Hunting for the missing spiders and TeV emissions from globular clusters and Galactic black hole binaries

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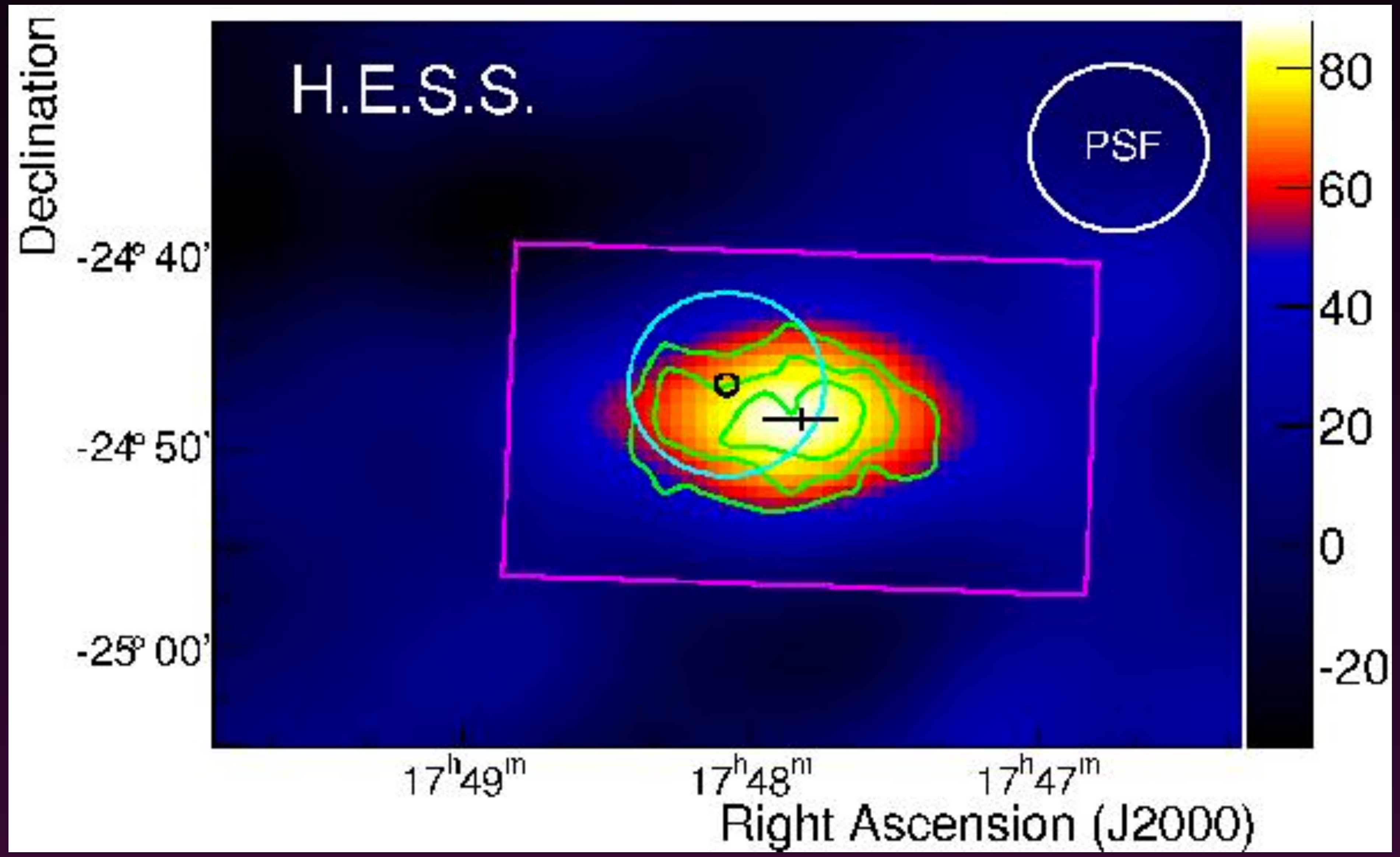
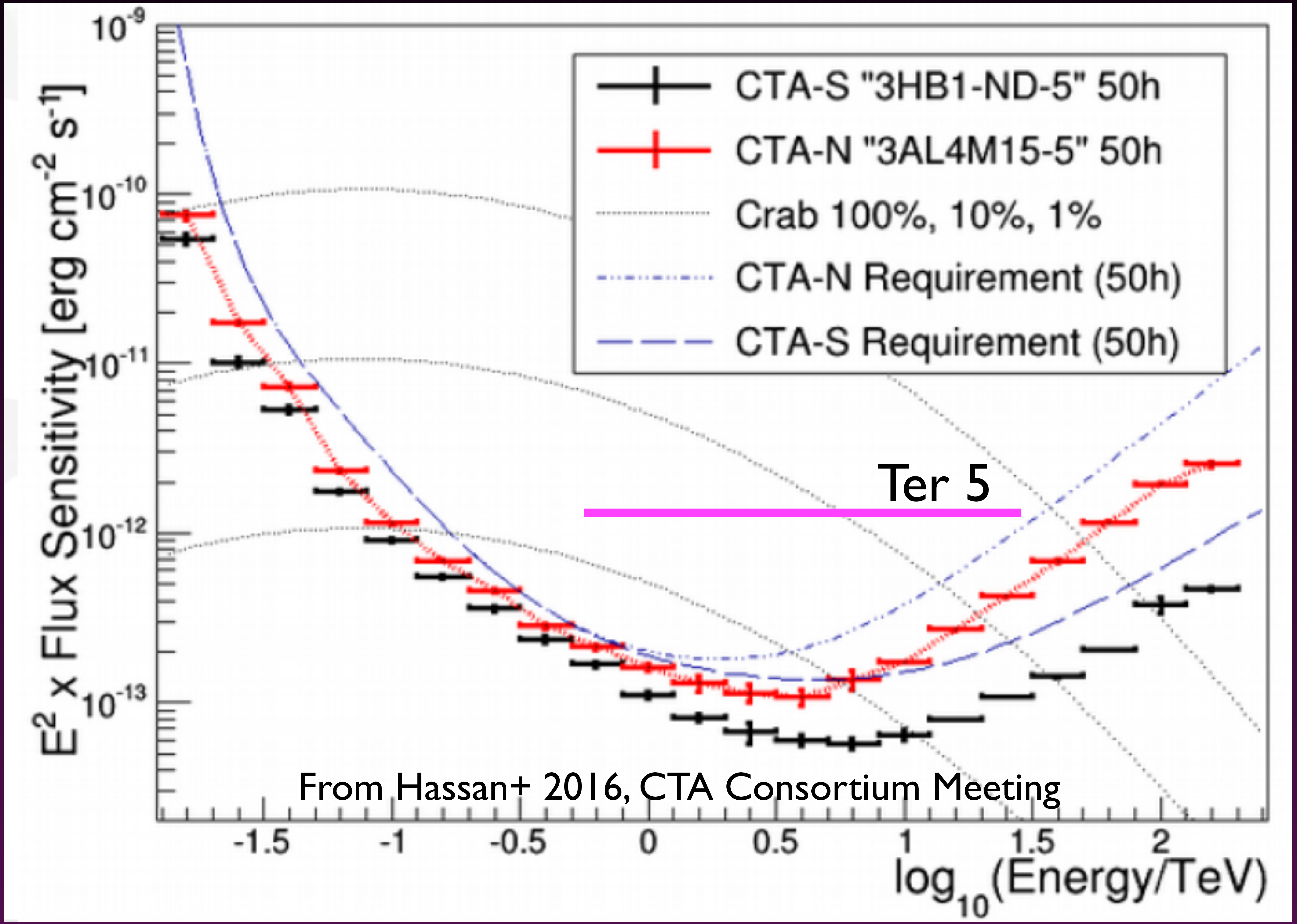
On behalf of the Fermi Asian Network (FAN)

TeV Observations of Globular Clusters



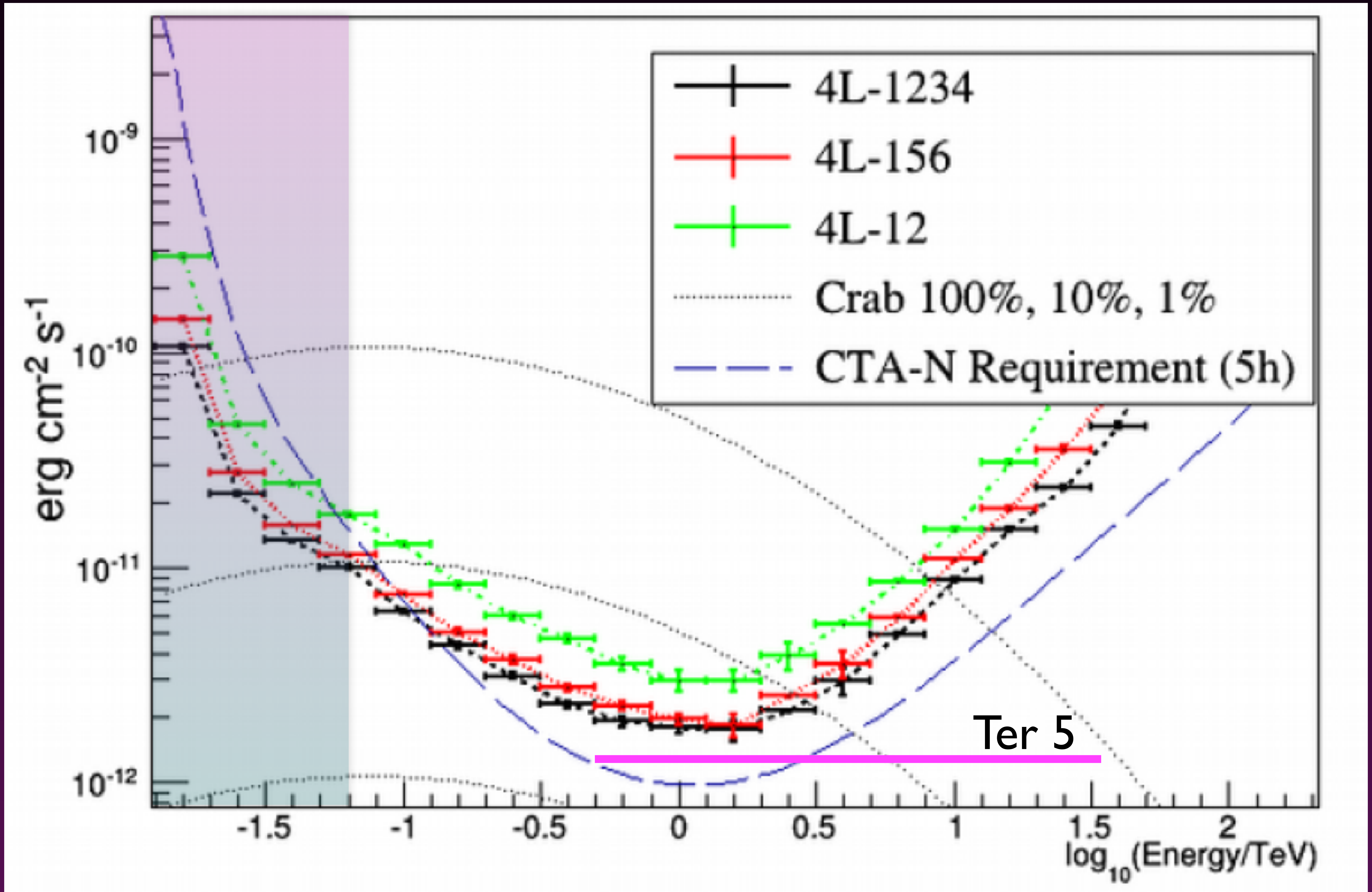
- Is the TeV emission associated with Ter 5?
- The TeV centroid is 4 arcmin from the centre of Ter 5, way outside the half-mass radius
- It is marginally within the tidal radius of the GC
- The TeV emission is extended

Prospects of CTA



- Case study: Ter 5
- Based on H.E.S.S. observations: 0.44-24 TeV photon flux = 1.2×10^{-12} $cm^{-2}s^{-1}$ (1.5% of Crab)

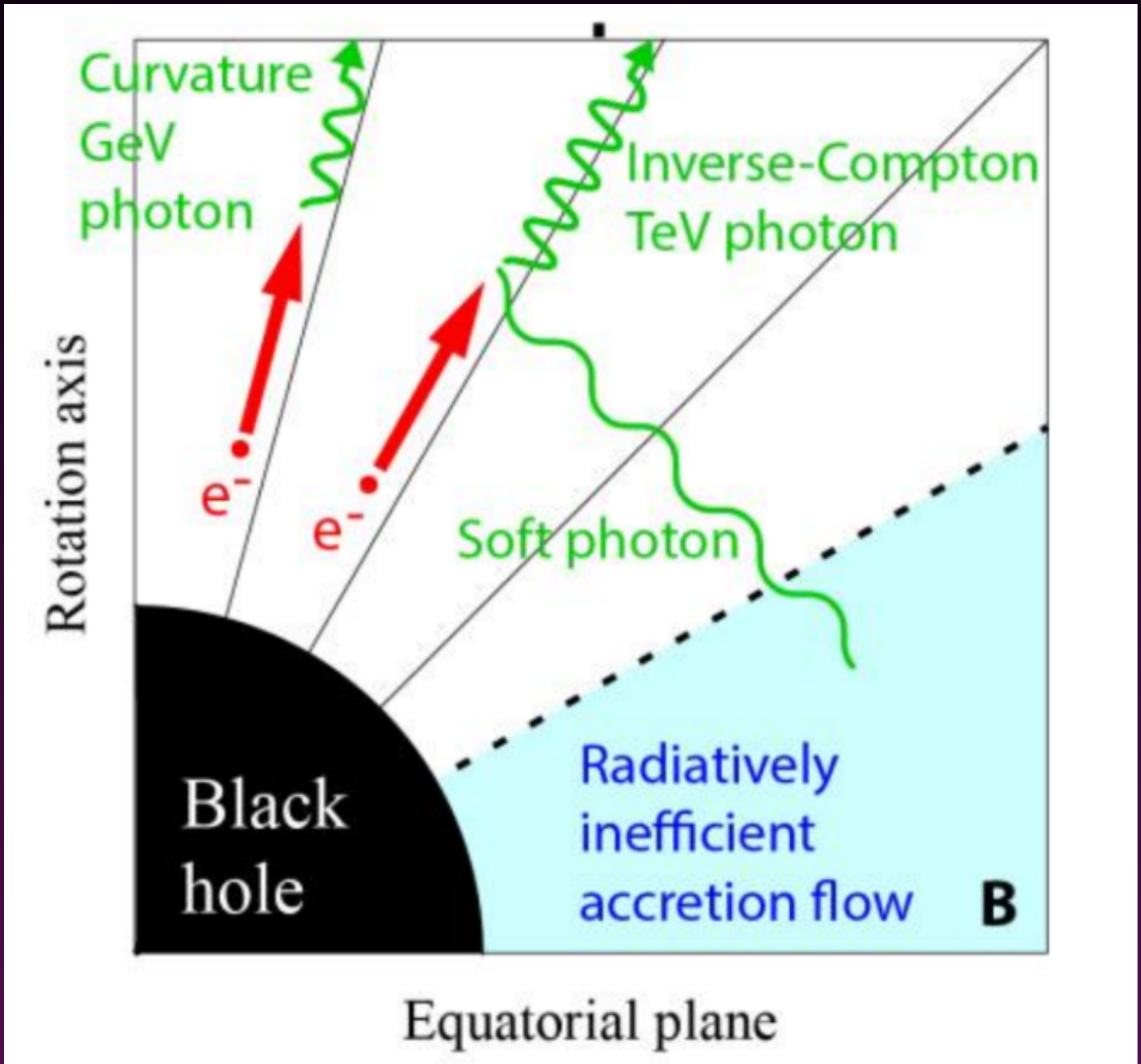
What about LST only?



GeV/TeV Emission of Galactic Black Hole Binaries

- Cyg X-3: AGILE (Tavani+ 2009), Fermi/LAT (2009)
- Cyg X-1: Fermi/LAT (Zanin+ 2016)
- V404 Cyg: Fermi/LAT (Loh+ 2016); very marginal detection
- V404 Cyg is the only low-mass X-ray black hole binary
- The observed gamma-rays are all associated with radio flux, indicating an origin related to relativistic jets and shocks
- Is jet the only mechanism to generate gamma-rays?
- The discovery of TeV emission from the radio galaxy IC 310 (Aleksic+ 2014) casts doubt on jet-related models. The observed parameters are not consistent with models.
- TeV emission could also be from a black hole gap arising in the polar funnel of a rotating BH magnetosphere (Beskin+ 1992; Hirotani & Okamoto 1998; Hirotani+ 2016)

Black Hole Gap Emission



Hirotani+ in prep.

- Unlike jet-related model, black hole gap model requires a black hole transient in quiescence.
- Very low accretion rate
- A radiatively inefficient accretion flow cannot provide enough photons to maintain a force-free magnetosphere via two-photon collisions
- In this charge-starved magnetosphere (BH gap), an electric field inevitably arises along the magnetic field line to accelerate electrons and positrons into ultra-relativistic energies.
- Large BH mass and spin


1A 0620-00
M= 11 M_solar
a= 0.9 M
d= 1160 pc
CTA 50 hrs
North
South
Photon energy flux (TeV^2 s^{-1} cm^{-1} TeV^{-1})
10^{-11}
10^{-12}
10^{-13}
10^{-14}
10^{-15}
10^{-16}
10^{-17}
meV eV keV MeV GeV TeV PeV
Photon energy
V404 Cyg
M= 12 M_solar
a= 0.9 M
d= 2390 pc
CTA 50 hrs
North
South
Photon energy flux (TeV^2 s^{-1} cm^{-1} TeV^{-1})
10^{-11}
10^{-12}
10^{-13}
10^{-14}
10^{-15}
10^{-16}
10^{-17}
meV eV keV MeV GeV TeV PeV
Photon energy

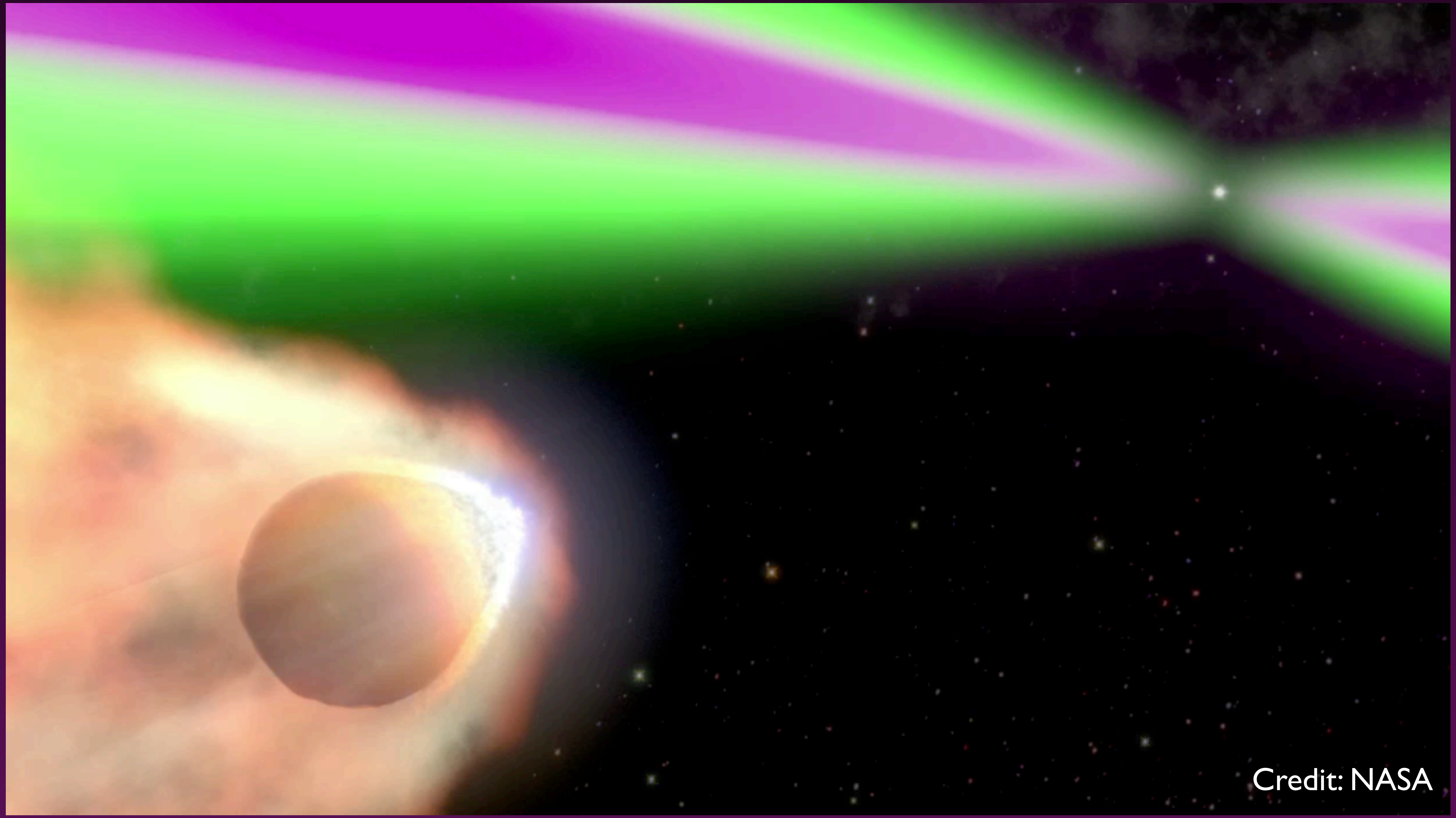
Lin+ 2017

Spiders: Black Widows and Redbacks

- MSPs in compact binary systems
  - $P_{orb} < 1$ day
  - Radio eclipses due to evaporating materials from the companion
  - Some show X-ray, optical (including colour), and gamma-ray modulation
- Black Widows
  - Very low mass ($< 0.05\ M_{\odot}$) companions
- Redbacks
  - Higher mass ($> 0.1\ M_{\odot}$) non-degenerate companions
  - Can show state transitions (MSP $\longleftrightarrow$ LMXB)

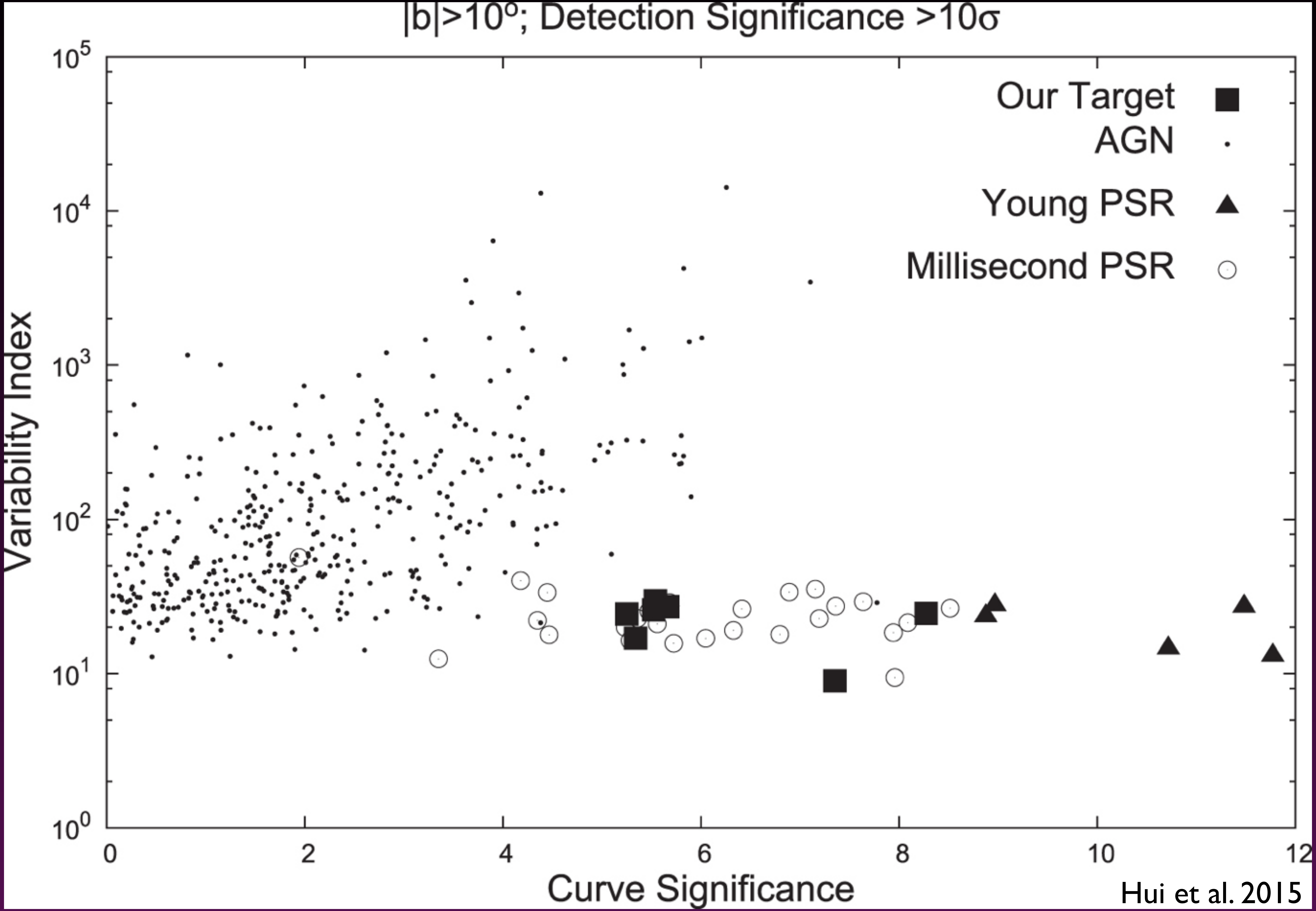
Spider MSPs

- Pulsar radiation can ablate the companion, leaving an isolated MSP at the end
- They are important systems to study the evolution and formation of MSPs
- Before the launch of Fermi in 2008, there are only 3 BW MSPs found out of > 100 MSPs.



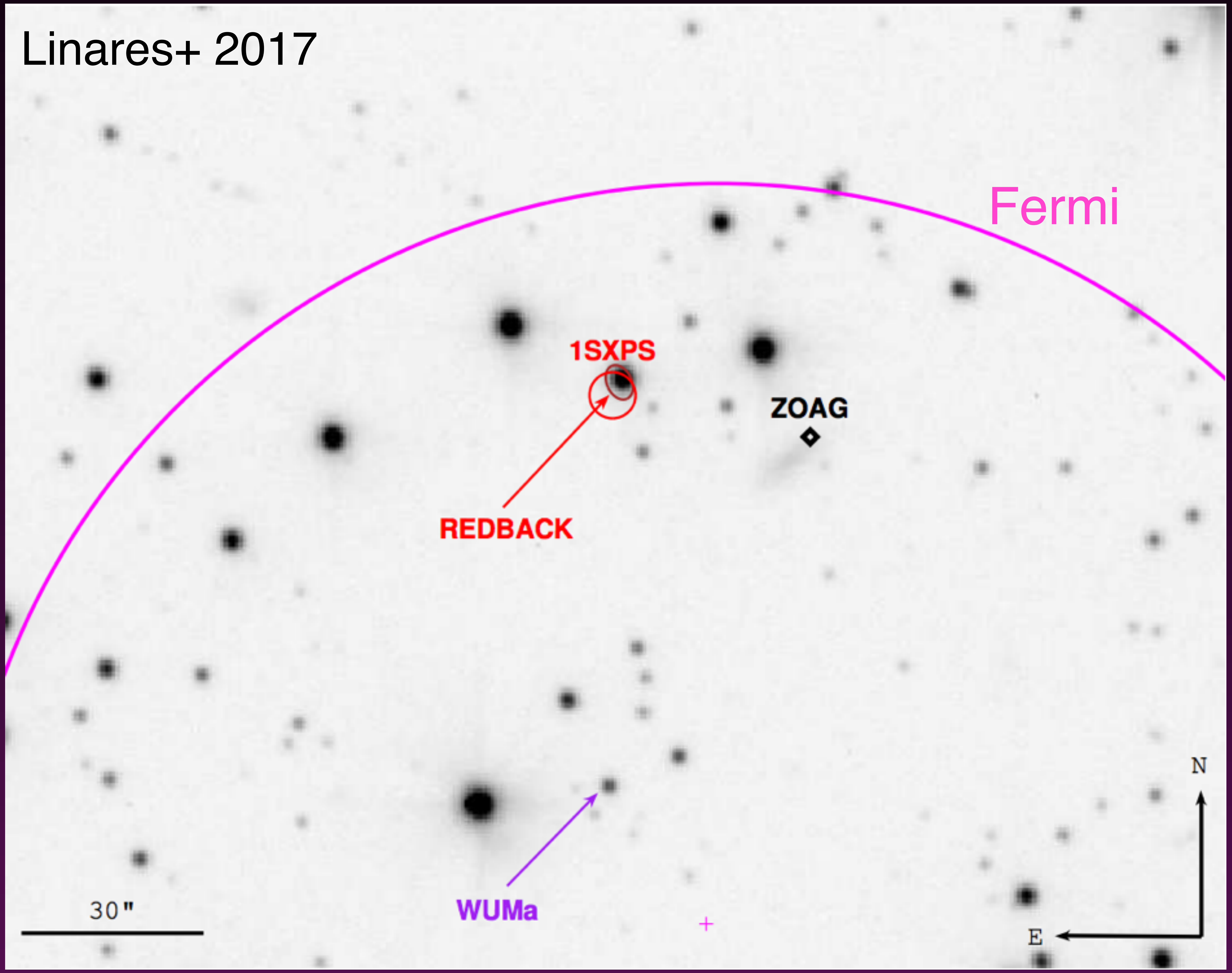
Unidentified Fermi Objects (UFOs) as Spider MSPs

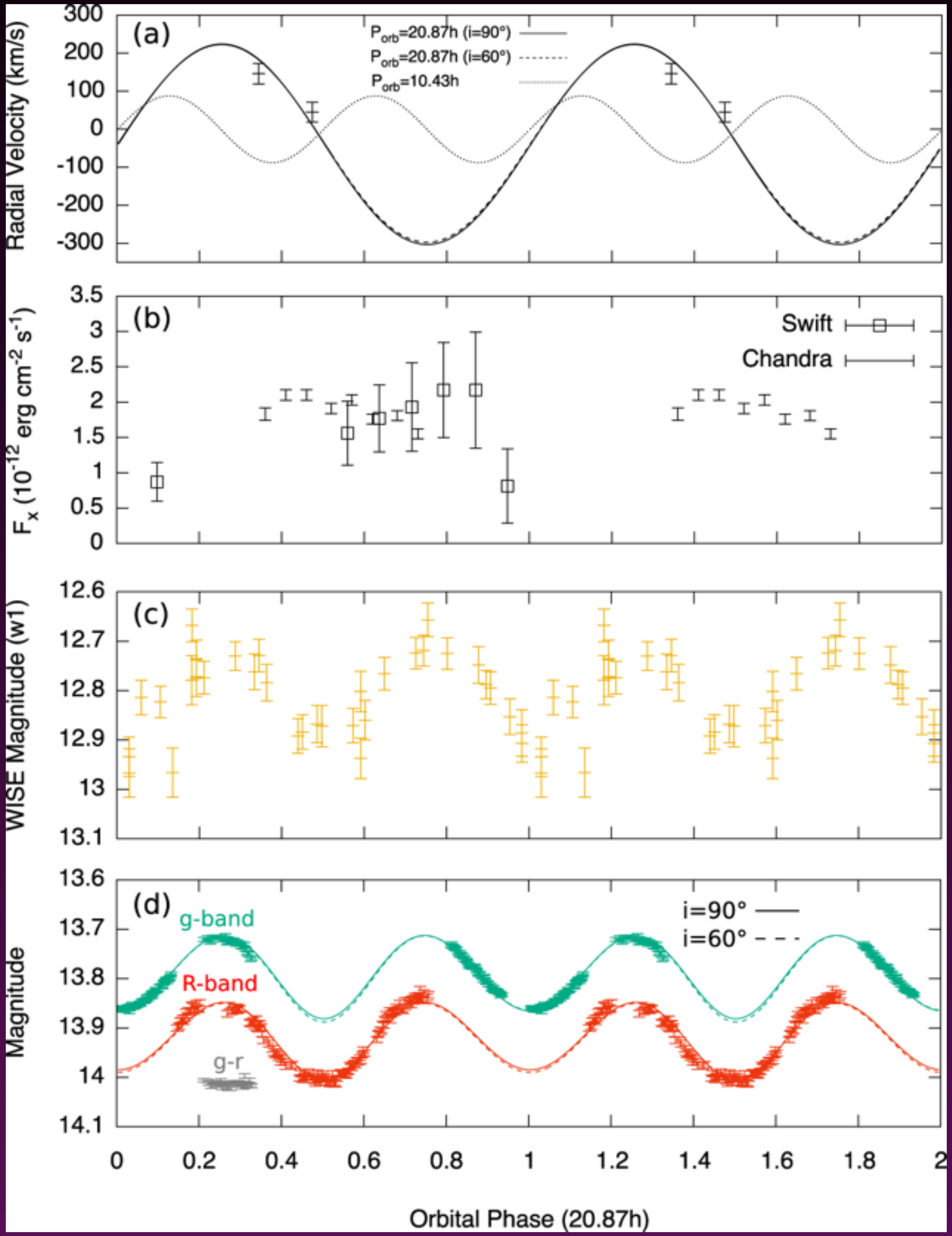
- Traditionally, MSPs are found with radio timing.
- Selection effects of radio biased the sample.
  - Timing in a compact system is difficult
  - Absorption and scattering in BW/RB is enormous
  - Radio plane survey
  - Usually discovered in globular clusters
- Fermi has changed the game
  - Radio/gamma-ray timing on Fermi sources
  - > 200 gamma-ray PSRs; nearly 100 MSPs; > 30 spiders



Hui et al. 2015

Unidentified Fermi Objects (UFOs) as Spider MSPs



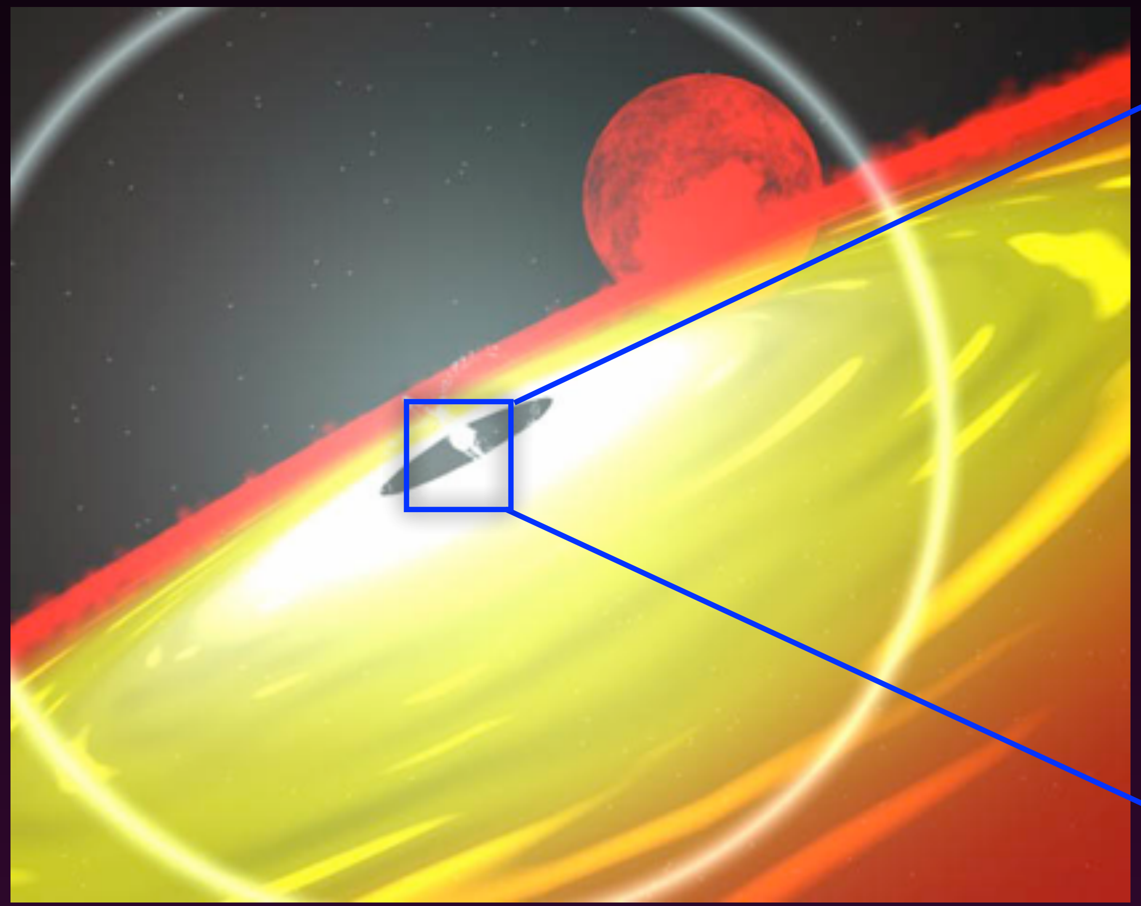


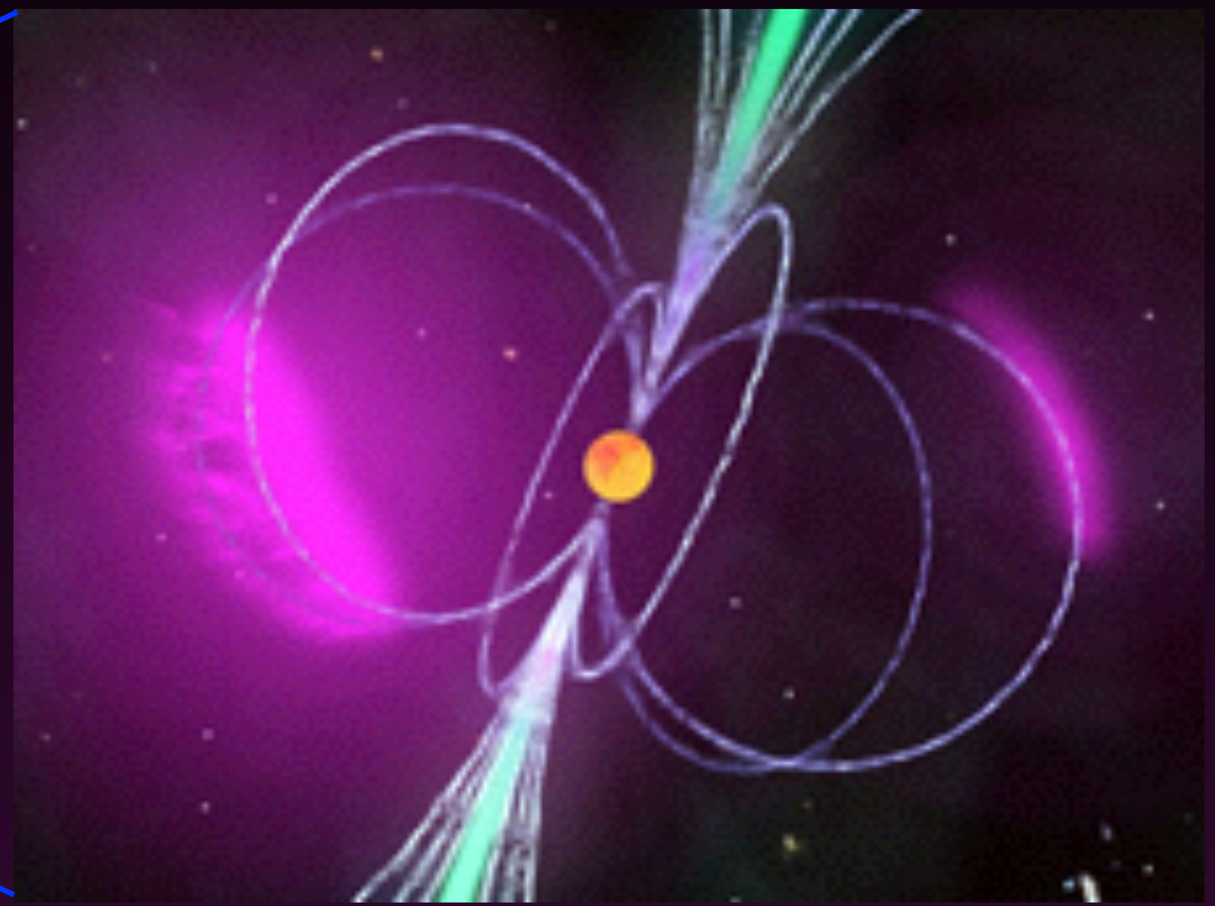
Li+ 2016

New BWs/RBs from UFOs

- 2FGL J1311.7-3429 = PSR J1311-3430 (Romani 2012)
- 1FGL J0523.5-2529 (Strader+ 2014)
- 2FGL J2039.6-5620 (Romani 2015; Salvetti+ 2015)
- 3FGL J1544-1125 (Bogdanov & Halpern 2015; tMSP candidate)
- 3FGL J1048.6+2338 = PSR J1048+2339 (Deneva+ 2016)
- 3FGL J0212.1+5320 (Li+ 2016; Linares+ 2017)
- 3FGL J0838.8-2829 (Halpern+ 2017)
- See also Hui+ 2015 and Salvetti+ 2017 for other candidates

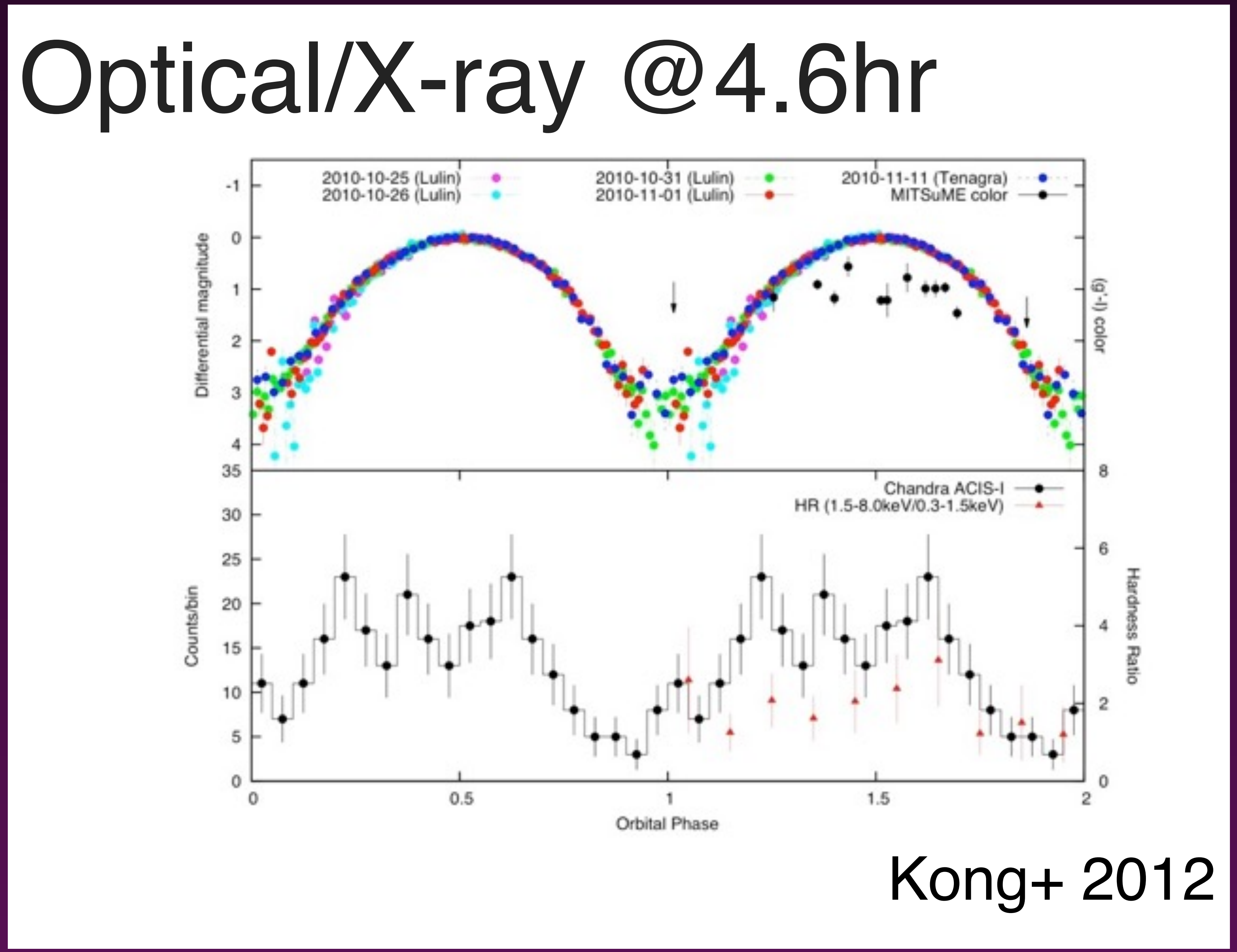
PSR J2339.7-0533

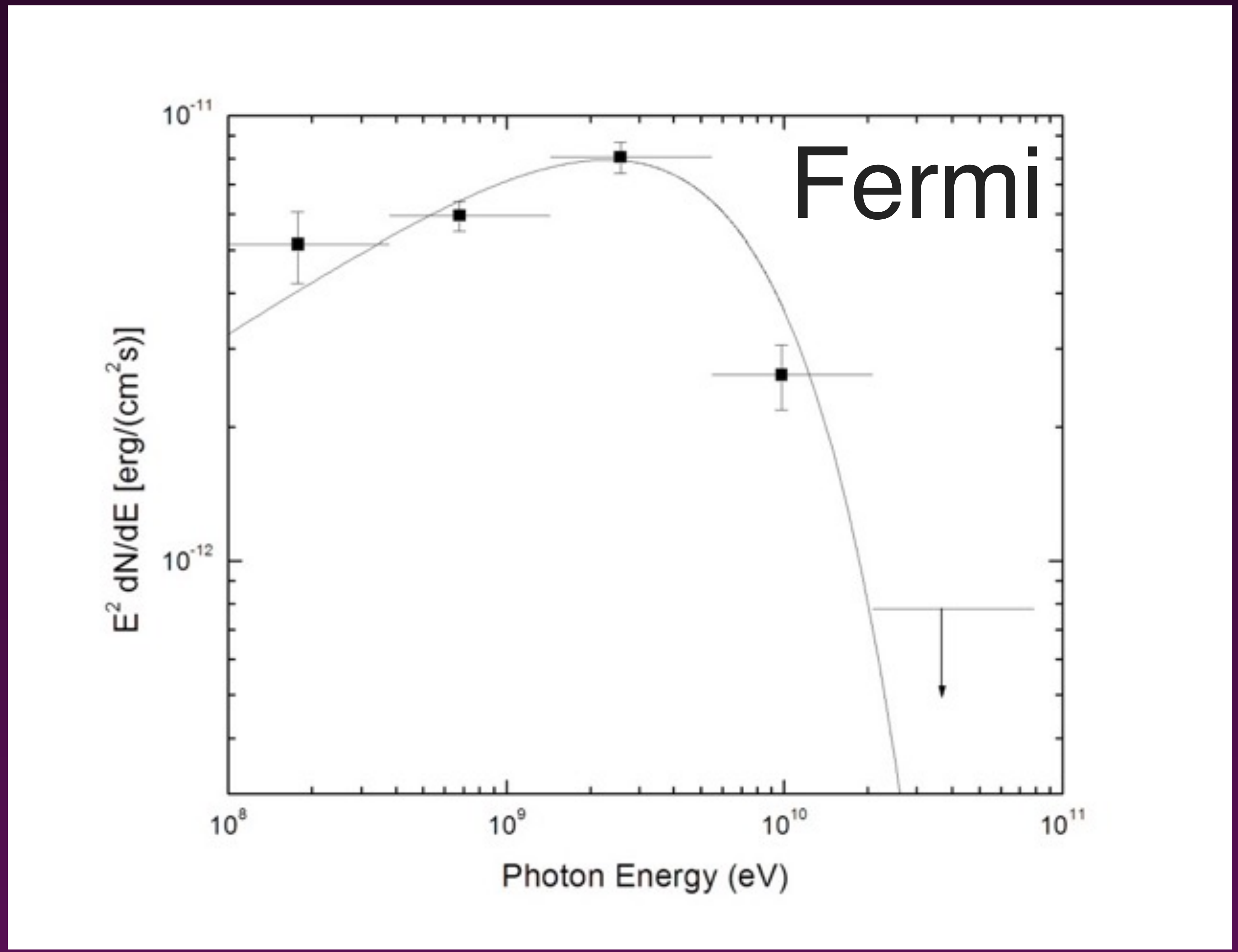




Irradiation on the companion

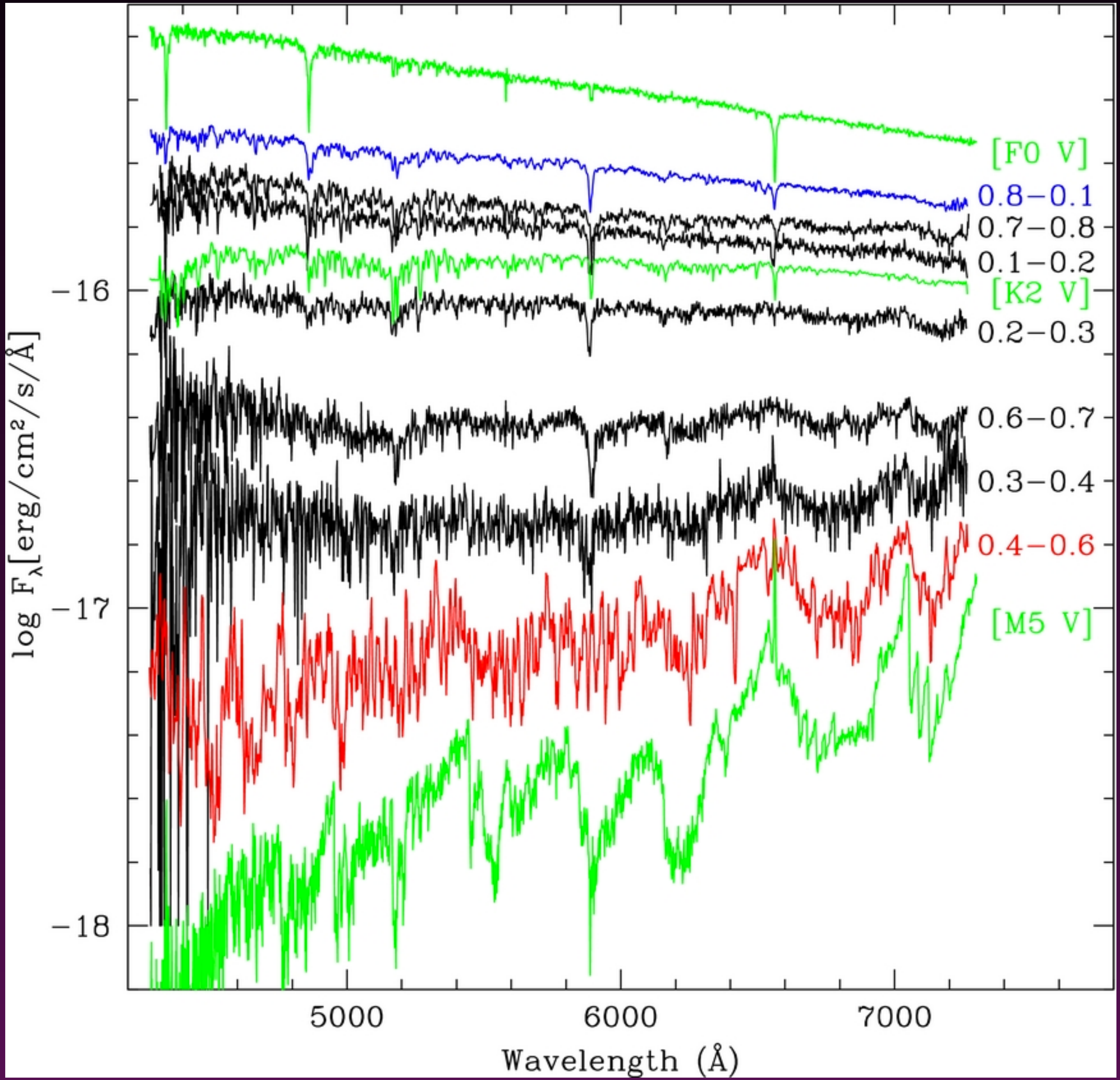
Intra-binary shock





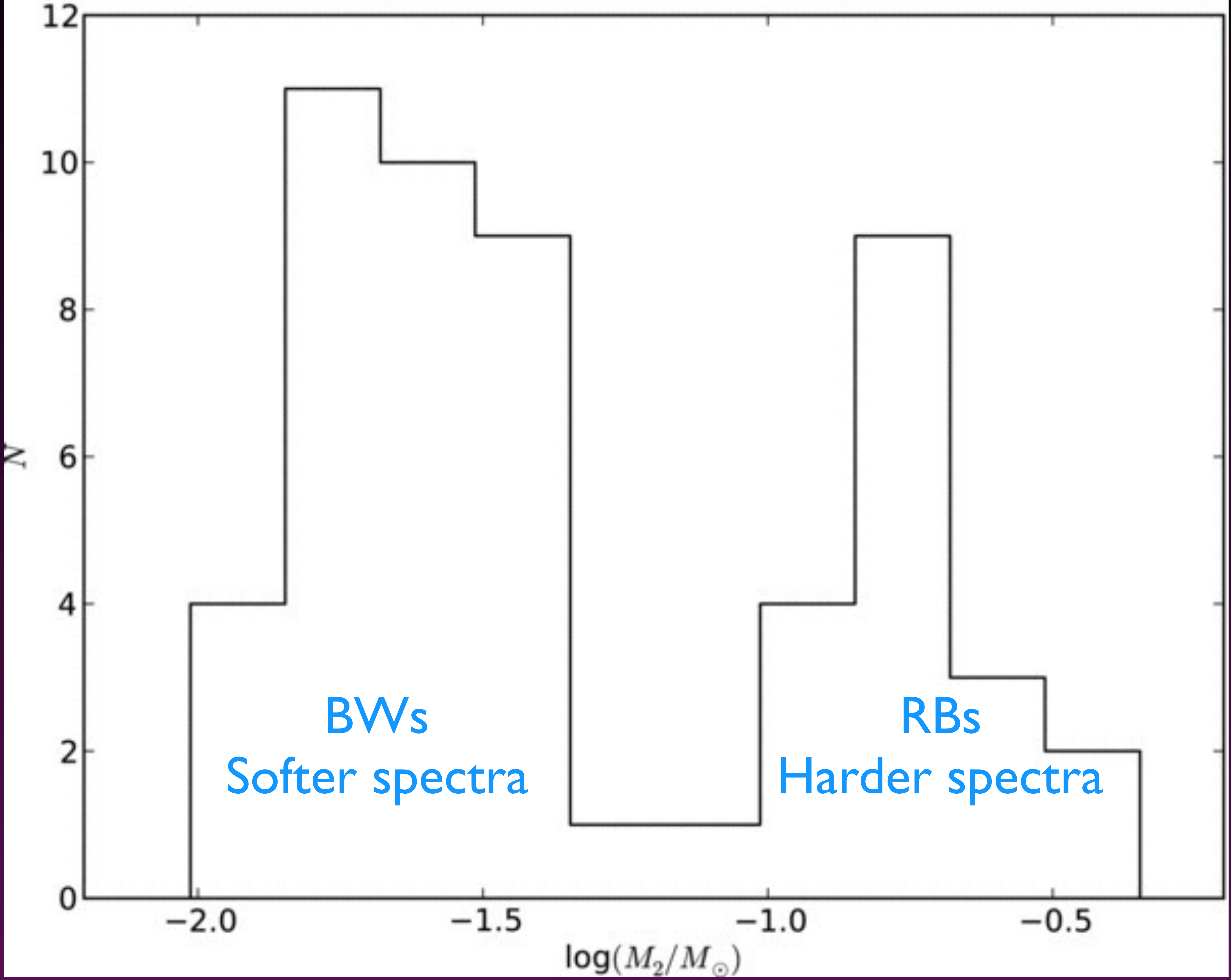
Pulsar magnetosphere

Heating on the companion's surface



Romani et al. 2011

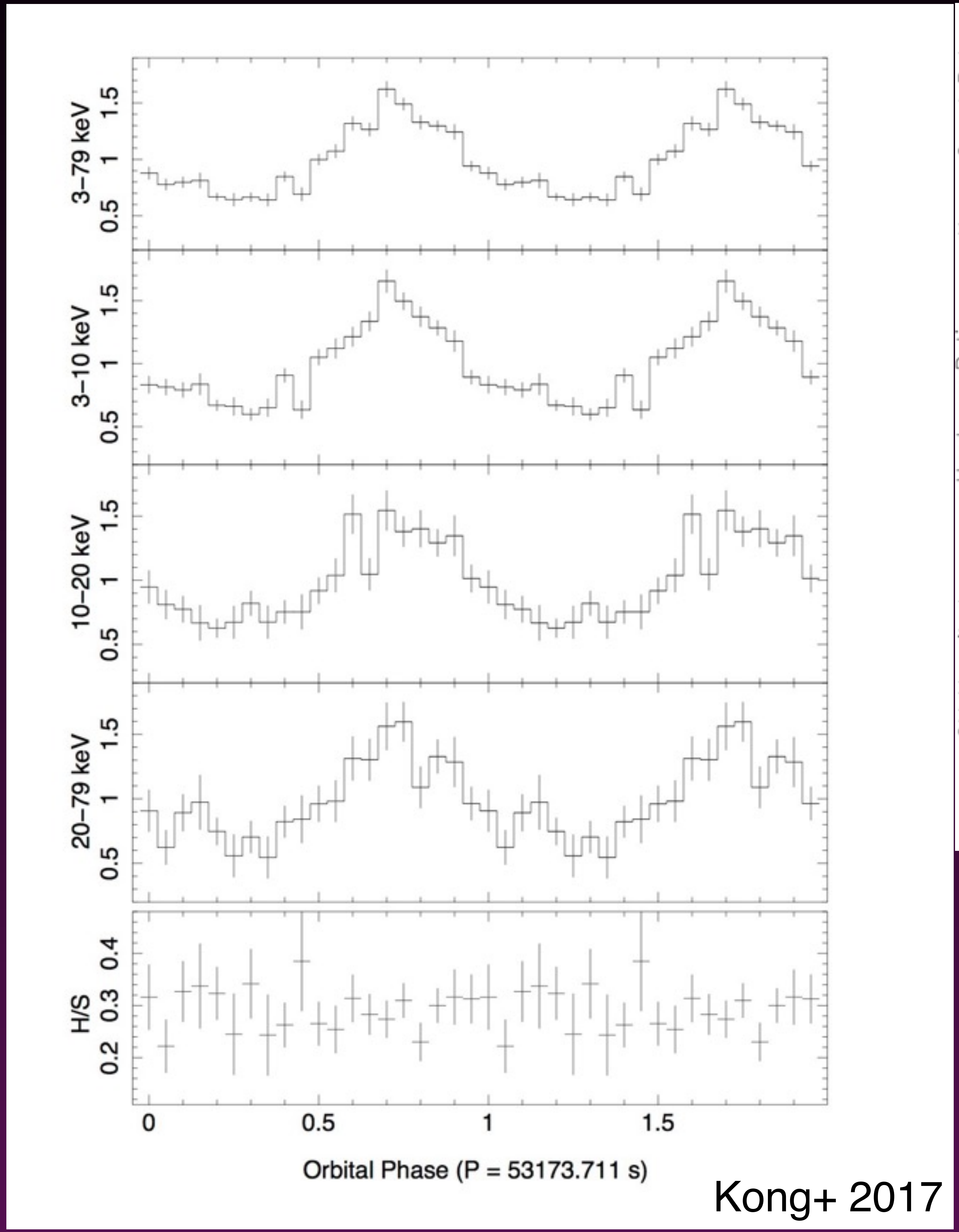
Companion's Mass of BWs and RBs

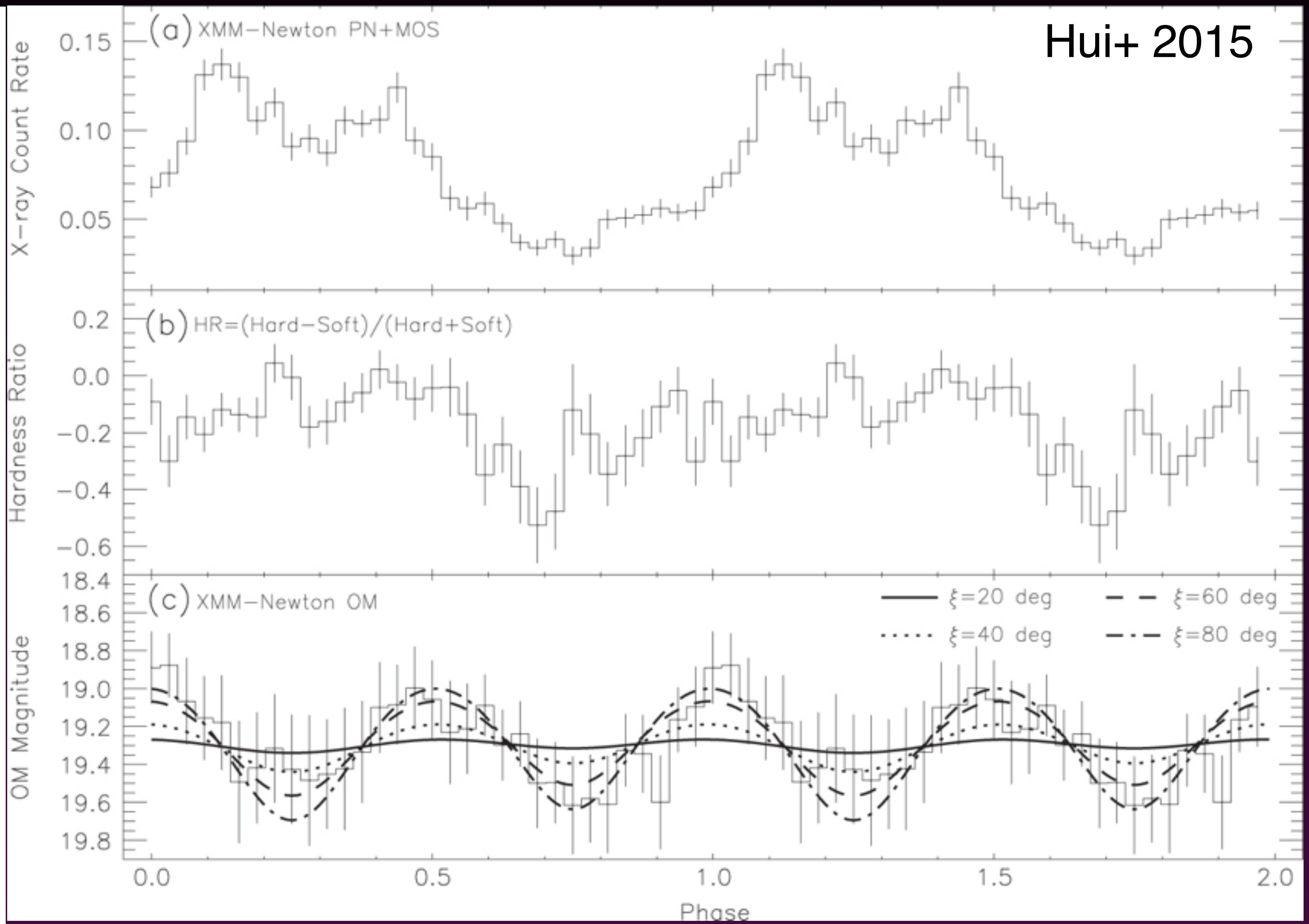


Chen et al. 2013

PSR J1723-2837

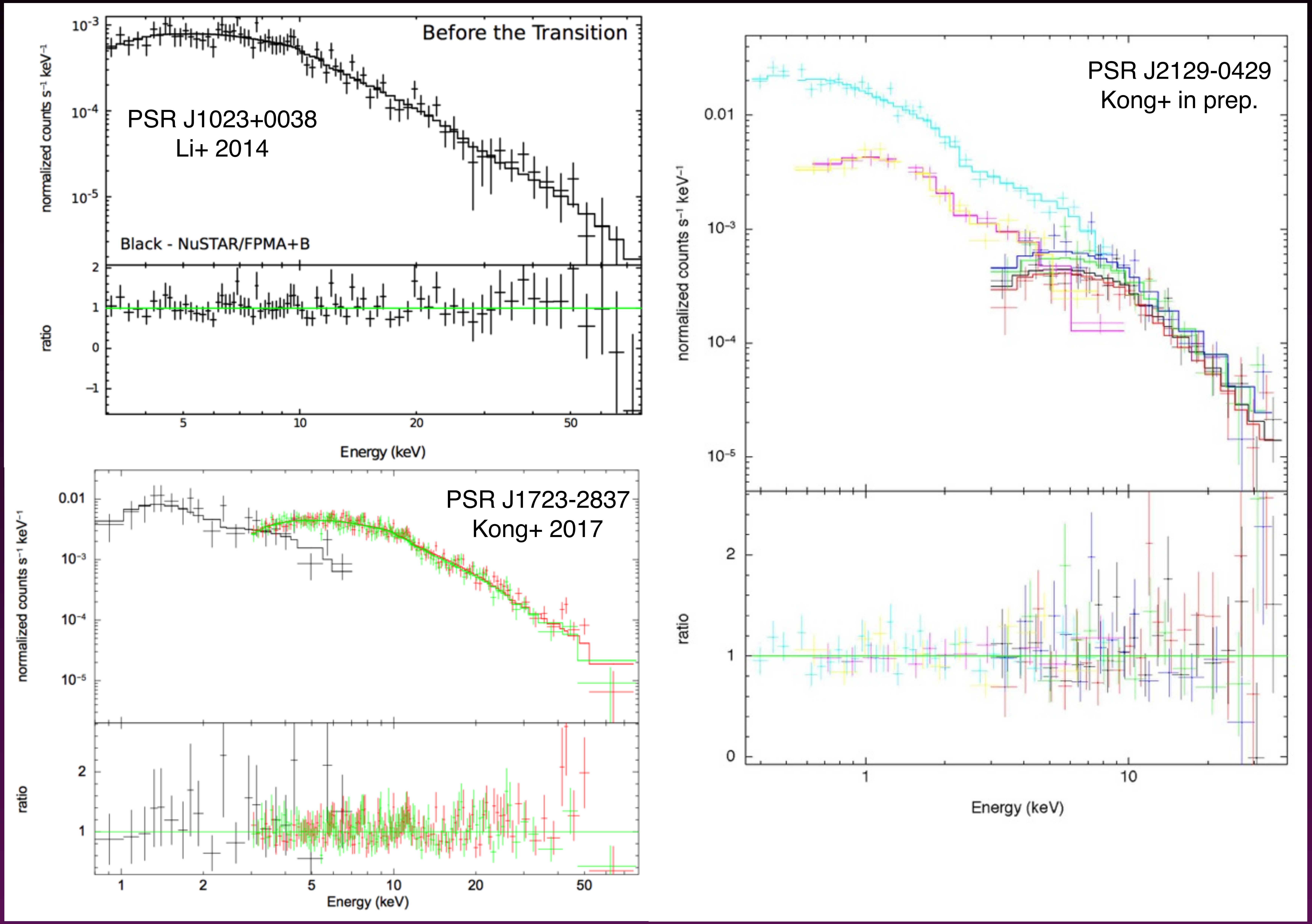
PSR J2129-0429





X-ray light curve profiles allow us to model the intra-binary shock (Romani+ 2016)

NuSTAR (3-79 keV) Observations of Spiders



- Non-thermal emission is seen as a power-law up to ~50 keV
- The spectrum of RB (Γ~1.3) is harder than that of BW (Γ>2). Lee+ submitted (see also David's talk)
- Is it due to different contribution of shocks?

Multi-wavelength Synergy and Beyond

- Gamma-ray data with X-ray/optical identification play a key role in searching missing MSPs when radio pulsation search fails. There are still many UFOs. Radio-faint isolated MSPs?
- The X-ray spectrum of RBs is harder than that of BWs. Why?
- Are BW and RB two distinct populations? Same evolution path?
- The Fermi BWs/RBs have the shortest orbital periods and highest NS masses
  - Optical/X-ray data are crucial in constraining the NS mass
  - Equation of State; mass gap of NS/BH
- TeV observations will allow us to study the shock physics