Modeling X-ray and gamma-ray emission in the intrabinary shock of pulsar binaries

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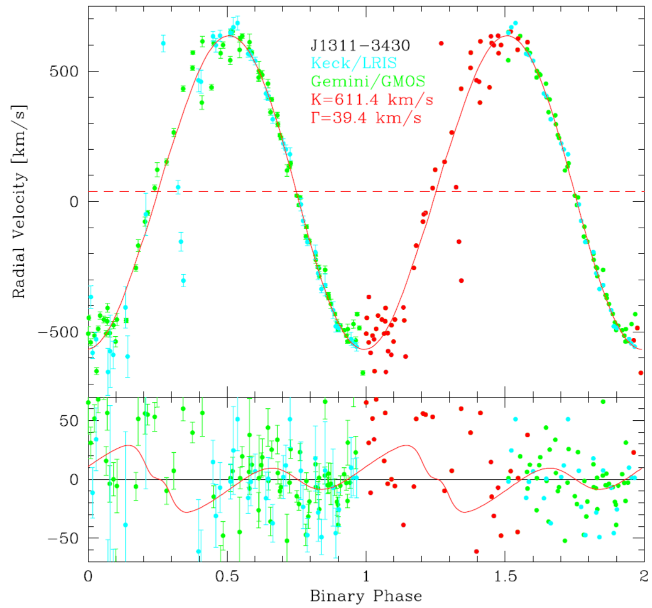
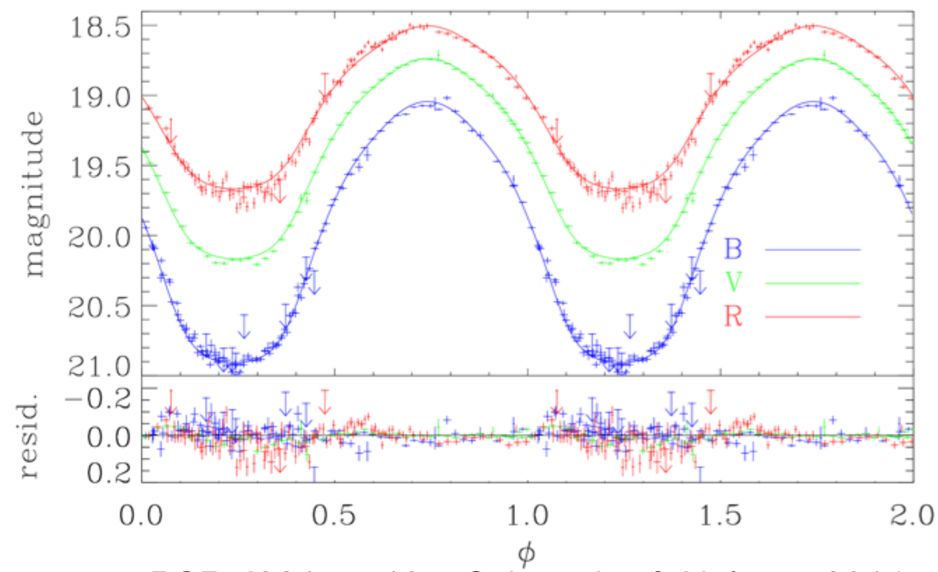
Mass of the neutron star in pulsar binaries has been estimated using the low-energy optical data



PSR J1311-3430, Romani et al. 2015



PSR J2215+5135, Schroeder & Halpern 2014

- **Orbital parameters of a binary are estimated by modeling the radial velocity measurements (mass ratio,** $q = M_{psr}/M_c$ **and the orbital light curve (inclination,** $\sin i$ **). Then, the mass of the neutron star can be estimated with the mass function**

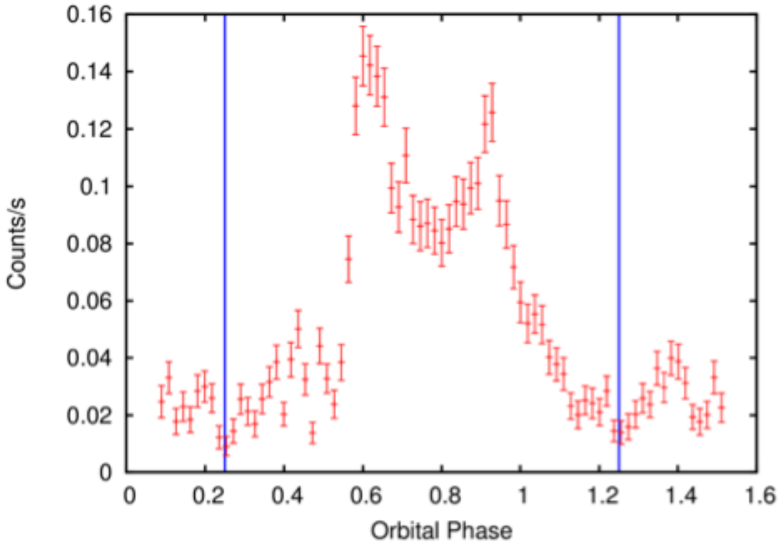
e.g.) $M_{psr} = 2.40 \pm 0.12 M_\odot$ **for PSR B1957+20 (van Kerkwijk et al. 2012)**

$M_{psr} = 1.97 - 2.45 M_\odot$ **for PSR J2215+5135 (Schroeder & Halpern, 2014)**

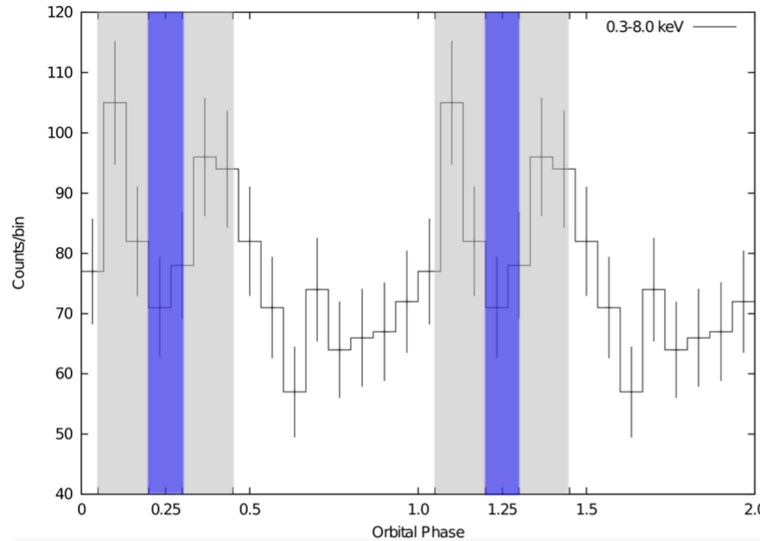
$M_{psr} = 1.8 \pm 2.7 M_\odot$ **for PSR J1311—3430 (Romani et al. 2015)**

- **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)**

High-energy modulation is seen in some binaries



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

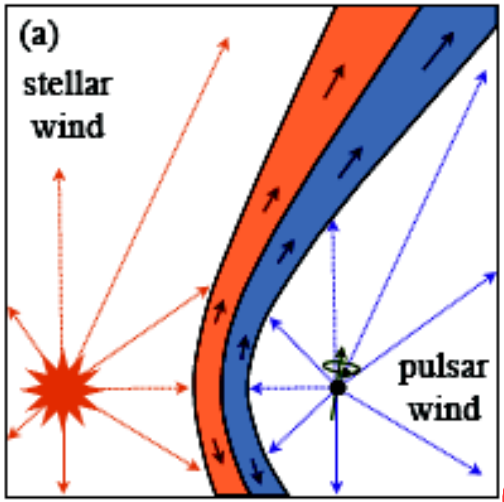


Chandra data for PSR B1957+20, Huang et al. 2012

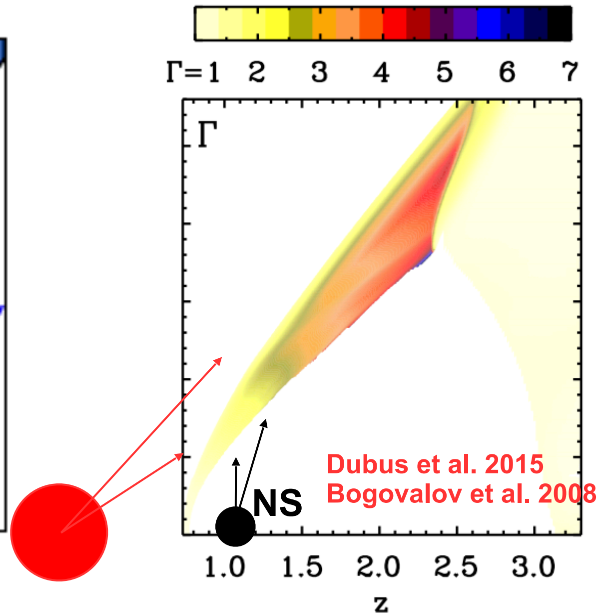
- Some pulsar binaries exhibit a peculiar light curve in the X-ray band
- Sometimes the LC peak has an interesting morphology; sometimes double peaks, sometimes single peak
- These may be explained by the intrabinary shock (IBS) emission, and can provide a way to estimate the orbital parameters

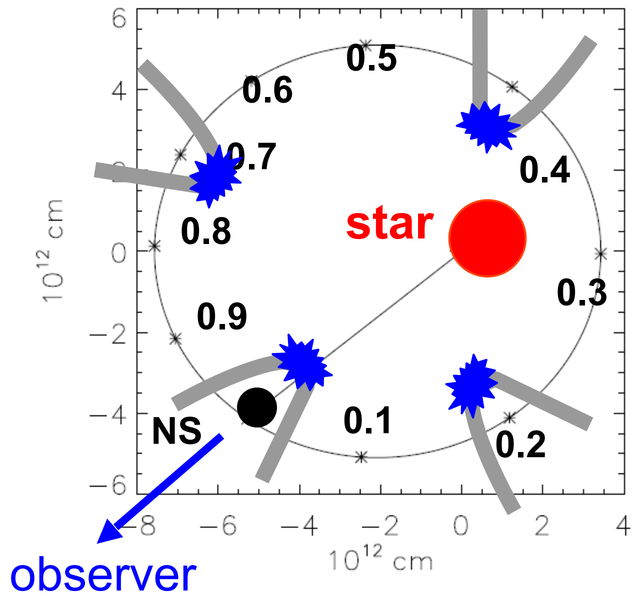
See also Wadiasingh et al. 2017 and …

Intrabinary shock is formed due to pressure balance of two winds in binaries



Dubus 2015

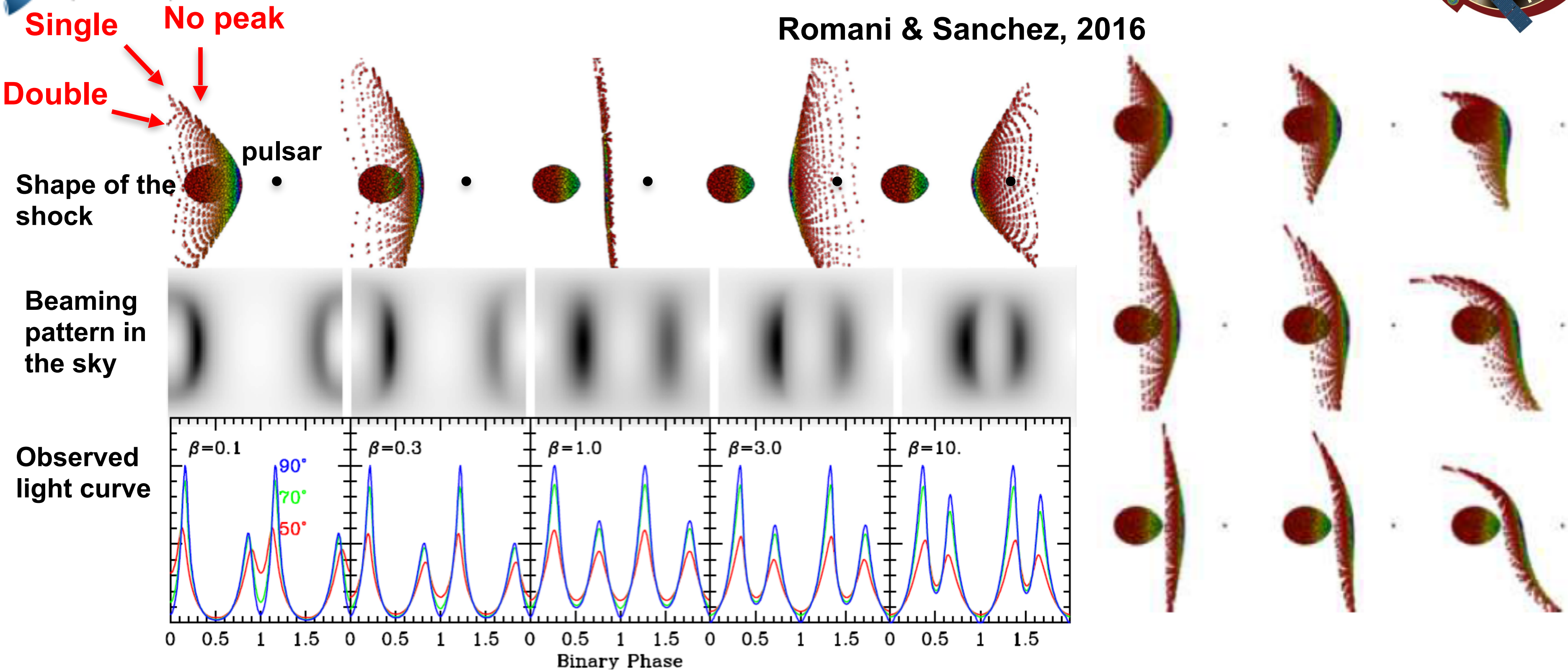




- Stellar wind interacts with the pulsar wind, making a contact discontinuity
- The winds are accelerated in the shocks and flow along the shock
- Bulk adiabatic acceleration happens in the flow (Bogovalov et al. 2008, Dubus et al. 2015)
- Depending on the viewing angle with respect to the shock tangent, the number of spikes may vary
- Also, broad orbital modulation can be from the low-Γ flow ( ) at the shock apex

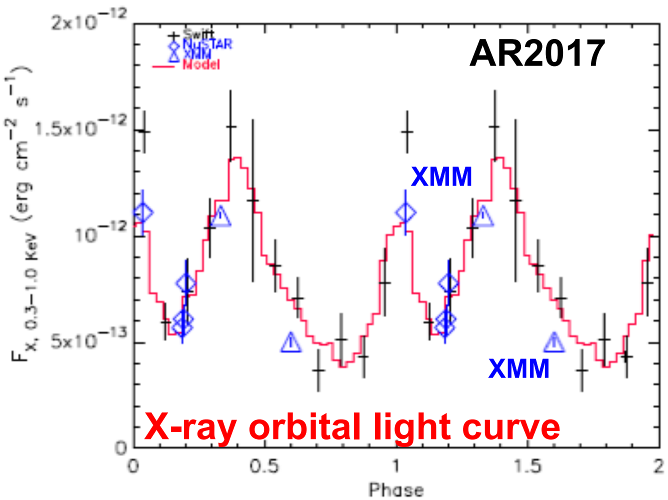
High-energy IBS emission may be used for estimating the inclination

Romani & Sanchez, 2016

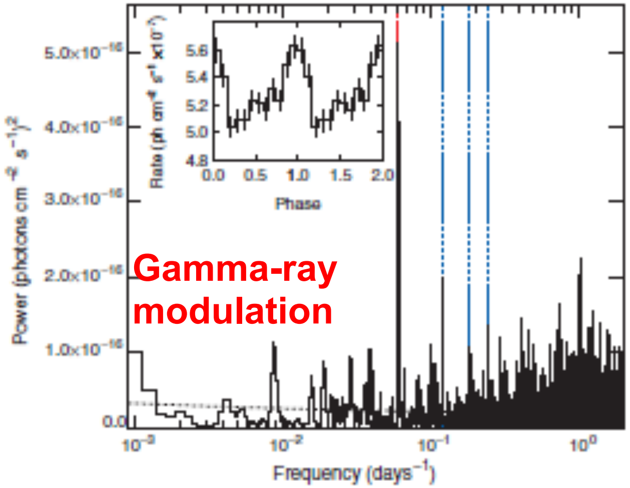


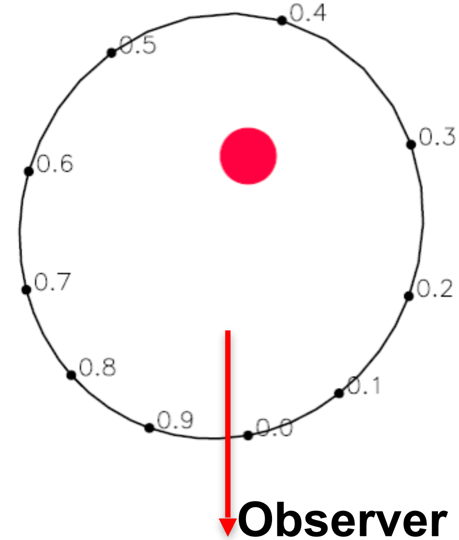
- Synchrotron beaming can produce peaks in the X-ray LC, $F_{\rm sync} \propto \delta_{\rm D}^{(5+p)/2}$
- The synchrotron emission is in the X-ray band and may go up to $\sim 100\delta_{\rm D}$, accessible with XMM/Fermi LAT
- The peak phase can differ depending on the wind flux ratio and the orbital speed
- The number of peaks (shape of the LC) depends on the inclination angle

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



The Fermi LAT Collaboration 2012



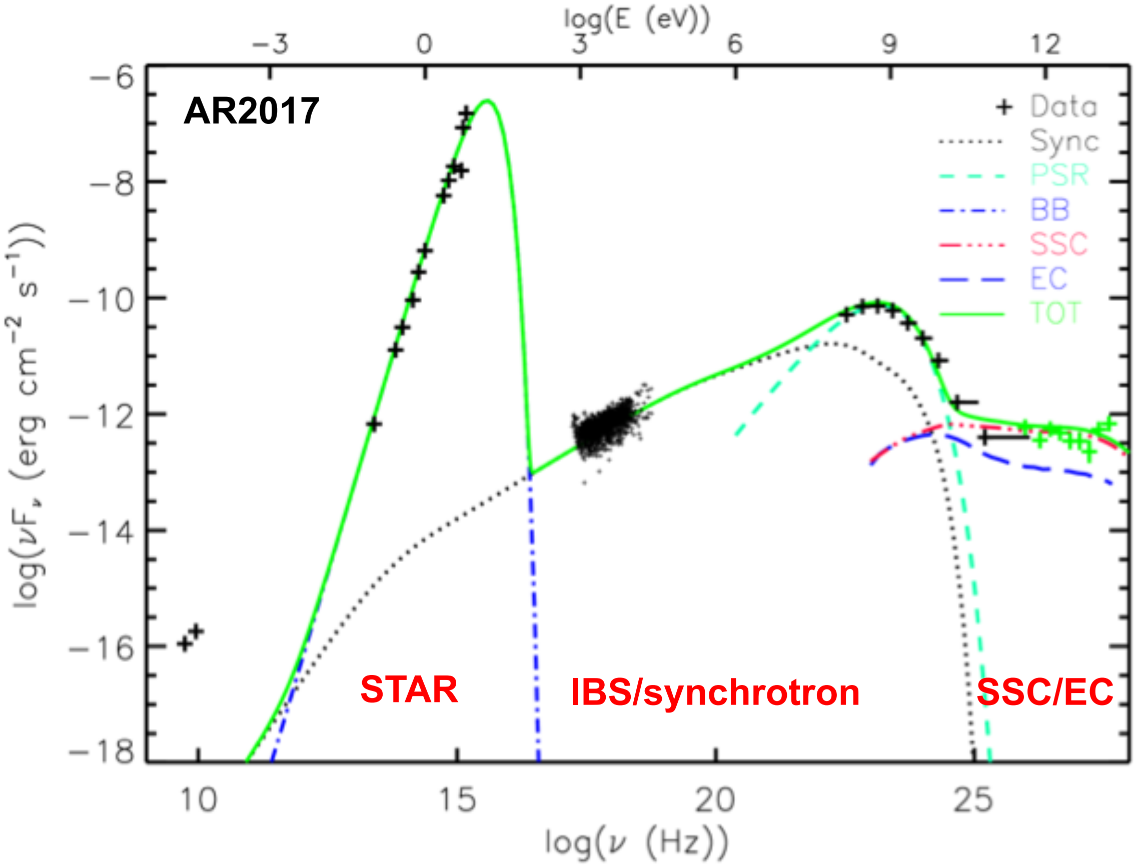


Gamma-ray binary: Persistent gamma-ray (GeV—TeV) flux is modulated

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

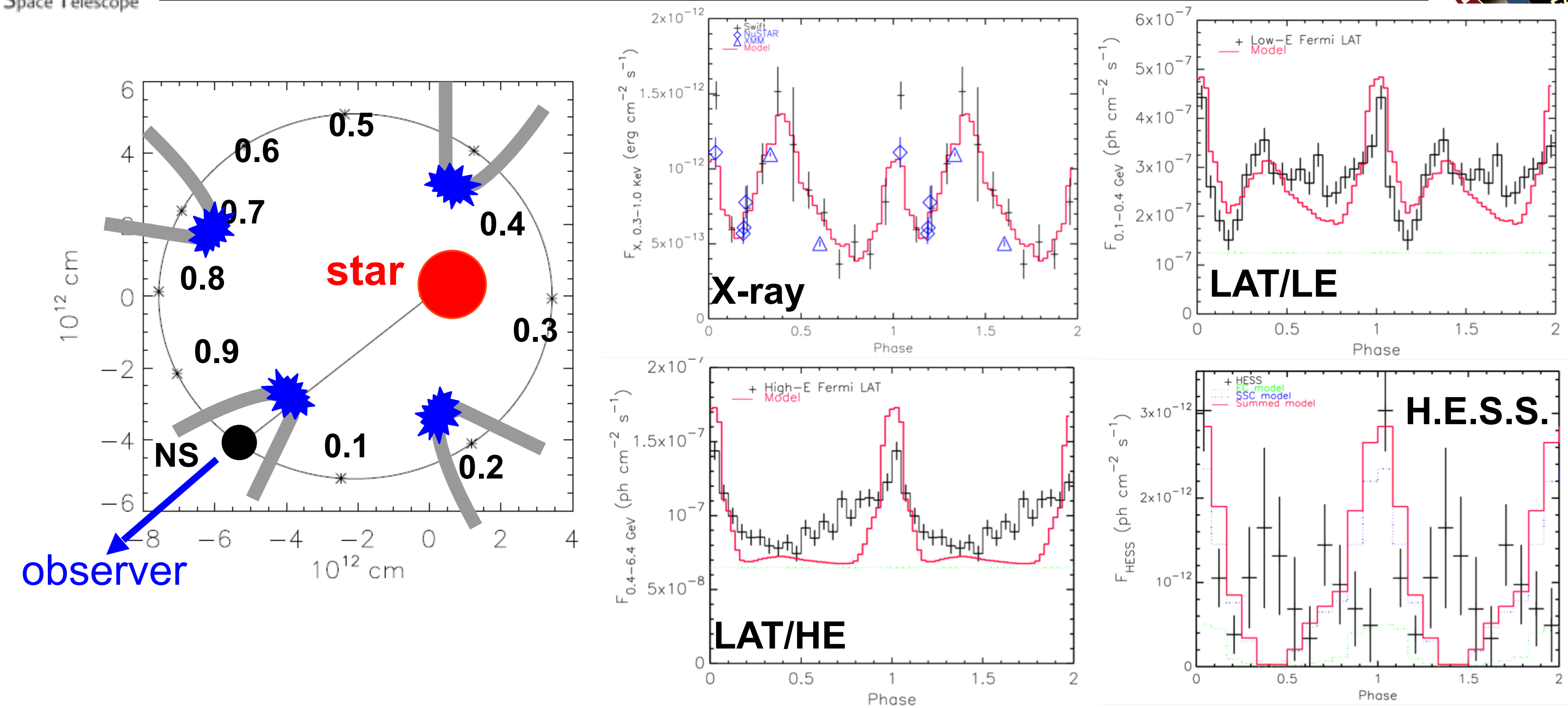
Compact object	unknown – Neutron star (NS) or Black Hole (BH)
Stellar companion	O6V((f))
Orbital Period	16.544 days
Inferior conjunction	at the gamma-ray maximum phase (scc+15)
Eccentricity	0.1–0.5
Inclination	>15 deg.

The broadband SED of J1018 is explained well by the IBS emission model



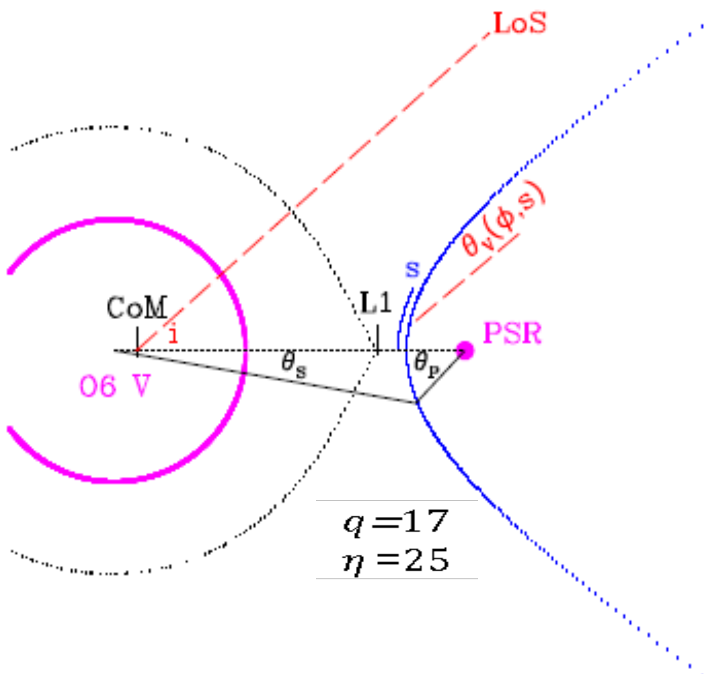
- The star emission dominates in the optical band (seeds for the external Compton)
- X-ray to low-energy LAT photons are produced by the synchrotron emission
- High-E LAT and H.E.S.S. bands are dominated by self-Compton and external Compton

The main features of the high-energy light curves can be reasonably reproduced with the model



- **The IBS emission model calculates the synchrotron, self-Compton, and external Compton emission over the shock surface at each orbital phase**
- **The X-ray to TeV 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**

We inferred the orbital parameters of J1018 using the IBS emission model



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
- Estimation of the shock tangent angle is crucial to estimating the inclination
- For an assumed momentum flux ratio of $\eta \approx 25$, we estimated the inclination of J1018 to be $\sim 50^\circ$
- The slightly asymmetric sinusoidal hump can be reproduced with $e \sim 0.35$

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