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Abstracts of recently accepted papers

$HCO^+(J = 4-3)$ mapping of the molecular disk around IRS 7 in Corona Australis

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Submillimetre $HCO^+(J = 4-3)$ mapping observations of the immediate environs of the infrared source IRS 7 in Corona Australis have provided corroborative evidence for the existence of the rotating molecular disk detailed in our earlier paper. An improved estimate of $0.8\,M_\odot$ for the mass of the central protostar is obtained.

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Resolution Requirements for Smoothed Particle Hydrodynamics Calculations with Self-gravity

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We determine a new resolution requirement for the Smoothed Particle Hydrodynamics (SPH) numerical method when self-gravity is included. Comparison calculations between an SPH code and an Eulerian grid code are performed. The calculations are of a computationally demanding molecular cloud collapse and fragmentation problem. We demonstrate that the results given by the two different hydrodynamic methods are in good agreement, so long as the minimum resolvable mass in the SPH calculations is always less than the Jeans mass. If this criterion is not satisfied, SPH may give incorrect results, with the stability of near-Jeans-mass clumps depending on the details of how the SPH code is implemented rather than on physical processes. We give examples, from the literature, of problems that have been encountered in simulations of star, galaxy and cosmological-structure formation where this resolution requirement is ignored.

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http://www.mpia-hd.mpg.de/MPIA/Projects/THEORY/preprints.html

The Structure and Appearance of Protostellar Accretion Disks: Limits on Disk Flaring

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Vertical structure models are used to investigate the structure of protostellar, α-law, accretion disks. Conditions investigated cover a range of mass fluxes (10^{-9} to $10^{-5} M_\odot yr^{-1}$), viscous efficiencies ($\alpha = 10^{-2}$ and 10^{-4}), and stellar masses (0.5 to 3 $M_\odot$). Analytic formulae for midplane temperatures, optical depths, and volume and surface densities are derived and are shown to agree well with numerical results. The temperature dependence of the opacity is shown to be the crucial factor in determining radial trends. We also consider the effect on disk structure of illumination from a uniform field of radiation such as might be expected of a system immersed in a molecular cloud core or other star forming environment: T_{amb} = 10, 20, & 100 K. Model results are compared to Hubble Space Telescope observations of HH30 and the Orion proplyds.

Disk shape is derived in both the Rosseland mean approximation and as viewed at particular wavelengths ($\lambda\lambda = 0.66$, 2.2, 60, 100, 350 & 1000 μm). In regions where the opacity is an increasing function of temperature (as in the molecular regions where $\kappa \propto T^2$), the disk does not flare, but decreases in relative thickness with radius under both Rosseland mean and single wavelength approximations. The radius at which the disk becomes shadowed from central object illumination depends on radial mass flow and varies from a few tenths to about 5 au over the range of mass fluxes tested. This suggests that most planet formation occurred in environments unheated by stellar radiation. Viewing the system at any single wavelength increases the apparent flaring of the disk but leaves the shadow radius essentially unchanged. External heating further enhances flaring at large radii, but, except under extreme illumination (100 K), the inner disk will shield the planet forming regions of all but the lowest mass flux disks from radiation originating near the origin such as from the star or from an FU Orionis outburst.

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The angular momentum evolution of low-mass stars

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We present a model for the evolution of surface rotation of stars in the mass range from 0.5 to 1.1M$_\odot$, from their first appearance in the HR diagram as T Tauri stars up to the age of the Sun. The model is based on 3 assumptions: i) nearly solid-body rotation, ii) pre-main sequence disk locking, iii) wind braking. The initial conditions and the calibration of the braking law are completely determined from observations. The model includes only 2 adjustable parameters: the distribution of disk lifetimes in the pre-main sequence and the velocity at which saturation of the angular momentum losses due to the stellar wind occurs.

We review all the observational results, including the most recent ones, that can be used to constrain the models, as well as theoretical work that puts limits onto the parameter space. We show that the currently available distributions of $v$sin$i$ for PMS, ZAMS and MS stars can be reasonably well reproduced by the model assuming solid-body rotation for stars in the mass-range from 0.5 to 1.1M$_\odot$. We deduce a median lifetime of 3 Myr for circumstellar accretion disks around pre-main sequence stars. By an age of 20 Myr, only 10% of the stars are still surrounded by disks. Stars with long disk lifetimes and low initial rotational velocities account for the large fraction of slow rotators ($v$sin$i\leq$20 km.s^{-1}) observed in young clusters. On the opposite, stars with short-lived disk reach the ZAMS with velocities up to 200 km.s^{-1} over the whole mass range investigated here.

In agreement with other models, we find that a mass-dependent saturation velocity for the angular momentum losses is required to account for the longer spin down timescale of lower mass stars on the zero-age main sequence. We argue that this assumption provides an alternative to the hypothesis of radiative core–convective envelope decoupling, which has been used in other models. Both the rapid spin down of fast rotators on the ZAMS and its mass-dependency are accounted for in the present solid-body rotation models. In particular, we show that the model predicts a distribution of rotational periods at the age of the Hyades for 0.5-1.1M$_\odot$ stars that is in close agreement with the observations. We conclude that the observed evolution of *moderate and fast rotators* on the early main sequence requires physical processes that lead to the redistribution of angular momentum in stellar interiors on a timescale much shorter than evolutionary timescales, such as dynamical rotational instabilities, gravity waves or MHD torques. The evolution of *slow rotators* ($v$sin$i\leq$10 km.s^{-1}), however, remains uncertain due to the currently uncomplete $v$sin$i$ distribution. Precise $v$sin$i$ measurements for slow rotators in young clusters, rather than upper limits, are required.

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Preprint available at: http://www.cfht.hawaii.edu/~bouvier/bouvier.html

Adaptive Optics Infrared Imaging-Polarimetry and Optical HST Imaging of Hubble's Variable Nebula (R Mon / NGC 2261): A Close Look at a Very Young Active Herbig Ae/Be star

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We present high resolution (FWHM=0.2″) near-IR (J,H, & K') adaptive optics images of the Herbig Ae/Be star R Mon. Optical HST WFPC2 PC camera archival images are also presented. For the first time adaptive optics were utilized to make high resolution (FWHM=0.2″) IR imaging polarimetry maps of R Mon. In addition, the first mid-IR array images (at 11.7 μm and 20.8 μm) of R Mon have been obtained. We also present new 3.16, 3.93, and 4.67 μm images.

We have found that R Mon is a 0.69″ binary star with a companion that dereddens onto the Classical T Tauri locus. Based on the near-infrared photometry of this companion we believe it is a 1.5 $M_\odot$ very young ($< 3\text{x}10^5$ yr) classical T Tauri star. The close presence of a young companion suggests that R Mon itself is a rare example of a very young isolated massive star.

At the highest resolutions R Mon is revealed to be extended by ∼0.1″ East-West, and ∼0.05″ North-South in the visible. The young R Mon star is not directly visible in the optical but appears as a resolved conical reflection nebula in scattered light. At infrared wavelengths the dense circumstellar dust is penetrated and R Mon appears to be an unresolved point source located 0.06±0.02″ south of the peak optical flux.

The large-scale optical-IR morphology of R Mon and its large reflection nebula (NGC 2261) suggests a thin bi-polar parabolic shell of dust. The appearance of the parabolic shell is consistent with an inclination of 20 ± 10^o from the plane of the sky. This inclination implies that R Mon is located 760 -280/+800 pc distant based on previous proper motion (Jones & Herbig 1982) and radial velocity (Brugel, Mundt & Buhrke 1984) measurements of R Mon's jet. Our high resolution (FWHM 0.2″) adaptive optics infrared polarimetry maps agree with the current interpretation that NGC 2261 is a reflection nebula illuminated by R Mon.

Interior to the parabolic shell there is a complex of twisted filaments along the eastern edge. These filaments resemble a double helical structure which is well described by a power law from $\sim 10^3$ to 10^5 AU from R Mon. This double helix may trace a twisted magnetic field above R Mon.

Based on HI emission line ratios we find the direct extinction towards R Mon to be A_V=13.1 mag in the infrared (λ>1.28 μm), falling to a lower value of A_V=3.6 mag in the optical ($\lambda < 1.28$ μm) where scattered light increasingly lowers the effective extinction in the line ratios. The large A_V=13.1 extinction is likely due to the dusty atmosphere of an inclined R∼100 AU optically thick accretion disk surrounding R Mon. A simple model of such an accretion disk+star system (with $M_{acc} \sim 8\text{x}10^{-5}$ $M_\odot$/yr, M_*=10.4 $M_\odot$, $R_*=2R_\odot$, and $T_* \sim 3.5\text{x}10^4$ K) reproduces the observed dereddened R Mon SED from the optical (0.4 μm) to the millimeter. Consideration of the lower extinction (A_V=3.6) on the path followed by the scattered visible light eliminated any need for an inner "gap" in the accretion disk model to reproduce the SED.

In general YSOs that are obscured in the optical but directly visible in the infrared will have different effective optical and infrared extinctions. Infrared extinctions derived from optical observations dominated by scattered light will be underestimates of the true IR extinction along the direct path. The use of an independent estimator of both the optical and infrared extinctions such as common upper level HI recombination lines is highly desirable. The utilization of the correct optical and infrared extinctions may relieve the need for optically thin inner disk gaps to explain YSO near-IR SEDs.

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to download the paper goto http://www.ifa.hawaii.edu/∼close/rmon.html

New proper motions of pre-main sequence stars in Taurus-Auriga

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We present proper motions of 72 T Tauri stars located in the central region of Taurus-Auriga (Tau-Aur). These proper motions are taken from a new proper motion catalogue called STARNET. Our sample comprises 17 classical T Tauri stars (CTTS) and 55 weak-line T Tauri stars (WTTS), most of the latter discovered by ROSAT. 53 stars had no proper motion measurement before.

Kinematically, 62 of these stars are members of the association. A velocity dispersion of less than 2-3 $\mathrm{km\,s^{-1}}$ is found which is dominated by the errors of the proper motions. This velocity dispersion correlates with a spread in distances.

Furthermore we present proper motions of 58 stars located in a region just south of the Taurus molecular clouds and compare the kinematics of the youngest stars in this sample (younger than $3.5 \cdot 10^7$ yrs) with the kinematics of the pre-main sequence stars (PMS) in the Taurus-Auriga association.From a comparison of the space velocities we find that the stars in the central region of Tau-Aur are kinematically different from the stars in the southern part.

Among the stars with large proper motions far off the Taurus mean motion we find 2 Pleiades candidates and 7 possible Pleiades runaway stars.

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Wind–Disk–Ambient Cloud Interactions in the Near Environment of T Tauri

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Fabry–Perot images of the near environment of T Tauri taken in the 2.122 μm, $v = 1 - 0$ S(1) quadrupole emission line of molecular hydrogen reveal a complex system of interlocking loops and arcs within 15" of the central stars. Long slit echelle spectra in the S(1) transition at several position angles indicate that the kinematics of the gas is also complex. To the north of T Tau, the redshift of the H_2 line increases linearly with distance. Lower resolution spectra covering the entire K and H photometric bands reveal shock excited H_2 and FeII throughout the region. Model fits to the molecular lines point to a constant or slightly decreasing excitation temperature with distance from the stars.

The interaction with the ambient molecular cloud of two, almost perpendicular outflow systems can explain the complex molecular hydrogen morphology of T Tau. Orbital motion may produce the apparent curvature of the structures. The NW–SE outflow probably energizes Burnham's Nebula to the south of the stars. This region contains several molecular hydrogen arcs resembling bow shocks opening back toward T Tau. Similar arcs, seen in previously published [SII] images, lie interior to the H_2, signalling the presence of a magnetic precursor to the shocks. The radial velocities and velocity dispersion in Burnham's Nebula remain enigmatic, however.

Spatially resolved near and mid-infrared photometry of the binary reveals evidence for circumstellar disks in both stars. These disks may collimate the outflows responsible for the H_2, [SII], and [FeII] structures. The spectral energy distribution of the infrared companion has a strong silicate absorption near 10 μm, while the primary shows the silicate feature in emission. This result resolves earlier contradictory observations, some of which showed little or no Si emission in the primary. After subtraction of a model photosphere plus disk, the companion's absorption feature appears somewhat wider than the primary's emission line, consistent with optical depth or particle size effects expected from the photometric properties of the stars. The model stellar radius of the visible primary, coupled with published $v \sin i$ observations, imply an inclination of the T Tauri system of 19°.

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Benchmark problems for dust radiative transfer

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When verifying a sophisticated numerical code, it is a usual practice to compare the results with reliable solutions obtained by other means. This work provides such solutions for the wavelength dependent dust radiative transfer problem. We define a set of benchmark problems in spherical geometry and solve them by three radiative transfer codes which implement different numerical schemes. Results for the dust temperature and emerging spectra agree to better than 0.1%, and can be used as benchmark solutions for the verification of the dust radiative transfer codes.

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LkHα225: evidence of the collimated outflow in the optical spectrum

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The results of integral-field and long-slit spectroscopy of the young double stellar object LkHα225, obtained on 6-meter telescope, are presented. The strong [SII] emission in the nebulous patch V1318M, located between the two stars, is found, indicating the shock excitation. Its physical parameters (radial velocity -80 km/s, electronic density up to 1600 cm^{-3}, rather low level of excitation) corroborate the presence of directed matter outflow from one of the stars. The strong variability of both stars is confirmed. The spectra of two additional emission objects in the region are discussed.

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A High-Resolution Study of Gas and Dust around Young Intermediate-Mass Stars: Evidence for Circumstellar Disks in Herbig Ae Systems

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As part of a long-term program of observations to search for and characterize disks of gas and dust around intermediate-mass counterparts to solar-mass T Tauri stars, we have probed the environments of seven pre-main sequence stars of spectral type Ae using millimeter-wave continuum and molecular line aperture synthesis imaging. In each case we identify a compact region of thermal continuum emission centered on the star. Upper limits to radii are in the range 200−300 AU for five members of our sample, and 680 AU for the relatively distant source HD 245185. We identify an elongated continuum source around HD 163296, with a semi-major axis of 110 AU. Adopting relatively high values for dust grain opacities, we obtain minimum masses of circumstellar dust and gas in the range 0.005−0.034 $M_\odot$ for the seven sources, assuming that the observed continuum emission is optically thin. We detect molecular line emission from gas regions centered on four of the stars. Two of these regions are spatially resolved and are found to be elongated, with semi-major axes of 310 and 450 AU for HD 163296 and AB Aur, respectively. Velocity gradients along the major axes of both of these structures point strongly to the presence of orbiting material in disk-like configurations, and we argue that the nebular environments of our entire sample include substantial disk components.

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Kinematics of the Molecular Sheath of the HH 111 Optical Jet

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We have observed the molecular outflow associated with the HH 111 optical jet at 6" resolution in the CO J=1-0 transition using the BIMA millimeter array. Both the CO kinematics and morphology indicate a striking hollow tubular structure surrounding the optical jet. The velocity component parallel to the jet increases with distance from the central star more rapidly than the component perpendicular to the jet. The data place constraints on jet-driven models for molecular outflows. The kinematics and structure are consistent with recent wide-angle, radial-wind models.

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The Wardle Instability in Interstellar Shocks: II. Gas Temperature and Line Emission

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We have modeled the gas temperature structure in unstable C-type shocks and obtained predictions for the resultant CO and H_2 rotational line emissions, using numerical simulations of the Wardle instability that were carried out by Stone (1997) and that have been described in a companion paper. Our model for the thermal balance of the gas includes ion-neutral frictional heating; compressional heating; radiative cooling due to rotational and rovibrational transitions of the molecules CO, H_2O and H_2; and gas-grain collisional cooling. We obtained results for the gas temperature distribution in – and H_2 and CO line emission from – shocks of neutral Alfvenic Mach number 10 and velocity 20 or $40\,\mathrm{km\,s^{-1}}$ in which the Wardle instability has saturated. Both two- and three-dimensional simulations were carried out for shocks in which the preshock magnetic field is perpendicular to the shock propagation direction; and a 2-D simulation was carried out for the case in which the magnetic field is obliquely oriented with respect to the shock propagation direction. Although the Wardle instability profoundly affects the density structure behind C-type shocks, most of the shock-excited molecular line emission is generated upstream of the region where the strongest effects of the instability are felt. Thus the Wardle instability has a relatively small effect upon the overall gas temperature distribution in – and the emission line spectrum from – C-type shocks, at least for the cases that we have considered. In none of the cases that we have considered thus far did any of the predicted emission line luminosities change by more than a factor 2.5, and in most cases the effects of instability were significantly smaller than that. Slightly larger changes in the line luminosities seem likely for 3-D simulations of oblique shocks, although such simulations have yet to be carried out and lie beyond the scope of this study. Given the typical uncertainties that are always present when model predictions are compared with real astronomical data, we conclude that Wardle instability does not imprint any clear observational signature on the shock-excited CO and H_2 line strengths. This result justifies the use of 1-D steady shock models in the interpretation of observations of shock-excited line emission in regions of star formation. Our 3-D simulations of perpendicular shocks revealed the presence of warm filamentary structures that are aligned along the magnetic field, a result of possible relevance to models of water maser emission from C-type shocks.

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Herbig Haro Objects in the Orion Nebula

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We have used the Hubble Space Telescope to image two regions of the Orion Nebula in low and high ionization emission lines. There appear to be two main systems of Herbig Haro objects in the Orion nebula – a 'North' System is centered slightly north of the BN and IRc2 sources, and a 'South' System centered south of the Trapezium stars. The North System appears to be the result of shocks on the near side of OMC-1, the host molecular cloud for M42. The sources of these HH objects is most likely to be instabilities in shocks driven by massive star winds penetrating into a region of decreasing ambient density. HH 201 displays many of the characteristics of the North System members but lacks a trailing H_2 finger. HH 208 and 209 share this latter property and also display a very different morphological form, which puts their association with the North System in doubt. The South System contains large shocks with a variety of morphologies. This system is most likely a combination of shocks in the ionized nebular gas and lower ionization shocks formed when jets from low mass young stars strike the neutral lid lying on the near side of M42.

Both shocks and photoionization affect the line excitation of HH objects in M 42, especially among the South System, where ultraviolet light from θ^1C Ori penetrates into the back side of a bow shock that moves toward the observer. Among the bow-shaped objects along the fingers in the North system, the highest excitation lines occur near the apices of the bows, as predicted by theory. Objects that lie closer to the Trapezium are more difficult to analyze because of stronger nebular emission, rendering the HH objects best visible in [O I] and [S II] emission.

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Preprints can be obtained from http://sparky.rice.edu/ hartigan/pub.html

Rotation in The Protostellar Envelopes around IRAS 04169+2702 and IRAS 04365+2535: The Size Scale for Dynamical Collapse

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We report interferometric observations of two embedded protostar candidates, IRAS 04169+2702 and IRAS 04365+2535 (TMC1-A), in the Taurus molecular cloud. The $C^{18}O$ ($J = 1-0$) emission from IRAS 04169+2702 reveals a flattened envelope, 2200 AU×1100 AU in size; there is a velocity gradient along the elongation axis, which in turn is perpendicular to the outflow direction. Since the rotational velocity corrected for inclination, 0.23 km s^{-1} at 370 AU, gives an unacceptably small dynamical mass of 0.02 $M_\odot$ within that radius, we speculate that there is additional radial motion, possibly infall, in the flattened envelope. Around IRAS 04365+2535, a compact ^{13}CO ($J = 1-0$) condensation ∼1400 AU in size was detected. Again, the velocity gradient is perpendicular to the associated molecular outflow, but a rotation velocity of 0.87 km s^{-1} at 580 AU radius is consistent with the condensation being a rotationally supported disk.

Combining our new data for the two sources with published observations of rotationally supported disks and infalling envelopes around five young stars associated with the Taurus molecular cloud enables us to compare local specific angular momenta of a significant sample of these sources on scales of 200–2000 AU with those of dense cores on 6000–80000 AU (0.03–0.4 pc) scales. The specific angular momenta for infalling envelopes and rotationally supported disks are relatively constant, ∼10^{-3} km s^{-1} pc, and are typically an order of magnitude smaller than those for dense cores. These results can be explained if the dynamical collapse of dense star forming cores takes place inside radii of ∼0.03 pc while the region outside this radius remains dynamically stable.

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CO (J=2–1) Line Observations of the Galactic Center Molecular Cloud Complex. II. Dynamical Structure and Physical Conditions

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A large scale $^{12}C^{16}O$ (J=2–1) survey of the inner a few hundred parsecs of the Galaxy has been conducted using the University of Tokyo-Nobeyama Radio Observatory 60 cm survey telescope. We have taken about 700 $^{12}C^{16}O$ (J=2–1) spectra in the region $-2.5° \le l \le 2.5°$ and $|b| \le 1°$ with 0.125° grid spacing, covering the entire region of the huge molecular cloud complex in the Galactic center. We refer to the CO (J=1–0) data taken with the Columbia 1.2 m telescope and calculate the J=2–1 to J=1–0 intensity ratio. Velocity channel maps and longitude-velocity maps of CO (J=2–1) line are presented with corresponding maps of J=2–1/J=1–0 intensity ratio.

Large scale CO maps enable us to identify several giant molecular cloud complexes and many characteristic features of molecular gas. We identify 15 molecular cloud complexes larger than ~ 30 pc in our CO (J=2–1) data. Their virial masses are at least an order of magnitude larger than the masses estimated from the CO luminosity. This discrepancy can be removed if we notice that they may not be gravitationally bound but be in pressure equilibrium with the hot gas and/or magnetic field in this region. Using the expressions of virial mass and CO mass for a cloud in pressure equilibrium case, we get the X-factor for the Galactic center molecular clouds as $X = 0.1 \times 10^{20}$ cm^{-2} (K km s^{-1})$^{-1}$, which is an order of magnitude lower than that in the Galactic disk ($X_0 = 3.0 \times 10^{20}$ cm^{-2} (K km s^{-1})$^{-1}$). We estimate the total molecular mass in the Galactic center as $M(H_2) \simeq 1 \times 10^7$ M$\odot$ as a lower limit; the actual total gas mass within the central 400 pc of the Galaxy must be $M(H_2) = (1-6) \times 10^7$ M$\odot$.

We diagnose the physical conditions of the molecular gas in the Galactic center using the intensity ratio between the J=2–1 and J=1–0 lines. Although the CO J=2–1/J=1–0 line intensity ratio is high (~ 0.74) in the midplane, molecular gas at $|b| > 0.25°$ exhibits low J=2–1/J=1–0 ratios (~ 0.6). The overall J=2–1/J=1–0 luminosity ratio is $R_{(2-1)/(1-0)} = 0.64 \pm 0.01$ if we include all the emission within $|b| \le 1$ °, $-2.5° \le l \le 2.5°$ and $|V_{\rm LSR}| \le 150$ km s^{-1}. This indicates that low density gas ≥ 50 pc away from the plane dominates the total CO luminosity of the central 400 parsecs of the Galaxy. The fractional distribution of the molecular gas with $R_{(2-1)/(1-0)}$ for each cloud complex clearly demonstrates the close relationship between the gas with very high ratio ($R_{(2-1)/(1-0)} \ge 1.0$) and associated UV sources.

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The residence time of dust grains in turbulent molecular clouds

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The residence time of dust grains inside turbulent molecular clouds is calculated . Earlier estimates of this time by Boland & de Jong (1982) have been criticized by Prasad et al. (1987) for not taking into account properly the turbulent character of the velocity field in molecular clouds which implies that the trajectory of a dust grain should be treated as a random walk. Taking some minimal assumptions regarding the turbulent velocity field a time scale is derived that depends on the Reynolds number of the flow. The near proportionality with Reynolds number of this time scale results in a much longer time scale over which dust grains will remain inside a molecular cloud.

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A Study of the Physics and Chemistry of TMC-1

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Preprints available on the WWW at http://ww-fcrao.phast.umass.edu/ or by request: preethi@newton.haystack.edu

We present a comprehensive study of the physical and chemical conditions along the TMC-1 ridge. Temperatures were estimated from observations of CH_3CCH, NH_3 and CO. Densities were obtained from a multi-transition study of HC_3N. The values of the density and temperature allow column densities for 13 molecular species to be estimated from statistical equilibrium calculations, using observations of rarer isotopomers where possible, to minimize opacity effects. The most striking abundance variations relative to HCO^+ along the ridge were seen for HC_3N, CH_3CCH and SO, while smaller variations were seen in CS, C_2H and HCN. On the other hand, the NH_3, HNC and N_2H^+ abundances relative to HCO^+ were determined to be constant, indicating that the so-called NH_3 peak in TMC-1 is probably a peak in the ammonia column density rather than a relative abundance peak. In contrast, the well studied cyanopolyyne peak is most likely due to an enhancement in the abundance of long-chain carbon species.

Comparisons of the derived abundances to the results of time-dependent chemical models show good overall agreement for chemical timescales around 10^5 years. We find that the observed abundance gradients can be explained either by a small variation in the chemical timescale from 1.2×10^5 to 1.8×10^5 years or by a factor of 2 change in the density along the ridge. Alternatively, a variation in the C/O ratio from 0.4 to 0.5 along the ridge produces an abundance gradient similar to that observed.

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Hubble Space Telescope Images of the HH 111 Jet

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We have observed the classic Herbig-Haro jet HH 111 with the Wide Field and Planetary Camera 2 aboard the *Hubble Space Telescope* (*HST*) through narrow-band filters isolating Hα and [S II]$\lambda\lambda 6716, 6731$ emission. The new images fully resolve the body of the jet into a series of small bow shocks, which we conclude form as fast jet material overruns slower, previously ejected jet material. Collisionally excited Hα emission that originates from a series of sharp arcs indicate the locations of shock fronts in the jet. The [S II] emission typically follows Hα in a cooling zone behind the shocks. In some, but not all cases, a Mach disk appears within the bow shocks. Some Balmer arcs form complete bow shocks, while others are one-sided. The jet has a pronounced sinuous structure which we ascribe to variations in the velocity and angle of ejection from the embedded driving source. The faintness of the shocks that propagate outside the jet beam suggests that the surrounding medium has a much lower density than the jet.

The major bow shocks along the flow, HH 111L and V, each show a sharp leading edge which is especially bright in Hα. As with other Hα arcs in the flow, we argue that this emission is collisionally excited at the shock fronts. Extended [S II]-bright layers offset from the leading Hα emission in each bow shock appear to indicate the post-shock cooling zones. Bright, low-excitation knots located along the jet axis and nested within the bow shocks may form part of the Mach disk in each working surface. HH 111L is resolved into at least two distinct bow-shaped arcs. Future *HST* observations may clarify as to whether we are observing two bow shocks merging in this object.

The new images enable us to reexamine the molecular outflow in HH 111. Weak shocks along the periphery of the jet appear to accelerate a tube of slow CO gas along the base of the HH 111 jet. High-velocity CO and H_2 emission observed along the axis of the jet likely originates in jet gas that has cooled and become molecular.

The three extended jets thus far observed by *HST* (HH 34, HH 47, and HH 111) share several morphological char-

acteristics which are best explained if variation in both velocity and direction produce most of the observable shocks in the flows. In all cases, the jets move into the wake of previously ejected jet material, and form shocks where they overrun slower jet gas. All three jets show faint Balmer arcs along the periphery of the jet beams, which may indicate a common mechanism by which their associated CO outflows are accelerated.

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Paper and figures are available at http://sparky.rice.edu/ hartigan/pub.html

Infrared Imaging of HH 25/26 and HH 42/128

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Images of the HH 25/26 and HH 42/128 systems obtained in the emission lines of H_2 1-0 S(1), [Fe II] 1.64 μm, and a 2.22 μm continuum filter are reported. A series of aligned H_2 knots has been discovered in association with HH 26, along with a new infrared continuum source located at the center of a previously-discovered CO outflow which may power the HH 26 knots. HIRES images from IRAS are used to investigate the structure of deeply embedded sources near HH 25 and HH 26. The infrared structure of HH 42 is compared with that seen in visible [S II] emission, and it is suggested that the HH 42/128 system has been produced by episodic outflows from a source located to the southwest of HH 42. Monochromatic [1.64], [2.12], and [2.22] mags are reported for stars detected in each field, as well as H_2 and [Fe II] emission-line fluxes for HH knots in each system.

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Synthetic Hertzsprung-Russell diagrams of Open Clusters

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New evolutionary models for pre-main sequence (PMS) stars ($0.4M_\odot \leq M \leq 5M_\odot$) of three different metallicities ($Z = 0.005$, $Z = 0.02$, and $Z = 0.04$) have been computed. Improvements have been made in the constitutive physics with the use of new opacity tables at low temperatures and new atmospheric models. We first compare our mass tracks with other recent PMS models and show that important deviations occur below $0.5M_\odot$, due to different treatments of the electrostatic corrections in cool degenerated matter. We first check the ability of our models to reproduce the ZAMS location and the low-mass end of the isochrones. From the turn-off in the M_V versus (B-V) diagram, we estimate ages of $4\,10^7$ for α Per cluster and between $8\,10^7$ and 10^8 yr for the Pleiades, ages comparable or lower than recent determinations including overshooting.

These evolutionary models are used to generate synthetic Hertzsprung-Russell Diagrams (HRD). We show that each of the different parameters, namely the initial mass function (IMF), the star formation rate (SFR) and the binary fraction affect in a specific way the morphology of the derived HRD. We propose to use these synthetic diagrams to constrain some of these quantities in observed open clusters. Applying this procedure to the Pleiades cluster, the observed morphology is best reproduced by invoking a large age dispersion ($\sigma_t \simeq 3 \times 10^7$ yr) and a binary fraction for F-G stars of 40 % ± 5 %.

Accepted by A&A

WWW address http://www-laog.obs.ujf-grenoble.fr/starevol/evol.html

The Wardle Instability in Interstellar Shocks: I. Nonlinear Dynamical Evolution

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The nonlinear evolution of unstable C-type shocks in weakly ionized plasmas is studied by means of time-dependent magnetohydrodynamical simulations. This study is limited to shocks in magnetically dominated plasmas (in which the Alfvén speed in the neutrals greatly exceeds the sound speed), and microphysical processes such as ionization and recombination are not followed. Both two-dimensional simulations of initially planar perpendicular and oblique C-type shocks, and fully three-dimensional simulation of a perpendicular shock are presented.

For the cases studied here, the instability results in the formation of dense sheets of gas elongated in the direction of shock propagation, and oriented perpendicular to the magnetic field. The formation of a weak J-type front is associated with the growth of the instability from an equilibrium shock structure. After saturation, the magnetic field structure consists of arches which bow outwards in the direction of shock propagation, and which are anchored by the enhanced ion-neutral drag in the dense sheets. In analogy to the magnetic buoyancy (Parker) instability, saturation occurs when the magnetic tension in the distorted field lines is balanced by drag in the sheets. For the magnetically dominated shocks studied here, the distortions in the magnetic field which produce saturation are very small. Nonetheless, the enhancements of the ion and neutral densities in the sheets is very large, between two and three orders of magnitude compared to the preshock values. At these high densities, recombination processes may be important. The sheets evolve slowly in time, so that shocks propagating in a homogeneous medium may leave behind a network of intersecting filaments and sheets of dense gas elongated in the direction of shock propagation and perpendicular to the mean field. The temperature structure and emission properties of unstable C-type shocks in the nonlinear regime are presented in a companion paper (Neufeld & Stone 1997).

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http://xxx.lanl.gov/abs/astro-ph/9704222

Direct Observations of the Ionizing Star in the UC HII Region G29.96−0.02: A Strong Constraint on the Stellar Birth Line for Massive Stars

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We have observed the ultracompact HII region G29.96−0.02 in the near infrared J, H, and K bands and in the Brγ line. By comparison with radio observations, we determine that the extinction to the nebula is $A_K = 2.14$ with a 3σ uncertainty of 0.25. We identify the ionizing star and determine its intrinsic K magnitude. The star does not have an infrared excess and so appears to be no longer accreting. The K magnitude and the bolometric luminosity allow us to place limits on the location of the ionizing star in the HR diagram. The 3σ upper limit on the effective temperature of the ionizing star is 42 500 K. We favor a luminosity appropriate for star with a mass in excess of about 60 $M_\odot$. The limit on the temperature and luminosity exclude stars on the ZAMS and stars within 10^6 yr of the ZAMS. Since the age of the UC HII region is estimated to be only about 10^5 yr, we suggest that this is direct evidence that the stellar birth line for massive stars at twice solar metallicity must be significantly redder than the ZAMS.

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A Coronagraphic Survey for Circumstellar Disks Around Main Sequence and Pre-Main Sequence Stars

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Ph.D dissertation directed by: David Jewitt

Ph.D degree awarded: December, 1996

We search for optical reflection nebulosity around ∼100 main sequence and pre-main sequence stars to test the hypothesis that Vega-like stars possess replenished dust disks. A Lyot coronagraph is used to suppress light from the central star and to observe the circumstellar environment closer to planet-forming regions than is possible through direct imaging. A model of scattered light from axisymmetric circumstellar disks is developed to establish the sensitivity limits of our observations.

Circumstellar nebulosities are detected around four main sequence stars: β Pic, BD +31° 643, HR 241, and HR 1307. No circumstellar disks are found around ∼100 other main sequence stars, including Vega, Fomalhaut, HD 98800, HR 4796, and 51 Oph. Non-detections of disks in the main sequence sample, combined with the sensitivity limits, suggest that the optical scattering cross-section of dust at 10^2-10^3 AU radii is not strongly correlated to the thermal cross-section at 1-10 AU radii.

We show that the prominence of the β Pic disk is primarily a result of its large scattering cross-section, rather than its edge-on inclination or close proximity to the Sun (Kalas & Jewitt 1996). Five types of asymmetry are identified and measured in the disk morphology (Kalas & Jewitt 1995). The observed tilt of the midplane may result from a small inclination ($\leq 5°$) of the disk to our line of sight, combined with a non-isotropic scattering phase function. The remaining four asymmetries indicate a non-axisymmetric distribution of orbiting dust particles between 150 and 800 AU projected radius. The disk may have been gravitationally perturbed in the past 10^2 to 10^3 years, though a perturbing agent is not detected.

A nebulosity imaged near the B5V double star BD +31° 643 is identified as a circumstellar disk candidate based on its morphological similarity to β Pic and our model disks (Kalas & Jewitt 1997). The disk has a position angle 131°, a projected radius of ∼2000 AU, an inclination of $i \leq 10°$, and a possible depletion of material within ∼2000 AU. Radiation pressure forces expel the observed dust on timescales several orders of magnitude shorter than the lifetime of the star. We hypothesize that the dust is replenished by the erosion of larger, unseen parent bodies with the same inclination distribution as the observed dust.

The reflection nebulosities imaged around HR 241 and HR 1307 resemble the Pleiades reflection nebulosities, with no disk-like morphology. Like the Pleiades, some Vega-like stars may interact transiently with the interstellar medium. We argue that far- infrared excess is not strictly correlated to replenished dust disks, and that a fraction of Vega stars are infrared cirrus hotspots.

Comma-like nebulosities imaged around pre-main sequence stars have position angles parallel to the midplanes of postulated circumstellar disks. We hypothesize that some comma-like nebulosities are perturbed circumstellar disks. Gravitational perturbations on Keplerian accretion disks by stellar flybys, or by companions with eccentric orbits, may redistribute disk material to larger radii, therefore making the material accessible to detection in optical scattered light. The solid bodies around β Pic may have experienced such a perturbation, explaining the disk's optical detectability among a sample of comparably dusty main sequence stars.

References:

Kalas, P. & Jewitt, D. 1995, *AJ*, 110, 794
Kalas, P. & Jewitt, D. 1996, *AJ*, 111, 1347
Kalas, P. & Jewitt, D. 1997, *Nature*, 386, 52

A High Resolution Study of Circumstellar Matter

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Ph.D dissertation directed by: Dr Patrick F. Roche

Ph.D degree awarded: January 1997

I present studies relating to the circumstellar matter in the vicinities of Young Stellar Objects (YSOs) and Planetary Nebulae (pn).

With regard to YSOs, this work contains high resolution near infrared images and imaging polarimetry of a small sample of embedded, low mass sources in the Class I phase of protostellar evolution. The data are analysed by comparison with Monte Carlo simulations in scattered light: models are tailored to individual sources using all available data and multiple iterations constrain the structure of the circumstellar matter. The results support the view that we observe a circumstellar envelope with a bipolar cavity, but show that dust in outflows can also play a prominent role in the near infrared and that structures are very varied. The derived masses are in good agreement with estimates obtained from submillimetre observations of the thermal continuum. Smooth, continuous density profiles are indicated in the envelope, which obscures a physically thin inner disk. The very high (up to 80%) degrees of polarisation observed in the envelopes show that the scattering is dominated by small, interstellar-type dust grains. The morphologies and high polarisations of the cores show that the protostars are usually obscured at this phase of evolution, even at 3.7 μm. Observational methods for high resolution imaging are discussed.

Spectra of the Unidentified Infrared bands in pn at 3 and 5 μm are presented. A relationship is proposed between the bands at 11.25, 5.25 and 3.4 μm in terms of combinations and overtones of C-H out-of-plane modes which may lead to a considerable simpification of the UIR-band spectrum. The 3.3 μm band is well correlated with C/O abundance and with the 3.4 μm band strength. The 3.4 μm band is found to be stronger in N-rich Type I pn, which are produced by relatively massive progenitor stars.

Evolution of Young Stars. Physics and Modeling of Accretion

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Ph.D degree awarded: December 1996

The stellar structure and evolution of low- and intermediate-mass stars is investigated in a context where the star is gaining mass from a circumstellar accretion disk.

The first part of this work, dedicated to standard evolution, presents new evolutionary models for pre-main sequence stars. These new computations are used to generate synthetic HR diagrams. We show that such a tool is well suited to reproduce the morphology of young clusters and allow to derive some physical parameters prevailing in these clusters such as the binarity rate or the duration of the star forming process.

The second part describes the stellar evolutionary code and the accretion model which determines how the accreted matter distributes inside the star. The formalism of the model is based on the Richardson criterion and takes into account the mechanical, thermal and chemical properties of the accreted matter. Numerical results indicate that accreted matter easily crosses the radiative atmosphere and that convection favors a rather uniform distribution of the accreted matter in the stellar interior.

The last part is devoted to the influence of the accretion process on stellar structure and evolution. Computations show that deuterium nuclear burning plays a crucial role during the pre-main sequence phase. For a specified range of accretion rates, we observe a expansion of the star along its Hayashi line. For higher accretion rates, characteristic of the star forming phase, we reproduce the birthline which represents an upper envelope of the pre-main sequence stellar distribution. Finally, we compare the structural and evolutionary differences between accreting and non-accreting tracks. We show that the arrival of accreted matter accelerates the star contraction on the Hayashi branch and, from its position in the HR diagram, an accreting star appears younger than in a standard scheme. We also analyze the influence of accretion on surface stellar abundances of light elements such as deuterium and lithium. We determine the areas in the HR diagram where accretion significantly increases the abundances of these elements. Finally, we illustrate the opportunities this accretion model opens to the study of the stellar rotational evolution.

POSTDOCTORAL POSITIONS
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CAUP accepts candidates for **two post-doctoral positions in Stellar Astrophysics**, namely in areas of stellar evolution and activity, circumstellar medium and young objects, astro-tomography and inversion techniques, helio and astero-seismology. Priority will be given to candidates with experience in multi-wavelength observations.

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For more information see also "http://www.astro.up.pt/".

New Books

Formación Estelar (Star Formation)

Edited by L.F. Rodríguez

The book, written entirely in spanish at the introductory graduate level, contains review articles by iberoamerican specialists in the field of star formation:

Global Properties of the Insterstellar Medium and the Formation of Stars *José Franco*

Radio Studies of Star-Forming Regions *Guido Garay*

Infrared Observations of Star-Forming Regions *Irene Cruz-González*

Star Formation in Molecular Clouds *Susana Lizano*

Dense Molecular Cores and Supersonic Bipolar Flows *José M. Torrelles*

Disks and Winds in Young Visible Objects *Nuria Calvet*

Fondo de Cultura Económica 1996, Softbound ISBN 968-16-4437-9
Price US$ 25.00 plus postage
For information on subsidiaries of this editorial house outside of México consult
http://genesis.astrosmo.unam.mx/~luisfr/

Herbig-Haro Objects and the Birth of Low Mass Stars

Edited by Bo Reipurth and Claude Bertout

The proceedings of IAU Symposium No. 182 held in Chamonix January 20 - 24, 1997 are now available on the Web at

http://www-laog.obs.ujf-grenoble.fr/meetings/iau182

The book is expected to be available from Kluwer later this summer. According to Kluwers rules, the Web site will at that time be closed. An announcement will be made here when the book has appeared.

Meetings

Parent Body and Nebular Modification of Chondritic Materials

An international workshop will be held before the 60th Annual Meeting of the Meteoritical Society, which takes place on July 21-25, 1997 in the Maui Prince Hotel, Hawaii, in order to advance our understanding of solar nebular and parent body processes from studies of modification features in chondrites and interplanetary dust particles. Although it is generally accepted that chondrules, CAIs and other chondrite components formed in the solar nebula, there is much disagreement about the identification in these components of specific features caused by subsequent nebular and asteroidal processes. The workshop is being organized to promote communications between theoreticians, who are developing models for asteroidal and nebula processes, and petrologists, chemists, physicists and astronomers, who study primitive materials.

For further information, please contact Mike Zolensky at NASA Johnson Space Center (zolensky@snmail.jsc.nasa.gov)

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).

Latex macros for submitting abstracts and dissertation abstracts are appended to each issue of the newsletter.

The Star Formation Newsletter is available on the World Wide Web, where you can access it via the ESO Portal (http://http.hq.eso.org/eso-homepage.html). You can also access it through the University of Massachusetts Astronomy World Wide Web server, the URL for its home page is http://www-astro.phast.umass.edu/

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