COOLNEWS

A RESEARCH NEWSLETTER DEDICATED TO COOL STARS AND THE SUN

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We present B and V light curves of a large stellar flare obtained with the Wide Field Camera at the Isaac Newton 2.5-m telescope (La Palma). The source object is a faint ($m_V = 21.38$) foreground star in the field of the Andromeda galaxy, with its most probable spectral type being dM4. We provide an estimate of the total flare energy in the optical range and find it to be of the order of 10^{35} erg. The cooling phase of the large flare shows three additional weak flare-like events, which we interpret as results of a triggering mechanism also observed on the Sun during large coronal mass ejections.

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Periodic Bursts of Coherent Radio Emission from an Ultracool Dwarf

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We report the detection of periodic (p = 1.96 hours) bursts of extremely bright, 100% circularly polarized, coherent radio emission from the M9 dwarf TVLM 513-46546. Simultaneous photometric monitoring observations have established this periodicity to be the rotation period of the dwarf. These bursts, which were not present in previous observations of this target, confirm that ultracool dwarfs can generate persistent levels of broadband, coherent radio emission, associated with the presence of kG magnetic fields in a large-scale, stable configuration. Compact sources located at the magnetic polar regions produce highly beamed emission generated by the electron cyclotron maser instability, the same mechanism known to generate planetary coherent radio emission in our solar system. The narrow beams of radiation pass our line of sight as the dwarf rotates, producing the associated periodic bursts. The resulting radio light curves are analogous to the periodic light curves associated with pulsar radio emission highlighting TVLM 513-46546 as the prototype of a new class of transient radio source.

the name of journal, for example: Accepted by ApJ Letters

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Diagnostics of Stellar Flares from X-ray Observations: from the Decay to the Rise Phase

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The diagnostics of stellar flaring coronal loops have been so far largely basedon the analysis of the decay phase. We derive new diagnostics from the analysis of the rise and peak phase of stellar flares. We release the assumption of full equilibrium of the flaring loop at the flare peak, according to the frequently observed delay between the temperature and the density maximum. From scaling laws and hydrodynamic simulations we derive diagnostic formulas as a function of observable quantities and times. We obtain a diagnostic toolset related to the rise phase, including the loop length, density and aspect ratio. We discuss the limitations of this approach and find that the assumption of loop equilibrium in the analysis of the decay leads to a moderate overestimate of the loop length. A few relevant applications to previously analyzed stellar flares are shown. The analysis of the flare rise and peak phase complements and completes the analysis of the decay phase.

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Photospheric and Chromospheric Activity on EY Dra

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Magnetic activity in the photosphere and chromosphere of the M dwarf EY Dra is studied and possible correlations between the two are investigated using photometric observations in the V and R bands and optical and near infrared spectroscopy. The longitudinal spot configuration in the photosphere is obtained from the V band photometry, and the chromospheric structures are investigated using variations in the Hα line profile and observations of the Paschen β line. The shape of the V band light-curve indicates two active regions on the stellar surface, about 0.4 in phase apart. The spectroscopic observations show enhanced Hα emission observed close to the phases of the photometrically detected starspots. This could indicate chromospheric plages associated with the photospheric starspots. Some indications of prominence structures are also seen. The chromospheric pressure is limited to $\log \mathrm{m_{TR}} < -4$ based on the non-detection of emission in the Paschen β wavelength region.

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Solar Abstracts

Inter-network Regions of the Sun at Millimetre Wavelengths

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The continuum intensity at wavelengths around 1 mm provides an excellent way to probe the solar chromosphere and thus valuable input for the ongoing controversy on the thermal structure and the dynamics of this layer.
The synthetic continuum intensity maps for near-millimetre wavelengths presented here demonstrate the potential of future observations of the small-scale structure and dynamics of internetwork regions on the Sun.
The synthetic intensity / brightness temperature maps are calculated on basis of three-dimensional radiation (magneto-) hydrodynamic (MHD) simulations. The assumption of local thermodynamic equilibrium (LTE) is valid for the source function. The electron densities are also treated in LTE for most maps but also in non-LTE for a representative model snapshot. Quantities like intensity contrast, intensity contribution functions, spatial and temporal scales are analysed in dependence on wavelength and heliocentric angle.
While the millimetre continuum at 0.3 mm originates mainly from the upper photosphere, the longer wavelengths considered here map the low and middle chromosphere. The effective formation height increases generally with wavelength and also from disk-centre towards the solar limb. The average intensity contribution functions are usually rather broad and in some cases they are even double-peaked as there are contributions from hot shock waves and cool post-shock regions in the model chromosphere. The resulting shock-induced thermal structure translates to filamentary brightenings and fainter regions in between. Taking into account the deviations from ionisation equilibrium for hydrogen gives a less strong variation of the electron density and with it of the optical depth. The result is a narrower formation height range although the intensity maps still are characterised by a highly complex pattern. The average brightness temperature increases with wavelength and towards the limb although the wavelength-dependence is reversed for the MHD model and the NLTE brightness temperature maps. The relative contrast depends on wavelength in the same way as the average intensity but decreases towards the limb. The dependence of the brightness temperature distribution on wavelength and disk-position can be explained with the differences in formation height and the variation of temperature fluctuations with height in the model atmospheres. The related spatial and temporal scales of the chromospheric pattern should be accessible by future instruments.
Future high-resolution millimetre arrays, such as the Atacama Large Millimeter Array (ALMA), will be capable of directly mapping the thermal structure of the solar chromosphere. Simultaneous observations at different wavelengths could be exploited for a tomography of the chromosphere, mapping its three-dimensional structure, and also for track-

ing shock waves. The new generation of millimetre arrays will be thus of great value for understanding the dynamics and structure of the solar atmosphere.

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Examination of the Solar Cycle Variation of foF2 for Cycles 22 and 23

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The variation of monthly median noon values of foF2 at Slough and Rome are examined by using different solar activity indices (solar flare index, relative sunspot number, solar flux at 2800 MHz, and Mg II index) for solar cycles 22 and 23 (1986 - 2006). We compared dependence of foF2 on solar activity indices by using a single regression analysis, and showed that qualitative similarity of the ionospheric foF2 with the solar indices depends on the solar cycle. We found that hysteresis effect shows generally lower foF2 for the rising branches compared to the falling branches of the two solar cycles, and the strength of the hysteresis effect varies from index to index as well as from cycle to cycle.

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Numerical Simulations of Fast and Slow Coronal Mass Ejections

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Solar coronal mass ejections (CMEs) show a large variety in their kinematic properties. CMEs originating in active regions and accompanied by strong flares are usually faster and accelerated more impulsively than CMEs associated with filament eruptions outside active regions and weak flares. It has been proposed more than two decades ago that there are two separate types of CMEs, fast (impulsive) CMEs and slow (gradual) CMEs. However, this concept may not be valid, since the large data sets acquired in recent years do not show two distinct peaks in the CME velocity distribution and reveal that both fast and slow CMEs can be accompanied by both weak and strong flares. We present numerical simulations which confirm our earlier analytical result that a flux-rope CME model permits describing fast and slow CMEs in a unified manner. We consider a force-free coronal magnetic flux rope embedded in the potential field of model bipolar and quadrupolar active regions. The eruption is driven by the torus instability which occurs if the field overlying the flux rope decreases sufficiently rapidly with height. The acceleration profile depends on the steepness of this field decrease, corresponding to fast CMEs for rapid decrease, as is typical of active regions, and to slow CMEs for gentle decrease, as is typical of the quiet Sun. Complex (quadrupolar) active regions lead to the fastest CMEs.

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Solar Rossby Wave 'Hills' Identified As Supergranules

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We explore the nature of 'hills' observed on the solar surface which had previously been attributed to Rossby waves. We investigate the solar hills phenomenon by analyzing the output from a synthetic model based solely on the observed solar photospheric convection spectrum. We show that the characteristics of these hills can be explained by the corrugation of the surface produced by the radial flows of the convection. The hills in our simulations are dominated by supergranules, a well-known component of solar convection. Rossby waves have been predicted to exist within the

Sun and may play an important role in the dynamics of the solar interior, including the Sun's differential rotation and magnetic dynamo. Our study suggests, however, that the hills observed at the solar limb do not confirm the existence of solar Rossby waves.

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Modified p-Modes in Penumbral Filaments?

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Aims. The primary objective of this study is to search for and identify wave modes within a sunspot penumbra.
Methods. Infrared spectropolarimetric time series data are inverted using a model comprising two atmospheric components in each spatial pixel. Fourier phase difference analysis is performed on the line-of-sight velocities retrieved from both components to determine time delays between the velocity signals. In addition, the vertical separation between the signals in the two components is calculated from the Stokes velocity response functions.
Results. The inversion yields two atmospheric components, one permeated by a nearly horizontal magnetic field, the other with a less-inclined magnetic field. Time delays between the oscillations in the two components in the frequency range $2.5 - 4.5$ mHz are combined with speeds of atmospheric wave modes to determine wave travel distances. These are compared to expected path lengths obtained from response functions of the observed spectral lines in the different atmospheric components. Fast-mode (i.e., modified p-mode) waves exhibit the best agreement with the observations when propagating toward the sunspot at an angle $\sim 50^\circ$ to the vertical.

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Grand Minima and Maxima of Solar Activity: New Observational Constraints

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Using a reconstruction of sunspot numbers stretching over multiple millennia, we analyze the statistics of the occurrence of grand minima and maxima and set new observational constraints on long-term solar and stellar dynamo models. We present an updated reconstruction of sunspot number over multiple millennia, from ^{14}C data by means of a physics-based model, using an updated model of the evolution of the solar open magnetic flux. A list of grand minima and maxima of solar activity is presented for the Holocene (since 9500 BC) and the statistics of both the length of individual events as well as the waiting time between them are analyzed. The occurrence of grand minima/maxima is driven not by long-term cyclic variability, but by a stochastic/chaotic process. The waiting time distribution of the occurrence of grand minima/maxima deviates from an exponential distribution, implying that these events tend to cluster together with long event-free periods between the clusters. Two different types of grand minima are observed: short (30–90 years) minima of Maunder type and long (>110 years) minima of Spörer type, implying that a deterministic behaviour of the dynamo during a grand minimum defines its length. The duration of grand maxima follows an exponential distribution, suggesting that the duration of a grand maximum is determined by a random process. These results set new observational constraints upon the long-term behaviour of the solar dynamo.

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T Tauri Stars: Mass Accretion and X-ray Emission

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Ph.D degree awarded: April 2007

I develop the first magnetospheric accretion model to take account of the observed complexity of T Tauri magnetic fields, and the influence of stellar coronae. It is now accepted that accretion onto classical T Tauri stars is controlled by the stellar magnetosphere, yet to date the majority of accretion models have assumed that the stellar magnetic field is dipolar. By considering a simple steady state accretion model with both dipolar and complex magnetic fields I find a correlation between mass accretion rate and stellar mass of the form $\dot{M} \propto M_*^{\alpha}$, with my results consistent within observed scatter. For any particular stellar mass there can be several orders of magnitude difference in the mass accretion rate, with accretion filling factors of a few percent. I demonstrate that the field geometry has a significant effect in controlling the location and distribution of hot spots, formed on the stellar surface from the high velocity impact of accreting material. I find that hot spots are often at mid to low latitudes, in contrast to what is expected for accretion to dipolar fields, and that particularly for higher mass stars, accreting material is predominantly carried by open field lines. Material accreting onto stars with fields that have a realistic degree of complexity does so with a distribution of in-fall speeds.

I have also modelled the rotational modulation of X-ray emission from T Tauri stars assuming that they have isothermal, magnetically confined coronae. By extrapolating from surface magnetograms I find that T Tauri coronae are compact and clumpy, such that rotational modulation arises from X-ray emitting regions being eclipsed as the star rotates. Emitting regions are close to the stellar surface and inhomogeneously distributed about the star. However some regions of the stellar surface, which contain wind bearing open field lines, are dark in X-rays. From simulated X-ray light curves, obtained using stellar parameters from the Chandra Orion Ultradeep Project, I calculate X-ray periods and make comparisons with optically determined rotation periods. I find that X-ray periods are typically equal to, or are half of, the optical periods. Further, I find that X-ray periods are dependent upon the stellar inclination, but that the ratio of X-ray to optical period is independent of stellar mass and radius.

I also present some results that show that the largest flares detected on T Tauri stars may occur inside extended magnetic structures arising from the reconnection of open field lines within the disc. I am currently working to establish whether such large field line loops can remain closed for a long enough time to fill with plasma before being torn open by the differential rotation between the star and the disc. Finally I discuss the current limitations of the model and suggest future developments and new avenues of research.

Thesis-related Publications: MNRAS, 367, 917; MNRAS, 371, 999; MNRAS, 373, 827; MNRAS, in press (astro-ph/0704.2958)

Editor's Note: The above thesis abstract is being cross-listed with the *Star Formation Newsletter*.

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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.

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