Fast Radio Bursts

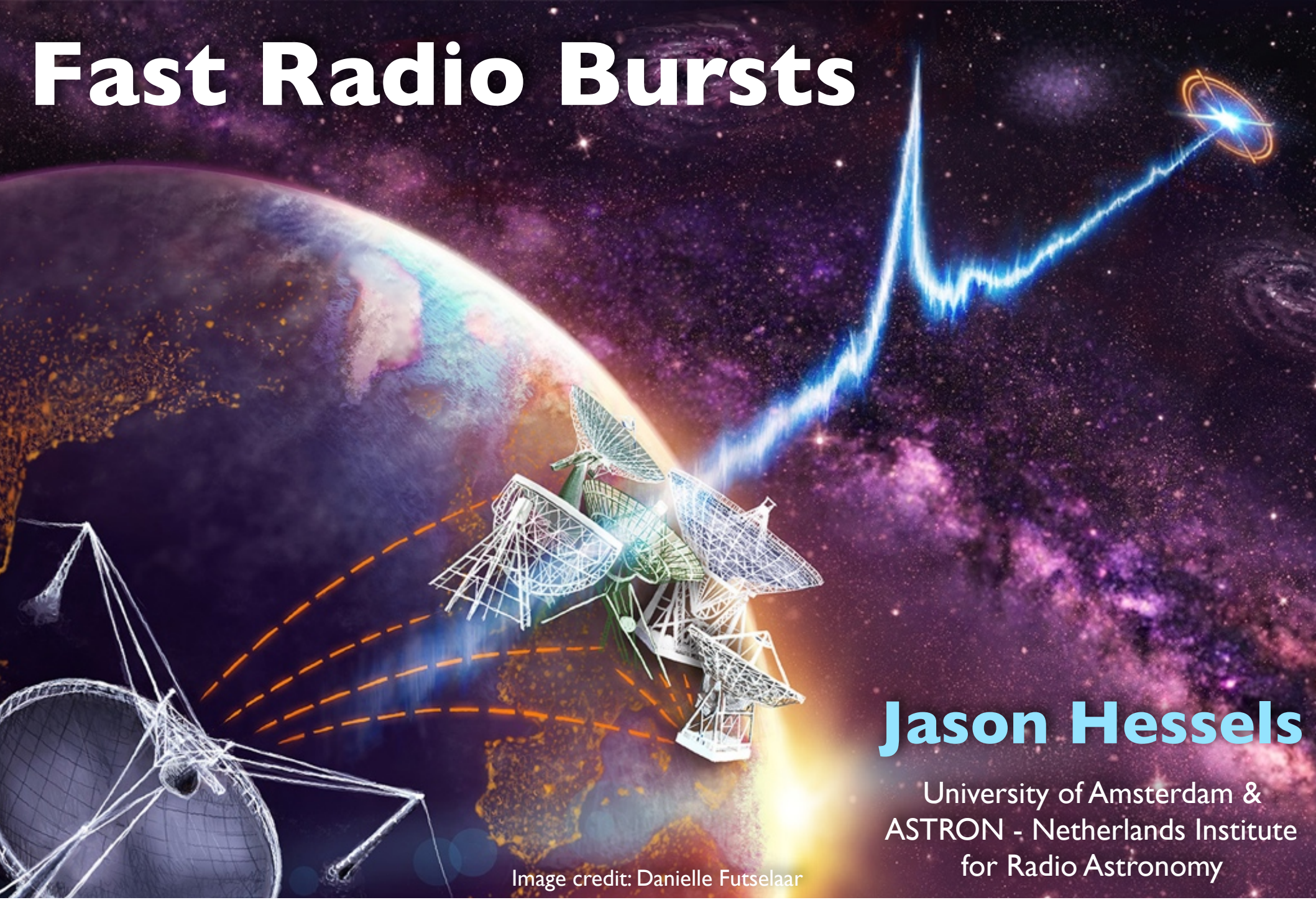


Image credit: Danielle Futselaar

Jason Hessels

University of Amsterdam &
ASTRON - Netherlands Institute
for Radio Astronomy

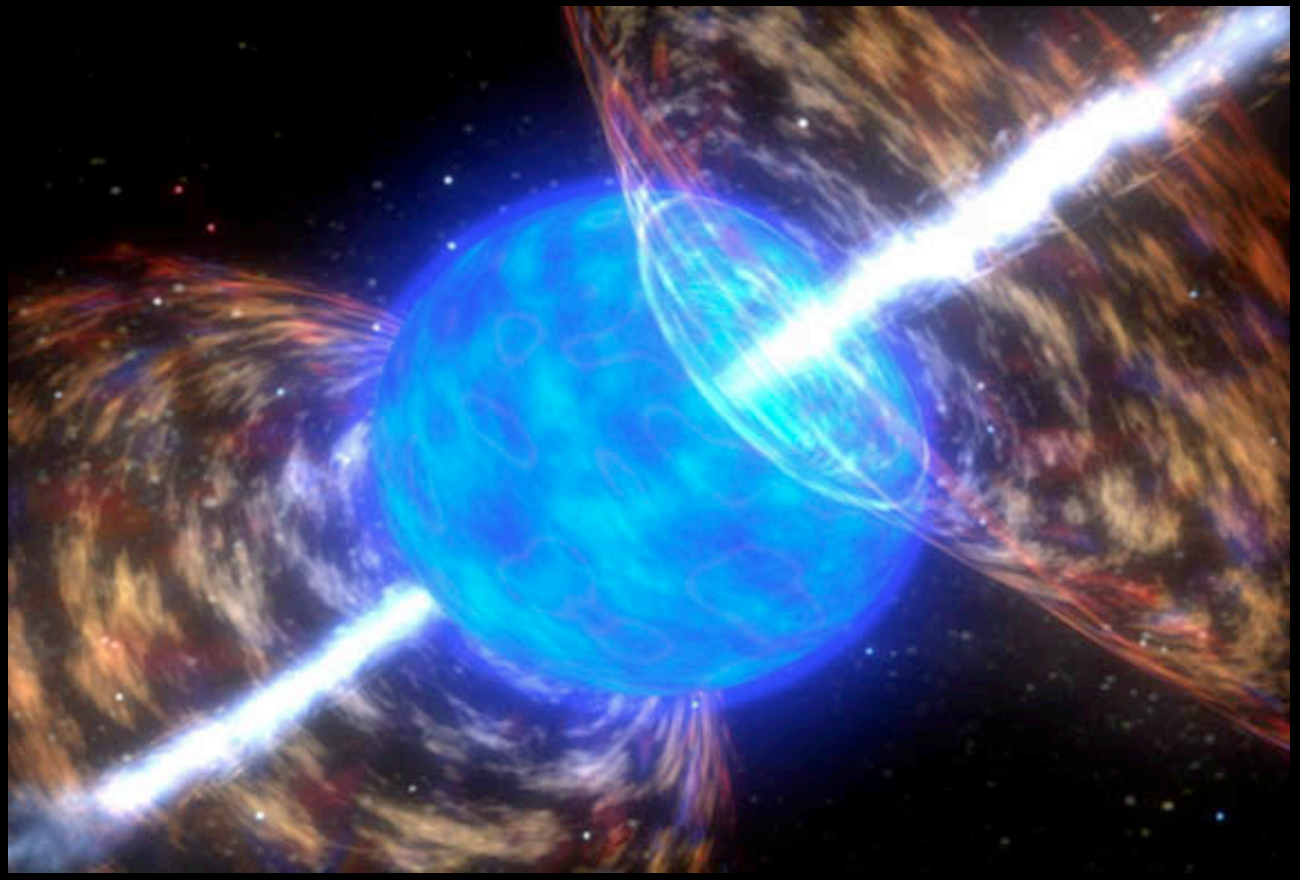
Universiteit van Amsterdam

European Research Council
Established by the European Commission

NWO
Netherlands Organisation
for Scientific Research

ASTRON
Netherlands Institute for Radio Astronomy

Gamma-ray Bursts

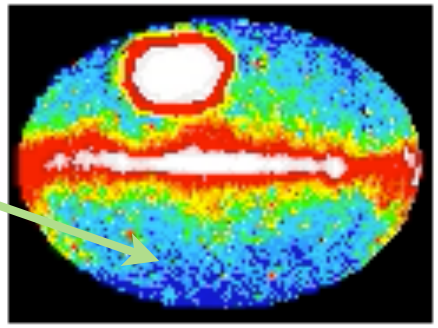


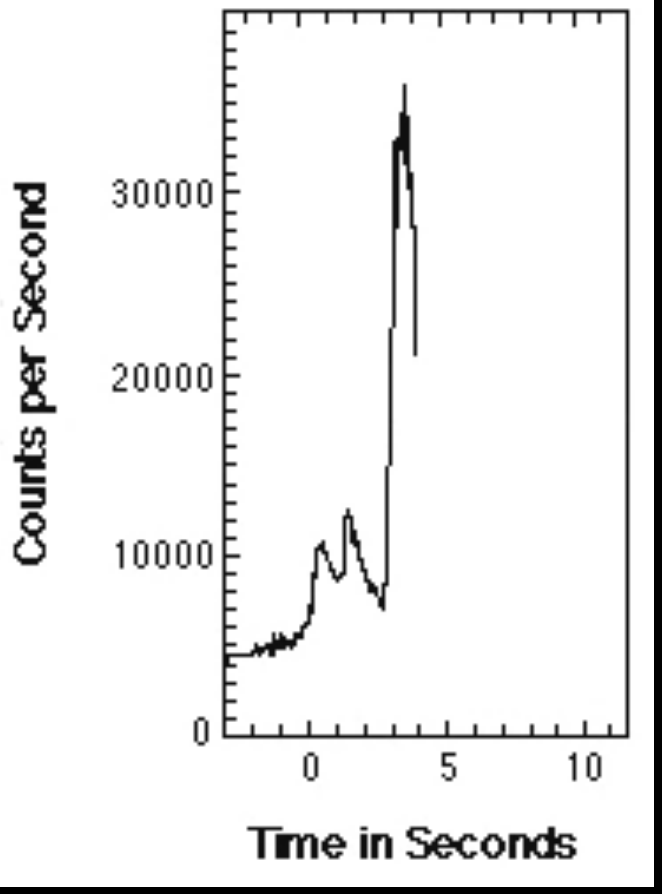
Are there also similar sirens of extreme (astro)physics to be found in the radio?

Gamma-ray Bursts

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

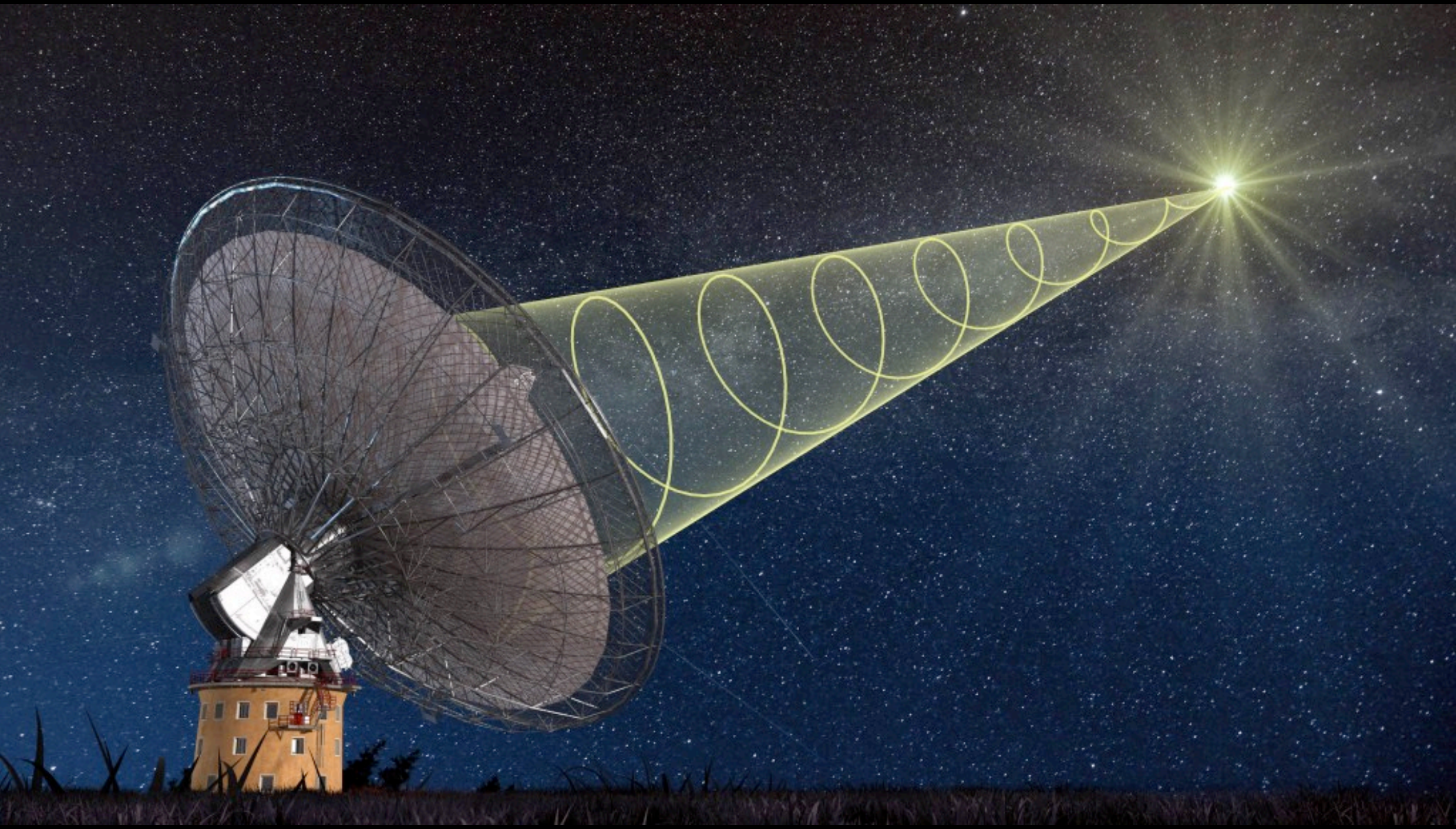
~10 days/FRB





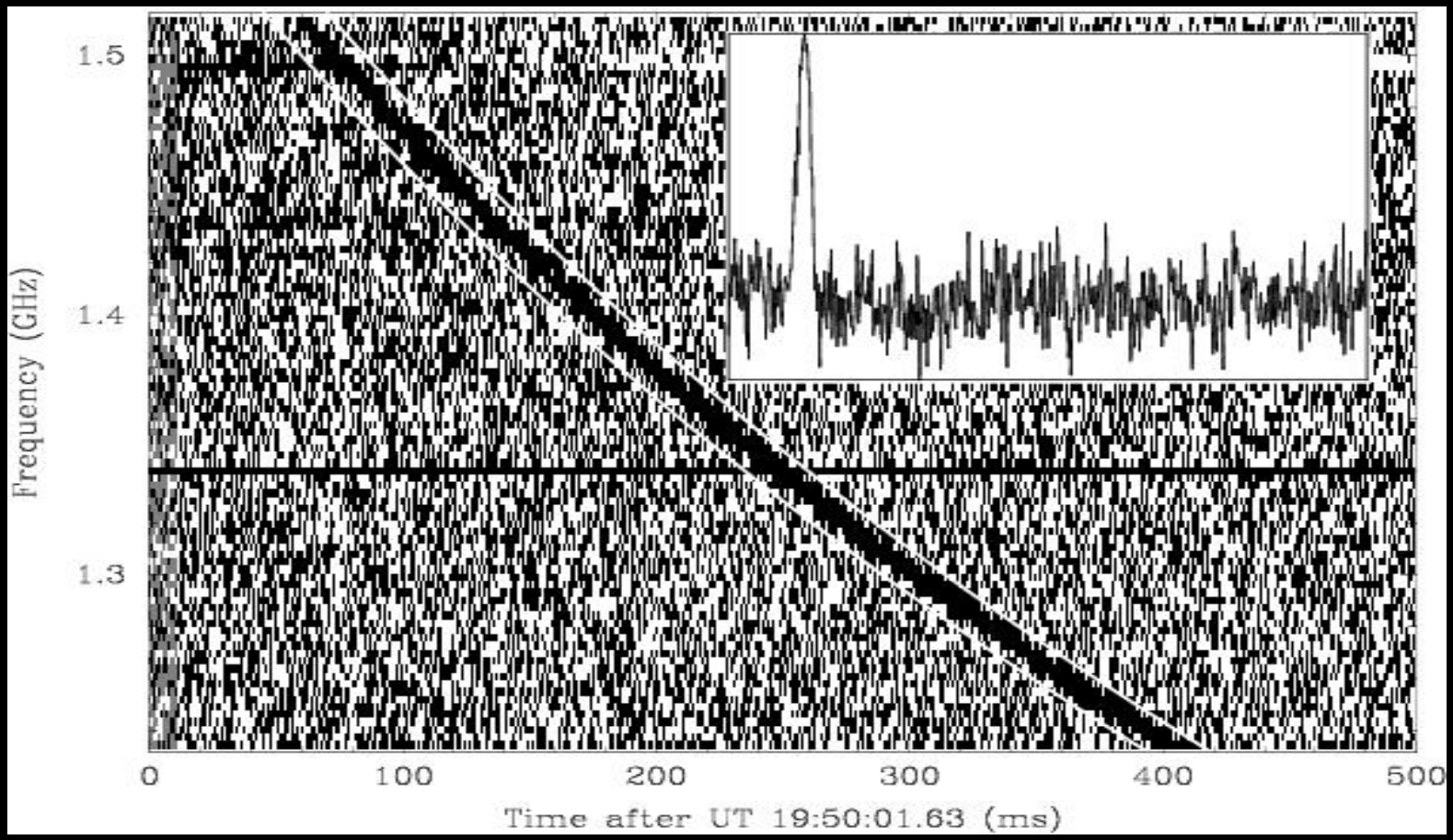
There is no sufficiently sensitive all-sky radio monitor, yet...

Fast Radio Bursts



Lorimer et al. 2007
Thornton et al. 2013

2007: The Lorimer Burst



Frequency

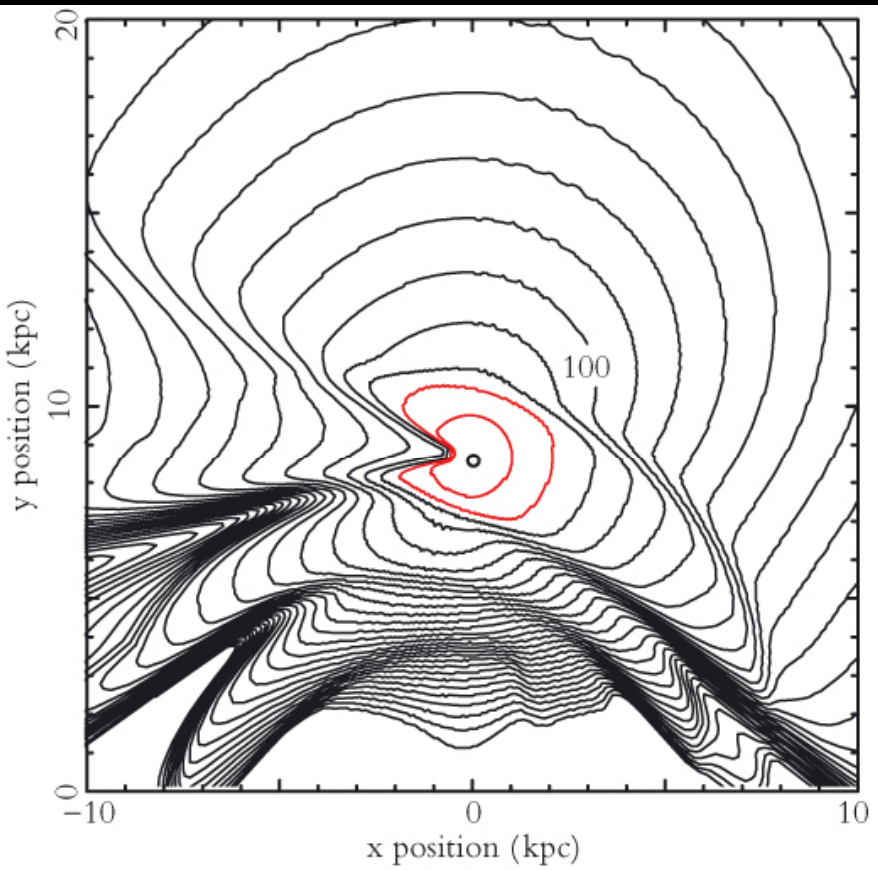
Time

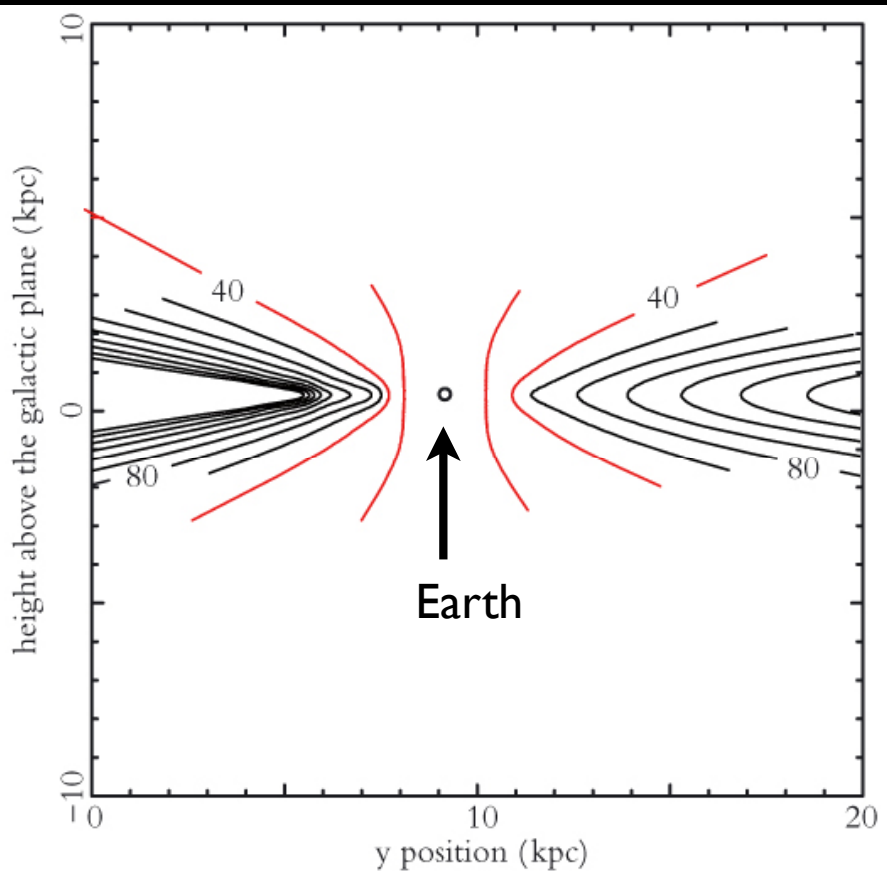
Lorimer et al. 2007

Galactic Dispersion

Galaxy top-down

Along Galactic plane

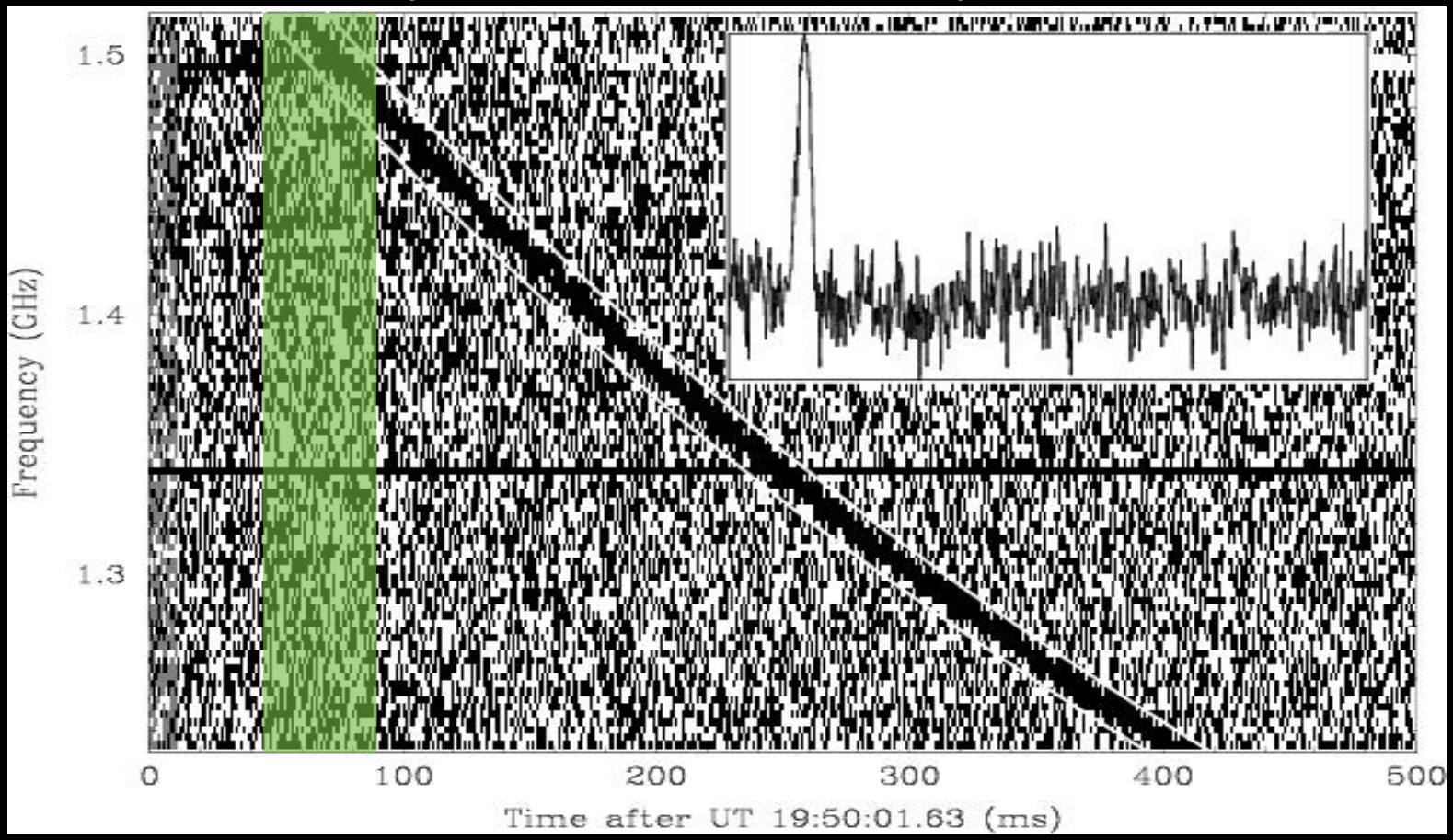




Contours of constant dispersion measure (NE2001 model; Cordes & Lazio)

2007: The Lorimer Burst

ISM (interstellar medium)



Frequency

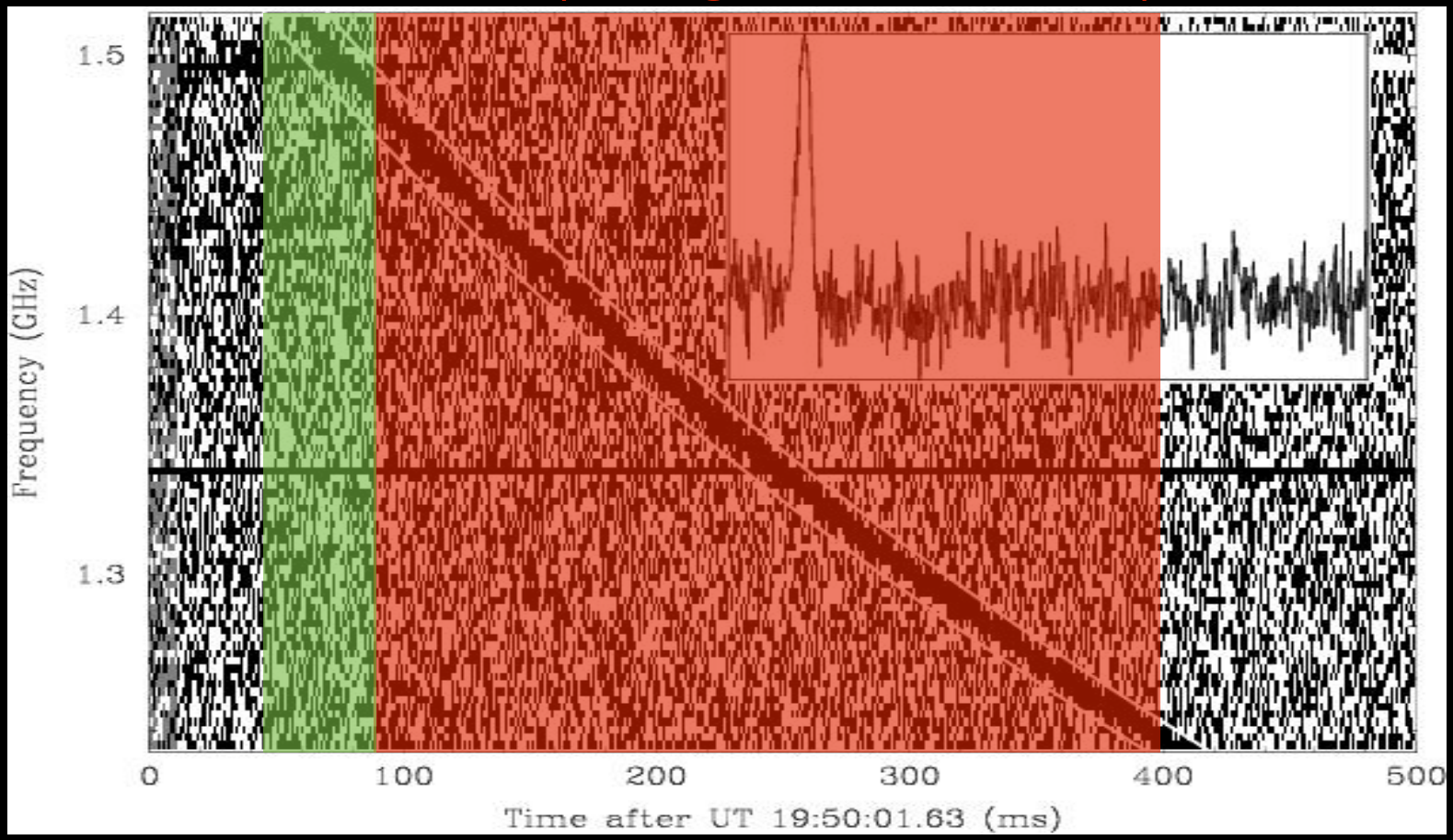
Time

Delay too large to come from just the galaxy

Lorimer et al. 2007

2007: The Lorimer Burst

ISM IGM (intergalactic medium) + Host?



Frequency ↑

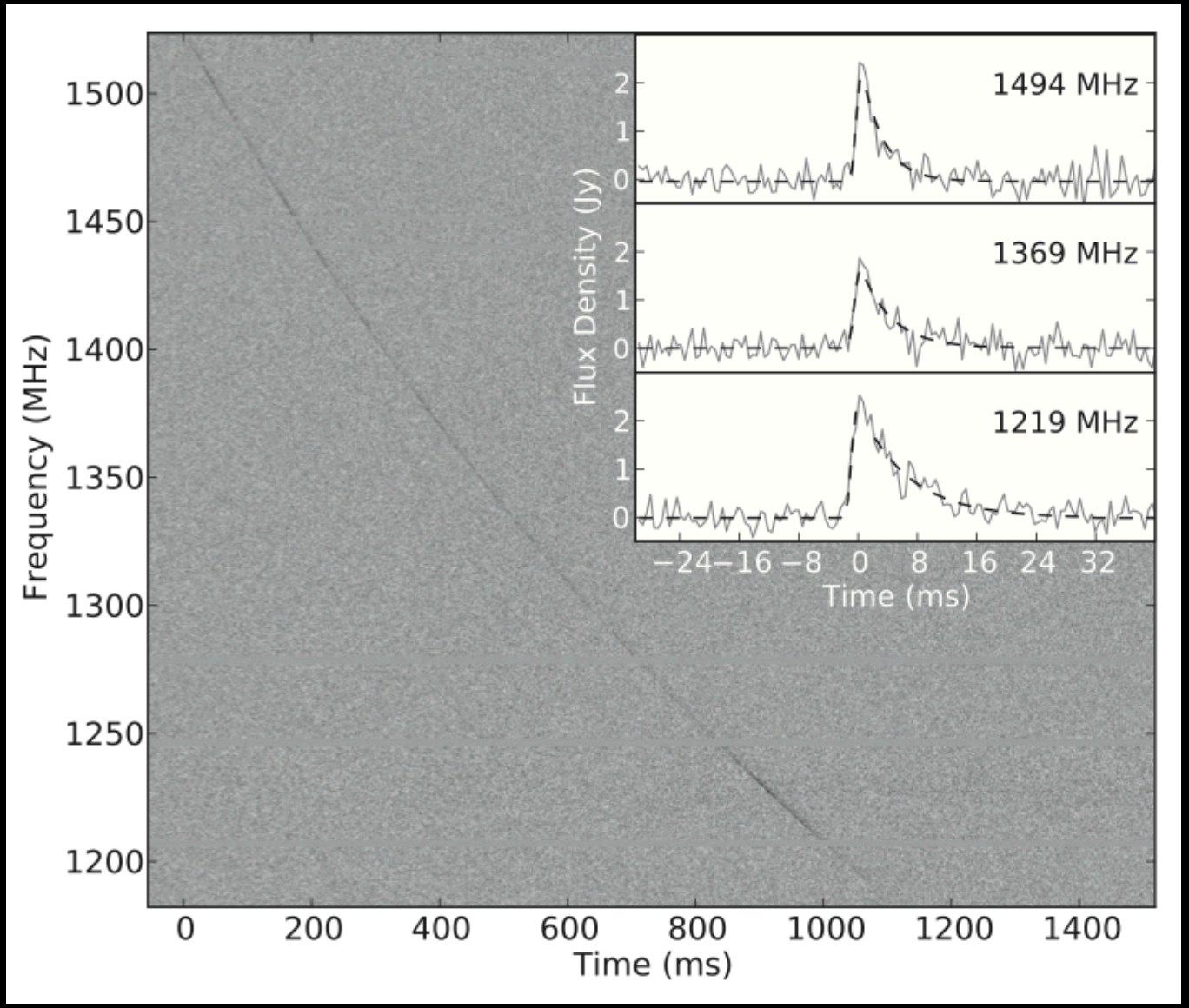
Time →

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.

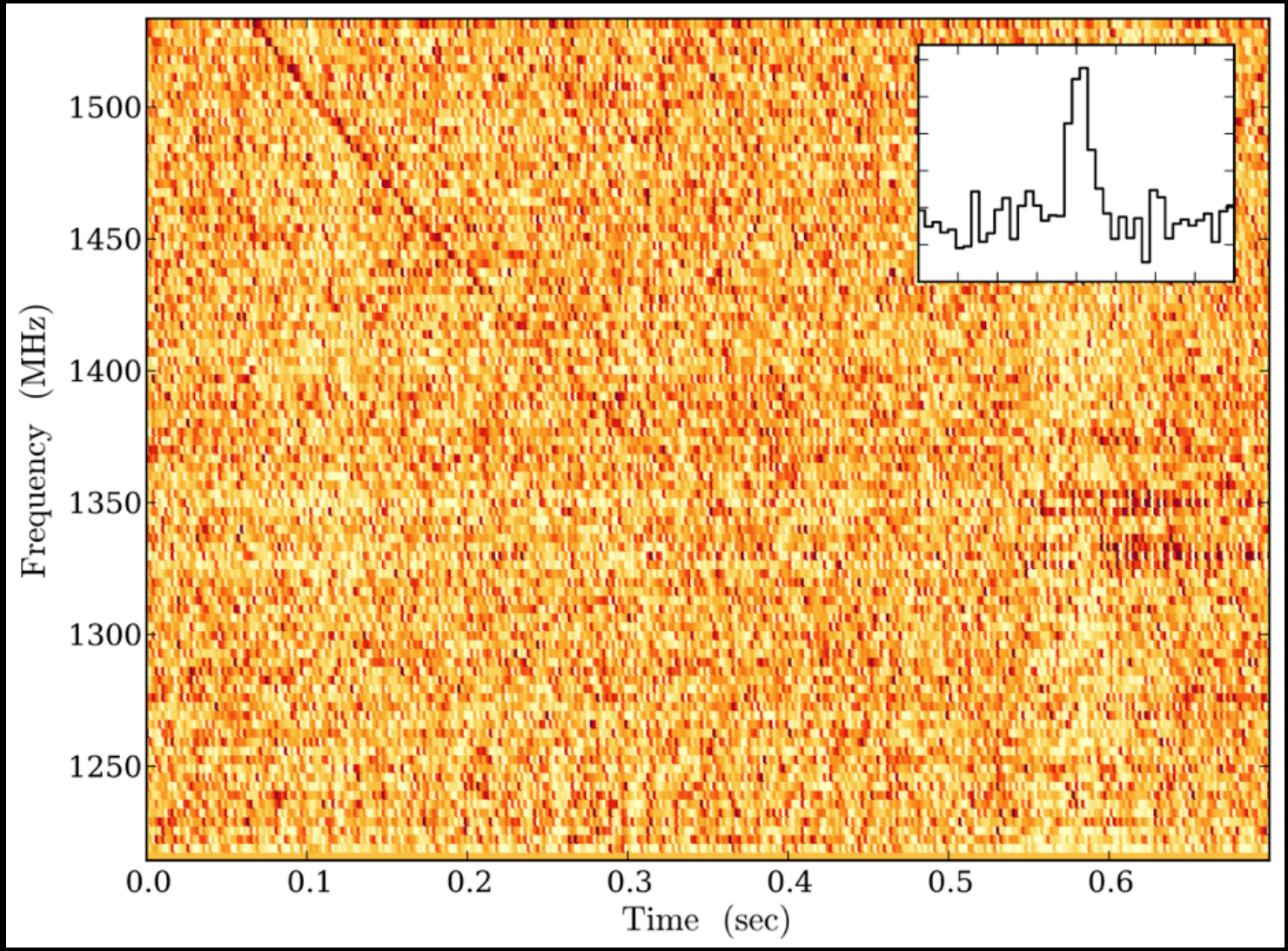
2013: The Thornton Bursts



There is a population of FRBs

Thornton et al. 2013

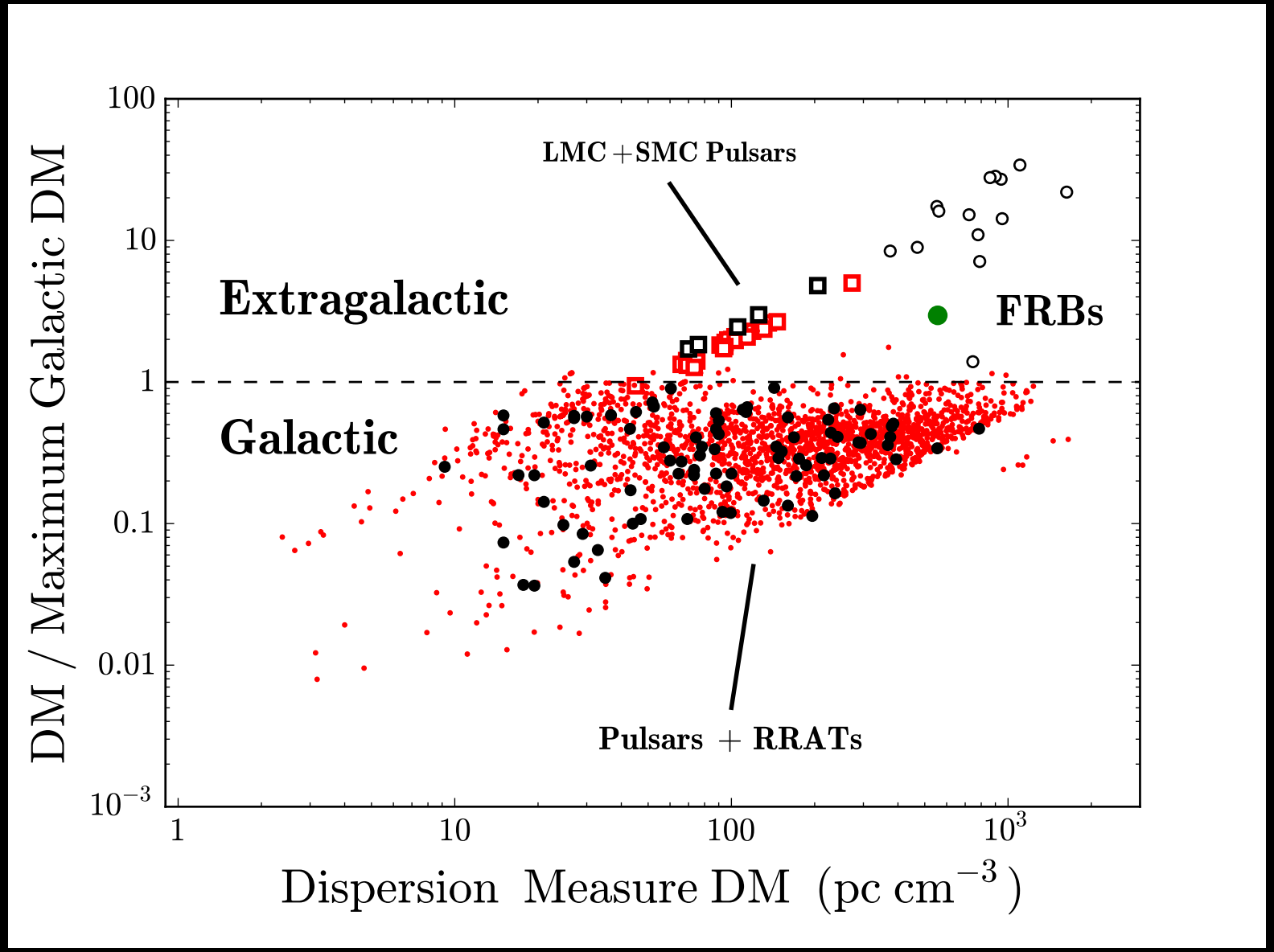
The Arecibo Burst



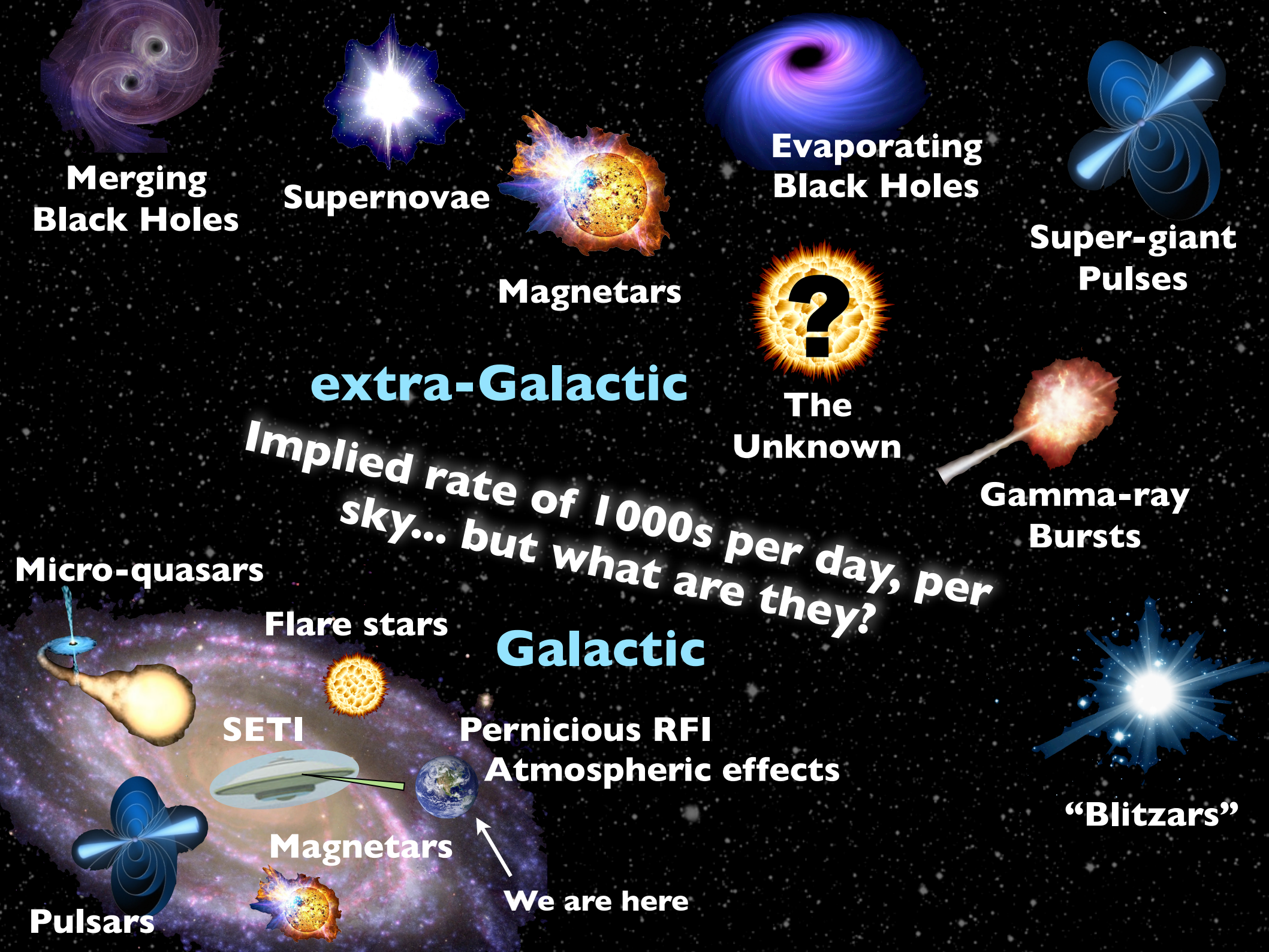
First non-Parkes FRB

Spitler, Cordes, Hessels et al. 2014

Of Mice & Pulsars/RRATs/FRBs



Cordes


Merging Black Holes
Supernovae
Magnetars
Evaporating Black Holes
Super-giant Pulses
?
The Unknown
extra-Galactic
Implied rate of 1000s per day, per sky... but what are they?
Gamma-ray Bursts
Micro-quasars
Flare stars
Galactic
SETI
Pernicious RFI
Atmospheric effects
"Blitzars"
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.

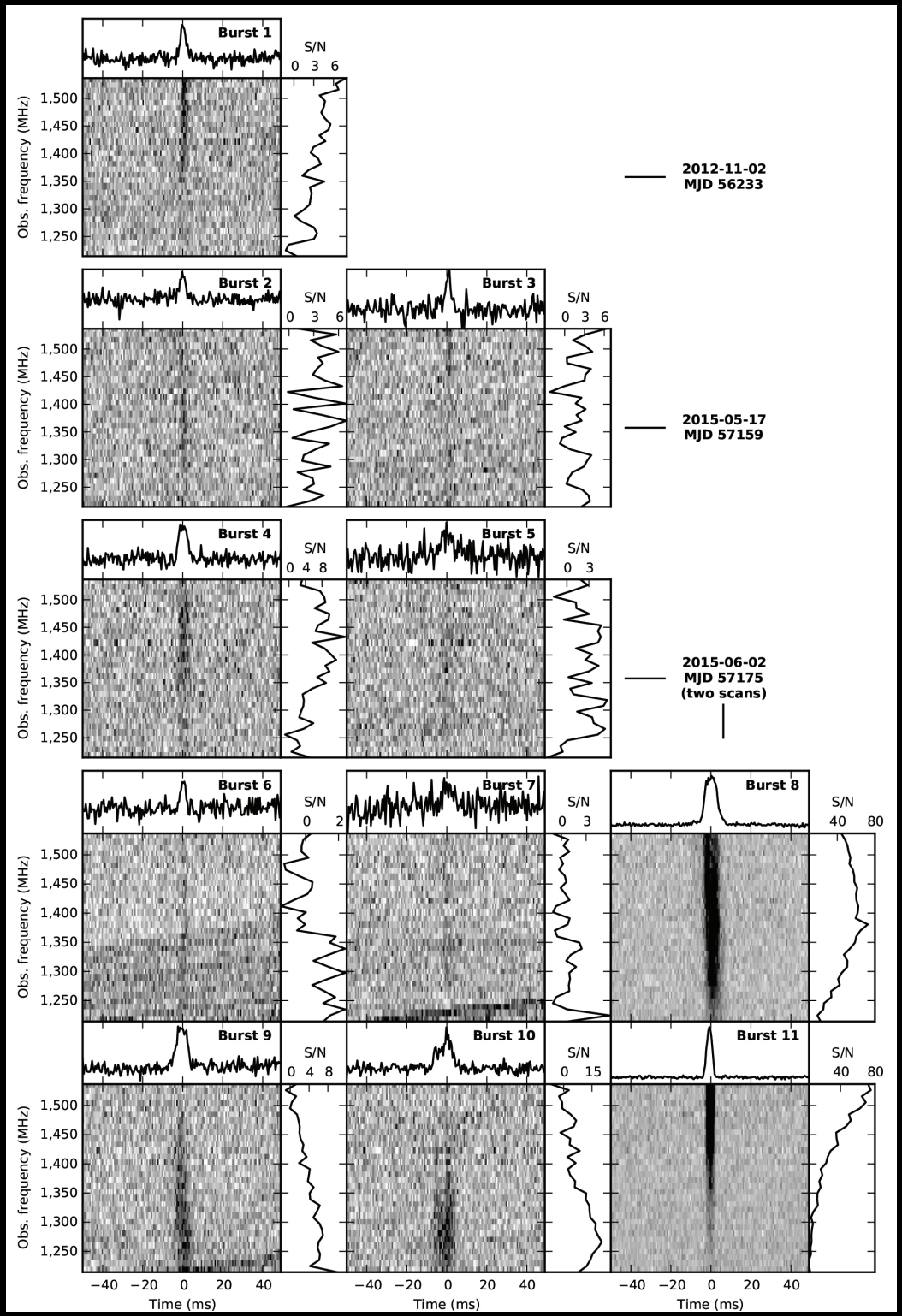
FRB observables

- 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)



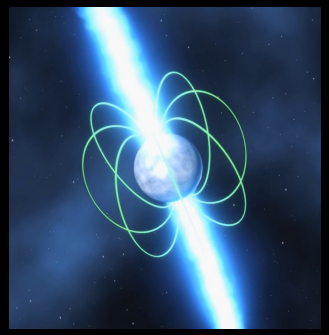
10 New AO Bursts!

First repeating Fast Radio Burst!

Spitler, Scholz, Hessels et al. 2016

Scholz

How many classes of FRBs?



Pulsar on steroids

Repeaters

(Spitler et al. 2016)

(CHIME/FRB Collab. 2019)

vs.

Cataclysm

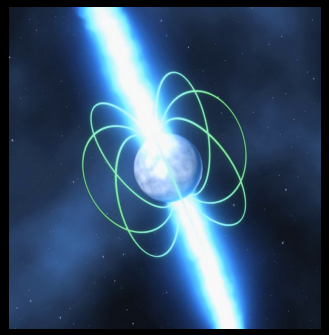
(Apparent?) non-repeaters

(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

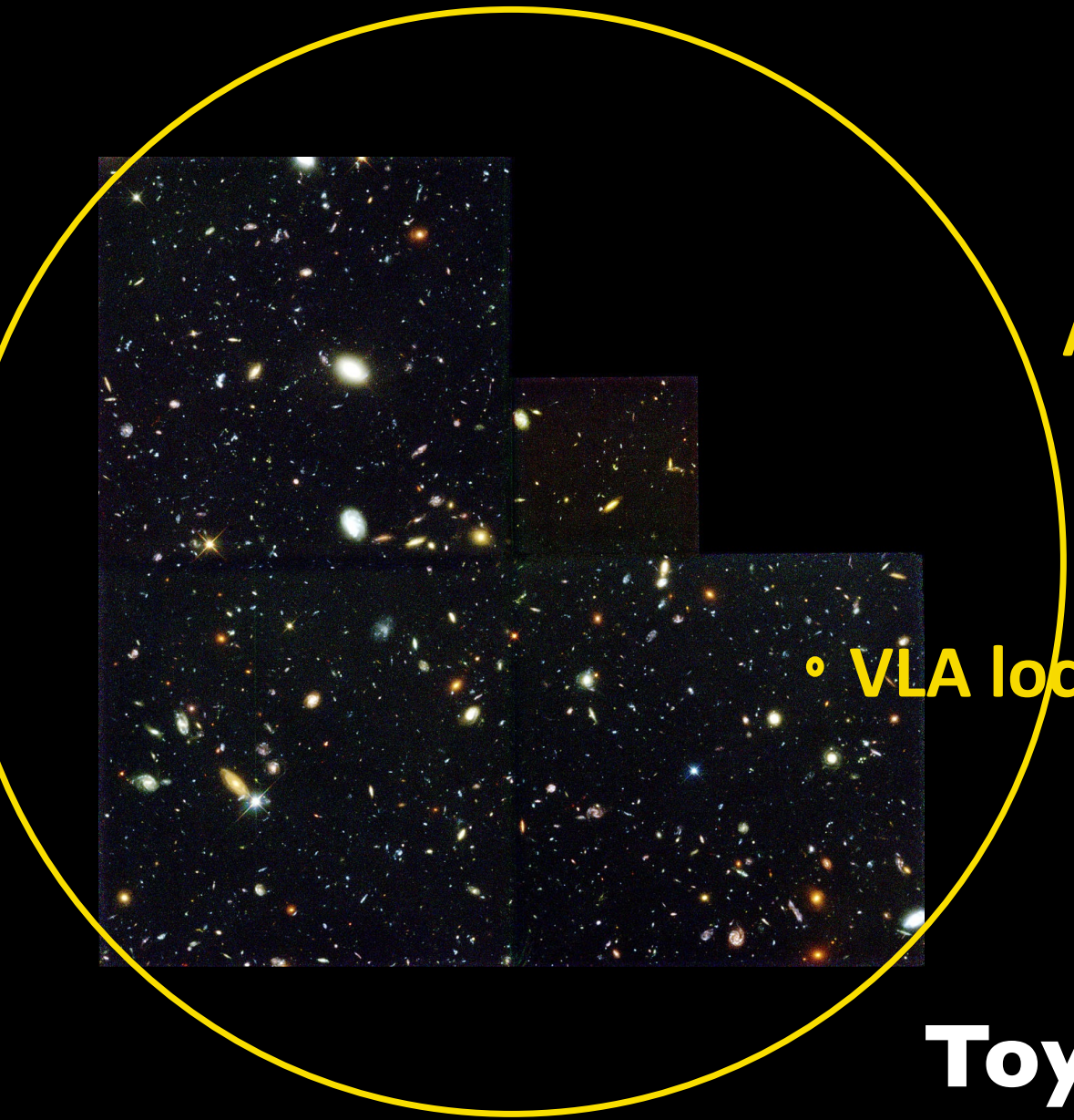
(Petroff et al. 2015)

FRB131104: 170hrs

FRB140514/110220: >50hrs

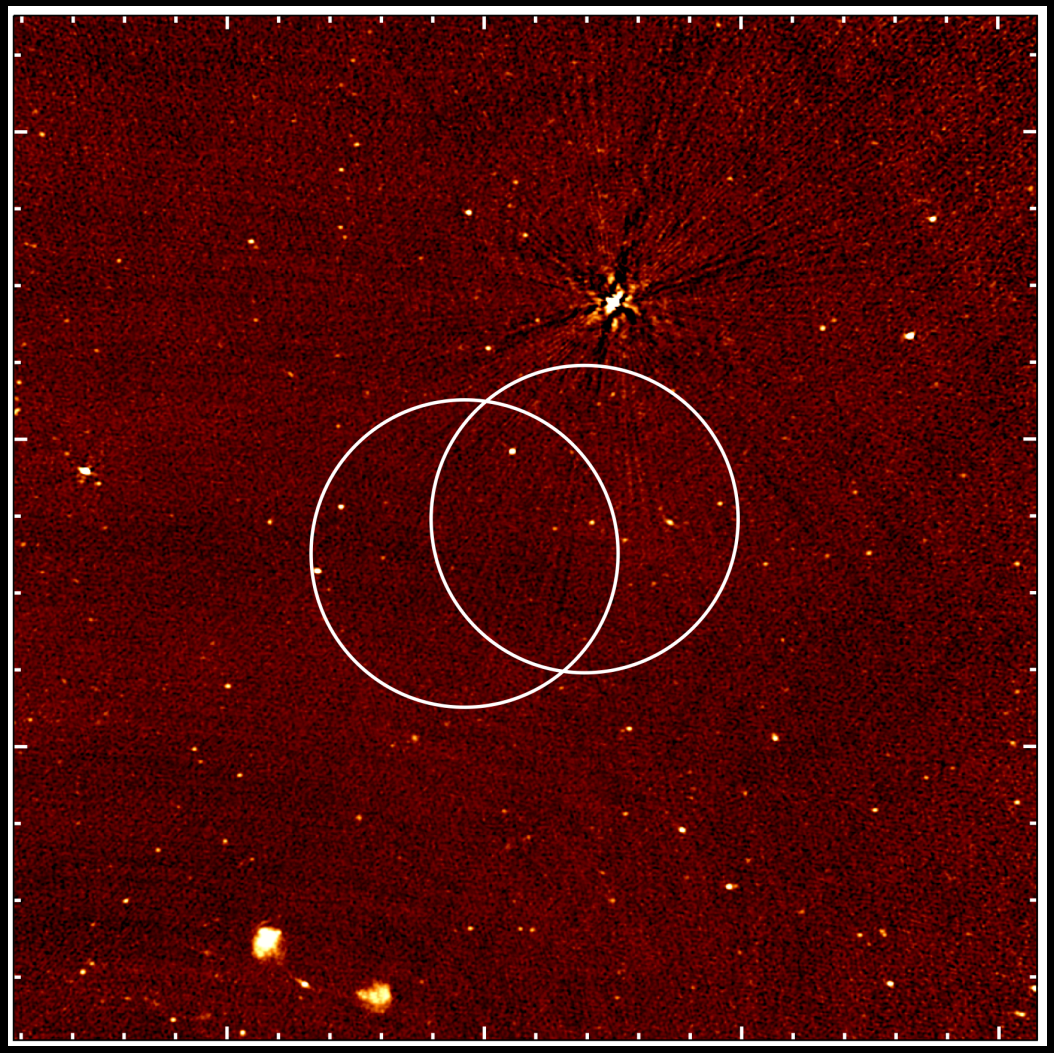
NB: according to the *arXiv*, there are >50 types of FRBs

The Need for Localization



Toy comparison with Hubble Deep Field

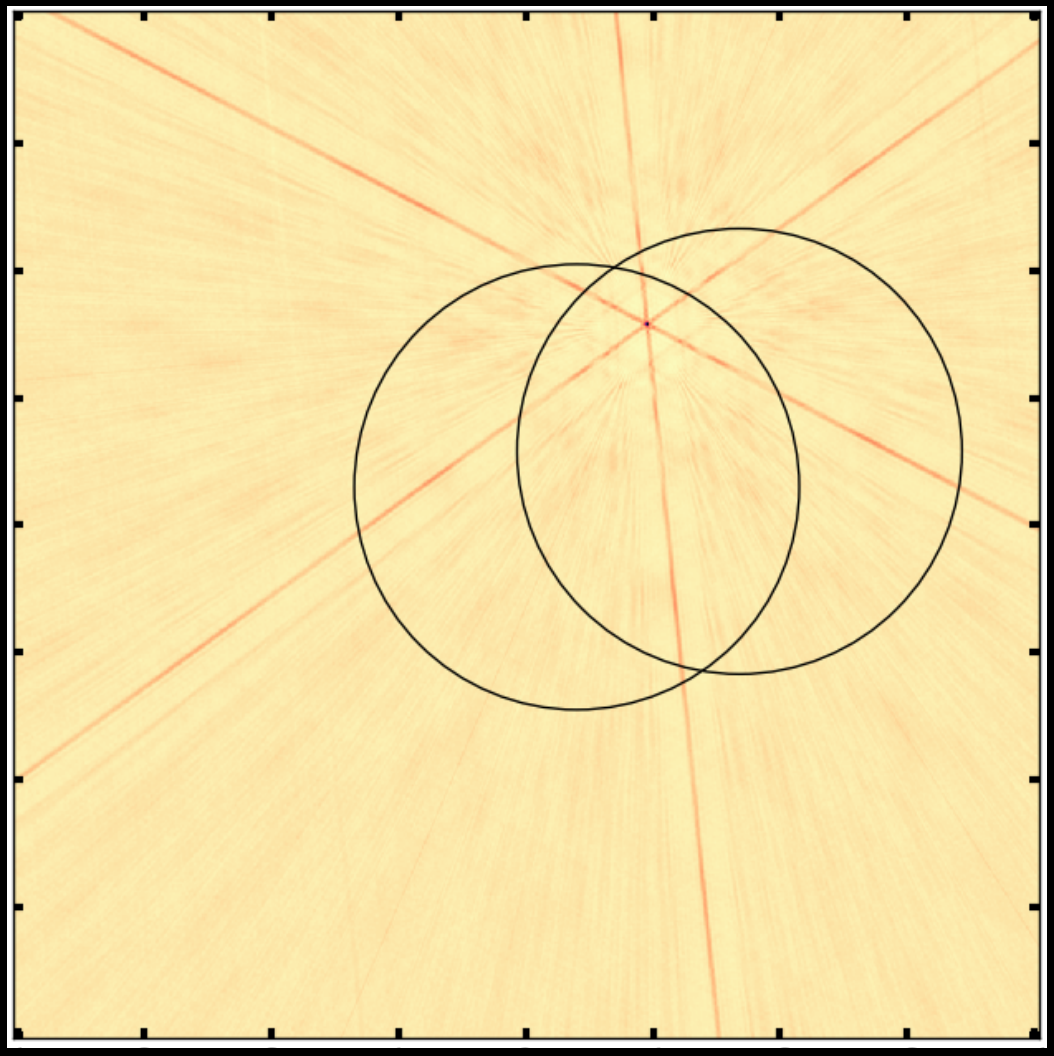
VLA Localization



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

Chatterjee et al. 2017

VLA Localization

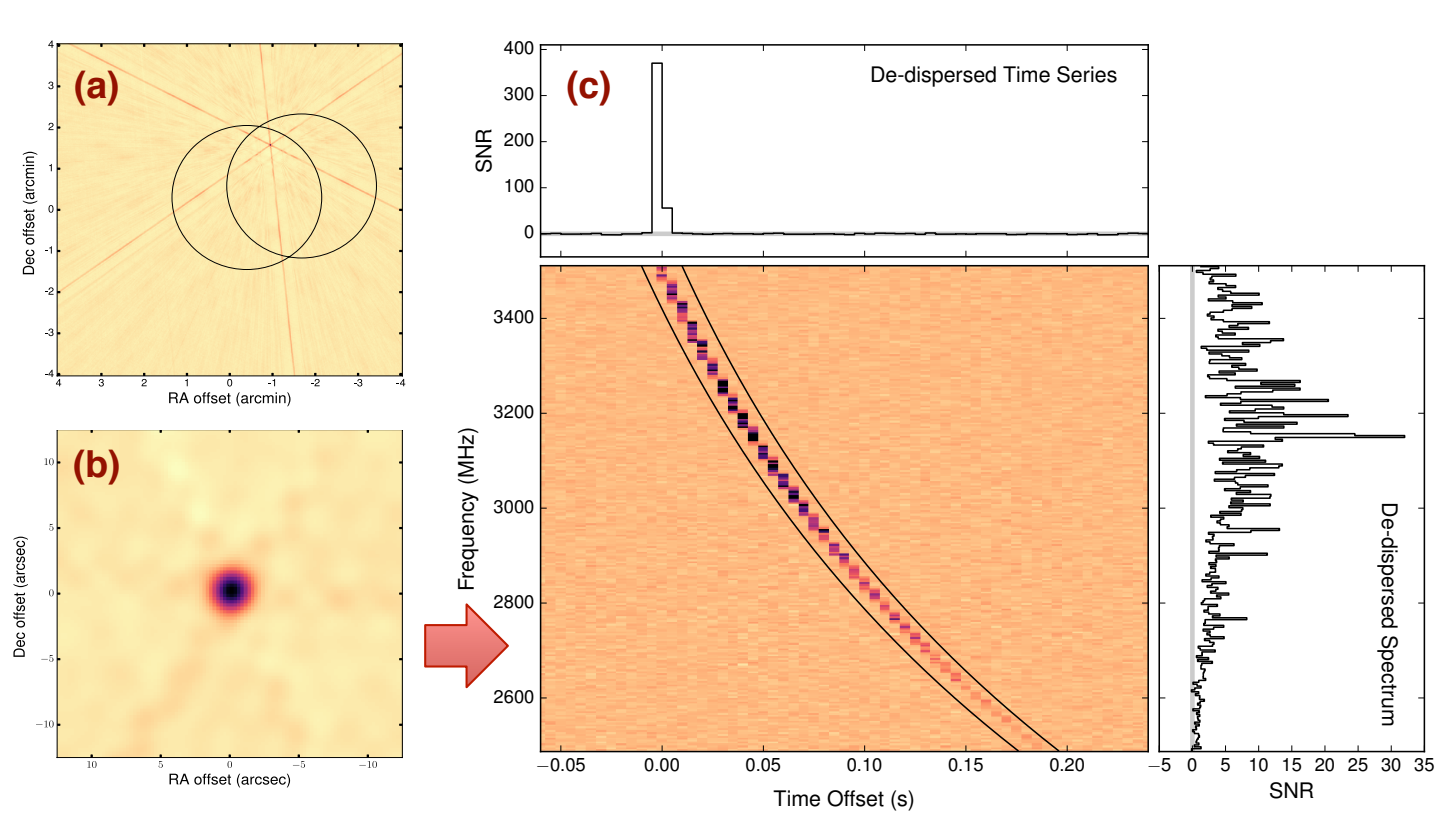


...and suddenly a burst (this is a 5-ms snapshot)

Chatterjee et al. 2017

VLA Localization

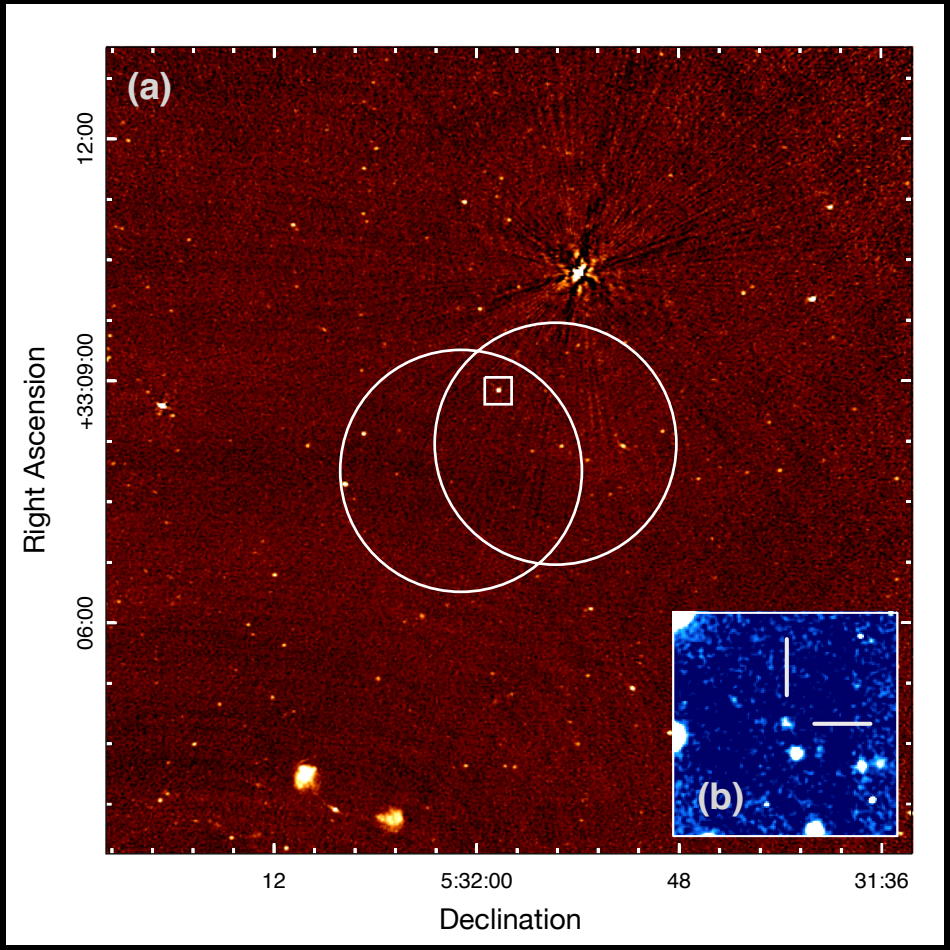
Localization to ~100mas



After tens of hours of observing and 1 year of trying

Chatterjee et al. 2017

VLA Localization

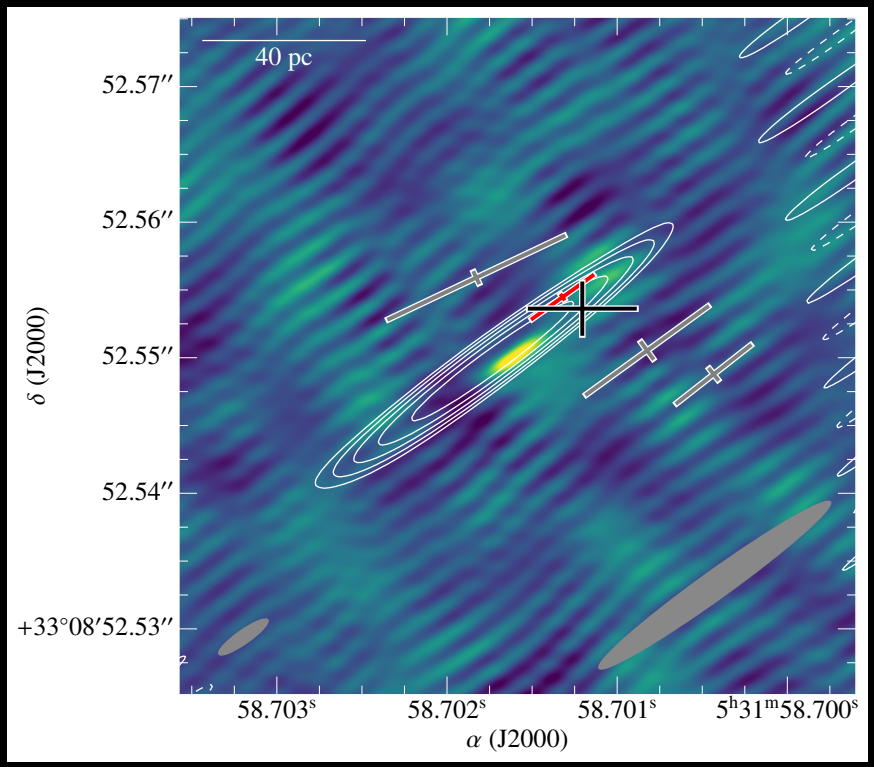


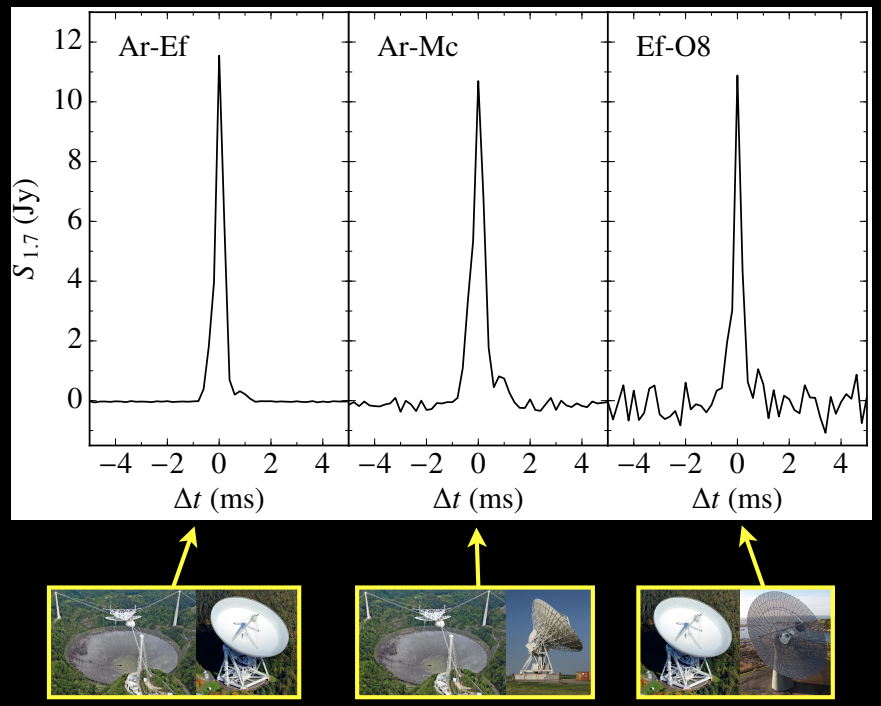
Association with persistent radio and optical sources

Chatterjee et al. 2017

Arecibo+EVN Localization

Localization to ~10mas



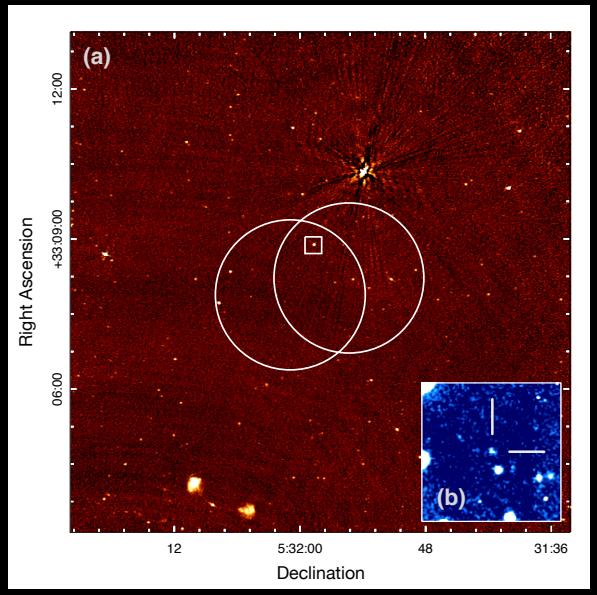


Bursts and persistent radio source are physically related

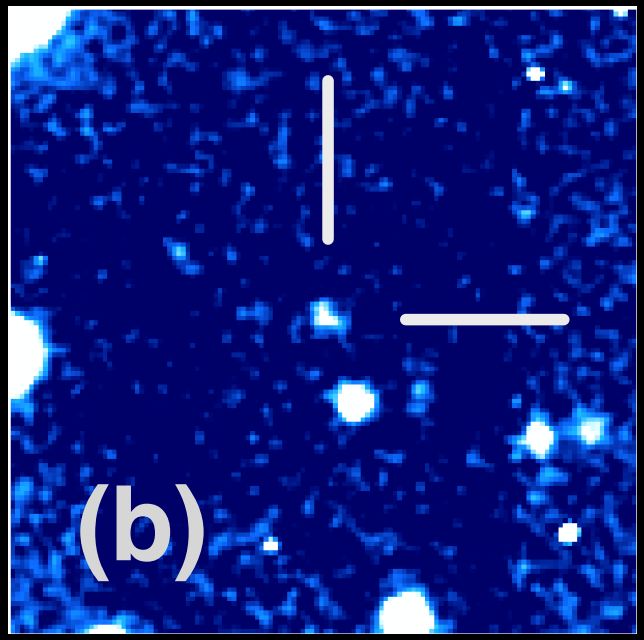
(coincident to within < 40 pc at 1Gpc)

Marcote et al. 2017

What is the optical source?

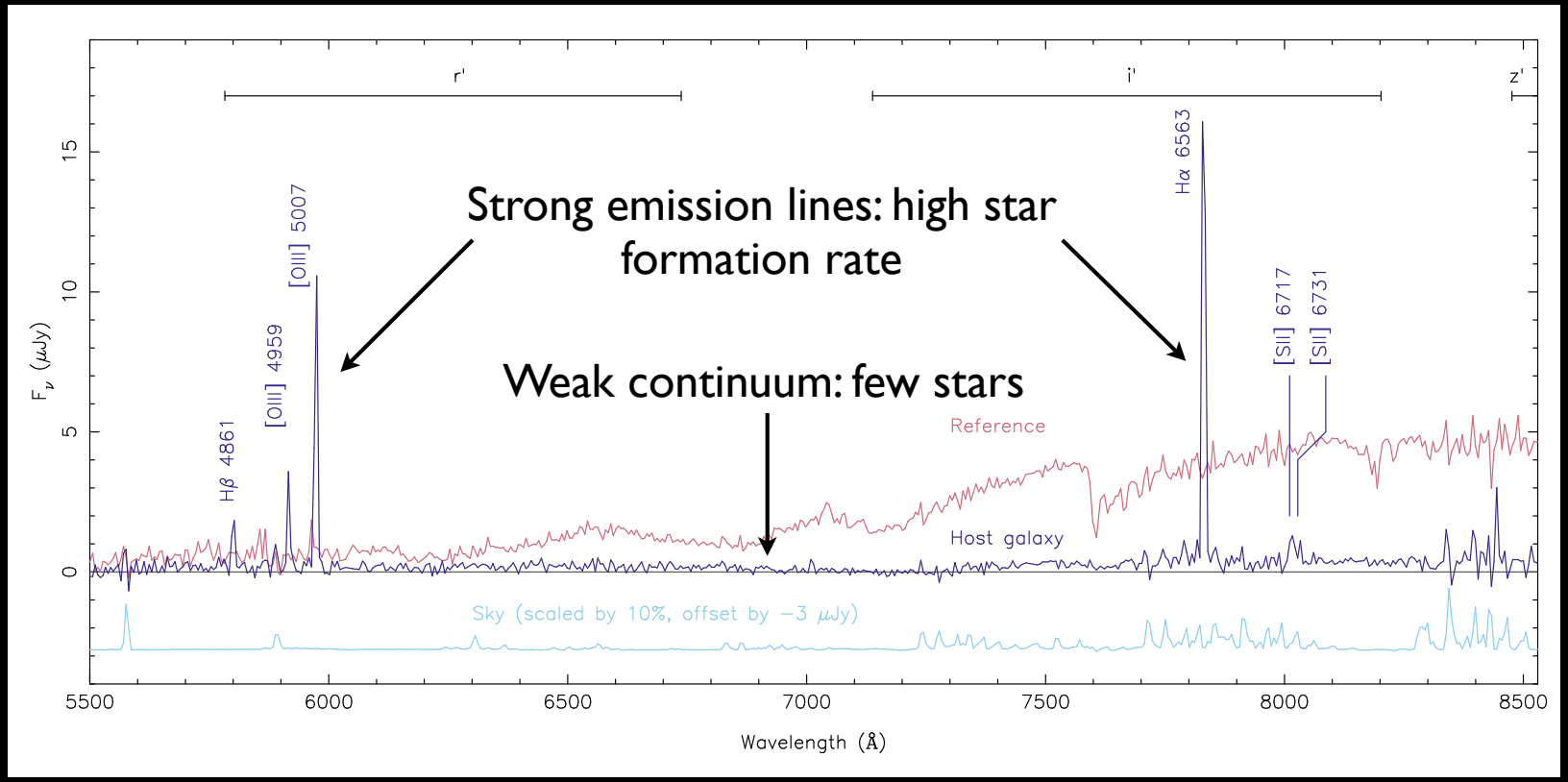


- 25th mag., roughly 100 million times fainter than the naked eye limit.
- Is this a star, or a (small) galaxy?



Gemini Redshift

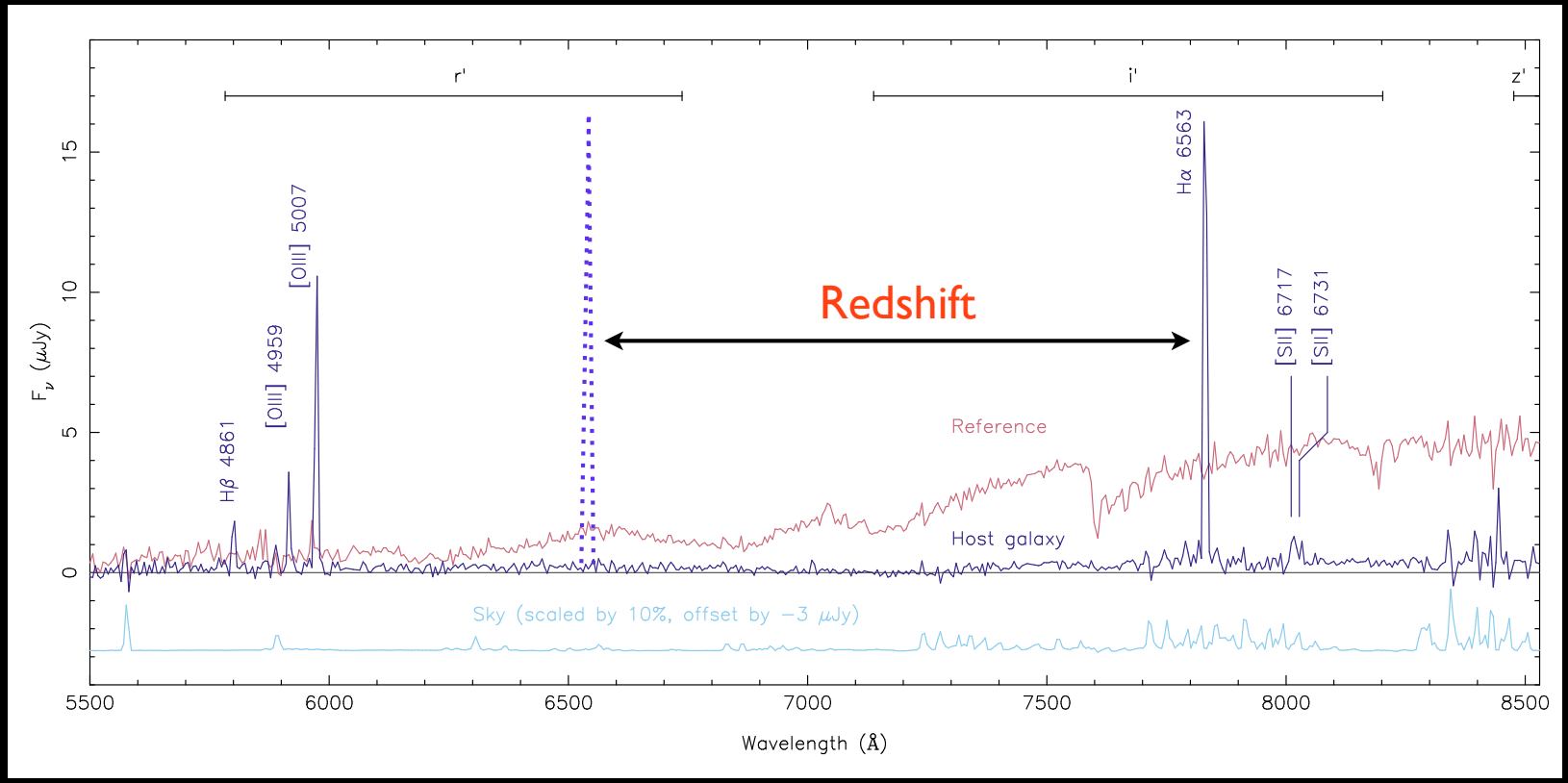
5.5 hours with the 8-m Gemini North



Tendulkar et al. 2017

Gemini Redshift

5.5 hours with the 8-m Gemini North

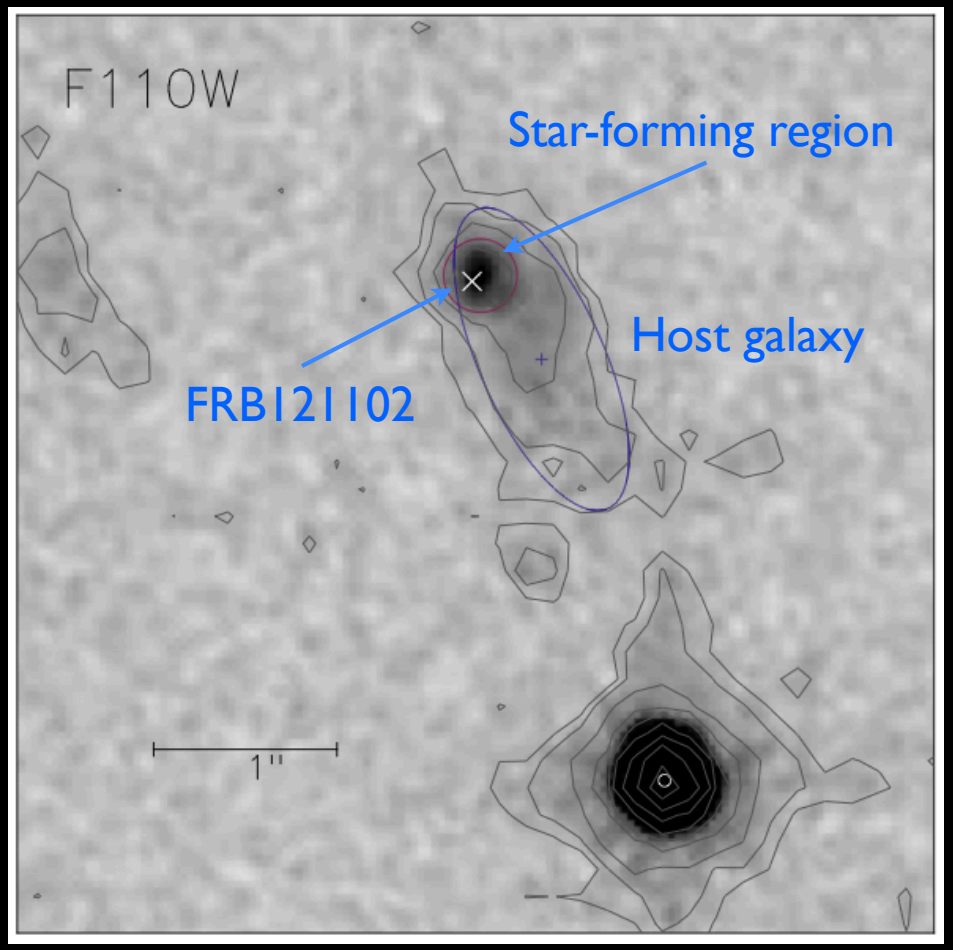


Host is a dwarf galaxy at z = 0.19 (~1Gpc)

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

Tendulkar et al. 2017

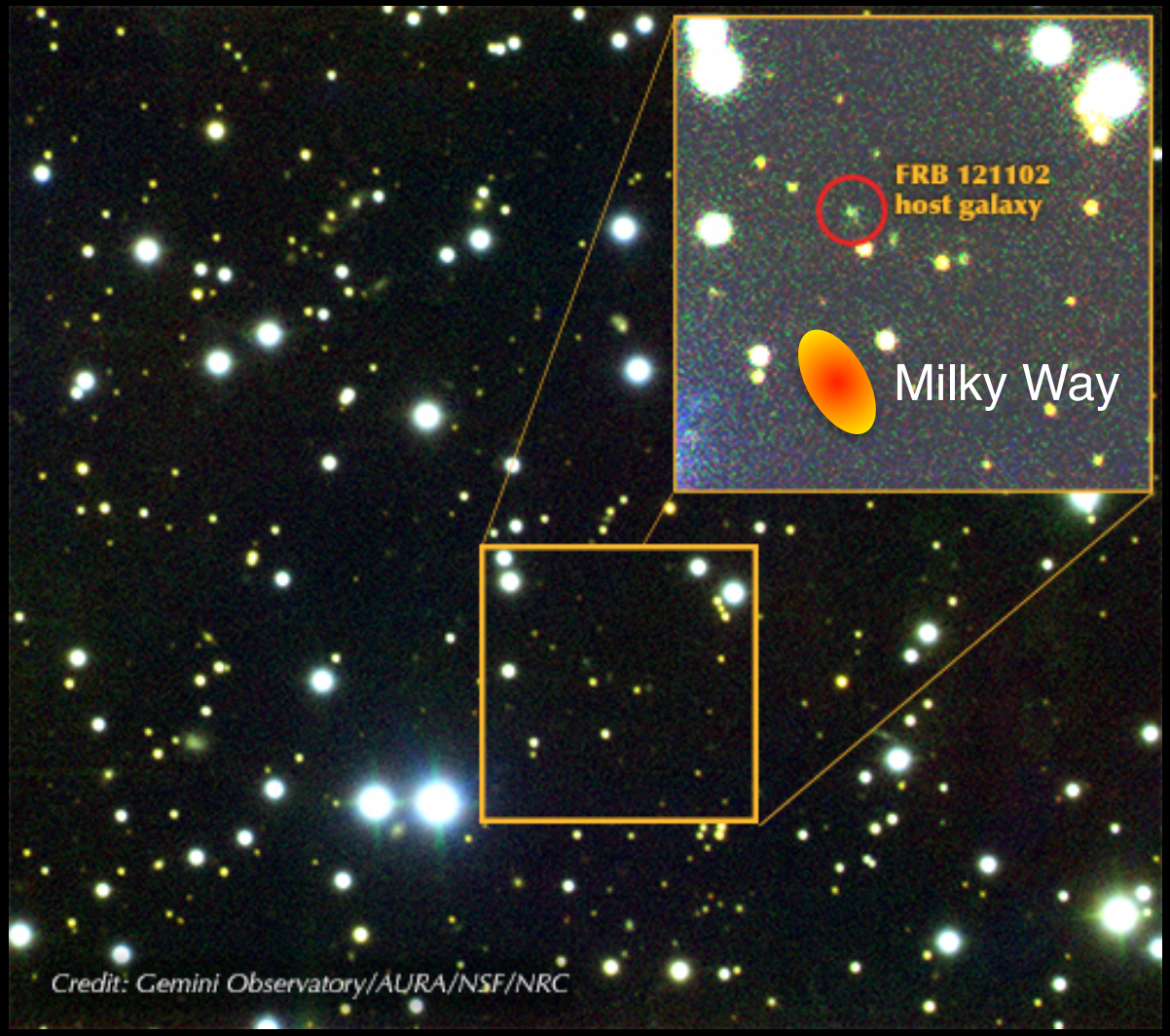
FRB121102 with HST



Clearly associated with a star-forming region in the host

Bassa et al. 2017

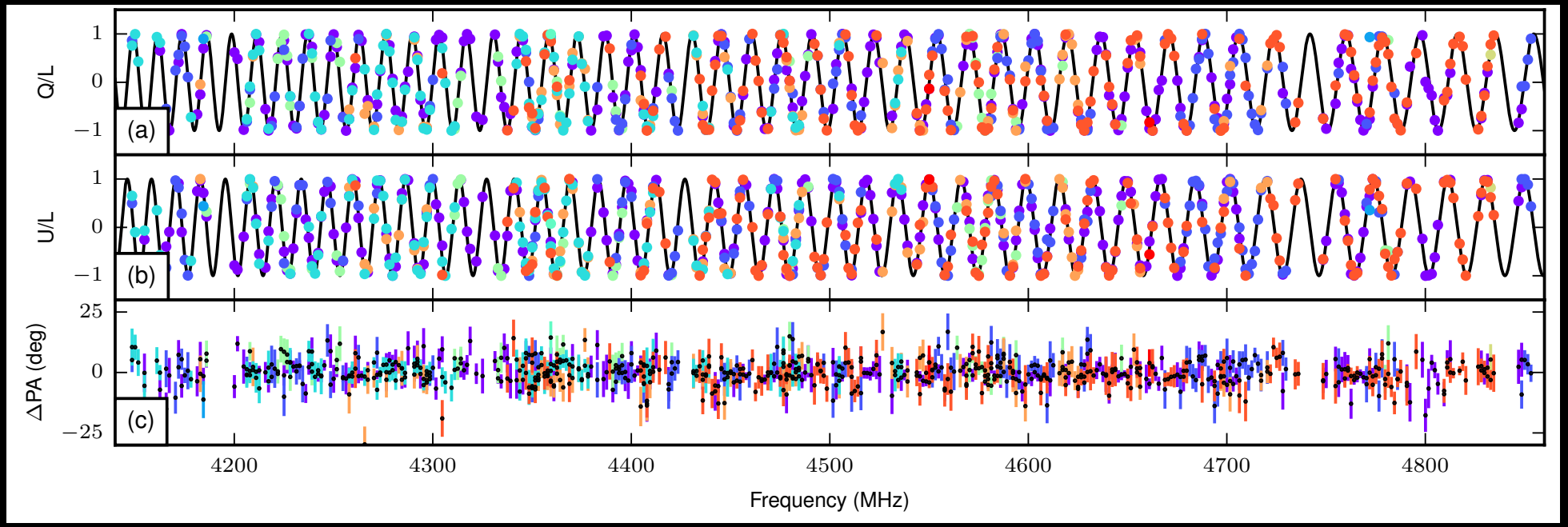
The Host Galaxy



- 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?

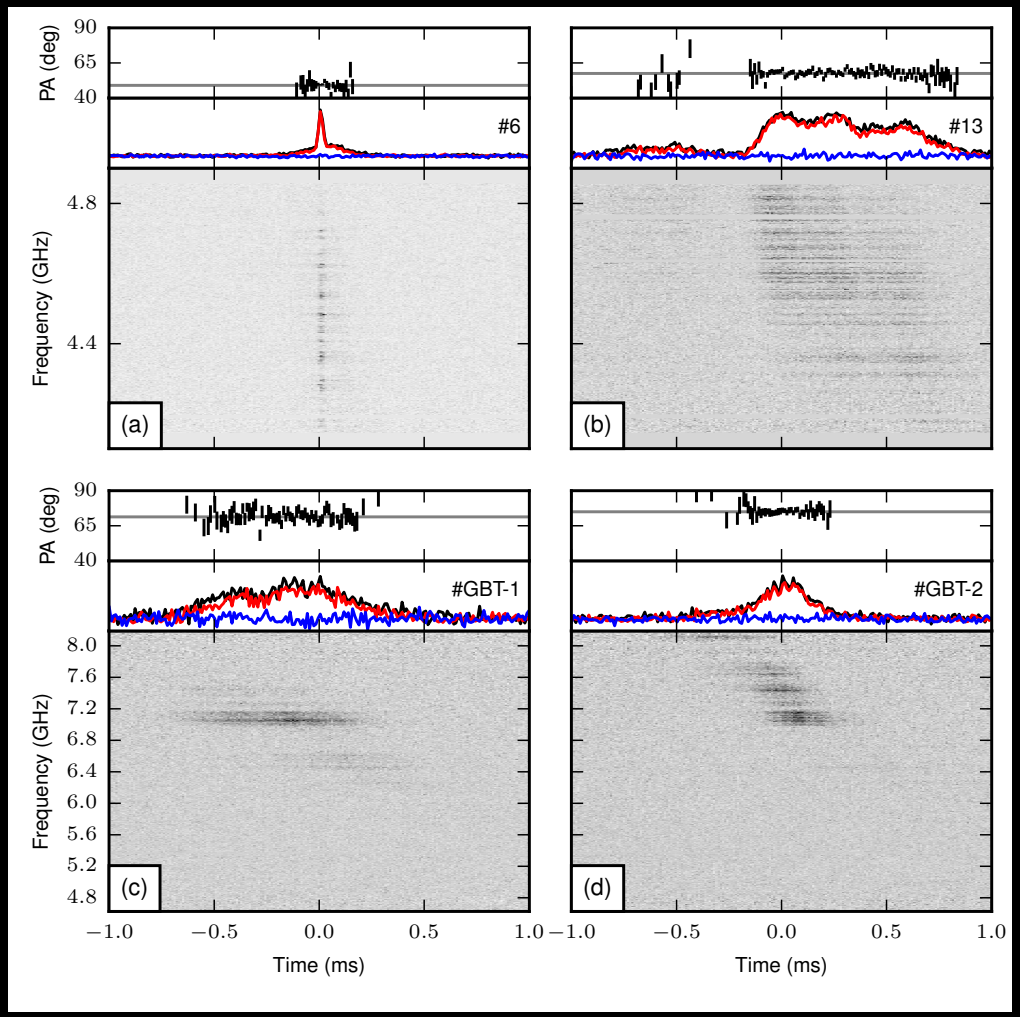
Rotation measure of FRB121102

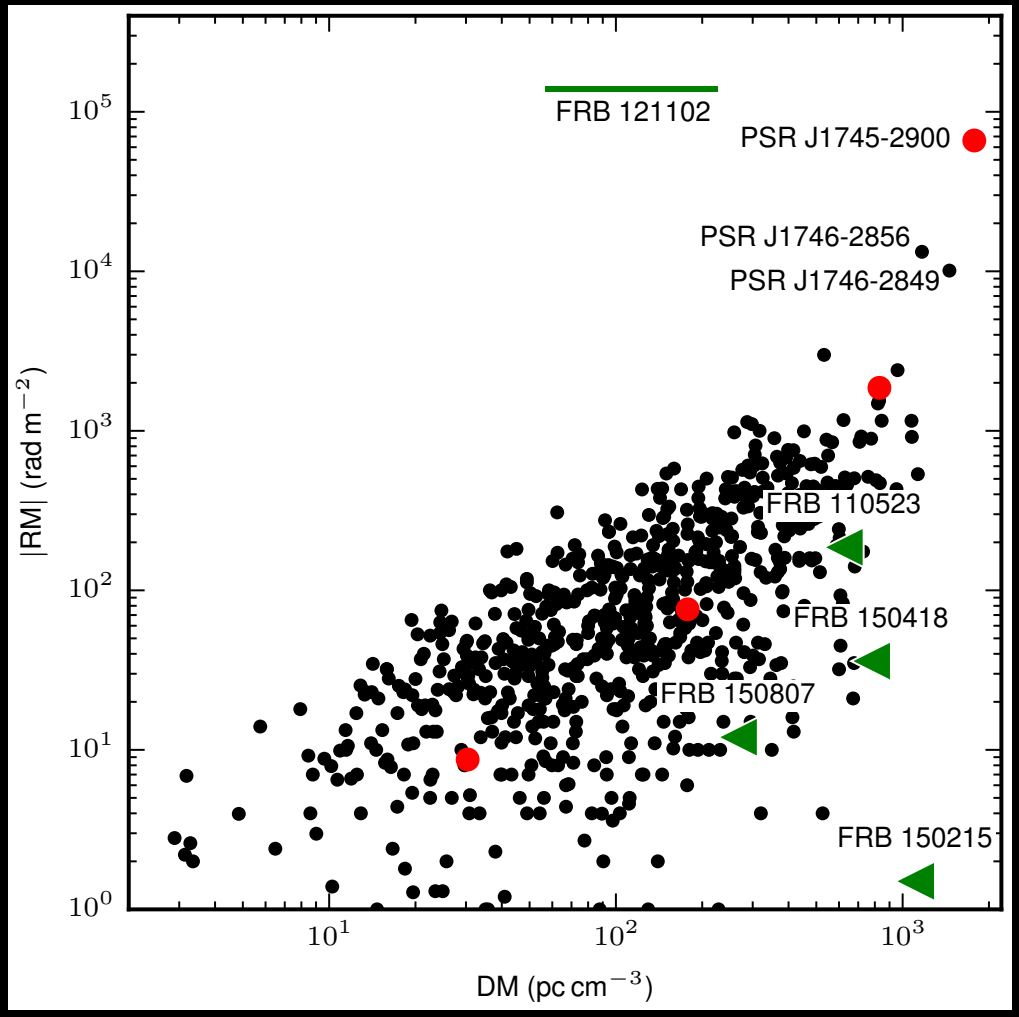


Michilli, Seymour, Hessels et al. 2018

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

Rotation measure of the Repeater

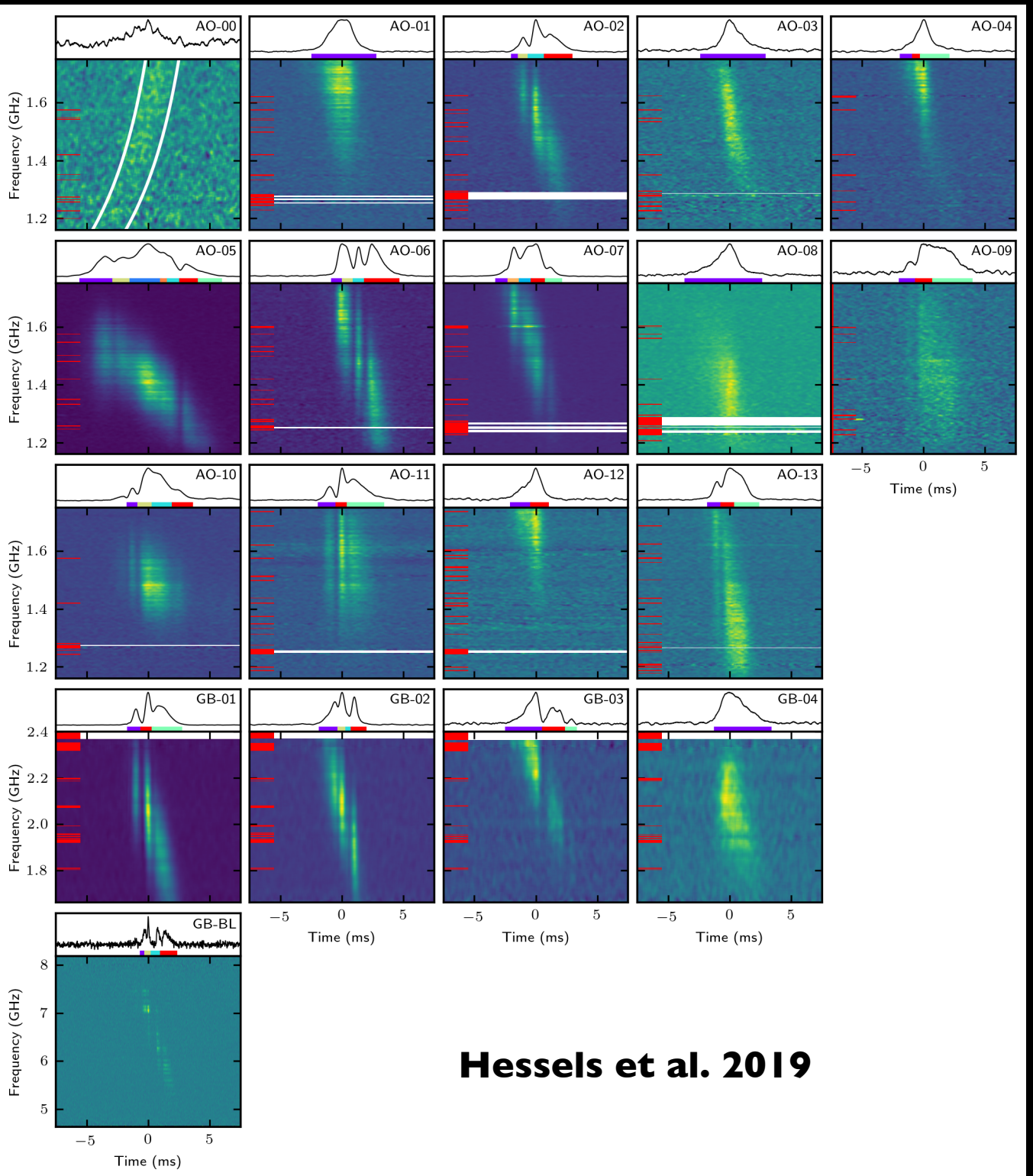




Michilli, Seymour, Hessels et al. 2018

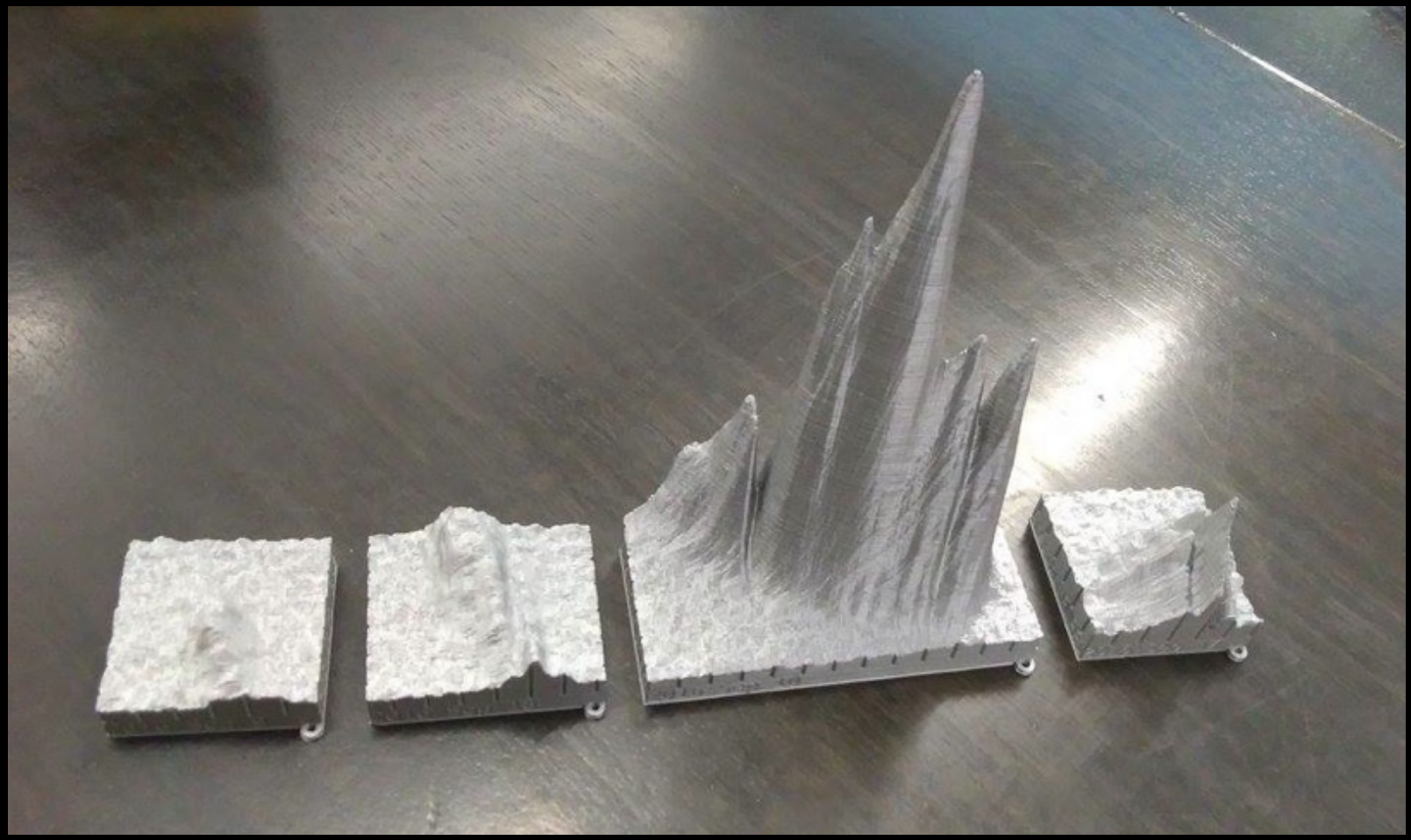
Bursts ~100% linearly polarized and can be ~30 microsec wide!

“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?

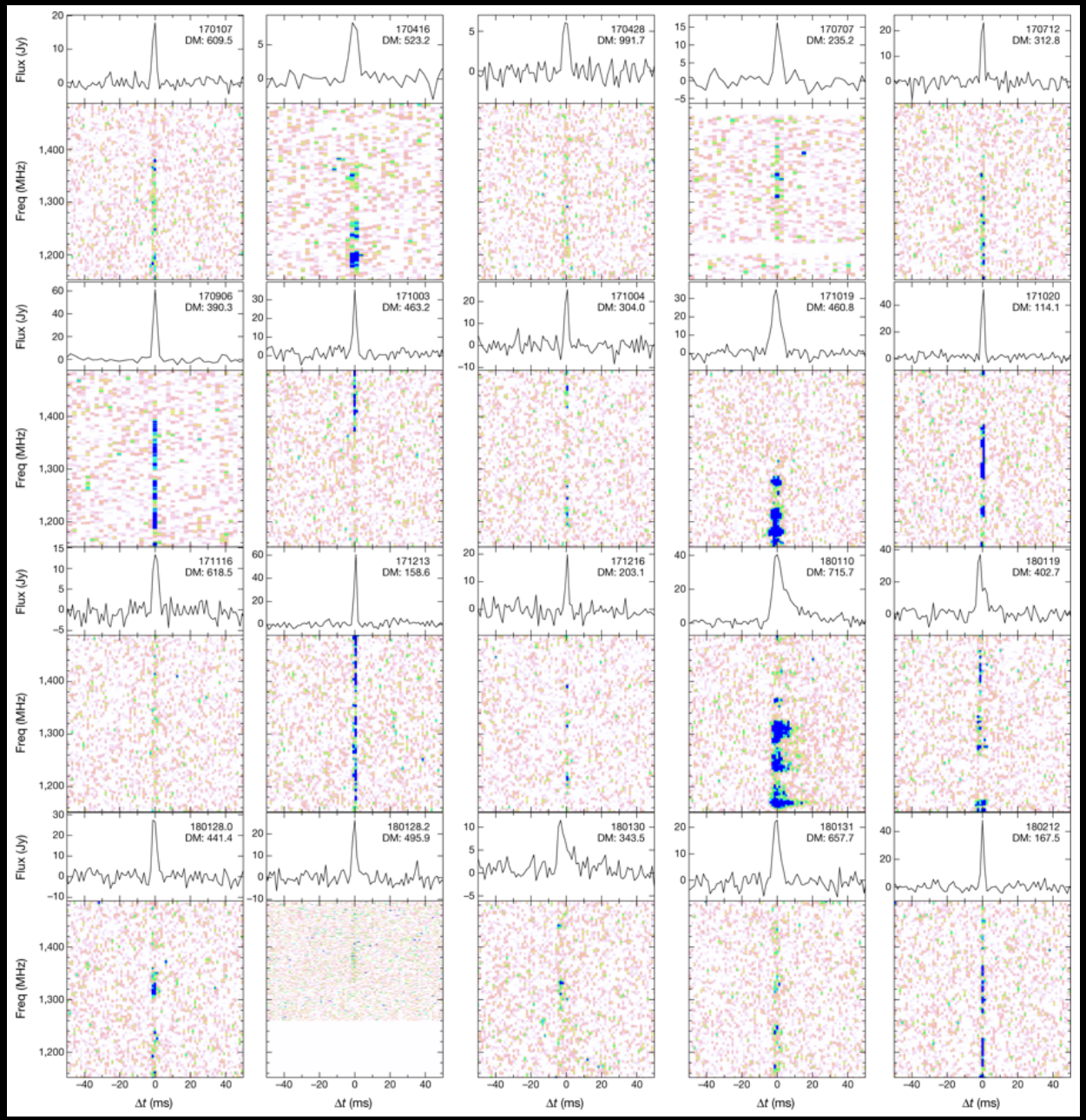
CHIME

ASKAP

UTMOST

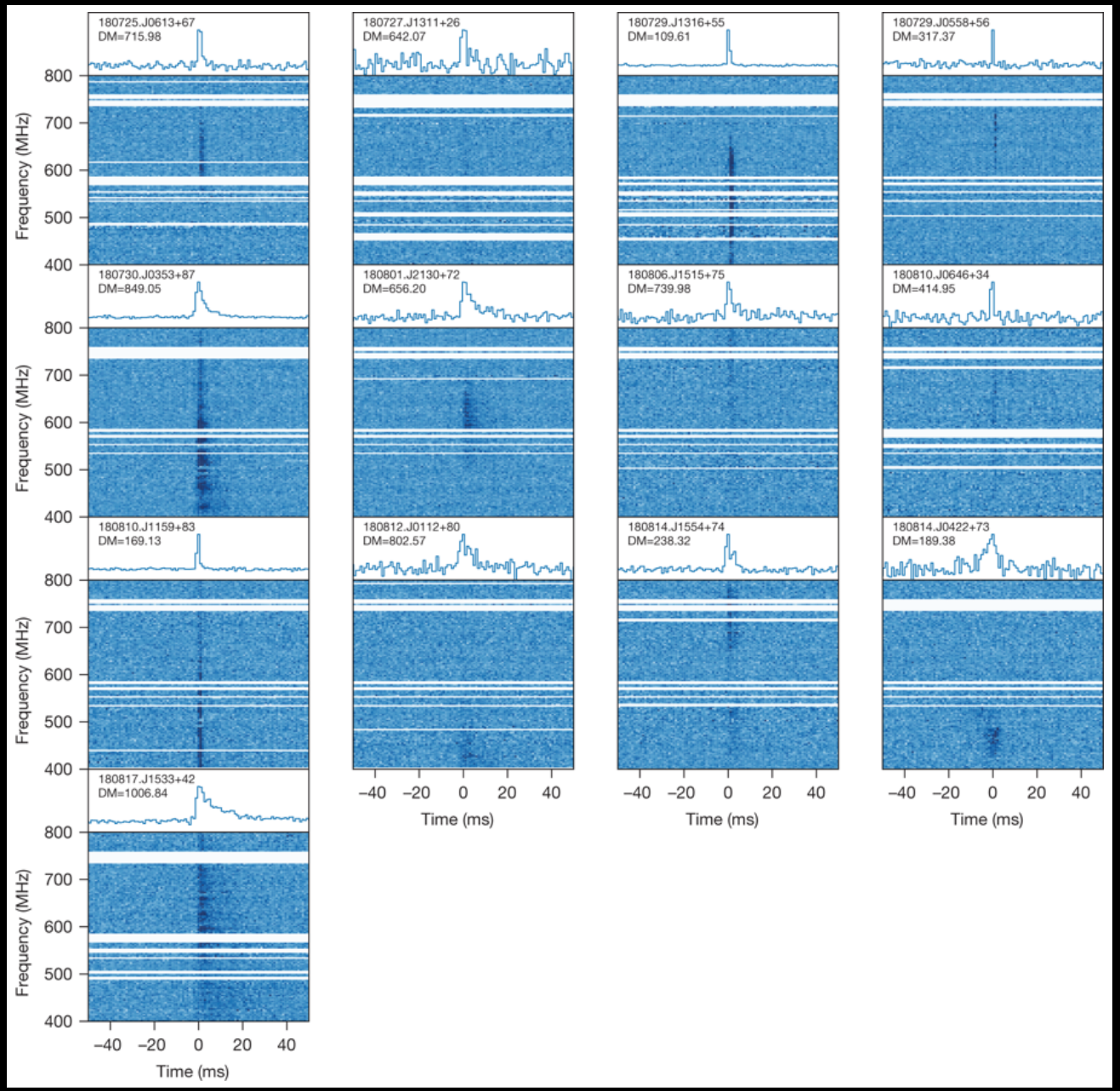
APERTIF

ASKAP FRBs



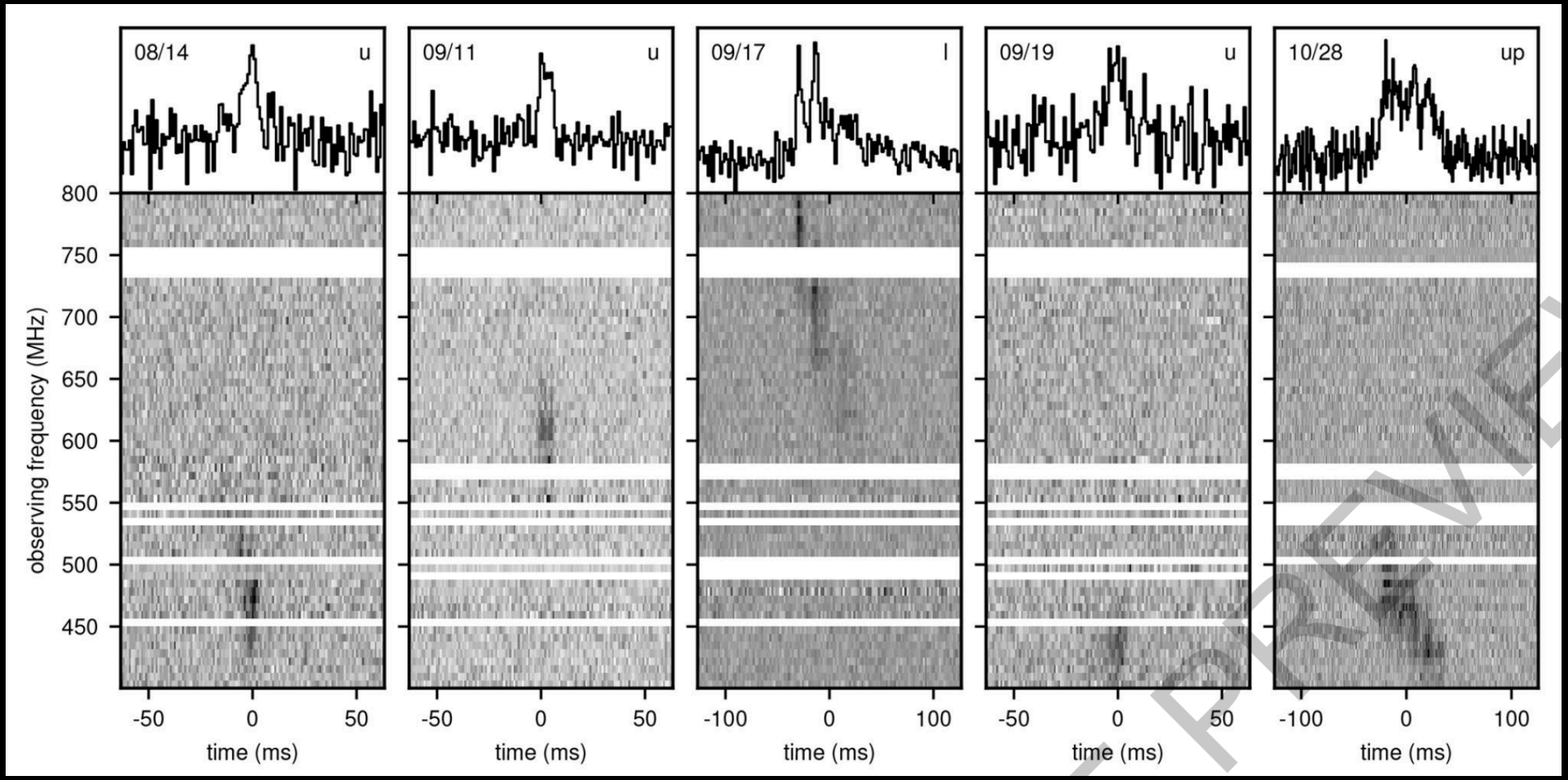
Shannon et al. 2018, Nature

CHIME FRBs



CHIME/FRB Collab. 2019, Nature

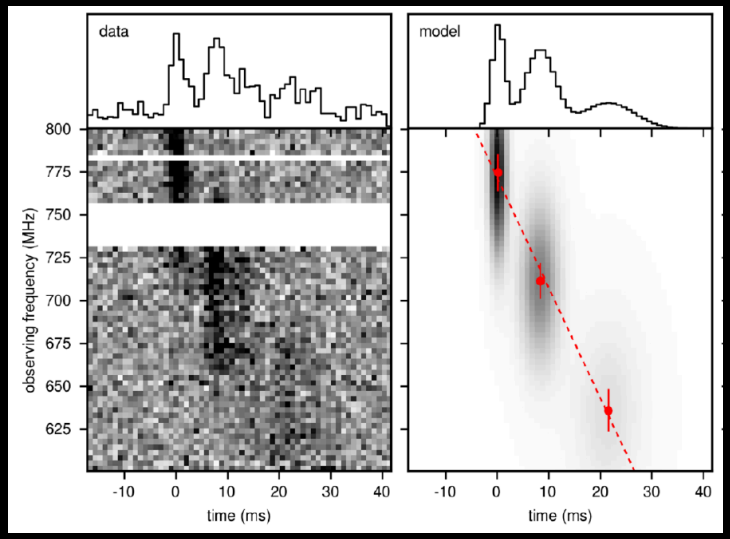
CHIME FRBs

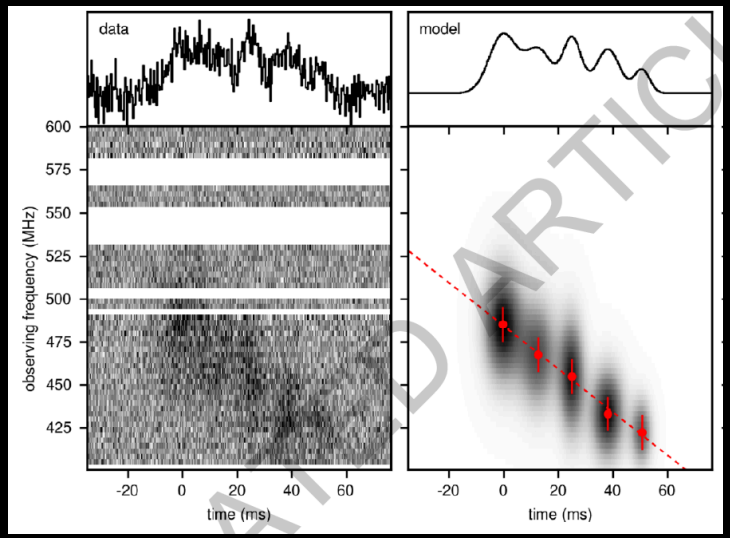


CHIME/FRB Collab. 2019, Nature

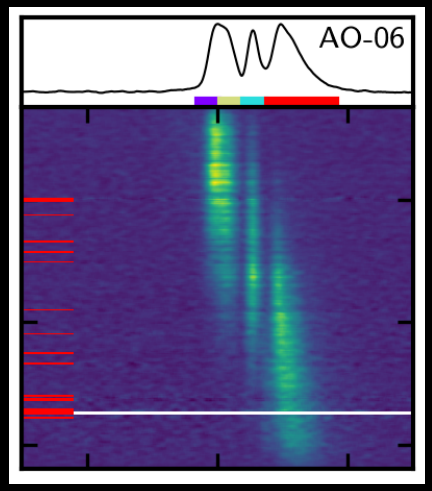
CHIME FRBs

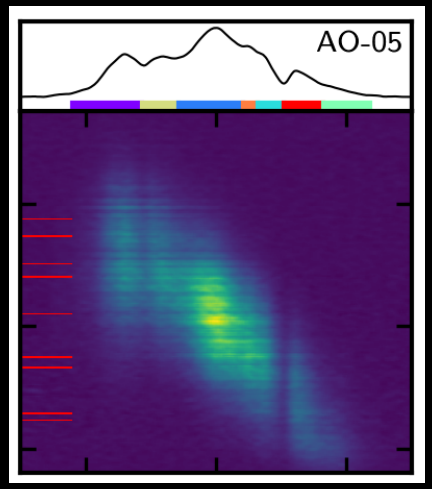
"R2"





"R1"





CHIME/FRB Collab. 2019, Nature

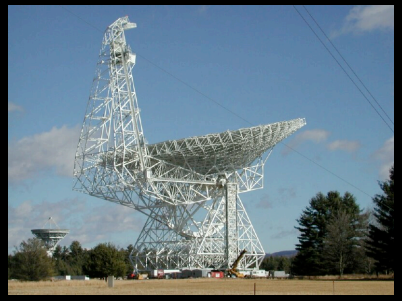
Hessels et al. 2019

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

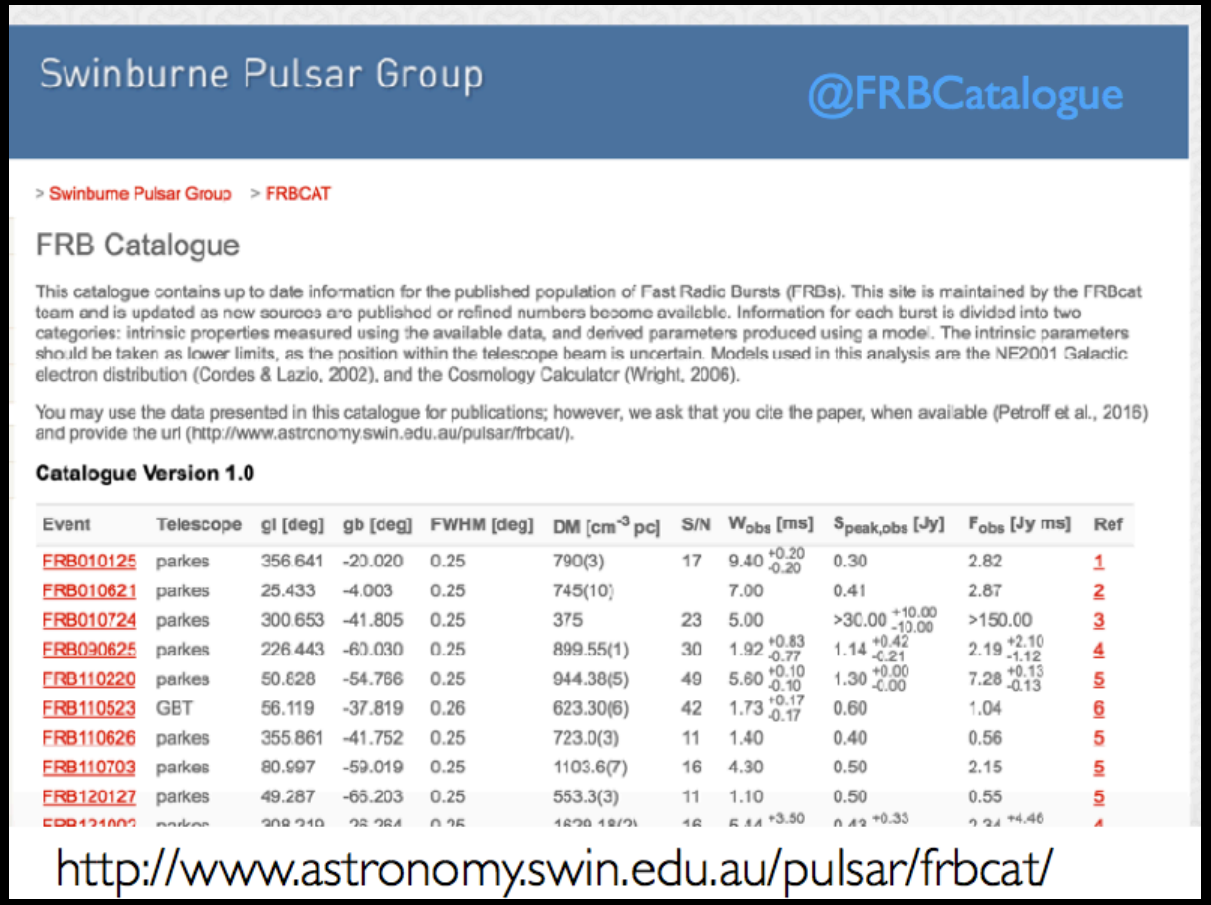
CHIME (0.6 GHz): 13
+ a lot more...

MWA (0.2 GHz): 0

Parkes (1.4 GHz): 24

UTMOST (0.8 GHz): 5

FRBCAT



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.