COOLNEWS

A RESEARCH NEWSLETTER DEDICATED TO COOL STARS AND THE SUN

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Stellar Abstracts

ROSAT Coronal Temperatures of Young Late Type Stars

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We analyze ROSAT X-ray spectra of a sample of young late type stars by fitting them with a continuous emission measure model with power-law temperature dependence up to a maximum temperature. This model gives successful fits to all spectra of our sample. While most of the spectra can also fitted equally successful with the frequently used two temperature model, we argue and provide evidence that the continuous temperature distribution model probably describes the coronal temperature structure in a more meaningful way.

From our fitting results we find a very good correlation between the X-ray surface flux and the maximum coronal temperature with the functional form $F_{\rm X} \propto T_{\rm max}^{(2.2\pm0.2)}$. This correlation extends over several orders of magnitude and is valid for the very young T Tauri stars as well as for the much older young main sequence stars in our sample. Since the X-ray surface flux is a good measure of the stellar activity and shows a clear dependence on the stellar rotational velocity, the correlation means that the coronal temperature is related to the X-ray activity and ultimately determined by stellar rotation.

Finally, we interpret our results with a simple analytic loop model and find that the coronae of the active young stars are probably dominated by loops with generally higher pressure as compared to typical solar active region loops.

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Photometry in the Open Clusters IC 2602 & NGC 6475

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CCD photometry has been obtained in the regions of the open clusters IC2602 and NGC6475 for the purpose of identifying likely optical counterparts to x-ray sources. Photometry has also been obtained for relatively bright stars

in both clusters in order to improve upon previous photometry and to assess membership. In IC2602, the new candidate members associated with x-ray sources include two visual binary systems with the secondary components being the lowest mass candidate members identified to date. In NGC6475, several possible optical counterparts to the strongest x-ray source in the field of the cluster have been given, though the true optical counterpart remains unknown.

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ROSAT Pointed Observations of the α Persei Cluster

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We extend the results of a previous ROSAT x-ray raster survey of the open cluster α Persei by the analysis of three 22−25 ksec ROSAT PSPC pointings in this relatively nearby (d $\sim$ 170 pc) and young (age $\sim$ 50 Myr) open cluster. The present study reports on those catalogued stars in the cluster region which are found to be associated, or possibly associated, with an x-ray source. Out of a total of 222 sources, approximately 80 sources are identified with a catalogued star. We detect all previously known K dwarfs, and a majority of M dwarfs within the higher sensitivity, inner PSPC regions. The results from the deep pointings are consistent with those from the previous raster survey of this cluster in terms of the x-ray luminosities measured for sources in common, the detection frequencies among cluster members as a function of spectral type, and the distribution of L_X as a function of color.

The x-ray detections and upper limits provided by the PSPC observations have been combined with the raster survey results to create a merged raster/PSPC dataset reflecting the x-ray properties of the α Per cluster. The $v \sin i$ − activity relation among G/K members is reviewed using the combined dataset. The α Per members with $v \sin i > 30$ km/s all show saturated levels of coronal activity, with the saturation level decreasing slowly from $\log(L_X/L_{bol}) \sim -3$ at 50 km/s to $\log(L_X/L_{bol}) \sim -3.4$ at 200 km/s. The stars with $v \sin i < 15$ km/s, most with only $v \sin i$ upper limits, show a wide range in coronal activity ($-4.3 < L_X/L_{bol} < -2.9$); we assume that coronal activity in α Per increases with increasing rotation rate for $v \sin i < 15$ km/s, but the functional form of the relation cannot be determined from existing data. The x-ray luminosity distribution functions among F−M α Per stars have been recomputed using the merged raster/PSPC dataset and compared to the Pleiades. The findings of the raster survey are confirmed, with F and G α Per dwarfs clearly exhibiting higher average emission than their Pleiades counterparts, while α Per K dwarfs show only slightly higher activity. The revised α Per M dwarf XLDF is in closer agreement with the Pleiades M dwarf distribution.

We discuss the apparent detection in x-rays of the one evolving blue supergiant member of this cluster, α Per itself. In addition, the sensitive PSPC observations may have detected x-ray sources associated with very low mass candidate cluster members at spectral type $\sim$ M5. We also provide a summary of the x-ray flare characteristics (peak $\sim 10^{31}$ ergs/s) for three α Per members.

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Doppler imaging of Stellar Surface Structure. III. The X-ray Source HD 116544 = IN Virginis

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We present the first Doppler image of the EXOSAT X-ray source EXO 1321.8–0203, recently identified to be a chromospherically active star exhibiting periodic light variations and consequently named IN Virginis. Our high-resolution spectra show IN Virginis to be a single-lined spectroscopic binary with an orbital period of 8.2 days, very strong Ca II emission, and an inverse P-Cygni type Hα line profile. A detailed spectrum synthesis yields a photospheric temperature of 4600±70 K and $\log g = 3.5 - 4.0$ and slight overabundance of the heavy elements but otherwise solar abundances.

We redetermine the photometric period from a new set of photometry obtained with a robotic photoelectric telescope in the years 1994 and 1995 and conclude that IN Virginis is more likely a K2-3 subgiant instead of a K5 dwarf or K4 subgiant as previously published.

The Doppler images from March 1994 show a cool polar spot that is dominated by a large appendage reaching a latitude of $+40°$. Its average temperature difference, photosphere minus polar spot, is 1000 K. Additionally, three equatorial spots are clearly recovered but have $\Delta T \approx 400$ K. Possibly, we also detected a warm equatorial feature with $\Delta T \approx -150$ K. We emphasize that Doppler imaging of IN Virginis is very challenging because of both the small $v \sin i$ of the star (24.0 $\mathrm{km\,s^{-1}}$) and its relatively cool photosphere causing many weak absorption-line blends. Still, maps from the different lines appear encouragingly similar.

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Coronae on Solar-like Stars

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The results of a complete and sensitive X-ray survey of all known stars of spectral type A, F, and G in the immediate solar vicinity with distances less than 13 pc are presented. The X-ray data were obtained primarily from the ROSAT all-sky survey (RASS); those program stars not detected in the RASS data, were subsequently studied in the ROSAT pointed observation program. The detection rate among the F stars in the sample is 95 %, that of the G stars 83 %, the non-detections being due to survey observations. On the other hand, none of the A-stars with spectral type earlier than A7 could be detected even in sensitive pointings. I conclude from this that coronal formation in stars with surface convection zones is universal. The X-ray luminosities range over about four orders of magnitude, and can be well described with a log-normal distribution. Large X-ray outputs are correlated with kinematic age as assessed from space motions. I show the existence of a correlation between the total emitted X-ray surface flux and spectral hardness, such that more luminous objects tend to have larger spectral hardness, thus implying higher coronal temperatures. The mean X-ray surface fluxes span the same range as is observed for various solar coronal features, with a rather well-defined minimum X-ray flux being present; this minimum X-ray surface flux agrees very well with the X-ray surface flux of solar coronal holes. It therefore appears that a coronal hole represents the minimum state of "activity" not only for the Sun but also for other stars. I discuss a few implications of this finding especially with regard to properties of stars in Maunder minima states. Accepted by A&A

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Environments of Active Close Binaries II: GK Hydrae and TY Pyxidis

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High-resolution spectroscopic observations were obtained for two eclipsing active close binary systems, GK Hydrae and TY Pyxidis. For GK Hya excess emission was observed in the Balmer lines and Mg I b lines while TY Pyx showed excess emission in the Balmer lines and Ca II H & K lines. The emission from GK Hya arises from a global phenomenon associated solely with the secondary component. The lack of significant He I D_3 excess absorption and an analysis of the flux ratio in the Balmer lines suggest that the emission originates in prominence-like material seen off the limb of the star. A marginal broad excess absorption band centered around the Balmer emission peaks may be caused by this material absorbing the stellar continuum against the disk with high (350 km $\mathrm{s^{-1}}$) line-of-sight turbulent velocities. The inference that plage-like regions and associated star-spots are not substantial on this star is in agreement with the lack of spot modulation in the photometric light curve. For TY Pyx the majority of the Hβ excess and a larger proportion of the Ca II core emission could be attributed to a global phenomenon on the primary. Analysis suggests that very large volumes are responsible for the emission, however, there is no observational evidence for the existence of discrete extended structures around TY Pyx.

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Lithium in Black Hole Binaries: the Case of X-ray Nova Muscae 1991

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We report the detection of the LiI λ6708 resonance line in the K4V secondary of the black-hole binary Nova Muscae 1991. The LiI feature changes with orbital phase, being stronger (EW$\sim$400mÅ) around ϕ=0.0 (observing the dark side of the secondary) and weaker (EW$\leq$190mÅ) around ϕ=0.5 (observing the side facing the compact object). This effect is interpreted as LiI ionization induced by UV/X-ray illumination of the inner hemisphere of the companion star. From the strength of the LiI feature observed around ϕ=0.0 we infer a photospheric lithium abundance of log N(Li)$\sim$3. However, this value is in fact a lower limit to the true Li abundance because we have not fully corrected for the LiI overionization expected from UV/X-ray illumination.

High lithium abundances are becoming a common feature in the secondaries of black hole binaries. After the Li detections in V404 Cyg, A0620-00 and GS2000+25, our observations of Nova Muscae not only add a new case to the list, but also demonstrate the impact of irradiation on the formation of the LiI line for the first time. The LiI features observed in the other black hole binaries are probably also affected by irradiation, although not as strongly as in Nova Muscae, and their Li abundances would be higher than previously thought. The most attractive scenario for explaining the origin of the high Li abundances in black hole binaries appears to be nucleosynthesis during the explosive accretion events that characterize these objects. We argue that our LiI detection in the secondary of X-ray Nova Muscae 1991, and the transient γ-ray narrow emission feature at 476 keV observed during the 1991 outburst, are both signatures of Li production around the black hole. We propose that the γ-ray emission line was due to ^{7}Be electron capture which yielded excited ^{7}Li atoms. This reaction is able to account for the central energy, narrow width and time scale of the observed γ-ray emission feature. The presence of Li on the surface of the secondary shows that Li atoms created during the outburst can escape and enrich the interstellar medium.

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Rotation, Turbulence, and Evidence for Magnetic Fields in Southern Dwarfs

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We model high resolution spectra using a simple radiative transfer analysis to derive projected rotational velocities ($v \sin i$) and macroturbulent velocity dispersions ($v_{\rm mac}$) for 49 southern dwarf stars (including many first-ever measurements). We compare our results to previous values, and estimate rotation periods ($P_{\rm rot}$) and sin i values where possible. We confirm that $v_{\rm mac}$ generally decreases with decreasing temperature for $T_{\rm eff} \geq 5000$ K. Magnetically active stars tend to show enhanced values of $v_{\rm mac}$. This may be due to a difference in the mean stellar convective properties, a change in the mean stellar temperature structure, or a combination of both. We identify a group of stars which exhibit correlations between the derived velocities and line Landé $g_{\rm eff}$ values, implying the presence of significant surface magnetic flux.

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ROSAT All-sky Survey Observations of Pop II Field Binaries: X-ray Activity of Old, Metal-poor Stellar Coronae

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This study represents the first X-ray observations of an extended sample of Pop II field binaries, aimed at investigating the properties of old, metal-poor stellar coronae. Analysing X-ray observations from the ROSAT all-sky survey, we detected only 13 (out of 86) Pop II systems (15% detection rate). The X-ray luminosity function, taking into account both detections and upper limits, has its median at $\log L_x \leq 28.1$ erg s^{-1}, indicating a low average X-ray luminosity, with a high-luminosity tail at $\log L_x \sim 29 - 31$ erg s^{-1}. The only extreme metal-poor system detected is HD 89499. Thus, the detection rate of extreme Pop II systems is lower than of intermediate Pop II, possibly indicating extreme Pop II to be typically less luminous. The X-ray luminosity is not very well correlated with orbital period; long-period Pop II binaries may have high X-ray luminosities and, surprisingly, short-period systems are not *per se* strong X-ray emitters. For a subsample of emission-line Pop II binaries, i.e. the halo component analogs to the RS CVn binaries, the median X-ray luminosity is at least one order of magnitude lower than for the RS CVns. The lower activity levels of the Pop II systems may be caused in part by the presence of fewer evolved stars in the sample and lower metallicity. The extremely old age of Pop II binaries may also give rise to the unexpectedly low X-ray luminosities of some systems (e.g., CD-481741, BD+53080).

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Effect of Chromospheric Activity on the Mean Colours of Late-type Stars

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In this paper we show, for the first time, the effect of activity on the $(U–B)_0$ vs. $(B–V)_0$ colour-colour diagram for a large sample of late type stars. We clearly see that for single-lined spectroscopic RS CVn systems there exists an ultraviolet excess over that recorded for quiescent stars of the same spectral type. The same effect is seen in main-sequence stars but to a lesser extent. From simple arguments we demonstrate that the cause is unlikely to be unresolved flaring, the combined effect of strong chromospheric emission lines, or X-ray/UV back-heating of the photosphere. White-light faculae are a reasonable candidate for the effect however. In our investigation we have not taken into account the effect that metallicity might have on the colour indices.

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Lithium Abundance in Field K and M Dwarfs

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It has recently been suggested that lithium abundance in late-type stars correlates with other stellar characteristics, such as age, chromospheric activity and rotation. For example the cooler components of RS CVn binaries have been compared with inactive field stars of the same spectral type.
To seek a further understanding of this important problem we have examined the lithium abundance anomaly in a sample of late-K and M-type dwarfs. High signal-to-noise, high spectral resolution spectra of a sample of such stars has been obtained using the William Herschel Telescope equipped with the Utrecht Echelle Spectrograph. The region of the Li I resonance line (λ6707.8Å) and nearby transitions of abundant elements (Fe,Ca,Si) have been studied as well as a correlation between Li abundance and chromospheric activity. It was found the correlation between Li abundance and chromospheric activity in the case of K dwarfs while M dwarfs do not reflect this relation.

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Solar Abstracts

On the Patterns of the Solar Granulation and Supergranulation

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We study the cellular patterns of the white–light granulation and of the chromospheric Ca II K supergranular network. We apply a gradient–based tesselation algorithm to define the cell outlines. The geometry of the patterns formed by the associated granular and supergranular flows are very similar, in spite of the substantial difference in length scale. We compare these patterns to generalized Voronoi foams, and conclude that both convective patterns are very nearly compatible with an essentially random distribution of upflow centers, with the downflow boundaries determined by the competing strengths of outflows of neighboring upwellings. There appears to be a slight clustering in upflow positions for the granulation, consistent with the granular evolution. This slight preference for large granules to be surrounded by somewhat smaller ones, makes the granular and supergranular patterns differ enough to allow a correct identification in 3 out of 4 cases by eye. The model analogy suggests that the range in outflow strengths is remarkably small. The patterns appear to be rather insensitive to the details of the competing forces which establish the pattern of the downflow network: similar patterns result under very different conditions, so that little can be learned about the details of the forces involved by studying the geometry of these patterns only.

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Ultraviolet Jets and Bright Points in the Solar Chromosphere. I. Search for One-to-One Relationships

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Ultraviolet spectrograms and spectroheliograms of the solar chromosphere are used to test the suggestion (Dere et al. 1986, Rutten & Uitenbroek 1991) that bright points observed at $\lambda = 1600$ Å, chromospheric jets observed in C I lines near $\lambda = 1560$ Å, and Ca II K_2V bright points are associated with each other and that they are all manifestations of the same wave interaction in the non-magnetic chromosphere. We search for spatio-temporal connections between 1600 Å bright points and C I blue jets using data from the HRTS VI rocket mission, comparing 1600 Å spectroheliograms and a co-spatial C I Dopplershift map on a pixel-by-pixel basis. We find no direct evidence for spatial co-location of bright points and jets, not for instantaneous correspondence and also not when allowing for phase delays as long as three minutes. Also, the average brightness evolution and its rms fluctuation are not obviously different between sites of large C I blueshift and the remaining surface.

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Ultraviolet Jets and Bright Points in the Solar Chromosphere. II. Statistical Correlations

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We use HRTS–VI rocket observations of the solar chromosphere to search for relationships between high-Dopplershift "jets" observed in the C I lines near $\lambda = 156\,\mathrm{nm}$ and internetwork "bright points" observed in the $\lambda = 160\,\mathrm{nm}$ continuum, in sequel to the analysis by Cook et. al 1996 which failed to find a direct connection between these phenomena. We now use the same data to establish statistical correlations between C I Dopplershift and 160 nm brightness modulation in internetwork areas. These mean relations emerge only after extensive spatial averaging and have small amplitude, but are definitely significant. They show that both C I Dopplershift and 160 nm brightness participate in oscillatory behavior with three-minute periodicity and mesoscale (8 Mm wavelength) as well as small-scale (1.4 Mm wavelength) spatial patterning. We find spatial and temporal phase relations between Dopplershift and brightness that confirm that jets and bright points should not be interpreted as isolated entities. Rather, they are chromospheric manifestations, with much pattern interference, of the oscillatory acoustic shock dynamics in the internetwork which also cause Ca II K_2V grains. Additional small-scale modulation is present which we attribute to waves with f-mode character.

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Is the Sun Changing Size?

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From new measurements conducted at the Pic du Midi Observatory with the scanning heliometer from July 1993 to May 1995, we deduced a variability of the solar oblateness with the solar cycle. Over the considered period, it is shown that the solar oblateness follows the daily solar activity variations. This time dependence as been first suggested by a Princeton group in 1985, but only as a conjecture. This would have important implications not only for the terrestrial climate, because changes in the Sun's total energy output implies a variability that climate modelers could not longer ignore, but also for astrometry and in providing information related to the internal structure and dynamics of the Sun.

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Effect of Newtonian Cooling on Waves in a Magnetized Isothermal Atmosphere

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We examine the influence of nonadiabatic effects on the modes of an isothermal stratified magnetic atmosphere. The present investigation is a continuation of earlier work by Hasan and Christensen-Dalsgaard (1992) and Banerjee, Hasan, and Christensen-Dalsgaard (1995, 1996), where the interaction of various elementary modes in a stratified magnetized atmosphere was studied in the purely adiabatic limit. The inclusion of radiative dissipation based on Newton's law of cooling demonstrates the importance of this effect in the study of magnetoatmospheric waves. We analyze the physical nature of magnetoacoustic gravity (or MAG) oscillations in the presence of Newtonian cooling and find that the eigenfrequency curves in the diagnostic diagram, as in the previous analysis, undergo *avoided crossings*. However, the qualitative nature of the mode interaction is strongly influenced by radiative dissipation, which leads to strong mode damping in the avoided-crossing regions. We demonstrate this effect for the interaction between the Lamb mode and a magnetic mode. Our results could be important in the analysis of waves in flux tubes on the Sun.

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The Sun As An X-Ray Star: Overview Of The Method

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We present a method to study the solar-stellar connection, i.e. the close similarity of the physical phenomena occurring on the Sun and on late-type active stars, taking advantage of the Yohkoh/SXT X-ray images. From such images we generate distributions of whole disk differential emission measure and from them we synthesize stellar-like solar spectra analogous to those collected with non-solar instruments. Here we present applications to ROSAT/PSPC- and ASCA/SIS-like observations, and we discuss test cases as well as future applications.

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Ph.D. Thesis Abstract

Seismology of the Solar Convection Zone

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Ph.D dissertation directed by: Michael J. Thompson

Ph.D degree awarded: June 1996

The thesis deals with the study of several problems associated with the solar convective envelope using seismic data. We start with a general introduction to the subject of solar seismology and convection. A general discussion on the seismic properties of solar models including asymptotic analysis are also reviewed having in mind their later use.

The detection of convective overshoot at the base of the solar convection zone is the first topic to be presented, starting with a discussion of the theoretically expected behaviour of the oscillations in the presence of overshooting. Using a variational principle for linear adiabatic nonradial oscillations an expression for the frequency changes due to overshoot at the base of the convection zone, modelled as predicted by several studies, is deduced. We then proceed to a detailed application to solar models. The implications of the assumptions present in the analysis are determined and their effect on the conclusions established. Finally, solar data are used to determine the extent and properties of the solar overshoot region, in the ligth of the results obtained for the solar models.

We then proceed to another application of the method developed in connection with overshoot, by investigating the possibility of determining the solar envelope helium abundance. This is done by using the effect of the second ionization of helium in the solar structure and frequencies of oscillation. The main advantages and limitations of this method are investigated.

A qualitative and quantitative study of the importance of how we model low-efficiency convection on the seismic properties of a solar model is also discussed. We introduce a general parametrization that has as particular cases the standard mixing length theory and other recently proposed corrections to this description. Using such a parametrization it is shown how significant can be the shift in absolute value of the frequencies due to this extremely thin region at the top of the solar convective envelope. We then proceed to analyse why this is so and attempt to constrain the available theoretical descriptions of convective energy transport in the solar envelope. Other effects associated with convection and also contributing to the discrepancy in the observed frequencies are also reviewed. We analyse some of these using numerical simulations of convection.

The main results of the above topics are reviewed and discussed with the suggestion of some possible implications to be considered in future in the concluding Chapter of the thesis. Also included in the thesis are two appendices which review the basics physics and mathematics involved both in calculating solar models and their frequencies of oscillation.

Thesis-related Publications: MNRAS 276, 283; A&A 283, 247; A&A 307, 624

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. The subject matter should pertain directly to cool stars (spectral types F,G,K, or M) or the sun. Both theoretical and observational abstracts are appropriate. Abstracts dealing with cool pre-main-sequence 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. A monthly call for abstracts will be issued and abstracts received by the last day of the month will usually appear in the following month's newsletter. Announcements of general interest to the cool star and solar communities may also be submitted for posting in the newsletter. These might include (but are not restricted to) the following: (i) *Job Openings* directed toward cool star or solar researchers, (ii) announcements of *Upcoming Meetings*, (iii) announcements of *Upcoming Observing Campaigns* for which participation is solicited from the community at large, (iv) reviews of *New Books*, and (v) *General Announcements* that provide or request research-related information. Please send all correspondence to the editor at coolnews@jila.colorado.edu. Abstract templates and back issues can be obtained from the COOLNEWS Web-page at

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