PSR J1023+0038: from radio MSP to accreting system

Anne Archibald (archibald@astron.nl)

ASTRON

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Transitional MSPs

There are now known three systems that have transitioned between radio MSP and accreting states:

- J1023: field MSP, found in pulsar survey, detailed study in both states
- M28I: cluster MSP, X-ray pulsations allowed identification; see Carlo Ferrigno’s talk
- XSS J12270-4859: field MSP, identified based on $\gamma$-rays; see Jayanta Roy’s talk

These systems share key observational features.
J1023 system properties

- 0.198-day orbit
- $0.2\ M_\odot$ companion
- 1.7-ms pulsar spin period
- $B = 10^8\ G$
- 1.37 kpc distance
- $\sim45^\circ$ inclination
MSP
Radio pulsar emission

Radio emission is messy:
- Eclipses
- Extra DM

Also seen in: M28I, XSS J12270
Radio pulsar emission

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Orbital period variations

Substantial wander in orbital phase
- No believable long-term orbital period derivative
- No plausible quasi-periodicity

Also seen in: M28I, XSS J12270
Companion

The companion is unusual:
- 1.8 times the radius expected given the mass
- Mildly irradiated

Multicolour light curve from Thorstensen and Armstrong 2005
X-ray emission

- X-rays in MSP state
  - $L_X = 0.02L_\odot \left(10^{32} \text{ erg s}^{-1}\right)$, hard power-law spectrum
- Orbital variability consistent with emission from a shock near L1
  - Reprocessing allows X-rays to explain irradiation

Also seen in: XSS J12270

Shock model from Bogdanov et al. 2011
J1023 is a γ-ray source
- 0.3$L_\odot$
- 3.7σ evidence for pulsations at the pulsar period

This is fairly typical for a MSP with $\dot{E} = 4 \times 10^{34}$ erg s$^{-1}$ (12$L_\odot$).

Also seen in: XSS J12270
Optical evidence for an accretion disc

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- Spectrum developed double-peaked emission lines
- Increased orbital modulation (heating increased by a factor $\sim 3$)

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Low X-ray luminosity

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  \[ \sim 3 \times 10^{33} \text{ erg s}^{-1} \]
  - Drastically lower than other systems known to accrete
  - “Quiescent”
- X-ray pulsations detected
  - Typical of AMXPs
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X-ray emission switches between three “modes”:

- **Low**
  - $5 \times 10^{32} \text{ erg s}^{-1}$, stable
  - No pulsations
  - Small fraction of the time; minutes

- **High**
  - $3 \times 10^{33} \text{ erg s}^{-1}$, stable
  - Pulsations
  - Majority of the time

- **Flare**
  - $\sim 10^{34} \text{ erg s}^{-1}$, variable
  - No pulsations
  - Occasional; minutes to hours

Also seen in: M28I, XSS J12270
- J1023 shows flat-spectrum variable radio emission
- $L_R/L_X$ more typical of a black hole than a NS

Also seen in: M28I, XSS J12270
In the accretion-disc state the $\gamma$-ray flux increased by a factor of $\sim 5$.

- No evidence for orbital modulation
- Unable to test for pulsations
  - Pulsars are among the very few non-variable Fermi sources

Also seen in: XSS J12270
Key features

In MSP state:
- Radio eclipsing
- Orbital period variations
- Orbitally modulated X-rays
- Irradiated Roche-lobe-filling companion

In accretion-disc state:
- Underluminous in X-rays
- X-ray mode switching
- X-ray pulsations
- Flat-spectrum radio continuum emission
- \(\gamma\)-ray brightening
Radio pulsar emission

- Eclipses
  - Variable
  - Longer at lower frequency
  - Occasionally not near 0.25

- Extra DM
  - Usually near eclipse
  - Sometimes at random phases
  - Varies from observation to observation
Radio pulsar emission

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The companion is unusual:

- 1.8 times the radius expected given the mass
- Possibly hydrogen-stripped/helium-enhanced
- Not even spherical
- May be magnetic

Companion
Thorstensen and Armstrong (2005) modelled the companion:

- Companion average temperature 5700 K
- Near side hotter by 400 K
- Well-fit by model with $2L_\odot$ isotropic primary