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# Period distribution of pulsars in the Magellanic Clouds: Propeller line versus Equilibrium period

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## 1 Introduction

A majority of HMXBs in LMC and SMC are transient X-ray sources which occasionally exhibit short powerful outbursts while spend most of the time in quiescence. As recently recognized [1] the quiescent states of some transients in the logarithmic diagram X-ray Luminosity — Pulsation Period fall on the straight line with the slope $\mathbf{-2.32 \pm 0.09\,(1\sigma)}$. The authors interpreted this line as the propeller line [2], below which accretion onto a neutron star faces a centrifugal barrier and stops. We point, however, that the equilibrium rotation of the pulsars can be an alternative interpretation of the finding.

## 2 Accretion scenarios

**Non-magnetic accretion** of gas onto a neutron star: The radius of magnetosphere is about the Alfvén radius

$$r_{\rm A} \sim \left(\frac{\mu^2}{\dot{\mathfrak{M}}\,(2GM_{\rm ns})^{1/2}}\right)^{2/7}. \qquad (1)$$

Here $\mu$ is the dipole magnetic moment of a neutron star, $\dot{\mathfrak{M}}$ is the mass accretion rate, $M_{\rm ns}$ is the mass of a star and $G$ is the gravitational constant.

**Magnetic levitation accretion** is a scenario in which a neutron star accretes from a non-Keplerian magnetically levitating disc (ML-disc), which is approaching the star up to the magnetospheric radius [3]:

$$r_{\rm ma} \sim \left(\frac{c\,m_{\rm p}^2}{16\sqrt{2}\,e\,k_{\rm B}}\right)^{2/13} \frac{\alpha_{\rm B}^{2/13}\mu^{6/13}\,(GM_{\rm ns})^{1/13}}{T_0^{2/13}\,\dot{\mathfrak{M}}^{4/13}}. \qquad (2)$$

Here $c$ is the speed of light, $m_{\rm p}$ is the mass of a proton, $e$ is the electron charge, $k_B$ is the Boltzmann constant, $T_0$ is the temperature of the matter at the inner radius of the ML-disc, and $\alpha_{\rm B}$ is the dimensionless efficiency parameter.

## 3 Propeller line

The propeller line is defined by equating the magnetospheric and the corotational radii. The position and the slope of the line depend on the scenario under consideration.

**Non-magnetized accretion:**

$$L_{\rm X,\,min} \approx 1.4\times10^{38}\ \text{erg s}^{-1} \times \mu_{30}^2\,M_{1.4}^{-2/3}\,R_6^{-1}\left(\frac{P_{\rm s}}{1\ \text{s}}\right)^{\mathbf{-2.33}}, \qquad (3)$$

where $L_{\rm X}$ is the X-ray luminosity of a pulsar, $\mu_{30} = \mu/(10^{30}\ \text{G cm}^3)$, $M_{1.4} = M_{\rm ns}/1.4M_\odot$, $R_6 = R_{\rm ns}/(10^6\ \text{cm})$ is the radius of a neutron star, and $P_{\rm s}$ is its spin period.

**Magnetic levitation accretion:**

$$L_{\rm X,\,min} \approx 2.6\times10^{35}\ \text{erg s}^{-1} \times \mu_{30}^{3/2}\,M_{1.4}^{1/6}\,R_6^{-1}\,T_6^{-1/2}\left(\frac{P_{\rm s}}{1\ \text{s}}\right)^{\mathbf{-2.17}}, \qquad (4)$$

where $T_6 = T_0/(10^6\ \text{K})$.

## 4 Equilibrium period

During its evolution a neutron star heads to the state in which the total torque exerted by the surrounding matter is zero. In the general case of magnetic levitation accretion the equation for the equilibrium period is [4]

$$P_{\rm eq} \simeq 0.5\,A_m\,P_{\rm orb}, \qquad (5)$$

where $A_m$ depends on the basic parameters of a neutron star and stellar wind of its massive companion, and $P_{\rm orb}$ is the orbital period of an HMXB. The minimum possible value of the equilibrium period in this case is

$$P_{\rm min}^{\rm eq} \sim 15\ \text{s} \times \mu_{30}^{6/7}\,M_{1.4}^{-2/7}\,R_6^{-3/7}\,L_{35}^{\mathbf{-1/2.33}}, \qquad (6)$$

where $L_{35} = L_{\rm X}/(10^{35}\ \text{erg s}^{-1})$.

The similarity between the equations (3) and (6) should not be surprising. It was shown [4] that the angular rotation velocity of a neutron star in an equilibrium state is roughly equal to the angular velocity of the matter at the magnetospheric boundary, which means that the radius of magnetosphere is approximately equal to the corotational radius.

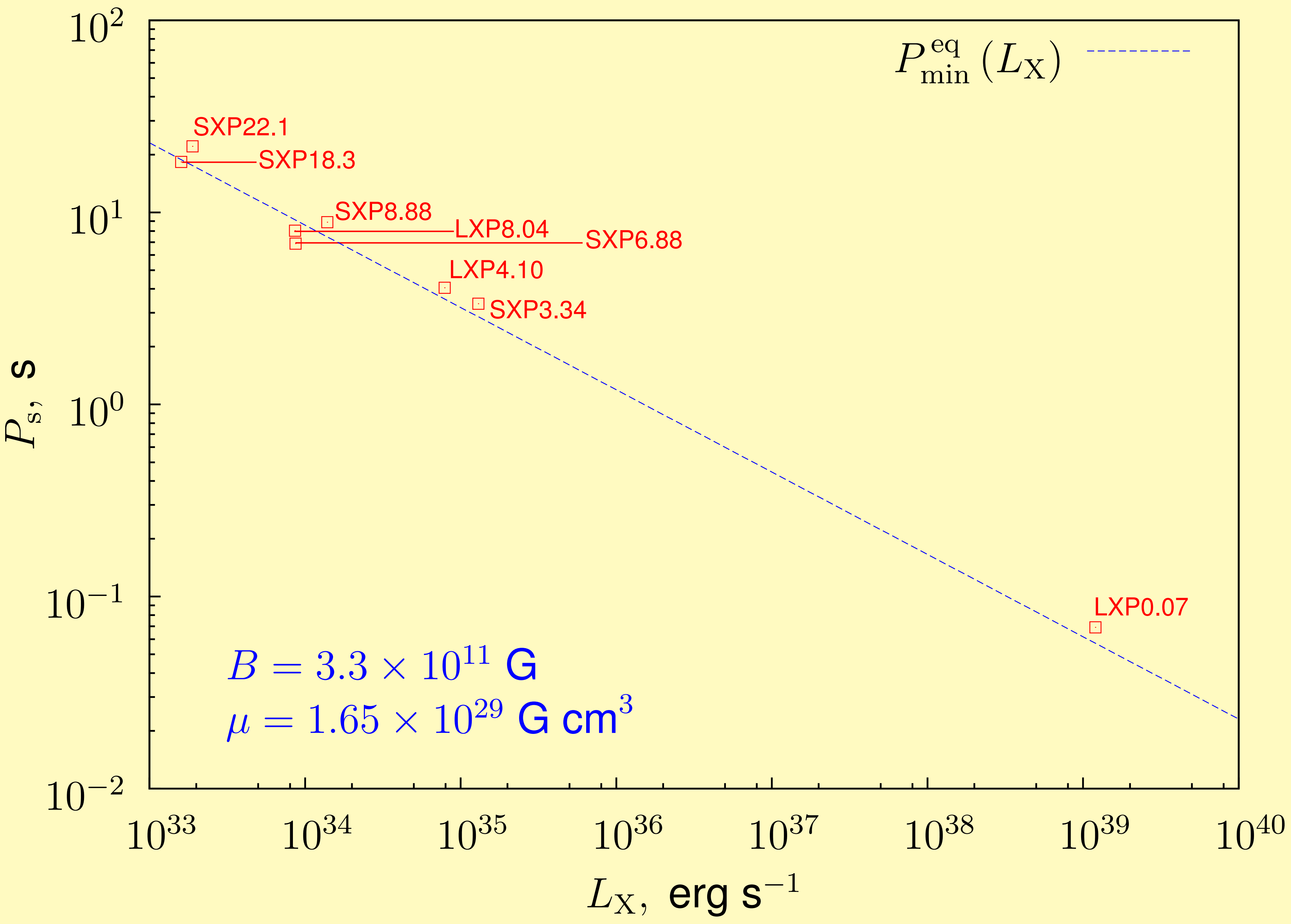

Figure 1: The $P_{\rm s}$ vs. $L_{\rm X}$ diagram

## References

[1] Christodoulou, D. M., Laycock, S., Yang, J., & Fingerman, S., 2016, ApJ, 829, 30

[2] Stella, L., White, N. E., & Rosner, R. 1986, ApJ, 308, 669

[3] Ikhsanov, N. R., Likh, Yu. S., & Beskrovnaya, N. G. 2014, Astron. Rep., 58, 376

[4] Ikhsanov, N. R., & Mereghetti, S. 2015, MNRAS, 454, 3760