Measuring the components of the binary Mira X Ophiuchi

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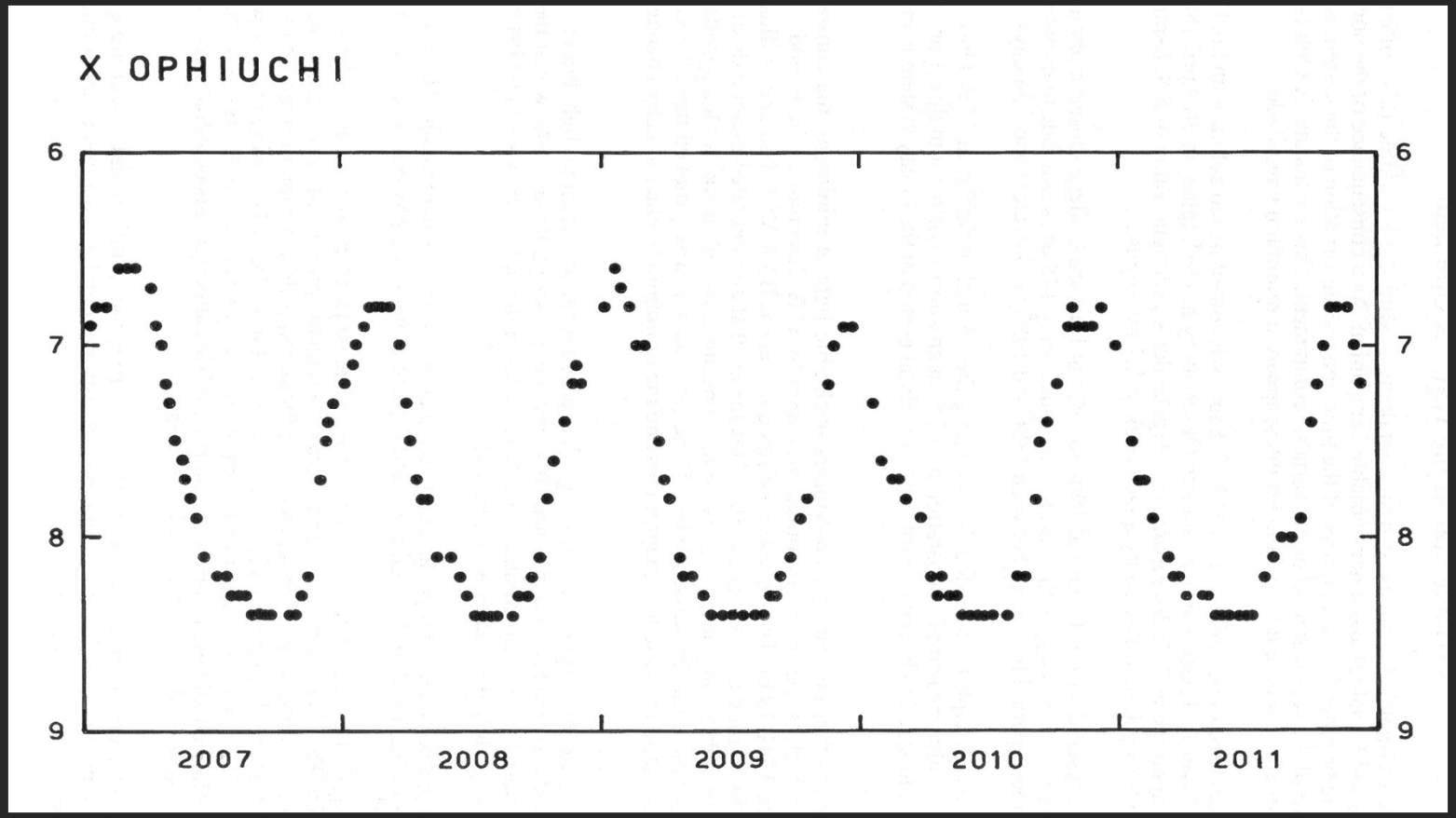
X Oph was Variable Star of the Year in the 2014 BAA Handbook

The article included this light curve from observations by John Toone



It appears that this is a binary containing a long period variable, possibly a Mira, and a faint constant companion which dominates when the Mira fades, hence the flat bottoms to the minima

Historical observations of X Oph (1)

- X Oph was first found to be variable by the Reverend Thomas Henry Espinell Compton Espin observing at Darlington in 1886
- In 1900 Hussey discovered the star to be a visual double using the 36-in refractor at Lick Observatory with a power of 1000. He measured the separation as 0.22 arcsec
- Cannon, in the Annals of the Harvard College Observatory in 1907, reported its magnitude range as 6.5 to 9.0, its period as 335 days and its spectral type as Md on the Draper spectral classification
- Van Biesbroeck, observing at Yerkes Observatory in 1920/1, deduced from visual brightness estimates that the more northerly component was the variable

Historical observations of X Oph (2)

- Merrill at Mt Wilson Observatory reported the spectral type as varying between M6e at maximum and K0 at minimum as the southern, presumed constant, component dominated. He gave the visual magnitude of the K-type star as 8.9 and the visual range of the M-type star as 6.8 to 12

- Various observers subsequently gave the minimum magnitude of the Mira-like star as 9.9 and 11.5, the magnitude of the constant star as 8.5 and its spectral type as K1III

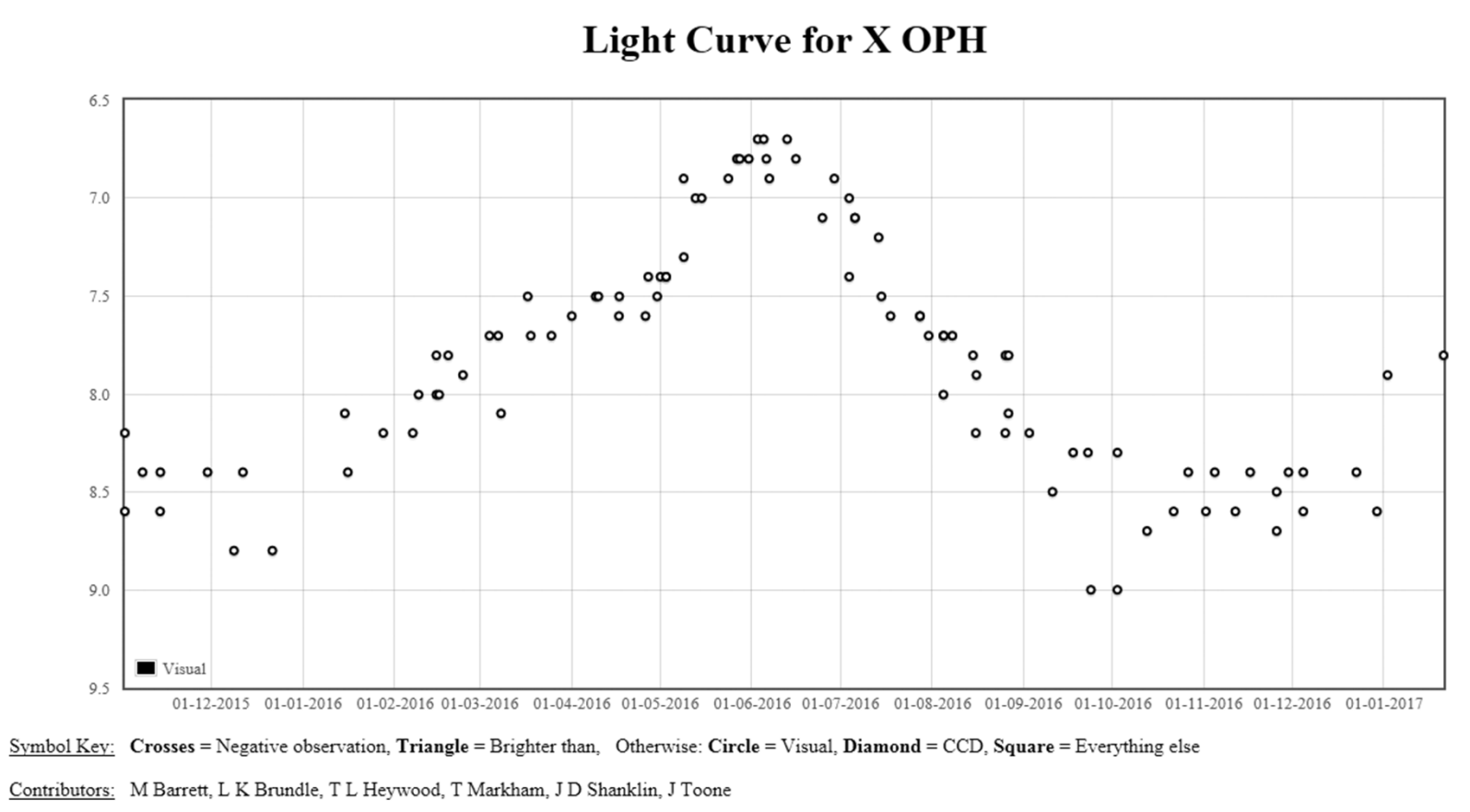
- VSX gives the spectral type as M5e-M9e

- Simbad gives the spectral type as M0-8e+K2III

So, in spite of the work of all these famous observers, there remains uncertainty about the true nature of the components of X Oph

Visual observations

This is the visual light curve of X Oph from six observers in the BAAVSS database from November 2015 to January 2017

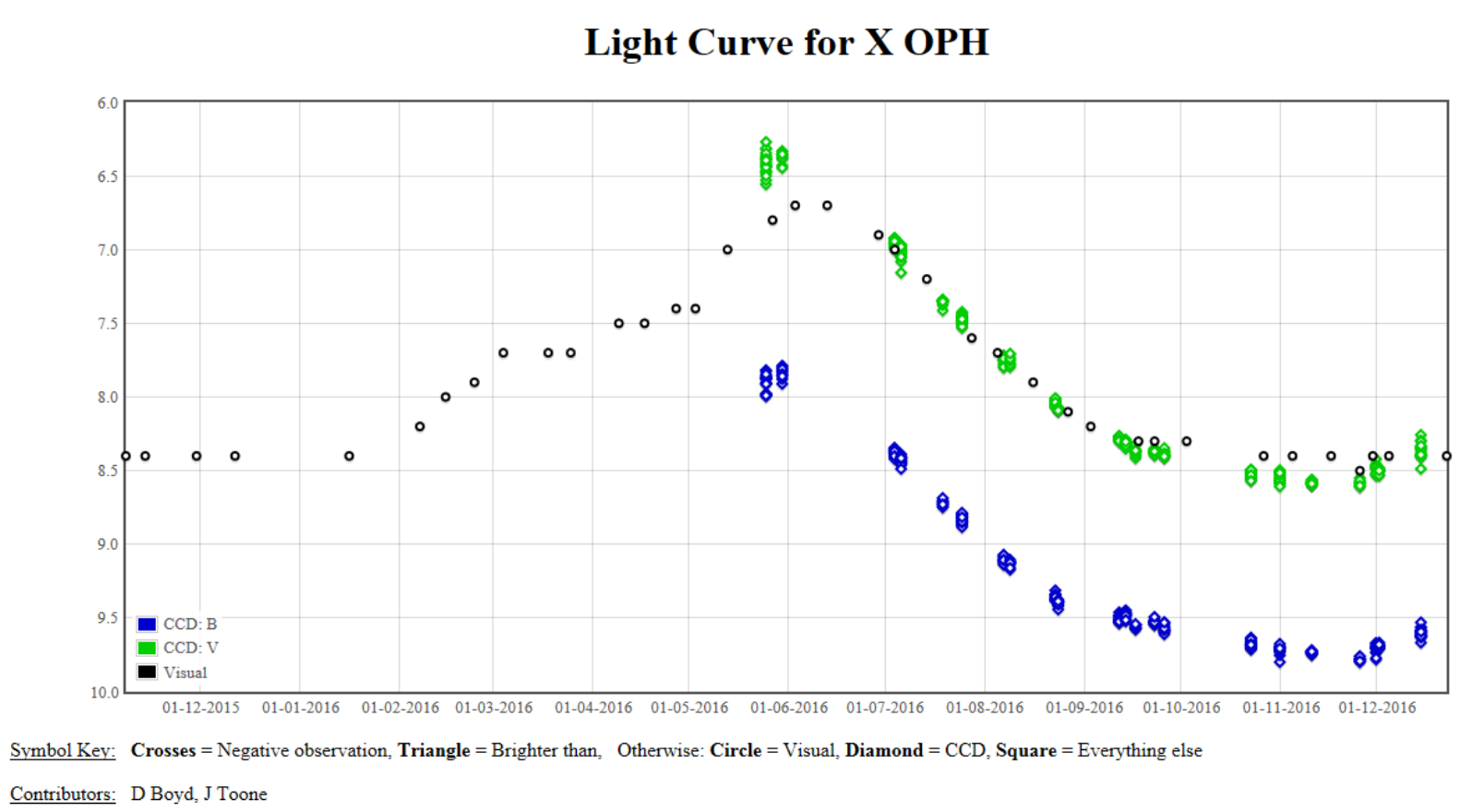


It passed through a maximum around JD 2457548 (8 June 2016) and a minimum around JD 2457695 (2 November 2016)

CCD photometric observations

I made observations of X Oph using B and V filters between May and Dec 2016 and reduced these to standard Johnson B and V magnitudes

The light curve below shows these measurements together with visual estimates made over the same period by one observer, John Toone



What do we know about X Oph?

- It is a binary system
- The northern component is variable, probably a Mira (here called the M star)
- The southern component is very likely constant (here called the K star)
- The magnitude of the M star varies within the range ~6.5 and ~12
- The spectral type of the M star is between M5 and M9 (and possibly varies)
- The magnitude of the K star is between 8.5 and 9
- The spectral type of the K star is between K0III and K2III
- The magnitudes of the M and K stars are linked by the binary magnitude

What don't we know about X Oph?

- The magnitude of the K star
- The spectral type of the K star
- The magnitude range of the M star
- The spectral type of the M star, possibly variable

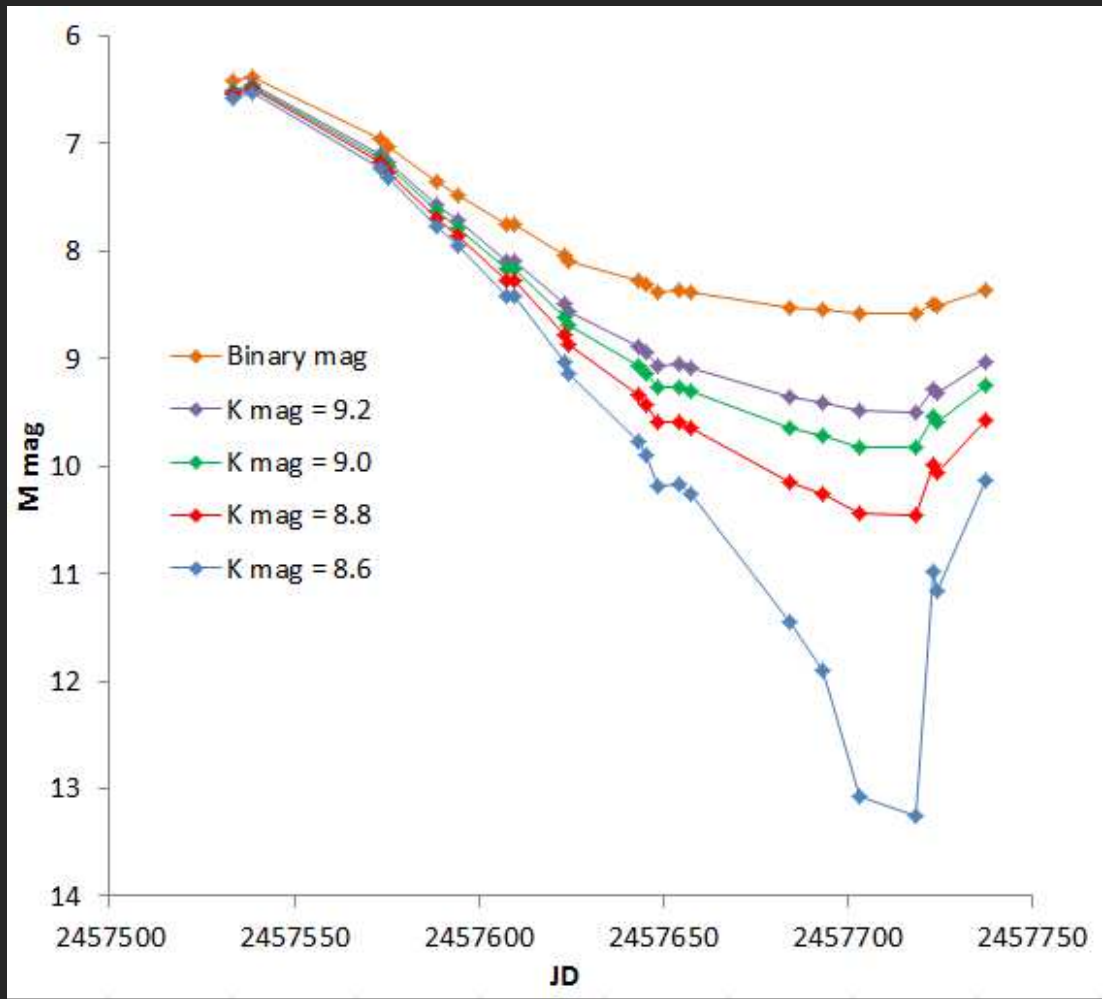
Magnitudes of the M and K stars

If B = measured magnitude of the unresolved binary system
and K = assumed magnitude of the K star (constant)
then M, the magnitude of the M star (variable), is given by

$$M = -2.5*\mathrm{Log}_{10}(10^{(-0.4*B)}-10^{(-0.4*K)})$$

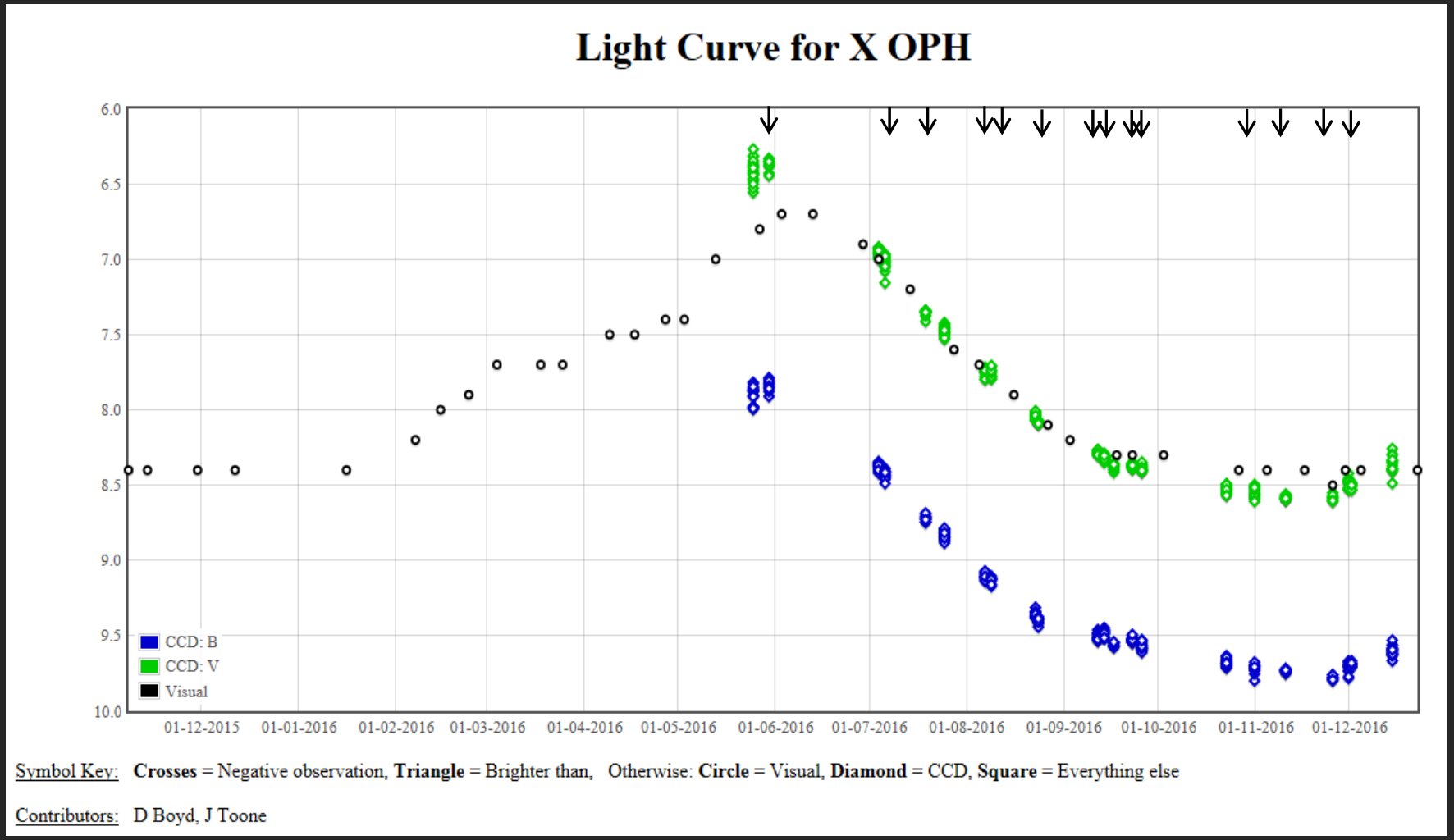
Plotting M for various values of the K star magnitude . . .

The most likely values for the K star magnitude are in the range 8.8 to 9.2

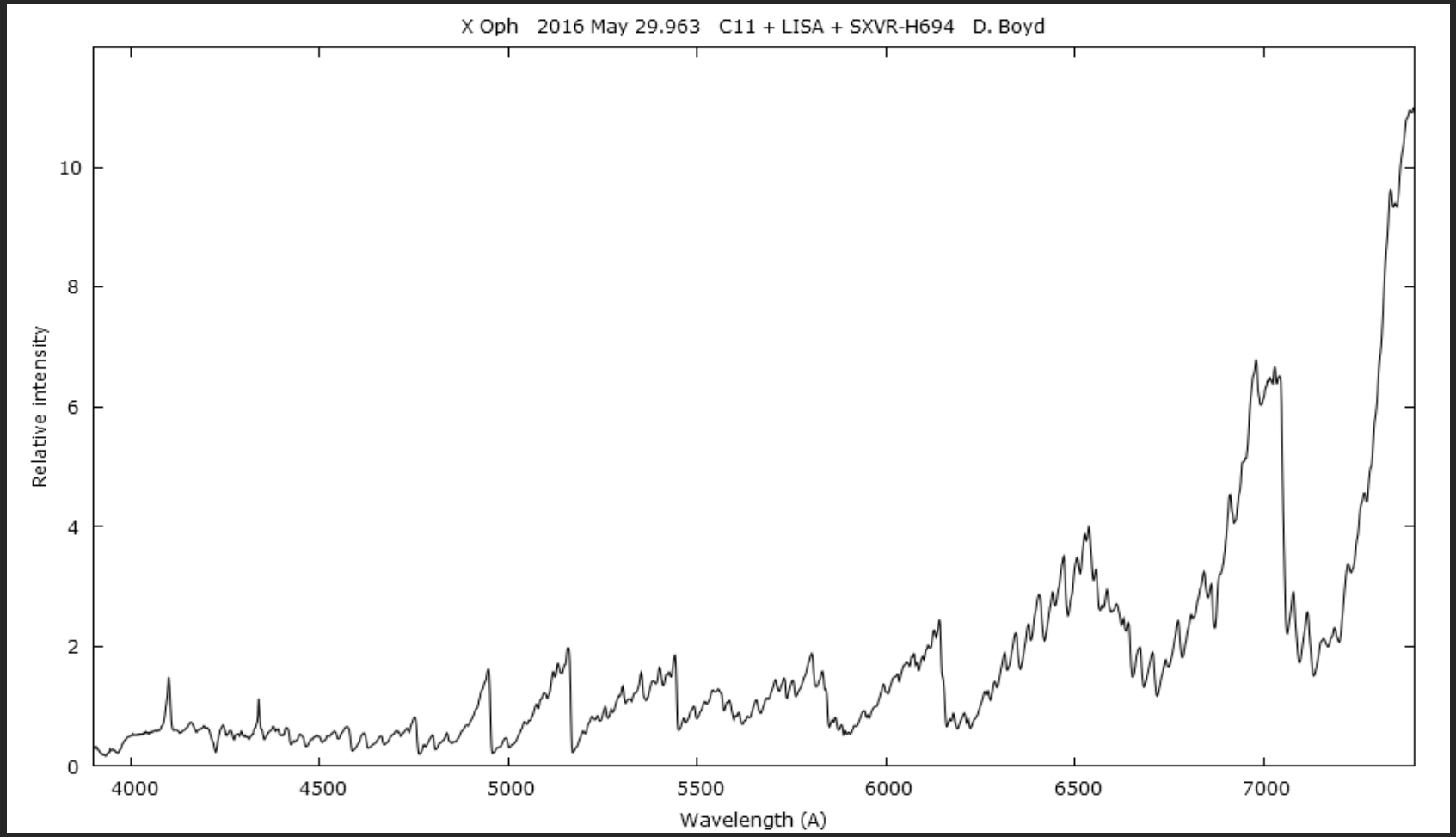


Spectroscopic observations of X Oph

I recorded spectra on 14 nights using a LISA spectrograph attached to a C11 scope



This spectrum of X Oph, a typical M-type spectrum, was taken on 29 May 2016

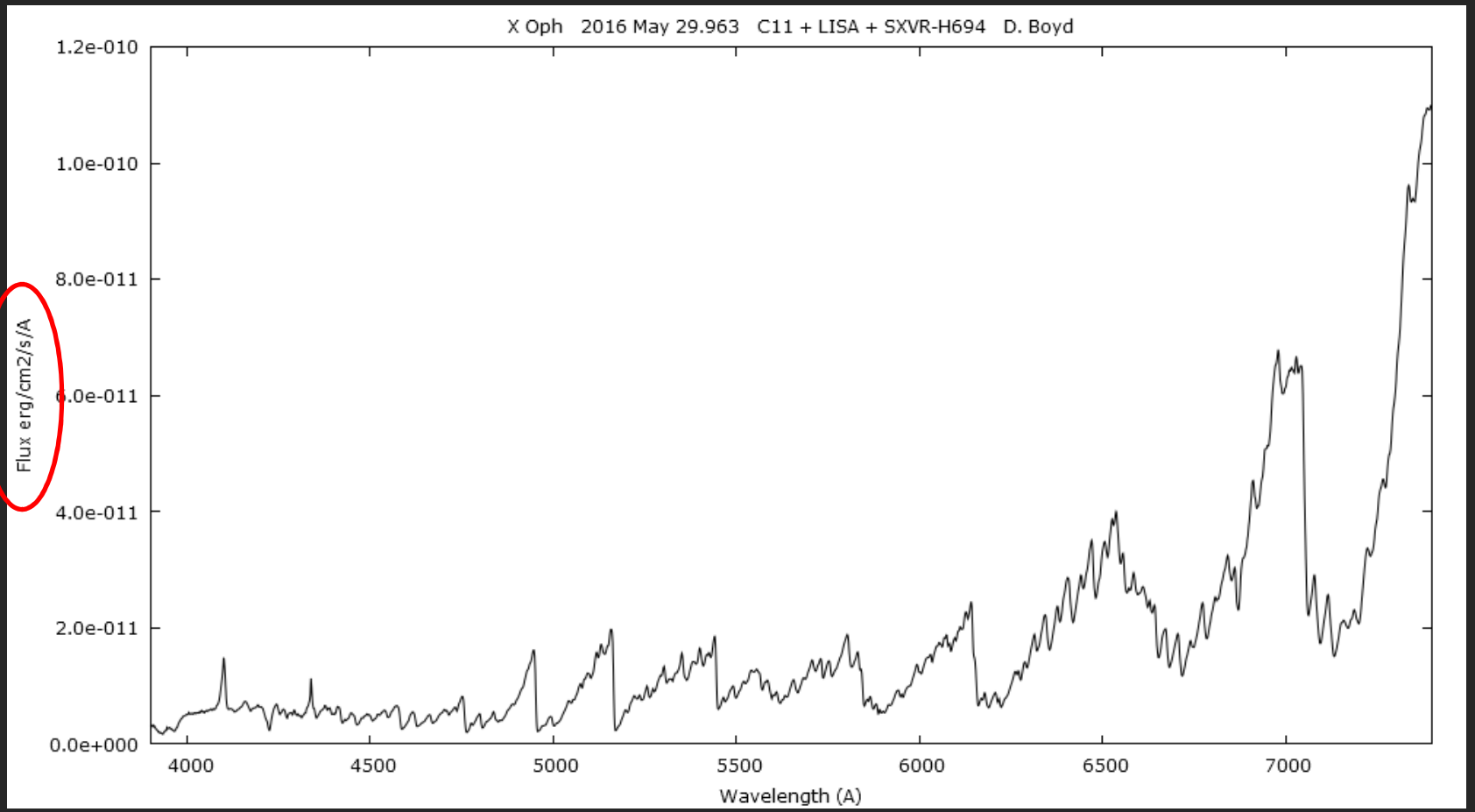


It covers the wavelength range 3900Å to 7400Å with 5Å spectral resolution

Combining photometry and spectroscopy

- This spectrum gives the relative flux (spectral energy) across the spectrum
- If we also have a V magnitude of X Oph recorded at the same time and calibrated with spectrophotometric standard stars, we can convert this relative flux spectrum to an absolute flux spectrum
- We can do this on each date for which we have both a magnitude and a spectrum

This is the same spectrum but now calibrated in absolute flux units

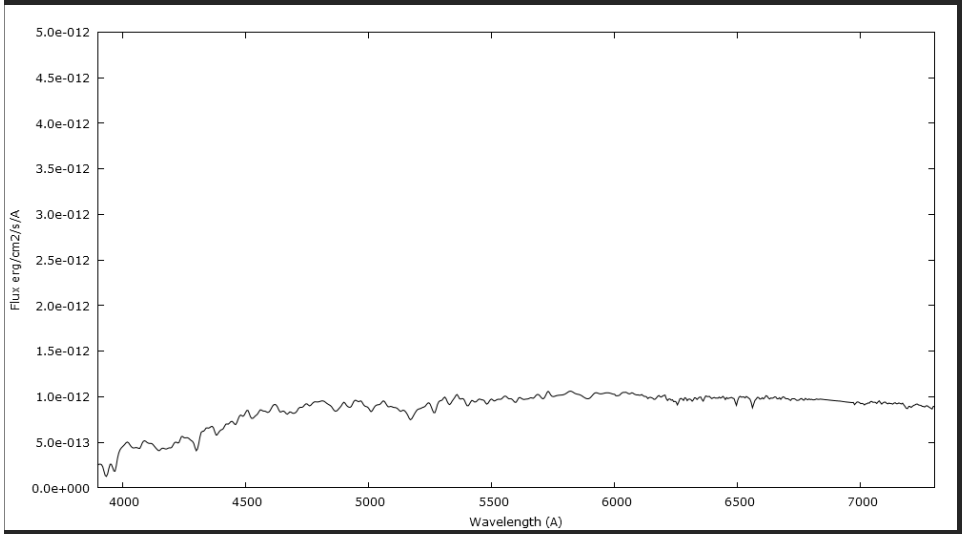


Flux is measured in ergs/cm^2/s/Å

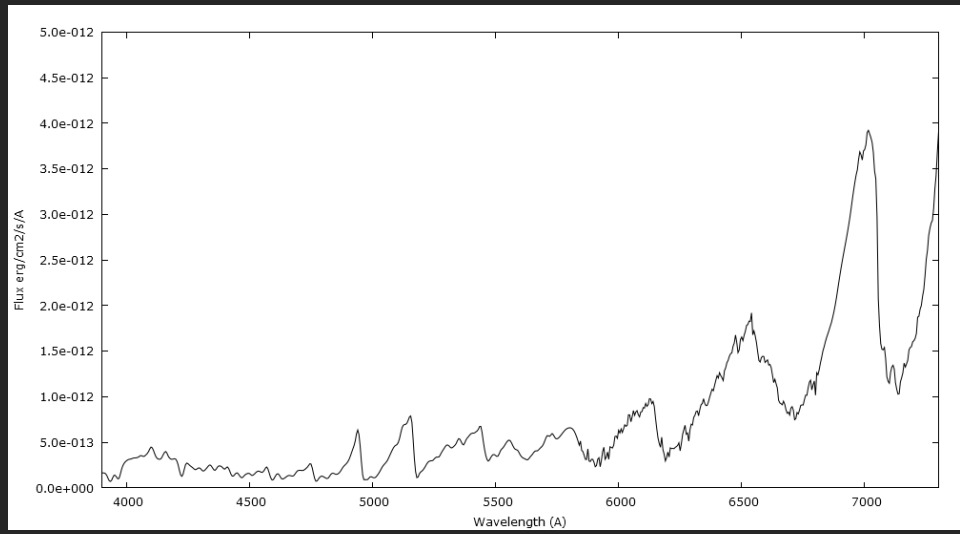
Can spectroscopy help? – potentially yes

- We can measure the absolute flux spectrum of the X Oph binary system on a particular date
- We know this is a sum of the absolute flux contributions of the M and K stars
- The absolute flux contribution of each star depends on its magnitude and spectral type
- Relative flux spectra for various spectral types can be found in the Pickles Stellar Spectral Flux Library
- If we assume magnitudes and spectral types for the two stars, we can synthesise their absolute flux spectra
- We can add these to create a synthesised absolute flux spectrum of X Oph

Example - synthesised spectra for 10 Nov 2016

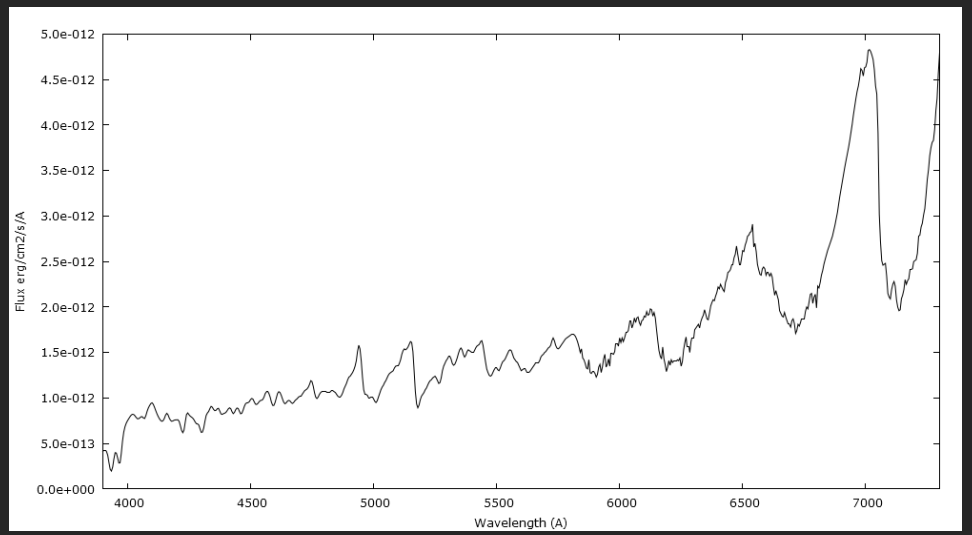


Synthesised K star spectrum with V=9.0 and K1III



Synthesised M star spectrum with V=9.82 and M7III

Flux scales are the same in all plots



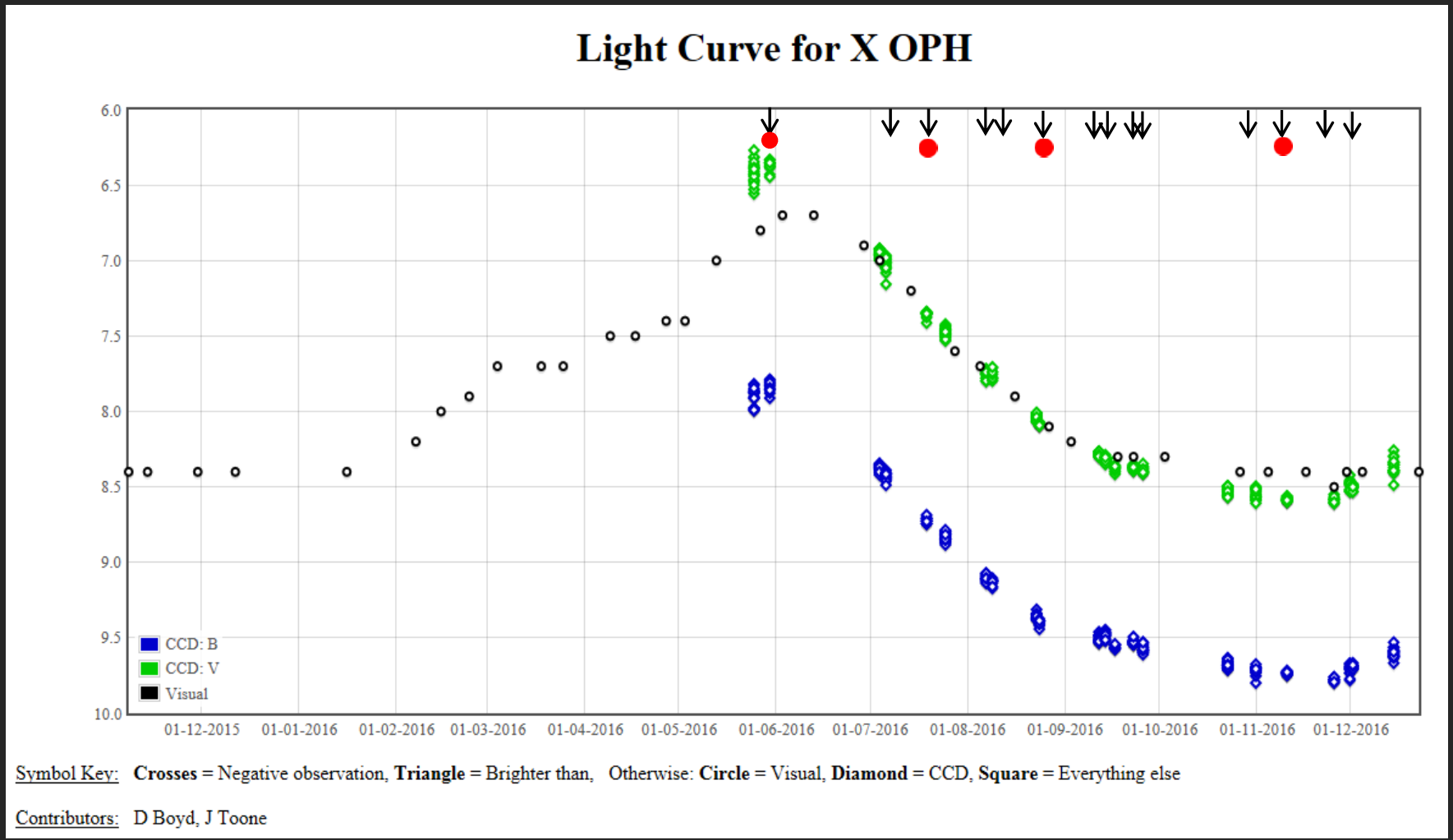
Synthesised X Oph spectrum with combined V magnitude of 8.58

Comparing the synthesised and measured spectra of X Oph

- We can vary the magnitudes and spectral types of the two stars to find the best match between the synthesised and measured spectra on each date
- The independent parameters are:
  - K star magnitude – M star magnitude then follows
  - K star spectral type
  - M star spectral type
- Best match is defined as the smallest rms difference between the synthesised and measured spectra over the wavelength range 3900Å to 7200Å
- Our aim is to look for a consistent set of parameter values over the range of dates
- We can do this for each date on which we measure an absolute flux spectrum and look for a consistent set of answers

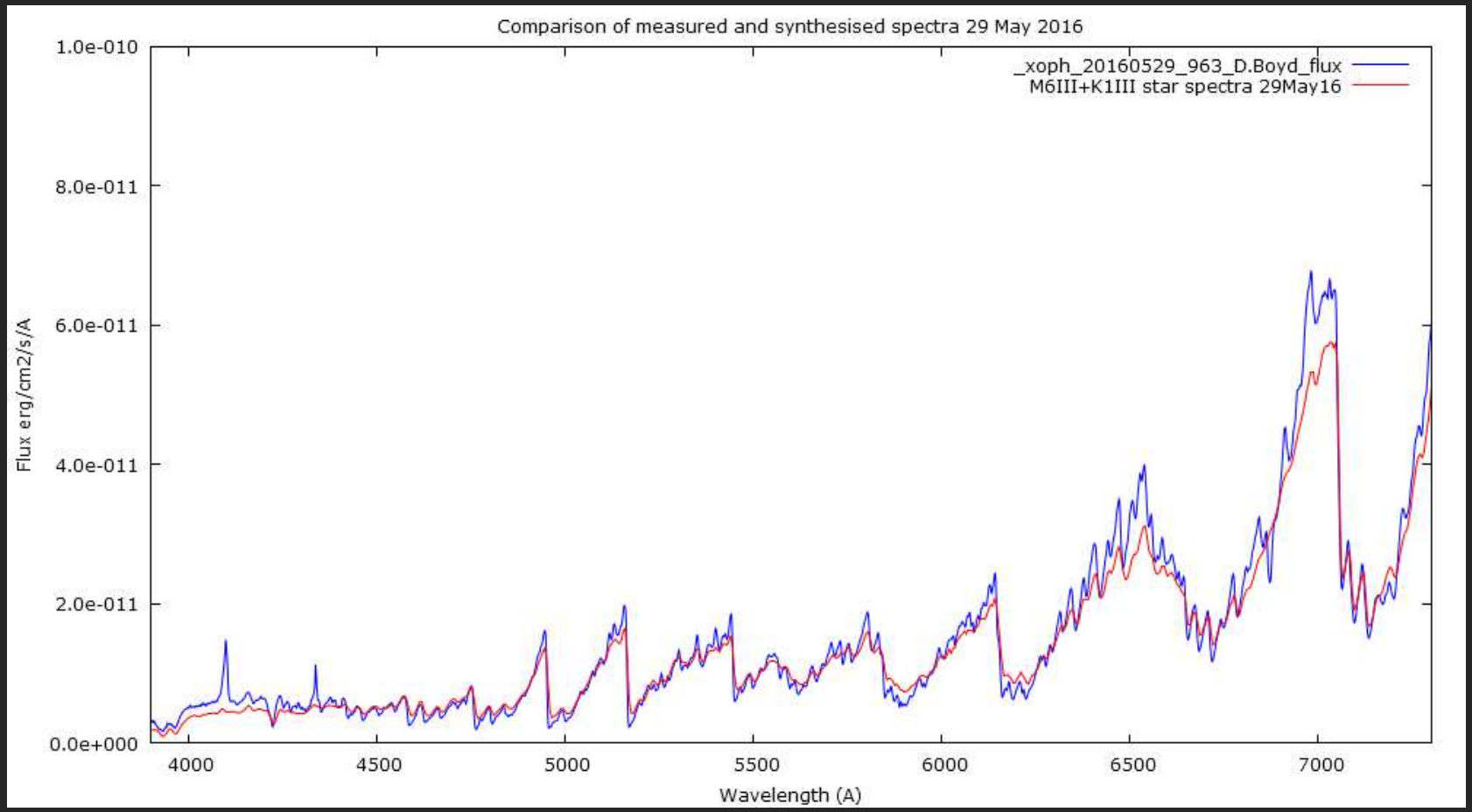
The following slides show results for four dates between maximum and minimum (indicated in red)

- 29 May 2016
- 18 July 2016
- 23 August 2016
- 10 November 2016



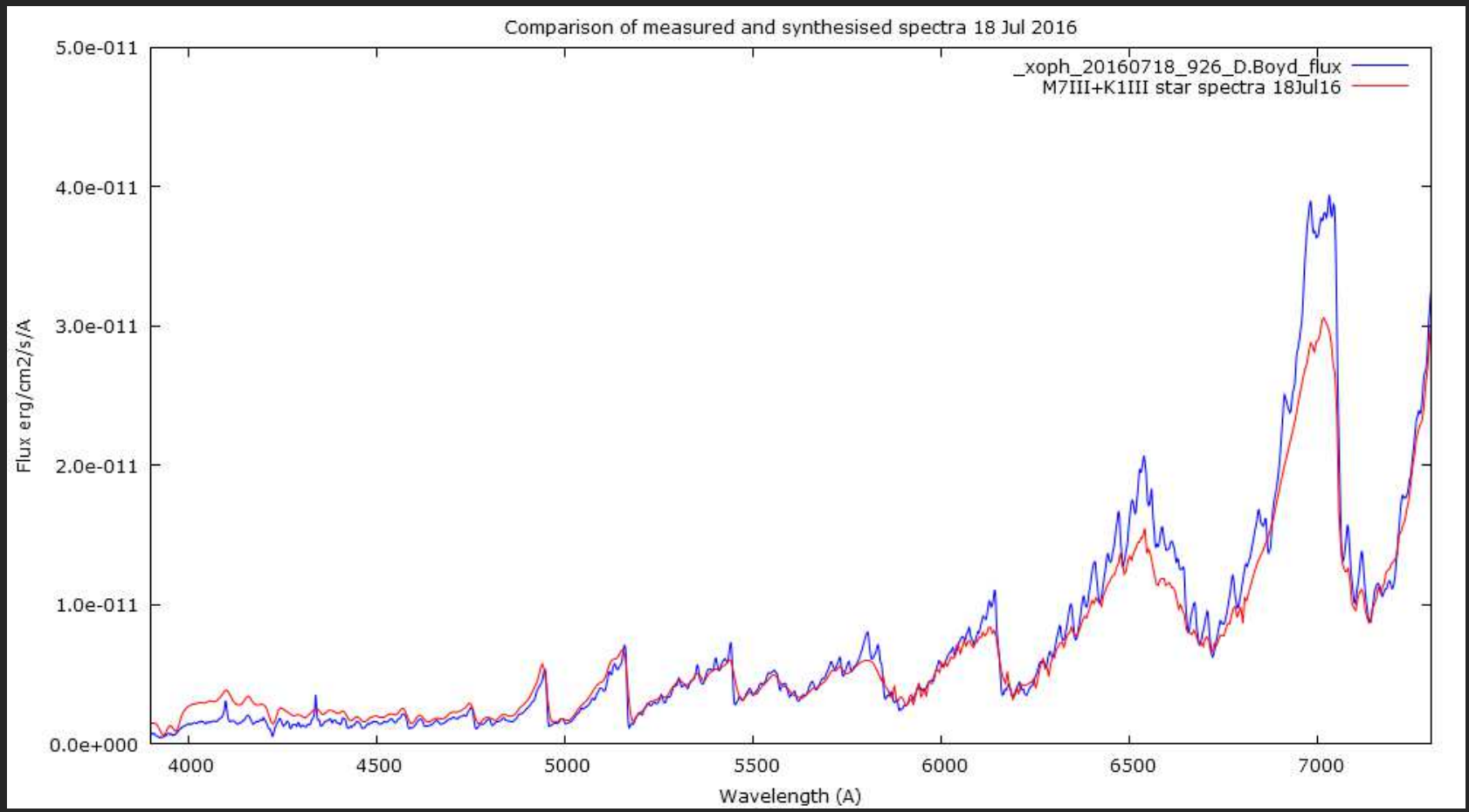
29 May 2016

Best match occurs with spectral types M6III and K1III and V=9.0 as the K star magnitude



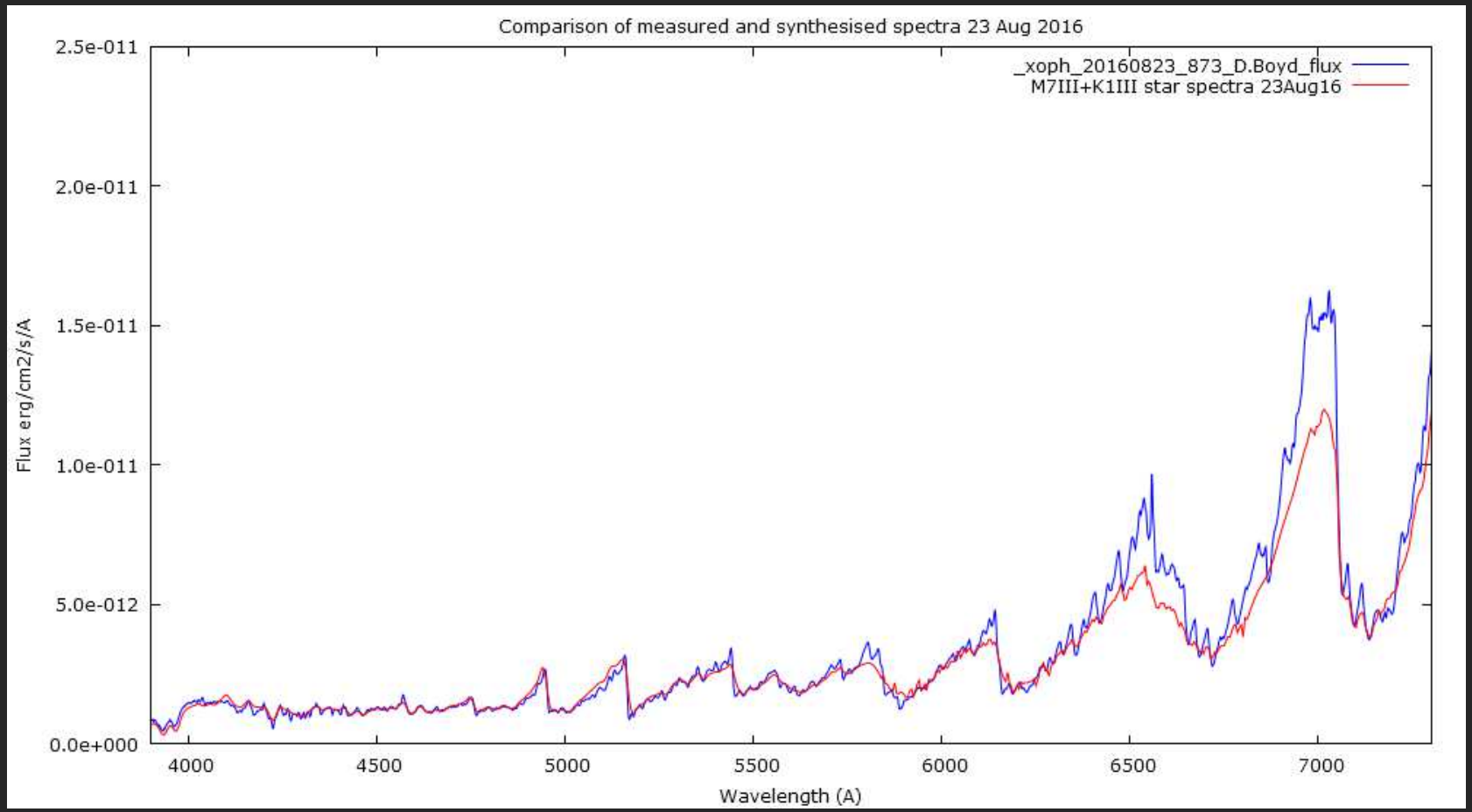
18 July 2016

Best match occurs with spectral types M7III and K1III and V=9.0 as the K star magnitude



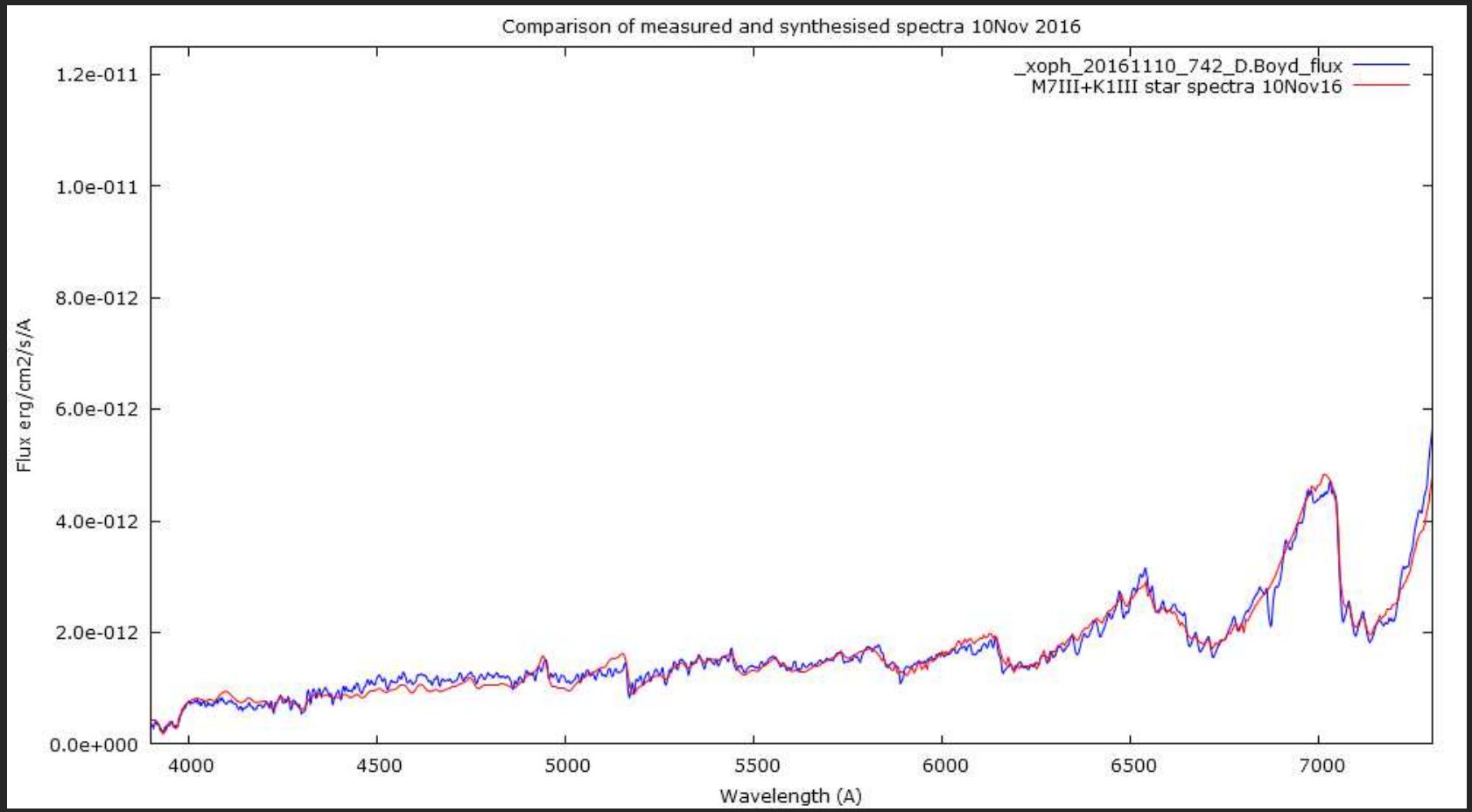
23 August 2016

Best match again occurs with spectral types M7III and K1III and V=9.0 as the K star magnitude



10 November 2016

Best match once again occurs with spectral types M7III and K1III and V=9.0 as the K star magnitude



Conclusions

Given the consistency of these results, my conclusion is that the parameter values for the components of X Oph during the period of these observations are as follows:

- The V magnitude of the K star is 9.0
- The spectral type of the K star is K1III
- The spectral type of the M star is M6III at maximum but changes to M7III as it fades and remains at M7III through minimum
- The V magnitude of the M star varies from 6.47 at maximum to 9.8 at minimum, a range of 3.36 magnitudes and consistent with being a Mira variable

These are the light curves of X Oph and its two components