THE STAR FORMATION NEWSLETTER

An electronic publication dedicated to early stellar evolution and molecular clouds

No. 80 — 11 May 1999 Editor: Bo Reipurth (reipurth@casa.colorado.edu)

Announcement

A General Catalogue of Herbig-Haro Objects, 2nd Edition

Bo Reipurth

This is the second, greatly expanded edition of the 1994 catalogue of Herbig-Haro objects, listing all currently known HH objects. For each object is given its HH number, previous designations if any, a position, the most probable energy source, and the region and distance. Additionally, extensive notes give a brief description of each object with detailed references to the literature. The catalogue will be updated as developments in the field require.

This catalogue will not be published in any journal. It can be downloaded from the WWW at

http://casa.colorado.edu/hhcat

Abstracts of recently accepted papers

Periodic Changes of Veiling and Circumstellar Grey Extinction in DF Tauri: Dust Clouds Spiraling into a T Tauri Star?

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We present 110 simultaneous BVI photometric measurements and low resolution (≈ 400) spectra obtained during 17 consecutive days on the Classical T Tauri star DF Tau. Applying a new method for veiling extraction from low resolution spectra, we derive veiling curves in the B and V photometric bands which closely resemble their corresponding light curves. Analysis of the combined light and veiling curves allows to disentangle the stellar and excess fluxes. The BV stellar fluxes derivation is validated by the I photometric curve which is only slightly contaminated by the excess. The stellar flux exhibits grey variations, up to a factor 2, between the B and I bands. In the first 12 days, these variations are periodic with two minima separated by about 6 days. Yet from day 13th, both the stellar flux *and* the veiling steadily increase. The overall picture emerging from these results is that of an optically thick accreting cloud, which partially occults the star. As this cloud, located initially within the corotation volume, spirals into the star, the accretion rate increases and its opacity decreases. We also discuss the stellar rotation period and the detection of flare events of few hours duration.

Accepted by Astron. & Astrophys. (Letters)

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

L1551-NE or L1551-IRS5: Which source drives HH 28/29?

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We have obtained deep high resolution interference filter images of the HH objects in the L1551 molecular cloud in 1990 and 1997, and we suggest that the well known and well studied objects HH 28 and 29 are driven by the deeply embedded class 0 source L1551-NE, not by the well known IRS 5 source. We find a new, small bipolar HH flow, HH 454, surrounding L1551-NE. This new HH flow is aligned along the axis of a highly collimated infrared jet from this source, is blueshifted by 110 km s^{-1} southwest of the source, and is redshifted by 100 to 130 km s^{-1} northeast of L1551-NE. A line through the L1551-NE source and along this well defined flow axis passes straight through HH 29, and within parts of the more distant HH 259 and HH 28. The proper motion of HH 29 exhibits a complex flow pattern with some knots appearing to move away from the nearby source IRS 5 while other parts are moving away from L1551-NE. The HH 29 object encompasses several bright, stationary knots which have faded between the two epoch images. When these stationary knots are excluded from the proper motion analysis, the resulting overall flow vector points away from L1551-NE, not from IRS 5. Most components of HH 259 and some parts of HH 28 also appear to be moving in a direction pointing away from L1551-NE rather than from IRS 5. In the opposite, red-shifted lobe, we find a new, distant HH object, HH 286, but it is unclear whether L1551-NE or IRS 5 is the driving source. Altogether, it appears that L1551-NE plays a much more prominent role than hitherto anticipated in the outflow activity of this highly complex and confused region.

Accepted by Astron. J.

Physical Conditions in Regions of Star Formation

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The physical conditions in molecular clouds control the nature and rate of star formation, with consequences for planet formation and galaxy evolution. The focus of this review is on the conditions that characterize regions of star formation in our Galaxy. A review of the tools and tracers for probing physical conditions includes summaries of generally applicable results. Further discussion distinguishes between the formation of low-mass stars in relative isolation and formation in a clustered environment. Evolutionary scenarios and theoretical predictions are more developed for isolated star formation, and observational tests are beginning to interact strongly with the theory. Observers have identified dense cores collapsing to form individual stars or binaries, and analysis of some of these support theoretical models of collapse. Stars of both low and high mass form in clustered environments, but massive stars form almost exclusively in clusters. The theoretical understanding of such regions is considerably less developed, but observations are providing the ground rules within which theory must operate. The most rich and massive star clusters form in massive, dense, turbulent cores, which provide models for star formation in other galaxies.

Accepted by Annual Reviews of Astronomy and Astrophysics

http://xxx.lanl.gov/abs/astro-ph/9905050

Ambipolar Diffusion in YSO Jets

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We address the issue of ambipolar diffusion in Herbig-Haro jets. The current consensus holds that these jets are launched and collimated via MHD forces. Observations have, however, shown that the jets can be mildly to weakly ionized. Beginning with a simple model for cylindrical equilibrium between neutral, plasma and magnetic pressures we calculate the characteristic time-scale for ambipolar diffusion. Our results show that a significant fraction of HH jets will have ambipolar diffusion time-scales equivalent to, or less than the dynamical time-scales. This implies that MHD equilibria established at the base of a HH jet may not be maintained as the jet propagates far from its source. For typical jet parameters one finds that the length scale where ambipolar diffusion should become significant corresponds to the typical size of large (parsec) scale jets. We discuss the significance of these results for the issue of magnetic fields in parsec-scale jets.

Accepted by Ap. J.

Spatially resolved spectroscopy of Z CMa components

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We present adaptive optics integral field spectrograph observations of the Z CMa binary in the 6203Å-6528Å band with a spectral resolution of 3200 and spatial resolution of 0.24 arcsec made with the OASIS instrument coupled to the PUE'O bonnette.

Using the binary parameters derived from speckle interferometry, we are able to recover the spectrum of each component, in spite of a spatial sampling (0.11 arcsec) similar to the system separation (0.1 arcsec). The component that dominates the optical continuum presents a spectrum similar to the one from the system in its pre-outburst phase. The other component (so-called "IR companion") shows an emission line spectrum.

Extended emission is detected in [OI]λ6300. This emission presents an unresolved peak plus an elongated structure, similar to that found in Classical T Tauri Stars' microjets. The low velocity component is unresolved and slightly shifted from the stellar continuum location. The high velocity component is extended but also contributes to the unresolved peak. This microjet is spatially associated with the infrared companion and with the system's powerful parsec-scale jet. The upper limit of the microjet width is 0.24 arcsec, and its length is ~ 1 *arcsec*. This size combined with the material velocity results in a dynamical time scale of $\sim$ 10 yrs, compatible with its origin in the 1987 outburst.

Accepted by A&A

A Multi-transition HCO^+ study of the NGC 2071 Molecular Outflow

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We present high angular resolution and multi-transition HCO^+ observations toward the NGC 2071 molecular outflow. Comparison of the high velocity (HV) HCO^+ and the near-IR H_2 in the molecular outflow shows a clear correlation. At high HCO^+ flow velocities the spatial coincidence is especially remarkable. In addition, the HV HCO^+ presents clear morphological and kinematical differences with the CO outflow. This differences appear not only in the HV HCO^+ emission associated with the H_2 but in the overall outflow. There is a clear HCO^+ emission enhancement, relative to CO, at increasing flow velocities. This enhancement is probably due to an abundance enhancement produced by a velocity dependent chemistry in the shocks. An overabundance of CH in low Mach shocks may cause the HCO^+ abundance enhancement. Because of the short cooling time for H_2, the correlation between the HCO^+ and the H_2 implies that HCO^+ emission can provide a useful tool to study in detail the current interactions of protostellar winds with the dense ambient medium. At the position of the extremely high velocity (EHV) CO component in the red

lobe we detect HCO^+ (J=3→2) emission within the velocity range of the EHV CO gas. This emission is roughly compatible with the expected HCO^+ emission associated with EHV gas arising from behind dissociative shocks.

Accepted by The Astrophysical Journal (Vol. 522, September 10 issue)

http://www.astro.uiuc.edu/~jgirart/curro.html

Detection of Methanol in a Class 0 Protostellar Disk

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We report the detection of emission from methanol in a compact source coincident with the position of the L1157 infrared source, which we attribute to molecules in the disk surrounding this young, Class 0 protostellar object. Using the Caltech Owens Valley Millimeter Array with a synthesized beam size of 2″, we detect spatially unresolved methanol emission in the $2_k - 1_k$ transitions at 3mm wavelength, which is coincident in position with the peak of the continuum emission. The gas phase methanol could be located in the central region (< 100 AU radius) of a flat disk or in an extended heated surface layer (~ 200 AU radius) of a flared disk. The fractional abundance of methanol $X(CH_3OH)$ is $\sim 2{\times}10^{-8}$ in the flat disk model, and $\sim 3{\times}10^{-7}$ for the surface layer of a flared disk. The large variation in the fractional abundance between the warm portion of the flared disk and the disk as a whole makes it plausible that substantial chemical processing via depletion and desorption has occurred.

Accepted by Ap.J. Letters

A Photometric Catalogue of Herbig Ae/Be Stars and Discussion of the Nature and Cause of the Variations of UXors

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UBVR photometric monitoring of Herbig Ae/Be stars and some related objects has been carried out at Maidanak Observatory in Uzbekistan since 1983. More than 71,000 observations of about 230 stars have been obtained and are made available for anonymous ftp. Virtually all Herbig Ae/Be stars observed are irregular variables (called "UXors" after UX Ori) but there is a wide range of amplitudes from barely detectable to more than 4 magnitudes in V. Our data confirm the results of previous studies which indicate that large amplitude variabiltiy is confined to stars with spectral types later than B8. The distribution of variability ranges is quite similar to what is seen in classical T Tauri stars. A careful search has failed to reveal any evidence for periodic variations up to 30 days which can be interpreted as rotation periods. This is a clear distinction between the light variations of low mass and high mass pre-main sequence stars. The Herbig Ae/Be stars evidently do not possess either the large, stable cool spots or persistent hot spots associated with strong surface magnetic fields and magnetically funneled accretion in classical T Tauri stars. A wide variety of shapes, time scales and amplitudes exists, but the most common behavior is well illustrated by the light curve of Lk Hα 234. There are two principal components: 1) irregular variations on timescales of days around a mean brightness level which changes on much longer timescale (typically years) sometimes in quasi-cyclic fashion, and 2) occasional episodes of deep minima, occuring at irregular intervals but more frequently near the low points of the brightness cycles. Our data suggest that many T Tauri stars of K0 and earlier spectral type share the same variability characteristics as Herbig Ae/Be stars and should be regarded as UXors. Two FUors, FU Ori and V1515 Cyg, also have recent light curves which are similar, in some respects, to UXors. The most developed model to account for the variations of some large amplitude UXors involves variable obscuration by circumstellar dust clumps orbiting the star in a disk viewed nearly edge on. However, there are problems in extending this model to the entire class, which lead us to propose an alternative mechanism - unsteady accretion. Evidence favoring the accretion model over the obscuration model is presented. It is suggested that the thermal instability mechanism responsible for outbursts in interacting binary system disks, and possibly FUors, may be the cause of the deep minima in UXors.

Accepted by Astron. J.

Molecular Jets and H_2O Masers in the AFGL 5142 Hot Core

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We present centimeter and millimeter continuum and molecular line images of the massive star-forming region AFGL 5142. A compact ($2''.5$) millimeter continuum core with integrated flux density of 125 mJy has been detected at 88 GHz. The emission peak coincides with a 1.5 mJy centimeter continuum source. A massive ($\sim 35\ M_\odot$) highly-collimated north-south outflow emanating from the core is seen in both the HCO^+ (1–0) and SiO (v=0,J=2–1) transitions. The millimeter continuum source coincides with a molecular core traced by the ambient velocity HCO^+ (1–0), SiO (v=0,J=2–1), and $H^{13}CO^+$ (1–0) emission. CH_3CN (14–13) and (12–11) spectra indicate a gas temperature $\sim$ 65 K in the innermost core. While the millimeter continuum emission is probably mostly due to optically thin thermal emission from dust grains, the centimeter continuum source is consistent with an ionized wind. From the Lyman continuum flux required to sustain the ionized gas, we estimate that the exciting source should be a B2 or earlier ZAMS star.

The 22 GHz H_2O masers most closely associated with the central object have undergone substantial variability in flux and position during three epochs spread over eight years. In addition, two new water maser features have been detected significantly offset (3-4$''$, 0.03 pc) from the centimeter continuum peak position. One of these maser features exhibits a linear structure of spots with spatial-kinematic evidence for a rotating circumstellar disk of radius 40 A.U., and dynamical mass of $\approx 1\ M_\odot$. The other is found to be associated with a near infrared source with large infrared excess. In addition to the 28 embedded stars previously seen in infrared images, we conclude that this cluster is concurrently forming both low and high mass stars.

Accepted by Astron. J. http://cfa-www.harvard.edu/~thunter

Molecular Gas in the NGC 6334 Star Formation Region

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We present millimeter and centimeter-wave spectroscopic observations of the southern massive star formation region NGC 6334. The cloud has been mapped in several transitions of CO, ^{13}CO, CS, and NH_3. The molecular gas shows a complex structure of filaments, in which the massive star formation occurs, and bubbles, some of which contain photodissociated gas. There is an anticorrelation between the presence of dense gas and the 6 cm radio flux: the hottest stars, with the hardest FUV radiation, have dispersed the dense gas from which they formed, whereas the cooler stars have not yet been able to do so. There is a velocity gradient along the star-forming ridge such that the radial velocity peaks in the center of the ridge. Several blueshifted emission features were discovered, one of which was identified with the '3-kpc' arm of the Galaxy.

Excitation model calculations were used to determine the physical conditions of the molecular gas in NGC 6334. The average kinetic temperature, hydrogen volume and column densities at the continuum sources are: $\overline{T_k} = 56 \pm 11$ K, log $\overline{n}_{H_2}$ (cm^{-3}) $= 3.5 \pm 0.3$, and $\overline{N}_{H_2}$ (10^{22} cm^{-2}) $= 7 \pm 4$, respectively. The properties of the molecular gas are compared to those in other massive star forming clouds to determine that NGC 6334 is representative of massive star forming regions in the Galaxy and can therefore be used to test the predictions of the theoretical models of photodissociation regions. The properties of the individual sites of star formation in the cloud are also discussed.

Accepted by Astrophys. J. Supp.

Preprints available at http://slime.bu.edu/~kraemer/

Galactic Anticenter CO Survey: I. Area $l = 178°$ to $186°$, $b = 3°.5$ to $6°$

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We have mapped a 17 square-degree section $(l, b) = (178°.0 \sim 186°.0,\ 3°.5 \sim 6°.0)$ of the Galactic Anticenter region in the ^{12}CO $J = 1 - 0$ line using the 3-mm SIS receiver on the 14-m telescope at the Taeduk Radio Astronomy Observatory. A total of 7,000 spectra has been obtained with a grid spacing of $3'$. The results of the observations are presented in the form of l-b and v-b contour maps. Molecular emission of the mapped area is found to be very extended and matches with the FIR emission boundary. The radial velocity of the molecular gas is found to be within the range of $v_{LSR} = -25 \sim +10$ km s^{-1}. We also found several small clouds located at $l = 180°$, $b = 5° \sim 6°$ having $v_{LSR} = -20$ km s^{-1}, which is quite anomalous in this direction. We identified 30 individual clouds within the mapped region with an arbitrary threshold temperature using a cloud identification code. Twelve subclouds were also identified from the largest cloud with a higher threshold temperature. The ratio of dust emission to CO integrated intensity for the Galactic Anticenter region is found to be similar to that of the dark clouds in solar neighborhood, and much less than that of giant molecular clouds, implying that the heating source within the clouds is minimal.

Accepted by Astronomy and Astrophysics Supplement Series

A Very Dense Low-mass Molecular Condensation in Taurus: Evidence for the Moment of Protostellar Core Formation

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We present evidence for a protostellar condensation that is very close to the moment of the formation of a protostellar core within a time scale of $\sim 10^4$yr. This starless condensation, named as MC27 in complete surveyed molecular condensations in Taurus, is ~ 0.1 pc in size and $\sim 3M_\odot$ in mass. It exhibits fairly strong and narrow $H^{13}CO^+$ emission of the J = 4–3, 3–2, and 1–0 transitions, as well as self-reversed profiles of HCO^+ J = 4–3 and 3–2. MC27 has density of $\sim 10^6$ cm^{-3} within $\sim$ 1000AU at the center, which is the highest value among the $\sim$ 40 starless condensations in Taurus. MC27 shows a sharply peaked density distribution; the molecular intensity is well fitted by a power law density distribution of $r^{\sim -2}$ over 0.02 pc $< r <$ 0.2 pc. A statistical analysis indicates a very short time scale of $\sim 10^4$ yrs, which is consistent with a free-fall time scale for the density of $\sim 10^6$ cm^{-3}. These properties strongly suggest that MC27 is in a very early stage of star formation. A Monte Carlo simulation of the present profiles indicates that the infall velocity at 2000 − 3000 AU should be 0.2 − 0.3 km/s while it is less than 0.3 km/s at $\leq$ 1000AU. This derived infall velocity profile can be explained by a dynamical collapse model of a supercritical condensation prior to formation of the first protostellar core by $\sim 10^{3-4}$ yr.

Accepted by Publ. Astron. Soc. Japan Letters.

Preprint available at http://www.a.phys.nagoya-u.ac.jp/~ohnishi/papers.html

Star formation in the Orion Nebula Cluster

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We study the record of star formation activity within the dense cluster associated with the Orion Nebula. The bolometric luminosity function of 900 visible members is well matched by a simplified, theoretical model for cluster formation. This model assumes that stars are produced at a constant rate, and distributed according to the field-star initial mass function. Our best-fit age for the system, within this framework, is 2×10^6 yr.

To undertake a more detailed analysis, we present a new set of theoretical, pre-main-sequence tracks. These cover all masses from 0.1 to 6.0 $M_\odot$, and start from a realistic stellar birthline. The tracks end along a zero-age main sequence which is in excellent agreement with the empirical one. As a further aid to cluster studies, we offer an heuristic procedure for the correction of pre-main-sequence luminosities and ages because of unresolved binary companions.

The Orion Nebula stars fall neatly between our birthline and zero-age main sequence in the HR diagram. All those more massive than about 8 $M_\odot$ lie close to the main sequence, as also predicted by theory. After accounting for the finite sensitivity of the underlying observations, we confirm that the population between 0.4 and 6.0 $M_\odot$ roughly follows a standard initial mass function. We see no evidence for a turnover at lower masses.

We next use our tracks to compile stellar ages, also between 0.4 and 6.0 $M_\odot$. Our age histogram reveals that star formation began at a low leve l some 10^7 yr ago, and has gradually accelerated to the present epoch. The period of most active formation is indeed confined to a few$\times 10^6$ yr, and has recently ended with gas dispersal from the Trapezium. We argue that the acceleration in stellar births, which extends over a wide range in mass, reflects the gravitational contraction of the parent cloud spawning this cluster.

Accepted by The Astrophysical Journal

The electronic version is available at: http://www.arcetri.astro.it/~starform/publ1999.htm

Critical Protoplanetary Core Masses in Protoplanetary Disks and the Formation of Short–Period Giant Planets

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We study a solid protoplanetary core undergoing radial migration in a protoplanetary disk. We consider cores in the mass range $\sim 1 - 10$ $M_\oplus$ embedded in a gaseous protoplanetary disk at different radial locations.

We suppose the core luminosity is generated as a result of planetesimal accretion and calculate the structure of the gaseous envelope assuming hydrostatic and thermal equilibrium. This is a good approximation during the early growth of the core while its mass is less than the critical value, M_{crit}, above which such static solutions can no longer be obtained and rapid gas accretion begins. The critical value corresponds to the crossover mass above which rapid gas accretion begins in time dependent calculations.

We model the structure and evolution of the protoplanetary nebula as an accretion disk with constant α. We present analytic fits for the steady state relation between disk surface density and mass accretion rate as a function of radius.

We calculate M_{crit} as a function of radial location, gas accretion rate through the disk, and planetesimal accretion rate onto the core. For a fixed planetesimal accretion rate, M_{crit} is found to increase inwards. On the other hand it decreases with the planetesimal accretion rate and hence the core luminosity.

We consider the planetesimal accretion rate onto cores migrating inwards in a characteristic time $\sim 10^3 - 10^5$ yr at 1 AU as indicated by recent theoretical calculations. We find that the accretion rate is expected to be sufficient to prevent the attainment of M_{crit} during the migration process if the core starts off significantly below it. Only at those small radii where local conditions are such that dust, and accordingly planetesimals, no longer exist can M_{crit} be attained.

At small radii, the runaway gas accretion phase may become longer than the disk lifetime if the mass of the core is too small. However, within the context of our disk models, and if it is supposed that some process halts the migration, massive cores can be built–up through the merger of additional incoming cores on a timescale shorter than for *in situ* formation. A rapid gas accretion phase may thus begin without an earlier prolonged phase in which planetesimal accretion occurs at a reduced rate because of feeding zone depletion in the neighborhood of a fixed orbit.

Accordingly, we suggest that giant planets may begin to form through the above processes early in the life of the protostellar disk at small radii, on a timescale that may be significantly shorter than that derived for *in situ* formation.

Accepted by ApJ

A High Resolution Polarimetry Map of the Circumbinary Disk around UY Aur

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We have obtained J band (1.2 μm) polarimetry observations of the circumbinary disk around UY Aurigae. These observations were made possible by the use of the University of Hawaii 36 element adaptive optics instrument, Hokupa'a, at the 3.35 m CFHT. The deep (120 min), high resolution (0.15") polarization images reveal a centrosymmetric polarization signature from the light scattered off the circumbinary dust disk which is 10^6 times fainter than the stars in the binary system. A comparison with a Mie scattering model of the circumbinary disk in UY Aurigae suggests that the polarization signature is dominated by the smallest grains in the disk (0.03 μm) and further supports the hypothesis that the resolved light seen in the optical and infrared originates from a large flattened disk of dust surrounding both stars.

Accepted by The Astrophysical Journal

VLA Detection of Protostars in OMC 2/3

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The OMC 2/3 molecular clouds contain one of the highest concentrations of protostars known in nearby molecular clouds. We have observed an area of about 6 by 15 arcminutes (0.8 by 2 pc) covering the OMC 2/3 regions with the Very Large Array in the D configuration at 3.6 cm, well matching the area of the 1300 μm survey of Chini et al. (1997). We detected 14 sources, of which it is highly probable that 11 sources are either protostars or very young stars. This testifies to the star forming activity and extreme youth of the OMC 2/3 region. The 3.6 cm flux is free-free emission probably due to shocks in outflowing material. Three of the sources are extended even with the relatively low resolution of the present observations, and two of these may be collimated radio jets. The large fraction of sub-millimeter continuum sources which have a radio continuum counterpart is evidence that outflow is common already at the very earliest evolutionary stages. No relation is found between the radio continuum flux and the 1300 μm flux of the associated sub-millimeter dust clumps.

Accepted by Astron. J.

The Spectral Correlation Function – A New Tool for Analyzing Spectral-Line Maps

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The "spectral correlation function" analysis we introduce in this paper is a new tool for analyzing spectral-line data cubes. Our initial tests, carried out on a suite of observed and simulated data cubes, indicate that the spectral correlation function [SCF] is likely to be a more discriminating statistic than other statistical methods normally applied. The SCF is a measure of similarity between neighboring spectra in the data cube. When the SCF is used to compare a data cube consisting of spectral-line observations of the ISM with a data cube derived from MHD simulations of molecular clouds, it can find differences that are not found by other analyses. The initial results presented here suggest that the inclusion of self-gravity in numerical simulations is critical for reproducing the correlation behavior of spectra in star-forming molecular clouds.

Accepted by Astrophys. J.

http://xxx.lanl.gov/abs/astro-ph/9903454

A Deep Long-slit Spectroscopic Study of the Two Bipolar Outflows from the T Tauri Binary System

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We present results of a new deep high-resolution long-slit spectroscopic study of the extended nebular line emission around the young binary T Tauri. The deduced position-velocity diagrams of the [O I], [N II], and [S II] lines have been used to investigate in great detail the complex geometric and kinematic structure of the mass outflows from the stellar binary components T Tau N and T Tau S. A large number of distinct extended outflow components, each of them characterized by its specific spatio-kinematic properties, has been identified. In addition to the brighter components (A, B, C, D, E, F) already decribed in detail by Böhm & Solf (1994) we have detected several much fainter components (G, H, I, J, K, L), some of them extending up to ∼40″ from the central binary.

The new data confirm the existence of two separate bipolar outflow systems associated with the binary: one of them oriented near the E-W direction and probably originating from the visible binary component T Tau N; the other one oriented near the N-S direction and probably originating from the infrared binary component T Tau S. In the E-W outflow, so far considered to be represented only by blue-shifted components (B, F, H) W of T Tau N, we have detected for the first time an indication for a red-shifted faint counterjet (G) E of T Tau, corresponding to the known HH 155 jet (H). In the N-S outflow, so far considered to be represented only by two components (C, D) near the central source (≤3″), two additional, rather faint components (I and J) have been detected which are located farther out (8″–15″) on opposite sides of the source. Both faint components present rather low velocities of opposite sign, but rather large velocity dispersions of about 75–100 km s^{-1} (FWHM). Using a biconical model for the outflow geometry we have derived an inclination angle of 79° with respect to the line of sight for the bipolar axis and deduced typical velocities of ∼91 km s^{-1} and ∼280 km s^{-1} in the faint outer regions (I, J) and the bright inner regions (C, D) of the N-S outflow, respectively.

We have compared the kinematic state (mean radial velocity and velocity dispersion) of the "hot" (partially) ionized gas of the outflows from the binary T Tau deduced from our forbidden line observations with that of the "warm" molecular gas determined from the v=1–0 S(1) line of H_2 observations by Herbst et al. (1997). In principal, the [S II] and H_2 emission regions refer to very different spatial regions of the outflows and hence the kinematic state of the two region does not have to be coupled to each other. In particular, it is expected that the velocity dispersion derived from the [S II] lines is much larger than that from the H_2 lines. These expectation are generally fulfilled by the observations, except for the "core" region of Burnham's nebula (component E) where the velocity dispersions of both the forbidden and the H_2 lines are approximately the same. These finding as well as other enigmatic properties of Burnham's nebula reported earlier are not yet understood.

Accepted by Astrophys. J.

Preprints available at hhtp://www.tls-tautenburg.de/research/tls-research/pub99.html

The Impact of the Massive Young Star GL 2591 on its Circumstellar Material: Temperature, Density and Velocity Structure

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The temperature, density and kinematics of the gas and dust surrounding the luminous (2×10^4 $L_\odot$) young stellar object GL 2591 are investigated on scales as small as ∼ 100 AU, probed by 4.7 μm absorption spectroscopy, to over 60,000 AU, probed by single–dish submillimeter spectroscopy. These two scales are connected by interferometric

86 − 115 and 226 GHz images of size 60,000 AU and resolution 2000 AU in continuum and molecular lines. The data are used to constrain the physical structure of the envelope and investigate the influence of the young star on its immediate surroundings.

The infrared spectra at $\lambda/\Delta\lambda \approx 40,000$ indicate an LSR velocity of the ^{13}CO rovibrational lines of -5.7 ± 1.0 km s^{-1}, consistent with the velocity of the rotational lines of CO. In infrared absorption, the ^{12}CO lines show wings out to much higher velocities, ≈ -200 km s^{-1}, than are seen in the rotational emission lines, which have a total width of ≈ 75 km s^{-1}. This difference suggests that the outflow seen in rotational lines consists of envelope gas entrained by the ionized jet seen in Brγ and [S II] emission. The outflowing gas is warm, $T > 100$ K, since it is brighter in CO $J = 6 \rightarrow 5$ than in lower-J CO transitions.

The dust temperature due to heating by the young star has been calculated self-consistently as a function of radius for a power-law density distribution $n = n_0 r^{-\alpha}$, with $\alpha = 1 - 2$. The temperature is enhanced over the optically thin relation ($T \sim r^{-0.4}$) inside a radius of 2000 AU, and reaches 120 K at $r \lesssim 1500$ AU from the star, at which point ice mantles should have evaporated. The corresponding dust emission can match the observed $\lambda \geq 50$ μm continuum spectrum for a wide range of dust optical properties and values of α. However, consistency with the C^{17}O line emission requires a large dust opacity in the submillimeter, providing evidence for grain coagulation. The $10 - 20$ μm emission is better matched using bare grains than using ice-coated grains, consistent with evaporation of the ice mantles in the warm inner part of the envelope. Throughout the envelope, the gas kinetic temperature as measured by H_2CO line ratios closely follows the dust temperature.

The values of α and n_0 have been constrained by modelling emission lines of CS, HCN and HCO^+ over a large range of critical densities. The best fit is obtained for $\alpha = 1.25 \pm 0.25$ and $n_0 = (3.5 \pm 1) \times 10^4$ cm^{-3} at $r = 30,000$ AU, yielding an envelope mass of (42 ± 10) M$_\odot$ inside that radius. The derived value of α suggests that part of the envelope is in free-fall collapse onto the star. Abundances in the extended envelope are 5×10^{-9} for CS, 2×10^{-9} for H_2CO, 2×10^{-8} for HCN and 1×10^{-8} for HCO^+. The strong near-infrared continuum emission, the Brγ line flux and our analysis of the emission line profiles suggest small deviations from spherical symmetry, likely an evacuated outflow cavity directed nearly along the line of sight. The $A_V \approx 30$ towards the central star is a factor of 3 lower than in the best-fit spherical model.

Compared to this envelope model, the OVRO continuum data show excess thermal emission, probably from dust. The dust may reside in an optically thick, compact structure, with diameter $\lesssim 30$ AU and temperature $\gtrsim 1000$ K, or the density gradient may steepen inside 1000 AU. In contrast, the HCN line emission seen by OVRO can be satisfactorily modelled as the innermost part of the power law envelope, with no increase in HCN abundance on scales where the ice mantles should have been evaporated. The region of hot, dense gas and enhanced HCN abundance ($\sim 10^{-6}$) observed with the *Infrared Space Observatory* therefore cannot be accommodated as an extension of the power-law envelope. Instead, it appears to be a compact region ($r < 175$ AU, where $T > 300$ K) where high-temperature reactions are affecting abundances.

Accepted by Ap. J.

Preprints available at http://xxx.lanl.gov/abs/astro-ph/9905035

Flows from young stars in the Serpens star forming region

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We have surveyed an area of 3.15 □° in the Serpens star forming region with the Tautenburg Schmidt telescope in the [SII]$\lambda\lambda$6716,6730 lines and the I-band searching for outflows from young stars. We find that the outflow activity is mainly concentrated on a region of about 15′ (1.3 pc) diametre around the Serpens Reflection Nebula (SRN). Here, we discovered six new groups of HH objects in addition to the already known HH 106/107, probably forming five or six independent outflows. Much further away from the SRN we observed two more outflows: a newly discovered object about 45′ south of the SRN near a group of nebulous stars, and the known HH 108/109, for which we present also near-infrared molecular hydrogen imaging. We discuss the potential exciting sources for the outflows in the Serpens dark clouds, and the connection between optical HH objects and molecular hydrogen knots observed in this region. We also note that there is only one parsec-scale flow seen among then HH flows in Serpens. We interpret this as the

flows breaking rapidly out of their dense parental clouds into the very tenuous surroundings, in which no further shock excitation of the true terminal working surfaces can take place.

Accepted by A&A

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Dissertation Abstracts

The Interplay between Dust, Gas, Ice, and Protostars

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One expects that the chemical and physical evolution of dust, gas, and ice in protostellar envelopes closely follows the evolution of protostars. During the cloud collapse, simple molecules are efficiently formed on grain surfaces, creating ice mantles. The shocks created by the protostellar outflow may sputter the ice mantles into the gas phase, while also species with high reaction barriers may be formed in the gas. Heating close to the protostar evaporates the ice mantles. Evaporated ices can drive a rich and varied chemistry in the hot cores, leading to the formation of more complex species. Furthermore, the UV field near massive stars, or bombardment by cosmic rays, may initiate reactions within ice mantles, leading to refractory dust material. Finally, the icy grains that have survived in the circumstellar disk, may be the building blocks of comets, which may have delivered the volatile reservoir to the terrestrial planets.

Many of the fundamental questions in our current picture of interstellar chemistry, and the interaction with the protostar are yet unanswered. What is the composition of the gas and ice mantles? How important are the various processes for molecule formation, and destruction? Are these processes the same for high and low mass objects? How does the protostellar disk evolve to planets and comets? In this thesis, observations of the Short Wavelength Spectrometer on board of the Infrared Space Observatory are analyzed, addressing many of the key questions.

The detection of solid and gaseous CH_4 are reported. The profile of the ice band shows that CH_4 is embedded in a mantle of polar molecules. The low abundance, and low gas/solid ratio indicate that CH_4 is formed on grain surfaces at low C/CO ratios. The detected warm CH_4 gas originates from out-gassing in the hot core. The importance of grain surface chemistry is sustained by the dominance of simple molecules in molecular clouds and star forming regions.

For the first time, solid $^{12}CO_2$ and $^{13}CO_2$ band profiles are studied toward a large sample of high and low mass protostars in various stages of their evolution. A great variety of absorption band profiles is seen, which appears to be the result of thermal processing. In particular, the massive hot core sources show a sequence of increasing heating time. However, compact H II regions show less sign of thermal processing, and thus there may be a fundamental difference in the way these sources have evolved.

The carbon isotope ratio is derived from solid $^{12}CO_2$ and $^{13}CO_2$ column densities. A value of 69±15 derived in the local ISM. A tentative gradient with galacto-centric radius is observed, in agreement with gas phase studies (CO, H_2CO). The CO_2 isotope ratio tends to be higher compared to CO, which would have important consequences for the origin of interstellar CO_2.

A complete 1.6-190 μm spectrum is presented for the low mass protostar Elias 29 in the ρ Ophiuchi molecular cloud. It contains a wealth of information, which is put in a general picture of the structure of this object. Hot CO and H_2O gas is detected, which we derive to be present close to the central heat source, on a scale of a circumstellar disk. Given the large abundance of hot gas, Elias 29 resembles the more evolved massive hot core sources. However, in contrast, the detected ice features (CO, H_2O, "6.8 μm", CO_2) show no sign of processing, and may be present in a disk or in the foreground cloud. Given the high extinction of Elias 29, the SED is surprisingly flat, and resembles that of the Herbig Ae star AB Aur, which is known to have a circumstellar disk. Broad H I emission lines, perhaps originating from accretion shocks, and extended CO J=6 $\rightarrow$ 5 line emission, revealing a dense outflow, are also reported.

Finally, laboratory experiments of CH_4, $^{12}CO_2$, and $^{13}CO_2$ in a large variety of ices and at a range of temperatures are presented in a way that facilitates comparison with observed interstellar features. Also, it is shown that the CO and CO_2 optical constants available in the literature are inconsistent. Using Mie scattering calculations in the Rayleigh limit, it is shown that '¡this translates in a large uncertainty in calculated cross sections for various grain shapes.

Hard copies of this thesis are available upon request. A postscript version can be found at
http://www.submm.caltech.edu/~boogert/thesis.html

Kinematics of T Tauri Stars in nearby Star Forming Regions

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The kinematics of T Tauri stars in the nearby star forming regions Taurus-Auriga, Chamaeleon, Lupus and Scorpius-Centaurus is studied using proper motions from the Hipparcos, PPM, ACT, TRC and STARNET proper motion catalogues. Especially the STARNET catalogue is very well suited for this purpose as it provides accurate proper motions for about 4.3 million stars, so that a large number of T Tauri stars is included in that catalogue. Where available, Hipparcos parallaxes and radial velocities are combined with the proper motions to calculate space velocities and velocity dispersions. In the Scorpius-Centaurus association, the favourable geometry allows for the determination of kinematical distances.

A large fraction of the stars in the samples belongs to the population of weak-line T Tauri stars discovered with the help of the X-ray satellite ROSAT during the last years. In contrast to classical T Tauri stars, which had preferentially been found very close to the densest cores of the cloud material in those star forming regions, weak-line T Tauri stars are distributed over larger regions in space. The kinematic signatures of processes producing such halos of weak-line T Tauri stars should still be visible, and the observed motions of the stars are analyzed in the framework of various star formation scenarios.

It turns out very clearly from the proper motion studies that any kind of ejection mechanism cannot be the dominant process in producing the observed halos of weak-line T Tauri stars, since the velocity vectors in general do not point away from the clouds where the stars presumably were born. Indeed a few candidate escaper stars which could have been ejected with relatively high velocities out of the denser regions can be identified in the samples, but ejection certainly cannot be invoked for the majority of the weak-line T Tauri stars to explain their current positions.

In particular, the most promising scenario varies for different star forming regions. The pre-main sequence stars found south of the Taurus-Auriga star forming region would approach the central cloud if they were located at roughly the same distance. If the cloud mass is large enough to form a bound system, this kind of relative motion could be interpreted as an oscillation of the stars around the cloud. In the Chamaeleon region however the motions of the wider distributed population of weak-line T Tauri stars seem to be more consistent with the so-called cloudlet model, which assumes that the stars were born locally out of rather small cloudlets which disappeared thereafter. In the Lupus region there is some evidence for the weak-line T Tauri halo to be part of Gould's belt, and in the Scorpius-Centaurus association finally the weak-line T Tauri stars seem to be distributed similarly to the OB stars with similar velocities.

ftp://cass98.ucsd.edu/sabine/

A Radiation Hydrodynamical Model for Protostar Formation

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Investigation of star formation processes has been a significant subject both for theoretical astrophysics and for observational astronomy. Nevertheless, many problems are left unresolved still to date especially in an early phase in the evolution where a protostar is under dynamical growth. The lack of our knowledge for protostar formation is a "missing link" in the evolutionary picture of star formation. In order to construct a theoretical model for protostar formation which is capable to account for recent observations, we have developed a numerical code for radiation hydrodynamic calculations. The numerical code is designed to yield the evolution of spectral energy distributions as well as the dynamical evolution. We established in this work a theoretical model for the whole evolution of protostar formation in a consistent scheme which is accountable for observations.

Numerical calculations are carried out to reveal physical processes in the formation of a $1M_\odot$ protostar. The whole evolution are pursued from the beginning of the first collapse to the end of the main accretion phase. We confirm that the typical features in the evolution are in good agreement with previous studies.

We consider two different initial conditions for the density distribution: homogeneous and hydrostatic cloud cores. For the initially homogeneous model, the accretion luminosity rapidly rises to the maximum value of $25L_\odot$ just after the formation of a protostar, and declines gradually as the mass accretion rate decreases. In contrast, the luminosity increases monotonically with time for the initially hydrostatic model. This discrepancy arises because the mass accretion rate varies depending on the inward acceleration in the initial condition, which affects the luminosity curve.

We confirm that the SED evolves from a 10K greybody spectrum to hotter spectra typical for class I and II sources. The SED for the class 0 sources corresponds to the age of 2×10^4yr, which is smaller by an order of magnitude than the typical age of class I objects. Considering possible non-spherically-symmetric effects, we suggest that observed class 0 sources should be the compound of the "genuine" class 0 that is as young as 10^4 yr and more evolved protostars on edge-on view. The contamination of older protostars are not negligible because they are intrinsically abundant than genuine class 0 objects.

Since observations indicate that the class 0 sources are typically more luminous than class I sources, we exclude the initially hydrostatic model where the luminosity increases monotonically with time. The initially homogeneous model, in contrast, is found to show the tendencies consistent with observations.

We have also developed a numerical code for non-LTE line transfer problems and applied it to protostar formation. For dynamical models, results from the radiation hydrodynamical calculations are used. We confirm that the computational results show double-peaked profiles in a stronger blue peak for optically thick molecular lines. Optically thin lines show single-peaked profiles with a slight blue asymmetry. These qualitative features are consistent with past studies. On the contrary to the remarks by a previous work we do not find overestimation of line widths. Furthermore, the infall motion produces wings extending to $v = \pm 2$km/s in line spectra, while wings could not be produced in previous studies. These results imply that simplified infall models such as the isothermal self-similar solutions adopted by previous authors are not suitable to the detailed modeling of line spectra.

On the basis of the results and other theoretical and observational evidence, we illustrate an evolutionary picture of protostar formation. In terms of the evolutionary time and the inclination to an observer, we find that protostellar objects are successfully categorized.

http://www.ccsr.u-tokyo.ac.jp/ ˜masunaga/index_prs.html

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