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## *Abstracts of recently accepted papers*

### **Episodic formation of cometary material in the outburst of a young Sun-like star**

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The Solar System originated in a cloud of interstellar gas and dust. The dust is in the form of amorphous silicate particles and carbonaceous dust. The composition of cometary material, however, shows that a significant fraction of the amorphous silicate dust was transformed into crystalline form during the early evolution of the protosolar nebula. How and when this transformation happened has been a question of debate, with the main options being heating by the young Sun and shock heating. Here we report mid-infrared features in the outburst spectrum of the young Sun-like star EX Lupi that were not present in quiescence. We attribute them to crystalline forsterite. We conclude that the crystals were produced through thermal annealing in the surface layer of the inner disk by heat from the outburst, a process that has hitherto not been considered. The observed lack of cold crystals excludes shock heating at larger radii.

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### **Protoplanetary Disk Structures in Ophiuchus**

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We present the results of a high angular resolution (0.3 arcsec  $\approx$  40 AU) Submillimeter Array survey of the 345 GHz (870  $\mu$ m) thermal continuum emission from 9 of the brightest, and therefore most massive, circumstellar disks in the  $\sim$ 1 Myr-old Ophiuchus star-forming region. Using two-dimensional radiative transfer calculations, we simultaneously fit the observed continuum visibilities and broadband spectral energy distribution for each disk with a parametric structure model. Compared to previous millimeter studies, this survey includes significant upgrades in modeling, data quality, and angular resolution that provide improved constraints on key structure parameters, particularly those that characterize the spatial distribution of mass in the disks. In the context of a surface density profile motivated by similarity solutions for viscous accretion disks,  $\Sigma \propto (R/R_c)^{-\gamma} \exp[-(R/R_c)^{2-\gamma}]$ , the best-fit models for the sample disks have characteristic radii  $R_c \approx$  20-200 AU, high disk masses  $M_d \approx$  0.005-0.14  $M_\odot$  (a sample selection bias), and a narrow range of radial  $\Sigma$  gradients ( $\gamma \approx$  0.4-1.0) around a median  $\gamma =$  0.9. These density structures are used in conjunction with accretion rate estimates from the literature to help characterize the viscous evolution of the disk material. Using the standard prescription for disk viscosities, those combined constraints indicate that  $\alpha \approx$  0.0005-

0.08. Three of the sample disks show large ( $R \approx 20\text{-}40$  AU) central cavities in their continuum emission morphologies, marking extensive zones where dust has been physically removed and/or has significantly diminished opacities. Based on the current requirements of planet formation models, these emission cavities and the structure constraints for the sample as a whole suggest that these young disks may eventually produce planetary systems, and have perhaps already started.

Accepted by Astrophysical Journal

<http://arxiv.org/abs/0906.0730>

## The diversity of methanol maser morphologies from VLBI observations

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The 6.7 GHz methanol maser marks an early stage of high-mass star formation, but the origin of this maser is currently a matter of debate. In particular it is unclear whether the maser emission arises in discs, outflows or behind shocks running into rotating molecular clouds. We investigated which structures the methanol masers trace in the environment of high-mass protostar candidates by observing a homogenous sample of methanol masers selected from Torun surveys. We also probed their origins by looking for associated H II regions and IR emission. We selected 30 methanol sources with improved position accuracies achieved using MERLIN and another 3 from the literature. We imaged 31 of these using the European VLBI Network's expanded array of telescopes with 5-cm (6-GHz) receivers. We used the VLA to search for 8.4 GHz radio continuum counterparts and inspected *Spitzer* GLIMPSE data at 3.6–8  $\mu\text{m}$  from the archive. High angular resolution images allowed us to analyze the morphology and kinematics of the methanol masers in great detail and verify their association with radio continuum and mid-infrared emission. A new class of "ring-like" methanol masers in star-forming regions appeared to be surprisingly common, 29% of the sample. The new morphology strongly suggests that methanol masers originate in the disc or torus around a proto- or a young massive star. However, the maser kinematics indicate the strong influence of outflow or infall. This suggests that they form at the interface between the disc/torus and a flow. This is also strongly supported by *Spitzer* results because the majority of the masers coincide with 4.5  $\mu\text{m}$  emission to within less than 1 arcsec. Only four masers are associated with the central parts of UC H II regions. This implies that 6.7 GHz methanol maser emission occurs before H II region observable at cm wavelengths is formed.

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## The kinematics of NGC1333-IRAS2A - a true Class 0 protostar

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Low-mass star formation is described by gravitational collapse of dense cores of gas and dust. At some point during the collapse, a disk is formed around the protostar and the disk will spin up and grow in size as the core contracts because of angular momentum conservation. The question is how early the disk formation process occurs. In this paper we aim to characterize the kinematical state of a deeply embedded, Class 0 young stellar object, NGC1333-IRAS2A, based on high angular resolution ( $1'' \approx 200$  AU) interferometric observations of HCN and H<sup>13</sup>CN  $J = 4\text{-}3$  from the Submillimeter Array, and test whether a circumstellar disk can be detected based on gas kinematic features. We adopt a physical model which has been shown to describe the object well and obtain a fit of a parameterized

model of the velocity field, using a two-dimensional axis-symmetric radiation transfer code. The parameterization and fit to the high angular resolution data characterize the central dynamical mass and the ratio of infall velocity to rotation velocity. We find a large amount of infall and very little rotation on all scales. The central object has a relatively low mass of  $0.25 M_{\odot}$ . As an object with a low stellar mass compared to the envelope mass, we conclude that NGC1333-IRAS2A is consistent with the suggestion that, as a Class 0 object, it represents the earliest stages of star formation. The large amount of infall relative to rotation also suggests that this is a young object. We do however find the need of a central compact component on scales of a few hundred AU based on the continuum data, which suggests that disk formation happens shortly after the initial gravitational collapse. The data do not reveal a distinct velocity field for this  $0.1 M_{\odot}$  component.

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<http://adsabs.harvard.edu/abs/2009arXiv0905.4575B>

## Multidimensional chemical modelling, II. Irradiated outflow walls

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Observations of the high-mass star forming region AFGL 2591 reveal a large abundance of  $\text{CO}^+$ , a molecule known to be enhanced by far UV (FUV) and X-ray irradiation. In chemical models assuming a spherically symmetric envelope, the volume of gas irradiated by protostellar FUV radiation is very small due to the high extinction by dust. The abundance of  $\text{CO}^+$  is thus underpredicted by orders of magnitude. In a more realistic model, FUV photons can escape through an outflow region and irradiate gas at the border to the envelope. Thus, we introduce the first 2D axi-symmetric chemical model of the envelope of a high-mass star forming region to explain the  $\text{CO}^+$  observations as a prototypical FUV tracer. The model assumes an axi-symmetric power-law density structure with a cavity due to the outflow. The local FUV flux is calculated by a Monte Carlo radiative transfer code taking scattering on dust into account. A grid of precalculated chemical abundances, introduced in the first part of this series of papers, is used to quickly interpolate chemical abundances. This approach allows to calculate the temperature structure of the FUV heated outflow walls self-consistently with the chemistry.

Synthetic maps of the line flux are calculated using a raytracer code. Single-dish and interferometric observations are simulated and the model results are compared to published and new JCMT and SMA observations. The two-dimensional model of AFGL 2591 is able to reproduce the JCMT single-dish observations and also explains the non-detection by the SMA. We conclude that the observed  $\text{CO}^+$  line flux and its narrow width can be interpreted by emission from the warm and dense outflow walls irradiated by protostellar FUV radiation.

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<http://arxiv.org/abs/0906.0588> and

<http://www.astro.phys.ethz.ch/staff/simonbr/papgridII.pdf>

## Chemical Modelling of Young Stellar Objects, I. Method and Benchmarks

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Upcoming facilities such as the Herschel Space Observatory or ALMA will deliver a wealth of molecular line observations of young stellar objects (YSOs). Based on line fluxes, chemical abundances can then be estimated by radiative transfer calculations. To derive physical properties from abundances, the chemical network needs to be modeled and fitted to the observations. This modeling process is however computationally exceedingly demanding, particularly if

in addition to density and temperature, far UV (FUV) irradiation, X-rays, and multi-dimensional geometry have to be considered.

We develop a fast tool, suitable for various applications of chemical modeling in YSOs. A grid of the chemical composition of the gas having a density, temperature, FUV irradiation and X-ray flux is pre-calculated as a function of time. A specific interpolation approach is developed to reduce the database to a feasible size. Published models of AFGL 2591 are used to verify the accuracy of the method. A second benchmark test is carried out for FUV sensitive molecules.

The novel method for chemical modeling is more than 250,000 times faster than direct modeling and agrees within a mean factor of 1.35. The tool is distributed for public use. Main applications are (i) fitting physical parameters to observed molecular line fluxes and (ii) derive chemical abundances for 2D and 3D models. They will be presented in two future publications of this series.

In the course of developing the method, the chemical evolution is explored: We find that X-ray chemistry in envelopes of YSOs can be reproduced by means of an enhanced cosmic-ray ionization rate with deviations less than 25%, having the observational consequence that molecular tracers for X-rays are hard to distinguish from cosmic ray ionization tracers. We provide the detailed prescription to implement this total ionization rate approach in any chemical model. We further find that the abundance of  $\text{CH}^+$  in low-density gas with high ionization can be enhanced by the recombination of doubly ionized carbon ( $\text{C}^{++}$ ) and suggest a new value for the initial abundance of the main sulphur carrier in the hot-core.

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## First detection of acceleration and deceleration in protostellar jets? Time variability in the Cha II outflows

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*Context.* Kinematical and time variability studies of protostellar jets are fundamental for understanding the dynamics and the physics of these objects. Such studies remain very sporadic, since they require long baselines before they can be accomplished.

*Aims.* We present for the first time a multi-epoch (20 years baseline) kinematical investigation of HH 52, 53, and 54 at optical and near-IR wavelengths, along with medium (optical) and high resolution (NIR) spectroscopic analyses, probing the kinematical and physical time variability conditions of the gas along the flows.

*Methods.* By means of multi-epoch and multi-wavelength narrow-band images, we derived proper motions (P.M.s), tangential velocities, velocity, and flux variability of the knots. Radial velocities and physical parameters of the gas were derived from spectroscopy. Finally, spatial velocities and inclination of the flows were obtained by combining both imaging and spectroscopy.

*Results.* The P.M. analysis reveals three distinct, partially overlapping outflows. Spatial velocities of the knots vary from  $50 \text{ km s}^{-1}$  to  $120 \text{ km s}^{-1}$ . The inclinations of the three flows are  $58 \pm 3^\circ$ ,  $84 \pm 2^\circ$ , and  $67 \pm 3^\circ$  (HH 52, HH 53, and HH 54 flows, respectively). In 20 years, about 60% of the observed knots show some degree of flux variability. Our set of observations apparently indicates acceleration and deceleration in a variety of knots along the jets. For about 20% of the knots, mostly coincident with working surfaces or interacting knots along the flows, a relevant variability in both flux and velocity is observed. We argue that both variabilities are related and that all or part of the kinetic energy lost by the interacting knots is successively radiated. The physical parameters derived from the diagnostics are quite homogeneous along and among the three outflows. The analysis indicates the presence of very light ( $N_{\text{H}} \sim 10^3 \text{ cm}^{-3}$ ), ionised ( $X_{\text{e}} \sim 0.2-0.6$ ), and hot ( $T_{\text{e}} \sim 14000-26000 \text{ K}$ ) flows, impacting a denser medium. Several knots are deflected, especially in the HH 52 flow. At least for a couple of them (HH 54 G and G0), the deflection originates from the

collision of the two. For the more massive parts of the flow, the deflection is likely the result of the flow collision with a dense cloud or with clumps. Finally, we discuss the possible driving sources of the flows.

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<ftp://ftp.tls-tautenburg.de/pub/caratti/aa11664.pdf>

## Deep MIPS Observations of the IC 348 Nebula: Constraints on the Evolutionary State of Anemic Circumstellar Disks and the Primordial-to-Debris Transition

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We describe new, deep MIPS photometry and new high signal-to-noise optical spectroscopy of the 2.5 Myr-old IC 348 Nebula. To probe the properties of the IC 348 disk population, we combine these data with previous optical/infrared photometry and spectroscopy to identify stars with gas accretion, to examine their mid-IR colors, and to model their spectral energy distributions. IC 348 contains many sources in different evolutionary states, including protostars and stars surrounded by primordial disks, two kinds of transitional disks, and debris disks. Most disks surrounding early/intermediate spectral-type stars ( $> 1.4 M_{\odot}$  at 2.5 Myr) are debris disks; most disks surrounding solar and subsolar-mass stars are primordial disks. At the  $1-2 \sigma$  level, more massive stars also have a smaller frequency of gas accretion and smaller mid-IR luminosities than lower-mass stars. These trends are suggestive of a stellar mass-dependent evolution of disks, where most disks around high/intermediate-mass stars shed their primordial disks on rapid, 2.5 Myr timescales. The frequency of MIPS-detected transitional disks is  $\sim 15-35\%$  for stars plausibly more massive than  $0.5 M_{\odot}$ . The relative frequency of transitional disks in IC 348 compared to that for 1 Myr-old Taurus and 5 Myr-old NGC 2362 is consistent with a transition timescale that is a significant fraction of the total primordial disk lifetime.

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## The fragmentation of expanding shells I: Limitations of the thin-shell approximation

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We investigate the gravitational fragmentation of expanding shells in the context of the linear thin-shell analysis. We make use of two very different numerical schemes; the FLASH Adaptive Mesh Refinement code and a version of the Benz Smoothed Particle Hydrodynamics code. We find that the agreement between the two codes is excellent. We use our numerical results to test the thin-shell approximation and we find that the external pressure applied to the shell has a strong effect on the fragmentation process. In cases where shells are not pressure-confined, the shells thicken as they expand and hydrodynamic flows perpendicular to the plane of the shell suppress fragmentation at short wavelengths. If the shells are pressure-confined internally and externally, so that their thickness remains approximately constant during their expansion, the agreement with the analytical solution is better.

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## An Analytic Column Density Profile to Fit Prestellar Cores

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We present a new analytical three-parameter formula to fit observed column density profiles of prestellar cores. It represents a line-of-sight integral through a spherically symmetric or disc-like isothermal cloud. The underlying model resembles the BonnorEbert model in that it features a flat central region leading into a power-law decline  $\propto r^{-2}$  in density, and a well-defined outer radius. However, we do not assume that the cloud is in equilibrium, and can instead make qualitative statements about its dynamical state (expansion, equilibrium, collapse) using the size of the flat region as a proxy. Instead of having temperature as a fitting parameter, our model includes it as input, and thus avoids possible inconsistencies. It is significantly easier to fit to observational data than the BonnorEbert sphere. We apply this model to L1689B and B68. We show that L1689B cannot be in equilibrium but instead appears to be collapsing, while our model verifies that B68 is not far from being a hydrostatic object.

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## The orientations of molecular clouds in the outer Galaxy: Evidence for the scale of the turbulence driver ?

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Supernova explosions inject a considerable amount of energy into the interstellar medium (ISM) in regions with high to moderate star formation rates. In order to assess whether the driving of turbulence by supernovae is also important in the outer Galactic disk, where the star formation rates are lower, we study the spatial distribution of molecular cloud (MC) inclinations with respect to the Galactic plane. The latter contains important information on the nature of the mechanism of energy injection into the ISM. We analyze the spatial correlations between the position angles (PAs) of a selected sample of MCs (the largest clouds in the catalogue of the outer Galaxy published by Heyer et al. 2001). Our results show that when the PAs of the clouds are all mapped to values into the (0,90) degrees interval, there is a significant degree of spatial correlation between the PAs on spatial scales in the range of 100-800 pc. These scales are of the order of the sizes of individual SN shells in low density environments such as those prevailing in the outer Galaxy and where the metallicity of the ambient gas is of the order of the solar value or smaller. These findings suggest that individual SN explosions, occurring in the outer regions of the Galaxy and in likewise spiral galaxies, albeit at lower rates, continue to play an important role in shaping the structure and dynamics of the ISM in those regions. The SN explosions we postulate here are likely associated with the existence of young stellar clusters in the far outer regions of the Galaxy and the UV emission and low levels of star formation observed with the GALEX satellite in the outer regions of local galaxies.

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## X-ray Photoevaporation-Starved T Tauri Accretion

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X-ray luminosities of accreting T Tauri stars are observed to be systematically lower than those of nonaccretors. There is as yet no widely accepted physical explanation for this effect, though it has been suggested that accretion somehow suppresses, disrupts or obscures coronal X-ray activity. Here, we suggest that the opposite might be the case: coronal X-rays modulate the accretion flow. We re-examine the X-ray luminosities of T Tauri stars in the Orion Nebula Cluster and find that not only are accreting stars systematically fainter, but that there is a correlation between

mass accretion rate and stellar X-ray luminosity. We use the X-ray heated accretion disk models of Ercolano et al. to show that protoplanetary disk photoevaporative mass-loss rates are strongly dependent on stellar X-ray luminosity and sufficiently high to be competitive with accretion rates. X-ray disk heating appears to offer a viable mechanism for modulating the gas accretion flow and could be at least partially responsible for the observed correlation between accretion rates and X-ray luminosities of T Tauri stars.

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## Spatially Resolved Mid-Infrared Imaging of the SR 21 Transition Disk

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We present mid-infrared (mid-IR) observations from Gemini/TReCS that spatially resolve the dust emission around SR 21. The protoplanetary disk around SR 21 is believed to have a cleared gap extending from stellocentric radii of  $\sim 0.5$  AU to  $\sim 20$  AU, based on modeling of the observed spectral energy distribution (SED). Our new observations resolve the dust emission, and our data are inconsistent with the previous model. We require the disk to be completely cleared within  $\sim 10$  AU, without the hot inner disk spanning  $\sim 0.25$ - $0.5$  AU posited previously. To fit the SED and mid-IR imaging data together, we propose a disk model with a large inner hole, but with a warm companion possibly surrounded by circumstellar material of its own residing near the outer edge of the cleared region. We also discuss a model with a narrow ring included in a large cleared inner disk region, and argue that it is difficult to reconcile with the data.

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## The Initial Conditions of Clustered Star Formation. I. NH<sub>3</sub> Observations of Dense Cores in Ophiuchus

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We present combined interferometer and single dish telescope data of NH<sub>3</sub> ( $J, K$ ) = (1,1) and (2,2) emission toward the clustered star forming Ophiuchus B, C, and F Cores at high spatial resolution ( $\sim 1200$  AU) using the Australia Telescope Compact Array, the Very Large Array, and the Green Bank Telescope. While the large-scale features of the NH<sub>3</sub> (1,1) integrated intensity appear similar to 850  $\mu\text{m}$  continuum emission maps of the Cores, on 15'' (1800 AU) scales we find significant discrepancies between the dense gas tracers in Oph B, but good correspondence in Oph C and F. Using the CLUMPFIND structure identifying algorithm, we identify 15 NH<sub>3</sub> clumps in Oph B, and three each in Oph C and F. Only five of the Oph B NH<sub>3</sub> clumps are coincident within 30'' (3600 AU) of a submillimeter clump. We find  $\nu_{\text{LSR}}$  varies little across any of the cores, and additionally varies by only  $\sim 1.5$  km s<sup>-1</sup> between them. The observed NH<sub>3</sub> line widths within the Oph B and F Cores are generally large and often mildly supersonic, while Oph C is characterized by narrow line widths which decrease to nearly thermal values. We find several regions of localized narrow line emission ( $\Delta\nu < \sim 0.4$  km s<sup>-1</sup>), some of which are associated with NH<sub>3</sub> clumps. We derive the kinetic temperatures of the gas, and find they are remarkably constant across Oph B and F, with a warmer mean value ( $T_K = 15$  K) than typically found in isolated regions and consistent with previous results in clustered regions. Oph C, however, has a mean  $T_K = 12$  K, decreasing to a minimum  $T_K = 9.4$  K toward the submillimeter continuum peak, similar to previous studies of isolated starless clumps. There is no significant difference in temperature toward protostars embedded in the Cores. NH<sub>3</sub> column densities,  $N(\text{NH}_3)$ , and abundances,  $X(\text{NH}_3)$ , are similar to previous

work in other nearby molecular clouds. We find evidence for a decrease in  $X(\text{NH}_3)$  with increasing  $N(\text{H}_2)$  in Oph B2 and C, suggesting the  $\text{NH}_3$  emission may not be tracing well the densest core gas.

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## **Molecular Clouds Toward RCW49 and Westerlund 2: Evidence for Cluster Formation Triggered by Cloud-Cloud Collision**

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We have made CO( $J = 2-1$ ) observations toward the H II region RCW 49 and its ionizing source, the rich stellar cluster Westerlund 2, with the NANTEN2 submillimeter telescope. These observations have revealed that two molecular clouds in velocity ranges of  $-11$  to  $+9$  km s<sup>-1</sup> and  $11$  to  $21$  km s<sup>-1</sup>, respectively, show remarkably good spatial correlations with the Spitzer IRAC mid-infrared image of RCW 49, as well a velocity structures indicative of localized expansion around the bright central regions and stellar cluster. This strongly suggests that the two clouds are physically associated with RCW 49. We obtain a new kinematic distance estimate to RCW 49 and Wd2 of  $5.4_{-1.4}^{+1.1}$  kpc, based on the mean velocity and velocity spread of the associated gas. We argue that the acceleration of the gas by stellar winds from Westerlund 2 is insufficient to explain the entire observed velocity dispersion of the molecular gas, and suggest a scenario in which a collision between the two clouds  $\sim 4$  Myr ago may have triggered the formation of the stellar cluster.

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## **A new modified-rate approach for gas-grain chemistry: Comparison with a unified large-scale Monte Carlo simulation**

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We compare the results of the unified Monte Carlo chemical model with the new modified-rate equation (MRE) method under a wide range of interstellar conditions, using a full gas-grain chemical network. In most of the explored parameter space, the new MRE method reproduces very well the results of the exact approach. Small disagreements between the methods may be remedied by the use of a more complete surface chemistry network, appropriate to the full range of temperatures employed here.

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## **Short-period variability in the Class II methanol maser source G12.89+0.49 (IRAS 18089-1732)**

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Time series are presented for the class II methanol maser source G12.89+0.49, which has been monitored for nine years at the Hartebeesthoek Radio Astronomy Observatory. The 12.2 and 6.7 GHz methanol masers were seen to exhibit rapid, correlated variations on timescales of less than a month. Daily monitoring has revealed that the variations have a periodic component with a period of 29.5 days. The period seems to be stable over the 110 cycles spanned by the

time series. There are variations from cycle to cycle, with the peak of the flare occurring anywhere within an eleven day window but the minima occur at the same phase of the cycle. Time delays of up to 5.7 days are seen between spectral features at 6.7 GHz and a delay of 1.1 day is seen between the dominant 12.2 GHz spectral feature and its 6.7 GHz counterpart.

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## AK Sco, First Detection of a Highly Disturbed Atmosphere in a Pre-Main-Sequence Close Binary

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AK Sco is a unique source: a  $\sim 10$  Myr old pre-main-sequence (PMS) spectroscopic binary composed of two nearly equal F5 stars that at periastron are separated by barely 11 stellar radii, so the stellar magnetospheres fill the Roche lobe at periastron. The orbit is not yet circularized ( $e = 0.47$ ) and very strong tides are expected. This makes AK Sco the ideal laboratory to study the effect of gravitational tides in the stellar magnetic field building up during PMS evolution. In this Letter, the detection of a highly disturbed ( $\sigma \approx 100 \text{ km s}^{-1}$ ) and very dense atmosphere ( $n_e = 1.6 \times 10^{10} \text{ cm}^{-3}$ ) is reported. Significant line broadening blurs any signs of ion belts or bow shocks in the spectrum of the atmospheric plasma. The radiative losses cannot be accounted for solely by the dissipation of energy from the tidal wave propagating in the stellar atmosphere or by the accreting material. The release of internal energy from the star seems to be the most likely source of the plasma heating. This is the first clear indication of a highly disturbed atmosphere surrounding a PMS close binary.

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## High-Mass Star Formation in the Near and Far 3 kpc Arms

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We report on the presence of 6.7 GHz methanol masers, known tracers of high-mass star formation, in the 3 kpc arms of the inner Galaxy. We present 49 detections from the Methanol Multibeam Survey, the largest Galactic plane survey for 6.7 GHz methanol masers, which coincide in longitude, latitude, and velocity with the recently discovered far-side 3 kpc arm and the well-known near-side 3 kpc arm. The presence of these masers is significant evidence for high-mass star formation actively occurring in both 3 kpc arms.

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## The Outflowing Wind of V1057 Cygni

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In 1970–71, V1057 Cyg rose from about  $m_{\text{pg}} \approx 16$  to a peak near 10.5 mag. It has subsequently faded to about  $B = 15$ , and although it appeared to be a T Tauri star (TTS) before the outburst, it now resembles a rather peculiar rapidly rotating G-type supergiant. Before the outburst, it showed unmistakable evidence of high-velocity outflow (by the suppression of emission Ca II  $\lambda 3968$  by the P Cyg absorption component of H $\epsilon$   $\lambda 3970$ ). Such outflow absorptions are currently found at many strong lines (H $\alpha$ , Na I D<sub>1,2</sub>, K I  $\lambda\lambda 7664, 7698$ , Ca II  $\lambda\lambda 8498, 8662, \dots$ ). The same

phenomenon has since been observed in a number of other FUors near maximum light, suggesting that it is a FUor characteristic that clearly differs from the outflows found in TTSS. The Li I resonance line at 6707 Å is relatively weak, and on high-resolution spectra obtained between 1997 and 2008 showed variable absorption structure on its shortward side that probably represents wind structure that is lost in the stronger lines. In addition, a narrow emission line at 6707 Å persists throughout the series and is the counterpart of the sharp emission lines that occur near the centers of many of the broad stellar absorption lines ( $v \sin i = 55 \text{ km s}^{-1}$ ) and that were responsible for the line-splitting phenomenon formerly regarded as evidence of a Keplerian disk. Given the evidence of a quasi-permanent outflow at V1057 Cyg, the hypothesis is advanced that a FUor outburst may be the result of a rapidly rotating TTS having contracted to a point of rotational instability, at which time it sheds enough material and angular momentum to resume contraction, until the next such event.

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## S-bearing molecules in Massive Dense Cores

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High-mass stars, though few in number, play a major role in the interstellar energy budget and the shaping of the Galactic environment. However, despite this importance, the formation of high-mass stars is not well understood, due to their large distances, short time scales, and heavy extinction.

Chemical composition of the massive cores forming high-mass stars can put some constraints on the time scale of the massive star formation: sulphur chemistry is of specific interest due to its rapid evolution in warm gas and because the abundance of sulphur bearing species increases significantly with the temperature.

Two mid-infrared quiet and two brighter massive cores are observed in various transitions ( $E_{\text{up}}$  up to 289 K) of CS, OCS, H<sub>2</sub>S, SO, SO<sub>2</sub> and of their <sup>34</sup>S isotopologues at mm wavelengths with the IRAM 30m and CSO telescopes. 1D modeling of the dust continuum is used to derive the density and temperature laws, which are then applied in the RATRAN code to model the observed line emission, and to derive the relative abundances of the molecules.

All lines, except the highest energy SO<sub>2</sub> transition, are detected. Infall (up to 2.9 km/s) may be detected towards the core W43MM1. The inferred mass rate is 5.8-9.4 10<sup>-2</sup> M<sub>⊙</sub>/yr. We propose an evolutionary sequence of our sources (W43MM1→IRAS18264–1152→IRAS05358+3543→IRAS18162–2048), based on the SED analysis. The analysis of the variations in abundance ratios from source to source reveals that the SO and SO<sub>2</sub> relative abundances increase with time, while CS and OCS decrease.

Molecular ratios, such as [OCS/H<sub>2</sub>S], [CS/H<sub>2</sub>S], [SO/OCS], [SO<sub>2</sub>/OCS], [CS/SO] and [SO<sub>2</sub>/SO] may be good indicators of evolution depending on layers probed by the observed molecular transitions. Observations of molecular emission from warmer layers, hence involving higher upper energy levels are mandatory to include.

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## A Search for Carbon-Chain-Rich Cores in Dark Clouds

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We present results of a survey of CCS, HC<sub>3</sub>N, and HC<sub>5</sub>N toward 40 dark cloud cores to search for "Carbon-Chain-Producing Regions(CCPRs)", where carbon-chain molecules are extremely abundant relative to NH<sub>3</sub>, as in L1495B, L1521B, L1521E, and the cyanopolyne peak of TMC-1. We have mainly observed toward cores where the NH<sub>3</sub> lines are weak, not detected, or not observed in previous surveys, and the CCS, HC<sub>3</sub>N, and HC<sub>5</sub>N lines have been

detected toward 17, 17, and 5 sources, respectively. Among them, we have found a CCPR, L492, and its possible candidates, L1517D, L530D, L1147, and L1172B. They all show low abundance ratios of  $[\text{NH}_3]/[\text{CCS}]$  (hereafter called the  $\text{NH}_3/\text{CCS}$  ratio) indicating the chemical youth. Combining our results with those of previous surveys, we have found a significant variation of the  $\text{NH}_3/\text{CCS}$  ratio among dark cloud cores and among molecular cloud complexes. Such a variation is also suggested by the detection rates of carbon-chain molecules. For instance, the  $\text{NH}_3/\text{CCS}$  ratios are higher and the detection rates of carbon-chain molecules are lower in the Ophiuchus cores than in the Taurus cores. An origin of these systematic abundance variation is discussed in terms of the difference in the evolutionary stage or the contraction timescale. We have also identified a carbon-chain-rich star-forming core, L483, where intense  $\text{HC}_3\text{N}$  and  $\text{HC}_5\text{N}$  lines are detected. This is a possible candidate for a core with "Warm Carbon-Chain Chemistry".

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## First Magnetic Field Detection on a Class I Protostar

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Strong stellar magnetic fields are believed to truncate the inner accretion disks around young stars, redirecting the accreting material to the high latitude regions of the stellar surface. In the past few years, observations of strong stellar fields on T Tauri stars with field strengths in general agreement with the predictions of magnetospheric accretion theory have bolstered this picture. Currently, nothing is known about the magnetic field properties of younger, more embedded Class I young stellar objects (YSOs). It is believed that protostars accrete much of their final mass during the Class I phase, but the physics governing this process remains poorly understood. Here, we use high resolution near infrared spectra obtained with NIRSPEC on Keck and with Phoenix on Gemini South to measure the magnetic field properties of the Class I protostar WL 17. We find clear signatures of a strong stellar magnetic field. Analysis of this data suggests a surface average field strength of  $2.9 \pm 0.43$  kG on WL 17. We present our field measurements and discuss how they fit with the general model of magnetospheric accretion in young stars.

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## Carbon Monoxide Observations of Small Dark Globules: II. Stability Analysis

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The stability of 12 small dark globules has been analyzed by using the full scalar virial theorem without magnetic field. We have applied the virial theorem to 18 sub-condensations identified from the column density maps of 12 globules. The sub-condensations are approximated by a uniform sphere of equivalent mass for simplicity. Based on the conventional simplified version of virial theorem, where the virial mass is compared with the LTE mass, we can only say that almost all the sub-condensations are approximately in a virial equilibrium. When we apply the full scalar virial theorem, where the sum of all the energy terms does not vanish and the time variation of the moment of inertia should be kept, one third of our sample cores are likely to collapse, one sixth of them are expected to expand, and the rest half of them are in a dense phase of an oscillatory equilibrium. The globules in the diffuse phase of the oscillatory equilibrium may not be detected by conventional means, because they are too rarefied to get CO molecules excited or to shield molecules from UV photons, or because they may not withstand the tidal disruption by neighboring clouds.

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# Molecular Line Profiles from a Core Forming in a Turbulent Cloud

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We calculate the evolution of molecular line profiles of HCO<sup>+</sup> and C<sup>18</sup>O toward a dense core that is forming inside a magnetized turbulent molecular cloud. Features of the profiles can be affected more significantly by coupled velocity and abundance structures in the outer region than those in the inner dense part of the core. The velocity structure at large radii is dominated by a turbulent flow nearby and accretion shocks onto the core, which resulting in the variation between inward and outward motions during the evolution of the core. The chemical abundance structure is significantly affected by the depletion of molecules in the central region with high density and low temperature. During the evolution of the core, the asymmetry of line profiles easily changes from blue to red, and vice versa. According to our study, the observed reversed (red) asymmetry toward some starless cores could be interpreted as an intrinsic result of outward motion in the outer region of a dense core, which is embedded in a turbulent environment and still grows in density at the center.

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# Massive Protoplanetary Disks in Orion Beyond the Trapezium Cluster

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We present Submillimeter Array observations of the 880  $\mu\text{m}$  continuum emission from three circumstellar disks around young stars in Orion that lie several arcminutes ( $> \sim 1$  pc) north of the Trapezium cluster. Two of the three disks are in the binary system 253-1536. Silhouette disks 216-0939 and 253-1536a are found to be more massive than any previously observed Orion disks, with dust masses derived from their submillimeter emission of  $0.045 M_{\odot}$  and  $0.066 M_{\odot}$ , respectively. The existence of these massive disks reveals that the disk mass distribution in Orion does extend to high masses, and that the truncation observed in the central Trapezium cluster is a result of photoevaporation due to the proximity of O-stars. 253-1536b has a disk mass of  $0.018 M_{\odot}$ , making the 253-1536 system the first optical binary in which each protoplanetary disk is massive enough to potentially form solar systems.

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# *Spitzer* Mapping of Molecular Hydrogen Pure Rotational Lines in NGC 1333: A Detailed Study of Feedback in Star Formation

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We present mid-infrared spectral maps of the NGC 1333 star-forming region, obtained with the infrared spectrometer on board the *Spitzer Space Telescope*. Eight pure H<sub>2</sub> rotational lines, from  $S(0)$  to  $S(7)$ , are detected and mapped. The H<sub>2</sub> emission appears to be associated with the warm gas shocked by the multiple outflows present in the region. A comparison between the observed intensities and the predictions of detailed shock models indicates that the emission arises in both slow (12-24 km s<sup>-1</sup>) and fast (36-53 km s<sup>-1</sup>) C-type shocks with an initial ortho-to-para ratio (*opr*) < ~1. The present H<sub>2</sub> *opr* exhibits a large degree of spatial variations. In the postshocked gas, it is usually about 2, i.e., close to the equilibrium value (~3). However, around at least two outflows, we observe a region with a much lower (~0.5) *opr*. This region probably corresponds to gas which has been heated up recently by the passage of a shock front, but whose ortho-to-para has not reached equilibrium yet. This, together with the low initial *opr* needed to reproduce the observed emission, provide strong evidence that H<sub>2</sub> is mostly in para form in cold molecular clouds. The H<sub>2</sub> lines are found to contribute to 25%-50% of the total outflow luminosity, and thus can be used to ascertain the importance of star formation feedback on the natal cloud. From these lines, we determine the outflow mass loss rate and, indirectly, the stellar infall rate, the outflow momentum and the kinetic energy injected into the cloud over the embedded phase. The latter is found to exceed the binding energy of individual cores, suggesting that outflows could be the main mechanism for core disruption.

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## Grain Alignment in OMC1 as Deduced from Observed Large Circular Polarization

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The properties of polarization in scattered light by aligned ellipsoidal grains are investigated with the Fredholm integral equation method (FIM) and the T-matrix method (Tmat), and the results are applied to the observed circular polarization in OMC1. We assume that the grains are composed of silicates and ellipsoidal (oblate, prolate, or tri-axial ellipsoid) in shape with a typical axial ratio of 2:1. The angular dependence of circular polarization  $p_c$  on directions of incident and scattered light is investigated with spherical harmonics and associated Legendre polynomials. The degree of circular polarization  $p_c$  also depends on the Rayleigh reduction factor  $R$  which is a measure of imperfect alignment. We find that  $p_c$  is approximately proportional to  $R$  for grains with  $|m|x_{eq} < 3 - 5$ , where  $x_{eq}$  is the dimensionless size parameter and  $m$  is the refractive index of the grain. Models that include those grains can explain the observed large circular polarization in the near-infrared,  $\approx 15\%$ , in the south-east region of the BN object (SEBN) in OMC1, if the directions of incidence and scattering of light is optimal, and if grain alignment is strong, i.e.,  $R < 0.5$ . Such a strong alignment cannot be explained by the Davis-Greenstein mechanism; we prefer instead an alternative mechanism driven by radiative torques. If the grains are mixed with silicates and ice, the degree of circular polarization  $p_c$  decreases in the 3  $\mu\text{m}$  ice feature, while that of linear polarization increases. This wavelength dependence is different from that predicted in a process of dichroic extinction.

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## A New Spectroscopic and Interferometric Study of the Young Stellar Object V645 Cygni

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*Aims.* We present the results of high-resolution optical spectroscopy, low-resolution near-IR spectroscopy and near-infrared speckle interferometry of the massive young stellar object candidate V645 Cyg, acquired to refine its fundamental parameters and the properties of its circumstellar envelope.

*Methods.* Speckle interferometry in the *H*- and *K*-bands and an optical spectrum in the range 5200-6680 Å with a spectral resolving power of  $R = 60\,000$  were obtained at the 6 m telescope of the Russian Academy of Sciences. Another optical spectrum in the range 4300-10 500 Å with  $R = 79\,000$  was obtained at the 3.6 m CFHT. Low-resolution spectra in the ranges 0.46-1.4 μm and 1.4-2.5 μm with  $R \sim 800$  and  $\sim 700$ , respectively, were obtained at the 3 m Shane telescope of the Lick Observatory.

*Results.* Using a novel kinematical method based on the non-linear modeling of the neutral hydrogen density profile in the direction toward the object, we propose a distance of  $D = 4.2 \pm 0.2$  kpc. We also suggest a revised estimate of the star's effective temperature,  $T_{\text{eff}} \sim 25\,000$  K. We resolved the object in both *H*- and *K*-bands. Using a two-component ring fit, we derived a compact component size of 14 mas and 12 mas in the *H*- and *K*-band, respectively, which correspond to 29 and 26 AU at the revised distance. Analysis of our own and previously published data indicates a  $\sim 2$  mag decrease in the near-infrared brightness of V645 Cyg at the beginning of the 1980's. At the same time, the cometary nebular condensation N1 appears to fade in this wavelength range with respect to the N0 object, representing the star with a nearly pole-on optically-thick disk and an optically-thin envelope.

*Conclusions.* We conclude that V645 Cyg is a young, massive, main-sequence star, which recently emerged from its cocoon and has already experienced its protostellar accretion stage. The presence of accretion is not necessary to account for the high observed luminosity of  $(2-6) \times 10^4 \text{ yr}^{-1}$ . The receding part of a strong, mostly uniform outflow with a terminal velocity of  $\sim 800 \text{ km s}^{-1}$  is only blocked from view far from the star, where forbidden lines form. The near-infrared size of the source is consistent with the dust sublimation distance close to this hot and luminous star and is the largest among all young stellar objects observed interferometrically to-date.

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## The discovery of new warm debris disks around F-type stars

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We report the discovery of four rare debris disks with warm excesses around F-stars, significantly increasing the number of such systems known in the solar neighborhood. Three of the disks are consistent with the predictions of steady state planetesimal disk evolution models. The oldest source, HD 169666, displays a dust fractional luminosity too high to be in steady state and we suggest that this system recently underwent a transient event of dust production. In addition, two spectra of this star separated by  $\sim$ three years show silicate emission features, indicative of submicron- to micron-sized grains. We argue that such small grains would be rapidly depleted and their presence in both spectra suggests that the production of small dust is continuous over at least on few years timescale. We predict that systems showing variable mid-infrared spectra, if exist, will provide valuable help in distinguishing the possible scenarios proposed for dust replenishment.

## A Multiwavelength Study of Young Massive Star-Forming Regions. III. Mid-Infrared Emission

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We present mid-infrared (MIR) observations, made with the TIMMI2 camera on the ESO 3.6 m telescope, toward 14 young massive star-forming regions. All regions were imaged in the *N* band, and nine in the *Q* band, with an angular resolution of  $\simeq 1''$ . Typically, the regions exhibit a single or two compact sources (with sizes in the range 0.008–0.18 pc) plus extended diffuse emission. The *Spitzer*–Galactic Legacy Infrared Mid-Plane Survey Extraordinaire images of these regions show much more extended emission than that seen by TIMMI2, and this is attributed to polycyclic aromatic hydrocarbon (PAH) bands. For the MIR sources associated with radio continuum radiation (Paper I) there is a close morphological correspondence between the two emissions, suggesting that the ionized gas (radio source) and hot dust (MIR source) coexist inside the H II region. We found five MIR compact sources which are not associated with radio continuum emission, and are thus prime candidates for hosting young massive protostars. In particular, objects IRAS 14593–5852 II (*only* detected at 17.7  $\mu\text{m}$ ) and 17008–4040 I are likely to be genuine O-type protostellar objects. We also present TIMMI2 *N*-band spectra of 8 sources, all of which are dominated by a prominent silicate absorption feature ( $\simeq 9.7 \mu\text{m}$ ). From these data we estimate column densities in the range  $(7–17) \times 10^{22} \text{ cm}^{-2}$ , in good agreement with those derived from the 1.2 mm data (Paper II). Seven sources show bright [Ne II] line emission, as expected from ionized gas regions. Only IRAS 12383–6128 shows detectable PAH emission at 8.6 and 11.3  $\mu\text{m}$ .

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## Filamentary Structure of Star-Forming Complexes

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The nearest young stellar groups are associated with “hubs” of column density exceeding  $10^{22} \text{ cm}^{-2}$ , according to recent observations. These hubs radiate multiple “filaments” of parsec length, having lower column density and fewer stars. Systems with many filaments tend to have parallel filaments with similar spacing. Such “hub-filament structure” is associated with all of the nine young stellar groups within 300 pc, forming low-mass stars. Similar properties are seen in infrared dark clouds forming more massive stars. In a new model, an initial clump in a uniform medium is compressed into a self-gravitating, modulated layer. The outer layer resembles the modulated equilibrium of Schmid-Burgk (1967), with nearly parallel filaments. The filaments converge onto the compressed clump, which collapses to form stars with high efficiency. The initial medium and condensations have densities similar to those in nearby star-forming clouds and clumps. The predicted structures resemble observed hub-filament systems in their size, shape, and column density, and in the appearance of their filaments. These results suggest that hub-filament structure associated with young stellar groups may arise from compression of clumpy gas in molecular clouds.

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# A Molecular Outflow Revealing Star Formation Activity in the Vicinity of the HII Region G034.8-0.7 and the SNR W44

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*Aims.* This work aims at investigating the molecular gas component in the vicinity of two young stellar object (YSO) candidates identified at the border of the HII region G034.8-0.7 that is evolving within a molecular cloud shocked by the SNR W44. The purpose is to explore signatures of star forming activity in this complex region.

*Methods.* We performed a near and mid infrared study towards the border of the HII region G034.8-0.7 and observed a  $90'' \times 90''$  region near  $18^h 56^m 48^s$ ,  $+01^\circ 18' 45''$  (J2000) using the Atacama Submillimeter Telescope Experiment (ASTE) in the  $^{12}\text{CO } J=3-2$ ,  $^{13}\text{CO } J=3-2$ ,  $\text{HCO}^+ J=4-3$  and  $\text{CS } J=7-6$  lines with an angular resolution of 22.

*Results.* Based on the infrared study we propose that the source 2MASS 18564827+0118471 (IR1 in this work) is a YSO candidate. We discovered a bipolar  $^{12}\text{CO}$  outflow in the direction of the line of sight and a  $\text{HCO}^+$  clump towards IR1, confirming that it is a YSO. From the detection of the  $\text{CS } J=7-6$  line we infer the presence of high density ( $>10^7 \text{ cm}^{-3}$ ) and warm ( $>60 \text{ K}$ ) gas towards IR1, probably belonging to the protostellar envelope where the YSO is forming. We investigated the possible connection of IR1 with the SNR and the HII region. By comparing the dynamical time of the outflows and the age of the SNR W44, we conclude that the possibility that the SNR triggered the formation of IR1 is unlikely. On the other hand, we suggest that the expansion of the HII region G034.8-0.7 is responsible for the formation of IR1 through the “collect and collapse” process.

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## The Perils of Clumpfind: The Mass Spectrum of Sub-structures in Molecular Clouds

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We study the mass spectrum of sub-structures in the Perseus Molecular Cloud Complex traced by  $^{13}\text{CO } (1-0)$ , finding that  $dN/dM \propto M^{-2.4}$  for the standard Clumpfind parameters. This result does not agree with the classical  $dN/dM \propto M^{-1.6}$ . To understand this discrepancy we study the robustness of the mass spectrum derived using the Clumpfind algorithm. Both 2D and 3D Clumpfind versions are tested, using 850  $\mu\text{m}$  dust emission and  $^{13}\text{CO}$  spectral-line observations of Perseus, respectively. The effect of varying threshold is not important, but varying stepsize produces a different effect for 2D and 3D cases. In the 2D case, where emission is relatively isolated (associated with only the densest peaks in the cloud), the mass spectrum variability is negligible compared to the mass function fit uncertainties. In the 3D case, however, where the  $^{13}\text{CO}$  emission traces the bulk of the molecular cloud, the number of clumps and the derived mass spectrum are highly correlated with the stepsize used. The distinction between “2D” and “3D” here is more importantly also a distinction between “sparse” and “crowded” emission. In any “crowded” case, Clumpfind should not be used *blindly* to derive mass functions. Clumpfind’s output in the “crowded” case can still offer a statistical description of emission useful in inter-comparisons, but the clump-list should not be treated as a robust region decomposition suitable to generate a physically-meaningful mass function. We conclude that the  $^{13}\text{CO}$  mass spectrum depends on the observations resolution, due to the hierarchical structure of MC.

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## Planet-planet scattering in planetesimal disks

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We study the final architecture of planetary systems that evolve under the combined effects of planet-planet and planetesimal scattering. Using N-body simulations we investigate the dynamics of marginally unstable systems of gas and ice giants both in isolation and when the planets form interior to a planetesimal belt. The unstable isolated systems evolve under planet-planet scattering to yield an eccentricity distribution that matches that observed for extrasolar planets. When planetesimals are included the outcome depends upon the total mass of the planets. For system masses exceeding about one Jupiter mass the final eccentricity distribution remains broad, whereas for lower mass planetary systems a combination of divergent orbital evolution and recircularization of scattered planets results in a preponderance of nearly circular final orbits. We also study the fate of marginally *stable* multiple planet systems in the presence of planetesimal disks, and find that for high planet masses the majority of such systems evolve into resonance. A significant fraction lead to resonant chains that are planetary analogs of Jupiter’s Galilean satellites. We predict that a transition from eccentric to near-circular orbits will be observed once extrasolar planet surveys detect sub-Jovian mass planets at orbital radii of 5-10 AU.

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## High-resolution 5 $\mu\text{m}$ Spectroscopy of Transitional Disks

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We present high-resolution *M*-band ( $\sim 5 \mu\text{m}$ ) spectra of 14 transitional disks—circumstellar disks with an optically thick outer zone but an inner region significantly depleted of small dust grains—obtained with NIRSPEC on the Keck II telescope. We detect CO emission from nine disks, and show that for the majority of these systems, the emission originates in the depleted inner disk region. We find that the presence of high 5  $\mu\text{m}$  veiling, strong CO emission, and high accretion rates are usually correlated, suggesting that at least two classes of transitional disks exist: those nearly completely cleared, and those only partially depleted, within their transition radius. *Cleared* inner disks are consistent with the presence of a close stellar companion, or with formation by photoevaporation. Of the cleared transitional disks, at least two (HD 98800 B and CoKu Tau/4) are known to be circumbinary with projected binary separations of several AU or less. *Partially depleted* inner disks most often have CO that extends to small ( $< \sim 1$  AU) radii, but compared to “classical” disks the CO excitation temperature is lower and the emission radii are larger than that expected for dust sublimation. These disks are consistent with the presence of a giant planet, and inconsistent with having been formed by photoevaporation. Although the inner regions of such disks are vertically optically thin in dust emission, line-of-sight opacities from the star can be large, and the complex physical and chemical processes therein make it difficult to derive a fiducial CO abundance with respect to molecular hydrogen. Thus, CO *M*-band lines are best suited to providing lower bounds as to the total inner disk gas mass. Amongst the partially depleted sources, veiling measurements and CO emission models demonstrate a great diversity of inner disk gas content and gas/dust ratios, suggesting a variety of planet-forming environments.

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## NGC7538 IRS1 - an ionized jet powered by accretion

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Analysis of high spatial resolution VLA images shows that the free-free emission from NGC 7538 IRS 1 is dominated by a collimated ionized wind. We have re-analyzed high angular resolution VLA archive data from 6 cm to 7 mm, and measured separately the flux density from the compact bipolar core and the extended ( $1''.5 - 3''$ ) lobes. We find that the flux density of the core is  $\propto \nu^\alpha$ , where  $\nu$  is the frequency and  $\alpha$  is  $\sim 0.7$ . The frequency dependence of the total flux density is slightly steeper with  $\alpha = 0.8$ . A massive optically thick hypercompact core with a steep density gradient can explain this frequency dependence, but it cannot explain the extremely broad recombination line velocities observed in this source. Neither can it explain why the core is bipolar rather than spherical, nor the observed decrease of 4% in the flux density in less than 10 years. An ionized wind modulated by accretion is expected to vary, because the accretion flow from the surrounding cloud will vary over time. BIMA and CARMA continuum observations at 3 mm show that the free-free emission still dominates at 3 mm. HCO<sup>+</sup> J = 1  $\rightarrow$  0 observations combined with FCRAO single dish data show a clear inverse P Cygni profile towards IRS 1. These observations confirm that IRS 1 is heavily accreting with an accretion rate  $\sim 2 \cdot 10^{-4} M_\odot/\text{yr}$ .

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## Dust Processing and Grain Growth in Protoplanetary Disks in the Taurus-Auriga Star-Forming Region

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Mid-infrared spectra of 65 T Tauri stars (TTS) taken with the Infrared Spectrograph (IRS) on board the *Spitzer Space Telescope* are modeled using populations of optically thin warm and cool grains to probe the radial variation in dust composition in the uppermost layers of protoplanetary disks. Most spectra with narrow emission features associated with crystalline silicates require Mg-rich minerals and silica, while a few spectra with these features suggest the presence of other components. IRS spectra indicating the presence of large amounts of warm enstatite of  $\sim 400$ - $500$  K require crystalline silicates (enstatite or forsterite) at temperatures lower than the median temperature of the cool dust in the models,  $\sim 127$  K; spectra showing a high abundance of other crystalline silicates (forsterite or silica) typically do not. A few spectra show  $10 \mu\text{m}$  complexes of very small equivalent width. They are fit well using abundant crystalline silicates but very few large grains, inconsistent with the expectation that a low peak-to-continuum ratio of the  $10 \mu\text{m}$  complex always indicates grain growth. Most of the spectra in our sample are fit well without using the opacities of large crystalline silicate grains. If large grains grow by agglomeration of submicron grains of all dust types, the amorphous silicate components of these aggregates must typically be more abundant than the crystalline silicate components. We also find that the more there is of one crystalline dust species, the more there is of the others. This could suggest that crystalline silicates are processed directly from amorphous silicates, whether through evaporation of the amorphous grains and condensation in chemical equilibrium or by annealing of the amorphous precursors. Alternatively, if one kind of crystalline silicate transforms into another kind, it suggests that the intermediate species transforms into the end-product species at a slower rate than the precursor transforms into the intermediate species; otherwise, there would be a negligible abundance of intermediate species. It is also found that the crystalline silicate abundance is correlated tightly with disk geometry, in the sense of higher crystallinity accompanying more-settled disks, which are commonly associated with growth and settling of grains. The abundance of large grains is also correlated with disks that are more highly settled, but with a wide range of large grain abundance for a given degree of settling. We interpret this range as that the settling of large grains is sensitive to individual disk properties. We also find that lower-mass stars have higher abundances of large grains in their inner regions.

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# Millimeter- and Submillimeter-Wave Observations of the OMC-2/3 region. IV Interaction between the Outflow and the Dense Gas in the Cluster Forming Region of OMC-2 FIR 6

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We have conducted millimeter interferometric observations of the Orion Molecular Cloud-2 (OMC-2) FIR 6 region at an angular resolution of  $\sim 4$  arcsec - 7 arcsec with the Nobeyama Millimeter Array (NMA). In the 3.3 mm continuum emission we detected dusty core counterparts of the previously identified FIR sources (FIR 6a, 6b, 6c, and 6d), and moreover, resolved FIR 6a into three dusty cores. The size and mass of these cores are estimated to be 1100-5900 AU and 0.19-5.5  $M_{\odot}$ , respectively. We found that in the  $^{12}\text{CO}$  ( $J=1-0$ ) emission FIR 6b, 6c, and 6d eject the molecular outflow and that the FIR 6c outflow also exhibits at least two collimated jet-like components in the SiO ( $J=2-1$ ) emission. At the tip of one of the SiO components there appears abrupt increase of the SiO line width ( $\sim 15 \text{ km s}^{-1}$ ), where the three resolved cores in FIR 6a seem to delineate the tip. These results imply the presence of the interaction and the bowshock front between the FIR 6c molecular outflow and FIR 6a.

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## Identifying the Young Low-mass Stars within 25 pc. I. Spectroscopic Observations

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We have completed a high-resolution ( $R \approx 60,000$ ) optical spectroscopic survey of 185 nearby M dwarfs identified using *ROSAT* data to select active, young objects with fractional X-ray luminosities comparable to or greater than Pleiades members. Our targets are drawn from the *NStars* 20 pc census and the *Moving - M* sample with distances determined from parallaxes or spectrophotometric relations. We limited our sample to 25 pc from the Sun, prior to correcting for pre-main-sequence overluminosity or binarity. Nearly half of the resulting M dwarfs are not present in the Gliese catalog and have no previously published spectral types. We identified 30 spectroscopic binaries (SBs) from the sample, which have strong X-ray emission due to tidal spin-up rather than youth. This is equivalent to a 16% SB fraction, with at most a handful of undiscovered SBs. We estimate upper limits on the age of the remaining M dwarfs using spectroscopic youth indicators such as surface gravity-sensitive indices (CaH and K I). We find that for a sample of field stars with no metallicity measurements, a single CaH gravity index may not be sufficient, as higher metallicities mimic lower gravity. This is demonstrated in a subsample of metal-rich radial velocity (RV) standards, which appear to have low surface gravity as measured by the CaH index, yet show no other evidence of youth. We also use additional youth diagnostics such as lithium absorption and strong H $\alpha$  emission to set more stringent age limits. Eleven M dwarfs with no H $\alpha$  emission or absorption are likely old ( $>400$  Myr) and were caught during an X-ray flare. We estimate that our final sample of the 144 youngest and nearest low-mass objects in the field is less than 300 Myr old, with 30% of them being younger than 150 Myr and four very young ( $< \sim 10$  Myr), representing a generally untapped and well-characterized resource of M dwarfs for intensive planet and disk searches.

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## The Long Lived Disks in the $\eta$ Chamaeleontis Cluster

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We present IRS spectra and revised MIPS photometry for the 18 members of the  $\eta$  Chamaeleontis cluster. Aged 8 Myr, the  $\eta$  Cha cluster is one of the few nearby regions within the 5-10 Myr age range, during which the disk fraction decreases dramatically and giant planet formation must come to an end. For the 15 low-mass members, we measure a disk fraction  $\sim 50\%$ , high for their 8 Myr age, and 4 of the 8 disks lack near-IR excesses, consistent with the empirical definition of “transition” disks. Most of the disks are comparable to geometrically flat disks. The comparison with regions of different ages suggests that at least some of the “transition” disks may represent the normal type of disk around low-mass stars. Therefore, their flattened structure and inner holes may be related to other factors (initial masses of the disk and the star, environment, binarity), rather than to pure time evolution. We analyze the silicate dust in the disk atmosphere, finding moderate crystalline fractions ( $\sim 10\text{-}30\%$ ) and typical grain sizes  $\sim 1\text{-}3\ \mu\text{m}$ , without any characteristic trend in the composition. These results are common to other regions of different ages, suggesting that the initial grain processing occurs very early in the disk lifetime ( $< 1$  Myr). Large grain sizes in the disk atmosphere cannot be used as a proxy for age, but are likely related to higher disk turbulence. The dust mineralogy varies between the  $8\text{-}12\ \mu\text{m}$  and the  $20\text{-}30\ \mu\text{m}$  features, suggesting high temperature dust processing and little radial mixing. Finally, the analysis of IR and optical data on the B9 star  $\eta$  Cha reveals that it is probably surrounded by a young debris disk with a large inner hole, instead of being a classical Be star.

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<http://www.mpia.de/homes/sicilia/aurora-publications.html>

## Hubble Space Telescope NICMOS Polarization Observations of Three Edge-on Massive YSOs

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Massive young stellar objects (YSOs), like low-mass YSOs, appear to be surrounded by optically thick envelopes and/or disks and have regions, often bipolar, that are seen in polarized scattered light at near-infrared wavelengths. We are using the  $0.2''$  spatial resolution of NICMOS on *Hubble Space Telescope* to examine the structure of the disks and outflow regions of massive YSOs in star-forming regions within a few kpc of the Sun. Here we report on  $2\ \mu\text{m}$  polarimetry of NGC 6334 V and S255 IRS1. NGC 6334 V consists of a double-lobed bright reflection nebula seen against a dark region, probably an optically thick molecular cloud. Our polarization measurements show that the illuminating star lies  $\sim 2''$  south of the line connecting the two lobes; we do not detect this star at  $2\ \mu\text{m}$ , but there are a small radio source and a mid-infrared source at this location. S255 IRS1 consists of two YSOs (NIRS1 and NIRS3) with overlapping scattered light lobes and luminosities corresponding to early B stars. Included in IRS1 is a cluster of stars from whose polarization we determine the local magnetic field direction. Neither YSO has its scattered light lobes aligned with this magnetic field. The line connecting the scattered light lobes of NIRS1 is twisted symmetrically

around the star; the best explanation is that the star is part of a close binary and the outflow axis of NIRS1 is precessing as a result of non-coplanar disk and orbit. The star NIRS3 is also offset from the line connecting its two scattered light lobes. We suggest that all three YSOs show evidence of episodic ejection of material as they accrete from dense, optically thick envelopes.

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## EX Lupi in quiescence

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EX Lup is the prototype of EXors, a subclass of low-mass pre-main sequence stars whose episodic eruptions are attributed to temporarily increased accretion. In quiescence the optical and near-infrared properties of EX Lup cannot be distinguished from those of normal T Tau stars. Here we investigate whether it is the circumstellar disk structure which makes EX Lup an atypical Class II object. During outburst the disk might undergo structural changes. Our characterization of the quiescent disk is intended to serve as a reference to study the physical changes related to one of EX Lupi's strongest known eruptions in 2008 Jan–Sep. We searched the literature for photometric and spectroscopic observations including ground-based, IRAS, ISO and Spitzer data. After constructing the optical–infrared spectral energy distribution (SED), we compared it with the typical SEDs of other young stellar objects and modeled it using the Monte Carlo radiative transfer code *RADMC*. A mineralogical decomposition of the 10  $\mu\text{m}$  silicate emission feature and also the description of the optical and near-infrared spectra were performed. The SED is in general similar to that of a typical T Tauri star, though above 7  $\mu\text{m}$  EX Lup emits higher flux. The quiescent phase data suggest low level variability in the optical–mid-infrared domain. Integrating the optical and infrared fluxes we derived a bolometric luminosity of 0.7  $L_{\odot}$ . The 10  $\mu\text{m}$  silicate profile could be fitted by a mixture consisting of amorphous silicates, no crystalline silicates were found. A modestly flaring disk model with a total mass of 0.025  $M_{\odot}$  and an outer radius of 150 AU was able to reproduce the observed SED. The derived inner radius of 0.2 AU is larger than the sublimation radius, and this inner gap sets EX Lup aside from typical T Tauri stars.

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## Chandra and Spitzer Imaging of the Infrared Cluster in NGC 2071

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We present results of a sensitive *Chandra* X-ray observation and *Spitzer* mid-IR observations of the infrared cluster lying north of the NGC 2071 reflection nebula in the Orion B molecular cloud. We focus on the dense cluster core known as NGC 2071-IR which contains at least nine IR sources within a 40''  $\times$  40'' region. This region shows clear signs of active star formation including powerful molecular outflows, Herbig-Haro objects, and both OH and H<sub>2</sub>O

masers. We use *Spitzer* IRAC images to aid in X-ray source identification and to determine YSO classes using mid-IR colors. *Spitzer* IRAC colors show that the luminous source IRS 1 is a class I protostar. IRS 1 is believed to be driving a powerful bipolar molecular outflow and may be an embedded B-type star or its progenitor. Its X-ray spectrum reveals a fluorescent Fe emission line at 6.4 keV, arising in cold material near the protostar. The line is present even in the absence of large flares, raising questions about the nature of the ionizing mechanism responsible for producing the 6.4 keV fluorescent line. *Chandra* also detects X-ray sources at or near the positions of IRS 2, IRS 3, IRS 4, and IRS 6 and a variable X-ray source coincident with the radio source VLA 1, located just 2'' north of IRS 1. No IR data are yet available to determine a YSO classification for VLA 1, but its high X-ray absorption shows that it is even more deeply-embedded than IRS 1, suggesting that it could be an even younger, less-evolved protostar.

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## High-precision C<sup>17</sup>O, C<sup>18</sup>O and C<sup>16</sup>O measurements in young stellar objects: analogues for CO self-shielding in the early solar system

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Using very high resolution ( $\lambda/\Delta\lambda \approx 95\,000$ ) 4.7  $\mu\text{m}$  fundamental and 2.3  $\mu\text{m}$  overtone ro-vibrational CO absorption spectra obtained with the CRIFES infrared spectrometer on the Very Large Telescope (VLT), we report detections of four CO isotopologues – C<sup>16</sup>O, <sup>13</sup>CO, C<sup>18</sup>O and the rare species, C<sup>17</sup>O – in the circumstellar environment of two young protostars: VV CrA, a binary T Tauri star in the Corona Australis molecular cloud, and Reipurth 50, an intermediate-mass FU Ori star in the Orion Molecular Cloud. We argue that the observed CO absorption lines probe a protoplanetary disk in VV CrA, and a protostellar envelope in Reipurth 50. All CO line profiles are spectrally resolved, with intrinsic line widths of  $\approx 3\text{--}4 \text{ km s}^{-1}$  (FWHM), permitting direct calculation of CO oxygen isotopologue ratios with 5-10% accuracy. The ro-vibrational level populations for all species can be reproduced by assuming that CO absorption arises in two temperature regimes. In the higher temperature regime, in which the column densities are best determined, the derived oxygen isotope ratios in VV CrA are:  $[\text{C}^{16}\text{O}]/[\text{C}^{18}\text{O}] = 690 \pm 30$ ;  $[\text{C}^{16}\text{O}]/[\text{C}^{17}\text{O}] = 2800 \pm 300$ , and  $[\text{C}^{18}\text{O}]/[\text{C}^{17}\text{O}] = 4.1 \pm 0.4$ . For Reipurth 50, we find  $[\text{C}^{16}\text{O}]/[\text{C}^{18}\text{O}] = 490 \pm 30$ ;  $[\text{C}^{16}\text{O}]/[\text{C}^{17}\text{O}] = 2200 \pm 150$ ,  $[\text{C}^{18}\text{O}]/[\text{C}^{17}\text{O}] = 4.4 \pm 0.2$ . For both objects, <sup>12</sup>C/<sup>13</sup>C are on the order of 100, nearly twice the expected interstellar medium (ISM) ratio. The derived oxygen abundance ratios for the VV CrA disk show a significant mass-independent deficit of C<sup>17</sup>O and C<sup>18</sup>O relative to C<sup>16</sup>O compared to ISM baseline abundances. The Reipurth 50 envelope shows no clear differences in oxygen CO isotopologue ratios compared with the local ISM. A mass-independent fractionation can be interpreted as being due to selective photodissociation of CO in the disk surface due to self-shielding. The deficits in C<sup>17</sup>O and C<sup>18</sup>O in the VV CrA protoplanetary disk are consistent with an analogous origin of the <sup>16</sup>O variability in the solar system by isotope selective photodissociation, confirmation of which may be obtained via study of additional sources. The higher fractionation observed for the VV CrA disk compared with the Reipurth 50 envelope is likely due to a combination of disk geometry, grain growth, and vertical mixing processes.

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## IRS Characterization of a Debris Disk around an M-type star in NGC2547

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We present 5 to 15 micron Spitzer Infrared Spectrograph (IRS) low resolution spectral data of a candidate debris disk around an M4.5 star identified as a likely member of the 40 Myr old cluster NGC2547. The IRS spectrum shows a silicate emission feature, indicating the presence of warm, small, (sub)micron-sized dust grains in the disk. Of the fifteen previously known candidate debris disks around M-type stars, the one we discuss in this paper is the first to have an observed mid-infrared spectrum and is also the first to have measured silicate emission. We combined the IRS data with ancillary data (optical, JHKs, and Spitzer InfraRed Array Camera and 24 micron data) to build the spectral energy distribution (SED) of the source. Monte Carlo radiation transfer modeling of the SED characterized the dust disk as being very flat ( $h_{100}=2\text{AU}$ ) and extending inward within at least  $0.13\text{AU}$  of the central star. Our analysis shows that the disk is collisionally dominated and is likely a debris disk.

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## A Parameter Study of the Dust and Gas Temperature in a Field of Young Stars

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We model the thermal effect of young stars on their surrounding environment in order to understand clustered star formation. We take radiative heating of dust, dust-gas collisional heating, cosmic-ray heating, and molecular cooling into account. Using DUSTY, a spherical continuum radiative transfer code, we model the dust temperature distribution around young stellar objects with various luminosities and surrounding gas and dust density distributions. We have created a grid of dust temperature models, based on our modeling with DUSTY, which we can use to calculate the dust temperature in a field of stars with various parameters. We then determine the gas temperature assuming energy balance. Our models can be used to make large-scale simulations of clustered star formation more realistic.

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## Observational Study of Sites of Triggered Star Formation: CO and Mid-Infrared Observations

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*Context.* Bright-rimmed clouds (BRCs) are isolated molecular clouds located on the edges of evolved HII regions. Star

formation within these clouds may have been triggered through the propagation of photoionisation-induced shocks driven by the expansion of the HII region.

*Aims.* The main focus of this paper is to investigate the current level of star formation within a sample of southern hemisphere BRCs and evaluate to what extent, if any, star formation may have been triggered.

*Methods.* In this paper we present the results of a programme of position-switched CO observations towards 45 southern BRCs. The  $^{12}\text{CO}$ ,  $^{13}\text{CO}$  and  $\text{C}^{18}\text{O}$   $J = 1-0$  rotational transitions were simultaneously observed using the 22-m Mopra telescope. We complement these observations with archival mid-infrared data obtained from the MSX and Spitzer, as well as submillimetre and radio data previously reported in the literature. Combining all of the available data with the observations presented here allows us to build up a comprehensive picture of the current level of star formation activity within a significant number of BRCs.

*Results.* Analysis of the CO, mid-infrared and radio data result in the clouds being divided into three distinct groups: a) clouds that appear to be relatively unaffected by the photoionisation from the nearby OB star(s); b) clouds that show evidence of significant interaction between the molecular material and the HII regions; c) clouds towards which no CO emission is detected, but are associated with strong ionisation fronts; these are thought to be examples of clouds undergoing an ionisation flash. We refer to these groups as spontaneous, triggered, and zapped clouds, respectively. Comparing the physical parameters of spontaneous and triggered samples we find striking differences in luminosity, surface temperature and column density with all three quantities significantly enhanced for the clouds considered to have been triggered. Furthermore, we find strong evidence for star formation within the triggered sample by way of methanol and  $\text{H}_2\text{O}$  masers, embedded mid-infrared point sources and CO wings, however, we find evidence of ongoing star formation within only two of the spontaneous sample.

*Conclusions.* We have used CO, mid-infrared and radio data to identify 24 of the 45 southern BRCs that are undergoing a strong interaction with their HII region. We can therefore exclude the other 21 sources ( $\sim 50\%$ ) from future studies of triggered star formation. Fourteen of the 24 interacting BRCs are found to be associated with embedded mid-infrared point sources and we find strong evidence that these clouds are forming stars. The absence of mid-infrared sources towards the remaining ten clouds and the lack of any other evidence of star formation within these clouds leads us to conclude that these represent an earlier evolutionary stage of star formation.

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## Periodic class II methanol masers in G9.62+0.20E

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We present the light curves of the 6.7 and 12.2 GHz methanol masers in the star forming region G9.62+0.20E for a time span of more than 2600 days. The earlier reported period of 244 days is confirmed. The results of monitoring the 107 GHz methanol maser for two flares are also presented. The results show that flaring occurs in all three masing transitions. It is shown that the average flare profiles of the three masing transitions are similar. The 12.2 GHz masers are the most variable of the three masers with the largest relative amplitude having a value of 2.4. The flux densities for the different masing transitions are found to return to the same level during the low phase of the masers, suggesting that the source of the periodic flaring is situated outside the masing region, and that the physical conditions in the masing region are relatively stable. On the basis of the shape of the light curve we excluded stellar pulsations as the underlying mechanism for the periodicity. It is argued that a colliding wind binary can account for the observed periodicity and provide a mechanism to qualitatively explain periodicity in the seed photon flux and/or the pumping radiation field. It is also argued that the dust cooling time is too short to explain the decay time of about 100 days of the maser flare. A further analysis has shown that for the intervals from days 48 to 66 and from days 67 to 135 the decay of the maser light curve can be interpreted as due to the recombination of a thermal hydrogen plasma with densities of approximately  $1.6 \times 10^6 \text{ cm}^{-3}$  and  $6.0 \times 10^5 \text{ cm}^{-3}$  respectively.

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# Modeling the Chemical Evolution of a Collapsing Prestellar Core in Two Spatial Dimensions

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*Context.* The physical conditions in a collapsing cloud can be traced by observations of molecular lines. To correctly interpret these observations the abundance distributions of the observed species need to be derived. The chemistry in a collapsing molecular cloud is not in a steady state as the density and temperature evolve. We therefore need to follow chemical reactions, both in the gas phase and on dust grains, as well as gas-grain interactions, to predict the abundance distributions.

*Aims.* Our aim is to model the abundances of molecules, in the gas phase and on grain mantles in the form of ice, from prestellar core collapse to disk formation. We want to investigate the need for grain surface reactions and compare our results with observed abundances, column densities, and ice-mantle compositions.

*Methods.* We use a 2-dimensional hydrodynamical simulation as a physical model from which we take the density, temperature, and the flow of the gas. Trace particles, moving along with the gas, are used to follow the chemistry during prestellar core collapse and disk formation. We calculated abundance profiles and column densities for various species. The evolution of these abundances and the composition of ices on grain mantles were compared to observations and we tested the influence of grain surface reactions on the abundances of species. We also investigated the initial abundances to be adopted in more detailed modeling of protoplanetary disks by following the chemical evolution of trace particles accreting onto the disk.

*Results.* Fractional abundances of  $\text{HCO}^+$ ,  $\text{N}_2\text{H}^+$ ,  $\text{H}_2\text{CO}$ ,  $\text{HC}_3\text{N}$ , and  $\text{CH}_3\text{OH}$  from our model with grain surface reactions provide a good match to observations, while abundances of  $\text{CO}$ ,  $\text{CS}$ ,  $\text{SO}$ ,  $\text{HCN}$ , and  $\text{HNC}$  show better agreement without grain surface reactions. The observed mantle composition of dust grains is best reproduced when we include surface reactions. The initial chemical abundances to be used for detailed modeling of a protoplanetary disk are found to be different from those in dark interstellar clouds. Ices with a binding energy lower than about 1200 K sublime before accreting onto the disk, while those with a higher binding energy do not.

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## The applicability of the viscous $\alpha$ -parameterization of gravitational instability in circumstellar disks

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We study numerically the applicability of the effective-viscosity approach for simulating the effect of gravitational instability (GI) in disks of young stellar objects with different disk-to-star mass ratios  $\xi$ . We adopt two  $\alpha$ -parameterizations for the effective viscosity based on Lin & Pringle (1990) and Kratter et al. (2008) and compare the resultant disk structure, disk and stellar masses, and mass accretion rates with those obtained directly from numerical simulations of self-gravitating disks around low-mass ( $M_* \sim 1.0 M_\odot$ ) protostars. We find that the effective viscosity can, in principle, simulate the effect of GI in stellar systems with  $\xi \lesssim 0.2 - 0.3$ , thus corroborating a similar conclusion by Lodato & Rice (2004) that was based on a different  $\alpha$ -parameterization. In particular, the Kratter et al.'s  $\alpha$ -parameterization has proven superior to that of Lin & Pringle's, because the success of the latter depends crucially on the proper choice of the  $\alpha$ -parameter. However, the  $\alpha$ -parameterization generally fails in stellar systems with  $\xi \gtrsim 0.3$ , particularly in the Class 0 and Class I phases of stellar evolution, yielding too small stellar masses and too large disk-to-star mass ratios. In addition, the time-averaged mass accretion rates onto the star are underestimated in the early disk evolution and greatly overestimated in the late evolution. The failure of the  $\alpha$ -parameterization in the case of large  $\xi$  is caused by a growing strength of low-order spiral modes in massive disks. Only in the late Class II phase, when the magnitude of spiral modes diminishes and the mode-to-mode interaction ensues, may the effective viscosity be used to simulate the effect of GI in stellar systems with  $\xi \gtrsim 0.3$ . A simple modification of the effective viscosity that takes into account

disk fragmentation can somewhat improve the performance of  $\alpha$ -models in the case of large  $\xi$  and even approximately reproduce the mass accretion burst phenomenon, the latter being a signature of the early gravitationally unstable stage of stellar evolution (Vorobyov & Basu 2006). However, further numerical experiments are needed to explore this issue.

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## 2-D simulations of FU Orionis disk outbursts

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We have developed time-dependent models of FU Ori accretion outbursts to explore the physical properties of protostellar disks. Our two-dimensional, axisymmetric models incorporate full vertical structure with a new treatment of the radiative boundary condition for the disk photosphere. We find that FU Ori-type outbursts can be explained by a slow accumulation of matter due to gravitational instability. Eventually this triggers the magnetorotational instability, which leads to rapid accretion. The thermal instability is triggered in the inner disk but this instability is not necessary for the outburst. An accurate disk vertical structure, including convection, is important for understanding the outburst behavior. Large convective eddies develop during the high state in the inner disk. The models are in agreement with Spitzer IRS spectra and also with peak accretion rates and decay timescales of observed outbursts, though some objects show faster rise timescale. We also propose that convection may account for the observed mild-supersonic turbulence and the short-timescale variations of FU Orionis objects.

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<http://adsabs.harvard.edu/abs/2009arXiv0906.1595Z>

## **PhD position in astrochemistry : Synthesis of astrophysically relevant organic molecules at the icy surface of interstellar grains: Theory and models**

The first phases of the formation of stars like the Sun are characterized by the synthesis of several complex organic molecules (hereinafter called COM), identified by their radio to far infrared rotational spectra. COM range from simple molecules such as methanol ( $\text{CH}_3\text{OH}$ ) to larger species such as methyl formate ( $\text{HC}(\text{O})\text{OCH}_3$ ). Whether COM form in the warm gas or whether the icy grains could act as catalysts is an open question. No systematic study has been carried out and a clear theoretical framework of reactions on surfaces covered by water ices is missing. In this context, the thesis aims at understanding how reactions on dust grains contribute to the formation of key COM in space. The work will be divided in two major parts shared between the two laboratories (PhLAM and LAOG): 1. Full characterization of the synthesis routes by performing quantum chemistry calculations (PhLAM): evidence for the reaction intermediates, calculation of the activation barriers first in gas phase, then with water molecules in the reaction ring. The goal will be to determine the most favorable synthesis routes in the interstellar context. 2. Description of the reaction dynamics with classical methods (LAOG): This approach is numerically more efficient and gives reaction kinetics and branching ratios. At the end of the thesis, the student should be experienced in quantum chemistry, classical and semi-classical calculations, that are theoretical skills applicable in various fields of physical chemistry. Required skills for the applicant: Knowledge in physical chemistry and/or fundamental physics and/or in astrophysics. Motivation for a theoretical work, for computer modeling and eventually for methodological developments. The skills in computer science and programming can be acquired during the PhD.

**Funding:** The PhD position is funded for 3 years by ANR (Agence Nationale pour la Recherche). The gross monthly salary will be around 1700 Euros. The position is through employment contract; the social benefits cover medical and dental insurance, parental leave, and retirement benefits.

Applications should be sent as quickly as possible to [celine.toubin@univ-lille1.fr](mailto:celine.toubin@univ-lille1.fr) and [laurent.wiesenfeld@obs.ujf-grenoble.fr](mailto:laurent.wiesenfeld@obs.ujf-grenoble.fr). Consideration of complete applications will begin immediately and will continue until a suitable candidate is identified. The thesis will start in September /October 2009.

## **Post Doc Position in Astrochemistry : Microwave spectroscopy of complex organic molecules (COM)**

**Description:** Many Complex Organic Molecules (COM) have been recently discovered in abundance in regions of star formation: up to a few percent of the carbon elemental abundance seems to be locked in these molecules, so important for life on Earth. However, very likely, we have revealed only the tip of the iceberg so far, and the ultimate molecular complexity in space remains a fascinating unanswered question. As the vast majority of interstellar molecules, COM are identified by observations of their rotational lines in the radio to far-infrared spectral range. Until recently, astrophysical observations were restricted to small spectral ranges around molecular lines selected a priori. With the advent of new and powerful spectral instruments (including the Far-Infrared Satellite Herschel), observations of large spectral ranges are becoming available. These large spectral scans possess a large fraction of unattributed lines that are likely from COM whose spectra have not yet been measured and characterized in the laboratory. The proposed Post-Doc project concerns the measurement of laboratory spectra and analysis to derive the molecular data

of COM suspected to be present in space and particularly important for pre-biotic chemistry, such as acetic acid and methylamine. The work will involve not only measuring and analysing laboratory spectra but also ensuring that existing spectroscopic data is available in a correct, common, easily useable electronic format for interpretation of astrophysical observations. The new spectral data will be compared with the astrophysical spectra already available and to be acquired with Herschel in the next years, which are in the hands of the members of the FORCOMS collaboration (see below). The Post-Doc will be fully involved in the molecular spectroscopy work of measurement and characterization of COM and will benefit from a close collaboration with the astrophysicists in FORCOMS.

Organization: The Post Doc position is available for 2 years, first for one year in the Cold-Universe department in the CESR in Toulouse (with Adam WALTERS and Karine DEMYK) then for a second year at the PhLAM laboratory in Lille (with Laurent MARGULES and Georges WLODARCZAK).

Required skills for the applicant: The candidate should have experience in analyzing and fitting laboratory spectra. Also, any or all of the following would strengthen the application: specific experience in treating problems of internal rotation; experience in laboratory spectroscopy in particular in the microwave region; an interest in astrophysics.

FORCOMS Project presentation: The proposed work is part of the project, funded by the French Agence Nationale de la Recherche (ANR), "FORMATION of Complex Organic Molecules in Space" (FORCOMS). The goal of the project is to answer two important open questions in the Astrochemistry field, regarding Complex Organic Molecules (COM): 1) What COM are synthesized during the protostellar phase of star formation and in what amount? 2) How are (some) COM synthesized and deuterated on the grain ice mantles? The FORCOMS team is highly interdisciplinary; it involves about 30 researchers from four French laboratories (LAOG and LPG in Grenoble, CESR in Toulouse and PhLAM in Lille) working, in a coordinated fashion, on astrophysical observations and modelling, molecular spectroscopy, theory of molecular collisions, laboratory experiment and theory on surface chemistry. In addition, the team has several close collaborations with researchers in Europe and worldwide. The post doc will be fully involved in the overall project, and will, therefore, benefit from being part of a highly interdisciplinary and international team.

Funding: The gross monthly salary will be around 2300 Euros. The position is through employment contract; the social benefits cover medical and dental insurance, parental leave, and retirement benefits. Applications should be sent as quickly as possible to [walters@cesr.fr](mailto:walters@cesr.fr) and [Laurent.Margules@univ-lille1.fr](mailto:Laurent.Margules@univ-lille1.fr). Consideration of complete applications will begin immediately and will continue until a suitable candidate is identified. The post-doc position will start in September /October 2009.

## **PhD position in Astrochemistry : Grain surface chemistry in protostellar environments**

Many Complex Organic Molecules (COM) have recently been discovered very abundant in regions of star formation: up to several percent of the carbon elemental abundance seems to be locked in these molecules, so important for life on Earth. Evidence, based on astronomical observations and laboratory experiments, leads us to think that several COM, like methanol ( $\text{CH}_3\text{OH}$ ) or methyl formate ( $\text{HCOOCH}_3$ ) for instance, are not formed in the gas phase, but rather on the surface of the dust grains. This surface-chemistry is poorly known, for lack of laboratory experiments and a comprehensive theory of the surface reactions. In fact, present astro-chemical models fail to reproduce the observed COM abundances. The proposed thesis deals with the modeling of surface chemistry applied to protostellar environments. The ultimate goal is to develop a model able to explain the astrophysical observations of both the existing data and the new data that will be soon provided by the 3-m space-borne telescope Herschel and the 60-antennae interferometer ALMA in the millimeter to far-infrared. The student will interact with the major experts of the topics in Europe and US, via existing collaborations between them and the host institute members. In addition,

the student will benefit from the other aspects of the FORCOMS project, which involve the development of a the theory of the reactions on water ices, laboratory experiments on the H and D atoms exchange, and observations with the census of the species observed in a low mass protostar, thought to be similar to the Sun's progenitor.

FORCOMS Project presentation: The proposed work is part of the project, funded by the French Agence Nationale de la Recherche (ANR), "FORMATION of Complex Organic Molecules in Space" (FORCOMS). The goal of the project is to answer two important open questions in the Astrochemistry field, regarding Complex Organic Molecules (COM): 1) What COM are synthesized during the protostellar phase of star formation and in what amount? 2) How are (some) COM synthesized and deuterated on the grain ice mantles? The FORCOMS team is highly interdisciplinary; it involves about 30 researchers from four French laboratories (LAOG and LPG in Grenoble, CESR in Toulouse and PhLAM in Lille) working, in a coordinated fashion, on astrophysical observations and modeling, molecular spectroscopy, theory on molecular collisions, laboratory experiments and theory of surface chemistry. In addition, the team has several tight collaborations with researchers in Europe and worldwide. The PhD student will be fully involved in the overall project, and will, therefore, benefit from a highly interdisciplinary and international team.

Funding: The PhD position is funded for 3 years by ANR (Agence Nationale pour la Recherche). The gross monthly salary will be around 1700 Euros. The position is through employment contract; the social benefits cover medical and dental insurance, parental leave, and retirement benefits. Applications should be sent as quickly as possible to Cecilia.Ceccarelli@obs.ujf-grenoble.fr. Consideration of complete applications will begin immediately and will continue until a suitable candidate is identified. The thesis will start in September /October 2009.

## **Post-doctoral position in "modeling the physics and chemistry of the interstellar medium". - Laboratory Universe and Theories (LUTH) - Paris Observatory**

In the context of the ANR project SCHISM (Structure and Chemistry of the InterStellar Medium), LUTH invites applications for a postdoctoral position to investigate surface chemical processes for interstellar purposes and its coupling with dynamical processes. The corresponding studies will be achieved via numerical modelisation and aim to be used for interpretation of forthcoming Herschel observations.

Thanks to higher spatial and spectral resolution, as the HIFI instrument on board Herschel and BURE 30m IRAM interferometer, the interaction between the UV radiation field and interstellar medium can be studied at an unprecedented depth. A key point is to better understand the coupling between gas phase chemistry and surface chemistry. New results from several laboratory experiments and theoretical studies allow to better constrain surface chemistry and quantitative modelling becomes feasible.

The objectives of this project is to implement in the Meudon PDR code surface chemical processes including possible stochastic effects due to the limited number of adsorption sites on small grains. Le Petit et al. (2009) have already introduced such effects for H<sub>2</sub>, HD and D<sub>2</sub> formation on grains by using moment equations as developed in the group of Pr Biham, at Hebrew University in Jerusalem. The post-doctoral position is intended to extend the method to formaldehyde and methanol formation on grains. The corresponding coupled moment equations have been set up by Barzel and Biham (2007) and should be introduced in an automated way together with the other gas phase processes described by rate equations. He (she) will then couple these processes to dynamical mechanisms as diffusion and turbulence. The applicant should have numerical analysis and software development skills. He (she) will also be closely associated to the interpretation of the expected exciting observational results coming from the HERSCHEL observations key programs the members of the SCHISM project are part of.

The candidate will work in collaboration with the LUTH - ISM team, Evelyne Roueff, Jacques Le Bourlot and Franck

Le Petit located at Meudon, close to Paris. The new code will then be used to study the influence of physical parameters such as grains temperature and grains size distribution in relevant astrophysical conditions.

Prospective applicants are encouraged to contact us by e-mail for further information. The position is expected to start in the fall of 2009. It is funded for two years. A CV, including a publication list and a brief motivation letter and research statement should be sent, either electronically or by regular mail. Three letters of reference should also reach us independently of the application.

The documents should be sent for July 31th, 2009. Late applications will continue to receive attention until the position is filled.

Contact: Evelyne Roueff, [evelyne.roueff@obspm.fr](mailto:evelyne.roueff@obspm.fr) & Franck.LePetit@obspm.fr

LUTH - Observatoire de Paris

Place Jules Janssen

92190 Meudon.

## Postdoctoral Fellow(s) - Exo-Planets, Brown Dwarfs and Young Stars

Applications are invited for one or more postdoctoral research position(s) at the University of Toronto to start in January 2010 or later. The successful candidate(s) will work with Prof. Ray Jayawardhana and his collaborators on observational and analytical studies of extra-solar planets, brown dwarfs and young stars, and will be encouraged to pursue independent research on related topics. On-going projects include high-contrast imaging searches for companions around young stars, the SONYC (Substellar Objects in Nearby Young Clusters) ultra-deep survey, photometric and spectroscopic studies of exo-planets, and investigations of brown dwarf variability, using data from VLT, Subaru, Gemini, Keck, Spitzer, Las Campanas and other major observatories. The position is for two years, with extension to a third year possible, and comes with funds for research expenses. Applicants should send a curriculum vitae, a description of research interests and plans and a list of publications, and should arrange for three letters of recommendation to be sent directly to the address below. E-mail submission preferred. Applications received before August 15 will receive full consideration. Early expressions of interest and inquiries are welcome.

Prof. Ray Jayawardhana, Dept. of Astronomy & Astrophysics, University of Toronto, 50 St. George Street, Room 101, Toronto, ON M5S 3H4, CANADA.

E-mail submission and inquiries: [rayjay@astro.utoronto.ca](mailto:rayjay@astro.utoronto.ca)

## *Meetings*

### **Assembly, Gas Content and Star Formation History of Galaxies**

**The Fourth North American ALMA Science Center Conference**

**September 21-24, 2009**

**Omni Hotel, Charlottesville, Virginia**

In the last two decades, the availability of large ground-based and space-based facilities and improved theoretical modeling have led to significant advances in our understanding of star formation, the gas cycle in galaxies, and galaxy assembly and evolution over cosmic time. With the next generation of long-wavelength ground- and space-based facilities set to become fully operational in the first half of the coming decade, the time is ripe to review the theoretical and observational progress that has been made in the areas of extragalactic star formation, interstellar gas properties and galaxy assembly, and to assess where science with facilities such as ALMA, EVLA, Herschel Space Telescope, and the JWST are likely to contribute transformational understanding in these areas.

A major goal of this meeting is to highlight the capabilities of ALMA, and its synergy with the EVLA, Herschel, JWST, etc., in driving transformational science in these key areas in the next decade.

Key issues to be addressed are:

- o Gas content, scaling relations, and diagnostics of the star formation rate at low and high redshift
- o Advances in the theory and modeling of galaxy assembly and star formation on small and large scales
- o The role of feedback from stellar winds, SNe and AGN in regulating star formation
- o The role of accretion and mergers in driving galactic evolution.

Additional information is available at:

<http://www.nrao.edu/meetings/galaxies09/>

This conference is sponsored by NRAO/AUI/NSF, with support from the University of Virginia.

### **From Circumstellar Disks to Planetary Systems**

**November 3-6 2009, Garching**

**An ESO-MPE-MPA-USM workshop**

The study of circumstellar disks and the formation of planetary systems is experiencing enormous progress in recent years. Thanks to wide-field imaging surveys with the Spitzer Space Telescope and ground-based near-infrared and submillimeter telescopes, unbiased samples of thousands of young stellar objects with disks down to 0.01 L<sub>Sun</sub> (brown dwarf regime) have been identified in the nearest molecular clouds. High angular resolution observations provide key insight into disk structure and evolution. New and exciting developments range from the characterization of disks in the embedded phase to the development of gaps and holes in a new set of transitional disks, and the direct detection of (proto)planets around pre-main sequence stars.

The goals of the workshop will be to review the status of the field and to discuss transformational programs that will be made possible with upcoming facilities. We propose to bring together the communities working with ground

based infrared large telescopes and interferometers, with space observatories and millimeter interferometers as well as theorists.

Main science topics include

\* Properties of circumstellar disks across the stellar mass spectrum

Evolution of protoplanetary disks

Chemistry in disks (gas phase and solids)

Initial phases of planet formation

Young (proto)planets

Planet-disk interactions

Debris disks

For more information and scientific rationale, see <http://www.eso.org/sci/meetings/disks2009/index.html>

Important dates:

Closing dates for abstracts: August 1 2009

Closing date for registration: September 10 2009

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

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

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

## Moving ... ??

If you move or your e-mail address changes, please send the editor your new address. If the Newsletter bounces back from an address for three consecutive months, the address is deleted from the mailing list.