

# Transient Science with the SKAO

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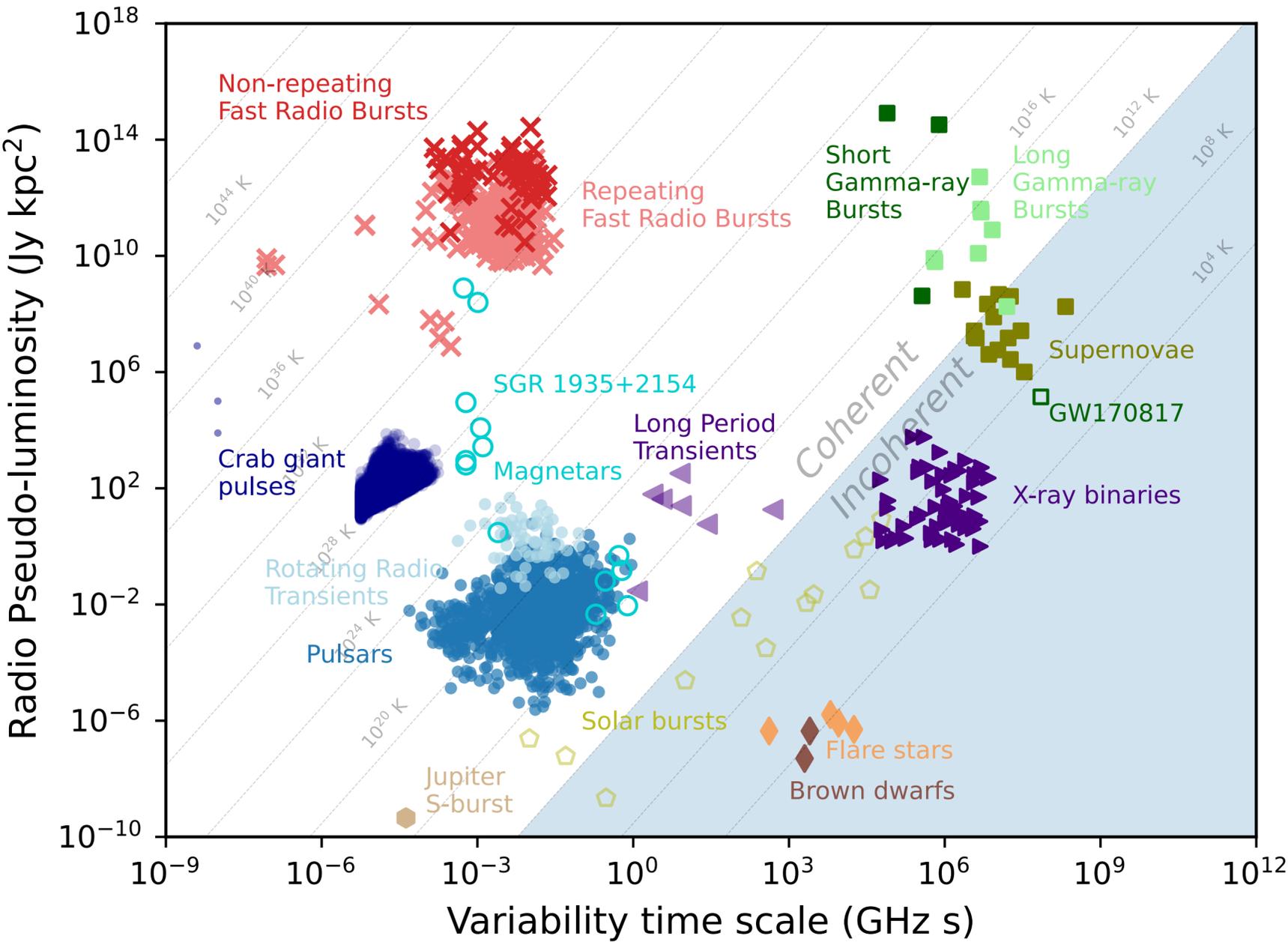
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Max-Planck-Institut  
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# Time domain astronomy

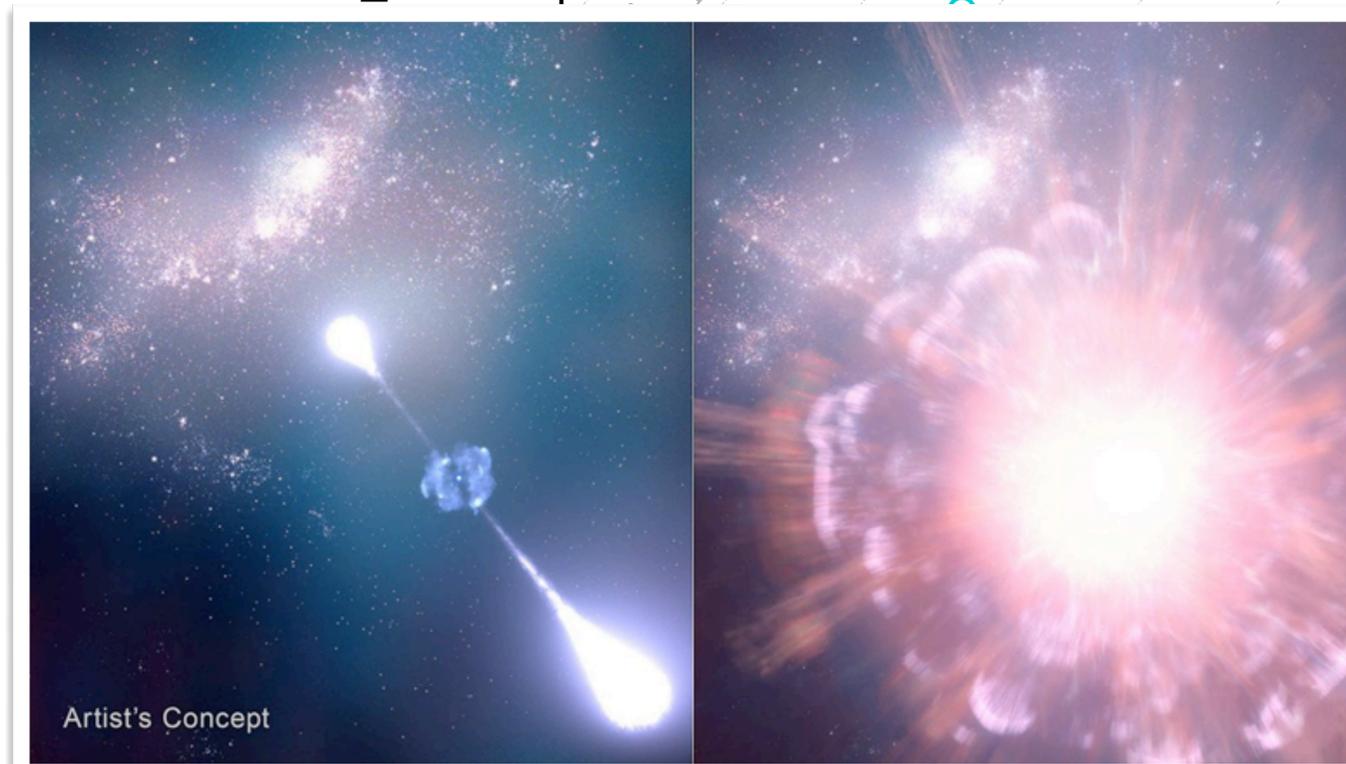
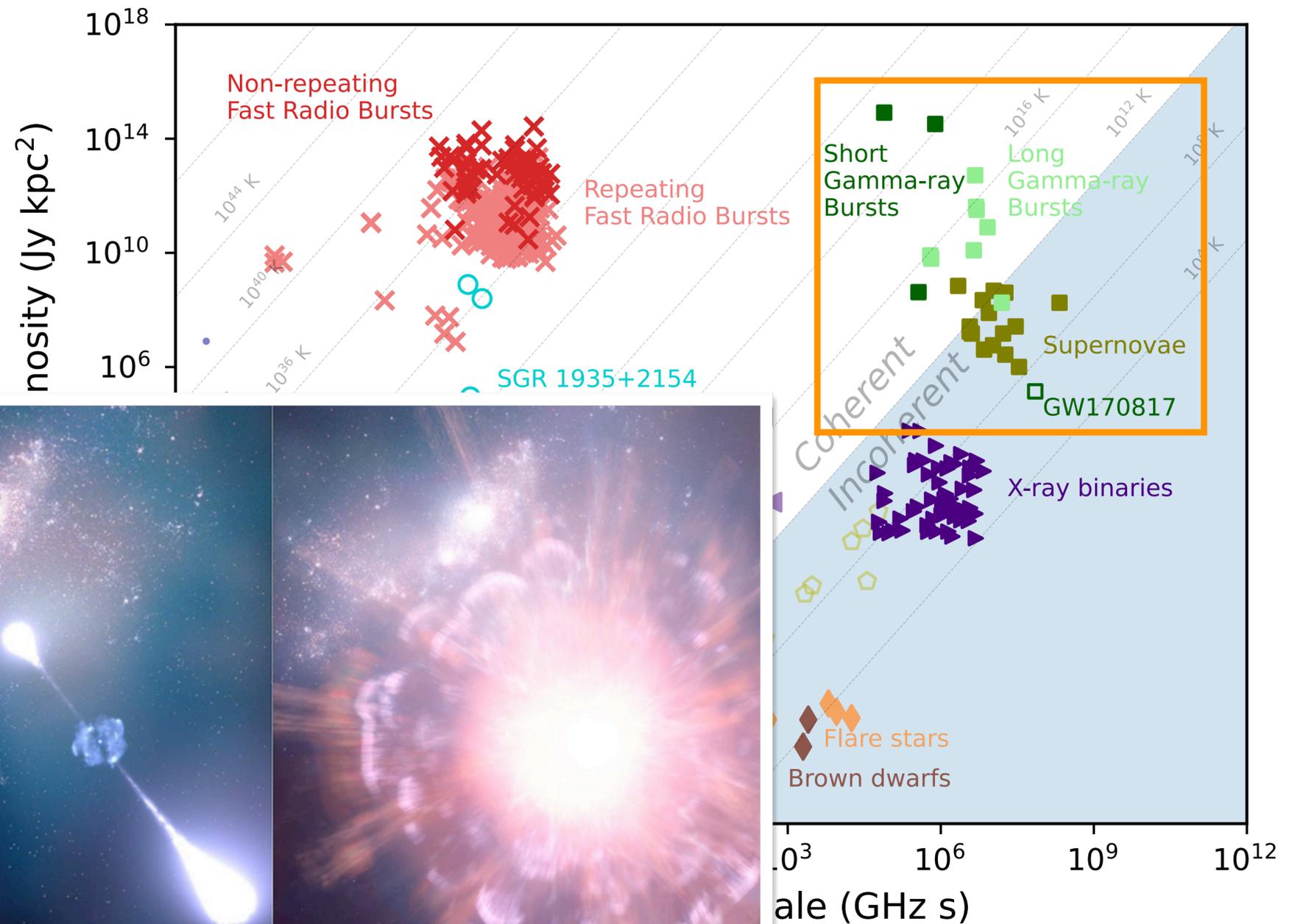
- Time evolution of source properties is a means of understanding the underlying physics
- Time variability occurs over many order of magnitude



Credit: <https://github.com/lgspitler/TransientPhaseSpace>

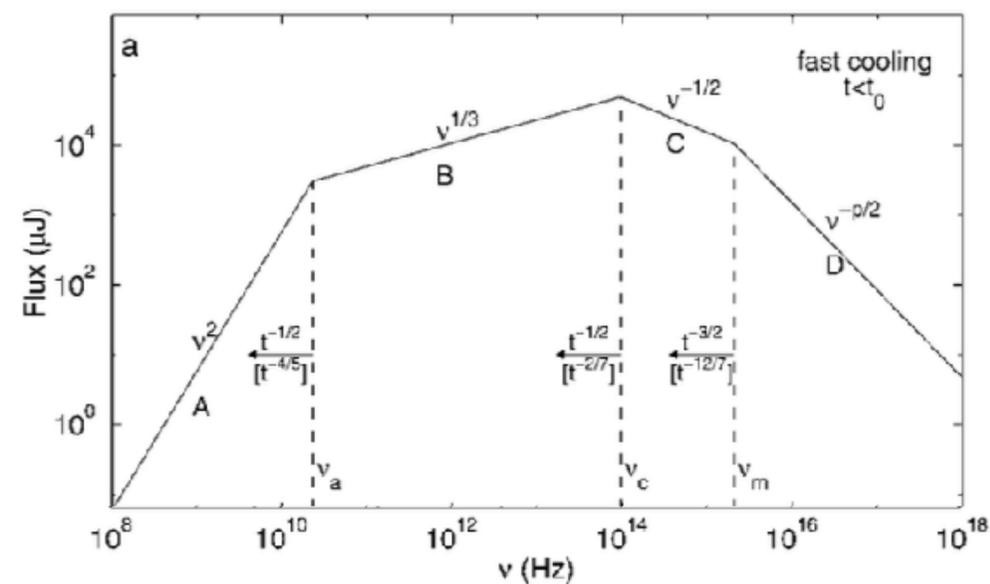
# Radio afterglows

- Associated with gamma-ray bursts, supernovae, gravitational wave mergers
- Synchrotron emission from relativistic ejecta in outward propagating shock front in the circumburst medium
- In some cases a jet is also formed



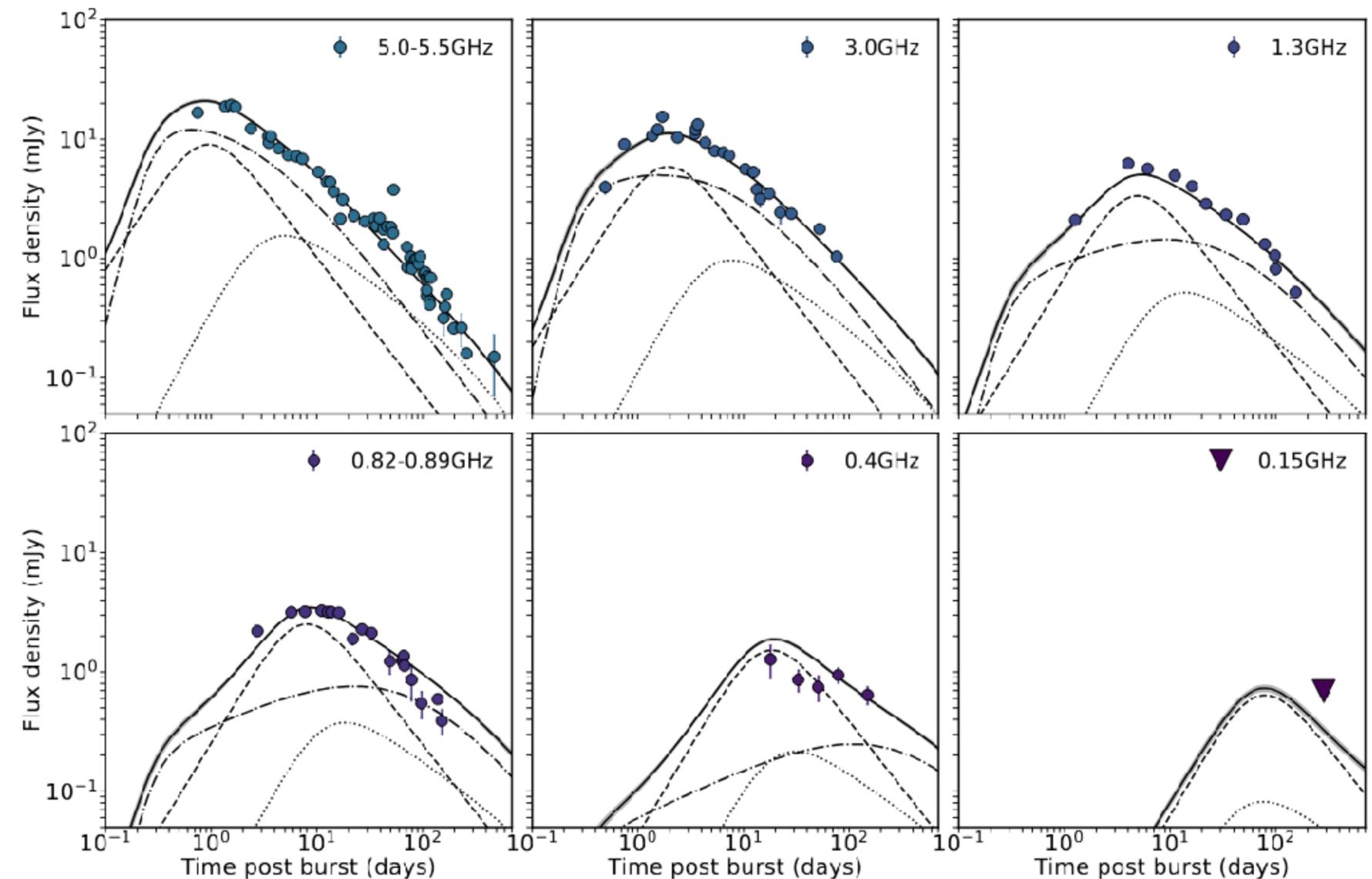
# GRB afterglows

- Broadband spectrum characterized by several “breaks”
- Shape of the spectrum evolves to lower frequencies at later times
- Time scale: cooling rate of relativistic electrons



Credit: Sari, et al., 1998, ApJ

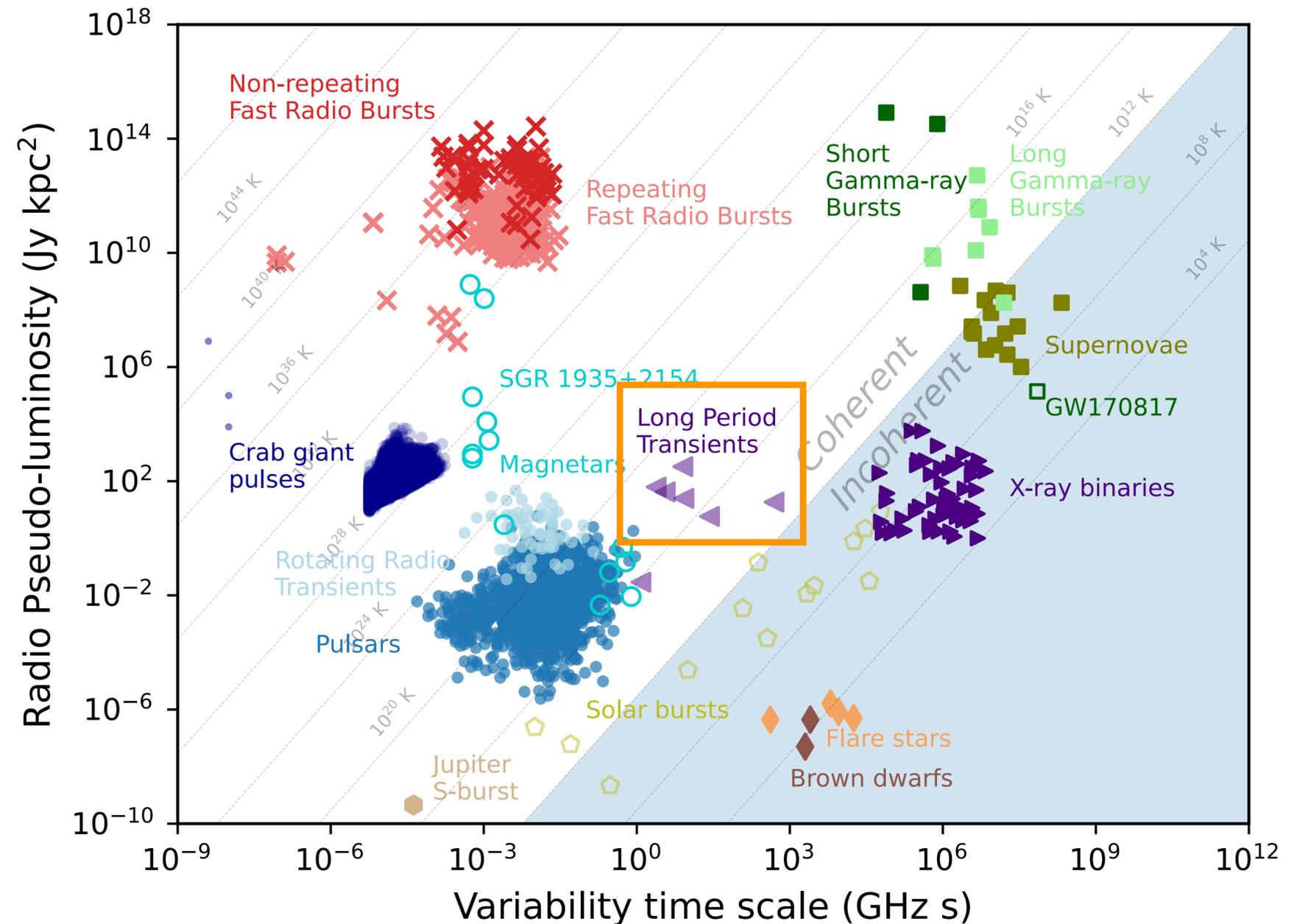
GRB 20221009A (“BOAT”)



Credit: Rhodes et al., 2024, MNRAS

# Long Period Transients

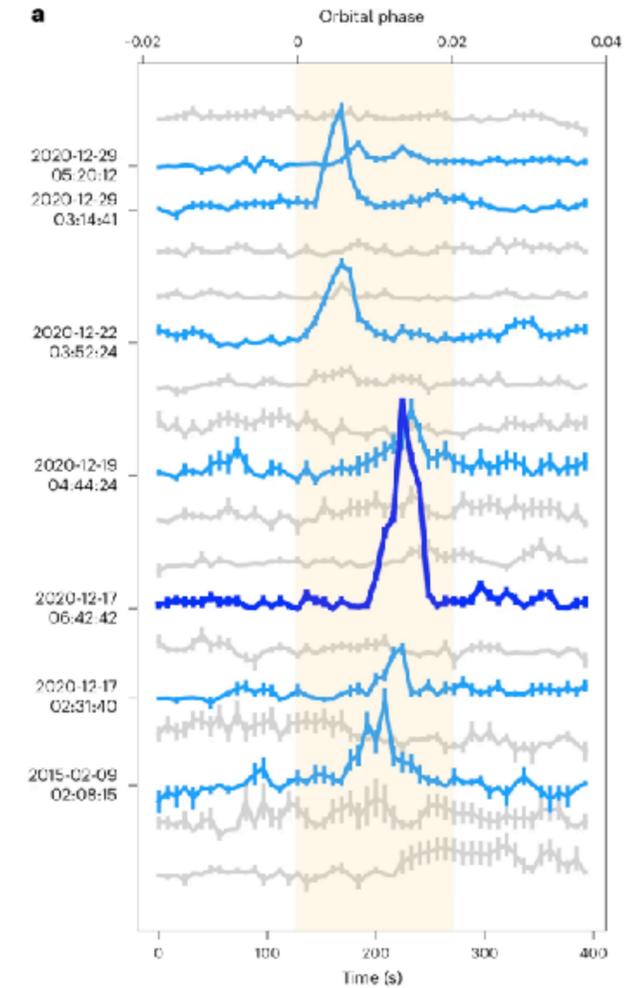
- Emerging population of radio sources with periods ranging from ~10 min to 2 hr.
- Recent review: Rea, Hurley-Walker, Caleb 2026
- Largely found in image-plane searches
- Timescale: rotation or orbital (motion)



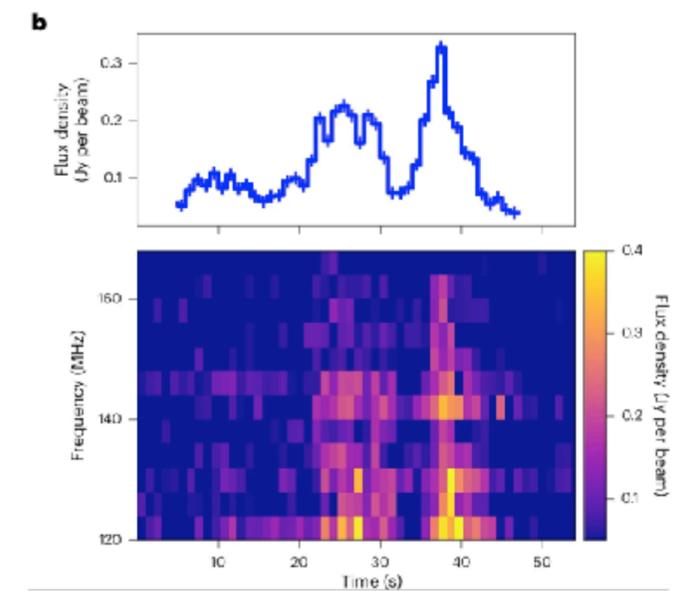
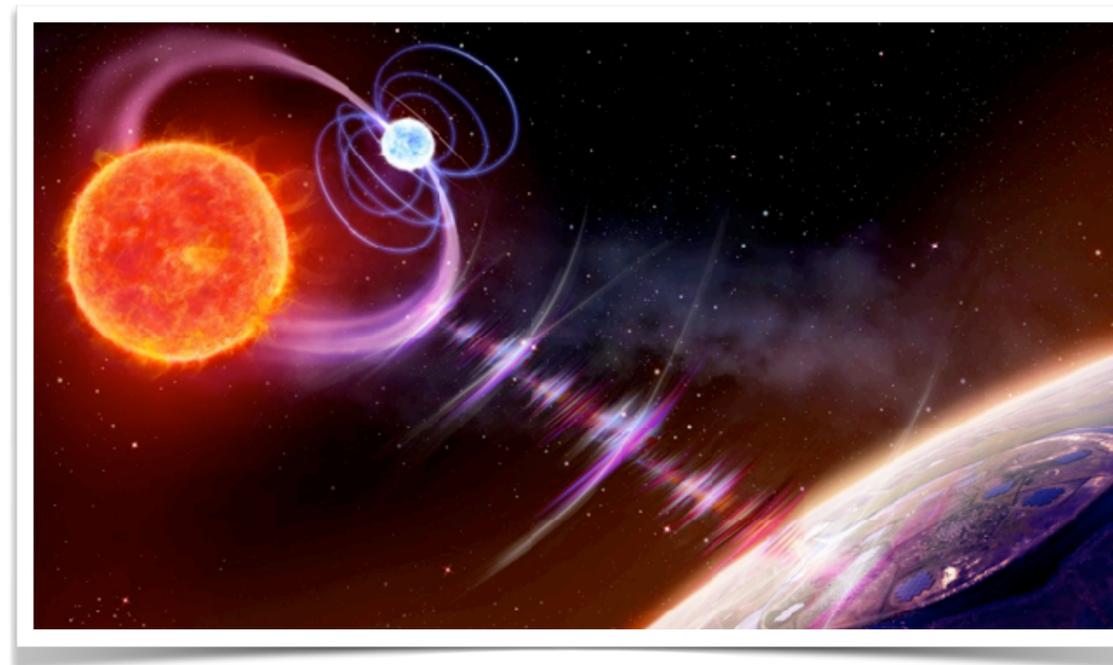
# Long Period Transients

- Periods of minutes to hours difficult to detect in beamforming data
- Sub-second substructure seen in beamforming data
- Astrophysical origin:
  - 3 of the ~12 LPTs been confirmed to be white dwarf - M dwarf binary
  - Slowly rotating magnetars?

ILT J1101 + 5521  
Light curves from LOFAR



Confirmed M-dwarf / WD dwarf binary



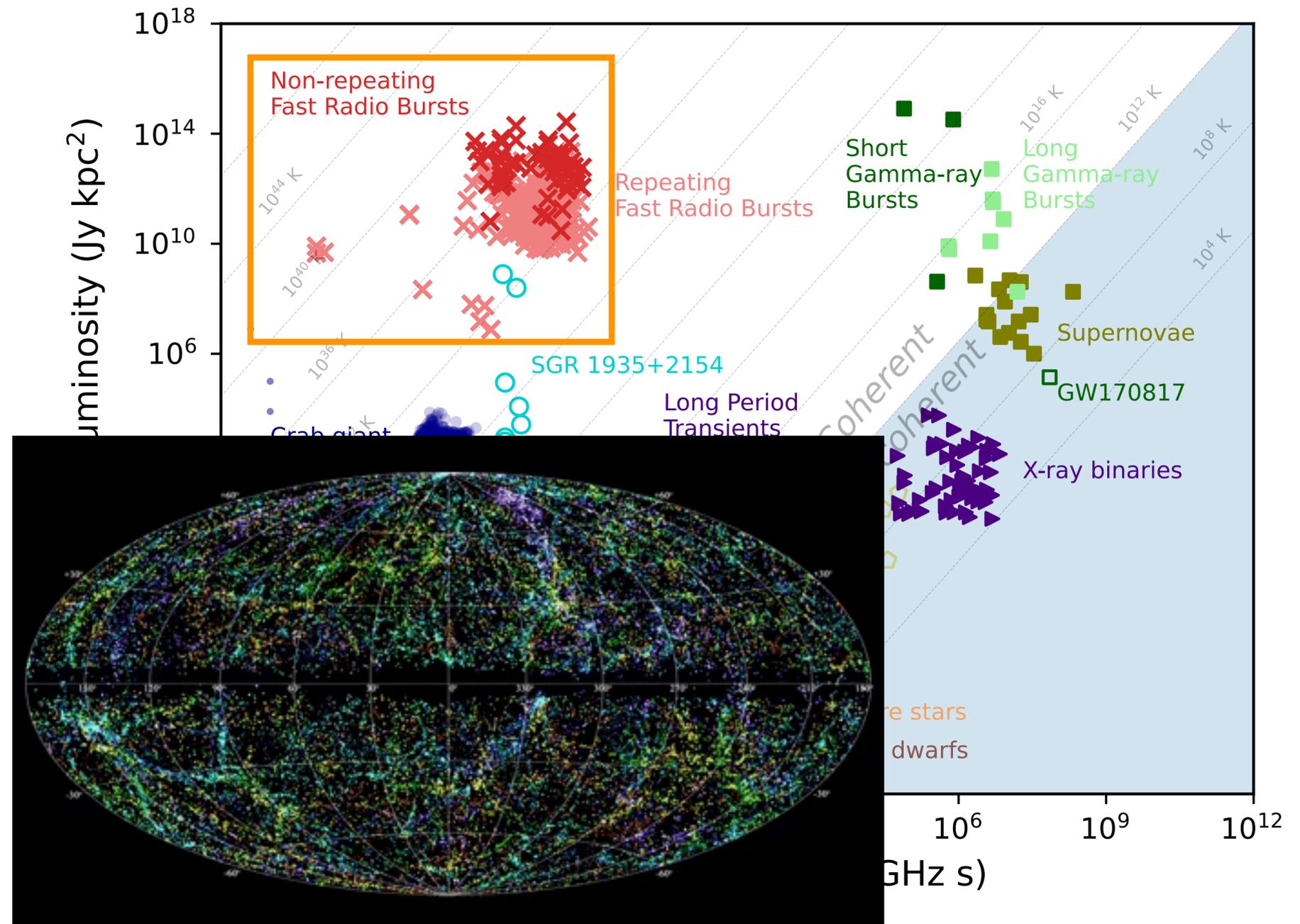
Credits:

(left) Danielle Futselaar ([artsource.nl](http://artsource.nl))

(right) de Ruiter et al., 2024, Nature Astronomy

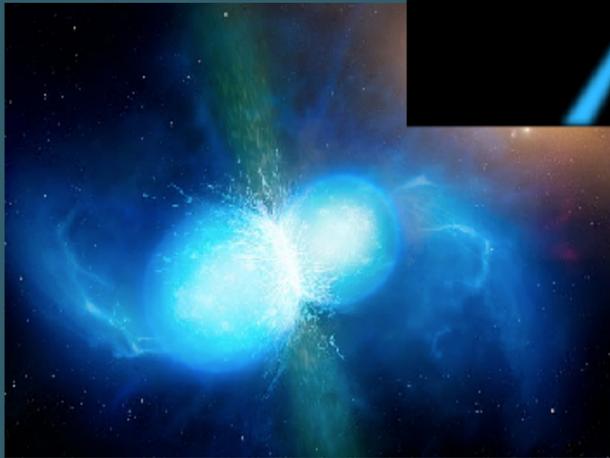
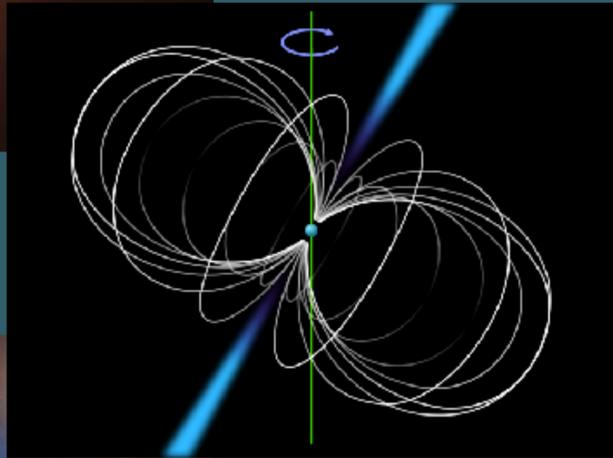
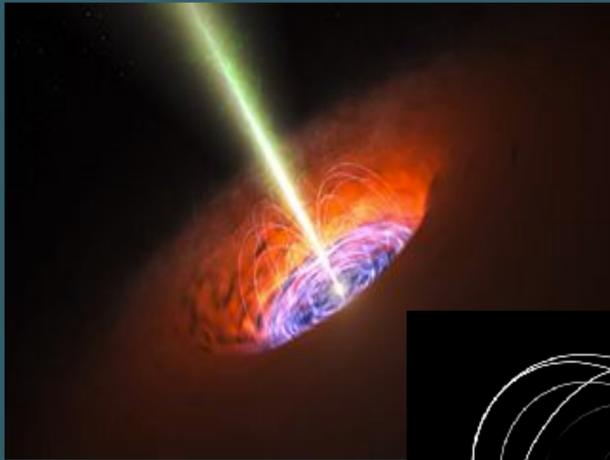
# Fast Radio Bursts

- Short duration ( $\mu\text{s}$ -ms) radio flashes of extragalactic origin
- Bursting emission only detected at radio frequencies
- Small fraction ( $\sim 5\%$ ) observed as “repeaters”
- Current numbers:
  - Total number of unique sources<sup>1</sup>: 4500+
  - Total number of repeaters<sup>1</sup>: 93
    - 100-10,000 bursts from most active repeaters

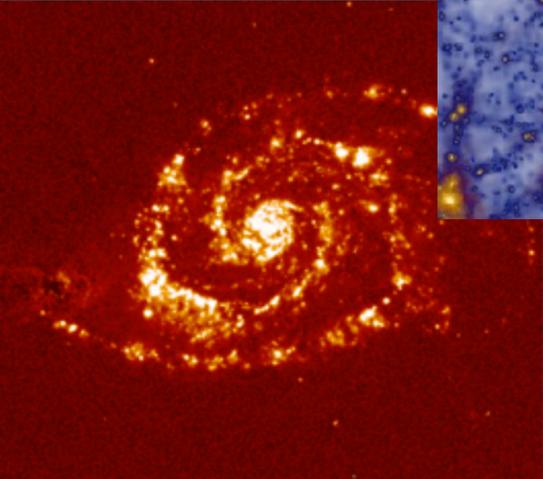
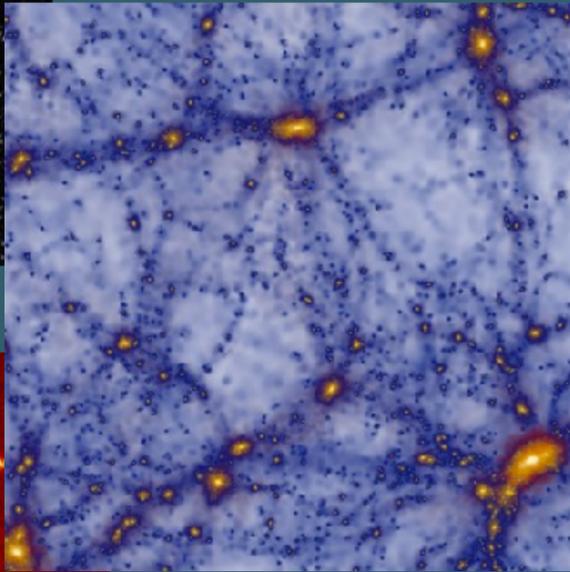
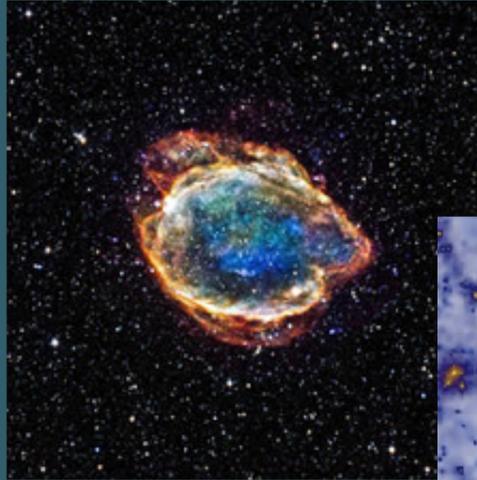


# FRBs: Astrophysical potential

Unknown high energy  
astrophysical progenitors



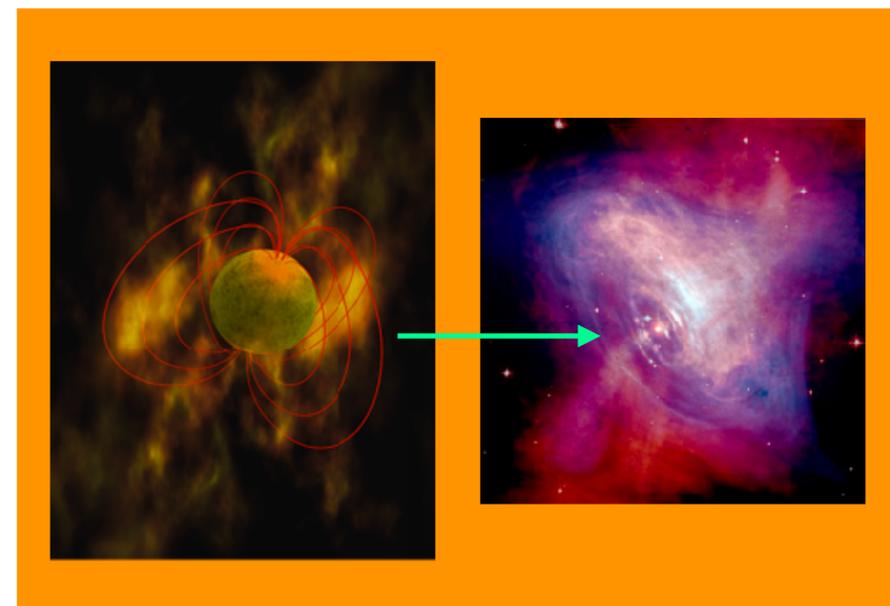
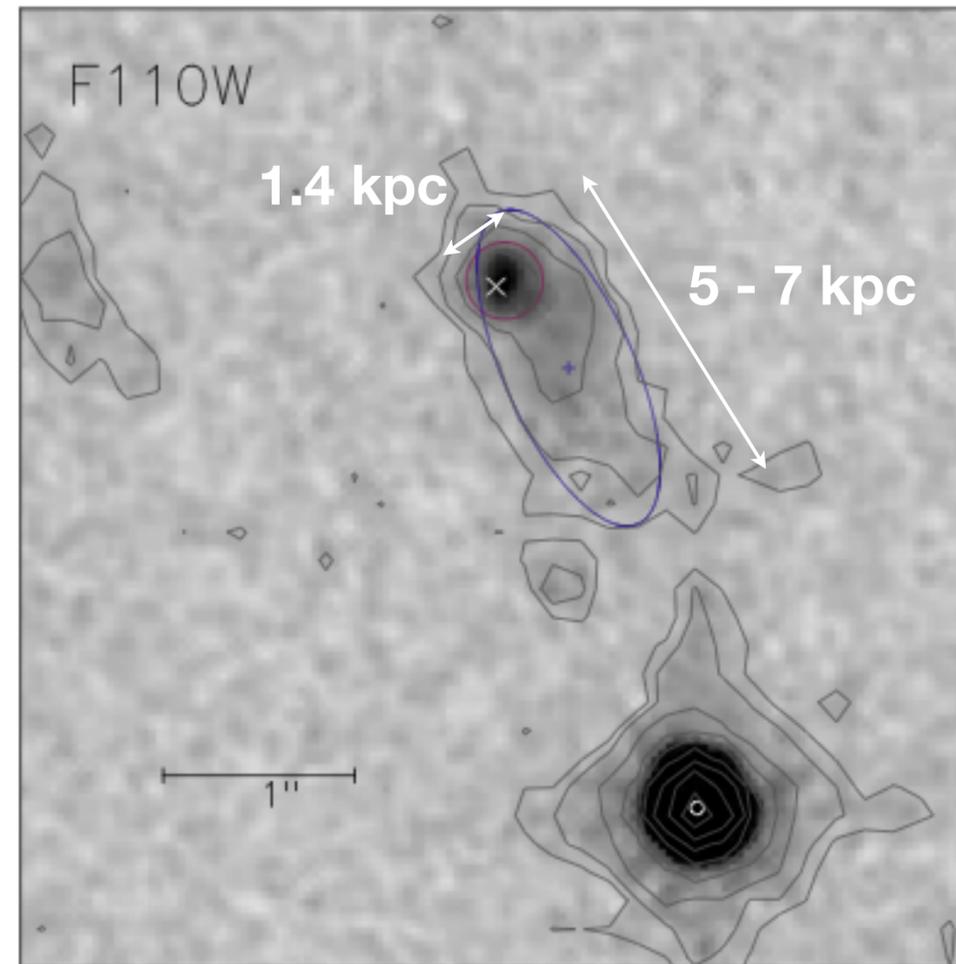
Measure physical properties  
of magnetoionized media



# FRBs: Importance of host environments

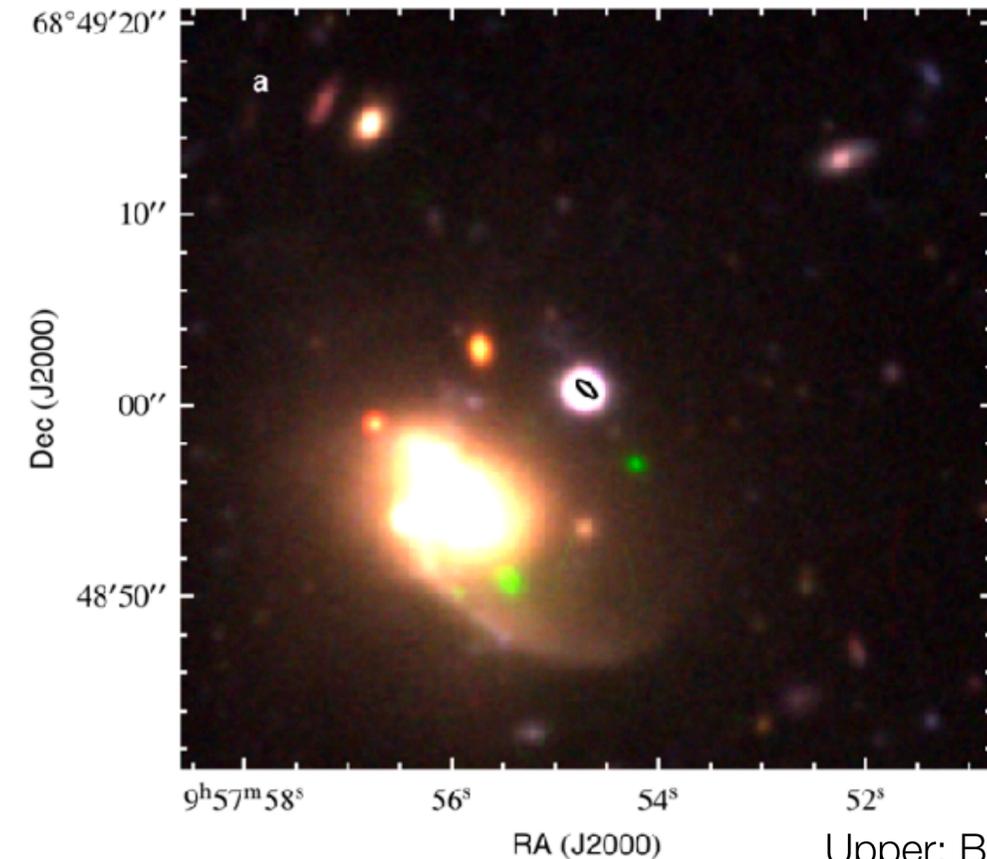
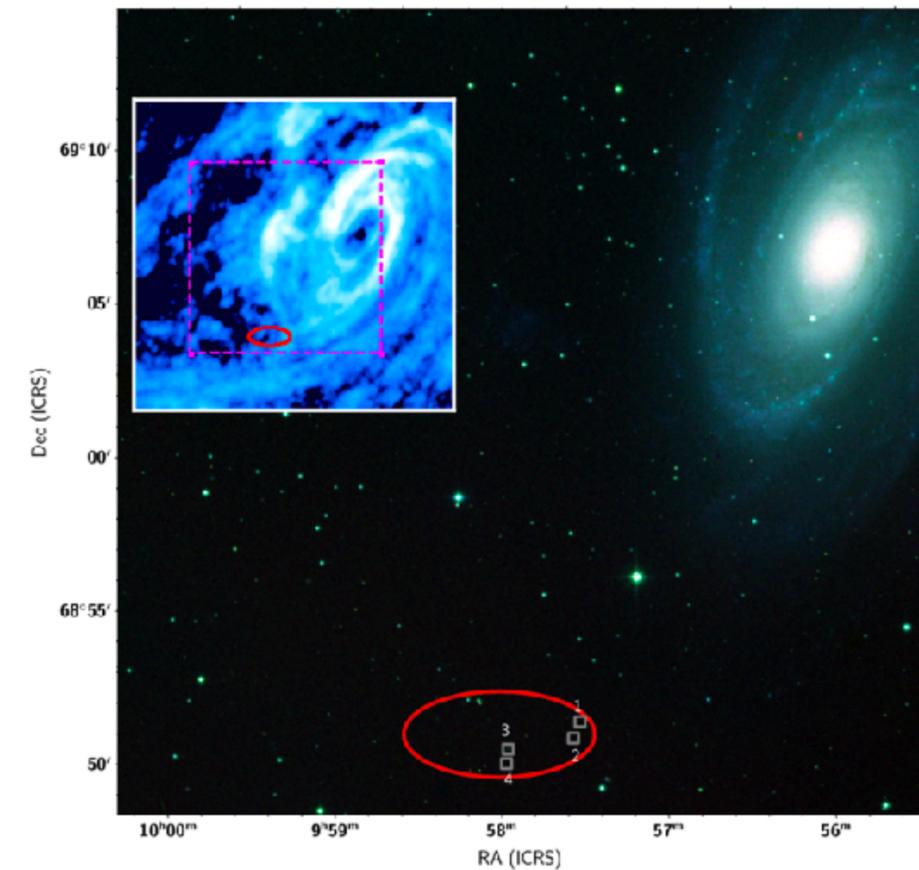
- Host galaxy of FRB 20121102A is a low metallicity dwarf
  - $M_{\star} \sim 10^8 M_{\odot}$
- Repeater sitting in a large HII region
- Properties of the host similar to those of superluminous SNe and long GRB
  - millisecond magnetar origin hypothesis
- Localization with VLBI essential

HST image of FRB 20121102A's host



# FRBs: Importance of host environments

- CHIME/FRB-discovered repeater
- Host: globular cluster in the halo of M81
- Localization with VLBI essential
- Now potential second case of an FRB in a globular cluster
- Best evidence to date for multiple formation channels for fast radio bursts

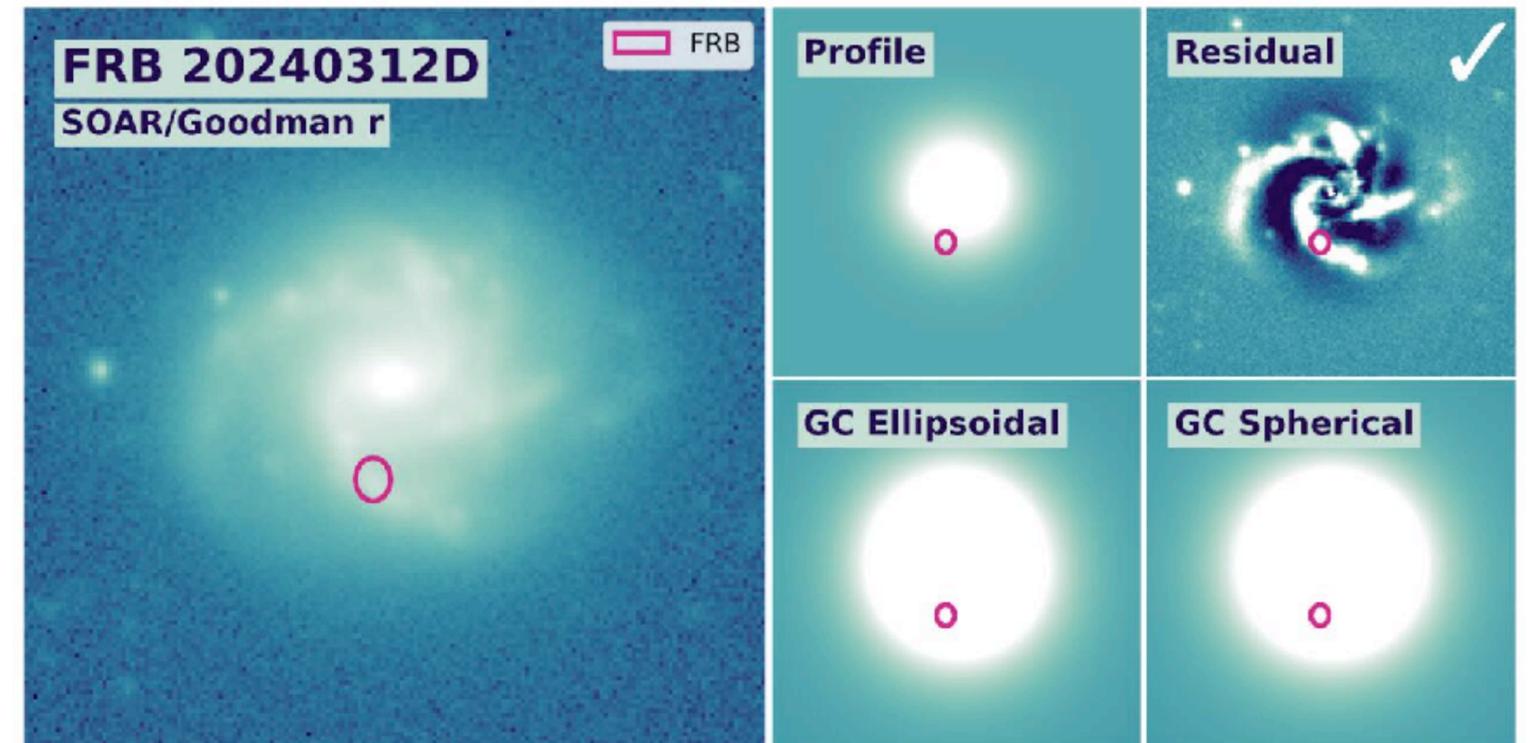
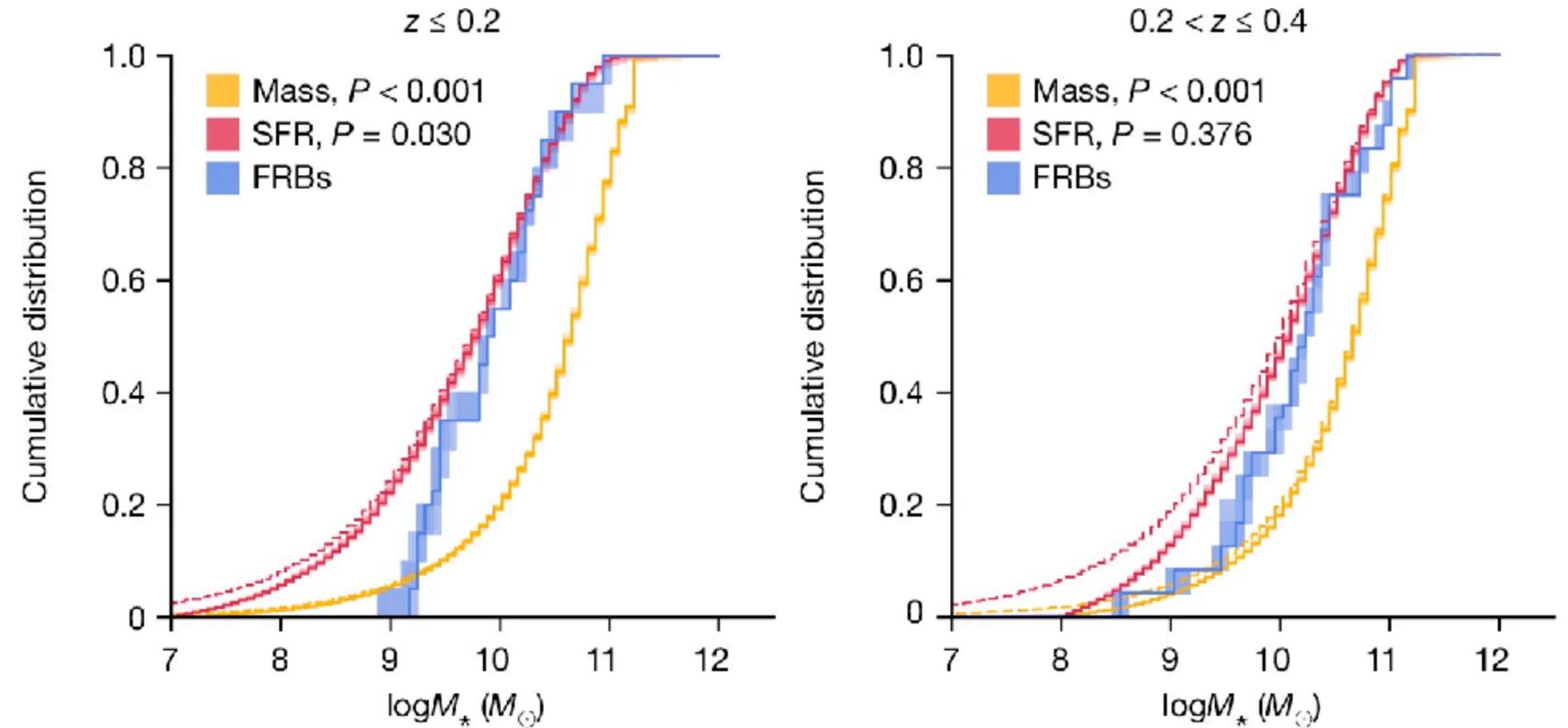


Upper: Bhardwaj et al. 2021

Lower: Kirsten et al. 2021

# FRBs: Importance of host environments

- Host demographics of 30 FRBs from the DSA-110 survey:
  - Preferentially star forming and have higher mass than the overall galaxy population
- FRBs and stellar light from a sample of 34 FRBs from ASKAP/CRAFT survey:
  - Most hosts have spiral arms
  - Small fraction consistent with Globular cluster origin
- No evidence for repeaters and non-repeaters coming from different host types



# Strengths of the SKAO

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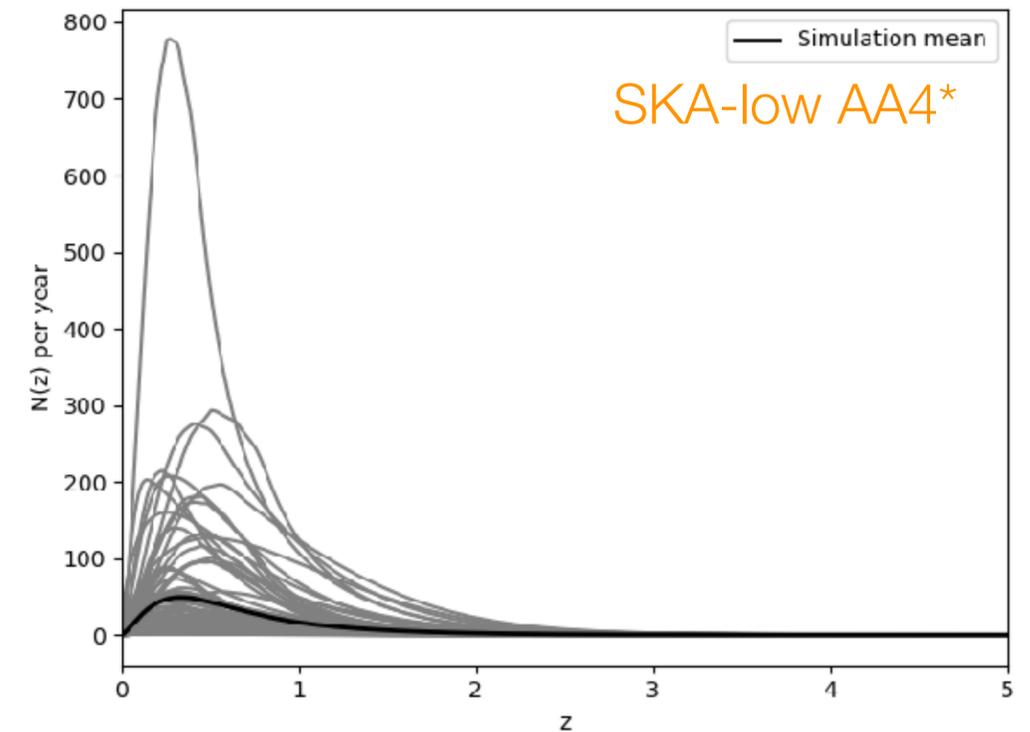
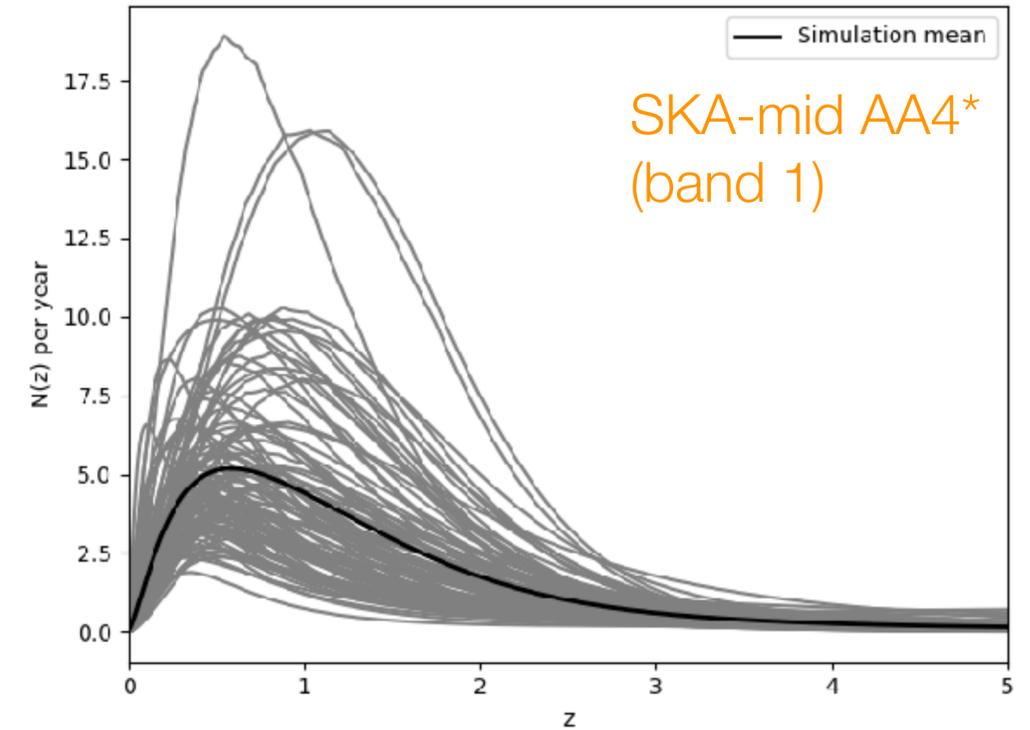
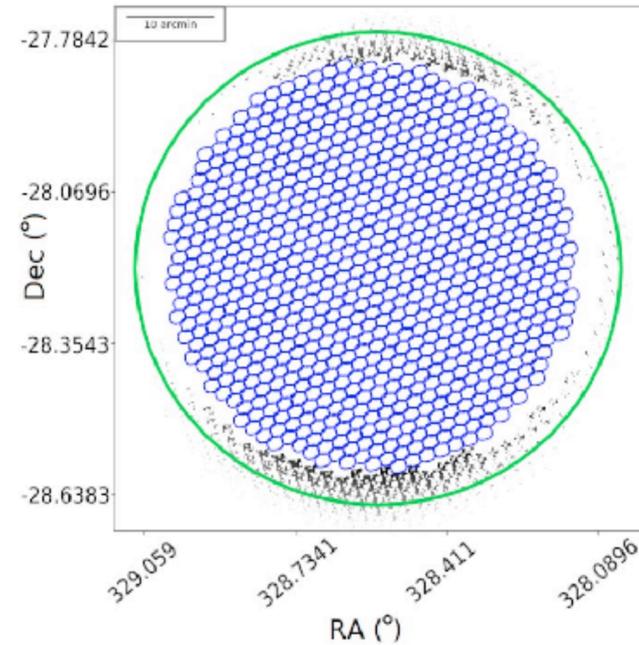
- Simultaneous, high fidelity radio images (ideally full Stokes and VLBI capabilities) and beamforming
- Broad frequency coverage:
  - SKA-mid bands  
1 (0.35-1 GHz), 2 (0.95 - 1.76 GHz)  
5a (4.6 - 8.5 GHz) & 5b (8.3 - 15.4 GHz)
  - SKA-low
    - Major step forward in sensitivity
- Southern hemisphere
  - See more of the Milky Way
  - Overlaps with major, large scale surveys (e.g. Rubin LSST)



Credits: (top) Heywood, SARA0  
(bottom) SKAO

# FRBs with the SKAO

- Primary observing strategy: blind surveys operating in commensal mode
  - Phased array beams are formed to tile the area of the primary beam
  - Trade off between the number of beams that can be formed and the maximum baseline of the dishes included
- Population synthesis simulations done for the SKA Science Chapter on *FRBs as Cosmological Probes*



Credit:

(left) Rajwade et al., 2022, MNRAS

(right) FRBs as Cosmological Tools, Caleb et al., submitted

Simulations by Clancy James

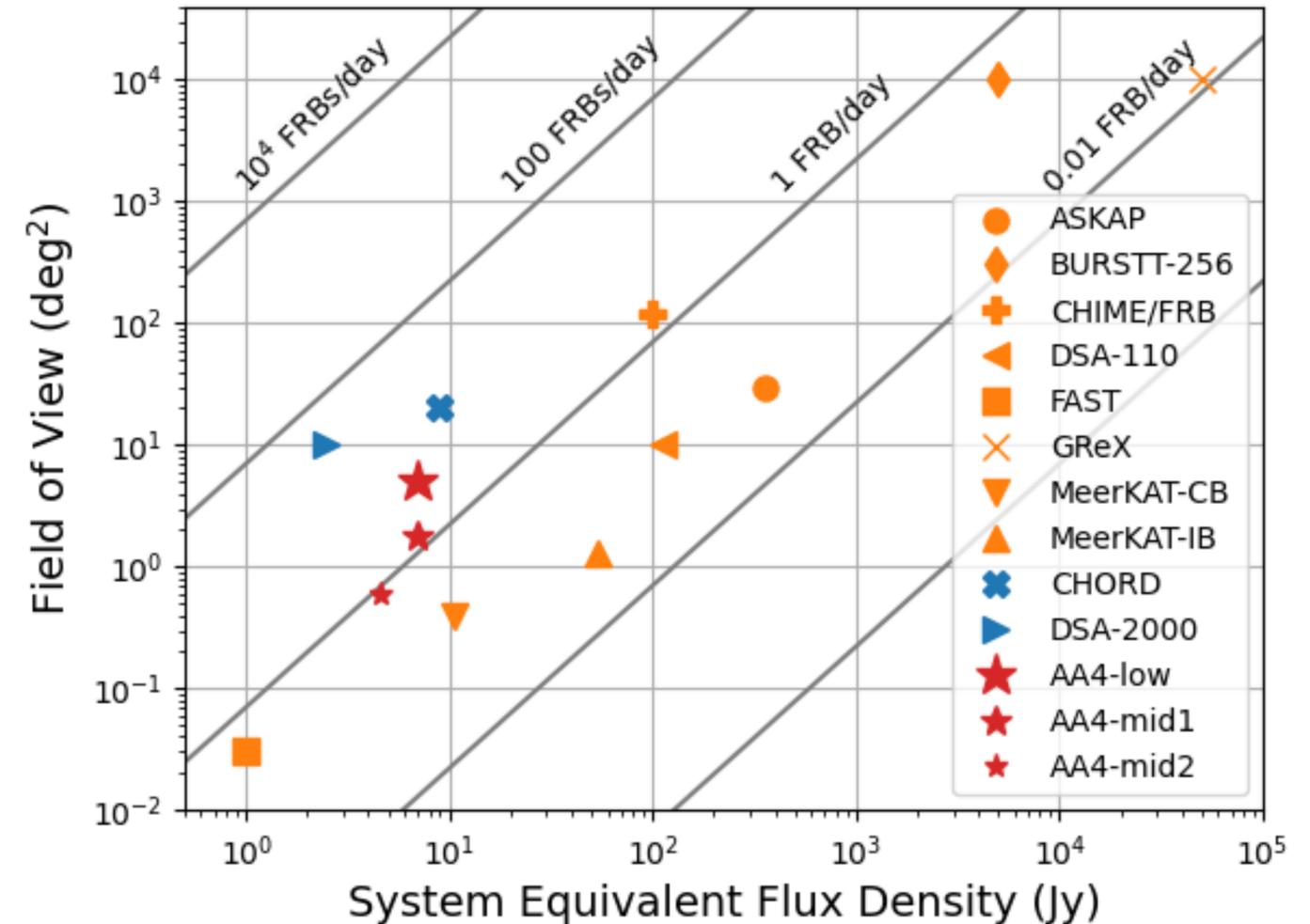
\*Prior to recently announced descoping

# FRBs with the SKAO

- Estimated detection rates:
  - SKA-mid:  $\sim 1 \text{ day}^{-1}$
  - SKA-low:  $\sim 4 \text{ day}^{-1}$   
(estimates poorly constrained due to few ongoing surveys in this band.)
- Higher detection rate than (most) current surveys but lower than FRB-driven projects under construction

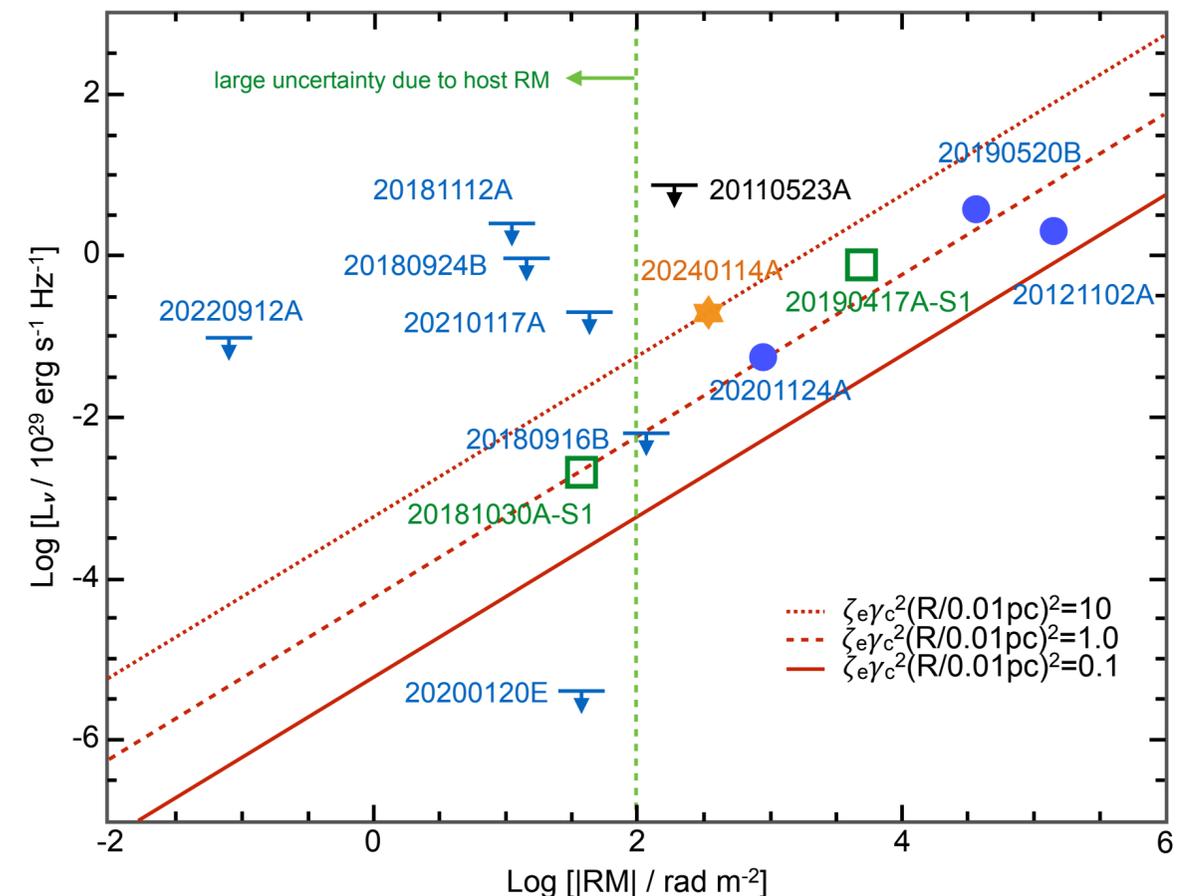
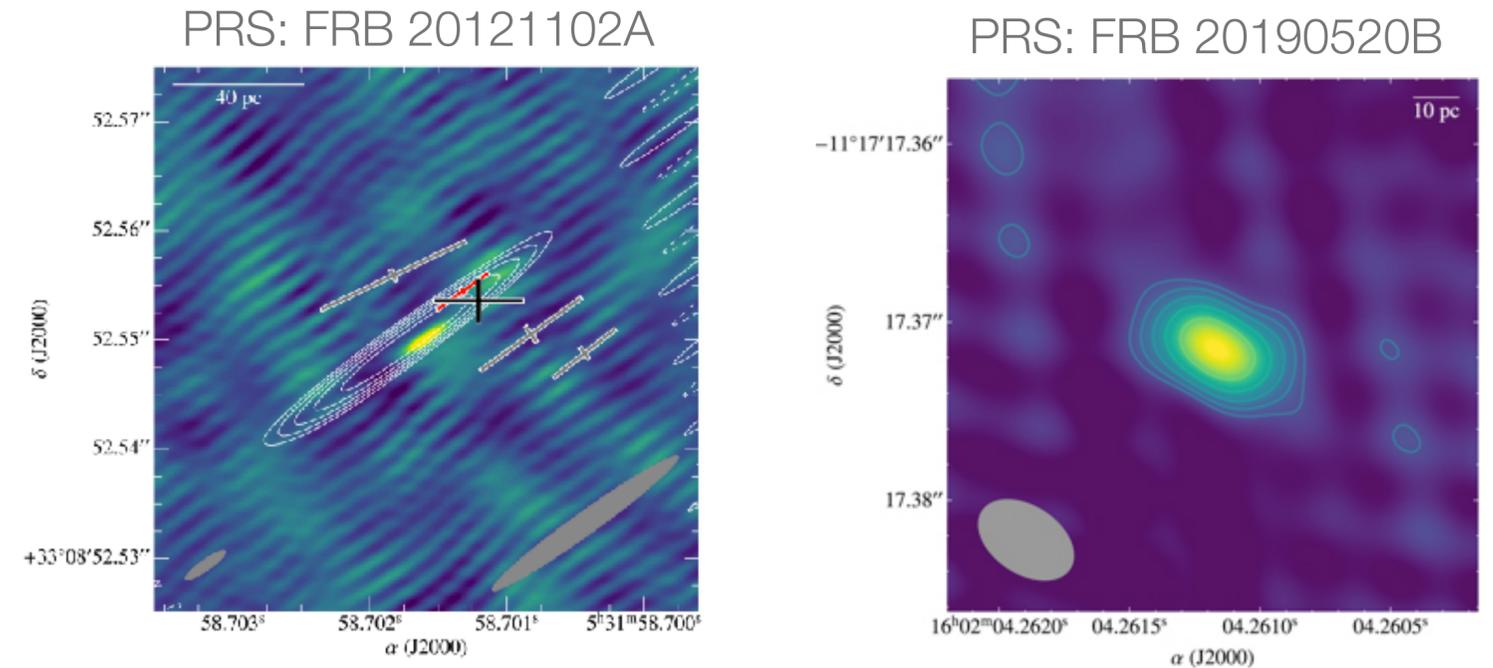
Estimated rates in 1 year of accumulated observing

| Stage | Band      | Nr. FRBs              | Nr. visible hosts     | Host fraction          |
|-------|-----------|-----------------------|-----------------------|------------------------|
| AA*   | Mid Band2 | $280^{+120}_{-110}$   | $220^{+100}_{-80}$    | $0.79^{+0.05}_{-0.05}$ |
|       | Mid Band1 | $390^{+270}_{-140}$   | $320^{+210}_{-110}$   | $0.83^{+0.04}_{-0.04}$ |
|       | Low       | $1320^{+5020}_{-750}$ | $1230^{+4800}_{-700}$ | $0.94^{+0.02}_{-0.02}$ |
| AA4   | Mid Band2 | $550^{+270}_{-210}$   | $420^{+200}_{-160}$   | $0.75^{+0.05}_{-0.05}$ |
|       | Mid Band1 | $790^{+530}_{-290}$   | $620^{+440}_{-220}$   | $0.79^{+0.05}_{-0.04}$ |
|       | Low       | $1490^{+5700}_{-860}$ | $1380^{+5420}_{-790}$ | $0.93^{+0.02}_{-0.03}$ |



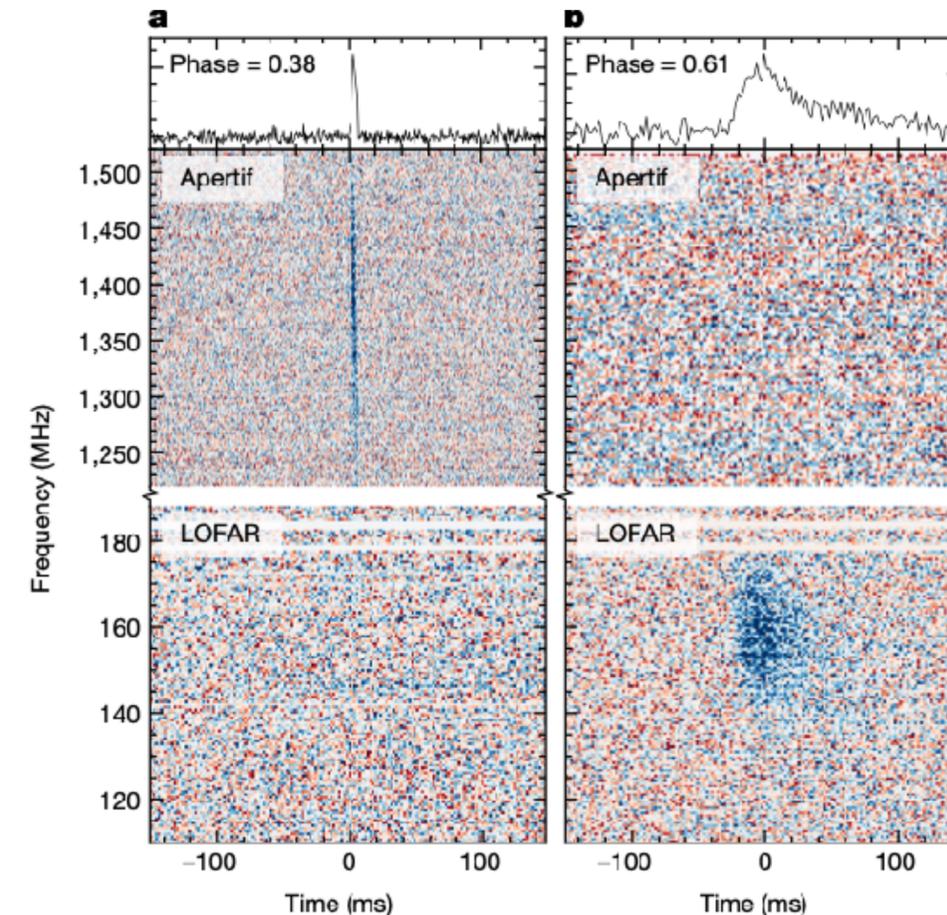
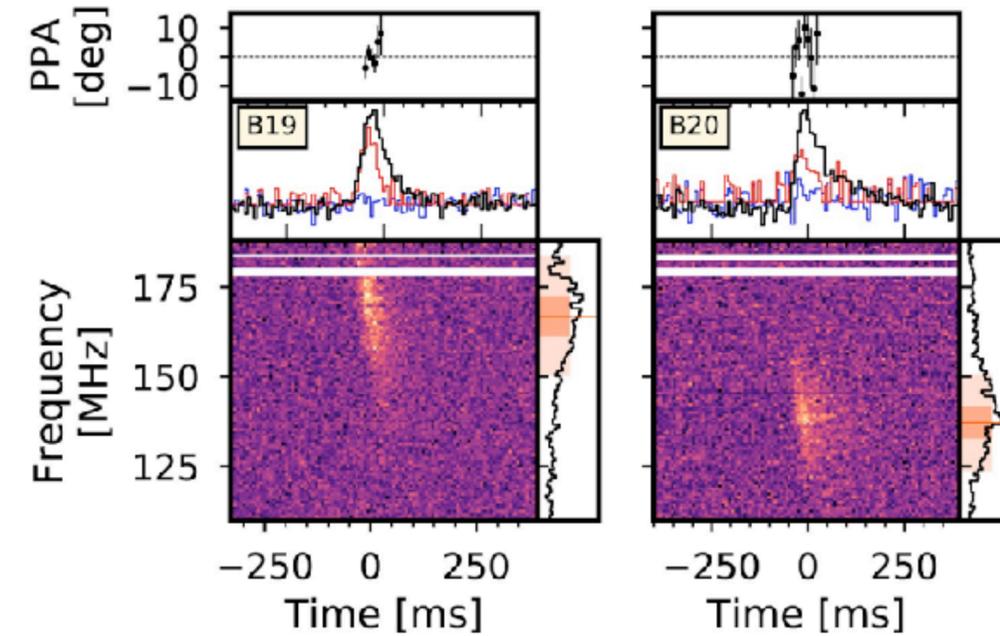
# Simultaneous radio images

- Immediately obtain radio image of the host galaxy
- Detection or constraints on presence of a persistent radio source
  - VLBI imaging essential
- FRB - Persistent Radio Sources (FRB-PRS)
  - Compact ( $\sim$ pc) radio sources associated with four (five?) highly active repeating FRBs
  - Current favored model: nebula being fueled by a energetic neutron star



# FRBs at Low Frequencies

- LOFAR searches primarily target FRBs discovered by other surveys
- Only FRB detected by LOFAR: repeater FRB 20180916B
- Chawla et al 2025:
  - 47 repeaters & 430 apparent non-repeaters
  - No detections
- Low frequencies particularly impacted by propagation effects



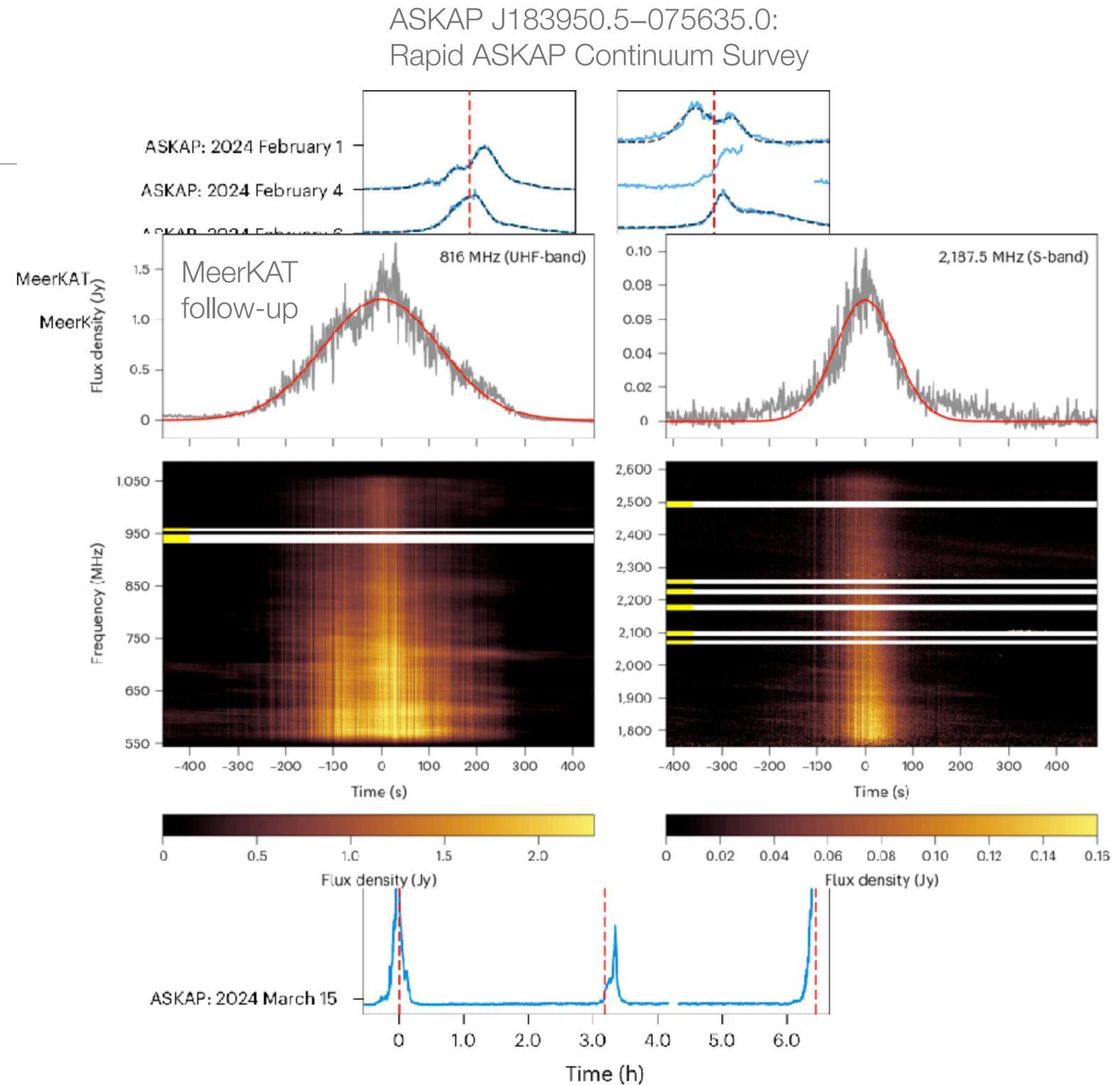
Credits:

(top) Gopinath et al, 2024, MNRAS

(bottom) Pastor-Marazuela et al, 2021, Nature

# Snapshot imaging: Long Period Transients

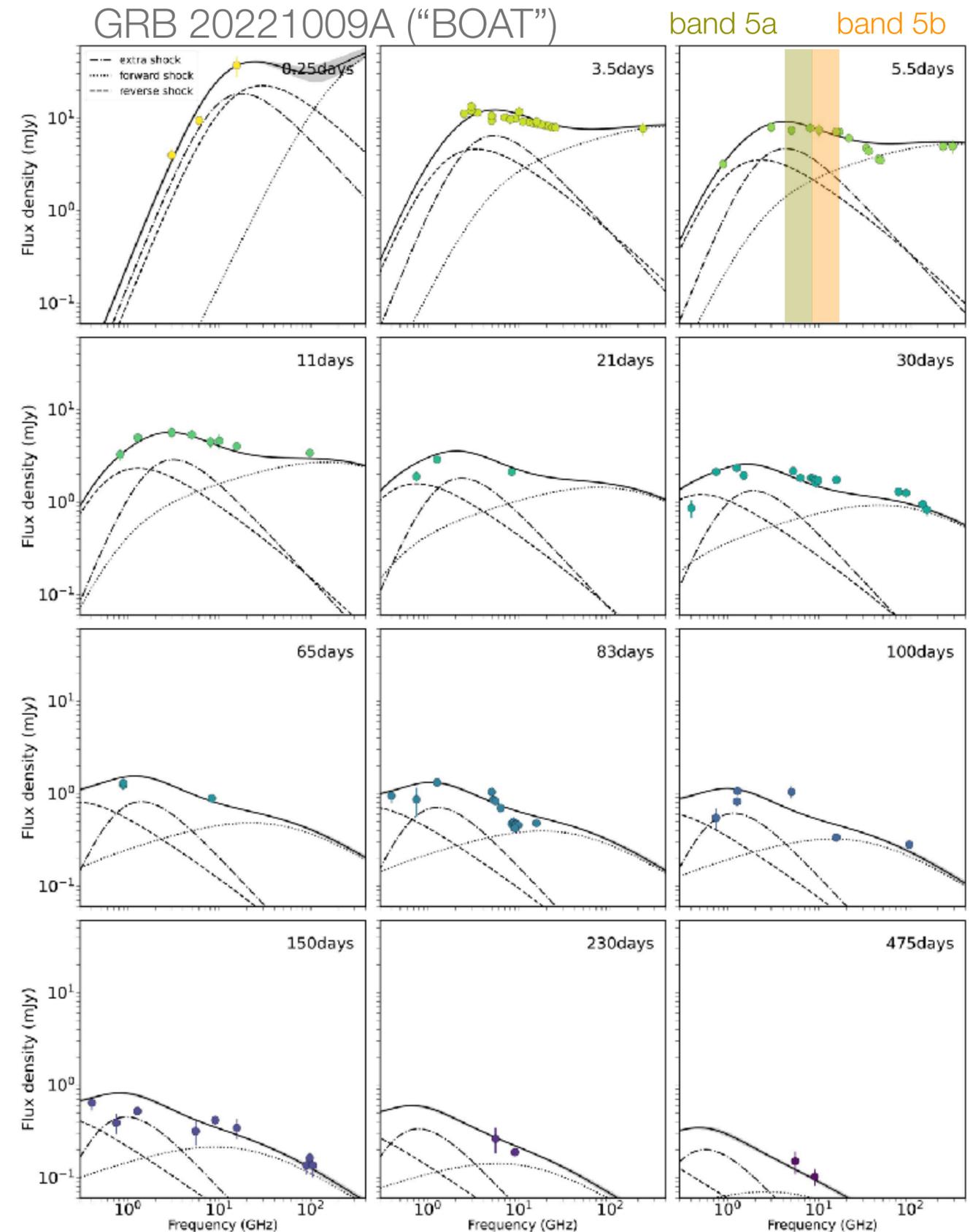
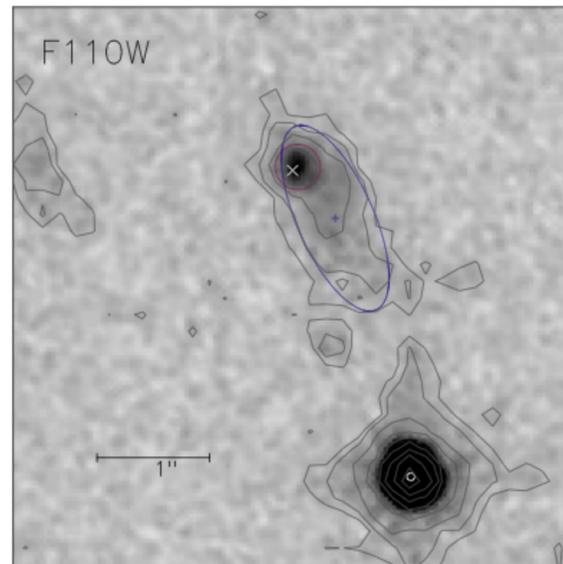
- 10 of 12 LPTs found in snapshot imaging
- Often commensally with other surveys
- Sub-second substructure seen in beamforming data
- Generally steep spectrum sources in the Galactic plane
- SKA-low
- Southern hemisphere
- Intermittent
- Regular monitoring



# Explosive transients and FRBs

- Band 5a/5b commonly used frequencies for monitoring GRB, SNe, GW afterglows
- Sub-class of GRBs and SNe thought to be powered by a newly formed ms-magnetar
- Detection of a repeating FRB associated with a long GRB/superluminous SN would prove the origin mode
- Burst searches require high frequencies to avoid free-free absorption in SNe ejecta

FRB 20121102's host



Credit:  
(left)

(right) Rhodes et al., 2024, MNRAS

# Summary & Questions

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- Major strengths of the SKAO for transient science:
  1. Simultaneous imaging and beamforming capabilities (ideally at VLBI-scales)
  2. Sensitive high ( $>4$  GHz) and low ( $<300$  MHz) frequency coverage
  3. Location in the southern hemisphere