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From the Editor

This issue of the Newsletter has unfortunately been significantly delayed due to a serious malfunction in our computer system.

Abstracts of recently accepted papers

Millimeter Interferometric Polarization Imaging of the Young Stellar Object NGC 1333/IRAS 4A

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We present a 3.4 mm polarization image of the dust emission associated with the young stellar object NGC 1333/IRAS 4A made with the Owens Valley Millimeter Array with $5''$ resolution. The integrated linear polarization of the dust continuum is 4% of the total intensity. The polarization is produced by magnetically aligned dust grains and arises from very dense gas ($n > 10^8$ cm^{-3}) indicating the dust alignment process remains viable in the dense protostellar envelope. The magnetic field directions inferred from our observations are aligned with features seen in the high velocity outflow emanating from IRAS 4A. The magnetic field directions are not aligned with the field on much larger scales as measured by optical and infrared selective extinction, suggesting significant field structure in the cloud core. The peak of the polarized emission is offset from the total intensity peak, perhaps indicating considerable unresolved structure in the magnetic field.

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Star Counts in Southern Dark Clouds: Corona Australis and Lupus

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Star counts technique is used towards southern dark globular filaments situated in the cloud complexes of Corona Australis and Lupus. Tables and maps of the distribution of visual extinction are presented for each filament. Lower limit masses for the filaments and condensations have been estimated and it is also given the central coordinates of the condensations. R CrA is the most massive active star forming region among the filaments studied in this work whereas Lupus 1, with almost the same lower limit of mass, has only a few T Tauri stars and just one young embedded object. The distribution of direction of the magnetic field in the condensations of Lupus, suggest that the condensation morphologies does not have any apparent relation with the magnetic field orientation

Astron. & Astrophy. Suppl.

The optical jet of RW Aurigae: excitation temperature and ionization state from long-slit spectra

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The physical properties of the optical jet associated with the T Tauri star RW Aurigae are discussed. The excitation temperature, the hydrogen ionization fraction, the electron and gas densities are estimated in various positions along the flow axis using a diagnostic technique originally developed for the study of the physical conditions in highly collimated Herbig-Haro jets (Bacciotti, Chiuderi & Oliva, 1995, A&A 296, 185). The receding portion of the jet (red lobe) has an ionization fraction which is slowly decreasing from about 25% near the star to about 2% at a distance of 6-7″ (∼1000 AU); the hydrogen density is roughly constant with a value of about 10^4 cm^{-3}; the temperature shows a slight decline, with typical values of about 4500 K. These results are consistent with the idea that the gas is initially ionized in the jet acceleration zone and that the physical conditions in the visible part of the jet are determined by time-dependent hydrogen recombination. It has not been possible to obtain any result for the blue lobe, due to the weakness of the [SII] 6716,6731 Å lines. The mass-loss and momentum rate in the flow (red lobe) are $\dot{M} \sim 5\ 10^{-8}$ M$_\odot$ yr^{-1} and $\dot{P} \sim 6.5\ 10^{-6}$ M$_\odot$ yr^{-1} km s^{-1}.

Accepted by A & A

The Narrow Emission Lines of T Tauri Stars

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We present the first comprehensive study of the narrow emission lines of T Tauri Stars (TTS). These narrow lines have been reported in the literature as originating in the stellar atmosphere and having gaussian type profiles centered at the stellar rest velocity, with a basewidth not larger than 50 km s^{-1}. Here, we concentrate on the CaII lines $\lambda\lambda$ 8498, 8542 and 8662 and the helium line λ 5876. After applying veiling corrections, the average narrow component line emission is found to be larger than that found in active main sequence stars: up to several times larger for classical T Tauri with strong rates of disk accretion. More striking is the finding that the resulting line emission strengths of these lines correlate with veiling. The correlation is confirmed on individual stars for which observations at several epochs exist and for which veiling varies widely on relatively short timescales. We also find a correlation between the narrow emission fluxes and the near infrared excesses for stars with low levels of veiling, which includes the few weak–lined TTS of the sample.

We discuss possible formation sites for the narrow emission lines in the classical TTS, and we present simple models to explain the observations. In these models, the excess line emission found for the stars with higher accretion rates is assumed to originate in localized regions near the magnetic footpoints of the accretion column. We refer to these hypothetical regions in the atmosphere collectively as the "hot chromosphere" since we assume they are additionally heated by the reprocessed energy of the colliding gas in the accretion process. Computing two chromospheric models: one representing the typical weak TTS chromosphere and the other representing the best guess at the "hot chromosphere", we find the following. The "hot chromosphere" is characterized by a steep temperature gradient beginning at low continuum optical depths in order to simultaneously give the large observed central flux and the relatively narrow baselines (50-60 km s^{-1}). The chromosphere temperature rise is not similar to the earlier deep chromosphere models in which a sudden chromospheric temperature rise is appended to the photosphere at relatively large mass column. For the most extreme cases (i.e. largest line fluxes), 20%, at most, of the star's surface must be covered by "hot chromospheric" regions.

Accepted by Astron. J.

RNO 43: a jet-driven super-outflow

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We present 21″-resolution, CO observations of the spectacular molecular outflow associated with RNO 43. This outflow extends over nearly 5 pc and is thus one of the largest known. The high velocity CO emission is broken up into several distinct regions of high excitation. Each of these regions subtends a small angle at the young stellar object driving the flow, and four show coincident optical emission in the form of Herbig-Haro objects, supporting the hypothesis that the collimated jet responsible for the Herbig-Haro objects also drives the molecular outflow. The jet is episodic and wanders in direction. We show that the asymmetries in the outflow can be explained by a symmetrical jet propagating in an asymmetrical cloud. The jet has had a considerable heating effect on a large fraction of the volume of its parent molecular cloud.

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Density Structure in Giant Molecular Cloud Cores

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We present the results of a multitransition study of HC_3N in cores of three giant molecular clouds in Orion, M17, and Cepheus A. In these regions we have mapped the J = 4 → 3, J = 10 → 9, J = 12 → 11, and J = 16 → 15 transitions of HC_3N over a $4' \times 12'$ area (360 positions) in Orion and a $4' \times 5'$ area (120 positions) in M17 and Cepheus A. We have used the results of a previous study of the temperature structure of the dense gas in the same cloud cores together with a non-LTE excitation model for HC_3N to derive the density of molecular hydrogen and the column density of HC_3N. In all we have computed densities for 133 positions in Orion, 46 positions in M17, and 14 positions in Cepheus A. Despite the differences between the clouds, the range of densities in the three cores is found to be quite similar, with derived values of n_{H_2} between 3×10^5 and 5×10^6 cm^{-3}.

The principal result of this study is that, in spite of the use of an optically thin tracer and the inclusion of an improved source temperature model, the density within each cloud core shows no evidence of large scale variations. These observations are consistent with the results of previous efforts which utilized other tracers of the dense gas and assumed a constant temperature for the cloud. An examination of the size scale of the clouds implied by the observed density and the $C^{18}O$ column density demonstrates that either each cloud has a strikingly (>10:1) flattened geometry, each with the short axis along the line of sight, or that the dense gas must be clumped and is filling only a small fraction of the volume ($\lesssim$5%). We have also examined the possibility of lower density material along the line of sight and find that the present data suggest a clump to interclump density ratio > 100.

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Rotation Periods of Stars in the Orion Nebula Cluster: The Bimodal Distribution

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Results from the 1992-93 season of imaging fields in the Orion Nebula Cluster at Van Vleck Observatory are presented. Data were obtained on 525 stars brighter than I $\sim$ 16 mag and 50 periodic variables were found, of which 27 are newly discovered. Light curves of these spotted stars are displayed. The number of rotation periods known for ONC members, based on four years of monitoring at VVO, now stands at 75 and a comprehensive list is given here. Since candidate objects were selected only by proper motion and position, without reference to spectral, X-ray, infrared or other properties, the sample provides a relatively unbiased view of the angular velocity distribution of low mass stars at an age of around one million years. Twenty-five stars have periods determined in more than one year and in 23 cases they agree to better than 1%. In one case the agreement is within 5% and in one case there is evidence of period doubling. Seventy stars have amplitudes consistent with cool spots; the other five are interpreted as hot spot stars. The frequency distribution of rotation periods is distinctly bimodal, confirming the discovery of Attridge & Herbst (1992). About one-third of the stars are rapid rotators with a median period of 2.55 days and dispersion of 0.7 days. The others are slow rotators with a median of 8.3 days, a dispersion of 3.8 days and a tail of very long period stars extending to 34.5 days. Six stars have rotation periods exceeding 12 days, which had been proposed as a limit for T Tauri stars. Our observations support theories of disk-regulated rotational evolution during the pre-main sequence phase. Slow rotators are interpreted as stars "locked" to their accretion disks and rapid rotators are presumed free of such locking. The gap in the frequency distribution at rotation periods near 4 days is interpreted as a portion of angular velocity space through which contracting stars pass quickly once released from the disk lock. We find a significant difference between the period distributions of the more and less nebulous fields within the ONC; the more nebulous (arguably younger) fields have a larger proportion of slow rotators. Combining the ONC sample with one drawn from the Tau-Aur region, we show that most pre-main sequence stars more nearly conserve angular velocity than angular momentum as they contract, consistent with predictions of the disk-interaction theories. A large amount of angular momentum loss appears to occur as a result of this process during the early stages of pre-main sequence evolution.

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The occurrence of H_2O masers in the early stages of star formation

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The results of a survey of 22.2 GHz water maser emission toward 39 young stellar objects (McCutcheon et al. 1991) are presented. The sample contains bright IRAS sources associated with molecular clumps, which may represent different phases of the early evolution of star forming regions, depending on the presence or absence of compact H II regions. We associate 19 water masers with the IRAS sources, 4 of which are new detections. Taking into account also previous detections of masers that were quiescent during our survey, the total number of sources which show maser emission is 22 (56% of the whole sample). This has to be taken as a lower limit if variability of the maser emission is considered. The maser percentage does not change for sources with or without a compact H II region. It is higher (68%) if we consider only sources associated with large CO linewidths.

Our H_2O observations confirm that water masers can occur at the earliest phases of the formation of high luminosity stars, much before the development of an ionized region detectable in the radio continuum, and that they are closely connected with molecular outflows.

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Further characteristics of the young triple system TY CrA

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The pre-main sequence star TY CrA is an eclipsing multiple system; in addition to the spectroscopic signatures of the primary and the secondary, lines from a third component were recently detected. Here we present high resolution spectra of the Li I 6708 Å, [S II] 6716,6731 Å, and [O I] 6300 Å lines. Observations were carried out with the Coudé Echelle Spectrograph at the 1.4 m ESO CAT Telescope, in remote control during the year 1994 and in La Silla in April 1995. [S II] and [O I] emission lines are undoubtedly detected. They are the first narrow emission lines observed so far in the TY CrA visible spectrum. Their origin remains uncertain, but they might be due to the tertiary component. Our long-term monitoring of the Li I lines of the tertiary component and previously published results allows us to derive its orbital motion around the binary system. We computed various possible fit for the orbit of this third component, and estimate its dynamical and physical attributes. The five solutions present in fact remarkable common features: 1) a semi-major axis of the order of 1 A.U., with an orbital period significantly less than 1 year; 2) a rather high eccentricity (four solutions have $e \simeq 0.5$); 3) a tertiary mass $m_3 \simeq 1.2$ – $1.4\,M_\odot$, although this parameter is weakly constrained (large uncertainty); 4) an inclination $i \simeq 16$ – $25°$. The orbit appears thus to be eccentric and highly inclined with respect to that of the binary. The tentative determinations of orbital elements for the tertiary need to be tested through additional high S/N data, in particular to reduce the number of relevant solutions.

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High-Velocity Ammonia emission Associated with the Young Stellar Object Serpens FIRS 1

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We have performed VLA, Haystack and Effelsberg 100 m ammonia observations of the molecular core associated with the highly collimated radio continuum jet of the very young stellar object (YSO) Serpens FIRS 1. An analysis of the overall morphology, kinematics, and excitation of the ambient cloud core is presented. In particular, the mean rotational temperature derived over a region of $2'\times2'$ around FIRS 1 is found to be 12 K, whereas it increases to 30 K at distances within $6''$ from FIRS 1, indicating that FIRS 1 is the dominant energy source in the cloud core. By averaging the blueshifted (V_{LSR} = –6.1→+5.7 km/s) and redshifted (V_{LSR} = +10.7→+22.5 km/s) spectral channels of the VLA data with respect to the ambient cloud velocity (V_{LSR} = 7.0-9.4 km/s), we have detected an excess of emission (above the expected continuum) that we identify as high-velocity ammonia emission associated with the YSO FIRS 1. The blue- and redshifted emissions seem to have a bipolar morphology, suggesting that they trace a bipolar ammonia outflow of $\sim20''$ in size and aligned with the radio continuum jet. We identify this high-velocity ammonia emission, with an estimated mass $M(H_2) \simeq 0.2\,[X_{NH_3}/10^{-8})]^{-1}\,M_\odot$, as associated with the molecular gas entrained by the radio jet. In addition, NH_3 (1,1), (2,2) and (3,3) spectra of this region taken with the Haystack and the Effelsberg 100 m telescopes show ammonia emission at even higher velocities (up to ∼30–40 km/s from the line center) than those observed with the VLA ($\lesssim$ 20 km/s), suggesting that the VLA observations cover only a fraction of the velocity range of the ammonia outflow. New VLA ammonia observations covering a higher velocity range are needed to fully map this high-velocity molecular emission and to confirm its bipolar distribution.

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Echelle spectroscopy of shocked H_2 in the L 1448 outflow

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Here we investigate the dynamical properties of the outflow from a Class 0 protostar. We have observed H_2 v=1-0 S(1) velocity profiles at eight slit positions in the northern lobe of the outflow driven by L 1448-mm (the VLA source L 1448C). Complex line profiles are observed throughout the region; the peak H_2 emission is everywhere strongly blue-shifted. The velocities of the line profile peaks also gradually increase along the length of the outflow. This we attribute to the bending of the flow towards the observer.

The flow produces numerous bow shocks along its length (as evidenced by the triangular H_2 profiles) that are intersperced with a turbulent shear layer (resulting in the more Gaussian profiles). Knot A is a superb example of a bow shock. Its spatial distribution corresponds to a C-type bow, and this is confirmed by our velocity-position analysis: the profiles are wide and double-peaked just behind the bow apex. There is also evidence that *all* the H_2 emission features are produced within an expanding wind of high Alfvèn speed. Analysis of the main "ridge" of emission suggests the presence of many small clumps, formed after the wind terminates at an oblique shock. We may therefore be witnessing the shredding and dispersal of the molecular cloud core by the L 1448-mm outflow.

A preprint, in PostScript format, can be obtained via the internet (from http://spitfire.mpia-hd.mpg.de/Preprints.html) or directly from one of the authors.

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Dust and Gas Distribution around T Tauri stars in Taurus-Auriga. I. Interferometric 2.7mm continuum and ^{13}CO J=1-0 observations

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We present new ^{13}CO J = 1→0 and 2.7 mm continuum interferometric observations of 33 young star systems located in Taurus-Auriga. Our goal was to compare the distribution, and hence the evolution, of the circumstellar material around young star singles and binaries. The sample included 2 triples, 16 binaries, 14 singles, and one object of unknown multiplicity.

We detected 2.7 mm continuum emission in 12 systems at S/N > 5 and have probable detections for another 5. V 773 Tau, a weak emission line binary system, is remarkable in that its 2.7 mm continuum decreased from ∼ 30 mJy to ∼ 0 mJy in less than six months. We find that the singles are, on average, stronger 2.7 continuum sources than the multiples, consistent with Osterloh & Beckwith's (1995) finding at 1.3 mm. Significant estimates of the sizes have been obtained for 8 singles. They imply large ($R > 150$ AU) disks, with relatively flat density distribution (emissivity flatter than $r^{-1.5}$). The spectral energy distributions in the millimeter range can be fitted using a dust emissivity law $K_\nu \propto \nu^\beta$ with value of β in the range 0.5 to 1.

Only DG Tau, Haro 6-5b and UY Aur have detectable ^{13}CO J = 1 → 0 emission. ^{13}CO emission, but no 2.7 mm continuum, is also found in the LkHα 332 region and near FS Tau; however, it does not appear to be associated with the known stars. Interpreting the observational results in terms of the circumstellar disk scenario, we find that, in all cases, disk masses derived from the dust emission at 2.7 mm are more than a factor of about 20 larger than the masses derived from the ^{13}CO J = 1→0 upper limit.

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Postcript files are available by WWW on IRAM home page: http://iram.fr/papers/papers.html or by anonymous ftp account to iram.fr: /dist/pub/papers/e021.ps.Z

A Survey of the Galactic Plane for 6.7-GHz Methanol Masers I: $l = 325^\circ - 335^\circ$; $b = -0.^\circ53 - 0.^\circ53$

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We report the results of the first complete survey of an area of the Galactic Plane for maser emission from the 6.7-GHz $5_1 \rightarrow 6_0$ A^+ transition of CH_3OH. The survey covers a 10.6-square-degree region of the Galactic Plane in the longitude range $325^\circ - 335^\circ$ and latitude range $-0.^\circ53 - 0.^\circ53$. The survey is sensitive to masers with a peak flux density greater than ~ 2.6 Jy. The weakest maser detected has a peak flux density of 2.3 Jy and the strongest a peak flux density of 425 Jy. We detected a total of 50 distinct masers, 26 of which are new detections. We show that many 6.7-GHz CH_3OH masers are not associated with *IRAS* sources, and that some are associated with sources that have colours differing from those of a typical ultra-compact HII region (UCHII). We estimate that the number of UCHII regions in the Galaxy is significantly more than suggested by *IRAS*-based estimates, possibly by more than a factor of two.

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Layered Accretion in T Tauri Disks

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We put forward a model for accretion disks around T Tauri stars. The model assumes that angular momentum transport is driven by magnetic fields, and can occur only in those parts of the disk that are sufficiently ionized that the gas can couple to the magnetic field. These regions lie at $R \lesssim 0.1$ AU, where collisional ionization is effective, and at $R \gtrsim 0.1$ AU in a layer of thickness $\approx 100\,\mathrm{g\,cm^{-2}}$ at the surface of the disk where cosmic ray ionization is effective.

The model predicts that the stellar accretion rate is about $10^{-8}\,M_\odot\,\mathrm{yr}^{-1}$, independent of the rate of infall onto the disk. Matter that is not accreted onto the star accumulates in the inner few AU of the disk at a rate of about $10^{-3}\,M_\odot$ in 10^4 yr. Given this buildup it is unlikely that accretion is steady. The effective temperature profile is $T_e \sim r^{-1/2}$ outside of 0.1 AU, which differs from the canonical $T_e \sim r^{-3/4}$. We calculate the expected spectral energy distribution for the disk and show that this temperature profile produces an infrared excess. Finally, we discuss some of the leading uncertainties in the theory.

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Non-LTE Effects in Ammonia

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The non-LTE effects in the NH_3 (J,K)=(1,1) absorption toward the DR21 HII region have been investigated using a spatial resolution of 1.7→3 arcseconds. The anomalies, found in the satellite hyperfine (HF) components, indicate significant, widespread departures from LTE. We present images of the LTE departure for the inner and outer pairs of NH_3 (1,1) HF components toward the HII region, and find surprisingly, that the degree of LTE departure for these HF components is spatially **anticorrelated**. Previous models predicted a spatial correlation. This unexpected result may be explained by a dynamic model involving both the infall and outflow of molecular material. Although weak emission in the redshifted outer HF component is widespread toward the continuum, an unresolved, high brightness temperature (≥600K) maser is found just SW of the continuum peak. This is the first proven instance of an interstellar maser in the NH_3 (1,1) level. The flux density of the maser is larger than the absolute value of the flux density of any

of the other HF components (seen in absorption), including the main component.

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Dynamics of embedded protostar clusters in clouds

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This is the abstract of your paper The dynamics of clumps and protostars in a young protocluster system embedded in its parent molecular cloud are studied here through numerical simulations. It is found that the presence of massive clumps and their dynamics strongly affects the motion of the lower mass protostars. Mass segregation of clumps due to dynamical drag by the interclump gas results in the formation of a dense central region and the lower mass protostars get preferentially ejected out of the cloud via gravitational encounters. The protostellar cluster is found to gradually expand with time forming a more extended system than the clumps. Thus, embedded protostar clusters are probably dynamically evolved systems with large halos of low mass protostars. This explains observations of T Tauri stars, which appear to be isolated from active star-forming sites and are in regions devoid of dense gas. As multiple star formation sites in clouds are common, outer members are subject to velocity perturbations due to massive clumps and other clusters, possibly leading to a faster removal of objects.

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The Unusually Rich Infrared Emission-Line Spectrum of a Deeply Embedded Low Luminosity YSO

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We have discovered a rich, near-infrared, emission-line spectrum from IRAS 04239+2436, a low-luminosity ($L \sim 1.3 L_{\odot}$) deeply embedded (Class I) source in the Taurus dark clouds. This Class I Young Stellar Object shows emission lines of Na I, H_2, H I Paβ, and nearly the entire H I Br series as well as prominent emission in the vibrational overtone bands of CO. This is the lowest luminosity YSO yet observed which exhibits CO overtone bands in emission and is the only source in a survey of approximately 100 low-luminosity YSOs which shows both strong CO and nearly the entire Br series of H I in emission. Unlike most other sources known to show this emission, the central star of this YSO is probably neither hot nor luminous enough to produce the observed CO emission via surface heating of an optically thick circumstellar disk. It is possible that the CO emission originates in a powerful stellar wind, but this cannot be confirmed with presently available data. The H_2, Na I, and H I emission lines are suggestive of a stellar wind, and we find that the H I Br γ line luminosity is consistent with published wind model calculations. The observed H I Paβ to Brγ line ratio falls within the range observed for T Tauri stars and within the range of wind model predictions, but we cannot be certain whether these as well as the other atomic lines form in a wind or in some other component of circumstellar gas. Higher spectral resolution observations are required to determine the exact origins of the CO and atomic emission features of this fascinating object.

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The β Pictoris phenomenon among young stars. III. The Herbig Ae stars WW Vul, RR Tau and BF Ori

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The Herbig Ae stars RR Tau, BF Ori and WW Vul are members of the small subclass of young stars with Algol-

type brightness variability. There are reasons to assume that they are surrounded by young protoplanetary disk-like envelopes, oriented edge-on and that they are young progenitors of the star β Pictoris. In this paper we present spectroscopic evidences for this assumption. They are based on the observations of variable redshifted absorption components in the sodium Na I D resonance lines, similar to those found in the spectrum of UX Ori. The shortest time scale of their observed variability is one day (BF Ori, WW Vul). Their maximum radial velocities reach 200-300 km s^{-1}, which corresponds to a distance from the star of a few stellar radii. As in the case of UX Ori we connect the formation of such absorption components with the evaporation of star-grazing bodies in the vicinity of young hot stars.

The fact that high-velocity redshifted absorption components are systematically observed in the sodium Na I D lines in the spectra of several UX Ori type stars, excludes the interpretation of this phenomenon by a special orientation of star-grazing orbits relative to the observer. We connect such an asymmetry with the evaporation of small (meteor-like) bodies which dissipate completely before the periastron of their orbits are reached, in their movements towards the stars.

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Orientation of the circumstellar disks of the Herbig Ae/Be stars and statistics of the H_α line profiles

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The results of statistical analysis of the published data on the photopolarimetric activity of Herbig Ae/Be stars and the H_α line profiles in their spectra are presented. They confirm the availability of connection between the type of the H_α profile and the level of photopolarimetric activity of young stars: the single profiles and the P Cygni ones are observed predominantly at the photometrically quiet stars whereas two-component profiles (typical for the disk accretion) more often in stars with a high level of the photometric activity. Existence of such a connection means that the variety of the observed H_α line profiles can be explained in the framework of one model of axially-symmetrical gas envelope observed under the different inclination to the line-of-sight. The mechanism of formation of such envelopes is discussed.

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Infrared lines for measuring the magnetic field strength of T Tauri stars

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Although magnetic fields are highly important for understanding the structure and evolution of T Tauri stars (TTS), very few attempts measure these fields have actually been reported, because of the high dispersion, and long integration times that are usually needed in the optical regime. In this paper we point out that the 1.5630-1.5695μm regime in the near infrared contains a number of suitable lines for this purpose, and present spectra which confirm the presence and strengths of these lines in the weak line T Tauri stars Tap 35 (=NTTS 042417+1744) and V410 Tau. We demonstrate that, using these lines and modern IR grating spectrometers such as the UKIRT's CGS4, the product fB of the filling factor (f) and the magnetic field strength (B) can be determined with an accuracy better than 500G in relatively short integration times if $vsini < 20$ km/s. In a quick exploratory observation we find that the lines in V410 Tau are too rotationally broadened to allow determination of a magnetic field but find an upper limit to fB of 2000G for the more slowly rotating weak line T Tauri star Tap35 using a spectrum with a total integration time of only 16 minutes.

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Activity on the classical T Tauri star BP Tauri

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We have made a detailed investigation of the short-term variability in optical light (UBVRI) of the classical T Tauri star BP Tauri. Photometric data (in UBVRI) were collected from Wendelstein Observatory, Germany in 1991, 1992 and 1993 with time-resolutions down to 1 sec and, from binning, fluctuations with total amplitudes down to a few milli-magnitudes could be resolved. Additional observations (in UBV) were collected in China. The total time of monitoring amounts to 135 hours.

The normal state of BP Tau is that it stays completely constant in brightness in all bands, or shows only very slow and smooth changes during a night, to the limit of detection. Brightenings, *events*, occurred on time-scales from 0.6 hours to a few hours but none of these reached a total amplitude > 0.3 mag. in U. As a rule these events do not have the characteristic flare profile as in the lightcurves of stellar surface flares. The total optical energies of the events are a few times 10^{35} erg, with a relatively small spread. The energy distributions at peak flux can be represented by black-body radiation. However, the inferred temperature is very low, $7000 - 8000$ K, and not significantly different from that derived for the background veiling. Hence, the events on BP Tau are very different from normal stellar flares.

From power analysis of the time series, we conclude that there is no power indicating frequent and short lasting phenomena, like surface flares. In particular there is no signal in the U band. Such flares would have been expected to be numerous in this high-sensitivity survey, however, if BP Tau had a magnetic surface activity comparable to that of ordinary flare stars. Also, there is no tail in the distribution of events towards smaller amplitudes and shorter durations.

We show that the events of BP Tau are consistent with inhomogeneous mass infall from magnetically controlled accretion between a circumstellar disk and a hot spot at the star. To account for the constancy in temperature and the distribution of events over frequency and amplitude, a model is proposed where the steady accretion of BP Tau is composed of small fragments which arrive close to the star in a random fashion. By simulations we show that such a flow can explain the smooth variations in the veiling and also the sudden occurence of events. In this "fractal" model, each event is composed of several superimposed fragments, which produce the sometimes complex light profiles.

Finally, we find regular long-term variations with a period of 6.6 days, which is in line with (but not exactly) the periods found by others.

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Time Dependent Photodissociation Regions

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We present theoretical models of the time dependent thermal and chemical structure of molecular gas suddenly exposed to far ultraviolet ($h\nu < 13.6$ eV) radiation fields, and the consequent time dependent infrared emission of the gas. We focus on the response of molecular hydrogen (H_2) for cloud densities ranging from $n = 10^3 - 10^6$ cm^{-3} and far ultraviolet (FUV) fluxes $G_0 = 10^3 - 10^6$ times the local FUV interstellar flux. For $G_0/n > 10^{-2}$ cm^3, the emergent H_2 vibrational line intensities are initially larger than the final equilibrium values. The H_2 lines are excited by FUV fluorescence and by collisional excitation in warm gas. Most of the H_2 intensity is generated at a characteristic hydrogen column density of $N \sim 10^{21}$ cm^{-2}, which corresponds to FUV optical depth of unity caused by dust opacity. The time dependence of the H_2 intensities arises because the initial abundances of H_2 at these depths is much higher than the equilibrium values, so that H_2 initially competes more effectively with dust in absorbing FUV photons. Considerable column densities of warm, $T \sim 1000$ K, H_2 gas can be produced by the FUV pumping of H_2 vibrational levels followed by collisional deexcitation which transfers the energy to heat. In dense ($n \gtrsim 10^5$ cm^{-3}) gas exposed to

high ($G_0 \gtrsim 10^4$) fluxes, this warm gas produces a 2-1S(1)/1-0S(1) H_2 line ratio of ~ 0.1, which mimics the ratio found in shocked gas. In lower density regions the FUV pumping produces a pure fluorescent ratio of ~ 0.5. We also present estimates of the time dependent intensities of OI(6300 Å), SII(6730 Å), FeII(1.64μm) and rotational OH and H_2O emission. Potential applications include star forming regions, clouds near AGNs, and planetary nebulae. We apply our models to five planetary nebulae and conclude that only BD +30°3639 shows evidence for enhanced H_2 emission due to (high) non-equilibrium H_2 abundances.

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Spectropolarimetry of the 3 micron ice feature towards the Becklin-Neugebauer object

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We present spectropolarimetry of the 3.1 μm water-ice feature in the Becklin-Neugebauer (BN) object in OMC-1 with substantially improved spectral resolution and signal-to-noise over previous observations. The well known increase in polarization within the ice feature is interpreted in terms of a model for aligned graphite and silicate grains with ice mantles. We identify polarization structure in the long wavelength (3.3 - 3.6 μm) wing of the ice profile, including a feature at 3.47 μm which matches closely the spectroscopic feature discovered in several protostars and attributed to carbonaceous material with diamond-like structure. We also show, for the first time, the occurrence of a systematic variation in the position angle of polarization across the ice feature in BN, indicating systematic differences in the relative numbers of core-mantle and unmantled grains along the line of sight, and a twist in the magnetic field orientation.

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A Near Infrared Study of the K3-50 Region of High Mass Star Formation

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In an ongoing study of high mass star formation regions in the near (1-5μm) infrared, we present J (1.2μm), H (1.65μm), K (2.23μm), and L" (3.81μm) broadband images as well as Brγ (n = 7→4, 2.166μm) and Brα (n = 5→4, 4.052μm) hydrogen recombination line images, and 3.29μm unidentified feature emission images of the K3-50 HII regions K3-50A and K3-50B, at a plate scale of ∼0."33 per pixel. The Brackett line images are combined with radio data to map the line of sight dust extinction to the compact HII region on small spatial scales. The 3.29μm emission is found to overlap and extend beyond the Brα and Brγ emission into the photo-dissociation region (PDR). We find clumps of dust extinction that may indicate a cluster of stars is in the process of forming. The overall structure of region K3-50A appears to be that of a rotating torus of dense gas with a bipolar ionized gas outflow br! eaking through to the north and south.

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A Magnetic Accretion Disk Model for the Infrared Excesses of T Tauri Stars

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We describe a magnetic accretion disk model for the infrared colors of T Tauri stars in the Taurus-Auriga molecular cloud. In this model, the stellar magnetic field truncates the disk several stellar radii above the stellar photosphere;

material then flows along magnetic field lines and forms a bright ring where the accretion stream impacts the star. The model successfully reproduces the observations for reasonable values of the magnetic field strength, 100–500 G; the stellar rotational period, 4–10 d; and the mass accretion rate, 10^{-8} to 10^{-6} $M_\odot\,yr^{-1}$. The truncation radius, R_0, lies well inside the corotation radius, R_c. We estimate $R_0/R_c \approx 0.6$–0.8 for CTTS in our sample. This result constrains models for the rotational evolution and bipolar outflows of pre-main sequence stars.

Magnetic disk models make several testable predictions. The near-IR colors should correlate with the stellar magnetic field and the rotational period. The magnitude of the near-IR veiling should strongly correlate with the stellar rotational period. Strong CO emission or absorption features should be present only in stars with high accretion rates. Observations also discriminate between various types of magnetic disk geometries if intrinsic stellar parameters – such as the stellar radius and magnetic field strength – are well-known.

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Aperture Synthesis ^{13}CO($J = 1-0$) Observations of the Molecular Gas around DG Tauri: Evidence for a Dispersing Gas Disk

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We made aperture synthesis ^{13}CO($J = 1 - 0$) observations of the molecular gas around a young star DG Tau, using the Nobeyama Millimeter Array. We have detected the gas in the velocity range $v_{\rm LSR} = 4.3 - 7.3$ km s^{-1}, and have revealed the velocity structure of the gas with velocity resolution 0.43 km s^{-1}. The molecular gas around DG Tau is found to have a disklike structure, with the major axis perpendicular to the blueshifted optical jet ejected from the star. The radius, mass, and inclination angle of the disk are estimated to be $\sim$ 2800 AU, 0.03 $M_\odot$, and 40°, respectively. It is noted that an expanding motion is distinct in the disk. The expanding velocity is about 1.5 km s^{-1}, which is larger than both the Kepler and free-fall velocities around DG Tau. Since the mechanical luminosity of the expanding motion is estimated to be 6×10^{-4} $L_\odot$, much smaller than the stellar luminosity of ~ 1 $L_\odot$, the expansion is possibly driven by the stellar wind from the central star. The disk model for the expanding gas around DG Tau is quite consistent with the structures of the reflection nebula and the blueshifted optical jet that were observed around the star. It would be reasonable to make the interpretation that the outer part of the large gas disk around the star, or the disk-shaped remnant of the envelope surrounding the star, is now being dispersed owing to the stellar wind during the evolution of a large protostellar disk into a compact protoplanetary one, because DG Tau has a flat spectral energy distribution and is considered to be evolving from a protostar to a T Tauri star.

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Near-infrared surface brightness observations of the Thumbprint Nebula and determination of the albedo of interstellar grains

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We have made near-infrared J, H and K bandpass imaging of a small, highly symmetric globule called the Thumbprint Nebula. At all these wavelengths the globule shows a surface brightness higher than the adjacent sky due to the radiation scattered by the globule. The intensity of the observed surface brightness is interpreted in terms of the scattering properties, i. e. albedo a and the form of the scattering function (phase function asymmetry parameter g) of the dust particles. Monte Carlo calculations for a spherical cloud have been used to solve the radiation transfer problem for different values of a and g.

The all-sky measurements of the DIRBE (Diffuse InfraRed Background Experiment) instrument aboard the COBE[1] (COsmic Background Explorer) satellite were used to calculate the galactic radiation field incident on the globule at 1.26 and 2.16 μm, while at 1.66 μm an interpolation has been used.

The values of a and g can not be determined separately, but the value of a is nearly independent of g for probable values of g ($0.0 < g < 0.8$). If it is assumed that the observed surface brightness is due solely to the scattered light then the grain albedo is 0.7 at 1.26 and 1.66 μm, and 0.6 at 2.16 μm, for $0.0 < g < 0.8$.

The reddening of the stars shining through the globule is used to determine the radial dust density distribution. The dust density distribution is found to be more centrally peaked than the density distribution of molecular gas.

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Mid-Infrared Imaging of Young Stellar Objects

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We present arcsecond resolution mid-infrared (8–13 μm) images and photometry of four young stellar objects (YSOs) — L1551-IRS5, HL Tau, AS 205, and AS 209 (V1121 Oph) — taken with the Berkeley Mid-Infrared Camera. For AS 205, a known T Tauri binary, we also present near-infrared JHK images and HKL$'$ speckle imaging data. All three single stars are unresolved in our mid-IR images, consistent with current models of the circumstellar material associated with these objects.

Our data is the first to resolve in the mid-IR both components of the close binary AS 205 (projected separation $\sim$1.3$''$ (210 A.U.)). Both stars are classical T Tauri stars and possess the 9.7 μm silicate feature in emission. AS 205 N is the IR brighter star in our data while published observations find it to be the optically fainter star. Assuming the IR excesses of both components arise from circumstellar disks, we find the emitting regions (the inner few A.U.) of the disks to be optically thick in the mid-IR. Pre-main sequence evolutionary models suggest the AS 205 system is non-coeval; we discuss possible explanations for this result and comment on the evolutionary status of this young binary.

All of our objects, except perhaps AS 205 South, exhibit changes in their mid-IR flux in measurements separated by intervals of days up to many years; the variations range from 30–300%. For the classical T Tauri stars AS 205 North and AS 209, the magnitude of the changes seems to discount the possibility the mid-IR variations have the same origin as the optical and near-IR variability of T Tauri stars, namely accretion-related features on or near the stellar photosphere. We speculate that the cause of the variability lies in the accretion disks of these objects; the data suggest disk accretion rate fluctuations of nearly an order of magnitude. The existence of large mid-IR variability argues that simultaneous multiwavelength observations are needed for a proper analysis of YSO spectral energy distributions.

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Spectroscopy of Possible Hα Emission Stars in Regions of High Galactic Latitude Molecular Clouds

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We present mid-resolution spectroscopic observations of 63 faint (V=12–16) stars identified by Kun (1992) as Hα emission candidates in an objective prism survey of several high galactic latitude molecular clouds. Only 4 stars in our sample (6%) are bona fide T Tauri stars on the basis of their strong Li absorption and Hα emission features. They have late M spectral types (M4–M5.5) and two of them form a visual binary with separation $\sim$7". The new T Tauris

are associated with the L 134 molecular complex, the northernmost extension of the Scorpio – Ophiuchus star forming region, which has been traditionally considered as a non-star forming region.

In the other high latitude clouds surveyed by Kun 1992, we have not found any T Tauri star in our follow-up spectroscopy. Most of the observed stars (∼80%) are late type dwarfs without detectable Hα emission in our spectra. Eight stars are M-dwarfs with Hα in emission, but no detectable Lithium absorption. They could be post T Tauri stars or older dMe stars; more data is necessary in order to establish their evolutionary status. Our results show that Kun (1992) was able to detect weak Hα emission lines (down to equivalent width of $\sim$ 1.5 Å) in faint stars near the plate magnitude limit (V∼16), but in many cases plate defects, absorption bands and/or overlying stars were taken as possible Hα emission. In this paper we correct Kun's previous indication that there may be numerous young stars associated to high latitude molecular clouds, and we severely constrain the presence of a population of T Tauri stars in these clouds. We note that none of our four T Tauri stars is located in an isolated translucent molecular cloud.

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The Location of Extremely High Velocity HCO^+ in the HH 7-11 Outflow

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In order to determine the location of extremely high velocity HCO^+ emission in the HH 7-11 outflow, BIMA array observations of the J=1→0 transition with $11'' \times 8.9''$ angular resolution were carried out. Two spatially unresolved clumps with average velocities ∼40 km s^{-1} blueward of the ambient material are detected. The two clumps are projected $<4''$ (1400 AU) and $25''$ (8800 AU) from SVS 13, the IR source which drives the outflow. EHV redshifted material is also observed, although it is not as easily separated from lower velocity material. No high velocity HCO^+ emission is observed toward the HH objects. The position of high-velocity HCO^+ emission relative to the exciting source in this region is similar to that observed in the L1551:IRS 5 outflow (Rudolph 1992). This similarity suggests that, as in the case of L1551:IRS 5, the high-velocity molecular material in the HH 7-11 outflow may have been entrained in the neutral atomic wind of SVS 13 as it passed through the surrounding cloud.

In addition, lower velocity HCO^+ J=1→0 emission traces a curved structure near HH 7, the most distant HH object from SVS 13. The symmetry axis of the curved structure is nearly coincident with the HH object outflow/jet axis, suggesting that the SVS 13 wind/jet is responsible for sweeping up molecular material which forms the curved structure.

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Molecular and atomic fractionation effects in the NGC 1977 molecular cloud

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The photon-dominated region (PDR) associated with the NGC 1977 molecular cloud has been observed at high resolution in the ^{13}CO and C^{18}O J = 2→1 and the [CI] $^3P_1$–$^3P_0$ lines. The $N(^{13}CO)/N(C^{18}O)$ ratio has been plotted against visual extinction (A_v) and fits a power law relation. The highest values, as expected, occur for observed positions with the lowest derived extinction, with $N(^{13}CO)/N(C^{18}O)$ exceeding the terrestrial value (5.5) for $A_v \leq 60$ magnitudes. In the outermost parts of the cloud ($A_v \leq 20$ magnitudes) the $N(^{13}CO)/N(C^{18}O)$ ratio is largest, up to 20. Comparison with similar observations of the S140 and Orion Bright Bar regions implies that higher incident UV field leads to increased fractionation effects. The $N(CI)/N(CO)$ ratio has been plotted against visual extinction, as derived from $N(C^{18}O)$, for the range A_v=20–100 magnitudes and also fits a power law relation. $N(CI)/N(CO)$ increases with decreasing extinction from ∼0.03–0.04 for A_v ∼100 mags. to ≥0.1 for A_v ∼20 mags., corresponding to positions near the edge of the HII region/molecular cloud interface. Comparison with identical observations of the S140 and Orion Bright Bar regions implies that, unlike $N(^{13}CO)/N(C^{18}O)$, the behaviour of $N(CI)/N(CO)$ is insensitive to incident UV field over this range of extinction.

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HH 110 Jet Near Infrared Imaging: The Outflow Mixing Layer

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We present near infrared images of the Herbig-Haro 110 jet centered at the molecular hydrogen lines v = 1-0 2.121 μm and v = 2-1 2.248 μm. In YSOs these lines are mostly excited by low velocity shocks and the energy released by turbulent processes. The ratio of these of lines provides us with a preliminary diagnostic of the molecular gas excitation. The HH 110 jet was selected for four reasons: (i) it has a complicated optical 'turbulent' morphology, (ii) it is close to a high density circumstellar environment (a molecular core), (iii) this object does not have an obvious driving source, and (iv) theoretical models suggest that this object corresponds to the early stages of a jet-cloud collision.

We find that the molecular hydrogen emission follows the optical Hα and [SII] emission in a 'straight' section of the jet (the northern $\sim 1'$), but it becomes shifted westward and separated from the optical emission afterwards. We suggest that these morphological properties of the molecular hydrogen emission are consistent with that of a boundary layer.

The 2.248 μm emission is faint in most condensations, except for the B1, E1, H1 and P1 knots, where it is clearly detected. The ratio of the 2.121 μm to the 2.248 μm lines for these knots ranges from 4.5 to 7.5 which implies excitation temperatures of $\sim 2400 - 3100$ K. The brightest condensation, H1, however, has a smaller ratio (~ 1.9) and a higher temperature (~ 5900 K), which suggests a non-isothermal jet structure. In those cases where the H_2 emission is likely to be due to shocks, the line ratios are small enough to be explained by either C or J-type shocks.

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Hubble Space Telescope Mapping of the Orion Nebula I: A Survey of Stars and Compact Objects

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We report on a survey of the brightest portions of the Orion Nebula made with the Wide Field Planetary Camera 2 of the Hubble Space Telescope. Fifteen pointings were made, each employing interference filters isolating the principal emission lines of HI, [NII], and [OIII] and another isolating an interval similar to the V bandpass. A careful survey of compact objects of stellar and nearly stellar appearance was made and astrometric solutions for individual fields were used to determine positions accurate to about 0.1".

349 stars were measured, down to about V=22. In addition to structures in several of the previously known Herbig-Haro objects, 153 compact sources that can be classified as proplyds were found. Proplyds are young stars surrounded by circumstellar material which is rendered visible by being in or near an HII region.

In the central region, where detection of proplyds is easiest, almost all of the low mass pre-Main Sequence stars have obvious circumstellar material. The fraction falls as one views areas away from the dominant photoionizing star Θ^1C Ori. Six new dark disk proplyds are found, bringing the total to seven. These are objects showing only in silhouette against the bright background of the HII region. Most of these are elliptical in form, indicating that they are circumstellar disks.

In addition to these compact sources, the new images allow detection of numerous large structures previously unreported from ground based observations. These include shells and shocks apparently related to Herbig-Haro objects and high velocity outflows from young stellar objects.

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ROSAT X-ray observations of the young cluster IC348

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We have observed the young stellar cluster IC348 in X-rays for the first time. In very deep pointings with the ROSAT PSPC and HRI we have detected a total of 116 X-ray sources. Most sources appear to be embedded ($A_V \approx 5$) in their parent molecular cloud. We use near-infrared (J, H, K) photometric data from the study of Lada & Lada (1995) to derive individual extinctions in order to calculate the X-ray luminosities. We find 56 stars to be probable new cluster members, presumably weak line T Tauri stars, because of their X-ray properties. Since previously 49 Hα emission line stars and 17 proper motion members were known, this nearly doubles the number of known member stars in IC348.

The early type (B5 – F5) stars do not appear to be intrinsic X-ray emitters. The late type stars display similar X-ray properties as those in other star forming regions. The weak line T Tauri stars seem to be stronger X-ray emitters than the classical T Tauri stars, but this difference may be caused by a selection effect. The total integrated X-ray luminosity in IC348 is at least 1.6×10^{32} erg/sec in the ROSAT band (0.1 – 2.4 keV). The possible influence of the X-radiation on the ionization state of the cloud and on its further evolution is briefly discussed.

We report the detection of several large X-ray flares in IC348 on timescales of typically a few hours. For some sources we also find variability on time scales of several years by comparing their count rates in the two pointed ROSAT observations and the ROSAT All Sky Survey. About 45% of the X-ray sources show considerable variability on long or short time scales.

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A giant X-ray flare on the young star P1724

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We present ROSAT X-ray observations as well as optical photometry and spectroscopy of the young stellar object P1724 in Orion. During a ROSAT observation in September 1992 P1724 showed a giant flare, where the X-ray count rate rose by more than a factor of 26 and then showed an exponential decay with a very long decay time of about 9 hours. P1724 is not a clear proper motion member to the Orion nebula association and, hence, its distance is not well established, but we present new spectroscopic and photometric evidence indicating that P1724 is a weak-line TTS associated with the Orion star forming region. For a distance of ≈ 500 pc, the total flare energy radiated in the ROSAT X-ray band (0.1 - 2.4 keV) is more than $\approx 5 \times 10^{37}$ erg. This is an order of magnitude above the highest energies of flares on young stars found so far, making this event the largest X-ray flare ever observed on a star.

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Clumpy Ultracompact H II Regions II: Cores, spheres and shells from subsonic flows

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We have modelled ultracompact HII regions (UCHIIR) in terms of steady subsonic ionized flows in a clumpy medium. Mass loss from neutral clumps allows the regions to be long lived. We examine the form of global flows for different dependences of the volume mass injection rate, $\dot{q}$, on radius and Mach number, and describe the solutions in detail. We find that three observed UCHIIR morphologies are reproduced with these models. Mach number independent flows which include a radial variation can give centre brightened core-halo morphologies. Mach number dependent flows reproduce naturally the uniform UCHIIR morphology. In a hybrid model, including subsonic and supersonic flows we

allow a supersonic wind to shock in the ionized region. The ionized subsonic gas has a high density and so dominates the emission. The shell produced has a velocity structure very different from that of fully supersonic models. Several morphologies of spherical UCHIIR can be understood in terms of these various models; however, kinematic data are crucial as a discriminant between them.

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An Evolutionary Diagram for Young Stellar Objects

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We present 1.3 *mm* continuum observations of a sample of Class I and Class 0 young stellar objects in nearby star-forming regions, with and without known outflow activity. The observations are considered together with published data on similar objects, and compared with more evolved T Tauri and Herbig Ae/Be stars. The photometric observations are shown on a bolometric luminosity vs. millimeter flux scaled at a distance D (L_{bol} vs. F^D_{mm}) diagram. We show that the objects of the sample lie in different areas of the L_{bol} - F^D_{mm} diagram according to their evolutionary status and outflow activity. General argument and simple model evolutionary tracks allow us to identify an evolutionary sequence on the L_{bol} - F^D_{mm} diagram which agrees with the observational data. All the youngest objects of our sample show outflow activity. Class I sources seem to excite outflows with dynamical times greater than $\gtrsim 10^4$ years and show a correlation between the bolometric luminosity and the millimeter continuum flux, which we call the "Outflow Strip": this correlation spans more than three orders of magnitude in luminosity. We suggest that the Outflow Strip originates in the deuterium burning process and that the protostars burn the majority of their deuterium while on the Outflow Strip. There is also good evidence that at the end of their lifetime on the Outflow Strip, the embedded outflow sources become visible Pre Main Sequence (hereafter PMS) stars with outflows. The outflow mechanical luminosity is also found to be better correlated to the mass of the disk/envelope system than to the central object luminosity.

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Physics of Accretion onto Young Stars : I Parametric Models

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The article will present the influence of accreting material on the structure of young stars. We model accretion through a formalism based upon the Richardson criterion which relates the power of buoyancy forces to the kinetic energy of turbulence. In our models we assume that in radiative regions matter is close to marginal stability and we generalize this formalism to convective zones. We take into account the angular momentum as well as the thermal and chemical properties of the accreted matter. We present figures that depict the profile of mass deposition in the star. We study parametrically peculiar aspects of the accretion physics such as how energy is transported through the accretion process or what is the effect of chemical composition differences between the star and the accretion disk or what is the result of accreting more or less angular momentum. The models show that very rapidly the accreted matter can reach the convective zone and eventually can be dragged to the center of the star. This approach will be soon incorporated into evolutionary models of young stellar objects.

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Observation of a Lunar Occultation of T Tau

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We observed the 16 December 1994 (UT) lunar occultation of the binary system T Tau in the infrared K and L' bands. T Tau N, the visible light star, and T Tau S, the IR luminous companion, appeared unresolved along the direction of the occultation. At L', both objects are smaller than 3 AU. At K, T Tau N and S are smaller than 1 AU. The natural interpretation is that both components are stellar and that the extinction along our line of sight to T Tau S is greater than to T Tau N. At the time of the occultation, the K-band flux of T Tau S had decreased to nearly the value it had before the flare that began in the late 1980's while the L'-band flux was still elevated; this flux decrease with time supports Ghez *et al.*'s (1991) suggestion that T Tau S experienced a FU Orionis-like outburst.

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Infall in Herbig Ae/Be Stars: What the Na D Lines Tell Us

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This paper discusses the origin of the redshifted absorption components observed in the Na D lines of some Herbig Ae/Be stars. We have computed non-LTE models of the thermal and ionization structure of gas clouds of different density, column density and chemical composition, from the solar one to that typical of CI-chondrites. The redshifted absorption lines can only form in small, dense, infalling gas clumps at distances $\leq$10 $R_\star$ from the star. If the gas has solar chemical composition, then the clump size must be $L \approx 10^{11}$ cm (about $R_\star$) and the density $n_H \geq 3 \times 10^{12}$ cm^{-3}. These conditions can be produced at the base of a column of gas falling into the star from a circumstellar accretion disk along magnetic lines. In this case, an accretion rate $\dot{M}_{acc} \geq 3 \times 10^{-7}$ $M_\odot$yr^{-1} and a stellar magnetic field of about 600 Gauss are required. As the gas metallicity increases, less dense clouds are required to fit the Na D observations. In the extreme case of a gas cloud resulting from the evaporation of CI-chondrite meteorites, it is $n_H \geq 5 \times 10^8$ cm^{-3}, $L \approx 10^{11}$ cm. The mass of the cloud is therefore of the order of 10^{20} gr, and the parental body must have a radius of 20 km at least. These results show that both scenarios, i.e., magnetospheric accretion and evaporation of star-grazing planetesimal bodies, are in principle possible.

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Photon Heating of Envelopes around Young Stellar Objects: An Explanation for CO J=6–5 Emission

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We propose that the narrow ^{12}CO and ^{13}CO J=6–5 emission observed toward many low mass young stellar objects is produced in molecular material in the circumstellar envelope which is heated by the 10,000 K radiation field generated in the inner part of the accretion disk. Ultraviolet photons traveling through the biconical cavity evacuated by the bipolar outflow are scattered by dust grains present in the low density material in the cavity. These photons are not energetic enough to photodissociate H_2 and CO, but can heat the envelope surrounding the cavity. The temperature structure and the CO excitation of this photon-dominated region are computed using 2-D Monte Carlo methods. It is found that the material is heated up to a few hundred K close to the cavity wall, and that the observed low–velocity

mid–J CO emission can be well explained by our model for a wide range in envelope density and stellar luminosity. Emergent CO spectra are compared to observations of the embedded low mass YSO IRAS 04361+2547 (TMR-1).

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Magnetic Fields in Cometary Globules I: CG 22

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We report first results from a program to study magnetic fields in Cometary Globules (CGs). These are clouds near massive stars showing a head-tail morphology. Linear optical polarisation measurements on stars seen projected on CG 22 in the Gum-Vela region are presented. A majority of the stars seen within the boundary of the cloud show a polarisation of $\sim 1\%$ with the electric field vector oriented parallel to the tail whereas those outside the boundary either show small polarisation with position angles parallel to the Galactic plane or no polarisation within the errors of our measurements. If the polarisation is due to dust grains aligned by magnetic field our results imply that the field in CG 22 is parallel to its tail. A rough estimate of the field strength ($\sim 30\ \mu$G) indicates that it may be important for the dynamics of the cloud. These results support the idea that magnetic fields play a role in producing the structures seen in the tails of the CGs. We suggest that the alignment of the magnetic field could only have been caused by the same process that shaped the tails. We also comment on the implications of the polarisation detected in the light from the star Wra 220, a T-Tauri star believed to have formed in the head of CG 22.

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Global Evolution of Solid Matter in Turbulent Protoplanetary Disks. I. Aerodynamics of Solid Particles

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The problem of planetary system formation and its subsequent character can only be addressed by studying the global evolution of solid material entrained in gaseous protoplanetary disks. We start to investigate this problem by considering the space-time development of aerodynamic forces that cause solid particles to decouple from the gas. The aim of this work is to demonstrate that only the smallest particles are attached to the gas, or that the radial distribution of the solid matter has no momentary relation to the radial distribution of the gas. We present the illustrative example wherein a gaseous disk of 0.245 $M_\odot$ and angular momentum of 5.6×10^{52} g cm^2 s^{-1} is allowed to evolve due to turbulent viscosity characterized by either $\alpha = 10^{-2}$ or $\alpha = 10^{-3}$. The motion of solid particles suspended in a viscously evolving gaseous disk is calculated numerically for particles of different sizes. In addition we calculate the global evolution of single-sized, noncoagulating particles. We find that particles smaller than 0.1 cm move with the gas; larger particles have significant radial velocities relative to the gas. Particles larger then 0.1 cm but smaller than 10^3 cm have inward radial velocities much larger than the gas, whereas particles larger than 10^4 cm have inward velocities much smaller than the gas. A significant difference in the form of the radial distribution of solids and the gas develops with time. It is the radial distribution of solids, rather than the gas, that determines the character of an emerging planetary system.

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Escape of T Tauri stars from young stellar systems

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The decay of nonhierarchical few-body systems ($N < 10$) is examined by direct numerical integration to determine statistically how size, shape, N, and rotation state influence the distribution of escape speeds for ejected stars. The initial conditions are chosen to represent realistic configurations for young stellar objects at the end of the accretion phase in fragmented protostellar clouds. If we adopt typical properties for molecular cloud cores and assume system sizes deduced from isothermal collapse calculations, we find that more than 60% of the escapers have speeds > 3 km/s. We propose that high-velocity stars produced during the decay of young multiple star systems contribute significantly to the halo of weak-line T Tauri stars recently discovered around star forming regions by the ROSAT all-sky X-ray survey.

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Young Star Clusters in Bright-Rimmed Clouds: Small-Scale Sequential Star Formation?

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A J/H/K imaging survey has been made for 44 bright-rimmed clouds associated with IRAS point sources of Sugitani et al. (1991). We have found small clusters of near-infrared sources having YSO colors in some of these objects, and most of the cluster members are considered to be older than the IRAS point sources and to be pre-main sequence stars such as T Tauri stars. In at least 6 bright-rimmed clouds, the clusters are elongated towards the bright rim tip or the exciting star(s) of the bright rim with the IRAS sources situated near the other end. There is a tendency that bluer (i.e., older) stars are located closer to the exciting star(s) and redder (i.e., younger) stars closer the IRAS sources. This asymmetric distribution of the cluster members strongly suggests small-scale sequential star formation or propagation of star formation from the side of the exciting star(s) to the IRAS position in a few 10^5yr time, due to the advance of the shock caused by the UV radiation from the exciting star(s).

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Gap Formation in Protoplanetary Disks

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Evolution of a protoplanetary disk under the tidal interaction between the disk and an embedded protoplanet is analyzed with a self consistent WKB approximation. We assume that the protoplanetary disk is infinitesimally thin and non-self-gravitating and that the protoplanet's orbit is circular. The protoplanet excites density waves at its Lindblad resonances. As they propagate throughout the disk, these waves carry a flux of angular momentum which is eventually deposited into the gas at the locations where the waves are dissipated viscously. Protoplanets with a sufficiently large mass can induce the formation of a gap in the disk. The size of the gap and the structure of the disk are determined by the wave propagation length scale which is a decreasing function of viscosity. For small effective viscosity, density waves propagate to inner regions near the protostellar surface. Using an α prescription, we find that a Jupiter-mass protoplanet can lead to the removal of the inner disk if $\alpha \leq 3 \times 10^{-4}$. For larger values of α, the

surface density in the disk surrounding the gap is adjusted in a manner such that the rapid orbital evolution by the protoplanet is prevented. We also inferred that $\alpha \sim 1.7 \times 10^{-2}$ in the disk around the binary T Tauri star GW Ori, based on the gap size derived from the observational data.

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First observations of the water vapour line at 557 GHz from the interstellar medium

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We report the first results of PIROG 7, a balloon-borne platform equipped with a 60 cm telescope and a heterodyne receiver designed for observations of the 557 GHz ($1_{10} \rightarrow 1_{01}$) line of ortho-$H_2O$. We describe the experiment, atmospheric transmission measurements, and astronomical observations of Orion. The lack of broad, centrally peaked line emission in this source, compared to the recently detected line of $H_2{}^{18}O$ at 548 GHz, indicates that the abundance of water is large and its emission optically thick. On the other hand, a weak and narrow absorption feature was detected toward Orion. While the signal-to-noise ratio of the observed absorption is such that it should only be considered as a tentative detection at the present moment, the result is consistent with the available information on the physical characteristics of the gas in this region. The feature can be interpreted as the result of absorption by a foreground ridge-like component of bright and wide emission arising from the warm gas in the high-velocity core of Orion.

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On the stability of an accretion disc containing a toroidal magnetic field

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We study the stability of an accretion disc with an embedded toroidal magnetic field to general perturbations. Disc models are considered in which the equilibrium variables depend on both the radial and vertical coordinates. We consider the full global problem in which the disc may be in the form of a narrow annulus or occupy a significant radial extent. Perturbations with azimuthal mode number m in the range zero up to the ratio of the radius to disc semi-thickness are considered.

Discs containing a purely toroidal magnetic field are always found to be unstable. We find spectra of unstable modes using local techniques. In the absence of dissipation, these modes may occupy arbitrarily small scales in the radial and vertical directions. One class of modes is driven primarily by buoyancy, while the other is driven by shear independently of the equilibrium stratification. The first type of instability predominates if the field is large, while the second type predominates if the field is weak and the underlying medium is strongly stable to convection.

We also investigate stability by solving the initial value problem for perturbations numerically. We find, for our disc models, that local instabilities predominate over any possible global instability. Their behaviour is in good accord with the local analysis. The associated growth rates become just less than the orbital frequency when the ratio of magnetic energy density to pressure reaches about ten percent.

Instabilities of the kinds discussed here may provide a mechanism for limiting the growth of toroidal fields in dynamo models of accretion discs.

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Tidally-induced Warps in T Tauri Discs. II. A Parametric Study of Spectral Energy Distributions

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We compute here the spectral energy distribution (SED) of warped T Tauri discs in a general way. In a previous paper (Terquem & Bertout 1993) we analytically calculated, in a linear aproximation, the response of a circumstellar disc to tidal forces due to a stellar companion in a non-coplanar young binary system. Here, we consider tidally-induced warps of larger amplitude, and we use these previous results to parametrize the disc deformation. We then compute the energy emitted in a given direction by the system of the warped disc and central star, taking into account shadowing effects.

We find that the parametrized warp model produces a broad variety of synthetic SEDs. Some of them are comparable to those of T Tauri stars with infra-red excess (Class II sources), whereas others resemble Class I protostellar sources. By comparing models with actual observations of both a T Tauri star with high spectral index and a Class I source, we find that the derived warp and disk parameters are not unrealistic, and we conclude that tidal interactions in T Tauri binary systems with intermediate separations must play a role in shaping the SEDs of these stars.

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Orbital motion of DF Tauri from speckle interferometry

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We report the evidence of the orbital motion of the binary star DF Tau. This result is obtained from visible speckle interferometry and uses lunar occultations of Chen et al. (1990, ApJ **357**, 224). It is the first step towards a direct determination of the dynamical mass of this young system. The portion of the orbit covered between the epochs of observation is still too small ($\sim 10\%$) to allow precise derivation of the orbital elements. We however provide a first estimate of the mass of the system as being $2.8 \pm 1.5\, M_\odot$. We investigate the incidence of the binarity of DF Tau on the modeling of its spectral energy distribution and discuss the nature of the components.

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The Molecular Core Associated with HH25-26: Contraction or Expansion

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We mapped the star formation region HH25-26 IR in the NH_3(1,1) and (2,2) transitions using the VLA in its D configuration. The study has been made with $5''$ angular resolution and 0.3 km s^{-1} velocity resolution.

As has been seen before, there is an elongated NH_3 core which lies perpendicular to the molecular outflow as traced in high velocity CO emission. In this experiment, the NH_3 core is resolved, showing a central cavity and a number of distinct velocity features. Heating is seen where the velocity features overlap spatially, and on the edges of the cavity, which is also seen as a reflection nebula with evidences for shock excitation. We have also detected what appears to be a new 1.3 cm continuum source on the wall of the cavity, associated with a 2.2μ point source and jet-like structure. It is not clear at this time whether this is truly continuum emission or high velocity ammonia emission. The overall

kinematics is complicated. A velocity gradient can be seen, together with the signatures for expanding or contracting motions.

We consider here two possible models: a) a disk or ring structure, slowly rotating and contracting, and b) an expanding cavity.

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The Structure of the IC 1396 Region

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We have made an extensive study of the molecular clouds associated with the H II region IC 1396 in the rotational transitions J=1−0 and J=2−1 of ^{12}CO and ^{13}CO and J=3−2 of ^{12}CO with an average spatial resolution of 2′.5 and an average sampling of about 2′.0, in order to get information on its structure and evolution.

On the basis of our observations, which cover an area of more than 6 deg^2, we can classify the molecular clouds into those directly associated with the ionizing O6.5V star HD 206267, producing the bright-rimmed clouds, and the cold gas along the line of sight, which is mainly foreground material. The bright-rimmed clouds show the presence of warmer molecular gas through higher ^{12}CO (2−1)/(1−0), ^{13}CO (2−1)/(1−0) and ^{12}CO (3−2)/(2−1) line ratios than the cold foreground gas. The warm clouds form roughly a shell-like arrangement with a diameter of 25 to 40 pc around HD 206267 (though most are slightly closer to the Sun than the O star), and they seem to be the remainder of the now dispersing molecular cloud which gave birth to the O6.5 star and the star cluster Tr 37 associated with it. All bright-rimmed clouds show internal structure on all size scales, including bipolar outflows. Optical, FIR (IRAS 12 to 100 μm) and CO maps are in close agreement over the whole region, especially for the bright-rimmed clouds: Exceptions are some optically bright (ionized) regions, which show FIR, but no CO emission, and the cold foreground clouds, which are very weak at FIR wavelengths.

The entire mass of the mapped IC 1396 region is estimated to be 12 000 $M_\odot$, which is composed of molecular (4000 $M_\odot$), atomic (5000 $M_\odot$), and ionized material (3000 $M_\odot$) in nearly equal amounts. The masses of the bright-rimmed clouds range from a few to several 100 $M_\odot$.

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Discovery of New Wide Binary Infrared Protostars

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We present observational evidence based on near-infrared array imaging of what could be not only candidates for infrared protostars (Class I objects) but also for wide binary infrared protostars found in Bok globules. The extremely early evolutionary stage of the objects is confirmed by the following facts: *i)* The objects are not present on the Palomar prints nor on optical CCD images reaching 19$^{\rm th}$ magnitude in the I-band; *ii)* The objects exhibit very red colors. Values of $(J-H)$ and $(H-K)$ are consistent with those of very embedded Class I objects surrounded by circumstellar dust emission.

The binary character of these pairs of objects is indicated by the following facts: *i)* At 2.2 μm, each pair appears to reside in common nebulosity indicating that they could be physically associated; *ii)* The separation between the stars in each pair is about 10 arcsec and they appear isolated within globule cores extending for several arcminutes in diameter.

The orientations of their associated molecular outflows, previously found by Yun & Clemens, are roughly perpendicular to the lines connecting the binaries. A millimeter continuum emission survey revealed that, at 1.3 mm, the sources are the two brightest low-mass young stellar objects discovered in Bok globules.

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A Search For Radio Continuum Emission From Young Stellar Objects in Bok Globules

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We present results of a VLA-D search of 3.6 cm continuum emission toward a selected sample of Bok globules carried out to better characterize their stellar contents. A total of forty-one radio sources were detected. Eleven of these sources are located within the optical extents of the globules and may correspond to embedded sources. We identify seven candidates to protostars of Class 0. We also identify five globules without any sign of star formation in infrared or centimeter wavelengths. These starless globules are candidates to being ideal laboratories for studying the physical conditions of pre-collapsing cloud cores. Virtually all the globules with positive radio continuum detections were also previously found to have associated molecular outflows. This result supports the scenario in which the radio continuum emission arise from shock-ionized circumstellar gas.

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A copy of this paper is available via the World Wide Web. Connect to http://delphi.cc.fc.ul.pt/papers/vla

Infrared coronal-line emission from PMS binaries: Testing the colliding winds model.

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We present model calculations of infrared-coronal-lines emission that arise from colliding supersonic winds in pre-main-sequence binary stars. For typical wind velocities between 300 and 500 km s^{-1}, the interaction region has a temperature range well suited for coronal lines to attain peak emissivities. Infrared spectral line observations at wavelengths $>1\mu$m can provide a unique opportunity to probe the physical conditions of the gas flows in these systems. We derive simple scaling laws that allow to estimate the coronal line fluxes as a function of the model parameters and compare the results with those obtained for the X-ray emission. The advantage of using coronal lines instead of X-rays to test the colliding winds paradigm is the greatly reduced abssorption at infrared wavelengths. Finally, we discuss the possibility of detecting the most intense lines from known binary systems.

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Dissertation Abstracts

Star Formation in Lynds 1641

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We conducted an extensive multi-wavelength study of the nearest giant molecular cloud, L1641, with the goal of characterizing its stellar populations. At a distance of approximately 500 pc, L1641 provides an excellent opportunity for studying star formation over the entire range of stellar masses, and the star formation history in a region thought representative of those dominating stellar production in the Milky Way.

Our approach combines imaging surveys at optical and infrared wavelengths with spectroscopic surveys at $\lambda\lambda$ 6000-9000Å to measure stellar luminosities and effective temperatures. Stellar ages and masses are then estimated from comparison of L_*, T_{eff} with pre-main sequence evolutionary tracks. The stars for which we have obtained classifiable spectra as well as optical (R, I) and near-infrared and near-infrared (J, H, K) photometry number ∼300, and are contained within four regions, each approximately $20'$ square (2.5 × 2.5 pc).

Our 2.25mμ images reveal both modest aggregates of several tens of stars and stars distributed at random across the face of the cloud; we find no evidence of rich (N $\gg$ 100 stars) clusters. The aggregate members appear to have formed within the past 1 Myr, while the distributed population contains both young stars (t < 1Myr) and stars ranging in age up to 30 Myr. From comparison of the fraction of the youngest stars forming in aggregates and in isolation, we conclude that stars born initially in aggregates comprise 25 - 50% of the total stars formed in L1641.

The observed frequency distribution of stellar ages enables a discussion of the star-forming history of the cloud. The L1641 cloud has been producing stars for nearly 30 Myr and over the last 10 Myr, the SFR has been roughly constant. We explore the implications of this result for the "off-cloud" spatial distribution of young stars.

Finally, we examine the circumstellar disk properties of stars in our spectroscopic sample. The frequency of disks, as inferred from infrared excess emission, is found to be higher for stars less massive than 1 $M_\odot$ than for more massive stars. We also find that at least six stars in L1641 have apparently retained their accretion disks beyond an age of 3 Myr.

The thesis is available on the World Wide Web at: http://decoy.phast.umass.edu/

The Chemical and Physical Structure of Giant Molecular Cloud Cores

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We present the results of a study of the emission from 33 molecular transitions in the GMC cores Orion A, M17, and Cepheus A. We have mapped the emission over a $4' \times 12'$ area in Orion, and a $4' \times 5'$ area in M17 and Cepheus A. We have used these observations to probe the physical and chemical structure within each core.

To derive the temperature we have used the J = 6 → 5 (K = 0,1,2) transitions of CH_3C_2H and the J = 1 → 0 transition of ^{12}CO. A comparison of temperatures obtained from the two thermometers in Orion and M17 show significant differences, which we propose are the result of a line of sight temperature gradient. Densities were determined through a multitransitional study of HC_3N. The density structure within each core is similar, showing no evidence of large scale variations, with values typically $n(H_2) \sim 10^6$ cm^{-3}.

The temperatures and densities determined directly from CH_3C_2H and HC_3N were used to derive abundances for 12 species in six positions in Orion A, and two positions in M17 and Cepheus A. Although abundance differences exist, in general, chemical abundances are found to be similar both within and among GMC cores. We have constructed a chemical model of GMC cores, accounting for variations with A_V, to compare with measured abundances. This model was found to be unable to reproduce the abundances of many molecules for any particular time. Both the inclusion of clumps and variations in the gas-phase C/O ratio within the model were examined to obtain between agreement with observations.

We found that the inclusion of clumps into the chemical model can reproduce the observed abundances of C^+ and C. However, due to the greater weight placed on the photon dominated region in smaller clumps, clumps have a detrimental effect on reproducing the abundances of other species. Models with a range of C/O ratios were also compared to the abundances measured in each cloud. Good agreement between model and observations was found for early times ($t \sim 10^5$ yr) and for C/O ∼ 0.8. The implications of these results on the evolutionary state of GMC cores are discussed.

New Jobs

Origins Research Associate

Carnegie Institution of Washington
Department of Terrestrial Magnetism
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Applications are invited for an anticipated NASA-supported postdoctoral research associateship in the general area of stellar and planetary system formation. The associate is expected to work with Alan Boss on theoretical models of the interactions of interstellar shock waves with dense cloud cores and on cosmochemical implications (e.g., for meteorites) of the transport and mixing processes occurring during protostellar collapse and disk evolution. The cosmogony group at DTM includes staff members Conel Alexander, Alan Boss, John Graham, and George Wetherill, and postdoctoral fellows Harold Butner, John Chambers, Prudence Foster, Munir Humayun, and David Rabinowitz. DTM has a network of DEC Alpha and Sun SPARC workstations and a video production capability.

The position requires a Ph.D. in a relevant field, experience with numerical hydrodynamics codes, and excellent computer skills. The position is anticipated to start after December 1, 1996, and is available for one year, with the expectation of a second year.

Applications should include a curriculum vita, a publication list, and three letters of recommendation to be sent directly to us by those familiar with your work. Completed applications are due by February 28, 1996. EOE/AE