COOLNEWS

A RESEARCH NEWSLETTER DEDICATED TO COOL STARS AND THE SUN

No. 115 — September 2005 Editor: Steve Skinner (coolnews@jila.colorado.edu)

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Stellar Abstracts

Keck/HIRES Spectroscopy of Four Candidate Solar Twins

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We use high S/N, high-resolution Keck/HIRES spectroscopy of 4 solar twin candidates (HIP 71813, 76114, 77718, 78399) pulled from our *Hipparcos*-based Ca II H & K survey to carry out parameter and abundance analyses of these objects. Our spectroscopic $T_{\rm eff}$ estimates are some ∼100 K hotter than the photometric scale of the recent Geneva-Copenhagen survey; several lines of evidence suggest the photometric temperatures are too cool at solar $T_{\rm eff}$. At the same time, our abundances for the 3 solar twin candidates included in the Geneva-Copenhagen survey are in outstanding agreement with the photometric metallicities; there is no sign of the anomalously low photometric metallicities derived for some late-G UMa group and Hyades dwarfs. A first radial velocity determination is made for HIP 78399, and *UVW* kinematics derived for all stars. HIP 71813 appears to be a kinematic member of the Wolf 630 moving group (a structure apparently reidentified in a recent analysis of late-type *Hipparcos* stars), but its metallicity is 0.1 dex higher than the most recent estimate of this group's metallicity. While certainly "solar-type" stars, HIP 76114 and 77718 are a few percent less massive, significantly older, and metal-poor compared to the Sun; they are neither good solar twin candidates nor solar analogs providing a look at the Sun at some other point in its evolution. HIP 71813 appears to be an excellent solar analog of age ∼8 Gyr. Our results for HIP 78399 suggest the promise of this star as a solar twin may be equivalent to the "closest ever solar twin" HR 6060; follow up study of this star is encouraged.

Accepted for publication in AJ (Nov. 2005)

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New Low Accretion-Rate Magnetic Binary Systems and their Significance for the Evolution of Cataclysmic Variables

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Discoveries of two new white dwarf plus M star binaries with striking optical cyclotron emission features from the Sloan Digital Sky Survey (SDSS) brings to six the total number of X-ray faint, magnetic accretion binaries that accrete at rates $\dot{M} \lesssim 10^{-13}\ M_\odot\ \mathrm{yr}^{-1}$, or <1% of the values normally encountered in cataclysmic variables. This fact, coupled with donor stars that underfill their Roche lobes and very cool white dwarfs, brand the binaries as post common-envelope systems whose orbits have not yet decayed to the point of Roche-lobe contact. They are pre-magnetic CVs, or pre-Polars. The systems exhibit spin/orbit synchronism and apparently accrete by efficient capture of the stellar wind from the secondary star, a process that has been dubbed a "magnetic siphon". Because of this, the measured accretion rates quantify the total wind loss rates from the cool companions in this forced rapid-rotation situation. Period evolution of the binaries will occur solely by gravitational radiation, which is very slow for periods >3 hr. Optical surveys for the cyclotron harmonics appear to be the only means of discovery, so the space density of pre-Polars could rival that of Polars, and the binaries provide an important channel of progenitors (in addition to the asynchronous Intermediate Polars). Both physical and SDSS observational selection effects are identified that may help to explain the clumping of all six systems in a narrow range of magnetic field strength around 60 MG.

Accepted by ApJ (to appear in Sept. 10, 2005)

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Solar-like Oscillations in α Centauri B

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We have made velocity observations of the star α Cen B from two sites, allowing us to identify 37 oscillation modes with $l = 0$–3. Fitting to these modes gives the large and small frequency separations as a function of frequency. The mode lifetime, as measured from the scatter of the oscillation frequencies about a smooth trend, is similar to that in the Sun. Limited observations of the star δ Pav show oscillations centred at 2.3 mHz with peak amplitudes close to solar. We introduce a new method of measuring oscillation amplitudes from heavily-smoothed power density spectra, from which we estimated amplitudes for α Cen A and B, β Hyi, δ Pav and the Sun. We point out that the oscillation amplitudes may depend on which spectral lines are used for the velocity measurements.

Accepted by ApJ

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A Further 'Degree of Freedom' in the Rotational Evolution of Stars

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Observational and theoretical investigations provide evidence for non-uniform spot and magnetic flux distributions on rapidly rotating stars, which have a significant impact on their angular momentum loss rate through magnetised winds. Supplementing the formalism of MacGregor & Brenner (1991) with a latitude-dependent magnetised wind model, we analyse the effect of analytically prescribed surface distributions of open magnetic flux with different shapes and degrees of non-uniformity on the rotational evolution of a solar-like star. The angular momentum redistribution inside the star is treated in a qualitative way, assuming an angular momentum transfer between the rigidly-rotating radiative and convective zones on a constant coupling timescale of 15 Myr; for the sake of simplicity we disregard interactions with circumstellar disks. We find that non-uniform flux distributions entail rotational histories which differ significantly from those of classical approaches, with differences cumulating up to 200% during the main sequence phase. Their impact is able to mimic deviations of the dynamo efficiency from linearity of up to 40% and nominal dynamo saturation limits at about 35 times the solar rotation rate. Concentrations of open magnetic flux at high latitudes thus assist in the formation of very rapidly rotating stars in young open clusters, and ease the necessity for a dynamo saturation at small rotation rates. However, since our results show that even minor amounts of open flux at intermediate latitudes, as observed with Zeeman-Doppler imaging techniques, are sufficient to moderate this reduction of the AM loss rate, we suggest that non-uniform flux distributions are a complementary rather than an alternative explanation for very rapid stellar rotation.

Accepted by A&A

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On the Orbital Period Modulation of RS CVn Binary Systems

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The Applegate's hypothesis proposed to explain the orbital period modulation of RS CVn close binaries (Applegate 1992, ApJ 385, 621) is considered in the framework of a general model to treat the angular momentum exchanges within the convective envelope of a magnetically active star. This model assumes that the convection zone is strictly adiabatic and that the Taylor-Proudman balance holds, leading to an internal angular velocity constant over cylindrical surfaces co-axial with the rotation axis. It turns out that the angular velocity perturbations, whatever their origin, can be expressed in terms of the eigenfunctions of the equation of angular momentum conservation with stress-free boundary conditions. Moreover, a lower limit for the energy dissipation rate in a turbulent convection zone can be set, thanks to the extremal properties of the eigenfunctions. This approach allows to put precise constraints on the amplitude and the radial profile of the angular velocity variations that are required to explain the observed orbital period changes in classical RS CVn binaries (i.e., with orbital period longer than $1-2$ days and a subgiant secondary component). It is found that an angular velocity change as large as 10% of the unperturbed angular velocity at the base of the stellar convection zone is needed. Such a large change is not compatible with the observations. Moreover, it would produce an energy dissipation rate much larger than the typical luminosities of the active components of RS CVn systems, except in the case that fast rotation and internal magnetic fields reduce the turbulent viscosity by at least two orders of magnitude with respect to the value given by the mixing-length theory. Therefore, the model proposed by Applegate should be rejected, at least in the case of classical RS CVn close binaries. Possible alternative models are briefly discussed, emphasizing the effects of intense magnetic fields ($\sim$ 10 T) on the internal structure of magnetically active stars and the dynamics of close binary systems.

Accepted by MNRAS

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Beryllium Enhancement as Evidence for Accretion in a Lithium-Rich F Dwarf

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The early F dwarf star "J37" in the open cluster NGC 6633 shows an unusual pattern of photospheric abundances, including an order of magnitude enhancement of lithium and iron-peak elements, but an under-abundance of carbon. As a consequence of its thin convection zone these anomalies have been attributed to either radiative diffusion or the accretion of hydrogen-depleted material. By comparing high resolution VLT/UVES spectra of J37 (and other F stars in NGC 6633) with syntheses of the Be II doublet region at 3131 Å, we establish that J37 also has a Be abundance (A(Be)$= 3.0 \pm 0.5$) that is at least ten times the cosmic value. This contradicts radiative diffusion models that produce a Li over-abundance, as they also predict photospheric Be depletion. Instead, since Be is a highly refractory element, it supports the notion that J37 is the first clear example of a star that has accreted volatile-depleted material with a composition similar to chondritic meteorites, although some diffusion may be necessary to explain the low C and O abundances.

Accepted by MNRAS

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Elemental Abundances in the Blanco 1 Open Cluster

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High resolution spectroscopy is used to determine the detailed chemical abundances of a group of eight F- and G-type stars in the young open cluster Blanco 1. An average [Fe/H] of +0.04 ±0.02 (internal error) ±0.04 (external error) is found, considerably lower than a previous spectroscopic estimate for this cluster. The difference is due mainly to our adoption of significantly cooler temperatures which are consistent with both photometric and spectroscopic constraints. Blanco 1 exhibits sub-solar [Ni/Fe] (−0.18 ±0.01 ±0.01), [Si/Fe] (−0.09 ±0.02 ±0.03), [Mg/Fe] (−0.14 ±0.02 ±0.03) and [Ca/Fe] (−0.09 ±0.03 ±0.03); ratios which are not observed among nearby field stars. The material from which Blanco 1 formed may not have been well mixed with interstellar matter in the galactic disc, which tallies with its current location about 240 pc below the galactic plane. A simultaneous deficit of Ni and alpha elements with respect to Fe is hard to reconcile with most published models of yields from supernovae of types Ia and II. The revised abundances for Blanco 1 indicate that overall radiative opacities in its stars, and hence convective zone properties at a given mass, are similar to those in the Pleiades at approximately the same age. This can explain a previous observation that the Li depletion patterns of G- and K-type stars in the two clusters are indistinguishable. The lower overall metallicity of Blanco 1 now make it less attractive as a target for discovering transiting, short period exoplanets.

Accepted by MNRAS

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Solar Abstracts

On the Size Distribution of Sunspot Groups in the Greenwich Sunspot Record 1874-1976

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We investigate the size distribution of the maximum areas and the instantaneous distribution of areas of sunspot groups using the Greenwich sunspot group record spanning the interval 1874 - 1976. Both distributions are found to be well described by log-normal functions. Using a simple model we can transform the maximum area distribution into the instantaneous area distribution if the sunspot area decay rates are also distributed log-normally. For single-valued decay rates the resulting snapshot distribution is incompatible with the observations. The current analysis therefore supports the results of Howard (1992) and Martínez Pillet et al. (1993). It is not possible to distinguish between a linear and a quadratic decay law, however, with the employed data set.

Accepted by A&A

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The Flares Associated With the Dynamics of the Sunspots

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In the present study, we consider six years data of spot groups that have well developed leading and following spots obtained from the Kodaikanal Observatory white light pictures and occurrence of H-alpha flares. From the daily observations, we compute the variations in rotation rates, meridional velocity, the areas and longitudinal separations. We find that among all these variations, the occurrence of abnormal rotation rates (the rotation rates that have greater than 1σ) and longitudinal minimum separation during the course of their evolution eventually lead to triggering of flares. We also find that the events of abnormal rotation rates, longitudinal minimum separation and the flares occur mainly during the 50-80% of the sunspots' life span indicating magnetic reconnection probably below ($0.935\ R_\odot$) the solar surface. Relevance of these results with the conventional theory of magnetic reconnection is briefly discussed.

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The Influence of Solar Activity on the Rainfall Over India : Cycle to Cycle Variations

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We use 130 (1871-2000) years data for studying correlative effects due to solar cycle and activity phenomena on the occurrence of the rainfall over India. For the period of different solar cycles, we compute the correlation coefficients and significance of correlation coefficients for the seasonal months of Jan-Feb (JF), March-May (MAM), June-September (JJAS) and October-December (OND) and, *annual mean* data. We find that: (i) with a moderate to high significance, Indian rainfall is correlated with the sunspot activity and, (ii) there is a overall trend that during the period of low sunspot activity, occurrence of rainfall is high compared to the period of high sunspot activity.

We speculate in this study a possible physical connection between the occurrence of the rainfall and the sunspot activities and, the flux of galactic cosmic rays. Some of the negative correlations between the occurrences of the sunspot and rainfall activities obtained for different solar cycle periods are interpreted as effects of aerosols on the rain forming clouds due to either intermittent volcanic eruptions or due to intrusion of interstellar dust particles in the earth's atmosphere.

To appear in *Journal of Astrophysics & Astronomy*

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Optical and EUV Observations of Solar Flare Kernels

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We present high-resolution spectral observations, covering the entire optical region (3800-9000 Å), of a solar flare observed during a multi-wavelength campaign. The flare, recorded on 2002 January 11, was a medium solar flare event (GOES class C7.5). The spectral observations were carried out using the Hamilton echelle spectrograph on the coudé auxiliary telescope at Lick Observatory and with the Coronal Diagnostic Spectrometer (CDS) on board SoHO. The high signal-to-noise optical spectra are analysed using the same techniques as we applied to stellar flare data. Hα images obtained at Big Bear Solar Observatory (BBSO), plus magnetograms obtained with the Michelson Doppler Imager (MDI) on board SoHO and Transition Region And Coronal Explorer (TRACE) 1600 Å were used in the flare analysis. We observe stellar-like behaviour in the main solar chromospheric activity indicators, which show either filling-in or emission during the flare. We find that the Balmer and Ca II lines show asymmetric profiles, with red-shifted wings and blue-shifted cores. This behaviour could be explained by material expanding. During the flare, the Mg I and Fe I lines show a filling-in of the line profile indicating that the flare affected the lower atmosphere. There is some evidence for pre-flare heating as seen in Fe XIX 592 Å. Furthermore, O V 629 Å shows an increase in flux some 10 min. before the coronal lines, perhaps indicating particle beam heating in the initial stages of the flare. We have also determined the main physical parameters at flare maximum. The electron densities and electron temperatures found for the flare imply that the Balmer emitting plasma originates in the chromosphere. The physical parameters obtained for the modelled flare are consistent with previously derived values for solar flares.

Accepted by A&A

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RHESSI Images and Spectra of Two Small Flares

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We studied the evolution of two small flares (GOES class C2 and C1) that developed in the same active region with different morphological characteristics: one is extended and the other is compact. We analyzed the accuracy and the consistency of different algorithms implemented in RHESSI software to reconstruct the image of the emitting sources, for energies between 3 and 12 keV. We found that all tested algorithms give consistent results for the peak position while the other parameters can differ at most by a factor 2. *Pixon* and *Forward-fit* generally converge to similar results but *Pixon* is more reliable for reconstructing a complex source. We investigated the spectral characteristics of the two flares during their evolution in the $3 - 25$ keV energy band. We found that a single thermal model of the photon spectrum is inadequate to fit the observations and we needed to add either a non-thermal model or a hot thermal one. The non-thermal and the double thermal fits are comparable. If we assume a non-thermal model, the non-thermal energy is always higher than the thermal one. Only during the very final decay phase a single thermal model fits fairly well the observed spectrum.

Accepted by Solar Phys.

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Kelu-1 is a Binary L Dwarf: First Brown Dwarf Science from Laser Guide Star Adaptive Optics

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We present near-infrared (1–2.4 μm) high angular resolution imaging of the nearby L dwarf Kelu-1 obtained with the sodium laser guide star adaptive optics (LGS AO) system on the Keck II Telescope. Kelu-1 was one of the first free-floating L dwarfs identified, and the origin of its overluminosity compared to objects of similar spectral type has been a long-standing question. Our images clearly resolve Kelu-1 into a 0.29″ (5.4 AU) binary with near-infrared flux ratios of ≈0.5 mags. A previous non-detection of binarity by *Hubble Space Telescope* demonstrates that the system is a true physical pair and that its projected orbital motion has been significant over the last 7 years. Binarity explains the properties of Kelu-1 that were previously noted to be anomalous compared to other early-L dwarfs. We estimate spectral types of L1.5–L3 and L3–L4.5 for the two components, giving model-derived masses of 0.05–0.07 $M_\odot$ and 0.045–0.065 $M_\odot$ for an estimated age of 0.3–0.8 Gyr. More distant companions are not detected to a limit of ≈5–9 M_{Jup}. The presence of Li 6708 Å absorption indicates that both components are substellar, but the weakness of this feature relative to other L dwarfs may arise from the fact that only Kelu-1B is Li-bearing. Determining if both or if only one of the components possesses lithium could constrain the age of Kelu-1 (and other Li-bearing L binaries) with higher precision than is possible for most ultracool field objects. These results are the first LGS AO observations of brown dwarfs and demonstrate the potential of this new instrumental capability for substellar astronomy.

Accepted by ApJ

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Very Low-mass Members of the Lupus 3 Cloud

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We report on a multi-band survey for very low-mass stars and brown dwarfs in the Lupus 3 cloud with the Wide Field Imager (WFI) at the ESO/MPG 2.2 m telescope on La Silla Observatory (Chile). Our multiband optical photometry is combined with available 2MASS *JHK* photometry to identify 19 new young stars and 3 brown dwarf candidates as probable members of this star forming region. Our objects are mostly clustered around the cloud core. Stars and brown dwarfs have similar levels of Hα emission, probably a signature of accretion. One object, a brown dwarf candidate, exhibits a near-infrared excess, which may indicate the presence of a disk, but its Hα emission cannot be confirmed due to its faintness in the optical passbands. We also find two visual pairs of probable Lupus 3 members that may be wide binaries.

A&A 440, 139-149 (2005)

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On the Frequency of Close Binary Systems Among Very Low-mass Stars and Brown Dwarfs

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We have used Monte Carlo simulation techniques and published radial velocity surveys to constrain the frequency of very low-mass star (VLMS) and brown dwarf (BD) binary systems and their separation (a) distribution. Gaussian models for the separation distribution with a peak at $a = 4$ au and $0.6 \leq \sigma(\log(a/\mathrm{au}) \leq 1.0$ correctly predict the number of observed binaries, yielding a close ($a < 2.6$ au) binary frequency of 17-30 per cent and an overall VLMS/BD binary frequency of 32-45 per cent. We find that the available N-body models of VLMS/BD formation from dynamically decaying protostellar multiple systems are excluded at > 99 per cent confidence because they predict too few close binary VLMS/BDs. The large number of close binaries and high overall binary frequency are also very inconsistent with recent smoothed particle hydrodynamical modelling and argue against a dynamical origin for VLMS/BDs.

Accepted by MNRAS

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Radial Velocity survey for Planets and Brown Dwarf Companions to Very Young Brown Dwarfs and Very Low-mass Stars in Cha I with UVES at the VLT

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We present results of a radial velocity (RV) survey for planets and brown dwarf companions to very young brown dwarfs and (very) low-mass stars in the Cha I star forming cloud. Time-resolved high-resolution echelle spectra have been taken with UVES at the VLT between 2000 and 2004 of Cha Hα 1–8 and Cha Hα 12 (M6–M8), B34 (M5), CHXR 74 (M4.5) and Sz 23 (M2.5). The achieved precision of the relative RVs range between 40 and 670 m/s and is sufficient to detect Jupitermass planets around the targets. This is the first RV survey of very young brown dwarfs and it probes multiplicity, which is a key parameter for formation in an as yet unexplored domain in terms of age, mass and orbital separation. We find that on time scales of 40 days and less the subsample of ten brown dwarfs and very low-mass stars ($M \leq 0.12\,M_\odot$, spectral types M5–M8) has constant RVs. Estimates for upper limits for masses of hypothetical companions for them range between $0.1\,M_{Jup}$ and $1.5\,M_{Jup}$ for assumed orbital separations of 0.1 AU. This hints at a rather small multiplicity fraction for very young brown dwarfs and very low-mass stars for orbital separations of $\leq$0.1 AU and orbital periods of $\leq$40 days. Furthermore, the non-variable objects demonstrate the lack of any significant RV noise due to stellar activity down to the precision necessary to detect giant planets. Thus, very young brown dwarfs and very low-mass stars are suitable targets for searches for RV planets. Three objects of the sample exhibit significant RV variations with peak-to-peak RV differences of 2–3 km s^{-1}. For the highest mass object observed with UVES (Sz 23, $\sim$0.3 $M_\odot$), the variations are on time scales of days and might be explained by rotational modulation. On the other hand, the brown dwarf candidate Cha Hα 8 (M6.5) and the low-mass star CHXR 74 (M4.5) display significant RV variations on times scales of $\geq$ 150 days, while they are both RV constant or show only much smaller amplitude variations on time scales of days to weeks, i.e. on time scales of the rotation periods. A suggested explanation for the detected RV variations of CHXR 74 and Cha Hα 8 are giant planets or very low-mass brown dwarfs of at least a few Jupiter masses orbiting with periods of several months or longer. Thus, the presented RV data indicate that orbital periods of companions to very young brown dwarfs and (very) low-mass stars are possibly several months or longer and orbital separations $\geq$ 0.2 AU. This parameter range has not been covered for all targets yet but will be probed by follow-up observations. Furthermore, we show that the scaled down equivalent to the brown dwarf desert found around solar-like stars would be a 'giant planet desert' around brown dwarf and very low-mass star primaries if formed by the same mechanism. The present data test its existence for the targets in the limited separation range of the survey. So far, no hints for companions in a 'giant planet desert' have been found.

Accepted by A&A

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Optical Studies of X-ray Peculiar Chromospherically Active Stars

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Ph.D degree submitted: August, 2005

A multiwavelength study of the late-type active stars, selected on the basis of their X-ray (Elvis et al. 1992; Schachter et al. 1996) and radio (Drake, S. A. private communication) luminosities is presented in this thesis. For FR Cnc, a photometric period 0.8267 ± 0.0004 d has been established. The strong variation in the phase and amplitude of the FR Cnc light curves when folded on this period implies the presence of evolving and migrating spots or spot groups on its surface. A photometric period of 18.802 ± 0.074d has been discovered in the star HD 81032. The shape and amplitude of the photometric light curves of FR Cnc, HD 81032, HD 95559 and LO Peg are observed to be changing from one epoch to another. The change in the amplitude is mainly due to a change in the minimum of the light curve, and this may be due to a change in the spot coverage. This indicates that photometric variability is due to the presence of dark spots on the surface of active star. Two groups of spots are identified for FR Cnc and LO Peg. The spots are found to migrate, and migration periods of 0.97 year and 0.93 year are determined from the 4 years of data. A migration period of 1.12 years for one group of spots in LO Peg is also determined. Formation of a new group of spots in the star HD 95559 was also seen during our observations. A single large group of spots is found to migrate, and a migration period of 7.32 ± 0.04 years is determined for HD 81032. The stars FR Cnc, HD 81032, HD 160934 and LO Peg are seen to be redder at the light minimum and we interpret this is due to the relatively cooler temperature of the darker regions present in the visible hemisphere. We find the lack of color-brightness correlation in the star HD 95559 and this may be due to the presence of bright faculae and plages like regions accompanied by dark spots in any one component of the this binary system. The optical spectroscopy of FR Cnc and HD 81032 carried out during 2002-2003, reveals the presence of strong and variable Ca II H and K, Hα and Hβ emission features indicative of high level of chromospheric activity. The chromospheric line emission for both stars seems to correlate with the photometric light curve, i.e. maximum at the light curve minimum, or minimum at the light curve maximum. The value of 5.3 for the ratio of the excess emission in Hα to Hβ, $E_{H\alpha}/E_{H\beta}$ for the star FR Cnc, suggests that the chromospheric emission may arise from an extended off-limb region. We have searched for the presence of color excesses in the near-IR JHK bands of these stars using 2MASS data, but none of them appear to have any significant color excess. The kinematics of the stars FR Cnc, HD 95559, HD 160934 and LO Peg suggest that these are younger than 0.6 Gyrs. The archival X-ray observations of HD 81032, HD 95559, HD 160934 and LO Peg carried out by with the ROSAT observatory were also analyzed. We did not find any significant variability in the X-ray light curve of the stars HD 95559. However, it appears from the X-ray light curve of HD 81032 that a moderate flare occurred during the RASS observations, with a peak of about 0.6 ct s^{-1} at approximately JD=244806.95 and half decay time of 2.6×10^4 s. A similar flare was also observed in HD 160934 with a peak about 0.2 ct s^{-1} (above its mean level) at JD = 2448123.12. A significant variability was found in the X-ray light curve of LO Peg. Rotational modulation appears to be present in the X-ray light curve of LO Peg. The best fit models to their X-ray spectra imply the presence of two coronal plasma components of differing temperatures and with sub-solar metal abundances. The inferred emission measures and temperatures of HD 95559 and LO Peg are similar to those found for other active dwarf stars. The observed X-ray spectrum and the inferred coronal plasma parameters for HD 81032 are typical of those seen in active stars such as RS CVn binaries. All of the optical and X-ray properties found for FR Cnc, HD 95559, HD 160934 and LO Peg are most consistent to the BY Dra type. However, for HD 81032 these properties suggest that it being an evolved RS CVn binary of the long-period type Correlations between various physical quantities (L_x,L_{rad}, P and B-V) of active stars have been

re-examined using a sample containing 248 active stars (101 dwarfs, 65 subgiants and 82 giants). It is a largest sample investigated so far. We did not find any appreciable changes in the correlations reported in previous studies.

In addition to above, an Imaging Polarimeter has been fabricated for use with liquid-N_2 cooled CCD camera and is designed to suit 104-cm Sampurnanand telescope with an f/13 focus at ARIES, Naini Tal. The instrument measures the linear polarization in broad B, V and R band, and has a field of view $\sim 2' \times 2'$.

Thesis-related Publications: AJ, 130, 1231; BASI, 32, 159; JAAp, 23, 9; IBVS No. 5153; JAAp, submitted

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