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Abstracts of recently accepted papers

HCN in Bok Globules: a Good Tracer of Collapsing Cores

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We have conducted a HCN (J=1-0) survey of dense cores in a sample of 24 star-forming and quiescent Bok globules. HCN emission was detected towards 11 of 13 globules containing embedded point sources with no HCN detection among 11 starless globules. As in other dark clouds, the J=1-0 hyperfine line intensity ratios vary from globule to globule and also with position toward the same globule, suggesting the presence of either a scattering envelope surrounding the core or a complex density structure.

We find that the J=1-0 transition of the HCN molecule can be used effectively to search for early stages of star formation in small molecular clouds: in the sample of star-forming cores, for 3 (of 5) sources mapped, there is good spatial coincidence (better than 6 arc sec) between the position of the peak integrated HCN emission and the location of the associated embedded source. Furthermore, this transition is well correlated with the YSO class, detecting preferentially Class I YSOs. Our results indicate that detecting strong (> 1 K km s^{-1}) HCN emission from a molecular cloud core seems to imply the presence of an embedded protostar and thus, indirectly, that of a collapsing core.

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Mass segregation in young stellar clusters

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We investigate the evolutionary effect of dynamical mass segregation in young stellar clusters. Dynamical mass segregation acts on a timescale of order the relaxation time of a cluster. Although some degree of mass segregation occurs earlier, the position of massive stars in rich young clusters generally reflect the cluster's initial conditions. In particular, the positions of the massive stars in the Trapezium Cluster in Orion cannot be due to dynamical mass segregation but indicate that they formed in, or near, the cluster's centre. Implications of this for cluster formation and for the formation of high-mass stars are discussed.

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Injection of Short-Lived Isotopes into the Presolar Cloud

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The evidence for short-lived isotopes such as ^{26}Al and ^{41}Ca in meteorites requires their production either by irradiation in the solar nebula, or by nucleosynthesis in a supernova or other evolved star. In the latter case, nucleosynthesis

must be followed promptly by injection of the isotopes into the presolar cloud, a feat presumably accomplished by the same stellar outflow that transported the isotopes to the presolar cloud and possibly triggered its collapse. If their nucleosynthesis occurs deep within an unmixed star, the short-lived isotopes may lag far behind the leading edge of the stellar outflow, perhaps preventing their injection. However, we show that lagging isotopes can be injected into a collapsing protostar with an efficiency similar to that of material in the leading edge of the outflow, because fast-moving isotopes initially far behind ($\sim$ parsecs) the leading edge impact and enter the cloud while the injection process is still underway. Isotope injection proceeds through Rayleigh-Taylor-like clumps in the shock-compressed target cloud.

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The Pre-Main-Sequence Eclipsing Binary TY Coronae Australis: Precise Stellar Dimensions and Tests of Evolutionary Models

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We analyse new photometric data for the Herbig Be eclipsing binary TY CrA which securely reveal the secondary eclipse, ~ 0.03 mag deep in y. From the light-curve solution and previous spectroscopic data, absolute dimensions of the primary and secondary stars are derived. The masses are found to be $M_1 = 3.16 \pm 0.02\ M_\odot$ and $M_2 = 1.64 \pm 0.01\ M_\odot$, the radii are $R_1 = 1.80 \pm 0.10\ R_\odot$ and $R_2 = 2.08 \pm 0.14\ R_\odot$, the luminosities are $L_1 = 67 \pm 12\ L_\odot$ and $L_2 = 2.4 \pm 0.8\ L_\odot$, and the effective temperatures are $T_1 = 12000 \pm 500$ K and $T_2 = 4900 \pm 400$ K. Here the uncertainties represent high-confidence limits, not standard deviations. The secondary star is a pre-main-sequence star located at the base of the Hayashi tracks. As such it is the youngest star with a dynamically measured mass. Given higher effective temperatures for the primary (e.g., 12500 K), solar-composition 1.64 $M_\odot$ evolutionary tracks of Swenson *et al.*, Claret, and D'Antona and Mazzitelli are all consistent with the properties of the TY CrA secondary and suggest an age of order 3 million years. The radius and projected rotation velocity of the secondary star is consistent with synchronous rotation. The primary star is located near the ZAMS, which for solar compositions is consistent with an age of 3 million years. However the primary star is not well-represented by any of the 3.16 $M_\odot$ evolutionary models, which predict somewhat higher effective temperatures than observed.

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The far infrared line spectrum of the protostar IRAS16293-2422

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We report mid-IR wavelength observations toward the low mass star forming region IRAS16293-2422 between 45μm - 197μm with the Long Wavelength Spectrometer (LWS) on board ISO, and of the CI(609μm) line observed with the JCMT. A map of the CII(157μm) line shows that the region is relatively uncontaminated by Photo-Dissociation Region-like emission; there is only weak diffuse CII emission, which results from the illumination of the cloud by a faint

UV field ($G_o \sim 6$). The observed CI(609μm) line intensity and narrow profile is consistent with this interpretation.

On-source, the LWS detected the OI(63μm) and several molecular lines. In this work we report and discuss in detail the lines which dominate the 43μm - 197μm spectrum, namely CO, H_2O and OH rotational lines and the OI(63μm) fine-structure line. Combining the CO J_{up}=14 to 25 observations with previous J_{up}=6 measurements, we derive stringent limits on the density ($\sim 3 \cdot 10^4$cm^{-3}), temperature ($\sim$1500 K), and column density ($\sim 1.5 \cdot 10^{20}$cm^{-2}) of the emitting gas. We show that this warm gas is associated with the outflow and that a low velocity, C-type shock can account for the characteristics of the CO spectrum.

If the observed H_2O and OH lines originate in the same region where the CO lines originate, the H_2O and OH abundance derived from the observed lines is [H_2O] / [H_2] $\sim 2 \cdot 10^{-5}$ and [OH] / [H_2] $\sim 5 \cdot 10^{-6}$ respectively. Given the relatively high temperature of the emitting gas, standard chemistry would predict all the gas-phase oxygen to be in water. The relatively low water abundance we observed may mean either that most of the oxygen is locked into grains or that the time scale required to convert the gas-phase oxygen into water is higher that the outflow time scale, or both. The relatively high abundance of OH with respect to H_2O gives support to the latter hypothesis.

Finally, we speculate that the OI(63μm) line emission originates in the collapsing envelope that surrounds the central object. The successful comparison of the observed flux with model predictions of collapsing envelopes gives a mass accretion rate toward the central object $\geq 3 \cdot 10^{-5} M_\odot$ yr^{-1} and an accretion shock radius larger than three times the protostar radius.

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www-laog.obs.ujf-grenoble.fr/ ceccarel/papers/lws-iras16293.ps

Adaptive Optics Imaging of the Circumbinary Disk Around the T Tauri Binary UY Aur: Estimates of the Binary Mass and Circumbinary Dust Grain Size Distribution

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We have obtained high resolution (FWHM=0.15″) deep images of the UY Aur binary at J, H, and K' with the University of Hawaii adaptive optics instrument. We clearly detect a R$\sim$500 AU circumbinary disk discovered with millimeter interferometry, making UY Aur the second young binary with a confirmed circumbinary disk. It appears that the disk is inclined $\sim 42^o$ from face on. We find that the near side of the disk is brighter than the far side by factors of 2.6, 2.7, and 6.5 times at K', H, & J respectively. The original GG Tau circumbinary disk has been reexamined and is found to have similar flux ratios of 1.5, 2.6, & 3.6 at K', H, & J respectively. A realistic power law distribution (p=4.7) of spherical dust aggregates, (composed of silicates, amorphous carbon, and graphite) that reproduces the observed ISM extinction curve, also predicts these observed flux ratios from Mie scattering theory. We find the observed preference of forward-scattering over bac! k-scattering is well fit (global χ^2 minimization) by Mie scattering off particles in the range $a_{min} = 0.03$ μm to $a_{max} = 0.5 - 0.6$ μm. The existence of a significant population of grain radii larger than 0.6 μm is not supported by the scattering observations.

Based on the observed disk inclination we derive an orbit for UY Aur where the mass for the binary is $1.61^{+0.47}_{-0.67}$ $M_\odot$. Based on the observed K7 and M0 spectral types for UY Aur A and B, accretion disk models for the inner disks around the central stars were constructed. The models suggest that small (lower limit R$\sim$5-10 AU) inner disks exist around B & A. It appears that B is accreting $\sim$5 times faster than A, and that both inner disks may be exhausted in $\sim 10^{2-3}$ yr without replenishment from the outer circumbinary disk. Our images suggest that these inner disks may indeed be resupplied with material through thin streamers of material that penetrate inside the circumbinary disk. Currently it appears that such a streamer may be close to UY Aur B. Comparison of our IR images and the millimeter images of the gas clearly show that the dust seen in our IR images traces the gas in the circumbinary disk, as was also the case with GG Tau.

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to download: http://www.ifa.hawaii.edu/$\sim$close/uyaur.html

Observations of shocked H_2 and entrained CO in outflows from luminous young stars

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Narrow-band, H_2 1-0 S(1) images of six luminous outflow regions are presented and discussed. In five of these regions, W 75N, S 140N, NGC 7538, AFGL 5180 and AFGL 490, H_2 shock features associated with molecular (CO) outflows are observed. We have discovered faint though extensive bow shocks in the W 75N outflow which indicate a total flow length of at least 3 pc. The Herbig-Haro knots that comprise the HH 251-254 outflow in S 140N are also observed in H_2; in addition, knots in the counterflow are discovered. Copious H_2 emission is also observed throughout the NGC 7538 region; filamentary structures to the northeast of the central cluster (IRS 1) are probably photodissociation fronts, although a jet-like structure is observed associated with the IRS 9 CO outflow. In AFGL 5180, a new, collimated H_2 jet is discovered to the east of the central cluster, and numerous knots and filaments are observed around the cluster itself which could be associated with the known CO outflow here. Lastly, H_2 line-emission is observed to the southwest of AFGL 490; in particular, a bright peak is found associated with a warm molecular clump in the CO outflow.

To complement these data, wide-field CO J=2-1 maps have also been obtained towards three regions; W 75N, S 140N and NGC 7538. When compared with the H_2 images, these provide new insight into each outflow region. Indeed, analysis of these data suggest that, although these flows are more massive and more energetic than their low-mass counterparts, they are nevertheless well-collimated, bipolar and possibly jet-driven. Molecular bow shocks, driven by an underlying, possibly variable stellar jet, may play a major role in this entrainment process.

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Preprints available from: http://www.jach.hawaii.edu/~cdavis/papers.html

Numerical simulations of the Kelvin-Helmholtz instability in radiatively cooled jets

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We present the results of simulations of the development of the Kelvin-Helmholtz (KH) instability in a cooled, slab symmetric system. The parameters were chosen to approximate the physical conditions typically found in jets from young stellar objects (YSOs). The effect of different methods of maintaining the initial equilibrium were examined for varying density. In addition, the effect of adjusting the width of the shear layer between the jet and ambient material was studied and found not to have significant long-term effects on the development of the instability.

We find that, in general, cooling acts to

- increase the level of mixing between jet and ambient material through the 'breaking' of KH induced waves on the surface of the jet
- increase the amount of momentum transferred from jet material to ambient material
- increase the time taken for shocks to develop in the flow
- reduce the strength of these shocks
- reduce the rate of decollimation of momentum flux

The first and second of these results appear to contradict the conclusions of Rossi et al. (1997) who carried out a similar study to ours but in cylindrical symmetry. It is found, however, that the differences between slab and cylindrical symmetry, while insignificant in the linear regime, explain the apparent discrepancy between our results and those of Rossi et al. (1997) in the non-linear regime.

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Disks in the UY Aur Binary

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We report interferometric images of the UY Aur binary in ^{13}CO J $= 1 \rightarrow 0$ and J $= 2 \rightarrow 1$ which reveal evidence for a large ($\geq 20''$) circumbinary disk around the two pre-main-sequence stars. This is the second detection of a circumbinary disk around T Tauri stars. A Keplerian rotation curve around a central mass of $\sim$1.2 $M_\odot$ provides a remarkably good fit to the velocity data. However, ^{13}CO emission at a systemic velocity close to the binary limits the accuracy of our disk model and a precise assessment of the disk mass. This emission could be related to the "streamers" imaged with adaptive optics around UY Aur. The continuum emission detected at the location of the binary can be attributed to partially resolved circumstellar disks around each star, with some contribution of free-free emission.

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Preprint available at the Grenoble Observatory Star Formation page:

http://www-laog.obs.ujf-grenoble.fr/liens/starform/formation.html

Imaging and Kinematical Studies of Young Stellar Object Jets in Taurus

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We report on an imaging and kinematical study of the jets and outflows emanating from DG Tau, DG Tau B, FS Tau B, T Tau, and CoKu-Tau 1. The kinematical data are based on proper-motion measurements and long-slit spectroscopy, and the imaging data on deep narrow-band [SII] $\lambda\lambda$6716,6731, Hα, and continuum images. The individual objects and their peculiarities are discussed in detail. The six investigated jets and flows differ from each other in their morphology, spatial extent and their degree of variations in velocity and in the ratio ζ between the knot pattern speed and the flow speed. Possible reasons for these large differences are briefly discussed. In DG Tau, FS Tau B, and T Tau strong velocity variations are indicated, while for DG Tau B very small velocity variations, if any, are observed ($\leq$ 7% in some flow sections). The small velocity variations in DG Tau B, together with large variations in the ζ-values in this and other YSO jets, pose severe difficulties for any model which explains the observed knots by internal shocks resulting from velocity variations. Our results on DG Tau B and other YSO jets strongly indicate that for a significant fraction of knots in YSO jets probably other mechanisms excite the internal shocks.

The bipolar outflow from FS Tau B apparently shows indications for a highly collimated *and* a poorly collimated flow in both outflow lobes. To our knowledge L1551-IRS 5 is the only other case where such an unusual situation is also indicated. About 60" north-east of FS Tau B we have found an independent faint 150" long jet-like outflow which is oriented approximately perpendicular to the FS Tau B jet and which we have designated FS Tau C (HH276).

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Spectroscopy of low mass pre-main sequence stars: photospheric spots and chromospheric activity

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We present high resolution spectra in the 6532-6745 Å wavelength range of 9 rapidly rotating ($v\sin i>$ 25 km/s) T Tauri stars. Among these stars, V410 Tau and HD 283572 have been monitored in more detail, covering 2.2 and 3.2 rotational periods, respectively. The data allow us to study the changes of the profiles of the H_α and several absorption lines. These changes are supposed to be related to the chromospheric emission and to the cold spots, respectively.

From the absorption line profiles of some lines of V410 Tau, the presence of several spots can be inferred. We have found that the equivalent width of some absorption lines varies according to the rotational period. There is a range for the amplitude of these variations, the maximum value corresponding to the Li I 6708 line (0.53–0.65 Å). Maximum equivalent widths are observed near the minimum of the light curve. The fact that these variations have not been previously detected may be partially due to the large amplitude of the continuum variability at the time of our observations. The H_α emission profile in V410 Tau also varies according to the rotational period. The data indicate a coincidence in longitude between the largest spot and the region in which the narrow emission component of the H_α line arises.

For HD 283572, some metallic absorption lines indicate the presence of a polar spot but the equivalent widths of all the observed lines present constant values, except for H_α. Variable emission contributes to the H_α absorption line and, due to the position of its maximum on the light curve, the region responsible for this emission could be related to the polar spot.

For the other stars of our sample the spectra present new information about their variability. HP Tau/G2 and, probably, VSB 78, show asymmetries in the Li I 6708 line, as expected from cold spots.

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Preprints are available by anonymous ftp from ftp.mpia-hd.mpg.de (“cd pub/matilde” and then “get litio.tar.gz”).

Probing the structure of molecular cloud cores: observations and modelling of C I and $C^{18}O$ in HH24–26

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We describe observations of the $C^{18}O$ J=2→ 1, 3→ 2 and C I $^3P_1 \rightarrow ^3 P_0$ lines towards the HH24–26 molecular cloud core. The $C^{18}O$ traces the north-south molecular ridge, but the dense clumps identified by previous high-resolution HCO^+ and dust continuum data do not stand out. Using H_2 column densities estimated from dust continuum measurements, we find that the CO abundance may be reduced by factors of at least 10 towards three positions (two of which are Class 0 protostars). Depending on the assumptions employed, the reduction may be as high as ∼50 towards the clump positions. The magnitude of the reduced abundances is in good agreement with chemical models of collapsing clouds in which molecules accrete onto dust grains. Alternative interpretations, retaining normal abundances, and relying on subtle optical depth and beam filling effects, are considered, but shown to be less likely.

The contrast in C I line intensity is low across the source. The greater part of the emission probably arises from the outer surface of the cloud but it is impossible to determine the exact contribution from C atoms deeper into the core as their emission cannot be separated from that arising at the surface.

Non-LTE radiative transfer modelling of the $C^{18}O$ emission towards the two class 0 sources HH24MMS and HH25MMS confirms a widespread reduction of the CO abundance by a factor of greater than 10 within a radius of 0.3 pc and not just close to the clumps. In HH24MMS, the abundance is required to rise again towards the centre of the model clouds in accordance with the rise in temperature near to the central embedded object where CO is desorbed from grains. Application of the same radiative transfer model to the C I emission provides little constraint on the carbon abundance profile although fits can be obtained for reasonable forms. The depletion of CO in the core, coupled with the lack of an infrared cluster, suggests that HH24–26 may be in the process of forming its first generation of stars.

Copies of preprints may be obtained from http://www-star.ukc.ac.uk/∼agg/research/pubs.html

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Monte Carlo simulations at very high optical depth: non-LTE transfer in H_2O in the protostellar object B 335

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We present a formulation of the Monte Carlo method which should be capable of treating radiative transfer problems even at very high optical depths ($\tau \gg 10^4$) and apply this tool to predict rotational H_2O line spectra for the protostellar object B 335 for future observational tests with space borne facilities. The physical model of the source is based on published observations in lines of CS, for which we obtain model results which are in agreement with previous computations. We apply our model also to line profiles of CO isotopomers observed at high spatial resolution and derive the total CO cooling rate for B 335. From the comparison with the derived H_2O cooling rates, we are led to conclude, quite generally, that H_2O is probably not the major coolant of low-mass protostellar collapse.

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http://www.astro.su.se/~rene/rl_private/pp.html

G34.24+0.13MM: A Deeply-Embedded Proto-B-Star

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By means of millimeter and submillimeter imaging, we have identified a massive protostellar object which coincides with a methanol maser and is not detectable in the continuum at centimeter wavelengths. Located 84″ (1.5 pc) southeast of the ultracompact HII (UCHII) region G34.26+0.15, the new object G34.24+0.13MM was discovered in a wide-field 350μm continuum image obtained with the Submillimeter High Angular Resolution Camera (SHARC) at the Caltech Submillimeter Observatory (CSO). Interferometric imaging at 225.7 and 110.7 GHz continuum have determined more precisely the position and angular diameter (2.″0, or 7600 A.U.) of the object. No source was detected at that position in 1.2 through 3.7μm imaging or 10 and 20μm photometry. Our observations are consistent with a cool dust core with temperature ~ 50 K, total gas mass $100 M_\odot$, and total luminosity in the range of $1600 - 6300 L_\odot$. Considering the high luminosity and lack of compact radio continuum emission, we conclude that this core probably contains a deeply embedded proto-B-star.

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postscript preprint available at http://cfa-www.harvard.edu/ thunter

Detection of the $^3P_2 \rightarrow {}^3P_1$ Submillimeter Transition of ^{13}C I in the Interstellar Medium: Implication for Chemical Fractionation

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We report the first detection of the submm emission from the ^{13}C isotope of atomic carbon in the ISM. The $F = 5/2 - 3/2$ component of the $^3P_2 - {}^3P_1$ transition was observed with the CSO in a region $\sim 4'$ S of Orion IRc2, near the western end of the Orion Bar. The ^{12}C to ^{13}C isotopic abundance ratio is 58 ± 12 corrected for opacity of the ^{12}C I line and the fractional intensity of the ^{13}C I hyperfine component (60%). This is in agreement with the value for the equivalent ratio in C^+. In comparison, our measurement of the $C^{18}O$ to $^{13}C^{18}O$ ratio from observations of 2–1 and 3–2 lines toward the same position gives a value of 75 ± 9. PDR models predict that the ^{12}C to ^{13}C abundance ratio is particularly sensitive to chemical fractionation effects. If $^{13}C^+$ is preferentially incorporated into ^{13}CO at cloud edges there will be a dramatic reduction in the abundance of ^{13}C. This is contrary to our observations, implying that the

importance of chemical fractionation is small or is compensated for by isotopic-selective photo-dissociation of ^{13}CO in this region with a large UV illumination.

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The Near-Infrared Extinction Law and Limits on the Pre-Main Sequence Population of the ρ Ophiuchi Dark Cloud

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We describe new techniques to measure the near-infrared (near-IR) extinction law and to place limits on the pre-main sequence stellar population of a dark cloud. We analyze JHK imaging data for the central 1 deg^2 of the ρ Ophiuchi cloud core (Barsony et al. 1997) and show that nearly all stars projected onto regions of low CS intensity, $I_{CS} \leq 10$ K km s^{-1}, are background stars. Most sources at larger CS intensities lie within cloud material. We use the background stars to derive the slope of the near-IR extinction law, $E_{J-H}/E_{H-K} = 1.57 \pm 0.03$. This result is consistent with previous extinction laws but has a factor of 2–3 smaller uncertainty. The new ρ Oph extinction law yields strong constraints on the number of previously undiscovered pre-main sequence stars in the cloud, 46 $\pm$ 11, and the number of previously undiscovered young stars with near-IR excesses, 15 $\pm$ 4. Neither limit exceeds the number of known pre-main sequence stars in the cloud, ~ 100. Thus, current samples of pre-main sequence stars are reasonably complete for K $\leq$ 14.

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Multiplicity of T Tauri Stars in Taurus after ROSAT

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We surveyed a sample of 75 T Tauri stars in the Taurus star forming region for companions. These stars were discovered with the help of ROSAT. The separation range covered is 0.13″ to 13″, where the lower limit is given by the diffraction limit of the telescope and the upper limit by confusion with background stars. Combined with the results of the preceding survey by Leinert et al. (1993), we now have surveyed a sample of 178 young stars in Taurus, 63 classical, 106 weak-line, and 9 unclassified T Tauri stars. Within this sample, we find 68 binaries, 9 triples, and 3 quadruples. After corrections to account for confusion with background stars and for a bias induced through X-ray selection, we count 74 binaries or multiples with a total of 85 companions in 174 systems. This corresponds to a degree of multiplicity (number of binaries or multiples divided by number of systems) of $(42.5 \pm 4.9)\,\%$, or to a duplicity, measured by the number of companions per system, of $(48.9 \pm 5.3)\,\%$, which is higher by a factor of (1.93 ± 0.26) compared to solar-type main-sequence stars. We find no difference in duplicity between classical and weak-line T Tauri stars. There is a difference between close and wide pairs in the sense that close pairs have a flat distribution of flux ratios, while the flux ratios of wide pairs are peaked towards small values.

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Preprints available at `http://www.mpia-hd.mpg.de/stars/preprint.html#koehler`

Formation and Collapse of Magnetized Spherical Molecular Cloud Cores

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We idealize the molecular clouds (from which dense cores are formed) as magnetized spheres, following a recent study by Safier, McKee & Stahler (1997). This idealization is motivated in part by analytical convenience and in part by the observation that isolated low-mass star-forming molecular cloud cores have typical elongations of a factor of about two. The evolution of such clouds due to ambipolar diffusion is followed numerically. The simplified geometry allows us to study not only the gradual enhancement of the central cloud density leading to core formation, but also the dynamic collapse that builds up a central protostellar object. It is during this latter accretion process that hydromagnetic shocks are predicted to occur by Li & McKee (1996). The spherical model enables us to explore their properties further.

During the core formation phase, we find that the evolution of our model cloud (in a new parameter region of comparable thermal and magnetic support against self-gravity) is qualitatively similar to those found previously: a relatively long quasi-static adjustment period is followed by a short period of "runaway" contraction, and a more or less power-law distribution of cloud density is established in a finite amount of time since the initiation of ambipolar diffusion. Interesting features appear in the core collapse phase. The most prominent among them are: a) the mass accretion rate onto the central object has a large initial peak, followed by a steady decline towards a more conventional value; b) for a many solar-mass cloud, accretion continues onto the central object well beyond a solar-mass. In order to form a low-mass star, some additional process(es), such as a powerful wind, must intervene to terminate the accretion before too much mass is assembled; c) the appearance of a magnetically-driven accretion shock in the infalling envelope, as predicted previously. The shock modifies significantly the distribution of magnetic flux, the flow dynamics and, to a lesser extent, the mass accretion rate onto the central object. Observational ramifications of these findings are discussed.

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Self-Similar Collapse of Magnetized Molecular Cloud Cores with Ambipolar Diffusion and the "Magnetic Flux Problem" in Star Formation

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We investigate the dynamic collapse of magnetized, singular isothermal spheres in the presence of ambipolar diffusion, using self-similarity technique. The spherical geometry, a crucial idealization first introduced by Safier, McKee & Stahler (1997) to study the evolution of magnetized clouds, is made possible by ignoring magnetic tension forces. We find that, in the limit of a complete coupling between magnetic fields and neutral matter, magnetized spheres collapse via an expansion wave solution, as in the (non-magnetized) singular isothermal case (Shu 1977). The presence of ambipolar diffusion modifies the collapse in two interesting ways. First, it smoothes out the kinky wavehead into an expansion wave of continuous (or "C"-) type. Second, ambipolar diffusion allows magnetic fields to decouple from rapidly-collapsing neutral matter at small radii near the central point mass, thereby reducing the amount of magnetic flux dragged into the origin. We obtain viable collapse solutions with various amounts of magnetic flux at the center, including special ones that have no central flux at all. In such special cases, the long-standing "magnetic flux problem" in star formation is completely resolved. Furthermore, we show that the decoupled magnetic flux drives a hydromagnetic accretion shock against the dynamically collapsing envelope, as suggested previously by Li & McKee (1996). Depending on the degree of coupling between magnetic fields and neutral matter and the amount of magnetic flux released from the central compact object, the accretion shock (which modifies the flow dynamics significantly) could either be of purely C-type or have an embedded J-subshock.

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A Radiation Hydrodynamical Model for Protostellar Collapse I. The First Collapse

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Dynamical collapse of a molecular cloud core and the formation of a star are investigated by performing radiation hydrodynamical calculations in spherical symmetry. The angle-dependent and frequency-dependent radiative transfer equation is solved without any diffusion approximations, and the evolution of the spectral energy distribution (SED) is examined.

In the present paper, as the first step in a series of our work, evolutions before hydrogen molecules begin to dissociate (so-called "the first collapse") are examined for different masses and initial temperatures of the parent cloud cores and for different opacities. Numerical results for a typical case ($T_{\rm in}$ = 10K and $\kappa_P(10K) \sim 0.01{\rm cm}^2 \cdot {\rm g}^{-1}$) show that the radius and mass of the first core are $\sim$ 5AU and $\sim 0.05 M_\odot$, respectively. These values are *independent* both of the mass of the parent cloud core and of the initial density profile. The analytical expressions for the radius, mass, and accretion luminosity of the first core are also obtained. The SED contains only cold components of a few×10K throughout the first collapse phase because the opaque envelope veils the first core from observers. We suggest that the molecular cloud cores with luminosities higher than $\sim 0.1 L_\odot$ should contain young protostars deep in the center even if they show no evidence for the existence of central stars in near-infrared and optical observations.

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Water Masers in the Circumstellar Environments of Young Stellar Objects

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We present a high resolution radio and millimeter wavelength study of five, low-mass, young stellar objects with known water maser emission: RNO15FIR, Orion A-W, L1157, B361, and L1251A. These objects are cold IRAS sources with far-infrared luminosities ranging from <6 to 40 $L_\odot$. Radio continuum observations are used to locate precisely the young stellar object(s) responsible for the far-infrared emission and to investigate their relationship to the water masers and tracers of their stellar winds. Compact radio continuum emission was detected within the IRAS error ellipse for Orion A-W, L1157, and L1251A; the spectral indices of their radio emission are consistent with thermal ionized winds. High resolution VLA H_2O observations located pairs of masers associated these radio sources within projected distances of 50 AU, 235 AU, and 150 AU, respectively, clearly placing these masers in the circumstellar environments of the young stellar objects. In Orion A-W, the strongest maser feature was used to self-calibrate the line and continuum data, resulting in the detection of a λ=1.3 cm continuum source offset 50±17 AU from the strongest maser. Due in part to the small separations of the masers and continuum sources, none of the masers could be identified with gravitationally unbound motions expected for a stellar wind origin.

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Preprint available on the WWW at http://newton.umsl.edu/˜ brucew

Proper Motions and Variability of the H_2 Emission in the HH 46/47 System

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We report here on the first proper motion measurements of molecular hydrogen emission features in the Herbig-Haro 46/47 outflow. Assuming a distance of 350 pc to this flow, the inferred tangential velocities range from a few tens to almost 500 km s^{-1}. The highest velocities are observed for H_2 knots either in, or close to, the jet/counterjet axes.

Knots constituting the wings of the large scale H_2 bow (see, for example, Eislöffel et al., 1994, Ap.J., 422, L91) are found to move much more slowly. These results appear to be in agreement with recent numerical simulations of H_2 emission from pulsed jets. We also report the first detection of variability in H_2 features for a young stellar object (YSO) outflow. It was found that several H_2 knots significantly changed their luminosity over the 4 year timebase used to conduct our study. This is in line with current estimates for the cooling time of gas radiating shocked H_2 emission in YSO environments.

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Are clouds collapsing at the 2' N position of Sgr B2 ?

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The 3 mm lines of HCO_2^+ and HNCO have been observed toward Sgr B2. Besides the well-known "Principal Cloud" and an extended envelope, we find another gas cloud 2' north of Sgr B2(M). This 2' N Cloud (hereafter 2' N), which may be located behind the Principal Cloud, has a total mass of $\sim 10^5$ $M_\odot$ and a diameter of ~ 7 pc. HCO_2^+ and HNCO exist mainly at 2' N and their column densities are about 2.2×10^{14} cm^{-2} and 2.3×10^{15} cm^{-2}, respectively. The fractional abundances of these species relative to molecular hydrogen appear to be enhanced by at least a factor of 10 compared to the Principal Cloud. We have also identified red- and blue-shifted high velocity components which move toward the 2' N position with projected velocities of $\pm$ 30 km s^{-1}. These components are located symmetrically around 2' N, along the Galactic plane, and have diameters of about 4–5 pc and masses of $\sim 1 \times 10^4$ $M_\odot$. The flow energies are large enough to initiate new star formation in the 2' N region on the free-fall time scale of 10^5 years. This large scale collapsing motion may cause a strong shock in the 2' N Cloud, and result in the enhancement of HCO_2^+ and HNCO.

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The initial conditions of star formation in the ρ Ophiuchi main cloud: wide-field millimeter continuum mapping

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We present the results of an extensive 1.3 mm continuum mosaicing study of the ρ Ophiuchi central region obtained at the IRAM 30-m telescope with the MPIfR 19–channel bolometer array. The mosaiced field covers a total area of ~ 480 arcmin^2, corresponding to ~ 1 pc^2 at a distance of 160 pc, and includes the DCO^+ dense cores Oph-A, Oph-B1, Oph-B2, Oph-C, Oph-D, Oph-E, and Oph-F. Our mosaic is sensitive to features down to $N_{H2} \sim 10^{22}$ cm^{-2} in column density. It is consistent with, but goes significantly deeper than, previous dust continuum studies of the cloud. For the first time, compact circumstellar dusty structures around young stellar objects are detected simultaneously with more extended emission from the dense cores and the ambient cloud. Thus, it becomes possible to directly study the genetic link between dense cores and young stars.
The diffuse cloud emission is itself fragmented in at least 58 small-scale, starless clumps harboring no infrared or radio continuum sources in their centers. Most of these starless fragments are probably gravitationally bound and pre-stellar in nature. Several of them exhibit a relatively flat inner intensity profile, indicating they are not as centrally condensed as the envelopes seen around the embedded (Class I and Class 0) protostars of the cloud. Ten other clumps appear to be sharply peaked, however, and may represent candidate 'isothermal protostars', i.e., collapsing cloud fragments

which have not yet developed a central hydrostatic core. The $\sim 6\,000$ AU fragmentation sizescale estimated from our ρ Oph 1.3 mm mosaic is consistent with the typical Jeans length in the DCO^+ cores and is at least five times smaller than the diameter of isolated dense cores in the Taurus cloud. In agreement with this short lengthscale for fragmentation, the circumstellar envelopes surrounding ρ Oph Class I and Class 0 protostars are observed to have finite sizes and to be significantly more compact than their Taurus counterparts.
The measured frequency distribution of pre-stellar clump masses is relatively shallow below $\sim 0.5\ M_\odot$, being consistent with $\Delta N/dm \propto m^{-1.5}$, but steepens to $\Delta N/dm \propto m^{-2.5}$ in the $\sim$ 0.5–2 $M_\odot$ mass range. This is reminiscent of the *stellar* initial mass function (IMF), suggesting the clumps we detect may be the *direct progenitors of individual stars*. Our observations therefore support theoretical scenarios in which gravitational fragmentation plays a key role in determining the stellar mass scale and the IMF.
Finally, the presence of several remarkable alignments of young stars and starless clumps in the 1.3 mm dust continuum mosaic supports the idea that various external agents, such as a slow shock wave originating in the Sco OB2 association, have induced core fragmentation and star formation in at least part of the cloud.

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Clustering of Pre-Main Sequence Stars in the Orion, Ophiuchus, Chamaeleon, Vela, and Lupus Star Forming Regions

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We study clustering of pre-main sequence stars in the Orion, Ophiuchus, Chamaeleon, Vela, and Lupus star forming regions. We calculate the average surface density of companions, $\Sigma(\theta)$, as a function of angular distance, θ, from each star. We employ the method of Larson [MNRAS, 272, 213 (1995)] for the calculation. In most of the regions studied, the function can be fitted by two power laws ($\Sigma \propto \theta^\gamma$) with a break as found by Larson (1995) for the Taurus star forming region. The power index, γ, is smaller at small separations than at large separations. The power index at large separations shows significant variation from region to region ($-0.8 < \gamma < -0.1$), while the power index at small separations does not ($\gamma \sim -2$). The power index at large separations relates to the distribution of the nearest-neighbor distance. When the latter can be fitted by the Poisson distribution, the power index is close to 0. When the latter is broader than the Poisson distribution, the power index is negatively large. This correlation can be interpreted as the result of the variation in the surface density within the region. At large separations, the power-law fit may indicate star formation history in the region and not the spatial structure like the self-similar hierarchical, or fractal one. Because of the velocity dispersion, stars move from the birthplaces and the surface density of coeval stars decreases with the age. When a star forming region contains several groups of stars with different ages, a power law may fit the average surface density of companions for it. The break of the power law is located around 0.01 - 0.1 pc. There is a clear correlation between the break position and the mean nearest-neighbor distance. The break position may reflect dispersal of newly formed stars.

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HIPPARCOS results for ROSAT-discovered young stars

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Out of ~ 500 Lithium-rich ROSAT counterparts, which are presumed to be low-mass pre-main sequence stars, 21 stars have been observed by HIPPARCOS. We study their parallaxes, proper motions, and photometric data. For 7 out of 10 Taurus and Lupus stars in our sample, proper motions and parallaxes are not inconsistent with membership to these

associations, while most of the stars in Chamaeleon and Scorpius appear to be young foreground stars. Combined with ground based photometry and spectroscopy, HIPPARCOS parallaxes allow us to place 15 stars on an H-R diagram. All these 15 stars are indeed pre-main sequence stars with ages from 1 to 15 Myr. Only two of the stars are located on the Hayashi-tracks, whereas the other 13 are post-T Tauri stars located on radiative tracks. Although this sample is admittedly small, containing only 3 % of the total sample of Lithium-rich ROSAT counterparts, it does not confirm recent predictions by other authors: We find no stars in the age range from 20 to 100 Myr. The foreground pre-main sequence stars may have been ejected towards us, or they belong to the Gould Belt system, a plane filled with young stars.

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Star Formation in the L1333 Molecular Cloud in Cassiopeia

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Radio and optical observations have been made in order to examine star formation in the dark cloud L1333 (α(1950) = $2^{\rm h}21.0^{\rm m}$, δ(1950) = 75°15′). A study of the cumulative distribution of field star distance moduli yields a distance value close to 180pc for the L1333 molecular cloud. ^{13}CO observations revealed two filamentary molecular clouds with distinct velocities of $V_{\rm LSR}$ ∼−2 and 3 km s^{-1}, respectively. Thirteen C^{18}O cores, characterized by an average molecular mass ($M_{\rm LTE}$) of $\sim 9 M_\odot$ and a mean density of $\sim 1.4\times10^4$ cm^{-3}, are embedded in the two ^{13}CO clouds. We have detected 18 Hα emission-line stars projected within or near the ^{13}CO clouds on objective-prism plates. They can be regarded as candidate pre-main-sequence stars formed in the clouds. Five *IRAS* sources with flux density distributions characteristic of young stellar objects (YSOs) are found in the area of the cloud. Three of the *IRAS* sources coincide with Hα emission-line stars, and the others with faint stars without detected Hα emission. One of the latter sources is associated with a C^{18}O core and exhibits a protostar-type infrared spectrum. The *IRAS* source exhibits a winglike feature of ∼1.6 km s^{-1} (full width at zero intensity) in C^{18}O, which may indicate that the YSO has an outflow. We note that the C^{18}O core has the smallest ratio of virial mass ($M_{\rm vir}$) to $M_{\rm LTE}$ among the C^{18}O cores in L1333, suggesting that star formation occurs preferentially in a core whose internal kinetic energy is low compared with the self-gravitational energy. A possible scenario for the past star formation activity is discussed.

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http://www.a.phys.nagoya-u.ac.jp/∼ayano/L1333.html

An X-ray study of the PMS population of the Upper Sco-Cen Association

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We have searched for low-mass pre-main-sequence stars in the nearby Upper Sco-Cen star-forming region using ROSAT observations analyzed with an innovative source detection method based on wavelet transforms. In a 5.2 ksec ROSAT PSPC image we find 32 sources down to a limiting flux of 3.9 10^{-14} erg cm^{-2} s^{-1}. In two HRI observations that cover with greater sensitivity approximately one-third of the same region we find 17 sources, down to a limiting flux of 1.4 10^{-14} erg cm^{-2} s^{-1}. Half of the HRI sources were not detected either in the PSPC pointed observation nor are they reported in the ROSAT Bright Source Catalog, nor in the final analysis of Einstein IPC data of the same region, which resulted in the detection of 18 sources down to a limiting flux of 9.1 10^{-14} erg cm^{-2} s^{-1}. Considering all the available X-ray data together, we have a total of 50 distinct X-ray sources, of which only 13 were previously reported as Einstein IPC sources in a sky region of nearly the same area as that surveyed in the present work. Our new analysis allows us to largely increase the census of likely PMS stars in the Upper Sco-Cen region and shows that the IPC survey

of PMS stars in this region by Walter and collaborators is more severely incomplete than previously reported. The likely PMS nature of the stellar counterparts of the faint X-ray sources is supported by follow-up optical spectroscopy of some of these sources, as well as by the presence of variability of X-ray emission in a substantial fraction of them, and by the characteristics of available X-ray spectral information.

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Synthetic Images and Long-slit Spectra of Protostellar Jets

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We construct synthetic images and long-slit spectra of protostellar jets modeled as steady-state x-winds. Assuming uniform ionization fractions and electron temperatures, we calculate non-LTE level populations for five-level atoms. Synthetic images in the [S II]λ6716/6731 and [O I]λ6300/6364 lines have roughly the same surface brightness as observed jets if we ignore their knotty structure. Long-slit spectra taken with the slit placed along the central axis of the jet, or slightly displaced laterally from it, provide strong evidence in support of the x-wind theory. In both the models and the actual objects, wide line profiles, containing both large positive and negative velocities, are often seen at the base of the flow, indicative of a wide-angle wind. As one progresses up the length of the slit, the line profiles narrow to straddle the projected velocity of a highly collimated jet.

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ISO observations of molecular hydrogen in the DR 21 bipolar outflow

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We demonstrate that a wide range of molecular hydrogen excitation can be observed in protostellar outflows at wavelengths in excess of 5μm. Cold H_2 in DR 21 is detected through the pure rotational transitions in the ground vibrational level (0-0). Hot H_2 is detected in pure rotational transitions within higher vibrational levels (1-1, 2-2, etc.). Although this emission is relatively weak, we have detected two 1-1 lines in the DR 21 outflow with the ISO SWS instrument. We thus investigate molecular excitation over energy levels corresponding to the temperature range 1015 K - 15722 K, without the uncertainty introduced by differential extinction when employing near-infrared data.

This gas is thermally excited. We uncover a rather low H_2 excitation in the DR 21 West Peak. The line emission cannot be produced from single C-shocks or J-shocks; a range of shock strengths is required. This suggests that bow shocks and/or bow-generated supersonic turbulence is responsible. We are able to distinguish this shock-excited gas from the fluoresced gas detected in the K-band, providing support for the dual-excitation model of Fernandes, Brand & Burton (1997).

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Preprints: http://www.astro.uni-wuerzburg.de/~smith/homepage.html, http://www.tls-tautenburg.de/research/research.html, http://www.jach.hawaii.edu/~cdavis/papers.html

Astrophysical Maser Radiation from a Turbulent Medium: Application to 25 GHz Methanol Masers

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Spectral and spatial distributions are calculated for astrophysical maser radiation that emerges from a turbulent medium. Turbulent velocity fields are created by sampling from Kolmogorov-like distributions. The maps of maser emission created in a turbulent medium appear as if the emission results from a collection of isolated clumps moving with different velocities, even though the physical quantities (other than velocity) are constant within the medium.

A detailed comparison is made with observational data about the 25 GHz methanol masers in OMC-1. There is evidence that key simplifications for the calculations – unsaturated masing and uniform excitation – are applicable for these masers. For the actual Kolmogorov distribution, the images are smaller and more numerous than are observed. The spectra also do not exhibit the observed irregularities. Velocity distributions that are somewhat steeper than the Kolmogorov power law lead to calculated images and spectra that reproduce characteristic features of the observations.

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HD 98800: A Unique Stellar System of Post-T Tauri Stars

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HD 98800 is a system of four stars, and it has a large infrared excess that is thought to be due to a dust disk within the system. In this paper we present new astrometric observations made with *Hipparcos* as well as photometry from *Hubble Space Telescope* WFPC2 images. Combining these observations and reanalyzing previous work allows us to estimate the age and masses of the stars in the system. Uncertainty in these ages and masses results from uncertainty in the temperatures of the stars and any reddening they may have. We find that HD 98800 is most probably about 10 Myr old, although it may be as young as 5 Myr or as old as 20 Myr. The stars in HD 98800 appear to have metallicities that are about solar. An age of 10 Myr means that HD 98800 is a member of the post-T Tauri class of objects, and we argue that the stars in HD 98800 can help us understand why post-T Tauris have been so elusive. HD 98800 may have formed in the Centaurus star-forming region, but it is extraordinary in being so young and yet so far from where it was born.

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The Ortho–H_2/Para–H_2 Ratio in Low-Velocity-Shocks

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New detailed MHD-shock model computations are carried out for low-velocity-shocks (LVS) of "C-type" that propagate through the molecular ISM. Unlike many other C-shock models that adopt a population of H_2 levels that is in thermal

equilibrium (static limit) and a fixed ortho-H_2/para-H_2-ratio (OPR), the present one assumes a level population that is, as well as the OPR, in a stationary state. This modification is necessary because the OPR of pre-shock gas is likely smaller than 3 as has been verified in H_2-observations of NGC2024.

Ortho-para interconversions occur mainly through collisions of H_2 with H^+, H_3^+, and H. The densities of H^+ and H_3^+ are generally low in C-shocks. These species convert only a small fraction of p–H_2 into o–H_2 during the passage of the shock. However, proton exchange reactions are the principle process for shock speeds $u_s \lesssim 15$ km s^{-1}. At higher shock speeds the OPR attains its equilibrium quickly through reactive H–H_2 collisions, owing to higher kinetic temperatures and atomic hydrogen abundances reached in the shocked gas. Ortho-para interconversions induced through H_2 interaction with dust grains and due to H_2 formation on dust were found to be too slow in LVS's.

A grid of models is calculated for pre-shock densities of $n_{\rm H} = 10^2$, 10^4, and 10^6 cm^{-3} and shock speeds from $u_s = 10$ to 30 km s^{-1}. It is demonstrated that the OPR attains 3 in regions of shocked gas only if $u_s \gtrsim 20$ km s^{-1} for pre-shock densities $\lesssim 10^3$ cm^{-3}, whilst $u_s \gtrsim 25$ km s^{-1} is required for higher densities. The OPR remains <3 for shocks with smaller speeds and may not even deviate much from its initial value at the lowest shock speeds examined. We present H_2 line intensities assuming an $OPR_{initial}$ of unity and 3. They are compared to those computed with models in which the level population is in thermal equilibrium.

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Four-colour photometry of eclipsing binaries. XXXIX. Light curves of the pre–main sequence triple system TY Coronae Australis

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Complete *uvby* light curves of the detached Herbig Be eclipsing binary TY Coronae Australis are presented. A total of 1789 photometric measurements in each of the four colours were obtained in 1989 and in 1992-1994. A detailed analysis of the y light curve obtained in 1992-1993 is published separately (Casey et al. 1997). The reflection nebula around the system contributes about 30% of the light in all four passbands. Here we present and discuss the non-eclipse-related photometric variability of the system. We suggest that these variations are the result of variable obscuration, possibly linked to dust shells physically associated to the system.

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