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Abstracts of recently accepted papers

Multiplicity among T Tauri stars in OB and T associations: Implications for binary star formation

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We present first results of a survey for companions among X-ray selected pre-main sequence stars, most of them being weak-line T Tauri stars (WTTS). These T Tauri stars have been identified in the course of optical follow-up observations of sources from the ROSAT All Sky Survey associated with star forming regions. The areas surveyed include the T associations of Chamaeleon and Lupus as well as Upper Scorpius, the latter being part of the Scorpius Centaurus OB association (Sco OB 2).

Using SUSI at the NTT under subarcsec seeing conditions we observed 195 T Tauri stars through a 1μm ("Z") filter and identified companions to 31 of them (among these 12 subarcsec binaries). Based on statistical arguments we conclude that almost all of them are indeed physical (i.e. gravitationally bound) binary or multiple systems. For 10 systems located in Upper Scorpius and Lupus, we additionally obtained spatially resolved near-infrared photometry in the J, H, and K bands with the MPIA 2.2m telescope at ESO, La Silla. The near-infrared colours of the secondaries are consistent with those of dwarfs and are clearly distinct from those of late type giant stars. Based on astrometric measurements of some binaries we show that the components of these binaries are common proper motion pairs, very likely in a gravitationally bound orbit around each other.

We find that the overall binary frequency among T Tauri stars in a range of separations between 120 and 1800 AU is in agreement with the binary frequency observed among main sequence stars in the solar neighbourhood. However, we note that within individual regions the spatial distribution of binaries – within a distinct range of separation – is non-uniform. In particular, in Upper Scorpius, WTTS in the vicinity of early type stars seem to be almost devoid of multiple systems, whereas in another area in Upper Scorpius half of all WTTS have a companion in a range of separation between $0.7''$ and $3.0''$. Furthermore, we find no preponderance of systems with *large* brightness differences between primary and companion stars (median $\Delta Z = 1.0^m \ldots 1.5^m$).

We conclude that binarity is established very early in stellar evolution, that the orbital parameters of *wide* binaries ($a \geq 120$AU) remain virtually unchanged during their pre-main sequence evolution, and that these *wide* binaries were formed either through collisional fragmentation or fragmentation of rotating filaments.

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The Location of Stellar Clusters in the Big Dent : an Age Gradient Along the Z-Axis

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The ages and locations of stellar clusters and individual Cepheid stars in the depression called "Big Dent" are analyzed. The z-locations of the cluster sample display a well defined z-age stratification. The Cepheid sample has ages between 3 to 8×10^7 yr and show a departure from the midplane similar to the one observed for clusters of the same age range. The existence of such an age gradient seems to corroborate previous hypothesis suggesting that the star formation activity was probably triggered by the same strong perturbation which originated the depression. A model in which the Big Dent was created by a collision of a high-velocity cloud with the Galactic disk is able to reproduce the observed gradient.

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Momentum Distribution of Protostellar Outflows

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In this paper we investigate the distribution of momentum in protostellar molecular outflows, and make comparisons with recent outflow models. In most flows, momentum peaks are found in the centers of the lobes, with minima towards the protostar and the edges of the flow. The peaks, which are typically offset by ≈ 0.1 to 0.6 pc from the star, are also seen in the distribution of mass, lobe cross-sectional area, and in individual channel maps.

The shape of the momentum distribution is compared with predictions of several types of models from the literature, i.e. outflows driven by wide-angle winds, jet bow shocks and steady state turbulent flows, and we find that none of them can account for momentum peaks located in the middle of the lobes. We discuss modifications which would make the models more consistent with the data, and argue in favor of a jet bow shock model in which the jet is variable in velocity and/or angle.

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A copy of the paper is available via the internet http://ral.berkeley.edu:8000/home.html.

Ambipolar Diffusion, Interstellar Dust, and the Formation of Cloud Cores and Protostars. IV. Effect of UV Ionization, and Magnetically Controlled Infall Rate

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We extend our previous studies of the self-initiated formation and contraction of protostellar cores (due to ambipolar diffusion) in axisymmetric, isothermal, self-gravitating, disklike, thermally supercritical but magnetically subcritical model molecular clouds, to include the effect of the external (interstellar) ultraviolet radiation field. UV ionization dominates cosmic-ray ionization up to optical depths of about 10, and increases the degree of ionization in the envelopes of model clouds by more than two orders of magnitude. It thereby decreases by a similar factor the rate at which ambipolar diffusion progresses in the envelopes.

We follow the evolution of four model clouds to a central density enhancement of 10^6 (e.g., from 2.6×10^3 to 2.6×10^9 cm^{-3}). Magnetically supercritical cores form on the initial central flux-loss timescale, which exceeds the dynamical timescale ($\simeq$ free-fall time) by a factor $10 - 20$. As in the case of no UV radiation, a typical magnetically supercritical core consists of a uniform-density central region and a "tail" of infalling matter with a power-law density profile $\propto r^s$, $-1.5 \gtrsim s \gtrsim -1.85$. Models that include the macroscopic (collisional) effects of grains have the evolution of their cores retarded (typically by 50%) with respect to models that account only for neutral-ion drag, independently of the effects of UV radiation. Model clouds that account for the effect of UV ionization have envelopes that are even better supported by magnetic forces than envelopes of models ionized only by cosmic rays. The effect that a well supported envelope has on an oblate cloud's central gravitational field is to increase the field strength, which speeds up the evolution of a core in a typical model cloud by 30%. In all cases the mass infall (or accretion) rate in (or from)

the magnetically supported envelope is controlled by slow ambipolar diffusion. The maximum mass infall rate in the cores of model clouds is $\simeq 4M_\odot$ Myr^{-1}. Ambipolar diffusion is so ineffective in the envelopes of model clouds with UV ionization that mass infall decreases precipitously outside the supercritical protostellar cores.

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Rotation Periods and Variability of Stars in the Trapezium Cluster

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Results from a fourth season (1993/94) of monitoring the Trapezium cluster in the Cousins I band at Van Vleck Observatory are reported. Data were obtained on 28 nights with multiple exposures on most. A periodogram technique described by Horne and Baliunas (1986) based on Scargle's method was used to search for periods. False alarm probablities must be carefully assessed when the sampling intervals are distributed in the manner of this study. Multiple observations per night allow us to effectively resolve problems with aliasing. Rotation periods are now known for nineteen cluster members; ten are confirmations of periods reported by Mandel & Herbst (1991) and/or Attridge & Herbst (1992) and nine are newly discovered. Seventeen of these are likely Type I (cool spot) variables and two are of Type IIp (hot spot). Periods range from 1.68 to 34.5 days and have a bimodal distribution similar to that found for the Orion Nebula cluster as whole. In this limited, but homogeneous sample, we find no trends in angular velocity with stellar mass, stellar age, or presence on an inner disk, as inferred from H-K excess. The existence of a bimodal period distribution is, however, strong evidence in favor of disk-regulated angular momentum evolution. Irregular variables are also common in the Trapezium cluster and we identify fourteen that have ranges exceeding 0.5 mag. Most of them exhibit light curves typical of classical T Tauri stars (Type II), but one has a much slower (perhaps FUor-like?) behavior, and three showed eclipse-like drops in brightness. They could be eclipsing binaries but no periods were found, so they are more likely to be Type III irregular variables (UXors). VIJHK photometry demonstrates that the large amplitude vartexas.ediables (LAVs), as a group, have substantial IR excesses, indicative of accretion disks, signifying that they are indeed CTTS. None of these stars are brighter than V = 14, in accord with the failure of spectroscopic surveys to detect CTTS in the Trapezium cluster, heretofore. Our data indicate that both CTTS and WTTS are present in the Trapezium cluster, but that the brightest WTTS are systematically brighter than the brightest CTTS by about 1.6 mag in V and 1.8 mag in I. A simple interpretation of this fact is that the CTTS (at least the LAVs) are of lower mass and cooler than the WTTS in this cluster.

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H_α emission from pre-main sequence stars

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We present the results of an H_α emission line observational study of a sample of 75 pre-main sequence stars consisting of 17 HAEBE, 47 CTT and 11 WTT stars. Approximately half of the stars are faint, with a brightness in the V band ≥ 13 . The spectra have been taken at resolutions ≈ 30 kms^{-1} and ≈ 80 kms^{-1}. The data shown provide information on equivalent width, radial velocity, variability and line profile.

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The Infrared Nebula and Outflow in Lynds 483

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Near infrared and submillimeter observations of IRAS 18148–0440 in the Lynds 483 dark cloud are presented. The near infrared images show nebulous emission extending up to $\sim 60''$ from the IRAS position. The IRAS source is not directly detected at any wavelength and is obscured by more than 70 magnitudes of visual extinction. Submillimeter continuum measurements indicate the presence of about $0.3 M_\odot$ of material within about 1900AU of the central star. At 2.2μm the near infrared nebula is bipolar with approximately cylindrical lobes which extend east and west of the IRAS source and coincide with the bipolar lobes of the CO outflow from the source. The western lobe of the nebula is significantly brighter than the eastern lobe and is spatially coincident with the blue shifted CO emission from the outflow. If the nebular lobes have equal intrinsic brightness, their apparent brightness implies that the outflow has an inclination angle of ~ 40 deg to the plane of the sky and that the density distribution within the dense gas around IRAS 18148–0440 has a radial profile steeper than r^{-1}. There is a bright knot of molecular hydrogen emission close to the end of the blue shifted CO with a jet-like feature extending from the knot back towards the location of the embedded star. The knot of emission is thought to be tracing the region where the stellar wind is impacting the surrounding dense gas. The observations suggest that IRAS 18148–0440 is very young and that its outflow is driven by a jet from the central star.

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The Circumstellar Molecular Core Around L1551 IRS-5

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We present maps of $C^{18}O$ and $C^{17}O$ J$= 2 \rightarrow 1$ emission toward the embedded young star L1551 IRS-5. The $C^{17}O$ emission traces a compact region $\sim$ 1900 AU in radius which is centered on the star which contains $\sim 0.1 M_\odot$ of material. The integrated $C^{17}O$ emission has a cross-like structure aligned in the cardinal directions which is very similar to the structure seen in the submillimeter continuum emission from this source. A spatially more extended component of material which contains an additional $0.1 M_\odot$ of material within $20''$ of IRS-5, also contributes to the $C^{17}O$ emission. The cross gas is warmer and has a larger velocity dispersion than the more extended gas. The motions of the extended material imply a virial mass of 1 to 3 $M_\odot$, which is dominated by the mass of the central star plus disk. The $C^{18}O$ lines have considerable line wing emission and part of the cross is evident in this wing emission. Comparison with existing maps of the outflow near IRS-5 suggests that the cross material is part of the heated wall of the cavity evacuated by the outflow. The presence of such structures near embedded stars complicates the search for accreting material. However, the properties of the extended $C^{17}O$ emission constrain the mass accretion rate in L1551 IRS-5 to be less than $1.4 \times 10^{-5} M_\odot yr^{-1}$. Comparison with the observed mass outflow rate from IRS-5 at a similar size scale suggests that there is currently little or no net accretion of material from the larger scale dense core into the central 2000AU radius region about IRS-5.

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Dense clumps in the L1630 molecular cloud: physical structure and properties

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This paper reports observations of six out of 42 interstellar molecular cloud cores identified by the CS survey of L1630 by Lada, Bally & Stark (1991). High resolution (14–20″) maps in J=3−2, 4−3 HCO^+ and 5−4 CS identify at least 22 emission maxima, 14 of which are associated with two of the former cores. Lower resolution (60″) maps of the J=1−0 HCO^+ emission show little or no evidence for the structure seen in the higher-J maps. Three of the six cores are significantly elongated – we conclude that they are probably filaments rather than fragmented discs or rings seen edge-on.

Most of the maxima are unresolved in a 14–20″ beam; therefore most of the virial mass estimates are upper limits. Those that are not suggest clump masses of a few $M_\odot$. Masses derived from dust continuum observations in one of the cores (number 23) are in good agreement with the virial masses.

LVG analysis has been applied to a two-component model of the cores in which the 1−0 HCO^+ emission traces a low density ($10^4\,cm^{-3}$) envelope while the 3−2 and 4−3 HCO^+ lines trace the higher density clumps ($10^6\,cm^{-3}$).

These clumps are excellent candidates for low-mass protostellar activity.

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The excitation of molecular hydrogen in HH 1 and in HH 7 to 11

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Results are presented on spectroscopic observations of near-infrared molecular hydrogen emission lines towards the Herbig-Haro objects HH 1 and HH 7 to 11. The inferred population densities in the observed H_2 levels towards HH 1 and HH 11 are well described by pure thermal distributions, and single excitation temperatures provide good fits. None of the levels have a significantly enhanced population density as should occur if non-thermal processes were involved. The H_2 emission towards HH 1 arises from collisional excitations in a gas of temperature around 2750 K, while contributions from FUV pumping, suggested elsewhere, are not present. The emission from HH 11 arises from gas at similar temperatures, and emission from H_2 re-formation is ruled out. Near-infrared emission of [FeII], present towards HH 1 and HH 7 to 11, is used to infer a reddening of E(B-V) $\approx$ 0.5 mag and an electron density of $n_e \approx 5000$ cm^{-3} towards HH 1. Towards individual knots in HH 7 to 11, reddenings range from E(B-V) = 2 to 7 mag. The H_2 and [FeII] observations together suggest the presence of curved J-type shocks, and rule out C-type bow shocks as the origin of the emission.

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Structure and excitation conditions of the southern part of the Orion B molecular cloud: a CO multiline study

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We present extended maps of ^{12}CO and ^{13}CO (J=2→1 and J=3→2) of the southern part of the Orion B region covering a $\sim20' \times 60'$ area (in ^{13}CO(2→1), and encompassing the NGC 2024 H II region, the interface region between NGC 2024 and the optical nebula IC434, the reflection nebula NGC 2023, and the Horsehead Nebula B33. The physical conditions in these different regions vary significantly due to the influence of the OB association lying to the west and due to the embedded stars. The CO emission originates from many clumps, most apparent in individual velocity channel maps. The observed low-J CO and isotopic CO line ratios are inconsistent with the standard interpretation in terms of a single temperature gas component along the line of sight in LTE. They require an outward temperature gradient on the cloud surface, as is naturally expected to arise from external UV heating. A consistent interpretation for both absolute line brightnesses and the intensity ratios can be reached in terms of PDR models. These indicate densities within the bulk of Orion B of at least close to 10^5 cm^{-3}. In addition we analyse the structure by subdividing the ^{13}CO(2→1) emission of Orion B into clumps using an automated procedure. The shape, orientation, LTE mass, virial mass, and stability of these clumps is examined. The mass spectrum of the clumps follows a power law, $dN/dM \propto M^{-\alpha}$, with $\alpha = 1.65 \pm 0.24$. We find an average volume filling factor of the clumps of 0.3 and a contrast between local and clump densities of 60 or higher.

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The outburst of the T Tauri star EX Lupi in 1994

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We have observed an outburst of the T Tauri star EX Lup in March 1994. We present both photometric (BVR) and spectroscopic (low and medium resolution) observations carried out during the decline after outburst. The star appears much bluer during outburst due to an increased emission of a hot continuum. This is accompanied by a strong increase of the veiling of photospheric lines. We observe inverse P Cygni profiles of many emission lines over a large brightness range of EX Lup. We briefly discuss these features towards the model of magnetospherically supported accretion of disk material.

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A Bipolar-Outflow Object in the field of M36

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We have discovered an object in the field of the Galactic open cluster M36 which exhibits a nebulous tail-like structure and a high velocity outflow. We first observed the jet morphology in optical images taken at the Michigan-Dartmouth-MIT (MDM) Observatory at Kitt Peak. This source, located at 05:36:05.9, 34:06:12 (J2000), is found to be coincident with IRAS 05327+3404. CO (1 − 0) observations (Wouterloot & Brand 1989) showed this object to be a strong emission-line source. We performed CO (2 − 1) observations at the James-Clerk-Maxwell Telescope at Mauna Kea which suggest that the outflow is bipolar in nature. Optical spectroscopy obtained at the La Palma Isaac-Newton 2.5m Telescope shows strong emission lines, reminiscent of Herbig-Haro emission and confirming the outflow. The object is probably not associated with M36, and may be a far-flung member of the nearby region of star formation, S235. The optical spectra are quite unusual. We conclude that the spectra represent two views of the same jet structure from different viewing angles, one the result of a reflection off the nebulous tail. The IRAS fluxes, optical morphology, and aspects of the optical spectra are similar to the FU Orionis system L1551 IRS 5, and may indicate that this object is also an FU Orionis star.

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Stellar Models with Rotation: an Exploratory Application to Pre-Main sequence Lithium Depletion

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Over the last 20 years, the surface abundance of Li has been derived for a significant number of low mass pre-main sequence (PMS) stars. Several works have pointed out the unexpected large Li spread for young stars of similar ages and masses. This spread still represents a challenge in our understanding of PMS stellar evolution. Almost in parallel, it has also become clear that there is a large dispersion in rotational velocities among PMS low mass stars. Recent observations indicate the existence of a Li-rotation relationship among weak-line T Tauri stars and confirm it among members of young open clusters (αPer, Pleiades). Such a link is most clear for PMS stars with masses around 0.8 $M_\odot$.

In this paper we present an exploratory study of the influence of rotation on Li depletion in PMS evolution. We have computed the contraction of 0.8-0.7 $M_\odot$ rotating stellar models (up to an age of 10^8 years) with constant angular momentum. We find that the presence of rapid rotation in PMS evolution significantly reduces the efficiency of Li depletion and allows to physically understand the observed Li abundance spread among late-type PMS stars. The effect of rotation on Li burning is enhanced for higher initial angular momentum and for higher efficiency of convective mixing. Also, we confim previous results that rotation changes the position of PMS tracks in the HR diagram. A rotating model is usually cooler than a standard one by a few percent, although the actual difference depends on age and initial angular momentum.

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Exponential Tails in the Centroid Velocity Distributions of Star-Forming Regions

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Probability density functions (pdfs) of ^{13}CO emission line centroid (line-of-sight, intensity-weighted average) velocities are presented for several densely sampled molecular clouds as quantitative descriptors of their underlying dynamics. Some are found to be approximately Gaussian in form, but most of the pdfs exhibit relatively broader, often nearly exponential, tails, similar to the behavior found for pdfs of velocity *differences* and *derivatives* (but not the velocity field itself) in experiments and numerical simulations of incompressible turbulence. Other non-turbulent processes can also give rise to non-Gaussian pdfs, although we know of no interpretations (turbulent or otherwise) that can unambiguously account for the nearly exponential tails. The centroid pdfs presented here are less sensitive to systematic motions, optical depth effects, and secondary thermal components than are individual molecular line profiles, which have also been used as pdf estimators and which have also been recently found to exhibit excess wing emission similar to the broad pdf tails found here. Accepted by Astrophys. J. Letters

Gravitational Infall in the Dense Cores L1527 and L483

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Lines of N_2H^+, C_3H_2, and H_2CO show kinematic evidence of gravitational infall in the star-forming dense core L1527, and probably also in L483. Three systematic trends appear to indicate infall motions, rather than outflow and rotation: (a) at each protostar position, line peak and centroid velocities get bluer by 0.1 to 0.3 km s^{-1} with lines of increasing optical depth; (b) in maps of C_3H_2 and H_2CO lines, line peak and centroid velocities get bluer by a similar amount as positions approach each protostar, and (c) C_3H_2 line widths in L1527 increase as positions approach the protostar. Also, in both sources H_2CO lines show the infall "signature" of spatially concentrated double-peaked profiles, with their blue peaks brighter than their red peaks, as seen previously in B335. Many asymmetric profiles have a single blueshifted peak with a red shoulder, rather than two peaks. Matching these profiles with an infall model appears to

require a departure from front-back spatial symmetry, due perhaps to effects of the bipolar outflow. In each source, H_2CO line wings show clear evidence of collimated outflow, even where the lower-velocity portion of the profile shows infall asymmetry.

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High Resolution Spectroscopy of Br γ Emission in Young Stellar Objects

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We have obtained high resolution spectra of the Brγ emission line in a small sample of low-luminosity embedded YSOs and active T Tauri stars. We find line profiles which possess broad wings (400-700 km/s FWZI) but which conspicuously *lack* the blueshifted absorption components generally expected for emission from a wind. Even T Tauri stars that show strong wind absorption features in the Hα and Na D lines show no obvious evidence of a wind origin for the Brγ line. These results imply that the winds in these YSOs are likely cooler than previously estimated and that mass loss rates derived from Brγ line strengths require reexamination. We also find a tendency for the centroid of the emission to be blueshifted with respect to the stellar velocity, as is often observed in the higher Balmer lines of T Tauri stars. This tendency is generally consistent with emission from *infalling* rather than outflowing gas. We discuss the physical origin of the infalling gas and the origin of the broad line wings.

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A turbulent model for the interstellar medium. II. Magnetic fields and rotation

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We present results from two-dimensional numerical simulations of a supersonic turbulent flow with parameters characteristic of the interstellar medium at the 1 kpc scale in the plane of the galactic disk, incorporating shear, thresholded and discrete star formation (SF), self-gravity, rotation and magnetic fields. A test of the model in the linear regime supports the results of the linear theory of Elmegreen (1991a). At low shear, a weak azimuthal magnetic field stabilizes the medium by opposing collapse of radial perturbations, while a strong field is destabilizing by preventing Coriolis spin-up of azimuthal perturbations (magnetic braking). At high shear, azimuthal perturbations are sheared into the radial direction before they have time to collapse, and the magnetic field becomes stabilizing again.

In the fully nonlinear turbulent regime, while some results of the linear theory persist, new effects also emerge. The production of turbulent density fluctuations appears to be affected by the magnetic field as in the linear regime: moderate field strengths cause a decrease in the time-integrated star formation rate, while larger values cause an increase. A result not predicted by the linear theory is that for very large field strengths, a decrease in the integrated SFR obtains again, indicating a "rigidization" of the medium due to the magnetic field. Other exclusively nonlinear effects are: a) Even though there is no dynamo in 2D, the simulations are able to maintain or increase their net magnetic energy in the presence of a seed uniform azimuthal component. b) A well-defined power-law magnetic spectrum and an inverse magnetic cascade are observed in the simulations, indicating full MHD turbulence. Thus, magnetic field energy is generated in regions of SF and cascades up to the largest scales. c) The field has a slight but noticeable tendency to be aligned with density features. This appears to be as much a consequence of the gas pushing on the magnetic field as due to constraints on gas motions because of the presence of the magnetic field. d) A "pressure cooker" effect is observed in which the magnetic field prevents HII regions from expanding freely, as in the recent results of Slavin & Cox (1993). e) The orientation of the large-scale azimuthal field appears to follow that of the large-scale Galactic shear. f) A tendency to exhibit *less* filamentary structures at stronger values of the uniform component of the magnetic field is present in several magnetic runs. Possible mechanisms that may lead to this result are discussed. g) For fiducial values of the parameters, the flow in general appears to be in rough equipartition between magnetic and kinetic energy. There is no clear domination of either the magnetic or the inertial forces. h) A median value of the magnetic field strength within clouds is $\sim 12\mu$G, while for the intercloud medium a value of $\sim 3\mu$G is found. Maximum contrasts of up to a factor of ~ 10 are observed.

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The Dynamic Stability of Rotating Protostars and Protostellar Disks: I. The Effects of Angular Momentum Distribution

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Modern studies of collapse and fragmentation of protostellar clouds suggest a wide variety of outcomes, depending on the assumed initial conditions. Individual equilibrium objects which result from collapse are likely to be in rapid rotation and can have a wide range of structures. We have undertaken a survey of parameter space in order to examine the role of dynamic instabilities in the subsequent evolution of these objects. Such instabilities can produce significant mass and angular momentum transport or, if violent enough, can lead to the breakup of the original object.

For the purposes of conducting a systematic study, we have so far considered only the $n = 3/2$ polytropic equilibrium states that might form from the collapse of uniformly rotating spherical clouds. We do not follow the collapses themselves, but use a simple procedure to 6cconnect presumed initial conditions to postcollapse equilibrium states. By varying the central concentration of the assumed initial cloud, we obtain equilibrium states distinguished primarily by their different specific angular momentum distributions. These equilibrium states range between starlike objects with angular momentum distributions analogous to the Maclaurin spheroids and objects which have moderately extended Keplerian disklike regions. Using a new SCF code to generate the $n = 3/2$ axisymmetric equilibrium states and an improved 3D hydrodynamics code, we have investigated the onset and nature of global dynamic instabilities in these objects.

The starlike objects are unstable to barlike instabilities at $T/|W| \geq 0.27$, where $T/|W|$ is the ratio of total rotational kinetic energy to gravitational potential energy. These instabilities are vigorous and lead to violent ejection of mass and angular momentum. As the angular momentum distribution shifts to the other extreme, one- and two-armed spiral instabilities begin to dominate at considerably lower $T/|W|$. These instabilities seem to be driven by mechanisms related to swing and SLING, but operating under conditions which are very different from those which are usually considered. In flattened objects, one-armed spirals dominate all other disturbances. Although these spirals tend to saturate at nonlinear amplitude, they do transport significant amounts of mass and angular momentum. It is unclear at present whether or not they ultimately lead to breakup of the equilibrium object. We conclude that the nature of the global instabilities encountered during the process of star formation can be quite sensitive to the angular momentum distribution of the protostar.

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Aperture Synthesis ^{12}CO and ^{13}CO Observations of DM Tauri: 350 AU Radius Circumstellar Disk

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We have made aperture synthesis observations of ^{12}CO (1-0), ^{13}CO (1-0), 2.6 mm, and 2.7 mm continuum emissions from a young star DM Tau with the Nobeyama Millimeter Array (NMA). It has been found from our observations that ^{12}CO gas with a size of 5".9 x 4".6 is associated with DM Tau and the systematic velocity gradient of ^{12}CO exists along P.A.=160°. The observational results suggest that DM Tau is surrounded by the disk structure of molecular gas ("circumstellar gas disk") with a radius of 350 AU and an inclination of 40° and that the kinematics of the disk is consistent with Keplerian rotation around DM Tau with a mass of 0.48 $M_\odot$. We have also detected the ^{13}CO, 2.6 mm, and 2.7 mm continuum emissions from the disk around DM Tau. The H_2 mass of the gas disk in the outer region (r>100 AU) is estimated to be 2.3×10^{-3} $M_\odot$ from the ^{12}CO and ^{13}CO emissions, and that in the inner region (r<100 AU) is 0.019 $M_\odot$ from 2.6 mm continuum flux. Although the disk around DM Tau is larger than the solar system, the disk may be a protoplanetary disk from the viewpoint that the mass of the disk is comparable to the minimum mass of the solar nebula ($\sim$ 0.01 $M_\odot$) and the kinematics of the disk is consistent with Keplerian rotation. The radial dependence of H_2 gas surface density of the disk is masses of the disk, unless the depletion of ^{13}CO occurs in the outer region. This power-law index of 2.0 ± 0.3 is significantly larger than the value of 1.5 adopted in the model of minimum solar nebula (Kyoto model). DM Tau is one of the young stars associated with the L1551 star-formingregion, including HL Tau, GG Tau, and a protostar, L1551-IRS 5. The systemic velocities of gas disks found around these stars in the different evolutional stages are in the very narrow range (V_{LSR} = 5.7 - 6.4 km s^{-1}), and the major axes of the disks are roughly perpendicular to the direction of the local magnetic field. It is likely that these stars were successively formed in the same parent cloud and that the magnetic field might play an important role in the formation of the stardisk systems.

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A New 3.25 Micron Absorption Feature toward Mon R2/IRS-3

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A new 3.2–3.5 μm spectrum of the protostar Mon R2/IRS-3 confirms our previous tentative detection of a new absorption feature near 3.25 μm. The feature in our new spectrum has a central wavelength of 3.256 μm (3071 cm^{-1}) and has a full-width at half maximum of 0.079 μm (75 cm^{-1}). We explore a possible identification with aromatic hydrocarbons at low temperatures, which absorb at a similar wavelength. If the feature is due to aromatics, the derived column density of C–H bonds is $\sim 1.8 \times 10^{18}$ cm^{-2}. If the absorbing aromatic molecules are of roughly the same size as those responsible for aromatic emission features in the interstellar medium, then we estimate that ~9% of the cosmic abundance of carbon along this line of sight would be in aromatic hydrocarbons, in agreement with abundance estimates from emission features.

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Star Clusters as a source of the Galactic halo field stars

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Sources of the galactic halo field stars are discussed. Current disruption rate of globular clusters do not enough for it. Reconstruction of primordial globular cluster system gives us the evaluation of its initial mass of about $10^8 M_\odot$. It is not enough to explain an origin of stellar component of the Galactic halo even if to take into account low efficiency of gravitationally bound systems formation. For the recent value of cluster formation efficiency (CFE $\approx$ 10%) extrapolated into the halo formation epoch, we can expect the total stellar mass connected with survived globular cluster population of $\sim 10^9 M_\odot$. It is less than the mass of stellar component of the Galactic halo ($\sim 10^{10} M_\odot$). Therefore we assume an existence of another population of low massive star clusters which may formed during turbulent collapse of the Galaxy and completely destroyed to the present. From this self-consistent scenario of formation and early evolution

of the clusters we obtain good enough prediction for the total mass of the Galactic halo.

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The structure and dynamics of NGC 1333 from ^{13}CO and C^{18}O observations.

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This paper presents a study of a dense molecular region, NGC 1333, and the relationship of the embedded infrared sources and young stellar objects to the structure of its molecular core. We use ^{13}CO and C^{18}O J $= 1 \rightarrow 0$ and J $= 2 \rightarrow 1$ observations, along with those of CS J $= 2 \rightarrow 1$ to characterize the structure of the core, calculate densities and masses. We find from our C^{18}O maps that the core consists of a cavity surrounded by a compressed shell of gas. Many of the infrared and outflow sources in NGC 1333 are located in the cavity. The winds from IRAS2, SSV13 and several other sources appear to provide the energy to sweep up the material, expand the cavity and compress the shell. We suggest that sequential star formation is taking place in NGC 1333 with SSV13 initiating this scenario. Several massive ($\sim 20 - 40$ M$_\odot$) condensations in the shell are potential sites for the next generation of star formation in NGC 1333.

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The low mass IMF in the ρ Ophiuchi cluster

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We compare the methods for estimating the masses of young, embedded stars developed by Comerón et al. 1993 and by Strom et al. 1995 and show them to be in good agreement. Spectra in the 2 μm region of three low mass objects, including a brown dwarf candidate, are also in agreement with the mass estimates using these methods. The spectrum of the brown dwarf candidate can be used to place an upper limit on its mass of 60% of the minimum required for hydrogen burning. This limit is independent of the photometric analysis, which we update in this paper to make use of new calculations of brown dwarf evolution. This new analysis indicates a mass for this object of roughly 40% of the minimum hydrogen burning mass.

The initial mass functions obtained for low mass stars in the ρ Ophiuchi cloud cores by Comerón et al. 1993 and by Strom et al. 1995 also agree well. The data have been combined to increase the statistical weight of the determination of the IMF. The IMF between 0.03 and 1 M$\odot$ can be fit satisfactorily by a power law with index in linear mass units of ~ -1.1, or in logarithmic units of ~ -0.1.

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The hydrodynamics of shock-cloud interactions in three dimensions

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Following Stone & Norman (1992), we present quantitative numerical studies of the interaction between a planar shock and small interstellar clouds with different shapes and orientations in three-dimensions (3-D). We assume that the dynamical time scale of the interaction is much smaller than that of other physical processes such as radiative cooling, thermal conduction, and gravitational contraction. As a result, we neglect these effects. The problem is therefore specified by only three parameters: the Mach number of the shock M, the ratio of the density of the cloud to that

of the ambient gas χ, and the adiabatic index γ. In this paper, we study strong shocks with $M = 10$, overdense clouds with $\chi = 10$, and assume $\gamma = 5/3$. We consider the evolution of clouds using three different initial geometries: (1) a spherical cloud, (2) a prolate cloud with the long axis aligned perpendicular to the shock normal, and (3) a prolate cloud with the long axis inclined at 45° to the shock normal. We find that, as in previous two-dimensional simulations, in each case 3-D clouds are strongly fragmented in a few dynamical time scales, and the cloud material is strongly mixed with the ambient gas by complex turbulent motions. However, the geometry of the clouds does affect both the acceleration of the cloud and the mixing rate of the cloud with the ambient gas. Most importantly, different initial geometries can change the morphology of the clouds in late stages of their evolution substantially; this makes observational identification of shocked clouds in young supernova remnants based on morphology alone more difficult. In each case very complex filamentary structures are observed in our simulations.

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Interferometric Observations of The Circumstellar Structure Around The Young Stellar Object in L1287

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Results of high-resolution interferometric observations of CS $(2-1)$ emission from the young stellar object, *IRAS* 00338+6312, and its neighboring region in L1287 are presented. Strong and localized emission has been detected. The global CS distribution appears elongated and has a size of 0.14 pc × 0.08 pc. The CS emission shows drastically different structures at different radial velocities, including a high-velocity bipolar pattern extended over 16 km s^{-1} and a flattened structure perpendicular to the outflow axis at lower velocities. The high-velocity lobes are clumpy and have been apparently accelerated. It is found that the *IRAS* source is located in the central part of the low-velocity CS structure, while three other optical features including the two FU Orionis candidates, RNO 1B & 1C, are located near or outside the edge of the low-velocity CS component. The possible driving source of the outflow in L1287 is discussed on the basis of the available data.

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Ammonia Maser in a Molecular Outflow toward W51

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We report the discovery of a $^{14}NH_3$ maser in the (J,K)=(3,3) transition towards the W51-NORTH HII complex. The maser line has a FWHM of 1.7 km s^{-1} and an asymmetric profile, suggesting multiple features in the velocity range. Measured with the VLA, the maser emission has a peak flux of 230 mJy and a maximum deconvolved size of 0.2″. These values set a lower limit to the brightness temperature of 1.3×10^4 K.

Thermal emission of ammonia was also detected towards this region. The elongated structure, velocity and temperature gradients, and high excitation of the thermal ammonia indicate that the (3,3) maser is excited in an expanding shell of a molecular outflow, powered possibly by the massive OB star D2. Molecular hydrogen densities and kinetic temperatures in the maser region are consistent with models of collisional pumping of the (3,3) maser.

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Dissertation Abstracts

The Structure and Evolution of Giant Molecular Clouds

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Ph.D dissertation directed by: Leo Blitz & Jack Welch

Ph.D degree awarded: May 1995

This thesis consists of a study of the density structure within two Galactic molecular clouds, and investigations into their evolution. There are eight chapters in all, of which 4 have been or are soon to be published in the Astrophysical Journal. Chapter 1 is the introduction. Chapter 2 describes a method for analyzing spectral line observations of cloud density structure. The aims and limitations of such an analysis are outlined. In Chapter 3 the method is applied to a proto-typical star forming cloud, the Rosette molecular cloud, and a thorough analysis of its structure is made. Molecular clumps, observed in ^{13}CO, are found to be embedded in a low density interclump medium, observed in HI. Many signs of the cloud's formation and evolution are found. The effect of the previous generation of star formation (the Rosette nebula) is assessed, and the conditions for present and future star formation within the remainder of the cloud are evaluated. Stars form in the most massive, gravitationally bound clumps within the cloud, and with an efficiency that increases with proximity to the HII region. The analysis of the Rosette cloud is used as a baseline to compare with a second molecular cloud, the Maddalena–Thaddeus cloud. This is, at the time of writing, the only massive cloud which is known not to be presently forming any OB stars. The overall, large scale view of the molecular, atomic and associated stellar components of this cloud is shown in Chapter 4: it is shown that there is associated massive star formation that is interacting with the cloud, forming a massive PDR several hundred parsecs in length, but that the bulk of the molecular material is non-star forming and in a very different evolutionary state to the Rosette cloud. ^{13}CO(1–0) observations of the density structure within the cloud are described in Chapter 5 and compared with the earlier results for the Rosette cloud. Structurally, the two clouds share many similarities, for example, the clump mass spectrum, mass–size relation, and isothermal clump profiles. But there are differences of scale between the two: the clumps in the Maddalena–Thaddeus cloud have high linewidths and are all gravitationally unbound. They also have have low peak column densities and shallow profiles relative to clumps of similar mass in the Rosette cloud. Further comparisons of the physical conditions in the two clouds are discussed in Chapter 6. Higher transition lines of CO and ^{13}CO and CS, a denser gas tracer, are observed. Kinetic temperatures are higher in the Rosette cloud and the ratio of CS to ^{13}CO emission is stronger. The focus shifts from these two clouds to the overall distribution of molecular clouds in the Galaxy in Chapter 7. Previous survey data is reevaluated and an OB association luminosity function and cloud mass spectrum is derived. A simple theoretical model is then used to calculate a joint distribution of OB associations in clouds, and used to compare with observed cloud-association pairings in the Galaxy. Most clouds with masses comparable to the Rosette or Maddalena–Thaddeus clouds ($M \sim 10^5\, M_\odot$) are predicted to contain only a few O and B stars. It is argued, then, that the Maddalena–Thaddeus cloud is an extreme evolutionary example of a rather common type of molecular cloud. Implications of the observations of its density structure and the comparison with the Rosette cloud are then interpreted in Chapter 8 in terms of an evolutionary scenario for molecular clouds.

New Books

Star Formation and Techniques in Infrared and mm-Wave Astronomy

Edited by T.P Ray and S.V.W.Beckwith

These are lecture notes from the Predoctoral Astrophysics School V, organized by the European Astrophysics Doctoral Network, held in Berlin, Germany, from 21 September to 2 October 1992.

The book is divided into three sections:

Part I. Star Formation

Part II. Techniques in Infrared and mm-Wave Astronomy

Part III. Student Presentations

The following lectures were held:

Molecular Clouds and Star Formation *(Sylvie Cabrit)*
1. Introduction; 2. Overall Properties of Molecular Clouds; 3. Star Formation in Molecular Clouds; 4. Molecular Outflows and Their Role in Star Formation.

An Introduction to T Tauri Stars *(Claude Bertout)*
1. The Visible Stellar Content of Dark Clouds; 2. Interpretation of Herbig's Criteria for TTS; 3. Nature of T Tauri Activity; 4. Summary.

Massive Stars and Their Interactions with Their Environment *(J.E. Dyson)*
1. Introduction; 2. Shocks and Ionization Fronts; 3. Ultra Compact HII Regions; 4. OB Stars and Clumps; 5. Effects of Groups of OB Stars.

Observing Far-Infrared and Sub-millimeter Continuum Emission *(J.P Emerson)*
1. Introduction & Philosophy; 2. Measurables: Flux Density & Specific Intensity; 3. Observing Frequency and Bandpass; 4. Allowing for Atmospheric Transmission; 5. Calibration & Determination of Atmospheric Transmission; 6. Cancellation of Sky & Telescope Emission; 7. Spatial Structures; 8. Sensitivity & How Long to Integrate, 9. Detection Systems; 10. Observational Capabilities; 11. Conclusions.

Near-Infrared Techniques for Studies of Star Formation *(S.V.W. Beckwith)*
1. Infrared Appearances of Young Stars; 2. Natural Limits to Observation; 3. Near-Infrared Observational Techniques; 4. Infrared Detectors; 5. Future Prospects.

High Spatial Resolution Infrared Observations – Principles, Methods, Results *(C. Leinert)*
1. Introduction; 2. Imaging; 3. The Turbulent Atmosphere; 4. Lunar Occultations; 5. Near-Infrared Speckle Interferometry; 6. Interferometry; 7. Adaptive Optics; 8. Concluding Appraisal.

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Disks, Outflows and Star Formation

Edited by Susana Lizano and José M. Torrelles

Proceedings of the conference "Disks, Outflows, and Star Formation" held in Cozumel, México from November 28 to December 2, 1994. The conference was organized by the Instituto de Astronomía of the Universidad Nacional Autónoma de México (IAUNAM).

The book contains the following articles:

Subarcsecond Observations of Radio Continuum from Jets and Disks (L. F. Rodríguez)
Disks and Outflows in the Orion Nebula as Determined by the HST (C. R. O'Dell)
Externally Illuminated Young Stellar Objects in the Orion Nebula (J. Bally, D. Devine, & R. Sutherland)
Photoevaporated Globules in HII Regions (S. Lizano & J. Cantó)
The Evolution of Photoionized Disks (H. W. Yorke)
Herbig-Haro Jets at Optical, Infrared and Millimeter Wavelengths (B. Reipurth & J. Cernicharo)
Radio Continuum Observations of Herbig-Haro Objects (S. Curiel)
Centimeter Continuum Emission from Outflow Sources (G. Anglada)
The Nature of the Radio Sources within Cepheus A East (G. Garay)
Outflows and Water Masers in Star-Forming Regions (M. Elitzur)
The Highly Collimated Bipolar Outflow NGC 2264G (C. J. Lada & M. Fich)
Models of HH Objects and Molecular Outflows (A. C. Raga)
Boundary Layers and Highly Supersonic Molecular Hydrogen Flows (J. E. Dyson, T. W. Hartquist, M. T. Malone, & S. D. Taylor)
Neutral Winds and Mixing Layers: The Case of L1551 (C. Giovanardi & S. Lizano)
Dense Cores in Molecular Clouds (M. Walmsley)
Signatures of Contracting Molecular Cores with Low-Mass Star Formation (J. M. Torrelles, J. F. Gómez, & G. Anglada)
Formation and Early Evolution of Protostellar Disks (P. Bodenheimer & G. Laughlin)
Gravitational Collapse and Binary Protostars (A. P. Boss)
Collapse of Magnetized Molecular Cloud Cores: Model Predictions versus Observations (D. Galli)
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Spectral Energy Distributions of Infalling Envelopes (N. Calvet)
Polarization Models of Embedded Protostars (B. A. Whitney)
The effect of the Environment on the Temperature Profile of Circumstellar Disks (A. Natta)
The Temperature Distribution of Circumstelar Disks (J. Cantó, P. D'Alessio, & S. Lizano)
Boundary Layer Solutions for T Tauri and FU Orionis Stars (R. Popham, R. Narayan, S. J. Kenyon, & L. Hartmann)
The FU Orionis Variable Stars: Accretion in Action (S. J. Kenyon)
The FU Orionis Outburst as a Thermal Accretion Event: Theoretical and Observational Implications (K. R. Bell)
Quasi-Geostrophic Vortices in Circumstellar Disks (F. C. Adams & R. Watkins)
Character of Dynamo-Generated Magnetic Fields in Viscous Protostellar Disks (T. F. Stepinski)
Disk-Driven Hydromagnetic Winds in Young Stellar Objects (A. Königl)
Observational Constraints on Disk Winds (L. Hartmann)
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Observational Evidence for the Importance of Magnetospheres in the Evolution of T Tauri Accretion Disk Systems (S. Edwards)
Initial Frequency, Lifetime and Evolution of YSO Disks (S. E. Strom)
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Models of Molecular Line Emission from Plotoplanetary Disks at Subarcsecond Resolution (J. F. Gómez & P. D'Alessio)
High Angular Resolution Imaging of Circumstellar Environment of Young Stars (F. Malbet)
Resolving Circumstellar Disks with the CSO-JCMT Interferometer (J. E. Carlstrom, O. P. Lay, R. E. Hills, & T. G. Phillips)

Expectations from New Instruments (P. T. P. Ho)
Summary of Conference (F. H. Shu)

The book has been published as Volume 1 in the *Revista Mexicana de Astronomía y Astrofísica, Serie de Conferencias*, (April 1995). 388 pages. ISSN-1405-2059.

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