COOLNEWS

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Stellar Abstracts

Alkali-Activity Correlations in Open Clusters

Jeremy R. King[1] & Simon C. Schuler[1]

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We present a census of correlations between activity measures and neutral resonance lines of the alkali elements Li I and K I in open clusters and star forming regions. The majority of very young associations and star formation regions show no evidence of Li-activity correlations, perhaps because their chromospheric activity indicators have a dominant origin in accretion processes with implied disk clearing timescales in the range of a few $\times 10^6$ to $\sim 4\times 10^7$ years. Alkali-alkali and/or -activity correlations are newly noted within IC 2391, M34, and perhaps Blanco 1 and NGC 6475. Global x-ray luminosities are not as robust indicators as traditional optical indicators of alkali-activity correlations, nor are Li I - K I relations. Intracluster alkali-activity correlations are *not* global, but are seen only within different intracluster subsamples, evincing rich behavior. Li- and K-activity correlations appear to go hand-in-hand, likely suggesting at least some part of intracluster Li variance is not due to real differential Li depletion. While up to $\sim$90% of the star-to-star variance in Li I and K I within such a subsample can be related to that in optical chromospheric emission, significant Li dispersion above observational scatter may remain even after accounting for this. We suggest, e.g., that *at least* 3 independent mechanisms (including a possible intra-cluster age spread) influence the distribution in the M 34 Li-$T_{\rm eff}$ plane. We argue that Li-activity correlations are not illusory manifestations of a physical Li-rotation connection. While an unexpected correlation between Li, chromospheric emission, and the λ6455 Ca I feature in cool M 34 dwarfs indicates the role of "activity" is played by spots/plages, we note that the alkali-"activity" correlations are qualitatively opposite in sign to other abundance anomalies being rapidly delineated in active, young, cool stars.

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Orbital Period Variation in Close Binaries from Radial Velocity Data and Magnetic Activity Cycles. II. HR 1099

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We studied orbital period changes in the non-eclipsing close binary HR 1099, one of the most bright members of the RS CVn class of magnetically active binary systems. Intermediate-resolution optical spectroscopy and IUE archive spectra were used to build radial-velocity curves yielding epochs of superior conjunction with an accuracy of 0.01 days. The final database ranged from 1976 to 2002 and allowed us a better assessment of the amplitude of the orbital period variation and its timescale. On the basis of such results, the mechanisms proposed to explain the observed period change were briefly discussed giving further support to the possible connection between the orbital period modulation and the change of the gravitational quadrupole moment of the K1 subgiant component, in the framework of the model elaborated by Lanza et al. (1998).

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Rotational Evolution of Low Mass Stars: The Case of NGC 2264

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Our study is based on an extensive photometric monitoring program in the young (2–4 Myr) open cluster NGC 2264 by Lamm et al. (2004a). This program resulted in a sample of 405 periodic variables which are most likely pre-main sequence (PMS) members of the cluster. The periodic variability of these stars results from the rotational modulation of the light by stellar spots. In this paper we investigate the rotation period evolution of young stars. This is done by comparing the period distribution of the older NGC 2264 with that of the younger Orion Nebular Cluster (ONC, age: $\sim$ 1 Myr) which is known from the literature. The age ratio between the two clusters was estimated on the basis of PMS models to be about $2^{+0.75}_{-0.5}$. We find that the period distribution of NGC 2264 is similar in form to the ONC but shifted to shorter periods. In both clusters the period distribution depends strongly on the mass and it is bimodal for higher mass stars with $M \geq 0.25\ M_{\odot}$ while it is unimodal for lower mass stars with $M \leq 0.25\ M_{\odot}$. In addition the lower mass stars rotate much faster on average than the higher mass stars. Quantitative comparison between the period distributions of both clusters suggests that a large fraction (about 80%) of stars have spun up from the age of the ONC to the age of NGC 2264. Based on this estimate and the estimated age ratio between the two clusters we find that the average spin up by a factor of 1.5 – 1.8 from the age of the ONC to the age of NGC 2264 is consistent with a decreasing stellar radius and conservation of angular momentum, for most stars. However, within NGC 2264 we did not find any significant spin up from the younger to older stars in the cluster. We also found indications for some ongoing disk-locking in NGC 2264, in particular for the higher mass stars. Our analysis of the period distribution suggests that about 30% of the higher mass stars in NGC 2264 could be magnetically locked into co-rotation with their inner disk. In the case of the lower mass stars, disk-locking seems to be less important for the rotational evolution of the stars. This interpretation is supported by the analysis of the stars' Hα emission. This analysis indicates that the locking period of the higher mass stars is about $P = 8$ days. For the lower mass stars this analysis indicates a locking period of about 2–3 days. We argue that the latter stars are probably not "completely" locked to their disk and propose an evolution scenario for these stars which we call "moderate angular momentum loss". In this scenario angular momentum is continuously removed from the stars but at a rate too low to lock the stars with a constant rotation period. We have done a detailed comparison with the recently published rotational period study of NGC 2264 of Makidon et al. (2004). Even though their obtained period distribution of their quality 1 data on NGC 2264 is indistinguishable within the statistical errors from ours, we come to quite different conclusions about the interpretation. One major reason for these discrepancies is probably the large inhomogeneity of the "whole" Orion region with which Makidon et al. (2004) compare their NGC 2264 data, while we compare our NGC 2264 data only with the ONC, which is the youngest and most homogeneous cluster of the Orion OBI association.

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XMM-Newton Observation of the Young Open Cluster Blanco 1. II.X-ray Variability and Flares.

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We study the X-ray variability of the young open cluster Blanco 1 observed with the EPIC camera on board of *XMM-Newton* X-ray observatory. The time coverage of EPIC observation has allowed us to address the short time scale (hours) variability, while the comparison with previous ROSAT observations has allowed us to investigate the variability on time scale of six years. On the time scale of hours, dM stars of the cluster are more variable than solar-mass stars. The main features of X-ray light curves in dM stars appear to be essentially flare-like events with typical duration of the order of a few ks, while dF–dG stars show smooth variations. Two intense flares were observed in the *ZS76* cluster member. From the analysis of the light curves and of the time resolved X-ray spectroscopy we infer that they occurred in arcades, made of several similar coronal loops ($\sim 10^{10}$ cm long), ignited at $\sim$ 15 ks time delay. Minor heat pulses may occur in the first flare. The similarity of the two flares and of the flaring inferred structures may suggest that the flares are physically connected to each other.
Amplitude variations on the time scale of 6 years are smaller than a factor 2, whereas a factor 10 is observed on the Sun in the same band. This implies a smaller amplitude of any analog of the 11-yr cycle on these young active coronae.

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X-ray Spectral and Timing Characteristics of the Stars in the Young Open Cluster IC 2391

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We present X-ray spectral and timing analysis of members of the young open cluster IC 2391 observed with the XMM-Newton observatory. We detected 99 X-ray sources by analysing the summed data obtained from MOS1, MOS2 and pn detectors of the EPIC camera; 24 of them are members, or probable members, of the cluster. Stars of all spectral types have been detected, from the early-types to the late-M dwarfs.

Despite the capability of the instrument to recognize up to 3 thermal components, the X-ray spectra of the G, K and M members of the cluster are well described with two thermal components (at $kT_1 \sim$ 0.3-0.5 keV and $kT_2 \sim$ 1.0-1.2 keV respectively) while the X-ray spectra of F members require only a softer 1-T model.

The Kolmogorov-Smirnov test applied to the X-ray photon time series shows that approximately 46% of the members of IC 2391 are variable with a confidence level >99%. The comparison of our data with those obtained with ROSAT/PSPC, nine years earlier, and ROSAT/HRI, seven years earlier, shows that there is no evidence of significant variability on these time scales, suggesting that long-term variations due to activity cycles similar to that on the Sun are not common, if present at all, among these young stars.

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On the Potassium-rotation Connection in Late-type Alpha Persei Stars

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We present measurements of the KI λ7699 line from spectra of 19 late-type members of the αPersei cluster obtained with the Intermediate Dispersion Spectrograph at the Isaac Newton Telescope. These stars span a narrow range of T_{eff} from 5091 K to 4771 K, and a wide range of $v \sin i$ values (9 $\mathrm{km\,s^{-1}}$–170 $\mathrm{km\,s^{-1}}$). We find empirically that larger rotational broadening increases the equivalent width of KI λ7699 linearly for $v \sin i$ values from 15 $\mathrm{km\,s^{-1}}$ to 75 $\mathrm{km\,s^{-1}}$. This correlation breaks down for $v \sin i > 75$ $\mathrm{km\,s^{-1}}$. After correction for this effect, we show that the potassium line equivalent widths do not correlate with $v \sin i$.

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The Ca II Infrared Triplet as a Stellar Activity Siagnostic I. Non-LTE Photospheric Profiles and Definition of the R_{IRT} Indicator

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This work is part of a larger project on the study of activity in stars of spectral type similar to, or later than the Sun, from PMS to ZAMS, based on the analysis of the high resolution CaII InfraRed Triplet (CaII IRT: λ = 8498, 8542, 8662 Å) observed profiles. Here, a preliminary study on the diagnostic power of these calcium lines has been performed by means of NLTE calculations of the line profiles with an approximate treatment of UV line-blanketing, for a grid of photospheric models with T_{eff}=4200, 5200, 6200 K, $\log g$=4.0, 4.5, 5.0 and [A/H]=0.0, -1.0, -2.0. We used these calculations to estimate the sensitivity of the profiles to changes in stellar parameters and the effect of departures from LTE. As found by other authors, the CaII triplet NLTE EQWs (equivalent widths) are quite sensitive to photospheric parameters, in particular to T_{eff} and [A/H]. On the other hand, we find that the dependence of the CaII triplet lines central depression (CD=1-central relative flux) on $\log g$ and T_{eff}, and to a lesser extent to [A/H], is very weak. The departure from LTE is negligible when we consider EQWs, unless very metal-poor atmospheres are considered, while CDs can be affected by NLTE by more than 20%. This analysis indicates that in the use of these lines as activity indicators (where the details of the line profile in the core are important), a NLTE treatment is required. Furthermore, we show that a new chromospheric indicator, which we denote R_{IRT}, can be derived from measurements of CaII IRT line central depressions, provided that rotational broadening is taken into proper account. In order to facilitate the use of the CaII IRT lines as activity diagnostics, we give interpolation formulae for estimating line CDs within the range of stellar parameters of our NLTE calculations.

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The Star Formation Region NGC 6530: Distance, Ages and Initial Mass Function

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We present astrometry and BVI photometry, down to $V \simeq 22$, of the very young open cluster NGC6530, obtained from observations taken with the Wide Field Imager camera at the MPG/ESO 2.2 m Telescope. Both the V vs. $B-V$ and the V vs. $V-I$ color-magnitude diagrams (CMD) show the upper main sequence dominated by very bright cluster stars, while, due to the high obscuration of the giant molecular cloud surrounding the cluster, the blue envelopes of the

diagrams at $V \geq 14$ are limited to the main sequence stars at the distance of NGC6530. This particular structure of the NGC6530 CMD allows us to conclude that its distance is about $d \simeq 1250$ pc, significantly lower than the previous determination of d=1800 pc.
We have positionally matched our optical catalog with the list of X-ray sources found in a Chandra-ACIS observation, finding a total of 828 common stars, 90% of which are pre-main sequence stars in NGC6530. Using evolutionary tracks of Siess et al. (2000), mass and age values are inferred for these stars. The median age of the cluster is about 2.3 Myr; in the mass range (0.6–4.0) $M_{\odot}$, the Initial Mass Function (IMF) shows a power law index $x = 1.22 \pm 0.17$, consistent with both the Salpeter index (1.35), and with the index derived for other young clusters ; towards smaller masses the IMF shows a peak and then it starts to decrease.

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The Heating of Cool-star Coronae: From Individual Loops to Global Flux-flux Scalings.

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We simulate surface field patterns for cool dwarf stars of widely different levels of activity and estimate the associated global coronal radiative losses. We find that the integrated X-ray brightness of coronae of cool stars is relatively insensitive to the patterns of their surface magnetic field, and that the X-ray flux is determined almost entirely by the magnetic flux through the stellar surfaces. This reconciles potentially inconsistent findings in the literature for the heating of solar and stellar coronae: solar studies suggested that the heating flux density entering coronal loops scales as $F_{\rm H} = \epsilon_0 \, B^{\beta}/L^{\lambda}$ (for a magnetic flux density B at the base of a loop of length L, with $\beta = 1.0 \pm 0.3$ and $\lambda = 1.0 \pm 0.5$), whereas combined solar and stellar data suggested that the X-ray flux density $F_{\rm X}$ from entire cool-star coronae depends only on the average magnetic flux density $\langle|\varphi|\rangle$ through the stellar photospheres. We find that the above two scalings are compatible because loop lengths and base magnetic flux densities are essentially uncorrelated for the global coronal loop ensemble and because the average loop lengths differ much less from star to star for Sun-like stars of different activity than the average base field strengths. In addition, we explore the scaling properties of the constant of proportionality ϵ_0 for stars of significantly different surface gravity.

Submitted to ApJ

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Solar Abstracts

DOT Tomography of the Solar Atmosphere III. Observations and Simulations of Reversed Granulation

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We compare high-quality image sequences from the Dutch Open Telescope (DOT) with synthetic image sequences obtained from 3D radiation-hydrodynamics simulations of the solar granulation. In particular, we study the subsonic brightness pattern observed in the wings of Ca II H & K called reversed granulation. The simulations reproduce the observed intensity contrast, time scales, and Fourier behaviour rather well. Most differences can be attributed to the lower resolution of the observations and the smaller geometrical extent of the simulation. We conclude that magnetic fields play no major role in the formation of reversed granulation.

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Wavelet Phase Coherence Analysis: Application to a Quiet–Sun Magnetic Element

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A new application of wavelet analysis is presented, which utilises the inherent phase information residing within the complex Morlet transform. The technique is applied to a weak solar magnetic network region, and the temporal variation of phase difference between *TRACE* 1700 Å and *SoHO*/SUMER C II 1037 Å intensities is shown. We present, for the first time in an astrophysical setting, the application of wavelet phase coherence, including a comparison between two methods of testing real wavelet phase coherence against that of noise. The example highlights the advantage of wavelet analysis over more classical techniques such as Fourier analysis, and the effectiveness of the former to identify wavepackets of similar frequencies but with differing phase relations is emphasized. Using co–temporal, ground–based Advanced Stokes Polarimeter measurements, changes in the observed phase differences are shown to result from alterations in the magnetic topology.

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Detection of Ultra-long-period Oscillations in an EUV Filament

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We report the first detection of long-period ($8-27$ hours) oscillatory intensity variations in a coronal filament. The filament is observed continuously as it crosses the solar disk in a 12-minute-cadence SoHO/EIT 195 Å uninterrupted data set. Cyclic intensity variations are found to be correlated along the filament, while the most pronounced oscillations are detected at its southern end for nearly 6 days. The dominant period of these oscillations is 12.1 hours and the amplitude of the intensity variations reaches approximately 10% of the background intensity. The ultra-long-period oscillations may be interpreted in terms of slow string MHD modes or may be connected with thermal over-stability associated with peculiarities of the cooling/heating function and with the effect of neutrals. These theoretical predictions however do not explain the spatial structure of the oscillations along the filament.

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Low-Mass and Substellar Abstracts

Quiescent X-ray Emission from an Evolved Brown Dwarf?

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I report on the X-ray detection of Gl 569 Bab. During a 25 ksec *Chandra* observation the binary brown dwarf is for the first time spatially separated in X-rays from the flare star primary Gl 569 A. Companionship to Gl 569 A constrains the age of the brown dwarf pair to $\sim 300-800$ Myr. The observation presented here is only the second X-ray detection of an evolved brown dwarf. About half of the observing time is dominated by a large flare on Gl 569 Bab, the remainder is characterized by weak and non-variable emission just above the detection limit. This emission – if not related to the afterglow of the flare – represents the first detection of a quiescent corona on a brown dwarf, representing an

important piece in the puzzle of dynamos in the sub-stellar regime.

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Rotation and Variability of Very Low Mass Stars and Brown Dwarfs Near ϵ Ori

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We explore the rotation and activity of very low mass (VLM) objects by means of a photometric variability study. Our targets in the vicinity of ϵ Ori belong to the Ori OB1b population in the Orion star-forming complex. In this region we selected 143 VLM stars and brown dwarfs (BDs), whose photometry in RIJHK is consistent with membership of the young population. The variability of these objects was investigated using a densely sampled I-band time series covering four consecutive nights with altogether 129 data points per object. Our targets show three types of variability: Thirty objects, including nine BDs, show significant photometric periods, ranging from 4 h up to 100 h, which we interpret as the rotation periods. Five objects, including two BDs, exhibit variability with high amplitudes up to 1 mag which is at least partly irregular. This behaviour is most likely caused by ongoing accretion and confirms that VLM objects undergo a T Tauri phase similar to solar-mass stars. Finally, one VLM star shows a strong flare event of 0.3 mag amplitude. The rotation periods show dependence on mass, i.e. the average period decreases with decreasing object mass, consistent with previously found mass-period relationships in younger and older clusters. The period distribution of BDs extends down to the breakup period, where centrifugal and gravitational forces are balanced. Combining our BD periods with literature data, we found that the lower period limit for substellar objects lies between 2 h and 4 h, more or less independent of age. Contrary to stars, these fast rotating BDs seem to evolve at constant rotation period from ages of 3 Myr to 1 Gyr, in spite of the contraction process. Thus, they should experience strong rotational braking.

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Laboratory Astrophysics Abstracts

Experimental Observation and Characterization of the Magnetorotational Instability

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Differential rotation occurs in conducting flows in accretion disks and planetary cores. In such systems, the magnetorotational instability can arise from coupling Lorentz and centrifugal forces to cause large radial angular momentum fluxes. We present the first experimental observation of the magnetorotational instability. Our system consists of liquid sodium between differentially rotating spheres, with an imposed coaxial magnetic field. We characterize the observed patterns, dynamics and torque increases, and establish that this instability can occur from a hydrodynamic turbulent background.

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Ph.D. Thesis Abstracts

Surveys for Low-mass Stars and Brown Dwarfs: Solar Neighbourhood and Intermediate-age Clusters α Per and Collinder 359

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Ph.D degree awarded: July 2004

In this thesis, we describe results of surveys for low-mass stars and brown dwarfs, including older ones in the nearby field and younger ones in more distant clusters.

First, we present the outcome of a proper motion survey conducted in the southern sky, aimed at finding some of the nearest and coolest neighbours to the Sun. We have uncovered numerous ultracool dwarfs within 50 parsecs, including two late-M dwarfs within 10 parsecs, four L dwarfs, an active M8.5 dwarf companion to a binary system at about 20 parsecs, and the closest brown dwarf binary, ε Indi Ba,Bb, at just 3.6 pc.

Second, we focus on the substellar mass function in young open clusters. We have carried out a wide-field near-infrared survey of a 0.7 square degree region in the α Per cluster, yielding new member candidates, including several brown dwarfs. In addition, we present optical spectroscopy of about 30 optically-selected cluster members. We confirm the membership of all probable candidates based on chromospheric activity and surface gravity measurements.

We have also conducted an optical survey of a 1.6 square degree area in Collinder 359 within the framework of a large Canada-France-Hawaii-Telescope Key Programme conducted with the CFH12K wide-field camera. New bona-fide members have been extracted from solar mass stars to brown dwarfs, yielding a revised distance of 500 ± 100 pc and an age of 80 ± 20 Myr for the cluster. We have derived the cluster luminosity and mass functions down into the substellar regime. The derived mass function continues rising into the substellar regime with a slope flatter than that estimated for Pleiades-like clusters, although the slopes might still be consistent within the uncertainties.

A pdf file of this thesis is available at the following URL: http://www.aip.de/groups/publications.html

Unveiling the Hidden Life of Stellar Embryos

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The earliest evolutionary phase of star formation, in which a deeply embedded protostar is known to exist, is the so-called Class 0 stage (André et al. 1993, ApJ 406, 122). Because protostars in this phase, called Class 0 sources, are difficult to detect, constraining their physical properties is a challenging task. In this dissertation I study the thermal emission from the dust of the circumstellar envelopes of Class 0 sources in order to investigate the physical structure (geometry, radial intensity profile, spatial temperature and spectral energy distributions (SEDs)), and the properties of these objects (mass, size, bolometric luminosity (L_{bol}) and temperature (T_{bol}), and age). Submillimetre Common-User Bolometer Array (SCUBA) imaging at 450 and 850 μm of the thermal dust emission of envelopes of Class 0 sources in the Perseus and Orion molecular cloud complexes, a model of the envelope, the implementation of techniques like the blackbody fitting and the 1D radiative transfer code (by Wolf, Henning & Stecktlum 1999, A&A 349, 839), and an evolutionary model for protostars (by Smith 2002, in "The Origins of Stars and Planets: the VLT view", ESO Astrophysics Symposia, eds. J. Alves & M. McCaughrean) provide a way to model and to interpret the structure of Class 0 sources, and to estimate their physical properties in an evolutionary context.

The main results of this study are: 1) From the continuum SCUBA maps, 36 submillimetre sources ($> 3\sigma$) are detected. Some of them are extended, and many contain multiple condensations, as well as extended diffuse features. Twelve of these objects are reported here for the first time, 15 sources are analyzed, and nine Class 0 sources are studied in detail. 2) An average value of the aspect ratio of the sample of 1.3 $\pm$ 0.1 is found, suggesting that the envelopes of Class 0 sources can be described approximately as spherically symmetric. Nevertheless, a departure of this symmetry in some cases is found. This mismatch could be produced by several factors like magnetic fields of energy densities sufficiently large to influence the object structure, the bipolar outflow, rapidly rotating structures, or high levels of angular momentum. 3) The sample consists of cool objects (T_{bol} ranges of $\sim$27-50 K) which have L_{bol} of $\sim$4-85 $L_{\odot}$. 4) The physical structure of a Class 0 envelope is characterized by the gas and dust temperature distribution $T(r) \propto r^{-q}$, and the density distribution $\rho(r) \propto r^{-p}$, with q=0.4 and p in the range of 1.5-2 (p=2 at younger ages and p=1.5 at later times). In the inner part of the envelope (10 AU), $T(r)$ departs from the single-power law index of 0.4, a phenomenon caused probably by thermal convection in the inner envelope. 5) From the thermal emission of the dust and following an emissivity model (Hildebrand 1983, QJRAS 24, 264), the average value of the gas and dust mass of a sample based on 15 sub-mm selected objects is 2.5 $\pm$ 0.6 $M_{\odot}$. Examination of the radial profiles of the sample shows that the objects are surrounded by extended envelopes. Typically, the sizes are $\sim$1500-6000 AU (at 450 μm) and $\sim$4000-9000 AU (at 850 μm). 6) A sublimation radius of 3-5 AU at 450 μm, τ=1 and p=2 ($\sim$10 AU for p=1.5) is estimated, which is roughly the same as the radius of the photosphere (because the gas that is accreted close to the central object is optically thick, the central source should radiate from this specific radius, where the layer changes between the optically thick and the thin regime). 7) The blackbody curve and the data-points show significant deviations at the Infrared Astronomy Satellite (IRAS) 12 and the 25 μm points for the Class 0 sample. If these data-points had correct flux measurements, the sources would exhibit an excess of mid-IR emission which could be caused by ongoing outflow/dust interactions. Because it is likely that these IRAS points are incorrect in some cases, further mid-IR observations of these objects are necessary to investigate the nature of this possible excess. 8) The

assumption of spherical symmetry in the envelope model is reasonable. Nevertheless, deviations from this geometry between observed and modeled SEDs at short wavelengths, and between observed and simulated radial profiles of relatively spherical Class 0 sources become extremely prominent. This discrepancy could be due to the exclusion of a non-spherical geometry, of cavities produced by molecular outflows, or of a flattened disk in the model; it could also be due to specific assumptions considered here, e.g. a single point-like nature of the sources, and a constant dust opacity with radius in the model. 9) For the sample of Class 0 sources, the model-dependent ages are in a range of 1-3 10^4 yr.

Abstract Guidelines

Abstracts for *COOLNEWS* are solicited for papers that have been recently accepted by or submitted to refereed journals, and for recent Ph.D. theses. Abstracts for conference proceedings articles are *not* posted in *COOLNEWS*. The subject matter should pertain directly to cool stars (spectral types F,G,K,M or L), substellar objects, or the sun. Both theoretical and observational abstracts are appropriate.

Abstracts dealing with cool pre-main-sequence (PMS) stars will generally not be included in *COOLNEWS*, since they are already covered by the *Star Formation Newsletter*. Exceptions to this rule will be considered if the subject matter is truly cross-disciplinary. If you wish to submit a cross-disciplinary abstract on PMS stars, then first submit it to the *Star Formation Newsletter*. After doing so, submit the abstract to *COOLNEWS* accompanied by a short e-mail stating that it has already been submitted to the *Star Formation Newsletter*, and summarizing why it will be of interest to the cool star/solar community at large.

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