Connecting Fast Radio Bursts to their progenitors:

demographic surveys and associated persisting radio sources with SKA

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Figure credits: NASA/CXC/University of Amsterdam/N.Rea et al. 2016 + DSS

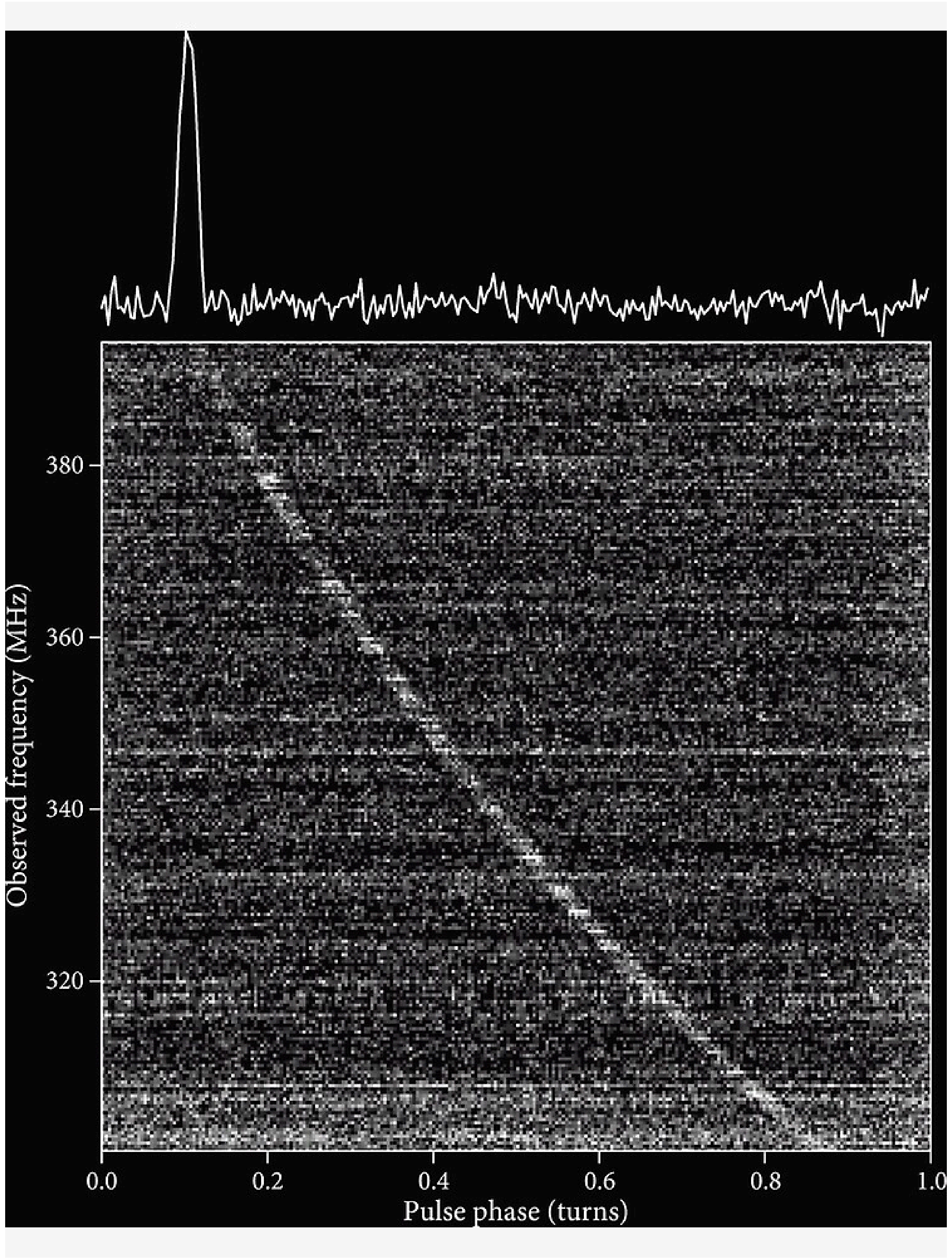
The Fifth National Workshop on the SKA Project, Bologna (Italy), 24-28 November 2025

Fast Radio Bursts (FRBs) in a (very tiny) nutshell

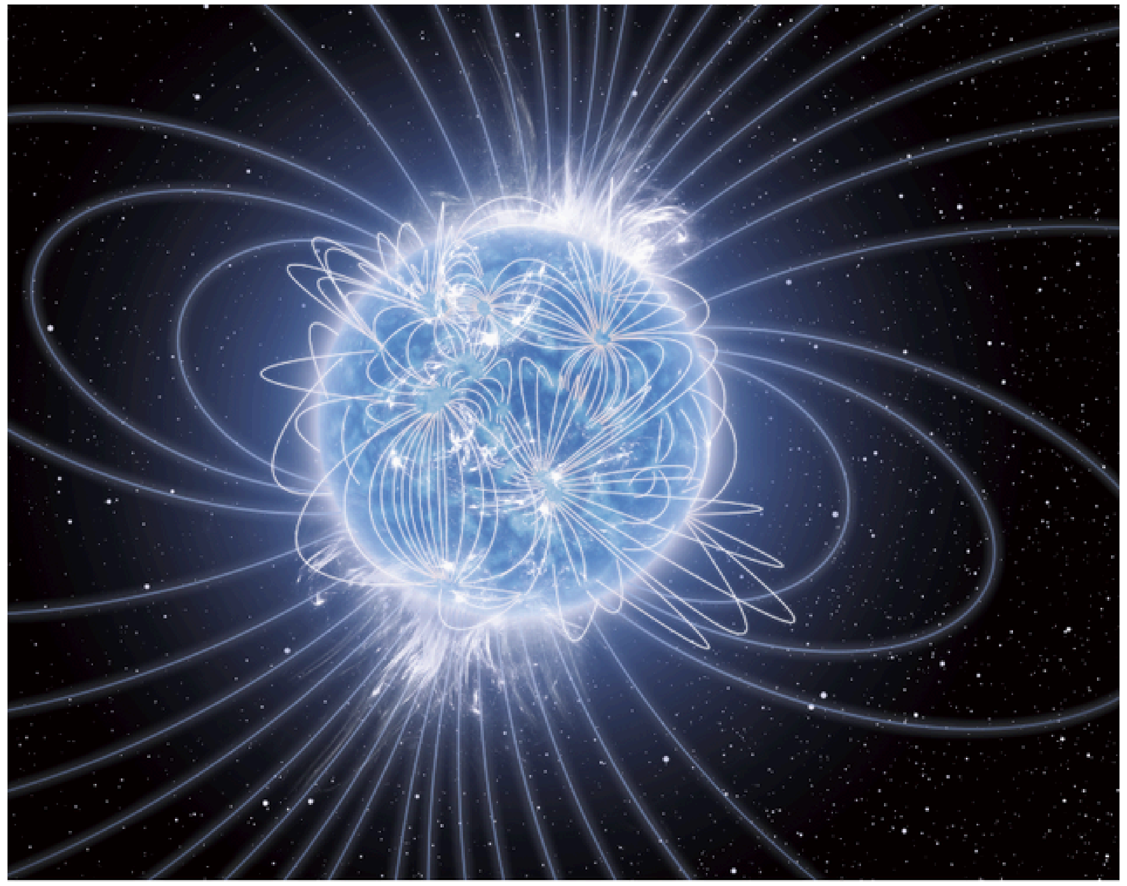
- Highly **dispersed** (-> exgtragalactic!) radio bursts of **millisecond** duration

- ~800 **different sources** of FRBs are known
    - majority are ***one-off*** *sources*
    - ~60 **repeaters** (no rotational periodicity found yet)
    - A handful of them show **hyperactivity** (up to 500 bursts/h)

- Most invoked progenitors are **magnetars**, i.e. neutron stars powered by the decay of large internal B fields (up to 10^{16} G, see e.g. Kaspi+17, Esposito+18, Rea & De Grandis+25 for reviews)



FRB progenitor(s)?



magnetars

Magnetars could be involved.

Main indications:

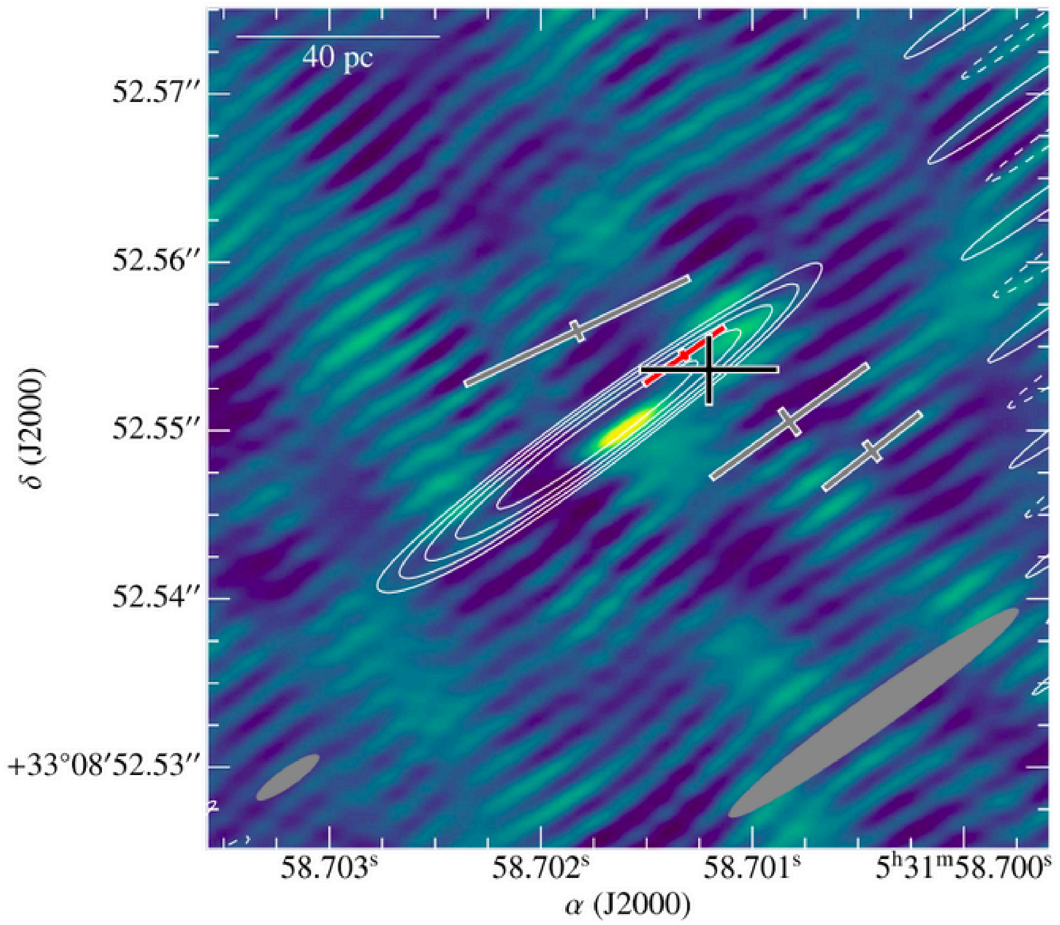
- **theoretically supported** (e.g. Popov & Postnov 07)
- Some FRBs are localized in **SF regions** (e.g. Tendulkar+17, Marcote+20)
- **short FRB duration --> compact** sources
- **high-RM FRBs --> complex magnetised** environment around them (e.g. Michilli+18)
- **A Galactic magnetar (SGR 1935+2154) emitted multiple FRB-like signals** (CHIME/FRB 20, Bochenek+20, Mereghetti+20, Tavani+20)

Limitations:

- Repeating FRBs **can be very active**! (while SGR 1935 is not..) (but see Margalit+20, Pelliciari+23, Geminardi,..,DP+25)
- Some **very active** repeaters (e.g. R1) are active since at least 13 yrs (and Galactic magnetars seem not.. see, e.g., Geminardi,..,DP+25)
- A nearby FRB pinpointed to a **globular cluster**.. CCSN magnetar hypothesis is **almost ruled out** for this specific source (Kirsten+22)
- Repeating FRBs could be also produced in **binary BHs** (e.g. Sridhar+24)

PRSs: an important link to FRB progenitors

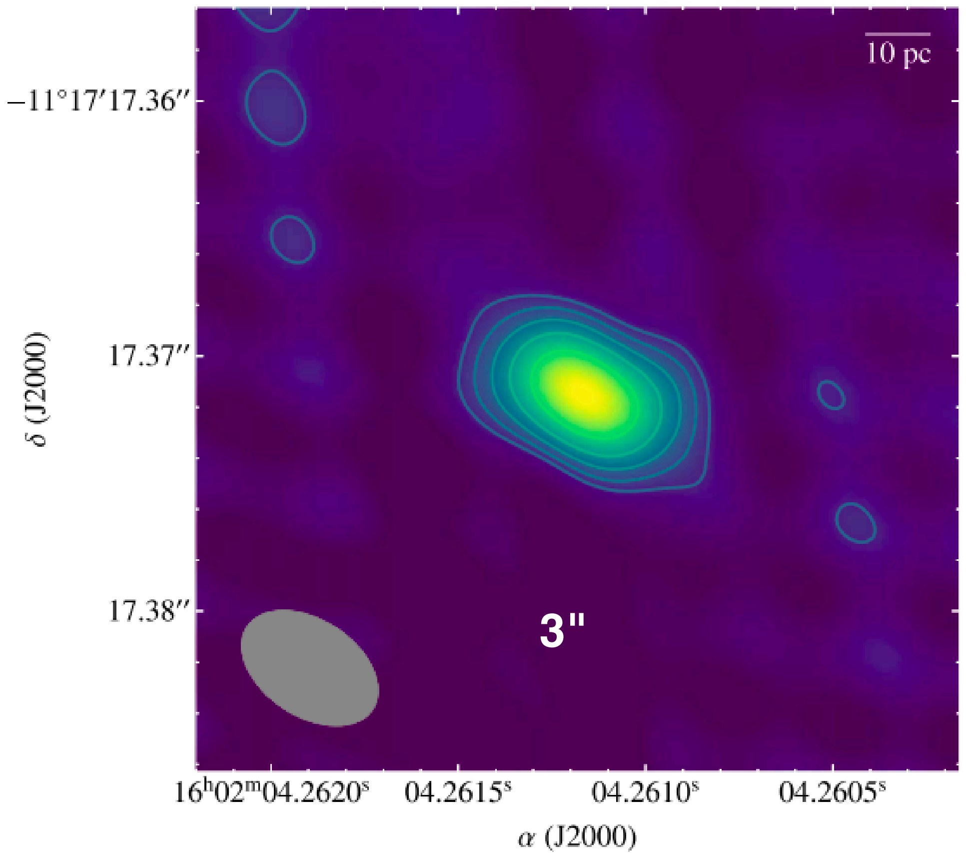
FRB 20121102A
(Marcote *et al.* 2017)



- **Four** active FRBs present *co-spatial* **persistent radio sources** (PRSs), too **bright** and **compact** (at pc scales) to be explained as star-formation processes.

see G. Bruni's talk!

- **Concordance picture for PRSs**: a strongly magnetized wind nebula powered by a central active **magnetar** (Margalit & Metzger 2018) or a compact binary system (e.g. BH-BH) accreting at Super-Eddington rate (e.g. Shridar *et al.* 2024)



FRB 20190520B
(Bhandari *et al.* 2023)

How to investigate FRB progenitors?

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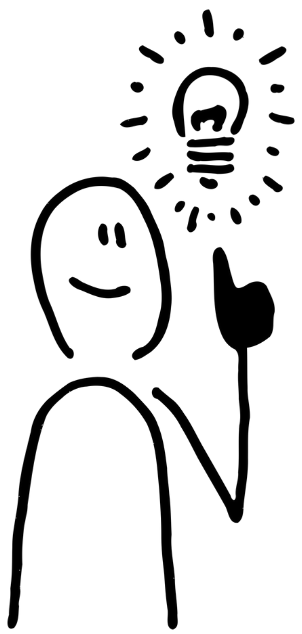
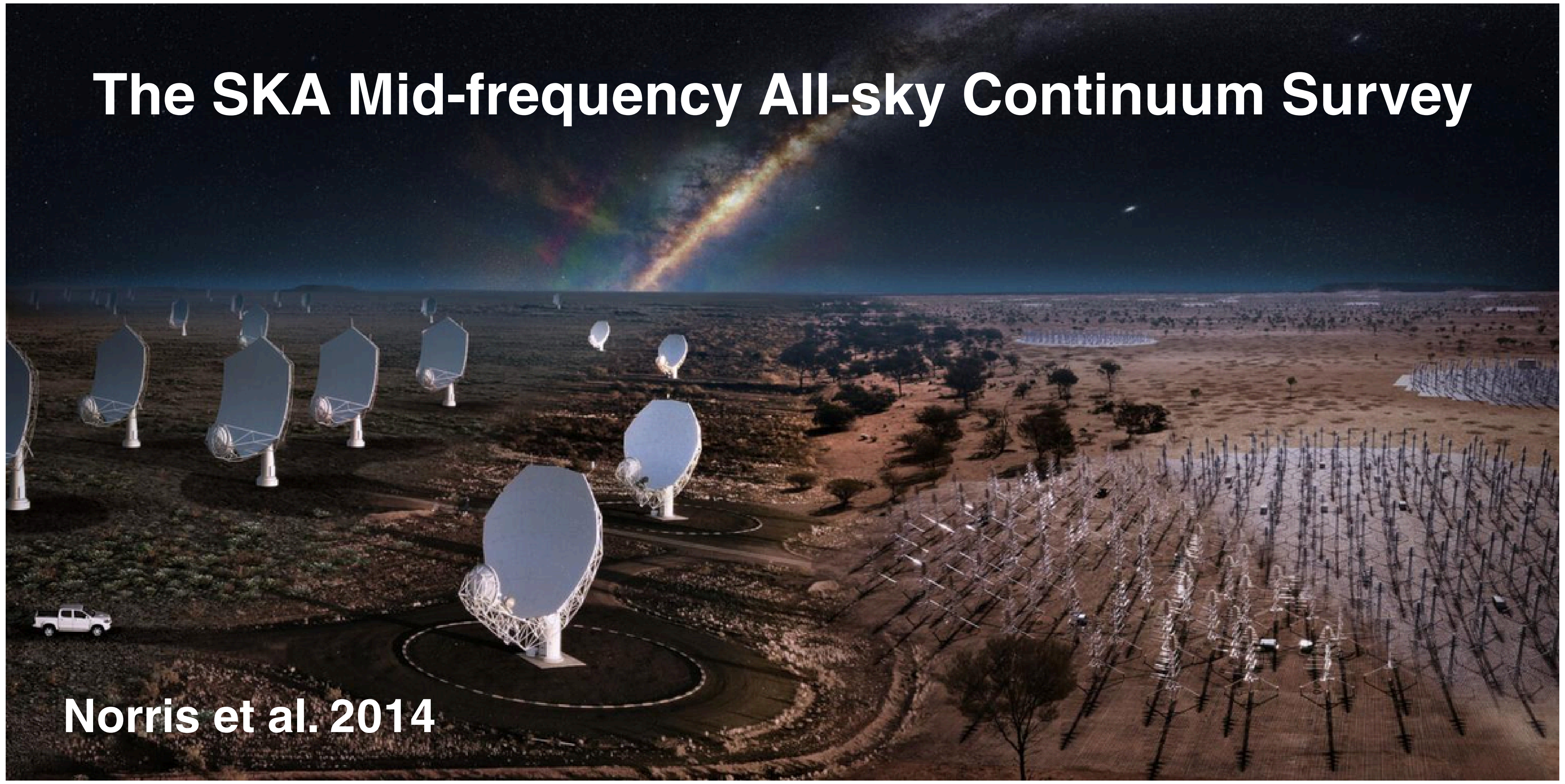
demographic surveys of FRBs!



with observations commensal with all-sky surveys, e.g.



Idea #1: Search FRBs in SF galaxies

Driver: investigate magnetar FRB rate

- **Nearby galaxies** are suitable to search for FRBs similar to the one emitted by the Galactic magnetar

- Magnetars are young objects, so one expect to find more of them the more the SFR of the galaxy is

- **Northern Cross:** Long monitoring (tot: **700 hrs**) on 7 SF galaxies. We got 0 detections → **limit on the FRB rate per magnetar** $\lambda_{\rm mag}$! (Pelliciari+23b)

- We derived the **total FRB rate expected** from the sample of 7 galaxies and compare it to our **non-detection** in 700 hrs (see Figure)

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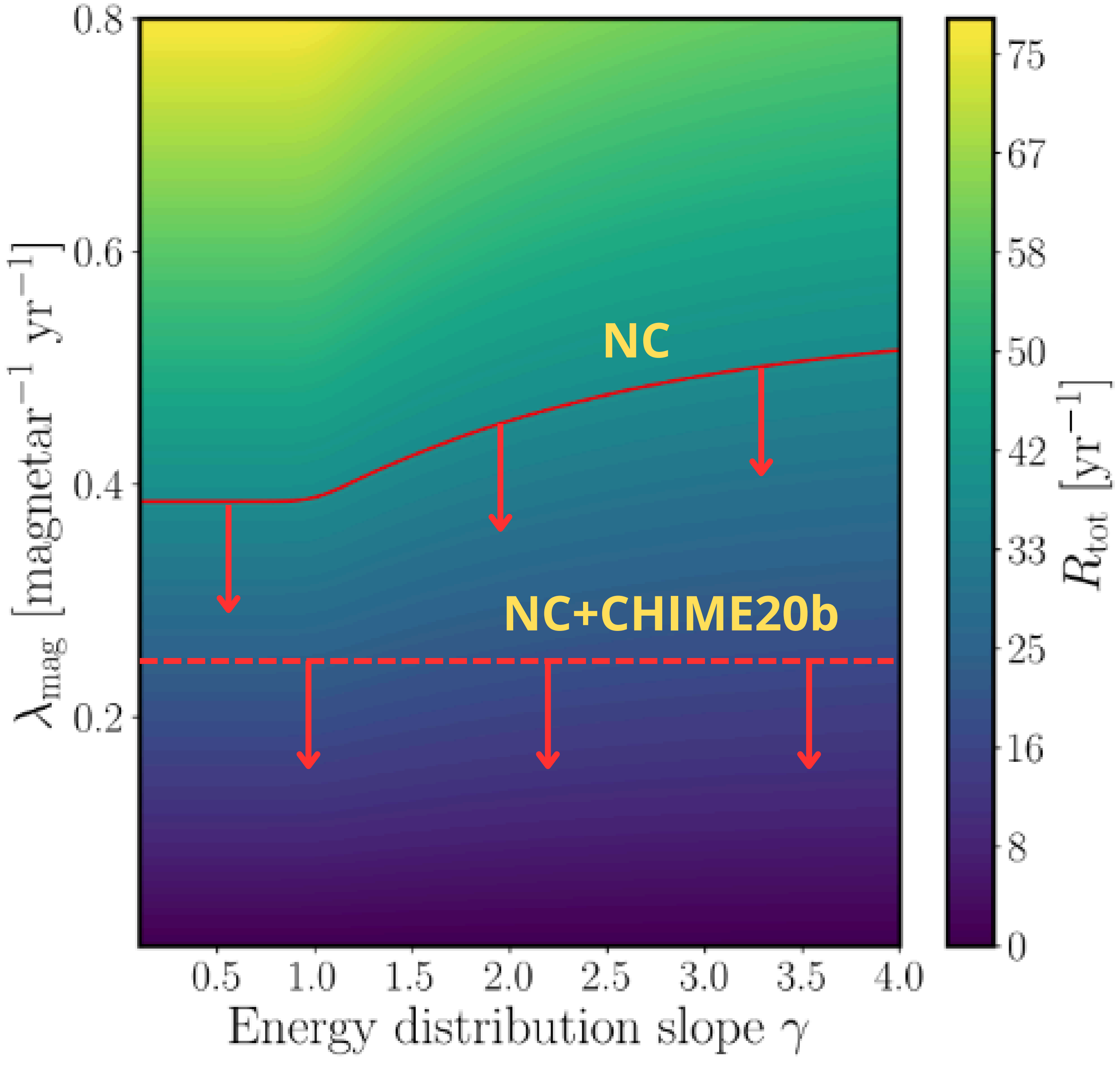
Pelliciari+23b



$$0.007 < \lambda_{\rm mag} < 0.45 \text{ magnetar yr}^{-1}$$

Are FRBs originating from *exotic* magnetars?

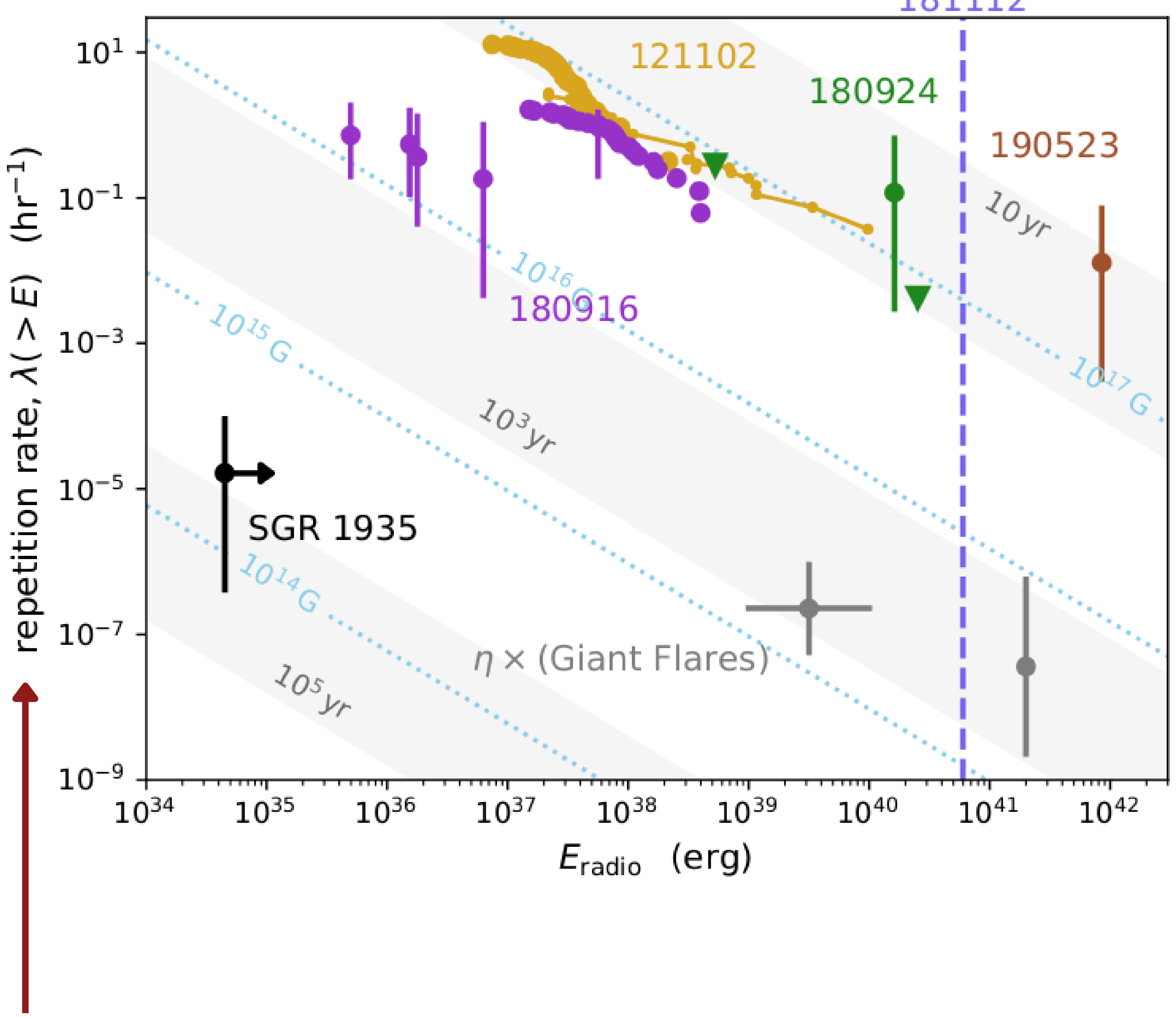
We **are not** observing magnetars as active as R1 in our own Galaxy (see also **Geminardi+25**)

One can (broadly) solve this issue by adding a **new class** of *exotic* magnetars with **stronger B fields, more active** and **born** at a much **lower birthrate than SGRs** (see Margalit+20)

↓

These observations can shed light on FRB progenitor**(s)** and ***exotic* magnetar** formation channels

Margalit+20

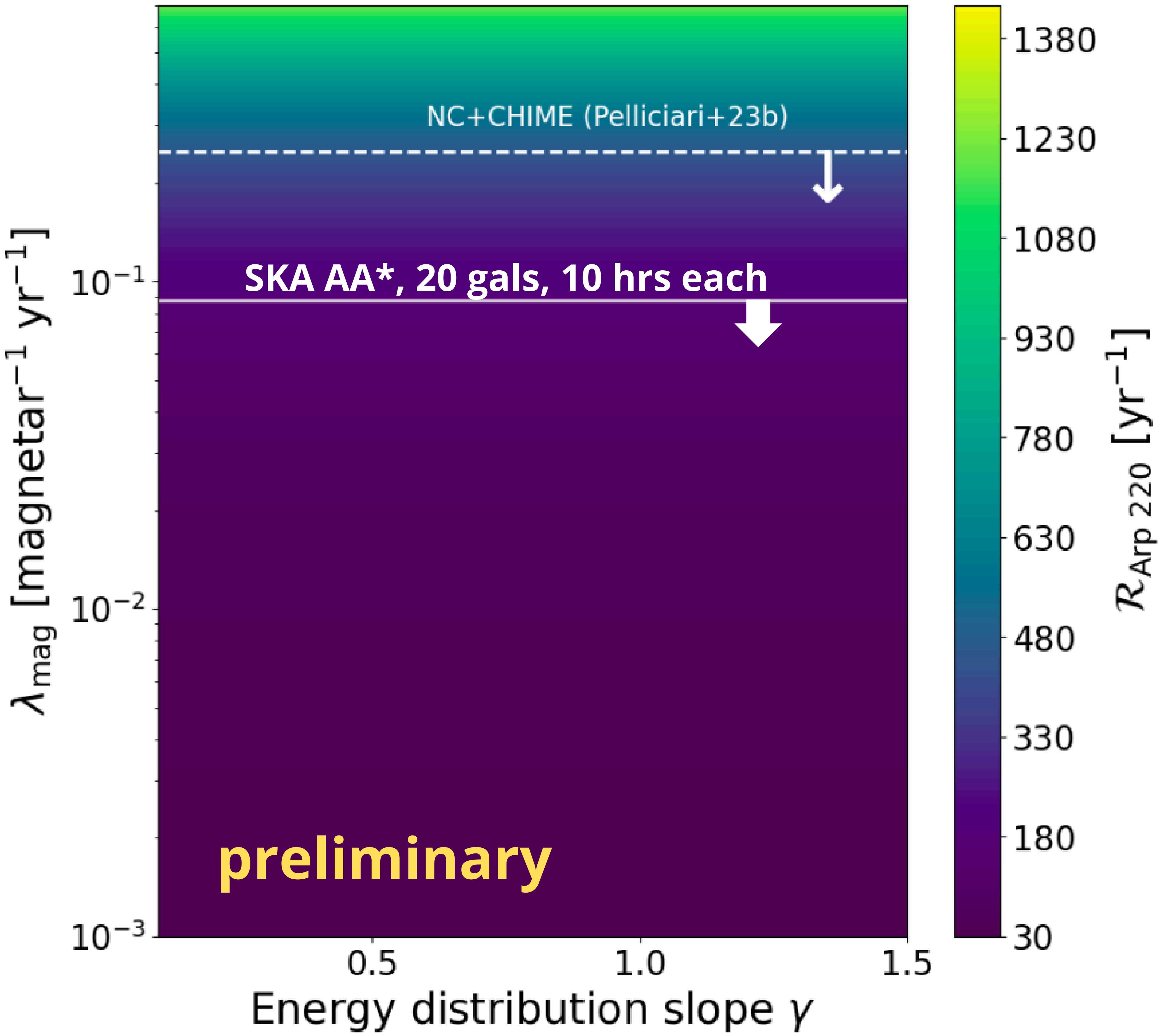


repetition rate per source

How SKA (AA*) can improve

- SKA-MID sensitivity (10σ = 3.5 mJy ms) is a factor **10000 better** than what consider in Pelliciari+23b (NC, 8 cylinders) → The maximum distance at which a SGR1935-like FRB would be detectable is a factor **100 larger**

- SKA **beamforming** capabilities will assess an FRB localization at **arcsec** level → in case of detection one can also study the local origin of the FRB

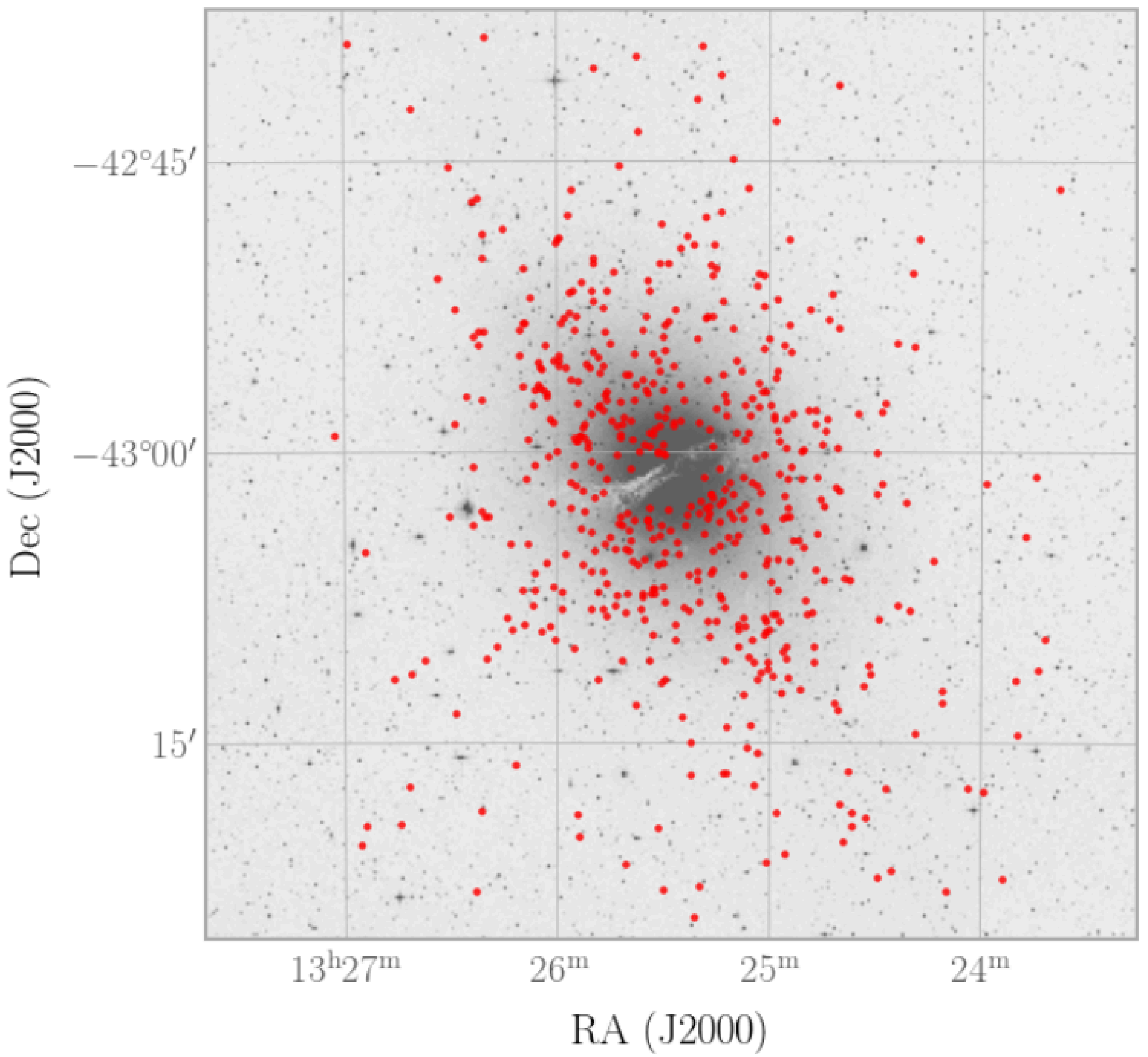


Not only nearby SF galaxies!

- Demographic searches for other types of galaxies, e.g. massive and/or dwarf galaxies (regardless of the SFR). Useful also for indirect PRS searches!

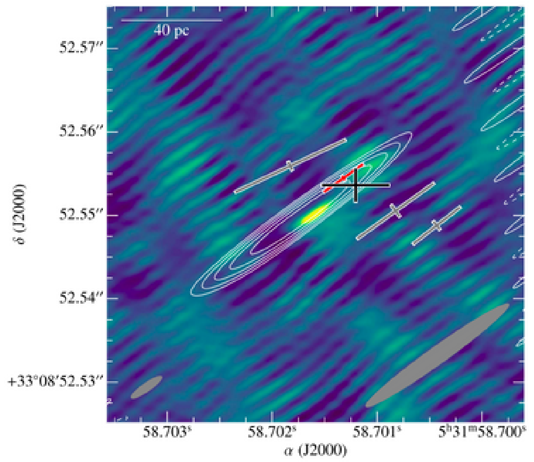
- Target a single nearby galaxy (or some of them) having a large number of **globular clusters,** leaveraging the beamforming capabilities of SKA (e.g. Centaurus A with hundreads of catalogued GCs within the SKA FoV)

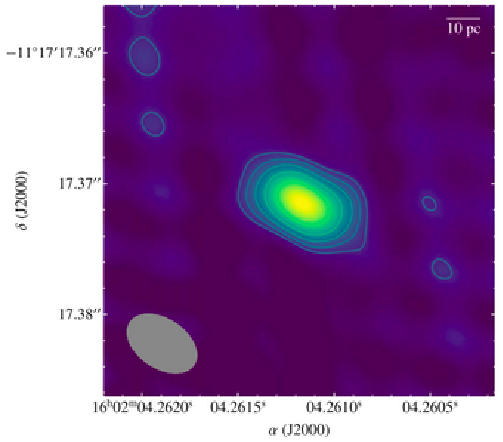
Position of CenA GCs (red, Hughes+21) within 2 deg)



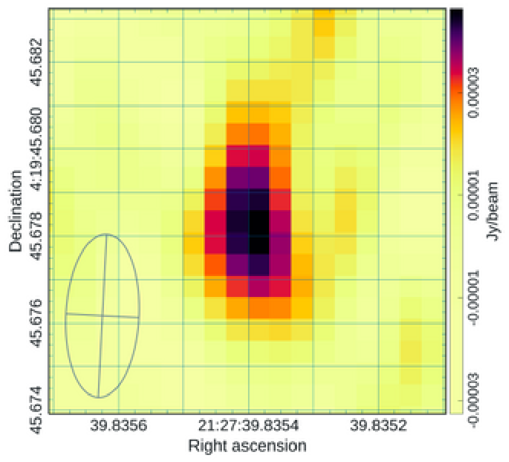
Idea #2: Discovering new PRSs!

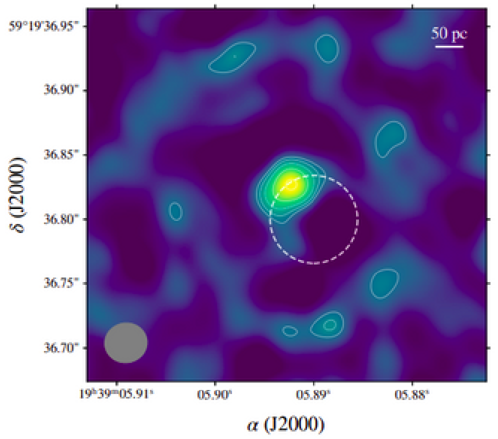
Just a handful of PRSs are known!





- 4 **confirmed** sources: FRBs **20121102** (Chatterjee+17, Marcote+17), **20190520B** (Niu+21,Bhandari+23), **20190417A** (Ibik+24, Moroianu+25), **20240114A** (Bruni+25)





- 2 **candidates**: FRBs **20181030A** (Ibik+24b), **20201124A** (Bruni+23)

Property	**FRB 20190417A**[a]	FRB 20121102A [b]	FRB 20190520B [c]	FRB 20240114A [e]
$\mathrm{DM_{host,rest}}$ ($\mathrm{pc\,cm^{-3}}$)	> 1212	$\lesssim 203$	137–707	142 ± 107
$\mathrm{RM_{rest}}$ ($\mathrm{rad\,m^{-2}}$)	5,038–6,441	4.4×10^4–1.5×10^5	$[-3.6, +2.0] \times 10^4$	449 ± 13
z	0.128	0.193	0.241	0.130
L_ν ($\mathrm{erg\,s^{-1}\,Hz^{-1}}$)	$\sim 8 \times 10^{28}$	$\sim 2 \times 10^{29}$	$\sim 3 \times 10^{29}$	$\sim 2 \times 10^{28}$
ν of above	(1.5 GHz)	(1.4 GHz)	(1.7 GHz)	(5 GHz)
Spectral index, α	-1.20 ± 0.40	-0.15 ± 0.08	-0.41 ± 0.04	-0.34 ± 0.21
Physical size (pc)	< 23	$\lesssim 0.7$	< 9	< 0.4
PRS-burst offset (pc)	< 26	< 40	< 80	~ 28
Host galaxy	Dwarf	Dwarf	Dwarf	Dwarf

Moroianu+25

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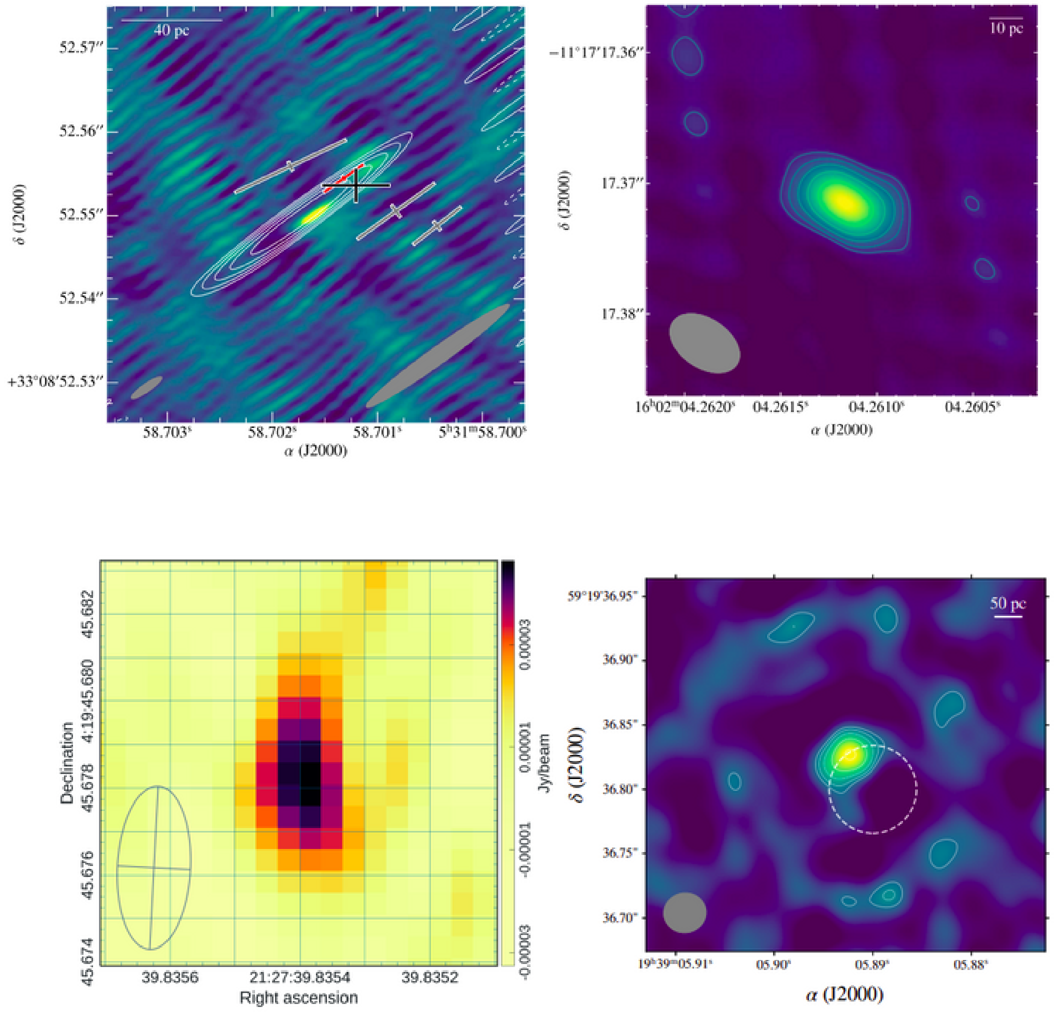

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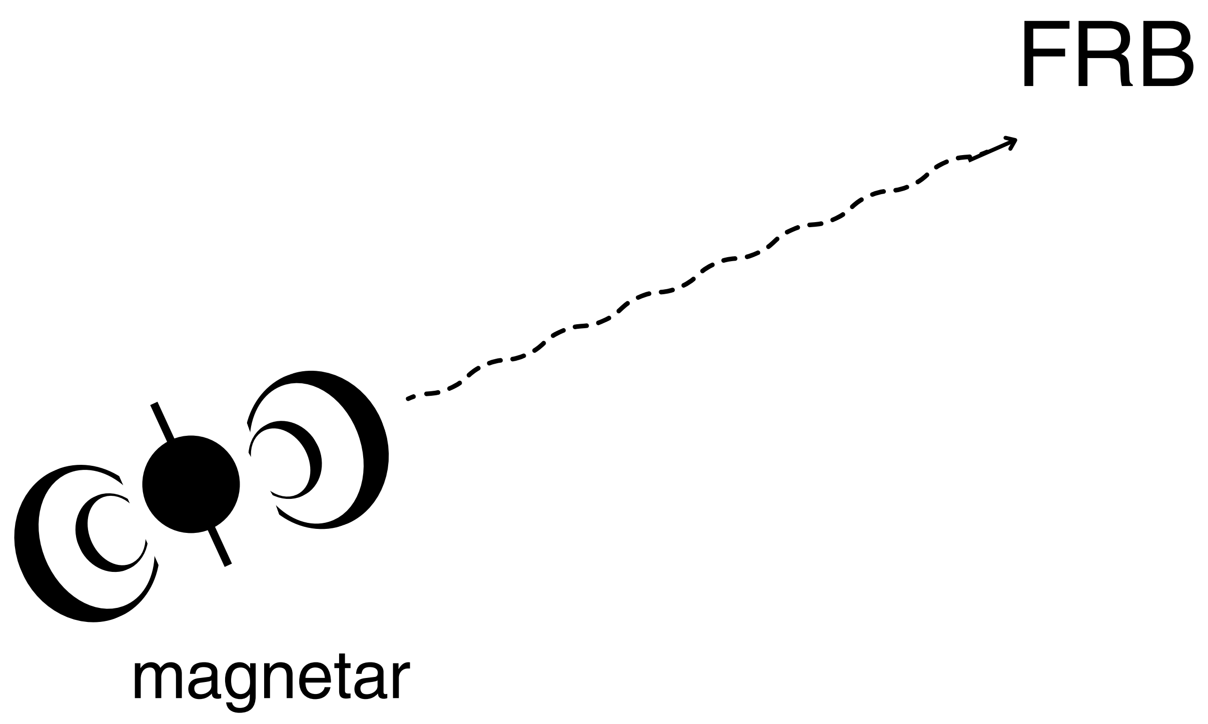
Moroianu+25

A schematic picture behind FRB-PRS systems



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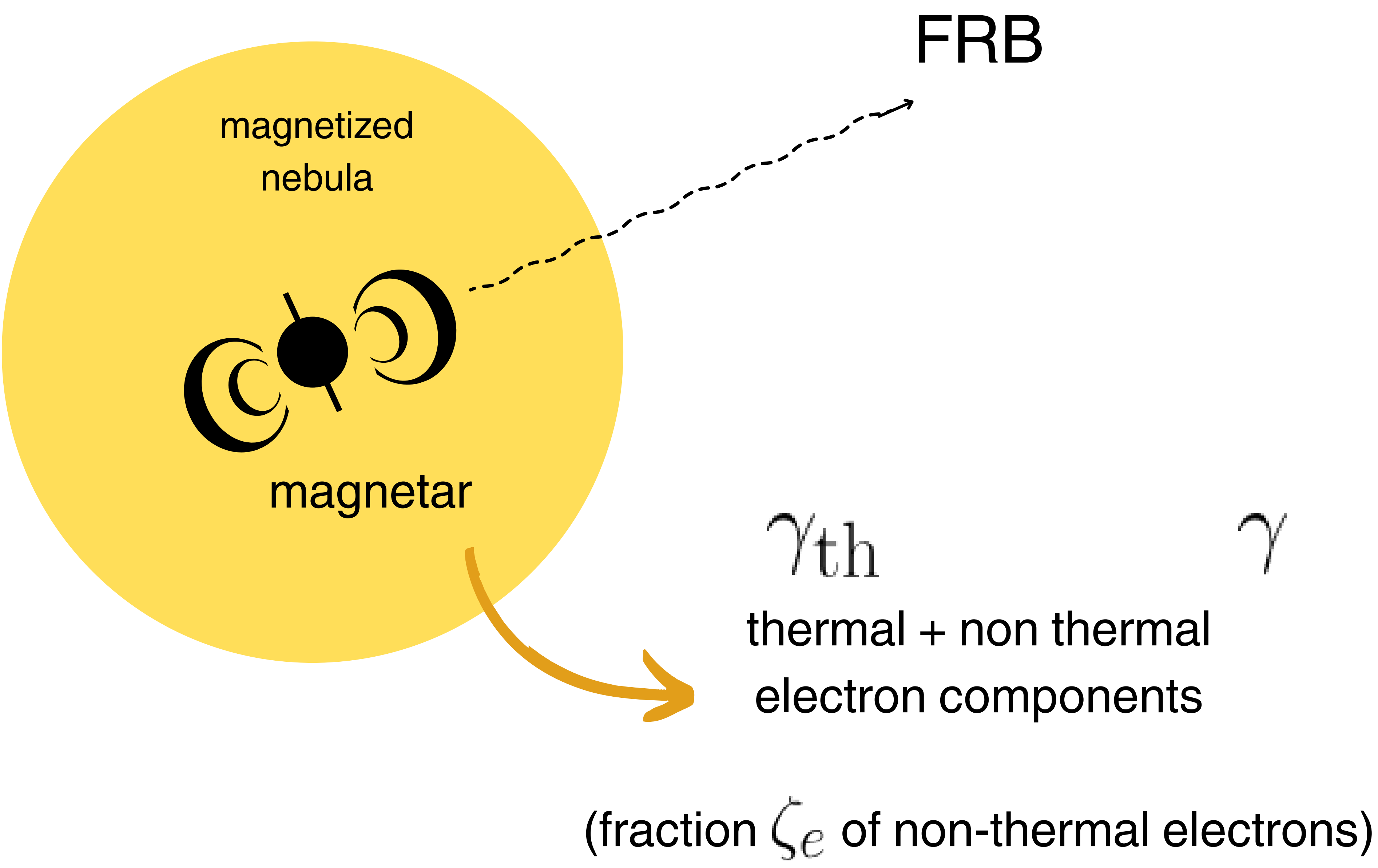
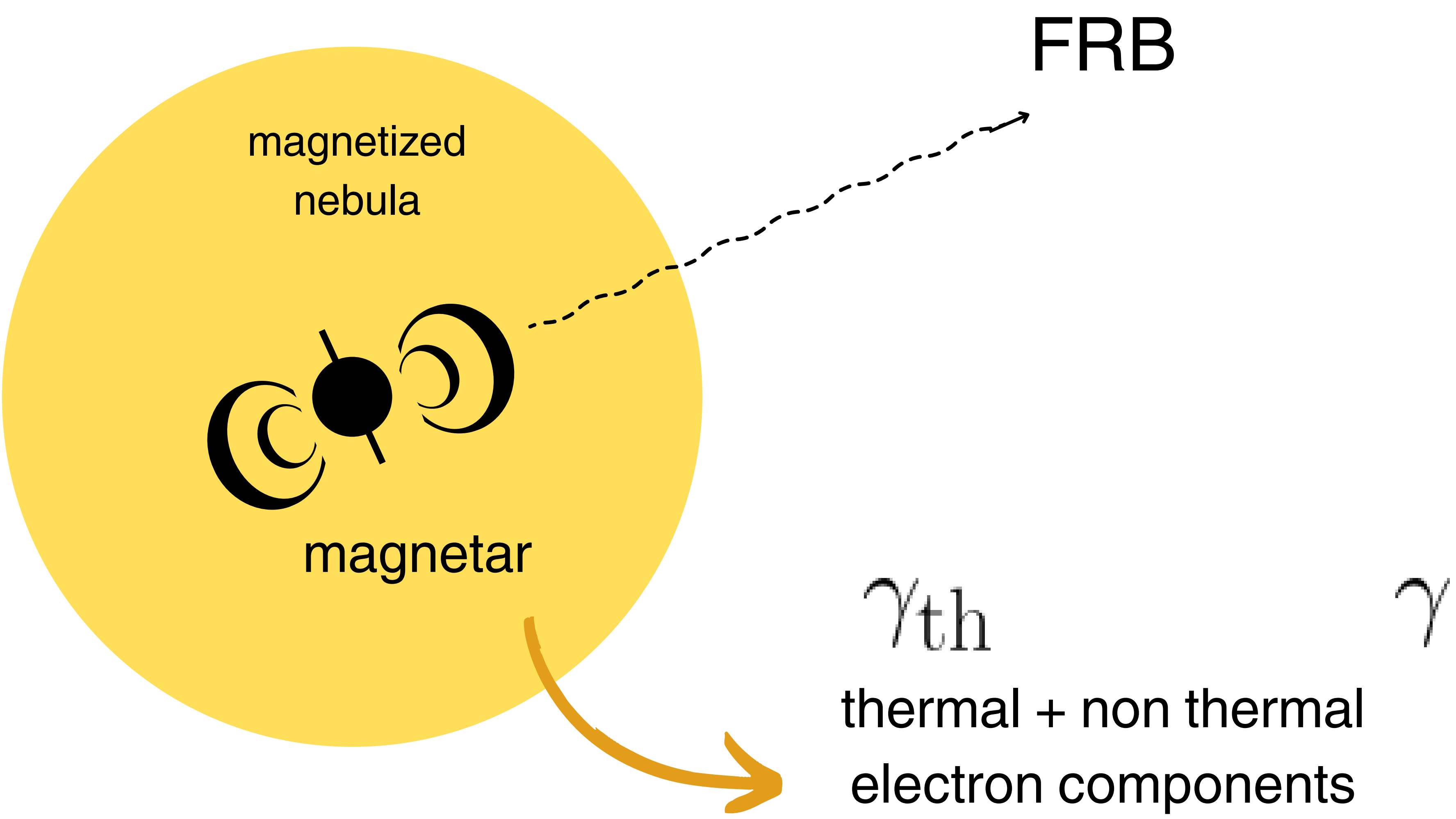


A schematic picture behind FRB-PRS systems

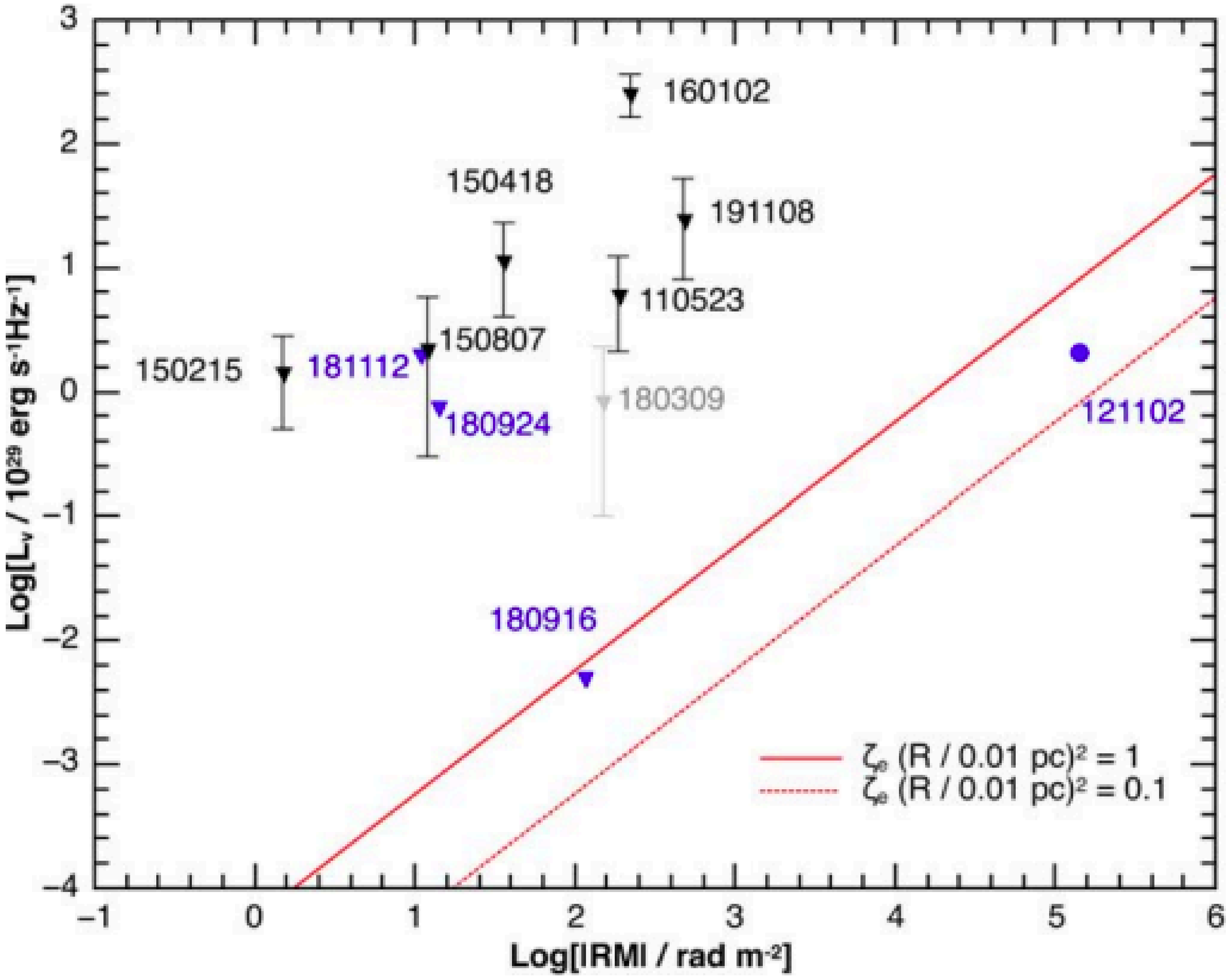
If the emitting region (PRS) **is the same** where RM originates, then a positive correlation between the RM and specific PRS luminosity is expected (Yang+20, Yang+22, Bruni+24)



(fraction ζ_e of non-thermal electrons)

$$L_\nu \approx 5.7 \times 10^{29} \text{ erg s}^{-1} \text{ Hz}^{-1} \left(\frac{\zeta_e \gamma_{\rm th}^2}{0.01}\right)\left(\frac{R}{1 \text{ pc}}\right)^2 \left(\frac{|\text{RM}_{\rm src}|}{10^3 \text{ rad m}^{-2}}\right).$$

The RM-Lnu relation (at the beginning)



From Yang+20

A 1.26 GHz search for PRSs with the uGMRT

Pelliciari et al. (in prep.)

24 FRB sources

13 rep.

11 one-offs

uGMRT

ID	Source name	z	RM_{obs} (rad m^{-2})	$F_{1.2}$ (μJy)	$L_{1.2}$ (10^{29} erg s^{-1} Hz^{-1})	Refs.
S1	r20180301A	0.3304(1)	−68(13)	< 36	< 1.12	1, 2, this work
S2	r20180814A	0.06835(1)	+700(1)	< 36	$< 4.2 \times 10^{-2}$	3, 4, this work
S3	r20190303A	0.06437(1)	−703.4(6)[a]	< 114	< 0.12	3, 4, this work
S4	20190523A	0.660(2)	–	< 39	< 5.4	5, this work
S5	**r20190417A**	0.12817(2)	+4429.8(4)	248(20)	1.05(8)	3, 4, 6, this work
S6	20190714A	0.2365	–	< 39	< 0.6	7, this work
S7	r20190804E	$0.30^{+0.06}_{-0.18}$	−196.0(2)	< 60	< 1.7	8, 9, this work
S8	r20191106C	0.10775(1)	+1044.4(2)	< 126	< 0.37	8, 9, 10, this work
S9	20191228A	0.2432(1)	–	< 45	< 0.73	1, this work
S10	20200216A	$0.46^{+0.08}_{-0.28}$	+2051(6)	< 39	< 2.7	11, this work
S11	r20201114A	$0.26^{+0.04}_{-0.16}$	+1348.7(3)	< 60	< 1.2	8, 10, this work
S12	r20201130A	$0.16^{+0.04}_{-0.10}$	+182.9(2)	< 54	< 0.42	8, 10, this work
S13	**20210317A**	$0.38^{+0.08}_{-0.24}$	+252(1)	116(14)	0.68(8)[b]	11, this work
S14	20210320C	0.2797	–	< 54	< 1.2	12, 13, this work
S15	20210807D	0.1292	–	< 54	< 0.23	14, this work
S16	20210117A	0.2145	+43(6)	< 45	< 0.56	1, 14, this work
S17	20211127I	0.0469	–	< 39	$< 2.1 \times 10^{-2}$	14, this work
S18	20211212A	0.0715	–	< 90	< 0.11	15, this work
S19	20220105A	0.2785	–	< 66	< 1.4	12, 13, this work
S20	r20230607A	0.22	−12249(2)	< 45	< 0.58	15, this work
S21	r20230814A	$0.64^{+0.10}_{-0.36}$	−19(1)	< 63	< 8.5	16, this work
S22	**r20240114A**	0.1300(2)	+338.1(1)	53(11)	0.31(4)	17, 18, this work
S23	r20240316A	$0.28^{+0.04}_{-0.18}$	–	< 48	< 1.1	19, this work
S24	r20240619D	$0.34^{+0.06}_{-0.22}$	−190(1)	< 54	< 1.9	20, this work

A 1.26 GHz search for PRSs with the uGMRT

+ 41 sources from literature

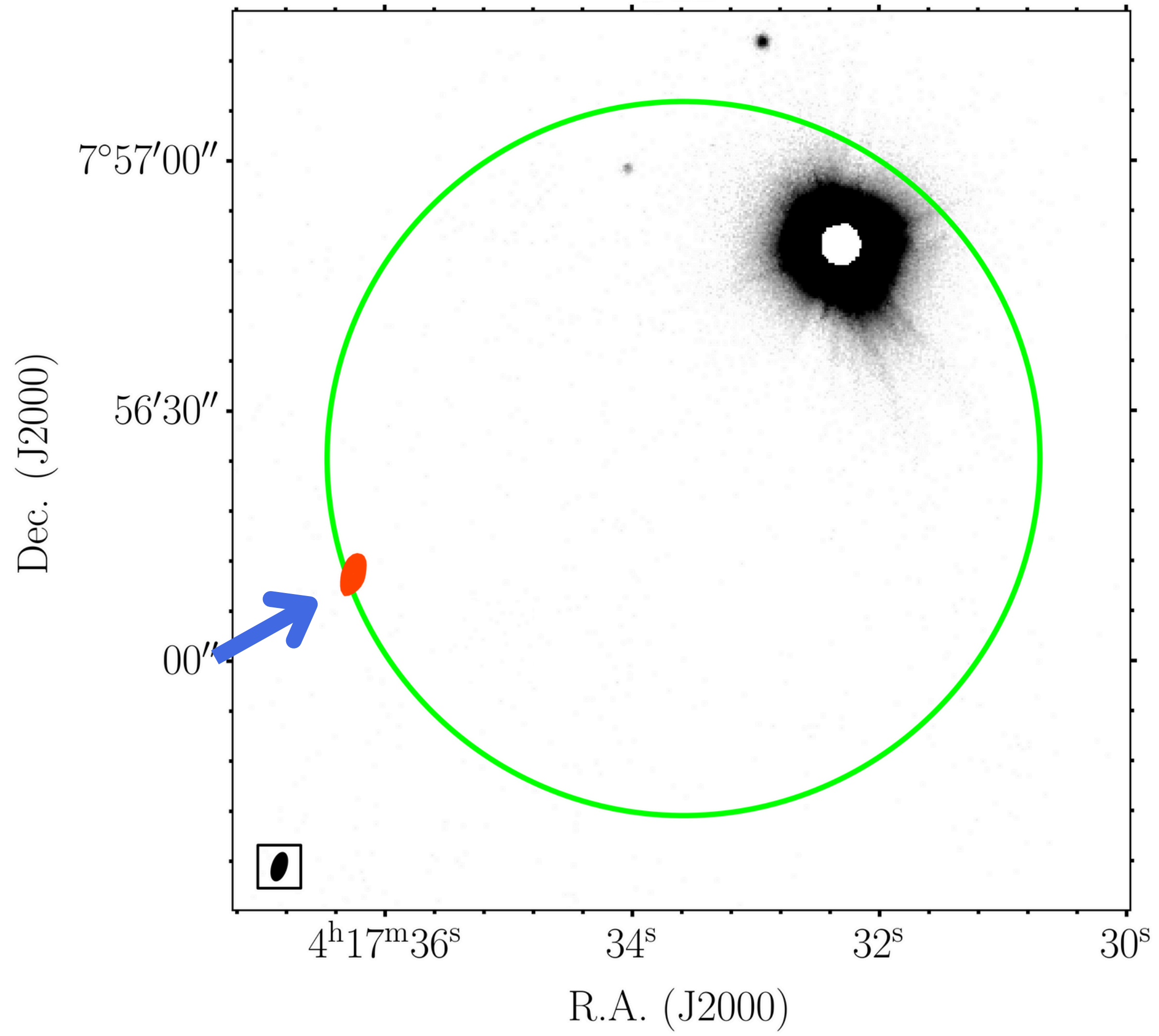
= **65 FRBs**

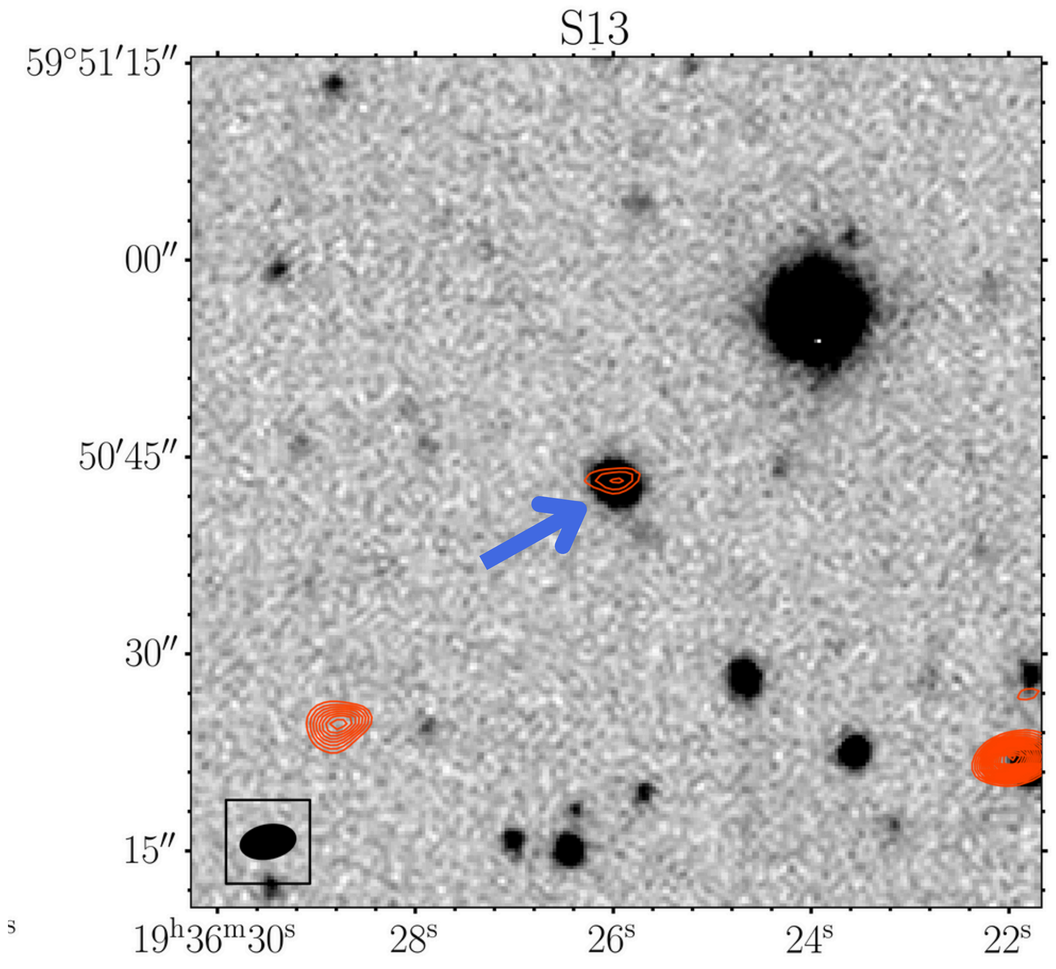
25 rep.
40 one-offs

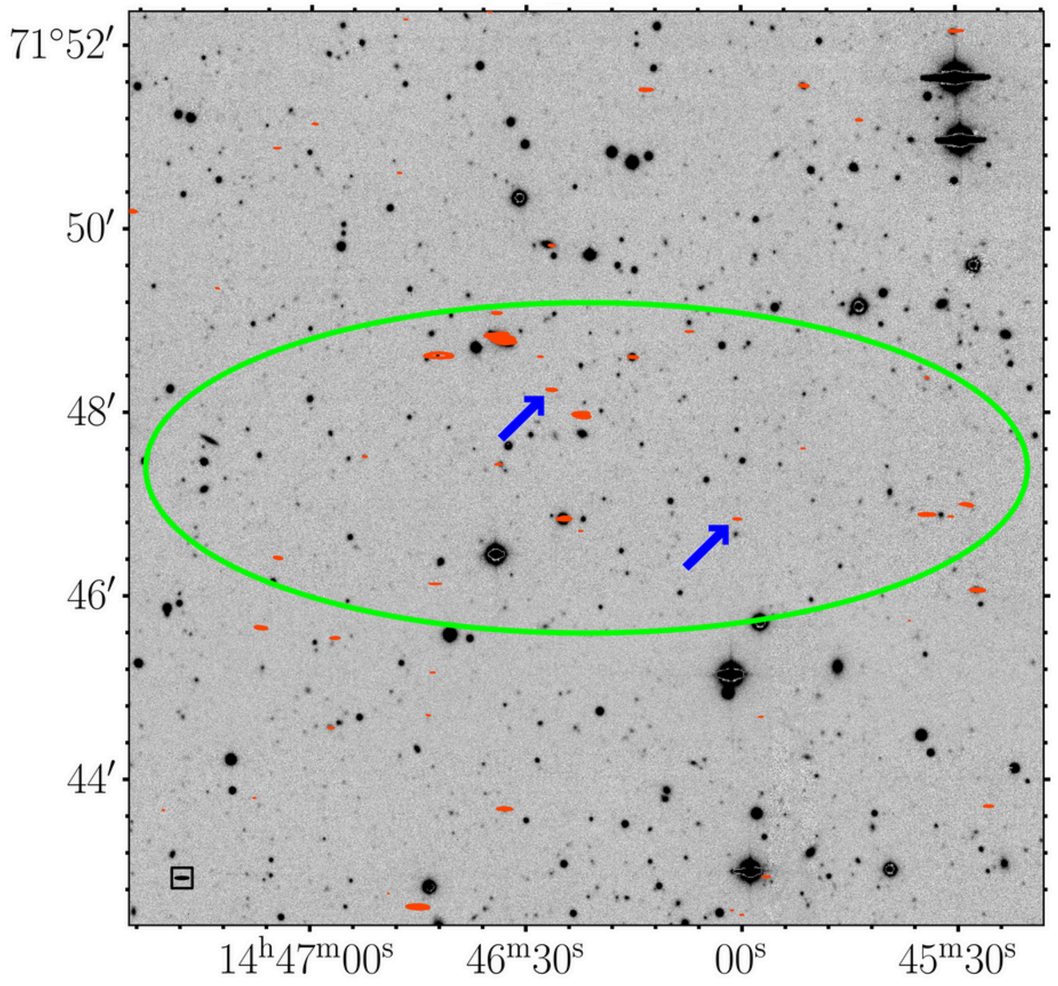
Pelliciari et al. (in prep.)

–	20110523A	0.6(2)	−186.1(1.4)	< 36	< 7.3	21, 22
R1	**r20121102A**	0.19273(8)	$(+6.7\times10^4$–$10^5)^a$	194(19)	1.9(2)	23 – 25
–	20150215A	0.7(2)	+2(11)	< 11.5	< 3.1	26
–	20150418A	0.6(2)	+36(52)	< 73	< 15	27
–	20150807A	0.2(1)	+12.0(7)	< 362	< 7.9	28
–	20160102A	$3.06^{+0.48}_{-1.35}$	−221(6)	< 46	< 148	29, 30
–	r20171019A	$0.44^{+0.08}_{-0.26}$	–	< 15.6	< 0.98	31
–	20171020A	0.0087(5)	–	< 142	$< 2.5\times10^{-3}$	32, 33
–	20180309A	0.2(1)	< 150	< 122	< 2.3	22, 35
R3	r20180916B	0.0337(2)	$-114.6(6)^a$	< 19	$< 5.3\times10^{-3}$	36, 37
–	20180924B	0.3214(2)	+14(1)	< 32	< 0.9	38
–	**r20181030A**	0.00385(2)	+36.6(2)	417(21)	$1.47(7)\times10^{-3}$	5, 39
–	20181112A	0.4755(2)	+10.9(9)	< 33	< 2.3	7, 40, 41
–	r20190102C	0.2913(2)	+110	< 30	< 2.3	7, 41
–	r20190117A	$0.34^{+0.06}_{-0.22}$	+76.3(4)	< 49	< 1.7	3, 39
–	r20190208A	$0.54^{+0.1}_{-0.3}$	$+36.3(7)^a$	< 16	< 2.3	3, 4, 39
R1-twin	**r20190520B**	0.241(1)	-2×10^5 ^{a}	218(9)	3.5(1)	41, 43
–	20190608B	0.1178	+353(2)	< 17	$< 6\times10^{-2}$	41, 44, 45
–	20190611B	0.378	+20(4)	< 750	< 31	7, 44
–	20190614D	$1.00^{+0.16}_{-0.54}$	–	< 34	< 12	46
–	r20190711A	0.522	+9(2)	< 45	< 3.7	32, 44
–	20191001A	0.2340(1)	+55.5(9)	< 68	< 1	47
–	20191108A	0.5(2)	+474(3)	< 222	< 38	48, 49
–	r20200120E	0.00013(6)	-36.9^a	< 21	$< 3.2\times10^{-6}$	50 – 52
–	20200428 (MW)	Milky Way	–	$1.37(8)\times10^6$	$< 2\times10^{-6}$	53 – 55
–	20200430A	0.1608	–	< 270	< 1.8	7, 56
–	20200906A	0.3688(1)	–	< 19	< 0.75	1
–	**r20201124A**	0.0978(2)	$-889.5(7)^a$	20(3.5)	4.8×10^{-2}	57 – 59
–	20220207C	0.04304(1)	+162.48(4)	< 290	< 0.13	60, 61
–	20220307B	0.2481(1)	−947(12)	< 290	< 4.9	60, 61
–	20220310F	0.4779(4)	+11.4(2)	< 280	< 19	60, 61
–	20220319D	0.01123(4)	+60(14)	< 281	$< 8.4\times10^{-3}$	60, 61
–	20220418A	0.6220(1)	+6(7)	< 273	< 33	60, 61
–	20220506D	0.3004(1)	−32(4)	< 292	< 7.4	60, 61
–	20220509G	0.0894(1)	−109(1)	< 288	< 0.58	60, 61
–	20220825A	0.24139(1)	+750(7)	< 288	< 4.6	60, 61
–	r20220912A	0.0771(1)	+0.08(5.39)	< 50	$< 7.4\times10^{-2}$	62, 63, 64
–	20220914A	0.1139	–	< 284	< 0.93	60
–	20220920A	0.1582(2)	−830(8)	< 290	< 1.9	60, 61
–	20221012A	0.28467(7)	166(18)	< 284	< 6.4	60, 61
–	20250316A	0.009	–	< 24.5	$< 3.1\times10^{-4}$	65, 66, 67

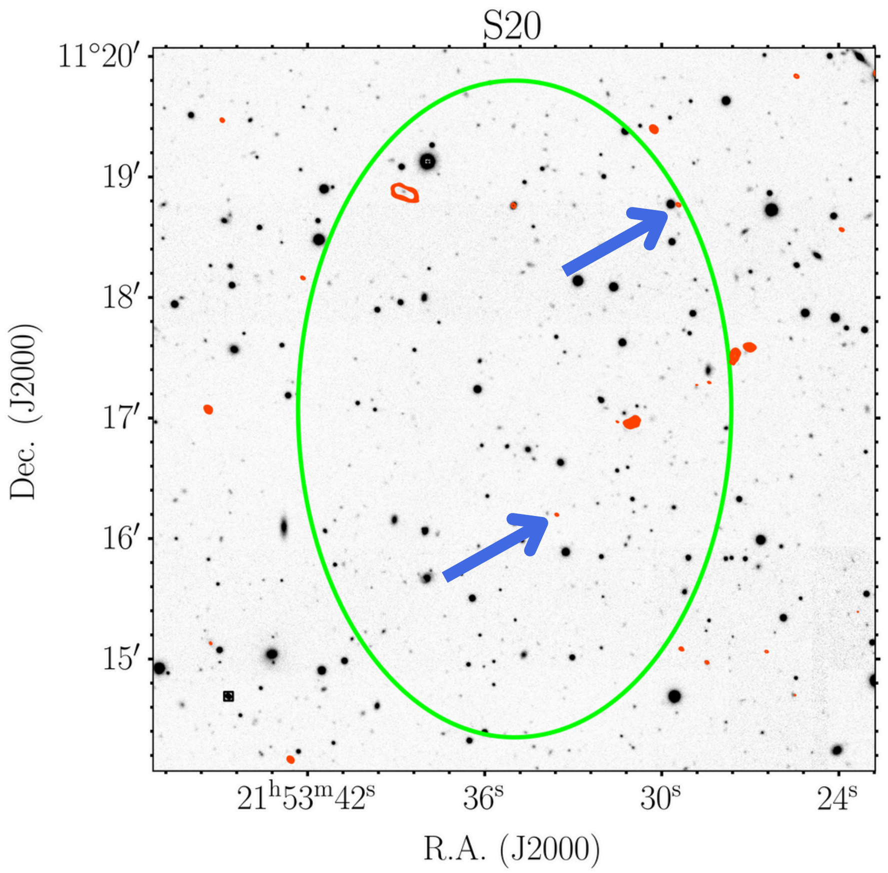
Finding new PRS candidates!







Pelliciari et al. (in prep)



6 new PRS candidates (i.e. compact at ≈ arcsec level and consistent with FRBs position)

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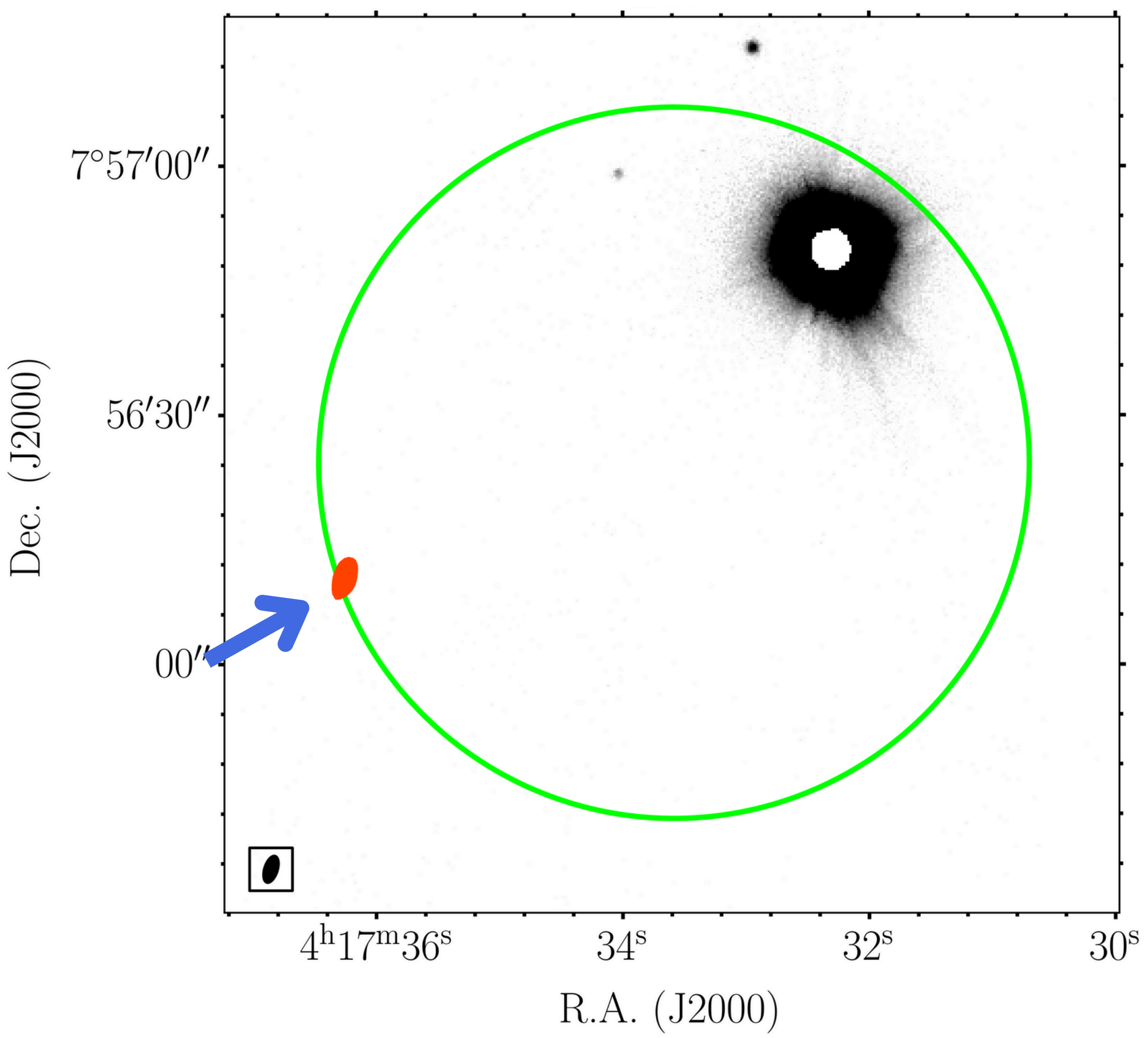
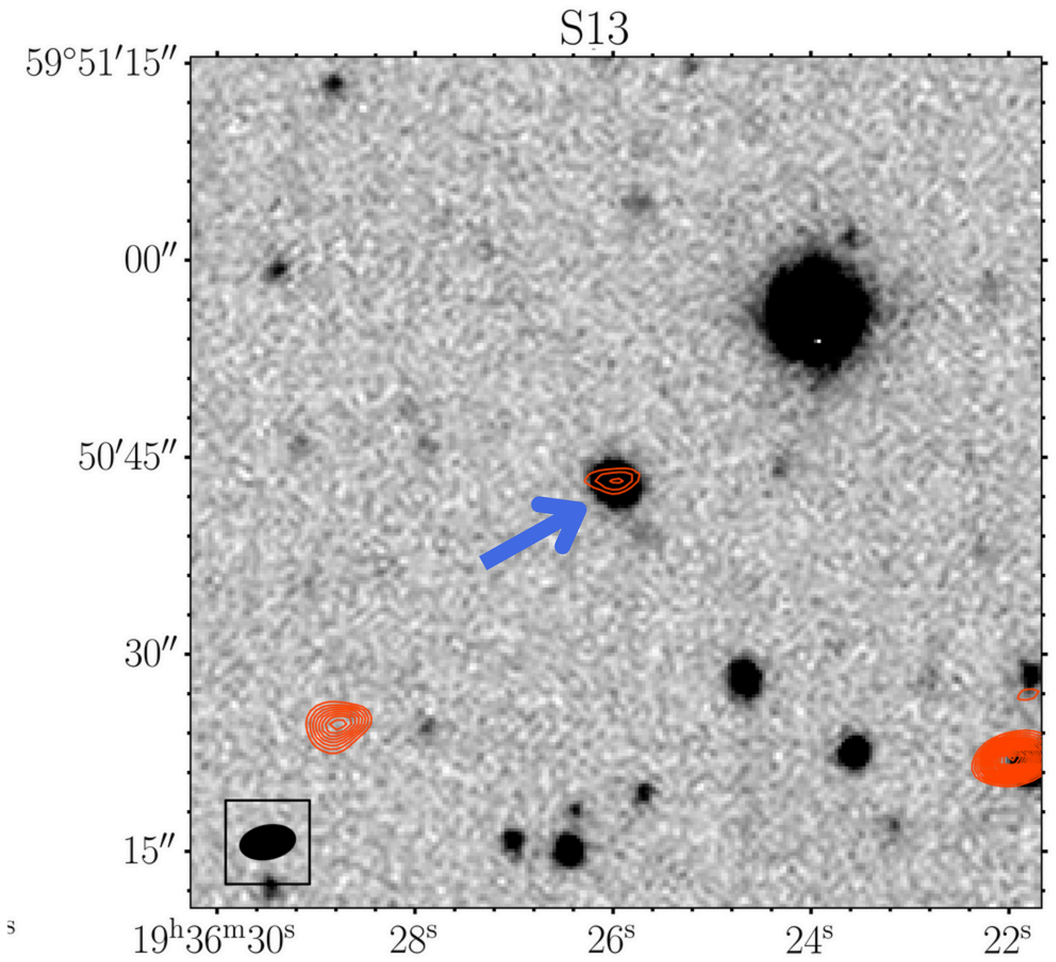
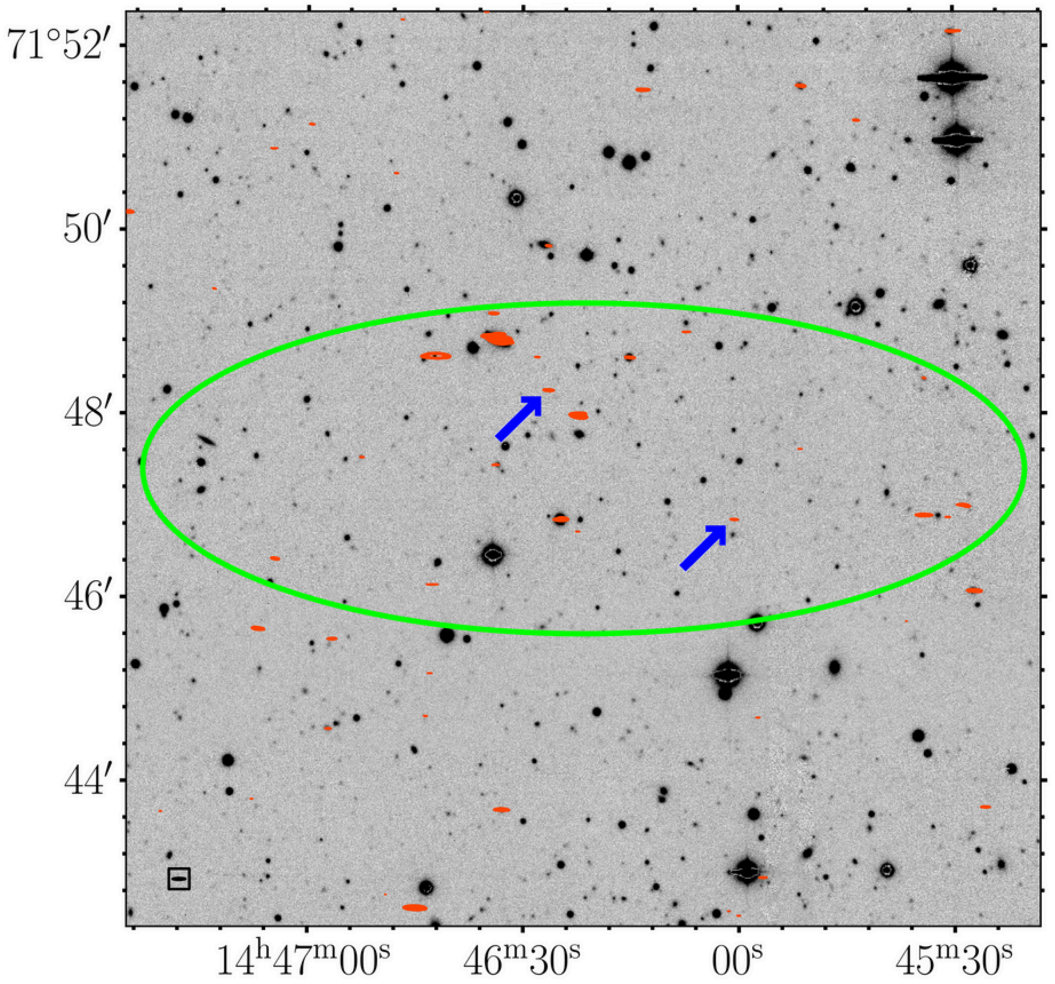
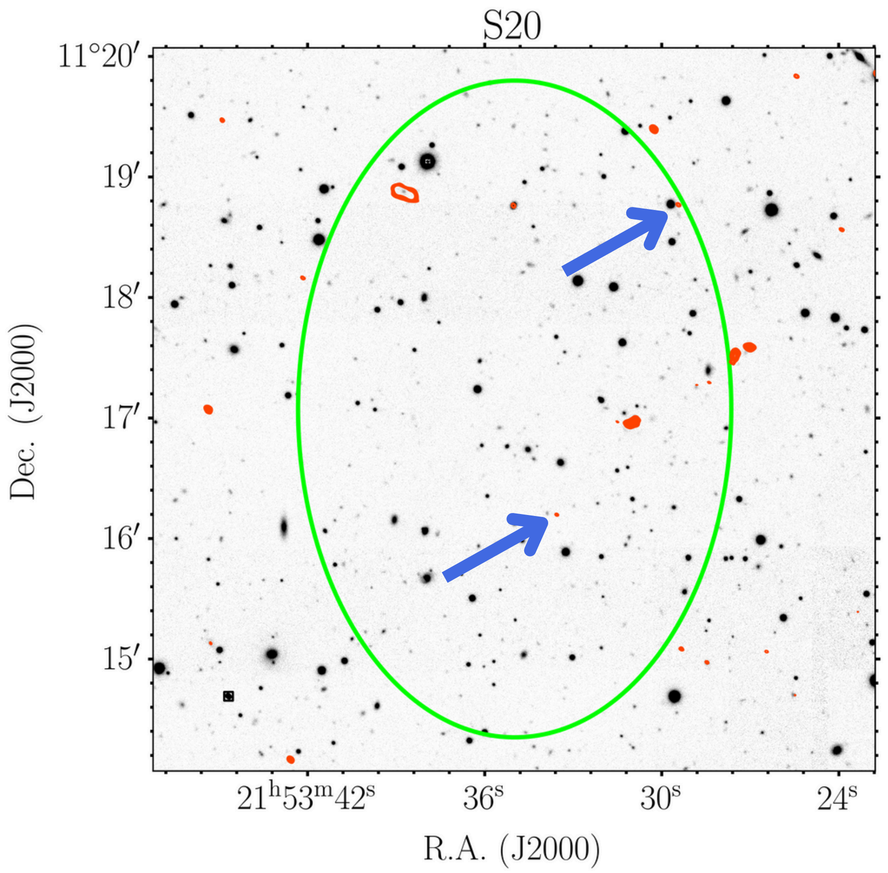






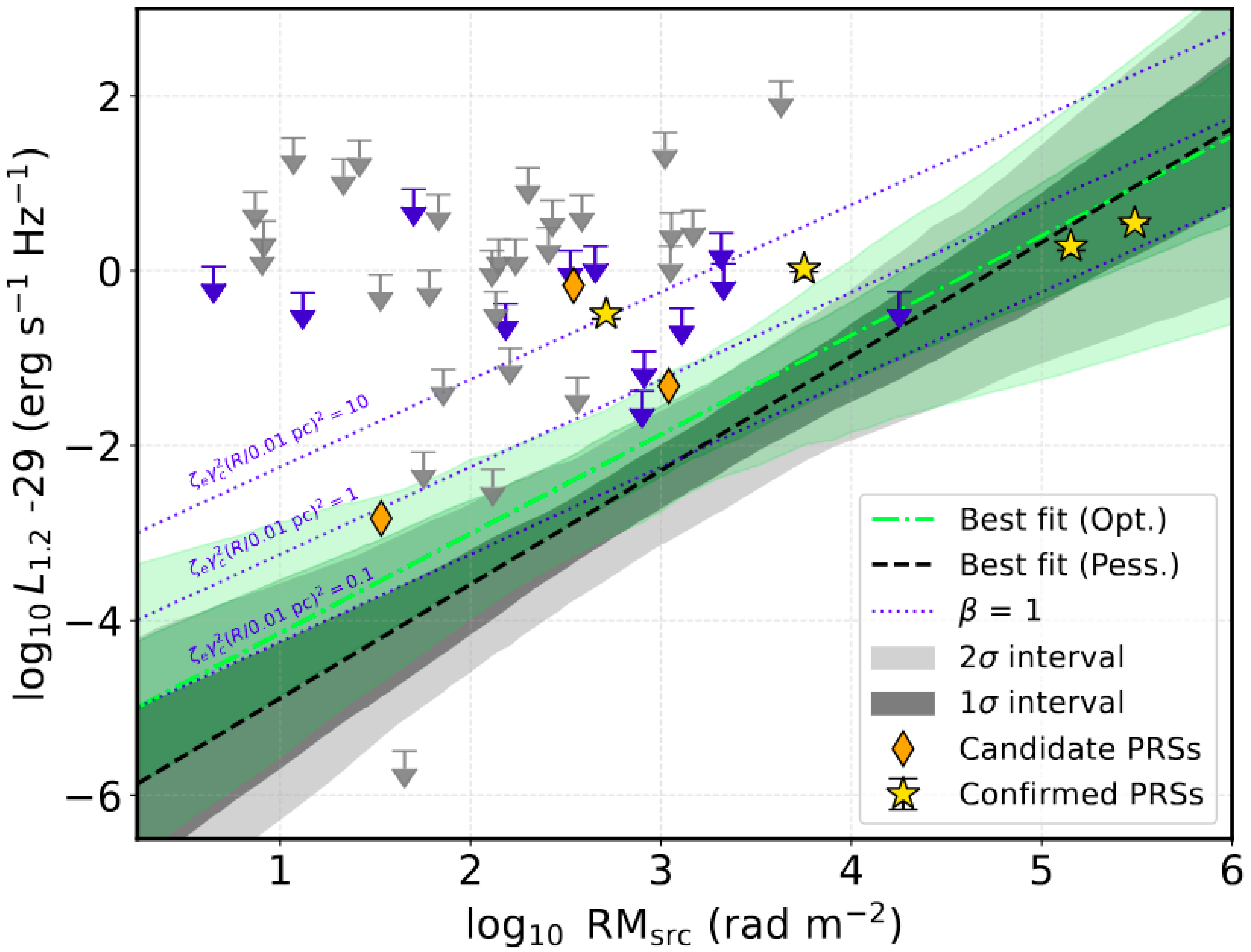
Pelliciari et al. (in prep)

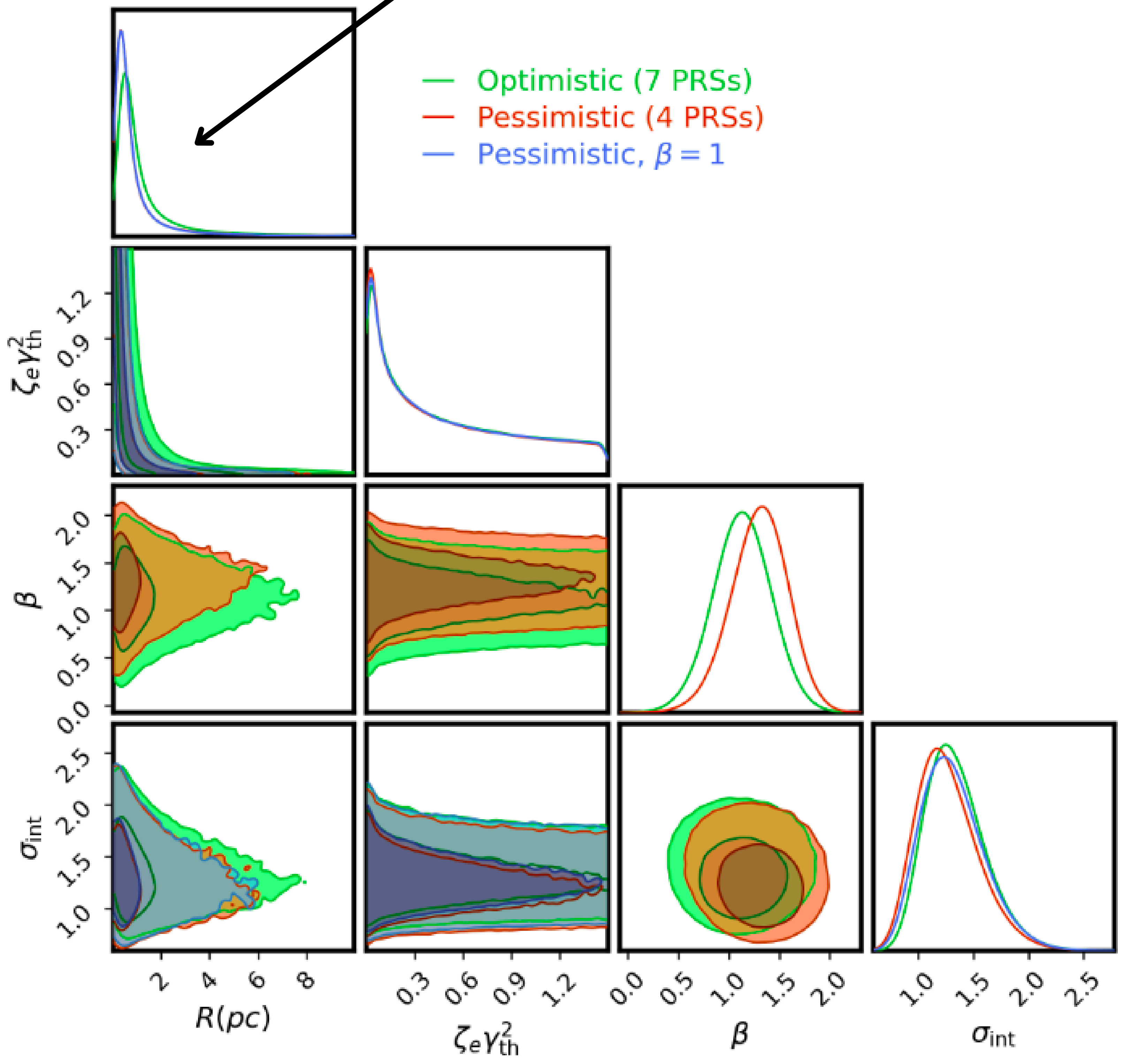


6 new PRS candidates (i.e. compact at ≈ arcsec level and consistent with FRBs position)

Results on the RM-L relation

Constraints on the PRS size!





Pelliciari et al. (in prep.)

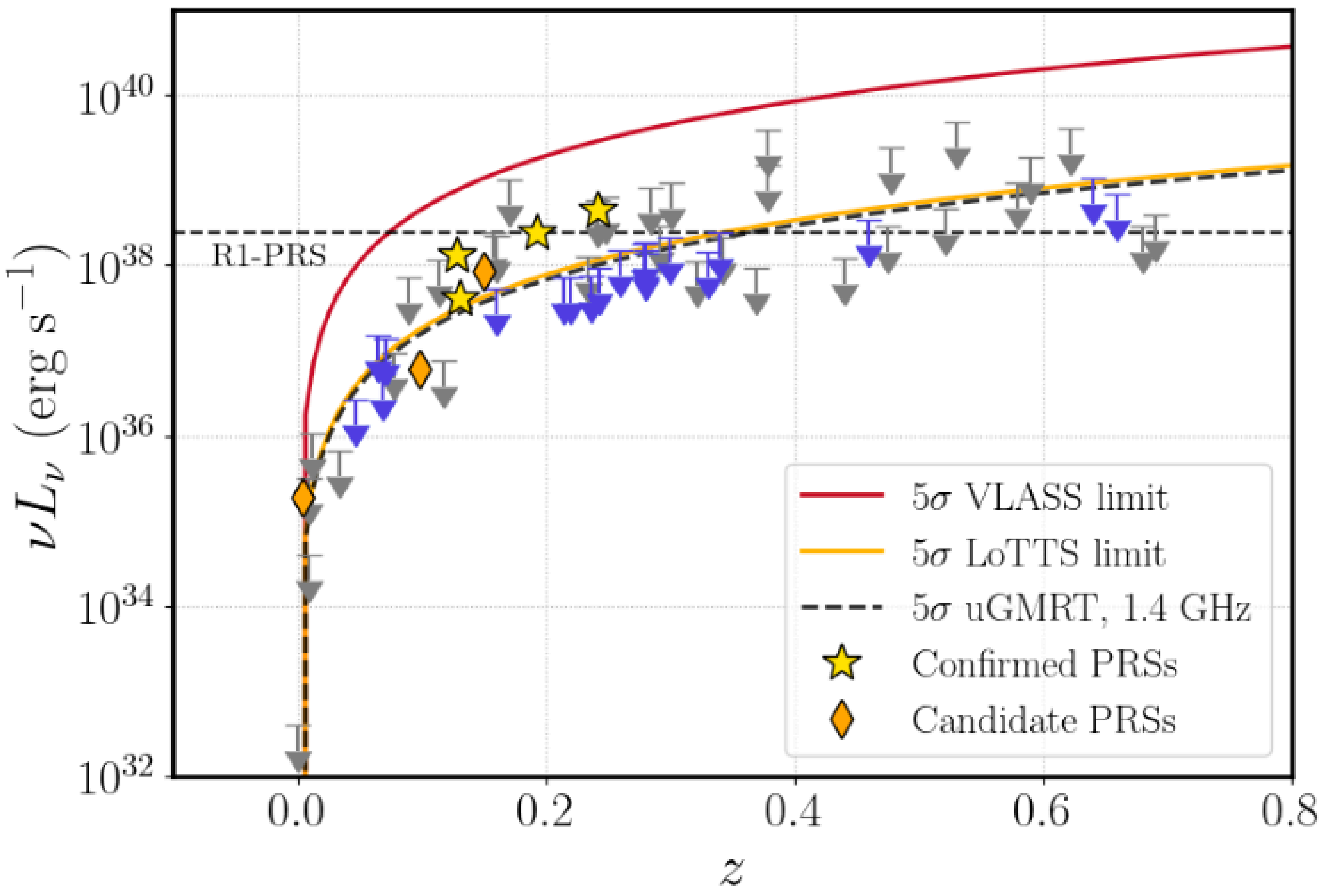
Occurrence of PRSs & SKA potential improvements

Confirmed PRSs occupy a narrow luminosity range!

The majority of luminosity limits are more stringent than PRS luminosities

→ **PRSs as luminous as R1-PRS are very rare!**

Is R1 (& R1-twin) an exotic/peculiar type of FRB?



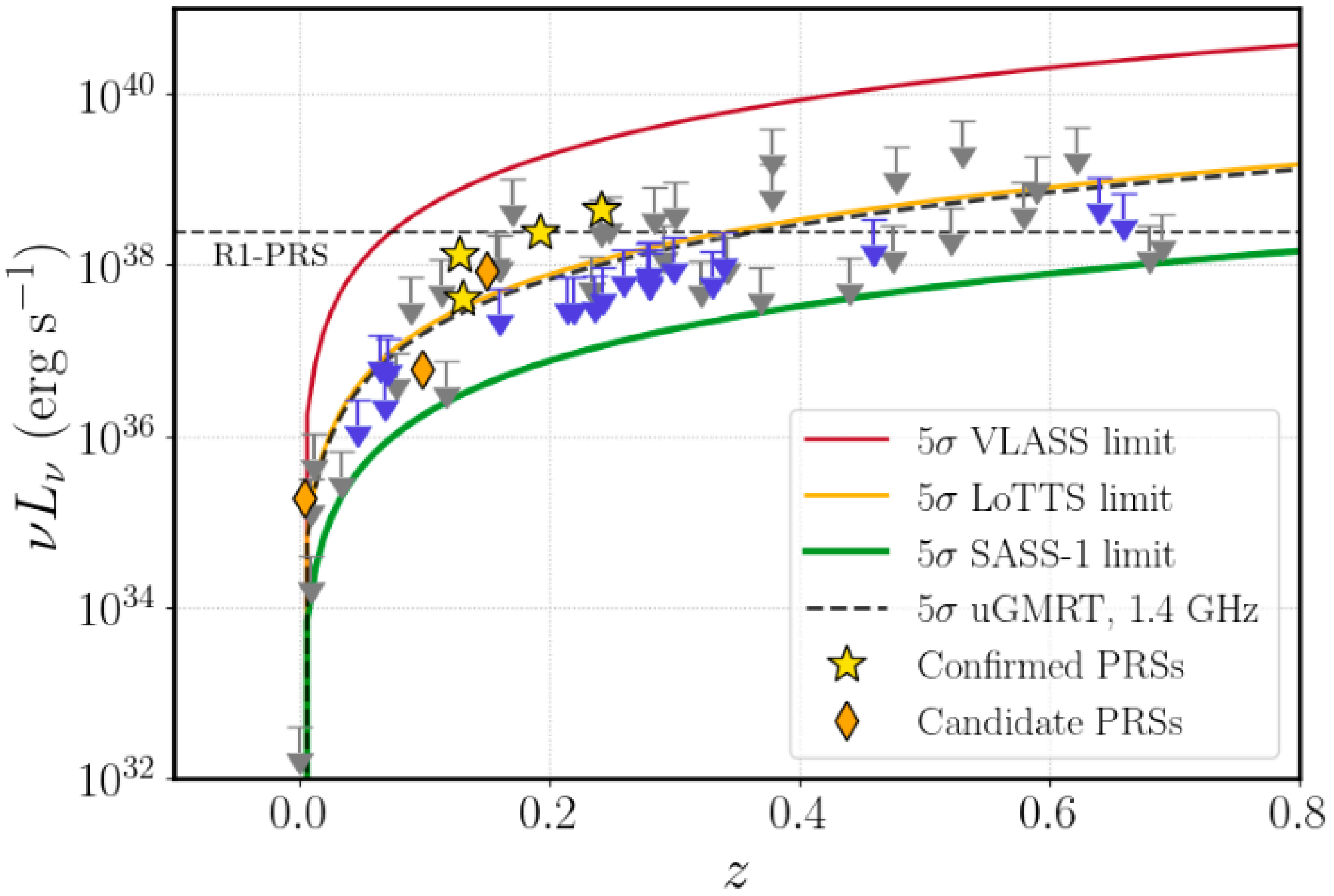
Pelliciari et al. (in prep.)

Occurrence of PRSs & SKA potential improvements

Considering the **SKA1 All-Sky continuum Survey (SASS-1)** as a reference, with 5σ = 10 μJy/beam sensitivity (Norris+14)

Also: **AA*** will have a synthesized beam approx. **5x better resolution** (1.3" x 0.5")

→ improvement also in the **PRS compactness** assessment



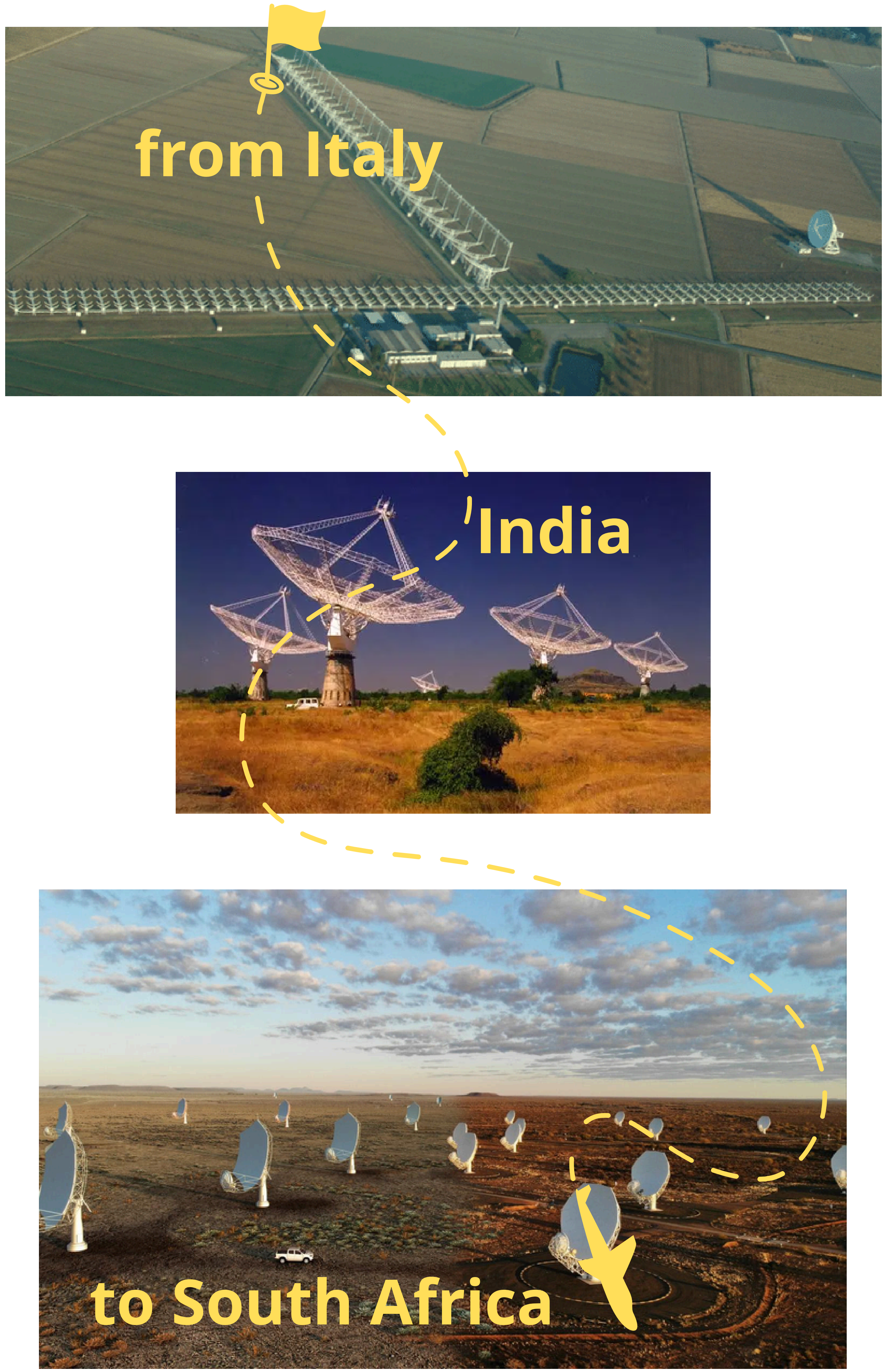
Pelliciari et al. (in prep.)

Conclusions

I presented two main ideas to study the **FRB progenitor(s)**, in particular the FRB-magnetar connection:

- **Demographic surveys on SF galaxies.** The FRB rate is expected to trace the SFR since magnetars are young objects. I presented the results from a survey on 7 SF galaxies, conducted with the **Northern Cross** radio telescope. From **no detection in 700 hrs** we were able to achieve a deep constraint on the FRB rate from magnetars similar to the Galactic SGR 1935+2154. This already provide an important hint for multi-formation channels for magnetars, with extragalactic, active FRBs originating from more exotic channels (e.g. AIC, MIC..). **SKA AA* will provide competitive (and deeper) constraints on the magnetar rate using 1/10 of the observing time and, at the same time, FRB localisations**

- **Demographic survey focusing on PRS search.** We conducted new uGMRT observations at 1.26 GHz and we constructed a large sample of 64 sources including also literature ones with a persistent luminosity limit available. This sample has been used to shed light on the **RM-Lnu expected correlation** and the **PRS occurrence on FRBs**. **SKA will provide deep observations fundamental for PRSs searches (in particular for high-z FRBs!)**



Conclusions

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