COOLNEWS

A RESEARCH NEWSLETTER DEDICATED TO COOL STARS AND THE SUN

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Stellar Abstracts

Lithium Abundances in the Old Open Cluster NGC 3960 from VLT/FLAMES Observations

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Old open clusters are very useful targets to investigate mechanisms responsible for lithium (Li) depletion during the main sequence. Comparison of the Li abundances in clusters of different age allows us to understand the efficiency of the Li destruction process. Our goal is the determination of membership and Li abundance in a sample of candidate members of the open cluster NGC 3960 (age ∼1 Gyr), with the aim to fill the gap between 0.6 and 2 Gyr in the empirical description of the behavior of the average Li abundance as a function of the stellar age. We use VLT/FLAMES Giraffe spectra to determine the radial velocities and thus the membership of a sample of 113 photometrically selected candidate cluster members. From the analysis of the Li line we derive Li abundances for both cluster members and non-members. 39 stars have radial velocity consistent with membership, with an expected fraction of contaminating field stars of about 20%. Li is detected in 29 of the RV members; we consider these stars as cluster members, while we make the reasonable assumption that the remaining 10 RV members without Li, are among the contaminating stars. Li abundances of the stars hotter than about 6000 K are similar to those of stars in the Hyades, while they are slightly smaller for cooler stars. This confirms that NGC 3960 is older than the Hyades. The average Li abundance of stars cooler than about 6000 K indicates that the Li Pop. I plateau might start already at ∼1 Gyr rather than 2 Gyr that is the upper limit previously derived in the literature. We also find that the fraction of field stars with high Li abundance (>1.5) is about one third of the whole sample, which is in agreement with previous estimates. The fraction of contaminating field stars is consistent with that previously derived by us from photometry.

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Chromospherically Active Stars. XXVI. The Double-Lined Late-Type Binary HD 19485 = WZ Arietis

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We have used spectroscopic observations to determine the orbital elements and some basic properties of the double-lined spectroscopic binary HD 19485 = WZ Ari. The orbital period is 6.247854 days and the orbit is circular. The G5 V primary and K0 V secondary are chromospherically active. One star or possibly both are synchronously rotating. Based on the *Hipparcos* parallax and the magnitude differences derived in this work, we find that both components are approximately 1 mag above the zero age main sequence, a result that is inconsistent with the assumption that the components are coeval. We discuss some possible solutions to this anomaly, but none of them satisfactorily resolve the problem.

Accepted by AJ

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A Spectral Atlas of Post-Main-Sequence Stars in ω Centauri: Kinematics, Evolution, Enrichment and Interstellar Medium

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We present a spectral atlas of the post-main-sequence population of the most massive Galactic globular cluster, ω Centauri. Spectra were obtained of more than 1500 stars selected as uniformly as possible from across the (B, B–V) colour-magnitude diagram of the proper motion cluster member candidates of van Leeuwen et al. (2000). The spectra were obtained with the 2dF multi-fibre spectrograph at the Anglo Australian Telescope, and cover the approximate range $\lambda \sim 3840$–4940 Å at a resolving power of $\lambda/\Delta\lambda \simeq 2000$. This constitutes the most comprehensible spectroscopic survey of a globular cluster. We measure the radial velocities, effective temperatures, metallicities and surface gravities by fitting ATLAS9 stellar atmosphere models. We analyse the cluster membership and stellar kinematics, interstellar absorption in the Ca II K line at 3933 Å, the RR Lyrae instability strip and the extreme horizontal branch, the metallicity spread and bimodal CN abundance distribution of red giants, nitrogen and s-process enrichment, carbon stars, pulsation-induced Balmer line emission on the asymptotic giant branch (AGB), and the nature of the post-AGB and UV-bright stars. Membership is confirmed for the vast majority of stars, and the radial velocities clearly show the rotation of the cluster core. We identify long-period RR Lyrae-type variables with low gravity, and low-amplitude variables coinciding with warm RR Lyrae stars. A barium enhancement in the coolest red giants indicates that 3$^{\rm rd}$ dredge-up operates in AGB stars in ω Cen. This is distinguished from the pre-enrichment by more massive AGB stars, which is also seen in our data. The properties of the AGB, post-AGB and UV-bright stars suggest that RGB mass loss may be less efficient at very low metallicity, [Fe/H]$\ll -1$, increasing the importance of mass loss on the AGB. The catalogue and spectra are made available via CDS.

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Effective Temperature vs. Line-depth Ratio for ELODIE Spectra: Gravity and Rotational Velocity Effects

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The dependence on the temperature of photospheric line-depth ratios (LDRs) in the spectral range 6190–6280 Å is investigated by using a sample of 174 ELODIE Archive stellar spectra of luminosity class from V to III. The rotational broadening effect on LDRs is also studied. We provide useful calibrations of effective temperature versus LDRs for giant and main sequence stars with $3800 \lesssim T_{\rm eff} \lesssim 6000$ K and $v\sin i$ in the range 0–30 km s^{-1}. We found that, with the exception of very few line pairs, LDRs, measured at a spectral resolution as high as 42 000, depend on $v\sin i$ and that, by neglecting the rotational broadening effect, the $T_{\rm eff}$ determination can be wrong by $\sim$100 K in the worst cases.

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Deriving Temperature, Mass and Age of Evolved Stars from High-resolution Spectra Application to field stars and the open cluster IC 4651

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Aims. We test our capability of deriving stellar physical parameters of giant stars by analysing a sample of field stars and the well studied open cluster IC 4651 with different spectroscopic methods.

Methods. The use of a technique based on line-depth ratios (LDRs) allows us to determine with high precision the effective temperature of the stars and to compare the results with those obtained with a classical LTE abundance analysis.

Results. (i) For the field stars we find that the temperatures derived by means of the LDR method are in excellent agreement with those found by the spectral synthesis. This result is extremely encouraging because it shows that spectra can be used to firmly derive population characteristics (e.g., mass and age) of the observed stars. (ii) For the IC 4651 stars we use the determined effective temperature to derive the following results. a) The reddening $E(B-V)$ of the cluster is 0.12 ± 0.02, largely independent of the color-temperature calibration used. b) The age of the cluster is 1.2 ± 0.2 Gyr. c) The typical mass of the analysed giant stars is $2.0 \pm 0.2 M_\odot$. Moreover, we find a systematic difference of about 0.2 dex in $\log g$ between spectroscopic and evolutionary values.

Conclusions. We conclude that, in spite of known limitations, a classical spectroscopic analysis of giant stars may indeed result in very reliable stellar parameters. We caution that the quality of the agreement, on the other hand, depends on the details of the adopted spectroscopic analysis.

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Mass Loss from Dusty, Low Outflow-Velocity AGB Stars II. The Multiple Wind of EP Aquarii

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CO rotational lines are frequently used to trace the outflows from AGB stars. Some profiles are composite, with a narrow component super-imposed on a broader one. These profiles have been interpreted in different ways, calling for episodic mass loss, a bipolar flow, or a circumstellar disk. To investigate the structure of one of these outflows, we have obtained detailed ^{12}CO(2-1) and ^{12}CO(1-0) maps of EP Aqr, a prototypical source with composite CO profiles. Interferometric data were acquired with the IRAM interferometer and combined with on-the-fly maps obtained at the IRAM 30-m. The resulting maps in ^{12}CO(2-1) and ^{12}CO(1-0) cover a field of $100'' \times 100''$ with a spectral resolution of $0.1\,\mathrm{km\,s^{-1}}$ and with beams of $1.7'' \times 1.0''$ and $3.5'' \times 1.8''$, respectively. The source is clearly resolved with a size of about $15''$ (FWHM). We do not observe any obvious departure from circular symmetry, but there is evidence of a ringed structure in the CO(2-1) map with enhanced intensity at $\sim 3.5''$ and $7.5''$ from the central star. The continuum level at 1.3 and 2.6 mm is consistent with the star's photospheric emission. We modeled the spatio-kinematic structure with Monte-Carlo radiative transfer simulations assuming spherical symmetry. We reached a reasonable fit to the map-integrated spectra, but not to the imaging data, possibly because the circumstellar shell of EP Aqr presents inhomogeneities on a scale that is not, or is only barely, resolved in our maps. EP Aqr may be a proto-typical oxygen-rich source for the class of theoretical models exhibiting mass loss variations on a $\sim 100\,\mathrm{yr}$ timescale discovered by Winters et al. (2000), which show a layered structure in their extended circumstellar shells.

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Solar Abstracts

On the Formation of Filament Channels

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From the Hα archive of the Big Bear Solar Observatory (BBSO) we have selected three examples showing fibril structures that change their orientation, over 1 or 2 days, from nearly perpendicular to nearly parallel to the polarity inversion line (PIL). In one case, the filament channel forms within a single decaying bipole; in the other two cases, it forms along the boundary between an active region and its surroundings. Comparing the Hα filtergrams with magnetograms from the Michelson Doppler Imager (MDI), we find that the fibrils become aligned with the PIL as supergranular convection brings opposite-polarity magnetic flux together; shearing motions along the PIL, when present, act mainly to accelerate the rate of diffusive annihilation. We conclude that the reorientation of the fibrils is due to the cancellation and submergence of the transverse field component ($B_\perp$), leaving behind the preexisting axial field component ($B_\parallel$). The latter may have been generated by photospheric differential rotation over longer timescales, or else was already present when the flux emerged. The filament channel forms slowly if $B_\parallel/B_\perp$ is initially small, as along the internal neutral line of a newly emerged bipole, but may appear within hours if this ratio is initially substantial, as where the dipole-like loops of an active region curve around its periphery. In all of our examples, filaments form within a day or so after the fibrils become aligned with the PIL, while barbs appear at a later stage, as flux elements continue to diffuse across the PIL and cancel with the majority-polarity flux on the other side.

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Widespread Occurrence of Trenching Patterns in the Granulation Field: Evidence for Roll Convection?

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Time-averaged series of granulation images are analysed using COLIBRI, a purpose-adapted version of a code originally developed to detect straight or curvilinear features in aerospace images. The algorithm of image processing utilises a nonparametric statistical criterion that identifies a straight-line segment as a linear feature (lineament) if the photospheric brightness at a certain distance from this line is on both sides stochastically lower or higher than at the line itself. Curvilinear features can be detected as chains of lineaments, using a criterion modified in some way. Once the input parameters used by the algorithm are properly adjusted, the algorithm highlights "ridges" and "trenches" in the relief of the brightness field, drawing white and dark lanes. The most remarkable property of the trenching patterns is a nearly-universally-present parallelism of ridges and trenches. Since the material upflows are brighter than the downflows, the alternating parallel light and dark lanes should reflect the presence of roll convection in the subphotospheric layers. If the numerous images processed by us are representative, the patterns revealed suggest a widespread occurrence of roll convection in the outer solar convection zone. In particular, the roll systems could form the fine structure of larger-scale, supergranular and/or mesogranular convection flows. Granules appear to be overheated blobs of material that could develop in convection rolls due to some instabilities of roll motion.

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Preprint available via arXiv [astro-ph] : http://arxiv.org/abs/0709.3251

Models of the Solar Chromosphere and Transition Region from SUMER and HRTS Observations: Formation of the EUV Spectrum of Hydrogen, Carbon, and Oxygen

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We present the results of optically-thick non-LTE radiative-transfer calculations of lines and continua of H, C I-IV, and O I-VI and other elements using a new one-dimensional, time-independent model corresponding to the average quiet-Sun chromosphere and transition region. The model is based principally on the Curdt et al. SUMER atlas of the extreme ultraviolet spectrum. Our model of the chromosphere is a semiempirical one, with the temperature distribution adjusted to obtain optimum agreement between calculated and observed continuum intensities, line intensities, and line profiles. Our model of the transition region is determined theoretically from a balance between a) radiative losses and b) the downward energy flow from the corona due to thermal conduction and particle diffusion, and using boundary conditions at the base of the transition region established at the top of the chromosphere from the semiempirical model. The quiet-Sun model presented here should be considered as a replacement of the earlier model C of Vernazza et al., since our new model is based on an energy-balance transition region, a better underlying photospheric model, a more extensive set of chromospheric observations, and improved calculations. The photospheric structure of the model given here is the same as in Table 3 of Fontenla, Avrett, Thuiller, & Harder. We show comparisons between calculated and observed continua, and between the calculated and observed profiles of all significant lines of H, C I-IV, and O I-VI in the wavelength range 67-173 nm. While some of the calculated lines are not in emission as observed, we find reasonable general agreement, given the uncertainties in atomic rates and cross sections, and we document the sources of the rates and cross sections used in the calculation. We anticipate that future improvements in the atomic data will give improved agreement with the observations.

To appear in ApJS

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Lithium Abundances of Very Low Mass Members of Chamaeleon I

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We present the first study of the lithium abundances of very low mass objects in Chamaeleon I close to the hydrogen burning mass limit based on atmospheric models and high-resolution spectroscopic observations. The studied objects, Cha Hα 2, 3, 4, 5, 6 and 8, are very young brown dwarf candidates and very low mass stars on the verge of lithium depletion.

For this analysis, we have computed a new "GAIA-cond" class model grid over effective temperatures from 2600 K to 3100 K, surface gravities from $\log(g) = 3.5$ to 5.5, and lithium abundances from $\log\epsilon = 0.0$ to 3.7, for two different line profile setups introduced in previous work. Calculated synthetic spectra are compared with high-resolution UVES / VLT echelle spectra of the objects.

We find good descriptions of the lithium resonance doublet lines at 6708 Å and of the surrounding pseudo-continuum and determine a consistent set of lithium abundances ($\log(\epsilon) = 1.55$). However, the derived lithium abundances are lower than the meteoritic one ($\log(\epsilon) = 3.31$) and that of higher mass stars in Cha I ($\log(\epsilon) = 3.1/3.4$ for LTE–/non-LTE–calculations). By modelling the TiO-line, we demonstrate that veiling does not make the lithium lines appear weaker. We can also rule out that the results are spoiled by the presence of spots.

A possible explanation for these results would be that the objects are either more massive, or much older, than previously thought, so that the lithium depletion has already started. Although the uncertainties of the masses and ages are large, they are not large enough as to explain the observed lithium depletion. Therefore, the most likely explanation is either a lack of understanding of the details of the formation of the lithium line, or a lack of understanding of the internal structure of the very young low-mass objects.

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Hubble Space Telescope Search for M Subdwarf Binaries

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We present *HST*/ACS observations of 19 nearby M subdwarfs in a search for binary systems. Other than the wide common proper motion pair LHS 2140/ 2139, none of our sdM and esdM targets are found to be binaries. Our survey is sensitive to equal-luminosity companions at close (2-8 AU) separations, while sub-stellar secondaries could have been detected at separations in the range of 6-30 AU. To check for wide binaries, we have compared the POSS I and II images in a field of view as large as $10'\times10'$, but could not detect a single co-moving star for any of the targets. Combining our results with those from Gizis & Reid, we have a binary fraction of 3% (1/28). Detection of a small number of M subdwarf binaries reported in the literature suggests a higher fraction than the one obtained here, probably comparable to that found for the more massive solar-type stars in the halo (13-15%). Comparison with the disk M dwarf fraction (~25%) however suggests multiplicity to be rare among the lowest mass halo stars, implying the two populations formed under different initial conditions. The low binary fraction in our survey could be explained by selection biases. A decrease in multiplicity has been observed in the disk for masses below $0.1M_\odot$, the peak in the disk mass function (MF). The globular cluster MF is found to peak at about $0.33M_\odot$, with a decrease in the number of stars per unit mass below the peak mass. Our sample being composed of stars with masses between ~0.2 and 0.085 $M_\odot$ suggests that a decrease in multiplicity similar to the disk may also be true for the halo stars, but perhaps below

a mass of $\sim 0.3 M_\odot$. A higher M subdwarf binary fraction may be obtained if the selected primaries have masses near or higher than the peak in the MF.

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Cross-Listed Abstracts

Editor's Note: The abstracts below on PMS stars are being cross-listed with the Star Formation Newsletter.

Keck HIRES Spectroscopy of Candidate Post T Tauri Stars

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We use high-signal-to-noise (∼150-450), high resolution ($R \sim 45,000$) Keck HIRES spectroscopy of 13 candidate post T Tauri stars to derive basic physical parameters, lithium abundances and radial velocities. We place our stars in the M_v-T_{eff} plane for use in determining approximate ages from pre-main sequence isochrones, and confirm these using three relative age indicators in our analysis: Li abundances, chromospheric emission and the kinematic U-V plane. Using the three age criteria we identify 5 stars (HIP 54529, HIP 62758, HIP 63322, HIP 74045, and HIP 104864) as probable post T Tauri stars with ages between 10 and 100 Myr. We confirm HIP 54529 as an SB2 and HIP 63322 as an SB1 star. We also examine irregular photometric variability of PTTs using the *HIPPARCOS* photometry annex. Two of our PTT stars exhibit near-IR excesses compared to Kurucz model flux; while recent work suggests classical T Tauri stars evince similar *JHK* excesses presumably indicative of non-photospheric (disk) emission, our results may be illusory artifacts of the chosen I-band normalization. Near-IR excesses we see in a literature-based sample of PTTs appear to be artifacts of previous spectral type-based $T_{\rm eff}$ values. Indeed, comparison of the homology of their observed and model photospheric SED's suggests that photometric temperatures are more reliable than temperatures based on spectral standards for the cooler temperature ranges of the stars in this sample. We conclude that our age oriented analysis is a robust means to select samples of nearby, young, isolated post T Tauri stars that otherwise masquerade as normal field stars.

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Observation of Enhanced X-ray Emission From the CTTS AA Tau During One Transit of an Accretion Funnel

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Context. Classical T Tauri stars are young solar-type stars accreting material from their circumstellar disks. Thanks to a favorable inclination of the system, the classical T Tauri star AA Tau exhibits periodic optical eclipses as the warped inner disk edge occults the stellar photosphere.
Aims. We intend to observe the X-ray and UV emission of AA Tau during the optical eclipses with the aim of localizing these emitting regions on the star.
Methods. AA Tau was observed for about 5 h per *XMM-Newton* orbit (2 days) over 8 successive orbits, which covers two optical eclipse periods (8.22 days). The *XMM-Newton* optical/UV monitor simultaneously provided UV photometry (UVW2 filter at 206 nm) with a ∼15 min sampling rate. Some V-band photometry was also obtained from the ground during this period in order to determine the dates of the eclipses.
Results. Two X-ray and UV measurements were secured close to the center of the eclipse ($\Delta V \sim 1.5$ mag). The UV flux is the highest just before the eclipse starts and the lowest towards the end of it. UV flux variations amount to a few 0.1 mag on a timescale of a few hours and up to 1 mag on a timescale of a week, none of which are correlated with the X-ray flux. We model it with a weekly modulation (inner disk eclipse), plus a daily modulation, which suggests a non-steady accretion, but needs a longer observation to be confirmed. No such eclipses are detected in X-rays. Within each 5 h-long observation, AA Tau has a nearly constant X-ray count rate. On a timescale of days to weeks, the X-ray flux varies by a factor of 2–8, except for one measurement where the X-ray count rate was nearly 50 times higher than the minimum observed level even though photoelectric absorption was the highest at this phase, and the plasma temperature reached 60 MK, i.e. a factor of 2–3 higher than in the other observations. This X-ray event, observed close to the center of the optical eclipse, is interpreted as an X-ray flare.
Conclusions. We explain the variable column density with the low-density accretion funnel flows blanketing the magnetosphere. The lack of X-ray eclipses indicates that X-ray emitting regions are located at high latitudes. Furthermore, the occurrence of a strong X-ray flare near the center of the optical eclipse suggests that the magnetically active areas are closely associated with the base of the high-density accretion funnel flow. We speculate that the impact of this free-falling accretion flow onto the strong magnetic field of the stellar corona may boost the X-ray emission.

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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.

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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