X-RAY EMISSION FROM REDBACKS

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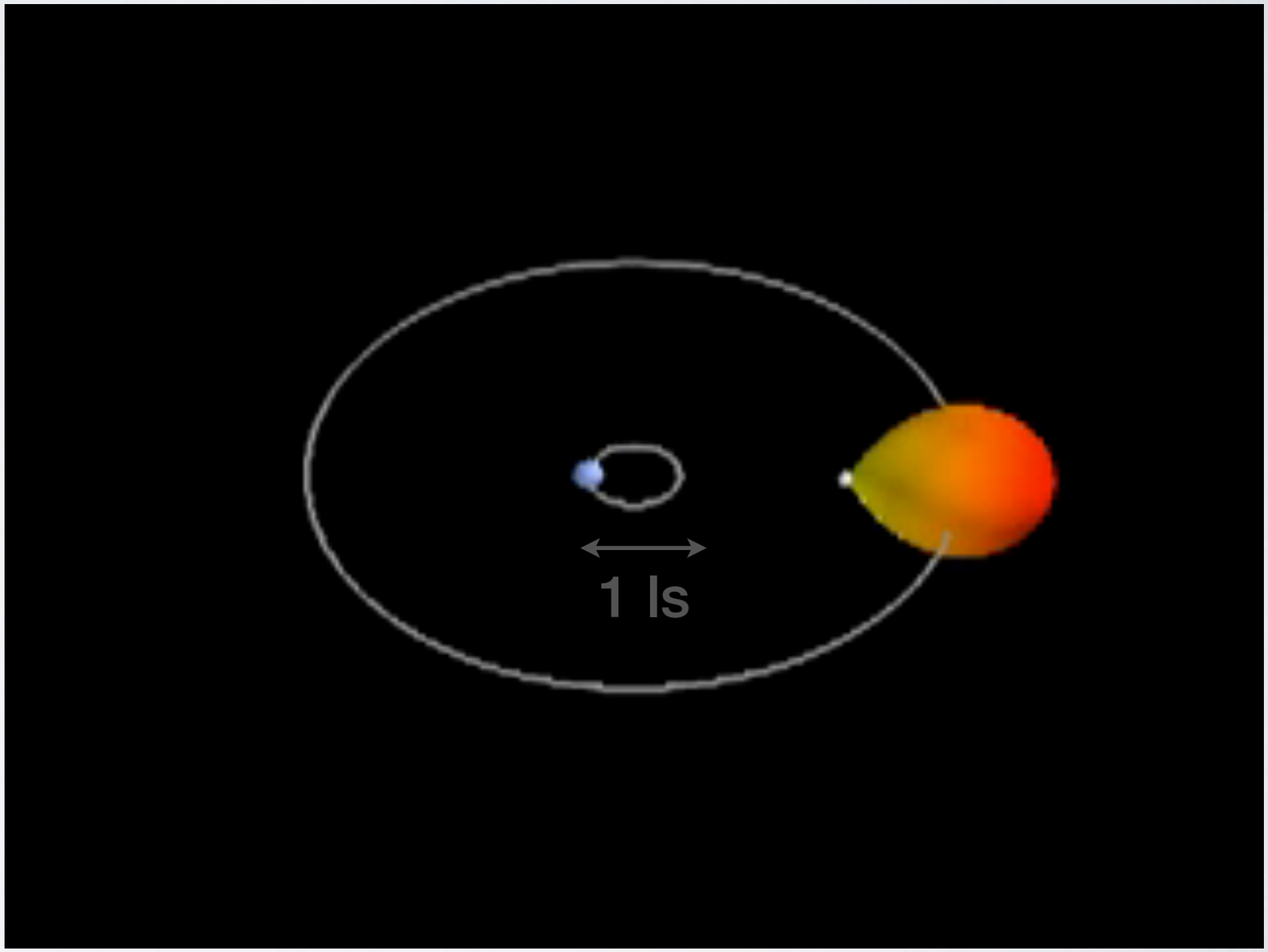
COLLABORATORS

Spiders: Very Compact Systems!

- Binary systems a few lightsec across
- Shock forced at companion ~10^4 light cylinder radii away (compared to ~$4X10^8$ for the Crab's inner torus)



Relativistic Wind Shocks in Spiders

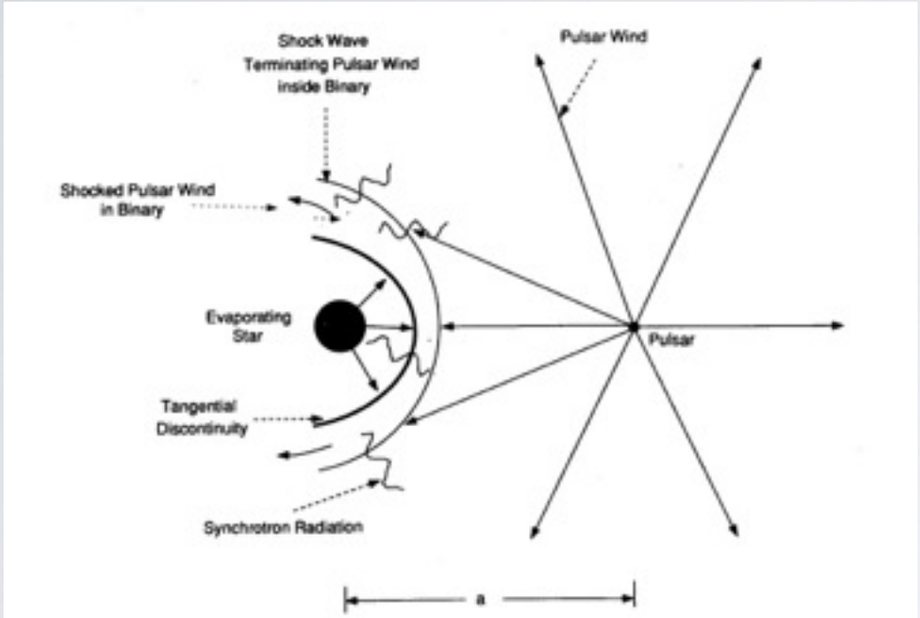
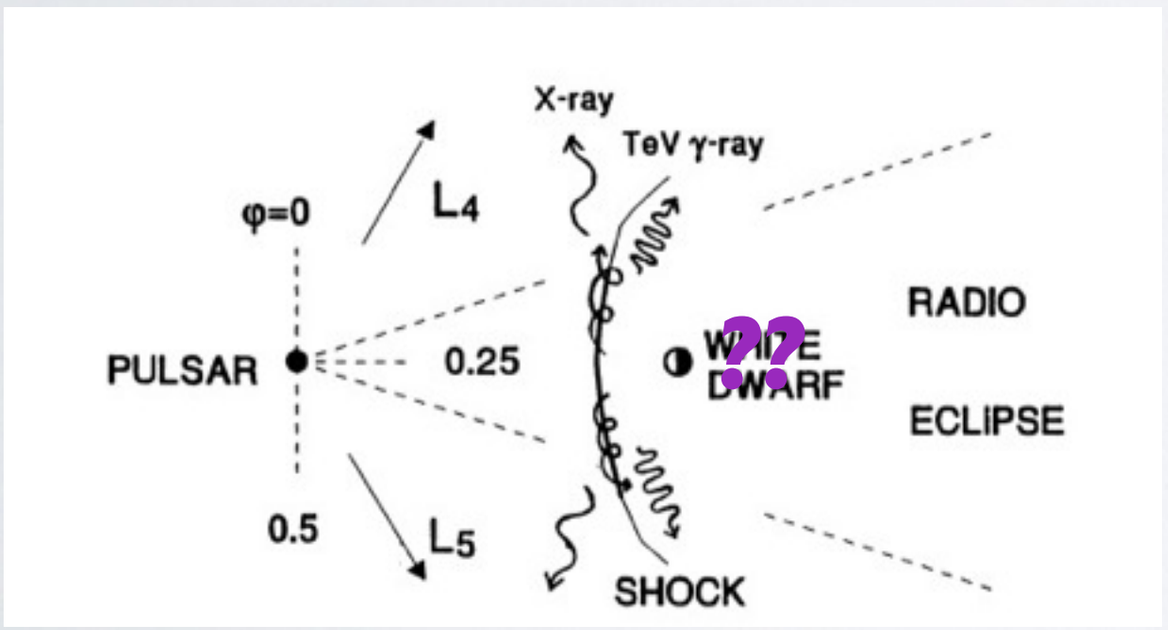


FIG. 2 Schematic representation of the shock geometry near the companion star.

Arons and Tavani 1993

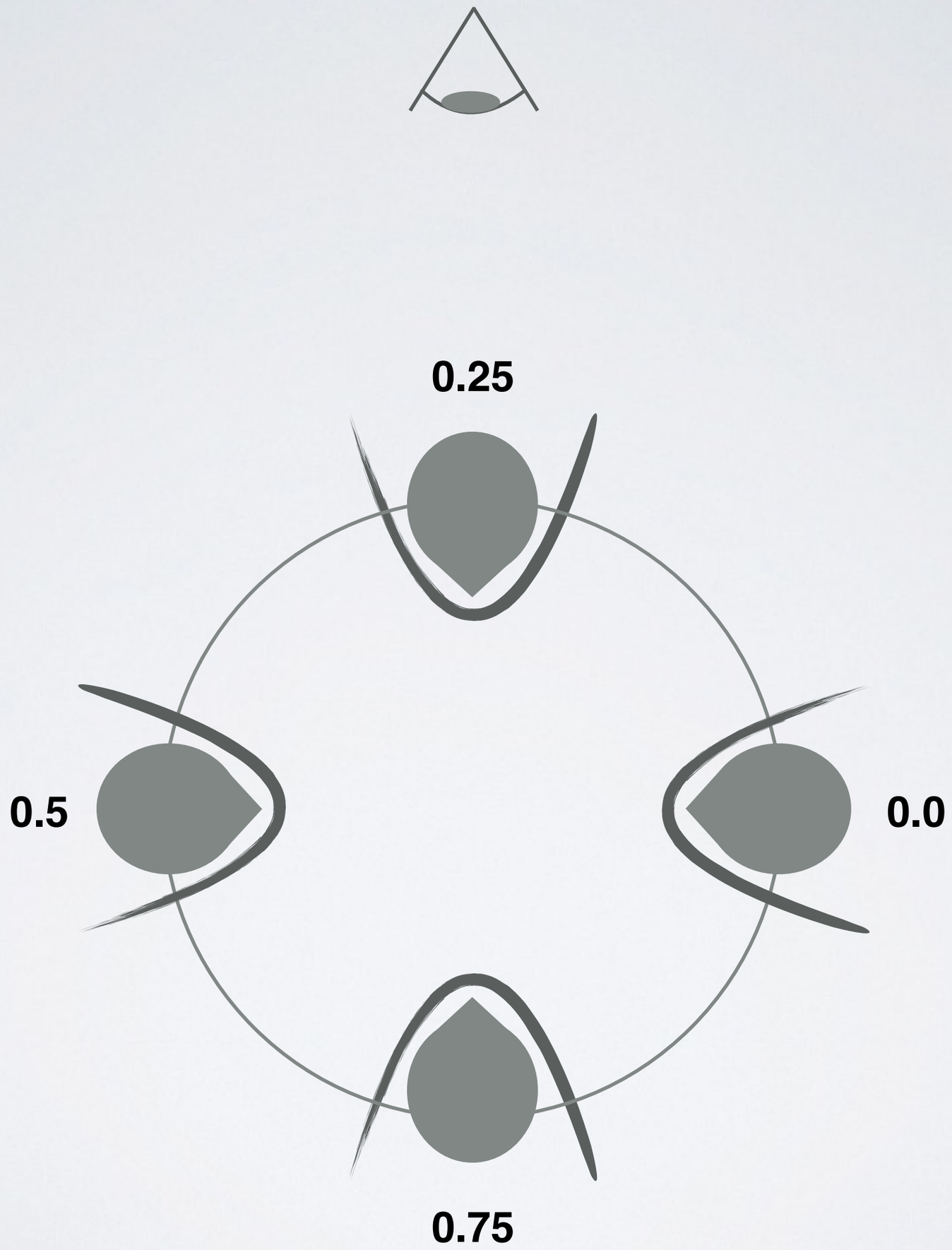


Raubenheimer et al. 1995

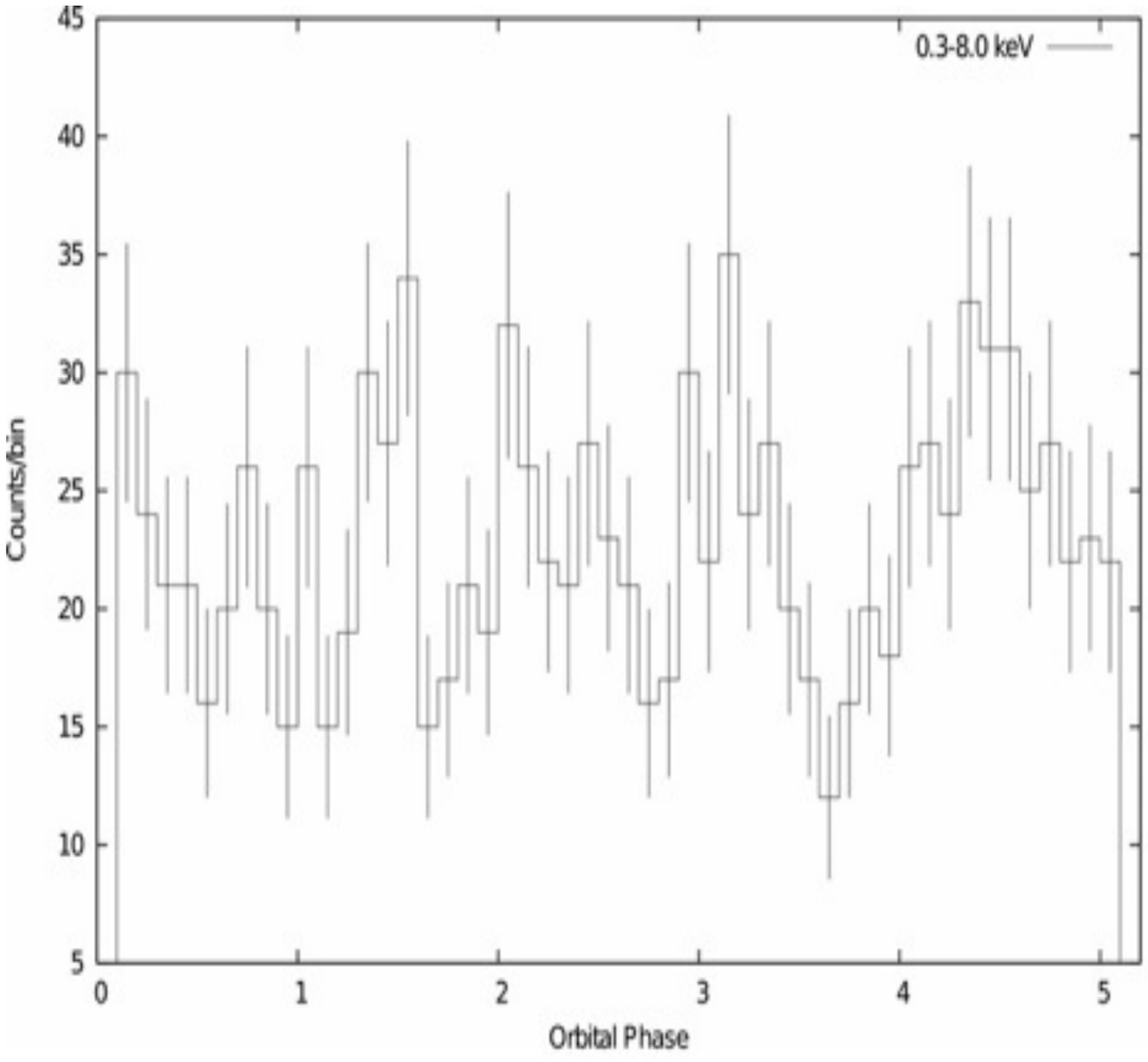
- Arons and Tavani (1993) model developed for high energy emission from original Black Widow, predicted electrons accelerated to 3 TeV in intrabinary shock
- $\dot{E} \sim 10^{34\text{-}35}$ erg/s
- Although circular, orbital modulation can arise from obscuration by shock, intrinsic emission beaming from magnetic field, and doppler boosting

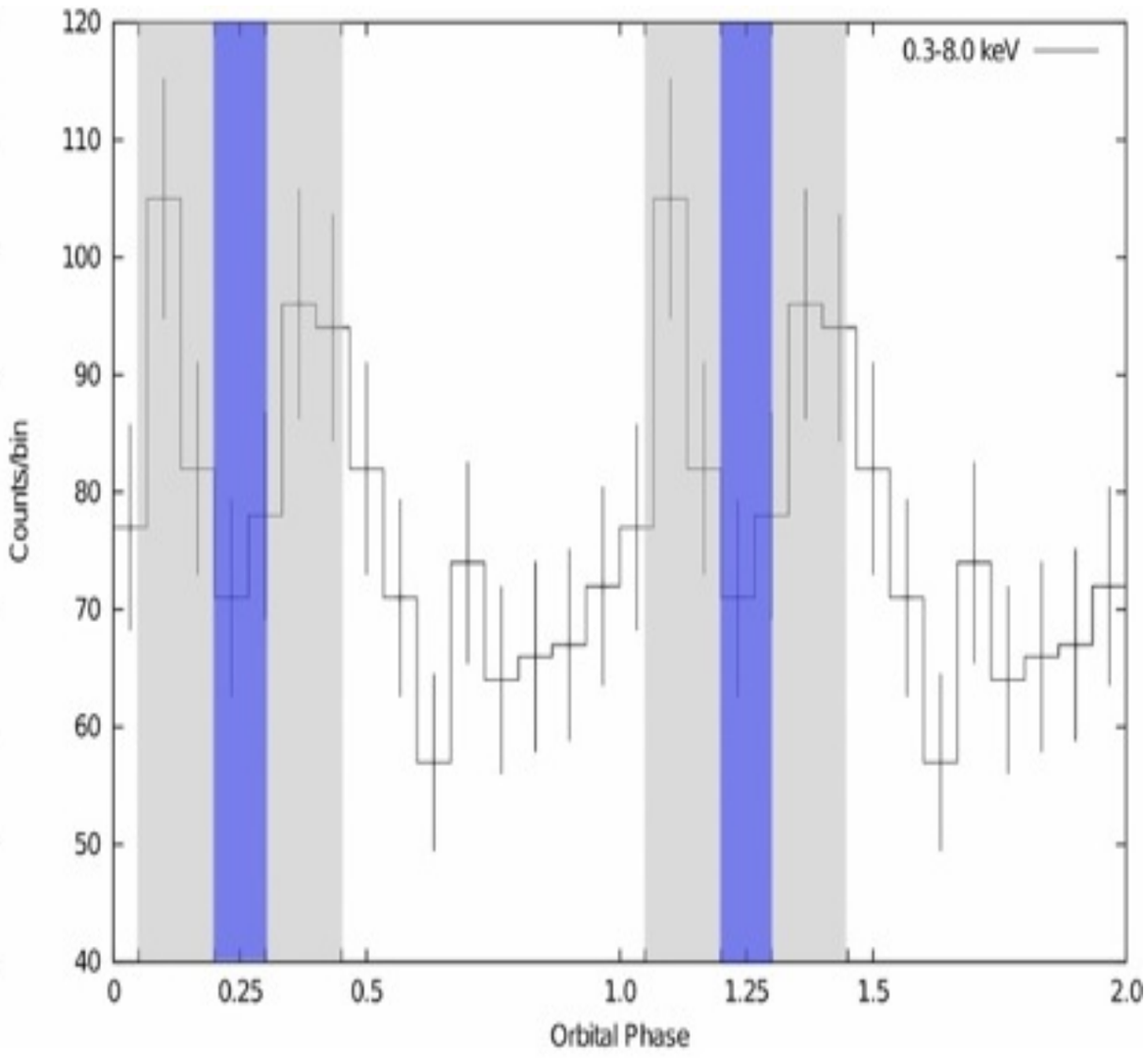
Shock distance of lt-secs
may imply high B, σ at shock

- Possibility of "hidden" γ-ray sources (Tavani 1993). Black Widow proposed source of TeV emission in 1995.
- Estimated luminosity depends on distance to shock, fraction of wind involved, magnetic field of pulsar, optical emission from companion, magnetization of wind, ion fraction
- Primarily still $\dot{E}/d^2$?


0.25
0.5
0.0
0.75

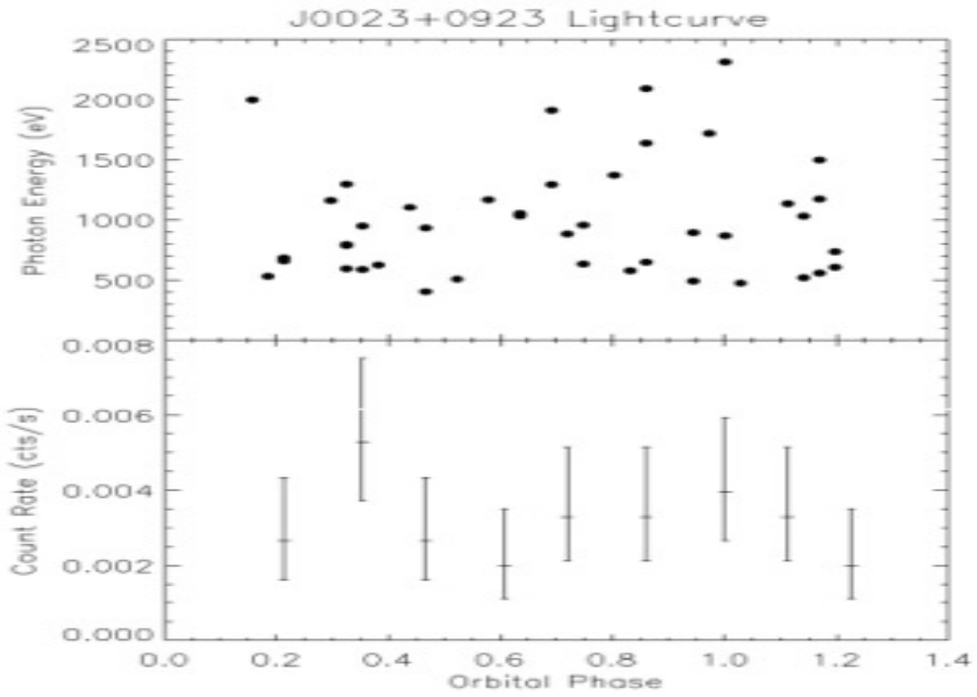
THE Black Widow PSR B1957+20

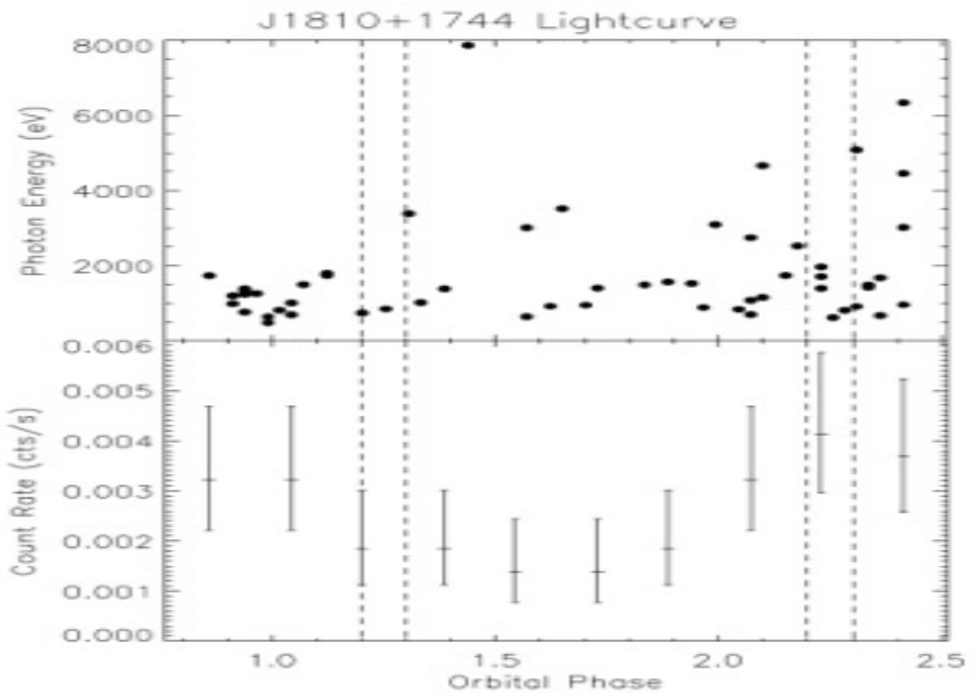


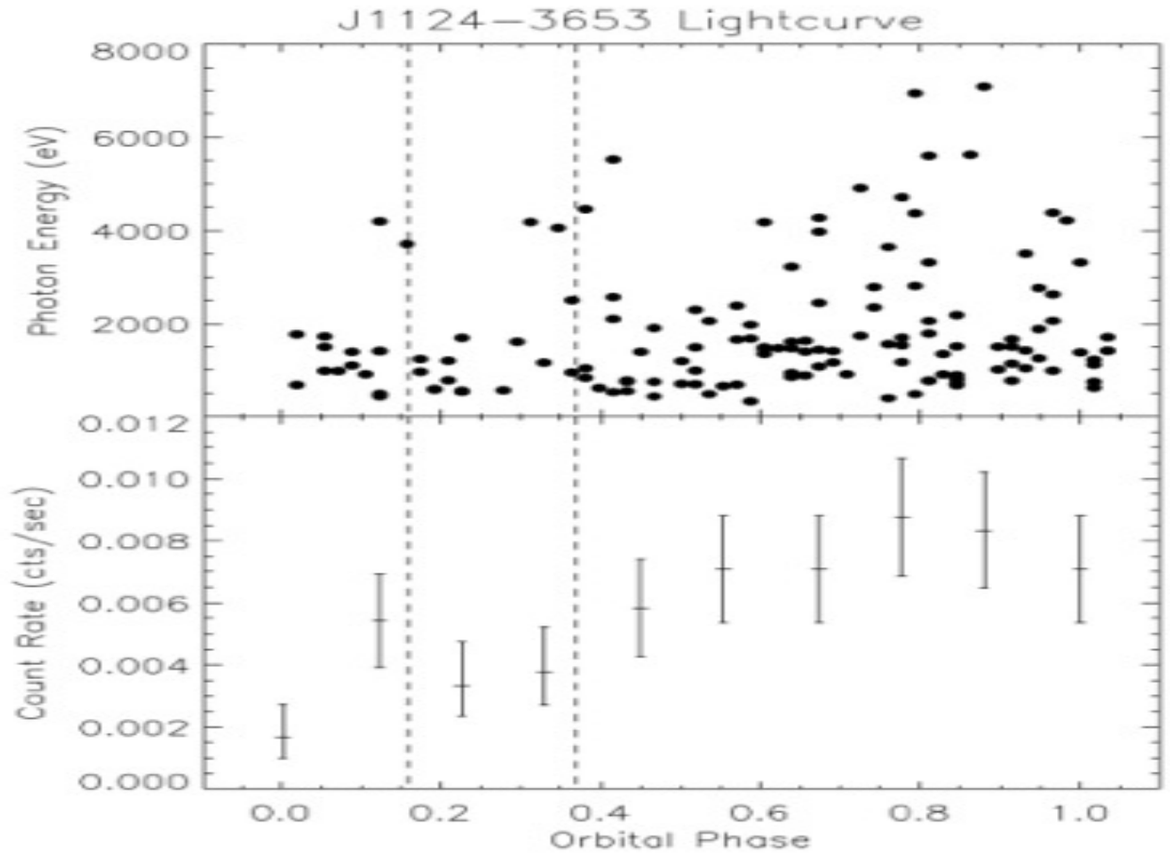


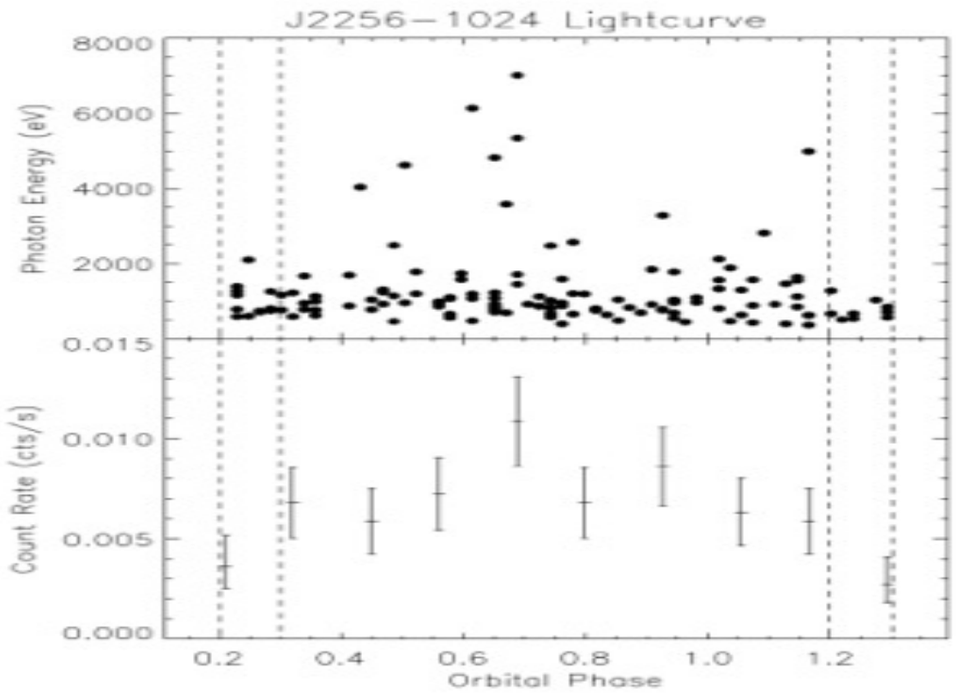
Huang et al. 2012

Some Other Black Widows



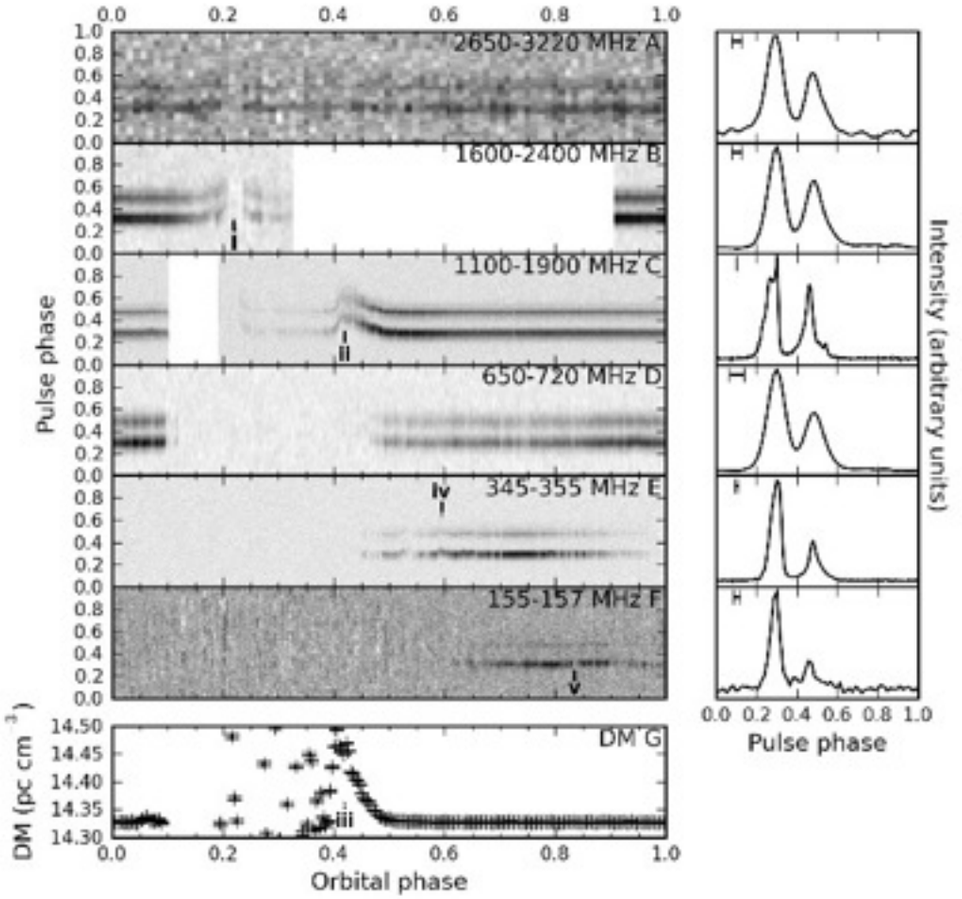






Gentile et al. 2014

PSR J1023+0038:
A Redback Caught in the Act!

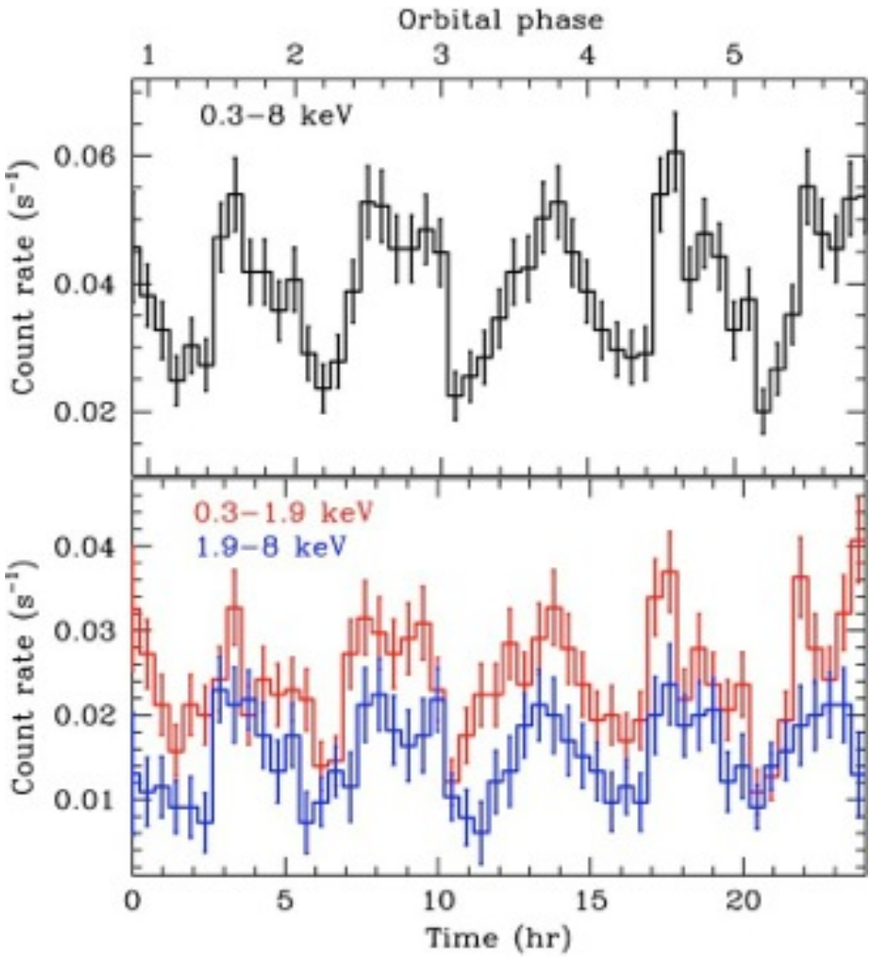


Archibald et al. 2009

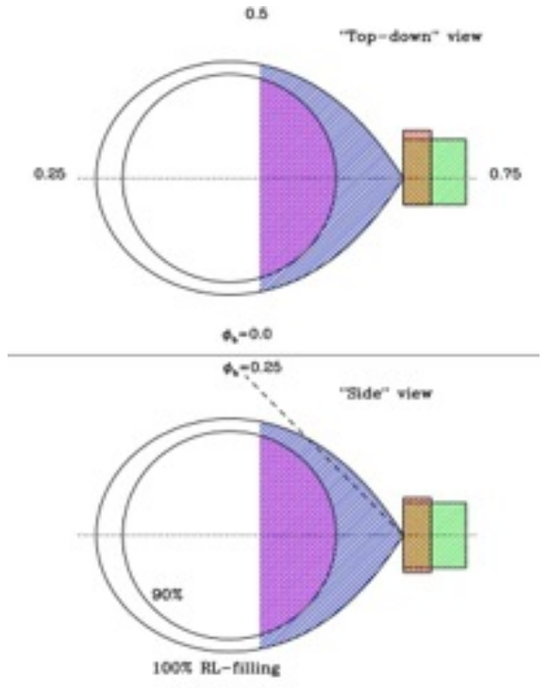
- 1.69 ms pulsar in 4.8hr orbit discovered in GBT 350MHz Drift Scan Survey (Archibald et al. 2009)
- 0.2 solar mass non-degenerate companion, luminosity a few tenths solar
- eclipses and orbitally modulated X-ray emission suggest intrabinary shock
- photon density near shock similar to PSR B1259-63
- Parallax measures d ~1.3 kpc compared to DM estimate of ~0.6 kpc (Deller et al. 2012).

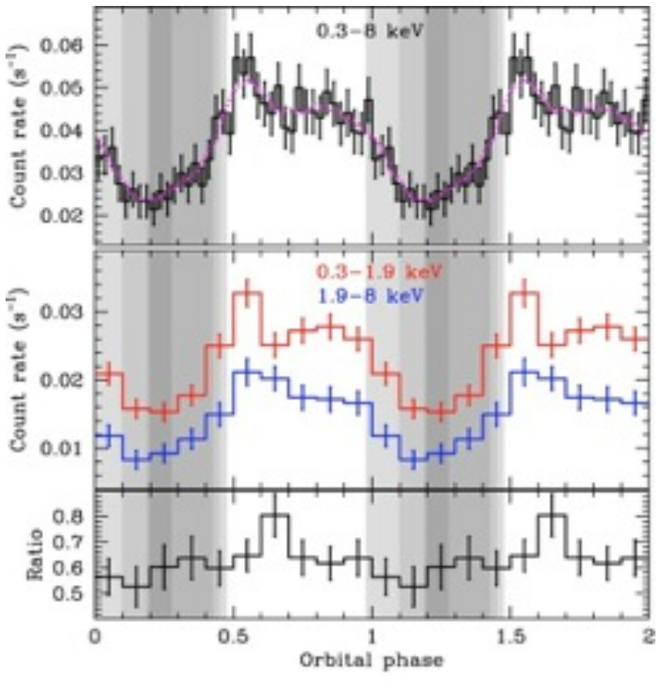
"The Redback spider is one of only two animals to date where the male has been found to actively assist the female in sexual cannibalism. In the process of mating, the much smaller male somersaults to place his abdomen over the female's mouthparts. In about 2 out of 3 cases, the female consumes the male while mating continues. Males who are not eaten die soon after mating."
-- Wikipedia

PSR J1023+0038 in X-Rays

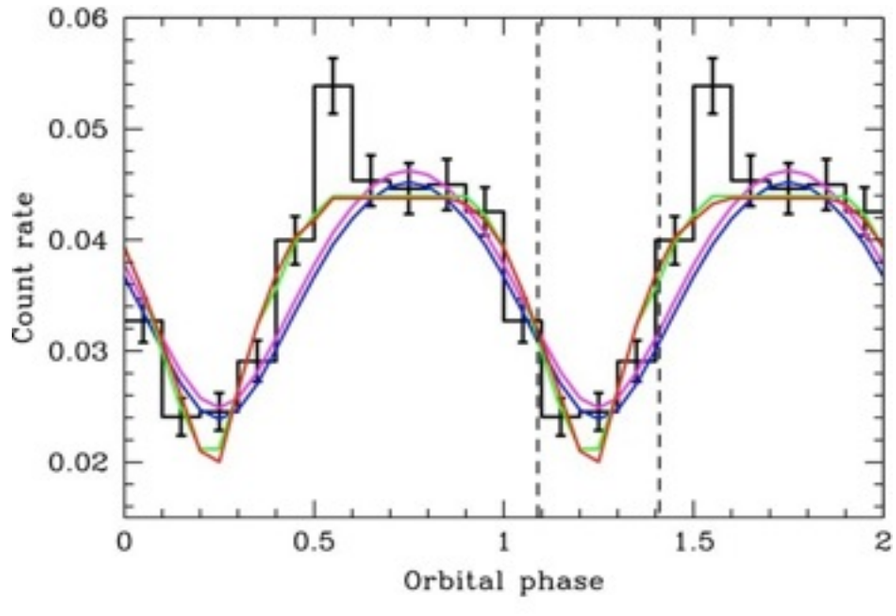


- Light Curve suggests emission site small — no larger than companion
- Luminosity suggests high magnetic field at shock (possibly high σ)?
- If wind equatorially enhanced, required efficiency is less



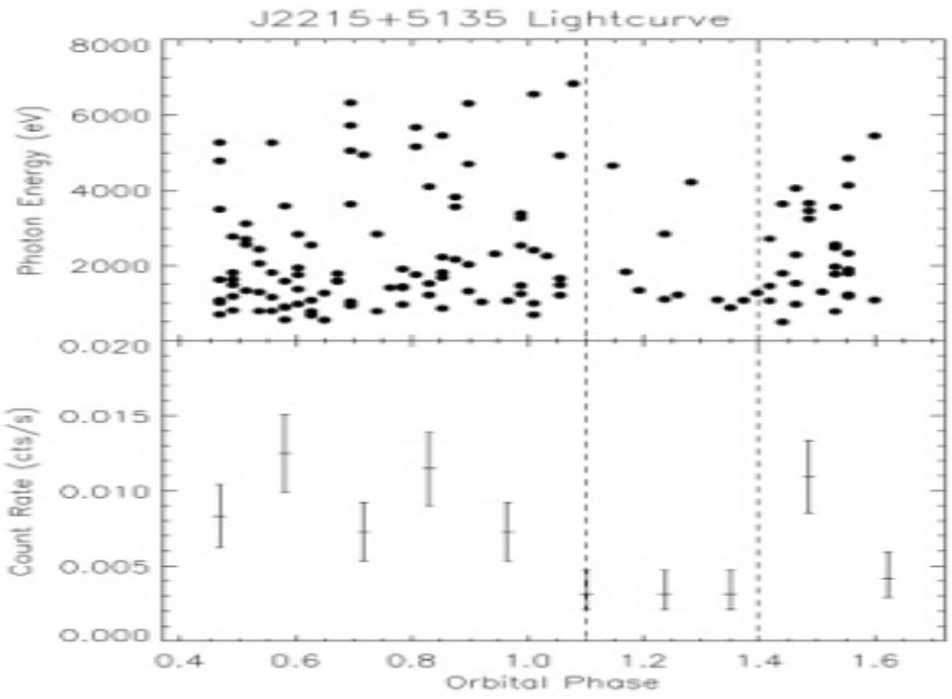


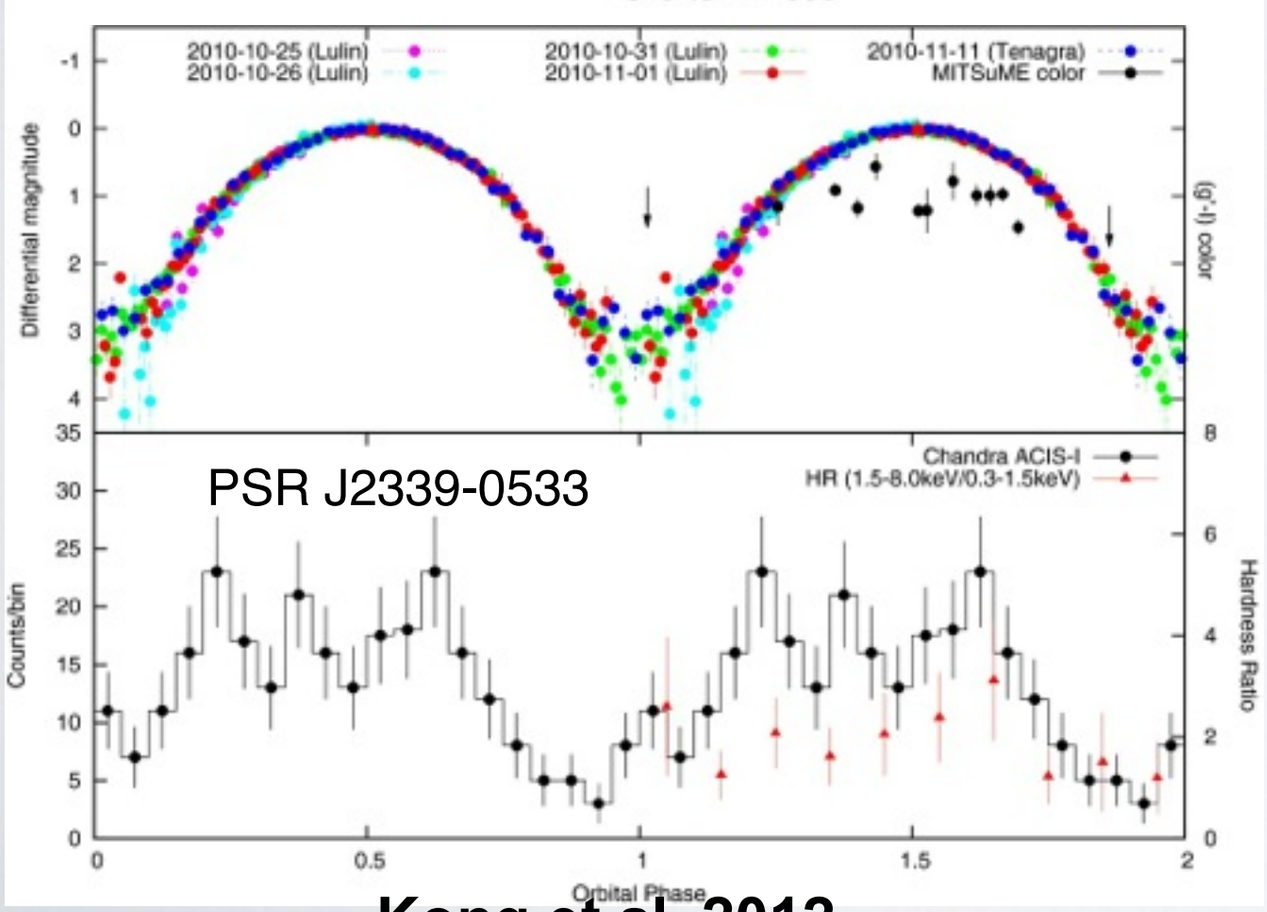
Bogdanov et al. 2011



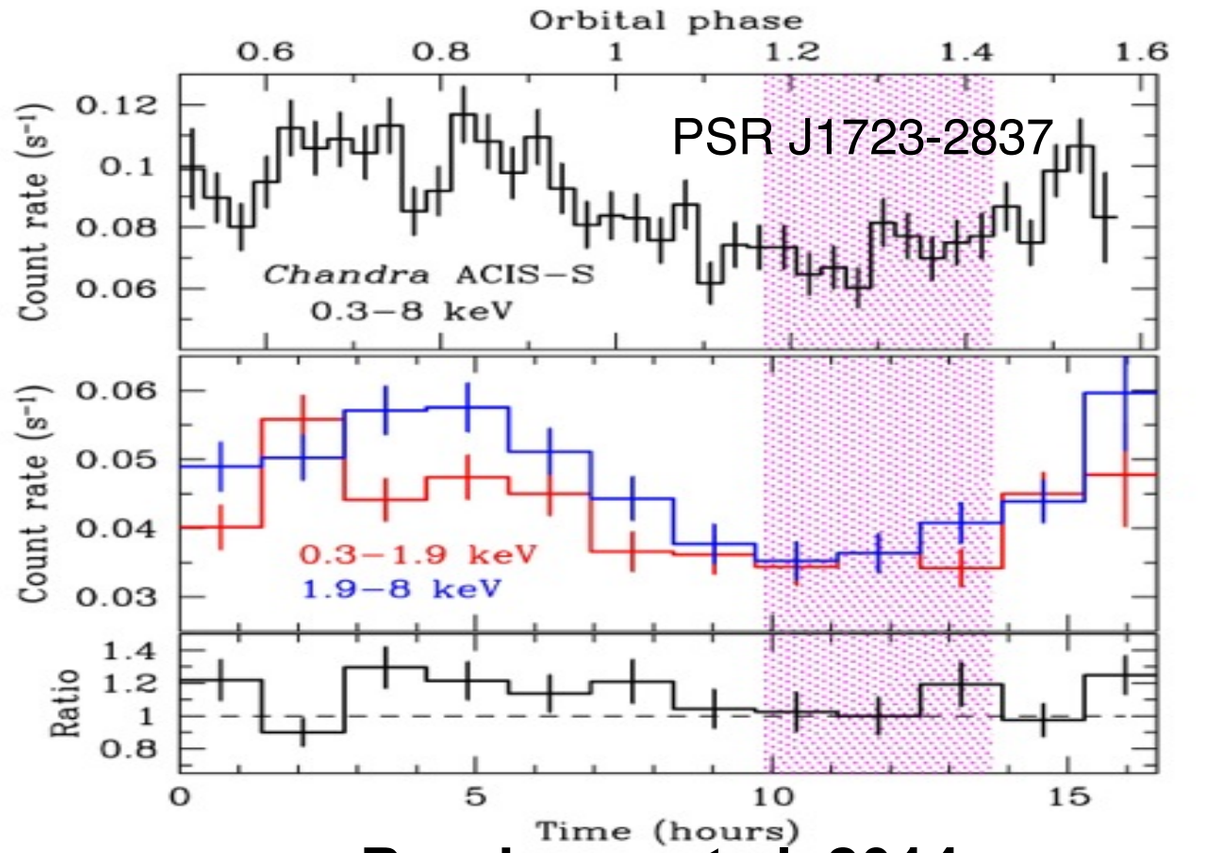
Some Other Redbacks

Gentile et al. 2014

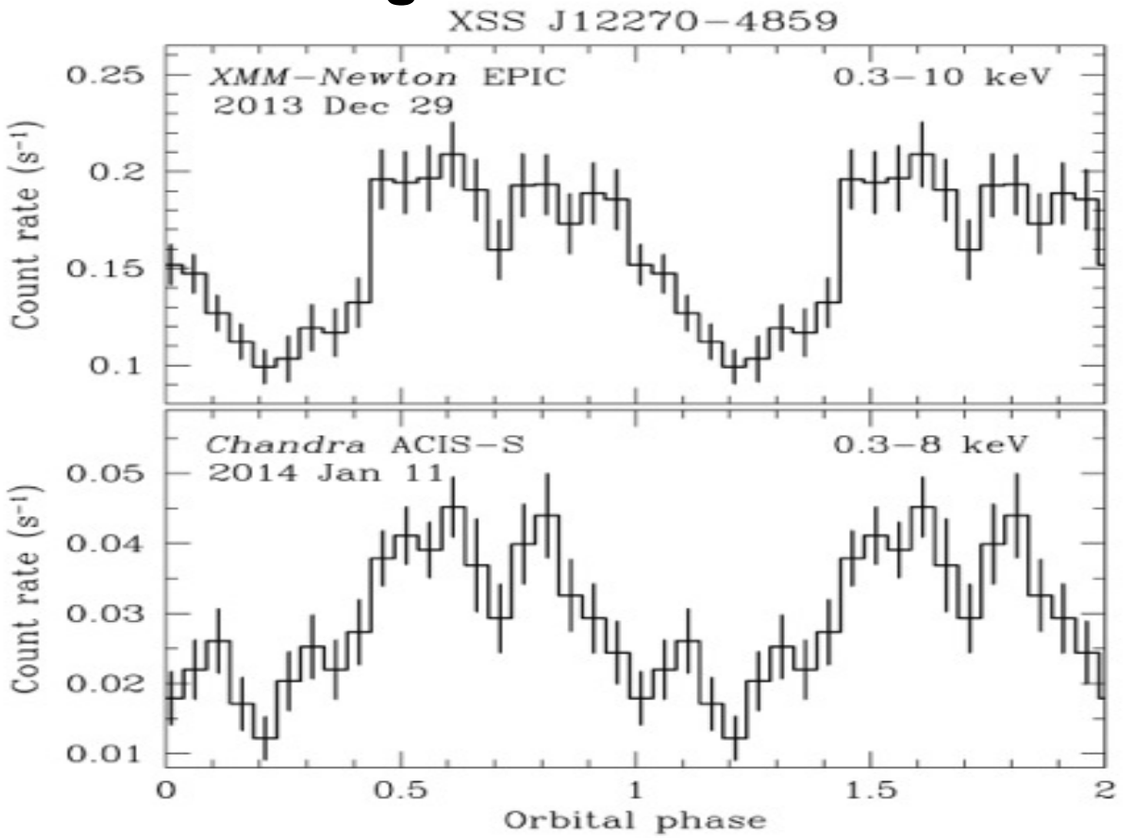




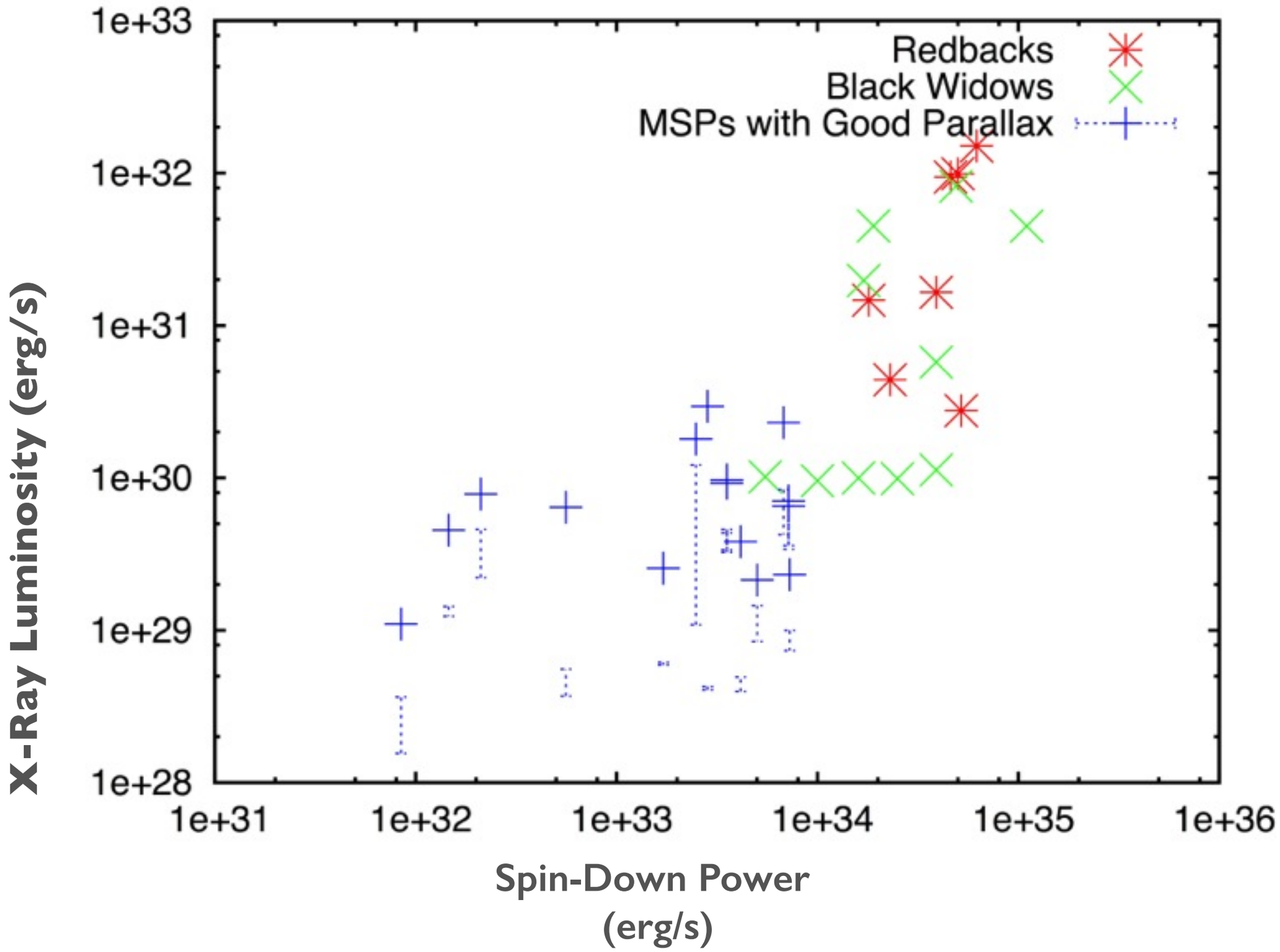
Kong et al. 2012



Bogdanov et al. 2014

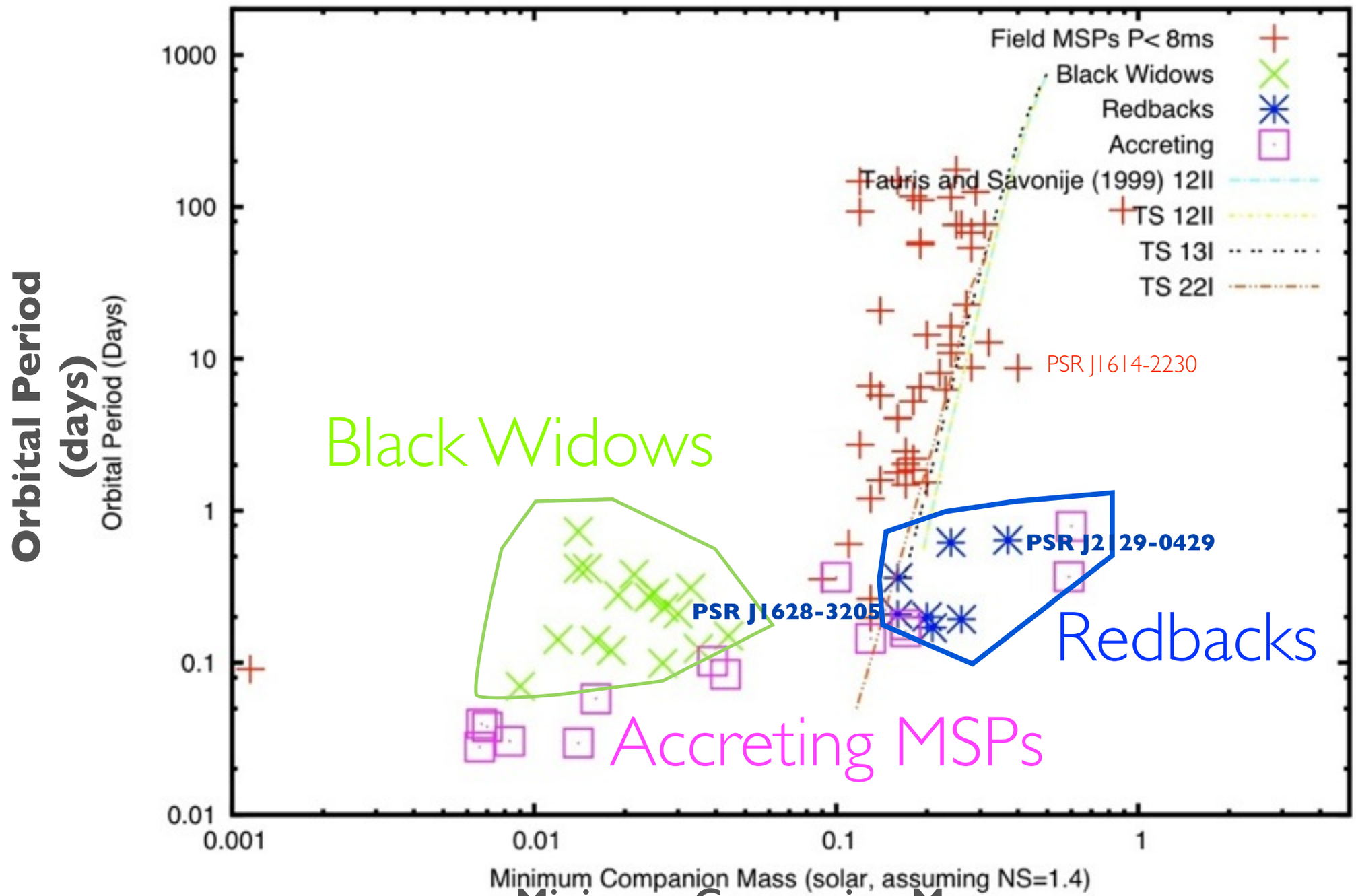


Black Widows and Redbacks
X-Ray Luminosity vs. Spin-Down Power

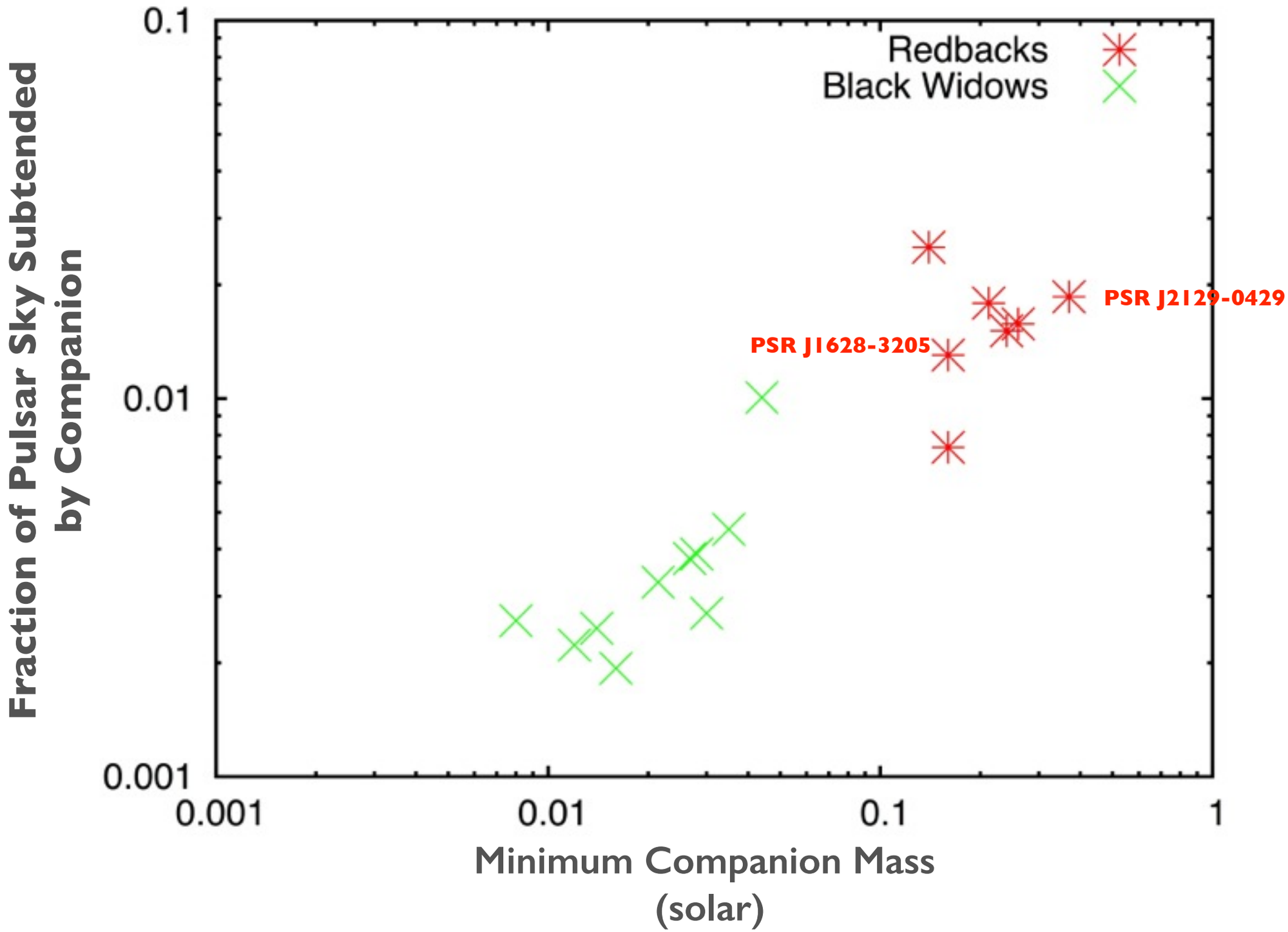


Black Widows and Redbacks
Minimum Companion Mass vs. Orbital Period

Pulsars P< 8ms

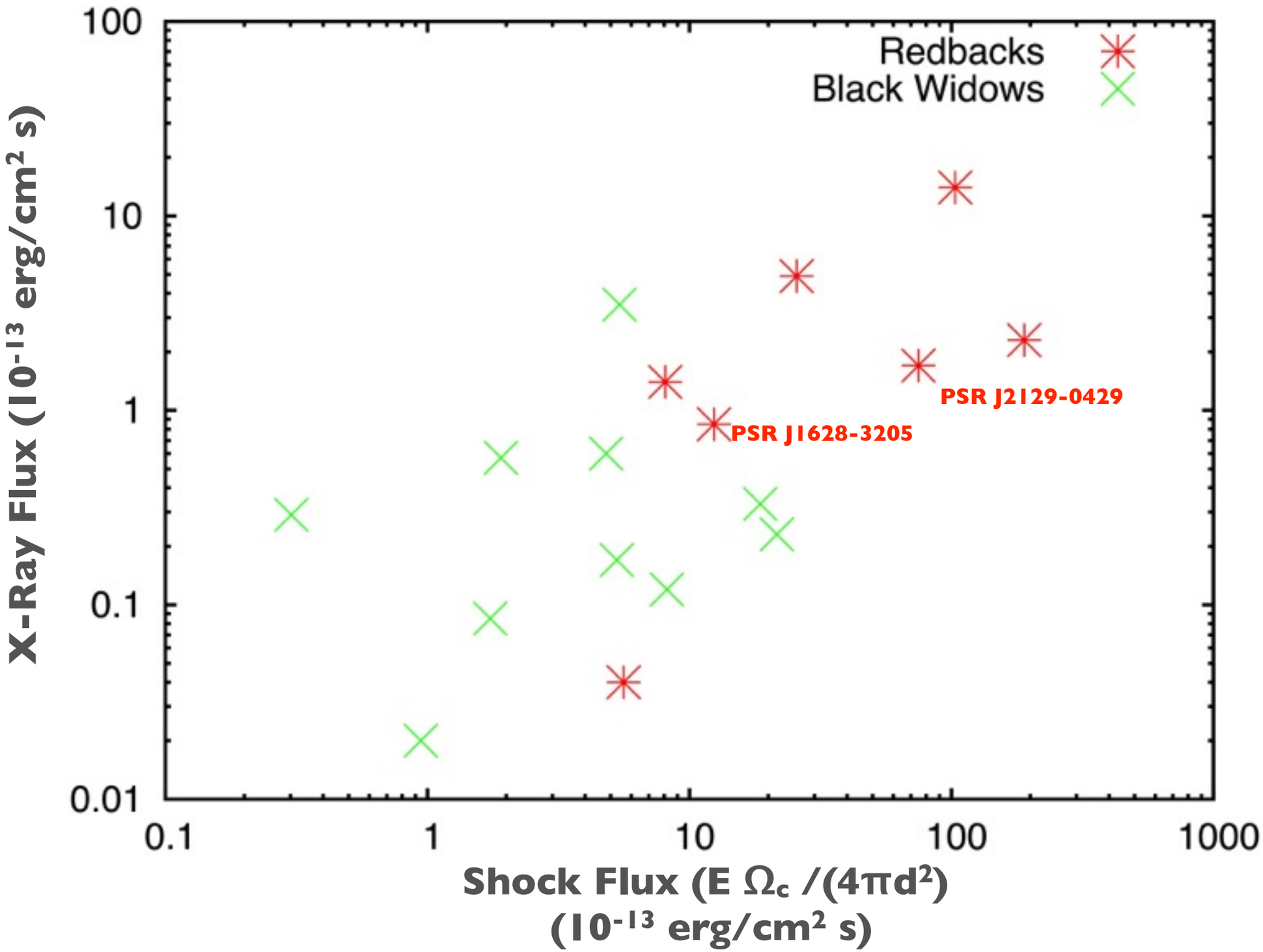


Black Widows and Redbacks
Minimum Companion Mass vs. Fraction of Sky



Black Widows and Redbacks
X-Ray Flux vs. Shock Flux

If pulsar wind isotropic, conversion of wind energy into soft X-rays ~1-10%

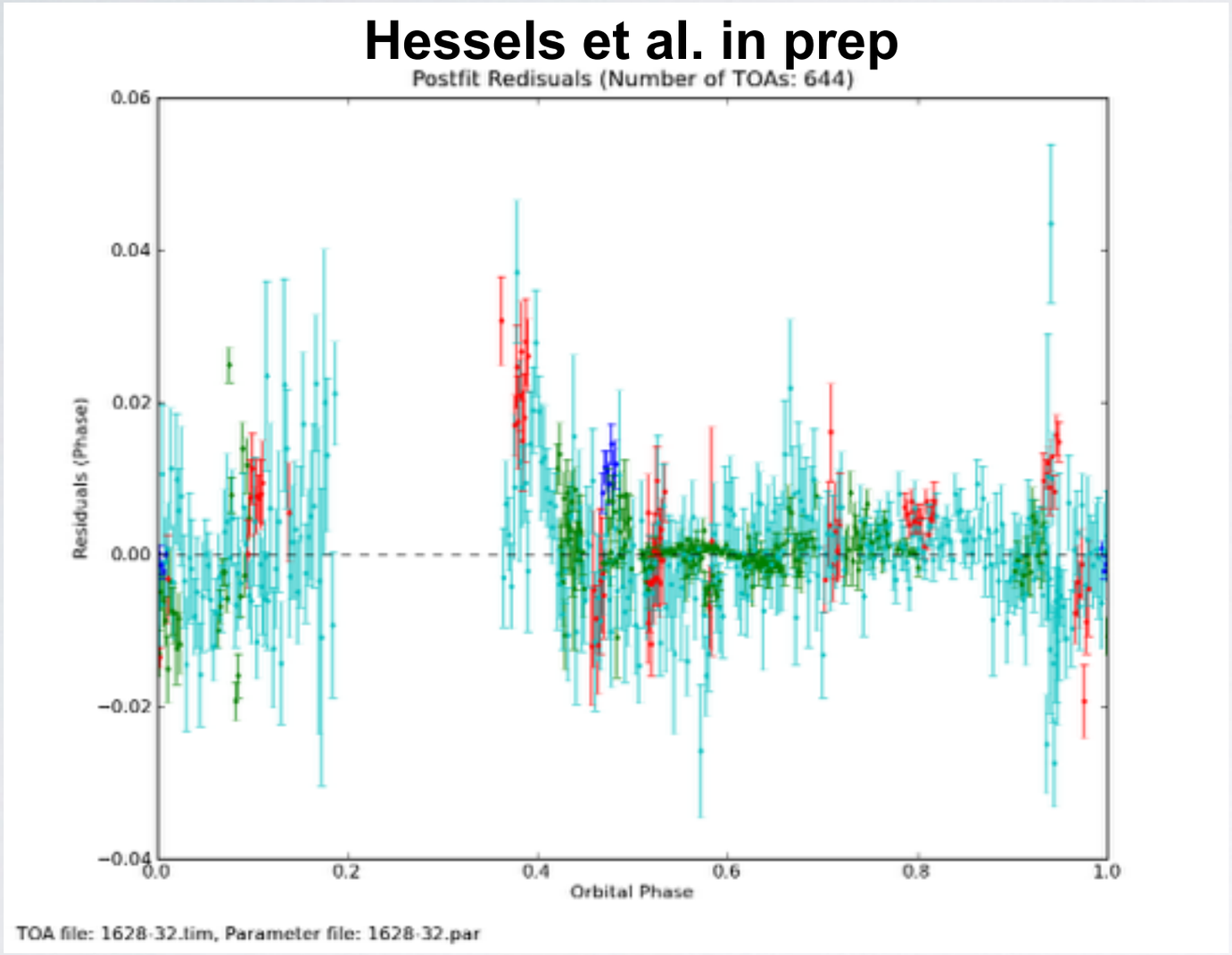


A Few Caveats

- MSP masses likely significantly greater than 1.4 solar, affecting Roche-lobe estimate of companion
- MSP radii possibly >10km, hence moment of inertia likely 1.5-4 times larger than canonical 10^{45}

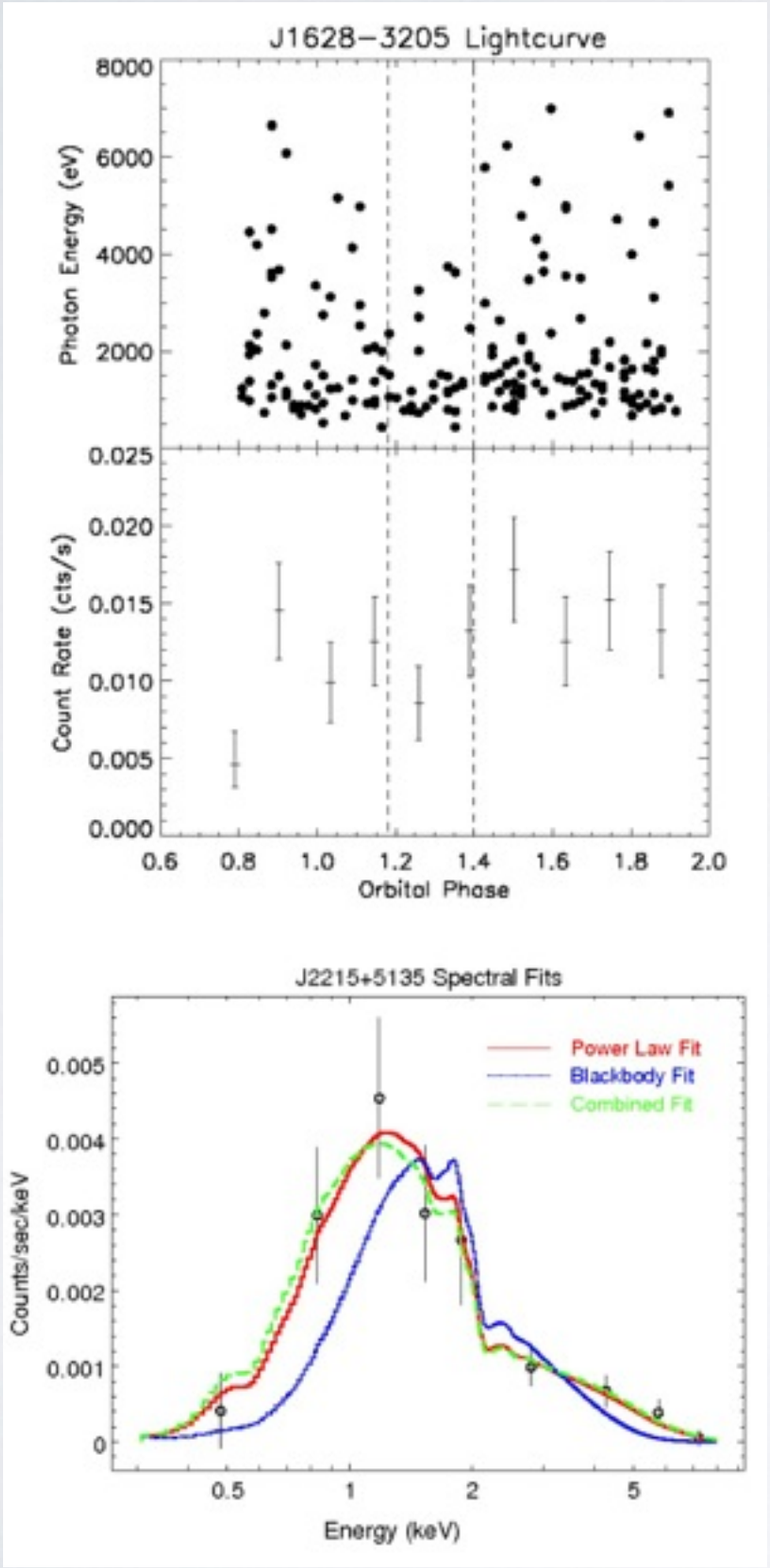
- Spin derivatives are affected by Shklovskii effect. Need proper motions, most are not corrected, ***Need more timing and/or VLBI!***
- Some have inclination estimates from optical lightcurves, some don't. ***Need more optical fits!***
- DM distances very rough. ***Need more parallaxes!***

PSR J1628-3205



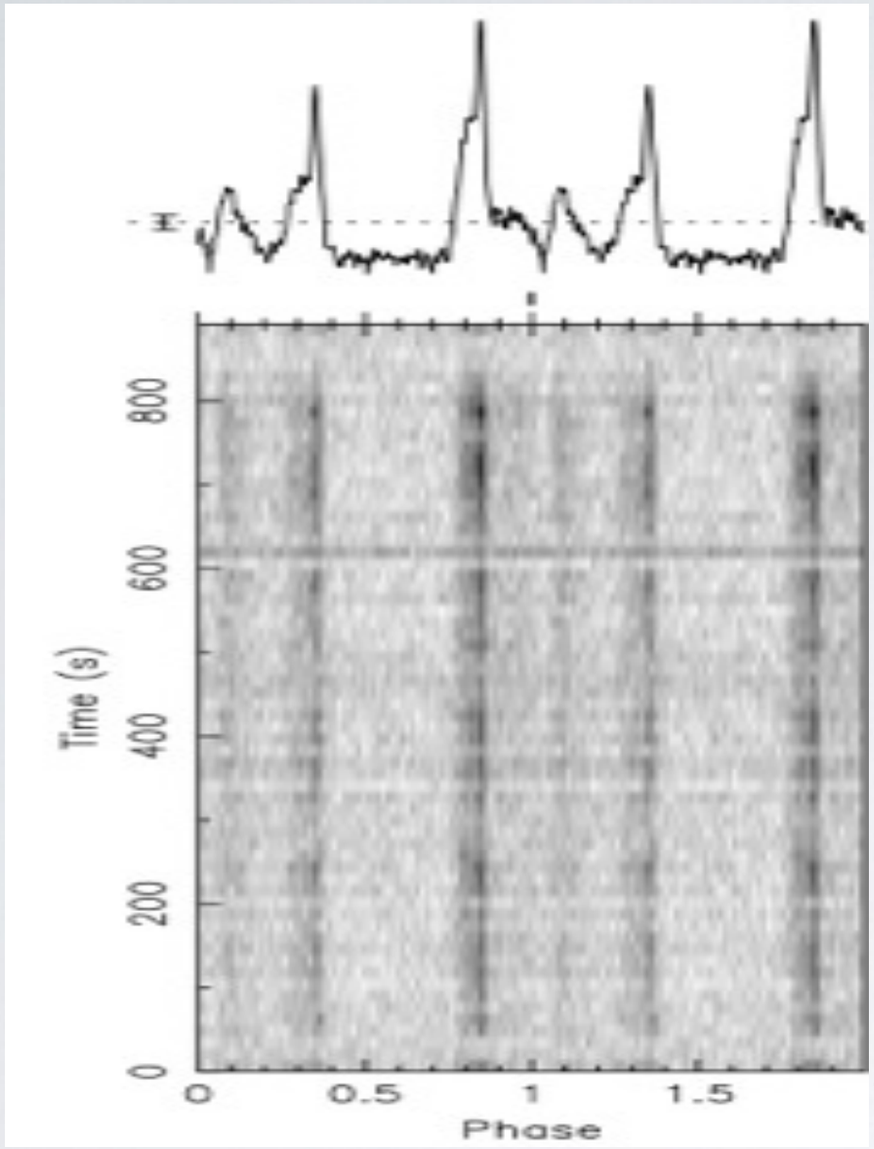
- 3.21 ms spin period
- 5.0 hr orbital period
- Minimum $M_C \sim 0.16\ M_{sol}$
- Shows radio eclipses
- $D_{ne2001} \sim 1.2$ kpc
- $\dot{B} \sim 2.2 \times 10^8$ G
- $\dot{E} \sim 1.8 \times 10^{34}$ erg
- Companion Roche Lobe filling, minimally heated (Li et al. 2014)

PSR J1628-3205

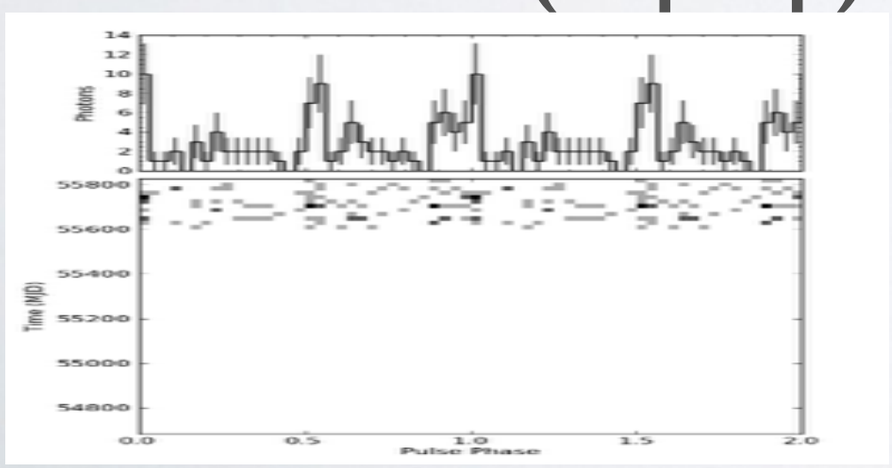


- 20 ks Chandra obs
- ~180 counts
- Power law component, probably blackbody as well
- $L_x \sim 2 \times 10^{31}$ erg
- Probably variable, need better statistics

PSR J2129-0429: A HIGH MAGNETIC FIELD REDBACK

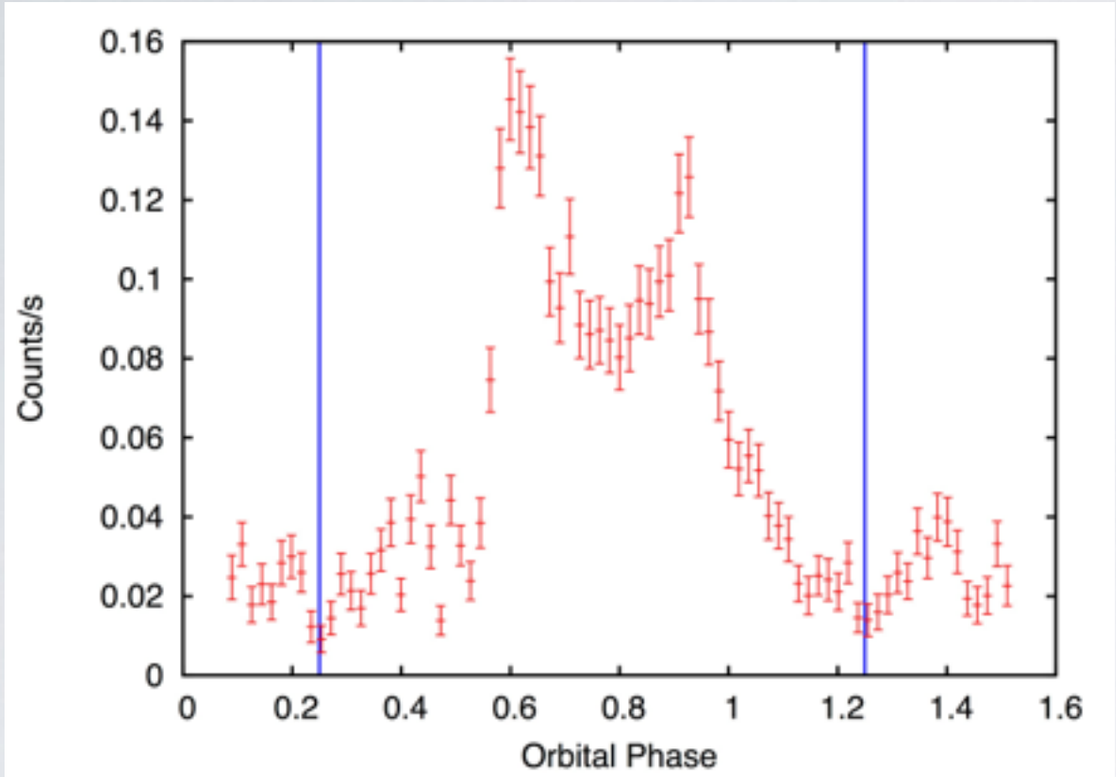


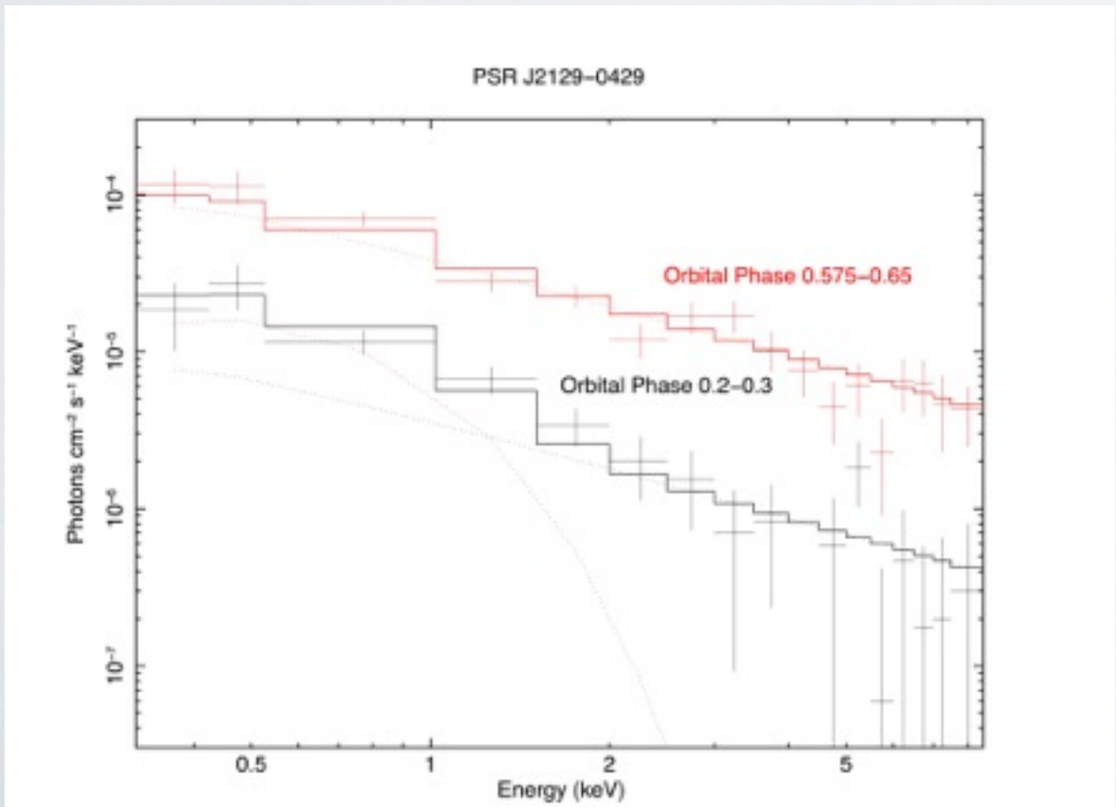
Hessels et al. (in prep)



- **7.61 ms period**
- **15.2 hr orbit**
- Orbital separation ~ 8000 light cylinder radii
- **Minimum M_C ~ 0.37 M_{sol}**
- Shows extensive radio eclipses
- E ~ 3.9 x 10^{34} erg
- **D_{NE2001} ~ 0.9 kpc**
- Bright UV Counterpart
- Filling Fraction ~95%, pulsar mass > 1.7 solar (Bellm et al. 2013)
- **B ~ 1.6 X 10^9 G**
- Large Orbital Period Changes
- Pulsations dominate γ-ray emission

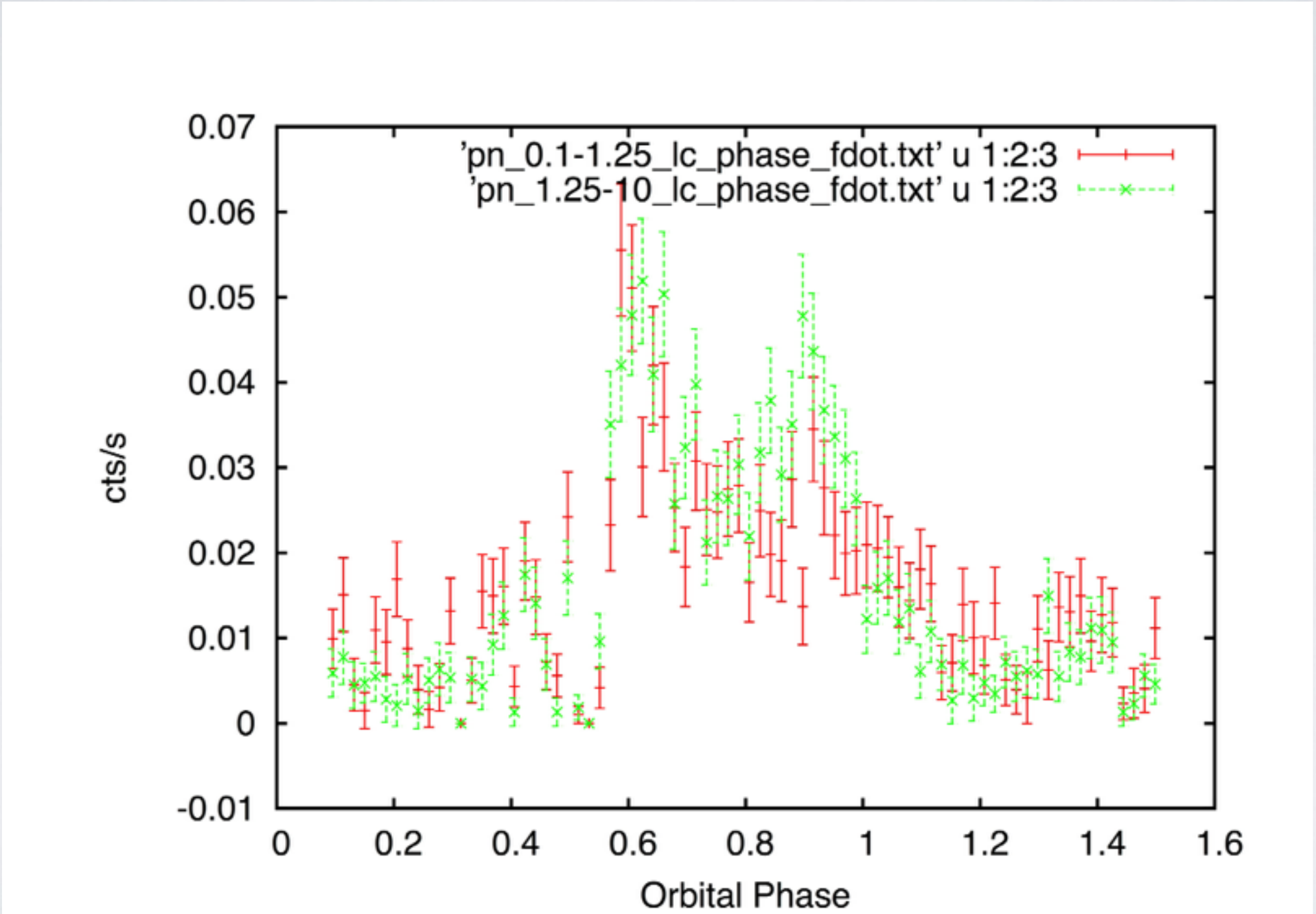
PSR J2129-0429: A HIGH MAGNETIC FIELD REDBACK

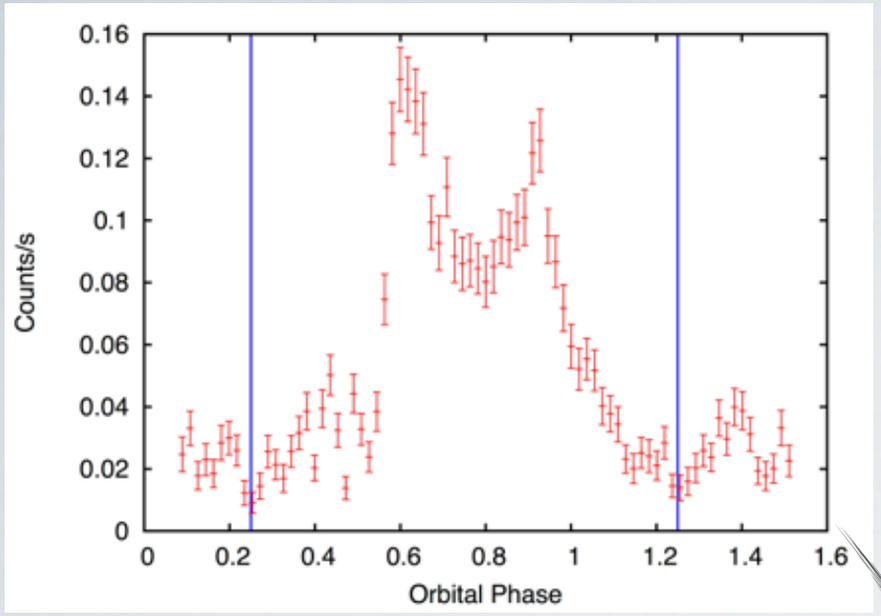


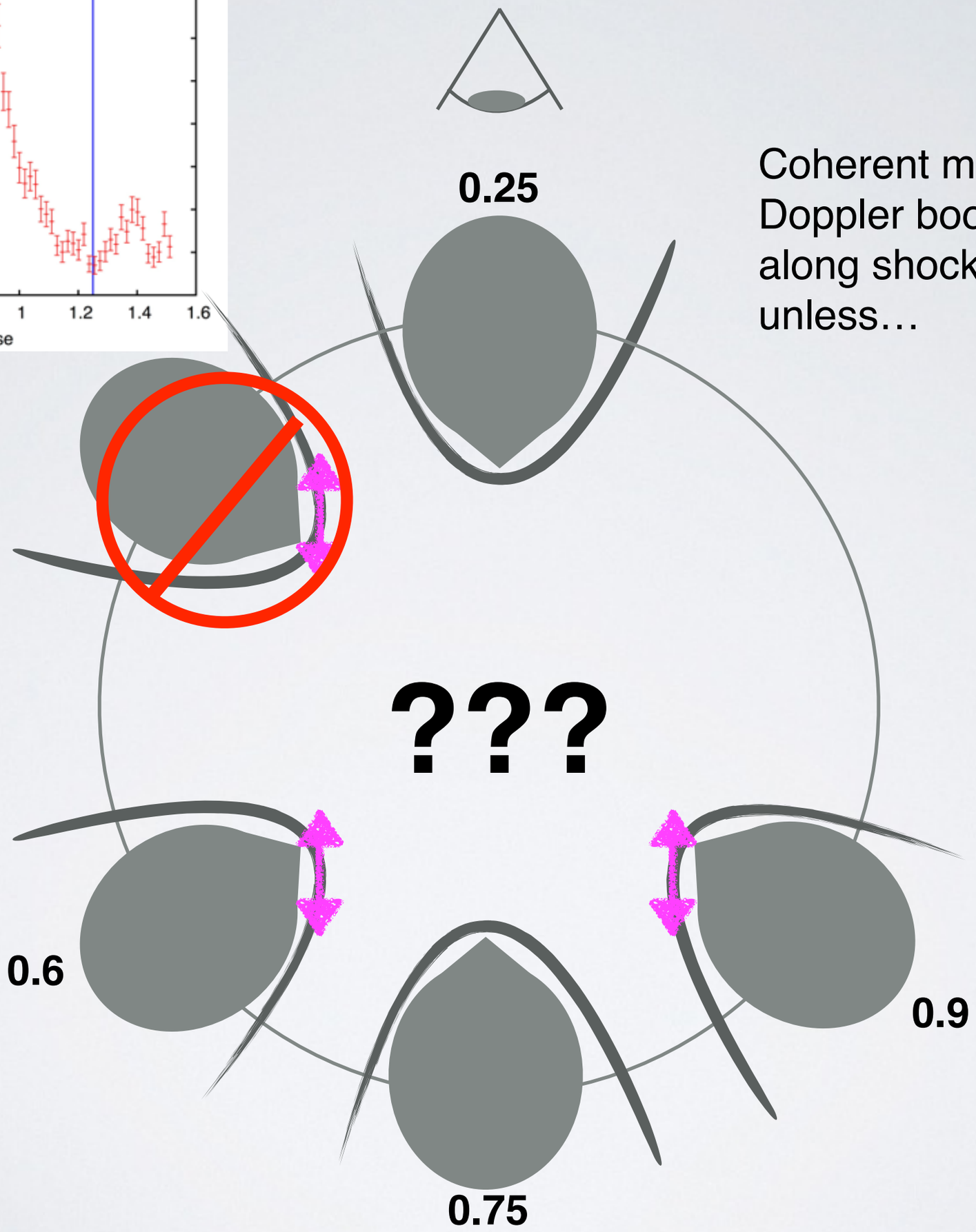


- 70 ks XMM-Newton observation (with no background flares!!!)
- Roughly constant blackbody component, typical of MSP surface emission ($L_{bb} \sim 10^{30}$ erg/s)
- Very hard ($\Gamma \sim 1.0$) power-law component varies by factor of 11
- Spectral index may change with orbital phase

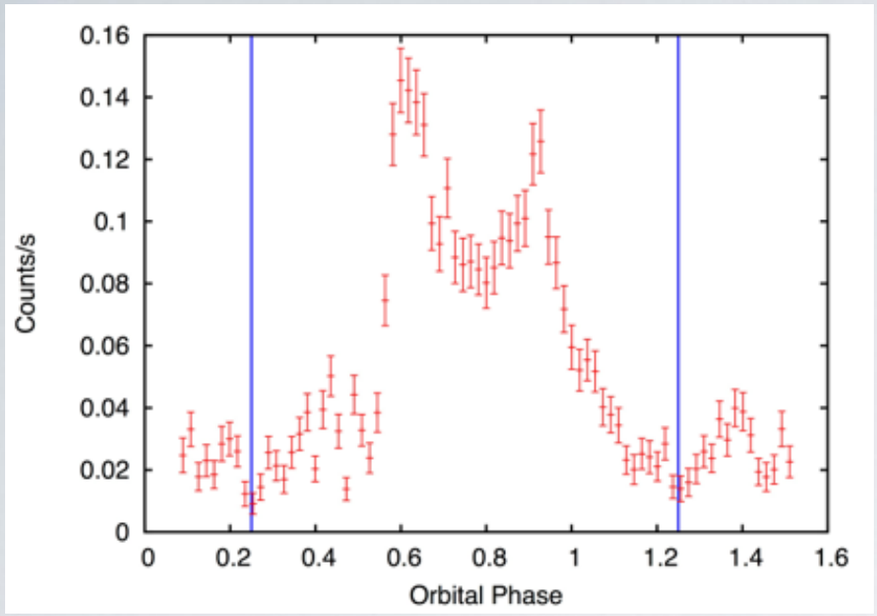
PSR J2129-0429: A HIGH MAGNETIC FIELD REDBACK

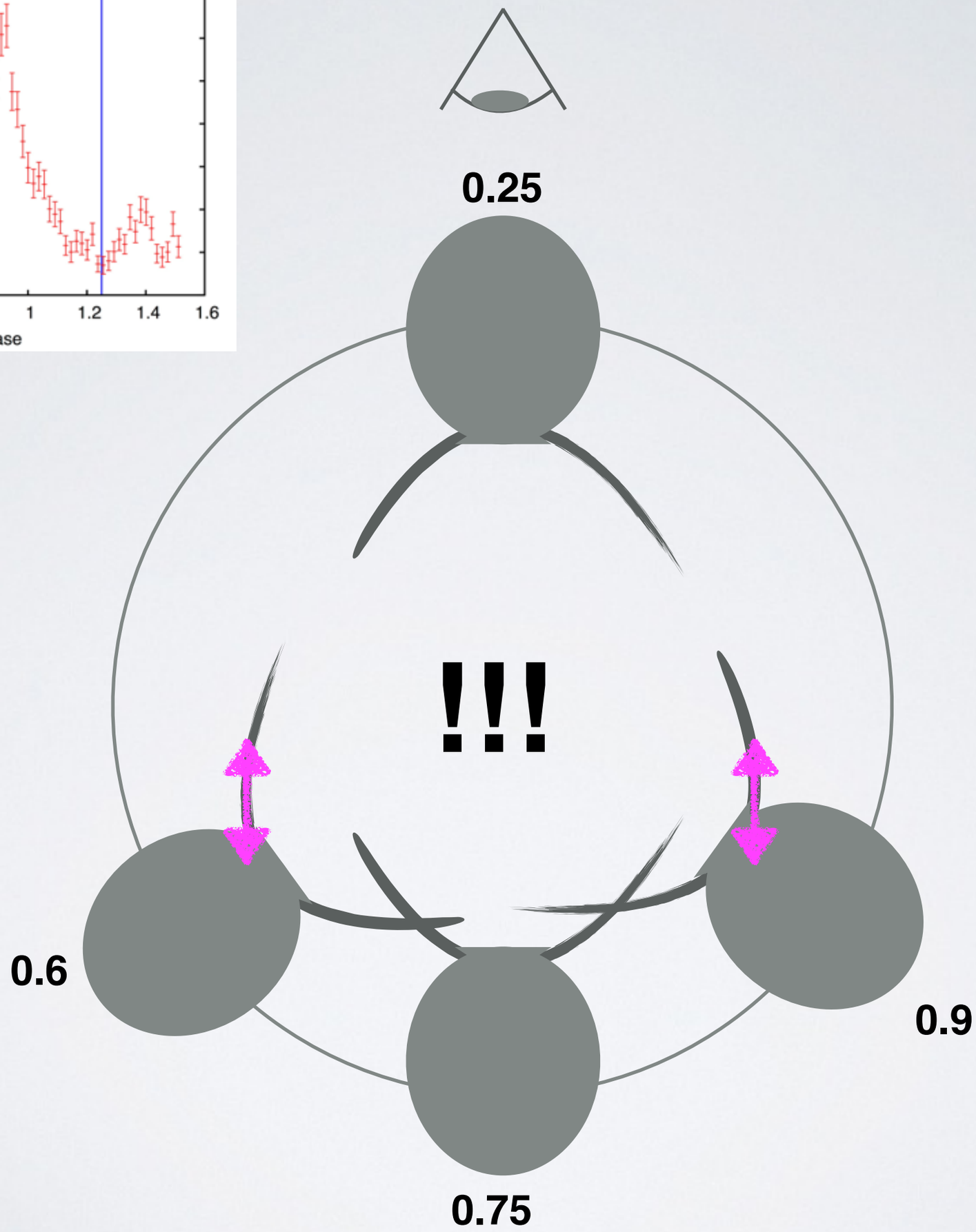






Coherent magnetic field and
Doppler boosting
along shock doesn't work
unless…


Counts/s
Orbital Phase
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6


0.25
!!!
0.6
0.9
0.75

Conclusions and questions about PSR J2129-0429 X-Ray emission (and Redbacks in general??)

- Shock likely not bigger than companion, otherwise why such large orbital variation?
- Emission highly beamed, as if wind strongly confined, maybe by B field of companion?
- Emission harder than PWN shock emission, and much more efficient
- Is wind concentrated in orbital plane (low magnetic inclination angle)?
- Is distortion of companion important?
- How much does light curve change from orbit to orbit? Could peaks be intermittent flares instead of regular feature?
- Are properties of the companion as important as the pulsar wind to the X-ray emission?