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Abstracts of recently accepted papers

Discovery of a subarcsec radio binary associated with the SVS13 star in the HH 7-11 region

Guillem Anglada[1], Luis F. Rodríguez[2], José M. Torrelles[3]

[1] Instituto de Astrofísica de Andalucía, CSIC, Camino Bajo de Huétor 24, E-18008 Granada, Spain
[2] Instituto de Astronomía, UNAM, Apdo. Postal 72-3 (Xangari), 58089 Morelia, Michoacán, Mexico
[3] Institut d'Estudis Espacials de Catalunya (IEEC/CSIC) and Instituto de Ciencias del Espacio (CSIC), Edifici Nexus, c/ Gran Capità 2-4, E-08034 Barcelona, Spain
E-mail contact: guillem@iaa.es

We report the discovery of a double radio continuum source (VLA 4A and 4B) associated with the optically visible star SVS13. The two components of the radio source are separated by $0''.3$, corresponding to a projected separation of 65 AU for a distance of 220 pc. We propose that the radio sources trace the components of a binary system. The observed separation implies a lower limit of $\sim$135 yr for the orbital period, for a binary system with a total mass of 2 $M_\odot$. We suggest that, as it is known to occur in other pre-main sequence binaries, the two components of the system could be in different evolutionary stages and/or suffer from different extinction, with the more extincted object being associated with the previously reported mm source, while the other component would correspond to the visible star SVS 13. Since an increase in the optical/near-infrared brightness of the SVS 13 star was observed around 1990, we speculate that such flux variations could be due to the reappearance of the optical component previously occulted by the circumstellar envelope/disk of dust associated with the mm component. The observed separation implies a radius of $\sim$60 AU for the presumed dust envelope, and suggests an orbital period of $\sim$1700 yr and a duration of the occultation of $\sim$185 yr. We expect that other subarcsec binary systems, that remain unresolved, could present an anomalous behavior that may be explained assuming the presence of a binary system whose components are in different evolutive stages, and/or suffer from different extinction.

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Preprint available at http://www.iaa.es/sg/preprints/index.html
http://www.astrosmo.unam.mx/~l.rodriguez/svs13preprint.ps.gz

Irradiated Herbig-Haro Jets in the Orion Nebula and Near NGC 1333

John Bally & Bo Reipurth

Department of Astrophysical and Planetary Sciences and Center for Astrophysics and Space Astronomy, University of Colorado, Campus Box 389, Boulder, CO 80309-0389, USA

E-mail contact: bally@casa.colorado.edu

We report the discovery of a dozen Herbig-Haro jets illuminated by the Lyman continuum ($\lambda < 912$Å) and/or softer far-ultraviolet (912Å $< \lambda <$ 2000Å) radiation fields of nearby high mass stars. Five irradiated outflows lie in the outer parts of the Orion Nebula (HH 502 through HH 506) and seven lie near the reflection nebula NGC 1333 in the Perseus molecular cloud (HH 333 through HH 336, and HH 497 through HH 499). These stellar outflows are powered by optically visible low mass young stars which suffer relatively low extinction and seem not to be embedded within opaque cloud cores. We propose that the UV radiation field has eroded residual material left over from their formation on a time-scale short compared to the ages of these star forming regions. Many of the irradiated jets exhibit unusual C-shaped symmetry. In the outskirts of the Orion Nebula, most irradiated jets appear to bend away from the core of the nebula. On the other hand, in NGC 1333, the C-shaped jets tend to bend back towards the cluster center. Jet bending in the Orion Nebula may be dominated by either the outflow of material from the nebular core or by the rocket effect pushing on the irradiated portion of a mostly neutral jet beam. But in NGC 1333, jet bending may indicate that the source stars have been ejected from the cluster core. Many irradiated jets are asymmetric with one beam much brighter than the other. When fully photo-ionized, irradiated jets may provide unique insights into the physical conditions within outflows powered by young stars, permitting the determination of the density and location of stellar ejecta even in the absence of shocks. We present a model for the photo-ionization of these outflows by external radiation fields and discuss possible mechanisms for producing the observed asymmetries. In particular, we demonstrate that the UV radiation field may alter the amount of cloud material entrained by the jet. Radiation induced variations in mass loading and beam heating can produce differences in the beam velocities and spreading rates, which in turn determine the surface brightness of the radiating plasma. In a bipolar irradiated jet in which both beams have the same mass loss rate and opening angle, the *slower* beam will appear brighter at a given distance from the source. On the other hand, if both beams spread orthogonal to the jet propagation direction with the same speed (e.g. both beams have the same internal sound speed or shocks with similar physical conditions), the *faster* beam will appear brighter at the same distance from the source. Thus, depending on the parameters, either the faster or slower beam of a jet can be brighter. Finally, we report the discovery of some large scale bow shocks which face the core of the Orion Nebula and which surround visible young stars. These wind-wind collision fronts provide further evidence for a large scale mass flow originating near the nebular core.

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Magnetic Fields and the Triaxiality of Molecular Cloud Cores

Shantanu Basu

Department of Physics and Astronomy, University of Western Ontario, London, Ontario N6A 3K7, Canada

E-mail contact: basu@astro.uwo.ca

We make the hypothesis that molecular cloud fragments are triaxial bodies with a large scale magnetic field oriented along the short axis. While consistent with theoretical expectations, this idea is supported by magnetic field strength data, which show strong evidence for flattening along the direction of the mean magnetic field. It is also consistent with early submillimeter polarization data, which show that the projected direction of the magnetic field is often slightly misaligned with the projected minor axis of a molecular cloud core, i.e., the offset angle Ψ is nonzero. We calculate distributions of Ψ for various triaxial bodies, when viewed from a random set of viewing angles. The highest viewing probability always corresponds to $\Psi = 0^\circ$, but there is a finite probability of viewing all nonzero Ψ, including even $\Psi = 90^\circ$; the average offset typically falls in the range $10^\circ - 30^\circ$ for triaxial bodies most likely to satisfy observational and theoretical constraints.

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Preprint available at http://www.astro.uwo.ca/~basu/pub.html

Variability of Southern T Tauri Stars I: The Continuum and the Hβ Inverse PCygni Profile of GQ LUPI

C. Batalha[1], D. F. Lopes[1] and N. M. Batalha [1,2]

[1] Observatório Nacional/CNPq, Rua General José Cristino, 77, Rio de Janeiro, RJ 20920-400, Brazil
[2] NASA Ames Research Center, Moffett Field, CA 94035-1000, USA
E-mail contact: celso@on.br

We present time series spectrophotometric observations of GQ Lupi, a typical representative of the YY Ori subgroup of T Tauri stars that show conspicuous inverse PCygni profiles. The data set consists of 32 exposures taken over 5 and 8 consecutive nights of May and July 1998, respectively, and covers the spectral range of 3100 Å $< \lambda <$ 5100 Å. The region redward and next to the Balmer jump varies significantly on a night–to–night basis and the amplitude of such variability decreases sharply at $\lambda >$ 4600 Å . The Balmer continuum slope indicates that the spectral energy distribution is governed by a gas of temperature greater than that of the stellar photosphere. The variability of the Balmer continuum flux has the largest amplitude. Flux increases in the B band are accompanied by concurrent flux increases in the U band. The contrary is not always verified.

The excess of continuum emission (veiling) for each exposure is computed throughout the spectral format. We find a tight anticorrelation between the veiling and the observed Balmer jump. We report the largest inverse PCygni profile ever observed at this resolution: the depth of the Hβ absorption component is nearly twice the height of the peak emission. Surprisingly, this absorption vanishes a few nights later. The time series of the redward absorption component behaves similarly to the veiling time series: the progressive weakening of the redward absorption is closely followed by a similar weakening of the excess continuum emission. If the absorption component is de–veiled, the correlation strengthens. Thus, large/small redward absorption = large/small veiling = small/large Balmer jump.

We model the emitting region by a gas of uniform temperature and density: each of the 32 exposures acting as a snapshot of such a region for a given stellar rotational phase. We explore models of temperature greater than 5000 K and number of hydrogen atoms (N_H) larger than 10^{13} cm^{-3}, extending the gas spectral energy distribution up to the blackbody of a given temperature. The resulting models indicate that the gas densities and the respective temperatures are strongly anticorrelated. In addition, the model time series show that the increase in the gas density is mirrored by an increase of the projected emitting area (filling factor). Large/small gas densities and filling factors are characterized by high/low observed veiling. As the accretion rate fades from night-to-night, the observed veiling decreases, as does the gas density and the total projected emitting area.

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CO mapping and multi-line-analysis of Cepheus B

H. Beuther[1,2], C. Kramer[2], B. Deiss[2,3] and J. Stutzki[2]

[1] Max-Planck-Institut für Radioastronomie, Auf dem Hügel 69, 53121 Bonn, Germany
[2] I. Physikalisches Institut der Univ. zu Köln, Zülpicher Str. 77, 50937 Köln, Germany
[3] Physikalischer Verein, Robert Mayer Str.2-4, 60054 Frankfurt am Main, Germany

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

We present large scale (approx. 15×15 arcmin) on-the-fly maps of the Cepheus B molecular cloud in the J=3–2 and 2–1 transitions of ^{12}CO, ^{13}CO and C^{18}O obtained with the KOSMA 3m-telescope. We use these maps to study the spatial variation of the excitation conditions of the molecular gas. Additional CI observations allow to refine our analysis.

The gas temperature is dominated by UV radiation from identified adjacent and embedded sources plus additional heating by a hot core in the north-west of the cloud. A spherical clump PDR model allows to reproduce the observed line ratios at most positions. Only ^{12}CO line ratios at the hot core position are inconsistent with this scenario and hence give evidence for additional heating mechanisms. Local volume densities are $\sim 2 \cdot 10^4$ cm^{-3} while the average volume density of Cepheus B is less than 10^3 cm^{-3}; thus, Cepheus B is highly clumped and the volume of these clumps fills only 2% to 4% of the whole cloud. Deep penetration of FUV radiation into the clumpy medium is consistent with the detection of [CI] emission from within the cloud. Abundance ratios of atomic carbon to CO are ≥ 0.2.

The ^{13}CO/C^{18}O integrated line intensity ratio rises significantly above the isotopic element ratio at the cloud edges where C^{18}O intensities are low. Possible explanations for this common observation in terms of fractionation and selective photodissociation on clump surfaces in a clumpy cloud are discussed.

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Preprint available at http://www.mpifr-bonn.mpg.de/staff/beuther/

On the occurrence of the 6.7 GHz CH_3OH maser emission in UCH II regions

C. Codella[1,2], and L. Moscadelli[3]

[1] Istituto di Fisica dello Spazio Interplanetario, CNR, Area di Ricerca Tor Vergata, Via Fosso del Cavaliere 100, 00133 Roma, Italy
[2] Observatorio Astronómico Nacional (IGN), Apartado 1143, E-28800, Alcalá de Henares (Madrid), Spain
[3] Stazione Astronomica di Cagliari, Loc. Poggio dei Pini, 09012 Capoterra (Cagliari), Italy

E-mail contact: codella@ifsi.rm.cnr.it

We present the results of a statistical survey of the 6.7 GHz CH_3OH and 22.2 GHz H_2O emissions towards a large homogeneous sample of ultracompact (UC) H II regions, performed to investigate the nature of the methanol emission:

does it point out ionized regions or does it trace earlier stages of the star forming process?

The present detection rates are almost identical: 23% for CH_3OH and 22% for H_2O. Even considered the uncertainties of the survey, the large number of non-detections is consistent with the scenario where methanol masers disappear during the UC phase, like water masers do. Moreover, the probability to have the CH_3OH counterpart of a H_2O source is at least 40%, indicating that these maser emissions are emphasizing two at least partly overlapping evolutionary phases. The comparison between the velocity ranges suggests that methanol and water masers form in different gas components related to the star forming process.

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A Lyα Bright Jet From A Herbig Ae Star

David Devine[1], C.A. Grady[1], R.A. Kimble, B. Woodgate[2], F.C. Bruhweiler, A. Boggess[3], J.L. Linsky[4] & M. Clampin[5]

[1] Goddard Space Flight Center, Code 681, Greenbelt, MD 20770, USA
[2] Laboratory for Astronomy and Solar Physics, Code 681, NASA Goddard Space Flight Center, Greenbelt, MD 20770, USA
[3] Institute for Astrophysics and Computational Sciences, The Catholic University of America, 20064, USA
[4] JILA, University of Colorado, Campus Box 389, Boulder, CO 80309, USA
[5] Space Telescope Science Institute, 3700 San Martin Dr., Baltimore, MD 21218, USA

E-mail contact: devine@gsfc.nasa.gov

We report the detection in Lyα of a collimated, bipolar outflow (HH 409) associated with the 1.5-10 Myr old Herbig Ae star HD 163296. A blue shifted jet is visible in Lyα and Si III extending towards the SW for at least 6″ (725 AU). The combination of low line-of-sight extinction and relative faintness of the central star near Lyα enables us to trace the jet to within an unprecedented 0.06″ (7.3 AU) of HD 163296. The jet has a radial velocity of 335-380 km s^{-1}, which is common for protostellar outflows. We also detected red shifted Lyα emission SW of the star that may be due to infall or a poorly collimated wind component. If the age of the star is correct, then protostellar outflows may last up to ten times longer than previously believed.

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The Density Structure of Ultracompact HII Regions

José Franco[1], Stan Kurtz[1], Peter Hofner[2], Leonardo Testi[3], Guillermo García-Segura[1] and Marco Martos[1]

[1] Instituto de Astronomía, Universidad Nacional Autónoma de México, Apdo. Postal 70-264, 04510 México D.F., Mexico
[2] Department of Physics, University of Puerto Rico, P. O. Box 23343, Rio Piedras, PR 00931; and NAIC, Arecibo Observatory
[3] Osservatorio Astrofisico de Arcetri, Largo Enrico Fermi 5, I-50125 Firenze, Italy

E-mail contact: s.kurtz@astrosmo.unam.mx

We report the density structure of the ultracompact HII regions G35.20−1.74, G9.62+0.19-E, and G75.78+0.34-H_2O. The density profiles are derived from radio continuum emission at wavelengths from 6 to 0.3 cm. In the case of G35.20−1.74, a cometary UC HII region with a core and a tail, the spectrum of the core varies as $S_\nu \propto \nu^{0.6}$, implying that the density structure is $n_e \propto r^{-2}$. The emission from the tail has a flatter spectrum, indicating that the density gradient is also negative, but shallower. For the case of G9.62+0.19, which is an HII region complex with several components, the spectrum of the region designated component E is $S_\nu \propto \nu^{0.95}$, corresponding to $n_e \propto r^{-2.5}$. The steepest spectral index, $S_\nu \propto \nu^{1.4}$, is for the super UC HII region G75.78+0.34-H_2O; its density stratification may be as steep as $n_e \propto r^{-4}$. The actual density gradient may be smaller, owing to an exponential (rather than a power-law) density distribution or to the effects of finite spatial extent. The contribution from dust emission and some of the possible implications of these density distributions are briefly discussed.

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http://www.arcetri.astro.it/ preprint/2000/list.html

A Micro Jet: A Protostar's Cry at Birth

Ray S. Furuya[1,2], Yoshimi Kitamura[3] H. Alwyn Wootten[4], Mark J. Claussen[5], Masao Saito[6], Kevin B. Marvel[7], and Ryohei Kawabe[8]

[1] Department of Astronomical Science, The Graduate University for Advanced Studies, Japan
[2] Present address: Osservatorio Astrofisico di Arcetri, Largo Enrico Fermi, 5-50125, Firenze, Italy
[3] Institute of Space and Astronautical Science, Yoshinodai, Sagamihara, Kanagawa 229-8510, Japan
[4] National Radio Astronomy Observatory, 520 Edgemont Road, Charlottesville, VA 22903, USA
[5] National Radio Astronomy Observatory, 1003 Lopezville Road, Socorro, NM 87801, USA
[6] Harvard-Smithsonian Center for Astrophysics, 60 Garden St, Cambridge, MA 02138, USA
[7] American Astronomical Society, Executive Office, 2000 Florida Avenue, NW, Suite 400 Washington DC 20009-1231, USA
[8] Nobeyama Radio Observatory, National Astronomical Observatory, Nobeyama 411, Minamimaki, Minamisaku, Nagano 384-1305, Japan

E-mail contact: furuya@arcetri.astro.it

We report the discovery, through VLBA observations of H_2O masers at 22 GHz, of a newly ejected extraordinarily compact protostellar jet — a micro jet — from the Class 0 protostar S106 FIR. The sub-AU resolution VLBA observations revealed the presence of a U-shaped distribution of the masers in the western blueshifted cluster. It has a length of 4 AU, a width of 3 AU and is located at a distance of 25 AU from the assumed position of the star around the middle point of the two maser clusters. The U-shaped distribution is considered to be a "micro bowshock" created by the impact of the Micro jet on the ambient cloud medium. We succeeded in tracking the proper motion of the micro bowshock; its velocity ranges from 25 to 45 km s^{-1}, estimated from the proper motions and line-of-sight velocities. In addition, this source stands unique among all 40 known Class 0 sources in its lack of an extensive molecular outflow, evidenced by our sensitive multi-transition CO searches with 10σ upper limits of $\sim 10^{-6} M_{\odot}$ per km s^{-1}. We propose that S106 FIR is an archetype of the youngest evolutionary class, a protostar observed just after the creation of the protostellar jet.

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pdf-file http://www.arcetri.astro.it/ furuya/preprint/2000/
ps-file http://www.arcetri.astro.it/ starform/publ2000.htm

The Magnetic Geometry of Pulsed Astrophysical Jets

T. A. Gardiner[1] & A. Frank[1]

[1] Dept. of Physics and Astronomy, University of Rochester, Rochester, NY 14627-0171, USA

example: E-mail contact: gardiner@pas.rochester.edu

Hypersonic, highly collimated, mass outflows (*jets*) are a ubiquitous phenomena in astrophysics. While the character of the jets differ, many exhibit some form of quasi-periodic clumping indicating the jet source is episodic or *pulsed.* The presence of pulsed jets in so many astrophysical contexts suggests a common formation mechanism. Such a process seems to have been found in *Magneto-centrifugal launching*, the combination of magnetic and centrifugal forces that occurs when a magnetized gaseous accretion disk orbits a central gravitating source. Observations of strong magnetic fields in jets are, however, rare or indirect. Thus the presence and effects of magnetic fields in YSO jets remains an unresolved issue of the highest importance. In this letter we focus on what should be expected for the structure of the fields in pulsed YSO jets. We show that combining velocity variability with an initial field configuration consistent with collimated, Magneto-centrifugally launched jets leads to a clear set of predictions concerning the geometry and relative strength of the magnetic field components in evolving YSO (and perhaps other) jets.

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preprints may be found at ftp://ftp.pas.rochester.edu/pub/afrank/papers/

The Structure and Emission of the Accretion Shock in T Tauri Stars II: the Ultraviolet Continuum Emission

Erik Gullbring[1], Nuria Calvet[2], James Muzerolle[2], and Lee Hartmann[2]

[1] Stockholm Observatory, SE-133 36 Saltsjöbaden, Sweden
[2] Harvard-Smithsonian Center for Astrophysics, 60 Garden St., Cambridge, MA 02138, USA

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

We compare accretion shock models with optical and ultraviolet spectra of pre-main sequence stars to (1) make the first determinations of accretion rates in intermediate mass T Tauri stars from continuum emission, and (2) derive improved estimates of accretion rates and extinctions for continuum T Tauri stars. Our method extends the shock models developed by Calvet & Gullbring to enable comparisons with optical and archival *International Ultraviolet Explorer* ultraviolet spectra. We find good agreement between the observations and the model predictions, supporting the basic model of magnetospheric accretion shocks as well as previous determinations of accretion rates and interstellar reddening for the low mass T Tauri stars. The accretion rates determined for the intermediate-mass T Tauri stars agree well with values obtained through other methods that use near-infrared hydrogen line strengths (Muzerolle et al. 1998).

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http://cfa-www.harvard.edu/sfgroup/

An accelerated Monte Carlo method to solve two-dimensional radiative transfer and molecular excitation: With applications to axisymmetric models of star formation.

Michiel R. Hogerheijde[1] and Floris F. S. van der Tak[2]

[1] Radio Astronomy Laboratory, Astronomy Department, 601 Campbell Hall, University of California, Berkeley, CA 94720-3411, USA
[2] Sterrewacht Leiden, P.O. Box 9513, 2300 RA Leiden, The Netherlands

E-mail contact: michiel@astro.berkeley.edu

We present a numerical method and computer code to calculate the radiative transfer and excitation of molecular lines. Formulating the Monte Carlo method from the viewpoint of cells rather than photons allows us to separate local and external contributions to the radiation field. This separation is critical to accurate and fast performance at high optical depths ($\tau > 100$). The random nature of the Monte Carlo method serves to verify the independence of the solution to the angular, spatial, and frequency sampling of the radiation field. These features allow use of our method in a wide variety of astrophysical problems without specific adaptations: in any axially symmetric source model and for all atoms or molecules for which collisional rate coefficients are available. Continuum emission and absorption by dust is explicitly taken into account but scattering is neglected. We illustrate these features in calculations of (i) the HCO^+ J=1–0 and 3–2 emission from a flattened protostellar envelope with infall and rotation, (ii) the CO, HCO^+, CN and HCN emission from a protoplanetary disk and (iii) HCN emission from a high-mass young stellar object, where infrared pumping is important. The program can be used for optical depths up to $10^3 - 10^4$, depending on source model. We expect this program to be an important tool in analysing data from present and future infrared and (sub) millimetre telescopes.

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Preprints of the paper are available at `http://astro.berkeley.edu/~michiel/pub.html`. The source code of the one-dimensional version of our code can be downloaded from `http://astro.berkeley.edu/~michiel/ratran.html`.

Distance and absorption features in the CG 30/CG 31/CG 38 complex

J. Knude[1] and A. S. Nielsen[1]

[1] Niels Bohr Institute for Astronomy, Geophysics and Physics, Juliane Maries Vej 30, DK-2100 København Ø, Denmark

E-mail contact: indus@astro.ku.dk

We report a possible confirmation of the short 200 pc distance to the cometary globules CG 30/31/38 suggested by a previously discussed (V − I) − V diagram to $V_{lim} \approx 20$ mag. New 2 magnitudes deeper V and I photometry centered on CG 31A indicate the presence of visual extinction $A_V = 5.6$ mag at 200 pc. In addition, we may have measured an

absorption gradient along the tail of CG 31C with A_V varying between 7.0 and 3.5 mag. The Hipparcos – Tycho−2 sample of double stars is used to demonstrate that the bright – red confinements in the colour−magnitude diagram, which we use to estimate the distance and absorption of nearby molecular clouds, probably can not be caused by duplicity.

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Infrared L Band Observations of the Trapezium Cluster: A Census of Circumstellar Disks and Candidate Protostars

Charles J. Lada[1], August A. Muench[1,2], Karl E. Haisch, Jr.[2], Elizabeth A. Lada[2], João F. Alves[3], Eric V. Tollestrup[1], and S. P. Willner[1]

[1] Harvard-Smithsonian Center for Astrophysics, 60 Garden Street Cambridge, MA 02138, USA
[2] Department of Astronomy, University of Florida, Gainesville, FL 32611, USA
[3] European Southern Observarory, Karl-Schartzschild-Strasse 2, 85748 Garching, Germany

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

We report the results of a sensitive near-infrared JHKL imaging survey of the Trapezium cluster in Orion. We use the JHKL colors to obtain a census of infrared excess stars in the cluster. Of (391) stars brighter than 12th magnitude in the K and L bands, 80% $\pm$ 7% are found to exhibit detectable infrared excess on the J-H, K-L color-color diagram. Examination of a subsample of 285 of these stars with published spectral types yields a slightly higher infrared excess fraction of 85%. We find that 97% of the optical proplyds in the cluster exhibit excess in the JHKL color-color diagram indicating that the most likely origin of the observed infrared excesses is from circumstellar disks. We interpret these results to indicate that the fraction of stars in the cluster with circumstellar disks is between 80-85%, confirming earlier published suggestions of a high disk fraction for this young cluster. Moreover, we find that the probability of finding an infrared excess around a star is independent of stellar mass over essentially the entire range of the stellar mass function down to the hydrogen burning limit. Consequently, the vast majority of stars in the Trapezium cluster appear to have been born with circumstellar disks and the potential to subsequently form planetary systems, despite formation within the environment of a rich and dense stellar cluster. We identify 78 stars in our sample characterized by K-L colors suggestive of deeply embedded objects. The spatial distribution of these objects differs from that of the rest of the cluster members and is similar to that of the dense molecular cloud ridge behind the cluster. About half of these objects are detected in the short wavelength (J and H) bands and these are found to be characterized by extreme infrared excess. This suggests that many of these sources could be protostellar in nature. If even a modest fraction (i.e., $\sim$ 50%) of these objects are protostars, then star formation could be continuing in the molecular ridge at a rate comparable to that which produced the foreground Trapezium cluster.

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Preprints available at http://cfa-www.harvard.edu/~gmuench/thesis/clusters/TRAP/traplband.html and via astro-ph/0008280.

A Shock-Induced PDR in the HH 80/81 Flow. Far Infrared Spectroscopy.

Sergio Molinari[1], Alberto Noriega-Crespo[2] and Luigi Spinoglio[3]

[1] Infrared Processing and Analysis Center, California Institute of Technology, MS 100-22, Pasadena, CA 91125, USA
[2] SIRTF Science Center, California Institute of Technology, MS 100-22, Pasadena, CA 91125, USA
[3] CNR-Istituto di Fisica dello Spazio Interplanetario, Area di Ricerca Tor Vergata, via Fosso del Cavaliere I-00133 Roma, Italy

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

The two spectrometers on board the Infrared Space Observatory were used to observe the Herbig-Haro objects HH 80, 81 and 80N, as well as their candidate exciting source IRAS 18162-2048. The fine structure lines of [OI]63μm, [OI]145μm and [CII]158μm are detected everywhere, while [NII]122μm and [OIII]88.3μm are only detected toward the HH objects; line ratios confirm for the first time the collisionally excited HH nature of HH 80N. No molecular line is detected in any of the observed positions. We use a full shock code to diagnose shock velocities v_s $\sim$100 km s^{-1} toward the HH objects, as expected from the optical spectroscopy. Since proper motions suggest velocities in excess of 600

km s^{-1}, the HH objects probably represent the interface between two flow components with velocity differing by $\sim$v$_s$. Aside from the flow exciting source, the [CII]158μm line is everywhere brighter than the [OI]63μm line, indicating the presence of a Photo-Dissociation Region (PDR) all along the flow. Continuum emission from the HH objects and from other positions along the flow is only detected longword of $\sim 50\mu$m, and its proportionality to the [CII]158μm line flux suggests it is PDR in origin. We propose that the FUV continuum irradiated by the HH objects and the jet is responsible for the generation of a PDR at the walls of the flow cavity. We develop a very simple model which strengthens the plausibility of this hypothesis.

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From Stars to Super-planets: the Low-Mass IMF in the Young Cluster IC348

Joan R. Najita[1], Glenn P. Tiede[1] and John S. Carr[2]

[1] National Optical Astronomy Observatories, 950 N. Cherry Ave., Tucson, AZ 85719, USA
[2] Naval Research Laboratory, 4555 Overlook Ave., Washington, D.C. 20375-5320, USA

E-mail contact: najita@noao.edu

We investigate the low-mass population of the young cluster IC348 down to the deuterium–burning limit, a fiducial boundary between brown dwarf and planetary mass objects, using a new and innovative method for the spectral classification of late-type objects. Using photometric indices, constructed from HST/NICMOS narrow-band imaging, that measure the strength of the 1.9μm water band, we determine the spectral type and reddening for every M-type star in the field, thereby separating cluster members from the interloper population. Due to the efficiency of our spectral classification technique, our study is complete from $\sim 0.7 M_\odot$ to 0.015 $M_\odot$. The mass function derived for the cluster in this interval, $dN/d\log M \propto M^{0.5}$, is similar to that obtained for the Pleiades, but appears significantly more abundant in brown dwarfs than the mass function for companions to nearby sun-like stars. This provides compelling observational evidence for different formation and evolutionary histories for substellar objects formed in isolation vs. as companions. Because our determination of the IMF is complete to very low masses, we can place interesting constraints on the role of physical processes such as fragmentation in the star and planet formation process and the fraction of dark matter in the Galactic halo that resides in substellar objects.

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Models of scattered light in UXORs

A. Natta[1] and B.A. Whitney[2]

[1] Osservatorio Astrofisico di Arcetri, Largo E.Fermi 5, I-50125 Firenze, Italy
[2] Space Science Institute, 3100 Marine St., Suite A353, Boulder, CO 80303-1058, USA

E-mail contact: natta@arcetri.astro.it

This paper offers an interpretation of the photometric and polarimetric variability of UXORs where the star is surrounded by an optically thick, flared circumstellar disk similar to pre-main–sequence disks. A screen of dust sporadically obscures the stellar radiation, causing a minimum of the stellar light. Using a Monte Carlo code developed by Whitney & Hartmann (1992) we compute the polarization and colors of the observed radiation, and compare it to the available observations. The agreement is remarkably good. We find that the UXOR phenomenon occurs for systems seen in a well-defined range of inclinations, roughly between 45^o and 65^o–68^o. About 1/2 of the optically visible Herbig Ae stars should be UXORs, i.e., have deep photometric minima accompanied by a large increase in the polarization fraction, provided that screens can form. The results are not sensitive to the disk parameters, as long as the disk intercepts about 20% of the stellar radiation. The screens causing the light minima have sizes of the order of 1–few stellar radii, optical depth $\tau_V \sim$3–5, and contain relatively small grains. We find a good fit to the observations with a MRN distribution with average radius ~ 0.03 μm. The lack of UXORs with low polarization in deep minima can be understood if the screens are confined in a region close to the disk plane. However, the nature and origin of the screens remain open questions.

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Density, Velocity, and Magnetic Field Structure in Turbulent Molecular Cloud Models

Eve C. Ostriker[1,2], James M. Stone [1] and Charles F. Gammie[3]

[1] Department of Astronomy, The University of Maryland
[2] The Institute for Theoretical Physics, U.C. Santa Barbara
[3] Departments of Physics and Astronmy, The University of Illinois

E-mail contact: ostriker@astro.umd.edu

We use three-dimensional (3D) numerical magnetohydrodynamic simulations to follow the evolution of cold, turbulent, gaseous systems with parameters chosen to represent conditions in giant molecular clouds (GMCs). We present results of three model cloud simulations in which the mean magnetic field strength is varied ($B_0 = 1.4 - 14$ μG for GMC parameters), but an identical initial turbulent velocity field is introduced. We describe the energy evolution, showing that (i) turbulence decays rapidly, with the turbulent energy reduced by a factor two after 0.4-0.8 flow crossing times ($\sim 2 - 4$ Myr for GMC parameters), and (ii) the magnetically supercritical cloud models gravitationally collapse after time ≈ 6 Myr, while the magnetically subcritical cloud does not collapse.

We compare density, velocity, and magnetic field structure in three sets of model "snapshots" with matched values of the Mach number $\mathcal{M} \approx 9, 7, 5$. We show that the distributions of volume density and column density are both approximately log-normal, with mean mass-weighted volume density a factor $3 - 6$ times the unperturbed value, but mean mass-weighted column density only a factor $1.1 - 1.4$ times the unperturbed value. We introduce a spatial binning algorithm to investigate the dependence of kinetic quantities on spatial scale for regions of column density contrast (ROCs) on the plane of the sky. We show that the average velocity dispersion for the distribution of ROCs is only weakly correlated with scale, similar to mean size-linewidth distributions for clumps within GMCs. We find that ROCs are often superpositions of spatially unconnected regions that cannot easily be separated using velocity information; we argue that the same difficulty may affect observed GMC clumps. We suggest that it may be possible to deduce the mean 3D size-linewidth relation using the lower envelope of the 2D size-linewidth distribution. We analyze magnetic field structure, and show that in the high density regime $n_{H_2} \gtrsim 10^3\mathrm{cm}^{-3}$, total magnetic field strengths increase with density with logarithmic slope $\sim 1/3 - 2/3$. We find that mean line-of-sight magnetic field strengths may vary widely across a projected cloud, and are not positively correlated with column density. We compute simulated interstellar polarization maps at varying observer orientations, and determine that the Chandrasekhar-Fermi formula multiplied by a factor ~ 0.5 yields a good estimate of the plane-of sky magnetic field strength, provided the dispersion in polarization angles is $\lesssim 25°$.

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Chemical Differentiation in Regions of Massive Star Formation

S.D. Rodgers and S.B. Charnley

Space Science Division, MS 245-3, NASA Ames Research Center, Moffett Field, CA 94035, U.S.A.

E-mail contact: rodgers@dusty.arc.nasa.gov

We have re-examined the origin of the apparent differentiation between nitrogen-bearing molecules and complex oxygen-bearing molecules that is observed in hot molecular cores associated with massive protostars. Observations show that methanol is an ubiquitous and abundant component of protostellar ices. Recent observations suggest that ammonia may constitute an appreciable fraction of the ices towards some sources. In contrast to previous theories that suggested that N/O differentiation was due to an anticorrelation between methanol and ammonia in the precursor grain mantles, we show that the presence of ammonia in mantles and the core temperature are key quantities in determining N/O differentiation. Calculations are presented which show that when large amounts of ammonia are evaporated alkyl cation transfer reactions are suppressed and the abundances of complex O-bearing organic molecules greatly reduced. Cooler cores (100 K) eventually evolve to an oxygen-rich chemical state similar to that attained when *no* ammonia was injected, but on a time-scale that is an order of magnitude longer ($\sim 10^5$ years). Hotter cores (300 K) never evolve an O-rich chemistry unless ammonia is almost absent from the mantles. In this latter case a complex

O-rich chemistry develops on an time-scale of $\sim 10^4$ years, as in previous models, but disappears in about 2×10^5 years after which time the core is rich in NH_3, HCN and other N-bearing molecules. There are thus two ways in which N-rich cores can occur. We briefly discuss the implications for the determination of hot core ages and for explaining N/O differentiation in several well-studied sources.

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Two Distant Embedded Clusters in the Outer Galaxy

Carlos A. Santos[1], João L. Yun[1], Dan P. Clemens[2], & Rui J. Agostinho[1]

[1]Centro de Astronomia e Astrofísica da Universidade de Lisboa, Observtatório Astronómico de Lisboa, Tapada da Ajuda, 1349-018 Lisboa, Portugal
[2]Institute for Astrophysical Research, Boston University, 725 Commonwealth Avenue, Boston, MA 02215, U.S.A.

E-mail contact: yun@oal.ul.pt

We report discovery of two distant embedded young stellar clusters located far in the outer Galaxy. The clusters are resolved in near-infrared images and seen as enhancements in the surface density of IR-excess stars centered close to IRAS 07255–2012. The clusters are embedded in a molecular cloud containing a CS dense core. The molecular cloud, as traced by CO (J=1-0) is elongated and extends over a region of 15×6 pc^2. ¿From the millimeter observations, we derive a kinematic distance of 10.2 kpc and a Galactocentric distance of 16.5 kpc, making these clusters among the most distant embedded clusters in the Galaxy. The main (richer) cluster is well confined to a region of about 1.2 pc in radius. Down to our detection limit of about $1 - 2$ $M_\odot$ at this distance, it contains at least 30 members. The smaller cluster contains at least 5 stars. They all exhibit near-infrared color excesses consistent with young stellar objects having circumstellar and/or envelope material. We estimate the star formation efficiency of this molecular cloud is about 4% to 10%.

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Warm Dust Emission Near W75N IRS1: Evidence for Multiple Energetic Outflows

D. S. Shepherd

National Radio Astronomy Observatory, Socorro, NM, USA

E-mail contact: dshepher@aoc.nrao.edu

This paper presents $0.8''$ to $3''$ resolution images of 1.3 and 3.3 millimeter continuum emission in the massive molecular outflow in W75 N. The mass of warm gas and dust near the center of the outflow is ~ 450 $M_\odot$ and represents approximately 45% of the core mass in the molecular cloud. Comparison of the distribution of warm dust emission with the locations of ultra-compact HII regions indicates that the source VLA 3 probably contributes the most to the outflow dynamics. The location of VLA 2 near the 1 mm continuum peak and the presence of H_2O masers suggests that this source may also contribute to the flow dynamics. The thermal jet source, VLA 1, has an estimated momentum rate that is three to four orders of magnitude less than that required to drive the large-scale CO outflow. If the ionized jet is the only outflow component, VLA 1, does not appear to be able to contribute significantly to the outflow energetics. Outflow parameter estimates that have been corrected for inclination and optical depth imply an outflow mass of more than a thousand solar masses and a mass outflow rate of ~ 0.2 $M_\odot$ yr^{-1}. It is extremely unlikely that a single young stellar object can produce a flow of this magnitude; thus, several energetic outflows may be active.

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Dynamical Masses of T Tauri Stars and Calibration of PMS Evolution

M. Simon[1], A. Dutrey[2], and S. Guilloteau[2]

[1] Dept. of Physics and Astronomy, SUNY, Stony Brook, NY, 11794-3800, USA
[2] Institut de Radio Astronomie Millimétrique, 300 Rue de la Piscine, F-38406 Saint Martin d'Hères, France

E-mail contact: msimon@astro.sunysb.edu

We have used the high sensitivity and resolution of the IRAM interferometer to produce sub-arcsecond ^{12}CO J=2-1 images of 9 protoplanetary disks surrounding T Tauri stars in the Taurus-Auriga cloud (7 singles and 2 binaries). The images demonstrate the disks are in Keplerian rotation around their central stars. Using the least square fit method described in Guilloteau & Dutrey (1998), we derive the disk properties, in particular its inclination angle and rotation velocity, hence the dynamical mass. Since the disk mass is usually small, this is a *direct* measurement of the stellar mass. Typically, we reach an internal precision of 10% in the determinations of stellar mass. The over-all accuracy is limited by the uncertainty in the distance to a specific star. In a distance independent way, we compare the derived masses with theoretical tracks of pre-main-sequence evolution. Combined with the mean distance to the Taurus region (140 pc), for stars with mass close to 1 solar mass, our results tend to favor the tracks with cooler photospheres (higher masses for a given spectral type). We find that in UZ Tau E the disk and the spectroscopic binary orbit appear to have different inclinations.

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Silicate Emission in the TW Hydrae Association

Michael L. Sitko[1], David K. Lynch[2], and Ray W. Russell[2]

[1] Department of Physics, University of Cincinnati, Cincinnati, OH 45221-0011, USA
[2] The Aerospace Corporation, Los Angeles, CA 90009, USA

E-mail contact: sitko@physics.uc.edu

The TW Hydrae Association is the nearest young stellar association. Among its members are HD 98800, HR 4796A, and TW Hydrae itself, the nearest known classical T Tauri star. We have observed these three stars spectroscopically between 3 and 13 μm. In TW Hya the spectrum shows a silicate emission feature that is similar to many other young stars with protostellar disks. The 11.2 μm feature indicative of significant amounts of crystalline olivine is not as strong as in some young stars and solar system comets. In HR 4796A, the thermal emission in the silicate feature is very weak, suggesting little in the way of (small silicate) grains near the star. The silicate band of HD 98800 (observed by us but also reported by Sylvester and Skinner 1996) is intermediate in strength between TW Hya and HR 4796A.

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The distribution of shock waves in driven supersonic turbulence

Michael D. Smith[1], Mordecai-Mark Mac Low[2] and Fabian Heitsch[3]

[1] Armagh Observatory, College Hill, Armagh BT61 9DG, Northern Ireland
[2] Department of Astrophysics, American Museum of Natural History, 79th St. at Central Park West, New York, New York, 10024-5192, USA
[3] Max-Planck-Institut für Astronomie, Königstuhl 17, D-69117 Heidelberg, Germany

E-mail contact: mds@star.arm.ac.uk, mordecai@amnh.org, heitsch@mpia-hd.mpg.de

Supersonic turbulence generates distributions of shock waves. Here, we analyse the shock waves in three-dimensional numerical simulations of uniformly driven supersonic turbulence, with and without magnetohydrodynamics and self-gravity. We can identify the nature of the turbulence by measuring the distribution of the shock strengths.

We find that uniformly driven turbulence possesses a power law distribution of fast shocks with the number of shocks inversely proportional to the square root of the shock jump speed. A tail of high speed shocks steeper than Gaussian results from the random superposition of driving waves which decay rapidly. The energy is dissipated by a small range of fast shocks. These results contrast with the exponential distribution and slow shock dissipation associated with decaying turbulence.

A strong magnetic field enhances the shock number transverse to the field direction at the expense of parallel shocks. A simulation with self-gravity demonstrates the development of a number of highly dissipative accretion shocks. Finally, we examine the dynamics to demonstrate how the power-law behaviour arises.

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Preprints available at: http://star.arm.ac.uk/ mds/ or http://xxx.lanl.gov/abs/astro-ph/0008125

The structure of the Orion Bar

C.M. Walmsley, A. Natta, E. Oliva, and L. Testi

[1] Osservatorio Astrofisico di Arcetri, Largo E.Fermi 5, I-50125 Firenze, Italy

E-mail contact: walmsley@arcetri.astro.it

We have obtained NIR spectral line maps of a limited region around the Orion Bar ionization front using the red and blue grisms of SOFI on the ESO NTT telescope. The wavelength range covered was from 0.95 to 2.3 μm. In addition to many well studied features, we detected two lines at 1.07 and 1.17 μm due to recombination to CI which have excitations above 60000 cm^{-1}. We also observe several features at around 1 micron of atomic nitrogen (at still higher excitations) which we believe are caused by fluorescence of UV lines at approximately 955 Å in gas within the ionization front. We give a brief analysis of this process showing that one can infer the relative UV intensities incident upon the ionization front on the basis of the NIR spectra. Analogously, the spatial distribution of the fluorescent OI 1.317 μm line allows one to infer the geometry of the ionization front. We consider various geometries and conclude that the Orion Bar is most likely to be a cylinder or filament in the plane of the sky. Maps in the 9840Å CI line were also obtained and compared with the corresponding intensity distribution in C91α from Wyrowski et al.(1997). These are emitted from the same general area but show differences in detail which are likely partly to be due to patchy extinction. The CI NIR line correlates well with molecular hydrogen emission away from the high density high radiation field layers of the Bar. The measured CI line ratios (in particular the ratio of the 0.984 and 1.07 μm lines) suggest higher temperatures in the C^+ layer than allowed from the measured radio line width. The explanation for this discrepancy is not clear but it points up the need for observations in the NIR with higher spectral resolution and in the radio with higher spatial resolution.

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Detection of Quiescent Molecular Hydrogen Gas in the Circumstellar Disk of a Classical T Tauri Star

David A. Weintraub [1], Joel H. Kastner[2] and Jeffrey S. Bary[1]

[1] Department of Physics & Astronomy, Vanderbilt University, P.O. Box 1807 Station B, Nashville, TN 37235, USA
[2] Carlson Center for Imaging Science, RIT, 54 Lomb Memorial Drive, Rochester, NY 14623, USA

E-mail contact: ; david.weintraub@vanderbilt.edu, bary@eggneb.phy.vanderbilt.edu, jhkpci@cis.rit.edu

We have detected emission from quiescent, molecular hydrogen gas in the disk around the classical T Tauri star TW Hya in the 1-0 S(1) line at 2.12183 μm, through high resolution spectroscopy using CSHELL on NASA's Infrared Telescope Facility. The H_2 line emission most likely is the result of excitation in the innermost region of the disk by stellar X-rays. This result demonstrates that X-ray ionization is a viable mechanism for excitation of H_2 in the gaseous disks of T Tauri stars. In addition, from these high resolution photospheric spectra we have measured the radial velocities of three T Tauri stars in the TW Hya Association, CD−33°7795, HD 98800, and TW Hya. We find that the radial velocities of these three stars are very similar to each other and to those of at least three other stars presumed to be members of the TW Hya Association, Hen 600 A, Hen 600B, and CD−29°8887. This result, combined with the similar proper motions of all six of these stars, lends support to the hypothesis that all of these stars share a common origin in a now-dispersed molecular cloud.

Accepted by Ap.J.

Dissertation Abstracts

An Observational Study of the Role of Magnetic Fields in Star Formation

Crystal Lee Brogan

Thesis work conducted at: University of Kentucky, Lexington KY, USA

Current address: University of Kentucky, 177 Chem-Phys Bldg., Lexington KY, 40506-0055

Address as of 08 Sept. 2000: National Radio Astronomy Observatory, P.O. Box O, Socorro NM, 87801

Electronic mail: cbrogan@aoc.nrao.edu

Ph.D dissertation directed by: Thomas H. Troland

Ph.D degree awarded: August 2000

It has become clear in recent years that magnetic fields play an important and perhaps crucial role in the process of star formation. For this reason, measurements of magnetic field strengths and morphology are an important component in ongoing attempts to understand star formation. The goal of this thesis is to significantly extend the available data on the strength and morphology of magnetic fields in star-forming regions using the Zeeman effect. The Very Large Array telescope observations described here include: (1) A Zeeman study of H I and OH gas toward the star-forming region M17; (2) A study of the W49 complex using the H I Zeeman effect; (3) A Zeeman study of OH (1720 MHz) masers toward five galactic supernova remnants (SNRs). Some of the results of these Zeeman observations include:

- The detection of an H I component at 20 km s^{-1} with line of sight field strengths (B_{los}) up to -700 μG toward the M17 H II region/M17 SW interface. The velocity and line width of this component closely match those of molecular emission lines from the M17 SW cloud, suggesting that this H I component originates from the photon dominated region along the interface. OH Zeeman observations toward M17 reveal a similar B_{los} in this region as well as three additional B_{los} detection regions along the NW edge of the interface. We also find that the M17 SW molecular cloud core is close to dynamic equilibrium. In our model, the static component of the magnetic field appears to supply about half the total pressure needed to support the M17 SW core, and the rest can be accounted for by internal motions.
- Significant B_{los} of 60 to 300 μG were detected toward W49A in H I velocity components at 4 and ~ 7 km s^{-1}. The W49A B_{los} show a significant *increase in field strength with higher resolution* especially for the ~ 4 km s^{-1} H I component. Based on comparisons with molecular data toward W49A, the ~ 4 km s^{-1} H I component appears to be directly associated with the W49A H II region ring, while the ~ 7 km s^{-1} H I component originates from a halo surrounding W49A. From these results, we estimate that W49A North is significantly subvirial and magnetically supercritical, and is therefore unstable to overall gravitational collapse. These results are in agreement with recent molecular observations which show evidence for the collapse of the ~ 7 km s^{-1} W49A halo (eg. Dickel et al. 1999).
- We detected significant magnetic fields between 0.2 to 2 mG in ten supernova remnant − OH (1720 MHz) masers. These masers are thought to arise when a supernova shock encounters relatively dense ($\sim 1 \times 10^3$ cm^{-3}) molecular gas. From comparison of the observed field values with theoretical maser studies we conclude that the thermal Zeeman equation overestimates $\mid \vec{B} \mid$ by less than a factor of five, and that these masers are likely to be saturated. The observed field strengths are consistent with the hypothesis that ambient magnetic fields were compressed via the SNR shock to the observed values. We also find that the magnetic pressure ($10^{-7} - 10^{-9}$ erg cm^{-3}) in the post-shock gas far exceeds the thermal pressure of the hot gas interior to the remnant.

These studies have added a number of new insights into the role that magnetic fields play in the process of star formation.

see also *http://www.pa.uky.edu/~brogan/publications.html*

T Tauri stars pictured at ultraviolet and x-rays

Vitor Costa

Thesis work conducted at: Centre for Astrophysics - University of Porto, Portugal

Current address: Centre for Astrophysics - University of Porto, Rua das Estrelas, 4150 Porto, Portugal

Electronic mail: vcosta@astro.up.pt

Ph.D dissertation directed by: M. Teresa V.T. Lago

Ph.D degree awarded: June 2000

Newly calibrated IUE spectra and ROSAT data for a sample of T Tauri stars have been investigated.

In the ultraviolet band a complete spectral atlases for our sample of stars is presented. We have identified the main spectral lines and the continuous emission. While for some stars the continuum is well explained by the sum of the stellar black body emission plus a hydrogenic component with a temperature in the range 1.4 to 5×10^4 K, there are however others which require a third component, i.e., black body emission at temperatures in the range 5900–9700 K covering a few percent of the stellar surface. In addition, we have utilised the observed line fluxes together with Emission Measure techniques to derive the temperature structure in the atmosphere of the stars. The behaviour of the stars is analysed showing noticeable differences. For the star LkHα 264 we have also established the connection between the UV analysis into optical ranges in terms of the continuum. The combined emission in the UV also fits the observed optical continuum well and we conclude that this star is an analogue of the Sun but displaying a much higher level of activity.

The stars in the sample have also been studied in X-ray allowing for some newly detections. Also fundamental parameters have been derived. Within the sample we analysed in more detail those stars for which there are more than one set of observations and looked for X-ray variability. Three stars in our sample, V410 Tau, TW Hya and CS Cha, allow a detailed spectral analysis and we have also searched for variability, both short- and long-term within the limits of the data. The results of the spectral analysis for these stars can be successfully described by a model of emission from two-temperature, hot, optically thin plasma in collisional equilibrium.

We have established the connection from the UV to the X-ray band extending the spectroscopic analysis from regions with plasma at temperatures below 10^4 K to regions at $\simeq 10^7$ K. From comparison with the Sun we concluded that the behaviour of the stars can be tentatively classified in three types.

A Test of Star Formation Theory: The Connection Between Rotation, Accretion, and Circumstellar Disks Among Low-Mass Pre-Main Sequence Stars

Keivan Guadalupe Stassun

Thesis work conducted at: University of Wisconsin—Madison, USA

Current address: University of Wisconsin, 475 N. Charter St., Madison, WI, 53706, USA

Electronic mail: keivan@astro.wisc.edu

Ph.D. dissertation directed by: Robert Mathieu

Ph.D. degree awarded: August 2000

Circumstellar disks have come to be seen as dominant players in the rotational evolution of low-mass stars during the pre-main-sequence (PMS) phase. In fact, most rotational evolution models today rely chiefly on magnetic disk-locking to successfully connect the rotational properties of T Tauri stars (TTS) to those of zero-age main sequence (ZAMS) stars. The principal aim of this dissertation is to summarize recent observations (Stassun et al. 1999; Stassun et al. 2000) that challenge this picture of disk-regulated PMS rotational evolution.

We present photometrically derived rotation periods for 254 stars in an area 40×80 arcmin centered on the Orion Nebula. We show that these stars are likely members of the young ($\sim 10^6$ yr) Orion OBIc/d association. The rotation period distribution we determine, sensitive to periods $0.1 < P_{\rm rot} < 8$ days, shows a sharp cutoff for periods $P_{\rm rot} < 0.5$ days, corresponding to breakup velocity for these stars; a population of stars rotating near breakup is already present at 1 Myr. Above 0.5 days the distribution is consistent with a uniform distribution; we do not find evidence for a "gap" of periods at 4–5 days. We find signatures of active accretion among stars at all periods; active accretion does not occur preferentially among slow rotators in our sample. We find no correlation between rotation period and the presence of near-infrared signatures of circumstellar disks.

We do not find compelling agreement between our observations and the requirements of the disk-locking hypothesis. We use near-IR photometry to argue that inner cavities in TTS disks are typically much smaller than allowed by theory for the regulation of stellar angular momentum. We further use mid-IR (primarily 10 μm) photometry to confirm that TTS lacking near-IR excesses do not harbor disks with large inner truncation radii. With a few exceptions, stars in our sample lacking near-IR excesses do not possess disks, truncated or otherwise. Evidently, many young stars can exist as slow rotators without the aid of present disk-locking, and there exist very young stars already rotating near breakup velocity whose subsequent angular momentum evolution will not be regulated by disks.

We discuss the implications of our results for rotational evolution models of PMS stars. We call into question the initial conditions assumed by the models, which typically begin their calculations with slow rotators possessing a small dispersion of rotation rates, and which have thus relied upon magnetic disk-locking to explain the large dispersion of rotation rates in young ZAMS clusters. We find that TTS at 1 Myr in fact possess a dispersion of rotation rates that matches or even exceeds that observed among low-mass Pleiads. We thus advocate new model initial conditions—in which low-mass stars at 1 Myr possess a large dispersion of rotation rates—that may allow the models to explain the angular momentum evolution of low-mass PMS stars in a way that does not depend upon disk-regulated phenomena.

We also present models of the photopolarimetric variability arising from hot accretion spots on TTS (Stassun & Wood 1999). The application of these models to further tests of magnetic disk-locking, and for constraining star/disk/spot parameters of TTS, is discussed. Finally, we describe in an Appendix a field-tested educational outreach program for minorities. A sample grant proposal and budget are provided for those wishing to replicate this E/PO model.

http://www.astro.wisc.edu/~keivan/pubs.html

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