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Abstracts of recently accepted papers

A circumstellar dust disk around T Tau N: Sub-arcsecond imaging at $\lambda = 3$ mm

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We present high-resolution imaging of the young binary, T Tauri, in continuum emission at λ=3 mm. Compact dust emission with integrated flux density 50 $\pm$ 6 mJy is resolved in an aperture synthesis map at $0.5''$ resolution and is centered at the position of the optically visible component, T Tau N. No emission above a 3σ level of 9 mJy is detected $0.7''$ south of T Tau N at the position of the infrared companion, T Tau S. We interpret the continuum detection as arising from a circumstellar disk around T Tau N and estimate its properties by fitting a flat-disk model to visibilities at $\lambda = 1$ and 3 mm and to the flux density at $\lambda = 7$ mm. Given the data, probability distributions are calculated for values of the free parameters, including the temperature, density, dust opacity, and the disk outer radius. The radial variation in temperature and density is not narrowly constrained by the data. The mostly likely value of the frequency dependence of the dust opacity, $\beta = 0.53^{+0.27}_{-0.17}$, is consistent with that of disks around other single T Tauri stars in which grain growth is believed to have taken place. The outer radius, R = 41^{+26}_{-14} AU, is smaller than the projected separation between T Tau N and S, and may indicate tidal or resonance truncation of the disk by T Tau S. The total mass estimated for the disk, $\log(M_D/M_\odot) = -2.4^{+0.7}_{-0.6}$, is similar to masses observed around many single pre–main-sequence sources and, within the uncertainties, is similar to the minimum nebular mass required to form a planetary system like our own. This observation strongly suggests that the presence of a binary companion does not rule out the possibility of formation of a sizeable planetary system.

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preprint available at http://astro.berkeley.edu/ rla/index.html

Discovery of multiple non-axially symmetric near-IR bow shocks around the pre-main sequence binary AFGL 961

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We present the discovery of multiple non-axially symmetric near-IR molecular hydrogen bow shocks around the high-mass pre-main sequence binary system AFGL 961. These data indicate that at periods one or both components of the binary have produced collimated outflows with associated shocks similar to those observed at visual wavelengths resulting in optical Herbig-Haro objects. We detect a minimum of four nebulous structures reminiscent of optical bow shocks together with five other diffuse objects with less well-defined morphology. The spatial location of the bow shocks and associated nebulous knots suggests that both components of the binary have, at times, actively driven outflows. At the present time, only the western component of the binary currently shows direct evidence of outflow activity in the form of ^{12}CO emission bandheads. The timescale between the outbursts that drive the outflows and

result in the creation of the NIR shock-excited nebulae is 300–500 years. This is similar to estimates made for related events in both optical Herbig-Haro sources and FU Orionis type stars.

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The gas/solid methane abundance ratio toward deeply embedded protostars

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We present the detection of ro-vibrational absorption lines of the deformation mode of gaseous CH_4 toward the massive protostars W 33A, and NGC 7538 : IRS9, using the SWS spectrometer on board of the Infrared Space Observatory. The observed lines indicate that the CH_4 gas is warm ($T \sim 90$ K), and has a low abundance ($\sim 4\ 10^{-7}$). The CH_4 ice in these lines of sight is embedded in a polar matrix (Boogert et al. 1996), and the gas/solid state abundance ratio is low (~ 0.5). We discuss models for the formation of interstellar CH_4. The observations impose strong limitations on time dependent gas phase models, e.g. a low initial CO/C ratio would be required, the CH_4 must have been formed and subsequently condensed on the grains within a narrow time window, and an additional mechanism would be necessary to form polar ice mantles. More likely, interstellar CH_4 is formed through grain surface reactions at a high CO/C ratio, which explains the low observed CH_4 abundance ($\sim 10^{-6}$), the presence of CH_4 in a polar ice, the low gas/solid ratio, and the absence of a strong cold CH_4 gas component. The observed warm CH_4 gas probably has sublimated from the grains in the 'hot core' region surrounding the protostar.

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http://www.astro.rug.nl/∼boog/research.html

Evolution of the Solar Nebula. IV. Giant Gaseous Protoplanet Formation

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The discovery of the first extrasolar planets, with masses in the range of $\sim 0.5 M_{Jup}$ (M_{Jup} = Jupiter mass) to $\sim 3 M_{Jup}$, demands a re-evaluation of theoretical mechanisms for giant planet formation. Here we consider a long-discarded mechanism, forming giant planets through the gravitational instability of a protoplanetary disk. Radiative hydrodynamical calculations of the thermal structure of an axisymmetric protoplanetary disk with a mass of $\sim 0.13 M_\odot$ (inside 10 AU), orbiting a solar-mass star, predict that the outer disk may be cool enough ($\sim 100 \pm 50$ K) to become gravitationally unstable. This possibility is investigated here with a fully three dimensional hydrodynamics code. Growth of significant nonaxisymmetry occurs within a few rotation periods of the outer disk, and can result in the formation of several discrete, multiple-M_{Jup} clumps in $< 10^3$ yrs. These giant gaseous protoplanets (GGPPs) are gravitationally bound and tidally stable, and so should eventually form giant planets. Modest-sized solid cores may form through dust grain growth and sedimentation prior to the centers of the GGPPs reaching planetary densities. The inner disk remains nearly axisymmetric throughout these phases, suggesting a scenario where the formation of terrestrial planets occurs slowly through collisional accumulation in the hot inner nebula, while rapid formation of GGPPs occurs in the cooler regions of the nebula. Falling disk surface densities would restrict GGPP formation to an annulus, outside of which icy outer planets would have to form slowly through collisional accumulation. GGPP formation occurs for both locally isothermal and locally adiabatic disk thermodynamics, provided that the Toomre Q stability parameter indicates instability ($Q_{min} \approx 1$). Low order modes, especially $m = 1$ and 2, are dominant. Provided that a means can be found for inducing massive protoplanetary disks to undergo the GGPP instability

(e.g., clumpy accretion of infalling gas onto a marginally stable disk), the GGPP mechanism appears to be a prompt alternative to the long-favored but protracted core accretion mechanism of giant planet formation. Observations hold the promise of deciding which of these two mechanisms is preferred by young stars.

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Dynamical Collapse of Nonrotating Magnetic Molecular Cloud Cores: Evolution Through Point-Mass Formation

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We present a numerical simulation of the dynamical collapse of a nonrotating, magnetic molecular cloud core and follow the core's evolution through the formation of a central point mass and its subsequent growth to a 1 $M_\odot$ protostar. The epoch of point-mass formation (PMF) is investigated by a self-consistent extension of previously presented models of core formation and contraction in axisymmetric, self-gravitating, isothermal, magnetically supported interstellar molecular clouds. Prior to PMF, the core is dynamically contracting and is not well approximated by a quasistatic equilibrium model. Ambipolar diffusion, which plays a key role in the early evolution of the core, is unimportant during the dynamical pre-PMF collapse phase. However, the appearance of a central mass, through its effect on the gravitational field in the inner core regions, leads to a "revitalization" of ambipolar diffusion in the weakly ionized gas surrounding the central protostar. This process is so efficient that it leads to a decoupling of the field from the matter and results in an outward-propagating hydromagnetic C-type shock. The existence of an ambipolar diffusion-mediated shock of this type was predicted by Li & McKee (1996), and we find that the basic shock structure given by their analytic model is well reproduced by our more accurate numerical results. Our calculation also demonstrates that ambipolar diffusion, rather than Ohmic diffusivity operating in the innermost core region, is the main field decoupling mechanism responsible for driving the shock after PMF.

The passage of the shock leads to a substantial redistribution, by ambipolar diffusion but possibly also by magnetic interchange, of the mass contained within the magnetic flux tubes in the inner core. In particular, ambipolar diffusion reduces the flux initially threading a collapsing ~ 1 $M_\odot$ core by a factor $\gtrsim 10^3$ by the time this mass accumulates within the inner radius ($\simeq 7.3$ AU) of our computational grid. This reduction, which occurs primarily during the post-PMF phase of the collapse, represents a significant step towards the resolution of the protostellar magnetic flux problem.

Our calculations indicate that a 1 $M_\odot$ protostar forms in $\sim 1.5 \times 10^5$ yr for typical cloud parameters. The mass accretion rate is time dependent, in part because of the C-shock that decelerates the infalling matter as it propagates outward: the accretion rate rises to $\simeq 9.4$ $M_\odot$ Myr^{-1} early on and decreases to $\simeq 5.6$ $M_\odot$ Myr^{-1} by the time a solar-mass protostar is formed. The infalling gas disk surrounding the protostar has a mass $\sim 10^{-2}$ $M_\odot$ at radii $r \gtrsim 500$ AU. A distinguishing prediction of our model is that the rapid ambipolar diffusion after the formation of a protostar should give rise to large ($\gtrsim 1$ km s^{-1}), and potentially measurable, ion–neutral drift speeds on scales $r \lesssim 200$ AU.

The main features of our simulation, including the C-shock formation after PMF, are captured by a similarity solution that incorporates the effects of ambipolar diffusion (Contopoulos, Ciolek, & Königl 1998).

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Effect of Ambipolar Diffusion on Ion Abundances in Contracting Protostellar Cores

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Numerical simulations and analytical solutions have established that ambipolar diffusion can reduce the dust-to-gas ratio in magnetically and thermally supercritical cores during the epoch of core formation. We study the effect that this has on the ion chemistry in contracting protostellar cores, and present a simplified analytical method that allows one to calculate the ion power-law exponent k ($\equiv d \ln n_{\rm i}/d \ln n_{\rm n}$, where $n_{\rm i}$ and $n_{\rm n}$ are the ion and neutral densities, respectively) as a function of core density. We find that, as in earlier numerical simulations, no single value of k can adequately describe the ion abundance for $n_{\rm n} \lesssim 10^9$ cm^{-3}, a result that is contrary to the "canonical" value of $k = 1/2$ found in previous static equilibrium chemistry calculations, and often used to study the effect of ambipolar diffusion in interstellar clouds. For typical cloud and grain parameters, reduction of the abundance of grains results in $k > 1/2$ during the core formation epoch (densities $\lesssim 10^5$ cm^{-3}). As a consequence, observations of the degree of ionization in cores could be used, in principle, to determine whether ambipolar diffusion is responsible for core formation in interstellar molecular clouds. For densities $\gg 10^5$ cm^{-3}, k is generally $\ll 1/2$.

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ISO observations of candidate young brown dwarfs

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ISOCAM measurements or upper limits for low mass members of the ρ Ophiuchi embedded cluster extend the sampling of the spectral energy distributions already obtained from the ground towards longer wavelengths, where emission by circumstellar material is significant. Good fits to the combined (ground-based + ISOCAM) photometry are obtained with theoretical models of pre-main sequence evolution, complemented with models of the spectrum of circumstellar emission, synthetic spectra of cold atmospheres, and an extinction law. The most important physical parameters of the targets, such as mass and luminosity, can be estimated with more confidence than with ground-based data alone, thanks to the much more robust reconstruction of the intrinsic spectral energy distribution made possible by the new ISOCAM data.

An object-by-object discussion, based on both published and new material, shows that estimates of the source temperatures from fitting of the photometry agree closely with spectroscopy for all seven sources where both techniques have been applied. The agreement between the new fits and those based on groundbased photometry alone is also reasonably good. Three of the sources are very likely to be young brown dwarfs, five are transitional, and three appear to be low mass stars.

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Self-Similar Collapse of Nonrotating Magnetic Molecular Cloud Cores

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We obtain self-similar solutions that describe the gravitational collapse of nonrotating, isothermal, magnetic molecular cloud cores. We use simplifying assumptions but explicitly include the induction equation, and the semianalytic solutions we derive are the first to account for the effects of ambipolar diffusion following the formation of a central point mass. Our results demonstrate that, after the protostar first forms, ambipolar diffusion causes the magnetic flux to decouple in a growing region around the center. The decoupled field lines remain approximately stationary and drive a hydromagnetic C-shock that moves outward at a fraction of the speed of sound (typically a few tenths of a kilometer per second), reaching a distance of a few thousand AU at the end of the main accretion phase for a solar-mass star. We also show that, in the absence of field diffusivity, a contracting core will not give rise to a shock if, as is likely to be the case, the inflow speed near the origin is nonzero at the time of point-mass formation. Although the

evolution of realistic molecular cloud cores will not be exactly self similar, our results reproduce the main qualitative features found in detailed core-collapse simulations (Ciolek & Königl 1998).

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Spectroscopic discovery of a bipolar jet from the Herbig Ae/Be star LkHα 233

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We present long-slit [SII]$\lambda\lambda$6716/6731 spectroscopic observations of the Herbig Ae/Be star, LkHα 233. An extended ($\gtrsim\pm5''$) high-velocity ($V_{\rm rad} \sim \pm$ 120kms^{-1}) bipolar Herbig-Haro (HH) jet is detected for the first time. Such jets are rare amongst Herbig Ae/Be stars. While the red-shifted counter-jet is observed to begin $0''.7$ from the centre of the stellar continuum emission, the blue-shifted jet can be traced right back to the continuum peak. We interpret this asymmetry as being due to the occultation of the counter-jet by a circumstellar disk. Given the distance to LkHα 233, the proposed disk has a maximum projected radius of 600 AU. The jet, at a position angle of 250°, is perpendicular to the inferred disk orientation based on polarization measurements and bisects the optical bipolar nebula associated with this star.

Close to the star itself ($\lesssim2''$) the [SII]$\lambda\lambda$6716/6731 emission is resolved into 2 velocity components. The high velocity component can be identified with the extended jet, whereas the broad low velocity component is probably a disk wind following the suggestion of Kwan & Tademaru (1995).

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Accretion Disks around Young Objects. I. The Detailed Vertical Structure

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We discuss the properties of an accretion disk around a star with parameters typical of classical T Tauri stars (CTTS), and with the average accretion rate for these disks. The disk is assumed steady and geometrically thin. The turbulent viscosity coefficient is expressed using the α prescription and the main heating mechanisms considered are viscous dissipation and irradiation by the central star. The energy is transported by radiation, turbulent conduction and convection.

We find that irradiation from the central star is the main heating agent of the disk, except in the innermost regions, $R < 2$ AU. The irradiation increases the temperature of the outer disk relative to the purely viscous case. As a consequence, the outer disk ($R > 5$ AU) becomes less dense, optically thin and almost vertically isothermal, with a temperature distribution $T \propto R^{-1/2}$. The decrease in surface density at the outer disk, decreases the disk mass by a factor of 4 respect to a purely viscous case. In addition, irradiation tends to make the outer disk regions stable against gravitational instabilities.

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Spatially resolved optical spectroscopy of the Herbig Ae/Vega-like binary star HD 35187

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We report on observations of the young binary system HD 35187 (SAO 77144). For the first time, we have obtained spatially resolved optical spectra of the individual stars. Analysis of their effective temperatures indicates that the stars have spectral types of A2 (HD 35187B) and A7 (HD 35187A). Analysis of the Hγ Balmer line indicates a luminosity class V for both stars. At the time of these observations, net Hα emission was only present towards HD 35187B. However, there is evidence that the photospheric Hα line in HD 35187A has been 'filled in' relative to its expected strength in an A7 star, so this star may also be associated with some process leading to Hα emission. Moreover, *both* stars exhibit absorption in the He I λ5876 line well in excess of that expected for their spectral types. Comparison with earlier observations reveals that both the Hα and He I lines are variable, so both stars are 'active' in some sense. We suggest that the variable He I absorption detected towards both stars is a result of chromospheric activity, and is not necessarily related to the circumstellar environment.

We find tentative evidence for a narrow Ca K circumstellar absorption line and excess red-shifted absorption of the Na D line profiles in the spectrum of HD 35187B, both of which are absent in the spectrum of HD 35187A. The heliocentric radial velocity of the presumed circumstellar Ca K line (+54.5 km s^{-1}) is similar to that of red-shifted circumstellar absorption lines previously identified in IUE spectra of this star, and the velocity range of the Na D absorption precisely match that of the UV circumstellar components. Moreover, by placing the stars on the H-R diagram (with the aid of the reliable Hipparcos distances) we find evidence that HD 35187B is dimmed by about 0.4 magnitudes of grey circumstellar extinction.

The detection of net Hα emission, circumstellar absorption lines, and significant circumstellar extinction for HD 35187B, suggests that it has far more mass in its circumstellar environment than its companion, and that the observed IR excess of this system originates from a disk surrounding HD 35187B alone.

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NGC 7129 FIRS 2: an intermediate-mass counterpart of Class 0 objects

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We present JCMT (sub)millimetre observations of the young source NGC 7129 FIRS 2 and HIRAS maps of the whole NGC 7129 region. The total integrated luminosity of FIRS 2 is $\approx 430\ L_\odot$. Its spectral energy distribution is described by a single-temperature grey body with $T = 35\,K$ and $\beta = 0.9$. The total mass is found to be $\sim 6\,M_\odot$. These and other properties indicate that FIRS 2 is an intermediate-mass counterpart of the low-mass Class 0 protostellar objects; in this sense, FIRS 2 is probably the youngest intermediate-mass object we know at present. The far-infrared emission of NGC 7129 is dominated by two sources: FIRS 1, which is located toward the HAeBe star LkHα 234, and FIRS 2. The cavity observed in the optical NGC 7129 reflection nebulosity and in radio emission lines is clearly observed in the HIRAS maps, particularly in the 25 μm band. The total estimated luminosity of the region is $\approx 4.5\ 10^3\ L_\odot$, consistent with the idea that the dust is heated by the cluster of HAeBe stars in NGC 7129.

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Polarization Of Astronomical Maser Radiation. IV. Circular Polarization Profiles

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Profile comparison of the Stokes parameters V and I is a powerful tool for maser data analysis, providing the first direct methods for unambiguous determination of (1) the maser saturation stage, (2) the amplification optical depth and intrinsic Doppler width of unsaturated masers, and (3) the comparative magnitudes of Zeeman splitting and Doppler linewidth. Circular polarization recently detected in OH 1720 MHz emission from the Galactic center appears to provide the first direct evidence for maser saturation.

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Two jets from the protostellar system L1551 IRS5

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HST and ground based observations of the jet emanating from the young stellar object L1551 IRS5 clearly show a structure with two components, one of which terminates in a working surface only 1500 AU from the originating sources. This particular jet is found to be less dense than the ambient medium. Its Mach disk is found to be very small – only $\sim$ 45AU. We show that this jet cannot be the driver of the large scale molecular outflow in L1551: The jet fails to provide the necessary momentum by at least a factor of a 100, and, having a dynamic age $\sim$ 3 orders of magnitude less than that of the outflow, this jet has no causal relationship with the molecular flow. The morphology and velocity field of the two components is consistent with them being separate entities, and we suggest that there are in fact two jets, possibly each originating from a different young stellar object.

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http://astro.estec.esa.nl/Pubs/pubs.html

A Photodissociated Region associated with the Compact HII Region near GGD 12-15

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We present VLA continuum (2, 3.6 and 20 cm) and line (HI 21-cm, C92α and H92α) observations toward the obscured cometary-like HII region located near the optical nebulosities GGD 12-15. We find that the H92α recombination line profile is asymmetric, probably due to a superposition of line emission from the HII region and from an underlying partially ionized medium (H^0). The observed kinematics of the ionized gas suggests that the HII region is undergoing a champagne flow. The C92α observations show that the C^+ emission arises from an extended region of $\sim$20$''$ in size, that is closely associated with the HII region. The C^+ emission has a line center velocity of 11.9 km s^{-1}, similar to the velocity of the ambient molecular cloud ($\sim$11 km s^{-1}). The 21-cm HI spectrum shows emission and absorption line components. The HI line in emission is detected from a region of $\sim$23$''$ in diameter, with a center velocity of 15.4 km s^{-1} and peaks to the east of the HII region. The absorption feature is unresolved ($\leq$22$''$), has a line center velocity of 11.7 km s^{-1} and lies in front of the HII region. Both the C92α and HI emissions are interpreted as arising from a photodissociated region (PDR) around the cometary HII region. An isothermal model has been used to derive the physical parameters of the photodissociated hydrogen gas around the HII region. We derive that the PDR region has an excitation temperature of $\sim$330 K, a hydrogen column density of $\sim 6 \times 10^{21}$ cm^{-2}, an HI number density of $\sim$1.5 $\times 10^4$ cm^{-3} and a HI mass of $\sim$5 $M_\odot$. The mass in photodissociated hydrogen is about three orders of magnitude larger than the mass in ionized hydrogen ($\sim 2 \times 10^{-3}$ $M_\odot$).

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The powering source and origin of the quadrupolar molecular outflow in L723

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We present the results of single-dish observations of CS (J=2-1 & J=3-2) and interferometric observations of CO (J=1-0) toward the center of the quadrupolar molecular outflow in L723. We have detected a compact CS condensation having a size of 0.04 pc and a mass of 0.55 $M_\odot$ toward the northeastern radio continuum source VLA 2 (AER91

2). The CO outflow also shows the distribution centered at VLA 2. These results suggest that the source VLA 2 is the young stellar object that is powering the conspicuous molecular outflow system. On the other hand, there is no enhancement in the CS intensity nor the CO outflow distribution toward the southwestern radio continuum source VLA 1 (AER91 1), indicating that the source VLA 1 does not contribute to the morphology of the quadrupolar outflow in L723.

The CO distribution observed with the interferometer delineates the western edge of the blue lobe and the northeastern edge of the red lobe revealed in the single-dish map, suggesting that the outflow in L723 is a single bipolar outflow with a wide opening angle of 120°–170° rather than two independent outflows. We found signs of interaction between the blueshifted outflow and the dense ambient gas; 1) there is a compact CS clump blueshifted by ∼1 km s^{-1}, the distribution of which show anticorrelation with the blueshifted CO outflow, 2) both CS and NH_3 spectra show the line broadening toward the blueshifted clump, and 3) there is a temperature enhancement at the boundary of the blueshifted clump of CS emission. It is likely that such interaction with the dense ambient gas has made the increased opening angle of the outflow, which accounts for the quadrupolar morphology.

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[O I] 63 μm Absorption in NGC 6334

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The [O I] 63 μm transition has been imaged around 5 FIR and radio continuum sources in the southern massive star formation region NGC 6334. The [O I] 63 μm line is found in absorption toward the FIR continuum source NGC 6334 V. This is the only the second case in which the [O I] 63 μm line has been seen in absorption against a continuum source. From the depth of the absorption line, the minimum column density of oxygen is calculated to be $N(O^0) \gtrsim 5 \times 10^{18}$ cm^{-2}. This amount of oxygen is consistent with [O I] 63 μm absorption due to atomic gas in the foreground molecular cloud.

The [O I] 63 μm line is found in emission toward the other four sources observed: NGC 6334 A, C, D and E. Single-component PDR models suggest densities of $n \sim 10^4$ cm^{-3} for these sources, based on previously observed [O I] 145 μm and [C II] 158 μm intensities. However, unphysically large FUV fields are implied for three of the sources, particularly for NGC 6334 A. Neither single- nor two-component photodissociation region models can explain the anomalously low [O I] 63 μm intensity toward NGC 6334 A nor the absorption toward NGC 6334 V. We suggest that self-absorption of the [O I] 63 μm line, such as has been suggested toward DR 21, is suppressing the observed [O I] 63 μm intensity. This underestimate leads to an overestimate of the derived FUV field strengths throughout NGC 6334. The discovery of several more star-forming sites in which the [O I] 63 μm is in absorption or self-absorbed implies that this line is not always a reliable PDR diagnostic because the PDR models do not treat the radiative transfer through the molecular cloud.

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Preprints available at: http://buast7.bu.edu/∼kraemer/

Aperture Synthesis $C^{18}O$ ($J = 1 - 0$) Observations of L 1551 IRS 5: Detailed Structure of the Infalling Envelope

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We report aperture synthesis $C^{18}O$ ($J = 1 - 0$) observations of L 1551 IRS 5 with a spatial resolution of $2''.8 \times 2''.5$ using the Nobeyama Millimeter Array. We have detected an emission component centrally condensed around IRS 5, as well as a diffuse component extending in the north-south direction from the centrally condensed component. The centrally condensed component, 2380 AU × 1050 AU in size, is elongated in the direction perpendicular to the outflow axis, indicating the existence of a flattened circumstellar envelope around L 1551 IRS 5. The mass of the centrally condensed component is estimated to be $0.062 M_\odot$. The position-velocity (P-V) diagrams reveal that the velocity field in the centrally condensed component is composed of infall and slight rotation. The infall velocity in the outer part is equal to the free-fall velocity around a central mass of $\sim 0.1 M_\odot$, e.g., 0.5 km s^{-1}at $r = 700$ AU, while the rotation velocity, 0.24 km s^{-1}at the same radius, gets prominent at inner radii with a radial dependence of r^{-1}.

We make up P-V diagrams for the model envelopes with vertical structure, in which the matter falls under the gravity and eventually settles down in Keplerian rotation inside the centrifugal radius, and compare them with the observed P-V diagrams of the centrally condensed component. The main characteristics of the observed P-V diagrams are reproduced by either (1) an envelope with a moderately flattened density distribution, or (2) a spherical envelope with a bipolar cavity whose half-opening angle is about 50°. Detailed comparison of the observed and model P-V diagrams suggests that the $C^{18}O$ ($J = 1 - 0$) emission from the outer part of the centrally condensed component is well reproduced with the models with the central mass $\sim 0.15 M_\odot$ and the mass infall rate $\sim 6 \times 10^{-6} M_\odot$ yr^{-1}. However, the higher velocity features of the emission near the star cannot be reproduced unless the central mass is taken to be $\sim 0.5 M_\odot$. These facts suggest either that the gas pressure and/or magnetic force dilute the effect of the gravity in the outer part of the envelope, or that the velocity structure inside the centrifugal radius deviates significantly from the Keplerian rotation.

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Emission Line Diagnostics of T Tauri Magnetospheric Accretion. I. Line Profile Observations

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We present high-resolution spectra of classical T Tauri stars in Taurus in the range 5800 - 9000 Å to critically examine the current theories of magnetospheric accretion. In this paper, we focus on the emission lines of hydrogen (the higher Paschen series and Hα), He I λ5876, O I λ7773 and λ8446, the Na D lines, and the Ca II infrared triplet. We argue that the magnetospheric infall zone is the likely source of emission for the hydrogen, oxygen and sodium lines for most of the stars in our sample. As has been previously shown, the calcium and helium lines have a narrow and a broad component; focussing on the broad components, we find that they are likely formed in the magnetosphere for at least several of the stars in the sample. Preliminary calculations indicate that the magnetospheric models developed to explain the Balmer lines predict significant Ca II, Paschen, and O I emission, roughly comparable to what is observed. However, in some of the stars, especially at high veilings, the case for line formation in the accretion flow is not clear. Finally, our results suggest that the Ca II IR triplet lines are good indicators of the accretion rate for all but the most weakly accreting T Tauri stars.

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

A Lithium-Survey for Pre-Main Sequence Stars in the Upper Scorpius OB Association

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We present the results of an intermediate resolution spectroscopic survey for pre-main sequence (PMS) stars in the Upper Scorpius OB association. In a 160 square-degree area we were able to identify 39 new PMS stars by follow up observations of X-ray selected stars with the multi object spectrograph FLAIR at the UK Schmidt Telescope.

We also investigated the completeness of our X-ray selected sample by observing more than 100 stars that were *not* detected as X-ray sources, but have proper motions indicating membership to Upper Sco. While the new X-ray selected PMS stars with known proper motions have kinematics consistent with membership, none of the X-ray quiet proper motions candidates is a PMS star. We conclude that our X-ray selected sample of PMS stars seems to be rather complete. For stars in the magnitude interval $11.5 \leq B \leq 13.5$ we derive a conservative lower limit of 75% completeness.

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http://www.astro.uni-wuerzburg.de/~preib/sco.html

Ionization structure and a critical visual extinction for turbulent supported clumps

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We show that the fractional ionization in a wide range of models of cloud chemistry undergoes a steep decline at extinctions of $A_{\rm V} \simeq 2 - 3$. We identify this extinction with the critical value for clumps in the Rosette Molecular Cloud: clumps with $A_{\rm V}$ above ~ 3 may contain embedded stars, while those with extinction below this value do not. We argue that the ionization decline at this critical extinction is directly related to the extent of turbulent support in the cloud. This leads us to investigate for the first time the chemical evolution of a cloud that is initially magnetically supported against collapse perpendicular to the field lines, but is collapsing along the field lines in a 1-D mode, up to an unknown but critical density. The fractional ionization corresponding to this critical density then allows ambipolar diffusion to control a collapse across the large-scale magnetic field as well as parallel to it. The results of the chemical evolution of a cloud undergoing this two-stage collapse are presented, and are shown to be sensitive tracers of the details of the collapse mode.

Accepted by Astronomy & Astrophysics

$H^{13}CO^+$ and CH_3OH Line Observations of Pre-stellar Dense Cores in the TMC-1C Region

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We have mapped the whole TMC-1C region in $H^{13}CO^+$ (J=1-0) and CH_3OH (J_K=2_0-1_0 A^+) lines at a grid spacing of 50" with the 45m telescope at Nobeyama Radio Observatory. We have also conducted high spacial resolution mapping observations at a grid spacing of 34" in both lines toward a $6' \times 6'$ portion in the south and a $4' \times 4'$ portion in the north of the TMC-1C region. We found that the structure of TMC-1C is filamentary in both molecular lines. The size and position angle of the filament are 0.75 pc $\times$ 0.17 pc and 135°, respectively. The filament consists of dense ($\sim 10^5$ cm^{-3}) cores which are traced by either $H^{13}CO^+$ or CH_3OH lines. We found that the distribution of cores seen in $H^{13}CO^+$ is quite different from the distribution of cores seen in CH_3OH. The LVG analyses indicate that this difference is due to relative abundance variation between $H^{13}CO^{+!}$ and CH_3OH in the cores b y about one order of magnitude. We have also carried out multi-transitional observations of C_3H_2 ($J_{K',K"}$=$2_{1,2}$-$1_{0,1}$, and $3_{1,2}$-$3_{0,3}$) at two

positions in the same cloud in order to estimate the molecular hydrogen densities for $H^{13}CO^+$ and CH_3OH cores, and found that the densities are around 10^5 cm^{-3} for both cores. These starless cores (no IRAS source), considered to be pre-stellar cores, seem to be at chemically different evolutionary stages; the $H^{13}CO^+$ cores are more evolved and closer to protostar formation than CH_3OH cores. On the other hand, we found no difference in physical properties, i.e., the size, line width, and mass, between $H^{13}CO^+$ and CH_3OH cores; the averages are about 0.07 pc, 0.3 km s^{-1}, and 2 $M_\odot$, respectively.

Accepted by Astrophysical J.

Molecular Cloud Cores in the Orion A Cloud. II. FCRAO CS (2−1) Data

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CS (2−1) data of the Orion A cloud obtained with the FCRAO 14 m telescope are shown. The CS (2−1) image shows the clumpy and filamentary structure of the Orion A cloud, as did our previous CS (1−0) image, obtained with the NRO 45 m telescope. The peak intensity T_{MB} (CS 2−1) decreases more steeply than T_{MB} (CS 1−0) toward the south along the filament. It is found that the gas density of the CS cores tends to be lower in the south of the cloud, and this explains the above difference in the line intensity decrease. From CS and $C^{34}S$ data, we estimated the optical depth of CS (2−1) to be moderately high (2−5), and that of CS (1−0) to be typically less than unity.

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http://www.nro.nao.ac.jp/ kt/

Outflow-infall Interactions as a Mechanism for Terminating Accretion in Protostars

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Protostar and disk formation begins with the collapse of a dense interstellar cl oud core. The core's envelope constitutes an infall region which fuels further growth of this disk and protostar. The stage when outflow and infall exist simultaneously, and how accretion is terminated, are very important but little understood. We present the first observational evidence for the interaction between a very wide opening angle outflow and infall in IRS1 in B5. The outflow angle is largest near the star indicating a widening of the outflow with time. Outside the outflow lobes we observe a narrow disk-like region undergoing infall. We interpret the widening of outflow as a natural mechanism to stop the infall, and hence, end the accreting phase in protostars. This observational evidence has broad implications for star and disk formation theories. If IRS1 in B5 is young, as indicated by the dynamical age of outflow, we can estimate that at the observed rate of outflow widening it will take $\sim 10^4$ yr to shut down the infall; therefore, the entire accretion phase lasts at least 20,000 yr after the onset of outflow.

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Dust grains and the structure of steady C-type magnetohydrodynamic shock waves in molecular clouds

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I examine the role of dust grains in determining the structure of steady, cold, oblique C-type shocks in dense molecular gas. Gas pressure, the inertia of the charged components, and changes in ionisation are neglected. The grain charge and rate coefficients for electron-neutral and grain-neutral elastic scattering are assumed constant at values appropriate to the shock interior. An MRN size distribution is accounted for by estimating an effective grain abundance and Hall parameter for single-size grains.

A one-parameter family of intermediate shocks exists for each shock speed v_s between the intermediate signal speed $v_A \cos\theta$ and $\sqrt{2} v_A \cot\theta$, where v_A is the preshock Alfvén speed and θ is the angle between the preshock magnetic field and the normal to the shock front. In addition, there is a unique fast shock for each $v_s > v_A$.

If the preshock density $n_{\rm H} \gtrsim 10^5\,{\rm cm}^{-3}$ and the preshock magnetic field satisfies $B({\rm mG})/{\rm n_H}(10^5\,{\rm cm}^{-3}) \lesssim 1$ grains are partially decoupled from the magnetic field and the field and velocity components within fast shocks do not lie in the plane containing the preshock field and the shock normal. The resulting shock structure is significantly thinner than in models that do not take this into account. Existing models systematically underestimate the grain-neutral drift speed and the heating rate within the shock front. At densities in excess of $10^8\,{\rm cm}^{-3}$ these effects may be reduced by the nearly-equal abundances of positive and negative grains.

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The Ionization Fraction in Dense Molecular Gas. I: Low Mass Cores

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Observations of $C^{18}O$, $H^{13}CO^+$, and DCO^+ toward 23 low mass cores are used to constrain the fractional ionization (electron abundance) within them. Chemical models have been run over a wide range of density, cosmic ray ionization rate, and elemental depletions, and we find that we can fit 20 of the 23 cores for densities, $n_{\rm H_2} = 1 - 3 \times 10^4\,{\rm cm}^{-3}$, moderate C and O abundance variations, and cosmic ray ionization rate, $\zeta_{\rm H_2} = 5 \times 10^{-17}\,{\rm s}^{-1}$. The derived ionization fractions lie within the range $10^{-7.5}$ to $10^{-6.5}$, with a median value, $x_{e,{\rm m}} = 9 \times 10^{-8}$ and typical errors for each individual core equal to a factor of 3. These values imply that the cores are weakly coupled to the magnetic field and MHD waves can propagate within them. The ambipolar diffusion timescale is about an order of magnitude greater than the free-fall time and the cores can be considered to be in quasistatic equilibrium. There is no significant difference between the molecular ionization for cores with and without embedded stars which suggests that the ionization balance in cores is primarily governed by cosmic rays alone.

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Preprint available at: http://cfa–www.harvard.edu/~jpw/papers/xe1.ps

Dissertation Abstracts

Signatures of Infall in Regions of Low Mass Star Formation

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Ph.D degree awarded: January 1998

We used mm-wavelength lines to probe the dense gas kinematics around nearby low mass young stellar objects (YSOs). We used optically thin lines to study the underlying core rest velocity, and optically thick lines to study the foreground absorption velocity field.

We surveyed 47 nearby low mass YSOs to determine the frequency of infall-like and expansion-like spectral signatures. We used $\delta v = (v_{thick} - v_{thin})/\Delta v_{thin}$, to characterize the spectral line asymmetries. The distribution of δv is skewed toward negative (blue-shifted) velocities. This excess is much more significant for Class 0 than for Class I sources, indicating that we detect infall motions toward Class 0 and not toward Class I sources.

We present maps of 12 YSOs from the survey having strong H_2CO line asymmetries. The H_2CO self-absorption features are concentrated toward the YSOs in all sources, having predominant infall-like line asymmetries over spatial scales of 0.01–0.04 pc, where the mean gas density is $\sim 10^5$ cm^{-3}. We derive typical infall speeds of 0.01–0.1 km s^{-1} over the cores, indicating mass accretion rates of $(0.1 - 10) \times 10^{-6}$ M$_\odot$ yr^{-1}. We find strong velocity gradients, up to 6 km s^{-1} pc^{-1}, close to the core half maximum contours, suggestive of core motions through an inter-core medium.

We present results of spherically symmetric radiative transfer calculations with a variety of cloud models. We find that the single most important parameter that determines the line profile shapes is the inward speed in the outer layers of the cores, which are predominantly responsible for the spectral line self-absorption.

Our main conclusions are

1. Infall motions are detected toward $40 - 50\%$ of Class 0 sources, and $< 10\%$ of Class I sources.
2. Most sources with infall motions have line widths dominated by non-thermal, rather than thermal motions
3. Infall motions are extended over spatial scales of 0.01–0.04 pc.
4. Infall motions are distinguishable from bipolar outflows by analyzing the spatial distribution of the line asymmetries.
5. Dense star forming cores are apparently moving in an inter core medium, consistent with them being gravitationally bound objects.
6. The observed strong line asymmetries require high infall speeds at large distances from the YSOs, which are inconsistent with pure inside-out collapse models.

New Books

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Proceedings of the workshop and spring school
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Contents:

The proceedings has been published as the 100th issue of the Communications from the Konkoly Observatory of the Hungarian Academy of Sciences. A copy will be sent to the libraries of the major astronomy institutions. Individuals interested in reading the book can download the compressed PostScript-version of the whole proceedings from the URL: *http://www.konkoly.hu/Mitteilungen/100.ps.Z*

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Accretion Phenomena and Related Outflows

Editors: D.T. Wickramasinghe, G.V. Bicknell and L. Ferrario

These are the proceedings of IAU Colloquium No. 163 held in Port Douglas, Australia between 15 and 19 July 1996. The book contains both observational and theoretical results, with emphasis on many review-type presentations. Accretion and resulting outflows are important processes in a wide variety of astrophysical settings and the book conveniently brings together for comparison new results related to objects ranging from young stars to AGN.

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