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High Resolution Infrared, Visible, and Ultraviolet Spectral Atlases of the Sun and Arcturus

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Abstract. Various groups of the co-authors have produced series of solar and stellar atlases. Some atlases are listed below and the most recent products described.

1. Solar Atlases

Wallace and collaborators (see Wallace et al. 1996) have produced a series of solar spectral atlases that are available both as free paper copies from the NSO[2] and in electronic format via anonymous ftp (argo.tuc.noao.edu, cd pub/atlas). The spectra are of the photospheric and umbral regions and cover from the optical longward to 22 μm in the infrared. To date the solar atlas series has eight volumes which are listed in Table 1. All the atlases are based on spectra obtained with the FTS at the McMath solar telescope. A sample page from the most recent solar atlas is shown in Figure 1.

1.1. Solar Line Identifications

Line identifications, which are given in paper copies of the atlases, are reasonably complete in the infrared and optical photospheric spectrum. However, identifications of the weak lines in the umbral atlases are quite incomplete. Many unidentified lines are almost certainly weak lines of well known molecules, e.g. H_2O and TiO. However, unidentified bands of other molecules also certainly exist. We recently identified a new band of FeH at 1.6 μm (Wallace & Hinkle 2001). Visible and near infrared umbral spectra, in particular the "Atlas of the Sunspot Spectrum in the Red and Infrared from 6642 to 11,230 Å." (NSO #98002), are of special interest because of the identifications of a number of molecular features including CN, TiO, FeH, and CaH as well as atomic features. A new solar band, the $B'^2\Sigma^+$ - $X^2\Sigma^+$ transition of MgH, was found in this red and near infrared spectrum (Wallace et al. 1999).

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Table 1. NSO Solar Atlas Series

NSO#	wavenumber limits (cm^{-1})	wavelength limits (Å)	Source
98001	13500 - 28000	3570 -7400	disk center
93001	8900 - 13600	7350 - 11230	disk center
91001	1850 - 9000	11000 - 54000	disk center
94001	460 - 630	160000 - 220000	disk center
00-001	15000 - 23000	4350 - 6660	cold umbra
98002	8900 - 15050	6600 - 11200	cold umbra
92001	1970 - 8460	11600 - 51000	cold umbra
94001	470 - 1233	81000 - 210000	cold umbra
01-001	4000 - 8640	11600 - 25000	selected umbras

2. Arcturus Atlases

We are now working on the last of three parts of a major project to produce an atlas of the Arcturus spectrum from 5 μm in the infrared to 1200 Å in the ultraviolet. The first two volumes of the atlas, covering the infrared and optical spectrum, have been published by the Astronomical Society of the Pacific. These atlases are available at modest cost (Astronomical Society of the Pacific – Orders, 390 Ashton Avenue, San Francisco, CA 94112 USA; Visible Atlas–$52.00; Infrared Atlas–$40.50)

2.1. Infrared

The infrared atlas illustrates the 0.9 to 5.3 μm spectrum. These spectra were observed with the FTS at the 4 meter Kitt Peak telescope. Telluric lines have been removed by reference to a telluric transmission spectrum. The entire infrared spectrum of Arcturus was observed on two dates, chosen to have opposite heliocentric shifts, to fill in many of the gaps caused by telluric lines. The Arcturus spectrum in the near infrared is dominated by diatomic molecular bands including CO, CN, HF, NH, OH, and SiO. There is also a rich atomic spectrum dominated numerically, as in the optical, by Fe I. There are relatively few unidentified lines, and those present are almost certainly from atomic transitions.

2.2. Optical

This atlas features CCD coude echelle spectra of Arcturus from 3600 to 9300 Å at a resolution of ~150000 and signal-to-noise ratio typically ~1000. The data are assembled from 469 segments extracted from 36 echellograms. Each page has a panel of Arcturus spectrum and a matching section of the solar flux spectrum. The spectrum is also supplied digitally on a companion CD-ROM to the atlas. The telluric line spectrum has been removed from the spectra by reference to a telluric transmission spectrum. Spectral line identifications are shown on each page.

As in the solar spectrum a number of modestly strong unidentified lines exist in the blue-violet. One molecular transition that clearly needs additional work in this spectral region is CN violet. CN violet dominates the Arcturus spectrum for at least 100 Å shortward of the 0-0 head at 3883 Å. Many more CN lines appear to be present than are in available line lists.

2.3. Ultraviolet

Using a combination of optical coude echelle, archival HST, and scheduled HST STIS spectra we are producing an atlas of the 1200-3800 Å region of the ultraviolet. A sample page is shown in Figure 2. The ultraviolet can be divided into three sections. The near UV from ~3000-3800 Å is similar to the optical spectrum in that it is line rich and resembles the solar spectrum. The 1200-2500 Å region is dominated by emission lines. The 2500-3000 Å region is one of transition between the emission and absorption spectrum. In the transition region line identification is very difficult due to large uncertainty in the placement of the continuum. Our work on the HST section of the atlas is preliminary at this time. However, there appear to be a number of unidentified emission lines.

In the ultraviolet Arcturus atlas, as was done in the optical Arcturus atlas, it was our intent to present a solar spectrum on each page as a reference spectrum. We were very surprised that ultraviolet solar spectra do not exist with the same quality as the Arcturus spectra. Over a substantial portion of the ultraviolet atlas we have been forced to use HST-STIS spectra of α Cen as a solar proxy.

Line identifications in the 2000-3200 Å ultraviolet are much less complete than in the infrared and optical. A large number of ultraviolet lines of modest strength remain unidentified in our plots of the 2000-3200 Å region. However, identifications in the solar spectrum shortward of ~2000 Å are quite complete. Note that our identifications are based entirely on line lists from laboratory spectroscopy. While many more line identifications are possible based on calculated spectra, additional laboratory work in the blue and violet is clearly desirable.

Acknowledgments. The solar atlas series is a publication of the National Solar Observatory. The National Optical Astronomy Observatory has underwritten the publication of the Arcturus Atlas Series. The page of the ultraviolet Arcturus atlas shown is based on observations made with the NASA/ESA Hubble Space Telescope, obtained from the Data Archive at the Space Telescope Science Institute, which is operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract NAS 5-26555. This work was partly funded through proposal #8614 provided by NASA through a grant from the Space Telescope Science Institute. NOAO is operated by the Association of Universities for Research in Astronomy, under cooperative agreement with the National Science Foundation.

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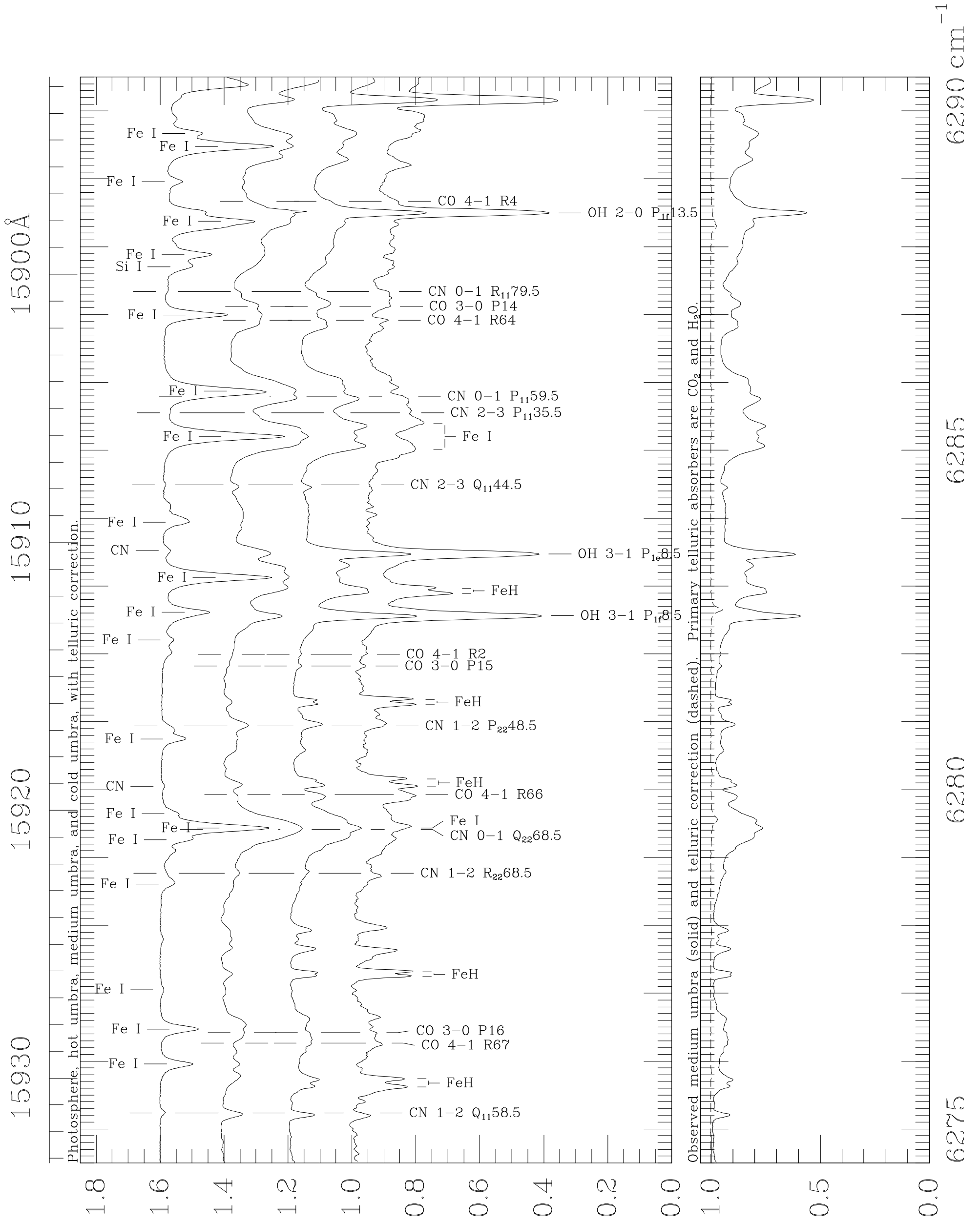

Figure 1. Spectra of the photosphere and three sunspots (at different temperatures) are seen in a page from NSO atlas #01-001. Note the FeH lines, which are doubled by the Zeeman effect.

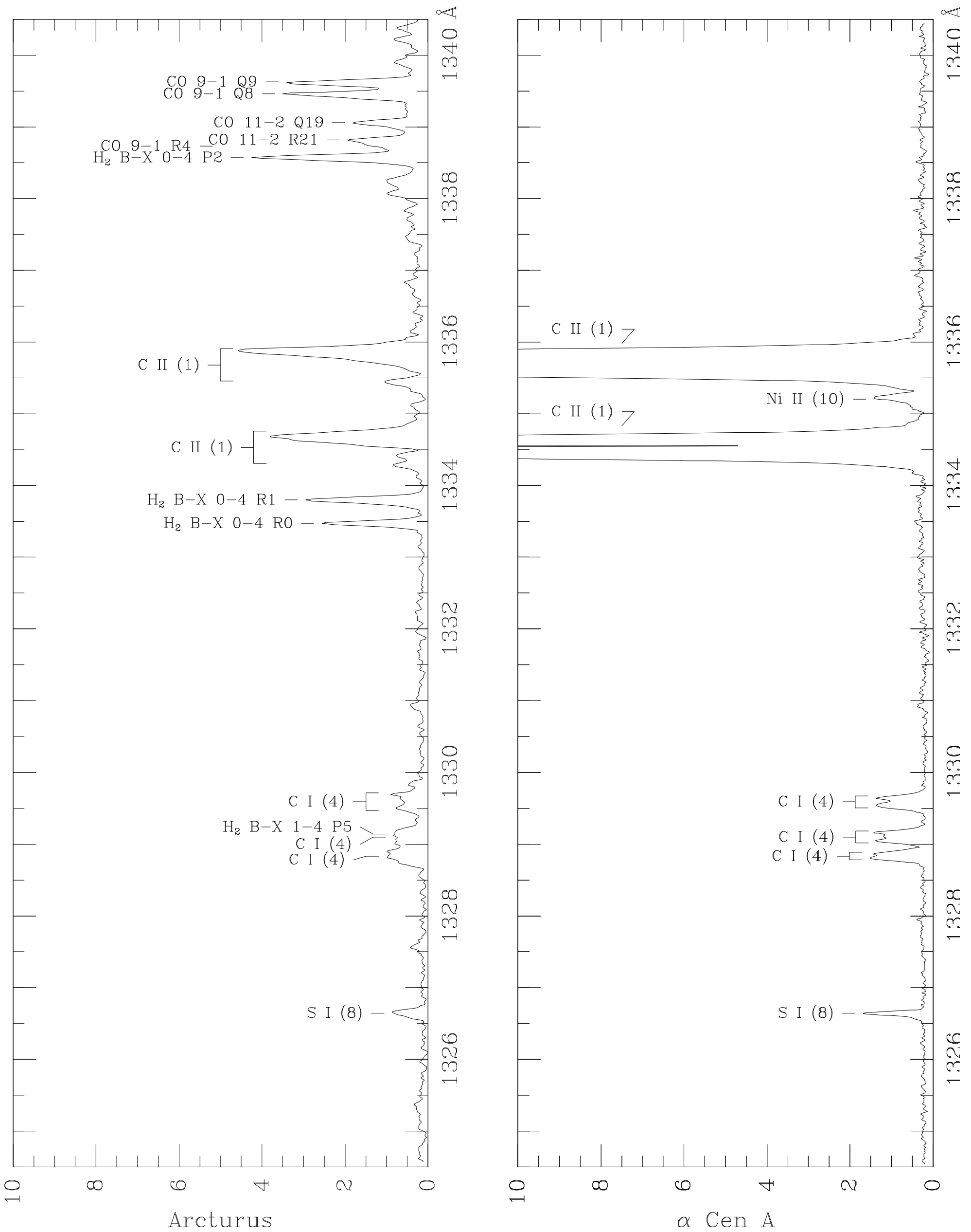

Figure 2. A draft page from the "Ultraviolet Atlas of the Arcturus Spectrum, 1160-3800 Å." which will be completed in 2002. This page shows the emission line region. Note the presence of molecular features.