Some theoretical work on *gamma-ray pulsar*, *double pulsars* and *BH binaries*

易疏序

During 2016/10-2017/12 with K.S. Cheng @HKU

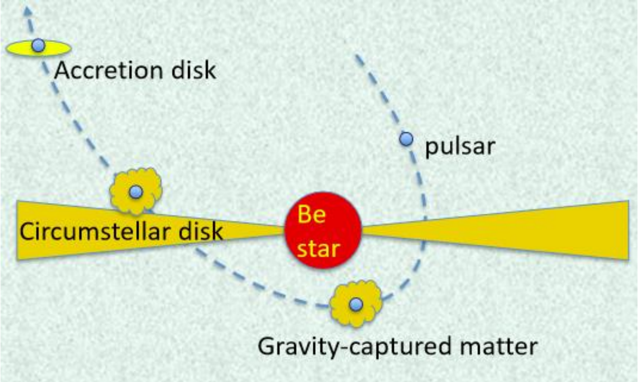
report on 2017/12 @ IHEP & PKU

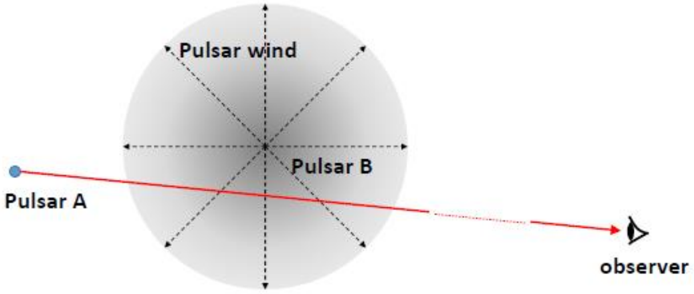
Outline

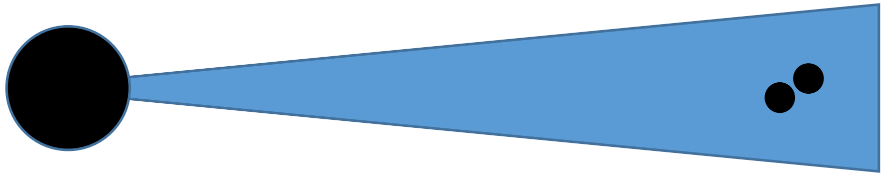
- GeV flare of B1259-63/LS 2883
- GeV emission of HESS J0632+057
- Propeller effect of B1259-63

- Study pulsar wind in double neutron stars

- BH binary in AGN disk as GW source
- GW-Cherenkov radiation

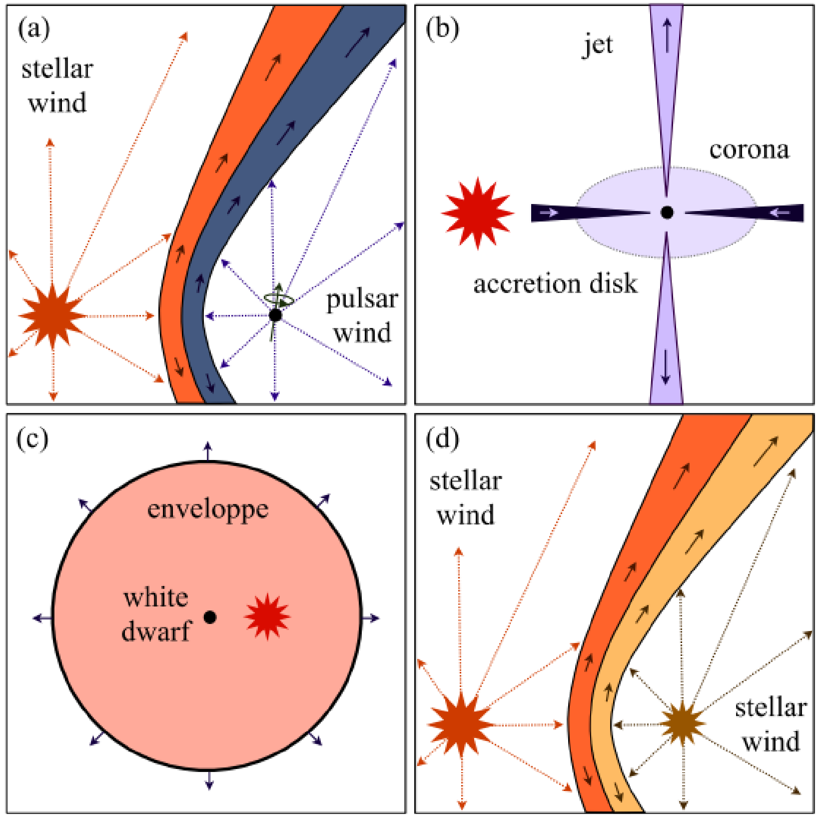




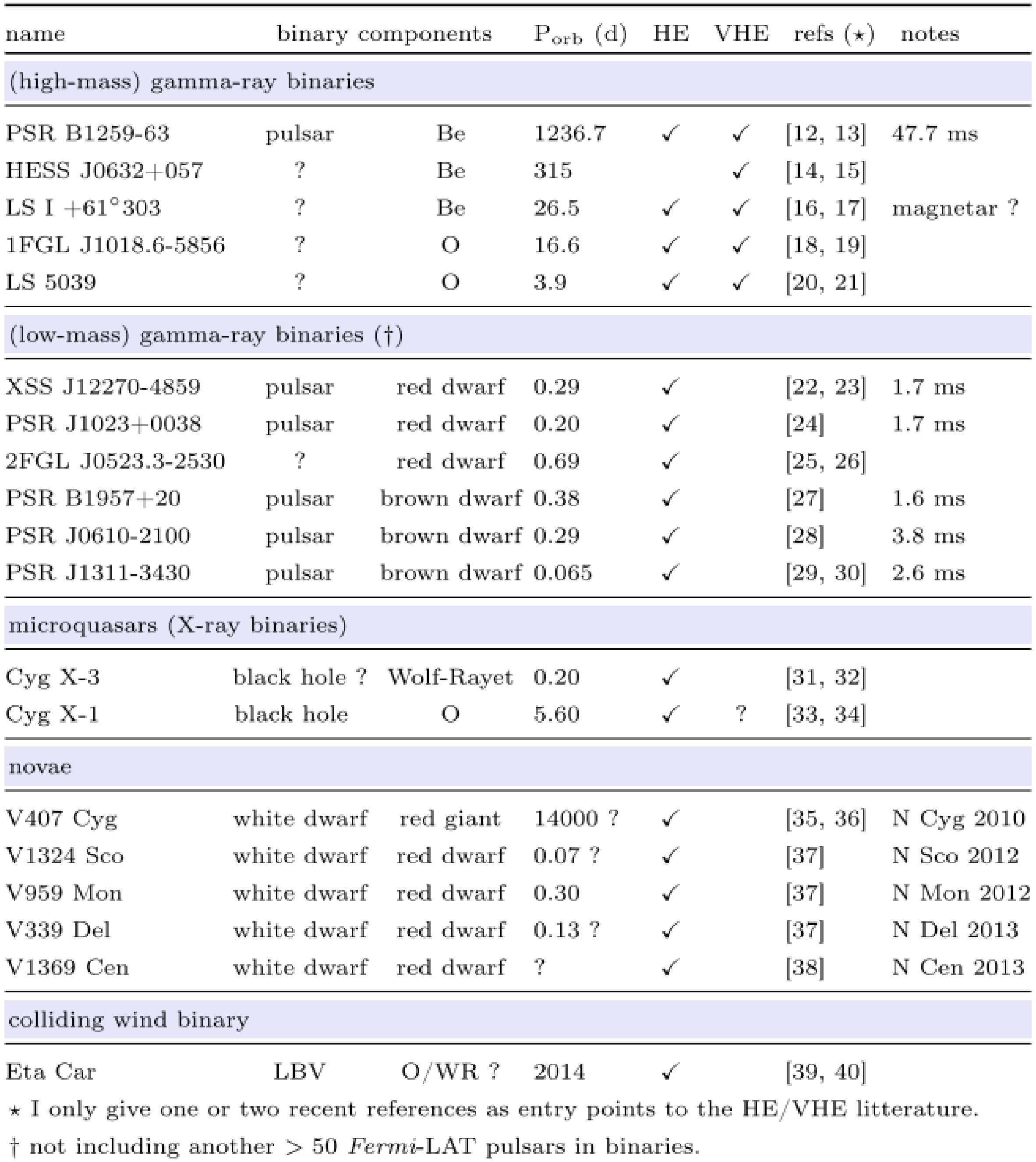


Gamma-ray binaries

- Variable, timescale~stellar mass binary
- High Energy (0.1-100 GeV) even Very high energy (>100 GeV)



Dubus 2015



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PSR B1259-63	pulsar	Be	1236.7	✓	✓	[12, 13]	47.7 ms
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LS I +61°303	?	Be	26.5	✓	✓	[16, 17]	magnetar ?
1FGL J1018.6-5856	?	O	16.6	✓	✓	[18, 19]	
LS 5039	?	O	3.9	✓	✓	[20, 21]	
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novae							
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colliding wind binary							
Eta Car	LBV	O/WR ?	2014	✓		[39, 40]	

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† not including another > 50 *Fermi*-LAT pulsars in binaries.

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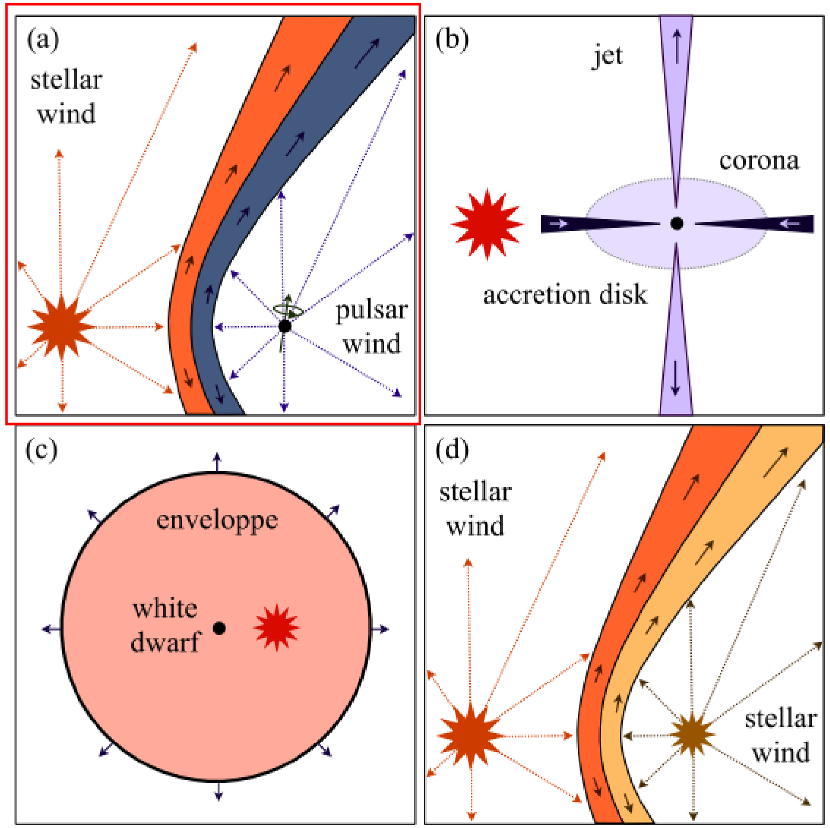

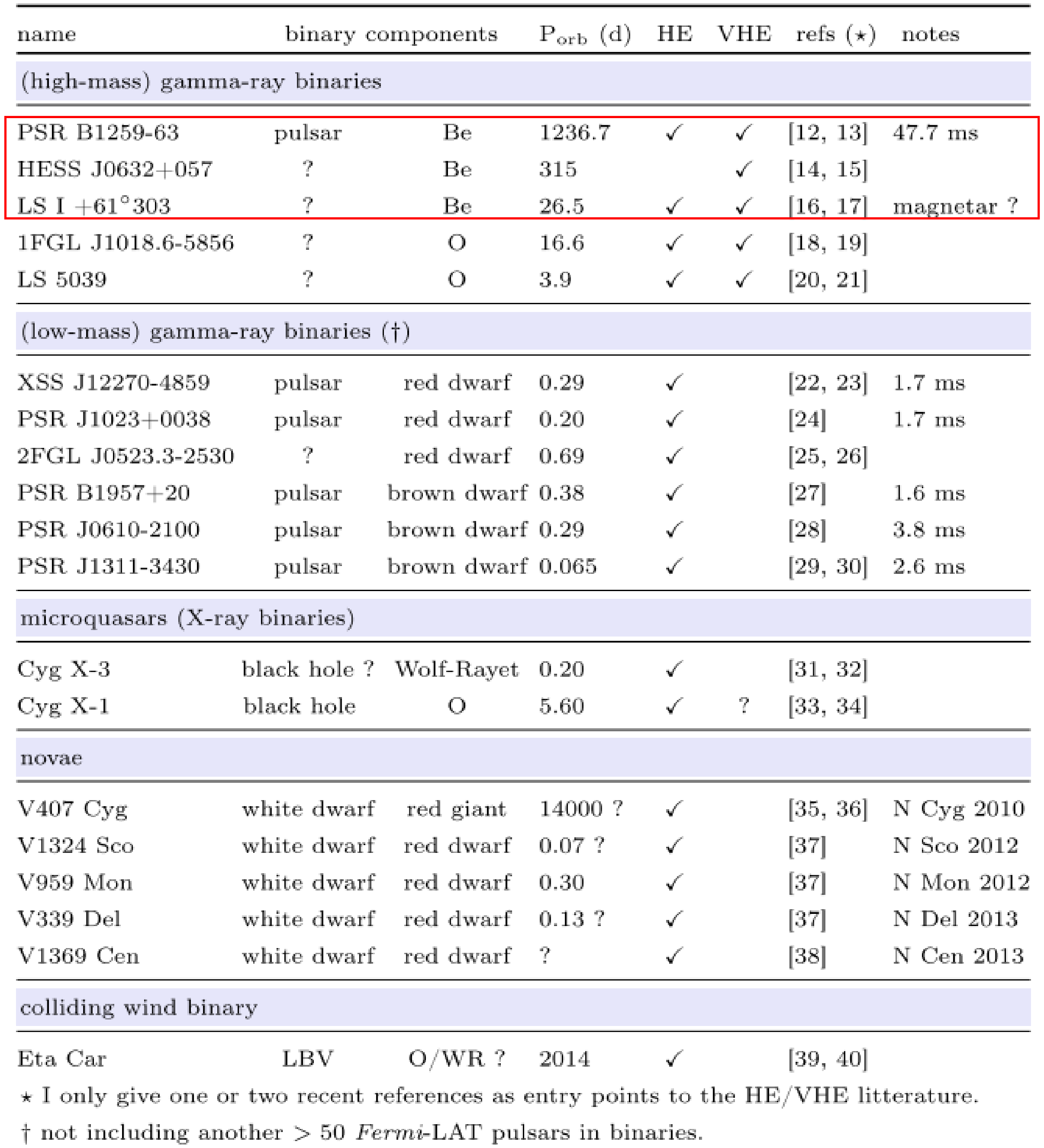

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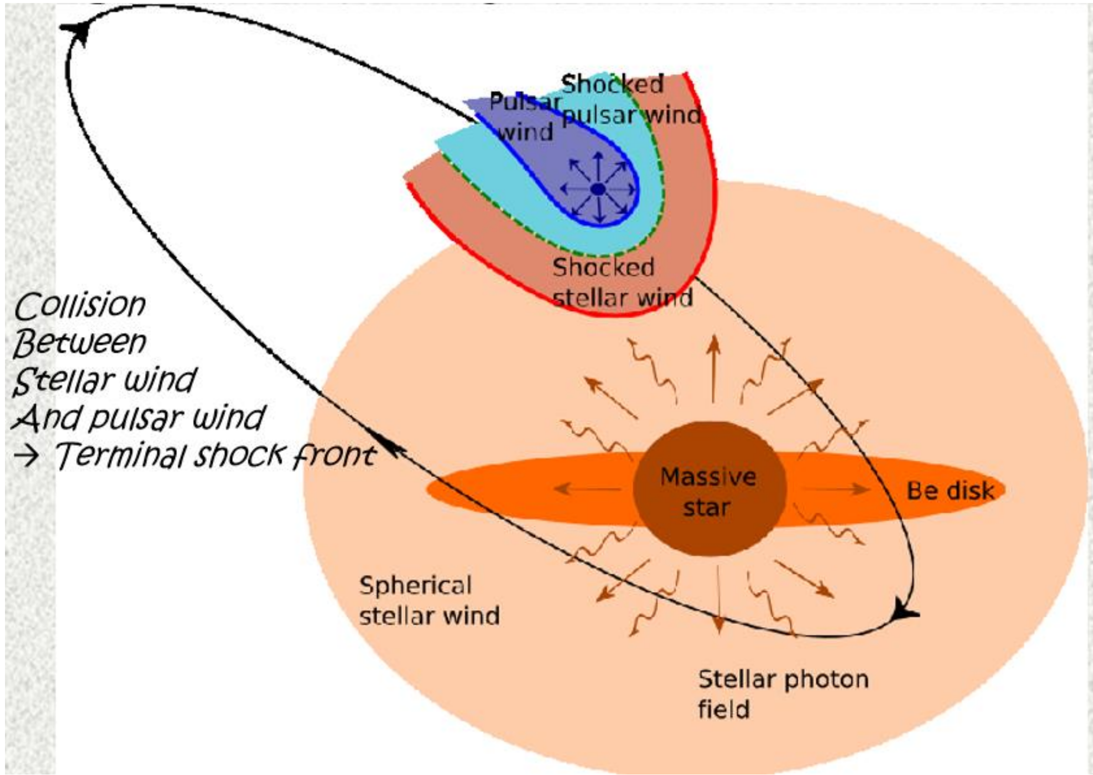
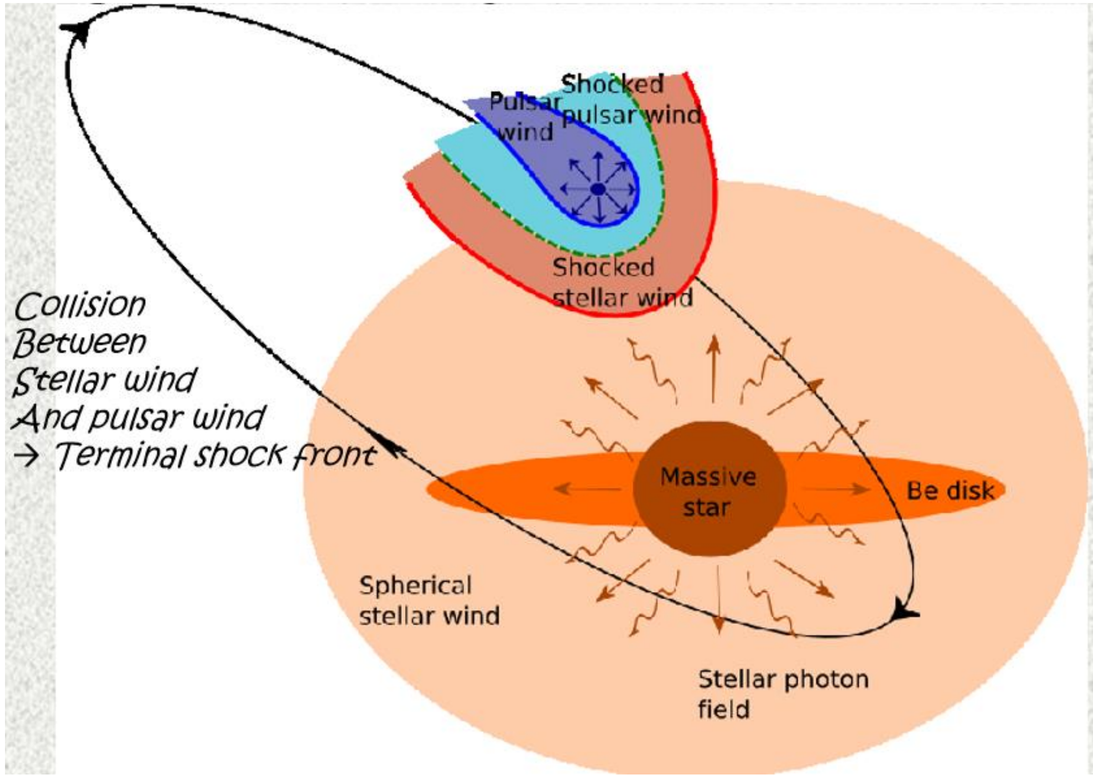
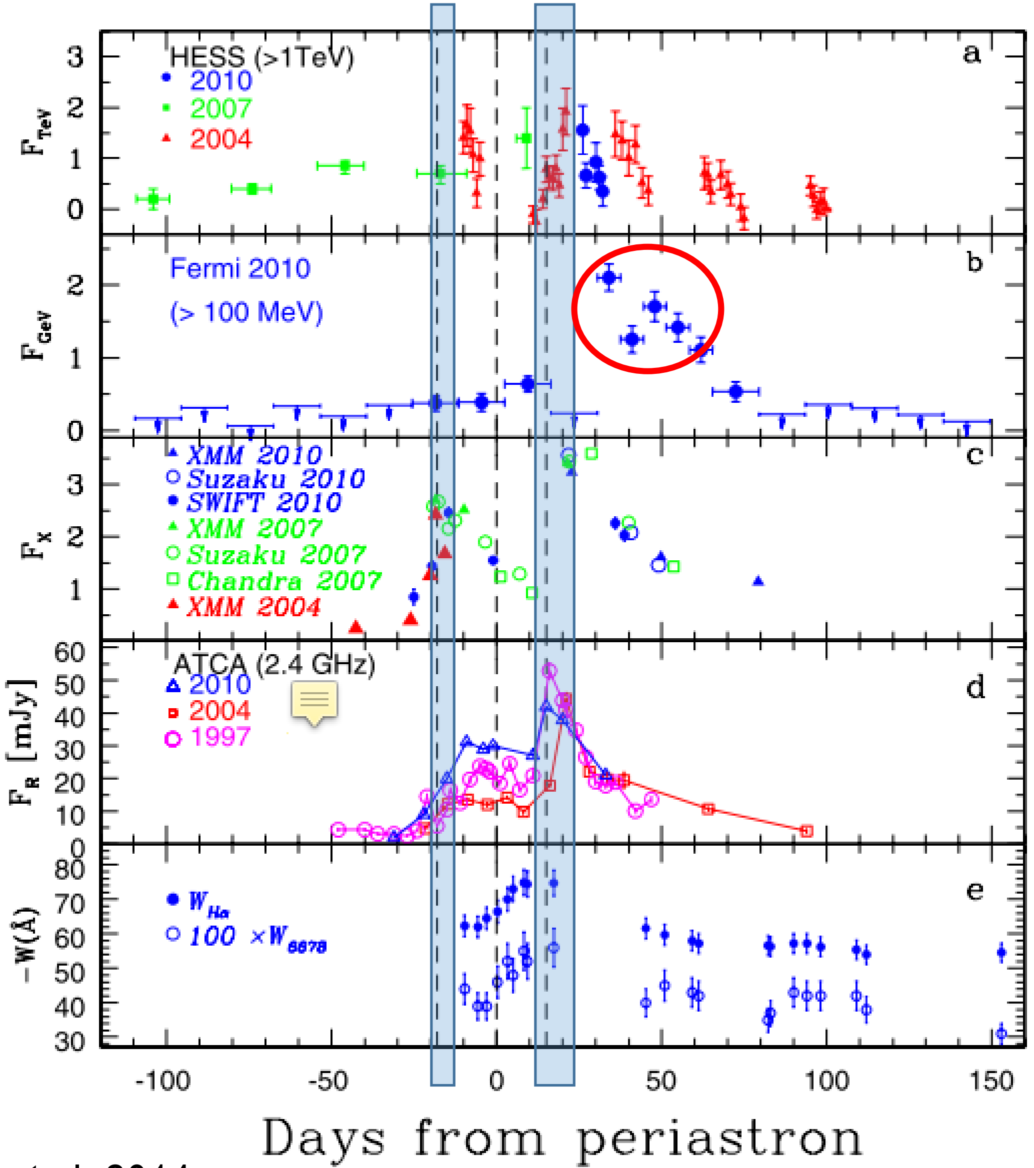
Pulsar-Be star binary



- B1259-63/LS 2883
- Main sequence star: 31 M_solar
- Pulsar: spin: 47.76 ms
- Orbital period: 1237 days
- Semi major axis 7.2 AU
- Eccentricity 0.87

PSR B1259-63/LS 2883

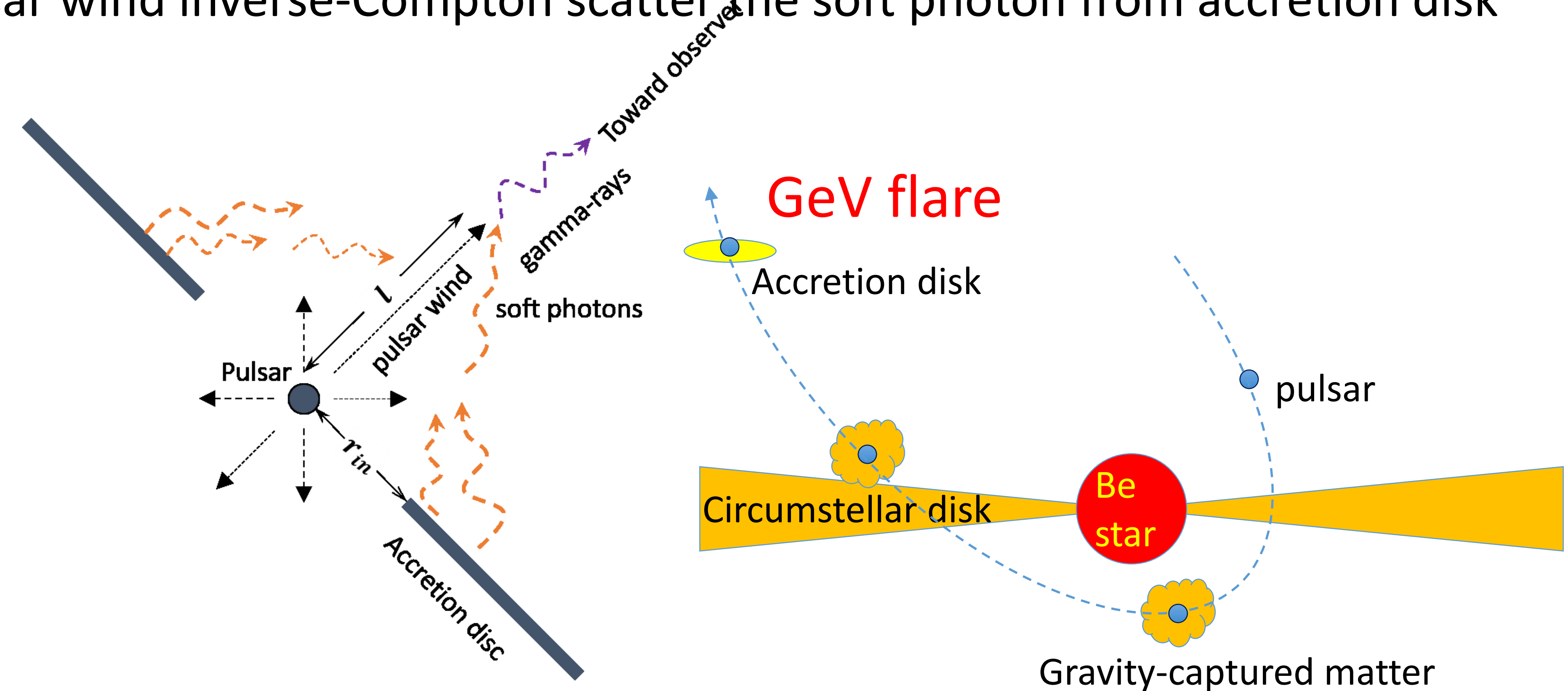




Chernyakova et al. 2014

Modeling the GeV flare of B1259-63

- Matter from circumstellar disk captured by gravity of pulsar
- An accretion disk forms.
- Pulsar wind inverse-Compton scatter the soft photon from accretion disk



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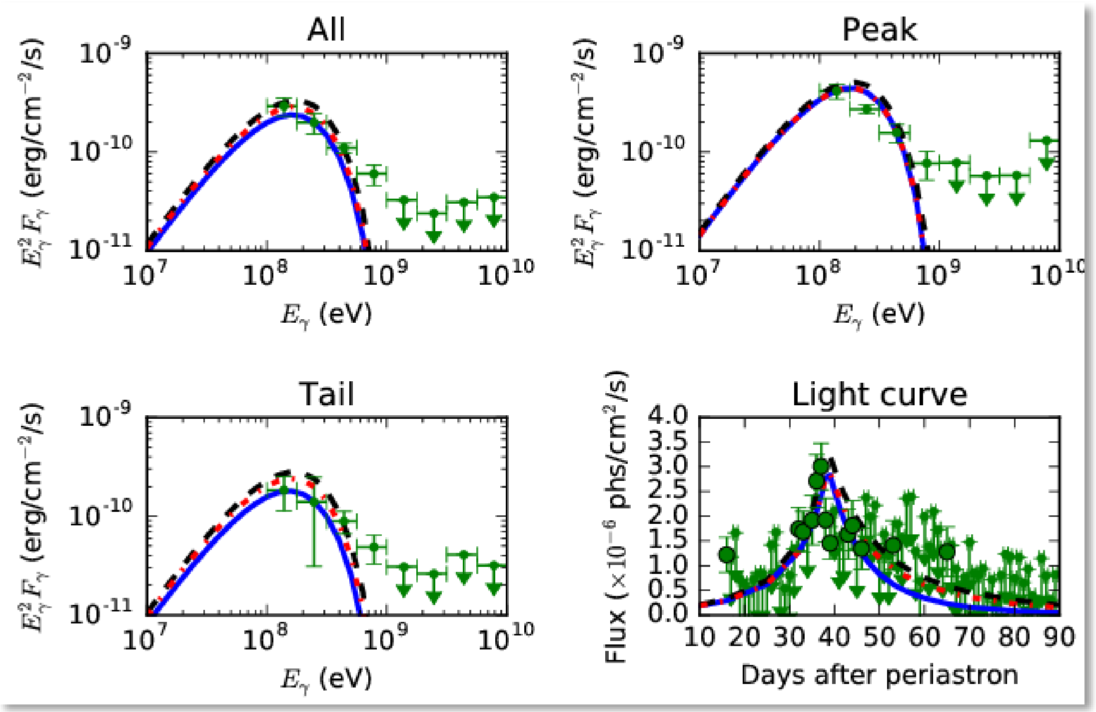
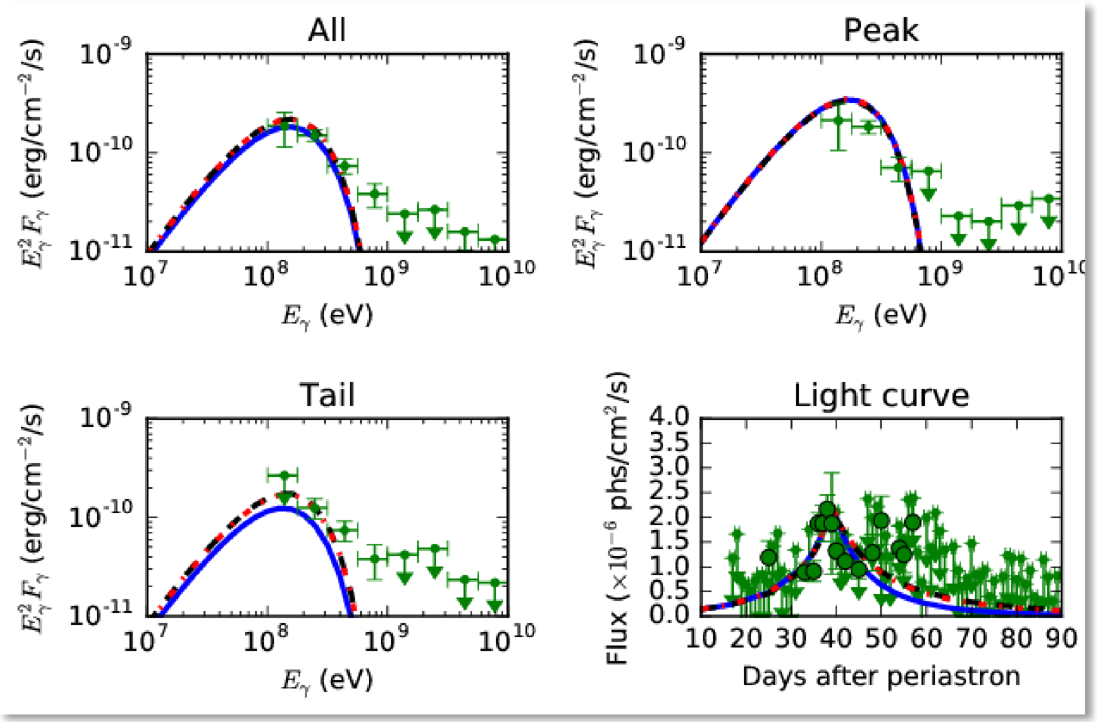


2010 periastron



2014 periastron

ApJ 844, 144, 2017

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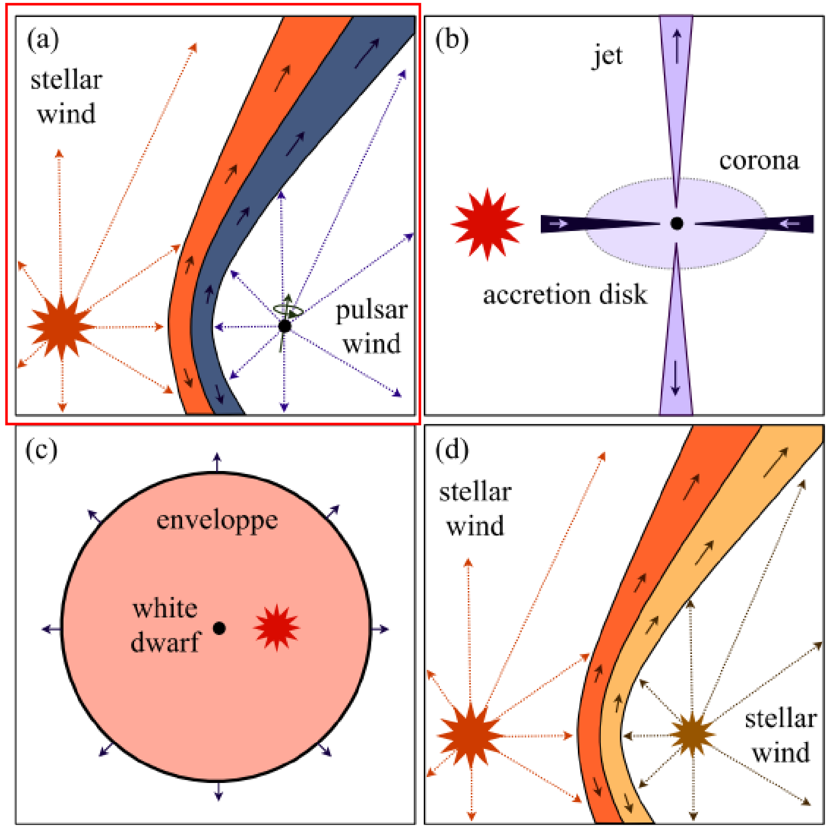

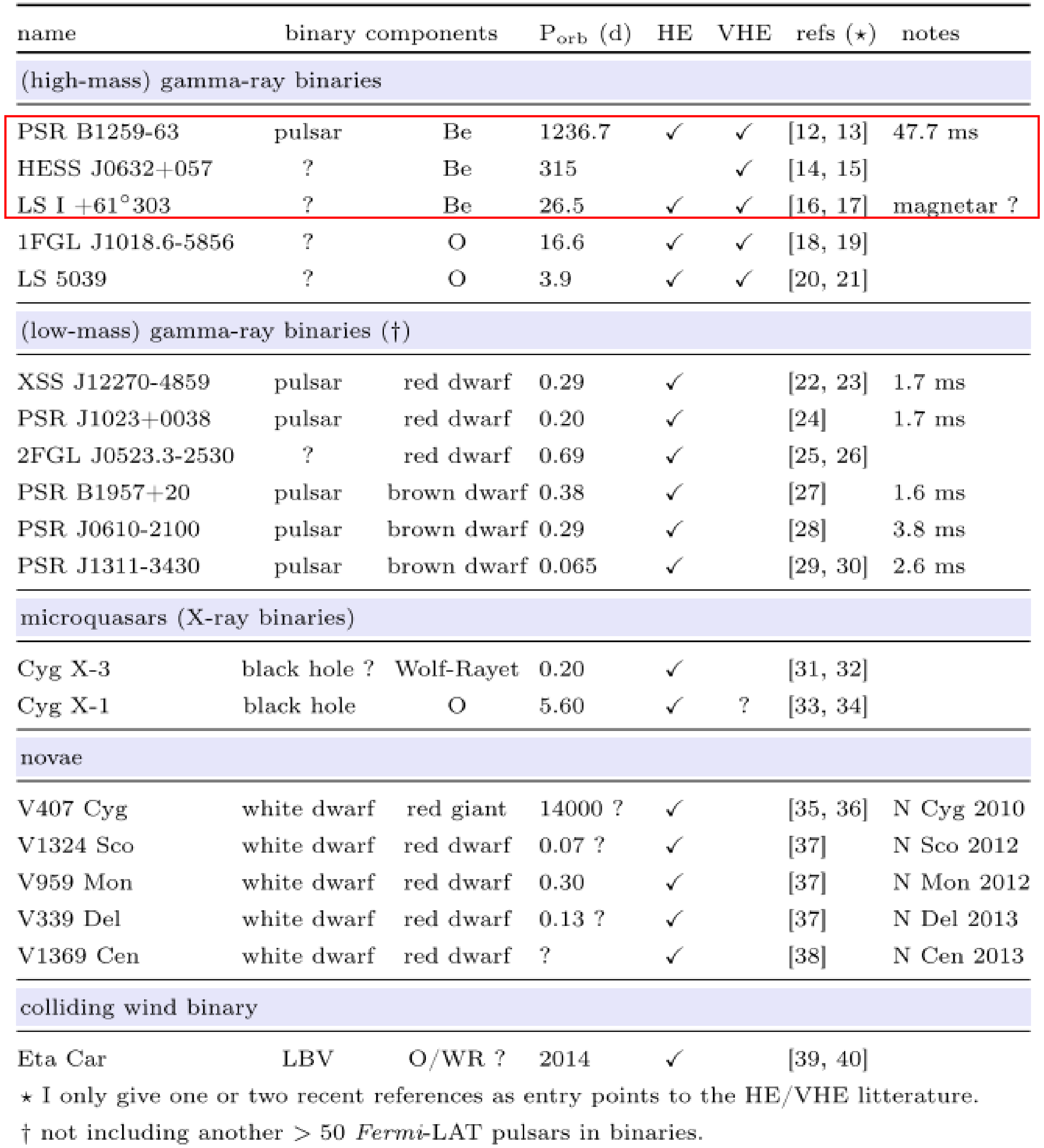

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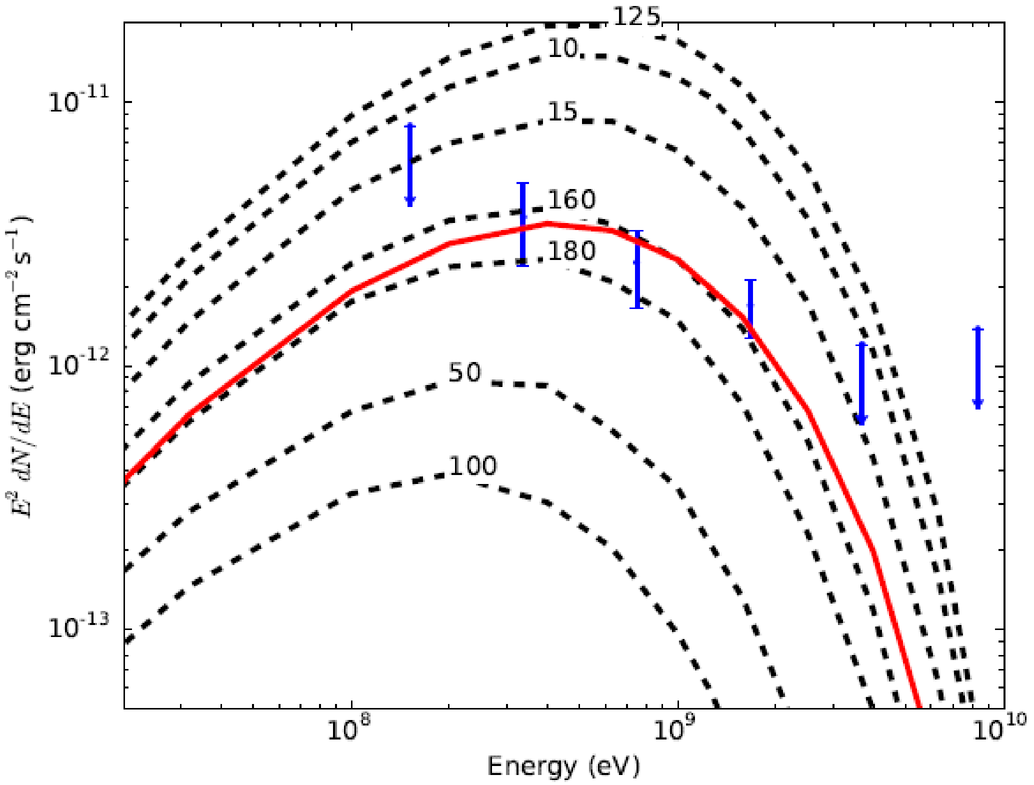
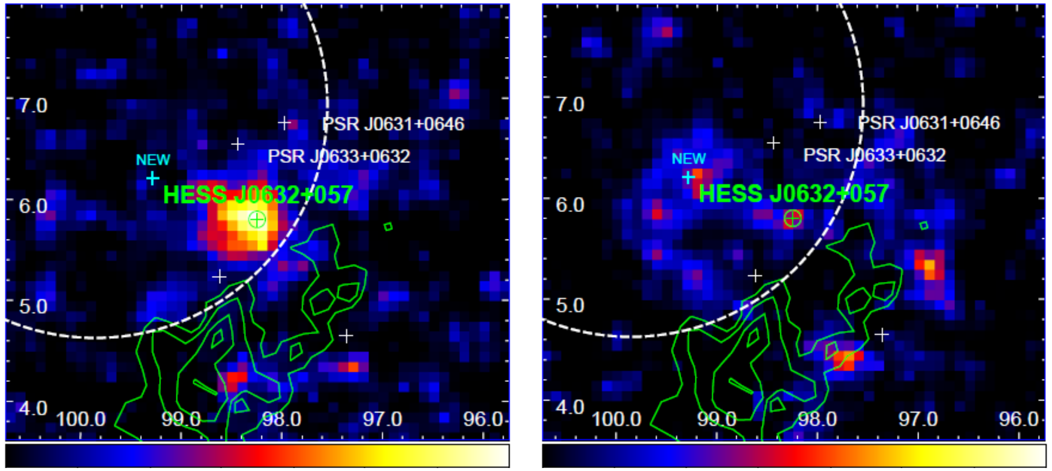
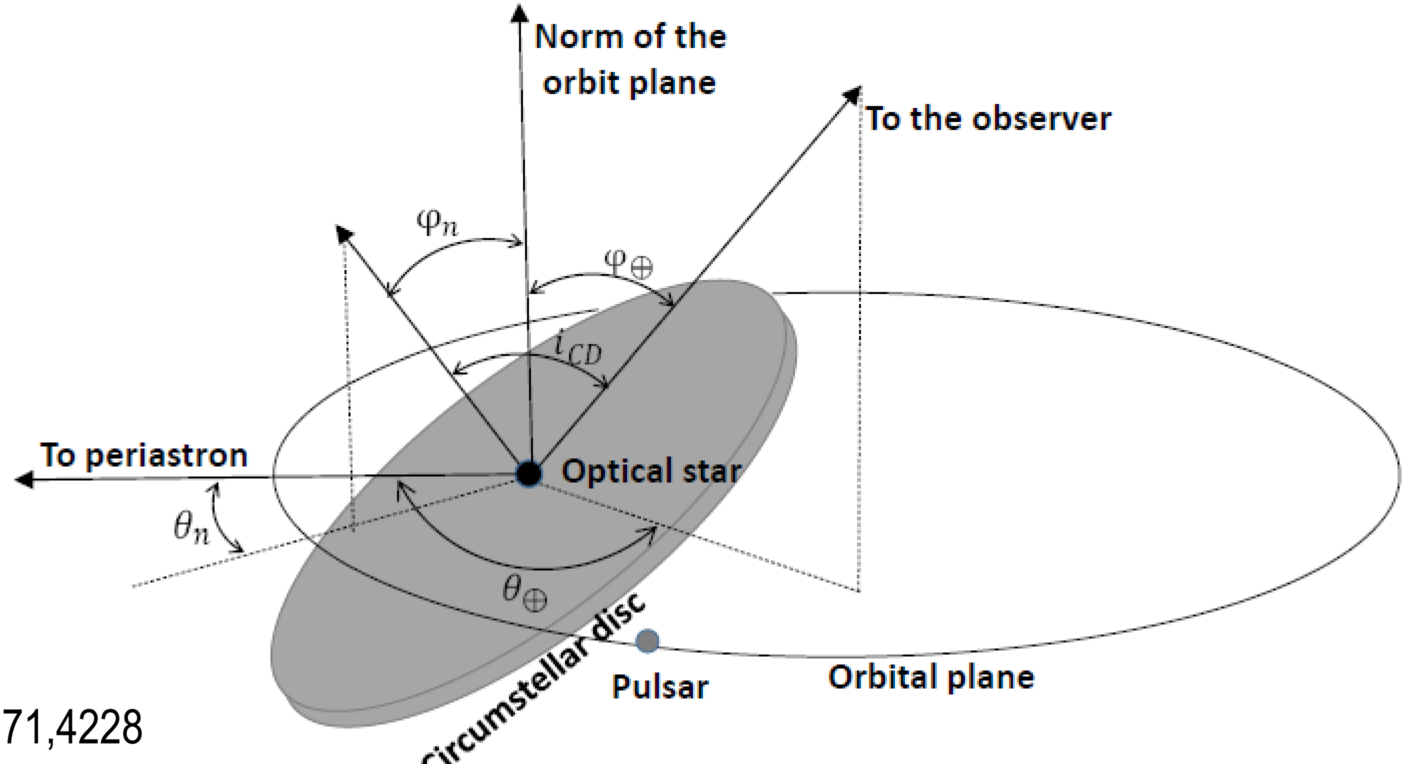
HESS J0632+057







MNRAS 471,4228

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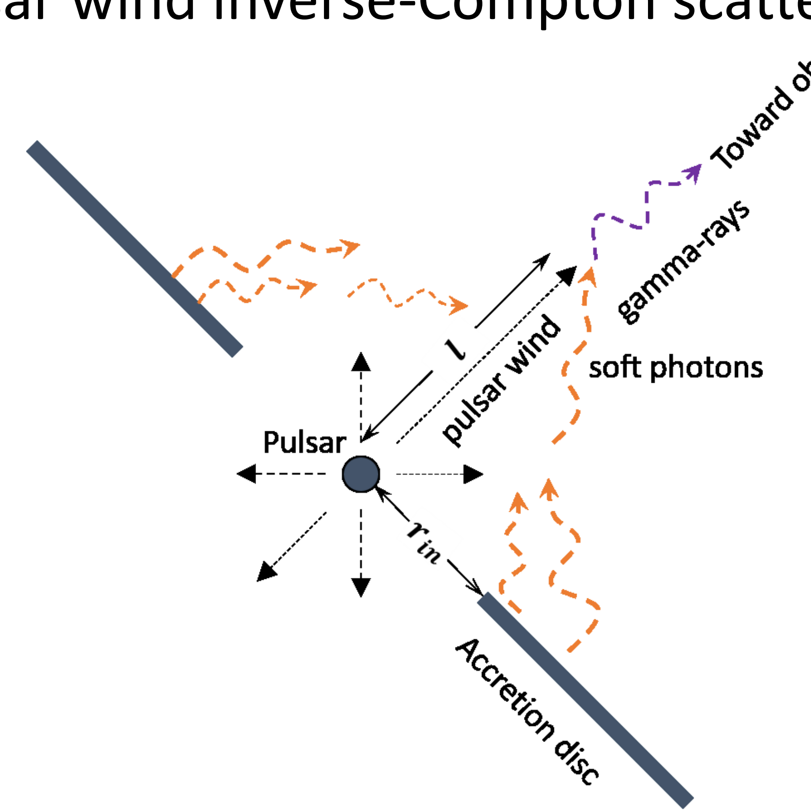
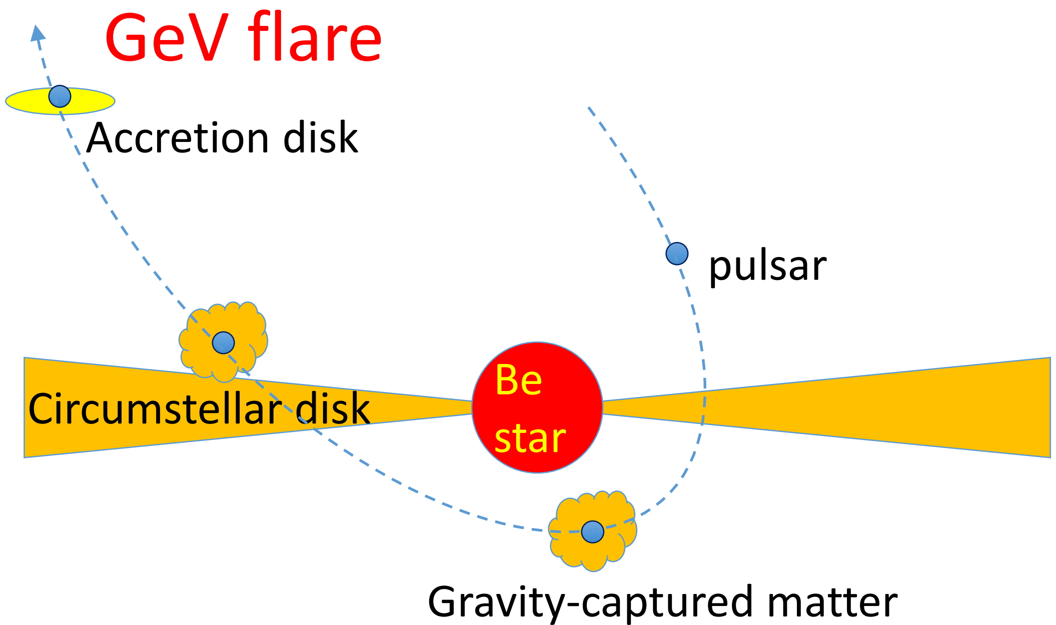




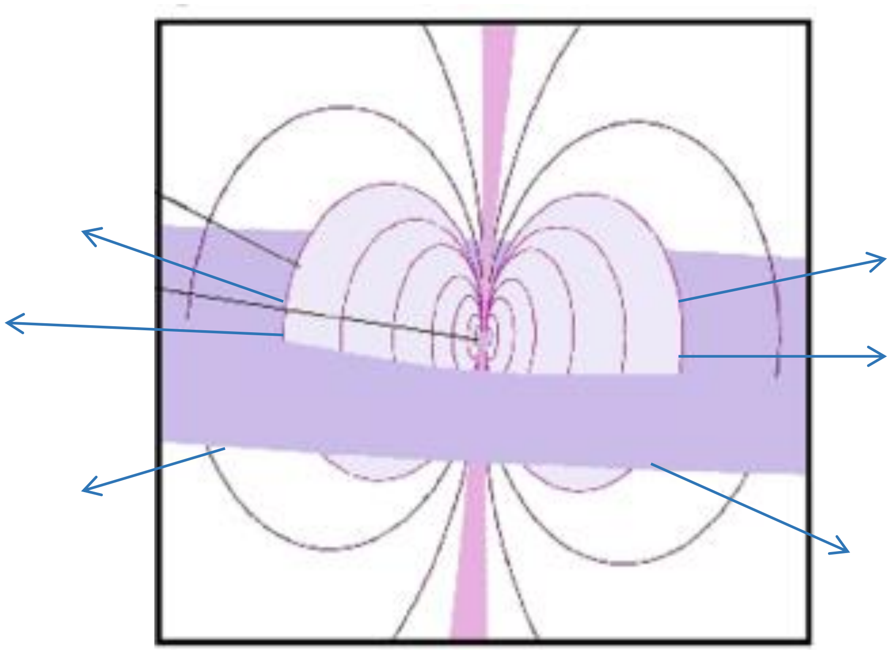
The Propeller effect

The magnetic pressure stops the accretion flow at r_M

Co-rotating velocity > Kepler velocity @ r_M

Matter on the accretion disk is ejected

A spin down torque on the pulsar by the accretion disk



The spin down torque

A phenomenological description (Menou et al. 1999; Liu et al. 2014):

degree of coupling between disk matter and field lines.

$$2\pi I\dot{\nu}_{\rm prop} = 2r_{\rm M}^2\dot{M}_{\rm acc}\left(\sqrt{\frac{GM_\star}{r_{\rm M}^3}} - 2\pi\nu\right)\chi,$$

The angular momenta of Keplerian motion per unit mass per time

The angular momenta of corotation per unit mass per time

The factor 2 in the right hand side of the above equation comes because there are two nearly equal contributions of the torque: the angular momenta transferred at the inner edge of the disc and the angular momenta transferred from the accretion flow to the magnetic field beyond the inner edge (Menou et al. 1999).

The spin down torque

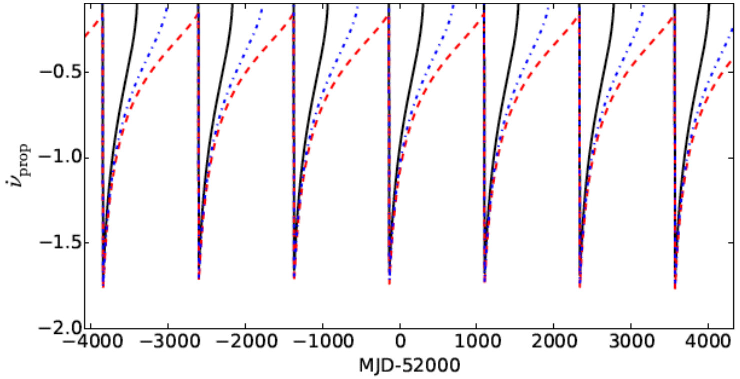


Figure 2. $\dot{\nu}_{\rm prop}$ due to the propeller torque, when $\dot{M}_{\rm eva} = 10^{13}, 5 \times 10^{12}$ and 3×10^{12} g/s (black-solid, blue-dash-dotted and red-dashed respectively), with the assumption that $\chi = 0.001$.

Repetitive with the orbital period

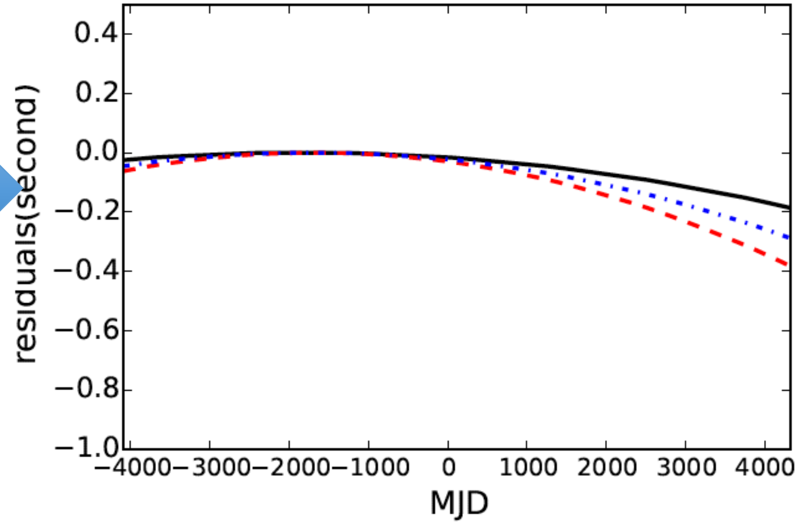


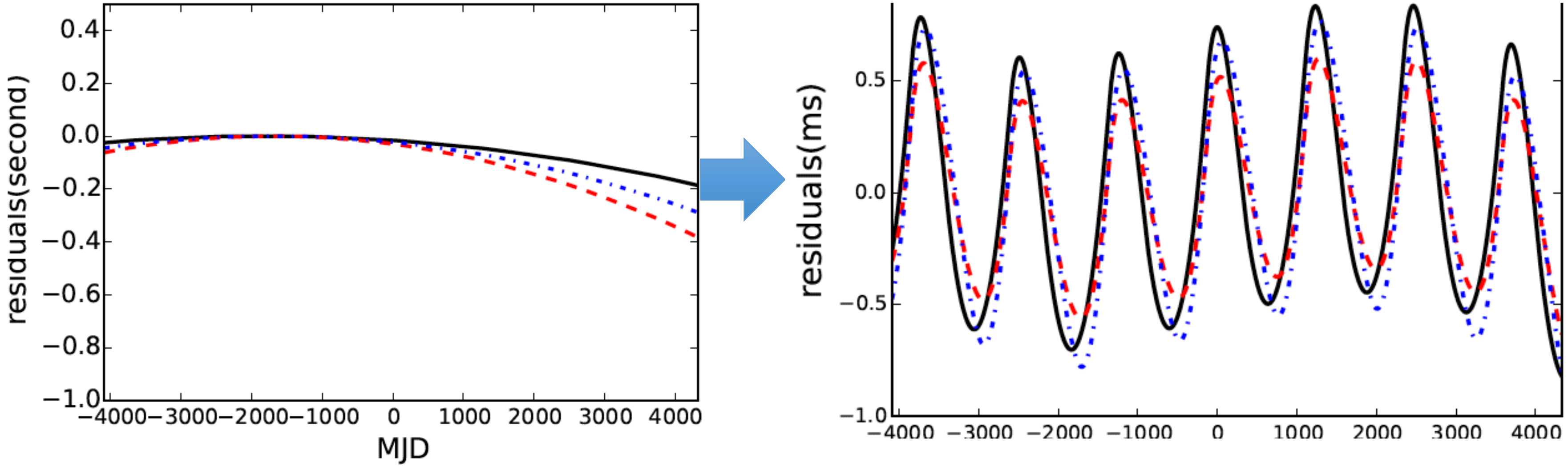
Figure 3. additional timing residuals due to the propeller barking when $\dot{M}_{\rm eva} = 10^{13}, 5 \times 10^{12}$ and 3×10^{12} g/s (black-solid, blue-dash-dotted and red-dashed respectively) and $\chi = 0.001$

the spin derivative

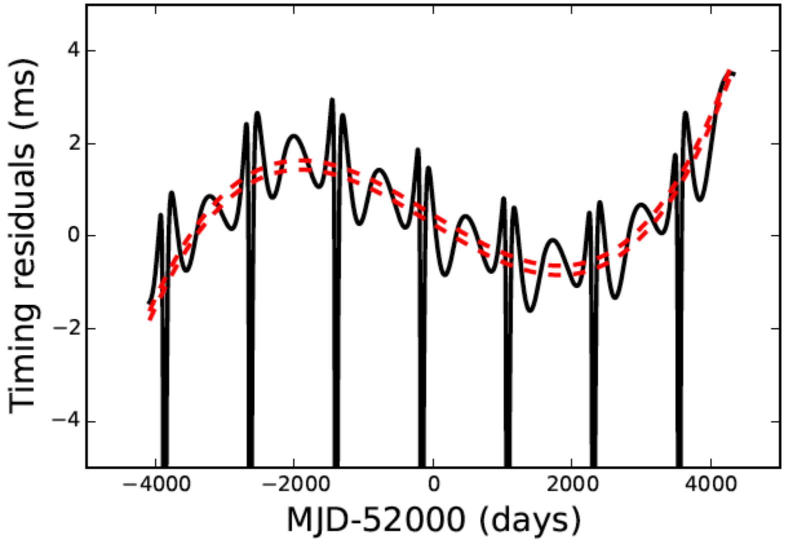
Timing residuals

Yi & Cheng, 2017, submitted to MN

The spin down torque



Large timing residuals of parabolic structure will be removed, when fitting a constant nudot



More timing residuals will be absorbed by fitting other binary parameters.

The red curve is the observed timing level residuals.

Yi & Cheng, 2017, submitted to MN

The timing residuals

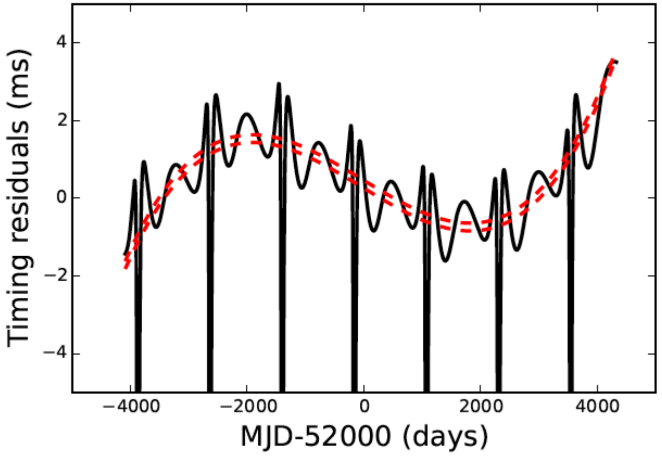


Figure 5. The timing residuals after all parameters refitted when $\dot{M}_{\rm eva} = 10^{13}$ g/s and $\chi = 0.001$. The dashed-red curves represent the upper and lower limit set by the TOA uncertainty and observed residuals.

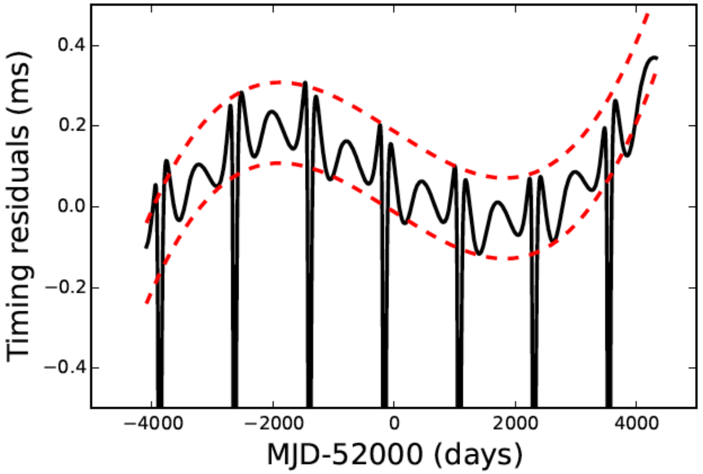


Figure 6. The same figure as in figure 5, but for $\chi = 10^{-4}$

If χ=1e-3, the predicted timing residuals is larger than the observation.

χ needs to be smaller than 1e-4, in order to fit with observation.

Yi & Cheng, 2017, submitted to MN

Is χ<=1e-4 physical?

$$2\pi|\dot{\nu}_{\rm prop}| \geqslant |\dot{M}_{\rm acc}\frac{GM_\star}{2r_{\rm M}}|/(I\Omega_\star). \quad (8)$$

The matter should be ejected at least with escaping velocity

$$2\pi I\dot{\nu}_{\rm prop} \approx -0.76\mu^{4/5} f^{2/5}\Omega^{3/5}\dot{M}^{3/5}, \quad (9)$$

The propeller torque by Romanova (2003)

where \mu is the magnetic dipole of the neutron star and f is a factor which the authors took f = 0.3.

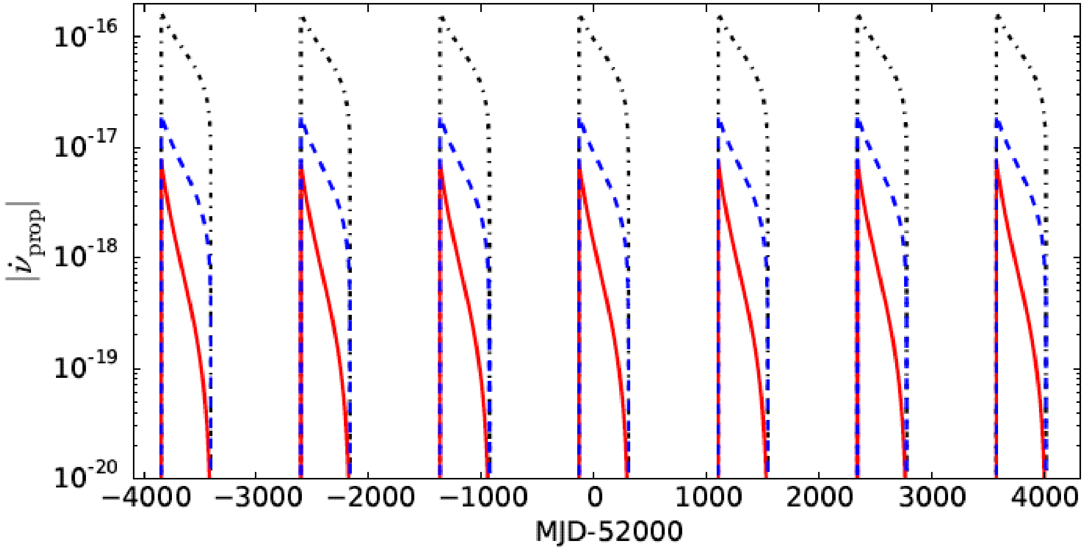


Figure 7. The absolute value of $\dot{\nu}_{\rm prop}$ when $\chi = 10^{-4}$ (black dotted), the lower limit of $|\dot{\nu}_{\rm prop}|$ set by inequality (8) (red solid) and $|\dot{\nu}_{\rm prop}|$ set by equation (9) (blue dash-dotted).

χ=1e-4 doesn't violent with (8) and (9)

Yi & Cheng, 2017, submitted to MN

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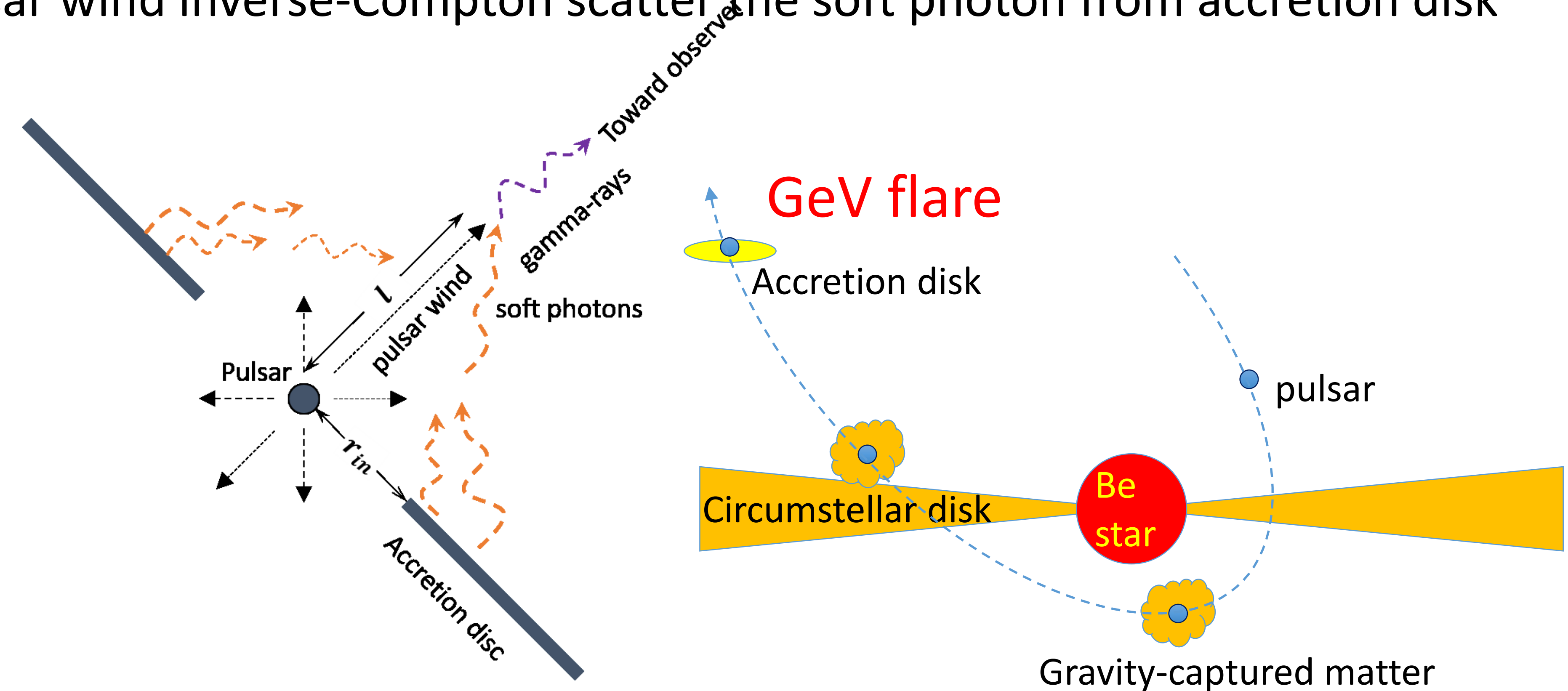


How pulsar wind accelerates?

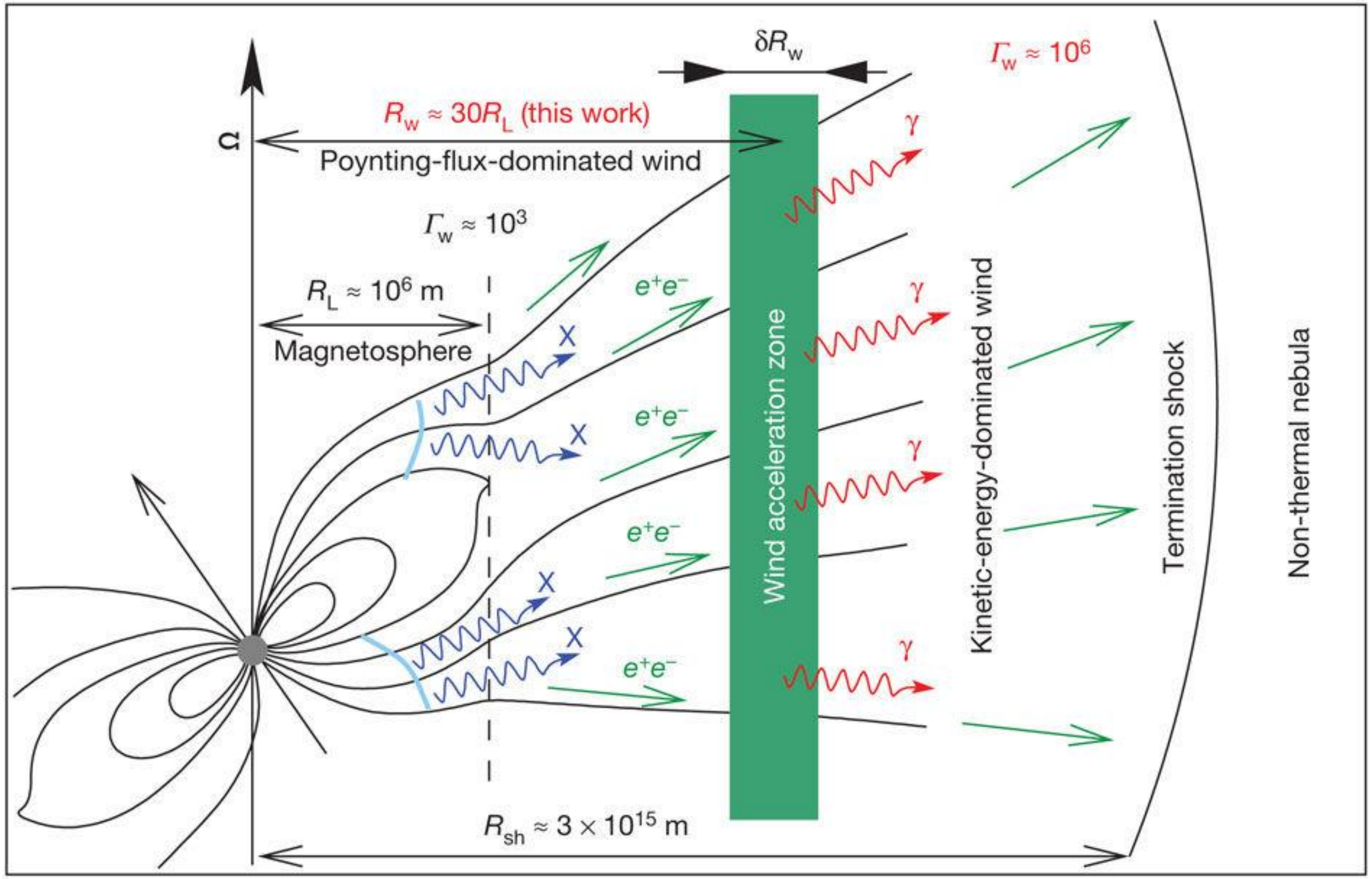
- The energy of Pulsar wind

=EMW+e$^{+/-}$

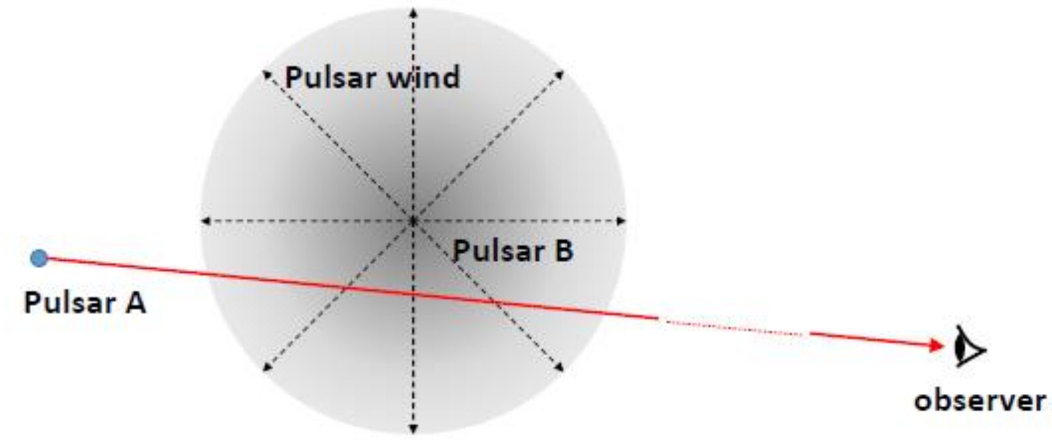
$$\sigma = W_{\mathrm{EM}}/W_{\mathrm{part}}.$$

$$\sigma = \sigma_{\mathrm{L}} \left(\frac{r}{r_{\mathrm{L}}} \right)^{-\alpha_\sigma}$$

Model dependent



The velocity and density distribution of e$^{+/-}$ in pulsar wind in double neutron stars



$$\delta\mathrm{DM} = \int_0^\infty \frac{1}{\sqrt{1-r_\mathrm{s}/r}} \frac{n'_\mathrm{e}}{(1-\beta\cos\theta)} dl.$$

Velocity distribution

Function of system geometry
And orbital phase

$$n_\mathrm{e}(r) = \frac{L_\mathrm{sd}}{4\pi\beta c^3 r^2 m_\mathrm{e}(1+\sigma)\gamma},$$

MNRAS 472, 400 (2017)

Orbital phase-modulated Dispersion measure

J0737-3039A/B

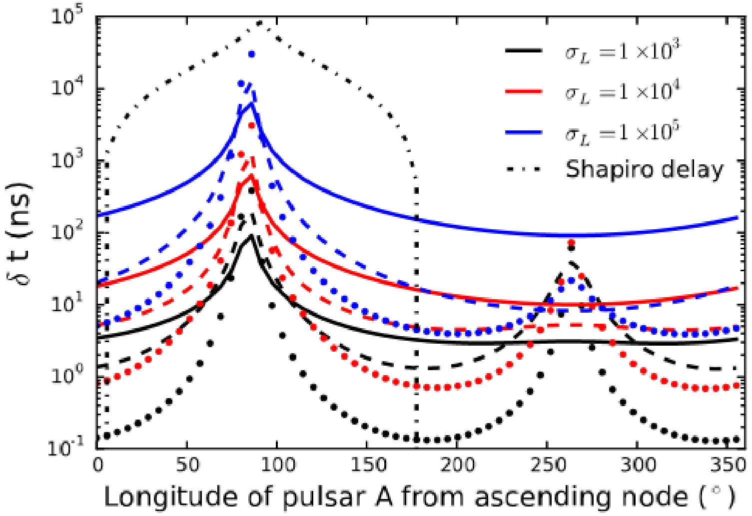


Figure 4. Time delay due to the additional DM in PSR J0737-3039A/B in the observing frequency of 300 MHz, compared with Shapiro delay (dash-dotted curve). The black, red and blue line colors correspond to $\sigma_L = 1\times10^3$, 1×10^4 and 1×10^5 respectively; The solid, dashed and dotted line styles correspond to $\alpha_\sigma = 0$, 1 and 2 respectively. For all curves, $\gamma_\infty = 10^3$ is adopted.

J1915+1606

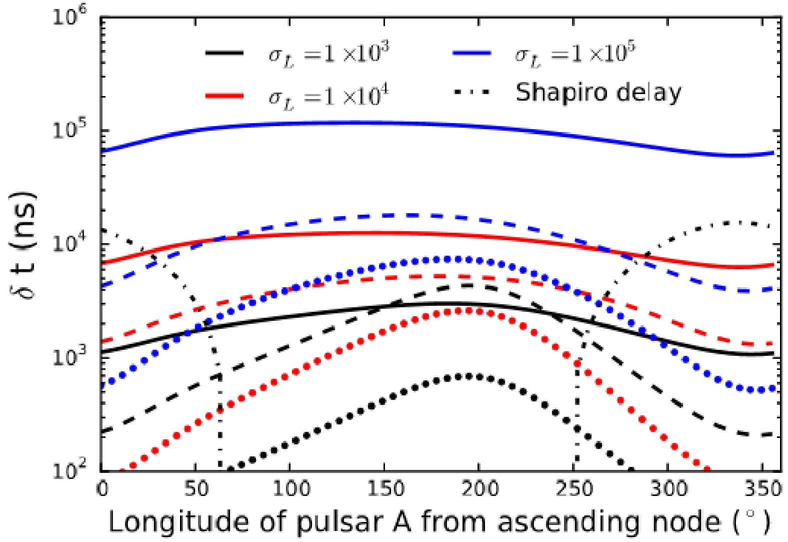


Figure 6. Time delay due to the additional DM in PSR J1915+1606 in the observing frequency of 300 MHz, compared with Shapiro delay (dash-dotted curve). The black, red and blue line colors correspond to $\sigma_L = 1\times10^3$, 1×10^4 and 1×10^5 respectively; The solid, dashed and dotted line styles correspond to $\alpha_\sigma = 0$, 1 and 2 respectively. For all curves, $\gamma_\infty = 10^3$ is adopted.

MNRAS 472, 400 (2017)

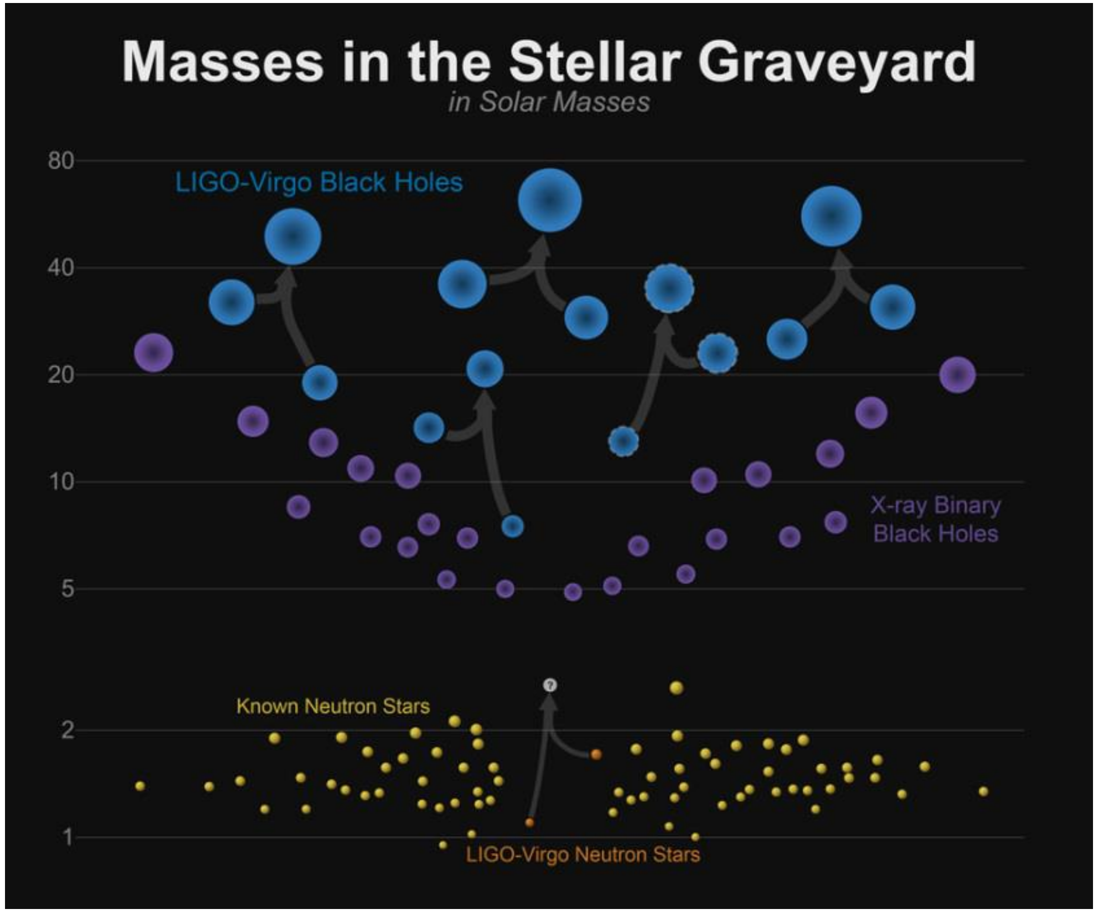
Feasibility of archival, current and further observation

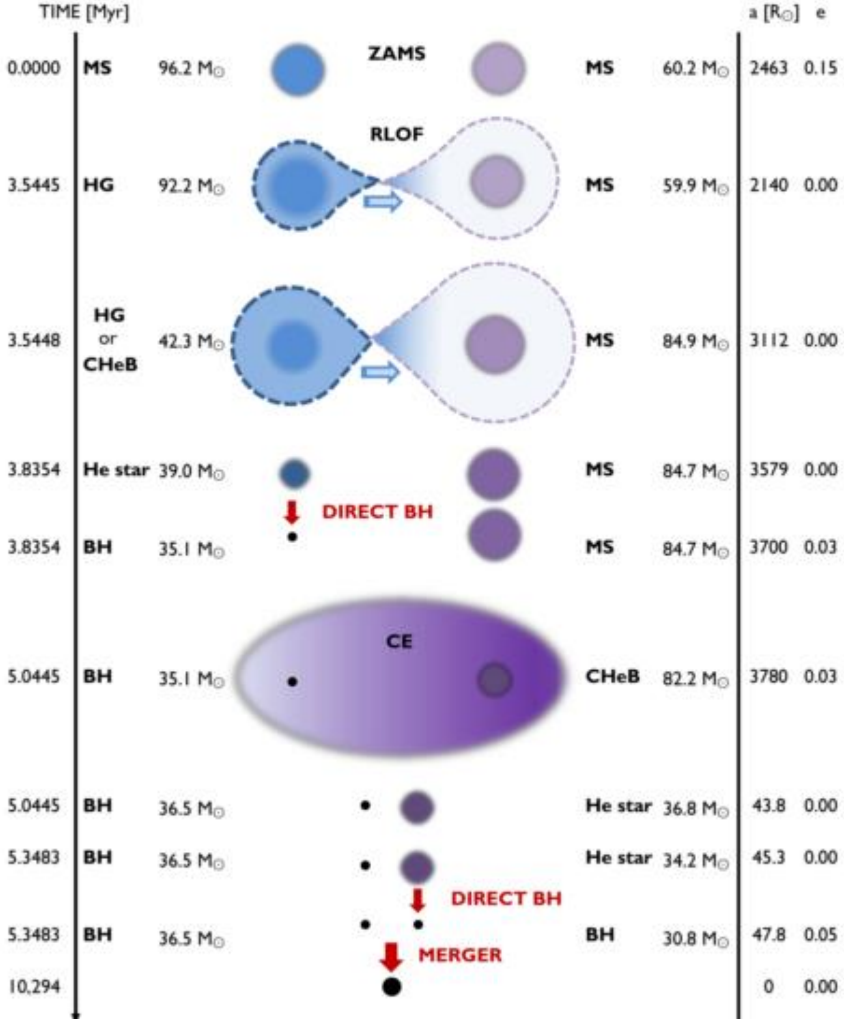
- PSR J0737-3039A/B: $L_{sp}=10^{30}$erg/s
- Best timing observation: 18μs with 30-s integration @ GBT, 820 MHz.
- Predicted time delay~10 μs at 300 MHz.
- Need at least 4 times longer integration time of GBT
- Or use larger telescope like ***FAST***

- PSR J1915+1606
- If $L_{sp}>10^{33}$ erg/s, predicted time delay can be up to 10~20 μs in 300 MHz.
- Best timing observation ~5 μs with 5-mininute integration @ Arecibo.
- May ready to be seen in archival data of Arecibo!
- Or set upper limit of L_sp

MNRAS 472, 400 (2017)

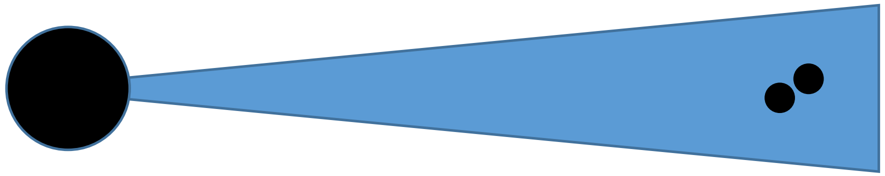
BH binary in AGN disk as GW source





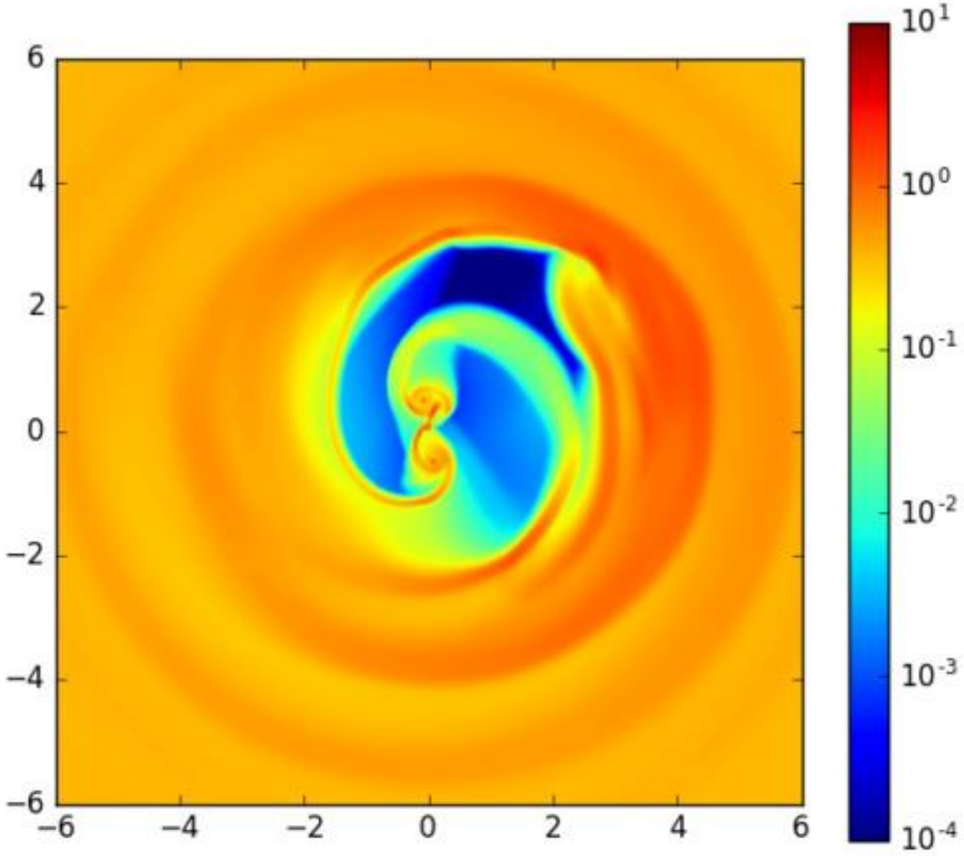
Belczynski et al. 2016

Alternative channel to M>20M_solar?



Supermassive BH in AGN

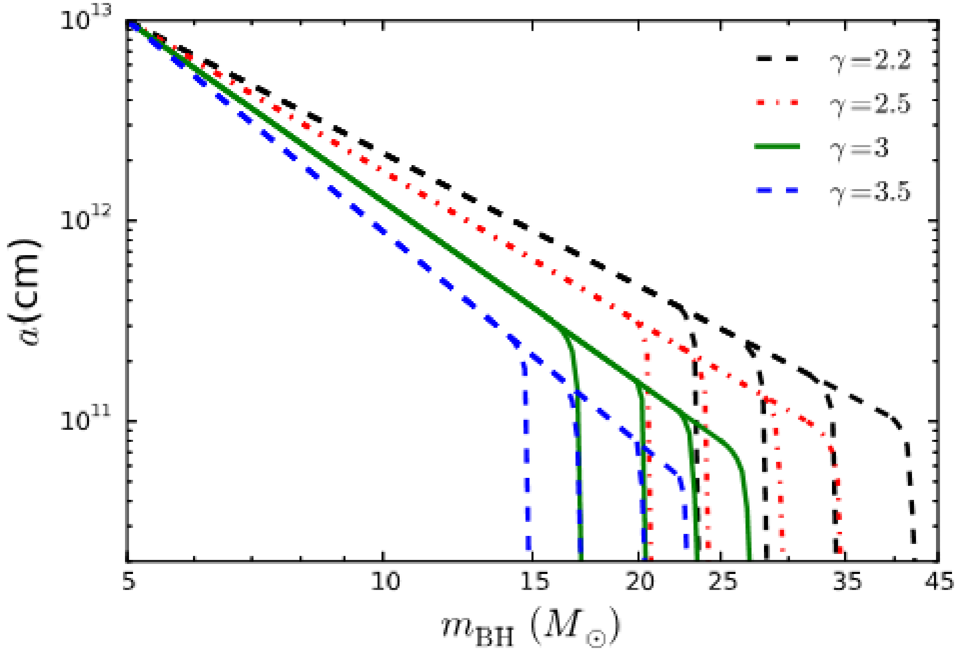
Stellar BH binary



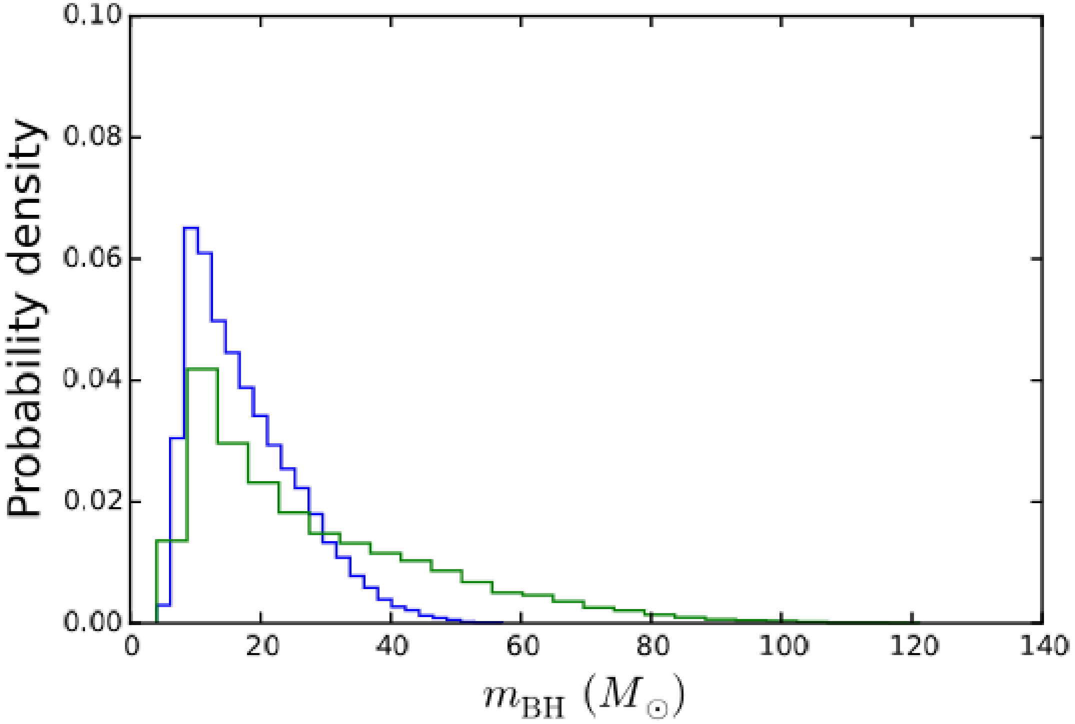
Tang et al. 2017

BH binary accreting in AGN disk

$$\frac{da_{12}}{dm_{\rm BH}} = -\gamma\frac{a}{m_{\rm BH}} - 7.88\times10^{-6}a_{12}^{-3}m_{\rm BH}^{2}\eta^{-1}.$$



Turn over: Coalescence & GW burst



Yi, Taam and Cheng, in prep.

EM counterpart of GW

- Associated with AGN
- EM counterpart in ~keV

$$L_{\rm EM} = 1.26 \times 10^{38} \times \frac{4\pi\eta}{\Delta\Omega}\frac{M}{M_\odot}\,{\rm ergs/s}$$

For $M = 50\,M_\odot$, $\eta = 100$ **and** $\Delta\Omega = 1$, $L_{\rm EM} = 8 \times 10^{42}$ **ergs/s.**

- $L_{AGN,X} < L_{EM}$

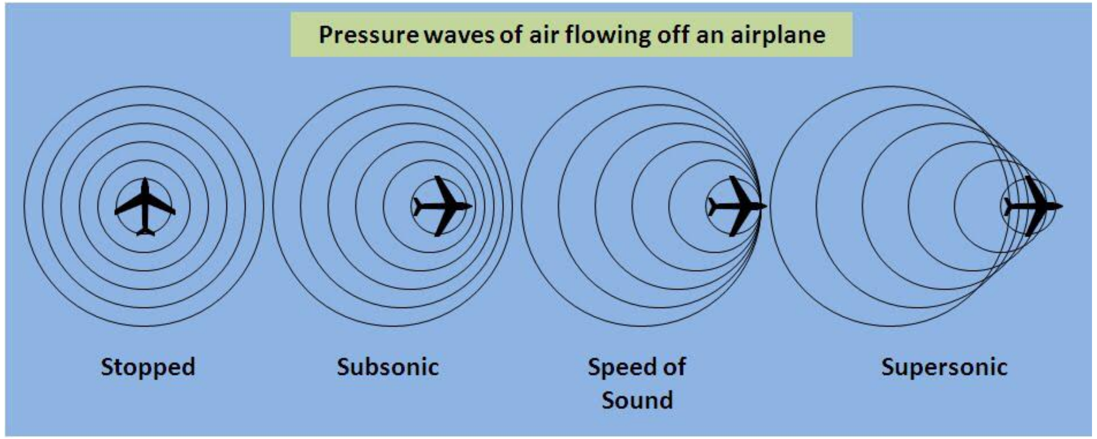
$$\alpha_{\rm ox} = -0.384\log(L_{\rm x}/L_{\rm o}),$$

$\alpha_{\rm ox} = 1.34$ **(Grupe et al. 2010), we find that** $L_{\rm o} < 2.5 \times 10^{46}$ **ergs/s**

- X-ray weak AGN, or low state AGN
  (η_{SMBH}<0.1 for M=1e8 $M_\odot$)

Yi, Taam and Cheng, in prep.

GW-Cherenkov radiation



- Sound wave: cone-shock
- EM wave: Cherenkov radiation
- GW wave: GW-Cherenkov radiation…

$$\frac{c^2}{c_{\mathrm{g}}^2} = 1 + \frac{4\pi G\rho}{3\omega_{\mathrm{g}}^2}, \left(\omega_{\mathrm{g}} \gg \sqrt{\frac{4\pi G\rho}{3}}\right).$$

$$\rho = 10^{12}\, M_\odot/\mathrm{Mpc}^3$$

$$\tau \equiv E/\dot{E}$$
$$> 10^{106} \left(\frac{\mathrm{eV}}{E}\right) \mathrm{s}.$$

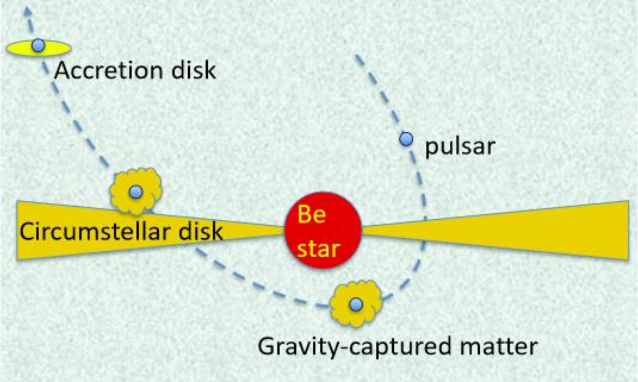
$E<10^{14}$ eV due to photon-photon scattering with CMB and Extragalactic background light

Nonzero but neglectable

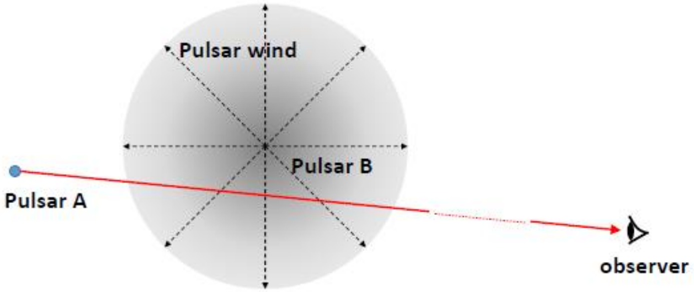
arXiv:1706.08722
Modern Physics Letters A, Volume 32, Issue 9, id. 1750059 (2017)

Outline

- GeV flare of B1259-63/LS 2883
- GeV emission of HESS J0632+057
- Propeller effect of B1259-63



- Study pulsar wind in double neutron stars



- BH binary in AGN disk as GW source
- GW-Cherenkov radiation