Cool Stars Sing the Blues - The Encore

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Abstract

High-dispersion spectra atlas of cool red giant stars in the blue and violet are presented. The spectra were obtained over a six-year time period with the stellar spectrograph of the McMath-Pierce telescope on Kitt Peak. Both N-type carbon stars and M-type oxygen-rich stars are presented from 3900 to 4600 Å, with the M-type stars containing both semiregular and Mira-type variables. The dominant absorption features in these stars at these wavelength result primarily from neutral metals, especially Fe, and the CH and CN diatomic molecules. The Miras also show strong emission lines during some of their pulsation cycle. Many of these emission lines result from fluorescence from the Mg II h & k lines in the UV. For these fluoresced features, comparisons are made between the Miras and the semiregular carbon-rich and oxygen-rich variables. Mg II profiles show a substantial circumstellar (CS) absorption from neutral metals especially Fe I in the Miras and the carbon-rich semiregulars. The oxygen-rich semiregulars show no hint of fluorescence in the optical as would be expected from the appearance of their unobscured Mg II profiles. Strangely, these "fluoresced" lines in the carbon stars show no hint of emission despite the large CS absorption by their "pumps" in the Mg II lines. This poster discusses the reasons for the lack of this fluoresced emission in these stars.

Observations

These observations of cool stars were taken with the McMath-Pierce telescope over a 5 year period in the early 1990s under the *National Solar Observatory's* Guest and Synoptic Observing Programs using the stellar spectrograph. The McMath-Pierce telescope focuses an *f*/24 beam with an image scale of 2.54 arcsec/mm onto a 5-slice internally-reflecting Bowen-Walraven image slicer (Jaksha 1989). The light from the slicer is passed through a Schott BG-3 (for the M-type stars) or BG-18 (for the N-type stars) filter in order to block unwanted spectral orders. Then the beam is sent into the stellar spectrograph containing a Milton and Roy III (i.e., blue) grating. The detector was a TI-4 800x800 thinned UV enhanced CCD. Guiding was performed directly from the target star via a thin broadband dichroic mirror over the image slicer. A Kinoptic transfer lens with resolution $\lambda/\Delta\lambda$ of 22 000 was used for half of the observations, and a 180 mm lens ($\lambda/\Delta\lambda$ = 30 000) for the other half producing slightly different spectral resolutions. All of the reductions, analyses, and plotting were carried out with IDL procedures written by the author.

Analysis

The analysis of these data focuses on line strengths of a few spectral features (a more detailed line analyses will be publish next year), in particular the Ca II and Ca I resonance lines (see Figures 1-3) and the Fe I line at 4202 Å which resides in optical multiplet 42. Stencel (1977) has carried out an analysis for the Ca II in a wide range of cool stars (F through M) and Judge et al. (1993) monitored Ca II H & K and Mg II h & k profile variations in M giants. The work presented here expands upon this previous work by focusing on stars cooler than 4000 K, including carbon stars. Stars cooler than ~3300 K (half way between R Lyr's and g Her's temp) have extremely weak or no Ca II *chromospheric* emission despite having Mg II emission in the UV (see Luttermoser 2000). In very cool stars, UV spectra show substantial overlying absorption in the Mg II emission. This is the cause of the Fe I fluorescence in the Mira stars. The semiregular carbon stars appear to show as much overlying absorption in Mg II as the oxygen-rich Miras (Luttermoser 2000). However, there is no apparent emission in the Fe I (42) in the semiregular carbon stars. Indeed, even the absorption is weak, no doubt due to blending with the strong CH band just longward of this feature (Wing 2006). But where do the absorbed Mg II k photons from Fe I (UV3) go? The answer likely lies in the total flux of the Mg II emission lines. Even though observed Mg II profiles in the O-rich Miras and the C-rich semiregulars appear similar, the Mg II emission underlying the CS absorption must be two-orders of magnitude larger in the Miras as compared to the carbon stars. There are simply not enough Mg II photons being scattered by the neutral Fe lines in the carbon stars to show up at visible wavelengths.

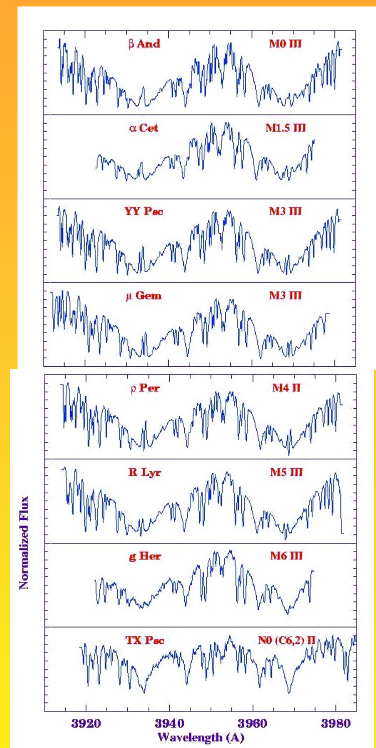

Figure 1. Ca II H & K region for 8 semiregular giant stars. Note that as one goes to cooler spectral types, the *chromospheric* emission weakens and the line wings weaken. The Al I resonance lines at 3944.0 and 3961.5 Å have virtually the same strength in all of these stars showing that Al is completely neutral in the photospheres of all these stars.

References

- Jaksha, D. 1989, private communication.
- Judge, P.G., Luttermoser, D.G., Neff, D.H., Cuntz, M., & Stencel, R.E. 1993, 105, 1973-1986.
- Luttermoser, D.G. 2000, ApJ, 536, 923-933.
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- Wing, R.F. 2006, private communication.

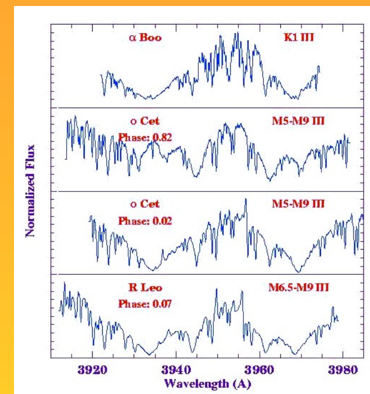
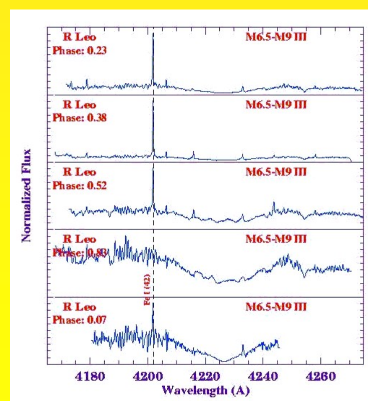


Figure 2. Ca II H & K spectra for 2 Mira-type red giant stars (R Leo and o Cet, Mira itself) and Arcturus for comparison (above) and Ca I 4226.7 Å in R Leo (below). Like the carbon star TX Psc, the Miras show no apparent emission in Ca II during these phases (note that Mg II h & k are also absent in these stars during phase 0). Note the enormous strength of the Al I resonance lines at phase 0.82 in Mira and the peculiar *filling in* of Ca II. The raw data of this spectrum was contaminated with scattered light at the 20% level, though my reduction software package does try to remove it. It's unlikely that this filling in results from the scattered light since it does not seem to affect the Al I lines. Comparing the picture below to that of Figure 3 shows the enormous effect of fluorescence from the UV Mg II k line which pumps the strong Fe I (42) line during part of the pulsation cycle in Miras.



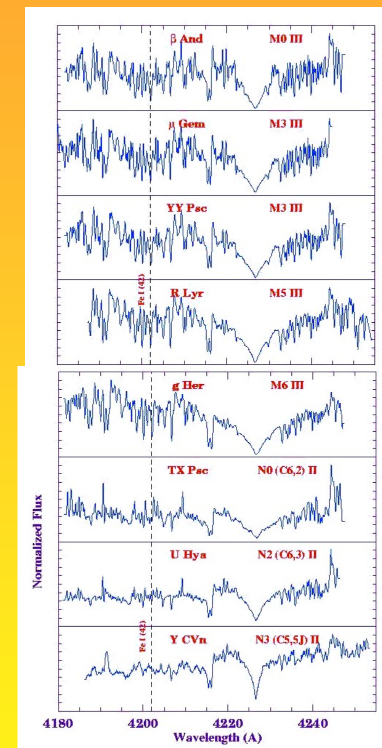


Figure 3. Spectra in the Ca I resonance line (4226.7 Å) region for 8 semiregular variables. Note that the Ca I line increases in strength with decreasing temperature reaching a maximum in TX Psc (about 3000 K), then decreasing in strength in the coolest stars in this sample (U Hya and Y CVn). This is due a reduction in the atomic Ca abundance due to a prolific molecule and carbon-based dust formation in these 2 very cool carbon stars. In addition, note the weak/non-existent strength of the Fe I (42) line at 4202 Å in the carbon stars as compared to the similar temperature oxygen-rich stars (R Lyr and g Her). Finally, the figure to the left shows enormous absorption in Ca I. These stars are similar in temperature to the carbon stars, but the Ca is not depleted as much in the oxygen-rich Miras as it is in the carbon stars.