Apparently Ultra-long Period Radio Sources from Self-lensed Pulsar Black Hole Binaries

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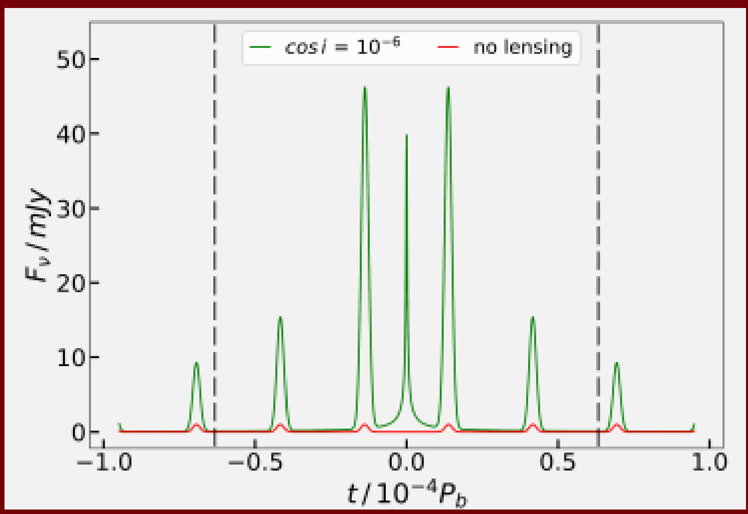
Abstract: Pulsar-black hole (BH) binary systems, which have not been found yet, are unique celestial laboratories for testing relativistic theories of gravity and understanding the formation of gravitational wave sources. We study the self-gravitational lensing effect in a pulsar-BH system on the pulsar's emission. Because this effect magnifies the pulsar signal once per orbital period, we find that it may generate apparently ultra-long period (hours to days) radio signals when the intrinsic pulsar signal is undetectable. We estimate that there may be hundreds of such systems in our galaxy that are observable for a radio telescope with a sensitivity of $\sim 10\ mJy$. The model is applied to two recently found puzzling long-period radio sources: J162759.5-523504.3 and PSR J0901-4046. If these two sources are self-lensed pulsar-BH systems, the BH mass will be $\sim 10^4$ and $\sim 10^2$ solar masses, respectively. Their coalescence time will become so small (~year) that they should have merged by now.



The light curve of the self-lensed pulses.

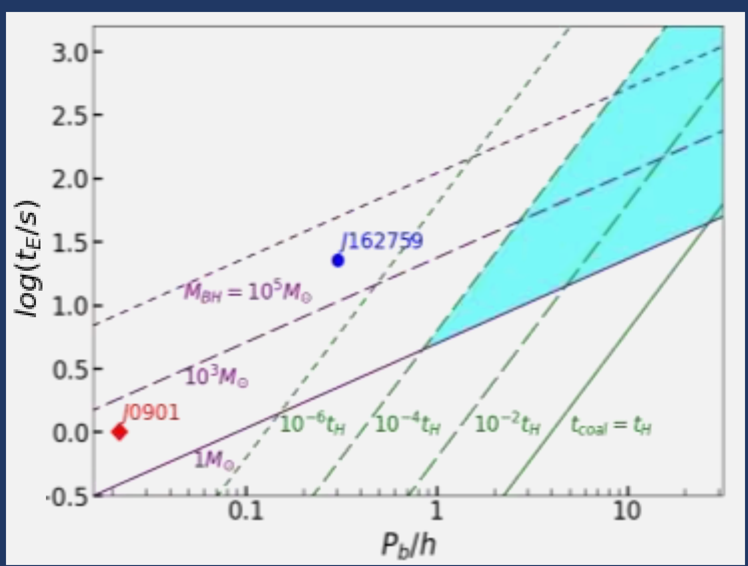
-- As pulsars are compact object, they can be treated as point-like sources. Thus the amplification of point source can be used :

$$A = \frac{u^2+2}{u\sqrt{u^2+4}} \approx \begin{cases} u^{-1}, & for\ u < 1 \\ 1+2u^{-4}, & for\ u \geq 2 \end{cases}$$

-- Assuming gaussian shape intrinsic pulses: $F(t) = F_p e^{[-2(\pi t/\rho)^2]} + F_0, -P/2 < t < P/2$

-- The flux of self-lensed pulses can be derived by: $F_{lens}(t) = A(u)F(t)$

-- In the figure: The green and red lines are corresponding to the self-lensing and intrinsic situation. The intrinsic emission from pulsar would be significantly brightened in an edge-on scenario. As the self-lensing effect happens in every orbital period, the lensed pulses will consist of apparently ultra-long period (hours to days) radio signals when the intrinsic pulsar signal is undetectable.

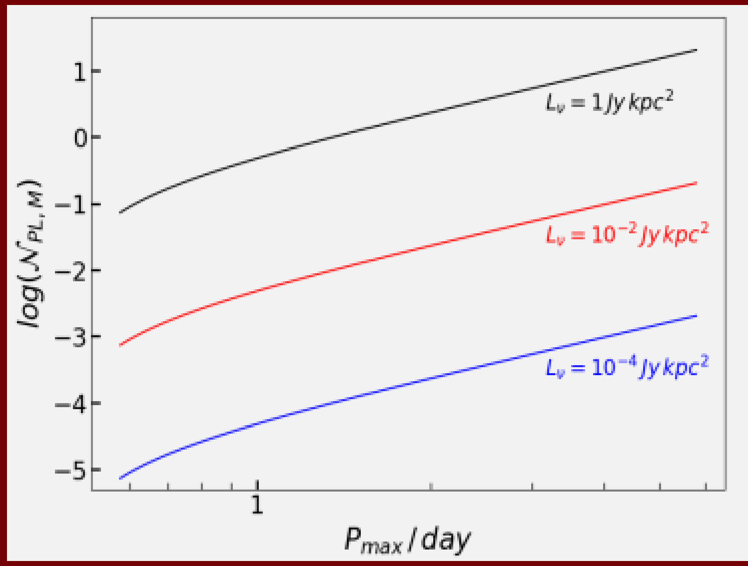


The parameter space

-- Taking the duration of the ultra-long period signal as Einstein transverse time t_E and the signal period as orbital period P_b.

-- Considering the coalescence time and BH mass, binaries in cyan area are ideal candidate for such signal, since they would not merge in a short time and the orbital period (hours to days) is not too long.

-- The recently found puzzling radio source: the 18.2 min J162759 and the 76s J0901 are also plotted, while they are more extreme case in our model.



The number of observable systems in the Milky way

-- The so-called optical depth of a lensing system τ, and the distribution of compact binary as the function of orbital period and BH mass are considered in the estimation for those binaries generate self-lensing effect:

$$\tau(A) = \frac{\pi R_E^2}{4\pi a^2} u^2(A); \quad N_{l,MW} = \int\int \rho(P_b, M_{BH})\, \tau(A)\, dP_b dM_{BH}$$

-- Assuming the intrinsic luminosity L_ν of pulsars are the same further and considering a telescope with $10\ mJy$ sensitivity. The amplification A is constrained by L_ν

-- There would be at most tens to hundred observable systems with ideal orbital period observed.

Conclusion:

-- The self-lensing effect in Pulsar-BH binaries would brighten the intrinsic emission from pulsar, which make it possible to observe those dim pulsars and generate unique ultra-long period radio signals, showing up as a slow pulsar.

-- Considering the coalescence time and BH mass, the ideal binaries for such signals should hours to days orbital period.

-- The recently found puzzling radio source: the 18.2 min J162759 and the 76s J0901 may not be the system we proposed. If they are, then a short coalescence time (~year) will be derived, which means they should have merged.

-- There would be at most tens to hundred observable systems observed in our galaxy.