Millisecond Pulsar γ-ray Emission: A Sign of Binary Interaction?

Anne Archibald (archibald@astron.nl)

ASTRON

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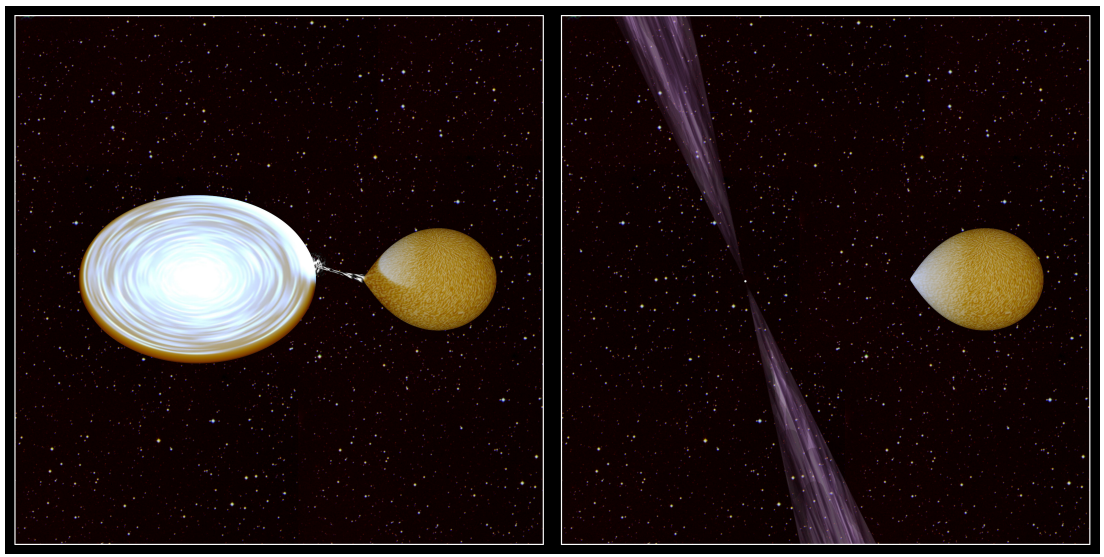
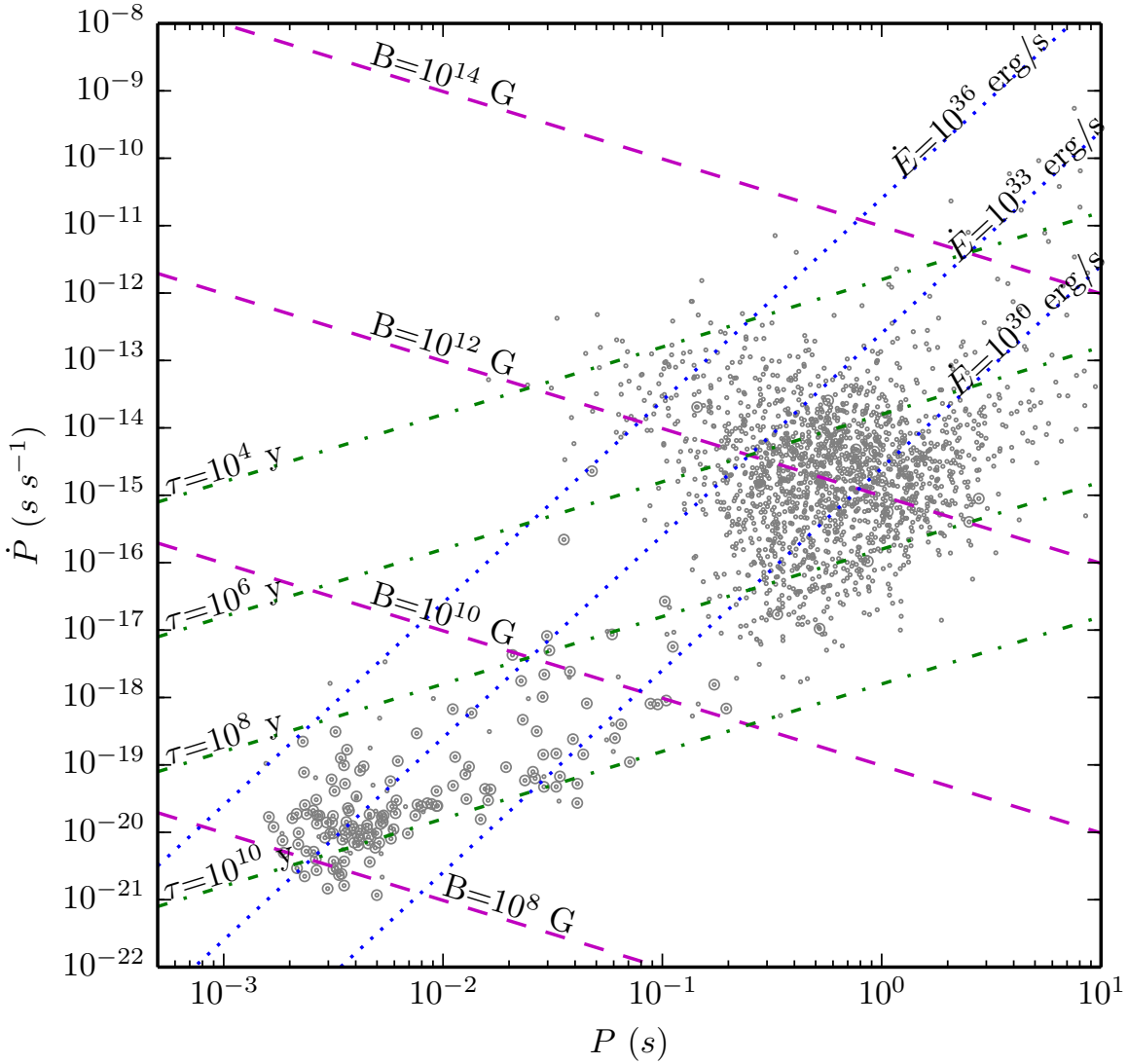


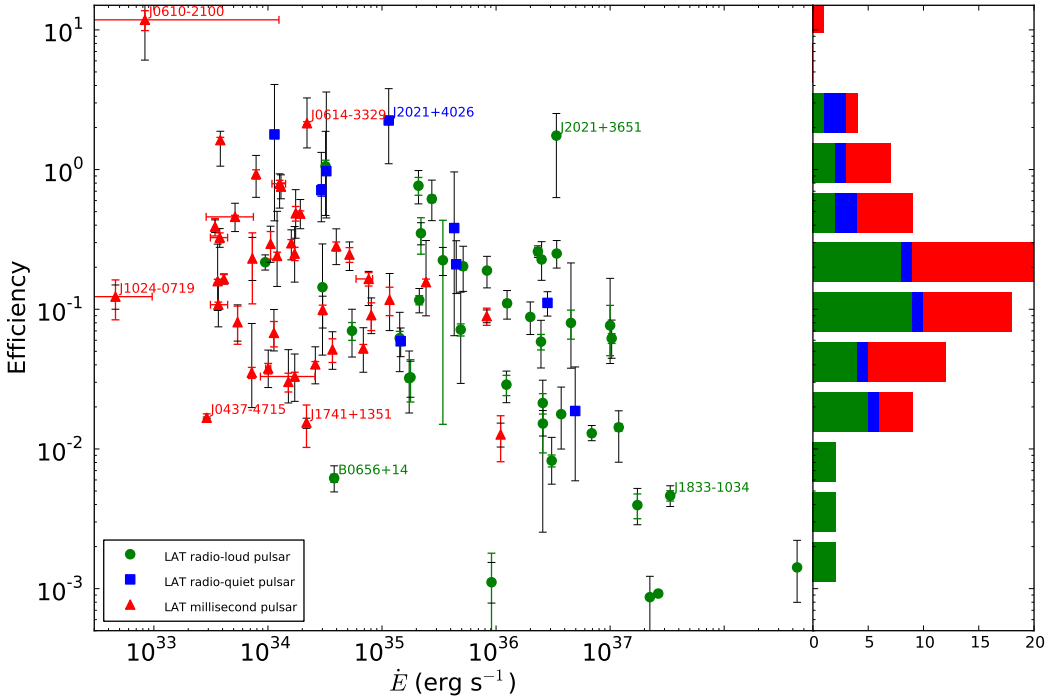
Pulsars



- Millisecond pulsars form a distinct population
  - Low magnetic field
  - Mostly binary
  - Very long-lived
  - Can be energetic
- Formation model: recycling
  - Details remain murky

Pulsars from the ATNF catalog

Pulsar γ-ray emission



Abdo et al. 2013 (second Fermi pulsar catalog)

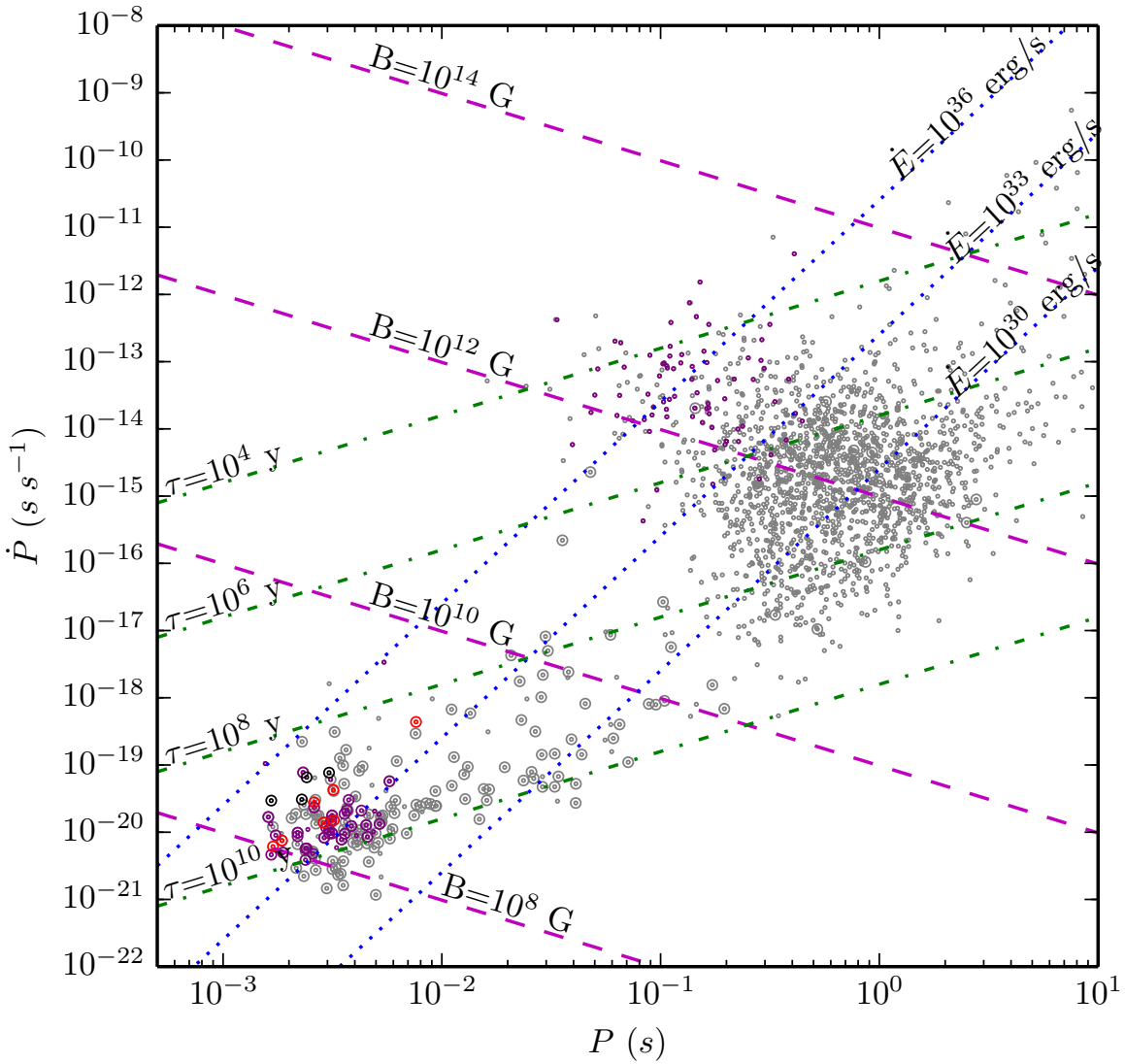
- The pulsar mechanism generically produces γ-rays
- Millisecond pulsar γ-ray efficiency not unusual
- Pulsars are *steady* γ-ray sources (mostly)

"Spiders"

There are two peculiar classes of MSPs, collectively called "spiders":

- MSPs in tight binary orbits ($\lesssim 1$ day) with low-mass companions
- Show signs of binary interaction, including some or all of:
  - Radio eclipses (variable, frequency-dependent)
  - Companion irradiation
  - X-rays from an intrabinary shock
  - Orbital period variations
- Divided based on companion mass:
  - Black widow: $\lesssim 0.1 M_\odot$, degenerate, not Roche-lobe-filling
  - Redback: ~ 0.1–$0.6 M_\odot$, main-sequence-like, usually Roche-lobe-filling

Spiders



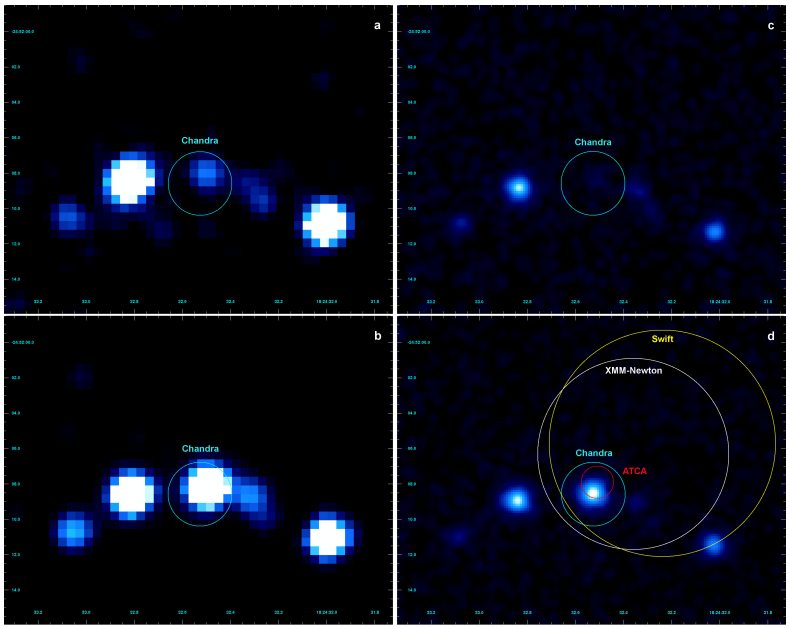
- Few were known until recently
- Many new spiders found based on Fermi observations
  - High $\dot{E}$?
  - Selection effects?
  - Non-pulsar γ-rays?

Redbacks (red) and black widows (black)

Transition objects

- Three objects have been observed to move between radio pulsar and accretion-disc states:
  - PSR J1023+0038: radio pulsar to accretion-disc state (plus past accretion-disc episode)
  - M28I: radio pulsar to polar-cap accretion back to radio pulsar
  - XSS J12270−4859: faint accretion-disc state to radio pulsar

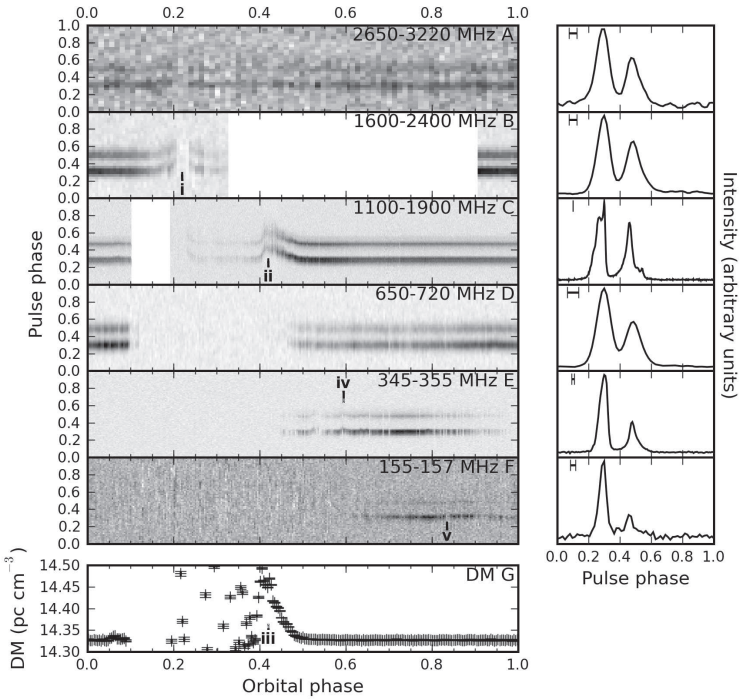
M28I



X-ray image of the core of M28I before and during activity, from Papitto et al. 2013

- Radio state:
  - Eclipsing radio pulsar
  - $L_X \lesssim 10^{32}$ erg/s
- Accretion-disc state:
  - X-ray pulsations
  - $L_X \approx 10^{36}$ erg/s
  - Thermonuclear bursts
  - Continuum radio emission
  - Peculiar rapid variability
  - No radio pulsations
- Transitions seem to take $<$ days to months
- Evidence for multiple transitions in the last few years
- 5.5 kpc

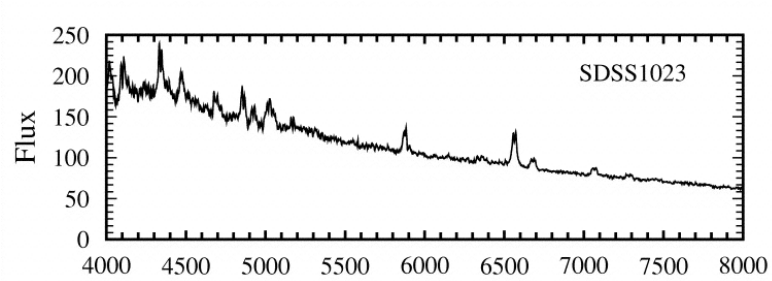
PSR J1023+0038



Radio eclipsing of PSR J1023+0038

- Radio state:
  - Eclipsing radio pulsar
  - Mildly heated G-coloured companion
  - Absorption-line spectrum
  - Orbital period variations
  - $L_X \approx 3 \times 10^{32}$ erg/s
  - X-ray pulsations
  - X-ray intrabinary shock
  - γ-ray pulsations
- 1.35 kpc

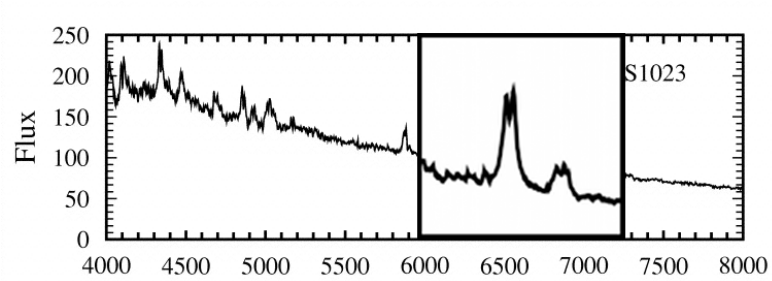
PSR J1023+0038



Optical spectrum from Szkody et al. 2006

- Historical episode:
  - Observed only optically
  - Occurred in 2000/2001
  - Lasted 1.5–3 years
  - Optical brightening, flickering
  - Emission line spectrum with double-peaked lines
  - X-ray upper limit $\sim 5 \times 10^{33}$ erg/s
- 1.35 kpc

PSR J1023+0038



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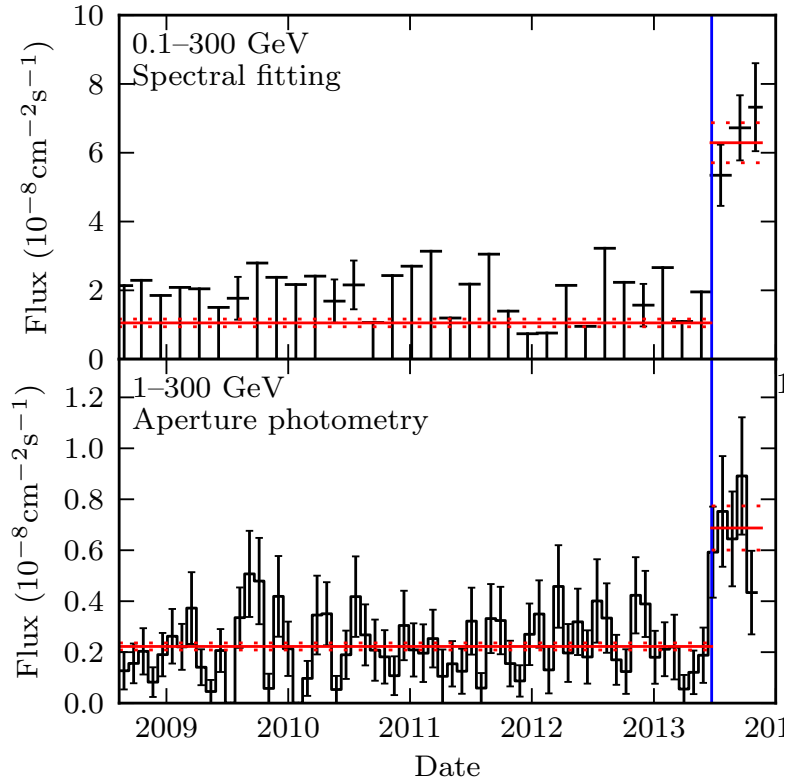
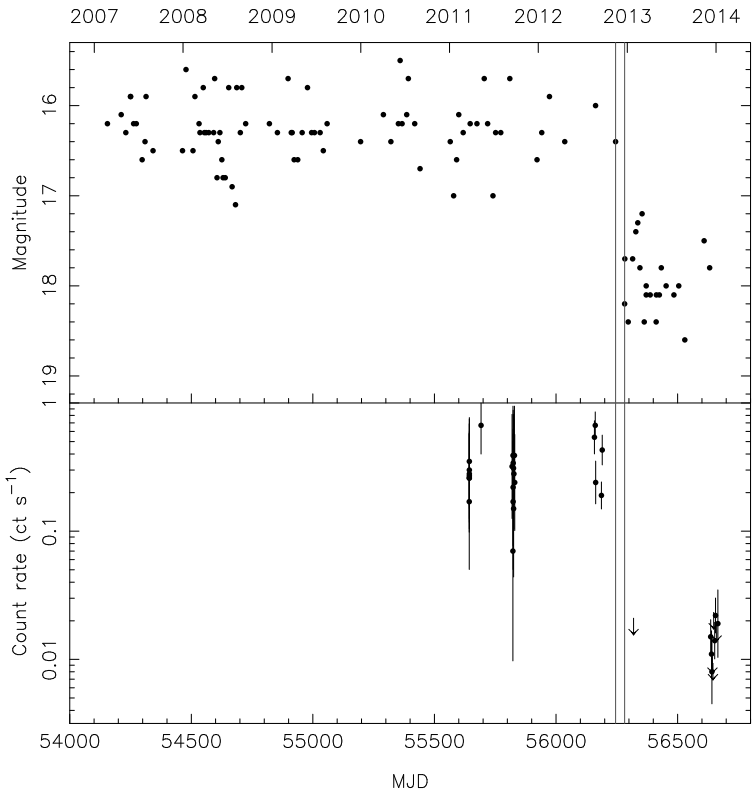


γ-ray brightening at radio disappearance

- Current accretion-disc state:
  - Began late 2013 June
  - Radio pulsations disappeared
  - Emission line spectrum with double-peaked lines
  - X-rays variable state-switching 2.5×10^{33} erg/s
  - Variable flat-spectrum radio continuum suggestive of a jet
  - γ-ray brightened by a factor of 5
- 1.35 kpc

XSS J12270-4859



γ-ray brightening at radio disappearance

- Accretion-disc state:
  - X-ray variability
  - $L_X \sim 10^{35}$ erg/s
  - Emission-line spectrum
  - γ-ray emission
- Current radio-pulsar state:
  - $L_x \sim 10^{32}$ erg/s
  - Eclipsing radio pulsar
  - Mid-G donor star (no emission lines)
  - Decrease in γ-ray emission by a factor of 1.5-2
- 1.4–3.6 kpc

What is happening in these transition objects?

- Radio pulsar states are typical redbacks
- M28I accretion-disc state nearly normal AMXP
  - M28I is too far to easily study faint accretion states
- J1023, XSS J12270 accretion-disc states peculiar:
  - Very low luminosity — propeller mode?
  - γ-ray emission
  - J1023 state-switching
- What triggers state switching?
  - Orbital period variations possibly due to companion shape changes may produce Roche-lobe overflow
  - Radio ejection mechanism may produce bistable state

Key puzzles

- Why have these systems stopped being full-fledged LMXBs?
- Do other LMXBs enter such low-luminosity accretion-disc states?
- What is going on in these peculiar accretion-disc states?
- How do these systems produce γ-rays?
- What is the ultimate fate of these systems?