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Abstracts of recently accepted papers

Rotational periods and starspot activity of young solar-type dwarfs in the open cluster IC 4665

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We present the results of a V-band photometric monitoring survey of 15 late-type dwarfs in the young open cluster IC 4665. Low-amplitude periodic light variations are found for 8 stars and ascribed to the modulation by starspots that cover typically a few percent of the stellar disk. Periods range from 0.6 to 3.7d, translating to equatorial velocities between 13 and 93 km.s^{-1}. That no period longer than 4d was detected suggests a relative paucity of extremely slow rotators ($V_{eq} << 10$ km.s^{-1}) among late-type dwarfs in IC4665. The fractional number of slow rotators in IC 4665 is similar to that of Alpha Per cluster, suggesting that IC 4665 is close in age to Alpha Per ($\sim$ 50 Myr).

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On Coagulation and the Stellar Mass Spectrum

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The importance of coagulation in the making of the stellar mass spectrum is studied using two coagulation indicators and the model of Lejeune and Bastien (1986). A search is made for correlations between these indicators and the physical characteristics of the four types of stellar groups investigated here: open clusters (54 cases), OB associations (16 cases), globular clusters (16 cases), and galaxies (13 cases). Although 1- coagulation is certainly not the only physical process which determines eventually the stellar mass spectrum and 2- the Lejeune and Bastien (1986) analytical solution describes only approximately the physics involved, we found that it fits the mass spectra extremely well. The fits are definitely much better than the usual power law fits. The results show that coagulation seems to be pretty independent of the conditions at which it takes place. The means of the coagulation indicators for each type of stellar group are found to be quite close to each other (within the limits of uncertainty), which adds more weight to these results. It is also found that the effects of coagulation are difficult to show, at least for stellar groups with ages greater than $\cong 10^7$ yr. A method of assessing the amount of mass loss by the cluster is also described.

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Twin Herbig-Haro Jets and Molecular Outflows in L1228

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We present new optical, near infrared, and millimeter wavelength observations of the dark cloud L1228 located in the Cepheus Flare. There are at least 2 active young stellar objects within a $2'$ diameter region in the L1228 cloud core that drive two separate Herbig-Haro (HH) outflows, a molecular hydrogen jet, and associated CO outflows. The red nebulous object RNO 129 (HH 198), located 1^o north of the L1228 cloud core, is a Herbig-Haro flow from a T-Tauri star located near the eastern end of the HH object.

The Herbig-Haro object HH 199 is associated with a large molecular outflow (L1228A) centered on a low luminosity (4 $L_\odot$) young stellar object IRAS 20582+7724, the brightest infrared source in this cloud core. The brightest visual wavelength components, HH 199R1 and R2, lie about $8'$ to the southwest of the IRAS source where the redshifted lobe of the CO outflow may be breaking out of the molecular cloud and have velocities up to 50 km s^{-1}. A chain of faint blueshifted ($V \approx -40$ to -150 km s^{-1}) HH objects, HH 199B1 through HH 199B6, lie to the northeast of the IRAS source towards the blueshifted lobe of the L1228A CO outflow. The projected distance between HH 199R2 and HH 199B6 is about $20'$ or nearly 2 pc. Near the center of this outflow, a chain of knots bright in the 2.122μm wavelength S(1) line of molecular hydrogen extends for about $1'$ along a nearly east-west axis on both sides of IRAS 20582+7724. This axis differs from that of the L1228A/HH 199 outflow by about 40^o. We consider a model in which the jet from IRAS 20582+7724 varies in its ejection direction. At present, the outflow as traced by the H_2 jet appears to be impacting dense C_3H_2 emitting clumps east and west of the IRAS source. A redshifted CO ridge extends $10'$ to the west of the IRAS source at the same orientation as the H_2 jet but a more prominent northeast-southwest ridge extends along the HH 199 optical axis from HH 199B6 in the northeast, through the IRAS source, to HH 199R2 in the southwest.

A periodic blueshifted ($V \approx -40$ to -150 km s^{-1}) chain of Herbig-Haro objects, HH 200, is superimposed on the redshifted lobe of the L1228A outflow. It is associated with low velocity blueshifted CO lobe of a second outflow, L1228B. The source of this jet is an embedded T-Tauri star located $1.5'$ northwest of IRAS 20582+7724. There is a faint HH object $9'$ to the northeast of the source of the HH 200 jet, directly opposite the location of the bright bow shock at the end of the blueshifted lobe of the HH 200 jet. This lobe may mark the location of an invisible counterjet. HH 200 has a projected length of over $18'$, corresponding to 1.8 pc (assuming a distance of 300 pc to L1228) and shows quasi-periodic knot spacing of roughly $1'$ corresponding to a projected spacing of 0.09 pc. At a flow velocity of 300 km s^{-1}, and an assumed outflow inclination angle of 45^o, this spacing may be a result of episodes of enhanced mass loss occurring roughly every 500 years.

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Magnetic Braking, Ambipolar Diffusion, and the Formation of Cloud Cores and Protostars: III. Effect of the Initial Mass-to-Flux Ratio

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Two previous papers have formulated the problem of the formation and contraction of protostellar cores in isothermal, rotating, self-gravitating, magnetically supported model molecular clouds, and presented results, respectively, for a typical case and for the effects of varying five dimensionless free parameters of the problem. In this paper, we study the effect of varying the sixth parameter $\mu_{\rm d,c0}$, the initial central mass-to-flux ratio in units of the critical value for collapse. Clouds with initial central mass-to-flux ratio ranging from highly subcritical ($\mu_{\rm d,c0} = 0.1$) to initially critical ($\mu_{\rm d,c0} = 1.0$) are studied. Core formation is initially quasistatic (i.e., negligible acceleration) for the subcritical clouds, but dynamic for the critical cloud. In the case of the critical cloud, magnetic-tension forces bring an end to

the magnetic-braking induced, initial phase of (dynamic) collapse (caused by the rapid loss of rotational support); quasistatic contraction follows. After ambipolar diffusion increases (quasistatically) the central mass-to-flux ratio above the critical value, cores in all model clouds enter a dynamic phase of contraction. We find that, by the end of the isothermal phase of contraction, at a central density enhancement of about 10^6 (e.g., from 3×10^3 cm^{-3} to 3×10^9 cm^{-3}), the widest range of core masses and angular momenta is obtained from the variation of the free parameter $\mu_{\rm d,c0}$; specifically, we find that $M_{\rm core} \propto \mu_{\rm d,c0}$, and $(J/M)_{\rm core} \propto \mu_{\rm d,c0}^2$. The observationally guided range of values of $\mu_{\rm d,c0}$ in our parameter study can explain naturally a range of core masses 3 - 30 $M_\odot$ and specific angular momenta $10^{19} - 10^{21}$ cm^2 s^{-1}.

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Modelling accretion in protobinary systems

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A method for following fragmentation simulations further in time using smoothed particle hydrodynamics (SPH) is presented. In a normal SPH simulation of the collapse and fragmentation of a molecular cloud, high-density regions of gas that form protostars are represented by many particles with small separations. These high-density regions require small time steps, limiting the time for which the simulation can be followed. Thus, the end result of the fragmentation can never be definitively ascertained, and comparisons between cloud fragmentation calculations and the observed characteristics of stellar systems cannot be made.

In this paper, each high-density region is replaced by a single, non-gaseous particle, with appropriate boundary conditions, which contains all the mass in the region and accretes any infalling mass. This enables the evolution of the cloud and the resulting protostars to be followed for many orbits or until most of the original cloud mass has been accreted.

The Boss & Bodenheimer standard isothermal test case for the fragmentation of an interstellar cloud is used as an example for the technique. It is found that the binary protostellar system that forms initially does not merge, but instead forms a multiple system. The collapse is followed to 4 initial cloud free-fall times when approximately 80% of the original mass of the cloud has been accreted by the protostars, or surrounds them in discs, and the remainder of the material has been expelled out to the radius of the initial cloud by the binary.

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Ionized Carbon in NGC 6334

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We have observed the 158 μm $^2P_{3/2} - {}^2P_{1/2}$ fine-structure transition of C^+ along the ridge of star formation in NGC 6334 with a velocity resolution comparable to that of millimeter-wave molecular and recombination lines. The C II radiation is bright and widespread, with integrated intensities $I_{\rm int} > 10^{-4}$ erg cm^{-2} s^{-1} sr^{-1} along a line extending over $16'$. There is a general correlation between regions of intense C II emission and warm dust and CO radiation, such as would be expected for phenomena which are all associated with star formation, but no small-scale correspondence is found. The C II excitation temperature is higher than that of the dust or CO. The line profiles are complex, with evidence for self-absorption as well as emission from H II regions. No single physical component of the gas appears responsible for the observed C II line profiles, as is usually the case for CO or recombination lines. Rather, the PDR, ionized gas, and colder or more tenuous material all contribute, with relative importance determined by the geometry and energetics of the region.

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Plateau de Bure Observations of HL Tau: Outflow motions in a remnant circumstellar envelope

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We present ^{12}CO (J=1-0) observations of HL Tau with the Plateau de Bure interferometer (PdBI, 3″ beam) and the IRAM 30-m (22″ beam). On a large scale, HL Tau drives an anisotropic, mostly redshifted bipolar outflow, and is located within a flattened remnant envelope roughly perpendicular to the jet axis, of mass ~ 0.2 M$_\odot$. PdBI maps reveal small-scale structures nested within these regions. A broad range of velocities is present. However, interferometric maps are severely contaminated by extended emission for velocities less than 0.8 km.s^{-1} from line center, which hampers a totally unambiguous interpretation. In the present analysis we concentrate on velocities sufficiently large to be mostly unaffected by this confusion problem.

We do not find convincing evidence for rotation in our data. We also identify several problems with the pure infall interpretation proposed by Hayashi et al. (1993). The required central mass would be at least $1.5 - 3.5$ M$_\odot$ for $i = 55°$-$80°$, which seems uncomfortably large. In addition, the detailed velocity structure and the asymmetry between blueshifted and redshifted gas are not well explained. Hence, infall alone cannot reproduce all of our observations. We derive an upper limit to the free-fall rate toward HL Tau of $\sim 6 - 9 \times 10^{-6}$ M$_\odot$/yr .

The problems encountered by an infall model, together with the known presence of a molecular outflow from HL Tau, lead us to propose that kinematics in the remnant envelope around HL Tau are heavily affected by entrained outflow motions. The distinctive blue/red asymmetric structure in our PdBI maps (blueshifted emission is weaker and mostly confined in the system midplane, while redshifted emission is stronger and more closely follows the jet axis) is then naturally accounted for, as the same asymmetry is observed in the large-scale bipolar outflow from HL Tau.

The action of jet bowshocks, or the steady-state entrainment of circumstellar gas, seems able to explain the transverse extent of the perturbed gas and its overall kinematics. The net molecular mass outflow rate is large ($\sim 4 - 10 \times 10^{-6}$ M$_\odot$ yr $^{-1}$), far exceeding the present disk accretion rate, and at least comparable to the envelope infall rate. Envelope clearing by jet entrainment could then be an important process regulating the inner disk accretion rate in HL Tau, as well as the transition to the fully optically revealed T Tauri stage.

If our estimates of outflow and infall rates are correct, the modest envelope mass ~ 0.2 M$_\odot$ inferred from our IRAM 30-m observations indicates that HL Tau has already accumulated most of its final stellar mass, and that it is in a relatively short-lived ($\leq 5 \times 10^4$ yr) phase of energetic mass ejection, leading to envelope dispersal.

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An analytical method for computing optically thick line profiles

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We present a simple-minded approach to the computation of line profiles in the limit of zero line width and infinite optical depth. The method is a generalisation of the model of Morris (1975). The line is assumed to arise from a spherical clump with a radial velocity field: both the expansion/collapse velocity and the excitation temperature of the emitting gas are described by a power law dependence on the clump radius. The computation turns out to be almost fully analytical. The model results are compared with profiles observed in the molecular environment surrounding ultracompact HII regions.

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Dust emission from protostars: the disk and envelope of HH24MMS

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High-resolution imaging of the protostar HH24MMS at wavelengths of 7 mm and 3.4 mm shows the dust emission to originate from two components: an unresolved disk and an extended envelope. The envelope is an order of magnitude more massive than the disk, suggesting that HH24MMS is very young, since the fraction of circumstellar material in an extended component probably decreases with the age of the forming star. For the disk, the frequency dependence of the dust mass opacity coefficient, β, is 0.68 ± 0.12, significantly lower than the interstellar medium value of 2. In the envelope β is less well constrained, but must lie in the range 0 to 1.9. Emission from the disk dominates at wavelengths longer than 3 mm, but the far-infrared emission is relatively weak. This suggests that the envelope is optically thick at wavelengths as short as 60 μm, and obscures the disk.

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Near Infrared Observations of Southern Young Multiple Systems

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We report observational results from near infrared slit scanning of 16 southern pre-main sequence multiple sources. For each system, we derive the angular separation and the magnitude difference in the J, H, K and in most cases L bands. Two systems (Sz 30 and LkHα 346) are found to be triple and four (Herschel 4636, LkHα 346, RNO 92 and VV CrA) exhibit a flux inversion among the components between 0.55 and 3.61 μm, that is, the secondary as defined in the visual begins to dominate the system light at infrared wavelengths.

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Molecular H_2 Emission in HH47A: HST GHRS and FOC Observations

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We present HST ultraviolet observations of the bow shock at the end of the HH 47 stellar jet obtained with the GHRS Spectrograph and the FOC Camera. The GHRS spectrum shows three prominent emission lines of H_2 which are produced by Lyα fluorescence, and one line that we cannot identify. Fluorescence from Lyα generated in the bow shock and Mach disk of HH 47A can account for the observed H_2 line fluxes provided that the H_2 absorbs about one-third of these Lyα photons. We find that our FOC image of HH 47A is made up of about 70% hydrogen two photon continuum and about 30% fluorescent H_2 emission. This image closely resembles optical [S II] and Hα images of HH 47A, but differs significantly from H_2 images of the region taken at near-infrared wavelengths. This is because

the two photon continuum and the Lyα photons which drive H_2 fluorescence both originate in the Hα emitting gas, and the Lyα mean free path is small.

The presence of molecular hydrogen in HH 47A is difficult to understand. If the H_2 forms in a dense region between the bow shock and the Mach disk, then the emission should be significantly more blueshifted than observed. Models that excite H_2 using C-shocks or magnetic precursors assume that molecular hydrogen exists in the preshock gas of HH 47A. However, this gas lies within the wake of a previous high velocity ejection from the star and is exposed to ionizing radiation from the Gum nebula, so we would not expect to find any H_2 in this region.

Numerical calculations indicate that the UV H_2 line emission may be produced by either reformed H_2 molecules in the region between the bow shock and the Mach disk or from a C-shock or Magnetic Precursor, while the near infrared H_2 emission observed in HH47A arises mainly from a C-shock or Magnetic Precursor along the wings of the bow shock. We propose that the scenario that best explains the current results is one where the HH47A bow shock is running into a clump of molecular gas which could be either co-moving with the preshock gas or nearly stationary with respect to the ambient cloud, primary on its more distant face.

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A copy of this paper is available via the World Wide Web at: http://cfa-www.harvard.edu/~curiel/papers.html

On the Global Stability of Magnetized Accretion Disks. II. Vertical and Azimuthal Magnetic Fields.

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We investigate the global stability of a differentially rotating fluid shell threaded by vertical and azimuthal magnetic fields to linear, axisymmetric perturbations. This system, which models a thick accretion disk in the vicinity of its midplane, is susceptible to the Velikhov-Chandrasekhar (VC) instability in the absence of the azimuthal field. In most cases, the azimuthal field tends to stabilize the VC instability, although strong fields (Alfvén speed of order the characteristic rotational speed in our incompressible model) are required for complete stabilization. Stability diagrams are constructed, indicating critical values of the two fields for instability. We find an additional strong field instability that arises when the azimuthal Alfvén speed exceeds the characteristic rotational speed. This instability, in the case of a freely bounded configuration, has certain similarities to the sausage instability for interpenetrating fields in plasma physics, and may be important for very massive disks or filamentary molecular clouds. An application to the L1641 region in Orion A is briefly discussed. Finally, we find that the effect of a radially varying vertical field (without an azimuthal field) is mainly stabilizing.

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Near-infrared and optical imaging of the L 1551-IRS 5 region – the importance of poorly collimated outflows from young stars

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The bipolar outflow from L 1551-IRS 5 is perhaps the archetypal example of the outflow phenomenon amongst young stellar objects (YSOs). In this paper we report on near-infrared observations of the L 1551-IRS 5 region in the 2.12 μm line of shocked H_2. Although copious amounts of emission are discovered in the blueshifted molecular lobe, surprisingly, none is found in the redshifted one. Generally the H_2 emission is knotty or amorphous. Only one H_2 emission region, HH 260, appears bow shock shaped in our data, with the axis of the bow pointing back towards IRS 5. Our H_2 observations are compared with high quality optical data obtained by us through [SII] $\lambda\lambda$6716,6731, Hα and nearby

narrowband continuum filters. There appears to be only a weak spatial correlation between the optical emission, recording shocks with $V_{shock} \geq 40$ km s^{-1}, and the shocked H_2 emission, which traces lower shock velocities. As an example, the IRS 5 jet is not detected at 2.12 μm. Much of the optical and near-infrared line emission is patchy, and covers a wide range of position angles as seen from IRS 5. All of this emission, however, is confined to an ovoid-shaped and presumably wind blown cavity which has a total extent of 0.45 pc and a dynamical age of about 2200 yrs. Within this emission-line cavity, which we refer to as the "Hα cavity", the high-velocity CO gas is also found. The slower CO gas and an additional cavity seen only in scattered light lie outside this emission line cavity.

The presence of both the highly-collimated jet from IRS 5 and the poorly-collimated flow seen much further away (as evidenced by the Herbig-Haro (HH) emission within the Hα cavity spread over a large range of position angles as seen from the source) is difficult to reconcile. In the past it has been suggested that there is a poorly collimated wind from the source in addition to the jet and that it is this component, rather than the jet, that drives the associated CO outflow and powers the large amount of "off-axis" HH emission. This idea, however, does not account for many of the observations in IRS 5 and in other poorly collimated outflows. We therefore suggest that the opening angle of the outflow varies with time so that sources like IRS 5 pass through alternative phases of poor and high degrees of collimation. In IRS 5, this scenario can in principle explain the observed "scattered light cavity" and shell of low-velocity CO gas, both of which enclose the "Hα cavity" and the high-velocity CO flow. The implications for other poorly collimated outflows from YSOs, and for the acceleration of their CO flows, is also examined. Finally, we briefly consider possible implications for the origin of cometary reflection nebulae.

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CO and shocked H_2 in the highly collimated outflow from VLA1623

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We show large-scale ^{12}CO and H_2 images of the outflow from the proposed 'class 0' young star VLA1623. Shocked H_2 emission is clearly associated for the first time from this flow. Most of the H_2 lies in compact knots, each of which is downstream from a peak in the high-velocity CO. The total outflow mass derived from the CO data is 0.32 $M_\odot$, most of which lies in the extended blue-shifted southeast flow. The outflow in this direction is ≥ 15 arcminutes ($0.7pc$) in length with an opening angle of $\leq 1.6°$. It can be divided into two regions: the first, within $0.07pc$ of the star, has a conical shape. Beyond this radius, the low-velocity CO has a limb-brightened morphology, with a narrower, centrally-peaked lane at high velocities; this is indicative of flow along the walls of a cylindrical cavity. We suggest that most expansion of the outflow cavity occurs within the initial $0.07pc$ of the source; beyond this the molecular flow is confined to a cylinder of constant width $\sim 0.03pc$. Comparison of the CO and H_2 results tend to suggest that the NW side of VLA1623 may contain two separate flows.

The near-infrared continuum image shows the dense cloud around the VLA1623 source in silhouette against a background nebula. There is no evidence of elongation perpendicular to the outflow direction, and the core has a sharp outer radius of $\sim 0.02pc$, with no surrounding lower-density accreting envelope. Fits to the radial distribution of extinction indicate a Gaussian rather than shallow power-law density gradient.

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Near–Infrared and Very High Sensitivity VLA 2 cm Continuum Observations of the HII Region G29.96−0.02

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The ultra–compact HII region G29.96−0.02 has been imaged at a frequency of 15 GHz using combined multiple VLA configuration data. The images show a remarkably complex structure. The edge–brightened arc–like core of the HII

region is embedded in low level emission extending over several tens of arcseconds ($1'' \approx 0.036$ pc). Filamentary–like structures are observed east of the core, some perpendicular to the symmetry axis of the arc–like core. These radio continuum observations are inconsistent with predictions of current models for ultra–compact HII regions. Near–infrared images have also been obtained with the USNO infrared camera. These images identify the position of the ionizing star and suggest that the HII region is embedded in a young stellar cluster. We suggest a model in which the radio continuum appearance of G29.96−0.02 may be explained simply by expansion in a highly anisotropic medium; more exotic models are not required. To the west, the HII region is expanding into a region with a relatively high ambient density. This denser region impedes the expansion of the HII region in that direction. Molecular material is photo–evaporated off a hot molecular core and is then swept back along pressure gradients, creating the cometary appearance. On the eastern side, the HII region freely expands into a less dense but still highly anisotropic ambient medium, thus creating the observed filamentary structure.

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Thermal Jets and H_2O Masers: The Case of HH 80-81

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We present high angular resolution ($\sim 0\farcs3$) VLA observations of the H_2O (22.2 GHz) maser emission toward the HH 80-81 thermal radio jet. We find that the H_2O maser is located at $\sim 7''$ to the NE of the core of the jet, clearly not coincident with it. A deep 3.5 cm VLA radio continuum map reveals the presence of a weak ($\sim 0.05 \pm 0.01$ mJy) radio source coincident in position (within $0\farcs1$) with the H_2O maser. In this region, the thermal jet and the H_2O maser are most probably being powered by different stars. We discuss this and other cases of thermal jets with nearby H_2O maser emission.

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Warm Molecular Gas Associated With Cometary H II Regions

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We present observations of the (J,K)=(2,2) and (3,3) inversion transitions of ammonia, made at $\sim 4''$ resolution with the VLA, in the direction of the G32.80+0.19 and G61.48+0.09 star forming regions, which contain cometary-like and compact H II regions. Our data reveal the presence, in both complexes, of compact ammonia structures, with sizes of ~ 0.2 pc, which are intimately associated with the regions of ionized gas. The ammonia clumps have excitation temperatures in the range $60 - 80$ K and molecular hydrogen densities in the range $0.7{-}5 \times 10^4$ cm^{-3}. We suggest that these warm ammonia clumps correspond to compact molecular structures, embedded within more extended molecular clouds, which have been heated by the radiation from the star that ionizes the associated HII region and possibly compressed by the shocks driven by the expansion of the HII region.

We find that the molecular clumps associated with the cometary-like HII regions are located near the head of the ionized region and have line center velocities similar to those of the ionized gas at the head position. These results imply that the cometary HII regions studied here, which exhibit strong gradient in the line center velocities along their symmetry axis, are experiencing the champagne phase of evolution. In particular the case of G61.48-0.09 is interesting because it seems that two champagne flows are occurring in this HII region. The ammonia clump associated with the most compact HII region within the G32.80+0.19 complex exhibits the (2,2) main HF line in absorption and the (3,3) main HF line in emission, which we explain as due to a blend, within a synthesized beam, of an emitting region of hot molecular gas and an absorbing region of cold gas in front of a continuum source.

Accepted by The Astrophysical Journal

Dust around Young Stars: Photopolarimetric Observations of the T Tauri Star BM And

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The results of photoelectric UBV observations of the T Tauri type variable BM And made during 1983-1991, as well as of simultaneous photopolarimetric $UBVRI$ observations of this star for 1990-93 are given. In the course of these observations both the brightest ($V = 11.6^m$) and the weakest ($V = 14.1^m$) states of this star were registered. It is shown that the initial reddening of the star during a minimum is stopped at the same brightness level and the star can be bluer in the color $U - B$ during the deepest part of minimum.

The decrease of brightness of BM And is accompanied by an increase of the linear polarization (up to 3-7%) simultaneously in all $UBVRI$ bands. These changes agree with the observed ones by Kardopolov & Rspaev (1991) and are, in their nature, similar to those observed in Herbig Ae stars with non-periodic Algol-type minima. The similar behaviour both of the color index and of the polarization of BM And and of these stars indicates that the stellar radiation scattered by dust particles in the circumstellar disk is the source of the intrinsic polarization and reduced blue radiation observed at the deepest minima. This intrinsic component of the linear polarization was separated from the observed one.

Study of the interstellar (IS) polarization of the nearby stars shows that IS magnetic field in this region has a regular structure, and the vector of intrinsic linear polarization of BM And is a parallel to the lines of magnetic force. The latter means that the circumstellar disk of BM And lies in the plane normal to IS magnetic field if the disk is optically thin. Such an orientation points to the important role of magnetic field during the initial stage of gravitational collapse of the protostellar cloud from which BM And was formed.

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Identification of Ionizing Sources and Young Stellar Objects in M17

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We have obtained high-quality 2-μm (K-band) spectra of 25 stars in the direction of the heavily extincted, Galactic star-forming region M17. Interloping cool field giants are a potential source of confusion, but K-band spectra combined with normal JHK colors can identify and distinguish these stars via their strong CO absorption features at $\lambda \geq 2.29\mu$m. Among the other sources, we have identified five stars as O type from their spectral lines of HI, HeI, HeII, and NIII by using a K-band classification system that we have developed (Hanson & Conti 1994, ApJ, 423,L142). These provide the number of Lyman continuum photons required by radio continuum observations. The remaining stellar objects, all but one with strong NIR excesses, show completely different spectral characteristics from known main-sequence stars. Three are completely featureless throughout the K band, four (possibly five) show CO bands in emission and two (candidate FU Orionis-like objects) have CO bands in absorption combined with extreme NIR excesses. We suggest that these stellar objects are relatively massive YSOs, still shrouded by circumstellar material.

Accepted by The Astrophysical Journal Letters

Studies of Embedded FIR sources in the vicinity of H_2O masers – I. Observations

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We have undertaken a search for sub-mm embedded cores associated with known water maser sources. For 44 water maser sources, we found sub-mm continuum emission from 40 (91 per cent) of them using the James Clerk Maxwell Telescope (JCMT). Some of the sources were then observed further. Maps were made in CO and $C^{18}O$ ($J = 2 \rightarrow 1$) and CS ($J = 5 \rightarrow 4$), using the JCMT, so that the molecular environment of the sources could be examined. In addition the Very Large Array (VLA) was used to find accurate positions for the water maser emission and hence any association with compact radio continuum sources. A preliminary examination of the data shows that most of the

water masers are on average closer than 0.1 pc to the corresponding sub-mm source. A more detailed analysis will follow in a later paper.

Accepted by Monthly Notices of the Royal Astronomical Society

Disk Winds from T Tauri Stars

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We examine the observed characteristics of the low velocity emission of forbidden lines in T Tauri stars and present arguments for a disk wind origin for that emission. Using the representative values of observed line luminosities and ratios, we find that the ionization fraction in the [OI] 5577 emission region is high, about 0.1, and that the mass loss rate in the disk wind is considerably smaller than the mass accretion rate in the disk. Assuming that the disk wind is caused by a torque exerted by the magnetic field in the disk, we obtain relations between the properties of the disk wind and the magnetic field parameters at the base of the wind. We find that the product B(phi)B(z) has a typical magnitude of about 0.4 (gauss)**2 at r=10**13 cm, and that centrifugal flinging via magnetic acceleration is needed to propel the wind. However, a large portion of the energy available from accretion is lost to radiation, owing to heating and ionization of the gas while it is being accelerated.

Accepted by Ap. J.

Time variable shocks in the UV: Long term IUE monitoring of HH 29

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We have used the IUE to the limit of its capability ($\sim 10^{-15}$ erg cm^{-2} s^{-1} Å^{-1}) and present results based on long term monitoring in the UV of the Herbig-Haro object HH 29, which is dynamically coupled to the outflow activity from the deeply embedded low mass stellar object IRS 5 in the L 1551 dark cloud. The eight years of IUE observations confirm the degree of variability of the object, originally discovered by Cameron & Liseau (1990; A&A 240, 409), both what concerns the amplitudes (factor of two) and short time scales (less than 0.5 yr). We have now also found declines in brightness with these short time scales, implying local particle densities clearly in excess of 10^4 cm^{-3}. The variations of the shortwave continuum ($\sim$ 1200–1950 Å) and of the high ionization species follow a similar pattern, whereas the intensity variations of forbidden lines from low ionization species appearanti-correlated. Such behaviour is consistent with HH 29 changing its degree of excitation with time, probably because of multiple shocks in the object. We argue that the Mg II *h&k* lines are optically thick which would explain why they are observed not to vary. From this we estimate that the true variability time scale of HH 29 is of the order of weeks (10^6 s) rather than that determined by the observing frequency, which is several months (10^7 s). The slope of the very blue shortwave continuum varies in time as well, which we interpret to be caused by changing temperatures as a consequen ce of the different shock waves passing through the object. Combining the IUE data with simultaneous ground based observations leads us to construct a two-phase model for HH 29 from which we derive the physical parameters of the object. In addition to a conventional component (10^4 K and 10^3 cm^{-3}), a hot component (several times 10^4 up to more than 10^5 K) having average densities at least as high as 10^6 cm^{-3} is required to reconcile with the observations. The volume filling factor of this gas is consequently small (on the order of 0.1–1%). From comparisons with the high excitation objects HH 1/2 we infer that the multi-phase conditions characterizing HH 29 probably also apply to other, less systematically observed HH objects. From the UV luminosity generated by the shocks in HH 29 ($0.5\,L_\odot$) we infer a lower limit to the rate at which the central source IRS 5 loses mass ($> 2\,10^{-5}\,M_\odot$ yr^{-1}). This limit on the mass loss rate is considerably larger than any conceivable mass accretionrate for the stellar object (probably significantly less than 10^{-5} $M_\odot$ yr^{-1}). Given also the observed variability of HH 29 we argue that the flow from IRS 5 is probably neither homogeneous nor steady in time. This could potentially reduce the mass loss rate otherwise needed to account for the observed radiative losses in the L 1551 flow.

Accepted by Astron. Astrophys.

BIMA Array CS J=2→1 Observations of Sagittarius B2

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Observations of the $J = 2 \rightarrow 1$ transition of CS toward the Sgr B2 star-forming region have been carried out using the BIMA (Berkeley-Illinois-Maryland Association) array. The angular and spectral resolutions are $9'' \times 14''$ ($\alpha \times \delta$) and 1.2 km s^{-1}, respectively. Results indicate that a high velocity (FWZI$\sim$60 km s^{-1}) molecular outflow is present in Sgr B2(M), a core which contains more than 20 compact and ultracompact H II regions. The mass of the outflow, derived assuming a normal CS abundance of 2×10^{-9}, is 8000 $M_\odot$. Because this derived mass is much higher than that derived from previous observations, it is likely that the fractional abundance of CS in the Sgr B2(M) outflow is significantly higher than the usual value. No CS emission is observed toward Sgr B2(N), a core/outflow source $\sim 50''$ north of Sgr B2(M). The absence of CS emission toward this core is due at least in part to self-absorption from the extensive molecular envelope. It is also possible that CS is underabundant toward the Sgr B2(N) core. CS absorption is observed toward both the Sgr B2(M) and (N) continuum sources. Much of the absorbing material is probably located in the extensive envelope of the Sgr B2 molecular cloud and other clouds not associated with Sgr B2 that lie along the same line-of-sight.

Accepted by ApJ

Discovery of Herbig-Haro Objects and Molecular Hydrogen Jets Near Bok Globule CB34

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We report the discovery of four new Herbig-Haro objects (HH 290 S, HH 290 N1, HH 290 N2, and HH 291) and molecular hydrogen jets associated with the star formation activity seen in Bok globule CB 34. The HH objects were discovered in narrow-band [SII] and H_α CCD images.

Two of these objects are also seen in a corresponding 2.12 μm $v = 1 - 0$ S(1) H_2 near-infrared image confirming their shock emission nature. These objects are likely to be driven by an embedded near-infrared source belonging to the aggregate of young stellar objects found by Alves & Yun (1995).

Additional shock emission features appear in the molecular hydrogen image. We identify two sets of infrared structures extending for about 0.15 pc and towards the region of highest extinction in the cloud. The features in each set are well aligned and are likely to trace the presence of embedded jets with high degrees of collimation.

Taken together, these features delineate three separate chains of shock excited nebulae. One chain is seen in both the optical and near-infrared images. Of the other two chains, one is seen partly in the optical and partly in the infrared, and the other is seen only in the infrared images.

Accepted by *The Astrophysical Journal*

A copy of this paper is available via the World Wide Web. Connect to http://delphi.cc.fc.ul.pt/papers/paperHH

Circum-Protostellar Environments III. Gas Densities and Kinetic Temperatures

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We have surveyed a complete, flux-limited, *IRAS*-selected sample of protostars in Taurus whose infrared through millimeter-wave properties indicate them to be younger than T Tauri stars. We have observed CS J=3-2, 5-4 and 7-6,

and H_2CO $J_{K_{-1}K_{+1}}$=$3_{03}-2_{02}$ and $3_{22}-2_{21}$, toward the central positions of all 25 objects. CS traces the dense gas in the circumstellar envelope, while H_2CO probes the kinetic temperature of the dense gas. Only three of the sources were detected in both transitions of H_2CO, making it of limited use as a temperature probe of these objects. Combining the CS- and H_2CO-derived properties with those previously derived from dust continuum emission, we have placed limits on the temperatures of the envelopes, typically 20K$\leq T_K \leq$50K. Derived envelope gas densities and CS column densities were typically a few$\times 10^6$ cm^{-3} and a few$\times 10^{12}$ cm^{-2} respectively. Where CS 5-4 was detected (roughly half of the observed sources), the derived envelope masses were consistent with those derived from dust emission (assuming a CS/H_2 abundance of 10^{-8}). Since most of the embedded (i.e. not optically visible) sources were detected in CS 5-4, and most of the visible sources were not, this may mean either that the CS-emitting envelope has dissipated in the more evolved objects (confirming Ohashi et al. 1991), or CS has become depleted.

L1551NE may have an asymmetric, double-peaked line profile like that of B335, suggestive of a collapsing envelope. L1551NE may be in transition from the much younger "class 0" protostar stage to the somewhat more evolved "class I" protostar stage.

Several of the sources have broad CS line wings probably originating from dense gas in a molecular outflow. In at least one case, the kinetic temperature of the outflowing gas may be greater than that in the envelope.

Accepted by Astroph. J.

Weak-line T Tauri stars south of Taurus

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We report on the discovery of 15 new weak-line T Tauri stars (wTTS) south of the Taurus molecular clouds based on the large database produced by the ROSAT All-Sky Survey. High-resolution spectroscopy of 109 optical counterparts of X-ray sources has been performed to measure their radial velocities in order to verify kinematic membership to the Taurus T association. Using additional mid-resolution spectroscopy of 44 sources we find that 15 stars exhibit TTS characteristics such as weak $H\alpha$ emission, Li 6708 Å absorption, and late spectral types. On the basis of their Lithium abundance we suspect that these 15 new wTTS are relatively young. Seven of them have radial velocities between 12 and 21 km/s, i.e. consistent with previously known TTS in Taurus molecular clouds, while other new wTTS lie up to 50 pc away from regions of ongoing star formation and have radial velocities far off the mean Taurus velocity. The region populated by wTTS in the direction of Taurus extends much further south than previously assumed.

Accepted by A.&A. (preprints are available from Ralph Neuhäuser, Internet: rne@hpth03.mpe-garching.mpg.de)

Formation of Lithium lines in very cool dwarfs

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We present LTE and NLTE results on the formation of LiI lines (λ6103, λ6708, and λ8126) in the atmospheres of solar metallicity dwarfs with effective temperatures in the range 5500 K to 2000 K. NLTE effects are governed by overionization of Li and by the interlocking effects of energy levels. For stars with effective temperature $\geq$ 4000 K, we confirm previous findings by Magazzù et al. (1992). NLTE corrections can lower the LTE Li abundances derived from strong LiI lines by up to 0.5 dex.

Our computations using model atmospheres with temperatures between 3000 K and 2000 K show that prominent LiI lines are formed. We give a set of line profiles, which support the feasability of the Li test for brown dwarfs. The ionization-dissociation equilibrium for Li species was carefully considered. NLTE effects on the LiI lines of very cool dwarfs are found to be small, implying corrections to the LTE Li abundances lower than 0.1 dex. Several numerical experiments have been carried out to estimate the effects of chromosphere-like structures on the formation of LiI lines. Our preliminary results suggest that in the presence of very strong chromospheres, the line strengths are reduced.

Accepted by Astronomy and Astrophysics (Main Journal)

Gravitational instability in turbulent, non-uniform media

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We present a gravitational instability analysis for a non-uniform medium, with "microturbulence" characterized by a kinetic energy spectrum $E(k) = Ak^{-\alpha}$, and within which density condensations ("clouds") follow a density-size scaling law of the form $\rho(k) = Bk^{\beta}$, where $k \sim 1/l$, and l is the scale size. Model terms are used for the turbulent pressure and for the scale dependence of the gravitational potential. Since the initial state is already non-uniform, this work bypasses the problem of cloud formation, and just focuses on the problem of cloud support against gravitational collapse.

We find that a variety of regimes exist depending on the parameters α and β. The case $\beta > 2$ implies a total inversion of the Jeans criterion, with small clouds being unstable and large clouds stabilized by turbulent pressure, regardless of the spectral index α. If $\beta < 2$, then two possibilities exist: if $\alpha + \beta < 3$, then the original Jeans criterion is recovered, while if $\alpha + \beta > 3$ small clouds are stabilized by thermal pressure, and large clouds are stabilized by turbulent pressure, with the possible existence of an intermediate range of cloud sizes that are unstable. The special case $\alpha + \beta = 3$ is discussed. It corresponds to virial balance between gravity and turbulent pressure at all cloud sizes. This case includes the empirical scaling relations $\rho \sim l^{-1}$ and $\Delta v \sim l^{1/2}$, although a continuum of other possible combinations exist. More generally, however, a wide range of stable configurations exist that do not require precise balance between gravity and turbulence at all cloud sizes.

Finally, we discuss the assumptions necessary to perform a linear instability analysis for this problem, in particular that of microturbulence. We conclude that this type of calculations can only provide crude guidelines for media with large-amplitude fluctuations such as the interstellar medium, a complete understanding of which most likely necessitates fully nonlinear calculations.

Accepted by Astron. Astrophys.

A Rapidly Moving Shell in the Orion Nebula

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A well resolved elliptical shell in the innner Orion Nebula has been investigated by monochromatic imaging plus high and low resolution spectroscopy. We find that it is of low ionization and the two bright ends are moving at -39 and -49 km s^{-1} with respect to OMC-1. There is no central object, even in the infrared J bandpass although H_2 emission indicates a possible association with the nearby very young pre-Main Sequence star J&W 352, which is one of the youngest pre-Main Sequence stars in the inner Orion Nebula. Many of the characteristics of this object(low ionization, blue shift) are like those of the Herbig Haro objects, although the symmetric form would make it an unusual member of that class. Accepted by The PASP July 1995 issue

Sub-arcsecond Imaging of W3(OH) at 87.7 GHz

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We report continuum observations of the W3(OH) region with the BIMA array at an effective frequency of 87.7 GHz with sub-arcsecond resolution ($0\farcs7 \times 0\farcs5$). The bright ultracompact HII region shows a shell-like morphology, consistent with an extrapolation from lower frequencies of optically thin free-free emission with no significant contribution from dust. A weak unresolved continuum source is detected $6''$ to the east of the ultracompact HII region, coincident with the elongated centimeter-wave synchrotron source associated with the TW object. The source brightness temperature is approximately 20 K, and the spectral index between 87.7 GHz and 111 GHz is characteristic of optically thin thermal

dust emission. Assuming standard dust properties, we estimate that the underlying source luminosity is $10^3 - 10^4$ $L_\odot$, and we derive a mass of $10 - 20$ $M_\odot$ for the emission region. We speculate that this represents circumstellar material about to be incorporated into a newly forming star, making the TW object the high-mass equivalent of a "Class 0" low-mass protostar.

Accepted by The Astrophysical Journal (Letters)

Stars approaching the Substellar Limit in the α Persei Young Open Cluster

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We present mid resolution optical spectroscopy of seven very low mass stars in the α Persei open cluster. The brown dwarf candidate AP0323+4853 (spectral type M6) is included in the sample. Our radial velocity measurements indicate that all of them are highly probable cluster members. Hα equivalent widths have been measured and compared with previous published data for other known members. A turnover in the chromospheric activity around spectral type M3-4 is observed. AP0323+4853, located in the cool side of the turnover is confirmed to exhibit large Hα variability. This object is the coolest α Persei member for which spectra are available and for which chromospheric activity has been measured.

Using the LiI doublet at λ670.8 nm, we derive upper limits to the atmospheric Li abundance in the sample and discuss them in the context of the most recent evolutionary tracks. The non-detection of Li in the spectrum of the brown dwarf candidate implies a mass greater than 0.08 $M_\odot$, and therefore it is not a substellar object. However, its position in the HR diagram suggests that this star is very close to the substellar limit.

Accepted by Astronomy and Astrophysics (Main Journal)

New Books

Kinematics and Dynamics of Diffuse Astrophysical Media

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H.C. van de Hulst: Cosmical Aerodynamics - Why was it so difficult?
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T.P Ray: Herbig Ae/Be Stars
J.M. Porter: Radiatively Driven Winds Using Lagrangian Hydrodynamics
K. Wood: Parametric Determination of the Inclination of Keplerian Circumstellar Discs from Spectropolarimetric Profiles of Scattered Lines
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S.J. Chapman et al.: Star Formation in Shocked Layers

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Meetings

Jets from Stars and Galactic Nuclei

to be held 3 to 7 July, 1995 in Bad Honnef, Germany

Organizer: Wolfgang Kundt (University of Bonn)

The jet phenomenon is encountered not only on (meta-)galactic scales but also on stellar scales, i.e. from several Mpc down to fractions of one pc. It shows very uniform morphologies: jets, knots (Herbig-Haros), heads (bowshocks), and lobes (cocoons), typical jet opening angles of 10^{-2}, no jet branching ever, cocoon elongations 1:5, jet/lobe-power ratios of 10^{-2} to 10^{+2}, sidedness, rapid core variability, superluminal knot motions, very broad spectra. For largely historical reasons, this rather uniform phenomenon has found very different explanations by theorists throughout the years: Beams of extremely relativistic pair plasma (bulk Lorentz factor above 10^2) were proposed for the extragalactic radio sources in Nature 288, 149 (1980), hydrogen bullets for SS 433, light beams shining through cloud holes for object 50 in Orion, supermassive black holes for the engines of the extragalactic sources, but very young stars, neutron stars, and white dwarfs for the engines of the stellar sources. In Ap.J. 429, L57 (1994), Begelman, Rees & Sikora collect old and new reasons in favour of bulk Lorentz factors above 10^2. In their forthcoming Ann.Rev. article, Kormendy and Richstone leave little evidence for the presence of supermassive black holes in the centers of nearby galaxies. Numerical simulations reported in Nature 354, 374 (1992), and more recently by Marti et al (Garching) show "unexpected" stabi- lity for jets of high bulk Lorentz factors. It therefore seems timely to critically compare the various proposed mechanisms for jet production, collimation, and upgrading. A key question will concern the in-situ acceleration of electrons (and positrons) to large Lorentz factors.

Up to 30 active participants are envisaged.

Further inquiries should be directed to the organizer (wkundt@astro.uni-bonn.de).