Binary comb model for FRB 121102

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2021 2/19 : Fast Radio Bursts: A Mystery Being Solved?

FRB 121102

FRB 121102 (First repeater)

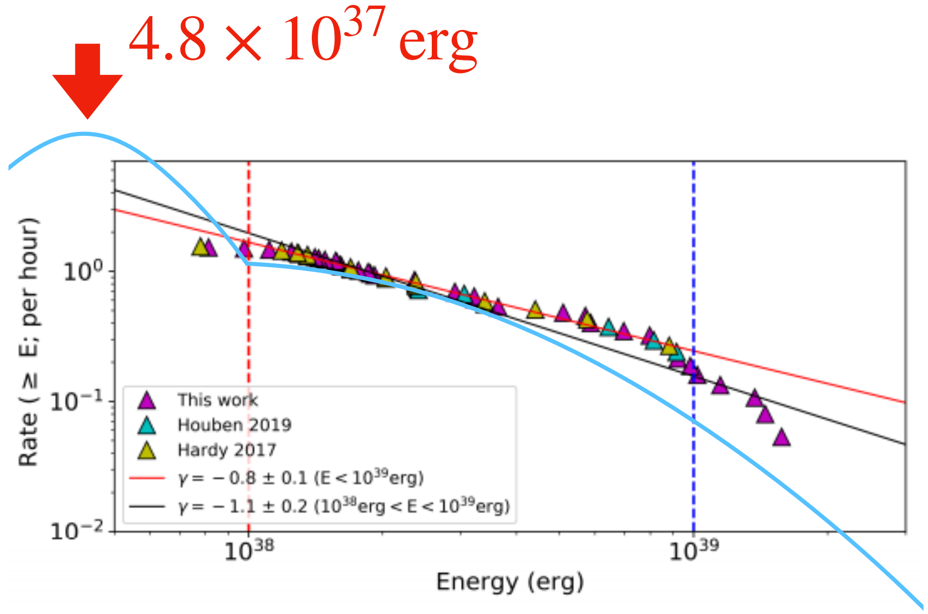
Burst energy peak $E_{\rm FRB} \sim 5 \times 10^{37}\,{\rm erg}$

${\rm DM} = 566\ {\rm cm^{-3}pc}$

$\Delta {\rm DM} \simeq 6\,{\rm cm^{-3}\,pc}$

High rotation measure

${\rm RM} = 1.46 - 1.33 \times 10^5\,{\rm rad/m^2}$



(Cruces et al. 2020)
& Di Li's talk

Host galaxy

Dwarf galaxy @$z = 0.193$ $\quad (D_L = 972\,{\rm Mpc})$

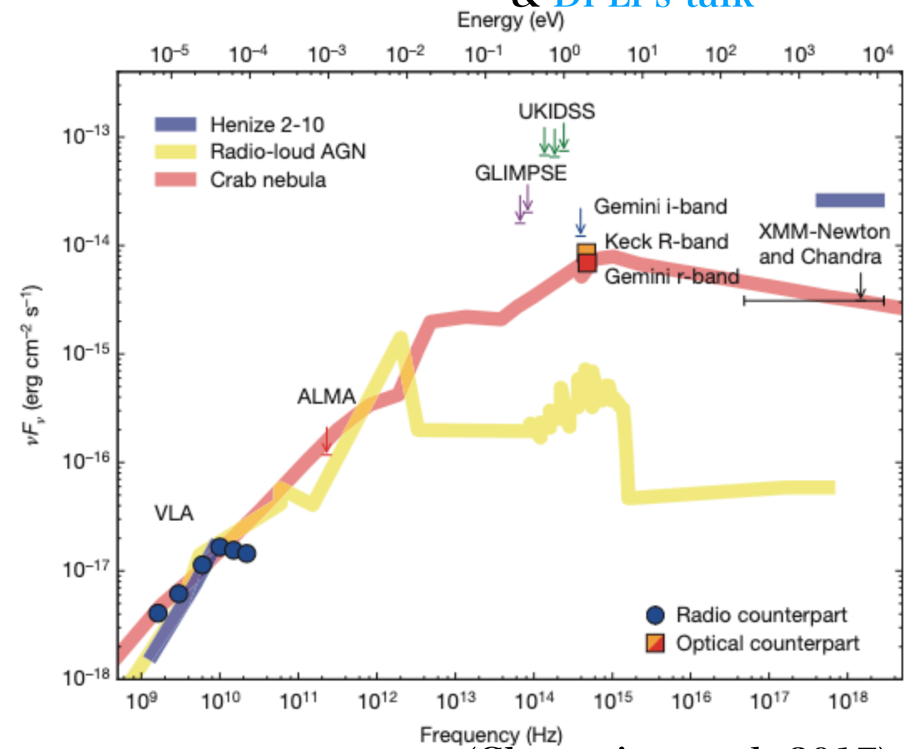
Mass $M_* \sim 4 - 7 \times 10^7 M_\odot$

Persistent radio emission

$\nu L_\nu \sim 10^{39}\,{\rm erg/s}$

size $< 0.7\,{\rm pc}$, off center

More details -> Li's talk



(Chatterjee et al. 2017)

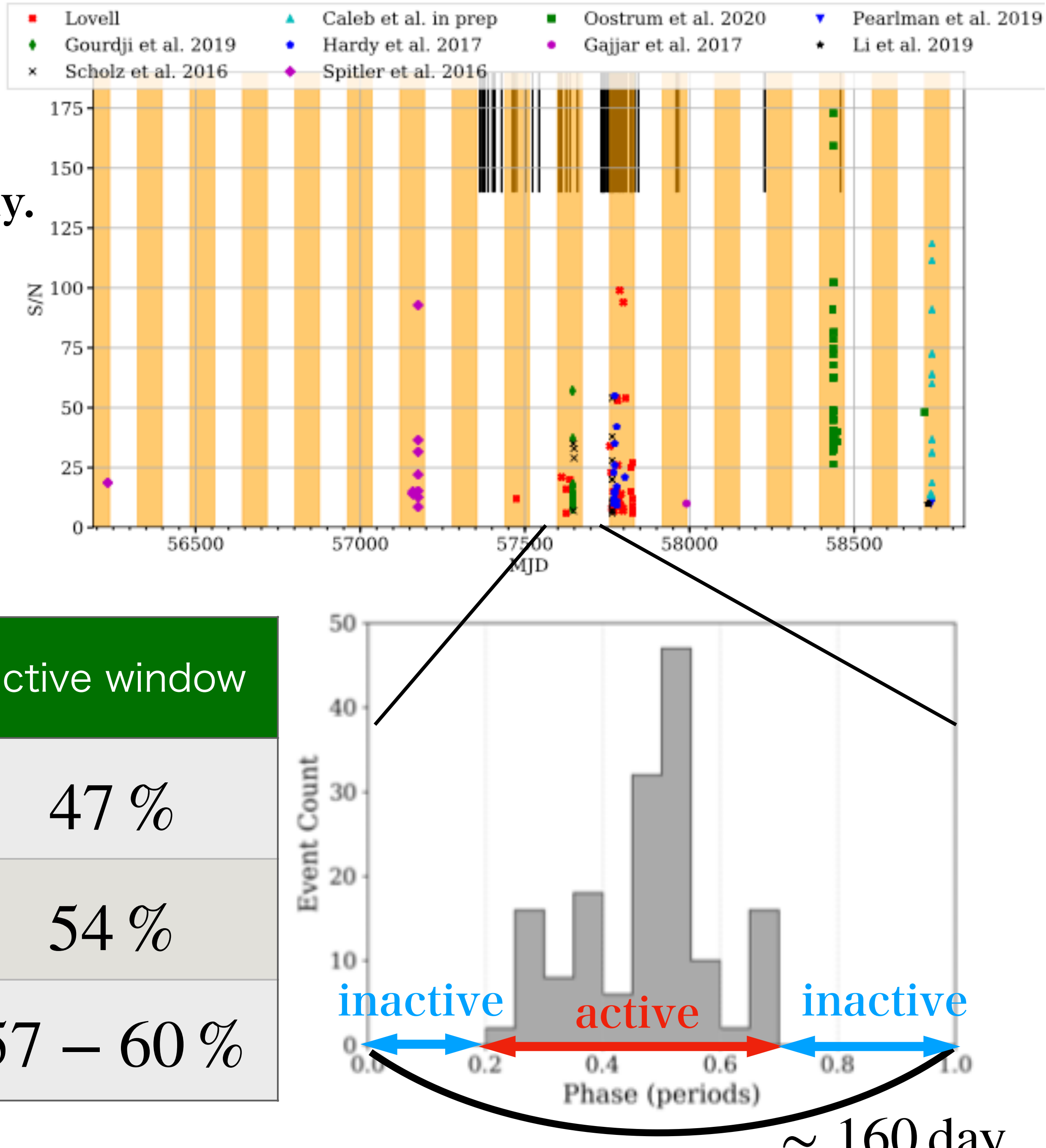
Periodicity of FRB 121102

Rajwade+ 2020

FRB 121102 shows periodic activity.

period ~ 160 day

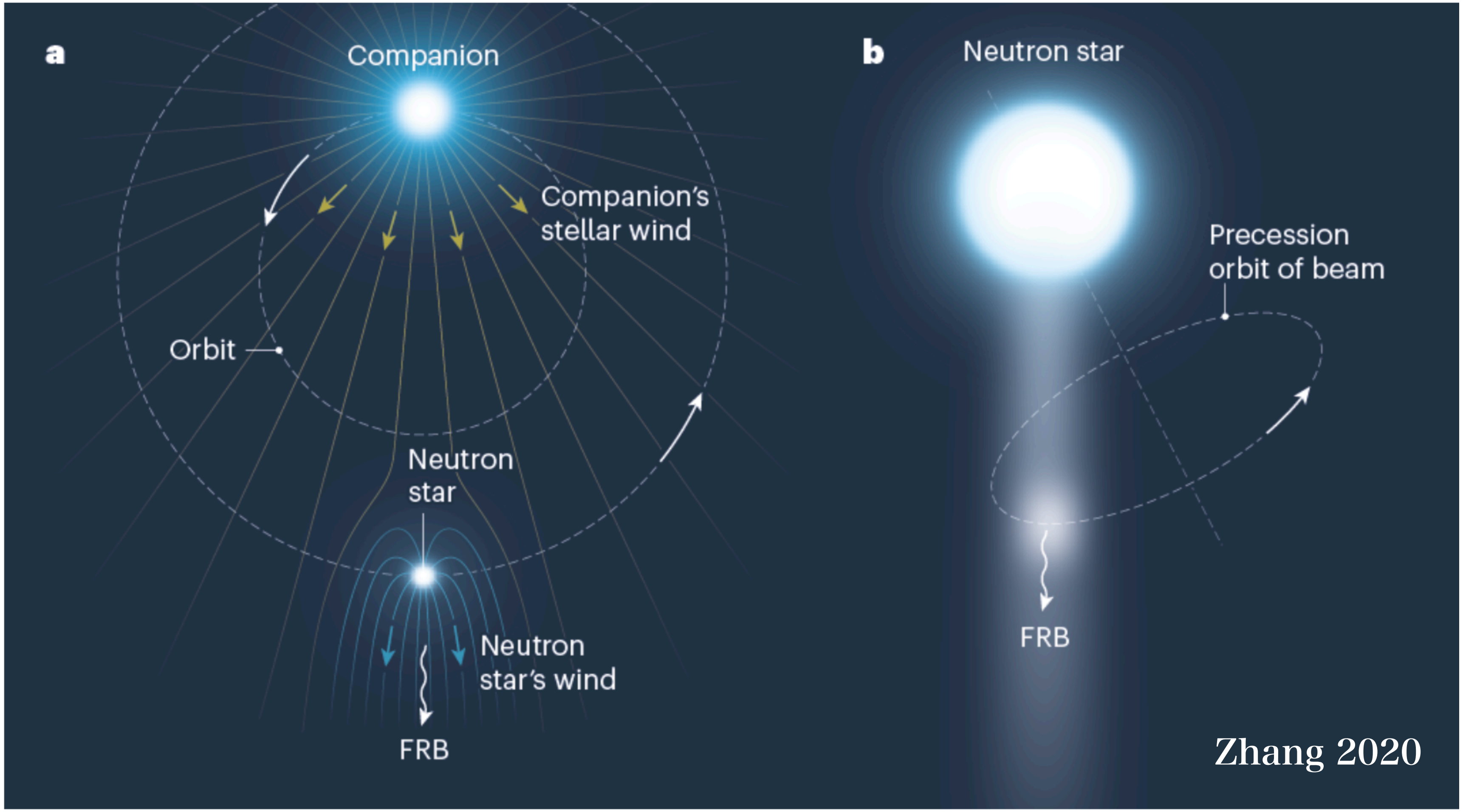
active window ~ 47 – 60 %



	period	active window
Rajwade + 2020	159^{+3}_{-8} day	47 %
Cruces + 2020	161 ± 5 day	54 %
Fast (Li's talk) 2021	157 day	57 – 60 %

Rajwade+ 2020

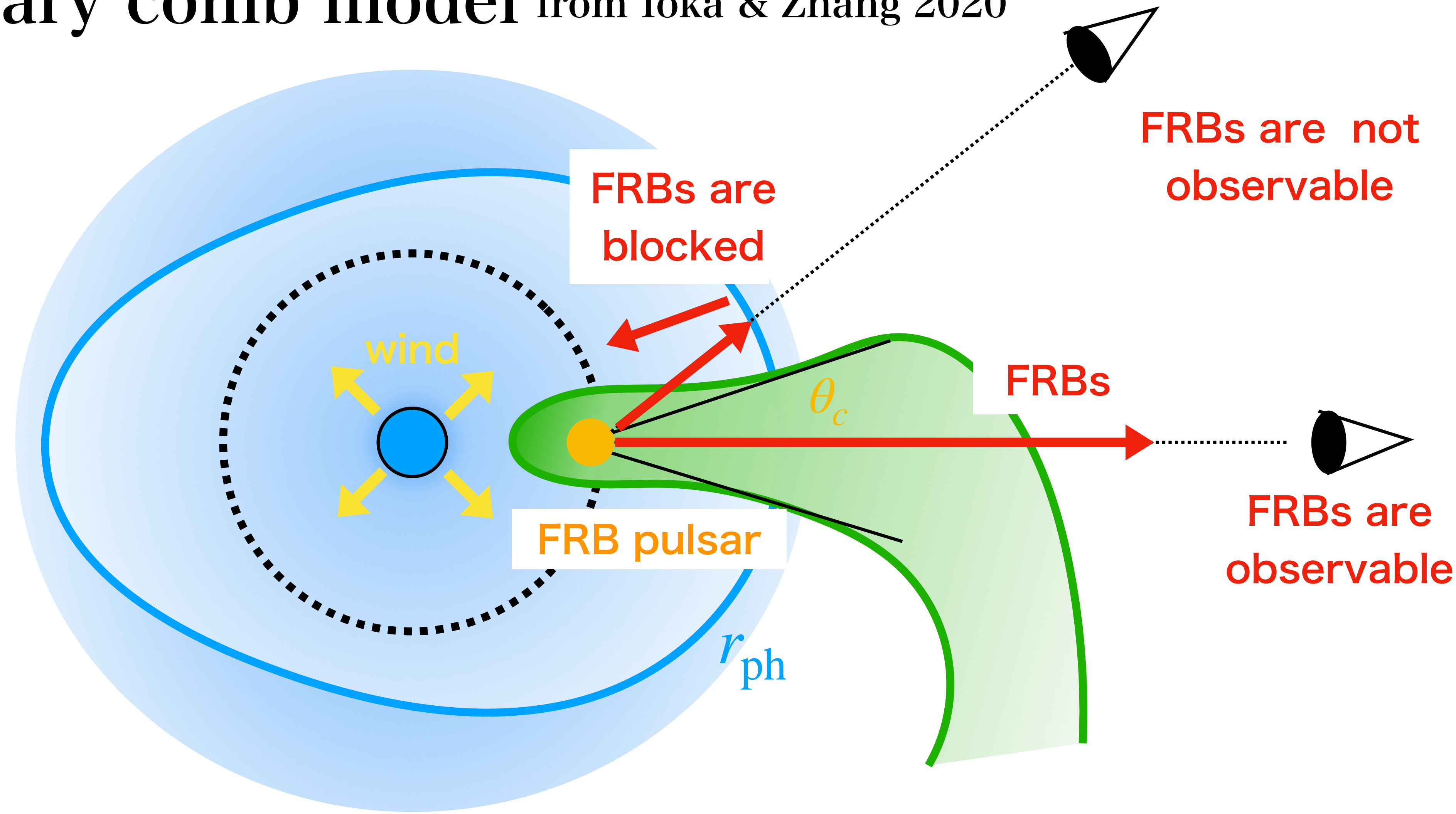
Models for periodic FRBs (FRB 180916)



The period of the FRB is due to..

- orbital period of the binary (Lyutikov+2020, Ioka & Zhang2020, Du+2020, Kuerban+2021, Deng+2021,…)
- precession period of the NS (Levin+2020, Zanazzi & Lai 2020, Yang+2020, Li & Zanazzi 2021, Sridhar+2021,…)

Binary comb model from Ioka & Zhang 2020



FRB 121102

Companion -> a massive star, a super massive BH, an intermediate-mass BH

period $\sim 160\,\mathrm{day}$ -> $a \sim 10^{13-14}\,\mathrm{cm}$

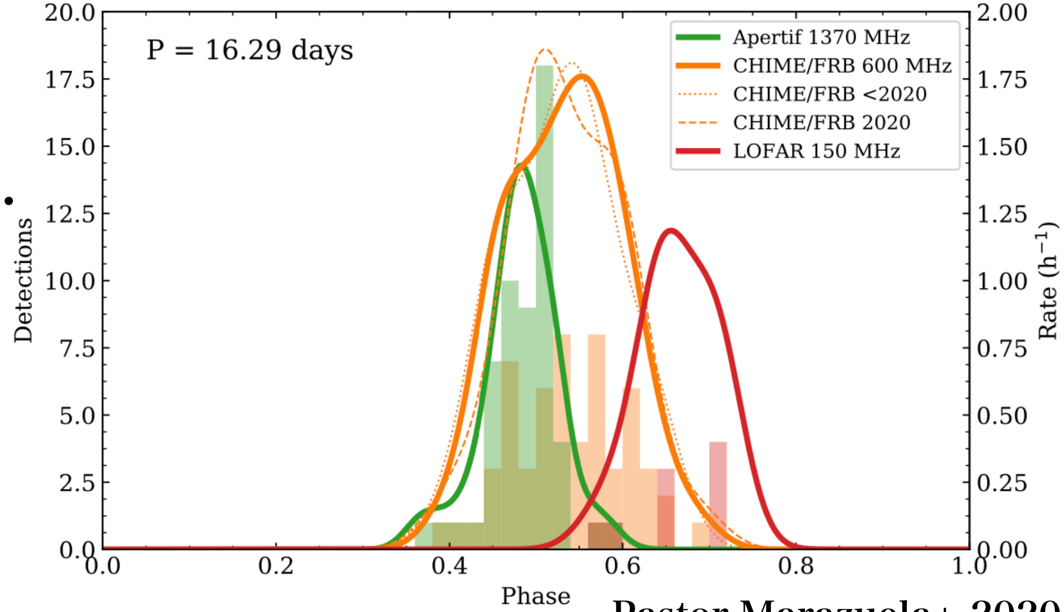
active window $\sim 47-60\,\%$ -> eccentric orbit can easily realize.

Frequency-dependence of the active window

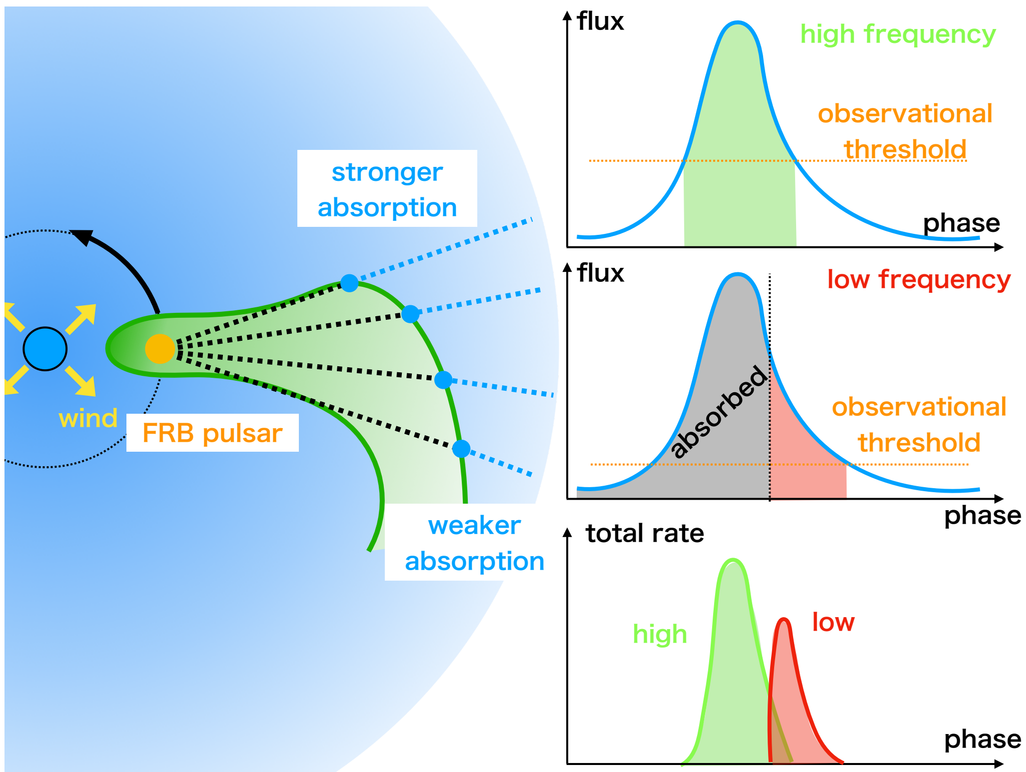
Binary comb model can explain
the frequency-dependence of FRB 180916.

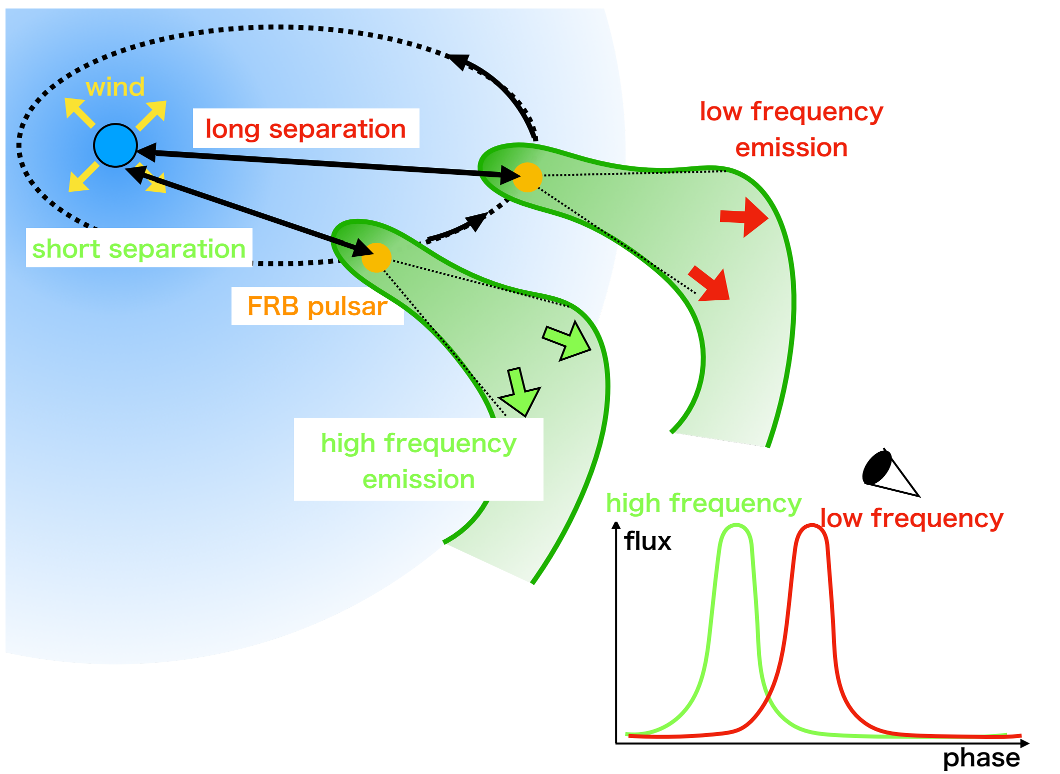
This model still alive.

I will talk about these models later.



Pastor-Marazuela+ 2020

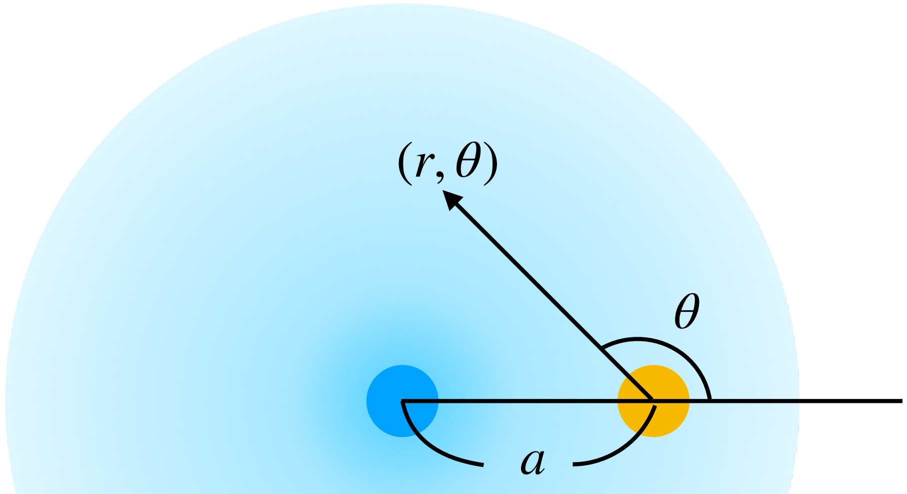




Binary systems and opacity

The optical depth of the companion wind.

Number density of the companion wind



$$n(r) = \frac{\dot{M}}{4\pi m_p V\left(r^2 + a_e^2 + 2a_e r\cos\theta\right)}$$

Thomson scattering

$$\tau_{\rm Th} \sim 6.7\times10^{-2}\left(\frac{\dot{M}}{10^{-5}M_\odot\,{\rm yr}^{-1}}\right)\left(\frac{V}{10^{-2}c}\right)^{-1}R_{13}^{-1}\begin{cases}\frac{\pi}{2}-\varphi & (\theta\neq 0,\pi)\\ (1+r/R)^{-1} & (\theta=0,\pi)\end{cases}$$

$$\sin\theta\ \tan\varphi = r/R + \cos\theta$$

Free-free absorption

$$\tau_{\rm ff}(r) \sim 1.8\times10^5 T_4^{-3/2}\nu_9^{-2}\bar{g}_{\rm ff}\left(\frac{\dot{M}}{10^{-5}M_\odot\,{\rm yr}^{-1}}\right)^2\left(\frac{V}{10^{-2}c}\right)^{-2}R_{13}^{-3}\begin{cases}\frac{1}{2\sin^3\theta}\left(\frac{\pi}{2}-\varphi-\frac{\sin 2\varphi}{2}\right) & (\theta\neq 0,\pi)\\ \frac{1}{3(1+r/R)^3} & (\theta=0,\pi)\end{cases}$$

Induced Compton scattering

$$\tau_{\rm IdC}(r) \sim 2.1\times10^4\,\nu_9^{-3}\left(\frac{\dot{M}}{10^{-5}M_\odot\,{\rm yr}^{-1}}\right)\left(\frac{V}{10^{-2}c}\right)^{-1}R_{13}^{-4}(L_{\rm FRB}\Delta t)_{38}\left[\frac{1}{x^2\left(1+x^2+2x\cos\theta\right)}\right]_{x=r/R},$$

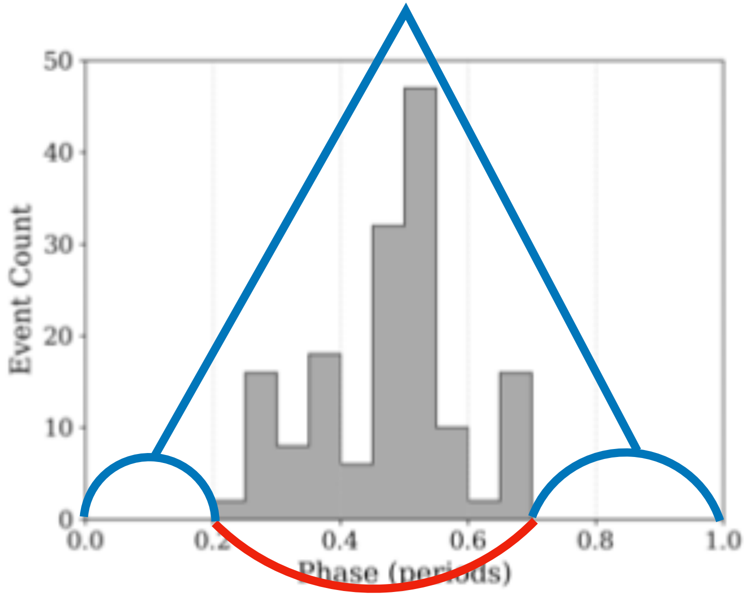
The binary is optically thick for FRBs

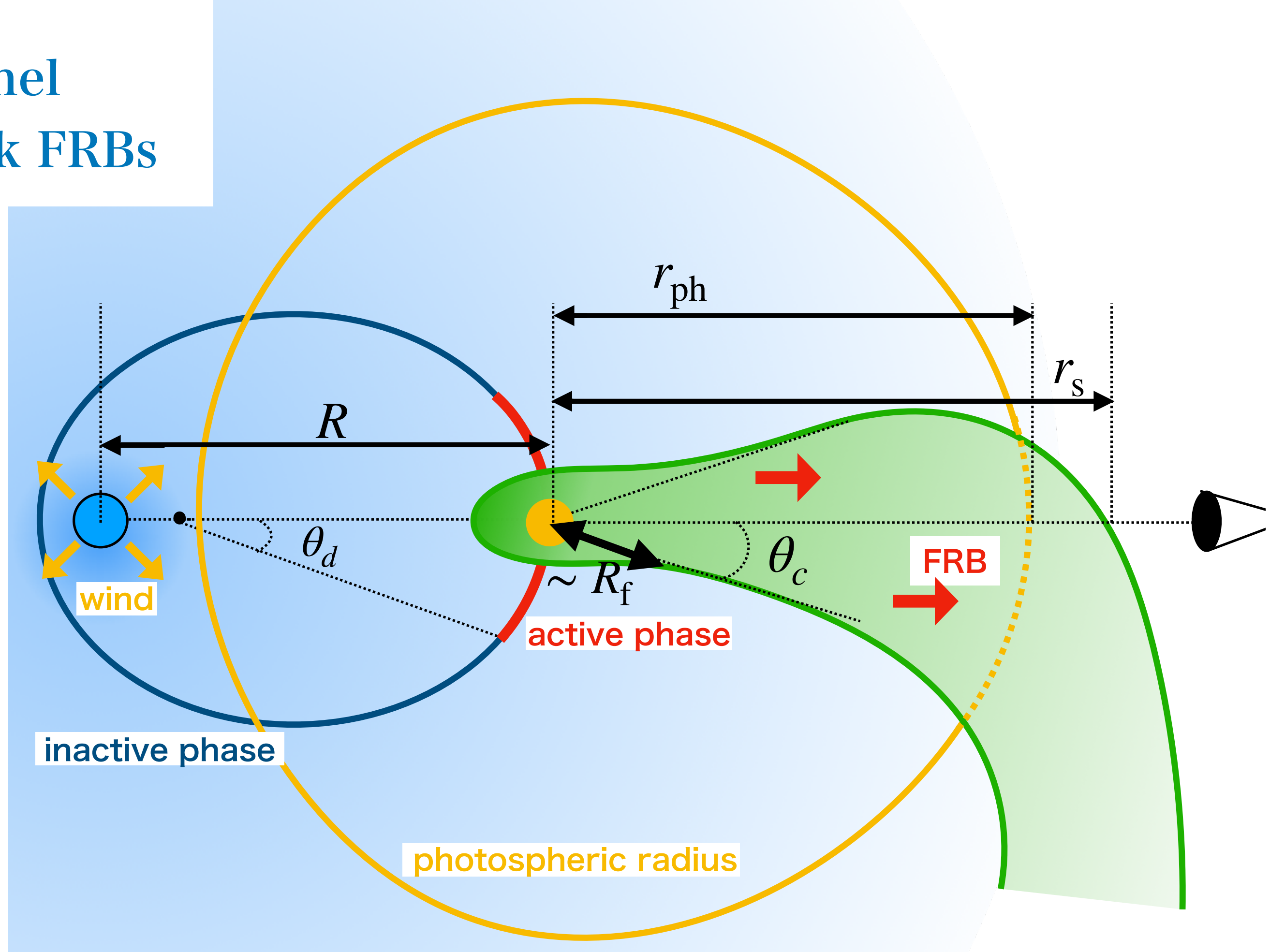
Funnel mode

Q. How the periodicity is realized in the optically thick binary?

A1. the funnel created by the FRB pulsar

Line of sight is out of the funnel
-> The companion wind block FRBs





Line of sight is in the funnel
-> Observable

Conditions for this model

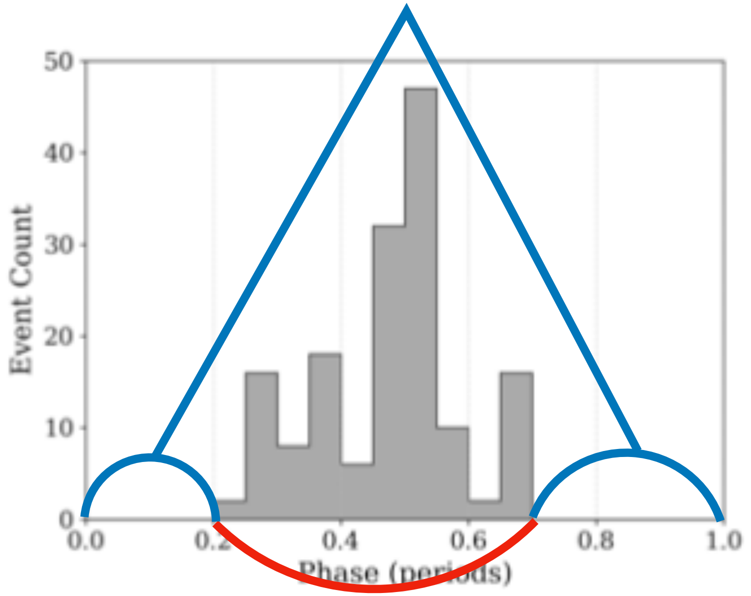
optically thick, appropriate θ_c, and $r_s > r_{ph}$

τ -crossing mode

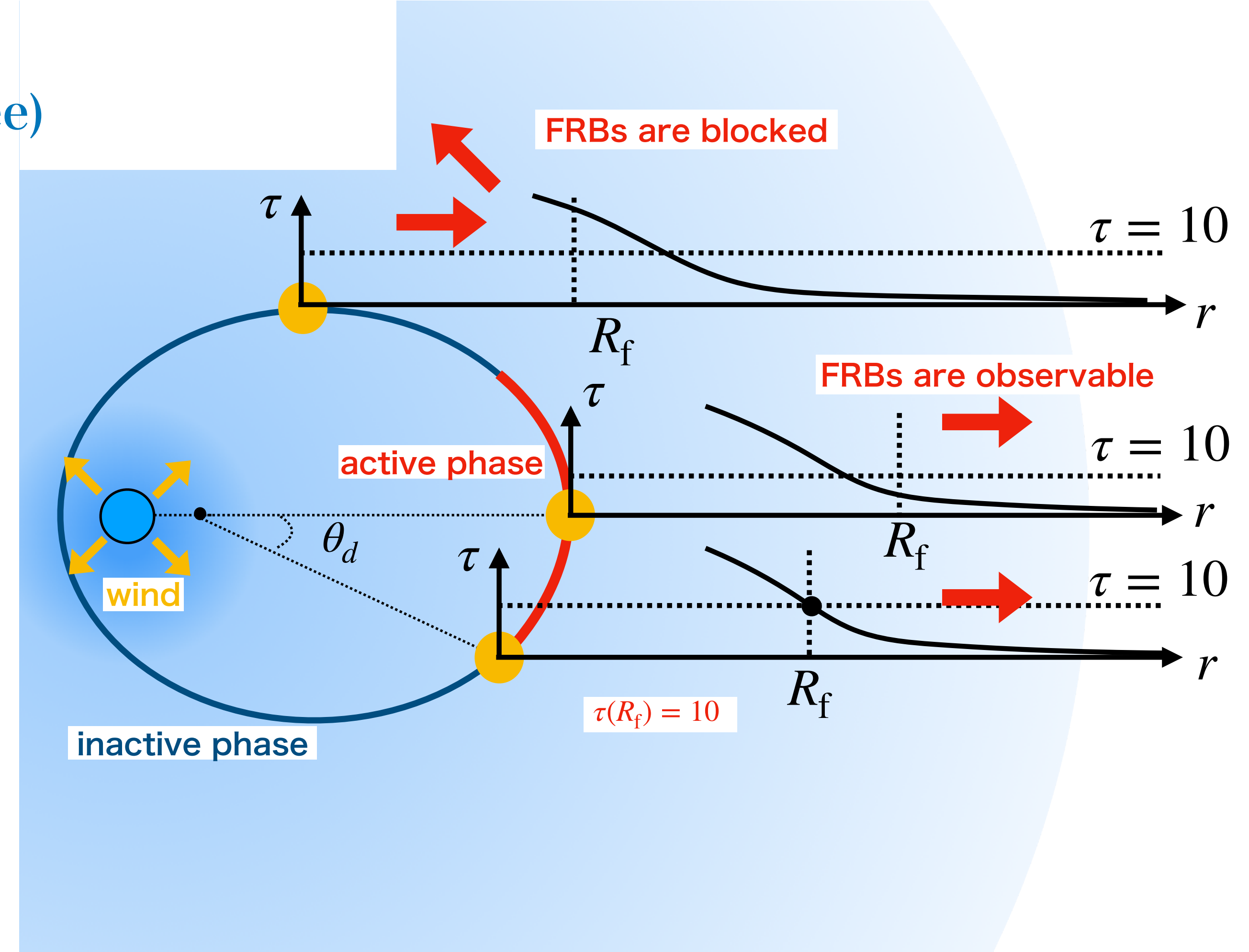
Q. How the periodicity is realized in the optically thick binary?

A2. the change of the optical depth in the orbital phase

Optically thick
(induced Compton or free-free)



Optically thin
for all scattering

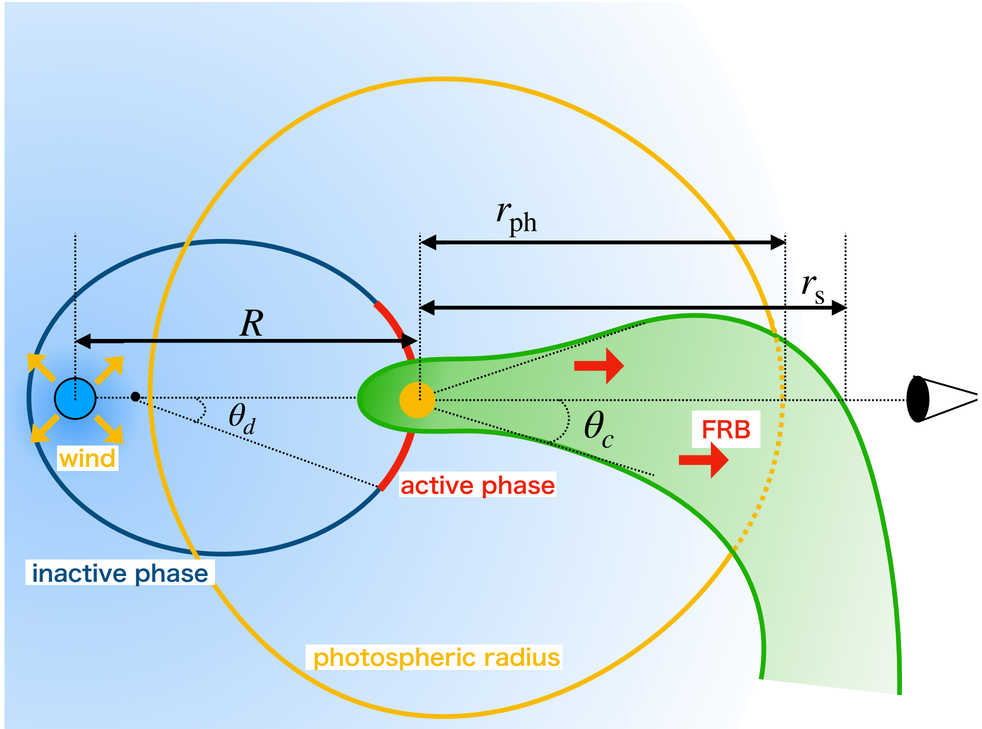


Conditions for this model

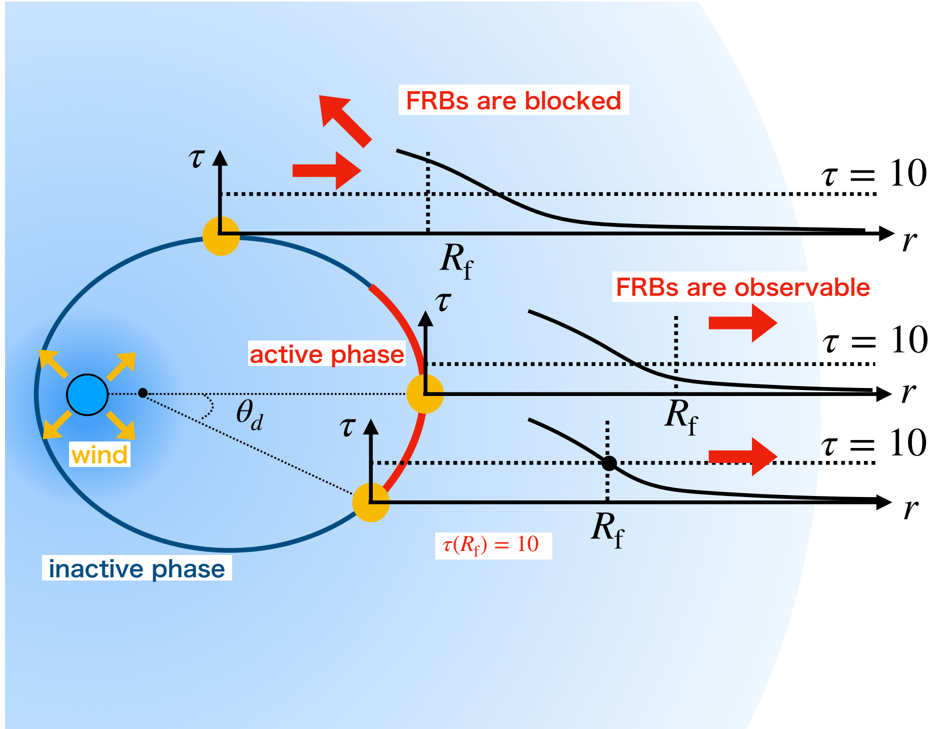
Optically thin@ active phase, thick@ inactive phase

Binary comb model for FRB 121102

Funnel mode



τ-crossing mode



Q. What binary is possible as a source of FRB 121102?

For given companion mass, and wind velocity,

What wind luminosity of FRB pulsar & mass-loss rate of the companion are possible

We used

period $\sim 160\,\mathrm{day}$, active window $\sim 47\,\%$, change in DM $\Delta\mathrm{DM} < 6\,\mathrm{cm}^{-3}\,\mathrm{pc}$,

persistent radio emission $L \sim 10^{39}\,\mathrm{erg/s}$, and burst energy $L_{\mathrm{FRB}}\Delta t = 5\times10^{37}\,\mathrm{erg\,s^{-1}}$.

Supermassive black hole companion

$M_c = 10^5 M_\odot$

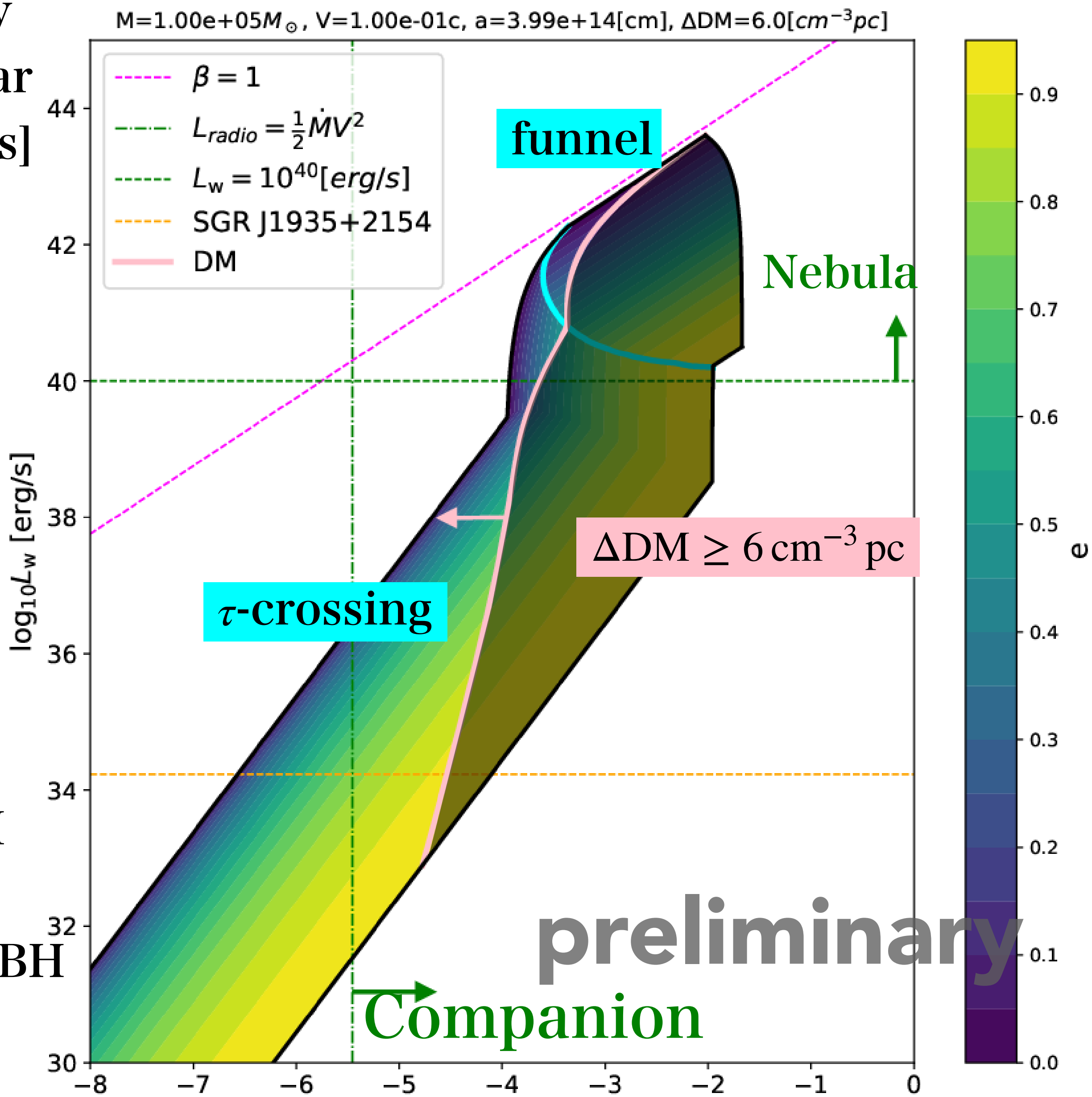
$V = 0.1c$

$a = 4 \times 10^{14}\,\mathrm{cm}$

Persistent radio emission
-> Powered by the SMBH ?
like AGNs

Change in the DM & the high RM
-> The variation of the disk wind
& high magnetic field near SMBH

Wind luminosity of the FRB pulsar [erg/s]



Mass-loss rate of the companion $[M_\odot/\mathrm{yr}]$

Massive star companion

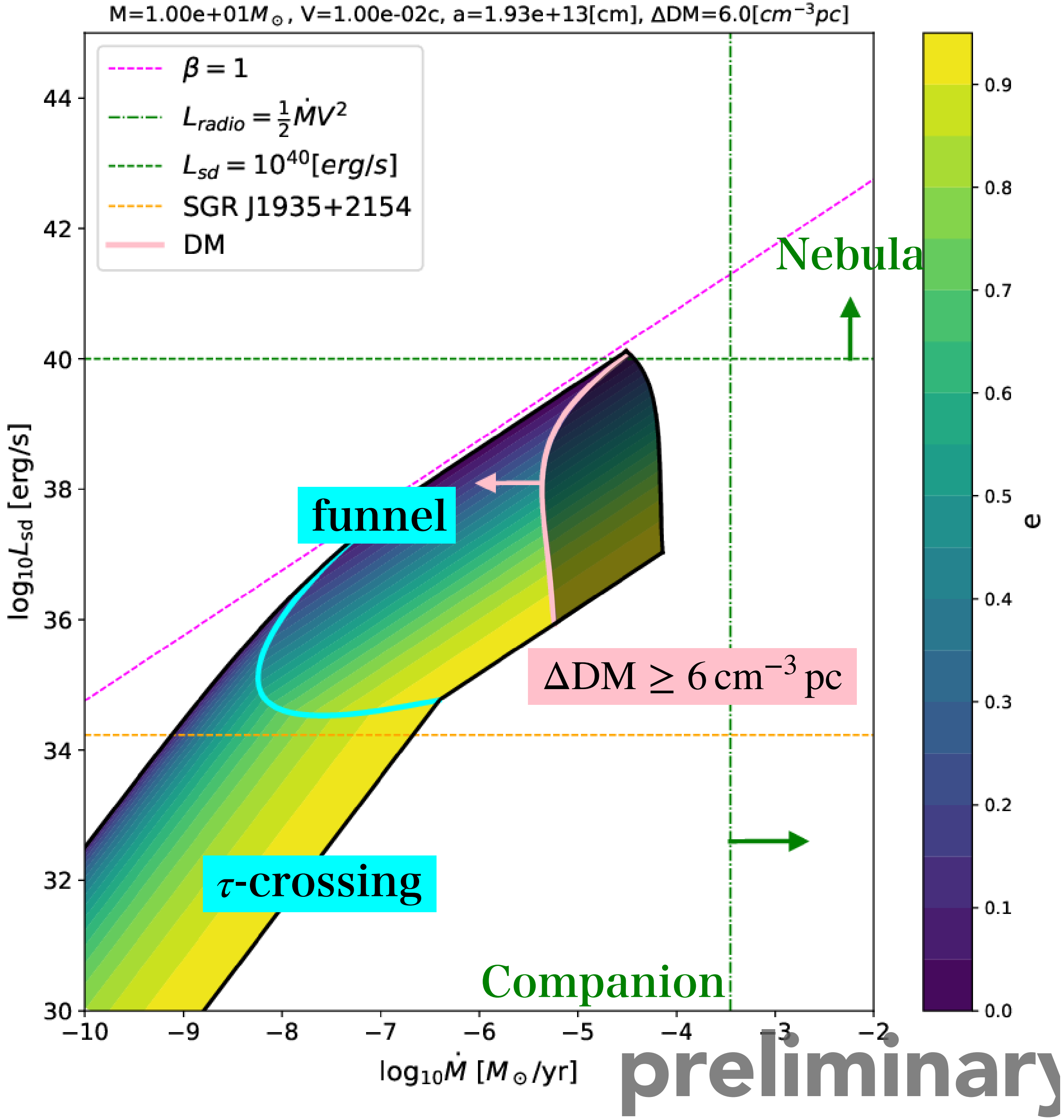
$M_c = 10 M_\odot$

$V = 0.01c$

$a = 2 \times 10^{13}$ cm

Persistent radio emission is not as luminous as FRB 121102.

The massive star companion $\neq$ The source of FRB 121102



Intermediate-mass black hole

$M_c = 10^3 M_\odot$

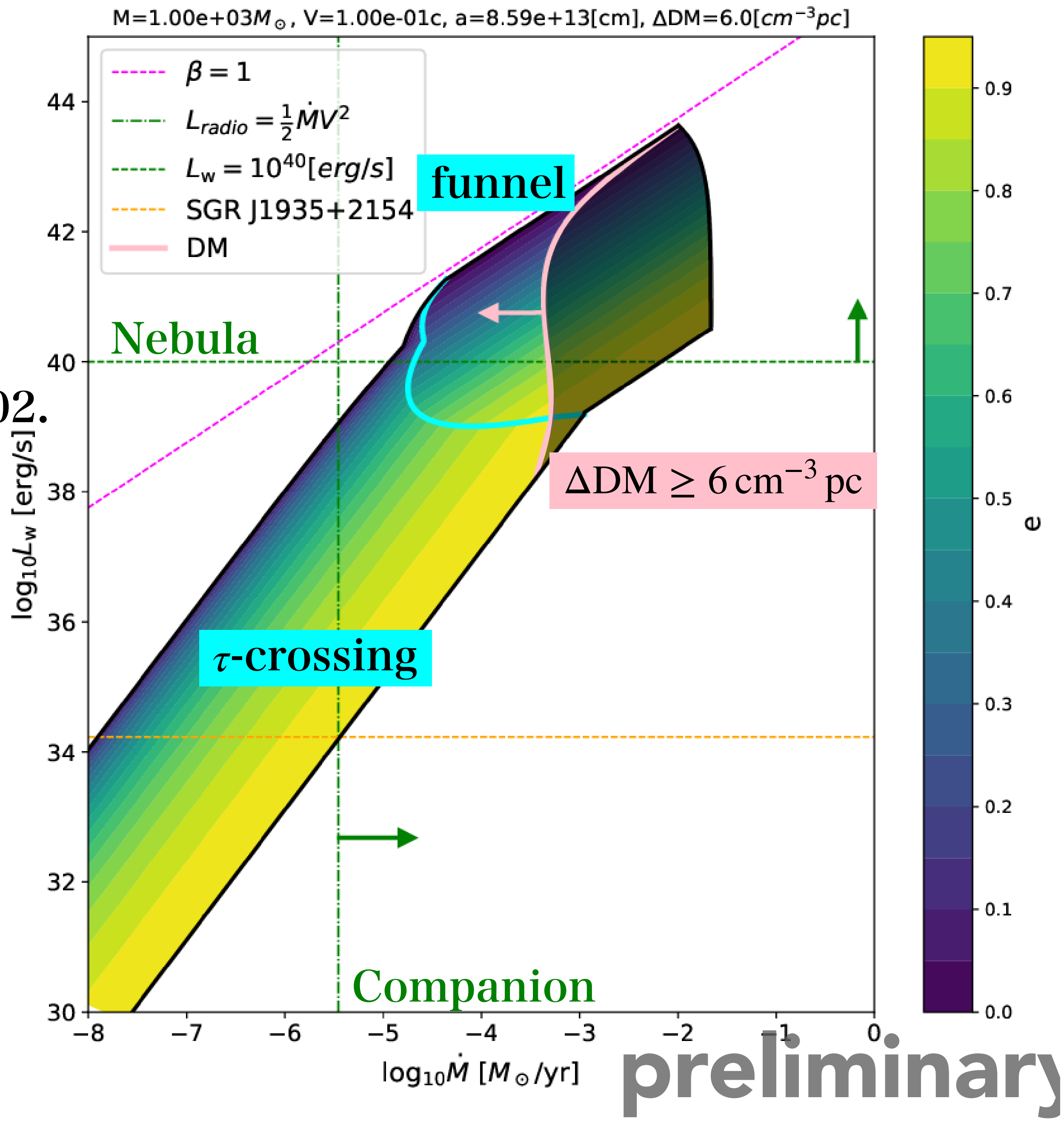
$V = 0.1c$

$a = 9 \times 10^{13}$ cm

IMBH also can explain FRB 121102.

High velocity wind is important.

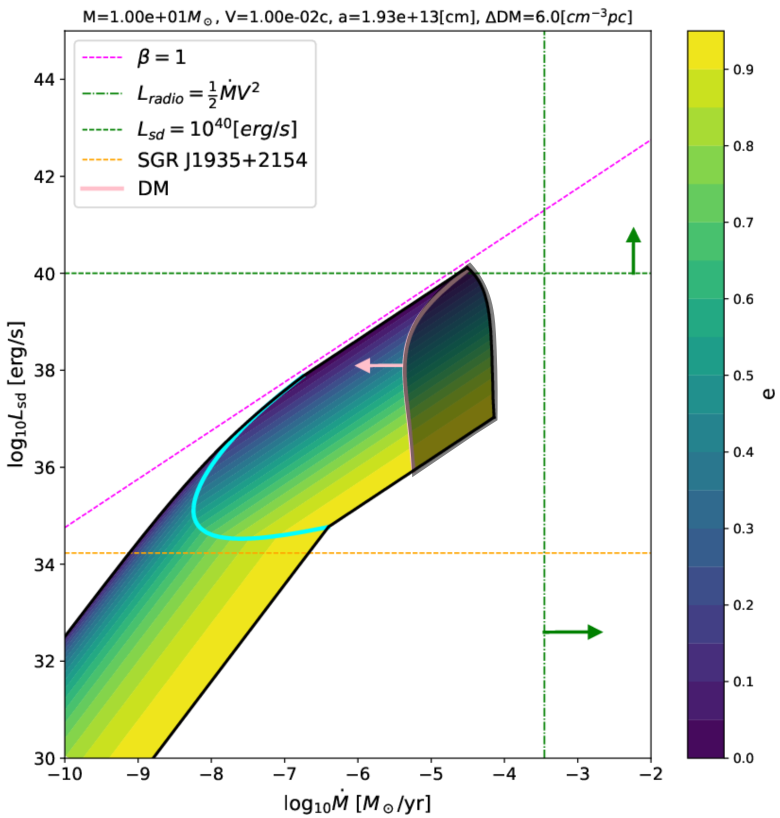
High velocity wind
-> long r_s : funnel gets larger
low $n(r)$: ΔDM gets smaller
high kinetic luminosity

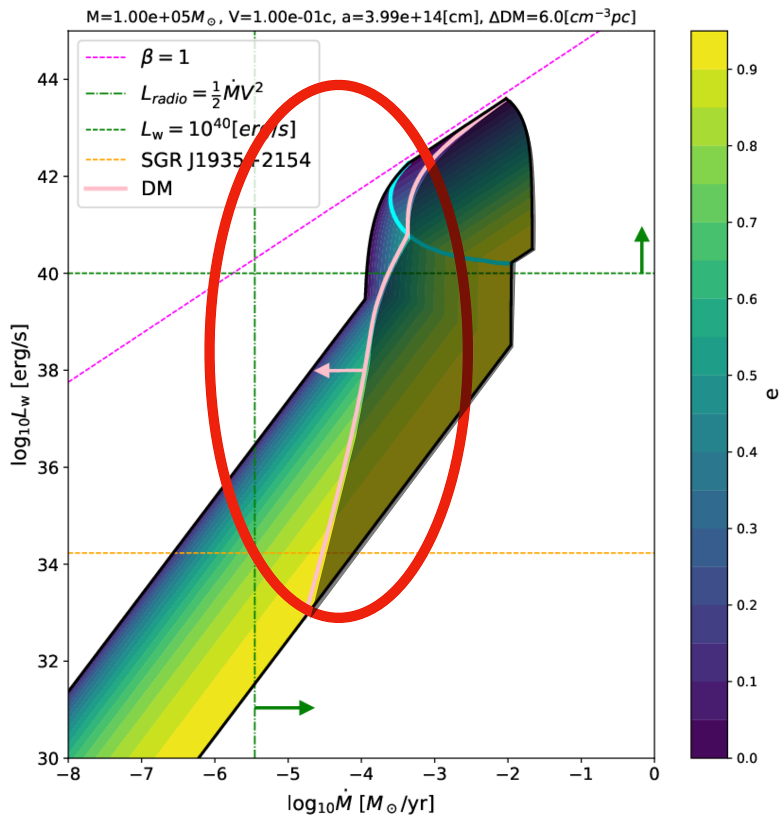


Short summary

- In the binary comb model, the SMBH companion can explain the periodicity, the active window, the change in the DM, and the persistent radio emission of FRB 121102.

Massive star case

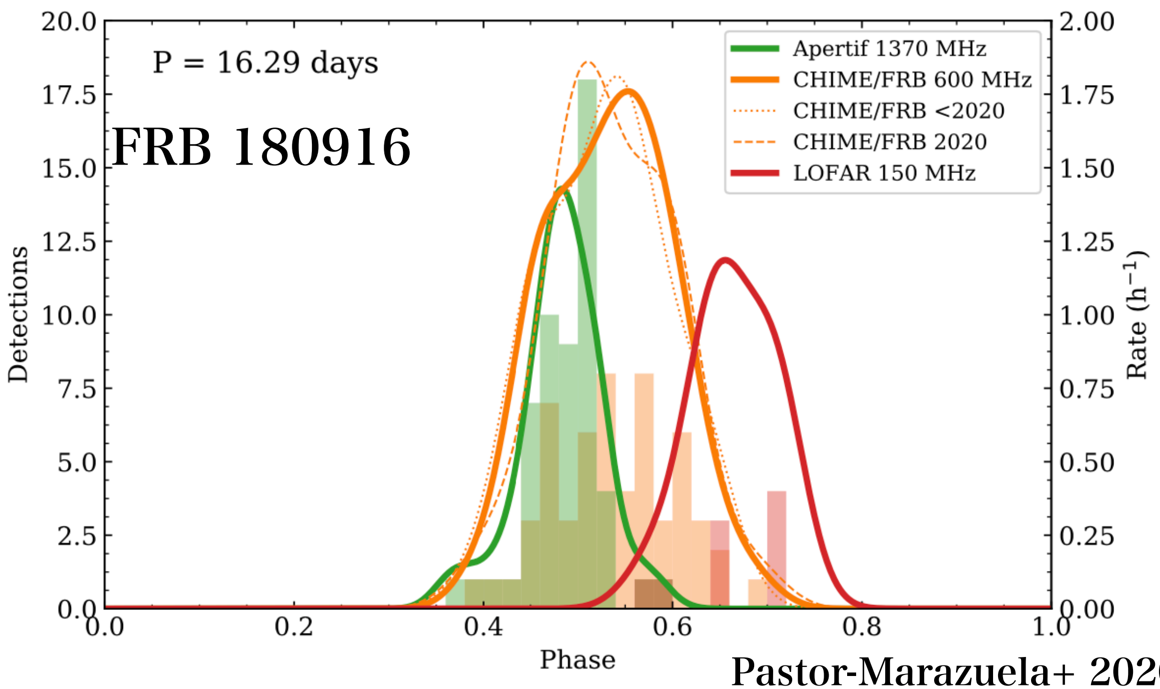




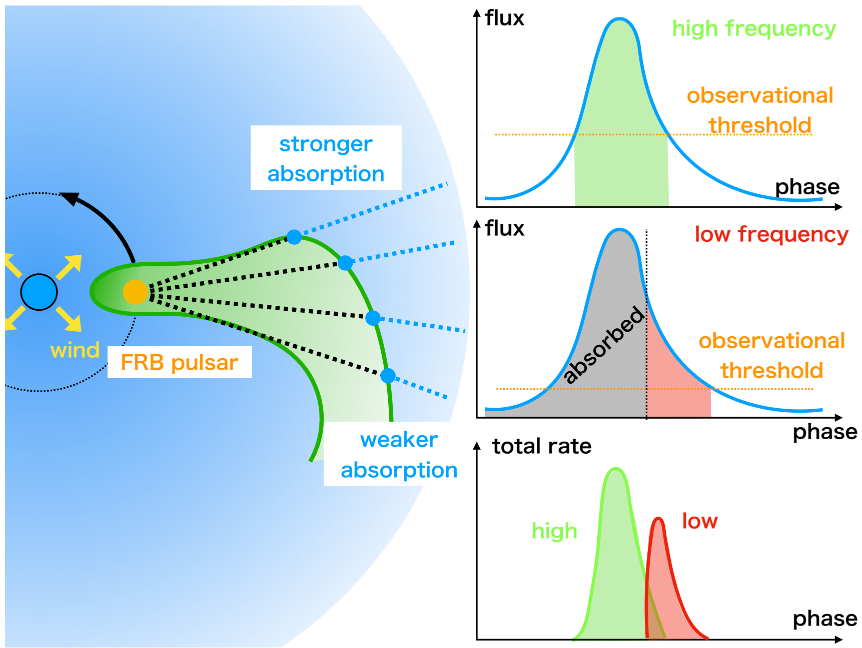
Frequency-dependence of the active window

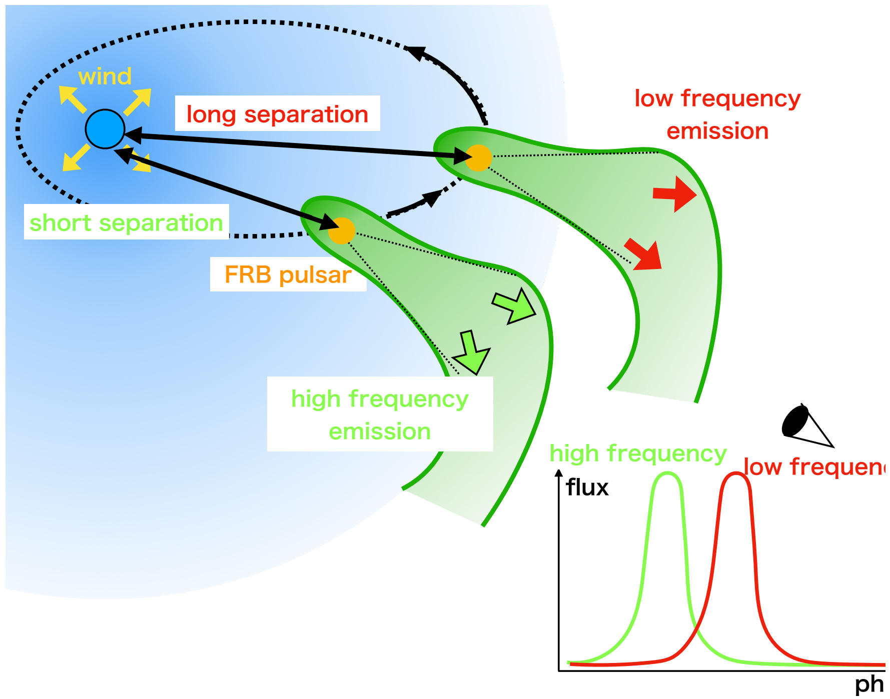
Binary comb model can explain
the frequency-dependence .

This model still alive.



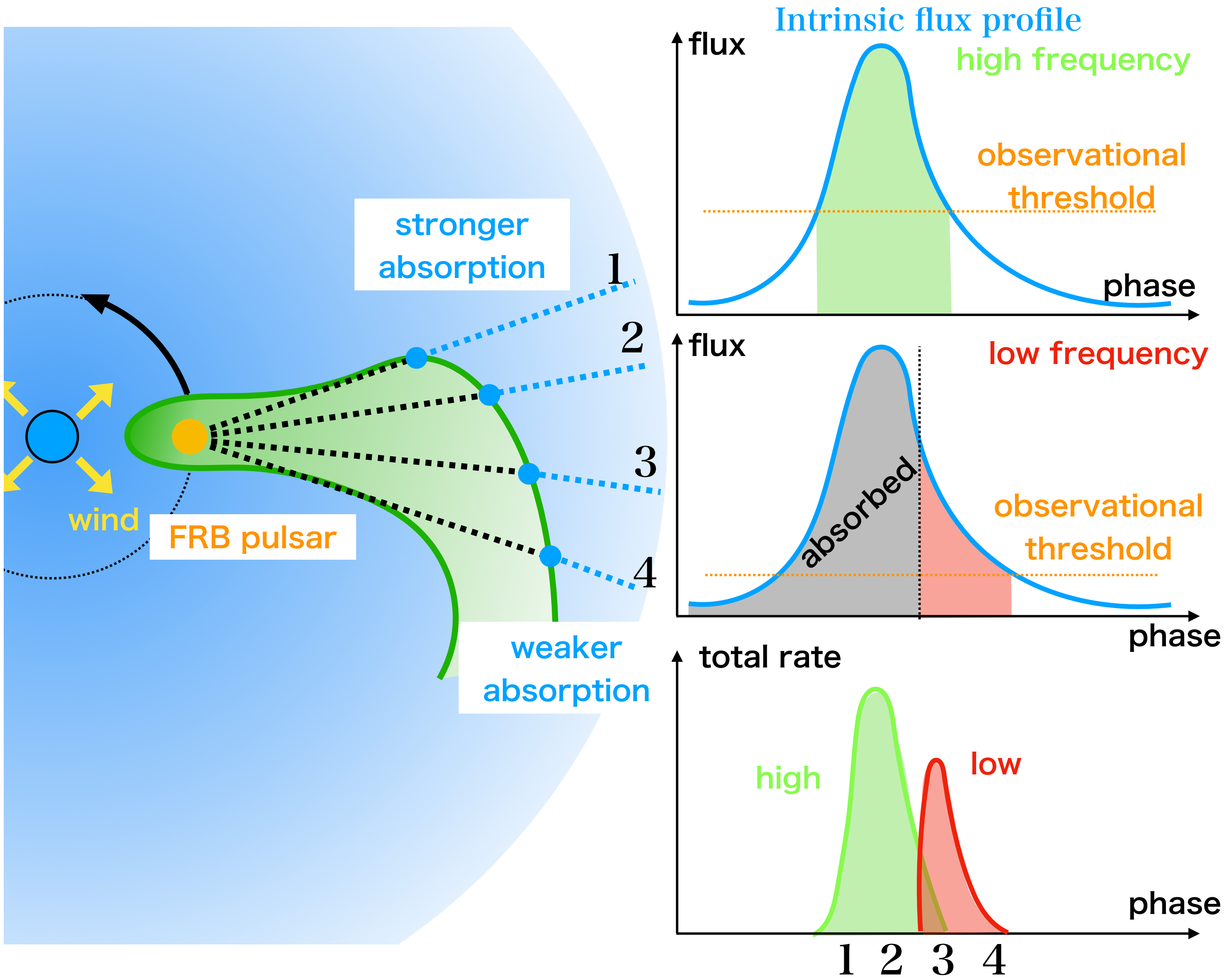
Pastor-Marazuela+ 2020





Frequency	phase	active window
High freq.	: early	short
Low freq.	: later	relatively long
Mid freq.	: early & middle	long

Frequency-dependence of the active window



High freq.

Observational threshold shorten the duty cycle

Low freq.

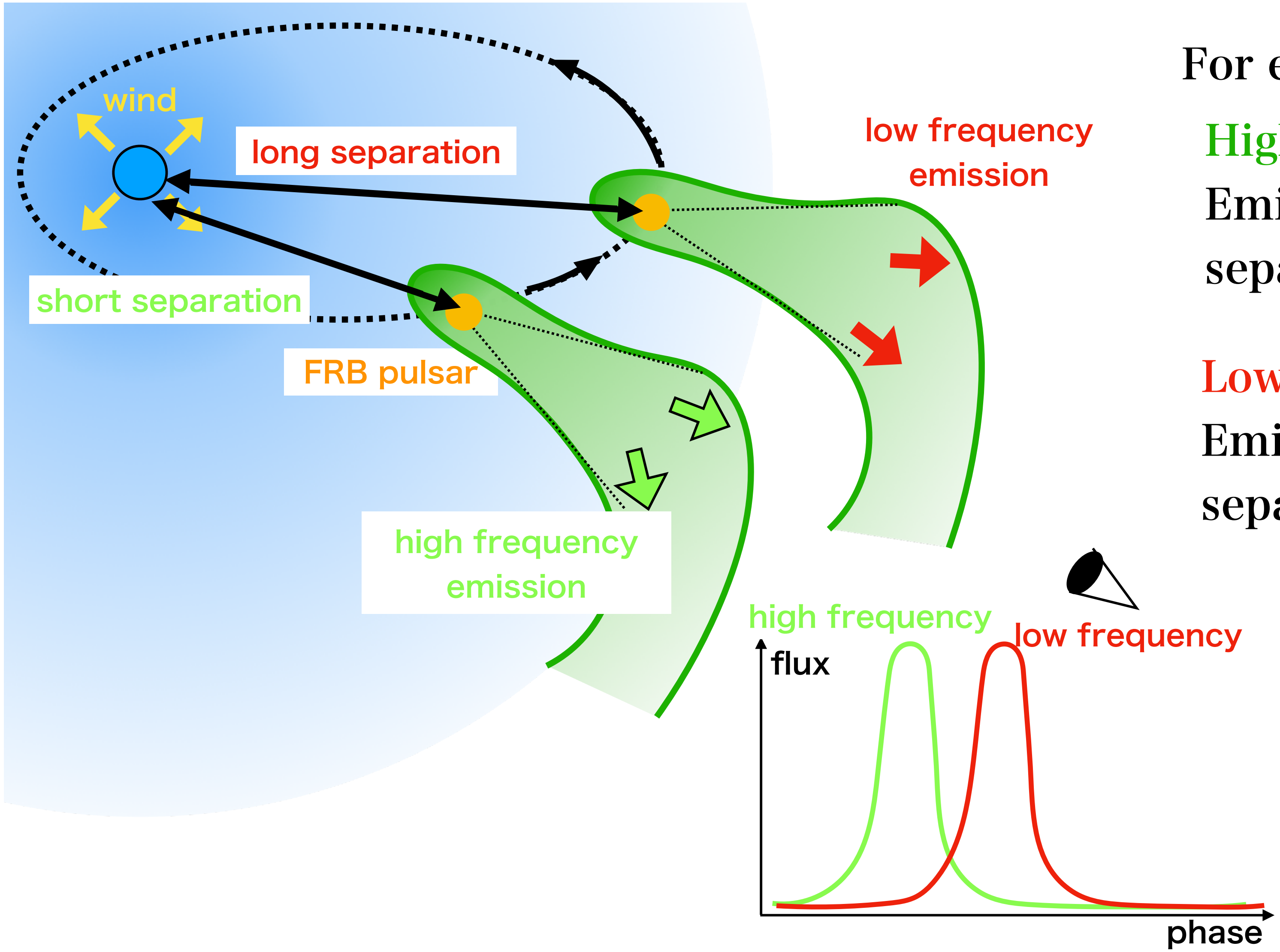
$$\tau_{\rm ff} \propto \nu^{-2}$$

$$\tau_{\rm IdC} \propto \nu^{-3}$$

FRBs in low frequency are scattered efficiently

Different sensitivities of the different telescopes
& Absorption in low frequency
-> The frequency-dependence of the active window

Frequency-dependence of the active window



For example,,,

High freq.
Emitted when the binary separation is short ?

Low freq.
Emitted when the binary separation is long ?

Unknown intrinsic emission mechanism
& Eccentric orbit
-> The frequency-dependence of the active window

Summary

- The binary comb model can explain the periodicity and the active window of FRB 121102.
  There are two mode for FRB to be observable.
  (funnel mode & τ-crossing mode)

- If a SMBH with $V = 0.1c$ is the companion,
  the persistent radio emission and the change in DM
  is explained.

- The frequency-dependence of the active window is also possible in the binary comb model.