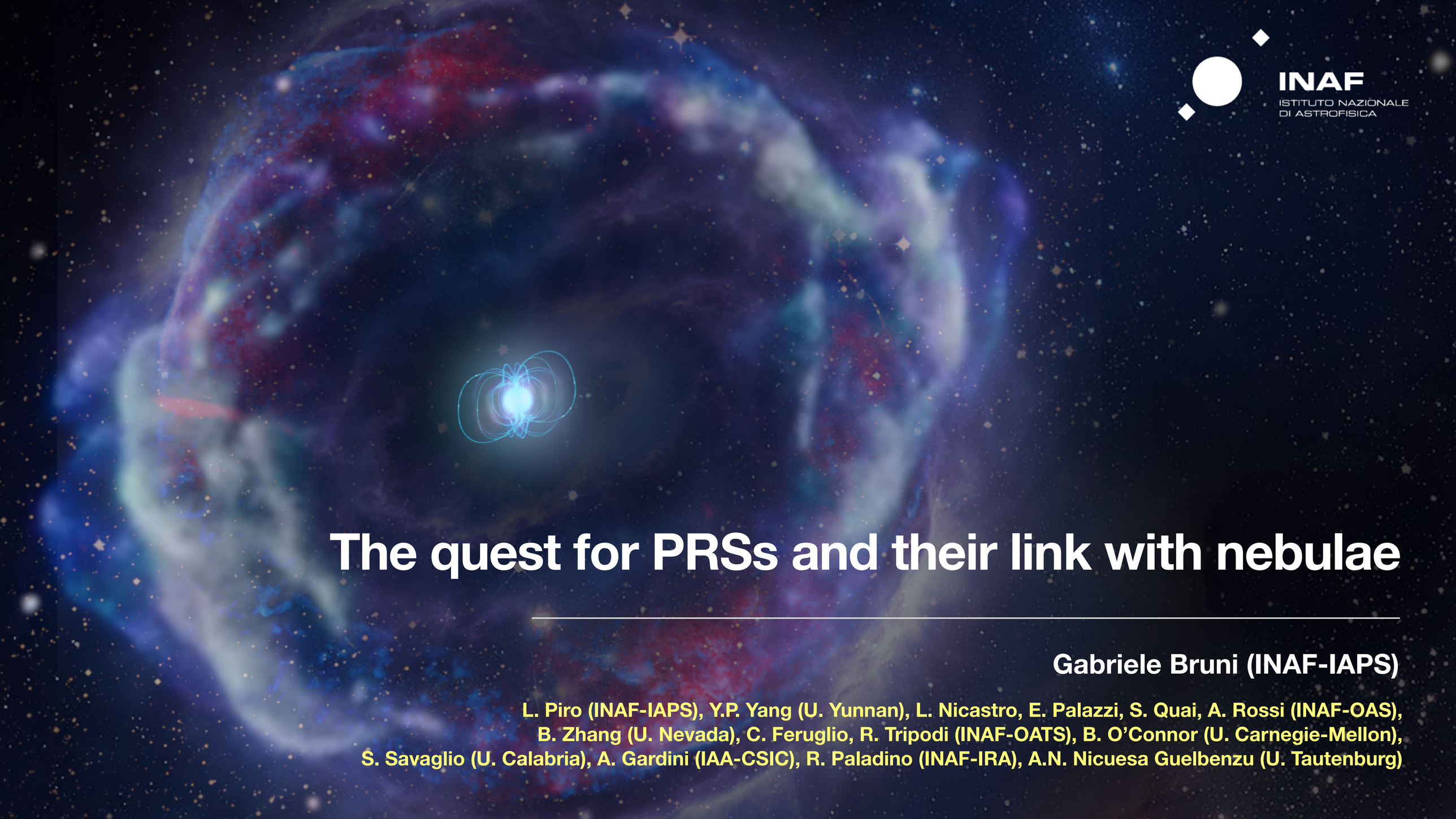

INAF
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DI ASTROFISICA

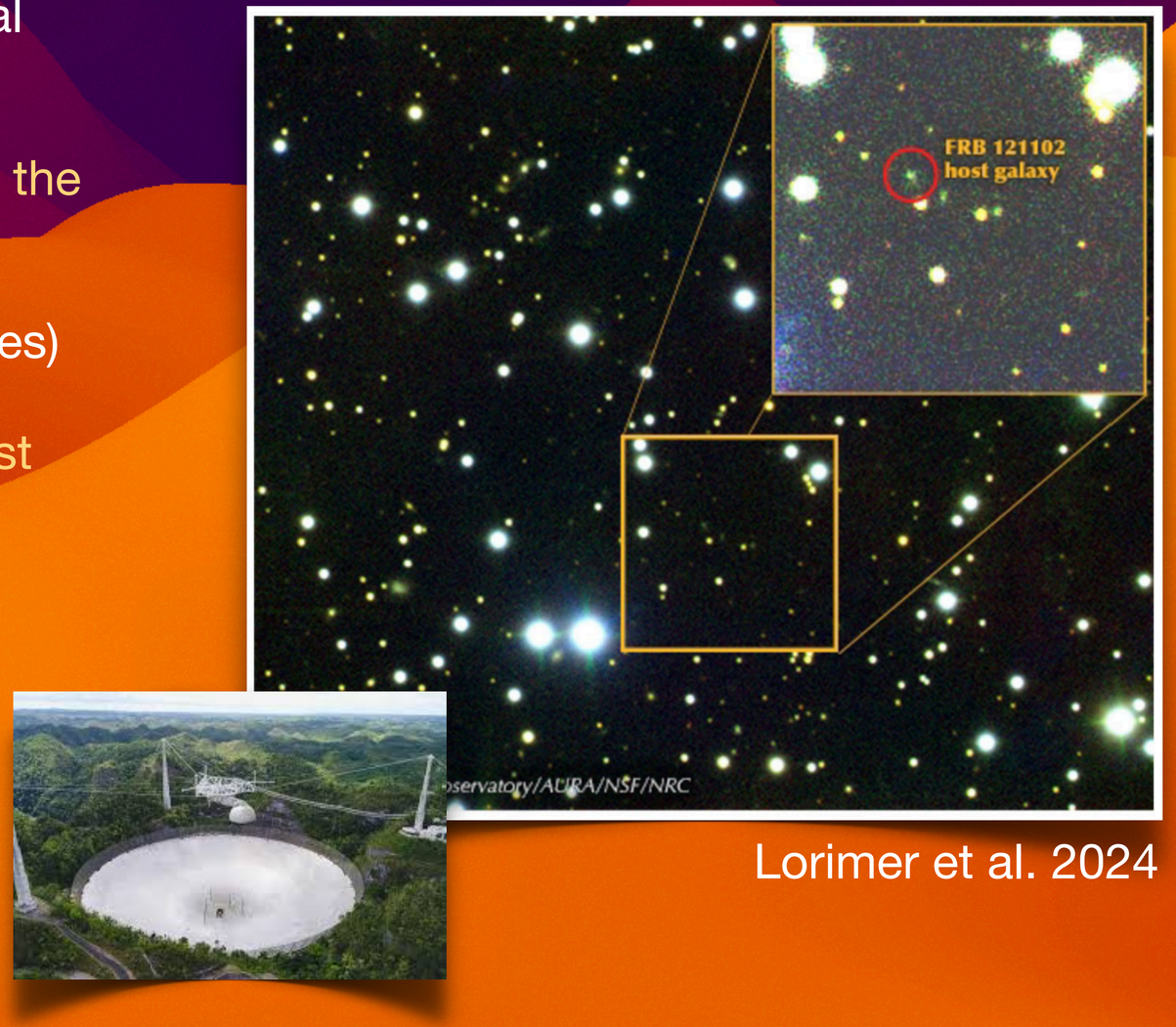
The quest for PRSs and their link with nebulae

Gabriele Bruni (INAF-IAPS)

L. Piro (INAF-IAPS), Y.P. Yang (U. Yunnan), L. Nicastro, E. Palazzi, S. Quai, A. Rossi (INAF-OAS),
B. Zhang (U. Nevada), C. Feruglio, R. Tripodi (INAF-OATS), B. O'Connor (U. Carnegie-Mellon),
S. Savaglio (U. Calabria), A. Gardini (IAA-CSIC), R. Paladino (INAF-IRA), A.N. Nicuesa Guelbenzu (U. Tautenburg)

Repeating FRB

- In 2014, FRB121102 was found in Arecibo archival data from 2012 (Spitler burst)
- In 2015 it reactivated, producing 11 bursts: it was the first repeating FRB
- Non-catastrophic nature (at least for repeating ones)
- Most importantly, first direct localization in the host galaxy with the VLA



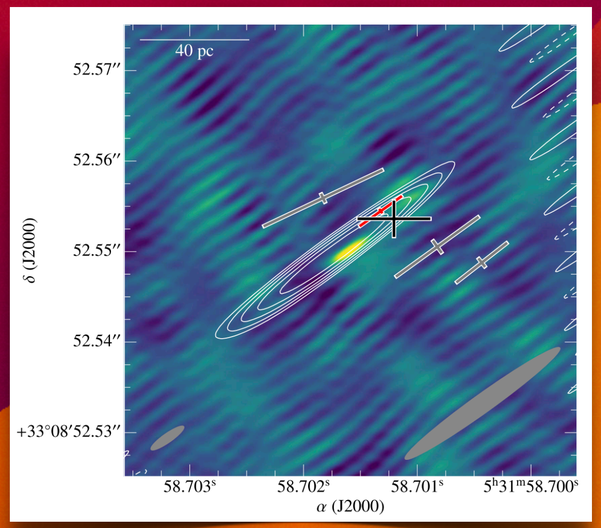
Lorimer et al. 2024

Persistent radio emission

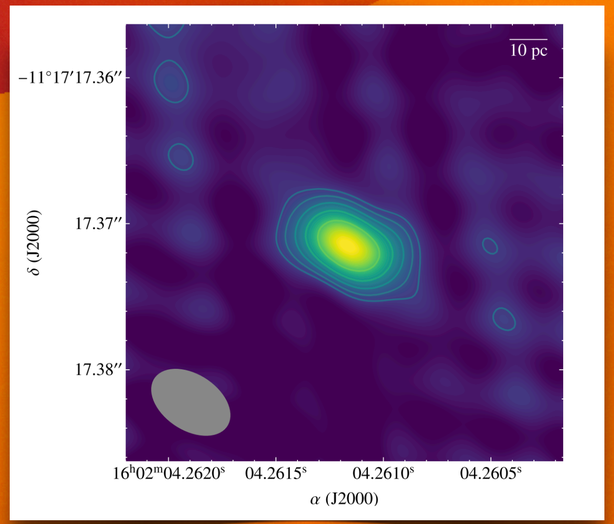
PRS consistent with nebular emission detected at pc-scale in three repeating FRB:

- FRB20121102A (Chatterjee et al 2017; Marcote et al. 2017)
- FRB 20190520B (Niu et al. 2022, Bhandari et al. 2023)
- FRB 20240114A (Bruni et al. 2025)

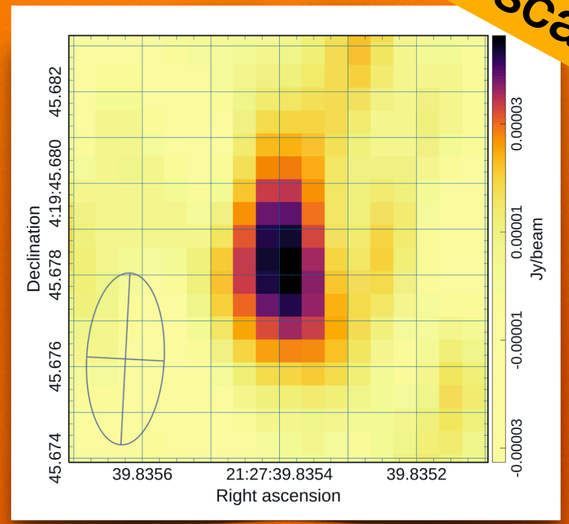
pc scale!



Marcote et al. 2017



Bhandari et al. 2023

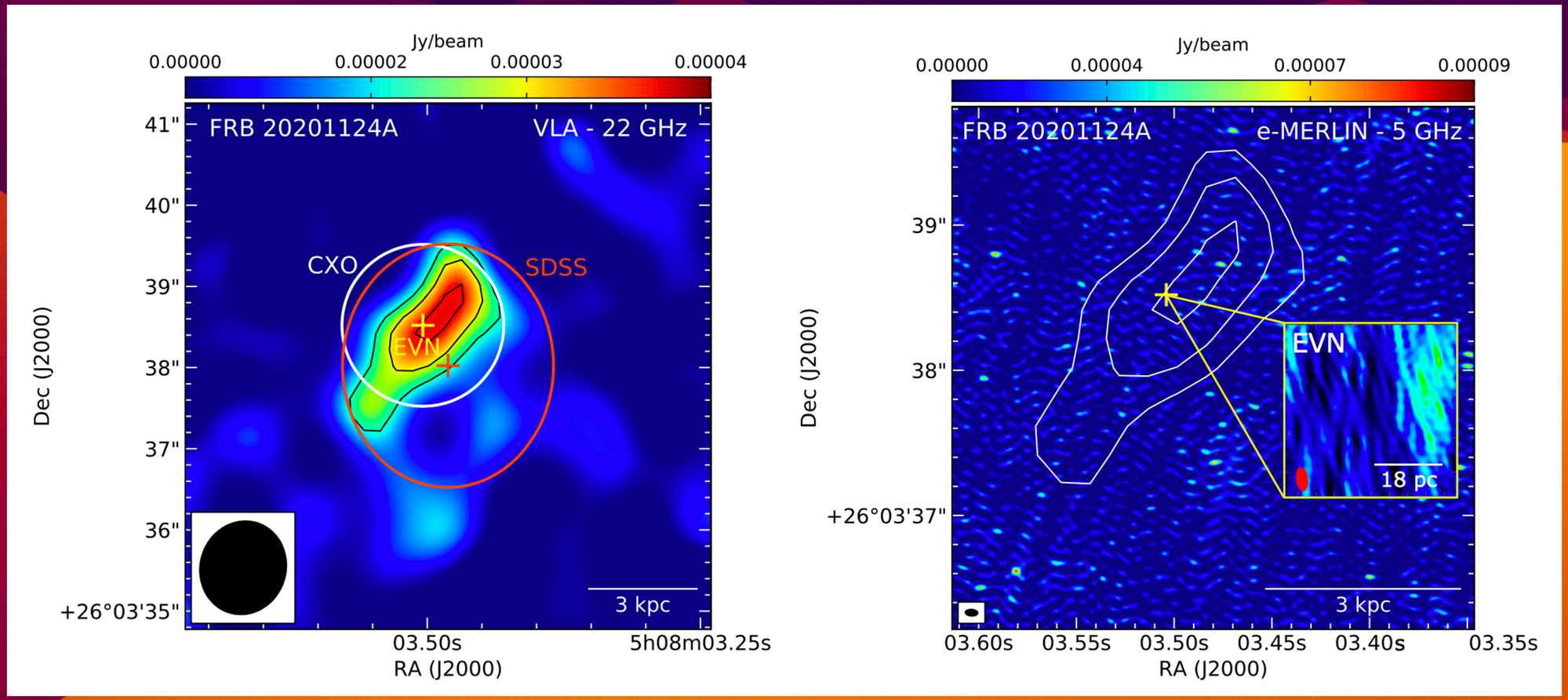


Bruni et al. 2025

The PRS associated with FRB 20201124A

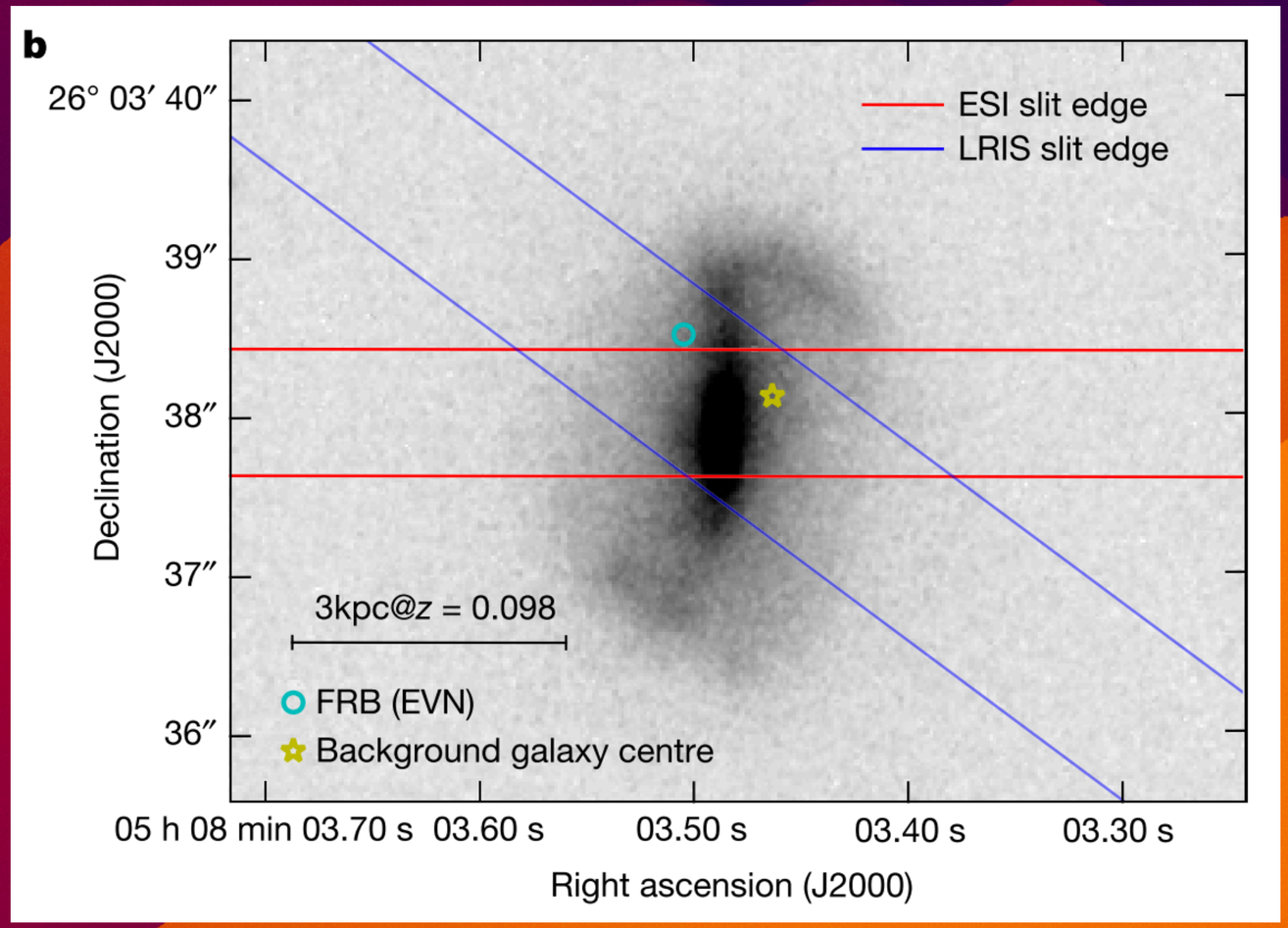
The case of FRB 20201124A

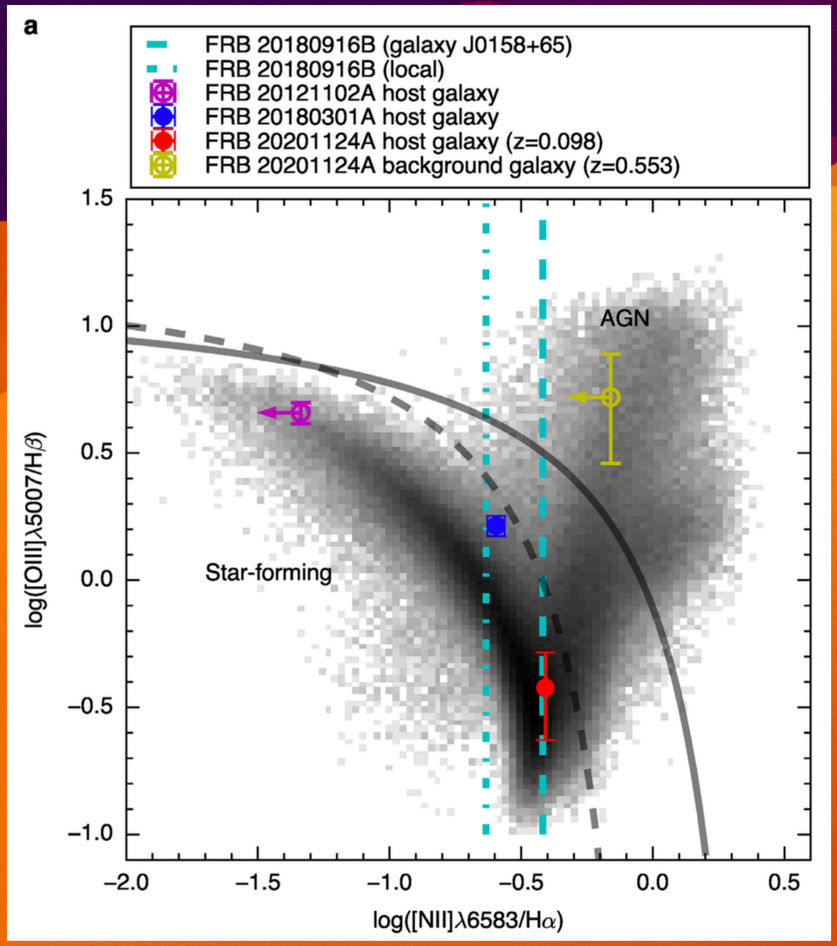
Piro et al. 2021



Extended (5 kpc) region in VLA observations, no compact emission on sub-kpc scales

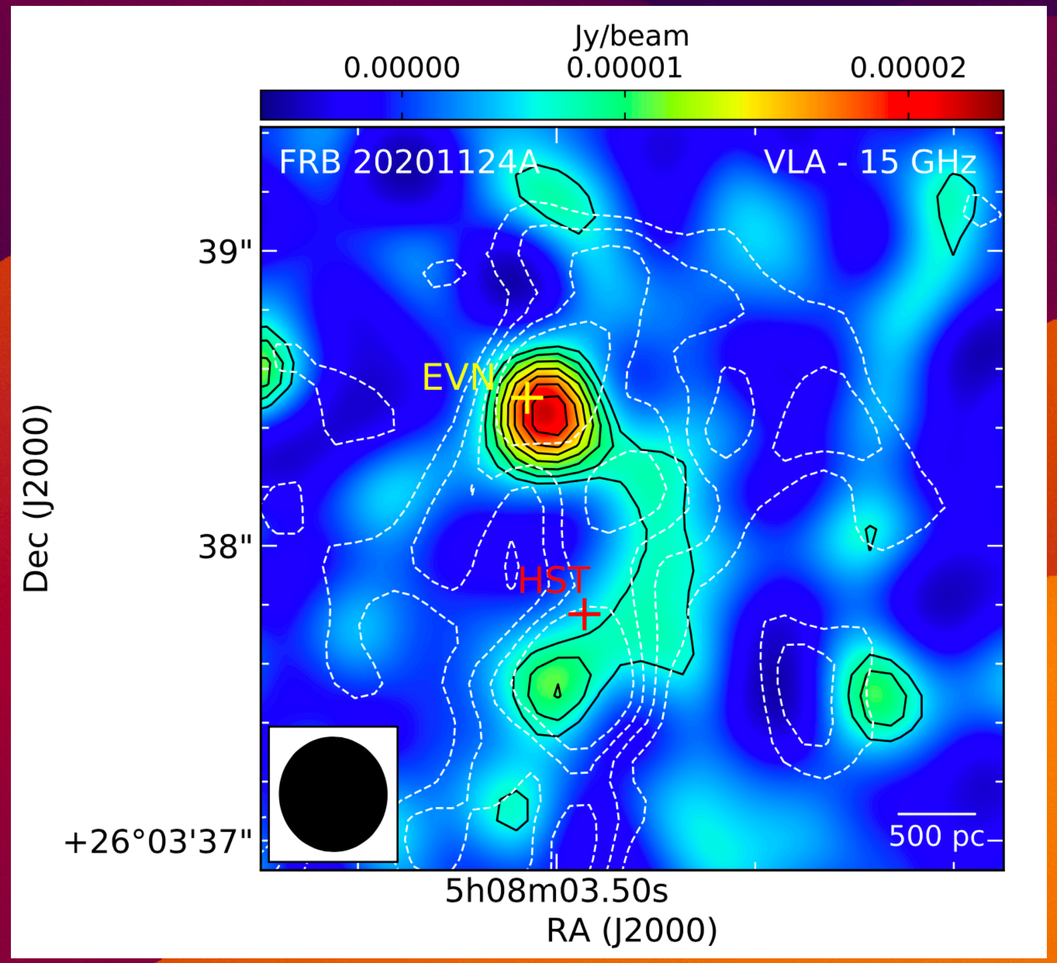
The case of FRB 20201124A



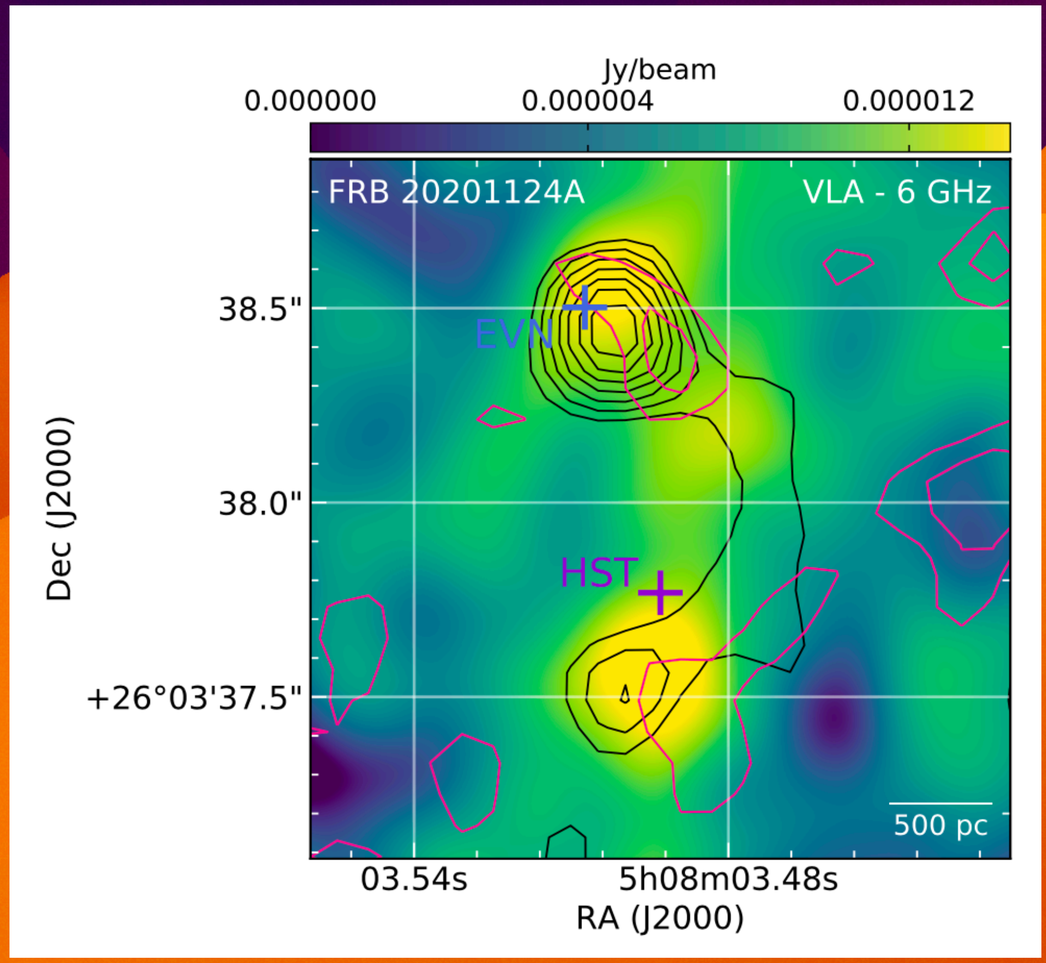


Xu et al. 2022

The discovery of a compact PRS



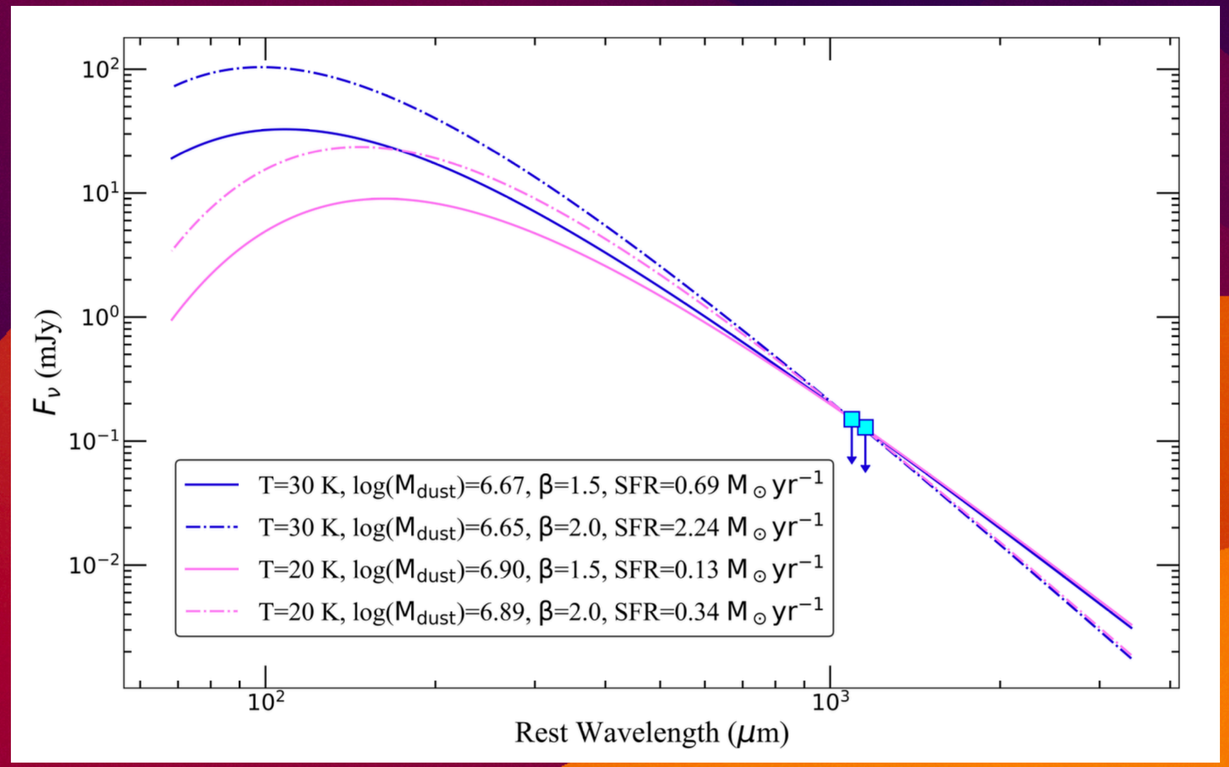
VLA (6+15 GHz)

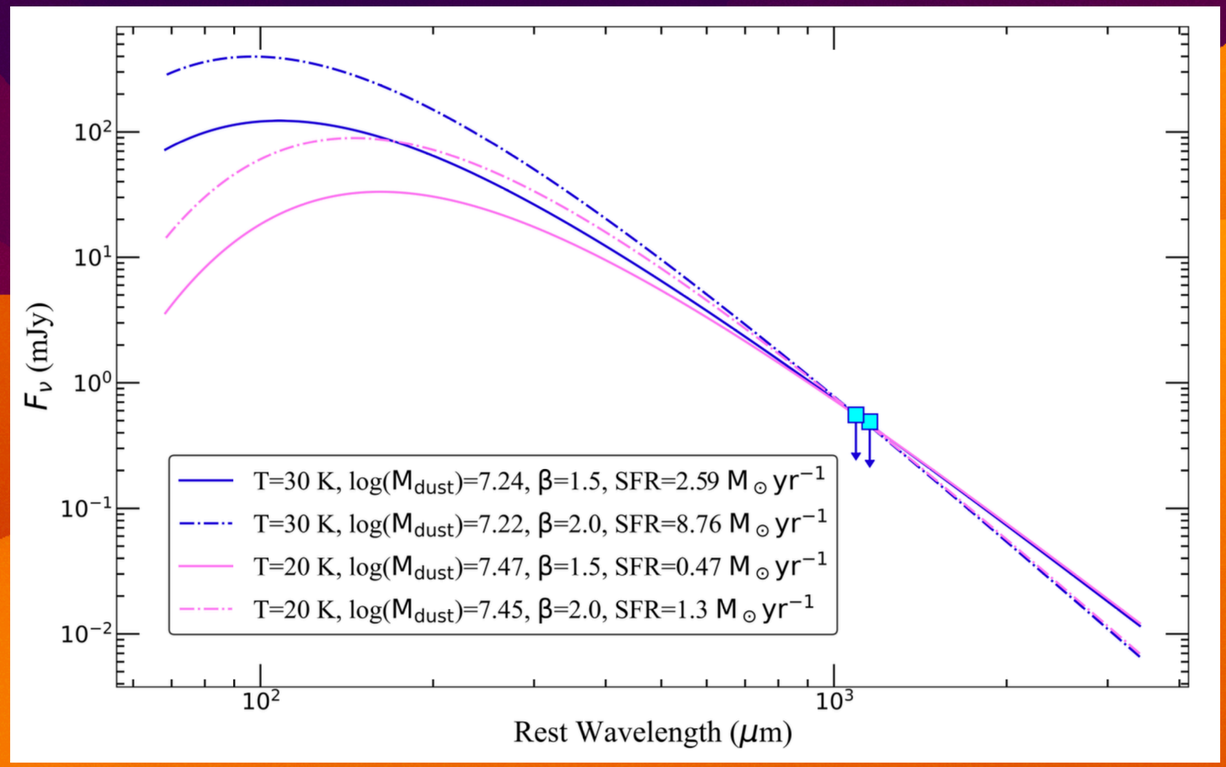


VLA (6+15+22 GHz)

Bruni et al. 2024, Nature

The dust component: NOEMA observations





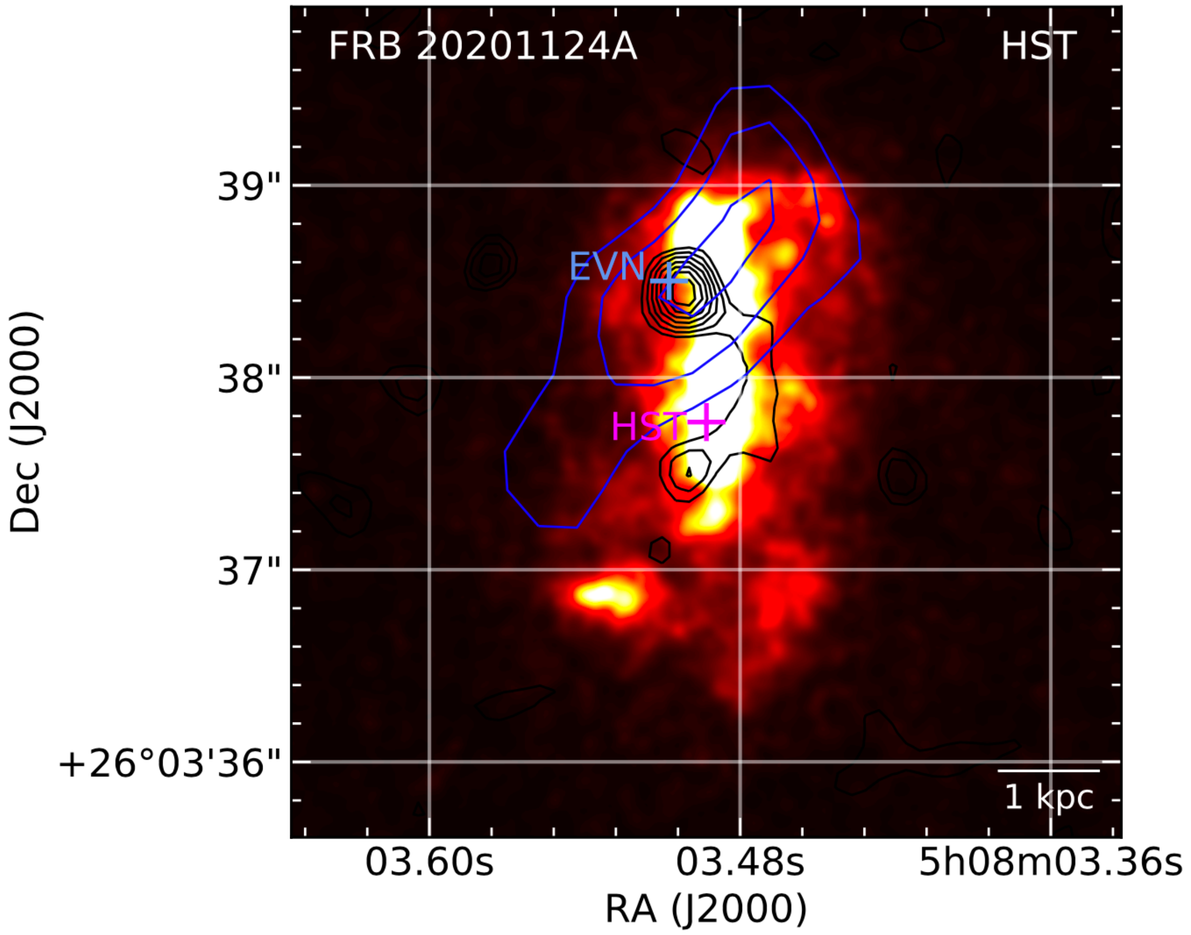
FRB region
(SFR<2.2 M/yr)

Host galaxy
(SFR<8.8 M/yr)

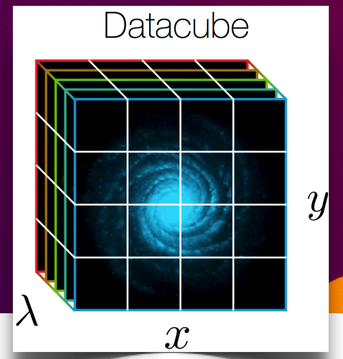
Bruni et al. 2024, Nature

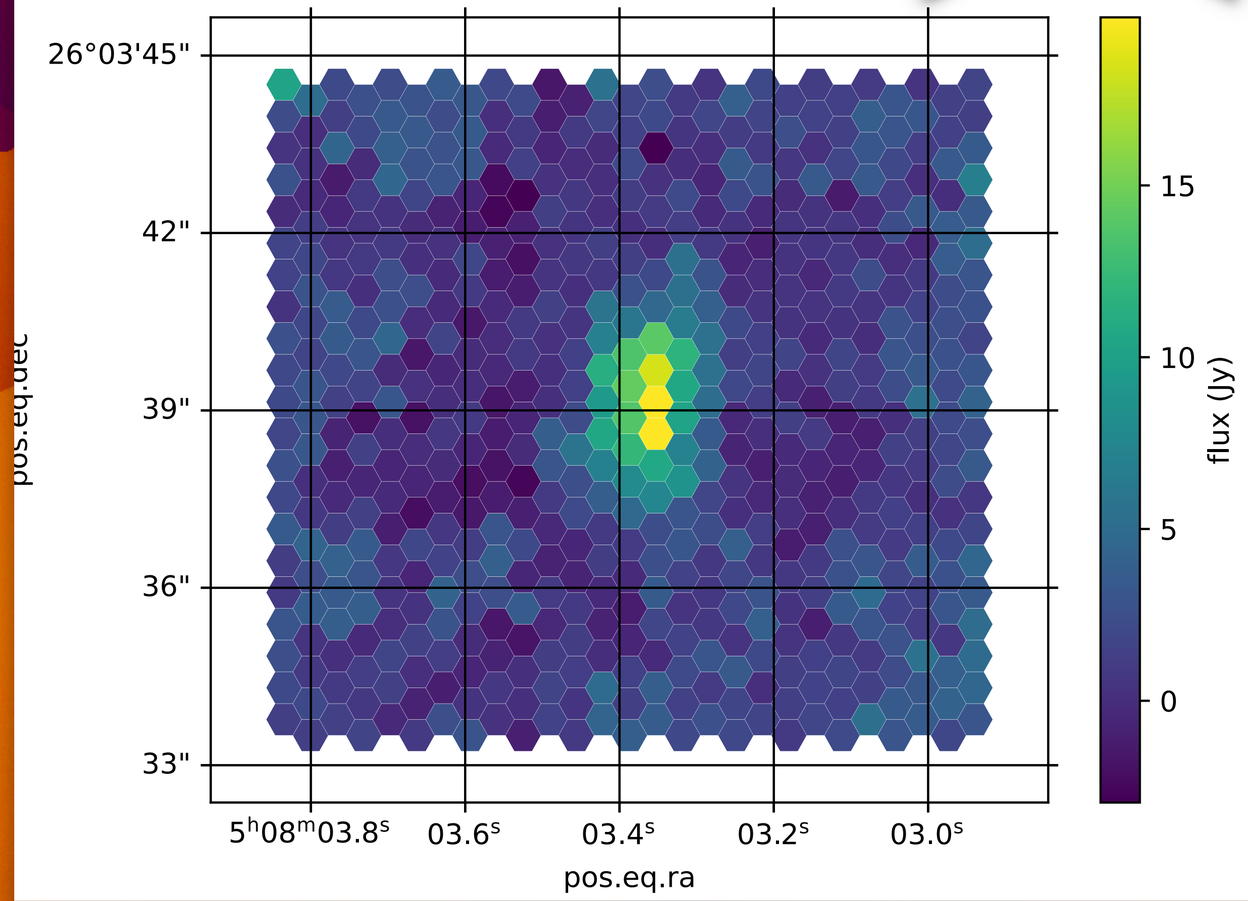
The host galaxy

Hubble



GTC/MEGARA

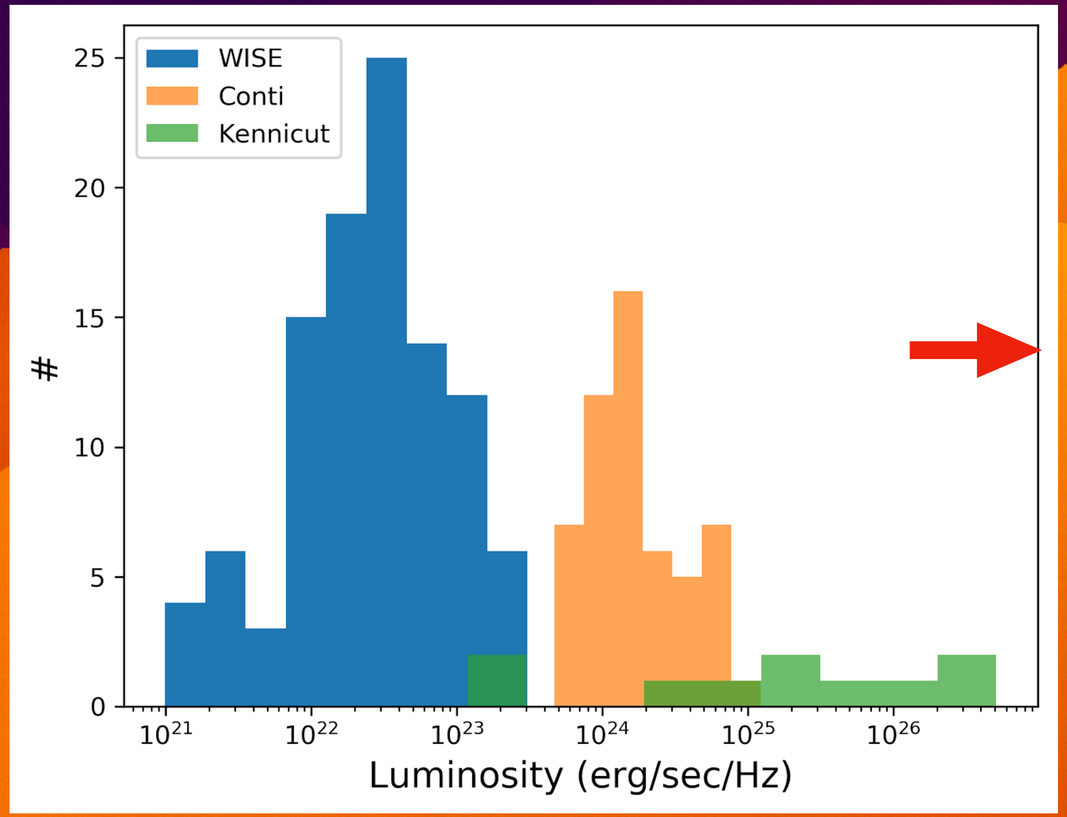




Bruni et al. 2024, Nature

Is it really a PRS?

- Size → < 700 pc (to be improved with HSA)
- NOEMA upper limit → Obscured SFR < 2.2 M/yr
- VLA detection → SFR > 3 M/yr
- GTC/MEGARA Halpha → SFR=0.4 M/yr
- Radio luminosity (4.9 x 10^27 erg/s/Hz) more than x10 higher than the largest, brightest SF regions



Where the PRS comes from?

The Astrophysical Journal, 895:7 (6pp), 2020 May 20 https://doi.org/10.3847/1538-4357/ab88ab

Are Persistent Emission Luminosity and Rotation Measure of Fast Radio Bursts Related?

Yuan-Pei Yang[1], Qiao-Chu Li[2,3], and Bing Zhang[4]
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[2] School of Astronomy and Space Science, Nanjing University, Nanjing 210093, People's Republic of China
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The Astrophysical Journal, 937:5 (22pp), 2022 September 20 https://doi.org/10.3847/1538-4357/ac8a4a

Radio Nebulae from Hyperaccreting X-Ray Binaries as Common-envelope Precursors and Persistent Counterparts of Fast Radio Bursts

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[2] Theoretical High Energy Astrophysics (THEA) Group, Columbia University, New York, NY 10027, USA
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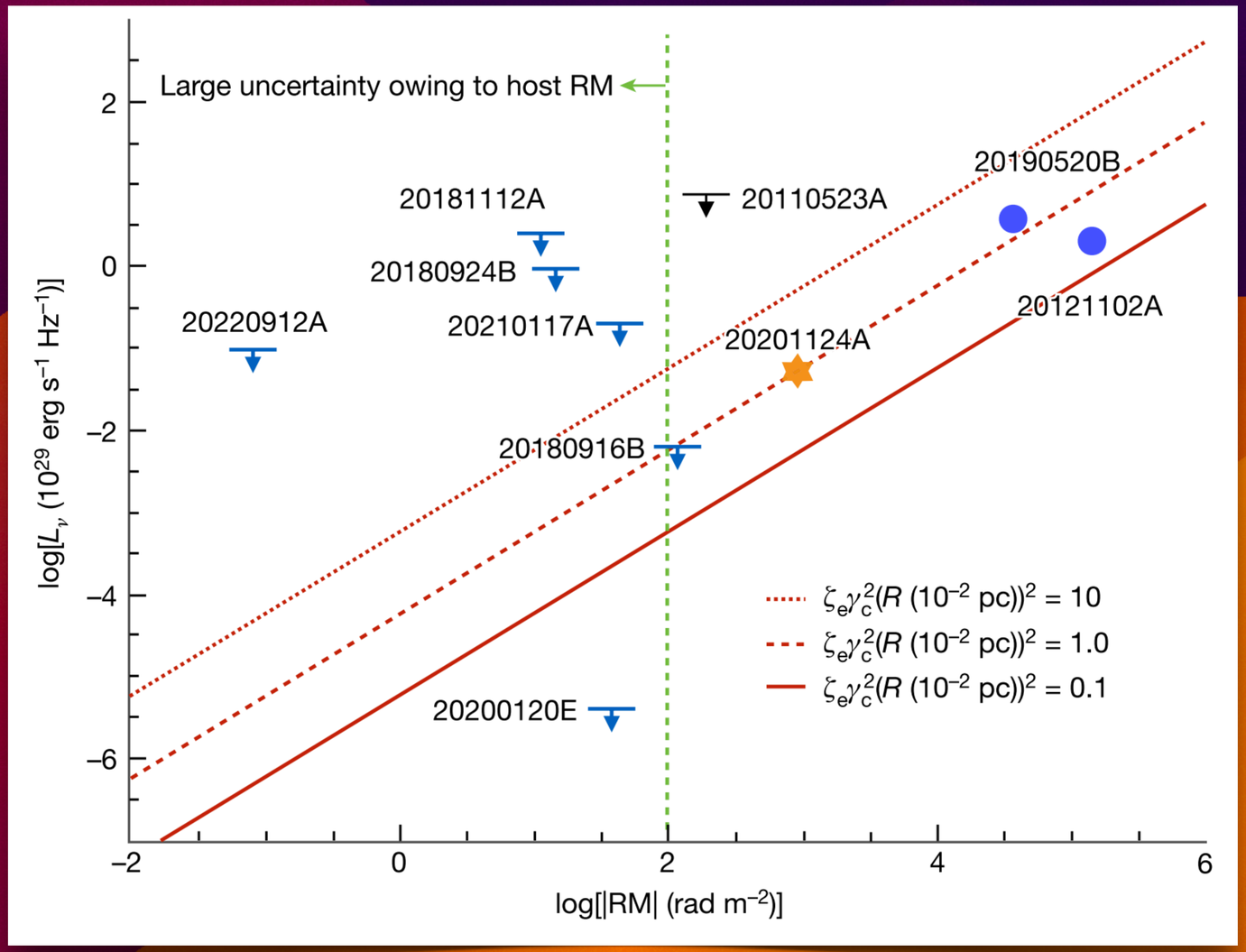
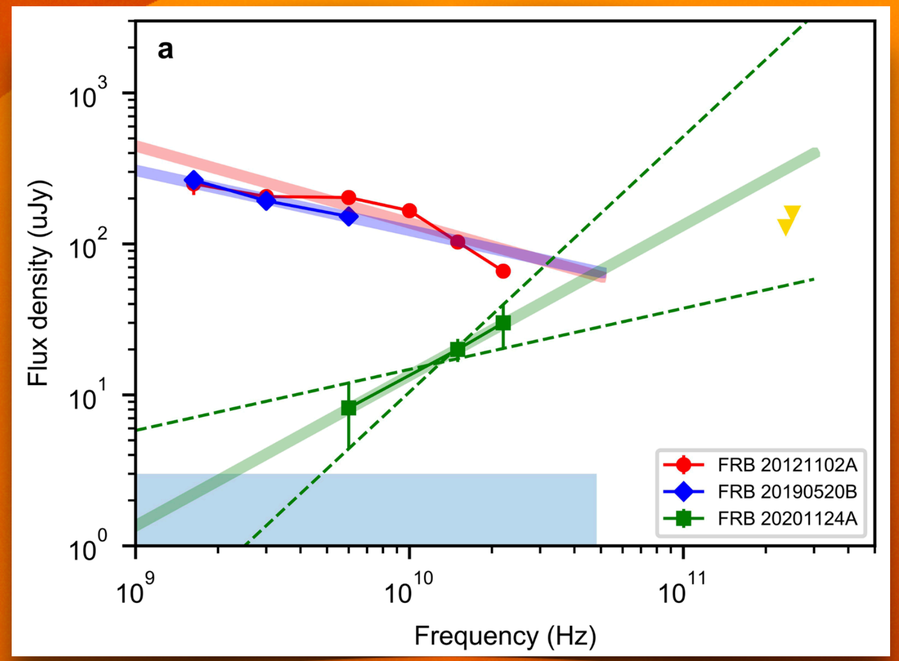
Received 2022 June 28; revised 2022 August 14; accepted 2022 August 15; published 2022 September 15

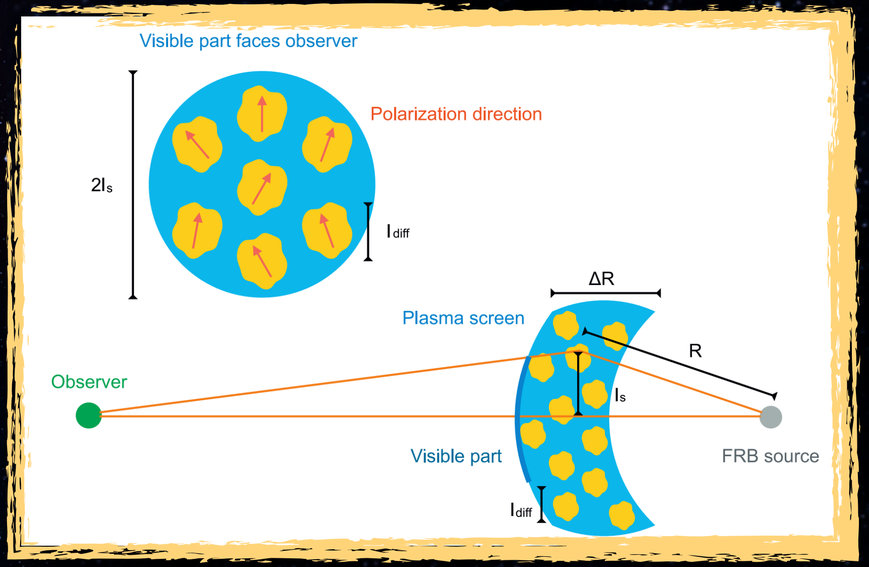
$$L_\nu \propto (\zeta_e \gamma_{\rm th}^2 R^2) \times |{\rm RM}|.$$





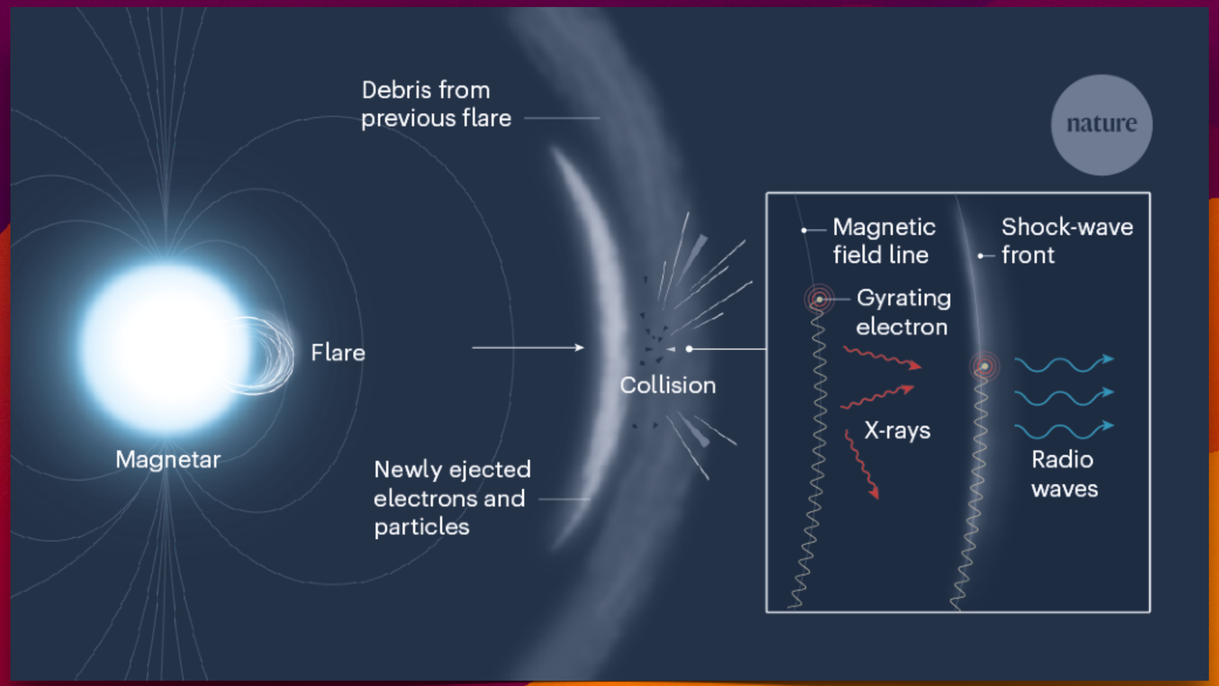
Bruni et al. 2024, Nature

Yang et al. 2022

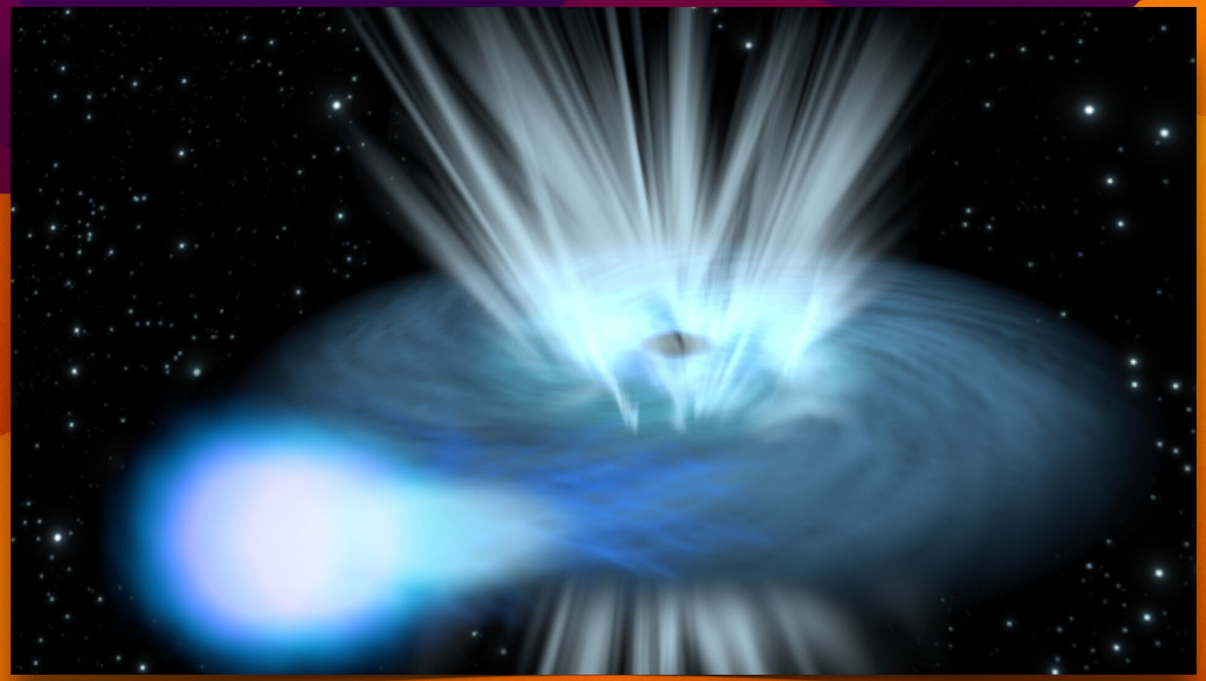


Possible central engines

Magnetar



Hyper-accreting XRB

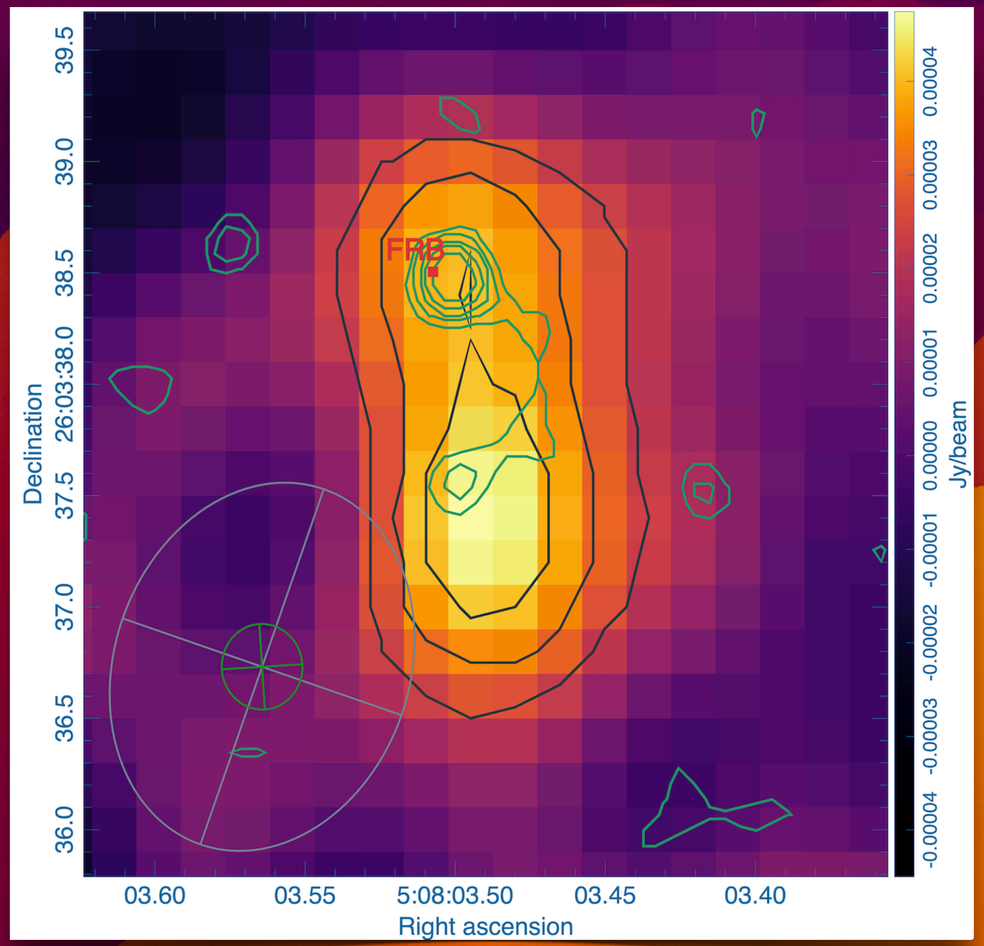


Sridhar et al. 2022

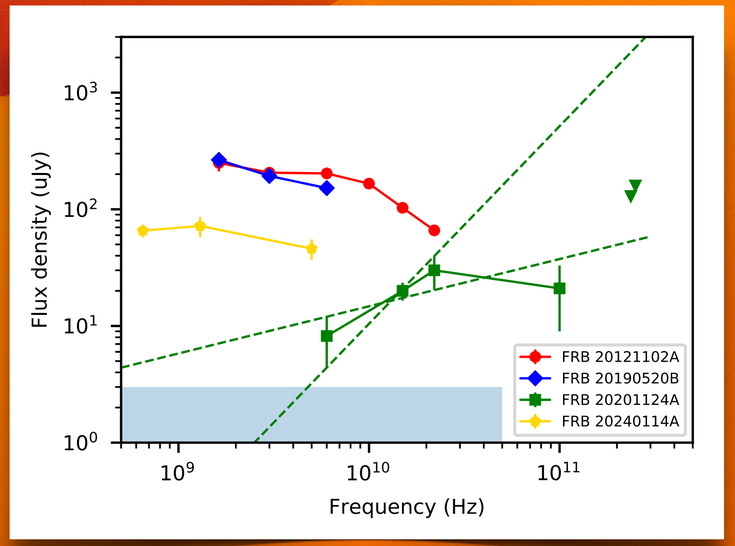
Both scenarios are consistent with the nebula model

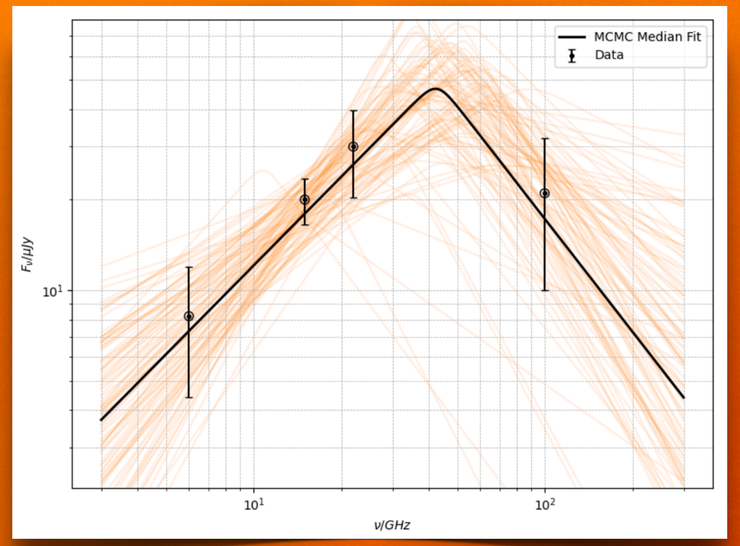
New constraints from ALMA

VLA (15 GHz) ⊕ ALMA (100 GHz)



- ALMA flux at 100 GHz suggest a spectral curvature





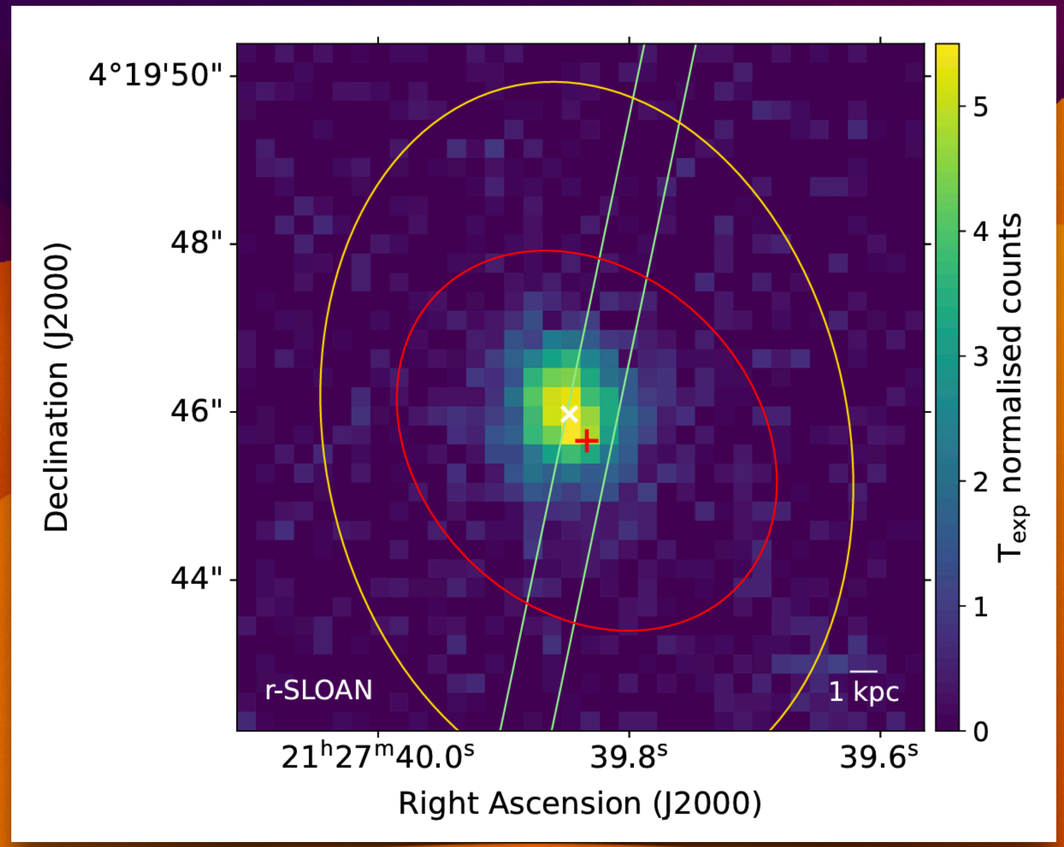
Pushing the limit…

- HSA (VLBA+Effelsberg+VLA) to detect the PRS and constrain the physical size on the mas scale
- 15 GHz: UL 30 uJy (RMS 6 uJy/beam)
- Flux from our VLA observations 20 uJy
- Even doubling the time, not doable…

A new case: the PRS associated with FRB 20240114A

A new case: PRS 20240114A

- First identified as possible counterpart with MeerKAT (Zhang+24, red circle) and uGMRT (Bhusare+24, yellow circle)
- Arcsec-resolution included the entire host, not allowing to exclude a star-forming origin
- VLBI observations at pc-scale can solve the issue…

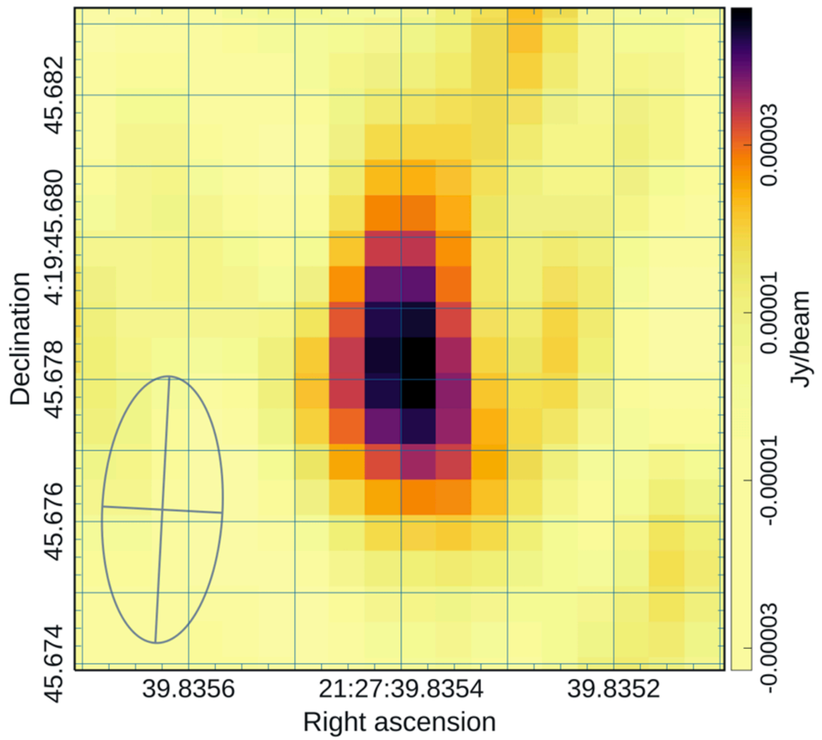


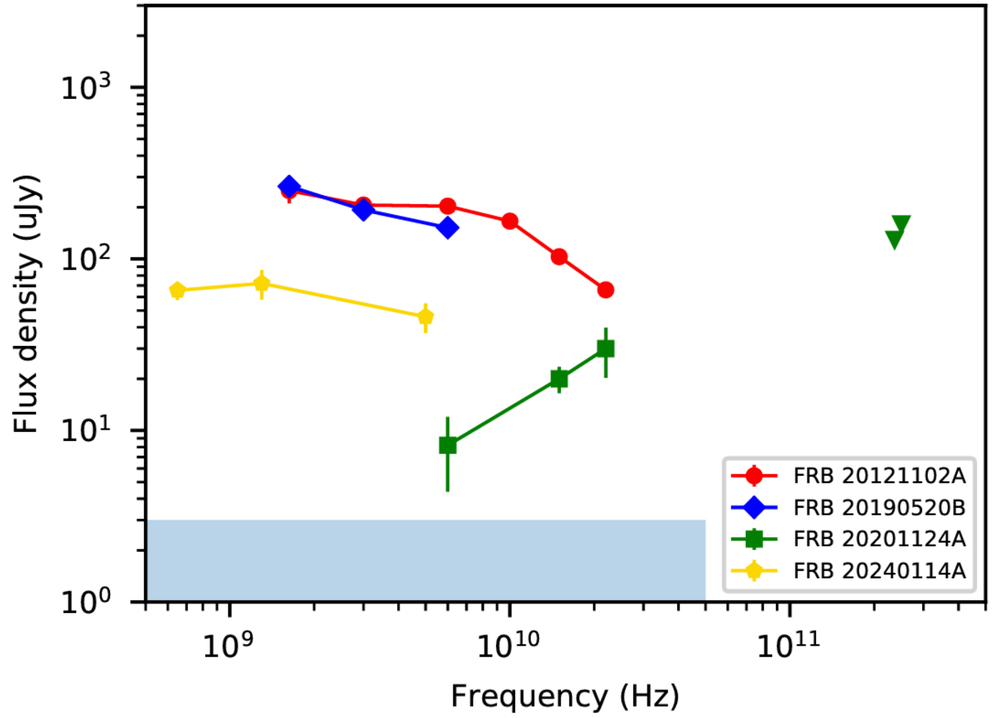
Bruni et al. 2025

A new case: PRS 20240114A

…We observed with the VLBA at 5 GHz, finding a compact source within the PRECISE error region

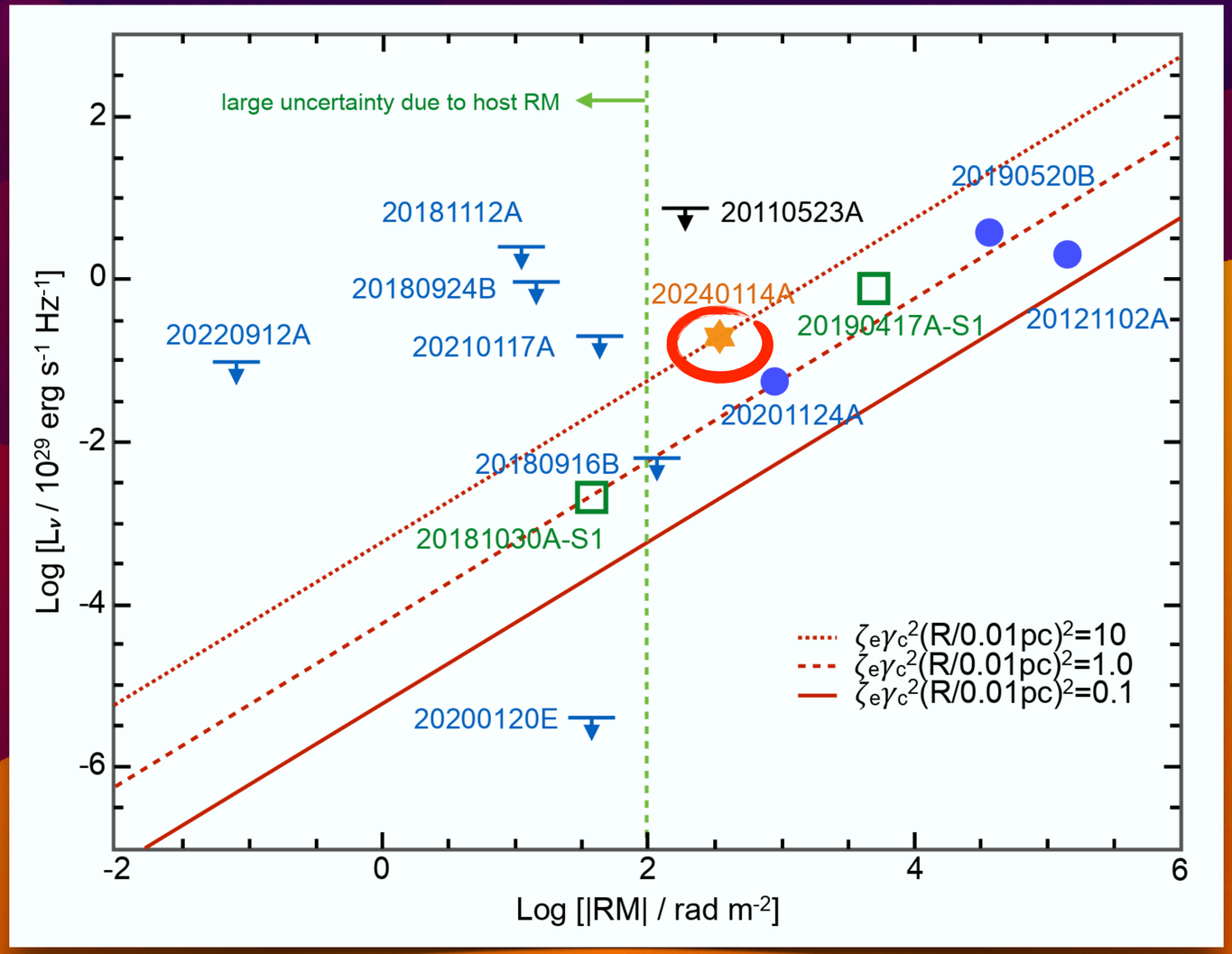
First indication of a peaked spectrum, to be verified through further VLBI observations





Bruni et al. 2025

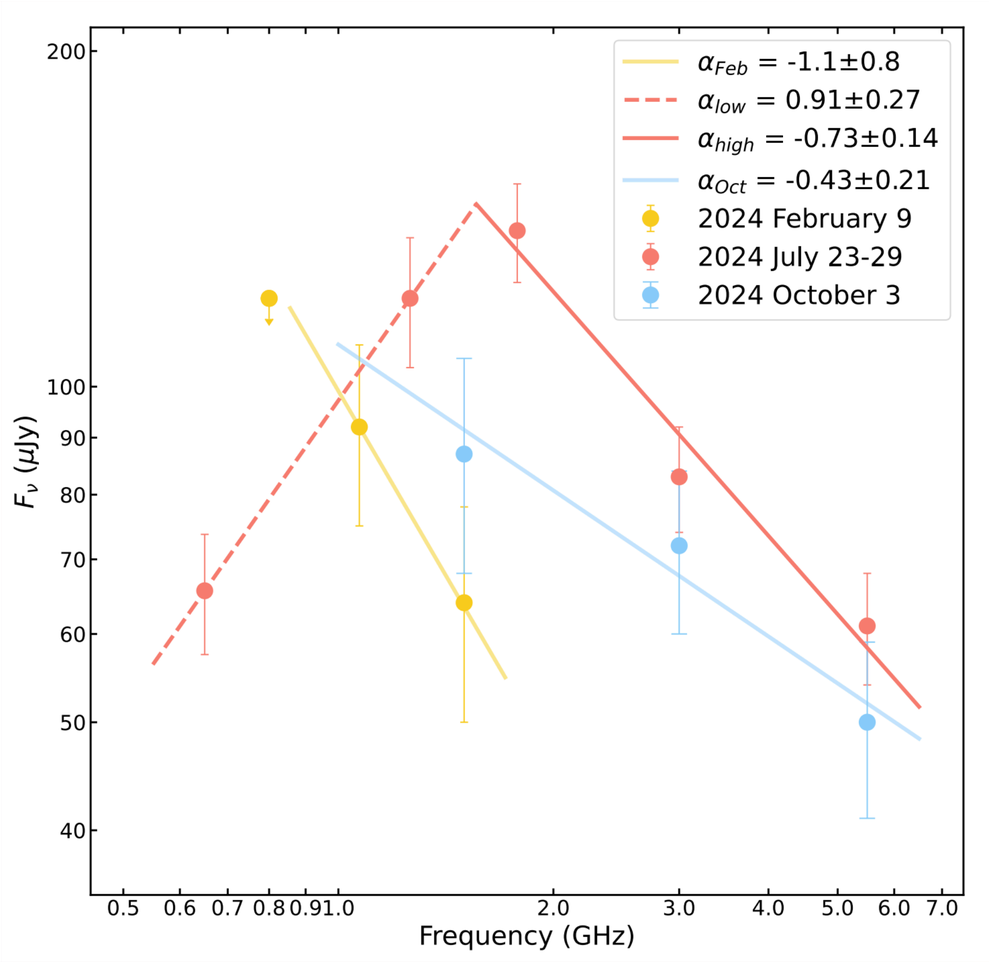
A new case: PRS 20240114A



Bruni et al. 2025

The radio luminosity and RM (340 rad/m^2) further support the nebular model

A new case: PRS 20240114A



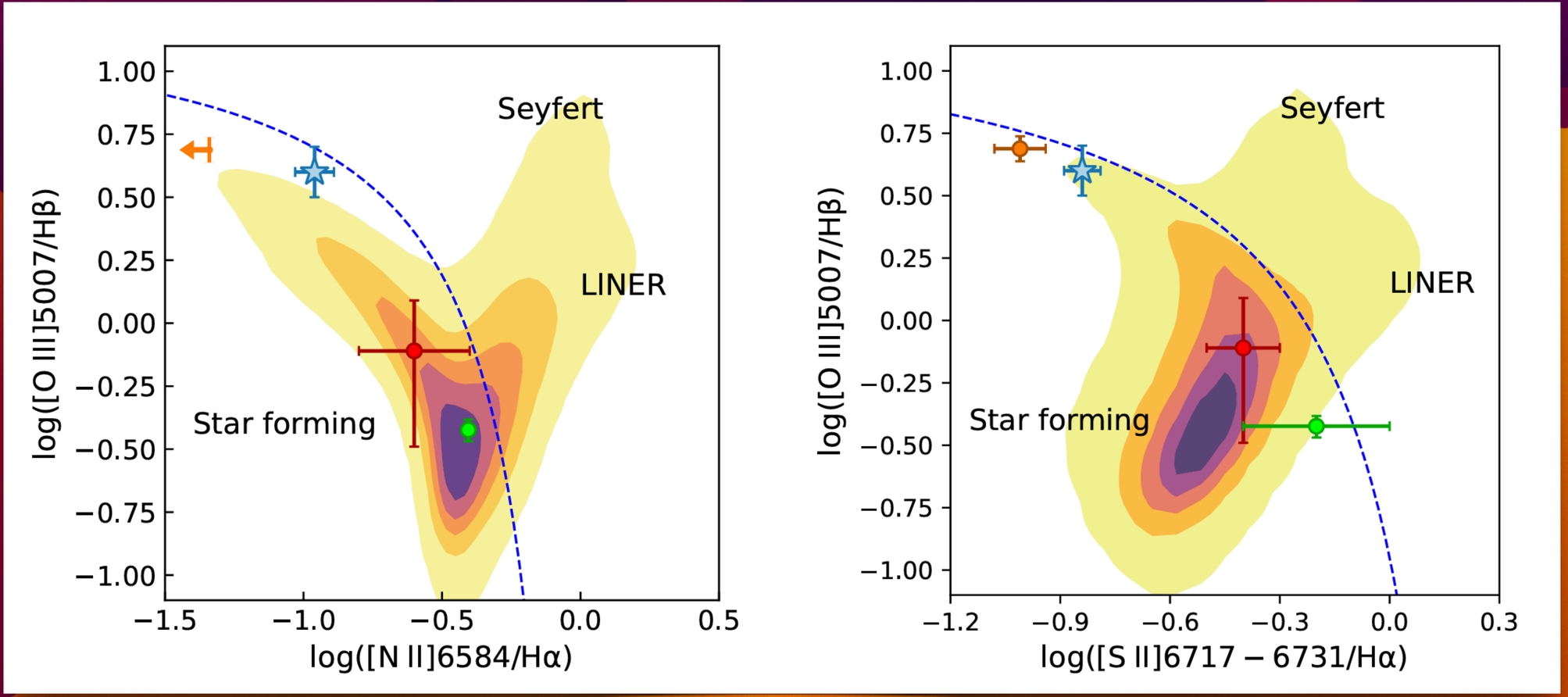
- Evidence for a peak at about 1 GHz from multi-epoch VLA observations
- Peak and flux variable on a timescale of months

A flaring radio counterpart to a fast radio burst reveals a newborn magnetized engine

Xian Zhang [1], Wenfei Yu [1], Zhen Yan [1], Yi Xing [1], and Bing Zhang [2,3]

[1] *Shanghai Astronomical Observatory, Chinese Academy of Sciences, Shanghai 200030, China*
[2] *The Nevada Center for Astrophysics, University of Nevada, Las Vegas, Las Vegas, NV 89154, USA*
[3] *Department of Physics and Astronomy, University of Nevada, Las Vegas, Las Vegas, NV 89154, USA*

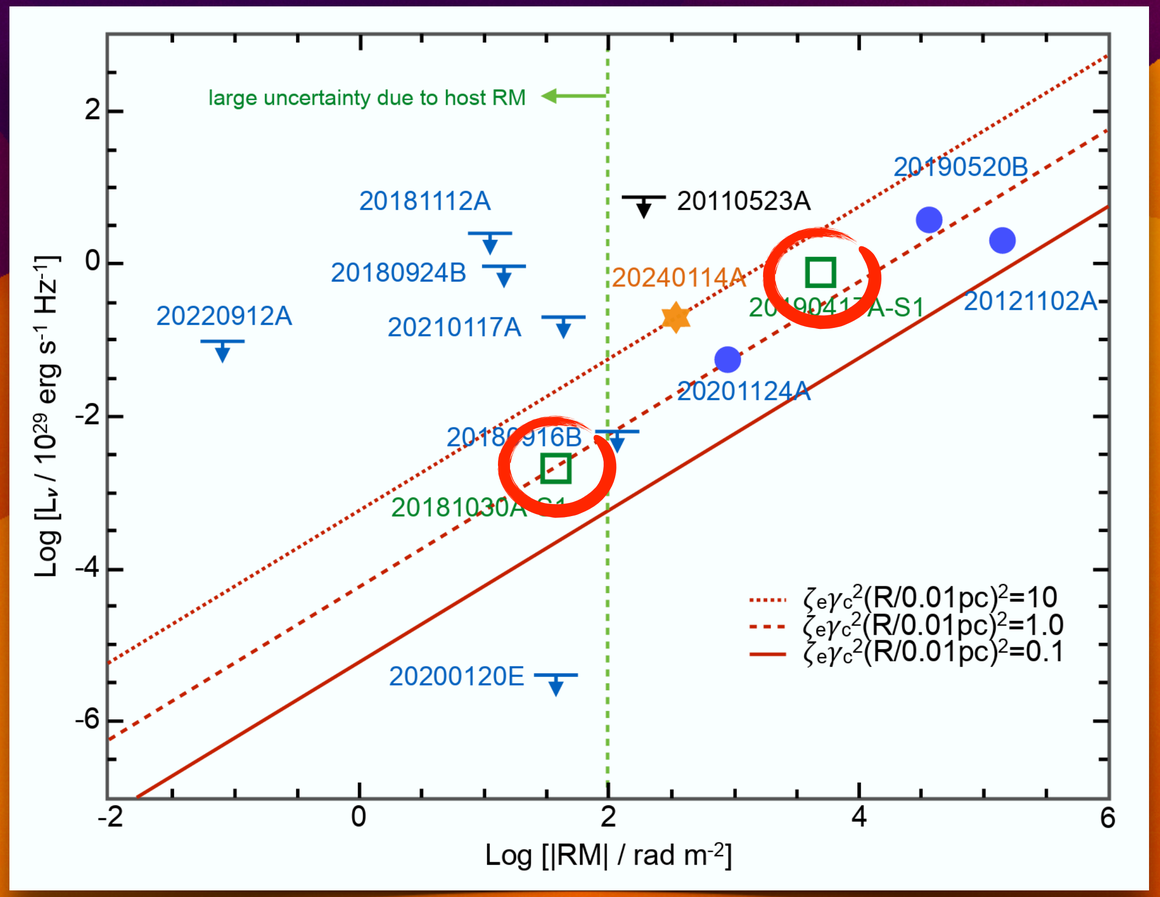
A new case: PRS 20240114A



Bruni et al. 2025

New PRS…

- PRS associated with FRB190417A (Ibik+24) confirmed with EVN observations at 1.4 GHz (PRECISE)
- L vs RM relation further confirmed!
- our EVN data at 5/8 GHz are underway, could constrain the spectral shape
- Also for FRB181030A (Ibik) and FRB240114 (possible variability with our previous VLBA detection)



Future prospects

- The 4 PRS discovered so far were associated to repeating FRB, and suggest a magnetar/X-ray binary nature for the central engine
- They were detected thanks to deep observations, by pushing the instrumental sensitivity at its limit. Both resolution and sensitivity are key to identify these faint counterparts
- A more statistical meaningful census can be build only with next generation instruments like SKA, SKA-VLBI and ngVLA, working in the uJy regime,
- The enhanced VLBI sensitivity will also allow to study them on the pc scale, further constraining the model