COOLNEWS

A RESEARCH NEWSLETTER DEDICATED TO COOL STARS AND THE SUN

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Coolnews on the Web

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Stellar Abstracts

The Stellar Rotation-Activity Relationship in Fully Convective M Dwarfs

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The coronal activity-rotation relationship is considered to be a proxy for the underlying stellar dynamo responsible for magnetic activity in solar and late-type stars. While this has been studied in considerable detail for partly-convective stars that are believed to operate an interface dynamo, it is poorly unconstrained in fully-convective stars that lack the necessary shear layer between radiative core and the convective envelope. We present new X-ray observations of 19 slowly-rotating fully-convective stars with rotation periods from the MEarth Project. We use these to calculate X-ray luminosities (or upper limits for undetected sources) and combine these with existing measurements from Wright & Drake (2016). We confirm the existence of fully-convective stars in the X-ray unsaturated regime and find that these objects follow the same rotation-activity relationship seen for partly-convective stars. We measure the power-law slope of the relationship between Rossby number (the ratio of the rotation period to the convective turnover time) and the fractional X-ray luminosity for X-ray unsaturated fully-convective stars for the first time, and find it to be consistent with that found for partly-convective stars. We discuss this implications of this result for our understanding of stellar magnetic dynamos in fully- and partly-convective stars. Finally, we also use this data to improve empirical estimates of the convective turnover time for fully-convective stars.

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A Low-Mass Eclipsing Binary Within the Fully Convective Zone from the NGTS

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We have discovered a new, near-equal mass, eclipsing M dwarf binary from the Next Generation Transit Survey. This system is only one of 3 field age (>1 Gyr), late M dwarf eclipsing binaries known, and has a period of 1.74774 days, similar to that of CM Dra and KOI126. Modelling of the eclipses and radial velocities shows that the component masses are $M_{\rm pri}$=0.17391$^{+0.00153}_{-0.00099}$ $M_{\odot}$, $M_{\rm sec}$=0.17418$^{+0.00193}_{-0.00059}$ $M_{\odot}$; radii are $R_{\rm pri}$=0.2045$^{+0.0038}_{-0.0058}$ $R_{\odot}$, $R_{\rm sec}$=0.2168$^{+0.0047}_{-0.0048}$ $R_{\odot}$. The effective temperatures are $T_{\rm pri} = 2995^{+85}_{-105}$ K and $T_{\rm sec} = 2997^{+66}_{-101}$ K, consistent with M5 dwarfs and broadly consistent with main sequence models. This pair represents a valuable addition which can be used to constrain the mass-radius relation at the low mass end of the stellar sequence.

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3D Non-LTE Corrections for Li Abundance and ^{6}Li/^{7}Li Isotopic Ratio in Solar-Type Stars I. Application to HD 207129 and HD 95456

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Convective motions in solar-type stellar atmospheres induce Doppler shifts that affect the strengths and shapes of spectral absorption lines and create slightly asymmetric line profiles. 1D LTE studies of elemental abundances are not able to reproduce this phenomenon, which becomes particularly important when modeling the impact of isotopic fine structure, like the subtle depression created by the ^{6}Li isotope on the red wing of the Li I resonance doublet line. The purpose of this work is to provide corrections for the lithium abundance, A(Li), and the ^{6}Li/^{7}Li isotopic ratio that can easily be applied to correct 1D LTE lithium abundances in G and F dwarf stars of approximately solar mass and metallicity for 3D and non-LTE (NLTE) effects. The corrections for A(Li) and ^{6}Li/^{7}Li are computed using grids of 3D NLTE and 1D LTE synthetic lithium line profiles, generated from 3D hydro-dynamical CO^{5}BOLD and 1D hydrostatic model atmospheres, respectively. The 3D NLTE corrections are then approximated by analytical expressions as a function of the stellar parameters. These are applied to adjust the 1D LTE isotopic lithium abundances in two solar-type stars, HD 207129 and HD 95456. The derived 3D NLTE corrections range between -0.01 and $+0.11$ dex for A(Li), and between -4.9 and -0.4 % for the ^{6}Li/^{7}Li isotopic ratio, depending on the adopted stellar parameters. In the case of the ^{6}Li/^{7}Li, our corrections are always negative, showing that 1D LTE analysis can significantly overestimate (up to 4.9 percentage points) the presence of ^{6}Li in the atmospheres of solar-like dwarf stars. These results emphasize the importance of reliable 3D model atmospheres combined with NLTE line formation for deriving precise isotopic lithium abundances. Although 3D NLTE spectral synthesis implies an extensive computational effort, the results can be made accessible with parametric tools like the ones presented in this work.

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For preprints via WWW: https://arxiv.org/abs/1807.04089

Beyond the Coronal Graveyard

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New *Chandra* High Resolution Camera pointings on the "non-coronal" red giant Arcturus (HD 124897; α Boo: K1.5 III) corroborate a tentative soft X-ray detection in a shorter exploratory exposure sixteen years earlier. The apparent source followed the (large) proper motion of the nearby bright star over the intervening years, and there were null detections at the previous location in the current epoch, as well as at the future location in the earlier epoch, reducing the possibility of chance coincidences with unrelated high-energy objects. The apparent X-ray brightness at Earth, averaged over the 98 ks of total exposure and accounting for absorption in the red giant's wind, is $\sim 2{\times}10^{-15}$ erg cm^{-2} s^{-1} (0.2–2 keV). Systematic errors in the energy conversion factor, devolving from the unknown spectrum, amount to only about 10%, smaller than the $\sim$30% statistical uncertainties in the count rates. The X-ray luminosity is only $3{\times}10^{25}$ erg s^{-1}, confirming Arcturus as one of *Chandra's* darkest bright stars.

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Solar Abstracts

The Magnetic Field Vector of the Sun-as-a-Star II. Evolution of the Large-Scale Vector Field Through Activity Cycle 24

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In the present work, we investigate how the large-scale magnetic field of the Sun, in its three vector components, has evolved during most of cycle 24, from 2010 Jan to 2018 Apr. To filter out the small-scale field of the Sun, present in high-resolution synoptic maps, we use a spherical harmonic decomposition method, which decomposes the solar field in multipoles with different ℓ degrees. By summing together the low-ℓ multipoles, we reconstruct the large-scale field at a resolution similar to observed stellar magnetic fields, which allows the direct comparison between solar and stellar magnetic maps. During cycle 24, the 'Sun-as-a-star' magnetic field shows a polarity reversal in the radial and meridional components, but not in the azimuthal component. The large-scale solar field remains mainly poloidal with $> 70\%$ of its energy contained in the poloidal component. During its evolution, the large-scale field is more axisymmetric and more poloidal when near minima in sunspot numbers, and with a larger intensity near maximum. There is a correlation between toroidal energy and sunspot number, which indicates that spot fields are major contributors to the toroidal large-scale energy of the Sun. The solar large-scale magnetic properties fit smoothly with observational trends of stellar magnetism reported in See et al. The toroidal ($\langle B^2_{\rm tor}\rangle$) and poloidal ($\langle B^2_{\rm pol}\rangle$) energies are related as $\langle B^2_{\rm tor}\rangle \propto \langle B^2_{\rm pol}\rangle^{1.38\pm0.04}$. Similar to the stellar sample, the large-scale field of the Sun shows a lack of toroidal non-axisymmetric field.

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For preprints via WWW: http://arxiv.org/abs/1807.06334

Highly Ionized Calcium and Argon X-ray Spectra from a Large Solar Flare

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X-ray lines of helium-like calcium (Ca XIX) between 3.17 Å and 3.21 Å and associated Ca XVIII dielectronic satellites have previously been observed in solar flare spectra, and their excitation mechanisms are well established. Dielectronic satellites of lower ionization stages (Ca XVII - Ca XV) are not as well characterized. Several spectra during a large solar flare in 2001 by the DIOGENESS X-ray spectrometer on the *CORONAS-F* spacecraft show the Ca XVII and Ca XVI satellites as well as lines of ionized argon (Ar XVII, Ar XVI) including dielectronic satellites. The DIOGENESS spectra are compared with spectra from a synthesis code developed here based on an isothermal assumption with various atomic sources including dielectronic satellite data from the Cowan Hartree–Fock code. Best-fit comparisons are made by varying the temperature as the code's input (Ar/Ca abundance ratio fixed at 0.33); close agreement is achieved although with adjustments to some ion fractions. The derived temperature is close to that derived from the two *GOES* X-ray channels, $T_{\rm GOES}$. Some lines are identified for the first time. Similar spectra from the *P78-1* spacecraft and the Alcator C-Mod tokamak have also been analyzed and similar agreement obtained. The importance of blends of calcium and argon lines is emphasized, affecting line ratios used for temperature diagnostics. This analysis will be applied to the *Solar Maximum Mission* Bent Crystal Spectrometer archive and to X-ray spectra expected from the ChemiX instrument on the Sun-orbiting *Interhelioprobe* spacecraft, while the relevance to X-ray spectra from non-solar sources is indicated.

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Nonkinematic Solar Dynamo Models with Double-Cell Meridional Circulation

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Employing the standard solar interior model as input we construct a dynamically-consistent nonlinear dynamo model that takes into account the detailed description of the Λ- effect, turbulent pumping, magnetic helicity balance, and magnetic feedback on the differential rotation and meridional circulation. The background mean-field hydrodynamic model of the solar convection zone accounts the solar-like angular velocity profile and the double-cell meridional circulation. We investigate an impact of the nonlinear magnetic field generation effects on the long-term variability and properties of the magnetic cycle. The nonlinear dynamo solutions are studied in the wide interval of the α effect parameter from a slightly subcritical to supercritical values. It is found that the magnetic cycle period decreases with the increasing cycle's magnitude. The periodic long-term variations of the magnetic cycle are excited in case of the overcritical α effect. These variations result from the hemispheric magnetic helicity exchange. It depends on the magnetic diffusivity parameter and the magnetic helicity production rate. The large-scale magnetic activity modifies the distribution of the differential rotation and meridional circulation inside convection zone. It is found that the magnetic feedback on the global flow affects the properties of the long-term magnetic cycles. We confront our findings with solar and stellar magnetic activity observations.

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How is a Bipolar Sunspot Group Conceived?

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The very conception and early development stage of AR 12548 are investigated based on SDO/HMI observations of

20–25 May 2016. Full-vector magnetic and velocity fields are analysed in parallel. In the growing bipolar magnetic (BMR), the leading-polarity magnetic element nucleates as a compact feature against the background of a distributed trailing-polarity field, in which a germ of the trailing-polarity element is already present. Both magnetic elements give rise to a couple of pores, which then evolves into a bipolar sunspot group. The growth of the leading (negative) polarity sets in abruptly and occurs rapidly while the trailing (positive) polarity grows smoothly and more slowly. There is also similar dissymmetry between the time variations of the negative and positive magnetic fluxes through some area encompassing the BMR. No signs of strong horizontal magnetic fields are detected between the growing leading and trailing magnetic poles of the BMR. No predominant upflow between the future locations of the magnetic poles precedes the origin of the BMR; instead, upflows and downflows are mixed, with some prevalence of downflows. Any signs of a large-scale horizontal divergent flow from the area when the BMR develops are missing; in contrast, a regular supergranulation and mesogranulation pattern remains intact. The observed scenario of early BMR evolution is in strong contradiction with the expectations following from the model of rising Ω-shaped loop of a flux tube of strong magnetic field..

Submitted to Solar Physics

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Prediction of Solar Cycle 25: A Nonlinear Approach

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Predicting the solar activity is an important task for space weather and solar physics. There are various approaches to predict the solar activity and these predictions are used in various areas such as planning space missions, approximating the mechanism of solar dynamo, etc. In this paper, a nonlinear prediction algorithm based on delay-time and phase space reconstruction is used to forecast the maximum of Solar Cycle 25. Apart from embedding dimension and delay-time which are the key parameters of such methods, we further found a new parameter (starting point) that should be taken into account to get better solar cycle predictions. This method was tested on last five solar cycles and the results are quite acceptable. We predicted that the maximum of Solar Cycle 25 will be at the year 2023.2 ± 1.1 with a peak sunspot number of 154 ± 12. Our results are compared with other available predictions.

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Solar Activity Over Nine Millennia: A Consistent Multi-Proxy Reconstruction

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Aims. The solar activity in the past millennia can only be reconstructed from cosmogenic radionuclide proxy records in terrestrial archives. However, because of the diversity of the proxy archives, it is difficult to build a homogeneous reconstruction. All previous studies were based on individual, sometimes statistically averaged, proxy datasets. Here we aim to provide a new consistent multi-proxy reconstruction of the solar activity over the last 9000 yr, using all available long-span datasets of ^{10}Be and ^{14}C in terrestrial archives.

Methods. A new method, based on a Bayesian approach, was applied for the first time to solar activity reconstruction. A Monte Carlo search (using the χ^2 statistic) for the most probable value of the modulation potential was performed to match data from different datasets for a given time. This provides a straightforward estimate of the related uncertainties. We used six ^{10} Be series of different lengths (from 500 – 10 000 yr) from Greenland and Antarctica, and

the global ^{14}C production series. The ^{10}Be series were resampled to match wiggles related to the grand minima in the ^{14}C reference dataset. The stability of the long data series was tested.

Results. The Greenland Ice-core Project (GRIP) and the Antarctic EDML (EPICA Dronning Maud Land) ^{10}Be series diverge from each other during the second half of the Holocene, while the ^{14}C series lies in between them. A likely reason for the discrepancy is the insufficiently precise beryllium transport and deposition model for Greenland, which leads to an undercorrection of the GRIP series for the geomagnetic shielding effect. A slow $6-7$ millennia variability with lows at ca. 5500 BC and 1500 AD in the long-term evolution of solar activity is found. Two components of solar activity can be statistically distinguished: the main component, corresponding to the "normal" moderate level, and a component corresponding to grand minima. A possible existence of a component representing grand maxima is indicated, but it cannot be separated from the main component in a statistically significant manner.

Conclusions. A new consistent reconstruction of solar activity over the last nine millennia is presented with the most probable values of decadal sunspot numbers and their realistic uncertainties. Independent components of solar activity corresponding to the main moderate activity and the grand-minimum state are identified; they may be related to different operation modes of the dynamo.

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Ph.D. Thesis Abstract

Solar Variability Over the Last 9000 Years

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Knowledge of solar irradiance variability is crucial to understand the influence of the Sun on the Earth's climate system. Direct space-based measurements of solar irradiance are only available since 1978 which is not sufficient for studying long-term solar variability. Thus longer records and reconstructions of the solar variability in the past are required. The directly observed sunspot number covers the last four centuries, while going further back in time one has to rely on indirect proxies of solar activity, such as concentrations of cosmogenic isotopes ^{10}Be and ^{14}C in terrestrial archives. They are produced in the upper terrestrial atmosphere by impinging galactic cosmic rays whose flux is modulated by the heliospheric magnetic field. Therefore, the signals in the cosmogenic isotopes share high similarities while short-term discrepancies can be seen attributed to the local climate and the systematic effects. To account for these issues, we constructed a state-of-the-art consistent multi-isotope composite from one global ^{14}C and six regional ^{10}Be data sets using a new Bayesian approach. This composite is then used to reconstruct the solar irradiance over the last 9000 years with the semi-empirical SATIRE-M (Spectral And Total Irradiance REconstruction, M for millennia) model. Furthermore, due to the sampling of the cosmogenic isotope data, the temporal resolution of the reconstructions with the SATIRE-M model is restricted to decadal so the information on the solar cycles is unfortunately averaged out. Hence, we developed a statistical approach to simulate the quasi 11-year solar cycle from the observed decadally-averaged sunspot numbers. This final solar irradiance reconstruction has been provided as a solar forcing input to climate models. This hopefully will help us to better understand the degree of the solar influence on the Earth's climate on long time scales.

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Upcoming Meeting

Cambridge Workshop on Cool Stars, Stellar Systems, & the Sun (CS 21)

June 2020

Toulouse, France

Dear Colleagues:

Cool Stars 20 in Cambridge/Boston, MA USA is over, and the abstracts, and videos/presentations of the plenary lectures can be found at:

https://coolstars20.github.io/abstracts.html

Manuscripts will be placed on zenodo.

Further information on CS 20: cs20@cfa.harvard.edu

Save the Date: Cool Stars 21, Toulouse, France: June 2020

This is the longest running independent astronomy conference, and it gets more exciting with each meeting. The meeting in Toulouse will also feature a visit to Pic du Midi Observatory and the Airbus Manufacturing Facility.

Abstract Guidelines

Abstracts for *COOLNEWS* are solicited for papers that have been recently accepted by or submitted to refereed journals, and for recent Ph.D. theses. Abstracts for conference proceedings articles are *not* posted in *COOLNEWS*. The subject matter should pertain directly to cool stars (spectral types F,G,K,M or L), substellar objects, or the sun. Both theoretical and observational abstracts are appropriate.

Abstracts dealing with cool pre-main-sequence (PMS) stars will generally not be included in *COOLNEWS*, since they are already covered by the *Star Formation Newsletter*. Exceptions to this rule will be considered if the subject matter is truly cross-disciplinary. If you wish to submit a cross-disciplinary abstract on PMS stars, then first submit it to the *Star Formation Newsletter*. After doing so, submit the abstract to *COOLNEWS* accompanied by a short e-mail stating that it has already been submitted to the *Star Formation Newsletter*, and summarizing why it will be of interest to the cool star/solar community at large.

A bimonthly call for abstracts will be issued. Announcements of general interest to the cool star and solar communities may also be submitted for posting in the newsletter. These might include (but are not restricted to) the following: (i) *Job Openings* directed toward cool star or solar researchers, (ii) announcements of *Upcoming Meetings*, (iii) announcements of *Upcoming Observing Campaigns* for which participation is solicited from the community at large, (iv) reviews of *New Books*, and (v) *General Announcements* that provide or request research-related information. Please send all correspondence to the editor at coolnews@jila.colorado.edu. Abstract templates and back issues can be obtained from the COOLNEWS Web-page at

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