COOLNEWS

A RESEARCH NEWSLETTER DEDICATED TO COOL STARS AND THE SUN

No. 122 — April 2006 Editor: Steve Skinner (coolnews@jila.colorado.edu)

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Water Vapor on Supergiants. The 12 micron TEXES Spectra of μ Cephei

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Several recent papers have argued for warm, semi-detached, molecular layers surrounding red giant and supergiant stars, a concept known as a MOLsphere. Spectroscopic and interferometric analyses have often corroborated this general picture. Here, we present high-resolution spectroscopic data of pure rotational lines of water vapor at 12 microns for the supergiant μ Cep. This star has often been used to test the concept of molecular layers around supergiants. Given the prediction of an isothermal, optically thick water-vapor layer in Local Thermodynamic Equilibrium around the star (MOLsphere), we expected the 12 micron lines to be in emission or at least in absorption but filled in by emission from the molecular layer around the star. Our data, however, show the contrary; we find definite absorption. Thus, our data do not easily fit into the suggested isothermal MOLsphere scenario. The 12 micron lines, therefore, put new, strong constraints on the MOLsphere concept and on the nature of water seen in signatures across the spectra of early M supergiants. We also find that the absorption is even stronger than that calculated from a standard, spherically symmetric model photosphere without any surrounding layers. A cool model photosphere, representing cool outer layers is, however, able to reproduce the lines, but this model does not account for water vapor emission at 6 microns. Thus, a unified model for water vapor on μ Cephei appears to be lacking. It does seem necessary to model the underlying photospheres of these supergiants in their whole complexity. The strong water vapor lines clearly reveal inadequacies of classical model atmospheres.

Accepted by ApJ

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For preprints via ftp or WWW: http://arxiv.org/abs/astro-ph/0603384

IR Photometry and a Model of the Dust Shell in V2108 Ophiuchi

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We present the results of JHKLM photometry of the oxygen Mira variable V2108 Oph (= IRC 10322 = IRAS 17119+0859) acquired in 2000-2004. The period of the brightness variations is refined (570 ± 3 days), and light and color curves in the near-IR are presented. The mean fluxes, color temperatures, and sizes for two blackbodies representing the combined radiation of the star and dust shell at minimum and maximum brightness are estimated. Additional IRAS data were used to compute a model with a spherically symmetric dust shell of silicate grains; the best-fit model has a radius for its inner boundary of 2.4×10^{14} cm, a dust temperature at this boundary of 1150 K, an optical depth of the shell at 0.55 μm of 16.8, and implies a distance to the star of 980 pc. We estimate the mass-loss rate for V2108 Oph to be $\dot{M} = 1.2 \times 10^{-5}$ M$_\odot$ yr^{-1} .

Accepted by Astronomy Reports

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Geometry of Giant Star Model Atmospheres: A Consistency Test

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We investigate the effect of a geometric inconsistency in the calculation of synthetic spectra of giant stars. Spectra computed with model atmospheres calculated in spherical geometry while using the plane-parallel approximation for line formation calculations (s_p), as well as the fully plane-parallel case (p_p), are compared to the consistently spherical case (s_s). We present abundance differences for solar metallicity models with $T_{\rm eff}$ ranging from 4000 to 6500 K and $\log g$ from 0.5 to 3.0 [cgs]. The effects are smaller for s_p calculations (-0.1 dex in the worst case) than for the p_p case (up to $+0.35$ dex for minority species and at most -0.04 dex for majority species), both with respect to the s_s case. In the s_p case the differences increase slightly with temperature, while in the p_p case they show a more complex behaviour. In both cases the effects decrease with increasing $\log g$ and increase with equivalent width. Within the parameter range of F, G and K giants, consistency seems to be less important than using a spherical model atmosphere. The abundance differences due to sphericity effects presented here can be used for error estimation in abundance studies relying on plane-parallel modelling.

Accepted by A&A

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For preprints via ftp or WWW: http://arxiv.org/abs/astro-ph/0603273

On the Use of Line Depth Ratios to Measure Starspot Properties on Magnetically Active Stars

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Photometric and spectroscopic techniques have proven to be effective ways to measure the properties of dark, cool starspots on magnetically active stars. Recently, a technique was introduced (e.g. Catalano et al. 2002) using atomic line depth ratios (LDR) to measure starspot properties. Carefully reproducing this technique using a new set of spectroscopic observations of active stars, we find that the LDR technique encounters difficulties, specifically by overestimating spot temperatures (because the atomic lines blend with titanium oxide absorption in cooler spots) and by not tightly constraining the filling factor of spots. While the use of LDR for active star studies has great promise, these concerns should be addressed before the technique is more widely applied.

Accepted by ApJ

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Global Magnetic Field of the Sun as a Star and of Convective Stars

This Report is Dedicated to the Memory of Andrew Severny

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In terms of the Babcock' and Leighton' phenomenological magneto-kinematic model of the solar cycle and in terms of standard α-Ω dynamo theory, there are only two main components of large-scale magnetic field on the Sun: toroidal magnetic field and poloidal field. The first results of the magnetic field measurements of the Sun as a star were published by A. Severny, and named as General Magnetic Field (GMF) of the Sun as a Star. What is the origin of the GMF?

Using frequencies for $P_1 = 26.929 \pm 0.015$ d and $P_2 = 27.144 \pm 0.015$ d, we can obtain main periods in the power spectrum for the GMF of the Sun as a star including the period of activity cycle. One of the initial periods is due to a rigid rotation of the radiative zone, and the second one is produced by differential rotation of the Sun's top layer. The Origin Magnetic Field of the Sun's radiative zone is captured by moving matter and transported up to the surface, where a beating of two main frequencies produces the observed picture.

The presence of a weak general magnetic field (up to some dozen Gausses) for 21 convective stars (F9-M3 spectral types and I-V luminosity classes) is detected nowadays. For two solar-like stars variations of the GMF as a function of the stellar rotation has been determined: for a more active and younger star than the Sun ξ Boo A (G8 V) with $P_{rot} = 6.198$ d, and for old solar-like star 61 Cyg A (K5 V) with $P_{rot} = 36.617$ d. For ξ Boo A GMF variations as a function of rotational period was confirmed using MuSiCoS Stokesmeter in 2003. The Crimea curve (1990-1999) shows domination of the dipole component contrary to the MuSiCoS curve for year 2003, which demonstrates the presence of quadrupole component. An existence of the GMF on convective stars with vigorous convective envelopes confirms a hypothesis that the GMF is a real phenomenon.

The GMF reflects properties of a stationary global magnetic field of the Sun's (convective star's) radiative interior on its surface, and there appears to be a third large-scale component of the magnetic field.

Accepted by Bulletin of the Crimean Astrophysical Observatory, Vol. 103

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Internal Stellar Rotation and Orbital Period Modulation in Close Binary Systems

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The orbital period modulation, observed in close binary systems with late-type secondary stars, is considered in the framework of a general model that allows us to test the hypothesis proposed by Applegate (1992, ApJ 385, 621). It relates the orbital period variation to the modulation of the gravitational quadrupole moment of their magnetically active secondary st ars produced by angular momentum exchanges within their convective envelopes. By considering the case of RS CVn binary systems, it is found that the surface angular velocity variation of the secondary component required by Applegate's hypothesis is between 4% and 12%, i.e., too large to be compatible with the observations and that the kinetic energy dissipated in its convection zone ranges from 4 to 43 times that supplied by the stellar luminosity along one cycle of the orbital period modulation. Similar results are obtained for other classes of close binary systems by applying a scaling relationship based on a simplified internal structure model. The effect of rapid rotation is briefly discussed finding that it is unlikely that the rotational quenching of the turbulent viscosity may solve the discrepancy. Therefore, the hypothesis proposed by Applegate is not adequate to explain the orbital period modulation of close binary systems with a late-type secondary.

Accepted by MNRAS

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Electron Density and Turbulence Gradients within the Extended Atmosphere of the M Supergiant Betelgeuse (α Orionis)

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The extended atmosphere of the M supergiant Betelgeuse is complex with cool plasma dominating the structure by mass and small amounts of embedded hotter chromospheric plasma. A major challenge is to understand the interrelationship and juxtaposition of these different components, which in turn may provide clues to the nature of the process of non-radiative heating and the mechanisms that drive mass loss. We examine the chromospheric C II] 2325Å multiplet emission line electron density diagnostic using spatially scanned *HST*/STIS echelle spectra. Escape probability models for the electron density sensitive line ratios reveal that the mean electron density decreases by 0.6 dex as the sightline goes from disk center to ±75 mas. Radiative transfer simulations using spherical model atmospheres show that this trend can be explained if the electron density declines with radius by nearly two dex across $\Delta R \sim 2R_*$. The emission profiles indicate that the chromospheric material corotates with the star and then becomes decoupled by ±75 mas from disk center. We find no evidence for radial outflow in the chromospheric plasma. We find that the strongest C II]] 2325Å emission lines are opacity broadened, and that the gradient of atmospheric turbulence is surprisingly small. Using empirical constraints we derive a relation between the relative C II column densities in the cool and chromospheric atmospheric components and the excitation temperature. These UV chromospheric results and previous radio analyses suggest that the chromosphere is pervasive but has a small filling factor at $\sim 3R_*$, suggestive of confinement and heating in magnetic structures.

Accepted by ApJ, Part 1

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Newly Discovered Active Binaries in the RasTyc Sample of Stellar X-ray Sources. I. Orbital and Physical Parameters of Six New Binaries

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We present the first results of follow-up optical observations, both photometric and spectroscopic, of stellar X-ray sources, selected from the *RasTyc* sample, resulting from the cross-correlation of ROSAT All-Sky Survey (RASS) and TYCHO catalogues. In particular, we report on the discovery of six late-type binaries, for which we have obtained good radial velocity curves and solved their orbits. We have performed an automatic spectral classification of both single-lined and double-lined binaries with codes properly developed by us and found two binaries composed of two main-sequence stars and four binaries with an evolved (giant or subgiant) component. Filled-in or pure emission Hα profiles, indicative of moderate or high level of chromospheric activity, have been observed. We have also detected, in nearly all the systems, a photometric modulation ascribable to surface inhomogeneities which is correlated with the orbital period, suggesting a synchronization between rotational and orbital periods. The position on the HR diagram of the components of the five sources with known parallax indicates three binaries containing only main-sequence stars and two single-lined systems with a giant component. The kinematical properties of two, or possibly four, of the observed systems are consistent with young disk population.

Accepted by A&A (17 March 2006)

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Bringing VY Canis Majoris Down to Size: An Improved Determination of Its Effective Temperature

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The star VY CMa is a late-type M supergiant with many peculiarities, mostly related to the intense circumstellar environment due to the star's high mass-loss rate. Claims have been made that would suggest this star is considerably more luminous ($L \sim 5 \times 10^5 L_\odot$) and larger ($R \sim 2800 R_\odot$) than other Galactic red supergiants (RSGs). Indeed, such a location in the H-R diagram would be well in the "Hayashi forbidden zone" where stars cannot be in hydrostatic equilibrium. These extraordinary properties, however, rest upon an assumed effective temperature of 2800-3000 K, far cooler than recent work have shown RSGs to be. To obtain a better estimate, we fit newly obtained spectrophotometry in the optical and NIR with the same MARCS models used for our recent determination of the physical properties of other RSGs; we also use $V-K$ and $V-J$ from the literature to derive an effective temperatures. We find that the star likely has a temperature of 3650 K, a luminosity $L \sim 6 \times 10^4 L_\odot$, and a radius of $\sim 600 R_\odot$ These values are consistent with VY CMa being an ordinary evolved $15 M_\odot$ RSG, and agree well with the Geneva evolutionary tracks. We find that the circumstellar dust region has a temperature of 760 K, and an effective radius ~130 AU, if spherical geometry is assumed for the latter. What causes this star to have such a high mass-loss, and large variations in brightness (but with little change in color), remains a mystery at present, although we speculate that perhaps this star (and NML Cyg) are simply normal RSGs caught during an unusually unstable time.

Accepted by ApJ

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The Effective Temperatures and Physical Properties of Magellanic Cloud Red Supergiants: The Effects of Metallicity

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We present moderate-resolution optical spectrophotometry of 36 red supergiants (RSGs) in the LMC and 39 RSGs in the SMC. Using the MARCS stellar atmosphere models to fit this spectrophotometry, we determine the reddenings, effective temperatures and other physical properties, such as bolometric luminosity and effective stellar radii, and compare these to stellar evolutionary models. As a self-consistency check, we also compare the broad-band colors $(V-K)_0$ and $(V-R)_0$ with the models. The $(V-R)_0$ results are in good agreement with those from fitting the optical spectrophotometry, but the $(V-K)_0$ results show metallicity-dependent systematic differences, amounting to 3-4% in effective temperature, and 0.2 mag in bolometric luminosity, at the metallicity of the SMC; we conclude that this is likely due to the limitations of static 1D models, as spectra of RSGs in the optical and IR may reflect different atmospheric conditions due to the large surface granulation present in these stars. We adopt the scales indicated by the optical spectrophotometry and $(V-R)_0$ colors, but accept that there is still some uncertainty in the absolute temperature scales. We find that the effective temperature scales for the LMC and SMC K-type supergiants agree with each other and with that of the Milky Way, while for M-type supergiants the scales are cooler than the Galactic scale by 50 K and 150 K, respectively. This is in the sense that one would expect: since the spectral classification of RSGs is based on the line strengths of TiO, stars with lower abundances of these elements have to be cooler in order to have the same strength. However, this effect is not sufficient to explain the shift in average RSG spectral type between the three galaxies. Instead, it is the effect that metallicity has on the coolest extent of the evolution of a star that is primarily responsible. Our new results bring the RSGs into much better agreement with stellar evolutionary theory, although the SMC RSGs show a considerably larger spread in effective temperatures at a given luminosity than do the LMC stars. This is expected due to the larger effects of rotational mixing in lower-metallicity stars, as higher helium abundance at the surface would lead to higher effective temperatures in the RSG phase. We also find that the distribution of reddening of RSGs in the Clouds is skewed significantly towards higher values, consistent with our recent finding that Galactic RSGs show extra extinction due to circumstellar dust.

Accepted by ApJ

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Bisectors of the Cross-correlation Function Applied to Stellar Spectra. Discriminating Stellar Activity, Oscillations and Planets

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Context: Bisectors of strong, single spectral lines, usually the Fe line, have traditionally been used to examine the velocity fields in stellar atmospheres. This requires high S/N often achieved by summing many individual spectra. Aims: We investigate whether bisectors derived from cross-correlation functions (CCF) of single-exposure spectra can be used to provide information on stellar atmospheres, and whether they can be used to discriminate between radial velocity changes caused by planets, magnetic activity and oscillations. Methods: Using a sample of bright stars observed with the HARPS spectrograph, we examine the shapes of the bisectors of individual strong spectral lines in summed spectra, comparing with similar studies in the literature. Moreover, we examine four different quantitative CCF bisector measures for correlations with radial velocity and stellar parameters. Results: We show that CCF bisector measures can be used for quantitative analysis, employing both the absolute values and the variations. From absolute values, $\log g$ and absolute magnitude can be approximated, and from the correlations with radial velocity one can distinguish between magnetic activity, oscillations and orbiting planets as the probable cause of radial velocity variations. We confirm that different isolated spectral lines show different bisector shapes, even between lines of the same element, calling for caution in trying to derive global stellar properties from the bisector of a CCF. For the active star HR 1362 we suggest from the bisector shape an extra photospheric heating caused by the chromosphere of several hundred degrees. We confirm the fill-in of spectral lines of the Sun taken on the daylight sky caused by Rayleigh-Brillouin and aerosol scattering, and we show for the first time that the fill-in has an asymmetric component.

Accepted by A&A

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For preprints via ftp or WWW: http://arxiv.org/abs/astro-ph/0604241

Study of a Transient Siphon Flow in a Cold Loop

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The nature of loops is still a matter of debate with several explanations having been put forward. Simultaneous spectral and imaging data have the capacity to provide a new insight into mass motions, dynamics and energetics of loops. We report on spectral data taken with the Solar Ultraviolet Measurements of Emitted Radiation spectrograph (SUMER) and imaging data from the Transition Region and Coronal Explorer (TRACE) of a transient event which occurred in a cold loop, lasting a few minutes. A sequence of TRACE images in the 1550 Å and 171 Å filters show a disturbance which originated at one foot-point and propagates along the loop. The SUMER slit was placed at the other foot-point of the loop. In order to interpret the results, numerical simulations were performed with the results then converted into observable quantities and compared with the data. During the event a radiance increase and a relative red shift of $\approx$ 20 km s^{-1} was detected in the N V 1238.82 Å line. 1D numerical simulations are performed and observable quantities derived from the results of the simulations. The observed dynamic behaviour of the N V 1238.82 Å line profiles was recovered. The results suggest that the observations could be interpreted in terms of a short-lived siphon flow reaching a speed of 120 km s^{-1} and driven by a nonlinear heating pulse. The energies required to drive the observed red-shifts are estimated to be about 10^{25} erg. The absence of a significant blue-shift caused by the return flow is explained A movie of the flow as seen in TRACE 1550 can be viewed at http://www.arm.ac.uk/~jgd/movie/siphon

Accepted by A&A

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Dynamic Features in the Solar Atmosphere with Unusual Spectral Line Enhancements and Doppler-shifts

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The solar atmosphere contains a wide variety of transient features, here, we discuss data relating to one such feature. High spectral and temporal resolution data from SUMER/SoHO plus high resolution images from TRACE are used. In the transient feature discussed, we see a factor of two enhancement in N V 1238, coupled with a factor of two decrease in O V 629 visible over 3–4 arcsec along the slit. Furthermore, the O V line shows a secondary component with a down-flow of $\approx$ 75 km s^{-1}, while the N V line shows only a small additional broadening of the line, despite the fact that both lines have over-lapping formation temperatures, with the peak formation temperature separated by log T_e = 0.08 – 0.12 (depending on the assumed atomic model). Inclusion of an electron density dependent ionization calculation will increase the N V radiance over that of O V at large electron densities. We suggest this feature can be explained via a highly focused jet at the O V/O VI formation temperature resulting from reconnection. Also, we believe that this event is not unique but that their detection depends on the availability of simultaneous spectral and imaging data of comparable spatial and temporal resolution. A movie of the feature can be viewed at http://www.arm.ac.uk/∼jgd/movie/jet

Accepted by A&A

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Macrospicules and Blinkers as Seen in Shutterless EIT 304 Å

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Small-scale transient phenomena in the solar atmosphere are believed to play a crucial role in the coronal heating and solar wind generation. This study aims at providing new observational evidence on blinkers and macrospicules appearance in imager data and in doing so, establish the long disputed relationship between these phenomena. We analyse unique high-cadence images in the transition region He II 304 Å line obtained in a shutterless mode of the Extreme-ultraviolet Imaging Telescope on board the Solar and Heliospheric Observatory. The data have a cadence of approximately 68 s and a pixel size of 2.62 arcsec. The events are identified through an automatic brightenings identification procedure. Features showing a jet-like structure seen in projection on the disk were selected and their light-curve further analysed. The temporal evolution of the intensity in three events is shown, two of them seen on-disk as jet-like features and one above the limb. The flux increase, size and duration derived from the light-curve of the on-disk events show an identity with the blinker phenomenon. Our analysis of these events suggest that macrospicules where viewed on-disk are normally classified as blinkers, although since the blinker classification is rather broad this does not necessarily imply that all blinkers are macrospicules. A movie of the different blinkers can be viewed at http://star.arm.ac.uk/∼madj/blinker/animation.gif.

Accepted by A&A

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Solar Carbon Monoxide, Thermal Profiling, and the Abundances of C, O, and Their Isotopes

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A solar photospheric "thermal profiling" analysis is presented, exploiting the infrared (2.3–4.6 μm) rovibrational bands of carbon monoxide (CO) as observed with the McMath-Pierce Fourier transform spectrometer (FTS) at Kitt Peak, and from above the Earth's atmosphere by the Shuttle-borne ATMOS experiment. Visible continuum intensities and center-limb behavior constrained the temperature profile of the deep photosphere, while CO center-limb behavior defined the thermal structure at higher altitudes. The oxygen abundance was self consistently determined from weak CO absorptions (for C/O$\equiv$ 0.5). Our analysis was meant to complement recent studies based on 3-D convection models which, among other things, have revised the historical solar oxygen (and carbon) abundance downward by a factor of nearly two; although in fact our conclusions do not support such a revision. Based on various considerations, an $\epsilon_{\rm O}$ = 700±100 ppm (parts per million relative to hydrogen) is recommended; the large uncertainty reflects the model sensitivity of CO. New solar isotopic ratios also are reported: ^{12}C/^{13}C=80±1, ^{16}O/^{17}O=1700±220, and ^{16}O/^{18}O=440±6; all significantly lower than terrestrial. CO synthesis experiments utilizing a stripped down version of the 3-D model—which has large temperature fluctuations in the middle photosphere, possibly inconsistent with CO "movies" from the Infrared Imaging Spectrometer (IRIS), and a steeper mean temperature gradient than matches visible continuum center-limb measurements—point to a lower oxygen abundance ($\sim$500 ppm) and isotopic ratios closer to terrestrial. A low oxygen abundance from CO—and other molecules like OH—thus hinges on the reality of the theoretically predicted mid-photospheric convective properties.

Accepted by ApJS

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Magnetic Field Confinement by Meridional Flow and the Solar Tachocline

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We show that the MHD theory that explains the solar tachocline by an effect of the magnetic field can work with the decay modes of a fossil field in the solar interior if the meridional flow of the convection zone penetrates slightly the radiative zone beneath. An equatorward flow of about 10 m/s penetrating to a maximum depth of 1000 km below the convection zone is able to generate almost horizontal field lines in the tachocline region so that the internal field is almost totally confined to the radiative zone. The theory of differential solar rotation indeed provides meridional flows of about 10 m/s and a penetration depth of $\lesssim$ 1000 km for viscosity values that are characteristic of a *stable* tachocline.

Accepted by A&A

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Ph.D. Thesis Abstracts

Determination of Physical Parameters of Magnetic Active Regions in Stars with Different Evolutionary Stages

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Ph.D degree awarded: February 2006

Understanding stellar magnetic activity phenomena is of paramount importance for stellar evolution and for planetary systems formation and their atmosphere and climate. The dynamo process that generates magnetic fields in stars is well understood and there is still no comprehensive model of solar and stellar magnetic activity. Stellar activity is characterized by tracers such as spots, plages, flares, prominences and winds. These features are the fingerprints of magnetic field lines and their detailed analysis provides constraints for theoretical models. Our knowledge can only advance if the active stars besides the Sun are included in our study. Therefore, it is necessary to carry out comprehensive studies of active stars with a wide range of stellar parameters and several varieties of activity phenomena.

In this thesis, I concentrate on emergence of active regions at photospheric and chromospheric levels, namely spots and plages, in stars with different evolutionary stages. Spots are cool areas on the surface of the stars and are supposed to be the result of the blocking effect on convection caused by magnetic flux-tube emersion. Plages are bright areas linked to emersion of magnetic flux tubes from the sub-photospheric convective level.

Starspot temperature represents an important parameter for the investigation of stellar magnetic activity, but its precise determination, relying only on light curve inversion techniques, is strongly hampered by the lack of solution uniqueness. Therefore, a method based on *line-depth ratios* (LDRs) as temperature discriminant has been developed. This technique is capable of resolving temperature differences less than 10 K. Thus, I have developed LDR–temperature calibrations in standard stars considering the effects on line profiles linked to metallicity, gravity, rotational velocity, spectrograph resolution. Moreover, combining temperature and light curve solutions, I am able with a spot model to determine, in a univocal way, starspot temperature and area in a sample of cool target stars.

Using the net Hα emission as indicator of plage presence, I have also studied the spot and plage association. As a matter of fact, the residual Hα profiles, obtained as the difference between the observed spectra and non-active templates, allows to study the chromospheric structures simultaneously to the photospheric ones. Thus, a simple plage model has been also applied to the Hα equivalent width curves to determine the plage area. In addition, I have also detected the intensity of the He I D_3 line to analyse the presence of surface features in the high chromosphere.

The observations of both standard and target stars have been performed with different instruments. In particular, the spectra have been acquired with FRESCO at Catania Astrophysical Observatory (Italy), ELODIE and AURELIE spectrographs at *Observatoire de Haute-Provence* (France) and SOFIN at Nordic Optical Observatory (Canarian Islands). The photometric observations have been performed with automated and not automated telescopes of Catania Astrophysical Observatory, Fairnborn Observatory (USA) and Ege University Observatory (Turkey).

Finally, starspot and plage physical parameters have been obtained for about twenty stars of different effective temperature and gravity and different evolutionary stages. The main results can be summarized as follows: i) starspot temperatures are more similar to solar penumbrae; ii) dwarf stars tend to have smaller spots compared to giant stars; iii) stars with higher gravity seem to have cooler (relative to their photosphere) spots compared to stars with lower gravity; iv) spatial association exists between surface inhomogeneities at different atmospheric levels; v) chromospheric plages are bigger for bigger photospheric spots.

Thesis-related Publications: A&A, 394, 1009; A&A, 432, 647; A&A, 446, 1129

Job Opening

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Helio and Astero-Seismology

Centro de Astrofisica da Universidade do Porto (Portugal)

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The financial support is provided by the European Network in Helio and Asteroseismology (HELAS, 2006-2009) and national funds from POCI (with a participation from FEDER). The positions are for one year, with an extension of up to three years. The postdoc will be actively involved in the coordination of the HELAS activities (up to 50solar and stellar modelling and outreach. She/he is also expected to be involved on the preparation and scientific exploitation of the CoRoT mission.

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Dr. Mario Joao P. F. G. Monteiro, email: mjm@astro.up.pt
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