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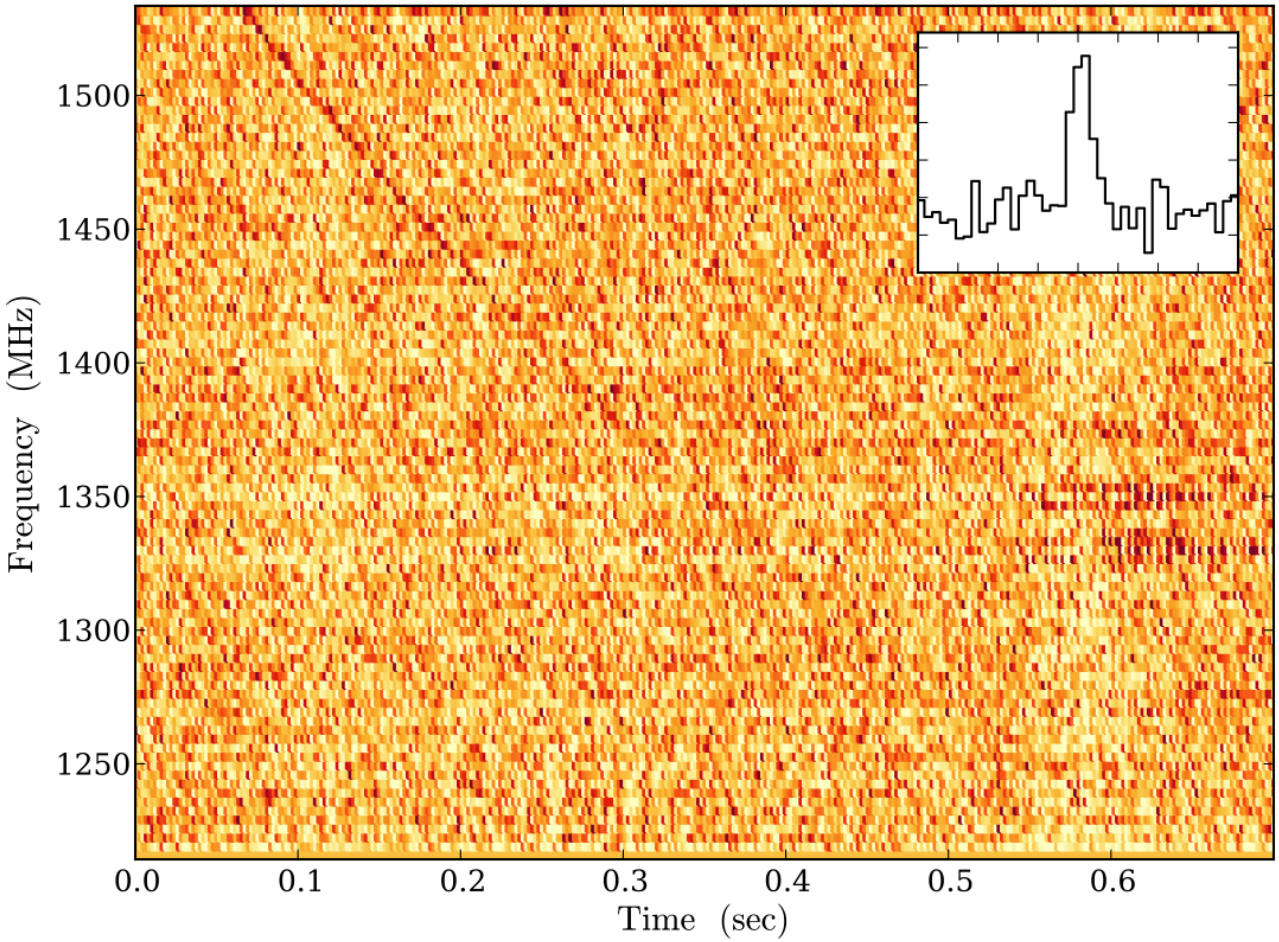
Cornell University

Fast Radio Bursts: Localizing FRB 121102 and Future Localization Efforts

FRB 121102: Arecibo detection of an FRB



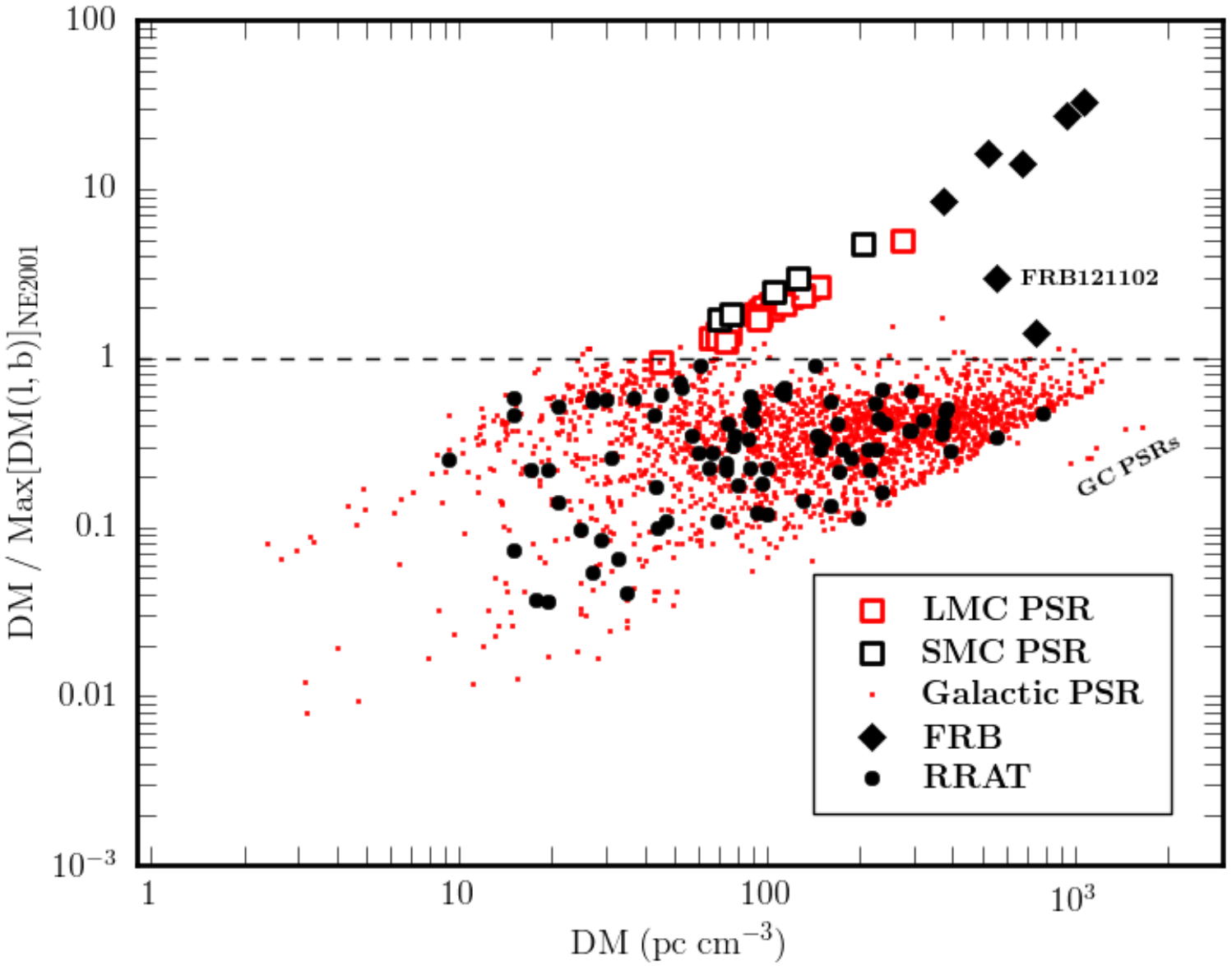
FRB 121102
(Spitler et al. 2014)

- l,b = 175°, –0.2°.
- DM = 557 pc cm^{-3}.
- Width = 3.0±0.5 ms.

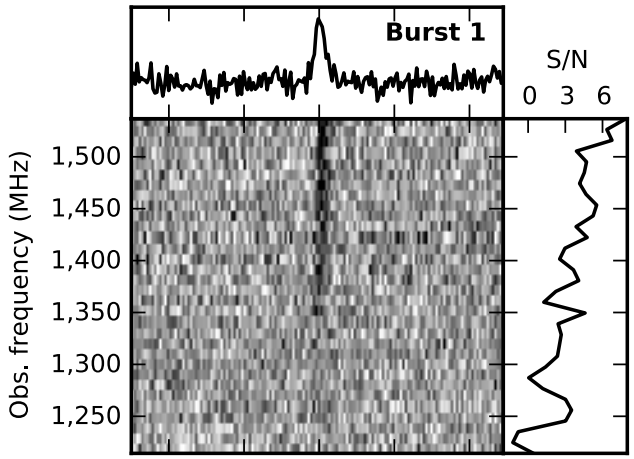
- Single PALFA beam.
- No re-detection in multiple deep obs.

- Fainter at lower f: Odd…?

FRB 121102: probably extragalactic?



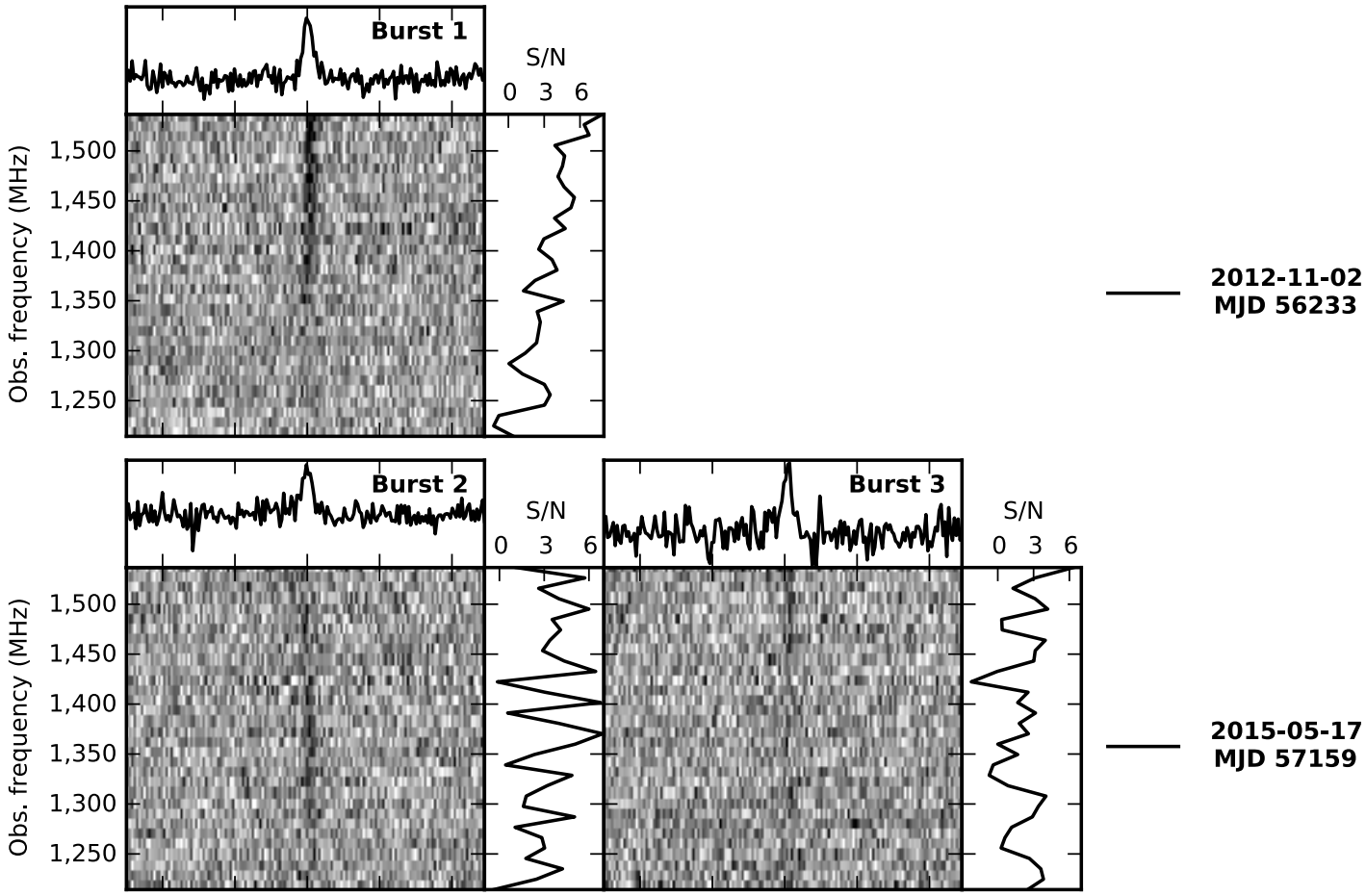
“A minor point of interest” re: FRB 121102



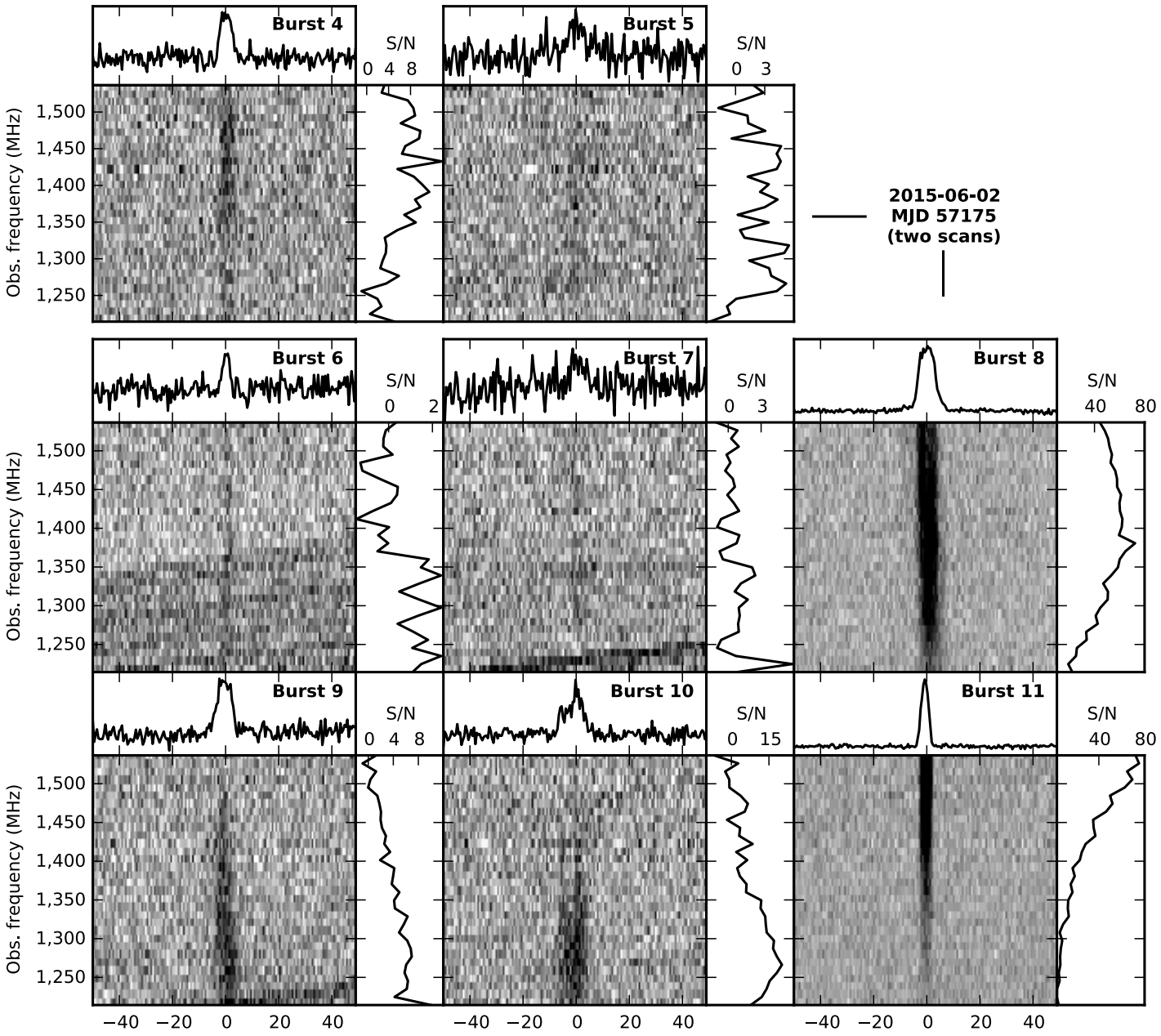
2012-11-02
MJD 56233

Re-observed with Arecibo in 2012: Nothing there.
Re-observed with Arecibo in 2013: Nothing there.
Re-observed with Arecibo in 2015: “A minor point of interest…”

“A minor point of interest” re: FRB 121102



FRB 121102 is a repeating source

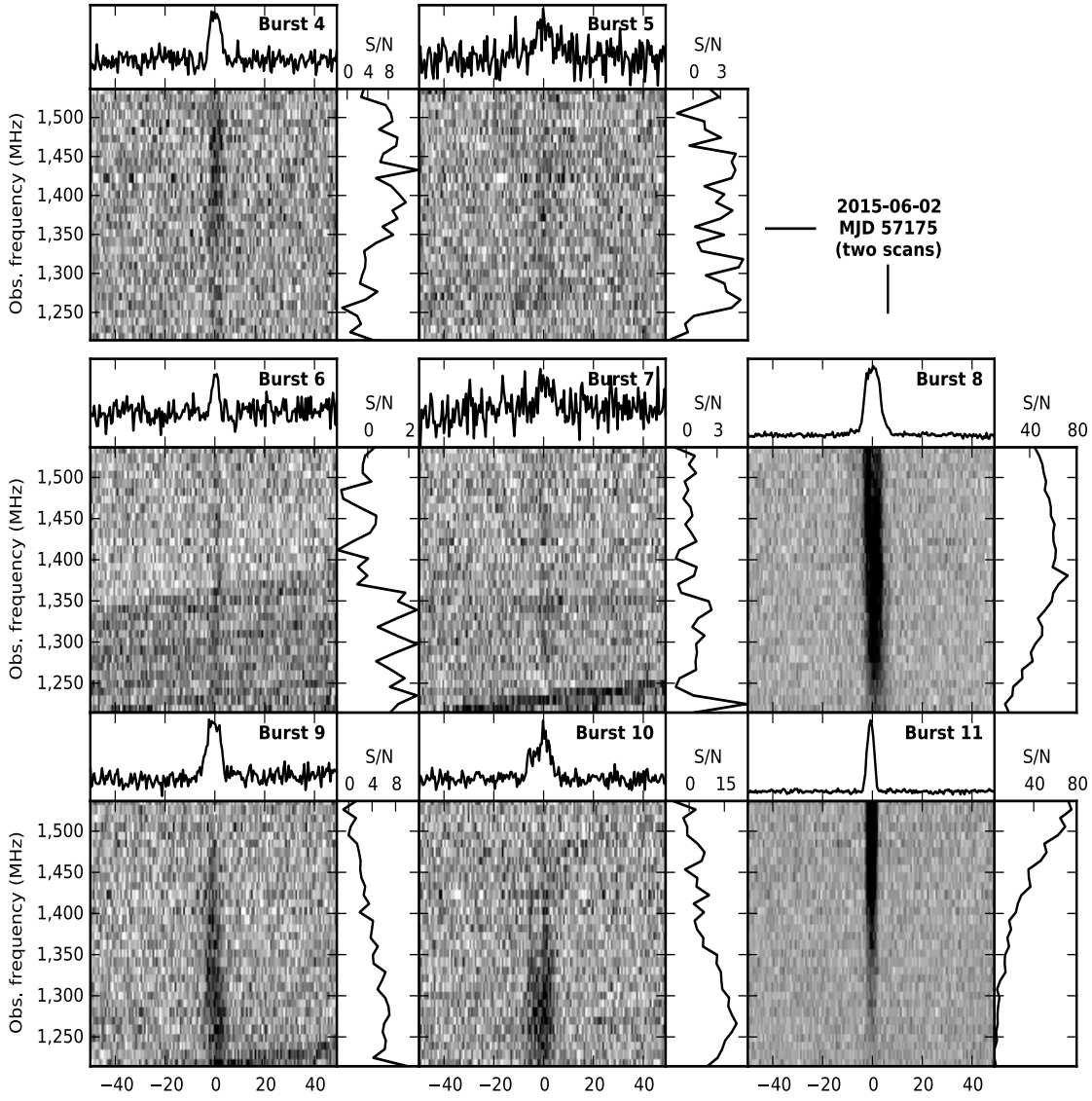


FRB 121102 is a repeating source

→ Rules out cataclysmic or explosive models, at least for this one source.

(Spitler et al. 2016, Nature)

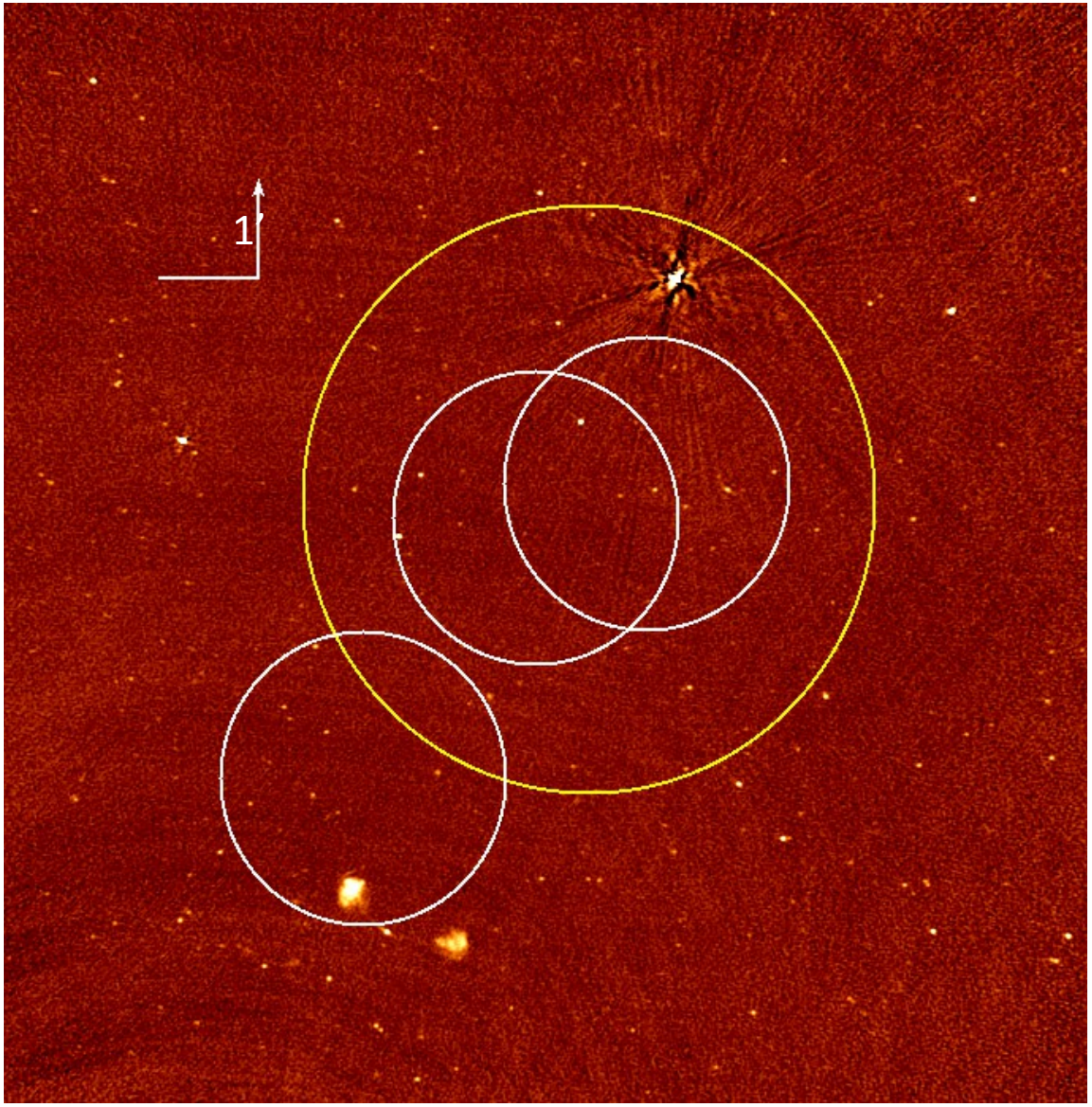
→ A better-than-random location to go fishing.



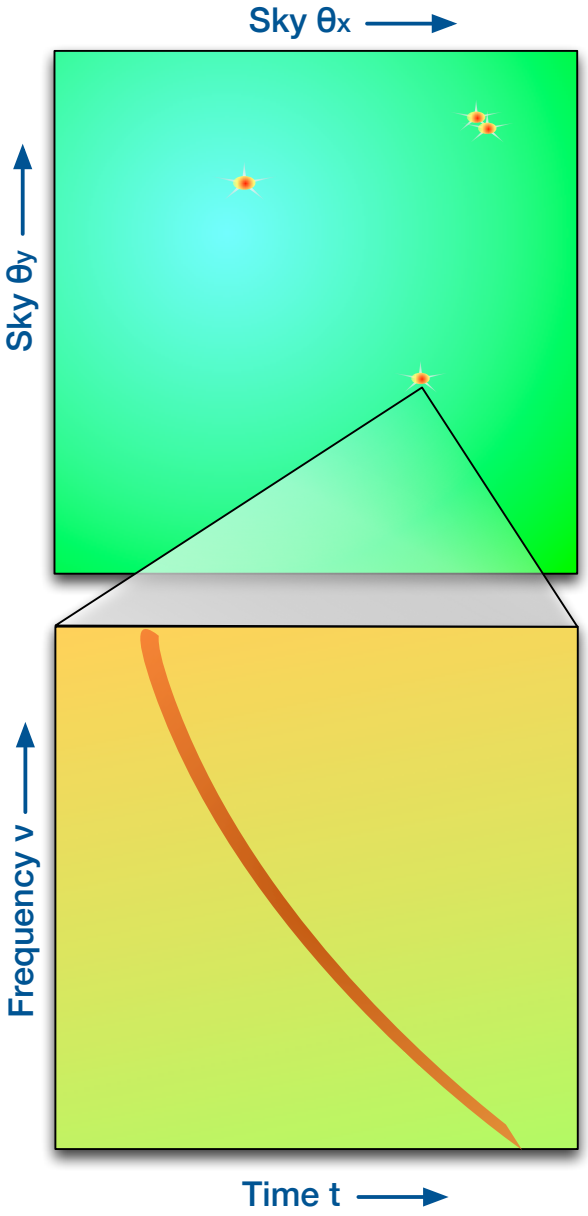
Localizing FRB 121102 – how?

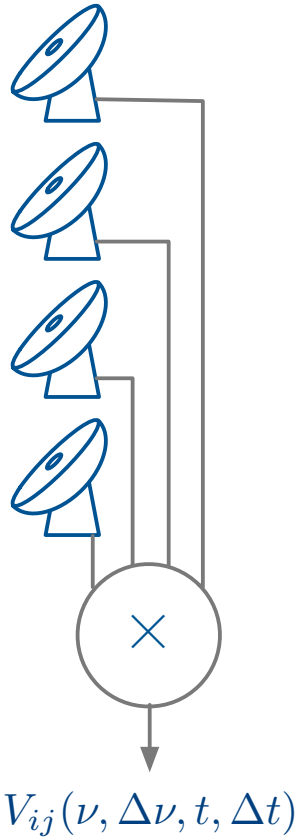
Arecibo detection beams cover dozens of sources in higher resolution VLA observations.

Original detection (Spitler et al. 2014) was apparently in a sidelobe.



Localizing FRB 121102 with the VLA





Fast sampled visibility data
(u, v, t, f).

→ 2.5 – 3.5 GHz.
→ 256 channels, 4 MHz each.
→ 5 ms visibility sampling.
→ 351 baselines.

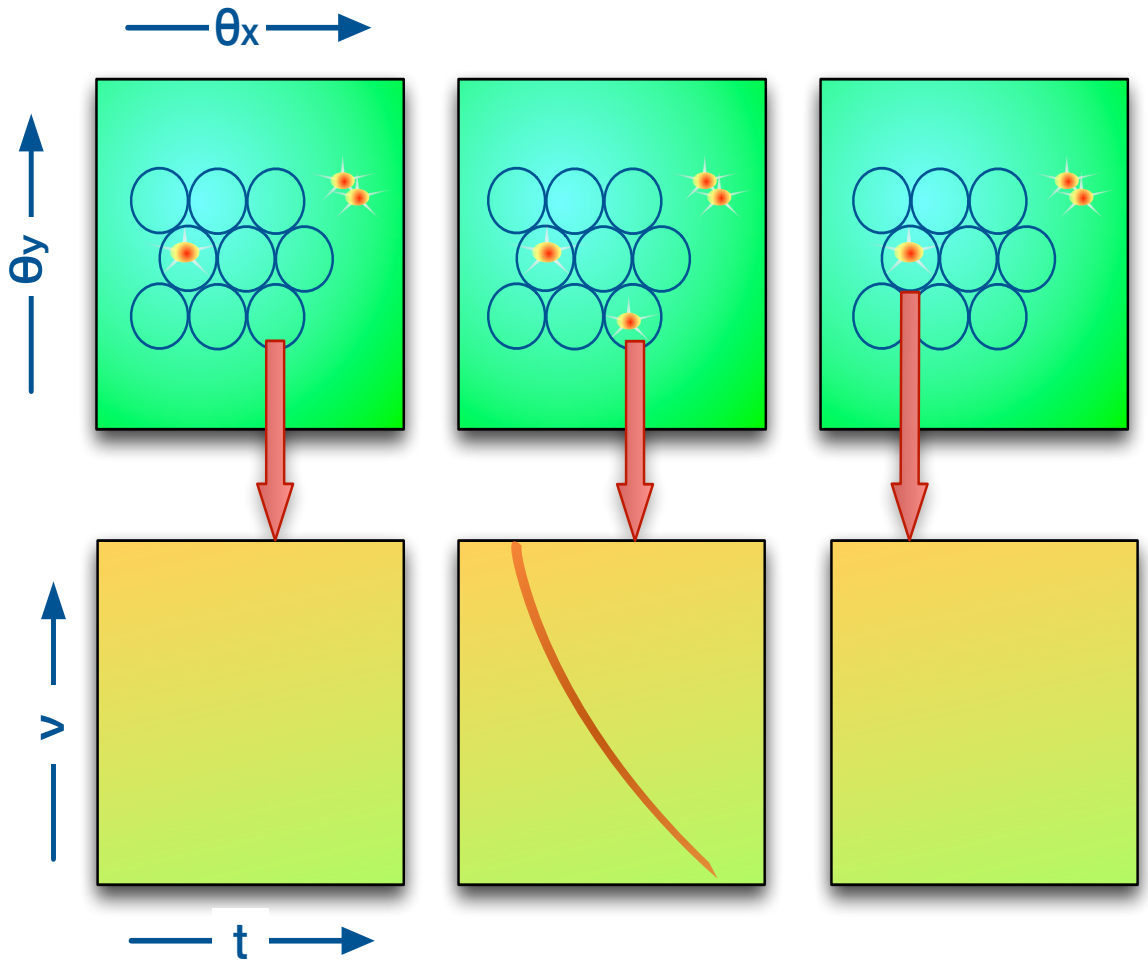
= 1 TB/hr correlated data.
(Set by correlator throughput limit.)

VLA localization

Fast sampled visibility data (u, v, t, f).

Beam-formed Search:

- Tile region with phased-up beams.
- Search for pulse in time domain (t, DM).

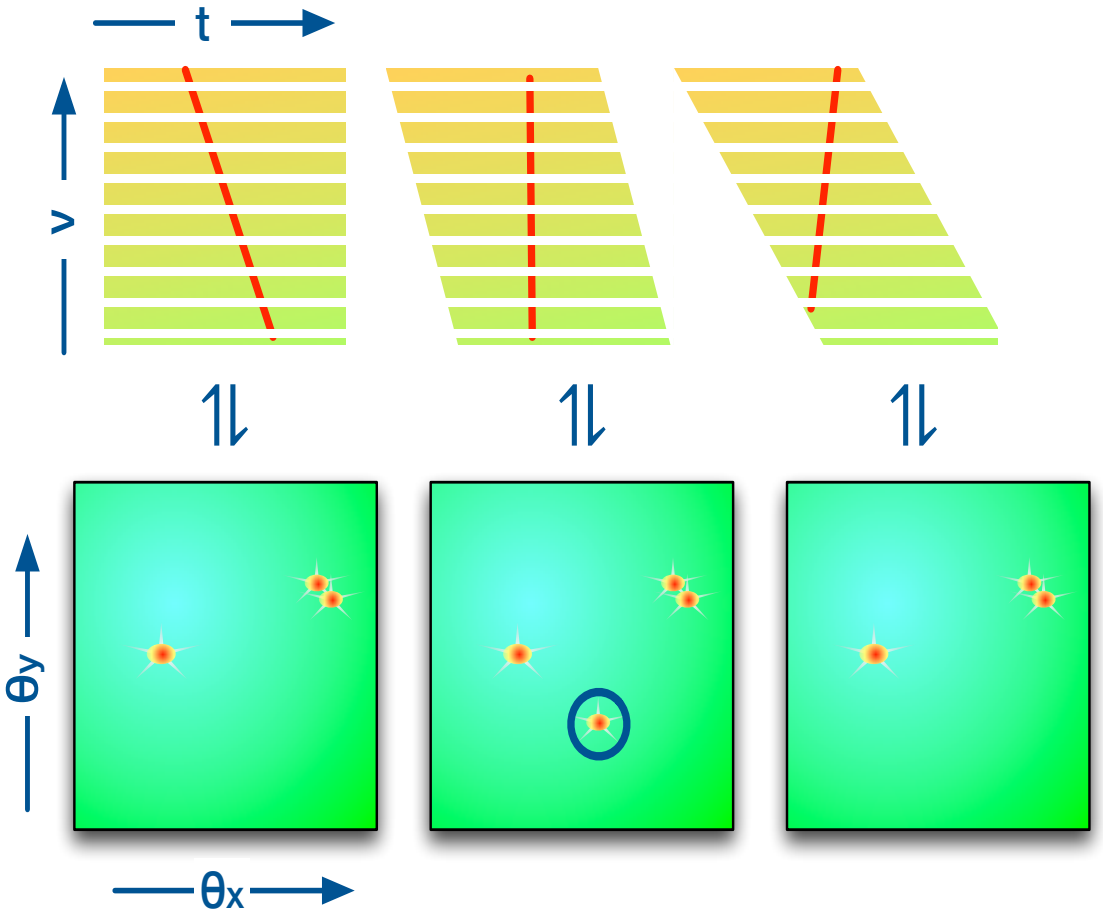


VLA localization

Fast sampled visibility data (u, v, t, f).

Millisecond Imaging:

- De-disperse visibilities, make images for each sample time.
- Search for transient source in image domain.



VLA localization

Fast sampled visibility data (u, v, t, f) for ~83 hours of observing.

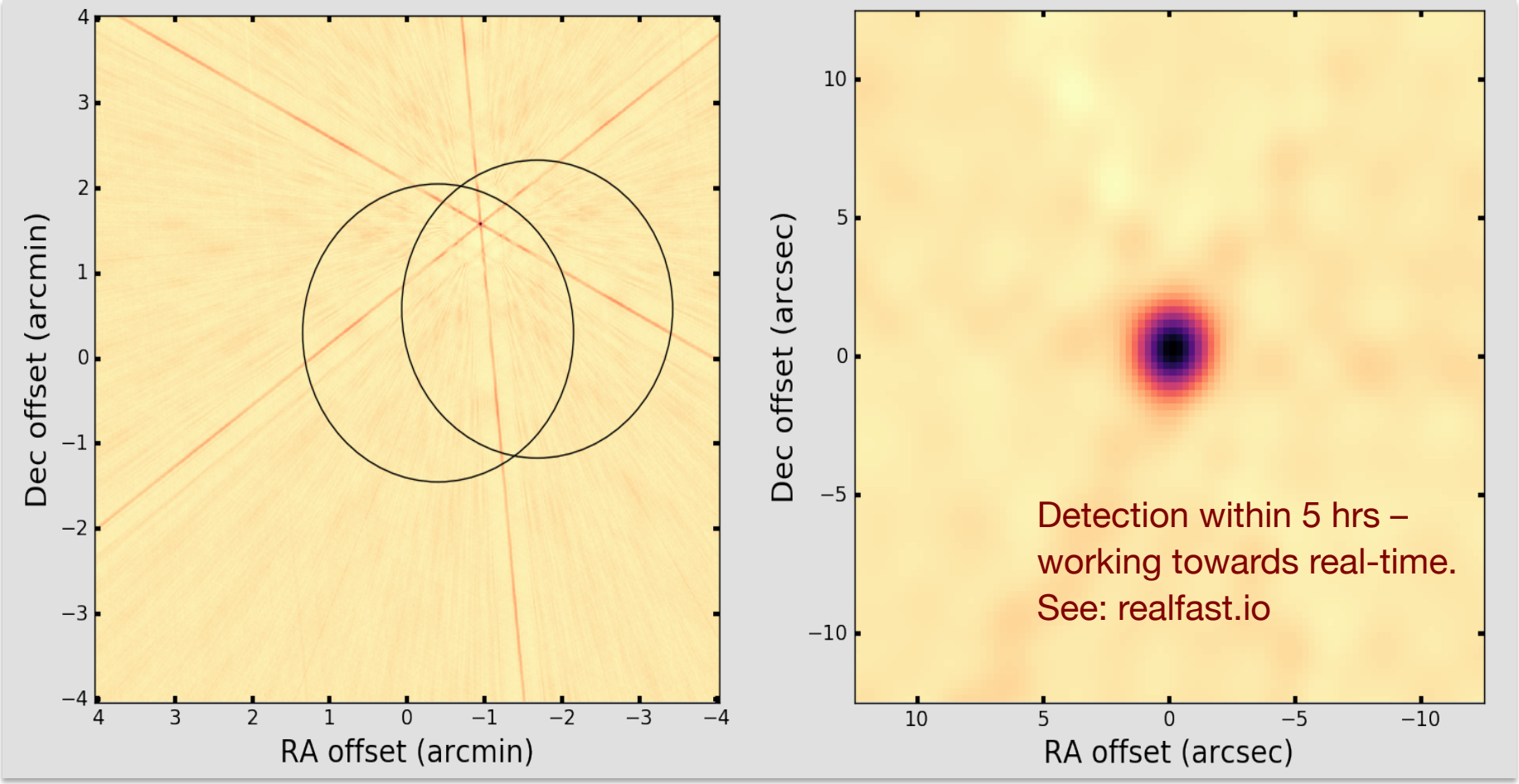
Millisecond Imaging:

- De-disperse visibilities, make images for each sample time.
- Search for transient source in image domain.

Beam-formed Single-pulse Search:

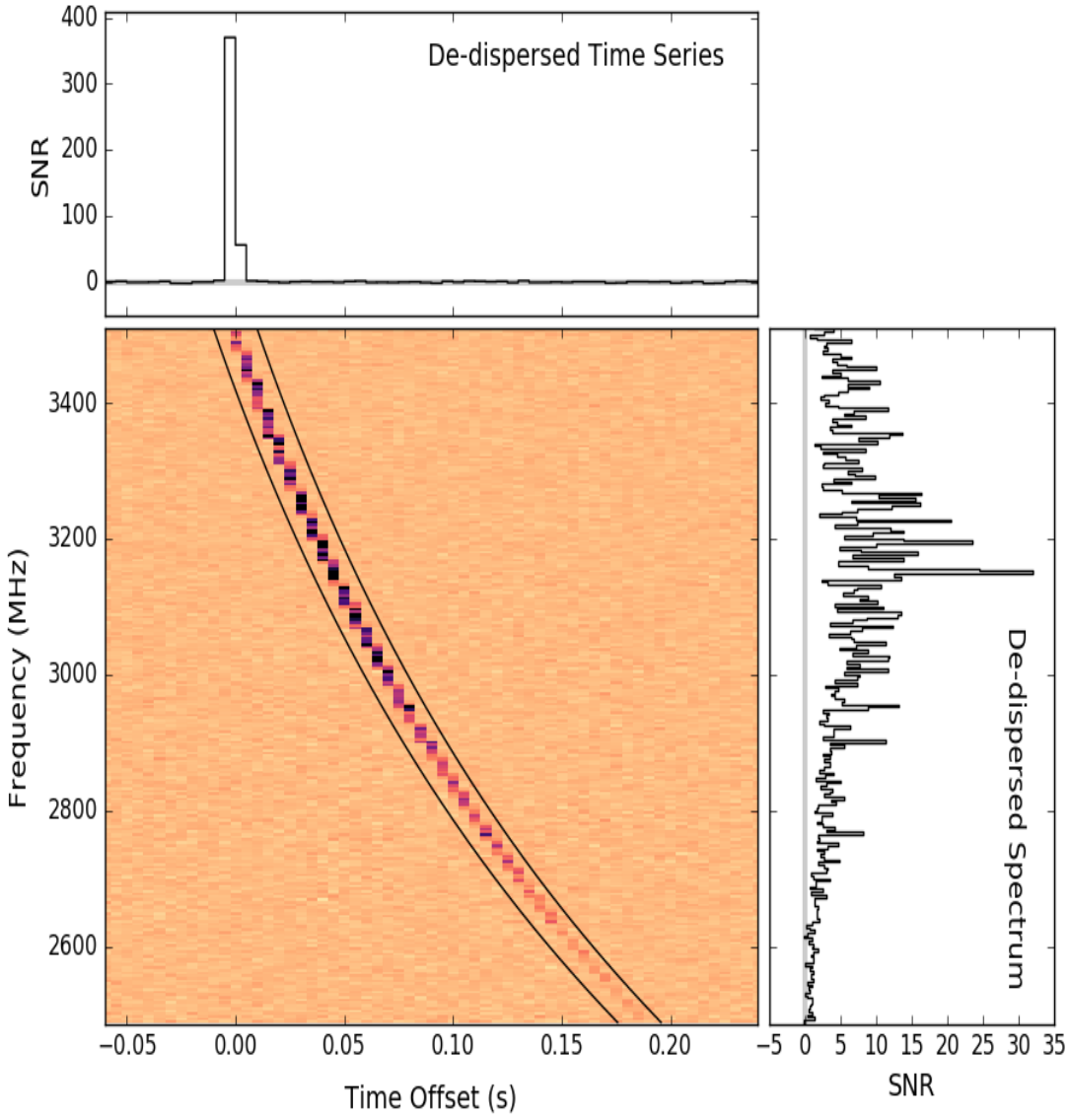
- Tile region with phased up beams.
- Search for pulse in time domain (t, DM).

VLA localization: success!



First on 2017 August 23, and then 8 more detections during campaign.

VLA beam-forming: pulse sweep

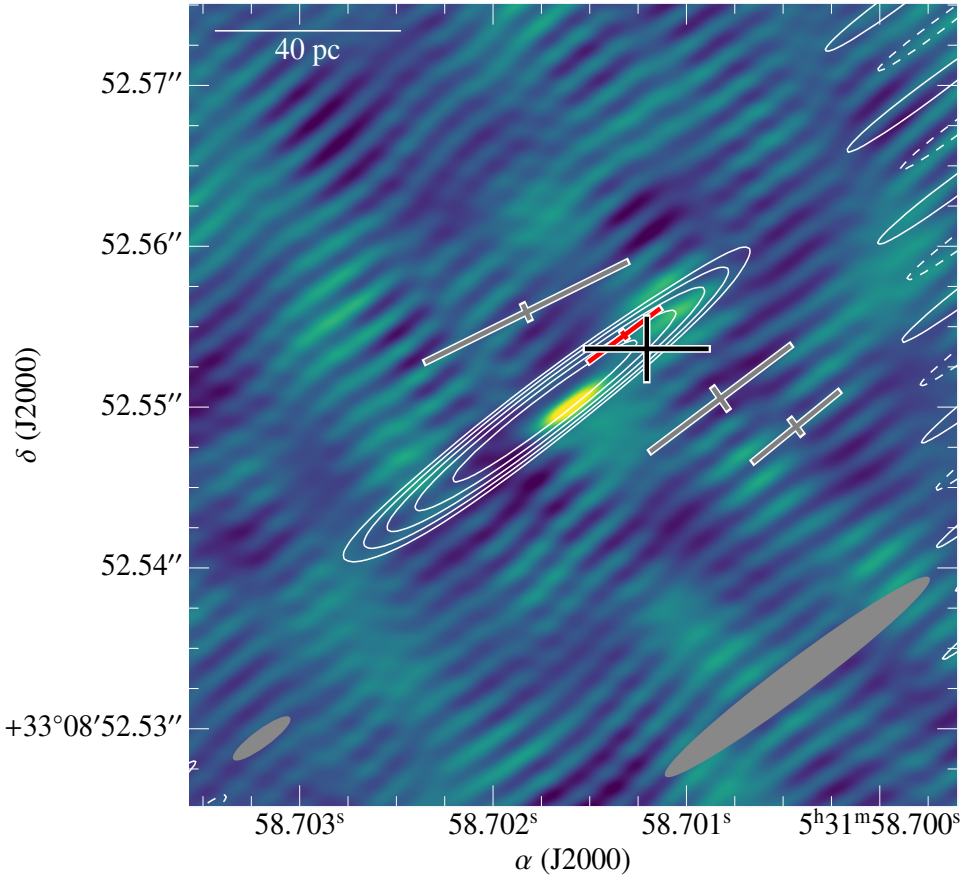


Pulse S/N ratio peaks at the image peak pixel.

Lines indicate v^{-2} sweep.

Work by graduate student Robert Wharton.

Detection with EVN+Arecibo



European VLBI Network

+ Arecibo observations:

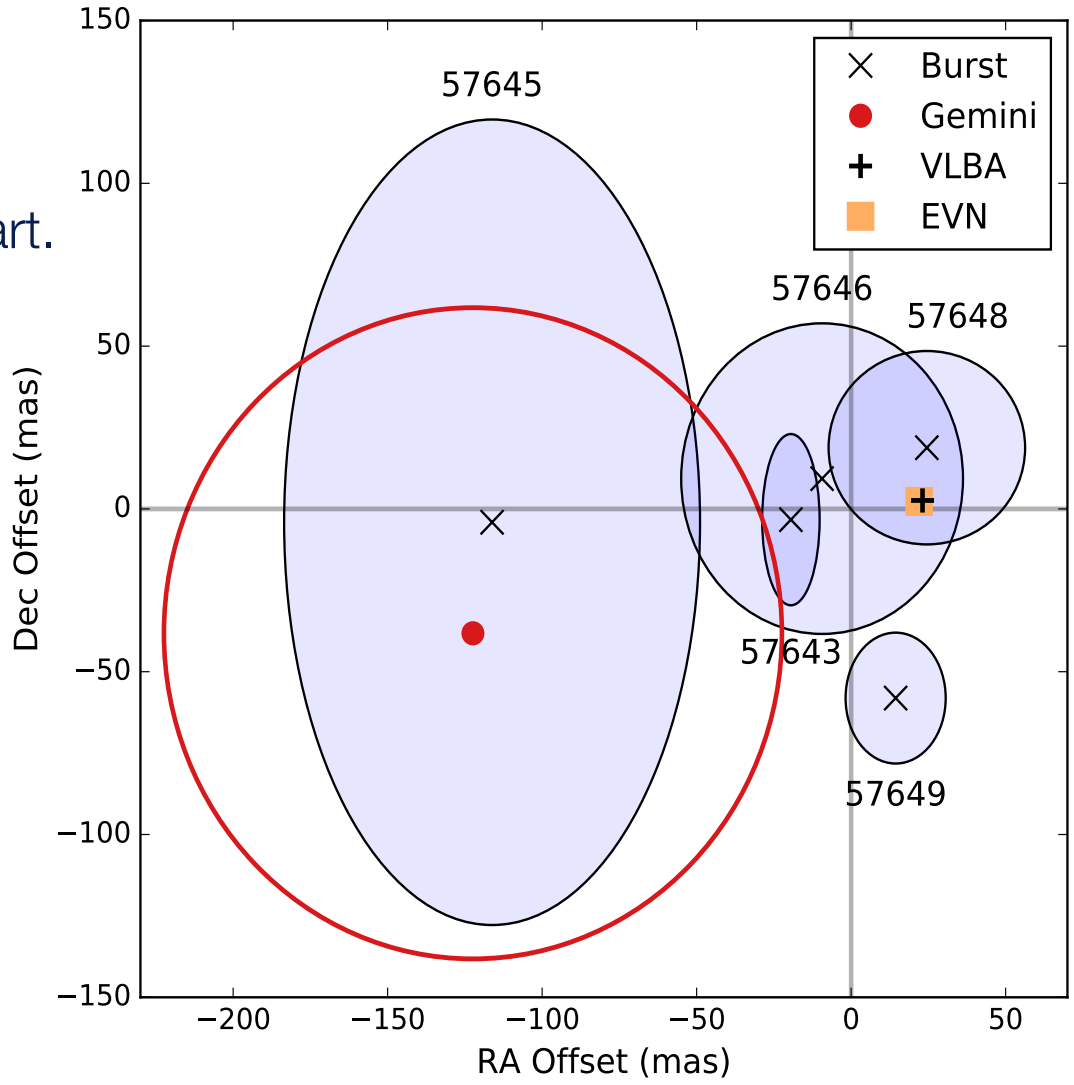
Burst coincides with persistent source to within ~15 mas.

→ Embedded in a nebula?

→ Active galactic nucleus?

Radio counterpart

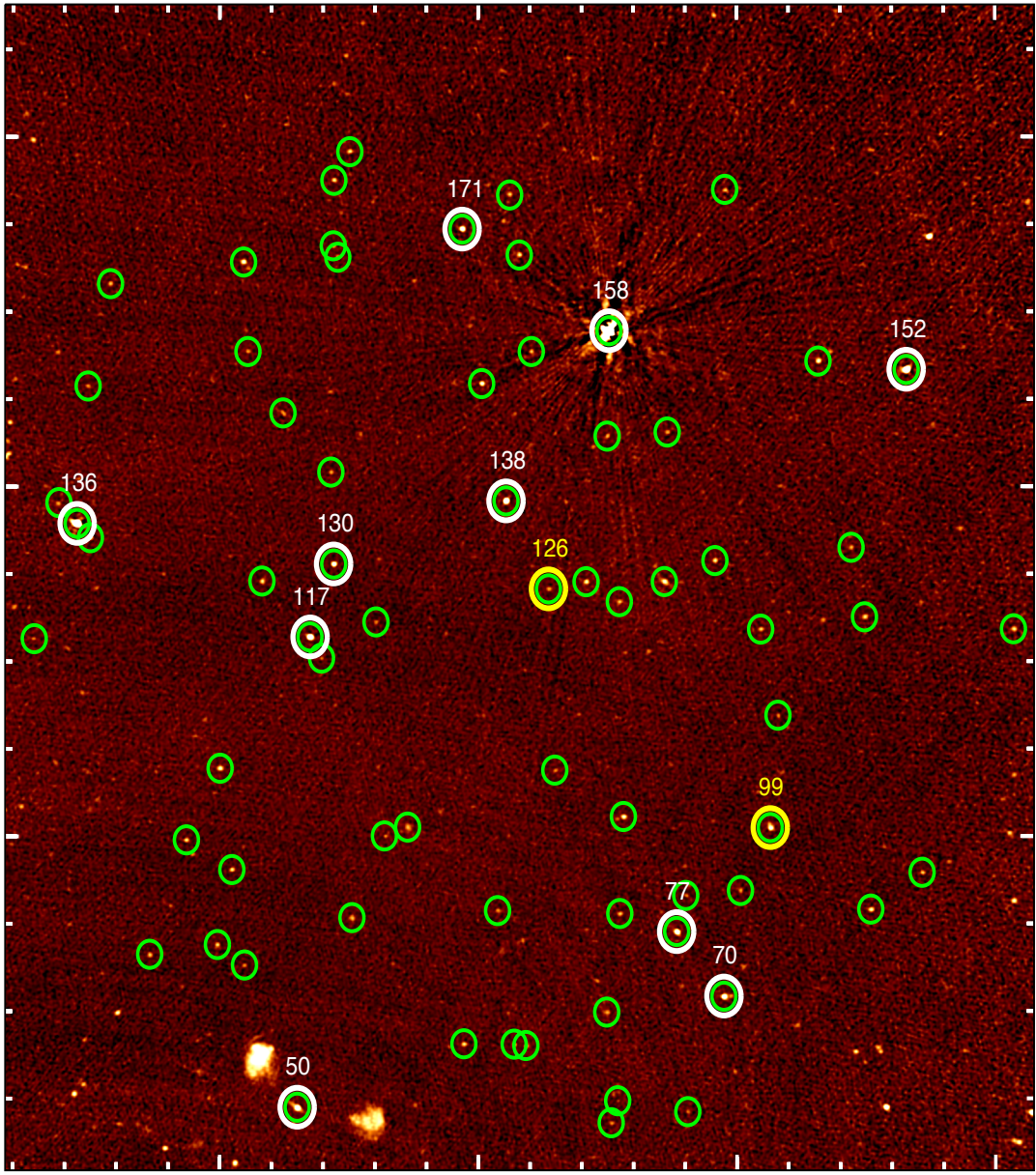
- Persistent, variable, 180 μJy radio counterpart.
- Separation <15 mas (<40 pc at 1 Gpc).

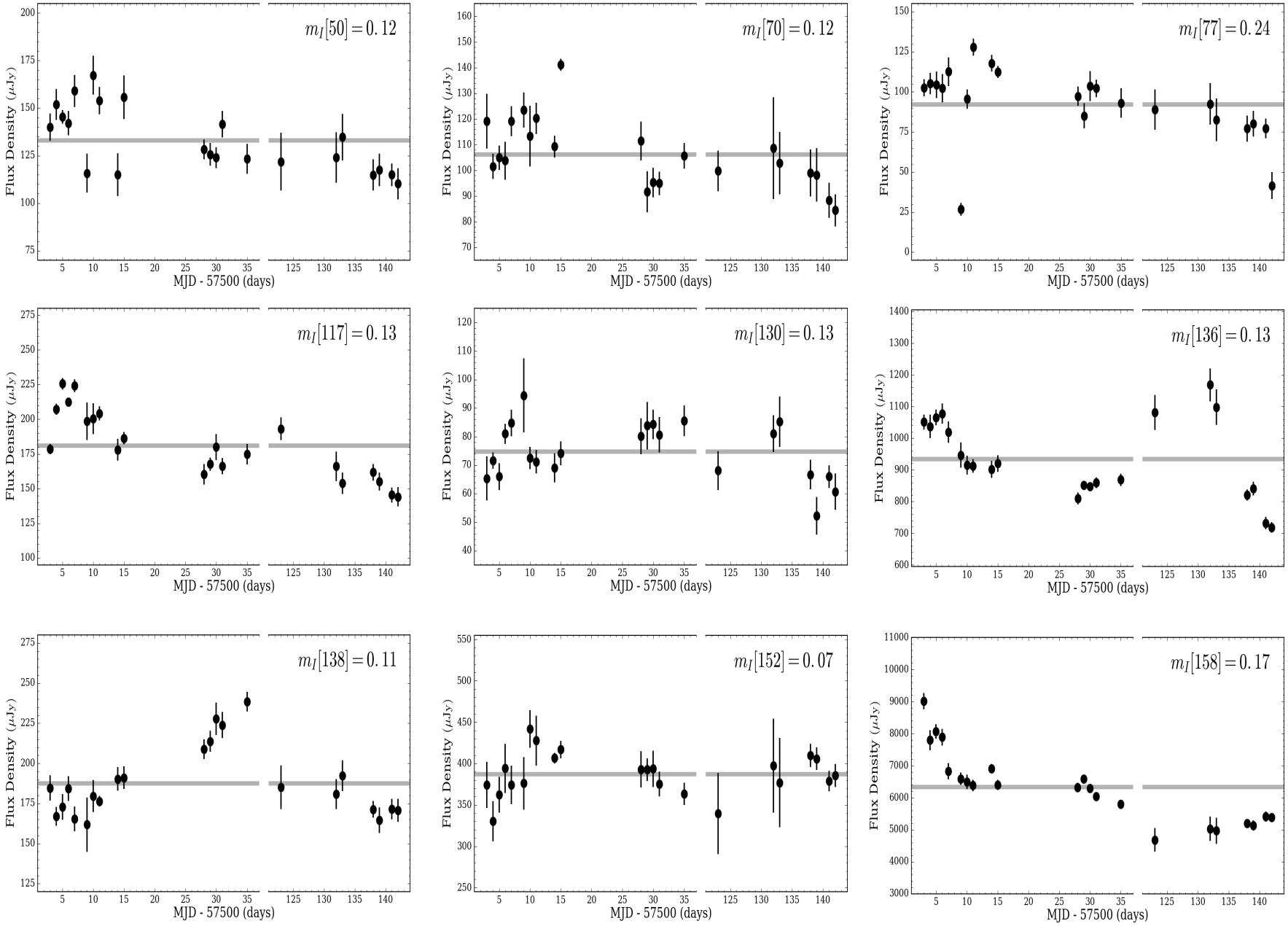


Field Variability

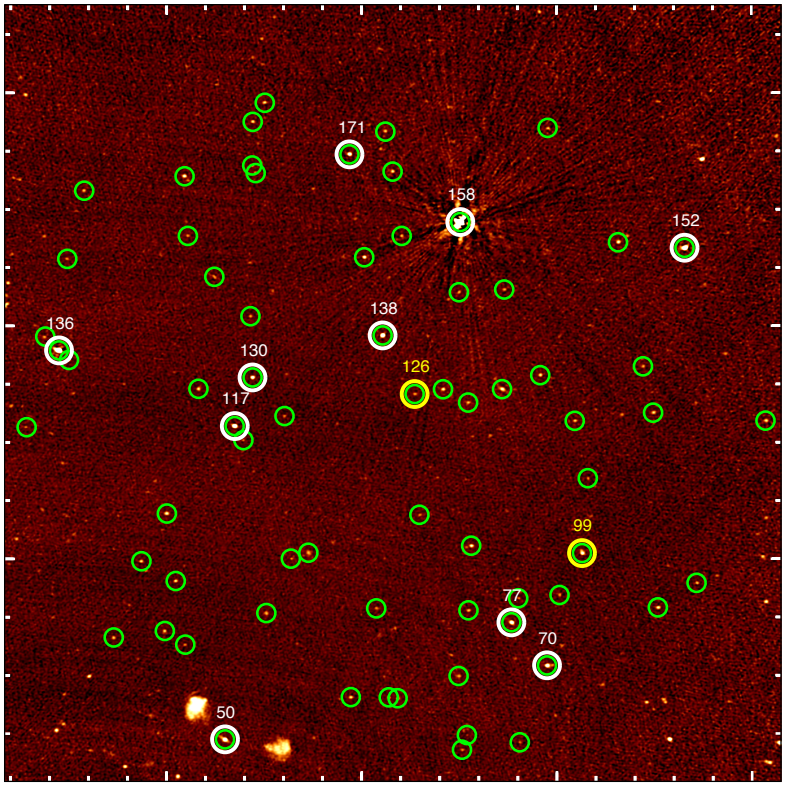
- 69 sources detected in ~most epochs.
- Variability is common.

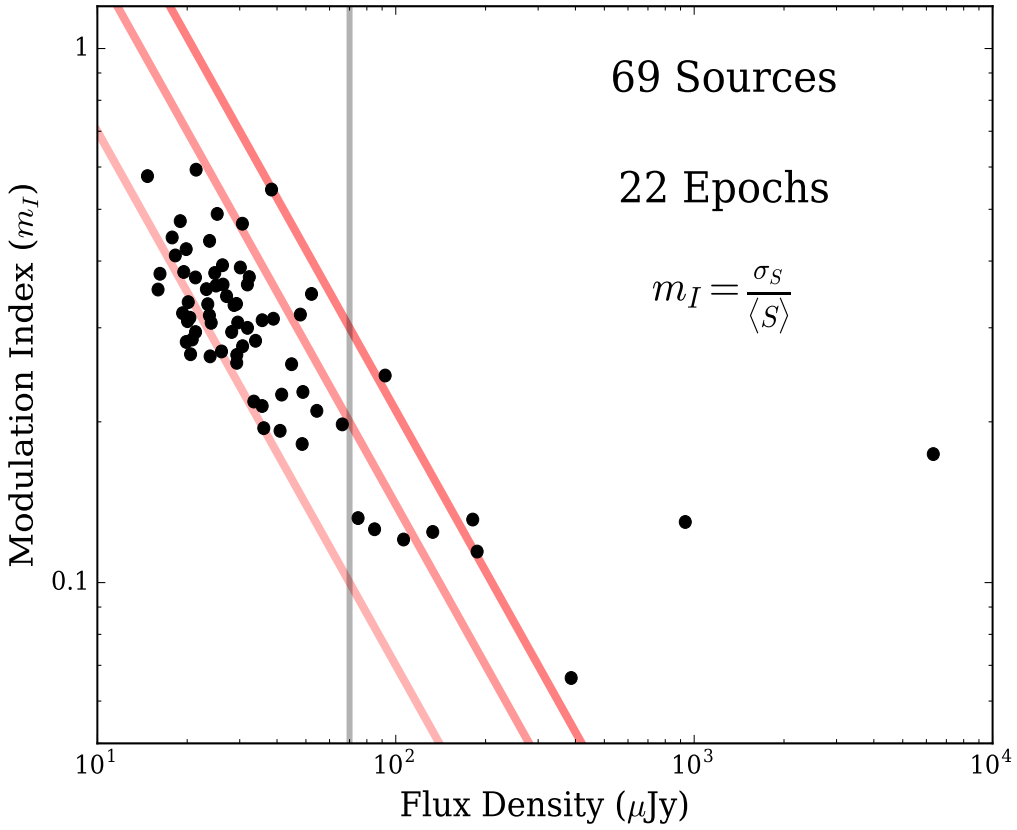
$$m_I = \sigma_S / \langle S \rangle$$



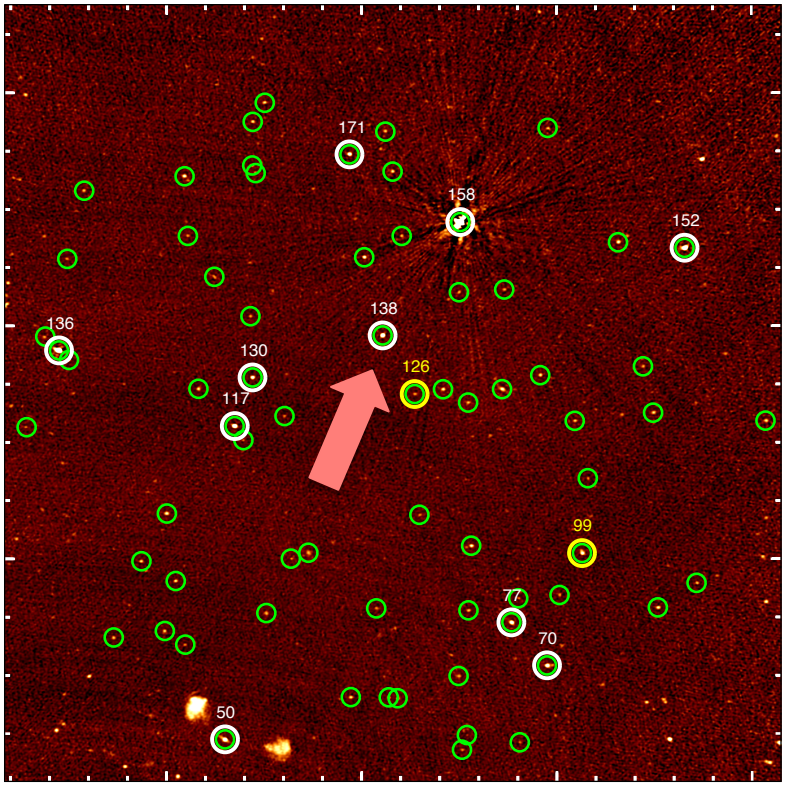

$m_I[50] = 0.12$
$m_I[70] = 0.12$
$m_I[77] = 0.24$
$m_I[117] = 0.13$
$m_I[130] = 0.13$
$m_I[136] = 0.13$
$m_I[138] = 0.11$
$m_I[152] = 0.07$
$m_I[158] = 0.17$
Flux Density (μJy)
MJD - 57500 (days)

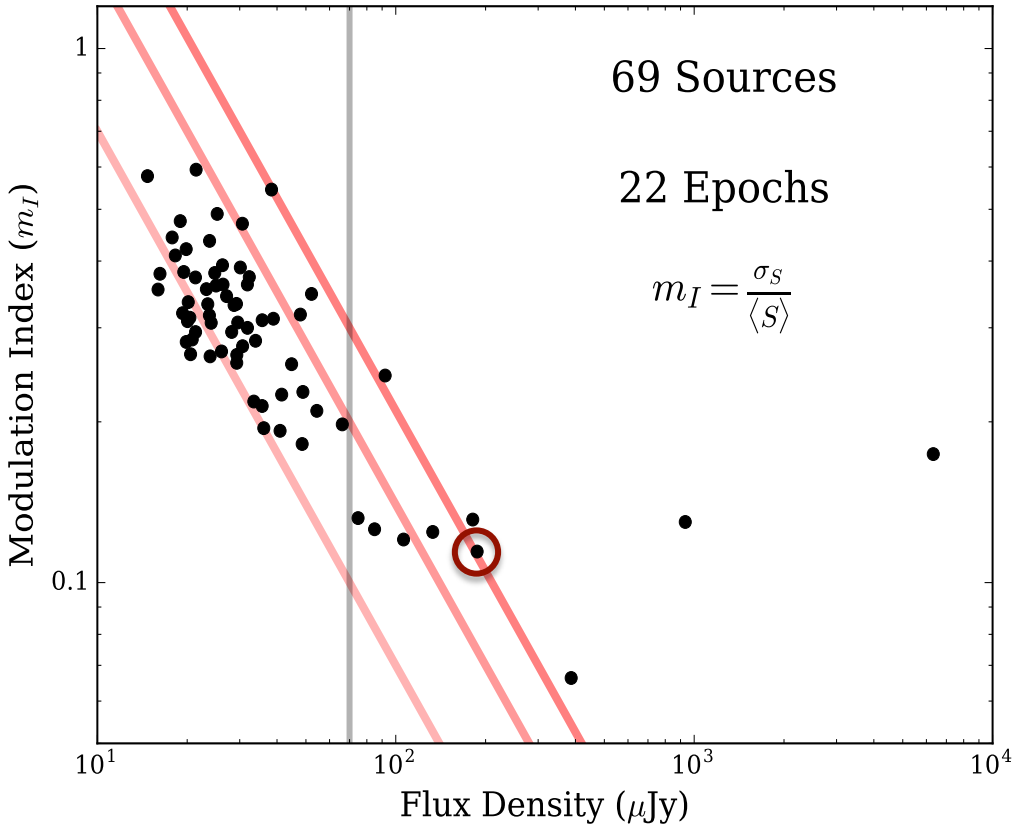
Field Variability





Field Variability

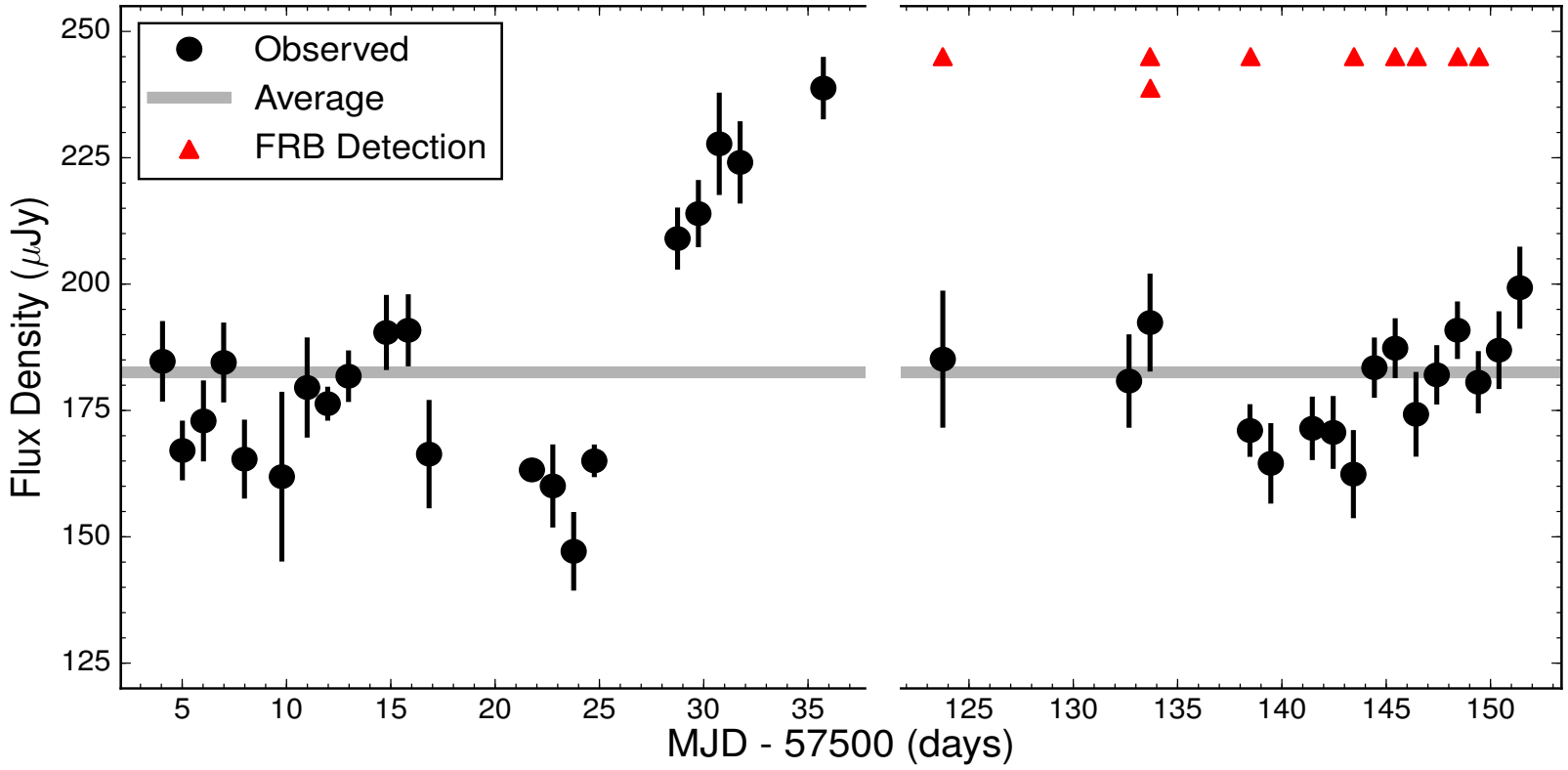




→ Host counterpart: variability may be necessary, but not sufficient.

What is the persistent radio source?

- Bursts appear to be sporadic, not a constant rate.

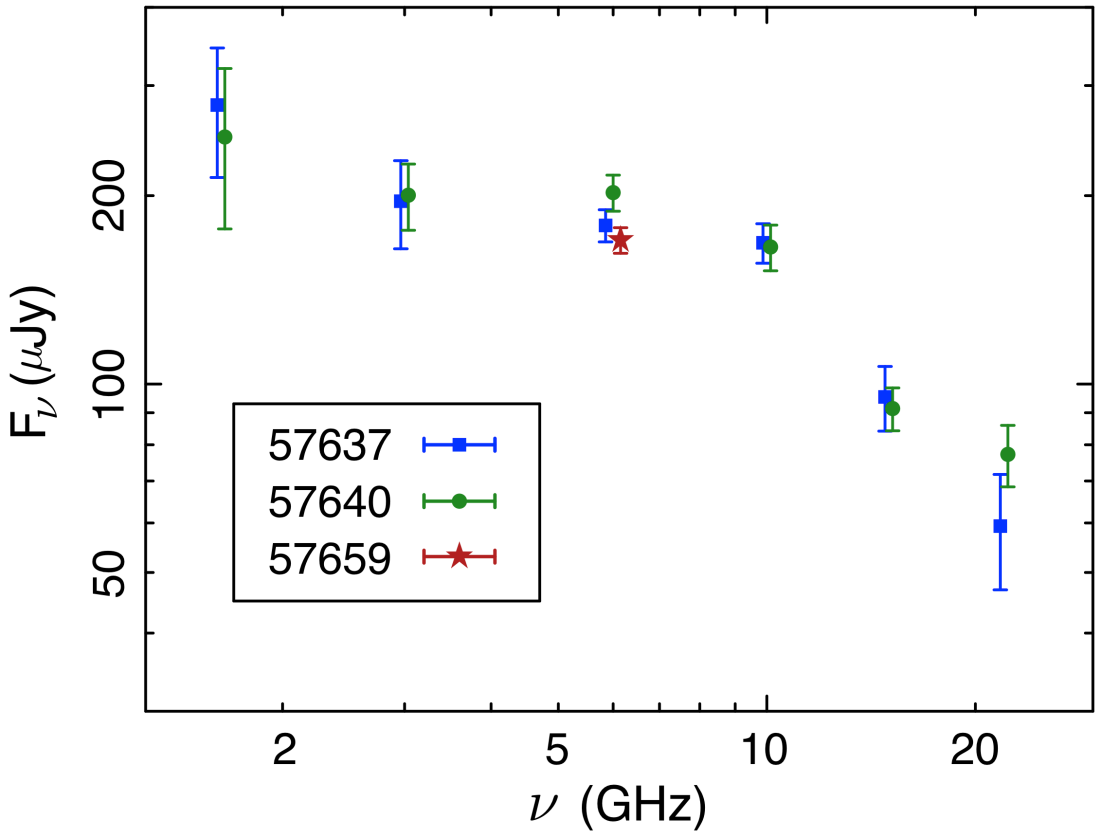


What is the persistent radio source?

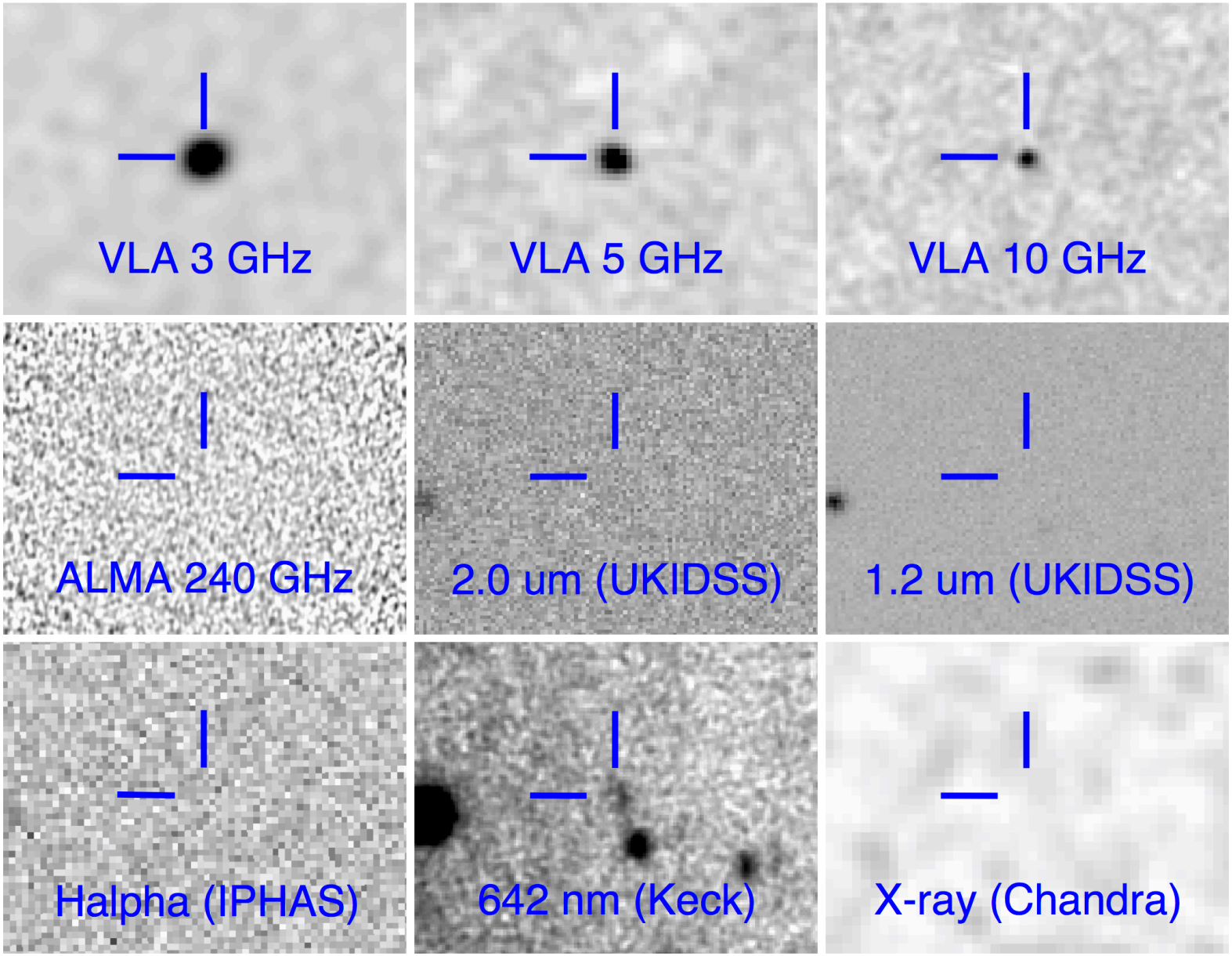
- Bursts appear to be sporadic, not a constant rate.
- Spectrum is non-thermal, but not a simple power law.

What is it?

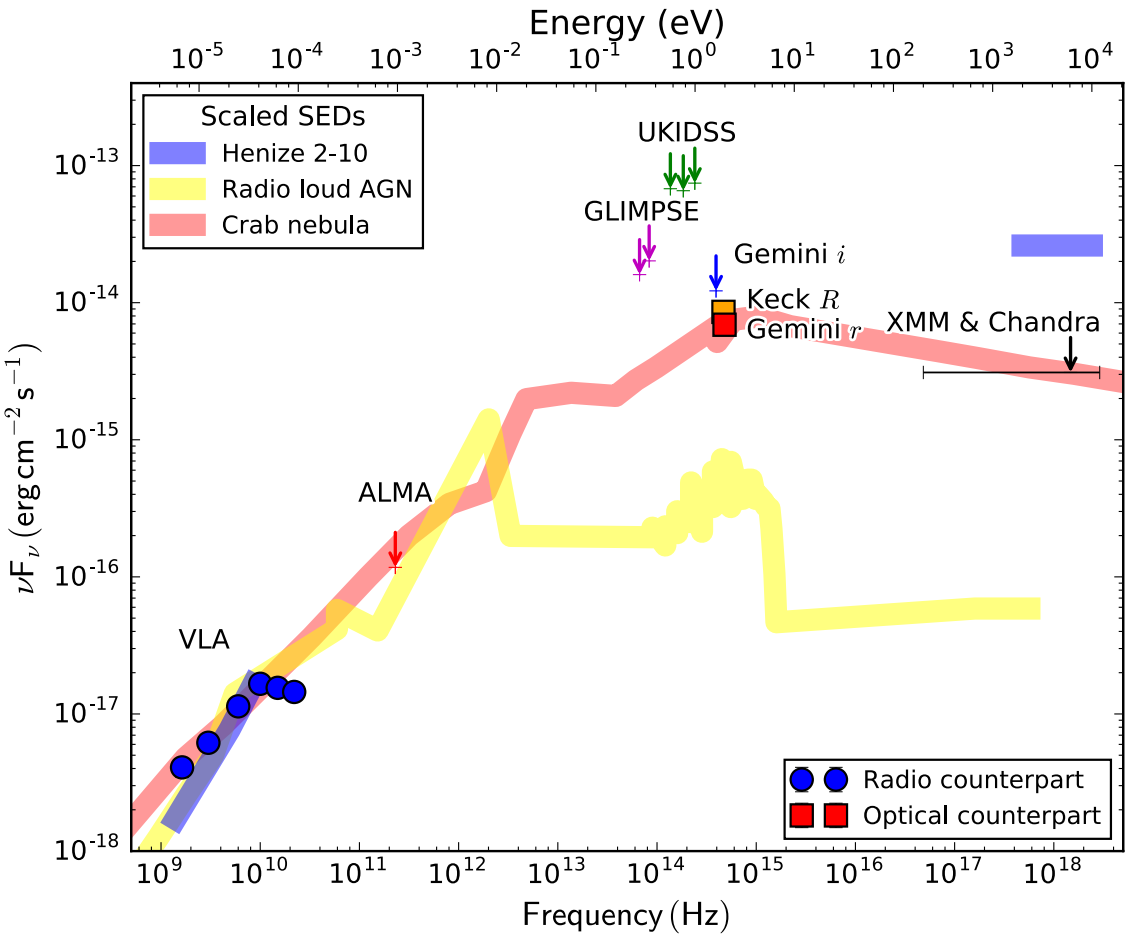
- AGN, maybe?
- Supernova remnant?
- Pulsar wind nebula?



Multi-wavelength counterparts



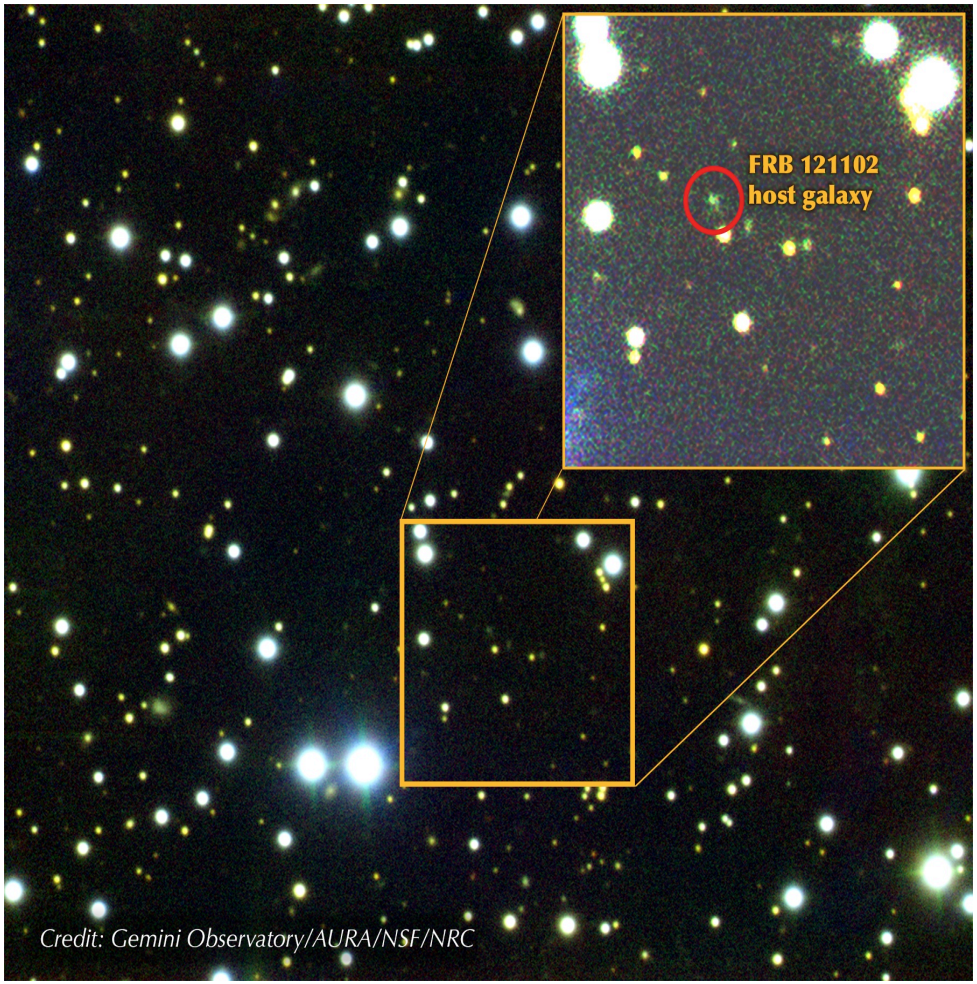
Broadband SED



What is it?

- AGN, maybe?
- Supernova remnant?
- Pulsar wind nebula?

No single known source appears to be a good match to the observed broad-band spectrum.



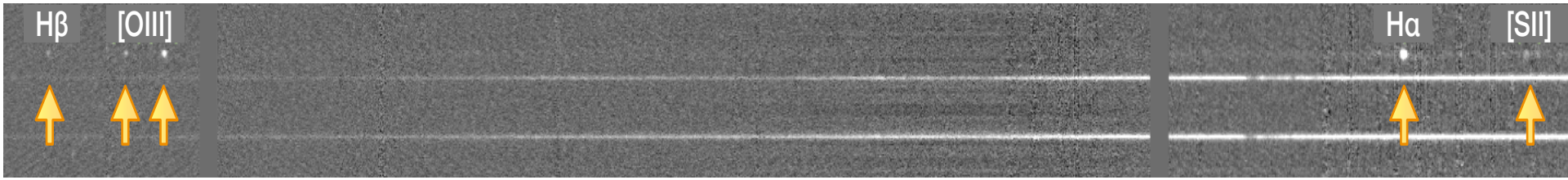
A Dwarf Galaxy Host

Deep imaging with Gemini:
25th magnitude counterpart.

→ Dwarf galaxy.

→ Emission dominated by spectral lines.

→ z = 0.193;
host is ~1 Gpc away.



The observational story so far:

- → FRB 121102 is a repeating source;
  can't be cataclysmic.
- → Localized FRB 121102, to ~15 milliarcsec precision.
- → Persistent, variable radio counterpart.
  But variability is not sufficient to identify the source.
- → Host is a dwarf galaxy at z~0.193,
  with high star formation and typical of LGRB or SLSNe hosts.

Not yet addressed:

→ Mechanism of the bursts.
Magnetar models? AGN models?

→ How typical is FRB 121102?
Do all FRBs repeat? Or are there multiple classes of FRBs?

→ How typical is the dwarf galaxy host and redshift?
More localizations are needed to answer that.

… Future Localizations?

Coming soon: CHIME

- → 80m x 100m, operating at 400-800 MHz.
- → Many FRB detections even with pessimistic assumptions.
- → Baseband data can allow post-detection beam-forming.
  0.3° x 0.2° beams; localization to ~10s of arcsec for bright bursts.

Coming soon: UTMOST-2D

→ UTMOST has already detected FRBs (Caleb et al. 2017).

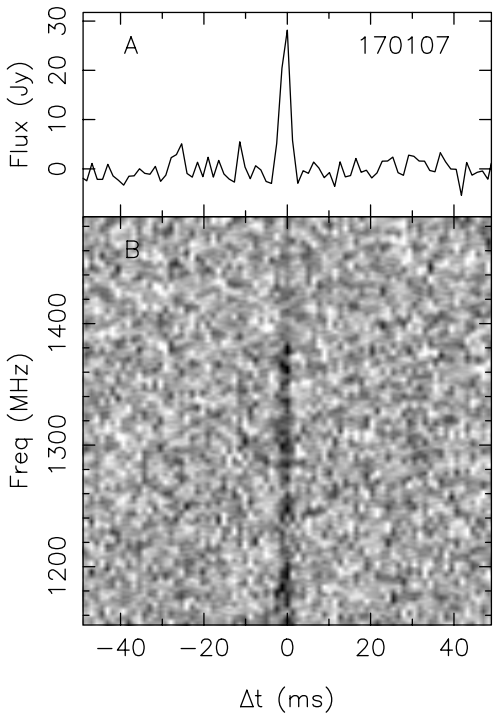
→ 843 MHz; ~9 sq deg FoV; 45” x 8.4° fan beams.

→ Outriggers to provide 60” x 45” beams,
Localization to ~3-5” for bright bursts.

Image courtesy Adam Deller / Swinburne

Coming soon: ASKAP-CRAFT

→ ASKAP-BETA has already detected FRBs in Fly's-Eye mode. (Bannister et al. 2017)



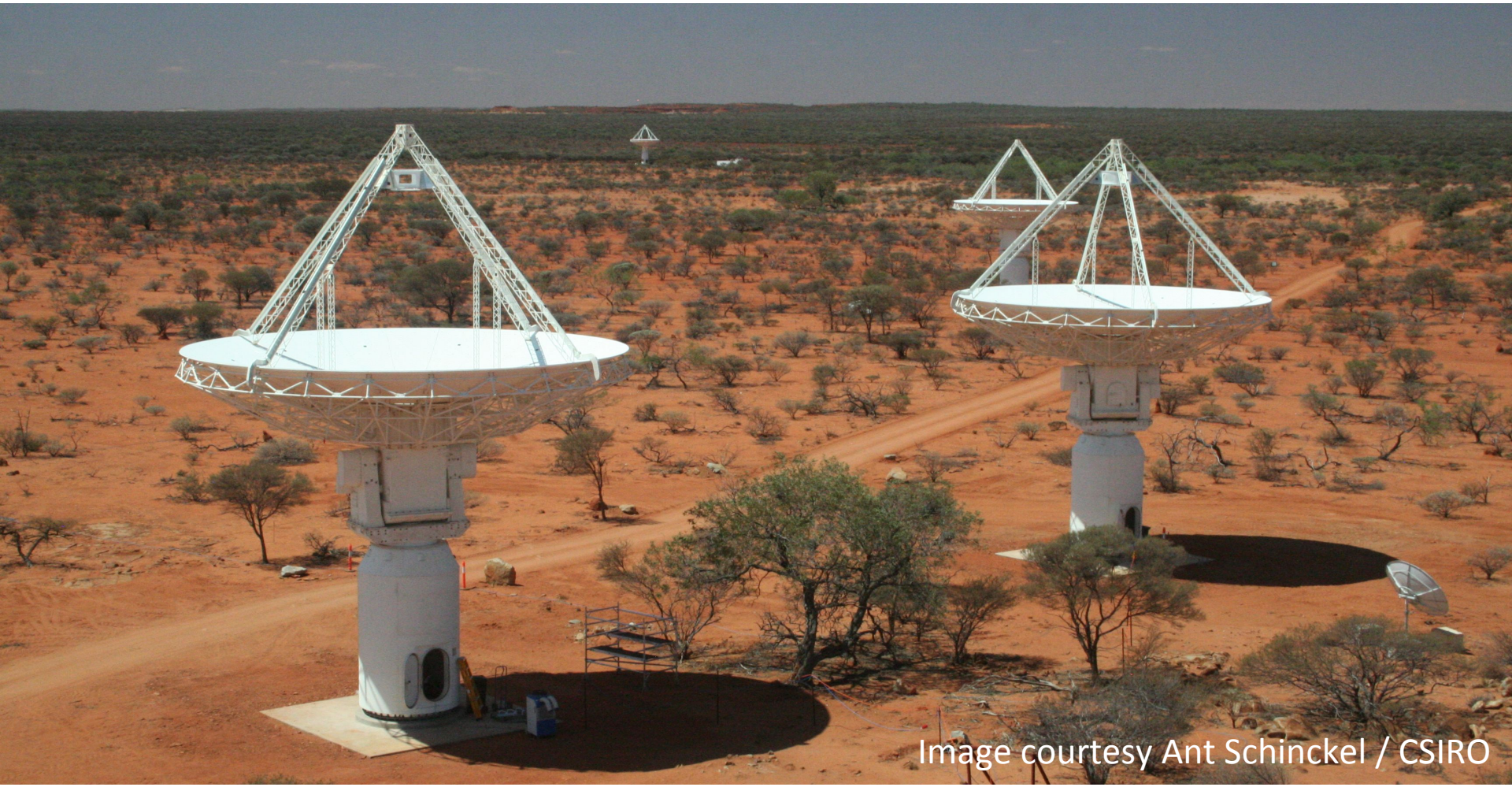
FRB 170107
DM: 609.5 pc cm^{-3}

Images courtesy Keith Bannister/ CSIRO

Coming soon: ASKAP-CRAFT

→ ASKAP-BETA has already detected FRBs in Fly's-Eye mode.

→ Full array needs to be commissioned for fast-dump interferometry.

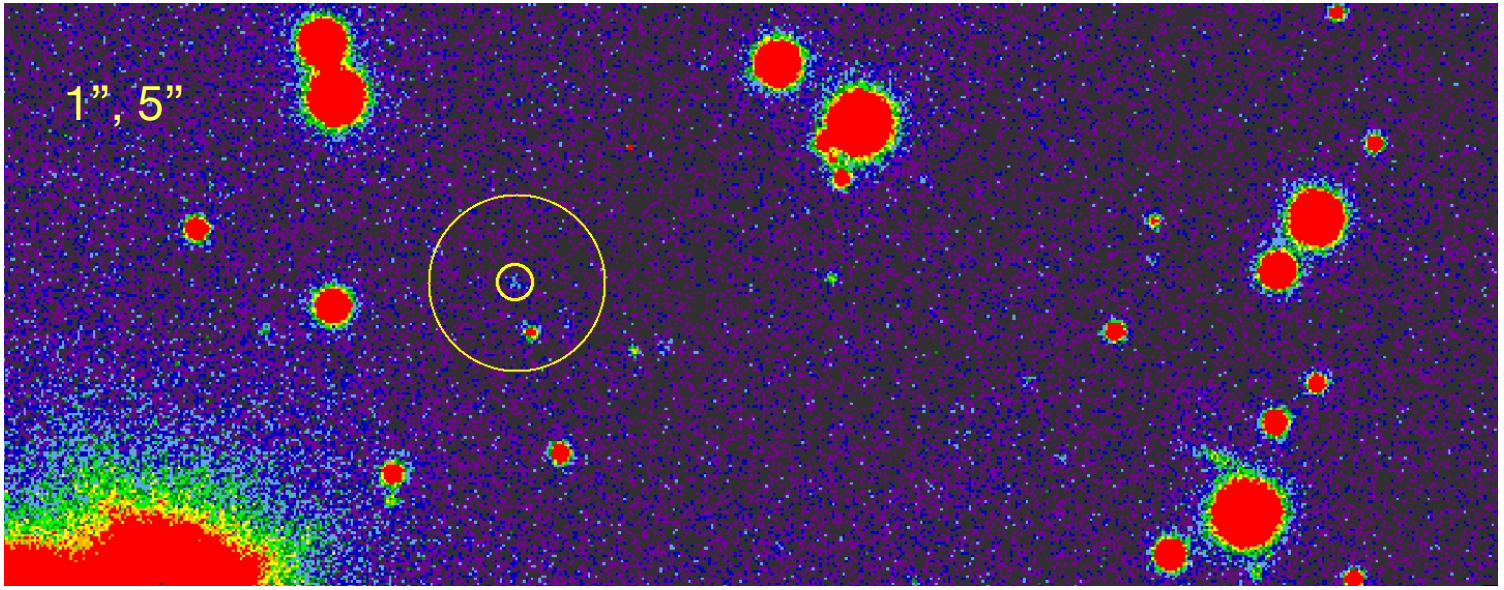


Already here: VLA

- → Mature instrument, exceptional flexibility.
- → New fast dump capability instrumental in FRB 121102 localization.
- → Heading towards full realtime commensal capability:
  See realfast.io and talk by Casey Law.

Future Localization Efforts (an incomplete summary)

Telescope	Area (sq m)	Frequency (MHz)	FoV (sq deg)	Beam (arcsec)	When?
CHIME	8,000	400—800	200	972 x 756	2018?
UTMOST-2D	18,000	790—865	6	60 x 45	Soon.
ASKAP	4,000	1200—1500	30	6 x 6	?
VLA	13,000	2000—4000	0.05	0.6 x 0.6	Now.



What's next?

- Mechanism of the bursts.
  → What models can be ruled out by observations?

- How typical is FRB 121102?
  Do all FRBs repeat? Or are there multiple classes of FRBs?
  → Find another repeating FRB.
  → Localize another host galaxy and find its redshift.

- Are FRBs useful for cosmology, or as probes of the IGM?
  → To be determined.

- Contributions from VLA, GBT, Arecibo;
  New telescopes coming on line: CHIME, UTMOST.