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Abstracts of recently accepted papers

A study of the Chamaeleon star forming region from the ROSAT all-sky survey: II. The pre-main sequence population

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We analyse the nature of the optical counterparts of the ROSAT all-sky survey (RASS) X-ray sources identified with new weak-line T Tauri (WTTS) stars in the Chamaeleon star forming region (SFR). The new WTTS are distributed throughout the whole SFR, while the classical T Tauri stars (CTTS) are found only in the cloud cores. Adopting a distance of 150pc we derive the stellar parameters and place the new WTTS in the H-R diagram. By comparison with theoretical pre-main sequence (PMS) evolutionary tracks, we find masses in the range of 0.2-2.5 $M_\odot$ and ages from a few 10^5yr to 5×10^7yr. Many of the youngest WTTS are located far away from the main Chamaeleon dark clouds. By comparing the properties of the new WTTS with those of the previously known Chamaeleon members, we obtain the following results: i) the new WTTS are, on average, the more massive and luminous PMS stars in Chamaeleon, while the Cha II population contains the lower-mass PMS stars; ii) for stellar masses between 2.5 and 0.5 $M_\odot$, the combined mass distribution of the PMS stars is consistent with the initial mass function (IMF) for field stars, but declines rapidly for masses between 0.5 and 0.1 $M_\odot$, where the strongest selection effects are expected; iii) a weak trend for increasing age with increasing angular distance from the cloud cores is observed but we cannot establish an age segregation since very young WTTS are also found far away from the molecular clouds; iv) the age distributions of the new WTTS and the Cha I population are nearly identical, while that of the Cha II population is shifted towards younger stars indicating that Cha II is probably in an earlier evolutionary phase as compared with Cha I and the new WTTS; v) no decrease of the number density of WTTS is observed with increasing distance to the clouds; vi) the level of X-ray emission of the new WTTS is higher than that of the previously known Chamaeleon members, and the fraction of energy released as X-ray emission, is higher in the new WTTS than in the Cha I TTS. The latter is similar to the X-ray emission level found in open clusters. Finally, we discuss possible mechanisms which may give rise to the observed spatial distribution of the PMS stars in Chamaeleon.

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A Thermal Radio Jet associated with the Quadrupolar Molecular Outflow in L723

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We have carried out VLA observations at subarcsecond resolution of the two radio continuum sources previously detected at lower angular resolution toward the center of the quadrupolar molecular outflow in L723. While the source VLA 1 appears unresolved at our angular resolution of $\sim 0\farcs3$, the source VLA 2 appears as clearly elongated approximately along the direction of the larger pair of lobes of the molecular outflow. This alignment and the flux density and deconvolved angular size dependences with frequency observed between 3.6 and 6 cm are consistent with VLA 2 being a thermal radio jet, and suggest that this source is related to the excitation of the larger pair of outflow lobes. Under this interpretation, the second, more compact lobe pair most probably constitutes an independent bipolar outflow, whose exciting source is still to be determined.

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A Burst of Herbig-Haro Flows in NGC 1333

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We report the discovery of over twenty groups of new Herbig-Haro (HH) objects in the NGC 1333 region of the Perseus molecular cloud, including some highly collimated jets. Our images contain over 30 groups of HH objects driven by over a dozen active outflow sources. Several of the new jets appear to be driven by optically visible stars, including HH 333, HH 334, and possibly HH 335 and HH 336. A spectacular jet, HH 333, lies nearly in the plane of the sky and has a length-to-width ratio exceeding 100 and may exhibit S-shaped point symmetry about a faint Hα emission line star. HH 336 is located towards the cloud edge and is also centered on a visible star. A large number of new HH objects lie to the south of the concentration of known young stellar objects near SVS 13. We use published millimeter wavelength CO and near-infrared H_2 maps and images to associate HH objects, H_2 emitting shocks, and CO outflows with more than a dozen potential driving sources. The high density of objects results in source confusion which limits the extent to which this can be done. Some HH objects are seen towards low extinction regions far from the opaque cloud cores and may trace parts of parsec scale outflows from embedded sources. The large number of collisionally excited nebulae in this young stellar cluster requires a nearly coeval microburst of star formation.

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Accretion During Binary Star Formation I. Ballistic Accretion

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We consider the effects of accretion, during binary star formation, on the mass ratio and separation of a 'seed' binary system. Numerical fragmentation calculations show that 'seed' binary systems may be formed during the gravitational collapse of molecular cloud cores. When initially formed, however, these protobinaries typically contain only a small fraction of the total mass of the cloud core. For the star formation process to reach completion, a protobinary system must grow in mass via accretion from the remainder of the infalling cloud. The accretion of, and interaction with, this matter affects the mass ratio, separation and eccentricity of the protobinary, and thus the final state of the system cannot be determined unless the effects of the accretion are known.

In this paper, the effects of accretion on the mass ratio and separation of an initially-circular protobinary system are determined as functions of the initial mass ratio of the protobinary and the specific angular momentum of the infalling cloud material. The effects are studied by modelling the cloud ballistically, with non-interacting particles which are accreted by the protostars. Qualitatively, it is found that the mass ratio and separation decrease for the accretion of low-specific-angular-momentum matter, and increase for the accretion of high-specific-angular-momentum material. The quantitative results, however, are found to depend critically on the assumed sizes of the protostars. As well as the effects on mass ratio and separation, the spin angular momentum of the accreted material is examined, and evidence is found that the circumstellar discs formed in a binary system may differ considerably between the two components.

The implications for the formation of binary stellar systems are discussed.

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http://www.mpia-hd.mpg.de/MPIA/Projects/THEORY/preprints.html

Accretion During Binary Star Formation II. Gaseous Accretion and Disc Formation

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We consider the effects of accretion during binary star formation. When a 'seed' protobinary system forms within a collapsing molecular cloud core, its final state is determined by the accretion of, or interaction with, the remaining cloud material as it falls on to the system. The binary's mass ratio and orbit and the formation of circumstellar and circumbinary discs are all dependent on the dynamics of this accretion process.

In this paper, we study the effects of accretion on the binary's mass ratio and separation. The gas is modelled using smoothed particle hydrodynamics (SPH) and the results are compared and contrasted with those obtained using ballistic calculations in an earlier paper. The inclusion of hydrodynamic effects also allows us to study the disc formation process. We determine what fractions of the infalling gas form circumstellar and circumbinary discs and find that, under some circumstances, a large circumstellar disc forms around the primary while the secondary has only a small circumstellar disc, or indeed no disc at all. The observational implications are discussed.

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Photometric observations of YY Orionis: New insight into the accretion process

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We report on photometric UBVRI observations of the star YY Orionis unveiling the existence of a periodic component in its light curve, with period 7.58 ± 0.15 days. We attribute this period to rotational modulation of the light curve by a large spot (or group of spots) located on the stellar surface. The amplitude variation as a function of wavelength indicates that the spotted area is hotter than the photosphere and covers about 10% of the projected stellar disk area, a larger surface than usually found for the hot spots of classical T Tauri stars. Comparing the properties of other spotted T Tauri stars with those of YY Ori, we find that the main difference lies in the much larger accretion rate of YY Ori. We show that in all cases the accretion luminosity emitted in the spotted regions represents only a fraction of the total accretion luminosity expected on the basis of the photospheric veiling and spectral energy distribution modelling. We discuss these findings and propose a new qualitative picture of the accretion process in YY Orionis and classical T Tauri stars.

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Accretion and the stellar mass spectrum in small clusters

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We investigate the effects of gas accretion on small clusters of young stars. The evolution of clusters containing 3-10

stars and between 0.1 to 90 % of their masses in the form of gas is followed using a three-dimensional SPH code with sink-particles to treat the accretion of gas onto the stars. The gas accretion by the stars is highly non-uniform in that a few of the stars accrete significantly more than the rest. The location of the star in the cluster potential and its possible membership in a binary or multiple system are the primary factors in determining the star's accretion rate. This competitive accretion process results in the formation of a spectrum of stellar masses even when the initial stellar masses are uniform. Small variations in the initial masses are overwhelmed by the accretion process whereas larger variations can affect the accretion dynamics as they affect the overall cluster potential. The differential accretion results in the massive stars being formed in the centre of the cluster. Their location is not due to an evolutionary effect of mass segregation. Implications of this competitive accretion process for determining the stellar mass spectrum are discussed.

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Solid methane toward deeply embedded protostars

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We report on the detection of an absorption feature near 7.67 μm toward the deeply embedded protostellar objects W 33A and NGC 7538 : IRS9, using the ISO Short Wavelength Spectrometer. Comparison with laboratory spectra shows that this feature can be identified as the ν_4 ('deformation') mode of solid state CH_4 embedded in polar molecules (i.e., H_2O and/or CH_3OH) in icy grain mantles. The solid CH_4 column density relative to solid H_2O is 0.4–1.9%. Unlike solid CO, solid CH_4 does not seem to be subjected to out–gassing toward the warm source W 33A. The low gas–to–solid ratio for CH_4 argues that CH_4 is formed on grains either by hydrogenation of accreted C or by ultraviolet processing of CH_3OH–rich ices.

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Discovery of a highly collimated molecular outflow in the southern Bok globule BHR 71

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We report observations of the southern Bok globule BHR 71 in the $J = 1 \rightarrow 0$ and $J = 2 \rightarrow 1$ lines of ^{12}CO, the $J = 1 \rightarrow 0$ lines of ^{13}CO and C^{18}O, and $(J,K) = (1,1)$ and (2,2) inversion lines of NH_3 made with angular resolution of $\sim 20''$ to $\sim 9'$. We also report 1.3 mm continuum observations made with SEST with $\sim 20''$ resolution. The low angular resolution molecular observations indicate that the globule has a diameter of ~ 0.5 pc, a kinetic temperature

of 11 K, a total mass of $\sim 40\ M_\odot$, and an average molecular density of $\sim 9 \times 10^3$ cm^{-3}. The high angular resolution observations reveal the presence, near the center of the globule, of a highly collimated bipolar outflow with lobes extending by ~ 0.3 pc in opposite directions from a strong 1.3 millimeter continuum source. The morphology and velocity structure of the flow is found to be well described by a biconical outflow that is inclined from the line of sight at an angle of $\sim 84°$, has a semi-opening angle of 15°, and in which the gas moves outwards with an approximate constant radial velocity (with respect to the cone apex) of ~ 28 km s^{-1}. The outflow appears to be driven by a very young stellar object with $L_{bol} \sim 9\ L_\odot$, whose characteristics at infrared and millimeter wavelengths are similar to those of the so-called Class 0 sources.

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Physical Properties of 90 AU to 250 AU Pre-Main-Sequence Binaries

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We have analyzed photometric and spectroscopic data of a sample of 14 spatially resolved pre-main-sequence binaries (separations 0.″6 to 1.″7) in the nearby (150 pc) low-mass star–forming regions of Chamaeleon, Lupus, and ρ Ophiuchi. The spectroscopic data have been obtained with the ESO New Technology Telescope (NTT) at La Silla under subarcsec seeing conditions. All binaries (originally unresolved) were identified as pre-main-sequence stars based on their strong Hα emission — which classifies them as classical T Tauri stars — and their association with dark clouds. One of the presumed binaries turned out to be a likely chance projection with the "primary" showing neither Hα emission nor Li absorption.

Using the spectral A index (as defined by Kirkpatrick et al. 1991), which measures the strength of the CaH band at 697.5nm relative to the nearby continuum, as a luminosity class indicator, we could show that the classical T Tauri stars in our sample tend to be close to luminosity class V.

Eight out of the 14 pairs could be placed on an H–R diagram. A comparison with theoretical pre-main-sequence evolutionary tracks yields that for *all* pairs the individual components appear to be coeval within the observational errors. This finding is similar to Hartigan et al. (1994) who detected that two third of the wider pairs with separations from 400 AU to 6000 AU are coeval. However, unlike Hartigan et al. for the wider pairs, we find no non-coeval pairs among our sample. Thus, the formation mechanism for a significant fraction of the wider pre-main-sequence binaries might be different from that of closer pre-main-sequence binaries. All of the latter appear to have formed simultaneously.

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Burnham's nebula (HH 255), a peculiar Herbig-Haro object

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Burnham's nebula has been consistently identified as a Herbig-Haro object, i.e. a radiating shock wave. Spectrophotometry shows that at least a considerable part of this shock wave must have a velocity of ≈90km/s or more. Recently position-velocity diagrams have shown that the centroid radial velocity and the radial velocity dispersion are unusually small in HH 255 causing problems in the detailed shock wave interpretation. A bow shock like structure is excluded. In order to get some insight into the physics of this enigmatic HH object we have studied the degree of ionization,the kinematic state, and the electron density as a function of position near the main axis of HH 255. We find that the ionization(visible in the steep increase in O^{++}, N^+ ions and in a decrease in C^0 and in Ca^+ occurs in a very narrow (1.″0-1.″5 wide) region which is centered at ≈3″ S of T Tau. In the same narrow region the centroid radial velocity

drops rapidly to zero and the radial velocity dispersion has a maximum and then drops rapidly to 25 km/s (FWHM). Beyond 4.″5 S of T Tau HH 255 looks qualitatively like a pure recombination zone. The [O III] lines and then the [N II] lines become gradually weak in comparison to the neutral and low ionization lines. However, this interesting region,which forms the bulk of HH 255, is about 100 times wider than the theoretical prediction for the recombination region of a plane shock with the same postshock density and the same shock velocity as HH 255. Consequently an interpretation of the zero radial velocity as a plane shock seen edge-on is also excluded.

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Origin of the mid-infrared emission and supersonic jet toward LkHα234

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We present high-resolution imaging of the region around the Herbig Ae/Be star LkHα234 in the 10μm and 17μm atmospheric windows and in the H_2 v=1-0 S(1) line and adjacent continuum. LkHα234 is unresolved at mid-infrared wavelengths (FWHM $< 1.3''$) and has a decreasing spectrum compatible with an accretion disk. A cold mid-infrared companion is revealed 2.7″ to the north-west of the optical star, corresponding well to the polarization centre identified in the K-band by Weintraub et al. (1994). The companion illuminates an arc-shaped reflection nebula with very red colours, and is associated with a radio continuum source, H_2O masers, and a bright extended H_2 emission knot, indicating that it is deeply embedded and has strong outflow activity. However, its role in driving the optical jet near LkHα234 is not clear. Our high-resolution H_2 image reveals that the jet has a complex structure, with an inner part at PA 226° emitting brightly in H_2, and an outer part at PA 252° seen only in [SII]. The inner H_2 jet does not point back exactly toward the infrared companion, indicating either that it is deflected after leaving that object, or that it is driven by a yet unidentified source. Available long-slit spectra favor the idea that the outer jet emitting in [SII] could be powered by the 10μm companion rather than by LkHα234. High-resolution [SII] imaging is required to test this hypothesis.

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OI(63μm)-determined Mass Loss Rates in Young Stellar Objects

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We present observations of the OI(63μm) emission toward five young, highly-collimated outflow sources: IRAS 16293-2422, VLA 1623, L1448-mm, L1448-IRS3, and NGC 1333-IRAS4A. We have partially mapped the OI(63μm) emission associated with the first three outflows, but have only made single beam observations of the latter two. We discuss how the OI(63μm) emission can be used to measure mass outflow rates and compare these with the determination of outflow rates from CO observations. We find that the OI-derived mass outflow rates are in good agreement with the CO-derived rates in 2 of the five sources, but are a factor $\sim 2-4$ times lower than the CO-derived rates in L1448-mm, L1448-IRS3 and IRAS 16293-2422. This provides additional support to arguments already made by numerous authors that the CO-derived rates may be overestimates. We discuss the correlation between the spatial distribution of the CO and OI emission and argue that the outflow occurs in multiple events that gradually evacuate the path of the wind through the ambient medium.

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Comparison of Star Formation in Five Nearby Molecular Clouds

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We have calculated bolometric temperature (T_{bol}) and bolometric luminosity (L_{bol}) for 383 young stellar objects in five molecular clouds within 200 pc in Corona Australis (CrA), Ophiuchus (Oph), Taurus (Tau), Chamaeleon (Cha), and Lupus (Lup). We used T_{bol}, L_{bol}, and bolometric luminosity-temperature (BLT) diagrams to characterize and compare the overall star formation activity of the clouds on a self-consistent basis. The main results are the following: (1) the YSO populations in the clouds can be differentiated by the fraction of their low-T_{bol} sources, which increases systematically from Lup and Cha to Tau and to Oph and CrA. This trend is interpreted as increasing current star forming activity in the same order; (2) the clouds with higher cold source fractions also seem to have higher bright source fractions; (3) In the BLT diagrams, the CrA and Oph sources are more uniformly distributed while the Cha and Lup sources are aggregated near the zero-age main-sequence (ZAMS). Tau sources appear to be an intermediate case. Taurus also seems to contain more cold ($T_{bol} < 1000K$) and low-luminosity ($L_{bol} < 1L_{\odot}$) sources than the other complexes; (4) The YSOs show a characteristic distribution in the median BLT diagram. This distribution is qualitatively consistent with the early YSO evolution from a protostar to a pre-main sequence star, and provides a unique observational test to star formation models; (5) for Lup pre-main sequence stars, the ratio of their T_{bol} to T_{eff} increases during their approach to the ZAMS. This increase can be explained by the disk and envelope dissipation during the pre-main sequence evolution; (6) the most active star forming clouds (Oph and CrA) also have denser molecular cores as measured by $C^{18}O$ J=1-0 line emission, suggesting that the star formation occurs in the densest parts of the molecular clouds; and (7) we find an anti-correlation between T_{bol} and $C_{18}O$ emission for the class 0 and I Tau sources ($T_{bol} < 650K$.) This shows that T_{bol} measures the intrinsic redness of YSOs, rather than their disk-envelope orientation. The disk orientation may have a more important effect on T_{bol} of the pre-main-sequence stars.

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Dust Filaments and Star Formation in OMC 2 and 3

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We have mapped the 1300 μm dust emission of a 6′ x 16′ field in the OMC 2 and 3 region and detected an extended filamentary structure with at least 11 embedded condensations in OMC 2 and 10 in OMC 3. Six have been observed previously at 1300 μm and two were also detected by *IRAS*. We observed 8 of the new sources at 6 wavebands from 350 to 2000 μm and derived upper limits for their FIR emission from the *IRAS* raw data. The mm/submm emission originates from cold dust ($T_d \sim 20$ K), and the individual components have gas masses of $5 < M_{gas} < 36\,M_{\odot}$. The ratio L_{bol}/L_{smm} is below 70 for six sources associated with OMC 3, indicating that they are Class 0 type objects. Condensations in the OMC 2 region have $L_{bol}/L_{smm} \leq 360$, suggesting an evolutionary effect from N to S. We report the discovery of a highly collimated bipolar CO outflow, most likely driven by the source OMC 3–MMS 8. The flow is over 5′ (0.7 pc) long and less than 1′ (0.15 pc) wide and is oriented nearly E–W. Less prominent outflows are associated with OMC 2–FIR 2/3 and OMC 3–MMS 6.

The 1300 μm continuum emission is confined to a ridge less than 1′ wide while the emission in J=2–1 ^{13}CO, C^{18}O, and CS is between 5′ to 10′ wide. The continuum emission is displaced towards the eastern side of the molecular ridge that contains it. Most 1300 μm sources lie in or close to line emission peaks. However, not all line emission

peaks contain prominent 1300 μm continuum sources. The curved filamentary structure of the large scale dust and molecular emission is likely the result of compression by the superbubble centered about 25 to 70 pc further north, plus the impact of energy from the younger 1c subgroup of the Orion OB association which lies 10 to 50 pc in front of our mapped region, and by the very recent expansion of the NGC 1977 and M 42 HII regions.

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Observations of Molecular Clouds in the HH 1-2 Region

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We observed the region of Herbig-Haro object HH 1-2 with several molecular lines. The emission is dominated by two large scale ($\sim$150″) elongations roughly parallel to each other in the HCO^+ $J = 3 \rightarrow 2$ line map. We discuss our results testing the two possibilities suggested in the literature: a molecular toroid around VLA 1 as suggested by Torrelles et al. (1994) and two physically disconnected elongations as suggested by Cernicharo (1991).

Around the central source, VLA 1, our HCO^+ $J = 4 \rightarrow 3$ and H_2CO $J_{K_{-1}K_{+1}} = 3_{03} \rightarrow 2_{02}$ maps all show a $\sim$40″ scale elongation nearly perpendicular to the HH 1-2 axis. We suggest that this molecular core is a disk/toroid-like structure. Our CO $J = 3 \rightarrow 2$ data reveal the existence of a molecular outflow around VLA 1. We also observed an HCO^+ clump downwind of HH 2, where the HCO^+ abundance is possibly enhanced by the shock. We also discuss the star formation activities around VLA 3.

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Adaptive Optics 0.2″ Resolution Infrared Images of HL Tauri: Direct Images of an Active Accretion Disk Around a Protostar

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We have obtained 0.2″ FWHM images of HL Tau at K′, H and J utilizing the University of Hawaii Adaptive Optics System at the 3.6m CFHT. These are the highest resolution deep images of HL Tau ever obtained in the infrared. They provide unique insight into HL Tau's circumstellar environment. An active accretion disk is directly resolved around HL Tau for the first time in the infrared. The physical characteristics of this accretion disk (R$\sim$150 AU, and P.A.$\sim$125° are consistent with the inner disk discovered by submillimeter (0.8 mm) interferometry by Lay et al. (1994), and confirmed by 2.7 mm interferometry by Mundy et al. (1996).

Bipolar cavities aligned with the accretion disk axis are for the first time detected in the infrared. We have monitored the upper cavity at comparable angular resolution for 3 epochs over the last two years. The cavity appears to be expanding at up to $\sim$30 km/sec. This cavity is estimated to have been created in an outburst in the direction of the optical jet $\sim$100 yrs ago.

Accurate photometry and astrometry were obtained for the nearby 0.3″ XZ Tau binary and the unresolved HL Tau star+inner disk at K′, H, and for the first time at J. The large H-K=2.14$\pm$0.11 color of the HL Tau point source indicates an extinction of A_J=7.73$\pm$0.42 mag ($A_V \sim 24$) along the line of sight to the star. Based on this large extinction, the SED for HL Tau's unresolved central source was dereddened. A simple accretion disk+star model reproduced the newly dereddened SED. The model assumed a large infalling envelope (as observed in ^{13}CO; c.f. Hayashi et al. 1993) accreting at $5\text{x}10^{-6} M_\odot$/yr onto a stable accretion disk (R=150AU) around a young 0.7$M_\odot$ PMS star. We find that to reproduce the observed SED, the central unresolved source in HL Tau is required to be a very young ($\sim 10^5$ yr) PMS star surrounded by an active accretion disk. The large observed extinction from the inclined disk implies an estimated accretion disk mass of $\sim 0.04 M_\odot$.

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To download a preprint link to http://www.ifa.hawaii.edu/$\sim$close/HLTAU.html

MWC 297, B1.5Ve: a zero-age main sequence star in the Aquila Rift

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Moderate resolution optical spectra of the significantly reddened Herbig Be star, MWC 297, are presented. The data are of sufficient quality that it has been possible to obtain a spectral type for this star by comparing heavy element absorption features with those present in early-B field stars of known spectral type. The best fit is to B1.5V, with an uncertainty of half a sub-type. It is estimated that $v \sin i$ for MWC 297 is about 350 $\pm$ 50 km s^{-1}, suggesting that the star's rotation axis is almost in the plane of the sky. The reddening towards this object is reviewed and is derived afresh from spectra at wavelengths spanning the B to R optical bands. Using $A_V \simeq 8$ and the absolute magnitude corresponding to B1.5V, it is argued that the distance to MWC 297 is 250 $\pm$ 50 pc rather than $\sim$500 pc as has recently been quoted in the literature. At this distance the star can be located very plausibly in the Aquila Rift.

We go on to present a MERLIN 5GHz radio map of the source which shows it to be markedly elongated in the N–S direction (to a dimension of 125 AU at 250 pc). Since, to within the errors, the direction of radio elongation is parallel to the direction of optical linear polarization (deduced from data published by Hillenbrand et al. 1992), the radio axis is more likely to trace outflow than an ionized circumstellar disk like those associated with classical Be stars. We also present and briefly discuss high resolution Brα and He I 1.083 μm line profiles obtained within a week of the optical spectra. The He I profile is very complex, but confirms that MWC 297 is an outflow source. It is noted that the H I emission lines are undoubtedly highly variable although the timescales for this are not yet clear.

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Molecular hydrogen in the outflow from Cep E

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We present images of the outflow from Cep E in the 1-0 S(1), the 2-1 S(1), and, for the first time in any outflow, the 3-2 S(3) line of molecular hydrogen. These are supplemented by [FeII]1.64μm and narrow-band continuum images. We find two almost perpendicular outflows emanating from Cep E. From these and from the spectral energy distribution the Cep E source appears to be a Class 0 binary. Wiggles and sideways positional offsets of bows in the flow are interpreted as due to precession. A crude precession model then yields estimates for the precession angle, precession period, and possibly also for the binary separation.

Line ratio maps, built from the molecular hydrogen images, yield the excitational state of the H_2 gas. Surprisingly, the 2-1 S(1)/1-0 S(1) and the 3-2 S(3)/1-0 S(1) line ratios are largely constant everywhere in the outflow. Models of slabs of gas at one single or two constant temperatures fail to account for our data, as do fluorescence, and planar J- and C-shock models. Moreover, J-type bow shocks are a possible, though not very probable, explanation for our data, since they work only if the bows are extremely wide. C-type bow shocks, on the other hand, explain our data well.

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Preprints may be obtained from: http://www.ifa.hawaii.edu/postdocs/jochen/ or http://atlas.cp.dias.ie/~cdavis/

Near-infrared Spectrophotometry of HH7–11

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Near-infrared emission-line imaging and long-slit spectroscopy of H_2 and [Fe II] emission lines in the 1.25 to 2.25 μm

wavelength range at multiple postions towards the Herbig-Haro objects HH7–11 and a nearby H_2 emission-line source, ASR 57, are presented. The relative line strengths are used to examine the processes responsible for exciting H_2 emission in these objects. All of the H_2 emission-line ratios are consistent with collisional excitation in these objects and no evidence is seen for non-collisional excitation mechanisms. Nonetheless, the H_2 level populations in HH7–11 are inconsistent with LTE predictions and show underpopulations relative to a Boltzmann distribution in accordance with the different critical densities of each level. The level populations are consistent with either a purely molecular gas or gas containing a mixture of H and H_2, provided that the gas has a range of temperatures and relatively low density. The slit positions towards HH7–11 sample a wide range of H_2 surface brightness and relative brightness of [Fe II] versus H_2 emission lines. The H_2 emission from HH7 is assumed to originate in a bow shock with decreasing shock velocity from the bow shock apex to the wings. Spectra are taken across HH7 using a series of slit positions in order to observe any changes in the spectra with velocity. The slit positions are chosen to include a wide range in shock conditions among the spectra, however the H_2 line ratios are similar at all of the observed positions, a result interpreted as evidence that the emission originates behind J-shocks.

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Postscript preprints are available via anonymous ftp in directory pub/everett/preprints at bessel.mps.ohio-state.edu

Ultraviolet Spectroscopy of the Hot Spot in the Classical T Tauri Star DI Cep

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T Tauris Stars (TTS) are low-mass pre-main-sequence stars that are accreting mass from the surrounding disc. The hot spots detected in some of them are probably heated by the release of gravitational energy in the accretion of the disc material to the star. In this work we study the UV spectrum of the hot spot detected in Di Cep to constrain the physical mechanisms heating the spot and to study the possible role of the magnetic field in channelling the accretion flow.

DI Cep is a Classical T Tauri Star (TTS) classified as G8 IV with a hot spot (T $\sim$ 8500 K) covering 1-3 % of the visible hemisphere. We present the results of a monitoring campaign carried out with the Short Wavelength spectrograph (1200-2000 Å) and the optical FES Camera of the International Ultraviolet Explorer (IUE) from July 12 to July 26, 1992 to study the temperature structure of the spot. The ultraviolet (UV) spectrum of DI Cep shows excess emission in the continuum from 1700 towards longer wavelengths with respect to a G8 IV star. The far UV spectrum is dominated by strong emission lines of O I, C IV, Si IV, Si II and Si III with typical surface fluxes of $\sim 10^6$ erg cm^{-2} s^{-1}. The UV fluxes (lines and continuum) vary in phase and reach the maximum when the optical flux (FES) does. The light curves are similar in all the lines: the emission from the *hot spot* is detected above a baseline flux produced by the stellar atmosphere. There is a broad range of temperatures in the spot (from 10^4 to 10^5 K) that is similar to that observed in the plages of magnetically active cool stars (e.g. II Peg). However, in DI Cep the *light curves of the UV lines and continuum are correlated with the optical light curve.*

DI Cep as a whole deviates only slightly from active stars in the C IV - Si II and C IV - C II flux-flux relations (there is a factor of 2 excess of Si II with respect to C IV when compared with the regression line fitted to active stars). This suggests that the chromosphere and transition region of DI Cep are heated by mechanisms similar to that of active stars. However the spot is significantly shifted from these relations in the flux-flux diagrams, diplaying an excess of Si II (or a defect of C IV) with respect to the surface fluxes emitted by magnetically active stars. The spot alone radiates as much energy as the rest of the atmosphere, an the spot surface fluxes are $\sim 10^8$ erg cm^{-2} s^{-1} (typically 2 orders of magnitude larger than those corresponding to the atmosphere). Our observations support the theories in which the accreting material is magnetically channelled onto the stellar surface. Variations in the temperature of the spot between observations taken 1 year appart suggest that the infalling material is more likely channelled by a transient loop structure attached to the star than by a strong stellar dipolar field.

The total energy radiated in the Far UV lines plus the UV continuum excess is ≥ 0.07 L$_\odot$. This can be accounted for by the accretion of $\geq 6 \times 10^{-9}$ M$_\odot$ yr^{-1} from the corotation radius (8.3 R$_*$).

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Interstellar CH^+ in Southern OB Associations

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Optical absorption line observations of interstellar CH^+ and CH are presented towards the southern OB associations CMa OB1, NGC 2439, Vela OB1, NGC 4755, and Cen OB1. A total of 5–11 stars per association were measured, with visual extinctions ranging from A_v = 1–5 mag. The CH^+ and CH velocities agree within the measurement errors. Towards a particular association, the CH^+ column density $N(CH^+)$ is correlated to the visual extinction of the background star. These findings weaken the possibility that magnetic shocks are the general mechanism that is required to produce interstellar CH^+. It is also found that $N(CH^+)$ is correlated to N(CH), which indicates that abundance of CH^+ is correlated to the optical depth of a cloud. The correlations are difficult to reconcile with scenarios where the sites of CH^+ formation is constrained to the surface of molecular clouds, such as in photon-dominated regions. The observations support ideas which involve turbulence as a major CH^+ production mechanism. In particular, the results presented here are in agreement with expectations from a scenario where the CH^+ formation proceeds in cool gas via a fraction of fast, non-Maxwellian H_2 or C^+, created by the dissipation of interstellar turbulence.

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A Search for Thermal Infrared Emission from Three Silhouette Disks in Orion

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We report the detection of mid-infrared emission from the Orion Nebula silhouette circumstellar disk 218-354. We also observed the fields of the silhouette objects 183-405 and 121-1925 but did not detect either source. Our fluxes for 218-354 confirm the near-infrared excess detected by McCaughrean & O'Dell (1996), and the optical to mid-infrared spectral energy distribution is similar to that of T Tauri stars with moderately luminous disks. A reddened stellar continuum plus a standard circumstellar disk model with a dust luminosity of $2L_\odot$ fit the available data fairly well and implies that we are only detecting emission from the innermost regions of the large disk seen in silhouette. However, our data are fit slightly better by a single-temperature dust model, so the warmest dust may be distributed in a thin ring rather than a continuous disk, perhaps implying a gap in the disk beyond 0.4 AU. Our upper limit for 183-405 shows that the mid-infrared luminosity of its disk is very weak relative its central star. In addition to the silhouette disk sources, our target fields also contain several other sources, four of which we detect in the mid-infrared. All of these sources show infrared excesses typical of circumstellar disks, supporting the suggestion that such disks are common in the Trapezium Cluster. The brightest such source, 180-403, has a very red spectral energy distribution and mid-infrared hydrocarbon features, and resembles the WL 16 protostar in the ρ Ophiuchi dark cloud.

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The Rotating Gas Toroid Surrounding The K3-50A Ionized Bipolar Outflow

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We present high spatial resolution, aperture synthesis images of K3-50A as part of an on-going study of high mass star formation regions. Maps in the HCO^+ (J = 1→0), $H^{13}CO^+$ (J = 1→0), and SiO (v = 0, J = 2→1) emission lines at $\sim 2.''5$ resolution reveal both a flattened cloud of dense molecular gas $\sim$ 1.1 pc in extent and a newly discovered inner torus $\sim$ 0.5 pc in extent. The axis of the inner torus is tilted $\sim 20^\circ$ with respect to the outer cloud. The inner torus

surrounds a bright continuum source, associated with the origin of a bipolar ionized gas outflow, and has HCO^+(J = 1→0) optical depth greater than 14. Chemical abundances in the inner torus are azimuthally asymmetric, possibly due to differential impact of the ionized outflow on the inner region of the torus. Comparison with a kinematic radiative transfer model confirms that the torus is rotating and the rotation axis of the inner torus is aligned with the ionized outflow. While the cloud is not in solid body rotation, the rotational velocity of material in the cloud increases with radius.

We estimate molecular abundance ratios by comparison with high resolution dust extinction maps previously obtained at the same spatial resolution. The abundance ratio $[HCO^+]/[H_2] = 3.9\times10^{-8}$, is enhanced, and falls in the upper range of typically measured values for star formation regions. SiO is likewise enhanced relative to both H_2 and to HCO^+. The ratio $[SiO]/[H_2] = 3.9\times10^{-10}$ is within the range observed toward shock-excited regions. The cloud mass is estimated to be ≥ 2600 $M_\odot$.

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Active Star Formation toward the Ultracompact HII Regions G45.12+0.13 and G45.07+0.13

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A multiwavelength study of the molecular cores containing the ultracompact HII (UCHII) regions G45.12+0.13 and G45.07+0.13 reveals a series of phenomenological differences that distinguish the age of these cores in terms of their development of high mass star formation. First, we report the discovery of massive, bipolar molecular outflows from both UCHII regions. The G45.12+0.13 UCHII region lies centered on a spatially extended, 6 km s^{-1} outflow that we have mapped in the CO J=2→1, 3→2, 6→5, ^{13}CO 2→1 and C^{18}O 2→1 transitions at the Caltech Submillimeter Observatory (CSO). The broad bipolar structure is optically-thick in the ^{12}CO line. The ^{13}CO measurements imply a large outflow mass of $4800M_\odot$ (12% of the total cloud mass). Interferometric observations with the Owens Valley Millimeter Array in the ^{13}CO 1→0 line resolve the gas into at least two outflows, one of which emanates from the 4.0 Jy 110 GHz source identified with the UCHII region. An additional outflow is driven by an adjacent young, embedded object which contributes to the extended submillimeter continuum emission imaged with the CSO bolometer array camera. Lying in a separate core a few arcminutes away, the G45.07+0.13 UCHII region contains H_2O masers and presents higher velocity (11 km s^{-1}) yet more compact CO emission. An outflow has been detected in the CO 6→5 transition along with a compact submillimeter continuum source. OVRO observations in the CS J=2→1 transition confirm a compact outflow centered on the 98 GHz continuum source toward which infall is also seen in the form of redshifted absorption. The multiple outflows, higher CO antenna temperatures, more extended submillimeter and radio continuum emission, and lack of H_2O masers all distinguish the core containing G45.12+0.13 as a more advanced site of massive star formation than the neighboring core containing G45.07+0.13.

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New 'weak-line'–T Tauri stars in Lupus

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We present first results obtained by a survey of the Lupus star forming region in search of new T Tauri stars. This study has been performed on the basis of deep pointed ROSAT observations in the Lupus dark clouds as well as data from the ROSAT All-Sky-Survey in the surrounding, less obscured regions. Our survey covers an area of about 230 square degrees, located between $15^h\,6^m$ and $16^h\,24^m$ in right ascension and between -47^o and -32^o in declination. Identification of ROSAT All-Sky-Survey sources in this area by means of optical spectroscopy revealed 89 T Tauri

stars, 86 of them 'weak-line' T Tauri stars (WTTS) not known from previous studies of this region. Our pointed ROSAT observations led to the identification of 47 more T Tauri stars, giving a total of 136 new T Tauri stars. The large area of our study, as compared with previous works, allows us to study the spatial distribution of WTTS in this star forming region on a large scale. We find the new WTTS to be distributed over the whole area of our survey, indicating that their spatial distribution might extend well beyond our study area. Contrary to the Lupus T Tauri stars known prior to this study, the WTTS discovered by the ROSAT All-Sky-Survey are not clustered in the regions of highest extinction, i.e. the dark clouds.

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The hydrodynamical response of a tilted circumbinary disc: linear theory and non–linear numerical simulations

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In this paper we present an analytical and numerical study of the response of a circumbinary disc subject to the tidal–forcing of a binary with a fixed circular orbit. We consider isentropic fluid discs with a range of thicknesses and binaries with a range of mass ratios, orbital separations and inclination angles.

Our numerical simulations are implemented using an SPH code such that we can consider the hydrodynamics fully in three–dimensions. For our unperturbed disc models, we find the numerical shear viscosity to be equivalent to a constant kinematic viscosity and we calibrate its magnitude. Writing a scaling relation for the shear viscosity manifest in our models, we deduce that the disc thickness cannot be varied without affecting the viscosity in these kinds of SPH disc models, as is supported by our numerical results.

It is found that maintainance of an inner cavity owing to the tidal truncation of the disc is effective for non–zero orbital inclinations. Also we show that our model discs may precess approximately like rigid bodies, provided that the disc is able to communicate on a length scale comparable to the inner boundary radius by either sonic or viscous effects, in a sufficiently small fraction of the local precession period. It is found also that the surface density in the disc should not decrease too rapidly with increasing radius, otherwise the disc may separate into disconnected annuli. Furthermore, the disc precession period may tend to infinity if the disc outer edge is allowed to become arbitrarily large, the disc suffering only a modest quasi–steady warp near the inner boundary.

When the disc response is linear, or weakly non–linear, the precession periods and the forms of warping that we measure in our numerical results yield reasonable quantitative agreement with the analytical expressions that we derive from a linear response calculation. For a stronger disc response the results can agree poorly with our linear analysis, although some qualitative features of the response remain intact. We demonstrate that the response of a disc of non–interacting particles is qualitatively different, showing a much larger kinematic disturbance and an ultimate global thickening of the disc.

This work is of relevance to a number of astrophysical phenomena of current interest in star and planet formation; these include tidal truncation and gap formation in accretion discs and the observational characteristics of some young stellar objects.

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Molecular Cloud/HII Region Interfaces in the Star Forming Region NGC 6357

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We have performed ^{12}CO(1–0), ^{12}CO(2–1), ^{13}CO(1–0), ^{13}CO(2–1), C^{18}O(1–0), C^{18}O(2–1), HCO$^+$(1–0) and H^{13}CO$^+$(1–0) observations towards two selected areas in the star forming complex NGC 6357 with angular resolutions from 21″ to 55″. In particular, we have mapped the molecular gas around the two HII regions G353.1+0.6 and G353.2+0.9 in the ^{12}CO(1–0) and ^{13}CO(1–0) transitions with a resolution of $\sim$ 43″. This improves on the coarser ^{12}CO(1–0) observations previously carried out by others. We have also studied the physical properties of gas along strips through the molecular cloud/HII region interfaces.

For G353.1+0.6, the observations confirm that an ionization front is eroding a warm, dense molecular cloud located to the north of the optical nebula. The molecular gas appears fragmented on a scale size $>$ 0.5 pc and not all the components are related to the HII region. There is evidence of a density increase near the front and indications of temperature gradients toward the exciting stars. This is further suggested by the presence of ^{12}CO(1–0) self-absorption produced by a cooler external layer. The isotopic ratio $X(^{13}\mathrm{CO})/X(\mathrm{C}^{18}\mathrm{O})$ decreases from the inner part of the clouds towards the front, contrary to what is theoretically predicted and observed in many other regions. This may be due to excitation or optical depths effects. An evolutionary scenario is proposed where the exciting stars form at the edge of a molecular cloud.

The morphology of G353.2+0.9 is rather different from what previously believed. Only a weak "bar" of molecular material was found to the south of the sharp ionization front observed optically and in the radio-continuum, and most of the molecular emission arises from regions behind or to the north of the HII region. This indicates that we are viewing a late stage "blister" configuration face-on. This region is fragmented on a scale size $>$ 0.5 pc, and a warm, dense and compact molecular fragment coincides with the elephant trunk visible in Hα images. Other clouds with high ($\sim$ 40 K) ^{12}CO(1–0) brightness temperatures surround the nebula to the north. Around their peaks, the ^{12}CO(2–1)/^{12}CO(1–0) main beam temperatures ratio is significantly $<$ 1, contrary to what is observed in G353.1+0.6. In both G353.1+0.6 and G353.2+0.9 a large range of radial velocities is observed close to the ionization fronts, and the molecular structures interacting with the ionized gas have virial masses greater than masses calculated under the assumption of LTE.

These observations have allowed us to better understand the morphology of the two regions and to sketch the physical properties of molecular clouds exposed to UV radiation. Dynamical interactions between ionized and molecular gas are used in order to estimate the age ($\lesssim$ a few 10^5 yrs) of both nebulae. Also the effects of UV radiation in determining the morphology of molecular gas are considered. The heating sources of the molecular clouds are the early type stars of the HII regions, at the edges of the clouds. The ^{12}CO(1–0) opacity, τ, seems to affect ^{12}CO(1–0) main beam temperatures and an empirical relation between τ and the visual extinction A_V has been determined.

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Submillimetre polarimetric observations of S140 and GL2591: investigating the role of viewing angle on observed polarization position angles

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We have measured the 800μm polarization at three positions towards S140 and at the flux peak towards GL2591. For both sources the implied magnetic field direction is neither parallel nor perpendicular to the outflow axis, implying an

'in-between' situation. A review of published submillimetre polarimetric observations of outflow sources implies this scenario is common. Whilst beamsize effects are not thought to be critical, comparison of these observations with the results from a recent theoretical model (Bonifácio & Emerson 1995) imply that the 'in-between' situations may actually be due to the effect of viewing angle on the observed polarization position angle. If the local magnetic field is uniform and perpendicular to the outflow axis the observed position angle of polarization for dichroic emission of aligned grains is highly dependent on the viewing angle. The surprising agreement between mid-infrared and submillimetre emissive polarization position angles for W3-IRS5, NGC7538-IRS1 and OMC1-IRc2, and their non-orthogonality to the mid-IR absorptive polarization position angles, has implications for the magnetic field configuration around these outflow sources. In particular, an hour-glass magnetic field geometry may be applicable.

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Reliable Galaxy-wide Identification of Ultra Compact HII Regions

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We examine the problem of reliably identifying UC HII regions from Galaxy-wide databases. It is shown that there will be significant contamination in the sample of potential UC HII regions, selected from IRAS PSC using the *two color* criterion of Wood & Churchwell, due to cloud cores with lower mass stars. We identify additional criteria to reduce this contamination. First, we use the differences in the radio emission between the cores with embedded high and low mass stars to segregate them. Then, through a latitude analysis we further improve the reliability. Effectively, the total number of potential UC HII regions is brought down by a factor of ~ 4. This reduction eases the *birth rate problem* for massive stars and offers a more reliable list of young massive stars for galactic structure studies. In the process, we have also identified a group of objects which may contain high mass equivalents of the class 0 objects and clusters of intermediate mass stars.

Accepted by MNRAS

LWS observations of the bright rimmed globule IC1396N

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We present the first far-infrared spectrum of the IRAS source associated with IC1396N, located in the HII region

IC1396 together with submillimeter and millimeter photometry. A rich spectrum of CO, OH, and H_2O lines are detected in the ISO-LWS spectrum, indicative of a warm, dense region, probably shock excited, around the source. Among the fine structure lines, [OIII] and [NIII] are also detected and can be explained by the presence of the O6 star HD206267 approximately 16 pc away.

The far infrared and submillimeter spectral energy distribution is fitted with a model assuming spherical grey-bodies with a radial power law of density and temperature. An accurate measure of the bolometric luminosity and an estimate of the total envelope mass are obtained.

Accepted by Astronomy & Astrophysics

Intermediate Teeth in Pulsed Jets: A Motivation for High-Resolution Observations

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Supersonic jets often contain a series of knots which can be interpreted as arising from a pulsating energy source. The pulsation model is here examined for uniquely-identifying signatures. Formulae are presented for the number, intensity and distribution of knots.

Our numerical and analytical calculations confirm that the classical sawtooth velocity structure contains intermediate teeth. The intermediate teeth are shown to possess high-velocity gradients, between 1.6 to 3 times the sawtooth gradient for models ranging between adiabatic and isothermal. Both sets of teeth weaken with distance with only positive gradients allowed. The leading shock of one pulse can catch up with the reflected shock of the pulse ahead. Then, the intermediate teeth form a new weaker sawtooth structure, with about half the original jump, upon which new teeth are weaned. This gives rise to a relatively long-period beat-type pattern. The associated velocity and spatial structures should soon be observable in protostellar jets.

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Preprints: http://www.astro.uni-wuerzburg.de

The T Tauri star population in the Lupus star forming region

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In a recent study, some 130 new *weak-line T Tauri stars* (WTTS) have been discovered in the Lupus star forming region (SFR). Some of these stars are seen projected onto regions of high obscuration, while others are located far from the Lupus dark clouds. In this paper we present photometric observations of a large sample of these WTTS. We estimate effective temperatures and luminosities for the stars observed, and derive masses and ages by comparison with theoretical evolutionary tracks. The mean age of WTTS seen in projection against the dark clouds is found to be lower than the mean age of WTTS discovered far from regions of high obscuration, and yet higher than the mean age of the *classical T Tauri stars* (CTTS) in Lupus. Moreover, while the CTTS in Lupus show an unusual predominance of very low-mass stars, the WTTS population in Lupus contains many stars with comparatively higher masses. Correlations between the X-ray emission and other stellar parameters, like bolometric luminosity, radius, mass, and age, are studied, and the results are discussed.

Accepted by A & A

Preprint available at http://www.lsw.uni-heidelberg.de/∼rwichman/YS.html

High resolution studies of protostellar condensations in NGC 2024

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We present interferometric $\lambda 3$ mm continuum and $C^{34}S$ (2−1) line observations towards the star forming NGC 2024 (south) molecular cloud core. The continuum of the prominent dust cores FIR 5 and FIR 6 is spatially resolved. FIR 5 separates into a binary or disk-envelope system.

We explore the physical characteristics of the cores by means of a radiative transfer modelling in spherical symmetry. Solutions with low bolometric luminosities ($L_{\rm bol} \sim 1 - 4\,{\rm L}_\odot$) and massive envelopes ($M_{\rm env} \sim$ a few $10\,{\rm M}_\odot$) fit the long wavelength spectral energy distributions best. Dust compositions allowing for thick ice coatings provide better agreement with the dynamical mass estimates derived from the kinematics of the surrounding gas clumps. The ambiguity of the models is severely confined by a recent $\lambda 350$ μm flux density limit from the *Heinrich-Hertz-Telescope* ($M_{\rm env} > 5\,{\rm M}_\odot$, $L_{\rm bol} < 30 - 80\,{\rm L}_\odot$). In all cases, the mass of the envelope exceeds limits on the mass of any embedded central object by order(s) of magnitude. The observations are suggestive of protostellar objects in their earliest phase of formation, with the bulk of its mass still to be accreted.

The $C^{34}S$ line emission arises from two clump ensembles near to, and likely associated with these dense cores – however, the cores proper still escape detection in their molecular emission. This striking anti-correspondence is suggestive of freeze-out of elements onto the surface of dust grains.

Accepted by Astronomy & Astrophysics

Molecular hydrogen observations of Cepheus A West

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The Herbig–Haro complex GGD37 is an active region in the west of Cepheus A. We have used the ISO Short Wavelength Spectrometer (SWS) to investigate the physics of this region by observations of molecular hydrogen and forbidden atomic and ionic emission lines over a wide wavelength and excitation energy range. We find excitation temperatures of the emitting molecular gas to be between 700 and 11000 K, the former being thermal in nature, whilst the latter implies a contribution from non–thermal processes. Gas densities in the emitting region are at least 10^5 cm^{-3}. An H_2 ortho–to–para ratio of 3, equal to the ratio of statistical weights, is consistent with our observations. The forbidden transitions can be modelled by a planar J–shock with pre–shock density of 10^3 to 10^4 cm^{-3} and velocity 70 to 80 km s^{-1}. The H_2 lines cannot be fit by either a single planar J– or C–shock, but instead require a combination of at least two C–shocks with different pre–shock density, shock velocity and covering factor.

Accepted by Astronomy and Astrophysics (Letters)

On Turbulent Pressure Confinement of Ultra-Compact HII Regions

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It has been proposed recently that the small size and long lifetime of ultracompact (UC) HII regions could be due to pressure confinement if the thermal pressure of the ambient gas is higher than previous estimates. We point out

that confinement by thermal pressure alone implies emission measures in excess of observed values. We show that turbulent pressure, inferred from observed non-thermal velocities, is sufficient to confine UC HII regions and explain their longevity. We predict an anti-correlation between the size of UC HII regions and the velocity dispersion of the ambient neutral gas, and show that it is consistent with existing observations.

Accepted by Astrophys. J. Letters

Two New T Tauri stars and a Candidate FU Orionis Star associated with Bok Globules

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We present photometric and spectroscopic evidence of two new T Tauri stars formed in the conditions of isolated small Bok globules. The spectral energy distributions of these objects display excess infrared emission, they are associated with optical reflection nebulae, and their optical spectra reveal Balmer emission lines and the Li I λ6707 Å absorption line. Additionnally, we report the discovery of what may be a new FU Orionis star seen towards Bok globule CB34. The star is about 4 magnitudes brighter than it appears on the Palomar plates and is associated with the aggregate of young stellar objects forming in Bok globule CB34.

Accepted by A&A.

Preprints of this paper are available via anonymous ftp from the directory pub/papers/FU at delphi.cc.fc.ul.pt

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Dissertation Abstracts

Young Binaries and Early Stellar Evolution

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Ph.D degree awarded: July 1996

Most main-sequence stars are members of binary or multiple systems. The same is true for pre-main-sequence (PMS) stars, as recent surveys have shown. Therefore studying star formation means to a large extent studying the formation of binary systems. Similarly, studying early stellar evolution primarily involves PMS binary systems. In this thesis I have studied the binary frequency among ROSAT selected T Tauri stars in the Chamaeleon T association and the Scorpius-Centaurus OB association, and the evolutionary status of Hα-selected PMS binaries in the T associations of Chamaeleon, Lupus, and ρ Ophiuchi.

The direct imaging and spectroscopic observations in the optical have been carried out under subarcsec seeing conditions at the ESO New Technology Telescope (NTT) at La Silla. Furthermore, high-spatial resolution images of selected PMS stars in the near infrared were obtained with the ESO adaptive optics system COME-ON+/ADONIS.

Among 195 T Tauri stars observed using direct imaging 31 binaries could be identified, 12 of them with subarcsec separation. Based on statistical arguments alone I conclude that almost all of them are indeed physical (i.e. gravitationally bound) binary or multiple systems. Using astrometric measurements of some binaries I showed that the components of these binaries are common proper motion pairs, very likely in a gravitationally bound orbit around each other. The overall binary frequency among T Tauri stars with a range of separations between 120 and 1800 AU is in agreement with the binary frequency observed among main-sequence stars in the solar neighbourhood. However, within individual regions the spatial distribution of binaries is non-uniform. In particular, in Upper Scorpius, weak-line T Tauri stars in the vicinity of early type stars seem to be almost devoid of multiple systems, whereas in another area in Upper Scorpius half of all weak-line T Tauri stars have a companion in a range of separation between $0\farcs7$ and $3\farcs0$.

For a sample of 14 spatially resolved PMS binaries (separations $0\farcs6$ to $1\farcs7$) located in the above mentioned T associations both photometric and spectroscopic information has been analyzed. All binaries (originally unresolved) were identified as PMS stars based on their strong Hα emission and their association with dark clouds. Using the spectral A index, which measures the strength of the CaH band at 697.5nm relative to the nearby continuum as a luminosity class indicator, I showed that the classical T Tauri stars in the sample tend to be close to luminosity class V. Eight out of the 14 pairs could be placed on an H–R diagram. When comparing with theoretical PMS evolutionary tracks the individual components of *all* pairs appear to be coeval within the observational errors. This result is similar to Hartigan et al. (1994) who found two thirds of the wider pairs with separations from 400 AU to 6000 AU to be coeval. However, unlike Hartigan et al.'s finding for the wider pairs, I find no non-coeval pairs. One of the presumed binaries in our sample (ESO Hα 281) turned out to be a likely chance projection with the "primary" showing neither Hα emission nor Li absorption.

Finally, using adaptive optics at the ESO 3.6m telescope, diffraction-limited JHK images of the region around the Herbig AeBe star NX Pup were obtained. The close companion (sep. $0\farcs128$) to NX Pup – originally discovered by HST – was clearly resolved and its JHK magnitudes were determined. A third object at a separation of $7\farcs0$ from NX Pup was identified as a classical T Tauri star so that NX Pup may in fact form a hierarchical triple system. I discuss the evolutionary status of these stars and derive estimates for their spectral types, luminosities, masses, and ages.

My conclusions are that binarity is established very early in stellar evolution, that the orbital parameters of *wide* binaries ($a \geq 120$AU) remain virtually unchanged during their PMS evolution, and that the components of the *wide* binaries were formed at the same time — perhaps either through collisional fragmentation or fragmentation of rotating filaments.

(Copies of the thesis (written in German) and related pre-/reprints are available from the author upon request.)

New Books

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7. Magnetic Fields
8. Galactic Structure, External Galaxies

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