

STIS Observations of the Hybrid-Chromosphere Star α TrA

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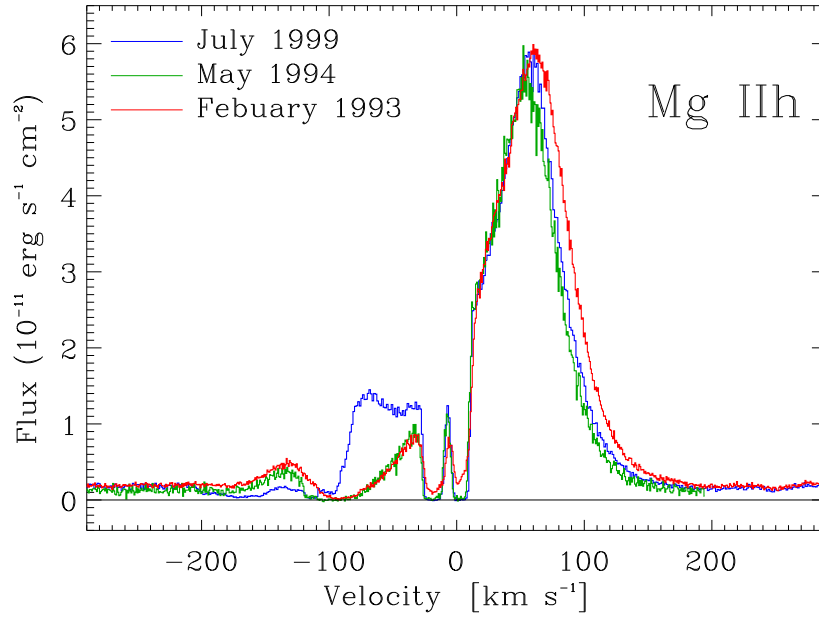
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Abstract. We present new STIS observations of α Trianguli Australis (HD 150798) obtained in 1999 July 23 and compare them with earlier GHRS spectra. We find an unusually high speed wind which shows significant opacity out to -200 km s^{-1} in lines of Mg II, C II, and Si III. There is no wind opacity seen in lines of Si IV, C IV, or N V. We estimate that the maximum temperature of the wind is in the range 17,000–20,000 K.

1. Observations of α TrA and Data Reduction

Alpha TrA (K2 II-III) is a prototype hybrid-chromosphere star, a class of stars first identified by Hartmann et al. (1980) on the basis of having both emission lines formed at 10^5 K and strong winds observed in the Mg II h and k lines. These stars have been studied with IUE, HST, the VLA, and X-ray satellites for the last 20 years because these stars may be a transition between solar-like stars, which have hot coronae and low mass loss rates, and the cool giants and supergiants, which have little or no hot gas but massive cool winds. We have obtained new high resolution spectra to answer the following questions: (1) Over what range of temperatures is there evidence for outflowing gas? (2) Has the wind changed since the first HST observations in 1993? (3) Is there velocity structure in the wind, and what is the shape of the wind velocity law? In a forthcoming paper, we will also infer the mass loss rate, measure the line redshifts and transition region electron densities, and look for evidence for microflare heating. Do the HST, x-ray, and radio data require a two-component atmosphere consisting of outflowing and static components, or can a one-component atmosphere model fit all of the data?

Table 1 summarizes the new STIS observations and the previous GHRS observations of α TrA. The STIS data were reduced using the STIS team IDL-based software that performed the flat fielding, dark rate subtraction, removal of data from bad/hot pixels, wavelength calibration (using on-board lamp spectra taken once per orbit), and absolute flux calibration. To remove the scattered light, which is especially important near the Lyman- α line, we used the ECHELLE-SCAT routine (Lindler 1999) in the STIS team software package. More than 100 emission lines are present in the E140M spectrum.

Figure 1. Observed profiles of the α TrA Mg II h line.

Date	Grating	Spectral Range ($\text{\AA}$)	Spectral Res. (km s^{-1})	Exposure Time (s)
1999 Jul 23	STIS E140M	1140–1735	6.5	9000
1999 Jul 23	STIS E230M	1720–2528	10.0	3270
1999 Jul 23	STIS E230H	2524–2796	2.6	1000
1999 Jul 23	STIS E230H	2724–2995	2.6	250
1993 Feb 10	GHRB EB-20	2792–2807	7.0	435
1993 Feb 10	GHRB G160M	1535–1570	15.0	3590
1994 May 01	GHRB EB-20	2789–2804	3.5	326
1994 May 01	GHRB G160M	1203–1240	10.0	653
1994 May 01	GHRB G160M	1203–1240	10.0	3046

2. Velocity Structure of the Wind Seen in the Mg II Lines

The presence of outflowing gas in a stellar wind is identified by blue-shifted absorption features seen in optically thick spectral lines. These lines formed by scattering in a geometrically extended wind show a classic P Cygni shape with both blue-shifted absorption, produced by outflowing gas in front of the star, and extra emission on the red side of the line, produced by scattering from outflowing gas behind (but not occulted by) the star.

Figure 1 shows the Mg II k line plotted in heliocentric velocity for the STIS observation (July 1999) and the two GHRB observations (February 1993 and May 1994). The two deep interstellar absorption features at $+3$ and -17 km s^{-1}

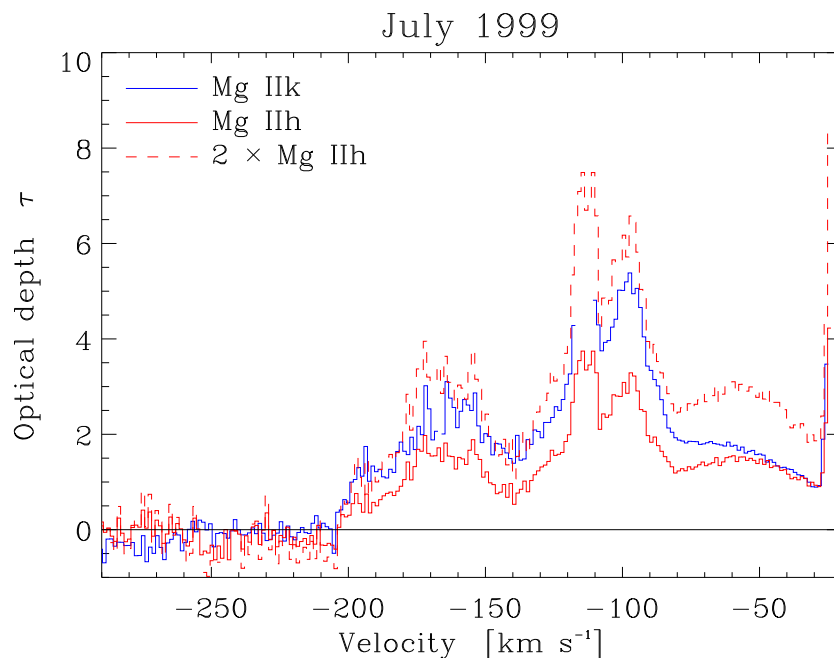


Figure 2. Optical depths in the Mg II h and k lines.

are interstellar. The pre-COSTAR February 1993 spectrum has additional scattered light and lower spectral resolution that is clearly seen in the interstellar features. The profiles at positive velocities are similar in shape although somewhat different in width. At velocities between -30 and -200 km s^{-1} , scattering in the wind in front of the star absorbs much of the Mg II emission from the stellar chromosphere, although the amount of opacity is a function of velocity and time. The profiles of the Mg II h ($2803 \text{ \AA}$) and k ($2796 \text{ \AA}$) lines in the July 1999 data set are very similar out to the end of the wind absorption near -200 km s^{-1} . The similarity of the profiles clearly shows that the wind opacity is structured and that the absorption is not due to other absorbing species.

In Figure 2 we plot the empirical wind optical depth τ_{-v} as a function of velocity for the Mg II h and k lines. We estimate the optical depth from $\tau_{-v} = \ln[f_{+v}/f_{-v}]$, where f_{+v} is the flux on the red side of the line where there is no wind absorption and f_{-v} is the observed flux at the same velocity on the blue side. This simple method overestimates the optical depth because the red side of the line includes photons scattered from behind the star. In this plot we have flipped the Mg II lines about zero velocity (heliocentric). Using the stellar radial velocity of -3.3 km s^{-1} produces minimal changes. Where the observed flux is zero (within 2σ), the optical depth is not plotted. The structure of the h line tracks the k line at all velocities, confirming that no other spectral lines are absorbing the wind. In Figure 2 we also plot twice the Mg II h line opacity to compare the column density in the two lines that differ in oscillator strength by a factor of 2. Between -80 and -200 km s^{-1} , the column densities are very similar with narrow peaks at -100 and -130 km s^{-1} and a broad peak centered

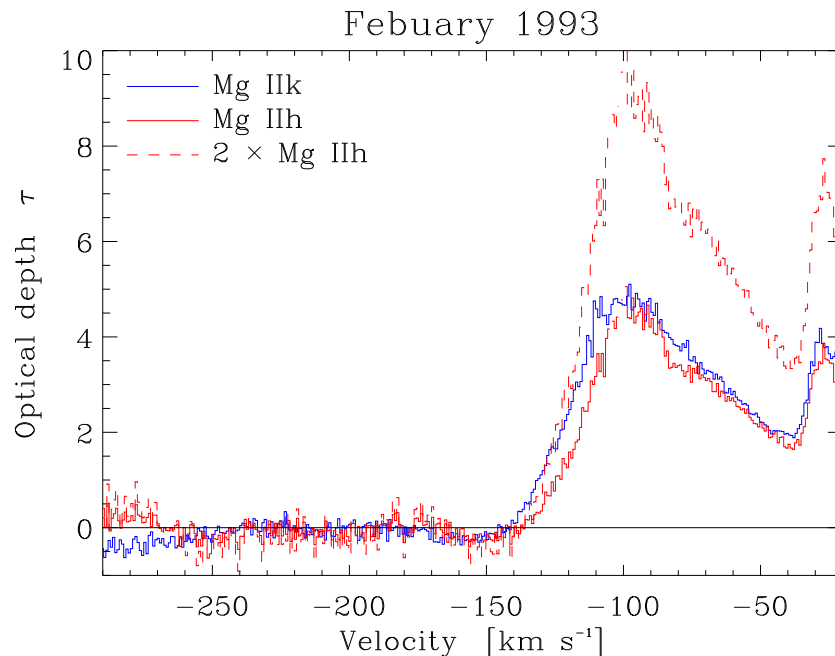


Figure 3. Optical depths in the Mg II h and k lines.

near -165 km s^{-1} . Below -80 km s^{-1} the column density plots differ probably because the red side of the h and k line profiles contain photons scattered from the back side of the star (see Harper et al. 1995).

3. Changes in the Wind Structure

Figure 3 shows the same optical depth and column density plots for the February 1993 data. The results are very different from the July 1999 data (Figure 2). In the 1993 and May 1994 data the wind opacity extends only to about -130 km s^{-1} and opacity plots rather than the column density plots of the two lines agree. Which of these profiles is typical for α TrA?

IUE obtained high resolution echelle spectra of the Mg II lines in α TrA on at least 32 occasions between 1979 February and 1993 July (a total of 74 individual spectra). While changes in the wind absorption structure are commonly seen in hybrid-chromosphere stars, a high speed wind profile shape like the STIS α TrA profile was observed only once before (IUE spectrum LWR13982 obtained on 1982 August 19). The other IUE spectra (e.g., Drake et al. 1984; Hartmann et al. 1985; IUE NEWSIPS archive) all look similar in shape to the 1993 and 1994 GHRS spectra.

In their wind model constructed to fit the 1993 Feb 10 data set, Harper et al. (1995) derived a terminal velocity of 100 km s^{-1} , turbulent velocity of 24 km s^{-1} , and $\dot{M} \geq 1.8 \times 10^{-10} \frac{A(\text{Mg})}{A(\text{Mg II})} M_{\odot} \text{ yr}^{-1}$. We have not yet computed a model to fit the 1999 July 23 data, but inspection of Figures 2 and 3 show that in July

1999 the wind had an unusually high speed with a terminal velocity near 200 km s^{-1} and far less absorption at -30 to -80 km s^{-1} compared to the 1994, 1993, and all but one of the earlier IUE spectra.

4. Thermal Structure of the Wind

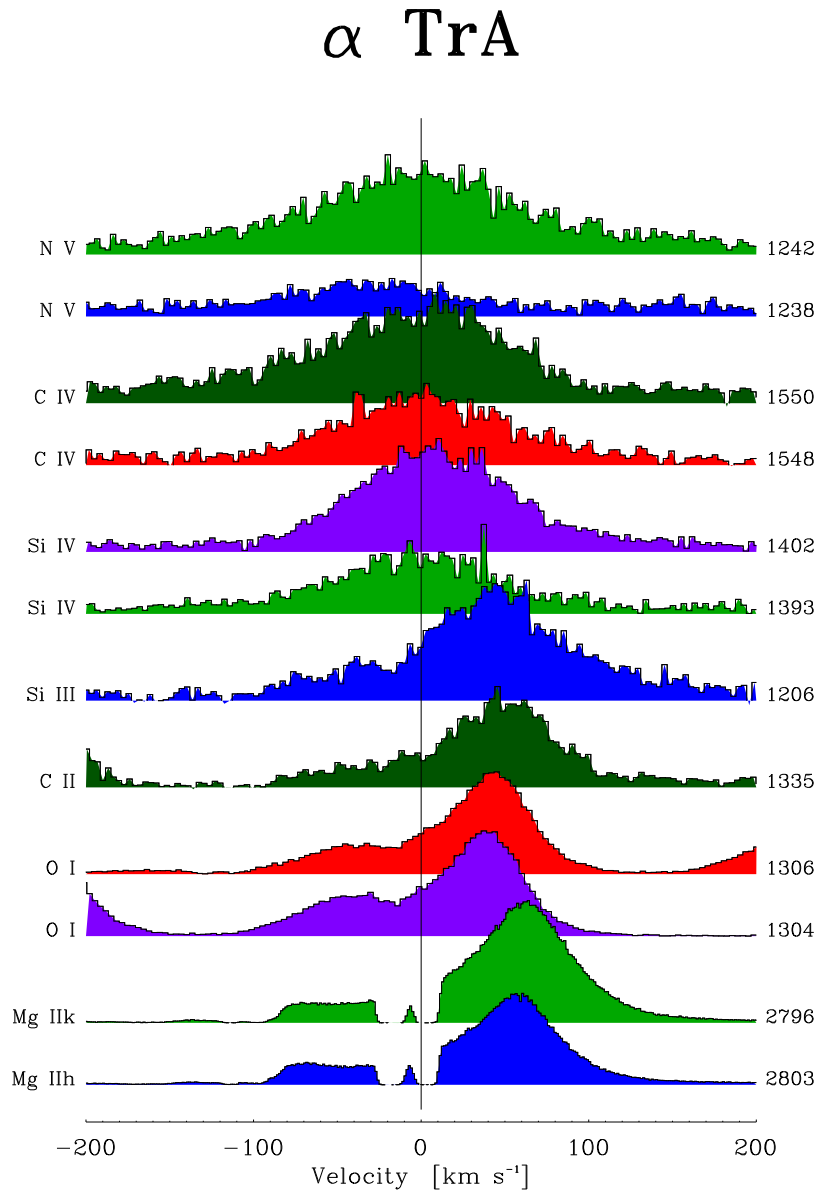
Is the wind opacity structure similar at higher temperatures to what is seen in the Mg II lines formed at roughly $5,000 \text{ K}$? Figure 4 shows the profiles of resonance lines arranged in order of decreasing temperature of line formation from N V ($150,000 \text{ K}$) at the top to Mg II ($5,000 \text{ K}$) at the bottom. The ground state O I $1302 \text{ \AA}$ and C II $1334 \text{ \AA}$ lines are not included because interstellar absorption is very strong. The velocity scale is heliocentric, but the radial velocity of the photosphere is only -3.3 km s^{-1} . There is no wind opacity in the Si IV, C IV, and N V lines. We call attention to the following important aspects of the data:

- The wind opacity in the O I lines ends at about -80 km s^{-1} .
- The C II and Si III lines show a very similar opacity structure to Mg II with the opacity extending out to about -200 km s^{-1} . The C II line even shows the double peak structure near -100 and -130 km s^{-1} .
- The Si IV, C IV, and N V lines show no obvious wind opacity, indicating that the wind is too cool for these lines to have appreciable abundance.
- On the basis of the relative opacity of the Si III and Mg II lines but no opacity in the Si IV lines, we estimate that the maximum wind temperature lies in the range $17,000\text{--}20,000 \text{ K}$. This is consistent with the value of $16,000\text{--}20,000 \text{ K}$ that Harper et al. (1999) estimated on the basis of the Mg II and Si III lines and radio data. There is no significant wind opacity in lines formed near 10^5 K in $\alpha \text{ TrA}$.
- We predict that the O VI lines (formed at $3 \times 10^5 \text{ K}$) will also show no significant wind opacity and that $\alpha \text{ TrA}$ does not have a wind with $T \geq 3 \times 10^5 \text{ K}$ gas as previously inferred from ORFEUS II spectra (Dupree & Brickhouse 1998). Upcoming FUSE observations should settle this question.

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5. References

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Figure 4. Emission line profiles for α TrA on 1999 July 23.