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A High-Resolution UV Spectral Atlas for Mira Variable Stars

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Abstract. The ultraviolet (UV) spectra of Mira variable stars have been studied for nearly three decades. The International Ultraviolet Explorer (IUE) space telescope observed these stars at both low and high dispersion. Later the Hubble Space Telescope (HST) obtained high-dispersion spectra both with the High Resolution Spectrograph (HRS) and the Space Telescope Imaging Spectrograph (STIS). This paper displays a STIS spectrum of the cool Mira-type variable star R Leo taken on 31 December 1998. On this date R Leo was at phase 0.37 in its light-curve cycle. This spectrum shows a large number of emission lines and identifications are made for nearly 200 of these features. Many of these emission lines were previously unrecorded in IUE and HRS spectra of Miras, such as the Fe II (UV33, 35, 158, 160, 161, 180, 181), Mn II (UV38), V II (UV43, 73), Zr II (UV58), and the Ni II (UV36) multiplets. The electron density diagnostic multiplet of C II] (UV0.01) gives an electron density of 10^9 cm^{-3} for R Leo at this phase. This is similar to the electron density found for the Mira star R Hya at phase 0.26 obtained with a HST/HRS spectrum. Finally, the photospheric spectrum was detected from 2980 Å (the long wavelength cut-off) down to 2450 Å.

1. Observations

Emission lines have been detected in the spectra of Mira-type variable stars for over 100 years. It has been shown that many of these emission lines result from effects of outward moving shock waves in the atmospheres of these stars. Two basic types of emission lines exist in the spectra of these stars: Collisionally excited lines (e.g., Mg II h & k) and fluoresced lines (e.g., Fe I (42) at 4202 Å and 4308 Å, see Luttermoser 1996). Fluoresced lines are pumped by photons from an emission line at a different wavelength from the fluoresced line (e.g., in the case of the Fe I (42) lines, Fe I (UV3) at 2795.006 Å absorb emission-line photons from the Mg II k line at 2795.523 Å, electrons then cascade back down a different transition giving rise to the Fe I (42) features). In the 1980s, the first UV spectra were obtained for Miras with the IUE space telescope. Unfortunately, IUE was only able to record the brightest emission lines at UV wavelengths. This changed with HST. I obtained data with the HRS of two different (but similar) Miras at two different phases: R Hya at phase 0.26 taken on 9 July 1996 and R Leo at phase 0.12 taken on 14 January 1997. The results from this work can be found in Luttermoser (2000). This paper presents the data obtained with STIS for R Leo at phase 0.37 as shown in Figure 1.

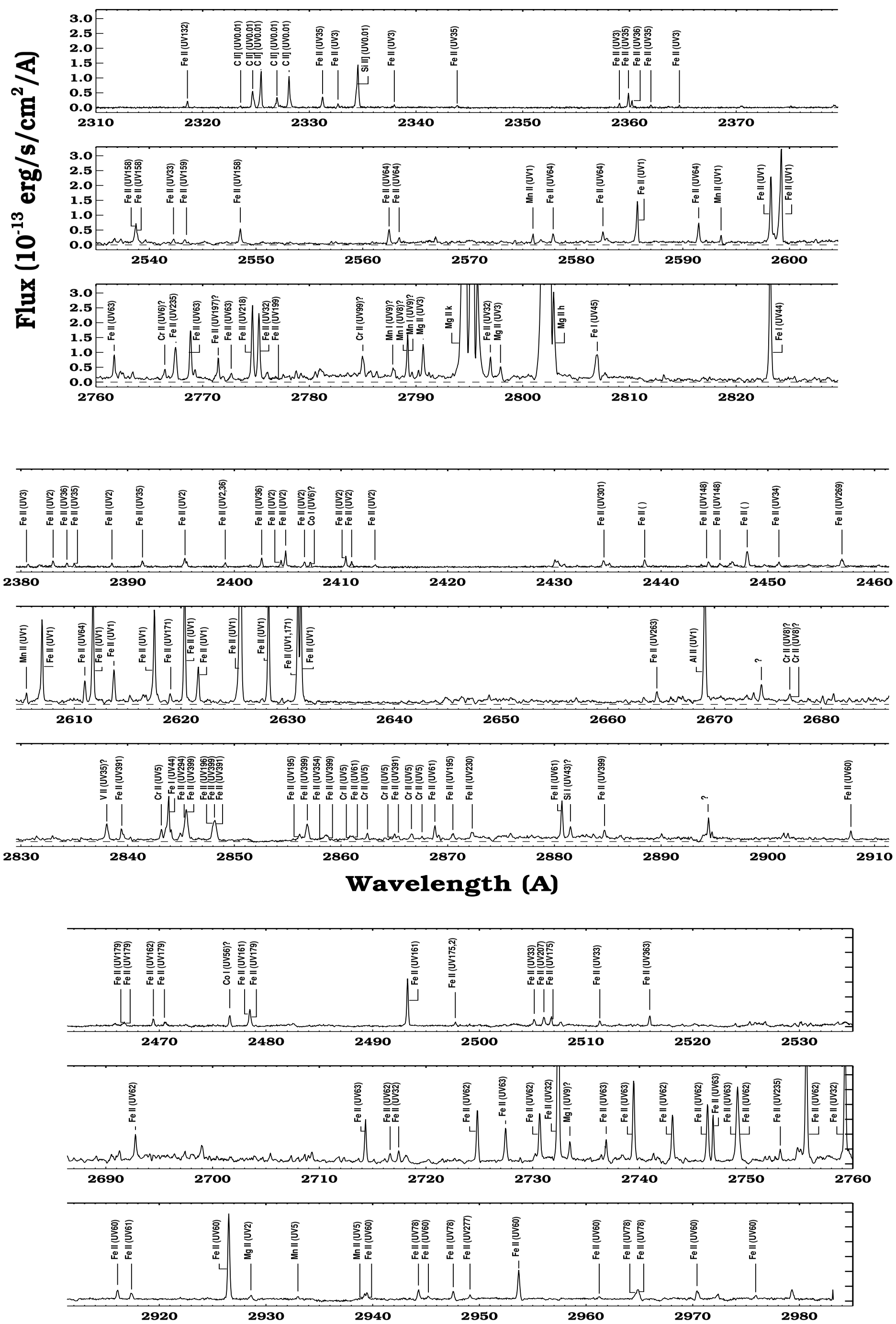

Figure 1. A UV spectral atlas of R Leo at phase 0.37 as observed on 31 December 1998. Prominent emission lines are labeled. This spectrum was obtain on 31 Dec 1998 with the NUV-MAMA detector, the 0.2x0.2 arcsec aperture, and the E230M grating, giving a resolving power of 10,000 (= 0.28 Å at Mg II h & k). The total exposure time was 184 minutes.

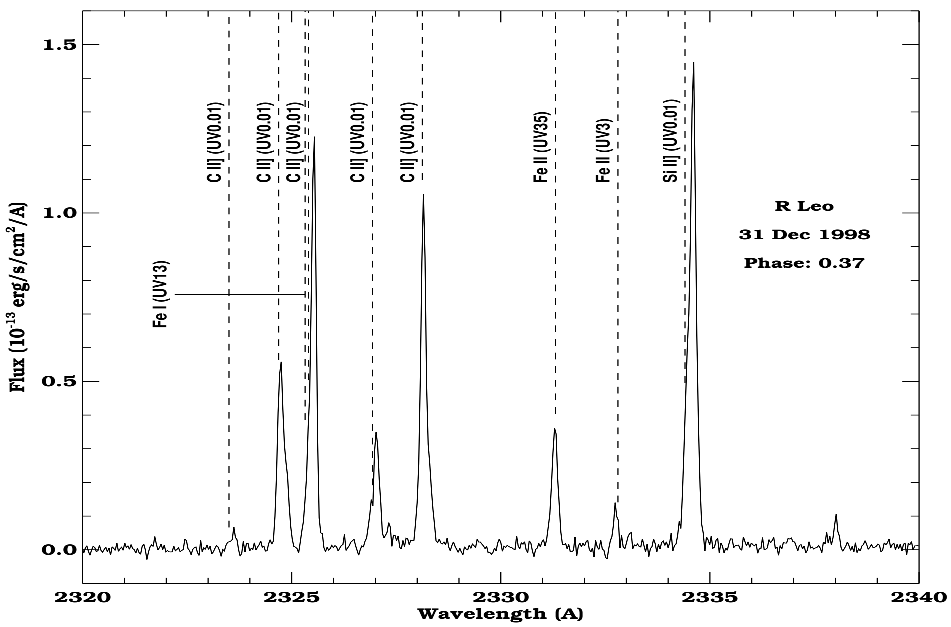

Figure 2. The C II] (UV0.01) multiplet as it appears in this STIS spectrum. Note that the usually strong line at 2325.4 Å is compromised by circumstellar absorption from an Fe I (UV13) transition (position marked with the left of the doublet dashed line) at 2325.3 Å.

2. Analysis

At UV wavelengths (as observed with IUE), emission lines do not appear until phase 0.15 where they continue to gain strength in time until reaching maximum strength around phase 0.3 to 0.4. Meanwhile the peak Balmer line flux at optical wavelengths occurs at phase 0 (which is defined to be the maximum visual brightness). Figure 1 shows a UV spectral atlas for R Leo at phase 0.37, near the phase when Miras show their peak UV emission. The center-of-mass velocity (+7.2 km/s) for R Leo (Hinkle et al. 1984) has been subtracted from the spectrum shown in Figure 1. Velocity shifts (with respect to the stellar rest frame), full-widths at half-maximums, integrated fluxes, and peak fluxes can be obtained from the author and will be published in a future paper. The majority of the emission features result from Fe II, which are typically blueshifted from -4 to -30 km/s (average of -13.6 km/s) with respect to the stellar rest frame.

One problem that has existed prior to the HST, was the inability of previous space telescopes (e.g., IUE) to record the C II] (UV0.01) multiplet near 2325 Å at high spectral resolution. These lines are important since flux ratios of various lines in this multiplet give an accurate measure of electron density in the region of the atmosphere giving rise to these lines (Stencel et al. 1981). As was seen in the HRS spectrum of R Hya (Luttermoser 2000) — the Fe I (UV45) emission line at 2806.984 Å also is seen in this STIS spectrum of R Leo. This fluoresced line was first discovered in the HST/HRS spectrum of the carbon star UU Aur

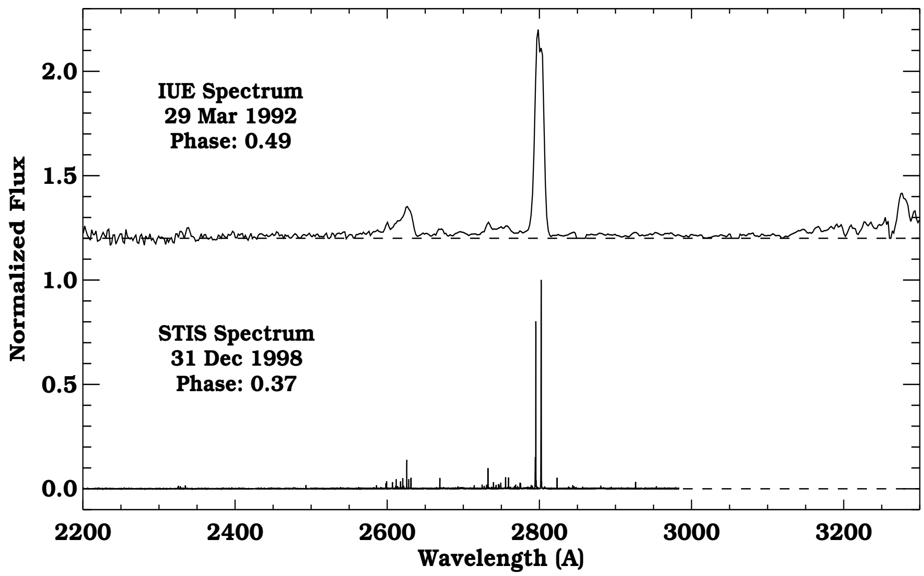

Figure 3. A comparison between an IUE low-dispersion spectrum of R Leo at phase 0.49 and the STIS spectrum presented in this paper.

(Johnson et al. 1995). This line is *pumped* by the thin C II] line at 2325.398 Å through an Fe I (UV13) transition at 2325.320 Å(see Figure 2). Since this C II] line is compromised by overlying absorption, the electron density is deduced from the fainter, noncompromised C II] lines at 2324.689 Å and 2326.930 Å. The ratio of these lines gives $n_e = 10^9$ cm^{-3}, which is similar to the electron density found for the Mira star R Hya at phase 0.26 obtained with a HST/HRS spectrum.

Figure 3 shows a comparison between a low-dispersion IUE spectrum of R Leo taken on 29 Mar 1992 when the star was at phase 0.49 (actually this spectrum is co-added from images LWP 22703, 22704, 22709, and 22710 giving a total exposure time of 55 minutes) and the STIS spectrum shown in Figure 1. One can clearly see how the individual emission lines in the various multiplets (Mg II h & k, Fe II (UV1), and Fe II (UV62,63) in particular) produce the emission features in the IUE spectrum.

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