

# THE STAR FORMATION NEWSLETTER

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## *Abstracts of recently accepted papers*

### **[O I] sub-arcsecond study of a microjet from an intermediate mass young star: RY Tau** **V. Agra-Amboage<sup>1</sup>, C. Dougados<sup>1</sup>, S. Cabrit<sup>2</sup>, P.J.V. Garcia<sup>3,4,1</sup> and P. Ferruit<sup>5</sup>**

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High-resolution studies of microjets in T Tauri stars (cTTs) reveal key information on the jet collimation and launching mechanism, but only a handful of systems have been mapped so far. We perform a detailed study of the microjet from the 2  $M_{\odot}$  young star RY Tau, to investigate the influence of its higher stellar mass and claimed close binarity on jet properties. Spectro-imaging observations of RY Tau were obtained in [O I] $\lambda$ 6300 with resolutions of 0.4'' and 135 km s<sup>-1</sup>, using the integral field spectrograph OASIS at the Canada-France-Hawaii Telescope. Deconvolved images reach a resolution of 0.2''. The blueshifted jet is detected within 2'' of the central star. We determine its PA, collimation, 2D kinematics, mass-flux rate, ejection to accretion ratio, and transverse velocity shifts taking accurately into account errors due to finite signal to noise ratio. The RY Tau system is shown to provide important constraints to several models of steady MHD ejection. The remarkably similar properties of the RY Tau microjet compared to jets from lower mass cTTs gives support to the common belief that the jet launching mechanism is universal over a broad range of stellar masses. The proximity between the jet PA and the PA of the photocenter variations observed by Hipparcos calls into question the interpretation of the latter in terms of binarity of RY Tau. Partial occultation events of the photosphere may offer an alternative explanation.

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### **An X-ray Survey of Low-Mass Stars in Trumpler 16 with Chandra**

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*Aims.* We identify and characterize low-mass stars in the  $\sim$ 3 Myr old Trumpler 16 region by means of a deep *Chandra* X-ray observation, and study their optical and near-IR properties. We compare the X-ray activity of Trumpler 16 stars with the known characteristics of Orion and Cygnus OB2 stars.

*Methods.* We analyzed a 88.4 ks *Chandra* ACIS-I observation pointed at the center of Trumpler 16. Because of diffuse X-ray emission, source detection was performed using the PWDetect code for two different energy ranges: 0.5-8.0 keV and 0.9-8.0 keV. Results were merged into a single final list. We positionally correlated X-ray sources with optical and 2MASS catalogs. Source events were extracted with the IDL-based routine ACIS-Extract. X-ray variability was

characterized using the Kolmogorov-Smirnov test and spectra were fitted by using XSPEC. The X-ray spectra of early-type, massive stars were analyzed individually.

*Results.* Our list of X-ray sources consists of 1035 entries, 660 of which have near-IR counterparts and are probably associated with Trumpler 16 members. From near-IR, color-color, and color-magnitude diagrams we compute individual masses of stars and their  $A_V$  values. The cluster median extinction is  $A_V = 3.6$  mag, while OB-type stars appear less absorbed, having  $A_V = 2.0$  mag. About 15% of the near-IR counterparts show disk-induced excesses. X-ray variability is found in 77 sources, and typical X-ray spectral parameters are  $N_H \sim 5.37 \times 10^{21} \text{ cm}^{-2}$  and  $kT \sim 1.95$  keV. The OB stars appear softer with a median  $kT \sim 0.65$  keV. The median X-ray luminosity is  $6.3 \times 10^{30} \text{ erg s}^{-1}$ , while variable sources show a larger median  $L_X$  value of  $13 \times 10^{30} \text{ erg s}^{-1}$ . OB-stars have an even higher median  $L_X$  of  $80 \times 10^{30} \text{ erg s}^{-1}$ , about 10 times that of the low-mass stars.

*Conclusions.* The Trumpler 16 region has a very rich population of low-mass X-ray emitting stars. A large fraction of its circumstellar disks have survived the intense radiation field of its massive stars. Stars with masses 1.5-2.5  $M_\odot$  display X-ray activity similar to the Cyg OB2 stars, but much less intense than observed for Orion nebula cluster members.

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## No evidence for mass segregation in young clusters

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**Aims.** We investigate the validity of mass segregation indicators commonly used in the analysis of young stellar clusters. **Methods.** We simulate observations by constructing synthetic seeing limited images of a 1000 massive clusters ( $10^4 M_\odot$ ) with a standard IMF and a King density distribution function. **Results.** We find that commonly used indicators are highly sensitive to sample incompleteness in observational data, and that radial completeness determinations do not provide satisfactory corrections, rendering the studies of radial properties highly uncertain. On the other hand, we find that under certain conditions, the global completeness can be estimated accurately, allowing for the correction of the global luminosity and mass functions of the cluster. **Conclusions.** We argue that there is currently no observational evidence for mass segregation in young compact clusters since there is not a robust way to differentiate between true mass segregation and sample incompleteness effects. Caution should then be exercised when interpreting results from observations as evidence for mass segregation.

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[http://www.astro.up.pt/~jascenso/mseg\\_v2.pdf](http://www.astro.up.pt/~jascenso/mseg_v2.pdf)

## V1647 Orionis: Keck/NIRSPEC 2 Micron Echelle Observations

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We present new Keck II NIRSPEC high-spectral resolution 2  $\mu\text{m}$  echelle observations of the young eruptive variable star V1647 Orionis. This star went into outburst in late 2003 and faded to its pre-outburst brightness after approximately 26 months. V1647 Orionis is the illuminating star of McNeil's Nebula and is located near M 78 in the Lynds 1630 dark cloud. Our spectra have a resolving power of approximately 18,000 and allow us to study in detail the weak absorption features present on the strong near-IR veiled continuum. An analysis of the echelle orders containing Mg I (2.1066  $\mu\text{m}$ ) and Al I (2.1099  $\mu\text{m}$ ), Br $\gamma$  (2.1661  $\mu\text{m}$ ), the Na I doublet (2.206 and 2.209  $\mu\text{m}$ ), and the CO overtone bandhead (2.2935  $\mu\text{m}$ ) gives us considerable information on the physical and geometric characteristics of the regions

producing these spectral features. We find that, at high-spectral resolution, V1647 Orionis in quiescence resembles a significant number of FU Orionis type eruptive variables and does not appear similar to the quiescent EX Lupi variables observed. This correspondence is discussed and implications for the evolutionary state of the star are considered.

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## Near-IR Spectroscopy of Young Stars in the Braid Nebula Star Formation Region in Cygnus OB7

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We present 1.4 to 2.5  $\mu\text{m}$  integral field spectroscopy of 16 stars in the Braid Nebula star formation region in Cygnus OB7. These data forms one aspect of a large-scale multi-wavelength survey aimed at determining an unbiased estimate of the number, mass distribution, and evolutionary state of the young stars within this one square degree area of the previously poorly studied Lynds 1003 molecular cloud. Our new spectroscopic data, when combined with 2MASS near-IR photometry, provide evidence of membership of many of these objects in the regions pre-main sequence population. We discuss both the characteristics of the young stars found in the region and the level of star forming activity present.

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## Simulating star formation in molecular cloud cores IV. The role of turbulence and thermodynamics

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*Context.* Observations suggest that low-mass stars condense out of dense, relatively isolated, molecular cloud cores, with each core spawning a small- $N$  cluster of stars.

*Aims.* Our aim is to identify the physical processes shaping the collapse and fragmentation of a  $5.4 M_{\odot}$  core, and to understand how these processes influence the mass distribution, kinematics, and binary statistics of the resulting stars.

*Methods.* We perform SPH simulations of the collapse and fragmentation of cores having different initial levels of turbulence ( $\alpha_{\text{TURB}} = 0.05, 0.10, 0.25$ ). We use a new treatment of the energy equation that captures (i) excitation of the rotational and vibrational degrees of freedom of  $\text{H}_2$ , dissociation of  $\text{H}_2$ , ionisation of H and He, and (ii) the transport of cooling radiation against opacity due to both dust and gas (including the effects of dust sublimation, molecules, and  $\text{H}^-$  ions). We also perform comparison simulations using a standard barotropic equation of state.

*Results* We find that – when compared with the barotropic equation of state – our more realistic treatment of the energy

equation results in more protostellar objects being formed, and a higher proportion of brown dwarfs; the multiplicity frequency is essentially unchanged, but the multiple systems tend to have shorter periods (by a factor  $\sim 3$ ), higher eccentricities, and higher mass ratios. The reason for this is that small fragments are able to cool more effectively with the new treatment, as compared with the barotropic equation of state. We also note that in our simulations the process of fragmentation is often bimodal, in the following sense. The first protostar to form is usually, at the end, the most massive, i.e. the primary. However, frequently a disc-like structure subsequently forms round this primary, and then, once it has accumulated sufficient mass, quickly fragments to produce several secondaries.

*Conclusions.* We believe that this delayed fragmentation of a disc-like structure is likely to be an important source of very low-mass stars in nature (both low-mass hydrogen-burning stars and brown dwarf stars); hence it may be fundamental to understanding the way in which the statistical properties of stars change – continuously but monotonically – with decreasing mass. However, in our simulations the individual cores probably produce too many stars, and hence too many single stars. We list the physical and numerical features that still need to be included in our simulations to make them more realistic; in particular, radiative and mechanical feedback, non-ideal magneto-hydrodynamic effects, and a more sophisticated implementation of sink particles.

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## Hypercompact H II Regions: Resolved Images of G34.26+0.15 A and B

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We report high angular resolution observations at  $\lambda = 7$  mm of the hypercompact (HC) HII regions G34.26+0.15 A and B. The images and the intensity profiles obtained give possible evidence of limb brightening, which may indicate the existence of inner “holes” in the ionized gas. These “holes” were previously inferred from a study of the spectra and angular sizes at different frequencies from lower angular resolution observations. Using a spherical ionized model bounded by an inner and an outer radii with an electron density gradient  $n_e \propto r^{-\alpha}$ , we can reproduce the 7 mm intensity profile, spectral energy distribution and observed angular sizes of both sources. These models indicate inner radii  $R_1 \sim 400$  AU, outer radii  $R_2 \sim 1000$  AU, and shallow density gradients with slopes  $\alpha \sim 0.3 - 1.0$ . These profiles are similar in physical size and shape to those found recently for the HC HII regions G24.78+0.08 A1 and G28.20-0.04N. Therefore, at least four HC HII regions seem to have thick shells of ionized gas with fractional widths,  $(R_2 - R_1)/R_2 \sim 0.1 - 0.6$ , in contrast with the thin ionized shells expected in the case of shells swept-up by stellar winds. More observations are needed to determine the origin of these thick ionized shells and their frequency of occurrence in the HC HII region stage.

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<http://www.crya.unam.mx/~m.avalos/ApJAvalos2009.pdf>

## Epsilon Eridani’s Planetary Debris Disk: Structure and Dynamics based on Spitzer and CSO Observations

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*Spitzer* and Caltech Submillimeter Observatory (CSO) images and spectrophotometry of  $\epsilon$  Eridani at wavelengths from 3.5 to 350  $\mu\text{m}$  reveal new details of its bright debris disk. The 350  $\mu\text{m}$  map confirms the presence of a ring at  $r = 11\text{--}28''$  (35–90 AU) observed previously at longer sub-mm wavelengths. The *Spitzer* mid- and far-IR images do not show the ring, but rather a featureless disk extending from within a few arcsec of the star across the ring to  $r \sim 34''$  (110 AU).

The spectral energy distribution (SED) of the debris system implies a complex structure. A model constrained by the surface brightness profiles and the SED indicates that the sub-mm ring emission is primarily from large ( $a \sim 135 \mu\text{m}$ ) grains, with smaller ( $a \sim 15 \mu\text{m}$ ) grains also present in and beyond the ring. The *Spitzer* IRS and MIPS SED-mode spectrophotometry data clearly show the presence of spatially compact excess emission at  $\lambda \gtrsim 15 \mu\text{m}$  that requires the presence of two additional narrow belts of dust within the sub-mm ring's central void. The innermost belt at  $r \sim 3$  AU is composed of silicate dust.

A simple dynamical model suggests that dust produced collisionally by a population of about 11  $M_{\oplus}$  of planetesimals in the sub-mm ring could be the source of the emission from both in and beyond the sub-mm ring. Maintaining the inner belts and the inner edge to the sub-mm ring may require the presence of three planets in this system including the candidate radial velocity object.

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## On the gravitational content of molecular clouds and their cores

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The gravitational term for clouds and cores entering in the virial theorem is usually assumed to be equal to the gravitational energy, since the contribution to the gravitational force from the mass distribution outside the volume of integration is assumed to be negligible. Such approximation may not be valid in the presence of an important external net potential. In the present work we analyze the effect of an external gravitational field on the gravitational budget of a density structure. Our cases under analysis are (a) a giant molecular cloud (GMC) with different aspect ratios embedded within a galactic net potential, including the effects of gravity, shear, and inertial forces, and (b) a molecular cloud core embedded within the gravitational potential of its parent molecular cloud.

We find that for roundish GMCs, the tidal tearing due to the shear in the plane of the galaxy is compensated by the tidal compression in the  $z$  direction. The influence of the external effective potential on the total gravitational budget of these clouds is relatively small (up to  $\sim 15 - 25\%$ ), although not necessarily negligible. However, for more filamentary GMCs, elongated on the plane of the galaxy, the external effective potential can be dominant and can even overwhelm self-gravity, regardless of whether its main effect on the cloud is to disrupt it or compress it. This may explain the presence of some GMCs with few or no signs of massive star formation, such as the Taurus or the Maddalena's clouds.

In the case of dense cores embedded in their parent molecular cloud, we found that the gravitational content due to the external field may be more important than the gravitational energy of the cores themselves. This effect works in the same direction as the gravitational energy, i.e., favoring the collapse of cores. We speculate on the implications of these results for star formation models, in particular that apparently nearly magnetically critical cores may actually be supercritical due to the effect of the external potential.

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# Modeling the Rotational Evolution of Young T Tauri Stars

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Measurements of rotational periods of pre-main-sequence stars in several young ( $\sim 1$  Myr) open clusters reveal a uniform trend. Stars with masses below  $0.25 M_{\odot}$  show a bimodal period distribution with fast and slow rotators clustered around 2 and 8 day periods, respectively, while the period distribution of low-mass stars lacks the slow-rotating component. In one popular interpretation of this observational result, the slow rotators are identified as “disk-locked” stars whose periods are fixed to the orbital periods at the inner edge of the accretion disk; the fast rotators are assumed to be stars that have lost their connection to the disk. We argue that this scenario can account for observations if the mass accretion rate in the disk declines with time. We construct a simple model for the period evolution in T Tauri stars (TTSs) that includes realistic prescriptions for the mass accretion rate, radius evolution, and transition between strong and weak accretion disk coupling. Using this model to simulate the cluster period distribution, we can qualitatively reproduce the observed results, but only if the accretion is allowed to continue after the disk and star are no longer locked. When the contribution from accretion is ignored, the unlocked stars tend to rotate slower than the locked population. Our model predicts a very strong mass segregation between the two peaks in the bimodal distribution, with lower mass stars and higher mass stars being the fast and slow rotators, respectively. This effect is not readily apparent in the data, although some of the discrepancy might be due to the uncertainties associated with measurements of stellar masses. Improved observational constraints on TTS masses could help support or rule out our prediction that the rotational periods of TTSs with masses above  $0.25 M_{\odot}$  are dependent on stellar mass.

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# First detection of glycolaldehyde outside the Galactic Center

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Glycolaldehyde is the simplest of the monosaccharide sugars and is directly linked to the origin of life. We report on the detection of glycolaldehyde ( $\text{CH}_2\text{OHCHO}$ ) towards the hot molecular core G31.41+0.31 through IRAM PdBI observations at 1.4, 2.1, and 2.9 mm. The  $\text{CH}_2\text{OHCHO}$  emission comes from the hottest ( $\geq 300$  K) and densest ( $\geq 2 \times 10^8 \text{ cm}^{-3}$ ) region closest ( $\leq 10^4$  AU) to the (proto)stars. The comparison of data with gas-grain chemical models of hot cores suggests for G31.41+0.31 an age of a few  $10^5$  yr. We also show that only small amounts of CO need to be processed on grains in order for existing hot core gas-grain chemical models to reproduce the observed column densities of glycolaldehyde, making surface reactions the most feasible route to its formation.

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<http://arxiv.org/abs/0811.3821>

# Analytical Solutions for Radiative Transfer: Implications for Giant Planet Formation by Disk Instability

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The disk instability mechanism for giant planet formation is based on the formation of clumps in a marginally-gravitationally unstable protoplanetary disk, which must lose thermal energy through a combination of convection and radiative cooling if they are to survive and contract to become giant protoplanets. While there is good observational support for forming at least some giant planets by disk instability, the mechanism has become theoretically contentious, with different three dimensional radiative hydrodynamics codes often yielding different results. Rigorous code testing is required to make further progress. Here we present two new analytical solutions for radiative transfer in spherical coordinates, suitable for testing the code employed in all of the Boss disk instability calculations. The testing shows that the Boss code radiative transfer routines do an excellent job of relaxing to and maintaining the analytical results for the radial temperature and radiative flux profiles for a spherical cloud with high or moderate optical depths, including the transition from optically thick to optically thin regions. These radial test results are independent of whether the Eddington approximation, diffusion approximation, or flux-limited diffusion approximation routines are employed. The Boss code does an equally excellent job of relaxing to and maintaining the analytical results for the vertical ( $\theta$ ) temperature and radiative flux profiles for a disk with a height proportional to the radial distance. These tests strongly support the disk instability mechanism for forming giant planets.

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Preprint available at <http://www.dtm.ciw.edu/boss/ftp/analyt/>

## An Infrared Census of Star Formation in the Horsehead Nebula

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At  $\sim 400$  pc, the Horsehead Nebula (B33) is the closest radiatively-sculpted pillar to the Sun, but the state and extent of star formation in this structure is not well understood. We present deep near-infrared (IRSF/SIRIUS  $JHK_S$ ) and mid-infrared (*Spitzer*/IRAC) observations of the Horsehead Nebula in order to characterize the star forming properties of this region and to assess the likelihood of triggered star formation. Infrared color-color and color-magnitude diagrams are used to identify young stars based on infrared excess emission and positions to the right of the Zero-Age Main Sequence, respectively. Of the 45 sources detected at both near- and mid-infrared wavelengths, three bona fide and five candidate young stars are identified in this  $7' \times 7'$  region. Two bona fide young stars have flat infrared SEDs and are located at the western irradiated tip of the pillar. The spatial coincidence of the protostars at the leading edge of this elephant trunk is consistent with the Radiation-Driven Implosion (RDI) model of triggered star formation. There is no evidence, however, for sequential star formation within the immediate  $\sim 1.5'$  (0.17 pc) region from the cloud/H II region interface.

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## Low-Resolution Spectroscopy and Spectral Energy Distributions of Selected Sources Towards $\sigma$ Orionis

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*Aims.* We study in detail nine sources in the direction of the young  $\sigma$  Orionis cluster, which is considered to be a unique site for studying stellar and substellar formation. The nine sources were selected because of their peculiar properties, such as extremely-red infrared colours or excessively strong H $\alpha$  emission for their blue optical colours.

*Methods.* We acquired high-quality, low-resolution spectroscopy ( $R \sim 500$ ) of the nine targets with ALFOSC at the Nordic Optical Telescope. We also re-analysed [24]-band photometry from MIPS/Spitzer and compiled the highest quality photometric dataset available at the *ViJHK<sub>S</sub>* passbands and the four IRAC/*Spitzer* channels, for constructing accurate spectral energy distributions between 0.55 and 24  $\mu\text{m}$ .

*Results.* The nine targets were classified into: one Herbig Ae/Be star with a scattering edge-on disc; two G-type stars; one X-ray flaring, early-M, young star with chromospheric H $\alpha$  emission; one very low-mass, accreting, young spectroscopic binary; two young objects at the brown-dwarf boundary with the characteristics of classical T Tauri stars; and two emission-line galaxies, one undergoing star formation, and another whose spectral energy distribution is dominated by an active galactic nucleus. We also discovered three infrared sources associated with overdensities in a cold cloud of the cluster centre.

*Conclusions.* Low-resolution spectroscopy and spectral energy distributions are a vital tool for measuring the physical properties and evolution of young stars and candidates in the  $\sigma$  Orionis cluster.

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## Density effect on multiwavelength luminosities on star-formation regions in NGC 3184 and NGC 3938

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We analyzed the regions of star formation in the spiral galaxies NGC 3184 and NGC 3938 from archive images for a wide range of wavelengths (NUV from GALEX, H $\alpha$  from JKT and KPNO, 8 and 24  $\mu\text{m}$  from Spitzer, and CO from BIMA). We used the Clump Find Algorithm to extract the properties of the star-forming tracers, identifiable as emission regions at each wavelength. We obtained a power-law relation between the luminosity and the emission region volume that scales as expected,  $L \propto V$ , for the H $\alpha$  and NUV emission, but the luminosity varies far more rapidly with the volume for the dust (8 and 24  $\mu\text{m}$ ) and molecular gas emitting regions in CO. This is interpreted as a change in the emissivity with the size of the cloud, either by an augmentation of the overall density or due to the presence of high density clumps, with high local emissivity coefficients. Although the clumpy nature of molecular gas may be unsurprising, the clumpy nature of mid-infrared emission regions, which could be explained by newly formed high to intermediate mass stars embedded in the dust providing the heating, is clearly revealed in both galaxies.

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## The Formation and Evolution of Planetary Systems: Description of the *Spitzer* Legacy Science Database

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We present the science database produced by the Formation and Evolution of Planetary Systems (FEPS) *Spitzer* Legacy program. Data reduction and validation procedures for the IRAC, MIPS, and IRS instruments are described in detail. We also derive stellar properties for the FEPS sample from available broadband photometry and spectral types, and present an algorithm to normalize Kurucz synthetic spectra to optical and near-infrared photometry. The final FEPS data products include IRAC and MIPS photometry for each star in the FEPS sample and calibrated IRS spectra.

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## Spitzer View of Young Massive Stars in the LMC HII Complex N44

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The HII complex N 44 in the Large Magellanic Cloud (LMC) provides an excellent site to perform a detailed study of star formation in a mild starburst, as it hosts three regions of star formation at different evolutionary stages and it is not as complicated and confusing as the 30 Doradus giant HII region. We have obtained *Spitzer Space Telescope* observations and complementary ground-based 4m *uBVJJK* observations of N 44 to identify candidate massive young stellar objects (YSOs). We further classify the YSOs into Types I, II, and III, according to their spectral energy distributions (SEDs). In our sample of 60 YSO candidates,  $\sim 65\%$  of them are resolved into multiple components or extended sources in high-resolution ground-based images. We have modeled the SEDs of 36 YSOs that appear single or dominant within a group. We find good fits for Types I and I/II YSOs, but Types II and II/III YSOs show deviations between their observed SEDs and models that do not include PAH emission. We have also found that some Type III YSOs have central holes in their disk components. YSO counterparts are found in four ultracompact HII regions and their stellar masses determined from SED model fits agree well with those estimated from the ionization requirements of the HII regions. The distribution of YSOs is compared with those of the underlying stellar population and interstellar gas conditions to illustrate a correlation between the current formation of O-type stars and previous formation of massive stars. Evidence of triggered star formation is also presented.

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Available at <http://www.astro.virginia.edu/~cc5ye/n44yso.pdf> ; also at <http://arXiv.org/abs/0901.1328>

## Kinematics of the Young Stellar Objects associated with the Cometary Globules in the Gum Nebula

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An analysis of proper motion measurements of the Young Stellar Objects (YSOs) associated with the Cometary Globules (CGs) in the Gum Nebula is presented. While earlier studies based on the radial velocity measurements of the CGs suggested expansion of the system of the CGs, the observed proper motion of the YSOs shows no evidence for expansion. In particular the kinematics of two YSOs embedded in CGs is inconsistent with the supernova explosion of the companion of  $\zeta$  Pup about 1.5 Myr ago as the cause of the expansion of the CG system. YSOs associated with the CGs share the average proper motion of the member stars of the Vela OB2 association. A few YSOs that have relatively large proper motions are found to show relatively low infrared excesses.

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# Episodic Magnetic Bubbles and Jets: Astrophysical Implications from Laboratory Experiments

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Collimated outflows (jets) are ubiquitous in the universe appearing around sources as diverse as protostars and extragalactic supermassive blackholes. Jets are thought to be magnetically collimated, and launched from a magnetized accretion disk surrounding a compact gravitating object. We have developed the first laboratory experiments to address time-dependent, episodic phenomena relevant to the poorly understood jet acceleration and collimation region. The experimental results show the periodic ejections of magnetic bubbles naturally evolving into a heterogeneous jet propagating inside a channel made of self-collimated magnetic cavities. The results provide a unique view of the possible transition from a relatively steady-state jet launching to the observed highly structured outflows.

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## A Photometrically and Morphologically Variable Infrared Nebula in L483

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We present narrow and broad K-band observations of the Class 0/I source IRAS 18148-0440 that span 17 years. The infrared nebula associated with this protostar in the L483 dark cloud is both morphologically and photometrically variable on a time scale of only a few months. This nebula appears to be an infrared analogue to other well-known optically visible variable nebulae associated with young stars, such as Hubble's Variable Nebula. Along with Cepheus A, this is one of the first large variable nebulae to be found that is only visible in the infrared. The variability of this nebula is most likely due to changing illumination of the cloud rather than any motion of the structure in the nebula. Both morphological and photometric changes are observed on a time scale only a few times longer than the light crossing time of the nebula, suggesting very rapid intrinsic changes in the illumination of the nebula. Our narrow-band observations also found that H<sub>2</sub> knots are found nearly twice as far to the east of the source as to its west, and that H<sub>2</sub> emission extends farther east of the source than the previously known CO outflow.

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## Characterising the Gravitational Instability in Cooling Accretion Discs

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In this paper we perform a systematic analysis of the structure induced by the onset of gravitational instabilities in cooling gaseous accretion discs. It is well known that for low enough cooling rates the disc reaches a quasi-steady configuration, with the instability saturating at a finite amplitude such that the disc is kept close to marginal stability. We analyse the dependence of the saturation amplitude on the imposed cooling rate, and we find that it scales with

the inverse square root of the cooling parameter  $\beta = t_{\text{cool}}/t_{\text{dyn}}$ . This indicates that the heating rate induced by the instability is proportional to the energy density of the density waves excited by the disc self-gravity. In particular, we find that at saturation the energy dissipated per dynamical time by weak shocks due to the gravitational perturbations is of the order of 20 per cent of the wave energy. We further perform a Fourier analysis of the disc structure, and subsequently determine the dominant radial and azimuthal wavenumbers of the density waves. While the number of spiral arms (corresponding to the azimuthal wavenumber) is fairly constant with radius, we find that the disc displays a range of radial wavenumbers whose mean increases with increasing radius. The dominant modes closely match the locally most unstable wavelength as predicted by linear perturbation analysis. As a consequence, we demonstrate numerically that the density waves excited in relatively low mass discs  $M_{\text{disc}}/M_* \sim 0.1$  are always close to co-rotation, deviating from it by approximately 10 per cent. This result can be understood in terms of the constancy of the Doppler-shifted phase Mach number of the flow – the pattern speed self-adjusts so that the flow into spiral arms is always sonic. This has profound effects on the degree to which the extraction of energy and angular momentum from the mean flow through density waves can be modelled as a viscous process. Our results thus provide (a) a detailed description of how the self-regulation mechanism is established for low cooling rates, (b) a clarification of the conditions required for describing the transport induced by self-gravity through an effective viscosity, (c) an estimate of the maximum amplitude of the density perturbation before fragmentation takes place, and finally (d) a simple recipe to estimate the density perturbation in different thermal regimes.

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## A Catalog of Extended Green Objects in the GLIMPSE Survey: A New Sample of Massive Young Stellar Object Outflow Candidates

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Using images from the *Spitzer* Galactic Legacy Infrared Mid-Plane Survey Extraordinaire (GLIMPSE), we have identified more than 300 extended 4.5  $\mu\text{m}$  sources (Extended Green Objects (EGOs), for the common coding of the [4.5] band as green in three-color composite InfraRed Array Camera images). We present a catalog of these EGOs, including integrated flux density measurements at 3.6, 4.5, 5.8, 8.0, and 24  $\mu\text{m}$  from GLIMPSE and the Multiband Imaging Photometer for *Spitzer* Galactic Plane Survey. The average angular separation between a source in our sample and the nearest *IRAS* point source is greater than 1'. The majority of EGOs are associated with infrared dark clouds (IRDCs), and where high-resolution 6.7 GHz CH<sub>3</sub>OH maser surveys overlap the GLIMPSE coverage, EGOs and 6.7 GHz CH<sub>3</sub>OH masers are strongly correlated. Extended 4.5  $\mu\text{m}$  emission is thought to trace shocked molecular gas in protostellar outflows; the association of EGOs with IRDCs and 6.7 GHz CH<sub>3</sub>OH masers suggests that the extended 4.5  $\mu\text{m}$  emission may pinpoint outflows specifically from massive protostars. The mid-IR colors of EGOs lie in regions of color-color space occupied by young protostars still embedded in infalling envelopes.

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# A top-heavy stellar initial mass function in starbursts as an explanation for the high mass-to-light ratios of ultra compact dwarf galaxies

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It has been shown recently that the dynamical  $V$ -band mass-to-light ratios of compact stellar systems with masses from  $10^6 M_{\odot}$  to  $10^8 M_{\odot}$  are not consistent with the predictions from simple stellar population (SSP) models. Top-heavy stellar initial mass functions (IMFs) in these so-called ultra compact dwarf galaxies (UCDs) offer an attractive explanation for this finding, the stellar remnants and retained stellar envelopes providing the unseen mass. We therefore construct a model which quantifies by how much the IMFs of UCDs would have to deviate in the intermediate-mass and high-mass range from the canonical IMF in order to account for the enhanced  $M/L_V$  ratio of the UCDs. The deduced high-mass IMF in the UCDs depends on the age of the UCDs and the number of faint products of stellar evolution retained by them. Assuming that the IMF in the UCDs is a three-part power-law equal to the canonical IMF in the low-mass range and taking 20% as a plausible choice for the fraction of the remnants of high-mass stars retained by UCDs, the model suggests the exponent of the high-mass IMF to be  $\approx 1.6$  if the UCDs are 13 Gyr old (i.e. almost as old as the universe) or  $\approx 1.0$  if the UCDs are 7 Gyr old, in contrast to 2.3 for the Salpeter-Massey IMF. If the IMF was as top-heavy as suggested here, the stability of the UCDs might have been threatened by heavy mass loss induced by the radiation and evolution of massive stars. The central densities of UCDs must have been in the range  $10^6$ - $10^7 M_{\odot} \text{ pc}^{-3}$  when they formed with star formation rates of  $10$ - $100 M_{\odot} \text{ yr}^{-1}$ .

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## The Effect of Stellar Winds on the Formation of a Protocluster

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We present smoothed particle hydrodynamics simulations of protoclusters including the effects of the stellar winds from massive stars. Using a particle-injection method, we investigate the effect of structure in close proximity to the wind sources and the short-time-scale influence of winds on protoclusters. We find that the structures such as discs and gaseous filaments have a strong collimating effect on winds. By a different technique of injecting momentum from point sources into our simulations, we compare the large-scale and long-term effects of isotropic and intrinsically collimated winds on protoclusters and find them to be similar, although the collimated winds take longer to exert a significant influence. We find that both types of wind are able to dramatically slow the global star formation process, but that the time-scale on which they can expel significant quantities of mass from the cluster is rather long (approaching 10 free-fall times). Clusters may then experience rapid star formation very early in their lifetimes, before switching to a mode where gas is gradually expelled, while star formation proceeds much more slowly over many free-fall times. This complicates any conclusions regarding slow star formation derived from measuring the star formation efficiency per free-fall time. We find that estimates of the efficacy of winds in dispersing clusters derived simply from the total wind momentum flux may not be very reliable. This is due to material being expelled from deep within stellar potential wells, often to velocities well in excess of the cluster escape velocity, and also to the loss of momentum flux through holes in the gas distribution. Winds have little effect on the accretion-driven stellar initial mass function (IMF) except at the very high mass end, where they serve to prevent some of the most massive objects accreting more material. Feedback does not result in the formation of further massive stars through the monolithic collapse of massive cores. We also find that the morphology of the gas, the rapid motions of the wind sources and the action of large-scale accretion flows prevent the formation of bubble-like structures. These effects may make it difficult to discern the influence of winds on very young clusters.

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# A census of molecular hydrogen outflows and their sources along the Orion A molecular ridge: characteristics and overall distribution

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*Aims.* A census of molecular hydrogen flows across the entire Orion A Giant Molecular Cloud is sought. With this paper we aim to associate each flow with its progenitor and associated molecular core, so that the characteristics of the outflows and outflow sources can be established.

*Methods.* We present wide-field near-infrared images of Orion A, obtained with the Wide Field Camera, WFCAM, on the United Kingdom Infrared Telescope. Broad-band K and narrow-band H<sub>2</sub> 1-0S(1) images of a contiguous  $\sim 8$  square degree region are compared to mid-IR photometry from the Spitzer Space Telescope and (sub)millimetre dust-continuum maps obtained with the MAMBO and SCUBA bolometer arrays. Using previously-published H<sub>2</sub> images, we also measure proper motions for H<sub>2</sub> features in 33 outflows, and use these data to help associate flows with existing sources and/or dust cores.

*Results.* Together these data give a detailed picture of dynamical star formation across this extensive region. We increase the number of known H<sub>2</sub> outflows to 116. A total of 111 H<sub>2</sub> flows were observed with Spitzer; outflow sources are identified for 72 of them (12 more H<sub>2</sub> flows have tentative progenitors). The MAMBO 1200  $\mu\text{m}$  maps cover 97 H<sub>2</sub> flows; 57 of them (59%) are associated with Spitzer sources and either dust cores or extended 1200  $\mu\text{m}$  emission. The H<sub>2</sub> jets are widely distributed and randomly orientated; the jets do not appear to be orthogonal to large-scale filaments or even to the small-scale cores associated with the outflow sources (at least when traced with the 11 arcsec resolution of the 1200  $\mu\text{m}$  MAMBO observations). Moreover, H<sub>2</sub> jet lengths ( $L$ ) and opening angles ( $\theta$ ) are not obviously correlated with indicators of outflow source age – source spectral index,  $\alpha$  (measured from mid-IR photometry), or (sub)millimetre core flux. It seems clear that excitation requirements limit the usefulness of H<sub>2</sub> as a tracer of  $L$  and  $\theta$  (though jet position angles are well defined).

*Conclusions.* We demonstrate that H<sub>2</sub> jet sources are predominantly protostellar sources with flat or positive mid-IR spectral indices, rather than disk-excess (or T Tauri) stars. Most protostars associated with molecular cores drive H<sub>2</sub> outflows. However, not all molecular cores are associated with protostars or H<sub>2</sub> jets. On statistical grounds, the H<sub>2</sub> jet phase may be marginally shorter than the protostellar phase, though must be considerably (by an order of magnitude) shorter than the prestellar phase. In terms of range and mean value of  $\alpha$ , H<sub>2</sub> jet sources are indistinguishable from protostars. The spread in  $\alpha$  observed for both protostars and H<sub>2</sub> outflow sources is probably a function of inclination angle as much as source age. The few true protostars without H<sub>2</sub> jets are almost certainly more evolved than their H<sub>2</sub>-jet-driving counterparts, although these later stages of protostellar evolution (as the source transitions to being a “disk excess” source) must be very brief, since a large fraction of protostars do drive H<sub>2</sub> flows. We also find that protostars that power molecular outflows are no more (nor no less) clustered than protostars that do not. This suggests that the H<sub>2</sub> emission regions in jets and outflows from young stars weaken and fade very quickly, before the source evolves from protostar to pre-main-sequence star, and on time-scales much shorter than those associated with the T Tauri phase, the Herbig-Haro jet phase, and the dispersal of young stellar objects.

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# SiO Outflow Signatures Toward Massive Young Stellar Objects with Linearly Distributed Methanol Masers

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*Context.* Methanol masers are often found in linear distributions, and it has been hypothesized that these masers trace circumstellar accretion disks around young massive stars. However, recent observations in H<sub>2</sub> emission have shown what appear to be outflows at similar angles to the maser distribution angles, not perpendicular as expected in the maser-disk scenario.

*Aims.* The main motivation behind the observations presented here is to use presence and morphology of an independent outflow tracer, namely SiO, to determine if there are indeed outflows present in these regions and if they are consistent or inconsistent with the maser-disk hypothesis.

*Methods.* For ten sources with H<sub>2</sub> emission, we obtained JCMT single-dish SiO (6-5) observations to search for this outflow indicator. We followed up those observations with ATCA interferometric mapping of the SiO emission in the (2-1) line in six sources.

*Results.* The JCMT observations yielded a detection in the SiO (6-5) line in nine of the ten sources. All of the sources with bright SiO lines display broad line wings indicative of outflow. A subset of the sources observed with the JCMT have methanol maser velocities significantly offset from their parent cloud velocities, supporting the idea that the masers in these sources are likely not to be associated with circumstellar disks. The ATCA maps of the SiO emission show five of the six sources do indeed have SiO outflows (the only non-detection being the same source that was a non-detection in the JCMT observations). The spatial orientations of the outflows are not consistent with the methanol masers delineating disk orientations. Overall, the observations presented here seem to provide further evidence against the hypothesis that linearly distributed methanol masers generally trace the orientations of circumstellar disks around massive young stars.

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## GMC formation by agglomeration and self gravity

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We investigate the formation of giant molecular clouds (GMCs) in spiral galaxies through both agglomeration of clouds in the spiral arms, and self gravity. The simulations presented include two-fluid models, which contain both cold and warm gas, although there is no heating or cooling between them. We find agglomeration is predominant when both the warm and cold components of the interstellar medium are effectively stable to gravitational instabilities. In this case, the spacing (and consequently mass) of clouds and spurs along the spiral arms is determined by the orbits of the gas particles and correlates with their epicyclic radii (or equivalently spiral shock strength). Notably GMCs formed primarily by agglomeration tend to be unbound associations of many smaller clouds, which disperse upon leaving the spiral arms. These GMCs are likely to be more massive in galaxies with stronger spiral shocks or higher surface densities. GMCs formed by agglomeration are also found to exhibit both prograde and retrograde rotation, a consequence of the clumpiness of the gas. At higher surface densities, self gravity becomes more important in arranging both the warm and cold gas into clouds and spurs, and determining the properties of the most massive GMCs. These massive GMCs can be distinguished by their higher angular momentum, exhibit prograde rotation and are more bound. For a  $20M_{\odot}\text{pc}^{-2}$  disc, the spacing between the GMCs fits both the agglomeration and self gravity scenarios, as the maximum unstable wavelength of gravitational perturbations in the warm gas is similar to the spacing found when GMCs form solely by agglomeration.

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## The $N_2D^+/N_2H^+$ ratio as an evolutionary tracer of Class 0 protostars

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*Context.* Deuterated ions, especially  $H_2D^+$  and  $N_2D^+$ , are abundant in cold ( $\sim 10$  K), dense ( $\sim 10^5$  cm<sup>-3</sup>) regions, in which CO is frozen out onto dust grains. In such environments, the  $N_2D^+/N_2H^+$  ratio can exceed the elemental abundance ratio of D/H by a factor of  $\approx 10^4$ .

*Aims.* We use deuterium fractionation to investigate the evolutionary state of Class 0 protostars. In particular, we expect the  $N_2D^+/N_2H^+$  ratio to decrease as temperature (a sign of the evolution of the protostar) increases.

*Methods.* We observed  $N_2H^+$  1-0,  $N_2D^+$  1-0, 2-1 and 3-2,  $C^{18}O$  1-0 and  $HCO^+$  3-2 in a sample of 20 Class 0 and borderline Class 0/I protostars. We determined the deuteration fraction and searched for correlations between the  $N_2D^+/N_2H^+$  ratio and well-established evolutionary tracers, such as  $T_{Dust}$  and the CO depletion factor. In addition, we compared the observational result with a chemical model.

*Results.* In our protostellar sample, the  $N_2H^+$  1-0 optical depths are significantly lower than those found in prestellar cores, but the  $N_2H^+$  column densities are comparable, which can be explained by the higher temperature and larger line width in protostellar cores. The deuterium fractionation of  $N_2H^+$  in protostellar cores is also similar to that in prestellar cores. We found a clear correlation between the  $N_2D^+/N_2H^+$  ratio and evolutionary tracers. As expected, the coolest, i.e. the youngest, objects show the largest deuterium fractionation. Furthermore, we find that sources with a high  $N_2D^+/N_2H^+$  ratio show clear indications of infall (e.g.  $\delta_v < 0$ ). With decreasing deuterium fractionation, the infall signature disappears and  $\delta_v$  tends to be positive for the most evolved objects. The deuterium fractionation of other molecules deviates clearly from that of  $N_2H^+$ . The  $DCO^+/HCO^+$  ratio stays low at all evolutionary stages, whereas the  $NH_2D/NH_3$  ratio is  $>0.15$  even in the most evolved objects.

*Conclusions.* The  $N_2D^+/N_2H^+$  ratio is known to trace the evolution of prestellar cores. We show that this ratio can be used to trace core evolution even after star formation. Protostars with an  $N_2D^+/N_2H^+$  ratio above 0.15 are in a stage shortly after the beginning of collapse. Later on, deuterium fractionation decreases until it reaches a value of  $\sim 0.03$  at the Class 0/I borderline.

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## X-Ray-Irradiated Protoplanetary Disk Atmospheres. I. Predicted Emission-Line Spectrum and Photoevaporation

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We present *mocassin* two-dimensional photoionization and dust radiative transfer models of a prototypical T Tauri disk irradiated by X-rays from the young pre-main-sequence star. The calculations demonstrate a layer of hot gas reaching temperatures of  $\sim 10^6$  K at small radii and  $\sim 10^4$  K at a distance of 1 AU. The gas temperatures decrease sharply with depth, but appear to be completely decoupled from dust temperatures down to a column depth of  $\sim 4 \times 10^{21}$  cm<sup>-2</sup>. We predict that several fine-structure and forbidden lines of heavy elements, as well as recombination lines of hydrogen and helium, should be observable with current and future instrumentation, although optical lines may be smothered by the stellar spectrum. Predicted line luminosities are given for the brightest collisionally excited lines (down to  $\sim 10^{-8} L_\odot$ ) and for recombination transitions from several levels of H I and He I. The mass-loss rate due to X-ray photoevaporation estimated from our models is of the order of  $10^{-8} M_\odot$  yr<sup>-1</sup>, implying a dispersal timescale of a few Myr for a disk of mass  $0.027 M_\odot$ , which is the mass of the disk structure model we employed. We discuss the limitations of our model and highlight the need for further calculations that should include the simultaneous solution of the two-dimensional radiative transfer problem and the one-dimensional hydrostatic equilibrium problem in the polar direction.

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# The Spitzer c2d Legacy Results: Star Formation Rates and Efficiencies; Evolution and Lifetimes

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The c2d Spitzer Legacy project obtained images and photometry with both IRAC and MIPS instruments for five large, nearby molecular clouds. Three of the clouds were also mapped in dust continuum emission at 1.1 mm, and optical spectroscopy has been obtained for some clouds. This paper combines information drawn from studies of individual clouds into a combined and updated statistical analysis of star formation rates and efficiencies, numbers and lifetimes for SED classes, and clustering properties. Current star formation efficiencies range from 3% to 6%; if star formation continues at current rates for 10 Myr, efficiencies could reach 15% to 30%. Star formation rates and rates per unit area vary from cloud to cloud; taken together, the five clouds are producing about 260  $M_{\odot}$  of stars per Myr. The star formation surface density is more than an order of magnitude larger than would be predicted from the Kennicutt relation used in extragalactic studies, reflecting the fact that those relations apply to larger scales, where more diffuse matter is included in the gas surface density. Measured against the dense gas probed by the maps of dust continuum emission, the efficiencies are much higher, with stellar masses similar to masses of dense gas, and the current stock of dense cores would be exhausted in 1.8 Myr on average. Nonetheless, star formation is still slow compared to that expected in a free fall time, even in the dense cores. The derived lifetime for the Class I phase is 0.54 Myr, considerably longer than some estimates. Similarly, the lifetime for the Class 0 SED class, 0.16 Myr, with the notable exception of the Ophiuchus cloud, is longer than early estimates. If photometry is corrected for estimated extinction before calculating class indicators, the lifetimes drop to 0.44 Myr for Class I and to 0.10 for Class 0. These lifetimes assume a continuous flow through the Class II phase and should be considered median lifetimes or half-lives. Star formation is highly concentrated to regions of high extinction, and the youngest objects are very strongly associated with dense cores. The great majority (90%) of young stars lie within loose clusters with at least 35 members and a stellar density of 1  $M_{\odot} \text{ pc}^{-3}$ . Accretion at the sound speed from an isothermal sphere over the lifetime derived for the Class I phase could build a star of about 0.25  $M_{\odot}$ , given an efficiency of 0.3. Building larger mass stars by using higher mass accretion rates could be problematic, as our data confirm and aggravate the “luminosity problem” for protostars. At a given  $T_{bol}$ , the values for  $L_{bol}$  are mostly less than predicted by standard infall models and scatter over several orders of magnitude. These results strongly suggest that accretion is time variable, with prolonged periods of very low accretion. Based on a very simple model and this sample of sources, half the mass of a star would be accreted during only 7% of the Class I lifetime, as represented by the eight most luminous objects.

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## Spectral Energy Distributions of High-Mass Protostellar Objects: Evidence of High Accretion Rates

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The spectral energy distributions (SEDs), spanning the mid-infrared to millimeter wavelengths, of a sample of 13 high-mass protostellar objects (HMPOs) were studied using a large archive of 2D axisymmetric radiative transfer models. Measurements from the *Spitzer* GLIMPSE and MIPS GAL surveys and the *MSX* survey were used in addition to our own surveys at millimeter and submillimeter wavelengths to construct the SEDs, which were then fit to the archive of models. These models assumed that stars of all masses form via accretion and allowed us to make estimates for

the masses, luminosities, and envelope accretion rates for the HMPOs. The models fit the observed SEDs well. The implied envelope accretion rates are high,  $\approx 10^{-2.5} M_{\odot} \text{ yr}^{-1}$ , consistent with the accretion-based scenario of massive star formation. With the fitted accretion rates and with mass estimates of up to  $\sim 20 M_{\odot}$  for these objects, it appears plausible that stars with stellar masses  $M_{*} > 20 M_{\odot}$  can form via accretion.

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## Magnetic Fields and Chemical Peculiarities of the Very Young Intermediate-Mass Binary System HD 72106

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The recently discovered magnetic Herbig Ae and Be stars may provide qualitatively new information about the formation and evolution of magnetic Ap and Bp stars. We have performed a detailed investigation of one particularly interesting binary system with a Herbig Ae secondary and a late B-type primary possessing a strong, globally ordered magnetic field. 20 high-resolution Stokes  $V$  spectra of the system were obtained with the ESPaDOnS instrument mounted on the CanadaFranceHawaii Telescope. In these observations we see clear evidence for a magnetic field in the primary, but no evidence for a magnetic field in the secondary. A detailed abundance analysis was performed for both stars, revealing strong chemical peculiarities in the primary and normal chemical abundances in the secondary. The primary is strongly overabundant in Si, Cr and other iron-peak elements, as well as Nd, and underabundant in He. The primary therefore appears to be a very young Bp star. In this context, line profile variations of the primary suggest non-uniform lateral distributions of surface abundances. Interpreting the  $0.639\,95 \pm 0.000\,09$  d variation period of the Stokes  $I$  and  $V$  profiles as the rotational period of the star, we have modelled the magnetic field geometry and the surface abundance distributions of Si, Ti, Cr and Fe using magnetic Doppler imaging. We derive a dipolar geometry of the surface magnetic field, with a polar strength  $B_{\text{d}} = 1230$  G and an obliquity  $\beta = 57^{\circ}$ . The distributions Ti, Cr and Fe are all qualitatively similar, with an elongated patch of enhanced abundance situated near the positive magnetic pole. The Si distribution is somewhat different, and its relationship to the magnetic field geometry less clear.

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## Spectroscopic Evidence for Gas Infall in GF 9-2

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We present spectroscopic evidence for infall motion of gas in the natal cloud core harboring an extremely young low-mass protostar GF 9-2. We previously discussed that the ongoing collapse of the GF 9-2 core has agreement with the Larson-Penston-Hunter (LPH) theoretical solution for the gravitational collapse of a core (Furuya et al.; paper I). To discuss the gas infall on firmer ground, we have carried out On-The-Fly mapping observations of the  $\text{HCO}^{+}$  (1–0) line

using the Nobeyama 45 m telescope equipped with the 25 Beam Array Receiver System. Furthermore, we observed the HCN (1–0) line with the 45 m telescope, and the HCO<sup>+</sup> (3–2) line with the Caltech Submillimeter Observatory 10.4 m telescope. The optically thick HCO<sup>+</sup> and HCN lines show blueskewed profiles whose deepest absorptions are seen at the peak velocity of optically thin lines, i.e., the systemic velocity of the cloud (paper I), indicating the presence of gas infall toward the central protostar. We compared the observed HCO<sup>+</sup> line profiles with model ones by solving the radiative transfer in the core under LTE assumption. We found that the core gas has a constant infall velocity of  $\sim 0.5$  km s<sup>-1</sup> in the central region, leading to a mass accretion rate of  $2.5 \times 10^{-5} M_{\odot} \text{ yr}^{-1}$ . Consequently, we confirm that the gas infall in the GF 9-2 core is consistent with the LPH solution.

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Preprint is available at <http://subarutelescope.org/staff/rsf/publication.html>

## Lack of PAH emission toward low-mass embedded young stellar objects

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Polycyclic Aromatic Hydrocarbons (PAHs) have been detected toward molecular clouds and some young stars with disks, but have not yet been associated with embedded young stars. We present a sensitive mid-infrared spectroscopic survey of PAH features toward a sample of low-mass embedded young stellar objects (YSOs). The aim is to put constraints on the PAH abundance in the embedded phase of star formation using radiative transfer modeling.

*Methods.* VLT-ISAAC L-band spectra for 39 sources and Spitzer IRS spectra for 53 sources are presented. Line intensities are compared to recent surveys of Herbig Ae/Be and T Tauri stars. The radiative transfer codes RADMC and RADICAL are used to model the PAH emission from embedded YSOs consisting of a pre-main-sequence star with a circumstellar disk embedded in an envelope. The dependence of the PAH feature on PAH abundance, stellar radiation field, inclination and the extinction by the surrounding envelope is studied.

*Results.* The 3.3  $\mu\text{m}$  PAH feature is undetected for the majority of the sample (97%), with typical upper limits of  $5 \times 10^{-16} \text{ W m}^{-2}$ . One source originally classified as class I, IRS 48, shows a strong 3.3  $\mu\text{m}$  feature from a disk. Compact 11.2  $\mu\text{m}$  PAH emission is seen directly towards 1 out of the 53 Spitzer Short-High spectra, for a source that is borderline embedded. For all 12 sources with both VLT and Spitzer spectra, no PAH features are detected in either. In total, PAH features are detected toward at most 1 out of 63 (candidate) embedded protostars ( $\sim 2\%$ ), even lower than observed for class II T Tauri stars with disks (11–14%). Models predict the 7.7  $\mu\text{m}$  feature as the best tracer of PAH emission, while the 3.3  $\mu\text{m}$  feature is relatively weak. Assuming typical class I stellar and envelope parameters, the absence of PAHs emission is most likely explained by the absence of emitting carriers through a PAH abundance at least an order of magnitude lower than in molecular clouds but similar to that found in disks. Thus, most PAHs likely enter the protoplanetary disks frozen out in icy layers on dust grains and/or in coagulated form.

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## Enhanced Dust Emission in the HL Tau Disc: a Low-Mass Companion in Formation?

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We have imaged the disc of the young star HL Tau using the Very Large Array (VLA) at 1.3 cm, with 0.08-arcsec resolution (as small as the orbit of Jupiter). The disc is around half the stellar mass, assuming a canonical gas mass conversion from the measured mass in large dust grains. A simulation shows that such discs are gravitationally unstable, and can fragment at radii of a few tens of au to form planets. The VLA image shows a compact feature in the disc at 65 au radius (confirming the 'nebulousity' of Welch et al.), which is interpreted as a localized surface density enhancement representing a candidate protoplanet in its earliest accretion phase. If correct, this is the first image of a low-mass companion object seen together with the parent disc material out of which it is forming. The object has an inferred gas plus dust mass of  $\approx 14 M_{\text{Jupiter}}$ , similar to the mass of a protoplanet formed in the simulation. The disc instability may have been enhanced by a stellar flyby: the proper motion of the nearby star XZ Tau shows it could have recently passed the HL Tau disc as close as  $\sim 600$  au.

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## A Mapping Survey of Massive CO Cores

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We mapped 21 star-forming regions with the  $^{12}\text{CO}$ ,  $^{13}\text{CO}$  and  $\text{C}^{18}\text{O}$  (1-0) lines using the 13.7-m telescope of Purple Mount Observatory. This mapping survey resolved 53  $^{13}\text{CO}$  cores, of which 22 are sourceless. We obtained the physical parameters of these cores. The relation between  $^{13}\text{CO}$  linewidth and core size and that between column density and core size were analysed. The cores 00211+6549-1 and 22566+5830 were found to have outflows. Systematic  $V_{\text{LSR}}$  shifts were detected in nine regions: 00211+6549, 00232+6437, 05168+3634, 19199+1358, 20160+3911, 22566+5830, 23042+6000, S146 and S270. Signatures of infall and cloud collision were found in regions 18507+0121 and 19199+1358, respectively. We studied the mass function of these  $^{13}\text{CO}$  cores. The core masses range from 3.40 to  $4.64 \times 10^4 M_{\odot}$ , and the core mass function is a power-law distribution of index  $-0.82 \pm 0.04$ .

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## Correlation between the spatial distribution of circumstellar disks and massive stars in the young open cluster NGC 6611. II: Cluster members selected with Spitzer/IRAC

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Context: the observations of the proplyds in the Orion Nebula Cluster, showing clear evidence of ongoing photoevaporation, have provided a clear proof about the role of the externally induced photoevaporation in the evolution of circumstellar disks. NGC 6611 is an open cluster suitable to study disk photoevaporation, thanks to its large population of massive members and of stars with disk. In a previous work, we obtained evidence of the influence of the strong UV field generated by the massive cluster members on the evolution of disks around low-mass Pre-Main Sequence members. That work was based on a multi-band BVIJHK and X-ray catalog purposely compiled to select the cluster members with and without disk.

Aims: in this paper we complete the list of candidate cluster members, using data at longer wavelengths obtained with Spitzer/IRAC, and we revisit the issue of the effects of UV radiation on the evolution of disks in NGC 6611.

Methods: we select the candidate members with disks of NGC 6611, in a field of view of  $33' \times 34'$  centered on the cluster, using IRAC color-color diagrams and suitable reddening-free color indices. Besides, using the X-ray data to

select Class III cluster members, we estimate the disks frequency vs. the intensity of the incident radiation emitted by massive members.

Results: we identify 458 candidate members with circumstellar disks, among which 146 had not been revealed in our previous work. Comparing of the various color indices we used to select the cluster members with disk, we claim that they detect the excesses due to the emission of the same physical region of the disk: the inner rim at the dust sublimation radius. Our new results confirm that UV radiation from massive stars affects the evolution of nearby circumstellar disks.

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[http://www.astropa.unipa.it/~mguarce/NGC6611\\_IRAC.ps](http://www.astropa.unipa.it/~mguarce/NGC6611_IRAC.ps)

## Revealing the fastest component of the DG Tau outflow through X-rays

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Some T Tauri stars show a peculiar X-ray spectrum that can be modelled by two components with different absorbing column densities. We seek to explain the soft X-ray component in DG Tau, the best studied of these sources, with an outflow model, taking observations at other wavelengths into consideration. We constrain the outflow properties through spectral fitting and employ simple semi-analytical formulae to describe properties of a shock wave that heats up the X-ray emitting region. The X-ray emission is consistent with its arising from the fastest and innermost component of the optically detected outflow. Only a small fraction of the total mass loss is required for this X-ray emitting component. Our favoured model requires shock velocities between 400 and 500 km s<sup>-1</sup>. For a density > 10<sup>5</sup> cm<sup>-3</sup> all dimensions of the shock cooling zone are only a few AU, so even in optical observations this cannot be resolved. This X-ray emission mechanism in outflows may also operate in other, less absorbed T Tauri stars, in addition to corona and accretion spots.

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## Jets, accretion, coronae and all that: The enigmatic X-rays from the Herbig star HD 163296

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Herbig Ae/Be stars (HAeBe) are pre-main sequence objects in the mass range  $2 M_{\odot} < M_{*} < 8 M_{\odot}$ . Their X-ray properties are uncertain and, as yet, unexplained. We want to elucidate the X-ray generating mechanism in HAeBes. We present a *XMM-Newton* observation of the HAeBe HD 163296. We analyse the light curve, the broad band and the grating spectra, fit emission measures and abundances and apply models for accretion and wind shocks. We find three temperature components ranging from 0.2 keV to 2.7 keV. The O VII He-like triplet indicates a X-ray formation region in a low density environment with a weak UV photon field, i. e. above the stellar surface. This makes an origin in an accretion shock unlikely, instead we suggest a shock at the base of the jet for the soft component and a coronal origin for the hot component. A mass outflow of  $\dot{M}_{\text{shock}} \approx 10^{-10} M_{\text{sun}} \text{ yr}^{-1}$  is sufficient to power the soft X-rays. HD 163296 is thought to be single, so this data represent genuine HAeBe X-ray emission. HD 163296 might be prototypical for its class.

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# Molecular Tracers of Embedded Star Formation in Ophiuchus

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In this paper we analyze nine SCUBA cores in Ophiuchus using the second-lowest rotational transitions of four molecular species (<sup>12</sup>CO, <sup>13</sup>CO, C<sup>18</sup>O, and C<sup>17</sup>O) to search for clues to the evolutionary state and star-formation activity within each core. Specifically, we look for evidence of outflows, infall, and CO depletion. The line wings in the CO spectra are used to detect outflows, spectral asymmetries in <sup>13</sup>CO are used to determine infall characteristics, and a comparison of the dust emission (from SCUBA observations) and gas emission (from C<sup>18</sup>O) is used to determine the fractional CO freezeout. Through comparison with Spitzer observations of protostellar sources in Ophiuchus, we discuss the usefulness of CO and its isotopologues as the sole indicators of the evolutionary state of each core. This study is an important pilot project for the JCMT Legacy Survey of the Gould Belt (GBS) and the Galactic Plane (JPS), which intend to complement the SCUBA-2 dust continuum observations with HARP observations of <sup>12</sup>CO, <sup>13</sup>CO, C<sup>18</sup>O, and C<sup>17</sup>O  $J = 3 \rightarrow 2$  in order to determine whether or not the cold dust clumps detected by SCUBA-2 are protostellar or starless objects. Our classification of the evolutionary state of the cores (based on molecular line maps and SCUBA observations) is in agreement with the Spitzer designation for six or seven of the nine SCUBA cores. However, several important caveats must be noted in the interpretation of these results. First, while these tracers may work well in isolated cores, care must be taken in blindly applying these metrics to crowded regions. Maps of larger areas at higher resolution are required to determine whether the detected outflows originate from the core of interest, or from an adjacent core with an embedded YSO. Second, the infall parameter may not be an accurate tracer of star-formation activity because global motions of the cloud may act to emulate what appears to be the collapse of a single core. Large mapping surveys like the GBS may be able to overcome some of this confusion and disentangle one outflow from another by mapping the full extent of the outflows and allowing us to find the originating object. As well, the higher-energy CO  $J = 3 \rightarrow 2$  transition used by the GBS has a higher critical density and so will trace the warm dense gas in the outflow rather than the lower density surrounding cloud material. The higher resolution of the GBS observations at 345 GHz ( $\theta_{FWHM} \approx 14''$  vs. our  $22''$ ) may also provide a clearer picture of activity in crowded fields.

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# Search for OB Stars Running Away From Young Star Clusters

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$N$ -body simulations have shown that the dynamical decay of the young ( $\sim 1$  Myr) Orion Nebula cluster could be responsible for the loss of at least half of its initial content of OB stars. This result suggests that other young stellar systems could also lose a significant fraction of their massive stars at the very beginning of their evolution. To confirm this expectation, we used the Mid-Infrared Galactic Plane Survey (completed by the *MidcourseSpaceExperiment* satellite) to search for bow shocks around a number of young ( $< \sim$  several Myr) clusters and OB associations. We discovered dozens of bow shocks generated by OB stars running away from these stellar systems, supporting the idea of significant dynamical loss of OB stars. In this paper, we report the discovery of three bow shocks produced by O-type stars ejected from the open cluster NGC 6611 (M16). One of the bow shocks is associated with the O9.5Iab star HD165319, which was suggested to be one of “the best examples for isolated Galactic high-mass star formation” (de Wit et al. 2005, A&A, 437, 247). Possible implications of our results for the origin of field OB stars are discussed.

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# IPHAS A-type Stars with Mid-IR Excesses in Spitzer Surveys

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We have identified 17 A-type stars in the Galactic Plane that have mid-IR excesses at 8  $\mu\text{m}$ . From observed colors in the  $(r'-H\alpha)-(r'-i')$  plane, we first identified 23050 early A-type main sequence (MS) star candidates in the Isaac Newton Photometric H-Alpha Survey (IPHAS) point source database that are located in *Spitzer* GLIMPSE Galactic Plane fields. Imposing the requirement that they be detected in all seven 2MASS and IRAC bands led to a sample of 2692 candidate A-type stars with fully sampled 0.6 to 8  $\mu\text{m}$  SEDs. Optical classification spectra of 18 of the IPHAS candidate A-type MS stars showed that all but one could be well fitted using main sequence A-type templates, with the other being an A-type supergiant. Out of the 2692 A-type candidates 17 (0.6%) were found to have 8- $\mu\text{m}$  excesses above the expected photospheric values. Taking into account non-A-Type contamination estimates, the 8- $\mu\text{m}$  excess fraction is adjusted to  $\sim 0.7\%$ . The distances to these sources range from 0.7 – 2.5 kpc. Only 10 out of the 17 excess stars had been covered by *Spitzer* MIPS GAL survey fields, of which 5 had detectable excesses at 24  $\mu\text{m}$ . For sources with excesses detected in at least two mid-IR wavelength bands, blackbody fits to the excess SEDs yielded temperatures ranging from 270 to 650 K, and bolometric luminosity ratios  $L_{\text{IR}}/L_{\star}$  from  $2.2 \times 10^{-3} - 1.9 \times 10^{-2}$ , with a mean value of  $7.9 \times 10^{-3}$  (these bolometric luminosities are lower limits as cold dust is not detectable by this survey). Both the presence of mid-IR excesses and the derived bolometric luminosity ratios are consistent with many of these systems being in the planet-building transition phase between the early protoplanetary disk phase and the later debris disk phase.

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## Wide-field Near-infrared Imaging of the L1551 Dark Cloud

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We present wide-field near-infrared images of the densest part of the L1551 dark cloud taken with the narrow-band filters for [Fe II]  $\lambda 1.644 \mu\text{m}$  and H<sub>2</sub> v=1–0 S(1) lines, together with the broad-band *H* and *K<sub>s</sub>* filters. Numerous [Fe II] and H<sub>2</sub> emission features were detected from the regions around HL/XZ Tau, HH 30, HH 262, L1551 NE and L1551 IRS 5. Most of the [Fe II] features are compact or jet-like, suggesting that the emission arises from fast shocks occurring in the ejecta of jets. The H<sub>2</sub> features are more diffuse and widely distributed in outflow lobes, with none of the H<sub>2</sub> features showing the well-collimated emission associated with jets. This implies that the H<sub>2</sub> emission originates from slower shocks where the ejecta interacts with ambient material. The outflow structure in the vicinity of the deeply embedded object L1551 NE is revealed, featuring a well-collimated, spatially continuous [Fe II] jet penetrating a fan-shaped infrared reflection nebula. The tangential velocities of knots in the L1551 NE jet are estimated to be 140–190 km s<sup>−1</sup> from their proper motions, implying an inclination of 45°–60° for the jet axis. A counter-jet from L1551 IRS 5 is detected for the first time in [Fe II]; this probably corresponds to the northern-most of the two jets on the blue-shifted side. The relative brightness of the counter-jet suggests a visual extinction of 20–30 mag. The [Fe II] emissions from collimated jets are relatively strong toward L1551 NE and L1551 IRS 5 compared to those toward HL Tau and HH 30. This implies that the jets from the former objects, which are more embedded, have a higher shock velocity and/or a larger gas density than the latter, more revealed objects. The results presented here show

that the near-infrared [Fe II] emission is a useful probe of well-collimated jets from deeply embedded sources, in much the same way that optical [S II] emission is used for relatively revealed objects.

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<http://www.naoj.org/staff/masa/L1551NIR.pdf>

## Effects of Magnetic Field Strength and Orientation on Molecular Cloud Formation

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We present a set of numerical simulations addressing the effects of magnetic field strength and orientation on the flow-driven formation of molecular clouds. Fields perpendicular to the flows sweeping up the cloud can efficiently prevent the formation of massive clouds but permit the build-up of cold, diffuse filaments. Fields aligned with the flows lead to substantial clouds, whose degree of fragmentation and turbulence strongly depends on the background field strength. Adding a random field component leads to a "selection effect" for molecular cloud formation: high column densities are only reached at locations where the field component perpendicular to the flows is vanishing. Searching for signatures of colliding flows should focus on the diffuse, warm gas, since the cold gas phase making up the cloud will have lost the information about the original flow direction because the magnetic fields redistribute the kinetic energy of the inflows.

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## Chemical Abundances of Late-Type Pre-Main Sequence Stars in the $\sigma$ Orionis Cluster

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*Context.* The young  $\sigma$  Orionis cluster is an important location for studying the formation and evolution of stars, brown dwarfs, and planetary-mass objects. Its metallicity, although it is a fundamental parameter, has not been well determined yet.

*Aims.* We present the first determination of the metallicity of nine young late-type stars in  $\sigma$  Orionis.

*Methods.* Using the optical and near-infrared broadband photometry available in the literature we derive the effective temperatures for these nine cluster stars, which lie in the interval 4300-6500 K (1-3  $M_{\odot}$ ). These parameters are employed to compute a grid of synthetic spectra based on the code MOOG and Kurucz model atmospheres. We employ a  $\chi^2$ -minimization procedure to derive the stellar surface gravity and atmospheric abundances of Al, Ca, Si, Fe, Ni and Li, using multi-object optical spectroscopy taken with WYFFOS+AF2 at the William Herschel Telescope ( $\lambda/\delta\lambda \sim 7500$ ).

*Results.* The average metallicity of the  $\sigma$  Orionis cluster is  $[\text{Fe}/\text{H}] = -0.02 \pm 0.09 \pm 0.13$  (random and systematic errors). The abundances of the other elements, except lithium, seem to be consistent with solar values. Lithium abundances are in agreement with the "cosmic"  ${}^7\text{Li}$  abundance, except for two stars which show a  $\log\epsilon(\text{Li})$  in the range 3.6-3.7 (although almost consistent within the error bars). There are also other two stars with  $\log\epsilon(\text{Li}) \sim 2.75$ . We derived an average radial velocity of the  $\sigma$  Orionis cluster of  $28 \pm 4 \text{ km s}^{-1}$ .

*Conclusions.* The  $\sigma$  Orionis metallicity is roughly solar.

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## Star Formation at Very Low Metallicity. V. The greater importance of initial conditions compared to metallicity thresholds

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The formation of the first stars out of metal-free gas appears to result in stars at least an order of magnitude more massive than in the present-day case. We here consider what controls the transition from a primordial to a modern initial mass function. It has been proposed that this occurs when effective metal line cooling occurs at a metallicity threshold of  $Z/Z_{\odot} > 10^{-3.5}$ . We study the influence of low levels of metal enrichment on the cooling and collapse of initially ionized gas in small protogalactic halos using three-dimensional, smoothed particle hydrodynamics simulations with particle splitting. Our initial conditions represent protogalaxies forming within a previously ionized H II region that has not yet had time to cool and recombine. These differ considerably from those used in simulations predicting a metallicity threshold, where the gas was initially cold and only partially ionized. In the centrally condensed potential that we study here, a wide variety of initial conditions for the gas yield a monolithic central collapse. Our models show no fragmentation during collapse to number densities as high as  $10^5 \text{ cm}^{-3}$ , for metallicities reaching as high as  $10^{-1} Z_{\odot}$ , far above the threshold suggested by previous work. Rotation allows for the formation of gravitationally stable gas disks over large fractions of the local Hubble time. Turbulence slows the growth of the central density slightly, but both spherically symmetric and turbulent initial conditions collapse and form a single sink particle. We therefore argue that fragmentation at moderate density depends on the initial conditions for star formation more than on the metal abundances present. The actual initial conditions to be considered still need to be determined in detail by observation and modeling of galaxy formation. Metal abundance may still drive fragmentation at very high densities due to dust cooling, perhaps giving an alternative metallicity threshold.

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## Identification of the TW Hydrae Association Member 2M1235-39: a Tertiary Component of the HR 4796 System

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*Aims.* We seek to determine whether the late-type star 2MASS J12354893-3950245 (2M1235-39) is a member of the TW Hya Association (TWA), a hypothesis suggested by its association with a bright X-ray source detected serendipitously by ROSAT and XMM-Newton and its ( $\sim 3'$ ) proximity to the well-studied (A+M binary) system HR 4796.

*Methods.* We used optical spectroscopy to establish the Li and H $\alpha$  line strengths of 2M1235-39, and determined its

proper motion via optical imaging. We also considered its X-ray and near-IR fluxes relative to the M star HR 4796B. *Results.* The optical spectrum of 2M1235-39 displays strong Li absorption and H $\alpha$  emission (equivalent widths of 630 mÅ and -6.7 Å, respectively). Comparison of the spectrum with that of a nearby field star, along with the DENIS catalog *IJK* magnitudes, indicates the spectral type of 2M1235-39 is M4.5. We measure a proper motion for 2M1235-39 that agrees, within the errors, with that of HR 4796.

*Conclusions.* The Li absorption and H $\alpha$  emission line strengths of 2M1235-39, its near-IR and X-ray fluxes, and its proper motion all indicate that 2M1235-39 is a TWA member. Most likely this star is a wide (13 500 AU) separation, low-mass, tertiary component of the HR 4796 system.

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## Molecules in the Disk Orbiting the Twin Young Suns of V4046 Sagittarii

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*Context.* Direct information concerning the physical conditions and chemistry within the Jovian planet-building zones of circumbinary disks surrounding pre-main sequence stars is essentially nonexistent, especially for the more evolved pre-MS systems in which planets may already be forming or may have formed.

*Aims.* We searched for a gaseous component within the dusty circumbinary disk around the nearby ( $D \sim 70$  pc), 12 Myr-old system V4046 Sgr a tight ( $9 R_{\odot}$ ) separation), short-period ( $P \sim 2.42$  day) binary with nearly equal component masses of  $\sim 0.9 M_{\odot}$  - so as to assess the mass, chemistry, and kinematics of this gaseous disk.

*Methods.* We conducted a mm-wave molecular line survey of V4046 Sgr with the 30 m telescope of the Institut de Radio Astronomie Millimétrique (IRAM). We use these data to investigate the kinematics, gas mass, and chemical constituents of the V4046 Sgr disk.

*Results.* We detected rotational transitions of  $^{12}\text{CO}$ ,  $^{13}\text{CO}$ , HCN, CN, and HCO $^{+}$ . The double-peaked CO line profiles of V4046 Sgr are well fit by a model invoking a Keplerian disk with outer radius of  $\sim 250$  AU that is viewed at an inclination  $i = 35^{\circ}$ . We infer minimum disk gas and dust masses of  $\sim 13$  and  $\sim 20$  Earth masses from the V4046 Sgr CO line and submm continuum fluxes, respectively. The actual disk gas mass could be much larger if the gas-phase CO is highly depleted and/or  $^{13}\text{CO}$  is very optically thick.

*Conclusions.* The overall similarity of the circumbinary disk of V4046 Sgr to the disk orbiting the single,  $\sim 8$  Myr-old star TW Hya a star/disk system often regarded as representative of the early solar nebula indicates that gas giant planets are likely commonplace among close binary star systems. Given the relatively advanced age and proximity of V4046 Sgr, these results provide strong motivation for future high-resolution imaging designed to ascertain whether a planetary system now orbits its twin suns.

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## Rapid Formation of Icy Super-Earths and the Cores of Gas Giant Planets

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We describe a coagulation model that leads to the rapid formation of super-Earths and the cores of gas giant planets. Interaction of collision fragments with the gaseous disk is the crucial element of this model. The gas entrains small collision fragments, which rapidly settle to the disk midplane. Protoplanets accrete the fragments and grow to masses of at least 1 Earth mass in roughly 1 Myr. Our model explains the mass distribution of planets in the Solar System and predicts that super-Earths form more frequently than gas giants in low mass disks.

## Exploring the consequences of pairing algorithms for binary stars

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Knowledge of the binary population in stellar groupings provides important information about the outcome of the star forming process in different environments (see, e.g., Blaauw 1991, and references therein). Binarity is also a key ingredient in stellar population studies, and is a prerequisite to calibrate the binary evolution channels. In this paper we present an overview of several commonly used methods to pair individual stars into binary systems, which we refer to as pairing functions. These pairing functions are frequently used by observers and computational astronomers, either for their mathematical convenience, or because they roughly describe the expected outcome of the star forming process. We discuss the consequences of each pairing function for the interpretation of observations and numerical simulations. The binary fraction and mass ratio distribution generally depend strongly on the selection of the range in primary spectral type in a sample. The mass ratio distribution and binary fraction derived from a binarity survey among a mass-limited sample of targets is thus not representative for the population as a whole. Neither theory nor observations indicate that random pairing of binary components from the mass distribution, the simplest pairing function, is realistic. It is more likely that companion stars are formed in a disk around a star, or that a pre-binary core fragments into two binary components. The results of our analysis are important for (i) the interpretation of the observed mass ratio distribution and binary fraction for a sample of stars, (ii) a range of possible initial condition algorithms for star cluster simulations, and (iii) how to discriminate between the different star formation scenarios.

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## The Nonisothermal Stage of Magnetic Star Formation. I. Formulation of the Problem and Method of Solution

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We formulate the problem of the formation and subsequent evolution of fragments (or cores) in magnetically-supported, self-gravitating molecular clouds in two spatial dimensions. The six-fluid (neutrals, electrons, molecular and atomic ions, positively-charged, negatively-charged, and neutral grains) physical system is governed by the radiative, nonideal magnetohydrodynamic (RMHD) equations. The magnetic flux is not assumed to be frozen in any of the charged species. Its evolution is determined by a newly-derived generalized Ohm's law, which accounts for the contributions of both elastic and inelastic collisions to ambipolar diffusion and Ohmic dissipation. The species abundances are calculated using an extensive chemical-equilibrium network. Both MRN and uniform grain size distributions are considered. The thermal evolution of the protostellar core and its effect on the dynamics are followed by employing the grey flux-limited diffusion approximation. Realistic temperature-dependent grain opacities are used that account for a variety of grain compositions. We have augmented the publicly-available Zeus-MP code to take into consideration all these effects and have modified several of its algorithms to improve convergence, accuracy and efficiency. Results of magnetic star formation simulations that accurately track the evolution of a protostellar fragment from a density  $\simeq 10^3 \text{ cm}^{-3}$  to a density  $\simeq 10^{15} \text{ cm}^{-3}$ , while rigorously accounting for both nonideal MHD processes and radiative transfer, are presented in a separate paper.

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## Rotating molecular outflows: the young T Tauri star in CB26

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The disk-outflow connection is thought to play a key role in extracting excess angular momentum from a forming proto-star. Though jet rotation has been observed in a few objects, no rotation of molecular outflows has been unambiguously reported so far. We report new millimeter-interferometric observations of the edge-on T Tauri star - disk system in the isolated Bok globule CB26. The aim of these observations was to study the disk-outflow relation in this 1 Myr old low-mass young stellar object. The IRAM PdBI array was used to observe 12CO(2-1) at 1.3 mm in two configurations, resulting in spectral line maps with 1.5 arcsec resolution. We use an empirical parameterized steady-state outflow model combined with 2-D line radiative transfer calculations and chi-square-minimization in parameter space to derive a best-fit model and constrain parameters of the outflow. The data reveal a previously undiscovered collimated bipolar molecular outflow of total length 2000 AU, escaping perpendicular to the plane of the disk. We find peculiar kinematic signatures that suggest the outflow is rotating with the same orientation as the disk. However, we could not ultimately exclude jet precession or two misaligned flows as possible origin of the observed peculiar velocity field. There is indirect indication that the embedded driving source is a binary system, which, together with the youth of the source, could provide the clue to the observed kinematic features of the outflow. CB26 is so far the most promising source to study the rotation of a molecular outflow. Assuming that the outflow is rotating, we compute and compare masses, mass flux, angular momenta, and angular momentum flux of disk and outflow and derive disk dispersal timescales of 0.5...1 Myr, comparable to the age of the system.

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## Local Star formation triggered by SN shocks in magnetized diffuse neutral clouds

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In this work, considering the impact of a supernova remnant (SNR) with a neutral magnetized cloud we derived analytically a set of conditions that are favorable for driving gravitational instability in the cloud and thus star formation. Using these conditions, we have built diagrams of the SNR radius,  $R_{SNR}$ , versus the initial cloud density,  $n_c$ , that constrain a domain in the parameter space where star formation is allowed. This work is an extension to previous study performed without considering magnetic fields (Melioli et al. 2006). The diagrams are also tested with fully 3-D MHD radiative cooling simulations involving a SNR and a self-gravitating cloud and we find that the numerical analysis is consistent with the results predicted by the diagrams. While the inclusion of a homogeneous magnetic field approximately perpendicular to the impact velocity of the SNR with an intensity  $\sim 1 \mu\text{G}$  within the cloud results only a small shrinking of the star formation zone in the diagram relative to that without magnetic field, a larger magnetic field ( $\sim 10 \mu\text{G}$ ) causes a significant shrinking, as expected. Though derived from simple analytical considerations these diagrams provide a useful tool for identifying sites where star formation could be triggered by the impact of a SN blast wave. Applications of them to a few regions of our own galaxy (e.g., the large CO shell in the

direction of Cassiopeia, and the Edge Cloud 2 in the direction of the Scorpious constellation) have revealed that star formation in those sites could have been triggered by shock waves from SNRs for specific values of the initial neutral cloud density and the SNR radius. Finally, we have evaluated the effective star formation efficiency for this sort of interaction and found that it is generally smaller than the observed values in our own Galaxy (sfe  $\sim 0.01 - 0.3$ ). This result is consistent with previous work in the literature and also suggests that the mechanism presently investigated, though very powerful to drive structure formation, supersonic turbulence and eventually, local star formation, does not seem to be sufficient to drive *global* star formation in normal star forming galaxies, not even when the magnetic field in the neutral clouds is neglected.

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## The Spitzer c2d Survey of Nearby Dense Cores. V. Discovery of a VeLLO in the “Starless” Dense Core L328

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This paper reports the discovery of a Very Low Luminosity Object (VeLLO) in the “starless” dense core L328, using the *Spitzer Space Telescope* and ground based observations from near-infrared to millimeter wavelengths. The *Spitzer* 8  $\mu\text{m}$  image indicates that L328 consists of three subcores of which the smallest one may harbor a source, L328-IRS while two other subcores remain starless. L328-IRS is a Class 0 protostar according to its bolometric temperature (44 K) and the high fraction ( $\sim 72\%$ ) of its luminosity emitted at sub-millimeter wavelengths. Its inferred “internal luminosity” ( $0.04 - 0.06L_{\odot}$ ) using a radiative transfer model under the most plausible assumption of its distance as 200 pc is much fainter than for a typical protostar, and even fainter than other VeLLOs studied previously. Note, however, that its inferred luminosity may be uncertain by a factor of 2 – 3 if we consider two extreme values of the distance of L328-IRS (125 or 310 pc). Low angular resolution observations of CO do not show any clear evidence of a molecular outflow activity. But broad line widths toward L328, and *Spitzer* and near-infrared images showing nebulosity possibly tracing an outflow cavity, strongly suggest the existence of outflow activity. Provided that an envelope of at most  $\sim 0.1M_{\odot}$  is the only mass accretion reservoir for L328-IRS, and the star formation efficiency is close to the canonical value  $\sim 30\%$ , L328-IRS has not yet accreted more than  $0.05M_{\odot}$ . At the assumed distance of 200 pc, L328-IRS is destined to be a brown dwarf

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## Infall and rotation motions in the HH 111 protostellar system: A flattened envelope in transition to a disk?

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We have mapped the central region of the HH 111 protostellar system in 1.33 mm continuum, C<sup>18</sup>O (J=2-1), <sup>13</sup>CO (J=2-1), and SO ( $N_J = 5_6 - 4_5$ ) emission at  $\sim 3''$  resolution with the Submillimeter Array. There are two sources, VLA 1 (=IRAS 05491+0247) and VLA 2, with the VLA 1 source driving the HH 111 jet. Thermal emission is seen in 1.33 mm continuum tracing the dust in the envelope and the putative disks around the sources. A flattened, torus-like envelope is seen in C<sup>18</sup>O and <sup>13</sup>CO around the VLA 1 source surrounding the dust lane perpendicular to the jet axis, with an inner radius of  $\sim 400$  AU ( $1''$ ), an outer radius of  $\sim 3200$  AU ( $8''$ ), and a thickness of  $\sim 1000$  AU ( $2''.5$ ). It

seems to be infalling toward the center with conservation of specific angular momentum rather than with a Keplerian rotation as assumed by Yang et al. 1997. An inner envelope is seen in SO, with a radius of  $\sim 500$  AU ( $1''.3$ ). The inner part of this inner envelope, which is spatially coincident with the dust lane, seems to have a differential rotation and thus may have formed a rotationally supported disk. The outer part of this inner envelope, however, may have a rotation velocity decreasing toward the center and thus represent a region where an infalling envelope is in transition to a rotationally supported disk. A brief comparison with a collapsing model suggests that the flattened, torus-like envelope seen in  $C^{18}O$  and  $^{13}CO$  could result from a collapse of a magnetized rotating toroid.

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## The Rosette Eye: the key transition phase in the birth of a massive star

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Massive protostars dramatically influence their surroundings via accretion-induced outflows and intense radiation fields. They evolve rapidly, the disk and infalling envelope being evaporated and dissipated in  $\sim 10^5$  years. Consequently, they are very rare and investigating this important phase of early stellar evolution is extremely difficult. Here we present the discovery of a key transient phase in the emergence of a massive young star, in which ultraviolet radiation from the new-born giant has just punctured through its natal core. The massive young stellar object AFGL 961 II is readily resolved in the near infrared. Its morphology closely resembles a cat's eye and is here dubbed as the Rosette Eye. Emerging ionized flows blow out an hourglass shaped nebula, which, along with the existence of strong near-infrared excess, suggests the existence of an accretion disk in the perpendicular direction. The lobes of the hourglass, however, are capped with arcs of static  $H_2$  emission produced by fluorescence. This study has strong implications for our understanding of how massive stars embark on their formation.

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## Large grains in disks around young stars: ATCA observations of WW Cha, RU Lup, and CS Cha

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CONTEXT - Grains in disks around young stars grow from interstellar submicron sizes to planetesimals, up to thousands of kilometres in size, over the course of several Myr. Thermal emission of large grains or pebbles can be best observed at centimetre wavelengths. However, other emission mechanisms can contribute, most notably free-free emission from stellar winds and chromospheric activity. AIMS - We aim to determine the mechanisms of centimetre emission for three T Tauri stars. WW Cha and RU Lup were recently found to have grain growth at least up to

millimetre sizes in their circumstellar disks, based on millimetre data up to 3.3 mm. CS Cha has similar indications for grain growth in its circumbinary disk. METHODS - The T Tauri stars WW Cha and RU Lup were monitored over the course of several years at millimetre and centimetre wavelengths, using the Australia Telescope Compact Array (ATCA). The new ATCA 7 mm system was also used to observe CS Cha at 7 mm. RESULTS - WW Cha was detected on several occasions at 7 and 16 mm. We obtained one detection of WW Cha at 3.5 cm and upper limits only for 6.3 cm. The emission at 16 mm was stable over periods of days, months, and years, whereas the emission at 3.5 cm is found to be variable. A second young stellar object, Ced 112 IRS 4, was found in the field of WW Cha at 16 mm. RU Lup was detected at 7 mm. It was observed at 16 mm three times and at 3 and 6 cm four times and found to be variable in all three wavebands. CS Cha was detected at 7 mm, but the signal-to-noise ratio was not high enough to resolve the gap in the circumbinary disk. The typical resolution of the 7 and 16 mm observations was  $5\text{?}10$  arcsec with rms  $0\text{:}2$  mJy. CONCLUSIONS - The emission at 3, 7, and 16 mm for WW Cha is well explained by thermal emission from millimetre and centimetre-sized pebbles. The cm spectral index between 3.5 and 6.3 cm is consistent with the emission from an optically-thick ionised wind, although the high variability of the cm emission points to a non-thermal contribution. The spectral energy distributions of both RU Lup and CS Cha from 1 to 7 mm are consistent with thermal emission from mm-sized grains. The variability of the longer-wavelength emission for RU Lup and the negative spectral index suggests non-thermal emission, arising from an optically-thin plasma.

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## Disks around Brown Dwarfs in the $\sigma$ Orionis Cluster

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We have performed a census of circumstellar disks around brown dwarfs in the  $\sigma$  Ori cluster using all available images from the Infrared Array Camera on board the *Spitzer Space Telescope*. To search for new low-mass cluster members with disks, we have measured photometry for all sources in the *Spitzer* images and have identified the ones that have red colors that are indicative of disks. We present five promising candidates, which may consist of two brown dwarfs, two stars with edge-on disks, and a low-mass protostar if they are bona fide members. Spectroscopy is needed to verify the nature of these sources. We have also used the *Spitzer* data to determine which of the previously known probable members of  $\sigma$  Ori are likely to have disks. By doing so, we measure disk fractions of  $\sim 40\%$  and  $\sim 60\%$  for low-mass stars and brown dwarfs, respectively. These results are similar to previous estimates of disk fractions in IC 348 and Chamaeleon I, which have roughly the same median ages as  $\sigma$  Ori ( $\tau \sim 3$  Myr). Finally, we note that our photometric measurements and the sources that we identify as having disks differ significantly from those of other recent studies that analyzed the same *Spitzer* images. For instance, previous work has suggested that the T dwarf S Ori 70 is redder than typical field dwarfs, which has been cited as possible evidence of youth and cluster membership. However, we find that this object is only slightly redder than the reddest field dwarfs in  $[3.6] - [4.5]$  ( $1.56 \pm 0.07$  vs.  $0.93\text{--}1.46$ ). We measure a larger excess in  $[3.6] - [5.8]$  ( $1.75 \pm 0.21$  vs.  $0.87\text{--}1.19$ ), but the flux at  $5.8 \mu\text{m}$  may be overestimated because of the low signal-to-noise ratio of the detection. Thus, the *Spitzer* data do not offer strong evidence of youth and membership for this object, which is the faintest and coolest candidate member of  $\sigma$  Ori that has been identified to date.

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## Thermal Effects of Circumplanetary Disk Formation around Proto-Gas Giant Planets

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The formation of a circumplanetary disk and accretion of angular momentum onto a protoplanetary system are investigated using three-dimensional hydrodynamical simulations. The local region around a protoplanet in a protoplanetary disk is considered with sufficient spatial resolution: the region from outside the Hill sphere to the Jovian radius is covered by the nested-grid method. To investigate the thermal effects of the circumplanetary disk, various equations of state are adopted. Large thermal energy around the protoplanet slightly changes the structure of the circumplanetary disk. Compared with a model adopting an isothermal equation of state, in a model with an adiabatic equation of state, the protoplanet's gas envelope extends farther, and a slightly thick disk appears near the protoplanet. However, different equations of state do not affect the acquisition process of angular momentum for the protoplanetary system. Thus, the specific angular momentum acquired by the system is fitted as a function only of the protoplanet's mass. A large fraction of the total angular momentum contributes to the formation of the circumplanetary disk. The disk forms only in a compact region in very close proximity to the protoplanet. Adapting the results to the solar system, the proto-Jupiter and Saturn have compact disks in the region of  $r < 21 r_{\text{Jup}}$  ( $r < 0.028 r_{\text{H,Jup}}$ ) and  $r < 66 r_{\text{Sat}}$  ( $r < 0.061 r_{\text{H,Sat}}$ ), respectively, where  $r_{\text{Jup}}$  ( $r_{\text{H,Jup}}$ ) and  $r_{\text{Sat}}$  ( $r_{\text{H,Sat}}$ ) are the Jovian and Saturnian (Hill) radius, respectively. The surface density has a peak in these regions due to the balance between centrifugal force and gravity of the protoplanet. The size of these disks corresponds well to the outermost orbit of regular satellites around Jupiter and Saturn. Regular satellites may form in such compact disks around proto-gas giant planets.

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## Maximum Stellar Mass Versus Cluster Membership Number Revisited

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We have made a new compilation of observations of maximum stellar mass versus cluster membership number from the literature, which we analyse for consistency with the predictions of a simple random drawing hypothesis for stellar mass selection in clusters. Previously, Weidner and Kroupa have suggested that the maximum stellar mass is lower, in low-mass clusters, than would be expected on the basis of random drawing, and have pointed out that this could have important implications for steepening the integrated galactic initial mass function (IGIMF) at high masses. Our compilation demonstrates how the observed distribution in the plane of maximum stellar mass versus membership number is affected by the method of target selection; in particular, rather low  $n$  clusters with large maximum stellar masses are abundant in observational data sets that specifically seek clusters in the environs of high-mass stars. Although we do not consider our compilation to be either complete or unbiased, we discuss the method by which such data should be statistically analysed. Our very provisional conclusion is that the data are not indicating any striking deviation from the expectations of random drawing.

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## Lithium Depletion of Nearby Young Stellar Associations

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We estimate cluster ages from lithium depletion in five pre-main-sequence groups found within 100 pc of the Sun: the TW Hydrae association,  $\eta$  Chamaeleontis cluster,  $\beta$  Pictoris moving group, Tucanae-Horologium association, and AB Doradus moving group. We determine surface gravities, effective temperatures, and lithium abundances for over 900 spectra through least-squares fitting to model-atmosphere spectra. For each group, we compare the dependence of lithium abundance on temperature with isochrones from pre-main-sequence evolutionary tracks to obtain model-dependent ages. We find that the  $\eta$  Cha cluster and the TW Hydrae association are the youngest, with ages of  $12 \pm$

6 Myr and  $12 \pm 8$  Myr, respectively, followed by the  $\beta$  Pic moving group at  $21 \pm 9$  Myr, the Tucanae-Horologium association at  $27 \pm 11$  Myr, and the AB Dor moving group at an age of at least 45 Myr (whereby we can only set a lower limit, since the modelsunlike real stars do not show much lithium depletion beyond this age). Here the ordering is robust, but the precise ages depend on our choice of both atmospheric and evolutionary models. As a result, while our ages are consistent with estimates based on Hertzsprung-Russell isochrone fitting and dynamical expansion, they are not yet more precise. Our observations do show that with improved models, much stronger constraints should be feasible, as the intrinsic uncertainties, as measured from the scatter between measurements from different spectra of the same star, are very low: around 10 K in effective temperature, 0.05 dex in surface gravity, and 0.03 dex in lithium abundance.

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## Formation of Interstellar Clouds: Parker Instability with Phase Transitions

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We follow numerically the nonlinear evolution of the Parker instability in the presence of phase transitions from a warm to a cold HI interstellar medium in two spatial dimensions. The nonlinear evolution of the system favors modes that allow the magnetic field lines to cross the galactic plane. Cold HI clouds form with typical masses  $\simeq 10^5 M_{\odot}$ , mean densities  $\simeq 20 \text{ cm}^{-3}$ , mean magnetic field strengths  $\simeq 4.3 \mu\text{G}$  (rms field strengths  $\simeq 6.4 \mu\text{G}$ ), mass-to-flux ratios  $\simeq 0.1 - 0.3$  relative to critical, temperatures  $\simeq 50 \text{ K}$ , (two-dimensional) turbulent velocity dispersions  $\simeq 1.6 \text{ km s}^{-1}$ , and separations  $\simeq 500 \text{ pc}$ , in agreement with observations. The maximum density and magnetic field strength are  $\simeq 10^3 \text{ cm}^{-3}$  and  $\simeq 20 \mu\text{G}$ , respectively. Approximately 60% of all HI mass is in the warm neutral medium. The cold neutral medium is arranged into sheet-like structures both perpendicular and parallel to the galactic plane, but it is also found almost everywhere in the galactic plane, with the density being highest in valleys of the magnetic field lines. ‘Cloudlets’ also form whose physical properties are in quantitative agreement with those observed for such objects by Heiles (1967). The nonlinear phase of the evolution takes  $\lesssim 30$  Myr, so that, if the instability is triggered by a nonlinear perturbation such as a spiral density shock wave, interstellar clouds can form within a time suggested by observations.

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## Near-Infrared Multiwavelength Imaging Polarimetry of the Low-Mass Proto-Stellar Object HL Tauri

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We present the *JHK*-band high-resolution polarimetric images of the low-mass proto-stellar object HL Tau using the adaptive optics-equipped CIAO instrument on the Subaru telescope. Our polarization images show a butterfly-shaped polarization disk with an  $\sim 0.9'' \times 3.0''$  extension. In the nebula, where polarization vectors are centro-symmetrically aligned, the polarization is as high as  $P_J \sim 30\%$ ,  $P_H \sim 42\%$ , and  $P_K \sim 55\%$ . On the other hand, low polarizations of  $P < 3\%$  in the *J*, *H*, and *K* bands and a low color excess ratio of  $E_{J-H}/E_{H-K}=1.1$  compared to the standard cloud value of 1.75 are detected towards the central star. We estimated the upper limit of the grain sizes  $a_{\text{max}}$  to be  $0.4 \mu\text{m}$  in the nebula and  $> \sim 0.7 \mu\text{m}$  in the line of sight towards the central star. Our high-resolution polarimetric data, which spatially resolves the polarization disk, provides us with important information about grain growth in the region close to the central star.

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## Effects of accretion flow on the chemical structure in the inner regions of protoplanetary disks

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We have studied the dependence of the profiles of molecular abundances and line emission on the accretion flow in the hot ( $> 100\text{K}$ ) inner region of protoplanetary disks. The gas-phase reactions initiated by evaporation of the ice mantle on dust grains are calculated along the accretion flow. We focus on methanol, a molecule that is formed predominantly through the evaporation of warm ice mantles, to show how the abundance profile and line emission depend on the accretion flow. Our results show that some evaporated molecules keep high abundances only when the accretion velocity is large enough, and that methanol could be useful as a diagnostic of the accretion flow by means of ALMA observations at the disk radius of  $< 10\text{AU}$ .

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## Cold gas as an ice diagnostic toward low mass protostars

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*Context.* Up to 90% of the chemical reactions during star formation occurs on ice surfaces, probably including the formation of complex organics. Only the most abundant ice species are however observed directly by infrared spectroscopy.

*Aims.* This study aims to develop an indirect observational method of ices based on non-thermal ice desorption in the colder part of protostellar envelopes.

*Methods.* The IRAM 30m telescope was employed to observe two molecules that can be detected both in the gas and the ice,  $\text{CH}_3\text{OH}$  and  $\text{HNCO}$ , toward 4 low mass embedded protostars. Their respective gas-phase column densities are determined using rotational diagrams. The relationship between ice and gas phase abundances is subsequently determined.

*Results.* The observed gas and ice abundances span several orders of magnitude. Most of the  $\text{CH}_3\text{OH}$  and  $\text{HNCO}$  gas along the lines of sight is inferred to be quiescent from the measured line widths and the derived excitation temperatures, and hence not affected by thermal desorption close to the protostar or in outflow shocks. The measured gas to ice ratio of  $\sim 10^{-4}$  agrees well with model predictions for non-thermal desorption under cold envelope conditions and there is a tentative correlation between ice and gas phase abundances. This indicates that non-thermal desorption products can serve as a signature of the ice composition. A larger sample is however necessary to provide a conclusive proof of concept.

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## Young Brown Dwarfs in the Core of the W3 Main Star-Forming Region

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We present the results of deep and high-resolution (FWHM  $\sim 0''.35$ ) *JHK* near-infrared observations with the Subaru telescope, to search for very low mass young stellar objects in the W3 Main star-forming region. The near-infrared survey covers an area of  $\sim 2.6$  arcmin<sup>2</sup> with  $10 \sigma$  limiting magnitude exceeding 20 mag in the *JHK* bands. The survey is sensitive enough to provide unprecedented details in W3 IRS 5 and IRS 3a regions and reveals a census of the stellar population down to objects below the hydrogen-burning limit. We construct *JHK* color-color and  $J - H/J$  and  $H - K/K$  color-magnitude diagrams to identify very low luminosity young stellar objects and to estimate their masses. Based on these color-color and color-magnitude diagrams, we identified a rich population of embedded YSO candidates with infrared excesses (Class I and Class II), associated with the W3 Main region. A large number of red sources ( $H - K > 2$ ) have also been detected around W3 Main, which are arranged from the northwest toward the southeast regions. Most of these are concentrated around W3 IRS 5. We argue that these red stars are most probably pre-main-sequence (PMS) stars with intrinsic color excesses. We find that the slope of the *K*-band luminosity function of W3 Main is lower than the typical values reported for young embedded clusters. Based on the comparison between theoretical evolutionary models of very low-mass pre-main sequence objects with the observed color-magnitude diagram, we find there exists a substantial substellar population in the observed region. The mass function does not show the presence of cutoff and sharp turnover around the substellar limit, at least at the hydrogen-burning limit. Furthermore, the mass function slope indicates that the number ratio of young brown dwarfs and hydrogen-burning stars in the W3 Main is probably higher than those in Trapezium and IC 348. The presence of mass segregation, in the sense that relatively massive YSOs lie near the cluster center, is seen. The estimated dynamical evolution time indicates that the observed mass segregation in the W3 Main may be the imprint of the star formation process.

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## Collapsing Hot Molecular Cores: A Model for the Dust Spectrum and Ammonia Line Emission of the G31.41+0.31 Hot Core

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We present a model aimed to reproduce the observed spectral energy distribution (SED) as well as the ammonia line emission of the G31.41+0.31 hot core. The hot core is modeled as an infalling envelope onto a massive star that is undergoing an intense accretion phase. We assume an envelope with a density and velocity structure resulting from the dynamical collapse of a singular logatropic sphere. The stellar and envelope physical properties are determined by fitting the observed SED. From these physical conditions, the emerging ammonia line emission is calculated and compared with subarcsecond resolution VLA data of the (4,4) transition taken from the literature. The only free parameter in this line fitting is the ammonia abundance. The observed intensities of the main and satellite ammonia (4,4) lines and their spatial distribution can be well reproduced provided it is taken into account the steep increase of the gas-phase ammonia abundance in the hotter ( $> 100$  K), inner regions of the core produced by the sublimation of icy mantles where ammonia molecules are trapped. The model predictions for the (2,2), (4,4), and (5,5) transitions, obtained with the same set of parameters, are also in reasonably agreement, given the observational uncertainties, with the single-dish spectra of the region available in the literature. The best fit is obtained for a model with a central star of  $\sim 25 M_{\odot}$ , a mass accretion rate of  $\sim 3 \times 10^{-3} M_{\odot} \text{ yr}^{-1}$ , and a total luminosity of  $\sim 2 \times 10^5 L_{\odot}$ . The outer radius of the envelope is 30,000 AU, where kinetic temperatures as high as  $\sim 40$  K are reached. The gas-phase ammonia abundance ranges from  $\sim 2 \times 10^{-8}$  in the outer region to  $\sim 3 \times 10^{-6}$  in the inner region. To our knowledge, this is the first time that the dust and molecular line data of a hot molecular core, including subarcsecond resolution data that spatially resolve the structure of the core, have been simultaneously explained by a detailed, physically self-consistent model. This modeling shows that hot, massive protostars are able to excite high excitation ammonia transitions up to the outer edge ( $\sim 30,000$  AU) of the large scale infalling envelopes.

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# On the frequency of $\text{N}_2\text{H}^+$ and $\text{N}_2\text{D}^+$

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*context* : Dynamical studies of prestellar cores search for small velocity differences between different tracers. The highest radiation frequency precision is therefore required for each of these species.

*aims* : We want to adjust the frequency of the first three rotational transitions of  $\text{N}_2\text{H}^+$  and  $\text{N}_2\text{D}^+$  and extrapolate to the next three transitions.

*methods* :  $\text{N}_2\text{H}^+$  and  $\text{N}_2\text{D}^+$  are compared to  $\text{NH}_3$  the frequency of which is more accurately known and which has the advantage to be spatially coexistent with  $\text{N}_2\text{H}^+$  and  $\text{N}_2\text{D}^+$  in dark cloud cores. With lines among the narrowests, and  $\text{N}_2\text{H}^+$  and  $\text{NH}_3$  emitting region among the largests, L183 is a good candidate to compare these species.

*results* A correction of  $\sim 10$  kHz for the  $\text{N}_2\text{H}^+$  (J:1-0) transition has been found ( $\sim 0.03 \text{ km s}^{-1}$ ) and similar corrections, from a few  $\text{m s}^{-1}$  up to  $\sim 0.05 \text{ km s}^{-1}$  are reported for the other transitions ( $\text{N}_2\text{H}^+$  (J:3-2) and  $\text{N}_2\text{D}^+$  (J:1-0), (J:2-1), and (J:3-2)) compared to previous astronomical determinations. Einstein spontaneous decay coefficients ( $A_{ul}$ ) are included.

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[http://aramis.obspm.fr/~pagani/freq\\_n2hp.pdf](http://aramis.obspm.fr/~pagani/freq_n2hp.pdf)

## Chemical modeling of L183 (= L134N) : an estimate of the ortho/para $\text{H}_2$ ratio

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**context** : The high degree of deuteration observed in some prestellar cores depends on the ortho-to-para  $\text{H}_2$  ratio through the  $\text{H}_3^+$  fractionation.

**aims** : We want to constrain the ortho/para  $\text{H}_2$  ratio across the L183 prestellar core. This is required to correctly describe the deuteration amplification phenomenon in depleted cores such as L183 and to relate the total (ortho+para)  $\text{H}_2\text{D}^+$  abundance to the sole ortho- $\text{H}_2\text{D}^+$  column density measurement.

**methods** : To constrain this ortho/para  $\text{H}_2$  ratio and derive its profile, we make use of the  $\text{N}_2\text{D}^+/\text{N}_2\text{H}^+$  ratio and of the ortho- $\text{H}_2\text{D}^+$  observations performed across the prestellar core. We use two simple chemical models limited to an almost totally depleted core description. New dissociative recombination and trihydrogen cation-dihydrogen reaction rates (including all isotopologues) are presented in this paper and included in our models.

**results** : We estimate the  $\text{H}_2\text{D}^+$  ortho/para ratio in the L183 cloud, and constrain the  $\text{H}_2$  ortho/para ratio: we show that it varies across the prestellar core by at least an order of magnitude, being still very high ( $\approx 0.1$ ) in most of the cloud. Our time-dependent model indicates that the prestellar core is presumably older than  $1.5\text{--}2 \times 10^5$  years but that it may not be much older. We also show that it has reached its present density only recently and that its contraction from a uniform density cloud can be constrained.

**conclusions:** A proper understanding of deuteration chemistry cannot be attained without taking into account the whole ortho/para family of molecular hydrogen and trihydrogen cation isotopologues as their relations are of utmost importance in the global scheme. Tracing the ortho/para H<sub>2</sub> ratio should also place useful constraints on the dynamical evolution of prestellar cores.

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## The Different Evolution of Gas and Dust in Disks around Sun-like and Cool Stars

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Planet formation is profoundly impacted by the properties of protoplanetary disks and their central star. However, how disk properties vary with stellar parameters remain poorly known. Here we present the first comprehensive, comparative Spitzer/IRS study of the dust and gas properties of disks around young sun-like stars (K1-M5) and cool stars/brown dwarfs (M5-M9). The comparison of these two large samples of over 60 sources reveal major differences in the evolution of both the dust and gas components.

We report the first detection of organic molecules in disks around brown dwarfs. The detection rate statistics and the line flux ratios of HCN and C<sub>2</sub>H<sub>2</sub> show a striking difference between the two samples, demonstrating a significant under-abundance of HCN relative to C<sub>2</sub>H<sub>2</sub> in the disk surface of cool stars. We propose this to originate from the large difference in the UV-irradiation around the two types of sources. The statistical comparison of the 10 micron silicate emission features also reveals a difference between the two samples. Cool stars and brown dwarfs show weaker features arising from more processed silicate grains in the disk atmosphere.

These findings complement previous indications of flatter disk structures and longer disk lifetimes around cool stars. Our results highlight important differences in the chemical and physical evolution of protoplanetary disks as function of stellar mass, temperature, and radiation field which should be taken into account in planet formation models. We note that the different chemistry of pre-planetary materials in the disk may also influence the bulk composition and volatile content of the forming planets. In particular, if exogenous HCN has played a key role in the synthesis of prebiotic molecules on Earth as proposed, then prebiotic chemistry may unfold differently on planets around cool stars.

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## First Confirmed Detection of a Bipolar Molecular Outflow from a Young Brown Dwarf

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Studying the earliest stages in the birth of stars is crucial for understanding how they form. Brown dwarfs with

masses between that of stars and planets are not massive enough to maintain stable hydrogen-burning fusion reactions during most of their lifetime. Their origins are subject to much debate in recent literature because their masses are far below the typical mass where core collapse is expected to occur. We present the first confirmed evidence that brown dwarfs undergo a phase of molecular outflow that is typical of young stars. Using the Submillimeter Array, we have obtained a map of a bipolar molecular outflow from a young brown dwarf. We estimate an outflow mass of  $1.6 \times 10^{-4} M_{\odot}$  and a mass-loss rate of  $1.4 \times 10^{-9} M_{\odot} \text{ yr}^{-1}$ . These values are over 2 orders of magnitude smaller than the typical ones for T Tauri stars. From our millimeter continuum data and our own analysis of Spitzer infrared photometry, we estimate that the brown dwarf has a disk with a mass of  $8 \times 10^{-3} M_{\odot}$  and an outer disk radius of 80 AU. Our results demonstrate that the bipolar molecular outflow operates down to planetary masses, occurring in brown dwarfs as a scaled-down version of the universal process seen in young stars.

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## A search for small-scale clumpiness in dense cores of molecular clouds

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We have analyzed HCN(1–0) and CS(2–1) line profiles obtained with high signal-to-noise ratios toward distinct positions in three selected objects in order to search for small-scale structure in molecular cloud cores associated with regions of high-mass star formation. In some cases, ripples were detected in the line profiles, which could be due to the presence of a large number of unresolved small clumps in the telescope beam. The number of clumps for regions with linear scales of  $\sim 0.2 - 0.5$  pc is determined using an analytical model and detailed calculations for a clumpy cloud model; this number varies in the range:  $\sim 2 \times 10^4 - 3 \times 10^5$ , depending on the source. The clump densities range from  $\sim 3 \times 10^5 - 10^6 \text{ cm}^{-3}$ , and the sizes and volume filling factors of the clumps are  $\sim (1 - 3 \times 10^{-3})$  pc and  $\sim 0.03 - 0.12$ . The clumps are surrounded by inter-clump gas with densities not lower than  $\sim (2 - 7) \times 10^4 \text{ cm}^{-3}$ . The internal thermal energy of the gas in the model clumps is much higher than their gravitational energy. Their mean lifetimes can depend on the inter-clump collisional rates, and vary in the range  $\sim 10^4 - 10^5$  yr. These structures are probably connected with density fluctuations due to turbulence in high-mass star-forming regions.

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<http://astro.appl.sci-nnov.ru/~pirogov/ar963p.pdf>

## Triggered star formation on the borders of the Galactic HII region RCW 82

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We are engaged in a multi-wavelength study of several Galactic HII regions that exhibit signposts of triggered star formation on their borders, where the collect and collapse process could be at work.

When addressing the question of triggered star formation, it is critical to ensure the real association between the ionized gas and the neutral material observed nearby. In this paper we stress this point and present CO observations of the RCW 82 star forming region. The velocity distribution of the molecular gas is combined with the study of young stellar objects (YSOs) detected in the direction of RCW 82. We discuss the YSO's evolutionary status using near- and mid-IR data. The spatial and velocity distributions of the molecular gas are used to discuss the possible scenarios for the star formation around RCW 82.

Several massive molecular condensations, together with star formation sites, are observed on the borders of RCW 82.

The shapes of the three brightest condensations suggest that they were pre-existent, i.e. not formed through the collect and collapse process. A thin layer of molecular material is observed surrounding the ionized gas, adjacent to the ionization front. This results from the sweeping up of neutral material around the expanding region. Several Class I YSOs are detected in the direction of this layer.

The numerous YSOs observed towards the bright molecular condensations bordering (and velocity-associated with) the ionized gas reveal the intense star formation activity in RCW 82. But this region is probably too young to have triggered star formation via the collect and collapse process.

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## Spatio-kinematic Structure at the Base of the [Fe II] Jets from L1551 IRS 5

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We present observational results of the [Fe II]  $\lambda 1.644 \mu\text{m}$  emission from the jets of L1551 IRS 5. The data sets were obtained through 13 fully sampled slits aimed at the base of the jets. These sets are used to construct a three-dimensional cube. The field of view was  $5.8'' \times 4.2''$ . We confirmed that the position of the knot PHK1 coincides with a stationary, point-like x-ray source within  $\pm 0.3''$ . The northern and southern jets are distinguished from each other at a point  $0.6''$  away from their driving sources. We also confirmed that the northern jet consists of well-separated high- and low-velocity components (HVC and LVC, respectively). The HVC has a terminal velocity of  $\sim 400 \text{ km s}^{-1}$  and shows a consistently narrow velocity width of  $40 \text{ km s}^{-1}$ . The LVC covers the velocity range from  $V_{LSR} = 0$  to  $-240 \text{ km s}^{-1}$  and has broad velocity widths of  $\sim 150\text{--}180 \text{ km s}^{-1}$ . These decrease with distance from the driving sources. The spatial width of the LVC varies from  $0.6''\text{--}0.7''$  at  $V_{LSR} \sim -200 \text{ km s}^{-1}$  to  $0.8''\text{--}0.9''$  at  $V_{LSR} \sim -30 \text{ km s}^{-1}$ . These characteristics are well understood in terms of the two types of outflow mechanisms that are working simultaneously: one is the HVC, which is launched in a narrow, inner radial region at  $0.04\text{--}0.05 \text{ AU}$ , and the other is the LVC, which is launched in a wider, outer radial region from within  $0.1\text{--}4.5 \text{ AU}$  of the accretion disk. Part of the LVC emission could arise in the gas entrained or shocked by the HVC. We also discuss the possibility that part of the HVC gas is thermalized at PHK1 to produce the x-ray emission and LVC.

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## Photometric Variability of the T Tauri Star TW Hya on Time-Scales of Hours to Years

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Microvariability & Oscillations of STars (MOST) and All Sky Automated Survey (ASAS) observations have been used to characterize photometric variability of TW Hya on time-scales from a fraction of a day to 7.5 weeks and from a few days to 8 yr, respectively. The two data sets have very different uncertainties and temporal coverage properties and cannot be directly combined, nevertheless, they suggest a global variability spectrum with 'flicker-noise' properties, that is with amplitudes  $a \propto 1/\sqrt{f}$ , over  $>4$  decades in frequency, in the range  $f=0.0003-10 \text{ c d}^{-1}$ . A 3.7 d period is clearly present in the continuous 11 d, 0.07 d time resolution, observations by MOST in 2007. Brightness extrema coincide with zero-velocity crossings in periodic (3.56 d) radial-velocity variability detected in contemporaneous spectroscopic observations of Setiawan et al. and interpreted as caused by a planet. The 3.56/3.7 d periodicity was entirely absent in the second, 4 times longer MOST run in 2008, casting doubt on the planetary explanation. Instead, a spectrum of unstable single periods within the range of 2-9 d was observed; the tendency of the periods to progressively shorten was well traced using the wavelet analysis. The evolving periodicities and the overall flicker-noise characteristics of the TW Hya variability suggest a combination of several mechanisms, with the dominant ones probably related to the accretion processes from the disc around the star.

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## The Clustering Behavior of Pre-Main Sequence Stars in NGC 346 in the Small Magellanic Cloud

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We present evidence that the star-forming region NGC 346/N66 in the Small Magellanic Cloud is the product of hierarchical star formation, probably from more than one star formation event. We investigate the spatial distribution and clustering behavior of the pre-main sequence (PMS) stellar population in the region, using data obtained with Hubble Space Telescope's Advanced Camera for Surveys. By applying the nearest neighbor and minimum spanning tree methods on the rich sample of PMS stars previously discovered in the region we identify ten individual PMS clusters in the area and quantify their structures. The clusters show a wide range of morphologies from hierarchical multi-peak configurations to centrally condensed clusters. However, only about 40 per cent of the PMS stars belong to the identified clusters. The central association NGC 346 is identified as the largest stellar concentration, which cannot be resolved into subclusters. Several PMS clusters are aligned along filaments of higher stellar density pointing away from the central part of the region. The PMS density peaks in the association coincide with the peaks of [OIII] and 8  $\mu\text{m}$  emission. While more massive stars seem to be concentrated in the central association when considering the entire area, we find no evidence for mass segregation within the system itself.

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## The structure of molecular clouds and the universality of the clump mass function

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Using a smoothed particle hydrodynamics (SPH) simulation of a star-forming region in a molecular cloud, we show that the emergence of a clump mass function (CMF) resembling the stellar initial mass function (IMF) is a ubiquitous feature of molecular cloud structure, but caution against its overinterpretation. We employ three different techniques to extract the clumps in this study. In the first two, we interpolate the SPH particle data to two- and three-dimensional grids before performing the clump-find, using position-position (PP) and position-position-velocity (PPV) information,

respectively. In the last technique, the clump-finding is performed on the SPH data directly, making use of the full three-dimensional position information. Although the CMF is typically similar to that observed in regions of nearby star formation, the individual clumps and their masses are found to be unreliable since they depend strongly on the parameters and the method of the clump-finding. In particular, we find that the resolution and orientation of the data make a significant difference to the resulting properties of the identified clumps in the PP and PPV cases. We conclude that making comparisons between a CMF and the stellar IMF should be done with caution, since the definition of a clump boundary, and hence the number of clumps and their properties, is arbitrary in the extraction method. This is especially true if molecular clouds are truly scale free.

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## ***Spitzer* Observations of L429: A Near-collapse or Collapsing Starless Core**

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We present *Spitzer* infrared observations of the starless core L429. The IR images of this core show an absorption feature, caused by the dense core material, at wavelengths  $\lesssim 70 \mu\text{m}$ . The core has a steep density profile, and reaches  $A_V > 35$  mag near the center. We show that L429 is either collapsing or in a near-collapse state.

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<http://arxiv.org/abs/0811.1581>

## **The chemical history of molecules in circumstellar disks. I. Ices**

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*Context.* Many chemical changes occur during the collapse of a molecular cloud to form a low-mass star and the surrounding disk. One-dimensional models have been used so far to analyse these chemical processes, but they cannot properly describe the incorporation of material into disks.

*Aims.* The goal of this work is to understand how material changes chemically as it is transported from the cloud to the star and the disk. Of special interest is the chemical history of the material in the disk at the end of the collapse.

*Methods.* A two-dimensional, semi-analytical model is presented that follows, for the first time, the chemical evolution from the pre-stellar core to the protostar and circumstellar disk. The model computes infall trajectories from any point in the cloud and tracks the radial and vertical motion of material in the viscously evolving disk. It includes a full time-dependent radiative transfer treatment of the dust temperature, which controls much of the chemistry. A small parameter grid is explored to understand the effects of the sound speed and the mass and rotation of the cloud. The freeze-out and evaporation of carbon monoxide (CO) and water (H<sub>2</sub>O), as well as the potential for forming complex organic molecules in ices, are considered as important first steps to illustrate the full chemistry.

*Results.* Both species freeze out towards the centre before the collapse begins. Pure CO ice evaporates during the infall phase and re-adsorbs in those parts of the disk that cool below the CO desorption temperature of  $\sim 18$  K. H<sub>2</sub>O remains solid almost everywhere during the infall and disk formation phases and evaporates within  $\sim 10$  AU of the star. Mixed CO-H<sub>2</sub>O ices are important in keeping some solid CO above 18 K and in explaining the presence of CO in comets. Material that ends up in the planet- and comet-forming zones of the disk ( $\sim 5$ –30 AU from the star) is predicted to spend enough time in a warm zone (several  $10^4$  yr at a dust temperature of 20–40 K) during the collapse to form first-generation complex organic species on the grains. The dynamical timescales in the hot inner envelope

(hot core or hot corino) are too short for abundant formation of second-generation molecules by high-temperature gas-phase chemistry.

Accepted by Astronomy & Astrophysics

<http://arxiv.org/abs/0901.1313>

(high-res version: <http://www.strw.leidenuniv.nl/~ruvisser/files/visser2009a.pdf>)

## Secular evolution of viscous and self-gravitating circumstellar discs

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We add the effect of turbulent viscosity via the  $\alpha$ -prescription to models of the self-consistent formation and evolution of protostellar discs. Our models are non-axisymmetric and carried out using the thin-disc approximation. Self-gravity plays an important role in the early evolution of a disc, and the later evolution is determined by the relative importance of gravitational and viscous torques. In the absence of viscous torques, a protostellar disc evolves into a self-regulated state with disk-averaged Toomre parameter  $Q \sim 1.5 - 2.0$ , non-axisymmetric structure diminishing with time, and maximum disc-to-star mass ratio  $\xi = 0.14$ . We estimate an effective viscosity parameter  $\alpha_{\text{eff}}$  associated with gravitational torques at the inner boundary of our simulation to be in the range  $10^{-4} - 10^{-3}$  during the late evolution. Addition of viscous torques with a low value  $\alpha = 10^{-4}$  has little effect on the evolution, structure, and accretion properties of the disc, and the self-regulated state is largely preserved. A sequence of increasing values of  $\alpha$  results in the discs becoming more axisymmetric in structure, being more gravitationally stable, having greater accretion rates, larger sizes, shorter lifetimes, and lower disc-to-star mass ratios. For  $\alpha = 10^{-2}$ , the model is viscous-dominated and the self-regulated state largely disappears by late times. The axisymmetry and low surface density of this model may contrast with observations and pose problems for planet formation models. The use of  $\alpha = 0.1$  leads to very high disc accretion rates and rapid (within 2 Myr) depletion of the disc, and seems even less viable observationally. Furthermore, only the non-viscous-dominated models with low values of  $\alpha = 10^{-4} - 10^{-3}$  can account for an early phase of quiescent low accretion rate  $\dot{M} \sim 10^{-8} M_{\odot} \text{ yr}^{-1}$  (interspersed with accretion bursts) that can explain the recently observed Very Low Luminosity Objects (VeLLOs). We also find that a modest increase in disc temperature caused by a stiffer barotropic equation of state ( $\gamma = 1.67$ ) has little effect on the disc accretion properties averaged over many disc orbital periods ( $\sim 10^4 \text{ yr}$ ), but can substantially influence the instantaneous mass accretion rates, particularly in the early embedded phase of disc evolution.

Accepted by MNRAS

## Uncovering the Outflow Driven by the Brown Dwarf LS-RCrA 1: H-alpha as a tracer of Outflow Activity in Brown Dwarfs.

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It is now apparent that classical T Tauri-like outflows commonly accompany the formation of young brown dwarfs. To date two optical outflows have been discovered and results presented in this paper increase this number to three. Using spectro-astrometry the origin of the LS-RCrA 1 forbidden emission lines in a blue-shifted outflow is confirmed. The non-detection of the red-shifted component of the outflow in forbidden lines, along with evidence for some separation between low and high velocity outflow components, do not support the hypothesis that LS-RCrA 1 has an edge-on accretion disk. The key result of this analysis is the discovery of an outflow component to the H $\alpha$  line. The H $\alpha$  line profile has blue and red-shifted features in the wings which spectro-astrometry reveals to also originate in the outflow. The discovery that H $\alpha$  emission in BDs can have a significant contribution from an outflow suggests the use of H $\alpha$  line widths as a proxy of mass accretion in BDs is not clear-cut. This method assumes that any contribution to the H $\alpha$  line flux from a possible outflow is negligible. Finally the fact that the H $\alpha$  line traces both lobes of the outflow while

only the blue-shifted lobe is seen in forbidden emission points to the presence of a dust hole in the accretion disk of LS-RCrA 1. This is commonly seen in CTTs and is assumed to signal the onset of planet formation.

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<http://adsabs.harvard.edu/abs/2009arXiv0901.0465W>

## Carbon isotope fractionation in protoplanetary disks

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We investigate the gas-phase and grain-surface chemistry in the inner 30 AU of a typical protoplanetary disk using a new model which calculates the gas temperature by solving the gas heating and cooling balance and which has an improved treatment of the UV radiation field. We discuss inner-disk chemistry in general, obtaining excellent agreement with recent observations which have probed the material in the inner regions of protoplanetary disks. We also apply our model to study the isotopic fractionation of carbon. Results show that the fractionation ratio,  $^{12}\text{C}/^{13}\text{C}$ , of the system varies with radius and height in the disk. Different behaviour is seen in the fractionation of different species. We compare our results with  $^{12}\text{C}/^{13}\text{C}$  ratios in the Solar System comets, and find a stark contrast, indicative of reprocessing.

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<http://www.jb.man.ac.uk/~pwoods/pubs/WoodsWillacy2008.pdf>

## Magnetic Properties of Young Stars in the TW Hydrae Association

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We present an analysis of infrared echelle spectra of five stars in the TW Hydrae Association (TWA). We model the Zeeman broadening in four magnetic-sensitive Ti I lines near 2.2  $\mu\text{m}$  and measure the value of the photospheric magnetic field averaged over the surface of each star. To ensure that other broadening mechanisms are properly taken into account, we also inspect several magnetically insensitive CO lines near 2.3  $\mu\text{m}$  and find no excess broadening above that produced by stellar rotation and instrumental broadening, providing confidence in the magnetic interpretation of the width of the Ti I lines. We then utilize our results to test the relationship between stellar magnetic flux and X-ray properties and compare the measured fields with equipartition field values. Finally, we use our results and recent results on a large sample of stars in Taurus to discuss the potential evolution of magnetic field properties between the age of Taurus ( $\sim 2$  Myr) and the age of TWA ( $\sim 10$  Myr). We find that the average stellar field strength increases with age; however, the total unsigned magnetic flux decreases as the stars contract onto the main sequence.

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## Non-steady Accretion in Protostars

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Observations indicate that mass accretion rates onto low-mass protostars are generally lower than the rates of infall to their disks; this suggests that much of the protostellar mass must be accreted during rare, short outbursts of

rapid accretion. We explore when protostellar disk accretion is likely to be highly variable. While constant  $\alpha$  disks can in principle adjust their accretion rates to match infall rates, protostellar disks are unlikely to have constant  $\alpha$ . In particular we show that neither models with angular momentum transport due solely to the magnetorotational instability (MRI) nor gravitational instability (GI) are likely to transport disk mass at protostellar infall rates over the large range of radii needed to move infalling envelope material down to the central protostar. We show that the MRI and GI are likely to combine to produce outbursts of rapid accretion starting at a few AU. Our analysis is consistent with the time-dependent models of Armitage, Livio, & Pringle (2001) and agrees with our observational study of the outbursting object FU Ori.

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<http://arxiv.org/abs/0811.1762>

The Star Formation Newsletter is a vehicle for fast distribution of information of interest for astronomers working on star formation and molecular clouds. You can submit material for the following sections: *Abstracts of recently accepted papers* (only for papers sent to refereed journals), *Abstracts of recently accepted major reviews* (not standard conference contributions), *Dissertation Abstracts* (presenting abstracts of new Ph.D dissertations), *Meetings* (announcing meetings broadly of interest to the star and planet formation and early solar system community), *New Jobs* (advertising jobs specifically aimed towards persons within the areas of the Newsletter), and *Short Announcements* (where you can inform or request information from the community).

**Latex macros for submitting abstracts and dissertation abstracts (by e-mail to [reipurth@ifa.hawaii.edu](mailto:reipurth@ifa.hawaii.edu)) are appended to each issue of the newsletter. You can also submit via the Newsletter web interface at <http://www2.ifa.hawaii.edu/star-formation/index.cfm>**

The Star Formation Newsletter is available on the World Wide Web at <http://www.ifa.hawaii.edu/users/reipurth/newsletter.htm>.

## **The star formation process in the Magellanic Clouds**

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The Magellanic Clouds offer unique opportunities to study star formation both on the global scales of an interacting system of gas-rich galaxies, as well as on the scales of individual star-forming clouds. The interstellar media of the Small and Large Magellanic Clouds and their connecting bridge, span a range in (low) metallicities and gas density. This allows us to study star formation near the critical density and gain an understanding of how tidal dwarfs might form; the low metallicity of the SMC in particular is typical of galaxies during the early phases of their assembly, and studies of star formation in the SMC provide a stepping stone to understand star formation at high redshift where these processes can not be directly observed. In this review, I introduce the different environments encountered in the Magellanic System and compare these with the Schmidt-Kennicutt law and the predicted efficiencies of various chemo-physical processes. I then concentrate on three aspects that are of particular importance: the chemistry of the embedded stages of star formation, the Initial Mass Function, and feedback effects from massive stars and its ability to trigger further star formation.

Accepted as invited review at the IAUS 256, The Magellanic System: Stars, Gas, and Galaxies, eds. Jacco van Loon, Joana Oliveira

<http://arxiv.org/abs/0812.2360>

## **The Clearing of Protoplanetary Disks and of the Protosolar Nebula**

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Circumstellar disks are a natural outcome of the star formation process and the sites where planets form. Gas, mainly hydrogen and helium, accounts for about 99% of the disk's initial mass while dust, in the form of submicron-sized grains, only for about 1%. In the process of forming planets circumstellar disks disperse: sub-micron dust grains collide and stick together to form larger aggregates; gas accretes onto the star, onto the cores of giant and icy planets, and evaporates from the disk surface. A key question in planet formation is the timescale and physical mechanism for the clearing of protoplanetary disks. How rapidly gas and dust disperse determines what type of planets can form.

In this chapter we compare the evolution of protoplanetary disks to that of the protosolar nebula. We start by summarizing the observational constraints on the lifetime of protoplanetary disks and discuss four major disk dispersal mechanisms. After, we seek constraints on the clearing of gas and dust in the protosolar nebula from the properties of meteorites, asteroids, and planets. Finally, we try to anchor the evolution of protoplanetary disks to the Solar System chronology and discuss what observations and experiments are needed to understand how common is the history of the Solar System.

Accepted by "Protoplanetary Dust" 2009 (eds. D. Apai & D. Lauretta, Cambridge University Press, Planetary Sciences series)

for preprints please contact I. Pascucci or S. Tachibana

## **Postdoctoral Position for Infrared Interferometry of Circumstellar Disks (University of Michigan)**

We seek a postdoctoral researcher to lead observations and analysis of disks around young stellar objects using the CHARA Interferometer and its new fringe tracking capability. The new fringe tracker will allow aperture synthesis imaging of inner disks of YSOs for the first time. Previous experience modeling and observing circumstellar disks is highly desired, with secondary emphasis on previous work using optical/infrared interferometers. The successful applicant will join the active and diverse star and planet formation group at UM, which includes Professors Fred Adams, Ted Bergin, Nuria Calvet, Lee Hartmann, and John Monnier. As a Postdoctoral Fellow, the successful applicant will also have access to available UM research facilities including the twin Magellan 6.5 meter telescopes in Chile, the MDM 1.3 meter and 2.4 meter telescopes on Kitt Peak, the 26 meter UM radio telescope and the departmental computing network.

This position is initially for one year and may be extended up to three years (subject to continued NSF funding and to annual performance review), and can begin as early as March 2009. Applicants should provide a vita, bibliography and a statement of research interests, and secure at least three letters of recommendation. Applications received prior to February 1, 2009, will receive first consideration. Please address all applications and recommendations to Prof. John Monnier at the above address (email submissions are preferred). The University of Michigan is an Equal Opportunity/Affirmative Action Employer. Women and minorities are encouraged to apply.

## **Schroedinger Fellowship in Star Formation Dublin Institute for Advanced Studies**

The Dublin Institute for Advanced Studies, is offering a five year Schroedinger Fellowship.

**Areas of interest** include outflows from young stars and brown dwarfs, protostellar disks and the initial mass function. The institute is a partner in building the Mid-Infrared Instrument (MIRI) for the James Webb Space Telescope and has recently become involved in the Gould Belt Survey to be carried out using Spitzer, Herschel, and the James Clark Maxwell Telescope. While the postdoctoral fellow is expected to work in the area of observations, he or she will be encouraged to interact closely with the astrophysical simulation group. Further information can be had by contacting Prof Tom Ray (tom.ray@dias.ie). The fellowship will be available from late 2009. The Institute is an equal opportunity employer.

Applications, to include a CV, publication list, short research plan, and the contact details of two referees should be sent, ideally as a single PDF file by e-mail to registraroffice@admin.dias.ie (with a cc to tom.ray@dias.ie) quoting "SCP0902 Star Formation Fellowship" in the subject field, to arrive on or before 31 March 2009. The position will remain open until filled.

The fellowship is offered subject to the general Irish public service regulations and employment legislation (e.g. regarding maternity leave, holiday entitlements, etc.) and includes generous pension provision.

## Postdoctoral Position in Star Formation with the Herschel infrared Galactic Plane Survey (Hi-GAL)

A Post-Doctoral Fellowship is available in the 'Star and Planetary Formation' group at the Istituto di Fisica dello Spazio Interplanetario (IFSI-INAF, Rome) in the framework of the Hi-GAL project. Hi-GAL is the Herschel satellite Open-Time Key-Project that will map the  $-60^\circ \leq l \leq 60^\circ$  portion of the Galactic Plane in five photometric bands between 60 and  $600\mu\text{m}$ . This fellowship is funded by the Italian Space Agency (ASI).

The selected candidate is expected to actively carry out and develop research activity in the field of Galactic Star Formation. Starting from the Hi-GAL data, but in the broader concept of a multi-wavelength Milky Way from the near infrared to the millimeter, novel approaches for science analysis using cross-mission continuum data will be encouraged. The successful candidate will work with Dr. S. Molinari (Hi-GAL PI).

The fellowship is expected to have the duration of one year, with an extension of two more years subject to a positive evaluation of the research activity carried out during the first year. The gross yearly salary will be in the range 28000 ÷ 33000 Euro, depending on the capabilities and experience of the selected candidate.

The candidates should have a PhD in Astronomy, with expertise in Star Formation with infrared and submillimeter data. Experience with continuum data from large-scale Galactic surveys and handling of large sources samples will be considered a plus.

Applications should include a Curriculum Vitae, a statement of research interests and a list of publications; the closing date is January 31, 2009. Applicants should also arrange for three letters of references to be sent independently. Applications should be sent to:

Mrs. Angela Rossetti  
IFSI-INAF  
Via Fosso del Cavaliere 100, 00133 Roma - Italy  
E-mail enquiries: molinari@ifsi-roma.inaf.it

## Postdoctoral and PhD Positions in the study of Magnetic Fields during Star Formation

Applications are invited for a postdoctoral and a PhD position in the newly established Emmy Noether research group led by Dr. Wouter Vlemmings on the topic of 'Magnetic fields during the birth and death of stars' at the Argelander Institute for Astronomy (AIfA) of the University of Bonn in Germany. The postdoctoral appointment will be for two years, with possible renewal. The PhD position will be for three years.

The postdoc and PhD projects will focus on radio, millimeter and sub-millimeter wavelength polarization observations of star forming regions. The postdoc will also carry out his/her own research in collaboration with the other group members.

The successful candidates will join the new Emmy Noether research group, which has close ties to the local ALMA Regional Center (ARC) node and its growing submillimeter-interferometry research group.

Interested applicants for the postdoctoral position should have a PhD in astrophysics by the start of the appointment. They should send a CV, description of research interests, a publication list and arrange for the submission of three letters of recommendation to wouter@astro.uni-bonn.de (att. Dr. Wouter Vlemmings). Applicants for the PhD position, please submit a CV, education history with transcripts of study record, and a brief description of research interests, and arrange for the submission of two letters of recommendation to above email address.

Applications received before 15 January 2009 will receive full consideration, but applications will be accepted until the position is filled. Women and minorities are particularly encouraged to apply.

For more information visit the Emmy Noether webpage at <http://www.astro.uni-bonn.de/~wouter/EN/> or contact Wouter Vlemmings at the email address above.

## *Meetings*

### **IUPAC 2009 Astrochemistry Symposium**

All members of the community are encouraged to attend the Astrochemistry Symposium to be held as part of the 42nd IUPAC CONGRESS - Chemistry Solutions, 2-7 August 2009 at the SECC, Glasgow, Scotland, UK.

Our Keynote Speakers :

Eric Herbst, The Ohio State University, USA

Ewine van Dishoeck, Leiden University, The Netherlands

Bruce Kay, Pacific Northwest National Laboratory, USA

David Clary, University of Oxford, UK

Stephen Leone, University of California, Berkeley and Lawrence Berkeley National Laboratory, USA

and invited speakers

Ludovic Biennier, Universite de Rennes 1, France

Francois Dulieu, Universite de Cergy-Pontoise, France

Wolf Geppert, Stockholm University, Sweden

Liv Hornekaer, University of Aarhus, Denmark

Mike McCarthy, Harvard-Smithsonian Center for Astrophysics, USA

Helen Roberts, Queen's University Belfast, UK

We now solicit abstracts and registration, (closing date Jan 16th 2009) particularly in areas of laboratory astrochemistry (gas phase, sample return analysis and solid state) theoretical chemistry and observational chemistry, any aspect of chemistry research linked with astronomy. We particularly encourage early career scientists and established scientists to apply for one of many oral or poster presentations. Some financial support is available for young scientists and PhDs.

We look forward to welcoming you to Glasgow in 2009 and putting Astrochemistry at the heart of Chemical Research in the 21st century.

For further information please do consult the web-site [www.iupac2009.org](http://www.iupac2009.org).

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