パルサー光度曲線の理論解析

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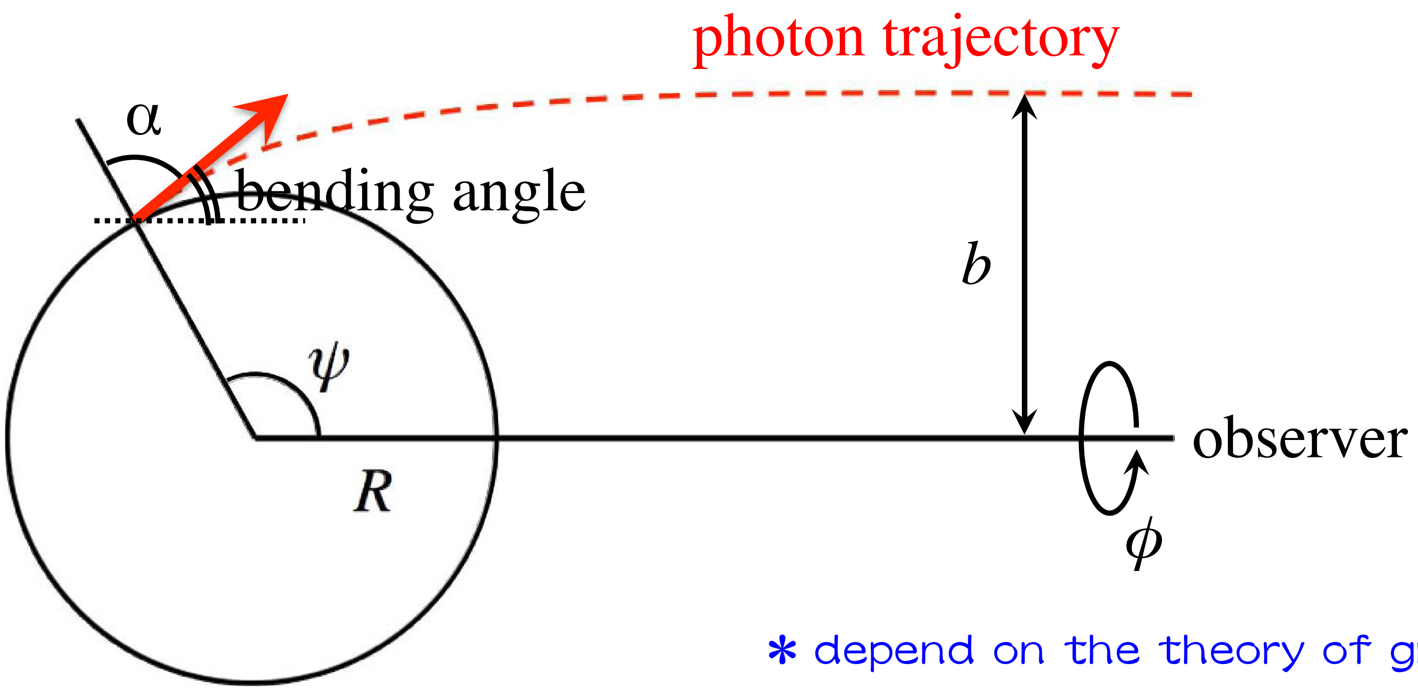
photon trajectory & deflection angle

- metric: $g_{\mu\nu}dx^\mu dx^\nu = -A(r)dt^2 + B(r)dr^2 + C(r)(d\theta^2 + \sin^2\theta d\psi^2)$
- deflection angle and impact parameter:

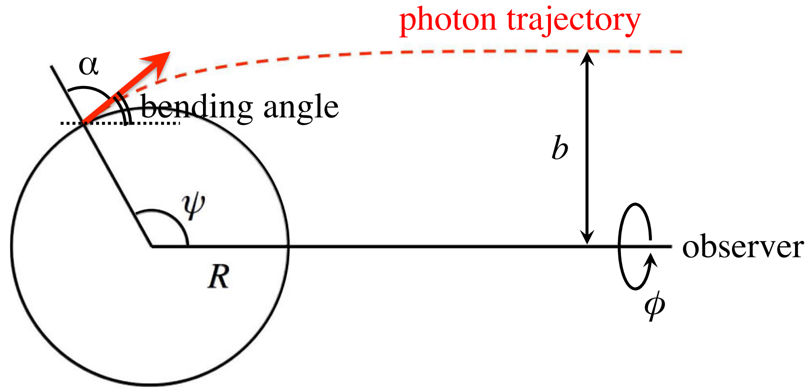
$$\psi(R) = \int_R^\infty \frac{dr}{C}\left[\frac{1}{AB}\left(\frac{1}{b^2} - \frac{A}{C}\right)\right]^{-1/2} \quad \text{where} \quad b = \sin\alpha\sqrt{\frac{C(R)}{A(R)}}.$$

- maximum value of ψ corresponds to the value when $\gamma = \pi/2$

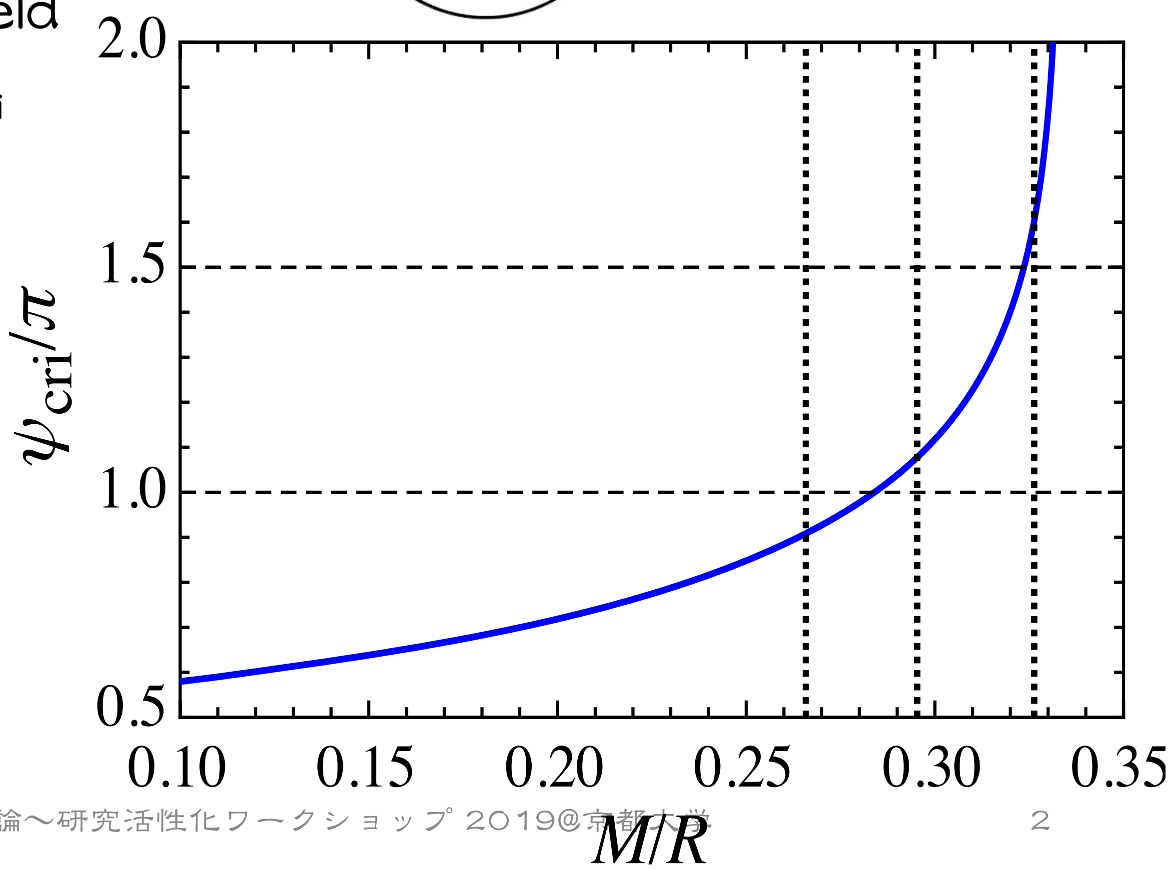


* depend on the theory of gravity

critical value of ψ

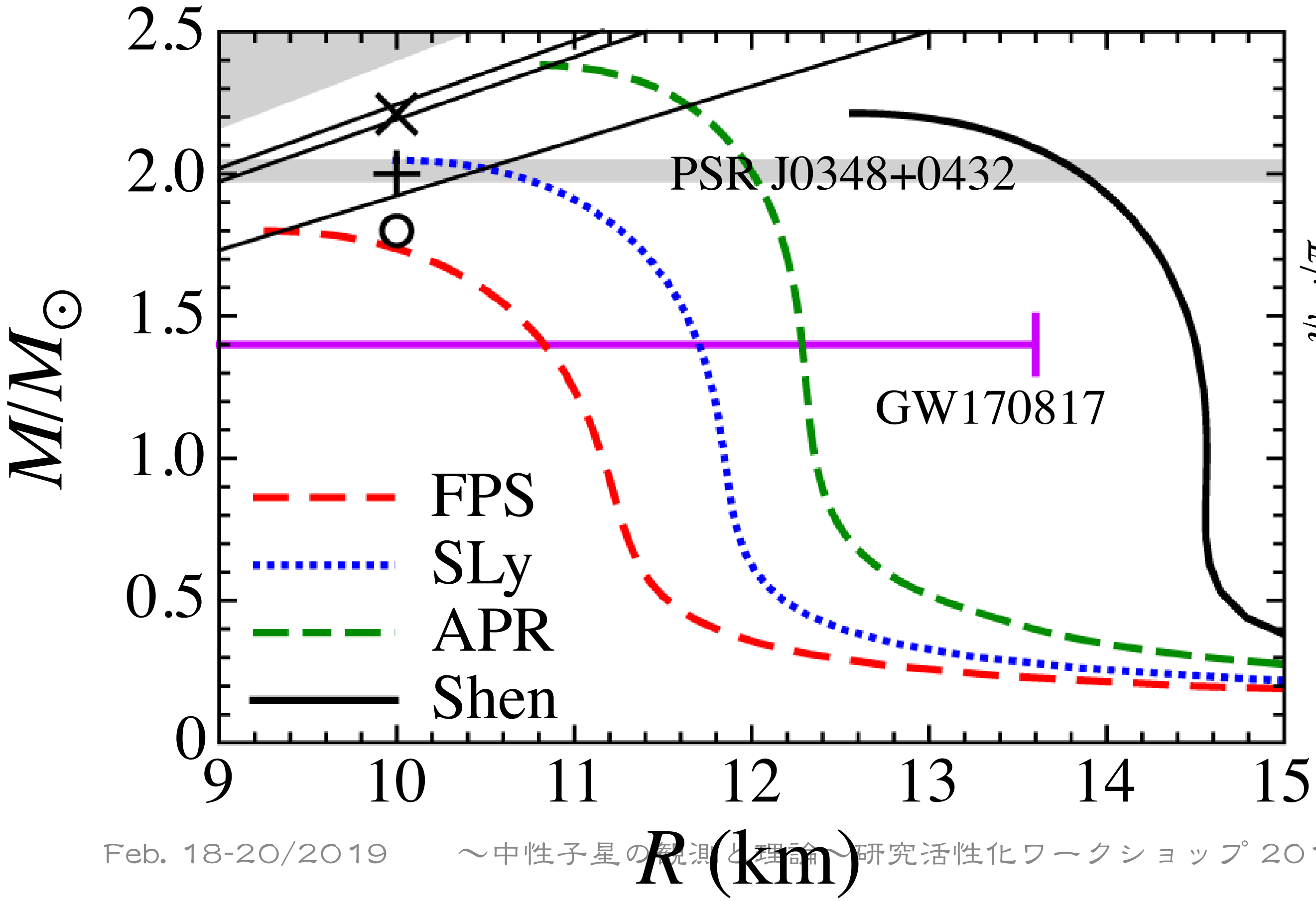


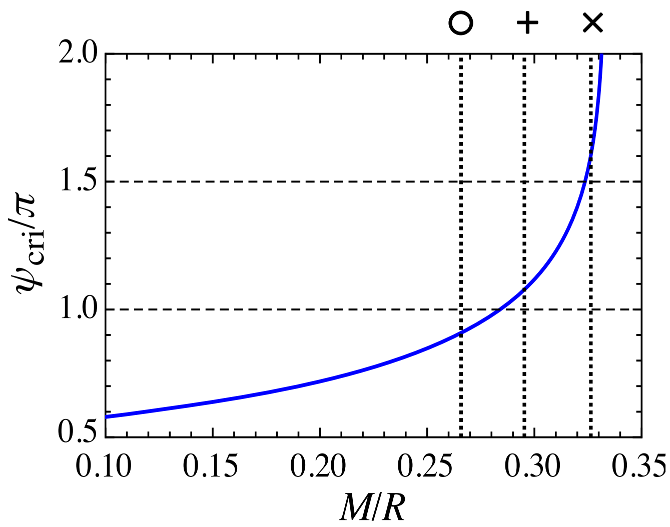
- as ψ increases, α also increases
  - at $\alpha = \pi/2$, ψ is maximum, which is denoted by ψ_{cri}
- as the gravitational field becomes stronger, ψ_{cri} increases
  - invisible zone exists, if $\psi_{cri} < \pi$
  - no invisible zone, if $\psi_{cir} > \pi$
    → multi photon paths



NS models

- we consider three NS models with M/M⊙=1.8, 2.0, & 2.21, fixing the radius to be 10 km.
  - $\psi_{\rm cri} = 0.908\pi$, $\psi_{\rm cri} = 1.078\pi$, $\psi_{\rm cri} = 1.604\pi$





pulse profile from NSs

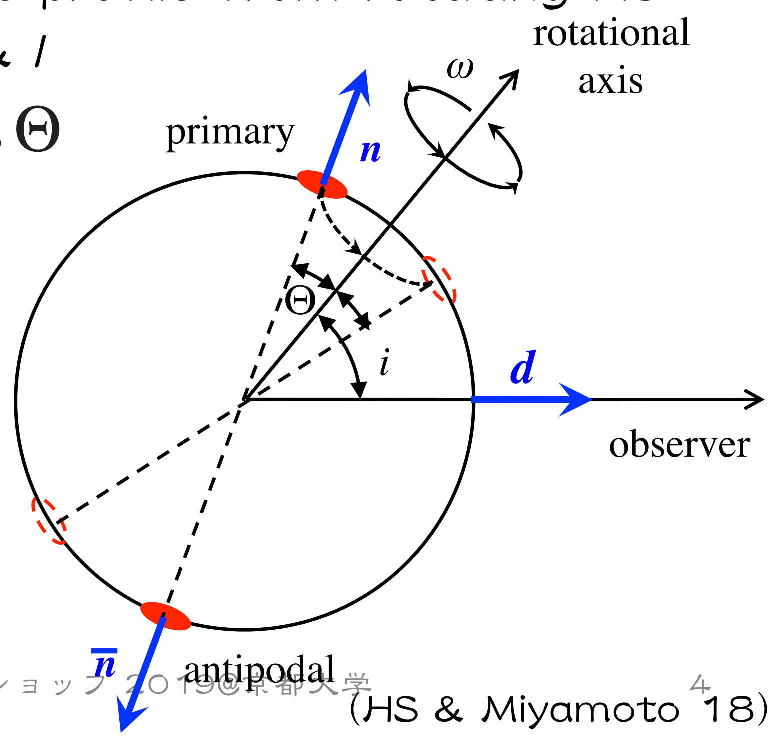
- adopting a pointlike spot approximation (Beloborocov 02),
- assuming the black body emission from the hot spot with isotropic intensity I_0
- Flux from area of $S_0 := \int dS = 4R^2 \delta\psi\delta\phi \sin\psi$: $F_*(\psi) = F_0 \sin\alpha\cos\alpha\frac{d\alpha}{d\psi}$, $F_0 := \frac{4I_0 A(R) R^2 \delta\psi\delta\phi}{D^2}$
- The observed flux: $F(\psi) = F_1 \cos\alpha \frac{d(\cos\alpha)}{d\mu}$ where $F_1 := I_0 \frac{sA(R)}{D^2}$
- Considering the observation of the pulse profile from rotating NS with angular velocity Ω with angles Θ & i

$$\mu(t) = \sin i \sin\Theta \cos(\omega t) + \cos i \cos\Theta$$

where $\mu = \cos\psi = \boldsymbol{n}_{\rm p} \cdot \boldsymbol{d}$

- observed flux from pulsar:

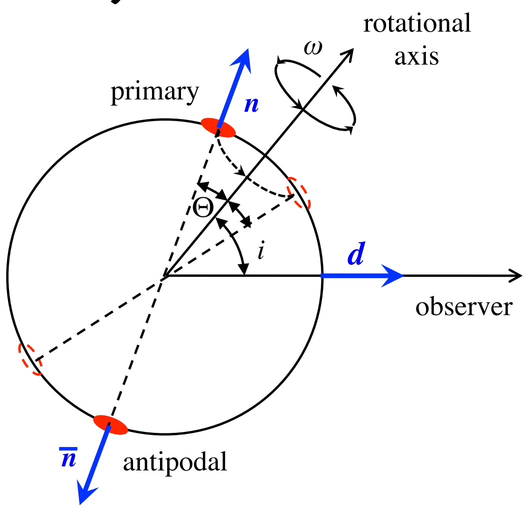
$$F_{\rm ob}(t) = F(t) + F_{\rm a}(t)$$

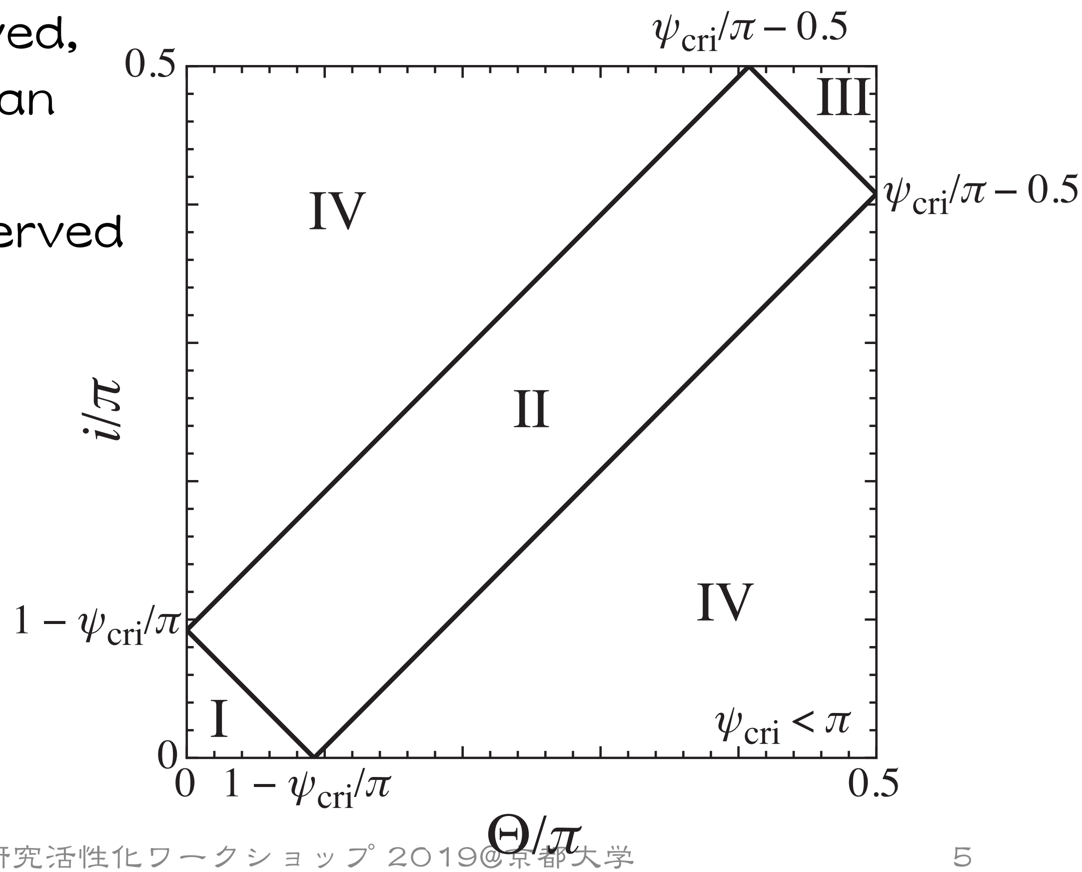


(HS & Miyamoto 18)

how to observe the hot spots: $1.8M_\odot$

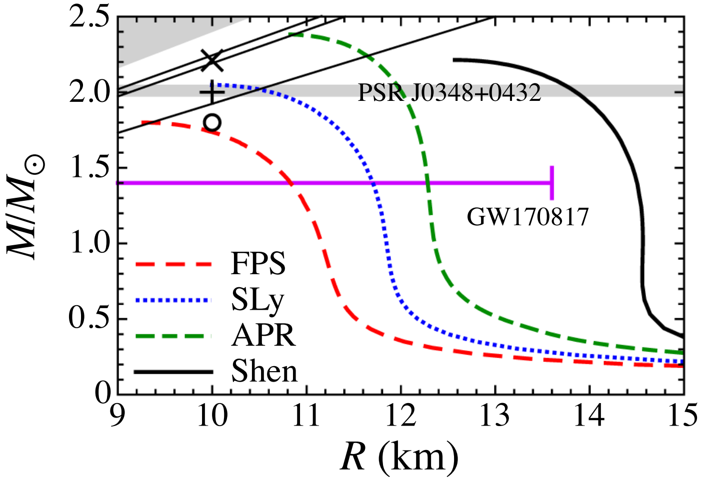
- depending on the angles Θ & *i*
  - I) only the primary spot can be observed at any time
  - II) the primary spot can be observed at any time and the antipodal spot can also be observed sometime
  - III) only the primary spot can be observed, or both spots can be observed, or only the antipodal spot can be observed
  - IV) the both stops can be observed at any time

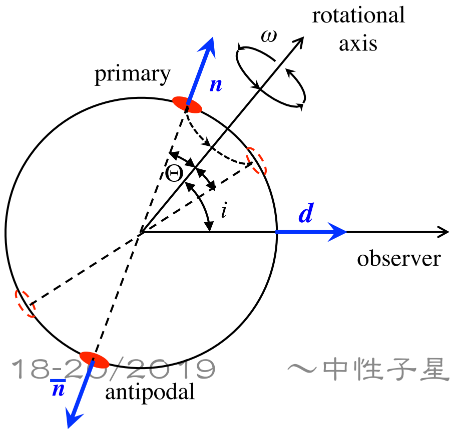


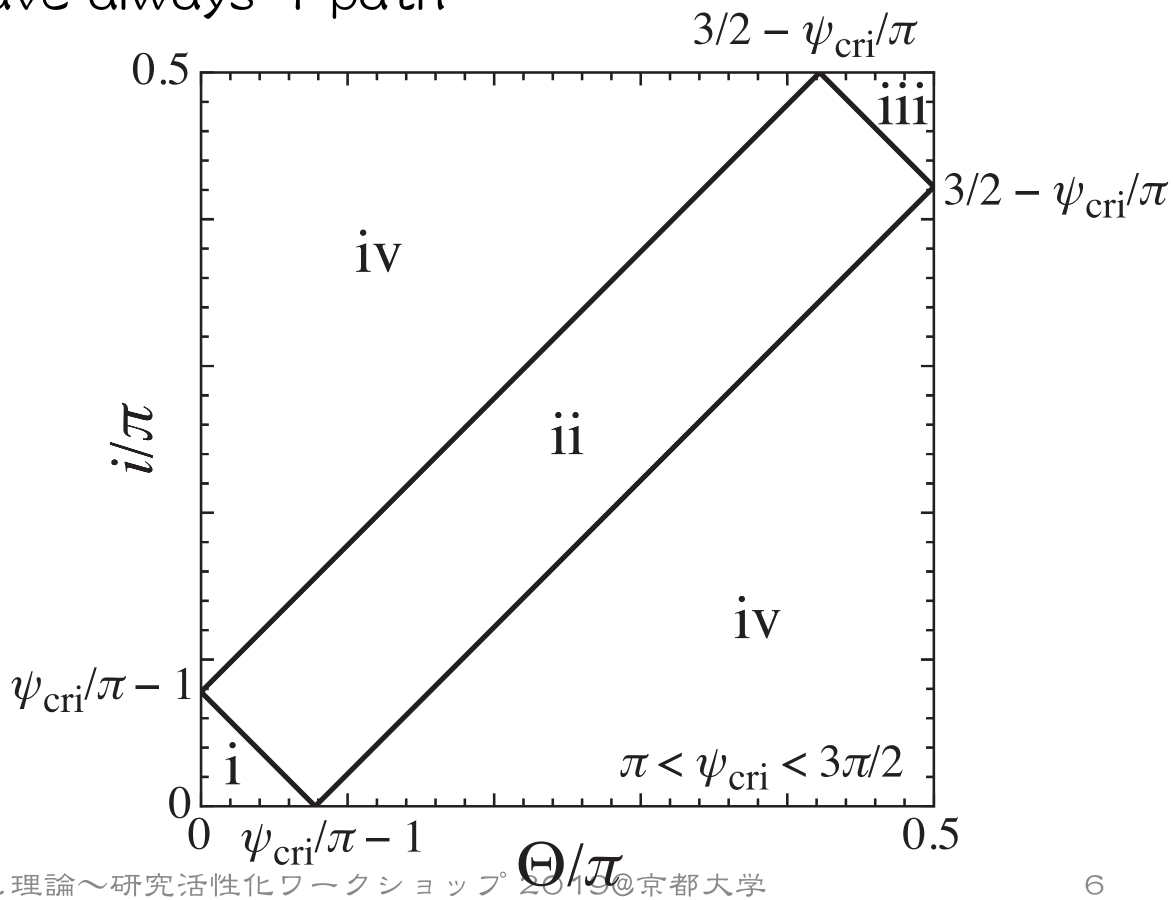


how to observe the hot spots: 2.0$M_\odot$

- depending on the angles Θ & /
  - i) the primary has always 1 path, the antipodal has always 2 paths
  - ii) the primary has always 1 path, the antipodal has sometime 2 paths
  - iii) the both have sometime 2 paths
  - iv) the both hot spots have always 1 path

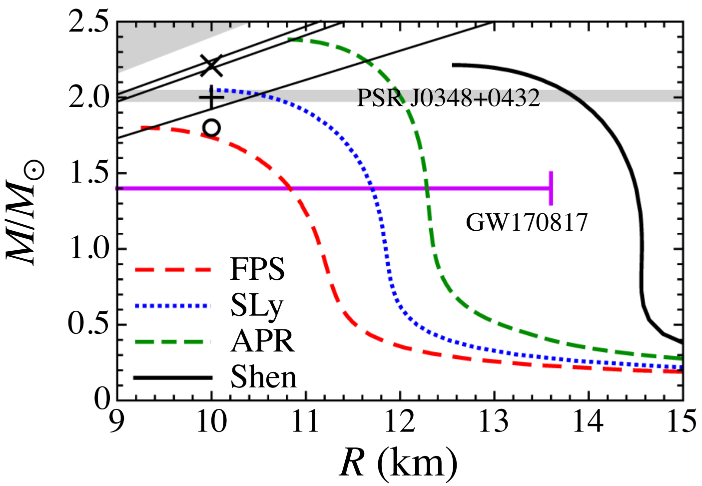


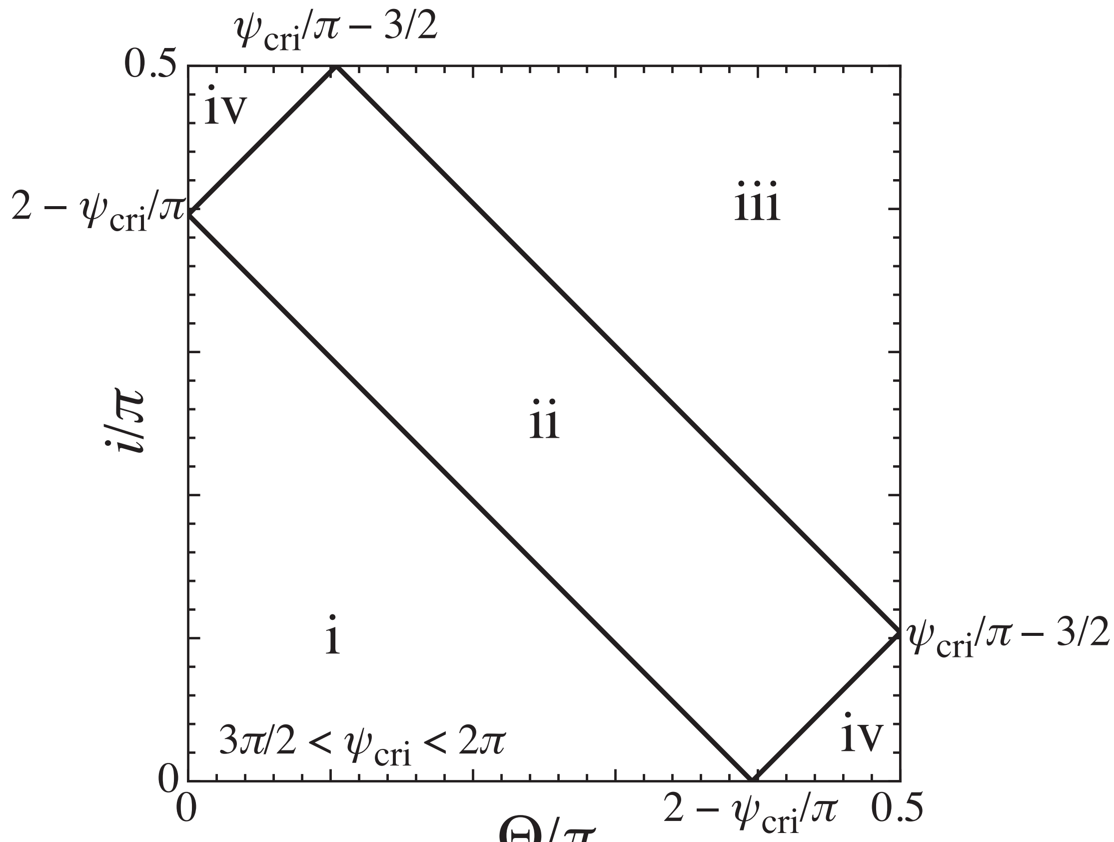




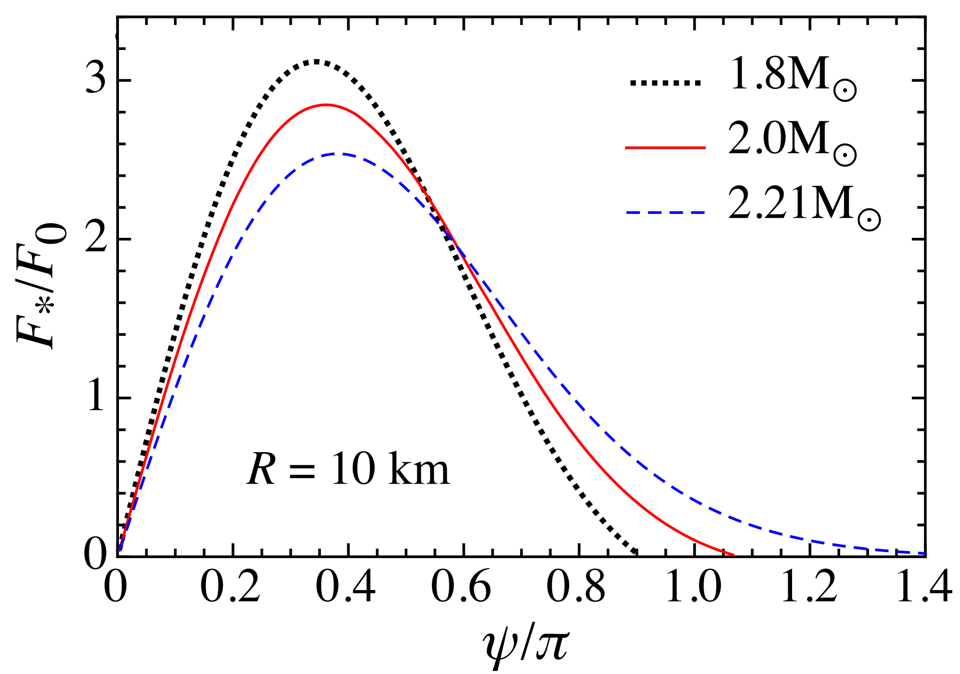
how to observe the hot spots: 2.21$M_\odot$

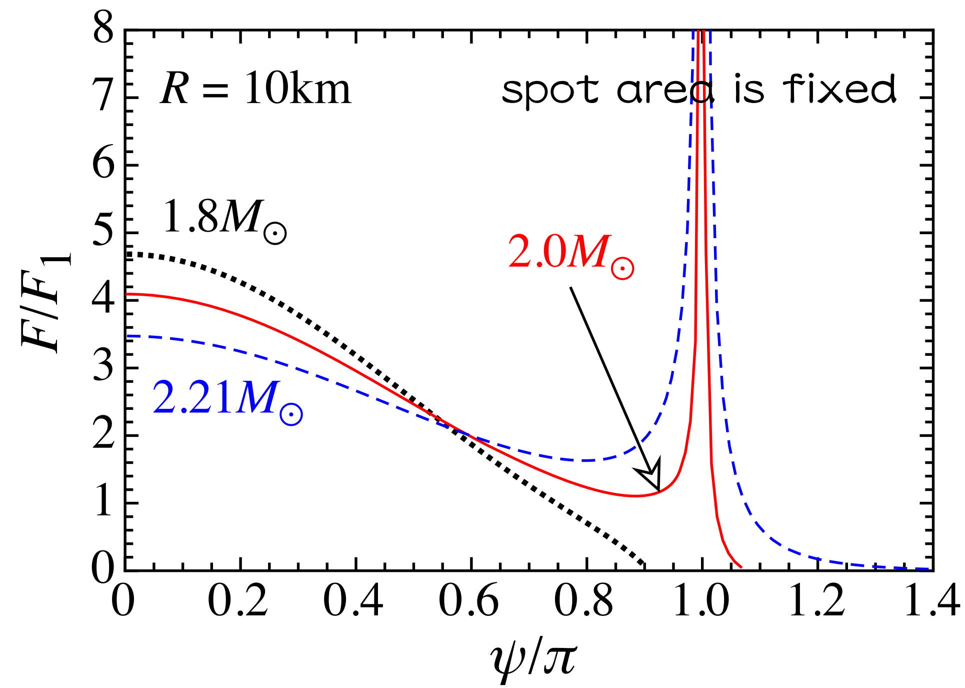
- depending on the angles Θ & i
  - i) the primary has always 1 path, the antipodal has always 2 paths
  - ii) the primary has sometime 2 paths, the antipodal has always 2 path
  - iii) the both have sometime 2 paths
  - iv) the both hot spots have always 2 paths





behavior of F/F_1, adopted (i, Θ)

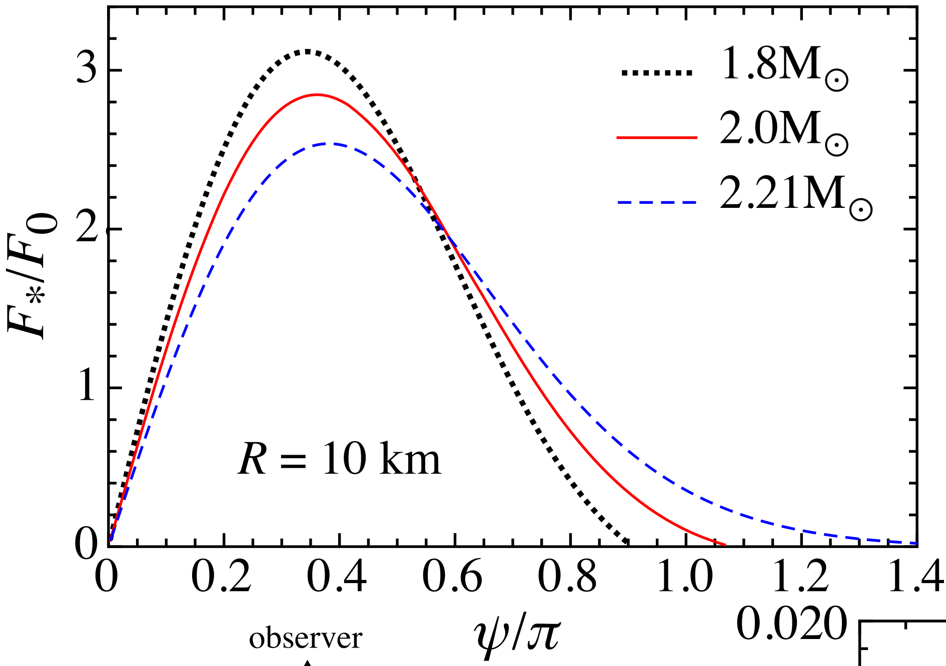


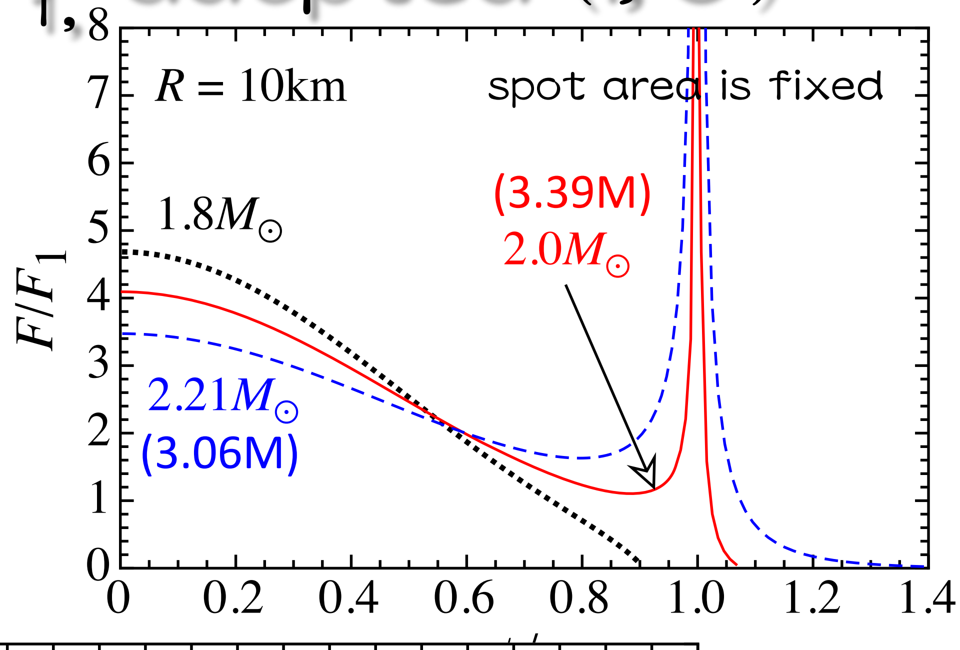


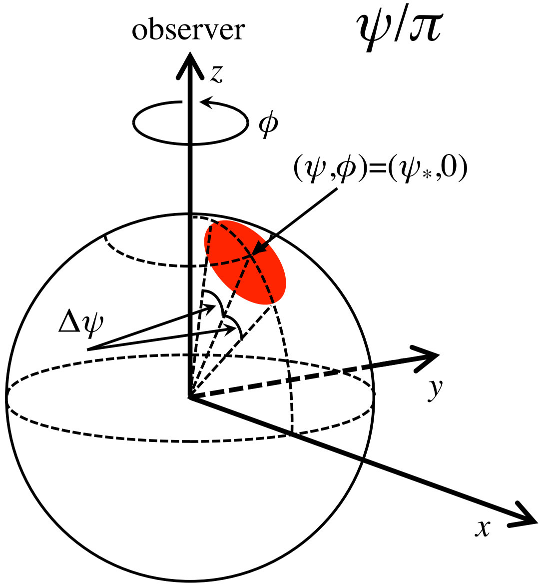
$$S_0 := \int dS = 4R^2 \delta\psi \delta\phi \sin\psi \quad F_*(\psi) = F_0 \sin\alpha \cos\alpha \frac{d\alpha}{d\psi} \quad F_0 := \frac{4I_0 A(R) R^2 \delta\psi\delta\phi}{D^2}$$

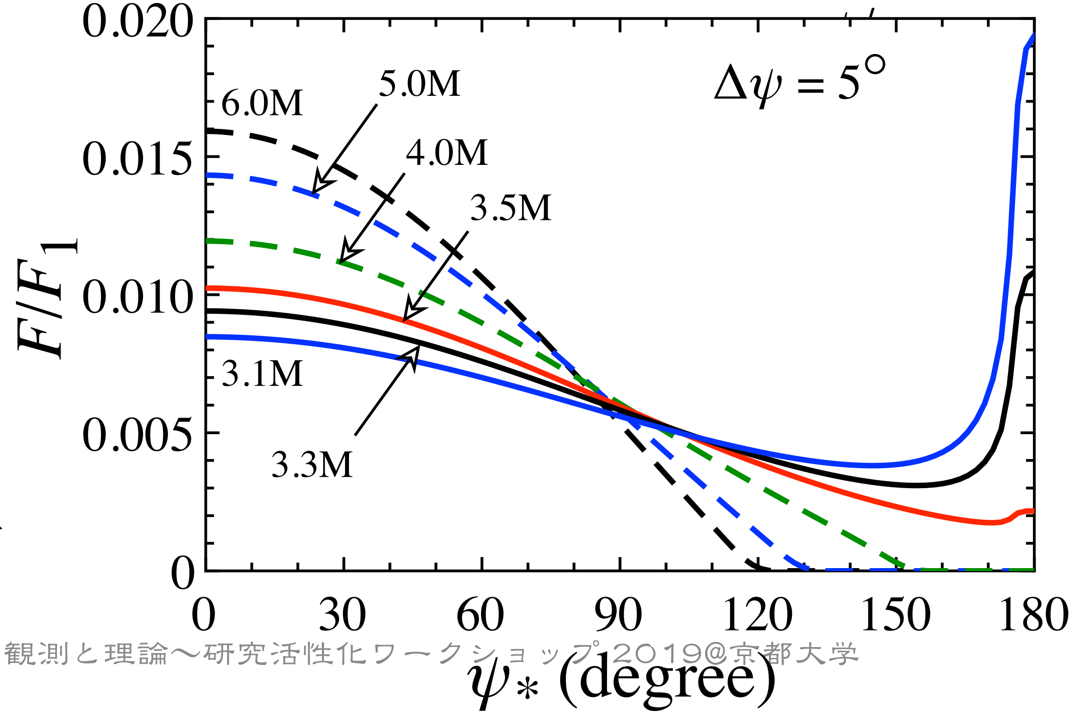
$$F(\psi) = F_1 \cos\alpha \frac{d(\cos\alpha)}{d\mu} \quad \text{where} \quad F_1 := I_0 \frac{sA(R)}{D^2}$$

behavior of F/F_1, adopted (i,Θ)

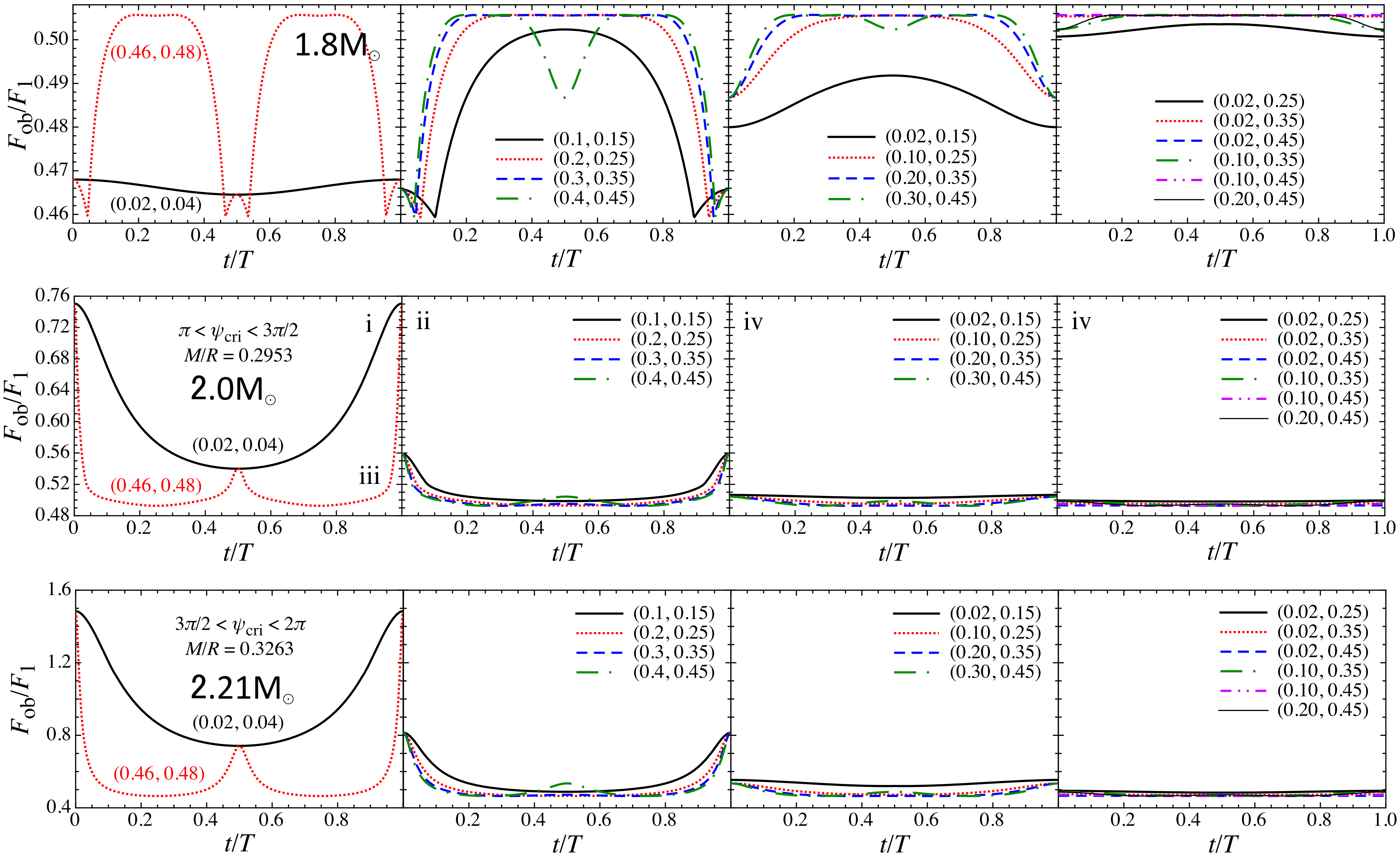






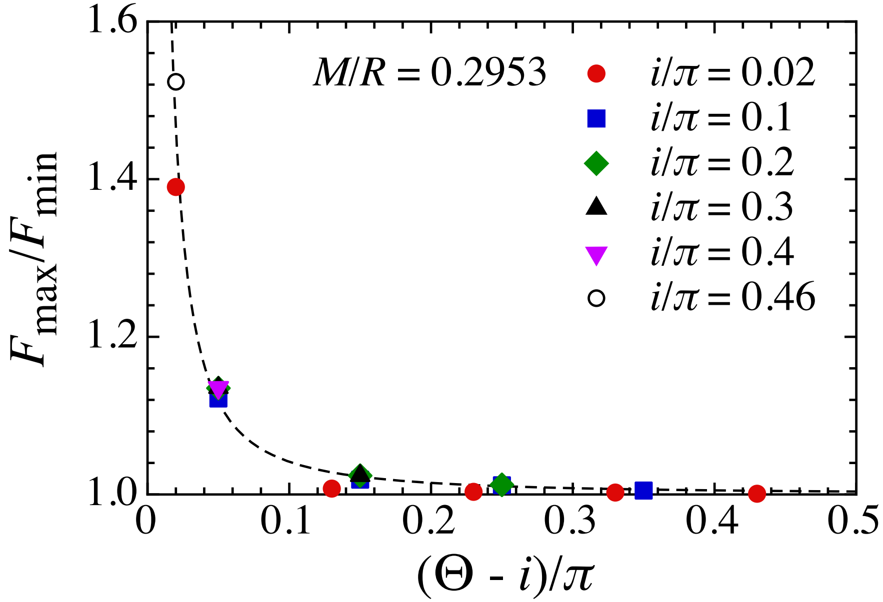


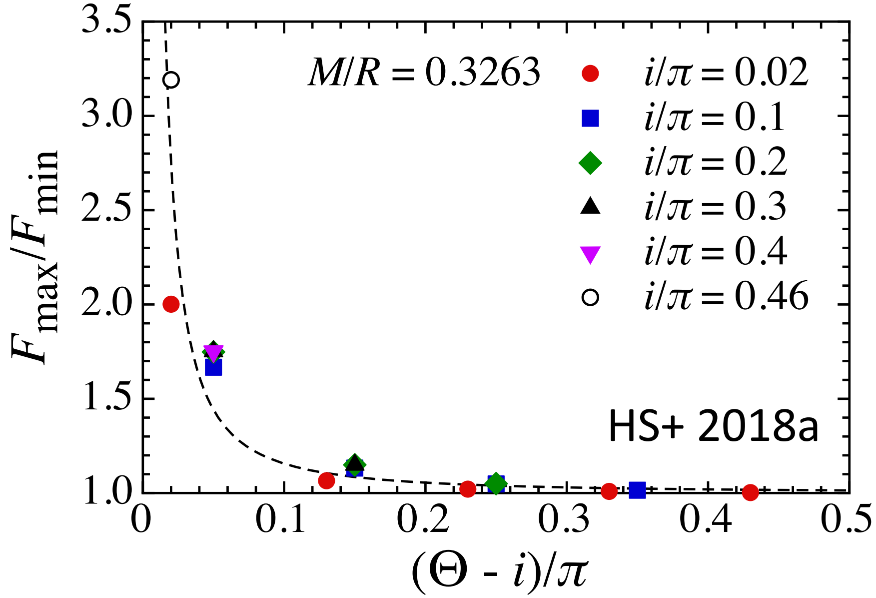
pulse profile from NSs



F_{max}/F_{min}

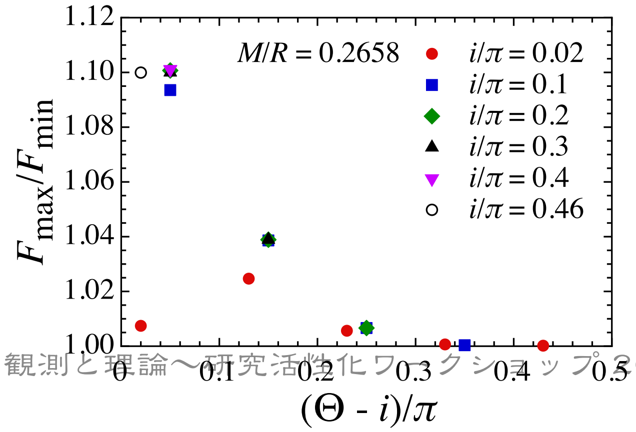
- Fmax/Fmin becomes very large for the NSs with M/R > 0.284 and for smaller (Θ - i)





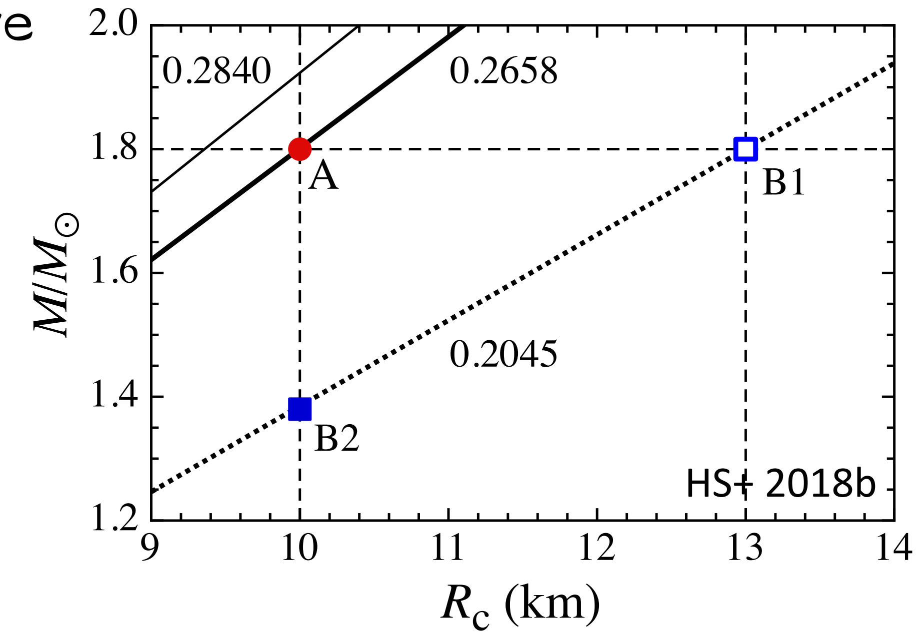
$$F_{max}/F_{min} = \frac{1.311 \times 10^{-3}}{|\Theta - i|^{3/2}} \pi^{3/2} + 1$$

$$F_{max}/F_{min} = \frac{4.935 \times 10^{-3}}{|\Theta - i|^{3/2}} \pi^{3/2} + 1$$



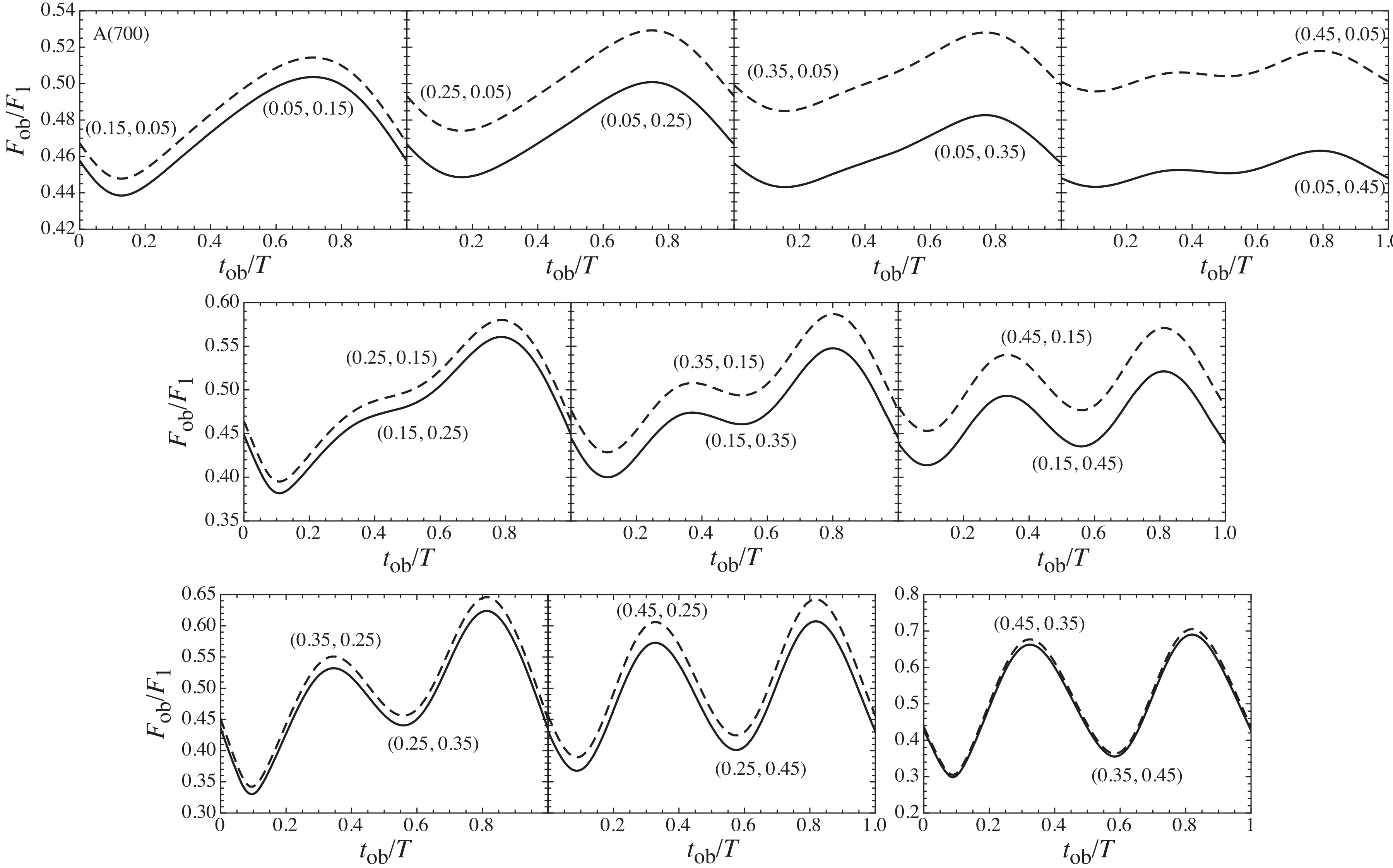
effect of rotation

- One should take into account
  - Doppler factor
  - time delay
- even though the neutron stars with the same M/R, the light curve also depends on R
- the modification of light curve
  - break the symmetry of (Θ, I)
  - break the symmety in time

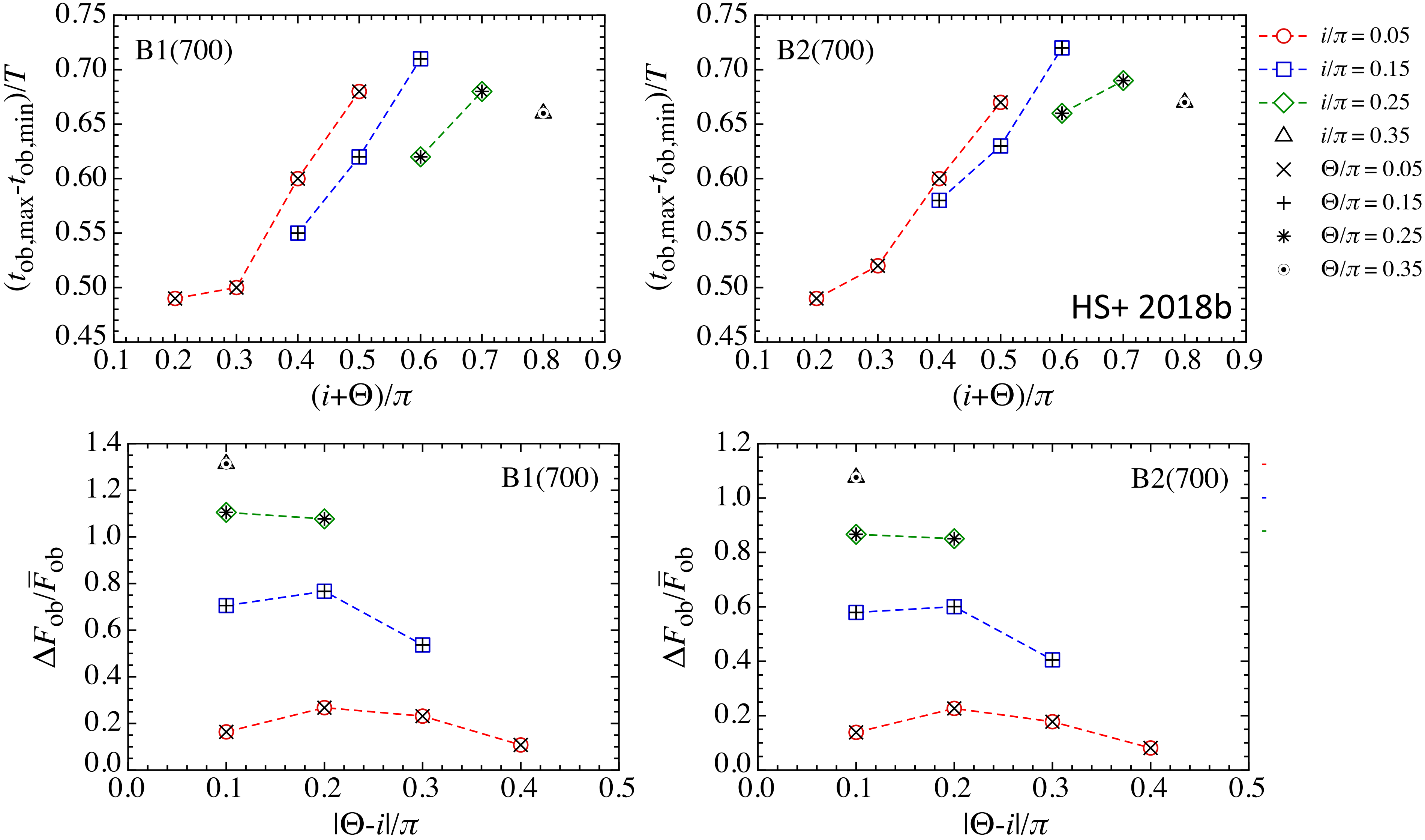


pulse profile $1.8M_\odot$

HS+ 2018b

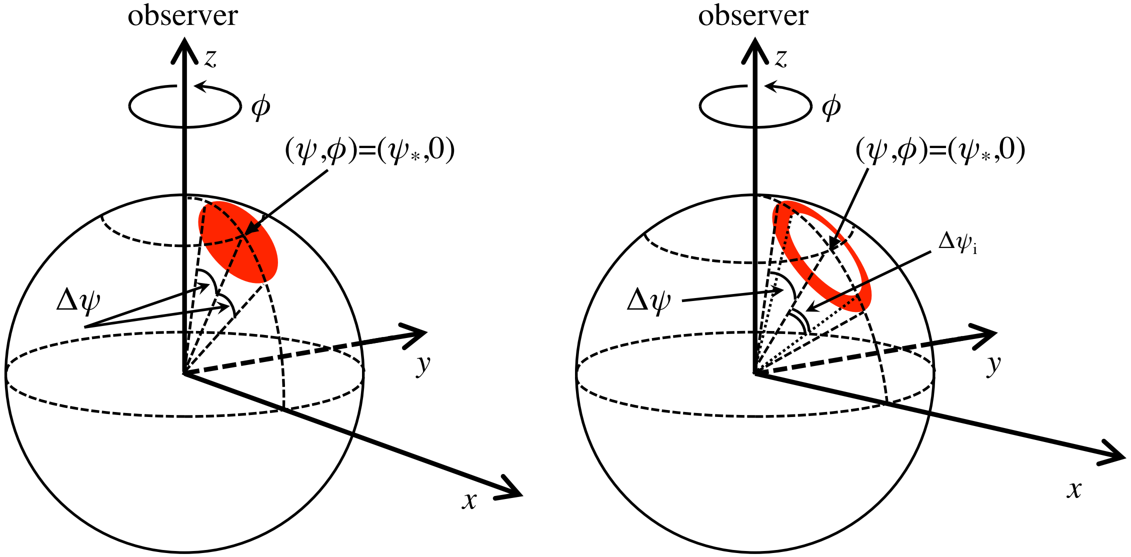


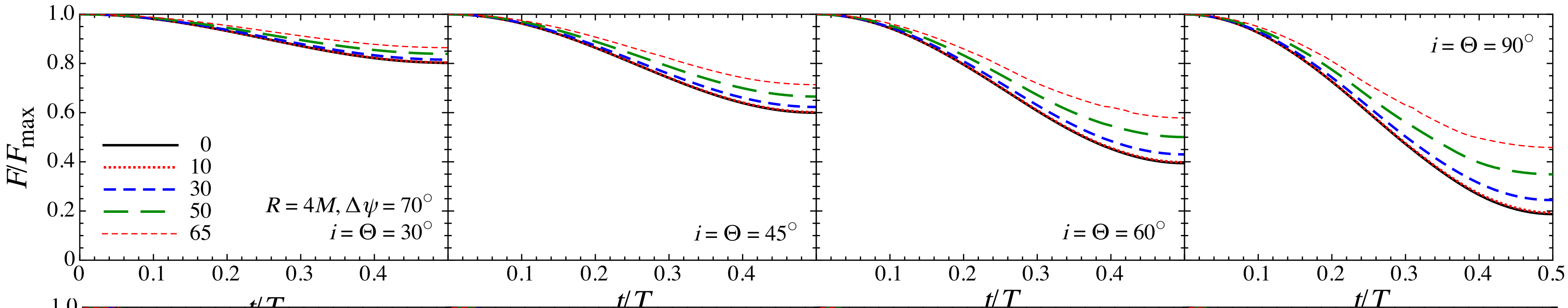
dependence on R

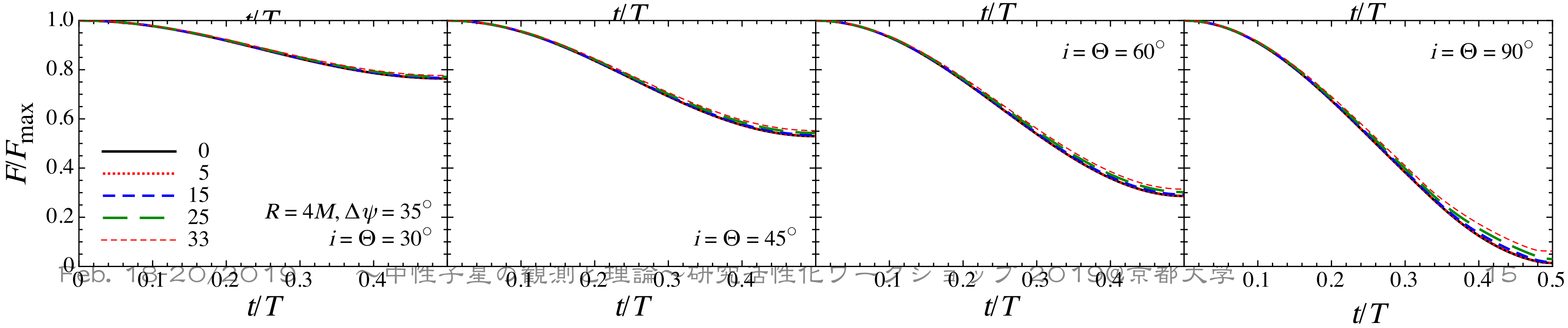


spot size effects

HS+ prep.







conclusion

- We investigate the pulse profile of highly compact rotating NS for which the bending angle exceeds $\pi/2$ ($M/R > 0.284$).
- We make a classification of the number of path from the primary and antipodal hot spots, dpending on the angles (i, Θ).
- We find that the pulse profiles of highly compact NSs are qualitatively different from those for the standard NSs.
  - In particular, F_{max}/F_{min} is significantly larger for highly compact NSs
- Light curve from a fast rotating NS depends on M/R and R.
- One would be able to constrain the EOS for NSs through the observations of pulse profiles with the help of the observational constraint on (i, Θ).