# COOLNEWS

A RESEARCH NEWSLETTER DEDICATED TO COOL STARS AND THE SUN

No. 2 — October 1995 Editor: Steve Skinner (coolnews@jila.colorado.edu)

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Editor's Note

Interest in COOLNEWS is growing and we have 36 abstracts listed this month. I am glad to see more participation from solar physicists, who contributed 8 abstracts for this issue. Thanks to those of you who sent in comments and suggestions by e-mail or by voicing your opinion at the Florence CS9 meeting.

As a cautionary note, I would like to urge everyone to use care when replying to the coolnews account. Please send mail *only* to coolnews@jila.colorado.edu. In particular, do *not* send or copy any e-mail to coolnews_rx_sort@jila.colorado.edu - this is the master mailing list and mail sent to this address will go out to all known cool star researchers on planet Earth (as two people have already discovered).

Stellar Abstracts

Medium Resolution Near Infrared (2.15μm–2.35μm) Spectroscopy of Late-type Main Sequence Stars

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We present an atlas of moderate resolution ($\lambda/\Delta\lambda \sim 1380$) 2.15$\mu$m to 2.35$\mu$m spectra of 33 luminosity class V stars of spectral type F3 to M6 in the MK classification system. We find that the equivalent widths of several spectral features vary significantly with temperature and typically allow effective temperature determination accurate to approximately $\pm$350 K.

Accepted by AJ

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Estimating the Total Radiative Power Output from the Hot Outer Layers of Late-type Stellar Atmospheres: How Many Lines are Required?

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The total radiative power output from the hot outer layers of six late-type stars (of different spectral types and luminosity class) is derived via an emission measure technique. This analysis was based on observational data from the spectral range 100Å to 3000Å obtained as a result of three separate satellite missions, i.e. Hubble Space Telescope, International Ultraviolet Explorer and the Extreme Ultraviolet Explorer. Solar observational data of active regions, coronal holes, sunspots, 'quiescent' regions and flares were also used. Based on the derived total power output from all of these different plasma, it is shown that a linear relationship involving a single transition region line can be used to provide an accurate estimate of the total power output as previously shown for the Sun. The derived relationship does not include losses due to hydrogen, nor the UV continuum which can be a large contributor, particularly for very active stars.

Accepted by A&A

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The Emission of the RS CVn binaries in the IRAS Passbands

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In the literature, there is an ambiguity pertaining to the existence of a far-IR excess in RS CVn systems. In the current paper we undertook a study of the behaviour of 103 such systems in the IRAS passbands. We found 72 acceptable detections in the 12μm band, and 40 in the 25μm band (50% more than the IRAS Point Source Catalog). Although our findings may be interpreted as indicating towards the existence of an excess beyond 12μm for some systems, the evidence is not conclusive in all but two cases. These are systems GX Lib and HR 7428, with Capella being the only system where the IRAS fluxes in all four bands originate from the stellar photosphere. Given the accuracy of the data we did not find 12μm excess for any system. We argue that the IRAS data alone cannot settle the issue, as their uncertainty is, in many cases, higher than what the Signal-to-Noise ratio of each observation implies. Furthermore, at the higher wavelength bands the IRAS angular resolution drops from 0.5 at 12μm to 2 at 100μm and the background becomes very complex, so one cannot be certain about the origin of the observed flux. The existence of IR excess in the RS CVn stars is important as far as the evolutionary scenarios for these systems are concerned. Future missions such as the Infrared Space Observatory will return more sensitive and accurate measurements and the ambiguity can be removed. The fluxes we quote will be helpful when planning these future observations, as we provide more accurate photometry and for a larger selection of sources than the IRAS Point Source Catalog.

Accepted by A&A

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Photometric Evidence for Widespread Spot Activity on the Primary Component of the Short-period RS CVn binary XY UMa

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A survey of published light curves, obtained since 1975, of the eclipsing RS CVn-type binary star XY UMa, coupled with results from a recent high-precision light curve, provides substantial evidence for the existence of a polar spot on the G2V primary component. The well-known and strong variability of the shape of the light curve has been explained by the presence of surface maculation, often at low latitudes, which varies on time-scales of ~ 1 month, and which may persist for longer intervals. The 20-year span of published light curves, however, shows that the entire system brightness varies by as much as 0.5 mag in the V band. No orbital phase is exempt from this longer-term variation, suggesting that the portion of the dominant primary component that is always visible – namely the polar region – is at least partly responsible for the long-term variation in system brightness.

It is proposed that the surface of the primary component of XY UMa is very like that seen in the rapidly rotating single G dwarf star AB Dor, and the RS CVn binary DM UMa, namely, dominated by a polar spot but with a second belt of spot activity at lower latitudes.

Accepted by MNRAS

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The Evolution of Surface Structures on AB Doradus

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We present the third set of a long-term series of Doppler images of the starspot distribution on AB Doradus, a rapidly rotating active K0 dwarf. The images were obtained from simultaneous spectroscopic and photometric observations taken on the Anglo-Australian Telescope and the European Southern Observatory in 1993 November. Our images show two active latitudes, a low-latitude band producing most of the photometric modulation, and a high-latitude band centred at 60^o. The spot distribution at low latitudes is very stable and persists over 5 stellar rotations. It is also remarkably similar to the distribution found in 1992 December. The high-latitude structure is more variable and seems to change on the order of a few rotation periods. In agreement with measurements from 1992 January, we find no indication for differential rotation on AB Doradus.

Accepted by MNRAS

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On the Coronal Field Topology in Warm Stars. Is Procyon a Warm Hybrid?

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The height up to which a coronal magnetic field line can remain closed is determined principally by the balance between the gas pressure, p_g, and the magnetic pressure, p_B. At an on-axis height, z, above an ideal dipole the magnetic pressure falls off as z^{-6} in the far-field regime where z exceeds the separation d_{AR} between the poles of the stellar active region. Thus for a given exponentially decreasing gas pressure, the smaller the dipole separation, d_{AR}, the lower the transition point at which p_g exceeds p_B where closed magnetic loops cannot be sustained. Because the maximum size of bipolar stellar active regions is likely to be limited by the depth of the convective envelope, this suggests that an increasing fraction of the field should open up for stars with progressively shallower convective envelopes. We discuss the available empirical evidence for this effect for F stars on or near the main sequence. This

has direct implications for the mechanism for the coronal dividing line for cool K-type giants proposed by Rosner *et al.* (1995, ApJ 442, L25), in that a similar – albeit more gradual – transition should take place for warm F-type main sequence and subgiant stars. The explanation of the Linsky–Haisch dividing line proposed by Rosner *et al.* depends on a change in the dynamo mode and a consequent change in surface-level size-scale of active regions. For F-type stars we expect a change in size scale, but not a change in dynamo mode, which allows a separation of the effects of these two changes on hot coronae. We also suggest that Procyon may be a "warm hybrid" star, an interpretation consistent with recent *HST* observations of an excess emission in the blue wings of transition–region lines, and with *EUVE* measurements of its coronal temperature structure and density.

Accepted by ApJ Letters

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Non-LTE Model Chromospheres of ζ Aurigae Stars

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Plane-parallel, one-component, non-LTE, semi-empirical model chromospheres have been constructed for the primary stars in the ζ Aurigae systems HR 6902 and 22 Vul. This has been acomplished by means of radiative-transfer calculations undertaken with a non-LTE multi-level radiative-transfer code, MULTI, and curves of growth applied to chromospheric eclipse spectra. The former are the subject of this paper, which is divided into two parts. The first briefly describes the observations and derivation of basic stellar parameters, while the second broaches the radiative-transfer calculations and conclusions which follow from them. In particular, the calculated model photospheres + chromospheres are used to investigate the relative contribution of primary and secondary star to the overall radiation field. The radiation field of the hot secondary is approximated by use of an appropriate Kurucz model atmosphere. Although the hot companion is wholly responsible for the ionisation of the metals, this is not the case as far as excitation is concerned. Use of a 47-level Fe atomic model demonstrates the intimate convolution between atomic and atmospheric physics. The chromospheres calculated by radiative-transfer methods are compared with those derived empirically by curves of growth and are found to be comparable in the line-forming region of Ca II H & K, Mg II h & k and the many Fe II lines. Finally, due to the effects of radiative transitions from high-lying levels which are enhanced by the radiation field of the hot companion, it is found that lines resulting from transitions from the $a\,^4F$, $a\,^4D$ and $a\,^4P$ levels of Fe II may not be used to derive an inner-wind temperature for 22 Vul. This is the first time that ζ Aurigae chromospheres have been the subject of such intensive radiative-transfer calculations.

Submitted to MNRAS

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Tidal Interaction Between Stars with Convective Envelopes and Dynamics of Triple Stars

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The low mass components are frequently observed in the triple stars. As a rule, the triple stars have the hierarchical structure: the close binary and the third distant component. The physical processes in the binary influence dynamics of the triple system. The goal of this study is the effect of tidal interaction inside the close binary on the stability of the hierarchical triple stars with convective envelopes. Plane triple systems with initially circular orbits of inner and outer binaries are investigated. The directions of revolution of both binaries coincide. The axes of stellar rotation are colinear to the vector of the orbital angular momentum of the triple system. We consider different versions of choice of initial rotational velocities, in particular the ones synchronized with orbital motion. It is shown that in case of rotational velocities less and equal to the synchronized ones, there is an increase of stability of the triple system. An opposite trend is found for the stars with rotational velocities larger than synchronized ones. The effects of tidal interactions to the stability of hierarchical triple stars could be estimated analytically using the theory of the close binary systems, besides the cases of strong perturbations from the heavy distant body and the ones of small tidal effects (small perturbations from the distant body and synchronization). The exact synchronization in close binaries is not attained because of the perturbations from the third body. The energy of orbital motion transfers into the energy of the components eternally.

Submitted to MNRAS

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The Radio Properties of the dMe Flare Star Proxima Centauri

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We present radio observations of the dM5.5e flare star Proxima Centauri at 20, 13, 6, and 3.5 cm. The star was only detected during an impulsive, highly circularly–polarized and apparently narrowband flare at 20 cm, similar to those seen on other dMe flare stars. This flare was detected in just ~1.7 hrs of observing time spanning a ~12 hr period, suggesting that Proxima Centauri may be a prolific producer of coherent bursts at 20 cm. On the other hand, despite ~30 hrs of observing time at both 6 and 3.5 cm over a 4 yr period, the star was not detected as either a flaring or a quasi–steady (quiescent) source at these wavelengths. We place an upper limit of $\sim 2 \times 10^{11}$ erg Hz^{-1} s^{-1} on its radio luminosity at 6 and 3.5 cm, the lowest detection threshold yet reached for a star other than the Sun. This upper limit is approximately equal to the radio luminosity of the active Sun (i.e., at or close to the peak in its activity cycle) outside of flares.

Our results place important constraints on the filling factor of ~500—1000 G magnetic loops containing X–ray–emitting plasma on Proxima Centauri. Because such loops should be optically thick to gyroresonance emission at cm wavelengths, their filling factor can be inferred directly from the measured stellar radio flux density. Our radio results imply that loops at temperatures $\sim 2 \times 10^7$ K, representative of the hot stellar X–ray component, have a filling factor of $\leq 13\%$. Loops at temperatures $\sim 3 \times 10^6$ K, similar in temperature to the non–flaring solar active region corona, have a filling factor of $\leq 88\%$. Our results are compatible with present empirical relationships for the magnetic field p arameters of late–type dwarf stars as applied to Proxima Centauri. Based on its measured rotation period ($P_{rot} \approx 41$ days) and the ratio of its soft X–ray to bolometric luminosity ($L_x/L_{bol} \approx 2.4 \times 10^{-4}$), these relationships predict that Proxima Centauri should be about an order of magnitude below the saturation limit in magnetic activity, where the entire surface of stars is thought to be covered by kilogauss X–ray loops. We compare our results with the contrasting case of UV Ceti, a dM5.5e flare star that according to the same empirical relationships should be approximately as magnetically active as Proxima Centauri. UV Ceti, however, displays quiescent radio emission with a luminosity that is more than an order of magnitude higher than the upper limit placed on Proxima Centauri.

Our radio observations place an upper limit of $\sim 7 \times 10^{-12}$ $M_\odot$ yr^{-1} on the mass–loss rate by any stellar wind (assumed to have a velocity of 300 km s^{-1}) from Proxima Centauri. This upper limit is almost 2 orders of magnitude lower than that inferred by Mullan et al. (1992) from mm wavelength observations of other dMe flare stars. We show that the high mass–loss rate inferred by Mullan et al. (1992) is untenable if our present understanding of the cm wavelength radio emission of dMe flare stars is correct.

Accepted by ApJ

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Loop Modeling of Coronal X-ray Spectra. I. General Properties

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This work is motivated by the widely accepted paradigm that the structure and features of stellar coronae are determined by plasma magnetically confined in coronal loops. In particular we address the question whether it is possible to devise diagnostics amenable to reveal some physical and geometric characteristics of static coronal loops from X-ray observations. We show that single-loop coronal models may give spectra differing in several respects from one- and two-temperature models, the differences being probably observable already with ASCA/SIS. We find that the spectra of our loop models are essentially determined by the plasma below one pressure scale height; therefore we do not need to consider deviations from Spitzer's conductivity which occur in the very diluted upper atmosphere.

We also find that widening of cross section of the loops may give observable effects depending on loop parameters

and that even a small fraction of the star's surface covered by compact coronal loops with dense plasma can easily dominate the emission from a corona and mask the emission from long and tenuous loops.

Finally we present an example of fitting a real ROSAT/PSPC observation with loop-emitted spectra.

Accepted by A&A

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Loop Modeling of Coronal X-ray Spectra. II. Parameter Constraints and Diagnostics

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We have investigated some aspects of the fitting of stellar X-ray spectra by means of hydrostatic models of coronal loops. We have performed an extensive set of simulations in which we have synthesized and fitted loop model spectra, considering the instrument responses of the *Einstein* Imaging Proportional Counter, of the *ROSAT* Position Sensitive Proportional Counter, and of the *ASCA* Solid-state Imaging Spectrometer, and we have derived theoretical confidence regions for the determination of the input loop parameters. We have found that our ability to constrain the loop model parameters depends on the distribution of the differential emission measure. More specifically, we have found that, for loops significantly below the pressure scale height, the spectral fitting allows to constrain well the plasma peak temperature and hence the product of the base pressure with the loop semi-length, but not each of the two separately, due to scale invariance of the equations describing the hydrostatic loop model of uniform pressure. For input loops with lengths of the order of the pressure scale height or larger, the spectral fitting yields closed confidence regions in the parameter space, allowing to constrain all the loop parameters, with different levels of discrimination depending on photon counting statistics and instrument energy response. Loops much longer than the star's radius and with relatively high base pressure behave like the short loops, because the pressure decrease along the loop is moderated by the local increase of the pressure scale height.

Accepted by A&A

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Rosat Observations of the Pleiades Cluster. I. X-ray Characteristics of a Coeval Stellar Population

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We report the results of a deep X-ray survey of the core region of the Pleiades cluster carried out with the ROSAT Observatory. In a single PSPC field ($\sim 1^\circ$ radius), we detect 99 of 214 Pleiades member stars, and compute upper limits for the remainder. We have detected all early dM stars which fell within 20 arcmin of the field center, where the instrument sensitivity is highest. We have computed maximum-likelihood integral X-ray luminosity functions in various $B-V$ intervals, and have compared the results with previous studies of Pleiades cluster. Our results support the contention that B and dA star 'detections' are likely due to X-ray emission from lower-mass companions; we confirm the existence of a stellar-age vs. X-ray–luminosity relation found with *Einstein* for dG stars, and extend it to dK and dM stars; and we construct an essentially statistically complete X-ray luminosity function for Pleiades dG stars and an almost complete X-ray luminosity function for dK stars. We have verified the stellar-rotation vs. X-ray–luminosity relation for Pleiades dG stars, and show that a similar relation does not hold for dK stars. Indeed, it appears that some stellar parameters other than age and/or rotation rate must affect the level of X-ray emission of Pleiades dG and dK stars. We demonstrate the lack of measurable variability in X-ray emission at small time scales of ~ 6 months (except for flares), and the presence of variability by a factor two on timescales of ~ 10 yr in at least 15% of Pleiades members. The magnitude of this variability (by $\sim$ a factor two) is too small to account for the spread of the X-ray luminosity functions.

Accepted by ApJS

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The Coronae of Low Mass Dwarf Stars

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We report the results of our analysis of pointed X-ray observations of nearby dMe and dM stars using the Position-Sensitive-Proportional-Counter (PSPC) on-board the *ROSAT* satellite (Roentgensatellit). In the cases of those M dwarf stars where PSPC pulse-height distributions of sufficient quality for spectral fitting were obtained, we derive key coronal plasma parameters in order to investigate stellar coronal structure in more detail. In particular, we utilize temperatures and emission measures inferred for one or more distinct components as constraints for the development of semi-empirical magnetic loop models as representations of the coronae of low mass stars. The consistency of these static models as adequate descriptions of the coronae of M dwarfs is then examined.

We find that the coronae of low mass dwarfs consist of two distinct thermal components: a "soft" component with T $\sim$ 2-4 $\times 10^6$ K and a "hard" component with T $\sim 10^7$ K. We find that the pulse-height spectra are systematically fit better with 'depleted' abundances compared to solar; the high-temperature emission component on dMe stars appears to contribute a systematically larger fraction of the total flux than the corresponding component in dM stars; and the high-temperature emission component on dMe stars is responsible for most of the observed variation in the count rate.

We have modeled the observed temperature components with hydrostatic coronal loop models, and find that: the low-temperature components can be modeled with loops of small size ($l \ll R_*$) and high pressure ($p_0 \gtrsim p_0$); and the high-temperature components require solutions with either small filling factors (~ 0.1), large loops ($l \gtrsim R_*$), and high base pressure ($p_0 \gtrsim p_0$), or very small filling factors ($\ll 0.1$), small loops ($l \lesssim R_*$), and very high pressure ($p_0 \gg p_0$). Based on these observational and model results, we conclude that coronal emission in dMe stars can be interpreted as arising from quiescent active regions (a quiescent, low-temperature component) and compact flaring structures (variable, high-temperature component).

Our conclusion that the coronal geometry for low-mass dwarf stars is dominated by a combination of relatively compact, quiescent loop configurations and an unstable flaring component has implications for both stellar dynamo theory and for our understanding of stellar angular momentum evolution. With regard to rotation in late-type stars, which has a direct bearing on dynamo action, we know from observations that the lowest-mass stars spin down (via magnetic braking) more slowly than the more nearly solar-type stars. The compact loops we find for the low-temperature component suggests a natural explanation for the observed mass-dependence of angular momentum evolution in late-type, main sequence stars.

Submitted to ApJ

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Comments on the Photometric Method for the Detection of Extrasolar Planets

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We offer further perspectives on the application of the photometric technique to the search for extrasolar planets. The principal obstacles to this approach include (1) the ambiguous interpretation of the photometric signature of a possible

transit event arising from the potential for confusion with stellar activity, and (2) the observational intensity of the search technique. We emphasize that the former issue can be addressed through multiband observations combined with considerations of the characteristic time scales of forms of stellar activity compared to that of a transit event. In the case of the latter concern, the advent of modern, automated telescope technologies offers the realistic prospect of meeting the demanding observational requirements of this approach.

We find that joint visual and near infrared observations are necessary to immediately distinguish between, for example, a planetary transit and a cool spot on the stellar surface. However, these observations by themselves do not appear sufficient to distinguish between a brown dwarf and a Jovian-size planetary companion of a dwarf M star. In such cases, other complementary observations will be necessary. We develop a computer simulation to estimate the average number of transits per year that would be presented for a stellar sample characterized by realistic properties in terms of spectral type distribution, effective temperatures, masses, and radii. A simple thermal model is adopted to estimate star-planet separations. The simulation suggests that the frequency of transit events will be dominated by M dwarf systems. This is due to the large number of these objects combined with the relative proximity to these cool stars within which planetary formation can occur according to current models.

Accepted by Icarus

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Lithium in Brown Dwarf Candidates: The Mass and Age of the Faintest Pleiads

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We present high–resolution optical spectroscopy and infrared photometry of one of the lowest luminosity Pleiads, PPL 15. Its cluster membership is strengthened by both its measured radial velocity and Hα strength. Its reported mass is 0.06 $M_\odot$, based on its I–band luminosity and the Pleiades age of 75 Myr (Stauffer, Hamilton & Probst 1994). We confirm its luminosity with JHK photometry. Such a low mass for PPL 15 implies that it should currently retain lithium, unlike all low mass Pleiads tested so far. Our Keck HIRES spectrum of PPL 15 indeed exhibits the lithium absorption feature with an equivalent width of 0.5 Å. We estimate the likelihood this detection is spurious to be less than one percent. Thus PPL 15 passes the lithium test for brown dwarf status.

Calculations of the luminosity as a function of mass and age for very low mass stars, along with the history of lithium depletion, have been provided by Nelson, Rappaport & Chiang (1993). Lithium *is* depleted in HHJ 3, which is only a little brighter than PPL 15. The self–consistent interpretation with both observations and theory is that the age of the Pleiades is ∼115 Myr. If so, the derived mass for PPL 15 increases to $\sim$0.078 $M_\odot$. The canonical 75 Myr age was derived from the upper main sequence turn–off, but it substantially increases if core convective overshoot is included. Such mixing could bring the two methods of age determination into agreement. It is therefore possible that the ages of young clusters have generally been underestimated. The luminosity of brown dwarfs in these clusters would thus have been overestimated.

ApJ, in press

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An Automated Search for Variability in Chromospherically Active Stars

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We have completed an automated photometric survey of 66 potential or known chromospherically active late-type stars with the 0.4-m Vanderbilt/Tennesse State robotic telescope. The precision of the observations from this telescope matches that predicted from scintillation noise alone and represents a significant improvement in the precision of prervious robotic telescope surveys of chromospherically active stars. Light variability has been detected and its period has been determined for 47 stars, 41 of which are newly discovered variables. The primary mechanism of

variability is rotational modulation of a spotted surface. In addition, we have detected eclipses in HD 62668 and HD 141690 and the ellipticity effect in HD 223971. The light variations of HD 181475 are the result of pulsation while the variability mechanism of HD 99267, a newly identified member of a small group of early-F stars, is so far unidentified. High-dispersion spectroscopic observations of all the variable stars also have been obtained and analyzed to determine spectral type, vsini, and velocity variability for each star. As a by-product of the spectral-type determinations, approximate abundances for a number of supposed metal-poor binaries have been determined by comparison with stars of known abundances. In most cases our abundances are much closer to the solar value than those previously measured. The minimum radius and Rossby number of each spotted star have been computed. We also have determined whether or not the spotted component of each binary system is synchronously rotating. Important questions remain about the evolutionary state or duplicity of some of our stars, including HD 17925, HD 22694, HD 29697, HD 51066, HD 72146, HD 98800, BD +13 13, BD +70 959. Candidates for Doppler imaging include HD 51066, HD 82286, HD 171488, and HD 208472.

To appear in December 1995 AJ

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The X-Ray Emission of A-Type Stars

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From X-ray images in the ROSAT public archives, we determine soft X-ray fluxes, or flux upper limits, for 74 A-type stars, which have been observed during deep integrations with the PSPC. Nine supposedly single, late A stars ($0.20 < B-V < 0.35$) are found to coincide with X-ray sources. The X-ray luminosities we infer for these stars range from levels comparable to the Active Sun, at $\log L_x \sim 27.6$, to much brighter emission levels similar to those observed for active late-type binary systems, near $\log L_x \sim 30.1$. Another 10 sources are identified with early A stars ($0.0 < B-V < 0.2$). Five of these are confirmed double stars, the rest are ostensibly single. The maximum luminosity we detect in the early A stars, $\log L_x = 30.1$, is $3\frac{1}{2}$ orders of magnitude brighter than the X-ray upper limits for the nondetected stars. Additional study, including radial velocity monitoring and/or optical interferometry, will be needed to determine whether the putatively single X-ray emitting stars are in fact single, or whether their emission is produced entirely or in part by unknown or unresolved binary companions. The level of X-ray emission associated with chemically normal, single A stars thus far appears to be uncorrelated with any obvious stellar property, including the rotation rate, which is known to greatly influence the dynamo activity and the X-ray emission levels of lower mass stars.

Accepted by PASP, November issue

Measurements of Starspot Area and Temperature on Five Active, Evolved Stars

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We present results from a study of starspot areas and temperatures on active stars using the 7055 Å and 8860 Å bands of the titanium oxide molecule. Because the two bands have different temperature sensitivities, the ratio of their strengths provides a measure of the spot temperature, while their absolute strengths are a function of total starspot area. We have analyzed the TiO bands of four active, evolved, single-lined spectroscopic binaries (EI Eridani, σ Geminorum, V1762 Cygni, and II Pegasi) and of the FK Comae star V1794 Cygni. Where possible, we compare our results with contemporaneous photometry, which is used to refine our estimate of the non-spotted photospheric temperature. We find that, over multiple epochs of observation, the spot filling factor ranges from below our detection threshold ($\approx 8\%$) to just under 60%. In some cases, we find that significant starspot coverage was likely present at historical light maxima. Our results suggest a possible correlation between increasing surface gravity and the temperature difference between the spotted and non-spotted photosphere. This might result from smaller starspot

magnetic field strengths on active stars of lower gravity and the corresponding decrease in the pressure and temperature contrast between the photosphere and the umbra.

Submitted to ApJ

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The Age-Related Properties of the HD 98800 System

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We present Keck Hires spectroscopy of the field K star system HD 98800, which has been found to have significant infrared emission from circumstellar material. The lithium abundances of the stars in HD 98800 are well above those of Pleiads of similar color, but activity levels and rotation in these stars are at or below Pleiades level. Thus it is not yet possible to say whether HD 98800 is or is not a pre-main sequence system, and it is possible that its components are on or near the Zero-Age Main Sequence.

However, the two visible objects that make up HD 98800 both have high levels of lithium and activity, strongly suggesting that they are physically related to one another. As shown by Torres et al. (1995), having these stars physically tied implies that their relative orbit is highly eccentric and highly inclined to our line of sight, and it also means that we are viewing the HD 98800 system at an unusual time in its orbit.

Accepted by ApJ

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GJ 1230: A Nearby Triple System

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We present Keck HIRES and Palomar spectra of the nearby system GJ 1230. Henry, Kirkpatrick, and Simons (1994) classified both the A and B components as M4.5 V and noted that the B component is apparently underluminous. High resolution spectra reveal that the A component is a short-period, near equal-mass binary. This fact, together with a slightly later classification for B and the kink in the HR diagram at M4.0-4.5 V, largely resolves the mystery of the luminosity discrepancy.

Accepted by AJ

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Random Spots on Chromoshperically Active Stars

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We have investigated the effect of large numbers of moderately sized spots placed randomly on a differentially rotating star as the explanation of the rotational light curves of magnetically active cool stars. This hypothesis produces light variation very similar to observed light curves of RS CVn binaries, provided there are of order 10-40 spots at any time, and provided individual spots have a finite lifetime.

Submitted to ApJ Letters

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The Distribution of Activity on SZ Piscium

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We use contemporaneous spectra and BV light curves to derive a model of the distribution of spots and active regions on the cooler component of SZ Psc for the 1993-94 season. Both spots and active regions were visible at all rotational phases of this spotted star. The lack of large distortions of Doppler profiles of optical lines argues for $\gtrsim$ 15 spots of $\lesssim$ 10 deg angular radius. Transition-region emission was constant to within ±12% over the orbit, nor was it eclipsed appreciably. This leads us to estimate that there are at least 20 active regions, perhaps several hundred. Chromospheric Mg II emission seems to have been proportional to the unspotted area of the star, not to the area of spots visible. We have detected one strong flare in transition-region lines during this program (at HJD 2,449,283.475). We also present new light-curve and radial-velocity solutions. These solutions find the more massive, cool star very close to its Roche lobe and the hot star rotating more slowly than synchronously, making SZ Psc an important system for the structure and evolution of binary stars.

Submitted to PASP

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HD 12545, a Study in Spottedness

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We have solved two sets of light curves of HD 12545 at its epoch of extreme spottedness in 1990-91, one of which coincides with an independent set analyzed recently by Strassmeier and Olah. Even for the huge amplitudes observed, these light-curve solutions did not give reliable determinations of several important spot properties. Specifically, we find that we could obtain acceptable solutions for a wide range of inclination; that spot temperature depends on inclination assumed, falling in the range $\Delta T = T_{star} - T_{spot} = 650\text{-}1200$ K for inclinations of 70-30 deg; that spot latitudes derived from the light curves are unreliable; and that our independent spot solutions disagree with Strassmeier and Olah's. On a more positive note, changes in the light curve over the past five years seem to have been caused primarily by rearrangement of persisting spot groups, and we note that the high level of activity implied by its Hα emission makes HD 12545 a prime candidate for a white-light flare star.

Submitted to PASP

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Absolute Measurements of Starspot Area and Temperature: II Pegasi in October 1989

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We are developing an empirical spectrum synthesis technique that yields independent measurements of starspot filling factor, f_S, and starspot temperature, T_S, by fitting TiO bands of differing temperature sensitivity. The absolute depth of the TiO bands constrains f_S, while the ratio of their depths is a function only of T_S. One strength of this technique is its ability to determine the spot parameters in traditionally difficult cases: slowly rotating stars, uniformly spotted stars, and stars that always have spots. For this initial study, we have used a simpler procedure of measuring the band depths in the most spotted star in our survey (the single-lined RS CVn binary system II Pegasi) and for a full grid of comparison stars (inactive G, K, and M dwarfs and giants). This yields T_S and f_Q for a given assumed temperature of the non-spotted photosphere, T_Q The latter was further constrained by the use of simultaneous photometry. We have analyzed a series of spectra of II Peg obtained throughout a single 6.7-day rotational cycle in 1989 October. We find that starspots on II Peg are better modeled by comparison spectra of giants than by dwarfs. Combining TiO analysis with contemporaneous photometry, we find that cool starspots ($T_S \approx$3500 K) are always visible, with a fractional projected coverage of the visible hemisphere varying from 54 to 64% as the star rotates. The nonspotted photosphere has a temperature $T_Q \approx$4800 K. Our results imply that even at the historical light maximum of V = 7.2, at least 34% of II Peg was covered by starspots.

Accepted by ApJ (to appear 20 October 1995)

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Rotational Modulation and Flares on RS CVn and BY Dra Stars XIX. Simultaneous IUE, ROSAT, VLA, and Visual Observations of TY Pyxidis

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In November 1990, we observed the eclipsing-binary system TY Pyxidis with the IUE satellite simultaneously with the ROSAT All-Sky Survey. The IUE and ROSAT/WFC observations covered the 3.2-day period of this system continuously, while the ROSAT/PSPC coverage was limited to 2.26 days. We also observed TY Pyx with the VLA for a total of 22 hours throughout this period, and we obtained simultaneous visual photometry and spectroscopy. We compare the rotational and eclipse modulation of the ultraviolet line fluxes and line profiles with the x-ray, extreme-ultraviolet, radio, and visual-light variability. We present the multi-wavelength light curves, and we compare the high-resolution Mg II profiles with the simultaneously obtained Ca II profiles. Although the visual light curve suggests the presence of large photospheric spots, no rotational modulation is evident in the ultraviolet, x-ray, and radio flux. This suggests that the outer atmosphere is more uniformly covered with magnetic activity than the photosphere. The rare absence of large flux variations permits us to study an RS CVn system with large intrinsic ultraviolet, x-ray, and radio fluxes but without complications introduced by large active regions or flares. Until now, among the extensively monitored RS CVn systems, only the long-period Capella has shown such a constant radiative output.

Submitted to A&A

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EUV Spectroscopy of Cool Stars: II. Coronal Structure of Selected Cool Stars Observed With EUVE

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We analyze the coronal EUV spectra of seven cool stars, solar–like single stars and components of RS CVn-like binaries, as observed with the Spectrometers of the Extreme Ultraviolet Explorer *EUVE* in the wavelength range 60–800Å with a resolution of $\lambda/\Delta\lambda \approx$ 160–320. The data constrain the coronal temperature structure between $\sim 10^5$ K up to $\sim 10^7$ K through a differential emission measure (DEM) analysis. The resulting DEM distributions show distinct features from source to source, but the common properties are: a) a relatively weak emission from coronal plasma below about 1 MK, b) a dominant component somewhere between 2 MK and about 10 MK, often peaking at solar–like coronal temperatures of 2 to 4 MK, and c) in all cases but χ^1 Ori a very hot component in the formal solution with a temperature exceeding several tens of 10^6 K. This hot tail in the DEM distribution may reflect, as discussed in this paper, one or several of the following sources or processes: a real hot component, a reduced coronal abundance of heavy elements, or scattering in some of the strongest coronal lines with subsequent photon destruction upon impact on the lower, dense atmosphere. Coronal electron densities of brightly emitting regions are constrained by an analysis of ratios of density-sensitive iron lines. Strengths of Fe XIX–Fe XXII lines (corresponding to a temperature range of T = 6–11 MK) for α Aur, AU Mic (of which the spectrum is dominated by a large flare), ξ UMa, and σ Gem suggest

typical electron densities in the range $n_e \sim 10^{12}$–10^{13} cm^{-3}. Cooler Fe X and Fe XII–Fe XIV lines (T = 1–2 MK) in the case of α CMi suggest $n_e \sim 10^9$–10^{10} cm^{-3}. In general, the electron densities of the hot 5–15 MK components are some three orders of magnitude larger than typical of the solar–like component around 2 MK; the volume filling factors of the hot components are therefore expected to be substantially smaller than those of the cooler component.

A&A, in press

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Spectroscopic EUVE Observations of the Active Star AB Doradus

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We present observations of the young rapidly-rotating (0.515 day) late-type star, AB Doradus (HD 36705), made by the Extreme Ultraviolet Explorer ($EUVE$) satellite. A spectrum from 80 to 700 Å with a resolution $\Delta\lambda \approx 0.5$–2 Å was accumulated between November 4–11, 1993, with an effective exposure time of about 40 hours. No obvious EUV flares were detected during the observation. The data constrain the coronal temperature structure between several 10^4 K up to roughly 2×10^7 K through a differential emission measure (DEM) analysis using the optically-thin MEKA plasma model. The resulting DEM distribution shows: a) dominant emission from plasma between about 2×10^6 K and 2×10^7 K, b) very little emission from plasma between 10^5 K and 2×10^6 K, and c) emission from plasma below about 10^5 K. If solar photospheric abundances are assumed, then the *formal* DEM solution also requires the significance of a strong high-temperature component (above about 3×10^7 K) in order to explain the strong continuum emission below about 150 Å. We believe that this component of the solution is not physical: it is not present in the solution if we assume lower iron abundance, or if there is significant resonance scattering in some of the stronger (mainly iron) spectral lines with subsequent photon absorption in the lower, dense atmosphere. Finally, the DEM analysis gives a best-fit value for the interstellar hydrogen column density of $N_H = (2.4 \pm 0.5) \times 10^{18}$ cm^{-2}.

ApJ, in press

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Spread of the Lithium Abundance in Halo Stars

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The observed scatter of the lithium abundance around a "plateau" is revisited for three samples of stars for which the temperature has been determined from either the excitation temperature, or the dereddened color $(b-y)_o$ or the profile of the H_α wings. Systematic differences are noted between the three methods of temperature determination. From sample to sample the rms observed scatter of the lithium abundance varies from 0.06 dex to 0.08 dex (to be compared to the value 0.13 previously found by Thorburn 1994, for another sample of stars). We show that in all cases but one, this scatter is fully explained by the temperature and equivalent width errors. The intrinsic scatter, if real, is small.

Accepted by A&A

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O IV Diagnostic Line Ratios in Solar EUV Spectra

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Recent calculations of electron and proton impact excitation rates in O IV are used to derive the intensity ratios of lines in the ~340–1350Å wavelength range as a function of electron temperature (T_e) and density (N_e). These results are presented in the form of ratio–ratio diagrams, which should in principle allow both N_e and T_e to be deduced for the O IV line emitting region of a plasma. Electron temperatures derived from ratio–ratio diagrams involving the 790Å/554Å ratio, in conjunction with observational data for several solar features obtained with the Harvard S-055 spectrometer on board *Skylab*, are found to be in reasonable agreement with the value of T_e expected from ionization equilibrium calculations. This provides some support for the theoretical diagnostics presented in this paper, and hence the atomic data used in their derivation. However other temperature and density sensitive ratios involving the O IV multiplets at 609Å, 625Å and 787Å could not be used to derive plasma parameters from the ratio–ratio diagrams, due to blending with lines of Mg X and S V.

Accepted by A&A

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Evolution of Two Small Solar Flares

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Data from the YOHKOH satellite have been analysed for two small flares (GOES class C) of total duration of 10 and 60 minutes. Upflows in S XV, Ca XIX and Fe XXV lines were compared and the presence of a range of upflow velocities was found. Emission from flare loop footpoints corresponding to plasma moving with a typical velocity of 200–400 $km\ s^{-1}$ is seen in soft X-ray images. In one of these events (23 June 1992), which occurred in sheared loops being part of a sparse magnetic arcade, with initial energy release taking place near one of the footpoints, a large proportion of upflowing plasma was seen at least 1 minute before the first peak in hard X-rays. In the second event (13 July 1992), the increase of soft X-ray emission began more than 3 minutes before, and weak mass upflows one minute before the rapid increase of temperature and the onset of the detectable hard X-ray emission. This event was probably triggered by emerging magnetic flux and accompanied by heating and restructuring of two nearby magnetic loops. In both events the emission measure of upflowing plasma is present simultaneously to, and is very well correlated in time with the hard X-ray flux in the 14–23 keV band. Differential emission measure in the temperature range $5 - 60\ 10^6$ K was derived from S XV, Ca XIX and Fe XXV line and continuum fluxes, and from images in two broad band soft X-ray filters, and used to analyse the thermal contribution to the hard X-ray emission. A non-thermal component of the hard X-ray emission is found at the peak of the 23 June 1992 flare. The hard X-ray emission in the 13 July 1992 flare is primarily thermal, however, a possibility of an enhanced tail of the electron energy distribution above 14 keV is also indicated. The chromospheric evaporation in these flares was driven both by electron beams and thermal conduction, with conduction predominating during most of the rise phase of the 13 July 1992 flare. In both events, the soft X-ray emission measure at flare maximum was a few times $10^{48}\ cm^{-3}$ with an electron temperature 19 and 24 $10^6 K$; the estimated lower limit of the electron density is $\sim 10^{11}\ cm^{-3}$. The broadening of Ca XIX spectral lines in the decay phase of these flares indicates persisting random motions with a velocity of 60 $km\ s^{-1}$, which is very

similar to the non-thermal broadening observed previously by SMM in M and X class flares.

Accepted by A&A

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Reconnection and Field Line Shrinkage in Solar Flares

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We use images of flare loops taken by the Soft X-ray Telescope (SXT) on Yohkoh to estimate the decrease in height that open field lines undergo after they have reconnected to form closed loops. Following previous practice, we refer to this decrease as field line shrinkage and assume that intensity structures trace out the field lines. For this study we examine two long duration events near the limb which have flare loops that continually grow with time. The shrinkage is determined by comparing the height of a field line when it lies at the outermost edge of the flare loop system with the height it has later on when it lies at the innermost edge. We find that the field lines shrink by about 20% of their initial height in one flare and by about 32% in the other. These values are within 5% of the shrinkage predicted by a simple model of the reconnecting field which assumes that the field is everywhere potential except for a current sheet extending upwards from the top of the loops. Numerical integration of the model density along the line of sight implies that most of the discrepancy between the observations and the theory is due to projection effects which occur when an arcade of loops is viewed at an arbitrary angle. Both flares have bright regions at the top of the loops, but in one flare the lower part of the region is cooler and denser than the rest of the loop while in the other flare it is not. Consideration of the mapping of the bright regions to the footpoint of the loops implies that the cool region is formed by a thermal instability downstream of a reconnection outflow in the uppermost part of the loop. The absence of a cool, dense region in the other flare may be because it is a very weak event with temperatures and densities too low to trigger a thermal instability.

Accepted by ApJ

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The Solar Iron Abundance: Not the Last Word

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Determinations of the solar iron abundance have converged to the meteoritic value with the Fe II studies of Holweger et al. (1990), Biémont et al. (1991) and Hannaford et al. (1992) and the Fe I results of Holweger et al. (1991). However, the latter authors pointed out that Blackwell et al. (1984) obtained a discordant result from similar oscillator strengths. A recent debate on this lingering discrepancy by the Oxford and Kiel contenders themselves has not clarified the issue. We do so here by showing that it stems from systematic differences between equivalent widths and oscillator strengths which masquerade as differences in fitted damping enhancement factors. We first discuss the various error sources in classical abundance determination and then emulate both sides of the debate with abundance fits of our own. Our emulation of the Oxford side shows that the abundance anomaly claimed by Blackwell et al. (1984) for solar Fe I 2.2 eV lines vanishes when equivalent width measurements from other authors are combined with better evaluation of the collisional damping parameter. On the Kiel side, we find that the oscillator strengths of Bard et al. (1991) used by Holweger et al. (1991) produce a suspicious trend when used to fit solar Fe I lines, whereas comparable application of oscillator strengths from Oxford does not. The trend is mainly set by categories of Fe I lines not measured at Oxford; for lines of overlap the two sets agree and deliver the iron abundance value $A_{\mathrm{Fe}} = 7.62 \pm 0.04$ which exceeds the meteorite value. The dissimilar lines may suffer from solar line-formation effects. We conclude that the issue of the solar iron abundance remains open. Definitive oscillator strengths are still needed, as well as verification of classical abundance determination by more realistic representations of the solar photosphere and of photospheric line formation.

Accepted by A&A

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Helioseismic Estimation of Convective Overshoot in the Sun

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By using the periodic signal present in the frequencies of oscillation due to the base of the solar convection zone, Monteiro, Christensen-Dalsgaard & Thompson gave an upper limit to the extent of a layer of convective overshooting in the Sun. Alternative studies have suggested that it may not be possible to do so since the amplitude of the signal does not vary monotonically with the extent of the layer.

In this work a new more complete set of models is used to compare the values of the amplitude obtained from the fitting of the signal with the expected amplitudes. These are determined using the assumption that the rapid variation occurring at the base of the convection zone and creating the periodic signal can be described as discontinuities of the sound-speed derivatives. The amplitude of the signal due to the discontinuity of the third derivative of the sound speed is then proportional to the derivative of the radiative gradient, while the amplitude resulting from the discontinuity of the second derivative is proportional to the difference between radiative and adiabatic gradients at the position where the transition occurs. The latter is non-zero only if overshoot is present.

Asymptotic predictions of the amplitudes of the signal in the p-mode frequencies are in good agreement with the values found from fitting models with substantial overshoot regions; as was also found by Monteiro *et al.*, the observed solar frequencies place severe limits on the extent of overshoot of this nature.

Accepted by MNRAS

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Seismic Properties of the Sun's Superadiabatic Layer. I. Theoretical Modelling and Parametrization of the Uncertainties

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Some alternatives to the traditional mixing-length theory (MLT) have recently been proposed for modelling convective heat transport inside stars. The ideal formulation is one that does not involve any free parameters. However, in our present state of ignorance we still need at least one free parameter in order to build solar models with the correct radius. Having adjusted this parameter (e.g. the mixing-length parameter α_c) to obtain the observed radius, we cannot discriminate non-seismically between different convective theories, regardless of how low-efficiency convection is treated. In this paper we consider how the additional information provided by global p-mode frequencies can be used to investigate low-efficiency convection at the top of the solar convective envelope and discriminate between different theories. We consider a parametrization which in addition to the mixing length has two further parameters: one (β_c) which regulates the relative degree of overadiabaticity (or inefficiency) of convection, and a second (m) that affects the transition between the regimes of efficient and inefficient convection. Our parametrization includes traditional MLT and the theory of Canuto & Mazzitelli as particular cases. We study the effect of varying these parameters by

constructing a series of envelope models with the same depth of the convection zone and computing their oscillation frequencies. We discuss our results in terms of kernels relating frequency changes to changes in the structure of the superadiabatic region.

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Quiet Sun Connection Between Intensity, Doppler Shift and Line Broadening in Solar UV Emission Lines

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The quiet Sun relations between the C IV line parameters, intensity, wavelength shift, and line broadening are studied with high spatial and spectral resolution. The material is ordered into equal intervals for one of the line parameters and conditional probabilities are calculated. As the Doppler velocity increases we find that redshifted profiles with a large intensity or line width constitute an increasing fraction of the total number of profiles in a given velocity interval. For blueshifted profiles, on the other hand, the conditional probabilities for finding a profile with considerable intensity or line width decrease as the line shift increases. Similar relations are found when the material is ordered according to intensity or line width values.

Accepted by ApJ Letters

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Metric Spikes and Electron Acceleration in the Solar Corona

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Short and narrowband spikes near the starting frequency of metric type III bursts have been searched and analyzed in Zurich radio spectrometer data. We find that the probability for the occurrence of *metric spikes* is related to the starting frequency of type III bursts; the association rate increases to 34% for groups of type III bursts with starting frequencies below 500 MHz. The frequency channel containing most of spikes has been cross-correlated in time with the frequency channels of type III bursts. The correlation is significant in all selected cases and is caused by the association of individual type III bursts with groups of spikes, proving beyond doubt that spikes and type III bursts are physically related. The cross-correlation also defines the average drift rate of the type III maximum and its relation to spikes. In the average, the peak time of *metric spikes* coincides with the correlated type III burst, extrapolated to the same frequency. This may be interpreted as the spike radiation being emitted at the same characteristic frequency as the type III emission. The generally higher polarization of spikes helps to distinguish them from type III bursts. Contrary to spikes at higher (decimetric) frequencies, 60% of *metric spike* events have the same sign of circular polarization as the associated type III bursts, 33% are opposite, while the polarization was not measurable for the rest of the type III bursts. Some of the *metric spike* events are associated with weak flare activity in H_α, but none has been found to be closely associated with a hard X-ray burst or a microwave event. *Metric spikes* are consistent with energy release at high altitudes producing low energy electron beams. If the spikes are caused by the same electron population as the type III bursts, its acceleration site must be below or in close proximity to the spike source.

Accepted by A&A

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