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Abstracts of recently accepted papers

Scattered near-IR CO emission bands in GGD27-IRS: observing the circumstellar environment of heavily obscured young PMS stars.

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We present the discovery of extended CO bandhead emission from 2.29–2.43μm in the northern near-IR bipolar reflection lobe of the high-luminosity pre-main sequence object GGD27-IRS. The emission appears correlated with the bright U-shaped nebulous feature seen in broad band images suggesting that this is one region of the nebula with a direct line-of-sight to the core region of the source i.e. to the young stellar object itself, its accretion disk and/or the dense inner parts of the CO outflow. We discuss the features observed in the long-slit spectroscopic observations presented and consider the nature and extent of both physical and geometrical information that can be indirectly obtained by observing reflection nebulosity in regions of high extinction where the young star itself is completely obscured from direct view.

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Sub-millimetre and near-IR observations of L1448: A curving H_2 Jet with multiple bow shocks

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A high-resolution (0.6 arcsec/pixel), narrow-band, H_2 v=1-0S(1) image of the high-velocity CO outflow in L1448 reveals a remarkable jet-like structure. The coincidence of this H_2 jet with the CO bipolar outflow implies a close association between the two phenomena. The H_2 jet comprises a series of knots, and three bow-shaped features equally spaced along the jet length which we associate with the sporadic nature of this outflow. K-band imaging of the source also shows a conical reflection nebula extending towards the H_2 jet structure, whilst maps in HCO^+ J=3-2 and CS J=5-4 show two peaks, one towards the source of the H_2 jet and CO outflow and the other towards the infrared source IRS3 situated to the north of this region. Together these observations suggest that the H_2 jet represents the shock interface between a stellar wind from the L1448-mm source and the surrounding molecular gas, though the CO outflow is not thought to result from, or be dependent on, this interaction.

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Herbig-Haro objects associated with extremely young sources in L 1527 and L 1448

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We present I, Hα, and [SII] CCD images of the dense cores L 1527 and L 1448. A diffuse reflection nebulosity is observed in L 1527. A red spectrum shows that superimposed on the reflection nebulosity there is HH emission of low excitation and very low radial velocity, v_{lsr} $\approx$5.2 km/s. The object is most probably excited by the very young Class 0 object IRAS 04368+2557. The data suggest that the IRAS source is surrounded by a dense, flattened circumstellar envelope seen edge-on and approximately oriented in a NS direction. The HH emission and reflection nebula are located along the polar direction of this envelope. A reflection nebulosity and HH emission is also observed in L 1448. We suggest that they are associated with the Class 0 object L 1448N (IRAS 03225+3034). Our findings increase to four the number of Class 0 objects associated with HH emission, which represents $\approx$ 30% of the Class 0 sources known to date.

Accepted by Astronomy and Astrophysics

Molecular Outflows from FU Orionis Stars

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We have detected molecular outflows toward 6 out of 8 FU Orionis stars that we observed in the J=3$\rightarrow$2 line of CO. Notably, FU Orionis itself does not show an outflow. Four of the sources were mapped, and two show evidence for multiple outflows. In both Z CMa and RNO 1b, nearby infrared sources may also be driving the outflows. Mass loss rates derived from the usual assumptions of momentum conservation range from $3 \times 10^{-8} M_{\odot} yr^{-1}$ to $2 \times 10^{-6} M_{\odot} yr^{-1}$ without corrections for optical depth in the CO lines. Corrections for optical depth raise these estimates by a factor of five on average. If the outflows are driven by repeated outbursts with peak mass-loss rates of $10^{-5} M_{\odot} yr^{-1}$, a duty cycle of 10^{-3} to 10^{-1} would be implied, consistent with other recent evidence. For preprints, email N. Evans (nje@astro.as.utexas.edu).

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A Dynamically Accreting Gas Disk around HL Tauri

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We present a new high quality observation of HL Tau carried out with Nobeyama Millimeter Array in the ^{13}CO ($J = 1 - 0$) emission. We have confirmed the presence of a gas disk elongated perpendicular to the optical jet. The disk has the mass and radius of 0.03 $M_{\odot}$ and 1400 AU, respectively, and is located outside the inner compact disk observed in the dust emission. Examination of the velocity field has revealed that accreting motion is dominated in the disk plane, although there is an indication of rotation at a speed of 0.2 kms^{-1} measured at 700 AU in radius. The observed radial velocity of 1 kms^{-1} is consistent with that obtained when the gas is dynamically accelerated by the central star. This means that the outer gas disk is undergoing dynamical accretion toward the central star/inner disk system, and that it is not a centrifugally supported viscous accretion disk. We estimate the mass accretion rate of $0.9 \times 10^{-5} M_{\odot}$ yr^{-1}, which is an order of magnitude larger than that estimated from the luminosity of the inner disk. This suggests that the accretion in the entire HL Tau disk system is non-steady.

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Water masers embedded in ultracompact H II regions: The W75N cloud core

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We present radio observations of the W75N star forming region consisting of: 1) high-resolution VLA radio continuum and H_2O maser maps, 2) CSO molecular maps in the CS and CO lines, 3) results from a six-year monitoring campaign of the H_2O maser emission with the 32-m Medicina telescope.

Using the VLA in A-configuration, we find that the 22 GHz H_2O maser spots in W75N spatially coincide with very weak, small diameter ($< 1''$) radio continuum sources at the center of the dense molecular cloud core. The very high optical obscuration ($A_v \geq 90$ mag), the high total luminosity of the source and the high electron density suggest that in W75N we are witnessing the first appearance of an ultracompact H II region (UCH II) produced by an early type star still deeply embedded in the progenitor molecular cloud. The H_2O maser - UCH II association may last only for the short time ($\sim 10^3$ y) needed by the H II to expand out to the distance where masers are formed. Both the H_2O and OH masers as well as the continuum sources extend a few seconds of arc along a roughly N-S line, matching the extension of the core evident in the CS J=7→6 map and nearly perpendicular to the axis of the molecular outflow. As traced by the CO J=3→2 transition, the origin of the outflow lies at the position of the UCH IIs, suggesting that they are associated with the powering source. The H_2O spectrum extends over ~ 30 km s^{-1}, with many distinct velocity components, part of which can be unambiguously identified with individual spatial components of the VLA H_2O map. The variability of the H_2O emission of each velocity component is very high, with time scales of the order of a few years and dynamic range almost up to two orders of magnitude. For the bluest velocity component, well isolated in the velocity and space domains, there is evidence of a continuous velocity drift of ~ 4 km s^{-1} over 2 years. The energy required for this acceleration is easily compatible with the mechanical energy input from the molecular outflow. We believe W75N to be an important source for further study as it presents all the typical aspects of a region where star formation just occurred and it may help unify the various aspects into a single evolutionary scheme.

Accepted by Astronomy and Astrophysics

Dust in discs around T Tauri stars: grain growth?

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We have made multi-band millimetre/submillimetre continuum observations of T Tauri systems in Taurus-Auriga to investigate the frequency dependence of the dust grain opacity and the properties of the discs around pre-main sequence low mass stars. Observations within the wavelength interval 350 to 2000 μm were made of the T Tauri systems DG Tau, Haro 6-13, DO Tau, DR Tau, DL Tau, and RY Tau. Their long-wavelength emission is thought to arise principally in the cool outer regions of extensive dusty circumstellar discs. We fit simple disc models and quantify both the quality of fit and the uncertainty on the model parameters by examining the variation of reduced χ^2 over parameter space. The discs in DL Tau and RY Tau appear to be optically thick out to the longest wavelengths at which we observed them. However for the remaining four discs we find optically thin emission, and we can use our new long-wavelength measurements to examine the frequency variation of dust grain opacity. The opacity coefficient (κ_ν) of dust grains is generally assumed to vary as a power law at long wavelengths and we find that the index of the opacity function β is ≈ 0.6. This value is significantly smaller than the observationally determined values often quoted for interstellar grains, and is smaller than that expected for crystalline materials at long wavelengths, where $2\pi a/\lambda << 1$. This confirms the low values for opacity indices reported by others (Beckwith & Sargent 1991) for the same sample of T Tauri systems. Although these low indices could be indicative of non-crystalline (amorphous) or fractal dust grains, they would also be expected for grains significantly larger than those in the general interstellar medium. This may indicate the growth and accumulation of grains prior to the formation of planetesimals. We estimate upper limits to mass accretion rates of $\sim 10^{-6} M_\odot$ yr^{-1}. We also find that the outer radii of the discs in our sample are in the approximate range 25 to 60 AU and the total mass of material (gas + dust) in each of the discs is $\gtrsim$ that estimated for the early solar nebula. Taken together, our results support the conclusion that many T Tauri stars are attended by protoplanetary discs.

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Structure and Chemistry in the Northwestern Condensation of the Serpens Molecular Cloud Core

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We present single dish and interferometric observations of gas and dust in the core of the Serpens molecular cloud, focusing on the northwestern condensation. Single dish molecular line observations are used to probe the structure and chemistry of the condensation while high resolution images of CS and CH_3OH are combined with continuum observations from λ=1.3 mm to λ=3.5 cm to study the subcondensations and overall distribution of dust.

For the northwestern condensation, we derive a characteristic density of 3×10^5 cm^{-3} and an estimated total mass of $\sim$70 M$_\odot$. We find compact molecular emission associated with the far-infrared source S68FIRS1, and with a newly detected subcondensation named S68N. Comparison of the large and small scale emission reveals that most of the material in the northwest condensation is *not* directly associated with these compact sources, suggesting a youthful age for this region. CO J=1$\rightarrow$0 observations indicate widespread outflow activity. However, no unique association of embedded objects with outflows is possible with our observations. The SiO emission is found to be extended with the overall emission centered about S68FIRS1; the offset of the peak emission from all of the known continuum sources and the coincidence between the blue-shifted SiO emission and blue-shifted high-velocity gas traced by CO and CS is consistent with formation of SiO in shocks. Derived abundances of CO and HCO^+ are consistent with quiescent and other star forming regions while CS, HCN, and H_2CO abundances indicate mild depletions within the condensation.

Spectral energy distribution fits to S68FIRS1 indicate a modest luminosity (50-60 L$_\odot$), implying that it is a low mass (0.5-3 M$_\odot$) young stellar object. Radio continuum observations of the triple source toward S68FIRS1 indicate that the lobe emission is varying on timescales $\leq$1 year while the central component is relatively constant over $\sim$14 years. The nature of a newly detected compact emission region, S68N, is less certain due to the absence of firm continuum detections; based on its low luminosity (<5 L$_\odot$) and strong molecular emission, S68N may be a pre-stellar sub-condensation of gas and dust.

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X-Ray Sources in Regions of Star Formation. V. The Low Mass Stars of the Upper Scorpius Association.

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We report follow-up investigations of EINSTEIN X-ray observations of the Upper Scorpius OB association. We identify 28 low mass pre-main sequence stars as counterparts of X-ray sources in the $\approx$7 square degrees of the OB association observed. Based on kinematics and lithium abundances, these stars are low mass members of the OB association. We use optical spectra and optical and near-IR photometry to determine the stellar luminosities, effective temperatures, masses, and ages. We show that the bolometric corrections and effective temperatures of the G and K stars are consistent with those of subgiants.

The low mass stars have isochronal ages of 1-2 Myr, depending on the choice of evolutionary models, with very small dispersion ($\sigma \approx$1 Myr). This age is significantly younger than the 5-6 Myr found for the more massive B stars. The small dispersion in stellar ages, less than 10% the sound-crossing time of the association, suggests that star formation was triggered. We present two scenarios for star formation in this association. In the two-episode scenario, formation of the low mass stars was triggered by a supernova explosion, and the low mass stars form quickly, with high efficiency.

Alternatively, high- and low mass star formation was all initiated at the same time, some 5-6 Myr ago, and the apparent systematic age difference is an artifact of how the isochrones are dated. The effect of the supernova is to terminate mass accretion and yield an apparently coeval population.

We show that the incompleteness in the X-ray sampling is about 65%, and is strongly dependent on stellar mass. After correction for incompleteness, we estimate there are about 2000 low mass members ($M<2M_{\odot}$) of this association. The mass function in this association is indistinguishable from that of the field. The ratio of naked to classical T Tauri stars is much larger than in Tau-Aur, and may be attributable to the local environment.

We also present observations of eight ROX sources associated with the ρ Oph cloud, and observations of non-PMS stars in our fields.

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The Giant Molecular Cloud Monoceros R2: I. Shell Structure

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We have obtained a 45" resolution, Nyquist-sampled map in $CO\ J = 1 - 0$ covering approximately a $3^{\circ} \times 3^{\circ}$ region of the giant molecular cloud Monoceros R2. The map consists of 167,000 spectra observed with the 15-element focal plane array system on the FCRAO 14m telescope. The data reveal that the large-scale structure of Mon R2 is dominated by a ~ 30 pc diameter largely hemispherical shell containing $\sim 4 \times 10^4\ M_{\odot}$ of molecular material and expanding at $\sim 3 - 4\ km\ s^{-1}$ with symmetry axis roughly along the line of sight. The dynamical time scale of the shell is estimated to be $\sim 4 \times 10^6$ years, which is consistent with the age of main sequence stars powering the clusters of reflection nebulae in this region. There is no evidence for a red-shifted shell on the far side of the interior "bubble", which is largely devoid of molecular material. Distortions of the shell are obvious, suggesting inhomogeneity of the cloud and possible presence of a magnetic field prior to its formation. Dense clumps in Mon R2, including the main core and the GGD 12-15 core, appear to be condensations located on the large shell. The reflection nebulae with their illuminating stars as well as embedded IRAS sources suggest that triggered star formation has taken place over a large part of the Mon R2 shell.

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Outflows from Young Stellar Objects in Bok Globules: Maps

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We have obtained ^{12}CO $J = 1 - 0$ spectral line maps of high-velocity gas outflows from a sample of 14 small Bok globules containing low-mass young stellar objects (YSOs). The observations were performed using the new 15-beam receiver (QUARRY) of the Five College Radio Astronomy Observatory.

Morphologically, the outflows in our sample exhibit small angular extents, and relatively wide angular lobes with the majority exhibiting low apparent degrees of collimation.

The presence of an outflow was found to be correlated with the value of the IRAS -based spectral index (between 12 and 25 μm) of the YSOs. Outflows were more frequently detected in those globules with the reddest IRAS point sources. These spectral indices are consistent with emission from objects in fairly early stages of the star formation process which are still deeply embedded in gas and dust.

Energetically, the outflows in our sample may be among the weakest and least massive found to date. Nevertheless,

both the outflow kinematics and energetics indicate that they may play an important role in cloud support and evolution.

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The [CII] 158 μm Emission from the Horsehead Nebula

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We have mapped the [C II] 158 μm line and observed several rotational lines of CO, ^{13}CO, and CS toward selected positions in the Horsehead extinction region in IC 434. The observations show that the region has a gas density of about 10^4 cm^{-3} and an external UV flux 20-100 times the average interstellar UV field. Although this is a regime where the C^+ emission varies rapidly with UV intensity, fine structure line emission from gas with this range of physical conditions has not been investigated previously. Comparisons of our results with models of photodissociation regions show that existing plane parallel photodissociation region models are in general agreement with the observed intensity. It is not necessary to invoke a clumpy structure in the boundary layer to explain the observations, but the overall geometry of the cloud is important in determining the distribution of C^+ emission.

Accepted by Astrophys. J.

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