

# THE STAR FORMATION NEWSLETTER

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## *Abstracts of recently accepted papers*

### **New multiple young stellar objects discovered by near-infrared speckle imaging**

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Results of a near-infrared high angular resolution study of young stellar objects (YSOs) are presented. The observations have been carried out in 1993 & 1994 with the speckle camera SHARP I at the ESO-NTT. It thus concerns southern hemisphere sources and covers LST range between 10:00 and 22:00 hours. The sources were selected because of their known degree of polarization at optical wavelengths. The sample is thus not biased towards membership in any clouds or associations.

From the 28 objects observed, twelve are point sources at our sensitivity ( $m_K < 12$ ) and resolution ( $\leq 0.2''$ ). Some of these are actually close binary that have been resolved by lunar occultation observations. Over the four extended objects observed, two corresponds to new discoveries. The other twelve stars are multiple. Nearly half of the latter were known as multiple but the degree of multiplicity was smaller than what we found (triple system instead of binary and even small star cluster). Only the new detected multiple sources are presented into detail.

As we looked for structures in a variety of molecular clouds, our sample is not homogeneous for studying the binarity of a class of objects, but does not present distinct overabundance of young binaries with respect to their main sequence counterparts. From the photometric and/or color indexes available, we constructed a J-H/H-K color-color diagram. Given the uncertainties, most of the sources fall in a region of the diagram that can be obtained by their position on the unreddened main sequence + giant locus and a normal reddening law. Based on the similarity of the position angle and the level of polarization with the interstellar values, we conclude that for half of the sources, the polarization is probably of interstellar origin. We also compared the projected position angle of a binary with the position angle of its polarization. A trend appears showing, within a molecular cloud, a distinct position of the WTTS and CTTS in this diagram. We however have to be cautious since the sample is small and the error bars large.

Accepted by Astronomy & Astrophysics

### **Evolution of Molecular Abundance in Protoplanetary Disks**

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We investigate the evolution of molecular abundance in quiescent protoplanetary disks which are presumed to be around weak-line T Tauri stars. In the region of surface density less than  $10^2 \text{ g cm}^{-2}$  (distance from the star  $\gtrsim 10 \text{ AU}$  in the minimum-mass solar nebula), cosmic rays are barely attenuated even in the midplane of the disk and produce

chemically active ions such as  $\text{He}^+$  and  $\text{H}_3^+$ . Through reactions with these ions CO and  $\text{N}_2$  are finally transformed into  $\text{CO}_2$ ,  $\text{NH}_3$ , and HCN. In the region where the temperature is low enough for these products to freeze onto grains, considerable amount of carbon and nitrogen is locked up in the ice mantle and is depleted from the gas phase in a time scale  $\lesssim 3 \times 10^6$  yr. Oxidized ( $\text{CO}_2$ ) ice and reduced ( $\text{NH}_3$  and hydrocarbon) ice naturally coexist in this part of the disk. The molecular abundance both in the gas phase and in ice mantle varies significantly with the distance from the central star.

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## The High Resolution IRAS Galaxy Atlas

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An atlas of the Galactic plane ( $-4.7\text{deg} < b < 4.7\text{deg}$ ) plus the molecular clouds in Orion, rho Ophiuchus, and Taurus-Auriga has been produced at 60 and 100 micron from IRAS data. The atlas consists of resolution-enhanced coadded images having 1 – 2 arcmin resolution as well as coadded images at the native IRAS resolution. The IRAS Galaxy Atlas, together with the DRAO HI line / 21 cm continuum and FCRAO CO (1-0) line Galactic plane surveys, both with similar ( $\sim 1$  arcmin) resolution, provide a powerful venue for studying the interstellar medium, star formation and large scale structure in our Galaxy. This paper documents the production and characteristics of the Atlas.

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Links to both the preprint and online access to the IGA images are provided at <http://www.extrasolar.com>.

## A study of the Chamaeleon star-forming region from the ROSAT All-Sky Survey. III. High resolution spectroscopic study

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We present the results of a high-resolution spectroscopic study on some 70 stars, discovered recently on the basis of the ROSAT all-sky survey spread over a wide area in the Chamaeleon star forming region and classified as new weak-line T Tauri stars. We refine the previous spectral type classification, based on low-resolution spectra, and characterize each star in the sample according to the  $\text{H}\alpha$  line profile.

We use the strength of Li I 6708, compared to Pleiades stars of the same spectral type, as a youth discriminator in order to recognize *bona-fide* pre-main sequence stars. According to the adopted “lithium criterion”, more than 50% of the stars in our sample are confirmed to be truly young, PMS stars (most having age less than  $5 \times 10^6$  yr), while the remaining part seems mostly composed by active, young, foreground main-sequence stars (possibly Pleiades-like), which contaminate the original sample. We confirm the existence of some very young stars far from the main Chamaeleon clouds, while we do not find clear evidence for the presence of post-T Tauri stars in our sample.

We find that 5 stars in the sample are spectroscopic binaries and 1 is a spectroscopic triple system. We derive radial and rotational velocities for all the stars in sample and analyse their distributions for different spectral type intervals. The radial velocity distribution shows a clear peak at about  $15 \text{ km s}^{-1}$ , which coincides with the radial velocity of stars and gas in the Cha I cloud. However, the velocity dispersion of the weak-line T Tauri stars appears much broader and,

possibly, a second peak is present around 16–18 km s<sup>-1</sup>. A clear segregation in radial velocity is observed between the strong-lithium and the weak-lithium stars, with the former showing radial velocities which, in most cases, fall in the interval 12 < RV [km/s] < 18, consistent with the radial velocity peak observed for the Cha I dark cloud, and the latter having somewhat different and more widely spread radial velocities. Some strong-lithium stars having radial velocities outside the aforementioned interval might be unrecognized spectroscopic binaries, but they may also be considered good candidates to be run-away T Tauri stars. The  $v \sin i$  distribution of the confirmed WTTS is found to resemble very closely that of other pre-ROSAT PMS stars. We conclude that the whole star forming region has a common origin, possibly related to the impact of a high-velocity cloud with the galactic plane.

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## L 1287 (H<sub>2</sub>O): Accretion disk-impinging-clumps traced by masers?

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An earlier multi-epoch high angular resolution study of the 22 GHz H<sub>2</sub>O maser emission from the dark cloud core L 1287 presented an unusual position-velocity distribution of the identified masers. Since the observational results could only unsatisfactorily be modeled in terms of an outflow association, the alternative interpretation of a disk origin is investigated in some more detail. Clumpy mass infall onto the accretion disk around the embedded protostar in L 1287 is identified as the hydrodynamic trigger mechanism for the maser excitation. Shock compressed clump layers are found likely to have the required density, temperature and column density for detectable 22 GHz H<sub>2</sub>O maser emission. A simplified model of the velocity field in the shocked clump layers leads to a remarkable agreement with the position-velocity distribution of the observed masers.

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<http://www.ita.uni-heidelberg.de/publications/preprints/1997/index.html>

## Highly Collimated Molecular Hydrogen Jets Near IRAS 05487+0255: NIR Imaging and Spectroscopy

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We present new narrow-band near-infrared images together with K band spectra of highly collimated bipolar jets close to the IRAS 05487+0255 source. The jets are located at  $\sim 50''$  West of the Herbig-Haro 110 outflow. The jets are not visible at optical wavelengths, and therefore, do not fall into the ‘standard’ Herbig-Haro object classification scheme. Nevertheless, they belong to an ever growing group of molecular hydrogen jets associated with YSOs which are optically undetected. The jets are very well collimated, with a length-to-width ratio  $\sim 10 - 20$ .

The spectra of the jet and counter-jet in the K-band show a limited number of H<sub>2</sub> emission lines which makes it difficult to obtain an accurate excitation temperature. We estimate  $T_{ex} = 1104 \pm 67$  K and  $T_{ex} = 920 \pm 156$  K for the red and blue jet components respectively. The radial velocities of the jet and counter-jet, based on the shift of the (1,0) S(1) 2.121  $\mu$ m line, are  $\sim -275 \pm 50$  km s<sup>-1</sup> and  $\sim 180 \pm 50$  km s<sup>-1</sup> respectively, suggesting an angle of  $\sim 30^\circ - 45^\circ$  between the jet and the line of sight. The H<sub>2</sub> emission of the entire jet extends for at least 40'' or  $\sim 0.1$  pc at the distance of Orion. If the flow velocity is comparable to that of the radial velocities, then the dynamical age of the system is quite short ( $\sim 500$  yrs), consistent with a young jet arising from an embedded source. Entrainment in a turbulent mixing layer may explain this morphology and spectral character.

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# High Spatial Resolution Imaging of Pre-Main-Sequence Binary Stars: Resolving the Relationship Between Disks and Close Companions

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In order to study the passive and active effects of young close companion stars and to constrain possible multiple star formation mechanisms, we have carried out a high resolution imaging program of six multiple T Tauri star systems using the Hubble Space Telescope from 0.3 - 0.9  $\mu\text{m}$  and ground-based speckle imaging from 1-2  $\mu\text{m}$ . Each system (GG Tau, UZ Tau, DF Tau, RW Aur, V773 Tau and V410 Tau) has at least one binary pair with separation between 0.''07 - 0.''4 (10 - 50 AU). In addition to the previously known companions, a third component is discovered in the V410 Tau system.

Many of the companion stars contribute significantly to the unresolved spectral energy distribution and thereby bias the inferred stellar and circumstellar properties. Age is the most systematically biased quantity; neglecting a companion causes an overestimate in age by a factor of  $\sim 2$  typically and more than 10 in the extreme.

Excess emission above the photospheric level is detected at ultraviolet (UV) and near-infrared (NIR) wavelengths for several of the components, which suggests that some close (10-50 AU) T Tauri binaries support at least a minimal circumstellar disk at an age of  $\sim 1$  Myr. These inner disks not only provide a potential reservoir of material for planetary formation, but also may play a key role in the evolution of the components' angular momenta.

Possible multiple star formation scenarios are explored in light of the components' relative stellar and circumstellar properties for systems studied here as well as wider and closer systems whose properties are reported in the literature. In summary, the components (1) are coeval, (2) have secondary mass and mass ratio distributions that appear to be independent of both the primary stars' mass and the binary separation, and (3) have UV and NIR excess emission that is either similar or more dominant in the primary. These properties support a scenario in which binary stars form via core fragmentation.

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## The Ammonia Core in L723: Hot Spots at the Center of the Quadrupolar Molecular Outflow

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We present the results of VLA  $\text{NH}_3$  and  $\text{H}_2\text{O}$  observations, as well as Haystack  $\text{C}^{18}\text{O}$ ,  $\text{C}^{18}\text{O}$ , and  $\text{H}_2\text{O}$  observations toward the center of the peculiar quadrupolar molecular outflow in L723. In  $\text{NH}_3$  we detected a high-density structure,  $\sim 1''.7$  long ( $\sim 0.15$  pc), elongated roughly in the east-west direction, with the radio continuum source VLA 2 located near its center. We find evidence in the ammonia maps for heating and line broadening toward VLA 2, confirming that this source is driving the large lobe pair of the quadrupolar molecular outflow. Additionally,  $\text{H}_2\text{O}$  maser emission is detected toward this radio continuum source. A second, very compact ammonia "hot spot" is observed  $10''$  west of VLA 2. This "hot spot" may be heated by a deeply embedded (still undetected) YSO, that could be the driving source of the more compact pair of molecular outflow lobes. No ammonia emission is detected at the position of the source VLA 1, which is probably a line-of-sight source.

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Preprint available on the WWW at <http://www-cfa.harvard.edu/~jgirart/curro.html>

## X-ray and Molecular Emission from the Nearest Region of Recent Star Formation

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The isolated young, Sun-like, star TW Hya and four other young stars in its vicinity are strong X-ray sources. Their similar X-ray and optical properties indicate that the stars comprise a physical association that is of order 20 million years old and which lies between about 40 pc and 60 pc (between about 130 and 200 light years) of Earth. TW Hya itself displays circumstellar CO, HCN, CN, and HCO<sup>+</sup> emission. These molecules probably orbit the star in a solar-system-size disk viewed more or less face-on while the star is likely viewed pole-on. Being at least three times closer than any well-studied region of star formation, the TW Hya Association serves as a testbed for study of X-ray emission from young stars and the formation of planetary systems around Sun-like stars.

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## Sub-arcsecond morphology and kinematics of the DG Tau jet in the [OI] $\lambda$ 6300 line

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We present the first 3D spectro-imaging observations of the [O I] $\lambda$ 6300 line in an active T Tauri star: DG Tau. The morphological structure of the mass outflow is revealed with unprecedented spatial resolution (0.35"). It consists of an unresolved inner peak containing two thirds of the total line flux, followed by a collimated jet-like body extending out to  $\sim 1.5''$  from the star, and two resolved knots at distances of 2.7'' and 4''. One of the outer knots possesses a curved morphology and transverse velocity gradient strongly suggestive of a resolved bowshock. Time variability in the ejection velocity (with timescale  $\Delta t \simeq 8.5$  yr) could explain the presence of such a bowshock, the spacing of knots at distances  $\geq 1''$  from the star, and the strong velocity gradients along the jet observed closer to the star. The unresolved inner peak, centered at  $\sim 20$  AU of the star, is apparently stationary and possibly linked to the initial jet collimation. Our size limit and absolute photometry for this peak set new constraints on the jet mass loss rate (between  $1.3 \times 10^{-8}$  and  $6.5 \times 10^{-6} M_{\odot} \text{ yr}^{-1}$ ), lowering previous estimates by a factor 5 to 25. Finally, our high sensitivity combined with velocity information allows us to detect unambiguously the counterjet of the system ( $v \simeq +230$  km/s), and to establish the existence of a diffuse halo of low-velocity [O I] emission, which might trace a wider flow or an extended scattering nebula.

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Preprint available at: <http://www-laog.obs.ujf-grenoble.fr/~lavalley/publist.html>

## A Search for Infall Motions Toward Nearby Young Stellar Objects

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We report observations of 47 candidate protostars in two optically thick lines (H<sub>2</sub>CO 2<sub>12</sub> – 1<sub>11</sub> and CS 2 – 1) and one optically thin line (N<sub>2</sub>H<sup>+</sup> 1 – 0) using the IRAM 30-m, SEST 15-m, and Haystack 37-m radio telescopes. The sources

were selected from the redness of their spectra ( $T_{bol} < 200$  K) and their near distance ( $d < 400$  pc). Most of the sources have asymmetric optically thick lines. The observed distribution of velocity differences,  $\delta V = (V_{thick} - V_{thin})/\Delta V_{thin}$ , is skewed toward negative (blue-shifted) velocities for both the  $H_2CO$  and CS samples. This excess is much more significant for Class 0 than for Class I sources, suggesting that we detect infall motions toward Class 0 and not toward Class I sources. This indicates a difference in the physical conditions in the circumstellar envelopes around Class I and Class 0 sources, but does not rule out the presence of infall onto Class I sources by e.g. lower opacity gas. Bipolar outflows alone, or rotation alone, cannot reproduce these statistics if the sample of sources has randomly oriented symmetry axes. We identify 15 spectroscopic infall candidates, of which 6 are new. Most of these infall candidates have primarily turbulent rather than thermal motions, and are associated with clusters rather than being isolated.

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

## The NGC 281 West Cluster I: Star Formation in Photoevaporating Clumps

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The NGC281 West molecular cloud is an excellent test case for studying star formation in the clumpy interface between a H II region and a giant molecular cloud. We present here a study based on new high resolution radio and near-infrared data. Using the IRAM 30-meter telescope, we have mapped the interface in the  $C^{18}O$  ( $2 \rightarrow 1$ ),  $C^{18}O$  ( $1 \rightarrow 0$ ), and  $C^{34}S$  ( $3 \rightarrow 2$ ) transitions with FWHP beamwidths  $\leq 22''$ . We have imaged the same region with the VLA in the 20, 6 and 2 cm continuum bands to obtain a complementary map of the ionized gas distribution with angular resolutions  $\leq 13''$ . In addition, we have obtained near-infrared  $J$  and  $K'$ -band images to detect young stars in the interface. The 30-meter data shows the molecular gas is concentrated into three clumps with masses of 570,  $> 210$ , and  $300 M_{\odot}$  and average volume densities of 1.4,  $> 1$ , and  $2 \times 10^4 \text{ cm}^{-3}$ . We detect  $C^{34}S$  ( $3 \rightarrow 2$ ) emission in two of the clumps, indicating peak densities in excess of  $5 \times 10^5 \text{ cm}^{-3}$  are attained in the clumps.

A comparison of the  $C^{18}O$  line data with the 20 cm continuum image suggests that the molecular clumps are being photoevaporated through their direct exposure to the UV radiation from neighboring OB stars. The luminosity and extent of the observed 20 cm emission are in good agreement with models of photoevaporative flows. We use these models to estimate the pressure exerted on the clumps by the ionized gas and find that it exceeds the internal, turbulent pressure of the clumps by a factor of a 2.5. Although a pressure equilibrium is not excluded given the uncertainties inherent in determining the pressures of the ionized and molecular gases, our best estimates of the clump and flow parameters favor the the existence of low velocity shocks ( $1.5 \text{ km s}^{-1}$ ) in the clumps. The clumps exhibit broad, non-gaussian lineshapes and complex kinematical structures suggestive of shocks. Further evidence for shocks is found in a comparison of position-velocity diagrams with published numerical simulations of imploding spherical clumps. We discuss the possibility that the knots of  $C^{34}S$  ( $3 \rightarrow 2$ ) emission trace gas compressed by converging shock waves.

The  $K'$ -band observations show a rich cluster of primarily low mass stars in the H II/molecular interface, which we argue is divided into two distinct sub-clusters. We associate one sub-cluster with the two clumps nearest the OB stars, and the second sub-cluster with the third clump. The two clumps nearest the OB stars contain an embedded stellar population, suggesting that star formation is ongoing. We discuss the impact of photoevaporation on star formation in these two clumps. We find that photoevaporation is dispersing the molecular gas from which the cluster is forming and estimate that the molecular gas will be completely evaporated in 2.5 Myr. Deep  $K'$ -band imaging of the two clumps show that the stars are detected primarily on the sides of the clumps facing the OB stars and in the adjoining H II region. We examine three explanations for this asymmetry: the acceleration of the molecular clumps away from the stars by photoevaporation (i.e. the rocket effect), the unveiling of young, embedded stars by ionization-shock fronts, and the triggered formation of stars by shocks advancing into the clumps. If shocks do indeed exist in the clumps, then we argue that shock triggered star formation is the best explanation of the asymmetry.

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## The Proper Motions of the Warm Molecular Hydrogen Gas in Herbig-Haro 1

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We have measured the proper motions of three molecular hydrogen ( $v = 1-0$  2.121  $\mu\text{m}$ ) knots in the Herbig-Haro 1 object using a 4.4 year baseline (1992-1997). The HH 1-F knot, which probably corresponds to the tip of the working surface of HH 1, has a proper motion of  $0.19 \pm 0.10$  ( $''/\text{yr}$ ) and a position angle of  $315^\circ \pm_{-25}^{+29}$ . This motion is comparable to that determined in the *atomic* emission lines of  $\text{H}\alpha$  and  $[\text{S II}] \lambda\lambda 6717/31$ , and confirms that the warm molecular  $\text{H}_2$  gas is partaking of the same motion as the atomic/ionic gas.

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## Search for $\text{H}_2\text{O}$ maser emission from high-latitude IRAS sources

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A high-sensitivity search for water maser emission at 22.2 GHz has been performed on a sample of 91 IRAS point sources at high-latitudes. The aim of the survey is to verify if these clouds are capable of star formation as indicated by the presence of water masers. The sample is based on the recent work of Magnani et al. (1995) who have identified 192 infrared objects from the IRAS Faint Source Survey possibly associated with translucent clouds at galactic latitudes  $|b| \geq 30^\circ$ . These IRAS sources have far-infrared colours typical of young stellar objects and pre-main-sequence stars and thus provide a starting list for further studies about their actual nature.  $\text{H}_2\text{O}$  maser emission is a good diagnostic of the presence of dense gas and of recent star formation. We did not find water maser emission at a level of 0.2–0.5 Jy ( $3\sigma$ ) in any of the 91 objects. The negative result indicates that these high-latitude sources do not represent potential sites of star formation, consistent with the fact that most high-latitude molecular clouds do not appear gravitationally bound.

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## On the rotational evolution of young low-mass stars

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Observations of young clusters indicate that a significant fraction of solar-type stars are rotating very slowly, with equatorial velocities less than  $10 \text{ km s}^{-1}$ . So far, models have failed to reproduce a sufficiently large proportion of these stars on the Zero-Age Main Sequence. On the basis of the idea that the mixing length in convection theories could depend on the size of the convective zone (Canuto & Mazzitelli 1991), we examine the influence of a varying mixing length parameter  $\alpha$  on the rotational evolution of solar-type stars. A decreasing  $\alpha$  (due to evolution) in the mixing length theory (MLT), leads to a slower contraction rate and to a larger stellar moment of inertia. The stellar spin up is consequently reduced and this helps to increase the number of very slow rotators present in young clusters. We also investigate the possibility that  $\alpha$  could depend on the rotation rate, and show the consequences of this parameterization for the lithium surface abundance.

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# Observations of [CI] and CO Absorption in Cold, Low Density Cloud Material Towards the Galactic Center Broad Line Emission

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We report the detection of a deep  ${}^3P_1 \rightarrow {}^3P_0$  [CI] absorption feature at  $v_{lsr} = 12 \text{ km s}^{-1}$  with a linewidth of  $6 \text{ km s}^{-1}$  towards extended line emission at a distance of  $11'$  from Sgr C. The 492 GHz observations were made with the Antarctic Submillimeter Telescope and Remote Observatory (AST/RO). The absorption feature allows the derivation of lower limits for the CI column density in the cold foreground material. The feature is unlikely to be caused by self-absorption within the [CI] emitting cloud because it is observed over a region at least  $4'$  across and is also seen in emission  $22'$  north of the Galactic plane in  ${}^{12}\text{CO J}=2-1$ . In order to determine the temperature and the abundance ratio of CI to CO in the foreground gas, we compare the observations with  ${}^{12}\text{CO}$  and  ${}^{13}\text{CO J}=1-0$  observations obtained with the Bell Labs 7 m antenna and with  ${}^{12}\text{CO}$  and  ${}^{13}\text{CO J}=2-1$  observations made with the KOSMA 3 m telescope. All these observations have about the same beam size. On the assumption that the background emission is not spatially associated with the absorbing cloud(s), a consistent model for the observed line intensities yields an excitation temperature of 3.5 K for  ${}^{13}\text{CO}$  and 5 K for [CI], implying low volume densities  $n(\text{H}_2) \lesssim 10^3 \text{ cm}^{-3}$ . The measured abundance ratio of CI to  ${}^{13}\text{CO}$  is  $\sim 34$ . This value is consistent with photochemical model calculations which predict an abundance ratio of CI to  ${}^{12}\text{CO}$  of  $\sim 1$  and a  ${}^{12}\text{CO}$  to  ${}^{13}\text{CO}$  ratio of  $\sim 30$  (reduced in comparison to the intrinsic  ${}^{12}\text{C}$  to  ${}^{13}\text{C}$  isotopic ratio of 60 by fractionation). The observed  ${}^{13}\text{CO}$  column density corresponds to an  $A_V$  of  $4.6^m$ , i.e., the hydrogen column density  $N(\text{H})$  is  $\sim 9 \times 10^{21} \text{ cm}^{-2}$ . This, together with the observed [CI] linewidth, indicates that the absorption is likely due to several translucent clouds.

We compare our results with line fluxes derived from the large-scale, low resolution COBE FIRAS spectral line survey of [CI]  ${}^3P_1 \rightarrow {}^3P_0$  and [CI]  ${}^3P_2 \rightarrow {}^3P_1$  emission in the galactic plane. Taking into account beam filling, the *lower limit* for the column density of cold ( $T_{ex} \leq 10 \text{ K}$ ) CI which is traced by our absorption observations is at least a factor of two higher than the column density of the warmer CI ( $T_{ex} \geq 20 \text{ K}$ ) detected in emission by COBE. Our results suggest that a substantial fraction of atomic carbon in the interstellar medium may be difficult to detect in [CI] emission, due to its low excitation.

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## Binary Search among X-ray Active Stars South of the Taurus Molecular Cloud

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We have conducted an R-band imaging survey of a ROSAT X-ray selected sample of 99 stars south of the Taurus-Auriga association using the WIYN 3.5m telescope under subarcsec seeing conditions (typically  $\sim 0.7''$ ). Recent optical spectroscopic identifications show that this sample contains 17 Pleiades-like stars, 17 emission-line stars, 32 active corona stars, and 32 stars judged to be younger than the Pleiades by the strength of their lithium absorption. A considerable fraction of these young Li-rich stars are probably weak-line T Tauri stars (TTS). In total, we resolve 21 binary stars, 3 of them having separations less than  $1.0''$ . Within the young Li-rich subsample, we find 9 companions in the separation range between  $0.6''$  and  $14''$ . The visual binary fractions among the young and active stars within the sample are similar and compatible with expectations from main-sequence field stars in the solar neighborhood. We

discuss some implications of these results for understanding the nature of the widespread, X-ray active, young stellar population recently identified around nearby star forming regions.

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## **Interferometric $^{13}\text{CO}$ Observations of the Cometary Bright-Rimmed Cloud No. 37 in IC1396: Evidence for Collapse Phase of Radiation-Driven Implosion?**

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Interferometric observations of the cometary bright-rimmed cloud BRC37 (GN21.38.9) located at the periphery of the HII region IC 1396 were made with the Nobeyama Millimeter Array (NMA) in the  $^{13}\text{CO}(J=1-0)$  transition. Although the global distribution of the molecular gas is consistent with the previous single dish results (Duvert et al. 1990, AA 233, 190), our high resolution data clearly show small scale structures with blueshifted velocity components corresponding to two clear tails stretching from the globule head toward the opposite direction to the exciting star of IC1396. The elongation direction of these tails and other circumstances suggest an interaction with the UV radiation from the exciting star of IC1396. The position-velocity diagram along the cloud axis shows a velocity pattern which may be explained by the collapsing gas motion. The morphology as well as the position-velocity diagram seems to be in agreement with the collapse phase of the recent 2D simulations of the radiation-driven implosion of the neutral globule due to UV radiation from OB stars (Lefloch & Lazareff 1994, AA 289, 559).

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## **A Radio Jet- $\text{H}_2\text{O}$ Maser System in W 75N(B) at 200 AU Scale: Exploring the Evolutionary Stages of YSOs**

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We have observed simultaneously with the VLA in its A configuration the 1.3 cm continuum and  $\text{H}_2\text{O}$  maser emission toward the star-forming region W 75N(B) with  $0.''1$  resolution using a powerful cross-calibration technique. Three continuum sources (VLA 1, VLA 2, and VLA 3) were detected in a region of  $1.''5$ . VLA 1 is elongated ( $0.''43 \times 0.''12$ ) approximately in the direction of the bipolar molecular outflow observed at scales of  $2''$ . The frequency dependence of the flux density and size is consistent with an optically partially-thick ionized thermal biconical jet. VLA 2 appears unresolved, while VLA 3 shows a bright core plus extended emission. We detected 29  $\text{H}_2\text{O}$  maser spots (spatial components) in a region of  $13'' \times 7''$  around W 75N(B). These masers are mainly distributed in two clusters, one associated with VLA 1 (11 maser spots) and the other one associated with VLA 2 (8 maser spots). One  $\text{H}_2\text{O}$  maser spot is associated with VLA 3. The masers associated with VLA 1 are distributed along the major axis of the radio jet. We conclude that VLA 1 is the powering source of the extended bipolar molecular outflow and that the water masers along the radio jet axis are delineating the outflow at scales of  $1''$ . On the other hand, the eight masers coincident with VLA 2 are distributed in a shell of  $0.''18 \times 0.''10$ , with a rough north-south velocity segregation that could indicate bound motions around this continuum source. From the comparison of  $\text{H}_2\text{O}$  and OH maser distribution in the region with respect to the three radio sources, we consider an evolutionary scheme in which  $\text{H}_2\text{O}$  masers are

excited in gravitationally bound material (e.g., in circumstellar disks) in less evolved young stellar objects, while in more evolved YSOs H<sub>2</sub>O masers preferentially trace outflows.

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<http://www.laeff.esa.es/eng/papers/abs97/laeff-9714.ps.Z>

## X-Ray Sources in Regions of Star Formation.

### VI. The R CrA Association as Viewed by *EINSTEIN*

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We report on optical identifications of X-ray sources in the vicinity of the R CrA association. We identify 11 low-mass pre-main-sequence stars as counterparts of 9 X-ray sources. We also find X-ray emission from coordinates consistent with the position of 3 bright late-B stars, although the emission may come from lower mass companions. The X-ray-selected stars lie along a narrow locus in the luminosity-temperature diagram at an age of about 7 Myr, which is considerably older than the estimated ages of the higher mass stars or of the IR-excess stars. We determine the physical characteristics of these stars, including masses, ages, and Lithium abundances. We estimate that the complete membership of the R CrA association amounts to about 90 stars, mostly older naked T Tauri stars, and that the population is consistent with the standard IMF.

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## Kinematics and Electron Temperatures in the Core of Orion A

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A map of the core of Orion A, with a 42'' resolution in the 64 $\alpha$  recombination line of hydrogen, covering  $\sim 5'$  by  $\sim 5'$ , is presented. The  $V_{\text{lsr}}$  distribution shows a complex variation about the center of the ionized gas emission: From  $\Delta\alpha = -200''$  to  $+300''$ , the  $V_{\text{lsr}}$  varies from  $-5 \text{ km s}^{-1}$  to  $+2 \text{ km s}^{-1}$  then to  $-4 \text{ km s}^{-1}$ , finally rising to  $+3 \text{ km s}^{-1}$ . A search for cold ( $T_e \sim 3000\text{K}$ ) ionized gas toward the KL nebula has revealed no measurable differences in  $T_e$  between this region and other parts of Orion A. The average  $T_e$  from our data is  $8300 \pm 200\text{K}$ . We find *no* significant difference between  $T_e$  values determined from radio recombination lines and those determined from forbidden optical lines of [O III], although the  $T_e$  value from Balmer decrement data is markedly lower. The turbulent velocity varies by  $< 5\%$  over the region mapped. On the basis of our 2.45' resolution, high dynamic range 6 cm continuum map, we find that the emission falls off faster in the East than in the West. We find support for the model in which Orion A is ionization bounded in the East but density bounded in the West. The ionized gas in the West is flowing in the direction of the Sun, while the more positive  $V_{\text{lsr}}$  values in the east may be caused by the flow of ionized gas off the foreground Dark Bay. This ionized region may have little fine scale structure, since there is little continuum emission in interferometer maps.

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## *Dissertation Abstracts*

# **The Spectral Signature of Accretion in Low-Mass Protostars: Observations and Non-LTE Modelling**

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Ph.D dissertation directed by: Dr. R. Güsten

Ph.D dissertation examined by: Prof. J. Schmid-Burgk, Prof. U. Klein

Ph.D degree awarded: 9 June 1997

This work demonstrates the feasibility of a study bringing together theoretical concepts of the earliest phase of low-mass star formation and its observational evidence. Thus, two aspects have been considered:

- **Observational evidence:** In order to detect protostellar collapse by virtue of kinematical features in spectral line profiles, both optically thick and optically thin tracers are needed. According to Leung & Brown (1977, ApJ 214, L73), a protostellar envelope undergoing collapse exhibits a red-shifted self-absorption in a molecular line transition if the excitation gradient is negative. Optically thin emission (e.g. from the corresponding isotopomere's line) corroborates the conclusions by ruling out the case of independent components filling the observing beam. The nearby ( $d \sim 200$  pc) globular filament L 1082 (no. 9 from a catalog assembled by Schneider & Elmegreen, 1979, ApJS 41, 87) provides at least three candidates showing unambiguous footprints of protostellar collapse. By means of millimeter-interferometry<sup>1</sup> as well as single dish spectroscopy and continuum imaging<sup>2</sup>, these candidates were identified and characterized. As moderately optically thick high-density tracers, the CS (2,1), (3, 2) and (5, 4) transitions have been observed. The optically thin (2, 1) lines of C<sup>34</sup>S and C<sup>18</sup>O were measured to confirm the evidence for collapse. Preliminary results from observations with ISOPHOT and ISOCAM were used to better constrain the luminosity of one of the collapse candidates, which subsequently has been classified as an extreme Class 0 protostar.
- **Theoretical concepts:** For reasons evidenced by the observed column density distributions and by systematic shifts of the molecular line emission across the sources, spherically-symmetric collapse has to be ruled out. Instead, scenarios such as core formation in sheet-like clouds (as proposed by Hartmann et al., 1994, ApJ 430, L49) and magnetic accretion shocks (Li & McKee, 1996, ApJ 464, 373) are discussed. Most models are calculated by semi-analytical methods.

The CS emission is severely affected by non-LTE effects in the subcritical envelope regions. Therefore, I developed a code to solve the excitation conditions in cylindrical symmetry, leaving off simplifying assumptions such as micro-turbulent approaches or the limiting case of a large velocity gradient. It is entirely possible to solve for the non-LTE radiative transfer problem with a classical ray-tracing approach: even for non-local coupling between radiation and matter, only part of a cloud has to be considered. Using a multivariate quadrature rule published by Steinacker et al. (1995, JQSRT), and second-order acceleration of convergence together with a modified convergence criterion (as proposed by Dickel & Auer, 1994, ApJ 437, 222), it has been possible to perform a parameter study considering the effects of inclination, rotation, and turbulence on the line profiles. As an example, a toroidal protostellar envelope, as seen in the CS lines, shows a red-shifted self-absorption feature if it is viewed from the edge. The feature disappears in case of a face-on orientation. – Finally, I tried to describe the observations in terms of the above models. At present, it is not possible to rule out either of the (simplifying) scenarios considered. Nevertheless, some features in the line profiles are reproduced, using models that satisfy constraints inferred from various mass estimates. Characteristic scale-heights are deduced that allow for a comparison with the period of the regularly spaced globules.

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<sup>1</sup>with the IRAM and BIMA interferometers

<sup>2</sup>using the IRAM 30 m telescope

## *New Books*

# **Herbig-Haro Flows and the Birth of Low Mass Stars**

Edited by **Bo Reipurth and Claude Bertout**

Proceedings of IAU Symposium No. 182 held in Chamonix, France 20-24 January 1997

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hosted by the  
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**Tonantzintla, Puebla, MEXICO**  
**January 12-16, 1998**

This conference is part of the Programa de Investigacion en Astrofisica Avanzada Guillermo Haro created in 1995 by INAOE. (<http://www.inaoep.mx/progharo/>)

Turbulence is universal and mysterious, and it remains as one of the major unsolved problems in physics and astrophysics. It is present in all terrestrial and astrophysical environments: close to our telescopes, it blurs and distorts our view of the skies, and in the interstellar medium, somehow, it removes angular momentum and leads to star formation. Jets, outflows, outburst, the atmosphere and the interstellar medium as a whole are all turbulent media.

This conference is aimed at revising our conceptions on the onset and properties of turbulence, and at summarizing the present status in observational, theoretical, and computational research in interstellar turbulence. It will also include turbulence in our atmosphere, which results in atmospheric seeing.

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