Draft version February 11, 2022
Typeset using LaTeX **modern** style in AASTeX61

A HOT SUBDWARF MODEL FOR THE 18.18 MINUTE PULSAR GLEAM-X

Abraham Loeb[1] and Dan Maoz[2]

[1] *Astronomy Department, Harvard University, 60 Garden St., Cambridge, MA 02138, USA*

[2] *School of Physics & Astronomy, Tel Aviv University, Tel Aviv 69978, Israel*

ABSTRACT

We suggest that the recently discovered, enigmatic pulsar with a period of 18.18 minutes, GLEAM-X J162759.5-523504.3, is most likely a hot subdwarf (proto white dwarf). A magnetic dipole model explains the observed period and period-derivative for a highly magnetized ($\sim 10^8$G), hot subdwarf of typical mass $\sim 0.5 M_\odot$ and radius $\sim 0.3 R_\odot$, and an age of $\sim 3 \times 10^4$ yr. The subdwarf spin is close to its breakup speed and its spindown luminosity is near its Eddington limit, likely as a result of accretion from a companion.

INTRODUCTION

A recent analysis of archival low-frequency radio data collected by the Murchison Widefield Array (MWA), has revealed an unusual pulsar in the Milky-Way, GLEAM-X J162759.5-523504.3, with a period of $P = 1091.1690(\pm 0.0005)$ s ($\approx$18.18 minutes) and a best-fit period derivative of $\dot{P} = 6 \times 10^{-10}$s s^{-1} (Hurley-Walker et al. 2022). The data set a maximum on the potential spin-down luminosity of a neutron star source, $\dot{E} < 1.2 \times 10^{28}$ erg s^{-1}, which is a few thousand times lower than the brightest pulses inferred for GLEAM-X, 4×10^{31} erg s^{-1}. As noted by the discovery team, the radio luminosities of pulsars usually constitute only a small fraction of their spindown luminosity, and therefore a neutron star origin for this pulsar is untenable. Below we show that a hot subdwarf (HSD) pulsar, a stellar core evolving towards a white dwarf state but not yet fully degenerate, satisfies the observational constraints.

MODEL

A misaligned rotator model for a pulsar consisting of a dipole magnetic field, B, and radius, R, yields a spindown luminosity,

$$\dot{E} = \left(\frac{4\pi^4}{9c^3}\right)\left(\frac{B^2R^6}{P^4}\right) = 10^{38} \text{ erg s}^{-1} \left(\frac{B}{10^8\text{G}}\right)^2 \left(\frac{R}{0.3R_\odot}\right)^6 , \quad (1)$$

where we have adopted an average value of $\sim 1/3$ for $\sin^2 \alpha$, with α the angle between the magnetic moment and the rotation axis (Shapiro et al. 1985). Indeed, AR Scorpii is a recently discovered 2-min period pulsar in a 3.5-hr orbit with an M-type star, in which the pulsar is powered by the spindown of a white dwarf with $B \lesssim 10^8$ G (Marsh et al. 2016; Buckley et al. 2017; Garnavich et al. 2021). Emulating that system but with typical HSD mass $M = 0.5(\pm 0.1)\ M_\odot$ (Zhang et al. 2009; Lynas-Gray 2021) and radius $R = 0.25(\pm 0.15)R_\odot$ (Heber 2009; Rebassa-Mansergas et al. 2019), suggests that the spindown luminosity could easily power the radio emission from GLEAM-X. Interestingly, the value of $\dot{E}$ for $B \sim 10^8$ G is close to the Eddington luminosity limit for a HSD mass of $M \sim 0.5M_\odot$, possibly maintaining a puffed-up HSD radius of $R \sim 0.3R_\odot$. The lack of a strong X-ray or UV counterpart for the radio detection may indicate that the HSD is young and still obscured in these spectral bands by the envelope of its red giant progenitor.

The spindown time in the magnetic dipole model is given by,

$$\frac{P}{\dot{P}} = \left(\frac{9c^3}{2\pi^2}\right)\left(\frac{IP^2}{B^2R^6}\right) = 2.5 \times 10^{12} \text{ s} \left(\frac{M}{0.5M_\odot}\right)\left(\frac{B}{10^8\text{G}}\right)^{-2}\left(\frac{R}{0.3R_\odot}\right)^{-4} , \quad (2)$$

where $I = (2/5)MR^2$ is the moment of inertia for a star of mass M and radius R. The measured value of $(P/\dot{P}) \approx 2 \times 10^{12}$ s, agrees naturally with the parameters of a highly magnetized HSD. It implies an age of $\sim (P/2\dot{P}) \sim 3 \times 10^4$yr for the HSD pulsar, which is consistent with a stellar remnant that has yet to cool to a white dwarf (Fleury et al. 2021). HSDs with rotation periods similar to that of GLEAM-X are known to exist (Kupfer et al. 2019).

CONCLUSIONS

The breakup period of a HSD,

$$P_{\rm break} \sim 2 \left(\frac{GM}{R^3}\right)^{-1/2} = 800 \text{ s} \left(\frac{M}{0.5 M_\odot}\right)^{-1/2} \left(\frac{R}{0.3 R_\odot}\right)^{3/2}, \quad (3)$$

is comparable to the observed period of GLEAM-X, making the observed rotation period physically plausible for a HSD that was spun up close to its maximum possible spin by accretion from a companion. The sporadic appearance of the observed pulses from the source, perhaps during only $\sim 2\%$ of the time, also suggests the presence of a companion star, which endowed the HSD pulsar with its rapid spin and high magnetic field.

In AR Scorpii (Marsh et al. 2016; Buckley et al. 2017; Garnavich et al. 2021), the companion M-type star is not in synchronous orbit with the white dwarf spin. A similar configuration in GLEAM-X would produce a few-seconds modulation in the pulse arrival time owing to the light travel time (Roemer delay), which in principle may be detectable in the existing data. The absence of such modulation would suggest either a lack of a companion (since birth, or after evolution - e.g. explosive destruction or unbinding of, or merger with, the companion) or a compact companion in an orbit that has been tidally synchronized with the HSD spin.

ACKNOWLEDGEMENTS

This work was supported in part by Harvard's *Black Hole Initiative*, which is funded by grants from JFT and GBMF (for A.L.). D.M. acknowledges support by European Research Council (ERC) FP7 Grant No. 833031, and grants from the Israel Science Foundation (ISF) and the German Israeli Science Foundation (GIF).

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