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## *Abstracts of recently accepted papers*

### **Lifetimes of Ultracompact HII Regions: High Resolution Methyl Cyanide Observations**

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We observed the dense molecular cores associated with two ultracompact HII regions, G5.89 + 0.4 and G34.3 + 0.2, in the  $J=6-5$  transitions of  $\text{CH}_3\text{CN}$  to probe the temperature and density of the gas. Simultaneously, each region was observed in the  $J=1-0$  transition of a CO isotope to probe the molecular column density. The molecular cores are found to have densities  $\sim 10^6 \text{ cm}^{-3}$  and kinetic temperatures of 90 K and 250 K, respectively. We also find possible evidence for infall of molecular gas toward the HII regions.

The lifetime of the HII region ultracompact phase is critically dependent on the properties of the surrounding molecular gas. Based on the number of ultracompact HII regions versus the total number of O stars, it has been suggested that the lifetime of the ultracompact phase is inconsistent with spherical expansion confined only by the ambient medium. We show that for the molecular cloud parameters given above and including the effect of the shell of neutral material formed by the expansion, pressure confinement by the ambient medium may significantly increase the lifetime of the ultracompact phase of the HII regions.

Accepted by Ap. J.

### **Probing the initial conditions of star formation: The structure of the prestellar core L1689B**

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In a recent JCMT submillimeter study, Ward-Thompson et al. (1994) obtained the first dust continuum maps of five low-mass dense cores among the sample of starless ammonia cores from Myers and colleagues. Here, we present the results of new 1.3 mm continuum mapping observations for one of these cores, L1689B, taken with the IRAM 30-m telescope equipped with the 7-channel and 19-channel MPIFR bolometer arrays. The new 1.3 mm data, L1689B, which were obtained in the 'on-the-fly' scanning mode, have better angular resolution and sensitivity than the earlier 800  $\mu\text{m}$  data, reaching an rms noise level of  $\sim 3 \text{ mJy}/13''$  beam. Our IRAM map resolves L1689B as an east-west elongated core of deconvolved size  $0.045 \text{ pc} \times 0.067 \text{ pc}$  (FWHM), central column density  $N_{\text{H}_2} \sim 1.5 \times 10^{22} \text{ cm}^{-2}$ , and mass  $M_{\text{FWHM}} \sim 0.6 M_{\odot}$ , in good agreement with our previous JCMT estimates. We confirm that the radial column density profile  $N(\theta)$  of L1689B is not consistent with a single power law with angular radius  $\theta$  but flattens out near its centre. Comparison with synthetic model profiles simulating our 'on-the-fly' observations indicates that  $N(\theta_{\text{maj}}) \propto \theta_{\text{maj}}^{-0.2}$  for  $\theta_{\text{maj}} \leq 25''$  and  $N(\theta_{\text{maj}}) \propto \theta_{\text{maj}}^{-1}$  for  $25'' < \theta_{\text{maj}} \leq 90''$ , where  $\theta_{\text{maj}}$  is measured along the major axis of the core. The observed mean profile is *not* consistent with a simple Gaussian source, being flatter than a Gaussian in its outer region. However, the profile measured along the minor axis of L1689B is significantly steeper and apparently consistent with a Gaussian 'edge' in the north-south direction. The mass, radius, and density of the

relatively flat central region are estimated to be  $\sim 0.3 M_{\odot}$ ,  $\sim 4000$  AU, and  $\sim 2 \times 10^5 \text{ cm}^{-3}$ , respectively.

The mass of L1689B and its large ( $> 30$ ) density contrast with the surrounding molecular cloud indicate that it is not a transient structure but a self-gravitating pre-stellar core. The flat inner profile and other measured characteristics of L1689B are roughly consistent with theoretical predictions for a magnetically-supported, flattened core either on the verge of collapse or in an early phase of dynamical contraction. In this case, the mean magnetic field in the central region should be  $\lesssim 80 \mu\text{G}$ , which is high but not inconsistent with existing observational constraints. Alternatively, the observed core structure may also be explained by equilibrium models of primarily thermally supported, self-gravitating spheroids interacting with an external UV radiation field.

The present study supports the conclusions of our previous JCMT survey and suggests that, in contrast with protostellar envelopes, most pre-stellar cores have flat inner density gradients which approach  $\rho(r) \propto r^{-2}$  only beyond a few thousand AU. This implies that, in some cases at least, the initial conditions for protostellar collapse depart significantly from a singular isothermal sphere.

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## Discovery of a jet emanating from the protostar HH24 MMS

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We report the results of new near-IR, radio continuum, and CO(3–2) observations of the immediate surroundings of the strong submillimetre dust source HH24 MMS. Our near-IR imaging reveals that a short jet of shocked molecular hydrogen is closely associated with the submm clump. The new 3.6 cm map shows that at least part of the radio emission is extended, on a scale consistent with the spatial extension of the near-IR jet. We interpret this elongated centimetre emission as free-free radiation from the shock-ionized portion of the jet. Although our CO(3–2) data do not have enough angular resolution to resolve a bipolar outflow in this complex region, they demonstrate that high-velocity molecular gas is associated with HH24 MMS. Altogether, these results support our earlier claim that the HH24 MMS clump contains a very young Class 0 protostar.

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## Evolution of the Solar Nebula. III. Protoplanetary Disks Undergoing Mass Accretion

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The physical structure of a protoplanetary disk determines the mechanisms responsible for the disk's dynamical evolution as well as how the earliest phases of planetary accumulation proceeded. Thermal and density profiles control the extent to which processes such as self-gravitational forces, convective instability, and magnetic fields contribute to the dynamical evolution of the disk. Thermal profiles also affect the chemical composition of the grain aggregates that eventually formed planetesimals through their control of the condensation and sublimation of iron, silicate, and ice grains. A two dimensional radiative hydrodynamics code has been used to compute a number of quasistatic models of protoplanetary disks. Variations explored by the models include changes in the disk mass, stellar mass, disk mass accretion rate, initial adiabat, radial density profile, energy source, and dust grain opacity. The models represent temporal 'snapshots' that can be used to infer the evolution of disks as, e.g., the disk mass or disk mass accretion rates decrease. A general property of low mass ( $\sim 0.02M_{\odot}$ ) disks being heated by mass accretion from the cloud envelope at  $\sim 10^{-6}$  to  $10^{-5}M_{\odot} \text{ yr}^{-1}$  is a relatively hot (midplane temperature  $T_m > 1200$  K) inner region surrounded by a much cooler ( $T_m \sim 100$  K) outer disk. Such a thermal profile naturally leads to the formation of rocky inner planets and icy outer planets, with the ice condensation point never falling closer than about 3 AU from the protostar – giant planets must form outside this radius. Midplane temperatures greater than 1200 K are consistent with the depletions of moderately volatile elements observed in inner solar system bodies. Disk temperatures drop sufficiently with vertical height or radial position, or with decreased disk mass or disk mass accretion rates, to permit the plausible

incorporation of both  $\sim 1200$  K and  $< 700$  K components in chondritic meteorites. Surface densities of low mass disks appear to be inadequate for the disk to evolve through gravitational torques, and the models tend to be largely stable with respect to convection, which could otherwise lead to turbulence and significant viscous torques. Thermal ionization of K and Na may allow the generation of significant magnetic fields near the midplane in the inner disk, while cosmic rays and short-lived nuclides ionize the outer disk, perhaps eliminating the possibility of a field-free gap between these two regions and allowing continued magnetically-driven inflow of disk mass to the protostar.

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## Protoplanetary Disks, Mid-IR Dips, and Disk Gaps

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The spectral energy distributions (SEDs) of pre-main-sequence (PMS) stars provide observational constraints on the physical properties of the protoplanetary disks that dominate PMS emission at wavelengths longer than a few microns. Many PMS stars have a peculiar signature: a relatively smooth SED from  $\sim 1\mu\text{m}$  to  $\sim 100\mu\text{m}$ , accompanied by a broad *dip* in the mid-infrared ( $\sim 10\mu\text{m}$ ). These mid-IR dips could be caused by gaps in a protoplanetary disk with a simple power law structure, or could arise in a *continuous* disk with a more realistic structure than the power law assumption permits. A two dimensional radiative hydrodynamics code has been used to construct a suite of detailed protoplanetary disk models where the thermal structure is determined by the balance between radiative cooling and compressional or viscous heating (Boss 1995). Here we use a two dimensional ray-tracing code (Yorke 1986) to compute the SEDs of these disk models for comparison with the nominal SED of the prototypical PMS star with a mid-IR dip, T Tau. We have reproduced the SED of the same disk as that used by Boss & Yorke (1993), which yielded a good fit to the T Tau spectrum, and have extended the results to include models with varied disk masses, stellar masses, inclinations, opacities, mass accretion rates,  $\alpha$ -viscosities, and midplane density profiles. For disks undergoing mass accretion from their envelopes at a rate of  $\sim 10^{-6} - 10^{-5} M_{\odot}/\text{yr}$ , disks with masses of  $\sim 0.01$  to  $0.02 M_{\odot}$  orbiting a solar-mass star yield SEDs close to that of T Tau. Variations in the dust grain opacity have relatively little effect, but a steeper midplane density profile ( $\rho_o \propto r^{-2}$ , instead of  $\rho_o \propto r^{-3/2}$ ) leads to a mid-IR *hump* rather than a dip. For a disk mass of  $\sim 0.02 M_{\odot}$ , disk mass accretion rates in the range of  $\sim 10^{-7} - 10^{-5} M_{\odot}/\text{yr}$  are indicated for T Tau. When viscous heating is employed, a viscous  $\alpha = 0.01$  yields a good fit, whereas  $\alpha = 0.1$  produces a large mid-IR excess. These SEDs should be useful for interpreting *ISO* and *SIRTF* observations of protoplanetary disks.

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## Azimuthal structures in the wind and chromosphere of the Herbig Ae star AB Aur. Results from the MUSICOS 1992 campaign.

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The observations of the MUSICOS 1992 campaign concerned three scientific programs, among which was the study of azimuthal structures in the wind and chromosphere of the pre-main sequence Herbig Ae star AB Aur.

The HeI5876 Å line of AB Aur, which is formed in the expanding chromosphere of this star, most probably in the innermost parts of its wind, was continuously monitored at a spectral resolution of 30000 for about 4 days. The line was discovered to be variable in a spectacular way, the profile changing from pure emission to a composite profile including a deep absorption component in the course of a few hours. In this paper we present strong clues that suggest a rotational modulation of the line, with a period corresponding to the stars rotation period of 32 hrs.

We confirmed the covariation of several non-photospheric spectral lines, formed at very different radial distances of the star, which strengthens the idea that the variability is the signature of azimuthal structures in the wind of AB Aur, most probably due to magnetically confined streams or loops emanating from the stellar surface.

We present the data collected during the MUSICOS 1992 campaign, but also a data set of the HeID3 line obtained with FOE at KPNO during the years 1991–1994 and a series of IUE spectra containing the Mg II h & k UV lines obtained one month prior to the campaign.

A thorough discussion of the possible interpretations of the spectacular variations of the HeI5876 Å line is presented.

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## High Resolution Millimeter Imaging of L1641N: Multiple Cores with a Young Stellar Group

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We report interferometric imaging of a young stellar group L1641N (IRAS 05338-0624) in the CS J = 3-2 line and the 2-mm continuum. Seven line emission peaks are identified within 0.1 pc of the IRAS position. The physical properties of these peaks (central velocity, line width, mass, and density) have been used to infer their nature. We conclude that three of these peaks (1-3) are likely to be real molecular gas condensations. These three cores are closely associated with the stellar group in which young stars have been continuously forming over the last few Myr. They are also more massive than the gas clumps detected interferometrically toward the well-known star forming cores in Taurus, and are thus capable of forming young stellar objects. The different core characteristics (mass, density, and the association with young stellar objects) suggest that these cores are at different stages of dense core evolution with cores ranging from quiescent pre-protostellar, to turbulent starless, and to actively star-forming.

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## Precessing Jets and Molecular Outflows: A 3-D Numerical Study

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We present 3-D numerical hydrodynamical simulations of precessing supersonic heavy jets to explore their evolution, how they differ from straight jets and how well they serve as a model for generating molecular outflows from Young Stellar Objects. The dynamics are studied with a number of high resolution simulations on a Cartesian grid (128x128x128 zones) using a high order finite difference method. A range of cone angles and precession rates were included in the study. Two higher resolution runs (256x256x256 zones) were made for comparison in order to confirm numerical convergence of global flow characteristics. Morphological, kinematical and dynamical characteristics of precessing jets are described and compared to important properties of straight jets and also to observations of YSOs.

In order to examine the robustness of precessing jets as a mean to produce molecular outflows around Young Stellar Objects, “synthetic observations” of the momentum distributions of the simulated precessing jets are compared to observations of molecular outflows. It is found that precessing jets match better the morphology, highly forward driven momentum and momentum distributions along the long axis of molecular outflows than do wind-driven or straight jet-driven flow models.

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## The galactic distribution and luminosity function of ultracompact HII regions

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The distribution of ultracompact HII regions in the IRAS Point Source Catalog in both galactic longitude and flux are studied in this paper, to derive the radial surface density profile in the galactic disk and the luminosity function under the assumptions of cylindrical symmetry and a position-independent luminosity function. An advantage of this approach is that the surface density profile is derived independently of kinematical information, allowing us to probe the inner regions of the galactic disk where kinematical distances become unreliable.

An interesting result of our analysis is the discovery of a star forming ring about 2 kpc from the galactic center, possibly associated with the Inner Lindblad Resonance as observed in external galaxies with strong bars. On the other hand, comparison with the mass function in the solar neighbourhood allows us to estimate the average lifetime of ultracompact HII regions, which appears to be less than  $10^5$  years, contrary to previous estimates. The luminosity function also suggests that this lifetime is not sensitive to the mass of the exciting star. The supernova rate in the galactic disk as derived from our results is found to be compatible with other current estimates.

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## AFGL 4029: a cluster of massive young stars

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The molecular cloud IC 1848A, located at the border of the extended H II region S 199, harbors the bright infrared source AFGL 4029. A young star cluster is observed in this direction. We present an optical and near infrared study of this cluster, which contains at least thirty B stars. The visual extinction affecting the stars attains 30 mag, and shows large variations on very small scales. The most massive star, possibly a B1V, ionizes the ultracompact H II region G138.300+1.558. The youngest object of the cluster, AFGL 4029-IRS 1 – identical to the radio source G138.295+1.555 – is a massive pre-main-sequence object illuminating a reflection nebula. AFGL 4029-IRS 1 is luminous ( $\sim 10^4 L_{\odot}$ ) and highly reddened ( $A_V = 25\text{--}30$  mag); displaying many of the spectral characteristics of pre-main-sequence objects (including bright and broad emission lines and the presence of Fe II emission), it is very similar to the most luminous Herbig Ae/Be stars. AFGL 4029-IRS 1 shows evidence of mass ejection: it emits an ionized stellar wind with terminal velocities of about  $400 \text{ km s}^{-1}$  and a mass loss rate of about  $7 \cdot 10^{-6} M_{\odot} \text{ yr}^{-1}$ ; it is associated with a CO outflow and a high velocity optical jet; a bright unresolved H<sub>2</sub> clump is observed in its vicinity. The whole complex is a very efficient star forming region, as about 10% of the mass of the parental molecular cloud has been used to form B stars.

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# Radiative Torques on Interstellar Grains: I. Superthermal Spinup

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Irregular dust grains are subject to radiative torques when irradiated by interstellar starlight. It is shown how these radiative torques may be calculated using the discrete dipole approximation. Calculations are carried out for one irregular grain geometry, and three different grain sizes. It is shown that radiative torques can play an important dynamical role in spinup of interstellar dust grains, resulting in rotation rates which may exceed even those expected from H<sub>2</sub> formation on the grain surface. Because the radiative torque on an interstellar grain is determined by the overall grain geometry rather than merely the condition of the grain surface, the resulting superthermal rotation is expected to be quite long-lived. By itself, long-lived superthermal rotation would permit grain alignment by normal paramagnetic dissipation on the “Davis-Greenstein” timescale  $\tau_{\text{DG}}$ . However, radiative torques arising from anisotropy of the starlight background can act directly to alter the grain alignment on times short compared to  $\tau_{\text{DG}}$ . Radiative torques must therefore play a central role in the process of interstellar grain alignment.

The radiative torques depend strongly on the grain size, measured by  $a_{\text{eff}}$ , the radius of a sphere of equal volume. In diffuse clouds, radiative torques dominate the torques due to H<sub>2</sub> formation for  $a_{\text{eff}} = 0.2\mu\text{m}$  grains, but are relatively unimportant for  $a_{\text{eff}} \leq 0.05\mu\text{m}$  grains. We argue that this may provide a natural explanation for the observation that  $a_{\text{eff}} \gtrsim 0.1\mu\text{m}$  grains in diffuse clouds are aligned, while there is very little alignment of  $a_{\text{eff}} \lesssim 0.05\mu\text{m}$  grains. We show that radiative torques are ineffective at producing superthermal rotation within quiescent dark clouds, but can be very effective in star-forming regions such as the M17 molecular cloud.

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Preprints: <http://www.astro.princeton.edu/~library> (POPe-668) or <http://xxx.lanl.gov/archive/astro-ph> (9605046).

## Triggering Star Formation with Stellar Ejecta

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We examine inducing the self-gravitational collapse of molecular cloud cores with stellar ejecta. We study the effect of winds of various strengths arriving at cloud cores modeled as marginally stable Bonnor-Ebert spheres, which are unstable both to collapse and to expansion. We find that some winds instigate collapse of the cloud core, while others result in expansion or destruction of the cloud. Collapse occurs when the incident momentum of the ejecta is greater than approximately  $0.1 M_{\odot} \text{ km/s}$ , for the standard  $\gamma = 1$  wind and  $1 M_{\odot}$  cloud scenario. The critical momentum which divides those cases which induce collapse and those which do not, scales as the mass of the cloud times its sound speed, which is  $0.2 M_{\odot} \text{ km/s}$  for the standard 10 K cloud. The critical momentum is exceeded for some supernova and many protostellar outflows, although if the wind has a velocity greater than approximately 100 km/s, the effective adiabatic index will be  $\gamma = 5/3$  and the cloud will be destroyed, through shredding into many pieces. The planetary nebulae of AGB stars appear to have momenta below the critical value. However, we found that a high wind temperature ( $T \sim 600 \text{ K}$ ), possibly characteristic of AGB star winds, could instigate collapse even in low momentum winds.

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## A Massive Cometary Cloud Associated with IC 1805

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High resolution, wide field imaging of <sup>12</sup>CO, 21cm line and continuum and IRAS far infrared emissions from the outer Galaxy has identified a massive cometary molecular cloud associated with IC 1805. The dense cloud is remnant molecular material within a large 10<sup>2</sup> pc sized cavity evacuated by the stellar winds and UV radiation field of the cluster O stars. A 37 pc long molecular tail points directly away from the sources of ionizing radiation and is likely due to the effective shielding of radiation by the dense gas and associated dust within the cometary head region. Maps of C<sup>18</sup>O J=1-0 and CS J=2-1 emissions are presented which constrain the column and mean volume densities within the cometary head region to 10<sup>22</sup> cm<sup>-2</sup> and 10<sup>4</sup> cm<sup>-3</sup> respectively. A 1155 L<sub>⊙</sub> point source embedded within the dense gas of the cometary head region provides evidence for ongoing star formation which may have been triggered by shocks driven by the ionization front.

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<http://fcrao1.phast.umass.edu/>

## An Outburst of a Deeply Embedded Star in Serpens

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We have discovered a substantial increase in the K-band brightness of a young, deeply embedded star in the Serpens NW star-forming region between 1994 August and 1995 July. The photometric history suggests a similarity to FUor or EXor outbursts. The star is more deeply embedded than any previous examples of those two types of eruptive events, however. Even in its bright state the object is invisible in J, only scattered radiation is seen in H, the K band is still dominated by scattered light, and only in L' and longer wavelengths do we see a pointlike source. The Serpens Deeply Embedded Outburst Star (DEOS) has been detected at 800 μm, confirming its very young age. Its spectrum between 2.0 μm and 2.5 μm is a very steep, pure continuum, steeper than any published spectrum of a young embedded star. It is most likely thermal radiation from dust enshrouding the young star and completely masks any of the spectral features characterizing less obscured FUors and EXors. The outburst luminosity is only ≈ 15 L<sub>⊙</sub>, so that the pre-outburst luminosity must have been very low. The Serpens DEOS is probably a young star of very low mass.

Accepted by the Astrophysical Journal

# Water Ice in the Disk Around the Protostar AFGL 2136 IRS 1

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The protostar AFGL 2136 IRS 1 illuminates the Juggler nebula and drives a massive molecular outflow. The line of sight toward AFGL 2136 also displays a rich spectrum of solid state absorption features. To investigate the distribution of ice-coated grains in the environment of IRS 1, we obtained narrow-band images at six near-infrared wavelengths surrounding and including the 3.08  $\mu\text{m}$  water ice feature. These images (specifically, a color map constructed from 2.14 and 3.60  $\mu\text{m}$  images) provide vivid evidence for the presence of a disk around IRS 1 and appear to reveal, for the first time, the detailed distribution of water ice in the local environment of a protostar. Models of the 2 to 4  $\mu\text{m}$  spectral energy distributions (SEDs) toward IRS 1 and the Juggler nebula suggest that the abundance of icy grains is larger along lines of sight through this disk than along lines of sight away from the equatorial plane of IRS 1. Thus, while we find evidence that icy grains exist throughout the cloud core containing AFGL 2136, it appears that the physical conditions in the circumstellar disk around IRS 1 are more conducive to ice mantle survival and/or growth than are conditions in its rarefied polar regions.

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A preprint is available via anonymous ftp to node space.mit.edu, directory ~ftp/pub/jhk/Juggler (consult the file README.paper3).

# Three Millimeter Molecular Line Observations of Sagittarius B2: II. High Resolution Studies of C<sup>18</sup>O, HNC, NH<sub>2</sub>CHO, and HCOOCH<sub>3</sub>

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High resolution imaging of C<sup>18</sup>O, HNC, NH<sub>2</sub>CHO, and HCOOCH<sub>3</sub> in Sgr B2 are presented in this study. The C<sup>18</sup>O emission mainly comes from the Sgr B2(M) and Sgr B2(N) dense cores, and the western gas clump HNO(M). Toward Sgr B2(M), the C<sup>18</sup>O column density is 2 times higher and the fractional abundance is 80 times higher than toward Sgr B2(N). In HNO(M), the narrow linewidth implies the C<sup>18</sup>O emission arises from the diffuse gas. The complex molecules NH<sub>2</sub>CHO and HCOOCH<sub>3</sub> were only detected toward the Sgr B2(N) core. The HNC K<sub>-1</sub> = 2 emission is detected only in Sgr B2(N) and is attributed to efficient radiative pumping, which indicates the significant presence of far-infrared field and warm dust grains. Only ~4% of the HNC was found in the K<sub>-1</sub> = 0 ladders in Sgr B2(N). The non-detection of the K<sub>-1</sub> = 2 emission toward Sgr B2(M) is caused by excitation and low abundance. In contrast, the HNC K<sub>-1</sub> = 0 emission mainly comes from the extended gas component: the far northern region and HNC(SW). For the K<sub>-1</sub> = 0 transitions, T<sub>rot</sub> = ~7 K. The low T<sub>rot</sub> and the apparent ubiquity of HNC suggest abundant HNC exists in the Sgr B2 envelope. The HNC K<sub>-1</sub> = 0 emission unveiled two spatially extended velocity components; the velocity gap between them covers the same LSR velocities of the Sgr B2 dense cores. If HNC is formed via surface reactions, the pervasive detection of HNC in the outer edges of Sgr B2 cloud core leads to the cloud-cloud collision postulate.

A north-south C<sup>18</sup>O bipolar structure was seen in Sgr B2(M) centered at the compact HII region F. The bipolar structure appears asymmetric and thus favors the outflow interpretation. The sharp outer edges of the C<sup>18</sup>O line profiles of the two lobes further support the outflow picture. The estimated outflow age is  $\sim 2 \pm 1 \times 10^4$  yr and the total mass is  $\sim 1700 M_{\odot}$ . The outflow masses for the blue and red lobes are  $\leq 360 M_{\odot}$  and  $\leq 410 M_{\odot}$ , respectively. The mass loss rate is thus  $\leq 0.037 M_{\odot} \text{ yr}^{-1}$ . The detection of outflows in Sgr B2(M) supports the gas dispersal picture and subsequent chemical variations disclosed by the HNO and HC<sup>13</sup>CCN emission void. Three distinct velocity components toward Sgr B2(N) were seen from the HNC K<sub>-1</sub> = 2 emission. The broad component is centered at the HII region K2 with a N-S velocity gradient, which is probably due to rotation. The mass of the rotating cloud is between  $\sim 630$  and  $1570 M_{\odot}$ . The two narrow components are located on the opposite sides of the K1-K2 ridge and are in fact the two lobes of a gas outflow. The estimated outflow age of Sgr B2(N) is  $\sim 6 \times 10^3$  yr, which is a factor of 3 younger

than Sgr B2(M). The outflow masses are  $\leq 200$  and  $\leq 300 M_{\odot}$  for the red and blue lobes, respectively. This yields a mass loss rate  $\leq 0.08 M_{\odot} \text{ yr}^{-1}$ , about two times higher than that of Sgr B2(M). All these suggest Sgr B2(N) is much younger than Sgr B2(M). Finally, high resolution imaging of the radiatively excited HNC  $K_{-1} = 2$  transition allows the separation of an apparent bipolar structure into a gas outflow and a rotating disk cloud.

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## The tidally induced warping, precession and truncation of accretion discs in binary systems: Three dimensional simulations

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We present the results of non linear, hydrodynamic simulations, in three dimensions, of the tidal perturbation of accretion discs in binary systems where the orbit is circular and not necessarily coplanar with the disc mid-plane. The accretion discs are assumed to be geometrically thin, and of low mass relative to the stellar mass so that they are governed by thermal pressure and viscosity, but not self-gravity. The parameters that we consider in our models are the ratio of the orbital distance to the disc radius,  $D/R$ , the binary mass ratio,  $M_s/M_p$ , the initial inclination angle between the orbit and disc planes,  $\delta$ , and the Mach number in the outer parts of the unperturbed disc,  $\mathcal{M}$ . Since we consider non self-gravitating discs, these calculations are relevant to protostellar binaries with separations below a few hundred astronomical units.

For binary mass ratios of around unity and  $D/R$  in the range 3 to 4, we find that the global evolution of the discs is governed primarily by the value of  $\mathcal{M}$ . For relatively low Mach numbers (i.e.  $\mathcal{M} = 10$  to 20) we find that the discs develop a mildly warped structure, are tidally truncated, and undergo a near rigid body precession at a rate which is in close agreement with analytical arguments. For higher Mach numbers ( $\mathcal{M} \approx 30$ ), the evolution is towards a considerably more warped structure, but the disc nonetheless maintains itself as a long-lived, coherent entity. A further increase in Mach number to  $\mathcal{M} = 50$  leads to a dramatic disruption of the disc due to differential precession, since the sound speed is too low to allow efficient communication between the disc's constituent parts. Additionally, it is found that the inclination angle between the disc and orbital angular momentum vectors evolves on a longer timescale which is probably the viscous evolution timescale of the disc.

The calculations are relevant to a number of observed astrophysical phenomena, including the precession of jets associated with young stars, the high spectral index of some T Tauri stars, and the light curves of X-ray binaries such as Hercules X-1 which suggest the presence of precessing accretion discs.

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## The Complex Kinematical Properties of the HH Objects Aligned with the HL Tauri and HH 30 Outflows

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In a previous paper we reported the detection of emission regions which might correspond to the heads of the HL Tauri and HH 30 jets. We now present preliminary proper motion measurements which appear to confirm these identifications. However, we also find that the possible head of the HH 30 jet has a radial velocity of  $\simeq -80 \text{ km s}^{-1}$ , which is in clear disagreement with the low ( $\simeq +18 \text{ km s}^{-1}$ ) radial velocity which has been measured for the jet. This result might imply that the jet not only has a change of direction of  $14^\circ$  in the plane of the sky (which is implied by the proper motion measurements) but is also curving towards us by an angle of  $\simeq 22^\circ$ .

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## **Spectroscopy of New Substellar Candidates in the Pleiades: Towards a Spectral Sequence for Young Brown Dwarfs**

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We present optical and near-infrared spectroscopy (600–1000 nm) of eight faint ( $I > 18$ ) very red ( $R-I > 2.2$ ) objects discovered in a deep CCD survey of the Pleiades cluster (Zapatero-Osorio et al. 1996). We compare them with reliable cluster members like PPl 15 and Teide 1, and with several field very late-type dwarfs (M4–M9.5), which were observed with similar instrumental configurations.

Using pseudocontinuum ratios we classify the new substellar candidates in a spectral sequence defined with reference to field stars of known spectral types. We also reclassify PPl 15 and Teide 1 in a self-consistent way. The likelihood of membership for the new candidates is assessed via the study of their photospheric features,  $H\alpha$  emission, radial velocity, and consistency of their spectral types and I-band magnitudes with known cluster members. Four of the new substellar candidates are as late or later than PPl 15 (M6.5), but only one, namely Calar 3 (M8), clearly meets all our membership criteria. It is indeed an object very similar to the brown dwarf Teide 1.

Out of the eight new substellar candidates, our “cautious” membership analysis leaves only Calar 3 as a Pleiades brown dwarf with a high level of confidence. This object, together with Teide 1, allows one to compare the spectroscopic characteristics of Pleiades brown dwarfs with those of old very cool dwarfs. The overall spectral properties are similar, but there are slight differences in the NaI doublet (818.3 nm, 819.5 nm), VO molecular band (740 nm), and some spectral ratios, which are probably related to lower surface gravity in the young Pleiades brown dwarfs than in field stars. Finally, we propose a way of improving future CCD-based brown dwarf surveys by using narrow-band near-IR pseudocontinuum filters.

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## **The Thermal Structure of Magnetic Accretion Funnel in YSOs**

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The thermal structure of gas inflowing along magnetic field lines of a young stellar object is determined self consistently. A young low-mass star (e.g., a classical T Tauri star) is assumed to possess a dipole magnetic field which disrupts a geometrically thin accretion disk and channels the incoming gas toward the stellar surface, leading to the formation of an accretion funnel which terminates in a shock at a high stellar latitude. It is shown that the accretion funnel is probably dust free and that collisional coupling between the ions and the neutrals is sufficient to ensure that even the neutral gas component follows the magnetic field lines. By solving the heat equation coupled to rate equations for hydrogen, the main physical processes which heat and cool the gas are identified. It is found that the principal heat source is adiabatic compression, due to the converging nature of the flow. The main coolants include bremsstrahlung radiation and line emission from the Ca II and Mg II ions. These ions play a major role in determining the gas thermodynamics, and behave as a thermostat which regulate the gas temperature. The ionization of the gas is found to be controlled by Balmer continuum photons, with Lyman continuum photons and collisional processes playing a minor role. For a typical T Tauri star, with an inflow rate of  $10^{-7} M_\odot \text{ yr}^{-1}$ , temperatures of  $\sim 6500 \text{ K}$  and

hydrogen ionization fractions ( $\frac{n_{\text{H}^+}}{n_{\text{H}}}$ ) of  $\sim 10^{-3} - 10^{-2}$  can be established in the accretion funnel. Furthermore, for large accretion rates ( $\gtrsim 10^{-6} M_{\odot} \text{ yr}^{-1}$ ), the gas does not heat appreciably; which may be the reason why those sources with strong inverse P Cygni line profiles are inferred to have relatively low accretion rates ( $\lesssim 10^{-7} M_{\odot} \text{ yr}^{-1}$ ). The largest temperatures and ionization fractions in the flow are established close to the stellar surface, where the gas velocity is large. Hence, these calculations may explain the ubiquity of high-velocity redshifted absorption features observed in the upper Balmer lines of classical T Tauri stars. Preliminary calculations of the hydrogen near-infrared Br $\gamma$  line suggest that the line strength produced in the magnetospheric accretion flow could account for that observed from classical T Tauri stars. However, this line is also likely to be optically thick, which is supported by the observed line profiles.

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## The Location of Complex Molecules in G34.3+0.2: Further Evidence for Grain-Surface Chemistry

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In order to determine the location of the complex molecules CH<sub>3</sub>OH, CH<sub>2</sub>CHCN, HCOOCH<sub>3</sub>, CH<sub>3</sub>CH<sub>2</sub>CN, CH<sub>3</sub>CH<sub>2</sub>OH, and CH<sub>3</sub>OCH<sub>3</sub> in the G34.3+0.2 star-forming complex, BIMA Array observations of transitions near 104 and 107 GHz were carried out with 13''  $\times$  8'' resolution. One site of complex molecule emission was detected. This core is located near the cometary H II region G34.3+0.2 C. The proximity of this core containing complex species to an ultracompact H II region is quite similar to the Sgr B2(N) core. This similarity suggests that, as appears to be the case in Sgr B2(N), a nearby, newly-formed massive star has evaporated grain mantles, releasing large amounts of complex species into the gas phase.

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## The Dispersing Cloud Core around T Tauri

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We have made <sup>13</sup>CO ( $J = 1 - 0$ ) observations of T Tauri with the Nobeyama Millimeter Array (NMA) and with the Nobeyama 45 m telescope. The <sup>13</sup>CO ( $J = 1 - 0$ ) emission detected with the NMA shows three different features: 1) a pair of ring-like features surrounding T Tauri with a radius of 30'' (corresponding to 4,200 AU at the distance of 140 pc to T Tauri) at the velocities blueshifted and redshifted by less than 1 km s<sup>-1</sup> from the systemic velocity, 2) a blueshifted compact feature 3'' east of T Tauri, and 3) another compact feature 7'' southwest of T Tauri at velocities redshifted by more than 1 km s<sup>-1</sup>. On the other hand, the <sup>13</sup>CO maps obtained with the 45 m telescope show a smoothly extended feature near the systemic velocity, which is missed in the NMA observations, as well as the above-mentioned three features. The total masses of gas detected with the NMA and the 45 m telescope are estimated to be (0.054–0.23) M<sub>⊙</sub> and (0.31–1.3) M<sub>⊙</sub>, respectively. The difference in the estimated mass between the two observations is mainly due to resolving out of the smoothly extended feature in the NMA observations.

The <sup>13</sup>CO rings are interpreted as biconical outflowing shells in a nearly pole-on configuration. The high-velocity stellar wind ejected from T Tauri is estimated to be energetic enough to drive these outflowing shells. We have analyzed the three-dimensional structure of the shells by correcting for the projection effect on the plane of the sky, and have found that the spatial extent of the shells is nearly equal to or slightly smaller than the typical size of the molecular cloud cores in the Taurus Molecular Cloud. This fact indicates that the outflowing shells are part of the parent cloud core which still remains around T Tauri, which is now dispersing under the influence of the stellar wind. Such an

environment around T Tauri is quite different from those around typical T Tauri stars, which are associated only with compact gaseous components. These results strongly suggest that T Tauri is one of the objects in the transitional phase from the protostar stage, where a central star is deeply embedded in an infalling envelope, to the T Tauri stage, where a central star is surrounded by a compact circumstellar disk instead of a spatially extended envelope.

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## A Simple Model of Spectral Line Profiles from Contracting Clouds

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A simple analytic model of radiative transfer in two parts of a contracting cloud matches a wide range of line profiles in candidate infall regions and provides a sensitive estimate of  $V_{in}$ , the characteristic inward speed of the gas forming the line. The model assumes two uniform regions of equal temperature and velocity dispersion  $\sigma$ , whose density and velocity are attenuation-weighted means over the front and rear halves of a centrally condensed, contracting cloud. The model predicts two-peak profiles for “slow” infall,  $V_{in} \ll \sigma$ , and red-shoulder profiles for “fast” infall,  $V_{in} \sim \sigma$ . A simple formula expresses  $V_{in}$  solely in terms of  $\sigma$  and of observable parameters of a two-peak line. We apply the model to fit profiles of high- and low-optical-depth lines observed in a dense core with no star (L1544,  $V_{in} = 0.006 \text{ km s}^{-1}$ ), with an isolated protostar (L1527,  $0.025 \text{ km s}^{-1}$ ), and with a small group of stars (L1251B,  $0.35 \text{ km s}^{-1}$ ). The mass infall rate obtained from  $V_{in}$  and the map size varies from 2 to  $40 \times 10^{-6} M_{\odot} \text{ yr}^{-1}$ , and agrees within a factor  $\sim 2$  in each core with the independently determined rate  $\sim \sigma^3/G$  for a gravitationally collapsing isothermal sphere. This agreement suggests that the inward motions derived from the line profiles are gravitational in origin.

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## Brown Dwarfs in the Pleiades Cluster: a CCD-based $R$ , $I$ survey

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We have obtained deep CCD  $R$  and  $I$  mosaic imaging of  $578 \text{ arcmin}^2$  within  $1^{\circ}.5$  of the Pleiades’ center – reaching a completeness magnitude  $I = 19.5$  – with the aim of finding free-floating brown dwarfs. Teide 1, the best *bona fide* brown dwarf discovered so far in the cluster (Rebolo, Zapatero Osorio & Martín 1995), arose as a result of a combined photometric and astrometric study of  $\sim 1/4$  of our covered area. The extension of our two-colour survey provides eight new additional brown dwarf candidates whose photometry is rather similar to that of Teide 1. Several of them are even fainter. Follow up low-resolution spectroscopy (Martín, Rebolo & Zapatero Osorio 1996) shows that one of them is indeed a Pleiades brown dwarf. Most of the remaining candidates are background late-M dwarfs which are contaminating our survey, possibly due to a small (previously unknown) cloud towards the cluster which affects some of our CCD fields. We did not expect any foreground M8–M9 field dwarf in our surveyed volume and surprisingly we have found one, suggesting that its number could be larger than inferred from recent luminosity function studies in the solar neighbourhood.

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## Detection of Periods for T Tauri Stars

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We present the results of UBrH $\alpha$ z monitoring of a sample of T Tauri stars. The method of differential CCD photometry was applied. The observations span a range of ten days and show that eleven out of twelve sources varied during this

time interval. These variations are correlated in all bands. Periods were detected (confidence level 99.99%) for eight out of eleven variable stars; one additional period was found at the 99.9% confidence level. Of those, one (BP Tau) agrees with previously published periods; two, GM Aur and IQ Tau, do not; six are new detections of periodicities. The sample is drawn from the Taurus-Auriga and Cepheus IV star-forming regions.

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## **H $\alpha$ Emission in Pre-Main Sequence Stars. I. An Atlas of Line Profiles**

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We present an atlas of very high resolution ( $R \sim 50000$ ) H $\alpha$  line profiles of 63 pre-main sequence stars, divided among 43 T Tauri stars, 18 Herbig Ae/Be stars, and 2 FU Orionis objects. H $\alpha$  emission is the most common and prominent spectroscopic feature of pre-main sequence stars, and although it is optically very thick it is still the most frequently modelled emission line in young stars. In T Tauri stars the principal models involve magnetically driven winds, and more recently the role of infalling magnetospheric material has been explored. For Herbig Ae/Be stars a variety of models have been proposed, current emphasis is directed towards obscuration by clumpy circumstellar disk structures. In order to provide constraints on such models, we have made a statistical analysis of the 63 high resolution profiles. We here ignore the considerable variability of the H $\alpha$  emission, which is discussed in detail in a second paper. Most of our observed lines show complex profiles due to an interplay between emission and absorption features, and we suggest a two-dimensional classification scheme to describe these line profiles, based on the relative height of a secondary peak to the primary peak, as well as whether the absorption is blue- or red-shifted. Among T Tauri stars, 25% have symmetric profiles, 49% have blueshifted absorption dips, and 5% have P Cygni profiles; the remaining 21% show a variety of redshifted absorptions. For Herbig Ae/Be stars symmetric lines are quite rare (11%), indeed almost all of these stars have deep and prominent central absorptions. We have measured the extent of the line wings for all of our stars at the  $I_{max}/40$  level, and find that almost all have very extended wings, with typical extents of  $\pm 350$  km/sec, but in high S/N spectra the wings can be traced to lower intensities, and velocities as high as  $\pm 900$  km/sec have been observed. Pronounced asymmetries of these extended wings are found for many stars, suggesting the possibility that the highest velocity material could be non-uniformly distributed. The equivalent widths of the H $\alpha$  emission in our sample of stars span two orders of magnitude, with a distribution that increases with decreasing equivalent width.

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## **Doppler imaging of stellar surface structure.**

### **II. The weak-lined T Tauri star V410 Tauri**

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We present a new Doppler image of the rapidly-rotating weak-lined T Tauri star V410 Tauri and compare this new map with one previously published from observations taken over a year earlier. We find cool spots at both equatorial latitudes and at high latitudes with the high latitude spots being cooler and showing greater area and having greater longevity than the equatorial spots. A comparison of the two maps shows little relative change in the positions of the equatorial spots compared to the spots at high latitude suggesting very little differential rotation and what there is appears to be in the same sense as the Sun. Global spot lifetime would appear to be on the order of the time interval between the two maps, that is about a year. There are several hot features evident supporting the claim for the existence of such features based on our map of Nov. 1992.

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## Radio observations in NH<sub>3</sub> and C<sub>2</sub>S toward small molecular clouds and around pre-main sequence stars

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We performed a radiofrequency survey toward seventeen Bok globules and around eight Herbig Ae/Be stars in the 23694.495 MHz NH<sub>3</sub>(J,K=1,1) and C<sub>2</sub>S 22344.033 MHz ( $J_N=2_1-1_0$ ) transition lines. Ten Bok globules do not contain IRAS point sources and are assumed to be not star forming at this time (inactive globules). Seven contain IRAS point sources and are supposedly associated with star forming regions (active globules). The Herbig Ae/Be stars are pre-main sequence objects still interacting with their parental cloud. The aim of the work is to establish a relationship between the chemical characteristics and the physical evolutionary stages of a small molecular cloud. Along this line, it has been recently proposed by Suzuki et al. (1992) that the ratio  $N[\text{NH}_3]/N[\text{C}_2\text{S}]$  may represent early or late stages of cloud evolution. The results of our investigation are discussed in the light of the above hypothesis. It appears that one of the supposed inactive globule, L1253, is, in fact, in an intermediate stage, which shows that the core contraction has already begun.

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## Bipolar Molecular Outflows in Massive Star Formation Regions

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Bipolar molecular outflows are a basic component of the star formation process. This is true for stars of all masses although it has not yet been well established how outflows associated with massive stars differ from those associated with low-mass stars. We present results from a project to identify bipolar outflows from massive young stellar objects (YSOs) and determine how they compare with low-mass YSO systems. Ten massive star formation regions with high velocity <sup>12</sup>CO(J=1-0) line wings were mapped with the Kitt Peak 12 m telescope using the On-the-Fly (OTF) mapping technique. Five of the regions have bipolar outflows. We determine accurate mass estimates of the molecular gas in the red and blue-shifted lobes by taking into account variations in the optical depth as a function of velocity in the flow. We find that the molecular outflows have masses between  $\sim 16$  and  $72 M_\odot$  and kinetic energies between  $\sim 10^{45}$  and  $10^{46}$  ergs. The outflows have significantly more mass and kinetic energy than those from low-mass YSOs. Of the remaining five regions, two have a clumpy distribution in <sup>12</sup>CO with multiple velocity components within the cloud complex, and three sources did not have sufficient S/N to map the high-velocity line wings. We combine our data with 18 additional outflow sources with stellar luminosities that range from  $0.6 L_\odot$  to  $2.1 \times 10^5 L_\odot$  to predict the luminosity of the star responsible for the outflow. We find that the stellar luminosities of the sources in our sample range from  $\sim 10^2 L_\odot$  to  $10^4 L_\odot$  which correspond to mid- to early-B type stars; the precursors of Herbig Be stars. One source, G173.58, has an IRAS source on the flow axis with the appropriate luminosity to drive the observed outflow. For the remaining four sources, there is no detectable UC HII region or isolated IRAS source with the appropriate luminosity to produce the observed molecular outflow. The outflows mapped in this work begin to fill in a region of outflow parameter space where relatively few sources have been studied and they help to bridge the gap between low-luminosity outflow sources and the few isolated outflows from massive O stars. Our data are consistent with the ideas that: 1)  $\dot{M}$  in a molecular outflow increases continuously with  $L_{bol}$  of the driving source over a range from  $\sim 1 L_\odot$  to  $\sim 10^6 L_\odot$ ; 2) one can predict the central source luminosity from the measured mass flux in the flow; 3) there is a clear  $M_{flow}$  versus age ( $t_d$ ) relationship for stars of all luminosities; and 4) the larger  $\dot{M}$  for higher luminosity sources implies that these objects produce massive outflows on short timescales relative to low-mass stars.

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## The Distribution of CS and NH<sub>3</sub> in Star-Forming Regions

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The molecules CS and NH<sub>3</sub> are expected on theoretical grounds to trace high density interstellar gas in a similar fashion. However, observations show that CS is often widespread while NH<sub>3</sub> appears concentrated in dense cores. This result is interpreted here in terms of a clumpy model of molecular clouds, and a differential rate for chemistry of the two species. These CS cores are unresolved and numerous; most of them probably disperse rather than collapse to form a star.

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## Extreme-Infrared (800 $\mu$ m) Polarimetry of the M17-SW Molecular Cloud with the JCMT

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Extreme-Infrared (800 $\mu$ m) linear polarization observations have been obtained at the JCMT on Mauna Kea in Hawaii, toward the elongated molecular cloud M17-SW located at a distance of 2.2 kpc. The six strongest dust peaks in total continuum intensity were observed. From the total intensity continuum observations, we find that the typical dust peaks in M17-SW have a mean size of 0.24 pc, a mean density of  $3.7 \times 10^5 \text{ cm}^{-3}$ , and a mean mass of  $245 M_{\odot}$ . From the polarimetric observations, we measure a mean polarized E-vector amplitude of  $2.0\% \pm 0.3\%$ , and we find that the mean E-vector position angle at extreme IR wavelengths is at  $\text{PA} = 169^{\circ} \pm 19^{\circ}$ . This mean E-vector PA is mostly parallel to the cloud elongation, which is at  $\text{PA} = 158^{\circ} \pm 10^{\circ}$ . It follows that the mean magnetic field vector is at  $\text{PA} = 79^{\circ} \pm 19^{\circ}$ , implying that the cloud's magnetic field is mostly perpendicular to the cloud elongation.

We have grouped the theoretical models for the magnetic fields in molecular clouds into eleven 'magnetic classes', according to the shape and the scale of the magnetic field involved. Comparisons are made between the predictions from these 11 classes and the JCMT observations for the B-vectors in the cloud M17-SW. Nine of the 11 magnetic classes are unlikely to pertain to M17-SW. The other two magnetic classes are: the class with a 1-dimensional cloud collapse along the localized magnetic field lines; and the class with the magnetic field vectors in the cloud being parallel to the surrounding magnetic field. These results suggest that a proper distance scale for the magnetic field involved is of the order of 10 pc to 100 pc outside the cloud (larger than the cloud size), and of the order of 1 pc to 10 pc inside the cloud M17-SW (larger than the clump sizes of 0.2 pc).

Two scenarios for the origin of the dust peaks in M17-SW are examined. The 'sequential star formation' scenario is supported, and our polarization data and other data cast doubts on the 'radially expanding shell' scenario for M17-SW.

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Available on WWW at: [HTTP://WWW.hia.nrc.ca/jcmt/m17mag\\_pub.html](http://WWW.hia.nrc.ca/jcmt/m17mag_pub.html) with a color figure including magnetic field lines at: [HTTP://WWW.hia.nrc.ca/jcmt/m17mag.jpg](http://WWW.hia.nrc.ca/jcmt/m17mag.jpg)

## <sup>15</sup>NH<sub>3</sub> towards ultracompact HII regions

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We have observed the (3,3) and (4,4) lines of <sup>15</sup>NH<sub>3</sub> toward a selection of ultracompact HII regions using the Effelsberg

100m telescope. The lines were detected in 6 sources. Toward the strong source G10.47+0.03, all metastable inversion transitions from (1,1) to (6,6) were detected. In addition,  $^{14}\text{NH}_3(3,3)$  was observed in 6 sources and the (4,2) and (5,4) non-metastable transitions of  $^{14}\text{NH}_3$  were detected in G10.47+0.03 and G31.41+0.31. We find beam averaged  $^{15}\text{NH}_3$  column densities of order  $10^{13} \text{ cm}^{-2}$  and temperatures between 100 and 300 K. Towards G10.47+0.03, the rotational temperature between metastable levels is found to be  $185 \pm 20$  K. Comparison with an LVG model allows us to deduce a kinetic temperature of  $240 \pm 40$  K. No evidence is found for maser characteristics in the  $^{15}\text{NH}_3(3,3)$  transition like those found in NGC 7538 by Mauersberger et al. (1986). The non-detection of  $^{15}\text{NH}_3(4,3)$  in G10.47+0.03 and G31.41+0.31 allows us to set an upper limit of  $5 \cdot 10^7 \text{ cm}^{-3}$  to the molecular hydrogen density in the hot cores. In comparison to column densities based upon optical depths derived from the relative intensities of hyperfine satellites of  $^{14}\text{NH}_3$ , we find column densities lower by a factor of 3–4 using  $^{15}\text{NH}_3$ . Possible explanations of this discrepancy are discussed.

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Available at: <http://www.ph1.uni-koeln.de/wyrowski>

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*Dissertation Abstracts*

**Accretion Disks around Young Stars**

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Ph.D degree awarded: April 1996

A method to calculate the structure and brightness distribution of accretion disks surrounding low and intermediate mass young stars is introduced and discussed. The method includes a realistic treatment of the energy transport mechanisms and disk heating by radiation from external sources.

The disk is assumed steady, geometrically thin and in vertical hydrostatic equilibrium. The turbulent viscosity coefficient is expressed using the  $\alpha$  prescription and the  $\alpha$  parameter and the mass accretion rate are assumed to be constant through the disk. Energy is transported in the vertical direction by: (a) a *turbulent flux*, computed self-consistently with the viscosity coefficient used to describe the viscous energy dissipation, (b) *radiation*, using the first moments of the transfer equation, the Eddington approximation, and the Rosseland and Planck Mean Opacities, and (c) *convection*, taking into account that the convective elements, not necessarily optically thick, lose energy by radiation and turbulent flux. This treatment of the energy transport mechanisms differs from previous work in this field, allowing one to extend, with confidence, the calculation of the disk structure to optically thin regimes.

The heating mechanisms considered, which affect the disk's structure and emission, are stellar radiation and a circumstellar envelope which reprocesses and scatters radiation from the star and from the disk itself. In addition to a detailed numerical calculation, an analytical self-consistent formulation of the irradiation of the disk is given. This analytical formulation allows one to understand and extend the numerical results. To evaluate the potential of the method presented in this thesis, a set of models of viscous non-irradiated and irradiated disks are computed. Their predictions are compared with observations of young stellar sources likely to have disks.

Given the disk structure and specifying its orientation with respect to the line of sight, the specific intensity distribution is calculated on the plane of the sky, integrating the radiative transfer equation along rays parallel to the line of sight. To this end, monochromatic opacities are used, which also allow us to construct tables of the Rosseland and Planck Mean Opacities. The disk structure and brightness distribution thus obtained are self-consistent with respect to the abundances and optical properties of the gas and the dust. With the disk intensity distribution, its spectrum is constructed and its colors are calculated in different spectral ranges. These are compared to observations of low mass young stars reported in the literature, for which the disk parameters are then inferred. It is found that the observed properties of a large fraction of classical T Tauri stars can be explained as emission from viscous disks irradiated by the central star or by a thin envelope and that the emission in the long wavelength range from a flat spectrum source like HL Tau is consistent with the predictions of a model in which a viscous disk is irradiated by an optically thick infalling envelope.

# The Structures, Kinematics, and Magnetic Natures of Starless Bok Globules

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Ph.D dissertation directed by: Dan Clemens

Ph.D degree awarded: January 1996

This dissertation presents an observational study of the magnetic fields, kinematics, and structures of small galactic molecular clouds known as starless Bok globules (SBGs).

Fourteen SBGs were polarimetrically imaged at optical wavelengths to characterize the structures of their embedded magnetic fields. More than 1000 stars (75 per SBG) were measured to 0.1% precision, as faint as apparent visual magnitude 17. SBGs show evidence of predominantly uniform fields, though strong coupling of the gas to embedded magnetic fields is unlikely. Non-uniform components of magnetic fields may contain 20% of total magnetic energy densities, and the magnetic field directions decorrelate on angular sizes of a few arcminutes.

To characterize SBG gas kinematics and density profiles, SBGs were mapped with very high spectral resolution in the lowest energy-state rotation lines of the carbon monoxide (CO) molecule and its isotopes at more than 100 positions per cloud. Most SBGs are differentially rotating and are more centrally condensed than other small molecular clouds. Their angular velocities are distributed in two groups: rapid rotators and slow rotators. Rotational kinetic energy in SBGs is not a significant source of support against gravity and external pressure. Most SBGs are too cold to be thermally supported, but non-thermal kinetic energies marginally exceed gravitational potentials. Analyses indicate that half are near virial equilibrium and half are expected to contract.

Core regions of SBGs were observed in the lines of ammonia  $\text{NH}_3$  and cyanoacetylene  $\text{HC}_3\text{N}$  which are sensitive to moderately high gas densities. No emission was detected, limiting central densities to less than  $10^4$  per cc, lower than in dark star-forming cloud cores, but similar to values seen in high galactic latitude clouds.

Key structural and kinematic parameters of SBGs are tested for correlations with magnetic field parameters. SBG rotation axis directions are well-correlated with cloud magnetic field directions, implying magnetic braking is no longer efficient at redistributing SBG angular momentum.

SBGs are found to be strongly condensed clouds exhibiting clumpy substructures and rotational motions well-correlated with the presence of embedded magnetic fields. A substantial fraction of these clouds may be the sites of future star formation.

*New Books*

**The Physics and Chemistry of Interstellar Molecular Clouds**

Edited by Gisbert Winnewisser and Guido C. Pelz

Proceedings of the 2nd Cologne-Zermatt Symposium held at Zermatt, Switzerland,  
21-24 September 1993

The book is divided into the following 8 sections:

1. Galactic Molecular Cloud Distribution
2. External Galaxies
3. Molecular Cloud Structure
4. Photon Dominated Regions
5. Interstellar Chemistry
6. Star Formation in Molecular Clouds
7. Molecular Outflows
8. New Instrumentation

The following are the principal papers presented at the meeting:

Three New Galactic CO Surveys (*P. Thaddeus, T.M. Dame, S. Digel, D. Puche*)

Molecular Clouds at the Edge of the Galaxy: Clouds of FOG (*J.G.A. Wouterloot, J. Brand*)

Far-Infrared [CII] Line Survey of the Galaxy (*Nakagawa et al.*)

Molecular Gas Surrounding the Galactic Center (*P.T.P Ho*)

Near-Infrared High-Resolution Imaging of the Galactic Center (*A. Eckart et al.*)

Dense Molecular Gas in Ultraluminous and High Redshift Galaxies (*S.J.E. Radford*)

Interstellar Molecules in the Large Magellanic Cloud (*L.E.B. Johansson*)

Magnetic Fields in Molecular Clouds (*R.M. Crutcher*)

Turbulence in Interstellar Clouds (*E. Falgarone*)

Theoretical Models of Photodissociation Regions (*D.J. Hollenbach, A.G.G.M. Tielens*)

Photon-Dominated Regions: Linking Observations and Theory (*D.T. Jaffe*)

Observations of  $^3\text{P}_1$  to  $^3\text{P}_0$  C I Emission from Molecular Clouds and Envelopes of Evolved Stars (*J. Keene*)

How Stable Are the Results of Simple Model Calculations of Interstellar Chemistry? (*E. Herbst*)

Interstellar Hydrides (*E.F. van Dishoeck*)

Chemical and Physical Gradients Along the OMC-1 Ridge (*H. Ungerechts et al.*)

Massive Star Nurseries (*E. Churchwell*)

Prospects for Submillimeter Observations (*T.G. Phillips*)

Additionally a large number of poster papers are presented.

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