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Abstracts of recently accepted papers

Dust Extinction and Molecular Cloud Structure: L977

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We report results of a near–infrared imaging survey of L977, a dark cloud in Cygnus seen in projection against the plane of the Milky Way. We use measurements of the near–infrared color excess and positions of the 1628 brightest stars in our survey to measure directly dust extinction through the cloud following the method described by Lada et al. (1994). We spatially convolve the individual extinction measurements with a square filter 90$''$ in size to construct a large–scale map of extinction in the cloud. We integrate over this map to derive a total mass of $M_{L977} = (660 \pm 30)$ $(D/500pc)^2$ $M_\odot$ and, via a comparison of source counts with predictions of a galactic model, estimate a distance to L977 of 500 $\pm$ 100 pc. We find a correlation between the measured dispersion in our extinction determinations and the extinction which is very similar to that found for the dark cloud IC 5146 in a previous study. We interpret this as evidence for the presence of structure on scales smaller than the 90$''$ resolution of our extinction map.

To further investigate the structure of the cloud we construct the frequency distribution of the 1628 individual extinction measurements in the L977 cloud. The shape of the distribution is similar to that of the IC 5146 cloud. Monte Carlo modeling of this distribution suggests that between $2 < A_V < 40$ mag (or roughly $1 < r < 0.1$ pc) the material inside L977 is characterized by a density profile $\rho(r) \propto r^{-2}$. Direct measurement of the radial profile of a portion of the cloud confirms this result.

At the lower galactic latitude of L977, we find both the mean and dispersion of the infrared colors of field stars to be larger than observed toward IC 5146. This produces an increase of about a factor of 2 in the minimum or threshold value of extinction that can be reliably measured toward L977 with this technique. Nevertheless the accuracy in an extinction map pixel is not significantly different toward L977 due to the increased number of field stars at this latitude. We also find an increase in the number of detected giant stars at the lower galactic latitude of the survey by almost a factor of two. Most of these excess stars suffer extraneous extinction and are probably red giants seen along the disc of the Milky Way up to distances $\sim$ 15 kpc and reddened by unrelated background molecular clouds along this direction of the Galaxy. We discuss a possible application of this observable to galactic structure studies on the plane of the Galaxy.

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Disk Mass Limits and Lifetimes of Externally Irradiated Young Stellar Objects Embedded in the Orion Nebula

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We present 1.3 millimeter wavelength interferometric observations of externally irradiated young stellar objects (proplyds) embedded within the Orion Nebula including the three largest circumstellar disks seen in silhouette against the background nebular light. One field is centered on the $2''$ diameter edge-on disk 114-426. The second field is centered on the large teardrop shaped object 182-413 (HST 10) which contains a very opaque $0.''4$ diameter edge-on disk. This field also contains four other proplyds including the large pure silhouette 185-405 (HST 16). We derive upper bounds on the dust masses of these disks from the absence of continuum emission and upper bounds on the gas masses from the lack of CO emission. These limits imply circumstellar disk masses less than 0.015 $M_\odot$ for the observed sources and upper bounds on the column density of ^{13}CO of N(^{13}CO) $< 1.5 \times 10^{15}$cm^{-2} averaged over the synthesized beam. Comparison with lower bounds on the dust content derived from the visibility of the circumstellar material in silhouette against the background nebular light and the extinction towards the embedded central star implies that ^{13}CO may be less abundant in these circumstellar environments than in normal molecular clouds. The non-detection statistics are combined with estimates of radiation-induced mass loss rates to derive an upper bound on the UV irradiation time for these young stellar objects. The young stellar objects in the Orion Nebula that are still surrounded by circumstellar material have been exposed to external UV radiation for less than 10^5 years and possibly for as little as 10^4 years.

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L43: the late stages of a molecular outflow

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Our new 21 arcsec resolution CO $J = 2-1$ map of the L43 dark cloud shows a poorly collimated molecular outflow, with little evidence for wings at velocities >10 km/s. The outflow appears not to be currently driven by a jet: its structure can instead be modelled as a slowly expanding shell. The shell may be compressed either by a wide-angled wind catching up with an existing shell (as in the case of planetary nebulæ), or by the thermal pressure of a hot low-emissivity medium interior to the shell. The outflow is most probably in a late stage of evolution, and appears to be in the process of blowing away its molecular cloud. We also present a 45 arcsec resolution CO J = 1-0 map of the whole molecular cloud, showing that the outflow structure is clearly visible even in the integrated intensity of this low excitation line, and suggesting that rapid mapping may prove useful as a way of finding regions of outflow activity. We also examine the immediate surroundings of the driving source with 450 μm imaging: this confirms that the outflow has already evacuated a bay in the vicinity of the young stellar object.

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Dynamically triggered star formation in giant molecular clouds

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A Lagrangian, particle-based numerical method (tree code gravity plus smoothed particle hydrodynamics) was used to simulate clump-clump collisions occurring within GMCs. The collisions examined were between 75$M_\odot$ clumps at a relative Mach number of $\mathcal{M} = 3$. The clumps were modelled using isothermal spheres which were individually in stable equilibrium.

The collisions formed shock-compressed layers, out of which condensed approximately co-planar protostellar discs of 7-60$M_\odot$ mass and 500-1000AU radius. Binary and multiple systems were the usual final state. Lower mass objects were also produced, but commonly underwent disruption or merger. Such objects occasionally survived by being ejected via a three-body slingshot event resulting from an encounter with a binary system.

The impact parameter b denotes how offset the clumps are from one another, with low values corresponding to near-head on collisions, and high values corresponding to grazing collisions. Varying b altered the processes by which the

protostellar systems formed. At low b a single central disc formed initially, and was then spun-up by an accretion flow, causing it to produce secondaries via rotational instabilities. At mid b the shocked layer which formed initially broke up into fragments, and discs were then formed via fragment merger. At large b single objects formed within the compressed leading edge of each clump. These became unbound from each other as b was increased further.

The effect of changing numerical factors was examined by : (i) colliding clumps which had been re-oriented before the collision (thus altering the initial particle noise), and (ii) by quadrupling the number of particles in each clump (thus increasing the resolution of the simulation). Both changes were found to affect the small-scale details of a collision, but leave the large scale morphology largely unaltered.

It was concluded that clump-clump collisions provide a natural mechanism by which multiple protostellar systems may form.

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The Jeans Mass Constraint and the Fragmentation of Molecular Cloud Cores

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The collapse and fragmentation of molecular cloud cores into binary and multiple protostar systems is a demanding computational problem in part because of the large range of length scales involved. Truelove et al (1997) proposed that the computational cell size Δx must be smaller than 1/4 of the Jeans length, λ_J, if artificial (numerical) fragmentation is to be avoided. For a uniform Cartesian grid, Truelove et al's (1997) Jeans condition is equivalent to ensuring that the mass of a cell never exceeds $\sim 1/64$ of a Jeans mass. It is shown here that for a nonuniform spherical grid, artificial fragmentation can be avoided provided that the cell size of a cube with approximately the same volume as the spherical coordinate cell $[\Delta x = (\Delta x_r \Delta x_\theta \Delta x_\phi)^{1/3}]$ is less than $\lambda_J/4$ (i.e., that the mass inside each cell is much less than a Jeans mass), even if one of the three cell lengths ($\Delta x_r, \Delta x_\theta$, or Δx_ϕ) exceeds $\lambda_J/4$. For a nonuniform grid, resolving a small fraction of a Jeans mass is less restrictive than resolving 1/4 of a Jeans length in each coordinate direction; resolving all three Jeans lengths is desirable but not necessary in order to avoid artificial fragmentation. The well-resolved collapse of an initially Gaussian-profile cloud is then followed with both isothermal and nonisothermal (Eddington approximation radiative transfer) thermodynamics and shown to lead to fragmentation into a binary protostar system in both cases. The Jeans mass constraint appears to a valuable indicator of physically-realistic fragmentation.

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Star Formation Environments and the Distribution of Binary Separations

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We have carried out K-band speckle observations of a sample of 114 X-ray selected weak-line T Tauri stars in the nearby Scorpius-Centaurus OB association. We find that for binary T Tauri stars closely associated to the early type stars in Upper Scorpius, the youngest subgroup of the OB association, the peak in the distribution of binary separations is at 90 A.U. For binary T Tauri stars located in the direction of an older subgroup, but not closely associated to early type stars, the peak in the distribution is at 215 A.U. A Kolmogorov-Smirnov test indicates that the two binary populations do not result from the same distribution at a significance level of 98%.

Apparently, the same physical conditions which facilitate the formation of massive stars also facilitate the formation of closer binaries among low-mass stars, whereas physical conditions unfavorable for the formation of massive stars lead to the formation of wider binaries among low-mass stars. The outcome of the binary formation process might

be related to the internal turbulence and the angular momentum of molecular cloud cores, magnetic field, the initial temperature within a cloud, or - most likely - a combination of all of these.

We conclude that the distribution of binary separations is not a universal quantity, and that the broad distribution of binary separations observed among main-sequence stars can be explained by a superposition of more peaked binary distributions resulting from various star forming environments. The overall binary frequency among pre-main-sequence stars in individual star forming regions is not necessarily higher than among main-sequence stars.

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Infrared and submilimetre studies of Vega-excess stars

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We report new infrared and submillimetre observations of a sample of 24 candidate Vega-excess stars, and derive CO masses, dust masses, gas to dust ratios and the strengths of various emission lines. Most of these stars have dustier discs that the class archetypes (Vega, Fomalhaut, βPic, etc.), yet, like the archetypes, all the stars observed in CO show the gas content of their discs to be depleted compared with molecular cloud values. We discuss how the extra dust content might imply that these stars are less evolved than the archetypes, and use other infrared and submillimetre characteristics to support this contention.

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VLBI Maps and Properties of the 6 GHz OH Masers in W3(OH)

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We present the first maps of the $^2\Pi_{\frac{3}{2}}, J = \frac{5}{2}, F = 3-3$ and $F = 2-2$ OH maser emission from W3(OH) at 6.035 and 6.031 GHz in both right and left circular polarizations. We used three antennas of the European VLBI Network to achieve a spatial resolution of a few milliarcseconds (mas). Our maps, restored with a beam of 5 x 6.5 mas, show complex OH emission structures in several velocity channels. Weak extended emission structures could be present together with point-like sources. The minimum brightness temperature derived for individual maser spots lies in the range $0.2-5\ 10^{10}$ K. The 6.035 GHz maser emission is concentrated in five distinct regions covering the western half of the compact HII region. There are significantly fewer features at 6.031 GHz although the overall spatial distributions of OH features of the $F = 3-3$ and $F = 2-2$ transitions are similar.

Nearly all OH features with nearby center velocities and opposite senses of circular polarization coincide to within one synthesized beamwidth. We identify these spatially paired components with Zeeman pairs and derive the associated magnetic field strengths, for which some changes have been observed since the first experiment made by Moran et al. (1978). The field always points away from us. The strengths deduced from the 6.035 GHz data range from 2 to 10 mG. At 6.031 GHz the field strengths are also ≤ 10 mG with the exception of a strong feature around -42.6 km s^{-1} which gives ≈ 15 mG. This is the highest field strength measured so far in an OH line.

From our observations we derived the absolute position of the maser emission to an accuracy of order 200 mas for both 6.035 and 6.031 GHz transitions. The fine scale alignment of the $F = 3-3$ and $F = 2-2$ OH emission maps was made using kinematical and other physical arguments. In the richest area of individual OH spots there is a good

match between the strongest 6.035 and 6.031 GHz masers which thus must be excited by similar physical processes. However, the conditions required to excite the 6.031 GHz maser seem to be slightly different from those at 6.035 GHz because the linewidths are narrower and the magnetic fields are stronger at 6.031 GHz.

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VLA Observations of Carbon Radio Recombination Lines toward the HII Region Complex S 88B

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We present high angular resolution VLA observations of the C92α, C110α, and C166α radio recombination lines of carbon from the region of massive star formation known as S 88B. The observations reveal that the carbon emission arises from two distinct components which are intimately associated with the compact (S 88B2) and cometary (S 88B1) regions of ionized gas within the complex. The brighter carbon component has an angular size of $\sim 6''\!.6$, an average line center velocity of 21.0 ± 0.5 km s^{-1}, an average line width of 5.1 ± 1.0 km s^{-1}, and is associated with the compact HII region. The second component has an angular size of $\sim$ 16" and is found projected toward the head of the cometary-like HII region. The average center velocity and width of the carbon line emission are 21.1 ± 0.7 km s^{-1}and 5.1 ± 1.7 km s^{-1}, respectively. The spatial location and velocity of both carbon regions suggest that the emission arises in layers of photodissociated gas at the interface between the molecular cloud and the regions of ionized gas which are undergoing a champagne phase.

From a model analysis of the dependence of the recombination line intensity with principal quantum number we conclude that the carbon emission originates in *warm photodissociated regions*. The electron temperatures and electron densities of the photodissociated gas are in the range between 400 to 600 K and 40 to 80 cm^{-3}, respectively. Further, we find that stimulated amplification of the background HII region continuum radiation contributes significantly to the carbon emission in both components.

We also detected emission in sulfur radio recombination lines from both components. We find that the ratios of sulfur to carbon line intensities are considerable larger than the [S/C] cosmic abundance ratio and that they vary with principal quantum number, with values in the range between 0.3 to 0.6. We attribute the large values of the intensity ratios to depletion of carbon in the gas phase by a factor of $\sim$5, and the variations with principal quantum number to stimulated emission effects in a region of low electron density ($n_e \sim 3$ cm^{-3}) and low temperature ($T_e \sim 50$ K) that surrounds the C^+ region.

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VLA Observations of Hydrogen and Helium Recombination Lines from Partially and Fully Ionized Gas in S 88B

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We present VLA observations of radio recombination lines of hydrogen (H92α, H110α and H166α) and helium (He92α) made toward the S 88B massive star forming region, which contains compact (S 88B2) and cometary (S 88B1) regions of ionized gas. We find that the profiles of the hydrogen line emission from the compact HII region exhibit remarkable differences with principal quantum number. The H110α profile is composed of two distinct components, a broad ($\Delta v \sim 31$ km s^{-1}) and a narrow ($\Delta v \sim 7$ km s^{-1}) component, having similar intensities. The H92α profile also

shows the presence of the broad and narrow components, but the bulk of the line emission is dominated by the broad component. Emission in the H166α line was not detected to a limit of 4 mJy. From a model of the observed line intensities and profiles we conclude that the emission from the narrow line corresponds to stimulated emission arising from a partially ionized medium contiguous with, and along the line of sight toward, the compact HII region. We find that the partially ionized gas has an electron temperature of $\sim$ 800 K, an electron density of $\sim$ 250 cm^{-3}, and an emission measure of $\sim 2 \times 10^3$ pc cm^{-6}, and suggest that the most likely source of ionization is X-rays from stellar winds. The broad line emission originates from an HII region with an electron temperature of $\sim 10^4$ K, an electron density of $\sim 7.5 \times 10^3$ cm^{-3}, and an emission measure of $\sim 8 \times 10^6$ pc cm^{-6}. The profiles of the H92α and H110α line emission from the cometary-like HII region show the presence of a single broad ($\sim$ 25 km s^{-1}) component. The intensities and profiles of these lines are well reproduced by a model in which the emission arises from an homogeneous, isothermal, region of ionized gas with an electron density of $\sim 4.8 \times 10^3$ cm^{-3}, an electron temperature of $\sim$ 13000 K, and an emission measure of $\sim 1 \times 10^7$ pc cm^{-6}. Emission in the helium line was detected only toward the cometary B1 region. We find that the helium to hydrogen integrated intensity ratio is 0.08 for the B1 region, while for the B2 region we derive an upper limit of ≤ 0.02. The low value of the *observed* He^+/H^+ abundance ratio of the compact HII region B2 can be simply explained as due to the low effective temperature of its ionizing source.

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Mid-Infrared Imaging of Orion BN/KL: II. Luminosity Sources, Extinction Distribution, and the Nature of IRc2

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We have recalculated the luminosities of IRc2 and the BN Object in the Orion BN/KL complex, and determined the distributions of color temperature and silicate absorption line strength over the region with much greater precision than before, using a complete set of well-sampled and nearly diffraction-limited array camera images of BN/KL at nine wavelengths between 4.8 and 20 μm. We find that the total infrared luminosity of IRc2 itself may be only L $\sim$ 1000 $L_\odot$ (much lower than the generally accepted value). However, the temperature and extinction distributions show that the significant luminosity source(s) in BN/KL must still be located within several arcseconds of IRc2. Our results, considered with recent radio continuum and maser emission observations, suggest that a luminous early-type star located at radio source "I" must be embedded close to IRc2, obscured by $\sim$ 60 mag of visual extinction from dust grains both local to IRc2 and in intervening clouds along the line-of-sight. The combined heating contributions of the hot stars ionizing the compact HII regions "I" (near IRc2), "B" (the BN Object) and "n", the compact IRc sources (including ten new peaks observed here), and near-infrared sources embedded near IRc2 can account for the observed $\sim 10^5$ $L_\odot$ total luminosity of the BN/KL complex.

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The Protostar in B335 – Near-Infrared Observations of the Class 0 Outflow –

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This Letter reports the results of very deep near-infrared imaging of the core of the star-forming Bok globule B335 in H, K, and the 2.12 μm H_2 $\nu = 1-0$ S(1) line emission. The outflow cavity associated with the Class 0 protostar embedded in B335 and features in the blueshifted outflow lobe are detected in the deep K-band images, mostly by emission from shock-excited molecular hydrogen. Only extremely faint traces of the outflow are seen in the H band. Several knots of S(1) emission are found near the edge of the globule on either side of the outflow. The cloud core is

outlined in absorption against diffuse H and K-band flux in B335, presumably scattered starlight.

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On the Binary Properties and the Spatial and Kinematical Distribution of Young Stars

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The effects which star cluster concentration and binarity have on observable parameters, that characterise the dynamical state of a population of stars after their birth aggregate dissolves, are investigated. To this end, the correlations between ejection velocity, binary proportion, mean system mass, binary orbital period and mass ratio are quantified for simulated aggregates. These consist of a few hundred low-mass binary and single stars, and have half-mass radii in the range 2.5 to 0.08 pc. The primordial binary-star population has a period distribution similar to that observed in Taurus-Auriga for pre-main sequence binaries. The findings presented here are useful for interpreting correlations between relative locations and proper motions, binary properties and masses of young stellar systems within and surrounding star forming regions, and of stellar systems escaping from Galactic clusters.

For the low-concentration binary-rich aggregates, the proportion of binaries decreases monotonically as a function of increasing ejection velocity after aggregate dissolution, as expected. However, this is not the case for initially highly concentrated binary-rich aggregates. The reason for this difference is the interplay between the disruption of binary systems and the initial depth of the potential well from which the stellar systems escape.

After aggregate dissolution, a slowly expanding remnant population remains. It can have a high binary proportion (80 per cent) with a high mean system mass, or a low binary proportion (less than about 20 per cent) with a low mean system mass, if it was born in a low- or a high-concentration aggregate, respectively. It follows that adjacent regions on the sky near some star-forming clouds can have young populations with different binary proportions and different mass functions, even if the binary proportion at birth and the initial mass function (IMF) were the same.

Binary systems that are ejected from the aggregate tend to be massive, and their mass ratio tends to be biased towards higher values. The mean system mass is approximately independent of ejection velocity between 2 and 30 km/s. Dynamical ejection from binary-rich aggregates adds, within 10 Myr, relatively massive systems to regions as far as 300 pc from active star-forming centres. Long-period systems cannot survive accelerations to high velocities. The present experiments show that a long-period ($> 10^4$ d) binary system with a large velocity (> 30 km/s) cannot be ejected from an aggregate. If such young systems exist, then they will have been born in high-velocity clouds.

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http://www.ita.uni-heidelberg.de/publications/preprints

Protostellar Cosmic Rays and Extinct Radioactivities in Meteorites

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Calcium-aluminum-rich inclusions (CAIs) and chondrules of chondritic meteorites may originate with the melting of dustballs launched by a magnetically driven bipolar outflow from the inner edge of the primitive solar nebula. Bombardment by protostellar cosmic-rays may make the rock precursors of CAIs and chondrules radioactive, producing radionuclides found in meteorites that are difficult to obtain with other mechanisms. Reasonable scalings from the observed hard X-rays for the cosmic-ray protons released by flares in young stellar objects yield the correct amounts of ^{41}Ca, ^{53}Mn, and ^{138}La inferred for meteorites, but proton- and alpha-induced transformations underproduce ^{26}Al by a factor of about 20. The missing ^{26}Al may be synthesized by ^{3}He nuclei accelerated in impulsive flares reacting primarily with ^{24}Mg, an abundant isotope in the target precursor rocks. The mechanism allows a simple explanation for the very different ratios of $^{26}Al/^{27}Al$ inferred for normal CAIs, CAIs with fractionated and unidentified nuclear (FUN) anomalies, and chondrules. The overproduction of ^{41}Ca by analogous ^{3}He reactions and the case of ^{60}Fe inferred for eucritic meteorites require special interpretations in this picture.

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An Analytic Flow Solution for YSO Jets

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We present an analytic solution for a jet flow from a young stellar object (YSO). This solution allows us to compute the speed, density, and magnetic field strength of the flow, but it is only true if YSO jet flows are powered by toroidal magnetic fields. We illustrate how the balance between centrifugal force and magnetic pressure provides the converging/diverging nozzle shape required to accelerate the flow.

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available from ftp://maestro.mel.dbce.csiro.au/pub/afdl/kurtl/YSOJet

HH 262: The Red Lobe of the L1551 IRS 5 Outflow

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HH 262 is a group of emitting knots located approximately $3.5'$ to the NE of the L1551 IRS 5 source. We present a detailed study of the kinematical properties of HH 262, based on proper motion measurements, and on high resolution imaging Fabry-Perot observations in the [S II] λ 6717 line. From these observations, we conclude that it indeed appears to be the case that HH 262 is associated with the red lobe of the L1551 IRS 5 outflow.

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Preprint available at `http://www.am.ub.es/~robert/preprints/hh262.ps.gz`

Imaging Polarimetry of Class I Young Stellar Objects

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We present near infrared imaging polarimetry of three Class I Young Stellar Objects in the Taurus-Auriga dark cloud. We use Monte Carlo simulations to analyse the flux distributions and polarization patterns of these three sources and five others from an earlier paper. In addition, we present high resolution polarimetry of HL Tau using the Shift and Add technique. Most YSOs in the sample display sharp, unresolved, peaks in the scattered light distribution. This is most simply explained by a strong concentration of matter in the centre, which we model by applying the $\rho \propto r^{-1.5}$ power law throughout the envelope. In terms of the Ulrich/Terebey, Shu and Cassen solution for the late stages of contraction of an initially spherical non-magnetic cloud, this corresponds to $r_c < 10$ au. However, this almost spherically symmetric density distribution is inconsistent with observations of flattened, disk-like structures

so we conclude that this solution is not appropriate and different initial conditions apply. The multiple scattering models with spherical grains do not reproduce some features of the observed polarization patterns, in particular the broad regions of aligned vectors seen in some sources. We interpret this as evidence for elongated aligned grains. The weak wavelength dependence of nebular morphology shows that the dust grains in circumstellar envelopes obey a much shallower extinction law than interstellar grains in the near infrared, which we describe by the opacity ratio $\kappa(J/K) = 1.8 \pm 0.3$, compared to the interstellar value of 3.25. We place an upper limit on albedo of $\omega < 0.6$ from 1.25-2.2 μm and we find $0.1 < \omega < 0.6$ at 2.2 μm. Analysis of the quadrupolar source IRAS 04302+2247 indicates that the scattering function is not highly forward throwing, which we express by the constraint g= $\langle cos(\theta) \rangle < 0.4$. With the addition of 2 more observables derived from the observed degrees of linear and circular polarization we identify 5 empirical constraints on the properties of circumstellar dust. After calculating these observables for grain mixtures with a wide range of refractive indices and a variety of size distributions we find that highly metallic spherical grains or highly elongated grains can satisfy these constraints and the size distribution extends to $a \gtrsim 0.35$ μm. Amorphous carbon is the most plausible absorptive component, since graphite appears to be ruled out by its strong dispersion in the near infrared.

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Further Observations of IRAS 04302+2247

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We present near infrared broad band and H_2 images of the quadrupolar source IRAS 04302+2247. High resolution data at 3.8 μm show that the circumstellar envelope has a high degree of axisymmetry: the asymmetry at shorter wavelengths is almost certainly due to extinction by dust in the cavity. Photometry of the flux peaks confirms that the source is variable but little change in appearance is observed between Nov 1995 and Sep 1997. We report the first clear detection of the molecular outflow in H_2 at 2.1 μm, revealing discrete streams which are inclined to the axis of cavity. The motion of knots in the outflow remains the most likely cause of the variability.

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T Tauri Stars Associated with Herbig-Haro Objects and Jets

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We have obtained deep [SII] $\lambda\lambda$6716,6731 and continuum images of the five classical T Tauri stars (cTTSs) DP Tau, RW Aur, V536 Aql, LkHα 321, and V1331 Cyg. These cTTSs were selected for our imaging study because they either showed strong P Cygni absorptions in their spectra (LkHα 321, V1331 Cyg) or are known to have bipolar jet-like outflows from long-slit spectroscopic studies (DP Tau, RW Aur, V536 Aql). For the latter three objects the spatial extent and structure of the outflows could be studied here for the first time. Also LkHα 321 and V1331 Cyg were found to be associated with Herbig-Haro (HH) objects and/or HH jets. In four cases the jets/outflows are bipolar, with the largest spatial extent seen in RW Aur (145″; 0.1 pc for d = 150 pc) and V1331 Cyg (360″; 1 pc for d = 550 pc). About 170″ west of LkHα 321 we have serendipitously discovered a faint HH source, which we designated LkHα 321 B.

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http://www.tls-tautenburg.de/research/research.html

High Resolution Millimeter-Wave Mapping of Linearly Polarized Dust Emission: Magnetic Field Structure in Orion

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We present 1.3 and 3.3 mm polarization maps of Orion-KL obtained with the BIMA array at approximately 4″ resolution. Thermal emission from magnetically aligned dust grains produces the polarization. Along the Orion "ridge" the polarization position angle varies smoothly from about 10° to 40°, in agreement with previous lower resolution maps. In a small region south of the Orion "hot core," however, the position angle changes by 90°. This abrupt change in polarization direction is not necessarily the signpost of a twisted magnetic field. Rather, in this localized region processes other than the usual Davis-Greenstein mechanism might align the dust grains with their long axes parallel with the field, orthogonal to their normal orientation.

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VLA Detection of the Exciting Source of the "Deflected" HH 270/110 System

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The HH object 110 is a well collimated jet that in initial studies seemed to lack an exciting source. More recent studies suggest that the exciting source of this jet is off-axis, producing a faint jet, known as HH 270, which is deflected in a grazing collision with a molecular cloud, thus producing HH 110. We present sensitive observations made at 6 and 3.6-cm with the VLA toward the HH 270/110 system in an attempt to test this hypothesis. An object with characteristics of a thermal radio jet was detected coincident with the infrared object proposed as the exciting source of the HH 270/110 system. This thermal radio jet appears elongated along the direction of HH 270. No radio continuum source was detected at the apex of the HH 110 flow. Altogether, our results thus strongly corroborate the proposed jet-collision interpretation of the HH 110/270 flow complex. Additionally, we have detected at both 3.6 and 6-cm the driving source of the nearby IRAS 05487+0255 bipolar molecular hydrogen jet.

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The interaction of the Galactic center filament system G359.54+0.18 with its ambient medium

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We present a multi-wavelength study of the Galactic center filament system G359.54+0.18 and potentially associated, nearby molecular clouds. The data include, (1) 3 mm multi-line observations of CS, HCO^+, and other molecular species, (2) observations of low-J transitions of ^{12}CO and ^{13}CO, (3) 5 GHz radio interferometric continuum emission observations and (4) H79α recombination line observations.

The high-sensitivity VLA images reveal continuum emission with a clumpy morphology towards the eastern tip of the nonthermal filaments. The transition from filamentary to clumpy structure appears to be continuous, implying association between the two. A dense molecular cloud is situated adjacent to the eastern border of the clumped continuum emission region. The cloud is part of the negative velocity feature, an elongated complex of Galactic center molecular clouds distinguished by its coherent kinematic structure across about a degree in longitude. A 3σ detection of H79α recombination line emission indicates that the extended continuum component is thermal in nature and links it kinematically to the molecular gas. A steep velocity gradient in the molecular cloud towards the interface to the HII region and the excitation conditions of the gas derived from our multiline survey also imply interaction between the

molecular cloud and the HII region. Higher angular resolution data confirm the association between the filaments and a second molecular cloud at a position where the nonthermal filaments are bent, as was previously suggested by Bally & Yusef-Zadeh (1989). The morphological and kinematic evidence for the interaction of the G359.54+0.18 nonthermal filaments with an HII region and molecular clouds makes G359.54+ 0.18 the fourth association of this kind observed in the Galactic center region.

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URL: http://www.astro.umd.edu/∼staguhn

Radio Emission from Young Stellar Objects Near LkHα 101

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We present results of a VLA 3.6 cm B configuration survey of a region around the Herbig Be star LkHα 101. We detect 16 sources down to 5 RMS thresholds of 0.25 mJy. Most of the sources are thought to be young stellar objects associated with the star formation region. Six of the objects have optical counterparts and at least two are weak-lined T Tauri stars. A large number exhibit high amplitude variability, indicating that gyrosynchrotron emission from flares just above the photosphere is a primary cause of the emission. We discuss the distance to the star formation region as implied by the radio flux densities and Hipparcos data. We present evidence that the region may be located at a distance typical of the Taurus-Auriga star formation complex, not at 800 pc as suggested by previous studies.

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ftp to pandora.colorado.edu, cd to pub/doneal, get vla.ps

On the Fractal Structure of Molecular Clouds

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We present a new method to analyze the structure of observed molecular cloud images which is the generalization of the *Allan-variance* method traditionally used in the stability and drift analysis of instrumentation and electronic devices. Applied to integrated intensity maps of two molecular cloud data sets, the method shows, together with an analysis of the phases of the cloud images, the observed structures to be well characterized by what is called a *fractional Brownian motion (fBm)*-structure in the context of fractal images. An *fBm*-structure results from a power law power spectrum of the image and a completely random distribution of the image phases. The power law index β of the power spectrum derived for two sample clouds turns out to be close to 2.8. For an *fBm*-structure, the power spectral index β determines other fractal measures such as the traditionally used box-counting dimension and the fractal dimension describing iso-intensity contours via their area-perimeter relation. We use a large data set covering observations at both large and small angular scales available for the Polaris Flare (Heithausen *et al.*, 1998, A&A 331, L65) as the sample cloud to test these concepts. The area-perimeter dimension independently measured for this cloud is consistent with $\beta = 2.8$. The *fBm*-concept allows easy generation of realistic density representations for model clouds, to be used in radiative transfer and other cloud simulations.

In a second step, we show that an ensemble of randomly positioned clumps with a power law mass spectrum $dN/dM \propto M^{-\alpha}$ gives an *fBm*-image. The power spectral index β, the mass spectral index α, and the power law index of the mass-size relation $M \propto L^{\gamma}$ turn out to be related: $\beta = \gamma(3 - \alpha)$. The value of γ derived via this relation and the independently determined values for α and β is consistent with the value directly determined for the sample cloud. Our analysis confirms the recent suggestion by Elmegreen & Falgarone (1996, ApJ 471, 816) that the mass distribution in molecular clouds is closely connected with their fractal structure, although the detailed form of the relation depends on the fractal structure model used.

We discuss the implications of these results, obtained for the 2-dimensional observed images, for the underlying 3-dimensional cloud density structure. With some extrapolating assumptions on the 3-dim structure, they imply that the 3-dimensional structure is very much broken up, with the surface growing proportional to the volume. Clearly, additional information on the velocity structure, and in particular its physical link to the assumed *fBm*-density structure, is needed to describe the relevant properties of molecular cloud line shapes and line radiative transfer.

The *fBm*-structure model allows an estimate on the observability of molecular cloud structure down to much smaller angular scales than presently reachable, e.g. with interferometric observations. It turns out that, due to the steepness of the image power spectrum, these will be extremely difficult. Only the next generation large mm-wave array will bring such observations into the regime of the feasible.

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preprints available via anonymous ftp on apollo.ph1.uni-koeln.de/pub/stutzki/fract_pap/fractal.ps

Radio Continuum-H_2O Maser Systems in NGC 2071: H_2O Masers Tracing a Jet (IRS 1) and a Rotating Protoplanetary Disk of Radius 20 AU (IRS 3)

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We have observed simultaneously the 1.3 cm continuum and H_2O maser emission toward the core of the star forming region NGC 2071 using the Very Large Array in its A configuration. Two 1.3 cm continuum sources have been detected in the region, coinciding respectively with the infrared sources IRS 1 and IRS 3. The radio emission in IRS 3 is consistent with an ionized thermal bipolar radio jet. Two clusters of H_2O maser spots are detected, one associated with IRS 1 (22 spots) and the other one associated with IRS 3 (13 spots). The H_2O maser distribution in IRS 1 seems to be tracing at scales of 300 AU the larger-scale H_2 outflow observed at a few thousands of AU from the exciting source. On the other hand, the H_2O masers in IRS 3 are distributed as an apparent disk of $\simeq 0.05''$ ($\simeq$ 20 AU) radius, oriented almost perpendicular to the major axis of the radio jet. There is a clear velocity gradient ($\simeq$ 0.35 km s^{-1} AU^{-1}) along the major axis of the H_2O maser distribution, which can be gravitationally bound by a central mass of $\simeq 1$ M$_\odot$. These results, together with the low-mass and early evolutionary stage of IRS 3, suggest that masers around this source are tracing a rotating protoplanetary disk within a proto solar-like system. This represents direct kinematic evidence of the smallest rotating circumstellar disk ever observed around a YSO.

We discuss the dichotomy of H_2O masers tracing either outflows or disks around YSOs, based on the evolutionary scheme proposed in our earlier work (Torrelles et al. 1997). We suggested that systems in which H_2O masers trace disks are less evolved than those in which masers trace outflows . In this scheme, IRS 3 would then represent a relatively less evolved object than IRS 1. This prediction is consistent with independent infrared observations showing that IRS 3 is at an earlier phase of evolution.

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Gas-cooling by dust during dynamical fragmentation

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We suggest that the abrupt switch, from hierarchical clustering on scales ≥ 0.04 pc, to binary (and occasionally higher multiple) systems on smaller scales, which Larson has deduced from his analysis of the grouping of pre–Main-Sequence stars in Taurus, arises because pre-protostellar gas becomes thermally coupled to dust at sufficiently high densities.

The resulting change from gas-cooling by molecular lines at low densities to gas-cooling by dust at high densities enables the matter to radiate much more efficiently, and hence to undergo dynamical fragmentation.

We derive the domain where gas-cooling by dust facilitates dynamical fragmentation. Low-mass ($\sim M_\odot$) clumps – those supported mainly by thermal pressure – can probably access this domain spontaneously, albeit rather quasistatically, provided they exist in a region where external perturbations are few and far between. More massive clumps probably require an impulsive external perturbation, for instance a supersonic collision with another clump, in order for the gas to reach sufficiently high density to couple thermally to the dust. Impulsive external perturbations should promote fragmentation, by generating highly non-linear substructures which can then be amplified by gravity during the subsequent collapse.

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The Confinement and Breakout of Protostellar Winds: Quasi-Steady Solution

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The driving sources of optical jets and molecular outflows may be accreting protostars. Accordingly, we consider the interaction of a spherical, protostellar wind with the time-dependent infall from a rotating parent cloud. The two flows collide in a shocked shell, whose evolution we follow numerically. Both wind and infall material enter the shell and flow down toward an equatorial disk. We assume that the shell is axisymmetric and evolves quasi-steadily, i.e., over a period long compared to the crossing time of the transverse flow.

At early times, no shell exists, as infall crushes the wind against the protostellar surface. When a steady-state shell does first appear, it is roughly spherical, with radius $r \sim 10^{13}$ cm. Gradually, the surface both swells and elongates in the direction of the cloud's rotational axis. This elongation is a response to the increasing centrifugal distortion of the infall. On the other hand, the main force confining the shell is *not* the infall ram pressure, but stellar gravity. Elongation continues until the polar radius extends to about 10^{16} cm, at which point our quasi-steady assumption breaks down. This event, which typically occurs some 10^5 years after the start of infall, marks the breakout of the wind. Comparing our theoretical results to observed outflow sources, we find that both the initial appearance and disruption of our shell occur too late after formation of the central protostar. We speculate that a fully time-dependent calculation will yield a phase of periodic advance and retreat of the shell, leading eventually to breakout.

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Electronic preprint available: http://astro.berkeley.edu/wilkin/franksworld.html

Dissertation Abstracts

The binarity of Herbig Ae/Be stars observed with Adaptive Optics and spectroscopy. A study of the triple system TY CrA

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Multiplicity is a major issue in stellar astrophysics. Firstly, any stellar formation theory must explain the large abundance of multiple systems among Main Sequence and young low-mass T Tauri stars. Secondly, binary studies allow the direct determination of physical parameters. In the case of Herbig Ae/Be (HAeBe) stars, the binarity status is not well known; furthermore, direct mass determination are required to test stellar evolution models for these young intermediate mass objects.

The first part of the thesis presents the results of *a systematic search for HAeBe binaries* in both hemispheres. Two complementary techniques were used to cover a large range of orbital period P: high angular resolution imaging with Adaptive Optics (AO) (binary separation ρ between $0.12''$ and few arcseconds, i.e. $P \approx$ many years), and high resolution visible spectroscopy to study short orbital period ($P \approx$ few hours to few months).

Among the 68 HAeBe stars observed with ADONIS–ESO and PUEO–CFH AO instruments, 30 binaries (18 discovered) have been detected. 42 HAeBe stars have been surveyed with the CES–ESO and ÉLODIE, AURÉLIE–OHP spectrographs. Radial velocity variations were found in 7 targets (4 are new spectroscopic binaries, 3 d. $< P <$ 166 d.). In addition, the ^{7}Li 6 708 Å absorption line (absent feature in simple HAeBe stars spectra) indicates the presence of a cooler companion in 6 HAeBe spectrum binaries, 4 of which are new detections.
The observed visual binary frequency for HAeBe stars is of the order of 50 %. For short period spectroscopic binaries (P $<$100 days), the observed frequency is about 10 %. Considering observational bias effects, these estimates are regarded as lower limits for the true HAeBe binary frequency.

Based on our multi-color AO images, *spectral types of twenty-two visual companions have been determined.* A trend is found such that companions of Ae stars are low-mass T Tauri stars (spectral type K–M), while companions of Be stars are intermediate mass stars (A–F). Companions usually have no infrared excess, nor do primaries with massive companions. Furthermore, X-ray emission in some HAeBe stars may well be explained by the presence of a T Tauri companion. However, because of bias effects, great care must be taken about these issues, and complementary observations are needed. Our observations provide clues for binary formation theories, but while fragmentation and capture via a circumstellar disk seem plausible mechanisms, disk instabilities and stellar capture scenarios cannot be ruled out.

The second part of the thesis is devoted to the study of TY CrA, the unique triple spectroscopic system among Herbig Ae/Be stars. We found this previously known eclipsing binary to be also a spectroscopic binary of SB2 type ($P = 2.9$ days), and we obtained the *first direct mass determination of an HAeBe star.* The orbital motion of a third companion around the central binary has been monitored, and a complete dynamical model of the triple system has been made. Our theoretical investigations show that the stability of the hierarchical system is insured by tidal effects inside the central eclipsing binary. To explain the puzzling subsynchroneous rotation of the primary star, a peculiar orientation, in which the primary is seen pole-on and its rotational axis is perpendicular to its orbital axis, is proposed.

The circumstellar environment of TY CrA has been studied. SWS, LWS–ISO data show polycyclic aromatic hydrocarbon emissions (some of them never observed from the ground in TY CrA), and [O I] 63, 146 μm and CII158 μm emission lines. These features may well be explained by the presence of a compact H II region and a photodissociation region associated with TY CrA. Adaptive Optics images in the near infrared obtained with and without coronograph show that the dusty environment must be confined very close to the star ($< 0.5'' = 65$ AU at 130 pc).

Photo-dissociated and Photoionized Regions Around Main Sequence Stars

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Molecular Clouds are the sites were stars are formed. The birth of a star results in a strong UV flux that propagates through the cold molecular material, dissociating and ionizing the gas. A shell of ionized gas (an HII region) forms around the star, both of which are encapsulated by a shell of photo-dissociated gas (the PDR). The extent of these regions depends mainly on the effective temperature of the star, the cloud density and the opacity of the dust grains – to a lesser extent on the metallicity of the star. In this thesis we calculate the rate of dissociating photons produced by main sequence stars of different spectral types and metallicities. The stellar fluxes are obtained using the LTE atmosphere models of Kurucz (1993, CD-ROOM 13; for stars with 7,500 K $\leq$ T_{eff} $\leq$ 50,000 K) and the N-LTE atmosphere models of Aufdenberg et al. (1998, ApJ, 498, 837; for stars with 30,000 K $\leq$ T_{eff} $\leq$ 51,230 K). In both cases we find that OB stars have a comparable rate of ionizing and dissociating photons. For cooler stars the dissociation rates are well above the ionization rates; the former becoming negligible when the T_{eff} $\leq$ 13,000 K. Metallicity effects are only important for stars with T_{eff} $\leq$ 15,000 K. In this case the dissociating rates increase approximately .5 dex as the metallicity goes from solar to 0.01 solar.

Using a radiative transfer code and the Kurucz models we calculate the size of the HII region and PDR for uniform density clouds (n(H) = 10, 10^3 and 10^5 cm^{-3}). The size of these regions are calculated for a medium where dust is optically thin to the UV radiation (regions with large grains; Landgraf & Grun 1997, Astro. Ph/11190) and a medium where dust is optically thick to the UV radiation. The results show that in an optically thin medium the PDRs are at least one order of magnitude larger than the HII regions; this difference is reduced to $\sim$0.5 dex in a medium where dust is optically thick to the UV radiation. In both cases the ratio of the size of the PDR to the size of the HII region increases as the T_{eff} of the star decreases. The dust opacity, on the other hand, becomes negligible for low cloud densities and for low mass stars.We also derived an analytical approximation to the size of the PDR for both media. The approximations differ with the numerical results by less than 30% (in the optically thin case and for T_{eff} $\geq$ 13000 K) and by less than 10 % in the optically thick case.

We also explored the effects of the PDR on the destruction of molecular clouds. Following the work by Franco, Shore & Tenorio-Tagle (1994, ApJ,436,745), and considering only the static case, we find that their estimates of the number of O stars that could be formed within a molecular cloud of given mass are reduced by approximately 30%. Note however, that the formation time of the H_2 molecule is $\sim 10^4$ times the HI recombination time and the expansion of the HII region will modify the effects of the PDR on the destruction of the molecular cloud. In any case, we conclude that intermediate mass stars contribute significantly to the overall HI produced in a burst of star formation, and the formation of PDRs reduces even more the number of O stars that can be produced by a molecular cloud.

In order to explore the dynamics of the composite region (HII+PDR) we constructed a spherical hydrodynamical code with radiative transfer. This study was limited to the case of high-density cloud cores (n(H)$\geq$ 10^5 cm^{-3}) where LTE is reached in shorth times and we can assume a constant temperature for the HII region and the PDR. In general the HII + PDR composite region includes two fronts, an ionization front (IF) and a dissociation front (DF). The expansion of the HII region follows the well known evolutionary phases described in earlier works. The evolution of the PDR can be summarized as follows: a shock front (DSF) is produced ahead of the DF due to the pressure differences between the atomic and molecular gas. The DF initially propagates supersonically, slowing down as it reaches its equilibrium radius. At approximately 0.6 times the hydrogen molecule formation time the DSF becomes evident (at this time the ionization shock has advanced into the PDR). Since the DF extends over several grid zones, the DSF in our model initially is formed at the internal border of the DF, increasing the density there and shielding the molecules ahead it. The DF then is left behind the shock front and the DSF continues to advance until it reaches pressure equilibrium with the molecular gas. We also found that, since dust absorption reduces considerably the amount of ionizing photons, the ultracompact HII region (UCHII) reaches pressure equilibrium with the ambient gas in short times compared to the case where dust is optically thin to UV radiation. This results in an UCHII with a size $\sim 10^{-2}$ times the size in the optically thin case. After this time the ISF advances into the PDR loosing strength until it becomes a sound wave. At these densities, the ISF is weakened to almost a sound wave before it reaches the DF and does not have a considerable effect on the expansion of the PDR.

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Accretion Processes in Star Formation

Lee Hartmann

Here is finally a monograph that provides an up-to-date, in-depth discussion of star formation at a level so the book can be used as a textbook for a graduate course in low mass star formation processes. There has for years been a lack of such a book, probably because it has seemed a daunting task to review a subject which is in such tremendous growth. Lee Hartmann, who is well known to all researchers in the field, has taken up the challenge, and has produced a superb book. It reviews our current knowledge of the processes governing the formation of stars, from the collapse and fragmentation of cold molecular gas clouds through to the formation and evolution of disks which may ultimately form planets. Each topic is covered at two levels. A descriptive narrative integrating both observational data and theoretical models is accessible to undergraduates or non-specialists. In addition, each topic is given a rigorous theoretical development with comparison to observations, and is appropriate for first-year graduate students or those desiring a deeper understanding of the underlying physics of how stars and accretion disks form and evolve. This book is a magnificent introduction for anyone who is seriously interested in learning about low mass star formation processes.

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