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HD 71636, A Newly Discovered Eclipsing Binary

Gregory W. Henry[1], Francis C. Fekel[1], James R. Sowell[2], and Joel S. Gearhart[2]

[1] Center of Excellence in Information Systems, Tennessee State University, 3500 John A. Merritt Blvd., Box 9501, Nashville, TN 37209
[2] School of Physics, Georgia Institute of Technology, Atlanta, GA 30332

Our differential BV photometric observations, acquired with an automated telescope at Fairborn Observatory, show that HD 71636 is an eclipsing binary. From follow-up red-wavelength spectroscopic observations we classify the primary and secondary as F2 dwarf and F5 dwarf, respectively. The system has a period of 5.01329 days and a circular orbit. We used the Wilson-Devinney program to solve simultaneously our BV light curves and radial velocities and determined a number of fundamental properties of the system. Comparison with evolutionary tracks indicates that both stars are well ensconced on the main sequence. The age of the system is about 1.2 billion yr.

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For preprints contact: henry@schwab.tsuniv.edu

HD 131861, A Double-line Spectroscopic Triple System

Francis C. Fekel[1], Gregory W. Henry[1], D. J. Barlow[2] and D. Pourbaix[3]

[1] Center of Excellence in Information Systems, Tennessee State University, 3500 John A. Merritt Blvd., Box 9501, Nashville, TN 37209 USA
[2] Department of Physics and Astronomy, University of Victoria, Victoria, British Columbia V8W 3P6 Canada
[3] Institut d'Astronomie et d'Astrophysique, Université Libre de Bruxelles, C.P. 226, Boulevard du Triomphe, 1050 Bruxelles, Belgium

Our red-wavelength spectroscopic observations of HD 131861, a previously known single-line multiple system, span 20 years. Lines of two components, the short-period F5 V primary and G8 V secondary, have been detected. The inner orbit is circular with a period of 3.5507439 days, while the outer orbit of the system has a period of 1642 days or 4.496 yr and a relatively low eccentricity of 0.10. Analysis of the *Hipparcos* data produces a well-determined astrometric orbit for the long-period system that has an inclination of 52 deg. Our photometric observations show shallow primary

and secondary eclipses of the short-period pair, and eclipse solutions result in an inclination of 81 deg. Thus, the long- and short-period orbits are not coplanar. The mass of the unseen third component is 0.7 solar masses, corresponding to a mid-K dwarf. The total mass of the system, 3.08 solar masses, leads to a semimajor axis of 4 AU for the outer orbit. The F5 V primary is rotating more slowly than synchronous, while the G8 V secondary may be synchronously rotating. The lithium abundance of the F5 V primary is similar to the initial lithium abundance found for Population I dwarfs and so indicates no significant dilution.

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For preprints contact: fekel@evans.tsuniv.edu

Rotational Modulation of the Radio Emission from the M9 Dwarf TVLM 513-46546: Broadband Coherent Emission at the Substellar Boundary?

G. Hallinan[1], A Antonova[2], J.G. Doyle[2], S. Bourke[1], W. F. Brisken[3], and A. Golden[1]

[1] Computational Astrophysics Laboratory, I.T. Building, National University of Ireland, Galway, Ireland
[2] Armagh Observatory, College Hill, Armagh BT61 9DG, N. Ireland
[3] National Radio Astronomy Observatory, P.O. Box O, Socorro, NM 87801

The Very Large Array was used to observe the ultracool, rapidly rotating M9 dwarf TVLM 513-46546 simultaneously at 4.88 GHz and 8.44 GHz. The radio emission was determined to be persistent, variable and periodic at both frequencies with a period of 2 hours. This periodicity is in excellent agreement with the estimated period of rotation of the dwarf based on its v sin i of 60 km/s. This rotational modulation places strong constraints on the source size of the radio emitting region and hence the brightness temperature of the associated emission. We find the resulting high brightness temperature, together with the inherent directivity of the rotationally modulated component of the emission, difficult to reconcile with incoherent gyrosynchrotron radiation. We conclude that a more likely source is coherent, electron cyclotron maser emission from the low density regions above the magnetic poles. This model requires the magnetic field of TVLM 513-46546 to take the form of a large-scale, stable, dipole or multipole with surface field strengths up to at least 3kG. We discuss a mechanism by which broadband, persistent electron cyclotron maser emission can be sustained in the low density regions of the magnetospheres of ultracool dwarfs. A second nonvarying, unpolarized component of the emission may be due to depolarization of the coherent electron cyclotron maser emission or alternatively, incoherent gyrosynchrotron or synchrotron radiation from a population of electrons trapped in the large-scale magnetic field.

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For preprints contact: gregg@it.nuigalway.ie

Using the Galactic Dynamics of M7 Dwarfs to Infer the Evolution of Their Magnetic Activity

Andrew A. West[1,2], John J. Bochanski[2], Suzanne L. Hawley[2], Kelle L. Cruz[3], Kevin R. Covey[2], Nicole M. Silvestri[2], I. Neill Reid[4], James Liebert[5]

[1] Astronomy Department, University of California, 601 Campbell Hall, Berkeley, CA 94720-3411
[2] Department of Astronomy, University of Washington, Box 351580, Seattle, WA 98195
[3] American Museum of Natural History, Department of Astrophysics, Central Park West at 79th St., New York, NY 10024
[4] Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218
[5] Department of Astronomy and Steward Observatory, University of Arizona, Tucson, AZ 85721

We present a spectroscopic study and dynamical analysis of ∼2600 M7 dwarfs. We confirm our previous finding that the fraction of magnetically active stars decreases with vertical distance from the Galactic plane. We also show that the mean luminosity of the Hα emission has a small but statistically significant decrease with distance. Using space motions for ∼1300 stars and a simple one-dimensional dynamical simulation, we demonstrate that the drop in the activity fraction of M7 dwarfs can be explained by thin disk dynamical heating and a rapid decrease of magnetic activity at a mean stellar age of ∼6-7 Gyr.

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For preprints contact: awest@astro.berkeley.edu [continued →]

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Five New Very Low Mass Binaries

G. Montagnier[1,2], D. Ségransan[2], J.-L. Beuzit[1], T. Forveille[3,1], P. Delorme[1], X. Delfosse[1], C. Perrier[1], S. Udry[2], M. Mayor [2], G. Chauvin[5], A.-M. Lagrange[1], D. Mouillet[4], T. Fusco[6], P. Gigan[7] and E. Stadler[1]

[1] Laboratoire d'Astrophysique de Grenoble, BP53, F-38041 Grenoble Cedex, France
[2] Observatoire de Genève, 51, chemin des Maillettes CH-1290 Sauverny, Switzerland
[3] Canada-France-Hawaii Telescope Corporation, 65-1238 Mamalahoa Highway, Kamuela, HI 96743, Hawaii U.S.A.
[4] Laboratoire d'Astrophysique de Toulouse et Tarbes, BP826 F-65008 Tarbes Cedex, France
[5] European Southern Observatory, Casilla 19001, Santiago 19, Chile
[6] ONERA-DOTA, BP72, 29 avenue de la Division Leclerc, F-92322 Châtillon Cedex, France
[7] Laboratoire d'Études Spatiales et d'Instrumentation Astrophysique, F-92195 Meudon Cedex, France

We report the discovery of companions to 5 nearby late M dwarfs (>M5), LHS1901, LHS4009, LHS6167, LP869-26 and WT460, and we confirm that the recently discovered mid-T brown dwarf companion to SCR1845-6357 is physically bound to that star. These discoveries result from our adaptive optics survey of all M dwarfs within 12 pc. The new companions have spectral types M5 to L1, and orbital separations between 1 and 10 AU. They add significantly to the number of late M dwarfs binaries in the immediate solar neighbourhood, and will improve the multiplicity statistics of late M dwarfs. The expected periods range from 3 to 130 years. Several pairs thus have good potential for accurate mass determination in this poorly sampled mass range.

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For preprints contact: Guillaume.Montagnier@obs.ujf-grenoble.fr

For preprints via ftp or WWW: http://arxiv.org/abs/astro-ph/0609059

The Coronal Ne/O Abundance of α Centauri

C. Liefke[1] and J. H. M. M. Schmitt[1]

[1] Hamburger Sternwarte, Universität Hamburg, Gojenbergsweg 112, D-21029 Hamburg, Germany

Recent improvements in the modeling of solar convection and line formation led to downward revisions of the solar photospheric abundances of the lighter elements, which in turn led to changes in the radiative opacity of the solar interior and hence to conflicts with the solar convection zone depth as inferred from helioseismic oscillation frequencies. An increase of the solar Ne/O abundance to values as observed for nearby stars has been proposed as a solution. Because of the absence of strong neon lines in the optical, neon abundances are difficult to measure and the correct solar and stellar Ne/O abundances are currently hotly debated. Based on X-ray spectra obtained with *XMM-Newton*, we determine a reference value of Ne/O for the inactive, solar-like star α Cen (primarily α Cen B, which is the dominant component in X-rays), with three independent, line-based methods, using differential emission measure reconstruction and an emission measure-independent method. Our results indicate a value of ≈ 0.28 for A_{Ne}/A_O in α Cen, approximately twice the value measured for the Sun, but still below the average value obtained for other stars. The low Ne/O abundance of the Sun is peculiar when compared to α Cen and other stars; our results emphasize the necessity to obtain more and accurate Ne/O abundance measurements of low activity stars.

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For preprints contact: cliefke@hs.uni-hamburg.de

The Influence of Magnetic Field on Oscillations in the Solar Chromosphere

D. Shaun Bloomfield[1,2], R. T. James McAteer[3], Mihalis Mathioudakis[1] and Francis P. Keenan[1]

[1] Department of Physics and Astronomy, Queen's University Belfast, Belfast, BT7 1NN, Northern Ireland, U.K.
[2] Max Planck Institut für Sonnensystemforschung, 37191 Katlenburg–Lindau, Germany
[3] NRC Research Associate, NASA / Goddard Space Flight Center, Solar Physics Branch, Code 682, Greenbelt, MD 20771, U.S.A.

Two sequences of solar images obtained by the *Transition Region and Coronal Explorer* in three UV passbands are studied using wavelet and Fourier analysis and compared to the photospheric magnetic flux measured by the Michelson Doppler Interferometer on the *Solar Heliospheric Observatory* to study wave behaviour in differing magnetic environments. Wavelet periods show deviations from the theoretical cutoff value and are interpreted in terms of inclined fields. The variation of wave speeds indicates that a transition from dominant fast–magnetoacoustic waves to slow modes is observed when moving from network into plage and umbrae. This implies preferential transmission of slow modes into the upper atmosphere, where they may lead to heating or be detected in coronal loops and plumes.

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For preprints contact: bloomfield@mps.mpg.de

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Electron Acceleration in Solar Flares: Theory of Spectral Evolution

Paolo C. Grigis[1] and Arnold O. Benz[1]

[1] Institute of Astronomy, ETH Zürich, Switzerland

Context. Stochastic acceleration is thought to be a key mechanism in the energization of solar flare electrons.
Aims. We study whether stochastic acceleration can reproduce the observed soft-hard-soft evolution of the spectral features of the hard X-ray emitted by suprathermal electron. We pay special attention to the effects of particle trapping and escape.
Methods. The Fokker-Planck equation for the electron distribution is integrated numerically using the coefficients derived by Miller et al. for transit-time damping acceleration. The electron spectra are then converted to photon spectra for comparison with RHESSI observation of looptop sources.
Results. The presence of particle escape softens the model spectra computed in the stochastic acceleration framework. The ratio between the efficiency of trapping and acceleration controls the spectral evolution which follows a soft-hard-soft pattern. Furthermore, a *pivot point* (that is, a common crossing point of the accelerated particle spectra at different times) is found at around 10 keV. It can be brought into agreement with the observed value of 20 keV by enhanced trapping through an electric potential.
Conclusions. The model proposed here accounts for the key features observed in the spectral evolution of hard X-ray emission from looptop sources.

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For preprints contact: pgrigis@astro.phys.ethz.ch

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Local Helioseismology and Correlation Tracking Analysis of Surface Structures in Realistic Simulations of Solar Convection

Dali Georgobiani[1], Junwei Zhao[1] and Alexander G. Kosovichev[1], David Benson[2], Robert F. Stein[2], Åke Nordlund[3]

[1] Hansen Experimental Physics Laboratory, Stanford University, Stanford, CA, 94305
[2] Physics and Astronomy Department, Michigan State University, East Lansing, MI 48824
[3] Niels Bohr Institute, Copenhagen University, Juliane Maries Vej 30, DK–2100 København Ø, Denmark

We apply time-distance helioseismology, local correlation tracking and Fourier spatial-temporal filtering methods to realistic supergranule scale simulations of solar convection and compare the results with high-resolution observations from the SOHO Michelson Doppler Imager (MDI). Our objective is to investigate the surface and sub-surface convective structures and test helioseismic measurements. The size and grid of the computational domain are sufficient to resolve various convective scales from granulation to supergranulation. The spatial velocity spectrum is approximately a power law for scales larger than granules, with a continuous decrease in velocity amplitude with increasing size. Aside from granulation no special scales exist, although a small enhancement in power at supergranulation scales can be seen. We calculate the time-distance diagram for f- and p-modes and show that it is consistent with the SOHO/MDI observations. From the simulation data we calculate travel time maps for surface gravity waves (f-mode). We also apply correlation tracking to the simulated vertical velocity in the photosphere to calculate the corresponding horizontal flows. We compare both of these to the actual large-scale (filtered) simulation velocities. All three methods reveal similar large scale convective patterns and provide an initial test of time-distance methods.

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For preprints contact: stein@pa.msu.edu

For preprints via WWW: http://www.www.pa.msu.edu/ steinr/papers/time-distance.06.pdf

Time-dependent Hydrogen Ionisation in 3D Simulations of the Solar Chromosphere

Jorrit Leenaarts [1] and Sven Wedemeyer-Böhm[2]

[1] Sterrekundig Instituut, Utrecht University, Postbus 80 000 NL–3508 TA Utrecht, The Netherlands
[2] Kiepenheuer Institut für Sonnenphysik, Schöneckstrasse 6, D–79104 Freiburg, Germany

Context: The hydrogen ionisation degree deviates substantially from statistical equilibrium under the conditions of the solar chromosphere. A realistic description of this atmospheric layer thus must account for time-dependent non-equilibrium effects.

Aims: Advancing the realism of numerical simulations of the solar chromosphere by improved numerical treatment of the relevant physics will provide more realistic models that are essential for interpretation of existing and future observations.

Methods: An approximate method for solving the rate equations for the hydrogen populations was extended and implemented in the three-dimensional radiation (magneto-)hydrodynamics code CO5BOLD. The method is based on a model atom with six energy levels and fixed radiative rates. It has been tested extensively in one-dimensional simulations. The extended method has been used to create a three-dimensional model that extends from the upper convection zone to the chromosphere.

Results: The ionisation degree of hydrogen in our time-dependent simulation is comparable to the corresponding equilibrium value up to 500 km above optical depth unity. Above this height, the non-equilibrium ionisation degree is fairly constant over time and space, and tends to be at a value set by hot propagating shock waves. The hydrogen level populations and electron density are much more constant than the corresponding values for statistical equilibrium, too. In contrast, the equilibrium ionisation degree varies by more than 20 orders of magnitude between hot, shocked regions and cool, non-shocked regions.

Conclusions: The simulation shows for the first time in 3D that the chromospheric hydrogen ionisation degree and electron density cannot be calculated in equilibrium. Our simulation can provide realistic values of those quantities for detailed radiative transfer computations.

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For preprints contact: j.leenaarts@astro.uu.nl

Modeling the Sun's Open Magnetic Flux

M. Schüssler[1] and I. Baumann[2]

[1] Max-Planck-Institut für Sonnensystemforschung, 37191 Katlenburg-Lindau, Germany
[2] Royal Observatory of Belgium, Avenue Circulaire 3, 1180 Bruxelles, Belgium

The heliospheric magnetic field can be extrapolated from the photospheric field distribution using models based upon various approximations. Such models are required for the reconstruction of the open solar magnetic flux prior to the time of direct measurements on the basis of surface flux transport simulations. We evaluate the consistency of extrapolation models with direct measurements of the heliospheric magnetic field. Furthermore, we study whether extrapolations on the basis of a surface flux transport model for the photospheric magnetic field reproduce the temporal evolution of the measured near-Earth magnetic field. We use the potential field source surface (PFSS) model and the current sheet source surface (CSSS) model to extrapolate the heliospheric field on the basis of the Wilcox Solar Observatory (WSO) synoptic maps of the solar surface field from 1976–2005. The results are compared with the near-Earth measurements of the radial heliospheric field and its independence of latitude found with *Ulysses*. Furthermore, we determine extrapolations on the basis of photospheric flux distributions computed with a surface flux transport code, using as input sunspot group areas from the SOON database. The CSSS model based upon WSO data, with a source surface located at $\geq 10R_{\odot}$ and cusp surface at $1.7R_{\odot}$, yields the best agreement with the measurements. The flux transport simulations reproduce the observed surface flux together with the open flux if the tilt angle of emerging bipolar magnetic regions is smaller than commonly assumed, but consistent with sunspot observations. The CSSS model with a source surface in the vicinity of the Alfénic point of the solar wind leads to a good extrapolation of the heliospheric field from solar surface data. A surface flux transport model based upon sunspot data with consistently calibrated tilt angles reproduces the observed evolution of the solar total open flux.

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For preprints contact: schuessler@mps.mpg.de

For preprints via ftp or WWW: http://www.mps.mpg.de/homes/schuessler/Schuessler_Baumann.pdf

XEST Abstracts

Editor's Note: The abstracts below present first results from the *XMM-Newton Extended Survey of the Taurus Molecular Cloud (XEST)*. These abstracts are being cross-listed with the *Star Formation Newsletter* and are included here since they address several topics of general interest to cool star researchers (e.g. magnetic activity, variability, the origin and nature of X-ray emission in young cool stars and brown dwarfs).

The XMM-Newton Extended Survey of the Taurus Molecular Cloud (XEST)

Manuel Güdel[1], Kevin R. Briggs[1], Kaspar Arzner[1], Marc Audard[2], Jerôme Bouvier[3], Eric D. Feigelson[4], Elena Franciosini[5], Adrian Glauser[1], Nicolas Grosso[3], Giusi Micela[5], Jean-Louis Monin[3], Thierry Montmerle[3], Deborah L. Padgett[6], Francesco Palla[7], Ignazio Pillitteri[8], Luisa Rebull[6], Luigi Scelsi[8], Bruno Silva[9,10], Stephen L. Skinner[11], Beate Stelzer[5], and Alessandra Telleschi[1]

[1] Paul Scherrer Institut, Würenlingen and Villigen, CH-5232 Villigen PSI, Switzerland
[2] Columbia Astrophysics Laboratory, Mail Code 5247, 550 West 120th Street, New York, NY 10027, USA
[3] Laboratoire d'Astrophysique de Grenoble, Université Joseph Fourier - CNRS, BP 53, F-38041 Grenoble Cedex, France
[4] Department of Astronomy & Astrophysics, Penn State University, 525 Davey Lab, University Park, PA 16802, USA
[5] INAF - Osservatorio Astronomico di Palermo, Piazza del Parlamento 1, I-90134 Palermo, Italy
[6] Spitzer Science Center, California Institute of Technology, Mail Code 220-6, Pasadena, CA 91125, USA
[7] INAF - Osservatorio Astrofisico di Arcetri, Largo Enrico Fermi, 5, I-50125 Firenze, Italy
[8] Dipartimento di Scienze Fisiche ed Astronomiche, Università di Palermo, Piazza del Parlamento 1, I-90134 Palermo, Italy
[9] Centro de Astrofísica da Universidade do Porto, Rua das Estrelas, 4150 Porto, Portugal
[10] Departamento de Matemática Aplicada, Faculdade de Ciêcias da Universidade do Porto, 4169 Porto, Portugal
[11] CASA, 389, University of Colorado, Boulder, CO 80309-0389, USA

Context: The Taurus Molecular Cloud (TMC) is the nearest large star-forming region, prototypical for the distributed mode of low-mass star formation. Pre-main sequence stars are luminous X-ray sources, probably mostly owing to magnetic energy release.
Aims: The *XMM-Newton Extended Survey of the Taurus Molecular Cloud* (XEST) presented in this paper surveys the most populated ≈5 square degrees of the TMC, using the *XMM-Newton* X-ray observatory to study the thermal structure, variability, and long-term evolution of hot plasma, to investigate the magnetic dynamo, and to search for new potential members of the association. Many targets are also studied in the optical, and high-resolution X-ray grating spectroscopy has been obtained for selected bright sources.
Methods: The X-ray spectra have been coherently analyzed with two different thermal models (2-component thermal model, and a continuous emission measure distribution model). Overall correlations with fundamental stellar parameters, derived from the previous literature, are presented. A few detections from *Chandra* observations have been added.
Results: The present overview paper introduces the project and provides the basic results from the X-ray analysis of all sources detected in the XEST survey. Comprehensive tables summarize the stellar properties of all targets surveyed. The survey goes deeper than previous X-ray surveys of Taurus by about an order of magnitude and for the first time systematically accesses very faint and strongly absorbed TMC objects. We find a detection rate of 85% and 98% for classical and weak-lined T Tau stars (CTTS resp. WTTS), and identify about half of the surveyed protostars and brown dwarfs. Overall, 136 out of 169 surveyed stellar systems are detected. We describe an X-ray luminosity vs. mass correlation, discuss the distribution of X-ray-to-bolometric luminosity ratios, and show evidence for lower X-ray luminosities in CTTS compared to WTTS. Detailed analysis (e.g., variability, rotation-activity relations, influence of accretion on X-rays) will be discussed in a series of accompanying papers.

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For preprints contact: guedel@astro.phys.ethz.ch [continued →]

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http://www.astro.phys.ethz.ch/papers/guedel/guedel_p_nf.html

A Statistical Analysis of X-ray Variability in Pre-main Sequence Objects of the Taurus Molecular Cloud

B. Stelzer[1], E. Flaccomio[1], K. Briggs[2], G. Micela[1], L. Scelsi[3], M. Audard[4], I. Pillitteri[1,3] and M. Güdel[2]

[1] INAF - Osservatorio Astronomico di Palermo, Piazza del Parlamento 1, I-90134 Palermo, Italy
[2] Paul Scherrer Institut, Würenlingen and Villigen, CH-5232 Villigen PSI, Switzerland
[3] Dipartimento di Scienze Fisiche ed Astronomiche, Sezione di Astronomia, Università di Palermo, Piazza del Parlamento 1, I-90134 Palermo, Italy
[4] Columbia Astrophysics Laboratory, Mail Code 5247, 550 West 120th Street, New York, NY 10027, USA

This work is part of a systematic X-ray survey of the Taurus star forming complex with XMM-Newton. We study the time series of all X-ray sources associated with Taurus members, to statistically characterize their X-ray variability, and compare the results to those for pre-main sequence stars in the Orion Nebula Cluster and to expectations arising from a model where all the X-ray emission is the result of a large number of stochastically occurring flares. The analysis of the lightcurves is based on a maximum likelihood algorithm that segments the time series in intervals of constant signal without the need of binning. Flares are defined with criteria that take into account the amplitude and the derivative of the segmented lightcurves. Variability statistics are evaluated for different classes of pre-main sequence stars (protostars, cTTS, wTTS, brown dwarfs), and for different spectral type ranges. Flare frequency and energy distribution are computed. We find that roughly half of the detected X-ray sources show variability above our sensitivity limit, and in $\sim 26\,\%$ of the cases this variability is recognized as flares. Variability is more frequently detected at hard than at soft energies. The variability statistics of cTTS and wTTS are undistinguishable, suggesting a common (coronal) origin for their X-ray emission. The frequency of large flares ($E > 10^{35}$ erg) on Taurus members is 1 event per star in 800 ksec. The typical duration of these flares – probably biased by the finite observing time – is about 10 ksec. We have for the first time applied a rigorous maximum likelihood method in the analysis of the number distribution of flare energies on pre-main sequence stars. In its differential form this distribution follows a power-law with index $\alpha = 2.4 \pm 0.5$, in the range typically observed on late-type stars and the Sun. The signature of the X-ray variability in the pre-main sequence stars in Taurus and Orion provides twofold support for coronal heating by flares: (i) The correlation between the maximum variability amplitude and the minimum emission level indicates that both flare and quiescent emission are closely related to the coronal heating process. (ii) The power-law index α derived for the flare energy distribution is large enough to explain the heating of stellar coronae by nano-flares ($\alpha > 2$), albeit associated with a rather large uncertainty that leaves some doubt on this conclusion.

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For preprints contact: stelzer@astropa.unipa.it

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New Pre-Main Sequence Candidates in the Taurus-Auriga Star Forming Region

L. Scelsi[1], A. Maggio[2], G. Micela[2], I. Pillitteri[2], B. Stelzer[2], K. Briggs[3], M. Güdel[3], N. Grosso[4], M. Audard[5] and F. Palla[6]

[1] Dipartimento di Scienze Fisiche ed Astronomiche, Sezione di Astronomia, Università di Palermo, Piazza del Parlamento 1, I-90134 Palermo, Italy
[2] INAF - Osservatorio Astronomico di Palermo, Piazza del Parlamento 1, I-90134 Palermo, Italy
[3] Paul Scherrer Institut, Würenlingen and Villigen, CH-5232 Villigen PSI, Switzerland [4] Laboratoire d'Astrophysique de Grenoble, Université Joseph-Fourier, 414, rue de la Piscine, F-38041 Grenoble Cedex, France [5] Columbia Astrophysics Laboratory, Mail Code 5247, 550 West 120th Street, New York, NY 10027, USA [6] INAF - Osservatorio Astrofisico di Arcetri, Largo E. Fermi 5, I-50125 Firenze, Italy

We have studied the X-ray source population of the Taurus Molecular Cloud (TMC) to search for new members of the Taurus-Auriga star forming region. Candidate members have been selected among the X-ray sources detected in 24 fields of the XMM-*Newton* Extended Survey of the Taurus Molecular Cloud, having an IR counterpart in the 2MASS catalog, based on color-magnitude and color-color diagrams. Their X-ray spectral properties have been compared with those of known members and other X-ray sources in the same fields but without a NIR counterpart. A search for flare-like variability in the time series of all new candidates and the analysis of the X-ray spectra of the brightest candidates have been used to identify sources with a high probability of membership. We have found that 347 of 1909 detected X-ray sources have an infrared counterpart in the 2MASS catalogue. Among them, we have selected 57 sources that are consistent with being new pre-main sequence star candidates at the distance of the Taurus-Auriga star forming region; the X-ray spectral properties of this sample are, on the whole, similar to the properties of known TMC members and different from those of X-ray sources without an IR counterpart, most of which are likely to be of extragalactic origin. For 12 such candidates, the likelihood of membership is very high, based on the relatively high plasma temperatures derived from their X-ray spectra and/or the observation of powerful flares in their light curves.

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For preprints contact: scelsi@astropa.unipa.it

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X-ray emission from the Young Brown Dwarfs of the Taurus Molecular Cloud

N. Grosso[1], K. R. Briggs[2], M. Güdel[2], S. Guieu[1], E. Franciosini[3], F. Palla[4], C. Dougados[1], J.-L. Monin[1,5], F. Ménard[1], J. Bouvier[1], M. Audard[6] and A. Telleschi[2]

[1] Laboratoire d'Astrophysique de Grenoble, Université Joseph-Fourier, F-38041 Grenoble cedex 9, France

[2] Paul Scherrer Institut, 5232 Villigen und Würenlingen, Switzerland

[3] INAF - Osservatorio Astronomico di Palermo, Piazza del Parlamento 1, I-90134 Palermo, Italy

[4] INAF - Osservatorio Astrofisico di Arcetri, Largo Enrico Fermi 5, I-50125 Firenze, Italy

[5] Institut Universitaire de France

[6] Columbia Astrophysics Laboratory, Columbia University, 550 West 120th Street, New York, NY 10027, USA

AIMS. We report the X-ray properties of young (~3 Myr) *bona fide* brown dwarfs of the Taurus Molecular Cloud (TMC). METHODS. The *XMM-Newton Extended Survey of the TMC* (XEST) is a large program designed to systematically investigate the X-ray properties of young stellar/substellar objects in the TMC. In particular, the area surveyed by 15 *XMM-Newton* pointings (of which three are archival observations), supplemented with one archival *Chandra* observation, allows us to study 17 brown dwarfs with M spectral types. RESULTS. Half of this sample (9 out of 17 brown dwarfs) is detected; 7 brown dwarfs are detected here for the first time in X-rays. We observed a flare from one brown dwarf. We confirm several previous findings on brown dwarf X-ray activity: a log-log relation between X-ray and bolometric luminosity for stars (with $L_*\leq 10\,\mathrm{L}_\odot$) and brown dwarfs detected in X-rays, which is consistent with a mean X-ray fractional luminosity $<\log(L_\mathrm{X}/L_*)> = -3.5 \pm 0.4$; for the XEST brown dwarfs, the median of $\log(L_\mathrm{X}/L_*)$ (including upper limits) is -4.0; a shallow log-log relation between X-ray fractional luminosity and mass; a log-log relation between X-ray fractional luminosity and effective temperature; a log-log relation between X-ray surface flux and effective temperature. We find no significant log-log correlation between the X-ray fractional luminosity and $EW(\mathrm{H}\alpha)$. Accreting and nonaccreting brown dwarfs have a similar X-ray fractional luminosity. The median X-ray fractional luminosity of nonaccreting brown dwarfs is about 4 times lower than the mean saturation value for rapidly rotating low-mass field stars. Our TMC brown dwarfs have higher X-ray fractional luminosity than brown dwarfs in the *Chandra Orion Ultradeep Project*. CONCLUSIONS. The X-ray fractional luminosity declines from low-mass stars to M-type brown dwarfs, and as a sample, the brown dwarfs are less efficient X-ray emitters than low-mass stars. We thus conclude that while the brown dwarf atmospheres observed here are mostly warm enough to sustain coronal activity, a trend is seen that may indicate its gradual decline due to the drop in photospheric ionization degree.

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X-rays from Jet-driving Protostars and T Tauri Stars

Manuel Güdel[1], Alessandra Telleschi[1], Marc Audard[2], Stephen L. Skinner[3], Kevin R. Briggs[1], Francesco Palla[4], and Catherine Dougados[5]

[1] Paul Scherrer Institut, Würenlingen and Villigen, CH-5232 Villigen PSI, Switzerland
[2] Columbia Astrophysics Laboratory, Mail Code 5247, 550 West 120th Street, New York, NY 10027, USA
[3] CASA, 389, University of Colorado, Boulder, CO 80309-0389, USA
[4] INAF - Osservatorio Astrofisico di Arcetri, Largo Enrico Fermi, 5, I-50125 Firenze, Italy
[5] Laboratoire d'Astrophysique de Grenoble, Université Joseph Fourier - CNRS, BP 53, F-38041 Grenoble Cedex, France

Aims: We study jet-driving protostars and T Tau stars to characterize their X-ray emission. We seek soft spectral components that may be due to shock emission, and search for soft, shock-induced emission displaced from the stellar position.
Methods: We study two stellar samples, the first consisting of lightly absorbed T Tau stars with strong jets, the other containing protostars with disks seen nearly edge-on. The former sample was observed in the *XMM-Newton Extended Survey of the Taurus Molecular Cloud* (XEST), while *Chandra* archival data provided observations of the latter.
Results: We confirm the previously identified peculiar spectrum of DG Tau A and find similar phenomenology in GV Tau and DP Tau, suggesting a new class of X-ray spectra. These consist of a lightly absorbed, very soft component and a strongly absorbed, very hard component. The latter is flaring while little variability is detected in the former. The absorption of the harder component is about an order of magnitude higher than expected from the optical extinction assuming a standard gas-to-dust mass ratio. For the absorbed protostars, only the hard, stellar X-ray component is found.
Conclusions: The flaring hard component represents active coronal emission. Its strong absorption is attributed to mass inflow from the accretion disk. The optical extinction is small because the dust has sublimated at larger distances. The little absorbed soft component cannot originate from the same location. Because the stars drive strong jets, we propose that the X-rays are generated in shocks in the jets. We find that for the three peculiar X-ray sources, the luminosity of the soft component roughly scales with the equivalent width of the [O I] λ 6300 line formed in the jets, and with the mass outflow rate. In the more strongly obscured protostars, the soft component is thus entirely absorbed, and only the hard, coronal component penetrates the envelope or the near-edge-on disk.

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For preprints contact: guedel@astro.phys.ethz.ch

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