



UNIVERSITEIT VAN AMSTERDAM

ASTRON

Netherlands Institute for Radio Astronomy



European Research Council

Established by the European Commission



Netherlands Organisation
for Scientific Research

**Jason
Hessels**

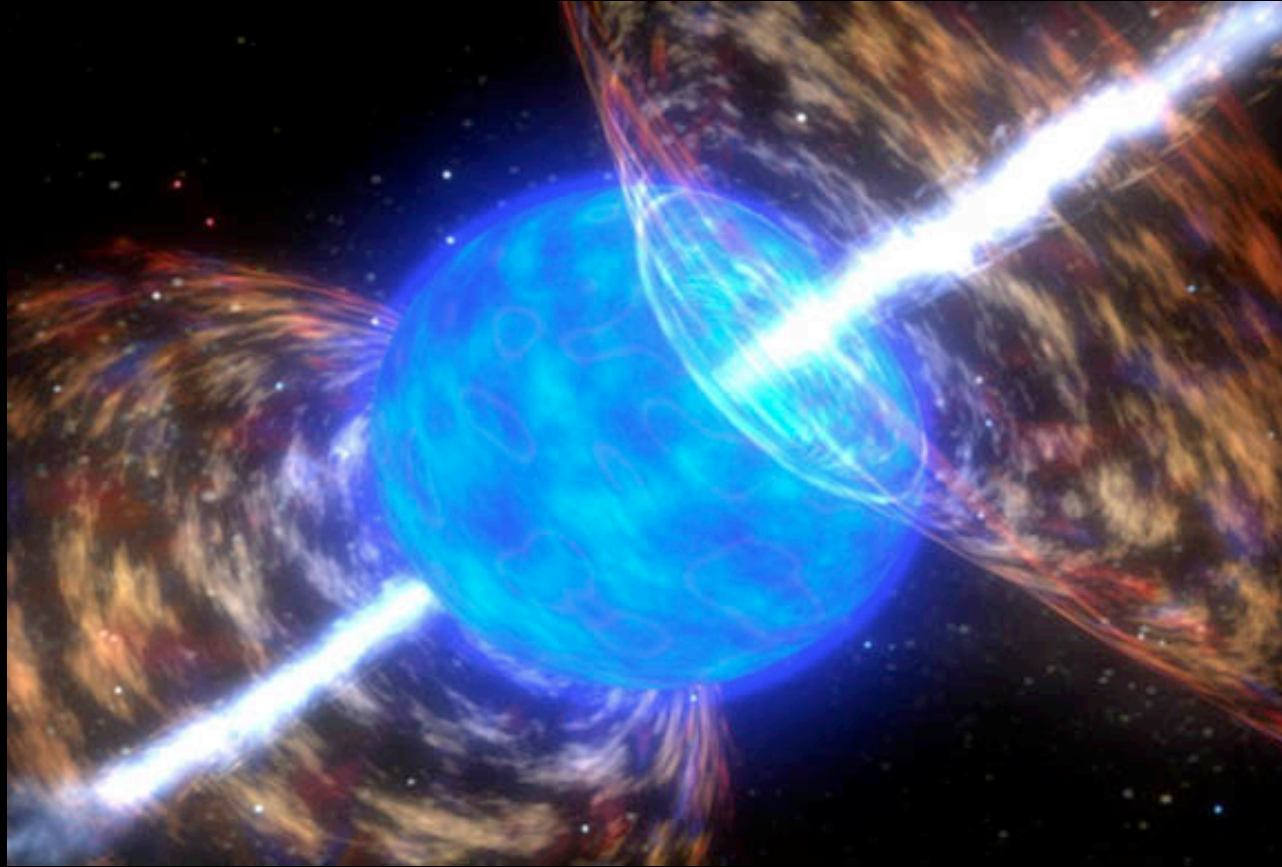
University of Amsterdam
&
ASTRON
Netherlands Institute for
Radio Astronomy

Fast Radio Bursts Observational Status & Open Puzzles



Image credit: Danielle Futselaar

Gamma-ray Bursts



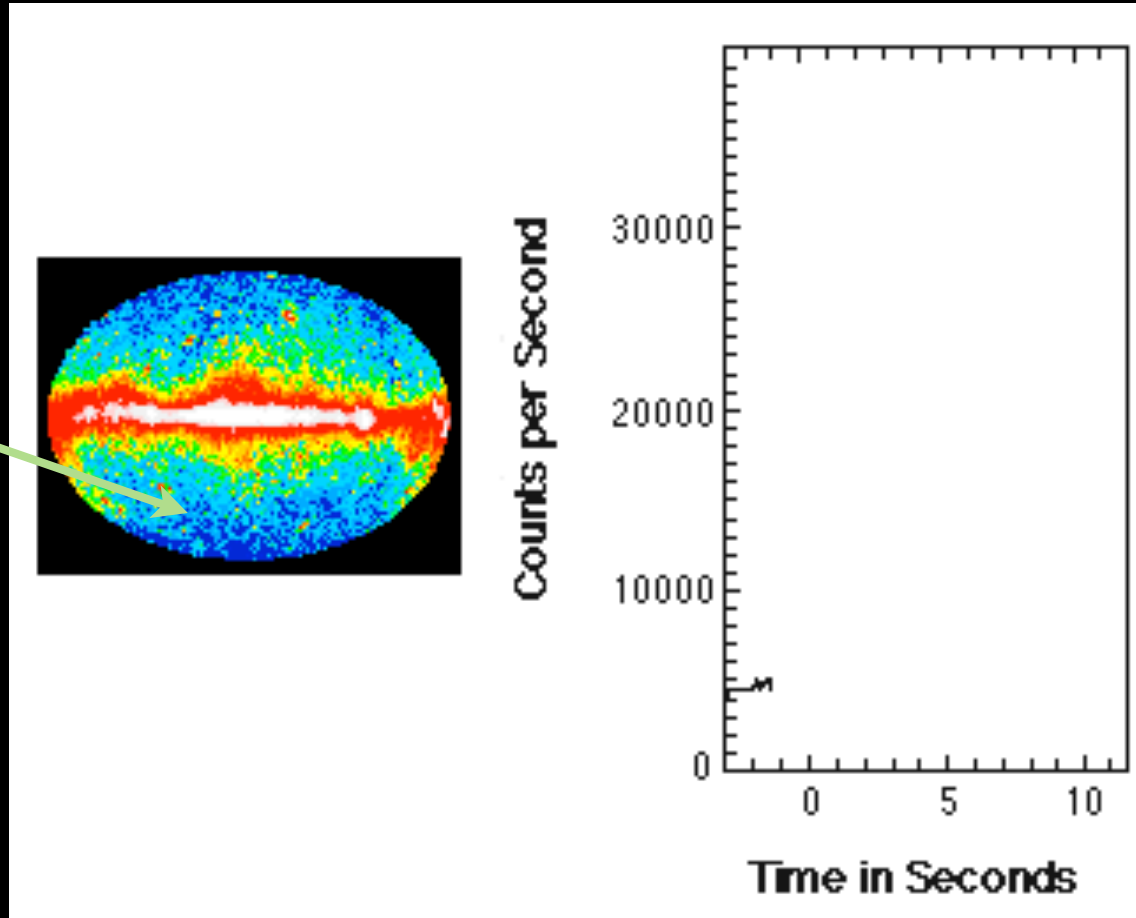
Are there also similar sirens of extreme (astro)physics to be found in the radio?

Gamma-ray Bursts

Typical FoV
of a radio
telescope is
 $\ll 1$ sq. deg.



~ 10 days/FRB



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

Propagation Effects

Observed
signal

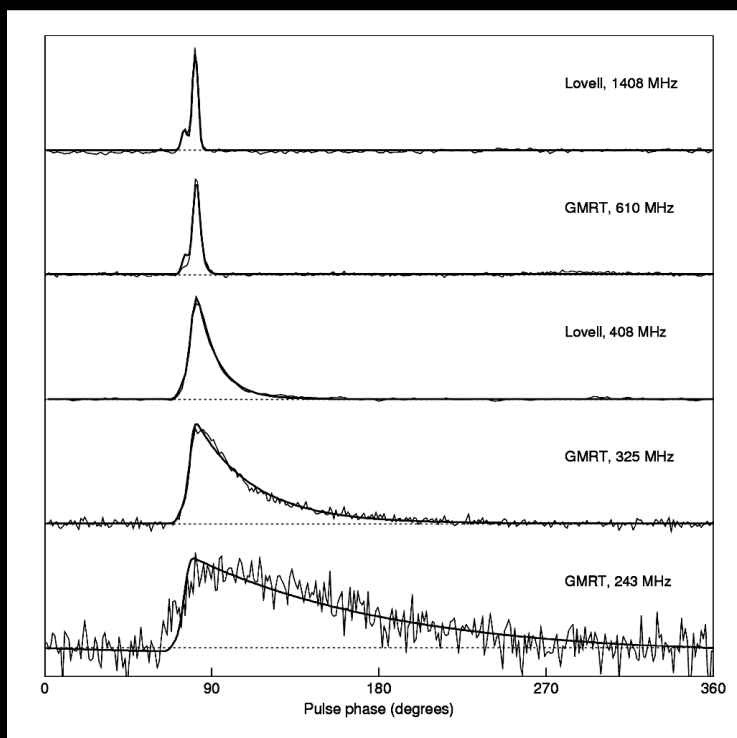
$$I(t) = g_r g_d S(t) * h_{DM}(t) * h_d(t) * h_{RX}(t) + N(t)$$

Emitted
signal

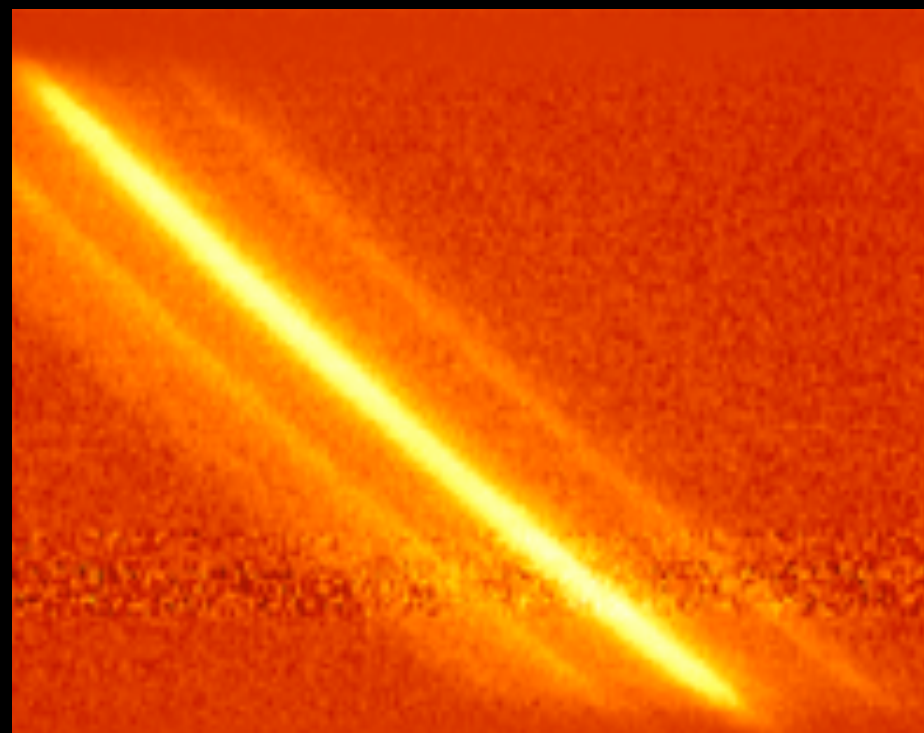
Scattering

Dispersion

Frequency
↑



Frequency
↑

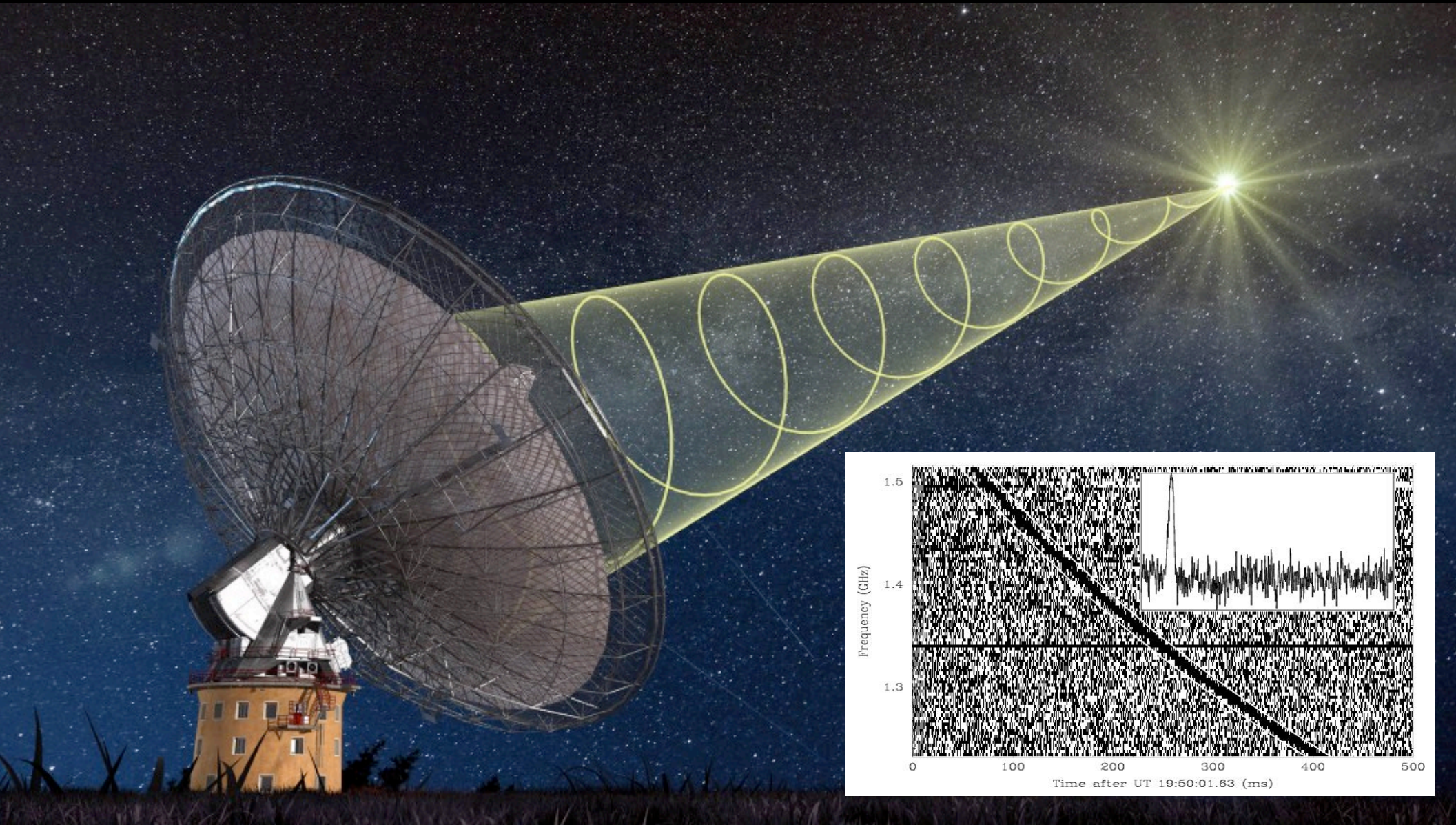


Time
→

Time
→

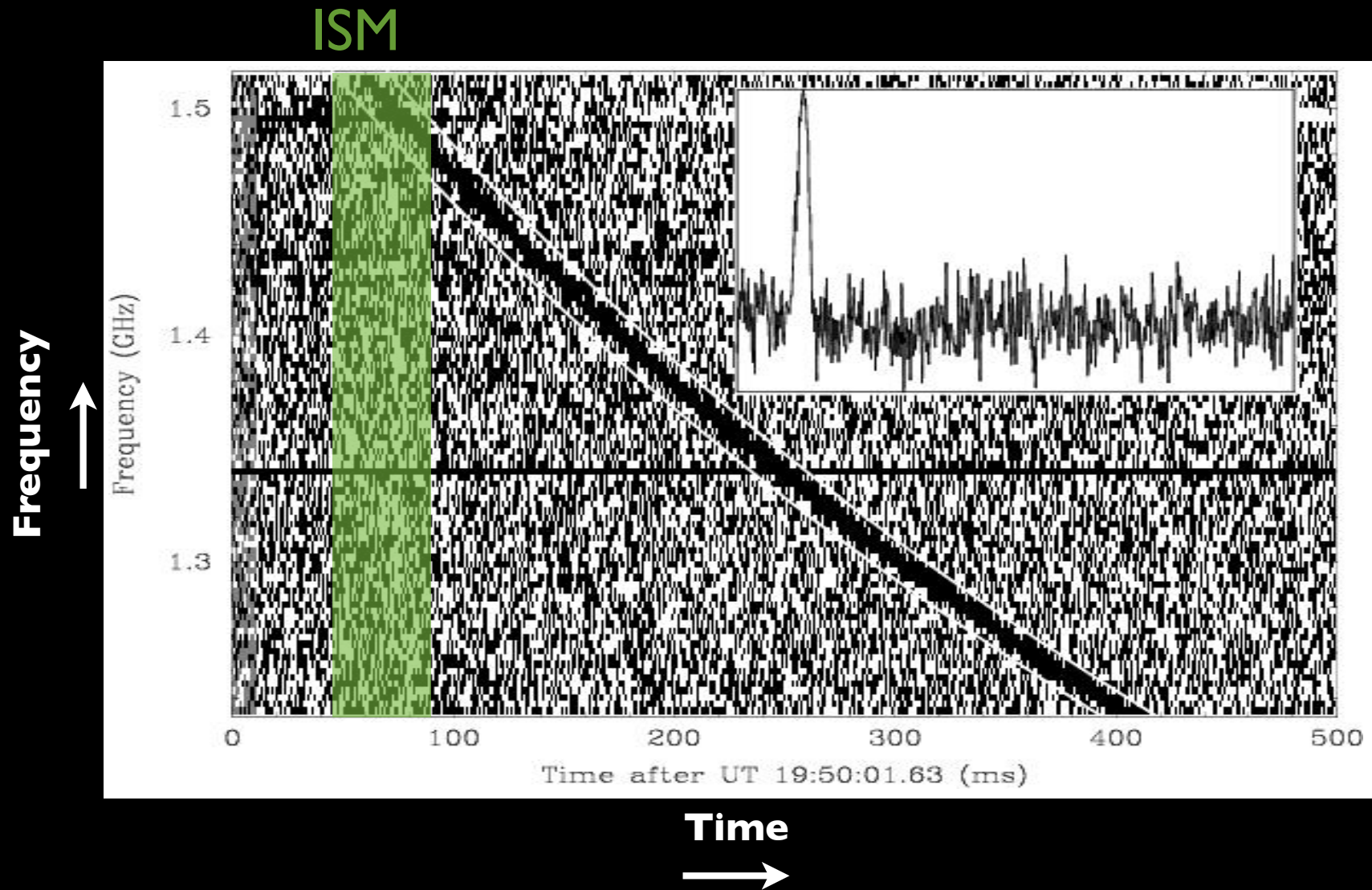
A hindrance but also a help

2007: The Lorimer Burst



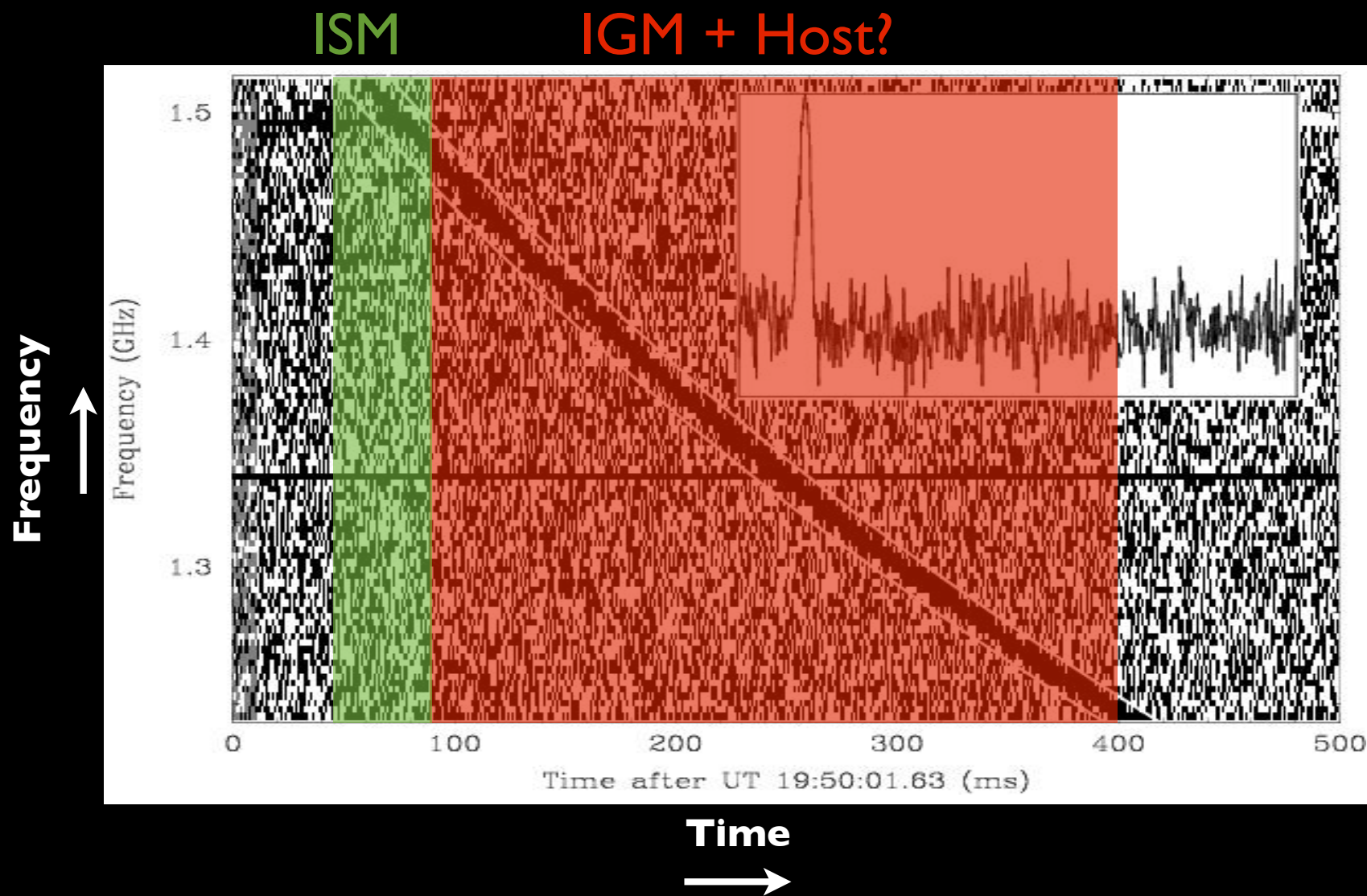
Lorimer et al. 2007

2007: The Lorimer Burst



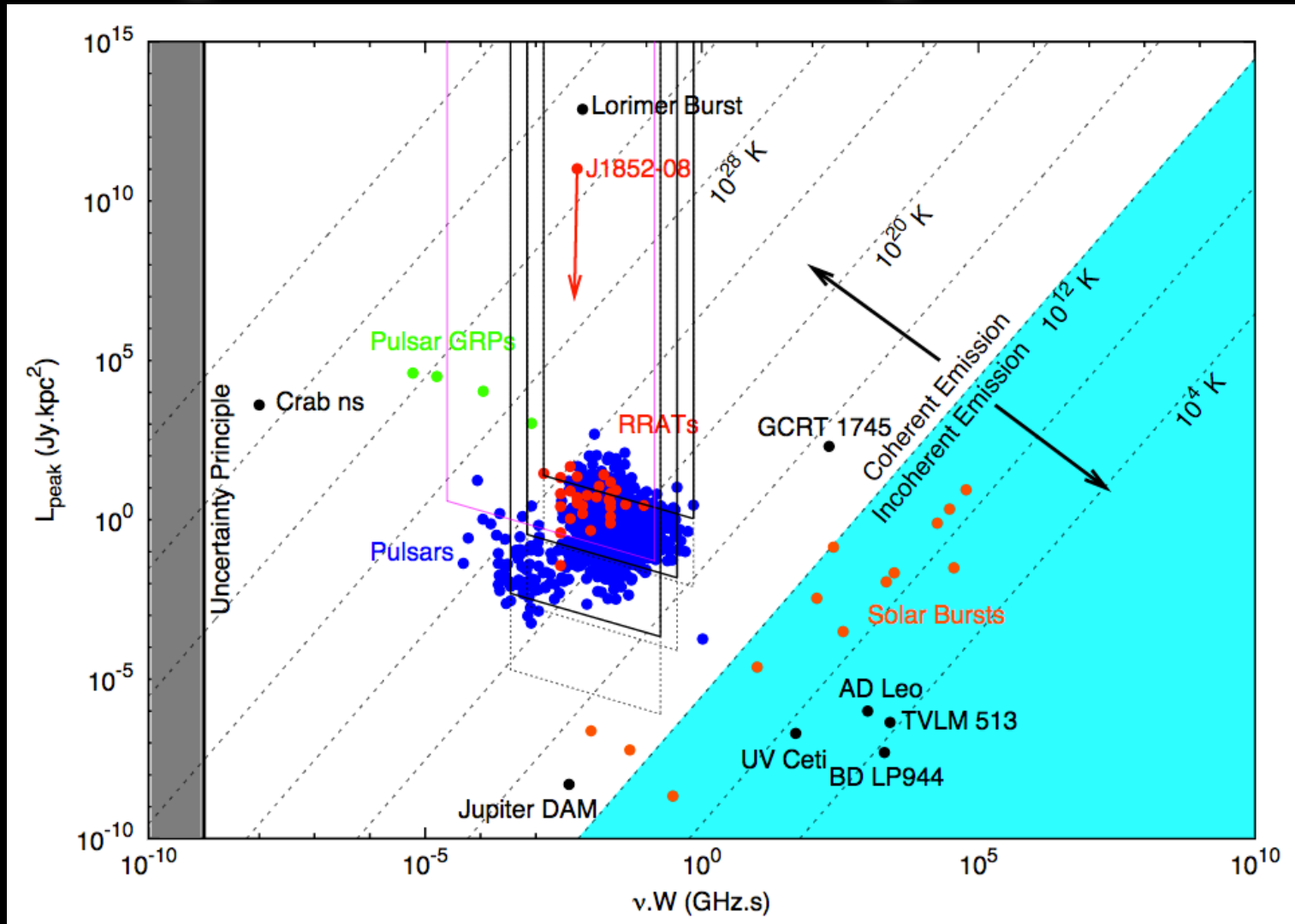
**Must be hundreds if not
thousands of these /sky/day**

2007: The Lorimer Burst



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

Charting a new area of parameter space



Keane et al. 2012

See also Cordes et al. 2004

Ye Olde FRB History

A few interesting FRB-like papers, in retrospect

< 2007

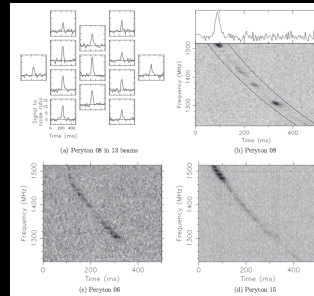


Time passes and no more bursts...

Perytons

(the Parkes microwave)

Burke-Spolaor et al. (2011)

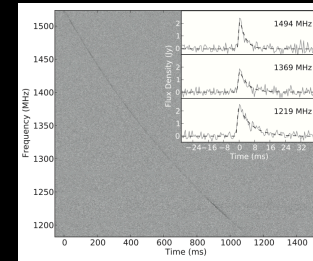


2011

The Thornton Bursts

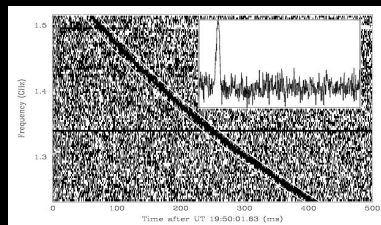
(a population of FRBs)

Thornton et al. (2013)



2013

2007

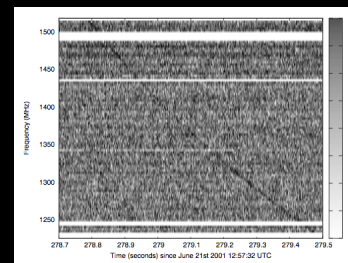


The Lorimer Burst

(the first FRB)

Lorimer et al. (2007)

2011



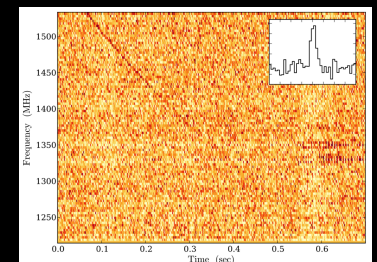
The Keane Burst

(an FRB or RRAT?)

Keane et al. (2011)

Keane et al. (2012)

2014



The Spitler Burst

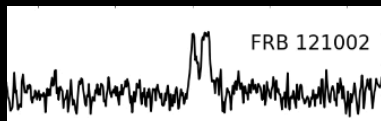
(first non-Parkes FRB)

Spitler et al. (2014)

Ye Olde FRB History

First multi-peak bursts

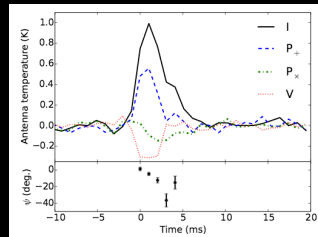
Champion et al. (2016)



2015

The Masui Burst
(first with an RM)

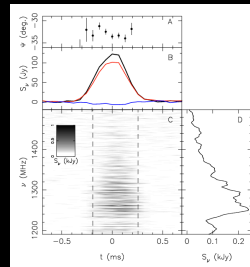
Masui et al. (2015)



2015

Another super-bright FRB
(Lorimer-like)

Ravi, Shannon et al. (2016)

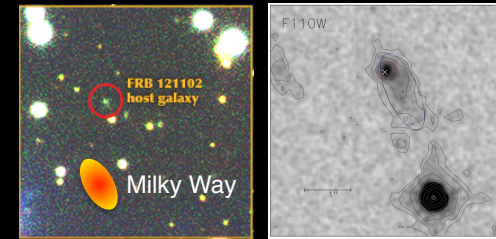


2016

FRB121102 host identified
(in a star-forming dwarf)

Tendulkar et al. (2017)

Bassa et al. (2017)

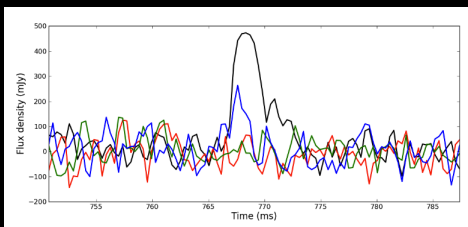


2017

Next repeater?
Next loc. & host?

< 2018

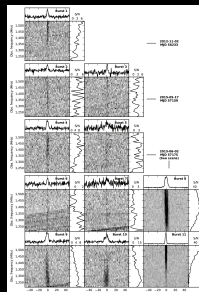
2015



First real-time burst & polarization

Petroff et al. (2015)

2016

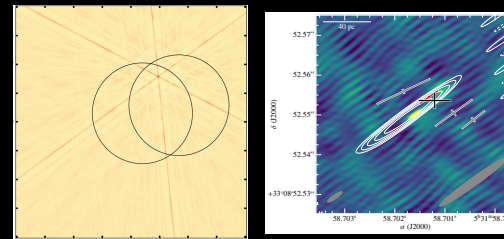


FRB121102: The Repeater
(still the only known)

Spitler et al. (2016)

Scholz et al. (2016)

2017

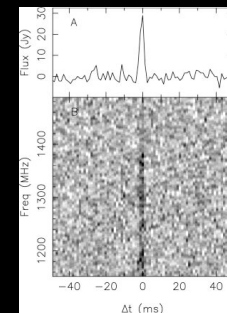


FRB121102 localized
(to milliarcseconds)

Chatterjee et al. (2017)

Marcote et al. (2017)

2017



UTMOST & ASKAP FRBs
(population deluge soon?)

Caleb et al. (2017)

Bannister et al. (2017)

FRB Discovery Scoreboard

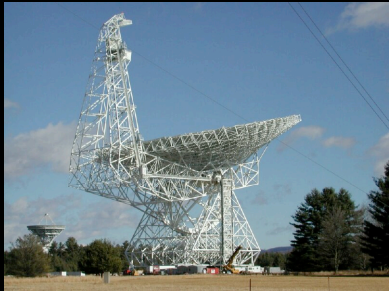


Arecibo (1.4 GHz): **1**

Arecibo (0.3 GHz): **0**



ASKAP (1.4 GHz): **3?**

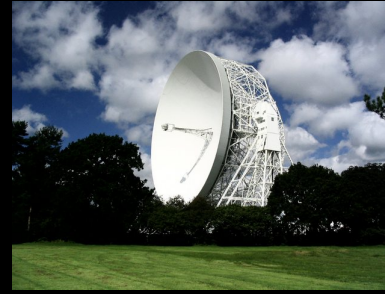


GBT (0.8 GHz): **1**

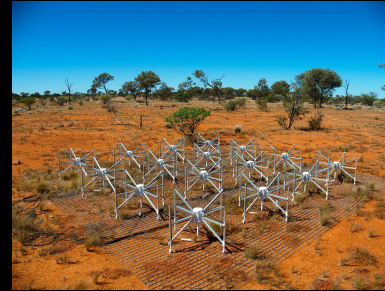
GBT (0.3 GHz): **0**



LOFAR (0.1 GHz): **0**



Lovell (1.4 GHz): **0**



MWA (0.2 GHz): **0**



Parkes (1.4 GHz): **21?**



UTMOST (0.8 GHz): **3**

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/>).

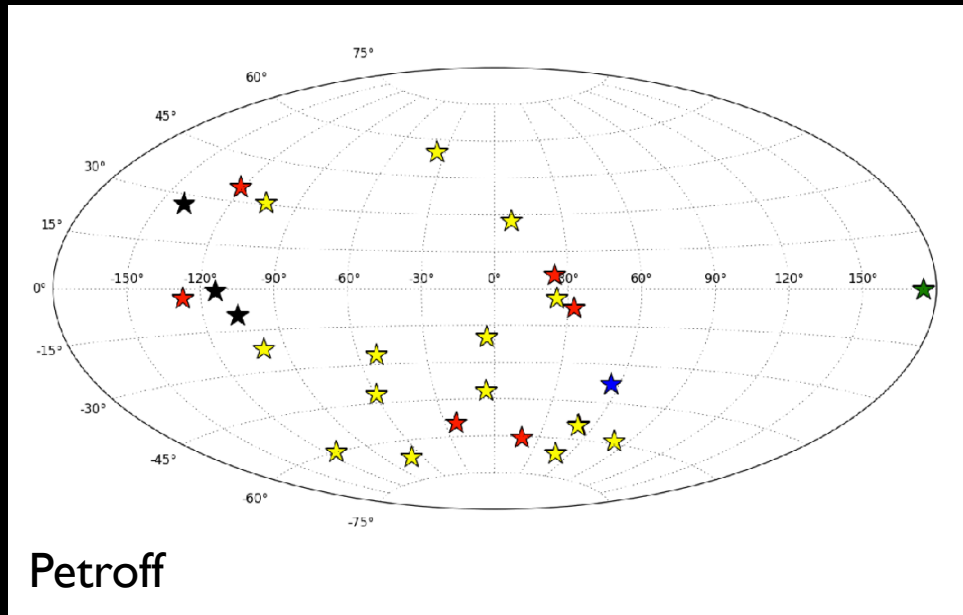
Catalogue Version 1.0

Event	Telescope	gl [deg]	gb [deg]	FWHM [deg]	DM [cm ⁻³ pc]	S/N	W _{obs} [ms]	S _{peak,obs} [Jy]	F _{obs} [Jy ms]	Ref
FRB010125	parkes	356.641	-20.020	0.25	790(3)	17	9.40 ^{+0.20} _{-0.20}	0.30	2.82	1
FRB010621	parkes	25.433	-4.003	0.25	745(10)		7.00	0.41	2.87	2
FRB010724	parkes	300.653	-41.805	0.25	375	23	5.00	>30.00 ^{+10.00} _{-10.00}	>150.00	3
FRB030625	parkes	226.443	-60.030	0.25	899.55(1)	30	1.92 ^{+0.83} _{-0.77}	1.14 ^{+0.42} _{-0.21}	2.19 ^{+2.10} _{-1.12}	4
FRB110220	parkes	50.628	-54.766	0.25	944.38(5)	49	5.60 ^{+0.10} _{-0.10}	1.30 ^{+0.00} _{-0.00}	7.28 ^{+0.13} _{-0.13}	5
FRB110523	GET	56.119	-37.819	0.26	623.30(6)	42	1.73 ^{+0.17} _{-0.17}	0.60	1.04	6
FRB110626	parkes	355.861	-41.752	0.25	723.0(3)	11	1.40	0.40	0.56	5
FRB110703	parkes	80.997	-59.019	0.25	1103.6(7)	16	4.30	0.50	2.15	5
FRB120127	parkes	49.267	-65.203	0.25	553.3(3)	11	1.10	0.50	0.55	5
FRB121002	parkes	208.210	-28.264	0.25	1620.18(2)	16	5.14 ^{+3.50} _{-3.50}	0.42 ^{+0.33} _{-0.33}	0.24 ^{+4.46} _{-4.46}	4

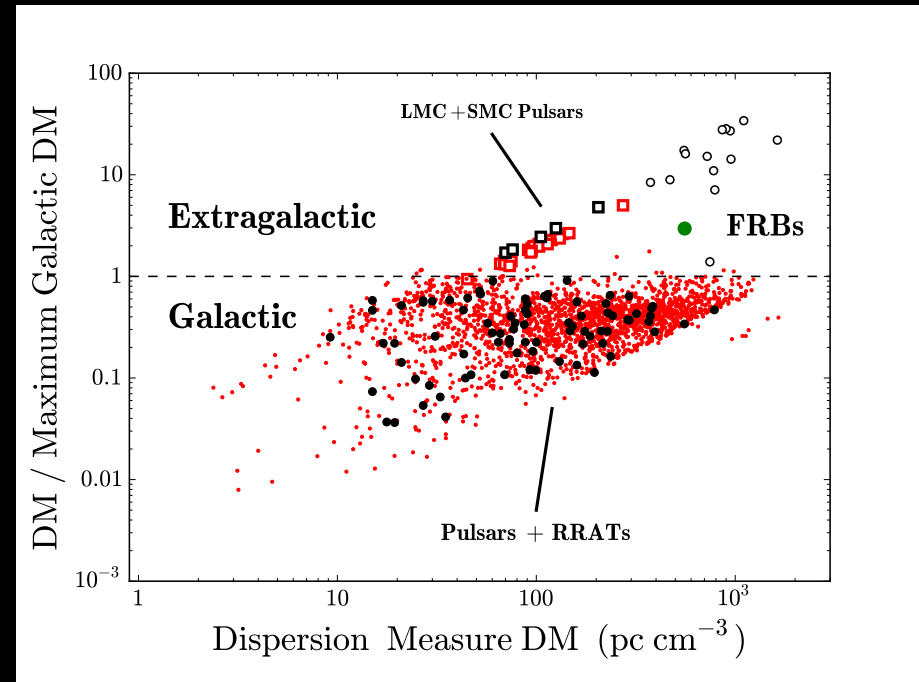
<http://www.astronomy.swin.edu.au/pulsar/frbcatalog/>

Petroff et al. (2016)

FRB Population



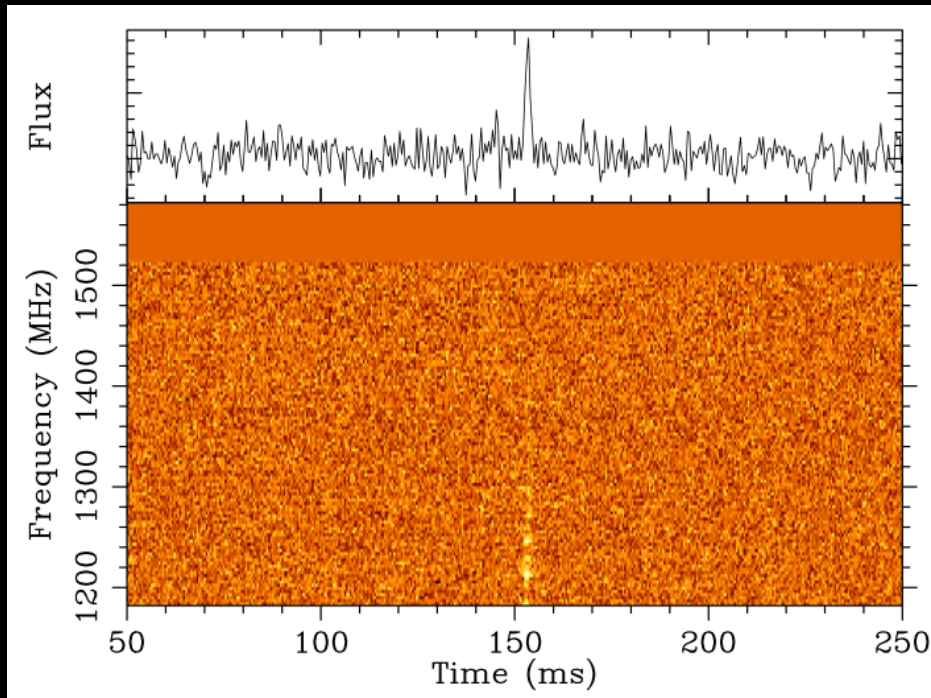
Parkes published GBT Arecibo
Parkes unpublished UTMOST



- ~29 known FRBs
- ~7 unpublished (or published on FB)
- Event rate is
 > 1000s /day/sky
- That's how small the field-of-view of a typical radio telescope is!

At the extremes

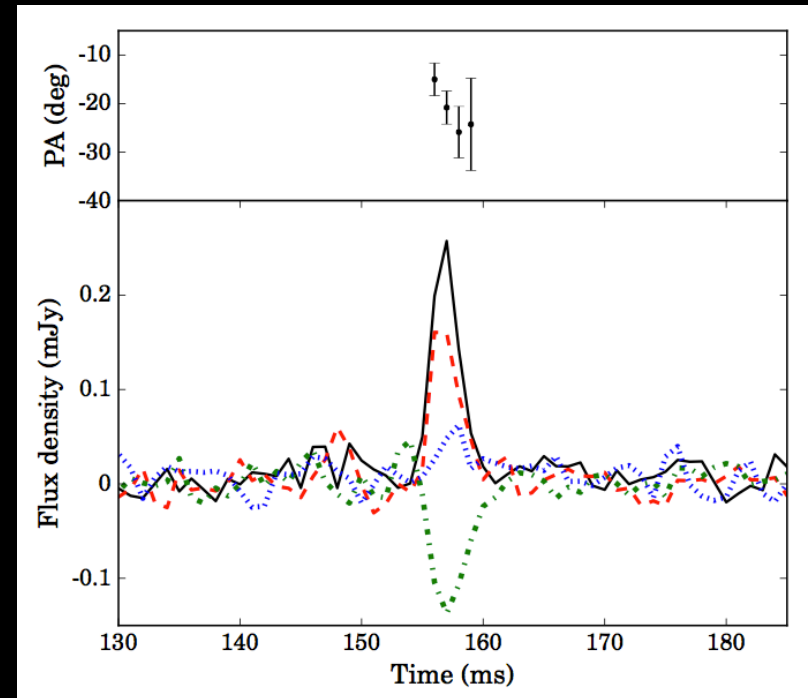
FRB 10214



Petroff

- $DM = 170 \text{ pc/cc}$
- $z < 0.05$
- Detected in outskirts of the receiver beams

FRB 160102



Caleb

- $DM = 2600 \text{ pc/cc}$
- $z < 2.1$
- $RM = -220 \text{ rad/m}^2$
- 1.1 ms, unscattered

FRB observables

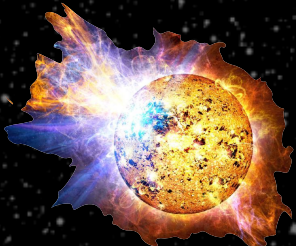
- Dispersion measure
- Dispersion index
- Scattering measure: LOS inhomogeneity
- Scattering index
- Polarization: local magnetic field
- Rotation measure: B-field in local environment
- Spectrum
- Scintillation
- Pulse width
- Pulse fluence (and luminosity if redshift is known)
- Pulse morphology
- 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



Merging Black Holes



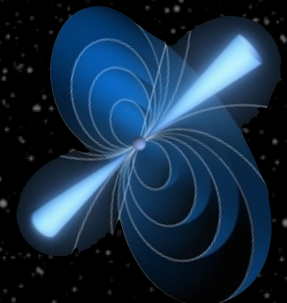
Supernovae



Magnetars



Evaporating Black Holes



Super-giant Pulses



The Unknown



Gamma-ray Bursts

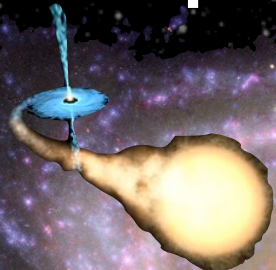
extra-Galactic

So what are they?

Galactic

Micro-quasars

Flare stars



SETI

Pernicious RFI Atmospheric effects



Magnetars

We are here



Pulsars



"Blitzars"

Observed FRB properties



Gruffalo model

Hessels et al. (*Nature*, submitted)

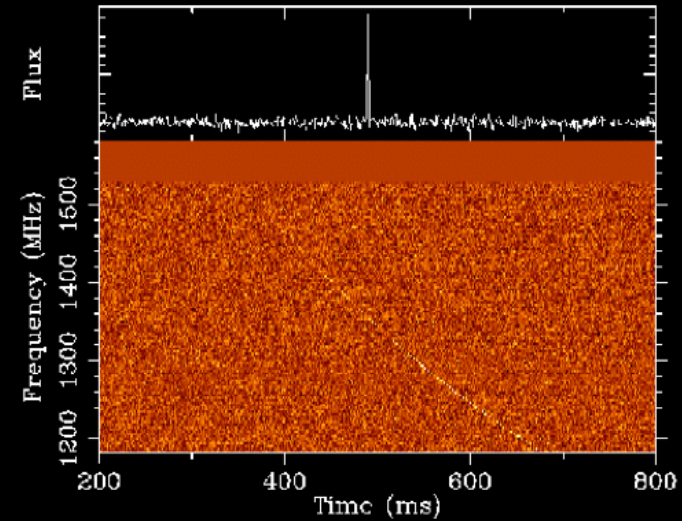
Observed FRB properties

Pulse widths:

0.3 - ~10ms (and longer?)

Some scattered; some not

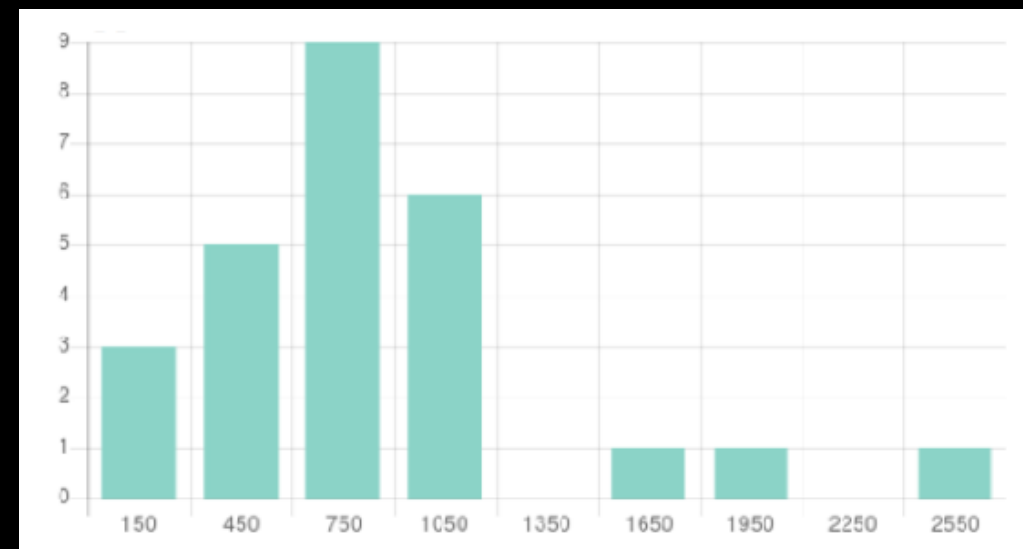
Are some intrinsically
delta functions?



Ravi, Shannon et al. (2016)

DMs: most between
500-1000 pc/cc

DM-Redshift: $0.05 < z < 2.1$
(assuming all from IGM)



Petroff

DM (pc/cc)

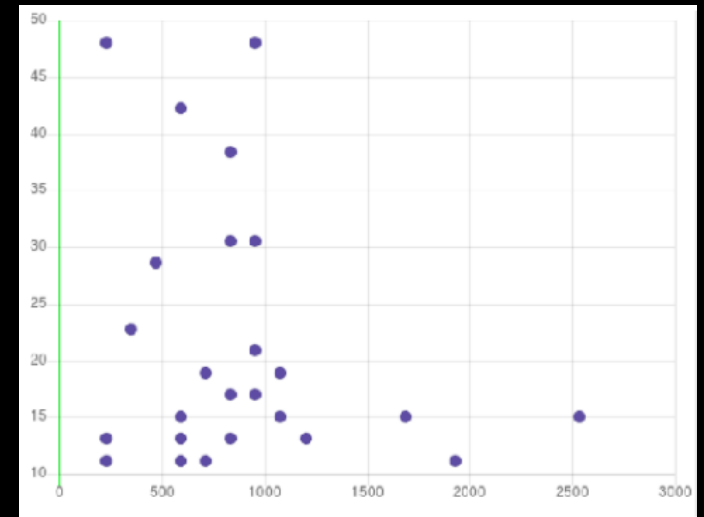
Observed FRB properties

Brightness: not strongly correlated with distance; not standard candles (beamed!).

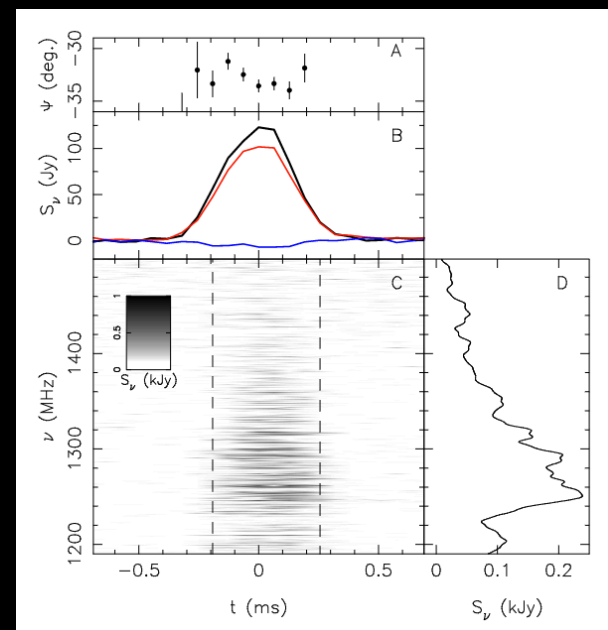
Some hint that the lower-DM ones might be closer.

Polarization: sometimes none, sometimes circular, sometimes linear

Rot. Measure: 2 FRBs with high RMs; 2 consistent with the expected Milky Way contribution



Petroff DM (pc/cc)



Ravi, Shannon et al. (2016)

Observed FRB properties

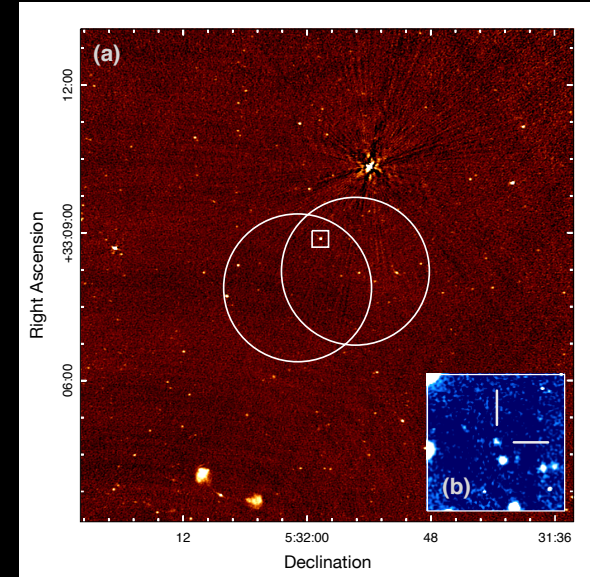
FRB121102 is a gold mine

Multi-wavelength persistent counterparts: radio (compact!) & optical (star formation!); no X-ray or gamma-ray

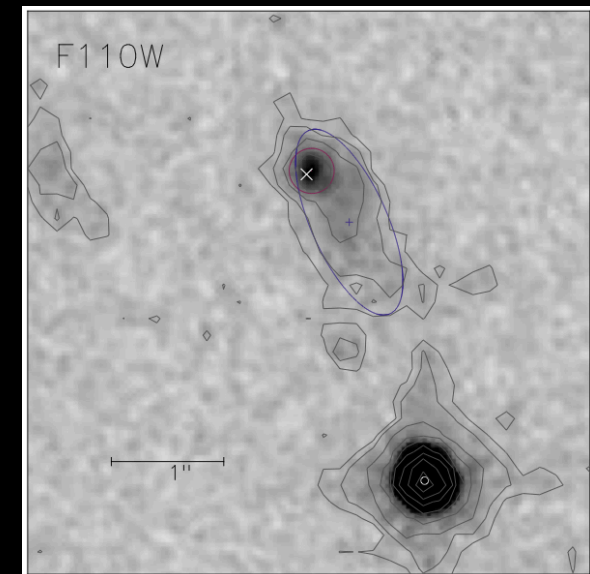
Multi-wavelength prompt emission: none.

Periodicity: none detected yet

Host: dwarf

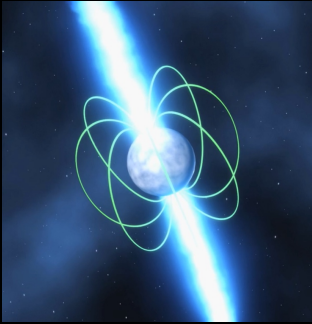


Chatterjee et al. (2017)



Bassa, Tendulkar et al. (2017)

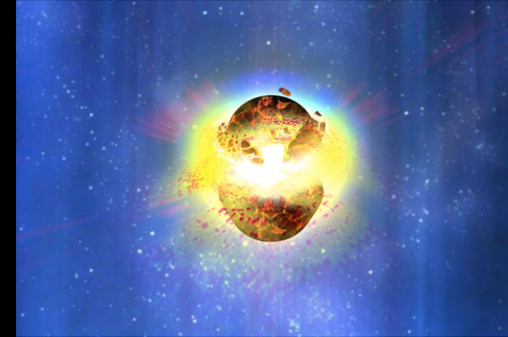
How many classes of FRBs?



Pulsar on steroids

Repeaters

(Spitler et al. 2016)



Cataclysm

(Apparent?) non-repeaters

(Petroff et al. 2015)

vs.

FRB 131104: 170hrs

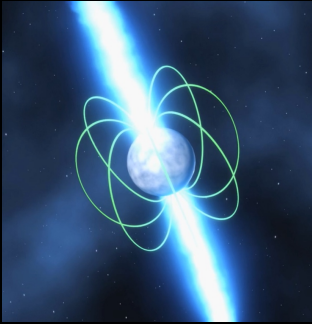
FRB 140514/110220: >50hrs

Diff widths and spectra?

Lensing?

Arecibo sensitivity matters?

How many classes of FRBs?

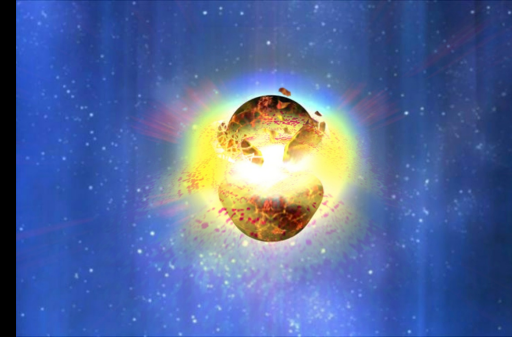


Pulsar on steroids

Repeaters

(Spitler et al. 2016)

vs.



Cataclysm

(Apparent?) non-repeaters

(Petroff et al. 2015)

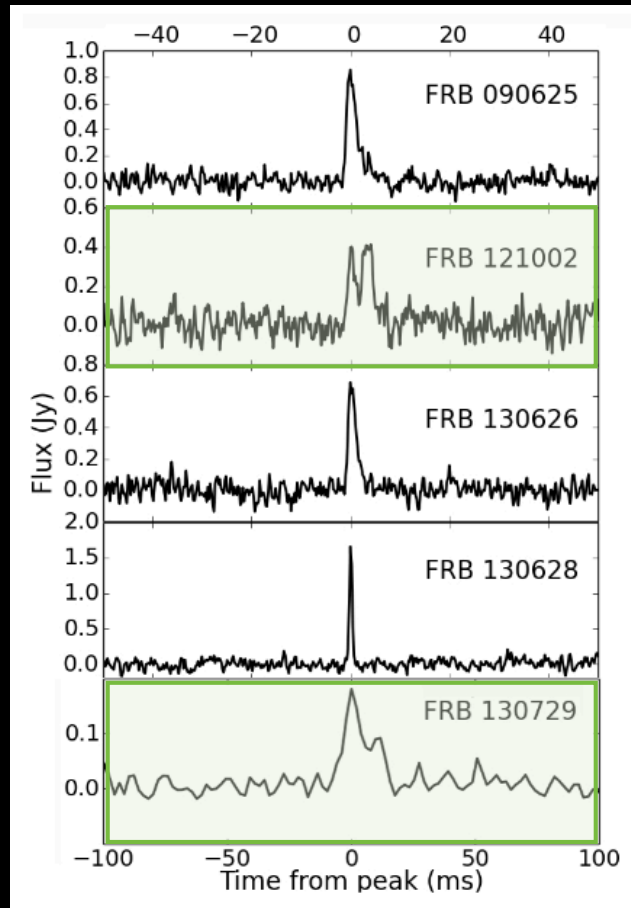
FRB131104: 170hrs

FRB140514/110220: >50hrs

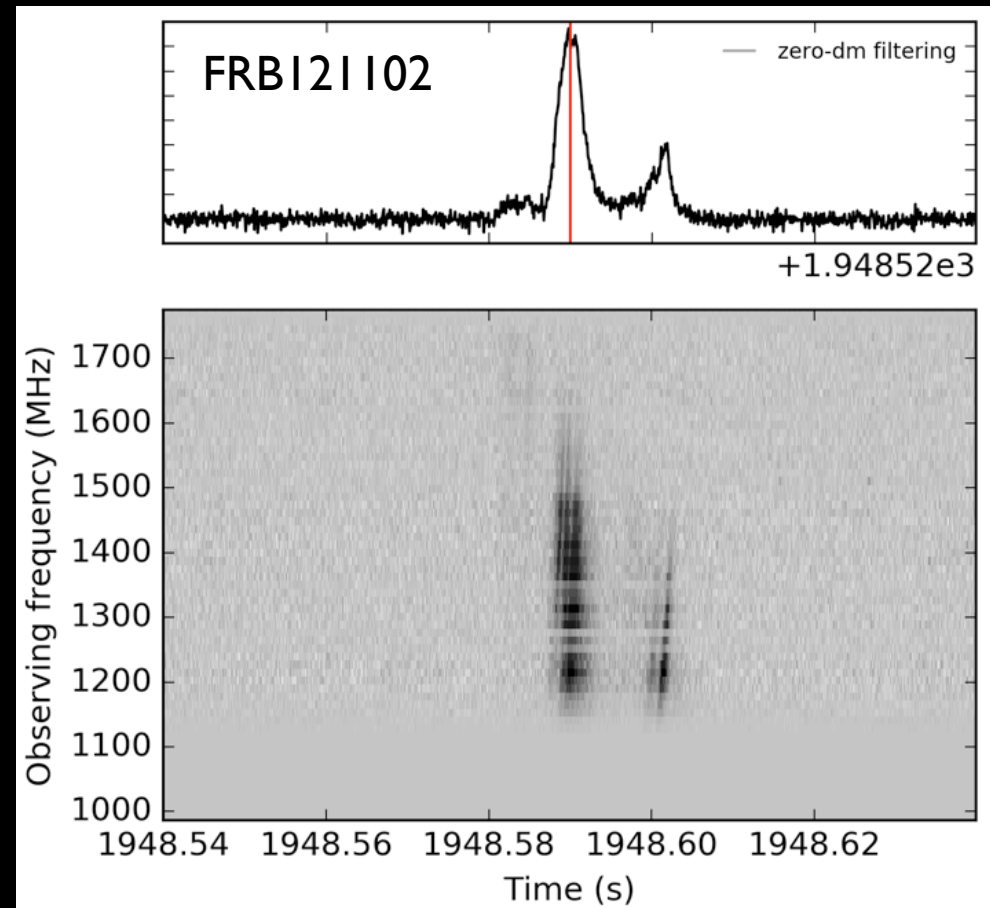
NB: according to the *arXiv*, there are >40 types of FRBs

Double-peaked bursts

At least some of the Parkes bursts are similar in this regard



Champion et al. (2016)

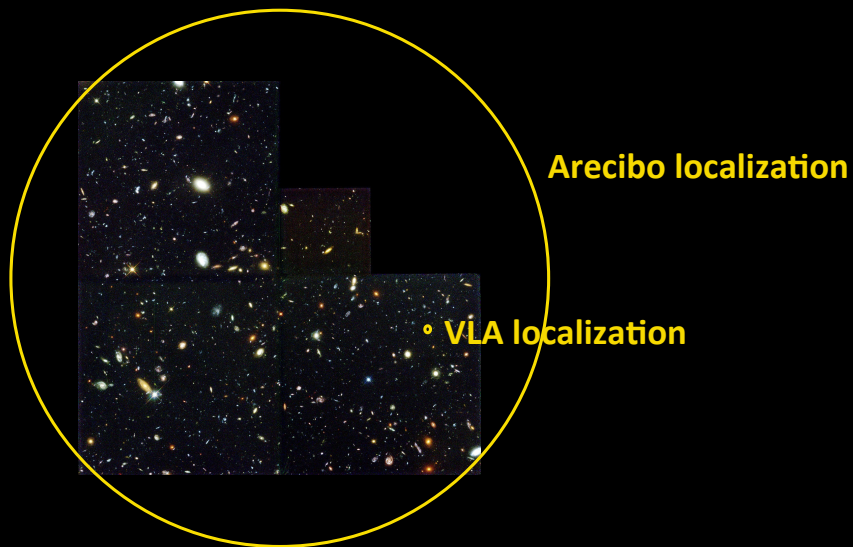


Michilli & Gourdji



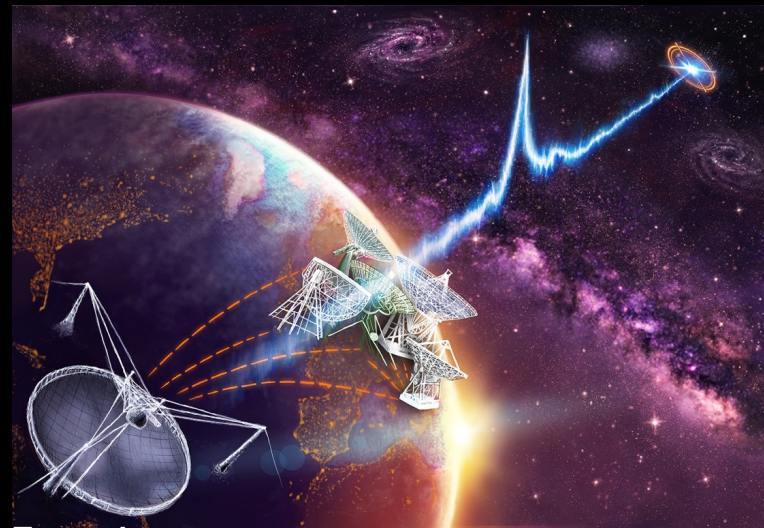
What are the host galaxies?

- Will all FRBs be hosted in low-metallicity, dwarf galaxies?
- **Requires:** more sub-arcsecond localizations and redshifts.

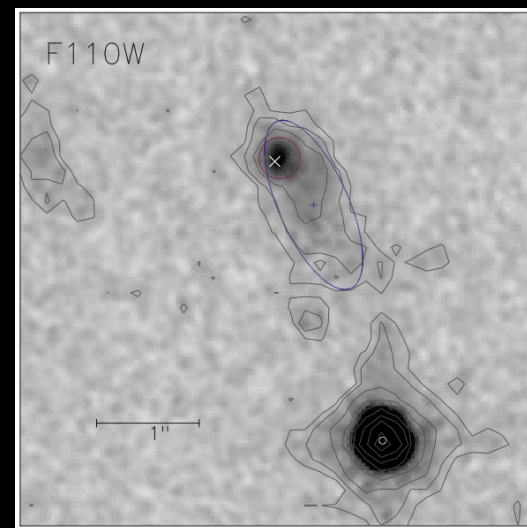


What are the host environments?

- Will all FRBs be hosted in starforming regions with compact radio counterparts?
- **Requires:** more milli-arcsecond radio localizations and sub-arcsecond optical observations. Also more RMs!



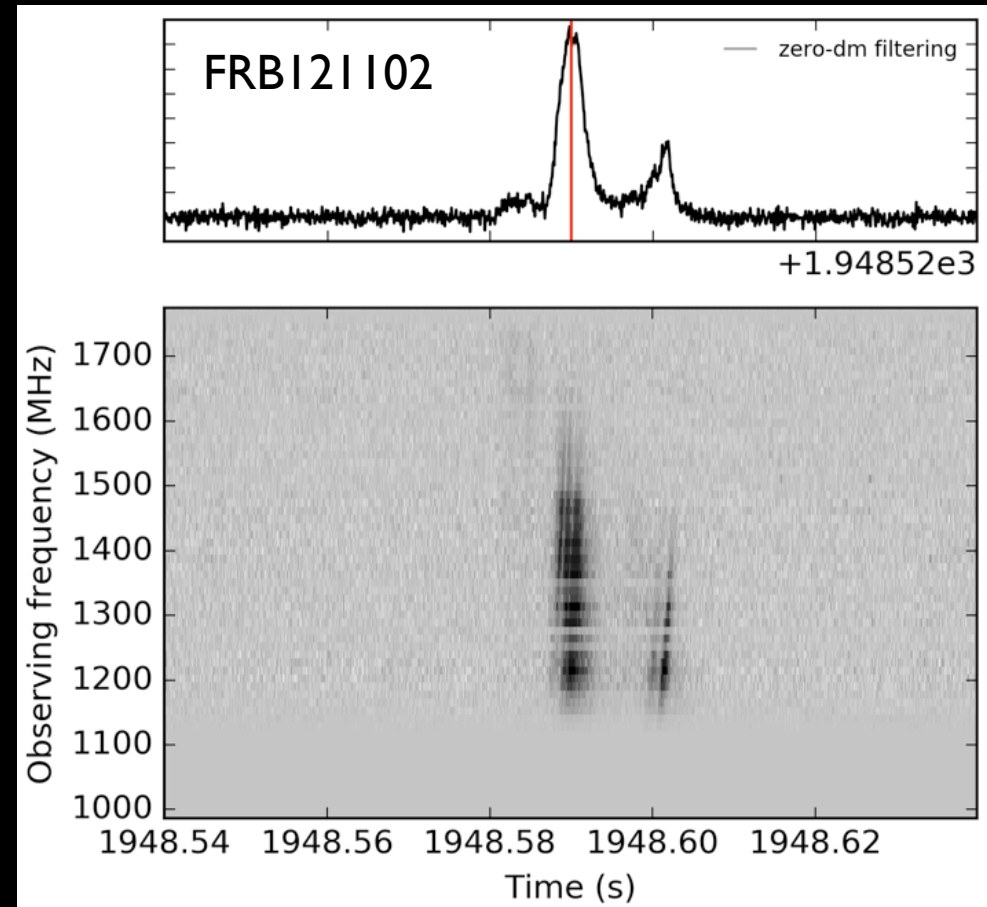
Futselaar



Bassa, Tendulkar et al. (2017)

What is the emission mechanism?

- Obviously coherent, but is the source rotational, magnetic, gravitational (accretion?)
- **Requires:** coherent dedispersion with full Stokes parameters. Wide-band observations. Base-band data. Very clever theorists.

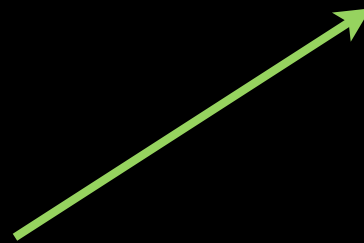


Michilli & Gourdji

What is the emission mechanism?

We've spent 50 years puzzling over how pulsars work, so it's great to see so many brilliant theorists ready for 50 years of FRB puzzles.

- **Requires:** coherent dedispersion with full Stokes parameters. Wide-band observations. Base-band data. Very clever theorists.



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!

Working and Upcoming FRB Factories

- Strike various balances between localization precision, yield, observing frequency and sensitivity
- More localizations before end of 2017?
- Double population in next year?



CHIME



ASKAP



UTMOST



APERTIF