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Abstracts of recently accepted papers

Magnetic field structure in protostellar envelopes

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We have imaged the linearly polarized emission toward the young stellar objects NGC 1333/IRAS 4A and IRAS 16293-2422. We suggest that the polarized emission from the dense protostellar environment arises from magnetically aligned dust grains and use these observations to investigate the magnetic field structure. The observations were obtained using the new polarimetric capabilities at 3 mm of the six element millimeter array of the Owens Valley Radio Observatory.

Toward IRAS 4A, the average polarization observed is 4.4% ± 0.7%. The magnetic field direction implied by the observations is roughly parallel to the direction of the bipolar molecular outflow. Structure is seen at $3''$ resolution in the linearly polarized image. The peak of the linear polarization is offset $1.''5$ from the peak of the total intensity and elongated perpendicular to the implied field direction. Models calculated with an hourglass magnetic field morphology in a spherically symmetric dusty envelope are consistent with the observations.

Toward IRAS 16293, the polarized emission is located between the two binary components and the polarization percentage at the peak of the polarized emission is 2.7 ± 0.7%. The magnetic field direction implied from our measurements is parallel to the major axis of the circumbinary disk. The polarized emission could be produced by a toroidal magnetic field in the circumbinary disk.

The high resolution of the interferometer provides a probe of the polarized emission at the high densities ($n \geq 10^8$ cm^{-3}) characteristic of protostellar envelopes and disks. The detection of polarized emission at these densities provides a test of grain alignment mechanisms. We conclude that alignment by paramagnetic relaxation of thermally rotating grains is unlikely due to the well coupled gas and grain temperatures, but alignment of suprathermally rotating grains is not ruled out.

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

First Overtone CO Variability in Young Stellar Objects

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We have monitored the 2.3 μm Δv=2 CO band heads towards young stellar objects that are predominantly of low luminosity (L< 10,000$L_\odot$) and show evidence of mass loss. The CO emission can be highly variable, on time scales as short as a few days. In DG Tau, the bands have been observed to disappear and reappear and may also have a periodic modulation. For the BN Object, the equivalent width has varied by a factor of 3; and for V1331 Cyg, the equivalent width doubled in nine days. Changes in equivalent width also occured in SSV 13, AS 353A, and 1548C27, while WL 16 and S106 have not shown variations. Of the 9 CO absorption sources re-observed, only the FU Ori type star V1057 Cyg went through a significant change in equivalent width. It also presents an unusual and variable band profile.

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A Proposed Modification of the Rate Equations for Reactions on Grain Surfaces

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The rate equations currently utilized for grain reactions in gas-grain chemical models of interstellar clouds are inappropriate under certain conditions because of the discrete nature of grain particles. Appropriate modifications are suggested, and calculated surface abundances for various molecules are tested against Monte Carlo calculations for three simple systems. In the first system, the gas is comprised of only O and H atoms which accrete on grain surfaces and subsequently react to form only the diatomic molecules H_2, OH, and O_2. In the second system, N atoms are also present in the gas, and the grain chemistry leads to more molecules, including the polyatomic species NH_3 and H_2O. In the third and final system, the gas contains H_2, and the contribution of this species to grain chemistry is considered. The modifications to the rate equations lead to reasonable agreement with the results of Monte Carlo simulations for all three systems. These modifications can then be used in time–dependent gas–grain chemical models until or if a more detailed but useable theory becomes available.

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Sub-arcsecond structure of hot cores in the NH_3(4,4) line

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We present high angular resolution ($\sim 0\farcs4$, corresponding roughly to 0.015 pc) VLA observations in the ammonia (4,4) inversion transition of 3 hot cores associated with UC HII regions (G10.47+0.03, G29.96–0.02, G31.41+0.31), We have for the first time resolved the emission from these structures and present maps of the integrated intensity and optical depth. The main findings of this work are the existence of velocity and temperature gradients in the cores, suggesting that they are rotating disk-like structures with temperature decreasing with increasing distance R from the centre as $R^{-3/4}$. In G10.47+0.03, the blue-shifted absorption seen towards three embedded UC HII regions is used to derive their position along the line of sight. Finally, the evolutionary status and the star formation efficiency of the three cores is discussed, and we conclude that at least in the case of G10.47+0.03 the Miller & Scalo (1979) Initial Mass Function is inappropriate to describe the stellar content of the core. Also, we suggest that early type stars tend to form from filaments of dense molecular gas which fragment along their axis.

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http://www.arcetri.astro.it/science/SF/preprint/h0643.ps.gz

Physical Association Between the Southern Coalsack and the Chamaeleon-Musca dark clouds

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The results of a photometric programme aiming to investigate the hypothesis of a physical association between the Southern Coalsack and the Chamaeleon-Musca dark clouds are presented. The analysis is based upon $uvby\beta$ photometry for 1017 stars selected from the Smithsonian Astrophysical Observatory star catalog to cover these clouds and the connecting area defined by the galactic coordinates: $308^\circ \geq l \geq 294^\circ$ and $-20^\circ \leq b \leq 5^\circ$. To ensure a more complete sample the data were complemented by $uvby\beta$ photometry for 213 stars of Kapteyn's Selected Area 203, that lies at the center of the Chamaeleon-Musca dark clouds complex.

The distribution of the colour excesses $E(b-y)$ for stars with line-of-sight *inside* and *outside* the dark clouds' contours indicates the presence of a local low absorption volume that is limited at 150 ± 30 pc from the Sun by an extended interstellar dust feature, and is followed by another region with almost no additional reddening for another 350 pc. Combined with other data on the local ISM, the existence of the dust feature permeating the whole connecting area and the identical distance of the Southern Coalsack and Chamaeleon-Musca dark clouds suggest that these clouds could be dense condensations in the diffuse medium composing the interface of the Local and Loop I Bubbles.

Apparently, the minimum column density of the dust feature does not show a clear dependence with the galactic longitude, but may increase with the galactic latitude in the sense that $[E(b-y)_{\rm min}, b] = [0\overset{\rm m}{.}050; 0^\circ] \rightarrow [0\overset{\rm m}{.}100; -8^\circ] \rightarrow [0\overset{\rm m}{.}150; -15^\circ]$. The quoted increase suggests either the approaching of the tangential point of a warped sheet-like structure of same column density and curved away from the Sun, or an inhomogeneous sheet-like structure roughly perpendicular to the galactic plane.

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Postscript file available: http://www.fisica.ufmg.br/∼wag/projects.html

HST Images of the High-Excitation Herbig-Haro Object HH 32

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We present high angular resolution emission-line and continuum images of the remarkable Herbig-Haro jet HH 32 obtained with the Wide Field and Planetary Camera 2 (WFPC2) aboard the *Hubble Space Telescope*. We have obtained narrow band [S II]$\lambda\lambda$6716,6731, [N II]λ6583 and Hα images, as well as an R continuum image, of this HH jet. The $0''.1$ spatial resolution (corresponding to 30 AU at the distance of HH 32) and the high signal-to-noise ratio of these WFPC2 images allow us to study this highly collimated outflow in unprecedented detail.

The images show differences between the stratification of the different emission lines. The knots are clearly resolved into complex structures that resemble working surfaces. The western side of the jet starts in a funnel-shaped structure that points toward the bright condensations HH 32D, 32B and 32A, while on the other side of the jet the dominant structure is an arc-like feature that points almost directly away from the young star AS 353A. The HH 32A condensation exhibits a region strong in [S II] that we identify as the Mach Disk at the tip of the jet. Finally, the HST images are used in conbination with previous, high resolution ground based observations (obtained with the Canada-France-Hawaii telescope) to obtain proper motion determinations. We find that the kinematical properties deduced from these proper motions are consistent with those of a jet moving at about 300 km/s, penetrating into the maternal cloud at an angle of 70° between the outflow axis and the plane of the sky. This is also consistent with the properties deduced from previously obtained high resolution spectra of HH 32.

We find that the kinematical properties deduced from these proper motions are completely consistent with previous proper motion measurements, as well as with the properties deduced from previously obtained, high resolution spectra of HH 32.

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The physical structure of the Herbig Haro object HH 29

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We have obtained Echelle spectra covering a number of important shock diagnostic emission lines, mapping out the full extent of the Herbig-Haro object HH29. Through this, the velocity field, the level of excitation and the electron density have all been determined with a spatial resolution of $1'' - 2''$ and a spectral resolution of 10 $\mathrm{km\,s^{-1}}$ – 20 $\mathrm{km\,s^{-1}}$ respectively. Our observations of shock diagnostic lines allow us to produce an empirical 3D description (velocity is the third dimension) of F(Hα), the level of excitation and the electron density. Our results indicate that HH29 is among the Herbig-Haro objects with the highest level of excitation. We derive electron densities of between a few thousand $\mathrm{cm^{-3}}$ and 10^4 $\mathrm{cm^{-3}}$ in 'clumps' interspersed in an 'inter-clump medium' of density ~ 300 $\mathrm{cm^{-3}}$. The spatial scale of the clumps is $\lesssim 2''$, and the velocity dispersion of individual clumps is on the order of 30km $\mathrm{s^{-1}}$ – 50 km $\mathrm{s^{-1}}$, implying that the 'knotty' structure obvious in high spatial resolution images also exist in 3 dimensions. Based on the morphological and spectroscopical data, HH29 appears to consist of a number of HH-knots where the shock is located on the side of the object oriented towards the originating source in some and on the opposite side in others. We find that HH29 is best explained as an aggregate of clumps interacting with ambient material on the side *away* from the originating source, and also being shocked by a faster wind on the side *towards* the originating source.

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

12 μm fine-structure emission line and continuum images of G333.6–0.2

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We present high spatial resolution (∼0.8 arcsec) diffraction-limited 12.8 μm Ne II fine-structure emission line and 12.5 μm continuum images of the bright southern compact H II region G333.6–0.2, taken with the mid-infrared imaging polarimeter NIMPOL. The two images show remarkably similar, compact, yet asymmetric, flux distributions. The [Ne II] image shows a complex structure near the ionizing source(s) which we interpret in terms of the ionization structure of the H II region. It is found that G333.6–0.2 is more likely to be excited by a cluster of O and B stars than a single star.

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Preprints available at `http://www.adfa.oz.au/physics/res/publns.html`.

Accretion and the Evolution of T Tauri Disks

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Using results and calibrations from a previous paper (Gullbring et al. 1997), we estimate disk accretion rates for pre-main sequence stars in the Taurus and Chamaeleon I molecular cloud complexes. The median accretion rate for T Tauri stars of age ~ 1 Myr is $\sim 10^{-8} M_{\odot} yr^{-1}$; the intrinsic scatter at a given age may be as large as an order of magnitude. There is a clear decline of mass accretion rates $\dot{M}$ with increasing age t among T Tauri stars. Representing this decline as $\dot{M} \propto t^{-eta}$, we estimate $1.5 \leq eta \leq 2.8$; the large uncertainty is due to the wide range of accretion rates at a given age, the limited age range of the sample, and errors in estimating stellar ages and accretion luminosities. Adopting values of eta near the low end of this range, which are more likely given probable errors and the neglect of birthline age corrections, masses accreted during the T Tauri phase are roughly consistent with disk masses estimated from mm-wave dust emission. Similarity solutions for evolving, expanding disks are used to investigate observational constraints on disk properties employing a minimum of parameters. For an assumed power law form of the disk viscosity with radius $\nu \propto R^{\gamma}$, $eta \geq 1.5$ corresponds to $\gamma \geq 1$. The limit $\gamma \sim 1$ corresponds to a roughly constant "α" in the Shakura-Sunyaev viscosity parameterization; using current observed disk sizes, we estimate $\alpha \sim 10^{-2}$ (on scales $\sim 10 - 100$ AU). Much of the observed variation in mass accretion rates can be accounted for by varying initial disk masses between 0.01 $M_{\odot}$ and 0.2 $M_{\odot}$, but this result may be strongly affected by the presence of binary companion stars. These results emphasize the need for older samples of stars for studying disk evolution.

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

Sub-arcsecond imaging at 267 GHz of a young binary system: Detection of a < 70 AU radius dust disk around T Tau N

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The young binary system T Tau was observed with the Owens Valley Millimeter Array in 267 GHz continuum and HCO^+ J=3–2 emission at 0.8″ resolution, with the JCMT–CSO single-baseline interferometer in 357 GHz continuum, and with the W. M. Keck telescope at λ=4 μm. The 267 GHz emission is unresolved with a flux of 397 ± 35 mJy, located close to the position of the optical star T Tau N. An upper limit of 100 mJy is obtained toward the infrared companion T Tau S. The 357 GHz continuum emission is unresolved, with a flux of 1.35 ± 0.68 Jy. HCO^+ J=3–2 was detected from a 2″ diameter core surrounding T Tau N and S. Both stars are detected at 4 μm, but there is no evidence of the radio source T Tau R.

We propose a model in which T Tau S is intrinsically similar to T Tau N, but is obscured by the outer parts of T Tau N's disk. A fit to the spectral energy distribution (SED) between 21 cm and 1.22 μm is constructed on this basis. Adopting a r^{-1} surface density distribution and an exponentially truncated edge, disk masses of 0.04 ± 0.01 $M_{\odot}$ and $6 \times 10^{-5} - 3 \times 10^{-3}$ $M_{\odot}$ are inferred for T Tau N and T Tau S, respectively. A 0.005–0.03 $M_{\odot}$ circumbinary envelope is also required to fit the millimeter to mid-infrared SED.

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Preprints available at: http://www.strw.leidenuniv.nl/~michiel/publications.html

The millimeter wavelength emissivity in IC5146

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We have observed a core in the northern streamer of the IC5146 cloud using the MPIfR 19-channel Bolometer system on the IRAM 30m telescope at a wavelength of 1.2mm. We smoothed our observations to the same angular resolution (30″) as a new map of the NIR extinction of this cloud (Lada, Alves, and Lada 1998) and in this way obtained direct measurements of the ratio of millimeter emissivity to dust extinction. Our results are compatible with a ratio of the visual extinction coefficient κ_v to the 1.2mm grain absorption coefficient $\kappa_{1.2}$ of $(4 \pm 2) \times 10^4$. This is in good agreement with the theoretical predictions for bare interstellar grains (Draine & Lee 1984; Mathis 1990). Within the errors our measurements are also consistent with recent models of grains with ice mantles whose size distribution has been modified due to coagulation but whose millimeter emissivities are not a strong function of grain size (Ossenkopf & Henning 1994). We find that the ratio of millimeter grain emissivity to visual extinction varies roughly inversely with the visual extinction over our map and interpret this as implying a gradient in dust temperature from roughly 8 K in the core interior ($A_V > 20$ mag) to 20 K in regions of low (5 mag) extinction. One consequence of our result is that the 1.2 mm intensity, by itself, is not a good tracer of mass in this cloud.

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Preprint available at http://www.ph1.uni-koeln.de/∼kramer/publications.html

The structure of the shock wave in the case of accretion onto low mass young stars

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The problem of calculation of the accretion shock wave structure in the case of young stars is formulated physically and mathematically. Some results of its numerical solution are presented and dependence of the shock wave structure on the parameters of the problem is demonstrated. It was found that relative intensities and profiles of lines in T Tauri stars spectra depend generally speaking on velocity and density of infall gas as well as on geometry of the accretion. It is concluded that results of the calculations can be used to solve the problem of young stars activity nature.

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Possible Stellar Metallicity Enhancements from the Accretion of Planets

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A number of recently discovered extrasolar planet candidates have surprisingly small orbits, which may indicate that considerable orbital migration takes place in protoplanetary systems. A natural consequence of orbital migration is for a series of planets to be accreted, destroyed, and then thoroughly mixed into the convective envelope of the central star. We study the ramifications of planet accretion for the final main sequence metallicity of the star. If maximum disk lifetimes are on the order of ~ 10 Myr, stars with masses near $1.0 M_\odot$ are predicted to have virtually no metallicity enhancement. On the other hand, early F and late A type stars with masses $M_* \approx 1.5$–$2.0\ M_\odot$ can experience significant metallicity enhancements due to their considerably smaller convection zones during the first 10 Myr of pre-main-sequence evolution. We show that the metallicities of an aggregate of unevolved F stars are consistent with an average star accreting ~ 2 Jupiter-mass planets from a protoplanetary disk having a 10 Myr dispersal time.

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A Young Star Near the Hydrogen Burning Limit

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We show that V410 X-ray 3, towards the L1495E star forming complex, is an object with a mass of 0.08-0.15 $M_\odot$ and an age of ~1 Myr. Nonetheless, it has emerged from its natal cloud and can be studied in detail throughout the optical and near-infrared, providing new insights to the character of very young and low-mass objects. It has spectral characteristics intermediate between those of late dwarfs and giants (e.g., first overtone CO typical of an M6 dwarf, but K I, Na I, and TiO/VO typical of an M6 giant and CaH intermediate between the luminosity classes). Its optical and IR photometric colors are consistent with those of an M6 dwarf. If the latest theoretical evolutionary tracks are valid at young ages and low masses, it appears that the hydrogen burning limit at an age of ~1 Myr occurs at a spectral type of M6 – M7.

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http://highz.as.arizona.edu/ kluhman/

The Low-Mass IMF in Young Clusters: L1495E

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We have developed a technique of IR spectral classification in which we use K-band spectra (R ~ 1000) to derive the spectral types and continuum veilings of young, late-type stars (~ 1 Myr, >G0). We show close agreement between the spectral types derived in this manner and those obtained optically. We complement previous optical spectroscopy with IR spectra of the most heavily embedded members of the young, embedded cluster L1495E. We critically analyze the translation between observable (spectral type, photometry) and theoretical ($T_{\rm eff}$, $L_{\rm bol}$) parameters, and use these data to construct an H-R diagram. We find that the evolutionary tracks of D'Antona & Mazzitelli (1994) imply a coeval population of $\leq$ 1 Myr and a plausible IMF. However, these models may underestimate the masses of objects near the hydrogen burning limit and below. The models of Swenson (1996) produce implausibly old ages and the models of Baraffe et al. (1997) yield somewhat old ages and an implausible IMF.

We use infrared imaging to show that the spectroscopic sample for this cluster may be seriously incomplete below ~ 0.15 $M_\odot$. After applying a completeness correction to the IMF derived with the tracks of D'Antona & Mazzitelli, we find no evidence for a turnover at low masses; the IMF appears roughly flat in logarithmic mass units. Comparing to the results of photometric studies of ρ Oph and NGC 2024, the IMF appears roughly invariant among star forming environments representing a two orders of magnitude range in the density of young stars. However, the detailed behavior of the IMF from low stellar masses into the substellar regime will remain uncertain until 1) better evolutionary tracks are available and 2) the sources in the photometric completeness correction can be spectroscopically confirmed as low-mass cluster members.

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http://highz.as.arizona.edu/ kluhman/

Candidate Main-Sequence Stars with Debris Disks: A New Sample of Vega-Like Sources

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Vega-like sources are main-sequence stars that exhibit IR fluxes in excess of expectations for stellar photospheres, most likely due to re-radiation of stellar emission intercepted by orbiting dust grains. We have identified a large sample of main-sequence stars with possible excess IR radiation by cross-correlating the *Michigan Catalog of Two-Dimensional Spectral Types for the HD Stars* with the *IRAS Faint Source Survey Catalog*. Some 60 of these Vega-like sources were not found during previous surveys of the *IRAS* database, the majority of which employed the lower sensitivity *Point Source Catalog*. Here, we provide details of our search strategy, together with a preliminary examination of the full sample of Vega-like sources.

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Weak and Post T Tauri Stars around B-type members of the Sco-Cen OB association

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I report medium-resolution (FWHM=1.9 Å) spectroscopic observations of six H_α emission stars proposed by Meyer et al. (1993) to be T Tauri stars formed in the vicinity of the B1 giant σSco, a bright member of the Sco-Cen OB association. Using spectroscopic criteria (spectral types, H_α and LiI equivalent widths), which are distance-independent, I classify these stars in different PMS classes. Taking data from the literature, a number of stars detected by X-ray observations around other B-type members of Sco-Cen are also classified. The current census of "bona-fide" low-mass PMS stars identified in about 9 deg.^{2} in Sco-Cen is 2 CTTS, 18 WTTS and 10 PTTS. The presence of a mixture of T Tauri and post T Tauri stars implies that previous results based on isochrone fitting that indicated an extremely young age ($\sim$1 Myr) for the Sco-Cen PMS low-mass population are incorrect. An average distance of about 125 pc for the Sco-Cen low-mass PMS stars, instead of the 160 pc used in previous works, is consistent with the Hipparcos parallaxes for many of the B-type stars and would lead to older H-R diagram ages. Taking into account that PTTS are generally fainter and harder to identify than WTTS, I argue that the WTTS/PTTS ratio in Sco-Cen may be of order of unity. This result suggests that the low-mass stars of the OB association span an age range similar to the B-type members (5–15 Myrs), i.e. the low and high-mass star populations are essentially coeval. Sco-Cen appears to be indeed a promising place to find many PTTSs in future surveys.

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Star Formation in Magnetic Clouds

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This paper reexamines the widely accepted assumption that low-mass stars form mainly in magnetically subcritical cloud cores and high-mass stars form in magnetically supercritical ones. As well as molecular clouds, cloud cores are shown to be magnetically supercritical because (1) although the cores are generally observed as portions of a molecular cloud having considerably higher column density than the surrounding, magnetically subcritical condensations embedded in a cloud can hardly have higher column density than the surrounding, and (2) if the cores are magnetically subcritical, it is difficult to maintain the nonthermal velocity dispersions widely observed in the cores for a significant fraction of their lifetime. For a magnetically supercritical condensation, which we call a core here, there is a critical value $P_{\rm cr}$ for the pressure $P_{\rm s}$ of the surrounding medium, above which the core cannot be in magnetohydrostatic equi-

librium and collapses; P_{cr} depends sharply on the core mass, the effective sound velocity in the core which includes the effect of turbulence, and the effective coefficient a_{eff} for the gravity diluted by magnetic force. The cloud core begins dynamical contraction when P_{cr} has decreased below the pressure P_s of the surrounding medium by some mechanisms. Dissipation of turbulence is the most important process of reducing P_{cr}. Therefore, in most cases the time scale of star formation in each core is the dissipation time of turbulence, which is several times the free-fall time of the core. For the cores of magnetic flux Φ very close to the critical flux Φ_{cr}, or with small $a_{eff} \approx 1 - (\Phi/\Phi_{cr})^2$, P_{cr} would not decrease below P_s even when turbulence has completely dissipated; this would happen only in very low-mass cores because of the sharp mass-dependence of P_{cr}. Such cores begin dynamical contraction after a_{eff} has increased somewhat due to magnetic flux loss from the central parts by ambipolar diffusion; only a slight loss of magnetic flux is enough for this because of sharp dependence of P_{cr} on Φ at $\Phi \approx \Phi_{cr}$, and the time scale of star formation in this case is not much different from the dissipation time of turbulence, though the probability that the cores have $\Phi \approx \Phi_{cr}$ must be low. It is shown implausible that cloud cores form from magnetically subcritical condensations via ambipolar diffusion.

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Millimeter continuum observations of X-ray selected T Tauri stars in Ophiuchus

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We present the results of 1.3 mm dust continuum observations for a sample of 17 X-ray selected T Tauri stars in the Ophiuchus star forming region performed with the MPIfR 7-channel bolometer array mounted at the IRAM 30 m Millimeter Radio Telescope. We have detected cold dust emission from 3 of the objects and have derived 3σ upper limits (~ 21 mJy on average) for the remaining objects. These upper limits suggest that the disk masses (gas + dust) are less than $5 \cdot 10^{-3}\,M_\odot$.

Combining our results with those obtained by André & Montmerle (1994) for a sample of 21 X-ray selected T Tauri stars (3 additional detections) we improve the statistical significance of our conclusions. As the frequency of circumstellar disks and the disk properties might depend on the selection criteria as well as local conditions, comparison is made with 1.3 mm surveys of Hα selected T Tauri stars in Chamaeleon, Lupus, Ophiuchus, and Taurus-Auriga.

In order to study the mass of cold dust in multiple systems we also observed a sample of 15 well known binaries, triples, and quadruples by 1.3 mm photometry. ¿From these observations we report the 1.3 mm detection of 4 multiple systems. It seems that the measured 1.3 mm flux density increases slightly with increasing binary separation.

In addition, we have mapped the hierarchical triple SR 24 at $\lambda = 1.3$ mm with the 7-channel bolometer array. We detected cold dust emission only from the southern component with a peak intensity of ~ 230 mJy and a corresponding circumstellar disk mass of $\sim 0.035\,M_\odot$ (gas + dust), while for the northern component we derived an upper limit of 10 % of the SR 24S peak flux density. The non-detection of 1.3 mm emission from SR 24N suggests a lack of cold circumstellar dust in the outer part of the disk, which might have been cleared by the close infrared companion $0\farcs2$ away from SR 24N.

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Observational Properties of the Orion Nebula Proplyds

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Hubble Space Telescope Planetary Camera images have been used to quantitatively determine key parameters characterizing emission line proplyds in the Orion Nebula. An earlier conclusion, that the objects are radiation bounded

ionization fronts, is confirmed and found to be in excellent agreement with the observations. Only a very loose correlation of proplyd size with distance from the ionizing star θ^1C Ori was found. The brightness distribution around the bright cusp facing θ^1C Ori is found to not be in agreement with simple spherical models. The brightness distribution along radial lines passing through the center of the proplyds was subjected to careful analysis, including the finite resolution of the camera. It was found that the proplyd atmospheres are more compact than the r^{-3} relation expected for a freely expanding gas, rather, the best fit is to a surface brightness decreasing as an exponential with a scale height of 7×10^{14} cm. This observation argues that the proplyds are not rapidly losing material and hence may not be shortlived objects, a conclusion also reached by consideration of their frequency and location. This also requires there to be a constraining force which is isotropic, since the scale height does not depend upon the orientation with respect to θ^1C Ori. Arguments are presented that this constraining force is provided by radiation pressure of nebular La photons acting on the dust mixed with the proplyd gas.

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Three Dimensional Non-LTE Radiative Transfer of CS in Clumpy Dense Cores

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With a Monte-Carlo radiative transfer code we have investigated excitation conditions of CS molecule in dense cores, and synthesized line profiles for several transitions of both CS and $C^{34}S$. We took two kinds of models of the dense core, a clumpy and a smooth models. In the clumpy model, the core is composed of many small clumps, whose volume filling factor, f, is unity in the central region of $r \leq 0.2R$, and then declines as $f \propto r^{-1.5}$. However, H_2 number density in the clump is kept constant and also independent of the clump position. The mean number density, $n_{H_2}(r)$, is thus constant in the central part and then decreases as the same power law. In the smooth model, the gas fills the core completely and its *local* density follows exactly the mean density of the clumpy model. For both models, each clump has thermal as well as bulk motions, velocity dispersion of the latter being proportional to $r^{0.5}$.

In the clumpy structured core, the excitation temperature of the CS transitions is found to be generally constant over an entire region. As a consequence the synthesized profile is of a Gaussian shape superposed with some wiggles, which reflects the existence of clumps under the bulk motion. The trend of flat distribution of excitation temperature becomes more prominent for optically thin transitions of the rarer species, $C^{34}S$. Only when the core becomes extremely thick in optical sense, the profiles develop flat top features with minor wiggles. On the other hand, wider profiles having self-absorption are synthesized in the smooth core. The self-absorption is formed by a steep gradient in the radial distribution of the excitation temperature. For optically thin $C^{34}S$ transitions, both the clumpy and smooth cores exhibit profiles close to a Gaussian shape.

Comparing line parameters derived in the Monte Carlo code and those by the LVG calculations, we found that only the clumpy models can give correct estimations of the density and abundance of the cores. Moreover we have shown that clump parameters such as clump size and number of clumps in a beam are reasonably estimated by Tauber (1996)'s simple method.

Since the opaque line reflects properties of a region of $\tau \sim 1$, local unbalance of bulk velocity distribution in the core, for instance, often results in blue peak stronger than red peak in the CS line profiles. Thus it should be noted that a combination of this feature of optically thick line and the single peak of thin one may not necessarily imply a signature of infall.

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The ΔV–L dependence and virial equilibrium of the dense molecular cloud cores

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The dependence between HCO^+ and $H^{13}CO^+$ linewidths and emission region sizes ($\Delta V \approx 2.9 \cdot L^{(0.5\pm0.1)}$) has been revealed for the sample of 12 dense molecular cloud cores associated with Sharpless H II regions. It is shown that the core masses calculated using IR-data in the approximation of isothermal dust are underestimated if dust temperature decreases outward edge of a core. For power-law density profile in a core, $\rho \propto r^{-\beta}$, there should be an upper limit on β–index ($\beta_{\rm max}$) which varies from 0.5 to 1.3 for the sample cores. It is impossible to conform model spectra and observational data for $\beta > \beta_{\rm max}$. Core masses for $\beta = 0.5$ are close to virial masses implying that the cores are probably close to the critical state on the threshold of gravitational instability. The observed correlation between ΔV and L cannot be explained by velocity dispersion–radius dependence resulting from logotrope equation of state which has been recently successfully applied for explanation of similar dependencies both in massive and low-mass cores. This fact implies also that the dense cores studied in the paper should be close to the critical state for which, irrespective of equation of state, the $\Delta V \propto (P_{\rm ext})^{1/4} L^{1/2}$ relation should hold, where $P_{\rm ext}$ is an external pressure on a core. The mean value of external pressure on the sample cores should be $P_{\rm ext}/k \approx 5.9 \cdot 10^6$ K·cm^{-3}.

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Molecular Hydrogen Line Emission from the Reflection Nebula Parsamyan 18

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The newly-commissioned University of New South Wales Infrared Fabry-Perot (UNSWIRF) has been used to image molecular hydrogen emission at 2.12 and 2.25 μm in the reflection nebula Parsamyan 18. P 18 is known to exhibit low values of the $(1-0)/(2-1)$ $S(1)$ ratio suggestive of UV-pumped fluorescence rather than thermal excitation by shocks. Our line ratio mapping reveals the full extent of this fluorescent emission from extended arc-like features, as well as a more concentrated thermal component in regions closer to the central exciting star. We show that the emission morphology, line fluxes, and gas density are consistent with the predictions of photodissociation region (PDR) theory. Those regions with the highest intrinsic $1-0$ $S(1)$ intensities also tend to show the highest $(1-0)/(2-1)$ $S(1)$ line ratios. Furthermore, variations in the line ratio can be attributed to intrinsic fluctuations in the incident radiation field and/or the gas density, through the self-shielding action of H_2. An isolated knot of emission discovered just outside P 18, and having both an unusually high $(1-0)/(2-1)$ $S(1)$ ratio and relative velocity provides additional evidence for an outflow source associated with P 18.

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S187:SCP 1 (H2): A Curved Molecular Hydrogen Outflow

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We imaged in the near-infrared the region associated with IRAS 01202+6133, which lies to the southeast of the Sharpless HII region S187, designated as S187IR. We report the discovery of a curved molecular hydrogen outflow that extends over a region of 76 arcsec (0.38 pc at D = 1 kpc), identified as S187:SCP 1 (H2). The outflow changes direction by more than 90 deg in a continuous way and is the most dramatic example of direction variability in a jet source known to date. The outflow driving source is probably an extreme T Tauri star identified as NIRS 1 located at the apex of the curved structure. The curved jet-like structure shows a sinuous chain of several emission knots located along an extended H_2 nebulosity. The similarity with the properties of optical Herbig-Haro jets observed in the near-IR allows us to conclude that S187:SCP 1 (H2) is a Herbig-Haro object. We discuss whether the supersonic side wind model proposed by Cantó and Raga (1995) provides the best physical scenario for the curved outflow seen in S187IR. According to this model, the initial angle of the jet results nearly opposite to the wind direction, the wind action is turning the jet through 150 deg, while the minimum radius of curvature of the jet results in 0.14 pc. Assuming typical values for T Tauri stars in molecular environments ($\dot{M} = 10^{-7}$ $M_\odot$/yr, $v_{jet} = 150$ km/s, $v_{sound} \equiv s = 10$ km/s, $n_a = 10^4$ cm^{-3}), the required wind velocity is 10 km/s, which is of the same order of magnitude as the typical velocities of T Tauri stars relative to their surrounding molecular clouds. Furthermore, the predicted position of the stagnation point, where the hydrostatic pressure in the jet equals the ram pressure of the wind, coincides with an observed H_2 emission maximum along the curved part of the outflow. The predicted curve extends to a bow shock-like H_2 nebulosity located 2 arcmin (0.46 pc at D =1 kpc) away from the curved outflow.

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Far-Infrared and Submillimeter Polarization of OMC-1 – Evidence for Magnetically Regulated Star Formation

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This paper presents large scale polarization maps (8' × 8') of the Orion molecular cloud (OMC-1) at far-infrared (100 μm; 35" resolution) and submillimeter (350 μm; 18" resolution) wavelengths. The magnetic field shows a pinch at scales less than 1/2 pc with a centroid that is on the OMC-1 ridge, a site of high mass star formation. We infer that gravitational collapse pulled the magnetic field into an hourglass shape. We estimate that the magnetic, kinetic, and gravitational energies are in equipartition on the ridge and that the magnetic energy dominates in the surrounding ambient envelope. We consider a model in which the ridge and thus high mass stars gravitationally collapsed out of a cloud that was initially supported by the magnetic field. At flux peaks there is a reduction in the percent polarization. This effect is discussed in relation to temperature, optical depth, and wavelength.

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Molecular Outflows from X-Ray Emitting Protostars in the Rho-Ophiuchi Dark Cloud

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We report CO ($J = 2-1, J = 1-0$) outflows from 4 X-ray emitting protostars (EL29, IRS44, WL6, WL10) in the ρ-Ophiuchi cloud core which have been firmly identified with the X-ray satellite, ASCA. The common feature of these outflows is that the blue and red lobes are largely overlapped, which indicates that the inclination angle between the outflow axis and line-of-sight is smaller than 30° (nearly pole-on configuration). Taking account of the hard X-ray transparency ($N_H \sim 10^{23}$ cm^{-2}) and the column density of a circumstellar disk ($N_H > 10^{24}$ cm^{-2}), it is naturally understood that hard X-rays emitted near the surface of protostars or the inner part of the disk are observed in the nearly pole-on configuration. The outflow detection rate (4/5) in the present observations shows that a low-mass

protostar emits X-rays even in the outflow phase of early stellar evolution.

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Observations of ^{13}C isotopomers of HC_3N and HC_5N in TMC-1: evidence for isotopic fractionation

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The ^{13}C substitutions of HC_3N ($H^{13}CCCN$, $HC^{13}CCN$, and $HCC^{13}CN$) were observed in TMC-1 using the J=2-1, 4-3, and 5-4 rotational transitions at 18, 36, and 45 GHz, respectively. The spectral lines of $HCC^{13}CN$ are stronger than those of $HC^{13}CCN$ in all observed transitions, while the spectral lines of $HC^{13}CCN$ and $H^{13}CCCN$ show similar intensity. These differences in the intensities are most probably due to ^{13}C isotopic fractionation in the formation process of HC_3N. The abundance ratios are 1.0 : 1.0 : 1.4 for [$H^{13}CCCN$] : [$HC^{13}CCN$] : [$HCC^{13}CN$] at the cyanopolyyne peak in TMC-1: the ^{13}C isotope is concentrated in a carbon atom adjacent to the nitrogen atom. Based on these observational results, the production mechanism of HC_3N was discussed. As a result, the formation reactions between a hydrocarbon molecule with two carbon atoms (e.g. C_2H_2) and a molecule with a ^{13}C enriched CN group can explain ^{13}C isotopic fractionation: a neutral-neutral reaction between C_2H_2 and CN is probably most important. The ratio of the contributions of two types of the HC_3N formation reactions which can and cannot produce ^{13}C isotopic fractionation is discussed. In addition, the ^{13}C isotopic species of HC_5N ($HC^{13}CCCCN$ and $HCCCC^{13}CN$) were also observed at the cyanopolyyne peak in TMC-1 using the J=9-8 rotational transitions at 23.7 GHz. The intensity of $HCCCC^{13}CN$ is marginally stronger than that of $HC^{13}CCCCN$. Furthermore, the (J,K)=(2,2) emission of NH_3 was simultaneously observed with the ^{13}C isotopic species of HC_5N. With the additional observation of the (J,K)=(1,1) emission of NH_3, the rotational temperature between the (1,1) and (2,2) levels, and the column density of NH_3 are determined for the cyanopolyyne peak in TMC-1.

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On the Properties of Dust Shells around Herbig Ae/Be Stars

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The properties of the dust grains and the dust shells of Herbig Ae/Be stars obtained from the modelling of the circumstellar extinction and polarization curves are discussed. The role of the light scattered in the shell is analyzed. Its contribution to the stellar fluxes is larger in the visual part of spectrum in the comparison with the ultraviolet one, especially for flattened shells seen pole-on. It is found that the minimum size of circumstellar grains and the mass of dust increase with the stellar luminosity. The observed polarization is proportional to the asphericity degree of visible shape of circumstellar shell.

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A Multi-Transition CO and CS(2–1) Comparison of a Star Forming and Non-Star Forming GMC

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CO(3–2), CO(1–0), and CS(2–1) observations of clumps in the the cold, low luminosity, cloud G216-2.5 discovered by Maddalena & Thaddeus are compared to the star forming Rosette molecular cloud. The comparisons suggest that the clumps in a cloud may be characterized as being either dormant, incipient star-forming, or star-forming. In the Rosette molecular cloud, each set accounts for, respectively, 80%, 10%, and 10% of the total mass, but in G216-2.5, nearly 100% of the clumps are dormant. The physical conditions of the clumps in both clouds suggest a mass agglomeration evolutionary sequence from dormant to star-forming clumps.

Detailed results for the clumps in both clouds are as follows. Clump excitation conditions are remarkably uniform in G216-2.5 but show a wide variation in the Rosette. CO(3–2) integrated intensities, and the ratio of 3–2 to 1–0 emission, are significantly greater in the star forming cloud and greatest of all in those clumps with embedded IRAS sources. The ratio of CO 3–2 to 1–0 linewidth is also greater in the Rosette cloud. Peak clump CO(1–0) temperatures are greater in the Rosette than G216-2.5 implying higher gas kinetic temperatures, and is highest of all for those clumps associated with IRAS sources. The ratios of peak CO 3–2 to 1–0 temperature, however, are comparable in the two clouds which imply that the volume density of emitting gas in the clumps in each cloud is similar, $n_{\mathrm{H}_2} \simeq 10^3\,\mathrm{cm}^{-3}$. The CS observations indicate the presence of denser gas, $n_{\mathrm{H}_2} \sim 10^5\,\mathrm{cm}^{-3}$, in the clumps in each cloud. CS integrated intensities are generally an order of magnitude weaker than ^{13}CO emission in each cloud, but the ratio of the two is a factor of two less in G216-2.5. CS to ^{13}CO linewidth ratios are also lower in G216-2.5, suggesting that there is a deficiency of dense gas relative to the Rosette. Again, the star forming clumps in the Rosette possess the highest ratios. In addition, CO(2–1) emission was mapped over the central region of G216-2.5, and compared to a CO(1–0) map. The ratio of 2–1 to 1–0 integrated intensities increases toward the clump edges, opposite to the Sakamoto et al. study of the Orion molecular cloud. High resolution ^{13}CO(2–1) maps of one clump in each cloud are compared to ^{13}CO(1–0) maps for evidence of further fragmentation. The 2–1 radial profile is steeper than the 1–0 profile in each clump, but decreases at the same relative rate in the two clumps despite their different absolute sizes.

We conclude that the differences between clouds and clumps that are forming stars are most readily apparent in the warmer, denser gas traced by the CO(3–2) and CS(2–1) observations, and note that there are two starless clumps in the Rosette with CO properties that are more characteristic of the star forming clumps than the other starless clumps: these are the best candidates for the sites of future star formation in the cloud.

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Dynamical Collapse in W51 Massive Cores: CS(3-2) and CH_3CN Observations

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We present interferometric observations of the W51 region at 2 mm with the Nobeyama Millimeter Array. The 320 MHz band centered at 147 GHz covers transitions of the CS (3-2), CH_3CN (8-7), H35α, CH_3OCH_3 (7-6), (6-6) and $HCOOCH_3$ (12-11), as well as the 2 mm continuum. Toward two dense cores W51e2 and e8, spectroscopic signatures of cloud collapse are present in all the molecular lines observed. Line asymmetries increase systematically toward transitions of larger optical depths, consistent with expected signatures of a centrally condensed infalling cloud. Furthermore, the disparity between the blue- and the red-shifted emission of the CS line enhances when the line is synthesized at higher angular resolution. Given that the continuum source is embedded in the core, we are able to locate the emitting gas of the blue-shifted emission on the rearside, and the gas of the red-shifted emission on the foreside of the central star. The new observations confirm our infall interpretations regarding the e2 and e8 cores

based on the NH_3 data.

The compact CH_3CN emission allows us to identify velocity gradient in the e2 and e8 cores. The gradient in the e2 core is consistent with the spin-up motions proposed by Zhang & Ho (1997).

CH_3CN emission reveals hot components in the W51e2, e8 and W51-North:Dust cores. The rotational temperature in each core is > 100 K.

In W51-North, we detected a dust peak coincident with the peak of the dense molecular core. There is no 3.6 cm continuum detected at a level of < 1 mJy. Although H_2O and OH masers in the neighborhood indicate outflow activities, high velocity gas is not apparent in the CS (3-2). This source may represent an extremely early evolutionary stage: the phase of massive protostars.

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Visit *http://cfa-www.harvard.edu/~qzhang* for preprint.

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The Effects of Massive Star Formation on the Interstellar Medium: Photodissociated and Molecular Gas in NGC 6334

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The far-ultraviolet (FUV) radiation of massive stars dominates the heating of the interstellar medium (ISM). The gas within the photodissociation regions (PDR), which this FUV radiation creates, dominates the cooling of the gaseous ISM. The goal of this thesis is to determine how the properties of the PDR and molecular gas are affected by the FUV fields of newly formed massive stars. NGC 6334, a nearby molecular cloud with several sites of massive star formation, was observed with airborne and ground-based telescopes in ionized carbon and neutral oxygen ([C II] 158 μm, [O I] 145 μm, and [O I] 63 μm) and in several molecular (CO, CS, and NH_3) transitions. These observations were compared to theoretical PDR models to test the models' validity.

The extended [C II] 158 μm emission in NGC 6334 indicates that the gas distribution is clumpy. The [O I] 63 μm line was observed for the first time in absorption against a continuum source. It was also fainter than predicted toward three other sources in the cloud. The [O I] 63 μm transition is probably self-absorbed by cooler foreground material, an effect not accounted for in the current PDR models. Until the models include the radiative transfer through the molecular cloud, the use of the [O I] 63 μm line as a PDR diagnostic is problematic at best.

The molecular emission in NGC 6334 shows a complex structure of filaments and bubbles, some of which are filled with PDR gas. The dense gas is anticorrelated with the 6 cm radio flux. The hottest stars have destroyed the remnants of the dense molecular gas from which they formed, while the other, cooler stars may not have hard enough radiation to dissociate the molecules, or have not had time to disperse the dense molecular gas. The CO data suggest temperatures ($T \sim 50$ K) and column densities ($N_{\mathrm{H_2}} \sim 10^{22}$ cm^{-2}) typical of those found in the warm molecular cores of other sites of massive star formation.

Finally, the properties of the individual sources are examined and a description of how each source fits into the broad scheme of massive star formation is presented.

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