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Abstracts of recently accepted papers

Evolution of Molecular Abundance in Gaseous Disks around Young Stars: Depletion of CO Molecules

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We investigate the evolution of molecular abundance in circumstellar disks around pre-main-sequence stars taking into account the adsorption of molecules onto grains as well as the reactions in the gas phase. We follow the molecular evolution for some model disks solving numerically the reaction equations. We show only the results on the abundance of CO molecules in the gas phase. There is a critical distance from the star, $R_{\rm crit}$, at which the temperature is equal to the critical temperature $\approx$ 20 K for the adsorption of CO molecules. At $R > R_{\rm crit}$, CO molecules are depleted rather rapidly from the gas phase mainly due to the adsorption. Even in the region just inside $R_{\rm crit}$, CO molecules are depleted slowly because by gas-phase reactions they are transformed into the other molecules which can be adsorbed more easily than CO. For the minimum-mass solar nebula extended to the region of radius $R \approx 800$ AU, for example, CO molecules in the gas phase at $R > R_{\rm crit} \approx 200$ AU are depleted by a few orders of magnitude in 10^5 to 10^6 yr, while at $R < R_{\rm crit}$ the depletion of CO is not significant in these time scales. This is consistent with the recent observations of the gaseous disks around some T Tauri stars.

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Heterodyne Spectroscopy of the 63 μm O I Line in M42

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We have used a laser heterodyne spectrometer to resolve the emission line profile of the 63 μm $^3P_1$ - $^3P_2$ fine-structure transition of O I at two locations in M42. Comparison of the peak antenna temperature with that of the 158 μm C II fine-structure line shows that the gas kinetic temperature in the photodissociation region near θ^1C is 175 - 220 K, the density is greater than 2×10^5 cm^{-3}, and the hydrogen column density is about 1.5×10^{22} cm^{-2}. A somewhat lower temperature and column density are found in the IRc2 region, most likely reflecting the smaller UV flux. The observed width of the O I line is 6.8 km s^{-1} (FWHM) at θ^1C, which is slightly broadened over the intrinsic linewidth by optical depth effects. No significant other differences between the O I and C II line profiles are seen, which shows that the narrow emission from both neutral atomic oxygen and ionized carbon comes from the PDR. The O I data do not rule out the possibility of weak broad-velocity emission from shock-excited gas at IRc2, but the C II data show no such effect, as expected from non-ionizing shock models.

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Collapse and Fragmentation of Molecular Cloud Cores. IV. Oblate Clouds and Small Cluster Formation

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Binary and multiple stars are believed to form primarily by the gravitational collapse of dense molecular cloud cores and fragmentation of the clouds into systems of protostars. Previous numerical calculations have shown that initially prolate (or cylindrical) cloud cores may collapse and fragment into binary or higher order protostellar systems. Observations of pre-collapse clouds are consistent with a significant fraction being *oblate* as well as prolate, yet the collapse of oblate clouds has not been investigated to date with a three-dimensional (3-D) hydrodynamics code. We present here 3-D calculations of the isothermal collapse of oblate cloud cores, with initial axial ratios of 2:1 and uniform or centrally condensed (Gaussian) radial density profiles. The calculations are performed with a spatially and temporally second order-accurate hydrodynamics code with relatively high resolution in the azimuthal direction ($N_\phi = 128$). Oblate clouds with moderate solid body rotation rates collapse in two steps. First, the clouds collapse along their short axes to form thin pancakes, which are unsupported by centrifugal effects. Second, the pancakes collapse radially inward along their midplanes until centrifugal support is achieved in their inner regions. During the second phase, the surface density of the pancakes becomes so high ($\sigma(r) > \sigma_J(r) \approx (c_s^2\pi)/(Gr)$) that the inner regions of the pancakes fragment into multiple protostars. Fragmentation occurs when the initial ratio of thermal to gravitational energy (α_i) is about 0.4 or less. Varying the ratio of rotational to gravitational energy (β_i) from 0.14 to 0.018 has relatively little effect, because the highly fragmentable pancakes are formed primarily as a result of the oblate geometry of the initial clouds rather than by rotational flattening. The most dramatic result is that oblate clouds appear to fragment into a larger number of protostars than do prolate clouds with similar values of α_i and β_i. The models imply that centrally condensed, oblate cloud cores close to virial equilibrium ($\alpha \approx 1/2$) should collapse and fragment into small clusters containing on the order of ten protostars.

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An Extension of Hierarchical Star Formation to Galactic Scales

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Star formation scaling laws and hierarchical patterns on galactic scales are investigated. The molecular cloud size-linewidth relation suggests that the duration of star formation in a region of size L should increase as $L^{1/2}$. This conjecture is supported by observations of star-forming regions in our Galaxy and by the distribution of Cepheid variables in the LMC. Extending this relation to galactic scales, we suggest that coherent star formation exists over regions much larger than a single star complex (>> 1 kpc), taking the form of sheared spiral arms whenever the dimension is larger than the galactic thickness. The properties of star-forming spirals in nearby flocculent galaxies are measured; they typically extend for at least 1/3 of the galaxy diameter and consist of ~ 5 star complexes separated by ~ 1 kpc. Star-forming spirals appear to be as self-gravitating as all other scales in the star-formation hierarchy. We propose that stars form in hierarchically clustered systems ranging from < 0.1 pc to multi-kpc scales, following the hierarchical distribution of the gas. This structure is generated on all scales by self-gravity and turbulence, with distortion from shear being relatively more important on large scales. Turbulent compression and energy loss (rather than collapse) determine the basic evolution time for a region. The hierarchical pattern disappears when the gas temporarily becomes structured by regular forces, as in spiral density waves and swept-up shells. Then clouds and young stars can appear like beads on a string because mild gravitational instabilities at the collapse threshold have a characteristic length of ~ 3 times the arm or filament width.

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Lynds 1527: An Embedded Protobinary System in Taurus

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Submillimeter continuum maps at 800μm of the embedded source IRAS 04368+2557 in L1527 in Taurus show that there are two sources separated by 20$''$, or 2800 AU. The secondary source is between 2 and 3 times less luminous than the primary source if both sources have similar spectral energy distributions. Large scale $C^{18}O$ J= $1 \rightarrow 0$ emission shows the sources to be embedded in a single dense core and observations of $C^{18}O$ and $C^{17}O$ show the sources to be associated with a compact region of high density gas. Three transitions of $C^{18}O$ show a velocity gradient between the two sources. On the smallest size scale, the $C^{18}O$ J= $3 \rightarrow 2$ emission has a velocity gradient of $3 - 7$km s^{-1}pc^{-1}. The proximity of the sources in both space and velocity suggest that they are a very young protobinary system. The estimated age of the primary source, 5×10^3 years, is much less than the estimated orbitial period, 1.4×10^5 years. The separation and young age of the system indicates that it formed through fragmentation of the dense core during collapse.

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From Ultracompact to Extended HII Regions

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The dynamical evolution of HII regions and wind-driven bubbles in dense clouds is studied. In particular, we address two different issues: 1) the conditions in which ultracompact HII (UCHII) regions can reach pressure equilibrium with their surrounding medium (and thereby stall their expansion), and 2) the appeareance of a powerful dynamic instability in expanding HII regions. At pressure equilibrium the ionized regions become static and, as long as the ionization sources and the ambient gas densities remain about constant, the resulting UCHII regions are stable and long lived. The equilibrium sizes and densities, $R_{\rm S,eq} \sim 3 \times 10^{-2} F_{48}^{1/3} T_{\rm HII,4}^{2/3} P_7^{-2/3}$ pc and $n_{i,\rm eq} \sim 4 \times 10^4 P_7 T_{\rm HII,4}^{-1}$ cm^{-3} (where F_{48} is the photoionizing flux in units of 10^{48} s^{-1}, P_7 is the pressure in units of 10^{-7} dyn cm^{-2}, and $T_{\rm HII,4}$ is the ion temperature in units of 10^4 K), are similar to those actually observed in UCHII regions. Similarly, ultracompact wind-driven bubbles can reach pressure equilibrium and the resulting final sizes are similar to those of UCHIIs. The same is true for a combined ultracompact structure consisting of an interior wind-driven cavity and an external HII region. For non-moving stars in a constant density medium, the lifetimes for all types of ultracompact objects only depend on the stellar lifetimes. For cases with a density gradient, depending on the core size and slope of the density distribution, some regions never reach the static equilibrium condition.

A powerful dynamic instability appears when cooling is included in the neutral gas swept up by an HII region, or a combined wind-HII region structure. This instability was first studied by Giuliani (1979), and is associated with the thin-shell instability described by Vishniac (1983). The internal ionization front exacerbates the growth of the thin-shell instability, creating a rapid shell fragmentation, and our numerical simulations confirm the linear analysis of Giuliani. The fragments tend to merge as the evolution proceeds, creating dense and more massive clumps, and are slowly eroded by ionization fronts. Thus, the resulting structures have a variety of shapes, sizes, densities, and lifetimes. Intriguing features such as "elephant trunks" and cometary-like globules can be easily explained as a result of this instability.

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On the dynamical state of high-latitude molecular clouds

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The size-line width relation and the size-density relation are analysed for the molecular clouds from the CfA 1.2m telescope CO survey at high latitudes in the second quadrant. It is found that $\Delta v \propto r^{0.5}$ and $n \propto r^{-0.8}$, with correlation coefficient $r = 0.66$ and $r = -0.86$, respectively. It is also shown that the virial mass is correlated to the CO luminosity, $log(M_{vir}) = (0.78 \pm 0.09) log(L_{\rm CO}) + (2.3 \pm 0.1)$. The size, line width, and radius for high latitude molecular clouds thus follow similar relations as found for giant molecular clouds. For the latter clouds these relations are usually interpreted as a consequence of virial equilibrium for clouds which are gravitational bound. It is shown that this interpretation is not valid for high latitude molecular clouds. The volume filling factor of molecular gas in high-latitude clouds is found to be rather low, less than 0.01. The pressure induced on the clouds by the surrounding HI gas is larger than the internal pressure induced by the motion of the molecular gas, indicating that the clouds are compressed by the external HI gas.

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High-Resolution Imaging of Circumstellar Gas and Dust in UZ Tauri: Comparing Binary and Single-Star Disk Properties

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We present $\lambda = 1.3$ and 3 mm aperture synthesis imaging of the multiple T Tauri system UZ Tauri. UZ Tau is a hierarchical triple composed of a single star, UZ Tau E, 530 AU distant from a 50 AU binary, UZ Tau W. Both dust and gas emission from the close binary are at least a factor of four lower than from the single star. Since UZ Tau E and W have similar stellar masses, luminosities, and ages, we conclude that the mass of dust and gas associated with UZ Tau W is reduced solely by the influence of a close companion. The disk emission from UZ Tau E is best interpreted as a circumstellar disk similar to those around other single T Tauri stars. In a $1''$-resolution aperture synthesis map, CO (2→1) emission is coincident with the continuum peak and elongated with a size of 300 AU (FWHM); a velocity gradient is seen along the long axis, consistent with rotation in a gaseous disk. The emission is elongated at position angle 19°, the same as the PA of previous polarization measurements. A disk model fit to the continuum spectral energy distribution (SED) of UZ Tau E yields a disk mass of 0.06 $M_\odot$. In contrast, no CO emission is detected from UZ Tau W, and its 1.3 mm continuum emission is unresolved in a $1''$ (FWHM) beam (corresponding to a 70 AU radius). The small extent of the emission and dynamical considerations imply that the 50 AU binary cannot be surrounded by any appreciable circumbinary disk; its mm-wave emission is from circumstellar disks around one or both components. The mass of the circumstellar material is in the range 0.002–0.04 $M_\odot$; the large uncertainty is due to the unknown temperature and surface density distributions of the material. The properties of the UZ Tau E disk are similar to those inferred for the early solar nebula; such a disk could give rise to a planetary system like our own. The mass of the UZ Tau W disk(s) is only marginally consistent with a "minimum mass solar nebula." The constraints on disk size in UZ Tau W indicate that reduced mm-wave flux may be linked to a disparity in the size of disks (and therefore of planetary systems) around single and binary stars.

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Molecular gas near HD 104237 and ε Cha

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We present the results of a search for molecular gas near the candidate Herbig Ae/Be star HD 104237 and its common proper motion companion ε Cha. The molecular gas found near these stars is clumpy, of very low mass, and is far from virial equilibrium. Our results can be interpreted as providing evidence in favour of the pre-main sequence nature of HD 104237 and, by implication, of ε Cha. We suggest that these stars may have recently cleared away the molecular cloud in which they have formed. The HD 104237/ε Cha system may be an example of isolated intermediate mass star formation within the complex of Chamaeleon dark clouds.

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Evolutionary Status of the Pre-Protostellar Core L1498

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L1498 is a classic example of a dense cold pre-protostellar core. To study the evolutionary status, the structure, dynamics, and chemical properties of this core we have obtained high spatial and high spectral resolution observations of molecules tracing densities of 10^3 to 10^5 cm^{-3}. We observed CCS, NH_3, C_3H_2, and HC_7N with NASA's DSN 70 m antennas. We also present large scale maps of $C^{18}O$ and ^{13}CO observed with the AT&T 7 m antenna. For the high spatial resolution maps of selected regions within the core we used the VLA for CCS at 22 GHz, and the OVRO-MMA for CCS at 94 GHz and CS (2-1). The 22 GHz CCS emission marks a high density ($n(H_2) > 10^4$ cm^{-3}) core which is elongated with a major axis along the SE-NW direction. NH_3 and C_3H_2 emissions are located inside the boundary of the CCS emission. $C^{18}O$ emission traces a lower density gas extending beyond the CCS boundary. Along the major axis of the dense core, CCS, NH_3 and C_3H_2 emission show evidence of limb brightening. The observations are consistent with a chemically differentiated onion-shell structure for the L1498 core, with NH_3 in the inner and CCS in the outer parts of the core. The high angular resolution (9" to 12") spectral line maps obtained by combining NASA Goldstone 70 m and VLA data resolve the CCS 22 GHz emission in the southeast and northwest boundaries into arc-like enhancements, supporting the picture that CCS emission originates in a shell outside the NH_3 emitting region. Interferometric maps of CCS at 94 GHz and CS at 98 GHz show that their emitting regions contain several small scale dense condensations. We suggest that the differences between the CCS, CS, C_3H_2, and NH_3 emission are due to a time dependent effect as the core evolves slowly. We interpret the chemical and physical properties of L1498 in terms of a quasi-static (or slowly contracting) dense core in which the outer envelope is still growing. The growth rate of the core is determined by the density increase in the CCS shell resulting from the accretion of the outer low density gas traced by $C^{18}O$. We conclude that L1498 could become unstable to rapid collapse to form a protostar in less than 5×10^5 years.

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Cross-section alignment of oblate grains

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Grain alignment enables studies of magnetic fields in molecular clouds. Mechanical alignment of grains by Alfvénic waves introduced in Lazarian (1994) was shown to be capable to account partially for the observed alignment. This

paper provides a quantitative account of a recently introduced mechanism of mechanical alignment of suprathermally rotating grains. These rapidly rotating grains are essentially not susceptible to random torques arising from gas-grain collisions, as the time-scales for such torques to have significant effect are orders of magnitude greater than the mean time between crossovers. Such grains can be aligned either by gaseous torques during short periods of crossovers or/and due to the difference in the rate at which atoms arrive at grain surface. The latter is a result of the difference in orientation of a grain in respect to the supersonic flow. This process, that we call cross-section alignment, is the subject of our present paper. We derive expressions for the measure of cross-section alignment for oblate grains and study how this measure depends upon the angle between the interstellar magnetic field and the gaseous flow and upon the grain shape.

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Ammonia and $C^{18}O$ in Globules

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A complete and unbiased survey of 237 dust globules from the catalog of Clemens & Barvainis (1988) has been made in the (1,1) and (2,2) inversion lines of ammonia. Whereas NH_3 (1,1) emission is found in 74 sources, the NH_3 (2,2) line is detected only in 17 sources. Complete ammonia maps of 15 globules show angular sizes of between 45" and 85". The FWHP angular sizes of these clouds based on the $C^{18}O$ (1-0) emission are between 2 and 9 arcminutes. Accurate determinations of the kinetic temperatures show that the temperatures of all the globules in the study are between 8.5 and 11.5 K. From NH_3 excitation temperatures of between 4.5 to 8 K we determine H_2 densities with typical values around (2–4)$\cdot 10^4$ cm^{-3}. Presumably, the more extended $C^{18}O$ emission arises from lower density gas. The masses of the mapped globules range up to 100 solar masses with typical values between 2 and 45 solar masses. Considerations of stability from a comparison of turbulent, thermal and gravitational energies show that all the globules are close to equilibrium.

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Photoevaporated Flows from HII Regions

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We model the dynamics of a fast, isothermal, ionized stellar wind loaded with mass injected from photoevaporated globules surrounding the massive star. The effect of the mass injection is to produce a density profile such that the ionization front can be trapped for 10^5 yr, depending on the physical characteristics of the neutral globules inside the HII region.

We find that for neutral globules with sizes $R_g \sim 0.01$ pc, masses of $M_g \sim 1 M_\odot$, and number densities $N_g \sim 2 \times 10^4$ pc^{-3}, thought to be representative of globules in regions of massive star formation, the implied mean density and size of the mass loaded regions of ionized gas are $\sim 10^3 - 10^4$ cm^{-3} and ~ 0.1 pc, respectively, similar to those of compact HII regions. Dust absorption of ionizing photons is important and decreases the densities of the mass loaded winds with respect to their dust free counterparts. Also, mass loaded winds with dust evolve more slowly since the dusty globules survive for longer times than the dust free ones.

Our models predict ionized flows with mass flow rates of $\dot{M} \sim 10^{-5} - 10^{-4}\,M_\odot$ yr^{-1}. These ionized flows could be studied in radio recombination lines. Assuming N_g does not decline sharply with distnace to the central star the ionized flow will recombine after the characteristic "Strömgren" radius r_S where ionizing photon rate goes to zero. Therefore, after this radius a neutral flow will adiabatically accelerate to a terminal velocity of $v_{HI} \sim 40$ km s^{-1}. Neutral flows of this type could be searched for in the neutral hydrogen line at 21cm in absorption against the continuum of the compact HII regions.

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HI "Tails" from Cometary Globules in IC1396

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IC 1396 is a relatively nearby (750 pc), large (>2°), HII region ionized by a single O6.5V star and containing bright-rimmed cometary globules. We have made the first arcmin resolution images of atomic hydrogen toward IC 1396, and have found remarkable "tail"-like structures associated with some of the globules and extending up to 6.5 pc radially away from the central ionizing star. These HI "tails" may be material which has been ablated from the globule through ionization and/or photodissociation and then accelerated away from the globule by the stellar wind, but which has since drifted into the "shadow" of the globules.

This report presents the first results of the Galactic Plane Survey Project recently begun by the Dominion Radio Astrophysical Observatory.

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Evidence for Multiple Outbursts from the Cepheus A Molecular Outflow

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We report evidence for multiple episodes of outflow activity in the Cepheus A star-forming region. We present new, high signal-to-noise CSO observations of ^{12}CO J=3→2, ^{13}CO J=3→2, and CS J=7→6 emission. We also present new, interferometric and single dish observations of ^{12}CO J=1→0 emission towards the Cepheus A molecular outflow. Using line core velocity centroid maps, we argue that the multiple self-absorption features in the CO J=3→2 line profiles are tracing cool shells of material swept-up by an episodic outflow. We present the results of a flexible 3-dimensional LTE outflow model and radiative transfer code that best explains the observations as tracing multiple generations of outflow. The difference in the dynamical time-scales between the "old" and "new" swept-up shells gives an estimate of $\sim 1.6 \times 10^5$ years between the two generations of outbursts. The high resolution ^{12}CO J=1→0 maps obtained by combining single dish observations with interferometric data clearly show a shell-like morphology at low velocities. This cool shell appears to encompass the hot, extremely high velocity (EHV) winds seen in the J=3→2 transition. The interferometric observations show that the current generation of outflow is being powered by the object Cepheus A - HW2. There is also evidence for redirection of the blueshifted lobe of the current generation of outflow, possibly by the extended NH_3 structure Cep A-3. We present a model of the outflow geometry that can explain most of the observed structures in Cepheus A.

The rotating, dense core traced by the CS observations is ~ 0.32 pc in diameter and has an estimated dynamical mass of 330 $M_\odot$. The velocity structure of the core suggests that it is being disrupted by the high-velocity winds driving the molecular outflow.

This new technique of extracting information from self-absorbed line profiles could be used to study other deeply embedded protostellar systems. Since outflows are believed to be intimately tied to accretion, such studies could lead to constraints on mass accretion models for young stellar objects.

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Excitations and line profiles of CO in clumpy molecular clouds: radiative interactions of clump and interclump media

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With a three dimensional Monte Carlo code of radiative transfer, we have investigated how the clump and interclump media interact with each other radiatively in exciting CO molecules in clumpy interstellar clouds. A spherical model cloud is divided into $\sim(4\pi/3)\times15^3$ cubic cells of equal size. Some of the cells filled with cold ($T_{k,c}$=10K) and dense gas are considered to be the clumps; while the rest with hot ($T_{k,ic}$=40K) rarefied gas the interclump medium. The clump density of $n_c(H_2)=(4\sim8)\times10^3$ cm^{-3} is kept an order of magnitude higher than the interclump density of $n_{ic}(H_2)=(2\sim4)\times10^2$ cm^{-3}.

For the optically thick ^{12}CO transitions, the excitation conditions in one medium are significantly affected by the presence of the other. As the volume filling factor of the clumps increases, the excitation temperatures in both media approach each other. This trend is more apparent for the high J transitions than for the low J ones. The change in the excitation conditions causes the ^{12}CO line intensities to increase by a factor of up to 3, as the volume filling factor increases from 0.0 to 0.3. An inclusion of the interclump gas with density as low as 2×10^2 cm^{-3} makes the whole cloud optically so thick that the ^{12}CO line emission is mostly emerging from the cloud surface and exhibits flat top features or self-absorption dips.

For the optically thin transitions of ^{13}CO, on the other hand, the excitation conditions in the interclump medium are rather insensitive to the clump volume filling factor. Syntheses of line profiles show that the bumpy structures of the ^{13}CO lines are originated mainly from the dense clumps. In this case the interclump gas makes the line intensities increase slightly.

Taking MBM12 as an example of clumpy clouds, we observed its core part with the 14m telescope of TRAO. We apply our model calculations to the CO J=1–0 spectra observed with a high S/N ratio and a fine velocity resolution to reveal the physical conditions inside. In order for the clumpy cloud model to be compatible with the observations, either CO molecules should be depleted in the interclump gas or the interclump space should not be completely filled with molecular gas.

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Protostellar Candidates in Southern Molecular Clouds

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In the course of an extensive 1300 μm mapping survey of star forming regions in southern molecular clouds, we have identified five regions which contain new protostellar candidates. The objects are generally separated from nearby known IRAS sources. This, together with their strong 1300 μm fluxes, points towards these objects being either protostars or prestellar clumps, rather than pre-main sequence stars. Some of these protostellar candidates have several components, suggesting the possibility that they may represent simultaneous formation of multiple stars. Cha–MMS1 is located between the lobes of a small compact, already known molecular outflow in the Ced 110 region of the Chamaeleon I molecular cloud, and is a likely candidate as the driving source of the nearby HH 49/50 objects. Cha–MMS2 lies between the lobes of a major, already known molecular outflow in the northern part of the Chamaeleon I cloud complex. Cir–MMS1 is located in a massive cloud core between the lobes of a major, already known molecular outflow in a large cloud complex in Circinus. B59–MMS1 is found in the little–studied molecular cloud B59, and Sco–MMS1 is embedded in an anonymous Bok globule in Scorpius.

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Occlusion Effects and the Distribution of Interstellar Cloud Sizes and Masses

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The frequency distributions of sizes of “clouds” and “clumps” within clouds are significantly flatter for extinction surveys than for CO spectral line surveys, even for comparable size ranges. A possible explanation is the blocking of extinction clouds by larger foreground clouds (occlusion), which should not affect spectral line surveys much because clouds are resolved in velocity space along a given line of sight. We present a simple derivation of the relation between the true and occluded size distributions, assuming clouds are uniformly distributed in space or are all at about the same distance. Because the occlusion is dominated by the largest clouds, we find that occlusion does not affect the measured size distribution except for sizes comparable to the largest size, implying that occlusion is not responsible for the discrepancy if the range in sizes of the samples is large. However, we find that the range in sizes for many of the published observed samples is actually quite small, which suggests that occlusion does affect the extinction sample and/or that the discrepancy could arise from the different operational definitions and selection effects involved in the two samples.

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The variable Herbig Ae star HR 5999: XII. Its circumstellar extinction law

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A study of the extinction law in the UV-visual-IR spectral regions has been made towards the variable Herbig Ae star HR 5999 at three brightness levels $V = 6\overset{m}{.}9$, $7\overset{m}{.}2$, and $7\overset{m}{.}3$. For comparison we have made an equivalent study of its proper motion non-variable companion HR 6000, which is embedded in the same dark cloud. The extinction law towards HR 6000 appears to be normal in the considered wavelength range. This means that the origin of any anomaly in the extinction law towards HR 5999 should be caused by the dust grains in the circumstellar envelope of this star.

The circumstellar extinction law of HR 5999, characterized by the R_V value, has been studied using the extinction calculations by Steenman & Thé (1991), in which it is assumed that the small grains are depleted. We found that for the spectral region considered the value of R_V is larger than 5.8. For the UV alone we found for $R_V^{\rm UV}$ a range between 3.3 to 3.9.

Above mentioned law has also been studied quantitatively using the multiple scattering model based on the Monte Carlo method of Voshchinnikov, Molster & Thé (1996). We have found that the extinction curve near the state of maximum brightness ($V = 6\overset{m}{.}9$) of HR 5999 can be produced by a nearly spherical ($A/B = 1.5$) shell, seen edge-on, and of which the dust grains of sizes smaller than about 0.01 μm are depleted. For the fainter brightness states, which we have also studied, additional extinction due to circumstellar dust clumps, obscuring the star, is assumed. From these conditions, we have found that the properties of the dust particles in the clumps differ from those in the shell. Among others, the smaller dust grains in the clumps are more depleted than in the above mentioned shell. The $R_V^{\rm cs}$ values found in the Monte Carlo calculations range from 2.5 to 3.2.

We suggest that the depletion of small grains is due to the sweeping effect of the radiation field of the central star.

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A preprint of this paper is available via the WWW at http://www.astro.uva.nl/preprints/preprints.html

A possible T Tauri companion to the long-term photometric variable HR 6000

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From Strömgren *uvby* photometry, obtained during the last 14 years, we demonstrate that HR 6000 shows long-term photometric variations with a small (about $0^{\rm m}_{.}03$ in u, $0^{\rm m}_{.}02$ in v and $0^{\rm m}_{.}01$ in b) amplitude. Whereas previous authors classified HR 6000 spectroscopically as A0/3 IIIp and photometrically as B7, we conclude that the observed properties of this system may be explained by inferring that HR 6000 is in fact a binary system, consisting of a B6 V star and a T Tauri companion. The combined spectrum of these two components may easily have been mistaken for a chemically peculiar early A-type star. This scenario also explains the observed small amount of infrared excess and the observed ROSAT X-ray flux of this system as arising from a T Tauri companion. Other traces of this companion have not been detected in our studies. Detection of the T Tauri companion with near-IR spectroscopy may be possible due to the significant contribution of the companion to the total flux at these wavelengths.

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A Multi-line Aperture Synthesis Study of Orion-KL

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We have mapped the Orion-KL region in 28 transitions of 16 molecular species (H_2CO, DCN, HDO, CH_3CH_2CN, HC_3N, SO_2, OCS, ^{29}SiO, SiO, SO, $H^{13}CN$, HCN, HCO^+, CH_3CN, CH_3OH, CO) near 3 millimeters wavelength using the BIMA array. The maps have $1'' - 6''$ angular resolution and $0.3 - 4$ km s^{-1} velocity resolution.

The images show two principal molecular concentrations in a ridge of dense gas, one toward the Kleinmann Low Nebula (KL), the other approximately $25''$ to the northeast, toward dust continuum source CS1. The "hot core", "compact ridge", and "plateau" spectral features all are associated with KL. This region has broad linewidths, high excitation emission, and unusual chemical abundances; it is associated with luminous infrared sources, masers, and a powerful bipolar outflow from at least one embedded young stellar object. By contrast, CS1 has narrower linewidths, lower temperatures, and only weak indications of star formation.

The maps provide evidence that the outflow from KL impacts and heats the southern edge of CS1. CH_3OH and CH_3CN emission peaks and a cluster of H_2O masers are seen here. The outflow may also be responsible for the velocity divergence of the ridge gas seen toward KL.

At $1''$ angular resolution the hot core appears as a chain of dense clumps offset approximately $1''$ east of radio continuum source I (IRc2). The HC_3N vibrational excitation temperature in the hot core is inferred to be 335 K.

The high abundance of HDO, DCN, and other deuterated species in the hot core indicates evaporation of icy grain mantles. CH_3OH, prominent in the compact ridge, appears to be liberated from the grain mantles at a lower temperature than H_2O, perhaps indicating that it is selectively evaporated from mixed molecular ices at ~ 120 K.

The "plateau" spectral feature looks quite different in different molecular tracers. Bright SiO v=0 emission appears to define a 1000 AU diameter flared disk around radio source I; weaker, thermal SiO emission appears to fill the infrared cavity around source I. SO and SO_2 form a shell of expanding gas, probably where the outflow shocks dense clumps along the periphery of the cavity. High velocity HCN and HC_3N emission seems to trace material ablated from these clumps.

The high velocity outflow probably originates from source I. It does not appear to be well-collimated, but instead expands in a wide angle cone. The outflow appears to be partially blocked to the southeast by the hot core clumps.

In an appendix, we present a table of column densities for each observed molecular species at 9 positions across the source, for comparison with chemical models. All the maps discussed in this paper are available in FITS format from the NCSA digital image library.

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Dissertation Abstracts

Activity and rotation of pre-main sequence stars

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Ph.D dissertation directed by: Teresa Lago

Ph.D degree awarded: March 1996

T Tauri stars constitute a peculiar class of irregular variable young ($< 10^7$ yr) and low mass stars (< 3 $M_\odot$), still evolving to the main sequence. Their spectral characteristics and other related phenomena, such as winds or accretion, are important for the study of stellar evolution and to improve our understanding of the Sun's earlier phases.

A sample of ten classic T Tauri stars has been extensively observed (one week) in the optical, at high resolution ($\lambda/\Delta\lambda > 2 \times 10^4$) and high signal-to-noise (> 40). Profiles of the Hα, He I and Na I D lines have been ob tained with the objective of studying the conditions prevailing both in the cooler and the hotter regions of the stellar atmosphere as well as the stellar activity. The high quality spectra and the quasi-simultaneous exposures in the two wavelength b ands allow the discussion of possible correlations (in equivalent width) between different lines and their variability in what concern the shape of the profiles. The high non-photospheric continuum of T Tauri stars, quite variable in some stars, need s to be accounted for. This has been done only for the stars displaying weak veiling, shown by the analysis of behaviour of the photospheric lines intensity during the week.

In this work we find, for some of stars in the sample, strong correlations between the lines of He I and Na D. Such correlations can be used to further constrain the physical parameters in the emitting regions and the dimension of such regions.

In a complementary analysis, we measured the rotational velocity, v sin$i$, for some of the stars, using Fourier analysis technique of the photospheric lines. The presence of a strong optical and ultraviolet continua may result in the shallowing and widening of the photospheric lines. Numerous simulations were carried out in order to estimate the limiting (smallest) rotational velocity that can be measured as a function of resolution and signal-to-noise ratio of the observations. As a consequence we were able to identify photospheric lines only in five out of the ten stars in th e sample. For the star LkHα 264, this was the first determination of v sin$i$.

New Books

Molecular Clouds and Star Formation

Proceedings of the 7th Guo Shoujing Summer School on Astrophysics

Edited by Chi Yuan & Junhan You

This volume is composed of four major in-depth yet pedagogic review articles on the subject of star formation, written by the foremost researchers in the field. Recent infra-red and millimeter radio observations of star formation in molecular clouds are respectively reviewed by Charlie Lada and Phil Myers, both of Harvard-Smithsonian Center for Astrophysics. The theoretical work is reviewed by Frank Shu of UC-Berkeley on the gravitational collapse of dense cores in a giant molecular cloud to form sunlike stars and Bruce Elmegreen of IBM-Watson on the instability of galactic-size regions, leading to large-scale star formation. Theoretical work is also complemented by an extensive review article on protostellar disks by Doug Lin. All articles have been written in a level most suitable for graduate students or young researchers who want to develop their research interest in the field, with the most complete literature survey to date. The volume is not an ordinary conference proceedings, but a text book to be used in graduate study in astrophysics. The volume also includes other short contributions from Paul Ho of Harvard-Smithsonian, Masa Hayashi of Tokyo University, Debra Elmegreen of Vassar, Jing-yao Hu of Beijing Observatory, Guo-xuan Sung of Shanghai Observatory, Chi Yuan of ASIAA and Wen-ping Chen of Central University, Taiwan.

The book contains the following chapters:

The Formation and Early Evolution of Stars: An Observational Perspective *(Charles J. Lada)*
Star Forming Molecular Clouds *(P. C. Myers)*
The Birth of Sunlike Stars *(Frank H. Shu)*
Star Formation on a Large Scale *(Bruce G. Elmegreen)*

Observations of Star Formation:
Herbig Ae/Be Stars *(Jing-yao Hu)*
Observations of Circumstellar Disks with Millimeterwave Molecular Line and Continuum Emissions *(Masahiko Hayashi)*
Circumstellar Environments around Young Stars *(Wen-ping Chen)*
Star Formation in the Galactic Center *(Paul Ho)*
Observations of Large Scale Star-forming Regions and Density Wave Triggering *(Debra Meloy Elmegreen)*

Theoretical Studies of Star Formation:
Proto-stellar Disks and the Solar Nebula *(D. N. C. Lin)*
Early Evolution of Planet-forming Disks *(Chi Yuan)*
Giant Molecular Clouds and Star Formation on The Galactic Scale *Guo-xuan Song*

Appendices:
Optical and Infrared Observational Facilities at Beijing Observatory *(Jing-yao Hu)*
Present Status and Future Development of Radio Observation in China *(Jing-sheng Wang & Zhi-cai Xu)*

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- Brown Dwarfs and the Very Low End of the IMF
- Clusters and Multiple Star Systems
- Galactic Star Formation
- Dynamical Processes Influencing Star Formation
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- Star Formation History in Ellipticals
- Star Formation History in Irreg and Dwarf Spheriodal Galaxies

A preliminary list of invited speakers includes:

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