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HD 13654: PROBABLY NOT AN ECLIPSING BINARY

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Munari (1992) drew attention to HD 13654 as a possible eclipsing, spectroscopic binary on the basis of radial velocity variations and spectroscopic changes. The primary has a well determined spectral type of A3V but this was apparently replaced on one of the ten spectra by a late-type star of spectral type around G9. The interpretation of this change was that the late-type secondary had eclipsed the primary. Given the large velocity amplitude, ~ 140 km s^{-1}, and likely orbital period, a few days, this interpretation seemed appropriate. The blue spectra showed no contamination by the secondary but a red spectrum did show some absorption lines attributable to the secondary. The luminosity change during eclipse is not known but as the secondary is only weakly visible in the red the difference is likely to be at least one or two magnitudes.

In an effort to identify past eclipses in this system the Hewitt Camera Plate Archive, held by the Crayford Manor House Astronomical Society, has been searched. Details of the camera and archive are given by Howarth (1992). The brightness of HD 13654 was estimated visually, using a fixed microscope and light table, on 35 plates taken between 1964 and 1989. The plates are unfiltered and a variety of panchromatic emulsions have been used, Ilford HP3, FP4, HPS and Kodak Professional Royal Pan 4141, which give a very broad band pass. The comparison stars used were BD+58°419 (A2), BD+58°426 (B9) and occasionally BD+58°427 (A0), and are of similar colour to HD 13654. On all the plates HD 13654 was found to be slightly fainter than BD+58°419 at V $\simeq$ 9.8, with no significant variation. No eclipses consistent with the spectroscopic changes were seen. It is possible that the times of the plates were unfortunately placed and real eclipses have been missed. If the eclipse occupies 0.1 in phase, then there is a probability of 0.025 that all 35 plates will miss an eclipse. While this chance is not impossibly small it is very suggestive that the system does not eclipse. Through correspondence with Dr Munari it now appears that there is some doubt over the eclipse spectrum, which may not have been of the correct star.

According to the Hipparcos and Tycho Catalogues (1997) HD 13654 is considered to be a suspected variable with a range in $V_{\rm T}$ of 9.5 – 10.8. However, closer inspection of the Tycho measurements reveals that the errors are very large, particularly for the faint values, and show no significant variation.

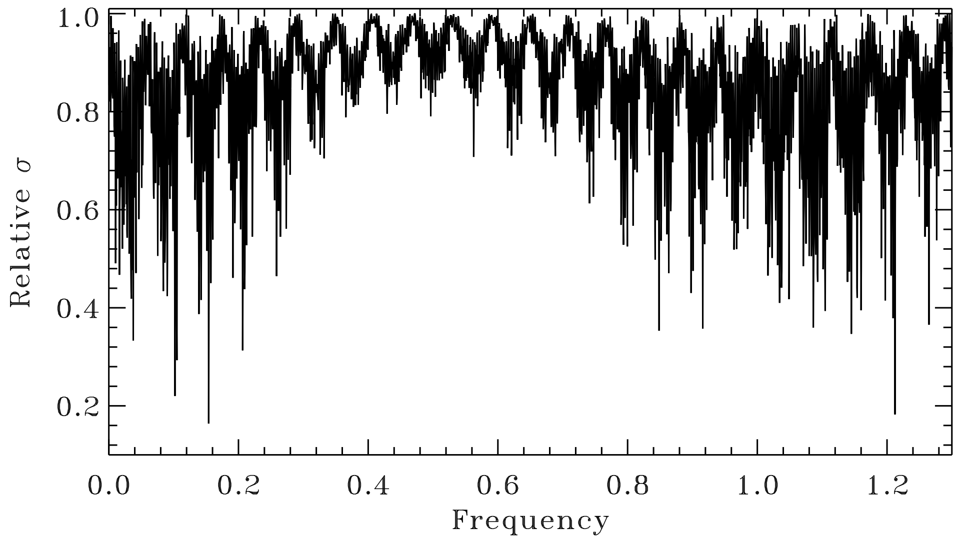

Figure 1. Least squares sine periodogram of the radial velocity measurements

The nine velocity measurements given by Munari have been subjected to a period analysis using a least squares sine periodogram. Although the number of measurements is rather small for this exercise the method is well suited to irregularly spaced, but high signal-to-noise data, much more so that the discrete Fourier methods. Given the large variation there is every expectation that this approach should reveal the correct period, the problem would lie in identifying it among the aliases. In the event aliasing is not too severe. The periodogram is given in Figure 1 and shows the relative standard error of the residuals as a function of trial frequency. Three periods are clearly identified above the rest, these are 9.8, 6.5 and 0.8 days. The periodogram was also calculated with the time of the eclipse spectrum included, using the systemic velocity, but it showed a much poorer reduction in the errors, such that no particular period could be clearly identified, suggesting that this velocity is inconsistent with the rest.

The orbital parameters of the three most likely periods are given in Table 1, together with derived values of the minimum mass of the secondary and minimum inclination of the system, assuming that the secondary in the less massive and less luminous component. The mass of the A3V star is assumed to be 2.1 $M_\odot$ (Allen 1973). It is immediately obvious that in a system with a period of 9.8 days the secondary exceeds this mass, so either the primary should be of an earlier spectral type or both stars should be visible with a similar spectral type. As only a single A-type spectrum is seen it means the 9.8 day period can be eliminated. It is also the least likely of the possible periods.

Table 1: Orbital solutions

Period (days)	K $km\,s^{-1}$	$f(m)$ $M_\odot$	σ $km\,s^{-1}$	$a_1 \sin i$ $R_\odot$	minimum mass	minimum inclination
0.82486±0.00003	69±6	0.028	7.3	1.12	0.11	22
6.4938±0.0033	85±7	0.414	6.3	10.91	2.04	67
9.8048±0.0052	86±7	0.648	7.9	16.66	2.55	90*

* Strictly undefined as the minimum mass is larger that the 2.1 $M_\odot$ assumed

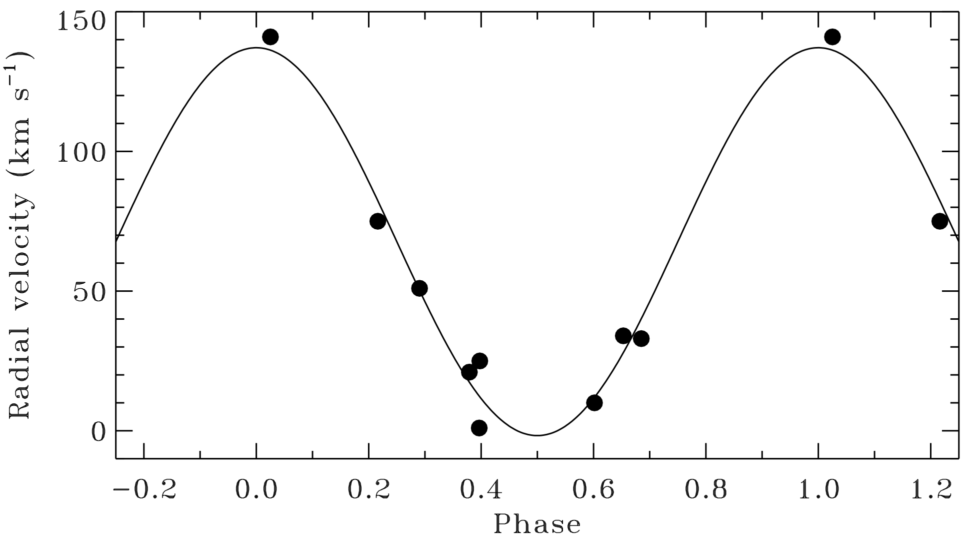

Figure 2. Radial velocity curve from the data of Munari using the 0.82486 day period.

The 6.5 day period gives the smallest residuals but the minimum mass of the secondary is only marginally less than that assumed for the primary. It therefore seems very unlikely that there would be a sufficient luminosity difference between the two for the secondary to pass unnoticed. Also, for this minimum mass, the inclination would be 90 degrees and the system would be eclipsing. If the photographic results are to be believed, the system is probably not eclipsing and avoiding this condition would increase the minimum mass, and with it, the visibility of the secondary.

For the 0.82 day period, both the minimum mass of the secondary and minimum inclination are correspondingly lower, so it is possible for the system to contain a secondary that is spectroscopically invisible. Assuming that the secondary is at least one magnitude fainter than the primary it will have a mass $m_2 < 1.5$ M$_\odot$ and the system will have an inclination, $i > 28$ degrees. However, the size of the system and radii of the components ($r_1 = 1.9, r_2 = 1.3$ R$_\odot$) means that system will be eclipsing for $i > 56$ degrees. Depending on the precise values of all the relevant parameters (for $m_2 = 0.7$ M$_\odot$, $r_2 = 0.7$ R$_\odot$ then $i > 60$ degrees will eclipse) there is still a range of inclinations, $i \sim 28 - 60$ degrees, where the system does not eclipse and stars of appropriate masses and luminosities may be accommodated. The orbital solution for this period is shown in Figure 2.

Irrespective of the periods suggested by the periodogram, dynamical arguments point to a short period; with 0.82486 days as the most likely candidate from the period analysis. Periods of less than one day are relatively common for A-type binaries and a wide range of secondaries is possible. Given the weak visibility of the secondary it is probably towards the lower end of the possible mass range, $0.7 < m_2 < 1.5$ M$_\odot$, giving an F or G star, with $28 < i < 60$ degrees.

It is a pleasure to thank Dr Munari for helpful correspondence on this system.

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