An Overview and Update of the Repeating FRB

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Max-Planck-Institut
für Radioastronomie

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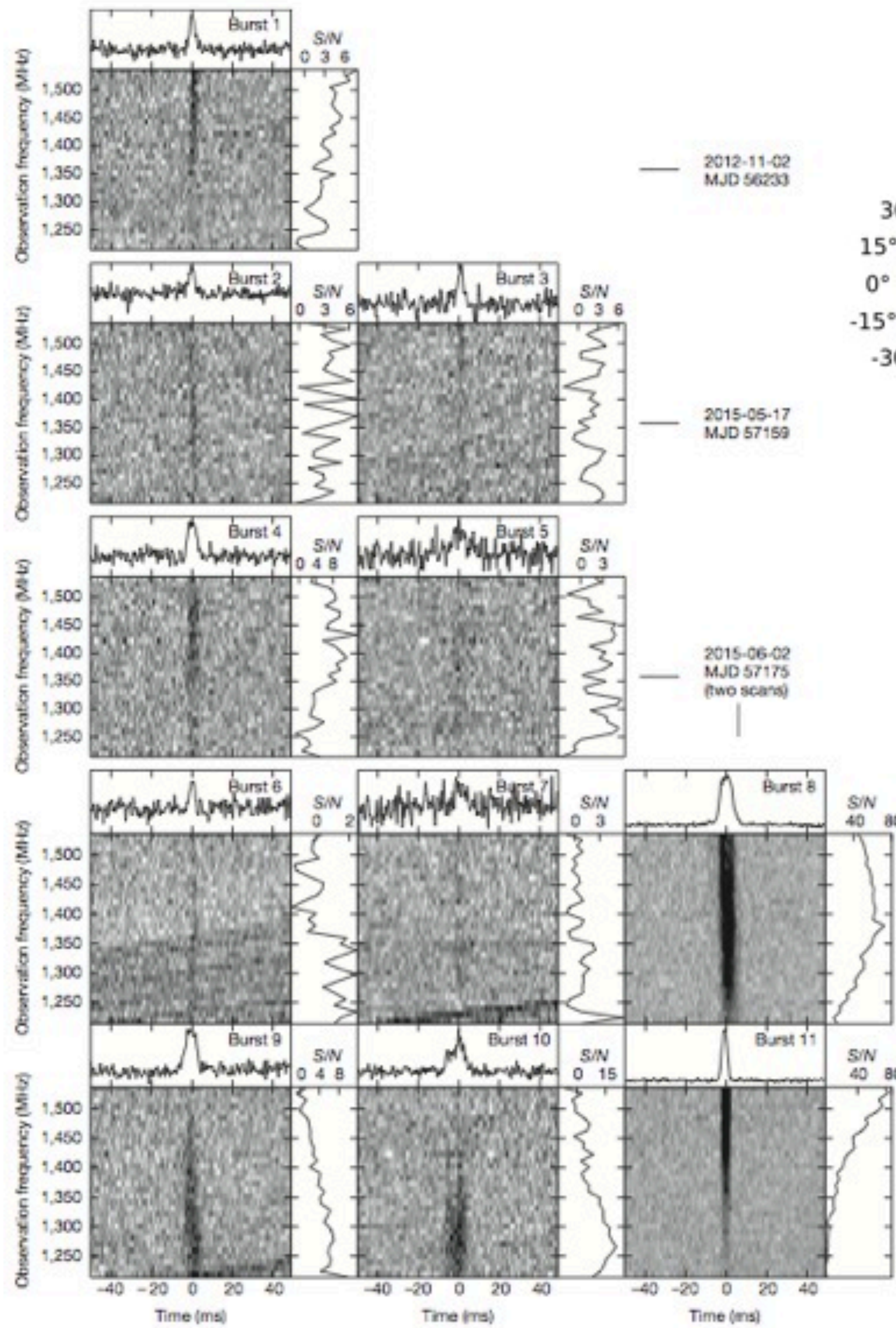
Overview

- Brief background on FRB 121102 and update on single dish observations
- What can we learn about the system from observing the bursts?
- What can we learn about system from observing its environment?

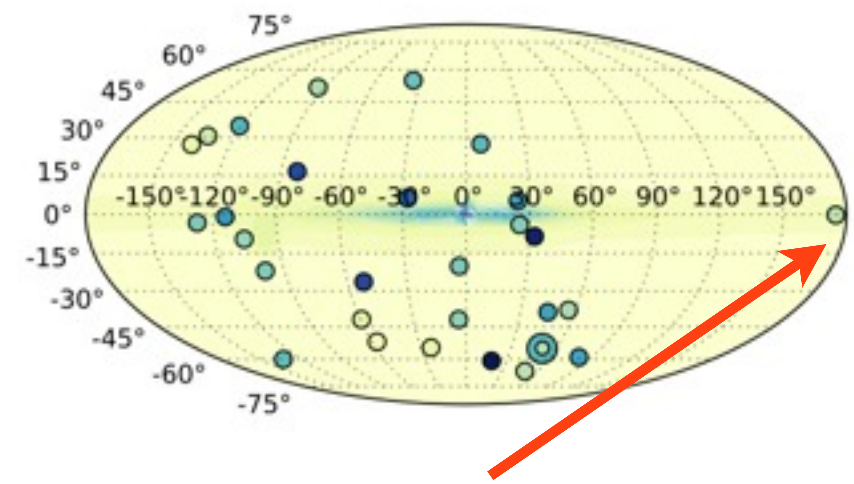
FRB 121102: the first (and so far only) repeating FRB

Discovered in archival processing in pulsar survey data (PALFA) from the Arecibo Observatory...

NAIC



Spitler et al, *Nature*, 2016

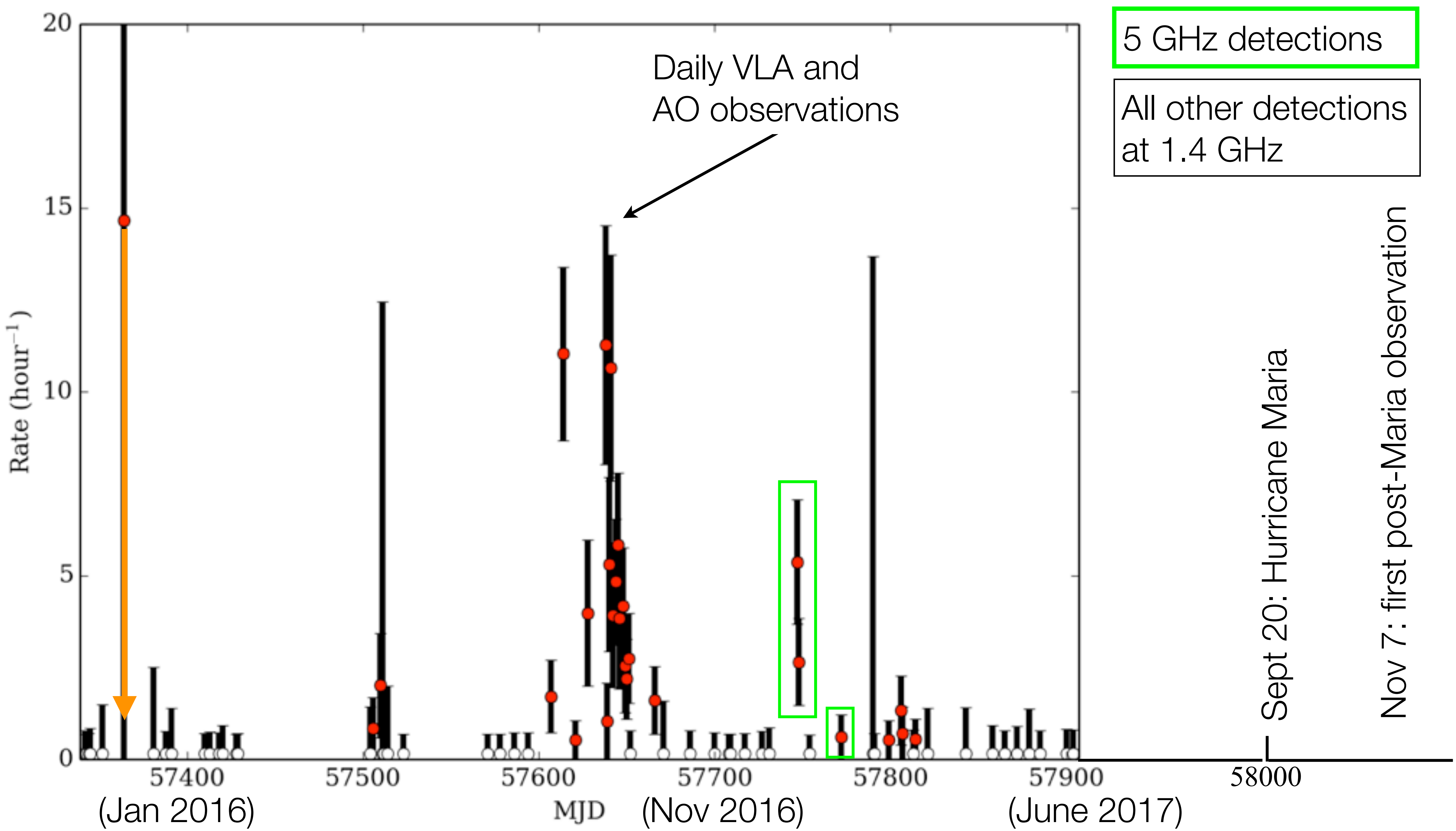


... in the Galactic plane

<u>AO Team</u>

Jason Hessels (U van A)
Andrew Seymour (NAIC)
Daniele Michilli (U van A)
Kelly Gourdji (U van A)

Arecibo monitoring of the “repeater”



What can we learn from observing the bursts?

- Radio observations
  - ~200 detections from 1.2 to 9 GHz
  - No detections (simultaneous or otherwise) below 1 GHz
  - Simultaneous, multi-telescope detections are rare
  - Highly non-Poissonian detection rate
  - Bursts highly polarized

- Higher energy (optical/X-ray / gamma-ray)
  - No detectable simultaneous bursty emission:
    - Scholz et al. 2017, Hardy et al. 2017

“Weird bursts”

Arecibo
1.2-1.7 GHz

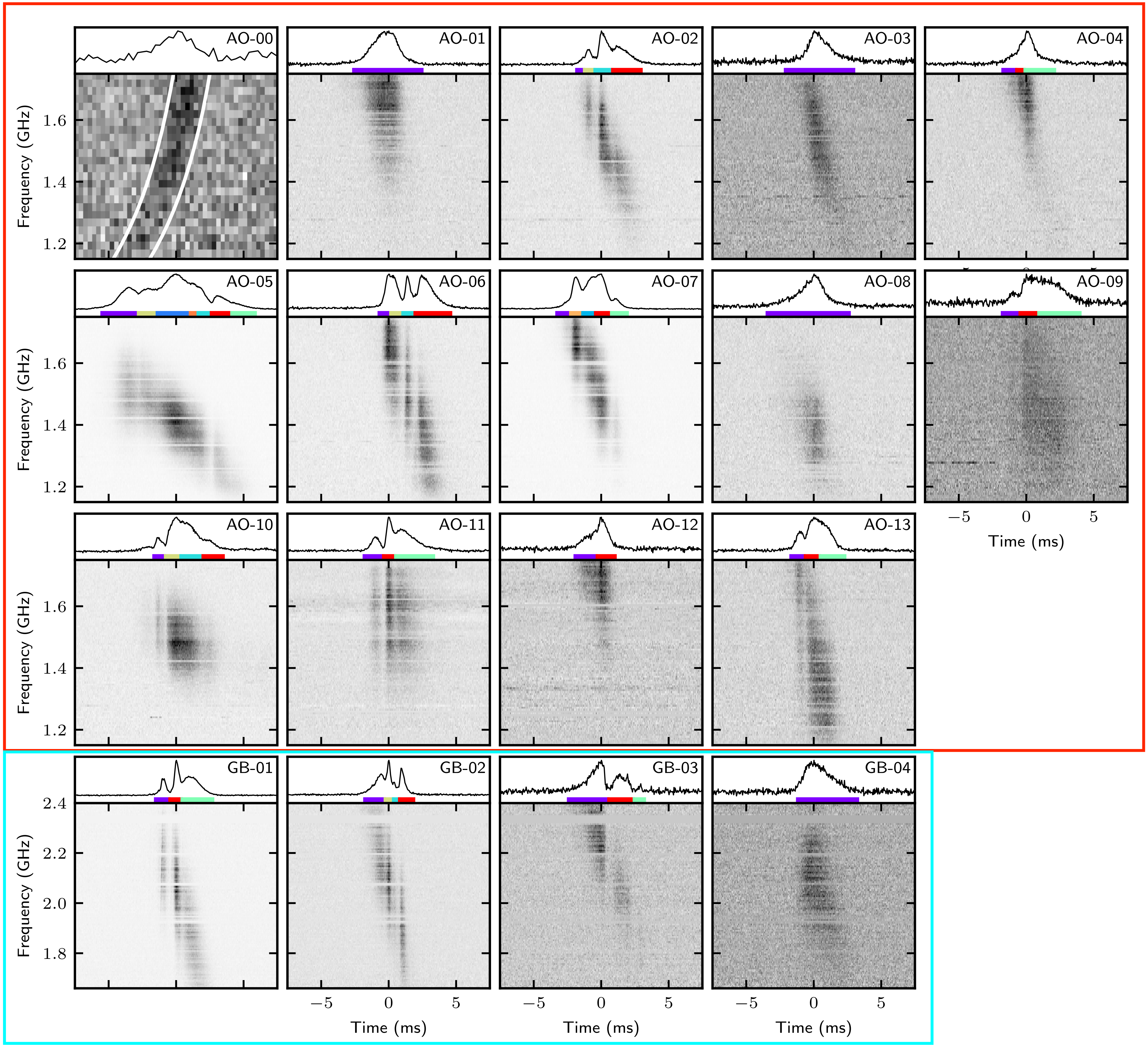
GBT
1.6-2.4 GHz

All bursts @ DM = 560.5 pc cc

Coherently dedispersed

S/N > 60

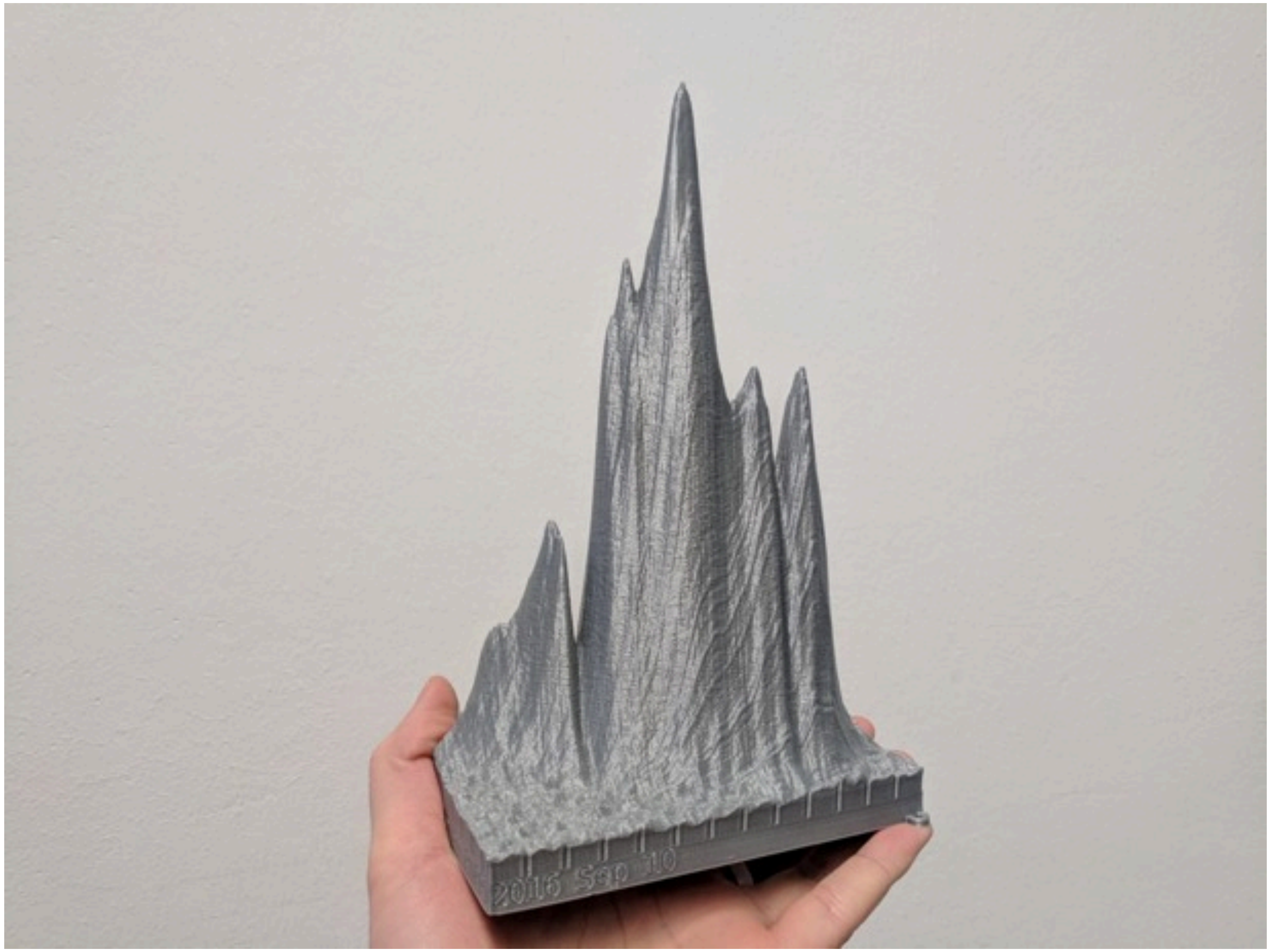
Detections during high-cadence Sept 2016 obs. (Except AO-00, GBT-03, GBT-04)



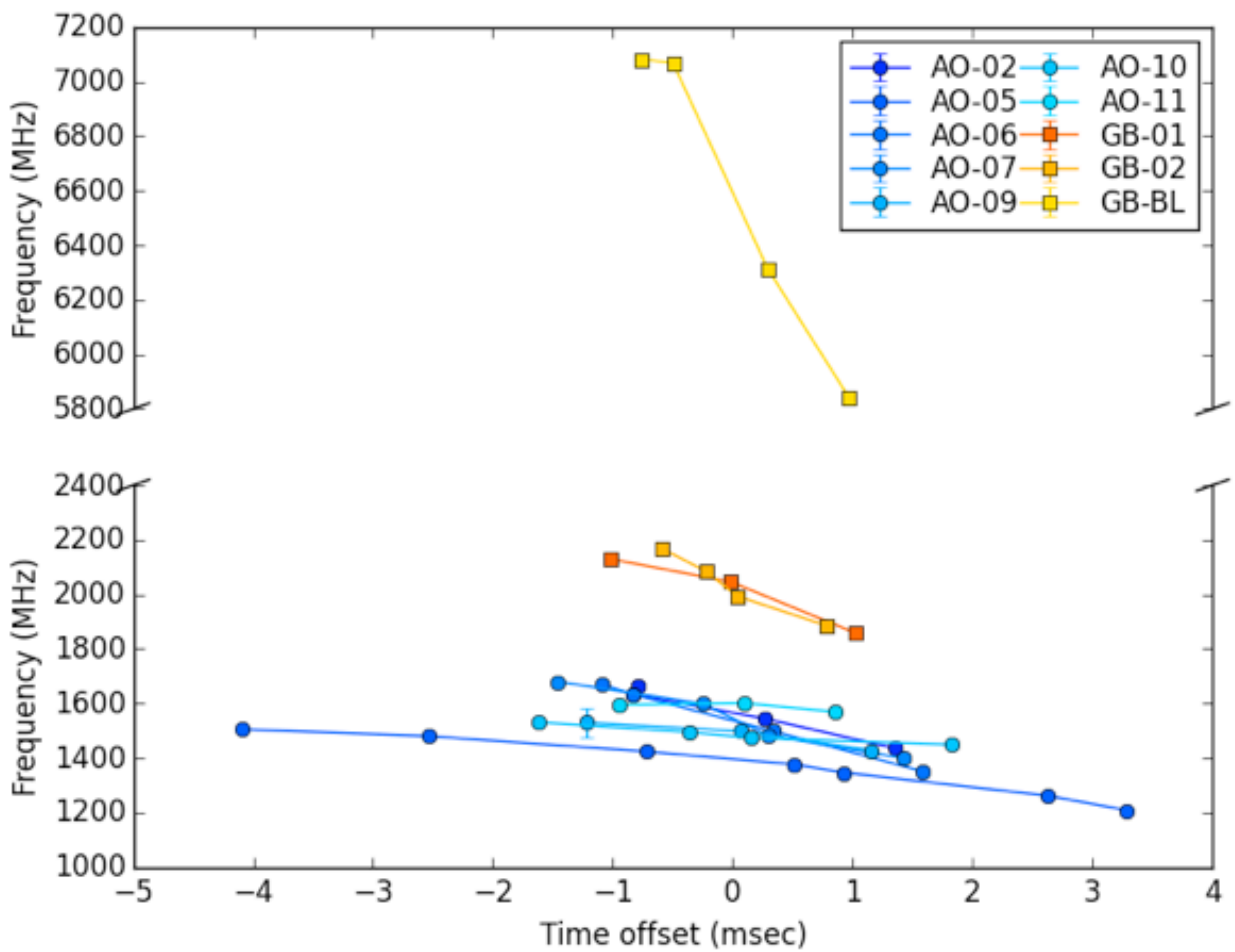
(Hessels et al., in prep)

Models for 3D printers developed by Anne Archibald

https://www.thingiverse.com/thing:2723399



Burst component drift rates



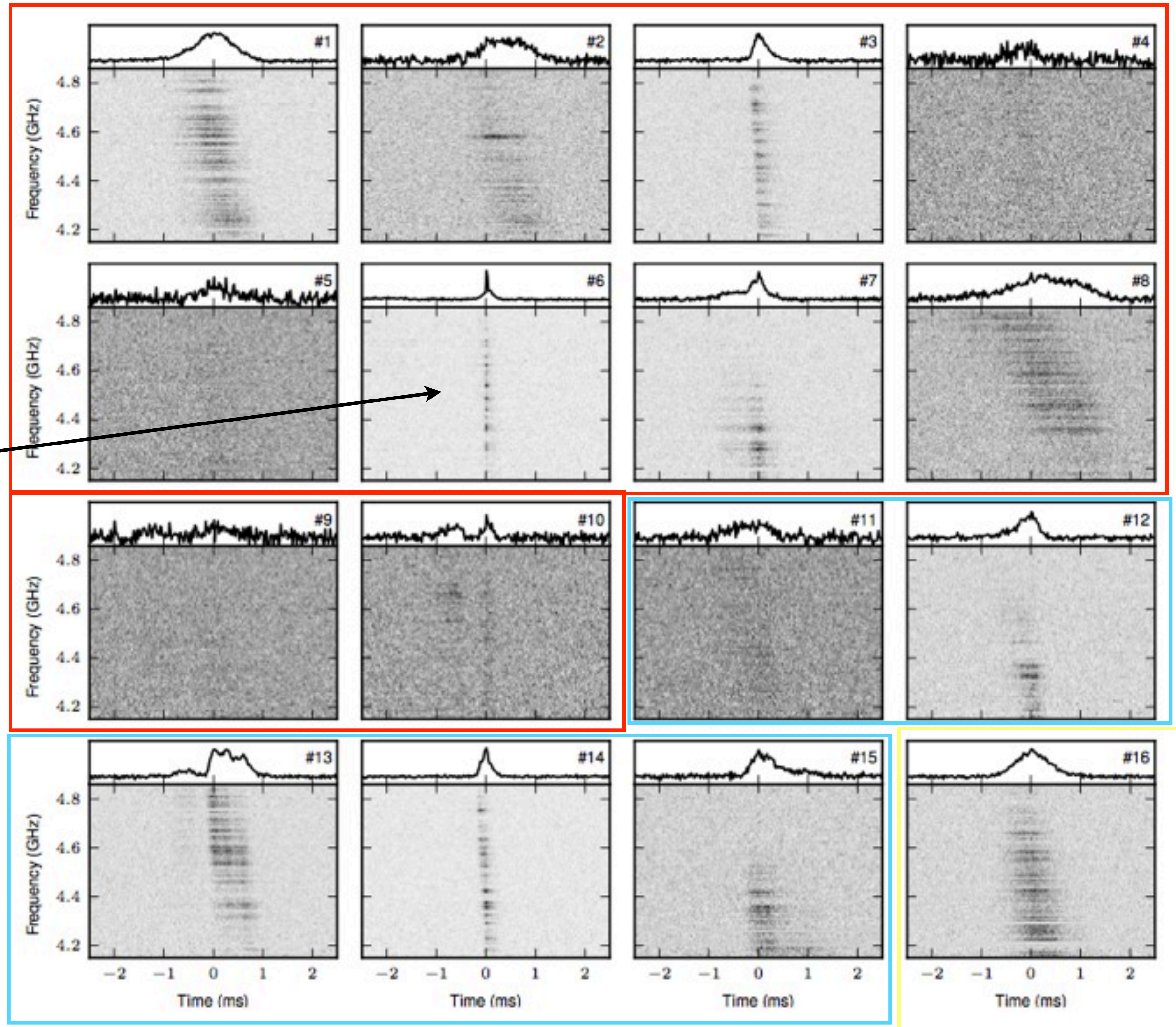
Arecibo 5 GHz detections with PUPPI

25 Dec 2016

26 Dec 2016

19 Jan 2016

20 μs burst duration

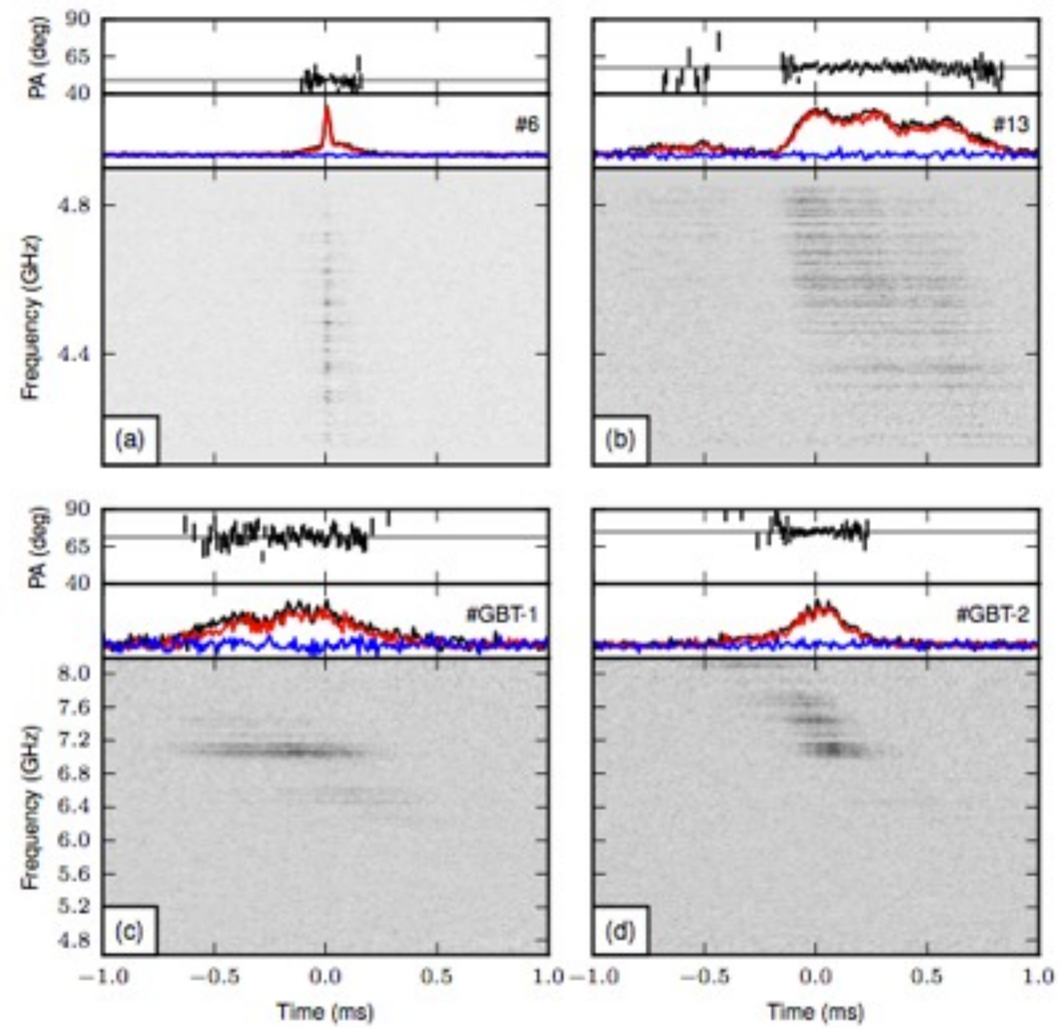


Narrow freq. striping is Galactic scintillation

(Michilli et al 2018)

Bursts 100% linearly polarized

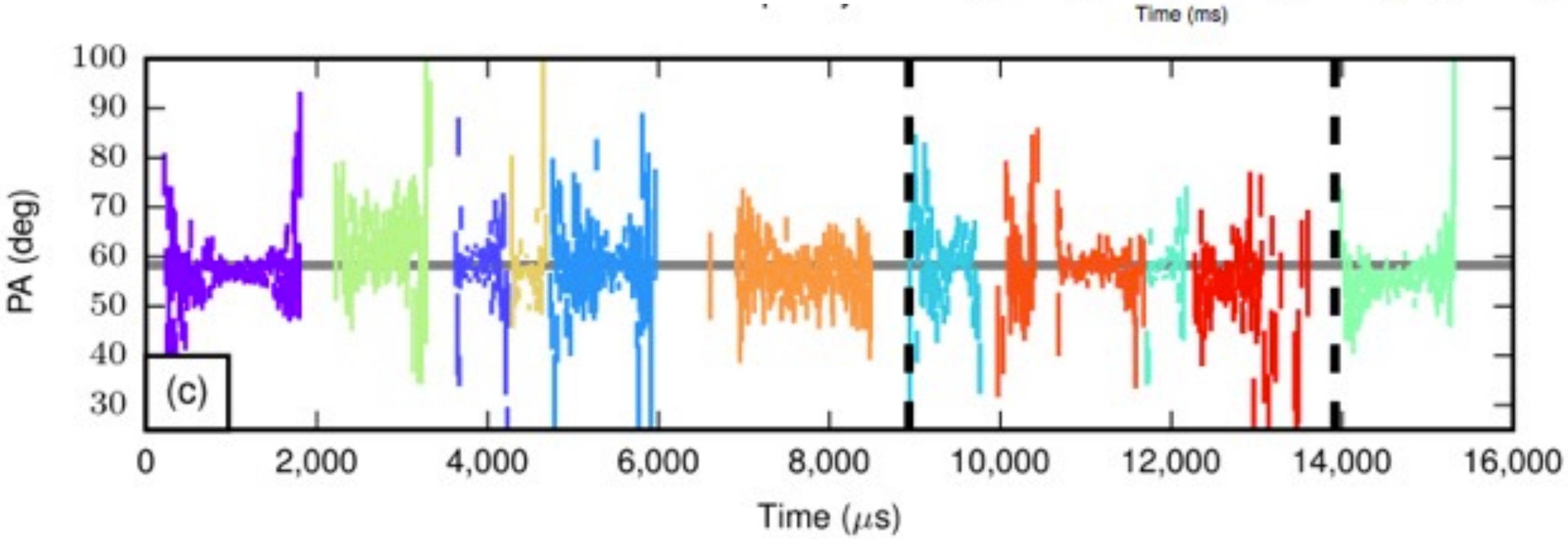
Once you can correct for the large rotation measure...



Arecibo Observatory

Green Bank Telescope (Breakthrough Listen) August 2017

Constant polarization angle during a burst and between bursts



(Michilli et al., 2018)

GBT Breakthrough Listen

Vishal Gajjar

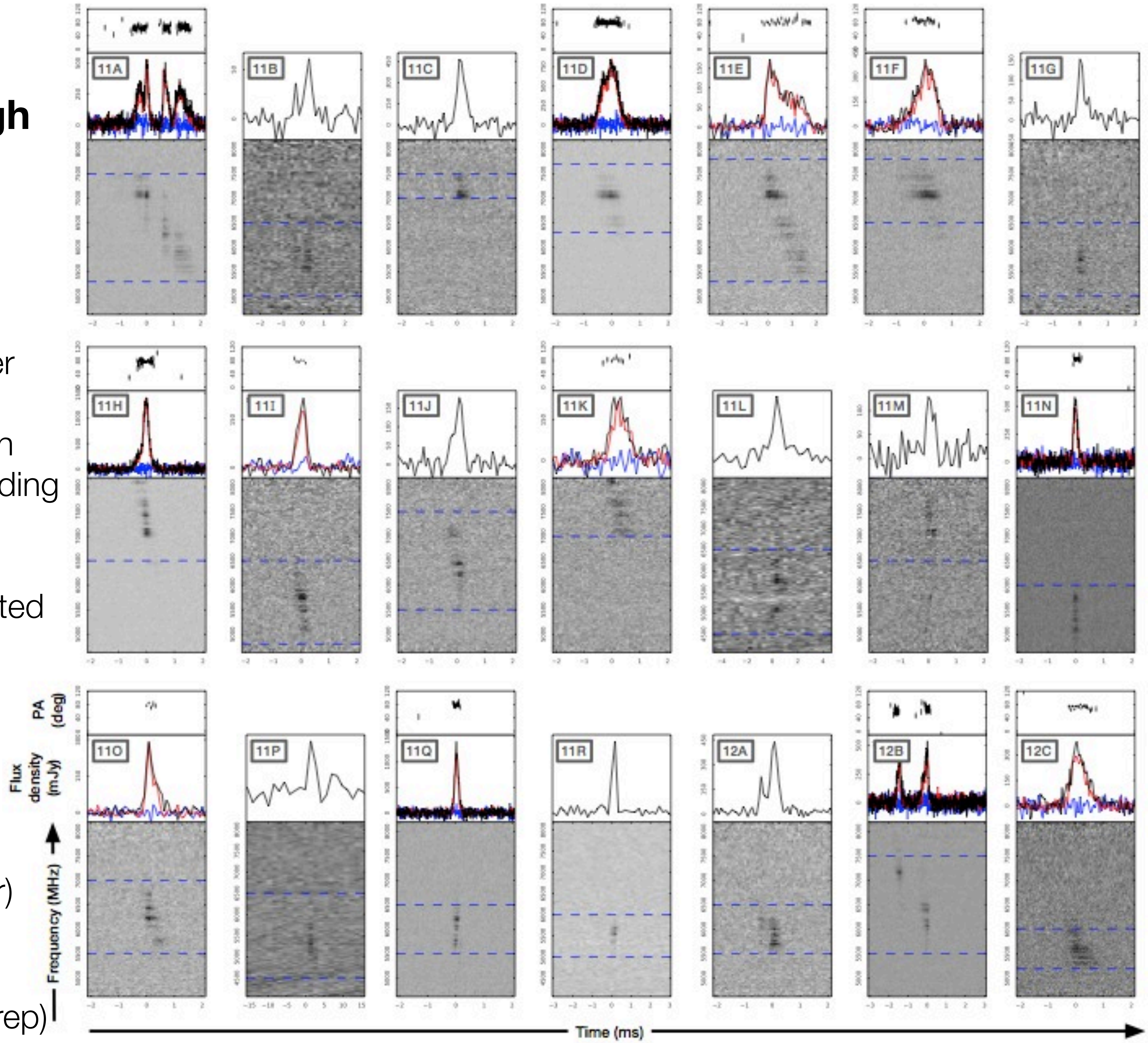
4-8 GHz receiver

BL backend with baseband recording

August 2017
21 bursts detected

Observed the source to "turn off"

(I will return to polarization later)



(Gajjar et al., in prep)

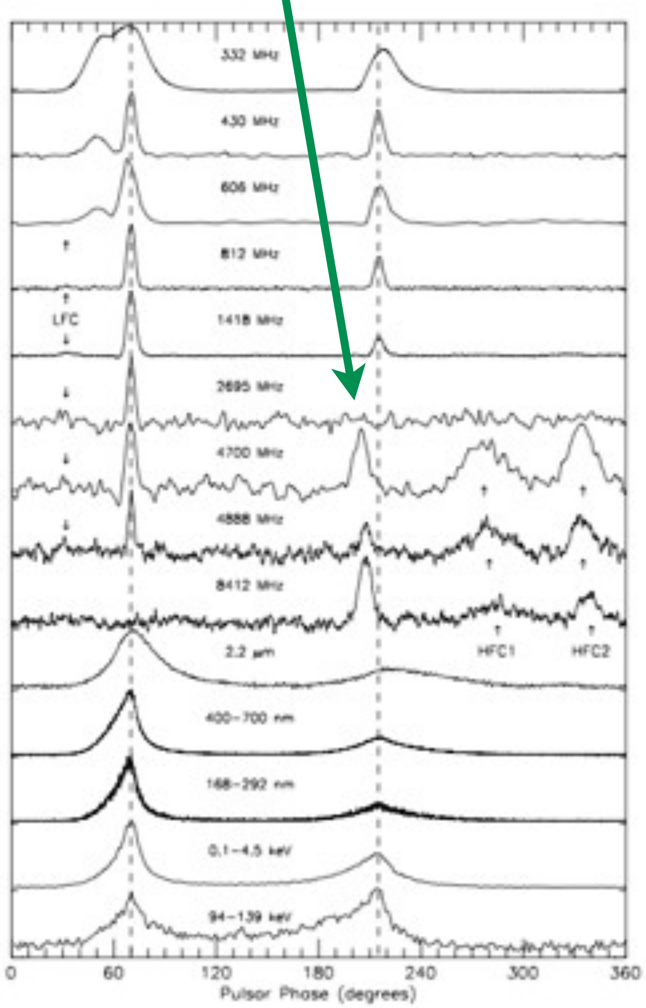
What can we learn from observing the bursts?

- What we need to explain...
  - Complex time-frequency structure
  - 100% linear polarization and flat and constant polarization angle
  - Perhaps, variable detection rate
- Possibilities:
  - Intrinsic emission mechanism
  - Extrinsic effect, i.e. propagation
  - Some combination of the two

Exception: Periodicity!

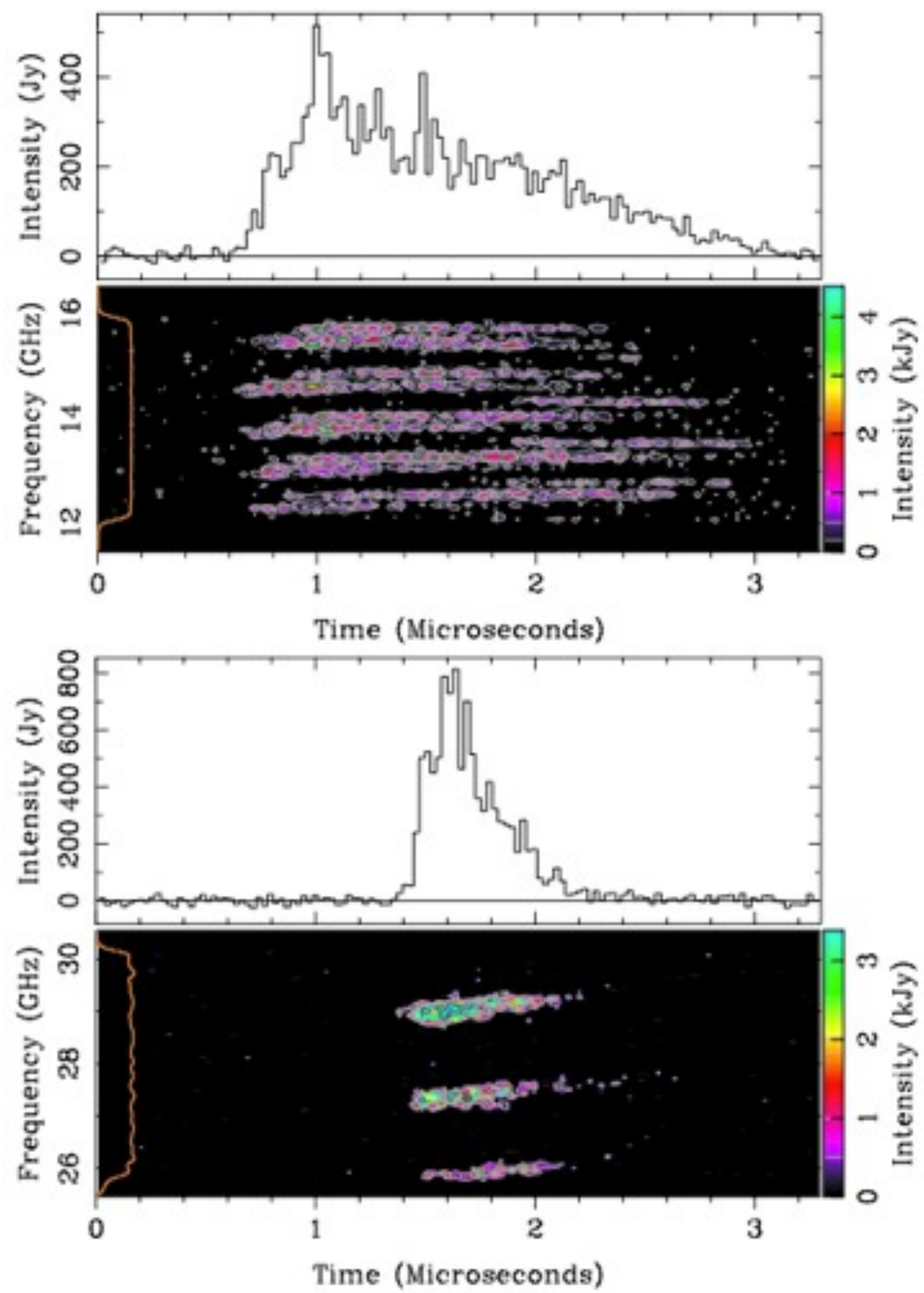
Intrinsic process: when in doubt... invoke the Crab pulsar

High frequency interpulse giant pulses

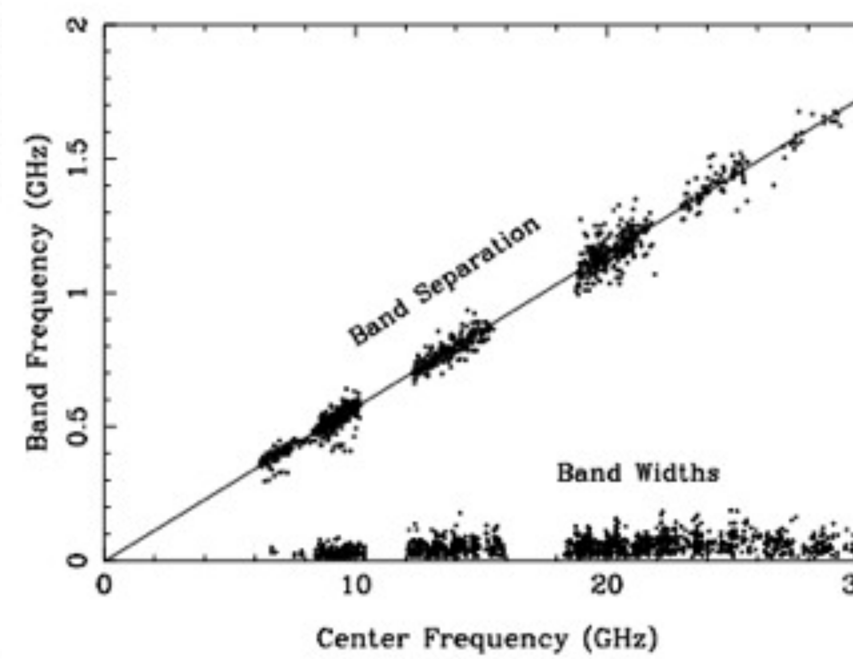


(Hankins & Eilek 2007)

Banded frequency structure



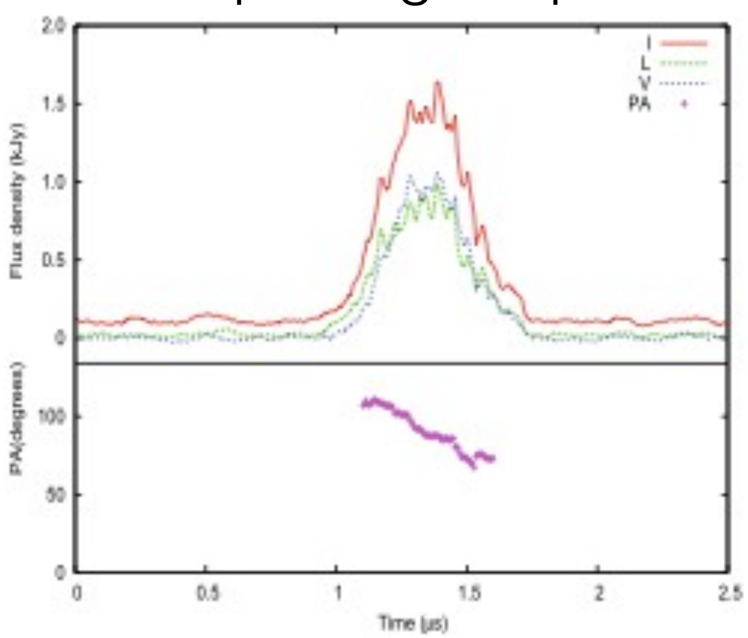
Separation of the bands increases linearly with frequency



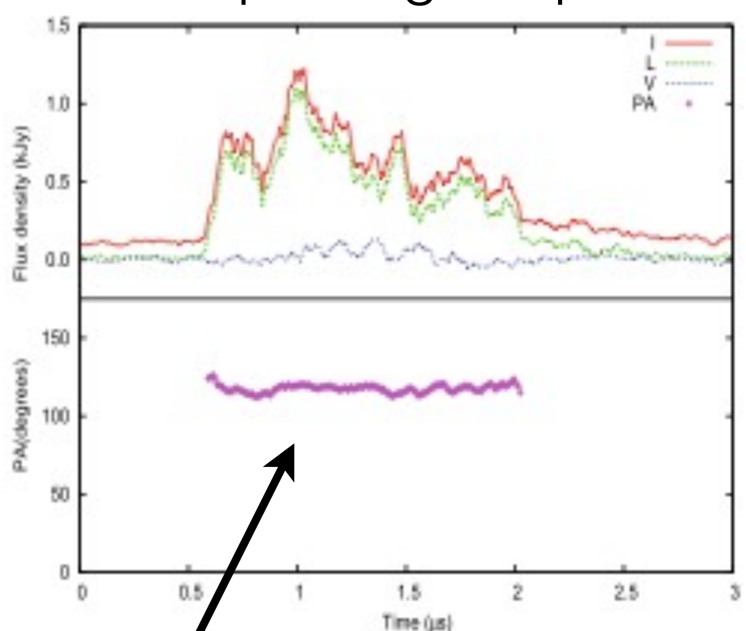
(Hankins, Eilek, Jones 2016)

Crab HF IP GP polarization

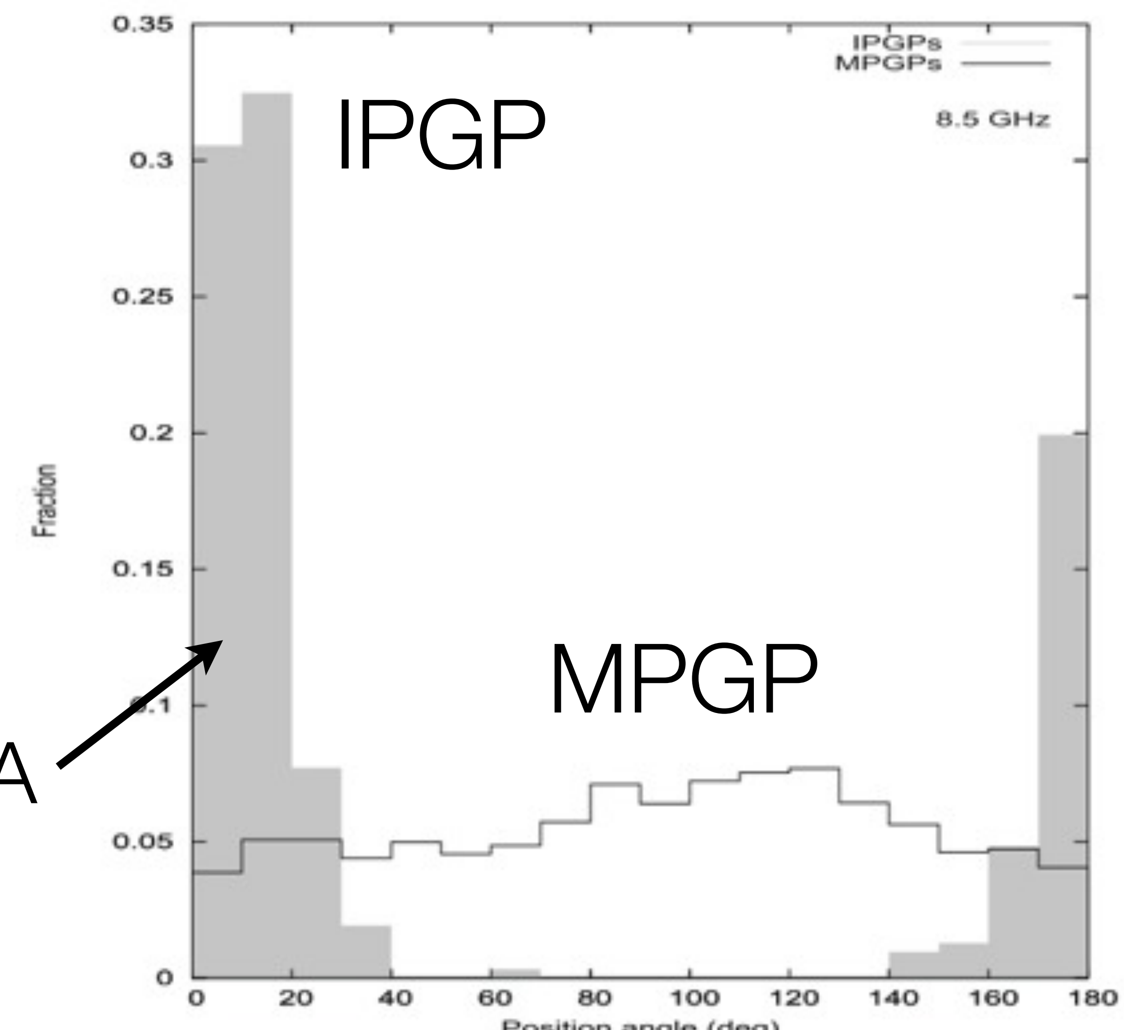
Main pulse giant pulse



Interpulse giant pulse



flat PA

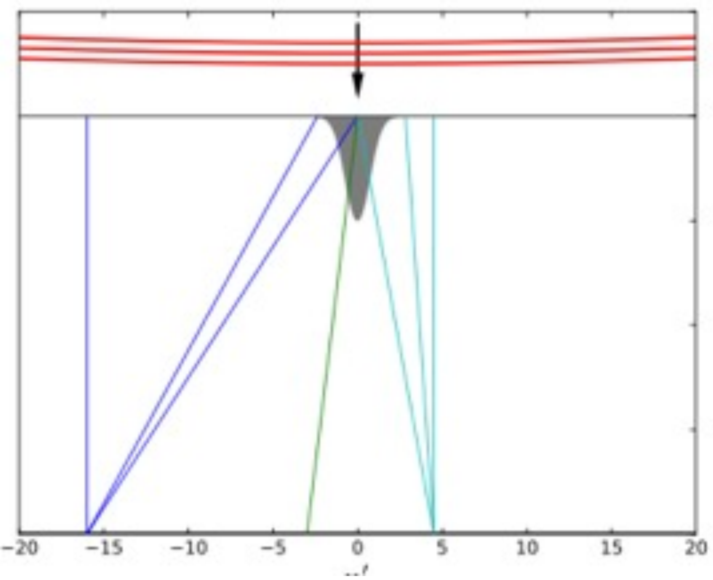


narrow range of PA

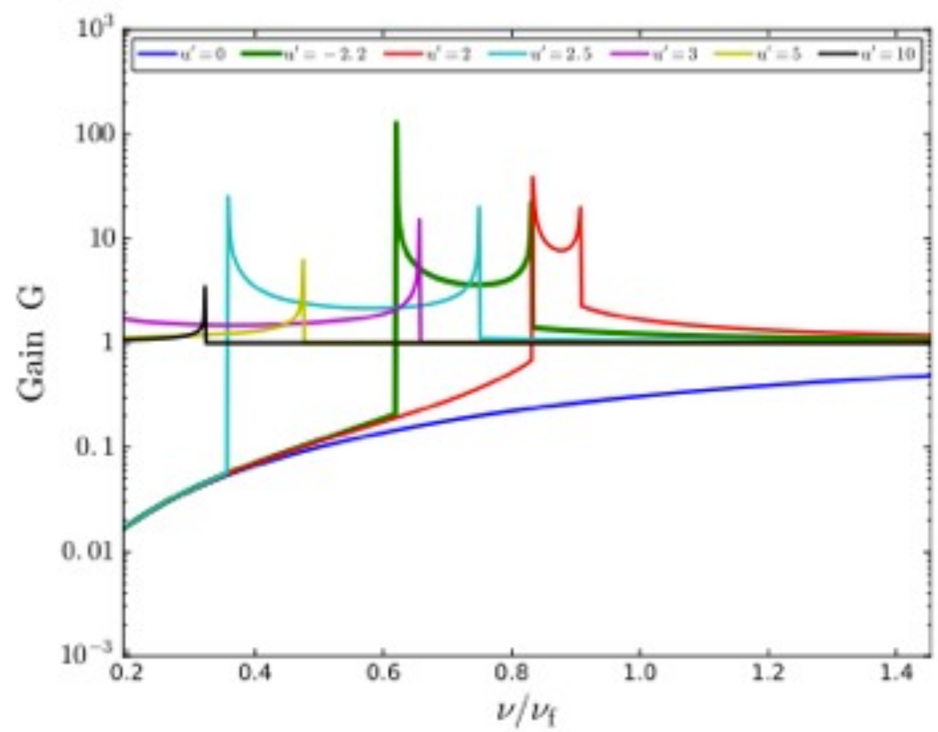
Jessner et al., 2010

Extrinsic process: Plasma Lensing

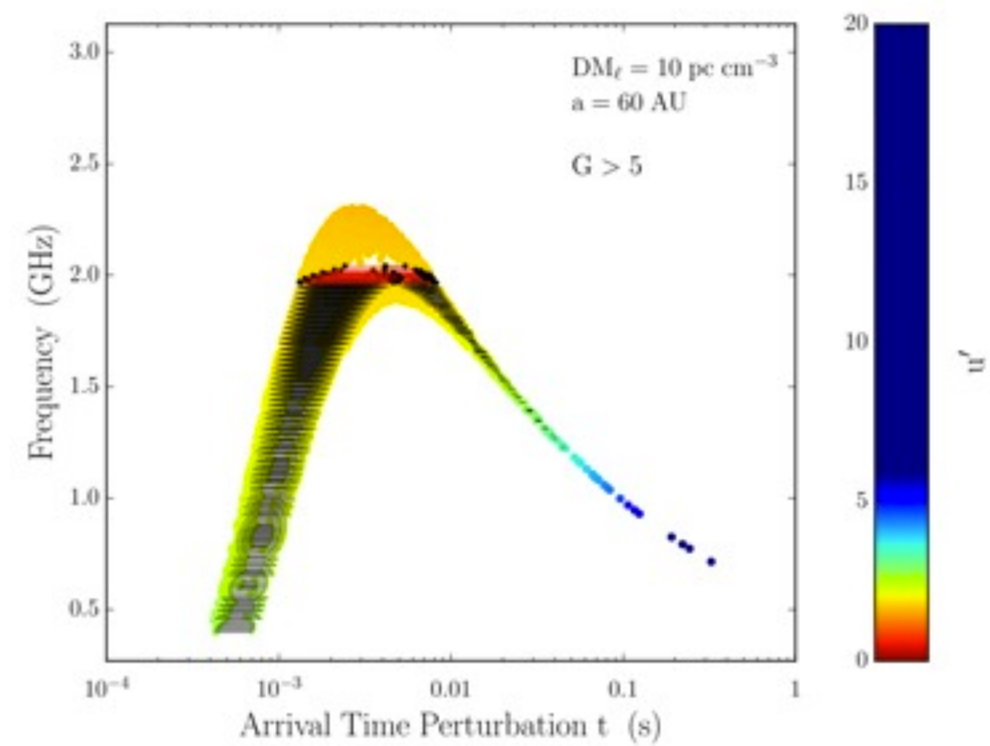
Multiple Images



Cuspy frequency structure
Significant gain boosts



Time delays between images



Cordes et al., ApJ, 842, 2017

Known plasma lensing phenomenon:

Extreme scattering events

Echos in profile of Crab pulsar

What can we learn by observing the environment?

- Arguably, a lot more...

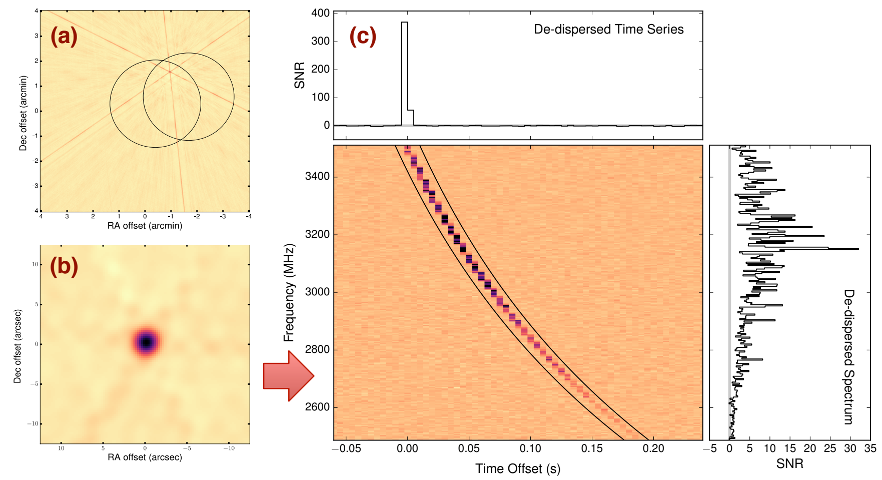
- (If you want to try to convince me the repeater comes from a different FRB population, show me the environments of “one-off” sources.)

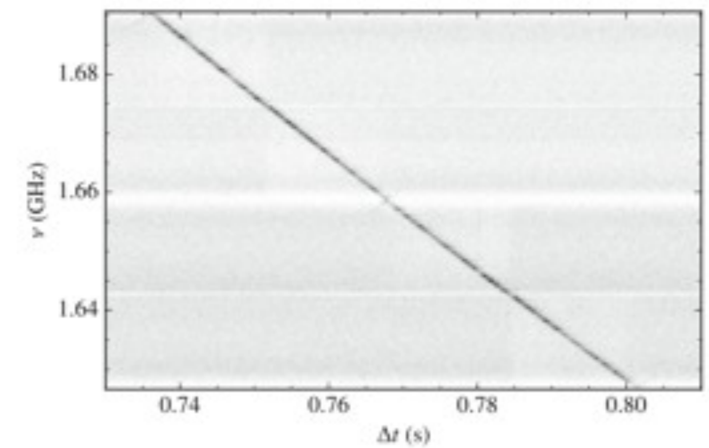
Radio localization

Very Large Array

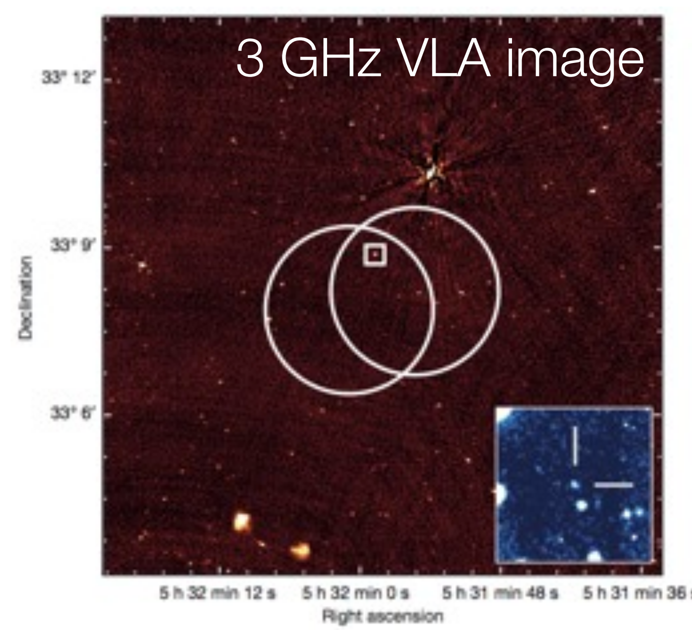
European VLBI Network

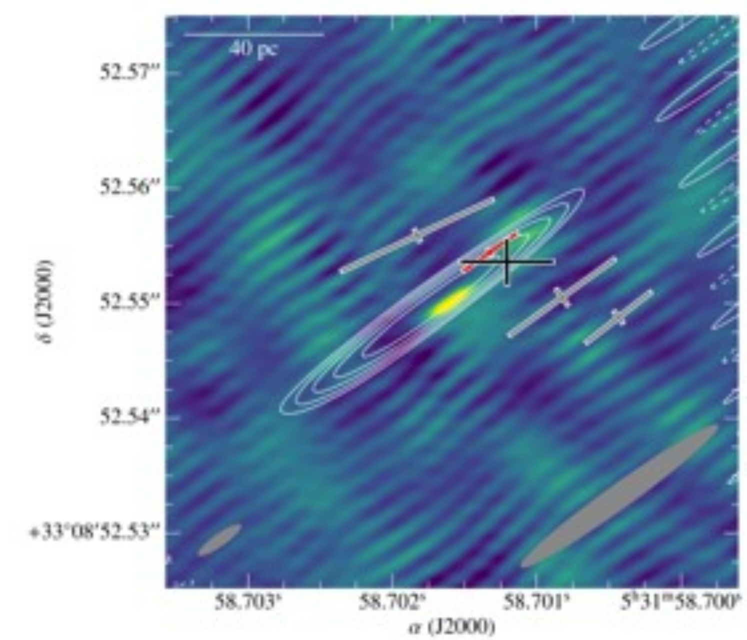
Bursting source:
Localized to sub-milliarcsecond precision





Persistent radio source:
Compact (<0.7 pc)
Spatially coincident with bursting source





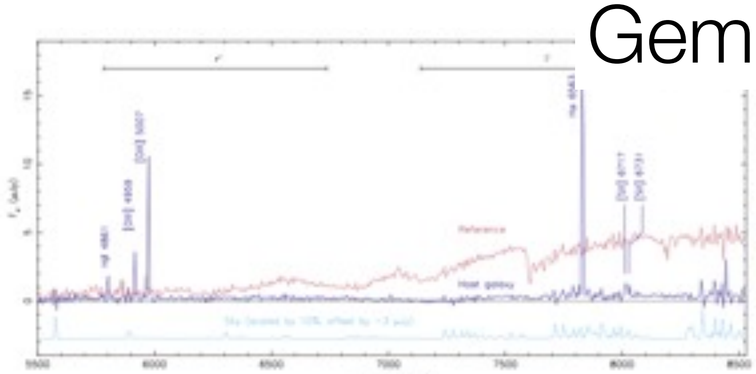
Chatterjee et al, *Nature*, 2017

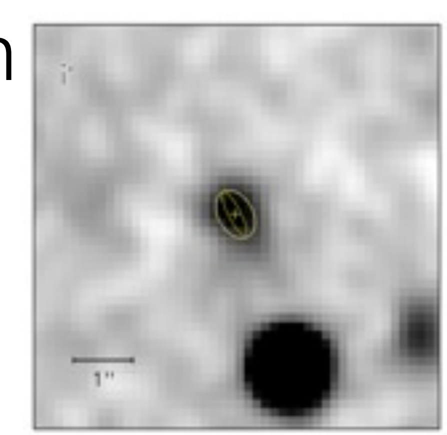
Marcote et al., *ApJL*, 2017

Optical follow-up

Host galaxy:
Redshift of 0.193
Low metallicity dwarf

Gemini North



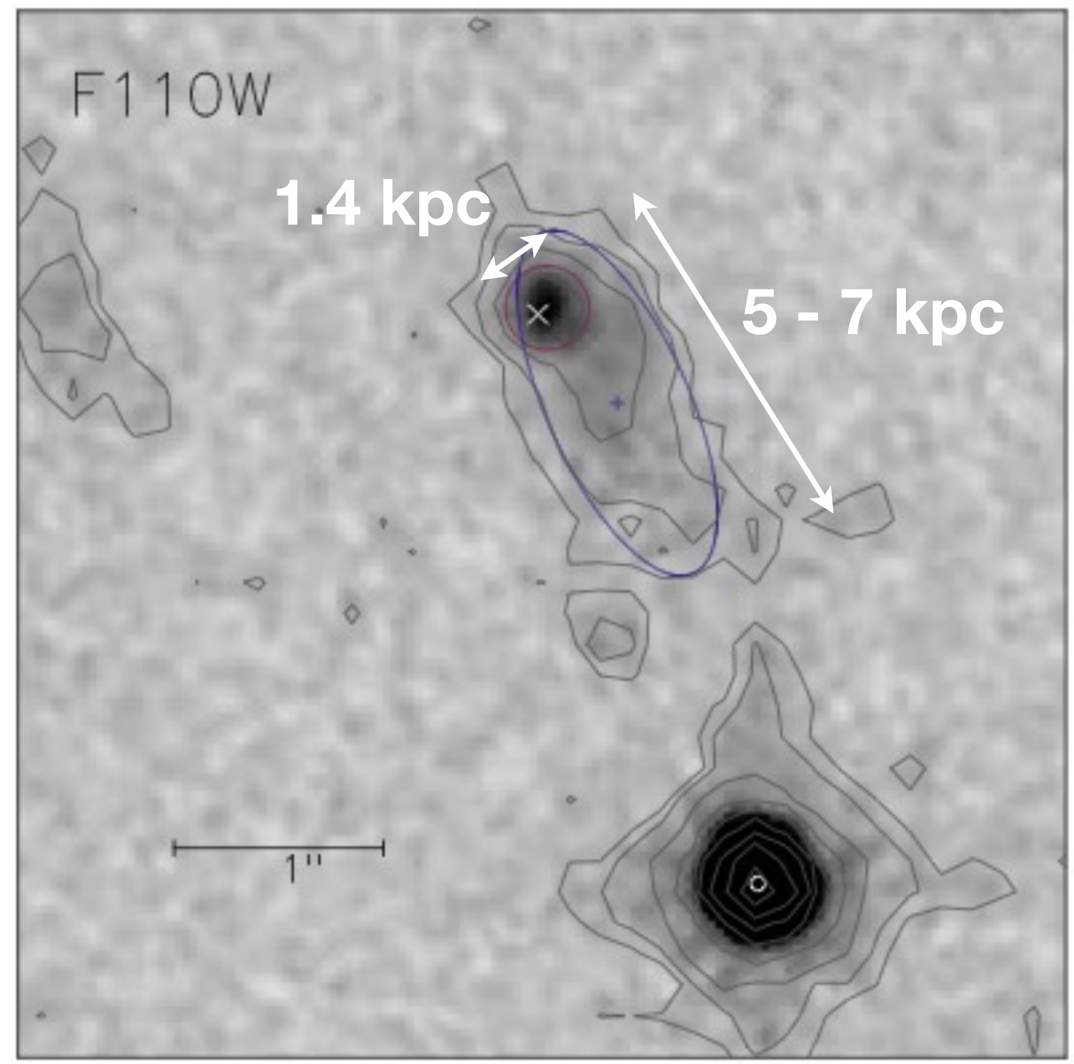


Tendulkar et al, *ApJL*, 2017

FRB 121102 located in large star formation region

- Host galaxy is a low metallicity dwarf
    - $M_\bigstar \sim 10^8 M_\odot$
    - Metallicity: $12 + \log_{10}(O/H) = 8 \pm 0.2$
    - SFR: $0.23 - 0.4\ M_\odot yr^{-1}$
- Persistent+bursting source sitting in a large HII region
- Similar to extreme emission line galaxies (EELGs)

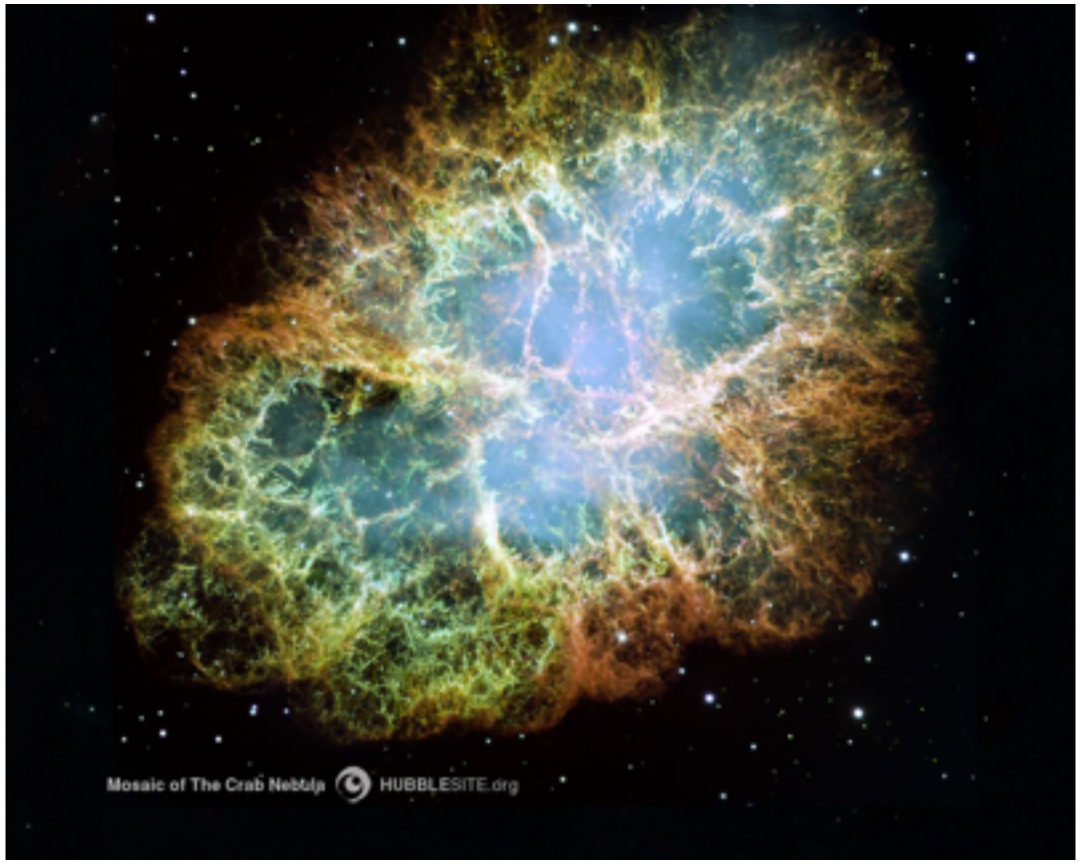
HST image



Bassa et al, ApJL, 843, 2017

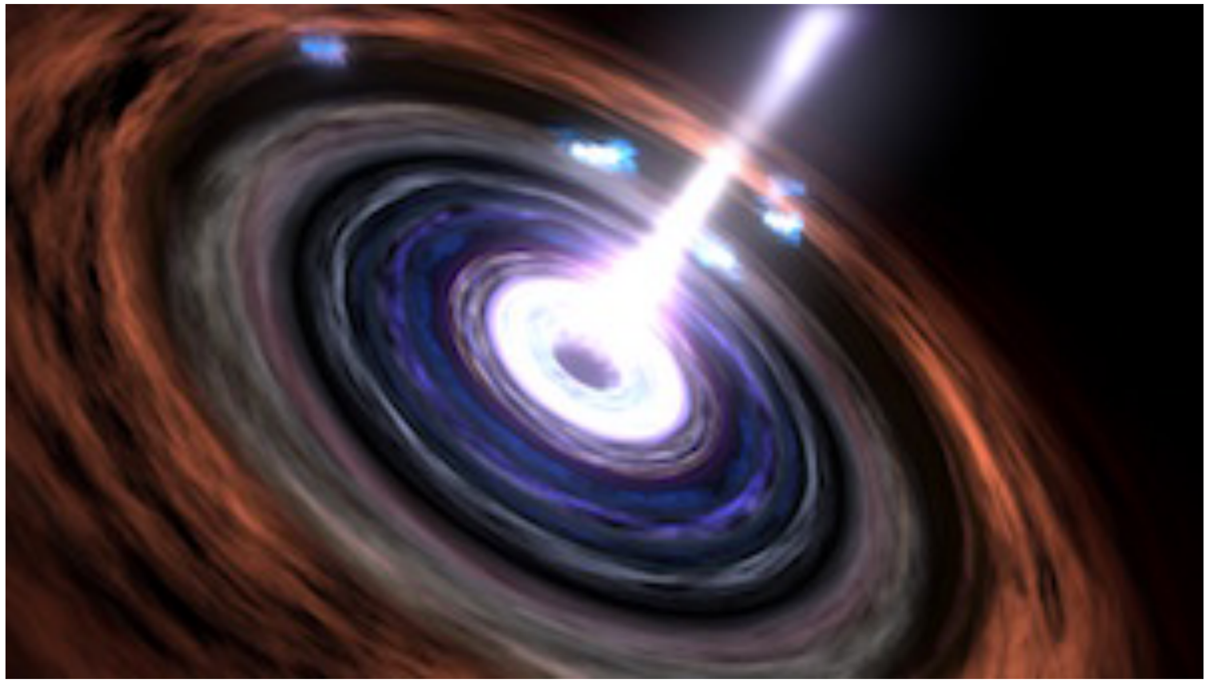
Two models

The burst source is a young magnetar in an energetic nebula



Credit: NASA/Hubble

The bursting source (neutron star?) is in the vicinity of an intermediate massive black hole



Credit: NASA/Goddard Space Flight Center Conceptual Image Lab

Model scoreboard

	millisecond magnetar (SLSNe/long GRB)	Intermediate mass black hole
Source of luminous bursts	✔	NS in vicinity?
Strong, spatially coherent magnetic field		
Radio luminosity of persistent source		
Location in star formation region		
Host galaxy properties		

✔ = easily explainable ✘ = less easily explainable

Rotation Measure

$$\theta_p = \frac{c^2}{\nu^2}\mathrm{RM}$$

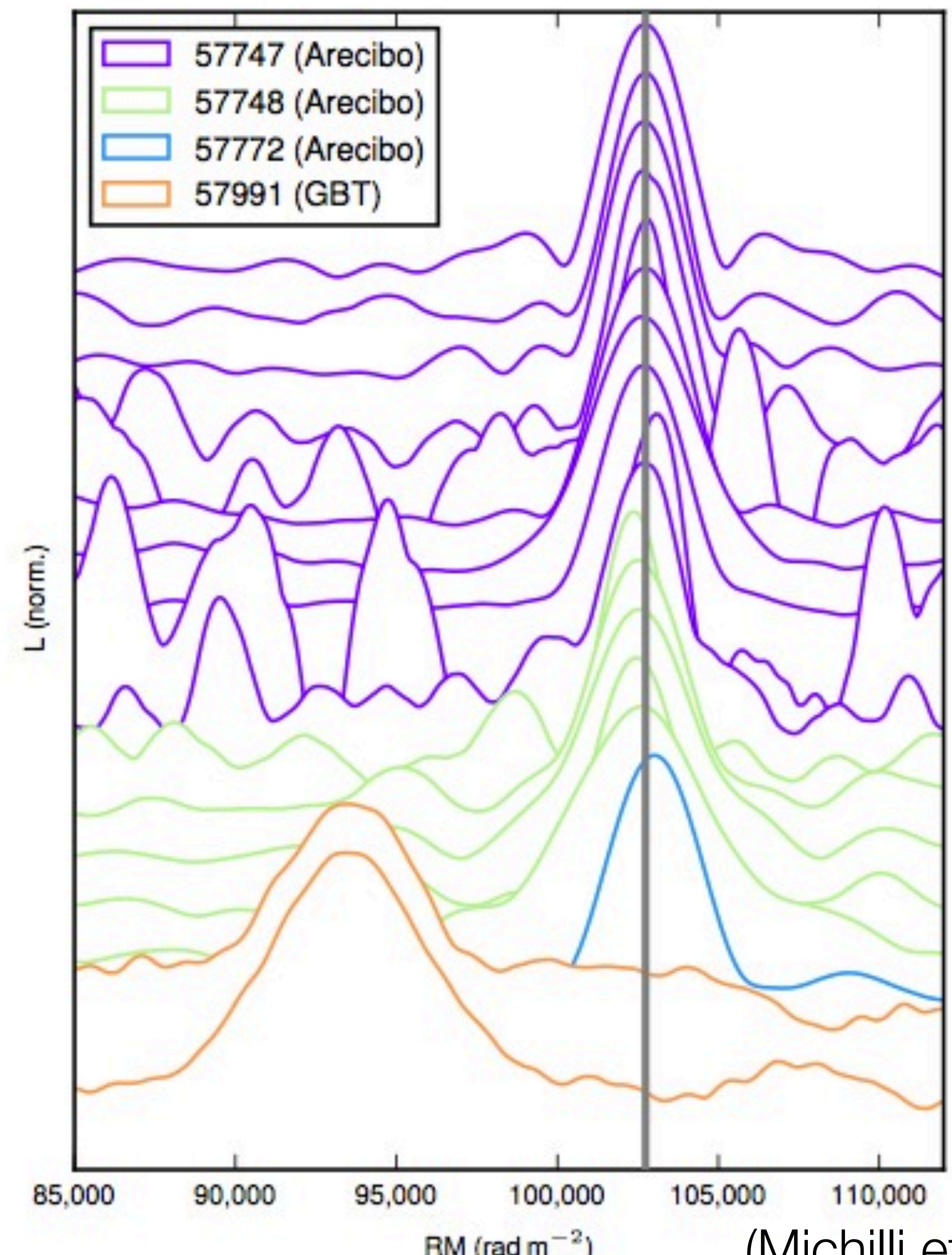
$$\mathrm{RM} = \int_0^D n_e(l) B_{||} dl$$

n_e = electron density $B_{||}$ = magnetic field along the line of sight

$$\mathrm{RM}_{\mathrm{source}} = (1+\mathrm{z})^2 \mathrm{RM}_{\mathrm{obs}}$$

$\mathrm{RM}_{\mathrm{source}}$ ~ 145,000 rad m^{-2} (AO)
$\mathrm{RM}_{\mathrm{source}}$ ~ 133,000 rad m^{-2} (GBT)

Explains why the bursts at 1.4 GHz show no polarization.



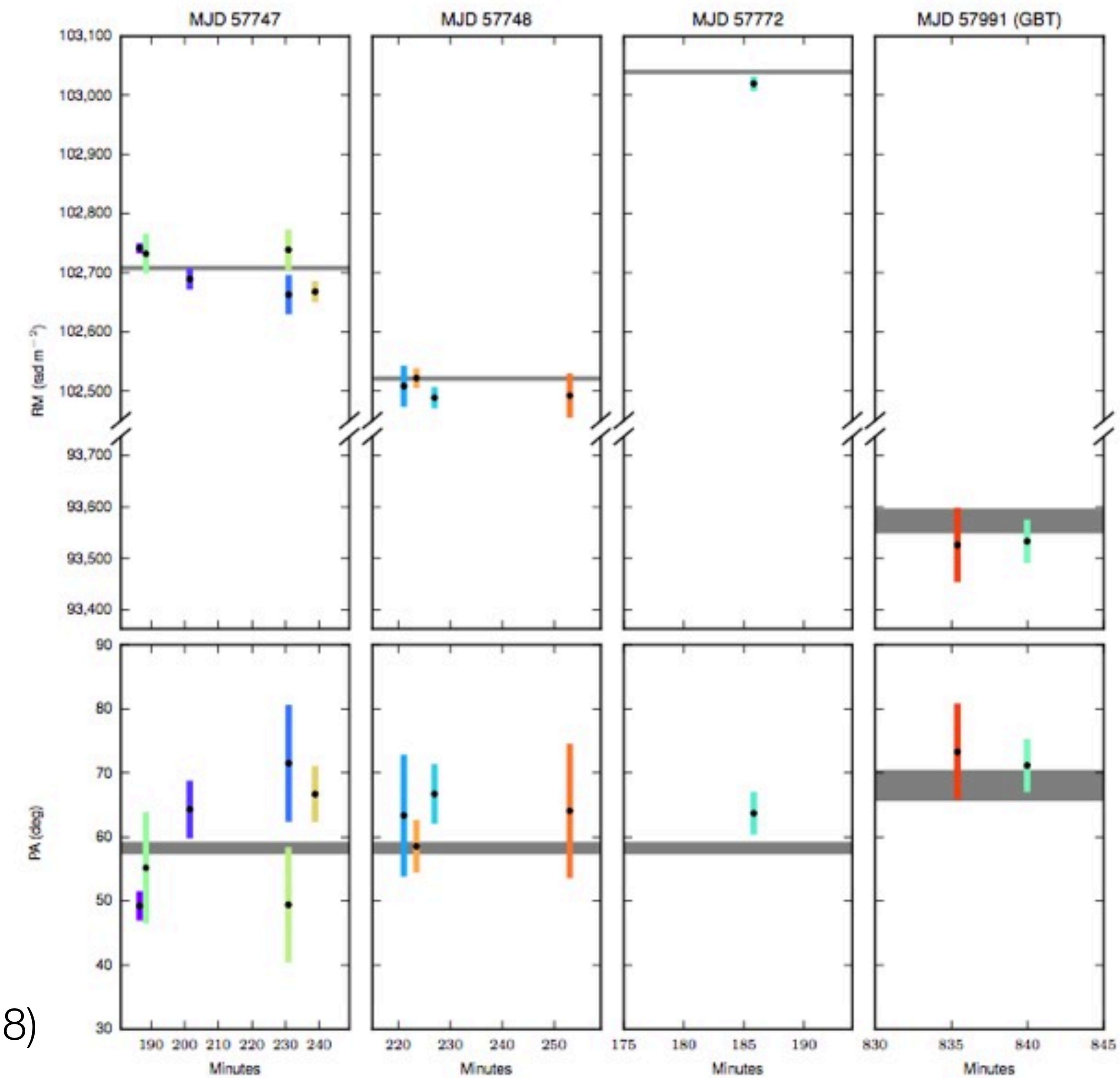
(Michilli et al 2018)

RM is time variable

$$B_{||} = \left(\frac{\mathrm{RM_{src}}}{0.81\ \mathrm{DM_{host}}} \right) \mathrm{mG}$$

$\mathrm{RM_{source}}$ ~ 145,000 rad m^{-2}
$\mathrm{DM_{host}}$ = 70 - 270 pc cm^{-3}
<u>B-field ~ 0.6 - 2.4 mG</u>

We argue that the magnetized plasma local to the source is responsible for the RM is local to the source.



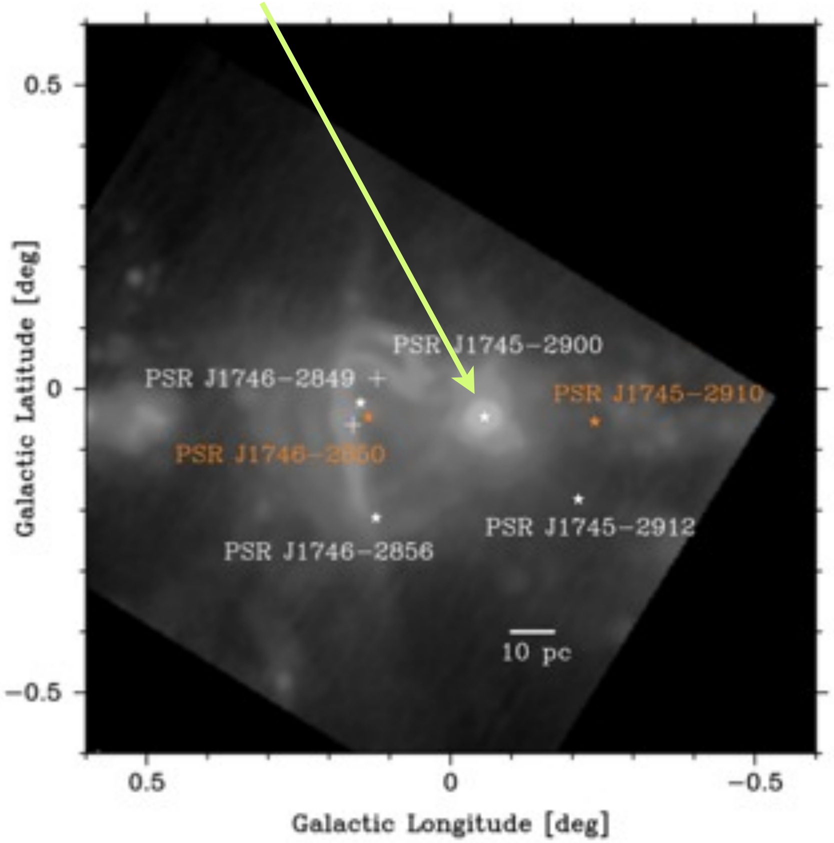
(Michilli et al 2018)

Interesting Galactic analog: Galactic center

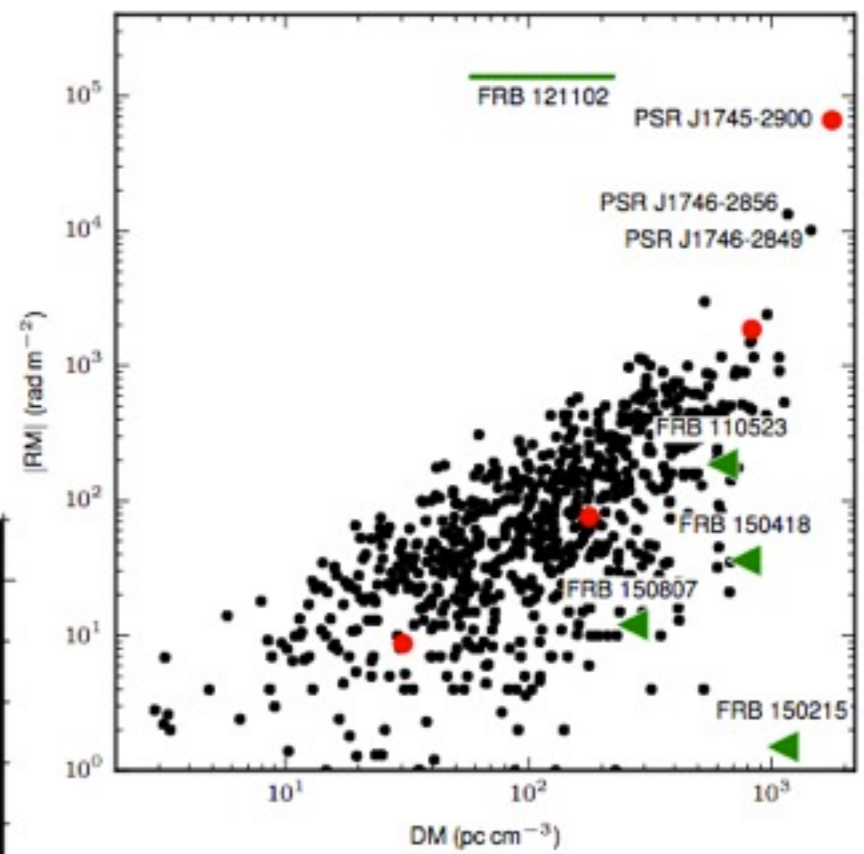
$RM_{Sgr\ A^*} \sim 4 \times 10^5$ rad m^{-2}

Six “GC” pulsars

J1745-2900 (aka the “GC magnetar”)
~0.1 pc from Sgr A*

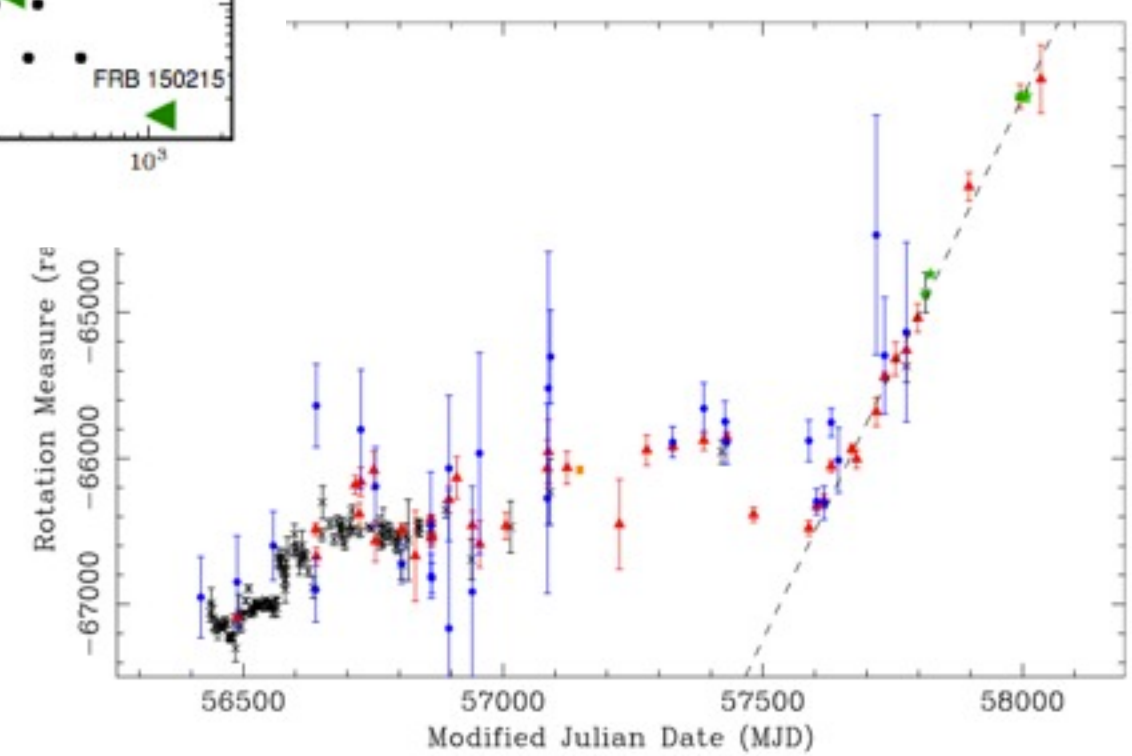


(Schnitzeler et al 2016)



(Michilli et al 2018)

RM of J1745-2900 also variable
DM is consistent with no variation



(Desvignes et al., ApJL, 852, 2018)

Model scoreboard

	millisecond magnetar (SLSNe/long GRB)	Intermediate mass black hole
Source of luminous bursts	✔	NS in vicinity?
Strong, spatially coherent magnetic field	✘ RMs ~10^5 rad m^{-2} have never been observed from a SNe/PWNe ? Maybe SLSNe/LGRBs simply different	✔ Galactic center

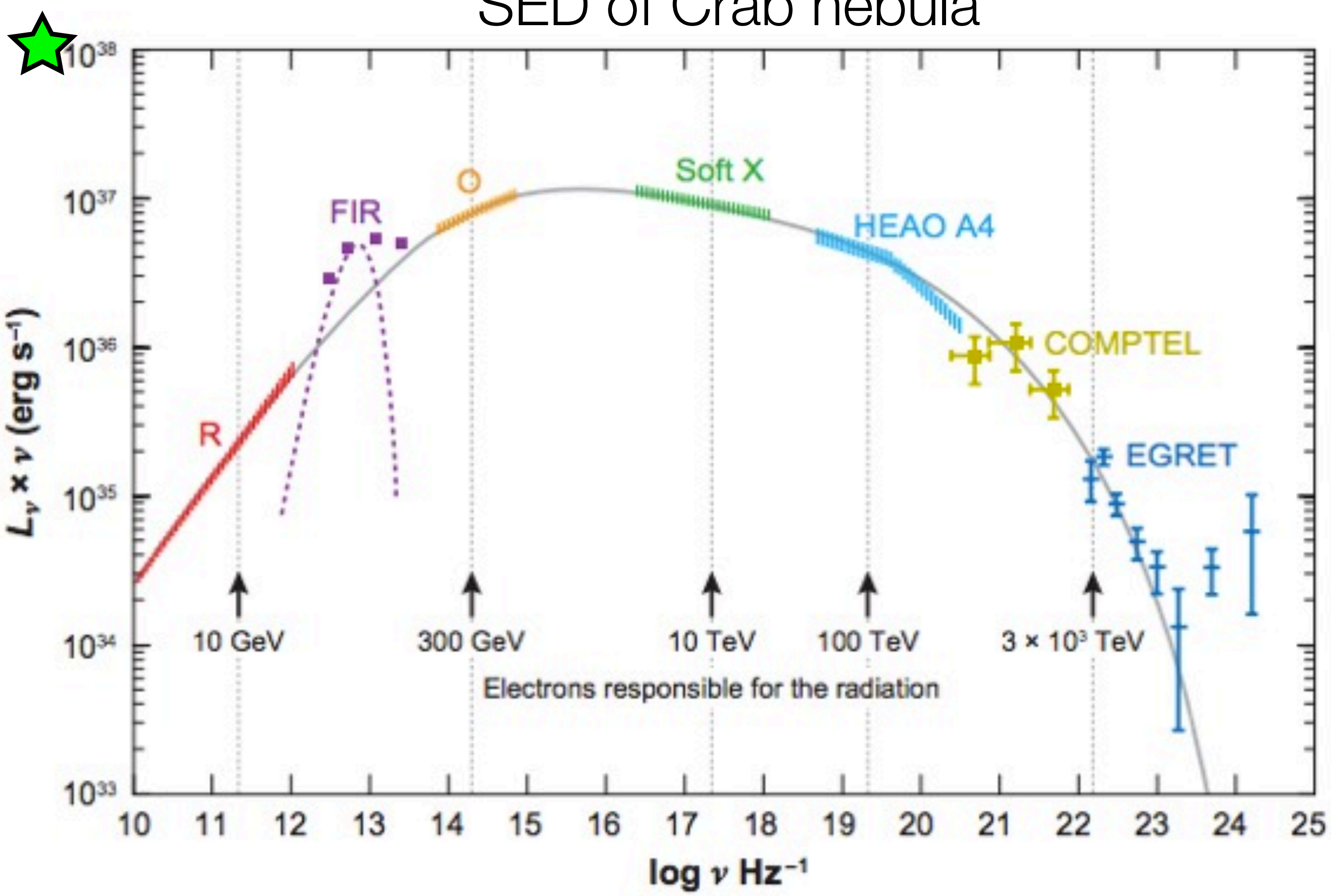
Luminosity of persistent radio source

FRB 121102:

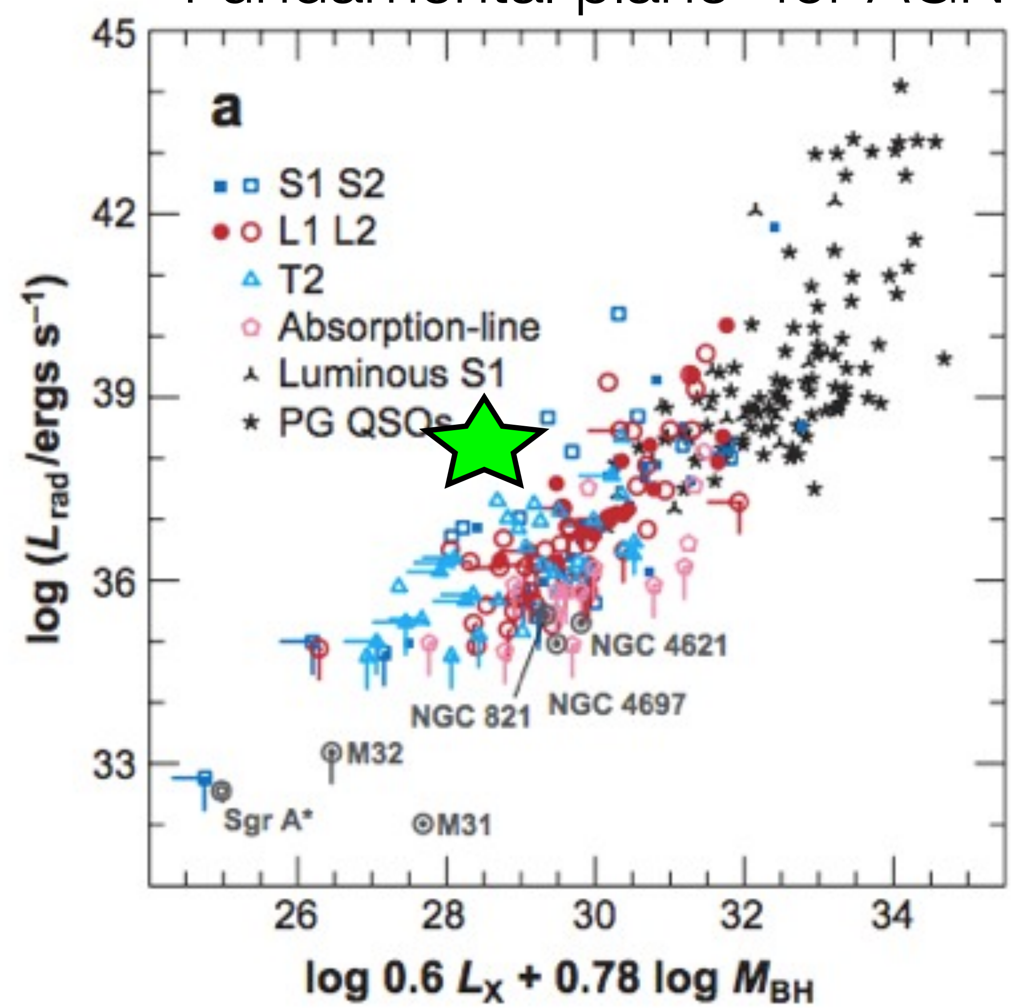
$L_{Radio,PS} \sim 10^{38}$ erg s^{-1}

$L_{X\text{-ray},PS} < 10^{41}$ erg s^{-1}

SED of Crab nebula



"Fundamental plane" for AGN



Hester, ARA&A, 2008

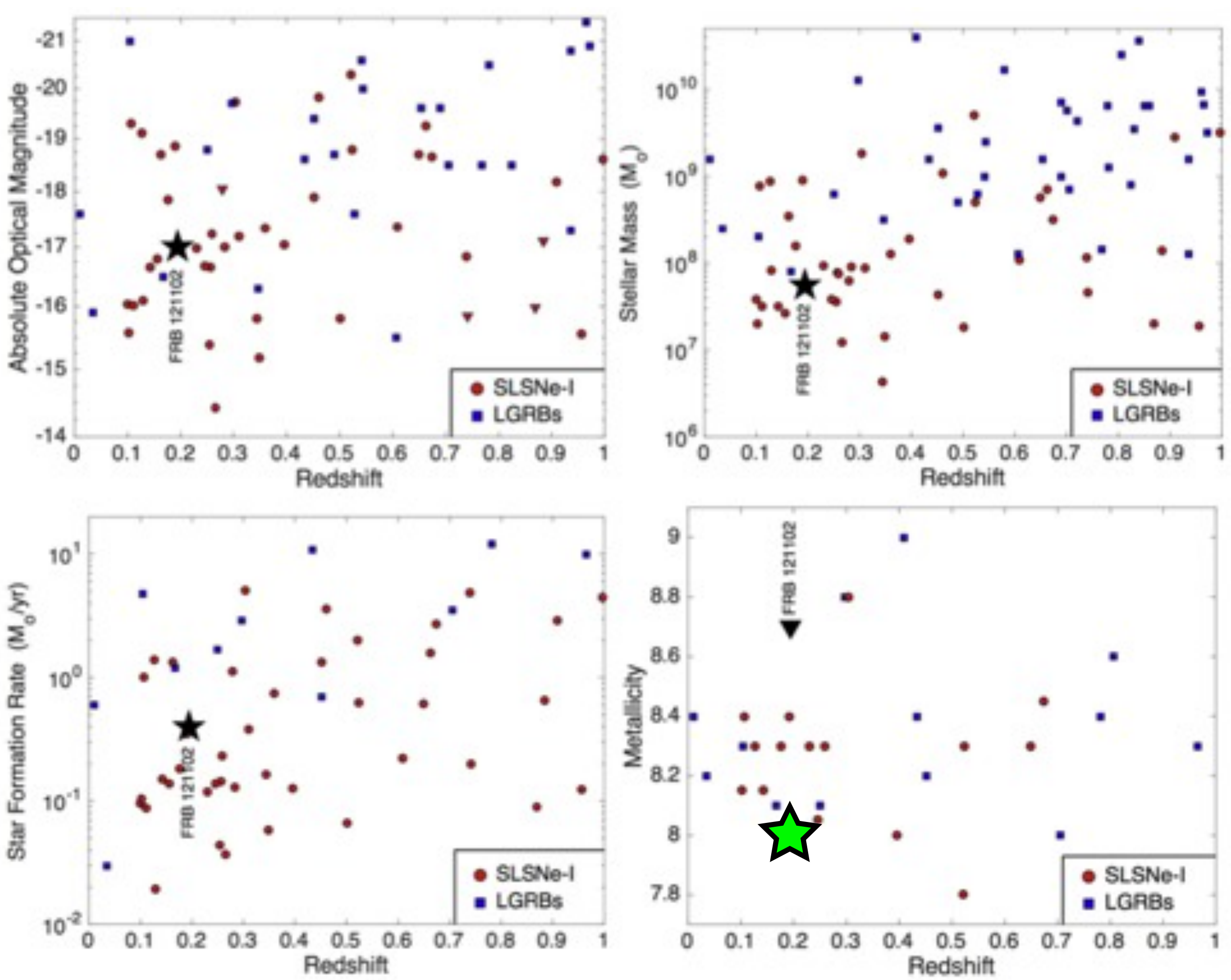
Ho, ARA&A, 2008

Model scoreboard

	millisecond magnetar (SLSNe/long GRB)	Intermediate mass black hole
Source of luminous bursts	✔	NS in vicinity?
Strong, spatially coherent magnetic field	?	✔
Radio luminosity of persistent source	✘	✔

Host galaxy properties

Host of FRB 121102 typical for hosts of SLSNe/LGRBs



Metzger et al., ApJ, 2017

Low luminosity AGNs are rare in dwarf galaxies

Optically selected (Reines et al 2013): 0.5%

X-ray selected (Mezcua et al 2018): 0.2%; only ~8% had radio emission

Radio / X-ray luminosities don't into the "fundamental plane"

Model scoreboard

	millisecond magnetar (SLSNe/long GRB)	Intermediate mass black hole
Source of luminous bursts	✔	✔
Strong, spatially coherent magnetic field	✘	✔
Radio luminosity of persistent source	✘	✔
Location in star formation region	✔	✘
Host galaxy properties	✔	✘

✔ = easily explainable ✘ = less easily explainable

Conclusions

- The repeating FRB has been an interesting case study in FRB localization
    - We know the source is associated with a compact, persistent radio source in a low-metallicity dwarf galaxy at z=0.193. It is embedded in a region of strong star formation and in an environment similar to the center of our galaxy.
    - Bursts show a complex phenomenology
    - Observing the source's environment did more to narrow down astrophysical models: young neutron star + SNe or NS in the vicinity of a low-luminosity AGN