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## *The CHANDRA Carina Complex Project: Special Issue of ApJS*

### **Carina OB Stars: X-ray Signatures of Wind Shocks and Magnetic Fields**

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The Chandra Carina Complex contains 200 known O- and B type stars. The Chandra survey detected 68 of the 70 O stars and 61 of 127 known B0-B3 stars. We have assembled a publicly available optical/X-ray database to identify OB stars that depart from the canonical  $L_X/L_{bol}$  relation, or whose average X-ray temperatures exceed 1 keV. Among the single O stars with high kT we identify two candidate magnetically confined wind shock sources: Tr16-22, O8.5 V, and LS 1865, O8.5 V((f)). The O4 III(fc) star HD 93250 exhibits strong, hard, variable X-rays, suggesting it may be a massive binary with a period of >30 days. The visual O2 If\* binary HD 93129A shows soft 0.6 keV and hard 1.9 keV emission components, suggesting embedded wind shocks close to the O2 If\* Aa primary, and colliding wind shocks between Aa and Ab. Of the 11 known O-type spectroscopic binaries, the long orbital-period systems HD 93343, HD 93403 and QZ Car have higher shock temperatures than short-period systems such as HD 93205 and FO 15. Although the X-rays from most B stars may be produced in the coronae of unseen, low-mass pre-main sequence companions, a dozen B stars with high  $L_X$  cannot be explained by a distribution of unseen companions. One of these, SS73 24 in the Treasure Chest cluster, is a new candidate Herbig Be star.

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[http://cochise.astro.psu.edu/Carina\\_public/special\\_issue.html](http://cochise.astro.psu.edu/Carina_public/special_issue.html)

<http://arxiv.org/abs/1103.1149>

### **A Catalog of Chandra X-ray Sources in the Carina Nebula**

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We present a catalog of ~14,000 X-ray sources observed by the ACIS instrument on the *Chandra X-ray Observatory* within a 1.42 square degree survey of the Great Nebula in Carina, known as the *Chandra Carina Complex Project* (CCCP). This study appears in a Special Issue of the ApJS devoted to the CCCP. Here, we describe the data reduction and analysis procedures performed on the X-ray observations, including calibration and cleaning of the X-ray event data, point source detection, and source extraction. The catalog appears to be complete across most of the field to an absorption-corrected total-band luminosity of  $\sim 10^{30.7}$  erg s<sup>-1</sup> for a typical low-mass pre-main sequence star. Counterparts to the X-ray sources are identified in a variety of visual, near-infrared, and mid-infrared surveys. The X-ray and infrared source properties presented here form the basis of many CCCP studies of the young stellar populations in Carina.

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<http://arxiv.org/abs/1102.5121>

## A Naive Bayes Source Classifier for X-ray Sources

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The *Chandra* Carina Complex Project (CCCP) provides a sensitive X-ray survey of a nearby starburst region over >1 square degree in extent. Thousands of faint X-ray sources are found, many concentrated into rich young stellar clusters. However, significant contamination from unrelated Galactic and extragalactic sources is present in the X-ray catalog. We describe the use of a naive Bayes classifier to assign membership probabilities to individual sources, based on source location, X-ray properties, and visual/infrared properties. For the particular membership decision rule adopted, 75% of CCCP sources are classified as members, 11% are classified as contaminants, and 14% remain unclassified. The resulting sample of stars likely to be Carina members is used in several other studies, which appear in a Special Issue of the ApJS devoted to the CCCP.

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## The Search for Low-mass Companions of B Stars in the Carina Nebula Cluster Trumpler 16

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We have developed lists of likely B3–A0 stars (called “late B” stars) in the young cluster Trumpler 16. The following criteria were used: location within 3' of  $\eta$  Car, an appropriate V and B-V combination, and proper motion (where available). Color and magnitude cuts have been made assuming an  $E(B-V) = 0.55 \text{ mag} \pm 0.1$ , which is a good approximation close to the center of Trumpler 16. These lists have been cross-correlated with X-ray sources found in the *Chandra* Carina Complex Project (CCCP). Previous studies have shown that only very rarely (if at all) do late main sequence B stars produce X-rays. We present evidence that the X-ray detected sources are binaries with low-mass companions, since stars less massive than  $1.4 M_{\odot}$  are strong X-ray sources at the age of the cluster. Both the median X-ray energies and X-ray luminosities of these sources are in good agreement with values for typical low-mass coronal X-ray sources. We find that 39% of the late B stars based on a list with proper motions have low-mass companions. Similarly, 32% of a sample without proper motions have low-mass companions. We discuss the X-ray detection completeness. These results on low-mass companions of intermediate mass stars are complementary to spectroscopic and interferometric results, and probe new parameter space of low mass companions at all separations. They do not support a steeply rising distribution of mass ratios to low masses for intermediate-mass ( $5M_{\odot}$ ) primaries, such as would be found by random pairing from the Initial Mass Function.

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## X-ray Star Clusters in the Carina Complex

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The distribution of young stars found in the *Chandra* Carina Complex Project (CCCP) is examined for clustering structure. X-ray surveys are advantageous for identifying young stellar populations compared to optical and infrared

surveys in suffering less contamination from nebular emission and Galactic field stars. The analysis is based on smoothed maps of a spatially complete subsample of about 3000 brighter X-ray sources classified as Carina members, and about 10,000 stars from the full CCCP sample. The principal known clusters are recovered, and some additional smaller groups are identified. No rich embedded clusters are present, although a number of sparse groups are found. The CCCP reveals considerable complexity in clustering properties. The Trumpler 14 and 15 clusters have rich stellar populations in unimodal, centrally concentrated structures several parsecs across. Non-spherical internal structure is seen, and large-scale low surface density distributions surround these rich clusters. Trumpler 16, in contrast, is comprised of several smaller clusters within a circular boundary. Collinder 228 is a third type of cluster which extends over tens of parsecs with many sparse compact groups likely arising from triggered star formation processes. A widely dispersed, but highly populous, distribution of X-ray stars across the about 50 pc CCCP mosaic supports a model of past generations of star formation in the region. Collinder 234, a group of massive stars without an associated cluster of pre-main sequence stars, may be part of this dispersed population.

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## Source Contamination in X-ray Studies of Star-Forming Regions: Application to the Chandra Carina Complex Project

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We describe detailed simulations of X-ray-emitting populations to evaluate the levels of contamination by both Galactic and extragalactic X-ray sources unrelated to a star-forming region under study. For Galactic contaminations, we consider contribution from main-sequence stars and giants (not including cataclysmic variables and other classes of accretion-driven X-ray binary systems) as they make the dominant contribution at the position of the Carina Nebula. The simulations take into consideration a variety of technical factors involving a Galactic population synthesis model, stellar X-ray luminosity functions, *Chandra* telescope response, source detection methodology, and possible spatial variations in the X-ray background and absorption through molecular clouds. When applied to the 1.42 square-degree field of the *Chandra* Carina Complex Project (CCCP), the simulations predict  $\sim 5000$  contaminating sources (1 source per square arcminute of the survey), evenly distributed across the field. The results of the simulations are further employed in a companion CCCP study to assign membership probabilities to individual sources.

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## Global X-ray Properties of the O and B Stars in Carina

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The key empirical property of the X-ray emission from O stars is a strong correlation between the bolometric and X-ray luminosities. In the framework of the *Chandra* Carina Complex Project, 129 O and B stars have been detected as X-ray sources; 78 of those, all with spectral type earlier than B3, have enough counts for at least a rough X-ray spectral characterization. This leads to an estimate of the  $L_X - L_{BOL}$  ratio for an exceptional number of 60 O stars belonging to the same region and triples the number of Carina massive stars studied spectroscopically in X-rays. The derived  $\log(L_X/L_{BOL})$  is  $\sim 7.26$  for single objects, with a dispersion of only 0.21dex. Using the properties of hot massive stars listed in the literature, we compare the X-ray luminosities of different types of objects. In the case of O stars, the  $L_X - L_{BOL}$  ratios are similar for bright and faint objects, as well as for stars of different luminosity classes or spectral types. Binaries appear only slightly harder and slightly more luminous in X-rays than single objects; the

differences are not formally significant (at the 1% level), except for the  $L_X - L_{BOL}$  ratio in the medium (1.0–2.5 keV) energy band. Weak-wind objects have similar X-ray luminosities but they display slightly softer spectra compared to 'normal' O stars with the same bolometric luminosity. Discarding three overluminous objects, we find a very shallow trend of harder emission in brighter objects. The properties of the few B stars bright enough to yield some spectral information appear to be different overall (constant X-ray luminosities, harder spectra), hinting that another mechanism for producing X-rays, besides wind shocks, might be at work. However, it must be stressed that the earliest and X-ray brightest amongst these few detected objects are similar to the latest O stars, suggesting a possibly smooth transition between the two processes.

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## X-ray Emission from the Double-binary OB-star System QZ CAR (HD 93206)

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X-ray observations of the double-binary OB-star system QZ Car (HD 93206) obtained with the Chandra X-ray Observatory over a period of roughly 2 years are presented. The orbit of systems A (O9.7 I+b2 v, PA = 21 d) and B (O8 III+o9 v, PB = 6 d) are reasonably well sampled by the observations, allowing the origin of the X-ray emission to be examined in detail. The X-ray spectra can be well fitted by an attenuated three temperature thermal plasma model, characterised by cool, moderate, and hot plasma components at  $kT \simeq 0.2, 0.7,$  and 2 keV, respectively, and a circumstellar absorption of  $\simeq 0.2 \times 10^{22} \text{ cm}^{-2}$ . Although the hot plasma component could be indicating the presence of wind-wind collision shocks in the system, the model fluxes calculated from spectral fits, with an average value of  $\simeq 7 \times 10^{-13} \text{ erg s}^{-1} \text{ cm}^{-2}$ , do not show a clear correlation with the orbits of the two constituent binaries. A semi-analytical model of QZ Car reveals that a stable momentum balance may not be established in either system A or B. Yet, despite this, system B is expected to produce an observed X-ray flux well in excess of the observations. If one considers the wind of the O8 III star to be disrupted by mass transfer the model and observations are in far better agreement, which lends support to the previous suggestion of mass-transfer in the O8 III + o9 v binary. We conclude that the X-ray emission from QZ Car can be reasonably well accounted for by a combination of contributions mainly from the single stars and the mutual wind-wind collision between systems A and B.

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## Candidate X-ray-emitting OB Stars in the Carina Nebula Identified Via Infrared Spectral Energy Distributions

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We report the results of a new survey of massive, OB stars throughout the Carina Nebula using the X-ray point source catalog provided by the *Chandra* Carina Complex Project (CCCP) in conjunction with infrared (IR) photometry from the Two Micron All-Sky Survey and the *Spitzer Space Telescope* Vela-Carina survey. Mid-IR photometry is relatively unaffected by extinction, hence it provides strong constraints on the luminosities of OB stars, assuming that their association with the Carina Nebula, and hence their distance, is confirmed. We fit model stellar atmospheres to the optical (UBV) and IR spectral energy distributions (SEDs) of 182 OB stars with known spectral types and measure the bolometric luminosity and extinction for each star. We find that the extinction law measured toward the OB stars has two components:  $A_V = 1\text{-}1.5$  mag produced by foreground dust with a ratio of total-to-selective absorption  $R_V = 3.1$

plus a contribution from local dust with  $R_V > 4.0$  in the Carina molecular clouds that increases as AV increases. Using X-ray emission as a strong indicator of association with Carina, we identify 94 candidate OB stars with  $L_{bol} \geq 10^4 L_\odot$  by fitting their IR SEDs. If the candidate OB stars are eventually confirmed by follow-up spectroscopic observations, the number of cataloged OB stars in the Carina Nebula will increase by  $\sim 50\%$ . Correcting for incompleteness due to OB stars falling below the  $L_{bol}$  cutoff or the CCCP detection limit, these results potentially double the size of the young massive stellar population.

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## A Pan-Carina YSO Catalog: Intermediate-mass Young Stellar Objects in the Carina Nebula Identified Via Mid-Infrared Excess Emission

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We present a catalog of 1439 young stellar objects (YSOs) spanning the 1.42 deg<sup>2</sup> field surveyed by the *Chandra* Carina Complex Project (CCCP), which includes the major ionizing clusters and the most active sites of ongoing star formation within the Great Nebula in Carina. Candidate YSOs were identified via infrared (IR) excess emission from dusty circumstellar disks and envelopes, using data from the *Spitzer Space Telescope* (the Vela-Carina survey) and the Two-Micron All Sky Survey. We model the 1–24  $\mu\text{m}$  IR spectral energy distributions of the YSOs to constrain physical properties. Our Pan-Carina YSO Catalog (PCYC) is dominated by intermediate-mass ( $2 M_\odot < m < \sim 10 M_\odot$ ) objects with disks, including Herbig Ae/Be stars and their less evolved progenitors. The PCYC provides a valuable complementary dataset to the CCCP X-ray source catalogs, identifying 1029 YSOs in Carina with no X-ray detection. We also catalog 410 YSOs with X-ray counterparts, including 62 candidate protostars. Candidate protostars with X-ray detections tend to be more evolved than those without. In most cases, X-ray emission apparently originating from intermediate-mass, disk-dominated YSOs is consistent with the presence of low-mass companions, but we also find that X-ray emission correlates with cooler stellar photospheres and higher disk masses. We suggest that intermediate-mass YSOs produce X-rays during their early pre-main sequence evolution, perhaps driven by magnetic dynamo activity during the convective atmosphere phase, but this emission dies off as the stars approach the main sequence. Extrapolating over the stellar initial mass function scaled to the PCYC population, we predict a total population of  $> 2 \times 10^4$  YSOs and a present-day star formation rate (SFR) of  $> 0.008 M_\odot \text{ yr}^{-1}$ . The global SFR in the Carina Nebula, averaged over the past  $\sim 5$  Myr, has been approximately constant.

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## Near-Infrared properties of the X-ray emitting young stellar objects in the Carina Nebula

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The Great Nebula in Carina (NGC 3372) is the best target to study in detail the process of violent massive star formation and the resulting feedback effects of cloud dispersal and triggered star formation. While the population of massive stars is rather well studied, the associated low-mass stellar population was largely unknown up to now. The near-infrared study in this paper builds on the results of the *Chandra* Carina Complex Project (CCCP), that detected 14,368 X-ray sources in the 1.4 square-degree survey region, an automatic source classification study that classified 10,714 of these X-ray sources as very likely young stars in Carina, and an analysis of the clustering properties of the X-ray selected Carina members. In order to determine physical properties of the X-ray selected stars, most of which were

previously unstudied, we used HAWK-I at the ESO VLT to conduct a very deep near-IR survey with sub-arcsecond angular resolution, covering an area of about 1280 square-arcminutes. The HAWK-I images reveal more than 600,000 individual infrared sources, whereby objects as faint as  $J \approx 23$ ,  $H \approx 22$ , and  $Ks \approx 21$  are detected at  $S/N \geq 3$ . While less than half of the Chandra X-ray sources have counterparts in the 2MASS catalog, the  $\sim 5$  mag deeper HAWK-I data reveal infrared counterparts to 6636 (= 88.8%) of the 7472 Chandra X-ray sources in the HAWK-I field. We analyze near-infrared color-color and color-magnitude diagrams to derive information about the extinctions, infrared excesses (as tracers for circumstellar disks), ages, and masses of the X-ray selected objects. The near-infrared properties agree well with the results of the automatic X-ray source classification, showing that the remaining contamination in the X-ray selected sample of Carina members is very low ( $< \sim 7\%$ ). The shape of the K-band luminosity function of the X-ray selected Carina members agrees well with that derived for the Orion Nebula Cluster, suggesting that, down to the X-ray detection limit around  $0.5 - 1 M_{\odot}$ , the shape of the IMF in Carina is consistent with that in Orion (and thus the field IMF). The fraction of stars with near-infrared excesses is rather small,  $< \sim 10\%$ , but shows considerable variations between individual parts of the complex. The distribution of extinctions for the diskless stars ranges from  $\sim 1.6$  mag to  $\sim 6.2$  mag (central 80th percentile), clearly showing a considerable range of differential extinction between individual stars in the complex.

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## An Introduction to the Chandra Carina Complex Project

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The Great Nebula in Carina provides an exceptional view into the violent massive star formation and feedback that typifies giant HII regions and starburst galaxies. We have mapped the Carina star-forming complex in X-rays, using archival *Chandra* data and a mosaic of 20 new 60-ks pointings using the *Chandra X-ray Observatory's* Advanced CCD Imaging Spectrometer, as a testbed for understanding recent and ongoing star formation and to probe Carina's regions of bright diffuse X-ray emission. This study has yielded a catalog of properties of  $>14,000$  X-ray point sources;  $>9800$  of them have multiwavelength counterparts. Using *Chandra's* unsurpassed X-ray spatial resolution, we have separated these point sources from the extensive, spatially-complex diffuse emission that pervades the region; X-ray properties of this diffuse emission suggest that it traces feedback from Carina's massive stars. In this introductory paper, we motivate the survey design, describe the *Chandra* observations, and present some simple results, providing a foundation for the 15 papers that follow in this *Special Issue* and that present detailed catalogs, methods, and science results.

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## The *CHANDRA* Carina Complex Project: Deciphering the Enigma of Carina's Diffuse X-ray Emission

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We present a 1.42 square degree mosaic of diffuse X-ray emission in the Great Nebula in Carina from the *Chandra X-ray Observatory* Advanced CCD Imaging Spectrometer camera. After removing  $>14,000$  X-ray point sources from the field, we smooth the remaining unresolved emission, tessellate it into segments of similar apparent surface brightness, and perform X-ray spectral fitting on those tessellates to infer the intrinsic properties of the X-ray-emitting plasma. By

modeling faint resolved point sources, we estimate the contribution to the extended X-ray emission from unresolved point sources and show that the vast majority of Carina's unresolved X-ray emission is truly diffuse. Line-like correlated residuals in the X-ray spectral fits suggest that substantial X-ray emission is generated by charge exchange at the interfaces between Carina's hot, rarefied plasma and its many cold neutral pillars, ridges, and clumps.

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## **The Integrated Diffuse X-ray Emission of the Carina Nebula Compared to Other Massive Star-forming Regions**

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The *Chandra* Carina Complex Project (CCCP) has shown that the Carina Nebula displays bright, spatially-complex soft diffuse X-ray emission. Here we 'sum up' the CCCP diffuse emission work by comparing the global morphology and spectrum of Carina's diffuse X-ray emission to other famous sites of massive star formation with pronounced diffuse X-ray emission: M17, NGC 3576, NGC 3603, and 30 Doradus. All spectral models require at least two diffuse thermal plasma components to achieve adequate spectral fits, a softer component with  $kT = 0.2\text{--}0.6$  keV and a harder component with  $kT = 0.5\text{--}0.9$  keV. In several cases these hot plasmas appear to be in a state of non-equilibrium ionization that may indicate recent and current strong shocks. A cavity north of the embedded giant HII region NGC 3576 is the only region studied here that exhibits hard diffuse X-ray emission; this emission appears to be nonthermal and is likely due to a recent cavity supernova, as evidenced by a previously-known pulsar and newly-discovered pulsar wind nebula also seen in this cavity. All of these targets exhibit X-ray emission lines that are not well-modeled by variable-abundance thermal plasmas and that might be attributed to charge exchange at the shock between the hot, tenuous, X-ray-emitting plasma and cold, dense molecular material; this is likely evidence for dust destruction at the many hot/cold interfaces that characterize massive star-forming regions.

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## **A *Chandra* ACIS Study of the Young Star Cluster Trumpler 15 in Carina and Correlation with Near-infrared Sources**

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Using the highest-resolution X-ray observation of the Trumpler 15 star cluster taken by the *Chandra X-ray Observatory*, we estimate the total size of its stellar population by comparing the X-ray luminosity function of the detected sources to a calibrator cluster, and identify for the first time a significant fraction ( $\sim 14\%$ ) of its individual members. The highest-resolution near-IR observation of Trumpler 15 (taken by the HAWK-I instrument on the VLT) was found to detect most of our X-ray selected sample of cluster members, with a K-excess disk frequency of  $3.8 \pm 0.7\%$ . The near-IR data, X-ray luminosity function, and published spectral types of the brightest members support a cluster age estimate (5–10 Myr) that is older than those for the nearby Trumpler 14 and Trumpler 16 clusters, and suggest that high-mass members may have already exploded as supernovae. The morphology of the inner  $\sim 0.7$  pc core of the cluster is found to be spherical. However, the outer regions (beyond  $\sim 2$  pc) are elongated, forming an 'envelope' of stars that, in projection, appears to connect Trumpler 15 to Trumpler 14; this morphology supports the view that these clusters are physically associated. Clear evidence of mass segregation is seen. This study appears in a Special Issue of the ApJS devoted to the *Chandra* Carina Complex Project (CCCP), a 1.42 square degree *Chandra* X-ray survey of the Great Nebula in Carina.

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## The Chandra Carina Complex Project View of Trumpler 16

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Trumpler 16 is a well-known rich star cluster containing the eruptive supergiant  $\eta$  Carinae and located in the Carina star-forming complex. In the context of the *Chandra* Carina Complex Project, we study Trumpler 16 using new and archival X-ray data. A revised X-ray source list of the Trumpler 16 region contains 1232 X-ray sources including 1187 likely Carina members. These are matched to 1047 near-infrared counterparts detected by the HAWK-I instrument at the VLT allowing for better selection of cluster members. The cluster is irregular in shape. Although it is roughly circular, there is a high degree of sub-clustering, no noticeable central concentration and an extension to the southeast. The high-mass stars show neither evidence of mass segregation nor evidence of strong differential extinction. The derived power-law slope of the X-ray luminosity function for Trumpler 16 reveals a much steeper function than the Orion Nebula Cluster implying different ratio of solar- to higher-mass stars. We estimate the total Trumpler 16 pre-main sequence population to be  $>6500$  Class II and Class III X-ray sources. An overall K-excess disk frequency of  $\sim 8.9\%$  is derived using the X-ray selected sample, although there is some variation among the sub-clusters, especially in the Southeastern extension. X-ray emission is detected from 29 high-mass stars with spectral types between B2 and O3.

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[http://cochise.astro.psu.edu/Carina\\_public/special\\_issue.html](http://cochise.astro.psu.edu/Carina_public/special_issue.html)

<http://arxiv.org/abs/1103.1126>

### *Abstracts of recently accepted papers*

## The Green Bank Telescope H II Region Discovery Survey II. The Source Catalog

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The Green Bank Telescope H II Region Discovery Survey has doubled the number of known H II regions in the Galactic zone  $343^\circ \leq \ell \leq 67^\circ$  with  $|b| \leq 1^\circ$ . We detected 603 discrete hydrogen radio recombination line (RRL) components at 9GHz (3cm) from 448 targets. Our targets were selected based on spatially coincident mid-infrared and 20cm radio continuum emission. Such sources are almost invariably H II regions; we detected hydrogen RRL emission from 95% of our target sample. The sensitivity of the Green Bank Telescope and the power of its spectrometer together made this survey possible. Here we provide a catalog of the measured properties of the RRL and continuum emission from the survey nebulae. The derived survey completeness limit, 180 mJy at 9 GHz, is sufficient to detect all H II regions ionized by single O-stars to a distance of 12 kpc. These recently discovered nebulae share the same distribution on the sky as does the previously known census of Galactic H II regions. On average, however, the new nebulae have fainter

continuum fluxes, smaller continuum angular sizes, fainter RRL intensities and smaller RRL line widths. Though small in angular size, many of our new nebulae show little spatial correlation with tracers associated with extremely young H II regions, implying that our sample spans a range of evolutionary states. We discovered 34 first quadrant negative-velocity H II regions, which lie at extreme distances from the Sun and appear to be part of the Outer Arm. We found RRL emission from 207 Spitzer GLIMPSE  $8.0\ \mu\text{m}$  “bubble” sources, 65 of which have been cataloged previously. It thus appears that nearly all GLIMPSE bubbles are H II regions and that  $\sim 50\%$  of all Galactic H II regions have a bubble morphology at  $8.0\ \mu\text{m}$ .

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<http://arxiv.org/abs/1103.5085>

## Resolved Images of Large Cavities in Protoplanetary Transition Disks

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Circumstellar disks are thought to experience a rapid “transition” phase in their evolution that can have a considerable impact on the formation and early development of planetary systems. We present new and archival high angular resolution ( $0.3\ \text{arcsec} \approx 40\text{--}75\ \text{AU}$ ) Submillimeter Array (SMA) observations of the  $880\ \mu\text{m}$  (340 GHz) dust continuum emission from 12 such transition disks in nearby star-forming regions. In each case, we directly resolve a dust-depleted disk cavity around the central star. Using two-dimensional Monte Carlo radiative transfer calculations, we interpret these dust disk structures in a homogeneous, parametric model framework by reproducing their SMA continuum visibilities and spectral energy distributions. The cavities in these disks are large ( $R_{\text{cav}} = 15\text{--}73\ \text{AU}$ ) and substantially depleted of small ( $\sim\mu\text{m}$ -sized) dust grains, although their mass contents are still uncertain. The structures of the remnant material at larger radii are comparable to normal disks. We demonstrate that these large cavities are relatively common among the millimeter-bright disk population, comprising at least 1 in 5 (20%) of the disks in the bright half (and  $\geq 26\%$  of the upper quartile) of the millimeter luminosity (disk mass) distribution. Utilizing these results, we assess some of the physical mechanisms proposed to account for transition disk structures. As has been shown before, photoevaporation models do not produce the large cavity sizes, accretion rates, and disk masses representative of this sample. It would be difficult to achieve a sufficient decrease of the dust optical depths in these cavities by particle growth alone: substantial growth (to meter sizes or beyond) must occur in large (tens of AU) regions of low turbulence without also producing an abundance of small particles. Given those challenges, we suggest instead that the observations are most commensurate with dynamical clearing due to tidal interactions with low-mass companions – young brown dwarfs or giant planets on long-period orbits.

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## V2492 Cyg: The Early Evolution of the 2010 Outburst

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We present Gemini-North optical and near-IR observations of a young eruptive star in Cygnus, designated by the AAVSO as V2492 Cyg. This object is one of two young stars, located within 2 degrees of each other, that recently brightened by around 5 mags and were reported as possible new FU Orionis-type variables.

The outburst spectrum of V2492 Cyg shows atomic emission features throughout the optical and near-infrared. In

the optical,  $H\alpha$  is in emission and has an associated blue-shifted absorption component. The far-red Ca II triplet lines are also in emission and, as with  $H\alpha$ , possess significant blue-shifted absorption. The optical TiO molecular bands are also in emission. In the near-infrared,  $Pa\beta$ ,  $Br\gamma$ , and the CO overtone bandheads are strongly in emission. Such spectral characteristics are very similar to those exhibited by both EX Lupi, the progenitor of the EXor class of eruptive variables, during its 2008 extreme outburst, and V1647 Ori during its elevated phase in 2003.

Additionally, we consider archival data on V2492 Cyg and investigate the pre-outburst nature of this young star. We construct a quiescent-phase spectral energy distribution which, via model fitting, gives insight into the circumstellar environment of the object prior to the current eruption.

Our investigation strongly suggests that the V2492 Cyg outburst appears to be more consistent with an EXor event, a fact supported by its recent 2 mag fading and stochastic variability.

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<http://www.ifa.hawaii.edu/~caa/papers/vsxj205126.pdf>

## High-mass star formation at high luminosities: W31 at $> 10^6 L_{\odot}$

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*Context:* High-mass star formation has been a very active field over the last decade, however, most studies targeted regions of luminosities between  $10^4$  and  $10^5 L_{\odot}$ . In contrast to that, the highest mass stars reside in clusters exceeding  $10^5$  or even  $10^6 L_{\odot}$ .

*Aims:* We want to study the physical conditions associated with the formation of the highest mass stars.

*Methods:* Therefore, we selected the W31 star-forming complex with a total luminosity of  $\sim 6 \times 10^6 L_{\odot}$  (comprised of at least two sub-regions) for a multi-wavelength spectral line and continuum study covering wavelengths from the near- and mid-infrared via (sub)mm wavelength observations to radio data in the cm regime.

*Results:* While the overall structure of the multi-wavelength continuum data resembles each other well, there are several intriguing differences. The  $24 \mu\text{m}$  emission stemming largely from small dust grains follows tightly the spatial structure of the cm emission tracing the ionized free-free emission. Hence warm dust resides in regions that are spatially associated with the ionized hot gas ( $\sim 10^4$  K) of the HII regions. Furthermore, we find several evolutionary stages within the same complexes, ranging from infrared-observable clusters, via deeply embedded regions associated with active star formation traced by  $24 \mu\text{m}$  and cm emission, to at least one high-mass gas clump devoid of any such signature. The  $^{13}\text{CO}(2-1)$  and  $\text{C}^{18}\text{O}(2-1)$  spectral line observations reveal a large kinematic breadth in the entire region with a total velocity range of approximately  $90 \text{ km s}^{-1}$ . Kinematic and turbulent structures are set into context. While the average virial mass ratio for W31 is close to unity, the line width analysis indicates large-scale evolutionary differences between the southern and northern sub-regions (G10.2-0.3 and G10.3-0.1) of the whole W31 complex. A color-color analysis of the IRAC data also shows that the class II sources are broadly distributed throughout the entire complex whereas the Class 0/I sources are more tightly associated with the active high-mass star-forming regions. The clump mass function – tracing cluster scales and not scales of individual stars – derived from the  $875 \mu\text{m}$  continuum data has a slope of  $1.5 \pm 0.3$ , consistent with previous cloud mass functions.

*Conclusions:* The highest mass and luminous stars form in highly structured and complex regions with multiple events of star formation not always occurring simultaneously but in a sequential fashion. Warm dust and ionized gas can spatially coexist, and high-mass starless cores with low-turbulence gas components can reside in the direct neighborhood of active star-forming clumps with broad line-widths.

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<http://www.mpia-hd.mpg.de/homes/beuther/papers.html>

# Elemental abundances of low-mass stars in the young clusters 25 Ori and lambda Ori

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*Aims:* We aim to derive the chemical pattern of the young clusters 25 Orionis and lambda Orionis through homogeneous and accurate measurements of elemental abundances.

*Methods:* We present FLAMES/UVES observations of a sample of 14 K-type targets in the 25 Ori and lambda Ori clusters; we measure their radial velocities, in order to confirm cluster membership. We derive stellar parameters and abundances of Fe, Na, Al, Si, Ca, Ti, and Ni using the code MOOG.

*Results:* All the 25 Ori stars are confirmed cluster members without evidence of binarity; in lambda Ori we identify one non-member and one candidate single-lined binary star. We find an average metallicity  $[Fe/H] = -0.05 \pm 0.05$  for 25 Ori, where the error is the 1-sigma standard deviation from the average. lambda Ori members have a mean iron abundance value of  $0.01 \pm 0.01$ . The other elements show close-to-solar ratios and no star-to-star dispersion.

*Conclusions:* Our results, along with previous metallicity determinations in the Orion complex, evidence a small but detectable dispersion in the  $[Fe/H]$  distribution of the complex. This appears to be compatible with large-scale star formation episodes and initial non-uniformity in the pre-cloud medium. We show that, as expected, the abundance distribution of star forming regions is consistent with the chemical pattern of the Galactic thin disk.

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# Organic Molecules and Water in the Inner Disks of T Tauri Stars

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We report high signal-to-noise Spitzer IRS spectra of a sample of eleven classical T Tauri stars. Molecular emission from rotational transitions of H<sub>2</sub>O and OH and ro-vibrational bands of simple organic molecules (CO<sub>2</sub>, HCN, C<sub>2</sub>H<sub>2</sub>) is common among the sources in the sample. The emission shows a range in both flux and line-to-continuum ratio for each molecule and in the flux ratios of different molecular species. The gas temperatures (200–800 K) and emitting areas we derive are consistent with the emission originating in a warm disk atmosphere in the inner planet formation region at radii < 2 AU. The H<sub>2</sub>O emission appears to form under a limited range of excitation conditions, as demonstrated by the similarity in relative strengths of H<sub>2</sub>O features from star to star and the narrow range in derived temperature and column density. Emission from highly excited rotational levels of OH is present in all stars; the OH emission flux increases with the stellar accretion rate, and the OH/H<sub>2</sub>O flux ratio shows a relatively small scatter. We interpret these results as evidence for OH production via FUV photo-dissociation of H<sub>2</sub>O in the disk surface layers. No obvious explanation is found for the observed range in the relative emission strengths of different organic molecules or in their strength with respect to water. We put forward the possibility that these variations reflect a diversity in organic abundances due to star-to-star differences in the C/O ratio of the inner disk gas. Stars with the largest HCN/H<sub>2</sub>O flux ratios in our sample have the largest disk masses. While larger samples are required to confirm this, we speculate that such a trend could result if higher mass disks are more efficient at planetesimal formation and sequestration of water in the outer disk, leading to enhanced C/O ratios and abundances of organic molecules in the inner disk. A comparison of our derived HCN to H<sub>2</sub>O column density ratio to comets, hot cores, and outer T Tauri star disks suggests that the inner disks are chemically active.

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# TIMASSS: The IRAS16293-2422 Millimeter And Submillimeter Spectral Survey - I. Observations, calibration and analysis of the line kinematics

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Unbiased spectral surveys are powerful tools to study the chemistry and the physics of star forming regions, as they can give a complete census of the molecular content and the observed lines probe the physical structure of the source. While unbiased surveys in the millimeter and sub-millimeter ranges observable from ground-based telescopes have previously been obtained towards several high mass protostars, very little exists on low mass protostars, believed to resemble our own Sun's progenitor. Aiming to fill up this gap, we carried out a complete spectral survey of the bands at 3, 2, 1 and 0.8 mm towards the solar type protostar IRAS16293-2422.

The observations covered about 200 GHz and were obtained with the IRAM-30 m and JCMT-15 m telescopes during about 300 hours of observations. Particular attention was devoted to the inter-calibration of the obtained spectra with previous observations. All the lines detected with more than  $3\sigma$  and free from obvious blending effects were fitted with Gaussians to estimate their basic kinematic properties. More than 4000 lines were detected (with  $\sigma \geq 3$ ) and identified, yielding a line density of approximately 20 lines per GHz, comparable to previous surveys in massive hot cores. The vast majority ( $\sim 2/3$ ) of the lines are weak and due to complex organic molecules. The analysis of the profiles of more than 1000 lines belonging 70 species firmly establishes the presence of two distinct velocity components, associated with the two objects, A and B, forming the IRAS16293-2422 binary system. In the source A, the line widths of several species increase with the upper level energy of the transition, a behavior compatible with gas infalling towards a  $\sim 1 M_{\odot}$  object. The source B, which does not show this effect, might have a much lower central mass of  $\sim 0.1 M_{\odot}$ . The difference in the rest velocities of both objects is consistent with the hypothesis that the source B rotates around the source A. This spectral survey, although obtained with single-dish telescope with a low spatial resolution, allows to separate the emission from 2 different components, thanks to the large number of lines detected. The data of the survey are public and can be retrieved on the web site <http://www-laog.obs.ujf-grenoble.fr/heberges/timasss>.

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<http://dl.dropbox.com/u/4048472/TIMASSS/i16293-pap1.v20.pdf>

## Methanol Maser Emission from Galactic Center Sources with Excess $4.5 \mu\text{m}$ Emission

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We present a study of signatures of on-going star formation in a sample of protostellar objects with enhanced  $4.5 \mu\text{m}$  emission ('green' sources) near the Galactic center. To understand how star formation in the Galactic center region compares to that of the Galactic disk, we used the Expanded Very Large Array to observe radiatively excited Class II

6.7 GHz CH<sub>3</sub>OH masers and collisionally excited Class I 44 GHz CH<sub>3</sub>OH masers, both tracers of high-mass star formation, toward a sample of 34 Galactic center and foreground ‘green’ sources. We find that 33±15% of Galactic center sources are coincident with 6.7 GHz masers, and that 44±17% of foreground sources are coincident with 6.7 GHz masers. For 44 GHz masers, we find correlation rates of 27±13% and 25±13% for Galactic center green sources and foreground green sources, respectively. Based on these CH<sub>3</sub>OH maser detection rates, as well as correlations of green sources with other tracers of star formation, such as 24 μm emission and infrared dark clouds (IRDCs), we find no significant difference between the green sources in the Galactic center and those foreground to it. This suggests that once the star formation process has begun, the environmental differences between the Galactic center region and the Galactic disk have little effect on its observational signatures. We do find, however, some evidence that may support a recent episode of star formation in the Galactic center region.

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## No substellar objects at the center of the Lupus 3 star forming cloud

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*Context:* Current surveys of nearby star forming regions and young aggregates, producing samples of objects spanning the entire mass range down to masses of a few Jupiter masses, can address questions on differences in the substellar mass function among different regions and the lowest masses of objects that can form in isolation.

*Aims:* Deep imaging of a selected area in the Lupus 3 star-forming region, characterized by a large number of known young stellar objects, has been carried out with the goal of producing a complete sampling of the mass function down to sub-Jupiter masses.

*Methods:*  $I_C J H K_S$  imaging complemented with intermediate-band imaging sensitive to methane absorption has been obtained with the VLT. The observed area measures 7'3 × 7'4 (0.42 × 0.43 pc<sup>2</sup> at 200 pc) and in approximately 70% of it the background is obscured by  $A_V < 5$  mag. Detection limits ( $3\sigma$ ) are  $I_C = 25.6$ ,  $J = 23.1$ ,  $H = 22.3$ ,  $K_S = 21.3$ . Cool objects with temperatures below 3000 K are identified by means of reddening-free indices. Objects cooler than ~ 1300 K should also be detectable by comparing the flux in the  $H$  and methane-continuum bands.

*Results:* The luminosities of the 17 cool objects identified are in all cases too low to be consistent with membership in the star forming region. Their number is in agreement with the statistical expectation for the background population of very low mass stars. A reexamination of known candidate young stellar objects leads to the exclusion of 8 of them, reducing the number of bona fide members in the area to 15, of which 10 lie in low extinction regions. The expectation based on the stars-to-brown dwarf ratios derived in other young aggregates is to find 2-3 new brown dwarfs, whereas none is found. The low-mass young stellar object Par-Lup3-3 is found to consist of two close components of similar brightness separated by 0''3. A very faint object is also detected 1''2 from the jet-driving very low mass star Par-Lup3-4 that, if confirmed as a physical companion, would have an estimated mass of 1 – 2 M<sub>Jup</sub>.

*Conclusions:* The absence of brown dwarfs in one of the most crowded areas of the Lupus 3 clouds, albeit limited by small-number statistics, argues against a mass function rich in very low-mass objects, as may have been expected if the apparent overabundance of mid-M spectral types in Lupus extended toward later types. The results also stress the importance of critically examining the actual nature of previously identified candidate young stellar objects at the time of drawing statistical conclusions on the substellar population.

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<http://www.eso.org/~fcomeron/lupus-deep.pdf>

## Physical and radiative properties of the first core accretion shock

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Radiative shocks play a dominant role in star formation. The accretion shocks on first and second Larson cores involve radiative processes and are thus characteristic of radiative shocks. In this study, we explore the formation of the first Larson core and characterize the radiative and dynamical properties of the accretion shock, using both analytical and numerical approaches. We developed both numerical radiation-hydrodynamics calculations and a semi-analytical model that characterizes radiative shocks in various physical conditions, for radiating or barotropic fluids. Then, we performed 1D spherical collapse calculations of the first Larson core, using a grey approximation for the opacity of the material. We considered three different models for radiative transfer: the barotropic approximation, the flux limited diffusion approximation, and the more complete M1 model. We investigate the characteristic properties of the collapse and of the first core formation. Comparison between the numerical results and our semi-analytical model for radiative shocks shows that the latter reproduces the core properties obtained with the numerical calculations quite well. The accretion shock on the first Larson core is found to be supercritical; i.e., the post and pre-shock temperatures are equal, implying that all the accretion shock energy on the core is radiated away. The shock properties are described well by the semi-analytical model. The flux-limited diffusion approximation is found to agree quite well with the results based on the M1 model of radiative transfer, and is thus appropriate for studying the star formation process and allows a tractable and relatively correct treatment of radiative transfer in multidimensional radiation-hydrodynamics calculations. In contrast, the barotropic approximation does not correctly describe the thermal properties of the gas during the collapse.

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<http://adsabs.harvard.edu/abs/2011arXiv1102.2921C>

## Radiation hydrodynamics with adaptive mesh refinement and application to prestellar core collapse. I. Methods

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Radiative transfer has a strong impact on the collapse and the fragmentation of prestellar dense cores. We present the radiation-hydrodynamics (RHD) solver we designed for the **RAMSES** code. The method is designed for astrophysical purposes, and in particular for protostellar collapse. We present the solver, using the co-moving frame to evaluate the radiative quantities. We use the popular flux-limited diffusion approximation under the grey approximation (one group of photons). The solver is based on the second-order Godunov scheme of **RAMSES** for its hyperbolic part and on an implicit scheme for the radiation diffusion and the coupling between radiation and matter. We report in detail our methodology to integrate the RHD solver into **RAMSES**. We successfully test the method in several conventional tests. For validation in 3D, we perform calculations of the collapse of an isolated  $1 M_{\odot}$  prestellar dense core without rotation. We successfully compare the results with previous studies that used different models for radiation and hydrodynamics. We have developed a full radiation-hydrodynamics solver in the **RAMSES** code that handles adaptive mesh refinement grids. The method is a combination of an explicit scheme and an implicit scheme accurate to the second-order in space. Our method is well suited for star-formation purposes. Results of multidimensional dense-core-collapse calculations with rotation are presented in a companion paper.

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# Star formation efficiency as a function of metallicity: from star clusters to galaxies

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We explore how the star formation efficiency in a protocluster clump is regulated by metallicity dependent stellar winds from the newly formed massive OB stars ( $M_{\star} \geq 5 M_{\odot}$ ) on their main sequence. The model describes the co-evolution of the mass function of gravitationally bound cores and of the IMF in a protocluster clump. Dense cores are generated uniformly in time at different locations in the clump, and contract over lifetimes that are a few times their free fall times. The cores collapse to form stars that power strong stellar winds whose cumulative kinetic energy evacuates the gas from the clump and quenches further core and star formation. This sets the final star formation efficiency,  $SFE_f$ . Models are run with various metallicities in the range  $Z/Z_{\odot} = [0.1, 2]$ . We find that the  $SFE_f$  decreases strongly with increasing metallicity. The  $SFE_f$ -metallicity relation is well described by a decaying exponential whose exact parameters depend weakly on the value of the core formation efficiency. We find that there is almost no dependence of the  $SFE_f$ -metallicity relation on the clump mass. This is due to the fact that an increase (decrease) in the clump mass leads to an increase (decrease) in the feedback from OB stars which is opposed by an increase (decrease) in the gravitational potential of the clump. The clump mass-cluster mass relations we find for all of the different metallicity cases imply a negligible difference between the exponent of the mass function of the protocluster clumps and that of the young clusters mass function. By normalizing the  $SFE$ s to their value for the solar metallicity case, we compare our results to  $SFE$ -metallicity relations derived on galactic scales and find a good agreement. As a by-product of this study, we also provide ready-to-use prescriptions for the power of stellar winds of main sequence OB stars in the mass range  $[5, 80] M_{\odot}$  in the metallicity range we have considered.

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## On the Distribution of Orbital Eccentricities for Very Low-Mass Binaries

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We have compiled a sample of 16 orbits for very low-mass stellar ( $< 0.1 M_{\odot}$ ) and brown dwarf binaries, including updated orbits for HD 130948BC and LP 415-20AB. This sample enables the first comprehensive study of the eccentricity distribution for such objects. We find that very low-mass binaries span a broad range of eccentricities from near-circular to highly eccentric ( $e \approx 0.8$ ), with a median eccentricity of 0.34. We have examined potential observational biases in this sample, and for visual binaries we show through Monte Carlo simulations that if we choose appropriate selection criteria then all eccentricities are equally represented ( $\lesssim 5\%$  difference between input and output eccentricity distributions). The orbits of this sample of very low-mass binaries show some significant differences from their solar-type counterparts. They lack a correlation between orbital period and eccentricity and display a much higher fraction of near-circular orbits ( $e < 0.1$ ) than solar-type stars, which together may suggest a different formation mechanism or dynamical history for these two populations. Very low-mass binaries also do not follow the  $e^2$  distribution of Ambartsumian, which would be expected if their orbits were distributed in phase space according to a function of energy alone (e.g., the Boltzmann distribution). We find that current numerical simulations of very low-mass star formation do not completely reproduce the observed properties of our binary sample. The cluster formation model of Bate agrees very well with the overall  $e$  distribution, but the lack of any high- $e$  ( $> 0.6$ ) binaries at orbital periods comparable to our sample suggests that tidal damping due to gas disks may play too large of a role in the simulations. In contrast, the circumstellar disk fragmentation model of Stamatellos & Whitworth predicts only high- $e$  binaries and thus is highly inconsistent with our sample. These discrepancies could be explained if multiple formation processes are responsible for producing the field population.

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# The Intermediate-mass Young Stellar Object 08576nr292: Discovery of a disk-jet system

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We present observations of the embedded massive young stellar object (YSO) candidate 08576nr292, obtained with X-shooter and SINFONI on the ESO *Very Large Telescope* (VLT). The flux-calibrated, medium-resolution X-shooter spectrum (300 – 2500 nm) includes over 300 emission lines, but no (photospheric) absorption lines and is consistent with a reddened disk spectrum. Among the emission lines are three hydrogen series and helium lines, both permitted and forbidden metal lines, and CO first-overtone emission. A representative sample of lines with different morphologies is presented. The H $\alpha$  and Ca II triplet lines are very strong, with profiles indicative of outflow and – possibly – infall, usually observed in accreting stars. These lines include a blue-shifted absorption component at  $\sim -125$  km s<sup>-1</sup>. The He I and metal-line profiles are double-peaked, with a likely origin in a circumstellar disk. The forbidden lines, associated with outflow, have a single blue-shifted emission component centered at  $-125$  km s<sup>-1</sup>, coinciding with the absorption components in H $\alpha$  and Ca II. SINFONI H- and K-band integral-field spectroscopy of the cluster environment demonstrates that the [Fe II] emission is produced by a jet originating at the location of 08576nr292. Because the spectral type of the central object cannot be determined, its mass remains uncertain. We argue that 08576nr292 is an intermediate-mass YSO with a high accretion rate ( $\dot{M}_{\text{acc}} \sim 10^{-6} - 10^{-5} M_{\odot} \text{ yr}^{-1}$ ). These observations demonstrate the potential of X-shooter and SINFONI to study in great detail an accretion disk-jet system, rarely seen around the more massive YSOs.

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## Water depletion in the disk atmosphere of Herbig AeBe stars

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We present high resolution ( $R \sim 100,000$ ) L-band spectroscopy of 11 Herbig AeBe stars with circumstellar disks. The observations were obtained with the VLT/CRIFRES to detect hot water and hydroxyl radical emission lines previously detected in disks around T Tauri stars. OH emission lines are detected towards 4 disks. The OH  ${}^2\Pi_{3/2}$  P4.5 (1+,1-) doublet is spectrally resolved as well as the velocity profile of each component of the doublet. Its characteristic double-peak profile demonstrates that the gas is in Keplerian rotation and points to an emitting region extending out to  $\sim 15\text{--}30$  AU. The OH emission correlates with disk geometry as it is mostly detected towards flaring disks. None of the Herbig stars analyzed here show evidence of hot water vapor at a sensitivity similar to that of the OH

lines. The non-detection of hot water vapor emission indicates that the atmosphere of disks around Herbig AeBe stars are depleted of water molecules. Assuming LTE and optically thin emission we derive a lower limit to the OH/H<sub>2</sub>O column density ratio  $> 1 - 25$  in contrast to T Tauri disks for which the column density ratio is  $0.3 - 0.4$ .

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## ***XMM-Newton* observations of the young open cluster around $\lambda$ Orionis**

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*Aims.* We studied the X-ray properties of the young ( $\sim 1-8$  Myr) open cluster around the hot (O8 III) star  $\lambda$  Ori and compared them with those of the similarly-aged  $\sigma$  Ori cluster to investigate possible effects of the different ambient environment.

*Methods.* We analysed an *XMM-Newton* observation of the cluster using EPIC imaging and low-resolution spectral data. We studied the variability of detected sources, and performed a spectral analysis of the brightest sources in the field using multi-temperature models.

*Results.* We detected 167 X-ray sources, of which 58 are identified with known cluster members and candidates, from massive stars down to low-mass stars with spectral types  $\sim M5.5$ . Another 23 sources were identified with new possible photometric candidates. Late-type stars have a median  $\log L_X/L_{\text{bol}} \sim -3.3$ , close to the saturation limit. Variability was observed in  $\sim 35\%$  of late-type members or candidates, including six flaring sources. The emission from the central hot star  $\lambda$  Ori is dominated by plasma at  $0.2-0.3$  keV, with a weaker component at  $0.7$  keV, consistently with a wind origin. The coronae of late-type stars can be described by two plasma components with temperatures  $T_1 \sim 0.3-0.8$  keV and  $T_2 \sim 0.8-3$  keV, and subsolar abundances  $Z \sim 0.1-0.3 Z_\odot$ , similar to what is found in other star-forming regions and associations. No significant difference was observed between stars with and without circumstellar discs, although the smallness of the sample of stars with discs and accretion does not allow us to draw definitive conclusions.

*Conclusions.* The X-ray properties of  $\lambda$  Ori late-type stars are comparable to those of the coeval  $\sigma$  Ori cluster, suggesting that stellar activity in  $\lambda$  Ori has not been significantly affected by the different ambient environment.

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## **Importance of the Initial Conditions for Star Formation - I. Cloud Evolution and Morphology**

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We present a detailed parameter study of collapsing turbulent cloud cores, varying the initial density profile and the initial turbulent velocity field. We systematically investigate the influence of different initial conditions on the star formation process, mainly focusing on the fragmentation, the number of formed stars, and the resulting mass distributions. Our study compares four different density profiles (uniform, Bonnor-Ebert type,  $\rho \propto r^{-1.5}$ , and  $\rho \propto r^{-2}$ ), combined with six different supersonic turbulent velocity fields (compressive, mixed, and solenoidal, initialised with two different random seeds each) in three-dimensional simulations using the adaptive-mesh refinement, hydrodynamics code FLASH. The simulations show that density profiles with flat cores produce hundreds of low-mass stars, either distributed throughout the entire cloud or found in subclusters, depending on the initial turbulence. Concentrated density profiles always lead to the formation of one high-mass star in the centre of the cloud and, if at all, low-mass stars

surrounding the central one. In uniform and Bonnor-Ebert type density distributions, compressive initial turbulence leads to local collapse about 25

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## Chemical Evolution of Protoplanetary Disks - The Effects of Viscous Accretion, Turbulent Mixing, and Disk Winds

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We calculate the chemical evolution of protoplanetary disks considering radial viscous accretion, vertical turbulent mixing, and vertical disk winds. We study the effects on the disk chemical structure when different models for the formation of molecular hydrogen on dust grains are adopted. Our gas-phase chemistry is extracted from the UMIST Database for Astrochemistry (Rate06) to which we have added detailed gas-grain interactions. We use our chemical model results to generate synthetic near- and mid-infrared local thermodynamic equilibrium line emission spectra and compare these with recent Spitzer observations. Our results show that if H<sub>2</sub> formation on warm grains is taken into consideration, the H<sub>2</sub>O and OH abundances in the disk surface increase significantly. We find that the radial accretion flow strongly influences the molecular abundances, with those in the cold midplane layers particularly affected. On the other hand, we show that diffusive turbulent mixing affects the disk chemistry in the warm molecular layers, influencing the line emission from the disk and subsequently improving agreement with observations. We find that NH<sub>3</sub>, CH<sub>3</sub>OH, C<sub>2</sub>H<sub>2</sub>, and sulfur-containing species are greatly enhanced by the inclusion of turbulent mixing. We demonstrate that disk winds potentially affect the disk chemistry and the resulting molecular line emission in a manner similar to that found when mixing is included.

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## Heating and Cooling Protostellar Disks

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We examine heating and cooling in protostellar disks using 3-D radiation-MHD calculations of a patch of the Solar nebula at 1 AU, employing the shearing-box and flux-limited radiation diffusion approximations. The disk atmosphere is ionized by stellar X-rays, well-coupled to magnetic fields, and sustains a turbulent accretion flow driven by magneto-rotational instability, while the interior is resistive and magnetically dead.

The turbulent layers heat by absorbing the light from the central star and by dissipating the magnetic fields. They are optically-thin to their own radiation and cool inefficiently. The optically-thick interior in contrast is heated only weakly, by re-emission from the atmosphere. The interior is colder than a classical viscous model, and isothermal.

The magnetic fields support an extended atmosphere that absorbs the starlight 1.5 times higher than the hydrostatic viscous model. The disk thickness thus measures not the internal temperature, but the magnetic field strength. Fluctuations in the fields move the starlight-absorbing surface up and down. The height ranges between 13% and 24% of the radius over timescales of several orbits, with implications for infrared variability.

The fields are buoyant, so the accretion heating occurs higher in the atmosphere than the stresses. The heating is localized around current sheets, caused by magneto-rotational instability at lower elevations and by Parker instability at higher elevations. Gas in the sheets is heated above the stellar irradiation temperature, even though accretion is much less than irradiation power when volume-averaged. The hot optically-thin current sheets might be detectable

through their line emission.

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## Dispersion of Magnetic Fields in Molecular Clouds. III

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We apply our technique on the dispersion of magnetic fields in molecular clouds to high spatial resolution Submillimeter Array polarization data obtained for Orion KL in OMC-1, IRAS 16293, and NGC 1333 IRAS 4A. We show how one can take advantage of such high resolution data to characterize the magnetized turbulence power spectrum in the inertial and dissipation ranges. For Orion KL we determine that in the inertial range the spectrum can be approximately fitted with a power law  $k^{-(2.9\pm 0.9)}$  and we report a value of 9.9 mpc for  $\lambda_{AD}$ , the high spatial frequency cutoff presumably due to turbulent ambipolar diffusion. For the same parameters we have  $\sim k^{-(1.4\pm 0.4)}$  and a tentative value of  $\lambda_{AD} \simeq 2.2$  mpc for NGC 1333 IRAS 4A, and  $\sim k^{-(1.8\pm 0.3)}$  with an upper limit of  $\lambda_{AD} \lesssim 1.8$  mpc for IRAS 16293. We also discuss the application of the technique to interferometry measurements and the effects of the inherent spatial filtering process on the interpretation of the results.

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## Extremely broad radio recombination maser lines toward the high-velocity ionized jet in Cepheus A HW2

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We present the first detection of the H40 $\alpha$ , H34 $\alpha$  and H31 $\alpha$  radio recombination lines (RRLs) at millimeter wavelengths toward the high-velocity, ionized jet in the Cepheus A HW2 star forming region. From our single-dish and interferometric observations, we find that the measured RRLs show extremely broad asymmetric line profiles with zero-intensity linewidths of  $\sim 1100$  km s<sup>-1</sup>. From the linewidths, we estimate a terminal velocity for the ionized gas in the jet of  $\geq 500$  km s<sup>-1</sup>, consistent with that obtained from the proper motions of the HW2 radio jet. The total integrated line-to-continuum flux ratios of the H40 $\alpha$ , H34 $\alpha$  and H31 $\alpha$  lines are 43, 229 and 280 km s<sup>-1</sup>, clearly deviating from LTE predictions. These ratios are very similar to those observed for the RRL maser toward MWC349A, suggesting that the intensities of the RRLs toward HW2 are affected by maser emission. Our radiative transfer modeling of the RRLs shows that their asymmetric profiles could be explained by maser emission arising from a bi-conical radio jet with a semi-aperture angle of 18°, electron density distribution varying as  $r^{-2.11}$  and turbulent and expanding wind velocities of 60 and 500 km s<sup>-1</sup>.

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## The Orbit of GG Tau A

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GG Tau A is a pre-main-sequence binary system that is encircled by a circumbinary disk with a sharp inner edge. We present a study of the orbit of the binary system GG Tau A and its relation to the circumbinary disk. Three new relative astrometric positions of the binary were obtained with NACO at the VLT. We combine these with data from the literature and fit orbit models to the dataset. We find that an orbit coplanar with the disk and compatible with the astrometric data is too small to explain the inner gap of the disk. On the other hand, orbits large enough to cause the gap are tilted with respect to the disk. If the disk gap is indeed caused by the stellar companion, then the most likely explanation is a combination of underestimated astrometric errors and a misalignment between the planes of the disk and the orbit.

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## A peculiar young eruptive star in the dark cloud Lynds 1340

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We conducted a long-term optical photometric and spectroscopic monitoring of the strongly variable, accreting young sun-like star [KOS94] HA 11, associated with the dark cloud Lynds 1340, that exhibited large amplitude (5–6 magnitudes in the  $I_C$  band) brightness variations on 2–3 years timescales, flat spectral energy distribution (SED), and extremely strong ( $300 < EW/\text{Å} < 900$ )  $H\alpha$  emission. In this Letter we describe the basic properties of the star, derived from our observations between 1999 and 2011, and put into context the observed phenomena. The observed variations in the emission spectra, near-infrared colors, and SED suggest that [KOS94] HA 11 (spectral type: K7–M0) is an eruptive young star, possibly similar in nature to V1647 Ori: its large-scale photometric variations are governed by variable accretion rate, associated with variations in the inner disk structure. The star recently has undergone strong and rapid brightness variations, thus its further observations may offer a rare opportunity for studying structural and chemical rearrangements of the inner disk, induced by variable central luminosity.

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## High Resolution Optical Spectra of HBC 722 after Outburst

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We report the results of our high resolution optical spectroscopic monitoring campaign ( $\lambda = 3800 - 8800 \text{ \AA}$ ,  $R = 30000$ )

– 45000) of the new FU Orionis-type object HBC 722. We observed HBC 722 with the BOES 1.8-m telescope between November 26 and December 29, 2010 and FU Orionis itself on January 26, 2011. We detect a number of previously unreported high-resolution K I and Ca II lines beyond 7500 Å. We resolve the H $\alpha$  and Ca II line profiles into three velocity components, which we attribute to both disk and outflow. The increased accretion during outburst can heat the disk to produce the relatively narrow absorption feature and launch outflows appearing as high velocity blue and red-shifted broad features.

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## Wide-field Infrared Survey Explorer Observations of Young Stellar Objects in the Western Circinus Molecular Cloud

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The Wide-field Infrared Survey Explorer has uncovered a population of young stellar objects in the Western Circinus molecular cloud. Images show the YSOs to be clustered into two main groups that are coincident with dark filamentary structure in the nebulosity. Analysis of photometry shows numerous Class I and II objects. The locations of several of these objects are found to correspond to known dense cores and CO outflows. Class I objects tend to be concentrated in dense aggregates, and Class II objects more evenly distributed throughout the region.

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## HD 135344B: A young star has reached its rotational limit

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We search for periodic variations in the radial velocity of the young Herbig star HD 135344B with the aim to determine a rotation period. We analyzed 44 high-resolution optical spectra taken over a time range of 151 days. The spectra were acquired with FEROS at the 2.2m MPG/ESO telescope in La Silla. The stellar parameters of HD 135344B are determined by fitting synthetic spectra to the stellar spectrum. In order to obtain radial velocity measurements, the stellar spectra have been cross-correlated with a theoretical template computed from determined stellar parameters. We report the first direct measurement of the rotation period of a Herbig star from radial-velocity measurements. The rotation period is found to be 0.16 d (3.9 hr), which makes HD 135344B a rapid rotator at or close to its break-up velocity. The rapid rotation could explain some of the properties of the circumstellar environment of HD 135344B such as the presence of an inner disk with properties (composition, inclination), that are significantly different from the outer disk.

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# CO<sub>2</sub> formation in quiescent clouds; an experimental study of the CO + OH pathway

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The formation of CO<sub>2</sub> in quiescent regions of molecular clouds is not yet fully understood, despite CO<sub>2</sub> having an abundance of around 10–34 % H<sub>2</sub>O. We present a study of the formation of CO<sub>2</sub> via the non-energetic route CO + OH on non-porous H<sub>2</sub>O and amorphous silicate surfaces. Our results are in the form of temperature-programmed desorption spectra of CO<sub>2</sub> produced via two experimental routes: O<sub>2</sub> + CO + H and O<sub>3</sub> + CO + H. The maximum yield of CO<sub>2</sub> is around 8 % with respect to the starting quantity of CO, suggesting a barrier to CO + OH. The rate of reaction, based on modelling results, is 24 times slower than O<sub>2</sub> + H. Our model suggests that competition between CO<sub>2</sub> formation via CO + OH and other surface reactions of OH is a key factor in the low yields of CO<sub>2</sub> obtained experimentally, with relative reaction rates  $k_{CO+H} \ll k_{CO+OH} < k_{H_2O_2+H} < k_{OH+H}, k_{O_2+H}$ . Astrophysically, the presence of CO<sub>2</sub> in low A<sub>V</sub> regions of molecular clouds could be explained by the reaction CO + OH occurring concurrently with the formation of H<sub>2</sub>O via the route OH + H.

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## Disk Imaging Survey of Chemistry with SMA: II. Southern Sky Protoplanetary Disk Data and Full Sample Statistics

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This is the second in a series of papers based on data from DISCS, a Submillimeter Array observing program aimed at spatially and spectrally resolving the chemical composition of 12 protoplanetary disks. We present data on six Southern sky sources – IM Lup, SAO 206462 (HD 135344b), HD 142527, AS 209, AS 205 and V4046 Sgr – which complement the six sources in the Taurus star forming region reported previously. CO 2–1 and HCO<sup>+</sup> 3–2 emission are detected and resolved in all disks and show velocity patterns consistent with Keplerian rotation. Where detected, the emission from DCO<sup>+</sup> 3–2, N<sub>2</sub>H<sup>+</sup> 3–2, H<sub>2</sub>CO 3<sub>03</sub> – 2<sub>02</sub> and 4<sub>14</sub> – 3<sub>13</sub>, HCN 3–2 and CN 2<sub>33/4/2</sub> – 1<sub>22/3/1</sub> are also generally spatially resolved. The detection rates are highest toward the M and K stars, while the F star SAO 206462 has only weak CN and HCN emission, and H<sub>2</sub>CO alone is detected toward HD 142527. These findings together with the statistics from the previous Taurus disks, support the hypothesis that high detection rates of many small molecules depend on the presence of a cold and protected disk midplane, which is less common around F and A stars compared to M and K stars. Disk-averaged variations in the proposed radiation tracer CN/HCN are found to be small, despite two orders of magnitude range of spectral types and accretion rates. In contrast, the resolved images suggest that the CN/HCN emission ratio varies with disk radius in at least two of the systems. There are no clear observational differences in the disk chemistry between the classical/full T Tauri disks and transitional disks. Furthermore, the observed line emission does not depend on measured accretion luminosities or the number of infrared lines detected, which suggests that the chemistry outside of 100 AU is not coupled to the physical processes that drive the chemistry in the innermost few AU.

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# On The Evolution of Dust Mineralogy, from Protoplanetary Disks to Planetary Systems

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Mineralogical studies of silicate features emitted by dust grains in protoplanetary disks and Solar System bodies can shed light on the progress of planet formation. The significant fraction of crystalline material in comets, chondritic meteorites and interplanetary dust particles indicates a modification of the almost completely amorphous interstellar medium (ISM) dust from which they formed. The production of crystalline silicates, thus, must happen in protoplanetary disks, where dust evolves to build planets and planetesimals. Different scenarios have been proposed, but it is still unclear how and when this happens. This paper presents dust grain mineralogy (composition, crystallinity and grain size distribution) of a complete sample of protoplanetary disks in the young Serpens cluster. These results are compared to those in the young Taurus region and to sources that have retained their protoplanetary disks in the older Upper Scorpius and  $\eta$  Chamaeleontis stellar clusters, using the same analysis technique for all samples. This comparison allows an investigation of the grain mineralogy evolution with time for a total sample of 139 disks. The mean cluster age and disk fraction are used as indicators of the evolutionary stage of the different populations. Our results show that the disks in the different regions have similar distributions of mean grain sizes and crystallinity fractions ( $\sim 10 - 20\%$ ) despite the spread in mean ages. Furthermore, there is no evidence of preferential grain sizes for any given disk geometry, nor for the mean cluster crystallinity fraction to increase with mean age in the 1 – 8 Myr range. The main implication is that a modest level of crystallinity is established in the disk surface early on ( $\leq 1$  Myr), reaching an equilibrium that is independent of what may be happening in the disk midplane. These results are discussed in the context of planet formation, in comparison with mineralogical results from small bodies in our own Solar System.

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## The Arecibo Methanol Maser Galactic Plane Survey - IV: Accurate Astrometry and Source Morphologies

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We present accurate absolute astrometry of 6.7 GHz methanol masers detected in the Arecibo Methanol Maser Galactic Plane Survey using MERLIN and the Expanded Very Large Array (EVLA). We estimate the absolute astrometry to be accurate to better than 15 and 80 mas for the MERLIN and EVLA observations, respectively. We also derive the morphologies of the maser emission distributions for sources stronger than 1 Jy. The median spatial extent along the major axis of the regions showing maser emission is  $\sim 775$  AU. We find a majority of methanol maser morphologies to be complex with some sources previously determined to have regular morphologies in fact being embedded within larger structures. This suggests that some maser spots do not have a compact core, which leads to them being resolved in high angular resolution observations. This also casts doubt on interpretations of the origin of methanol maser emission solely based on source morphologies. We also investigate the association of methanol masers with mid-infrared emission and find very close correspondence between methanol masers and 24  $\mu\text{m}$  point sources. This adds further credence to theoretical models that predict methanol masers to be pumped by warm dust emission and

firmly reinforces the finding that Class II methanol masers are unambiguous tracers of embedded high-mass protostars.

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## Disk Evolution in OB Associations - Deep Spitzer/IRAC Observations of IC 1795

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We present a deep *Spitzer*/IRAC survey of the OB association IC 1795 carried out to investigate the evolution of protoplanetary disks in regions of massive star formation.

Combining *Spitzer*/IRAC data with Chandra/ACIS observations, we find 289 cluster members. An additional 340 sources with an infrared excess, but without X-ray counterpart, are classified as cluster member candidates. Both surveys are complete down to stellar masses of about  $1 M_{\odot}$ . We present pre-main sequence isochrones computed for the first time in the *Spitzer*/IRAC colors. The age of the cluster, determined via the location of the Class III sources in the [3.6]-[4.5]/[3.6] color-magnitude diagram, is in the range of 3 - 5 Myr.

As theoretically expected, we do not find any systematic variation in the spatial distribution of disks within 0.6 pc of either O-type star in the association. However, the disk fraction in IC 1795 does depend on the stellar mass: sources with masses  $>2 M_{\odot}$  have a disk fraction of  $\sim 20\%$ , while lower mass objects ( $2-0.8 M_{\odot}$ ) have a disk fraction of  $\sim 50\%$ . This implies that disks around massive stars have a shorter dissipation timescale.

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## A Spitzer Survey of Mid-infrared Molecular Emission from Protoplanetary Disks. II. Correlations and Local Thermal Equilibrium Models

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We present an analysis of Spitzer-IRS observations of H<sub>2</sub>O, OH, HCN, C<sub>2</sub>H<sub>2</sub>, and CO<sub>2</sub> emission, and Keck-NIRSPEC observations of CO emission, from a diverse sample of T Tauri and Herbig Ae/Be circumstellar disks. We find that detections and strengths of most mid-IR molecular emission features are correlated with each other, suggesting a common origin and similar excitation conditions for this mid-infrared line forest. Aside from the remarkable differences in molecular line strengths between T Tauri, Herbig Ae/Be and transitional disks discussed in Pontoppidan et al. (2010), we note that the line detection efficiency is anti-correlated with the 13/30  $\mu\text{m}$  SED spectral slope, which is a measure of the degree of grain settling in the disk atmosphere. We also note a correlation between detection efficiency and H $\alpha$  equivalent width, and tentatively with accretion rate, suggesting that accretional heating contributes to line excitation. If detected, H<sub>2</sub>O line fluxes are correlated with the mid-IR continuum flux, and other co-varying system

parameters, such as  $L_*$ . However, significant sample variation, especially in molecular line ratios, remains, and its origin has yet to be explained. LTE models of the  $\text{H}_2\text{O}$  emission show that line strength is primarily related to the best-fit emitting area, and this accounts for most source-to-source variation in  $\text{H}_2\text{O}$  emitted flux. Best-fit temperatures and column densities cover only a small range of parameter space, near  $\sim 10^{18} \text{ cm}^{-2}$  and 450 K for all sources, suggesting a high abundance of  $\text{H}_2\text{O}$  in many planet-forming regions. Other molecules have a range of excitation temperatures from  $\sim 500 - 1500$  K, also consistent with an origin in planet-forming regions. We find molecular ratios relative to  $\text{H}_2\text{O}$  of  $\sim 10^{-3}$  for all molecules, with the exception of CO, for which  $n(\text{CO})/n(\text{H}_2\text{O}) \sim 1$ . However, LTE fitting caveats and differences in the way thermo-chemical modeling results are reported make comparisons with such models difficult, and highlight the need for additional observations coupled with the use of line-generating radiative transfer codes.

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## The Physics of Protoplanetary Dust Agglomerates. VI. Erosion of Large Aggregates as a Source of Micrometer-sized Particles

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Observed protoplanetary disks consist of a large amount of micrometer-sized particles. Dullemond & Dominik (2005) pointed out for the first time the difficulty in explaining the strong mid-IR excess of classical T-Tauri stars without any dust-retention mechanisms. Because high relative velocities in between micrometer-sized and macroscopic particles exist in protoplanetary disks, we present experimental results on the erosion of macroscopic agglomerates consisting of micrometer-sized spherical particles via the impact of micrometer-sized particles. We find that after an initial phase, in which an impacting particle erodes up to 10 particles of an agglomerate, the impacting particles compress the agglomerate's surface, which partly passivates the agglomerates against erosion. Due to this effect the erosion halts within our error bars for impact velocities up to  $\sim 30 \text{ m s}^{-1}$ . For larger velocities, the erosion is reduced by an order of magnitude. This outcome is explained and confirmed by a numerical model. In a next step we build an analytical disk model and implement the experimentally found erosive effect. The model shows that erosion is a strong source of micrometer-sized particles in a protoplanetary disk. Finally we use the stationary solution of this model to explain the amount of micrometer-sized particles in observational infrared data of Furlan et al. (2006).

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## Near-Infrared Imaging Polarimetry Toward Serpens South: Revealing the Importance of the Magnetic Field

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The Serpens South embedded cluster, which is located at the constricted part in a long filamentary infrared dark cloud, is believed to be in very early stage of cluster formation. We present results of near-infrared (*JHKs*) polarization observations toward the filamentary cloud. Our polarization measurements of near-infrared point sources indicate a well-ordered global magnetic field that is perpendicular to the main filament, implying that the magnetic field is likely

to have controlled the formation of the main filament. On the other hand, the sub-filaments, which converge on the central part of the cluster, tend to run along the magnetic field. The global magnetic field appears to be curved in the southern part of the main filament. Such morphology is consistent with the idea that the global magnetic field is distorted by gravitational contraction along the main filament toward the northern part that contains larger mass. Applying the Chandrasekhar-Fermi method, the magnetic field strength is roughly estimated to be a few  $\times 100 \mu\text{G}$ , suggesting that the filamentary cloud is close to magnetically critical as a whole.

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## Measuring Organic Molecular Emission in Disks with Low Resolution Spitzer Spectroscopy

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We explore the extent to which Spitzer IRS spectra taken at low spectral resolution can be used in quantitative studies of organic molecular emission from disks surrounding low mass young stars. We use Spitzer IRS spectra taken in both the high and low resolution modules for the same sources to investigate whether it is possible to define line indices that can measure trends in the strength of the molecular features in low resolution data. We find that trends in HCN emission strength seen in the high resolution data can be recovered in low resolution data. In examining the factors that influence the HCN emission strength, we find that the low resolution HCN flux is modestly correlated with stellar accretion rate and X-ray luminosity. Correlations of this kind are perhaps expected based on recent observational and theoretical studies of inner disk atmospheres. Our results demonstrate the potential of using the large number of low resolution disk spectra that reside in the Spitzer archive to study the factors that influence the strength of molecular emission from disks. Such studies would complement results for the much smaller number of circumstellar disks that have been observed at high resolution with IRS.

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## Against of all odds? Forming the planet of the HD196885 binary

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HD196885Ab is the most 'extreme' planet-in-a-binary discovered to date, whose orbit places it at the limit for orbital stability. The presence of a planet in such a highly perturbed region poses a clear challenge to planet-formation scenarios. We investigate this issue by focusing on the planet-formation stage that is arguably the most sensitive to binary perturbations: the mutual accretion of kilometer-sized planetesimals. To this effect we numerically estimate the impact velocities  $dv$  amongst a population of circumprimary planetesimals. We find that most of the circumprimary disc is strongly hostile to planetesimal accretion, especially the region around 2.6AU (the planet's location) where binary perturbations induce planetesimal shattering  $dv$  of more than 1km/s. Possible solutions to the paradox of having a planet in such accretion-hostile regions are 1) that initial planetesimals were very big, at least 250km, 2) that the binary had an initial orbit at least twice the present one, and was later compacted due to early stellar encounters, 3) that planetesimals did not grow by mutual impacts but by sweeping of dust (the 'snowball' growth mode identified by Xie et al., 2010b), or 4) that HD196885Ab was formed not by core-accretion but by the concurrent disc instability mechanism. All of these 4 scenarios remain however highly conjectural

## The immediate environment of the Class 0 protostar VLA1623, on scales of $\sim 50$ -100 AU, observed at millimetre and centimetre wavelengths

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We present high angular resolution observations, taken with the Very Large Array (VLA) and Multiple Element Radio Linked Interferometer Network (MERLIN) radio telescopes, at 7 mm and 4.4 cm respectively, of the prototype Class 0 protostar VLA1623. At 7 mm we detect two sources (VLA1623A & B) coincident with the two previously detected components at the centre of this system. The separation between the two is 1.2 arcsec, or  $\sim 170$  AU at an assumed distance of 139 pc. The upper limit to the size of the source coincident with each component of VLA1623 is  $\sim 0.7$  arcsec, in agreement with previous findings. This corresponds to a diameter of  $\sim 100$  AU at an assumed distance of 139 pc. Both components show the same general trend in their broadband continuum spectra, of a steeper dust continuum spectrum shortward of 7 mm and a flatter spectrum longward of this.

We estimate an upper limit to the VLA1623A disc mass of  $\leq 0.13 M_{\odot}$  and an upper limit to its radius of  $\sim 50$  AU. The longer wavelength data have a spectral index of  $\alpha \sim 0.6 \pm 0.3$ . This is too steep to be explained by optically thin free-free emission. It is most likely due to optically thick free-free emission. Alternatively, we speculate that it might be due to the formation of larger grains or planetesimals in the circumstellar disc. We estimate the mass of VLA1623B to be  $\leq 0.15 M_{\odot}$ . We can place a lower limit to its size of  $\sim 30 \times 7$  AU, and an upper limit to its diameter of  $\sim 100$  AU. The longer wavelength data of VLA1623B also have a spectral index of  $\alpha \sim 0.6 \pm 0.3$ . The nature of VLA1623B remains a matter of debate. It could be a binary companion to the protostar, or a knot in the radio jet from VLA1623A.

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## *Abstracts of recently accepted major reviews*

### **The Plaskett Lecture: Star Formation in the Perseus Molecular Cloud**

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Large-scale surveys of the Perseus molecular cloud have provided many clues as to the processes occurring during star formation. Here, analysis of both column density maps and kinematic data (maps and pointed data) are discussed and compared with predictions from simulations. Results include a column density threshold for the formation of dense star-forming cores and that the dense cores are quiescent within their local environment, while the molecular cloud as a whole has turbulent motions that are dominated by large-scale modes. Some of these results have already been used to constrain models of star formation, and the others can be included as future tests of the models. The next few years of star formation research promises to provide exciting advances to the field, particularly with the Gould Belt Legacy Surveys in progress at several facilities, including the James Clerk Maxwell Telescope (JCMT).

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<http://xxx.lanl.gov/abs/1104.4269>

The Star Formation Newsletter is a vehicle for fast distribution of information of interest for astronomers working on star formation and molecular clouds. You can submit material for the following sections: *Abstracts of recently accepted papers* (only for papers sent to refereed journals), *Abstracts of recently accepted major reviews* (not standard conference contributions), *Dissertation Abstracts* (presenting abstracts of new Ph.D dissertations), *Meetings* (announcing meetings broadly of interest to the star and planet formation and early solar system community), *New Jobs* (advertising jobs specifically aimed towards persons within the areas of the Newsletter), and *Short Announcements* (where you can inform or request information from the community).

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## Outflow and infall in high-mass star forming regions

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Ph.D degree awarded: March 2011

High-mass stars form together with clusters of low-mass stars. Therefore, understanding their formation mechanism and evolution necessarily involves investigating massive molecular clumps, which are the sites where whole stellar clusters form. The main goal of the present PhD thesis has been to study observationally outflowing and infalling motions within such regions, mostly through millimetre observations of molecular lines.

A first  $^{13}\text{CO}(2-1)$  and  $\text{C}^{18}\text{O}(2-1)$  survey has aimed at searching for outflows towards a sample of 11 very luminous high-mass molecular clumps known to be undergoing massive star formation. With a sample composed largely of more luminous objects than in previous studies, this work complements analogous surveys performed by other authors by adding the missing highest luminosity sources. We find that molecular outflows are present in all the observed sources. From a comparison between our results and those found by other authors at lower masses, it is clear that the outflow parameters (mass loss rate, mechanical force, luminosity, etc) increase with the bolometric luminosity of the clumps and with the ionising photon rate of the associated UC HII regions, indicating that high-mass stars drive more powerful outflows.

In the last 15 years, the observational study of infrared dark clouds has provided evidence that these objects may be associated with the earliest evolutionary phases of star and cluster formation. This, together with recent theoretical predictions which set a minimum column density of a clump to form a massive star, has motivated a second single-dish survey towards a sample of 48 massive molecular clumps. The sample is composed of both IR-dark and IR-luminous objects, i.e. objects in different evolutionary states, and covers a wide range of column densities.  $\text{HCO}^+(1-0)$ ,  $\text{HCN}(1-0)$ , and  $\text{C}^{18}\text{O}(2-1)$  mapping in search of infall and outflow signatures was performed towards each sample source. Our findings indicate that, in terms of outflow frequency and energetics, both IR-dark and IR-luminous molecular clumps present equivalent signatures of star formation activity. The most important result is that we measure a surface density threshold of  $0.3 \text{ g cm}^{-2}$  above which outflows are detected in 100% of cases and are also more massive. This suggests that the formation of high-mass stars requires sufficiently high clump column densities, agreeing with the theoretical predictions. A low infall detection rate is measured, but this is significantly higher for the IR-dark sub-sample, suggesting that these objects could be associated with the onset of star formation.

Further  $\text{SiO}(2-1)$  and  $(3-2)$  single-pointing observations towards an extended version of our sample (adding up 57 sources in total) resulted in the detection of extended SiO wings in almost 90% of our targets, which confirms that high-velocity molecular outflows are present in most of the sample sources. Remarkably, a decay in the SiO outflow luminosity with  $L_{\text{bol}}/M$ , a parameter which we consider a rough estimate of time or evolutionary phase. This result is analogous to what is found in the low-mass regime and represents the first clear evidence of a decrease of SiO outflow luminosity with time in a homogeneous sample of high-mass molecular clumps in different evolutionary stages.

[http://www.arcetri.astro.it/~sepulcre/tesi\\_final.pdf.gz](http://www.arcetri.astro.it/~sepulcre/tesi_final.pdf.gz)

## *New Jobs*

### **Postdoctoral Research Scientist: Gas Evolution in Protoplanetary Systems**

The Kapteyn Astronomical Institute in Groningen, The Netherlands, invites applications for a postdoctoral research scientist. The successful candidate is expected to actively participate in the Herschel Open Time Key Program GASPS ('Gas Evolution in Protoplanetary Systems', PI: Dent) and to carry out research related to protoplanetary disks. He or she will also help preparing and carrying out ALMA observing programs.

The group of Dr. Kamp is strongly involved in research on the structure and evolution of protoplanetary disks linking sophisticated two-dimensional thermo-chemical disk models with new multi-wavelength observational data. Research topics in Groningen currently include cosmology, galaxy evolution, star and planet formation and interstellar matter. The postdoctoral research scientist will encounter a stimulating scientific environment being in the same building as SRON, the PI institute and Instrument Control Center for the HIFI instrument. Staff from the Kapteyn Astronomical Institute and SRON are involved in many galactic and extragalactic Herschel Key Programs. Thus, there is an exciting range of opportunities to establish new collaborations. The Kapteyn Institute is part of the Netherlands Research School for Astronomy and belongs to the top research institutions in Astronomy worldwide.

Interested applicants should have a PhD in astrophysics or physics and proven experience in far-infrared and/or submm observations, including analysis of line data and good knowledge of (molecular) spectroscopy. The ability to work in an international team and a good command of the English language are essential. Experience with the Herschel/PACS instrument and/or submm facilities is an asset. The University of Groningen offers a salary dependent on qualifications and work experience up to a maximum of EUR 4374 (scale 11) gross per month for a full-time position. The duration of the contract is 2 years with a possible extension to a third year.

Interested candidates should send application material, including a curriculum vitae, a brief statement of past research and future plans, and arrange for three letters of reference to be sent to Dr. Inga Kamp, Kapteyn Astronomical Institute, P.O. Box 800, 9700 AV Groningen, The Netherlands (E-mail address: kamp *at* astro.rug.nl). Selection of candidates will start May 16, 2011, and will continue until the position is filled.

### **Post-doctoral position in the field of interstellar medium and Astrochemistry in Paris**

The project SCHISM (Structure and Chemistry of the Interstellar medium) is a four year French research project led by J. Pety, aiming at deepening our understanding of the interplay of the physics in chemistry in shaping the interstellar medium. (schism.ens.fr). The project involves three teams located in IRAM-Grenoble (J Pety), Observatoire de Paris-Meudon (F. Le Petit) and Ecole Normale Supérieure (M. Gerin). In this framework, we are offering a two year post-doctoral contract to work in the ENS-Paris group. The group has access to the French and European millimeter and submillimeter telescopes (IRAM and through ESO), and to excellent local and French computing facilities. It is also deeply involved in the scientific exploitation of the Herschel satellite, as a member of the HIFI instrument team. The main project is the PRISMAS key programme, dedicated to the study of the diffuse interstellar medium by submillimeter and far infrared absorption spectroscopy. The PRISMAS project is surveying the ground state lines of the main interstellar hydrides (CH, CH<sup>+</sup>, NH, NH<sub>2</sub>, NH<sub>3</sub>, OH<sup>+</sup>, H<sub>2</sub>O<sup>+</sup>, H<sub>2</sub>O, H<sub>3</sub>O<sup>+</sup>, HF, etc.) by absorption spectroscopy towards a restricted sample of massive star forming regions.

We are looking for a young scientist interested in joining the project, with some expertise in molecular astrophysics. He/she will be in charge of part of the PRISMAS data (and follow-up) analysis and processing, as well as to the associated scientific analysis and chemical modeling. Therefore a preference will be given to scientists with a previous knowledge of millimeter and submillimeter data analysis, but all applications are welcome.

The post-doctoral position is offered for two years. The approximate net monthly salary will be 2200 euros. The preferred starting date is Sept 1st, 2011. Applications must be sent by email to maryvonne.gerin *at* ens.fr no later than Mays 31st, including a CV, publication list, a short statement of research. At least one reference letter must also be sent to the same address.

Contact persons: M. Gerin (maryvonne.gerin@ens.fr) and Jerome Pety (pety@iram.fr)

Included Benefits: Social security and retirement benefits are included according to the French social security rules.

## *Meetings*

### **The panchromatic view of star formation and proto-planetary disks in diverse environments**

Progress in studying star and planet formation over the last decade has been immense. Spurred by the impetus of major space-based facilities such as Spitzer, Hubble and Chandra, many of the Galaxy's more prominent star-forming regions have now been mapped from radio to X-rays. Recent sub-millimeter access to molecular species and interferometric techniques from optical to radio are also providing detailed insights into protoplanetary disk chemistry and structure in many of these regions. This two-session "Meeting in a Meeting" at the 218th meeting of the American Astronomical Society will focus on the most recent key observations and modeling that is shaping current ideas on how stars and planets form and evolve, from low-mass star forming regions to starbursts. The discussion will point the directions for observational and theoretical attack in the coming new era of ALMA and JWST.

Time, date and location:

10.00-11.30am, 2.00-3.30pm, May 25th 2011

America Central, The Westin Copley Place, Boston, MA

SOC:

Jeremy J. Drake, Nicholas J. Wright, Mario G. Guarcello

Invited Speakers:

Lee Hartmann (Michigan), Leisa Townsley (Penn State), Scott Wolk (SAO), Robert Gutermuth (Smith College), Karin Oberg (SAO), Catherine Espaillat (SAO).

Contact:

jdrake *at* head.cfa.harvard.edu

#### **Moving ... ??**

If you move or your e-mail address changes, please send the editor your new address. If the Newsletter bounces back from an address for three consecutive months, the address is deleted from the mailing list.