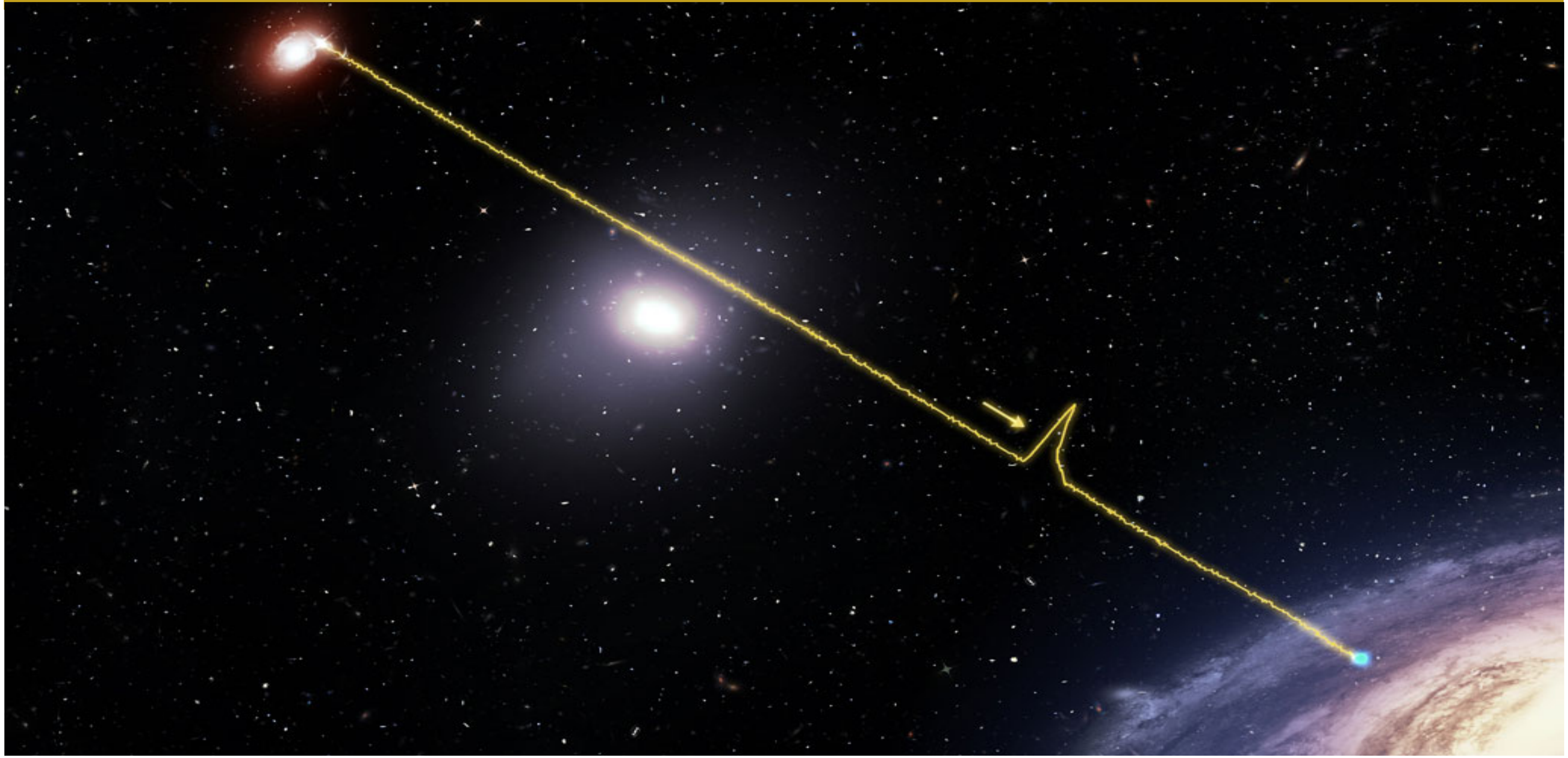
XVII Marcel Grossman Meeting
Pescara - 11/07/2024

A new model for Fast Radio Bursts



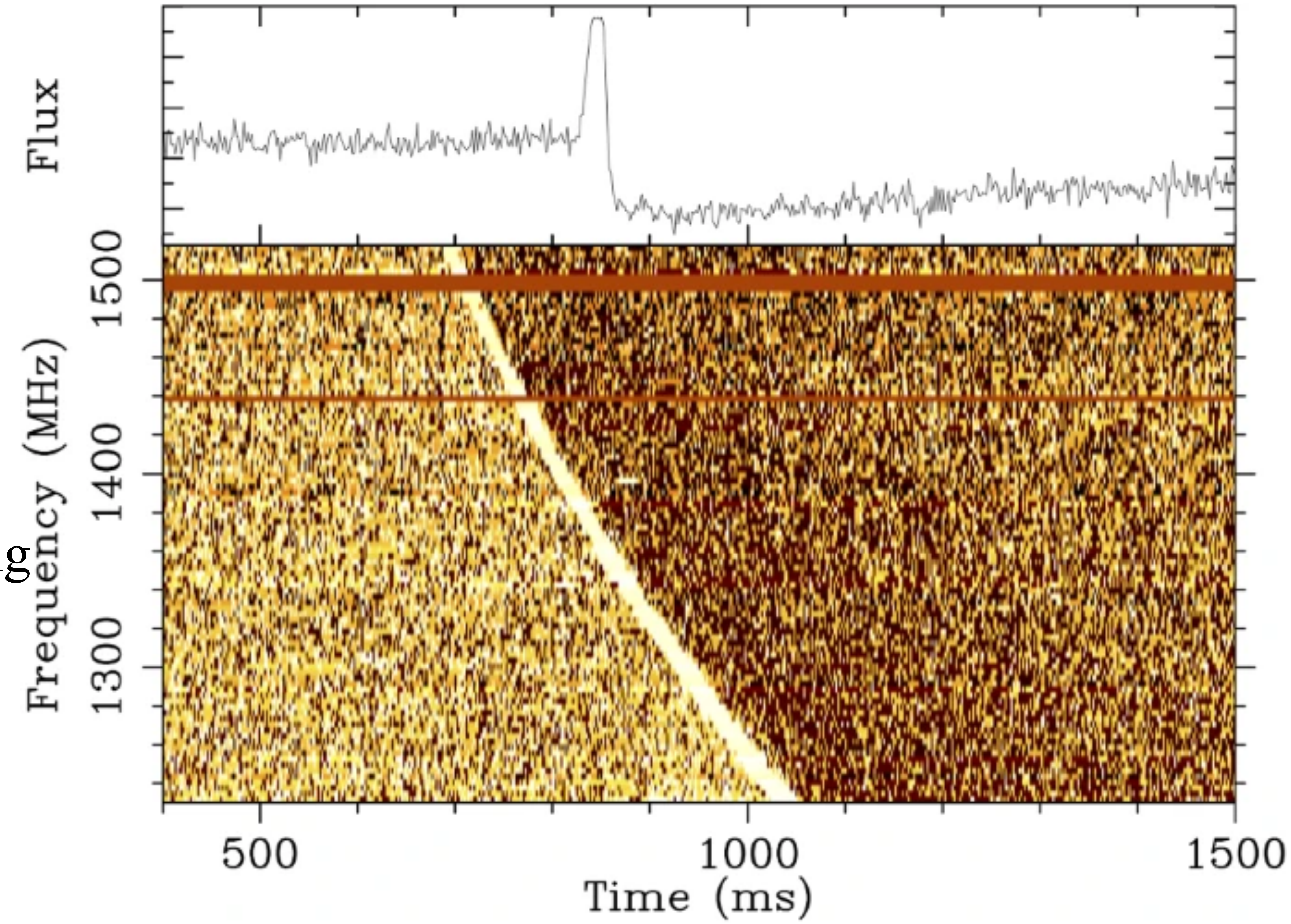
"Sapienza" Università di Roma
Virgo-Roma

SOME KEY PROPERTIES OF FRBs

Fast Radio Bursts (FRBs)

(a) ms-long radio bursts with huge brightness temperature $T_b > 10^{31}$ K $\Rightarrow$ coherent emission
$\Delta E_{\rm iso} \sim 10^{30} - 10^{42}$ erg

(b) some of them are **repeaters**, and some of the latter identified host galaxies (not all related to star forming regions, e.g. **FRB 20200120E ∈ GC in M81**)
Two very powerful repeaters have persistent radio counterparts with $L_{1.4\rm GHz} \sim 10^{39-40}$ erg/s and related to star-forming regions



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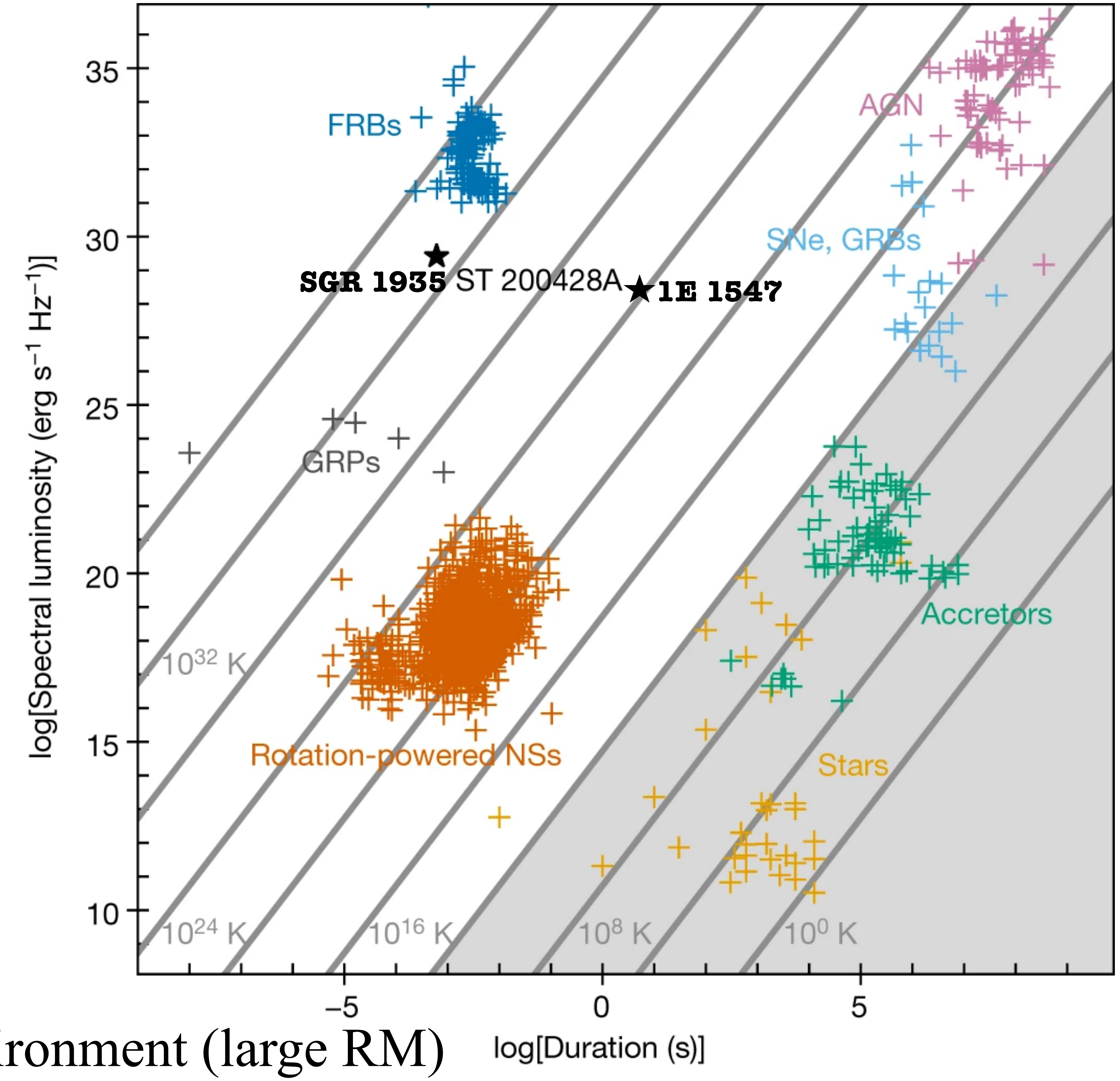

(c) one repeater clearly indicates a highly magnetised environment (large RM)

(d) the huge energy budget (and short timescales) strongly favour magnetic over, e.g. spin, energy

(e) a couple of galactic magnetars have emitted FRB-like flares
ARE WE SEEING VERY YOUNG (< 100 yrs) MAGNETARS?

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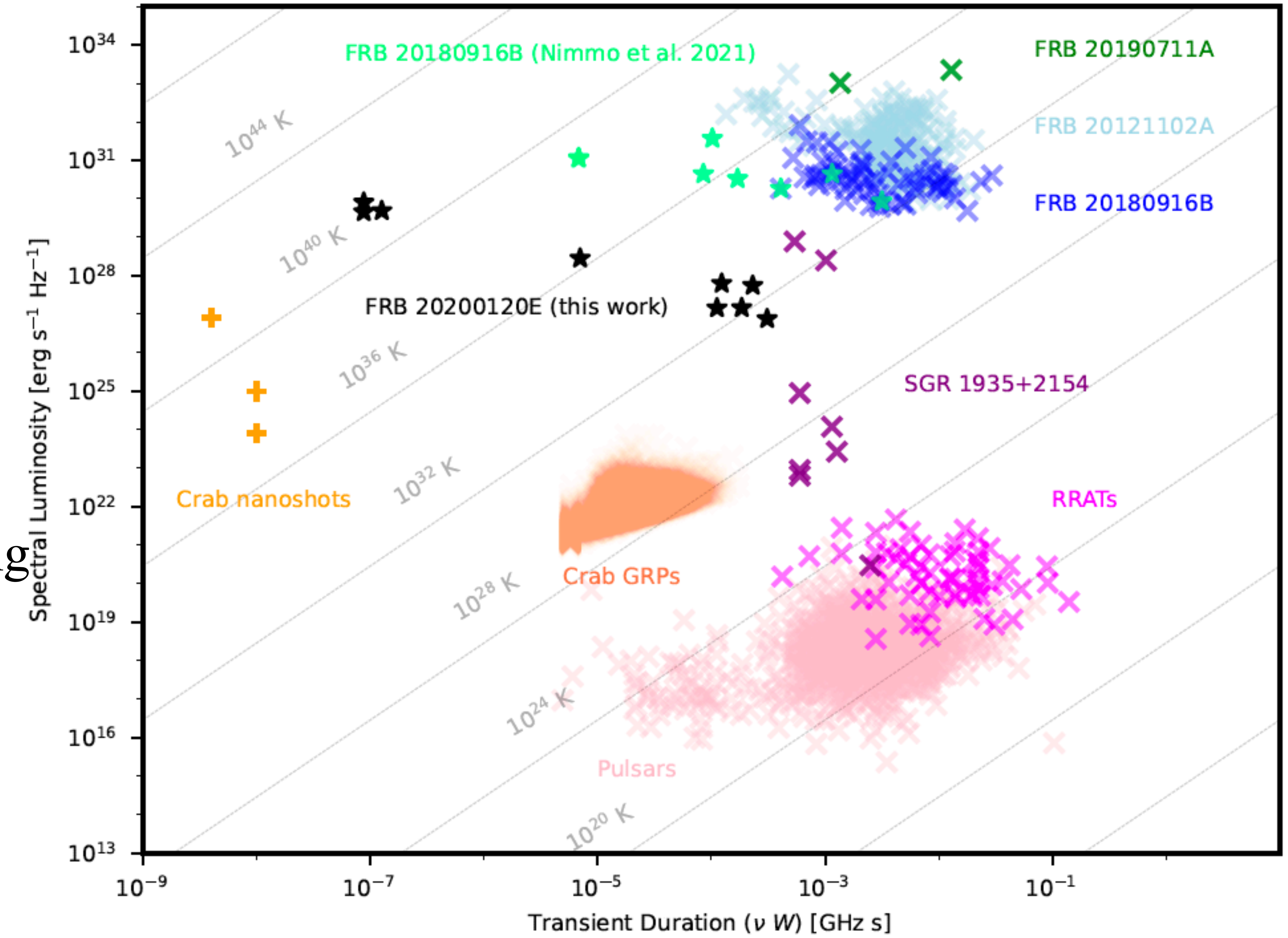

(f) two proposed associations FRBs+BNS mergers (~ hr delay) Moroianu et al. 2022; Rowlinson et al. 2023)
(i) not conclusive, yet the potential is clear
(ii) BNS mergers may contribute a small minority of FRBs, given the widely different all-sky rates. Magnetars formed in core-collapse represent a viable progenitor for the bulk of FRBs

SOME KEY PROPERTIES OF FRBs

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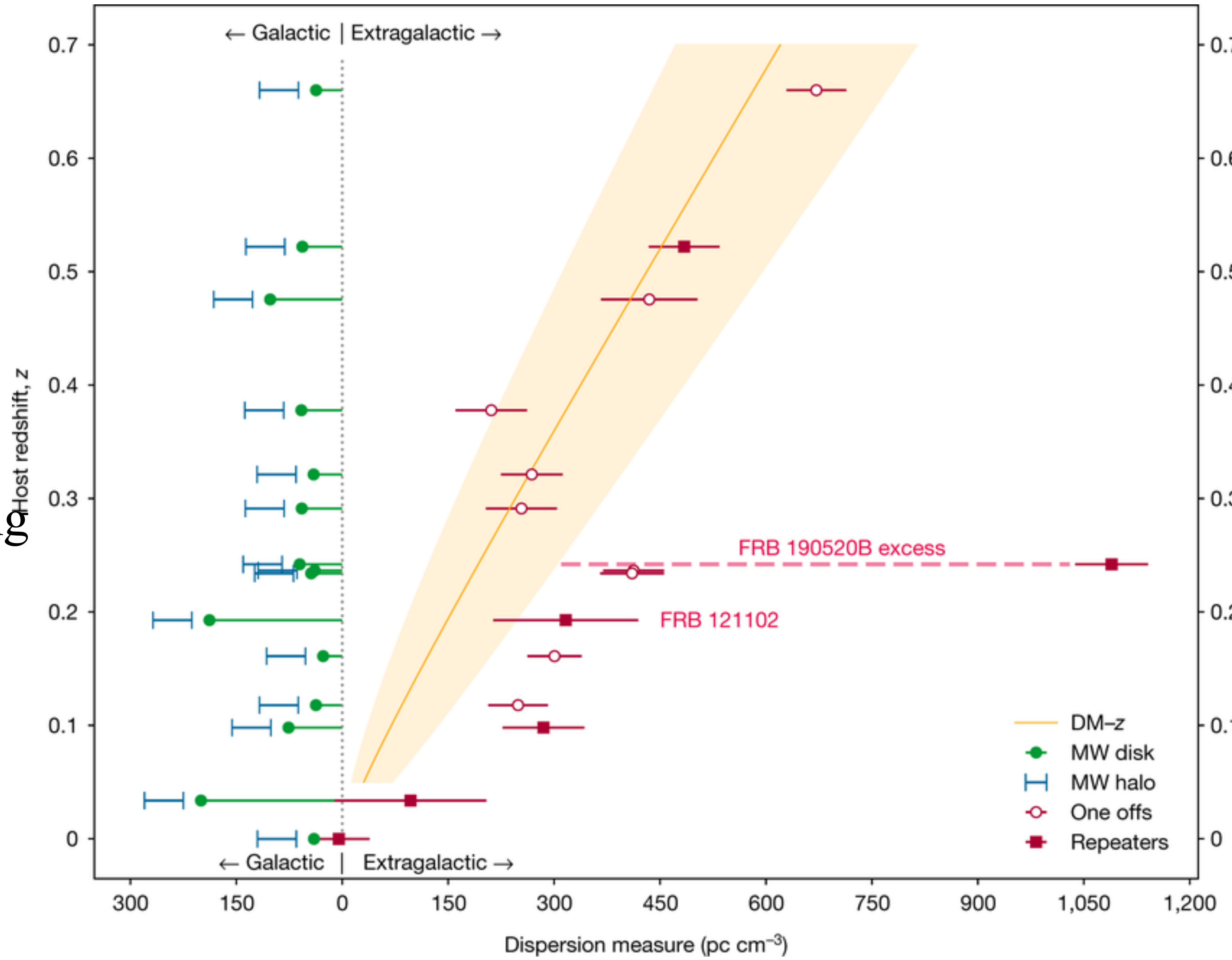
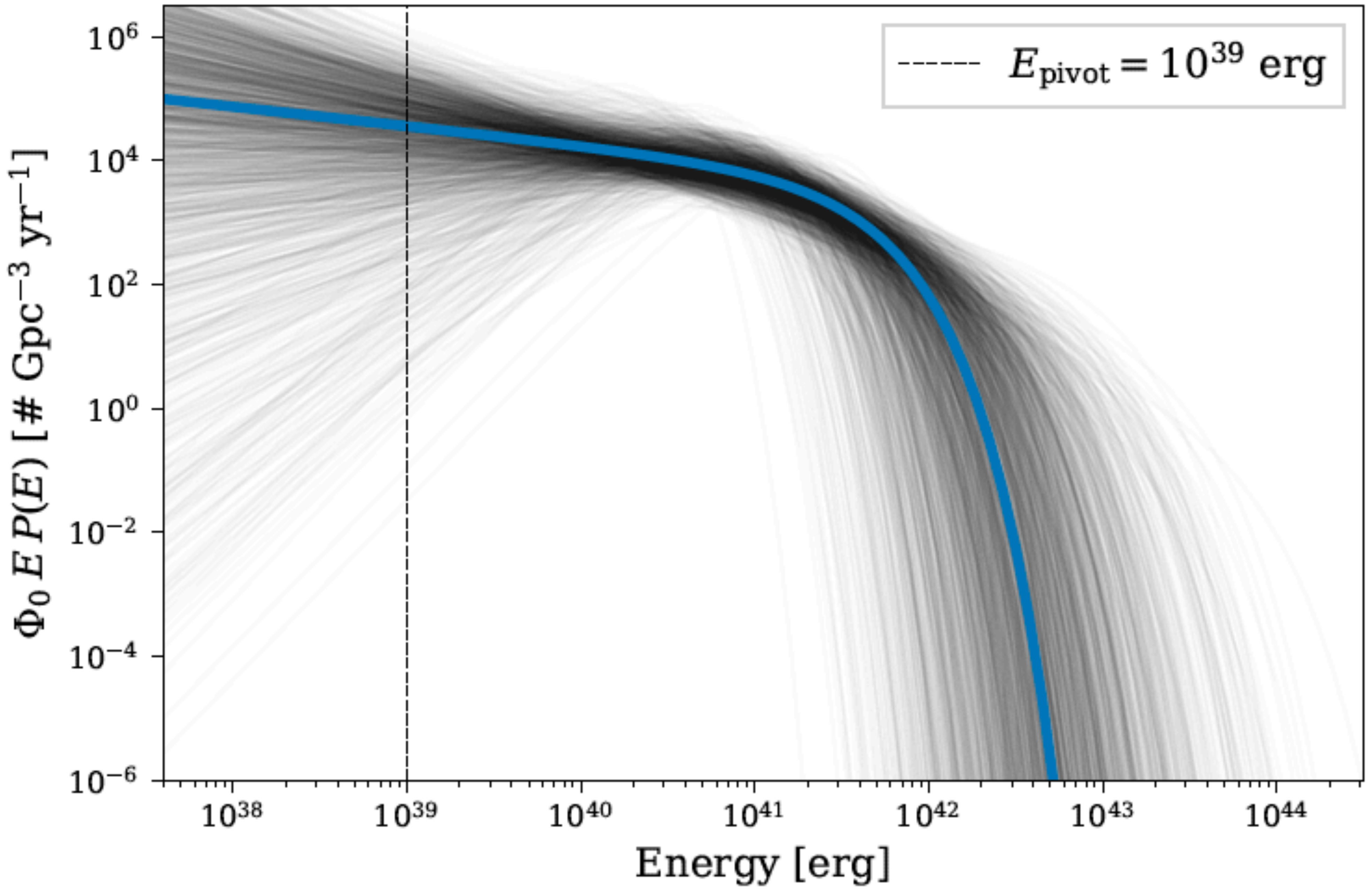


(g) FRBs are also studied as potential probes of the distribution of diffuse IGM out to cosmological distances, due to their large DM, large RMs (in some cases) and being highly affected by scattering broadening and scintillation (e.g. Petroff et al. 2022, Pilia 2022)

SOME KEY PROPERTIES OF FRBs

FRBs: Event energy distribution



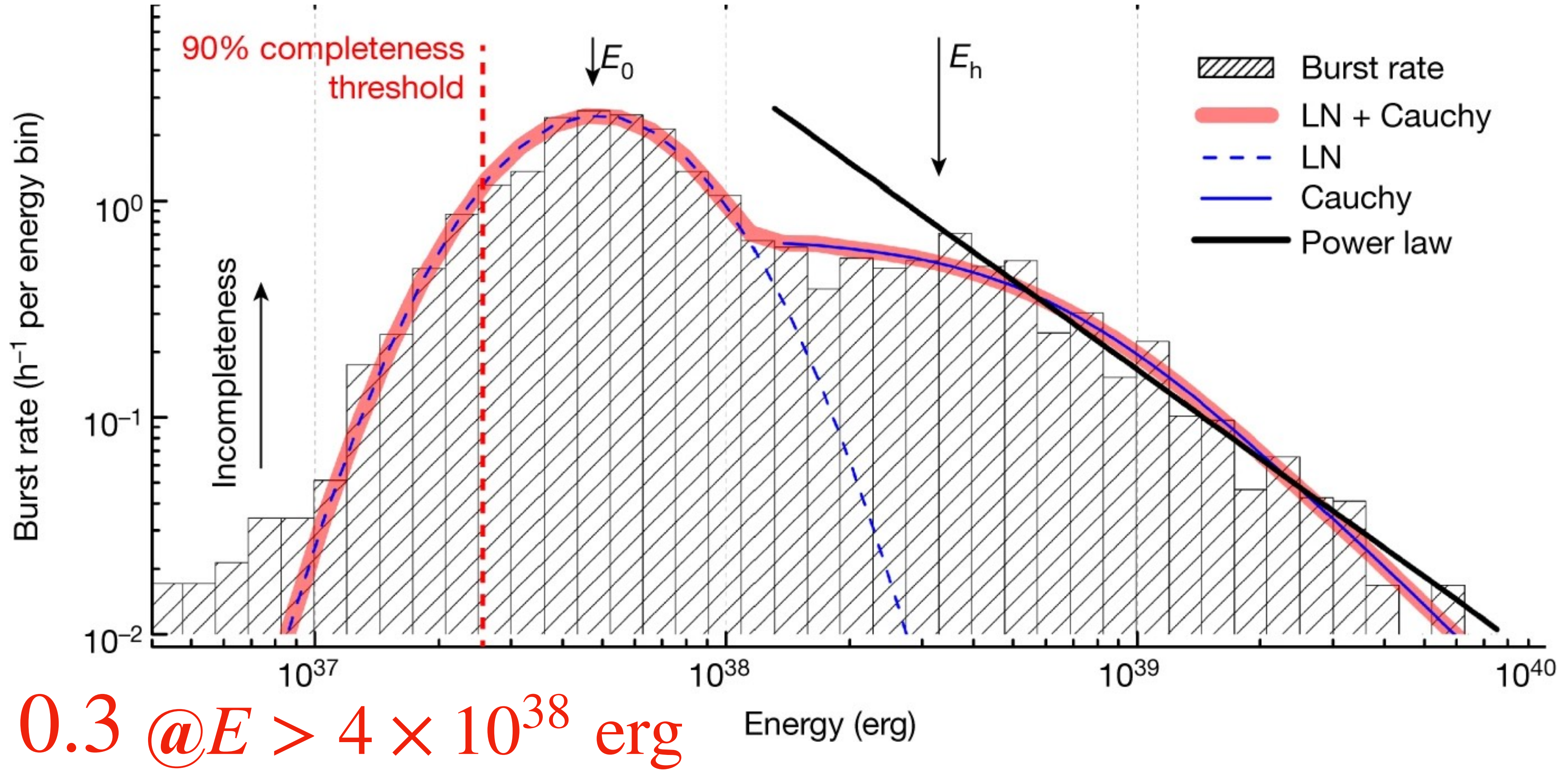
$$\frac{dN}{dE} \propto E^{-\gamma}$$

$\gamma = 1.4^{+0.7}_{-0.4}$ **Shin et al. (2022)**
1st CHIME Catalog

$\gamma = 2.2^{+0.15}_{-0.1}$ **James et al. (2022)**
ASKAP & Parkes

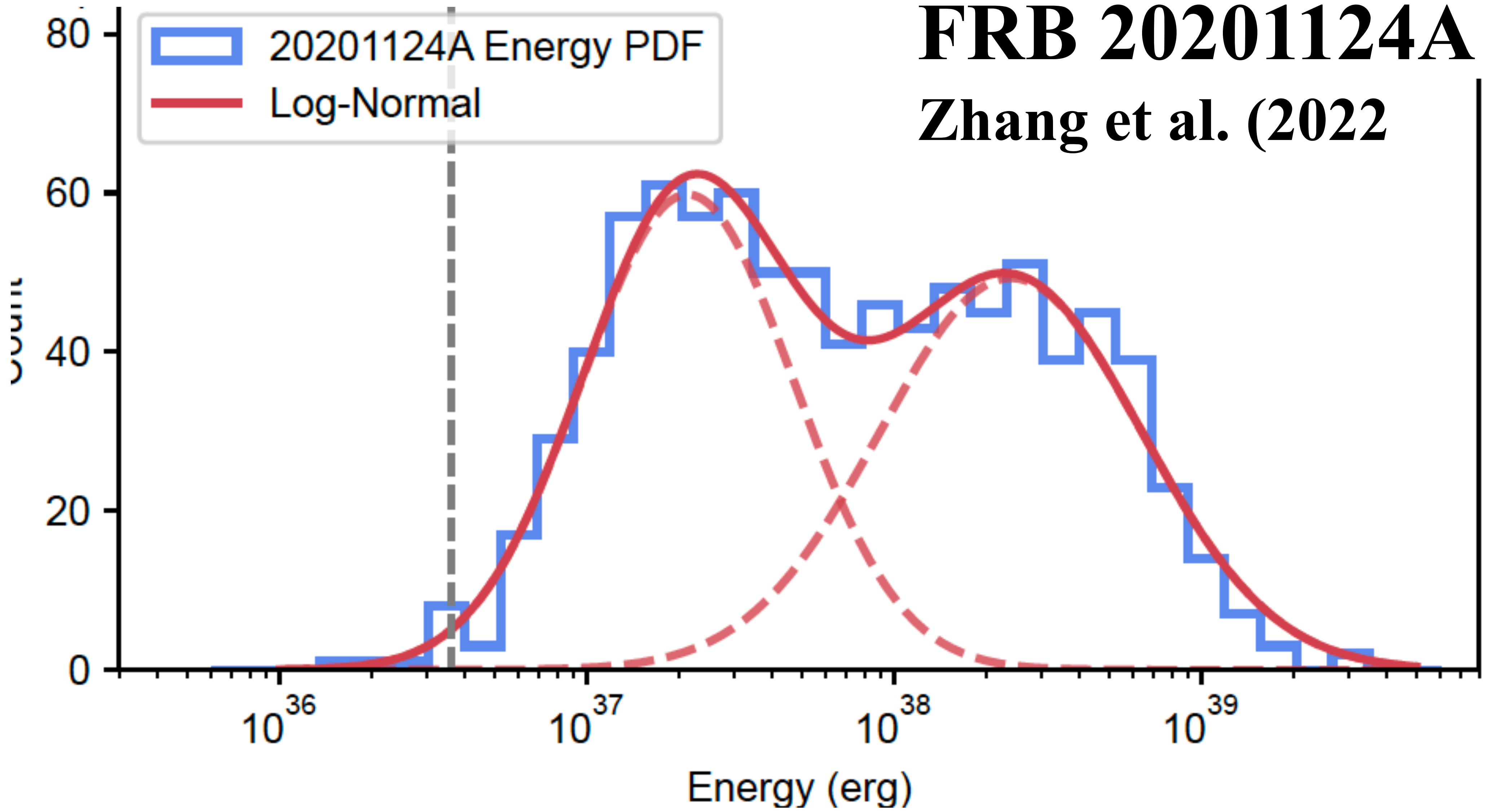
$\gamma = 2.8^{+0.3}_{-0.3}$ **Lu et al. (2020)**
Heterogenous sample of FRBs

FRB 20121102
Li et al. (2021)



$\gamma = 1.85 \pm 0.3$ @$E > 4 \times 10^{38}$ erg

FRB 20201124A
Zhang et al. (2022



SOME KEY PROPERTIES OF FRBs

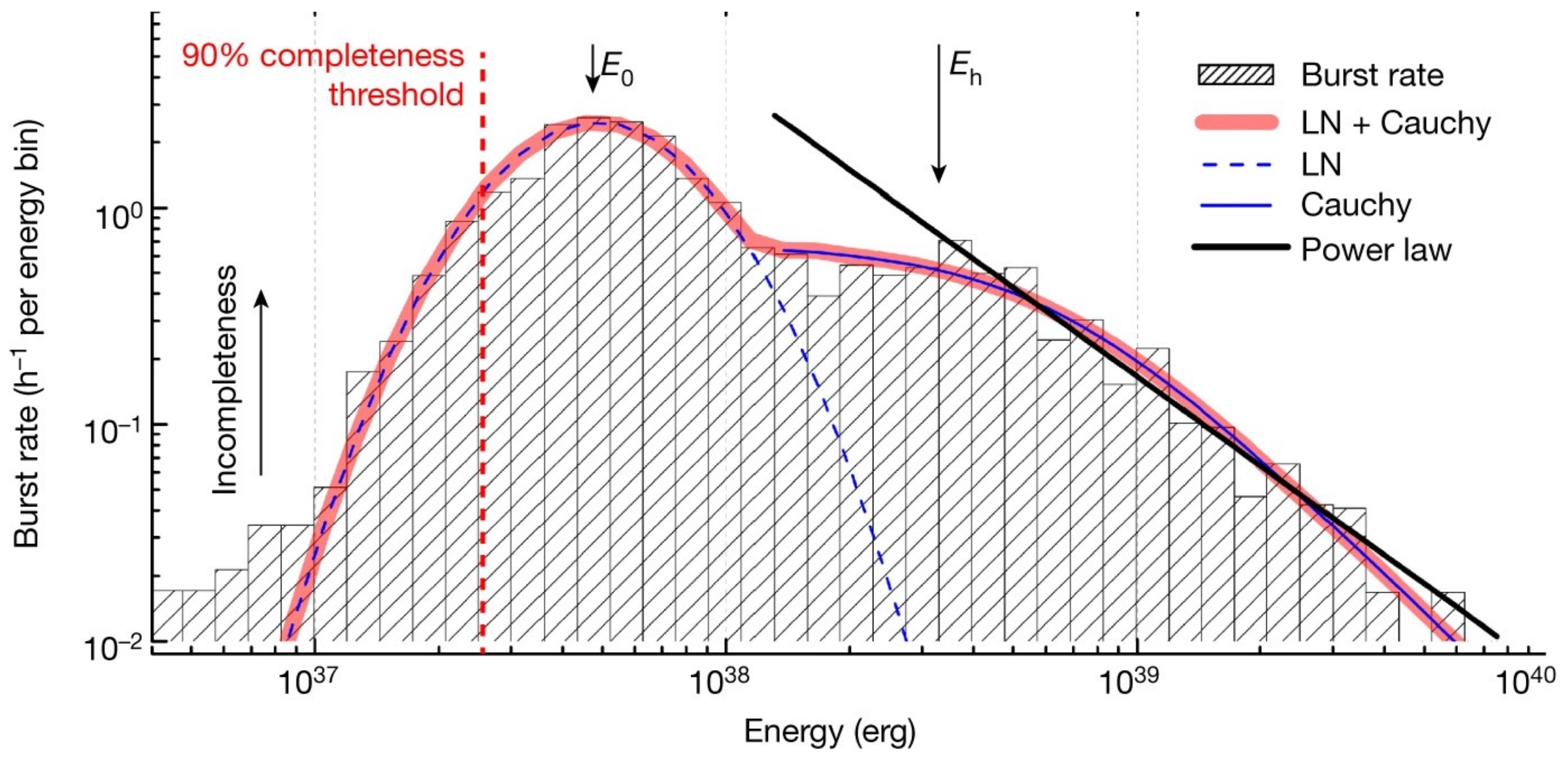
FRBs: Energy Budget

Both repeaters are energetically very challenging, as they persistently release an average $\sim 10^{36}$ erg/s in coherent radio bursts

$$E_{\rm TOT} > 3 \times 10^{49}\ {\rm erg}\ \ \Delta t_{\rm kyrs} \epsilon_{r,-3}^{-1}$$

Total isotropic energies $E_{\rm iso} > 10^{40}$ erg and luminosities $L_{\rm iso} > 10^{42}$ erg/s of most powerful and distant FRBs are also very challenging to explain

FRB 20121102
Li et al. (2021)



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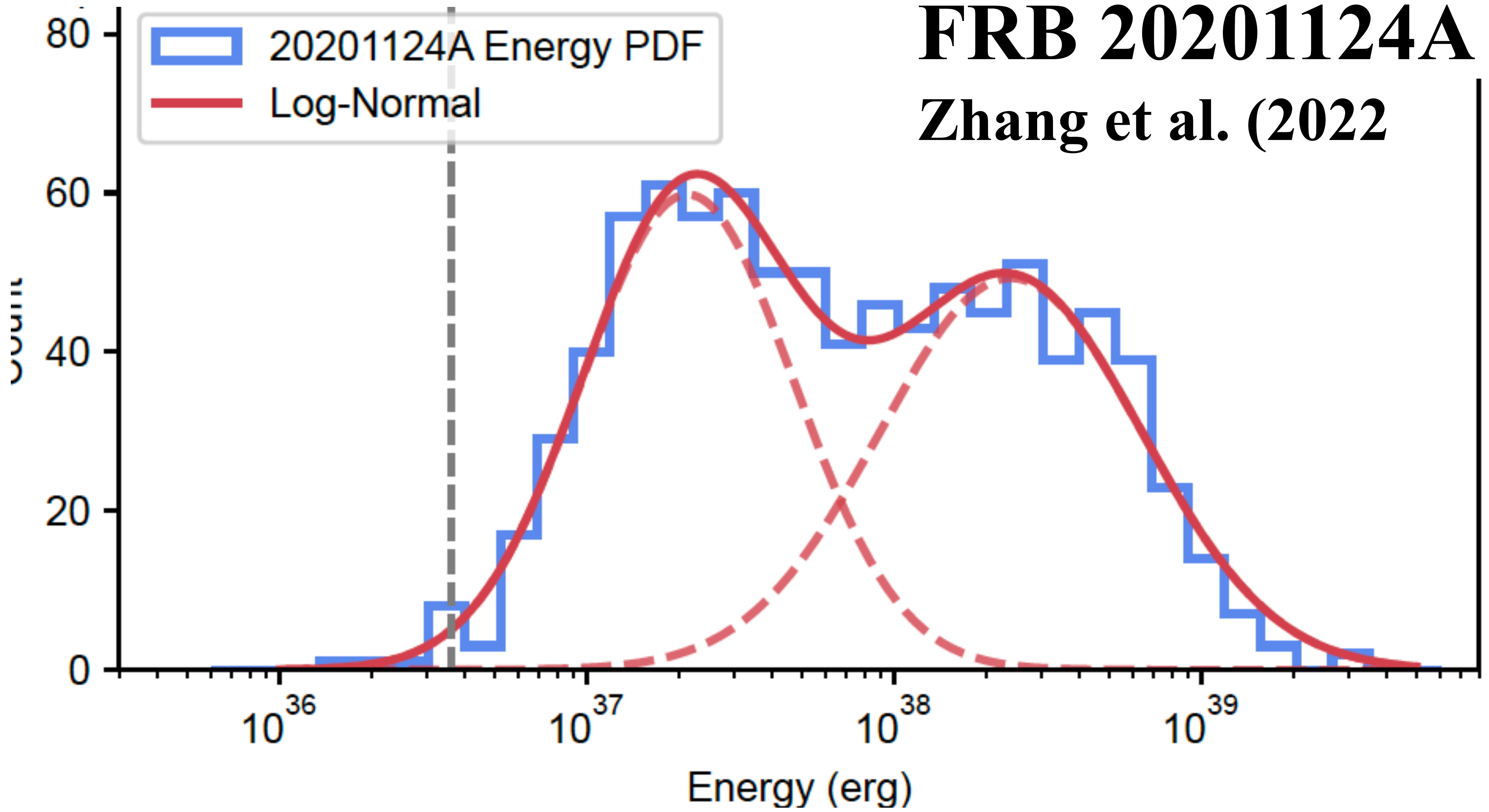
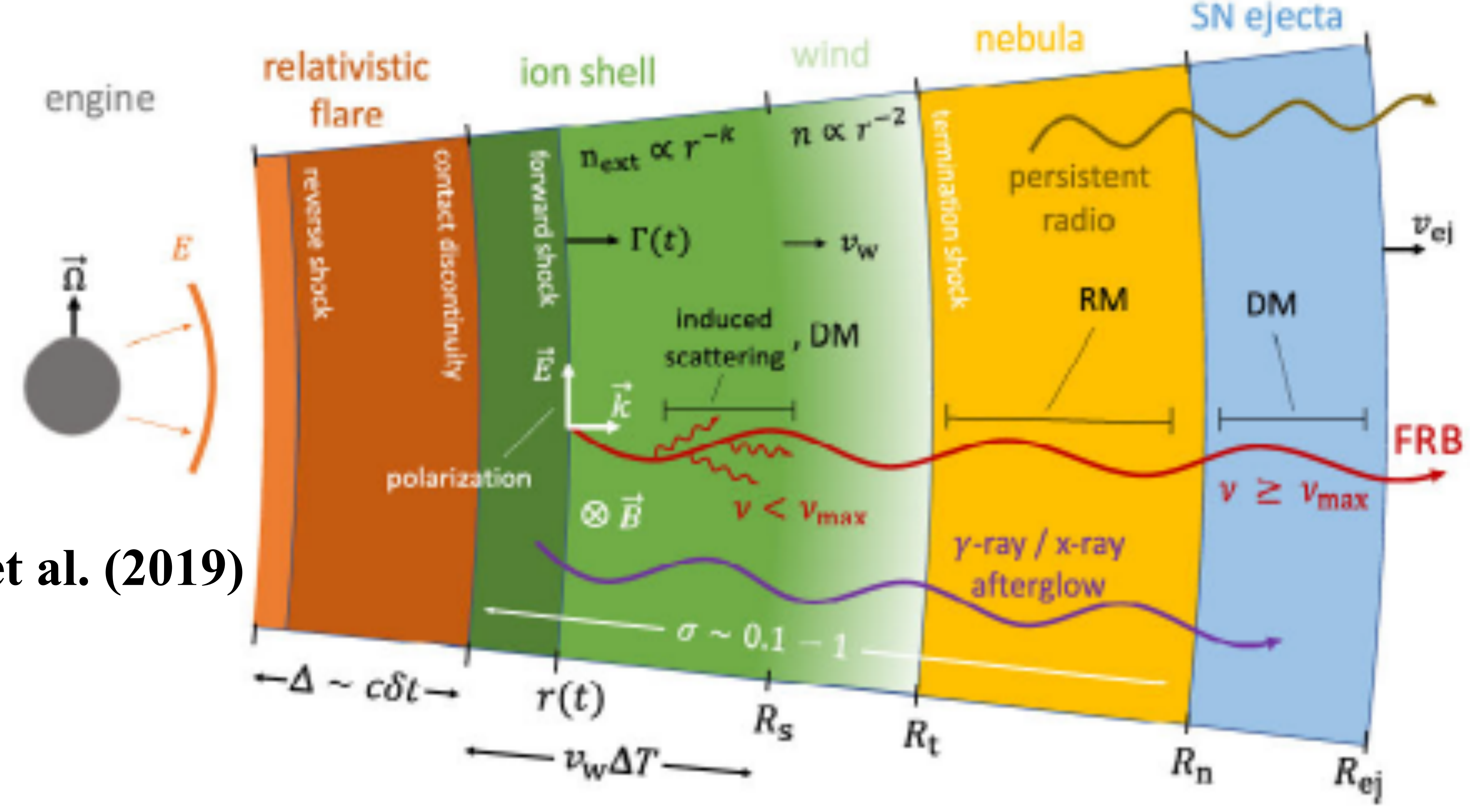
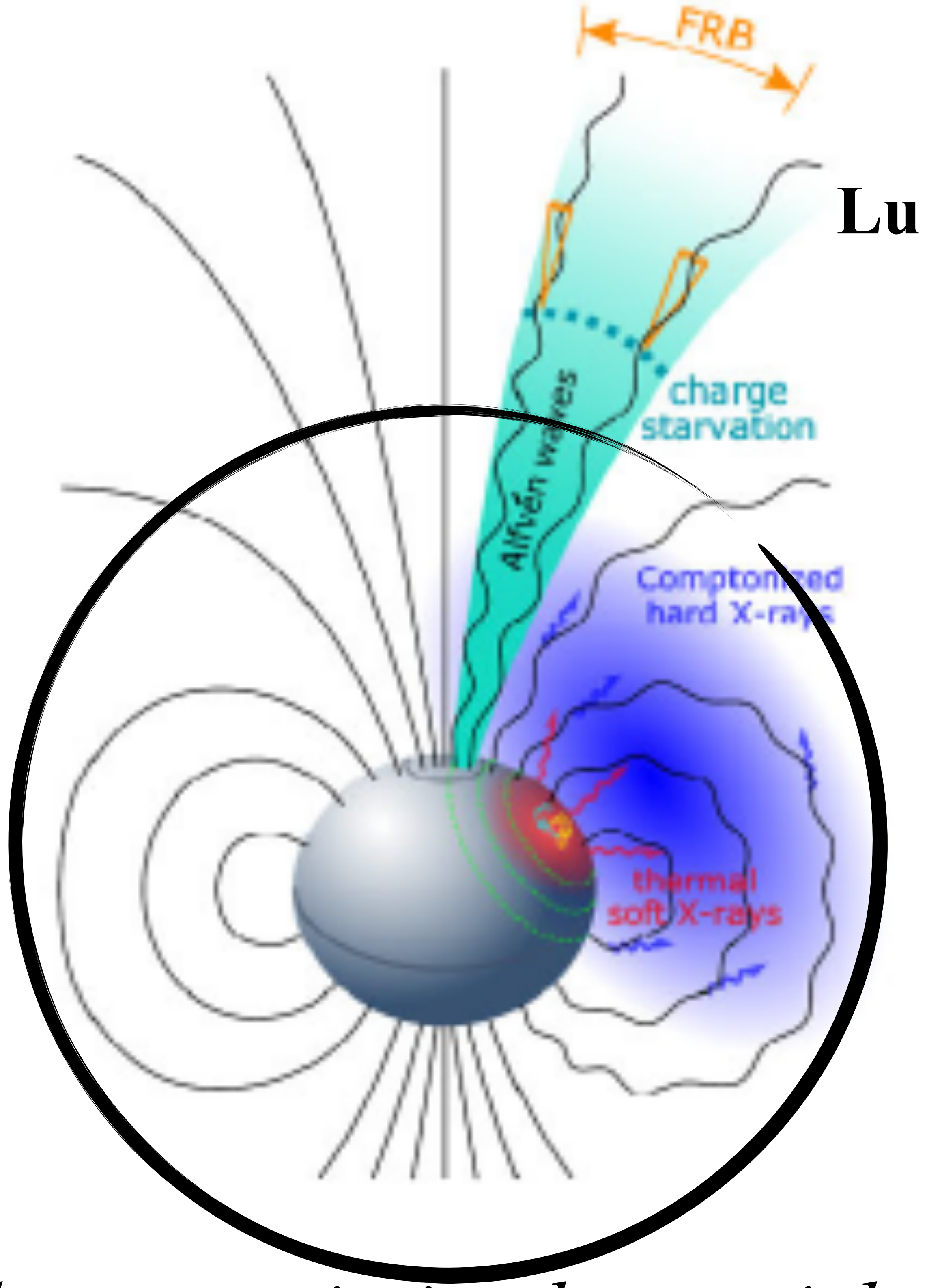


TWO CLASSES OF NS MODELS



Metzger et al. (2019)



Lu et al. (2020)

Synchrotron Maser in relativistic shocks driven in the surrounding medium by (giant) flares

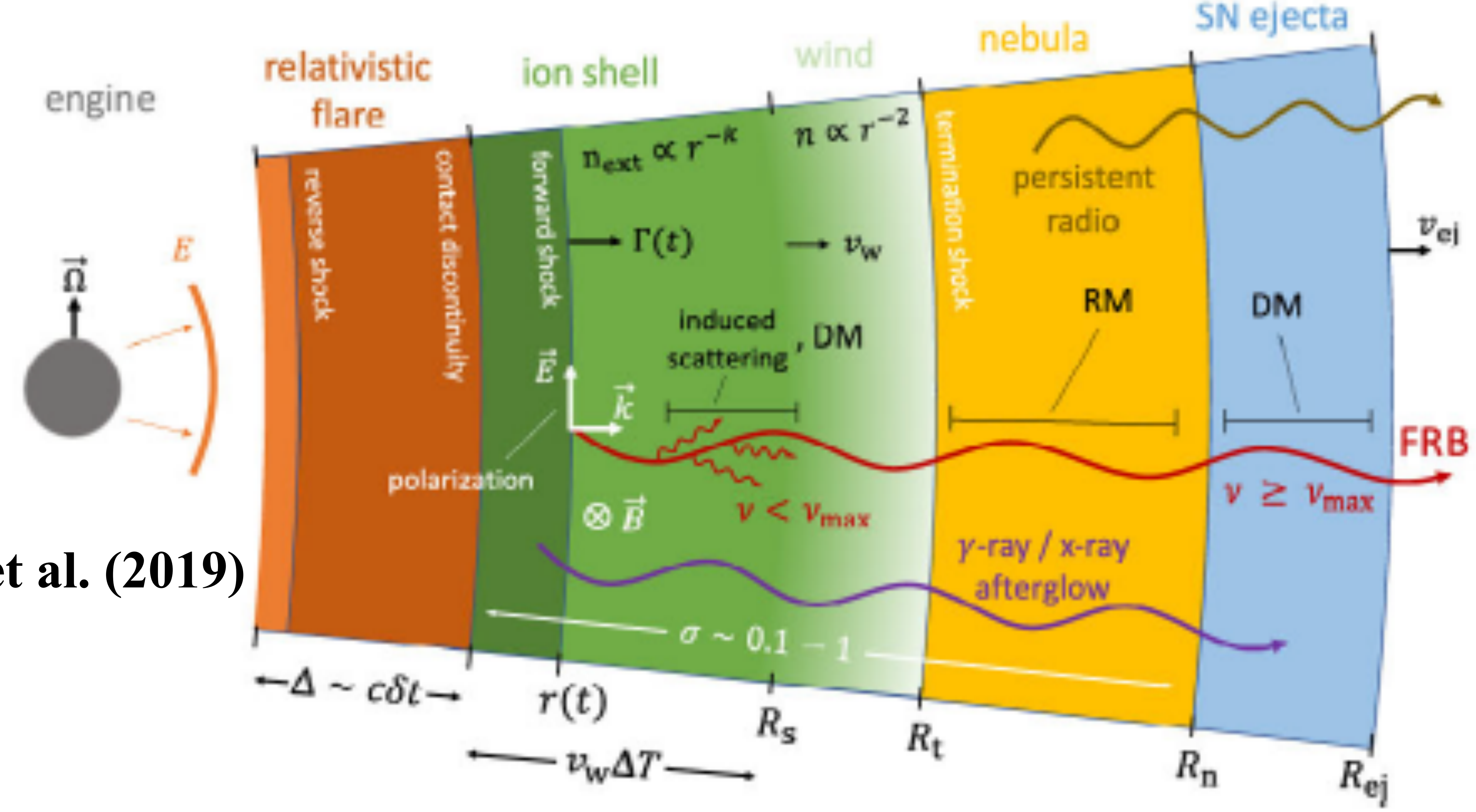
Lyubarski 2014
Beloborodov 2017, 2019
Metzger et al. 2019
Margalit, Metzger &. Sironi 2020

Coherent emission by particle bunching due to current instabilities at magnetospheric reconnection events

Lyutikov 2016+
Lu et al. 2020

Highly magnetized environment to create the conditions for coherent emission

TWO CLASSES OF NS MODELS



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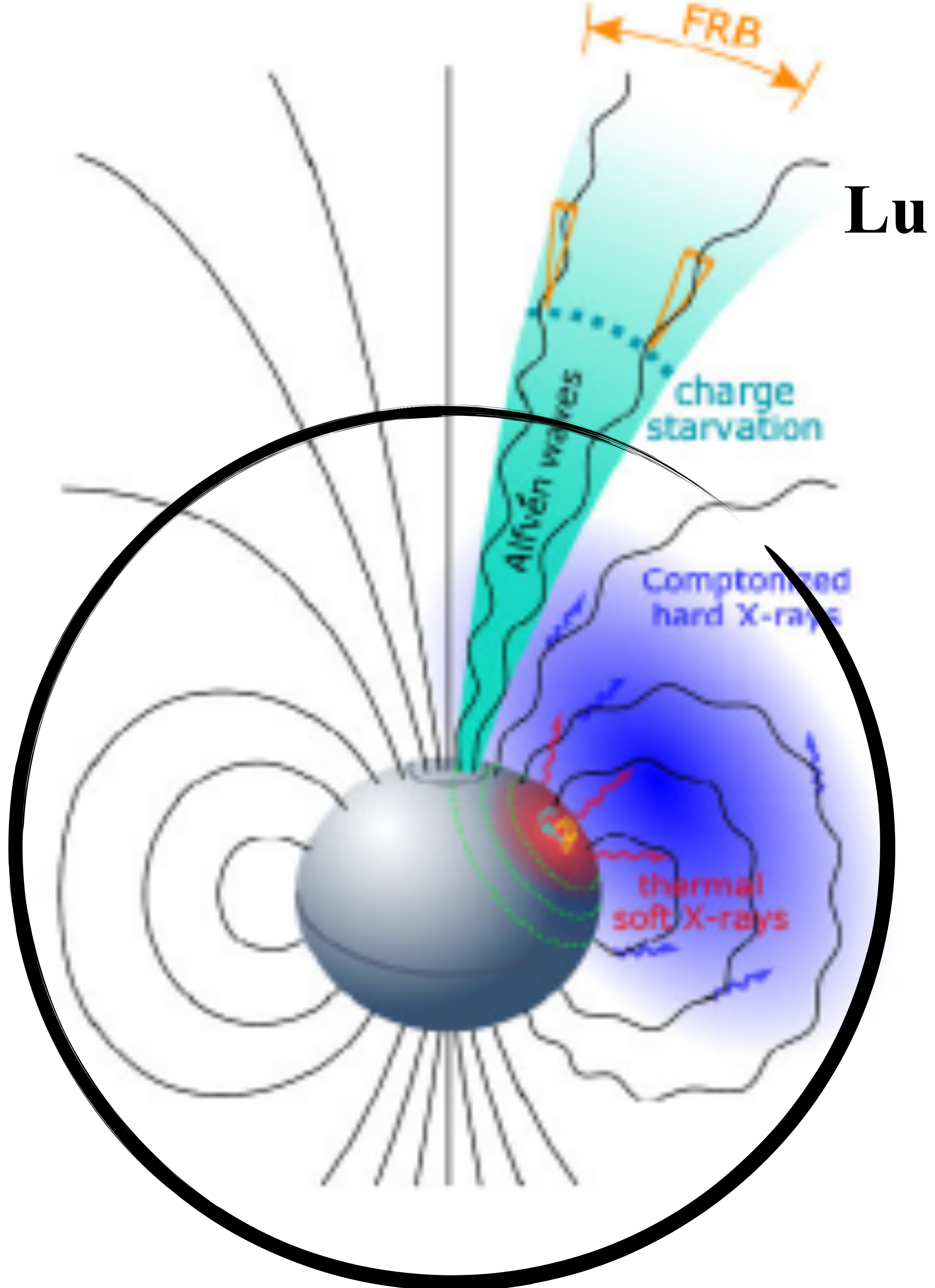


Lu et al. (2020)

Synchrotron Maser in relativistic shocks driven in the surrounding medium by (giant) flares

$$\delta t \geq \frac{R\zeta^2}{2c\Gamma^2} \approx 30\mu s\ R_{10}\zeta_{-1}^2\Gamma_1^2$$

sub-μs variability would probably rule out this option

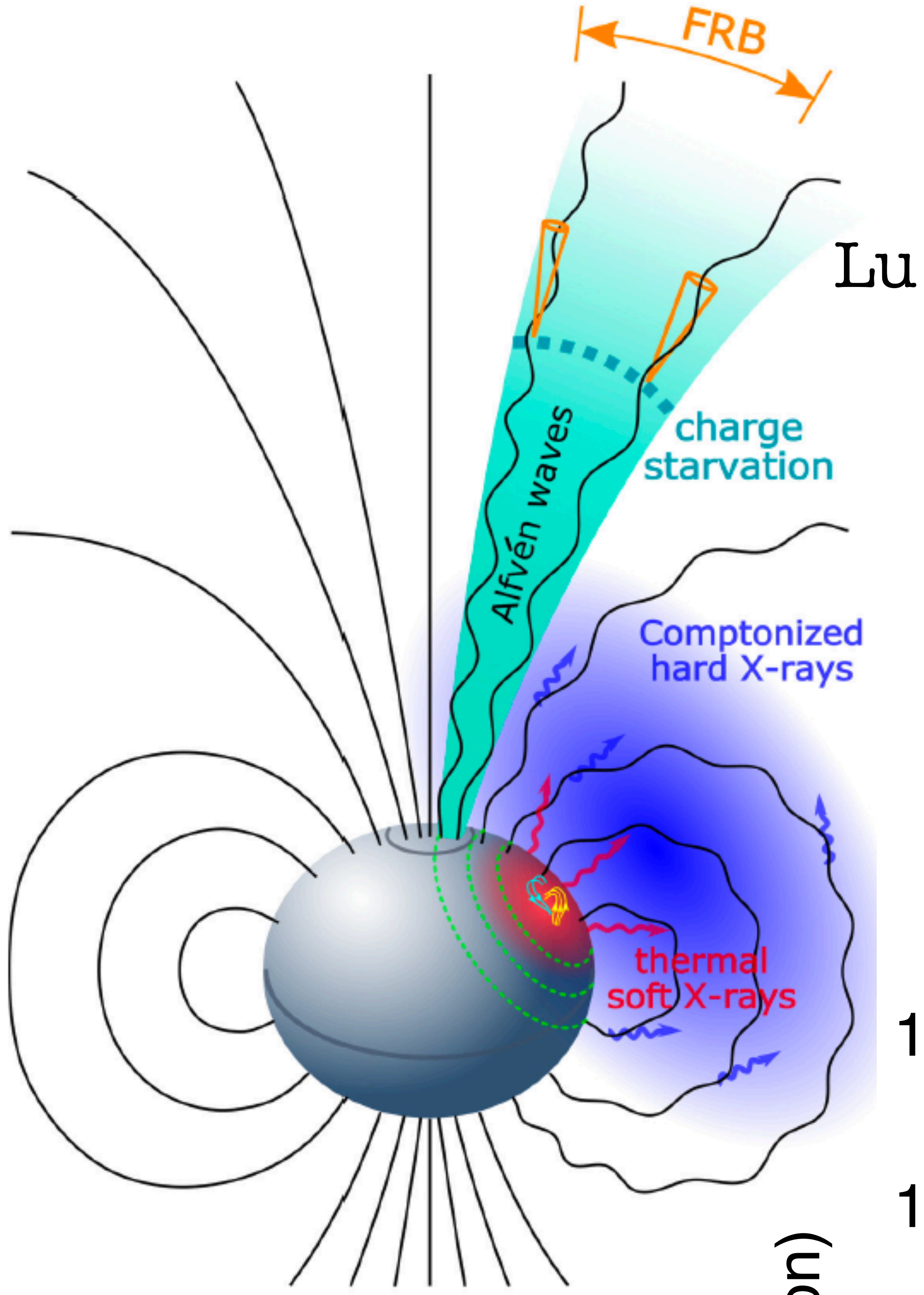
e.g. Petroff et al. (2022)

Coherent emission by particle bunching due to current instabilities at magnetospheric reconnection events

Propagation effects may constrain visibility of radio waves to viewing directions not far from magnetic axis *and* to NS rotating with period < 1 s

Beloborodov (2021) Qu et al. (2022) Lyutikov (2023)

TWO CLASSES OF NS MODELS



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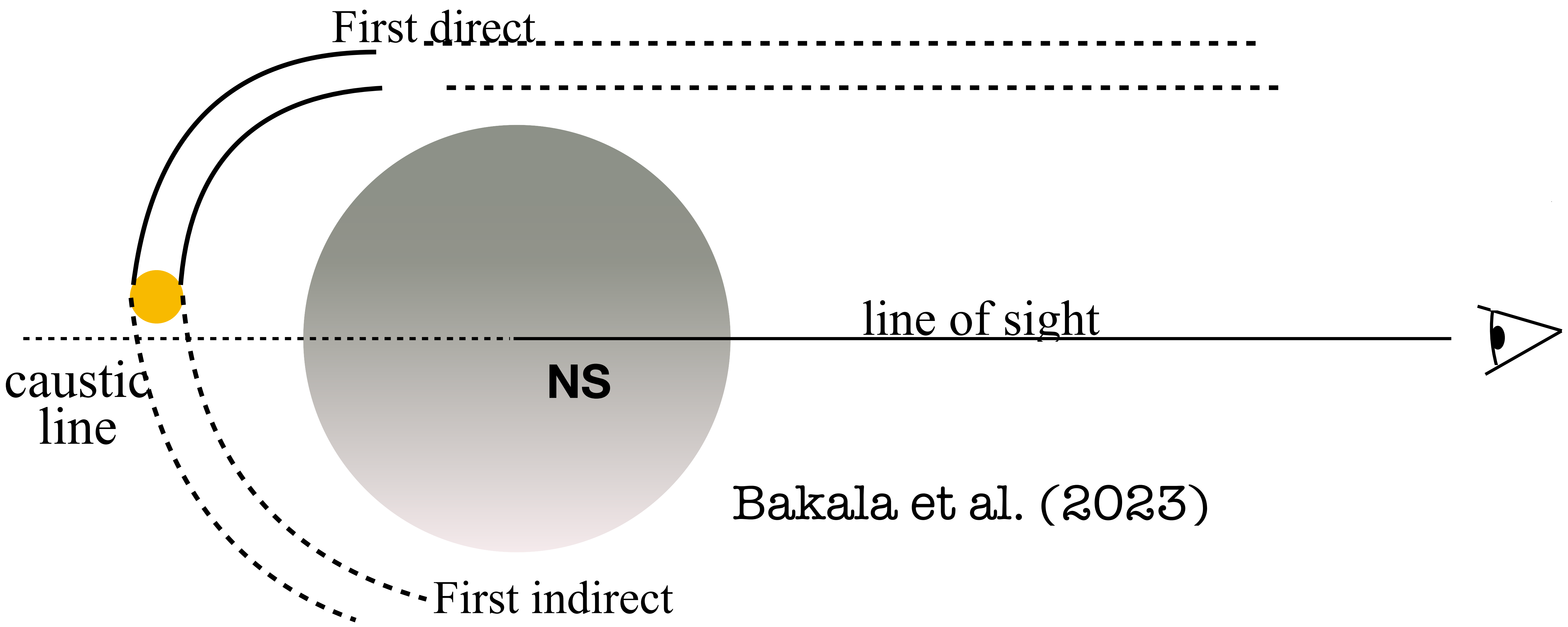
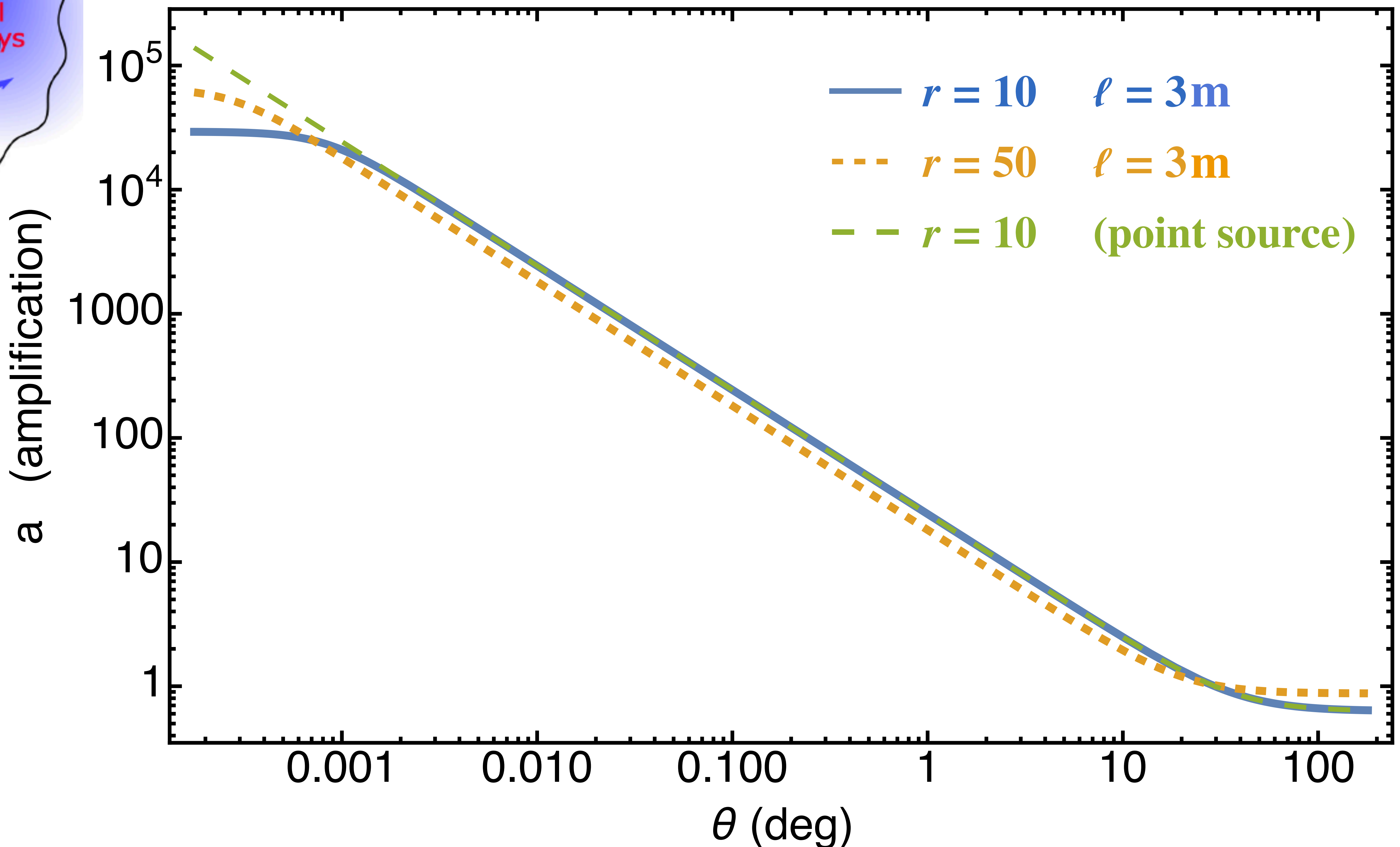
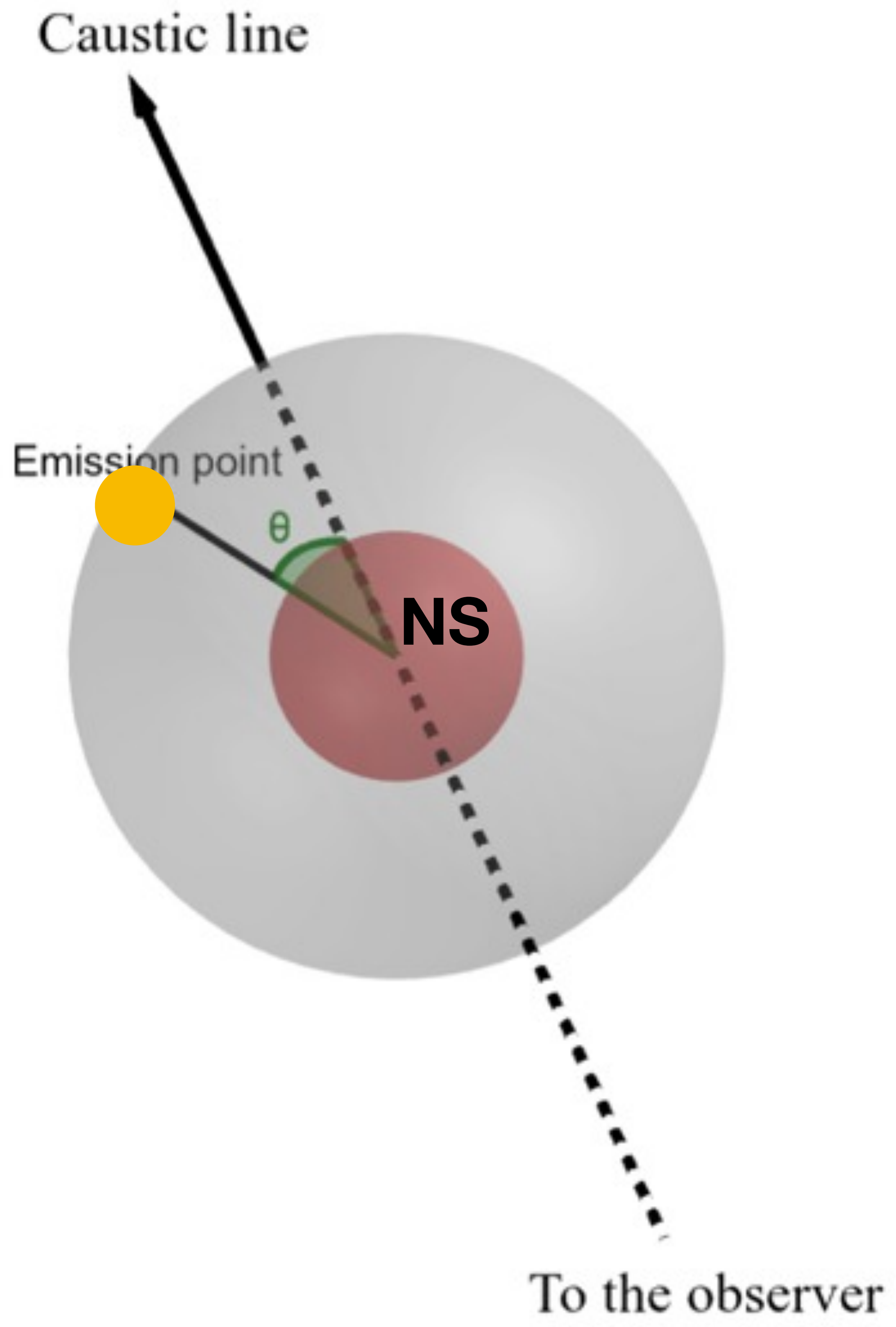
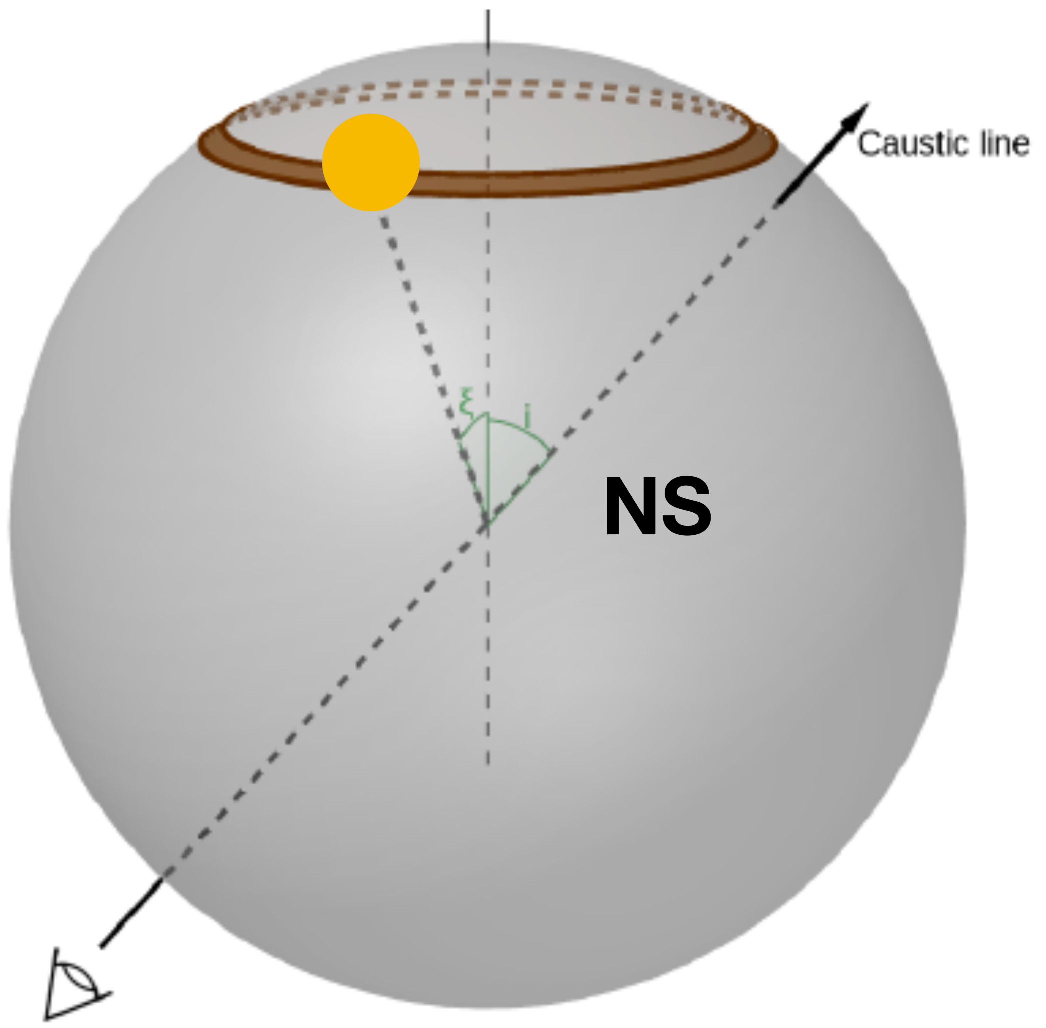


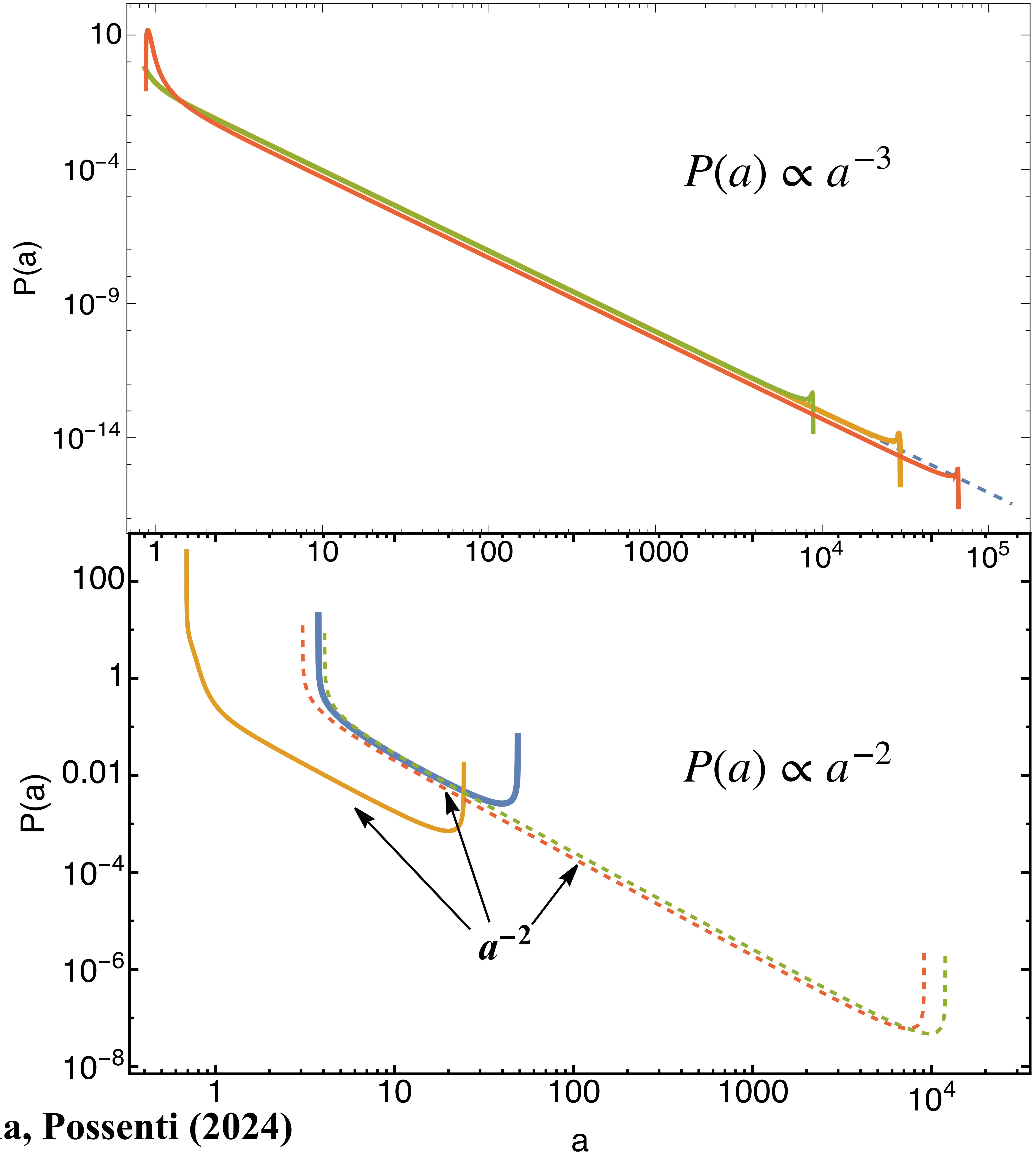
Bakala et al. (2023)



GRAVITATIONAL SELF-LENSING OF MAGNETOSPHERIC FLARES







Dall'Osso, La Placa, Stella, Possenti (2024)

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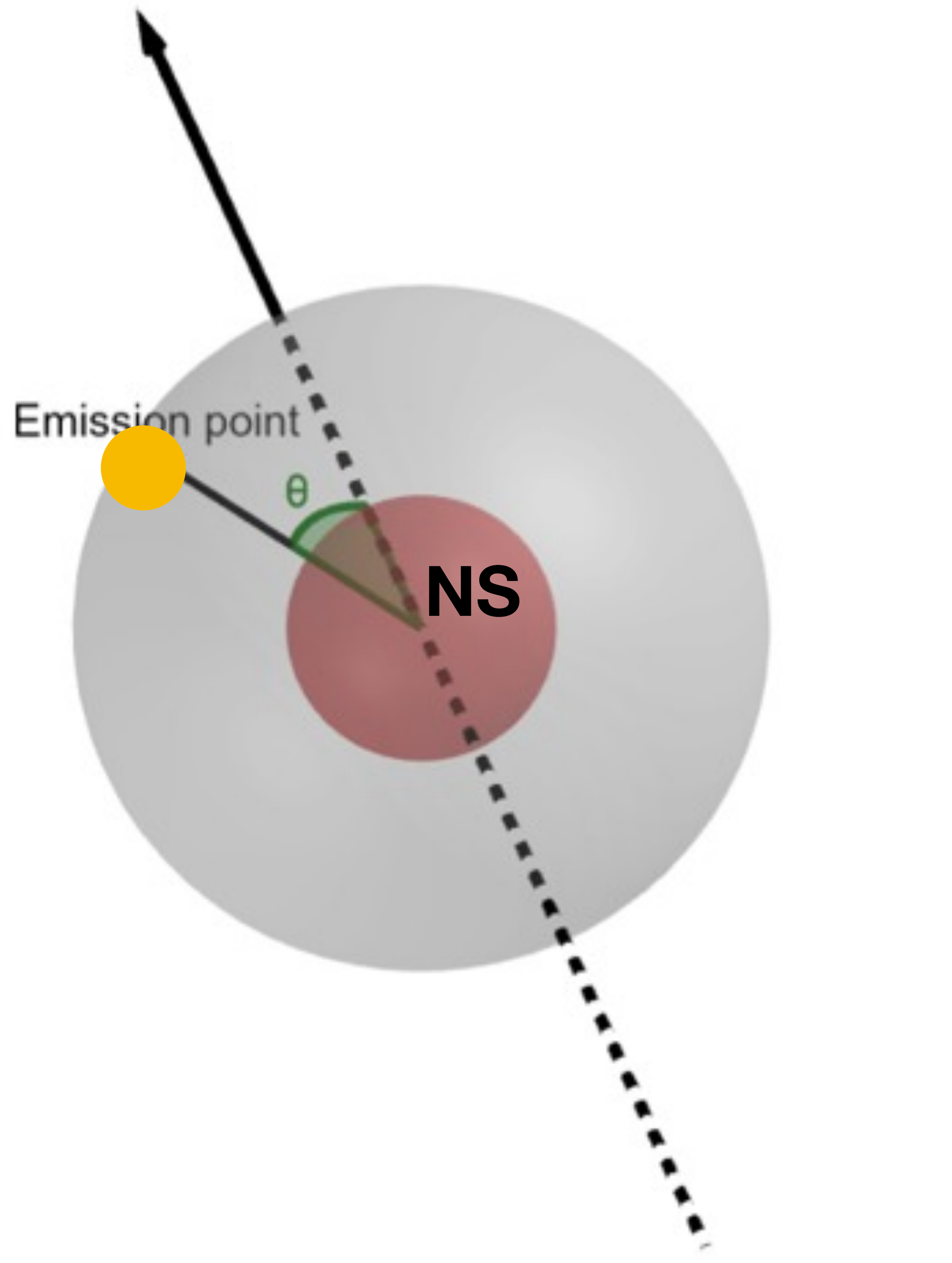

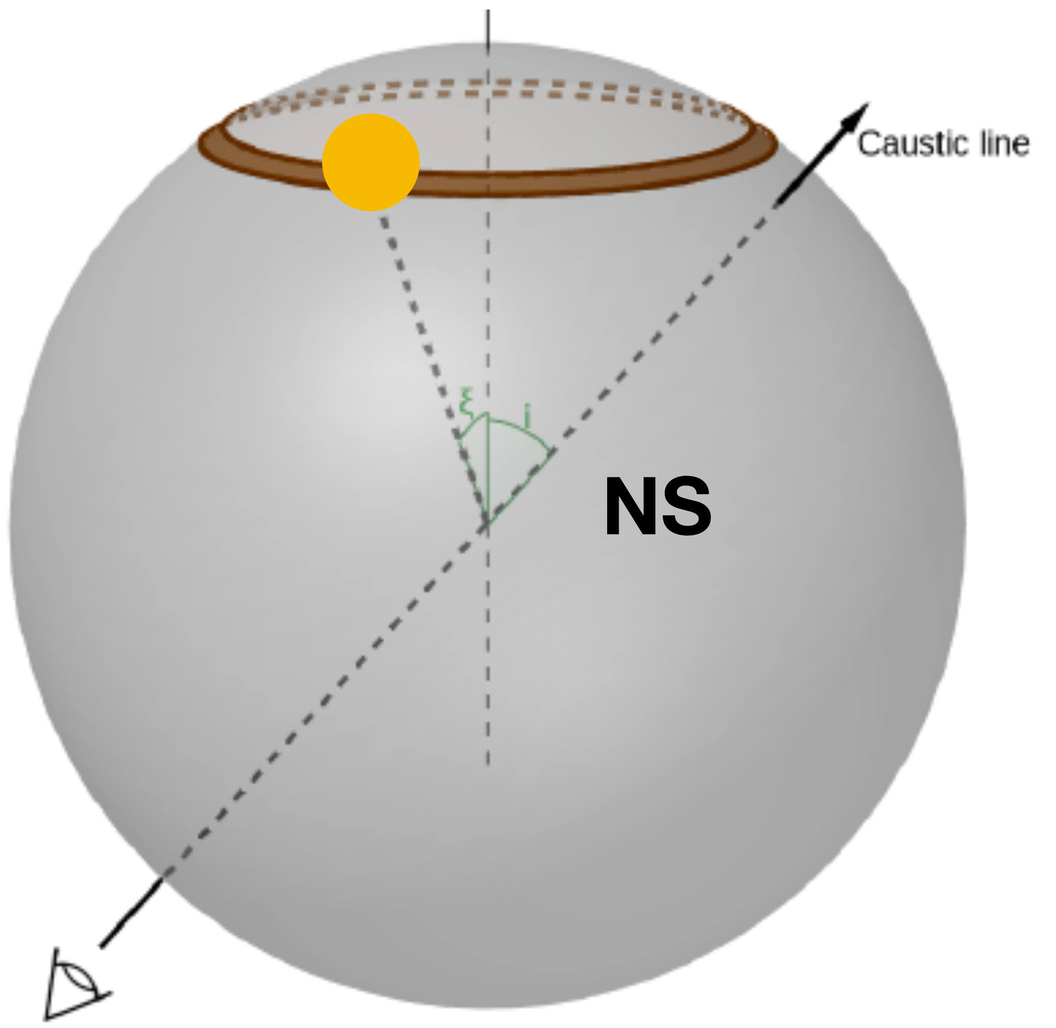

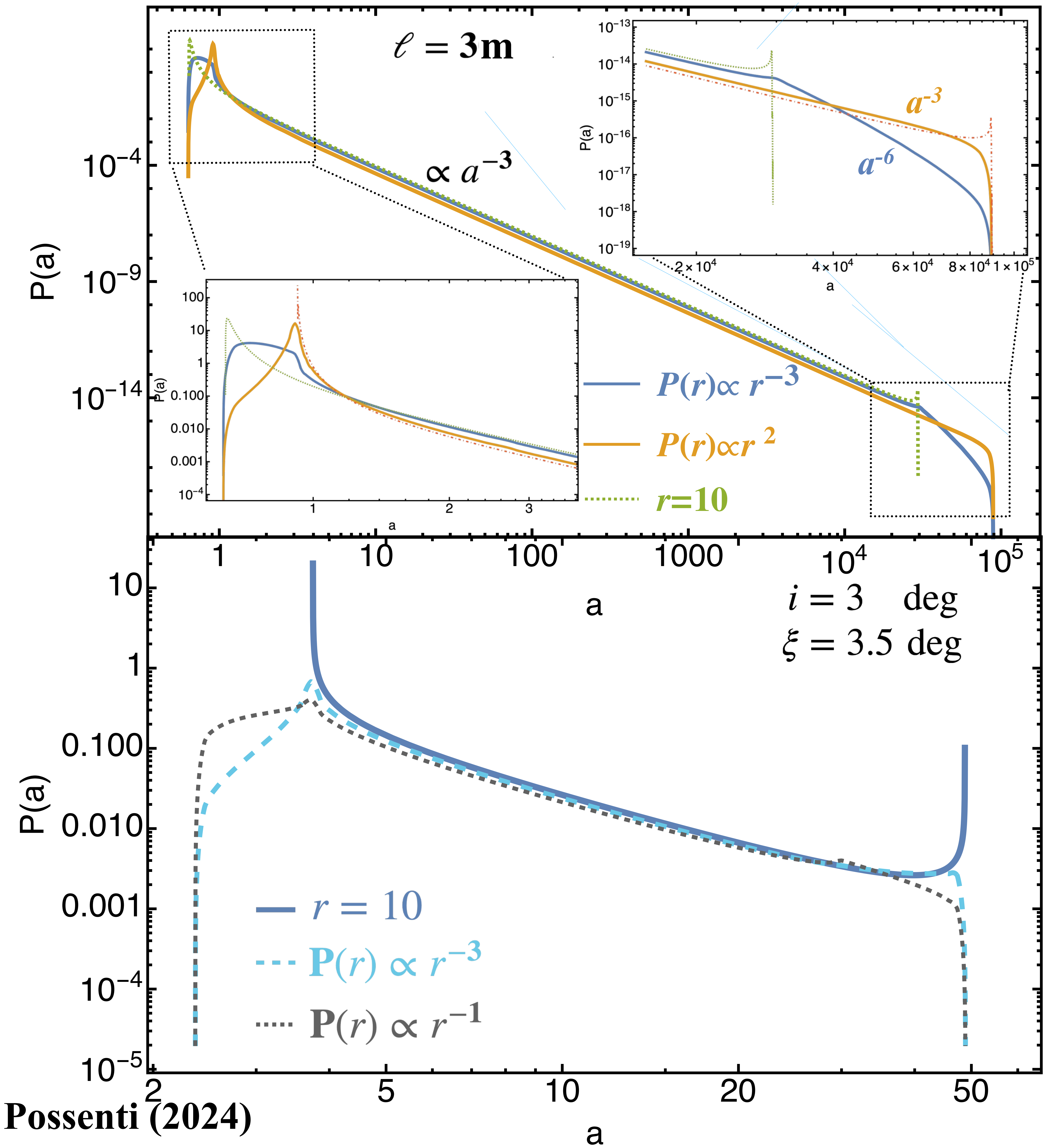

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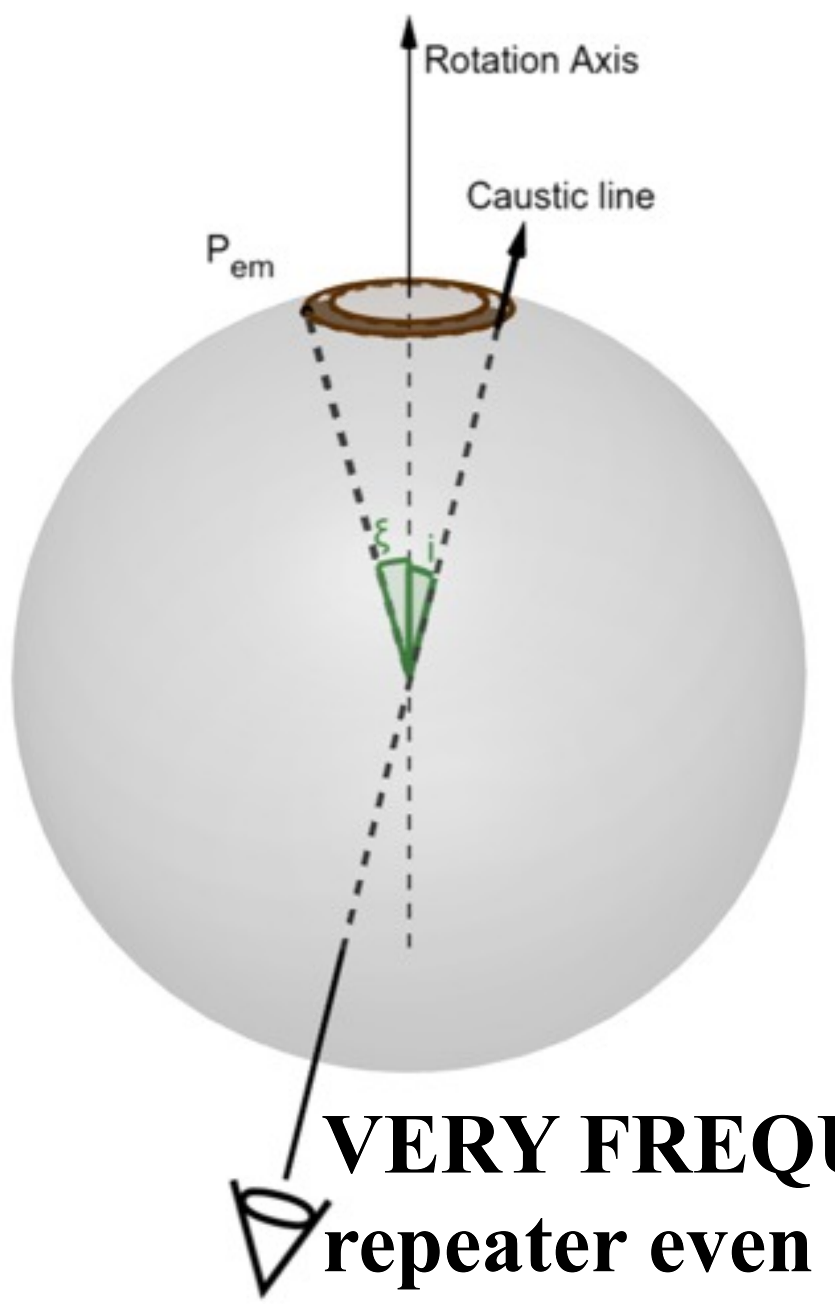
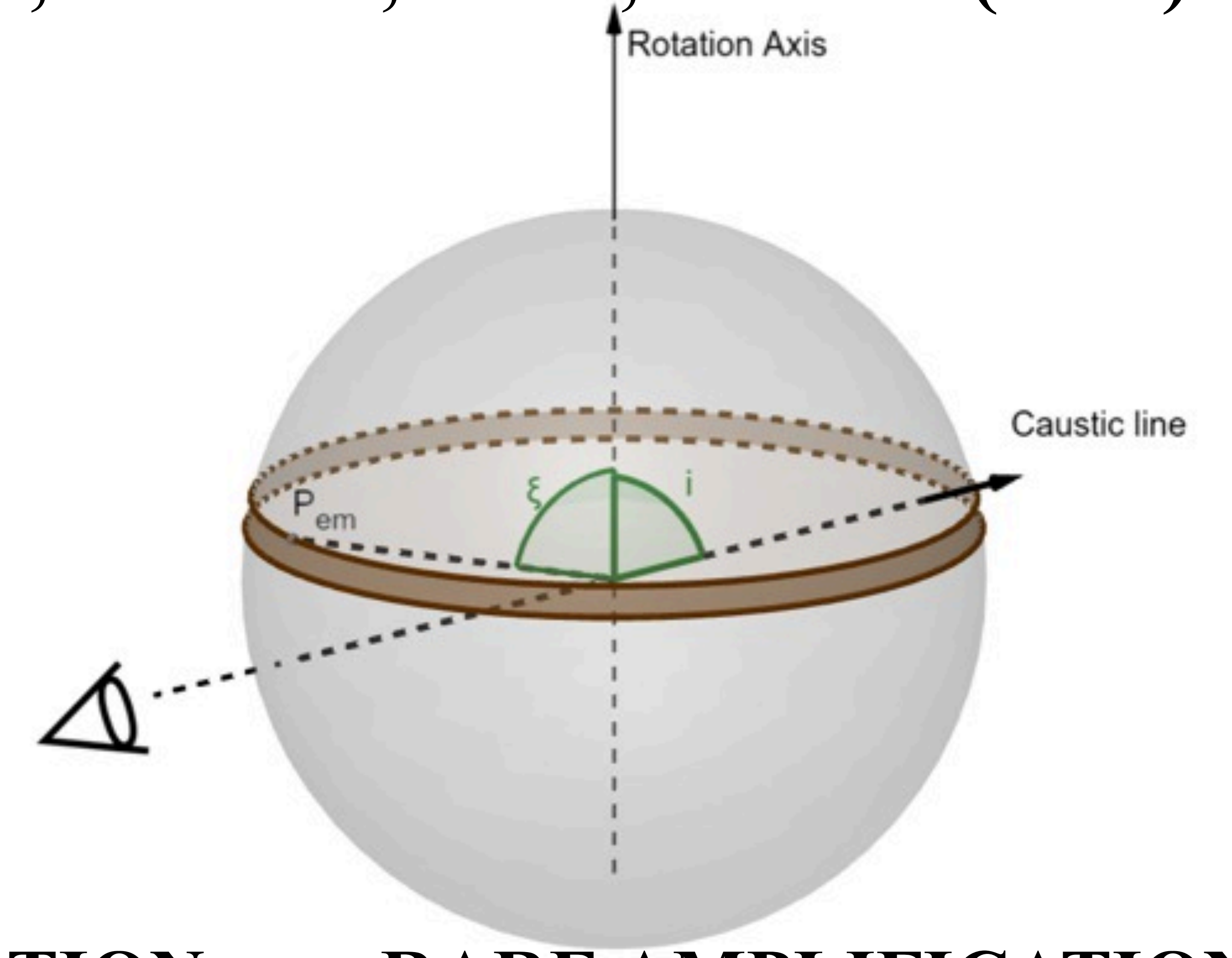
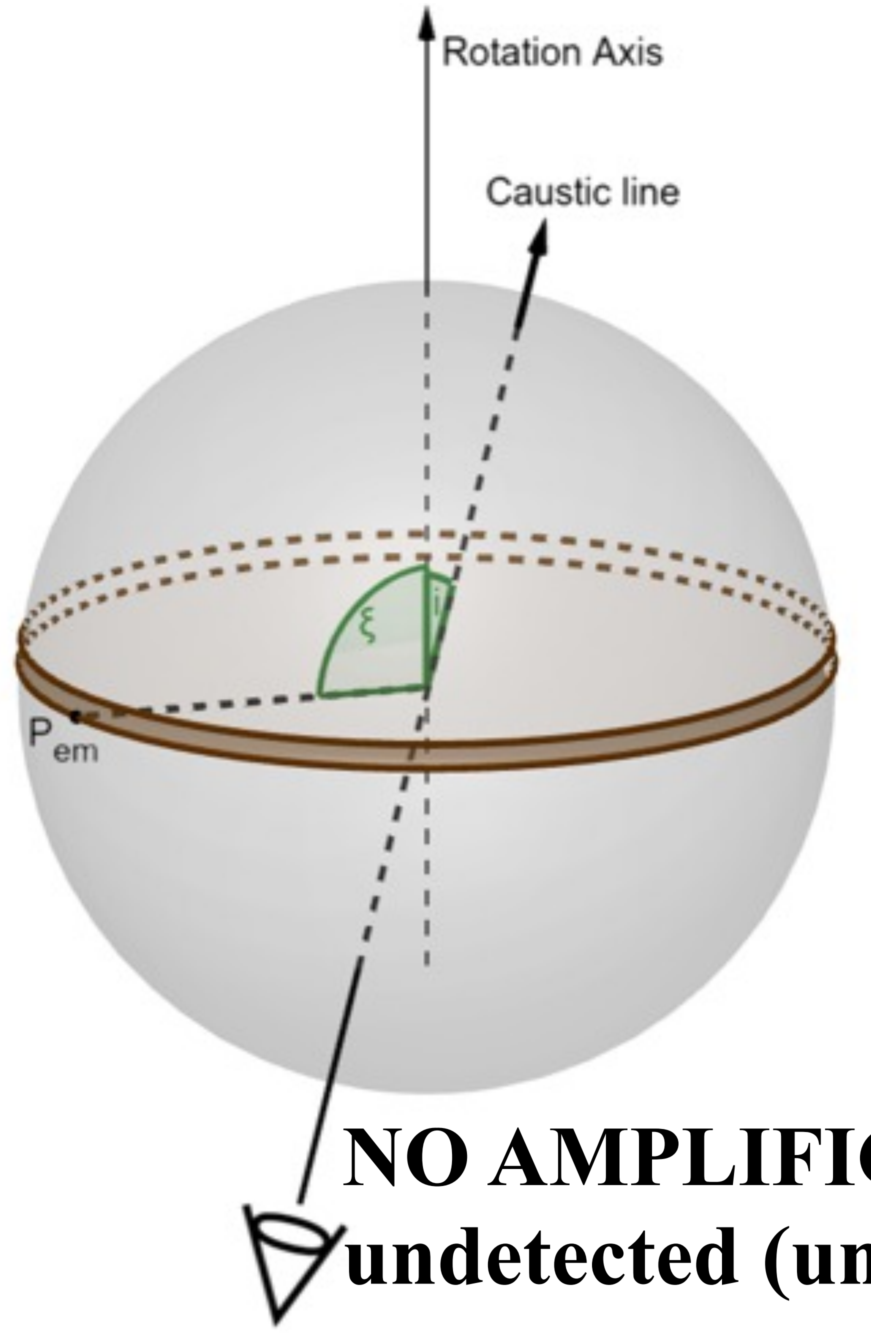


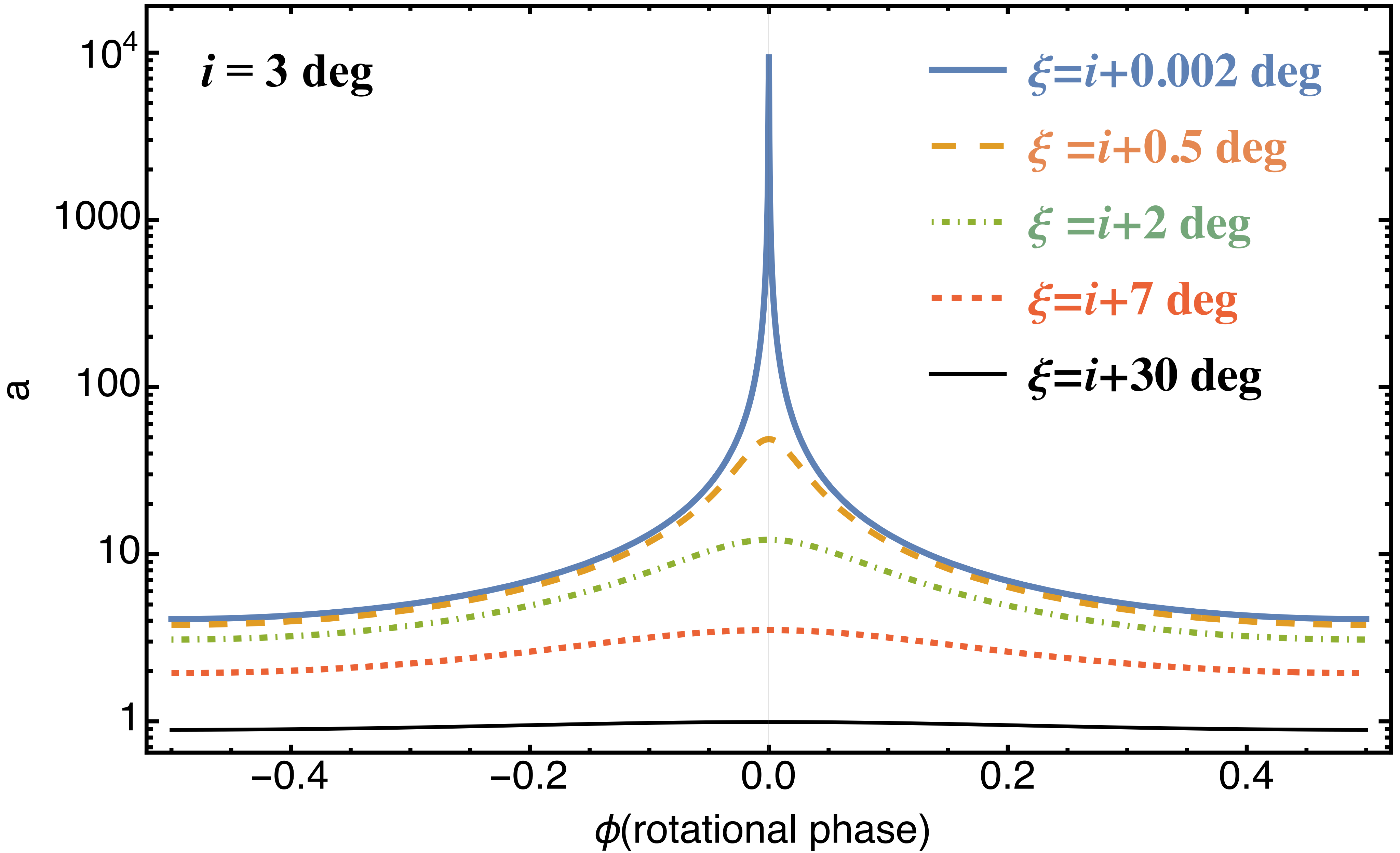
VERY FREQUENT AMPLIFICATION: repeater even with short obs. time

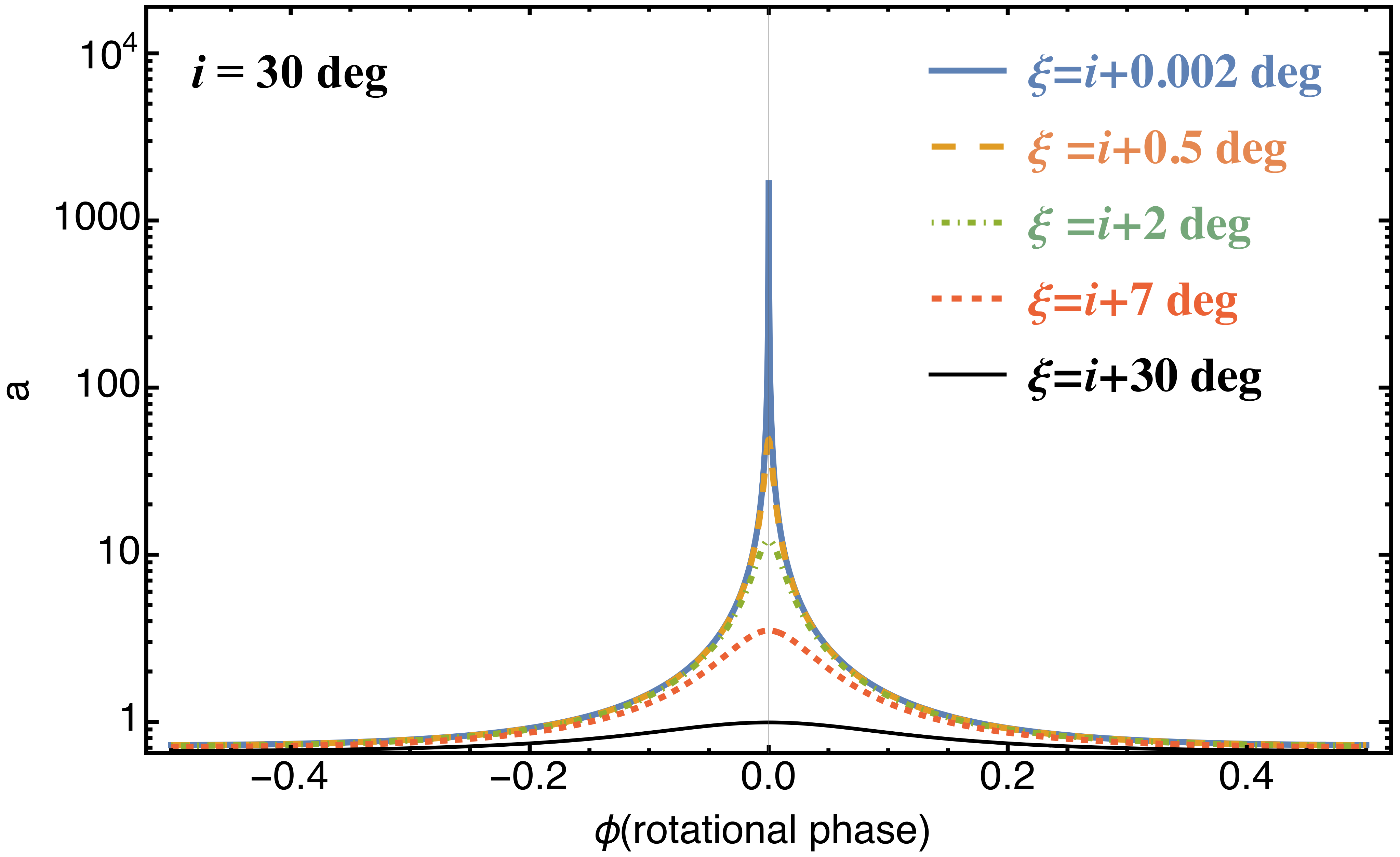


RARE AMPLIFICATION: one-offs (will become a repeater in the future)



NO AMPLIFICATION: undetected (unless nearby)





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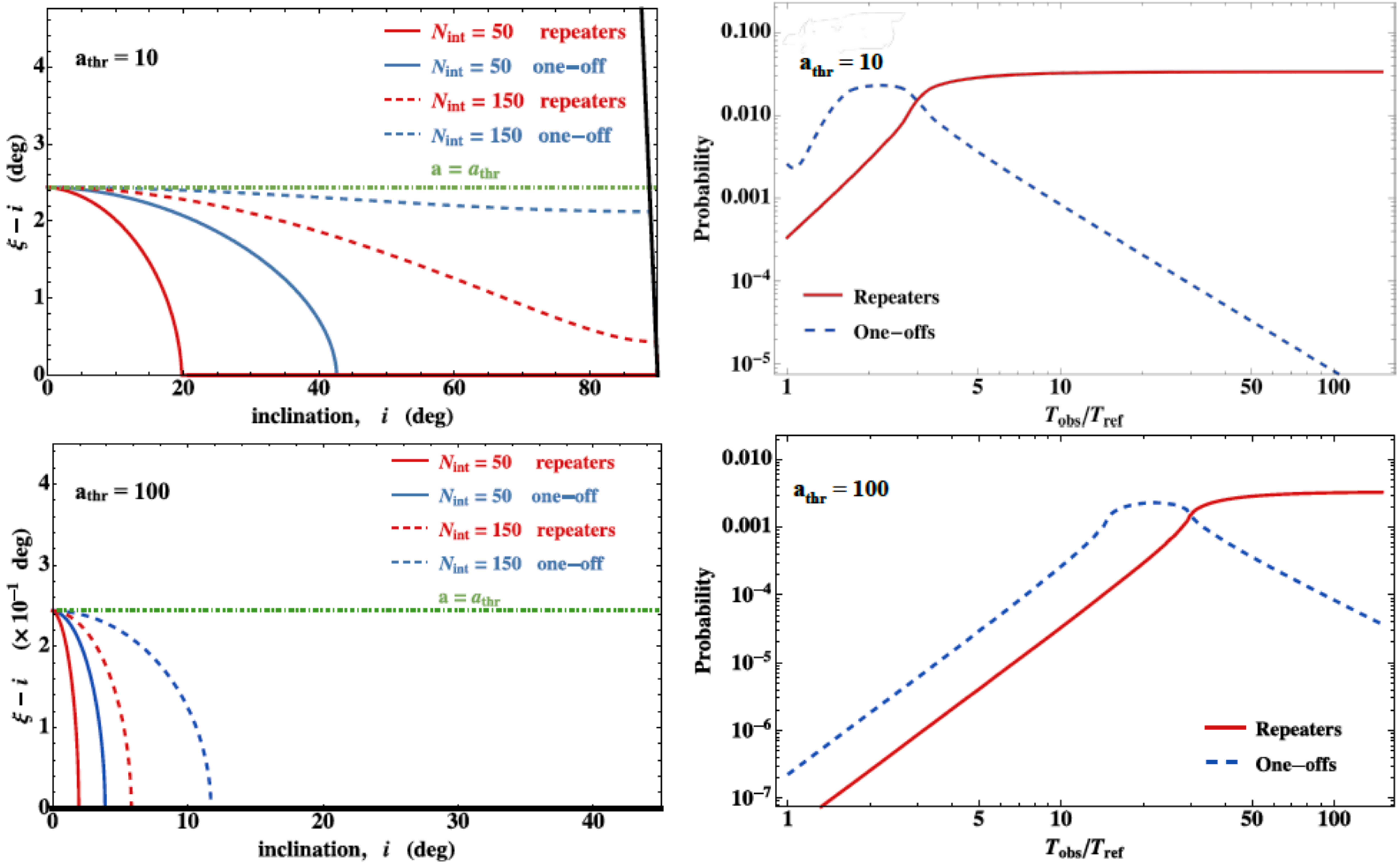
Dall'Osso, La Placa, Stella, Possenti (2024)

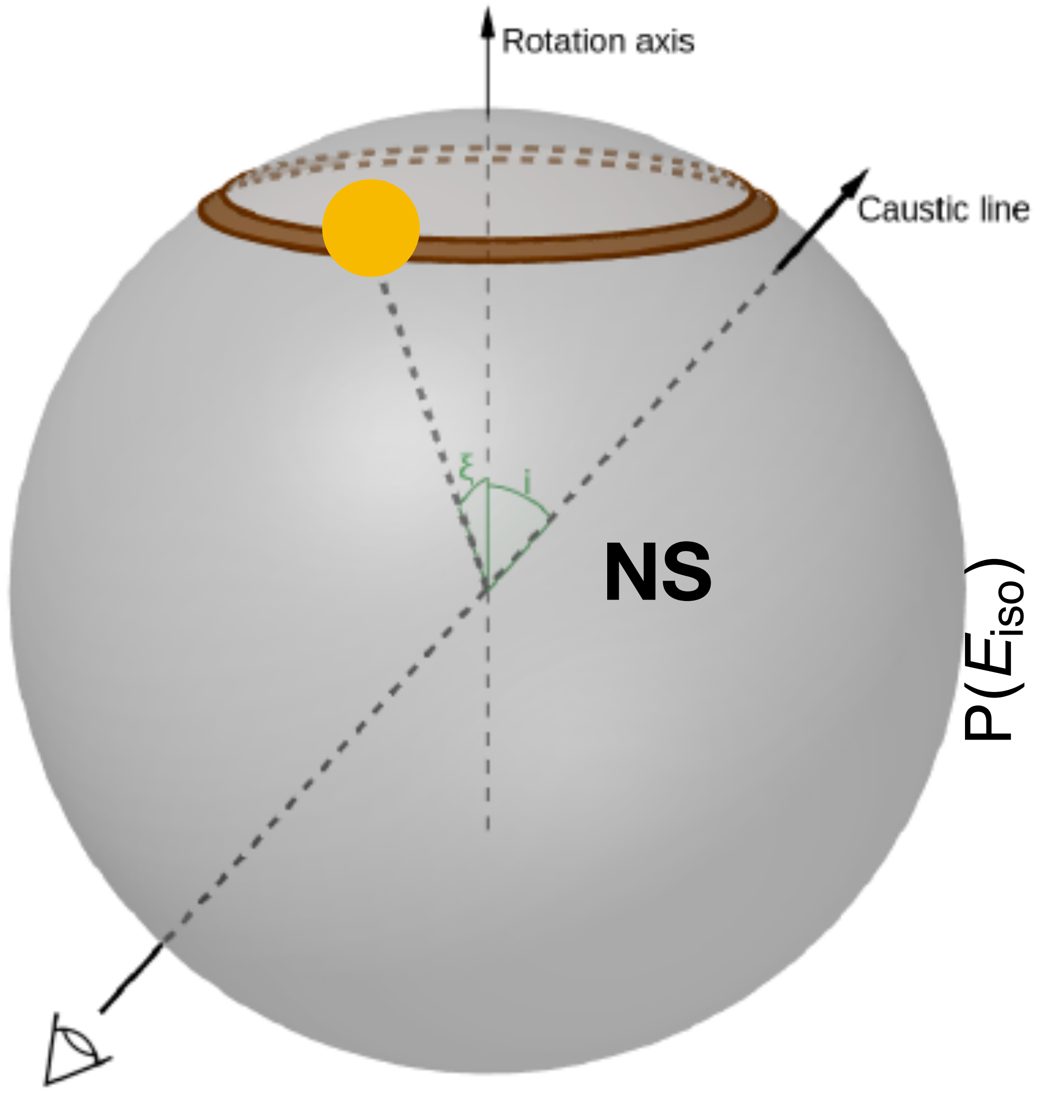


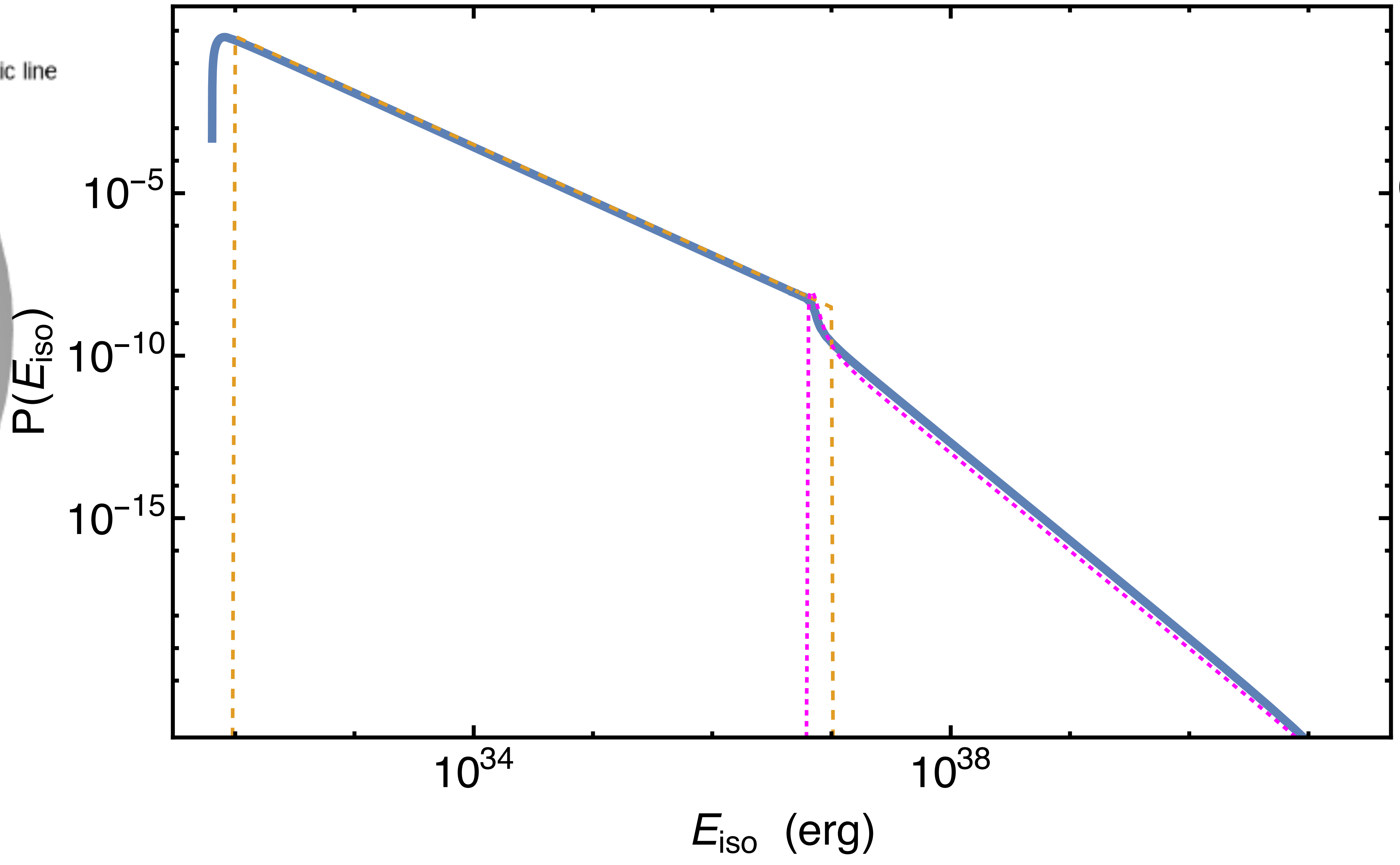
GRAVITATIONAL SELF-LENSING OF MAGNETOSPHERIC FLARES

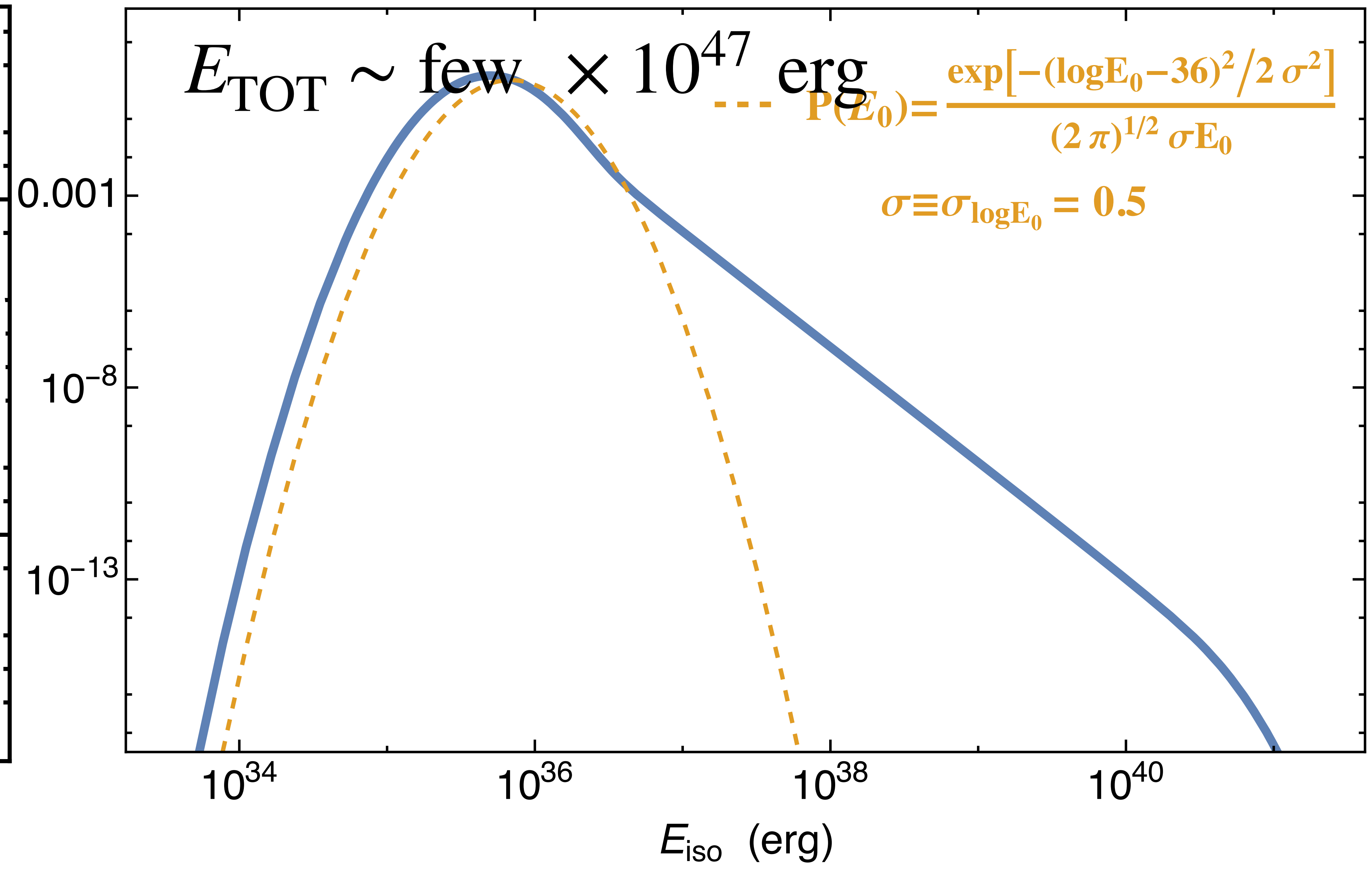
Dall'Osso, La Placa, Stella, Possenti (2024)

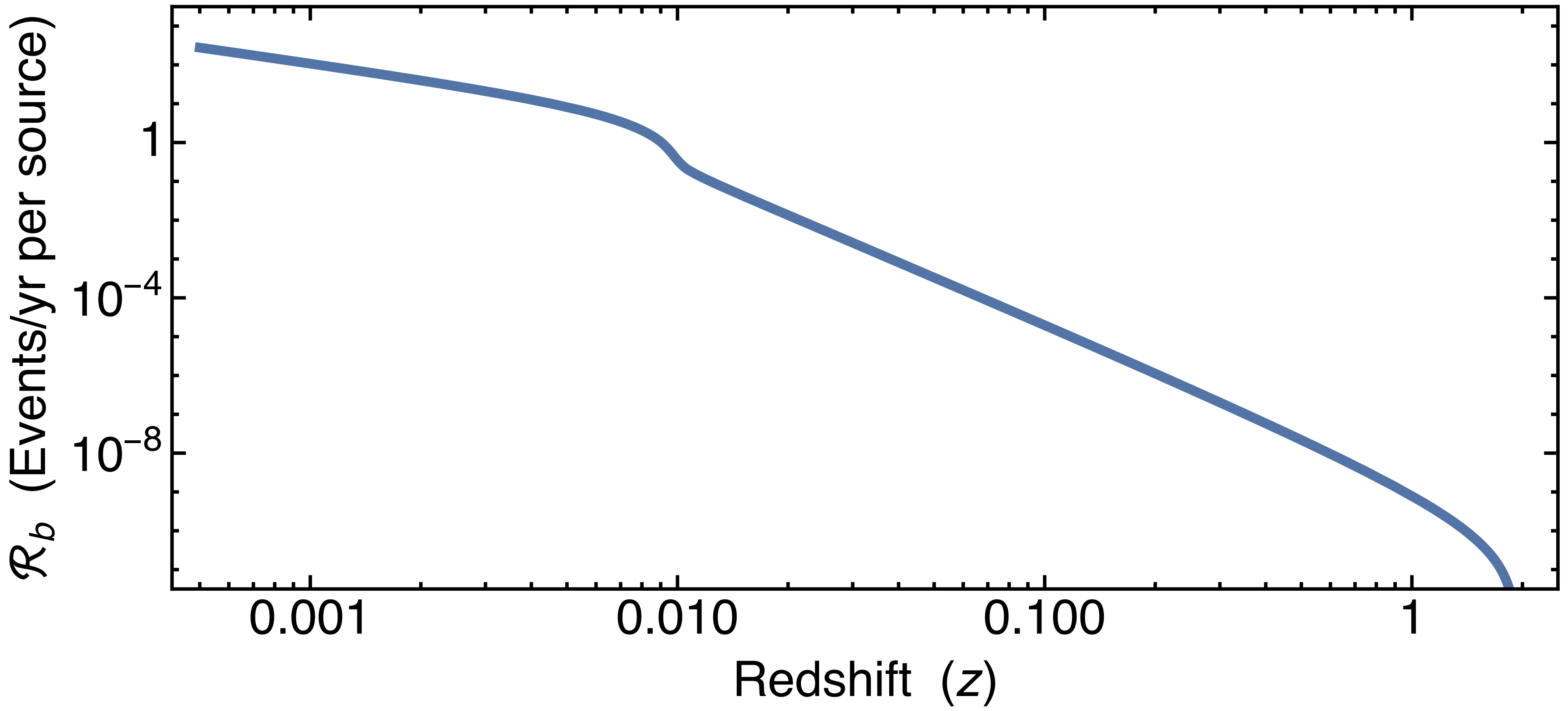
$\mathscr{R} \sim 0.3 \ \mathrm{day}^{-1}$

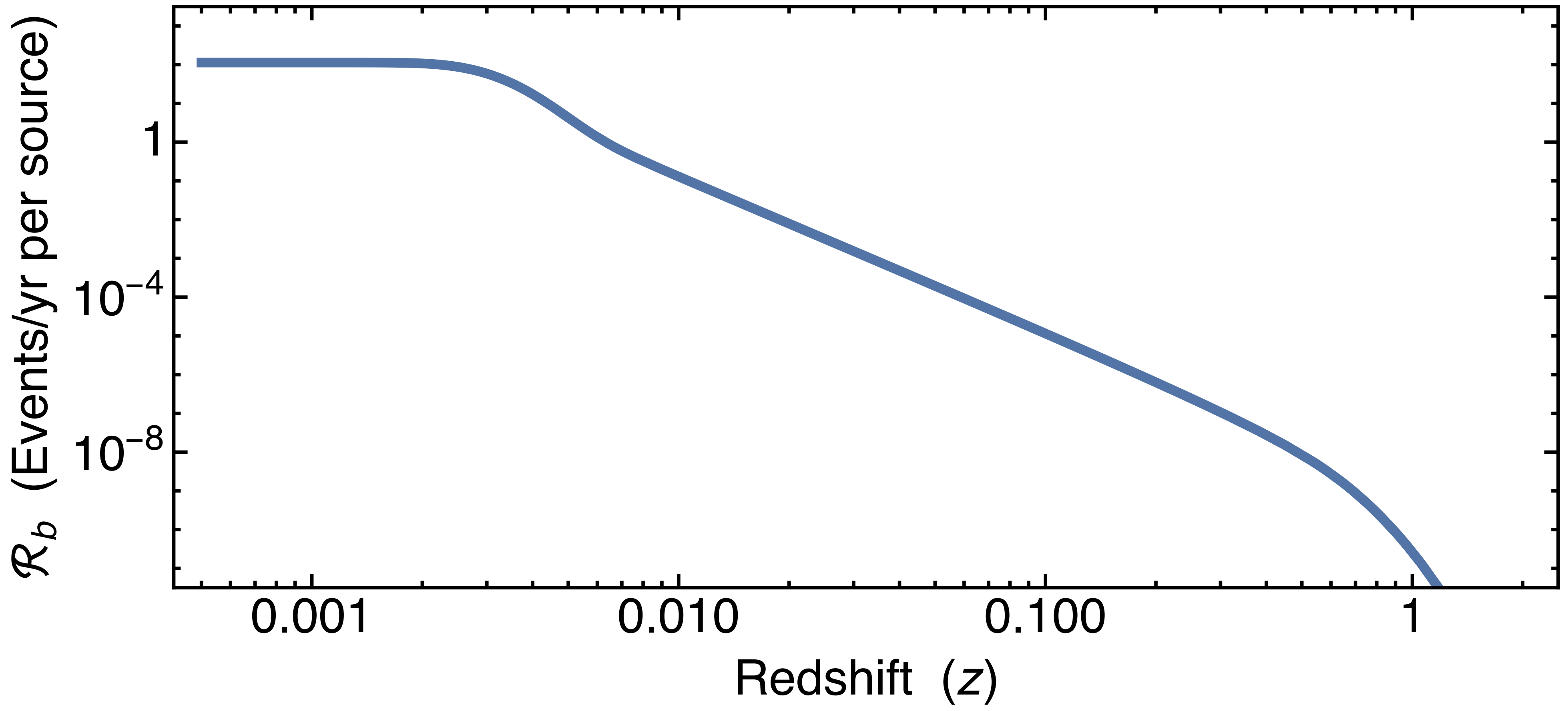
INTRINSIC EVENT RATE PER SOURCE





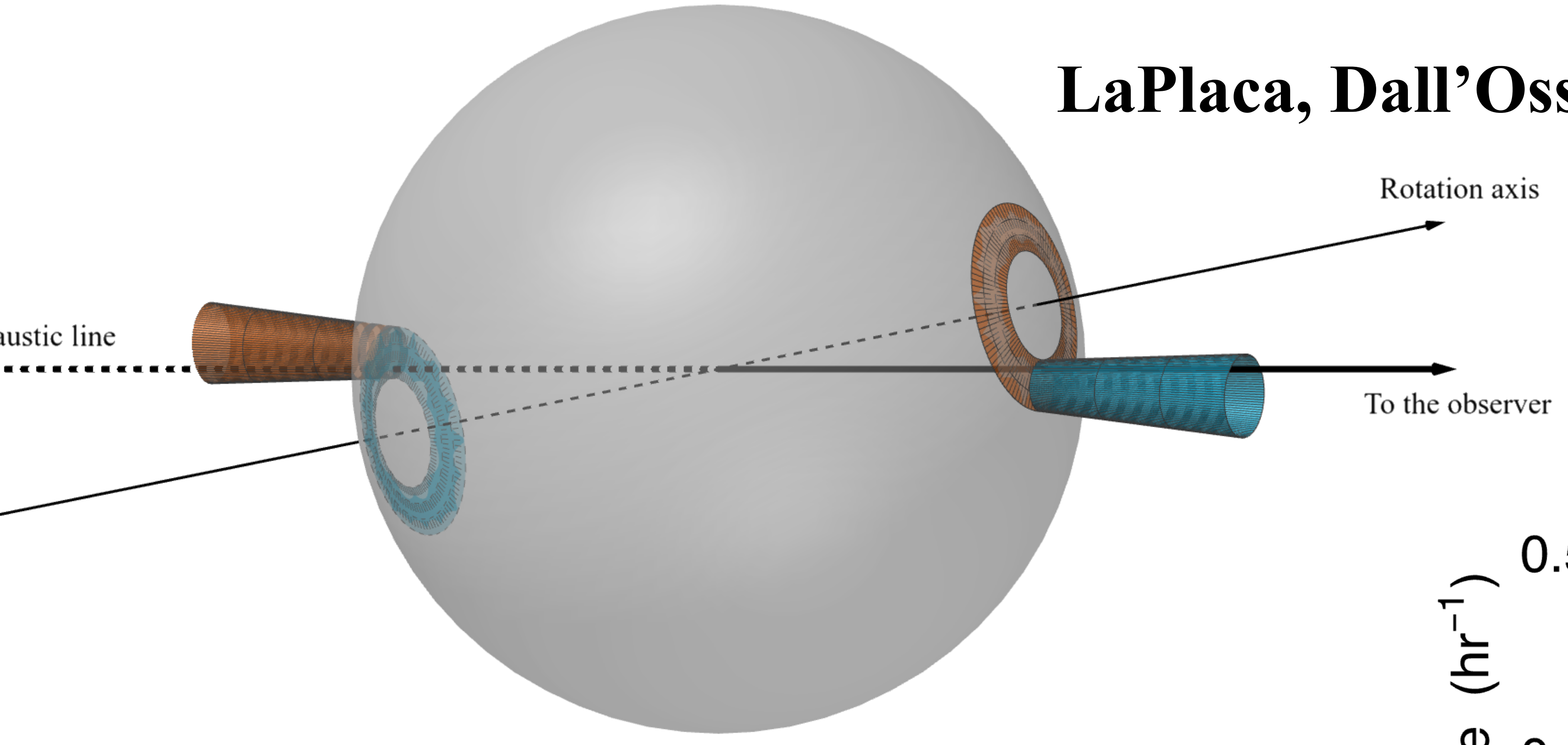






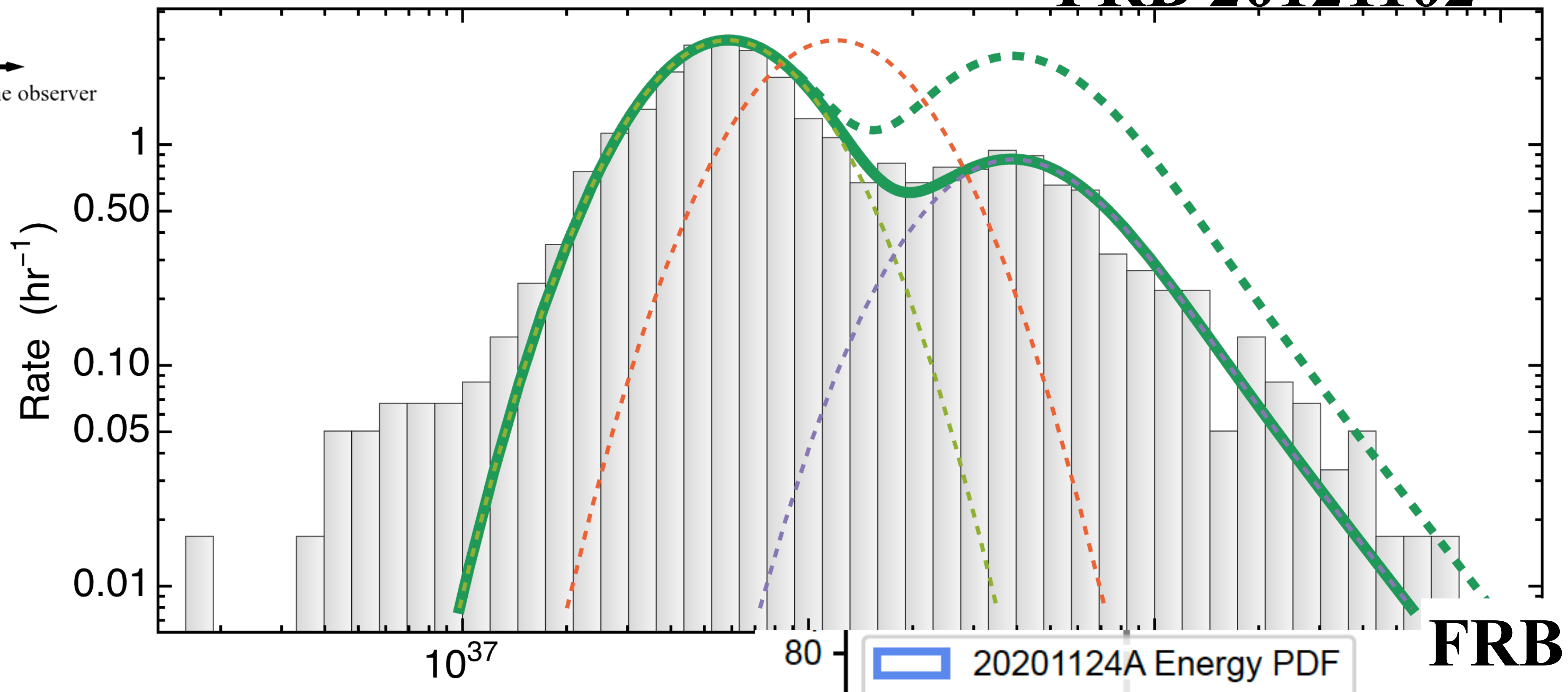
GRAVITATIONAL SELF-LENSING: UNDERSTANDING STRONG REPEATERS

LaPlaca, Dall'Osso, Stella, Possenti (in preparation)



Li et al. (2021)

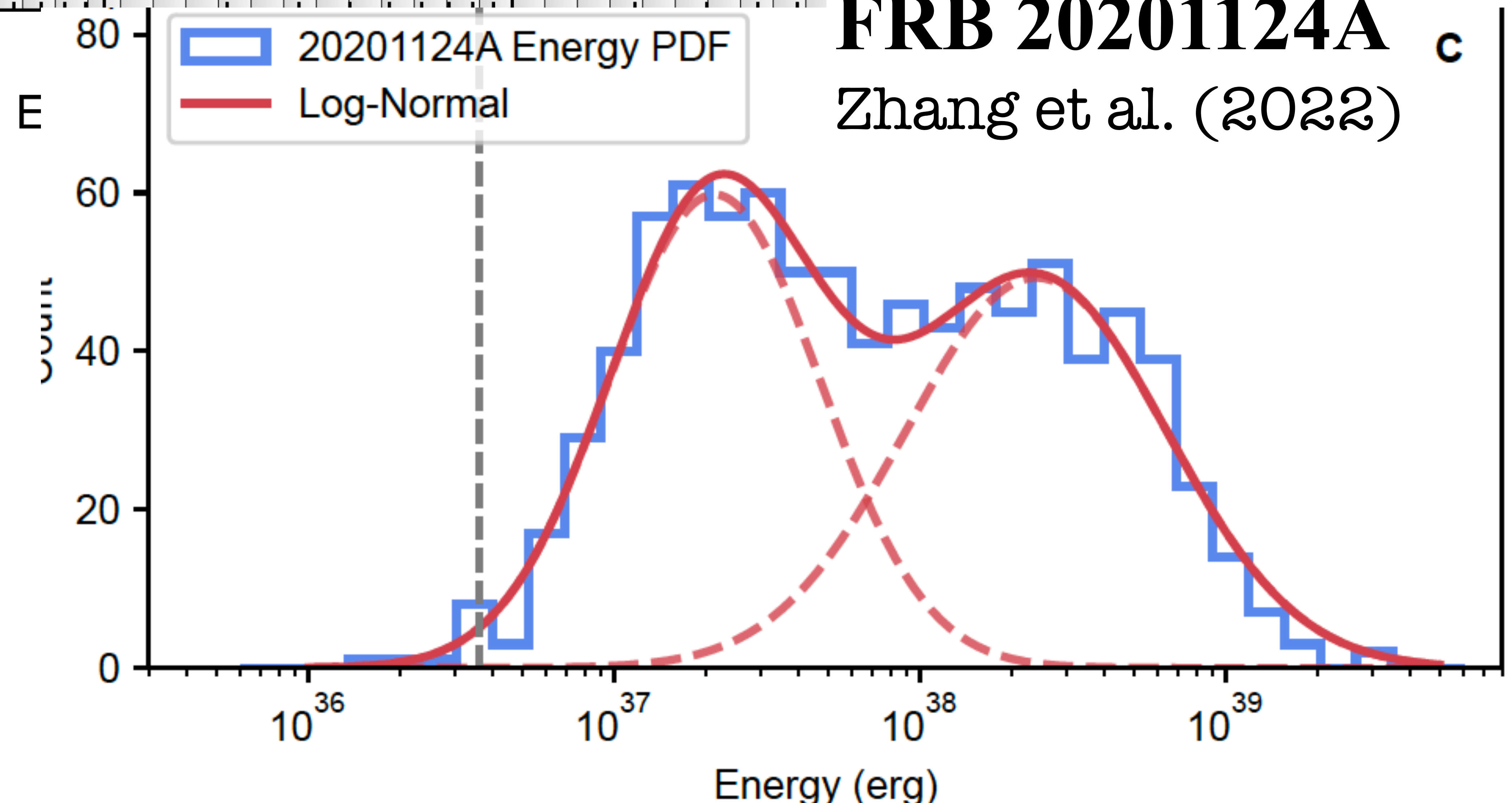
FRB 20121102



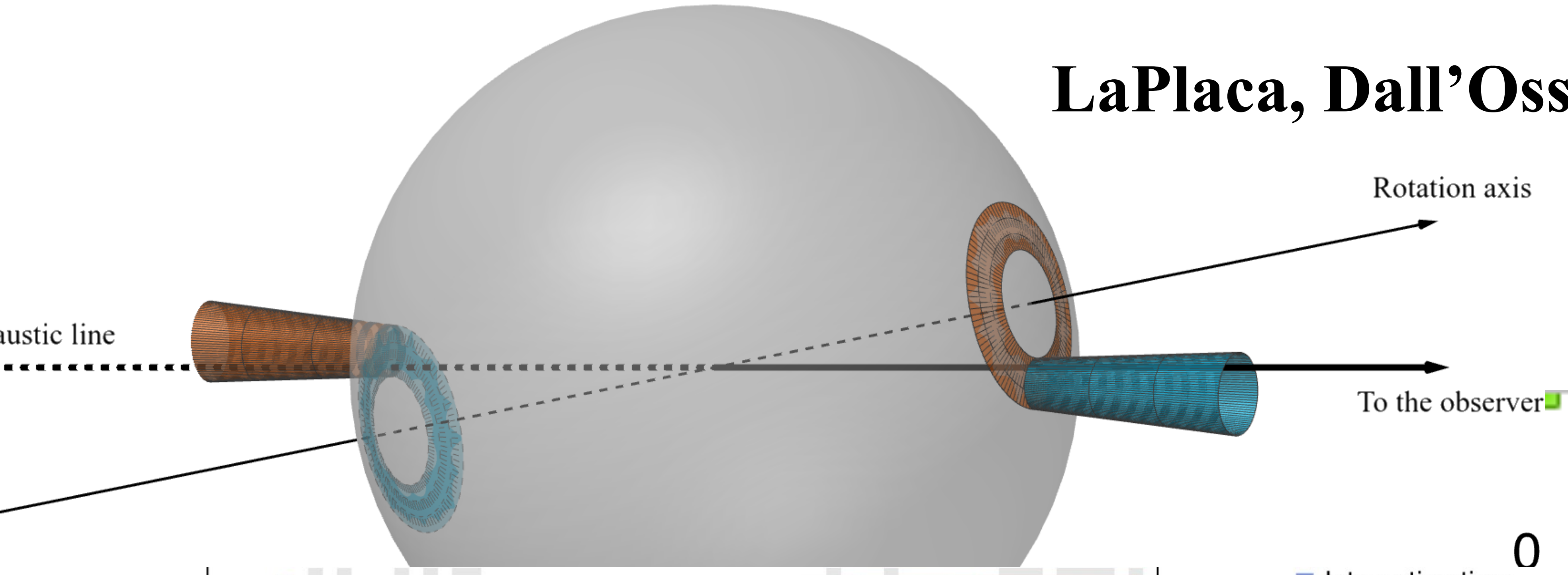
VERY FREQUENT AMPLIFICATION:
Geometry of very active repeaters can be significantly constrained

FRB 20201124A

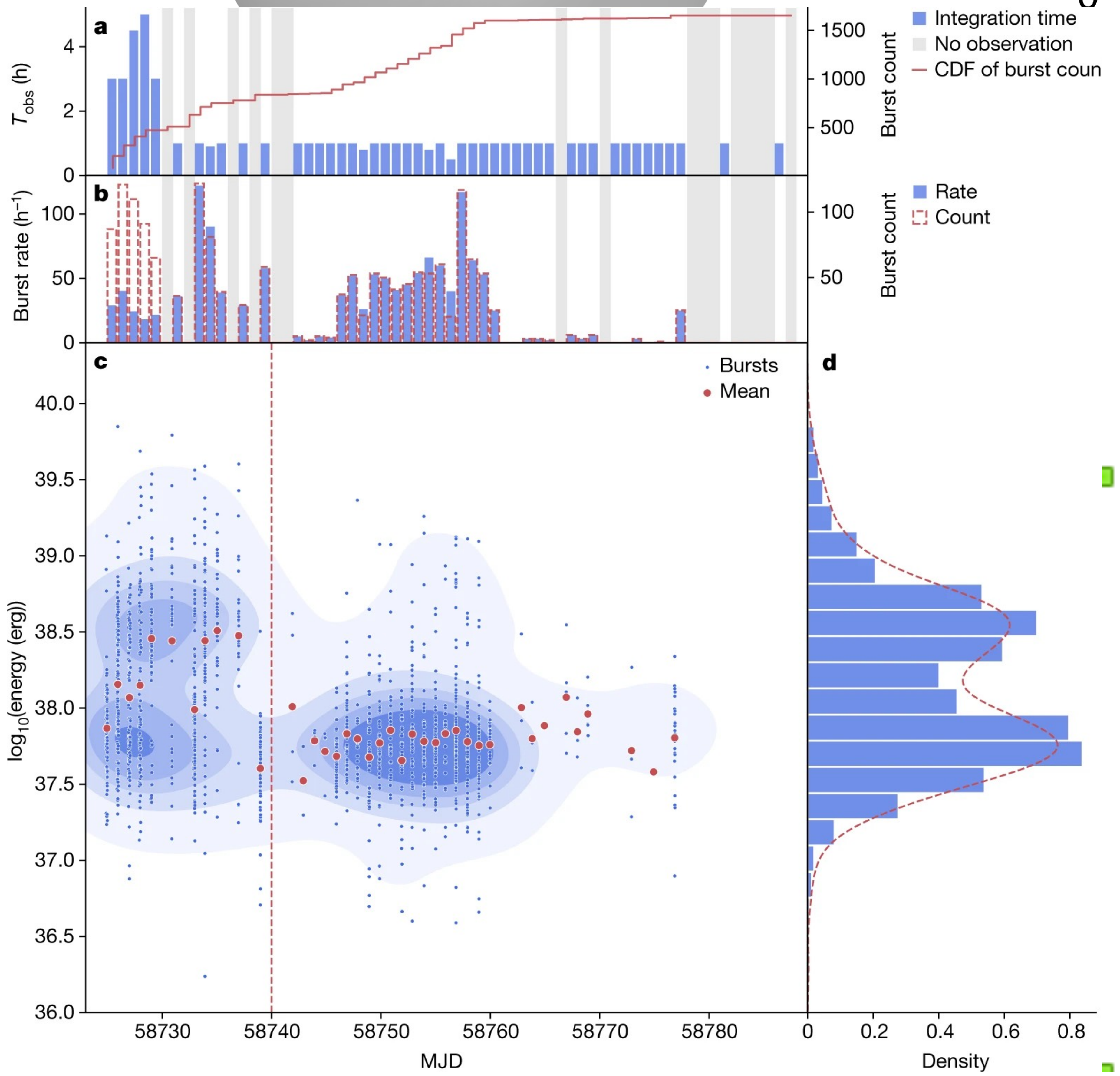
Zhang et al. (2022)



SEARCHING MORE INFO FROM EM OBSERVATIONS: FRBs



LaPlaca, Dall'Osso, Stella, Possenti (in preparation)



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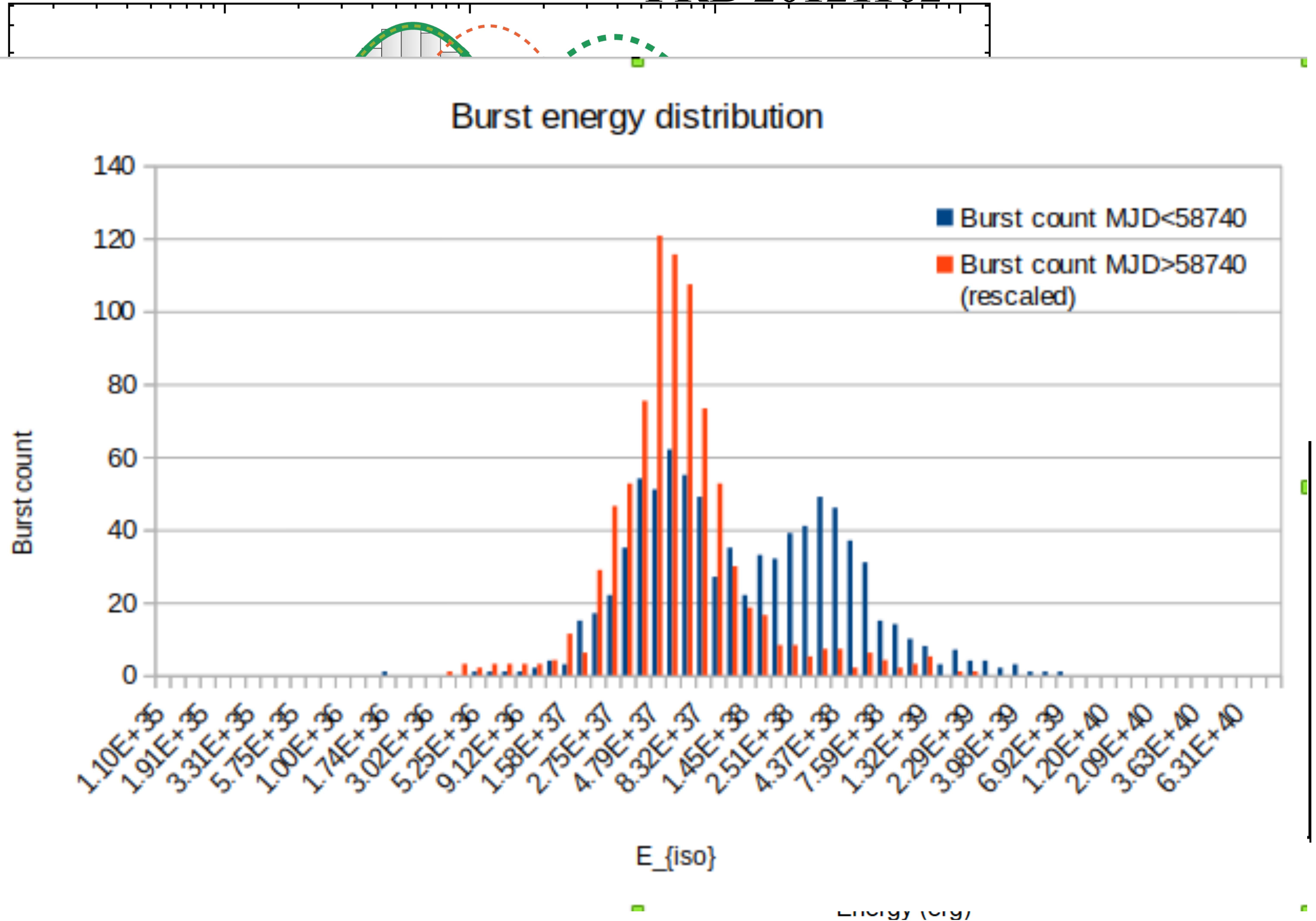

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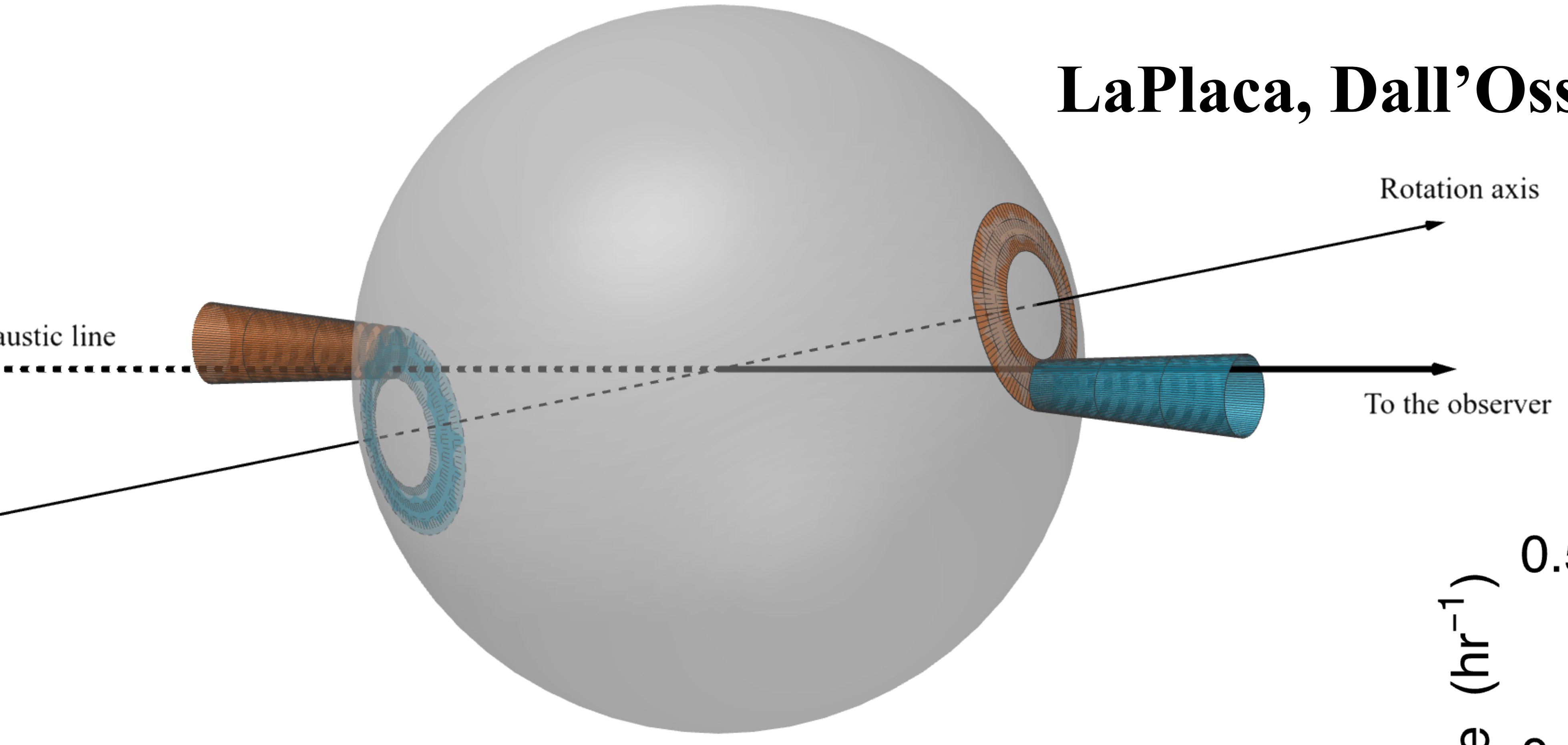

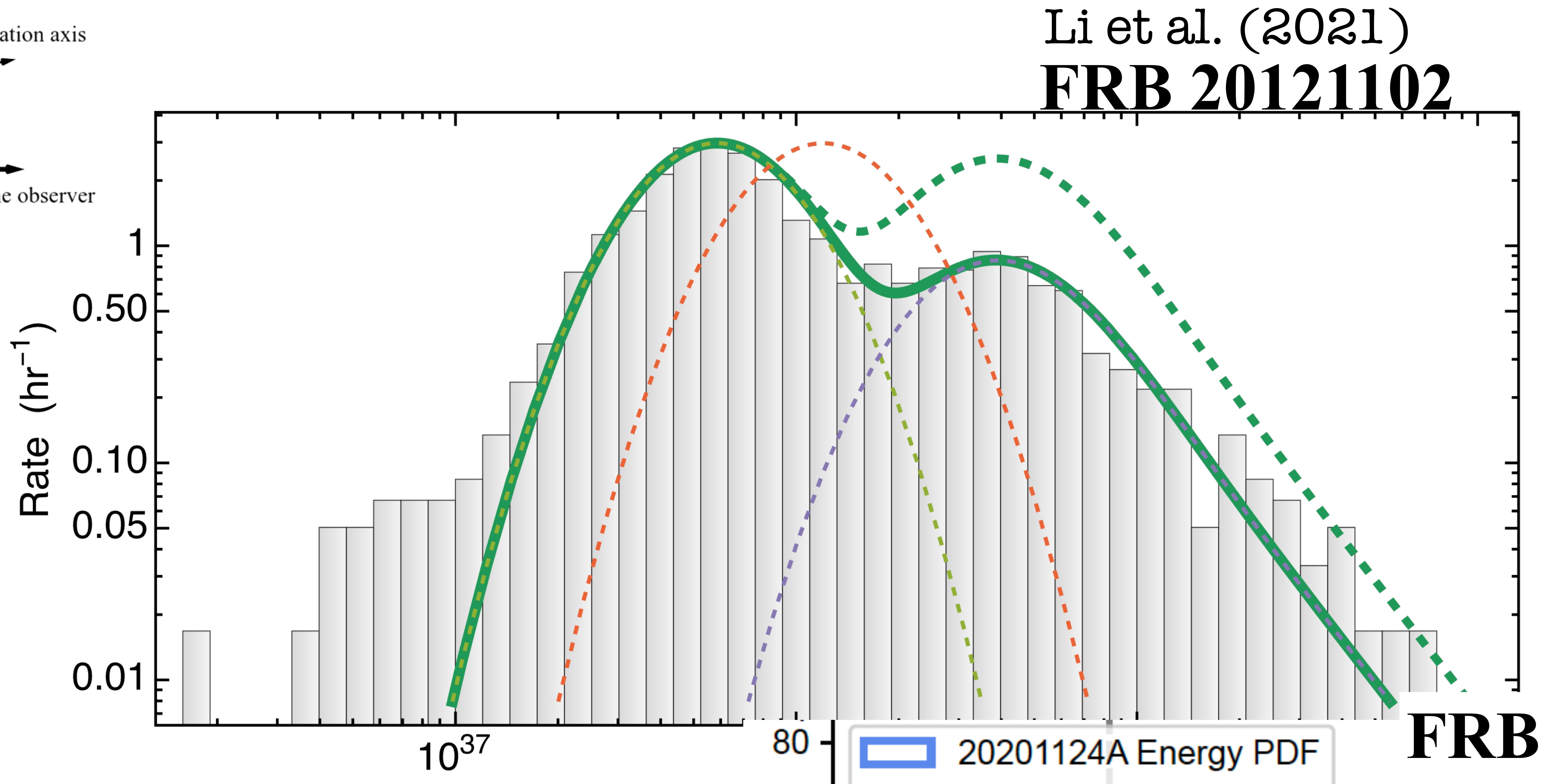

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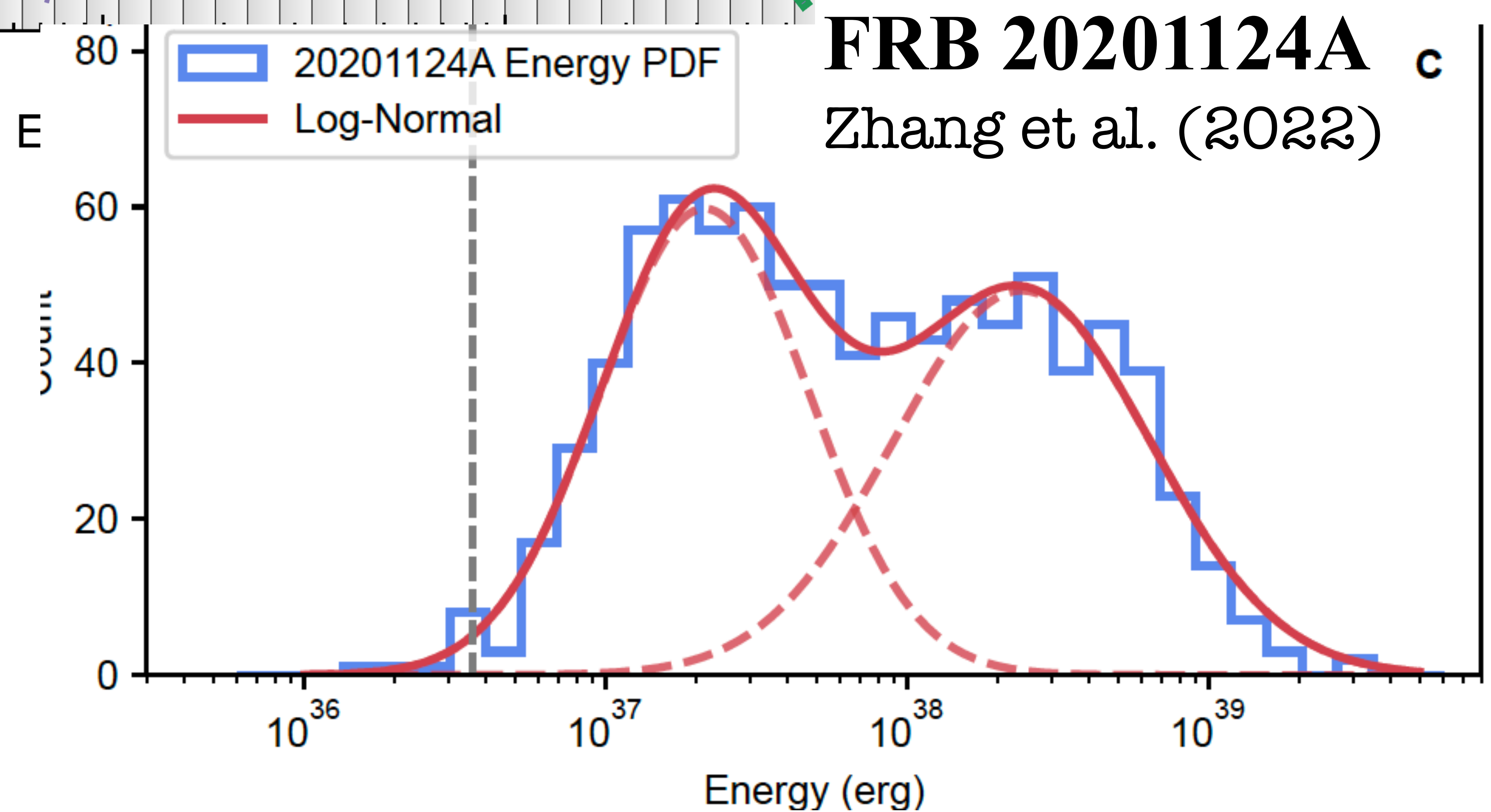
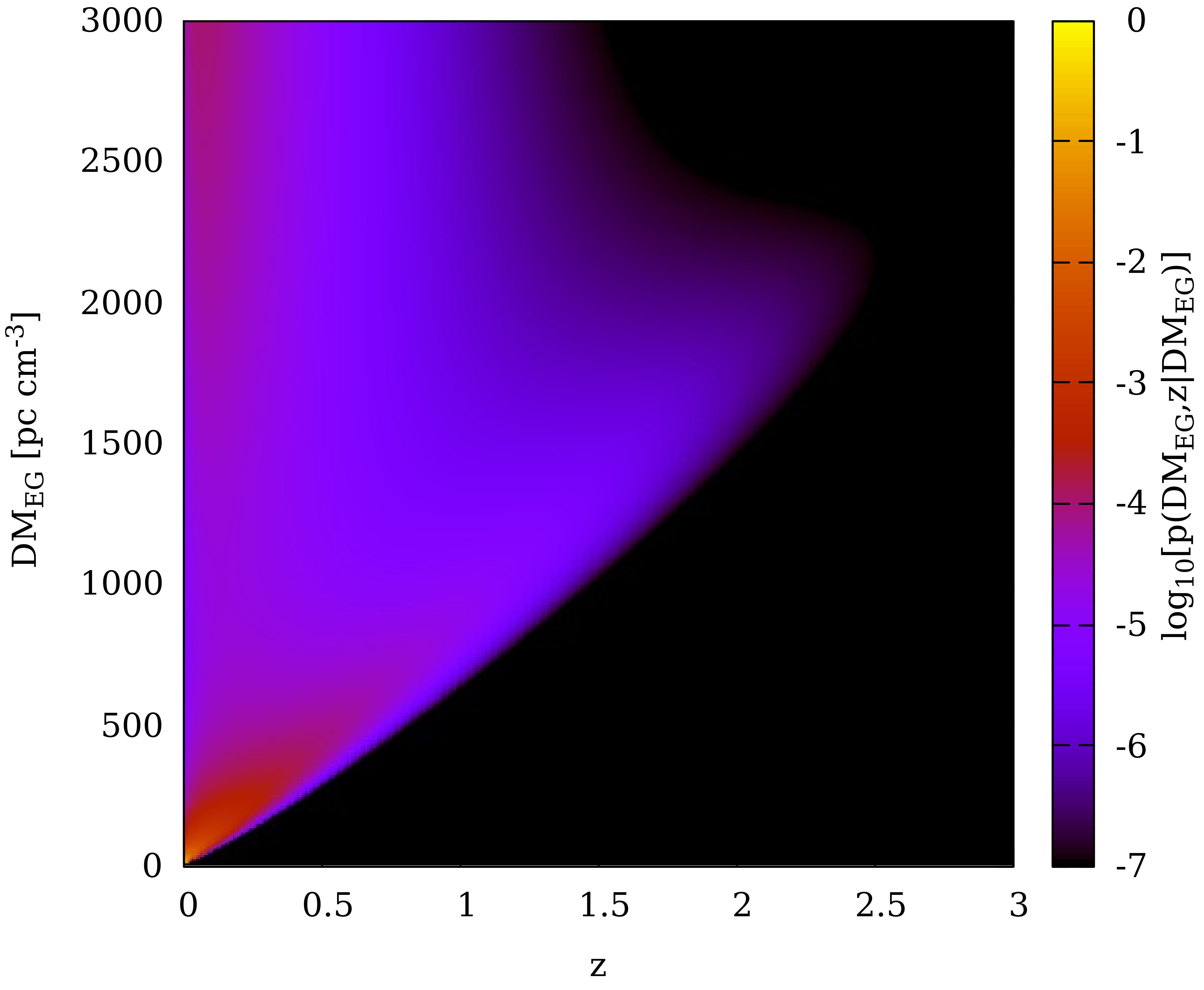
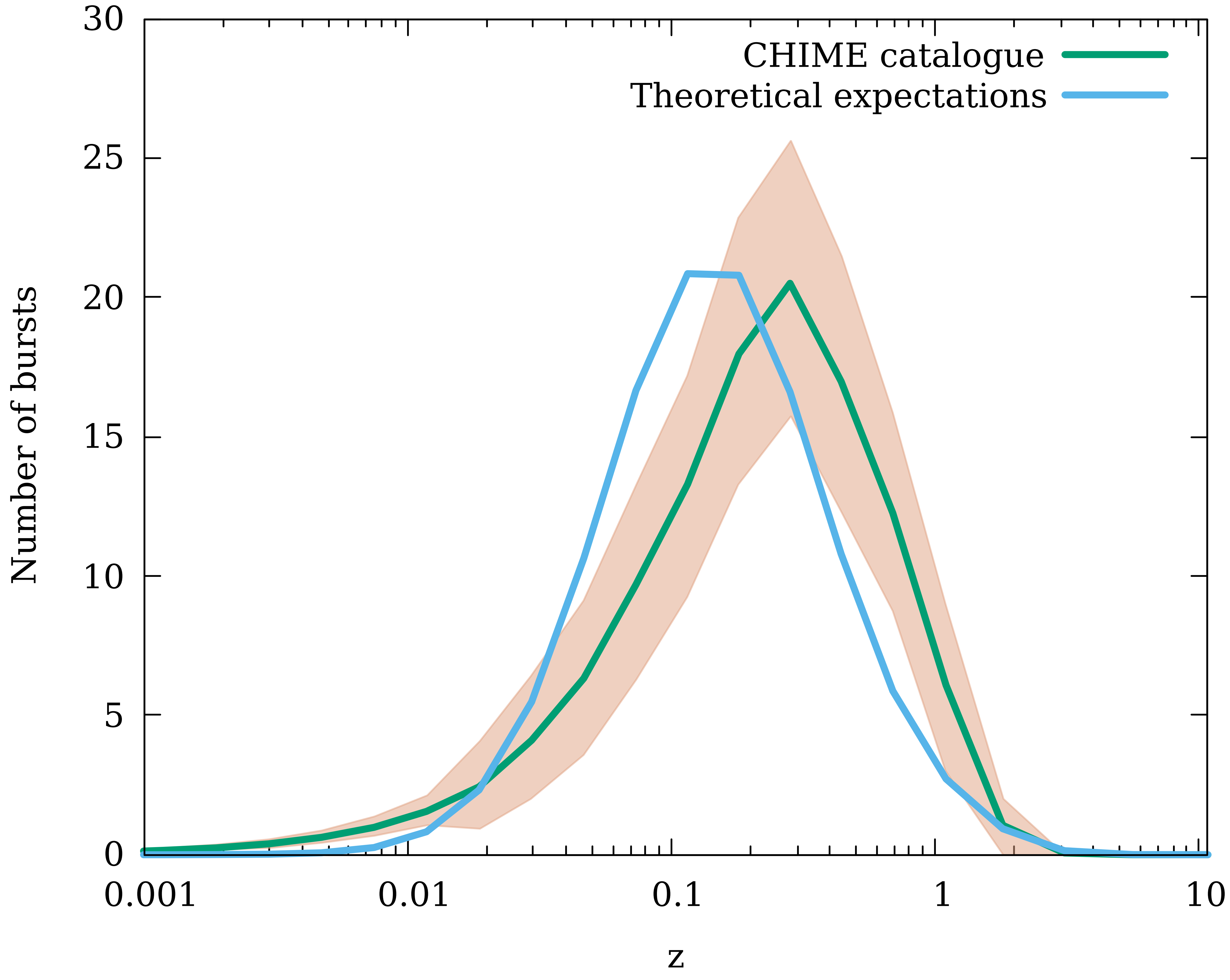


We can place robust lower limits to these sources energy budget, which indicate $E > \text{several} \times 10^{49}\ \text{erg}\ \dfrac{\epsilon_r}{10^{-5}}$

SEARCHING MORE INFO FROM EM OBSERVATIONS: FRBs

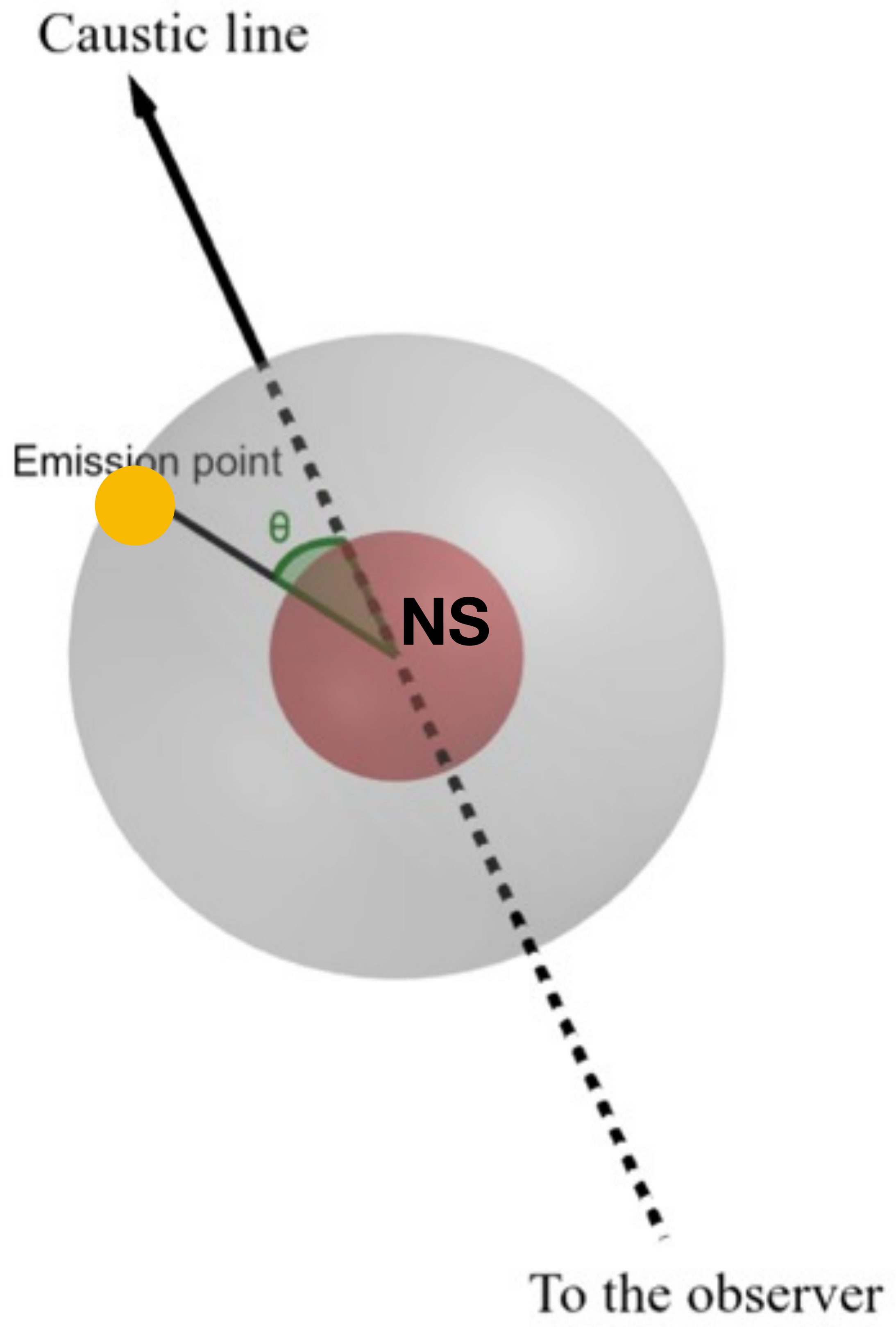
Adopting (a) magnetar population tracking the cosmic SFR, (b) the same *intrinsic* event rate for all sources, (c) the same log-normal energy distribution of the events in each source and (d) the probabilistic DM vs. *z* relation by James et al. (2022)

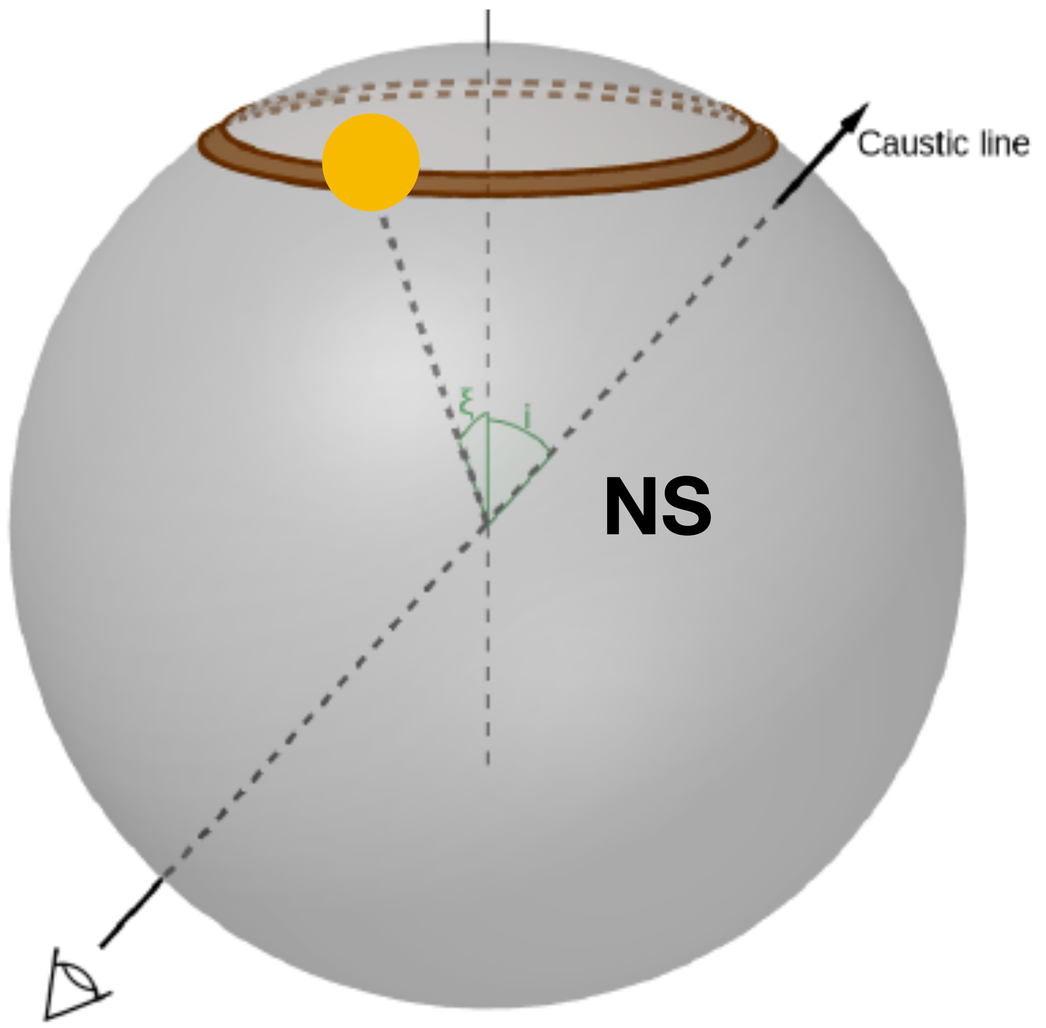


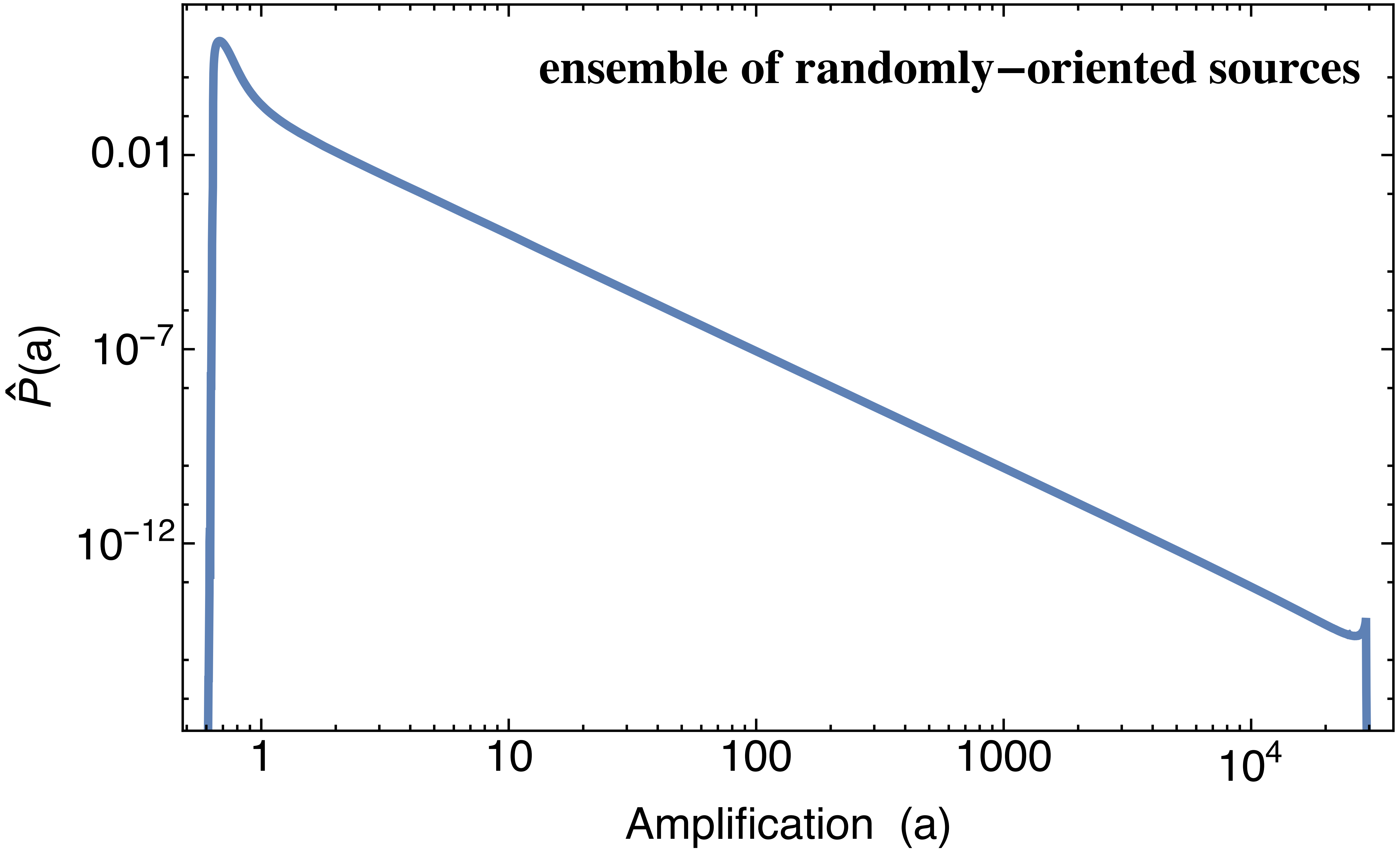


LaPlaca, Dall'Osso, Stella, Possenti (in preparation)

GRAVITATIONAL SELF-LENSING OF MAGNETOSPHERIC FLARES







Dall’Osso, La Placa, Stella, Possenti (2024)

SUMMARY

1. Comprehensive **multi-messenger approach to the search for newly born magnetars,** aimed at exploiting all our astrophysical knowledge to enhance the GW search efficiency and the extraction of physics information from future detections

2. **GW searches for long transients:** a thorough improvement of the existing pipeline GFH is under way, which envisions a combination of ML-based algorithms and a refinement of standard semi-coherent methods with the implementation of new filtering techniques.
   The goal is to reach an horizon of $\gtrsim 5$ Mpc during O5 (and post-O5) of the LVK, within which we expect one event every ~ 5 yrs. These searches will be available, and further improved, for ET, that will reach a much larger horizon and event rate.

3. **Shock breakouts** - especially in core-collapse SNe - will **represent the most common EM trigger for GW pipelines,** and can also provide key constraints on the GW signal parameters: it will be crucial to further improve theoretical light curve modelling

4. **Gamma-ray Bursts and Fast Radio Bursts can provide key information on the physical parameters of newly born magnetars**, constraining the GW search parameter space.

5. **Future prospect: A neutrino signature**, either from the core-collapse or from the energetic outflow/jet produced by the newly born magnetar, **would be extremely valuable**. Theoretical and observational efforts needed in both these instances.