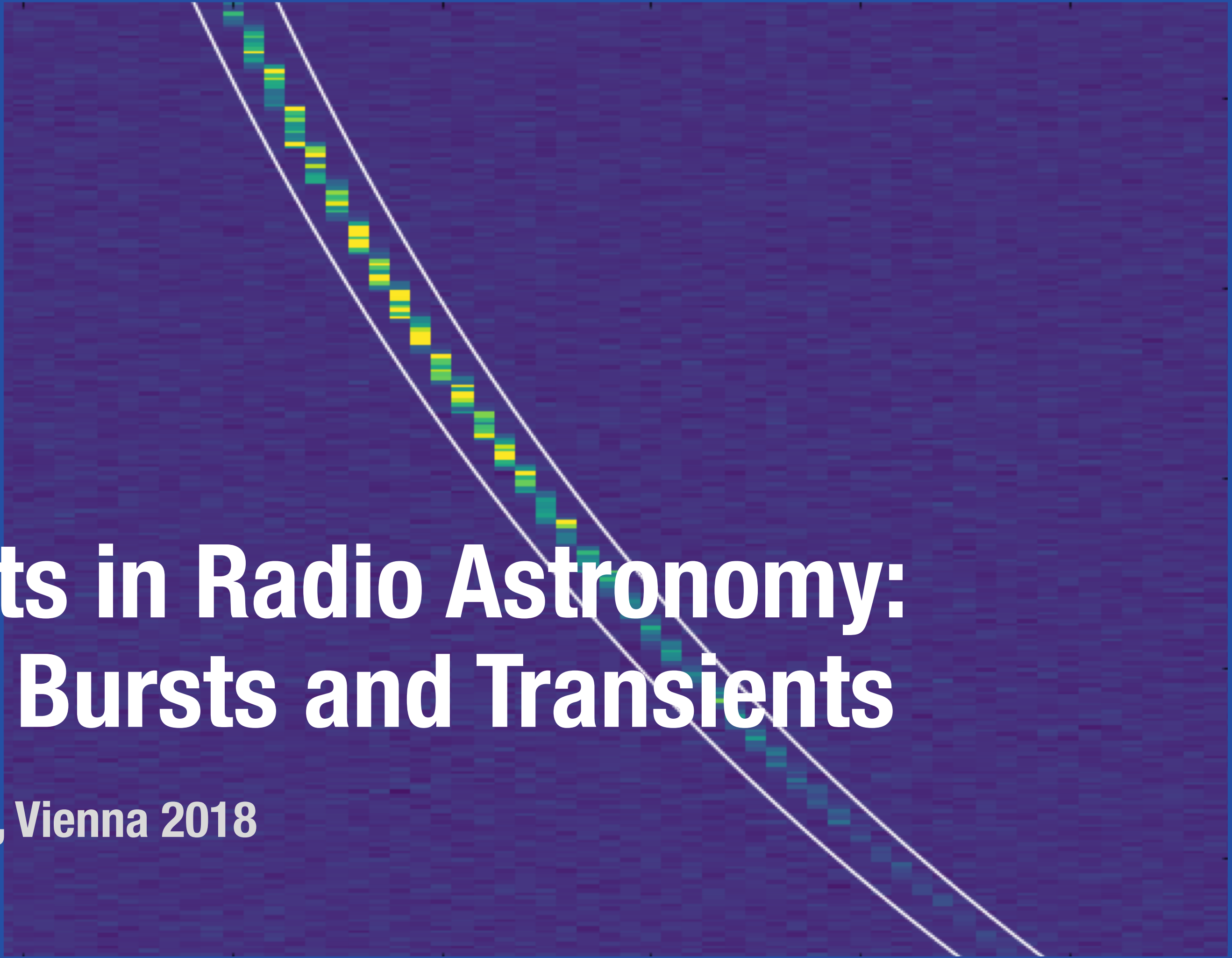
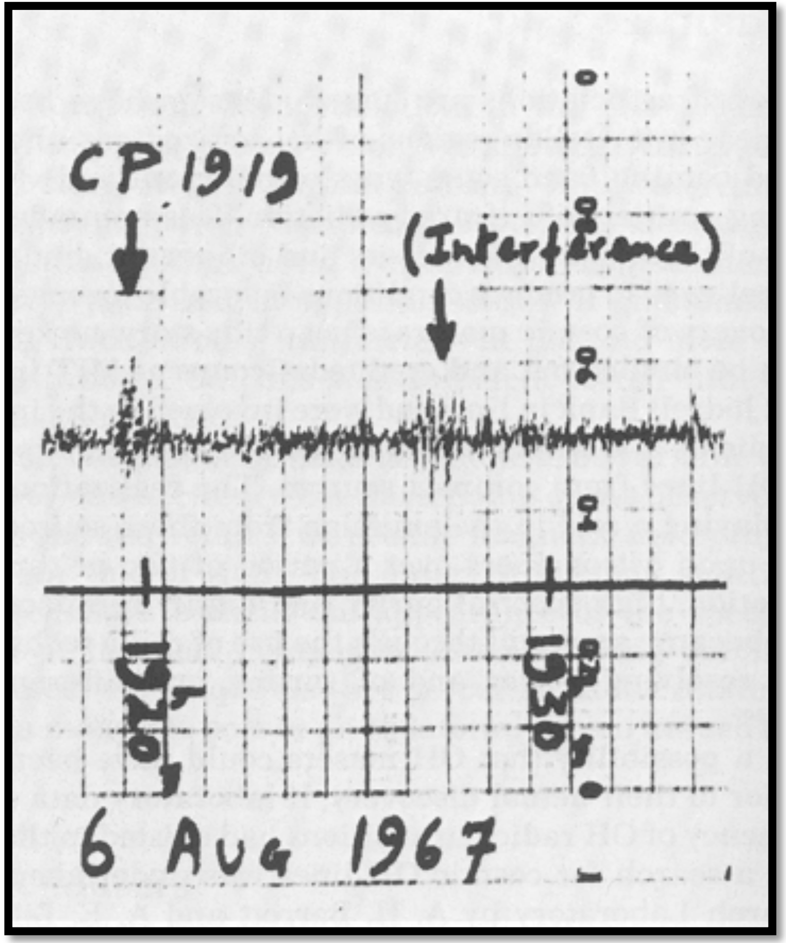


Shami Chatterjee
Cornell University

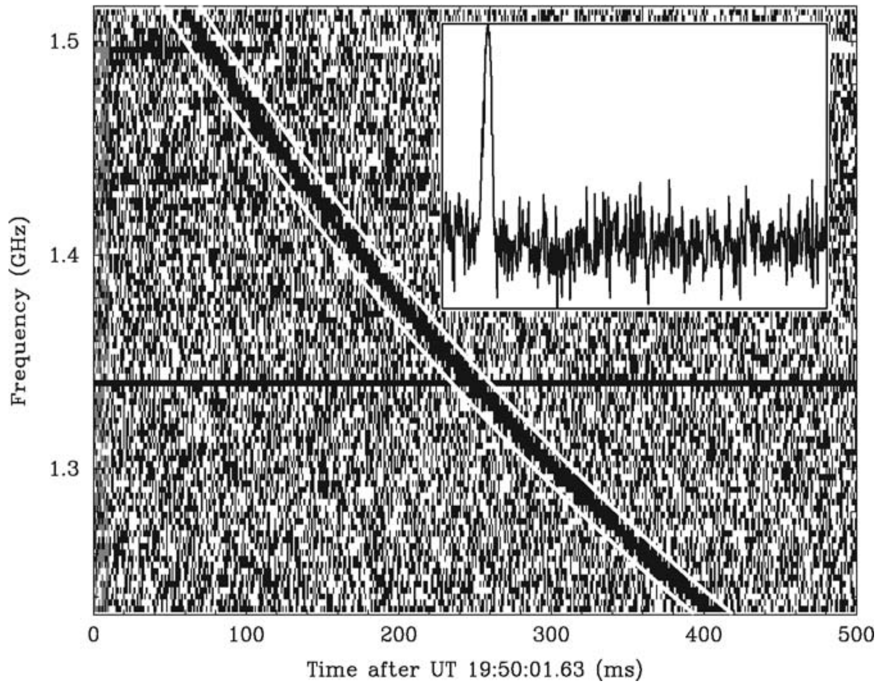
New Results in Radio Astronomy: Fast Radio Bursts and Transients

IAU General Assembly, Vienna 2018



CP 1919
(Interference)
1920
1930
6 AUG 1967

Fast Radio Bursts



- Bright, millisecond flashes of radio waves.
- Swept in frequency: pulse dispersion ~ f^{-2}.
- Dispersion measure indicates extragalactic origin.

Lorimer et al. 2007, Science,
A Bright Millisecond Burst of Extragalactic Origin

The known FRB population

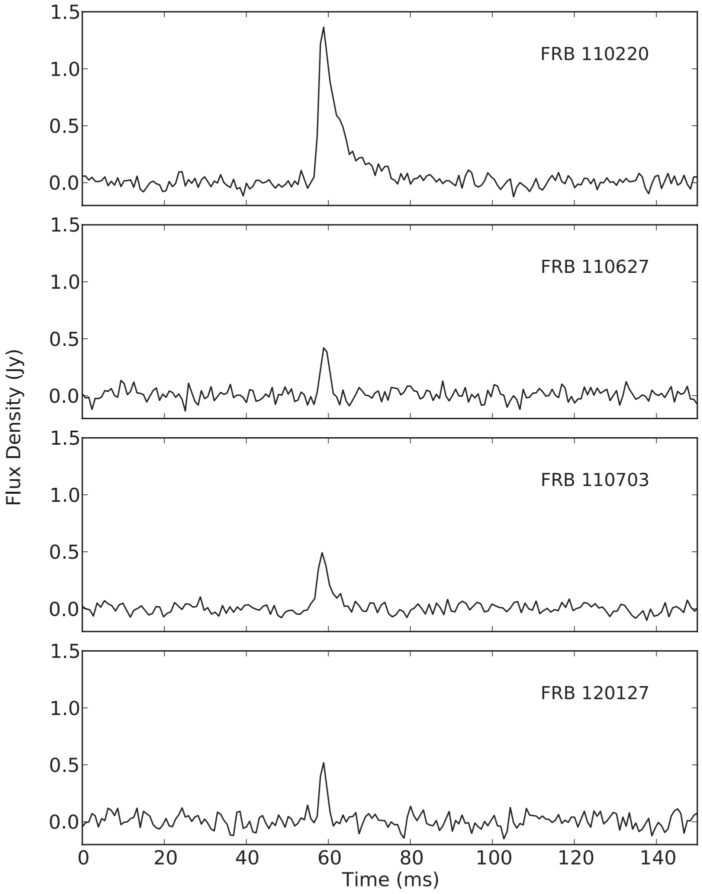
- ~ 30 sources known so far.

  Detected at Parkes, Arecibo, Green Bank, UTMOST, ASKAP, CHIME.

- Inferred all-sky rate ~ 5000 / sky / day.

  (Depends on detection threshold.)

Thornton et al. (2013) →

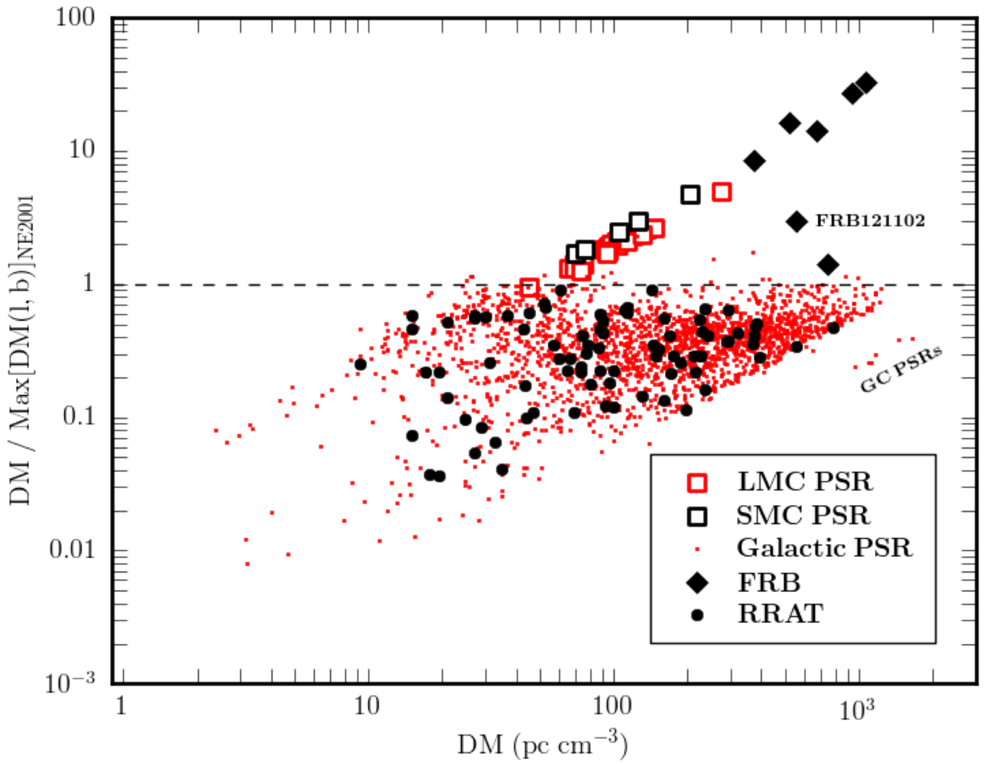


The known FRB population

- ~ 30 sources known so far.
- Inferred all-sky rate
  ~ 5000 / sky / day.
- Dispersion measures:
  DM = 175 … 2600 pc cm^{-3}.
- DM / $DM_{\text{Milky Way}}$ = 1.2 … 33.

➔ Extragalactic;
Milky Way + IGM + Host DM.

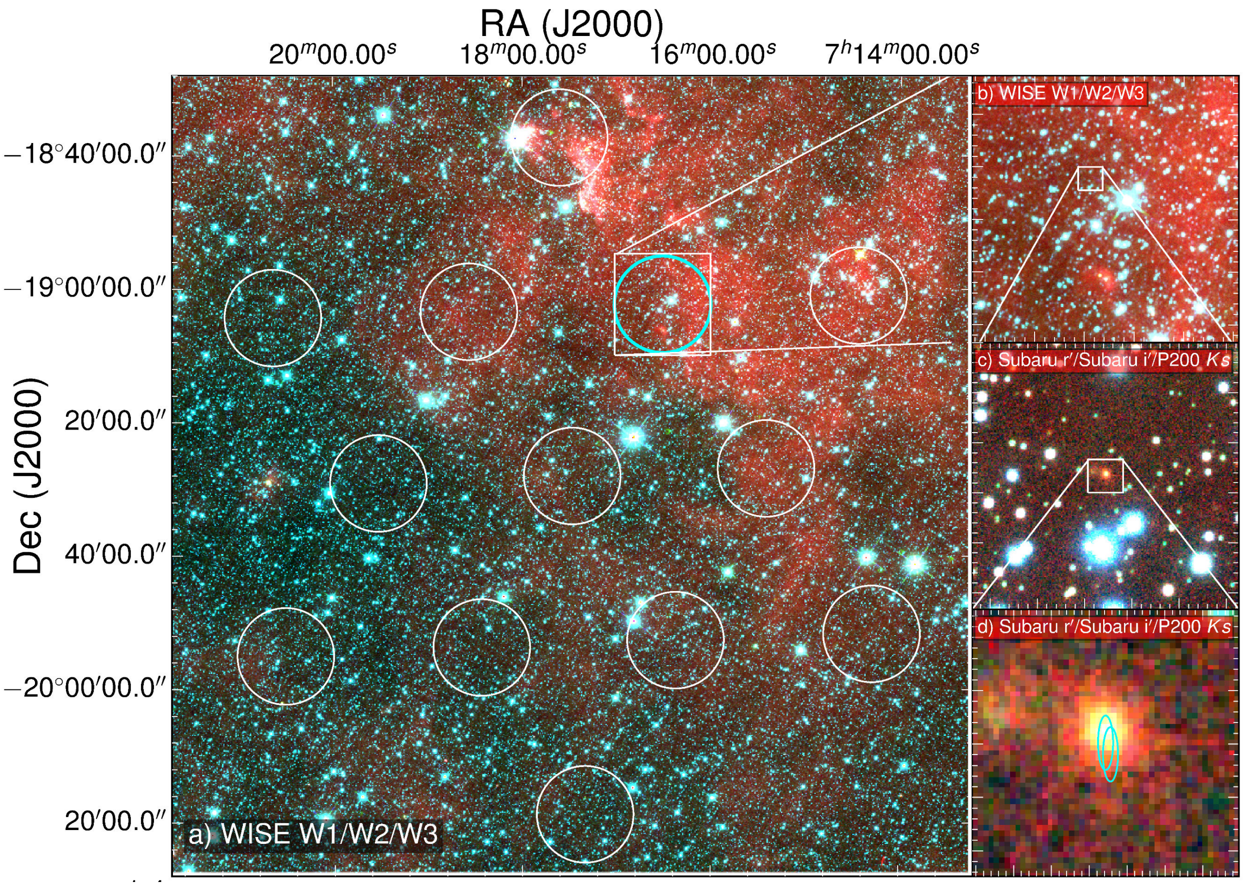
➔ Very high energy densities!



Need host identification to make progress

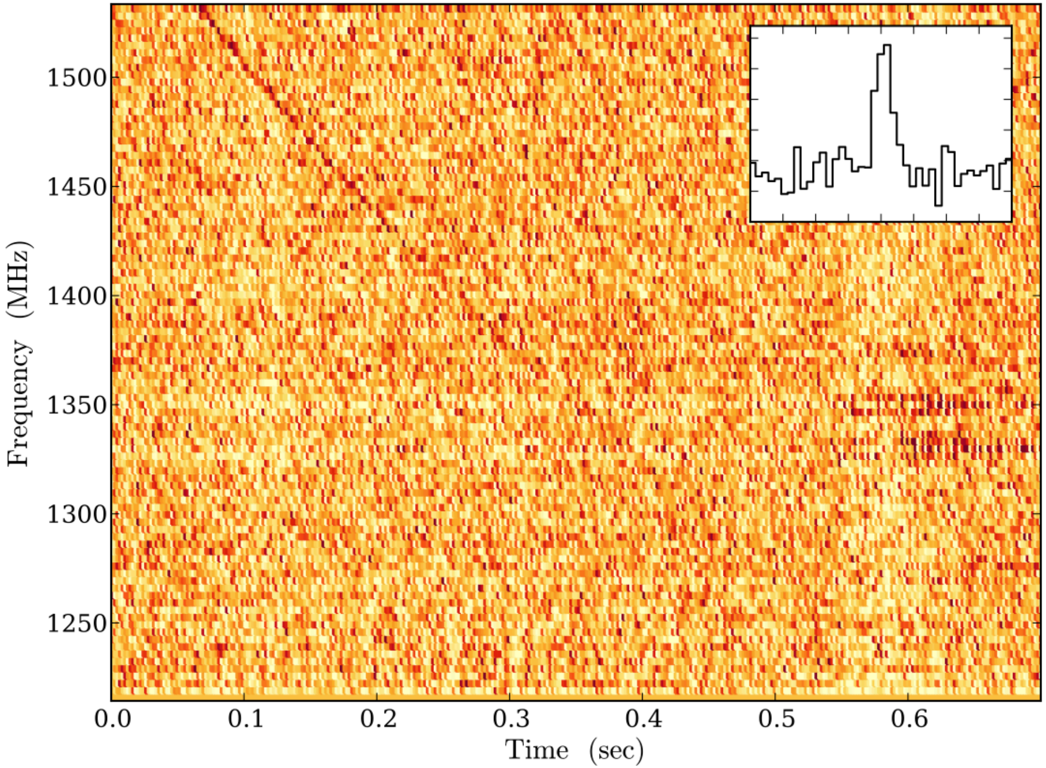
- Need ~1" resolution for unique host IDs.
- Single dish radio telescope beams are not fine enough.

Keane et al. (2016) →



FRB 121102: A very special case

- Discovered at Arecibo.
- l,b = 175°, −0.2°.
- DM = 557 pc cm^{-3}.
  (DM_{NE2001} = 188 pc cm^{-3}.)
- Width = 3.0±0.5 ms.
- No re-detection in multiple deep follow-ups…



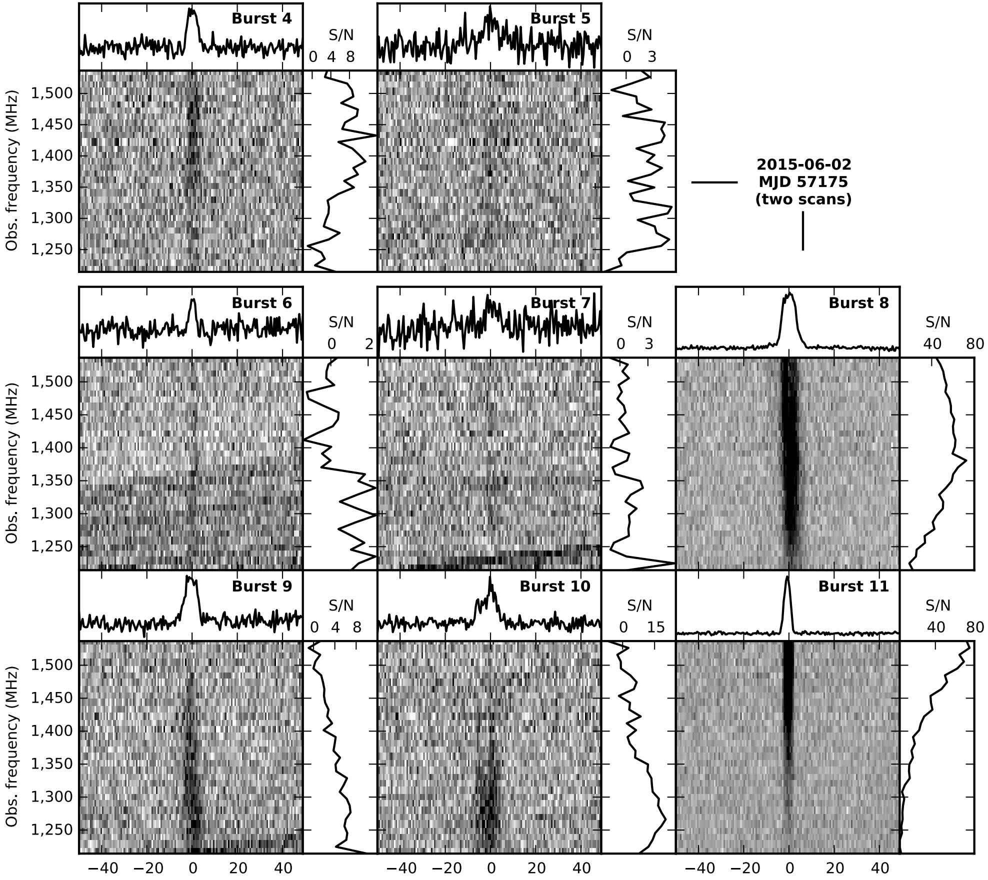
Spitler et al. 2014,
"Fast Radio Burst discovered in the Arecibo Pulsar ALFA Survey"

FRB 121102 is a repeating source!

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

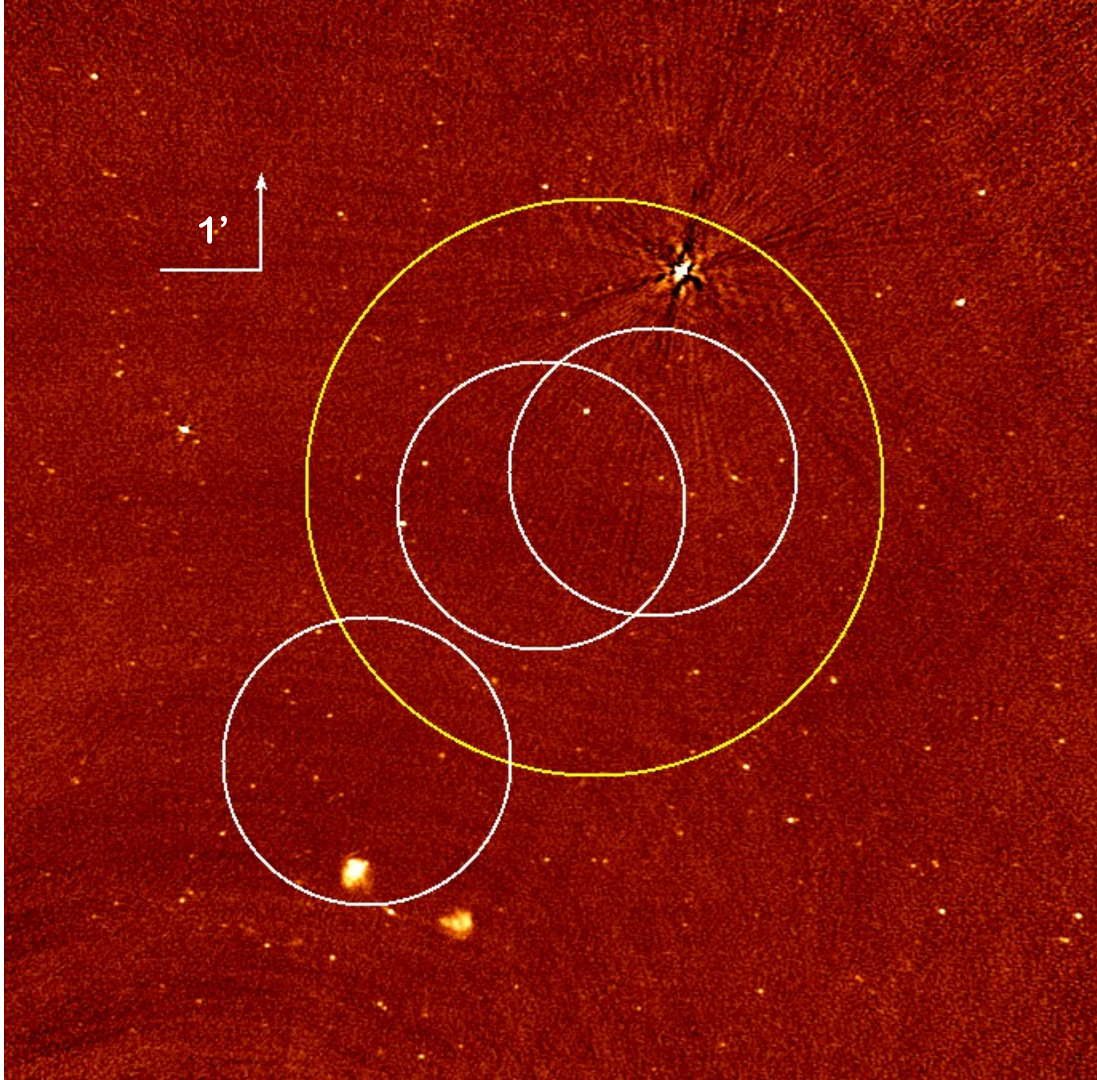
→ A better-than-random location to go fishing.

Spitler et al. 2016, Nature, "A repeating fast radio burst"



So where is it?

Arecibo detection beams (and sidelobes!) cover dozens of sources.



VLA localization

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

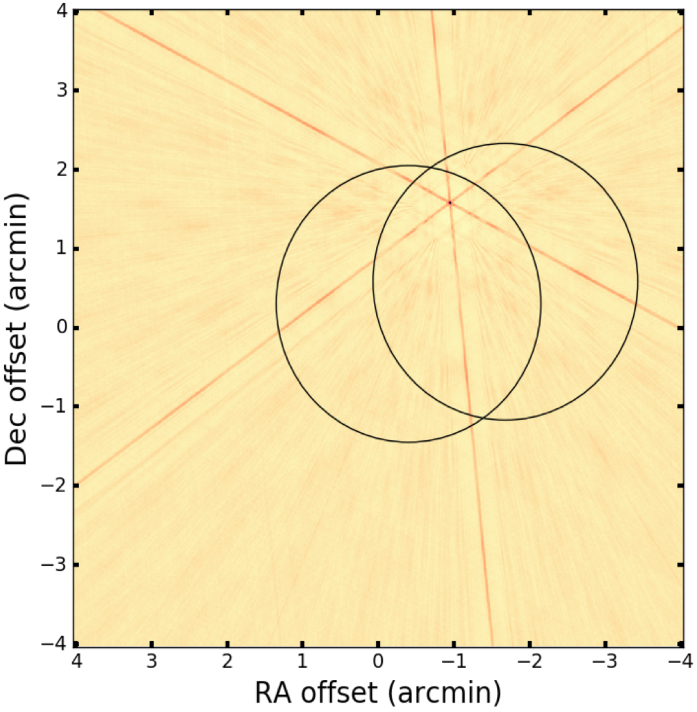
Millisecond Imaging:

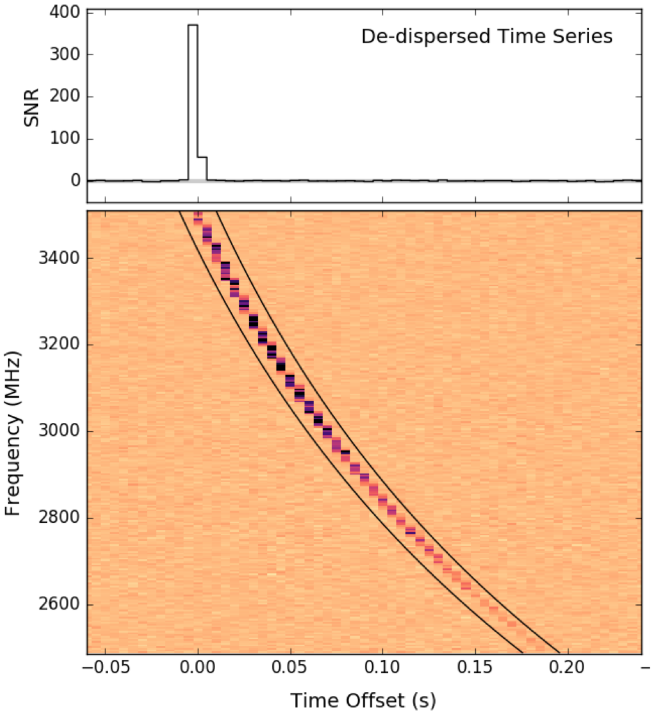
- De-disperse visibilities, make images for each sample time.
- Search for transient source in image domain.

Beam-formed Single-pulse Search:

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

VLA localization: success!





Localization from millisecond imaging (Casey Law);

Pulse sweep from beam-forming (Robert Wharton).

Chatterjee et al. 2017, Nature,
"A direct localization of a fast radio burst and its host"


nature
THE INTERNATIONAL WEEKLY JOURNAL OF SCIENCE
MYSTERY OBJECT
Precise localization of fast radio burst reveals distant host and enigmatic persistent source
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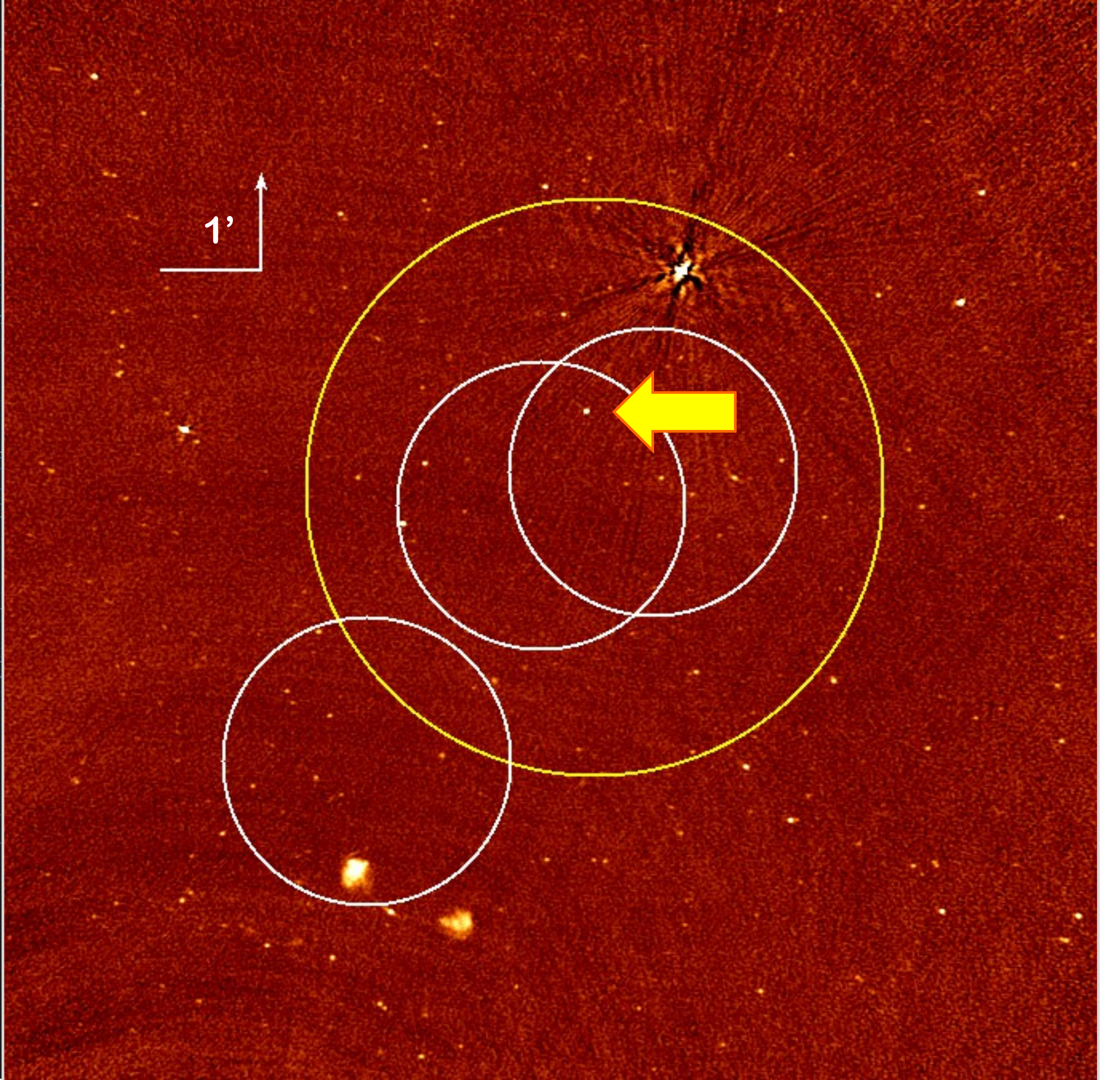
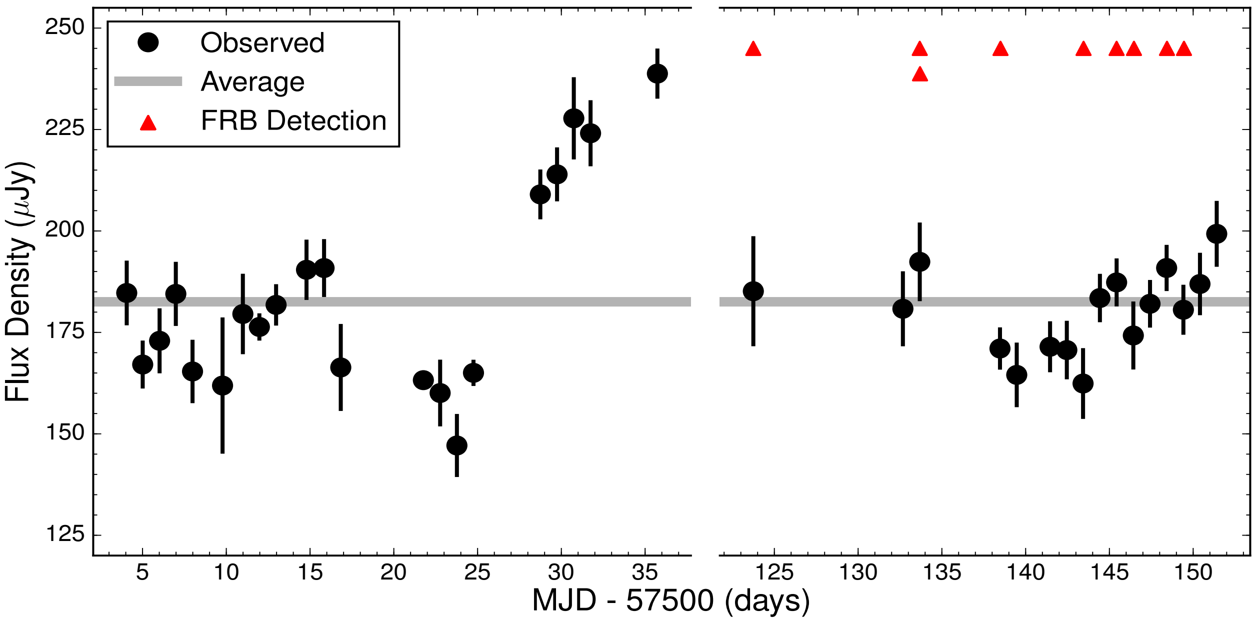
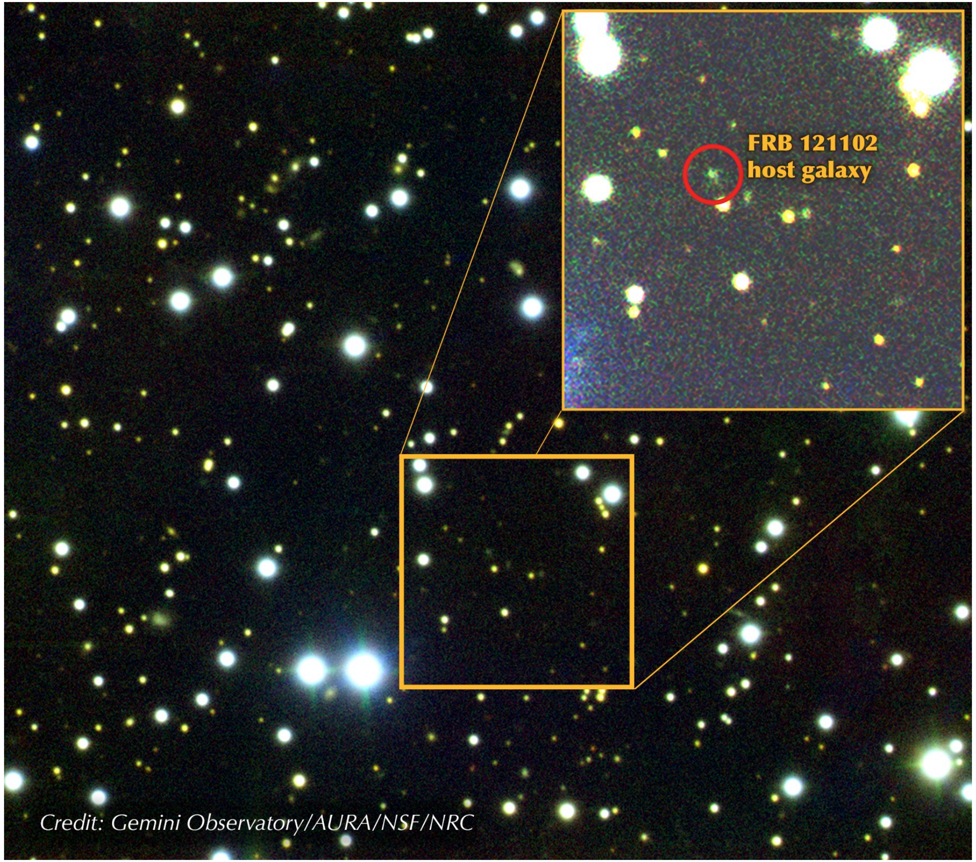

1’

Radio counterpart: Persistent radio source



- Bursts are sporadic.
- Persistent, variable, 180 μJy radio counterpart.
- Non-thermal.
- AGN? PWN? SNR?

Chatterjee et al. (2017)



Host galaxy ID

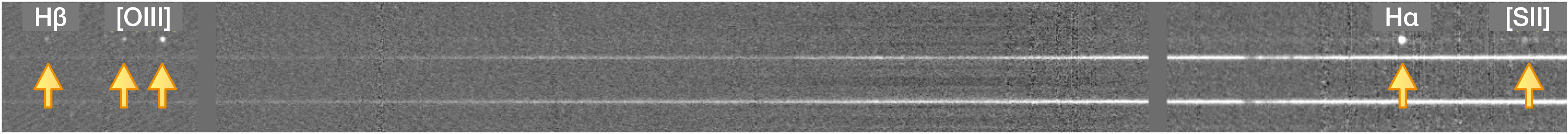
Deep imaging with Gemini:
25th magnitude counterpart.

→ Dwarf galaxy.

→ Emission dominated by spectral lines.

→ z = 0.193;
host is ~1 Gpc away.

← Tendulkar et al. 2017, "The host galaxy and redshift of the repeating FRB 121102"



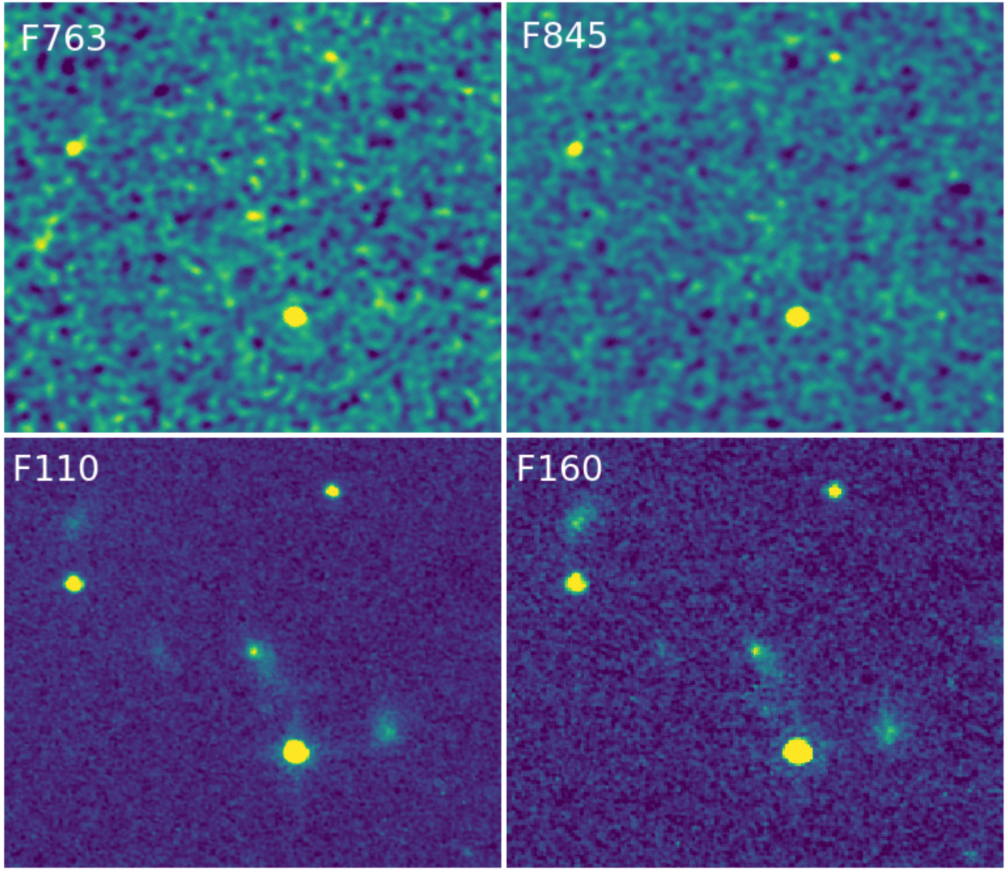
Host galaxy morphology and environment

- HST observations:
  Dwarf galaxy emission is dominated by single bright knot – star formation.

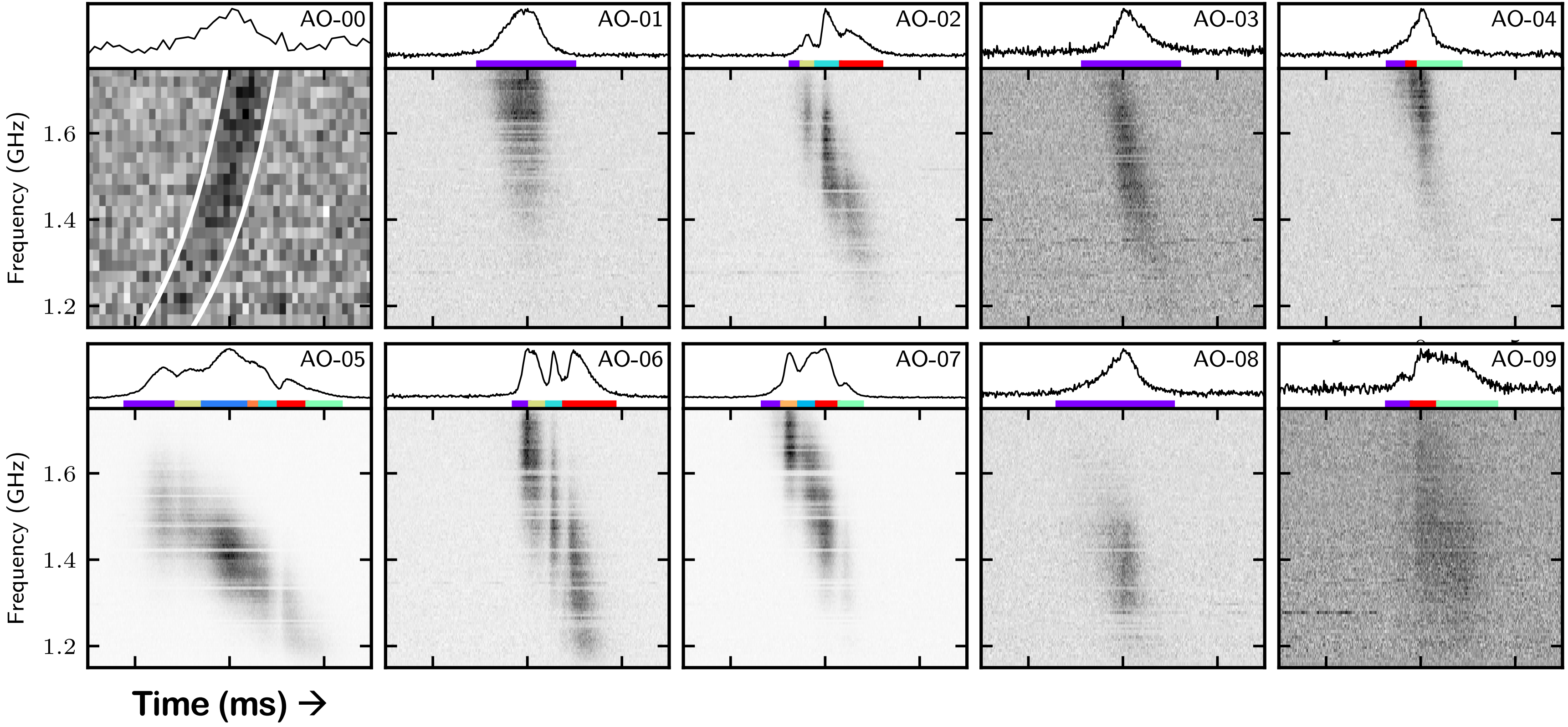
- Coincident with FRB and persistent counterpart.

➔ Connection to massive stars, magnetars, LGRBs, SLSNe?

Bassa et al. (2017) →

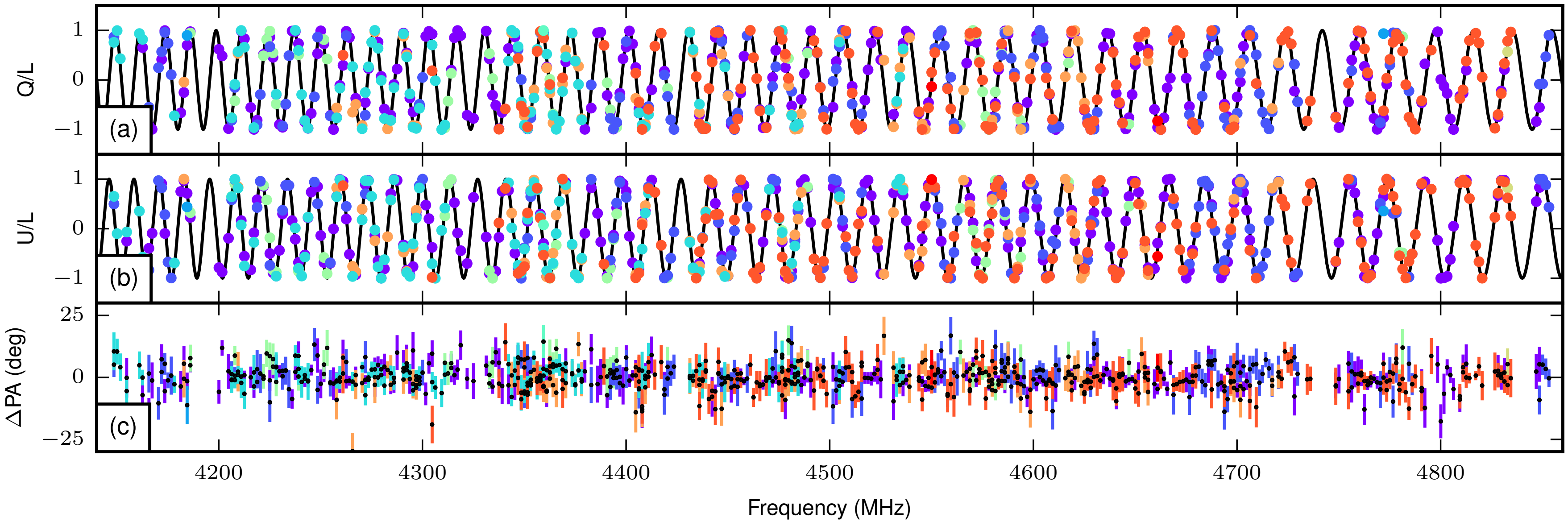


Frequency structure in bursts: Plasma lensing?



FRB 121102: Detection of polarization

Six bright bursts at Arecibo, 4-5 GHz: 100% linear polarization.



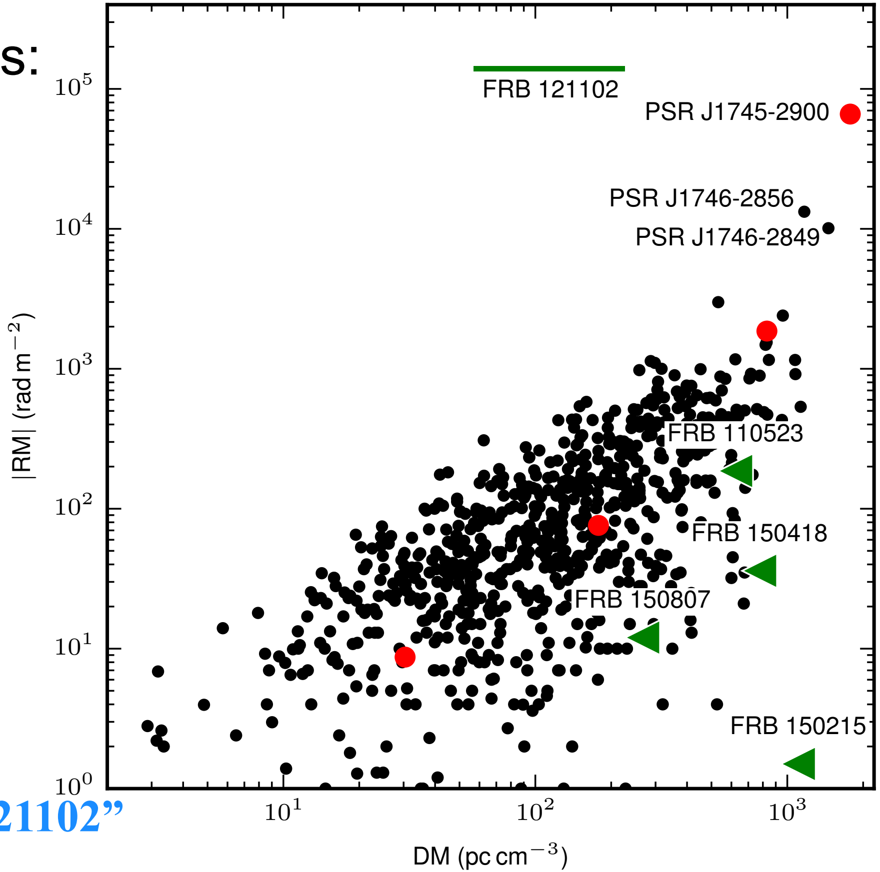
Michilli et al. 2018, Nature,

“An extreme magneto-ionic environment associated with fast radio burst source FRB 121102”

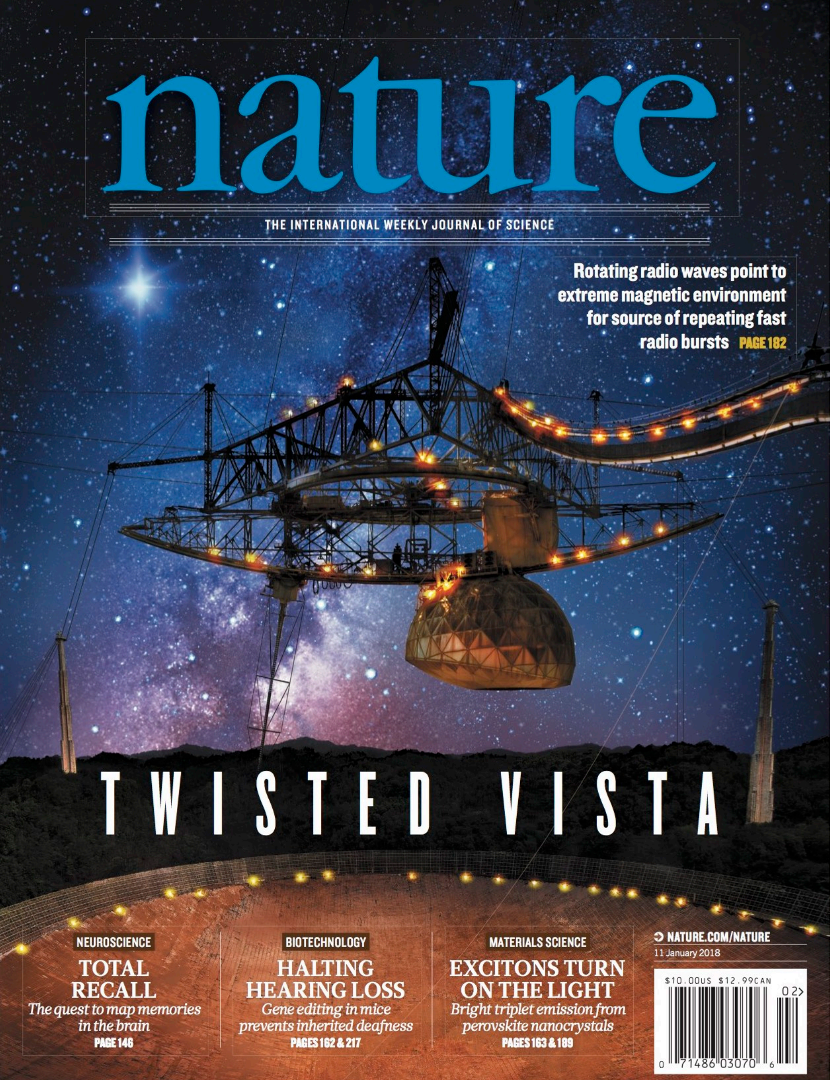
An extreme magneto-ionic environment

High frequency FRB121102 detections:

- 100% linear polarization.
- RM_{src}
  $= RM_{obs}(1+z)^2$
  $= 1.46 \times 10^5$ rad m^{-2}.



Michilli et al. 2018, Nature,
"An extreme magneto-ionic environment associated with fast radio burst source FRB 121102"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THE INTERNATIONAL WEEKLY JOURNAL OF SCIENCE
Rotating radio waves point to extreme magnetic environment for source of repeating fast radio bursts PAGE 182
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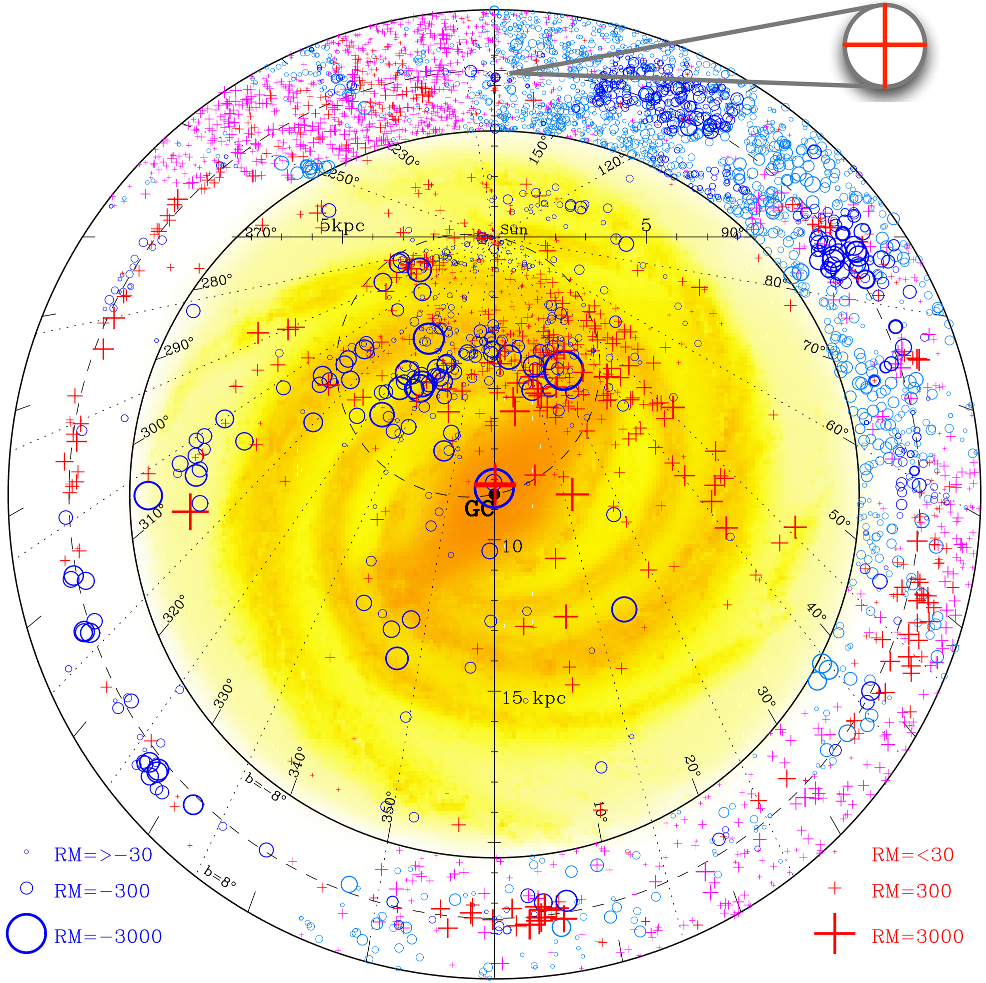
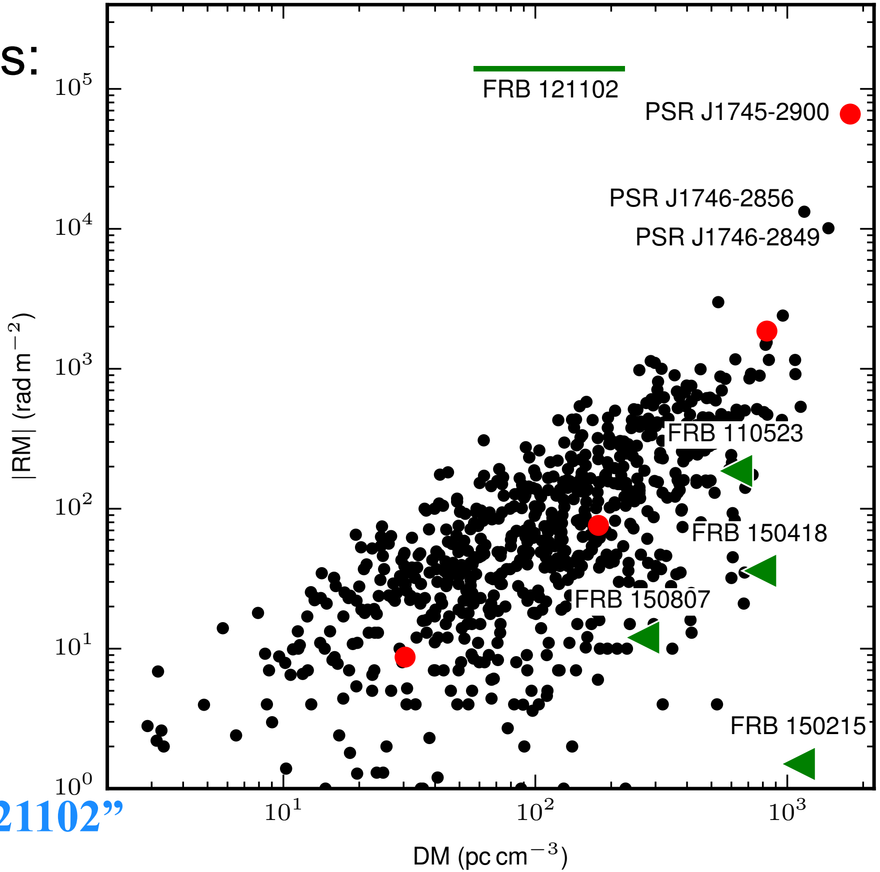

Sun
5kpc
5
10
15 kpc
GC
b=-8°
b=8°
RM=>-30
RM=-300
RM=-3000
RM=<30
RM=300
RM=3000

An extreme magneto-ionic environment

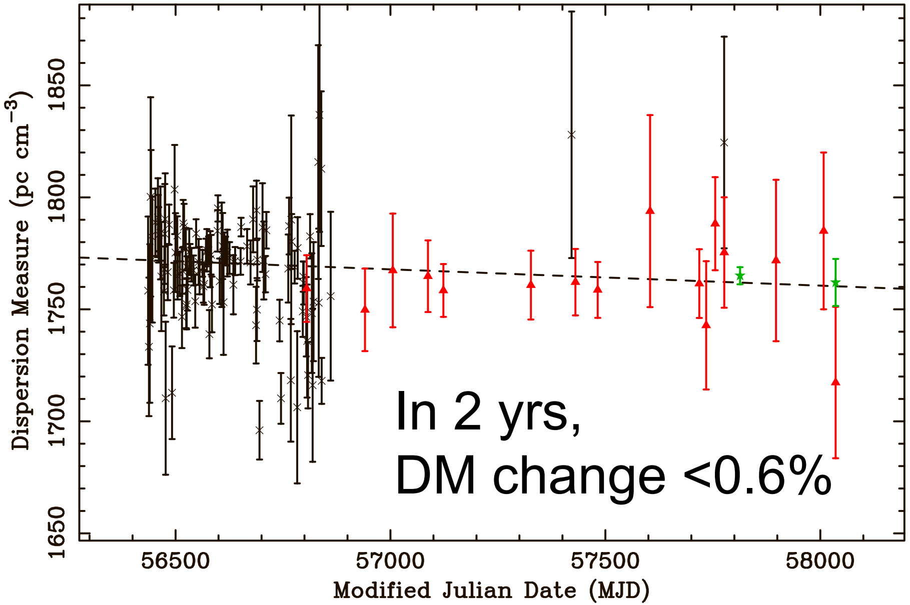
High frequency FRB121102 detections:
- 100% linear polarization.
- RM_{src}
  $= RM_{obs}(1+z)^2$
  $= 1.46 \times 10^5$ rad m^{-2}.

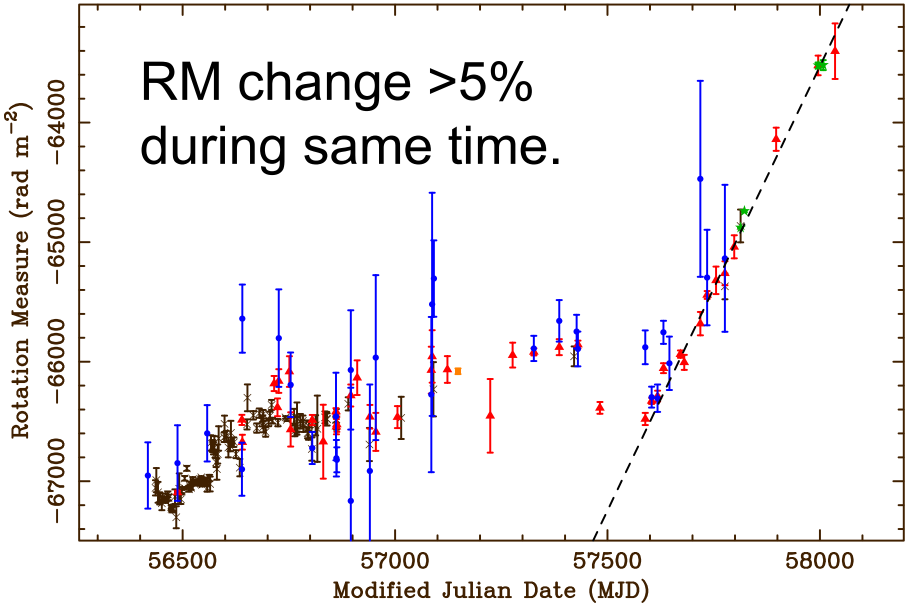
→ Only comparable environment is our Galactic center.

Michilli et al. 2018, Nature,
"An extreme magneto-ionic environment associated with fast radio burst source FRB 121102"



The GC magnetar: DM and RM





➔ Significant change in projected B field.

Desvignes et al., 2018

Large magnetic field variations towards the GC magnetar

So what produces an FRB?

- Repeating source.

➔ At least <u>this</u> FRB is not powered by an explosive mechanism.

- FRB (and persistent radio source) coincides with star-forming region.
- Dwarf galaxy looks like an EELG.

➔ Connection to massive stars, magnetars, LGRBs, SLSNe?

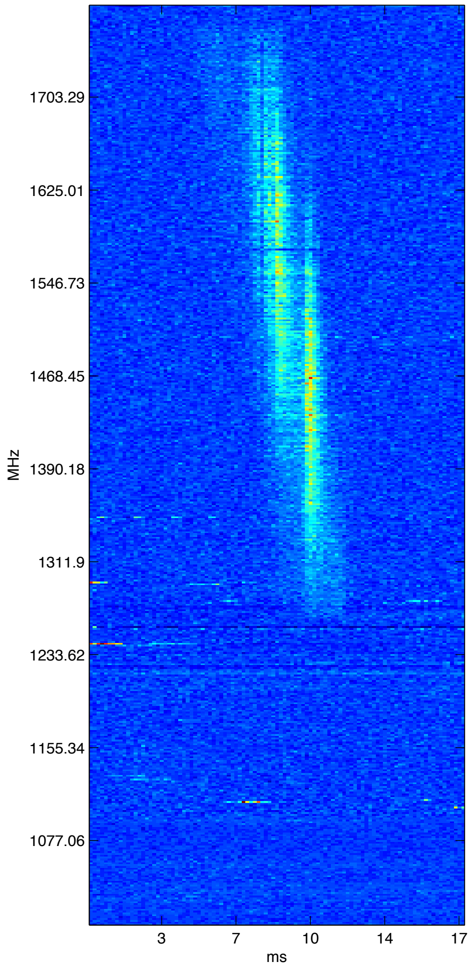
- Dwarf galaxy host suggests N_{galaxy} is relevant, not M_{stars}.
- High (and changing) RM, without proportional evolution in DM, resembles the environment of Sgr A*.

➔ Connection to a massive black hole?

FRBs: Some things we don't know

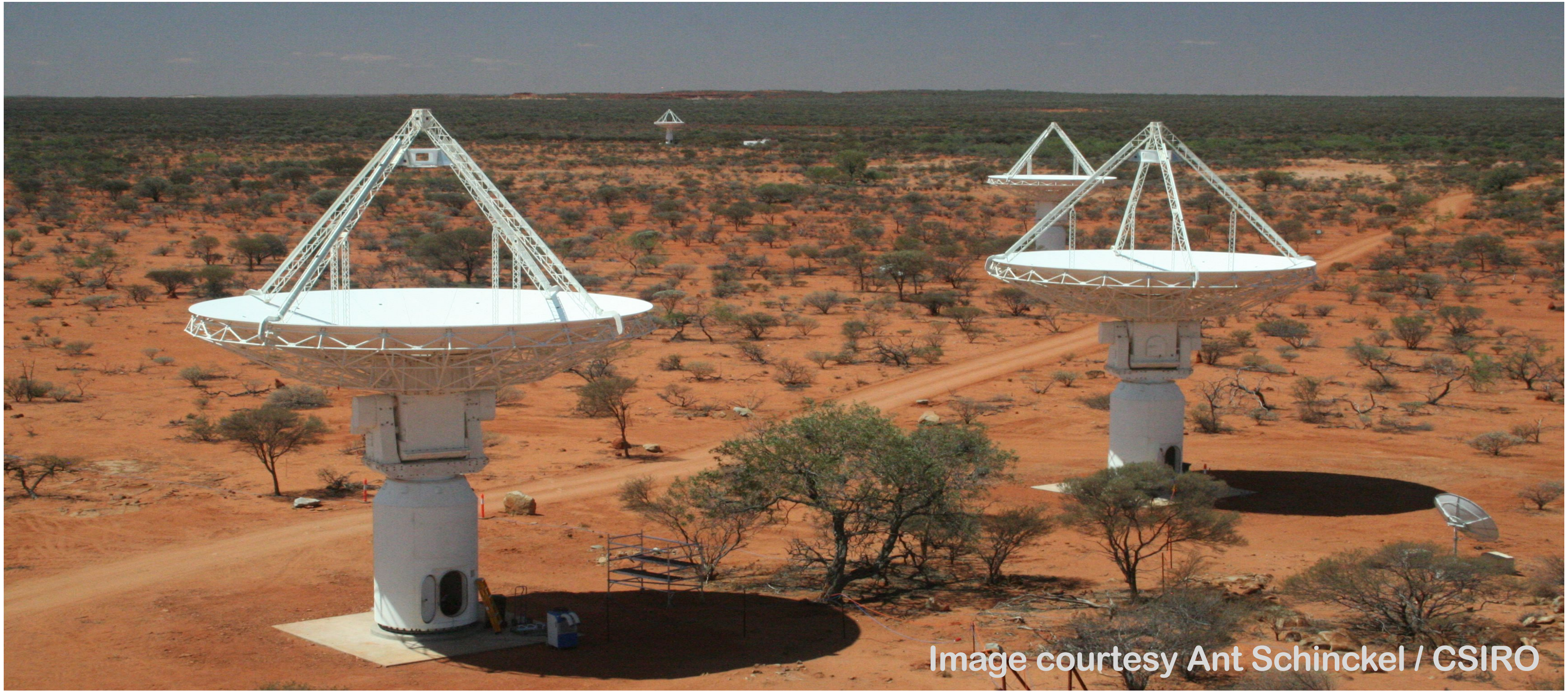
- Is FRB 121102 representative of all FRBs?
  → Do they all potentially repeat?
  → Is a dwarf galaxy host "typical"?

- Mechanism for FRBs?
  $E \approx 10^{38}$ erg $(\delta\Omega/4\pi)\ D^2_{Gpc}\ (A/0.1 Jy\text{-}ms)\ \Delta\nu_{GHz}$.
  → Magnetar models, AGN, exotica?
  → How significant is lensing?



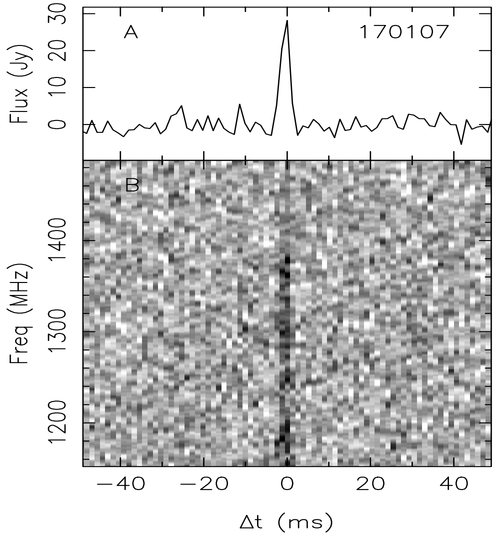
More FRBs from ASKAP

- → ASKAP has already detected FRBs in Fly's-Eye mode.
- → Full array needs to be commissioned for fast-dump interferometry.

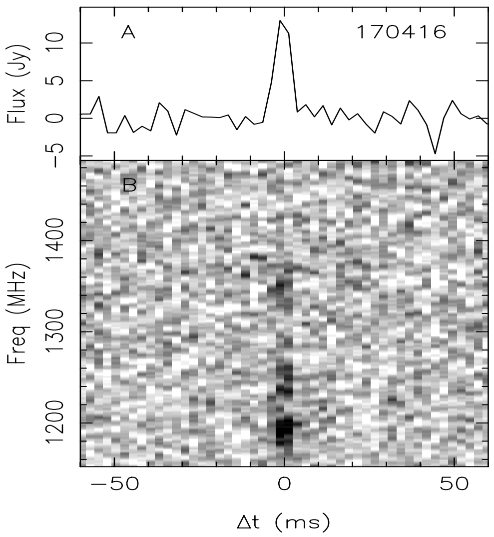


More FRBs from ASKAP

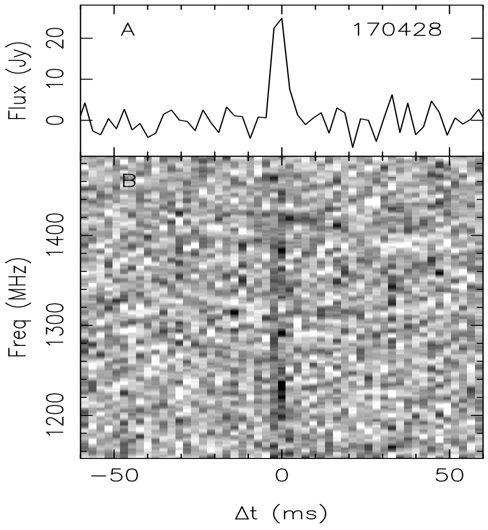
→ ASKAP has already detected FRBs in Fly's-Eye mode.
(Bannister et al. 2017, Shannon et al. 2018)



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



FRB 170416
DM: 523.2(2) pc cm^{-3}



FRB 170428
DM: 991.7(8) pc cm^{-3}

Images courtesy Keith Bannister/ CSIRO

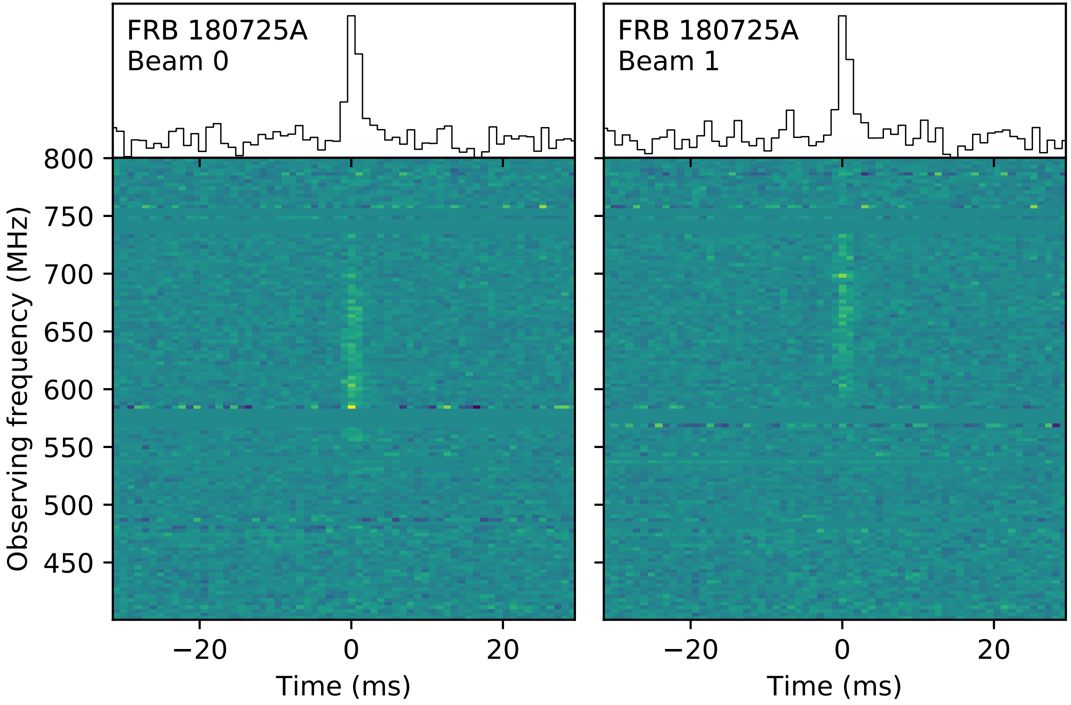
More FRBs from CHIME

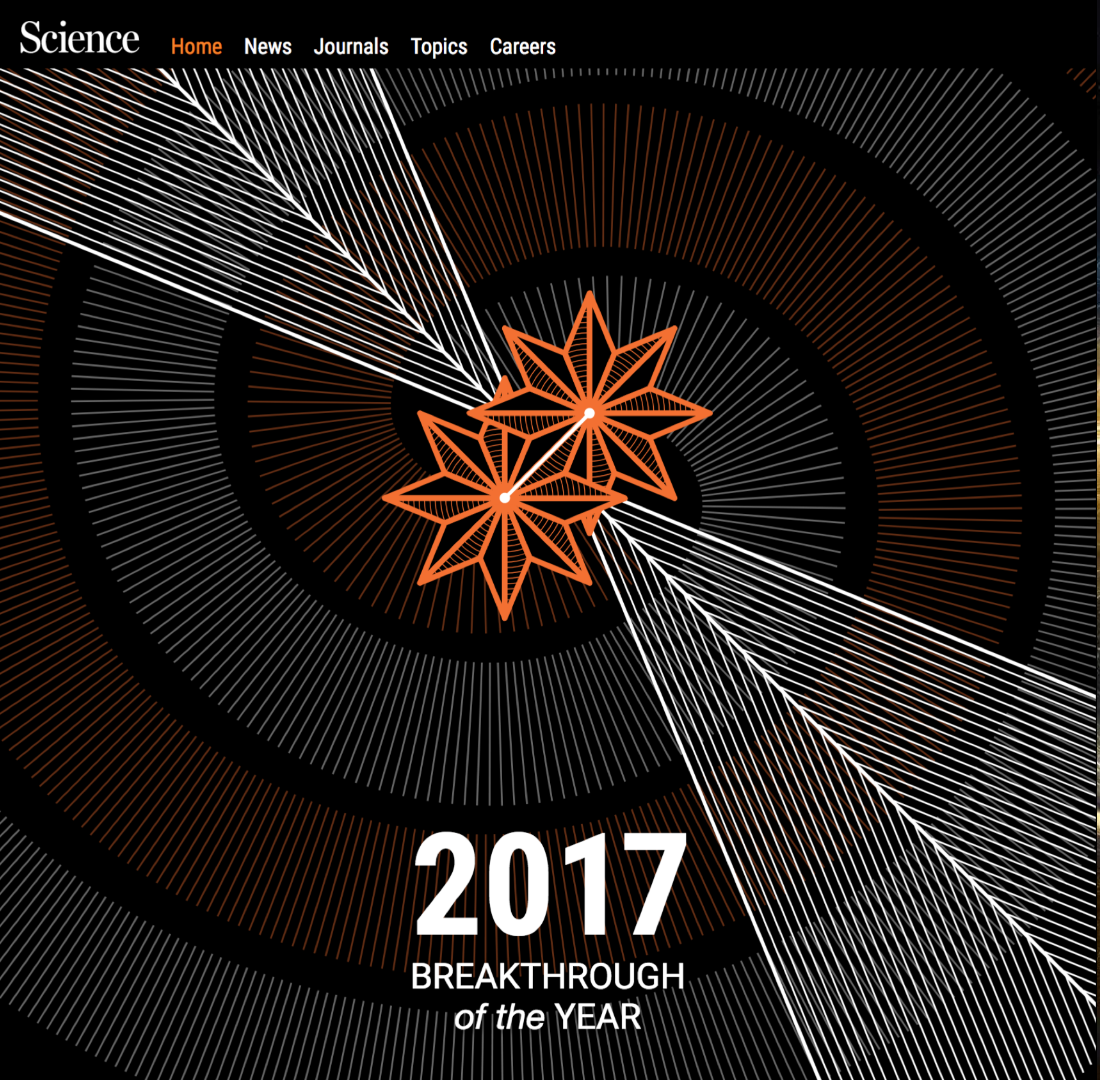
- → 80m x 100m, operating at 400-800 MHz.
- → Many FRB detections even with pessimistic assumptions.

More FRBs from CHIME

→ 80m x 100m, operating at 400-800 MHz.

→ First FRBs already in hand. **(Atel #11901, Boyle et al.)**





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Vol. 551, No. 7678

Relativistic Jet and Dynamical Ejecta

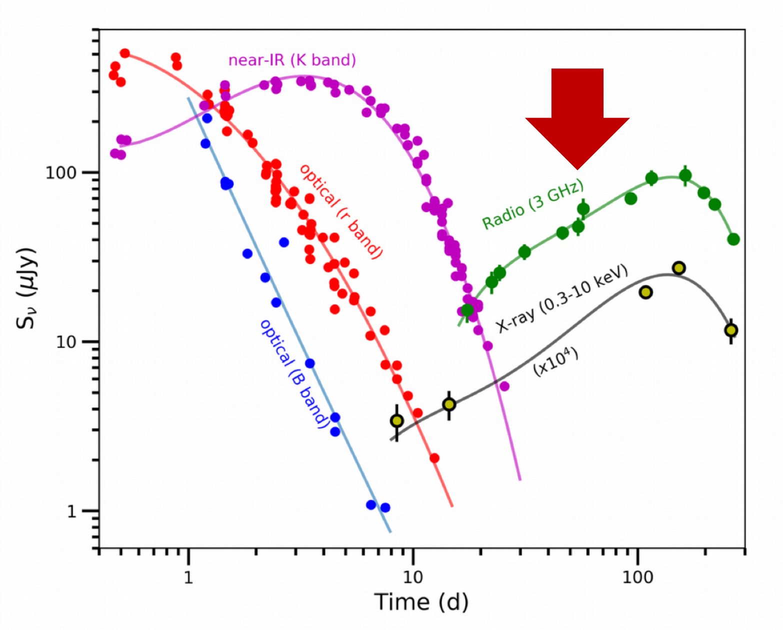
Non-thermal afterglow:

- Synchrotron emission from shock-accelerated electrons.
- “Simple” physics: energy, density, geometry.

Relativistic Jet and Dynamical Ejecta

Non-thermal afterglow:

- Synchrotron emission from shock-accelerated electrons.
- "Simple" physics: energy, density, geometry.



Radio observations, VLA 3 GHz:
- Slow rise, turnover, and decline.
- Light curve discriminates between models.

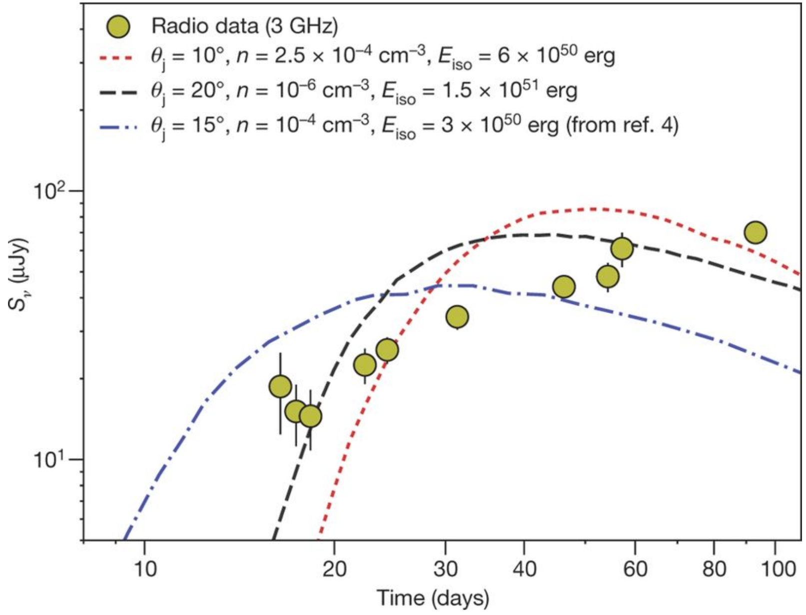
Relativistic Jet and Dynamical Ejecta

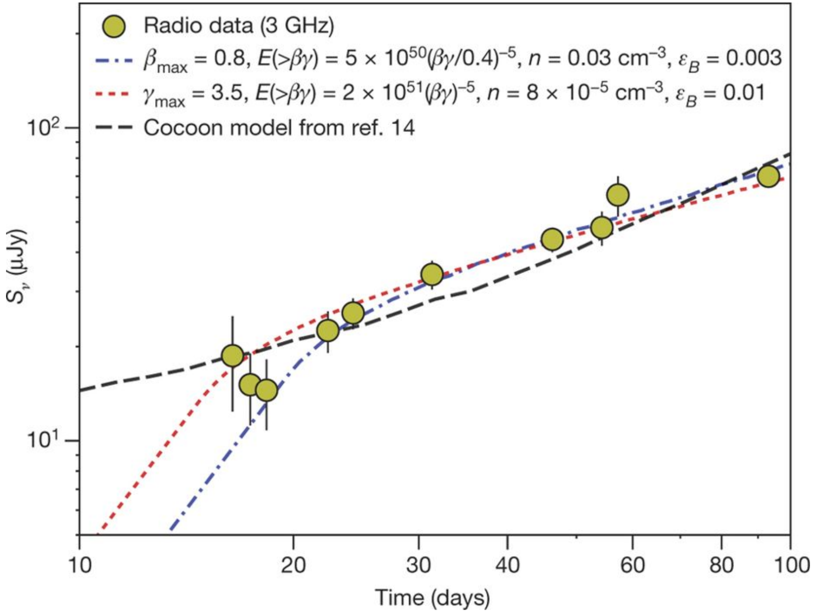
VLA obs at 3 GHz

➔ Simple jet models are disfavored.

➔ Mildly relativistic wide-angle outflow is required.

Mooley et al., 2018a, Nature





Relativistic Jet and Dynamical Ejecta

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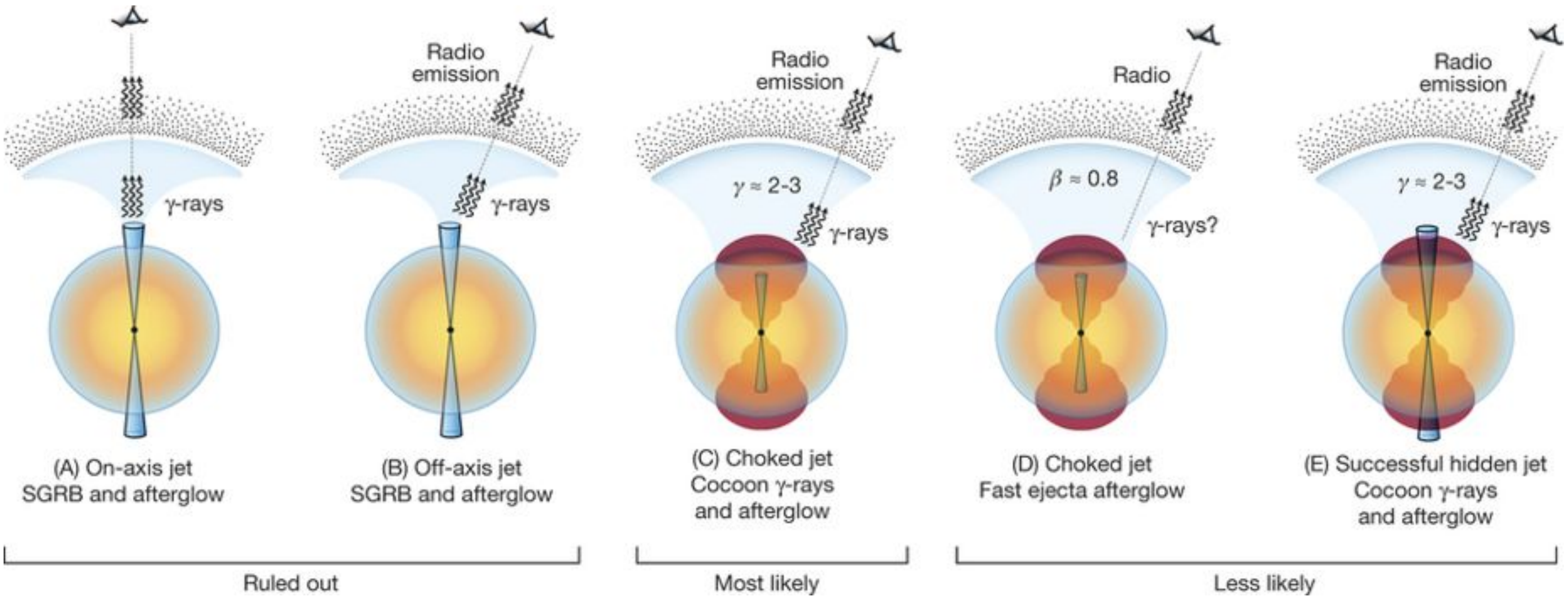
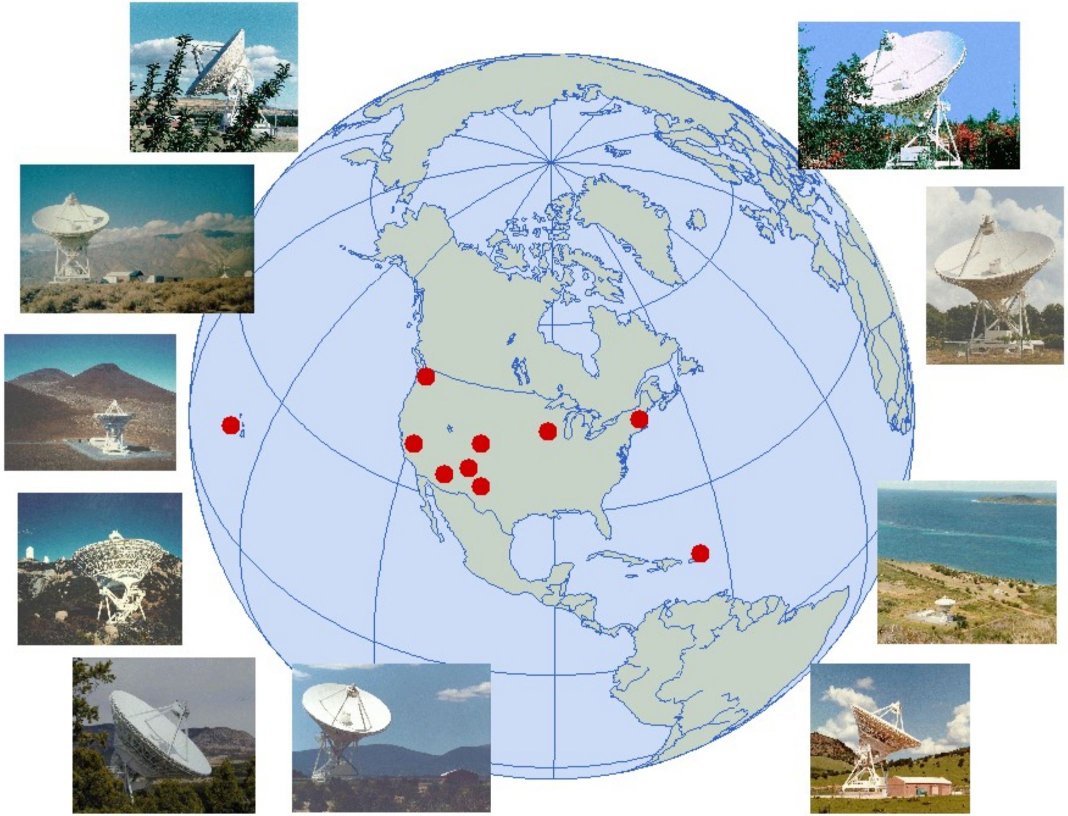


But was there a jet?

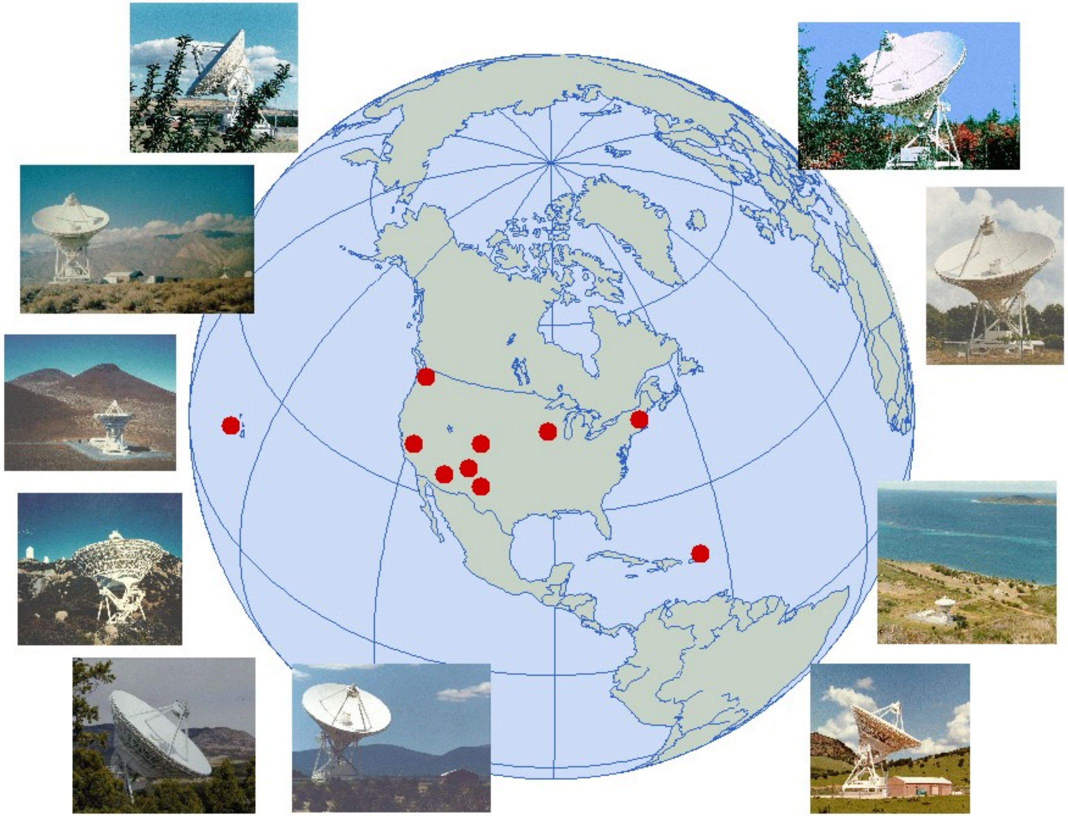


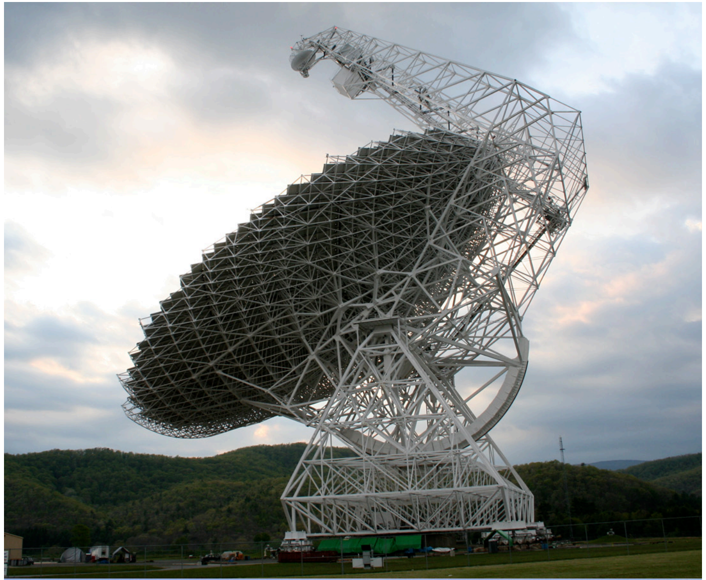
Key test for a jet:
Expect proper motion from superluminal expansion.

The VLBA lacks enough sensitivity on its own …

→ More collecting area.

HSA observations

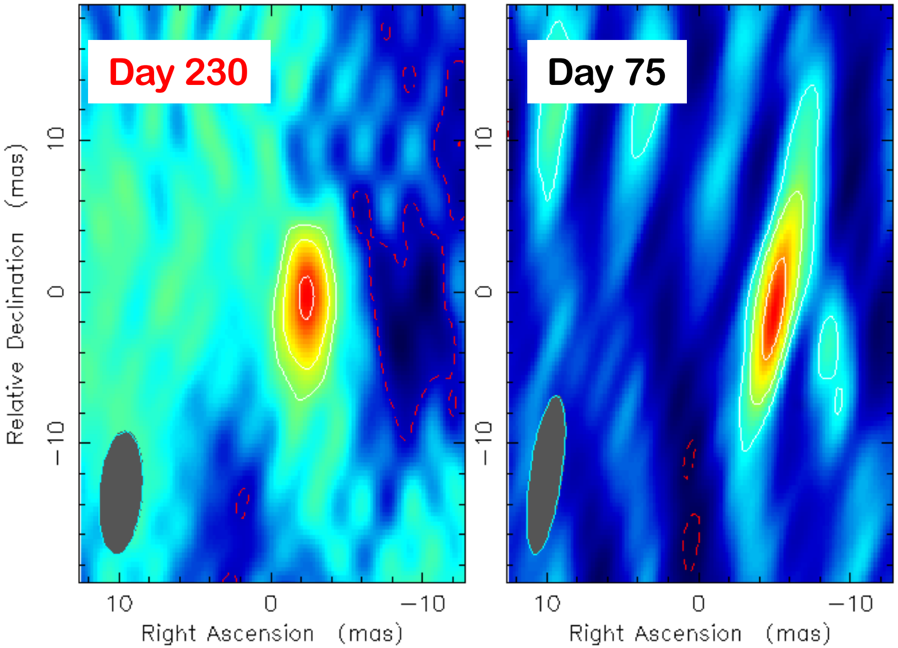


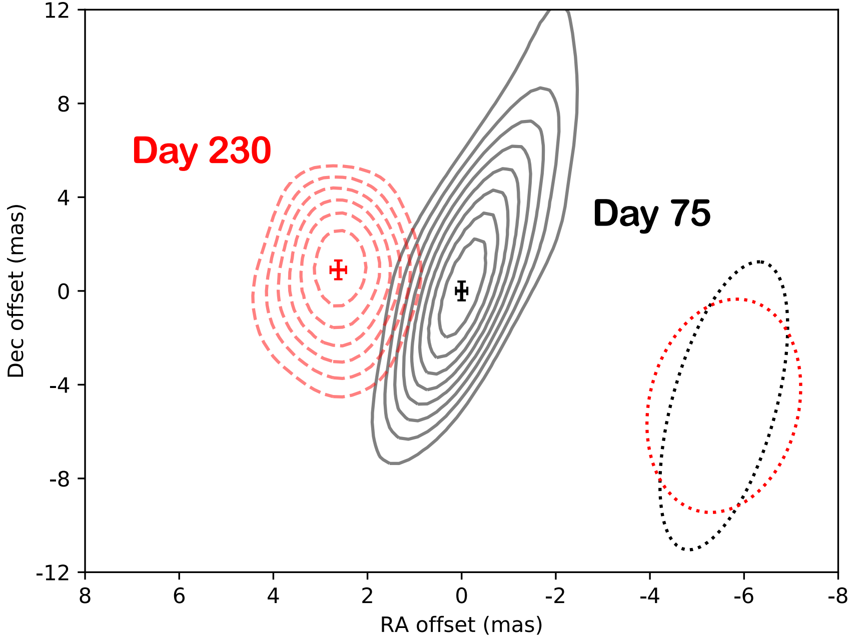


HSA observations

Unresolved blob;
Proper motion: 2.7±0.3 mas over 155 days.

Mooley, Deller, Gottlieb et al., 2018b, Nature, accepted



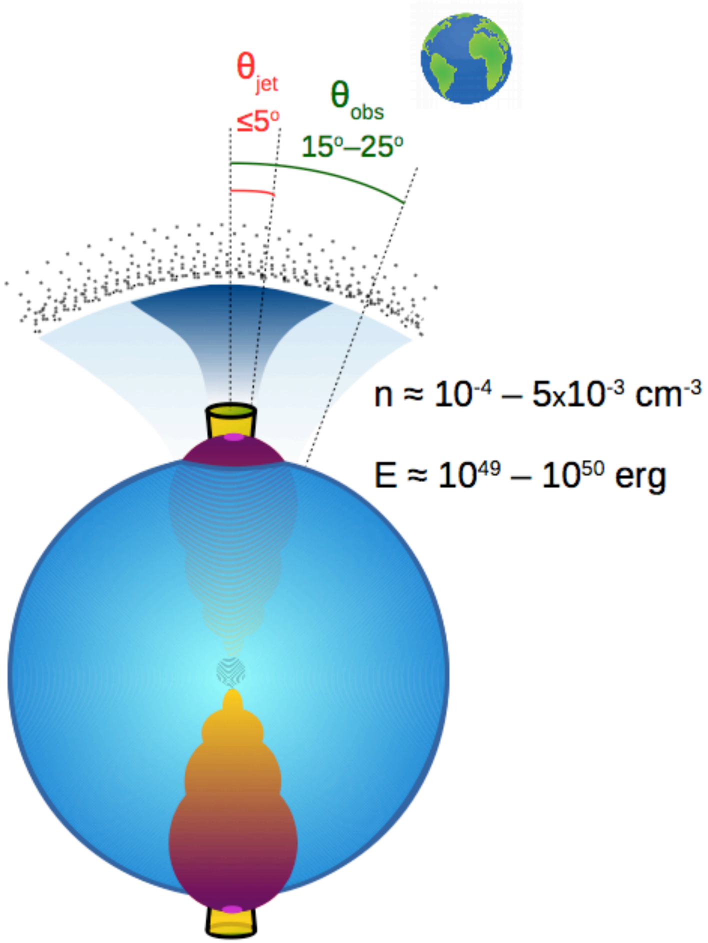


HSA observations

Unresolved blob;
Proper motion: 2.7±0.3 mas over 155 days.

➔ Superluminal motion, β_{app}~4.
➔ Narrow jet, Γ_0>10.
➔ Narrow jet <5°, inclined ~20±5° to LOS.

➔ SGRBs come from NS-NS mergers.



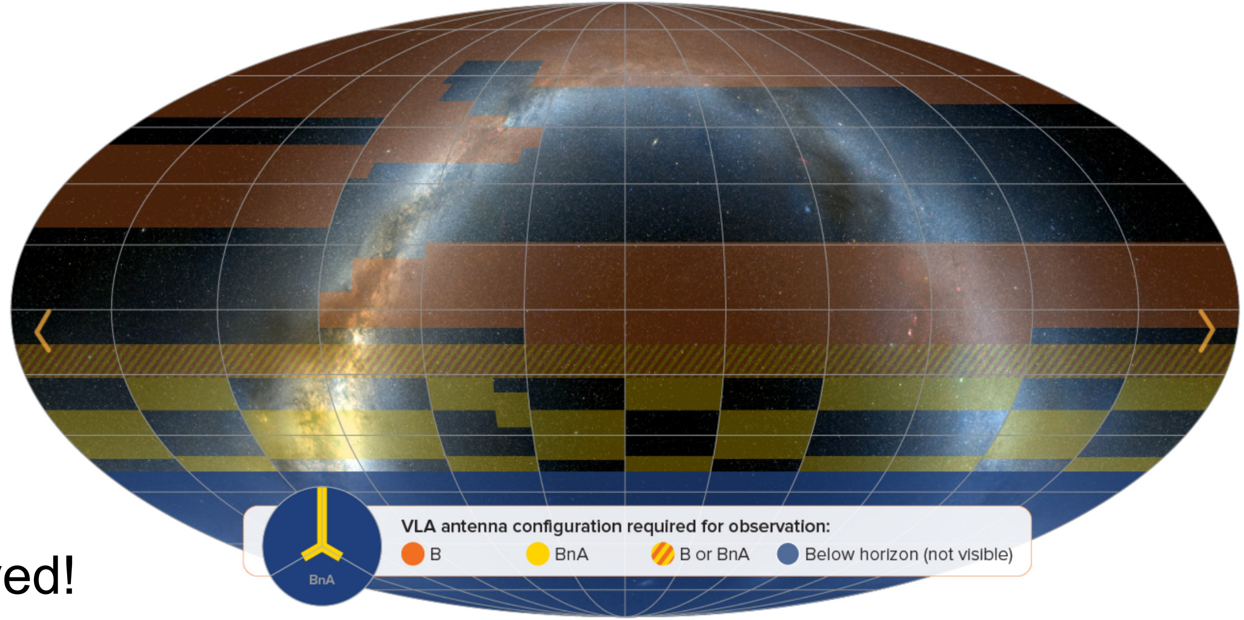
Mooley, Deller, Gottlieb et al., 2018b, Nature, accepted

The VLA Sky Survey

The radio sky offers unique discovery space for transients – orphan GRB afterglows, merger aftermaths, FRB hosts, more.

VLASS:

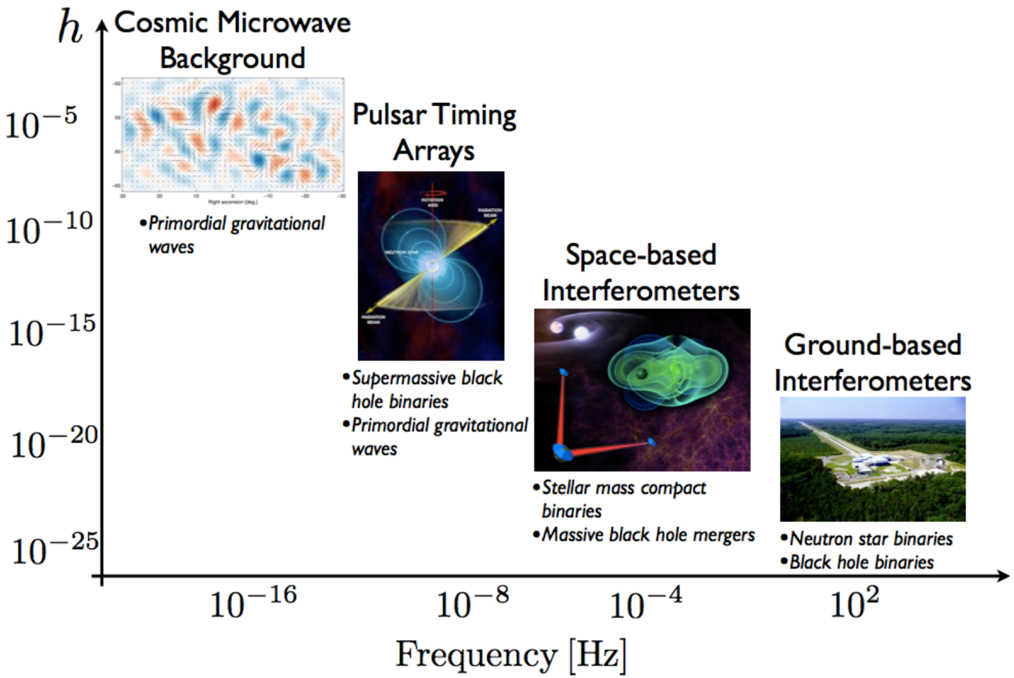
- 2.5” resolution
- 2 – 4 GHz
- 120 μJy RMS
- 3 epochs,
  32 months apart
- All sky (Dec>-40°)



Epoch 1A is now observed!
Please see: http://vlass.org
Contact SSG co-chairs Chatterjee, Clarke to get involved.

If GWs from NS-NS, BH-BH mergers are exciting…

Low frequency GWs



Mergers of <u>supermassive</u> BHs:

→ Trace the history of mass assembly in the Universe.

→ GW periods are ~years, so a Galactic-scale detector is required.

→ Radio timing of pulsars.

Pulsar timing arrays: Galactic-scale GW detectors

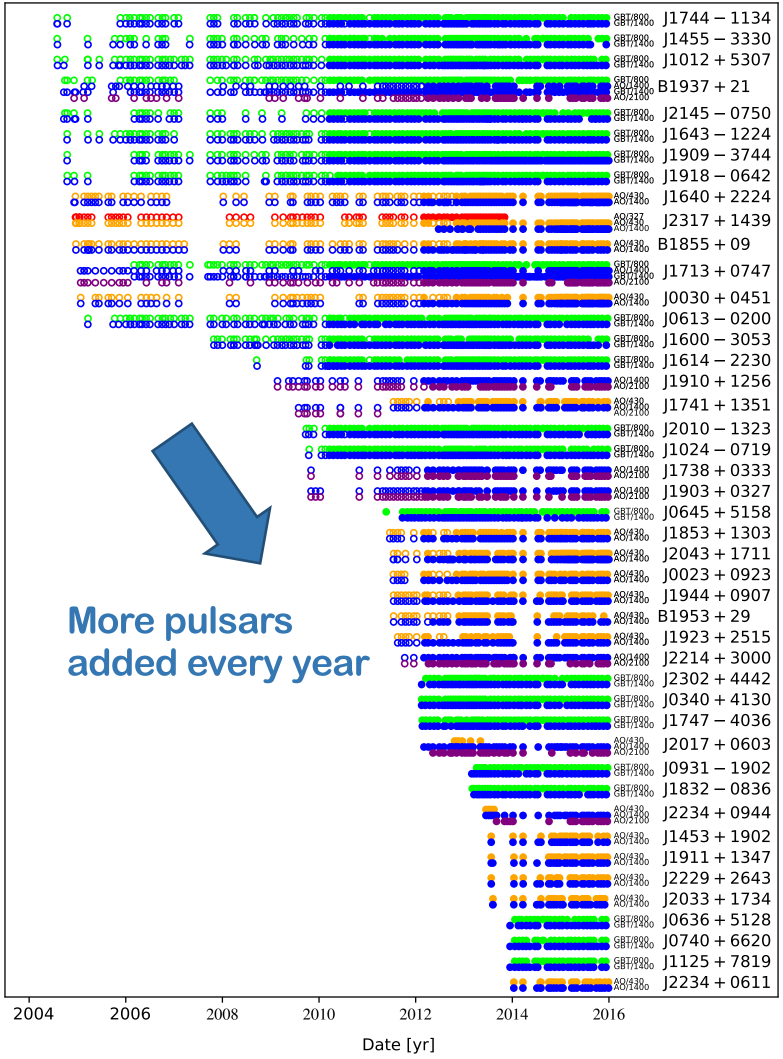
The NANOGrav collaboration:

→ Precision timing of an expanding array of millisecond pulsars.

→ Arecibo, Green Bank.

→ 12.5 year data release is coming.

→ Interesting limits on the stochastic GW background at nanoHz frequencies.



Pulsar timing arrays: a truly international partnership