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Abstracts of recently accepted papers

Outflows in the Orion Nebula: HH 540 from the Beehive Proplyd

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We present *Hubble Space Telescope* ACS images of the giant proplyd 181-826 in the southern Orion Nebula. This object exhibits a variety of known proplyd properties – an optically-visible central star, a silhouette disk, a bright proplyd ionization front, and a bipolar microjet emerging along the disk axis which powers a larger Herbig-Haro flow. The proplyd ionization front is remarkable because of its large size (a radius of about 800 AU) and because of its corrugated structure consisting of a set of co-axial rings with the same orientation as the embedded silhouette disk. The rings are centered on the disk/jet axis, and we discuss possible mechanisms for their formation. The silhouette disk has an outer radius of about 160 AU and its axis is inclined by an angle of about 60 degrees with respect to our line-of-sight. A prominent reflection nebula protrudes along the disk axis toward the south, marking the base of the approaching outflow, and a faint knot on the north side of the disk indicates that the nebula is bipolar. Fabry-Perot images reveal a high-velocity blueshifted jet with a mass loss rate of about 10^{-8} $M_\odot$ yr^{-1} emerging along the disk axis. It has a velocity (corrected for the outflow inclination angle) of about 160 km s^{-1}, and can be traced for about an arcminute toward the south. A chain of three lower-velocity blueshifted bow shocks, collectively known as HH 540, extend several arcminutes south of 181-826 along the same axis, tracing a large-scale outflow powered by this jet.

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A New Probe of the Planet-Forming Region in T Tauri Disks

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We present new observations of the FUV (1100-2200 Å) radiation field and the near- to mid-IR (3–13.5 μm) spectral energy distribution (SED) of a sample of T Tauri stars selected on the basis of bright molecular disks (GM Aur, DM Tau, LkCa15). In each source we find evidence for Ly α induced H_2 fluorescence and an additional source of FUV continuum emission below 1700 Å. Comparison of the FUV spectra to a model of H_2 excitation suggests that

the strong continuum emission is due to electron impact excitation of H_2. The ultimate source of this excitation is likely X-ray irradiation which creates hot photo-electrons mixed in the molecular layer. Analysis of the SED of each object finds the presence of inner disk gaps with sizes of a few AU in each of these young ($\sim$1 Myr) stellar systems. We propose that the presence of strong H_2 continuum emission and inner disk clearing are related by the increased penetration power of high energy photons in gas rich regions with low grain opacity.

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Evidence for an inner molecular disk around massive Young Stellar Objects

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We present observations of CO overtone bandhead emission toward four massive Young Stellar Objects (spectral type O6–B5). The high signal-to-noise ratio K-band spectra were obtained with *VLT-ISAAC* at a resolution $\Delta v = 30$ km s^{-1}, sufficient to resolve the bandheads, but not the individual J-lines. We are able to explain the shape of the lines by assuming a simple isothermal keplerian disk model seen at different inclinations. The gas temperature ranges from 1500 to 4500 K and the CO column density is between 0.1 and 4×10^{21} cm^{-2}. The emission probably arises within the first few astronomical units of the disk, consistent with the high gas temperature. Our results indicate that molecules can survive close to a hot star and suggest that dense ($n_{\rm H} > 10^{10}$ cm^{-3}) inner disks may be relatively common at an advanced stage of high-mass star formation.

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Millimeter Observations of the HH 222 Region

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The HH 222 streamers in Orion and their associated non-thermal radio jet form a unique object, whose nature remains enigmatic. We have carried out a set of detailed millimeter observations around the non-thermal radio source in several transitions of the CO, ^{13}CO, C^{18}O and CS molecules. We find that the radio source is not associated with any molecular outflow nor located within a dense molecular core, and is therefore very unlikely to be a newborn star. The observations are in principle consistent with the radio source being a more evolved T Tauri star undergoing an energetic event, but it could also be an evolved object (an X-ray binary or a microquasar) accidentally passing through the large Orion cloud complex.

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The ionizing star of the North America and Pelican nebulae

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We present the results of a search for the ionizing star of the North America (NGC 7000) and the Pelican (IC 5070) nebulae complex. The application of adequate selection criteria to the 2MASS JHK_S broad-band photometry allows

us to narrow the search down to 19 preliminary candidates in a circle of 0°5 radius containing most of the L935 dark cloud that separates both nebulae. Follow-up near-infrared spectroscopy shows that most of these objects are carbon stars and mid-to-late-type giants, including some AGB stars. Two of the three remaining objects turn out to be later than spectral type B and thus cannot account for the ionization of the nebula, but a third object, 2MASS J205551.25+435224.6, has infrared properties consistent with it being a mid O-type star at the distance of the nebulae complex and reddened by $A_V \simeq 9.6$. We confirm its O5V spectral type by means of visible spectroscopy in the blue. This star has the spectral type required by the ionization conditions of the nebulae and photometric properties consistent with the most recent estimates of their distance. Moreover, it lies close to the geometric center of the complex that other studies have proposed as the most likely location for the ionizing star, and is also very close to the position inferred from the morphology of cloud rims detected in radio continuum. Given the fulfillment of all the conditions and the existence of only one star in the whole search area that satisfies them, we thus propose 2MASS J205551.25+435224.6 as the ionizing star of the North America / Pelican complex.

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http://www.eso.org/∼fcomeron/ngc7000.ps.gz

Probing the evolutionary status of starless cores through N_2H^+ and N_2D^+ observations

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We have undertaken a survey of N_2H^+ and N_2D^+ towards 31 low-mass starless cores using the IRAM 30-m telescope. Our main objective has been to determine the abundance ratio of N_2D^+ and N_2H^+ towards the nuclei of these cores and thus to obtain estimates of the degree of deuterium enrichment, a symptom of advanced chemical evolution according to current models. We find that the $N(N_2D^+)/N(N_2H^+)$ ratio is larger in more "centrally concentrated cores" with larger peak H_2 and N_2H^+ column density than the sample mean. The deuterium enrichment in starless cores is presently ascribed to depletion of CO in the high density ($> 3 \times 10^4$ cm^{-3}) core nucleus. To substantiate this picture, we compare our results with observations in dust emission at 1.2 mm and in two transitions of $C^{18}O$. We find a good correlation between deuterium fractionation and $N(C^{18}O)/N(H_2)_{1.2\ mm}$ for the nuclei of 14 starless cores. We, thus, identified a set of properties that characterize the most evolved, or "pre–stellar", starless cores. These are: higher N_2H^+ and N_2D^+ column densities, higher $N(N_2D^+)/N(N_2H^+)$, more pronounced CO depletion, broader N_2H^+ lines with infall asymmetry, higher central H_2 column densities and a more compact density profile than in the average core. We conclude that this combination of properties gives a reliable indication of the evolutionary state of the core. Seven cores in our sample (L1521F, OphD, L429, L694, L183, L1544 and TMC2) show the majority of these features and thus are believed to be closer to forming a protostar than are the other members of our sample. Finally, we note that the subsample of Taurus cores behaves more homogeneously than the total sample, an indication that the external environment could play an important role in the core evolution.

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http://cfa-www.harvard.edu/ acrapsi/publications/

Genetic Algorithm-Based Exploration of Three Filament Models: A Case for the Magnetic Support of the G11.11-0.12 Infrared-Dark Cloud

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The G11.11-0.12 infrared-dark cloud has a filamentary appearance, both in extinc tion against the diffuse infrared emission of the Galactic plane and in emission at 850μm. We use a novel computational technique based on an advanced genetic algorithm to explore thoroughly 3 different models of self-gravitating, pressure truncated filaments and to constrain their parameters. Specifically, the models tested are the non-magnetic Ostriker (1964) model, a generalized version of the magnetic Stodólkiewicz (1963) model, and the magnetic Fiege & Pudritz (2000a) model. Previous results showed that G11.11-0.12 has a much steeper $\sim r^{-4}$ radial density profile than other filaments, where the density varies approximately as r^{-2}, and that this steep density profile is consistent with the Ostriker (1964) model. We present a more complete analysis that shows that the radial structure of G11.11-0.12 is consistent with regimes of each of these models. All of the magnetic models that agree with the data are threaded by a dominant poloidal magnetic field, and most have dynamically significant fields. Thus, G11.11-0.12 is an excellent candidate for radial support by a magnetic field that is predominantly poloidal. We predict the polarization patterns expected for both magnetic models and show that the two magnetic models produce different polarization patterns that should be distingished by observations.

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Which are the youngest protostars? Determining properties of confirmed and candidate Class 0 sources by broad-band photometry

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We searched the literature to obtain a complete list of known Class 0 sources. A list of 95 confirmed or candidate objects was compiled. To the best of our knowledge, all published broad-band observations from 1 μm to 3.5 mm have been collected and are assembled in a catalogue. These data were used to determine physical properties (T_{bol}, L_{bol}, L_{smm}/L_{bol}, M_{env}) and for a uniform classification. 50 sources possess sufficient observational data and are classified as Class 0 or Class 0/1 objects. The source properties are compared with different evolutionary models to infer ages and masses, and their correlations are investigated. About 25% of the sources are found to be in a quiet accretion phase or possess a significantly different time evolution of the accretion rate than the average. In Taurus, with its isolated star formation mode, this seems especially to be the case.

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Evolution of self-gravitating magnetized disks. I- Axisymmetric simulations

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In this paper and a companion work, we report on the first global numerical simulations of self-gravitating magnetized tori, subject in particular to the influence of the magnetorotational instability (MRI). In this work, paper I, we restrict our calculations to the study of the axisymmetric evolution of such tori. Our goals are twofold: (1) to investigate how self-gravity influences the global structure and evolution of the disks; and (2) to determine whether turbulent density inhomogeneities can be enhanced by self-gravity in this regime.

As in non self-gravitating models, the linear growth of the MRI is followed by a turbulent phase during which angular momentum is transported outward. As a result, self-gravitating tori quickly develop a dual structure composed of an inner thin Keplerian disk fed by a thicker self-gravitating disk, whose rotation profile is close to a Mestel disk. Our

results show that the effects of self-gravity enhance density fluctuations much less than they smooth the disk, and giving it more coherence. We discuss the expected changes that will occur in 3D simulations, the results of which are presented in a companion paper.

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Evolution of self–gravitating magnetized disks. II- Interaction between MHD turbulence and gravitational instabilities

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We present 3D magnetohydrodynamic (MHD) numerical simulations of the evolution of self–gravitating and weakly magnetized disks with an adiabatic equation of state. Such disks are subject to the development of both the magnetorotational and gravitational instabilities, which transport angular momentum outward. As in previous studies, our hydrodynamical simulations show the growth of strong $m = 2$ spiral structure. This spiral disturbance drives matter toward the central object and disappears when the Toomre parameter Q has increased well above unity. When a weak magnetic field is present as well, the magnetorotational instability grows and leads to turbulence. In that case, the strength of the gravitational stress tensor is lowered by a factor of about 2 compared to the hydrodynamical run and oscillates periodically, reaching very small values at its minimum. We attribute this behavior to the presence of a second spiral mode with higher pattern speed than the one which dominates in the hydrodynamical simulations. It is apparently excited by the high frequency motions associated with MHD turbulence. The nonlinear coupling between these two spiral modes gives rise to a stress tensor that oscillates with a frequency which is a combination of the frequencies of each of the modes. This interaction between MHD turbulence and gravitational instabilities therefore results in a smaller mass accretion rate onto the central object.

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Chandra Orion Ultradeep Project: Observations and Source Lists

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We present a description of the data reduction methods and the derived catalog of more than 1600 X-ray point sources from the exceptionally deep January 2003 Chandra X-ray Observatory (*Chandra*) observation of the Orion Nebula

Cluster and embedded populations around OMC-1. The observation was obtained with *Chandra*'s Advanced CCD Imaging Spectrometer (ACIS) and has been nicknamed the *Chandra* Orion Ultradeep Project (COUP). With an 838 ks exposure made over a continuous period of 13.2 days, the COUP observation provides the most uniform and comprehensive dataset on the X-ray emission of normal stars ever obtained in the history of X-ray astronomy.

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http://www.astro.psu.edu/users/gkosta/COUP_Methodology.pdf

Massive Star Formation in the W49 Giant Molecular Cloud: Implications for the Formation of Massive Star Clusters

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We present results from $JHKs$ imaging of the densest region of the W49 molecular cloud. In a recent paper (Alves & Homeier 2003), we reported the detection of (previously unknown) massive stellar clusters in the well-known giant radio HII region W49A, and here we continue our analysis. We use the extensive line-of-sight extinction to isolate a population of objects associated with W49A. We constrain the slope of the stellar luminosity function by constructing an extinction-limited luminosity function, and use this to obtain a mass function. We find no evidence for a top-heavy MF, and the slope of the derived mass function is -1.6 ± 0.3. We identify candidate massive stars from our color-magnitude diagram, and we use these to estimate the current total stellar mass of $5 - 7 \times 10^4$ $M_\odot$ in the region of the W49 molecular cloud covered by our survey. Candidate ionizing stars for several ultra-compact HII regions are detected, with many having multipe candidate sources. On the global molecular cloud scale in W49, massive star formation apparently did not proceed in a single concentrated burst, but in small groups, or subclusters. This may be an essential physical description for star formation in what will later be termed a 'massive star cluster'.

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http://xxx.lanl.gov/abs/astro-ph/0409410

Testing the Reality of Strong Magnetic Fields on T Tauri Stars: The Naked T Tauri Star Hubble 4

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High resolution optical and infrared (IR) echelle spectra of the naked (diskless) T Tauri star Hubble 4 are presented. The K band IR spectra include 4 Zeeman sensitive Ti I lines along with several magnetically insensitive CO lines. Detailed spectrum synthesis combined with modern atmospheric models is used to fit the optical spectra of Hubble 4 in order to determine its key stellar parameters: $T_{\rm eff} = 4158 \pm 56$ K; $\log g = 3.61 \pm 0.50$; [M/H] $= -0.08 \pm 0.05$; $v \sin i = 14.6 \pm 1.7$ km s^{-1}. These stellar parameters are used to synthesize K band spectra to compare with the observations. The magnetically sensitive Ti I lines are all significantly broadened relative to the lines produced in the non-magnetic model, while the magnetically insensitive CO lines are well matched by the basic non-magnetic model. Models with magnetic fields are synthesized and fit to the Ti I lines. The best fit models indicate a distribution of magnetic field strengths on the stellar surface characterized by a mean magnetic field strength of 2.51 ± 0.18 kG. The mean field is a factor of 2.0 greater than the maximum field strength predicted by pressure equipartition arguments. To confirm the reality of such strong fields, we attempt to refit the observed profiles using a two component magnetic model in which the field strength is confined to the equipartition value representing plage-like regions in one component, and the field is allowed to vary in a cooler component representing spots. It is shown that such a model is inconsistent with the optical spectrum of the TiO bandhead at 7055 Å.

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Bondi Accretion in the Presence of Vorticity

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The classical Bondi-Hoyle formula gives the accretion rate onto a point particle of a gas with a uniform density and velocity. However, the Bondi-Hoyle problem considers only gas with no net vorticity, while in a real astrophysical situation accreting gas invariably has at least a small amount of vorticity. We therefore consider the related case of accretion of gas with constant vorticity, for the cases of both small and large vorticity. We confirm the findings of earlier two dimensional simulations that even a small amount of vorticity can substantially change both the accretion rate and the morphology of the gas flow lines. We show that in three dimensions the resulting flow field is non-axisymmetric and time dependent. The reduction in accretion rate is due to an accumulation of circulation near the accreting particle. Using a combination of simulations and analytic treatment, we provide an approximate formula for the accretion rate of gas onto a point particle as a function of the vorticity of the surrounding gas.

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Rotational evolution of low mass stars: The case of NGC 2264

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Our study is based on an extensive photometric monitoring program in the young (2–4 Myr) open cluster NGC 2264 by Lamm et al. (2004a). This program resulted in a sample of 405 periodic variables which are most likely pre-main sequence (PMS) members of the cluster. The periodic variability of these stars results from the rotational modulation of the light by stellar spots. In this paper we investigate the rotation period evolution of young stars. This is done by comparing the period distribution of the older NGC 2264 with that of the younger Orion Nebular Cluster (ONC, age: $\sim$ 1 Myr) which is known from the literature. The age ratio between the two clusters was estimated on the basis of PMS models to be about $2^{+0.75}_{-0.5}$. We find that the period distribution of NGC 2264 is similar in form to the ONC but shifted to shorter periods. In both clusters the period distribution depends strongly on the mass and it is bimodal for higher mass stars with $M \geq 0.25\ M_{\odot}$ while it is unimodal for lower mass stars with $M \leq 0.25\ M_{\odot}$. In addition the lower mass stars rotate much faster on average than the higher mass stars. Quantitative comparison between the period distributions of both clusters suggests that a large fraction (about 80%) of stars have spun up from the age of the ONC to the age of NGC 2264. Based on this estimate and the estimated age ratio between the two clusters we find that the average spin up by a factor of 1.5 – 1.8 from the age of the ONC to the age of NGC 2264 is consistent with a decreasing stellar radius and conservation of angular momentum, for most stars. However, within NGC 2264 we did not find any significant spin up from the younger to older stars in the cluster. We also found indications for some ongoing disk-locking in NGC 2264, in particular for the higher mass stars. Our analysis of the period distribution suggests that about 30% of the higher mass stars in NGC 2264 could be magnetically locked into co-rotation with their inner disk. In the case of the lower mass stars, disk-locking seems to be less important for the rotational evolution of the stars. This interpretation is supported by the analysis of the stars' Hα emission. This analysis indicates that the locking period of the higher mass stars is about $P = 8$ days. For the lower mass stars this analysis indicates a locking period of about 2–3 days. We argue that the latter stars are probably not "completely" locked to their disk and propose an evolution scenario for these stars which we call "moderate angular momentum

loss". In this scenario angular momentum is continuously removed from the stars but at a rate too low to lock the stars with a constant rotation period. We have done a detailed comparison with the recently published rotational period study of NGC 2264 of Makidon et al. (2004). Even though their obtained period distribution of their quality 1 data on NGC 2264 is indistinguishable within the statistical errors from ours, we come to quite different conclusions about the interpretation. One major reason for these discrepancies is probably the large inhomogeneity of the "whole" Orion region with which Makidon et al. (2004) compare their NGC 2264 data, while we compare our NGC 2264 data only with the ONC, which is the youngest and most homogeneous cluster of the Orions OBI association.

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Polarimetric variations of binary stars. VI. Orbit-induced variations in the pre-main-sequence binary AK Sco

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We present simultaneous UBV polarimetric and photometric observations of the pre-main-sequence binary AK Sco, obtained over 12 nights, slightly less than the orbital period of 13.6 days. The polarization is a sum of interstellar and intrinsic polarization, with a significant intrinsic polarization of 1% at 5250Å, indicating the presence of circumstellar matter distributed in an asymmetric geometry. The polarization and its position angle are clearly variable on time scales of hours and nights, in all 3 wavelengths, with a behavior related to the orbital motion. The variations have the highest amplitudes seen so far for pre-main-sequence binaries (≈1%, ≈ 30°) and are sinusoidal with periods similar to the orbital period and half of it. The polarization variations are generally correlated with the photometric ones: when the star gets fainter, it also gets redder and its polarization increases. The color-magnitude diagram $B - V$, V exhibits a ratio of total to selective absorption $R = 4.3$ higher than in normal interstellar clouds ($R = 3.1$). The interpretation of the simultaneous photometric and polarimetric observations is that a cloud of circumstellar matter passes in front of the star, decreasing the amount of direct, unpolarized light, and hence increasing the contribution of scattered (blue) light. We show that the large amplitude of the polarization variations can not be reproduced with a single scattering model and axially symmetric circumbinary or circumstellar disks.

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The Spin of Accreting Stars: Dependence on Magnetic Coupling to the Disc

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We formulate a general, steady-state model for the torque on a magnetized star from a surrounding accretion disc. For the first time, we include the opening of dipolar magnetic field lines due to the differential rotation between the star and disc, so the magnetic topology then depends on the strength of the magnetic coupling to the disc. This coupling is determined by the effective slip rate of magnetic field lines that penetrate the diffusive disc. Stronger coupling (i.e., lower slip rate) leads to a more open topology and thus to a weaker magnetic torque on the star from the disc. In the expected strong coupling regime, we find that the spin-down torque on the star is more than an order of magnitude smaller than calculated by previous models. We also use our general approach to examine the equilibrium ('disc-locked') state, in which the net torque on the star is zero. In this state, we show that the stellar spin rate is roughly an order of magnitude faster than predicted by previous models. This challenges the idea that slowly-rotating, accreting protostars are disc locked. Furthermore, when the field is sufficiently open (e.g., for mass accretion rates $\geq 5 \times 10^{-9} M_\odot$ yr^{-1}, for typical accreting protostars), the star will receive no magnetic spin-down torque from the disc at all. We therefore conclude that protostars must experience a spin-down torque from a source that has not yet been considered in the star-disc torque models—possibly from a stellar wind along the open field

lines.

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Search for Accretion Events of Circumstellar Matter in UX Ori Stars

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During some Algol-like minima flare-like events in the optical light curves of UX Ori-type stars were observed. Flare-like events with amplitudes $0^m.15 - 1^m.0$ in the V passband sometimes were observed after the minimum of the star brightness. After the flare the star returns to the initial state. UV-excesses with an amplitude of $U-B = 0^m.15-0^m.20$ sometimes appear near the minimum brightness, but not simultaneously with the optical flare. We suggest that these flare-like phenomena indicate the fall of a large amount of circumstellar matter onto the young star.

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Star-forming protoclusters associated with methanol masers

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We present a multiwavelength study of five methanol maser sites which are not directly associated with a strong ($>$ 100 mJy) radio continuum source: G 31.28+0.06, G 59.78+0.06, G 173.49+2.42 (S231, S233IR), G 188.95+0.89 (S252, AFGL5180) and G 192.60-0.05 (S255IR). These radio-quiet methanol maser sites are often interpreted as precursors of ultra-compact HII regions or massive protostar sites. In this work, the environment of methanol masers is probed from mid-IR to millimetre wavelengths at angular resolutions of $8'' - 34''$. Spectral energy distribution (SED) diagrams for each site are presented, together with mass and luminosity estimates. Each radio-quiet maser site is always associated with a massive ($>$ 50 $M_\odot$), deeply embedded ($A_v >$ 40 mag) and very luminous ($> 10^4$ $L_\odot$) molecular clump, with $L_{total} \propto M_{gas}^{0.75}$. These physical properties characterise massive star-forming clumps in earlier evolutionary phases than HII regions. In addition, colder gas clumps seen only at mm-wavelengths are also found near the methanol maser sites. These colder clumps may represent an even earlier phase of massive star formation. These results suggest an evolutionary sequence for massive star formation from a cold clump, seen only at mm wavelengths, evolving to a hot molecular core with a two-component SED with peaks at far-IR and mid-IR wavelengths, to an (ultra-compact) HII region. Alternatively, the cold clumps might be clusters of low-mass YSOs, in formation near the massive star-forming clusters. Finally, the values of the dust grain emissivity index (β) range between 1.6 and 1.9.

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Kinematics of stars and brown dwarfs at birth

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We use numerical N-body simulations in order to test whether the kinematics of stars and brown dwarfs at birth depend on mass. In particular we examine how initial variations in velocity dispersion can affect the spatial distribution of stellar and substellar objects in clusters. We use 'toy' N-body models of a Pleiades-like cluster in which brown dwarfs have their own velocity dispersion $\sigma_{V_{\rm BD}}$ which is k times larger than the stellar one.

We find that in order to match the broad agreement between the brown dwarf fraction in the field and in the Pleiades, the velocity dispersion of brown dwarfs at birth has to be less than twice the stellar velocity dispersion, i.e. cannot exceed a few km/s in the Pleiades cluster. In order to discern more subtle differences between the kinematics of brown dwarfs and stars at birth, our simulations show that we need to look at clusters that are much less dynamically evolved than the Pleiades. One might especially seek evidence of high velocity brown dwarfs at birth by examining spatial distribution of stars and brown darfs in clusters that are about a crossing timescale old.

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The Star Formation Region NGC6530: distance, ages and Initial Mass Function

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We present astrometry and BVI photometry, down to $V \simeq 22$, of the very young open cluster NGC6530, obtained from observations taken with the Wide Field Imager camera at the MPG/ESO 2.2 m Telescope. Both the V vs. $B-V$ and the V vs. $V-I$ color-magnitude diagrams (CMD) show the upper main sequence dominated by very bright cluster stars, while, due to the high obscuration of the giant molecular cloud surrounding the cluster, the blue envelopes of the diagrams at $V \geq 14$ are limited to the main sequence stars at the distance of NGC6530. This particular structure of the NGC6530 CMD allows us to conclude that its distance is about $d \sim 1250$ pc, significantly lower than the previous determination of d=1800 pc.
We have positionally matched our optical catalog with the list of X-ray sources found in a Chandra-ACIS observation, finding a total of 828 common stars, 90% of which are pre-main sequence stars in NGC6530. Using evolutionary tracks of Siess et al. (2000), mass and age values are inferred for these stars. The median age of the cluster is about 2.3 Myr; in the mass range (0.6–4.0) $M_{\odot}$, the Initial Mass Function (IMF) shows a power law index $x = 1.22 \pm 0.17$, consistent with both the Salpeter index (1.35), and with the index derived for other young clusters ; towards smaller masses the IMF shows a peak and then it starts to decrease.

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Fast [Fe II] Wind with a Wide Opening Angle from L1551 IRS 5

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We present new velocity-resolved spectra of the [Fe II] λ1.644 μm line emission toward the L1551 IRS 5 outflow. The spectra were taken toward the bright [Fe II] knots PHK1 and PHK2 with the slit positions perpendicular to the northern jet. We have two major conclusions: (1) At PHK1 located 1.″2 away from the L1551 IRS 5 VLA sources, the spatial profile of the low radial velocity component at $V_{\rm LSR} \sim -110$ km s^{-1} shows two spatial subcomponents with their FWHMs of 0.″83 and 2.″84. The wide subcomponent has an wide opening angle of $\sim$100°, which is consistent with the opening angle suggested by the broad velocity width of the narrow one. It favors the interpretation that both

subcomponents of the LVC arise from the same outflow. The gas corresponding to the wide subcomponent fills the space between the optical jet and the shell of the CO molecular outflow, and may be sweeping up envelope material in the vicinity of the protostars. (2) At PHK2 located $\sim 4\farcs2$ away from the VLA sources, we confirmed that the northern jet has two radial velocity components: $V_{\rm LSR} \sim -270$ km s^{-1} and -140 km s^{-1}. The former velocity component is highly collimated because it has the same spatial width of $0\farcs78$ at both of the two [Fe II] knots.

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ISO Observations of the Galactic Center Interstellar Medium: Ionized Gas

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We present fine structure and recombination lines observations of the ionized gas toward a sample of 18 sources located within 300 pc of the center of the Galaxy (hereafter Galactic center, GC). The sources were selected as molecular clouds located far from thermal continuum sources. The fine structure lines from [NII] and [SIII] have been detected in 16 sources. In 10 sources we have even detected the [OIII] 88 μm line. Several techniques have been used to determine lower and upper limits to the extinction toward each source to correct the observed line fluxes. The derived electron densities of the ionized gas vary from ~ 100 to ≤ 30 cm^{-3}. For some sources we were able to derive N, S and Ne abundances. We found that they are similar to those measured in the HII regions in the 5-kpc ring and in the nuclei of starburst galaxies. The fine structure lines ratios measured for all the sources can be explained by photo-ionization with an effective temperature of the ionizing radiation of 32000-37000 K and an ionization parameter, U, of $-1 > \log U > -3$. The highest excitation is found in the Radio Arc region but it does not decrease smoothly with distance. There must be more ionizing sources distributed over the Galactic center than the known clusters of massive stars. Most of the clouds are located far (up to 45 pc for M-0.96+0.13) from the prominent continuum complexes (Sgr C, B ...). However, it is possible that the clouds are ionized by escaped photons from those complexes. The comparison of the effective temperatures of the ionizing radiation to the measured Lyman continuum photons emission rate imply that the clouds are indeed ionized by distant sources. The excitation ratios, effective temperature and ionization parameter measured in the GC are similar to those found in some low excitation starburst galaxies. The [NeIII]/[NeII] line ratios measured in the GC sources are consistent with the results of the Thornely et al. (2000) model for a short burst of massive star formation less than 8 Myr ago. We have also found that the [NeII] 13 μm to far-infrared continuum ratio measured for the GC sources is similar to that of external galaxies, supporting the idea by Sturm et al. (2002) that the far-infrared continuum in Active Galaxies is dominated by dust heated by stellar radiation rather than by the AGN.

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Rotation and variability of very low mass stars and brown dwarfs near ϵ Ori

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We explore the rotation and activity of very low mass (VLM) objects by means of a photometric variability study. Our targets in the vicinity of ϵ Ori belong to the Ori OB1b population in the Orion star-forming complex. In this region we selected 143 VLM stars and brown dwarfs (BDs), whose photometry in RIJHK is consistent with membership of the young population. The variability of these objects was investigated using a densely sampled I-band time series covering four consecutive nights with altogether 129 data points per object. Our targets show three types of variability: Thirty objects, including nine BDs, show significant photometric periods, ranging from 4 h up to 100 h, which we interpret as the rotation periods. Five objects, including two BDs, exhibit variability with high amplitudes up to 1 mag which is at least partly irregular. This behaviour is most likely caused by ongoing accretion and confirms that VLM objects undergo a T Tauri phase similar to solar-mass stars. Finally, one VLM star shows a strong flare event of 0.3 mag

amplitude. The rotation periods show dependence on mass, i.e. the average period decreases with decreasing object mass, consistent with previously found mass-period relationships in younger and older clusters. The period distribution of BDs extends down to the breakup period, where centrifugal and gravitational forces are balanced. Combining our BD periods with literature data, we found that the lower period limit for substellar objects lies between 2 h and 4 h, more or less independent of age. Contrary to stars, these fast rotating BDs seem to evolve at constant rotation period from ages of 3 Myr to 1 Gyr, in spite of the contraction process. Thus, they should experience strong rotational braking.

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http://www.tls-tautenburg.de/research/tls-research/pub2004.html

Photometric Identification of the Low-Mass Population of Orion OB1b I: The σ Ori Cluster

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We report an optical photometric survey of 0.89 deg^2 of the Orion OB1b association centered on σ Ori. This region includes most of the σ Ori cluster, the highest density region within Orion OB1b. We have developed a statistical procedure to identify the young, low-mass, pre-main sequence population of the association. We estimate that the cluster has $\sim$160 members in the mass range ($0.2 \leq M \leq 1.0$ M$_\odot$). The cluster has a radius of $\sim$3-5 pc and an estimated age of 2.5$\pm$0.3 Myrs. We estimate that the total mass of the cluster is 225$\pm$30 M$_\odot$. This mass is similar to the estimated mass of the $\sim 5\times10^5$ year old cluster NGC 2024. NGC 2024 and σ Ori appear to be a well matched pair of clusters, except for the $\sim$2 Myr difference in their ages.

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Preprints are available at www.ess.sunysb.edu/wsherry/sigoriI.ps.

Accretion, Kinematics and Rotation in the Orion Nebula Cluster: Initial Results from Hectochelle

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We present results from high-resolution spectra of 237 stars in the Orion Nebula Cluster (ONC) obtained during two engineering runs with the Hectochelle multifiber echelle spectrograph on the 6.5m MMT. The ONC is the nearest populous young (ages $\sim$ 1 Myr) cluster, and is therefore an important object for studies of the evolution of protoplanetary disks. Using the high spectral resolution of Hectochelle, we are able to distinguish stellar accretion and wind emission line profiles from nebular emission lines, and identify accreting members of the cluster from Hα profiles with greater accuracy than previously possible. We find 15 new members, based on Li 6707 Å absorption and Hα emission. Line profiles of Hα of some objects that are not too contaminated by nebular emission show features characteristic of mass inflow and ejection. We also present rotational velocities as part of an initial investigation into angular momentum evolution of very young stars, confirming a difference between CTTS and WTTS that had been found in period analysis. Finally, we present an initial study of the radial velocity dispersion of the brighter stars in the central cluster. The very small dispersion derived, $\leq 1.8 km/s$, is in good agreement with estimates from proper motions.

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http://cfa-www.harvard.edu/cfa/youngstars/publications.html

New Silhouette Disks with Reflection Nebulae and Outflows in the Orion Nebula and M43

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We report the detection of several new circumstellar disks seen in silhouette against background nebular light in the outskirts of the Orion nebula and the neighboring HII region M43. These were detected as part of our Hα survey of Orion with the Advanced Camera for Surveys on-board the *Hubble Space Telescope*. Several of the disks show bipolar reflection nebulae, microjets, or pronounced temporal variability of their central stars. The relatively large fraction of bipolar reflection nebulae or microjets in our sample may be a selection effect caused by the faint nebular background far from the Trapezium. Two disks in our sample are large and particularly noteworthy: A nearly edge-on disk, d216-0939, is located several arcminutes northwest of M43 and resembles the famous HH 30 disk/jet system in Taurus. It drives the 0.15 pc long bipolar outflow HH667, and exhibits a remarkable asymmetric reflection nebula caused by the tilt of the flared disk. With a diameter of $\sim$2.6 arcsec (1200 AU), d216-0939 is as large as the giant edge-on silhouette disk d114-426 in the core of the Orion Nebula. The large disk d253-1536 is located in a binary system embedded within an externally-ionized giant proplyd in M43. The disk exhibits distortions which we attribute to tidal interactions with the companion star. The bipolar jet HH668 emerges from the proplyd ionization front in a direction orthogonal to the disk, and can be traced to the young star embedded within it. A bow shock lies 54 arcsec south of this binary system along the outflow axis. Proper motions over a 1.4 yr baseline confirm that these emission knots are indeed moving away from d253-1536, with speeds as high as $\sim$330 km s^{-1} in the HH668 microjet, and slower motion farther from the star.

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Mapping the Outflow from G5.89-0.39 in SiO(5-4)

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We have mapped the ultracompact H II region, G5.89-0.39, and its molecular surroundings with the Submillimeter Array at $2''.8 \times 1''.8$ angular resolution in 1.3 mm continuum, SiO($J = 5 \rightarrow 4$), and eight other molecular lines. We have resolved for the first time the highly energetic molecular outflow in this region. At this resolution, the outflow is definitely bipolar and appears to originate in a 1.3 mm continuum source. The continuum source peaks in the center of the H II region. The axis of the outflow lines up with a recently discovered O5V star.

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Spherical Infall in G10.6-0.4: Accretion Through an Ultracompact HII Region

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We present high resolution ($0.''12 \times 0.''079$) observations of the ultracompact HII region G10.6-0.4 in 23 GHz radio continuum and the NH_3(3,3) line. Our data show that the infall in the molecular material is largely spherical, and does not flatten into a molecular disk at radii as small as 0.03 pc. The spherical infall in the molecular gas matches in

location and velocity the infall seen in the ionized gas. We use a non-detection to place a stringent upper limit on the mass of an expanding molecular shell associated with pressure driven expansion of the HII region. These data support a scenario in which the molecular accretion flow passes through an ionization front and becomes an ionized accretion flow onto one or more main sequence stars, not the classical pressure-driven expansion scenario. In the continuum emission we see evidence for externally ionized clumps of molecular gas, and cavities evacuated by an outflow from the central source.

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A Near–Infrared/Millimeter–Wave Study of Six Fourth Quadrant High- Mass Star Formation Regions

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We present near–infrared and millimeter wave observations of six high mass star forming regions in the fourth quadrant: RCW 108, G333.6, RCW 117, RCW 122, NGC 6334 I, and G351.6. These regions have have heliocentric distances of 1.3 - 3.0 kpc, and total luminosities ranging from 0.5 to 3×10^5 $L_\odot$. Millimeter maps taken in transitions of $C^{18}O$, HC_3N, CO, and SiO with the Swedish-ESO Submillimetre Telescope 15 m telescope detail the structure and kinematics of the clouds. Near–infrared K–band images of the same regions obtained with the MPG/ESO 2.2–meter telescope are used to map the stellar surface density. The ceioone line shows extended high column density gas, with column densities ranging from 10^{22} to 3×10^{23} cm^{-2}; in contrast, the HC_3N ($15 \rightarrow 14$) emission shows eight sharply peaked dense cores. We examine these cores for recent and ongoing star formation by searching for high-velocity, non-Gaussian wings on the CO ($1 \rightarrow 0$) and SiO ($2 \rightarrow 1$) lines, peaks in the surface density of stars, and positional coincidences with *IRAS* point sources, as well as masers and HII regions reported in the literature. All of the cores show evidence of ongoing star formation. NGC 6334 I(N) stands out as a unique case in which an outflow has formed and masers have appeared, but no *IRAS* source, K–band cluster, or ultra compact HII region has yet formed; our data support previous claims that this is a rare example of a core at the earliest stages of forming a cluster of high and low mass stars.

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Polarimetric line profiles for scattering off rotating disks

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We predict polarimetric line profiles for scattering off rotating disks using a Monte Carlo technique. We have discovered that there is a marked difference between scattering of line emissionby a disk that reaches the stellar surface, and a disk with an inner hole. For the case with an inner hole, we find *single* position-angle rotations, similar to those predicted by analytic models. For the case of an undisrupted disk, we find *double* rotations in the position angle – an effect not reported before. We show that this new effect is due to the finite-sized star interacting with the disk's rotational velocity field. Since a gradual increase of the hole size transforms the double rotations smoothly back into single ones – as the line emission object approaches that of a point source – our models demonstrate the diagnostic potential of line polarimetry in determining not only the disk inclination, but also the size of the disk inner hole.

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Modelling the optical properties of composite and porous interstellar grains

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There are indications that interstellar and interplanetary dust grains have an inhomogeneous and fluffy structure. We investigate different methods to describe light scattering by such composite particles. Both a model of layered particles and discrete dipole calculations for particles with Rayleigh and non-Rayleigh inclusions are used.

The calculations demonstrate that porosity is a key parameter for determining light scattering. We find that the optical properties of the layered particles depend on the number and position of layers if the number of layers is small ($\lesssim 15$). For a larger number of layers the scattering characteristics become independent of the layer sequence. The optical properties of particles with inclusions depend on the size of inclusions provided the porosity is large. The scattering characteristics of very porous particles with inclusions of different sizes are found to be close to those of multi-layered spheres.

We compare the results of these calculations with the predictions of the effective medium theories (EMT) which are often used in astronomy as a tool to calculate the optical properties of composite particles. The results of our analysis show that the internal structure of grains (layers versus inclusions) only slightly affects the optics of particles provided the porosity does not exceed 50%. It is also demonstrated that in this case the optical properties of composite grains calculated with EMT agree with the results of the exact method for layered particles. For larger porosity, the standard EMT rules (i.e., Garnett and Bruggeman rules) give reliable results for particles with Rayleigh inclusions only.

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2-D Models of Protostars: III. Effects of Stellar Temperature

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We model how the mid-infrared colors of Young Stellar Objects (YSOs) vary with stellar temperature. The spectral energy distribution (SED) of each object has contributions from thermal emission of circumstellar dust, from direct stellar photospheric emission, and from scattered stellar emission. We first isolate the effects of stellar contributions (direct+scattered) to the SED using homologous "Class I" models: the distribution of circumstellar matter is chosen to scale with stellar temperature $T_\star$ such that the shape of the thermal contribution to the SED remains constant. The relative contribution of stellar direct and scattered light varies with $T_\star$, changing the $1-10\mu$m (mid-infrared; MIR) colors. Stellar light contributes more to the MIR emission of YSOs with lower temperature stars ($T_\star \sim 4000$ K) because the emission peak wavelength of the star is closer to that of the thermal radiation. In YSOs with hotter central stars, since the peak of the stellar and thermal spectra are more separated in wavelength, the $1-10\mu$m spectrum is closer to a pure thermal spectrum and the objects are redder.

Next we consider realistic Class 0, I, and II source models and find that the other dominant effect of varying stellar temperature on YSO SEDs is that of the inner disk wall: In high-$T_\star$ models, the dust destruction radius is much further out with a consequently larger inner disk wall that contributes relatively more to the $2-10\mu$m flux. This effect partially offsets that of the stellar contribution leading to varying behaviors of the $2-10\mu$m flux: In Class 0 sources, the trend is for higher $T_\star$ models to have redder colors. In Class I sources, the trend applies with some exceptions. In Class II sources, $2-10\mu$m colors become redder going from $T_\star = 4000$ to 8000 due to decreasing stellar contribution

at $T_\star = 8000K$, and then become blue again from 8000 to 31500 K due to increasing inner disk wall contribution. Near edge-on inclinations, the color behavior is completely different.

Our modeled MIR protostellar colors have implications for interpretations of *Spitzer* IRAC observations of star formation regions: It is commonly assumed that the slope of the SED at $1 - 10\mu$m is directly related to evolutionary state. We show that inclination effects, aperture size, scattered light, and stellar temperature cause a broad spread in the colors of a source at a single evolutionary state. Color-magnitude diagrams can help sort out these effects by separating sources with different $T_\star$ based on their different brightness (for sources at the same distance).

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Note: Radiation transfer codes used in this paper are available at http://gemelli.spacescience.org/∼bwhitney/codes

On the Observability of Giant Protoplanets in Circumstellar Disks

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We investigate the possibility to detect giant planets that are still embedded in young circumstellar disks. Based on models with different stellar, planetary, and disk masses, and different radial positions of the planet we analyze the resulting submillimeter appearance of these systems. We find that the influence of the planet on the spectral energy distribution could not be distinguished from that of other disk parameters. However, dust reemission *images* of the disks show that the hot region in the proximity of a young planet, along with the gap, could indeed be detected and mapped with the Atacama Large Millimeter Array in the case of nearby circumstellar disks (d<100 pc) in approximate face-on orientation.

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The interstellar $C^{18}O/C^{17}O$ ratio in the solar neighbourhood: The ρ Oph cloud

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Observations of up to ten carbon monoxide (CO and isotopomers) transitions are presented to study the interstellar $C^{18}O/C^{17}O$ ratio towards 21 positions in the nearby (d∼140 pc) low-mass star forming cloud ρ Oph. A map of the $C^{18}O$ J=1–0 distribution of parts of the cloud is also shown. An average $^{12}C^{18}O/^{12}C^{17}O$ isotopomeric ratio of 4.11 ± 0.14, reflecting the $^{18}O/^{17}O$ isotope ratio, is derived from Large Velocity Gradient (LVG) calculations. From LTE column densities we derive a ratio of 4.17±0.26. These calculations also show that the kinetic temperature decreases from about 30 K in the cloud envelope to about 10 K in the cloud cores. This decrease is accompanied by an increase of the average molecular hydrogen density from 10^4 cm^{-3} to $\geq 10^5$ cm^{-3}. Towards some lines of sight $C^{18}O$ optical depths reach values of order unity.

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Preprints available at astro-ph/0410091

Abstracts of papers in Nature and Science

Because of embargoes on preprints for Nature and Science, abstracts for these two journals will be accepted for papers that have already been published

Substructure in the Circumstellar Disk around the Young Star AU Mic (GJ 803)

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Keck adaptive optics imaging with a physical resolution of 0.4 AU resolves the inner (15–80 AU) disk of AU Mic (GJ 803), the nearest known scattered light disk to Earth. The inner disk is asymmetric and possesses a sharp change in structure at 35 AU. The disk also shows spatially localized enhancements and deficits at 25–40 AU separations. The overall morphology points to the influence of unseen larger bodies and resembles structures expected from recent planet formation. AU Mic is coeval with the archetypical debris disk system β Pictoris, and the similarities between their two disks point to synchronous disk evolution. Multiple indications of substructure appear to be common in circumstellar disks at an age of $\approx$12 Myr.

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http://arxiv.org/abs/astro-ph/0408164

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Dissertation Abstracts

Surveys for low-mass stars and brown dwarfs: Solar Neighbourhood and intermediate-age clusters α Per and Collinder 359

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Ph.D degree awarded: July 2004

In this thesis, we describe results of surveys for low-mass stars and brown dwarfs, including older ones in the nearby field and younger ones in more distant clusters.

First, we present the outcome of a proper motion survey conducted in the southern sky, aimed at finding some of the nearest and coolest neighbours to the Sun. We have uncovered numerous ultracool dwarfs within 50 parsecs, including two late-M dwarfs within 10 parsecs, four L dwarfs, an active M8.5 dwarf companion to a binary system at about 20 parsecs, and the closest brown dwarf binary, ε Indi Ba,Bb, at just 3.6 pc.

Second, we focus on the substellar mass function in young open clusters. We have carried out a wide-field near-infrared survey of a 0.7 square degree region in the α Per cluster, yielding new member candidates, including several brown dwarfs. In addition, we present optical spectroscopy of about 30 optically-selected cluster members. We confirm the membership of all probable candidates based on chromospheric activity and surface gravity measurements.

We have also conducted an optical survey of a 1.6 square degree area in Collinder 359 within the framework of a large Canada-France-Hawaii-Telescope Key Programme conducted with the CFH12K wide-field camera. New bona-fide members have been extracted from solar mass stars to brown dwarfs, yielding a revised distance of 500 ± 100 pc and an age of 80 ± 20 Myr for the cluster. We have derived the cluster luminosity and mass functions down into the substellar regime. The derived mass function continues rising into the substellar regime with a slope flatter than that estimated for Pleiades-like clusters, although the slopes might still be consistent within the uncertainties.

A pdf file of this thesis is available at the following URL: http://www.aip.de/groups/publications.html

Deuteration in low-mass protostars

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Ph.D degree awarded: September 2004

Despite the low deuterium abundance in the Universe (D/H $\sim 1.5\times10^{-5}$), high abundances of deuterated molecules are detected in star forming regions, with a fractionation (*i.e.* the ratio of deuterated over main isotopomer) higher than the cosmic abundance of deuterium by several orders of magnitude. Particularly, warm dense gas in hot cores around low-mass protostars is enriched in deuterated species, with even high observed abundances of doubly-deuterated species such as D_2CO. These deuterated molecules provide valuable tools to probe the physical conditions occurring during star formation. Deuteration is thought to be driven by the small energy differences between a deuterated species and the normal isotope. Because the temperatures indicated by the fractionation are much lower than the present gas temperatures in hot cores, the observed deuterations are thought to reflect a previous cold phase. Likely these molecules formed during the preceding prestellar core phase – either in the gas phase or on the grain surface – and were stored in an ice mantle which evaporated once the YSO heated its environment above the ice sublimation temperature.

We study in this thesis the physical and chemical processes leading to the high molecular deuteration observed in low-mass protostellar environments. We present observations of deuterated molecules (namely methanol, formaldehyde and water) both in the gas and in the icy mantles of dust grains in the envelope surrounding such objects. Millimeter observations unveiled a high deuteration of methanol in the gas of the envelope. In particular, triply-deuterated methanol was detected with a fractionation $CD_3OH/CH_3OH \sim 1\%$ in IRAS16293-2422. The observed fractionations are consistent with the scenario of formation of methanol on dust grain surfaces. Deuterated methanol and formaldehyde were then searched for and detected on a sample of low-mass Class 0 protostars, suggesting that this high deuteration is common in this class of objects. Analysis of the gas-phase water emission in the IRAS16293-2422 envelope leads paradoxically to a fractionation one order of magnitude lower, in agreement with the upper limit on water deuteration in ices, derived by near-infrared observations towards slightly more evolved objects. The last chapter of the thesis presents a grain chemistry model that studies in details water fractionation.

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UNIVERSITY OF TOLEDO

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Questions or requests for further information about the position may be addressed to Prof. Karen Bjorkman, Search Committee Chair (karen@astro.utoledo.edu). Prospective applicants can learn more about the department from our web page, http://www.physics.utoledo.edu , and information about the university, http://www.utoledo.edu . Applicants should submit a curriculum vitae, research and teaching statements, and the names, addresses (including e-mail), and phone numbers of at least three references to: Chair, Astrophysics Faculty Search Committee, Dept. of Physics & Astronomy, MS #111, University of Toledo, Toledo, OH 43606-3390. The application deadline is January 20, 2005.

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