profiles consist of a narrow (2 km s^{-1}) component, plus a very wide ($> 20 \text{ km s}^{-1}$) component. Both spectral components peak within $20''$ of a previously-detected OH 1720 MHz maser. We name this source 3C 391:BML (broad molecular line); it provides a new laboratory, similar to IC 443 but on a larger scale, to study shock interactions with dense molecular gas. The wide spectral component is relatively brighter in the higher-excitation lines. We interpret the wide spectral component as post-shock gas, either smoothly accelerated or partially dissociated and reformed behind the shock. The narrow component is either the pre-shock gas or cold gas reformed behind a fully dissociative shock. Using the 3 observed CS lines, we measured the temperature, CS column density, and H_2 volume density in a dense clump in the parent molecular cloud as well as the wide-line and narrow-line portions of the shocked clump. The physical conditions of the narrow-line gas are comparable to the highest-density clumps in the giant molecular cloud, while the wide-line gas is *both* warmer and denser. The mass of compressed gas in 3C 391:BML is high enough that its self-gravity is significant, and eventually it could form one or several stars.

Accepted by Astrophys. J.

Photoevaporation of protostellar disks IV. Externally illuminated disks

Sabine Richling¹ and Harold W. Yorke^{1,2}

¹ Astronomisches Institut der Universität Würzburg, Am Hubland, D-97074 Würzburg, Germany

² MS 169-506, Jet Propulsion Laboratory, Pasadena, CA 91109-8099, U.S.A.

E-mail contact: richling@astro.uni-wuerzburg.de

By means of numerical simulations we investigate the photoevaporation of protostellar disks. Here we concentrate on the evolution of disks under the influence of an external Lyman continuum radiation field. The morphological evolution is illustrated in detail for the case of a relatively massive disk exposed to a modest ionizing flux. Cometary tails develop and break off into filaments which leave the immediate vicinity of the disk with the evaporating flow. It evolves into a relatively undisturbed disk completely enveloped by the ionization front. A low mass star-disk system is used to investigate the dependence of the evolution on the distance from the ionizing source. Distances and external EUV flux are adapted to the situation of the proplyds close to the Trapezium star θ^1 Ori C. The low-mass system becomes extremely deformed through the asymmetrical illumination. The total mass of the disk fragments which break off during the cometary phase ($\sim 2 \times 10^4 \text{ yr}$) is of order 10% of the disk mass. With decreasing distance the densest parts of the disk remnant are more strongly disturbed. The dependence of the final photoevaporation rate on the distance $\dot{M}_{\text{ph}} \propto d^{-1.1}$ is consistent with analytical models.

For comparison with observations we use a 3D ray-tracing procedure to calculate spectra, continuum maps and $\text{H}\alpha$ line profiles. During the cometary phase the elongated tails of the low mass system are recognizable at almost all frequencies ranging from the radio region to the near-infrared. Furthermore, the disk remnants viewed face-on from the direction of the source appear as round heads in $\text{H}\alpha$ resembling this class of proplyds quite well.

Accepted by Astronomy & Astrophysics

Destruction of the Environment of the BN-KL Nebula

Luis Salas¹, Margarita Rosado², Irene Cruz-González², Leonel Gutiérrez¹, Jorge Valdez¹, Abel Bernal², Esteban Luna¹, Elfego Ruiz² and Francisco Lazo¹

¹ Instituto de Astronomía, UNAM, Apdo. Postal 877, Ensenada, B.C. 22830, México

² Instituto de Astronomía, UNAM, Apdo. Postal 70-264, C.U., México, D.F. 04510, México.

E-mail contact: salas@bufadora.astrosen.unam.mx

We describe observations of the 2.12 μm molecular hydrogen emission in Orion, using an IR Fabry-Perot interferometer with a spectral resolution of 24 km/s and a 2'' spatial resolution, covering a region of 3.6' \times 3.6' (0.46 \times 0.46 pc²) that contains the H₂ filamentary finger system located to the northwest of the Trapezium. We develop a simple model to explain the observed low velocity structure as described by its radial moments: intensity, velocity centroid, velocity dispersion and skewness. We assume a strong wind of 230 km/s produced by IRc2 interacting with a set of molecular clumps with density of $5.6 \times 10^5 \text{ cm}^{-3}$. This simple model provides a good match to the observed moments, gives clues to the development of filaments or fingers and entrainment of the molecular material, and associates the observed high velocity blueshifted emission to the region. The driving source of the wind requires a high mass loss rate and thus is likely IRc2. The H₂ line emission is produced by a slow J-shock (20 km/s) in the clumps with an emissivity proportional to $v^{1.8}$. Estimates for the total wind mass and clumps mass yield 0.5 M_{\odot} and 15 M_{\odot} inside a radius of 1' (0.1 pc). The individual clumps have masses and sizes of few $\times 10^{-3} M_{\odot}$ and 0.007 pc, respectively. We conclude that the central 0.1 pc region surrounding the BN-KL nebula in front of OMC-1 is in the process of being disrupted by the strong wind of IRc2 on a timescale of 2000 yr.

Accepted by Astrophysical Journal.

Kinematics of the HH 43 Flow: Evidence for a Precessing Jet?

R.D. Schwartz¹ and T.P. Greene²

¹ Dept. of Physics and Astronomy, U. of Missouri-St. Louis, 8001 Natural Bridge Road, St. Louis, MO 63121, USA

² 477 Victory Avenue, Mountain View, CA 94043, USA

E-mail contact: schwartz@newton.umsl.edu

High spectral resolution long-slit spectra of HH 43 obtained in the 1-0 S(1) line of H₂ are reported. A direct image of HH 43 obtained in the 1-0 S(1) line reveals a close correspondence with knots as seen in optical [S II] and H α emission. We suggest that ambient molecular gas is being entrained and shocked by an atomic flow. The position-velocity diagram along the central axis of HH 43 as seen in H₂ reveals a sinusoidal-like structure with a semi-amplitude of 8 km s⁻¹ and a spatial wavelength of about 8000 A.U. A direct H α image of HH 43 shows evidence for a morphological wiggle with a semi-amplitude of about 2'' and which has the same spatial wavelength and phase seen in the 8 km s⁻¹ kinematic oscillation. These data suggest that HH 43 may be produced by a precessing jet in a close pre-main sequence binary system. Possible system parameters are explored.

Accepted by Astron. J.

Preprint available through <http://newton.umsl.edu/~schwartz/>

A ring of organic molecules around HD 97300

R. Siebenmorgen¹, A. Natta², E. Krügel³, T. Prusti¹

¹ ISO Science Operations Centre, Astrophysics Division of ESA, Villafranca del Castillo, P.O. Box 50727, E-28080 Madrid, Spain

² Osservatorio Astrofisico di Arcetri, Largo E. Fermi 5, I-50125 Firenze, Italy

³ MPIfR, Auf dem Hügel, D-5300 Bonn, Germany

E-mail contact: rsiebenm@iso.vilspa.esa.es

This paper presents spectro-photometric images of the pre-main-sequence Herbig AeBe star HD 97300 in the mid-IR obtained with ISOCAM on board of ISO. The images show extended emission, an elliptical ring structure of size about 0.045 \times 0.03 pc as well as two peaks of emission, separated by about 3'' (240 AU). One of the two peaks coincides with the position of HD 97300, while the other may be an embedded companion. The data show that the emission in this

region is dominated by the infrared emission bands centered at 6.2, 7.7, 8.7, 11.3 and 12.5 μm , with a very small contribution from continuum emission at longer wavelengths. We fit the spectra with a dust model including organic molecules such as polycyclic aromatic hydrocarbons, very small graphite and very small silicates, as well as large grains. The fit to the ISOCAM data is very good if one applies a classical oscillator model for the infrared emission bands. Our fitting procedure allows us to estimate the total mass of the ring, which is $\sim 0.03M_{\odot}$. Its possible origin is briefly discussed.

Accepted by Astronomy & Astrophysics

Preprint available at: <http://isowww.estec.esa.nl/science/publications.html>

Magnetic Accretion and Photopolarimetric Variability in Classical T Tauri Stars

Keivan Stassun¹ and Kenneth Wood²

¹ Astronomy Dept., Univ. Wisconsin, 475 N. Charter St., Madison, WI 53706, USA

² Smithsonian Astrophysical Observatory, 60 Garden St., Cambridge, MA 02138, USA

E-mail contact: keivan@astro.wisc.edu, kenny@claymore.harvard.edu

We employ a Monte Carlo radiation transfer code to investigate the multi-wavelength photopolarimetric variability arising from a spotted T Tauri star surrounded by a dusty circumstellar disk. Our aim is to assess the ability of the magnetic accretion model to explain the observed photopolarimetric variability of classical T Tauri stars, and to identify potentially useful observational diagnostics of T Tauri star/disk/spot parameters. We model a range of spot sizes, spot latitudes, inner disk truncation radii, and system inclination angles, as well as multiple disk and spot geometries. We find that the amplitude, morphology, and wavelength dependence of the photopolarimetric variability predicted by our models are generally consistent with existing observations; a flared disk geometry is required to reproduce the largest observed polarization levels and variations. Our models can further explain stochastic polarimetric variability if unsteady accretion is invoked, in which case irregular — but correlated — photometric variability is predicted, in agreement with observations.

We find that variability in percent polarization is by itself an unreliable diagnostic as certain system geometries do not produce any variability in linear polarization (contrary to the commonly held notion that hot spots will necessarily produce periodic polarimetric variability). Observations of variability in polarization position angle, however, could provide useful constraints on system inclination. The observation of wavelength-dependent polarization position angles, attributed by some to interstellar effects, is naturally explained by our models. Certain system geometries yield peculiar photometric light curve morphologies, the observation of which could also serve to constrain system inclination. We do not find useful diagnostics of disk truncation radius, nor do we find significant differences when we model the spots as rings.

We also investigate the reliability of modeling spot parameters via analytic fits to multi-band photometric variations. We find that commonly used analytic models consistently recover input model parameters but that inferred spot temperatures are more sensitive to uncertainties in the photometric data than previous modeling would suggest.

Accepted by ApJ (1999, 510)

Preprints: <http://xxx.lanl.gov/abs/astro-ph/9808267/>

A Candidate Protoplanet in the Taurus Star Forming Region

S. Terebey¹, D. Van Buren², D. L. Padgett², T. Hancock¹, and M. Brundage²

¹ Extrasolar Research Corporation, 569 S. Marengo Ave., Pasadena, CA 91101, USA

² Jet Propulsion Laboratory, IPAC 100-22, Caltech, Pasadena CA 91125, USA

E-mail contact: terebey@extrasolar.com

HST/NICMOS images of the class I protostar TMR-1 (IRAS04361+2547) reveal a faint companion with $10.0'' = 1400$ AU projected separation. The central protostar is itself resolved as a close binary with $0.31'' = 42$ AU separation, surrounded by circumstellar reflection nebulosity. A long narrow filament seems to connect the protobinary to the faint companion TMR-1C, suggesting a physical association. If the sources are physically related then we hypothesize that TMR-1C has been ejected by the protobinary. If TMR-1C has the same age and distance as the protobinary

then current models indicate its flux is consistent with a young giant planet of several Jovian masses.

Accepted by ApJL

<http://xxx.lanl.gov/abs/astro-ph/9808302>

<http://www.extrasolar.com>

Star formation in clusters: a survey of compact mm-wave sources in the Serpens core

Leonardo Testi and Anneila I. Sargent

Division of Physics, Matematics and Astronomy, California Institute of Technology, MS 105-24, Pasadena, CA 91125, USA

E-mail contact: lt@astro.caltech.edu, afs@astro.caltech.edu

We report the results of a millimeter interferometric survey of compact 3 mm continuum sources in the inner $5.5' \times 5.5'$ region of the Serpens core. We detect 32 discrete sources above 4.0 mJy/beam, 21 of which are new detections at millimeter wavelengths. By comparing our data with published infrared surveys, we estimate that 26 sources are probably protostellar condensations and derive their mass assuming optically thin thermal emission from dust grains. The mass spectrum of the clumps, $dN/dM \sim M^{-2.1}$, is consistent with the stellar initial mass function, supporting the idea that the stellar masses in young clusters are determined by the fragmentation of turbulent cloud cores.

Accepted by The Astrophysical Journal Letters

<http://astro.caltech.edu/~lt/preprints/preprints.html>

High-Resolution Imaging of NH₃ Inversion Lines toward W3 Main

A.R.Tieftrunk¹, R.A.Gaume² and T.L.Wilson^{3,4}

¹ ESO, Casilla 19001, Santiago 19, Chile

² US Naval Observatory, 3450 Massachusetts Avenue NW, Washington, DC 20392-5420, USA

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

⁴ SMTO, Steward Observatory, The University of Arizona, Tucson, AZ 85721, USA

E-mail contact: atieftru@eso.org

Three-arcsecond angular resolution (0.03 pc at 2.3 kpc) images of the (J,K) = (1,1) and (2,2) NH₃ inversion lines toward W3 Main are presented. These observations show NH₃ emission from individual clumps and filaments embedded in the lower density ammonia gas, previously observed with a spatial resolution of 40". Toward the molecular core W3 East we detect NH₃ emission with broad line profiles from a very compact (FWHM $\approx 5''$) and dense clump toward IRS 5 and weaker emission from compact clumps near IRS 11. The molecular clump toward IRS 5 is associated with a cluster of young low-mass stars and hypercompact H II regions tracing recent high-mass star formation. Toward the molecular core W3 West, which is luminous in the submillimetre but has no embedded H II continuum or NIR sources, we detect NH₃ emission with narrow line profiles from a more extended ($\approx 25''$) and clumpy region. A thin NH₃ filament, less than 8" wide, stretches more than 40" away from IRS 4, northeast of W3 West, curving around the compact H II region W3 H. Toward the ultracompact H II region W3 B we find ammonia in absorption. The VLA data presented here are in support of models which suggest that star formation seems to be occurring in bursts toward the W3 GMC. Extended NH₃ emission is detected only toward a quiescent core with no associated star formation. In comparison, toward the active star-forming cores the NH₃ is dispersed and underabundant. In the lower density gas surrounding these dense cores, the expanding H II regions appear to sweep up the remnant ammonia gas into thin filaments.

Accepted by Astron. & Astrophys.

Spectroscopy of Brown Dwarf Candidates in the ρ Ophiuchi Molecular Core

Bruce A. Wilking¹, Thomas P. Greene², and Michael R. Meyer³

¹ Dept. of Physics & Astronomy, Univ. of Missouri-St. Louis, 8001 Natural Bridge Road, St. Louis, MO 63121, USA

² Lockheed Martin Missiles & Space, 3251 Hanover St., Palo Alto, CA 94304-1191, USA

³ Steward Observatory, University of Arizona, Tucson, AZ 85721, USA

E-mail contact: brucew@newton.umsl.edu

We present an analysis of low resolution infrared spectra for 20 brown dwarf candidates in the core of the ρ Ophiuchi molecular cloud. Fifteen of the sources display absorption-line spectra characteristic of late-type stars. By comparing the depths of water vapor absorption bands in our candidate objects with a grid of M dwarf standards, we derive spectral types which are independent of reddening. Optical spectroscopy of one brown dwarf candidate confirms the spectral type derived from the water bands. Combining their spectral types with published near-infrared photometry, effective temperatures and bolometric stellar luminosities are derived enabling us to place our sample on the Hertzsprung-Russell diagram. We compare the positions of the brown dwarf candidates in this diagram with two sets of theoretical models in order to estimate their masses and ages. Considering uncertainties in placing the candidates in the H-R diagram, six objects consistently lie in the brown dwarf regime and another five objects lie in the transition region between stellar and substellar objects. The ages inferred for the sample are consistent with those derived for higher mass association members. Three of the newly identified brown dwarfs display infrared excesses at $\lambda=2.2 \mu\text{m}$ suggesting that young brown dwarfs can have active accretion disks. Comparing our mass estimates of the brown dwarf candidates with those derived from photometric data alone suggests that spectroscopy is an essential component of investigations of the mass functions of young clusters.

Accepted by the Astronomical Journal

Preprint available on the WWW at <http://newton.umsl.edu/~brucew>

ASCA Observations of the Chamaeleon II Dark Cloud

Shigeo Yamauchi¹, Kenji Hamaguchi², Katsuji Koyama^{2,3}, and Hiroshi Murakami²

¹ Faculty of Humanities and Social Sciences, Iwate University, 3-18-34, Ueda, Morioka, Iwate 020-8550, Japan

² Department of Physics, Graduate School of Science, Kyoto University, Sakyo-ku, Kyoto 606-8502, Japan

³ CREST: Japan Science and Technology Corporation (JST), 4-1-8 Honmachi, Kawaguchi, Saitama 332-0012, Japan

E-mail contact: yamauchi@hiryu.hss.iwate-u.ac.jp

ASCA results of 8 X-ray sources in the Chamaeleon II dark cloud are presented. Six sources were identified as low-mass young stellar objects, either Class II–III sources or T Tauri stars with X-ray temperatures and luminosities in the range of 0.8–3 keV and $10^{29.9}$ – $10^{31.1}$ erg s⁻¹, respectively. Two of them showed time variability: one with typical flare profile and the other with a light curve showing fast-rise and gradual decay. These variable sources exhibited a higher temperature than did those of the other sources with less time variability. We found a high-temperature, time-variable, and moderately absorbed X-ray source which has no cataloged counterpart at any other wavelength. We also found hard X-rays at the position of a Herbig Ae candidate with an extremely large N_{H} of 2×10^{23} H cm⁻², one order of magnitude higher than that estimated from the optical extinction. The origin of the X-rays, including these two sources, are discussed.

Accepted by Publ. Astron. Soc. Japan

A Hipparcos Census of the Nearby OB Associations

P.T. de Zeeuw¹, R. Hoogerwerf¹, J.H.J. de Bruijne¹, A.G.A. Brown² and A. Blaauw^{3,1}

¹ Sterrewacht Leiden, Postbus 9513, 2300 RA Leiden, The Netherlands

² Instituto de Astronomía U.N.A.M., Apartado Postal 877, Ensenada, 22800 Baja California, México

³ Kapteyn Instituut, Postbus 800, 9700 AV Groningen, The Netherlands

E-mail contact: debuyne@strw.leidenuniv.nl, hoogerw@strw.leidenuniv.nl

A comprehensive census of the stellar content of the OB associations within 1 kpc from the Sun is presented, based on Hipparcos positions, proper motions, and parallaxes. It is a key part of a long-term project to study the formation, structure, and evolution of nearby young stellar groups and related star-forming regions.

OB associations are unbound ‘moving groups’, which can be detected kinematically because of their small internal velocity dispersion. The nearby associations have a large extent on the sky, which traditionally has limited astrometric membership determination to bright stars ($V \lesssim 6^{\text{m}}$), with spectral types earlier than $\sim B5$. The Hipparcos

measurements allow a major improvement in this situation. Moving groups are identified in the Hipparcos Catalogue by combining de Bruijne's refurbished convergent point method with the 'Spaghetti method' of Hoogerwerf & Aguilar. Astrometric members are listed for 12 young stellar groups, out to a distance of ~ 650 pc. These are the 3 subgroups Upper Scorpius, Upper Centaurus Lupus and Lower Centaurus Crux of Sco OB2, as well as Vel OB2, Tr 10, Col 121, Per OB2, α Persei (Per OB3), Cas-Tau, Lac OB1, Cep OB2, and a new group in Cepheus, designated as Cep OB6. The selection procedure corrects the list of previously known astrometric and photometric B- and A-type members in these groups, and identifies many new members, including a significant number of F stars, as well as evolved stars, e.g., the Wolf-Rayet stars γ^2 Vel (WR11) in Vel OB2 and EZ CMa (WR6) in Col 121, and the classical Cepheid δ Cep in Cep OB6. Membership probabilities are given for all selected stars. Monte Carlo simulations are used to estimate the expected number of interloper field stars. In the nearest associations, notably in Sco OB2, the later-type members include T Tauri objects and other stars in the final pre-main sequence phase. This provides a firm link between the classical high-mass stellar content and ongoing low-mass star formation. Detailed studies of these 12 groups, and their relation to the surrounding interstellar medium, will be presented elsewhere.

Astrometric evidence for moving groups in the fields of R CrA, CMa OB1, Mon OB1, Ori OB1, Cam OB1, Cep OB3, Cep OB4, Cyg OB4, Cyg OB7, and Sct OB2, is inconclusive. OB associations do exist in many of these regions, but they are either at distances beyond ~ 500 pc where the Hipparcos parallaxes are of limited use, or they have unfavorable kinematics, so that the group proper motion does not distinguish it from the field stars in the Galactic disk.

The mean distances of the well-established groups are systematically smaller than the pre-Hipparcos photometric estimates. While part of this may be caused by the improved membership lists, a recalibration of the upper main sequence in the Hertzsprung-Russell diagram may be called for. The mean motions display a systematic pattern, which is discussed in relation to the Gould Belt.

Six of the 12 detected moving groups do not appear in the classical list of nearby OB associations. This is sometimes caused by the absence of O stars, but in other cases a previously known open cluster turns out to be (part of) an extended OB association. The number of unbound young stellar groups in the Solar neighbourhood may be significantly larger than thought previously.

Accepted by *Astronomical Journal*, January 1999 issue

The Star Formation Newsletter is a vehicle for fast distribution of information of interest for astronomers working on star formation and molecular clouds. You can submit material for the following sections: *Abstracts of recently accepted papers* (only for papers sent to refereed journals, not reviews nor conference notes), *Dissertation Abstracts* (presenting abstracts of new Ph.D dissertations), *Meetings* (announcing meetings broadly of interest to the star formation and interstellar medium community), *New Books* (giving details of books relevant for the same community), *New Jobs* (advertising jobs specifically aimed towards persons within our specialty), and *Short Announcements* (where you can inform or request information from the community).

Latex macros for submitting abstracts and dissertation abstracts are appended to each issue of the newsletter.

The Star Formation Newsletter is available on the World Wide Web, where you can access it via the ESO Portal (<http://http.hq.eso.org/eso-homepage.html>). You can also access it through the University of Massachusetts Astronomy World Wide Web server, the URL for its home page is <http://www-astro.phast.umass.edu/>

Dissertation Abstracts

Near Infrared Hydrogen Lines as Diagnostic of Accretion and Winds in Young Stellar Objects

Daniel F. M. Folha

Thesis work conducted at: Queen Mary & Westfield College, University of London, UK

Current address: Centro de Astrofísica da Universidade do Porto, Rua das Estrelas, s/n, 4150 Porto, Portugal

Electronic mail: dfmf@astro.up.pt

Ph.D dissertation directed by: J. P. Emerson

Ph.D degree awarded: August 1998

The magnetospheric accretion model for T Tauri stars provides a possible answer for the long standing problem in low mass star formation of how angular momentum is shed in order to keep the rotational velocities as low as observed despite accreting matter from a quasi-Keplerian accretion disk. Given its importance for a better understanding of T Tauri stars the model should be thoroughly tested observationally. The work presented in this Thesis tests some aspects of the magnetospheric accretion model by using high spectral resolution observations of near infrared hydrogen lines. The presence of winds in T Tauri stars and their possible influence on the line profiles of near infrared hydrogen lines is also investigated. These lines are optically thinner than the more commonly studied Balmer lines and may give better indications of accretion.

A sample of 50 T Tauri stars, mostly from the Taurus-Auriga complex, was chosen. $\text{Pa}\beta$ line profiles were obtained for 49 of these stars and $\text{Br}\gamma$ profiles for 37 of the stars in the sample. Emission at $\text{Pa}\beta$ was observed for 41 stars and emission at $\text{Br}\gamma$ was found for 30 stars. The most conspicuous features in the line profiles is the almost complete absence of blueshifted absorption components and the high frequency of inverse P Cygni profiles (IPC). At $\text{Pa}\beta$, 34% of the profiles are IPC while at $\text{Br}\gamma$ 20% are IPC. The redshifted absorption features indicate infall at velocities of about 200 km s^{-1} , compatible with free fall from a few radii out as expected in a magnetospheric accretion picture. In general, line profiles are broad centrally peaked with slightly blueshifted line peaks. These observations are consistent with the $\text{Pa}\beta$ and $\text{Br}\gamma$ lines forming predominantly in infalling material. Radiative transfer calculations of the $\text{Pa}\beta$ and $\text{Br}\gamma$ line profiles in a very simplified spherically symmetric situation are discussed and the results compared with the observations.

The identification of photospheric lines in the observed spectra allows the computation of the veiling at J for 75% of the observed stars and at K for 70% of the stars. Average values are $\langle r_J \rangle = 0.56$ and $\langle r_K \rangle = 1.31$. In the remaining 25% of the stars at J and 30% of stars at K no photospheric lines were identified, i.e. they were observed to be 'continuum' stars in the observed wavelengths regions. The implications of these results are discussed.

Thesis available through <http://astro.up.pt/users/dfmf/Thesis/thesis.html>

Fragmentation of Molecular Clouds: The Initial Phases of a Stellar Cluster

Ralf S. Klessen

Thesis work conducted at: Max-Planck-Institut für Astronomie, Heidelberg, Germany

Current address: Sterrewacht Leiden, Postbus 9513, 2300 RA Leiden, The Netherlands

Electronic mail: klessen@strw.leidenuniv.nl

Ph.D dissertation directed by: Andreas Burkert

Ph.D degree awarded: June 1998

Using smoothed particle hydrodynamics in combination with the special-purpose hardware device GRAPE, we numerically investigate the initial phases of the star-formation process. We follow the dynamical evolution and fragmentation of large regions within molecular clouds to form a cluster of protostellar cores. Adopting an isothermal description of self-gravitating gas, we show that even this simple model is able to explain many of the observed features of star-forming regions and identify the processes that dominate the formation and evolution of protostellar cores. The number of protostellar cores that form during the evolution is roughly proportional to the number of Jeans masses contained in the system initially. The overall dynamical behavior of the system is insensitive to the adopted initial conditions, since it evolves through a sequence of highly probabilistic events.

The interplay between self-gravity and gas pressure creates a complex network of clumps, sheets and filaments, and the subsequent evolution leads to the formation of a bound cluster of protostellar cores. These grow in mass via accretion from the available gas reservoir and are subject to highly unpredictable N -body interactions. The spatial and dynamical properties of the protostellar cluster are remarkably similar to the properties of observed young stellar clusters. Furthermore, we find that the angular momenta of protostellar cores are correlated with their location. The mass spectrum of gas clumps can be well approximated by a power-law distribution $dN/dM \propto M^{-1.5}$, comparable to observed molecular clouds. In contrast, the mass spectrum of protostellar cores is best described by a log-normal distribution which peaks roughly at the overall Jeans mass of the system. With the appropriate scaling, this is in excellent agreement with the IMF for multiple stellar systems and suggests a star-formation efficiency which ranges from 5 – 15 %.