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*Abstracts of recently accepted papers*

## Statistics of superimposed flares in the Taurus molecular cloud

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*Context.* Stochastically occurring flares provide a possible mechanism of coronal heating in magnetically active stars such as T Tauri objects in star-forming regions.

*Aims.*We investigate the statistics of stellar X-ray light curves from the XMM-Newton Extended Survey of the Taurus Molecular Cloud (XEST).

*Methods.* To this end, the light curve is modeled as superimposed flares occurring at random times and with random amplitudes. The flare shape is estimated non-parametrically from the observations, while the flare amplitude distribution is modeled as a truncated power law, and the flare times are assumed as uniformly distributed. From these model assumptions, predictions on the binned counts are derived and compared with the observations.

*Results.* From a sample of 22 XEST observations matching the above model assumptions we find that the majority of cases have flare amplitude distributions with slopes steeper than two. This favours the role of small flares in coronal heating for 5 targets, of which, however, 4 are foreground or background main-sequence stars.

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## Unbinned maximum-likelihood estimators for low-count data - Applications to faint X-ray spectra in the Taurus molecular cloud

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Traditional binned statistics such as $\chi^2$ suffer from information loss and arbitrariness of the binning procedure, which is especially important at low count rates as encountered in the XMM-Newton Extended Survey of the Taurus Molecular Cloud (XEST). We point out that the underlying statistical quantity (the log likelihood L) does not require any binning beyond the one implied by instrumental readout channels, and we propose to use it for low-count data. The performance of L in the model classification and point estimation problems is explored by Monte-Carlo simulations of Chandra and XMM-Newton X-ray spectra, and is compared to the performances of the binned Poisson statistic (C), Pearson's $\chi^2$ and Neyman's $\chi^2_N$, the Kolmogorov-Smirnov, and Kuiper's statistics. It is found that the unbinned log likelihood L performs best with regard to the expected chi-square distance between true and estimated spectra,

the chance of a successful identification among discrete candidate models, the area under the receiver-operator curve of reduced (two-model) binary classification problems, and generally also with regard to the mean square errors of individual spectrum parameters. The $\chi^2(\chi^2_N)$ statistics should only be used if more than 10 (15) predicted counts per bin are available. From the practical point of view, the computational cost of evaluating L is smaller than for any of the alternative methods if the forward model is specified in terms of a Poisson intensity and normalization is a free parameter. The maximum-L method is applied to 14 XEST observations, and confidence regions are discussed. The unbinned results are compared to binned XSPEC results, and found to generally agree, with exceptions explained by instability under re-binning and by background fine structures. In particular, HO Tau is found by the unbinned method to be rather cool (kT $\sim$ 0.2 keV), which may be a sign of shock emission. The maximum-L method has no lower limit on the available counts, and allows to treat weak sources which are beyond the means of binned methods.

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## Can Protostellar Jets Drive Supersonic Turbulence in Molecular Clouds?

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Jets and outflows from young stellar objects are proposed candidates to drive supersonic turbulence in molecular clouds. Here, we present the results from multi-dimensional jet simulations where we investigate in detail the energy and momentum deposition from jets into their surrounding environment and quantify the character of the excited turbulence with velocity probability density functions. Our study include jet–clump interaction, transient jets, and magnetised jets. We find that collimated supersonic jets do not excite supersonic motions far from the vicinity of the jet. Supersonic fluctuations are damped quickly and do not spread into the parent cloud. Instead subsonic, non-compressional modes occupy most of the excited volume. This is a generic feature which can not be fully circumvented by overdense jets or magnetic fields. Nevertheless, jets are able to leave strong imprints in their cloud structure and can disrupt dense clumps. Our results question the ability of collimated jets to sustain supersonic turbulence in molecular clouds.

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http://www.ita.uni-heidelberg.de/~banerjee/publications/jet_paper.pdf

## A comprehensive set of simulations studying the influence of gas expulsion on star cluster evolution

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We have carried out a large set of N-body simulations studying the effect of residual-gas expulsion on the survival rate and final properties of star clusters. We have varied the star formation efficiency, gas expulsion timescale and strength of the external tidal field, obtaining a three-dimensional grid of models which can be used to predict the evolution of individual star clusters or whole star cluster systems by interpolating between our runs. The complete data of these simulations is made available on the Internet.

Our simulations show that cluster sizes, bound mass fraction and velocity profile are strongly influenced by the details of the gas expulsion. Although star clusters can survive star formation efficiencies as low as 10% if the tidal field is weak and the gas is removed only slowly, our simulations indicate that most star clusters are destroyed or suffer dramatic loss of stars during the gas removal phase. Surviving clusters have typically expanded by a factor 3 or 4 due to gas removal, implying that star clusters formed more concentrated than as we see them today. Maximum expansion factors seen in our runs are around 10. If gas is removed on timescales smaller than the initial crossing time, star clusters acquire strongly radially anisotropic velocity dispersions outside their half-mass radii. Observed velocity profiles of star clusters can therefore be used as a constraint on the physics of cluster formation.

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## The hyperyoung HII region in G24.78+0.08 A1

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*Context.* G24.78+0.08 A1 is a $20M_{\odot}$ star surrounded by a hypercompact (HC) HII region, driving a CO bipolar outflow, and located at the center of a massive rotating toroid undergoing infall towards the HC HII region. Recent water maser observations suggest that the HC HII region is expanding and accretion onto the star is halted.
*Aims.* To confirm the expansion scenario proposed for the HC HII region on the basis of recent $H_2O$ maser observations.
*Methods.* We carried out continuum VLA observations at 1.3 cm and 7 mm with the A array plus Pie Town configuration to map the HC HII region towards G24.78+0.08 A1.
*Results.* The emission of the HC HII region has been resolved and shows a ring-shape structure. The profiles of the emission obtained by taking slices at different angles passing through the barycenter of the HC HII region confirm the shell structure of the emission. The ratio between the inner and the outer radius of the shell, $R_{\rm i}/R_{\rm o}$, derived by fitting the normalized brightness temperature profile passing through the peak of the 7 mm emission, is 0.9, which indicates that the shell is thin. The deconvolved outer radius estimated from the fit is 590 AU. These results imply that the HC HII region in G24 A1 cannot be described in terms of a classical, homogeneous HII region but is instead an ionized shell. This gives support to the model of an expanding wind-driven, ionized shell suggested by the kinematics and distribution of the $H_2O$ masers associated with the HC HII region. According to this model, the HC HII region is expanding on very short times scales, 21–66 yr.

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## Polarization of Dust Emission in Clumpy Molecular Clouds and Cores

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Grain alignment theory has reached the stage where quantitative predictions of the degree of alignment and its variations with optical depth are possible. With the goal of studying the effect of clumpiness on submillimeter and far-infrared polarization, we have computed the polarization due to alignment via radiative torques within clumpy models of cores and molecular clouds. Our models were based on a highly inhomogeneous simulation of compressible MHD turbulence. A reverse Monte Carlo radiative transfer method was used to calculate the intensity and anisotropy of the internal radiation field, and the subsequent grain alignment was computed for a power-law size distribution of grains using the DDSCAT package for radiative torques. The intensity and anisotropy of the intracloud radiation field show large variations throughout the models but are generally sufficient to drive widespread grain alignment. The P-I relations for our models reproduce those seen in observations. We show that the degree of polarization observed is extremely sensitive to the upper grain size cutoff and is less sensitive to changes in the radiative anisotropy. Furthermore, despite a variety of dust temperatures along a single line of sight through our models and among dust grains of different sizes, the assumption of isothermality among the aligned grains does not introduce a significant error. Our calculations indicate that submillimeter polarization vectors can be reasonably good tracers for the underlying magnetic field structure, even for relatively dense clouds (AV $\sim$ 10 to the cloud center). The current predictive power of the grain alignment theory should motivate future polarization observations using the next generation of multiwavelength submillimeter polarimeters such as those proposed for SOFIA.

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## The $10^5\,L_\odot$ High-Mass Protostellar Object IRAS 23151+5912

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*Context:* While most sources above $10^5\,L_\odot$ have already formed an Ultracompact HII region (UCHII), this is not necessarily the case for sources of lower luminosity. Characterizing sources in the transition phase, i.e., very luminous objects without any detectable free-free emission, is important for a general understanding of massive star formation.
*Aims:* Characterizing one of the most luminous High-Mass Protostellar Objects (HMPO) that has not yet formed any detectable UCHII region.
*Methods:* The region was observed with the Submillimeter Array in three different array configurations at 875 $\mu$m in the submm continuum and spectral line emission at sub-arcsecond resolution.
*Results:* The 875 $\mu$m submm continuum emission has been resolved into at least two condensations. The previously believed driving source of one of the outflows, the infrared source IRS1, is $\sim 0.9''$ offset from the main submm peak. The data do not allow to differentiate whether this offset is real, either caused by different sources or a shift of the photo-center due to scattering, or whether it is only due to poor astrometry of the infrared data. Over the entire 4 GHz bandwidth we detect an intermediate dense spectral line forest with 27 lines from 8 different species, isotopologues or vibrationally-torsionally excited states. Temperature estimates based on the $CH_3OH$ line series result in values of $T(\text{Peak1}) \sim 150 \pm 50$ K and $T(\text{Peak2}) \sim 80 \pm 30$ K for the two submm peak positions, respectively. The SiO(8–7) red- and blue-shifted line maps indicate the presence of two molecular outflows. In contrast, the vibrationally-torsionally excited $CH_3OH$ line exhibits a velocity gradient approximately perpendicular to one of the outflows. With a size of approximately 5000 AU and no Keplerian rotation signature, this structure does not resemble a genuine accretion disk but rather a larger-scale rotating toroid that may harbor a more common accretion disk at its so far unresolved center.

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http://www.mpia.de/homes/beuther/papers.html

## Outflow and dense gas emission from massive Infrared Dark Clouds

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Infrared Dark Clouds are expected to harbor sources in different, very young evolutionary stages. To better characterize these differences, we observed a sample of 43 massive Infrared Dark Clouds, originally selected as candidate high-mass starless cores, with the IRAM 30 m telescope covering spectral line tracers of low-density gas, high-density gas, molecular outflows/jets and temperature effects. The SiO(2–1) observations reveal detections toward 18 sources. Assuming that SiO is exclusively produced by sputtering from dust grains, this implies that at least in 40% of this sample star formation is on-going. A broad range of SiO line-widths is observed (between 2.2 and 65 km s$^{-1}$), and we discuss potential origins for this velocity spread. While the low-density tracers $^{12}$CO(2–1) and $^{13}$CO(1–0) are detected in several velocity components, the high-density tracer $H^{13}CO^+$(1–0) generally shows only a single velocity component and is hence well suited for kinematic distance estimates of IRDCs. Furthermore, the $H^{13}CO^+$ line-width is on average 1.5 times larger than that of previously observed $NH_3$(1,1). This is indicative of more motion at the denser core centers, either due to turbulence or beginning star formation activity. In addition, we detect $CH_3CN$ toward only six sources whereas $CH_3OH$ is observed toward approximately 40% of the sample. Estimates of the $CH_3CN$ and $CH_3OH$ abundances are low with average values of $1.2 \times 10^{-10}$ and $4.3 \times 10^{-10}$, respectively. These results are consistent with chemical models at the earliest evolutionary stages of high-mass star formation. Furthermore, the

$CH_3OH$ abundances compare well to recently reported values for low-mass starless cores.

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## The X-ray activity-rotation relation of T Tauri stars in Taurus-Auriga

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*Context.* The Taurus-Auriga star-forming complex hosts the only population of T Tauri stars in which an anticorrelation of X-ray activity and rotation period has been observed.

*Aims.* We aim to explain the origin of the X-ray activity-rotation relation in Taurus-Auriga. We also aim to put the X-ray activity of these stars into the context of the activity of late-type main-sequence stars and T Tauri stars in the Orion Nebula Cluster.

*Methods.* We have used XMM-Newton's European Photon Imaging Cameras to perform the most sensitive survey to date of X-ray emission (0.3-10 keV) from young stars in Taurus-Auriga. We investigated the dependences of X-ray activity measures - X-ray luminosity, $L_{\rm X}$, its ratio with the stellar luminosity, $L_{\rm X}/L_\star$, and the surface-averaged X-ray flux, $F_{\rm XS}$ - on rotation period and compared them with predictions based solely on the observed dependence of $L_{\rm X}$ on a star's $L_\star$ and whether it is accreting or not. We tested for differences in the distributions of $L_{\rm X}/L_\star$ of fast and slow rotators, accretors and non-accretors, and compared the dependence of $L_{\rm X}/L_\star$ on the ratio of the rotation period and the convective turnover timescale, the Rossby number, with that of late-type main-sequence stars. *Results.* We found significant anticorrelations of $L_{\rm X}$ and $F_{\rm XS}$ with rotation period, but these could be explained by the typically higher stellar luminosity and effective temperature of fast-rotators in Taurus-Auriga and a near-linear dependence of $L_{\rm X}$ on $L_\star$. We found no evidence for a dependence of $L_{\rm X}/L_\star$ on rotation period, but for accretors to have lower $L_{\rm X}/L_\star$ than non-accretors at all rotation periods. The Rossby numbers of accretors and non-accretors were found to be the same as those of late-type main-sequence stars showing saturated X-ray emission.

*Conclusions.* Non-accreting T Tauri stars show X-ray activity entirely consistent with the saturated activity of fast-rotating late-type main-sequence stars. Accreting T Tauri stars show lower X-ray activity, but this cannot be attributed to their slower rotation.

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## Rotational period of GQ Lupi

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*Aims.* We wanted to determine the rotation parameters of GQ Lup A, thereby constraining the evolutionary history of the GQ Lup system.

*Methods.* We have undertaken a photometric monitoring campaign on GQ Lup A consisting of two epochs spaced one year apart. We also searched the photometric archives to enlarge the data set.

*Results.* We were able to determine the photometric period ( $8.45 \pm 0.2$ days) in both epochs in several photometric bands. This periodicity could also be found in some of the archival data. The combined false-alarm probability is 0.015. The variation is most likely caused by hot spots on the surface of GQ Lup A. This, combined with high-resolution spectra ($v \sin i$) allows calculation of GQ Lup A's inclination ( $i = 27 \pm 5°$). Radial velocity data also contains this period but is inconclusive. Nevertheless, the RV data supports the interpretation that hot spots cause the photometric variation. We use the known K-band variability, amplitude, and phase of GQ Lup A together with a new image of GQ Lup A+b, taken quasi-simultaneously with our monitoring of the star, to confirm the magnitude and, hence, luminosity of the companion

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## On some aspects of the stirring rate of planetesimal velocities by a protoplanet

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We discuss some aspects of the evolution of the relative velocities of a swarm of planetesimals stirred by a protoplanet. We show that the prescriptions most commonly used in semi-analytical 'oligarchic growth' models overestimate the relative velocities of planetesimals by a non-negligible factor. We discuss the probable origin of this discrepancy, proposing a correction factor that provides good agreement between these prescriptions and the results of numerical experiments. The proposed correction factor can be easily implemented in semi-analytical accretion models.

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## X-ray Flares in Orion Low Mass Stars

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X-ray flares are common phenomena in pre-main sequence stars. Their analysis gives insights into the physics at work in young stellar coronae. The Orion Nebula Cluster offers a unique opportunity to study large samples of young low mass stars. This work is part of the *Chandra* Orion Ultradeep project (COUP), an $\sim 10$ day long X-ray observation of the Orion Nebula Cluster (ONC).
Our main goal is to statistically characterize the flare-like variability of 165 low mass ($0.1 - 0.3 M_\odot$) ONC members in order to test and constrain the physical scenario in which flares explain all the observed emission. We adopt a maximum likelihood piece-wise representation of the observed X-ray light curves and detect flares by taking into account both the amplitude and time derivative of the count-rate. We then derive the frequency and energy distribution of the flares.
The high energy tail of the energy distribution of flares is well described by a power-law with index $\sim 2.2$. We test the hypothesis that light curves are built entirely by overlapping flares with a single power law energy distribution. We constrain the parameters of this simple model for every single light curve. The analysis of synthetic light curves obtained from the model indicates a good agreement with the observed data.
Comparing low mass stars with stars in the mass interval ($0.9 - 1.2 M_\odot$), we establish that, at $\sim 1$ Myr, low mass and

solar mass stars of similar X-ray luminosity have very similar flare frequencies. Our observational results are consistent with the following model/scenario: the light curves are entirely built by overlapping flares with a power-law intensity distribution; the intense flares are individually detected, while the weak ones merge and form a pseudo-quiescent level, which we indicate as the characteristic level.

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http://www.astropa.unipa.it/Library/preprint.html

## Gas-grain chemistry in cold interstellar cloud cores with a microscopic Monte Carlo approach to surface chemistry

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*Aims.* We have recently developed a microscopic Monte Carlo approach to study surface chemistry on interstellar grains and the morphology of ice mantles. The method is designed to eliminate the problems inherent in the rate-equation formalism to surface chemistry. Here we report the first use of this method in a chemical model of cold interstellar cloud cores that includes both gas-phase and surface chemistry. The surface chemical network consists of a small number of diffusive reactions that can produce molecular oxygen, water, carbon dioxide, formaldehyde, methanol and assorted radicals.

*Methods.* The simulation is started by running a gas-phase model including accretion onto grains but no surface chemistry or evaporation. The starting surface consists of either flat or rough olivine. We introduce the surface chemistry of the three species H, O and CO in an iterative manner using our stochastic technique. Under the conditions of the simulation, only atomic hydrogen can evaporate to a significant extent. Although it has little effect on other gas-phase species, the evaporation of atomic hydrogen changes its gas-phase abundance, which in turn changes the flux of atomic hydrogen onto grains. The effect on the surface chemistry is treated until convergence occurs. We neglect all non-thermal desorptive processes.

*Results.* We determine the mantle abundances of assorted molecules as a function of time through $2 \times 10^5$ yr. Our method also allows determination of the abundance of each molecule in specific monolayers. The mantle results can be compared with observations of water, carbon dioxide, carbon monoxide, and methanol ices in the sources W33A and Elias 16. Other than a slight underproduction of mantle CO, our results are in very good agreement with observations.

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## Inside-Out Evacuation of Transitional Protoplanetary Discs by the Magneto-Rotational Instability

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How do T Tauri disks accrete? The magneto-rotational instability (MRI) supplies one means, but protoplanetary disk gas is typically too poorly ionized to be magnetically active. Here we show that the MRI can, in fact, explain observed accretion rates for the sub-class of T Tauri disks known as transitional systems. Transitional disks are swept clean of dust inside rim radii of ∼10 AU. Stellar coronal X-rays ionize material in the disk rim, activating the MRI there. Gas flows from the rim to the star, at a rate limited by the depth to which X-rays ionize the rim wall. The wider the rim, the larger the surface area that the rim wall exposes to X-rays, and the greater the accretion rate. Interior to the rim, the MRI continues to transport gas; the MRI is sustained even at the disk midplane by super-keV X-rays that Compton scatter down from the disk surface. Accretion is therefore steady inside the rim. Blown out by radiation pressure, dust largely fails to accrete with gas. Contrary to what is usually assumed, ambipolar diffusion, not Ohmic dissipation, limits how much gas is MRI-active. We infer values for the transport parameter $\alpha$ on the order of a percent for the prototypical systems GM Aur, TW Hyd, and DM Tau. Because the MRI can only afflict a finite radial column of gas at the rim, disk properties inside the rim are insensitive to those outside. Thus our picture provides one robust setting for planet-disk interaction: a protoplanet interior to the rim will interact with gas whose density, temperature, and transport properties are definite and decoupled from uncertain initial conditions. Our study also supplies half the answer to how disks dissipate: the inner disk drains from the inside out by the MRI, while the outer disk photoevaporates by stellar ultraviolet radiation.

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## A close look at the heart of RCW 108

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*Context:* The IRAS 16362-4845 star-forming site in the RCW 108 complex contains an embedded compact cluster that includes some massive O-type stars. Star formation in the complex, and in particular in IRAS 16362-4845, has been proposed to be externally triggered by the action of NGC 6193.

*Aims:* We present a photometric study of the IRAS 16362-4845 cluster sensitive enough to probe the massive brown dwarf regime. In particular, we try to verify an apparent scarcity of solar-type and low-mass stars reported in a previous paper (Comerón et al. 2005, A&A, 433, 955).

*Methods:* Using NACO at the VLT we have carried out adaptive optics-assisted imaging in the $JHK_SL'$ bands, as well as through narrow-band filters centered on the Br$\gamma$ and the $H_2$ $S(1)$ $v = 1 \rightarrow 0$ lines. We estimate individual line-of-sight extinctions and, for stars detected in the three $JHK_S$ filters, we estimate the contribution to the $K_S$ flux caused by light reprocessed in the circumstellar environment. We also resolve close binary and multiple systems. We use the $K$ luminosity function as a diagnostic tool for the characteristics of the underlying mass function.

*Results:* IRAS 16362-4845 does contain young low-mass stars. Nevertheless, they are far less than those expected from the extrapolation of the bright end of the $K$ luminosity function towards fainter magnitudes. We estimate a total stellar mass of 370 $M_\odot$. Nearly all the cluster members display $L'$ excesses, whereas $K_S$ excesses are in general either absent or moderate ($< 1$ mag). We also detect an extremely red object with $(K_S - L') > 9$, likely to be a Class I source.

*Conclusions:* The fact that solar-type and low-mass stars are present in numbers much smaller than those expected from the number of more massive members hints at an initial mass function deficient in low mass stars as compared to that of other young clusters such as the Trapezium. The origin of this difference is unclear, and we speculate that it might be due to external triggering having started star formation in the cluster, perhaps producing a top-heavy initial mass function. We also note that there are no detectable systematic differences between the spatial distributions of bright and faint cluster members. Such absence of mass segregation in the spatial distribution of stars may also support external triggering having played an important role in the history of the RCW 108 region.

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`http://www.eso.org/~fcomeron/iras16362.pdf`

## Observing the gas temperature drop in the high-density nucleus of L 1544

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*Context.* The thermal structure of a starless core is crucial for our understanding of the physics in these objects and hence for our understanding of star formation. Theory predicts a gas temperature drop in the inner ∼5000 AU of the pre-stellar core L 1544, but there has been no observational proof of this.

*Aims.* We performed VLA observations of the $NH_3$ (1, 1) and (2, 2) transitions towards L 1544 in order to measure the temperature gradient between the high density core nucleus and the surrounding core envelope. Our VLA observation for the first time provide measurements of gas temperature in a core with a resolution smaller than 1000 AU. We have also obtained high resolution Plateau de Bure observations of the 110 GHz 111-101 para-$NH_2D$ line in order to further constrain the physical parameters of the high density nucleus.

*Methods.* We combine our interferometric $NH_3$ and $NH_2D$ observations with available single dish measurements in order to estimate the effects of flux loss from extended components upon our data. We have estimated the temperature gradient using a model of the source to fit our data in the u,v plane. As the $NH_3$(1, 1) line is extremely optically thick, this also involved fitting a gradient in the $NH_3$ abundance. In this way, we also measure the [$NH_2D$] /[$NH_3$] abundance ratio in the inner nucleus.

*Results.* We find that indeed the temperature decreases toward the core nucleus from 12 K down to 5.5 K resulting in an increase of a factor of 50% in the estimated density of the core from the dust continuum if compared with the estimates done with constant temperature of 8.75 K. Current models of the thermal equilibrium can describe consistently the observed temperature and density in this object, simultaneously fitting our temperature profile and the continuum emission. We also found a remarkably high abundance of deuterated ammonia with respect to the ammonia abundance (50% ± 20%), which proves the persistence of nitrogen bearing molecules at very high densities ( $2\times10^6$ cm$^{-3}$) and shows that high-resolution observations yield higher deuteration values than single-dish observations. The $NH_2D$ observed transition, free of the optical depth problems that affect the $NH_3$ lines in the core center, is a much better probe of the high-density nucleus and, in fact, its map peak at the dust continuum peak. Our analysis of the $NH_3$ and $NH_2D$ kinematic fields shows a decrease of specific angular momentum from the large scales to the small scales.

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## The Origin of the Arches Stellar Cluster Mass Function

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We investigate the time evolution of the mass distribution of pre-stellar cores (PSCs) and their transition to the initial stellar mass function (IMF) in the central parts of a molecular cloud (MC) under the assumption that the coalescence of cores is important. Our aim is to explain the observed shallow IMF in dense stellar clusters such as the Arches cluster. The initial distributions of PSCs at various distances from the MC center are those of gravitationally unstable cores resulting from the gravo-turbulent fragmentation of the MC. As time evolves, there is a competition between the PSCs rates of coalescence and collapse. Whenever the local rate of collapse is larger than the rate of coalescence in a given mass bin, cores are collapsed into stars. With appropriate parameters, we find that the coalescence-collapse model reproduces very well all the observed characteristics of the Arches stellar cluster IMF; Namely, the slopes at high and low mass ends and the peculiar bump observed at $\sim 5-6\ M_{\odot}$. Our results suggest that today's IMF of the Arches cluster is very similar to the primordial one and is prior to the dynamical effects of mass segregation becoming important

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## HD 97048: a closer look at the disk

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*Aims.* Large ground-based instruments, like VISIR on the VLT, providing diffraction-limited (∼0.3 arcsec) images in the mid-infrared where strong PAH features appear, enable us to see the flaring structure of the disks around Herbig Ae stars. Although progress has been made in modelling the disk with radiative transfer models able to reproduce the spectral energy distribution (SED) of Herbig Ae stars, the constraints brought by images have not been yet fully exploited. We investigate whether these new observational imaging constraints can be accounted for by predictions based on existing models of passive, centrally irradiated hydrostatic disks made to fit the SEDs of the Herbig Ae stars.

*Methods.* The images taken by VISIR in the 8.6 and 11.3 μm aromatic features reveal a large flaring disk around HD 97048 inclined to the line of sight. To analyse the spatial distribution of these data, we use a disk model that includes the most up to date understanding of disk structure and physics around Herbig Ae stars with grains in thermal equilibrium, in addition to transiently-heated PAHs.

*Results.* We compare the observed spatial distribution of the PAH emission feature and the adjacent continuum emission with predictions based on existing full disk models. Both SED and spatial distribution are in very good agreement with the model predictions for common disk parameters.

*Conclusions.* We take the general agreement between observations and predictions as strong support for the physical pictures underlying our flared disk model.

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## Jet-driven molecular outflows from Class 0 sources: younger and stronger than they seem?

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The momentum, age and momentum injection rate (thrust) of molecular outflows are key parameters in theories of star formation. Systematic biases in these quantities as inferred from CO line observations are introduced through simplified calculations. These biases were quantified for radially expanding flows. However, recent studies suggest that the youngest outflows may be better described by jet-driven bowshocks, where additional biases are expected.

We investigate quantitatively the biases in momentum, age, and thrust estimates in the case of young jet-driven molecular outflows, and propose more accurate methods of determining these quantities.

We use long-duration (1500 yr) high resolution numerical simulations in concert with the standard observational methods of inferring the relevant quantities to quantify the systematic biases in these calculations introduced, in particular, by dissociation, erroneous inclusion of transverse momentum, and hidden material at cloud velocity. Jet/ambient density contrasts of 0.1-1 are considered, leading to bow speeds of $60 - 135\ \mathrm{km\,s^{-1}}$.

When mass-weighted velocities are used, lifetimes are overestimated by typically an order of magnitude. The molecular thrust is then underestimated by similar amounts. Using the maximum velocity in CO profiles gives better results, if empirical corrections for inclination are applied. We propose a new method of calculating the lifetime of an outflow which dramatically improves estimates of age and molecular thrust independent of inclination. Our results are applicable to younger flows which have not broken out of their parent cloud.

Published correlations between the molecular flow thrust and the source bolometric luminosity obtained with the maximum CO velocity method should remain valid. However, dissociation at the bow head may cause the observable thrust to underestimate the total flow thrust by a factor of up to $2 - 4$, depending on the bow propagation speed and the magnetic field strength. Detailed evaluation of this effect would greatly help to better constrain the efficiency of

the ejection mechanism in protostars.

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## Giant Planet Migration in Viscous Power-Law Disks

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Many extrasolar planets discovered over the past decade are gas giants in tight orbits around their host stars. Due to the difficulties of forming these "hot Jupiters" in situ, they are generally assumed to have migrated to their present orbits through interactions with their nascent disks. In this paper, we present a systematic study of giant planet migration in power-law disks. We find that the planetary migration rate is proportional to the disk surface density. This is inconsistent with the assumption that the migration rate is simply the viscous drift speed of the disk. However, this result can be obtained by balancing the angular momentum of the planet with the viscous torque in the disk. We have verified that this result is not affected by adjusting the resolution of the grid, the smoothing length used, or the time at which the planet is released to migrate.

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## On the Rapid Collapse and Evolution of Molecular Clouds

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Stars generally form faster than the ambipolar diffusion time, suggesting that several processes short circuit the delay and promote a rapid collapse. These processes are considered here, including turbulence compression in the outer parts of giant molecular cloud (GMC) cores and GMC envelopes, GMC core formation in an initially supercritical state, and compression-induced triggering in dispersing GMC envelopes. The classical issues related to star formation timescales are addressed: high molecular fractions, low efficiencies, long consumption times for CO and HCN, rapid GMC core disruption and the lack of a stable core, long absolute but short relative timescales with accelerated star formation, and the slow motions of protostars. We consider stimuli to collapse from changes in the density dependence of the ionization fraction, the cosmic ray ionization rate, and various dust properties at densities above $\sim 10^5$ cm$^{-3}$. We favor the standard model of subcritical GMC envelops and suggest they would be long lived if not for disruption by rapid star formation in GMC cores. The lifecycle of GMCs is illustrated by a spiral arm section in the Hubble Heritage image of M51, showing GMC formation, star formation, GMC disruption with lingering triggered star formation, and envelope dispersal. There is no delay between spiral arm dustlanes and star formation; the classical notion results from heavy extinction in the dust lane and triggered star formation during cloud dispersal. Differences in the IMF for the different modes of star formation are considered.

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## Probing the Dust and Gas in the Transitional Disk of CS Cha with Spitzer

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Here we present the *Spitzer* IRS spectrum of CS Cha, a member of the ∼2 Myr old Chamaeleon star-forming region, which reveals an optically thick circumstellar disk truncated at ∼43 AU, the largest hole modeled in a transitional disk to date. Within this inner hole, $\sim 5\times10^{-5}$ lunar masses of dust are located in a small optically thin inner region which extends from 0.1 to 1 AU. In addition, the disk of CS Cha has bigger grain sizes and more settling than the previously modeled transitional disks DM Tau, GM Aur, and CoKu Tau/4, suggesting that CS Cha is in a more advanced state of dust evolution. The *Spitzer* IRS spectrum also shows [Ne II] 12.81 $\mu$m fine-structure emission with a luminosity of $1.3 \times 10^{29}$ ergs $s^{-1}$, indicating that optically thin gas is present in this ∼43 AU hole, in agreement with $H_\alpha$ measurements and a UV excess which indicate that CS Cha is still accreting $1.2 \times 10^{-8}$ $M_\odot$ $yr^{-1}$. We do not find a correlation of the [Ne II] flux with $L_X$, however, there is a possible correlation with $\dot{M}$, which if confirmed would suggest that EUV fluxes due to accretion are the main agent for formation of the [Ne II] line.

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## A 3-mode variable ejection velocity, precessing jet model for HH 30

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*Context.* HH 30 is a Herbig-Haro (HH) jet showing a chain of aligned knots (with knots covering a range of sizes and knot separations), pointing towards what appears to be a highly fragmented "head". The chain of knots is detected out to 140′′, and the head is an elongated group of knots centred at a distance of 290′′ from the source.

*Aims.* In the paper of Anglada et al. (2006, A&A, submitted), it is suggested that this jet is the result of a multi-period variable velocity ejection, and also having a precession of the outflow axis. The question that we address in our paper is whether or not this ejection variability results in a leading working surface with the high fragmentation of the "head" of the HH 30 jet.

*Methods.* In order to do this, we take at face value the parameters calculated by Anglada et al. (2006) for the ejection variability and the precession and use them to compute a 3D, radiative jet simulation. Our simulation includes a treatment of the non-equilibrium ionization state of the gas, and allows us to compute synthetic emission line maps, which can be compared directly with previously published images of HH 30.

*Results.* We find that our simulation does produce a leading working surface with a striking resemblance to the head of HH 30. We obtain a fragmented emission structure with an extent both along and across the outflow axis that agrees well with the observed jet head.

*Conclusions.*It then appears to be clear that the variable ejection implied by the chain of knots close to the HH 30 source has a direct effect on the head of the jet, producing a highly fragmented structure that is comparable with observations. This is the first time that such a connection has been proven for an HH outflow.

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## Optical and infrared properties of V1647 Orionis during the 2003-2006 outburst. I The reflection nebula

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Aims. The recent outburst of the young eruptive star V1647 Orionis has produced a spectacular appearance of a new reflection nebula in Orion (McNeil's nebula). We present an optical/near infrared investigation of McNeil's nebula. This analysis is aimed at determining the morphology, temporal evolution and nature of the nebula and its connection to the outburst.

Methods. We performed multi epoch B, V, $R_C$,$I_C$, $z_{gunn}$, and $K_S$ imaging of McNeil's nebula and V1647 Ori as well as $K_S$ imaging polarimetry. The multiband imaging allows us to reconstruct the extinction map inside the nebula. Through polarimetric observations we attempt to disentangle the emission from the nebula from that of the accretion disk around V1647 Ori. We also attempt to resolve the small spatial scale structure of the illuminating source.

Results. The energy distribution and temporal evolution of McNeil's nebula mimic that of the illuminating source. The extinction map reveals a region of higher extinction in the direction of V1647 Ori. Excluding foreground extinction, the optical extinction due to McNeil's nebula in the direction of V1647 Ori is $A_V \sim 6.5$ mag. The polarimetric measurement shows a compact high polarization emission around V1647 Ori. The percentage of K band linear polarization goes from 10 − 20 %. The vectors are all well aligned with a position angle of $90° \pm 9°$ degree East of North. This may correspond to the orientation of a possible accretion disk around V1647 Ori. These findings suggest that the appearance of McNeil's nebula is due to reflection of light by pre-existing material in the surroundings of V1647 Ori. We also report on the discovery of a new candidate brown dwarf or protostar in the vicinity of V1647 Ori as well as the presence of clumpy structure within HH 22A.

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## Optical and infrared properties of V1647 Orionis during the 2003-2006 outburst. II. Temporal evolution of the eruptive source

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Aims. The occurrence of new FU Orionis-like objects is fundamental to understand the outburst mechanism in young stars and their role in star formation and disk evolution. Our work is aimed at investigating the properties of the recent outburst of V1647 Ori.

Methods. Using optical and mid infrared long slit spectroscopy we monitored V1647 Ori in outburst between February 2004 and January 2006.

Results. The optical spectrum is characterized by H$\alpha$ and H$\beta$ in P-Cygni profile and by many weak Fe I and Fe II emission lines. Short timescale variability was measured in the continuum and line emission. On January 2006 we detected for the first time forbidden emission lines ([OI], [S II] and [Fe II]). These lines are likely produced by an Herbig-Haro object driven by V1647 Ori. The mid infrared the spectrum of V1647 Ori is flat and featureless at all epochs. The SED changed drastically: the source was much redder in the early outburst than in the final phase. The magnitude rise and the SED of V1647 Ori resembles that of an FUor while the duration and recurrence of the outburst resemble that of a EXor. The optical spectrum is clearly distinct from either the absorption line spectrum of an FUor or the T Tauri-like spectrum of an EXor.

Conclusions. Our data are consistent with a disk instability event which led to an increase of the mass accretion rate. The data also suggest the presence of a circumstellar envelope around the star+disk system. The peculiar N band spectrum might be explained by dust sublimation in the outer layers of the disk. The presence of the envelope and the outburst statistics suggest that these instability events occur only in a specific stage of a Class I source (e.g. in the transition phase to an optically visible star surrounded by a protoplanetary disk). We discuss the outburst mechanisms in term of the thermal instability model.

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## Infrared Extinction toward Nearby Star-forming Regions

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We present an independent estimate of the interstellar extinction law for the Spitzer IRAC bands, as well as a first attempt at extending the law to the 24 $\mu$m MIPS band. The source data for these measurements are observations of five nearby star-forming regions: the Orion A cloud, NGC 2068/2071, NGC 2024/2023, Serpens, and Ophiuchus. Color excess ratios $E_{H-K_S}/E_{K_S-[\lambda]}$ were measured for stars without infrared excess dust emission from circumstellar disks/envelopes. For four of these five regions, the extinction laws are similar at all wavelengths and differ systematically from a previous determination of the extinction law, which was dominated by the diffuse ISM, derived for the IRAC bands. This difference could be due to the difference in the dust properties of the dense molecular clouds observed here and those of the diffuse ISM. The extinction law at longer wavelengths toward the Ophiuchus region lies between that to the other four regions studied here and that for the ISM. In addition, we extended our extinction law determination to 24 $\mu$m for Serpens and NGC 2068/2071 using Spitzer MIPS data. We compare these results against several ISO extinction law determinations, although in each case there are assumptions which make absolute comparison uncertain. However, our work confirms a relatively flatter extinction curve from 4 to 8 $\mu$m than the previously assumed standard, as noted by all of these recent studies. The extinction law at 24 $\mu$m is consistent with previous measurements and models, although there are relatively large uncertainties.

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## Searching for coronal radio emission from protostars using very-long-baseline interferometry

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*Aims.*In order to directly study the role of magnetic fields in the immediate vicinity of protostars, we use Very-Long-Baseline Interferometry (VLBI), aiming at the detection of non-thermal centimetric radio emission. This is technically the only possibility to study coronal emission at sub-AU resolution.

*Methods.* We performed VLBI observations of the four nearby protostars HL Tau, LDN 1551 IRS5, EC 95, and YLW 15 in order to look for compact non-thermal centimetric radio emission. For maximum sensitivity, we used the High Sensitivity Array (HSA) where possible, involving the Very Long Baseline Array (VLBA), the phased Very Large Array (VLA), as well as the Arecibo, Green Bank, and Effelsberg radio telescopes.

*Results.* While all four protostars were detected in VLA-only data, only one source (YLW 15 VLA 2) was detected in the VLBI data. The possibility of non-detections due to free-free absorption, possibly depending on source geometry, is considered.

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## The origin of the molecular emission around the southern hemisphere Re 4 IRS - HH 188 region

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*Aims.* We present SEST observations of the molecular environment ahead of the southern Herbig-Haro object 188

(HH 188), associated with the low-mass protostar Re 4 IRS. We have also used the SuperCosmos H$\alpha$ survey to search for H$\alpha$ emission associated with the Re 4 IRS - HH 188 region. The aim of the present work is to study the properties of the molecular gas and to better characterize this southern star forming region.

*Methods.* We mapped the $HCO^+$ 3-2 and $H^{13}CO^+$ 1-0 emission around the YSO and took spectra of the $CH_3OH$ $2_0$-$1_0$ A+ and $2_{-1}$-$1_{-1}$ E and SO $6_5$-$5_4$ towards the central source. Column densities are derived and different scenarios are considered to explain the origin of the molecular emission.

*Results.* $HCO^+$ arises from a relatively compact region around the YSO; however, its peak emission is displaced to the south following the outflow direction. Our chemical analysis indicates that a plausible scenario is that most of the emission arises from the cold, illuminated dense gas ahead of the HH 188 object. We have also found that HH 188, a high excitation object, seems to be part of a parsec scale and highly collimated HH system. Re 4 IRS is probably a binary protostellar system, in the late Class 0 or Class I phase. One of the protostars, invisible in the near-IR, seems to power the HH 188 system.

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## Clustered Star Formation in the Small Magellanic Cloud. A Spitzer/IRAC View of the Star-Forming Region NGC 602/N 90

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We present Spitzer/IRAC photometry on the star-forming HII region N 90, related to the young stellar association NGC 602 in the Small Magellanic Cloud. Our photometry revealed bright mid-infrared sources, which we classify with the use of a scheme based on templates and models of red sources in the Milky Way, and criteria recently developed from the Spitzer Survey of the SMC for the selection of candidate Young Stellar Objects (YSOs). We detected 57 sources in all four IRAC channels in a 6.2' x 4.8' field-of-view centered on N 90; 22 of these sources are classified as candidate YSOs. We compare the locations of these objects with the position of optical sources recently found in the same region with high-resolution HST/ACS imaging of NGC 602, and we find that 17 candidate YSOs have one or more optical counterparts. All of these optical sources are identified as pre-main sequence stars, indicating, thus, ongoing clustered star formation events in the region. The positions of the detected YSOs and their related PMS clusters give a clear picture of the current star formation in N 90, according to which the young stellar association photo-ionizes the surrounding interstellar medium, revealing the HII nebula, and triggering sequential star formation events mainly along the eastern and southern rims of the formed cavity of the parental molecular cloud.

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## Formation and Collapse of Quiescent Cloud Cores Induced by Dynamic Compressions

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We present numerical hydrodynamical simulations of the formation, evolution and gravitational collapse of isothermal molecular cloud cores induced by turbulent compressions in spherical geometry. A compressive wave is set up in a constant sub-Jeans density distribution of radius $r = 1$ pc. As the wave travels through the simulation grid, a shock-bounded spherical shell is formed. The inner shock of this shell reaches and bounces off the center, leaving behind a central core with an initially almost uniform density distribution, surrounded by an envelope consisting of the material in the shock-bounded shell, with a power-law density profile that at late times approaches a logarithmic slope of $-2$ even in non-collapsing cases. The central core and the envelope are separated by a mild shock. The resulting density structure resembles a quiescent core of radius $< 0.1$ pc, with a Bonnor-Ebert-like (BE-like) profile, although it has significant dynamical differences: it is initially non-self-gravitating and confined by the ram pressure of the infalling material, and consequently, growing continuously in mass and size. With the appropriate parameters, the core mass eventually reaches an effective Jeans mass, at which time the core begins to collapse, until finally a singularity is formed. Thus, there is necessarily a time delay between the appearance of the core and the onset of its collapse, but this is not due to the dissipation of its internal turbulence as it is often believed, but rather to the time necessary for it to reach its Jeans mass. These results suggest that pre-stellar cores may approximate Bonnor-Ebert structures which are however of variable mass and may or may not experience gravitational collapse, in qualitative agreement with the large observed frequency of cores with BE-like profiles. In our collapsing simulations, a time $\sim 0.5$ Myr typically elapses between the formation of the core and the time at which it becomes gravitationally unstable, and another $\sim 0.5$ Myr are necessary for it to complete the collapse.

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http://www.astrosmo.unam.mx/˜g.gomez/publica/be.pdf

## CO cooling rates for clumpy and turbulent molecular clouds

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*Aims.* Based on a stochastic radiative transfer model (SRTM), which accounts for density and velocity fluctuations with a finite correlation length, we have calculated CO cooling rates for a molecular gas at temperatures $T_{\rm gas} =$ (10-100) K and densities $n_{\rm H} = (10^2 - 10^6)$ cm$^{-3}$. In particular, we are interested in how the cooling rates are modified by inhomogeneities of the density distribution and a finite correlation length of the turbulent velocity field.

*Methods.* Assuming spherical symmetry, we solved the generalized radiative transfer equation simultaneously with the rate equations (full NLTE problem). Depending on the temperature assumed, we took up to 18 rotational levels of the CO molecule into account.

*Results.* Our results show that the finite correlation length of the turbulent velocity field has a great influence on the CO cooling rates. In general, the volume averaged cooling rates are noticeably decreasing with an increasing correlation length of the velocity field except for very high CO cloumn densities. The stochastic density fluctuations, on the other side, tend to increase the CO cooling efficiency. For an inhomogeneous stochastic density distribution, cooling by the high rotational lines of CO is substantially enhanced. Most of the radiation is emitted from cloud regions with higher density than the average. In addition, an inhomogeneous density field reduces the effect of photon trapping, which leads to a further increase of the cooling rate. A comparison of the SRTM results with earlier work of Neufeld et al. (1995, ApJS, 100, 132) and Juvela et al. (2001, ApJ, 563, 853) is given. It turns out that their predictions and findings can be reproduced rather well by choosing the parameters describing the stochastic density and velocity field appropriately.

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## Molecular Hydrogen Outflows in the Central Arcseconds of the T Tauri System

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We present new, near-infrared, adaptive optics observations of the enigmatic pre-main-sequence object T Tauri, using broadband filter imagery, long-slit spectroscopy, and Fabry-Perot imaging spectra. The broadband filter images spatially resolve the three stellar components of T Tau in the H, Ks, and L′ photometric bands. We clearly detect T

Tau Sb in the J band, and place upper limits on the J brightness of the infrared companion, T Tau Sa. The K-band spectrum of the T Tau S binary also resolves both components, and confirms strong Br$\gamma$ emission in both stars and photospheric features in Sb. We also report 2.058 $\mu$m helium recombination radiation associated with T Tau Sb. The Fabry-Perot channel map centered on the v = 10 S(1) line of molecular hydrogen shows a number of spatially extended structures, including a loop of emission north of the stars that is also visible in continuum frames taken at $\pm$900 km s$^{-1}$ from the line center. The continuum-subtracted $H^2$ image displays bow shock structures associated with the southeast-northwest and east-west outflows. The east-west jet system also shows bright, oblique shocks lining the flow channel. The part of the long-slit spectrum that overlaps this channel wall displays $H^2$ line ratios consistent with shock heating. This region also corresponds to the brightest knot of UV fluorescent emission reported by Saucedo and coworkers. The Fabry-Perot images unambiguously identify T Tau S binary as the source of the east-west outflow, although we cannot yet determine which of the two components produces the jet.

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## ASTE Submillimeter Observations of a Young Stellar Object Condensation in Cederblad 110

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We present results of submillimeter observations of a low-mass young stellar objects (YSOs) condensation in the Cederblad 110 region of the Chamaeleon I dark cloud with Atacama Submillimeter Telescope Experiment. Our $HCO^+(J{=}4\text{-}3)$ map reveals a dense molecular gas with an extent of $\sim$ 0.1 pc, which is a complex of two envelopes associated with class I sources Ced110 IRS4 and IRS11 and a very young object Cha-MMS1. The other two class I sources in this region, IRS6 and NIR89, are located outside the clump and have no extended $HCO^+$ emission. $HCO^+$ abundance is calculated to be $2.6 \times 10^{-10}$ for MMS1 and $3.4 \times 10^{-9}$ for IRS4, which are comparable to the reported value for other young sources. Bipolar outflows from IRS4 and IRS6 are detected in our $^{12}CO(J{=}3\text{-}2)$ map. The outflow from IRS4 seems to collide with Cha-MMS1. The outflow has enough momentum to affect gas motion in MMS1, although no sign has been detected to indicate that a triggered star formation has occurred.

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## The formation of an eccentric gap in a gas disc by a planet in an eccentric orbit

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We investigate the effect of a planet on an eccentric orbit on a two-dimensional low-mass gaseous disc. At a planet eccentricity above the planet's Hill radius divided by its semimajor axis, we find that the disc morphology differs from that exhibited by a disc containing a planet in a circular orbit. An eccentric gap is created with eccentricity that can exceed the planet's eccentricity and precesses with respect to the planet's orbit. We find that a more massive planet is required to open a gap when the planet is on an eccentric orbit. We attribute this behaviour to spiral density waves excited at corotation resonances by the eccentric planet. These act to increase the disc's eccentricity and exert a torque opposite in sign to that exerted by the Lindblad resonances. The reduced torque makes it more difficult for waves driven by the planet to overcome viscous inflow in the disc.

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## Dynamics of Dense Cores in the Perseus Molecular Cloud

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We survey the kinematics of over one hundred and fifty candidate (and potentially star-forming) dense cores in the Perseus molecular cloud with pointed $N_2H^+$(1-0) and simultaneous $C^{18}O$(2-1) observations. Our detection rate of $N_2H^+$ is 62%, rising to 84% for JCMT SCUBA-selected targets. In agreement with previous observations, we find that the dense $N_2H^+$ targets tend to display nearly thermal linewidths, particularly those which appear to be starless (using Spitzer data), indicating turbulent support on the small scales of molecular clouds is minimal. For those $N_2H^+$ targets which have an associated SCUBA dense core, we find their internal motions are more than sufficient to provide support against the gravitational force on the cores. Comparison of the $N_2H^+$ integrated intensity and SCUBA flux reveals fractional $N_2H^+$ abundances between $10^{-10}$ and $10^{-9}$. We demonstrate that the relative motion of the dense $N_2H^+$ gas and the surrounding $C^{18}O$ gas is less than the sound speed in the vast majority of cases ($\sim$90%). The point-to-point motions we observe within larger extinction regions appear to be insufficient to provide support against gravity, although we sparsely sample these regions.

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## Outflow and Infall in a Sample of Massive Star-forming Regions

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We present single-pointing observations of SiO, $HCO^+$, and $H^{13}CO^+$ from the James Clerk Maxwell Telescope toward 23 massive star-forming regions previously known to contain molecular outflows and ultracompact H II regions. We detected SiO toward 14 sources and suggest that the nondetections in the other nine sources could be due to those outflows being older and without ongoing shocks to replenish the SiO. We serendipitously detected $SO_2$ toward 17 sources in the same tuning as $HCO^+$. We detected $HCO^+$ toward all sources, and suggest that it is tracing infall in nine cases. For seven infall candidates, we estimate mass infall rates between 1 $\times 10^{-2}$ and 2 $\times 10^{-5}$ $M_\odot$ $yr^{-1}$. Seven sources show both SiO detections (young outflows) and $HCO^+$ infall signatures. We also find that the abundance of $H^{13}CO^+$ tends to increase along with the abundance of SiO in sources for which we could determine abundances. We discuss these results with respect to current theories of massive star formation via accretion. From this survey, we suggest that perhaps both models of ionized accretion and halted accretion may be important in describing the evolution of a massive protostar (or protostars) beyond the formation of an H II region.

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## New Very Low Mass Binaries in the Taurus Star-forming Region

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We surveyed 13 very low mass (VLM; M $\lesssim$ 0.2 $M_\odot$) objects in the Taurus star-forming region using near-infrared diffraction-limited imaging techniques on the W. M. Keck I 10 m telescope. Of these 13 objects, five were found to be binary, with separations ranging from 0.04〃 to 0.6″ and flux ratios from 1.4 to 3.7. In all cases, the companions are likely to be physically associated with the primaries (probability $\gtrsim 4\sigma$). Using the theoretical models of Baraffe et al. (1998), we find that all five new companions, as well as one of the primaries, are likely brown dwarfs. The

discovery of these systems therefore increases the total number of known, young VLM binaries by ∼50%. These new systems, along with other young VLM binaries from the literature, have properties that differ significantly from older field VLM binaries in that the young systems have wider separations and lower mass ratios, supporting the idea that VLM binaries undergo significant dynamical evolution ∼510 Myr after their formation. The range of separations of these binaries, four of which are over 30 AU, argues against the ejection scenario of brown dwarf formation. While several of the young, VLM binaries discovered in this study have lower binding energies than the previously suggested minimum for VLM binaries, the apparent minimum is still significantly higher than that found among higher mass binaries. We suggest that this discrepancy may be due to the small mass of a VLM binary relative to the average perturbing star, leading to more substantial changes in their binding energy over time.

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## The distance and neutral environment of the massive stellar cluster Westerlund 1

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*Context.* In spite of a large number of recent publications about the massive stellar cluster Westerlund 1, its distance from the Sun remains uncertain with values as low as 1.1 kpc, but largely between 4 and 5 kpc.

*Aims.* The goal of this study is to determine a distance to Westerlund 1 independent of the characteristics of the stellar population and to study its neutral environment, using observations of atomic hydrogen.

*Methods.* The HI observations are taken from the Southern Galactic Plane Survey to study HI absorption in the direction of the HII region created by the members of Westerlund 1 and to investigate its environment as observed in the HI line emission. A Galactic rotation curve was derived using the recently revised values for the Galactic centre distance of $R_\odot = 7.6$ kpc, and the velocity of the Sun around the Galactic centre of $\Theta_\odot = 214$ km s$^{-1}$. This rotation curve successfully predicts the location of the Tangent point gas and the velocity of the Sagittarius Arm outside the solar circle on the far side of the Galaxy to within 4 km s$^{-1}$. Compared to the typically used values of $R_\odot = 8.5$ kpc and $\Theta_\odot = 220$ km s$^{-1}$ this reduces kinematically determined distances by more than 10%.

*Results.* The newly determined rotation model leads us to derive a distance of $3.9 \pm 0.7$ kpc to Westerlund 1, consistent with a location in the Scutum-Crux Arm. Included in this estimate is a very careful investigation of possible sources of error for the Galactic rotation curve. We also report on small expanding HI features around the cluster with a maximum dynamic age of 600 000 years and a larger bubble which has a minimum dynamic age of 2.5 million years. Additionally we re-calculated the kinematic distances to nearby HII regions and supernova remnants based on our new Galaxic rotation curve.

*Conclusions.* We propose that in the early stages of the development of Wd 1 a large interstellar bubble of diameter about 50 pc was created by the cluster members. This bubble has a dynamic age similar to the age of the cluster. Small expanding bubbles, with dynamical ages ∼0.6 Myr are found around Wd 1, which we suggest consist of recombined material lost by cluster members through their winds.

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## The primordial binary population II: Recovering the binary population for intermediate mass stars in Sco OB2

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We characterize the binary population in the young and nearby OB association Scorpius OB2 (Sco OB2) using available observations of visual, spectroscopic, and astrometric binaries with intermediate-mass primaries. We take into account observational biases by comparing the observations with simulated observations of model associations. The available data indicate a large binary fraction ($> 70\%$ with $3\sigma$ confidence), with a large probability that all intermediate mass stars in Sco OB2 are part of a binary system. The binary systems have a mass ratio distribution of the form $f_q(q) \propto q^{\gamma_q}$, with $\gamma_q \approx -0.4$. Sco OB2 has a semi-major axis distribution of the form $f_a(a) \propto a^{\gamma_a}$ with $\gamma_a \approx -1.0$ (Öpik's law), in the range $5\,R_\odot < a < 5 \times 10^6\,R_\odot$. The log-normal period distribution of Duquennoy & Mayor results in too few spectroscopic binaries, even if the model binary fraction is 100%. Sco OB2 is a young association with a low stellar density; its current population is expected to be very similar to the primordial population. The fact that practically all stars in Sco OB2 are part of a binary (or multiple) system demonstrates that multiplicity is a fundamental factor in the star formation process, at least for intermediate mass stars.

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## Grain Retention and Formation of Planetesimals near the Snow Line in MRI-driven Turbulent Protoplanetary Disks

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The first challenge in the formation of both terrestrial planets and the cores of gas giants is the retention of grains in protoplanetary disks. In most regions of these disks, gas attains sub-Keplerian speeds as a consequence of a negative pressure gradient. Hydrodynamic drag leads to orbital decay and depletion of the solid material in the disk, with characteristic timescales as short as only a few hundred years for meter-sized objects at 1 AU. In this Letter, we suggest a particle retention mechanism that promotes the accumulation of grains and the formation of planetesimals near the water sublimation front or "snow line." This model is based on the assumption that, in the regions most interesting for planet formation, the viscous evolution of the disk is due to turbulence driven by the magnetorotational instability (MRI) in the surface layers of the disk. The depth to which MRI effectively generates turbulence is a strong function of grain size and abundance. A sharp increase in the grain-to-gas density ratio across the snow line reduces the column depth of the active layer. As the disk evolves toward a quasisteady state, this change in the active layer creates a local maximum in radial distribution of the gas surface density and pressure, causing the gas to rotate at super-Keplerian speed and halting the inward migration of grains. This scenario presents a robust process for grain retention that may aid in the formation of protogas giant cores preferentially near the snow line.

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## Excitation conditions in the Orion molecular cloud obtained from observations of ortho- and para-lines of $H_2$

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*Aims.* We seek to study excitation mechanisms in the inner region of the Orion Molecular Cloud by comparing observations of ortho- and para-lines of $H_2$ with theoretical models of slow shocks and photodissociation regions.

*Methods.* K-band observations of $H_2$ obtained with the Canada-France-Hawaii 3.6 m telescope using the PUEO adaptive optics system are reported. Data were centered on the Becklin-Neugebauer object northwest of the Trapezium

stars. Narrow-band filters were used to isolate emission from the v=1-0 S(1) ortho- and v=1-0 S(0) para-lines at a spatial resolution of 0.″45 (∼200 AU). We are able to combine their intensity to obtain the column densities of rovibrationally excited ortho and para H2 levels of the molecular gas at high spatial resolution.

*Results.* The resulting line ratios show variations between 2 and the statistical equilibrium value of 6. We find 4 different classes of emission, characterised by the ratio of the v=1-0 S(1) and S(0) line brightness and the absolute line brightness. Shock models are used to estimate the physical properties of pre-shock density and shock velocity for these 4 classes. We find that the pre-shock density is in the range of $10^5 - 10^7$ cm$^{-3}$ and shock velocities lie between 10 and 40 km s$^{-1}$. Studies of individual objects, using additional constraints of shock velocity and width, allow quite precise physical conditions to be specified in three prominent bow shocks, one with a shock speed of $18 \pm 2$ km s$^{-1}$ and pre-shock density $1 \pm 0.5 \times 10^6$ cm$^{-3}$ ($3\sigma$) and two with shock speeds of $36 \pm 2$ km s$^{-1}$ and pre-shock densities of $7.5 \pm 2.5 \times 10^4$ cm$^{-3}$.

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## The Relationship Between Molecular Gas Tracers and Kennicutt-Schmidt Laws

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We provide a model for how Kennicutt-Schmidt (KS) laws, which describe the correlation between star formation rate and gas surface or volume density, depend on the molecular line chosen to trace the gas. We show that, for lines that can be excited at low temperatures, the KS law depends on how the line critical density compares to the median density in a galaxy's star-forming molecular clouds. High critical density lines trace regions with similar physical properties across galaxy types, and this produces a linear correlation between line luminosity and star formation rate. Low critical density lines probe regions whose properties vary across galaxies, leading to a star formation rate that varies superlinearly with line luminosity. We show that a simple model in which molecular clouds are treated as isothermal and homogenous can quantitatively reproduce the observed correlations between galactic luminosities in far infrared and in the CO$(1 \rightarrow 0)$ and HCN$(1 \rightarrow 0)$ lines, and naturally explains why these correlations have different slopes. We predict that IR-line luminosity correlations should change slope for galaxies in which the median density is close to the line critical density. This prediction may be tested by observations of lines such as HCO$^+(1 \rightarrow 0)$ with intermediate critical densities, or by HCN$(1 \rightarrow 0)$ observations of intensely star-forming high redshift galaxies with very high densities. Recent observations by Gao et al. hint at just such a change in slope. We argue that deviations from linearity in the HCN$(1 \rightarrow 0)-$IR correlation at high luminosity are consistent with the assumption of a constant star formation efficiency.

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## c2d itSpitzer IRS Spectra of Disks around T Tauri Stars. III. [Ne II], [Fe I], and $H_2$ gas-phase lines

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We present a survey of mid-infrared gas-phase lines toward a sample of 76 circumstellar disks around low mass pre-main sequence stars from the *Spitzer* "Cores to Disks" legacy program. We report the first detections of [Ne II] and [Fe I] toward classical T Tauri stars in ∼ 20 % respectively ∼ 9 % of our sources. The observed [Ne II] line fluxes and upper limits are consistent with [Ne II] excitation in an X-ray irradiated disk around stars with X-ray luminosities $L_X = 10^{29} - 10^{31}$ erg s$^{-1}$. [Fe I] is detected at $\sim 10^{-5} - 10^{-4}\,L_\odot$, but no [S I] or [Fe II] is detected down to $\sim 10^{-6}\,L_\odot$.

The [Fe I] detections indicate the presence of gas-rich disks with masses of $\gtrsim 0.1 M_J$. No $H_2$ 0-0 S(0) and S(1) disk emission is detected, except for S(1) toward one source. These data give upper limits on the warm ($T \sim 100-200$ K) gas mass of a few Jovian masses, consistent with recent T Tauri disk models which include gas heating by stellar radiation. Compact disk emission of hot ($T \gtrsim 500$ K) gas is observed through the $H_2$ 0-0 S(2) and/or S(3) lines toward $\sim 8$ % of our sources. The line fluxes are, however, higher by more than an order of magnitude than those predicted by recent disk models, even when X-ray and excess UV radiation are included. Similarly the [Ne II]/$H_2$ 0-0 S(2) ratios for these sources are lower than predicted, consistent with the presence of an additional hot molecular gas component not included in current disk models. Oblique shocks of stellar winds interacting with the disk can explain many aspects of the hot gas emission, but are inconsistent with the non-detection of [S I] and [Fe II] lines.

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## Radiative torques: analytical model and basic properties

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We attempt to get a physical insight into grain alignment processes by studying basic properties of radiative torques (RATs). For this purpose we consider a simple toy model of a helical grain that reproduces well the basic features of RATs. The model grain consists of a spheroidal body with a mirror attached at an angle to it. Being very simple, the model allows analytical description of RATs that act upon it. We show a good correspondence of RATs obtained for this model and those of irregular grains calculated by ddscat. Our analysis of the role of different torque components for grain alignment reveals that one of the three RAT components does not affect the alignment, but induces only for grain precession. The other two components provide a generic alignment with grain long axes perpendicular to the radiation direction, if the radiation dominates the grain precession, and perpendicular to magnetic field, otherwise. The latter coincides with the famous predictions of the DavisGreenstein process, but our model does not invoke paramagnetic relaxation. In fact, we identify a narrow range of angles between the radiation beam and the magnetic field, for which the alignment is opposite to the DavisGreenstein predictions. This range is likely to vanish, however, in the presence of thermal wobbling of grains. In addition, we find that a substantial part of grains subjected to RATs gets aligned with low angular momentum, which testifies that most of the grains in diffuse interstellar medium do not rotate fast, that is, rotate with thermal or even subthermal velocities. This tendency of RATs to decrease grain angular velocity as a result of the RAT alignment decreases the degree of polarization, by decreasing the degree of internal alignment, that is, the alignment of angular momentum with the grain axes. For the radiation-dominated environments, we find that the alignment can take place on the time-scale much shorter than the time of gaseous damping of grain rotation. This effect makes grains a more reliable tracer of magnetic fields. In addition, we study a self-similar scaling of RATs as a function of $\lambda/a_{eff}$. We show that the self-similarity is useful for studying grain alignment by a broad spectrum of radiation, that is, interstellar radiation field.

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## Models of the collisional damping scenario for ice-giant planets and Kuiper belt formation

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Chiang et al. [Chiang, E., Lithwick, Y., Murray-Clay, R., Buie, M., Grundy, W., Holman, M., 2007. In: Protostars and Planets V, pp. 895911] have recently proposed that the observed structure of the Kuiper belt could be the result of a dynamical instability of a system of not, vert, similar primordial ice-giant planets in the outer Solar System. According to this scenario, before the instability occurred, these giants were growing in a highly collisionally damped environment according to the arguments in Goldreich et al. [Goldreich, P., Lithwick, Y., Sari, R., 2004. Astrophys. J. 614, 497507; Annu. Rev. Astron. Astrophys. 42, 549601]. Here we test this hypothesis with a series of numerical simulations using a new code designed to incorporate the dynamical effects of collisions. We find that we cannot reproduce the observed Solar System. In particular, Goldreich et al. [Goldreich, P., Lithwick, Y., Sari, R., 2004. Astrophys. J. 614, 497507; Annu. Rev. Astron. Astrophys. 42, 549601] and Chiang et al. [Chiang, E., Lithwick, Y., Murray-Clay, R., Buie, M., Grundy, W., Holman, M., 2007. In: Protostars and Planets V, pp. 895911] argue that during the instability, all but two of the ice giants would be ejected from the Solar System by Jupiter and Saturn, leaving Uranus and Neptune behind. We find that ejections are actually rare and that instead the systems spread outward. This always leads to a configuration with too many planets that are too far from the Sun. Thus, we conclude that both Goldreich et al.'s scheme for the formation of Uranus and Neptune and Chiang et al.'s Kuiper belt formation scenario are not viable in their current forms.

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## Multi-wavelength observations of Southern Hot Molecular Cores traced by methanol masers - I. Ammonia and 24 GHz Continuum Data

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We present observations of the (1,1), (2,2), (4,4) and (5,5) inversion transitions of para-ammonia (NH3) and 24 GHz continuum, taken with the Australia Telescope Compact Array toward 21 southern Galactic hot molecular cores traced by 6.7 GHz methanol maser emission. We detect NH3(1,1) emission toward all 21 regions and 24 GHz continuum emission toward 12 of the regions, including 6 with no reported 8 GHz continuum counterparts. In total, we find the 21 regions contain 41 NH3(1,1) cores. We extract characteristic spectra for every core at each of the NH3 transitions and present both integrated intensity maps and channel maps for each region. The NH3(4,4)+(5,5) emission is always unresolved and found at the maser position indicating that the methanol masers are found at the warmest part of the core. We observe large asymmetries in the NH3(1,1) hyperfine line profiles and conclude this is due to a number of dense, small clumps within the beam. We derive properties of the ionised gas and find the 24 GHz continuum sources not detected at 8 GHz are always coincident with both NH3 and methanol masers in contrast to those detected at 8 + 24 GHz which are generally offset from the methanol masers. We investigate the possibility that the former may be hyper-compact HII regions. Finally, we separate the cores into five groups, based on their association with NH3, methanol maser and continuum emission. From the different physical properties of the cores in the groups, we discuss the possibility that these groups may represent cores at different evolutionary stages of the massive star formation process.

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## Embedded Stellar Populations towards Young Massive Star Formation Regions I. G305.2+0.2

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We present deep, wide-field J, H and Ks images taken with IRIS2 on the Anglo Australian Telescope, towards the massive star formation region G305.2+0.2. Combined with 3.6, 4.5, 5.8 and 8.0 micron data from the GLIMPSE survey on the Spitzer Space Telescope, we investigate the properties of the embedded stellar populations. After removing

contamination from foreground stars we separate the sources based on their IR colour. Strong extended emission in the GLIMPSE images hampers investigation of the most embedded sources towards the known sites of massive star formation. However, we find a sizeable population of IR excess sources in the surrounding region free from these completeness effects. Investigation reveals the recent star formation activity in the region is more widespread than previously known.

Stellar density plots show the embedded cluster in the region, G305.24+0.204, is offset from the dust emission. We discuss the effect of this cluster on the surrounding area and argue it may have played a role in triggering sites of star formation within the region. Finally, we investigate the distribution of IR excess sources towards the cluster, in particular their apparent lack towards the centre compared with its immediate environs.

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## An infrared view of the EXor variables: on the case of V1118 Ori

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We investigate the relationship between the IR observed properties of the EXor variables and the mechanisms active during their evolutionary stage typical of the pre-main-sequence phase. To this aim, we have constructed a catalog containing all the IR (1-100 $\mu$m) photometric and spectroscopic observations appearing during the last 30 years in the literature. Moreover, new results of our monitoring program based on near-and mid-IR photometry and near-IR spectroscopy and polarimetry of one object (V1118 Ori) typical of the EXor class are presented, complementing those given in a previous paper and related to a different activity period. Our catalog indicates how the database accumulated so far, stemming from a fortuitous monitoring of the stellar activity, is inadequate for any statistical study of the EXor events. Nevertheless, all the observational evidence can be interpreted into a coherent scheme. The sources that present the largest brightness variations tend to become bluer while brightening. The scenario of the disk accretion hypothesis based on the viscous friction between particles agrees with the observational evidence. The new results on V1118 Ori confirm such a general view. The striking novelty is represented by a near-IR spectrum of V1118 Ori taken 1 yr after the last monitored outburst: any emission line previously detected has now totally disappeared at our sensitivity. For the same source, mid-IR photometry is provided here for the first time and allows us to construct a meaningful SED. The first polarimetric data indicate that the source is intrinsically polarized and its spotted and magnetized surface becomes recognizable during the less active phases.

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## Dynamical Expansion of H II Regions from Ultracompact to Compact Sizes in Turbulent, Self-Gravitating Molecular Clouds

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The nature of ultracompact *HII* regions (UCHRs) remains poorly determined. In particular, they are about an order of magnitude more common than would be expected if they formed around young massive stars and lasted for one dynamical time, around $10^4$ yr. We here perform three-dimensional numerical simulations of the expansion of an *HII* region into self-gravitating, radiatively cooled gas, both with and without supersonic turbulent flows. In the non-turbulent case, we find that *HII* region expansion in a collapsing core produces nearly spherical shells, even if the ionizing source is off-center in the core. This agrees with analytic models of blast waves in power-law media. In the turbulent case, we find that the *HII* region does not disrupt the central collapsing region, but rather sweeps up a shell of gas in which further collapse occurs. Although this does not constitute triggering, as the swept-up gas would eventually have collapsed anyway, it does expose the collapsing regions to ionizing radiation. These objects can have radio flux densities consistent with unresolved UCHRs. We suggest that these objects, which will not all themselves form massive stars, may form the bulk of observed UCHRs. As the larger shell will take over $10^5$ years to complete its evolution, this could solve the timescale problem. Our suggestion is supported by the ubiquitous observation of more diffuse emission from compact *HII* regions surrounding UCHRs.

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## Champagne flow and triggered star formation in NGC 1893

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Using H$\alpha$ grism spectroscopy and optical and 2MASS photometry of the fields containing NGC 1893 and two emission nebulae, Sim 129 and Sim 130, we show the presence of a number of H$\alpha$ and NIR excess sources towards the region between HD 242935 and the two emission nebulae. Among them a large majority of these pre-main sequence candidate sources are concentrated towards regions closer to Sim 129 and Sim 130. Age distribution of these sources (namely main sequence stars in the cluster, including HD 242935, young sources located in the region between HD 242935 and two nebulae and those located inside Sim 129) obtained from their positions in optical $V$, $V-I$ color-magnitude diagram strongly suggest "small scale sequential star formation" along the axes of the clouds caused by the outward advance of ionization/shock front from the $HII$ region. The IRAS source, IRAS 05198+3325, identified with CPM 16 is a Herbig Be (B3) type star showing H$\alpha$ and CaII triplet lines in emission. From the orientation of the two emission nebulae it is suggested that HD 242935 is most likely responsible for the cometary morphology of the two nebulae and the trigger of star formation in the region. From the global distribution of the interstellar material, it is also suggested that the same source is responsible for the champagne flow causing the entire molecular cloud to have a cometary appearance.

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## Mass and Temperature of the TWA 7 Debris Disk

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We present photometric detections of dust emission at 850 and 450 $\mu$m around the pre-main-sequence M1 dwarf TWA 7 using the SCUBA camera on the James Clerk Maxwell Telescope. These data confirm the presence of a cold dust disk around TWA 7, a member of the TW Hydrae Association (TWA). Based on the 850 $\mu$m flux, we estimate the mass of the disk to be 18 $M_{lunar}$ (0.2 $M_\oplus$) assuming a mass opacity of 1.7 cm$^2$ g$^{-1}$ with a temperature of 45 K. This makes the TWA 7 disk (d = 55 pc) an order of magnitude more massive than the disk reported around AU Microscopii (GL 803), the closest (9.9 pc) debris disk detected around an M dwarf. This is consistent with TWA 7 being slightly younger than AU Mic. We find that the mid-IR and submillimeter data require the disk to be comprised of dust at a range of temperatures. A model in which the dust is at a single radius from the star, with a range of temperatures according to grain size, is as effective at fitting the emission spectrum as a model in which the dust is of uniform size, but has a range of temperatures according to distance. We discuss this disk in the context of known disks in the TWA and around low-mass stars; a comparison of masses of disks in the TWA reveals no trend in mass or evolutionary state (gas-rich vs. debris) as a function of spectral type.

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## The lower mass function of the young open cluster Blanco 1: from $30M_{Jup}$ to $3M_{\odot}$

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We performed a deep wide field optical survey of the young ($\sim 100 - 150$ Myr) open cluster Blanco 1 to study its low mass population well down into the brown dwarf regime and estimate its mass function over the whole cluster mass range. The survey covers 2.3 square degrees in the $I$ and $z$-bands down to $I \simeq z \simeq 24$ with the CFH12K camera. Considering two different cluster ages (100 and 150 Myr), we selected cluster member candidates on the basis of their location in the $(I, I - z)$ CMD relative to the isochrones, and estimated the contamination by foreground late-type field dwarfs using statistical arguments, infrared photometry and low-resolution optical spectroscopy. We find that our survey should contain about 57% of the cluster members in the $0.03 - 0.6M_{\odot}$ mass range, including 30-40 brown dwarfs. The candidate's radial distribution presents evidence that mass segregation has already occured in the cluster. We took it into account to estimate the cluster mass function across the stellar/substellar boundary. We find that, between $0.03M_{\odot}$ and $0.6M_{\odot}$, the cluster mass distribution does not depend much on its exact age, and is well represented by a single power-law, with an index $\alpha = 0.69 \pm 0.15$. Over the whole mass domain, from $0.03M_{\odot}$ to $3M_{\odot}$, the mass function is better fitted by a log-normal function with $m_0 = 0.36 \pm 0.07M_{\odot}$ and $\sigma = 0.58 \pm 0.06$. Comparison between the Blanco 1 mass function, other young open clusters' MF, and the galactic disc MF suggests that the IMF, from the substellar domain to the higher mass part, does not depend much on initial conditions. We discuss the implications of this result on theories developed to date to explain the origin of the mass distribution.

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## $\eta$ Cha: abnormal IMF or dynamical evolution ?

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$\eta$ Chamaeleontis is a unique young ($\sim 9$ Myr) association with 18 systems concentrated in a radius of $\approx 35$ arcmin, i.e. 1pc at the cluster distance of 97pc. No other members have been found up to 1.5 degrees from the cluster centre. The cluster mass function is consistent with the IMF of other rich young open clusters in the higher mass range but shows a clear deficit of low mass stars and brown dwarfs with no objects below $0.1M_{\odot}$. The aim of this paper is to test whether this peculiar mass function could result from dynamical evolution despite the young age of the cluster. We performed N-body numerical calculations starting with a log-normal IMF and different initial conditions in terms of number of systems and cluster radius using the code NBODY3. We simulated the cluster dynamical evolution over 10 Myr and compared the results to the observations. We found that it is possible to reproduce $\eta$ Cha when starting with a very compact configuration (with $N_{init} = 40$ and $R_0 = 0.005$pc) which suggests that the IMF of the association might not be abnormal. The high initial density might also explain the deficit of wide binaries that is observed in the

cluster.

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## The dust, planetesimals and planets of HD 38529

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HD 38529 is a post-main sequence G8III/IV star (3.5 Gyr old) with a planetary system consisting of at least two planets having $M\sin i$ of 0.8 $M_{Jup}$ and 12.2 $M_{Jup}$, semimajor axes of 0.13 AU and 3.74 AU, and eccentricities of 0.25 and 0.35, respectively. *Spitzer* observations show that HD 38529 has an excess emission above the stellar photosphere, with a signal-to-noise ratio (S/N) at 70 $\mu$m of 4.7, a small excess at 33 $\mu$m (S/N=2.6) and no excess <30 $\mu$m. We discuss the distribution of the potential dust-producing planetesimals from the study of the dynamical perturbations of the two known planets, considering in particular the effect of secular resonances. We identify three dynamically stable niches at 0.4–0.8 AU, 20–50 AU and beyond 60 AU. We model the spectral energy distribution of HD 38529 to find out which of these niches show signs of harboring dust-producing plantesimals. The secular analysis, together with the SED modeling resuls, suggest that the planetesimals responsible for most of the dust emission are likely located within 20–50 AU, a configuration that resembles that of the Jovian planets + Kuiper Belt in our Solar System. Finally, we place upper limits ($8\times10^{-6}$ lunar masses of 10 $\mu$m particles) to the amount of dust that could be located in the dynamically stable region that exists between the two planets (0.25–0.75 AU).

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## A Spitzer Census of the IC 348 Nebula

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Spitzer mid-infrared surveys enable an accurate census of young stellar objects by sampling large spatial scales, revealing very embedded protostars, and detecting low-luminosity objects. Taking advantage of these capabilities, we present a Spitzer-based census of the IC 348 nebula and embedded star cluster, covering a 2.5 pc region and comparable in extent to the Orion Nebula. Our Spitzer census supplemented with ground-based spectra has added 42 Class II T Tauri sources to the cluster membership and identified ∼20 Class 0/I protostars. The population of IC 348 likely exceeds 400 sources after accounting statistically for unidentified diskless members. Our Spitzer census of IC 348 reveals a population of Class I protostars that is anticorrelated spatially with the Class II/III T Tauri members, which comprise the centrally condensed cluster around a B star. The protostars are instead found mostly at the cluster periphery about ∼1 pc from the B star and spread out along a filamentary ridge. We further find that the star formation rate in this protostellar ridge is consistent with that rate which built the older exposed cluster, while the presence of 15 cold, starless, millimeter cores intermingled with this protostellar population indicates that the IC

348 nebula has yet to finish forming stars. Moreover, we show that the IC 348 cluster is of order 35 crossing times old, and, as evidenced by its smooth radial profile and confirmed mass segregation, is likely relaxed. While it seems apparent that the current cluster configuration is the result of dynamical evolution and its primordial structure has been erased, our finding of a filamentary ridge of Class I protostars supports a model in which embedded clusters are built up from numerous smaller subclusters. Finally, the results of our Spitzer census indicate that the supposition that star formation must progress rapidly in a dark cloud should not preclude these observations that show it can be relatively long lived.

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## The IC1396N proto-cluster at a scale of ∼250 AU

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*Aims.* We investigate the mm-morphology of IC 1396 N with unprecedented spatial resolution to analyze its dust and molecular gas properties, and draw comparisons with objects of similar mass.

*Methods.* We have carried out sensitive observations in the most extended configurations of the IRAM Plateau de Bure interferometer, to map the thermal dust emission at 3.3 and 1.3 mm, and the emission from the $J = 13_k \rightarrow 12_k$ hyperfine transitions of methyl cyanide ($CH_3CN$).

*Results.* We unveil the existence of a sub-cluster of hot cores in IC 1396 N, distributed in a direction perpendicular to the emanating outflow. The cores are embedded in a common envelope of extended and diffuse dust emission. We find striking differences in the dust properties of the cores ( $\beta \simeq 0$) and the surrounding envelope ( $\beta \simeq 1$), very likely testifying to differences in the formation and processing of dust material. The $CH_3CN$ emission peaks towards the most massive hot core and is marginally extended in the outflow direction.

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## Photon-dominated region modeling of the CO and [C I] line emission in Barnard 68

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*Aims.* We use the Barnard 68 dark globule as a test case for a spherically symmetric PDR model exposed to low-UV radiation fields. With a roughly spherical morphology and an accurately determined density profile, Barnard 68 is ideal for this purpose. The processes governing the energy balance in the cloud surface are studied in detail.

*Methods.* We compare the spherically symmetric PDR model by Störzer, Stutzki & Sternberg (1996) to observations of the three lowest rotational transitions of $^{12}CO$, $^{13}CO$ J = 2 → 1, and J = 3 → 2, as well as the [C I] $^3P_1 \rightarrow ^3P_0$ fine structure transition. We study the role of polycyclic aromatic hydrocarbons (PAHs) in the chemical network of the PDR model and consider the impact of depletion, as well as of a variation in the external FUV field.

*Results.* We find it difficult to simultaneously model the observed $^{12}CO$ and $^{13}CO$ emission. The $^{12}CO$ and [C I] emission can be explained by a PDR model with an external FUV field of 1-0.75 $\chi_0$, but this model fails to reproduce

the observed $^{13}CO$ by a factor of ∼2. Adding PAHs to the chemical network increases the [C I] emission by 50% in our model but makes [C II] very faint. The CO depletion only slightly reduces the $^{12}CO$ and $^{13}CO$ line intensity (by $\lesssim$10% and $\lesssim$20%, respectively). Predictions for the [C I] $^2P_{3/2} \rightarrow ^2P_{1/2}$, [C I] $^3P_2 \rightarrow ^3P_1$, and $^{12}CO$ J = 5 → 4 and 4 → 3 transitions are presented. This allows a test of our model with future observations (APEX, NANTEN2, HERSCHEL, SOFIA).

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## Evolution of dust and ice features around FU Orionis objects

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We present spectroscopy data for a sample of 14 FUors and 2 TTauri stars observed with the Spitzer Space Telescope or with the Infrared Space Observatory (ISO). Based on the appearance of the 10 micron silicate feature we define 2 categories of FUors. Objects showing the silicate feature in absorption (Category 1) are still embedded in a dusty and icy envelope. The shape of the 10 micron silicate absorption bands is compared to typical dust compositions of the interstellar medium and found to be in general agreement. Only one object (RNO 1B) appears to be too rich in amorphous pyroxene dust, but a superposed emission feature can explain the observed shape. We derive optical depths and extinction values from the silicate band and additional ice bands at 6.0, 6.8 and 15.2 micron. In particular the analysis of the $CO_2$ ice band at 15.2 micron allows us to search for evidence for ice processing and constrains whether the absorbing material is physically linked to the central object or in the foreground. For objects showing the silicate feature in emission (Category 2), we argue that the emission comes from the surface layer of accretion disks. Analyzing the dust composition reveals that significant grain growth has already taken place within the accretion disks, but no clear indications for crystallization are present. We discuss how these observational results can be explained in the picture of a young, and highly active accretion disk. Finally, a framework is proposed as to how the two categories of FUors can be understood in a general paradigm of the evolution of young, low-mass stars. Only one object (Parsamian 21) shows PAH emission features. Their shapes, however, are often seen toward evolved stars and we question the object's status as a FUor and discuss other possible classifications.

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## High spatial resolution mid-infrared observations of the low-mass young star TW Hya

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We want to improve knowledge of the structure of the inner few AU of the circumstellar disk around the nearby T Tauri star TW Hya. Earlier studies have suggested the existence of a large inner hole, possibly caused by interactions with a growing protoplanet.

We used interferometric observations in the N-band obtained with the MIDI instrument on the Very Large Telescope Interferometer, together with 10 $\mu$m spectra recorded by the infrared satellite Spitzer. The fact that we were able to determine N-band correlated fluxes and visibilities for this comparatively faint source shows that mid-infrared interferometry can be applied to a large number of low-mass young stellar objects.

The mid-infrared spectra obtained with Spitzer reveal emission lines from H I (6-5), H I (7-6), and [Ne II] and show

that over 90% of the dust we see in this wavelength regime is amorphous. According to the correlated flux measured with MIDI, most of the crystalline material is in the inner, unresolved part of the disk, about 1 AU in radius. The visibilities exclude the existence of a very large ($3-4$ AU radius) inner hole in the circumstellar disk of TW Hya, which was required in earlier models. We propose instead a geometry of the inner disk where an inner hole still exists, but at a much reduced radius, with the transition from zero to full disk height between 0.5 and 0.8 AU, and with an optically thin distribution of dust inside. Such a model can comply with SED and mid-infrared visibilities, as well as with visibility and extended emission observed in the near-infrared at 2 $\mu$m. If a massive planet was the reason for this inner hole, as has been speculated, its orbit would have to be closer to the star than 0.3 AU. Alternatively, we may be witnessing the end of the accretion phase and an early phase of an inward-out dispersal of the circumstellar disk.

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## A decreased probability of habitable planet formation around low-mass stars

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Smaller terrestrial planets ($\leq 0.3\,\mathrm{M}_\oplus$) are less likely to retain the substantial atmospheres and ongoing tectonic activity probably required to support life. A key element in determining if sufficiently massive "sustainably habitable" planets can form is the availability of solid planet-forming material. We use dynamical simulations of terrestrial planet formation from planetary embryos and simple scaling arguments to explore the implications of correlations between terrestrial planet mass, disk mass, and the mass of the parent star. We assume that the protoplanetary disk mass scales with stellar mass as $M_{disk} \propto f\, M_\star^h$, where $f$ measures the relative disk mass, and $1/2 < h < 2$, so that disk mass decreases with decreasing stellar mass. We consider systems without Jovian planets, based on current models and observations for M stars. We assume the mass of a planet formed in some annulus of a disk with given parameters is proportional to the disk mass in that annulus, and show with a suite of simulations of late-stage accretion that the adopted prescription is surprisingly accurate. Our results suggest that the fraction of systems with sufficient disk mass to form $> 0.3\,\mathrm{M}_\oplus$ habitable planets decreases for low-mass stars for every realistic combination of parameters. This "habitable fraction" is small for stellar masses below a mass in the interval 0.5 to 0.8 $\mathrm{M}_\odot$, depending on disk parameters, an interval that excludes most M stars. Radial mixing and therefore water delivery are inefficient in lower-mass disks commonly found around low-mass stars, such that terrestrial planets in the habitable zones of most low-mass stars are likely to be small and dry.

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## Radial and vertical angular momentum transport in protostellar discs

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Angular momentum in protostellar discs can be transported either radially, through turbulence induced by the magnetorotational instability (MRI), or vertically, through the torque exerted by a large-scale magnetic field. We present a model of steady-state discs where these two mechanisms operate at the same radius and derive approximate criteria for their occurrence in an ambipolar diffusion dominated disc. We obtain "weak field" solutions - which we associate with the MRI channel modes in a stratified disc - and transform them into accretion solutions with predominantly radial angular-momentum transport by implementing a turbulent-stress prescription based on published results of numeri-

cal simulations. We also analyze "intermediate field strength" solutions in which both radial and vertical transport operate at the same radial location. Our results suggest, however, that this overlap is unlikely to occur in real discs.

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## Star formation in young star cluster NGC 1893

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We present a comprehensive multi-wavelength study of the star-forming region NGC 1893 to explore the effects of massive stars on low-mass star formation. Using near-infrared colours, slitless spectroscopy and narrow-band $H\alpha$ photometry in the cluster region we have identified candidate young stellar objects (YSOs) distributed in a pattern from the cluster to one of the nearby nebulae Sim 129. The $V, (V-I)$ colour-magnitude diagram of the YSOs indicates that majority of these objects have ages between 1 to 5 Myr. The spread in the ages of the YSOs may indicate a non-coeval star formation in the cluster. The slope of the KLF for the cluster is estimated to be $0.34 \pm 0.07$, which agrees well with the average value ($\sim 0.4$) reported for young clusters. For the entire observed mass range $0.6 < M/M_{\odot} \leq 17.7$ the value of the slope of the initial mass function, '$\Gamma$', comes out to be $-1.27 \pm 0.08$, which is in agreement with the Salpeter value of -1.35 in the solar neighborhood. However, the value of '$\Gamma$' for PMS phase stars (mass range $0.6 < M/M_{\odot} \leq 2.0$) is found to be $-0.88 \pm 0.09$ which is shallower than the value ($-1.71 \pm 0.20$) obtained for MS stars having mass range $2.5 < M/M_{\odot} \leq 17.7$ indicating a break in the slope of the mass function at $\sim 2M_{\odot}$. Estimated '$\Gamma$' values indicate an effect of mass segregation for main-sequence stars, in the sense that massive stars are preferentially located towards the cluster center. The estimated dynamical evolution time is found to be greater than the age of the cluster, therefore the observed mass segregation in the cluster may be the imprint of the star formation process. There is evidence for triggered star formation in the region, which seems to govern initial morphology of the cluster.

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## Molecular Outflows and a Mid-Infrared Census of the Massive Star-Formation Region Associated with IRAS 18507+0121

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We have observed the central region of the IR-dark cloud filament associated with IRAS 18507+0121 at millimeter wavelengths in CO(J=1−0), $^{13}$CO(J=1−0), and C$^{18}$O(J=1−0) line emission and with the *Spitzer Space Telescope* at mid-IR wavelengths. Five massive outflows from two cloud cores were discovered. Three outflows are centered on or near an Ultracompact HII (UC HII) region (G34.4+0.23) while the remaining two outflows originate from the millimeter core G34.4+0.23 MM. Modeling of the SEDs of the mid-IR sources identified 31 young stellar objects in the filament with a combined stellar mass of $\sim 127 \pm 27\,M_{\odot}$. An additional 22 sources were identified as probable

cluster members based on the presence of strong 24 $\mu$m emission. The total star formation efficiency in the G34.4 cloud filament is estimated to be $\sim 7\%$ while the massive and intermediate mass star formation efficiency in the entire cloud filament is estimated to be roughly 2%. A comparison of the gravitational binding energy with the outflow kinetic energy suggests that the compact core containing G34.4+0.23 MM is being destroyed by its molecular outflows whereas the outflows associated with more massive core surrounding the G34.4 UC Hii region are not likely to totally disrupt the cloud. Additionally, a qualitative evaluation of the region appears to suggest that stars in this region may have formed in two stages: first lower mass stars formed and then, a few Myrs later, the more massive stars began to form.

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## Electromagnetic fields in jets

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The magnetic fields and energy flows in an astronomical jet described by our earlier model are calculated in detail. Though the field distribution varies with the external pressure function p(z), it depends only weakly on the other boundary conditions. Individual field lines were plotted; the lines become nearly vertical at the bottom and are twisted at the top. An animation of a field line's motion was made, which shows the line being wound up by the accretion disc's differential rotation and rising as a result of this. The distribution of Poynting flux within the jet indicates that much of the energy flows up the jet from the inside of the accretion disc but a substantial fraction flows back down to the outside.

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## Radiative transfer in SPH and applications in the collapse of molecular clouds

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*Aims:* We introduce and test a new and highly efficient method for treating the thermal and radiative effects in the energy equation in SPH simulations of star formation.

*Methods*: The method uses the density and gravitational potential of each particle to make an estimate of the particle's optical depth, which in turn regulates the particle's heating and cooling. The effects of (i) the rotational and vibrational degrees of freedom of $H_2$, $H_2$ dissociation, $H^0$ ionisation, He first and second ionisation, (ii) the opacity changes due to e.g. ice mantle melting, the sublimation of dust, molecular and $H^-$ contributions, and (iii) the thermal inertia, are all captured at minimal computational cost.

*Results:* We apply this new method to simulate the collapse of a 1-$M_\odot$ molecular cloud of initially uniform density and temperature. At first, the collapse proceeds almost isothermally, with the temperature rising as $\sim \rho^{0.08}$ which is similar to the Larson (2005) relation. The cloud starts heating fast when the optical depth to the of the cloud centre reaches unity ($\sim 7 \times 10^{-13}$ g cm$^{-3}$). The first core forms at $\rho \sim 4 \times 10^{-9}$ g cm$^{-3}$ and steadily increases in mass. When the temperature at the centre reaches 2,000 K molecular hydrogen starts to dissociate and the second collapse begins, leading to the formation of the second (protostellar) core. The results are very similar to the Masunaga & Inutsuka (2000) detailed calculation.

We also study (i) the collapse of a 1.2-$M_\odot$ cloud, which initially has uniform density and temperature, (ii) the collapse of a 1.2-$M_\odot$ rotating cloud, with an $m = 2$ density perturbation, and uniform initial temperature, and (iii) the smoothing of temperature fluctuations in a static, uniform density sphere. The new algorithm performs very well

and reproduces the results of previous authors. The method is computationally efficient; the computational time is comparable to a standard SPH simulation with a barotropic equation of state. Furthermore, it is relatively easy to implement and can be applied to both particle- and grid-based codes.

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## Herbig-Haro Objects - Tracers of the Formation of Low-mass Stars and Sub-stellar Objects

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Herbig-Haro objects (HHOs) are caused by outflows from young objects. Since the outflow relies on mass accretion from a circumstellar disk, it indicates ongoing growth. Recent results of infrared observations yielded evidence for disks around brown dwarfs. This suggests that at least a certain fraction of brown dwarfs forms like stars. Thus, young sub-stellar objects might cause HHOs as well. We present selected results of a general survey for HHOs based on DSS-II plates and CCD images taken with the Tautenburg Schmidt telescope. Numerous young objects could be identified due to their association with newly detected HHOs. In some cases the luminosity is consistent with very low-mass stars or close to sub-stellar values. This holds for L1415-IRS and a few infrared sources embedded in other dark clouds (e.g., GF9, BHR111). The question on the minimum mass for outflow activity is addressed.

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## Emission Line Variability of the Accreting Young Brown Dwarf 2MASSWJ1207334-393254: From Hours to Years

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We have obtained a series of high-resolution optical spectra for the brown dwarf 2MASSWJ1207334-393254 (2M 1207). Two consecutive observing nights at the ESO Very Large Telescope with the UVES spectrograph yielded a timeseries with a resolution of $\sim 12$ min. Additional high-resolution optical spectra were obtained months apart at the Magellan Clay telescope using the MIKE instrument. Combined with previously published results, these data allow us to investigate changes in the emission line spectrum of 2M 1207 on timescales of hours to years. Most of the emission line profiles of 2M 1207 are broad, in particular that of H$\alpha$, indicating that the dominant fraction of the emission must be attributed to disk accretion rather than to magnetic activity. From the H$\alpha$ 10 % width we deduce a relatively stable accretion rate between $10^{-10.1...-9.8}\,M_{\odot}$/yr for two nights of consecutive observations. Therefore, either the accretion stream is nearly homogeneous over (sub-)stellar longitude or the system is seen face-on. Small but significant variations are evident throughout our near-continuous observation, and they reach a maximum after $\sim 8$ h, roughly the timescale on which maximum variability is expected across the rotation cycle. Together with past measurements, we confirm that the accretion rate of 2M 1207 varies by more than one order of magnitude on timescales of months to years. Such variable mass accretion yields a plausible explanation for the observed spread in the $\dot{M} - M$ diagram. The magnetic field required to drive the funnel flow is on the order of a few hundred G. Despite the obvious presence of a magnetic field, no radio nor X-ray emission has been reported for 2M 1207. Possibly strong accretion suppresses magnetic activity in brown dwarfs, similar to the findings for higher mass T Tauri stars.

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## A multi-transition molecular line study of candidate massive young stellar objects associated with methanol masers

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*Aims.* We characterize the molecular environment of candidate massive young stellar objects (MYSOs) signposted by methanol masers.

*Methods.* Single pixel observations of 10 transitions of $HCO^+$, CO and CS isotopomers were carried out, using the IRAM 30 m telescope. We studied a sample of 28 targets for which the 6.7 GHz maser emission positions are known with a sub-arcsecond accuracy.

*Results.* The systemic velocity inferred from the optically thin lines agrees within $\pm 3$ km s$^{-1}$ with the central velocity of the maser emission for most of the sources. About 64% of the sources show line wings in one or more transitions of CO, $HCO^+$ and CS species, indicating the presence of molecular outflows. Comparison of the widths of line wings and methanol maser emission suggests that the 6.7 GHz maser line traces the environment of MYSO of various kinematic regimes. Therefore, conditions conducive for the methanol maser can exist in the inner parts of molecular clouds or circumstellar discs as well as in the outer parts associated with molecular outflows. Calculations of the physical conditions based on the CO and $HCO^+$ lines and the CS line intensity ratios refine the input parameters for maser models. Specifically, a gas number density of $< 10^7$ cm$^{-3}$ is sufficient for strong maser emission and a high methanol fractional abundance ($> 5 \times 10^{-7}$) is required.

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## ATCA 1.2 cm Observations of the Massive Star Forming Region G305.2+0.2

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We report on Australia Telescope observations of the massive star forming region G305.2+0.2 at 1.2 cm. We detected emission in five molecules towards G305A, confirming its hot core nature. We determined a rotational temperature of 26 K for methanol. A non-LTE excitation calculation suggests a kinematic temperature of order 200 K. A time dependent chemical model is also used to model the gas phase chemistry of the hot core associated with G305A. A comparison with the observations suggest an age of between 2 $\times 10^4$ and 1.5 $\times 10^5$ years.We also report on a feature to the SE of G305A which may show weak Class I methanol maser emission in the line at 24.933 GHz. The more evolved source G305B does not show emission in any of the line tracers, but strong Class I methanol maser emission at 24.933 GHz is found 3″ to the east. Radio continuum emission at 18.496 GHz is detected towards two *HII*regions. The implications of the non-detection of radio continuum emission toward G305A and G305B are also discussed.

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## Magnetic Fields in Protoplanetary Disks

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Magnetic fields likely play a key role in the dynamics and evolution of protoplanetary disks. They have the potential to efficiently transport angular momentum by MHD turbulence or via the magnetocentrifugal acceleration of outflows from the disk surface. Magnetically-driven mixing has implications for disk chemistry and evolution of the grain population, and the effective viscous response of the disk determines whether planets migrate inwards or outwards. However, the weak ionisation of protoplanetary disks means that magnetic fields may not be able to effectively couple to the matter. I examine the magnetic diffusivity in a minimum solar nebula model and present calculations of the ionisation equilibrium and magnetic diffusivity as a function of height from the disk midplane at radii of 1 and 5 AU. Dust grains tend to suppress magnetic coupling by soaking up electrons and ions from the gas phase and reducing the conductivity of the gas by many orders of magnitude. However, once grains have grown to a few microns in size their effect starts to wane and magnetic fields can begin to couple to the gas even at the disk midplane. Because ions are generally decoupled from the magnetic field by neutral collisions while electrons are not, the Hall effect tends to dominate the diffusion of the magnetic field when it is able to partially couple to the gas, except at the disk surfaces where the low density of neutrals permits the ions to remain attached to the field lines.

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## On the Likelihood of Supernova Enrichment of Protoplanetary Disks

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We estimate the likelihood of direct injection of supernova ejecta into protoplanetary disks using a model in which the number of stars with disks decreases linearly with time, and clusters expand linearly with time such that their surface density is independent of stellar number. The similarity of disk dissipation and main-sequence lifetimes implies that the typical supernova progenitor is very massive, ∼75100 $M_\odot$. Such massive stars are found only in clusters with $gtrsim 10^4$ members. Moreover, there is only a small region around a supernova within which disks can survive the blast yet be enriched to the level observed in the solar system. These two factors limit the overall likelihood of supernova enrichment of a protoplanetary disk to $\lesssim 1\%$. If the presence of short-lived radionucleides in meteorites is to be explained in this way, however, the solar system most likely formed in one of the largest clusters in the Galaxy, more than 2 orders of magnitude greater than Orion, where multiple supernovae impacted many disks in a short period of time.

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## A Combined *Spitzer* & *Chandra* Survey of Young Stellar Objects in the Serpens Cloud Core.

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We present *Spitzer* and *Chandra* observations of the nearby (∼260 pc) embedded stellar cluster in the Serpens Cloud Core. We observed, using *Spitzer's* IRAC and MIPS instruments, in six wavelength bands from 3 to 70 $\mu m$, to detect thermal emission from circumstellar disks and protostellar envelopes, and to classify stars using color-color diagrams and spectral energy distributions (SEDs). These data are combined with *Chandra* observations to examine the effects of circumstellar disks on stellar X-ray properties. Young diskless stars were also identified from their increased X-ray emission.

We have identified 138 YSOs in Serpens: 22 class 0/I, 16 flat spectrum, 62 class II, 17 transition disk, and 21 class III stars; 60 of which exhibit X-ray emission. Our primary results are the following: 1.) ten protostars detected previously in the sub-millimeter are detected at $\lambda < 24$ $\mu$m, seven at $\lambda < 8$ $\mu$m, 2.) the protostars are more closely grouped than more evolved YSOs (median separation : $\sim 0.024$ pc), and 3.) the luminosity and temperature of the X-ray emitting plasma around these YSOs does not show any significant dependence on evolutionary class. We combine the infrared derived values of $A_K$ and X-ray values of $N_H$ for 8 class III objects and find that the column density of hydrogen gas per mag of extinctions is less than half the standard interstellar value, for $A_K > 1$. This may be the result of grain growth through coagulation and/or the accretion of volatiles in the Serpens cloud core.

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## Origin of the Metallicity Dependence of Exoplanet Host Stars in the Protoplanetary Disk Mass Distribution

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The probability of a star hosting a planet that is detectable in radial velocity surveys increases $P_{\rm pl}(Z) \propto (10^Z)^2$, where $Z$ is stellar metallicity. Models of planet formation by core accretion reproduce this trend, since the protoplanetary disk of a high metallicity star has a high density of solids and so forms planetary cores which accrete gas before the primordial gas disk dissipates. This paper considers the origin of the form of the metallicity dependence of $P_{\rm pl}(Z)$. We introduce a simple model in which detectable planets form when the mass of solid material in the protoplanetary disk, $M_{\rm s}$, exceeds a critical value. In this model the form of $P_{\rm pl}(Z)$ is a direct reflection of the distribution of protoplanetary disk masses, $M_{\rm g}$, and the observed metallicity relation is reproduced if $P(M_{\rm g} > M_{\rm g}^{'}) \propto (M_{\rm g}^{'})^{-2}$. We argue that a protoplanetary disk's dust mass measured in sub-mm observations is a relatively pristine indicator of the mass available for planet-building and find that the disk mass distribution derived from such observations is consistent with the observed $P_{\rm pl}(Z)$ if a solid mass $M_{\rm s} > 0.5 M_{\rm J}$ is required to form detectable planets. Any planet formation model which imposes a critical solid mass for detectable planets to form would reproduce the observed metallicity relation, and core accretion models are empirically consistent with such a threshold criterion. While the outcome of planet formation in individual systems is debatable, we identify 7 protoplanetary disks which, by rigid application of this criterion, would be expected to form detectable planets and may provide insight into the physical conditions required to form such planets. A testable prediction of the model is that the metallicity dependence should flatten both for $Z > 0.5$ dex and as more distant and lower mass planets are discovered. Further, combining this model with one in which the evolution of a star's debris disk is also influenced by the solid mass in its protoplanetary disk, results in the prediction that debris disks detected around stars with planets should be more infrared luminous than those around stars without planets in tentative agreement with recent observations.

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## Early Cosmological H II/He III Regions and Their Impact on Second-Generation Star Formation

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We present the results of three-dimensional radiation hydrodynamics simulations of the formation and evolution of early H II/He III regions around the first stars. Cooling and recollapse of the gas in the relic H II region is also followed in a full cosmological context, until second-generation stars are formed. We first carry out ray-tracing simulations of ionizing radiation transfer from the first star. Hydrodynamics is directly coupled with photoionization heating as well as radiative and chemical cooling. The photoionized hot gas is evacuated out of the host halo at a velocity of ∼30 km $s^{-1}$. This radiative feedback effect quenches further star formation within the halo for over tens to a hundred million years. We show that the thermal and chemical evolution of the photoionized gas in the relic H II region is remarkably different from that of a neutral primordial gas. Efficient molecular hydrogen production in the recombining gas enables it to cool to ∼100 K, where fractionation of $HD/H_2$ occurs. The gas further cools by HD line cooling down to a few tens of kelvins. Interestingly, at high redshifts (z > 10), the minimum gas temperature is limited by that of the cosmic microwave background with $T_{CMB} = 2.728(1 + z)$. The gas cloud experiences runaway collapse when its mass is ∼40 $M_\odot$, which is significantly smaller than a typical clump mass of ∼200300 $M_\odot$ for early primordial gas clouds. We argue that massive, rather than very massive, primordial stars may form in the relic H II region. Such stars might be responsible for early metal enrichment of the interstellar medium from which recently discovered hypermetal-poor stars were born.

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## MHD simulations of jet acceleration from Keplerian accretion disks - The effects of disk resistivity

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*Context.* Accretion disks and astrophysical jets are used to model many active astrophysical objects, such as young stars, relativistic stars, and active galactic nuclei. However, existing proposals for how these structures may transfer angular momentum and energy from disks to jets through viscous or magnetic torques do not yet provide a full understanding of the physical mechanisms involved. Thus, global stationary solutions have not explained the stability of these structures; and global numerical simulations that include both the disk and jet physics have so far been limited to relatively short time scales and narrow (and possibly astrophysically unlikely) ranges of viscosity and resistivity parameters that may be crucial to defining the coupling of the inflow-outflow dynamics.

*Aims.* We present self-consistent, time-dependent simulations of supersonic jets launched from magnetized accretion disks, using high-resolution numerical techniques. In particular we study the effects of the disk's magnetic resistivity, parametrized through an $\alpha$-prescription, in determining the properties of the inflow-outflow system. Moreover we analyze under which conditions steady state solutions of the type proposed in the self-similar models of Blandford & Payne can be reached and maintained in a self-consistent nonlinear stage.

*Methods.* We used the resistive MHD FLASH code with adaptive mesh refinement (AMR), allowing us to follow the evolution of the structure on a long enough time scale to reach steady state. A detailed analysis of the initial configuration state is given.

*Results.* We obtain the expected solutions within the axisymmetric (2.5 D) limit. Assuming a magnetic field around equipartition with the thermal pressure of the disk, we show how the characteristics of the disk-jet system, such as the ejection efficiency and the energetics, are affected by the anomalous resistivity acting inside the disk.

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## Circumbinary Molecular Rings Around Young Stars in Orion

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We present high angular resolution 1.3 mm continuum, methyl cyanide molecular line, and 7 mm continuum observations made with the Submillimeter Array and the Very Large Array, toward the most highly obscured and southern part of the massive star forming region OMC1S located behind the Orion Nebula. We find two flattened and rotating molecular structures with sizes of a few hundred astronomical units suggestive of circumbinary molecular rings produced by the presence of two stars with very compact circumstellar disks with sizes and separations of about 50 AU, associated with the young stellar objects 139-409 and 134-411. Furthermore, these two circumbinary rotating rings are related to two compact and bright *hot molecular cores*. The dynamic mass of the binary systems obtained from our data are $\geq 4$ $M_\odot$ for 139-409 and $\geq 0.5$ $M_\odot$ for 134-411. This result supports the idea that intermediate-mass stars will form through *circumstellar disks* and jets/outflows, as the low mass stars do. Furthermore, when intermediate-mass stars are in multiple systems they seem to form a circumbinary ring similar to those seen in young, multiple low-mass systems (e.g., GG Tau and UY Aur).

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# Molecular fingerprints of star formation throughout the Universe
## - a space-based infrared study -

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Ph.D degree awarded: May 2007

Organic chemistry plays an important role in the study of the physics and evolution of the warm dense Interstellar Medium (ISM). This warm dense ISM is found in very different environment, e.g. in the disks around low-mass young stellar objects (YSOs), in the envelopes of massive-YSOs, and in the nuclei of Ultra Luminous Infrared Galaxies (ULIRGS). The excitation temperatures and abundances of the observed molecules provide the observer with a physicochemical snapshot of the regions. The abundances of the molecules depend strongly on temperature, density, radiation field (UV, Infrared and X-ray) and initial composition of the gas. A prime example is high temperature organic chemistry. At high temperatures ($> 300\,$K), the hydrocarbon and nitrogen chemistries are enhanced because most of the oxygen is converted into water by neutral-neutral reactions. The abundances of molecules such as acetylene ($C_2H_2$), methane ($CH_4$) and hydrogen cyanide (HCN) can be enhanced by orders of magnitude while at the same time the formation of carbon dioxide ($CO_2$) is reduced as its primary formation route through the hydroxyl radial OH is blocked.

Infrared spectroscopy is instrumental in the study of the chemistry in the dense ISM as many molecules have transitions in the infrared. Some also have transitions in the submm, e.g. HCN which allows to put further constraints on the physical parameters. Space based instruments, not being hindered by the earth atmosphere, allow us to study all molecular species which have transitions in the infrared. The molecular absorption and emission features are often weak. Therefor a major challenge in using these instruments is to understand the instrumental characteristics and translating that knowledge into usable reduction algorithms. Most of the data used in this thesis are obtained with space based spectrographs, ISO-SWS and *Spitzer*-IRS, pushing them to their limits. As this has been an important aspect of the work done in preparation of the science papers it receives ample credit in chapters 2 and 3 of the thesis.

Chapter 4 is devoted to the study of molecular absorption features ($C_2H_2$ and HCN), observed with ISO SWS, as evolutionary tracers of massive star formation. For the study of low mass star forming regions a sample of *Spitzer*-IRS spectra from the *Spitzer* legacy programme "From Molecular Cores to Planet-Forming Disks" are used. This involves two papers on molecular hydrogen and atomic fine structure emission lines (chapter 5 and 6). Chapter 5 presents the first detections of [Ne II] and [Fe I] toward classical T Tauri stars in $\sim 20\,\%$ respectively $\sim 9\,\%$ of the disk sources in the c2d sample. Chapter 7 present observations of $C_2H_2$, HCN and $CO_2$ toward IRS 46 tracing high temperature organic chemistry in the inner disk around the young star. The final chapter is devoted to *Spitzer*-IRS observations toward deeply obscured nuclei of a sample of luminous and ultraluminous infrared galaxies (LIRGS and ULIRGS). Warm (300 - 800 K) and abundant gaseous $C_2H_2$ and HCN is observed which is associated with a phase of deeply embedded star formation where the extreme pressures and densities of the nuclear starburst environment have inhibited the expansion of H II regions and the global disruption of the star forming molecular cloud cores, and 'trapped' the star formation process in an 'extended' Hot Core phase.

http://www.strw.leidenuniv.nl/events/phdtheses/lahuis/
http://hdl.handle.net/1887/11950

# *Meetings*

## THE COSMIC AGITATOR - MAGNETIC FIELDS IN THE GALAXY: 60 years of studies of the interstellar magnetic field

The magnetic field of the galaxy was discovered in observations made in 1948. Since that time, the galactic magnetic field has challenged (and often annoyed) observers and theorists alike. This meeting will celebrate sixty years of studies of the interstellar magnetic field.

The meeting will take place in Lexington, Kentucky USA, in the heart of the beautiful Bluegrass region. Lexington and its environs are known for picturesque countryside, thoroughbred race horses, and fine bourbon whiskey asleep many years in the wood.

The meeting web site is http://thunder.pa.uky.edu/magnetic/

# *Short Announcements*

## Presentations at the "Multiplicity in Star Formation" Workshop

Presentations given at the "Multiplicity in Star Formation", held in Toronto on 2007 May 16-18, are now available online at http://www.astro.utoronto.ca/msf/program.html The program consisted of 46 short talks on theory and observations related to the formation and early evolution of stellar and sub-stellar systems. The workshop was sponsored by the University of Toronto Department of Astronomy & Astrophysics and the Canadian Institute for Theoretical Astrophysics, with additional support from the Connaught Fund.