Observational Connection of Radio Emissions from Pulsars with Their X-ray Properties

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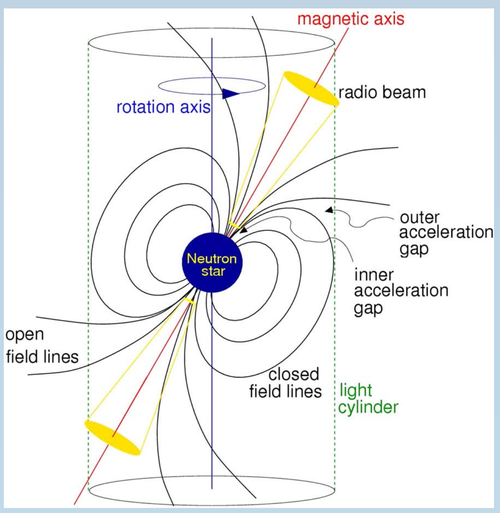
Introduction

So far, the radiation mechanisms of pulsars have remained mysterious. This study presents the observational connection of radio emission from X-ray-emitting pulsars with their X-ray properties. We found that the radio luminosity (L_ν) of pulsars is tightly correlated with their temperature (kT). We also found that the group of pulsars with higher temperatures shows a different trend from those with lower temperatures. The analysis of the radio emissions of the pulsars may reveal differences between pulsars with different X-ray emission properties and may provide further understanding of the emission mechanism of pulsars.

Proposed Emission Mechanism



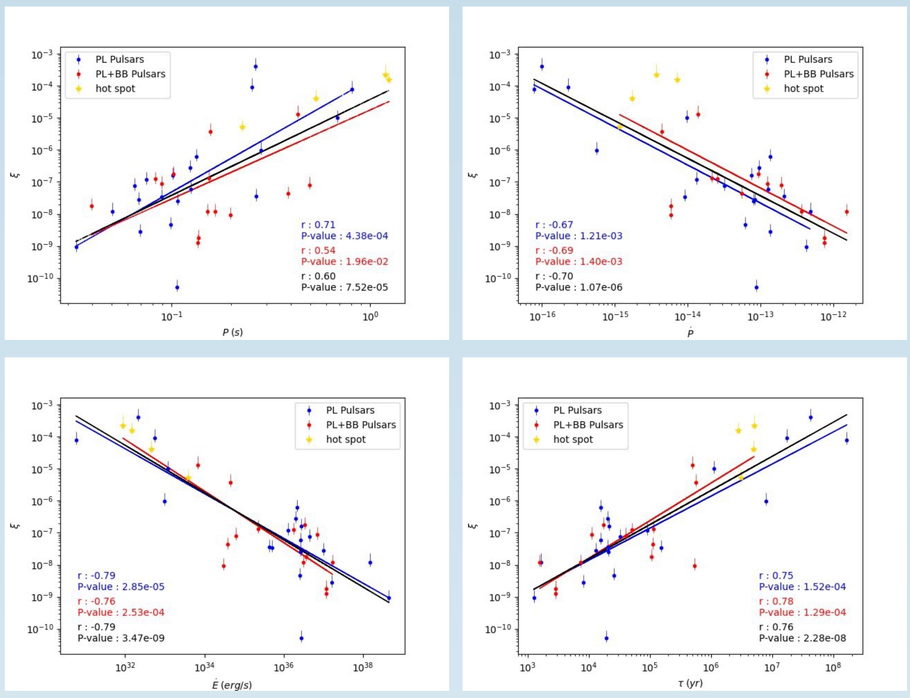
Thermal Emission

- Bombardment of charged particles from the polar cap
- Surface emission of the neutron star due to inertial heat

Non-thermal Emission

- Synchrotron radiation of secondary electron-positron pair plasmas in strong magnetic field
- Polar cap model:
  1) Curvature radiation
  2) Inverse Compton scattering of thermal X-rays
- Outer gap model
  Photon-photon pair production with the thermal X-rays from the stellar surface or non-thermal X-rays produced by the cascade

Radio Luminosity vs. Timing Properties

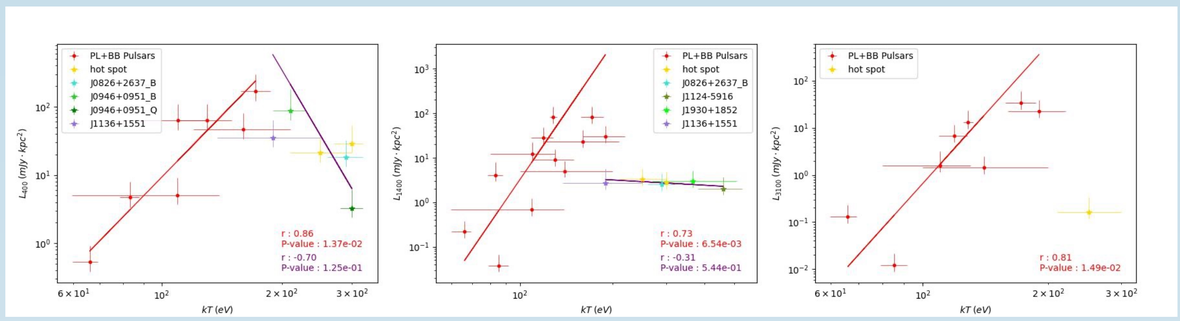


- Pulsars do not show correlations between their radio luminosity and their timing properties.
- The radio efficiency $\xi = L_r/\dot{E}$ of pulsars strongly correlates with the timing properties.

$$\xi \propto P^{3.00\pm0.52}$$
$$\xi \propto \dot{P}^{-1.17\pm0.17}$$
$$\xi \propto \tau^{1.07\pm0.12}$$
$$\xi \propto \dot{E}^{-0.74\pm0.08}$$

- The correlations between ξ and the timing properties may indicate that the radio luminosity of pulsars is independent of their timing properties.

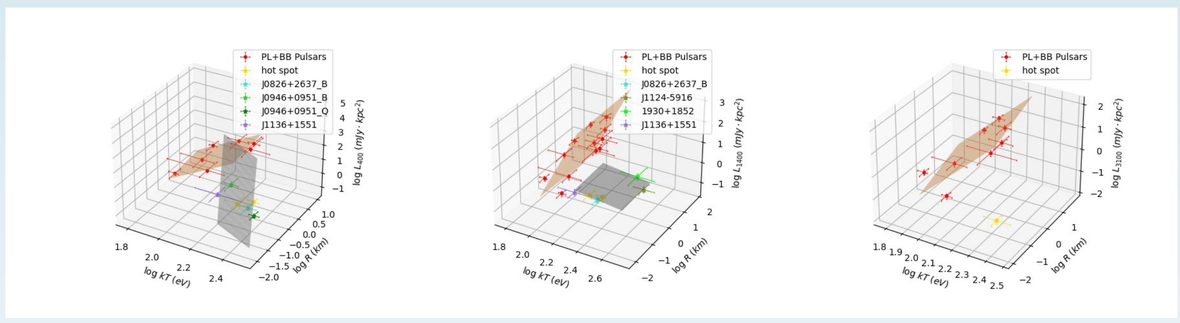
Radio Luminosity vs. X-ray Properties



- By L_ν and kT, pulsars are divided into two groups.
- Pulsars in the group of lower temperatures show a strong positive correlation between L_ν and kT.

$$L_{400} \propto kT^{5.99\pm0.65} \quad (\chi_\nu{}^2 = 0.709)$$
$$L_{1400} \propto kT^{10.06\pm2.24} \quad (\chi_\nu{}^2 = 4.323)$$
$$L_{3100} \propto kT^{9.79\pm2.39} \quad (\chi_\nu{}^2 = 5.421)$$

- 5 pulsars in the high-temperature group show a characteristic of a hot spot. Among the 5 hot spot pulsars, 3 of them are also mode-switching pulsars.



- The relation of L_ν and thermal X-ray properties of pulsars in the low-temperature group:

$$L_{400} \propto kT^{5.79\pm0.79}R^{(0.23\pm0.26)} \quad (\chi_\nu{}^2 = 0.668)$$
$$L_{1400} \propto kT^{6.25\pm1.44}R^{(0.72\pm0.36)} \quad (\chi_\nu{}^2 = 3.929)$$
$$L_{3100} \propto kT^{6.83\pm1.85}R^{(0.38\pm0.43)} \quad (\chi_\nu{}^2 = 7.024)$$

- Pulsars may have a fundamental plane by L_ν, kT, and R.