Spectroscopic Wonders During The 2010 Eclipse Of Epsilon Aurigae

R. Leadbeater[1], C. Buil[2], T. Garrel[3], S. Gorodenski[4], J. Hopkins[5], B. Mauclaire[6], J. Ribeiro[7], L. Schanne[8], O. Thizy[9], R. Stencel[10]

1. Three Hills Observatory, UK 2. Castanet Tolosan, France 3. Observatoire de Foncaude, France 4. Blue Hills Observatory, USA 5. Hopkins Phoenix Observatory, USA 6. Observatoire du Val de l'Arc, France 7. Observatório do Instituto Geográfico do Exército, Portugal 8. Völklingen, Germany 9. Shelyak Instruments, France 10. University of Denver.

Background

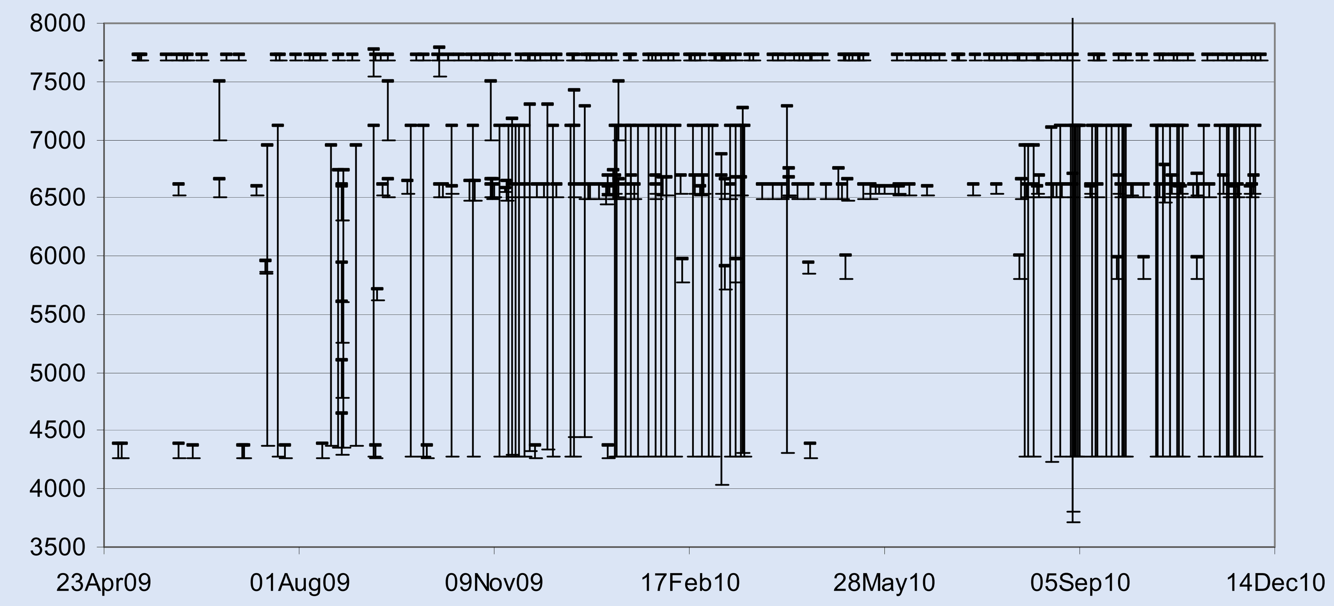
Epsilon Aurigae is a naked eye eclipsing binary system with a period of 27.1 years and a primary eclipse of about two years. Despite having been studied for almost two centuries, our understanding of the exact nature of the system, the primary star and its unseen companion is far from complete. Each eclipse a new generation of astronomers equipped with the latest technology tackle the problem. Advances in sensor technology and the availability of affordable high resolution spectrographs has allowed a network of advanced amateurs using small aperture telescopes to contribute during this eclipse.

Spectrograph and 0.28m telescope at Three Hills Observatory

Observations

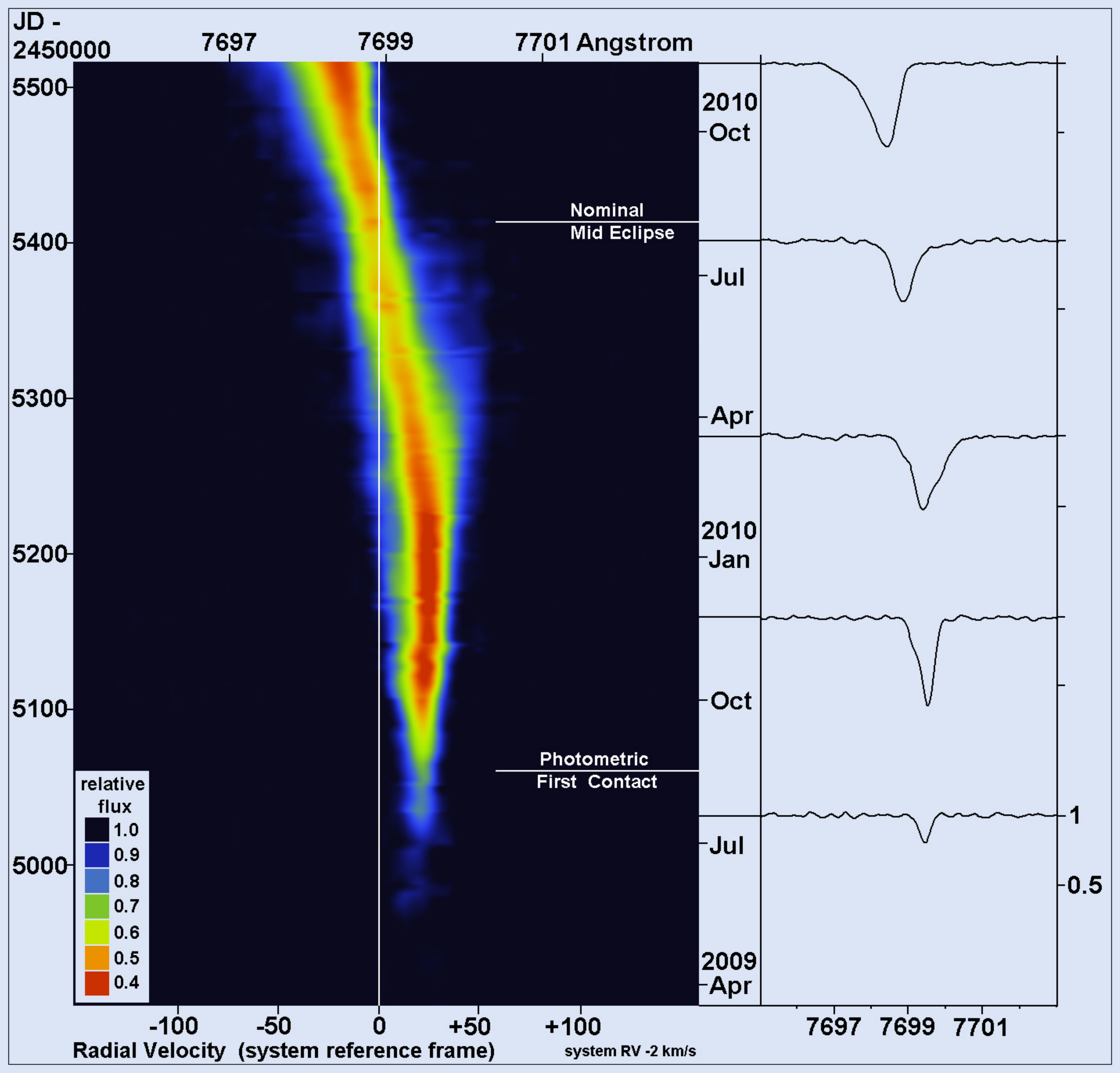
These observations form part of the continuing work undertaken by the International Epsilon Aurigae Campaign organised by two of the authors (Stencel & Hopkins). Nominal dates for 1st and 4th contact are 15th Aug 2009 and 15th May 2011 with mid eclipse 4th Aug 2010. 480 spectra have been taken covering the period from pre eclipse to mid December 2010. A table of all spectra is linked from the campaign website. This paper covers data collected by 8 observers, 6 equipped with Lhires III Littrow spectrographs covering narrow wavelength ranges at a nominal resolution of 0.35A. Two observers (Buil & Thizy) used eShel echelle spectrographs covering 4300-7000A at a lower resolution of 0.6A. Coverage using the higher resolution instruments was concentrated on the H alpha, Sodium D and 7699A Potassium lines. **Continuous coverage of H alpha and K 7699A was achieved throughout the eclipse at a typical interval of 3-4 days, including the usually poorly observed period around solar conjunction.**

The spectra are normalised to the continuum, heliocentric corrected and telluric lines have been removed. Except for a few spectra around solar conjunction, the SNR is better than 100. The wavelength calibration accuracy is better than 2km/s, verified using telluric lines. Where low and high resolution data have been combined, a Gaussian filter has been applied to the high resolution data.



Summary of observations during eclipse by date and wavelength

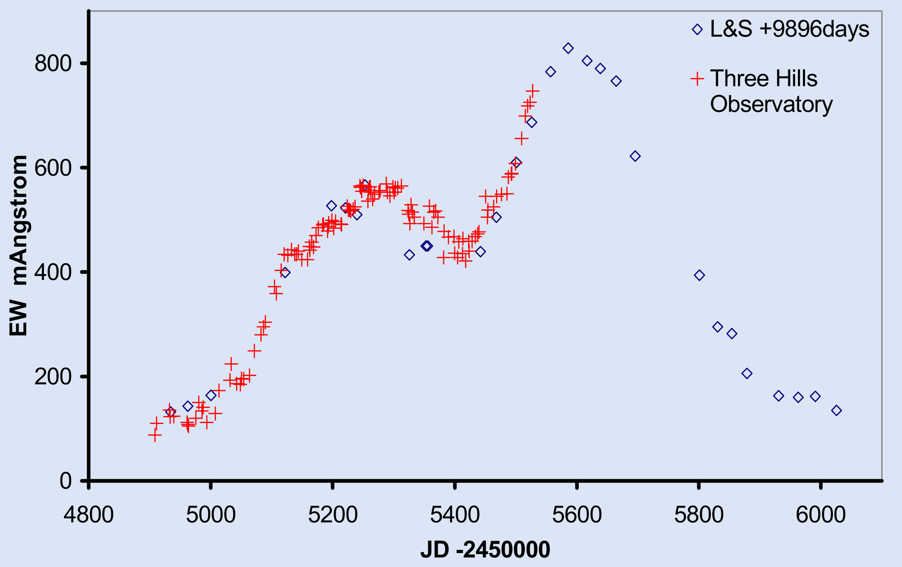
The 7699A Neutral Potassium Line



Contour plot showing the evolution of the 7699A neutral potassium line after removal of the interstellar component seen outside eclipse. Coverage is 140 days before first contact to 100 days after predicted mid eclipse. It is generated from 124 spectra, all recorded at Three Hills Observatory using a modified Lhires III at a resolution of 0.3A. Included are a selection of typical line profiles.

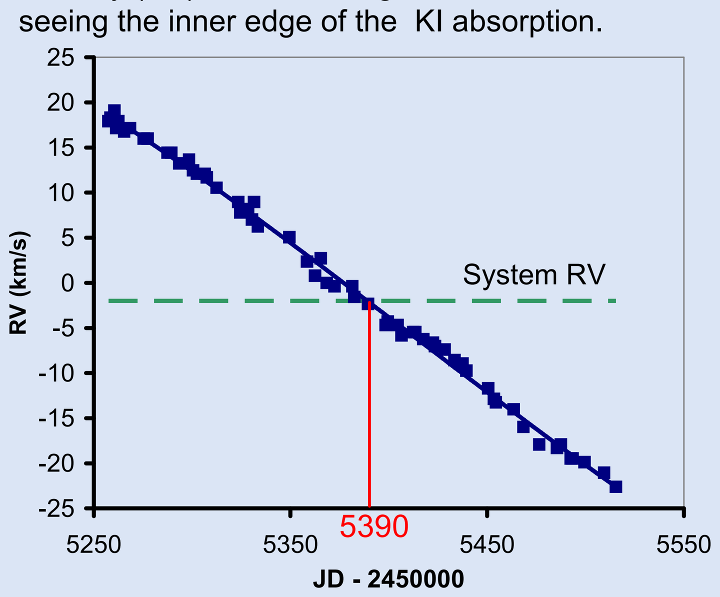
During eclipse, additional spectral lines from an extended atmosphere around an opaque eclipsing disc are seen superimposed on the primary F star spectrum. The neutral potassium line at 7699A (KI 7699) is particularly interesting as it does not appear in the F star spectrum and so can be used to directly observe the eclipsing object (after removal of a constant interstellar component). Slices through the disc can be examined as they are illuminated in turn by the F star. This line was also studied by Lambert and Sawyer (L&S) during the 1983 eclipse but **the much higher cadence of the current observations reveals significant additional detail.**

The eclipsing object was first detected at the KI 7699 wavelength on RJD 4976, some 83 days before the brightness started to drop at RJD 5059. The radial velocity of the line was typically +18km/s during ingress and first part of totality, moving to the blue around mid eclipse.



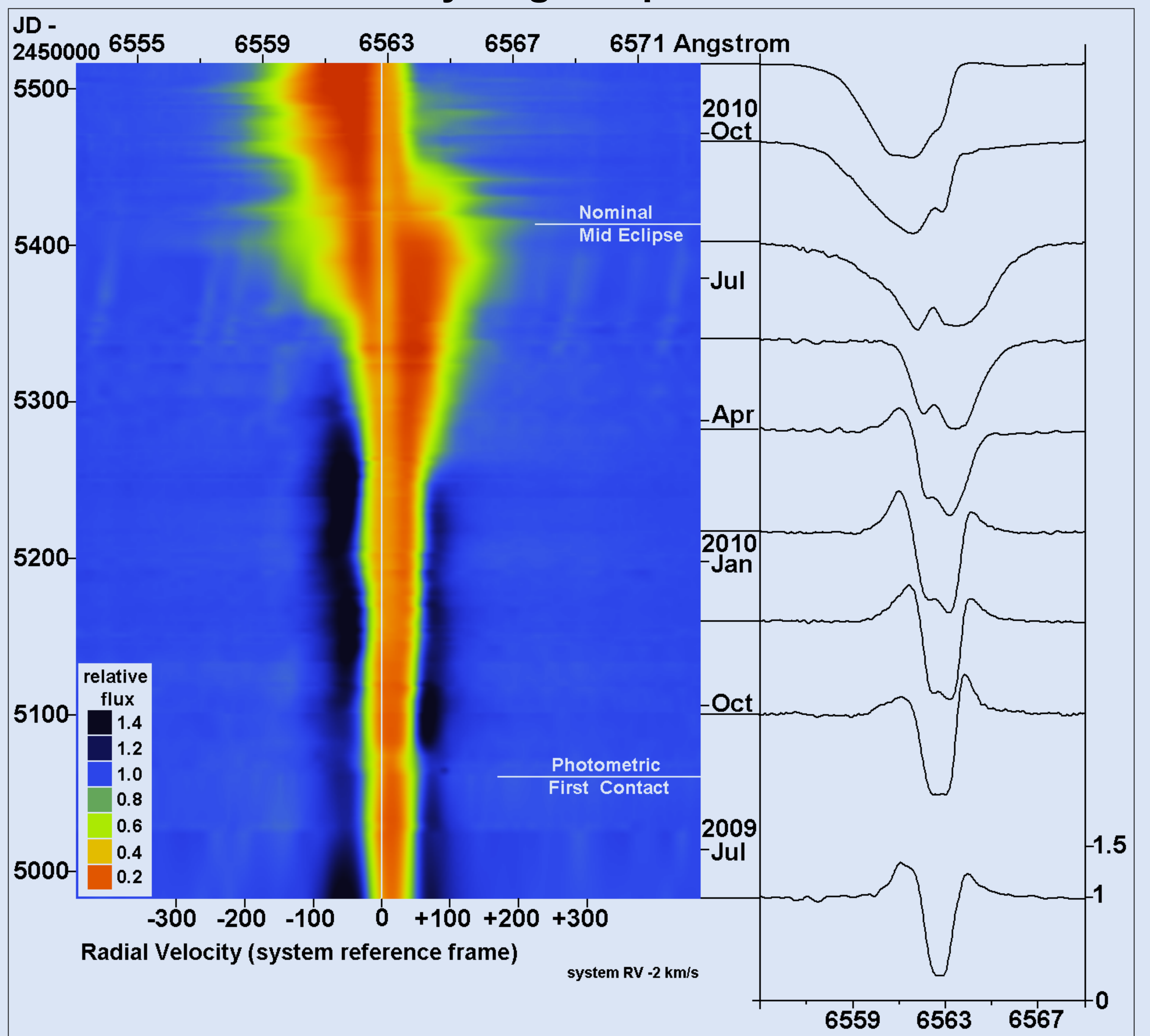
The trend of the total Equivalent Width (EW) of the line during ingress and early totality (plotted here including the interstellar component) broadly follows that seen by L&S. **There is evidence of pauses in the rate of increase of EW during ingress.** These have been interpreted as an indication of structure within the disc (Leadbeater and Stencel 2010).

From RJD 5300 to 5400 the EW fell on the approach to mid eclipse. This is interpreted as a region of low KI absorption close to the centre of the disc. **The EW trend in this region diverges significantly from that seen by L&S**, implying there has been a change in this inner region. The variability in EW increased during this period which coincides with instability seen at the red edge of the profile. The Radial Velocity (RV) of the red edge of the line also decreased over this period which is consistent with seeing the inner edge of the KI absorption.



The RV of the complete line is difficult to interpret as it is the combined result of the RV of all the material in front of the F star at a given time. By looking at the RV of particular parts of the line some conclusions can be drawn however. The RV of the core of the line (measured in the region <75% of minimum flux) plotted against time shows the RV_{core} **equalled** RV_{system} **at RJD 5390.** For a symmetric eclipsing disc this would represent the point when the centre of the F star and the eclipsing disc were aligned along our line of sight. This occurred **23 days before the mid eclipse date (RJD 5413) predicted from past photometric data.**

The Hydrogen alpha Line



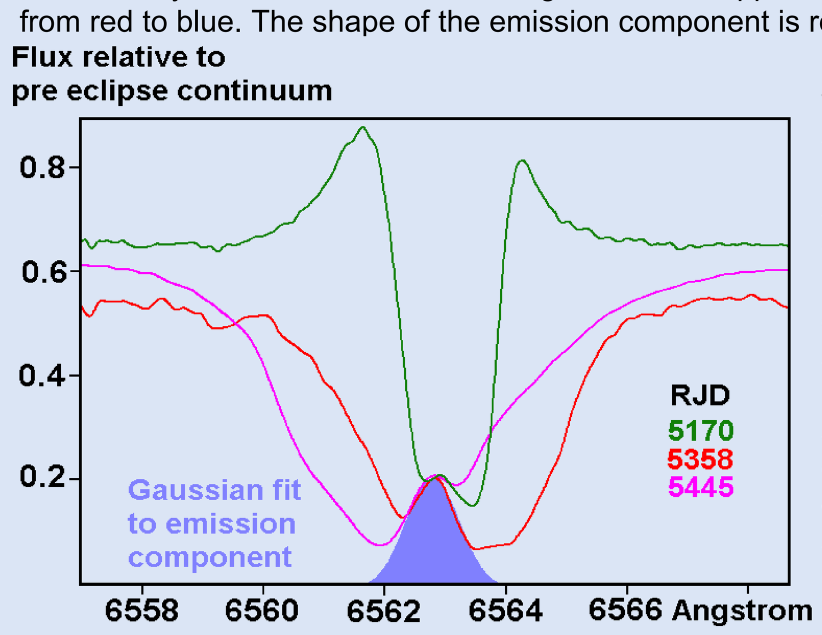
Contour plot showing the evolution of the H alpha line from pre first contact to approximately 100 days after predicted mid eclipse. It is generated from 159 spectra from all observers. The resolution is 0.6A. Also shown are a selection of typical line profiles at a higher resolution of 0.35A .

Outside eclipse the H alpha line profile comprises a central absorption core flanked by emission features on the red and blue wings. These features are highly variable outside eclipse, making it difficult to quantify precisely the contribution from the eclipsing body during eclipse. Despite this, some features unique to the eclipse phase can be identified.

During ingress and into totality the absorption core deepened and broadened slightly on the red side. From RJD 5250 onwards this additional absorption broadened rapidly engulfing first the red emission and by RJD 5340 also the blue emission component. (Note this is in contrast to the KI 7699A line absorption which started decreasing in intensity during this phase) Between RJD 5380 and 5460, through the mid eclipse point, the additional absorption moved to the blue and at RJD 5520 the red emission feature reappeared (visible in the top line profile).

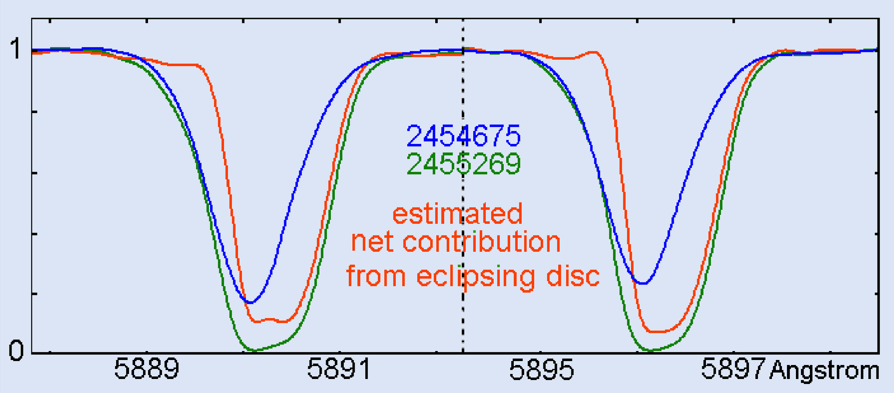
A hidden emission component

An emission component appeared in the core of the H alpha line close to the rest wavelength from RJD 5150 onward as the absorption increased in this region. This became more clearly defined as the surrounding flux level dropped further and moved across the region from red to blue. The shape of the emission component is revealed as the absorption region broadened and swept across it through mid eclipse. A selection of spectra is shown plotted relative to the pre eclipse continuum level. (by scaling the individual normalised continuum levels using R mag).



It is clear that the constant emission component is only revealed as the surrounding flux level drops (analogous to a rock being uncovered at low tide). A Gaussian fit to the emission component is shown centred on 6562.85 A with a FWHM of 1.0 A and an Equivalent Width of 210 mA

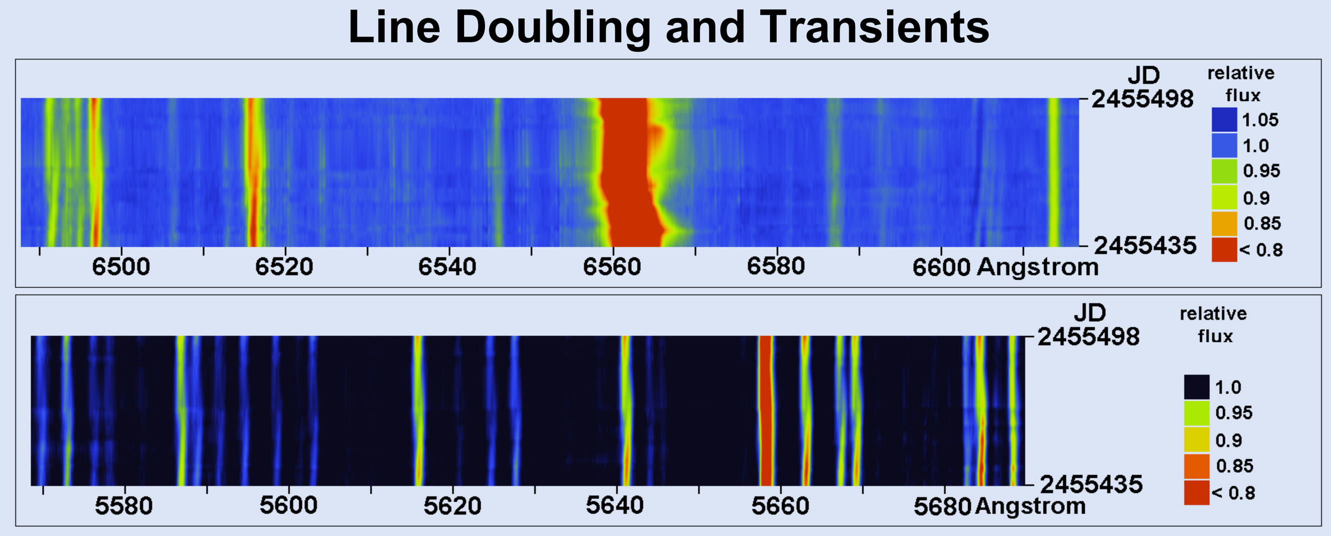
The Sodium D lines



The absorption spectrum of the eclipsing disc can be seen superimposed on many of the F star lines. Precise separation of the disc component is hampered however by the variability of the F star. An estimate of a typical Na D line profile produced by the disc during the first part of totality is shown here.

Note the depth of the disc component absorption. This implies that **the region of the disc producing the Na D absorption covers at least 90% of the uneclipsed portion of the F star.**

Line Doubling and Transients



Contour plot showing line doubling (C Buil eShel, 0.6A resolution)

Throughout the eclipse, quasi periodic variations in radial velocity of the order of 10 -15km/s have been seen in the F star lines. These are similar in magnitude to the residuals to the system orbital parameter fit produced by Stefanik et al. Around RJD 5470 however **an instance of line doubling was detected simultaneously in lines throughout the spectrum.** The degree of split was up to 60km/s. Another similar instance of doubling was seen ~80 days later (not shown) .

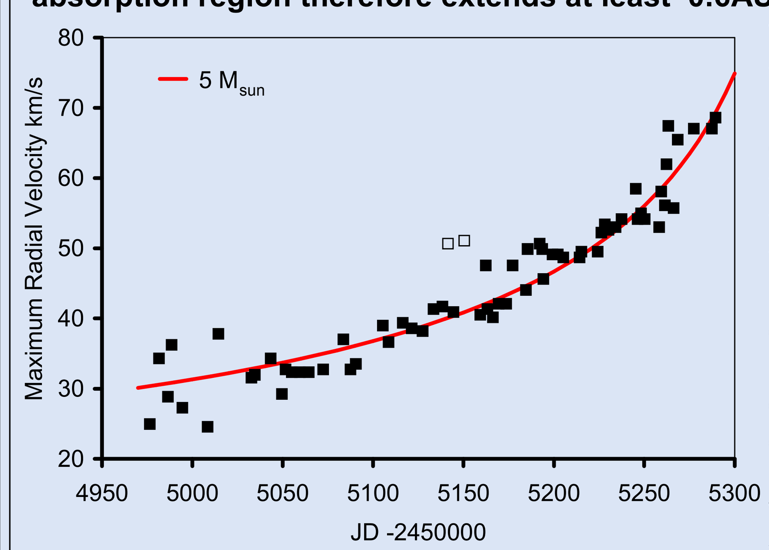
A line at 6604A can be seen weakly in emission in the plot above where it also shows evidence of doubling at a different phase compared with that seen in the absorption lines. This line was also seen in emission earlier in the eclipse between RJD 5255 and 5273

Distribution of the eclipsing disc atmosphere

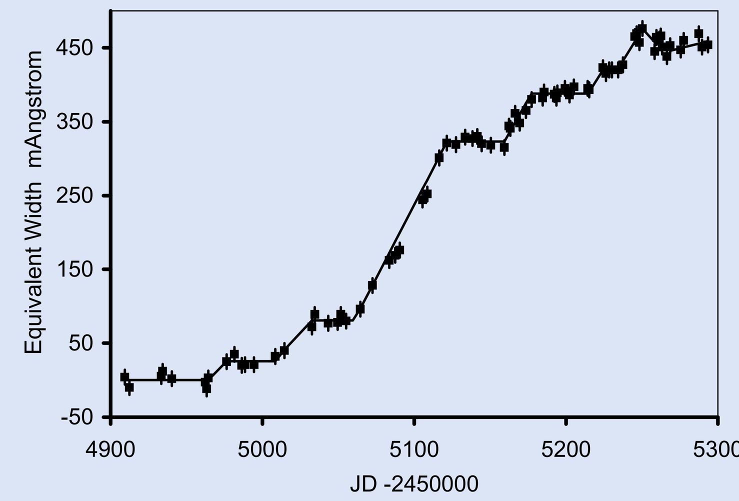
For the purposes calculating the distribution of material in the extended atmosphere of the disc, the dimensions of the system as per the HHS model for the system have been used (Hoard, Howell and Stencel 2010). A constant value of 22km/s (1.27AU/100days) was adopted for the relative velocity of the two components during eclipse.

The first appearance of the KI 7699 absorption on RJD 4976 corresponds to **a radius of 4.9 AU for the outer limit of the extended atmosphere of the disc, 1.1AU beyond the part of the disc seen photometrically.**

The NaD line data suggest that the extended atmosphere extends sufficiently out of the plane of the disc to cover at least 90% of the uneclipsed part of the F star. Interferometry shows the opaque part of the disc just covering the lower part of the star. (Kloppenborg et al 2010) **The Na D absorption region therefore extends at least 0.6AU above the opaque part of the disc.**



The depth of the KI 7699 absorption due to the disc is significantly less than that for Na D. If the regions producing the absorption extend a similar distance out of the plane of the disc, then the disc must be partially transparent at the KI 7699 wavelength. If the material in the disc is moving in Keplerian orbits around a central object then during ingress and into totality the maximum RV seen in the KI line will be generated by disc material in the innermost orbit in front of the F star at that particular time. By plotting the RV of the red edge of the line **We can therefore propose an orbital velocity profile of the disc. This gives a a good fit to a theoretical curve for material in circular orbits around a central object of 5 solar masses** between RJD 5030, 29 days before photometric first contact, to RJD 5300 when the red edge RV levelled off abruptly. This date also corresponds to the point where the EW curve starts to drop. **It is likely that this point corresponds to the inner extent of the KI absorption at a radius of 0.8AU** based on the HSS dimensions for the system.



During ingress, the EW of the contribution of the eclipsing disc to the KI 7699A absorption (after removal of the interstellar component) increased in a series of steps. **This has been interpreted as an indication of (possibly ring like) structures within the disc.** (Leadbeater & Stencel 2010). Continued observation during egress may help to clarify this.

References and Acknowledgements

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