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Abstracts of recently accepted papers

Chemical Evolution in Pre-Protostellar and Protostellar Cores

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The chemistry of developing and collapsing low mass protostellar cores is followed using a chemical code with a time varying density. Two evolutionary scenarios are represented, gravitational collapse in the presence of magnetic fields and the slow core growth by accretion near equilibrium. The chemical code includes gas phase reactions and depletion onto grains with both CO and H₂O ice mantles. We find that various species will selectively deplete from the gas phase at times which correspond to the middle–late stages of dynamical evolution when the densities are highest. These depletions do not depend in detail on the dynamical solution and should exist for any centrally condensed density profile. Sulfur-bearing molecules are particularly sensitive to the density increase: CS, SO, and C₂S show significant depletions both on a strongly bound water mantle and on the weakly bound CO covered grain surface. In contrast, CO and HCO⁺ show large depletions only for a H₂O grain mantle, and remain in the gas phase for models with CO grain mantles. Two species, NH₃ and N₂H⁺, do not deplete from the gas phase for the densities considered in our models. We also find that for very high densities, $n_{H_2} > 10^6 \text{ cm}^{-3}$, depletion becomes important for all molecules. The effects of coupling chemistry and dynamics on the resulting physical evolution are discussed. We compare our results to current high resolution observations of pre-protostellar cores and to more evolved objects, and suggest that ratios of the abundances of few species can be used in concert with our models as sensitive discriminators between different stages of core and star formation.

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Properties of the Monoceros R2 Stellar Cluster

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We present an extensive study of the stellar population of an embedded cluster in the MonR2 molecular cloud based upon a wide field ($\sim 15' \times 15'$) J, H, and K band mosaic, deep near-infrared imaging at J, H, K, and $n\text{bL}'$ bands of the central cluster region, and spectroscopic observations of 34 stars. By comparing the properties of the MonR2 cluster with other star forming regions, we ultimately hope to learn how the properties and formation of stars of various masses are related to the local physical conditions. The K band star counts indicate that the MonR2 cluster extends over a $\sim 1.1 \text{ pc} \times 2.1 \text{ pc}$ area with a FWHM cluster size of $\sim 0.38 \text{ pc}$. Within this region the cluster contains ~ 309

stars brighter than $m_K = 14.5^m$ and > 475 stars over all magnitudes with a central stellar volume density of ~ 9000 stars pc^{-3} . We have further explored the properties of the cluster by using the spectroscopic and photometric data to construct an extinction-limited sample of 115 stars in the central $0.77 \text{ pc} \times 0.77 \text{ pc}$ region of the cluster that is designed to contain all stars with $A_V \leq 11.3^m$ and stellar masses $\geq 0.1 M_\odot$. As a lower limit, 62% of the stars in this sample contain a near-infrared excess at K and/or L band. The K band excess fraction may be as high as 72% if the accretion characteristics of the stars in the MonR2 cluster are similar to stars in Taurus–Auriga. An initial reconnaissance of the stellar mass function suggests that the ratio of high to low mass stars in the extinction-limited sample is consistent with the value expected for a Miller–Scalo IMF. We do not find compelling evidence for mass segregation in the extinction-limited sample for stellar masses $< 2 M_\odot$, although the most massive star ($\sim 10 M_\odot$) in the cluster appears to be forming near the cluster center. The properties of the MonR2 cluster are similar to other rich young clusters in the solar neighborhood, such as NGC 2024 and the Trapezium.

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Preprints available from <http://www.ifa.hawaii.edu/postdocs/carp/>

The disk-outflow system around the high-mass (proto)star IRAS 20126+4104

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We have used the Pico Veleta 30-m telescope and the Plateau de Bure interferometer to obtain maps of the molecular gas associated with IRAS 20126+4104 in 11 rotational transitions. We also present near infrared images of the same region taken with the TIRGO and NOT telescopes. A molecular clump centred on the H₂O masers associated with the IRAS source is found. A molecular bipolar outflow is clearly evidenced by the interferometer maps in the HCO⁺(1–0) line, originating at the center of the clump; also, the images in the K-band continuum and in the H₂ $v = 1 \rightarrow 0$ $S(0)$ vibrational line trace the same bipolar structure seen in HCO⁺. A flattened structure elongated in the direction perpendicular to the outflow axis is seen in the CH₃CN(5–4) line: we interpret this as a rotating disk with a very young massive early type star at its centre. We conclude that IRAS 20126+4104 represents a beautiful example of a disk-outflow system associated with an early type (proto)star, prior to the development of an ultracompact HII region.

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Cold Dust around Herbig-Haro Energy Sources: Morphology and New Protostellar Candidates

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We present 1300 μm maps of regions centered on the energy sources of 20 HH objects in order to study the distribution of circumstellar matter around these young stellar objects. The data show that the emission generally originates from a rather compact region which is embedded in a more diffuse environment. The relative contribution of the compact component to the total emission varies from 15 to 100%. About half of the compact components appear spherically symmetric while the other half displays an elongated structure. There is, however, no correlation between the optical jet axis and the flattened dust structures, indicating that collimation occurs on smaller scales. Close to the energy

source of HH 114 we discovered a so far unknown mm-source with $L_{bol}/L_{smm} < 100$ suggesting that it is still in its early protostellar evolutionary stage. In three other regions we detected similar unknown mm-sources without *IRAS* counterparts, indicating that they are also likely new protostellar candidates.

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The molecular environment of H₂O masers: VLA ammonia observations

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We present the results of single dish and interferometric observations of ammonia towards 5 sources selected from a sample of H₂O and OH masers associated with star forming regions. The Medicina telescope was used to observe the NH₃(1,1), (2,2), and (3,3) inversion transitions. High resolution maps in the NH₃(2,2) and (3,3) lines and in the 1.3 cm continuum were then obtained with the Very Large Array. The main result of this research is to confirm the belief that H₂O masers form in hot dense molecular cores which are sites of massive star formation. We also find evidence for the H₂O maser phase to be prior to the appearance of an ultracompact HII region around the embedded high mass star(s).

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<http://www.arcetri.astro.it/~testi/preprints.html>

Velocity Resolved Fabry-Perot Imaging of Molecular Hydrogen in OMC-1

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We present a velocity resolved data cube of the distribution of the v=1-0 S(1) line of molecular hydrogen from the source OMC-1. With ~ 1.5 arcsec spatial resolution and 14 km s^{-1} velocity resolution, obtained with a scanning Fabry-Perot interferometer, it provides the most extensive database yet obtained on both the distribution and dynamics of the shocked molecular gas in this source. The line profiles are broad and generally smooth all over the source, with total extent (FWZI) up to $\sim 150 \text{ km s}^{-1}$. We have identified, however, two distinct components to the line profiles which have different spatial distributions. Over the entire source, strong emission from a central velocity component is present, close to the ambient cloud velocity, while emission from high velocity components (both red- and blue-shifted) is confined to discrete condensations. The central velocity component peaks, on average, at $v_{LSR} \sim +12 \text{ km s}^{-1}$, with an average FWHM of $\sim 37 \text{ km s}^{-1}$, but shows subtle variation across the source. In particular, the strongest emission region, Peak 1 to the north-west, is both slightly blue-shifted and broader than Peak 2 to the south-east of OMC-1. We interpret this emission as the result of an isotropic steady wind from the IRc2 complex being loosely collimated by a disk, so that it flows close to the plane of the sky but with Peak 1 pointing slightly towards us, and interacting with ambient molecular gas to excite the molecular hydrogen emission.

In addition, high velocity emission components (centred at $\sim -35 \text{ km s}^{-1}$ and $+40 \text{ km s}^{-1}$ with FWHM of $\sim 30 \text{ km s}^{-1}$) are found in discrete locations, primarily along an emission ridge running north along the Peak 1 region and towards the circumstellar disk about the IRc2 complex. We develop an analytical shock model to demonstrate that these discrete emission knots closely resemble the emission expected from partially resolved bow-shocks. We ascribe

these features as additional ‘bullets’ to those identified by Allen & Burton (1993) in [FeII] at greater distances from the source, but which have been revealed by their interaction with the dense, ambient molecular gas. They likely originate from a temporally-limited event less than 1000 years ago. We provide new estimates on their energetics and momenta of all the bullets, and speculate on their origin.

A copy of the paper may be obtained directly from : <http://star.herts.ac.uk/preprints.html>

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Prompt entrainment in the variable molecular jet from RNO 15-FIR

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Optical, near-infrared, and sub-millimetre observations of the outflow from the young (Class I/Class 0) source RNO 15-FIR indicate that it is jet-driven, and that the “prompt” or bow shock entrainment mechanism dominates over “turbulent” entrainment. The CO J=3-2 observations presented in this paper reveal a collimated, bipolar, molecular outflow driven by RNO 15-FIR. The peaks in the CO outflow lobes are coincident with compact H₂ line emission features. We also find that the mass and momentum distributions in both flow lobes decrease with distance from the source, and that localised “peaks” in these distributions coincide with the H₂ knots. It is likely, therefore, that the H₂ knots represent bow shocks along the jet which accelerate ambient gas into the flow via a prompt entrainment mechanism.

Careful analysis of the data also suggests that the molecular outflow is “wiggling”. This variation in flow direction is possibly due to the orbital motion of the outflow source about some unseen binary companion. The orbital period and binary separation estimated from a sinusoidal fit to the wiggling along the flow suggest two embedded sources with a combined mass of roughly 12 solar masses.

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A preprint (with embedded figures) is available from either <http://www.cp.dias.ie/~cdavis/> or <http://www.ifa.hawaii.edu/postdocs/jochen/>.

Parsec-Scale Jets from Young Stars

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We present deep, large-scale [SII] $\lambda\lambda 6716, 6731$ images of Herbig-Haro (HH) flows and jets in HH 34, RNO 43, HH 38/43, and the HH 24 region. In all of these regions new emission knots and filaments are seen to connect previously known HH objects. We find three bipolar outflows which have total projected lengths of more than 1.5 pc, and two more objects in which a blueshifted lobe of more than 0.6 pc is observed together with a shorter redshifted lobe. The large extent of these outflows consequently implies dynamical ages of about 10⁴ years on average. With such a life time HH jets are perfectly able to transfer enough momentum to the surrounding medium to drive CO outflows.

Most of the jets studied here do not show very large gaps of emission between the source and the flow end, indicating that long phases of total inactivity of the source (i.e. with durations $\geq 30\%$ of the dynamical age) usually do not occur. We argue that the rather strong changes in flow direction over a relatively short part of the total outflow length observed in some of the outflows is difficult to explain by precession of the jet beam.

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Preprints may be obtained from: <http://www.ifa.hawaii.edu/postdocs/jochen/>

Detection of H₂ fluorescent emission from the DR 21 bipolar outflow

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Near-infrared emission lines of molecular hydrogen (H₂) measured in the K window (2.01 to 2.43 μm) and covering energy levels from 6000 K to 24000 K, show indication for different excitation conditions in the east and western lobes of shock excited H₂ in the DR 21 bipolar outflow. We use H₂ excitation diagrams to demonstrate that neither J- or C-type shocks can explain the observed line ratios. The higher H₂ line ratios measured for the eastern lobe are a clear indication of enhanced excitation for the high-excitation levels of the H₂ molecule, which may be caused by shock-produced Ly α resonance pumping or by direct UV excitation of H₂ from the central H II region. This is consistent with the eastern lobe being bordering the central H II region and therefore producing higher FUV fluxes. We show that the observed H₂ emission can be interpreted by a simple two-component emission model consisting of a bow C-type shock which produces the low excitation H₂ emission and a FUV radiation field that produces the high excitation emission through H₂ fluorescence. The H₂ line ratios are best fitted for a PDR model with parameters: FUV field in the range $10^2 \leq G_0 \leq 10^3$ and pre-shock density $n_0 \geq 3 \times 10^3 \text{ cm}^{-3}$. Using the PDR models investigated here, we suggest that in DR 21 the ortho to para ratio is 1.8 in the fluorescent emission component.

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The Bipolar Optical Outflow Associated with PV Cephei

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We describe deep $10' \times 19'$ CCD images of the bipolar [S II] jet emanating from the Herbig Ae/Be star PV Cephei. The ~ 2.3 pc long jet exhibits a clear S-shaped morphology and lies within the lobes of the molecular outflow. The 23 HH knots – including 21 new detections – suggest an intermittent outflow with major eruptions every 2000 yr. We model the morphology of the optical outflow with a simple precessing jet; our preferred model has a large inclination to the line-of-sight, $i \sim 80^\circ$; an opening angle for the precession axis, $\theta \sim 45^\circ$; and a modest precession period of ~ 8300 yr. The close association of optical and radio outflows – together with our simple dynamical jet model – is consistent with Masson & Chernin's (1993) picture where a precessing optical jet carves out cavities in an infalling envelope and drives a molecular outflow.

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Simultaneous optical and ROSAT X-ray observations of the classical T Tauri star BP Tauri

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The classical T Tauri star BP Tauri has been simultaneously observed with UBVRI high-speed photometry at a time resolution of 2 sec and with the ROSAT PSPC detector during five nights. BP Tauri showed brightness variations on time scales ranging from nights to hours both in the optical and in the X-ray band, however, the night-to-night variations in the optical and X-ray spectral regions were not correlated. On one occasion, a short term optical event

with an amplitude in U of $\sim 0.05^m$ and a time duration of 1.2 hours occurred, with no corresponding increase in the X-ray count rate during the decay of the event. In conclusion, the observations show that there are no detectable correlations between the optical and X-ray variability of BP Tau on time scales ranging from 1 hour to days. We discuss the possibility that the optical variability of BP Tau is related to accretion of circumstellar material onto the central star, while the X-ray emission presumably comes from magnetically active regions.

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Spatial and kinematic properties of the forbidden emission line region of T Tauri stars

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We have carried out a long-slit spectroscopic survey for 38 T Tauri stars (TTSs) to study the spatial and kinematic properties of their forbidden emission line (FEL) regions. With these observations we hope to provide more insight into the complex physical structure of the outflows from young stars on the smallest spatial scales observable by long-slit spectroscopy. Due to the differential nature of the observational method, information on the spatial properties (offset from the stellar continuum and spatial width) on sub-arcsec (sub-seeing) scales can be obtained. For most TTSs the [OI] $\lambda\lambda 6300, 6363$, [NII] $\lambda 6583$ and [SII] $\lambda\lambda 6716, 6731$ lines have been investigated at a typical spatial resolution of $1.5''$ and a velocity resolution of $20 - 50 \text{ km s}^{-1}$. A sub-sample of 9 closeby stars (Haro 6-10, XZ Tau, UZ Tau E, HN Tau, DO Tau, DP Tau, UY Aur, RW Aur and V536 Aql) has been extensively studied and the direction of their outflows has been approximately determined by taking spectra at several slit position angles, if not known from emission-line CCD imaging. The spatial and kinematic properties of the FEL regions of these 9 TTSs are described in detail. Together with 3 additional stars discussed in the literature, a sample of 12 stars provides the basis for the following main results of our survey: The so-called high-velocity component (HVC) of the FELs (or gas of high velocity which presumably represents in many cases a HVC being blended with emission of lower velocity) is generally spatially more extended than the so-called low-velocity component (LVC, or gas near the stellar velocity). In the [SII] $\lambda 6731$ line the centroid of the high-velocity gas is located typically at distances of $0.6''$ from the TTS while for the low-velocity gas this value is smaller on average by more than a factor of 3. Comparing the spatial properties of the high-velocity gas among the investigated FELs, it turns out that the largest spatial width and the largest offset of the centroid from the star is usually observed in the [NII] $\lambda 6583$ line, while the emission region is most compact in the [OI] $\lambda 6300$ line. In [OI] the centroid of the high-velocity gas is typically offset by only $0.2''$ from the star whereas in [SII] and [NII] 3 and 3.5 times larger average values have been measured, respectively. In the case of the low-velocity gas, the smallest offset of the emission centroid is also observed in [OI] (typically $0.1''$ in [OI] and $0.2''$ in [SII]).

Our data provide additional support for the model of Kwan & Tademaru (1988, 1995) according to which the HVC observed in the FELs of many TTSs is formed in a well-collimated jet, while the LVC represents gas from a physically distinct flow component (possibly a disk wind or a disk corona). The larger spatial extent of the high-velocity gas in [SII] and [NII] compared to that in [OI] is most probably the result of a jet decreasing in density with increasing distance from the source combined with an increase in excitation. The decrease of the electron density with distance is rather obvious for a jet with diverging stream lines, but why the electron temperature increases is unclear.

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Evidence for Cleared Regions in the Disks Around Pre–Main-Sequence Spectroscopic Binaries

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Combining new infrared photometry with data in the literature, we have compiled spectral energy distributions (SEDs)

from optical to millimeter wavelengths for four low-mass pre-main-sequence spectroscopic binaries ($a < 1$ AU) showing infrared excesses. Three of these binaries have small or no excess emission at $\lambda = 1\text{--}5 \mu\text{m}$ but large excess emission at longer wavelengths, suggesting cleared regions within circumbinary disks. The inferred sizes of these gaps or holes are consistent with theoretical predictions for dynamical clearing by stellar companions. In contrast, the binary AK Sco has a power-law SED with no evidence of reduced near-infrared emission. Nonetheless, a strong $9.8 \mu\text{m}$ silicate emission feature suggests the presence of optically thin dust, and the near-infrared emission can be produced by very small amounts ($\sim 10^{-9} M_{\odot}$) of material within a gap or hole. Thus a dynamically cleared region may exist in AK Sco but is not required by the data.

That three of these binaries (and several other short-period pre-main-sequence binaries) have near-infrared excesses indicative of hot material near the stars is significant given that circumstellar disk radii are limited to less than 0.06 AU (or several stellar radii). The spatial distribution of the near-infrared-emitting material may not be disk-like. Continued replenishment is necessary, perhaps from circumbinary disks.

Circumbinary disk masses around short-period pre-main-sequence binaries range from $0.06 M_{\odot}$ to less than $10^{-4} M_{\odot}$. The larger disk masses are sufficient to substantially influence the binaries' orbital eccentricities during their pre-main-sequence lifetimes.

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Particle Trapping Eddies in Protoplanetary Accretion Disks

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In this paper, we present a new mechanism for number density enhancement and size segregation of particles in a non-laminar accretion disk, e.g. the solar nebula. It can be shown that, if there is a vortical flow with a rotational frequency smaller than the local orbital frequency of the disk and a rotational axis parallel to the midplane of the nebula, particles will be trapped and concentrated in the gas flow. Due to the centrifugal force, a particle can be driven out of an eddy. It will be shown that this process is inhibited by the gravitational force induced by the protostar. Candidates for such slowly circulating flows are turbulent flow features in a size range close to the integral size of the turbulence as well as huge convection cells. The efficiency of the particle concentration depends on the coupling of the particle to the gas, i.e. the friction time. On account of the mass dependence of the friction time, a given eddy becomes a trap for particles of a characteristic size and causes a local change in the dust density. We calculate the maximal dust inhomogeneity due to this process. The strongest effect was observed for mm-sized particles, which can be concentrated by a factor of 100 within only 100 years. Our general estimates do not depend on special turbulence or convection models. In addition, we compare the analytical estimates with the results of numerical simulations of the dust motion. The effect will have an impact on the dust coagulation process and may be a link to the size distribution of chondrules.

Preprints available at <http://www.astro.uni-jena.de/Users/klahr/Eddy.ps.gz>

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Intrinsic Near-Infrared Excesses of T Tauri Stars: Understanding the Classical T Tauri Star Locus

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We re-examine the observed near-infrared properties of T Tauri stars and interpret them with the aid of accretion disk models. Based upon a careful analysis of the *de-reddened* near-infrared colors, we find that T Tauri stars exhibit

a surprisingly narrow range in $(J - H)/(H - K)$ and $(H - K)/(K - L)$ color-color diagrams. We find that accretion disk models with a range of accretion rates ($10^{-8}M_{\odot}yr^{-1} < \dot{M} < 10^{-6}M_{\odot}yr^{-1}$), inner-disk radii ($1 - 6R_{*}$), and viewing angles can account for the distribution of intrinsic near-infrared excesses. If the assumptions upon which our models are based are correct, we find that: i) the disk accretion rates needed to explain the observations are consistent with those inferred from optical spectroscopic studies; and ii) inner-disk holes are required in order to explain the range of observed intrinsic near-infrared excesses. Our model results suggest that a given near-IR excess requires a minimum disk accretion rate, though larger accretion rates can be accommodated with specific combinations of inner disk hole size and viewing inclinations. Further, we combine optical veiling measurements, knowledge of stellar SEDs and reddening, in order to estimate infrared photometric flux excesses for our sample of T Tauri stars. Assuming a distribution of mass accretion rates inferred from optical veiling studies, and a random distribution of viewing inclinations, we examine the plausible range of inner-disk hole sizes. The absence of inner-disk holes predicts near-IR excesses larger than those observed. Inner-disk holes exclusively $> 8R_{*}$ are inconsistent with the observations, whereas hole sizes between $2-6 R_{*}$ are well-matched to the data. Finally we examine the impact of our results on attempts to characterize the accretion properties of embedded young star clusters.

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<http://www.mpia-hd.mpg.de/MPIA/Projects/STARS>

DG Tau B: The Interaction of an Atomic Jet with Ambient Molecular Gas

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We have made high resolution ($4''$) observations of the 2.6 mm continuum and CO (1-0) line emission associated with the young stellar object DG Tau B. The aperture synthesis CO map clearly shows that redshifted emission is symmetrically distributed about the DG Tau B optical jet and extends at least 6000 AU to the northwest of the unresolved continuum source. By contrast, blueshifted CO emission is confined to a compact region, less than 500 AU in radius. Within 1000 AU of the star, the redshifted CO emission is elongated, brightest along its central axis, and unresolved in the transverse direction. Beyond 1000 AU, the flow broadens and begins to bifurcate. The morphology of the CO emission provides compelling evidence that the extended molecular outflow is driven by the highly collimated atomic jet. The spatial correspondence between knots in the optical jet and the successive broadenings of the outflow supports the hypothesis that the molecular outflow is produced by the action of multiple working surfaces in a time-varying jet.

Accepted by Astrophys. J. Letters

Optical high-resolution spectroscopy of ROSAT detected late-type stars south of the Taurus molecular clouds

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We study 111 late-type stars found with optical follow-up observations of ROSAT All-Sky Survey sources south of the Taurus molecular clouds. Some 30 of them have been claimed to be weak-line T Tauri stars, low-mass pre-main sequence (PMS) stars, based mainly on the presence of strong lithium 6708Å absorption in intermediate-resolution ($\sim 1\text{Å}$) spectra. We obtained single-order echelle spectra at blue wavelengths for 106 of these stars, in order to measure their radial and rotational velocities, and investigate their angular momentum evolution and kinematic membership to the Taurus clouds. In addition, we obtained echelle spectra with high ($\sim 0.25\text{Å}$) resolution for seven stars to measure precisely the lithium equivalent width $W_{\lambda}(\text{Li})$. We find that $\sim 1\text{Å}$ resolution is sufficient in order not to overestimate

$W_\lambda(\text{Li})$, e.g. due to blending. Of our 111 stars, 19 are located on the λ Ori cloud, nine of which are K-type stars with lithium in excess of the zero-age-main-sequence (ZAMS) level, i.e. are PMS stars. At least 40 of the remaining 92 off-cloud stars display detectable lithium, 24 of which are lithium-excess stars, i.e. show lithium at least as strong as IC 2602 stars with the same spectral types. Of those 24 stars, nine (25% of the off-cloud stars with detectable lithium) are PMS stars isolated from cloud material; all have spectral type K, and three of them are spectroscopic binaries. 15 off-cloud stars have spectral type G and lithium comparable to IC 2602 stars, i.e. may have already arrived on the ZAMS just like G-type IC 2602 stars. However, all these 24 off-cloud lithium-excess stars are probably not older than IC 2602 ($\sim 3 \cdot 10^7$ yrs). We discuss possible sites and modes of origin of the isolated PMS stars south of Taurus.

Accepted by Astrophysics and Astronomy

Pre-prints available from Ralph Neuhauser at rne@mpe-garching.mpg.de

Thackeray's Globules in IC 2944

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We have studied the complex of small globules discovered by A.D. Thackeray in the southern HII region IC 2944. They are located precisely on the line-of-sight to the luminous OB stars in the region, and thus appear as shadows against the bright HII region. Thanks to this geometry, exceptionally fine details can be discerned on CCD images, which show that the globules are generally sharp-edged and highly structured, and that the complex contains a multitude of fragments in all sizes down to the resolution element of about one arcsec (1800 AU). CO millimeter observations reveal that the largest globule consists of two kinematically separate entities, with masses of about 11 and 4 M_\odot . Very large velocity differences exist between the various globules, suggesting that the globules comprise a highly dynamic system perhaps one million years old. We believe that the globules are the remnants of an elephant-trunk observed from behind, originating as a Rayleigh-Taylor instability in an expanding neutral shell powered by the hot HII region. The globule complex is now in an advanced stage of disintegration. We have found no evidence for star formation in any of the globules.

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Dust around young stars. Photopolarimetric activity of the classical Herbig Ae/Be star RR Tauri.

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The classical Herbig Ae/Be star RR Tau is known as a highly variable young star with an amplitude of variability of about 4^m in the V pass-band. In this paper we present the results of coordinated Crimea-Dodaira multi-band photopolarimetric observations of this star which cover fully the observed interval of its brightness changes. Within the observed interval of its light variations the linear polarization of RR Tau anti-correlates with its brightness changes. The dependence of the linear polarization on the stellar magnitude agrees well with the model according to which the main source of the intrinsic polarization of RR Tau is scattered radiation by the circumstellar disk-like dust envelope (probably the protoplanetary disk) seen edge-on or under a small inclination to the line-of-sight, and that the brightness variations are caused by variable obscuration of the star by revolving circumstellar dust clouds.

A comparison with previous photopolarimetric observations of this star shows that the Stokes parameters of its polarized radiation are quite stable on a time scale of about 7 years. By using this fact we have separated the interstellar and intrinsic components of the observed polarization. The numerical modeling of the intrinsic linear polarization together with the colour-magnitude diagrams of RR Tau show that the circumstellar disk-like envelope around this star is strongly flattened and that the characteristic size of the grains is intermediate between that of interstellar dust and dust in the old protoplanetary disk of β Pictoris. We assume on the basis of this analysis that RR Tau is surrounded by a young protoplanetary disk and that it can be considered as a young progenitor of β Pictoris.

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Star Formation in Cold, Spherical, Magnetized Molecular Clouds

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We present an idealized, spherical model of the evolution of a magnetized molecular cloud due to ambipolar diffusion. This model allows us to follow the quasi-static evolution of the cloud's core prior to collapse and the subsequent evolution of the remaining envelope. By neglecting the thermal pressure gradients in comparison with magnetic stresses and by assuming that the ion velocity is small compared with the neutral velocity, we are able to find exact analytic solutions to the MHD equations. We show that, in the case of a centrally condensed cloud, a core of finite mass collapses into the origin leaving behind a quasi-static envelope, whereas initially homogeneous clouds never develop any structure in the absence of thermal stresses, and collapse as a whole. Prior to the collapse of the core, the cloud's evolution is characterized by two phases: a long, quasi-static phase where the relevant timescale is the ambipolar diffusion time (treated in this paper), and a short, dynamical phase where the characteristic timescale is the free-fall time. The collapse of the core is an “outside-in” collapse. The quasi-static evolution terminates when the cloud becomes magnetically supercritical; thereafter its evolution is dynamical, and a singularity develops at the origin—a protostar. After the initial formation of the protostar, the outer envelope continues to evolve quasi-statically, while the region of dynamical infall grows with time—an “inside-out” collapse. We use our solution to estimate the magnetic flux trapped in the collapsing core and the mass accretion rate onto the newly formed protostar.

Our results agree, within factors of order unity, with the numerical results of Fiedler & Mouschovias (1992) for the physical quantities in the midplane of a collapsing, magnetized, axisymmetric cloud up to the onset of dynamical collapse. Our simple approach thus captures the basic physics of a self-gravitating, magnetized cloud in which the evolution is driven by ambipolar diffusion. It also enables us to treat the evolution of the accretion onto the protostar after collapse, for which detailed numerical results are as yet unavailable. Remarkably, we find that at late times the accretion rate becomes comparable to that of a non-magnetized, singular isothermal sphere, provided that the ionization is due to galactic cosmic rays.

Accepted by Ap. J.

<http://www.astro.umd.edu/~safier/preprints/clouds.html>

Dust evolution in protoplanetary accretion disks

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The time evolution of dust particles in circumstellar disk-like structures around protostars and young stellar objects was investigated. For the first time, we coupled the dust evolution directly to the evolution of the disk and followed the influence of opacity changes due to collisional aggregation on the dynamics of the disk. For that purpose, we numerically simulated the dynamical evolution of a turbulent protoplanetary accretion disk described by a time-dependent one-dimensional (radial) “alpha” model. Within this model, the growth of dust grains due to coagulation

was calculated by solving numerically the non-linear Smoluchowski equation. As physical processes leading to relative velocities between the grains, Brownian motion, turbulence, and drift motion were taken into account. In contrast to other studies, we especially considered particle-cluster agglomeration (PCA) as growth mode but also included cluster-cluster agglomeration (CCA) into our considerations. For time periods of 100 years and disk radii up to 100 AU, the mass distributions of coagulated dust grains were calculated. From these mass spectra, we determined the corresponding Rosseland mean dust opacities. The variations of the dust grain opacity drive changes in the energetic structure of the protoplanetary disk which again influences the accretion process itself. Our results show three evolutionary stages of the PCA process. For CCA particles, there is no dust growth after the disappearance of the smallest grains. The different characteristic timescales for the coagulation at different radii result in the restructuring of the dust region of the protoplanetary disks. Significant changes in the thermal and optical structure of the disk occur.

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A High Spatial Resolution Study of the ON2 Massive Star Forming Region

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We present $5'' - 10''$ resolution images of the ON2 cloud core in the molecular lines $^{12}\text{CO}(J=1-0)$, $\text{SiO}(v=0, J=2-1)$, $\text{H}^{13}\text{CO}^+(J=1-0)$ and $\text{SO}_2(8_{3,5} - 9_{2,8})$ and three millimeter continuum obtained with the Berkeley-Illinois-Maryland Array (BIMA) mm-wave interferometer. For the ^{12}CO line, additional observations were obtained with the NRAO 12 m telescope to recover extended emission missed by the interferometer. We find evidence for at least four massive, energetic molecular outflows from young stellar objects within a 1.5 pc region. Three of these are identified by bipolar high velocity ^{12}CO emission, and a fourth is suggested by SiO and SO_2 emission. Continuum emission is detected from the ultracompact (UC) HII region, G75.78+0.34, and also from two deeply embedded YSOs, one of which (source 3) may be the driving engine of the dominant central outflow G75 C. Approximately half of the SiO emission observed is not obviously linked to the proposed molecular outflows and perhaps traces additional shock activity within ON2. The high resolution observations support the conclusion reached previously that a near-simultaneous massive star formation event occurred in the ON2 complex $\sim 10^4$ years ago. The presence of molecular outflows in the cloud core shows that this event was not isolated to the cloud edges.

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Clustering of Young Stars in Taurus, Ophiuchus, and the Orion Trapezium

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The surface densities of companions, or equivalently, the two-point correlation functions, of the Taurus, Ophiuchus, and Orion Trapezium star forming regions (SFRs) display remarkably consistent and systematic behavior. They are indistinguishable in the binary regime with a steep power-law dependence in companion separation. The transition between the binary and large-scale clustering regimes is inversely related to stellar density of the SFR. The large-scale clustering regime can be described by a fractal structure that is roughly the same over the 3 decades of stellar density of these SFRs.

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ASCA Observations of the Barnard 209 Dark Cloud and an Intense X-ray Flare on V773 Tau

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ASCA detected an intense X-ray flare on the weak-lined T Tauri star V773 Tau (= HD283447) during a 30 ksec observation of the Barnard 209 dark cloud in September 1995. This star is a spectroscopic binary (K2V + K5V) and shows signs of strong magnetic surface activity including a spot-modulated optical light curve. The flare was seen only during its decay phase but is still one of the strongest ever recorded from a T Tauri star with a peak luminosity $L_x = 10^{32.4}$ ergs s⁻¹ (0.5 - 10 keV), a maximum temperature of at least 42 million K, and energy release $\gtrsim 10^{37}$ ergs. A shorter *ASCA* observation taken five months later showed V773 Tau in a quiescent state ($L_x = 10^{31.0}$ ergs s⁻¹) and detected variable emission from the infrared binary IRAS 04113+2758.

The differential emission measure (DEM) distribution during the V773 Tau flare shows a bimodal temperature structure that is almost totally dominated by hot plasma at an average temperature of ≈ 37 million K. Using information from time-resolved spectra, we examine the flare decay in terms of solar flare models (cooling loops and two-ribbon flares) and also consider possible nonsolar behavior (interbinary flares, star-disk flares, and rotational X-ray modulation). Solar models are unable to reproduce the unusual convex-shaped X-ray light curve, which decays slowly over a timespan of at least one day. However, the light curve decay is accurately modeled as a sinusoid with an inferred X-ray period of 2.97 days, which is nearly identical to the optical rotation period(s) of the two K-type components. This provides tantalizing evidence that the flaring region was undergoing rotational occultation, but periodic X-ray variability is not yet proven since our *ASCA* observation spans only one-third of a rotation cycle.

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Inverse P Cygni variability in the Classical T Tauri star DR Tauri

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We have detected inverse P Cygni type profiles at H δ in the spectrum of DR Tau. These profiles appeared and disappeared on a timescale of hours. Since our dataset is of high time resolution, we can use the variability to place constraints on the size of the obscuring region, which we interpret to be a magnetically funnelled accretion stream crossing the line of sight.

Accepted by MNRAS

Near-Infrared Imaging Polarimetry of Embedded Young Stars in the Taurus-Auriga Molecular Cloud

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We describe near-infrared (JHK) imaging polarimetry of 21 embedded protostars in the Taurus-Auriga molecular cloud. These objects display extended, highly polarized reflection nebulae with V-shaped, unipolar, and bipolar

morphologies. Most sources have $P_K \approx 5\%$ – 20% in an $8''$ aperture; a few objects have $P_K \lesssim 5\%$. The polarization increases towards shorter wavelengths and is generally aligned perpendicular to the long axis of the reflection nebula.

We develop an analytic scattering model for the near-IR colors and polarizations of embedded protostars. Our Taurus data require visual extinctions, $A_V \approx 25$ – 60 mag, comparable to those predicted for models of collapsing clouds. The ratio of scattered flux to intrinsic source flux ranges from $F_s/F_0 \approx 0.001$ at $1.25 \mu\text{m}$ to $F_s/F_0 \approx 0.015$ at $3.5 \mu\text{m}$. These results indicate that the observed ratio of scattered light to direct (extincted) light increases from $F_s/F_d \sim 0.1$ at $3.5 \mu\text{m}$ to $F_s/F_d \sim 25$ at $1.25 \mu\text{m}$. Our data further require intrinsic colors of $0.6 \lesssim \text{J-H} \lesssim 0.9$, $0.3 \lesssim \text{H-K} \lesssim 0.6$, and $0.4 \lesssim \text{K-L} \lesssim 1.2$ for the central sources of Taurus protostars.

We adopt the Terebey, Shu, & Cassen solution for an infalling, rotating protostellar cloud and use a two dimensional Monte Carlo radiative transfer code to model the near-IR polarization data for this sample. Our results indicate envelope parameters in agreement with previous estimates from broadband spectral energy distributions and near-IR images. We estimate infall rates, $\dot{M} \sim 2$ – $5 \times 10^{-6} M_\odot \text{yr}^{-1}$; centrifugal radii, $R_c \sim 10$ – 50 AU; and opening angles of the bipolar cavity, $\theta_h \approx 10^\circ$ – 20° , for a typical object.

Standard grain parameters can explain the near-IR colors and polarizations of Taurus protostars. The polarization maps show that Taurus grains have a high maximum polarization at K, $P_{max,K} \gtrsim 80\%$. The large image sizes of this sample further imply a high K-band albedo, $\omega_K \approx 0.3$ – 0.4 .

Model polarization maps indicate that the size of the “polarization disk” increases with the size of the instrumental point spread function. Relating the morphology of polarization vectors to disk or envelope properties thus requires some care and a good understanding of the characteristics of the instrument.

Accepted by The Astrophysical Journal

The photon dominated regions associated with NGC 2023 and S 140

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We have used the Effelsberg 100-m telescope to observe the C91 α radio recombination line towards the photon-dominated regions associated with NGC 2023 and S 140. This has been supplemented with observations of the C¹⁸O (2–1) and (3–2) lines using the 3-m KOSMA telescope. We have analyzed the C91 α observations using 1-dimensional homogeneous models in order to derive estimates of the density and ultraviolet radiation field. Towards both sources, our radio line data suggest densities of 10^5cm^{-3} although we have evidence for a drop-off to a value of around 10^4cm^{-3} at offsets of 0.4 pc from the exciting star in NGC 2023. The molecular line data towards NGC 2023 are also consistent with high densities (certainly above 10^4 and probably of order 10^5cm^{-3}). We discuss the influence of clumping on these models and conclude that densities as high as 10^6cm^{-3} are possible in both the molecular and carbon line emitting gas.

Accepted by Astronomy & Astrophysics

Preprints are available at <http://www.ph1.uni-koeln.de/~wyrowski>

Young Stellar Objects in Lynds 1641: a submillimetre continuum study

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We present observations of the $350 \mu\text{m}$ – 1.3mm continuum emission of a sample of ten Class I young stellar objects in the Lynds 1641 (L1641) molecular cloud. These observations, together with IRAS data, are used to determine and discuss the properties of the circumstellar dust. We interpret these results in an evolutionary scheme and we find that,

in our sample, the exponent of the dust opacity law, β , seems to increase with time.

Accepted by Astronomy & Astrophysics

Preprint available at <http://alpha0.cnrs-mrs.fr/publications/ArtPerCom97.html>

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Dissertation Abstracts

The use of H α emission for the analysis of the atmospheres of T Tauri stars

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Ph.D degree awarded: November 1996

A set of spectra made at high resolution for a sample of 43 T Tauri stars at H α are presented, in total 198 spectra; repeated observations were made of 22 stars on time scales of a day to several years. We discuss the profile types and propose a new classification scheme, using four classes and two subclasses. The statistical distribution of the profile types shows those with two peaks where the blue one is the lower, but still higher than 50% of the red one, is the most common type (14 stars) closely followed by objects with symmetrical line profiles (11 stars). The profiles show a large span in equivalent widths, from 1.4 Å to 277 Å, with the red wing dominating for stars with W_{eq} higher than 70 Å.

The extended wings of the lines were also examined, using the height of $I_{max}/40$ as reference level. The profiles with symmetrical line wings dominate, but two thirds of the stars have asymmetrical line wings. The extent of the blue and red wings have the same distribution centered around 300 km/s.

We have also followed the behaviour of the lines with time, with regard to changes of profile type and of equivalent width, both on short time scales with a maximum time interval of 1 week, and on longer time scales of months to years. The profile type remains rather stable on short time scales, 78 % do not change type, while on longer time scales the number decreases to 50 % . With regard to the equivalent width, some stars show little variation, while others are significantly variable.

A model was developed to try to explain the line profiles observed, in the context of a spherically symmetric wind and using the code RAMIDUS. We used the Sobolev method to compute the radiation field at the line transitions, but a new term was introduced to account for the continuum radiation produced by the envelope, and a very simple but accurate procedure was used to evaluate the escape probabilities. The conditions in the wind are computed at predefined points by solving the system of equations of statistical equilibrium. To evaluate the continuum field, needed also to compute the photoionization and induced recombination rates, the envelope was divided in layers limited by those points where the conditions were to be computed. These rates were evaluated by a formal integration over the entire atmosphere. The continuum was established by the bound-free processes, bremsstrahlung, the negative ion of hydrogen and the angle dependent Thomson scattering.

We used an atmosphere extending for 10 stellar radii, isothermal and composed only of hydrogen. For the atomic model, a hydrogen atom of 15 levels of the principal quantum number with all sub-levels was used. The solutions were then investigated for a wind with a rapidly increasing velocity, with gas temperatures between 6000 K and 12000 K, a density at the base around 10^{12} cm $^{-3}$ and T_* between 4000 K and 5000 K. The results showed that the ionization fraction of the wind is highly sensitive to the parameters involved, and can be fully ionized or neutral, depending on the assumed density, electron temperature and velocity field.

The profiles were computed by a formal integration of the equation of radiative transfer. Special attention was paid to the line broadening mechanisms, Doppler , Stark, Van der Waals, resonance and electron scattering. The resulting line profiles are symmetric or of P Cygni type with extended wings that in many cases reach far beyond the maximum wind velocity.

New Books

Disks and Outflows around Young Stars

Edited by S. Beckwith, J. Staude, A. Quetz & A. Natta

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