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Collapse and Fragmentation of Molecular Cloud Cores. V. Loss of Magnetic Field Support

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The fragmentation mechanism has been quite successful at providing an explanation for the formation of binary stars during the collapse phase of dense cloud cores. However, nearly all fragmentation calculations to date have ignored the effects of magnetic fields, whereas magnetic fields are generally regarded as the dominant force in molecular clouds. Here we present the first three dimensional, radiative hydrodynamical models of the collapse and fragmentation of dense molecular cloud cores, including the effects of magnetic fields and ambipolar diffusion. Starting from a prolate, Gaussian cloud that would collapse and fragment in the absence of magnetic fields (a thermally supercritical cloud), we introduce sufficient magnetic field support (through the magnetic field pressure, $B^2/8\pi$, with $B = B_o(\rho/\rho_o)^\kappa$) to ensure a magnetically subcritical (stable) cloud. The effects of ambipolar diffusion are then simulated by reducing the magnetic pressure scaling factor (B_o) over a specified time interval ($= t_{AD}$), leading to a magnetically supercritical cloud and collapse. When t_{AD} is about 10 free fall times or less, fragmentation into a binary can still occur; for longer t_{AD} , fragmentation is stifled by the slow onset of collapse. While binary fragmentation is possible in a magnetically-supported cloud, the outcome depends critically on the time scale for ambipolar diffusion. Estimates of the time scale for ambipolar diffusion in dense clouds turn out to be roughly equal to this critical value, suggesting that whether fragmentation occurs or not depends on the detailed characteristics of the cloud and its collapse.

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Forbidden Emission Lines in Herbig Ae/Be Stars

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The absence of high velocity redshifted forbidden lines in classical T-Tauri stars (Appenzeller et al. 1984; Edwards et al. 1987) has long been taken as evidence of opaque circumstellar disks: Disks which occlude the receding component of the stellar wind or outflow, allowing only the blueshifted emission to be observed. There has been some controversy in the literature recently as to whether a disk model is appropriate to the higher mass counterparts of the T-Tauri stars: the Herbig Ae/Be stars. With this controversy in mind, and a search for such occluding effects, we present part of a comprehensive study of 56 Herbig Ae/Be stars, 28 of which are observed to possess detectable [OI] λ 6300 emission. It was found that those stars with [OI] λ 6300 emission can be divided into four distinct groups as determined by line profiles and velocities. Roughly 15% (4) of the sample show both high and low velocity blueshifted forbidden emission lines reminiscent of the line profiles of classical T-Tauri stars with extended outflows. Of the three remaining groups, the first shows low velocity blueshifted emission with centroid velocities in the range $-55 \text{ km s}^{-1} \leq v_c \leq -10 \text{ km s}^{-1}$ (14 stars), the second unshifted ($|v_c| \leq 5 \text{ km s}^{-1}$) symmetrical forbidden emission lines (7 stars) and the third group of 3 stars low velocity ($10 \text{ km s}^{-1} \leq v_c \leq 15 \text{ km s}^{-1}$) redshifted emission. No Herbig Ae/Be star was found to possess strongly redshifted forbidden line emission. The clear tendency towards blueshifted velocities not only implicitly suggests the presence of occluding disks around these stars but there also appears to be a link between the degree of embeddedness and the amount of forbidden line shift. An evolutionary effect may be responsible in the sense that, as the star

becomes less enshrouded, the high velocity (jet) component of the forbidden line emission disappears first, followed by a decrease in the velocity of the low velocity component and finally by its disappearance altogether. The low velocity forbidden line emission is most likely a disk wind, the line profile being broadened as a result of the rotation of the disk. It is found that the line widths of the low velocity forbidden line emission are broader than those found in the classical T-Tauri stars. There is also evidence of acceleration in the outflow, traced by an increase in the blueshifted velocities from the [OI] λ 6300 to the [SII] $\lambda\lambda$ 6717/6731 lines.

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Intercloud Structure in a Turbulent, Fractal Interstellar Medium

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Pervasive turbulence and fractal structure in the interstellar gas imply the existence of large holes and gaps, filling $\geq 80\%$ of the volume, that may be identified with the intercloud medium (ICM). Such an ICM needs no supernovae or other localized sources for clearing; extensive supernova clearing seems unlikely anyway on both observational and theoretical grounds. Fractal clouds produce fractal ionization zones (FIZ) in which O-star radiation can travel at least twice as far as in a standard Stromgren sphere, and they contain extensive holes covering $\sim 50\%$ of the sky through which this radiation can reach the Galactic halo.

Clouds in a fractal medium are not randomly distributed like standard clouds in the conventional model; they are highly clumped and clustered. If most of the interstellar gas is in such fractal cloud complexes, then there are on average 3 per kiloparsec on a line of sight. These 3 alone produce the observed 8 "standard-cloud" absorption lines per kiloparsec by placing ~ 5 absorption features on each occupied line of sight through a cloud and none on the unoccupied lines of sight. The mean length of an unoccupied line of sight is ~ 600 pc.

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The Multiplicity of Pre-Main Sequence Stars in Southern Star Forming Regions

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High resolution studies of young stars in the star forming regions of Taurus and Ophiuchus have revealed a large population of multiple star systems. To test how applicable this earlier result is for other star forming regions, we have carried out a K[2.2 μ m] band multiplicity survey of pre-main sequence stars located in the dark cloud complexes Chameleon, Lupus, and Corona Australis. This survey, which was conducted with both speckle and direct imaging techniques, covers a binary star separation range of 0."1 to 12" (15 - 1,800 AU) and identifies 25 companion stars of which 9 are new detections. The companion star fraction over the separation range covered by this survey is estimated to be 0.52 ± 0.11 , in agreement with Taurus (0.58 ± 0.08) and Ophiuchus (0.50 ± 0.12). A comparison of the direct imaging portion of this survey with Reipurth & Zinnecker's (1993) optical multiplicity study reveals that 4% of the overlap sample have "infrared companions", companions too red to be detected at optical wavelengths. This suggests that infrared surveys will systematically measure a slightly higher companion star fraction compared to optical surveys. The result of combining all K-band surveys of dark cloud complexes, which cover the separation range 15 - 1800 AU, shows a factor of two excess of the companion star fraction for young stars compared to that for the solar-type stars in the solar neighborhood (0.54 ± 0.06 vs. 0.26 ± 0.04).

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X-Ray Ionization of Protoplanetary Disks

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In the light of new observations of star forming regions by *ASCA* and *ROSAT*, we assess the ability of young stars to ionize their own circumstellar disks with stellar coronal X-rays. Although stellar winds may absorb soft X-rays, hard X-rays can penetrate to large column densities and, until they are absorbed, produce ionization rates greater than standard estimates for Galactic cosmic rays. As in previous studies of the external ionization of protoplanetary disks by cosmic rays, we find that X-ray ionization produces a surface layer that is well-coupled to disk magnetic fields at \sim AU distances. The properties of the surface layer depend on the characteristics of the X-ray source, and thus on the evolutionary status of the central star. Even if Galactic cosmic rays are efficiently excluded by magnetized winds, stellar X-ray irradiation alone may provide sufficient ionization for disks to accrete via the Balbus-Hawley instability. The resulting vertically-layered structure of disks at \sim AU distances (a well-coupled surface layer overlying a poorly-coupled, deeper layer) may lead to divergent dynamical evolution in the two regions. While accretion in the surface layer contributes to the buildup of the mass of the star, the quiescent conditions in the poorly-coupled, deeper layer appear to be conducive to the formation of planets.

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The Stability of Radiatively Cooling Jets: I. Linear Analysis

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The results of a spatial stability analysis of a two-dimensional slab jet in which optically thin radiative cooling is dynamically important are presented. We study both magnetized and unmagnetized jets at external Mach numbers of 5 and 20. We model the cooling rate using two different cooling curves: one appropriate to interstellar gas, and the other to photoionized gas of reduced metallicity. Thus, our results will be applicable to both protostellar (Herbig-Haro) jets, and optical jets from active galactic nuclei.

We present analytical solutions to the dispersion relations in useful limits and solve the dispersion relations numerically over a broad range of perturbation frequencies. We find that the growth rates and wavelengths of the unstable Kelvin-Helmholtz (K-H) modes are significantly different from the adiabatic limit, and that the form of the cooling function strongly affects the results. In particular, if the cooling curve is a steep function of temperature in the neighborhood of the equilibrium state, then the growth of K-H modes is reduced relative to the adiabatic jet. On the other hand, if the cooling curve is a shallow function of temperature, then the growth of K-H modes can be enhanced relative to the adiabatic jet by the increase in cooling relative to heating in overdense regions. Inclusion of a dynamically important magnetic field does not strongly modify the important differences between an adiabatic and cooling jet, provided the jet is highly supermagnetosonic and not magnetic pressure dominated. In the latter case, the unstable modes behave more like the transmagnetosonic magnetic pressure dominated adiabatic limit. We also plot fluid displacement surfaces associated with the various waves in a cooling jet in order to predict the structures which might arise in the nonlinear regime. This analysis predicts that low frequency surface waves and the lowest order body modes will be the most effective at producing observable features in the jet.

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S255-2, The Formation of a Stellar Cluster

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As part of an ongoing study of high mass star formation regions, we have imaged the S255-2 triple HII region in near-infrared broadband wavelength bands J (1.23 μm), H (1.65 μm), K (2.23 μm), and at 3.3 μm . We have also obtained images in the $Br\gamma$ and $Br\alpha$ hydrogen recombination lines, in the H_2 $v = 1 \rightarrow 0$ S(1) line and in the 3.29 μm dust feature emission band. The region consists of a circular core of stars and YSOs, as well as nebulosity, and a more diffuse stellar cluster. The Brackett line emission from the region is at least a factor of ten greater than the value estimated from the radio continuum flux density, assuming case B recombination. The strongest source of $Br\alpha$ line emission is IRS1b and this source appears to be an ionizing wind source. The central core region contains a narrow band of $Br\gamma$ and H_2 emission that we postulate is an ionized jet. The 3.29 μm and H_2 emission are found in a bubble-like region that overlaps and extends beyond the $Br\alpha$ and $Br\gamma$ emission into the photodissociation region (PDR). S255-2 appears to be a young cluster of stars still in the process of forming.

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Kinematic Studies of Herbig-Haro Objects in the Orion Nebula

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Kinematic studies of most of the Herbig-Haro objects in M42 have been carried out. The proper motions of some of these objects have been determined through HST narrow band filter images taken four years apart; radial velocities of these objects have been obtained from high resolution échelle spectra taken at the Kitt Peak observatory using the Coudé Feed system. The three dimensional kinematic properties of these objects are presented. Proper interpretations of the data are discussed.

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Available on WWW at: <http://spacsun.rice.edu/~hux/pub.html>

The Infrared Companions of T Tauri Stars

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The Infrared Companions (IRCs) associated with several normal low-mass pre-main sequence (T Tauri) stars pose an interesting problem for theories of binary star formation. The IRCs have very low infrared color temperatures and large infrared excesses which have led observers to suggest that they may be less evolved objects such as protostars. This paper presents an attempt to understand the IRCs as a class by examining a broad range of observations and applying simple arguments and models. We propose that the IRCs may represent relatively normal young low-mass stars experiencing episodes of enhanced circumstellar extinction, possibly due to rapid accretion of disk material perturbed by their gravitational influence at aphelion or perihelion.

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Spectroscopic evidence of mass infall towards an embedded infrared source in the globule DC 303.8-14.2

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We present millimeter molecular line observations towards the embedded infrared source IRAS 13036-7644, located in the globule DC 303.8-14.2. The CS($J=2-1$) lines show asymmetrical profiles characteristic of a cloud undergoing gravitational collapse, i.e. double-peaked profiles with a brighter blue-shifted component. In contrast the HCO⁺($J=1-0$) line shows towards the IRAS source a double-peaked profile with a brighter red-shifted component, and a velocity gradient across the cloud. The hyperfine components of HCN($J=1-0$) transition show both kinds of double-peaked profiles, and a velocity gradient. We interpret these results as a simultaneous infall of the dense gas in the core and a non-collapsing envelope.

The IRAS source drives a bipolar molecular outflow detected in the ¹²CO($J=1-0$) transition.

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On Protostellar Disks in Herbig Ae/Be Stars

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The spectral shape of IR emission from Herbig Ae/Be stars has been invoked as evidence for accretion disks around high-mass protostars. Instead, we present here models based on spherical envelopes with $r^{-1.5}$ dust density profile that successfully explain the observed spectral shapes. The spectral energy distributions (SEDs) of eight primary candidates for protostellar disks are fitted in detail for all wavelengths available, from visual to far IR. The only envelope property adjusted in individual sources is the overall visual optical depth, and it ranges from 0.3 to 3. In each case, our models properly reproduce the data for both IR excess, visual extinction and reddening. The success of our models shows that accretion disks cannot make a significant contribution to the radiation observed in these pre-main sequence stars.

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Infrared Images and Millimeter Data of Cold Southern IRAS Sources

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We present near-infrared (H,K'), CO (2-1), CS (2-1) and 1.3 millimeter continuum data for 31 southern objects ($\delta(1950) \leq 10^\circ$) known to have extremely red IRAS colors ($F_\nu(100\mu\text{m}) > F_\nu(60\mu\text{m}) > F_\nu(25\mu\text{m}) > 20 \times F_\nu(12\mu\text{m})$). The data are meant to help reveal new, very young stellar objects.

K'-band near-infrared counterparts to the IRAS point sources are detected in 22 of 25 good K' images. Most K' counterparts are multiples. 18 of 21 objects were detected in CS, implying the presence of dense gas. Completing the set of CS (2-1) spectra by including the data of Bronfman *et al.* (1996), we still find only 3 non-detections among all 31 objects; these were also not detected in K'. Wings indicative of outflows are found in a large fraction (20/30) of CO spectra. 26 of 31 mm continuum observations were detections and point to the presence of large amounts of circumstellar matter. Most objects have 10^3 up to 10^5 solar luminosities; we speculate that they contain at least one massive star capable of producing a compact/ultracompact HII region.

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Post-T Tauri stars: a false problem

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We consider the problem of the apparent lack of old T Tauri stars in nearby star forming regions in the framework of the standard model of low-mass star formation. We argue that the similarity between molecular cloud lifetimes and the ambipolar diffusion timescale implies that star formation does not take place instantaneously, nor at a constant rate. Thus, models based on the assumption of a constant star formation rate overestimate the predicted number of stars of ages greater than 2-5 Myr. We argue that the probability of finding a large population of old stars in a star forming region is *intrinsically* very small. It is therefore unlikely that the dispersed X-ray sources found by ROSAT at large distances from molecular cloud complexes can be identified with such a population. We conclude that the post-T Tauri problem is by and large not existent.

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On the stability of an accretion disc containing a toroidal magnetic field: The effect of resistivity

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We extend a previous study of the global stability of a stratified differentially rotating disc containing a toroidal magnetic field to include the effect of a non zero resistivity η . We consider the situation when the disc is stable to convection in the absence of the magnetic field. The most robust buoyancy driven unstable modes, which occur when the field is strong enough, have low azimuthal mode number m . They grow exponentially apparently belonging to a discrete spectrum. They exist for the dimensionless ratio $\eta/(H^2\Omega)$ smaller than $\sim 10^{-2}$, where Ω is the angular velocity and H is the disc semithickness. In contrast the magnetorotational modes develop arbitrarily small radial scale and show transient amplification as expected from a shearing sheet analysis. The most robust modes of this type are local in all directions. Because of their more global character, the buoyancy driven modes may be important for the generation of large scale fields and outflows.

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Rotating Protostars and Protostellar Disks. I. Equilibrium Models.

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This paper is part of a series dealing with the structure and dynamic stability of rotating protostellar cores. As a first step in our study, we have generated numerical equilibrium models for isentropic, axisymmetric protostellar cores in rapid rotation. These models represent endstates for collapse from two different types of initial pre-collapse cloud conditions, chosen to be reasonable cases for the formation of low or intermediate-mass stars on the basis of other theoretical or observational work. Specifically, we consider the equilibrium cores which would form from the collapse of uniformly rotating clouds with the density distributions of singular isothermal spheres and of truncated Gaussian spheres.

The major structural differences between the two sequences are largely due to their distinct angular momentum distributions. The protostellar cores which result from singular isothermal initial conditions can be readily interpreted

as slowly rotating stars surrounded by massive, rotationally-supported disks. A ‘star’ and ‘disk’ are not easily distinguished for the Gaussian cases, but the outer regions of these models are typically in rapid, nearly Keplerian rotation. For reasonable assumptions about parameters, the most rapidly rotating protostellar cores that we can calculate accurately correspond to highly flattened disk or star/disk systems of roughly solar mass with equatorial radii of a few AU’s or less. For the protostellar cores that result from the collapse of singular isothermal spheres, we find that a significant range in parameter space exists in which protostellar disks are much smaller than the typical dimensions usually considered for the solar nebula. These conditions may be conducive to the formation of relatively compact planetary systems such as 51 Pegasi. Our axisymmetric star/disk models are fully two dimensional in the sense that both the vertical disk structure and the central starlike regions are resolved. These models will be used as a numerical laboratory for studies of various dynamic processes in protostellar disks.

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<http://cosmic.arc.nasa.gov:8082/pickett/prep.html>

Kinematics of the Ursa Major Molecular Clouds

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We present a kinematic analysis of the atomic and molecular gas in the Ursa Major molecular clouds. The analysis is based on a new CO survey of the complex made with linear resolution of 0.05 pc and existing H I observations.

The clouds lie in projection on an expanding shell of material known as the North Celestial Pole loop. The molecular structure of the complex is dominated by several long (> 5 pc) filaments, some of which are both extremely straight and extremely narrow (< 0.2 pc across). These filaments are enclosed in a sheath of neutral atomic hydrogen that has a kinematic signature distinct from the surrounding atomic gas. The tips of the filaments are regions of enhanced IRAS 12 μm and 25 μm emission. We find an offset of up to 4 km s^{-1} between the centroid velocities of the CO and H I, a large-scale velocity gradient in the gas of $\sim 0.3 \text{ km s}^{-1} \text{ pc}^{-1}$, and a similar large-scale gradient in the H I line width. The CO velocity field follows a trend similar to the H I, but is much less organized. A weak line width gradient in the CO may also be present.

We present a model in which the clouds lie near the surface of the expanding bubble and, after having interacted with the bubble’s wind, are now slowly “sliding” down the bubble towards the Galactic plane. This model adequately accounts for the atomic-molecular velocity offset, the velocity gradients, the line width gradient, and the IRAS colors.

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<http://cfa-www.harvard.edu/agoodman/Ursa/ursam.html>

High Resolution Observations of HI Zeeman Absorption toward DR 21

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DR 21 has been imaged in HI at high resolution ($\sim 5''$) in both left and right circular polarization with the VLA. The continuum emission is nearly totally absorbed with opacities > 5 over about 20 km s^{-1} ; the FWHM line width is unusually large ($\sim 35 \text{ km s}^{-1}$). At least three components are present: two narrow ones at $V_{\text{LSR}} = -5 \text{ km s}^{-1}$ and $+10 \text{ km s}^{-1}$ and a negative-velocity wing whose opacity can be measured out to $V_{\text{LSR}} = -30 \text{ km s}^{-1}$ in some places. No positive velocity wing is detected. The midpoint of the negative-velocity wing varies between -25 and -10 km s^{-1} and the full extent is typically $\gtrsim 20 \text{ km s}^{-1}$. The wing is detected over most of the HII region core except in the very southwest corner, near HII region C and in the northern region around HII region D. The opacity in the wing is ~ 0.5 toward the eastern diffuse continuum emission and rises to ~ 2 toward the HII core. This negative-velocity

HI absorption is probably associated with the high-velocity outflow seen in CO. The velocity field of this outflow gas shows a high negative velocity tube through the center of the HII region with lower negative velocities near the edge of the tube. The HI gas appears to be accelerating away from the southwest of the core, from a position close to HII region C. This location for the origin of the outflow is consistent with that inferred from the CO observations.

Zeeman measurements were made toward the DR 21 compact HII region core. No magnetic field ($|\mathbf{B}| < 50 \mu\text{G}$) is detected in the narrow line component at $V_{\text{LSR}} = +10 \text{ km s}^{-1}$; a strong magnetic field of a few hundred microgauss is observed at a position near the HII core in the HI gas at negative velocities.

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BIMA ^{13}CO Observations of W3

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The W3 molecular cloud core has been observed with the BIMA and NRAO 12 m telescopes in the ^{13}CO ($J = 1-0$) and C^{18}O ($J = 1-0$) lines. Two BIMA fields were imaged, centered on the infrared sources IRS 5 and IRS 4 ($80''$ west of IRS 5). In order to observe large scale structure, a full-synthesis cube was made with a resolution of $9''.5 \times 8''.0$. Additionally a high-resolution cube was made with only the IRS 5 pointing of BIMA to investigate the distribution of gas near IRS 5 at high angular resolution.

The total H_2 masses of the molecular cores associated with IRS 4 and IRS 5 are 1700 and 1100 M_{\odot} , respectively. Six clumps are identified. Derived H_2 masses of the clumps are between 120 and 480 M_{\odot} and under simple geometrical assumptions, $n(\text{H}_2)$ is between 1.8 to $4.5 \times 10^5 \text{ cm}^{-3}$. The virial masses of the clumps are within 30% of the derived H_2 masses. For the clumps located at IRS 5 and $20''$ south of IRS 4 ^{13}CO opacities derived were 0.3 and 0.7, respectively. At the positions of IRS 4 and IRS 5, individual clumps are observed; the IRS 4 clump in particular has a $n(\text{H}_2)$ a factor of two larger than the other clumps.

At the position of IRS 5, the high-resolution data show a velocity structure, which suggests two clumps, one north and another south of IRS 5. Integrating the emission from these clumps gives an H_2 mass of 110 M_{\odot} . Using the derived H_2 column density toward IRS 5 and a previous HI Zeeman result, we can derive the ratio $|\mathbf{B}|/N_{\text{H}}$ (which is proportional to the magnetic flux to mass ratio Φ_{B}/M). The determined ratio is near the magnetically critical value, which is consistent with the standard theory of high mass star formation.

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Extensive High-Resolution ^{12}CO Imaging of L1641 in Orion

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We obtained extensive ^{12}CO $J=1-0$ images along the minor axis of the L1641 cloud in Orion with a $15''$ (0.03 pc) beam spaced by $34''$. Besides bright ridgelike emission in the middle of the cloud, we detected CO emission almost everywhere within the outermost boundary of the cloud.

There are at least two distinct populations of molecular gas — well-defined “clumps” with high brightness temperature ($\approx 25 \text{ K}$) and small linewidth ($\approx 1.5 \text{ km s}^{-1}$), and “extended components” with low brightness temperature ($\approx 2.5 \text{ K}$) and broad linewidth ($\approx 2.5 \text{ km s}^{-1}$). The ^{12}CO $J=1-0$ emission shows clumpy features even in the periphery of the cloud. The clumps dominate the CO luminosity from the central ridge region and are severely overlapped, while they are isolated in the periphery of the cloud. The extended component is widely distributed especially in the eastern side

of the cloud, and seems to be connected to the atomic gas layer in the Galactic plane. It lacks notable substructures at our spatial resolution and exhibits a surface filling factor very close to unity. The extended component does not fill the interclump space at least in the velocity domain. The ridge component may be separating from the extended molecular material.

To deduce physical conditions of molecular gas, we conducted simultaneous $^{12}\text{CO } J=2-1/J=1-0$ strip-scan observations along the minor axis of the cloud with higher sensitivity and denser sampling. Molecular gas density estimated from excitation analysis of the ^{12}CO emission was $\geq 3 \times 10^3 \text{ cm}^{-3}$ in the clumps and $\approx 2 \times 10^2 \text{ cm}^{-3}$ in the extended component. The peripheral region of the cloud is fainter in CO brightness not because the surface filling factor of emitting gas is smaller but because the emission is dominated by the tenuous extended component with low brightness temperature.

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<http://www.nro.nao.ac.jp/seiichi/ref/Orion45.ps>

http://www.nro.nao.ac.jp/seiichi/image/orion_it.ps

http://www.nro.nao.ac.jp/seiichi/image/orion_pk.ps

The molecular envelope around T Tauri and the nature of NGC1555

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We present maps of the $^{12}\text{CO}(3-2)$ and $\text{C}^{18}\text{O}(2-1)$ emission around T Tauri. By comparison of the two lines measured with similar spatial resolution we are able to discriminate between the different components of molecular circumstellar material and to derive constraints for possible source models. In particular we are able to trace the outflowing molecular components. We propose a multiple outflow system with stellar wind envelope interaction to explain the morphology and dynamics of the $^{12}\text{CO}(3-2)$ and $\text{C}^{18}\text{O}(2-1)$ emitting gas.

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The Stability of Radiatively Cooling Jets: II. Nonlinear Evolution

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We use two-dimensional time-dependent hydrodynamical simulations to follow the growth of the Kelvin-Helmholtz (K-H) instability in cooling jets into the nonlinear regime. We focus primarily on asymmetric modes which give rise to transverse displacements of the jet beam. A variety of Mach numbers and two different cooling curves are studied. The growth rates of waves in the linear regime measured from the numerical simulations are in excellent agreement with the predictions of the linear stability analysis presented in Paper I. In the nonlinear regime the simulations show that asymmetric modes of the K-H instability can affect the structure and evolution of cooling jets in a number of ways. We find that jets in which the growth rate of the sinusoidal surface wave has a maximum at a so-called “resonant” frequency can be dominated by large amplitude sinusoidal oscillations near this frequency. Eventually growth of this wave can disrupt the jet. On the other hand, nonlinear body waves tend to produce low amplitude wiggles in the shape of the jet, but can result in strong shocks in the jet beam. In cooling jets these shocks can produce dense knots and filaments of cooling gas within the jet. Ripples in the surface of the jet beam caused by both surface and body waves generate oblique shock “spurs” driven into the ambient gas. Our simulations show these shock “spurs” can accelerate ambient gas at large distances from the jet beam to low velocities, representing a new mechanism by which low velocity bipolar outflows may be driven by high velocity jets. Rapid entrainment and acceleration of ambient gas

may also occur if the jet is disrupted.

For parameters typical of protostellar jets, the frequency at which K-H growth is a maximum (or highest frequency to which the entire jet can respond dynamically) will be associated with perturbations with a period of ~ 200 yrs. Higher frequency (shorter period) perturbations excite waves associated with body modes that produce internal shocks and only small amplitude wiggles within the jet. The fact that most observed systems show no evidence for large amplitude sinusoidal oscillation leading to disruption is indicative that the perturbation frequencies are generally large, consistent with the suggestion that protostellar jets arise from the inner regions ($r < 1$ AU) of accretion disks.

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Models of the Spectral Energy Distributions of FU Orionis Stars

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Observed spectral energy distributions (SEDs) of FU Orionis, V1057 Cygni, and V1515 Cygni are fit by theoretical spectra, which are calculated from models consisting of outbursting accretion disks together with flattened envelopes. Temperature in the envelopes is determined by approximate radiative equilibrium with a central source. The disk models are two-dimensional and include reprocessing of disk radiation by the disk. The theoretical spectra are calculated using a radiative transfer code and frequency-dependent opacities, at a spectral resolution of $\lambda/\Delta\lambda = 14$. Excellent matches to the data are obtained for all three objects with reasonable model parameters. Radiative transfer is also used to calculate a time series of images showing the progress of an outburst as imaged through a *B*-band filter.

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Preprints available at <http://www.ucolick.org/~neal/preprints.html>

An observational study of Cometary Globules near the Rosette Nebula

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Molecular line observations are reported of two regions containing small cometary globules at the edge of the Rosette Nebula. Observations of the CO, ¹³CO and C¹⁸O $J = 2 - 1$, and CO $J = 4 - 3$ molecular lines towards Globule 1, the most prominent of the group, show it has a well-developed head-tail structure, with a head diameter ~ 0.4 pc, and a tail extending ~ 1.3 pc behind it. The major axis of the system points about 45 degrees away from the direction to the centre of the Rosette Nebula (which contains the [presumed] illuminating stars), and 20 degrees out of the plane of the sky, along a projected line towards the luminous (924 L_☉) infrared source IRAS 06314+0427. The CO lines have a complex velocity structure; with a pronounced broadening at the front of the head (as viewed from IRAS 06314+0427); a velocity gradient ~ 1.4 km s⁻¹ along the tail, and material at the front of the head is blue-shifted by ~ 0.5 km s⁻¹ compared to surrounding gas. The CO $J = 2 - 1$ line intensity peaks towards the front of the head, and along the edges of the tail. The ¹³CO $J = 2 - 1$ antenna temperatures in the head are very similar to those of CO, suggesting very high opacities or column densities, or that there is significant CO self-absorption. There is a narrow rim of CO $J = 4 - 3$ emission around the front of the head over a limited velocity range, which correlates with the position of a faint optical rim, and a narrow ridge of 2 μm H₂ emission. These data give strong support to the Radiation Driven Implosion (RDI) model of Lefloch and Lazareff (1994), which was developed to explain the physical structure of cometary globules. Using an RDI simulation, a remarkably good fit to the data has been obtained,

allowing the CO, ^{13}CO and C^{18}O spatial structures and velocity field to be modelled. This simulation suggests that Globule 1 is $\sim 400,000$ years old, and has a mass $\sim 50 M_{\odot}$. Additional observations towards the region close to IRAS 06314+0427 show that it is associated with an intense molecular concentration lying at the northern end of a ~ 5 pc long molecular ridge, with a mass $\sim 330 M_{\odot}$, and lies close to the centre of a shell-like condensation.

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Preprint available at: <http://www-star.qmw.ac.uk/physics/Preprints.html>

On Scaling Laws and Alfvénic Magnetic Fluctuations in Molecular Clouds

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Under the basic assumption that the observed turbulent motions in molecular clouds are Alfvénic waves or turbulence, we emphasize that the Doppler broadening of molecular line profiles directly measures the velocity amplitudes of the waves instead of the Alfvén velocity. Assuming an equipartition between the kinetic energy and the Alfvénic magnetic energy, we further propose the hypothesis that observed standard scaling laws in molecular clouds imply a roughly scale-independent fluctuating magnetic field, which might be understood as a result of strong wave-wave interactions and subsequent energy cascade. We predict that $\sigma_v \propto \rho^{-0.5}$ is a more basic and robust relation in that it may approximately hold in any regions where the spatial energy density distribution is primarily determined by wave-wave interactions, including gravitationally unbound regions. We also discuss the fact that a scale-independent σ_B^2 appears to contradict existing 1-D and 2-D computer simulations of MHD turbulence in molecular clouds.

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Studies of dense cores in regions of massive star formation V. Structure and kinematics of dense cores from ammonia observations

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We present results of the observations of 17 molecular clouds associated with bright FIR sources in the NH_3 (1,1) and (2,2) lines with the 100-m radio telescope in Effelsberg. The lines were detected in 11 clouds and 10 of them have been mapped in these lines. The kinetic temperatures, sizes, masses and mean densities of the ammonia cores have been derived.

For most of the detected clouds the masses derived under the assumption of a relative ammonia abundance of $\chi(\text{NH}_3) = 3 \times 10^{-8}$ are close to virial masses. However, in S 88 B the ratio M/M_{vir} is only ~ 0.1 and in a few other cases this ratio is significantly lower than unity which may indicate ammonia underabundance. Almost all objects with the signs of underabundance are among the most luminous IR sources in our sample.

Most of the mapped cores are elongated with noticeable velocity gradients along the major axis. The most prominent example is S 255. S 87 has a two-component structure with 2 distinct velocity components which overlap partly spatially. In about half of the mapped sources the NH_3 line widths increase near the peaks of the ammonia emission. The kinetic temperatures are centrally peaked. They reach 20–28 K in the centre and drop to 15–20 K at the edges of the ammonia emitting regions.

In S 76 E a weak extended emission in the (1,1) line at the velocity blue-shifted by $\sim 5 \text{ km s}^{-1}$ relative to the core emission was detected. Hyperfine intensity anomalies in the (1,1) transition were found in S 199 in addition to the known case of these anomalies in S 87.

Accepted by Astron. Astrophys. Suppl. (<ftp://astar.helsinki.fi/pub/igor/nh3.ps.gz>)

Short Announcements

DUSTY: A New Radiative Transfer Code

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A new code for radiative transfer in dusty envelopes, DUSTY, is now available for public evaluation. The program provides an exact solution for spherically symmetric shells with arbitrary density distribution, grain chemistry and sizes, etc. The code was designed for general public usage and has a flexible, friendly input/output interface.

For a centrally heated shell, DUSTY calculates the radiation field throughout the envelope including dust scattering, absorption and emission. DUSTY has built in optical properties for the most common types of astronomical dust. It supports various analytical forms for the density distribution, and can perform a full dynamical calculation for radiatively driven winds around late-type stars. The spectral energy distribution of the central source can be specified analytically as either Planckian or broken power-law. In addition, arbitrary dust optical properties, density distributions and external radiation can be entered in user supplied files. A single DUSTY run can process an unlimited number of models, with each input set producing a run of optical depths, as specified. The user controls the detail level of the output, which can include both spectral and imaging properties as well as other quantities of interest.

We wish to improve both the program and its manual through user feedback. Persons interested in using DUSTY and providing such feedback should contact us at the e-mail address provided.

The Star Formation Newsletter is a vehicle for fast distribution of information of interest for astronomers working on star formation and molecular clouds. You can submit material for the following sections: *Abstracts of recently accepted papers* (only for papers sent to refereed journals, not reviews nor conference notes), *Dissertation Abstracts* (presenting abstracts of new Ph.D dissertations), *Meetings* (announcing meetings broadly of interest to the star formation and interstellar medium community), *New Books* (giving details of books relevant for the same community), *New Jobs* (advertising jobs specifically aimed towards persons within our specialty), and *Short Announcements* (where you can inform or request information from the community).

Latex macros for submitting abstracts and dissertation abstracts are appended to each issue of the newsletter.

The Star Formation Newsletter is available on the World Wide Web, where you can access it via the ESO Portal (<http://http.hq.eso.org/eso-homepage.html>). You can also access it through the University of Massachusetts Astronomy World Wide Web server, the URL for its home page is <http://www-astro.phast.umass.edu/>

Moving ... ??

If you move or your e-mail address changes, please send the editor your new address. If the Newsletter bounces back from an address for three consecutive months, the address is deleted from the mailing list.

New Jobs

POSTDOCTORAL POSITIONS INSTITUTO DE ASTRONOMIA, UNIVERSIDAD NACIONAL AUTONOMA DE MEXICO

Applications are invited for several postdoctoral positions at the Instituto de Astronomia at the Universidad Nacional Autonoma de Mexico (UNAM), in Mexico City, with branches in Ensenada, Baja California and Morelia, Michoacan.

Positions are available in theory and observation with emphasis on the following research areas and places: Star Formation (Morelia), Galactic and Extragalactic Dynamics (Ensenada), IR Studies of Galaxies, Blue Galaxies and Extragalactic HII Regions, Interacting Pairs of Galaxies, Induced Starbursts and Active Galactic Nuclei, Ionized Gas in Elliptical and Lenticular Galaxies, Chemical Evolution of Galaxies and Physics of Diffuse Nebulae (Mexico City).

Successful applicants will have access to the National Observatory of Mexico in San Pedro Martir, Baja California, with 0.84m, 1.5m and 2.1m telescopes; low and high resolution spectrographs, optical CCD cameras, an IR camera/spectrograph, a mid-IR camera, a Fabry-Perot scanning Interferometer and Stromgren and Johnson photometers. A network of workstations is available with access to a CRAY-Y/MP (Mexico City) and a SG minisupercomputer (Ensenada). Information can be found on the WEB at <http://www.astrocu.unam.mx/>, or requested from aguilar@bufadora.astrosen.unam.mx

Positions are for 1 year with option of renewal for another. Applicants should send a letter of intention, curriculum vitae, publication list, a statement of research interests and arrange for two letters of recommendation. Materials should be sent by January 15th, 1997 to:

Dr. Luis A. Aguilar
Postdoctoral Committee
Instituto de Astronomia/UNAM
P.O. Box 439027
San Ysidro, CA 92143-9027, U.S.A.

Notifications will be made by February 15th, 1997.

UMIST LECTURESHIP IN ASTROPHYSICS

Applications are invited for the above tenured post. We are seeking a dynamic person with a strong research record and interests which complement and extend those of the current members of the Astrophysics Group (T J Millar, I Cherchneff and G A Fuller). Current interests of the Group include astrochemistry, star formation, late stages of stellar evolution, and interstellar and circumstellar matter. We are interested particularly in candidates with a background in theoretical, observational and/or instrumental aspects of molecular astrophysics. The appointee will be expected to play a role in the development of astrophysics courses for undergraduates in physics.

It is hoped that the successful candidate can be in post by 1 June 1997 but a slightly later appointment may be possible by mutual agreement. Informal enquiries may be made to Professor T J Millar on 0161-200-3677, or via e-mail (tjm@ast.phy.umist.ac.uk). Details of the Astrophysics Group can be found on our WWW pages at <http://saturn.phy.umist.ac.uk:8000/>

Commencing salary will be within the Lecturer A or B scales (£15,154 – £26,430 per annum).

To receive an application form and further details, please contact The Personnel Office, UMIST, PO Box 88, Manchester M60 1QD, England (e-mail: Janet.Hunter@umist.ac.uk) or telephone our 24 hour answerphone service on 0161-200-4050. Please quote reference PHY/A/158. The closing date for receipt of applications is 31 January 1997.

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Meetings

PRELIMINARY ANNOUNCEMENT

PROTOSTARS AND PLANETS IV

(July 5-10, 1998 – University of California, Santa Barbara)

EDITORS

Vince Mannings (California Institute of Technology), Alan Boss (Carnegie Institution of Washington, Washington D.C.), Sara Russell (National Museum of Natural History, Smithsonian Institution, Washington D.C.)

Please see WWW site <http://astro.caltech.edu/~vgm/ppiv>

I. MOTIVATION AND INITIAL PREPARATION

We have witnessed during the 1990s an unprecedented rate of progress in the multi-disciplinary fields of star and planet formation. A breathtaking array of recent observations and discoveries has complemented increasingly sophisticated modeling of the evolution of protostars and the dispersal of protoplanetary disks, and has advanced our understanding of the growth of grains and planetesimals en route to the formation of planets. Examples of discoveries include the identification of members of the Kuiper Belt population of comets in our own Solar System, the direct optical imaging of disk-like structures surrounding young stars in the Orion Nebula, observations of the spectral-line signatures of the disruption of comets within the inner-disk environments of main-sequence and pre-main-sequence stars, and the indirect detection of extrasolar planetary bodies. Within the past year, the pace of progress has been accelerated further by, for example, the arrival of the *Galileo* mission at Jupiter which, by prolonged study of both the planet and its diverse system of satellites, promises rich insights to the conditions and processes in the Solar nebula during the protoplanetary accretion stage. Simultaneously, the *Infrared Space Observatory* is now providing a wealth of new spectral line, photometric and imaging observations of molecular clouds, embedded protostars, and circumstellar disks.

We believe that the time is right to begin preparations for a comprehensive review that will both appraise the recent developments and identify new questions to be addressed. In July of 1998 we will hold a five-day study meeting at the University of California, Santa Barbara. The response to this announcement will help us to compile a list of topics to be aired at the meeting, and to produce an initial table of contents for the review. By late 1999 we will publish the review as the fourth entry in the *Protostars and Planets* series, which is a subset of the Space Science Series of the University of Arizona Press. Publication will be in association with Tom Gehrels, General Editor of the Space Science Series, and the book will be limited to around 1000 pages. Tom supervised the first *Protostars and Planets* meeting in 1978, which led to the publication of a successful book. Subsequent conferences in 1984 and 1990 established a tradition of producing authoritative books that reviewed contemporary knowledge of the formation of stars and planetary systems. In keeping with the principal aim of the Space Science Series, each *Protostars and Planets* book has served as a reference work for established researchers and as a thorough introduction for young scientists entering the field. We will maintain this standard and, as before, an organizing committee and the editors will select speakers and authors from amongst expert researchers who respond to this announcement. Detailed outlines of chapters will then be requested, and contributors will be expected to submit drafts of their review chapters no later than one month before the meeting. A short interval of time will be granted following the conference to allow revision, after which all contributions will be sent to referees. It is likely that word limits and page-charges will be imposed – the latter will be around \$35/page.

We wish to hear from meteoriticists, planetary scientists, astronomers and theorists. We solicit your interest in participating in the meeting and in possibly contributing to the review, and we invite you to complete our indication-of-interest form. Please make this announcement known to friends and colleagues who may also be interested.

II. INDICATION OF INTEREST

To obtain an indication-of-interest form for *Protostars and Planets IV*, please consult the PPIV web site at <http://astro.caltech.edu/~vgm/ppiv>, or please send a request by e-mail to ppiv@astro.caltech.edu.