A Nebular Origin for the Persistent Radio Emission of Fast Radio Bursts

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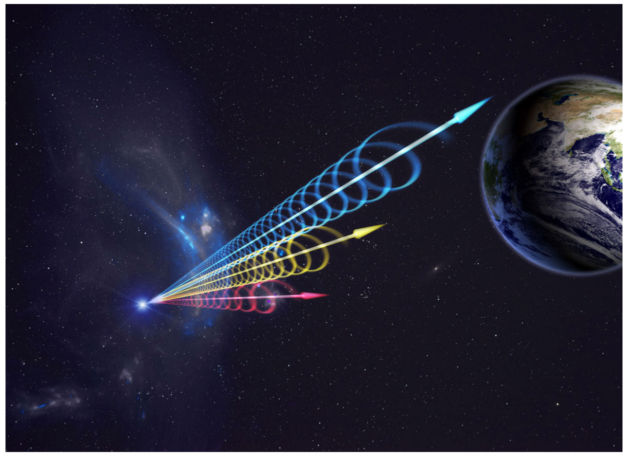
Collaborators:Gabriele Bruni (IAPS), Luigi Piro (IAPS), Bing Zhang (UNLV), etc.

References: Bruni, Piro, Yang et al. 2024, Nature accetpted, arXiv: 2312.15296

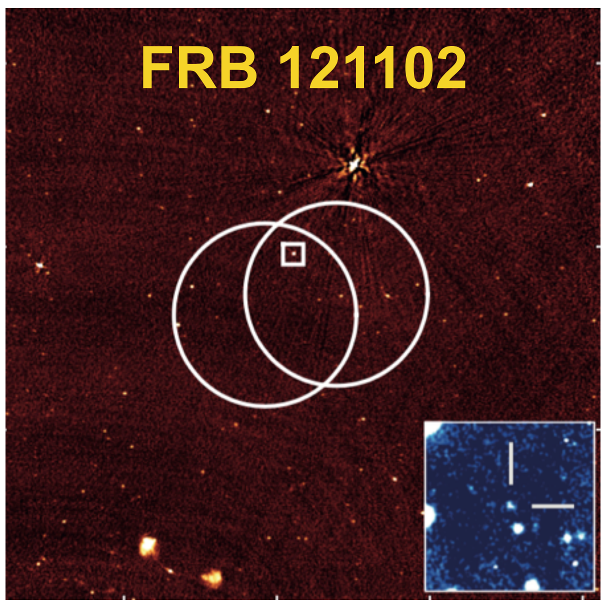


2024/06/12, @ Journal Club, SWIFAR

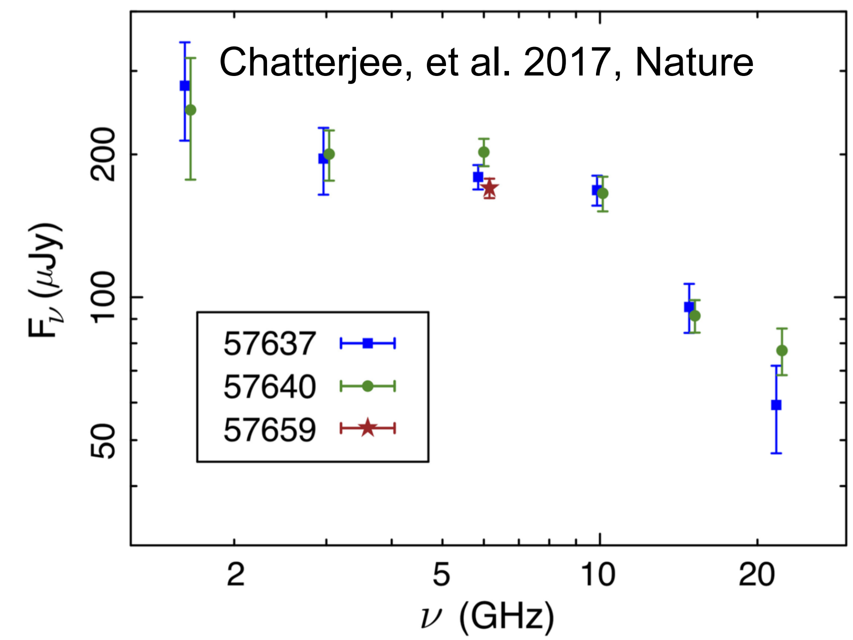
PRSs of Two FRB Repeaters

FRB Name	DM_{obs}[a] ($pc\,cm^{-3}$)	DM_{MW}[b] ($pc\,cm^{-3}$)	z[c]	d_L[d] (Gpc)	RM[e] ($rad\,m^{-2}$)	F_ν[f] (μJy)	ν[g] (GHz)	L_ν[h] ($10^{29} erg\,s^{-1}\,Hz^{-1}$)
FRB 20121102A	557	188	0.19273	0.98	1.4×10^5	180	1.7	2.1
FRB 20190520B	1204.7	113	0.241	1.25	-3.6×10^4	202	3	3.8

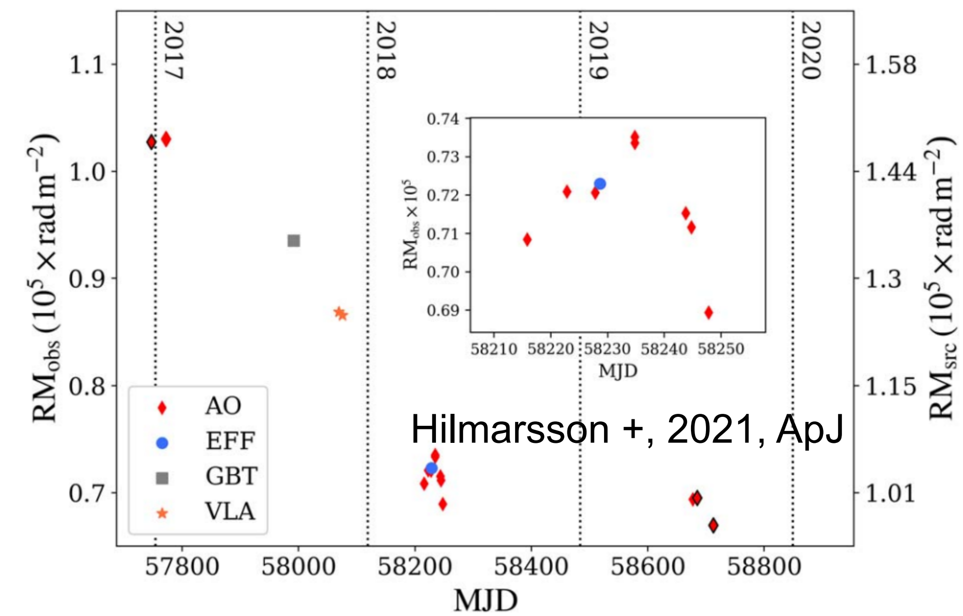
PRS Image

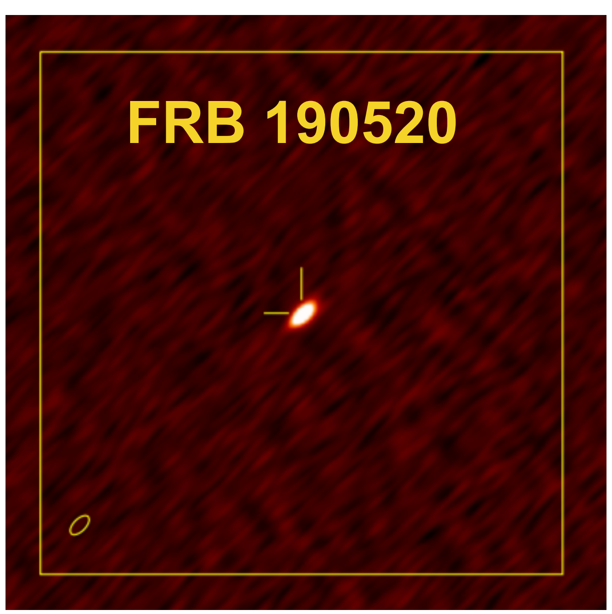


PRS SED

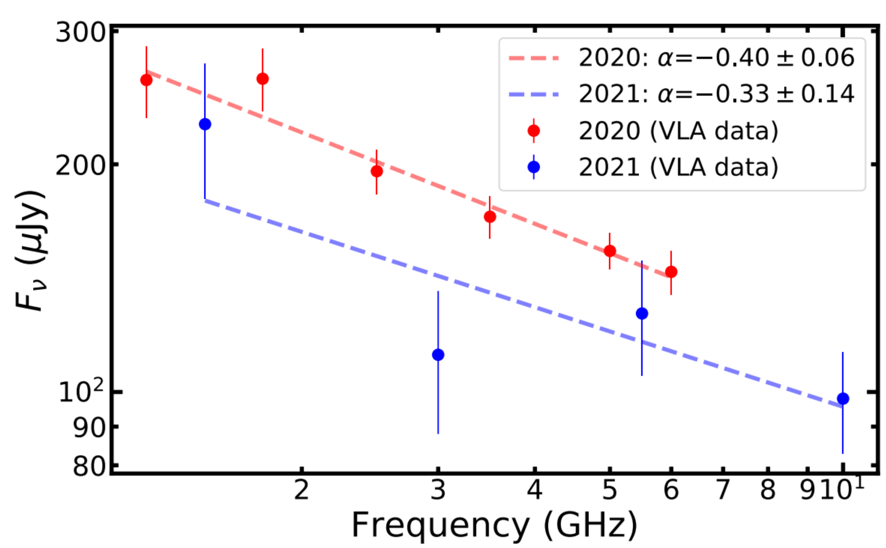


FRB's RM Evolution

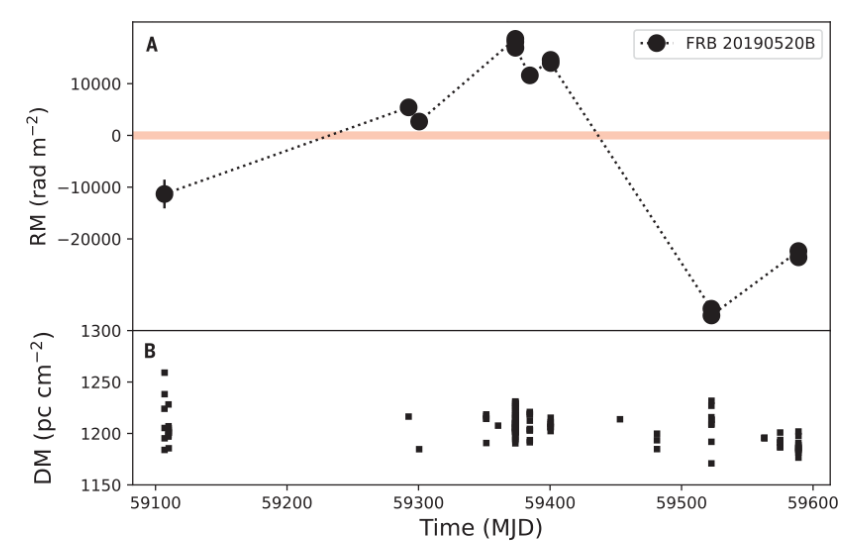




Niu, et al. 2022, Nature

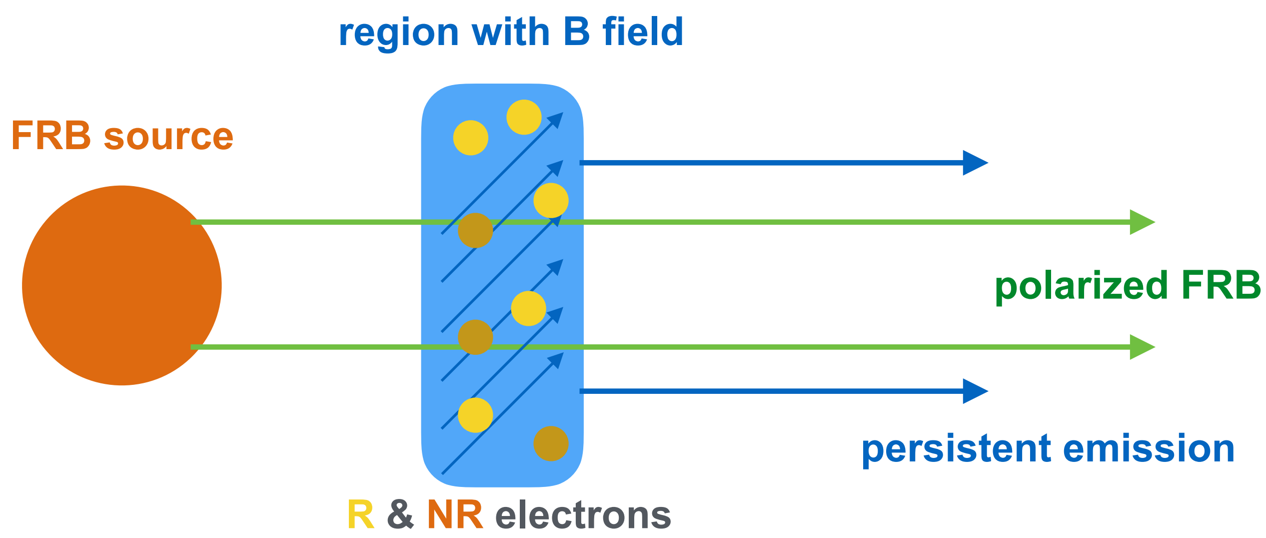


Zhang et al., 2023, ApJ

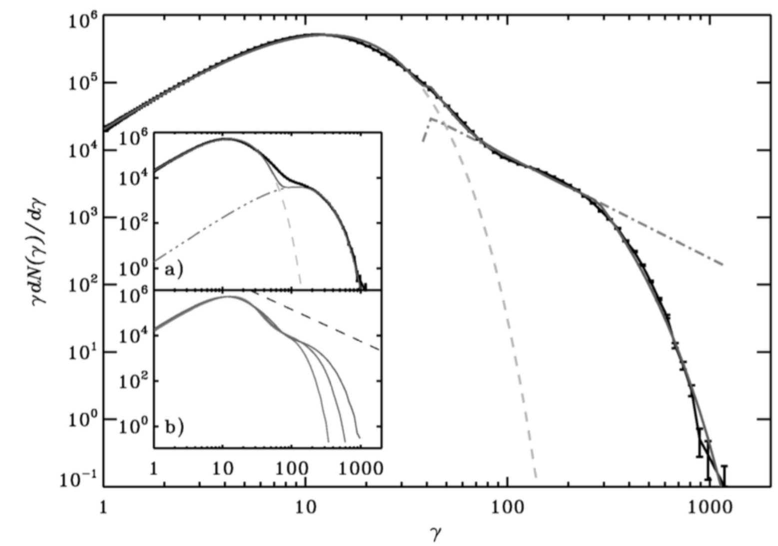


Anna-Thomas + **Yang**, 2022, Science

Predicted PRS-RM Relation



Electron distribution: e.g., Spitkovsky (2008)



- The RM contributed by the **accelerated electrons** is given by

$$\mathrm{RM} \simeq \frac{e^3}{2\pi m_e^2 c^4} B_\parallel \Delta R \int \frac{n_e(\gamma)}{\gamma^2} d\gamma = \frac{e^3}{2\pi m_e^2 c^4} \frac{n_{e,0} B_\parallel}{\gamma_c^2} \Delta R,$$

$$\gamma_c^2 \equiv \frac{\int n_e(\gamma) d\gamma}{\int [n_e(\gamma)/\gamma^2] d\gamma}.$$

effect of relativistic mass

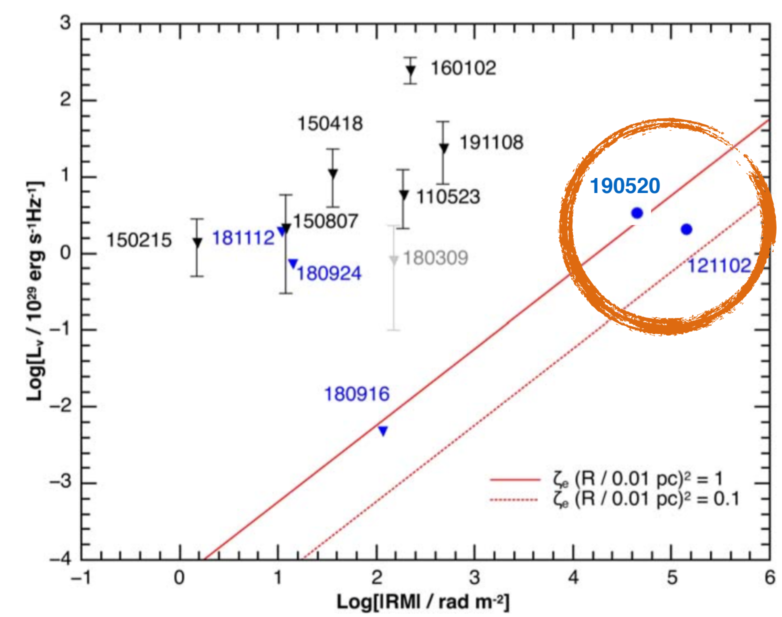
- The **synchrotron power** and relativistic electrons are

$$P_\nu \simeq P/\nu = m_e c^2 \sigma_\mathrm{T} B/3e \qquad N_e = 4\pi R^3 \zeta_e n_e/3.$$

- By eliminating B, maximum specific luminosity is

$$L_\nu = \frac{64\pi^3}{27} \zeta_e \gamma_c^2 m_e c^2 R^2 |\mathrm{RM}| \simeq 5.7 \times 10^{28}\ \mathrm{erg\ s^{-1}\ Hz^{-1}} \times \zeta_e \gamma_c^2 \left(\frac{|\mathrm{RM}|}{10^4\ \mathrm{rad\ m^{-2}}}\right) \left(\frac{R}{10^{-2}\ \mathrm{pc}}\right)$$

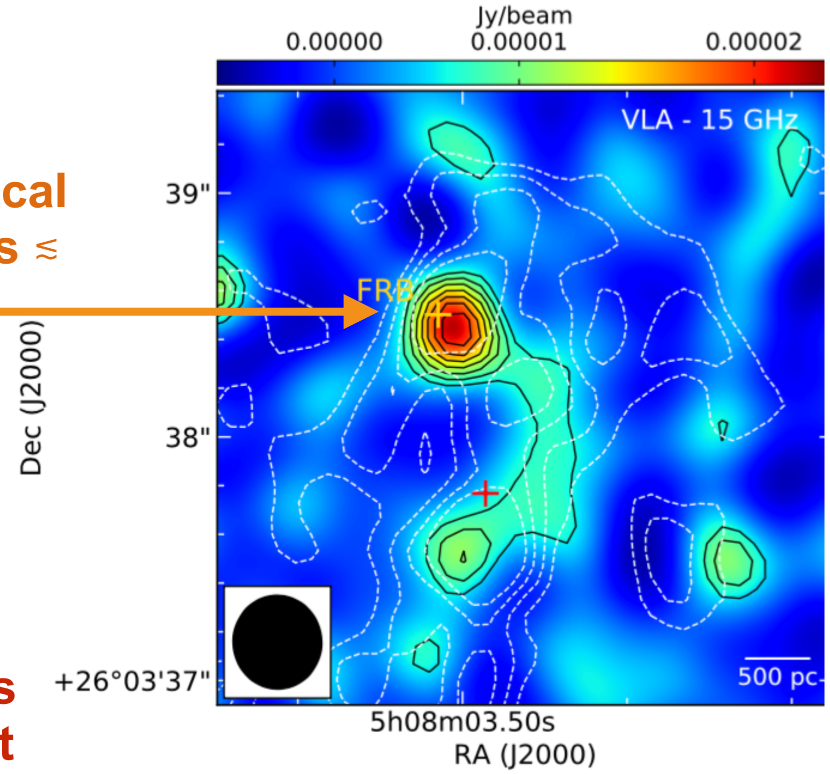
PRS-RM relation

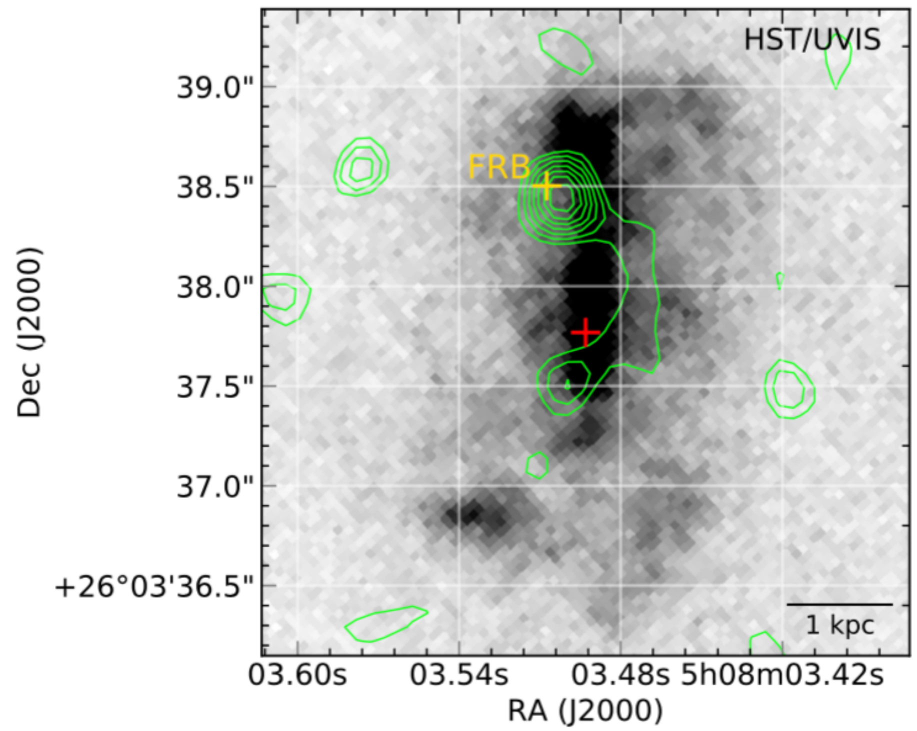


Yang +, 2020, ApJ; **Yang** +, 2022, ApJL,

Compact PRS of FRB 20201124A

Projected physical size at 15 GHz is ≲ 700 pc

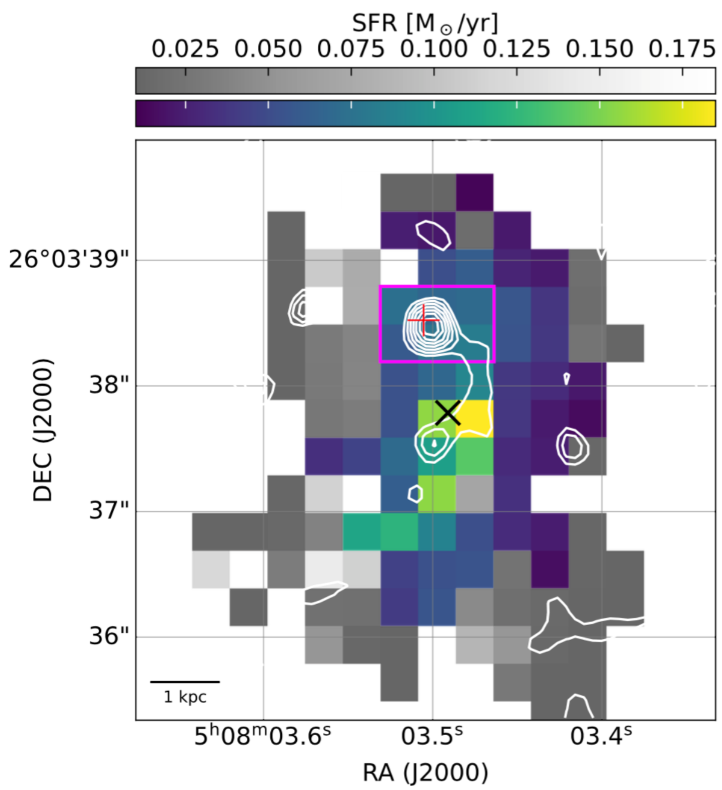


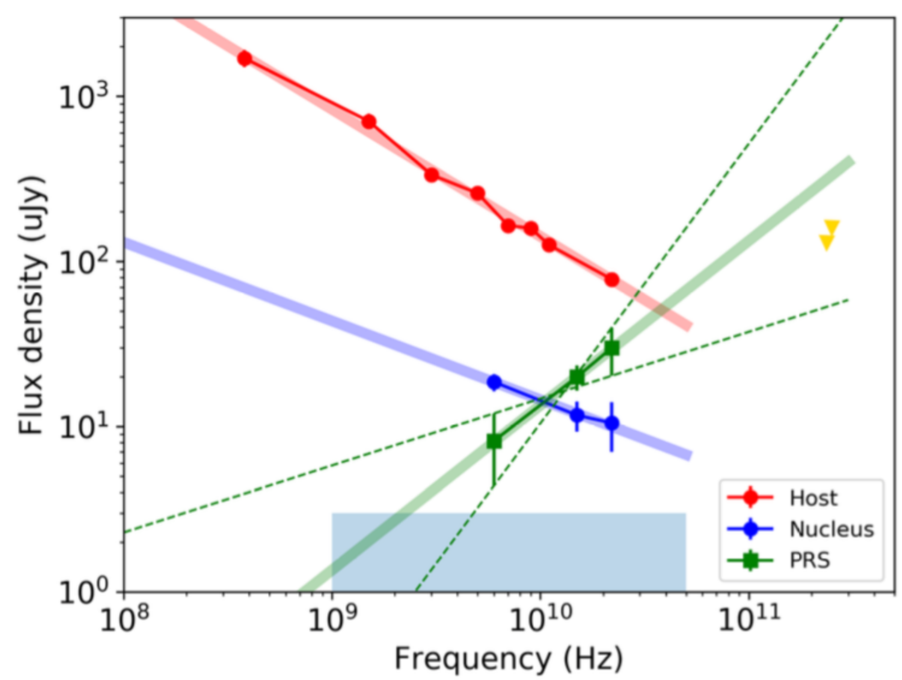


1. highest SFR is towards the host galaxy's center

2. close to the FRB position, an SFR of ~ 0.4 $M_\odot\ yr^{-1}$ is measured,

3. in order to account for the observed radio flux density, a SFR ≳ 3 $M_\odot\ yr^{-1}$ would be needed





1. the inverted spectrum is unlike the spectral shape of star formation

2. the radio luminosity of star forming regions is much lower than the PRS luminosity.

3. no other wavelength counterparts were found

Bruni, Piro, **Yang**, et al. 2024, Nature, accepted

SED of Compact PRS

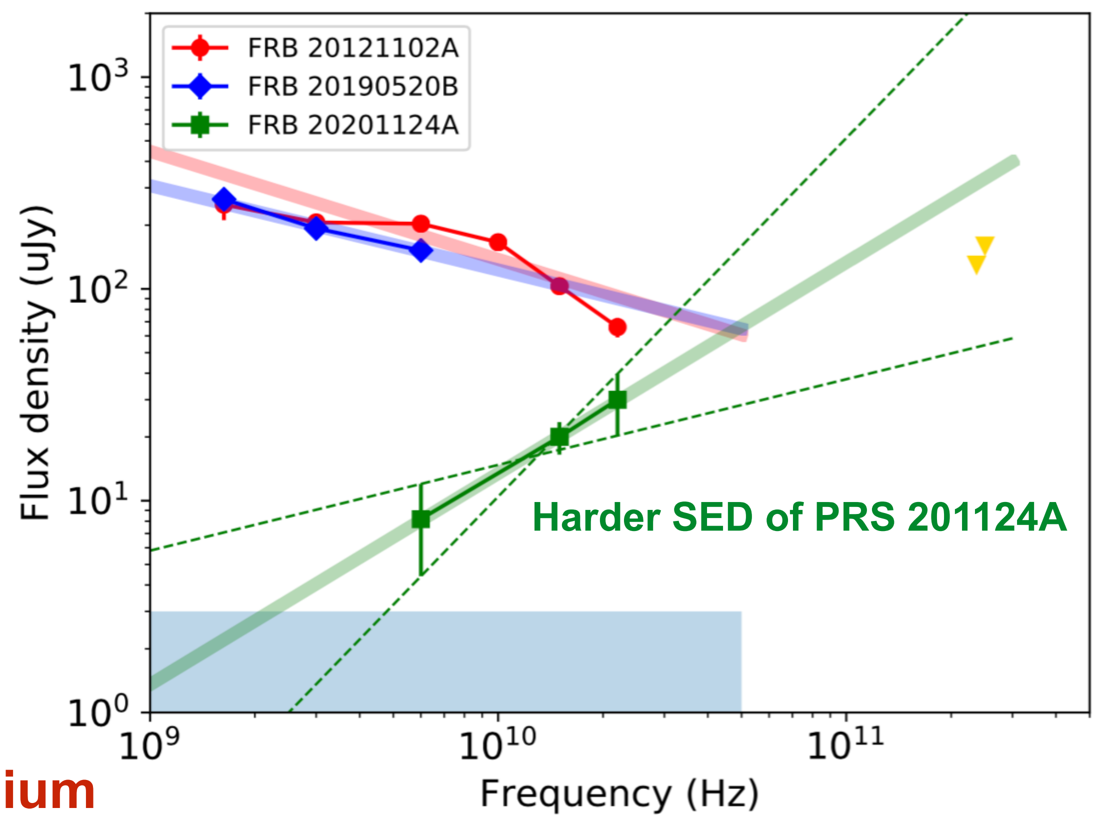
- **The spectral index of the PRS is consistent with ~1/3 within 1.5σ**
- According to synchrotron radiation, the minimum Lorentz factor of the accelerated electrons is required to be

$$\nu_m \simeq \frac{\gamma_m^2 eB}{2\pi m_e c} \gtrsim (22-240)\ \mathrm{GHz},$$

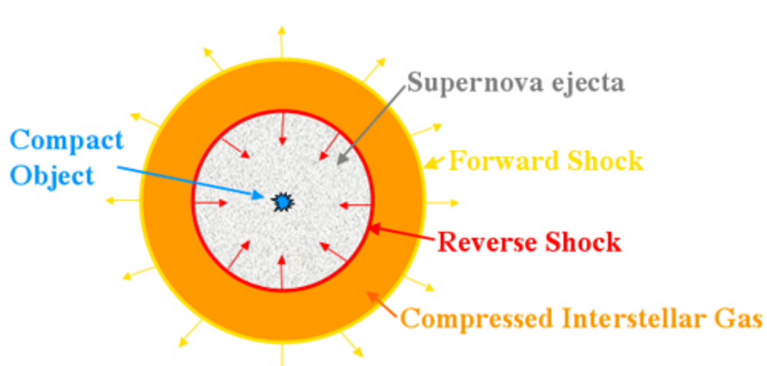
- leading to

shocked magnetized medium

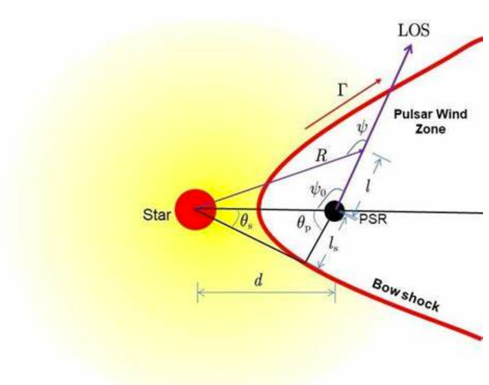
$$\left(\frac{\gamma_m}{10^3}\right)^2 \left(\frac{B}{10\ \mathrm{mG}}\right) \gtrsim (0.8-8.6).$$

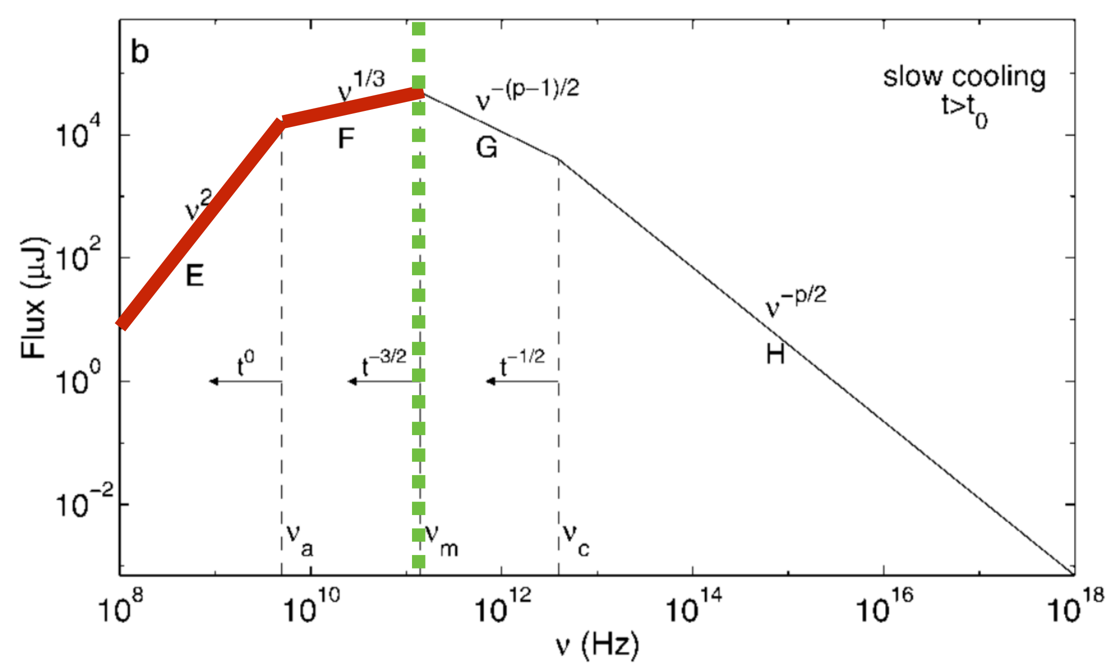


(1) PWN or SNR



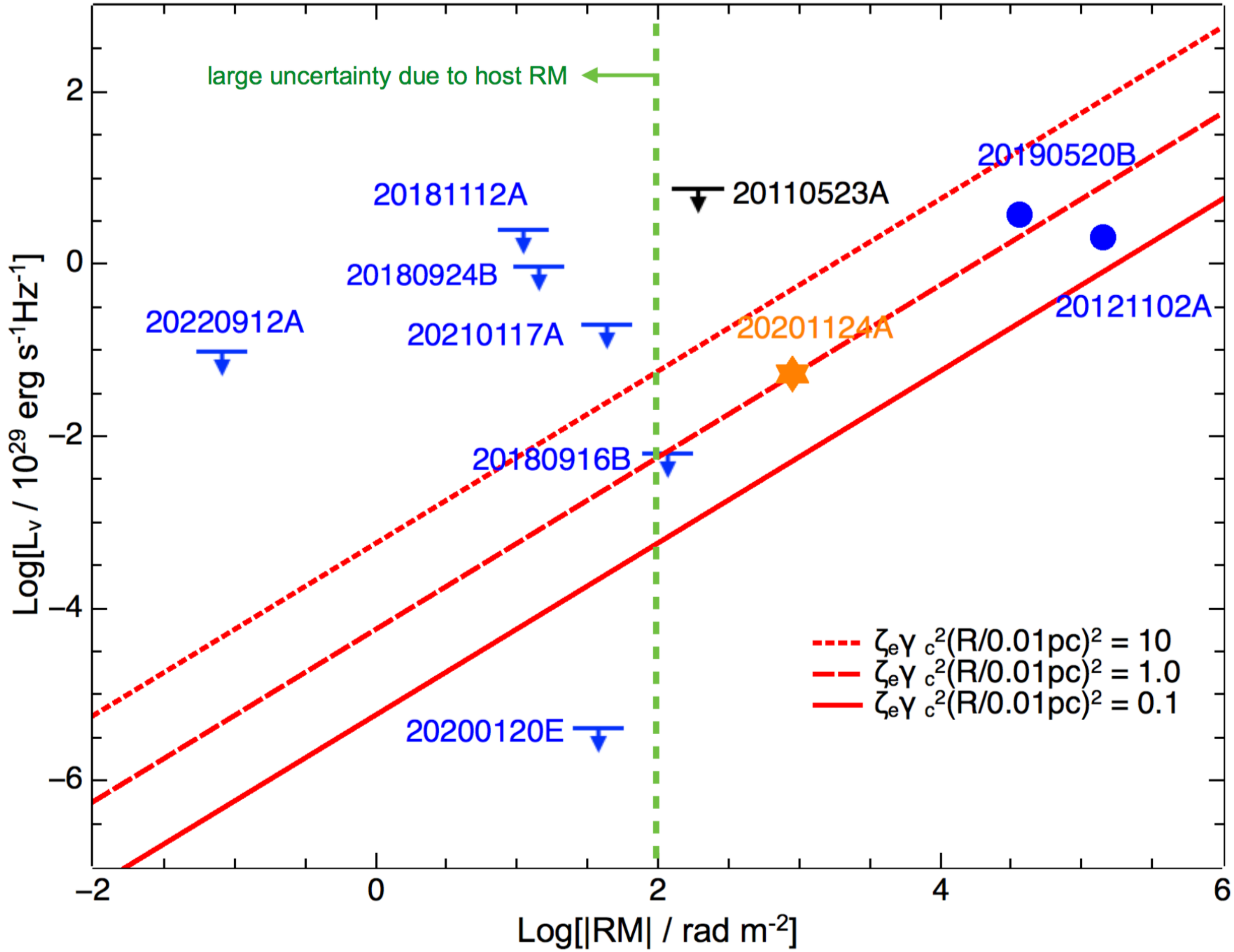
(2) Bow Shock in Binary





Synchrotron SED: Sari et al. 1998, ApJ

Relation between PRSs and FRBs



Bruni, Piro, **Yang**, et al. 2024, Nature, accepted

Summary

- PRS as one of the multiwavelength counterpart play an important rule in revealing the FRB origin. Three FRBs with high RM value are associated with PRSs
- Compact PRS could be generated by **synchrotron heating by repeating FRB** in a self-absorbed synchrotron nebula.
- We show that theoretically there should be **a simple relation between RM and the luminosity of the persistent source of an FRB source** if the observed RM mostly arises from the persistent emission region.
- We report here the detection of **a third, less luminous PRS associated with FRB 20201124A** significantly expanding the predicted relation into the low luminosity – low RM regime
- The **distribution of PRS luminosity and RM** could be used to constrain the PRS mechanism

Thank You!