Studying intrabinary shock emission in pulsar binaries

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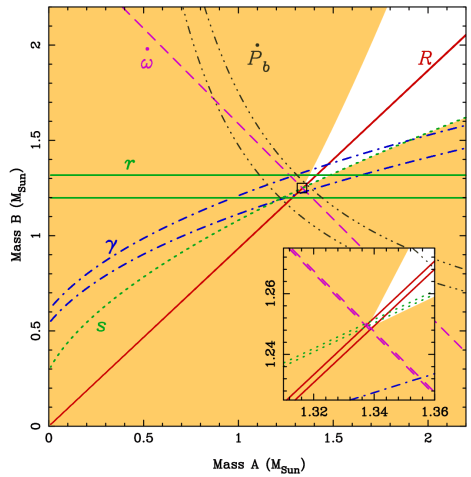
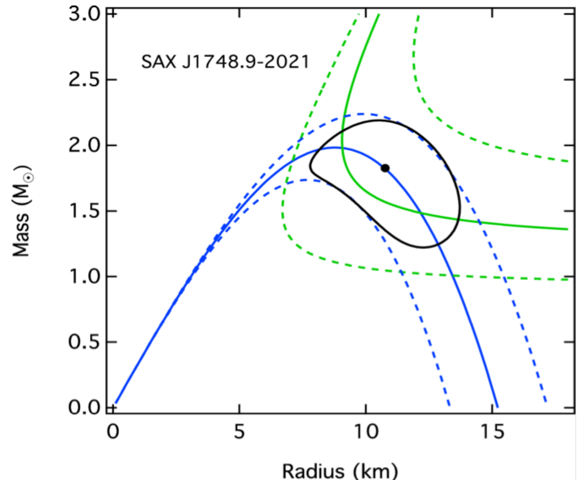
on behalf of the Fermi-LAT Collaboration

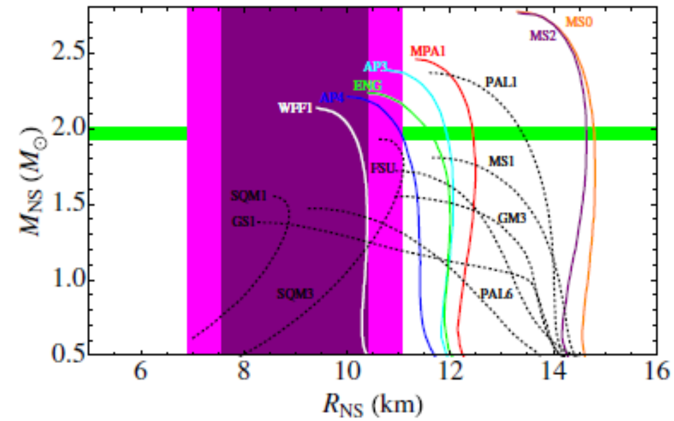
Mass and Radius of a neutron star can give us important clues to the state of matter under extreme density



Kramar et al. 2006
Radio timing



Ozel et al. 2015
X-ray bursts

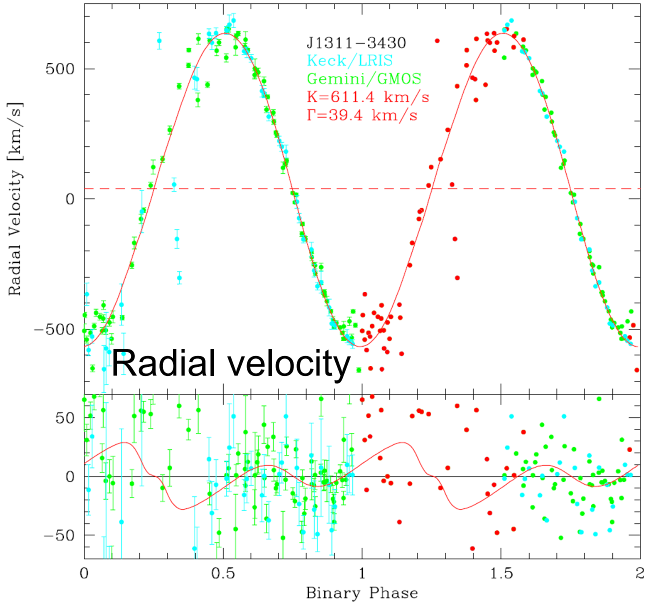


Equation of state
Guillot et al. 2014

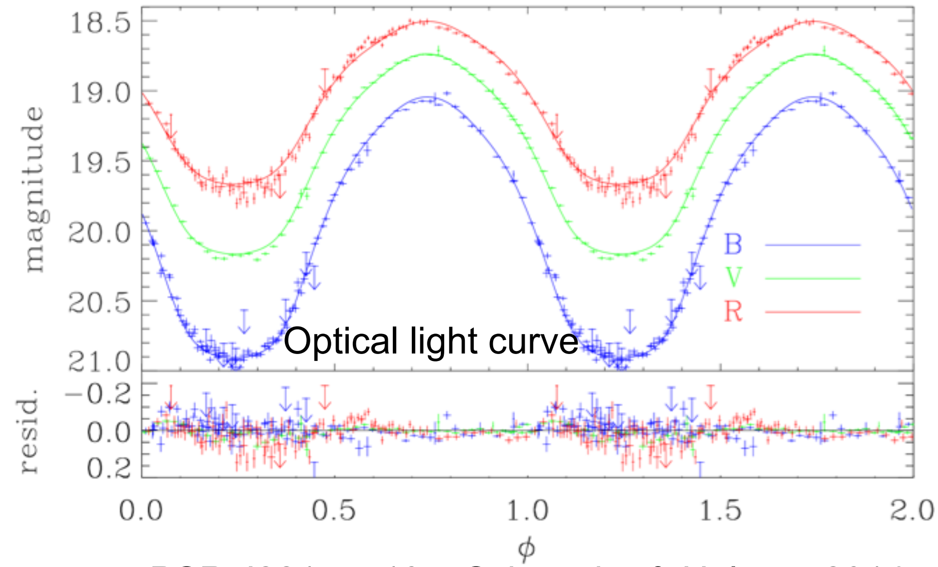
- **Measurements of Mass and/or Radius: radio timing, X-ray bursts…**
- **Constraining EoS can tell what kind of matter there exists under extreme condition, e.g., density > 2×10^{14} g cm^{-3}**
- **Mass of the neutron star in a pulsar binary can be estimated using the mass function**

$$M_{PSR} = \frac{4\pi^2 x^3 q(1+q)^2}{G\, P^2 \sin^3 i}$$

For nonrelativistic binaries, the accurate radio timing method is not applicable



PSR J1311-3430, Romani et al. 2015



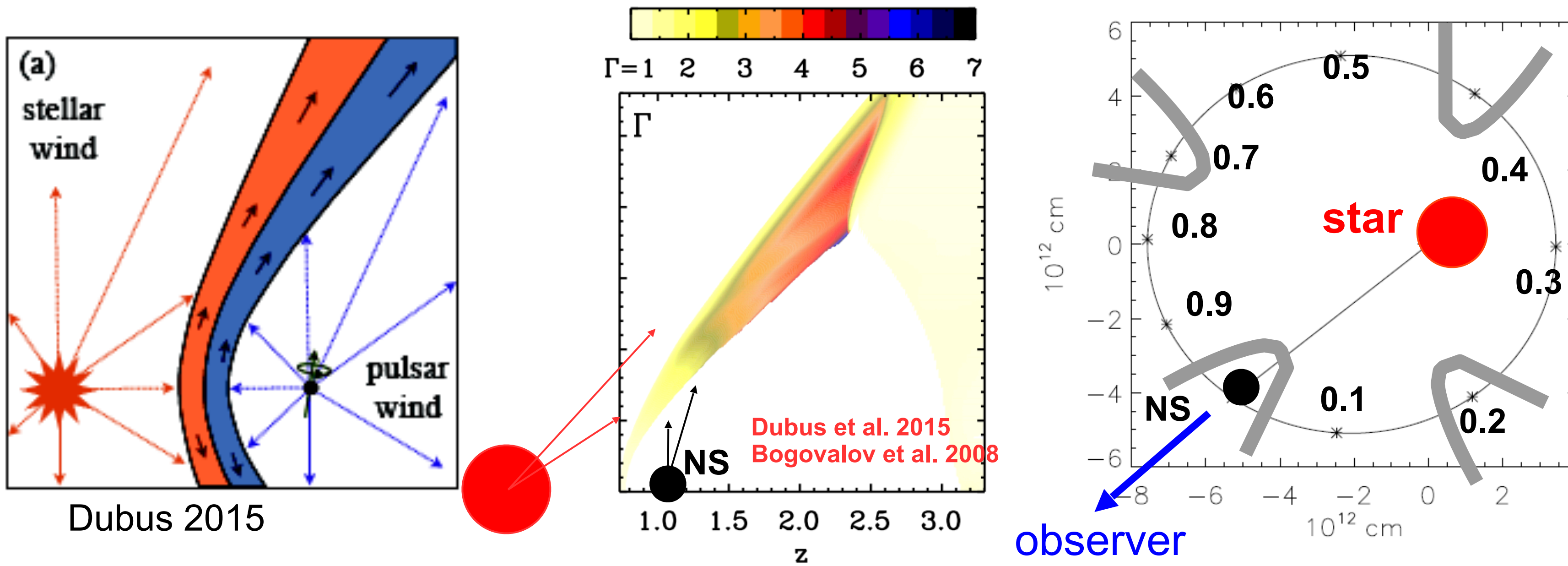
PSR J2215+5135, Schroeder & Halpern 2014

- **Modeling the radial velocity and/or the optical light curve (heating pattern) provide estimation on parameters in the mass function (e.g., mass ratio q and inclination sin i)**

- **This method was used for inferring the mass of the neutron star in some pulsar binaries: MNS = 1.8—2.7 Msun (PSR B1957+20, J2215+5135, PSR J1311—3430) (e.g., van Kerkwijk et al. 2012, Schroeder & Halpern, 2014, Romani et al. 2015)**

- **This method is subject to large systematic uncertainties due to the heating pattern correction** $M_{psr} \propto (K_{\rm corr}/\sin i)^3$ **(e.g., Romani et al. 2015)**

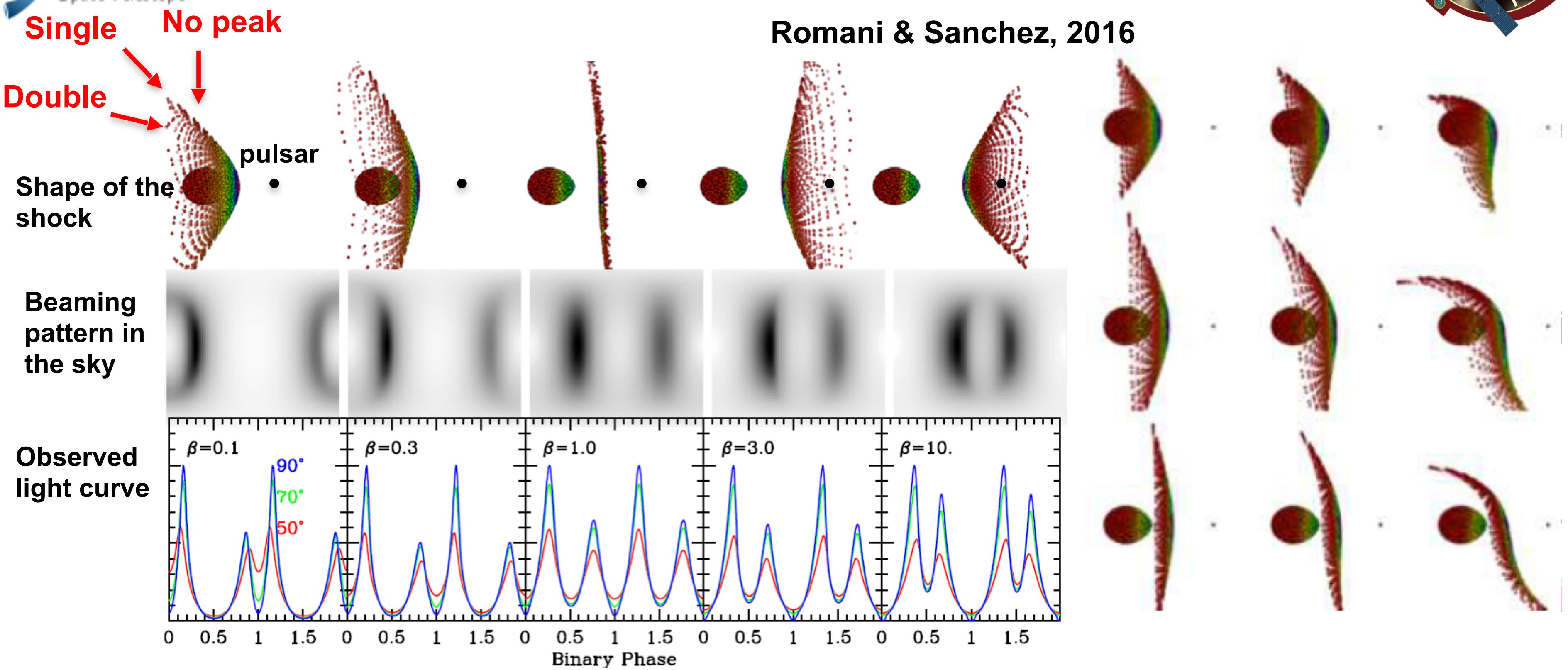
Pulsar binaries may have an intrabinary shock which can help to determine the orbital parameters



- **Winds of the two stars may form a contact discontinuity and shocks (paraboloid envelops)**
- **Particles in the pulsar wind shock are relativistic and can produce beamed emission (Bogovalov et al. 2008, Dubus et al. 2015)**
- **Synchrotron beaming can produce spikes in the X-ray LC** $F_{\rm sync} \propto \delta_{\rm D}^{(5+p)/2}$
- **The number of spikes (shape of the LC) depends on the inclination angle**

Shape and the number of spikes of IBS emission may be used for estimating the inclination

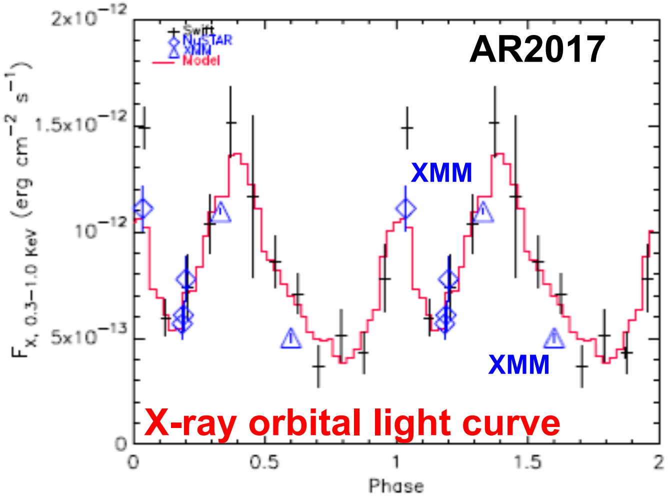
Romani & Sanchez, 2016



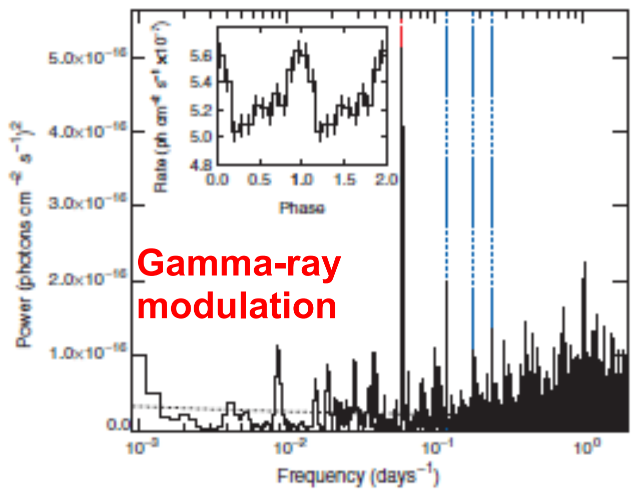
- The shape of the shock envelop can be compared with the synchrotron light curve to give constraints on the inclinations

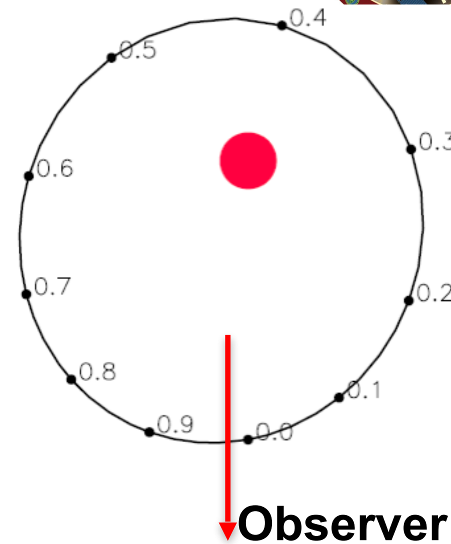
- Of course, the shape of LC changes depending on the wind strength ratio and the orbital speed

We applied the IBS model to the gamma-ray binary 1FGL J1018.6—5856 (An & Romani, 2017)



The Fermi LAT Collaboration 2012





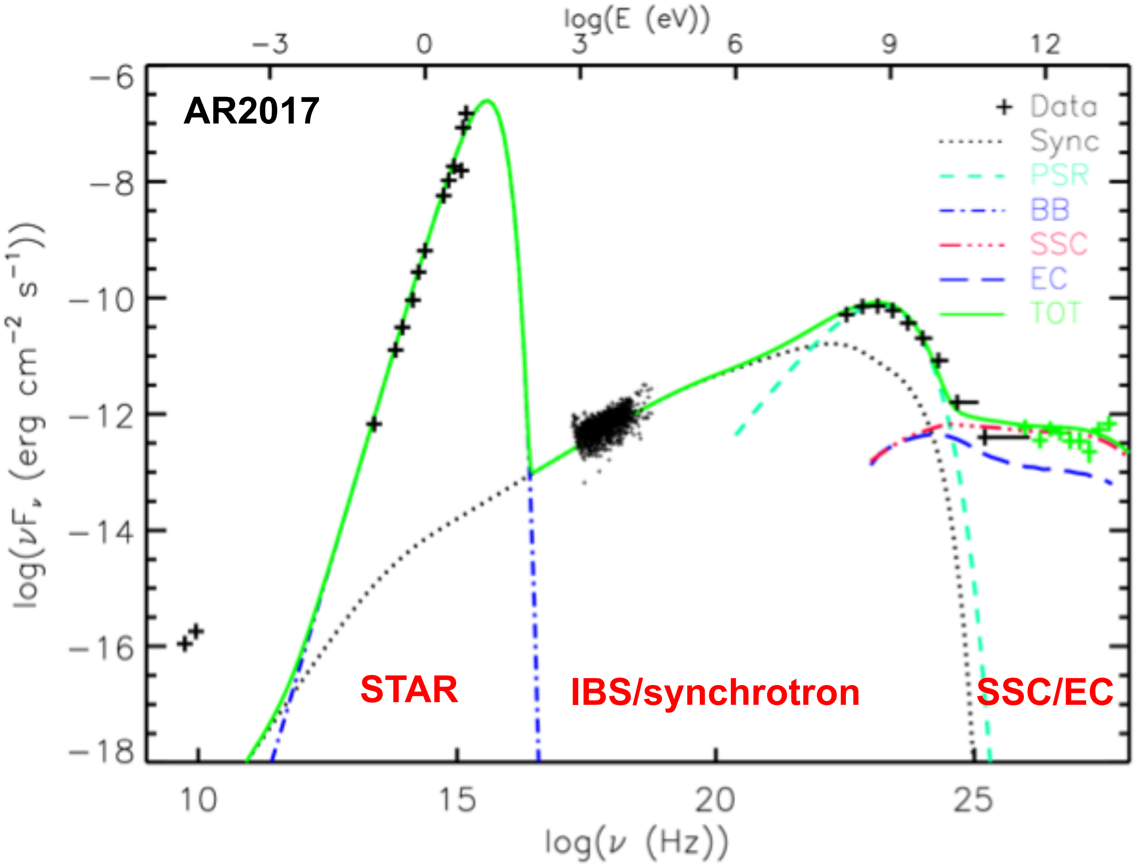
Gamma-ray binary: Persistent gamma-ray (GeV—TeV) flux is modulated

1FGL J1018.6-5856: (fermiLAT12, wr15, scc+15, HESS15, abb+15)

Compact object	Likely a Neutron star (NS)
Inferior conjunction	at X-ray/gamma-ray maximum (scc+15)
Eccentricity	0.1–0.5
Inclination	>15 deg.

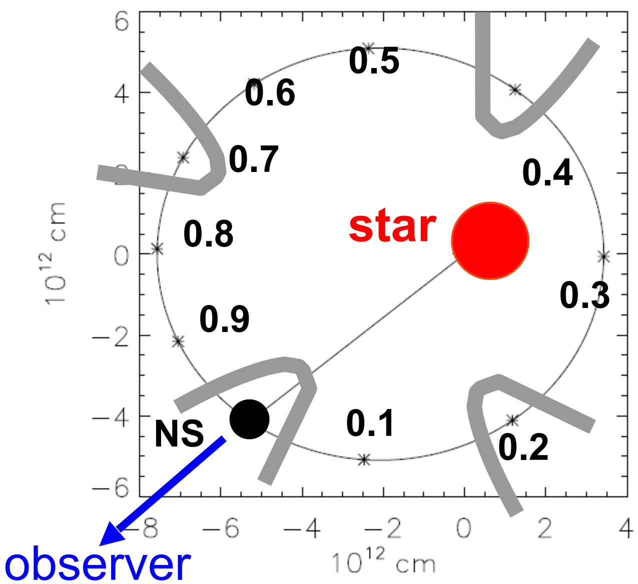
The X-ray spike at phase 0 seen in this system is interpreted as the IBS emission

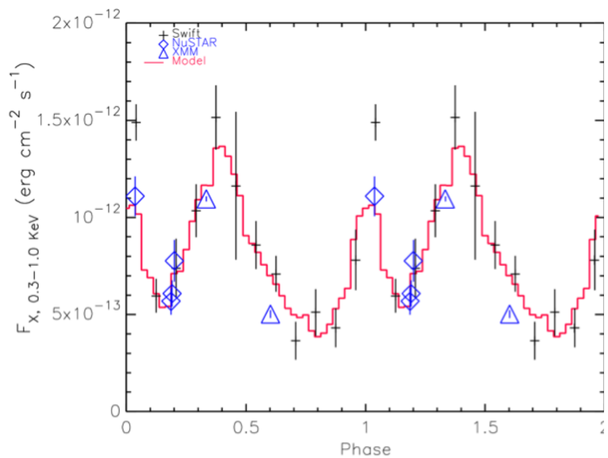
Bright high-energy emission suggests that there may be IBS in this system



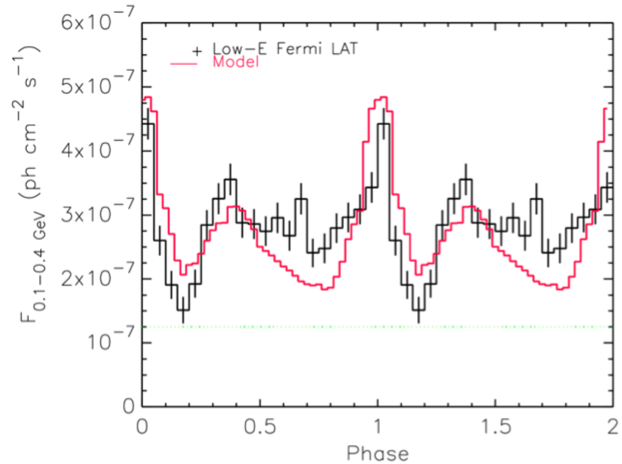
- The measured broadband SED is explained by the stellar emission in the optical band (seeds for the external Compton), the synchrotron emission in the X-ray-to-LAT band, and self-Compton and external Compton emission in the highest energy band
- The phase-averaged SED is explained well by the IBS model

The main features of the synchrotron light curve can be reproduced with the model





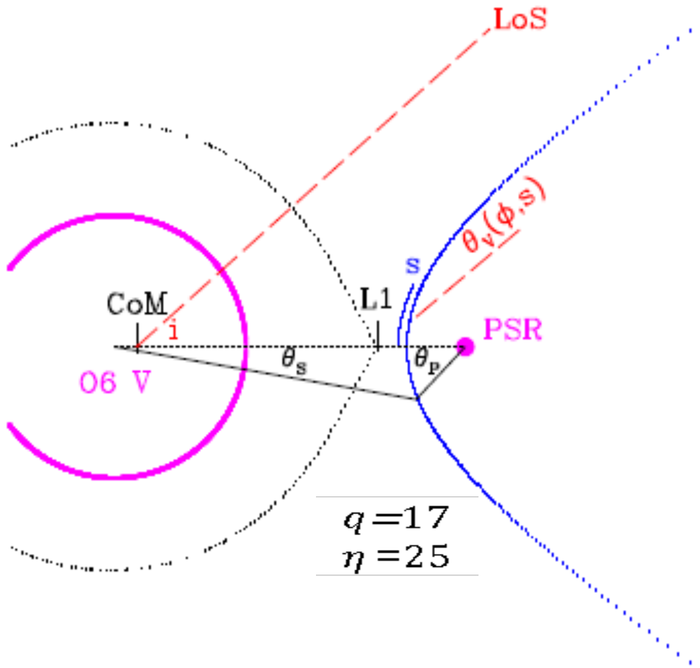
X-ray



LAT/Low Energy

- **The X-ray to LAT spike at phase 0 (pulsar inferior conjunction) is explained with the beamed emission of the shock seen near the tangent of the shock**
- **Using the broad hump in the X-ray light curve, the eccentricity can be inferred**
- **The highest-energy LC is more complicated and require some additional considerations (e.g., gamma-gamma absorption, secondary emission)**

LC modeling provides reasonable constraints on the orbital parameters of J1018



Parameter	Symbol	Value
Eccentricity	e	0.35
Inclination	i	$50°$
Momentum flux ratio	η	25 (assumed)

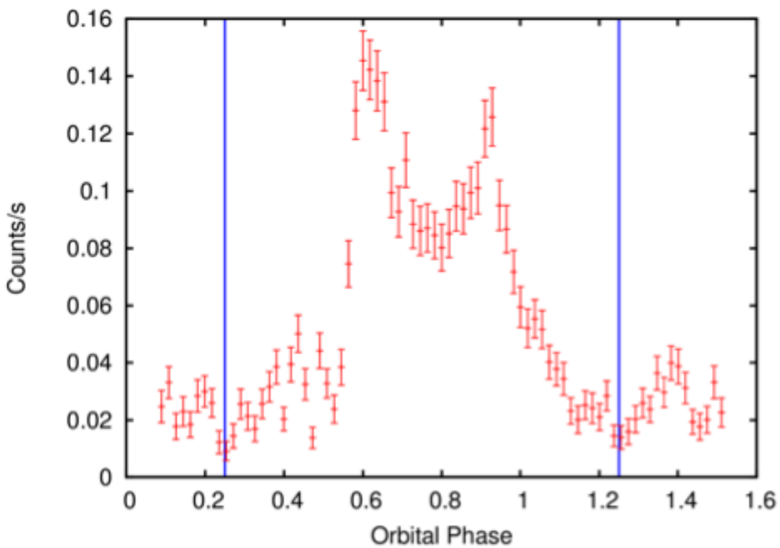
$$r(\theta_p) = r_{psr}\sin\theta_s/\sin(\theta_p + \theta_s)$$

$$r_{psr} = \frac{a(1-e)}{1+e\cos\phi}\frac{1}{1+\sqrt{\eta}}$$

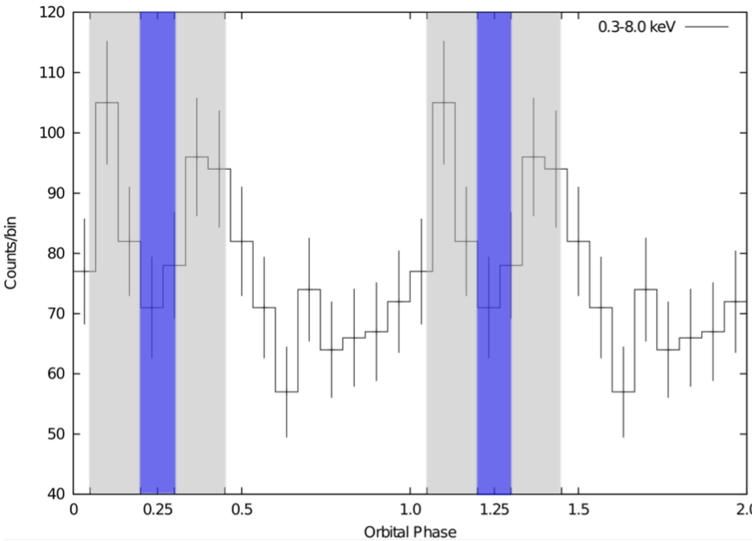
Canto et al. (1996)

- **The single-peaked spike at phase 0 suggests that the LoS is near the shock tangent (determined by the "unmeasured" wind momentum flux ratio)**
- **Assuming momentum flux ratio of $\eta \approx 25$ (for a typical O star and a pulsar), we estimate the inclination of J1018 to be $\sim 50°$**
- **The slightly asymmetric sinusoidal hump implies $e \sim 0.35$**

The model can be applied to some other pulsar binaries as well



XMM data for PSR J2129—0429, Roberts et al. 2015



Chandra data for PSR B1957+20, Huang et al. 2012

- **Some pulsar binaries exhibit a peculiar light, having double peaks for example**
- **These may be explained by the intrabinary shock (IBS) model with LoS crossing the IBS twice per orbit (i.e., large inclination)**

See also Romain & Sanchez 2016, Wadiasingh et al. 2017 and …

Summary

- We developed an Intrabinary shock emission model for pulsar binaries and applied the model to the emission of 1FGL J1018.6—5856

- The model explains the high-energy emission with the synchrotron and Compton radiation

- Peculiar X-ray light curves in pulsar binaries may be produced by beamed emission of particles flowing along the shock and can be used for estimating the inclination

- There are still large uncertainties due to unconstrained properties of the flow and the winds in pulsar binaries; further theoretical (MHD) and observational studies (X-ray/optical) can help constrain those better