A Look Inside a Star: The Evolved Main-Sequence Channel and Hydrogen Depleted Ultracompact Binaries

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Introduction

The evolved main sequence channel is now thought to contribute significantly to the population of Cataclysmic Variables (CVs) with periods below the period minimum [1]. In this channel, a white dwarf begins accreting material from a companion just as its main sequence life ends. The evolution leads to a binary with decreasing hydrogen fraction, a period below the hydrogen period minimum and a flipped CNO abundance. That is, the N/C ratio is much larger than seen in most CVs. Here, we present Large Binocular Telescope (LBT) optical spectra and Hubble Space Telescope (HST) ultraviolet spectra of CSS120422:111127+571239. CSS1204 is a CV with a period of 56 minutes and visible hydrogen emission lines [2]. Normally, CVs with this short orbital period show only helium lines, indicating CSS1204 has had a rare binary evolution. The LBT spectra also show rarely seen Si II optical emission lines (λ = 6347 Å). The HST UV spectra reveal strong N V and Si IV emission lines, but no detectable C IV. The anomalous carbon/nitrogen ratio is seen in a small number of other CVs [3] and, along with the presence of H in the spectrum, appears to be the signature of the evolved main-sequence channel.

A Change in the Optical

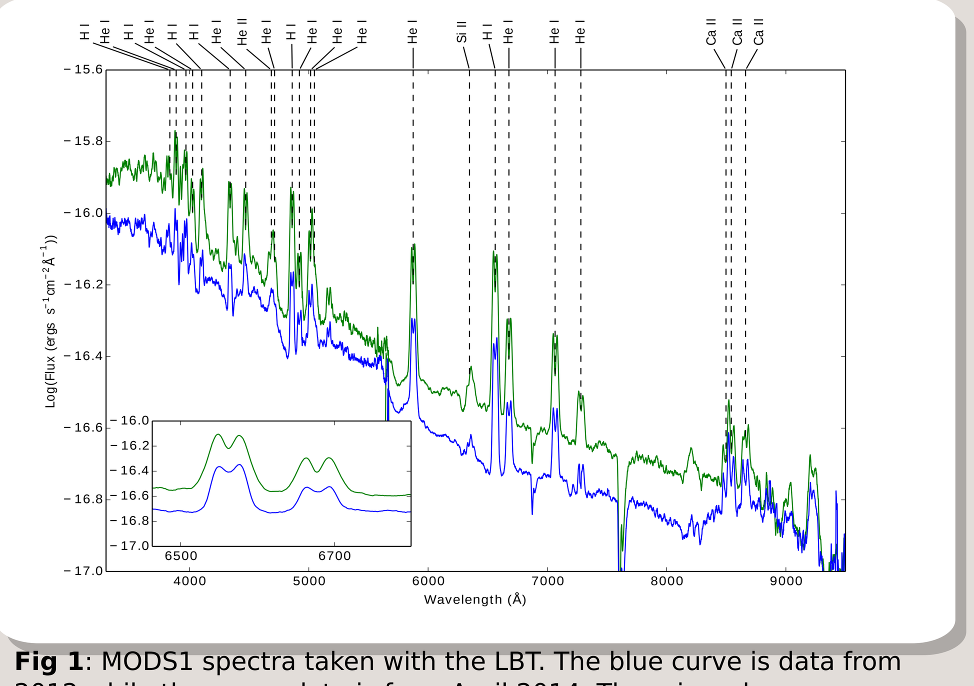

Fig 1: MODS1 spectra taken with the LBT. The blue curve is data from 2012 while the green data is from April 2014. There is a clear enhancement of the emission lines since 2012. The inset shows the increase in peak to peak separation in the Hα and He I lines

Optical Spectrosopy of CSS120422 was carried out on the 24th of April 2014, using the MODS 1 spectrograph. The spectra were flat fielded and debiased, and wavelength and flux calibrated using data taken during the same run. Each exposure was 200s long. The averaged spectrum on the blue and red arms can be seen in Fig 1, along with the spectra taken of CSS120422 using MODS in 2012. Table 1 shows the equivalent width of the most prominent lines.

Line	E.W. 2012	E.W. 2014
Hα	-60	-93
Hβ	-22	-36
He I (5876 Å)	-34	-67
He II (4686 Å)	-12	-22
Si II (6347 Å)	-7	-13

Table 1: Equivalent widths of several lines measured from LBT spectra in both 2012 and 2014.

The strong hydrogen and helium emission lines are not expected in a CV with a period below the period minimum which formed by the double degenrate channel or by the helium burning channel.

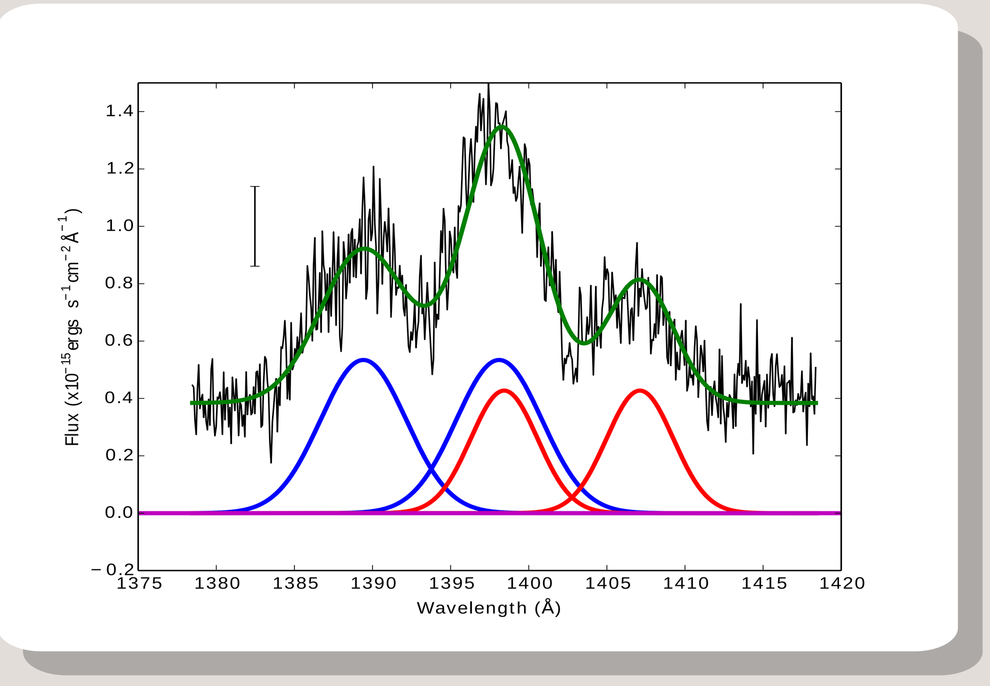

Fig 5: Fitting the Si IV doublet at 1393 Å and 1402 Å using 4 gaussian profiles gives a good match to the observed triple peaked structure. The peak to peak seperation of each line is 4.3 Å. The same method was used to try and fit the N V triple peaked structure, which occured due to the Nitrogen V doublet at 1238 Å and 1242 Å. Teh typical size of an error bar in the spectrum is also shown

Feature	Flux ($\times 10^{-15}$ ergs cm^{-2} s^{-1})
N V	16±3
Si IV	12±2
C IV	<5
He II	6±3

Table 1: Measured flux values for prominent emission lines in the HST spectrum.

HST UV Spectra

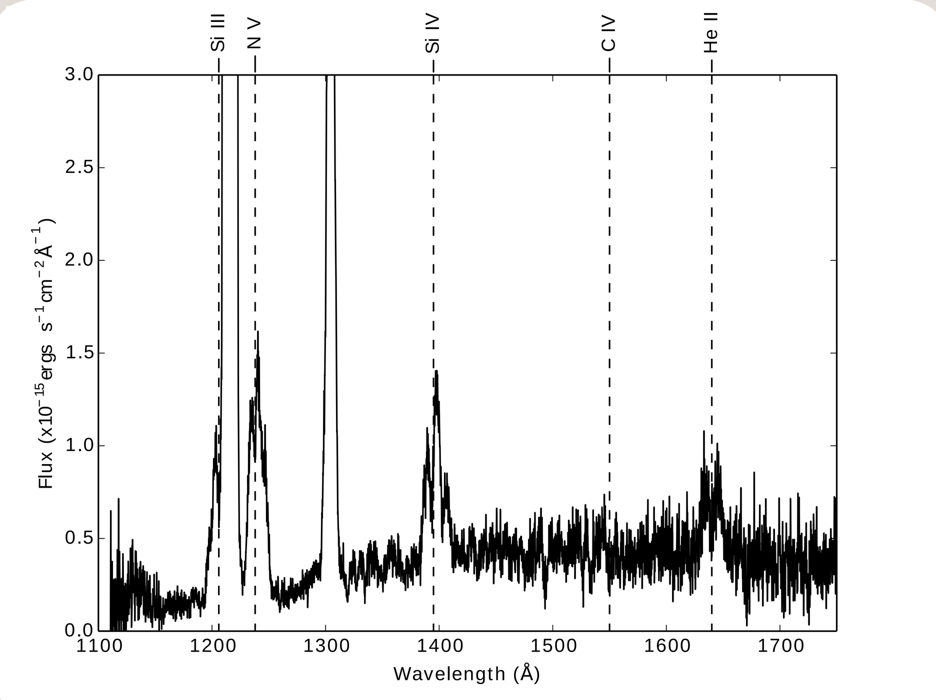

Fig 2: HST Spectra with grating in first position. All strong emission features are marked, as is the absence of the C IV line expected at 1548 Å. Spectra are binned to 0.24 Å

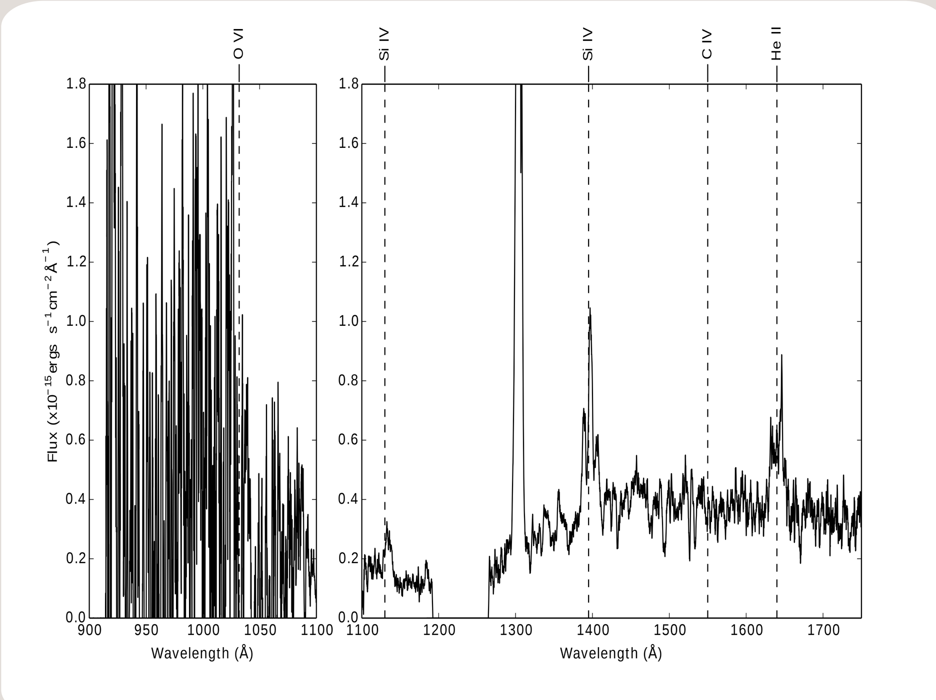

Fig 3: HST Spectra with grating in second position. All strong emission features are marked, as is the absence of the C IV line expected at 1548 Å and the O VI line expected at 1032 Å. The left portion of the plot has binning of 1 Å due to the poor sensitivity of COS below 1100 in this grating position, while the right has binning of 0.24 Å

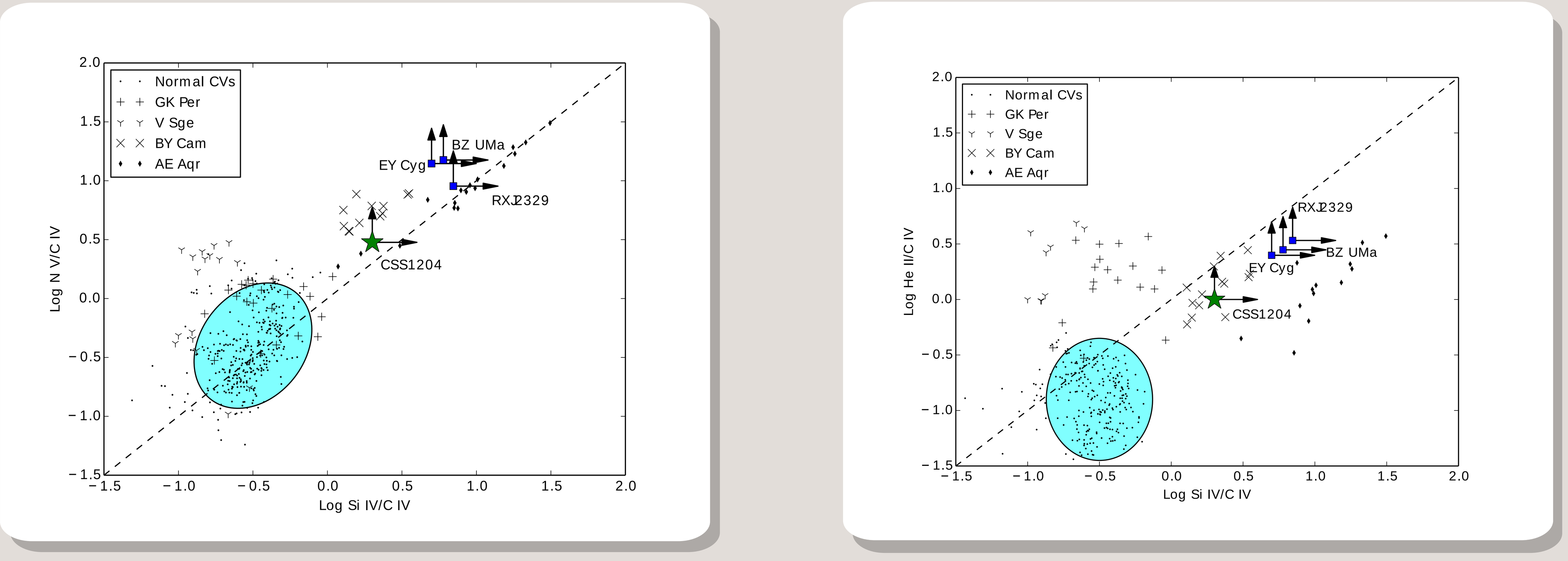

Fig 4: Ultraviolet line flux ratios in CVs. The teal ellipse shows the line ratios for most normal CVs, where the secondary star is prsumed to be a nearly solar abundance star. The line ratios of BZ Uma, RX J23239, Ey Cyg, AE Aqr, BY Cam and CSS1204 suggest accretion from CNO processed material. The line ratios for EY Cyg, BZ Uma and RXj2329 are taken from Gansicke et al. 2003, while the rest of data are archival IUE data and were kindly provided by C. Mauche: see Mauche et al. (1997)

HST Observations of CSS120422 were carried out using the Cosmic Origins Spectrograph on the Far Ultraviolet (FUV) channel, with the G140L grating (wavelength range of 900-2150 Å). 2 grating positions were used. The first 5 exposures cover 1100 Å to 1700 Å. The averaged spectrum can be seen in Fig 2. The second 5 exposures cover the range from 900-1200 Å and 1260-1700 Å (Fig 3). This was done in an attempt to measure the O IV line at 1032 Å to determine the CNO ratio of the system.

Fig 4 shows the N V/ C IV ratio versus Si IV/C IV ratio for CSS120422 along with BZ UMa, EY Cyg and RXJ2329, which are CVS discovered by Gansicke et al. [3] to display a flipped CNO abundance. Also plotted are the abundances of normal CVs along with some other peculiar CVs.

The over abundance of Nitrogran compared to Carbon in CSS120422 suggests that the material in the accretion disk originated from CNO processed material in the secondary star. For CNO processed material to be available for accretion, periods of long high rate mass transfer must have been present in the system. This is made possible by 2 mechanisms. First, the mass ratio of the system initally being larger than 1, that is the companion was more massive than the white dwarf. If this was true, then a period of thermal timescale mass transfer (TTSMT) would have happened [4].

Secondly, if the companion had just finished hydrogen core burning after the common envelope stage, then the time until the star becomes fully convective is longer, and the period of detechment known as the period gap lasts for less time than in conventional CVs, allowing for an overall longer period of mass transfer [1].

If both of these conditions are met, then the CNO processed material in the hydrogen burning shell can be exposed before it has had time to reach equilibrium, meaning there is an over abundance of N compared to C due to the long time scales required for the

$$p + {}^{14}N \rightarrow {}^{15}O + \gamma$$

reaction to take place, since the average lifetime of a ^{14}N nucleus in a solar abundance star is 5 X 10^8 years before it encounters a proton. It is the exposure and accretion of this rarely seen layer of the star that leads to the C/N inversion witnessed in CSS120422.

Conclusions

The peak-to-peak seperation of the Si IV doublet in the HST data was found to be 830 km/s, while the peak-to-peak separaton of the Hα line was found to be 550 km/s. This is in accordance with the Si IV doublet coming from an inner, higher excitation region of the disk than the Halpha line.

HST observations of CSS120422 have revealed powerful Si IV and N V emission lines, with no carbon lines visible. The carbon-nitrogen anomaly, along with the observed hydrogen in the optical spectrum, strongly indicates that CSS120422 is a product of the Evolved Main Sequence channel, where the flipped CN ratio arises from accretion of CNO procssed material.

Future work will be carried out to find more short period CVs formed by the EMS channel, and also to see how the hydrogen abundance changes with decreasing period.

References

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