Hα spectral monitoring of ε Aurigae 2009-2011 eclipse

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ABSTRACT

Aims. We present and analyze ε Aurigæ data concerning the evolution of the Hα line on the occasion of the 2009 International observation campaign launched to cover the eclipse of this object.

Methods. We visually inspect the dynamical spectrum constructed from the data and analyze the evolution with time of the EW (Equivalent Width) and of the radial velocity.

Results. The spectroscopic data reveal many details which confirm the complexity of the ε Aurigæ system. The object is far from being understood. In particular, according to our measurements, the eclipse duration has been underestimated. A complete analysis of details revealed by our data would require much time and effort. Observers are encouraged to continue monitoring the Hα line out of eclipse in the hope that it will provide further important information.

Key words. ε Aurigæ – epsilon Aurigae – 2009-2011 eclipse – eclipsing binary – spectroscopy – Hα line – equivalent width – radial velocity – amateur spectroscopic survey.

1. Introduction

ε Aurigæ is one of the most intriguing eclipsing star systems which has puzzled astronomers for nearly 200 years. The main eclipsing period is close to 27.1 years and the first spectroscopic surveys were undertaken during the 1929 and 1956 eclipses. A large campaign was also organized for 1982-1984. For a review of literature prior to the 2009-2011 eclipse, see Guinan & DeWarf 2008. There are also numerous papers being prepared as a result of the 2009-2011 eclipse. Despite the concentrated efforts, some aspects of ε Aurigæ remains a mystery.

ε Aurigæ is classified as an A8Iab star in an Algol type eclipsing binary system (SIMBAD). The prevailing model is of an F-type star with a hot clumpy Hydrogen disc and an object of unknown nature which produces an eclipse phenomenon lasting almost 2 years every 27.1 years. There may be a mid-eclipse brightening but solar proximity makes the photometry suspect at those times. Recently, it has been suggested that the eclipsing object is a 550 K dusty disk seen edge on, heated on the side facing the F star to 1100 K which may contain a B5V star (Hopkins et al. 2011) that could contribute to emission wings surrounding Hα line. Light curves feature 0.1 magnitude variations both inside outside eclipse. Variations have also been observed in the Equivalent Width (EW) and Radial velocity of spectral lines outside eclipse. These variations might be F star oscillations and wind.

During the 1982-1984 eclipse, this star was studied by amateur observers using multiband photometric methods. The ε Aurigæ system was not clearly described despite all the acquired data.

Twenty-seven years later, an international campaign was organized to manage both spectroscopic and photometric observations by amateur observers with the aim of producing data with improved time resolution compared with that achieved during previous eclipses. In this article, we present amateur spectroscopic Hα line monitoring from February 12, 2008 to November 12, 2011.

2. Observations

In 2008, Jeff Hopkins organized the international observation campaign of the 2009 ε Aurigæ eclipse. We acquired more than 250 high resolution spectra of the Hα line covering the three years around eclipse. These show significant variability throughout this period. The effect of the eclipse is clearly seen in this line from the end of April 2010 to end of April 2011. The spectra used in this study were recorded by five observers in Europe.

Most observations were made using LHIRES3 spectrographs. C. Buil used an eShell spectrograph that covers

1 http://www.hposoft.com/Campaign09.html
2 LHIRES3 and eShell are products from Shelyak Instrument, Grenoble, France: http://www.shelyak.com
wavelengths from 4500 Å to 7000 Å. Telescope diameters were between 0.2 m and 0.3 m. Spectral resolution is above 10,000 and most of the time around 15,000. Mean exposure time was 2,000 s. All setups are reported in Table 1.

3. Reduction and analysis method

The raw observations are available from Robin Leadbeater’s ε Aurigae survey web page. The spectra were reduced using standard procedures to produce calibrated and normalized lines profiles. Most of the reduction was done using SpcAudace pipelines. The reduction steps were: preprocessing, geometric corrections and registration. Then line profiles were extracted with sky background subtraction. Wavelength calibration was done using calibration lamp spectra before and after each acquisition series to minimise the effects of calibration drifts. The instrumental response was then removed. An offset was computed using telluric lines to achieve a final a wavelength calibration RMS uncertainty of 0.03 Å. Finally a heliocentric velocity correction was applied depending on the observation date. All wavelengths λ are given in Å (Angström).

Equivalent Width measurements were computed between λ6550 and λ6577 using linear integration and an extracted continuum obtained from a fit to the local star continuum. The Chalabaev algorithm was used to estimate the uncertainty, which is mostly dependent on the signal-to-noise ratio, and appears to over-estimate the uncertainty compared with the actual scatter observed around the long term trend.

Radial velocities is computed in two steps because the Hα line is asymmetric:

1. The Gaussian flank of the line was reproduced on the opposite side of the symmetry axis (theoretical wavelength of the line) and shifted to fit the line’s opposite flank.
2. A Gaussian fit of these two flanks gave a measure of the line center.

A dynamical spectrum was computed using 177 spectra corrected to heliocentric velocity and cropped to λ6550-λ6575. A linear interpolation was used to produce an image with a 1-day sampling interval. Such interpolation doesn’t introduce bias for our analysis as the purpose of Figure 6 is to show global behavior of the eclipse spread over several hundred days. Dates are logged in MJD (that is, JD–2400000). All computations were performed in SpcAudace. The monitoring covers a period of 719 days.

Most of the information generated by our monitoring of the Hα line is contained in this dynamical spectrum.

Analyzing this complex image turns out to be cumbersome, however. This is the reason why we have simplified the analysis by concentrating on the evolution with time of the EW that can be compared to V magnitude, and of the radial velocity that can be used to study eclipsing phenomena. Of course we have to keep in mind that EW loses its physical meaning when applied to complex line profiles lines, as it is the case for ε Aurigae, are likely to result from a combination of several sources. But before analyzing these quantities, let us first examine the spectral line profiles at dates that show important transitions.

4. Behaviour of the wings

Outside eclipse, the Hα line profile comprises a central absorption core flanked by emission features on the red and blue wings (see Fig. 1). These features are highly variable as described by Golovin (Golovin 2008).

In the region of the Hα line absorption profiles are identified as telluric lines at λ6543.91, λ6547.71, λ6548.32, λ6552.63, λ6557.17, λ6568.81, λ6572.09, λ6574.85 and λ6586.68.

As we can see in Figures 2 and 3 from MJD 55250 onwards there was additional absorption in the core which broadened rapidly, engulfing first the red emission and by MJD 55340 also the blue emission component. Note this is in contrast to the KI λ7699 line absorption which started decreasing in intensity during this phase (Leadbeater et al. 2011).

During ingress and into totality (see spectra at MJD 55390.44 and MJD 55496.42) through the mid-eclipse point, the absorption core deepened and broadened slightly on the red side. The additional absorption moved to the
Table 1. Equipment information for observation of ǫ Aurigæ.

| Observer name | Telescope | Spectrograph | Resolution | Mean SNR | Spectral range (Å) | Number of spectra |
|---------------|-----------|--------------|------------|----------|-------------------|------------------|
| C. Buil       | SCT 0.28 m | eShell       | 10 000     | 164      | 4500-7000         | 96               |
| T. Garrel     | SCT 0.21 m | Lhires3      | 15 000     | 108      | 6500-6630         | 87               |
| B. Mauclaire  | SCT 0.30 m | Lhires3      | 15 000     | 224      | 6500-6700         | 34               |
| R. Leadbeater | SCT 0.25 m | Lhires3      | 15 000     | 98       | 6500-6700         | 25               |
| A. Lopez      | SCT 0.28 m | Lhires3      | 15 000     | 164      | 6500-6700         | 5                |

At the beginning of the decreasing phase (see spectrum at MJD 55627.46), the Hα line became narrower, with an emission component at the red side. Then, from MJD 55853.42, the blue edge emission component returned as just before eclipse. After the main eclipse phase (see spectrum at MJD 55878.39), the blue and red wings were both present but small, starting to resemble the pre-eclipse profile (Figure 1).

At the end of the survey period there still appears to be an excess absorption on the blue side of the central absorption region compared with typical pre-eclipse spectra, possibly due to the continued presence of the eclipsing disc. However, the inherent variability of this at all phases makes the statement uncertain.

Today’s understanding (Stencel 2011) is that the F star is semi-stable and capable of producing variability in lines in and out of eclipse. The disk is only modifying the optical spectrum during its passage.

5. Equivalent width evolution with time

EW measurements were computed between λ6550 and λ6577. Although the signal-to-noise ratio varies between observations and includes telluric lines which impact on EW, the effect most of the time is rather small. The data quality allows a reliable estimation of the EW. As mentioned earlier, the single quantity EW is a gross simplification of the complex nature of the line.

However, this quantity is the integral of the distribution of luminosity versus wavelength. It can thus be compared to similar integrals such as the V magnitude. As shown in Figures 3 and 4, equivalent width (EW) and V magnitude (V mag.) are anti-correlated. Given that EW>0 for absorption lines, the eclipsing object occults the F star Hydrogen disk as first minimum in EW and in V mag. evolution are both close to MJD 55250, and as second minimum and V magnitude evolution are also both close to MJD 55630. These dates define totality inner limits (see Table 2).

While second and third contacts (and mid-eclipse) times are well-defined by our EW as a function of Date trend (Figure 3), the definition of first and fourth contact times are less obvious here and do not correspond to photometric contacts: these dates (second and third contacts) are likely to be linked with the densest ends of the eclipsing object.

During the eclipse phase and outside it too, there are many small variations in EW and V mag. This suggests that the occulting object and F star Hydrogen disk may be clumpy. The F star may have also an intrinsic pulsating activity (Kemp 1986 and Stencel 2011) that produces such variations.

Hα EW has irregular variations like small steps during its increasing and decreasing phases. Similar behavior has been observed on the KI λ7699 absorption line. It has been interpreted as an indication of structures (possibly ring-like) within the disc (Leadbeater & Stencel 2010). Continued observation during egress may help to clarify this.
Fig. 3. Plot showing evolution with time of Equivalent Width computed between λ6550 and λ6577. Note the two minima at MJD 55250 ±2 and MJD 55630 ±2 corresponding to second and third contacts dates.

Fig. 4. Light curve of ε Aurigae using data from the AAVSO International Database showing V magnitude evolution within time. Light curve courtesy of AAVSO.

6. Radial velocity evolution with time

Figures 2 and 4 show how shapes are shifted in radial velocity. During eclipse (see spectra at MJD 55390.44 and MJD 55496.42), the absorption line became red shifted (+14.79 ± 1.37 km/s). During the end phase of the eclipse (see spectrum at MJD 55627.46), the Hα line first returned to the position seen at MJD 55390.44 and then the absorption line became blue shifted (−31.59 ± 1.54 km/s at MJD 55853.42). See Table 2 for measurements at key dates.

| MJD (day) | Radial velocity (km/s) |
|----------|-----------------------|
| 55 199.24 | +19.46 ± 1.54         |
| 55 390.44 | +14.79 ± 1.37         |
| 55 436.49 | −38.10 ± 1.54         |
| 55 521.46 | −60.36 ± 1.54         |
| 55 819.46 | −31.59 ± 1.54         |

Table 3. Radial velocity measurements of ε Aurigae at key dates.

7. In quest of new models

The light variations of ε Aurigae in and out of eclipse have been the object of many studies.

During the 1983 eclipse Kemp and Henson (Kemp 1986) analyzed polarization data. They suggested that the F star is a non-radial pulsator and that its surrounding disk is tilted with respect to the orbit.

In 1991, Ferluga (Ferluga 1991) suggested that to explain the shape of the light curve, the disk is not a continuous aggregate of dust, but instead a series of rings with a Cassini-like division. This model was more or less validated by observations.

During this eclipse, a wide variety of observations have been undertaken: infrared, ultraviolet, interferometry, photometry, and high resolution spectral monitoring. Thus, a considerable amount of information is now available (see...
8. Conclusions

Our Ha monitoring of $\epsilon$ Aurigae shows that, contrary to what was forecast, the effects of the eclipse extended beyond December 2011. Post-eclipse observations are needed. R. Stencel welcomes any outside eclipse spectroscopic contributions to the campaign over the coming months and years, especially those covering the Na D lines.

We have observed similarities and discrepancies between the EW and V magnitude evolution with time. The discrepancies remain to be explained, but that is beyond the scope of this article. We also were able to define key dates in the eclipsing phenomenon. However, much remains to be analyzed. Obviously the H$_\alpha$ monitoring brings a lot of information which should place many constraints on the models conceived by scientists about $\epsilon$ Aurigae.

Amateur spectroscopists are now able to monitor bright targets with a spectral resolution of about 15,000. Suitably equipped amateurs constitute a team with long term monitoring capacity which is widely distributed over the planet.

In any case, we hope that this information will help scientists to solve the mysteries hidden behind this fascinating object.

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Stencel 2010 and Hopkins et al. 2011 for an overview). It now remains to develop a model that fits all the data at hand. Undoubtedly, the high resolution spectral monitoring data will be very important for constraining these models.
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