

# Fast Radio Bursts



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Image credit: Danielle Futselaar



UNIVERSITEIT VAN AMSTERDAM



European Research Council  
Established by the European Commission

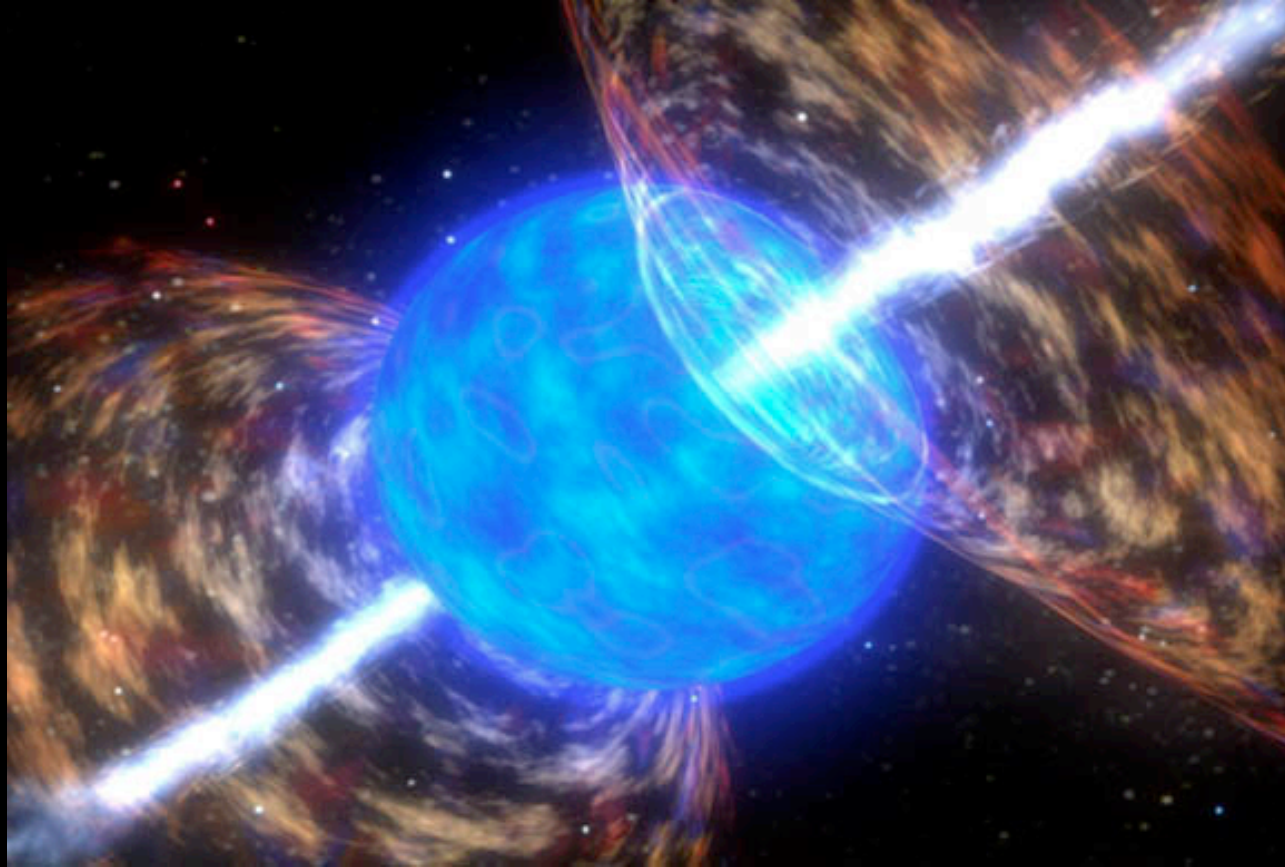


Netherlands Organisation  
for Scientific Research

**ASTRON**

Netherlands Institute for Radio Astronomy

# Gamma-ray Bursts



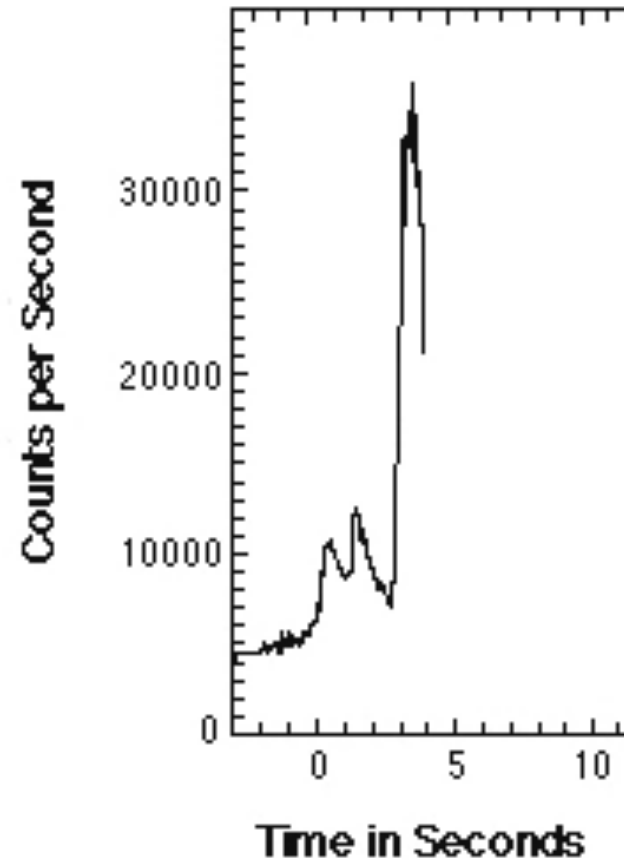
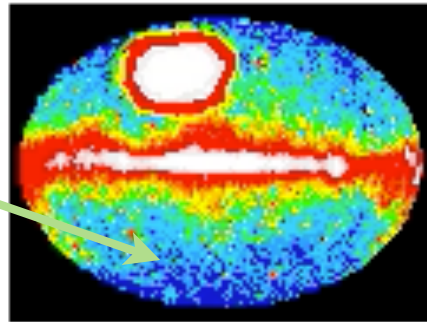
**Are there also similar sirens of extreme (astro)physics to be found in the radio?**

# Gamma-ray Bursts

Typical FoV  
of a radio  
telescope is  
<< 1 sq. deg.

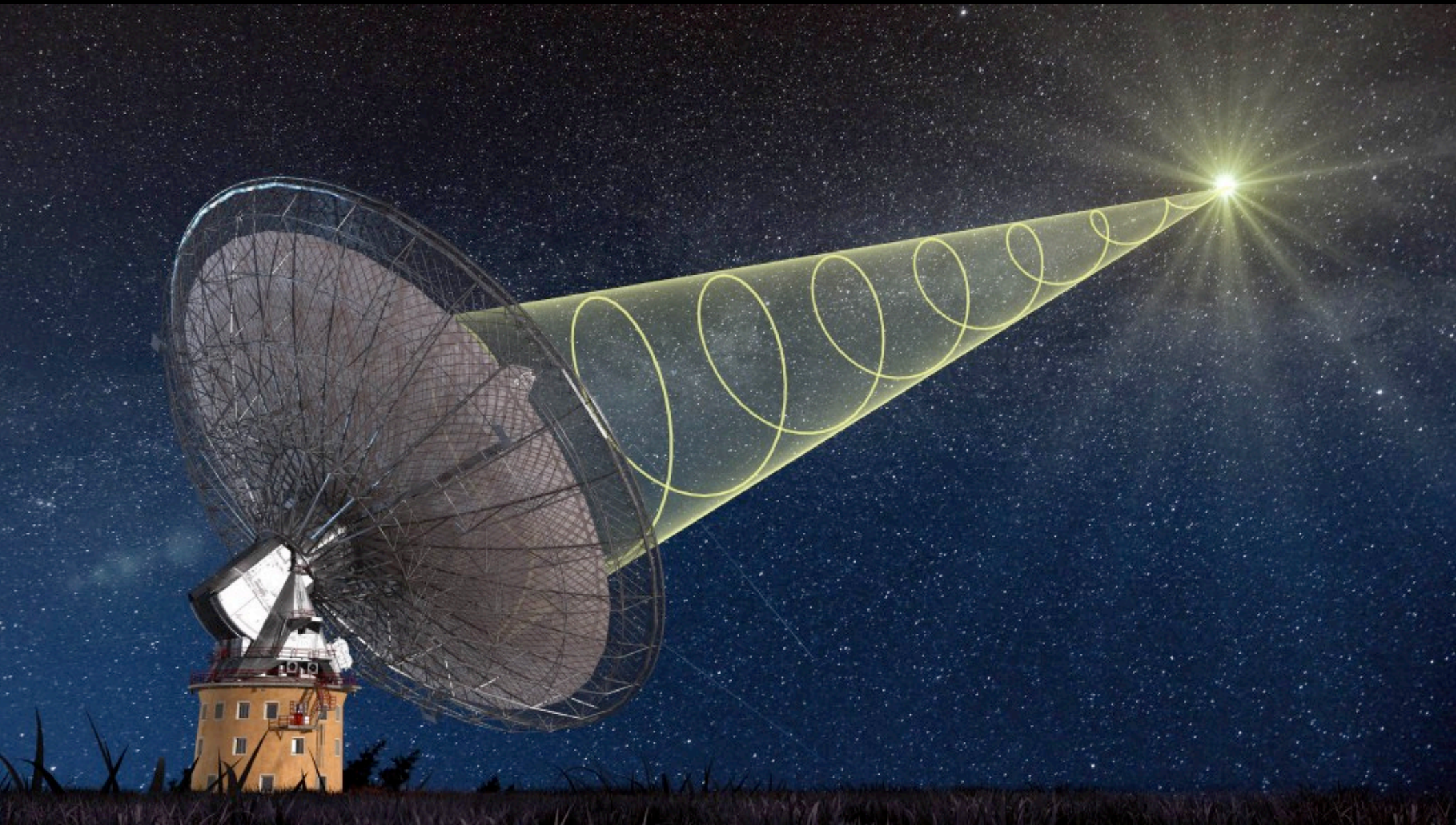


~10 days/FRB



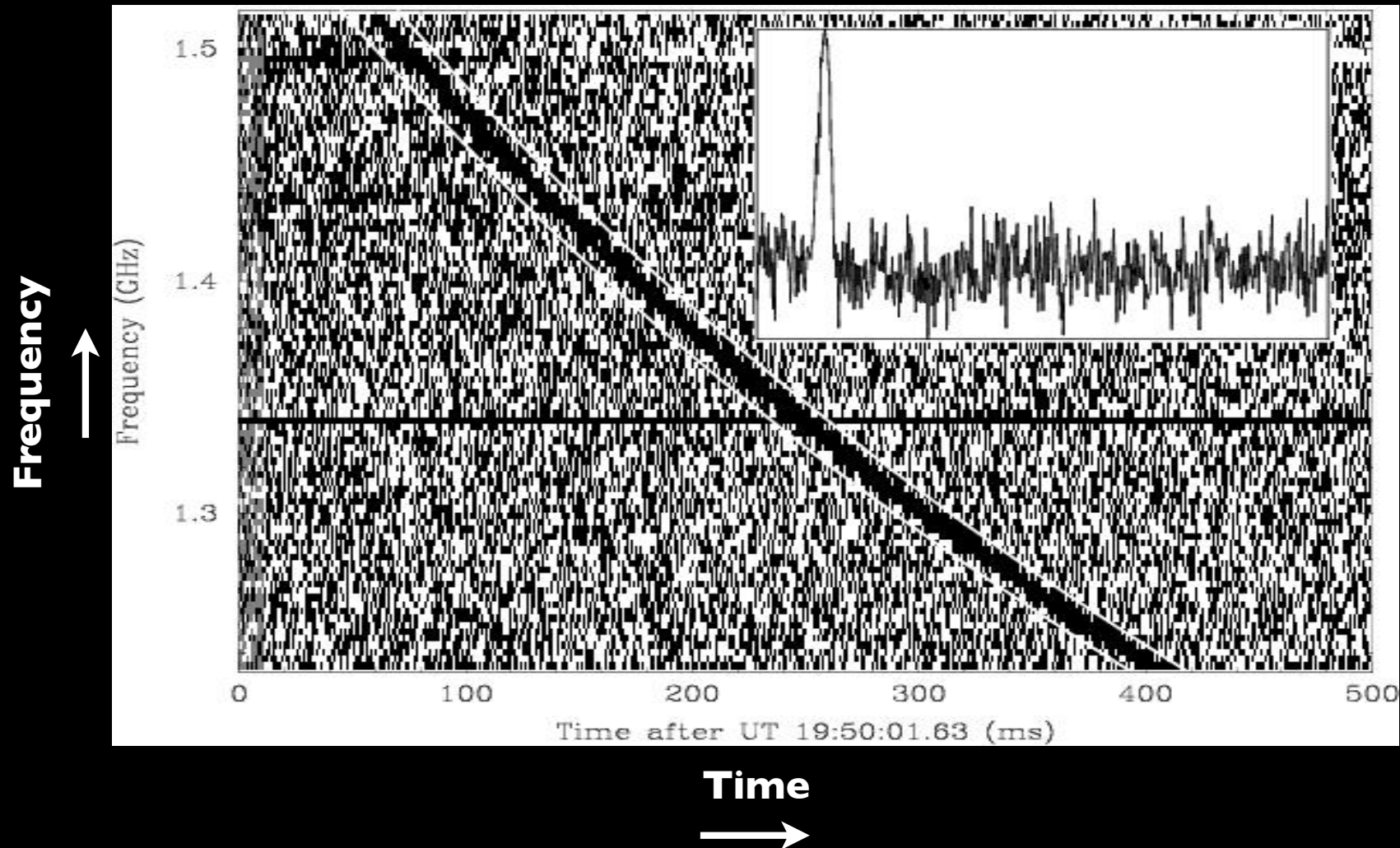
**There is no sufficiently sensitive all-sky  
radio monitor, yet...**

# Fast Radio Bursts



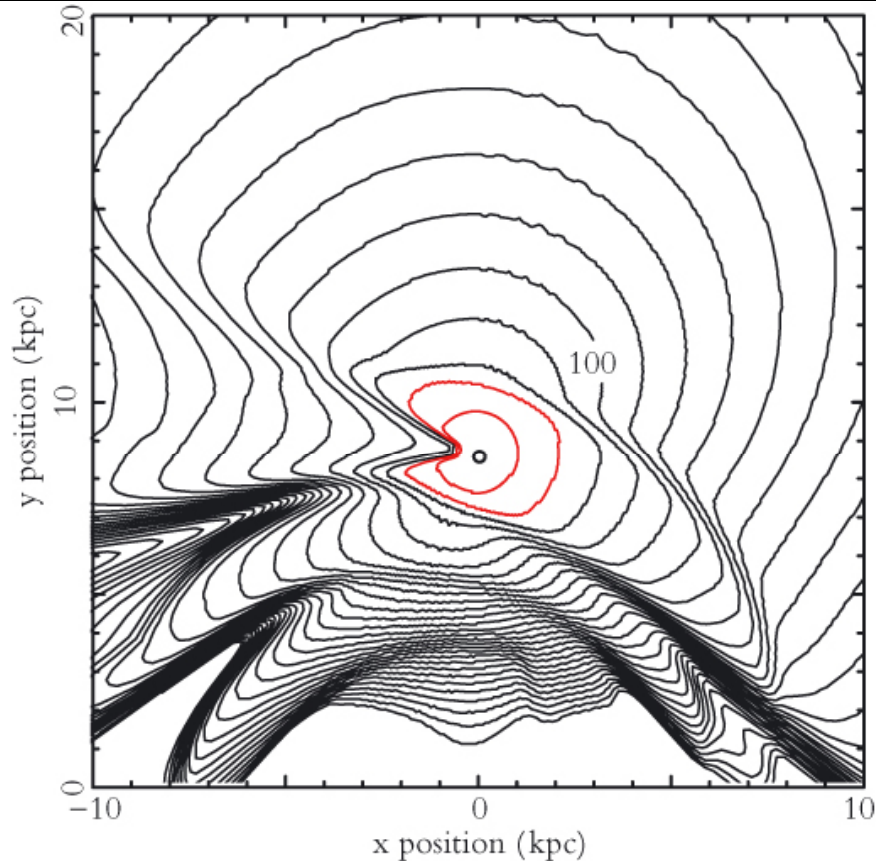
**Lorimer et al. 2007**  
**Thornton et al. 2013**

# 2007: The Lorimer Burst

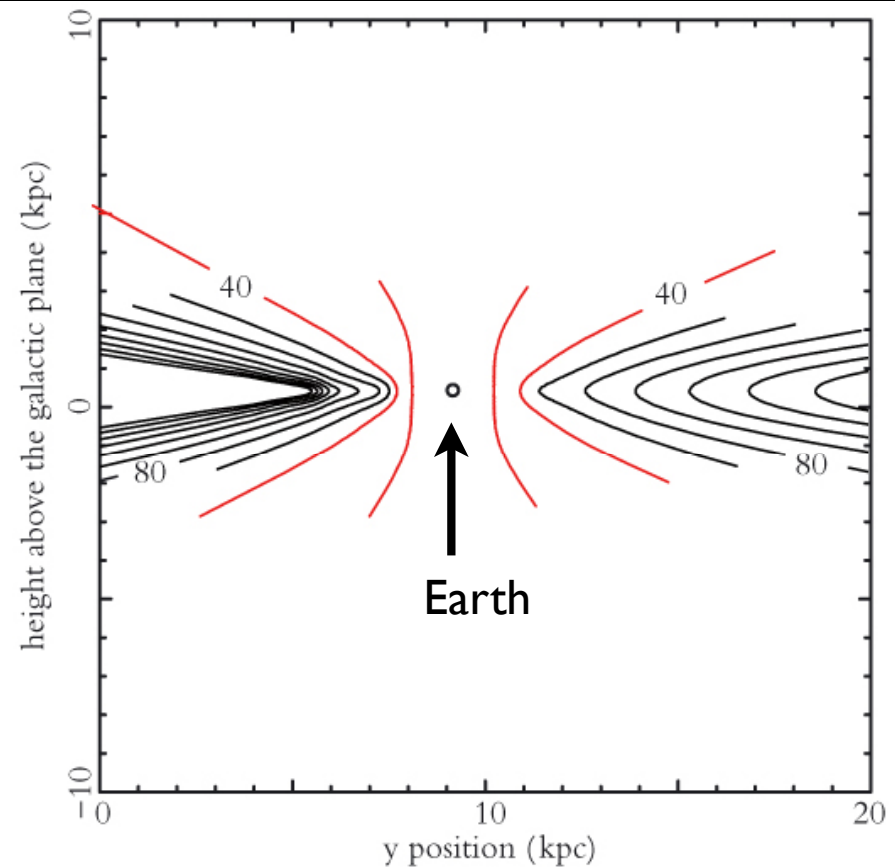


# Galactic Dispersion

Galaxy top-down



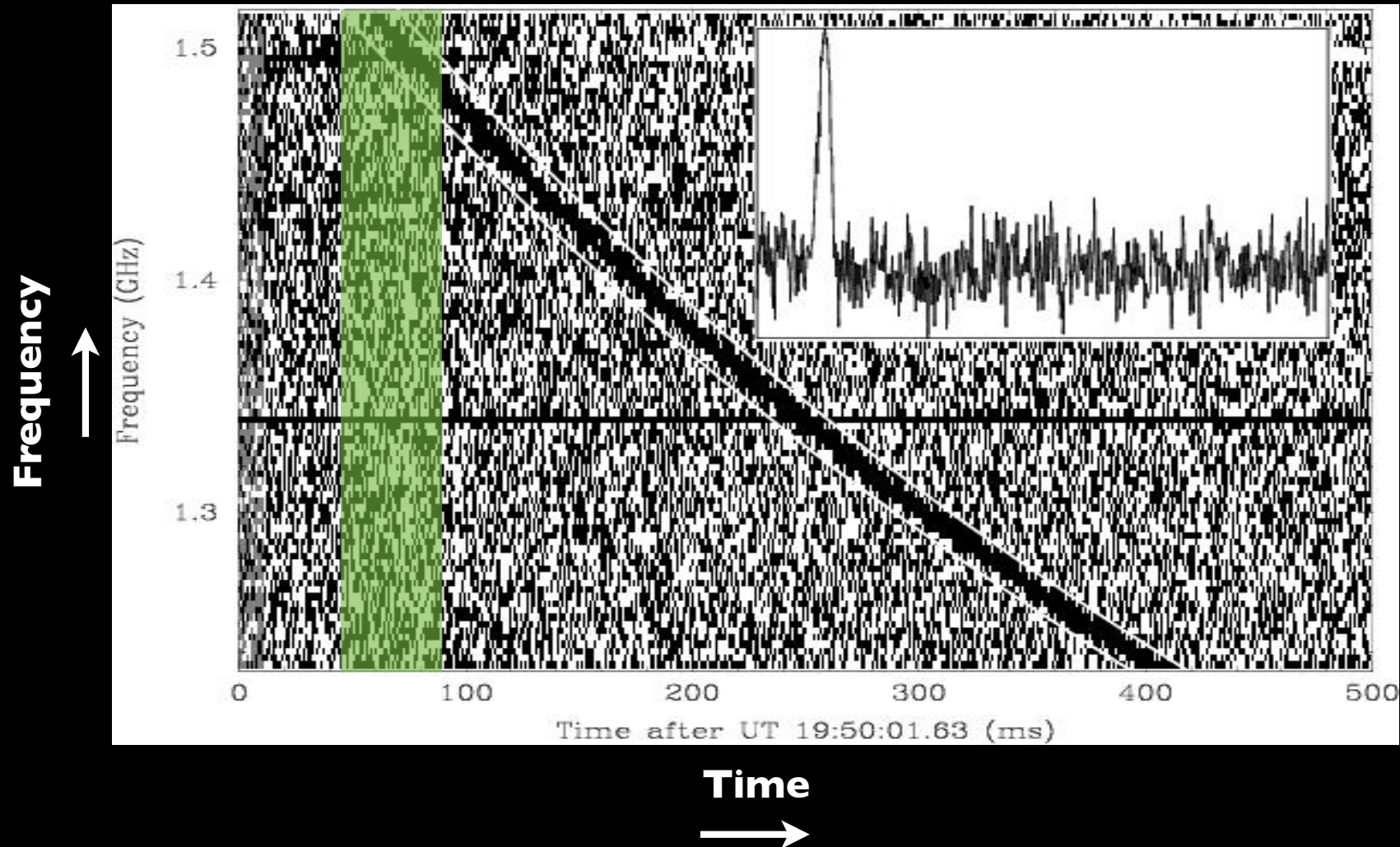
Along Galactic plane



**Contours of constant dispersion measure  
(NE2001 model; Cordes & Lazio)**

# 2007: The Lorimer Burst

ISM (interstellar medium)

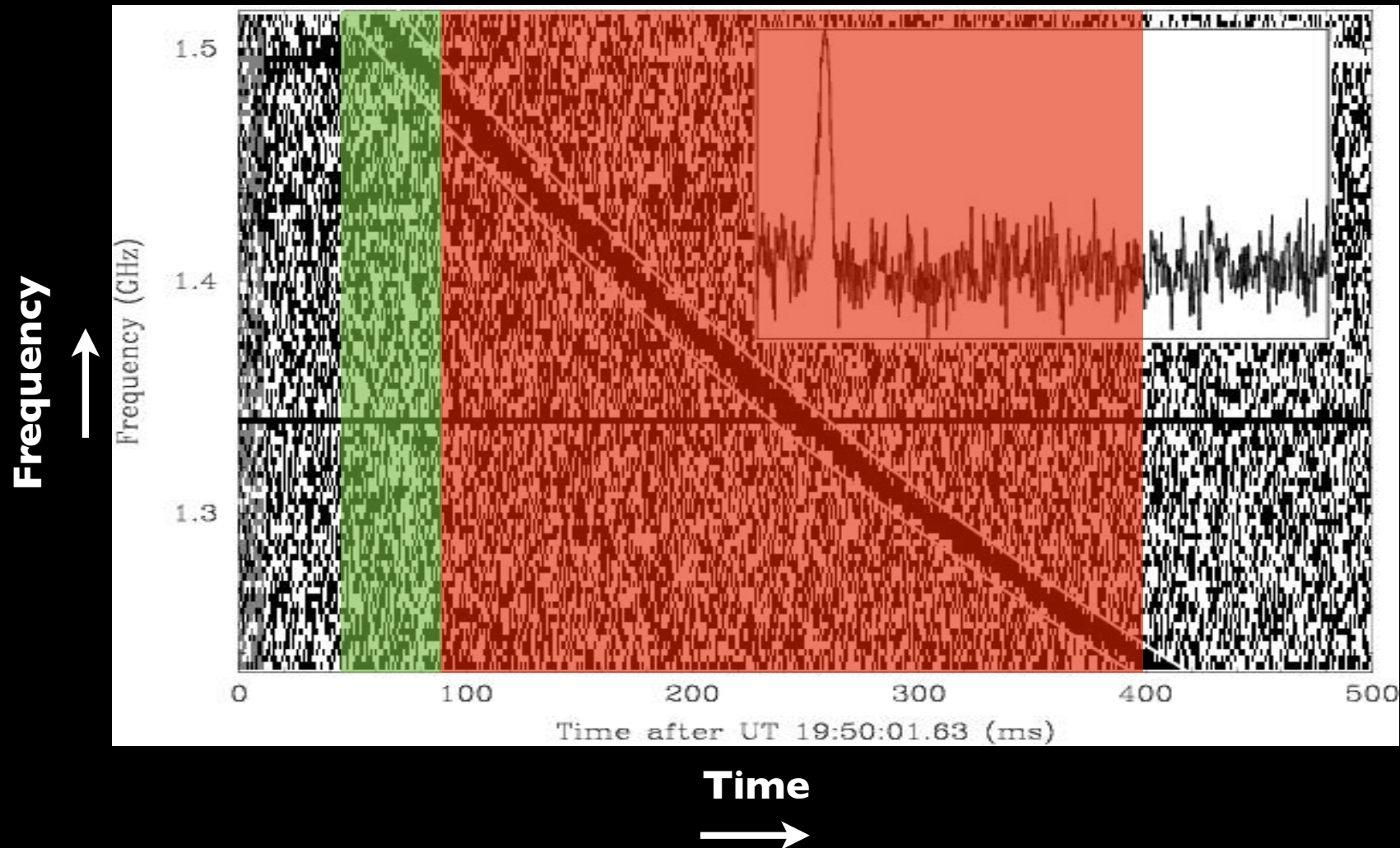


**Delay too large to come  
from just the galaxy**

Lorimer et al. 2007

# 2007: The Lorimer Burst

ISM IGM (intergalactic medium) + Host?



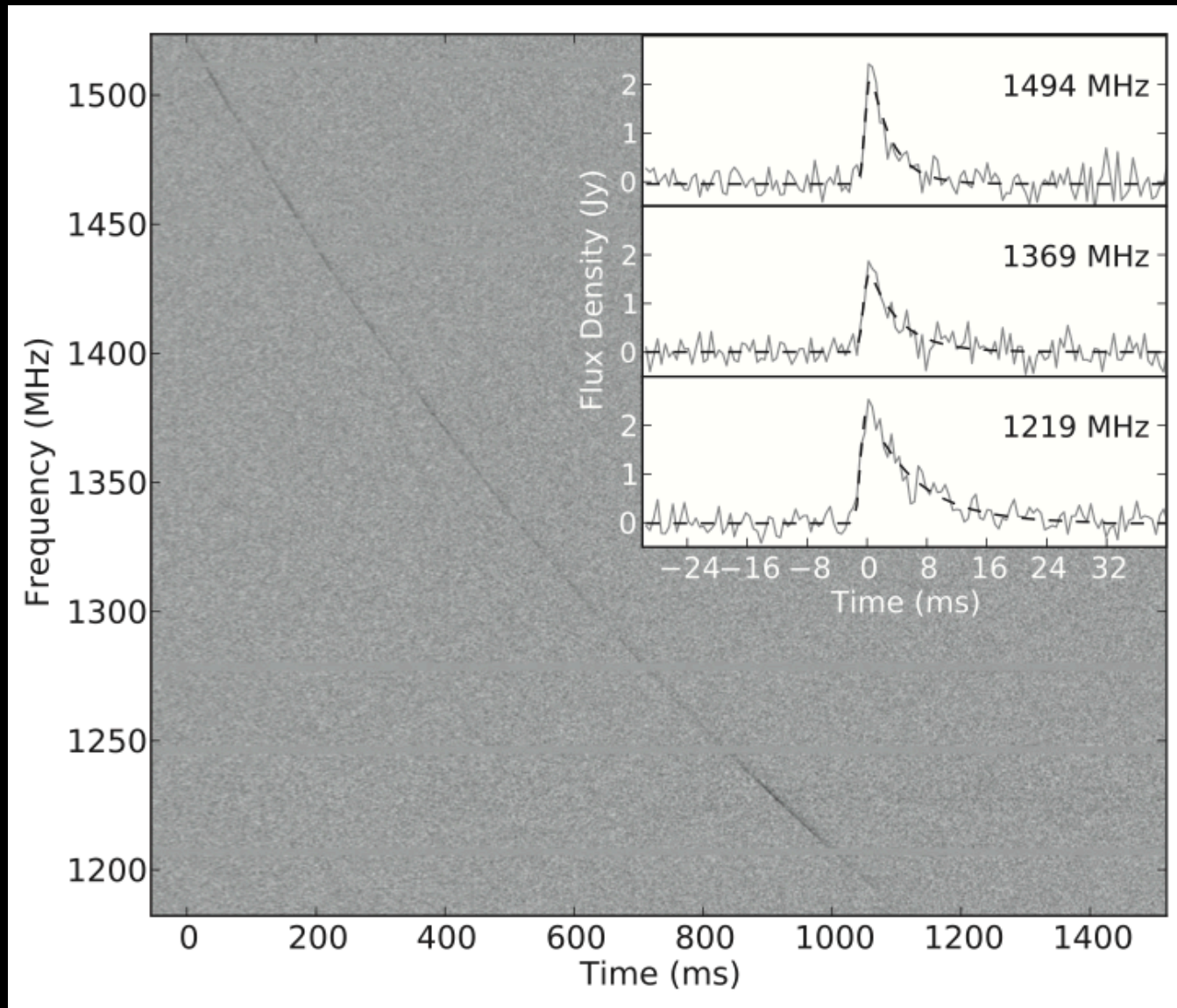
**Delay too large to come  
from just the galaxy**

Lorimer et al. 2007



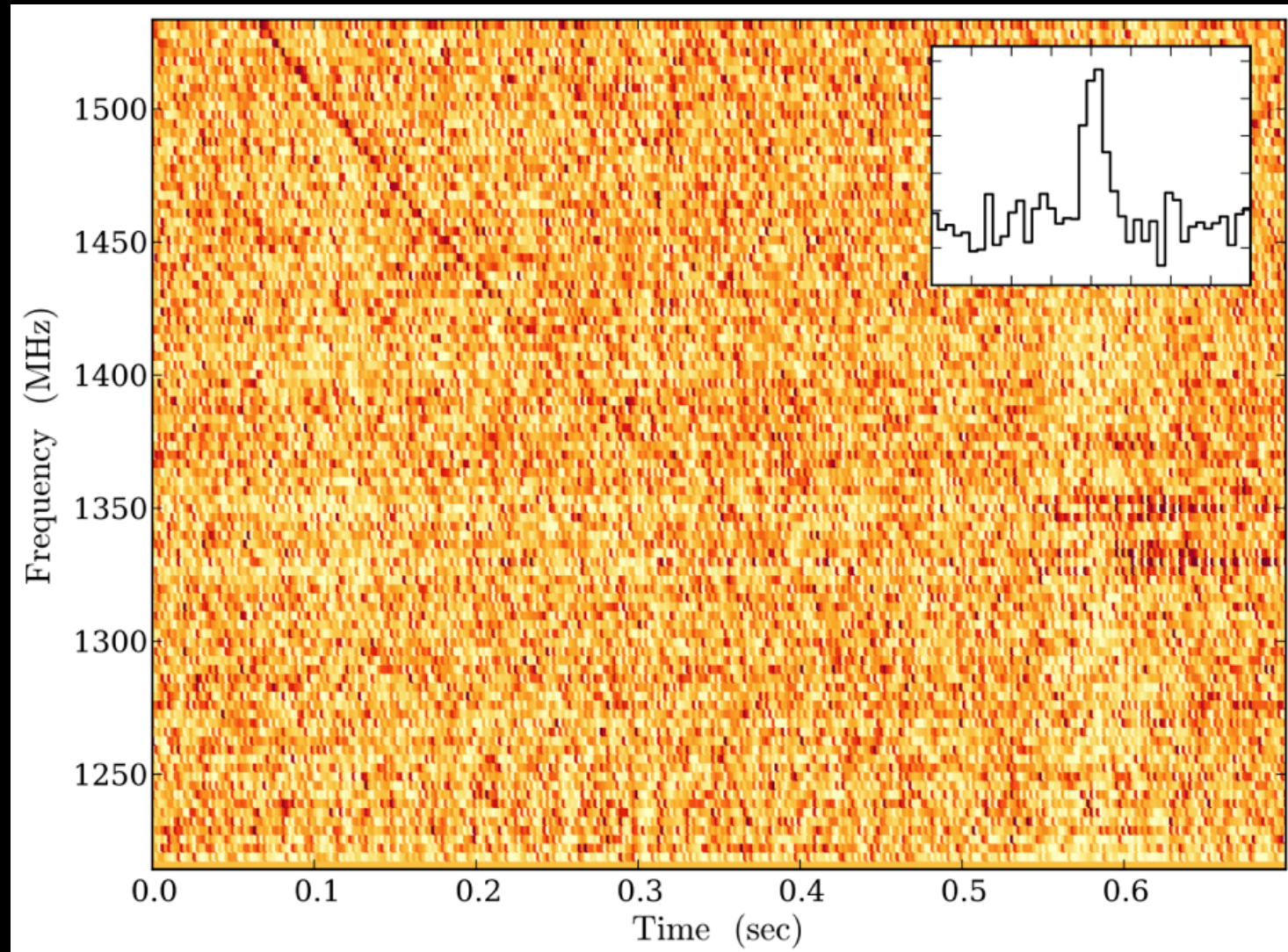
**...time passes, people are getting frustrated  
that they can't find more such bursts.**

# 2013: The Thornton Bursts



**There is a population of FRBs**

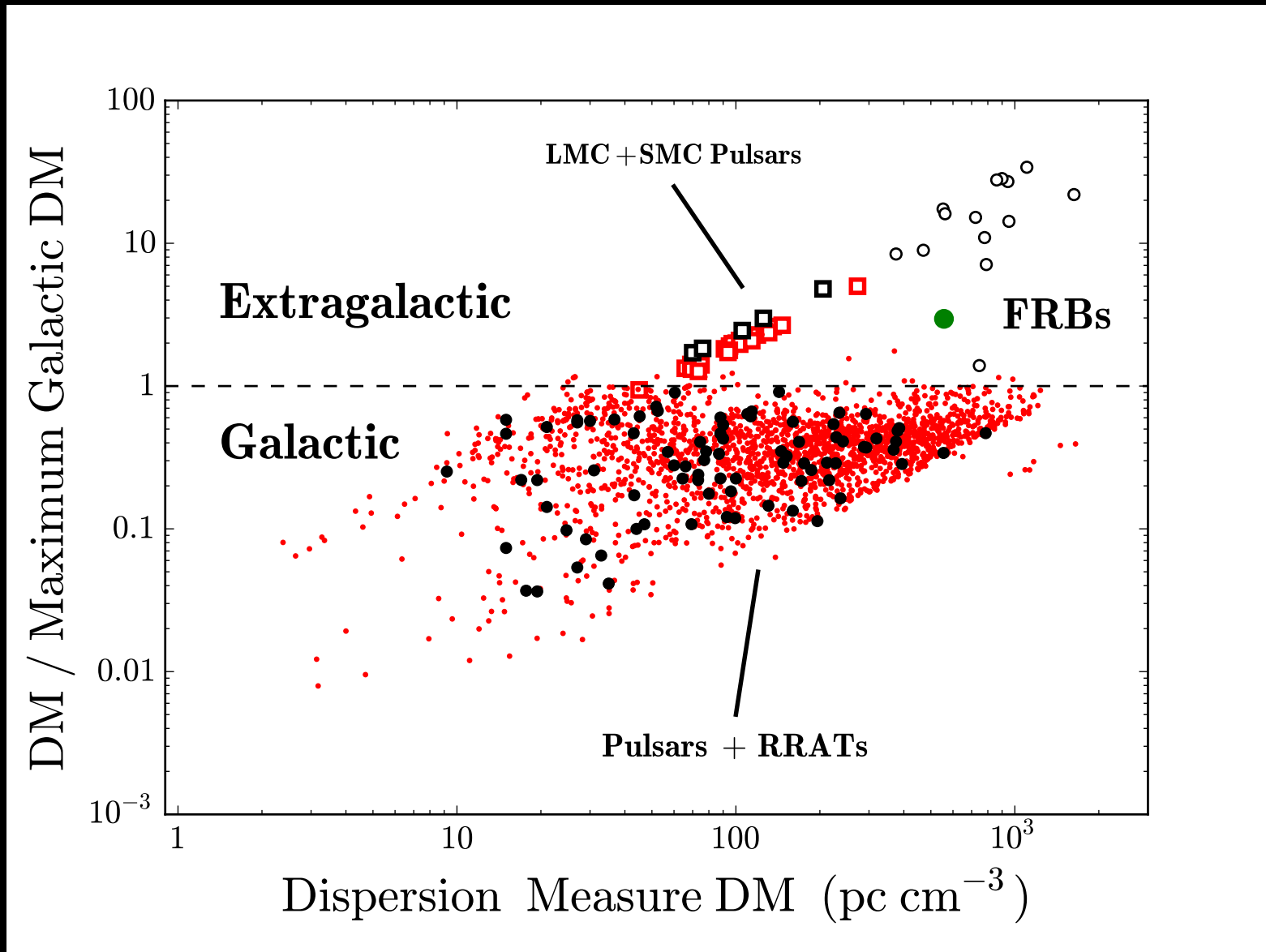
# The Arecibo Burst



## First non-Parkes FRB

Spitler, Cordes, Hessels et al. 2014

# Of Mice & Pulsars/RRATs/FRBs





**Merging  
Black Holes**



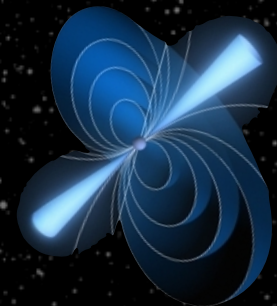
**Supernovae**



**Magnetars**



**Evaporating  
Black Holes**



**Super-giant  
Pulses**



**The  
Unknown**



**Gamma-ray  
Bursts**

**extra-Galactic**

**Implied rate of 1000s per day, per  
sky... but what are they?**

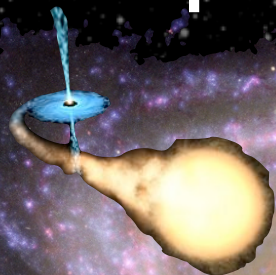
**Galactic**



**"Blitzars"**

**Micro-quasars**

**Flare stars**



**SETI**



**Pernicious RFI**

**Atmospheric effects**



**Magnetars**



**We are here**



**Pulsars**

# Why important?

- **Sites of extreme energy density. Important probes of extreme (astro)physics?**
- **New type of astrophysical object?**
- **Probes of intervening material.**

# FRB observables

- Dispersion measure
- Dispersion index
- Scattering measure: LOS inhomogeneity
- Scattering index
- Polarization: local magnetic field
- Rotation measure: B-field in local environment
- Spectrum
- Scintillation
- Pulse width
- Pulse fluence (and luminosity if redshift is known)
- Pulse morphology
- Non-dispersive pulse drifts in time-frequency
- Periodicity or lack thereof
- Host galaxy and position therein as well as redshift
- Sky and redshift distributions
- Constraints on prompt optical, X-ray & gamma-ray emission
- Constraints on optical, X-ray & gamma-ray afterglow

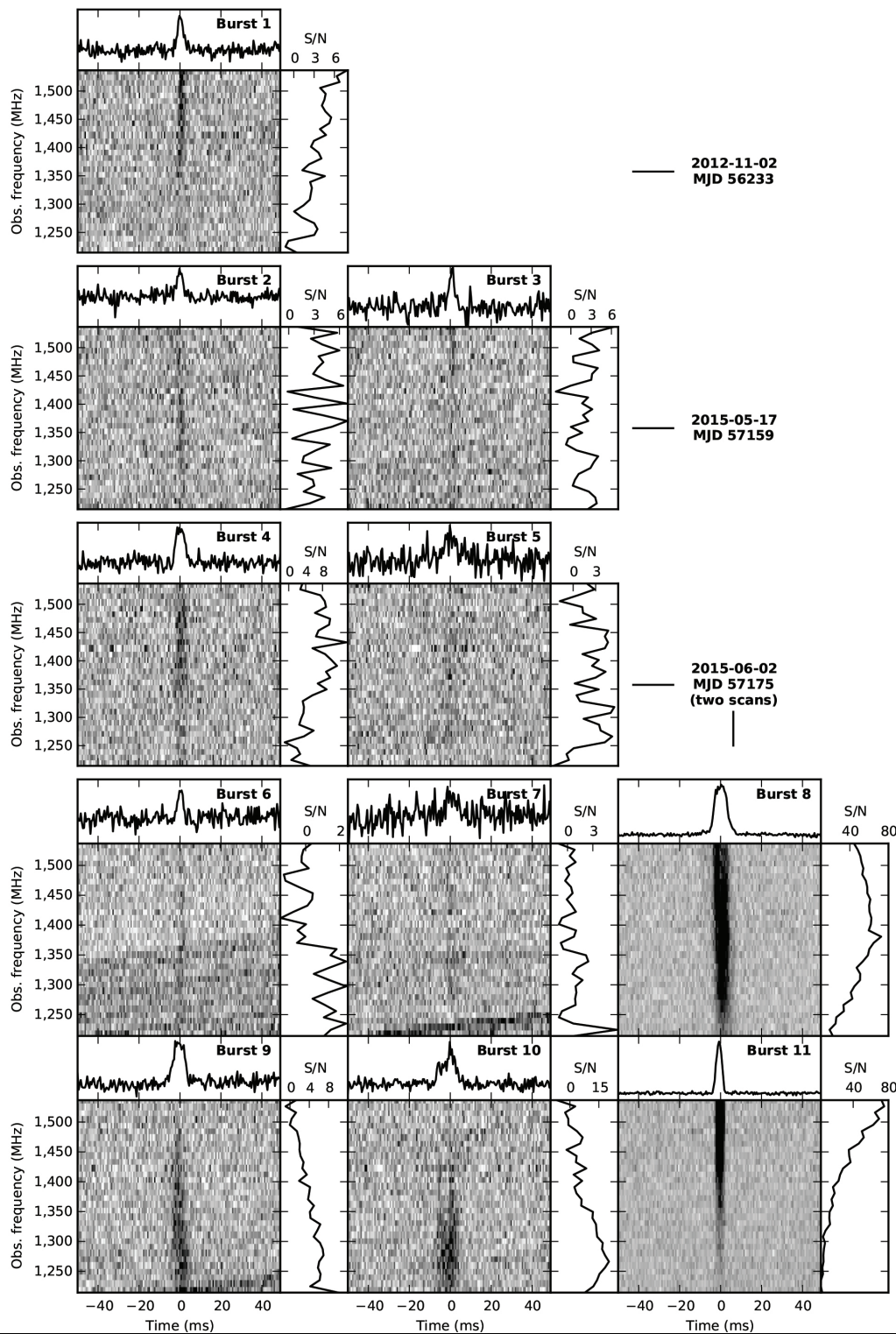
# Observed FRB properties



Gruffalo model

Hessels et al. (*Nature*, submitted)

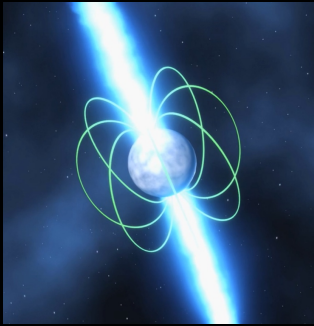
# 10 New AO Bursts!



First **repeating**  
Fast Radio Burst!

Spitler, Scholz, Hessels et al. 2016

# How many classes of FRBs?



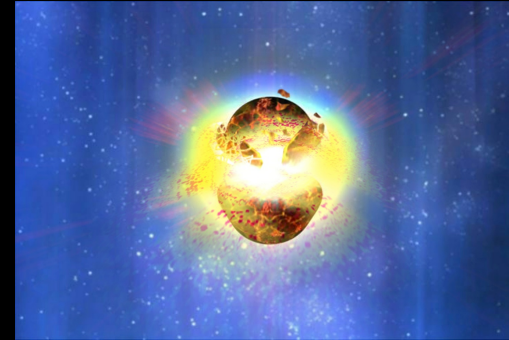
Pulsar on steroids

## Repeaters

(Spitler et al. 2016)

(CHIME/FRB Collab. 2019)

vs.



Cataclysm

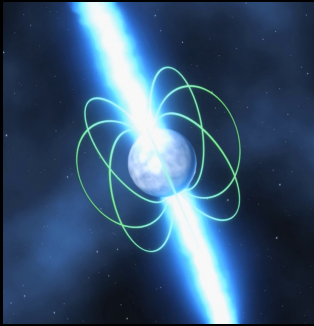
## (Apparent?) non-repeaters

(Petroff et al. 2015)

FRB131104: 170hrs

FRB140514/110220: >50hrs

# How many classes of FRBs?



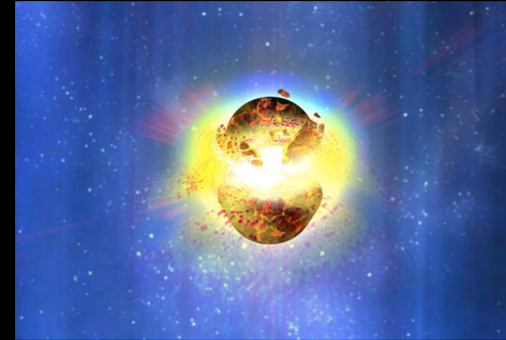
Pulsar on steroids

**Repeaters**

(Spitler et al. 2016)

(CHIME/FRB Collab. 2019)

vs.



Cataclysm

**(Apparent?) non-repeaters**

(Petroff et al. 2015)

FRB131104: 170hrs

FRB140514/110220: >50hrs

**NB: according to the *arXiv*, there are >50 types of FRBs**

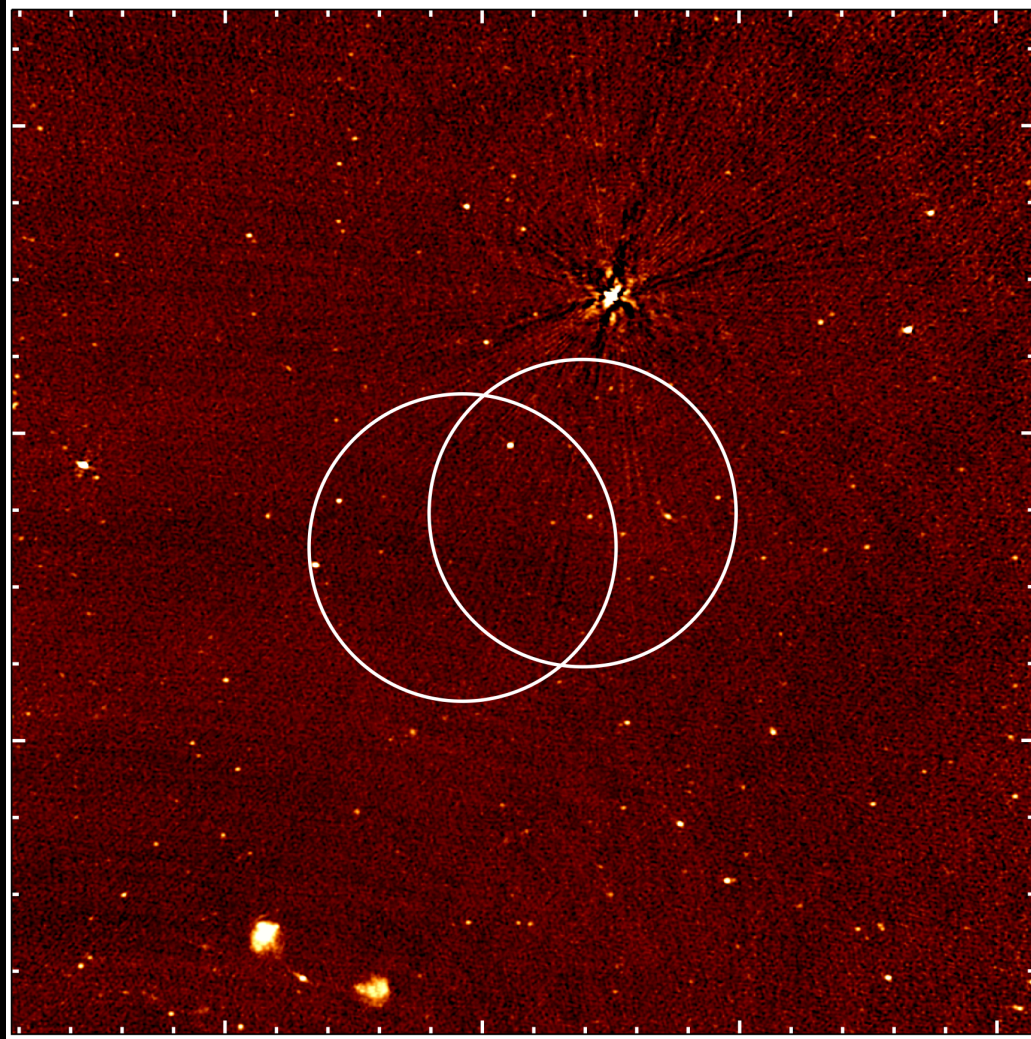
# The Need for Localization

**Arecibo localization**

• **VLA localization**

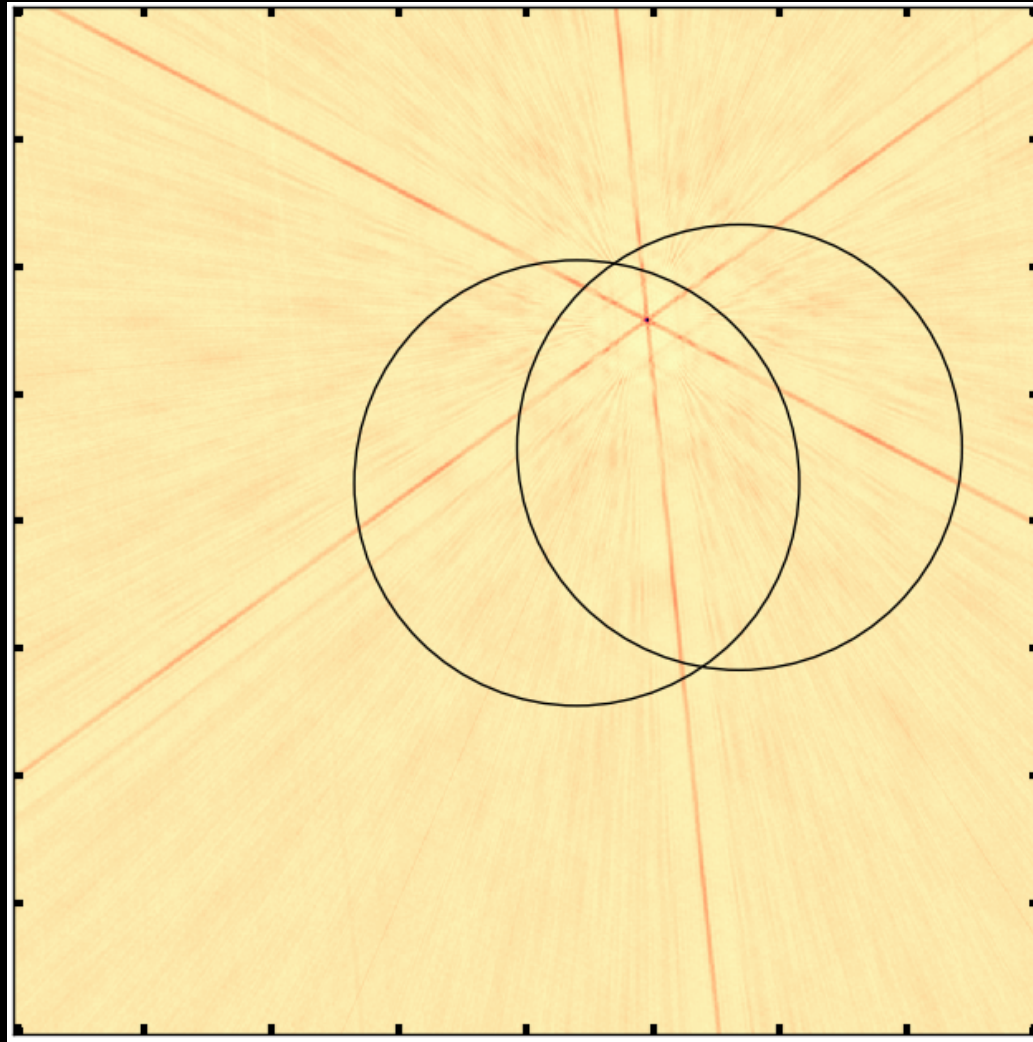
**Toy comparison with  
Hubble Deep Field**

# VLA Localization



**10s of radio sources in an ultra-deep (10s of hrs) VLA image**

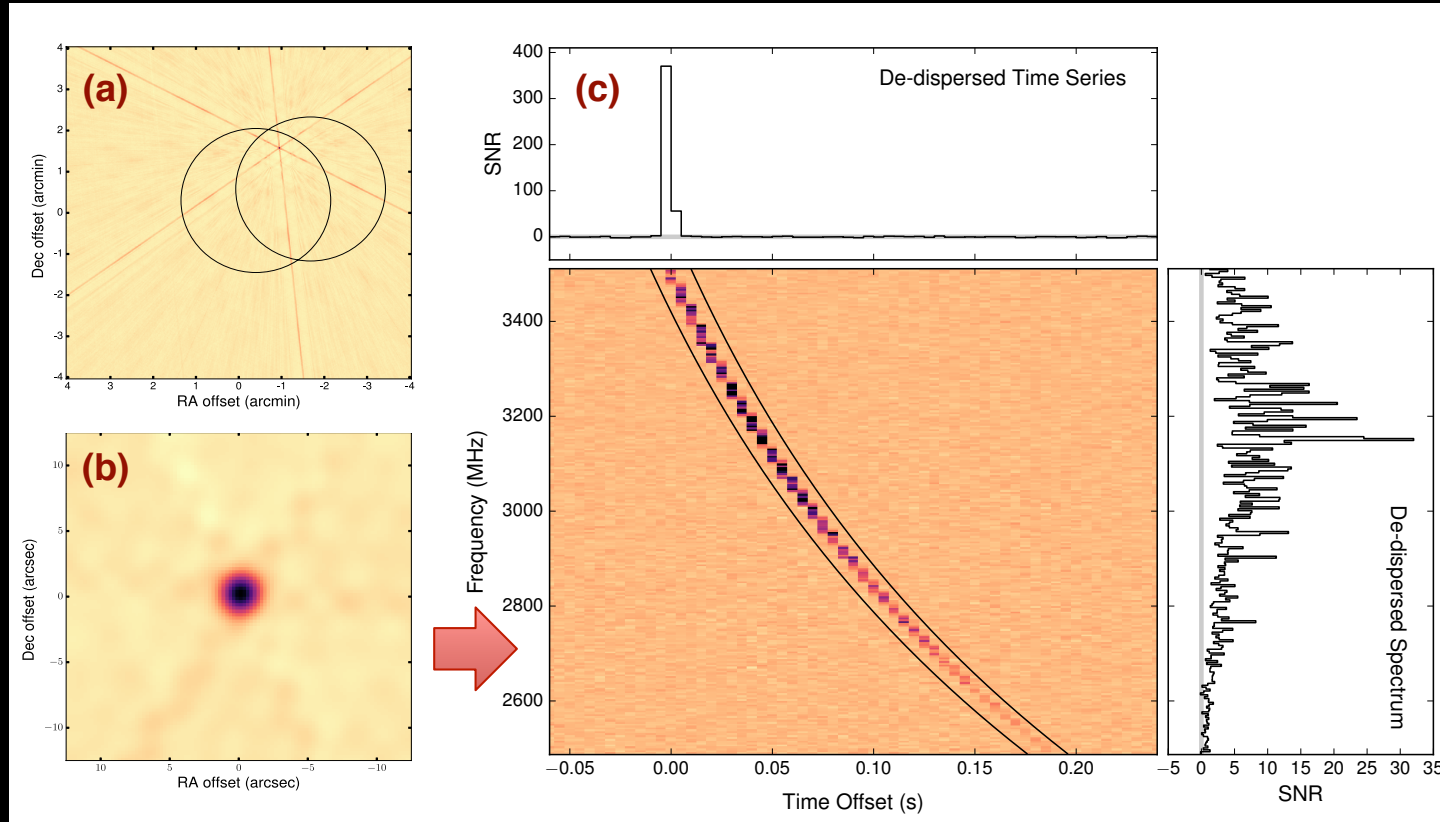
# VLA Localization



**...and suddenly a burst  
(this is a 5-ms snapshot)**

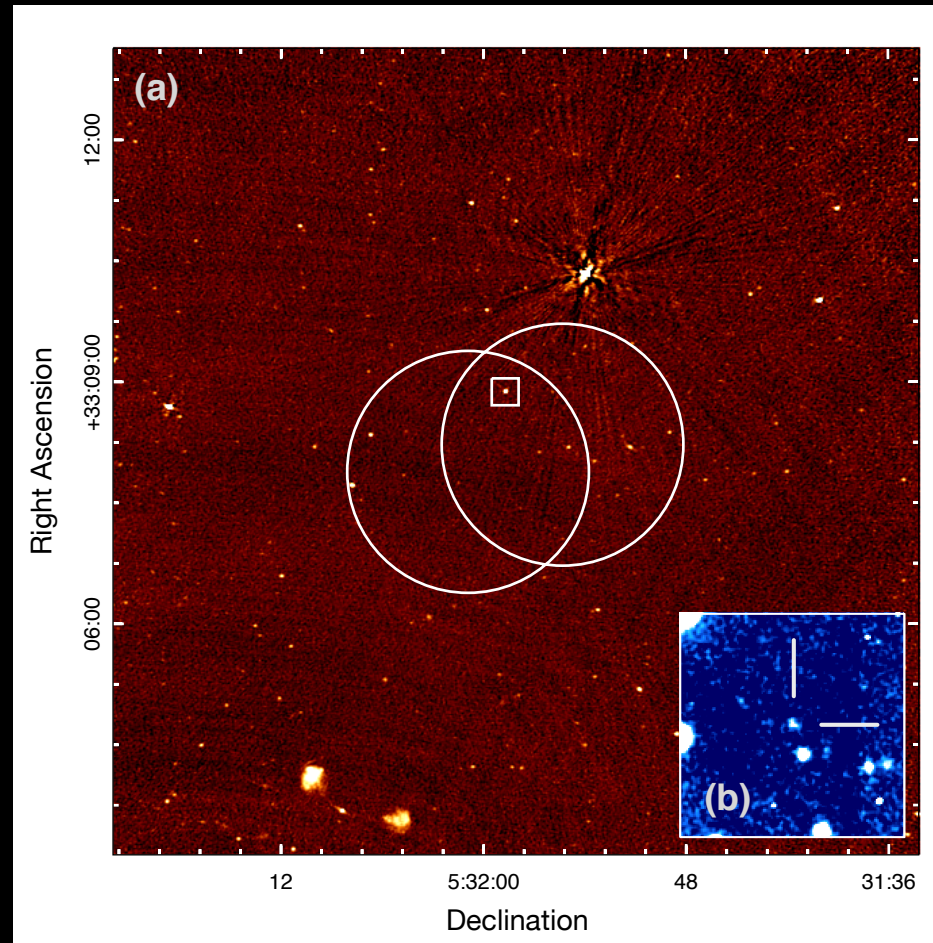
# VLA Localization

Localization to  $\sim 100\text{mas}$



After tens of hours of observing  
and 1 year of trying

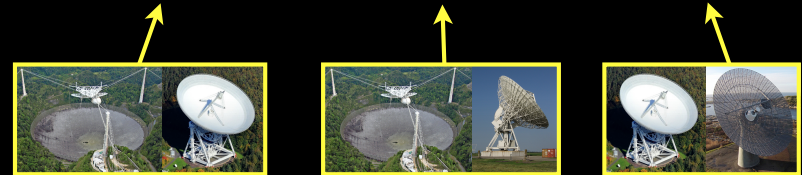
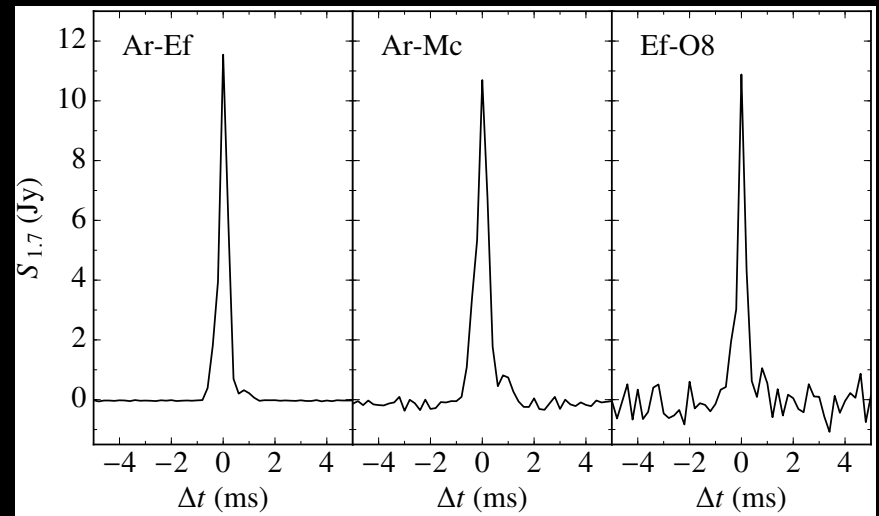
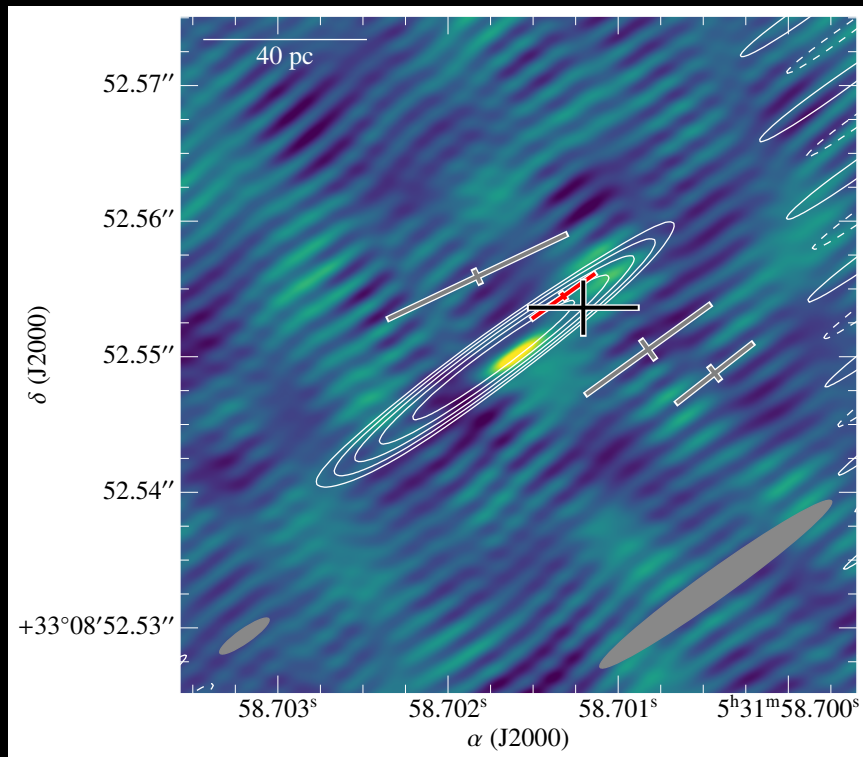
# VLA Localization



**Association with persistent  
radio and optical sources**

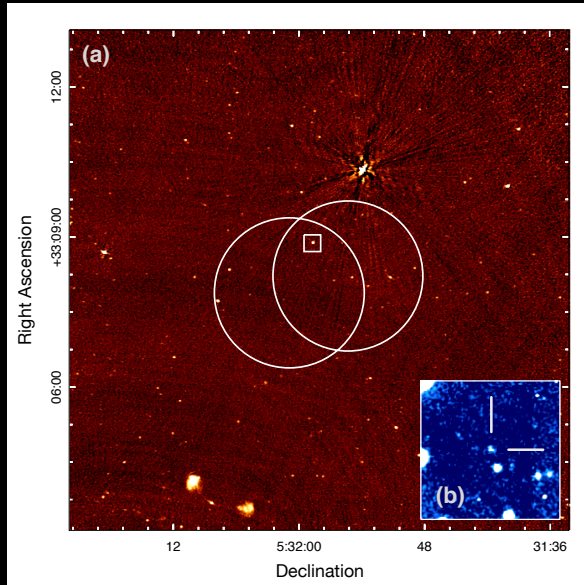
# Arecibo+EVN Localization

Localization to  $\sim 10\text{mas}$

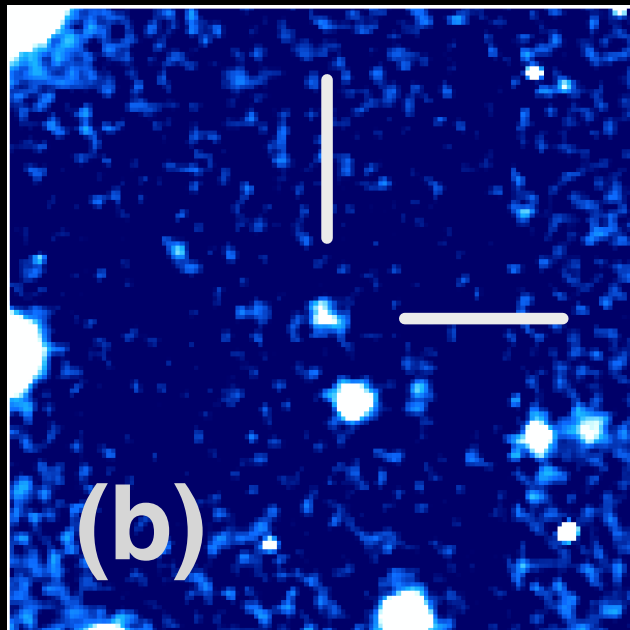


**Bursts and persistent radio source are physically related**  
(coincident to within  $< 40\text{ pc}$  at 1 Gpc)

# What is the optical source?

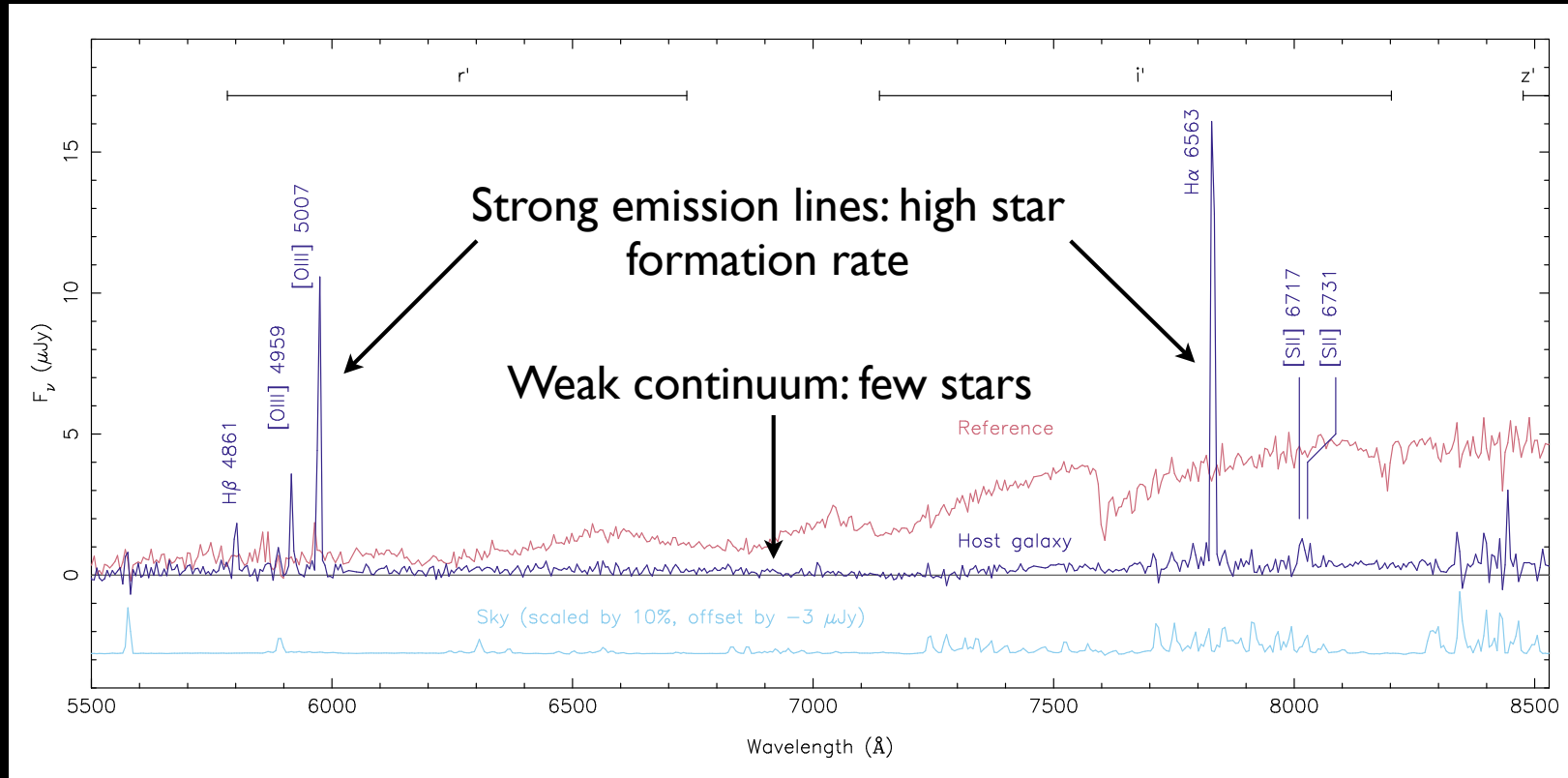


- 25th mag., roughly 100 million times fainter than the naked eye limit.
- Is this a star, or a (small) galaxy?



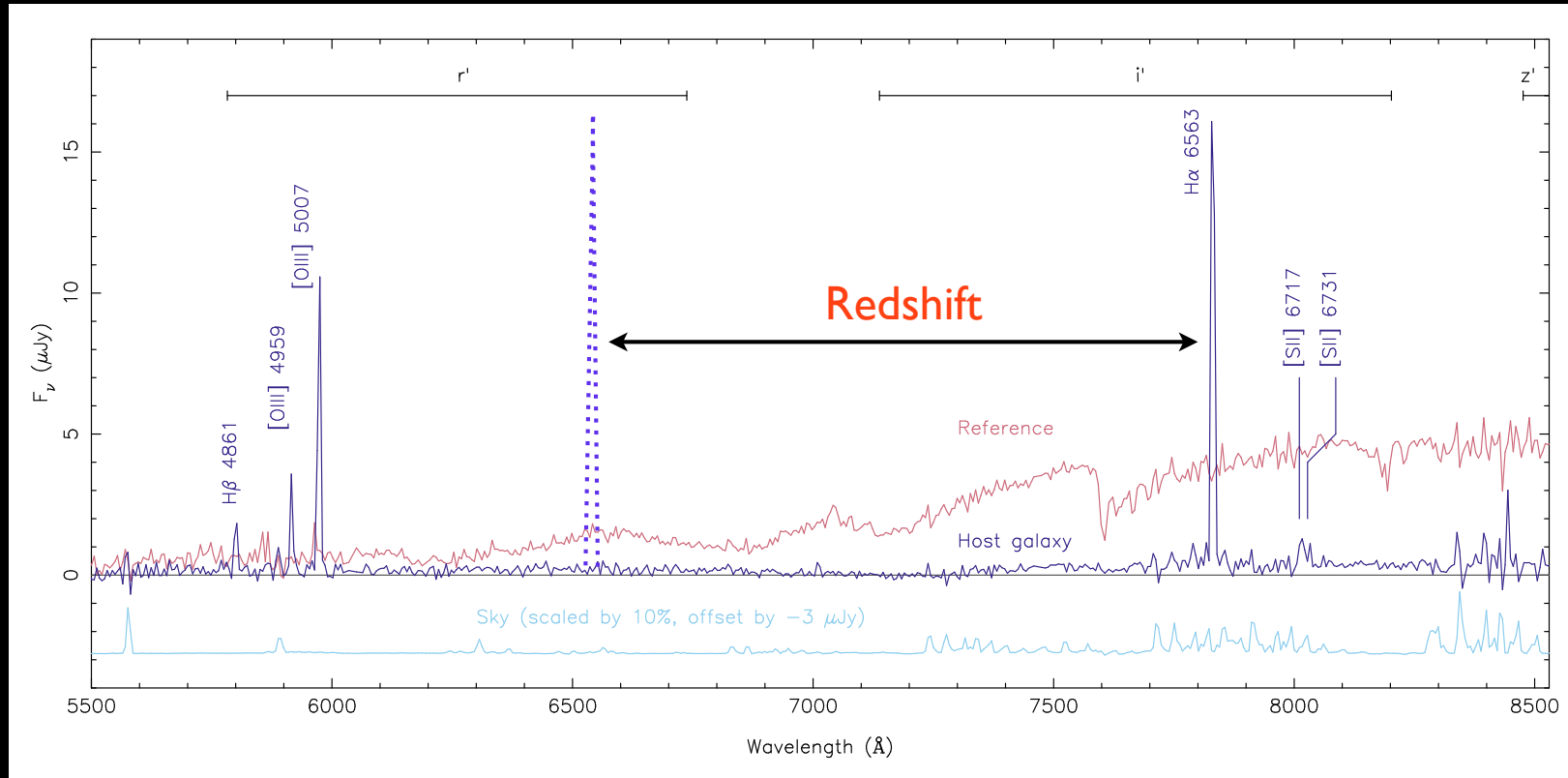
# Gemini Redshift

5.5 hours with the 8-m Gemini North



# Gemini Redshift

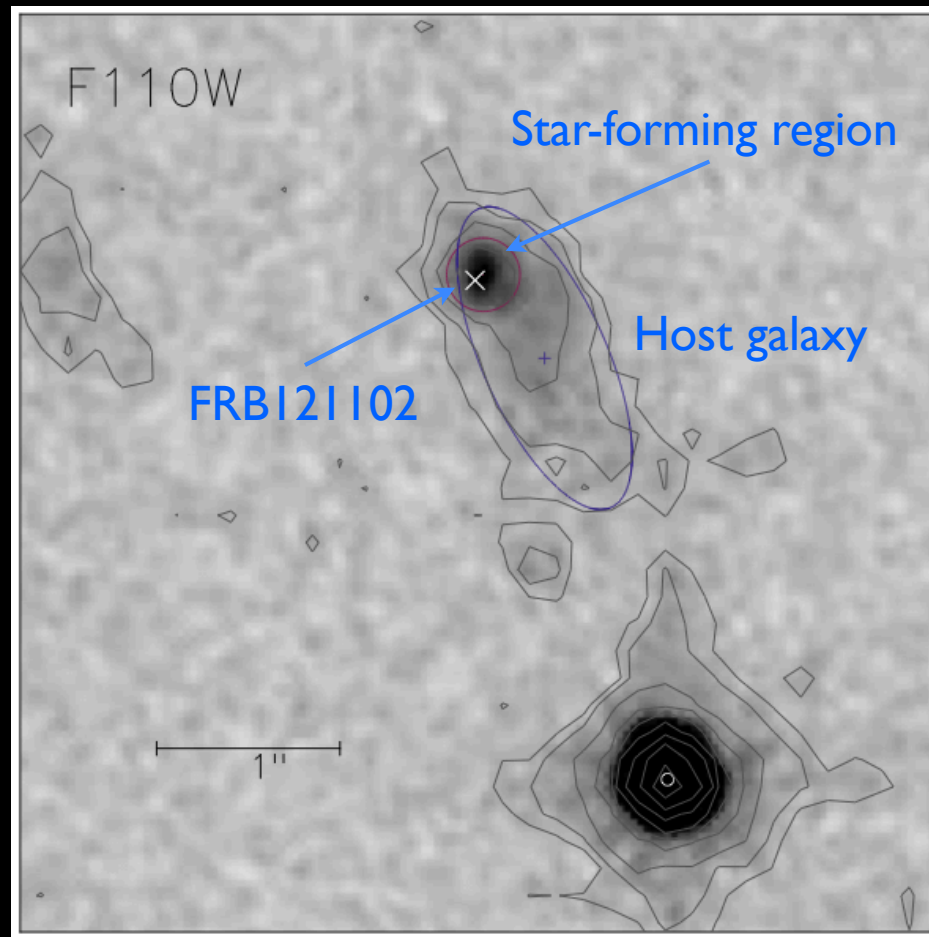
5.5 hours with the 8-m Gemini North



**Host is a dwarf galaxy at  $z = 0.19$  ( $\sim 1\text{Gpc}$ )**

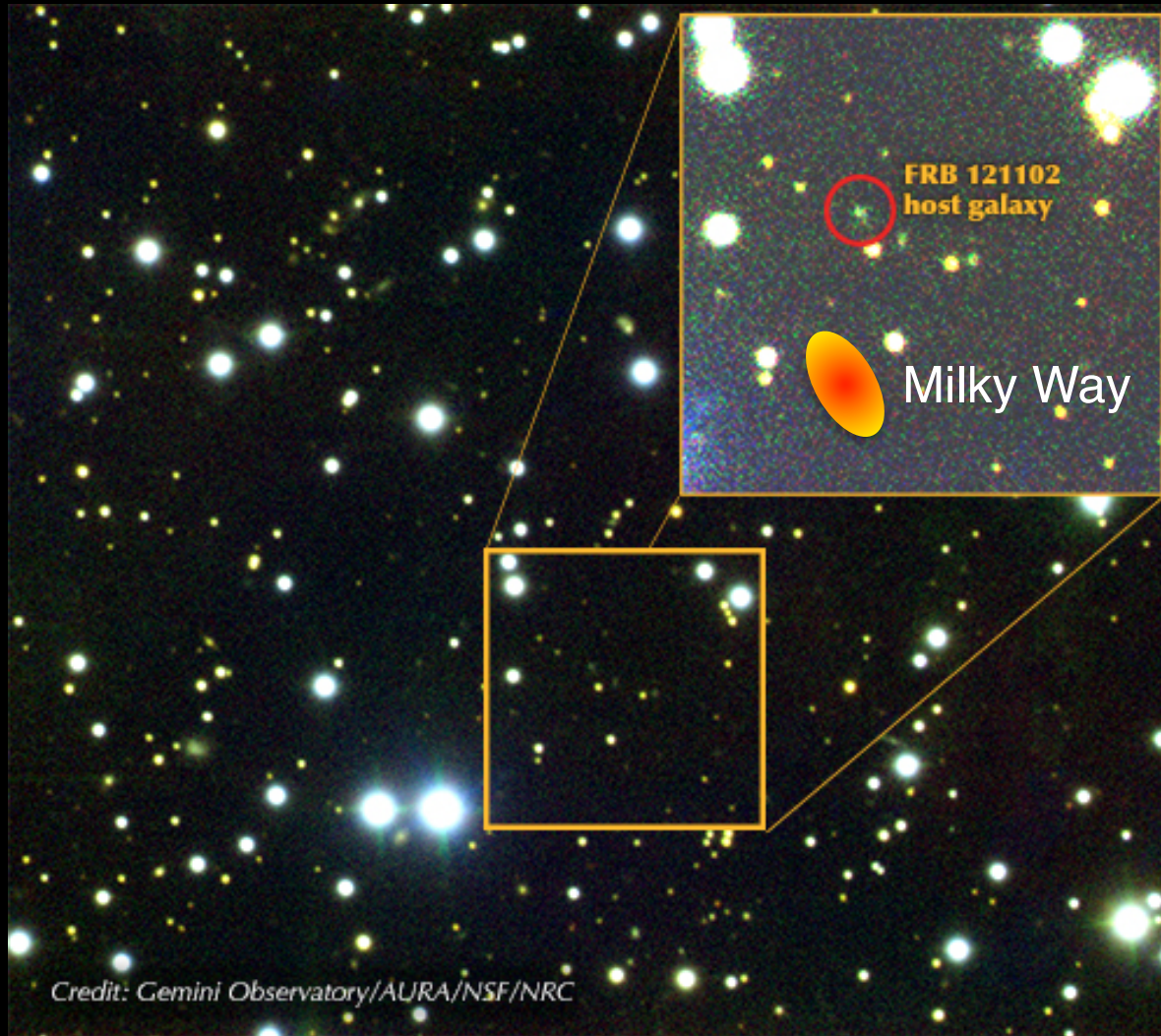
(sets energy scale of bursts,  $\sim 10^{40}$  erg/s)

# FRB 211102 with HST



**Clearly associated with a star-forming region in the host**

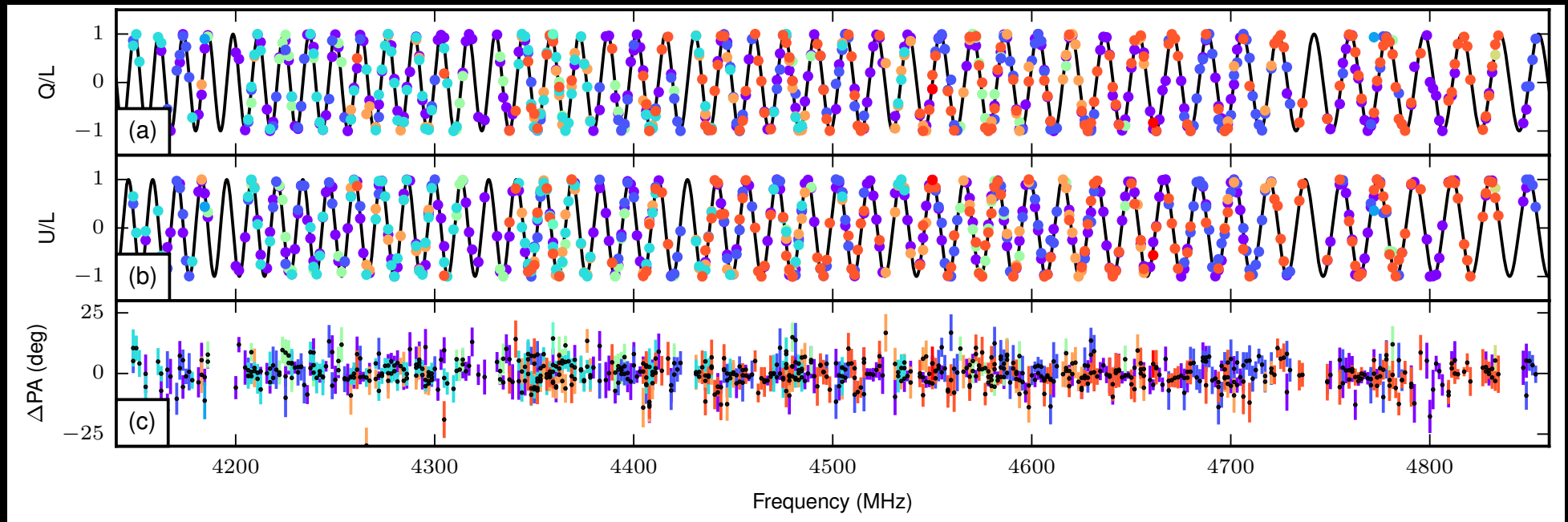
# The Host Galaxy



- 25th mag., roughly 100 million times fainter than the naked eye limit.
- Each burst (briefly) outshines all other stars in the galaxy!!
- 1000x less massive than the Milky Way.

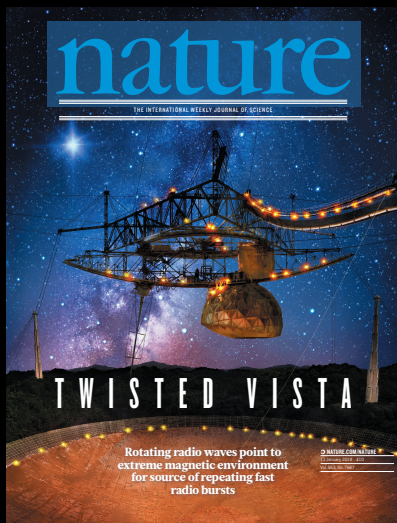
**Relation to long GRBs and  
superluminous SNe?**

# Rotation measure of FRB 121102

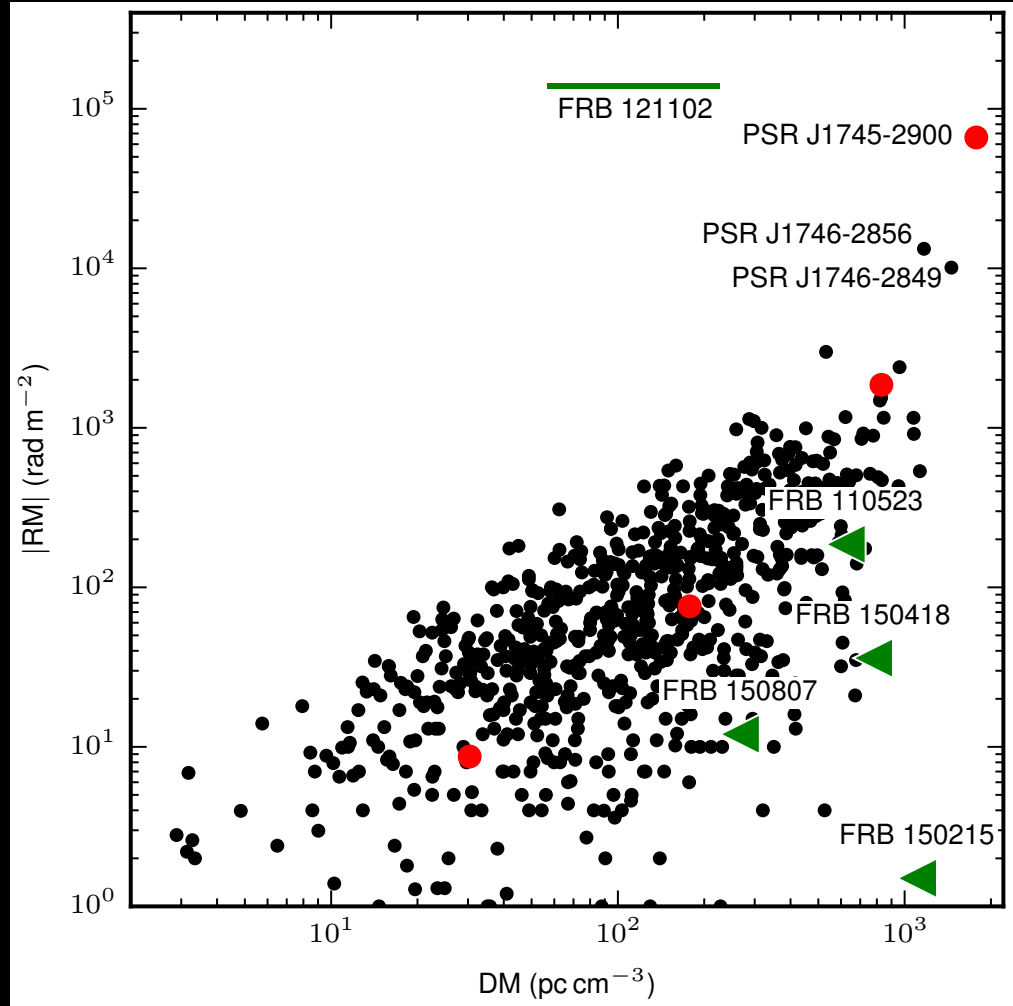
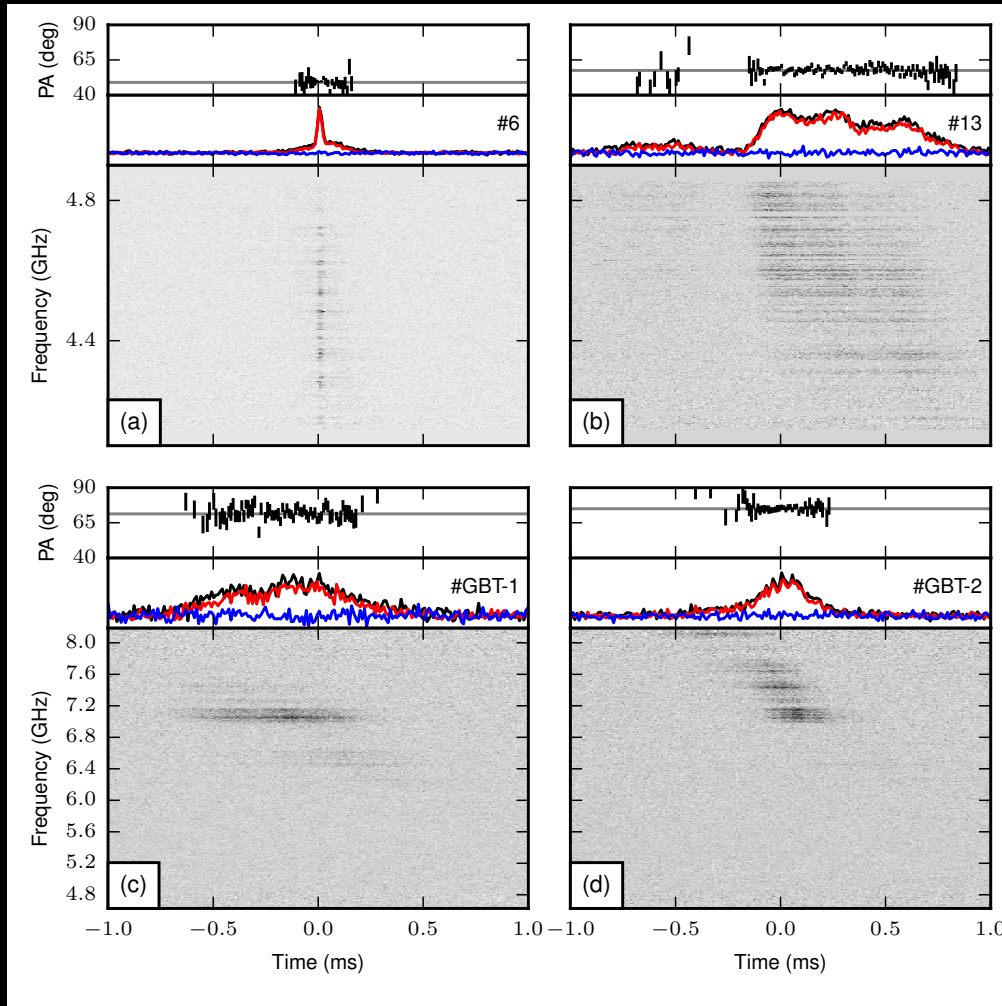


**Michilli, Seymour, Hessels et al. 2018**

Rotation measure  $\sim 140,000 \text{ rad m}^{-2}$   
in the source reference frame:  
 $(1+Z)^2$ , here  $Z = 0.193$



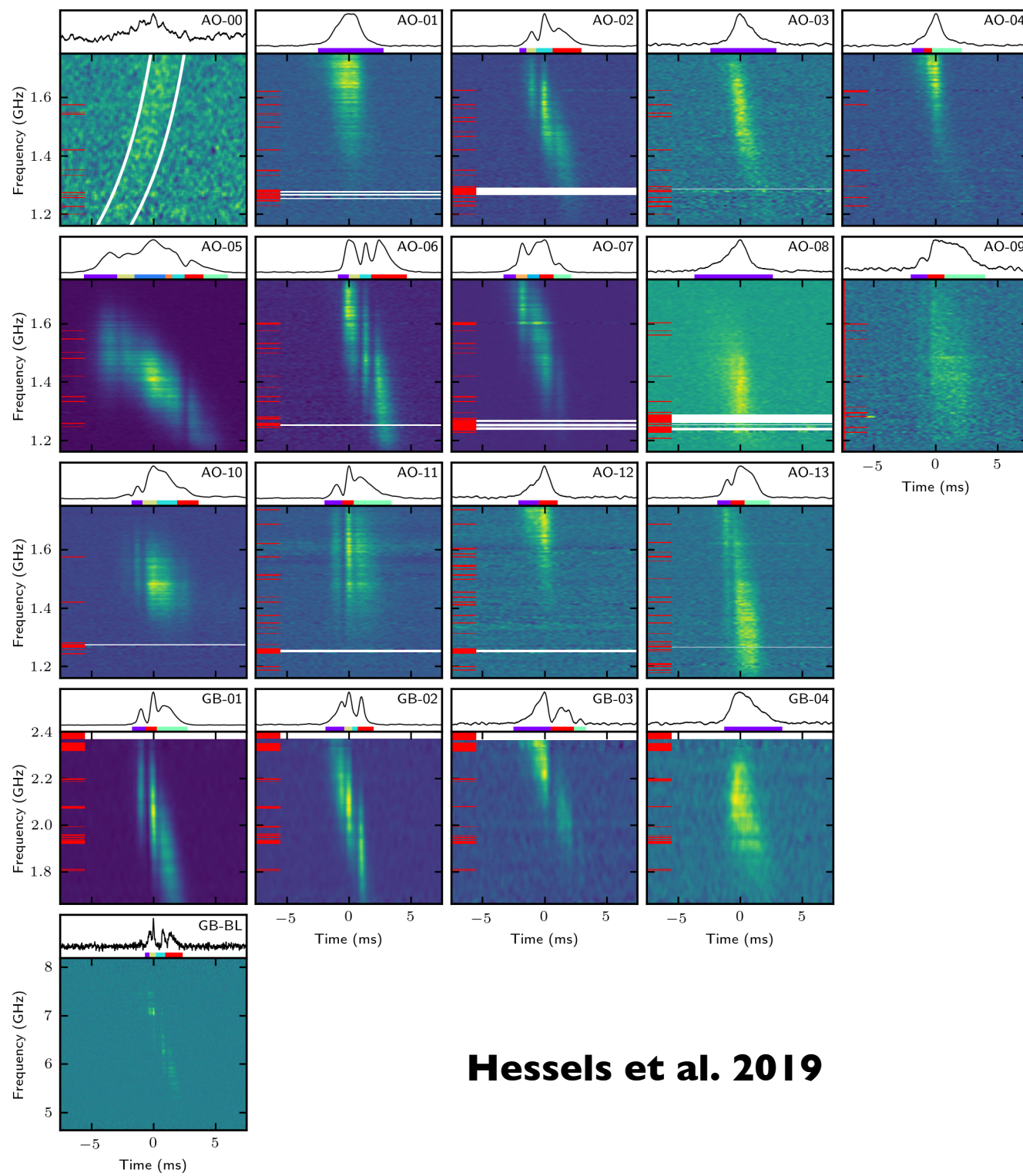
# Rotation measure of the Repeater



**Michilli, Seymour,  
Hessels et al. 2018**

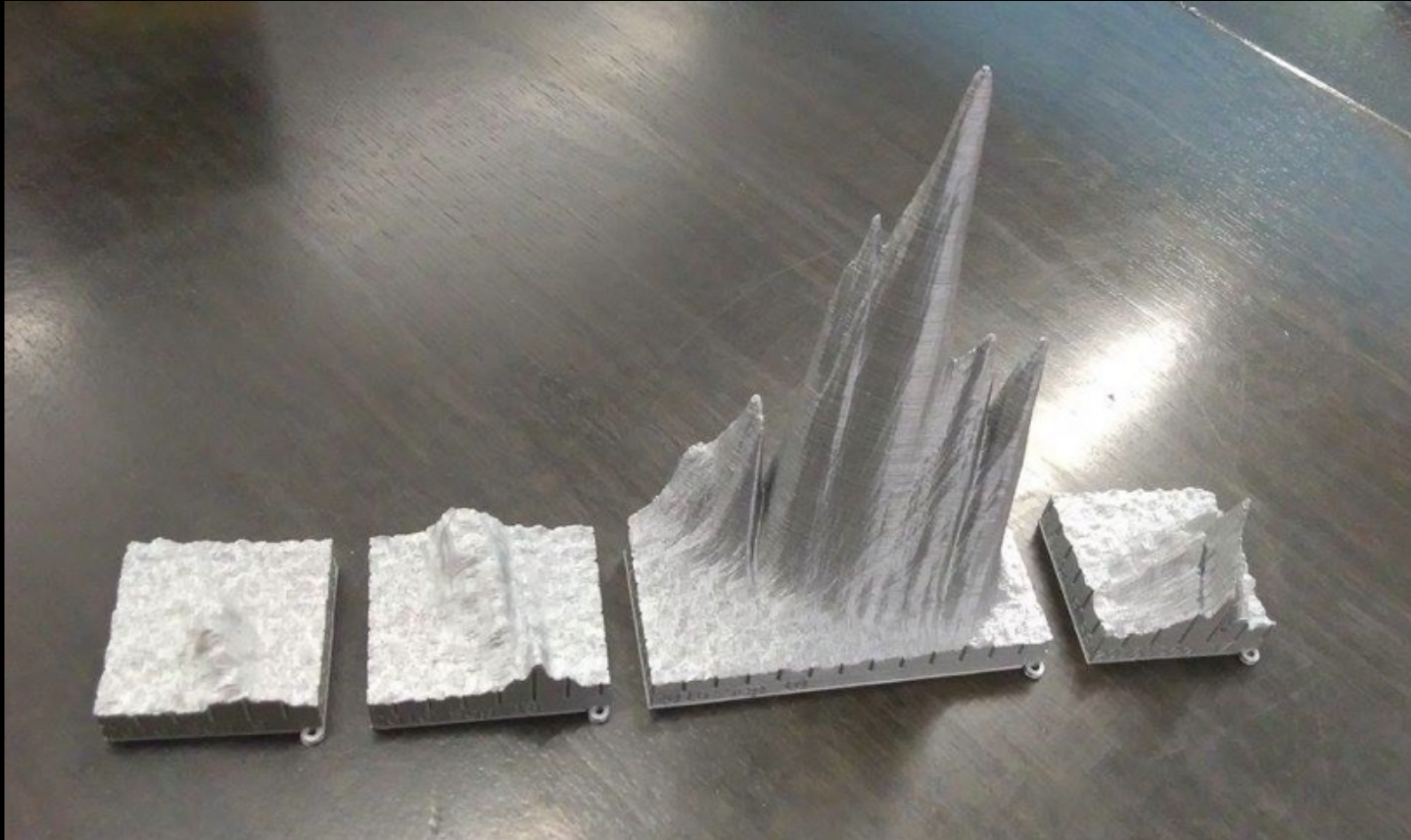
**Bursts ~100% linearly polarized and  
can be ~30 microsec wide!**

# “Weird” Bursts



**Hessels et al. 2019**

# **“Weird” Bursts**



**Anne Archibald**

# **World's worst keychain**

# Working and Upcoming FRB Factories

- Strike various balances between localization precision, yield, observing frequency and sensitivity
- More localizations before end of 2019?
- Triple population in next year?



CHIME



ASKAP

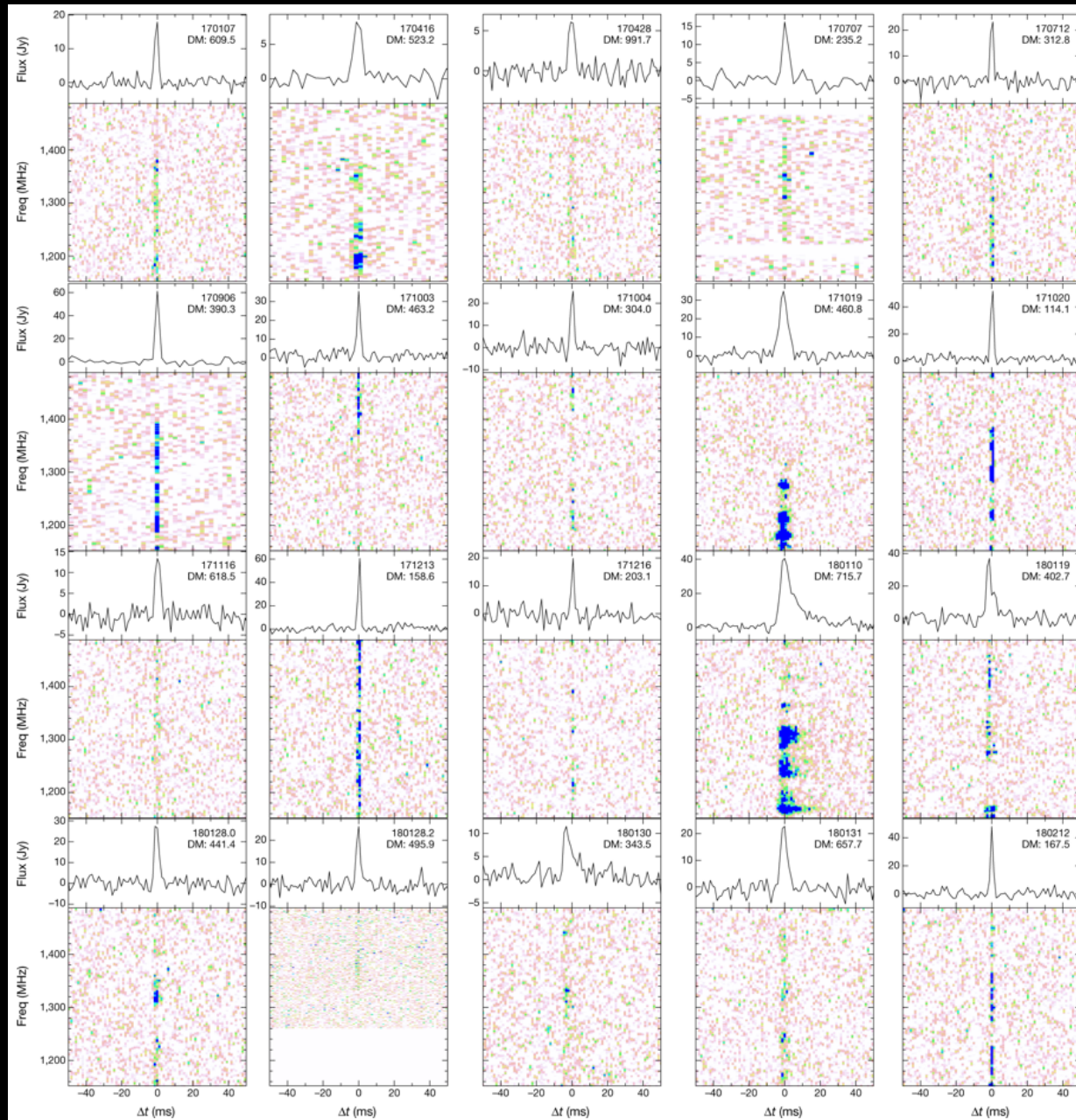


UTMOST



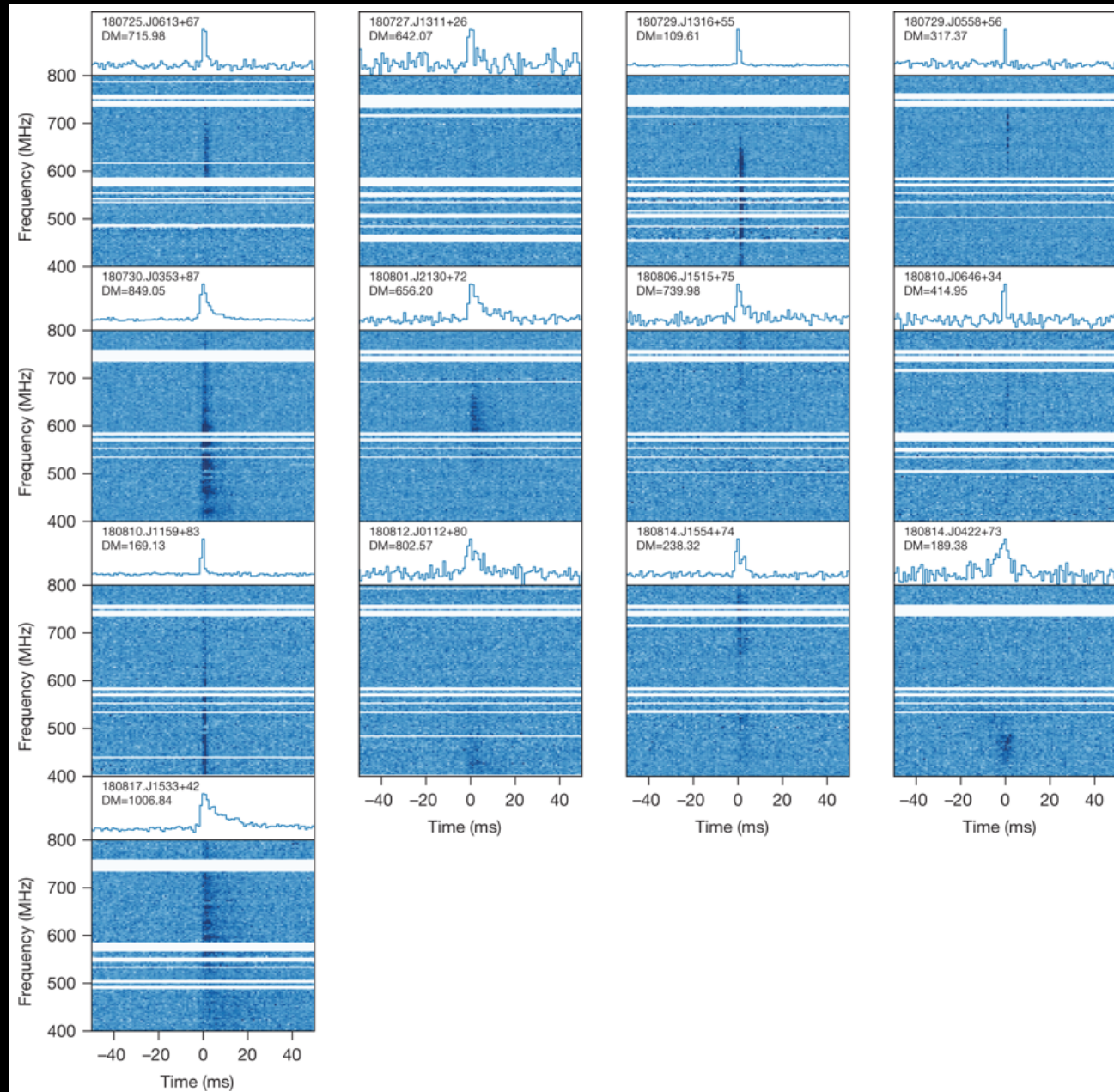
APERTIF

# ASKAP FRBs

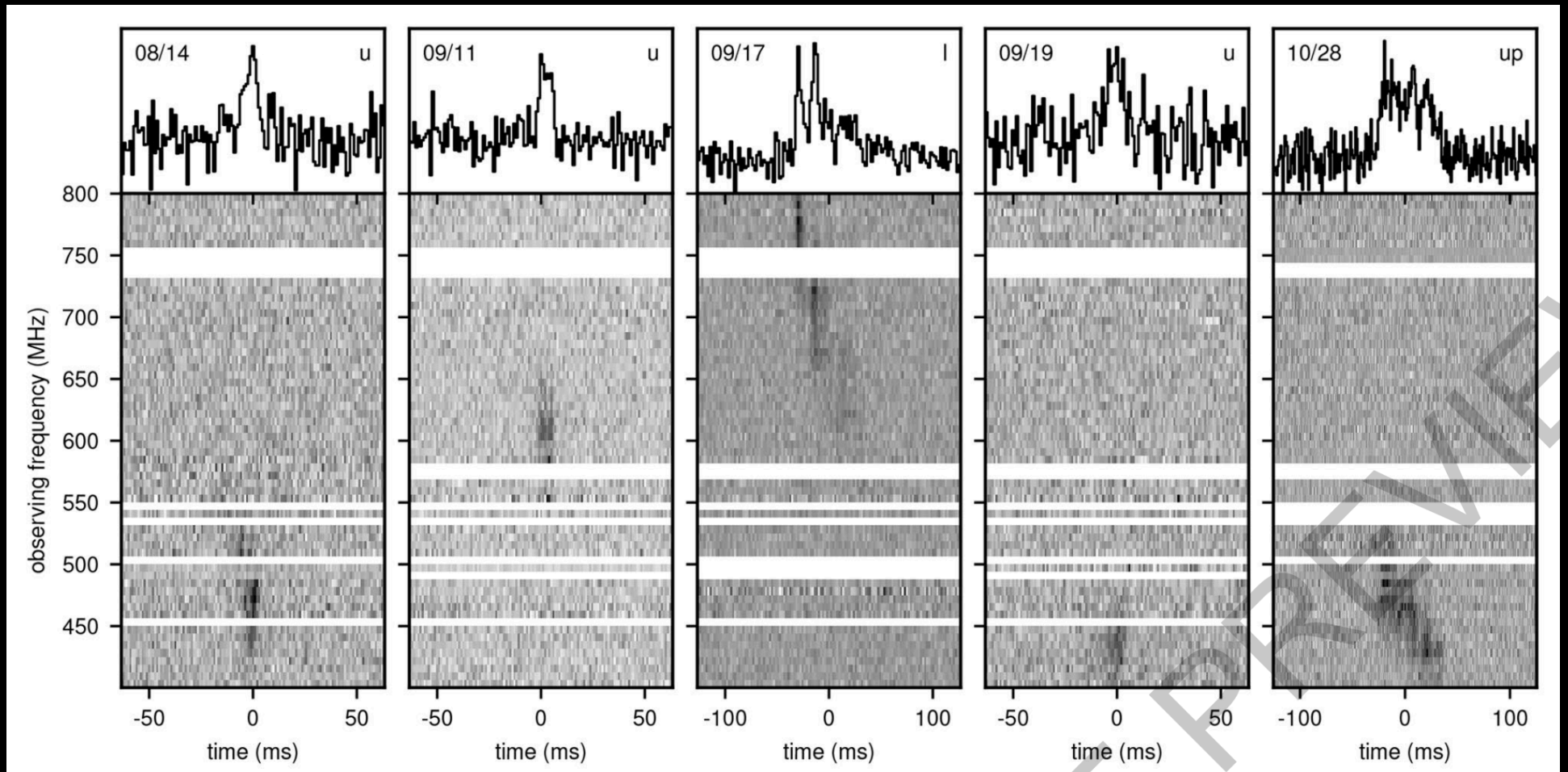


Shannon et al. 2018, Nature

# CHIME FRBs

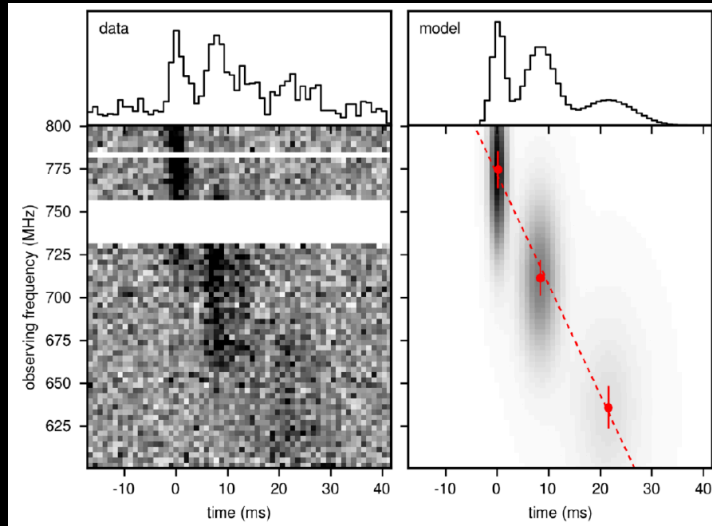


# CHIME FRBs

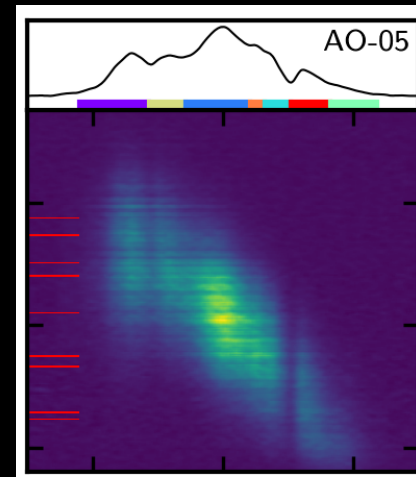
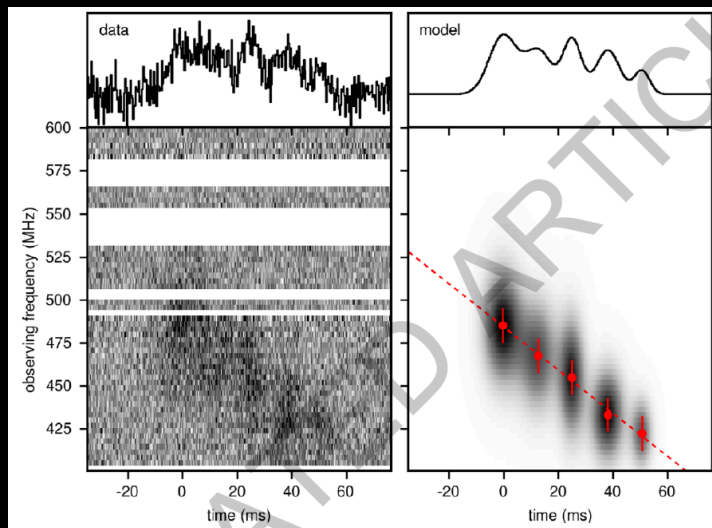
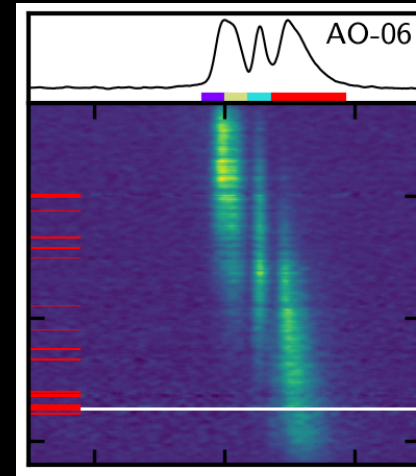


# CHIME FRBs

“R2”



“R1”



# FRB Discovery Scoreboard

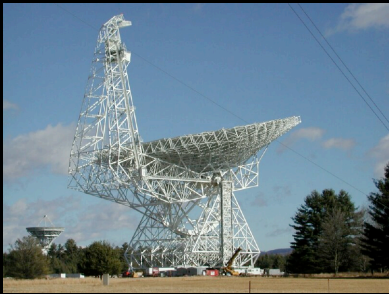


Arecibo (1.4 GHz): **1**

Arecibo (0.3 GHz): **0**



ASKAP (1.4 GHz): **25**



GBT (0.8 GHz): **1**

GBT (0.3 GHz): **0**



LOFAR (0.1 GHz): **0**



CHIME (0.6 GHz): **13**  
+ a lot more...



MWA (0.2 GHz): **0**



Parkes (1.4 GHz): **24**



UTMOST (0.8 GHz): **5**

# FRBCAT

Swinburne Pulsar Group

@FRBCatalogue

> Swinburne Pulsar Group > FRBCAT

## FRB Catalogue

This catalogue contains up to date information for the published population of Fast Radio Bursts (FRBs). This site is maintained by the FRBcat team and is updated as new sources are published or refined numbers become available. Information for each burst is divided into two categories: intrinsic properties measured using the available data, and derived parameters produced using a model. The intrinsic parameters should be taken as lower limits, as the position within the telescope beam is uncertain. Models used in this analysis are the NE2001 Galactic electron distribution (Cordes & Lazio, 2002), and the Cosmology Calculator (Wright, 2006).

You may use the data presented in this catalogue for publications; however, we ask that you cite the paper, when available (Petroff et al., 2016) and provide the url (<http://www.astronomy.swin.edu.au/pulsar/frbcatalog/>).

### Catalogue Version 1.0

Event	Telescope	gl [deg]	gb [deg]	FWHM [deg]	DM [ $\text{cm}^{-3}$ pc]	S/N	$W_{\text{obs}}$ [ms]	$S_{\text{peak,obs}}$ [Jy]	$F_{\text{obs}}$ [Jy ms]	Ref
<a href="#">FRB010125</a>	parkes	356.641	-20.020	0.25	790(3)	17	9.40 <sup>+0.20</sup> <sub>-0.20</sub>	0.30	2.82	<a href="#">1</a>
<a href="#">FRB010621</a>	parkes	25.433	-4.003	0.25	745(10)		7.00	0.41	2.87	<a href="#">2</a>
<a href="#">FRB010724</a>	parkes	300.653	-41.805	0.25	375	23	5.00	>30.00 <sup>+10.00</sup> <sub>-10.00</sub>	>150.00	<a href="#">3</a>
<a href="#">FRB030625</a>	parkes	226.443	-63.030	0.25	899.55(1)	30	1.92 <sup>+0.83</sup> <sub>-0.77</sub>	1.14 <sup>+0.42</sup> <sub>-0.21</sub>	2.19 <sup>+2.10</sup> <sub>-1.12</sub>	<a href="#">4</a>
<a href="#">FRB110220</a>	parkes	50.628	-54.786	0.25	944.38(5)	49	5.60 <sup>+0.10</sup> <sub>-0.10</sub>	1.30 <sup>+0.00</sup> <sub>-0.00</sub>	7.28 <sup>+0.13</sup> <sub>-0.13</sub>	<a href="#">5</a>
<a href="#">FRB110523</a>	GBT	56.119	-37.819	0.26	623.30(6)	42	1.73 <sup>+0.17</sup> <sub>-0.17</sub>	0.60	1.04	<a href="#">6</a>
<a href="#">FRB110626</a>	parkes	355.861	-41.752	0.25	723.0(3)	11	1.40	0.40	0.56	<a href="#">5</a>
<a href="#">FRB110703</a>	parkes	80.697	-59.019	0.25	1103.6(7)	16	4.30	0.50	2.15	<a href="#">5</a>
<a href="#">FRB120127</a>	parkes	49.287	-65.203	0.25	553.3(3)	11	1.10	0.50	0.55	<a href="#">5</a>
<a href="#">FRB131103</a>	parkes	209.240	-25.264	0.25	1626.18(2)	46	6.44 <sup>+3.50</sup> <sub>-0.42</sub>	0.42 <sup>+0.33</sup> <sub>-0.04</sub>	2.24 <sup>+4.46</sup> <sub>-0.16</sub>	<a href="#">4</a>

<http://www.astronomy.swin.edu.au/pulsar/frbcatalog/>

**Petroff et al. (2016)**

# What Good are They to Anybody Anyway?

- Sites of extreme energy density. Important probes of extreme (astro)physics?

- New type of astrophysical object?

- Probes of intervening material.

We are here

Boom!

