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## *Abstracts of recently accepted papers*

### **Magnetic Interactions in Pre-Main-Sequence Binaries**

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Young stars typically have strong magnetic fields, so that the magnetospheres of newly formed close binaries can interact, dissipate energy, and produce synchrotron radiation. The V773 Tau A binary system, a pair of T Tauri stars with a 51 day orbit, displays such a signature, with peak emission taking place near periastron. This paper proposes that the observed emission arises from the change in energy stored in the composite magnetic field of the system. We model the fields using the leading order (dipole) components and show that this picture is consistent with current observations. In this model, the observed radiation accounts for a fraction of the available energy of interaction between the magnetic fields from the two stars. Assuming antisymmetry, we compute the interaction energy  $E_{\text{int}}$  as a function of the stellar radii, the stellar magnetic field strengths, the binary semi-major axis, and orbital eccentricity, all of which can be measured independently of the synchrotron radiation. The variability in time and energetics of the synchrotron radiation depend on the details of the annihilation of magnetic fields through reconnection events, which generate electric fields that accelerate charged particles, and how those charged particles, especially fast electrons, are removed from the interaction region. However, the major qualitative features are well described by the background changes in the global magnetic configuration driven by the orbital motion. The theory can be tested by observing a collection of pre-main-sequence binary systems.

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### **Magnetically Controlled Accretion Flows onto Young Stellar Objects**

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Accretion from disks onto young stars is thought to follow magnetic field lines from the inner disk edge to the stellar surface. The accretion flow thus depends on the geometry of the magnetic field. This paper extends previous work by constructing a collection of orthogonal coordinate systems, including the corresponding differential operators, where one coordinate traces the magnetic field lines. This formalism allows for an (essentially) analytic description of the geometry and the conditions required for the flow to pass through sonic points. Using this approach, we revisit the problem of magnetically controlled accretion flow in a dipole geometry, and then generalize the treatment to consider magnetic fields with multiple components, including dipole, octupole, and split monopole contributions. This

approach can be generalized further to consider more complex magnetic field configurations. Observations indicate that accreting young stars have substantial dipole and octupole components, and that accretion flow is transonic. If the effective equation of state for the fluid is too stiff, however, the flow cannot pass smoothly through the sonic points in steady state. For a multipole field of order  $\ell$ , we derive a general constraint on the polytropic index,  $n > \ell + 3/2$ , required for steady transonic flow to reach free-fall velocities. For octupole fields, inferred on surfaces of T Tauri stars, the index  $n > 9/2$ , so that the flow must be close to isothermal. The inclusion of octupole field components produces higher densities at the stellar surface and smaller areas for the hot spots, which occur at higher latitudes; the magnetic truncation radius is smaller (larger) for octupole components that are aligned (anti-aligned) with the stellar dipole. This contribution thus increases our understanding of magnetically controlled accretion for young stellar objects and can be applied to a variety of additional astrophysical problems.

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## Distinguishing between H II regions and planetary nebulae with Hi-GAL, WISE, MIPS-GAL, and GLIMPSE

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*Context.* H II regions and planetary nebulae (PNe) both emit at radio and infrared (IR) wavelengths, and angularly small H II regions can be mistaken for PNe. This problem of classification is most severe for H II regions in an early evolutionary stage, those that are extremely distant, or those that are both young and distant. Previous work has shown that H II regions and PNe can be separated based on their infrared colors.

*Aims.* Using data from the *Herschel* Hi-GAL survey, as well as WISE and the *Spitzer* MIPS GAL and GLIMPSE surveys, we wish to establish characteristic IR colors that can be used to distinguish between H II regions and PNe.

*Methods.* We perform aperture photometry measurements for a sample of 126 H II regions and 43 PNe at wavelengths from 8.0  $\mu\text{m}$  to 500  $\mu\text{m}$ .

*Results* We find that H II regions and PNe have distinct IR colors. The most robust discriminating color criteria are  $[F_{12}/F_8] < 0.3$ ,  $[F_{160}/F_{12}] > 1.3$ , and  $[F_{160}/F_{24}] > 0.8$  (or alternately  $[F_{160}/F_{22}] > 0.8$ ), where the brackets indicate the log of the flux ratio. All three of these criteria are individually satisfied by over 98% of our sample of H II regions and by  $\sim 10\%$  of our sample of PNe. Combinations of these colors are more robust in separating the two populations; for example all H II regions and no PNe satisfy  $[F_{12}/F_8] < 0.4$  and  $[F_{160}/F_{22}] > 0.8$ . When applied to objects of unknown classification, these criteria prove useful in separating the two populations. The dispersion in color is relatively small for H II regions; this suggests that any evolution in these colors with time for H II regions must be relatively modest. The spectral energy distributions (SEDs) of H II regions can be separated into “warm” and “cold” components. The “cold” component is well-fit by a grey-body of temperature 25 K. The SEDs of nearly two-thirds of our sample of H II regions peak at 160  $\mu\text{m}$  and one third peak at 70  $\mu\text{m}$ . For PNe, 67% of the SEDs peak at 70  $\mu\text{m}$ , 23% peak at either 22  $\mu\text{m}$  or 24  $\mu\text{m}$ , and 9% (two sources) peak at 160  $\mu\text{m}$ .

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<http://arxiv.org/abs/1110.3303>

## A Closer Look at the LkCa 15 Protoplanetary Disk

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We present 870 micron observations of dust continuum emission from the LkCa 15 protoplanetary disk at high angular resolution (with a characteristic scale of  $0.25'' = 35$  AU), obtained with the IRAM Plateau de Bure interferometer and supplemented by slightly lower resolution observations from the Submillimeter Array. We fit these data with simple morphological models to characterize the spectacular ring-like emission structure of this disk. Our analysis indicates that a small amount of 870 micron dust emission ( $\sim 5$  mJy) originates inside a large (40-50 AU radius) low optical depth cavity. This result can be interpreted either in the context of an abrupt decrease by a factor of  $\sim 5$  in the radial distribution of millimeter-sized dust grains or as indirect evidence for a gap in the disk, in agreement with previous inferences from the unresolved infrared spectrum and scattered light images. A preliminary model focused on the latter possibility suggests the presence of a low-mass (planetary) companion, having properties commensurate with those inferred from the recent discovery of LkCa 15b.

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## A Multi-Epoch Simultaneous Water and Methanol Maser Survey

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We report a multi-epoch, simultaneous 22 GHz water and 44 GHz Class I methanol maser line survey toward 180 intermediate-mass young stellar objects, including 14 Class 0, 19 Class I objects, and 147 Herbig Ae/Be stars. We detected water and methanol maser emission toward 16 (9 %) and 10 (6 %) sources with 1 new water and 6 new methanol maser sources. The detection rates of both masers rapidly decrease as the central (proto)stars evolve, which is contrary to the trends in high-mass star-forming regions. This suggests that the excitations of the two masers are closely related to the evolutionary stage of the central (proto)stars and the circumstellar environments. Water maser velocities deviate on average 9 km/s from the ambient gas velocities whereas methanol maser velocities match quite well with the ambient gas velocities. For both maser emissions, large velocity differences ( $|v_{\text{H}_2\text{O}} - v_{\text{sys}}| > 10$  km/s and  $|v_{\text{CH}_3\text{OH}} - v_{\text{sys}}| > 1$  km/s) are mostly confined to Class 0 objects. The formation and disappearance of water masers is frequent and their integrated intensities change by up to two orders of magnitude. In contrast, methanol maser lines usually show no significant change in intensity, shape, or velocity. This is consistent with the previous suggestion that water maser emission originates from the base of an outflow while 44 GHz Class I methanol maser emission arises from the interaction region of the outflow with the ambient gas. The isotropic maser luminosities are well correlated with the bolometric luminosities of the central objects. The fitted relations are  $L_{\text{H}_2\text{O}} = 1.71 \times 10^{-9} (L_{\text{bol}})^{0.97}$  and  $L_{\text{CH}_3\text{OH}} = 1.71 \times 10^{-10} (L_{\text{bol}})^{1.22}$ .

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## Stellar, brown dwarf and multiple star properties from a radiation hydrodynamical simulation of star cluster formation

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We report the statistical properties of stars, brown dwarfs and multiple systems obtained from the largest radiation hydrodynamical simulation of star cluster formation to date that resolves masses down to the opacity limit for fragmentation (a few Jupiter masses). The initial conditions are identical to those of previous barotropic calculations published by Bate, but this time the calculation is performed using a realistic equation of state and radiation hydrodynamics. The calculation uses sink particles to model 183 stars and brown dwarfs, including 28 binaries and 12 higher-order multiple systems, the properties of which are compared the results from observational surveys.

We find that the radiation hydrodynamical/sink particle simulation reproduces many observed stellar properties very well. In particular, whereas using a barotropic equation of state produces more brown dwarfs than stars, the inclusion of radiative feedback results in a stellar mass function and a ratio of brown dwarfs to stars in good agreement with observations of Galactic star-forming regions. In addition, many of the other statistical properties of the stars and brown dwarfs are in reasonable agreement with observations, including multiplicity as a function of primary mass, the frequency of very-low-mass binaries, and general trends for the mass ratio and separation distributions of binaries. We also examine the velocity dispersion of the stars, the distributions of disc truncation radii due to dynamical interactions, and coplanarity of orbits and sink particle spins in multiple systems. Overall, the calculation produces a cluster of stars whose statistical properties are difficult to distinguish from observed systems, implying that gravity, hydrodynamics, and radiative feedback are the primary ingredients for determining the origin of the statistical properties of low-mass stars.

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<http://arxiv.org/pdf/1110.1092>

Animations available from <http://www.astro.ex.ac.uk/people/mbate/>

## **Giant Planet Formation by Disk Instability: Flux-Limited Radiative Diffusion and Protostellar Wobbles**

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Giant planet formation by gravitational disk instabilities has become theoretically and observationally acceptable at large distances, but remains theoretically contentious at distances inside about 20 AU. Several new three dimensional hydrodynamics models are presented, where radiative transfer is handled in the flux-limited diffusion approximation from the very start of the model, rather than being employed only after clumps have begun to form. The three models show that the use of the flux-limiter has little appreciable effect on the early evolution of a disk instability, in agreement with the conclusions of the previous models, which studied later phases. In addition, two new models are presented where the central protostar is either held fixed or is allowed to wobble in such a manner as to preserve the center of mass of the star-disk system. While spiral arms and clumps form in both models, the wobbling protostar model appears to be better able to form self-gravitating clumps that could contract to form gas giant protoplanets. Combined with previous results, the new models imply that disk instability should be able to form self-gravitating clumps inside, as well as outside, 20 AU in suitably massive and cool protoplanetary disks.

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<http://www.dtm.ciw.edu/users/boss/ftp/fluxwobble.pdf>

## **Collapse of massive magnetized dense cores using radiation-magneto-hydrodynamics: early fragmentation inhibition.**

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We report the results of radiation-magneto-hydrodynamics calculations in the context of high mass star formation, using for the first time a self-consistent model for photon emission (i.e. via thermal emission and in radiative shocks) and with the high resolution necessary to resolve properly magnetic braking effects and radiative shocks on scales  $\lesssim 100$  AU. We investigate the combined effects of magnetic field, turbulence, and radiative transfer on the early phases of the collapse and the fragmentation of massive dense cores. We identify a new mechanism that inhibits initial fragmentation of massive dense cores, where magnetic field and radiative transfer interplay. We show that this interplay becomes stronger as the magnetic field strength increases. Magnetic braking is transporting angular momentum outwards and

is lowering the rotational support and is thus increasing the infall velocity. This enhances the radiative feedback owing to the accretion shock on the first core. We speculate that highly magnetized massive dense cores are good candidates for isolated massive star formation, while moderately magnetized massive dense cores are more appropriate to form OB associations or small star clusters.

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## First detection of Hydrogen Chloride towards protostellar shocks

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We present the first detection of hydrogen chloride in a protostellar shock, by observing the fundamental transition at 626 GHz with the Herschel HIFI spectrometer. We detected two of the three hyperfine lines, from which we derived a line opacity  $\leq 1$ . Using a non-LTE LVG code, we constrained the HCl column density, temperature and density of the emitting gas. The hypothesis that the emission originates in the molecular cloud is ruled out, as it would imply a too dense gas. Conversely, assuming that the emission originates in the 10''–15'' size shocked gas previously observed at the IRAM PdB interferometer, we obtain:  $N(\text{HCl})=0.7\text{--}2\times 10^{13}\text{ cm}^{-2}$ , temperature  $> 15\text{ K}$  and density  $> 3\times 10^5\text{ cm}^{-3}$ . Combining with the Herschel HIFI CO(5–4) observations allows to further constrain the gas density and temperature,  $10^5\text{--}10^6\text{ cm}^{-3}$  and 120–250 K, as well as the HCl column density,  $2\times 10^{13}\text{ cm}^{-2}$ , and, finally, abundance:  $\sim 3\text{--}6\times 10^{-9}$ . The estimated HCl abundance is consistent with that previously observed in low- and high- mass protostars. This puzzling result in the L1157-B1 shock, where species from volatile and refractory grains components are enhanced, suggests either that HCl is not the main reservoir of chlorine in the gas phase, against previous chemical models predictions, or that the elemental chlorine abundance is low in L1157-B1. Astrochemical modelling suggests that HCl is in fact formed in the gas phase, at low temperatures, prior to the occurrence of the shock, and that the latter does not enhance its abundance.

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## CID: Chemistry in disks VI. Sulfur-bearing molecules in the protoplanetary disks surrounding LkCa15, MWC480, DM Tau, and GO Tau

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We study the content in S-bearing molecules of protoplanetary disks around low-mass stars. We used the new IRAM 30-m receiver EMIR to perform simultaneous observations of the  $1_{10} - 1_{01}$  line of  $\text{H}_2\text{S}$  at 168.8 GHz and  $2_{23} - 1_{12}$

line of SO at 99.3 GHz. We compared the observational results with predictions coming from the astrochemical code NAUTILUS, which has been adapted to protoplanetary disks. The data were analyzed together with existing CS J=3-2 observations. We fail to detect the SO and H<sub>2</sub>S lines, although CS is detected in LkCa15, DM Tau, and GO Tau but not in MWC 480. However, our new upper limits are significantly better than previous ones and allow us to put some interesting constraints on the sulfur chemistry. Our best modeling of disks is obtained for a C/O ratio of 1.2, starting from initial cloud conditions of H density of  $2 \times 10^5 \text{ cm}^{-3}$  and age of  $10^6 \text{ yr}$ . The results agree with the CS data and are compatible with the SO upper limits, but fail to reproduce the H<sub>2</sub>S upper limits. The predicted H<sub>2</sub>S column densities are too high by at least one order of magnitude. H<sub>2</sub>S may remain locked onto grain surfaces and react with other species, thereby preventing the desorption of H<sub>2</sub>S.

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<http://hal.archives-ouvertes.fr/lab/l3ab/>

## 37 GHz Methanol Masers: Horsemen of the Apocalypse for the Class II Methanol Maser Phase?

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We report the results of a search for class II methanol masers at 37.7, 38.3 and 38.5 GHz towards a sample of 70 high-mass star formation regions. We primarily searched towards regions known to show emission either from the 107 GHz class II methanol maser transition, or from the 6.035 GHz excited OH transition. We detected maser emission from 13 sources in the 37.7 GHz transition, eight of these being new detections. We detected maser emission from three sources in the 38 GHz transitions, one of which is a new detection. We find that 37.7 GHz methanol masers are only associated with the most luminous 6.7 and 12.2 GHz methanol maser sources, which in turn are hypothesised to be the oldest class II methanol sources. We suggest that the 37.7 GHz methanol masers are associated with a brief evolutionary phase (of 1000-4000 years) prior to the cessation of class II methanol maser activity in the associated high-mass star formation region.

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## Comparing star formation models with interferometric observations of the protostar NGC 1333 IRAS 4A. I. Magnetohydrodynamic collapse models

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Observations of dust polarized emission toward star forming regions trace the magnetic field component in the plane of the sky and provide constraints to theoretical models of cloud collapse. We compare high-angular resolution observations of the submillimeter polarized emission of the low-mass protostellar source NGC 1333 IRAS 4A with the predictions of three different models of collapse of magnetized molecular cloud cores. We compute the Stokes parameters for the dust emission for the three models. We then convolve the results with the instrumental response of the Submillimeter Array observation toward NGC 1333 IRAS 4A. Finally, we compare the synthetic maps with the data, varying the model parameters and orientation, and we assess the quality of the fit by a  $\chi^2$  analysis. High-angular resolution observations of polarized dust emission can constraint the physical properties of protostars. In the case of NCC 1333 IRAS 4A, the best agreements with the data is obtained for models of collapse of clouds with mass-to-flux ratio  $> 2$  times the critical value, initial uniform magnetic field of strength  $\sim 0.5 \text{ mG}$ , and age of the order of a few  $10^4 \text{ yr}$  since the onset of collapse. Magnetic dissipation, if present, is found to occur below the resolution level

of the observations. Including a previously measured temperature profile of NCC 1333 IRAS 4A leads to a more realistic morphology and intensity distribution. We also show that ALMA has the capability of distinguishing among the three different models adopted in this work. Our results are consistent with the standard theoretical scenario for the formation of low-mass stars, where clouds initially threaded by large-scale magnetic fields become unstable and collapse, trapping the field in the nascent protostar and the surrounding circumstellar disk. In the collapsing cloud, the dynamics is dominated by gravitational and magnetic forces.

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<http://www.aanda.org/articles/aa/pdf/forth/aa17813-11.pdf>

## Meridional circulation in turbulent protoplanetary disks

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Based on the viscous disk theory, a number of recent studies have suggested there is large scale meridional circulation in protoplanetary disks. Such a flow could account for the presence of crystalline silicates, including calcium- and aluminum-rich inclusions (CAIs), at large distances from the sun. This paper aims at examining whether such large-scale flows exist in turbulent protoplanetary disks. High-resolution global hydrodynamical and magnetohydrodynamical (MHD) numerical simulations of turbulent protoplanetary disks were used to infer the properties of the flow in such disks. By performing hydrodynamic simulations using explicit viscosity, we demonstrate that our numerical setup does not suffer from any numerical artifact. The aforementioned meridional circulation is easily recovered in viscous and laminar disks and is quickly established. In MHD simulations, the magnetorotational instability drives turbulence in the disks. Averaging out the turbulent fluctuations on a long timescale, the results fail to show any large-scale meridional circulation. A detailed analysis of the simulations show that this lack of meridional circulation is due to the turbulent stress tensor having a vertical profile different from the viscous stress tensor. A simple model is provided that successfully accounts for the structure of the flow in the bulk of the disk. In addition to those results, possible deviations from standard vertically averaged  $\alpha$  disk models are suggested by the simulations and should be the focus of future work. Global MHD numerical simulations of fully ionized and turbulent protoplanetary disks are not consistent with the existence of a large-scale meridional flow. As a consequence, the presence of crystalline silicates at large distance for the central star cannot be accounted for by that process as suggested by recent models based on viscous disk theory.

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<http://arxiv.org/abs/1102.0671>

## Infall and outflow within 400 AU from a high-mass protostar 3-D velocity fields from methanol and water masers in AFLG 5142

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Observational signatures of infalling envelopes and outflowing material in early stages of protostellar evolution, and at small radii from the protostar, are essential to progress in the understanding of the mass-accretion process in star formation. In this letter, we report a detailed study of the accretion and outflow structure around a protostar in the well-known high-mass star-forming region AFGL 5142. We focus on the mm source MM-1, which exhibits hot-core chemistry, radio continuum emission, and strong water (H<sub>2</sub>O) and methanol (CH<sub>3</sub>OH) masers. Remarkably, our

Very Long Baseline Interferometry (VLBI) observations of molecular masers over six years provided us with the 3-D velocity field of circumstellar molecular gas with a resolution of 0.001–0.005 arcsec and at radii  $<0''.23$  (or 400 AU) from the protostar. In particular, our measurements of CH<sub>3</sub>OH maser emission enabled, for the first time, a direct measurement of infall of a molecular envelope (radius of 300 AU and velocity of 5 km s<sup>-1</sup>) onto an intermediate- to high-mass protostar. We estimate an infall rate of  $6 \times 10^{-4} n_8 M_{\odot} \text{ yr}^{-1}$ , where  $n_8$  is the ambient volume density in units of 10<sup>8</sup> cm<sup>-3</sup> (required for maser excitation). In addition, our measurements of H<sub>2</sub>O maser (and radio continuum) emission identify a collimated bipolar molecular outflow (and ionized jet) from MM–1. The evidence of simultaneous accretion and outflow at small spatial scales, makes AFGL 5142 an extremely compelling target for high-angular resolution studies of high-mass star formation.

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## A Herschel Search for Cold Dust in Brown Dwarf Disks: First Results

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We report initial results from a *Herschel* program to search for far-infrared emission from cold dust around a statistically significant sample of young brown dwarfs. The first three objects in our survey are all detected at 70 $\mu$ m, and we report the first detection of a brown dwarf at 160 $\mu$ m. The flux densities are consistent with the presence of substantial amounts of cold dust in the outer disks around these objects. We modeled the SED's with two different radiative transfer codes. We find that a broad range of model parameters provides a reasonable fit to the SED's, but that the addition of our 70 $\mu$ m, and especially the 160 $\mu$ m detection enables strong lower limits to be placed on the disk masses since most of the mass is in the outer disk. We find likely disk masses in the range of a few  $\times 10^{-6}$  to  $10^{-4}$  solar masses. Our models provide a good fit to the SED's and do not require dust settling.

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## Filaments and ridges in Vela C revealed by *Herschel*: from low-mass to high-mass star-forming sites

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We present the first *Herschel* PACS and SPIRE results of the Vela C molecular complex in the far-infrared and submillimetre regimes at 70, 160, 250, 350, and 500  $\mu$ m, spanning the peak of emission of cold prestellar or protostellar cores. Column density and multi-resolution analysis (MRA) differentiates the Vela C complex into five distinct sub-regions. Each sub-region displays differences in their column density and temperature probability distribution functions (PDFs), in particular, the PDFs of the ‘Centre-Ridge’ and ‘South-Nest’ sub-regions appear in stark contrast to each other. The Centre-Ridge displays a bimodal temperature PDF representative of hot gas surrounding the HII region RCW 36 and the cold neighbouring filaments, whilst the South-Nest is dominated by cold filamentary structure. The column density PDF of the Centre-Ridge is flatter than the South-Nest, with a high column density tail, consistent with formation through large-scale flows, and regulation by self-gravity. At small to intermediate scales MRA indicates

the Centre-Ridge to be twice as concentrated as the South-Nest, whilst on larger scales, a greater portion of the gas in the South-Nest is dominated by turbulence than in the Centre-Ridge. In Vela C, high-mass stars appear to be preferentially forming in ridges, i.e., dominant high column density filaments.

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## Detection of the Water Reservoir in a Forming Planetary System

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Icy bodies may have delivered the oceans to the early Earth, yet little is known about water in the ice-dominated regions of extra-solar planet-forming disks. The Heterodyne Instrument for the Far-Infrared on-board the Herschel Space Observatory has detected emission from both spin isomers of cold water vapor from the disk around the young star TW Hydrae. This water vapor likely originates from ice-coated solids near the disk surface hinting at a water ice reservoir equivalent to several thousand Earth Oceans in mass. The water’s ortho-to-para ratio falls well below that of Solar System comets, suggesting that comets contain heterogeneous ice mixtures collected across the entire solar nebula during the early stages of planetary birth.

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## Submillimeter Observations of Dense Clumps in the Infrared Dark Cloud G049.40-00.01

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We obtained 350 and 850  $\mu\text{m}$  continuum maps of the infrared dark cloud G049.40–00.01. Twenty-one dense clumps were identified within G049.40–00.01 based on the 350  $\mu\text{m}$  continuum map with an angular resolution of about  $9.6''$ . We present submillimeter continuum maps and report physical properties of the clumps. The masses of clumps range from 50 to 600  $M_{\odot}$ . About 70% of the clumps are associated with bright 24  $\mu\text{m}$  emission sources, and they may contain protostars. The most massive two clumps show extended, enhanced 4.5  $\mu\text{m}$  emission indicating vigorous star-forming activity. The clump size-mass distribution suggests that many of them are forming high mass stars. G049.40–00.01 contains numerous objects in various evolutionary stages of star formation, from pre-protostellar clumps to H II regions.

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# Accretion of Rocky Planets by Hot Jupiters

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The observed population of Hot Jupiters displays a stunning variety of physical properties, including a wide range of densities and core sizes for a given planetary mass. Motivated by the observational sample, this paper studies the accretion of rocky planets by Hot Jupiters, after the Jovian planets have finished their principal migration epoch and become parked in  $\sim 4$ -day orbits. In this scenario, rocky planets form later and then migrate inward due to torques from the remaining circumstellar disk, which also damps the orbital eccentricity. This mechanism thus represents one possible channel for increasing the core masses and metallicities of Hot Jupiters. This paper determines probabilities for the possible end states for the rocky planet: collisions with the Jovian planets, accretion onto the star, ejection from the system, and long-term survival of both planets. These probabilities depend on the mass of the Jovian planet and its starting orbital eccentricity, as well as the eccentricity damping rate for the rocky planet. Since these systems are highly chaotic, a large ensemble ( $N \sim 10^3$ ) of simulations with effectively equivalent starting conditions is required. Planetary collisions are common when the eccentricity damping rate is sufficiently low, but are rare otherwise. For systems that experience planetary collisions, this work determines the distributions of impact velocities – both speeds and impact parameters – for the collisions. These velocity distributions help determine the consequences of the impacts, e.g., where energy and heavy elements are deposited within the giant planets.

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# Millimeter interferometric observations of FU Orionis-type objects in Cygnus

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*Context.* FU Orionis-type objects (FUors) are low-mass young eruptive stars that probably represent an evolutionary phase characterized by episodic periods of increased accretion rate from the circumstellar disk to the star. Theory predicts that a circumstellar envelope, the source of continuous mass infall onto the disk, is necessary for triggering such accretion bursts.

*Aims.* We intend to study the spatial and velocity structure of circumstellar envelopes around FUors by means of molecular line observations at millimeter wavelengths. We target three prototypical FUors, as well as an object possibly in a pre-outburst state.

*Methods.* We present archival PdBI interferometric observations of the J=1–0 line of  $^{13}\text{CO}$  at 110.2 GHz. For three of our targets, these represent the first millimeter interferometric observations. The data allow study of the molecular environment of the objects with a spatial resolution of a thousand AU and a velocity resolution of  $0.2 \text{ km s}^{-1}$ .

*Results.* Strong, narrow  $^{13}\text{CO}(1-0)$  line emission is detected from all sources. The emission is spatially resolved in all cases, with deconvolved sizes of a few thousand AUs. For V1057 Cyg and V1331 Cyg, the emitting area is rather compact, suggesting that the origin of the emission is a circumstellar envelope surrounding the central star. For V1735 Cyg, the  $^{13}\text{CO}$  emission is offset from the stellar position, indicating that the source of this emission may be a small foreground cloud, also responsible for the high reddening of the central star. The  $^{13}\text{CO}$  emission towards V1515 Cyg is the most extended in the sample, and it apparently coincides with the ring-like optical reflection nebula associated with V1515 Cyg.

*Conclusions.* We suggest that millimeter interferometric observations are indispensable for a complete understanding of the circumstellar environment of FUors. Any theory of the FUor phenomenon that interprets the geometry of the circumstellar structure and its evolution using single-beam measurements must be checked and compared to interferometric observations in the future.

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## Near-IR Polarimetry Around 30 Doradus: I. Separation of the Galactic Sources

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A  $20 \text{ arcmin} \times 20 \text{ arcmin}$  region around 30 Doradus in the Large Magellanic Cloud (LMC) is observed and analyzed in the near-infrared. We obtain polarimetry data in the  $J$ ,  $H$ , and  $K_s$  bands using the SIRIUS polarimeter SIRPOL at the Infrared Survey Facility 1.4 m telescope. We measure the Stokes parameters of 2562 point-like sources to derive the degree of polarization and the polarization position angles. We discuss the statistics of the groups classified by color-magnitude diagram and proper motions of the sources, in order to separate the Galactic foreground sources from those present in the LMC. We notice that groups classified by the proper motion data show a tendency towards different polarimetric properties.

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## Variations in the Mass Functions of Clustered and Isolated Young Stellar Objects

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We analyze high quality, complete stellar catalogs for four young (roughly 1 Myr) and nearby (within  $\sim 300$  pc) star-forming regions: Taurus, Lupus3, ChaI, and IC348, which have been previously shown to have stellar groups whose properties are similar to those of larger clusters such as the ONC. We find that stars at higher stellar surface densities within a region or belonging to groups tend to have a relative excess of more massive stars, over a wide range of masses. We find statistically significant evidence for this result in Taurus and IC348 as well as the ONC. These differences correspond to having typically a  $\sim 10 - 20\%$  higher mean mass in the more clustered environment. Stars in ChaI show no evidence for a trend with either surface density or grouped status, and there are too few stars in Lupus3 to make any definitive interpretation. Models of clustered star formation do not typically extend to sufficiently low masses or small group sizes in order for their predictions to be tested but our results suggest that this regime is important to consider.

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## LkCa 15: A Young Exoplanet Caught at Formation?

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Young and directly imaged exoplanets offer critical tests of planet-formation models that are not matched by RV surveys of mature stars. These targets have been extremely elusive to date, with no exoplanets younger than 10–20 Myr and only a handful of direct-imaged exoplanets at all ages. We report the direct imaging discovery of a likely (proto)planet around the young ( $\sim 2$  Myr) solar analog LkCa 15, located inside a known gap in the protoplanetary disk

(a “transitional disk”). Our observations use non-redundant aperture masking interferometry at 3 epochs to reveal a faint and relatively blue point source ( $M_{K'} = 9.1 \pm 0.2$ ,  $K' - L' = 0.98 \pm 0.22$ ), flanked by approximately co-orbital emission that is red and resolved into at least two sources ( $M_{L'} = 7.5 \pm 0.2$ ,  $K' - L' = 2.7 \pm 0.3$ ;  $M_{L''} = 7.4 \pm 0.2$ ,  $K' - L' = 1.94 \pm 0.16$ ). We propose that the most likely geometry consists of a newly-formed (proto)planet that is surrounded by dusty material. The nominal estimated mass is  $\sim 6 M_{Jup}$  according to the 1 Myr hot-start models. However, we argue based on its luminosity, color, and the presence of circumplanetary material that the planet has likely been caught at its epoch of assembly, and hence this mass is an upper limit due to its extreme youth and flux contributed by accretion. The projected separations ( $71.9 \pm 1.6$  mas,  $100.7 \pm 1.9$  mas, and  $88.2 \pm 1.8$  mas) and deprojected orbital radii (16, 21, and 19 AU) correspond to the center of the disk gap, but are too close to the primary star for a circular orbit to account for the observed inner edge of the outer disk, so an alternate explanation (i.e., additional planets or an eccentric orbit) is likely required. This discovery is the first direct evidence that at least some transitional disks do indeed host newly-formed (or forming) exoplanetary systems, and the observed properties provide crucial insight into the gas giant formation process.

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## The Role of Multiplicity in Disk Evolution and Planet Formation

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The past decade has seen a revolution in our understanding of protoplanetary disk evolution and planet formation in single star systems. However, the majority of solar-type stars form in binary systems, so the impact of binary companions on protoplanetary disks is an important element in our understanding of planet formation. We have compiled a combined multiplicity/disk census of Taurus-Auriga, plus a restricted sample of close binaries in other regions, in order to explore the role of multiplicity in disk evolution. Our results imply that the tidal influence of a close ( $< 40$  AU) binary companion significantly hastens the process of protoplanetary disk dispersal, as  $\sim 2/3$  of all close binaries promptly disperse their disks within  $< 1$  Myr after formation. However, prompt disk dispersal only occurs for a small fraction of wide binaries and single stars, with  $\sim 80\%$ – $90\%$  retaining their disks for at least  $\sim 2$ – $3$  Myr (but rarely for more than  $\sim 5$  Myr). Our new constraints on the disk clearing timescale have significant implications for giant planet formation; most single stars have  $3$ – $5$  Myr within which to form giant planets, whereas most close binary systems would have to form giant planets within  $< 1$  Myr. If core accretion is the primary mode for giant planet formation, then gas giants in close binaries should be rare. Conversely, since almost all single stars have a similar period of time within which to form gas giants, their relative rarity in RV surveys indicates either that the giant planet formation timescale is very well-matched to the disk dispersal timescale or that features beyond the disk lifetime set the likelihood of giant planet formation.

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## A cluster of outflows in the Vulpecula Rift

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We present  $^{12}\text{CO}$ ,  $^{13}\text{CO}$  and  $\text{C}^{18}\text{O}$  ( $J=3-2$ ) observations of a new cluster of outflows in the Vulpecula Rift with HARP-B on the JCMT. The mass associated with the outflows, measured using the  $^{12}\text{CO}$  HARP-B observations and assuming a distance to the region of 2.3 kpc, is  $129 M_{\odot}$ , while the mass associated with the dense gas from  $\text{C}^{18}\text{O}$  observations is  $458 M_{\odot}$  and the associated sub-millimeter core has a mass of  $327 \pm 112 M_{\odot}$  independently determined

from Bolocam 1.1mm data. The outflow-to-core mass ratio is therefore  $\sim 0.4$ , making this region one of the most efficient observed thus far with more than an order of magnitude more mass in the outflow than would be expected based on previous results. The kinetic energy associated with the flows,  $94 \times 10^{45}$  ergs, is enough to drive the turbulence in the local clump, and potentially unbind the local region altogether. The detection of SiO (J=8–7) emission toward the outflows indicates that the flow is still active, and not simply a fossil flow. We also model the SEDs of the four YSOs associated with the molecular material, finding them all to be of mid to early B spectral type. The energetic nature of the outflows and significant reservoir of cold dust detected in the sub-mm suggest that these intermediate mass YSOs will continue to accrete and become massive, rather than reach the main sequence at their current mass.

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## HD 144432: a young triple system

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We present new imaging and spectroscopic data of the young Herbig star HD 144432 A, which was known to be a binary star with a separation of 1.47 arcsec. High-resolution NIR imaging data obtained with NACO at the VLT reveal that HD 144432 B itself is a close binary pair with a separation of 0.1 arcsec. High-resolution optical spectra, acquired with FEROS at the 2.2m MPG/ESO telescope in La Silla, of the primary star and its co-moving companions were used to determine their main stellar parameters such as effective temperature, surface gravity, radial velocity, and projected rotational velocity by fitting synthetic spectra to the observed stellar spectra. The two companions, HD 144432 B and HD 144432 C, are identified as low-mass T Tauri stars of spectral type K7V and M1V, respectively. From the position in the HRD the triple system appears to be co-eval with a system age of  $6 \pm 3$  Myr.

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## Substellar Objects in Nearby Young Clusters (SONYC) V: New brown dwarfs in $\rho$ Ophiuchi

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SONYC – *Substellar Objects in Nearby Young Clusters* – is a survey program to investigate the frequency and properties of substellar objects with masses down to a few times that of Jupiter in nearby star-forming regions. For the  $\sim 1$  Myr old  $\rho$  Ophiuchi cluster, in our earlier paper we reported deep, wide-field optical and near-infrared imaging using Subaru, combined with 2MASS and Spitzer photometry, as well as follow-up spectroscopy confirming three likely cluster members, including a new brown dwarf with a mass close to the deuterium-burning limit. Here we present the results of extensive new spectroscopy targeting a total of  $\sim 100$  candidates in  $\rho$  Oph, with FMOS at the Subaru Telescope and SINFONI at the ESO’s Very Large Telescope. We identify 19 objects with effective temperatures at or below 3200 K, 8 of which are newly identified very-low-mass probable members of  $\rho$  Oph. Among these eight, six objects have  $T_{\text{eff}} \leq 3000\text{K}$ , confirming their likely substellar nature. These six new brown dwarfs comprise one fifth of the known substellar population in  $\rho$  Oph. We estimate that the number of missing substellar objects in our survey area is  $\sim 15$ , down to  $0.003 - 0.03 M_{\odot}$  and for  $A_V = 0 - 15$ . The upper limit on the low-mass star to brown dwarf

ratio in  $\rho$  Oph is  $5.1 \pm 1.4$ , while the disk fractions are  $\sim 40\%$  and  $\sim 60\%$  for stars and BDs, respectively. Both results are in line with those for other nearby star forming regions.

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## Star formation in dense clusters

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A model of core-clump accretion with equally likely stopping describes star formation in the dense parts of clusters, where models of isolated collapsing cores may not apply. Each core accretes at a constant rate onto its protostar, while the surrounding clump gas accretes as a power of protostar mass. Short accretion flows resemble Shu accretion, and make low-mass stars. Long flows resemble reduced Bondi accretion and make massive stars. Accretion stops due to environmental processes of dynamical ejection, gravitational competition, and gas dispersal by stellar feedback, independent of initial core structure. The model matches the field star IMF from 0.01 to more than 10 solar masses. The core accretion rate and the mean accretion duration set the peak of the IMF, independent of the local Jeans mass. Massive protostars require the longest accretion durations, up to 0.5 Myr. The maximum protostar luminosity in a cluster indicates the mass and age of its oldest protostar. The distribution of protostar luminosities matches those in active star-forming regions if protostars have a constant birthrate but not if their births are coeval. For constant birthrate, the ratio of YSOs to protostars indicates the star-forming age of a cluster, typically  $\sim 1$  Myr. The protostar accretion luminosity is typically less than its steady spherical value by a factor of  $\sim 2$ , consistent with models of episodic disk accretion.

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## Formation of Organic Molecules and Water in Warm Disk Atmospheres

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Observations from Spitzer and ground-based infrared spectroscopy reveal significant diversity in the molecular emission from the inner few AU of T Tauri disks. We explore theoretically the possible origin of this diversity by expanding on our earlier thermal-chemical model of disk atmospheres. We consider how variations in grain settling, X-ray irradiation, accretion-related mechanical heating, and the oxygen-to-carbon ratio can affect the thermal and chemical properties of the atmosphere at 0.25-40 AU. We find that these model parameters can account for many properties of the detected molecular emission. The column density of the warm (200-2000 K) molecular atmosphere is sensitive to grain settling and the efficiency of accretion-related heating, which may account, at least in part, for the large range in molecular emission fluxes that have been observed. The dependence of the atmospheric properties on the model parameters may also help to explain trends that have been reported in the literature between molecular emission strength and mid-infrared color, stellar accretion rate, and disk mass. We discuss whether some of the differences between our model results and the observations (e.g., for water) indicate a role for vertical transport and freezeout in the disk midplane. We also discuss how planetesimal formation in the outer disk (beyond the snowline) may imprint a chemical signature on the inner few AU of the disk and speculate on possible observational tracers of this process.

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# The Ionization Fraction in the DM Tau Protoplanetary Disk

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We present millimeter-wave observations of several molecular ions in the disk around the pre-main-sequence star DM Tau and use these to investigate the ionization fraction in different regions of the disk. New Submillimeter Array (SMA) observations of  $\text{H}_2\text{D}^+$   $J=1_{1,0} - 1_{1,1}$ ,  $\text{N}_2\text{H}^+$   $J=4-3$  and  $\text{CO}$   $J=3-2$  are presented.  $\text{H}_2\text{D}^+$  and  $\text{N}_2\text{H}^+$  are not detected and using the  $\text{CO}$   $3-2$  disk size the observations result in an upper limit of  $<0.47 \text{ K km s}^{-1}$  for both lines, a factor of 2.5 below previous single-dish  $\text{H}_2\text{D}^+$  observations. Assuming LTE, a disk midplane temperature of 10–20 K and estimates of the  $\text{H}_2\text{D}^+$   $o/p$  ratio, the observed limit corresponds to  $N_{\text{H}_2\text{D}^+} < 4 - 21 \times 10^{12} \text{ cm}^{-2}$ . We adopt a parametric model for the disk structure from the literature and use new IRAM 30 meter telescope observations of the  $\text{H}^{13}\text{CO}^+$   $J=3-2$  line and previously published SMA observations of the  $\text{N}_2\text{H}^+$   $J=3-2$ ,  $\text{HCO}^+$   $J=3-2$  and  $\text{DCO}^+$   $J=3-2$  lines to constrain the ionization fraction,  $x_i$ , in three temperature regions in the disk where theoretical considerations suggest different ions should dominate: (1) a warm, upper layer with  $T > 20 \text{ K}$  where  $\text{CO}$  is in the gas-phase and  $\text{HCO}^+$  is most abundant, where we estimate  $x_i \simeq 4 \times 10^{-10}$ , (2) a cooler molecular layer with  $T = 16-20 \text{ K}$  where  $\text{N}_2\text{H}^+$  and  $\text{DCO}^+$  abundances are predicted to peak, with  $x_i \simeq 3 \times 10^{-11}$ , and (3) the cold, dense midplane with  $T < 16 \text{ K}$  where  $\text{H}_3^+$  and its deuterated isotopologues are the main carriers of positive charge, with  $x_i < 3 \times 10^{-10}$ . While there are considerable uncertainties, these estimates are consistent with a decreasing ionization fraction into the deeper, colder, and denser disk layers. Stronger constraints on the ionization fraction in the disk midplane will require not only substantially more sensitive observations of the  $\text{H}_2\text{D}^+$   $1_{1,0} - 1_{1,1}$  line, but also robust determinations of the  $o/p$  ratio, observations of  $\text{D}_2\text{H}^+$  and stronger constraints on where  $\text{N}_2$  is present in the gas phase.

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# The Observable Prestellar Phase of the IMF

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The observed similarities between the mass function of prestellar cores (CMF) and the stellar initial mass function (IMF) have led to the suggestion that the IMF is already largely determined in the gas phase. However, theoretical arguments show that the CMF may differ significantly from the IMF. In this Letter, we study the relation between the CMF and the IMF, as predicted by the IMF model of Padoan and Nordlund. We show that 1) the observed mass of prestellar cores is on average a few times smaller than that of the stellar systems they generate; 2) the CMF rises monotonically with decreasing mass, with a noticeable change in slope at approximately  $3-5 M_\odot$ , depending on mean density; 3) the selection of cores with masses larger than half their Bonnor-Ebert mass yields a CMF approximately consistent with the system IMF, rescaled in mass by the same factor as our model IMF, and therefore suitable to estimate the local efficiency of star formation, and to study the dependence of the IMF peak on cloud properties; 4) only one in five pre-brown-dwarf core candidates is a true progenitor to a brown dwarf.

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# The effects of dynamical interactions on planets in young substructured star clusters

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We present  $N$ -body simulations of young substructured star clusters undergoing various dynamical evolutionary sce-

narios and examine the direct effects of interactions in the cluster on planetary systems. We model clusters initially in cool collapse, in virial equilibrium and expanding, and place a 1 Jupiter-mass planet at either 5 au or 30 au from their host stars, with zero eccentricity. We find that after 10 Myr  $\sim 10$  per cent of planets initially orbiting at 30 au have been liberated from their parent star and form a population of free-floating planets. A small number of these planets are captured by other stars. A further  $\sim 10$  per cent have their orbital eccentricity (and less often their semi-major axis) significantly altered. For planets originally at 5 au the fractions are a factor of 2 lower. The change in eccentricity is often accompanied by a change in orbital inclination which may lead to additional dynamical perturbations in planetary systems with multiple planets. The fraction of liberated and disrupted planetary systems is highest for subvirial clusters, but virial and supervirial clusters also dynamically process planetary systems, due to interactions in the substructure.

Of the planets that become free-floating, those that remain observationally associated with the cluster (i.e. within two half-mass radii of the cluster centre) have a similar velocity distribution to the entire star cluster, irrespective of whether they were on a 5 au or a 30 au orbit, with median velocities typically  $\sim 1 \text{ km s}^{-1}$ . Conversely, those planets that are no longer associated with the cluster have similar velocities to the non-associated stars if they were originally at 5 au ( $\sim 9 \text{ km s}^{-1}$ ), whereas the planets originally at 30 au have much lower velocities ( $3.8 \text{ km s}^{-1}$ ) than the non-associated stars ( $10.8 \text{ km s}^{-1}$ ). These findings highlight potential pitfalls of concluding that (a) planets with similar velocities to the cluster stars represent the very low-mass end of the IMF, and (b) planets on the periphery of a cluster with very different observed velocities form through different mechanisms.

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## The evolution of binary populations in cool, clumpy star clusters

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Observations and theory suggest that star clusters can form in a subvirial (cool) state and are highly substructured. Such initial conditions have been proposed to explain the level of mass segregation in clusters through dynamics, and have also been successful in explaining the origin of trapezium-like systems. In this paper we investigate, using  $N$ -body simulations, whether such a dynamical scenario is consistent with the observed binary properties in the Orion Nebula Cluster (ONC). We find that several different primordial binary populations are consistent with the overall fraction and separation distribution of visual binaries in the ONC (in the range 67 – 670 au), and that these binary systems are heavily processed. The substructured, cool-collapse scenario requires a primordial binary fraction approaching 100 per cent. We find that the most important factor in processing the primordial binaries is the initial level of substructure; a highly substructured cluster processes up to 20 per cent more systems than a less substructured cluster because of localised pockets of high stellar density in the substructure. Binaries are processed in the substructure before the cluster reaches its densest phase, suggesting that even clusters remaining in virial equilibrium or undergoing supervirial expansion would dynamically alter their primordial binary population. Therefore even some expanding associations may not preserve their primordial binary population.

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## Formation and dissolution of leaky clusters

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Massive Galactic clusters ( $> 1000 M_{\odot}$ ) exhibit a clear correlation between cluster density, size and age and can be sorted in two categories, i.e. starburst and leaky clusters. The reason for the existence of two types of massive clusters is an open question. However, the answer is probably connected to a different formation histories of the two types.

In this study we concentrate on leaky clusters only and investigate possible formation scenarios and gas expulsion phase.

This is done by using existing observational data and numerical results of embedded cluster properties.

Assuming that a clear correlation between cluster density, size and age exists, it is shown that the density-radius development over time for embedded clusters can be approximated by  $\rho \approx 100 * r^{-1.3} M_{\odot} pc^{-3}$ . The consequences for the star formation process in leaky clusters are discussed and found to favour an inside-out star formation scenario with an initially low but later accelerated star formation rate. It is shown how the leaky clusters form in a unique sequential manner and that rapid gas expulsion is responsible for the 80-90% mass loss over the next 20 Myr.

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## Multi-wavelength observations of the young binary system Haro 6-10: The case of misaligned discs

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*Context.* We present a multi-wavelength, high-resolution observational survey of the young binary system Haro 6-10 (GV Tau, IRAS 04263+2426), which harbours one of the few known infrared companions.

*Aims.* The primary goal of this project is to determine the physical and geometrical properties of the circumstellar and circumbinary material in the Haro 6-10 system.

*Methods.* High-resolution optical (HST/WFPC2) and near-infrared (VLT/NACO) images in different bands were analysed to investigate the large-scale structures of the material around the binary. Mid-infrared interferometry (VLTI/MIDI) and spectroscopy (TIMMI2 at the 3.6m ESO telescope) were carried out to determine the structure and optical depth of the circumstellar material around the individual components.

*Results.* The multi-wavelength observations suggest that both components of the binary system Haro 6-10 are embedded in a common envelope. The measured extinction indicates a dust composition of the envelope similar to that of the interstellar medium. Each component of the system has a circumstellar disc-like structure typical of young stars. The discs are highly misaligned: the northern component is seen almost edge-on and the southern component is an almost face-on disc.

*Conclusions.* The two main formation scenarios of binary systems with misaligned discs are the gravitational capture of a passing object in a dense environment and the fragmentation of the collapsing molecular cloud. Given the low-density environment of the Taurus-Aurigae star-forming region, the first scenario is unlikely for Haro 6-10. The binary system most probably formed via fragmentation of two different parts of the collapsing molecular cloud combined with other dynamical processes related to the cloud and/or the protostars. This can also be the explanation for other binary systems with an infrared companion.

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## A single-dish survey of the HCO<sup>+</sup>, HCN, and CN emission toward the T Tauri disk population in Taurus

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(Abridged) As the stellar X-ray and UV light penetration of a protoplanetary disk depends sensitively on the dust properties, trace molecular species like HCO<sup>+</sup>, HCN, and CN are expected to show marked differences from photo processing effects as the dust intent in the disk evolves. We investigate the evolution of the UV irradiation of the

molecular gas in protoplanetary disks around a sample of classical T Tauri stars in Taurus that exhibit a wide range in grain growth and dust settling properties. We obtained  $\text{HCO}^+$  (J=3-2), HCN (J=3-2), and CN (J=2-1) observations of 13 sources with the JCMT. Our sample has 1.3 mm fluxes in excess of 75 mJy, indicating the presence of significant dust reservoirs; a range of dust settling as traced through their spectral slopes between 6, 13, and 25 microns; and varying degrees of grain growth as extrapolated from the strength of their 10-micron silicate emission feature. We compare the emission line strengths with the sources' continuum flux and infrared features, and use detailed modeling based on two different model prescriptions to compare typical disk abundances for  $\text{HCO}^+$ , HCN, and CN with the gas-line observations for our sample. We detected  $\text{HCO}^+$  (3-2) toward 6 disks, HCN (3-2) from 0 disks, and CN (2-1) toward 4 disks. For the complete sample, there is no correlation between the gas-line strengths or their ratios and either the sources' dust continuum flux or infrared slope.

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## Substellar Objects in Nearby Young Clusters (SONYC) IV: A census of very low mass objects in NGC1333

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SONYC – *Substellar Objects in Nearby Young Clusters* – is a program to investigate the frequency and properties of young substellar objects with masses down to a few times that of Jupiter. Here we present a census of very low mass objects in the  $\sim 1$  Myr old cluster NGC1333. We analyze near-infrared spectra taken with FMOS/Subaru for 100 candidates from our deep, wide-field survey and find 10 new likely brown dwarfs with spectral types of M6 or later. Among them, there are three with  $\gtrsim$ M9 and one with early L spectral type, corresponding to masses of 0.006 to  $\lesssim 0.02 M_{\odot}$ , so far the lowest mass objects identified in this cluster. The combination of survey depth, spatial coverage, and extensive spectroscopic follow-up makes NGC1333 one of the most comprehensively surveyed clusters for substellar objects. In total, there are now 51 objects with spectral type M5 or later and/or effective temperature of 3200 K or cooler identified in NGC1333; 30-40 of them are likely to be substellar. NGC1333 harbours about half as many brown dwarfs as stars, which is significantly more than in other well-studied star forming regions, thus raising the possibility of environmental differences in the formation of substellar objects. The brown dwarfs in NGC1333 are spatially strongly clustered within a radius of  $\sim 1$  pc, mirroring the distribution of the stars. The disk fraction in the substellar regime is  $< 66\%$ , lower than for the total population (83%) but comparable to the brown dwarf disk fraction in other 2-3 Myr old regions.

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## A new code to study structures in collisionally active, perturbed debris discs. Application to binaries

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Debris discs are traditionally studied using two distinct types of numerical models: statistical particle-in-a-box codes to study their collisional and size distribution evolution, and dynamical N-body models to study their spatial structure. The absence of collisions from N-body codes is in particular a major shortcoming, as collisional processes are expected to significantly alter the results obtained from pure N-body runs. We present a new numerical model, to study the

spatial structure of perturbed debris discs at dynamical and collisional steady-state. We focus on the competing effects between gravitational perturbations by a massive body (planet or star), collisional production of small grains, and radiation pressure placing these grains in possibly dynamically unstable regions. We consider a disc of parent bodies at dynamical steady-state, from which small radiation-pressure-affected grains are released in a series of runs, each corresponding to a different orbital position of the perturber, where particles are assigned a collisional destruction probability. These collisional runs produce successive position maps that are then recombined, following a complex procedure, to produce surface density profiles for each orbital position of the perturbing body. We apply our code to the case of a circumprimary disc in a binary. We find pronounced structures inside and outside the dynamical stability regions. For low  $e_B$ , the disc's structure is time varying, with spiral arms in the dynamically "forbidden" region precessing with the companion star. For high  $e_B$ , the disc is strongly asymmetric but time invariant, with a pronounced density drop in the binary's periastron direction

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## Hall diffusion and the magnetorotational instability in protoplanetary discs

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The destabilising effect of Hall diffusion in a weakly-ionised, Keplerian disc allows the magnetorotational instability (MRI) to occur for much lower ionisation levels than would otherwise be possible. However, simulations incorporating Hall and Ohm diffusion give the impression that the consequences of this for the non-linear saturated state are not as significant as suggested by the linear instability. Close inspection reveals that this is not actually the case as the simulations have not yet probed the Hall-dominated regime. Here we revisit the effect of Hall diffusion on the magnetorotational instability and the implications for the extent of MHD turbulence in protoplanetary discs, where Hall diffusion dominates over a large range of radii.

We conduct a local, linear analysis of the instability for a vertical, weak magnetic field subject to axisymmetric perturbations with a purely vertical wave vector. In contrast to previous analyses, we express the departure from ideal MHD in terms of Hall and Pedersen diffusivities  $\eta_H$ , and  $\eta_P$ , which provide transparent notation that is directly connected to the induction equation. This allows us to present a crisp overview of the dependence of the instability on magnetic diffusivity. We present analytic expressions and contours in the  $\eta_H$ - $\eta_P$  plane for the maximum growth rate and corresponding wave number, the upper cut-off for unstable wave numbers, and the loci that divide the plane into regions of different characteristic behaviour. We find that for  $\text{sign}(B_z)\eta_H < -2v_A^2/\Omega$ , where  $v_A$  is the Alfvén speeds and  $\Omega$  is the Keplerian frequency, Hall diffusion suppresses the MRI irrespective of the value of  $\eta_P$ .

In the highly-diffusive limit the magnetic field decouples from the fluid perturbations and simply diffuses in the background Keplerian shear flow. The diffusive MRI reduces to a diffusive plane-parallel shear instability with effective shear rate  $\frac{3}{2}\Omega$ . We give simple analytic expressions for the growth rate and wave number of the most unstable mode. We review the varied and confusing parameterisations of magnetic diffusion in discs that have appeared in the literature, and confirm that simulations examining the saturation of the instability under Hall-Ohm diffusion are consistent with the linear analysis and have yet to probe the "deep" Hall regime  $|\eta_H| > \eta_P > v_A^2/\Omega$  characteristic of protoplanetary discs where Hall diffusion is expected to overcome resistive damping.

Finally, we illustrate the critical effect of Hall diffusion on the extent of dead zones in protoplanetary discs by applying a local stability criterion to a simple model of the minimum-mass solar nebula at 1 au, including x-ray and cosmic-ray ionisation and a population of 1  $\mu\text{m}$  grains. Hall diffusion increases or decreases the MRI-active column density by an order of magnitude or more, depending on whether B is parallel or antiparallel to the rotation axis, respectively. We conclude that existing estimates of the depth of magnetically active layers in protoplanetary discs based on damping by Ohm diffusion are likely to be wildly inaccurate.

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# Magnetic Flux Expulsion in Star Formation

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Stars form in dense cores of magnetized molecular clouds. If the magnetic flux threading the cores is dragged into the stars, the stellar field would be orders of magnitude stronger than observed. This well-known “magnetic flux problem” demands that most of the core magnetic flux be decoupled from the matter that enters the star. We carry out the first exploration of what happens to the decoupled magnetic flux in 3D, using a MHD version of the ENZO adaptive mesh refinement code. The field-matter decoupling is achieved through a sink particle treatment, which is needed to follow the protostellar accretion phase of star formation. We find that the accumulation of the decoupled flux near the accreting protostar leads to a magnetic pressure buildup. The high pressure is released anisotropically, along the path of least resistance. It drives a low-density expanding region in which the decoupled magnetic flux is expelled. This decoupling-enabled magnetic structure has never been seen before in 3D MHD simulations of star formation. It generates a strong asymmetry in the protostellar accretion flow, potentially giving a kick to the star. In the presence of an initial core rotation, the structure presents an obstacle to the formation of a rotationally supported disk, in addition to magnetic braking, by acting as a rigid magnetic wall that prevents the rotating gas from completing a full orbit around the central object. We conclude that the decoupled magnetic flux from the stellar matter can strongly affect the protostellar collapse dynamics.

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## **The Chemical Composition of Comets - Emerging Taxonomies and Natal Heritage**

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Cometary nuclei contain the least modified material from the formative epoch of our planetary system, and their compositions reflect a range of processes experienced by material prior to its incorporation in the cometary nucleus. Dynamical models suggest that icy bodies in the main cometary reservoirs (Kuiper Belt, Oort Cloud) formed in a range of environments in the protoplanetary disk, and (for the Oort Cloud) even in disks surrounding neighboring stars of the Sun's birth cluster. Photometric and spectroscopic surveys of more than 100 comets have enabled taxonomic groupings based on free radical species and on crystallinity of rocky grains. Since 1985, new surveys have provided emerging taxonomies based on the abundance ratios of primary volatiles. More than 20 primary chemical species are now detected in bright comets. Measurements of nuclear spin ratios (in water, ammonia, and methane) and of isotopic ratios (D/H in water and HCN; <sup>14</sup>N/<sup>15</sup>N in CN and HCN) have provided critical insights on factors affecting formation of the primary species. The identification of an abundant product species (HNC) has provided clear evidence of chemical production in the inner coma. Parallel advances have occurred in astrochemistry of hot corinos, circumstellar disks, and dense cloud cores. In this review, we address the current state of cometary taxonomy and compare it with current astrochemical insights.

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## Star Formation and the Hall Effect

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Ph.D degree awarded: July 2011

Magnetic fields play an important role in star formation by regulating the removal of angular momentum from collapsing molecular cloud cores. Hall diffusion is known to be important to the magnetic field behaviour at many of the intermediate densities and field strengths encountered during the gravitational collapse of molecular cloud cores into protostars, and yet its role in the star formation process is not well-studied. This thesis describes a semianalytic self-similar model of the collapse of rotating isothermal molecular cloud cores with both Hall and ambipolar diffusion, presenting similarity solutions that demonstrate that the Hall effect has a profound influence on the dynamics of collapse.

Two asymptotic power law similarity solutions to the collapse equations on the inner boundary are derived. The first of these represents a Keplerian disc in which accretion is regulated by the magnetic diffusion; with an appropriate value of the Hall diffusion parameter a stable rotationally-supported disc forms, but when the Hall parameter has the opposite sign disc formation is suppressed by the strong diffusion. The second solution describes the infall when the magnetic braking is so efficient at removing angular momentum from the core that no disc forms and the matter free falls onto the protostar.

The full similarity solutions show that the size and sign of the Hall parameter can change the size of the protostellar disc by up to an order of magnitude and the accretion rate onto the protostar by  $1.5 \times 10^{-6} M_{\odot} \text{ yr}^{-1}$  when the ratio of the Hall to ambipolar diffusion parameters moves between the extremes of  $-0.5 \leq \tilde{\eta}_H/\tilde{\eta}_A \leq 0.2$ . These variations (and their dependence upon the orientation of the magnetic field with respect to the axis of rotation) create a preferred handedness to the solutions that could be observed in protostellar cores using next-generation instruments such as ALMA.

Hall diffusion also determines the strength of the magnetic diffusion and centrifugal shocks that bound the pseudo and rotationally-supported discs, and can introduce subshocks that further slow accretion onto the protostar. In cores that are not initially rotating Hall diffusion can even induce rotation, which could give rise to disc formation and resolve the magnetic braking catastrophe. The Hall effect clearly influences the dynamics of gravitational collapse and its role in controlling the magnetic braking and radial diffusion of the field would be worth exploring in future numerical simulations of star formation.

<http://arxiv.org/abs/1110.2168>

## *New Jobs*

### **PhD positions in the Formation and Evolution of Exoplanets Lund University**

Lund University invites applicants to up to three PhD positions working on theoretical models of planet formation and evolution of planetary systems, funded independently by a Starting Grant from the European Research Council and by the Swedish Research Council. Two students will be supervised by Dr. Anders Johansen and one jointly between Dr. Anders Johansen and Prof. Melvyn B. Davies.

The PhD students will work on theoretical/computational models of planet formation and orbital evolution. Planet formation research at Lund Observatory focuses on hydrodynamical models of planet formation and orbital dynamics models of planetary systems. Together with the current group members and a new postdoc funded by the European Research Council, the new PhD students will work in an inspiring environment towards the common goal of formulating and testing a new planet formation theory framework that is self-consistent as well as consistent with observational constraints.

For details on how to apply please visit <http://www.astro.lu.se/vacancies/>.

Closing date: 14 November 2011

### **Star formation in the Universe (University Assistant - 6 years)**

The University of Vienna is seeking outstanding applicants for a 6 year postdoctoral position in the field of Star and Planet Formation, although all outstanding applicants in any field will be considered for the position. Expertise with IR and/or Radio observations is especially welcome. The applicant will be part of the research group led by Professor João Alves ([www.joaualves.org](http://www.joaualves.org)). Participation in teaching activities at a modest level is expected. The Institute is undergoing a major new development with the establishment of three new chairs in astrophysics. It offers a stimulating research environment with staff working in various areas of astrophysics. As a member state of ESO and ESA, Austria has access to their first-class facilities. The department is involved in, or is planning participation in major observatories of ESO (VLT instrumentation, ELT) and ESA/JAXA/NASA (Spica, Gaia, Plato, Euclid, JWST). The city of Vienna, where the applicant will be located, scored highest in the world for overall quality of living according to a Mercer's 2010 survey.

Review of applications starts November 1st, 2011 and will continue until the position is filled. Applications should be sent electronically and should include: CV, publication list, and a brief description of past research and future plans. Three letters of reference should also be sent.

### **Johannes Kepler Postdoctoral Program in Astrophysics University of Vienna**

The University of Vienna announces an opening in its Johannes Kepler Postdoctoral Program in Astrophysics. Johannes Kepler positions are awarded to outstanding postdoctoral scientists demonstrating a high research profile in observational, numerical, or theoretical astrophysics in areas covered at the Department of Astronomy in Vienna. Kepler postdocs will carry out their independent research programs, but are strongly encouraged to engage in collaborations within the Department. A modest level of teaching is expected.

The present announcement is for a position *dedicated preferentially to the area of galactic star formation, pre-main sequence stars and in particular research on protoplanetary disks and planet formation*, but excellent candidates in other fields of the Department's research will also be considered. Johannes Kepler positions are awarded for four years. Funds are made available to support travel expenses and conference participation.

The Kepler postdoc will have access to all observatories of ESO and ESA; for numerical work, two in-house clusters and, for high-performance computing, the Vienna Scientific Cluster will be accessible. The institute provides a lively research environment including approx. 70 staff members, postdocs, and PhD students. There are many opportunities to interact within ongoing or planned instrument projects related to ESA or ESO observatories.

Applications include a CV, a publication list, a summary of past research (max 2 pages) and an outline of the proposed research program for the duration of the employment (max. 4 pages). These documents must be submitted electronically as a PDF file to the above address or via <http://jobcenter.univie.ac.at/en/applications/> (job #2500).

Review starts 21 November 2011 but applications submitted thereafter will be fully considered until the post is filled. Applicants should arrange for three letters of reference sent by the referees directly to the same address. Future announcements will be made upon availability of positions. Female candidates are especially encouraged to apply. For inquiries, contact Prof. M. Guedel ([manuel.guedel@univie.ac.at](mailto:manuel.guedel@univie.ac.at)). Note that a similar position is presently available in the group of Prof. J. Alves at the same institute.

## **Postdoctoral Position in Protoplanetary Disk Research University of Vienna**

The University of Vienna is seeking applications for a postdoctoral research position in the framework of an FP7 international project on protoplanetary disks and planet formation. The successful applicant will work in the group of Prof. Manuel Güdel at the Department of Astronomy. Principal tasks will include collection of multiwavelength data of circumstellar disks and central stars from existing observatories (Herschel, Spitzer, EVLA, ALMA, HST, XMM-Newton, Chandra, etc) and respective data archives, the subsequent analysis of those data, and detailed interpretation using advanced disk models including radiative transfer, chemistry, gas and dust physics. A specific focus will be on short-wavelength (UV, X-ray) radiation and its interaction with circumstellar disk material.

The position will be awarded for four years if started by 1 April 2012 and correspondingly less if started thereafter. The postdoctoral researcher will be a member of an international team funded through the FP7-SPACE-2011 “DiscAnalysis” collaborative project. The team includes partners in St. Andrews (P. Woitke, J. Greaves), Groningen (I. Kamp), Amsterdam (R. Waters), Grenoble (F. Ménard), and Austria (M. Güdel). The project is supported by an exchange program to visit participating institutes for up to several weeks each. Gross salary in Vienna is approx. 60,000 Euros per annum.

Applications include a CV, a publication list, and a summary (max. 2 pages) of past research. These documents should be submitted electronically as a PDF file to the above address. Evaluation will start November 21, 2011, and will continue until the position is filled. Applicants should arrange for three letters of reference sent by the referees directly to the same address. Female candidates are especially encouraged to apply. For inquiries, contact Prof. M. Güdel ([manuel.guedel@univie.ac.at](mailto:manuel.guedel@univie.ac.at)).

## **PhD Position in St.Andrews, Scotland, UK, in Protoplanetary Disc Research**

We seek applications for a 3.5-year PhD position in the Astronomy Group, to work with Dr Jane Greaves and Dr Peter Woitke in the field of circumstellar discs and planet formation. The research includes the collection of existing and planning of future observations, from X-ray to millimetre wavelengths, using telescopes like XMM, HST, VLT, Spitzer, Herschel, JCMT, eMerlin, and ALMA. The student will collate such data from telescope archives and compile a database to form the basis for multi-wavelength analysis by novel disc models. Much of this data has never been analysed and so there are exciting opportunities for new discoveries, as well as for follow-up observations. The work requires to communicate to observers as well as to modellers, and to figure out how to best compare models with observations. The skills required include logic, persistence, and willingness to learn to process astronomical data at many different wavelengths. Some previous experience or interest in database coding would be an advantage.

The research is funded by FP7-SPACE-2011, exploitation of space exploration data, collaborative project #284405 (“DiscAnalysis”), and will be carried out simultaneously in five different European institutions, among them Amsterdam (NL), Groningen (NL), Grenoble (F), coordinated from St Andrews (UK). For more information about the Astronomy group in St Andrews, see <http://star-www.st-and.ac.uk/astronomy>. The ability to work in a team is an important factor for the choice of candidates. Applicants will take part in outreach activities and in an exchange programme to visit the participating institutes for the duration of several weeks each. Formal education in advanced

astronomy is required as part of the PhD and is offered via the post-graduate courses of the Scottish Universities Physics Alliance (SUPA).

Applications include a CV and a summary of any research projects undertaken for previous degree. We encourage applicants to apply online via <https://www.vacancies.st-andrews.ac.uk>, or alternatively, by email to [peter.woitke@st-andrews.ac.uk](mailto:peter.woitke@st-andrews.ac.uk). If you are unable to do this, please call +44 (0)1334 462571 for an application pack. Applicants should arrange for two letters of reference sent by the referees directly to the same address. Applications will be considered until a suitably qualified student is appointed.

Duration of PhD funding will be from 1 January 2012 to 30 June 2015.

Informal enquiries to Dr. P. Woitke ([peter.woitke@st-andrews.ac.uk](mailto:peter.woitke@st-andrews.ac.uk)) or Dr. J. Greaves ([jsg5@st-andrews.ac.uk](mailto:jsg5@st-andrews.ac.uk)).

Closing Date: Friday, 11.11.11. Interview Date: late November. Please quote Ref No: FP7 Greaves Woitke

## J. Mayo Greenberg fellowship at Leiden Observatory

Leiden Observatory and the Leids Universiteits Fonds have pleasure in inviting applications for the fifth J. Mayo Greenberg Scholarship Prize. The purpose of the prize is to provide an opportunity for a talented graduate student to carry out research and/or receive education at Leiden Observatory in one or more of the fields that were of interest to Professor Greenberg. These include: Laboratory astrophysics, Dust in the early Universe, Dust in the Milky Way and other galaxies, Comet formation, Origin of life.

Although applications will be considered from the whole world, preference will be given to applicants resident in developing countries. Candidates should have sufficient educational background in the field to benefit from attendance at graduate courses or participation in the research.

The Scholarship Prize will support a visit to Leiden for a maximum duration of 9 months. In very exceptional circumstances there may be a possibility of extending the visit for a longer period.

Applications for the 2012 Prize should be received before **30 November 2011**. These should include (i) a curriculum vitae, with details of relevant background, (ii) a statement containing the purpose for which the grant is requested and (iii) a motivation for the request. Applicants should arrange for 2 – 3 references to be sent under separate cover.

Applications should be addressed to: Professor G.K. Miley, Chairman, Selection Committee, J. Mayo Greenberg Scholarship Prize, Sterrewacht, Postbus 9513, 2300 RA Leiden, The Netherlands.

Applications can also be sent via email to [drost@strw.leidenuniv.nl](mailto:drost@strw.leidenuniv.nl), with the relevant documentation as attachments in MSWord, latex, pdf or postscript format.

## McLean Postdoctoral Fellowship Exo-Planets, Brown Dwarfs and Young Stars University of Toronto

Applications are invited for a postdoctoral fellowship at the University of Toronto to start in 2012. The successful candidate, designated as McLean Postdoctoral Fellow, will work with Prof. Ray Jayawardhana and his collaborators on observational and analytical studies of extra-solar planets, brown dwarfs and young stars, and will be encouraged to pursue independent research on related topics. On-going projects include high-contrast imaging searches for sub-stellar companions around young stars, photometric and spectroscopic studies of extra-solar planets (including a successful CFHT Large Program), investigations of brown dwarf variability and multiplicity, and the SONYC (Substellar Objects in Nearby Young Clusters) ultra-deep survey, using data from VLT, Subaru, Gemini, Keck, Spitzer, CFHT, and other major observatories. The position is for two years, with extension to a third year possible, and comes with a competitive salary and funds for research expenses. Applicants should send a curriculum vitae, a description of research interests and plans and a list of publications, and should arrange for three letters of recommendation to be sent directly to [rayjay@astro.utoronto.ca](mailto:rayjay@astro.utoronto.ca). All materials should be submitted electronically. Applications received before 2011 December 15 will receive full consideration. Early expressions of interest and inquiries are welcome.

## **Cosmochemistry**

**Harry Y. McSween and Gary R. Huss**

This is a new graduate textbook on the interdisciplinary subject of cosmochemistry, written by two highly acclaimed scientists in the field. Broadly defined, cosmochemistry is the study of the chemical composition of the universe and the processes that produced those compositions. In practice, cosmochemistry mainly focuses on the solar system and the processes involved in its formation and evolution. Meteorites, interplanetary dust particles, and returned lunar samples allow a hands-on analysis with modern laboratory techniques, complemented by results inferred from astronomical observations and astrophysical theory. The book provides an authoritative discussion of the many new techniques and results of cosmochemistry, which have shaped our understanding of the formation of the solar system, and thus are of great interest for star and planet formation studies.

The 14 chapters plus an appendix are listed below. Included in every chapter are boxes, with detailed information on particular subtopics. Each chapter is completed with a summary section, a set of questions, suggestions for further reading, and a list of relevant references.

### **Contents**

- 1. Introduction to cosmochemistry**
  - 2. Nuclides and elements: the building blocks of matter**
  - 3. Origin of the elements**
  - 4. Solar system and cosmic abundances: elements and isotopes**
  - 5. Presolar grains: a record of stellar nucleosynthesis and processes**
  - 6. Meteorites: a record of nebular and planetary processes**
  - 7. Cosmochemical and geochemical fractionations**
  - 8. Radioisotopes as chronometers**
  - 9. Chronology of the solar system from radioactive isotopes**
  - 10. The most volatile elements and compounds: organic matter, noble gases, and ices**
  - 11. Chemistry of anhydrous planetesimals**
  - 12. Chemistry of comets and other ice-bearing planetesimals**
  - 13. Geochemical exploration of planets: Moon and Mars as case studies**
  - 14. Cosmochemical models for the formation of the solar system**
- Appendix: Some analytical techniques commonly used in cosmochemistry**

Cambridge University Press 2010, ISBN 978-0-521-87862-3

549 pages, hardcover US\$78.00

Available from <http://www.cambridge.org/us/knowledge/isbn/item2709615/>

## **The labyrinth of star formation**

**Crete, Greece, 18-22 June, 2012**

**A conference dedicated to Prof. Anthony Whitworth**

### **Scientific Rationale**

Theoretical and observational studies over the last decade have given a new impetus in our understanding of star and planet formation. New powerful ground-based and space telescopes are currently unveiling the secrets of young stars from their earliest stages of formation until planets form around them. At the same time old theories are tested, new ideas are born, and new theories are emerging. Thus, instead of being on the top of a mountain admiring the star formation view, we are still in a labyrinth looking for answers.

This meeting will honour the contributions to star formation of Prof. Anthony Whitworth (Cardiff University, UK), and offer the opportunity to celebrate his 66th birthday. The program will be designed so as to reflect his past and current interests and it will include both invited and contributed talks. In the spirit of ancient Greek symposia it would be full of science, but also fun and story-telling.

### **Topics**

- The initial stages of star formation
- The formation of binary stars
- The minimum mass for star formation: low-mass stars and brown dwarfs
- The connection between star formation and planet formation
- Triggered star formation, HII regions
- The CMF-IMF relation and the statistical properties of low- and high-mass stars
- New frontiers in computational methods of star formation

### **Location**

The conference will take place at the Orthodox Academy of Crete (OAC), which is located at the village of Kolymvari, near Chania, on the north west region of Crete, Greece. The OAC is a modern conference centre situated in a beautiful location near the sea and next to a 17th-century monastery.

### **SOC members**

Philippe André, Matthew Bate, Ian Bonnell, Cathie Clarke, Patrick Hennebelle, Simon Goodwin (Co-Chair), Shu-ichiro Inutsuka, Ralf Klessen, Pavel Kroupa, Mark Krumholz, Mark McCaughrean, Jan Palouš, Derek Ward-Thompson (Co-chair), Hans Zinnecker

### **LOC members**

Annabel Cartwright, Thomas Bisbas, David Hubber, Spyros Kitsionas, Dimitris Stamatellos (Chair), Steffi Walch, Richard Wünsch

### **Registration**

To register please visit <http://www.astro.cf.ac.uk/newsandevents/conferences/antfest>

There will be a limit of 140 participants. The deadline for registration and payments is **1st April 2012**.

For more information please email: D.Stamatellos *at* astro.cf.ac.uk