THE STAR FORMATION NEWSLETTER

An electronic publication dedicated to early stellar evolution and molecular clouds

No. 102 — 1 April 2001 Editor: Bo Reipurth (reipurth@casa.colorado.edu)

Abstracts of recently accepted papers

Two-dimensional Distributions and Column Densities of Gaseous Molecules in Protoplanetary Disks II.—Deuterated Species and UV Shielding by Ambient Clouds

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We have investigated the two-dimensional (R, Z) distribution of deuterated molecular species in circumstellar disks around young stellar objects. The abundance ratios between singly deuterated and normal molecules ("D/H ratios") in disks evolve in a similar way as in molecular clouds. Fractionation is caused by rapid exchange reactions that are exothermic because of energy differences between deuterated and normal species. In the midplane region, where molecules are heavily depleted onto grain surfaces, the D/H ratios of gaseous molecules are higher than at larger heights. The D/H ratios for the vertical column densities of NH_3, H_2O, and HCO^+ are sensitive to the temperature, and decrease significantly with decreasing radial distance for $R \lesssim 300$ AU. The analogous D/H ratios for CH_4 and H_2CO, on the other hand, are not very sensitive to the temperature in the range ($T = 10 - 50$ K) we are concerned with, and do not decrease with decreasing R at $R \geq 50$ AU. The D/H column-density ratios also depend on disk mass. In a disk with a larger mass, the ratios of deuterated species to normal species are higher, because of heavier depletion of molecules onto grains. In the second part of the paper, we report molecular column densities for disks embedded in ambient cloud gas. Our results suggest that CN and HCO^+ can be tracers of gaseous disks, especially if the central object is a strong X-ray source . Our results also suggest that the radial distributions of CN, C_2H, HCN, and H_2CO may vary among disks depending on the X-ray luminosity of the central star.

Accepted by A&A

http://nova.planet.sci.kobe-u.ac.jp/~aikawa/paper_list.html

The Mass-Velocity and Position-Velocity Relations in Episodic Outflows

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While observational evidence for the episodic nature of young stellar outflows continues to mount, existing numerical and theoretical models of molecular outflows assume they are formed by the interaction of a non-episodic wind from a young stellar object with an ambient cloud. In this *Letter* we estimate and discuss the effects of episodicity on the mass-velocity and position-velocity relations observed in molecular outflows. We explain how many recent observational results disagree with the predictions of non-episodic outflow models, and we offer simple explanations for the discrepancies. In particular, we discuss how an episodic stellar outflow can steepen the power-law slope of the mass-velocity relation in a molecular outflow. And, we illustrate how an episodic outflow can produce multiple "Hubble-wedges" in the position-velocity distribution of a molecular outflow. With a little more information than we have now, it may be possible to use the "fossil record" embedded in a molecular outflow's mass-velocity and position-velocity relations to reconstruct the history of a young stellar object's mass ejection episodes.

Accepted by The Astrophysical Journal Letters

preprints available at:
`http://cfa-www.harvard.edu/sfgroup/` (CfA Star Formation/ISM www page)
`http://cfa-www.harvard.edu/∼harce/papers`
astro-ph/0103483

When Star Birth meets Star Death: A Shocking Encounter

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The Bok globule B175, located towards a giant region of patchy extinction 10 degrees above the Galactic plane known as the Cepheus Flare, is currently engaged in a chance encounter with a B9.5V star, producing a prominent reflection nebula, Ced 201. Partly due to the presence of this star, a fairly accurate distance estimate of 400 pc can be derived for B175. An imaging and spectroscopic study of B175 led to the discovery of a new HH object, HH 450, emerging from a deeply embedded and cold IRAS source, 22129+7000. Furthermore, we find several parsec-scale filaments of emission that trace the rim of a new supernova remnant, G110.3+11.3, which appears to be approaching the globule. This remnant is located near the edge of a large, 6 degree radius HI and CO cavity that coincides with a bright diffuse soft X-ray enhancement, probably due to several recent supernova explosions. At 400 pc, G110.3+11.3 is one of the closer known supernova remnants. The supernova remnant and the HH flow appear to be heading towards a frontal collision in about a 1000 years.

Accepted by ApJ Letters

Preprints available at http://casa.colorado.edu/reipurth/preprints.htm

Molecular Excitation and Differential Gas-Phase Depletions in the IC 5146 Dark Cloud

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We present a combined near-infrared and molecular-line study of $25' \times 8'$ area in the Northern streamer of the IC 5146 cloud. Using the technique pioneered by Lada et al 1994, we construct a Gaussian smoothed map of the infrared extinction with the same resolution as the molecular line observations in order to examine correlations of integrated intensities and molecular abundances with extinction for $C^{17}O$, $C^{34}S$, and N_2H^+. We find that over a visual extinction range of 0 to 40 magnitudes, there is good evidence for the presence of differential gas-phase depletions in the densest portions of IC 5146. Both CO and CS exhibit a statistically significant (factor of ~ 3) abundance reduction near $A_V \sim 12$ magnitudes while, in direct contrast, at the highest extinctions, $A_V > 10$ magnitudes, N_2H^+ appears relatively undepleted. Moreover, for $A_V < 4$ magnitudes there exists little or no N_2H^+. This pattern of depletions is consistent with the predictions of chemical theory. Through the use of a time and depth dependent chemical model we show that the near-uniform or rising N_2H^+ abundance with extinction is a direct result of a reduction in its destruction rate at high extinction due to the predicted and observed depletion of CO molecules. The observed abundance threshold for N_2H^+, $A_V^{th} \sim 4$ mag, is examined in the context of this same model and we demonstrate how this technique can be used to test the predictions of depth-dependent chemical models. Finally, we find that cloud density gradients can have a significant effect on the excitation and detectability of high dipole moment molecules, which are typically far from local thermodynamic equilibrium. Density gradients also cause chemical changes as reaction rates and depletion timescales are density dependent. Accounting for such density/excitation gradients is crucial to a correct determination and proper interpretation of molecular abundances.

Accepted by Astrophysical Journal

Preprint available at `http://xxx.lanl.gov/abs/astro-ph/0103521` or `http://cfa-www.harvard.edu/∼ebergin`

ISOCAM observations of the ρ Ophiuchi cloud: Luminosity and mass functions of the pre-main sequence embedded cluster

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We present the results of the first extensive mid-infrared (IR) imaging survey of the ρ Ophiuchi embedded cluster, performed with the ISOCAM camera on board the ISO satellite. The main ρ Ophiuchi molecular cloud L1688, as well as the two secondary clouds L1689N and L1689S, have been completely surveyed for point sources at 6.7 μm and 14.3 μm. A total of 425 sources are detected in ~ 0.7 deg^2, including 16 Class I, 123 Class II, and 77 Class III young stellar objects (YSOs). Essentially all of the mid-IR sources coincide with near-IR sources, but a large proportion of them are recognized for the first time as YSOs. Our dual-wavelength survey allows us to identify essentially all the YSOs with IR excess in the embedded cluster down to $F_\nu \sim$ 10–15 mJy. It more than doubles the known population of Class II YSOs and represents the most complete census to date of newly formed stars in the ρ Ophiuchi central region. There are, however, reasons to believe that several tens of Class III YSOs remain to be identified below $L_\star \sim 0.2$ L$_\odot$. The mid-IR luminosities of most ($\sim 65\%$) Class II objects are consistent with emission from purely passive circumstellar disks. The stellar luminosity function of the complete sample of Class II YSOs is derived with a good accuracy down to $L_\star \sim 0.03$ L$_\odot$. It is basically flat (in logarithmic units) below $L_\star \sim 2$ L$_\odot$, exhibits a possible local maximum at $L_\star \sim 1.5$ L$_\odot$, and sharply falls off at higher luminosities. A modeling of the luminosity function, using available pre-main sequence tracks and plausible star formation histories, allows us to derive the mass distribution of the Class II YSOs which arguably reflects the initial mass function (IMF) of the embedded cluster. After correction for the presence of unresolved binary systems, we estimate that the IMF in ρ Ophiuchi is well described by a two-component power law with a low-mass index of -0.35 ± 0.25, a high-mass index of -1.7 (to be compared with the Salpeter value of -1.35), and a break occurring at $M_{\rm flat} = 0.55 \pm 0.25\,M_\odot$. This IMF is flat with no evidence for a low-mass cutoff down to at least $\sim 0.06\,$M$_\odot$.

Accepted by A&A

Available on http://xxx.lanl.gov/ (astro-ph/0103373)

Formation of Planetary-Mass Objects by Protostellar Collapse and Fragmentation

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Searches for very low mass objects in young star clusters have uncovered evidence for free-floating objects with inferred masses possibly as low as 5 to 15 Jupiter masses (M_{Jup}), similar to the masses of several extrasolar planets. We show here that the process which forms single and multiple protostars, namely collapse and fragmentation of molecular clouds, might be able to produce self-gravitating objects with initial masses less than $\sim 1 M_{Jup}$, provided that magnetic field tension effects are important and can be represented approximately by diluting the gravitational field. If such fragments can be ejected from an unstable quadruple protostar system, prior to gaining significantly more mass, protostellar collapse might then be able to explain the formation of free-floating objects with masses below

$13 M_{Jup}$. These objects might then be best termed “sub-brown dwarf stars”.

Accepted by Astrophysical Journal (Letters)

Preprint available at http://www.ciw.edu/boss/ftp/formff/

Extended D_2CO emission: the smoking gun of grain surface-chemistry

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We present new observations of the H_2CO and D_2CO emission around IRAS16293-2422, a low mass protostar in the ρ Ophiuchus complex. Bright H_2CO and D_2CO emission is detected up to 40′′ from the center, corresponding to a linear distance of ∼5000 AU. The derived H_2CO abundance profile has two jumps at $r \leq 150$ AU and $r \leq 700$ AU, where the dust temperature reaches 100 K and 50 K respectively. The measured $[D_2CO]/[H_2CO]$ abundance ratio in the envelope is between 0.03 and 0.16, an extremely high value. We demonstrate that the present new observations can only be explained if the D_2CO (and H_2CO) are formed during the previous cold pre-collapse phase, stored in the grain mantles, and released in the gas phase during the pre-collapse phase. We consider the two main competing theories for mantle formation, i.e. pure accretion against grain surface chemistry, and we conclude that the former theory cannot explain the present observations, whereas grain active chemistry very naturally does. We found that the mantles are evaporated because of the thermal heating of the grains by the central source and that in the outer cold envelope H_2CO and D_2CO molecules are embedded in CO-rich mantles which sublimate when the dust is warmer than 25 K. Finally, the present day H_2CO and D_2CO abundances very probably reflect the mantle composition. We argue that mantles have likely formed in an onion-like structure with the innermost ice layers more enriched of H_2CO molecules and we give estimates of the CO hydrogenation efficiency across the envelope and/or in different ices.

Accepted by Astron. & Astrophysics

http://www-laog.obs.ujf-grenoble.fr/activites/starform/formation.html#new2001

Sub-arcsecond Imaging of SiO in the HH 211 Protostellar Jet

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We present images of the HH 211 molecular jet in the SiO v=0, J=1–0 line at 43 GHz made with the Very Large Array at approximately 0.5 arcsec resolution. The SiO emission appears to trace primarily internal bowshocks in the outflow, suggesting that the dust and molecular gas are accelerated via prompt entrainment at internal working surfaces in the jet. There is also some evidence for limb-brightening of the SiO emission, indicating that SiO emission may also arise from entrainment in the jet's boundary layer. Excitation temperatures of $\gtrsim$ 150–200 K are inferred from the SiO emission. Enhancements in the SiO abundance of $\sim 10^6$ over interstellar values are observed, and the possible origin of the SiO is discussed.

Accepted by ApJ

Preprint available at http://www.nrao.edu/∼cchandle/preprints/preprints.html

Multifractal Scaling, Geometrical Diversity, and Hierarchical Structure in the Cool Interstellar Medium

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Multifractal scaling (MFS) refers to structures that can be described as a collection of interwoven fractal subsets which exhibit power-law spatial scaling behavior with a range of scaling exponents (concentration, or singularity, strengths) and dimensions. The existence of MFS implies an underlying multiplicative (or hierarchical, or cascade) process. Panoramic column density images of several nearby star-forming cloud complexes, constructed from IRAS data, are shown to exhibit such multifractal scaling, which we interpret as indirect but quantitative evidence for nested hierarchical structure. The relation between the dimensions of the subsets and their concentration strengths (the "multifractal spectrum") appears to satisfactorily order the observed regions in terms of the mixture of geometries present, from strong point-like concentrations, to line-like filaments or fronts, to space-filling diffuse structures. This multifractal spectrum is a global property of the regions studied, and does not rely on any operational definition of "clouds." The range of forms of the multifractal spectrum among the regions studied implies that the column density structures do not form a universality class, in contrast to indications for velocity and passive scalar fields in incompressible turbulence, providing another indication that the physics of highly compressible interstellar gas dynamics differs fundamentally from incompressible turbulence. There is no correlation between the geometrical properties of the regions studied and their level of internal star formation activity, a result that is also apparent from visual inspection. We discuss the viability of the multifractal spectrum as a measure of the structural "complexity" of the regions studied, and emphasize the problematic dependence of all structural descriptors on the subjective pre-selection of the region to be described. A comparison of IRAS 100 μm column density (not intensity) images with ^{13}CO, visual extinction, and C^{18}O data suggests that structural details are captured by IRAS up to at least 30 magnitudes of visual extinction, except in the vicinity of embedded stars, and that lower-column density connective structure not seen by other methods is revealed.

Accepted by The Astrophysical Journal

Full paper available at astro-ph/9707102

Observations of Molecular Clouds in the HH 270/110 Region

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We present the millimeter continuum and molecular line observations of the middle condensation of the L1617 cloud. Various molecular structures were found in the HCO$^+$ and the HCN lines. The driving source of the HH 270 flow was detected in the continuum and is surrounded by a flattened dense molecular core with possible infall motion. The HCO$^+$ and the HCN emission at the ambient cloud velocity are enhanced along the HH 270 jet axis, but the molecular clumps do not show a kinematic sign of outflow. The enhancement could be caused by irradiation from shocks. In the immediate vicinity of HH 110A, the northernmost knot of HH 110, neither a continuum source nor any evidence of jet-cloud collision was found. To the west of HH 110, there is a filamentary structure of dense gas which contains at least two outflow sources. The driving source of the IRS 2 jet was detected in the continuum.

Accepted by the Astrophysical Journal

Preprint: http://www.asiaa.sinica.edu.tw/minho/pubs/

A Submillimeter Study of the Star-Forming Region NGC 7129

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New molecular (^{13}CO J=3−2) and dust continuum (450 μm and 850 μm) maps of the NGC7129 star forming region are presented. The maps include the Herbig Ae/Be star LkHα 234, the far-infrared source NGC 7129 FIRS2 and several other pre-stellar sources embedded within the molecular ridge. The data are complemented with C^{18}O J=3−2 spectra at several positions within the mapped region.

Both the submillimeter and the ^{13}CO emission show a similar morphology, displaying a sharp boundary towards the cavity. The submillimiter maps also reveal a second source, SMM 2, which is not clearly seen in any earlier data set. This is either a pre-stellar core or possibly a protostar. Also, the highest continuum peak emission is identified with the deeply embedded source IRS 6 a few arcseconds away from LkHα 234. These new 450 and 850 μm observations are combined with previous continuum observations of the three compact far-infrared sources in the field, in order to make fits to the spectral energy distributions and to obtain the source sizes, dust temperatures, luminosities, and masses. For nine positions where both ^{13}CO and C^{18}O spectra are available, gas masses have been obtained and compared with masses derived from the continuum fluxes. The masses are found to be consistent, implying little or no CO depletion onto grains. The dust emissivity index is found to be low towards the dense compact sources, $\beta \sim 1 - 1.6$, and high, $\beta \sim 2.0$, in the surrounding cloud.

Accepted by Astrophysical Journal

Proper Motion of the EHV SiO J=2→1 Emission in L1448

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We report the first measurements of proper motions in a molecular outflow by using interferometric rotational line observations. We observed and mapped with the BIMA (Berkeley Illinois Maryland Association) millimeter array the extremely high velocity (EHV) SiO J=2→1 emission associated with the L1448 molecular outflow. Comparisons were made with the Plateau de Bure (PdB) interferometer maps carried out 8.5 years earlier. We obtained proper motions of up to $0.12''$ yr^{-1}, which imply absolute velocities of 180 km s^{-1} and an outflow inclination of 21° to the plane of the sky, in agreement with previous modeling of the CO emission. These proper motions suggests that the EHV emission in L1448 has a short time scale. These results strongly suggest that with the new generation of powerful interferometric arrays the combination of high spectral and angular resolution with high sensitivity will permit a detailed 3-D picture of the kinematics of molecular outflows.

Accepted by ApL Letters

www.am.ub.es/∼jgirart/curro.html

Barnard's Merope Nebula Revisited: New Observational Results

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IC 349 is a small, fan-shaped reflection nebula located only $30''$ from 23 Tau; its nucleus is by a factor 15 the brightest area of the Pleiades nebulosity. We propose that IC 349 is a fragment of the Tau-Aur molecular cloud that has been encountered by the Pleiades in that cluster's southward motion, and is being illuminated and shaped by the radiation field of 23 Tau. New HST multicolor imagery, and the structure, colors and surface brightness of IC 349 are discussed

in terms of that hypothesis. What is known of the space motion of the nebula (obtained from the molecular-line radial velocity of the Taurus clouds and proper motions of the T Tauri stars therein), what can be inferred for the properties of the nebula from its color, and what is expected from radiation pressure theory appear to be compatible with this cloudlet-encounter hypothesis.

Accepted by Astron. J., June 2001 issue

Search for low-mass PMS companions around X-ray selected late B stars

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We have observed 49 X-ray detected bright late B-type dwarfs to search for close low-mass pre-main sequence (PMS) companions using the European Southern Observatory's ADONIS (Adaptive Optics Near Infrared System) instrument. We announce the discovery of 21 new companions in 9 binaries, 5 triple, 4 quadruple system and 1 system consisting of five stars. The detected new companions have K magnitudes between $6^{m}.5$ and $17^{m}.3$ and angular separations ranging from 0."2 and 14."1 (18-2358 AU).

Accepted by A & A

K band Spectroscopy of Luminous Young Stellar Objects

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We present the spectroscopy from 2.0 to 2.33 μm of 32 luminous Young Stellar Objects (YSOs) which are presumed to be precursors of Herbig Ae/Be stars. From these stars, Brγ, H_2, CO, HeI, and FeII were found in emission with the detection rate of 97 %, 34 %, 22 %, 9 % and 3 %, respectively. We compared the spectral features with those of Herbig Ae/Be stars in the literature to investigate the spectral behavior of intermediate- to high-mass YSOs, and to search for their relations to the Spectral Energy Distributions (SEDs). H_2 emission is detected only in Class I SEDs with particularly large spectral indices. The detection of H_2 emission is related to the degree of the dispersal of circumstellar envelopes where H_2 molecules are probably excited by shocks from outflows. On the other hand, Brγ emission, which is generally thought to occur in stellar wind close to the stars, does not depend on the SEDs. This indicates that stellar wind from luminous YSOs does not change much from the embedded phase to the optically visible phase. CO emission is also independent of the SEDs, but the detection rate is much lower than that of Brγ emission. Probably more strict physical conditions of circumstellar disks and stellar radiation are necessary for CO emission to take place.

Accepted by Astron. J. June 2001 (Vol. 121, No. 4)

The Formation of Stellar Clusters: Time Varying Protostellar Accretion Rates

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Identifying the processes that determine strength, duration and variability of protostellar mass growth is a fundamental ingredient of any theory of star formation. I discuss protostellar mass accretion rates $\dot{M}$ from numerical models which follow molecular cloud evolution from turbulent fragmentation towards the formation of stellar clusters. In a dense cluster environment, $\dot{M}$ is strongly time varying and influenced by the mutual interaction of protostellar cores and their competition for accretion from the common cluster gas reservoir. Even for protostars with similar final mass, the accretion histories may differ dramatically. High-mass stars build up in the central parts of dense, cluster-forming cloud regions. They begin to form in the early phases of cluster evolution, and continue to grow at a high rate until the available gas is exhausted or expelled by feedback. Lower-mass stars tend to form at later phases, and $\dot{M}$ declines rapidly after a short initial phase of strong growth. I present a simple fit formula for the time evolution of the average $\dot{M}$ for protostars of different masses in a dense cluster environment.

Accepted by ApJ Letters

Preprint available at http://www.ucolick.org/ ralf/Preprints/p11.abstract.html

On the origin of the distribution of binary-star periods

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Pre-main sequence and main-sequence binary systems are observed to have periods, P, ranging from one day to 10^{10} days and eccentricities, e, ranging from 0 to 1. We pose the problem if stellar-dynamical interactions in very young and compact star clusters may broaden an initially narrow period distribution to the observed width. N-body computations of extremely compact clusters containing 100 and 1000 stars initially in equilibrium and in cold collapse are preformed. In all cases the assumed initial period distribution is uniform in the narrow range $4.5 \leq \log_{10} P \leq 5.5$ (P in days) which straddles the maximum in the observed period distribution of late-type Galactic-field dwarf systems. None of the models lead to the necessary broadening of the period distribution, despite our adopted extreme conditions that favour binary–binary interactions. Stellar-dynamical interactions in embedded clusters thus cannot, *under any circumstances*, widen the period distribution sufficiently. The wide range of orbital periods of very young and old binary systems is therefore a result of cloud fragmentation and immediate subsequent magneto-hydrodynamical processes operating within the multiple proto-stellar system.

Accepted by ApJ

http://xxx.lanl.gov/abs/astro-ph/0103429

Doubly deuterated molecular species in protostellar environments

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We report the detection of the doubly deuterated forms of ammonia (ND_2H) and formaldehyde (D_2CO) towards 16293E, a newly identified low–luminosity protostar in the ρ–Ophiucus molecular complex. The abundances of ND_2H and D_2CO compared to their hydrogenated counterparts NH_3 and H_2CO are ~ 3 % and 40 ± 20 %, respectively. To date, 16239E is thus the source with the highest levels of multiple deuteration: $[ND_2H]/[NH_3]$ is 5 to 6 times larger there than in the only other astronomical source where ND_2H has ever been found: the dense ammonia core of L134N; and $[D_2CO]/[H_2CO]$ is more than 5 times higher than in the proto–binary system IRAS16293–2422. The relative abundances of doubly deuterated molecules in low–luminosity protostars is much higher than their current gas–phase [D]/[H] ratio would suggest; and, therefore, likely reflect active grain surface chemistry followed by some desorption process.

Accepted by the Astrophysical Journal Letters

http://www.astrosmo.unam.mx/ l.loinard/publi.html

The kinematics of molecular clumps surrounding hot cores in G29.96−0.02 and G31.41+0.31

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We present high angular resolution interferometric observations of the 3 and 1.3 mm continuum emission, and HCO^+(1–0) and SiO(2–1) v=0 lines, obtained with the Owens Valley Radio Observatory millimeter-wave array, toward two hot cores (HCs) associated with two well known ultracompact (UC) HII regions: G29.96−0.02 and G31.41+0.31. These HCs are believed to host young forming massive stars which have been suggested to be surrounded by massive rotating accretion disks. The aim of these new observations is to study the structure and kinematics of the molecular clumps surrounding the HCs and nearby UC HII regions at moderately high angular resolution. Our observations reveal that the clumps within which the HCs and UC HII regions are embedded have a complex kinematical structure. The total mass of the clumps is estimated to be in the range 1000–3000 $M_\odot$, consistent with previous findings. Our observations also show compelling evidence that the clump in G29.96−0.02 is contracting onto the HC position, suggesting that the accretion process onto the massive young stellar object embedded in the HC is still ongoing. In these objects the kinematical structure that we observe is also compatible with the presence of a massive rotating disk within the HC, even though we cannot prove this suggestion with our data. The case of G31.41+0.31 is more complicated, and our data, although consistent with the presence of an inner disk and an infalling envelope around it, do not have the required spatial resolution to resolve the different structu res.

Accepted by A&A

http://www.arcetri.astro.it/∼lt/preprints/preprints.html

Submillimeter Imaging Polarimetry of the NGC 7538 Region

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Imaging polarimetry of the 850 μm continuum emission in the NGC 7538 region, obtained with the SCUBA Polarimeter, is presented. The polarization map is interpreted in terms of thermal radiation by magnetically aligned dust grains. Two prominent cores associated with IRS 1 and IRS 11, IRS 1(SMM) and IRS 11(SMM), are found in the surface brightness map. Although these cores look similar in surface brightness, their polarization shows striking differences. In IRS 11(SMM), the polarization vectors are extremely well ordered, and the degrees of polarization are quite high with an average of ∼3.9 %. In IRS 1(SMM), on the other hand, the directions of polarization vectors are locally disturbed, and the degrees of polarization are much lower than those of IRS 11(SMM). These differences suggest that small scale fluctuations of the magnetic field are more prominent in IRS 1(SMM). This can be interpreted in terms of the difference in evolutionary stage of the cores. Inside IRS 1(SMM), which seems to be at a later evolutionary stage than IRS 11(SMM), substructures such as subclumps or a cluster of infrared sources have already formed. Small scale fluctuations in the magnetic field could have developed during the formation of these substructures. The distribution of magnetic field directions derived from our polarization map agrees well with those of molecular outflows associated with IRS 1(SMM) and IRS 11(SMM). Comparisons of energy densities between the magnetic field and the outflows show that the magnetic field probably plays an important role in guiding the directions of the outflows.

Accepted by ApJ.

astro-ph/0103334, http://stars.sci.ibaraki.ac.jp/~momose/publication.html

Infrared and Millimetric Study of the Young Outflow Cepheus E

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The Cepheus E outflow has been studied in the mid and far infrared using the ISO CAM and LWS instruments, and at millimetric wavelengths using OVRO. In the near and mid-IR, its morphology is similar to that expected for a jet driven outflow, where the leading bow shocks entrain and accelerate the surrounding molecular gas. As expected, fine structure atomic/ionic emission lines arise from the bow shocks, at both the Mach Disk and the stagnation tip, where J-shocks are dominant. The H_2, H_2O and CO molecular emission could arise further 'downstream' at the bow shock wings where the shocks (v $= 8 - 35$ km s^{-1}) are oblique and more likely to be C-type. The ^{13}CO emission arises from entrained molecular gas and a compact high velocity emission is observed, together with an extended low velocity component that *almost* coincides spatially with the H_2 near-IR emission. The millimetric continuum emission shows two sources. We identify one of them with IRAS 23011+6126, postulating is the driver of the Cepheus E outflow; the other, also an embedded source, is likely to be driving one of other outflows observed in the region. Finally, we suggest that the strong [C II] 158 μm emission must originate from an extended photo-dissociation region, very likely excited by the nearby Cepheus OB3 association.

Accepted by Astrophys. J.

http://arXiv.org/abs/astro-ph/0103065

A reconsideration of disk properties in Herbig Ae stars

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This paper presents state-of-the-art spectral energy distributions (SEDs) of four Herbig Ae stars, based in part on new data in the mid and far-infrared and at millimeter wavelengths. The SEDs are discussed in the context of circumstellar disk models. We show that models of irradiated disks provide a good fit to the observations over the whole range of wavelengths. We offer a possible solution to the long-standing puzzle caused by the excess emission of Herbig Ae stars, where a large fraction of the stellar luminosity is re-radiated between ∼1.25 and 7 μm, with a peak at about 3 μm. We suggest that this general behaviour can be caused by dust evaporation in disks where the gas component is optically thin to the stellar radiation, as expected if the accretion rate is very low. The creation of a puffed-up inner wall of optically thick dust at the dust sublimation radius can account for the near-infrared characteristics of the SEDs. It can also naturally explain the H and K band interferometric observations of AB Aur (Millan-Gabet et al. 2001), which reveal a ring of emission of radius ∼0.3 AU. Finally, irradiated disk models can easily explain the

observed intensity of the 10 μm silicate features and their variation from star to star.

Accepted by Astron. Astrophys.

available at http://www.arcetri.astro.it/~starform/publ2001.htm

FUSE and HST/STIS Observations of Hot and Cold Gas in the AB Aurigae System

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We present the first observations of a Herbig Ae star with a circumstellar disk by the *Far Ultraviolet Spectroscopic Explorer* (*FUSE*), as well as a simultaneous observation of the star obtained with the *Hubble Space Telescope* Space Telescope Imaging Spectrograph (STIS). The spectra of AB Aurigae show emission and absorption features arising from gasses that have a wide range in temperature, from hot OVI emission to cold H_2 and CO absorption. Emissions from the highly ionized species OVI and CIII present in the *FUSE* spectrum are redshifted, while absorption features arising from low-ionization species like OI, NI, and SiII are blueshifted and show characteristic stellar wind line-profiles. We find the total column density of H_2 toward AB Aur from the *FUSE* spectrum, $N(\mathrm{H_2}) = (6.8 \pm 0.5) \times 10^{19}$ cm^{-2}. The gas kinetic temperature of the H_2 derived from the ratio $N(J = 1)/N(J = 0)$ is 65 ± 4 K. The column density of the CO observed in the STIS spectrum is $N(\mathrm{CO}) = (7.1 \pm 0.5) \times 10^{13}$ cm^{-2}, giving a CO/H_2 ratio of $(1.04 \pm 0.11) \times 10^{-6}$. We also use the STIS spectrum to find the column density of HI, permitting us to calculate the total column density of hydrogen atoms, the fractional abundance of H_2, and the gas-to-dust ratio.

Accepted by Astrophysical Journal Letters

http://arXiv.org/abs/astro-ph/0103084

New models of interstellar gas-grain chemistry. III. Solid CO_2.

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Solid carbon dioxide is observed to be an abundant interstellar ice component towards both quiescent clouds and active star-forming regions. Our recent models of gas-grain chemistry, appropriate for quiescent regions, severely underproduce solid CO_2 at the single assumed gas density and temperature. In this paper, we investigate the sensitivity of our model results to changes in these parameters. In addition, we examine how the nature of the grain surface affects the results and also consider the role of the key surface reaction between O and CO. We conclude that the observed high abundance of solid CO_2 can be reproduced at reasonable temperatures and densities by models with diffusive surface chemistry, provided that diffusion of heavy species such as O occurs efficiently.

Accepted by MNRAS

Aromatic Hydrocarbons, Diamonds, and Fullerenes in Interstellar Space: Puzzles to be Solved by Laboratory and Theoretical Astrochemistry

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New research is presented, and previous research is reviewed, on the emission and absorption of interstellar aromatic hydrocarbons. Emission from aromatic hydrocarbons dominate the mid-infrared emission of many galaxies, including our own Milky Way galaxy. Only recently have aromatic hydrocarbons been observed in absorption in the interstellar medium, along lines of sight with high column densities of interstellar gas and dust. Much work on interstellar aromatics has been done, with astronomical observations and laboratory and theoretical astrochemistry. In many cases the predictions of laboratory and theoretical work are confirmed by astronomical observations, but in other cases clear discrepancies exist which provide problems to be solved by a combination of astronomical observations, laboratory studies, and theoretical studies. The emphasis of this paper will be on current outstanding puzzles concerning aromatic hydrocarbons which require further laboratory and theoretical astrochemistry to resolve. This paper will also touch on related topics where laboratory and theoretical astrochemistry studies are needed to explain astrophysical observations, such as a possible absorption feature due to interstellar "diamonds" and the search for fullerenes in space.

Accepted by Spectrochimica Acta Part A: Molecular & Biomolecular Spectroscopy

http://www.astronomy.ohio-state.edu/ sellgren/saa.html or http://xxx.lanl.gov/abs/astro-ph/0010138

Dusty Debris Around Solar-Type Stars: Temporal Disk Evolution

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Using ISO-ISOPHOT we carried out a survey of almost 150 stars to search for evidence of emission from dust orbiting young main sequence stars, both in clusters and isolated systems. Over half of the detections are new examples of dusty stellar systems, and demonstrate that such dust can be detected around numerous stars older than a few $\times 10^6$ years. Fluxes at 60 μm and either 90 or 100 μm for the new excess sources together with improved fluxes for a number of IRAS-identified sources are presented. Analysis of the excess luminosity relative to the stellar photosphere shows a systematic decline of this excess with stellar age consistent with a power law index of -2.

Accepted by ApJ

preprints available at: http://www.arXiv.org/abs/astro-ph/0103185

Circumstellar structure of RU Lupi down to au scales

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We have used the technique of spectro-astrometry to study the milli-arcsecond scale structure of the emission lines in the T Tauri star RU Lupi. The wings of the Hα emission are found to be displaced from the star towards the south-west (blue wing) and north-east (red wing) with angular scales of 20-30 milli-arcsecs. This structure is consistent with a bipolar outflow from the star. From a study of the variability of the intensity and position spectra we argue that a combination of magnetically-driven bipolar outflow and accreting gas contribute to the Hα emission. On the other hand, the [OI] and [SII] emission are displaced from the star to the south-west but at much larger distances than the Hα, hundreds of milli-arcsecs for the high-velocity component (HVC) and down to 30 milli-arcsecs for the low-velocity components (LVC). The presence of both red-shifted and blue-shifted outflows in Hα but only a blue-shifted outflow

in the forbidden lines can be explained if the disc obscures the red-shifted forbidden line outflow, but a disc gap with outer radius 3-4 au allows the red-shifted Hα to be seen. This gap could be induced by an unseen companion.

Accepted by MNRAS

http://arXiv.org/abs/astro-ph/0103311

The Stellar Composition of the Star Formation Region CMa R1 – II. Spectroscopic and Photometric Observations of 9 Young Stars

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We present new high and low resolution spectroscopic and photometric data of nine members of the young association CMa R1. All the stars have circumstellar dust at some distance as could be expected from their association with reflection nebulosity. Four stars (HD 52721, HD 53367, LkHα 220 and LkHα 218) show Hα emission and we argue that they are Herbig Be stars with discs. Our photometric and spectroscopic observations on these stars reveal new characteristics of their variability. We present first interpretations of the variability of HD 52721, HD 53367 and the two LkHα stars in terms of a partially eclipsing binary, a magnetic activity cycle and circumstellar dust variations, respectively. The remaining five stars show no clear indications of Hα emission in their spectra, although their spectral types and ages are comparable with those of HD 52721 and HD 53367. This indicates that the presence of a disc around a star in CMa R1 may depend on the environment of the star. In particular we find that all Hα emission stars are located at or outside the arc-shaped border of the H II region, which suggests that the stars inside the arc have lost their discs through evaporation by UV photons from nearby O stars, or from the nearby (< 25 pc) supernova, about 1 Myr ago.

Accepted by Monthly Notices of the Royal Astronomical Society

http://cfa-www.harvard.edu/∼mancker/cmastars.ps.gz

Near-infrared coronagraphic imaging of the circumstellar disk around TW Hydrae

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We present ground-based near-infrared (H-band) imaging of the circumstellar disk around the nearby classical T Tauri star TW Hydrae. The scattered light image shows a face-on disk with radius 4 arcseconds (corresponding to 225 AU) and a morphology which agrees with recent images from the Hubble Space Telescope and the Very Large Array. The best fit power-law for the disk's radial surface brightness profile obeys the law $r^{-3.3\pm0.3}$. We use our image and published continuum flux densities to derive properties of the disk with a simple model of emission from a flat disk. The best-fit values for disk mass and inner radius are 0.03 $M_\odot$ and 0.3 AU; best-fit values for temperature, density, and grain opacity power law exponents (q, p, and β) are 0.7, 1.3, and 0.9, respectively. These properties are similar to those of disks around classical T Tauri stars located in more distant molecular clouds. Because of TW Hydrae's nearby location and pole-on orientation, it is a uniquely favorable object for future studies of radial disk structure at the classical T Tauri stage.

Accepted by ApJL

http://www.hep.upenn.edu/ trilling/papers.html or http://xxx.lanl.gov/abs/astro-ph/0103458

The Probability Distribution Function of Column Density in Molecular Clouds

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We discuss the probability distribution function (PDF) of column density resulting from density fields with lognormal PDFs, applicable to molecular clouds. For magnetic and non-magnetic numerical simulations of compressible, isothermal turbulence, we show that the autocorrelation function (ACF) of the density field decays over short distances compared to the simulation size. A "correlation length" can be defined as the distance over which the density ACF has decayed to, for example, 10% of its zero-lag value. The density "events" along a line of sight can thus be assumed to be independent over distances larger than this, and the Central Limit Theorem should be applicable. However, using random realizations of lognormal fields, we show that the convergence to a Gaussian is extremely slow in the high-density tail. As a consequence, the column density PDF is not expected to exhibit a unique functional shape, but to transit from a lognormal to a Gaussian form as the column length increases, and with decreasing variance. For intermediate path lengths, the column density PDF assumes a nearly exponential decay. For cases with a density contrast of 10^4 (resp. 10^6), as found in intermediate-resolution simulations, and expected from GMCs to dense molecular cores, the required length for convergence is at least a few hundred (resp. several thousand) independent events. Therefore, we suggest that all 3D MHD simulations to date are insufficiently resolved for obtaining a reasonably converged Gaussian PDF for the column density.

Observationally, our results imply that the column length (in units of the correlation length) may be inferred from the shape of the column density PDF in optically-thin-line or extinction studies: as the path length increases, the PDF is expected to undergo the shape sequence mentioned above. A similar behavior is expected for underlying density PDFs with finite-extent power-law ranges, which should be characteristic of lower density, non-isothermal gas (with temperatures ranging from a few hundred to a few thousand degrees). Finally, we note that for long path lengths (over a few hundred independent events), the dynamic range in column density is small ($\lesssim$ a factor of 10), but this is only an averaging effect, with no implication on the dynamic range of the underlying density distribution.

Accepted by Astrophys. J.

Full paper available at astro-ph/0103199.

Observational Constraints on the Formation and Evolution of Binary Stars

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We present a high spatial resolution multi-wavelength survey of 44 young binary star systems in Taurus-Auriga with separations of 10 - 1000 AU. These observations, which were obtained using the Hubble Space Telescope and the NASA Infrared Telescope Facility, quadruple the number of close (< 100 AU) binary stars with spatially resolved measurements from 0.3 to 2.2 μm and are the first 3.6 μm measurements for the majority of the companion stars in the sample.

Masses and ages are estimated for the components observed at optical wavelengths. The relative ages of binary star components are more similar than the relative ages of randomly paired single stars within the same star forming region. This is the first statistically significant evidence for coeval formation. Only one of the companion masses is substellar, from which we conclude that the apparent overabundance of T Tauri star companions relative to main-sequence star companions is not due to a wealth of substellar secondaries that would have been missed in main-sequence surveys.

The circumstellar environments of binary star systems are studied in this work through three diagnostics - the infrared color $K - L$, the ultraviolet excess ΔU, and Hα emission. Several conclusions are drawn. First, the mass accretion rates for primary stars are similar to single stars, which suggests that companions as close as 10 AU have little effect on the mass accretion rate. Second, although most classical T Tauri star binaries retain both a circumprimary and a circumsecondary disk, there are several systems with only a circumprimary disk. Systems with only a circumsecondary

disk are rare. This suggests that circumprimary disks survive longer than circumsecondary disks. Third, primary stars accrete at a higher rate, on average, than secondary stars. This is most likely because of their larger stellar mass, since the mass accretion rates for both single and binary T Tauri stars exhibit a moderate mass dependence. Fourth, approximately 10% of T Tauri binary star components have very red near-infrared colors ($K - L > 1.4$) and unusually high mass accretion rates. This phenomenon does not appear to be restricted to binary systems, however, since a comparable fraction of single T Tauri stars exhibit the same properties. These high accretion stars are probably not at an earlier stage of evolution, as has been proposed. Their semblance of younger protostars at optical and infrared wavelengths is most likely because of their similar high levels of accretion, which are above the norm for T Tauri stars, and not because of similar ages.

The stellar and circumstellar properties are also used to indirectly trace the evolution of circumbinary material. In contrast to single T Tauri stars, which have disk dissipation timescales comparable to their ages, the disk dissipation timescales for binary T Tauri stars are roughly 1/10 of their ages. Replenishment of the inner circumstellar disks may be necessary to explain the continuing disk accretion in these systems. The longer disk lifetimes of circumprimary disks, despite their higher depletion rates, suggests that circumprimary disks are being preferentially replenished, possibly from a circumbinary reservoir with low angular momentum relative to the binary. Further support for circumbinary reservoirs comes from the observed correlated presence of circumprimary and circumsecondary disks for binaries with separations of less than ~ 200 AU. The presence of disks appears uncorrelated for wider binaries. Additionally, binaries with separations of less than ~ 100 AU exhibit a higher fraction of high mass ratio (m_s/m_p) pairs than wider binaries. These separation dependent properties can be explained if the components are being replenished from a common circumbinary reservoir with low angular momentum. The components of the closest pairs are expected to be more equally replenished than the widest pairs, which consequently sustains both disks and drives their mass ratio toward unity. Overall, the results of this study corroborate previous work that suggests fragmentation is the dominant binary star formation mechanism; disk instabilities and capture seem unlikely.

Accepted by ApJ.

Preprint available at: http://xxx.lanl.gov/abs/astro-ph/0103098

Millimeter continuum image of the circumstellar disk around the young star Haro 6-5B

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Aperture synthesis observations of dust continuum emission at 2 mm from the class I object Haro 6-5B, made with the Nobeyama Millimeter Array (NMA), are presented. A disklike structure which coincides with the dark lane in the visible and near-infrared images is clearly resolved with a small synthesized beam of 1.33 $\times$ 1.21 arcsec with its position angle (P.A.) of 134^o. The beam-deconvolved size of the disk is 2.33 $\times$ 0.97 arcsec at P.A. = 138^o, and the total flux density is 36.7 $\pm$ 2.6 mJy. The radius and inclination angle of the disk derived from the image are 309 $\pm$ 18 AU and 67 $\pm$ 5^o, respectively. By model fitting of the spectral energy distribution (SED) of Haro 6-5B with these values, the power-law index of the dust opacity, β, is derived to be 1.05 $\pm$ 0.04 and the disk mass is calculated to be $0.021 \pm 0.002\, M_\odot$. No extended emission with 1000 AU scale is detected, suggesting that the envelope around Haro 6-5B has been almost dissipated and that the object is a transient source from the protostar stage to the T Tauri stage.

Accepted by Astrophysical Journal Letters

Discovery of a molecular outflow, near-infrared jet and HH objects towards IRAS 06047−1117

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We report discovery of a new young stellar object driving a point-symmetric, near-infrared jet and molecular outflow. The YSO is associated with IRAS 06047−1117 and is embedded in a dense molecular cloud core located southeast of Orion A. The jet is seen in the H_2 $v = 1 - 0$ line at 2.12μm and extends over a total length of about $\sim$0.4 pc. The driving source is optically invisible and has near-infrared colors and a spectral energy distribution consistent with a Class I source with an estimated luminosity of 6 $L_\odot$. Two Herbig-Haro objects are seen in Hα images located close to the positions of maximum H_2 emission.

Accepted by *Astronomy & Astrophysics Letters*

http://www.oal.ul.pt/papers/IRAS06047-1117

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Magnetic Field Effects on the Structure and Evolution of Herbig-Haro Jets

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In this work, the structure and evolution of Herbig-Haro (HH) jets is analyzed with the help of three-dimensional (3-D), Smoothed Particle Hydrodynamics simulations. We have carried out the first 3-D magneto-hydrodynamics (MHD) numerical simulations of steady-state and pulsed, radiativelly cooling jets, adopting parameters that are suitable for HH jets in the literature (e.g., de Gouveia Dal Pino & Cerqueira, Astro. Lett. and Commun. 1996, 34, 303). We show that the inclusion of the magnetic field, for which we have used different initial configurations and intensities ($\beta = 8\pi p/B^2 \simeq 0.1$, 1 and ∞; or $B \simeq 260\mu$G, 83 μG and 0), enhances the jet collimation, particularly in the case of helical and toroidal fields. In the case of steady-state simulations, we show that the appearance of internal crossing shocks, which are excited by the MHD Kelvin-Helmholtz (K-H) instability is inhibited when radiative cooling is taken into account. Therefore, MHD K-H instabilities seem to play a secondary role in the formation of internal emission knots along the jet beam of HH jets, where the radiative cooling is very important (Cerqueira & de Gouveia Dal Pino 1999, ApJ, 510, 828). We show that the presence of magnetic fields can significantly affect the morphology of the steady-state jets close to the head (Cerqueira, de Gouveia Dal Pino & Herant, 1997, ApJ, L185). In particular, both the helical and the toroidal fields, unlike the longitudinal field, can inhibit the formation of the cold, dense structures that are found to develop in this region in purely hydrodynamic simulations (which are due to Rayleigh-Taylor and global thermal instabilities). We have also performed 3-D simulations of pulsed jets. In this case, the bright emission knots observed along the HH jets are naturally explained by the pulses which quickly steepen into double shock structures as they propagate downstream (forming the so-called internal working surfaces; IWS's). We show that the presence of different magnetic field topologies in close equipartition with the gas does not introduce relevant effects on the overall morphology of the HH jets. However, the magnetic fields can significantly affect the detailed structure and emission properties of the head and internal knots with respect to purely hydrodynamic calculations, particularly for helical and toroidal geometries (Cerqueira & de Gouveia Dal Pino 2001a, ApJ *Letters*, 550, in press). We have estimated the Hα emission within the knots and found that the intensity in this line could be up to $4-5$ times larger than that found in the pure HD case. For the different adopted magnetic field configurations, we find that the toroidal component steepens within the IWS's, while the longitudinal component attains its maximum intensity between the IWS's. Our simulations of pulsed jet with an initially helical magnetic field topology show the development of the kink mode of the MHD Kelvin-Helmholtz instability which promotes a gentle wandering of the jet axis. Some features previously detected in 2-D MHD simulations seem to be smoothed out in the 3-D flows. For example, we find no evidence for the appearance of the so-called nose-cones which are often detected in two-dimensional numerical simulations involving toroidal fields (see Cerqueira & de Gouveia Dal Pino 2001b, ApJ, submitted). Since there is no direct observational evidence of such structures in the HH jets, the present findings stress the importance of fully 3-D studies of these objects.

Particle Splitting: A New Method for SPH Star Formation Simulations

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Ph.D degree awarded: December 2000

Particle Splitting is a new algorithm invented for use with self-gravitating SPH codes. It is designed to enable numerical simulations to obey the Jeans condition at all times (but it could be used in other contexts, to satisfy other conditions which require high resolution locally). With particle splitting, all coarse particles in regions of interest, are erased and replaced by sets of fine particles, increasing the numerical resolution of the simulations. A new algorithm for calculating smoothing lengths was added to our code, to accommodate the mixing of different mass particles. Our particle splitting SPH code reproduced the results of standard test simulations.

Simulations of rotating clouds with m=2 density perturbations produce a binary and a bar. We confirm that fragmentation of the bar should be attributed to inadequate resolution. By applying Particle Splitting to such simulations, we reproduce the results of high resolution finite difference simulations (Truelove *et al.* and Klein *et al.*), where bar fragmentation is absent. We obtain these results with great computational economy.

We apply Particle Splitting to simulations of clump-clump collisions. We investigate the influence of clump mass, clump velocity and collision impact parameter on the structures formed. We show that such collisions lead to the formation of shocked layers. Networks of filaments or spindles, and groups of protostellar discs form within the layers. In all collisions, fragmentation of the filaments was the common mechanism producing the groups of protostars. Low-mass secondary companions to the protostars may form subsequently by instabilities in the discs and/or dynamical interaction between the protostars. However, due to time-step requirements, we cannot follow the disc evolution for long enough to explore the formation of secondaries.

We show that all the protostars formed have mass accretion rates of $\sim$5 x 10^{-5} $M_\odot$ yr^{-1} for the first 10-20 thousand years after their formation. This mechanism shows 10-20% Star Formation efficiency. The efficiency increases with increasing clumps mass. Collisions with impact parameter b <0.4 and Mach number $\mathcal{M}$ $\geq$10 give the highest efficiency. We predict the existence of filaments with n_{H_2} $\geq$5 x 10^5 cm^{-3} in sites of dynamical Star Formation. These filaments could be observed in NH_3 or CS line radiation, in star forming regions lying within 1 kpc.

Center for Star Formation Studies 2001 Summer Workshop: Star Formation in the Galactic Context

Saturday, July 14 - Thursday, July 19 (lectures start the morning of the 15th),
Univerisity of California at Santa Cruz

This workshop has a maximum capacity of 125 people. Room and board for the 5 days costs around $400, and there is a $35 registration fee. There will also be a separate charge for a banquet dinner which will be held in a local restaurant.

To register, contact Cathy Clausen at cclausen@natsci.ucsc.edu.

The following is a preliminary agenda. Look for an up-to-date schedule on the Center's web page at `www-space.arc.nasa.gov/~csf`.

I. Nearby Star Formation, with an emphasis on the"Big Picture" of Galactic Star Formation.

A. Large Scale ISM Turbulence, Flows, Cloud Formation

• Javier Ballesteros, Mordecai MacLow, Richard Klein, Phil Myers

B. Chemical Evolution of Molecular Material and the Dynamical Evolution of Molecular Clouds

• J . Alves, P. Caselli, Malcolm Walmsley, David Wilner, John Scalo

C. Clusters and Associations in the Solar Neighborhood

• Lee Hartmann (tentative), Charles Lada, Lynn Hillenbrand, Fransesco Palla, Leonardo Testi, Michael Meyer, Fred Adams

II. Clustering of Star Formation in Different Environments

A. Globular Clusters and Super Star Clusters in Starburst Galaxies

• Cesar Briceno, Doug Lin (tentative), Ralph Pudritz

III. Star Formation and the ISM in low-Z Spiral/Disk Galaxies

A. Observations, Global Star Formation Rates and Correlations

• R. Kennicut (tentative), E. Ostriker, Frank Shu, R. Allen, Tony Wong, Annette Ferguson

IV. Dwarf Galaxies

• Leo Blitz, Liese Van Zee, Eva Grebel (tentative), K.-Y. Lo (invited), Arthur Wolfe

V. Starburst Phenomenon

• Dieter Lutz (invited), James Graham (invited), Timothy Heckman, Jonathon Tan

VI. Regulated Star Formation and Feedback Processes

• Andrea Ferrara, Jasper Sommer-Larson (invited), Crystal Martin, David Hollenbach