Intermittency and paucity of accretion-powered millisecond X-ray pulsars

Consistent with emitting spots moving close to rotation poles

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Accretion-powered X-ray pulsars

- Weakly-magnetic NSs accreting matter from a low mass companion
- Emission is powered by accretion of matter from disk via B-field onto NS surface
- NSs accreting from a high-mass companion are moderately spinning (~1Hz, Giacconi et al. 1971)
- The discovery of a millisecond rotation-powered radio pulsar by Backer et al. (1982) and the interpretation as recycled led to the prediction of accreting millisecond pulsars (MSPs)
- Discovery of rapidly rotating (>~100 Hz) accretion-powered pulsars was made possible with the Rossi X-ray Timing Explorer (‘95-’12)
- Recycling through transfer of angular momentum. Last phase of accretion (Roche-lobe decoupling) crucial for final spin period; up to 50% of $E_{\text{kin}}$ lost (Tauris 2012).
- Interesting because they constrain the evolution of the spin and magnetic field before turning on as radio MSPs
Accretion-powered millisecond pulsars (APMSPs)

- Detected in just 14 out of >130 NS LMXBs, none from ~12 nuclear-powered MSPs
- All are transients with spin frequencies 182-619 Hz
- The detected fractional rms amplitudes of most are just a few % (~2%—14%)
- Significant amplitude variations occur on timescale of hours (e.g. 2%—19%)
- The fractional rms amplitudes of their first overtone are typically <~3%
- Fluctuations in the time of arrivals of up to ~0.3 cycles
Intermittent accretion-powered oscillations

Appearance and disappearance of oscillations in 3 “intermittent” APMSPs within >~200s, with the fractional rms amplitudes of the fundamental being < 3.5% and those of the first overtone < 0.4%

Possible association with thermonuclear bursts
• We consider one or two (antipodal or on same hemisphere) circular isotropically-emitting bright spots of varying size and inclination with respect to the rotation axis, as well as different observer angles.

• We use the Schwarzschild+Doppler (Miller & Lamb `98) GR approximation to trace light rays from the neutron star surface to the observer, including special relativistic energy boosts and aberration, and time delays.

Modest changes in the position of the brightness pattern on the stellar surface can cause sudden appearance and disappearance of pulsations (intermittency). When observable, waveforms have small amplitudes and harmonic content.
Further inferences from near-axis moving spots

1. Proximity of magnetic and rotation poles can explain the weak modulation and nearly sinusoidal waveforms of most accretion-powered MSPs.

2. Modest wandering in the location of the X-ray emission region due to changes in the inner disk and accretion flow into the magnetosphere can produce the observed variations of pulse amplitudes and phases.

3. Proximity of the magnetic and rotation poles may also explain why accretion-powered pulsations have not yet been detected in many neutron stars in LMXBs that are thought to have dynamically important magnetic fields:
   - Stable spots within a couple of degrees from the rotation axis produce undetectable oscillations
   - Rapid spot movements produce oscillations undetectable also at larger inclinations

Contour of fractional rms amplitude for antipodal spots observed from 45 deg

Patruno et al 2009
Summary

• Careful studies of LMXBs with RXTE have revealed 3 intermittent APMSPs providing a missing link between X-ray pulsing and non-pulsing accreting NSs.

• Pulsations appear and then disappear in timescales of minutes to hours, have small amplitudes of the fundamental ($< 3.5\%$) and the harmonics ($< 0.4\%$).

• This picture is consistent with modest wandering of emission regions on the surface of accreting neutron stars, if they are nearly aligned rotators. This nearly-aligned moving spot model also reproduces the relatively small amplitudes, sinusoidal waveforms, and large apparent phase variations in the persistent APMSPs, and can explain their paucity from other LMXBs.

• This discovery opens a large window for further improvements in our theoretical understanding of APMSPs and the evolution of their spins and magnetic fields before turning on as radio pulsars.