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Abstracts of recently accepted papers

The extraordinary outflow towards G5.89–0.39

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We have observed four rotational transitions of SiO in its ground vibrational state towards the ultracompact HII region and outflow source G5.89–0.39, using the Pico Veleta 30-m and Effelsberg 100-m radio telescopes and the Very Large Array radio interferometer. This allowed us to probe the low-velocity gas in the flow “hidden” from view in CO observations due to contamination by ambient gas and self-absorption. The projected flow diameter is 0.08 pc with a NE-SW bipolarity. The thermal pressure (P_{therm}/k) in the outflowing gas, determined from a statistical equilibrium analysis of the SiO lines, is about 10^8 K cm^{-3} . Based on NH_3 and CO observations, the kinetic temperature of the outflowing gas is around 100 K. The combined results imply densities of order 10^6 cm^{-3} in the outflow region. The fractional abundance of SiO relative to H_2 , based on comparisons of our data with CO spectra of Choi et al. (1993), is 1 to 3×10^{-9} in the outflowing gas. We estimate the total mass in the outflow to be about $77 L_{\odot}$.

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A molecular disk and dense outflow in Corona Australis

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The central region of the molecular outflow in the R Coronae Australis cloud was mapped in $\text{HCO}^+(J = 1 - 0)$, $\text{H}^{13}\text{CO}^+(J = 1 - 0)$, $\text{HCO}^+(J = 3 - 2)$ and $\text{C}^{18}\text{O}(J = 2 - 1)$ with the SEST. In addition to the maps, selected positions were observed in $\text{SiO}(J = 2 - 1, v = 0)$. The observations reveal a complex system consisting of a dense core, a rotating molecular disk around the infrared source IRS 7 and a dense, bipolar molecular outflow. The molecular disk is located close to the northeastern edge of the core and is obscured by outlying material from the foreground core. The disk’s radius is greater than 3000 AU and its mass is greater than $0.01 M_{\odot}$. The alignment, in the plane of the sky, between the molecular disk’s rotational axis and the extended NE-SW chain of Herbig-Haro objects in the vicinity is excellent. The mass of the central protostar IRS 7 is greater than $0.6 M_{\odot}$. The dense outflow corresponds to the compact E-W directed outflow detected previously by Levreault (1988). The Herbig Ae/Be star R CrA is eliminated as a candidate driver for the dense, bipolar outflow. IRS 7 is the most likely driver for this outflow. The ejection axes of the blue and redshifted lobes of the bipolar outflow are substantially misaligned with respect to each other and with

respect to the rotational axis of the molecular disk. The masses and momenta of the red and blueshifted components of the bipolar outflow are very well balanced with representative values being $0.06 M_{\odot}$ and $0.22 M_{\odot} \text{ km s}^{-1}$ respectively. The observations exclude centrifugal acceleration of material from the molecular disk as the driving mechanism and source for the outflow. There is evidence of interaction between the disk/outflow system and the dense foreground core: the approaching flow collides with the outer regions of the core causing a powerful shock which is manifest as $\text{SiO}(J = 2 - 1, v = 0)$ emission and the Herbig–Haro objects HH104 A and B. In addition, a bridge of redshifted material extends from the foreground core to the receding side of the molecular disk. We suggest that this feature represents an accretion stream feeding the molecular disk.

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Preprints of this paper are available via anonymous ftp from the directory pub/moray/CrA at astar.helsinki.fi

Ammonia observations towards molecular and optical outflows

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We observed the $(J, K) = (1, 1)$ and $(J, K) = (2, 2)$ inversion transitions of the NH_3 molecule towards several regions with molecular or optical outflows: RNO 43, HH 83, HH 84, HH 86/87/88, L1641-N, L100, L483, L673, IRAS 20188+3928, L1228, L1048, HHL 73, L1251 (IRAS 22343+7501 and IRAS 22376+7455) and L1262, using the 37 m radio telescope of the Haystack Observatory. Additionally, we searched for the $6_{16-5_{23}}$ H_2O maser line towards nine regions, detecting a weak H_2O maser near IRAS 20188+3928. We detected and mapped NH_3 emission in 14 of the 15 regions observed, and we estimated physical parameters for the high density gas. We systematically found that the position of the best candidate for the outflow excitation in each region is very close to an NH_3 emission peak. From a statistical study of the data presented in this paper, together with previously published data, we conclude that the NH_3 line emission is more intense towards molecular outflow sources than towards sources with only optical outflows. Therefore, molecular outflows appear to be associated with larger amounts of high density gas. This result suggests a possible evolutive scheme in which young objects associated with molecular outflows lose progressively their neighboring high-density gas, weakening both the NH_3 emission and the molecular outflow in the process, and making optical jets more easily detectable as the total amount of gas decreases.

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COYOTES IV: the rotational periods of low-mass Post-T Tauri stars in Taurus.

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We monitored the light variations of 58 weak-line T Tauri stars in Taurus, recently discovered in the X-ray wavelength

range during the ROSAT All-Sky Survey. We derive photometric periods for 18 stars, all but one being ascribed to rotational modulation by stellar spots. The exception is a 37.6d period assigned to the orbital motion of a new pre-main sequence spectroscopic binary. Two thirds of the stars in our sample have an age larger than 10 Myr and up to 40 Myr, thus filling the observational gap that previously existed between T Tauri stars on convective tracks and ZAMS dwarfs for the determination of the rotational evolution of young low-mass stars. The rotational periods are found to range from 0.5 to 7.5 days, most periods being shorter than 5 days. This result provides direct evidence for the spin up of solar type stars as they contract on pre-main sequence radiative tracks, as predicted by recent models of angular momentum evolution. The paucity of long periods ($P \geq 5\text{d}$, i.e., $V_{eq} \leq 10 \text{ km s}^{-1}$) in the sample of post-T Tauri stars leaves, however, the origin of the numerous slow rotators observed in young clusters an open issue.

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FIR Line Emission From Collapsing Protostellar Envelopes

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We present a theoretical model that computes the chemical evolution, thermal balance and line emission from the collapsing gas of the envelopes that surround protostars. This is the first attempt to self-consistently calculate the line spectrum from the infalling gas with a model which includes dynamics, chemistry, heating and cooling, and radiative transfer. For the dynamics we have adopted the “inside-out” spherical collapse of an isothermal cloud (Shu 1977) valid for $r \geq r_c$, where the centrifugal radius $r_c \sim 10^{14} - 10^{15}\text{cm}$. A time-dependent chemical code follows the chemical composition of the envelope during the collapse.

The main chemical result is that the inner regions ($r \leq 10^{15}\text{cm}$) have high H_2O abundances caused by the evaporation of H_2O ice from grains when dust temperatures exceed $\sim 100 \text{ K}$ and by gas phase chemical reactions when gas temperatures exceed $\sim 200 \text{ K}$. The gas is heated mainly by absorption of (dust continuum) NIR photons by H_2O molecules in the inner regions, by compressional heating in an intermediate zone, and by collisions of gas with warm dust grains in the outer regions ($r \geq 10^{17}\text{cm}$). The gas is cooled by H_2O rotational lines in the inner regions, by the [OI] $63\mu\text{m}$ fine structure line and CO rotational lines in the intermediate region, and by CO rotational lines in the outer zones. The gas temperature roughly tracks the grain temperature for $10^{14}\text{cm} \leq r \leq 10^{17}\text{cm}$, ranging from about 300K to 10K.

We present the computed spectrum of a $1M_\odot$ protostar accreting at a rate of $10^{-5}M_\odot\text{yr}^{-1}$. The H_2O lines and the [OI] $63\mu\text{m}$ line will be easily detectable by the spectrometers on board the Infrared Space Observatory (ISO). The [OI] $63\mu\text{m}$ line and the mid J ($J \sim 7 - 15$) CO lines can be detected by the Kuiper Airborne Observatory (KAO) or the Stratospheric Observatory For Infrared Astronomy (SOFIA), and certain low J CO lines can be detected by ground based telescopes. We also present a large number of other models in which we test the sensitivity of the spectrum to the variations in the three main parameters of our model: the inner radius of spherically symmetric infall (e.g., the centrifugal radius), the amount of H_2O ice evaporated into the gas, and the mass accretion rate. We show how H_2O lines, CO lines and the [OI] $63\mu\text{m}$ line can be used to estimate these three parameters and how resolved line profiles will show the velocity signature of the collapse. Comparison between an infalling and a static envelope with similar density, chemical and dust temperature structure shows that line fluxes alone are not enough to unmistakably distinguish the two cases. Observable H_2O masers may be produced in the innermost collapsing gas at $r \sim 4 \cdot 10^{14}\text{cm}$.

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Properties of low mass objects in NGC 2024

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We have obtained deep JHK imaging of the central region of the NGC 2024 embedded cluster, allowing three-color measurements of 151 sources. We show that contamination by background sources is small, and we reject a small number of sources that are probably foreground. We use a Monte Carlo isochrone fitting technique to estimate the luminosities and masses of the low mass members of the embedded cluster. We find that the IMF between ~ 0.04 and $\sim 0.5 M_{\odot}$ can be fitted within the errors with a power law of slope -1.2 in linear mass units (or -0.2 in logarithmic units). There is no indication of a turnover of the IMF at the bottom of the main sequence; it appears to continue down to $\sim 0.04 M_{\odot}$ with no significant deviation (within our moderately large errors) from the power law. This estimate of the IMF includes only the primary members of binary (or multiple) systems. Of a subset of 35 sources, 24 (69 %) appear to have infrared excesses indicating possible circumstellar disks, supporting previous arguments that disk formation is not inhibited in high density clusters.

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Optical polarimetry, high-resolution spectroscopy and IR analysis of the Chamaeleon I dark cloud.

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We present optical polarimetry and high resolution spectroscopy of a sample of stars toward the Chamaeleon I dark cloud. We use our polarimetry which includes 33 stars to study the wavelength dependence of the degree and position angle of polarization.

From fits to the normalized wavelength dependence of interstellar polarization, we derive estimates of λ_{Max} ranging from 4500 Å to 6700 Å, and P_{Max} ranging from 3 to 8%. The values of λ_{Max} were found to be well correlated with the IRAS 100 μm intensity, while P_{Max} was found to increase with E_{B-V} .

High resolution spectra of the Ca II, CH, and CH⁺ lines were obtained for 10 stars, which show two components of Ca II in absorption at $3.0 < v_{LSR} < 5 \text{ km s}^{-1}$, and $v_{LSR} = -3.0 \text{ km s}^{-1}$ and a single strong molecular CH absorption component at $3.0 < v_{LSR} < 5.0 \text{ km s}^{-1}$.

From our data we found, by interpretation of the various correlations between the polarimetry, photometry and IRAS fluxes, the following:

the probable presence of shocked molecular gas; a warm molecular CH component; small dust grains at the edges of the cloud, and larger grains in the central parts, which are causing the polarization.

Our results provide a consistent picture of the gas and dust content in the Cha I region, where larger grains, responsible of the starlight polarization, exist in the center of the cloud, surrounded by envelopes of warmer molecular and atomic material.

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A Fractal Origin for the Mass Spectrum of Interstellar Clouds

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Interstellar molecular clouds have power law size L and mass M distributions of the form $n(L)dL = L^{-\alpha_L}dL$ and $n(M)dM = M^{-\alpha_M}dM$, where $M \propto L^\kappa$ is also a power law. These relations are shown to result from the fractal and scale-free nature of interstellar gas with power indices that are independent of distance. The results are $\alpha_L = 1 + D$ and $\alpha_M = 1 + D/\kappa$ for interstellar fractal dimension $D = 2.3 \pm 0.3$ and a value of κ in the range 2.4–3.7, as determined from cloud surveys in the literature. The same fractal dimension also results from the expected relation $D = \kappa$ when the $M(L)$ correlation includes many different surveys, spanning a range of 10^{10} in mass. These results imply that interstellar CO clouds are the unresolved parts of a pervasive fractal structure in the interstellar gas. The similarity between $n(M)$ for interstellar clouds and $n(M)$ for globular clusters suggests that the clusters formed inside fractal progenitor clouds at a nearly constant efficiency.

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The pre-main-sequence spectroscopic binary 162814–2427: models versus observations

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Models of stars with masses between 0.5 and 1.5 M_\odot evolving in the pre-main-sequence have been computed using a multiple shooting point hydrodynamic code. The theoretical results are compared with the most recent observational data available for the double-lined pre-main-sequence spectroscopic binary 162814–2427. A comparison with theoretical models computed with different input physics concerning the opacities, the equation of state and the convection treatment of superadiabatic regions is also done. Our reference model agrees well with the dynamical mass ratio and the assumption of coeval formation of the binary components. Accordingly, assuming a K4 primary and a K5 secondary we estimate the mass of the primary and secondary to be 1.10 and 1.00 M_\odot , respectively, with an age of 3.7 million years.

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Near-Infrared Spectra and the Evolutionary Status of Young Stellar Objects: Results of a 1.1 – 2.4 μm Survey

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We present the results of a moderate resolution ($R \sim 500$) 1.15 – 2.42 μm near-IR spectroscopic survey of young stellar objects (YSOs), FU Ori type stars, and MK spectral standards. The survey sample includes approximately 100 mostly low-mass YSOs characterized by a wide range of spectral energy distributions (SEDs) and evolutionary states which are drawn from the Ophiuchus, Taurus, and other nearby star forming regions. As part of this study we also present the first systematic, flux-limited spectroscopic survey of an entire population of YSOs embedded within a single molecular cloud (Ophiuchus).

In general we find the shapes of YSO spectra to be correlated with SED class such that the most embedded objects generally have the steepest IR spectra. Many YSOs also show absorption features similar to those of (mostly late-type) MK standard stars. For sources in the flux-limited sample, we find that the strengths of atomic and CO absorption features are closely related to SED class and evolutionary state. In particular, these line strengths generally decrease from the revealed Class III phase to the Class II phase to the self-embedded Class I phase where absorption features

are typically absent at the resolution of our survey, confirming trends found in earlier studies. This correlation of absorption strength with SED class can be explained by a systematic increase in the veiling of an underlying stellar photosphere from Class III to Class I objects. The likely source of this veiling is continuum emission from increasing amounts of luminous circumstellar material surrounding these objects. Moreover, it appears that the absence of absorption features and the resulting large veilings of Class I sources are likely related to significantly increased levels of accretion/infall compared to Class II and III sources.

Most YSOs in our study appear to have surface gravities which range between those of giant and dwarf stars. Flat-spectrum YSOs have the lowest surface gravities of all objects in our flux-limited Ophiuchus sample. FU Ori stars have even lower surface gravities, similar to those of giant or supergiant stars, suggestive of line formation in disks rather than stellar photospheres. The FU Ori type stars and a few other YSOs show deep and broad H₂O absorptions, indicative of cool ($T \leq 3000$ K) disks or stellar photospheres. Many Class I and Class II objects show relatively strong H I emission lines which probably originate in a partially ionized circumstellar region. However, mostly Class I objects show detectable H₂ emission lines.

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Disk Accretion and the Stellar Birthline

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We present a simplified analysis of some effects of disk accretion on the early evolution of fully-convective, low-mass pre-main sequence stars. Our analysis builds on the previous seminal work of Stahler, but differs in that the accretion of material occurs over a small area of the stellar surface, such as through a disk or magnetospheric accretion column, so that most of the stellar photosphere is free to radiate to space. This boundary condition is similar to the limiting case considered by Palla & Stahler for intermediate-mass stars. We argue that for a wide variety of disk mass accretion rates, material will be added to the star with relatively small amounts of thermal energy. Protostellar evolution calculated assuming this “low-temperature” limit of accretion generally follows the results of Stahler because of the thermostatic nature of deuterium fusion, which prevents protostars from contracting below a “birthline” in the HR diagram. Our calculated protostellar radii tend to fall below Stahler’s at higher masses; the additional energy loss from the stellar photosphere in the case of disk accretion tends to make the protostar contract. The low-temperature disk accretion evolutionary tracks never fall below the deuterium-fusion birthline until the internal deuterium is depleted, but protostellar tracks can lie above the birthline in the HR diagram if the initial radius of the protostellar core is large enough, or if rapid disk accretion (such as might occur during FU Ori outbursts) adds significant amounts of thermal energy to the star. These possibilities cannot be ruled out by either theoretical arguments or observational constraints at present, so that individual protostars might evolve along a multiplicity of birthlines with a modest range of luminosity at a given mass. Our results indicate that there are large uncertainties in assigning ages for the youngest stars from HR diagram positions, given the uncertainty in birthline positions. Our calculations also suggest that the relatively low disk accretion rates characteristic of T Tauri stars below the birthline cause low-mass stars to contract only slightly faster than normal Hayashi track evolution, so that ages for older pre-main sequence stars estimated from HR diagram positions are relatively secure.

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The IRAS2 and IRAS4 Outflows and Star Formation in NGC 1333

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We report the first detection of the western bowshock component from IRAS2 in NGC 1333 along with observations

of previously detected shocks and outflow winds from this source and those from IRAS4. We compare the shock and outflow distributions from these two young stellar objects, and the locations of other YSOs, with the overall distribution of the dense molecular gas in the star forming core using high spatial resolution observations of CS ($J = 2 \rightarrow 1$, $3 \rightarrow 2$, and $5 \rightarrow 4$) emission made with the IRAM 30 m antenna. These comparisons provide a new picture of the morphology and dynamics of the star forming core of NGC 1333. The CS maps show: 1) a large cavity with many YSOs just at the inner edge of the cavity; 2) a dense compressed shell at 8 km s^{-1} ; and, 3) a gas layer at 7 km s^{-1} probably located inside the cavity. We find that the IRAS2 and IRAS4 outflows impact different gas layers as indicated by the spatial association of the red and blue shifted lobes, and that IRAS2 is located near the front edge of the CS shell. The burst of star formation, which has shaped NGC 1333, is occurring in the compressed shell traced by CS and now appears to be in a late evolutionary stage.

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The Luminosity Function of OB Associations in the Galaxy

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OB associations ionize the interstellar medium, producing both localized H II regions and diffuse ionized gas. The supernovae resulting from these associations pressurize and stir the interstellar medium. Using Smith, Biermann, and Mezger's compilation of radio H II regions in the Galaxy, and Kennicutt, Edgar, and Hodge's optical study of H II regions in nearby galaxies, we show that the luminosity distribution of giant OB associations in the Galaxy can be fit by a truncated power-law of the form $\mathcal{N}_a(> S) = \mathcal{N}_{au}[(S_u/S) - 1]$, where S is the ionizing photon luminosity, $\mathcal{N}_a(> S)$ is the number of associations with a luminosity of at least S , and S_u is the upper limit to the distribution. The coefficient \mathcal{N}_{au} is the number of the most luminous associations, with a luminosity between $0.5S_u$ and S_u . For the Galaxy, $\mathcal{N}_{au} = 6.1$; the fact that the number of the most luminous associations is significantly larger than unity indicates that there is a physical limit to the maximum size of H II regions in the Galaxy. To extend the luminosity distribution to small H II regions, we assume that the birthrate of associations, $\dot{\mathcal{N}}_a(> \mathcal{N}_*)$, is also a truncated power law, $\dot{\mathcal{N}}_a(> \mathcal{N}_*) \propto [(\mathcal{N}_{*u}/\mathcal{N}_*) - 1]$, where \mathcal{N}_* is the number of stars in the association. For large associations, the ionizing luminosity is proportional to the number of stars, $S \propto \mathcal{N}_*$; for smaller associations, we use both an analytic and a Monte Carlo approach to find the resulting luminosity distribution $\mathcal{N}_a(> S)$.

H II regions are generally centrally concentrated, with only the dense central regions being bright enough to appear in radio catalogs. Anantharamaiah postulated that radio H II regions have extended envelopes in order to account for diffuse radio recombination line emission in the Galaxy. Some of these envelopes are visible as the ionized "worms" discussed by Heiles and coworkers. We estimate that on the average the envelopes of radio H II regions absorb about twice as many ionizing photons as the radio H II regions themselves. Allowing for the ionizing radiation which is absorbed by dust (about 25% of the total), we find that the maximum ionizing photon luminosity of a Galactic OB association is $S_u \simeq 4.9 \times 10^{51} \text{ photons s}^{-1}$, corresponding to an H α luminosity of about $5 \times 10^{39} \text{ erg s}^{-1}$. The total ionizing luminosity of this distribution of OB associations can account for the thermal radio emission and the N II far infrared emission of the Galaxy. The number of massive stars in the associations is consistent with estimates of the rate of massive star supernovae in the Galaxy. Associations produce several generations of stars over their lifetimes, and the largest associations are predicted to produce about 7000 supernova progenitors. Fitting the surface density of associations to an exponential of the form $d\mathcal{N}_a(\mathcal{N}_*)/dA \propto \exp(-R/H_R)$ with a scale length $H_R = 3.5 \text{ kpc}$ gives a number of OB associations in the solar neighborhood that is consistent with observation. The H II envelopes contribute to pulsar dispersion measures, and can account for the increased dispersion measure observed in the inner Galaxy.

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The L1457 Molecular/Atomic Cloud Complex: HI and CO Maps

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L1457 is the closest known molecular cloud (65pc), and lies near the edge of the local hot bubble, and well out of the galactic plane ($b \sim -34^\circ$). We have mapped an $8^\circ \times 8^\circ$ region at 35' resolution, and a $3^\circ \times 5^\circ$ region at $\sim 2'$ resolution, in HI 21cm emission. We have also mapped a $2^\circ \times 4^\circ$ region at 2' resolution in ^{12}CO J=1-0. We find that there is an extended component of atomic gas, clearly associated with the molecular complex, and comparable to it in total mass. The HI structure at small scales in the vicinity of the molecular clouds is remarkable, consisting largely of long, narrow filaments $<20'$ (0.2pc) in width and $1^\circ - 4^\circ$ in length. A thin ($<10'$) limb-brightened atomic halo is seen to surround the CO at some velocities, but is ill-defined at other velocities. The halo may be disturbed by external pressure, perhaps from the hot gas in the local bubble.

The molecular clouds are part of a large structure $\sim 5^\circ \times 3^\circ$ in extent with a small “funnel-shaped” extension to the south. The structure, which we call the L1457 atomic/molecular complex, is dominated by HI in the north and H_2 in the south extension. Roughly half the mass of the complex is molecular. The structure of this complex at both large- and small-scale suggests that the south end has been recently compressed.

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<http://www.jach.hawaii.edu/gms/preprints>

Dense Gas and Star Formation: Characteristics of Cloud Cores Associated with Water Masers

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We have observed 150 regions of massive star formation, selected originally by the presence of a water maser, in the J = 5-4, 3-2, and 2-1 transitions of CS, and 49 regions in the same transitions of C^{34}S . Over 90150 regions were detected in the J = 2-1 and 3-2 transitions of CS and 75 were detected in the J=5-4 transition. We have combined the data with the J = 7-6 data from our original survey (Plume et al. 1992) to determine the density by analyzing the excitation of the rotational levels. Using Large Velocity Gradient (LVG) models, we have determined densities and column densities for 71 of these regions. The gas densities are very high (the mean log of the density is 5.9), but much less than the critical density of the J=7-6 line. Small maps of 25 of the sources in the J = 5-4 line yield a mean diameter of 1.0 pc. The mean virial mass is 3800 solar masses. The mean ratio of bolometric luminosity to virial mass (L/M) is 190, about 50 times higher than estimates using CO emission, suggesting that star formation is much more efficient in the dense gas probed in this study. The gas depletion time for the dense gas is roughly 1.3×10^7 yr. We find no statistically significant linewidth–size or density–size relationships in our data. Instead, both linewidth and density are larger for a given size than would be predicted by the usual relationships. We find that the linewidth increases with density, the opposite of what would be predicted by the usual arguments. We estimate that the luminosity of our Galaxy (excluding the inner 400 pc) in the CS J = 5-4 transition is 15 to 23 L_\odot , considerably less than the luminosity in this line within the central 100 pc of NGC 253 and M82. In addition, the ratio of far-infrared luminosity to CS luminosity is higher in M82 than in any cloud in our sample.

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Available from lanl server (<http://xxx.lanl.gov>) as astro-ph/9609061.

The Ecological Balance of Low Mass Star Formation Regions

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It has been quite widely speculated that the momentum injected by bipolar outflows from young stars into their surroundings might feed the turbulence of the placental molecular clouds. In this way a balance could be attained, in which the turbulence leads to the formation of low mass stars, and the outflows from these stars then feed momentum and energy into the turbulent motions, counterbalancing the effect of the turbulent dissipation.

For such a balance to be possible, it is clear that an efficient coupling between the outflows and the turbulent motions is necessary. This paper describes a possible coupling mechanism, in which a precessing jet is scattered into “bullets” and “shells” travelling in different directions by the interaction with high density clumps present in the surrounding environment. The bullet and shell structures have a high interaction cross section, and are therefore easily trapped within the molecular cloud, in which they deposit the momentum of the jet in the form of high vorticity eddies of complex morphology.

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A Compilation of Optical Spectrophotometric Observations of Herbig-Haro Objects and its Tentative Interpretation

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This paper presents a compilation that includes a large fraction of the spectrophotometric observations of Herbig-Haro (HH) objects published (by a number of different authors) from 1981 through 1993. Our compilation includes 45 separate condensations of 31 different outflows, for all of which both blue and red spectra (in the range from ~ 3700 Å to ~ 8000 - 10000 Å) are available. From this data set, we have chosen a number of line ratios (namely, [O III] 5007/H β , [Ne III] 3868/H β , [O II] (3726+3729)/H β , [N II] 6583/H β , [O I] 6300/H α , [N I] (5198+5200)/H β , [Ca II] 7291/H α , [S II] (4068+4076)/H β and [S II] (6717+6731)/H α) which are not strongly affected by reddening. We then study the different correlations that are found between these line ratios, and compare the results with predictions from shock wave models.

Quite surprisingly, we find that while the observed “high excitation” line ratios ([O III] 5007/H β and [Ne III] 3868/H β) and the “low excitation” line ratios ([O I] 6300/H α and [N I] (5198+200)/H β) can be easily reproduced with shock wave models of velocities from 20 to 400 km s⁻¹, clear problems appear for other line ratios, in particular for [S II] (6717+31)/H α . These results present interesting questions about the interpretation of HH object spectra in terms of plane-parallel or “quasi-1D” bowshock models. The fact that there is no indication that in any HH object the shock velocity indicated by the [O III] 5007/H β or [Ne III] 3868/H β is larger than ~ 95 km s⁻¹ is surprising.

We also use the compiled data set to derive a quantitative criterion (based on the [O III] 5007/H β and [S II] (6717+6731)/H α line ratios) to divide HH spectra into the high, intermediate and low excitation categories. Finally, we obtain empirical determinations of n_e (from the [S II] 6731/6717 ratio) for the HH condensations of our sample.

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Near-Infrared Photometric Monitoring of Young Stellar Objects

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This paper reports infrared JHK photometry of 15 young stellar objects sampled at intervals of a few days to a few weeks during the winters of 1991 and 1992. Accretion luminosity dominates the near-infrared flux of most of the sources. Observed variations ranged between one tenth to one full magnitude during the monitoring period and were well correlated at all three wavelengths. Variations by individual sources in the $(H - K)$ vs. $(J - H)$ color-color diagram indicate that such changes can be explained by some combination of variable extinction of the stellar photosphere and changes in the accretion properties of the sources. The amplitude of K-band source variability is weakly correlated with $(K - L)$ excess, which is a reliable accretion diagnostic. Included are near-infrared light curves for V410 Tau, a rapidly-rotating, heavily-spotted weak-emission T-Tauri star as a demonstration of the accuracy and consistency of the photometric measurements (typically 2-4%) and for comparison with the extensive body of existing visible-wavelength observations.

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Preprint available at <http://pegasus.phast.umass.edu/preprints/tts.html>

Interferometric Observations of Outflows from Low-Mass Protostars in Taurus

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We have mapped CO $J=1-0$ outflows from two low-mass protostar candidates in Taurus, IRAS 04365+2535 (TMC1-A) and IRAS 04368+2557 (L1527), using the Nobeyama Millimeter Array. The outflow structure is compared with deep near-infrared images obtained by IR array detectors.

The molecular outflow from IRAS 04365+2535 (TMC1-A) shows a clear bipolar structure whose blue-shifted lobe extends to the north-west and red-shifted one to the south-east. The extension of the blue-shifted lobe is consistent with that of the monopolar infrared reflection nebula, suggesting the presence of a large (~ 2500 AU) tilted dust disk or elongated envelope which obscures the other side of the nebula, i.e., the red-shifted lobe.

The outflow associated with IRAS 04368+2557 (L1527) appears to be almost perfectly in the plane of the sky with blue-shifted and red-shifted lobes significantly overlapped with each other. Both lobes show clear bow-tie shaped, shell-like structure whose geometrical center is coincident with a radio continuum point-like source. Deep near-infrared images have revealed that a faint bipolar infrared nebulosity is associated with the “edge-on” molecular outflow. The central source, totally invisible even at near-infrared wavelengths, might be heavily obscured by a disk or an elongated envelope whose size is comparable to the IR nebula ($\sim 10,000$ AU).

These two IRAS sources show large difference in their near-infrared appearance even though they have similar physical properties including bolometric luminosity, association of CO outflows, and submillimeter/millimeter flux. This difference might be due to the inclination effect: the central part of IRAS 04368+2557 is more heavily obscured ($A_V \sim 70$ mag) along the line of sight than that of IRAS 04365+2535 by the envelope of a disk-like structure with almost edge-on geometry. The difference of the appearance of CO outflow between these two sources is consistent with this interpretation. Although IRAS 04368+2557 is regarded as a Class 0 source, our observations suggest that this source could be similar to IRAS 04365+2535, a Class 1 source, in nature, except for the geometry of the circumstellar envelope.

Accepted by AJ

A search for clustering around Herbig Ae/Be stars

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We present the results of new near-infrared observations of the fields around a sample of 19 Herbig Ae/Be stars. The observations reveal the population of young stars that accompanies the formation of intermediate-mass stars.

The richness of the detected star clusters is investigated. We find a clear dependence of the richness of the cluster on the spectral type of the Herbig Ae/Be star, confirming that the mode of formation of intermediate-mass stars represents the transition between the high-mass and the low-mass modes. In particular, we find that the cluster nature of star formation appears at a significant (i.e. detectable) level for stars of B7 spectral type or earlier.

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<http://www.arcetri.astro.it/~testi/preprints.html>

H₂ infrared line emission from S140: a warm PDR

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ISO SWS spectra of H₂ pure rotational and ro-vibrational transitions, as well as [FeII], and [SiII] fine structure lines were obtained for one position on the photodissociation region (PDR) adjacent to the bright rim of the S140 HII region. The gas density is $\approx 10^4 \text{ cm}^{-3}$ and the incident UV flux $\chi \approx 400$ at the location of the ionization front. Our PDR model analysis shows that the relative H₂ line intensities are characteristic of low-density fluorescent emission and that the gas temperature is $T > 500\text{K}$ in the partially dissociated gas. A comparison of predicted and observed fine structure line intensities permits an estimate of the abundances of Fe and Si.

Accepted by A&A Letters

s140.ps via anonymous ftp from: mpehp1.mpe-garching.mpg.de, pub/bertoldi/s140

A multiwavelength study of star formation in the very young open cluster NGC 6530

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The distance and formation history of the very young open cluster NGC 6530 were investigated by studying a total of 132 probable member stars of this open cluster. It was concluded that the distance to NGC 6530 is $1.8 \pm 0.2 \text{ kpc}$, and its interstellar reddening $E(B - V)$ is $0^{\text{m}}30$. Furthermore, we conclude that the extinction law of the intracluster material is normal (i.e. $R_V = 3.1$), but anomalous extinction laws were found for several more embedded stars in the cluster. Of the 132 stars included in this study, 11 are suspected to be variable, five show H α in emission and nine show an infrared excess. Among the member stars of NGC 6530, three were found to be part of the Herbig Ae/Be stellar class, whereas two others are possible members of this stellar group as well. Also, one cluster member is probably a new massive post-AGB star, whereas the same could possibly apply to another member star. Finally, from the distribution of post- and pre-main sequence stars in the cluster’s HR-diagram, it was concluded that the process

of star formation in NGC 6530 must have started a few times 10^7 years ago and, for the less massive stars, is probably still going on today.

Accepted by Astronomy & Astrophysics Supplement Series

A preprint of this paper is available via WWW at <http://www.astro.uva.nl/preprints/preprints.html>

SWS H₂ observations in the BD+40°4124 group

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We report the detection of pure rotational lines of H₂ observed in the direction of three young stellar objects in the BD+40°4124 group, with the short-wavelength spectrometer (SWS) on board ISO. The rotational population distributions of all three stars are consistent with a thermal distribution. The derived kinetic temperatures are ≈ 500 K for BD+40°4124 and LkH α 224 and ≈ 800 K for LkH α 225. The amounts of molecular hydrogen detected are 0.01 to 0.04 M_{\odot} . The relative abundances of ortho- and para-hydrogen are consistent with a high temperature equilibrium distribution. We conclude that the molecular hydrogen emission in all three regions appears to lie behind approximately 10–25^m of visual extinction and is probably not directly associated with any of the optical sources.

Accepted by Astronomy & Astrophysics (Letters)

A preprint of this paper is available via WWW at <http://www.astro.uva.nl/isostar/preprints.html>

The Galactic Distribution of OB Associations in Molecular Clouds

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Molecular clouds account for half of the mass of the interstellar medium interior to the solar circle, and for all current star formation. Using cloud catalogs of two CO surveys of the first quadrant, we have fit the mass distribution of molecular clouds to a truncated power law in a similar manner as the luminosity function of OB associations in the companion paper to this work. After extrapolating from the first quadrant to the entire inner Galaxy, we find that the mass of cataloged clouds amounts to only 40% of current estimates of the total Galactic molecular mass. Following Solomon & Rivolo we have assumed that the remaining molecular gas is in cold clouds, and normalize the distribution accordingly. The predicted total number of clouds is then shown to be consistent with that observed in the solar neighborhood where cloud catalogs should be more complete. Within the solar circle, the cumulative form of the distribution is $\mathcal{N}_c(> M) = 105[(M_u/M)^{0.6} - 1]$, where \mathcal{N}_c is the number of clouds, and $M_u = 6 \times 10^6 M_{\odot}$ is the upper mass limit. The large number of clouds near the upper cutoff to the distribution indicates an underlying physical limit to cloud formation or destruction processes. The slope of the distribution corresponds to $d\mathcal{N}_c/dM \propto M^{-1.6}$, implying that although numerically most clouds are of low mass, most of the molecular gas is contained within the most massive clouds.

The distribution of cloud masses is then compared to the Galactic distribution of OB association luminosities to obtain statistical estimates of the number of massive stars expected in any given cloud. The likelihood of massive star formation in a cloud is determined, and it is found that the median cloud mass that contains at least one O

star is $\sim 10^5 M_\odot$. The average star formation efficiency over the lifetime of an association is about 5%, but varies by more than two orders of magnitude from cloud to cloud, and is predicted to increase with cloud mass. O stars photoevaporate their surrounding molecular gas, and even with low rates of formation, they are the principal agents of cloud destruction. Using an improved estimate of the timescale for photoevaporation and our statistics on the expected numbers of stars per cloud, we find that $10^6 M_\odot$ GMCs are expected to survive for about 3×10^7 yr. Smaller clouds are disrupted, rather than photoionized, by photoevaporation. The porosity of H II regions in large GMCs is shown to be of order unity, which is consistent with self-regulation of massive star formation in GMCs. On average, 10% of the mass of a GMC is converted to stars by the time it is destroyed by photoevaporation.

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Preprint available from <http://cfa-www.harvard.edu/~jpw>

Sub-arcsecond VLA Observations of HL Tau: Imaging the Circumstellar Disk

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We report high resolution observations of HL Tau at 6 cm, 3.6 cm and 7 mm using the VLA in B configuration. The new centimeter wavelength data are in accord with previous observations, taking into account resolution and sensitivity, and provide no evidence for time variability. At 7 mm, we have used a “fast-switching” calibration technique to partially overcome the problem of atmospheric phase fluctuations and achieve sub-arcsecond angular resolution. The 7 mm image, which is dominated by dust emission, shows a flattened structure with Gaussian deconvolved size $0.75 \pm 0''.1 \times 0.35 \pm 0''.1$ ($105 \pm 14 \times 50 \pm 14$ AU) and major axis PA $125 \pm 10^\circ$. This orientation is similar to that found at shorter wavelengths and is approximately orthogonal to the optical jet axis, consistent with a dusty accretion disk surrounding the star.

Accepted by Astrophysical Journal (Letters)

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, not reviews nor conference notes), *Dissertation Abstracts* (presenting abstracts of new Ph.D dissertations), *Meetings* (announcing meetings broadly of interest to the star formation and interstellar medium community), *New Books* (giving details of books relevant for the same community), *New Jobs* (advertising jobs specifically aimed towards persons within our specialty), and *Short Announcements* (where you can inform or request information from the community).

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Dissertation Abstracts

Observational aspects of Herbig Ae/Be stars and of candidate young A/B stars

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Ph.D dissertation directed by: Prof. Dr. P.S. Thé

Ph.D degree awarded: June 1996

The thesis consists of several studies on candidate young stars of which most material is published or in press and which can be divided into three parts roughly.

Part A is about Herbig Ae/Be stars. A complete review of the observational properties of HAeBes is given in *Chapter A1* together with a renewed up-to-date catalogue of HAeBes and HAeBe candidates. As an example of the selection of HAeBes from candidate stars, the observational properties of three candidates is discussed in *Chapter A2*. They are in particular interesting as they are relatively bright with respect to other HAeBes candidates. An advantage of bright HAeBes is that high resolution spectroscopy can be obtained. For two well know HAeBe objects with a favourable oriented disk, UX and BF Ori, a high resolution spectroscopy monitoring programme is presented in *Chapters A3* and *A4*. First results presented indicate that the disk material of UX Ori is accreting in the form of comet-like bodies. Such pioneering results are also found for BF Ori but more details of the cometaries are given.

As discussed in *Chapter A1*, the IR-excess is one of the fundamental discriminators for the selection of HAeBe candidates. A good understanding of the origin of the IR-excess of HAeBe candidates is necessary to study the disk material that ultimately could produce (proto-)planetary systems. *Chapter A5* discusses the amount of IR-excess of HAeBe candidates and ideas about the probable origin.

In Part B objects are discussed which were originally selected as HAeBe candidates, but for which a more detailed analysis of the observational characteristics show that they are probably more evolved. This group contains very interesting objects as is shown in *Chapters B1*, *B2* and *B3*, in which the discovery of a new galactic Luminous Blue Variable (LBV) is reported, WRA 751.

A well known B[e] star is HD 45677. The B[e]-group was collected to consist of evolved objects with masses less than those of LBVs and comparable with B[e] stars observed in the LMC. In recent publications, however, HD 45677 was described as a possible Herbig Be star. In *Chapter B4* new observational evidences together with the analyses of about 100 years of known brightness measurements of this star indicate that its PMS nature must be questioned.

Another object for which the PMS status is doubtful is HD 147196. A Be star located in the dark cloud region ρ Ophiuchus. In *Chapter B5* we show that the emission line nature of this object is variable, which indicate the difficulties to select homogeneous samples on the bases of spectral observations. Finally in *Chapter B6* we discuss the possible youth of HR 6000, an object not showing any observable peculiarities at first sight. But being the close neighbour of HR 5999, a comparable youth is likely. Indeed, a weak near-IR excess, photometric variability and being a strong X-ray source, suggest the presence of a T Tauri companion.

In Parts A and B we have encountered various difficulties to make a clear and easy distinction between PMS stars and more evolved objects. In the case of young open clusters such problems are less severe. For this reason in Part C a study of the well known very young open cluster NGC 6611 is presented. The results are reported in two chapters: in *Chapter C1* the stars in the cluster field are studied, from which a HRD can be constructed, giving necessary information about some cluster properties such as distance and age; we use these findings in *Chapter C1* to study in detail objects which were previously recognised as PMS candidates, in order to discover true HAeBe objects. Although we find a large number of early type stars being in the PMS phase, we find only scarcely objects with clear HAeBe characteristics. It is therefore discussed that the clearing mechanism on the circumstellar material must work on a very short timescale and that not all of them go through a HAeBe-phase. This conclusion is discussed with an eye to the recent finding af EGGs in the field of this cluster.

Meetings

1997 Gordon Research Conference on Origins of Solar Systems

June 15-20, 1997

New England College, Henniker, New Hampshire

The 1997 Gordon Research Conference on Origins of Solar Systems will include sessions on circumstellar disks, meteorites and presolar grains as probes of the solar nebula, depletion of volatile elements in planetary material, solar nebula evolution, the outer solar system, and the formation and detection of planets around other stars. Contributed papers in the form of poster talks are welcomed.

Further information about the conference can be obtained from either the Chair, John Kerridge (address: Department of Chemistry 0317, UCSD, La Jolla, CA 92093, USA; email: jkerridg@ucsd.edu) or from the Vice-Chair, Alan Boss (address: Dept. of Terrestrial Magnetism, 5241 Broad Branch Road, Washington DC 20015, USA; email: boss@dtm.ciw.edu).

International School of Space Chemistry

"ETTORE MAJORANA" CENTRE FOR SCIENTIFIC CULTURE

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Formation and Evolution of Solids in Space

Erice, Sicily, Italy, 10 - 20 March, 1997

Director of the Center : Prof. A. Zichichi

Director of the School : Prof. J.M. Greenberg

Directors of the Course : Prof. J.M. Greenberg and Prof. J.F. Kerridge

GENERAL INFORMATION: The course is primarily addressed to advanced graduate students and post-docs but senior scientists are also welcome. Interdisciplinarity is stressed.

The objective of the meeting is to follow the chemical and physical evolution of solid particles from their origins in the stellar atmospheres, and supernovae through interstellar space to the formation of stars and planetary systems. The latest data from the Infrared Satellite Observatory (ISO), as well as other modern observational results, laboratory simulations, and microprobe techniques will be emphasized along with theory.

WHERE AND WHEN ? The course will take place in Erice, Sicily, Italy from March 10 to 20, 1997.

PARTICIPATION: No special application form is required. Closing date for application is January 31, 1997. Applications should be addressed to the director :

Prof. J. Mayo Greenberg, Huygens Laboratorium, Postbus 9504, 2300 RA Leiden The Netherlands (Tel. 31-71-5275804, Fax. 31-71-5275819, e-mail: mayo@rulhl1.LeidenUniv.nl)

COST: The total fee, which includes full board and lodging (arranged by the School), is 1,000 US dollars. Thanks to the generosity of the sponsoring Institutions, partial support can be granted to some deserving students who need financial help. Requests to this effect must be specified and justified in the letter of application.

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TOPICS:

Dusty disks around young stellar objects - Interplanetary dust particles - Laboratory simulations of dust - From cometary nuclei to cometary atmospheres - Observations and models of gas-grain interactions in star-forming regions - The laboratory approach to stardust mineralogy - Scattering by complex systems - Interplanetary particle dynamics - Chemical and physical evolution of interstellar dust - Dust around stars in and beyond the main-sequence - Polycyclic aromatic hydrocarbons - Organic matter in the interstellar medium - Interstellar dust in meteorites and interplanetary dust - In situ measurements of evolved solids in space - Observational constraints on the composition of interstellar grains - The formation and destruction of interstellar dust - Optical modelling of interstellar dust - Chemical modelling of clouds - Protostellar regions - Infrared spectroscopy of dust - Cosmic connections

PURPOSE OF THE COURSE:

The chemical processes in the universe appear as a complex tapestry with subject matter ranging from molecules in the "empty space between stars" to the formation of solar systems and the origin of life. Each region in space and in the laboratory requires its own scientific methodology with the transitions from one to the other sometimes obscured by specialization. One of the principal aims of this Course is to provide bridges between the scientific and technical disciplines.

The subject of "Formation and Evolution of Solids in Space" has become one of the forefront activities of astronomy and astrophysics, with the current operation of the Infrared Satellite Observatory (ISO), the recent advances in laboratory astrophysics and the expected results from the various space missions to comets (Rosetta, etc.). It is the intention of the proposed institute to follow the evolution of the solid particles in interstellar space and to show how they are represented within the present solar system. The application of vastly improved (within the last 2 years) microprobe techniques on the micro-meteoroids collected in the earth's atmosphere reveal more and more convincing evidence of interstellar dust origins. Some of the components of interstellar dust which formed in stellar atmospheres are identified with mineral components in comet dust, in meteorites as well as in interplanetary particles. Abundant constituents of interstellar dust are those which bear the infrared signature of molecules containing carbon, oxygen and nitrogen and which are formed and evolve chemically and physically in the clouds of gas and dust in the space between the stars. How are all the molecular constituents of interstellar dust, comet dust and interplanetary dust related? Can probes of protostars and young stellar objects reveal how solar systems form? Disks of dust around young stars may be precursors of planet formation. Some types of meteorites appear to have structures and signatures not so different from comets even though they have very different origins. Why is this so?

For updated information please check <http://www.strw.LeidenUniv.nl/agli/mayo.html>.

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