COOLNEWS

A RESEARCH NEWSLETTER DEDICATED TO COOL STARS AND THE SUN

No. 4 — December 1995 Editor: Steve Skinner (coolnews@jila.colorado.edu)

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From the Editor

With the year-end holidays approaching and the AAS meeting in mid-January, many of you 'cooleagues' will have plenty to do during the next month without the additional burden of newsletter abstracts. COOLNEWS will thus take a holiday break with no issue planned for January. The next issue will appear in mid-February (abstracts due January 31). Enjoy the holidays and best wishes for the New Year. - Steve Skinner

Stellar Abstracts

Searching for Periodicity in Weighted Time Point Series

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Consistent statistics for two methods of searching for periodicity in a series of weighted time points are formulated. An approach based on the bootstrap method to estimate the accuracy of detected periodicity is presented. These methods are then applied to study the solar and stellar active longitudes in Jetsu et al. (1995: A&A, submitted) and Jetsu (1995: A&A, submitted), respectively.

Submitted to A&A

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The Active Longitudes of λ Andromedae, σ Geminorum, II Pegasi and V711 Tauri

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Nonparametric methods to search for periodicity in a weighted or nonweighted time point series are applied to the central meridian passage epochs of starspots on four chromospherically active stars: λ Andromedae, σ Geminorum, II Pegasi and V711 Tauri. The rotation periods of the active longitudes for these objects are uniquely determined, regardless of the presence of differential rotation and phase shifts of the centres of main activity. The temporal changes of the long–term distribution of the starspots in one of these objects, σ Geminorum, resembles the "flip-flop"–phenomenon detected earlier only in FK Comae Berenices.

Submitted to A&A

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The Eclipsing Radio Emission of the Precataclysmic Binary V471 Tauri

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We present strong evidence confirming the presence of eclipses in the centimeter radio emission of the eclipsing binary V471 Tau, comprising a K2 dwarf and a white dwarf. In observations spanning 2 complete orbital periods, we detected one eclipse per orbit: in all we observed one near–complete radio eclipse, the ingress phase of two other radio eclipses, and the egress phase of yet another radio eclipse. The minimum of the near–complete radio eclipse observed is centered at the orbital phase $\phi = 0$ when the white dwarf is eclipsed and directly behind the K dwarf, and has a full width of $\Delta\phi \approx 0.3$; by comparison, the optical eclipse of the white dwarf occupies only $\Delta\phi = 0.066$. Inside eclipse the total flux density of V471 Tau falls to a level $\sim$20% of that outside eclipse, implying that a large fraction of the radio emission originates from the region between the two stars. Outside eclipse the radio emission varies slowly and follows, in large part, the same phase dependence over the two observed orbits (separated by one orbit). This suggests that much of the modulation observed outside eclipse may be due to an apparent change in the observed radiation pattern of the source with orbital revolution, rather than intrinsic variability in the radio emission process. From the data, we place constraints on the physical parameters of both the occulter and the occulted radio source; we find that the radio source is most probably radiating by nonthermal gyrosynchrotron emission. We favour a model where the radio–emitting electrons are accelerated by the interaction (collision) between the magnetospheres of the K dwarf and the white dwarf. This region of interaction is likely to be located very close to the surface of the white dwarf, leading naturally to a picture where the radio emission originates from large magnetic structures associated with the K dwarf. Such a model can qualitatively explain many of the features observed in the radio light-curve. The proposed magnetic structures

may provide the means by which mass is transferred from the K dwarf to the white dwarf, accounting partly or wholly for the inferred accretion of the white dwarf.

Accepted by ApJ

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The Behaviour of the Excess Ca II H & K and Hϵ Emissions in Chromospherically Active Binaries

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In this work we analyze the behaviour of the excess Ca II H & K and Hϵ emissions in a sample of 73 chromospherically active binary systems (RS CVn and BY Dra classes), of different activity levels and luminosity classes. This sample includes the 53 stars analyzed by Fernández-Figueroa et al. (1994) and the observations of 28 systems described by Montes et al. (1995c). By using the spectral subtraction technique (subtraction of a synthesized stellar spectrum constructed from reference stars of spectral type and luminosity class similar to those of the binary star components) we obtain the active-chromosphere contribution to the Ca II H & K lines in these 73 systems. We have determined the excess Ca II H & K emission equivalent widths and converted them into surface fluxes. The emissions arising from each component were obtained when it was possible to deblend both contributions.

We have found that the components of active binaries are generally stronger emitters than single active stars for a given effective temperature and rotation rate.

A slight decline of the excess Ca II H & K emissions towards longer rotation periods, P_{rot}, and larger Rossby numbers, R_0, is found. When we use R_0 instead of P_{rot} the scatter is reduced and a saturation at $R_0 \approx 0.3$ is observed.

A good correlation between the excess Ca II K and Hϵ chromospheric emission fluxes has been found. The correlations obtained between the excess Ca II K emission and other activity indicators (C IV in the transition region, and X-rays in the corona) indicate that the exponents of the power-law relations increase with the formation temperature of the spectral features.

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Effective Temperature-Colour and Surface Brightness-Colour Relationships for the Latest-type Stars

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New calibrations of six broad-band optical and near infrared colours ($U-B$, $B-V$, $V-R$, $V-I$, $R-I$ and $V-K$) against accurate effective temperatures ($T_{\rm eff}$) derived from empirical and semi-empirical (infrared flux) methods for G, K and M giants are presented. Polynomial coefficients for these relationships are given. We also present independent relationships between the visual surface brightness parameter $F_{\rm V}$ and the colours $(V - R)$, $(V - I)$, $(R - I)$ and $(V - K)$. We find that $(U-B)$ and $(B-V)$ are unsuitable as $T_{\rm eff}$ indicators. The tightest relationship in each case is found for the $(V-K)$ index. Our mean relationships agree reasonably well with similar relationships derived by other authors, where such are available. These relationships are suitable for use in the determination of spot areas and temperatures in active late-type stars.

Submitted to A&A

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A Search for Optical Flares on Chromospherically Active Stars

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We have surveyed four years of archival UBV photometry of 69 chromospherically active stars obtained with the Phoenix-10 automatic photoelectric telescope on Mt. Hopkins in search of optical flares on these stars. We demonstrate that, while flares can be detected in these data, the number of events observed on evolved stars remains very small. Flares were found only on UX Arietis (1), II Pegasi (3), and AR Piscium (1). All three of these stars are close binaries and show Hα in emission at all orbital phases. We also look briefly at the occurance of flares on extremely active stars with respect to spot visibility and find no preference for optical flares to occur at minimum light.

Submitted to PASP

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Short–term Chromospheric Variability in α Tauri (K5 III): Results from IUE Time Series Observations

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We evaluate time series observations of chromospheric lines (Mg II, Mg I, C II) for the K giant α Tau obtained using the IUE LWP camera at high dispersion. These observations cover a timespan of about two weeks in February – March 1994 and were designed to resolve variations occurring within hours, days and weeks. We consider the observational results in relation to theoretical acoustic heating models motivated by the fact that α Tau may exhibit a basal (i.e., minimum) level of chromospheric activity. The data reveal flux variations between the extremes of 8% in Mg II h+k and 15% in each emission component. These variations occur on time scales as short as 8 h, but not on time scales longer than $\sim$ 3 d. For the h and k components, flux variations occurring on a time scale as short as 1.5 h are also found. These changes are often not correlated (and are sometimes even anticorrelated), leading to remarkable differences in the h/k ratios. We argue that these results are consistent with the presence of strong acoustic shocks, which can lead to variable Mg II line emission when only a small number of strong shocks are propagating through the atmosphere. We deduce the electron density in the C II] λ2325 Å line formation region to be log $N_e \simeq 9.0$, in agreement with previous studies. Our data provide evidence that the Mg II basal flux limit for K giants might be a factor of 4 higher than originally suggested by Rutten et al. (1991) [A&A 252, 203].

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Forty Days in the Life of CF Tuc (=HD 5303). The Longest Stellar X-ray Flare Observed with ROSAT

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A ROSAT PSPC observation of an exceptional long–duration flare on the partially eclipsing RS CVn–type binary CF Tuc (=HD 5303) is presented. With a total duration of 9 days this flare is the longest coherent stellar X–ray flare ever observed. Also the rise time of $\approx$ 1.5 days is exceptional. The event released 1.4×10^{37} erg in the PSPC bandpass ($0.1 - 2.4$ keV), thereby making this giant outburst one of the most energetic stellar flare events known. The measured e–folding decay time of 0.9 day implies either a very extended flaring volume with low densities or the occurence of reheating. Neither modulation on the 2.8 day rotation time scale nor eclipses are seen, with the

immediate implication that either the size of the flaring volume was at least comparable to the size of the active star (most likely as large as the larger binary component) or that the flare occured within the circumpolar region of its visible pole. Both scenarios point at an event whose morphology is quite different from that of solar flares. Results from spectral analysis performed with a variety of thermal plasma models demonstrate that one–temperature models with an unusually low metal abundance of $z = 0.1$ are at least as good as the canonical two–temperature models with solar abundances. We present flare modelling using two different approaches, i.e. the quasi–static cooling loop model by van den Oord & Mewe (1989) describing only the flare decay phase and the two–ribbon flare model by Kopp & Poletto (1984).

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Multiwavelength Observations of Two Moderate Rotation RS CVN Systems: V815 Herculis and IM Pegasi

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Near-to-simultaneous ultraviolet and visual spectroscopy of two moderate $v\sin i$ RS CVn systems, V815 Herculis ($v\sin i$ = 27 km s^{-1}) and IM Pegasi ($v\sin i$ = 24 km s^{-1}), are presented along with contemporaneous $UBV(RI)_c$ photometry. These data were used to probe inhomogeneities in the chromospheres and photospheres, and the possible relationship between them. Variability is observed at all wavelengths, some indicators showing rotationally modulated fluctuations. We use *UBVRI* photometry and TiO spectra to estimate temperatures, area, and locations of photospheric spots on IM Peg. Evidence is presented that the spot temperature in IM Peg has changed over a possible solar-like spot cycle. Radial velocities of V815 Her indicate that the system is actually triple.

Submitted to AJ

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About the Width of the Theoretical Lower Main Sequence. Consequences for the Determination of the $\Delta Y/\Delta Z$ Ratio in the Solar Neighbourhood

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We discuss the relation between the main sequence thickness and chemical composition variations. With the help of theoretical zero–age main sequence models between 0.7 and 1.0 $M_\odot$, computed with an advanced physical description of the stellar interiors, in a range of metallicities typical from Population I stars (0.008$\leq Z \leq$0.034), we establish a theoretical relation between the relative helium to metal enrichment, $\Delta Y/\Delta Z$, and the main-sequence broadening, represented in this work by ΔM_{bol}.

The locus in the Hertzsprung-Russell diagram of 69 low mass stars closer than 25 pc is analyzed, taking into account the present available metallicities for 25 of them. Models show that $\Delta Y/\Delta Z$ should be *higher* than 2.0 in the *solar neighbourhood* to account for the observational main sequence width. As a consequence an helium abundance lower limit of Y=0.246 is found in the solar neighbourhood. This value is presently loosely constrained by the observational uncertainties. A new step towards the $\Delta Y/\Delta Z$ determination is expected in the very near future, when accurate values of the stellar luminosities as determined by Hipparcos will permit more definite conclusions.

Accepted by A&A

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The Heliolatitudinal Gradient of the Solar Wind During Solar Minimum Conditions Modelled by Exact Hydrodynamic Solutions

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The heliolatitudinal dependence of observations of the solar wind macroscopic quantities such as the averaged proton speed and density is modelled during solar minimum conditions when the rotational and magnetic axes roughly coincide. Published observations via the technique of interplanetary scintillations for the previous two solar cycles were used, as well as recent data from the plasma experiment aboard the ULYSSES spacecraft, which also refer to the declining phase of the present solar cycle. A class of exact, two-dimensional solutions of the full set of steady HD equations is used which is obtained analytically through a nonlinear separation of the variables. The three parameters which emerge in these solutions are fixed from such observations, as well as from observations of solar rotation. The solutions are consistent with observational inferrences that during solar minimum and the declining phase of the solar activity cycle, there is a strong heliolatitudinal gradient in rotation averaged proton speed between about $400 - 800$ $km\ s^{-1}$ from equator to pole. This modelling also agrees with previous findings that the gradient in wind speed with the latitude is offset by a gradient in density such that the mass and momentum flux vary relatively little.

Accepted by Geophysical Research Letters

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Is the Longitudinal Distribution of Solar Flares Nonuniform?

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Two methods of searching for periodicity in weighted time point series are applied to earlier major solar flare data during three decades (1956–1985). The results of this analysis are tested against new solar flare data during the four years 1989–1993. Active longitudes rotating with a constant synodic period of $22.^{d}069 \pm 0.^{d}012$ could explain the complete data set over both hemispheres. The nonuniform distribution of the flare activity with this period displays two active longitudes separated by 180°, but also shows other detailed features. No significant periodicity is detected on the southern solar hemisphere, whereas active zones rotating with a constant synodic period of $26.^{d}722 \pm 0.^{d}015$ are present in the earlier and new data on the northern hemisphere. The main peculiarity is that two highly significant periodicities ($22.^{d}07/26.^{d}72$) are detected in the same data. The phenomena detected are interpreted as a signature of a long–lived nonaxisymmetric component of the solar magnetic field below the visible surface.

Submitted to A&A

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Sunspot Irradiance Deficit, Facular Excess, and the Energy Balance of Solar Active Regions

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Plage areas and intensities derived from Ca II K spectroheliograms are used as a proxy for the facular irradiance excess of solar active regions for the period 19 August to 4 September 1980. Applying a calibration method proposed by

Vršnak et al. (1991) and adopting it for photometrically measured plage intensities, the "Photospheric Facular Index" with constant facular contrast $C_P = 0.0185$ is replaced by a scheme of variable C_P, depending on the plage brightness. An increase of C_P from 0.015 to $\simeq$ 0.025 is found for plage areas varying from a few tens to approx. 6000 millionths of solar hemispheres (μh).

Combining the facular irradiance excess with sunspot deficits (as determined for the same period by Steinegger et al. 1990) yields good agreement with the irradiance variations measured by SMM/ACRIM, using a center–to–limb variation of C_P according to Chapman & Meyer (1986). For 60 active regions out of this period, the luminosity ratio of facular excess to sunspot deficit decreases about 4 for regions with sunspot areas of 30 μh to $\simeq$ 0.4 for sunspots of areas $\simeq$ 1000 μh. Additionally, we find a decrease of the plage to sunspot area ratio from about 30 for small spots with areas around 30 μh to 3 for spots larger than 1000 μh.

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A New Estimate of the Quadrupole Moment of the Sun

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Recent solar observations at Pic du midi Observatory are reported that yield a value of J2 = $(2.57 \pm 2.36) \times 10^{-6}$ for the quadrupole moment of the Sun, which means a solar oblateness Δ = (Req-Rpol)/Req of
$\Delta = (1.20 \pm 0.35) \times 10^{-5}$.

These observations were conducted from July, 1993 to July, 1994 after several improvements of the scanning heliometer. This instrument operates by fast photoelectric scans of opposite limbs of the Sun quasi-simultaneously, which provides the distance between both inflection points of the limb profiles. Any number of solar diameters in any position angle can be measured, within a time interval short enough to minimize the scattering of the observational parameters. Errors due to atmospheric deterioration are discussed. The results are compared to previous values obtained by other authors.

Accepted by Solar Physics

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Ph.D. Thesis Abstract

Structural and Chemical Evolution of Intermediate-mass Asymptotic Giant Branch Stars

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Ph.D degree awarded: September 1995

This thesis studies the structural and chemical evolution of asymptotic giant branch (AGB) stars, with special emphasis on the fluorine production during the thermally pulsing AGB (TP-AGB) phase. For that purpose, a new one-dimensional stellar evolution code has been designed in order to reach the high degree of accuracy in the stellar models required to follow the nucleosynthesis during the TP-AGB phase (Chapter II). The improvements include an extensive nuclear network comprising 47 nuclides from H to S and seed nuclei in order to mimick the s-process nucleosynthesis, and new mesh distribution techniques. Special care is also exercised to correctly handle the growth of convective zones into regions of variable chemical composition.

The structural and chemical evolution of three stars with masses M and metallicities Z ($M = 3\,\mathrm{M}_\odot$,$Z = 0.02$), ($M = 6\,\mathrm{M}_\odot$,$Z = 0.02$) and ($M = 3\,\mathrm{M}_\odot$,$Z = 0.001$) have been followed in detail from the pre-main sequence up to the first dozen thermal pulses. These are described in chapter III, with particular attention to the properties during the AGB phase.

The analysis of the fluorine production in our AGB models is presented in chapter IV. The results reveal that the variations of the level of ^{19}F production during the evolution is very sensitive to the maximum temperature reached at the base of the pulse. Comparison of surface fluorine enhancements with observations is presented. Predictions of surface fluorine abundances in low-metallicity stars, for which no observations are reported yet, are also presented.

The postcript file of the thesis is available upon request at the above e-mail address.

Environments of Active Close Binary Stars

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This work involves a study of the environments of magnetically active late-type close binary stars of the RS CVn and Algol types. High-resolution optical spectroscopic data and dual-frequency radio interferometric data have been analysed. Conclusions are drawn regarding the presence of solar-like prominence and plage material and the existence of large radio coronae surrounding these systems. The results are discussed in terms of solar/stellar activity in general and its implications in the binary environment.

In the optical the technique of spectral subtraction has been implemented for eclipse observations of RS CVn binaries. The ER Vulpeculae system showed excess emission in the Hα, Ca II IRT and Mg Ib lines and excess absorption in the He I D_3 line. The analysis suggested that plage-like material was present. Excess emission was found in the Hα, Hβ and Mg Ib lines of GK Hydrae. The results indicated that prominence-like material was present. For TY Pyxidis excess emission was found in the Hβ and Ca II H & K lines. Analysis suggested very large volumes are responsible for the emission. No evidence was found in any system for discrete prominence-like extended structures although a global mass upflow of $\sim$10 km s^{-1} was observed in ER Vulpeculae.

Radio observations have been made of the complete orbital cycles of two active close binaries. By studying the radio flux evolution it has been possible to derive limits to the extent and location of the radio emitting regions in these objects. The corona of the RS CVn binary CF Tucanae was found to be at least as large as the binary separation. Evidence was found for the existence of an intra-binary emission region in the Algol binary V505 Sagitarii. The emission of both objects was consistent with a gyrosynchrotron process. The results demonstrate that magnetic field interactions and induction may be important factors in the radio emission from active close binary stars.

This work concludes that extended material is not a characteristic of the RS CVn binaries in general although prominence-like material probably exists in many. Also the details of radio coronal structure in active close binary stars is found to be dependent on the relative activity levels of the stellar components.

The Stellar Population at the Galactic Center and the Mass Distribution in the Inner Galaxy

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Near infrared (1.25 μm $-$ 2.2 μm) imaging and spectroscopy are used to investigate the massive stellar population at the Galactic center and the mass distribution in the inner Galaxy. **Beware:** Cool star readers who read past the first section will encounter hot stars, but in a cool way (through near infrared spectra).

The Mass Distribution in the Inner Galaxy

Radial velocities are presented for approximately 40 M giant stars in each of four optically obscured, off-axis fields toward the Galactic bulge at projected radii between 150 pc and 300 pc from the Galactic center. These velocities are used to compute mean radial velocities and radial velocity dispersions along an axis which is 55° from the major axis of the Galaxy.

The M giant kinematics were used to investigate the mass distribution in the inner Galaxy at projected radii between 150 pc and 300 pc where the large extinction due to dust had precluded studies at optical wavelengths. These kinematics were compared to the axisymmetric dynamical model of Kent (1992, ApJ, 387, 381) and the non-axisymmetric bar model of Zhao (1994, Ph.D. Dissertation, Columbia University). Both models are generally consistent with the observations; the bar model may provide a marginally better match.

The velocity dispersion in the innermost field is 153 km s^{-1} $\pm$ 17 km s^{-1}, 1 to 2 σ ($\sim$ 15 $-$ 30 km s^{-1}) higher than either Kent's or Zhao's model prediction and higher than observed anywhere else in the inner Galaxy. This means that we have yet to observe a decrease in the velocity dispersion toward smaller radii as we might expect if the bulge and Galactic center populations are to join smoothly together.

A simple dynamical model of the Galactic bulge is developed using the tensor virial theorem. The model is based, in part, on the mean kinematics described above and a new spatial density distribution based on the near infrared surface brightness distribution of the stellar population within $\sim$ 10° of the Galactic center (GC) as observed by the Cosmic Background Explorer (Dwek et al. 1995, ApJ, 445, 716). The new density distribution is highly triaxial (bar shaped) and taken to rotate with a pattern speed of 81 km s^{-1}kpc^{-1}. The model predicts a bulge mass of 2.8×10^{10} $M_{\odot}$, significantly larger than previous estimates. This value is most dependent on the adopted pattern speed and the angle which the bar major axis makes with our line of sight ($\sim$ 20°, Dwek et al. 1995). Smaller pattern speeds and/or angles would lead to similar mass estimates as previous bar models.

The Population of Massive Stars at the Galactic Center

R ($\equiv \lambda/\Delta\lambda$) $\approx$ 570 resolution K band (2.2μm) spectra are also presented for the He I emission-line sources at the Galactic center (GC); an H band (1.65μm) spectrum is also presented for the most prominent He I star, the AF star. These are compared to similar spectra for nine galactic and Large Magellanic Cloud (LMC) early type mass losing stars, including Ofpe/WN9, WN, and LBV stars. While the GC and comparison star spectra show some morphological similarities, larger He I equivalent widths are found in the AF source and two galactic early type mass losing stars than in any of the LMC stars. Several of the GC He I sources are found to have higher He I velocity widths than any of the galactic or LMC early type mass losing stars. The velocity width difference may be due to differences in the GC and LMC environments in which the otherwise similar stars formed, e.g. the metallicity may be significantly higher at the GC. The He I equivalent width difference may be due to differences in evolutionary states between the stars.

The GC He I sources are not likely to be normal OB giant/supergiants, early type WC, or WN7-8 stars based on a comparison of the present work to published spectra of these types. The value of the bolometric correction, $BC_K = M_{bol} - M_K$, is estimated for the GC sources as a function of effective temperature from published data on

LBV, WN9, and Ofpe/WN9 stars, and combined with limits on the effective temperature to place the GC sources in the Hertzsprung–Russell diagram. The effect of the He I stars on the GC environment through ionizing radiation and mass loss were estimated. These estimates suggest that the He I stars could provide much of the bolometric radiation observed through re-radiation by dust in the far infrared and the ionizing radiation implied by the observed nebular excitation in the GC. The mass loss, as estimated from these spectra, appears insufficient to supply the excitation by shock heating of molecular material observed previously in the GC.

The investigation of the GC massive stellar population includes the discovery of a Wolf-Rayet star located at 0.5 pc projected radius from the center of the Galaxy. This is the first such object to be discovered near the GC; its discovery has strong implications for the character and extent of recent star formation in the region.

The He I stars probably represent recent ($\lesssim 10^7$ yr) star formation at the GC. One possibility is that a burst of star formation occurred within this time, of which the He I stars are the most luminous tracers. The discovery of a Wolf-Rayet star at the GC strongly enhances this possibility. For the first time, we now begin to see a wide range of evolutionary states of massive stars in the GC including the He I stars and an M2 supergiant. This would be expected for a burst of star formation involving a range of masses. The Wolf-Rayet star mentioned above was classified as a WC9 star based on its K band spectrum and its existence points to star formation at epochs even earlier than 10^7 yr ago.

Thesis-related Publications: ApJ, 422, 111; ApJ, 440, L17, ApJ, 441, 611; ApJ, 444, L89; ApJ, 449, 623

Abstract Guidelines

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