

SS 433 – On masses and He II emission line data

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Abstract.

For very many years the recessional velocity variation of the He II line at 4686 Å has been taken as a measure of the orbital velocity of the accreting black hole, powering microquasar SS 433. A recent paper has presented an extensive data set in which this emission line is not eclipsed by the donor Companion, thereby casting doubt on such use. The mass of the compact object can be obtained without knowing the speed of the compact object; knowledge of the mass ratio determines this speed. The resulting value is in agreement with the recessional velocity variation of C II emission lines; lines eclipsed by the Companion to the same extent as the photosphere of the accretion disk. The mass of the black hole is $\sim 15 M_{\odot}$.

1. Introduction.

Since 1990 the variation in radial velocity of the He II emission line at 4686 Å has been taken as yielding the orbital velocity of the compact accretor in this remarkable binary. This velocity is ~ 175 km/s (Fabrika & Bychkova 1990, Fabrika 1997) and has been used in attempts to extract the masses of the binary and its components, for examples see Hillwig et al 2004, Blundell et al 2008, Bowler 2018. A recent paper (Dodin et al 2026) analysing a large data set finds that the He II line therein is not eclipsed by the Companion, in that it doubles in intensity relative to the continuum background during eclipse of the latter. The implication is that the source lies far outside the photosphere and hence cannot be relied upon to share the speed of the compact object (Dodin et al 2026). In the light of these new data, I have returned to earlier work (Blundell et al 2008, Bowler 2018) to investigate what can survive discarding knowledge of the speed of the compact object.

2. The circumbinary disk

The circumbinary disk was first observed and established as reported in Blundell et al 2008; understanding of these data improved later and the most complete discussion is to be found in Bowler 2013. The essential ingredient is that the inner ring of a stable circumbinary disk is located at a radius $\sim 2A$ from the centre of mass of the binary system, where A is the separation of the two components. Then, from the dynamics of circular orbits, the relevant equations (from Blundell et al 2008) are

$$\frac{R}{r} = f(q)(1 + q) \quad (1)$$

$$\frac{V}{v} = (1 + q)/\sqrt{f(q)} \quad (2)$$

$$M = 1.35f(q)^{1.5} \left(\frac{V}{100}\right)^3 \quad (3)$$

In these equations R is the radius of the inner rim of the disk, related to A by $R = f(q)A$, where $f(q)$ (slowly varying with the mass ratio q) is ~ 2 . V is the rotational velocity of the inner rim of the disk, v the orbital speed of the compact object. In (3) the mass of the system M is in solar masses, V in km/s and the coefficient is for a period of 13.08 days. I take as known the ratio R/r (2.62; Bowler 2018) and V (240 km/s; Bowler 2013). Then from (1) q is determined as a function of $f(q)$, from (2) v is determined (if not known) and the mass of the binary system is determined by (3). From $q = m/M$ and the mass of the system is calculated

the mass of the compact object m and of the companion M . Everything of interest is listed, as a function of the one unknown $f(q)$, in the Table below.

Table

$f(q)$	q	V/v	v km/s	M	m
2.0	0.31	0.92	260	53	12.5
1.9	0.38	1.0	240	49	13.4
1.8	0.46	1.09	220	45	14.1
1.7	0.54	1.18	203	41	14.4
1.6	0.63	1.28	188	38	14.7
1.5	0.75	1.43	168	34	14.6
1.4	0.87	1.58	152	31	14.4
1.3	1.0	1.76	136	28	14.0

The mass of the binary system M and the orbital speed of the compact object v vary by a factor of 2 over the plausible range for $f(q)$. In contrast, the mass of the compact object is rather tightly constrained.

3. Other constraints, independent of He II emission lines

The first of these constraints is an entirely independent determination of the mass ratio q , derived from the very slow change in the period of the binary orbit (Cherepashchuk et al 2018). That value is 0.72; the table above shows that this is sufficient to establish a compact mass $\sim 15M_{\odot}$ and corresponds to an orbital velocity of the compact object ~ 175 km/s. This is of course the value for long taken for granted.

The second constraint is from a measure of the velocity of the compact object from C II emission lines eclipsed (twice) by the companion. These data (Bowler 2020) track a C II doublet over two orbital cycles, day by day. Relative to the continuum, these lines retain a constant intensity; they are eclipsed. A nearby He I line doubles in relative intensity during eclipse; it is not eclipsed. The radial velocity variation of C II corresponds to a source orbiting with a speed of 176 km/s. This matches the speed inferred from the constancy of period and again is approximately the traditional value. Applying either of these constraints to the Table gives everything; alternatively this pair of constraints give the same results without reference to the circumbinary disk.

4. Remarks on He II emission line data

The ancient data analysed in Fabrika & Bychkova 1990, Fabrika 1997 yielded a velocity for the compact object ~ 175 km/s and the authors report that their sample is almost totally eclipsed by the Companion (see also Fig. 4 in Hillwig et al 2004). Given the results above, it seems very likely that in fact they had found a true measure of the orbital velocity of the compact object. The data in Dodin et al 2026 seem to have been drawn from He II emission under very different circumstances, from sources remote from the compact object that perhaps did not contribute to the data of 1990, 1997. There are two reasonably well understood possible sources, as far as one can judge from He I lines. The first is the circumbinary disk itself (Bowler 2013); treated as in Dodin et al 2026 I would expect such a hypothetical source to yield an apparent orbital velocity ~ 150 km/s. The second is the wind from the accretion disk (Bowler 2011); the apparent orbital speed depending on how long emission from a particular wind packet lasts. This is an attractive possibility, for winds can be intermittent and gusty. A short lived source would track the compact object; longer lived packets smear the orbital velocity and retain a reduced memory, perhaps ~ 120 km/s. Either

possibility could match the data in Dodin et al 2026 but even this is speculative; what happens during possible optical flares, or in other gas streams that could act as a source of He II, is beyond speculation.

5. Conclusion

The data displayed in Dodin et al 2026 demonstrate that there can exist in SS 433 sources of the He II emission line that are not eclipsed by the Companion and therefore cannot be relied upon to track the radial velocity variation of the compact object. I conclude that there are sufficient other data to bypass use of He II lines if necessary, determining the mass of the compact object to be $\sim 15M_{\odot}$ and its orbital velocity to be ~ 175 km/s, like the original result from He II in Fabrika & Bychkova 1990, Fabrika 1997.

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