COOLNEWS

A RESEARCH NEWSLETTER DEDICATED TO COOL STARS AND THE SUN

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Enjoy - Steve Skinner.

Stellar Abstracts

Atmospheric Models of Flare Stars: The Flaring State of AD Leo

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We compute a set of semi-empirical atmospheric models for a large flare on the dMe star AD Leo, assuming different filling factors. These are the first models computed to match both the continuum observations, and a wide set of chromospheric spectral lines. We found that the models with a filling factor between 1 and 5% give good agreement between the computed and observed spectral features. Since the main differences between the predicted and observed emission are in the continuum above 4500 Å and in H_α, simultaneous observations in these spectral features are needed to better determine the filling factor, and whether the area coverage of the flare depends on height.

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ROSAT PSPC X-ray Spectral Survey of W UMa Systems

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A spectral survey of X-ray-bright W UMa-type contact-binary systems has been undertaken with the *ROSAT* position sensitive proportional counter (PSPC). For the longer observations, timing studies are also possible. *ROSAT* PSPC observations were obtained on seven W UMa systems: VW Cep, XY Leo, BV/BW Dra, SW Lac, W UMa, V839 Oph and AK Her. Data for an eighth target, 44i Boo, were retrieved from the archive. In addition, we have used the *ROSAT* High Resolution Imager (HRI) to resolve the common-proper-motion pair BV/BW Dra (separation ≈ 16 arcsec). Two-temperature models, for an optically thin plasma, adequately describe the PSPC spectra, with the cooler component at $T_{cool} \approx 2.3 \times 10^6$ K and the hotter component at $T_{hot} \approx 1.0 \times 10^7$ K. The total luminosities, in the *ROSAT* band (0.1–2.4 keV), range from 4.4×10^{29} to 3.3×10^{30} erg s^{-1}. In comparison with published PSPC spectral surveys of two other classes of active binary, namely RS CVn and BY Dra systems (Dempsey et al.), the W UMa systems appear to have, in general, lower values of $VEM_{hot} : VEM_{cool}$, i.e. relatively less material at the highest temperatures. There is also evidence that T_{hot} is lower in the W UMa systems. In general, the PSPC light-curves were constant to within ~ 20 per cent over the course of each observation. VW Cep was observed in both quiescent and active states. During a flare-like event the X-ray flux increased by a factor of two. The temperature of the hotter component rose by a factor of ≈ 1.5, whilst the volume emission measure increased five-fold.

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Measuring Stellar Oscillations Using Equivalent Widths of Absorption Lines

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Kjeldsen et al. (1995, AJ **109**, 1313) have developed a new technique for measuring stellar oscillations and claimed a detection in the G subgiant η Boo. The technique involves monitoring temperature fluctuations in a star via their effect on the equivalent width of Balmer lines. In this paper we use synthetic stellar spectra to investigate the temperature dependence of the Balmer lines, Ca II, Fe I, the Mg b feature and the G band. We present a list of target stars likely to show solar-like oscillations and estimate their expected amplitudes. We also show that centre-to-limb variations in Balmer-line profiles allow one to detect oscillation modes with $\ell \leq 4$, which accounts for the detection by Kjeldsen et

al. of modes with degree $\ell = 3$ in integrated sunlight.

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Rotational Velocity for Lithium-rich Evolved Stars

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Precise rotational velocities have been determined for 12 lithium-rich giant stars using the CORAVEL spectrometer. Except for HD 9746, the lithium-rich giants show normal rotational velocities with respect to typical lithium-normal giants of the same spectral type. Further, we have found no sign of binarity for the lithium-rich giants.

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On the Link Between Coronal Activity and Orbital Period in Evolved Binary Stars

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The analysis of the relationship between X–emission flux and orbital period indicates a drop in the X–ray emission of binaries with evolved components at orbital periods of about 100 days. Intense X–ray emitters have an orbital period lower than 100 days, whereas with an orbital period greater than about 100 days are weak X–ray emitters. This critical period corresponds to the orbital period separating binary systems with circular orbits from those of eccentric orbits.

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Radiation Transfer of Gyrosynchrotron Emission in Stellar Environments

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Non-thermal radio emission has been detected from several kinds of active stars. Polarization and intensity measurements of the quiescent (i.e. non-flaring) emission indicate gyrosynchrotron emission. A three-dimensional magnetic field model for the stellar field is presented and the gyrosynchrotron intensity and polarization emerging from such a model is calculated and compared with observations. Model spectra agree well with observations. Model polarization results indicate that the emission region is more complex than the simple model and may indicate the presence of multipole components in the field, small loops of flux near the stellar surface and significant energy loss in the radiating electron distribution over time.

Submitted to Solar Physics

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Simultaneous EUVE & ASCA Observations of AB Dor: Temperature Structure & Abundances of the Quiescent Corona

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We have analyzed EUV and X-ray spectra of the non-flaring state of AB Dor, obtained from simultaneous observations with EUVE and ASCA. The coronal temperature structure and the coronal elemental abundances have been derived by jointly fitting the spectra, including lines and continuum. We have applied a multi–temperature fitting method and we have found that an optically thin plasma model with *solar abundances* (relative to hydrogen) does not yield a good fit. A 4-T fit allowing the abundances of the more important elements (Fe, S, Si, Mg, Ne, and O) plus four other less important abundances (N, Ar, Ca, and Ni) to vary improves the fit markedly. This results in values of the first 6 abundances relative to solar photospheric values that are significantly (a factor 2–3) below solar except for Ne, which is solar, while most of the the remaining four abundances are consistent both with solar and reduced abundances. In the course of the 4-T fitting we have determined a best-fit value for the interstellar hydrogen column density of $N_{\rm H}$ = $(2.0 \pm 0.5)\ 10^{18}\ {\rm cm}^{-2}$. We have applied four differential emission measure (DEM) distribution analysis techniques, *viz.*: (i) regularization method, (ii) polynomial method, (iii) clean algorithm, and (iv) genetic algorithm. The four different methods all yield a qualitatively similar DEM, showing two maxima in the temperature intervals 5–8 MK and 20– 30 MK. Our analysis demonstrates the great value of simultaneous ASCA and EUVE observations in determining the fundamental parameters of stellar coronae.

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CCD Astrometry of Southern Very Low-Mass Stars

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CCD astrometry of a sample of southern Very Low-Mass (VLM) stars, obtained on the 2.2 m telescope at the European Southern Observatory, La Silla is presented. Trigonometric parallaxes have been determined for 13 stars, and proper motions for a further 2 stars. Photometry in the I and K passbands is also presented for the astrometric program stars, and is used to construct an M_K:I–K colour-magnitude diagram. Astrometric observations were made of the canonical very late M-dwarf, VB 10 through a narrow band ($\Delta\lambda$=90 Å) filter. These data confirm that the effects of differential colour refraction can be substantially reduced by the use of such filters, without impacting astrometric precision.

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The Lithium Abundance Dispersion in the Pleiades?

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High resolution, high signal to noise spectra have been taken of seven K dwarf stars from the Pleiades cluster, in a very narrow range of colours. The aim of the experiment was to determine whether the large scatter in lithium abundances observed at any given colour redder than $(B-V)_{\rm o} = 0.8$ (Soderblom et al., 1993a), is due to errors in the abundances derived from the resonance line of lithium at 6708Å. Since the resonance line is formed high in the atmosphere of the stars, it is questionable whether the equivalent width tells us useful information about the chemical abundance of lithium. Chromospheric emission (CE), for instance, could affect the measured equivalent width of the line. The subordinate line at 6104 Åwould not be so badly affected, since it is formed lower in a star's atmosphere. This report shows that there are, indeed, systematic differences in the lithium abundances derived from the two lines.

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The Extreme Ultraviolet Spectrum of the Nearby K-dwarf ϵ Eri

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We present and discuss the extreme ultraviolet spectrum of the nearby K2 dwarf ϵ Eri obtained with the spectrometers onboard the *Extreme Ultraviolet Explorer Satellite* (EUVE). In the EUVE spectrum of ϵ Eri we detect emission lines attributable to iron in the ionisation stages IX to XXI, thus covering a rather large temperature range from $< 10^6$ K to 10^7 K. While the lines in the lowest and highest ionisation stages are relatively weak, the strongest lines detected are from Fe XV and XVI, from which we infer a peak in the differential emission measure distribution at coronal temperatures of log $T_c \sim 6.4$; significant emission measure is, however, also present at both higher and lower temperatures. This is in contrast to both lower activity stars whose EUV spectra are dominated by cooler Fe lines in the range 170–180 Å as well as the more active stars whose EUV spectra are dominated by hotter Fe lines in the range 110–135 Å . Finally, a density determination using line ratios of Fe XIII and Fe XIV results in coronal densities for ϵ Eri which are similar to solar active region densities.

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CF Tucanae – Another Case of a Coronal MAD Syndrome ?

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We present and discuss an EUV spectrum of the RS CVn binary CF Tuc obtained with the short wavelength (SW) spectrometer on board the EUVE satellite. In addition to a continuum, only two spectral lines attributed to Fe XXII and Fe XXIII are detected. We show that the EUVE data can be reconciled with a solar abundance plasma only if most of CF Tuc's emission measure is located at temperatures of $\approx 10^8$ K; alternatively, the plasma must be iron depleted with most of the emission measure located at the peak temperature of the observed line contribution functions. A comparison with previously obtained ROSAT PSPC spectra argues strongly in favor of the latter situation. As a consequence, we are forced to the conclusion that the iron abundance in the corona of CF Tuc is reduced with respect to solar values by factors between five and ten. The reasons for the occurrence of this metal abundance deficiency syndrome (MADS) are unclear at present; however, for the specific case of CF Tuc, the extremely low coronal iron abundance might possibly result from an anomalously low photospheric iron abundance.

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Photometry and Spectroscopy of Serendipitous X-ray Sources Detected by the *Einstein* Satellite

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Three serendipitous X-ray sources detected by the *Einstein* satellite were photometrically and spectroscopically observed at the European Southern Observatory. Spectral types, distances and X-ray fluxes have been estimated. Optical variability with a period of 4.7 days was detected for 1E0315.7-1955, which is likely to be a PMS object. Optical variability with a period of 9.1 days was detected for 1E0505.0-0527 (K2IV+F9V), which is likely to be a classical RS CVn-type variable. The third object of the sample, 1E1127.9-1502 (G0V+G5V), was almost constant during early

1990 but has shown evidence of optical variability one year later.

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Lithium Abundance in a Volume Limited Sample of Nearby Main Sequence G and K Stars

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We present observations of the Li I 6707.8 Å line in a volume limited sample of main sequence stars of spectral types ranging from late F down to M0, selected from the Gliese catalog of nearby stars, discussing the behavior of lithium abundance along the main sequence. An unexpected result from our survey is that a low but measurable abundance of surface lithium ($-0.5 < N(\mathrm{Li}) < -1.0$) is found to be a common feature in the cooler dwarfs in our sample. Possible explanations for the widespread presence of lithium in very cool dwarfs are discussed, with emphasis on the possibility of lithium being produced in stellar flares. We also discuss the feasibility of using kinematic age indicators for studying the lithium-age relationship, and show that surface lithium is found to be essentially uncorrelated with kinematic age indicators for the dwarfs in our sample.

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Wind-accretion Induced Rapid Rotation and a New Class of Active Star

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A physical model is presented to explain the occurrence of wide binary systems discovered at EUV wavelengths, such as 2RE J0044+093, which consist of a hot white-dwarf and an ultra-rapidly rotating K-dwarf. It is difficult to explain the rapid rotation of the K-dwarf as a consequence of either youth or close binarity because of the length of the evolutionary and cooling timescales for the white-dwarf and the lack of any radial velocity variations. It is proposed that accretion of the slow, massive wind from the asymptotic giant branch (AGB) progenitor of the white-dwarf, by the low mass secondary in a detached configuration, can transfer sufficient angular momentum to produce these systems. For a range of AGB masses, and wind velocities of 10-20 $\mathrm{km\,s^{-1}}$, it is found that secondary spin up to periods of less than 10 hr can take place for final orbital separations of up to 100 AU. If the secondaries are wind-accretion induced, rapidly rotating stars (or WIRRing stars), they could show signs of chemical enrichment in carbon and s-process elements, such as barium, that were present in the AGB wind. The detection of such over-abundances would lend firm support for this hypothesis and provide an evolutionary link between WIRRing stars and Barium-giants. It is also suggested that the rapidly rotating, late-type central stars of planetary nebulae, such as Abell 35, are the progenitors of WIRRing stars, seen shortly after the mass accretion phase.

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On the Origin of the Ultra-fast Rotators in Young Star Clusters

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In this paper we present a series of evolutionary models of low-mass stars, including rotation, that begin on the deuterium main-sequence as suggested by Palla and Stahler (1991). We find that angular momentum loss must saturate on the pre-main sequence if we are to account for the presence of the ultra-fast rotators (UFRs) in young

star clusters. This is in agreement with the saturation in chromospheric emission observed by Stauffer (1994) and others. The saturation threshold required to produce the lower envelope of the observations is different for G, K and M stars, with lower-mass stars saturating at lower angular velocities. The result seems to indicate that convection is an important contributor to the magnetic fields of low-mass stars.

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Detection of Strong Magnetic Fields on M Dwarfs

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We have detected Zeeman splitting of the Fe I line ($g_{\rm eff}$= 2.5) at 8468.40 Å in the very active M4.5Ve stars Gliese 729 and Gliese 873 (EV Lac). High resolution ($R = 120,000$), low noise ($\sim 0.5\%$) spectra show clear Zeeman shifted σ components from which we infer field strengths of 2 to 4 kG, independent of uncertainties in model atmospheres. Similar observations of a sequence (M0V–M5V) of low activity M dwarfs demonstrate that the wing components in the 8468.40 Å line are not due to the ubiquitous TiO lines in the vicinity. This strongly suggests that discrepancies in the shape of the magnetically sensitive iron line are due to magnetic fields, rather than differences in photospheric temperature. By fitting the ratio of active to inactive line profiles with simple one–component models, we estimate that $50 \pm 13\%$ of the photosphere of EV Lac is covered by 3.8 ± 0.5 kG magnetic fields, while $50 \pm 13\%$ of Gliese 729 is covered by 2.6 ± 0.3 kG fields. This confirms earlier reports (Saar & Linsky 1985; Saar 1994a) of large magnetic fields on M dwarf flare stars. We see evidence for a distribution of magnetic field strength, spatially across the surface and/or with depth. The twofold increase in field strength relative to G and K dwarfs is predicted by flux tube equilibrium arguments, but the 1 kG difference in the measured field strengths for these two stars suggests that field strengths may also grow with activity as the photospheric filling factor approaches unity.

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Mass-Luminosity Relationship and Lithium-Depletion for Very-Low-Mass Stars

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We derive mass-luminosity relationships for very-low-mass stars ($0.06 < m/M_\odot < 0.6$) for different metallicities. Calculations are conducted with the different non-grey atmosphere models presently available to illustrate the uncertainties in the stellar models. The theoretical mass-magnitude relation reproduces accurately the *observed* relationship in the V-band (Henry & McCarthy 1993), but still underestimates the flux in the K-band by ~ 0.5 mag, a consequence of the still inaccurate water opacities. Calculations based on the grey approximation are shown to yield incorrect results over the entire mass-range of interest. We also show that the fate of objects near the hydrogen-burning limit depends significantly on the treatment of the atmosphere. Non-grey effects yield cooler and less luminous objects for a given mass near the stellar/substellar transition, and thus a *lower* hydrogen-burning minimum mass, $m \approx 0.07\, M_\odot$, for solar metallicity.

The depletion of lithium along evolution is considered in detail and we give age vs lithium-abundances relations which provide useful guides to determine the mass and the age of spectroscopically observed low-mass objects.

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Mass-Spectral Class Relationship for M-dwarfs

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We derive mass - spectral class relationships for M-dwarfs in the mass-range $0.075 \le m/M_{\odot} \le 0.6$, which corresponds to a spectral-range M0 to M10. The stellar models are based on the most recent non-grey atmosphere models presently available. The results are in excellent agreement with the observed relationship derived by Kircpatrick and McCarthy (1994) for dwarfs of spectral type earlier than M7. We show that the spectral subclass is definitely not a linear function of mass and increases abruptly as the substellar mass limit is approached. This behavior reflects the observed trends in color, magnitude and luminosity as a function of the mass and stems from the very physical properties of very low mass stars.

Objects older than 1 Gyr with a spectral type earlier than M10 (for solar metallicity) are predicted to be main sequence very-low-mass stars. For objects with such a spectral class to be bona-fide brown dwarfs, they must be younger than 1 Gyr.

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Flare Energetics: Analysis of a Large Flare on YZ CMi Observed Simultaneously in the Ultraviolet, Optical and Radio

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The results of coordinated observations of the dMe star YZ CMi at optical, UV and radio wavelengths during 3 - 7 February 1983 are presented. YZ CMi showed repeated optical flaring with the largest flare having a magnitude of 3.8 in the U-band. This flare coincided with an IUE exposure which permits a comparison of the emission measure curves of YZ CMi in its flaring and quiescent state. During the flare a downward shift of the transition zone is observed while the radiative losses in the range $10^4 - 10^7$ K strongly increase. The optical flare is accompanied with a radio flare at 6 cm, while at 20 cm no emission is detected. The flare is interpreted in terms of optically thick synchrotron emission. We present a combined interpretation of the optical/radio flare and show that the flare can be interpreted within the context of solar two-ribbon/white-light flares. Special attention is paid to the bombardment of dMe atmospheres by particle beams. We show that the characteristic temperature of the heated atmosphere is almost independent of the beam flux and lies within the range of solar white-light flare temperatures. We also show that it is unlikely that stellar flares emit black-body spectra. The fraction of accelerated particles, as follows from our combined optical/radio interpretation is in good agreement with the fraction determined by two-ribbon flare reconnection models.

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On the Link Between Rotation and Lithium Depletion in Subgiant Stars

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We present projected rotational velocity *vsini* for 65 F, G and K subgiant stars. In this work we study the link between rotation and lithium abundance in this luminosity class. In particular, we look for possible effects of rotational braking on the lithium depletion. We show that a sharp decrease in lithium abundances parallels the rotational discontinuity, located at F8IV, in all its aspects. We have found some dependence of lithium abundance upon rotation for single subgiants, but there is no evident correlation between lithium abundance and rotational velocity for binary subgiant stars.

Submitted to A&A

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Solar Abstracts

Maintenance of the Solar Cycle by the Gravitational Field of the Solar System Through Variations Imposed on the Sun's Rotation

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In this paper we investigate the role of the Solar System Dynamics ('SSD') in exciting the global torsional MHD waves in the Sun, whose interference seems to produce the solar magnetic cycle (Gokhale & Javaraiah 1995), and whose dominant frequencies seem to be in the neighborhood of the frequencies of planetary conjunctions (Javaraiah & Gokhale 1995).

First we show that the MHD equation for the global interaction of rotation and magnetic field inside the Sun must contain a latitude-dependent term, 'δT_{inert}', representing the inertial torque caused by the variations (if any) in the average angular velocity, $< \omega >$, of the Sun's rotation.

From conservation of angular momentum of the solar system about its barycenter, using solar system ephemerides, we show that $< \omega >$ varies with r.m.s. amplitude 4 nHz and frequencies near planetary orbital frequencies. We also show that Sun's spin and orbital torques T_{spin} and T_{orb} have strongly coupled variations with frequencies in the neighborhood of the conjunction frequencies '$\omega_{pp'}$' of the major planets. The corresponding inertial torque is much stronger than the electromagnetic torque, and can 'force' the torsional MHD modes with frequencies $\sim \omega_{pp'}$.

The Fourier spectrum of the rate of emergence of toroidal magnetic flux out of the Sun (determined from the sunspot data) confirms the existence of coupling of the solar-cycle related MHD oscillations with the oscillations in T_{spin} and T_{orb}.

The reason for occurrence of the frequencies $\omega_{pp'}$, is explained. The work done by the inertial torque, and the gravitational energy of the solar system, are shown to be adequate for maintaining the solar activity at the observed rate for a duration comparable to the Sun's life.

The following aspects of the proposed mechanism are briefly discussed : (i) possibility of existence of a 'steady' poloidal field of 'suitable' form and strength, (ii) potential use of the model in predicting the rate of sunspot activity. Implications of the suggested mechanism in the context of stellar gravitational environment, rotation, activity, mass loss, etc. are pointed out.

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A Topological Decomposition of Sobolev Functions and the Localization of Energy in Ideal Plasmas

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Motivated by the property of frozen-in topological invariants in ideal plasmas we pose the problem of giving an intrinsic characterization of the weak closure of $\{f(D), : D \in \mathcal{D}\}$, the collection of all compositions of a given $H_0^1(\Omega)$ function f with domain (in some cases,measure preserving diffeomorphisms) $\mathcal{D}$,and we offer partial results towards such a characterization. We define weak diffeomorphism classes which are closed under weak limits .These provide a rigorous setting in which the variational problems introduced by Aly and Low (following earlier work by Grad on fusion related geometries) to model coronal arches, using a quasi-static ,2D arcade geometry and with global frozen-in invariants as constraints at a given time step,can be reexamined,in the hope of rigorously establishing the existence of current sheets at a critical value of the shear (or other) parameter. Topological invariants which are preserved under weak limits are closely related to those preserved when the flow of the plasma becomed turbulent (say in relaxing to a (quasi-static) equilibrium) and hence to robust topological invariants which are preserved not in a pointwise ,but rather in a (spatially) averaged sense.They thus provide a tool complementary to those developped recently by Wright and Berger who began an investigation to determine robust topological invariants preserved by reconnection events.

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On the Multifractal Distribution of Solar Magnetic Fields

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Many studies have pointed out fractal and multifractal properties of photospheric magnetic fields, but placing the various approaches into context has proven difficult. Although fractal quantities are defined mathematically in the asymptotic limit of infinite resolution, real data cannot approach this limit. Instead, one must compute fractal dimensions or multifractal spectra within a limited range of finite scales. The consequent effects of this are explored by calculation of fractal quantities in finite images generated from analytically known measures and also from solar data. We find that theorems relating asymptotic quantities need not hold for their finite counterparts, that different definitions of fractal dimension that merge asymptotically give different values at finite scales, and that apparently elementary calculations of dimensions of simple fractals can lead to incorrect results. We examine the limits of accuracy of multifractal spectra from finite data and point out that a recent criticism of one such approach is incorrect.

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Dynamics of the Solar Granulation – V. The Intergranular Space

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This investigation is based on a spectrogram of extraordinary spatial resolution selected from a series of 80 spectrograms taken with the vacuum tower telescope at Izaña (Tenerife) in May 1994. The wavelength range was $\lambda\lambda$: 491.00 – 491.40 nm and includes both magnetically sensitive and insensitive spectral lines. The spectrograph slit intersected parts of the border and interior of Ca II network cells, thus permitting a comparative study of the granular dynamics at varying, but moderate, levels of magnetic activity.

As diagnostic tools we use the Doppler shift variation of line cores, which is associated with spatially resolved velocity structures, and the line broadening variation, which is a signature of unresolved velocity fluctuations. We discuss in particular the granular dynamics and the intermittency of the line broadening within the intergranular space as functions of height and position relative to network cells.

Our results suggest that the magnetic field in the network is not only located preferentially in the intergranular space, but furthermore coincides with regions of enhanced line broadening. We confirm that the Doppler shift variation is reduced in regions of enhanced magnetic field, but we find that this reduction affects the entire range of granular scales. The slopes of the velocity power spectra are independent of the magnetic activity level. This result is surprising, since on the basis of classical MHD turbulence theory one would have expected shallower power spectra in magnetically active regions. The line broadening variation is much less sensitive to the magnetic field than the line shift variation.

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Ph.D. Thesis Abstract

Study of Sun's Long Period Oscillations

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Since the 1930's the so-called "eleven-year" sunspot cycle (known since 1840's), has been identified to be a manifestation of the '~ 22 yr' solar magnetic cycle. Earlier theories of this phenomenon were based on the concept of the Sun's global Alfvenic oscillations maintained by interaction of rotation with magnetic field. Discovery of the reversal of polar magnetic fields (and the lack of clinching evidence for a non-reversing poloidal field) led to the belief that the Sun's magnetic field must be maintained wholly by a "turbulent dynamo" (dynamo maintained by turbulence in the Sun's convective envelope). In spite of several lacunae in the theory (e.g. its 'kinematical' nature), the 'turbulent dynamo models' became very popular due to their mathematical elegance. In late eighties, it was ultimately shown that for consistency with the distribution of sunspot activity in latitude and time (the so-called 'buterfly diagrams') a ' turbulent dynamo model' needs a negative radial gradient of the Sun's internal rotation. On the contrary helioseismology, led to a definite conclusion that this gradient is either zero or in fact positive. In 1980's, it also became known that the photospheric rotation shows presence of 'torsional oscillations' closely related to the solar magnetic cycle. Thus it became necessary to revisit the oscillatory models.

This work deals with questions related to such 'long period (MHD) oscillations of the Sun, in contrast to the 'acoustic' and 'gravity mode' oscillations which have periods ~ 5 minutes and ~ tens of minutes to hours respectively.

The thesis starts with a general review of the observations related to the solar magnetic cycle, and of the results of a Legendre-Fourier analysis of the latitude-time distribution of magnetic field as inferred from the Grenwich sunspot data during 1874-1976. This analysis indicated that the solar cycle may be resulting from superposition of 'forced' global oscillations of frequencies = 1/21.6 yr (and its odd multiples) and l = 1,3,..17, whose amplitudes and phases were approximately constant during 1874-1976. The toroidal orientations of the activity related fields indicated the 'torsional' nature of the underlying oscillations and the long periods of the latter indicated their 'Alfvenic MHD' nature.

The main problem was to model the internal poloidal magnetic field to see if it exists and whether it can sustain global MHD oscillations. The thrust of this thesis work is in modeling the 'steady' part of this field. In Chapter 3, it has been shown that the 'steady' part of the internal poloidal field must have its field lines along the iso-rotation contours of the Sun's internal rotation. This implies, for a field with symmetry about the axis of the Sun's rotation,

a direct functional relation between the 'flux-function' of the field and the angular velocity of the internal rotation as a function of radial coordinate and latitude. Assuming the 'steady' field to be 'current-free' and its flux-function to be linearly related to the angular velocity, I have determined the coefficients in the flux-function and the coefficients in the linear relation from a 'least-square fit' to the helio-seismologically inferred internal rotation.

The resulting model gives an excellent fit in the convection zone but the fit is not so good in the outer part of the radiative core where helio-seismological information on rotation is qualitatively reliable. Moreover, the 'current-free' assumption implies a field-singularity at the Sun's centre. Hence, in Chapter 4, I assume, for the field in the radiative core, a form given by Chandrasekhar's solution of the diffusion equation. The resulting 'improved model' keeps the excellent fit in the convective envelope and obtains a very good fit in the outer radiative core. It is likely that the agreement may continue all the way to the centre when the rotation there becomes better known in future.

This 'improved model' enabled me to estimate the ratio of the leading terms (deviation from uniformity) with which the field must have started to diffuse at the Sun's 'zero-age' on the main sequence.

In all these models a crucial term in the form of the flux function is provided by the boundary condition that the field lines crossing the surface must ultimately merge with a uniform field at large distances. This term enables one to 'normalise' the Sun's internal field to the interstellar field (or vice-versa), and both to the non-reversing part of the photospheric poloidal flux if and when it is determined with sufficient accuracy.

In Chapter 5, I have computed the Alfven-wave travel times along different field lines in a few *ad-hoc* models of the 'steady' parts of the internal poloidal field and also in the two models constructed by me. In Table 5.1, I gave an inter-comparison of these. This comparison shows that the improved model is perhaps best suited for sustaining global torsional oscillations.

I also showed that the non-reversing poloidal field crossing the Sun's surface must be $\sim 10^{-2}$ Gauss if the period of the fundamental mode has to agree with the observed dominant period in the solar cycle. This is much below the limit on its observational detection. Thus, it has been shown that the presence of such a 'steady' field of 'primordial' origin is not observationally ruled out.

Once the 'steady' part of the field and the coefficients of the relation between the flux-function and angular velocity are determined, the 'steady' part of the rotation becomes known. Subtracting this from with the observed rotation, I determined the residual rotation. If errors are neglected, this represents the time-dependent part of the rotation. It has been shown that this time-dependent part of rotation has a substantial component varying as the fourth power of the sine of latitude, as expected from the analysis of the sunspot data given in Chapter 2.

Thus, this work constitutes an important contribution in modeling the Sun's internal poloidal part of the magnetic field which varies on diffusion time scales and, in studying its role in producing solar activity and maintaining the solar cycle. It also chalks out direction for various studies in the future.

Thesis-related Publications: ApJ, 407, 359; ApJ, 448, 437; IAU Symp 138, 375; " Inside the Stars", ASP-Conf Series, vol 40, p.66

Meeting Summary

Advanced Study Institute on Solar and Astrophysical MHD Flows

The NATO Advanced Study Institute (ASI) on Solar and Astrophysical Magnetohydrodynamic (MHD) Flows was held from June 11/95 - 23/95, 25 km outside Heraklion, Crete, Greece at the Fodele Beach Hotel and Conference Center. It was attended by 150 scientists from 24 different countries, including Western and Eastern European countries, North and South America, Japan, Israel, Russia, Ukraine, Bulgaria, Romania, Poland, Czech and Slovak Republics and it was directed by Prof. K. Tsinganos.

The ASI focused on the similarities of the MHD approach in several key problems of solar and astrophysical MHD flows, such as, Magnetoconvection and Dynamos, MHD Flows in Sunspots, Coronal Loops and Prominences, Coronal Mass Ejections and Coronal Heating, Solar and Stellar Wind-type Flows, Astrophysical Jets, Collimated Outflows from Young Stellar Objects, Flows Associated with Symbiotic Stars, Accretion-Ejection Flows from Active Galactic Nuclei, and Flows in the Interstellar Medium.

Astrophysicists became more aware and interested of problems and methods employed by solar plasma researchers and vice versa, several new ideas for modelling new observations naturally emerged as a result of the excellent review lectures, while new collaborations started at the ASI. At the same time, spectacular new observations by the *Hubble Space Telescope* of accretion discs and jets, impressive resolution pictures of the Sun in X-rays by the *Yohkoh* satellite and the solar wind by *Ulysses*, as well as observations from several ground based optical and radio telescopes presented by established observational plasma astrophysicists attracted the attention of the local and national news media which provided extensive coverage of the ASI.

At the Institute a workshop was dedicated to the interests of the founder of this field of research, Prof. E.N. Parker, who plannned to retire shortly after the ASI. In the ASI reviews were presented on topics to which Parker has immensely contributed, as new developments in the Parker instability in the interstellar medium, the Parker formation of current sheets in magnetized plasmas, new developments in magnetic reconnection, sunspot models and also a generalisation of the Parker model of the solar wind via exact self-similar solutions of the MHD equations.

The social program included slide presentations on the history of Crete including the Minoan and Byzantine times and visits to the Knossos palace and the archaeological museums.

The more than 60 posters and short contributions (most of them reporting first-class results) will be published in a special edition of the journal Astrophysical Letters & Communications. The review lectures, edited by K. Tsinganos, will be published by Kluwer in a Volume containing 31 chapters dealing with flows of cosmic plasmas, from the interior of the Sun and the solar wind to jets of young stars and of the most distant AGN and quasars. These reviews include extended chapters by:

- E.N. Parker on Some Questions and Conjectures on the Origin of Stellar and Galactic Magnetic Fields and Some Implications of Solar and Stellar Activity,
- M. Schussler on Magnetic Flux Tubes and the Solar Dynamo,
- S. Tsuneta on The Dynamic Solar Corona in X-rays,
- B.C. Low on Flares, Coronal Mass Ejections and Coronal Heating,
- E. Priest on Magnetic Reconnection,
- J. Thomas on Siphon Flows in Solar Magnetic Flux Tubes and Sunspots,
- M. Goossens on MHD Waves in Magnetic Flux Tubes,
- A. Pouquet on HD and MHD Turbulence,
- W. Feldman on Ulysses Observations of the Solar Wind out of the Ecliptic,
- P. Charbonneau on The Solar Corona as a Minimum Energy System,
- R. Henriksen on Molecular Outflows from Protostars,
- T. Ray on Jets and MHD Outflows Associated with Young Stars,
- T. Mouschovias on The Parker Instability and Multifluid MHD,
- K. Macgregor on Stellar Winds,
- J. Heyvaerts on Astrophysical Jets and Accretion Disks,
- H. Lesch on Magnetic Reconnection in Accretion Disk Coronae,
- F. Mirabel on Microquasars and Relativistic Outflows in our Own Galaxy,
- M. Kafatos on Jets and MHD Outflows Associated with Symbiotic Stars,
- K. Shibata on Numerical Simulations of Solar and Astrophysical MHD Flows,
- E. Trussoni on Exact MHD Solutions for Self-similar Outflows,

- S. Bogovalov on Time Dependent Simulations of Rotating Magnetospheres,
- A. Ferrari Phenomenology and Large Scale Modelling of Jets,
- K. Tsinganos on Critical Points and Separatrices in Self-similar MHD Flows,
- G. Pelletier on Accretion-Ejection Flows in AGN,
- M. Camenzind on Relativistic MHD Outflows,
- J. Biretta on HST Observations of Galactic and Extragalactic Jets

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Announcements

The Closure of the McMath-Pierce Solar-Stellar Program

The initial decision by the NSO to close the program was based on an evaluation of its priorities in the face of increasing budgetary stringencies. Despite the high scientific productivity of this program, which contributed about 50% of the observational papers from the McMath-Pierce Telescope, its relevance to the scientific goals of solar and stellar physics, and the recently completed upgrade of the spectrograph through the introduction of cross-dispersion, it was decided that the NSO/NOAO could no longer continue to support it.

The NOAO facilities available to support solar-stellar research now reside entirely within KPNO. These include instruments for high-to-moderate resolution spectroscopy such as the coude feed and the Mayall 4-m echelle. In addition, the WIYN telescope is equipped with a multi-object spectrograph. The NOAO time on the WIYN is queue-scheduled, thus offering the possibility of conducting variability studies and surveys efficiently. A cryogenic echelle–Phoenix–which offers high spectral resolutions in the infrared will be commissioned next year. I will be investigating, in collaboration with KPNO staff, the prospects for constructing and installing a bench-mounted, high resolution spectrograph at the Mayall 4-m telescope that could be used for synoptic studies. In addition, I have agreed to serve on a committee to review the specifications for the high resolution spectrograph planned for the Gemini 8-m telescope in Chile (Gemini South). My review will concentrate on the suitability of the spectrograph design for research programs in late-type stars.

In conclusion, Sidney Wolff has expressed her commitment to work with the solar-stellar community to provide the instrumentation, TAC evaluation procedures and telescope scheduling that are needed to address the scientific goals of solar-stellar astrophysics (see the December 1995 NOAO Newsletter). I encourage you to contact me, Dr. Wolff and the KPNO/CTIO Users Committee with your suggestions on how the NOAO and the Gemini 8-m Telescopes Program can best serve the needs of the stellar community.

Mark Giampapa (giampapa@noao.edu)

Forthcoming NOAO/KPNO Newsletter Article:
Opportunities for Solar-Stellar Research at KPNO

With the closure of the McMath-Pierce solar-stellar program, many of the research goals of solar-stellar astrophysics that require optical and infrared observations can be served by the current and planned facilities that reside within KPNO (and CTIO). In this note, we briefly review some of the key areas in solar-stellar physics that can be addressed through the use of KPNO facilities.

The *0.8-m coude feed telescope* includes a classical coude' echelle spectrograph that can achieve spectral resolving powers of over R=200,000. This facility is successfully used for *Doppler imaging* of active RS CVn systems. Observing runs as long as two weeks have been conducted recently for this purpose. *Magnetic field measurements* on late-type stars that rely on the detection of the subtle signature of Zeeman broadening in the wings of magnetically sensitive lines can be accomplished at the feed for bright objects. Another research area that requires the high spectral resolutions available with the spectrograph at the feed is *convection*, i.e., the measurement of line bisectors and their variation due to global convective motions in the stellar photosphere.

The *WIYN telescope with the Hydra multi-object spectrograph and the CCD Imager* includes a queue observing mode. Hence, variability studies as well as surveys can be carried out efficiently. The wide-field capability is especially useful for the *study of cluster members* and the evolution of parameters related to *stellar activity*. Examples of long-term projects might include investigations of magnetic *activity cycles, luminosity variability and rotational modulation of activity* in the members of open clusters. The Hydra bench-mounted spectrograph includes gratings for moderate-low dispersion work along with an echelle grating. The echelle grating is limited to resolving powers of about R=20,000.

The cryogenic echelle–*Phoenix*–will offer an important new capability for solar-stellar physics. Phoenix will provide resolutions from R=50,000 to R=100,000 in the K and H bands where there are important magnetic line diagnostics. Its eventual placement at the *2.1-m* and then the **Mayall 4-m** will enable the acquisition of high quality spectra of faint stars, thereby enabling an important expansion of the data-base of cool stars for which we have reliable *magnetic field measurements*. The *Mayall 4-m echelle* yields "intermediate" resolutions up to about R=67,000. Combined with its large-aperture, *Doppler imaging experiments* on some rapidly rotating, active stars are feasible. In addition, time-resolved spectroscopy of stellar flares can be carried out with this instrument/telescope combination. We are investigating the prospects for placing a new, high resolution (R = 150,000) bench-mounted spectrograph at the Mayall 4-m.

Finally, we are actively exploring the use of current KPNO instrumentation in the exciting area of *asteroseismology*. The initial experiments involve the observations of nearby, bright late-type subgiants using the *coude feed and the 2.1-m.* We will report on our progress in this initiative in the next NOAO Newsletter. If you have any comments or questions about adapting your research programs in solar-stellar astrophysics to existing KPNO instrumentation and facilities, please contact Mark Giampapa.

Mark Giampapa (giampapa@noao.edu) and Caty Pilachowski (catyp@noao.edu)

Upcoming Meetings

X-ray Imaging and Spectroscopy of Cosmic Hot Plasmas
March 11 - 14, 1996 – Tokyo, Japan
Contact: F. Makino (ascasymp@astro.isas.ac.jp) or
http://www.astro.isas.ac.jp/

2nd Napoli Thinkshop: The Inconstant Sun
March 18, 1996 – Napoli, Italy
Contact: G. Cauzzi (gcauzzi@astrna.na.astro.it) or C. Marmolino (marmolino@na.infn.it) or
http://oacosf.na.astro.it/thinkshop.html

Spectroscopic Diagnostics of Small-Scale Structure in Stellar Atmospheres
March 27 - 28, 1996 – Glasgow, Scotland
Contact: S. Jeffery (csj@st-and.ac.uk)

The Solar Cycle: Recent Progress and Future Research I
March 28 - 30, 1996 – Tucson, Arizona
Contact: J. Zirker (jzirker@noao.edu)

The Solar Cycle: Recent Progress and Future Research II
April 1 - 4, 1996 – Hermosillo Sonora, Mexico
Contact: A. Sanchez-Ibarra (tsm96@fisica.uson.mx)

Solar and Heliospheric Plasma Physics
May 13 - 18, 1996 – Thessaloniki, Greece
Contact: Univ. of Thessaloniki (spm-96@astro.auth.gr) or
http://www.astro.auth.gr/spm-96/main.html

The Carbon Star Phenomenon (IAU Symp. 177)
May 27 - 31, 1996 – Antalya, Turkey
Contact: R. Wing (wing.1@osu.edu)

Stellar Ecology
June 23 - 29, 1996 – Elba, Italy
Contact: R. Rood (rtr@ninkasi.astro.virginia.edu)

Abstract Guidelines

Abstracts for *COOLNEWS* are solicited for papers that have been recently accepted by or submitted to refereed journals, and for recent Ph.D. theses. The subject matter should pertain directly to cool stars (spectral types F,G,K, or M) or the sun. Both theoretical and observational abstracts are appropriate. Abstracts dealing with cool pre-main-sequence stars will generally not be included in *COOLNEWS*, since they are already covered by the *Star Formation Newsletter*. Exceptions to this rule will be considered if the subject matter is truly cross-disciplinary. A monthly call for abstracts will be issued and abstracts received by the last day of the month will usually appear in the following month's newsletter. Announcements of general interest to the cool star and solar communities may also be submitted for posting in the newsletter. These might include (but are not restricted to) the following: (i) *Job Openings* directed toward cool star or solar researchers, (ii) announcements of *Upcoming Meetings*, (iii) announcements of *Upcoming Observing Campaigns* for which participation is solicited from the community at large, and (iv) *General Announcements* that provide or request research-related information. Requests for abstract templates and all other correspondence should be sent to the editor at coolnews@jila.colorado.edu .