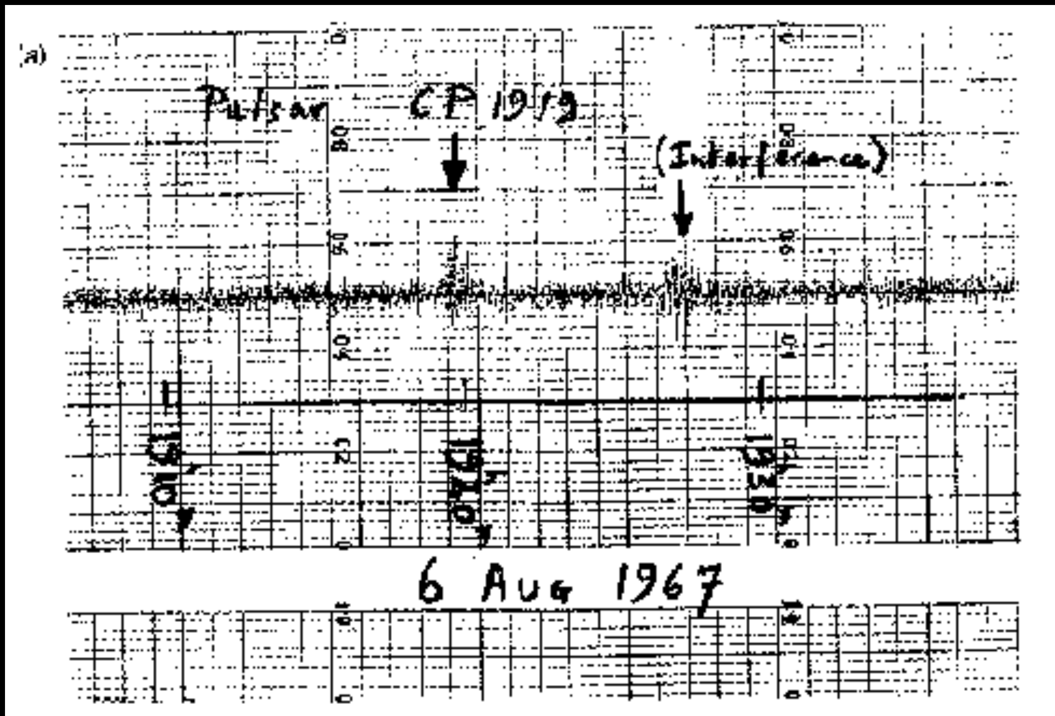
Fast Radio Bursts – Nature's Cosmological Probes

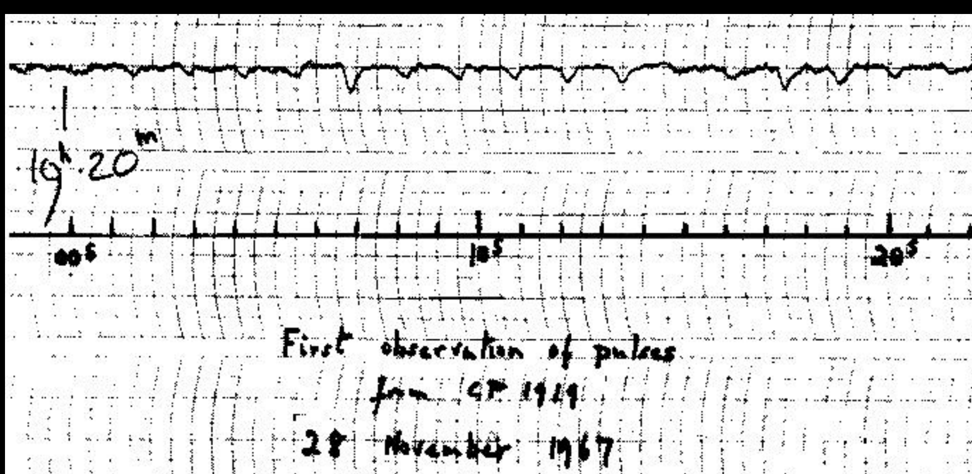
Duncan Lorimer, Dept. of Physics and Astronomy, West Virginia University

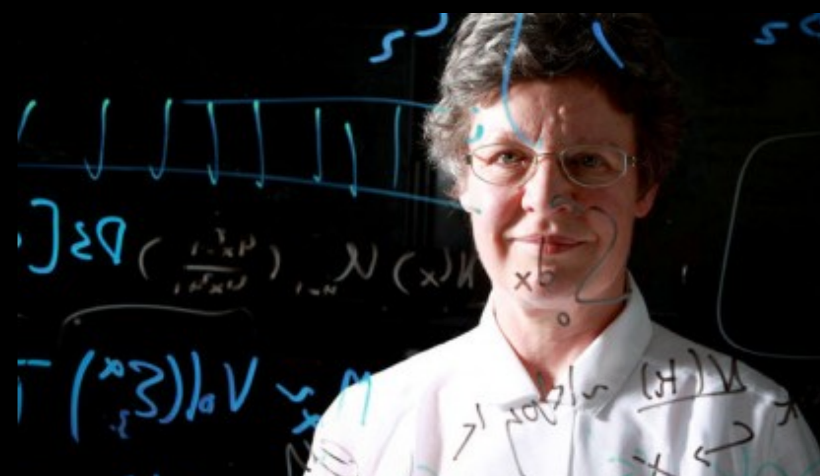
FRB fact sheet

- Relatively bright radio sources (~ Jy at 1 GHz)
- Broad range of spectral behavior (100 MHz ~ few GHz)
- Uniform sky distribution
- Large all-sky rate (1000s/day > 1 Jy)
- Highly dispersed (>> PSRs)
- Weakly scattered (<< PSRs)
- Narrow pulses with rich morphology
- Wide range of polarization observed
- 138 currently published
  - We'll hear about forthcoming CHIME catalog this week.
- 22 FRBs are known to repeat
- 13+1 FRBs have associated host galaxies
- 1 FRB-like source associated with a Galactic magnetar


Pulsar CP 1919
(Interference)
6 Aug 1967


1967


19h 20m
00s
10s
20s
First observation of pulses
from CP 1919
28 November 1967

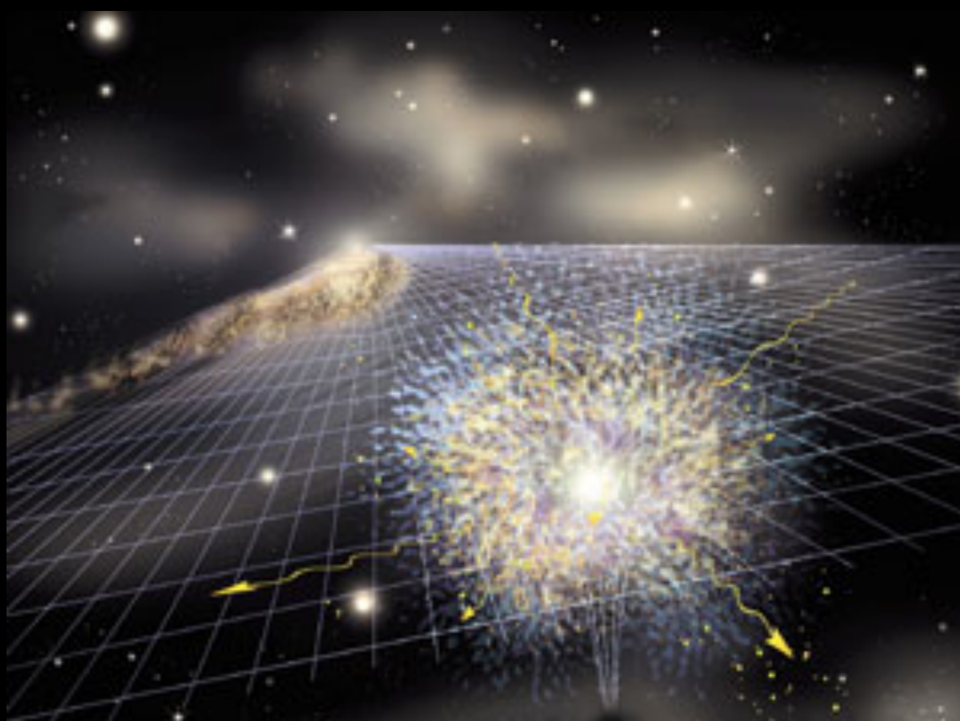


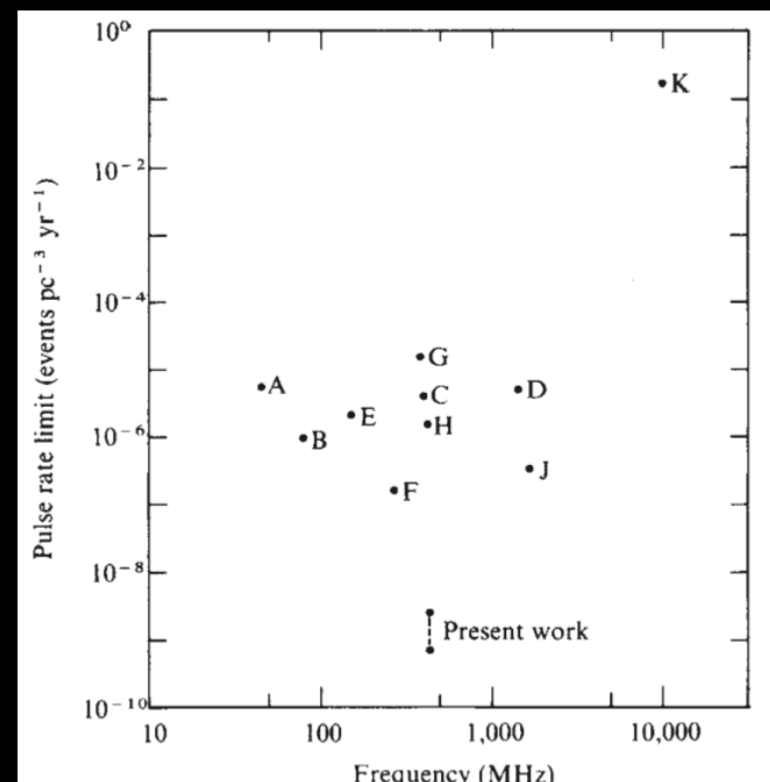
1968

1979

Nature Vol. 277 11 January 1979

A sensitive search for radio pulses from primordial black holes and distant supernovae





1979

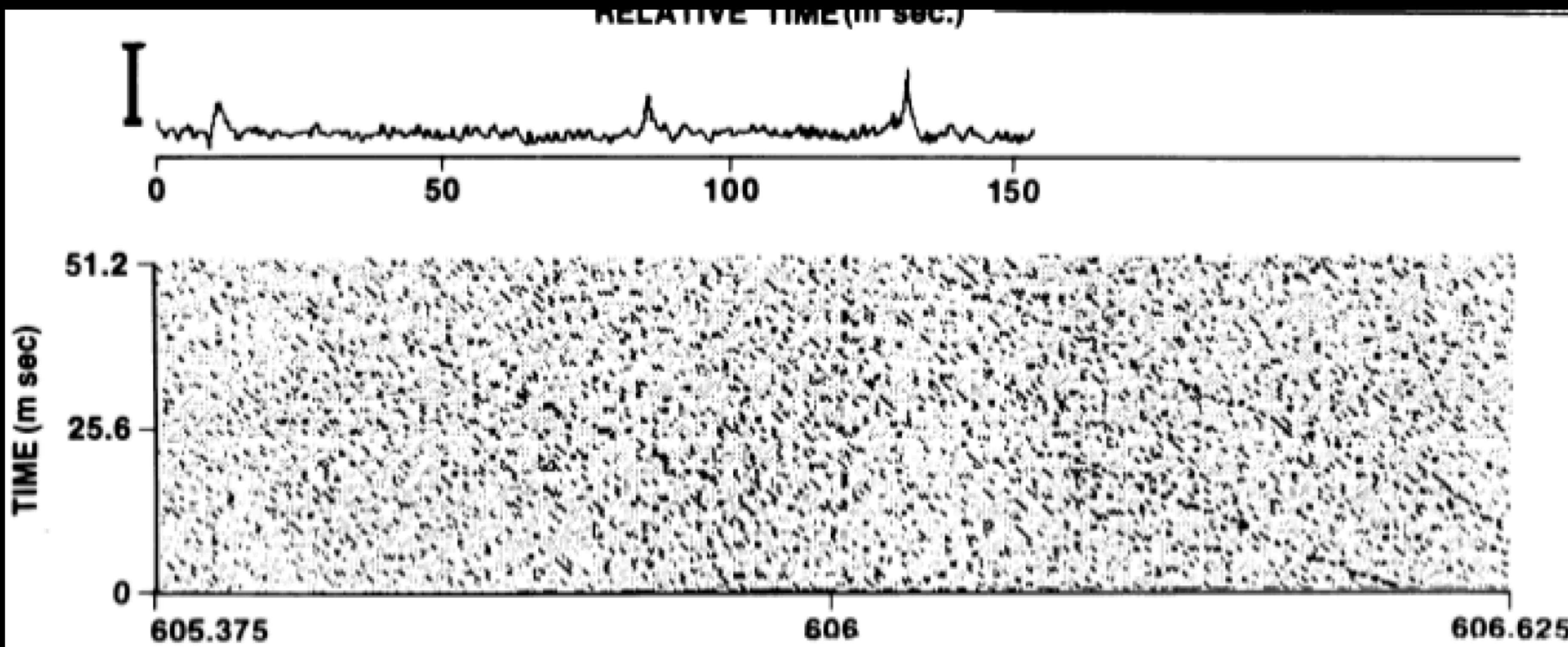
DISCOVERY OF MILLISECOND RADIO BURSTS FROM M87

I. R. LINSCOTT AND J. W. ERKES[1]
Dudley Observatory, Schenectady, New York

Received 1979 August 10; accepted 1979 December 19

ABSTRACT

Highly dispersed radio pulses have been detected from M87 at radio frequencies of 430, 606, and 1420 MHz. The pulse sweep rates scale with the third power of the observing frequency as expected from the cold plasma law. The sweep rates correspond to dispersion measures in the range $1\text{–}5 \times 10^3$ parsec cm^{-3}. The pulses frequently appear grouped together separated within the group by approximately 50 ms. Peak power levels of 100 Jy and temporal widths of a few ms for individual pulses are found, and the group repetition rate is of the order of 1 s^{-1}.



1973/1993

Possibility of Determining Intergalactic Gas Density by Radio Observations of Flares of Remote Sources

V. L. GINZBURG

Nature **246**, 415(1973) | Cite this article

RADIO DISPERSION AS A DIAGNOSTIC OF GAMMA-RAY BURST DISTANCES

DAVID M. PALMER
Goddard Space Flight Center, Greenbelt, MD 20771
e-mail: palmer@tgrs.gsfc.nasa.gov
Received 1993 June 10; accepted 1993 August 17

ABSTRACT

If gamma-ray bursts sources emit even a small fraction of their energy in the radio spectrum, dispersion measurements of this emission would determine the distance to the source and thereby greatly constrain theoretical models. If a GRB is at $z \sim 1$, or is beyond the Galactic center and in the Galactic plane, the signal at low frequencies ($\sim$25 MHz) will be delayed by $\sim$1 hr, which is enough time to allow a radio telescope to be pointed toward the GRB location. Such a measurement could detect a GRB with $L_{\mathrm{Radio}}/L_{\gamma\text{-ray}} \gtrsim 10^{-7}$, while an observation at higher frequencies could detect a GRB with $L_R/L_\gamma \gtrsim 10^{-8}$, both of which are much more sensitive than the current upper limit of $L_R/L_\gamma \lesssim 10^{-3.5}$. A dispersion measurement for an extragalactic GRB would also observe for the first time the intergalactic plasma, which may be the dominant form of baryonic matter in the universe.

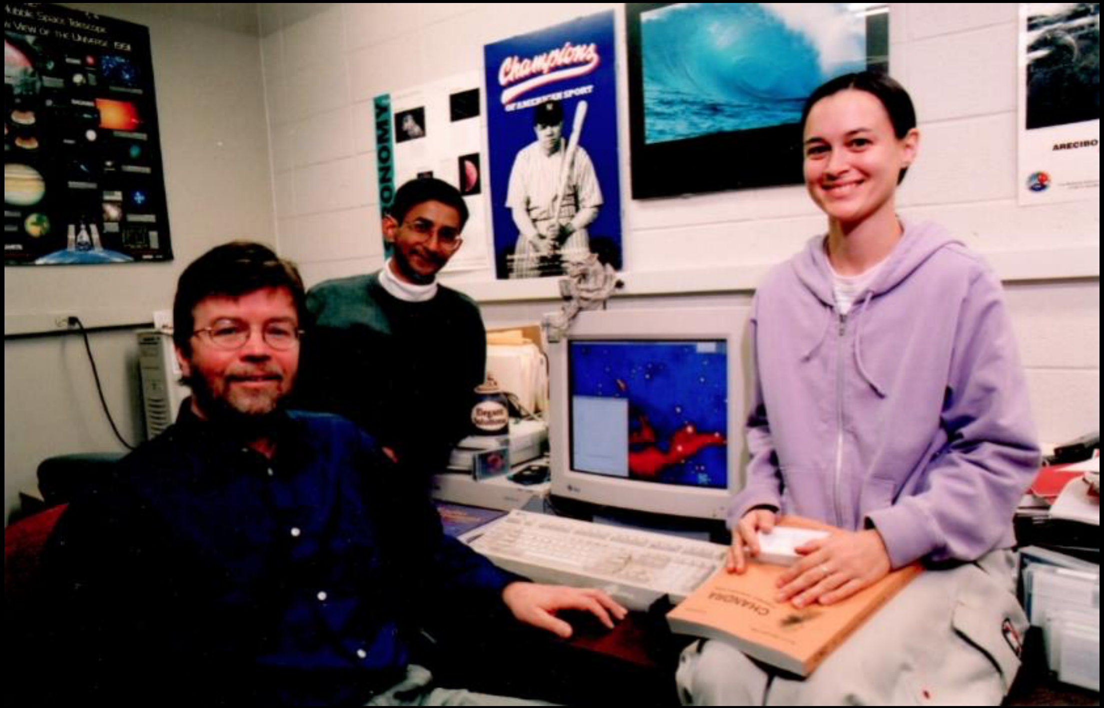
2003

SEARCHES FOR FAST RADIO TRANSIENTS

J. M. Cordes[1] and M. A. McLaughlin[2]

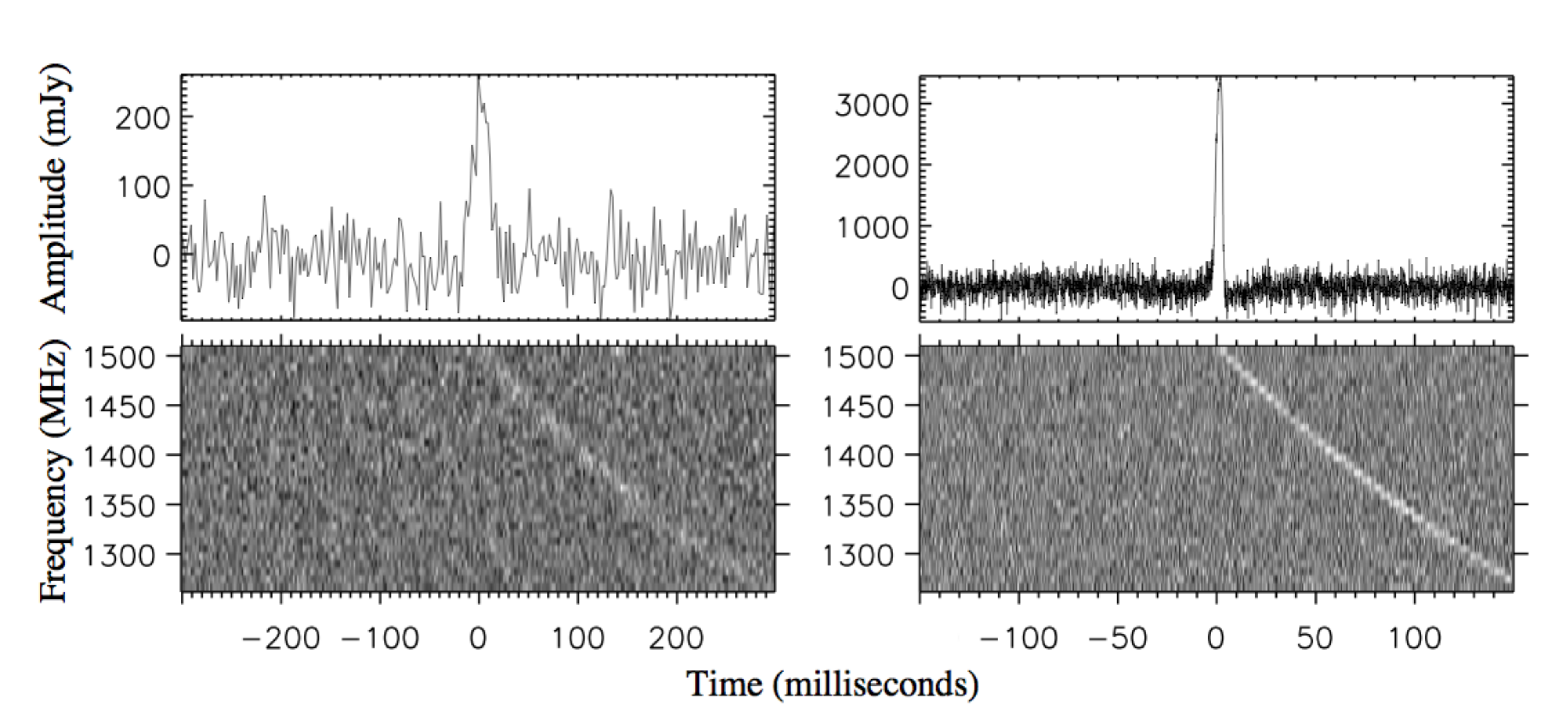
Received 2003 April 21; accepted 2003 July 2

"...the next few decades will undoubtedly bring about a greater understanding of radio-bursting objects, including Crab-like pulsars in other galaxies, counterparts to high-energy bursting sources, and other classes of objects that are yet to be discovered."



Jim Cordes, Shami Chatterjee, Maura McLaughlin
Cornell Astronomy lab, circa 2000.

Rotating Radio Transients (RRATs)



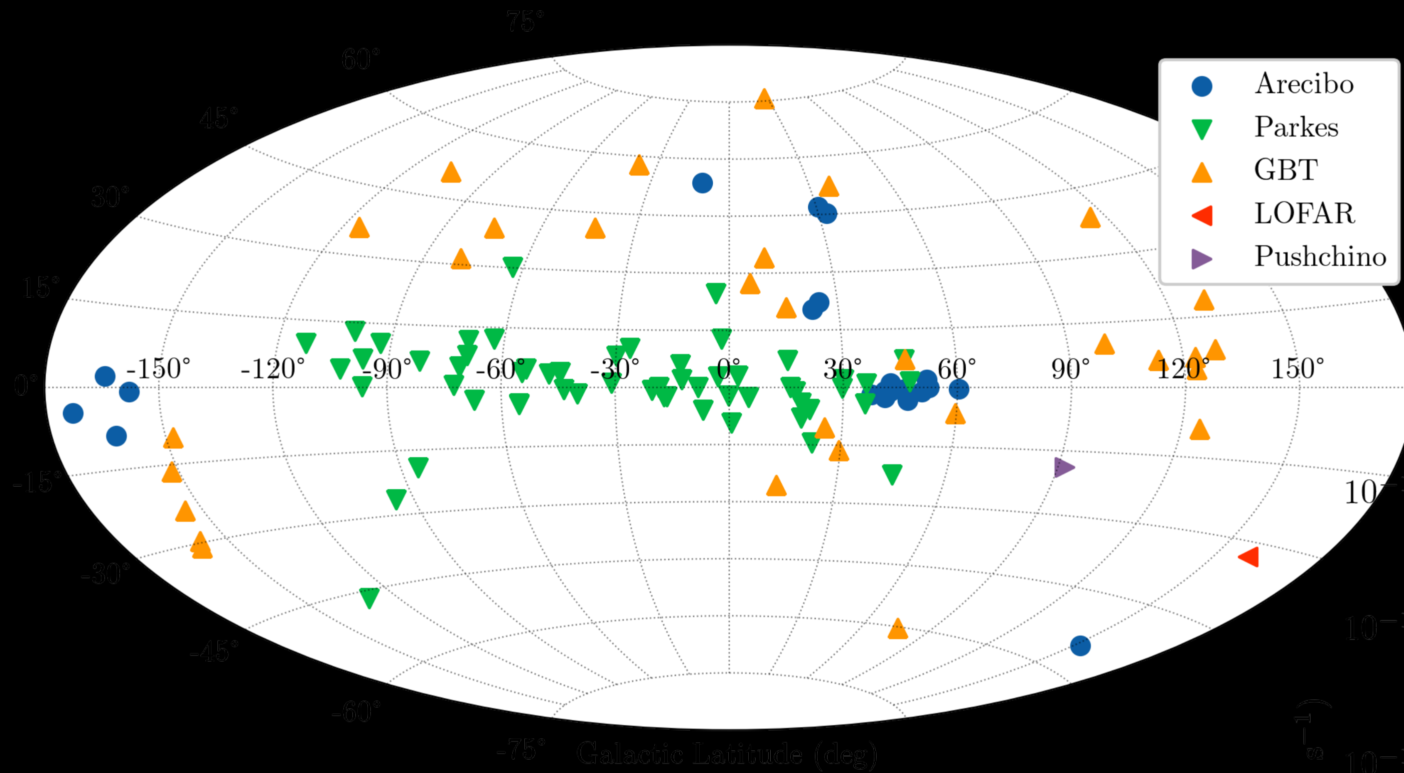
McLaughlin et al. (2006)

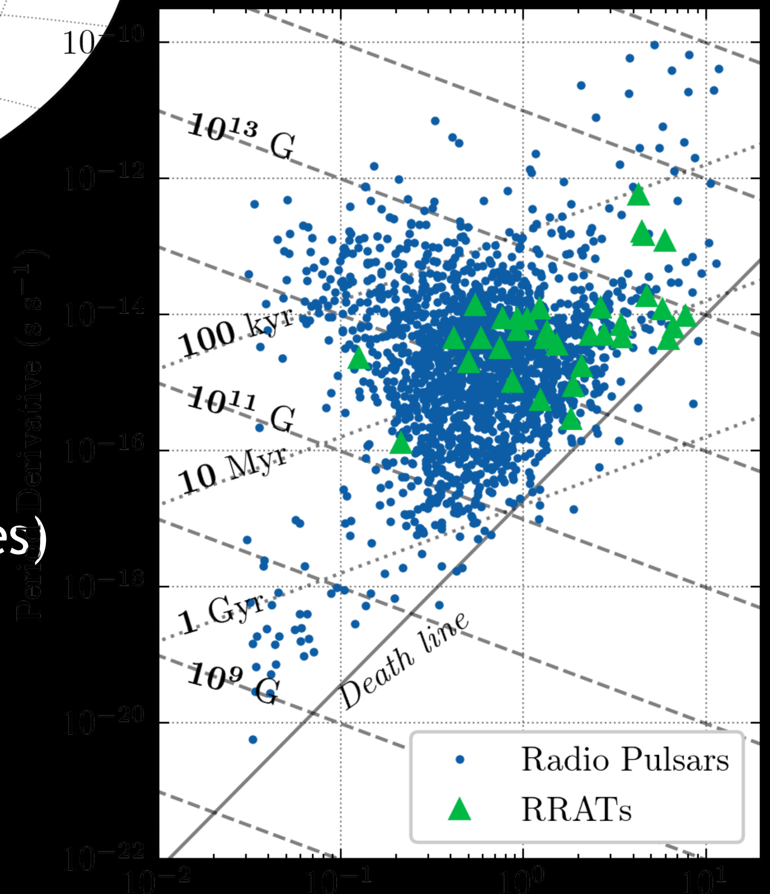
Units of DM [cm^{-3} pc]

Rule of thumb for MW:
D ~ (DM/30) kpc

$$\mathrm{DM} = \int_0^D n_e dl \simeq \overline{n_e} D$$

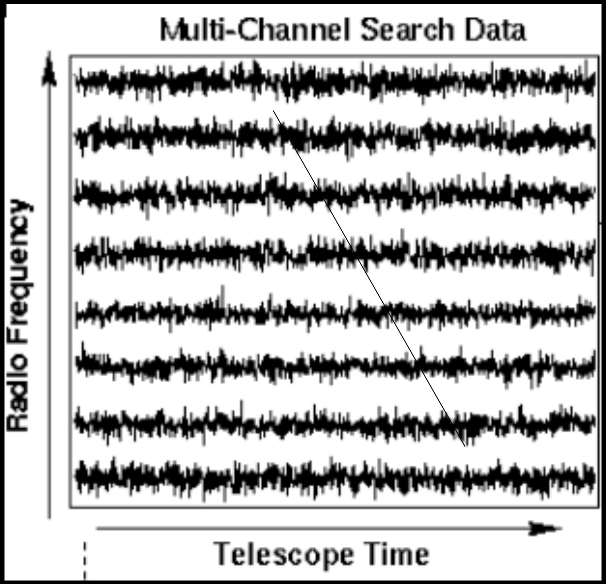
Rotating Radio Transients (RRATs)



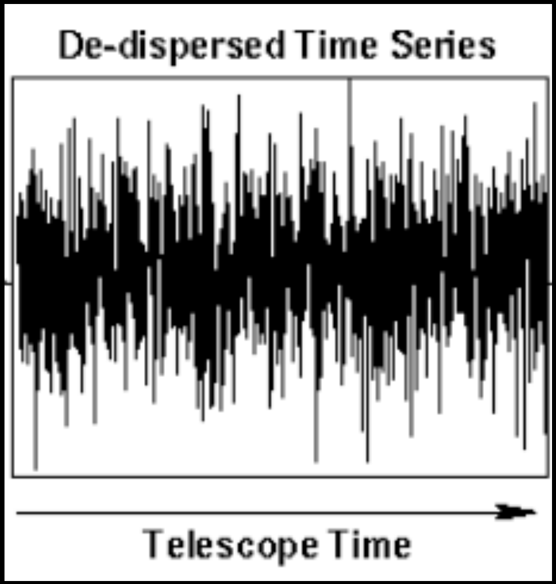


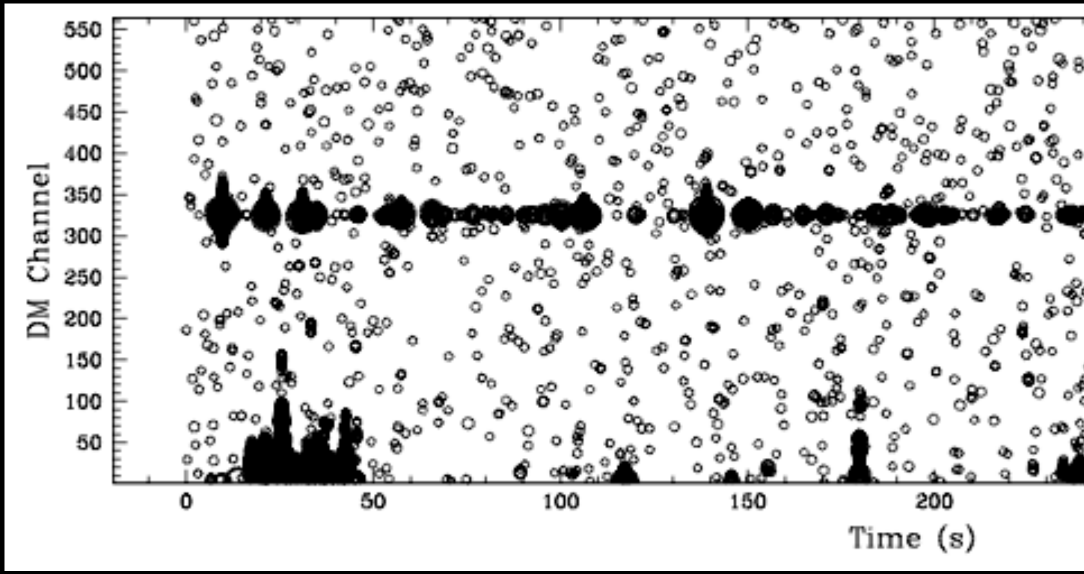
Source: Agarwal et al. (2021) in prep.
http://astro.phys.wvu.edu/rratalog (122 sources)

Single-pulse search pipeline



DM

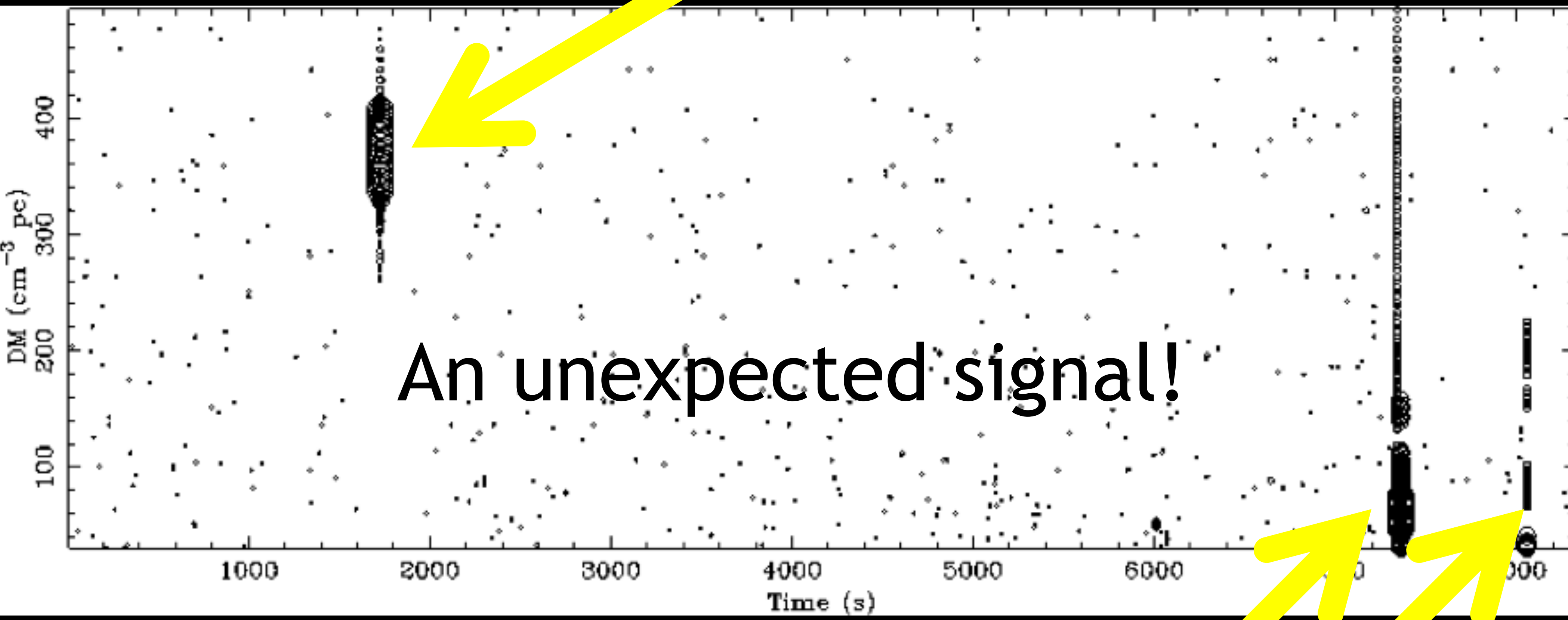




Cordes & McLaughlin (2003)

An unexpected signal!

DM = 375. (10x higher than MW)



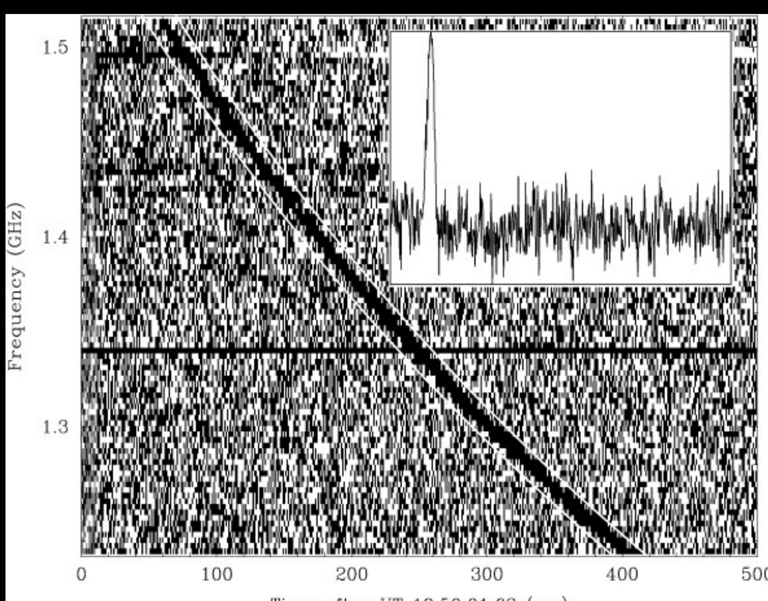
Interference

2007

A Bright Millisecond Radio Burst of Extragalactic Origin

D. R. Lorimer,[1,2]* M. Bailes,[3] M. A. McLaughlin,[1,2] D. J. Narkevic,[1] F. Crawford[4]

Pulsar surveys offer a rare opportunity to monitor the radio sky for impulsive burst-like events with millisecond durations. We analyzed archival survey data and found a 30-jansky dispersed burst, less than 5 milliseconds in duration, located 3° from the Small Magellanic Cloud. The burst properties argue against a physical association with our Galaxy or the Small Magellanic Cloud. Current models for the free electron content in the universe imply that the burst is less than 1 gigaparsec distant. No further bursts were seen in 90 hours of additional observations, which implies that it was a singular event such as a supernova or coalescence of relativistic objects. Hundreds of similar events could occur every day and, if detected, could serve as cosmological probes.



DM = 375

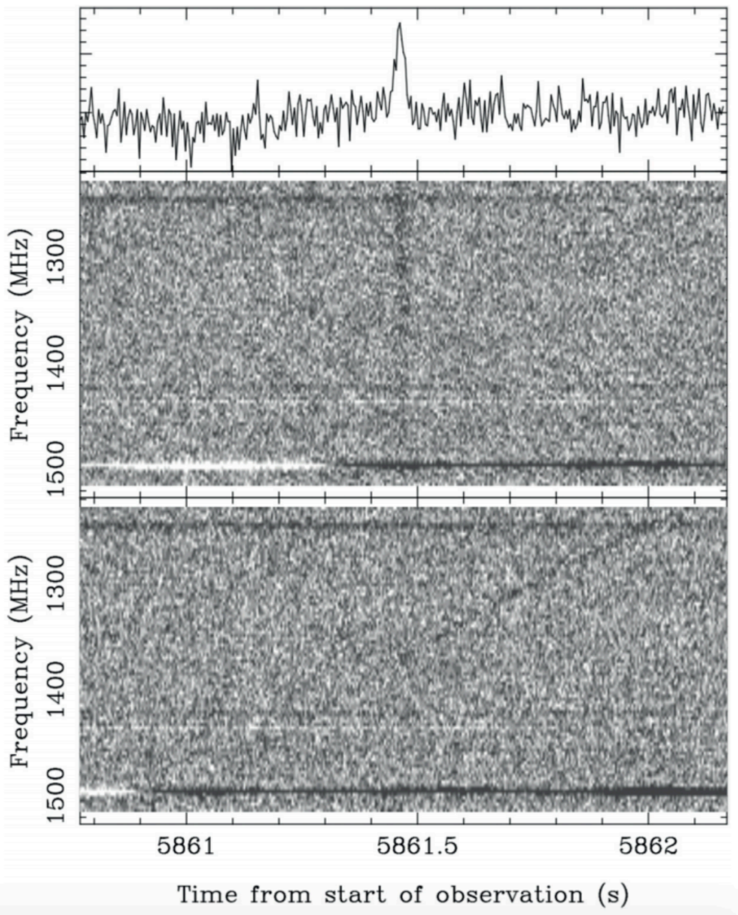
W = 15 ms

2019: Hindsight is 20-20

MNRAS **484,** L147–L150 (2019) doi:10.1093/mnrasl/slz023
Advance Access publication 2019 February 20

A new fast radio burst in the data sets containing the Lorimer burst

S.-B. Zhang,[1,2,3,4★] G. Hobbs ,[3★] S. Dai,[3★] L. Toomey,[3] L. Staveley-Smith ,[4,5] C. J. Russell[6] and X.-F. Wu[1]



DM = 1187
W = 24 ms

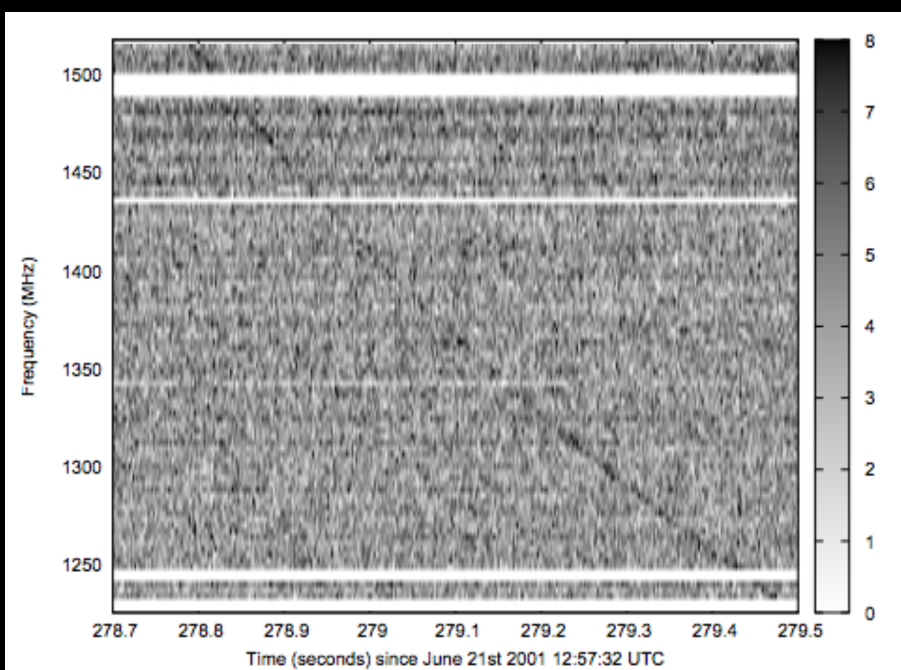
What might've been!

2013

On the origin of a highly-dispersed coherent radio burst

E.F. Keane[1], B.W. Stappers[2], M. Kramer[1,2] & A.G. Lyne[2]
[1] *Max Planck Institut für Radioastronomie, Auf dem Hügel 69, 53121 Bonn, Germany.*
[2] *University of Manchester, Jodrell Bank Centre for Astrophysics, School of Physics & Astronomy, Manchester M13 9PL, UK.*

"The burst is also consistent with the radio signal theorised from an annihilating mini black hole."

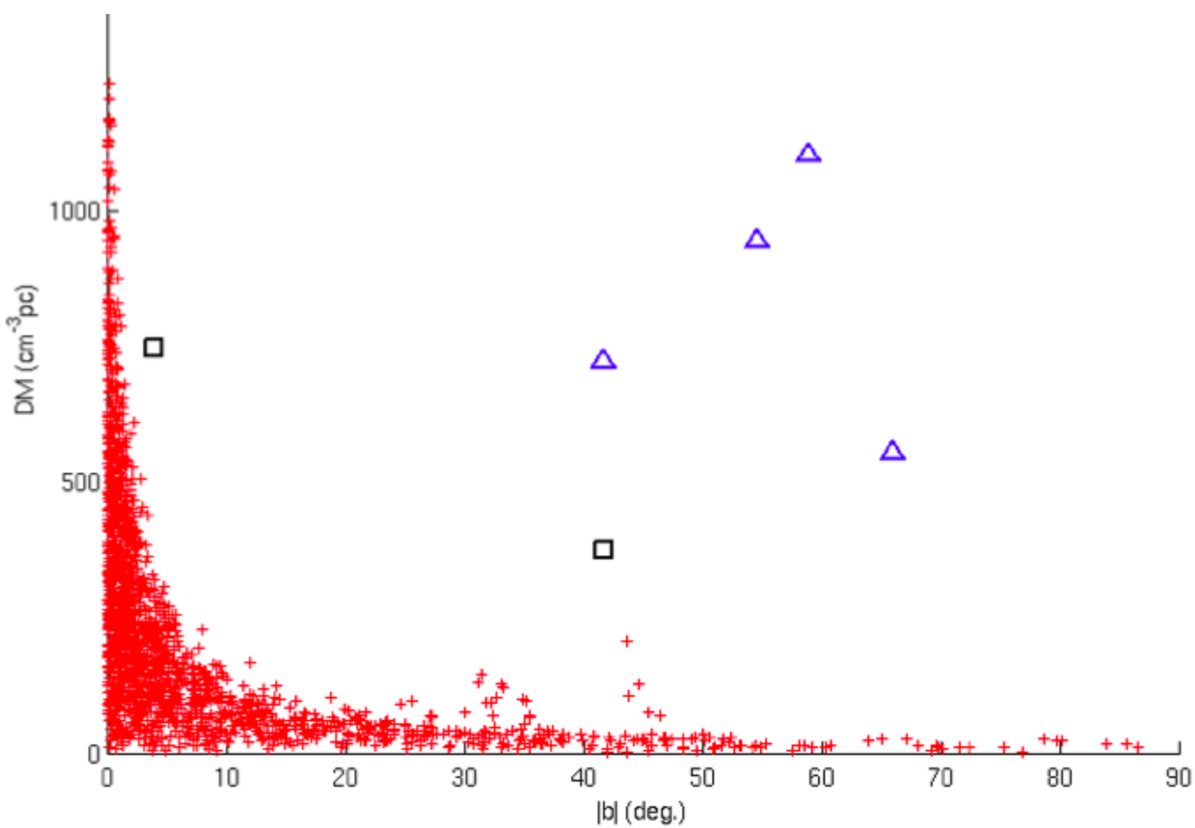


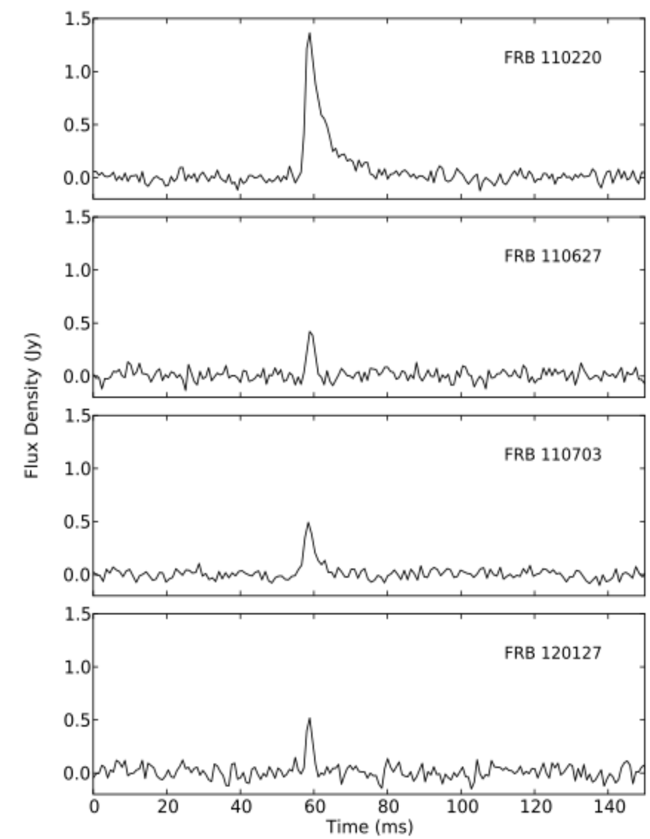
DM = 746
W=8 ms

2013

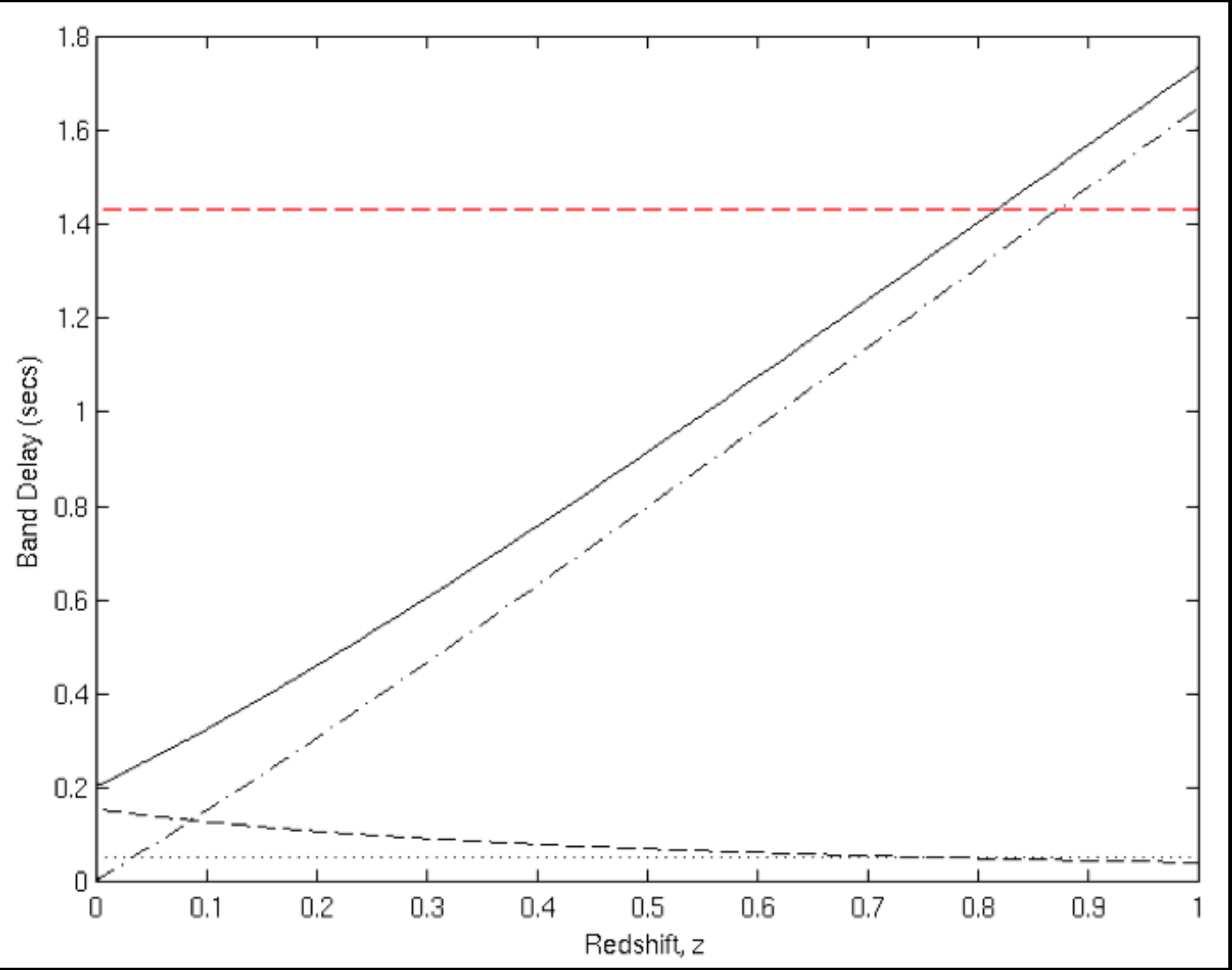
A Population of Fast Radio Bursts at Cosmological Distances

D. Thornton,[1,2]* B. Stappers,[1] M. Bailes,[3,4] B. Barsdell,[3,4] S. Bates,[5] N. D. R. Bhat,[3,4,6] M. Burgay,[7] S. Burke-Spolaor,[8] D. J. Champion,[9] P. Coster,[2,3] N. D'Amico,[10,7] A. Jameson,[3,4] S. Johnston,[2] M. Keith,[2] M. Kramer,[9,1] L. Levin,[5] S. Milia,[7] C. Ng,[9] A. Possenti,[7] W. van Straten[3,4]



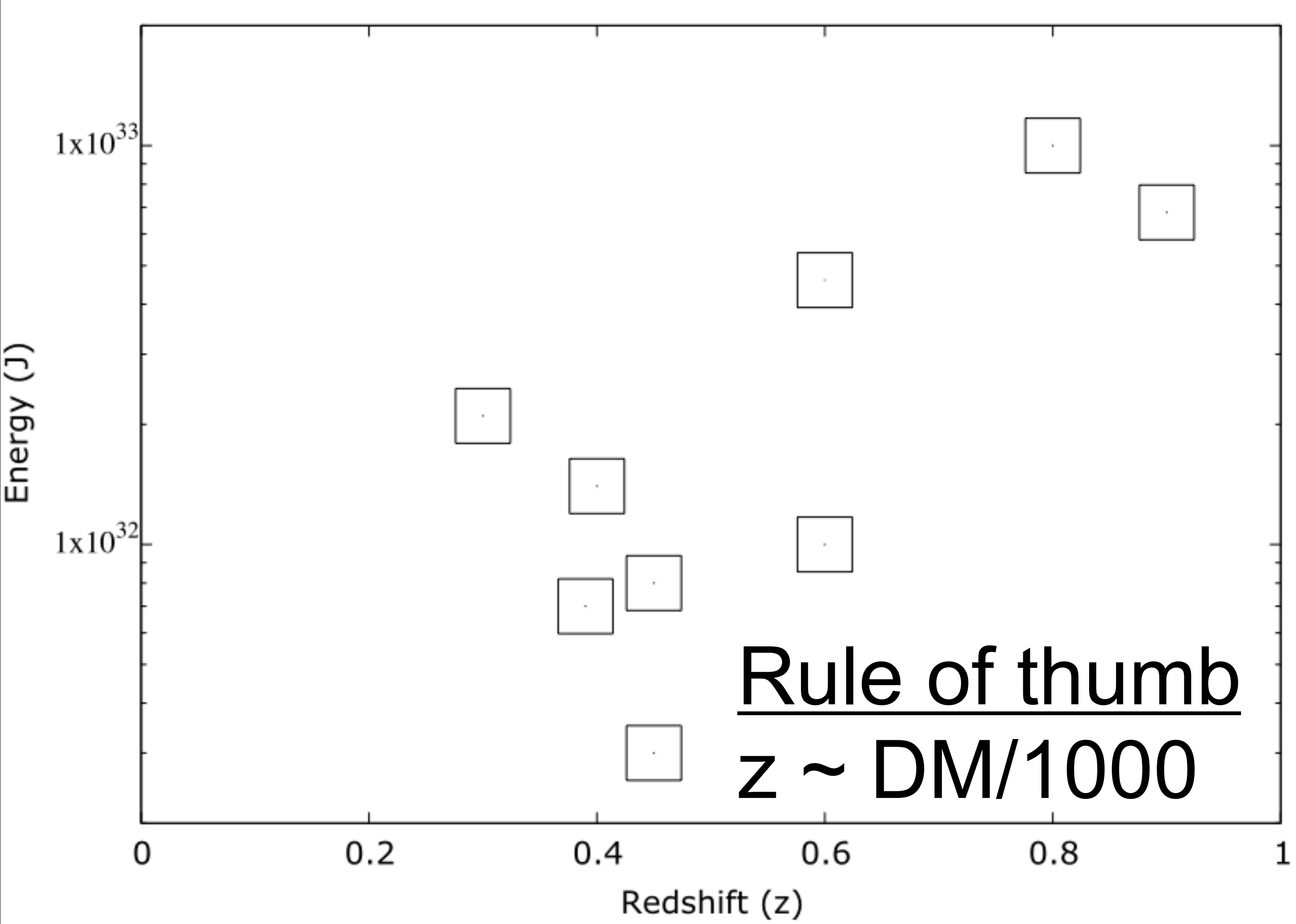


DM delay in FRB 110220

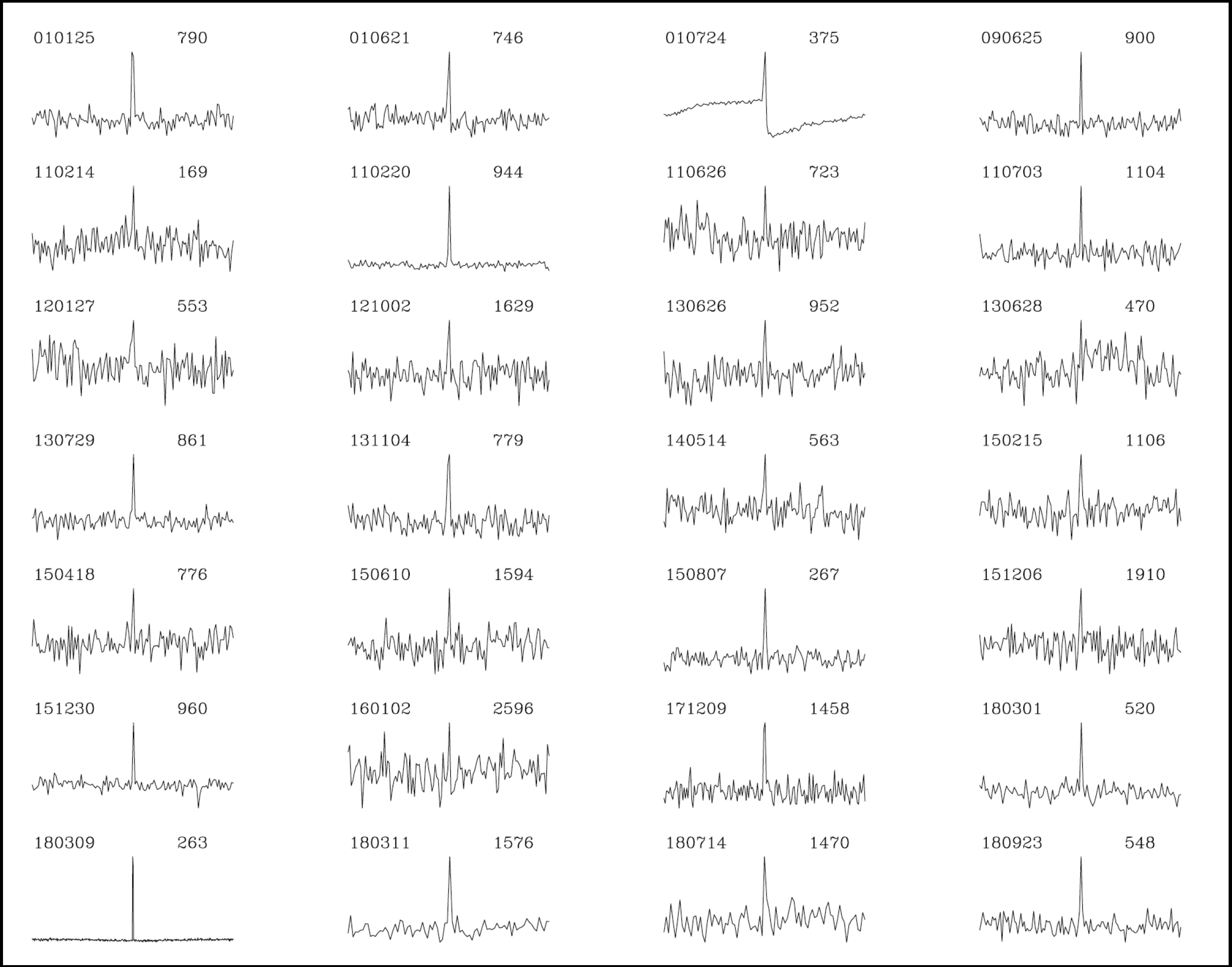


Credit: Thornton et al. (2013)

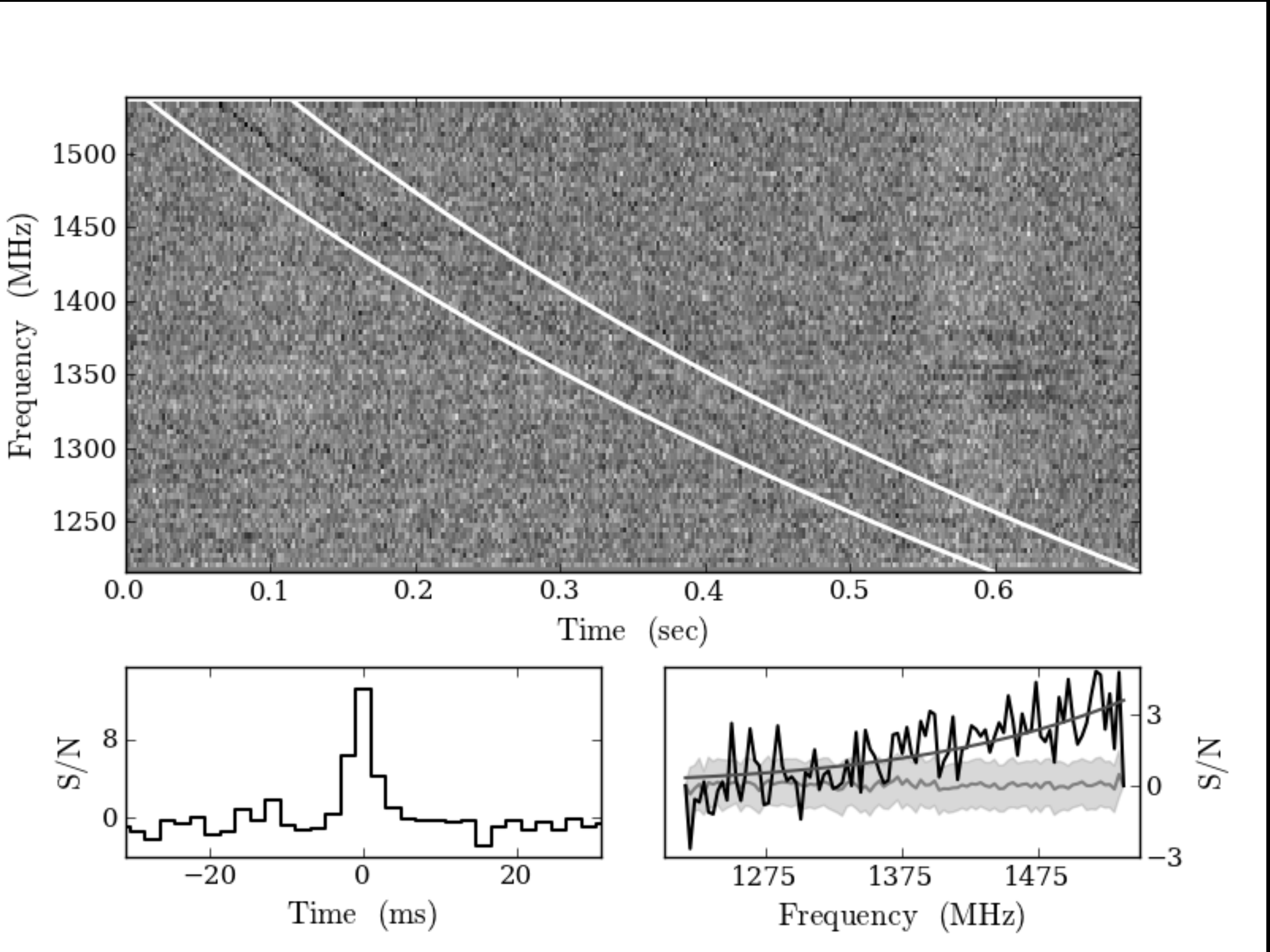
Energy and redshift ESTIMATES



Most early discoveries came from PKS



2014: FRB 121102 at Arecibo

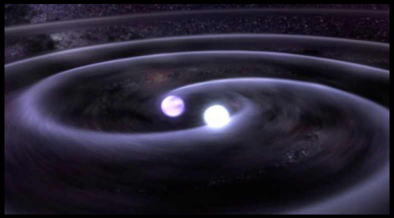


More theories than bursts!

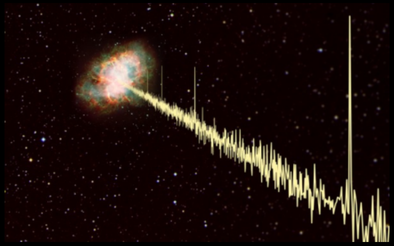
- Colliding compact objects (e.g. NS-NS)
- Supernovae
- Collapsing NS → BH (blitzar)
- Black hole absorbing NSs
- Giant pulses from pulsars/magnetars
- Neutron star – asteroid belt interaction
- More exotic (strange) star interactions
- Galactic Flare Stars
- Light sails
- Dark matter
- Cosmic strings
- White holes
- Extra-terrestrial signals

2016: FRB 121102 repeats!

→ No!



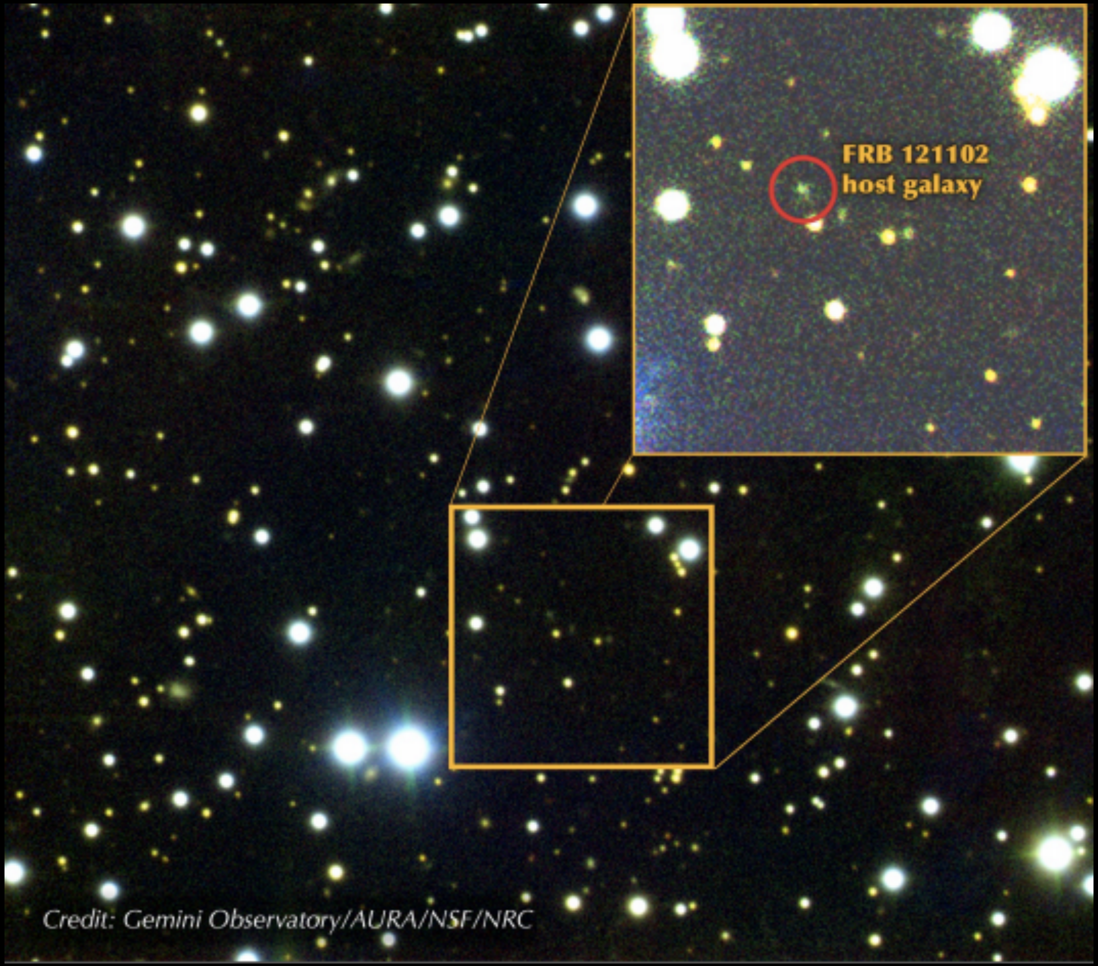
→ No!



→ Maybe?

… or maybe something else?

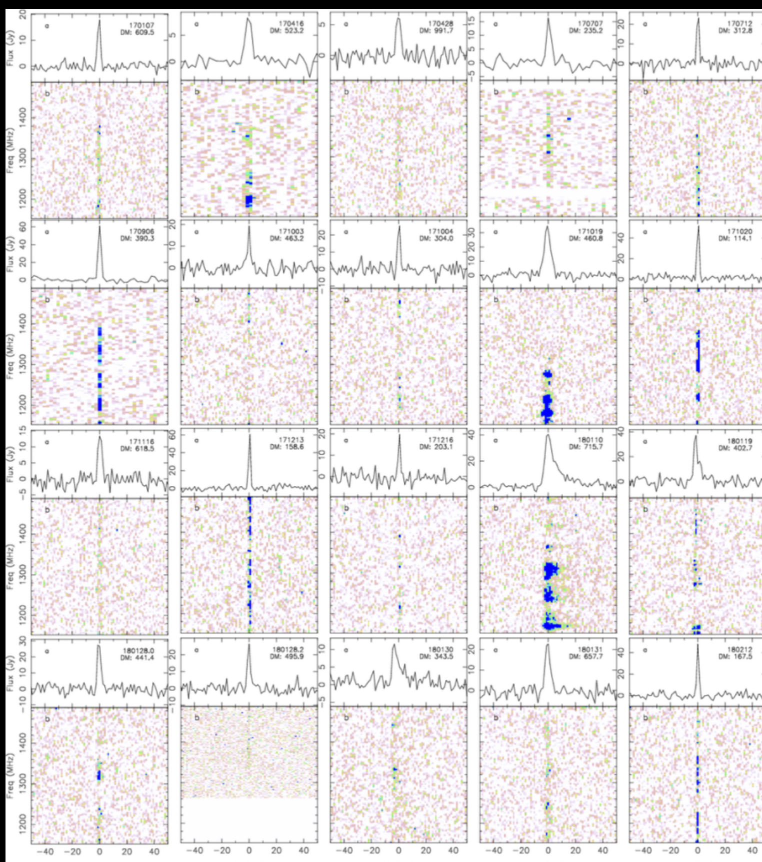
2017: FRB 121102 localized!



z = 0.19

(2.3 billion yr)

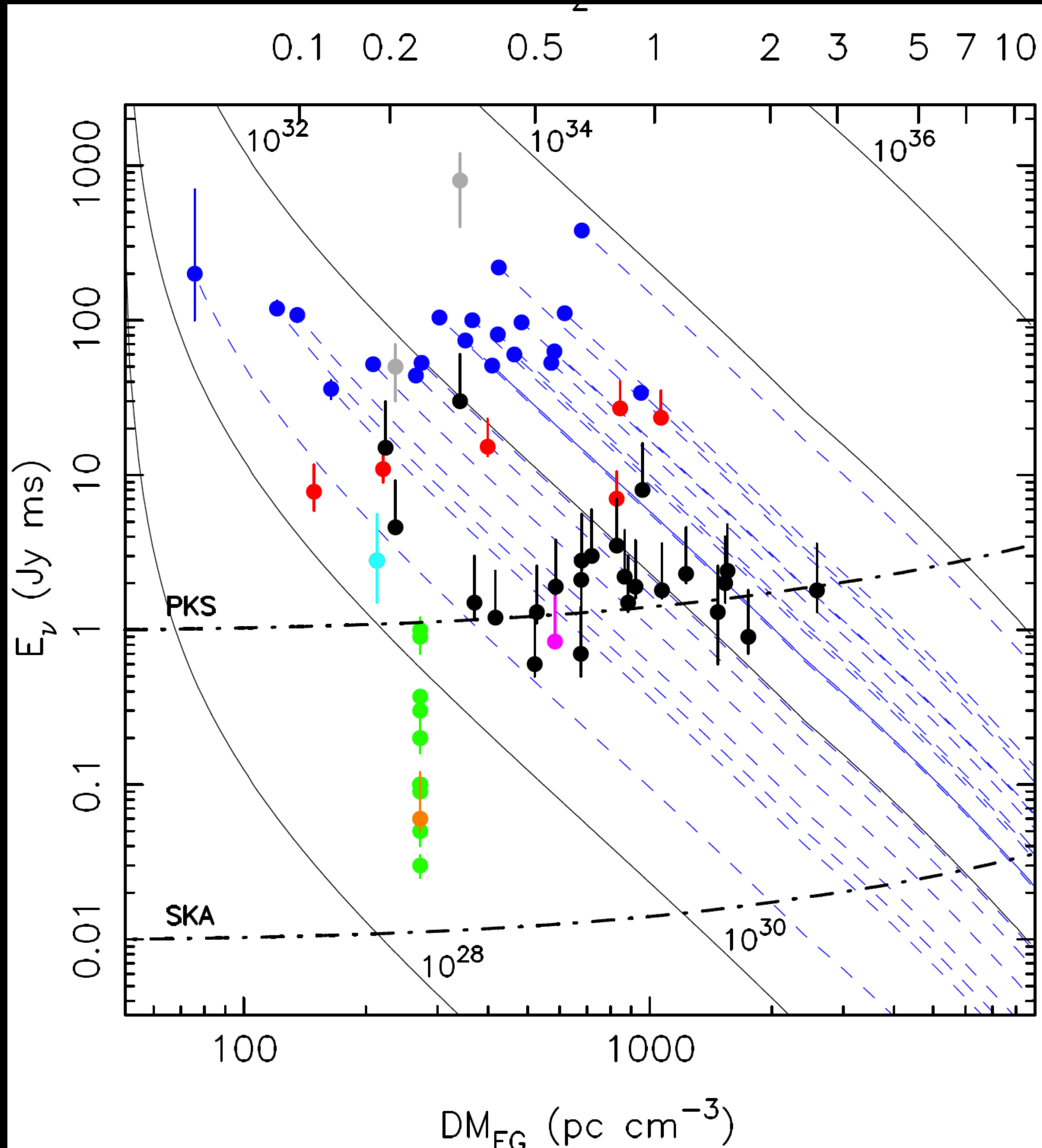
2018: ASKAP



20 FRBs in initial survey

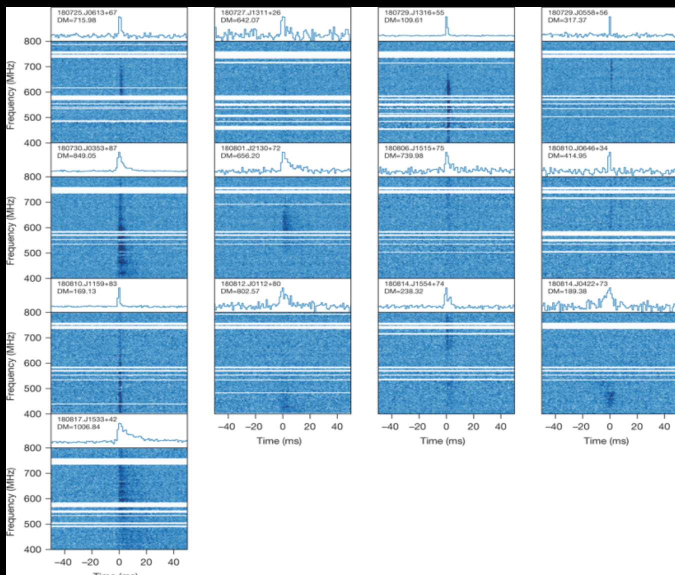
No repetitions in >1000h

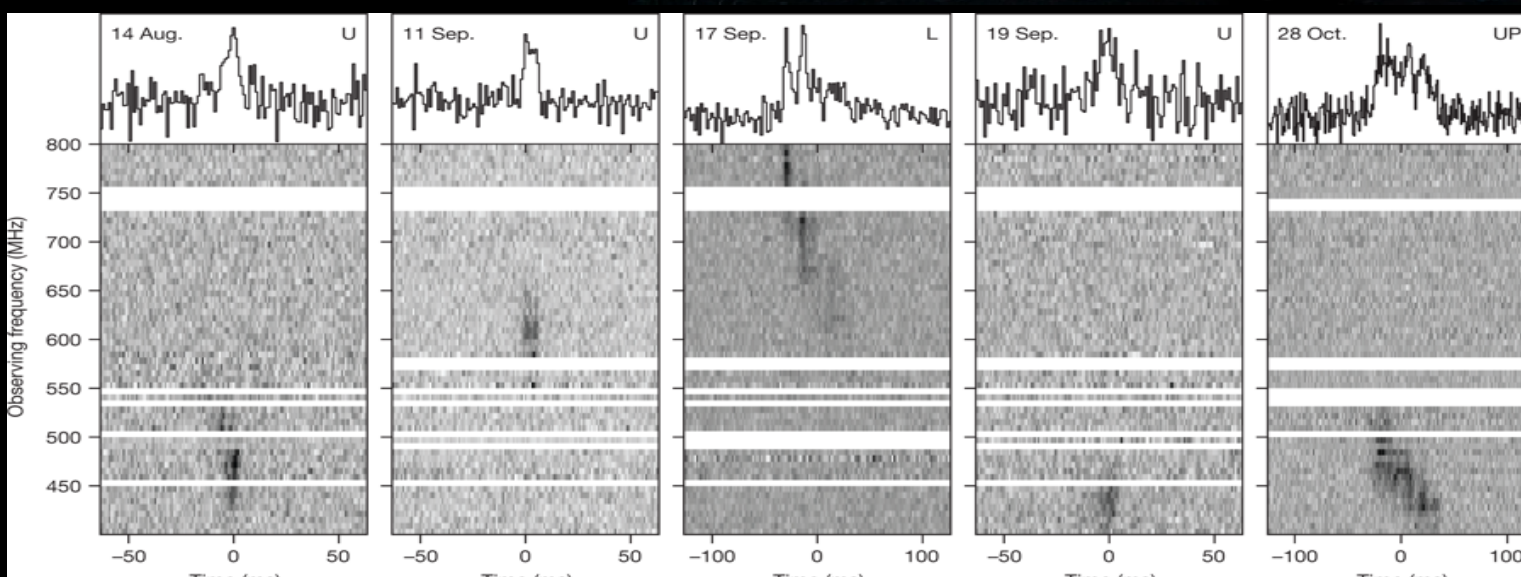
Credit: Shannon et al. *Nature* ***562***, 386 (2018)



Credit: Petroff, Hessels, Lorimer (2019)

2019: CHIME





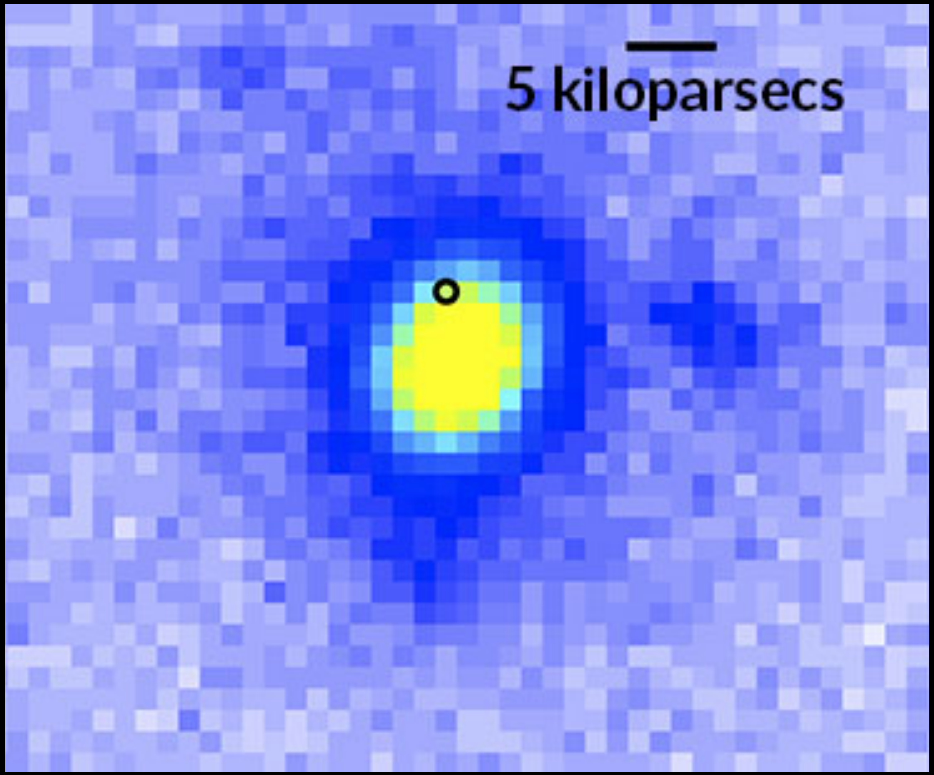
Credit: CHIME/FRB Collaboration *Nature* **566**, 235–238 (2019)

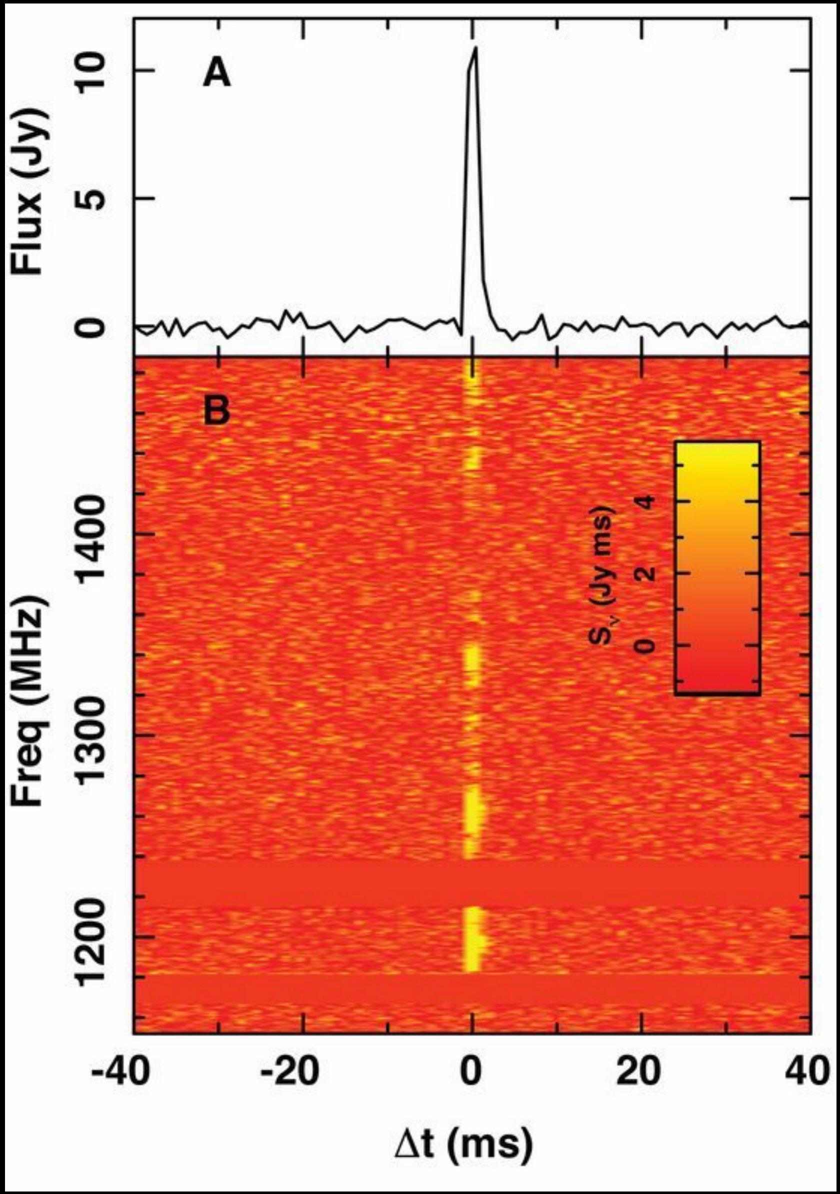
Credit: CHIME/FRB Collaboration *Nature* **566**, 230–234 (2019)

2019: ASKAP

z = 0.32

(4.0 billion yr)

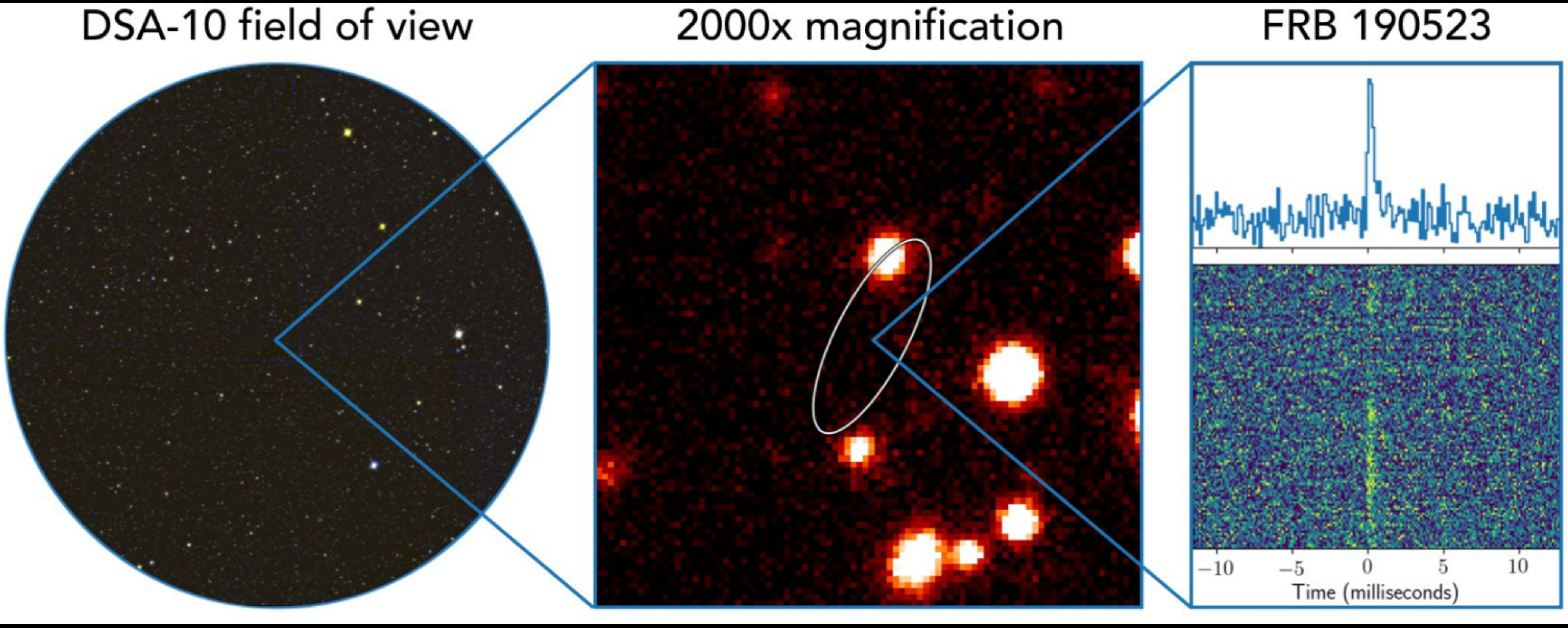




Credit: Bannister et al. Science *DOI: 10.1126/science.aaw5903* (2019)

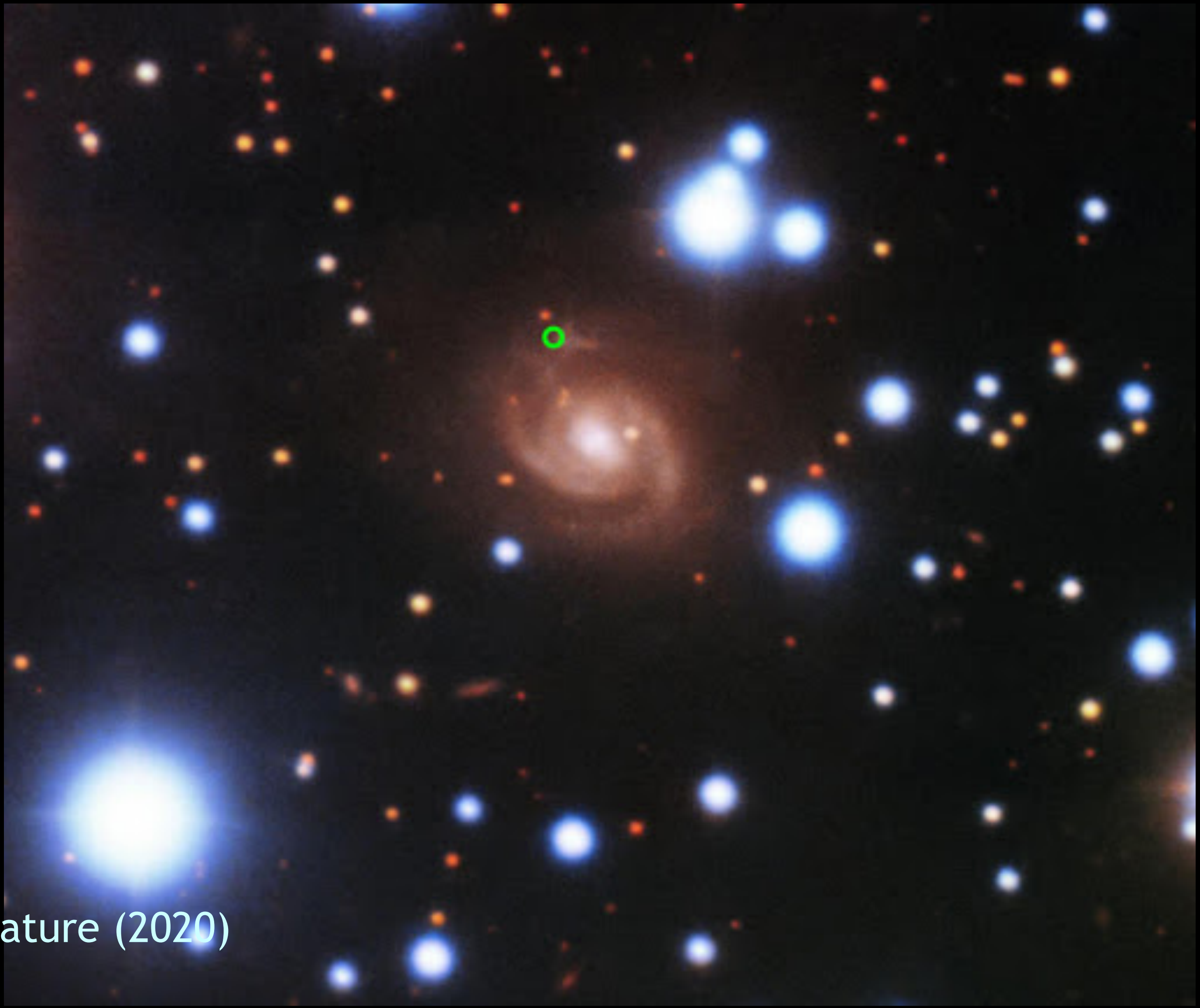
2019: DSA

z = 0.66
(7.9 billion yr)



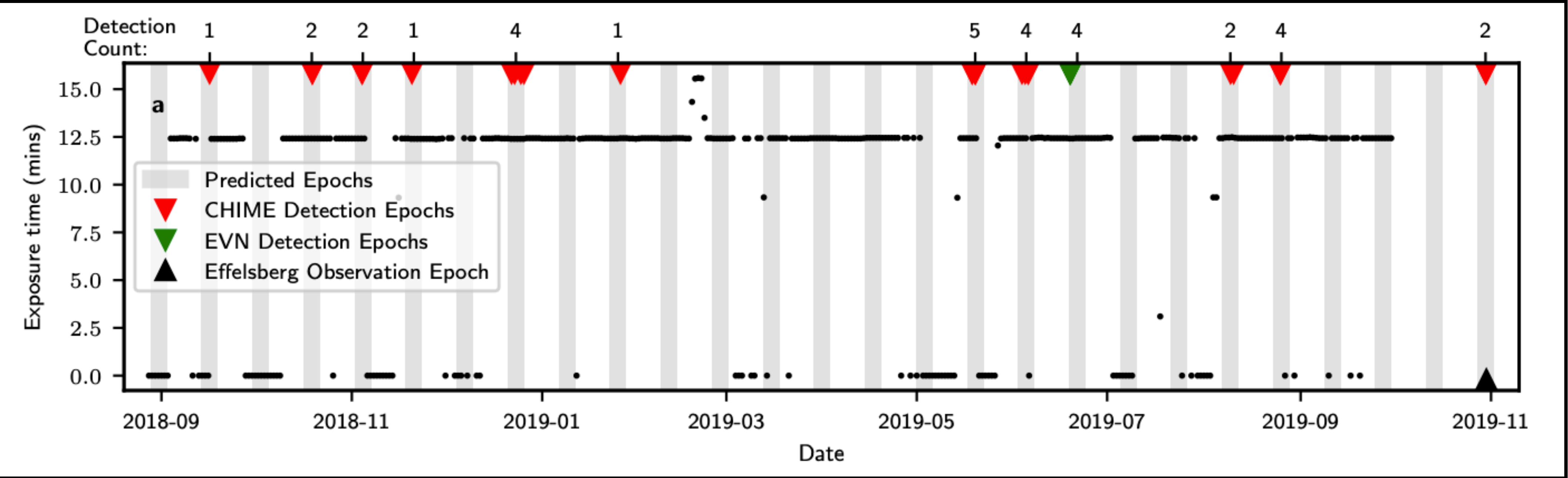
2020: CHIME

z = 0.0037
(350 million lyr)



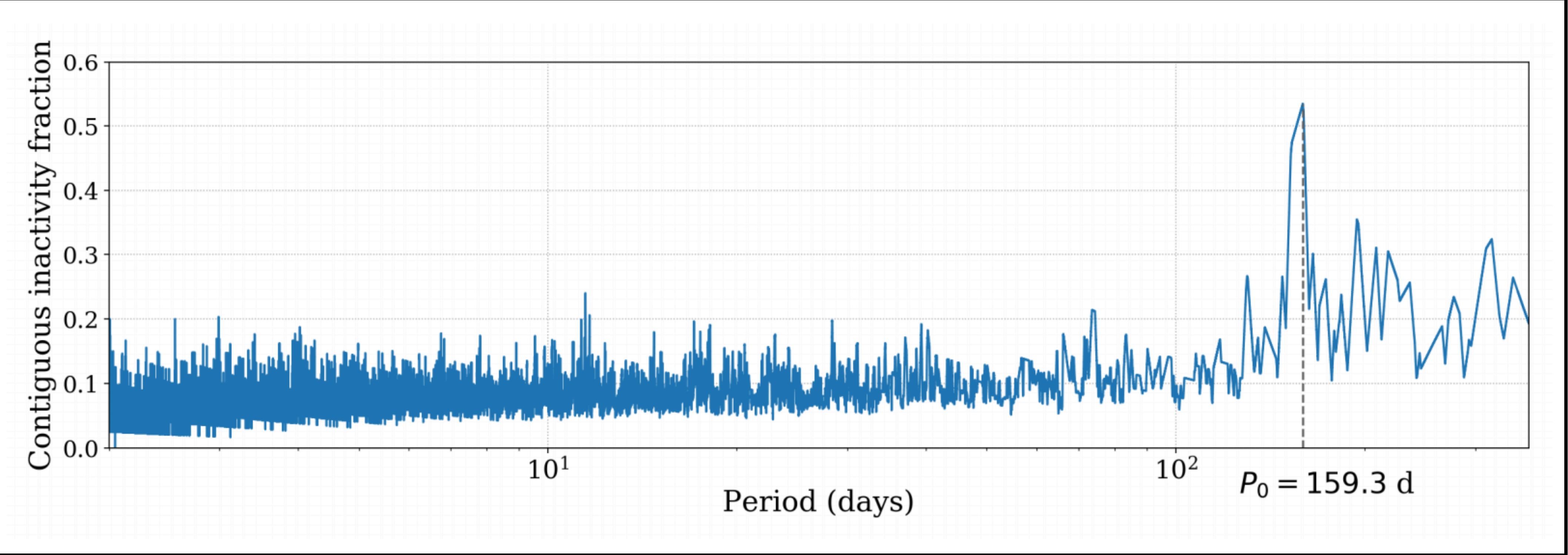
Credit: Marcote et al. Nature (2020)

2020: Periodically Repeating FRBs



FRB 190916.J0158+65
Credit: CHIME collaboration et al. (2020)

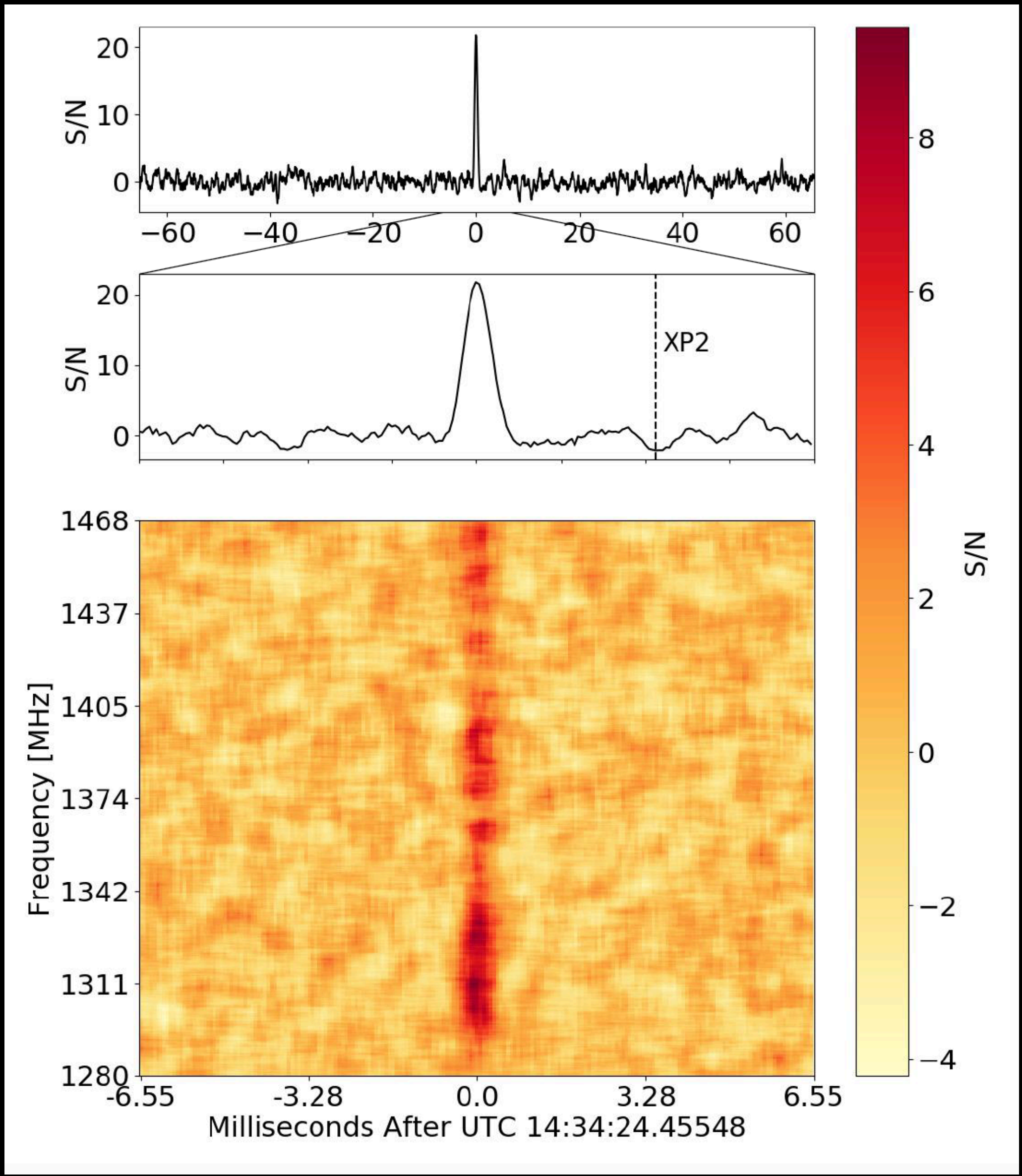
2020: Periodically Repeating FRBs

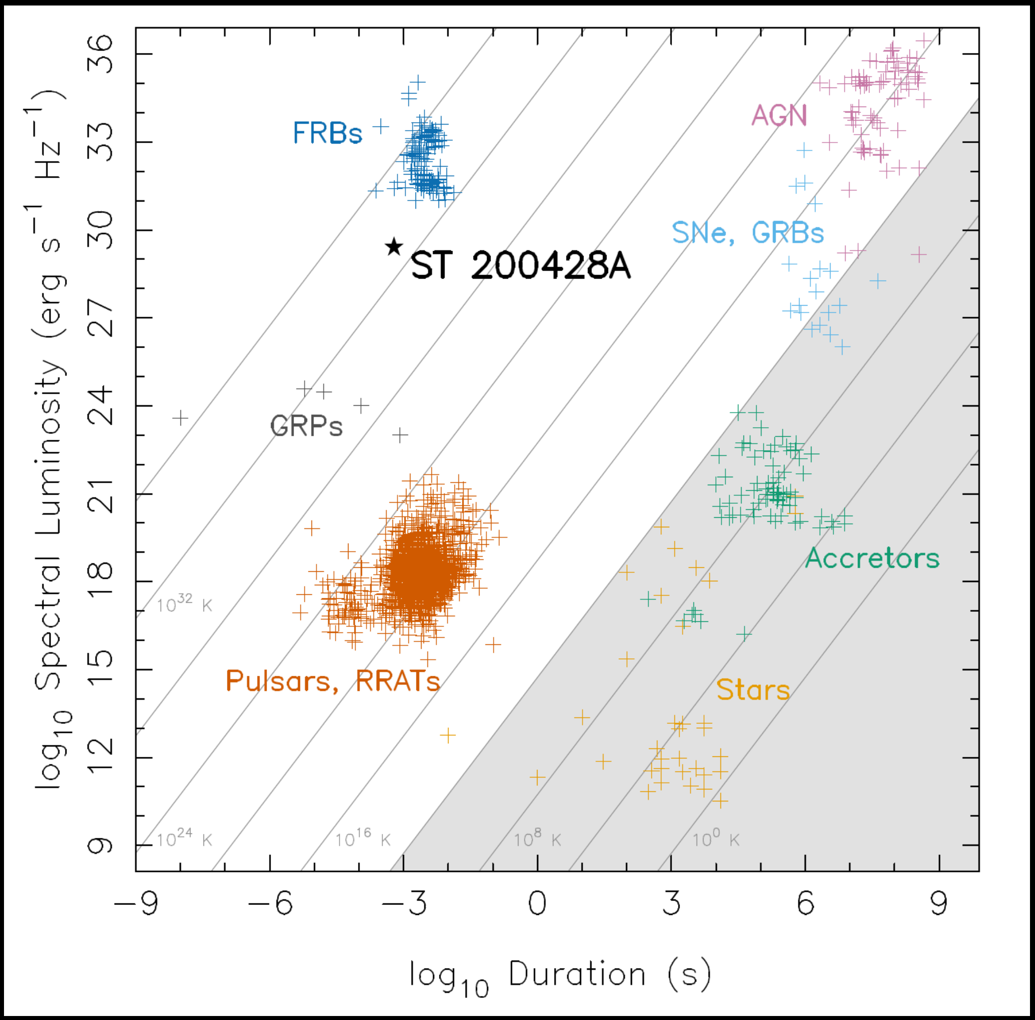


159.3 day periodicity?!?

Credit: Rajwade et al. (2020)

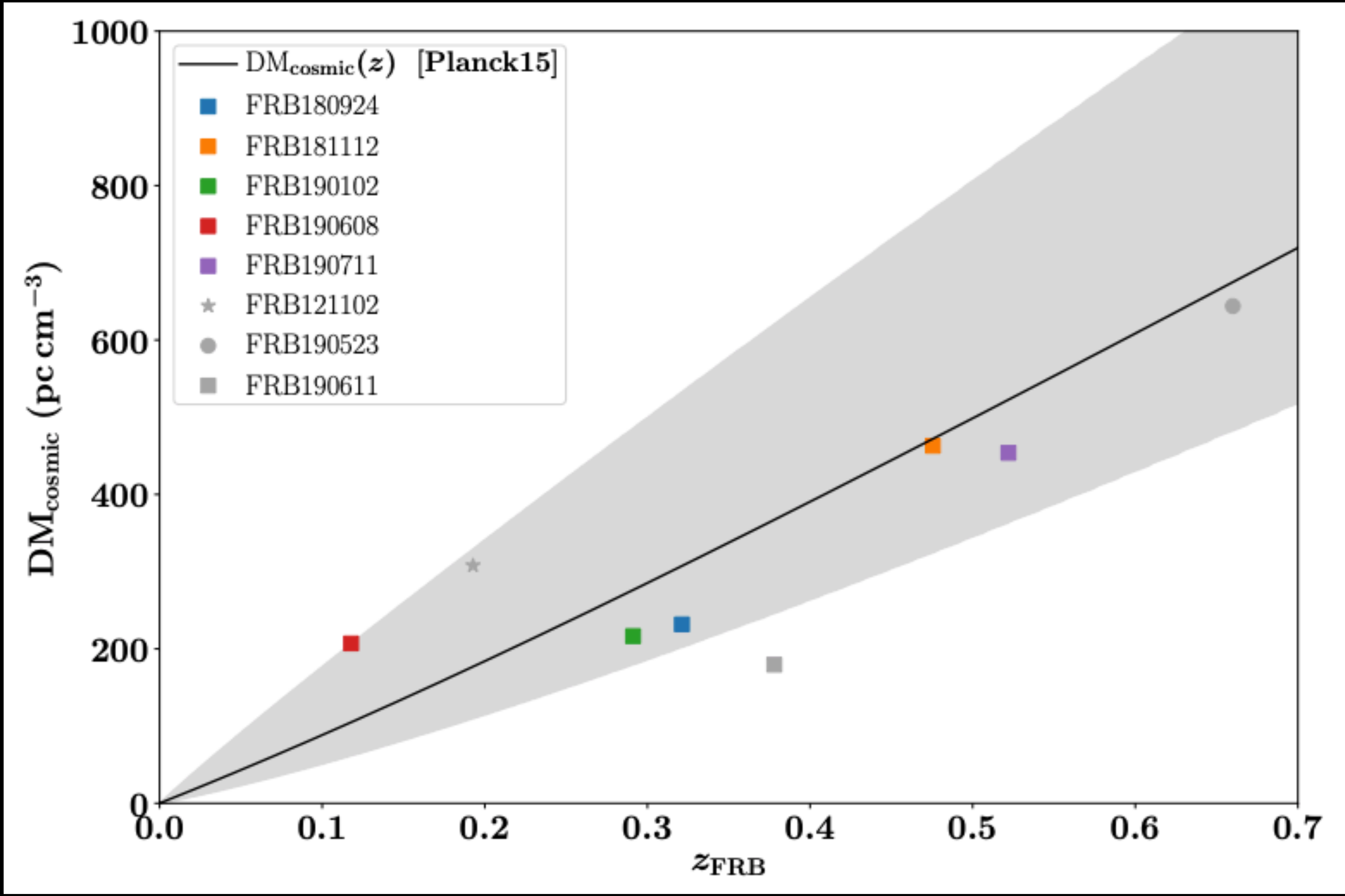
2020: A Galactic FRB!





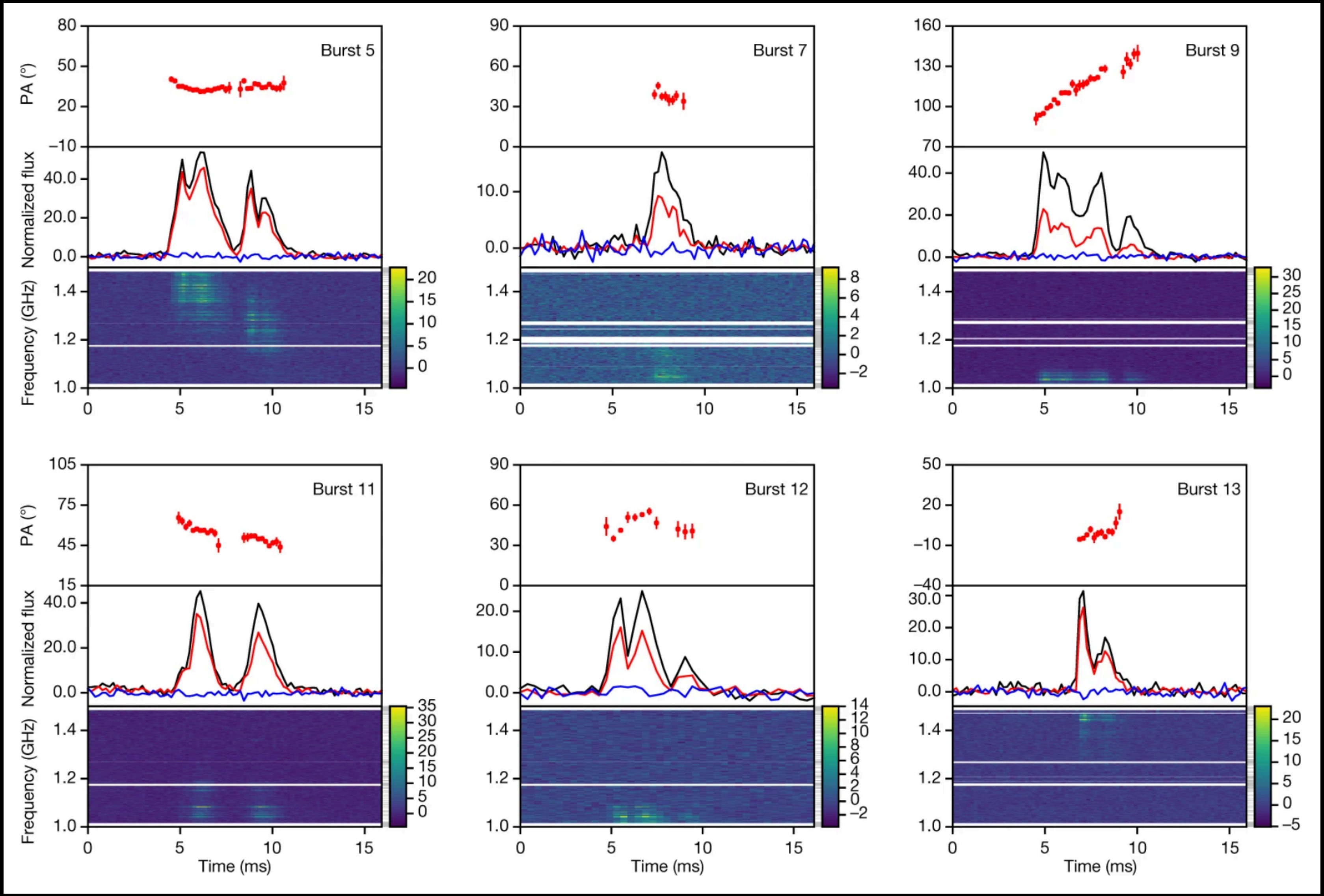
FRB 200428 and SGR 1935+2154
Bochanek et al. 2020; CHIME et al. 2020

2020: The Macquart Relationship



Macquart et al. Nature 2020

2020: Pulsar-like polarimetry



Luo et al. Nature 2020

A bright future ahead!

Some (of many) open questions…

- Do all FRBs repeat?
  - Repeater pulses appear to be different
- How many populations are there?
- Are all repeaters periodic?
- What are the host galaxies telling us?
- What is/are the event rate(s)?
- What about the periodicities
  - Suggestive of binary/precessional nature?
- What about beaming?
  - The radio pulsar interpretation implies this is significant
- What is/are the DM/redshift distribution(s)?
  - Recent work by James et al. suggest that this is following the SFR
- What is/are the luminosity functions?
  - They are not standard candles
  - Schechter distribution