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Comment on "A non-interacting low-mass black hole – giant star binary system"

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Thompson et al. (Reports, 1 November 2019, p. 637, Science) interpreted the unseen companion of the red giant star 2MASS J05215658+4359220 as most likely a black hole. We argue that if the red giant is about one solar mass, its companion can be a close binary consisting of two main-sequence stars. This would explain why no X-ray emission is detected from the system.

Thompson et al. (*1*) argued that the invisible companion in a 83-day orbit around the red giant star 2MASS J05215658+4359220 is most likely a black hole, with a mass of $3.3^{+2.8}_{-0.7}$ solar masses ($M_\odot$). If this companion was a normal non-degenerate star, its light would have been detectable in the spectral energy distribution (SED) of the red giant, but was not.

This approach assumes a normal single unseen companion star. However, in wide binaries the companion can itself be a closer binary composed of two normal stars with an orbital period of the order of a few days. Such hierarchical triple systems are quite common (*2*). The luminosity L of a main sequence star depends strongly on its mass M ($L \propto M^{3.5}$), so a close binary consisting of two stars of equal mass has a luminosity about 6 times smaller than that of a single star with their combined mass. The light of such a binary companion might be undetectable in the SED of the red giant.

Thompson et al. argue that the red giant most likely has a mass of $3.2\ M_\odot$, but show that its high carbon-to-nitrogen ratio [C/N] is consistent with a lower mass of $1\ M_\odot$ (*1*). Spectroscopic determination of a red giants mass from model atmospheres can be uncertain by a factor of 3 (*3*), which would allow for a red giant mass of about $1\ M_\odot$.

For the higher red giant mass, the companion is $3.3^{+2.8}_{-0.7}\ M_\odot$. If it were a close binary, the binary components would be $\sim 1.65\ M_\odot$ each, which would have been detectable in the SED of the red giant (*1*). In this case a black hole companion is the only remaining possibility.

In the alternative case of a $1\ M_\odot$ red giant, the mass of the unseen companion is $\geq 1.8\ M_\odot$ (*1*), so the companion could be a very close binary of two main-sequence stars of about $0.9\ M_\odot$, each, which would be of spectral type K0-4V with 0.44 solar luminosities ($L_\odot$) (*4*). Their combined luminosity would be less than 0.5% of the $> 200\ L_\odot$ luminosity of the red giant, which is undetectable.

Such a triple star system is expected to be dynamically stable if the ratio between the semi-major axis of the outer star and that of the inner binary is $\gtrsim 3.0$ (*5*). Using Keplers third law, the upper limit on the orbital period of the inner binary is ~ 20 days. This would be consistent with a wide range of possible binaries, including very close systems of K-type main sequence stars. These are common, and often have a distant third companion (*6*).

A black hole that accretes matter from the red giants wind would form an accretion disc, which might be detectable in X-ray emission. The physics of accretion of neutron stars and black holes is very similar. In both cases the accreting object becomes a strong X-ray source. There are thirteen known red-giant X-ray binaries, known as symbiotic X-ray binaries (*7, 8*). Six of them are regularly pulsating X-ray sources (*8*), showing that neutron stars accreting from the winds of red giants produce sources with X-ray luminosities, $L_X = 10^{32}$ to $10^{36}\ \mathrm{erg\,s^{-1}}$. We expect similar values for accreting black holes. As Thompson et al. (*1*) show, using Bondi–Hoyle accretion (*9*), for typical red giant wind velocities, the black hole in the $3.2\ M_\odot$ giant case will capture 1% of the total red-giant mass loss rate.

The wind mass-loss rate of red giants is given by (*10*):

$$\dot{M}_\mathrm{w} = 4 \times 10^{-13}\ \eta_R\, L\, R\, M^{-1} \qquad M_\odot\,\mathrm{yr}^{-1} \tag{1}$$

where η_R is the efficiency parameter for wind mass loss and L, R and M are the luminosity, radius and mass of the giant in solar units. Observations of red giant wind mass loss (*11*) show $\eta_R = 0.477 \pm 0.070$. Applying the nominal values for 2MASS J05215658+4359220, $L = 331\ L_\odot$, $R = 30\ R_\odot$ (*1*), and assuming the X-ray energy release $\Delta U = 0.1\ mc^2$ for a mass m accreted onto a black hole, we obtain $L_X = 2.5 \times 10^{34}\ \mathrm{erg\,s^{-1}}$ for a 3.2 $M_\odot$ giant with a 3.3 $M_\odot$ black hole. Thompson et al. (*1*) find a lower expected value of $L_X = 1.4 \times 10^{33}\ \mathrm{erg\,s^{-1}}$. Such X-ray luminosities would be easily detectable, but no X-ray emission from the system is observed.

We consider a $1\ M_\odot$ red giant with a close-binary companion to be more consistent with the observational constraints on this system as it does not produce detectable light, nor X-ray emission, and the high [C/N] abundance ratio is normal for a $1\ M_\odot$ red giant (*1*). A $3.2\ M_\odot$ red giant with a companion black hole would make this system unusual on three independent accounts: i) the [C/N] ratio of the giant would be unusually high for giants of this mass; ii) it has a black hole of unusual mass; and iii) an explanation must be found for the lack of X-ray emission.

We conclude that the unseen companion of 2MASS J05215658 might not be a black hole.

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References

1. T. A. Thompson, *et al.*, *Science* **366**, 637 (2019).
2. S. Rappaport, *et al.*, *Astrophys. J.* **768**, 33 (2013).
3. J. Auman, Jason R., *Astrophys. J.* **157**, 799 (1969).
4. G. Torres, J. Andersen, A. Giménez, *Astron. Astrophys. Review* **18**, 67 (2010).
5. S. Mikkola, *Multiple Stars Across the H-R Diagram*, S. Hubrig, M. Petr-Gotzens, A. Tokovinin, eds. (2008), p. 11.
6. A. Tokovinin, *Mon. Not. R. Astron. Soc.* **389**, 925 (2008).
7. R. H. D. Corbet, J. L. Sokoloski, K. Mukai, C. B. Markwardt, J. Tueller, *Astrophys. J.* **675**, 1424 (2008).
8. L. R. Yungelson, A. G. Kuranov, K. A. Postnov, *Mon. Not. R. Astron. Soc.* **485**, 851 (2019).
9. K. Davidson, J. P. Ostriker, *Astrophys. J.* **179**, 585 (1973).
10. D. Reimers, *Memoires of the Societe Royale des Sciences de Liege* **8**, 369 (1975).
11. I. McDonald, A. A. Zijlstra, *Mon. Not. R. Astron. Soc.* **448**, 502 (2015).