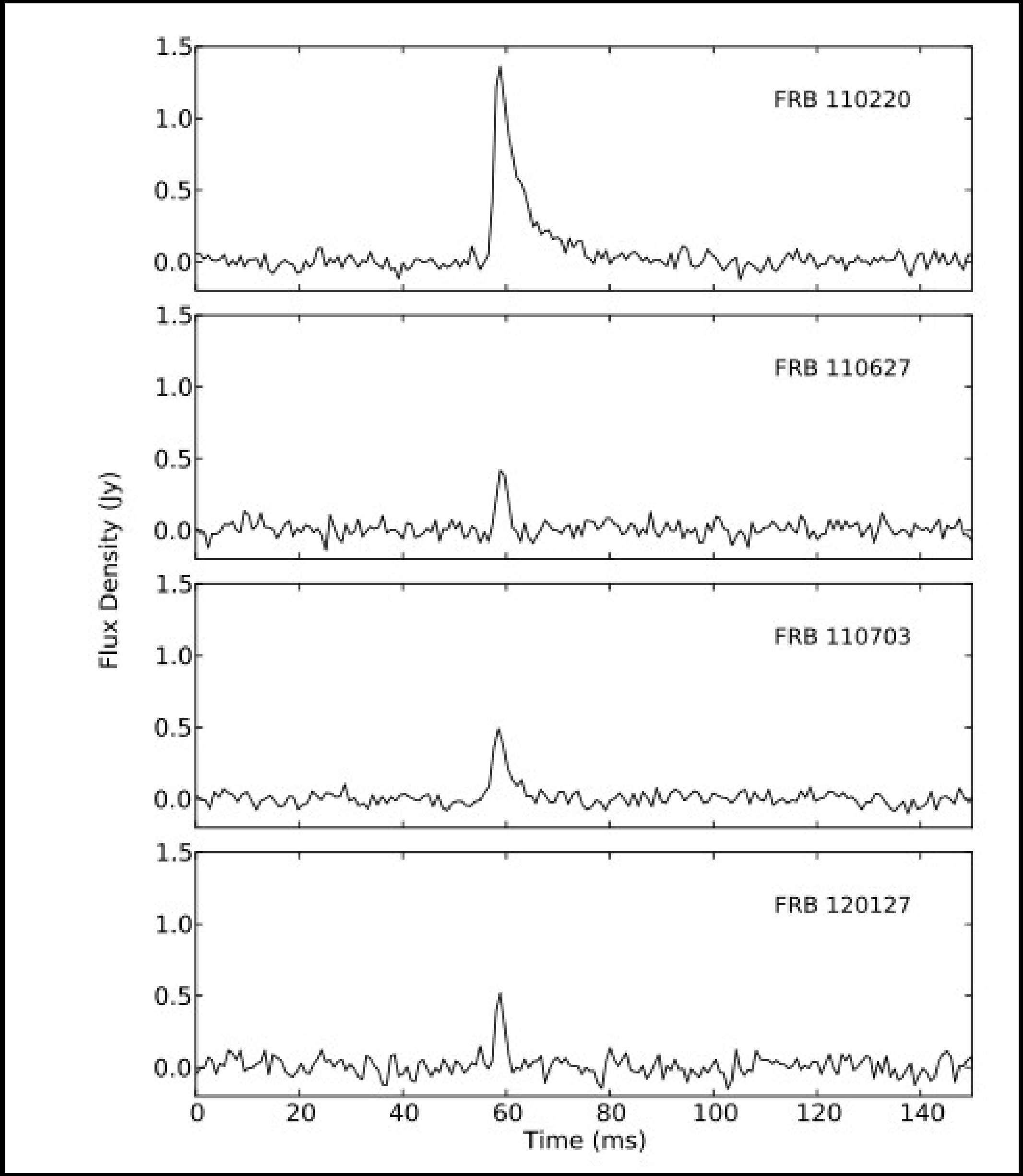
Fast Radio Bursts : The Story So Far...

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

Credit: Swinburne

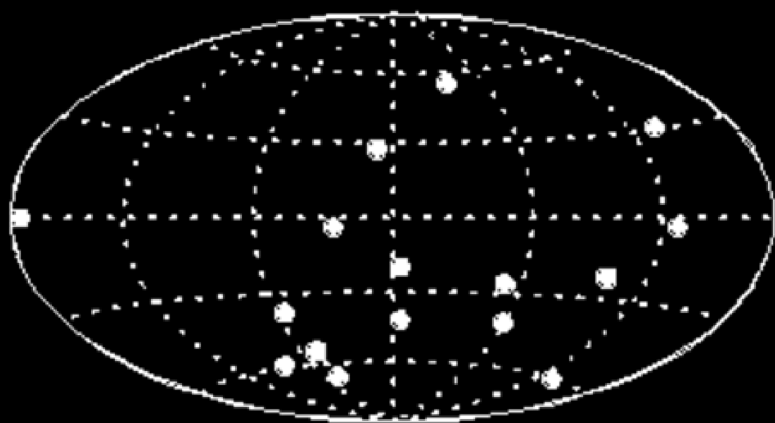
FRB lowdown

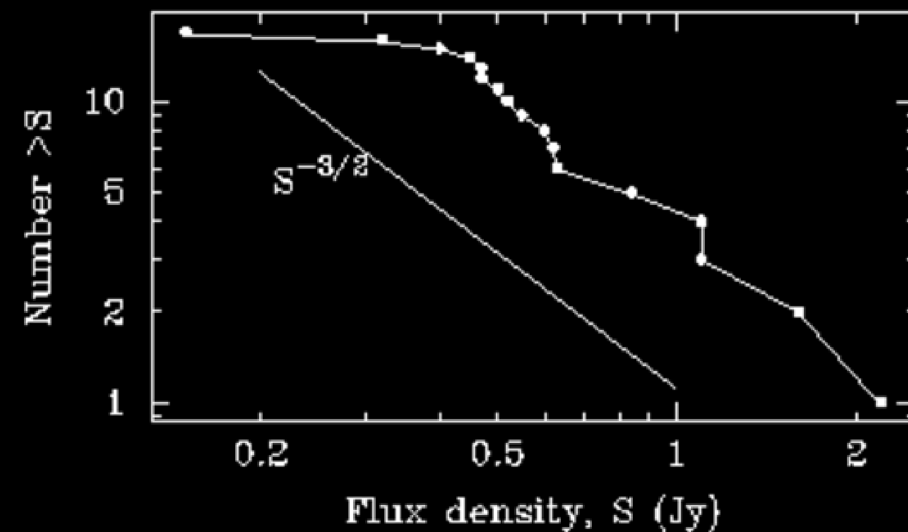
- 17 published so far
- (~5 unpublished)
- Flux > 0.5 Jy @ 1.4 GHz
- Pulse widths > few ms
- Highly dispersed
- Weakly scattered
- 1/16 so far repeats!
- Few arcmin localization
- No counterparts so far
- ~few x 1000/day/sky

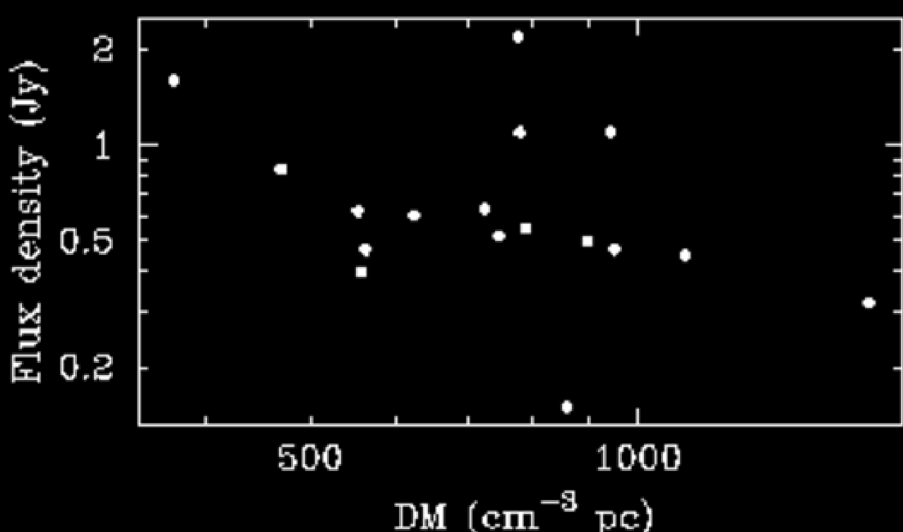


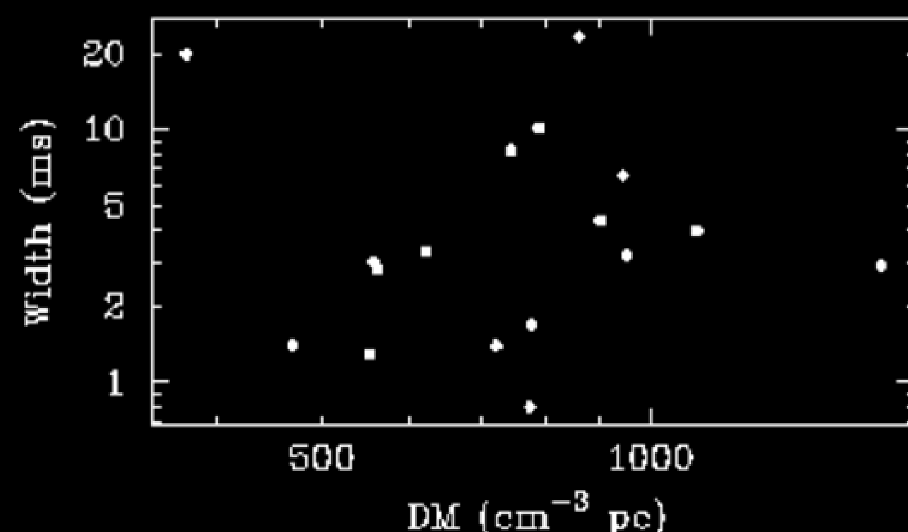
Credit: Thornton et al. (2013)

Some simple statistics



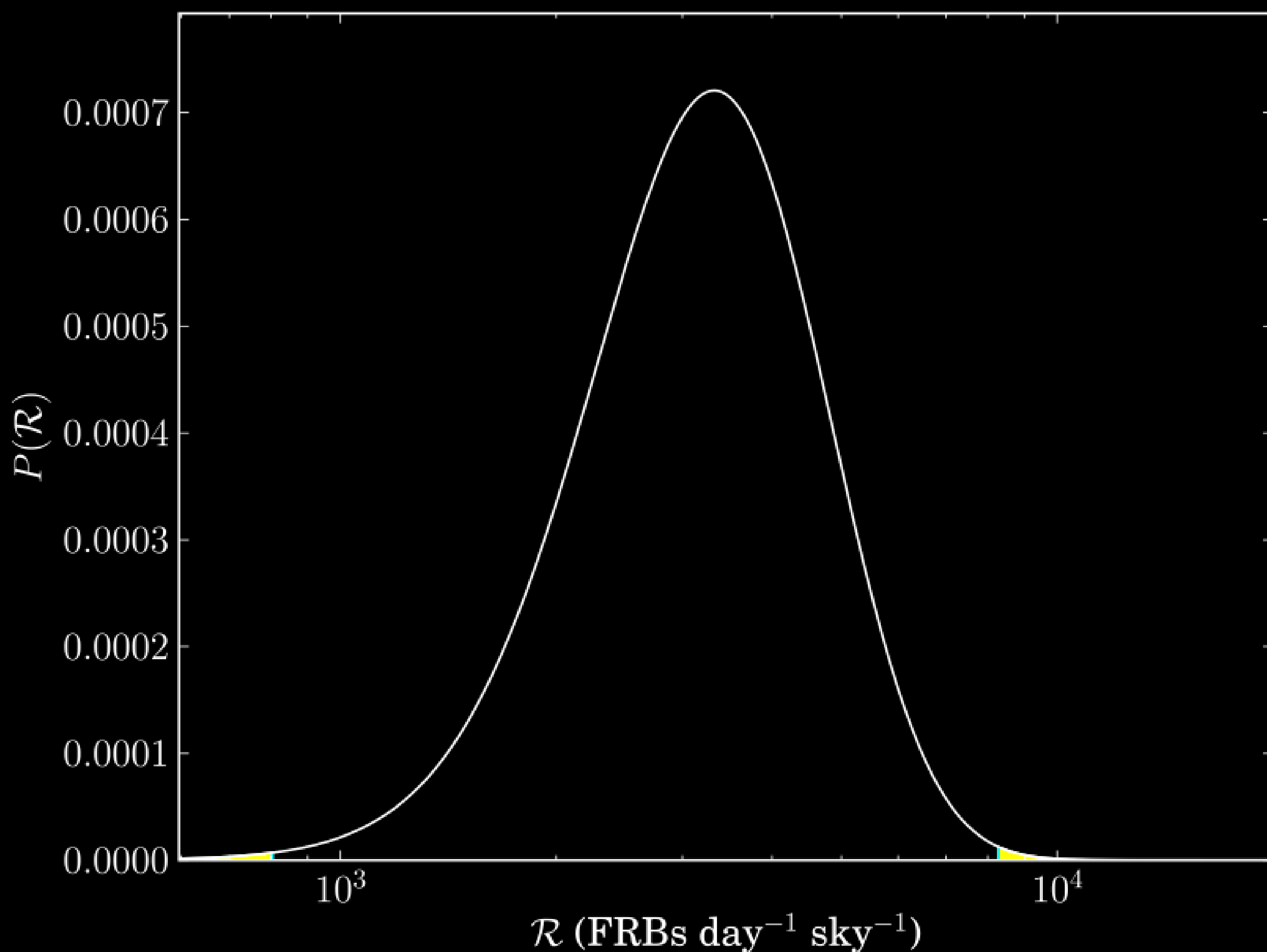






http://www.astronomy.swin.edu.au/pulsar/frbcat

All-sky event rate



Credit: Rane et al. (2015)


NATIONAL GEOGRAPHIC
Photograph by Miloslav Druckmüller
MAGELLANIC CLOUDS, DECEMBER 2
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http://soundcloud.com/duncan-lorimer/fast-radio-bursts
NATIONAL GEOGRAPHIC
Photograph by Miloslav Druckmüller
MAGELLANIC CLOUDS. DECEMBER
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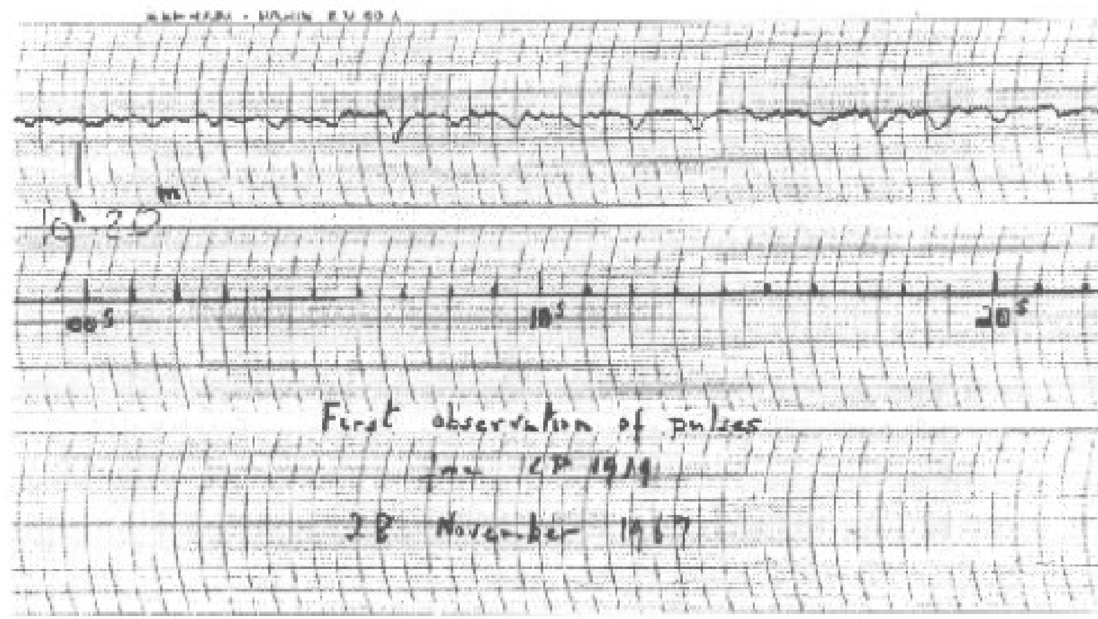
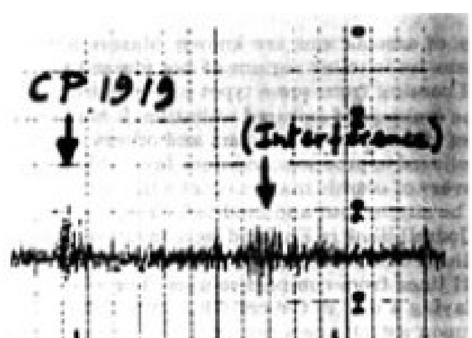
1967





Observation of a Rapidly Pulsating Radio Source

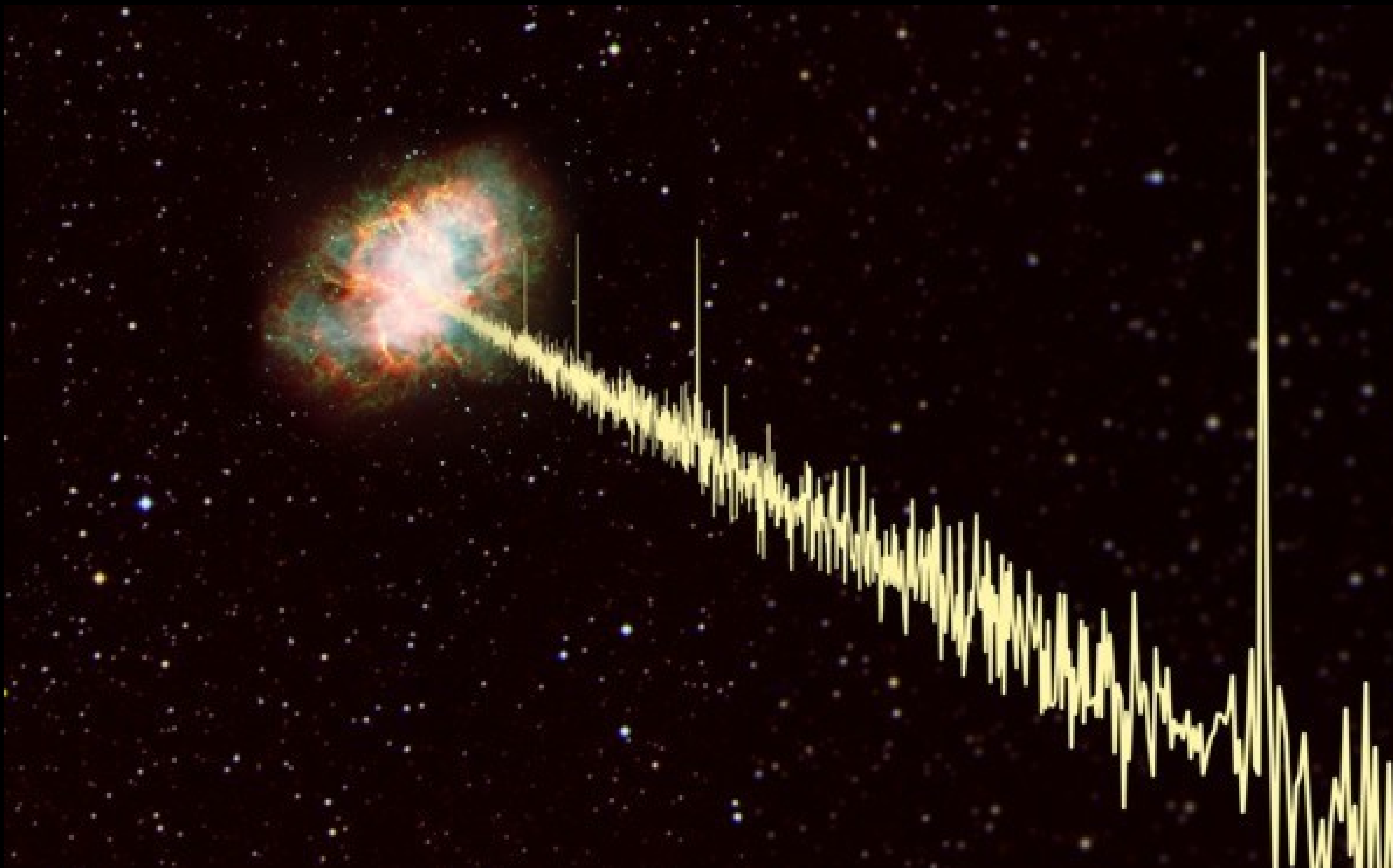
by

A. HEWISH
S. J. BELL
J. D. H. PILKINGTON
P. F. SCOTT
R. A. COLLINS

Mullard Radio Astronomy Observatory,
Cavendish Laboratory,
University of Cambridge

Unusual signals from pulsating radio sources have been recorded at the Mullard Radio Astronomy Observatory. The radiation seems to come from local objects within the galaxy, and may be associated with oscillations of white dwarf or neutron stars.

50th Anniversary Meeting at Jodrell Bank next September...

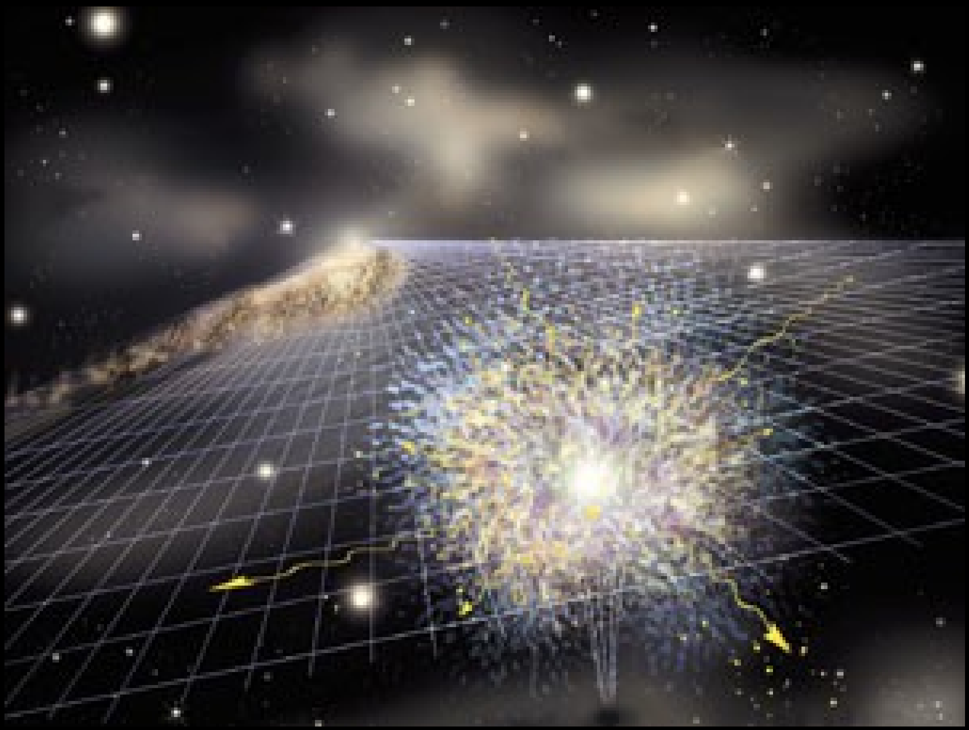


Credit: Joeri van Leeuwen

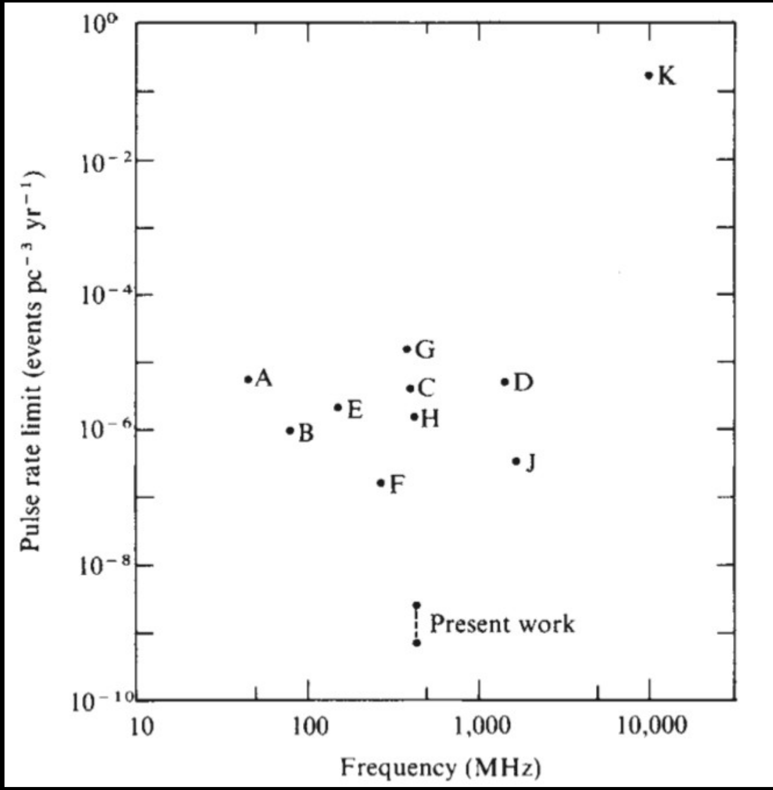
1979

Nature Vol. 277 11 January 1979

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



Credit: Aurore Simonet



Phinney & Taylor (1979)

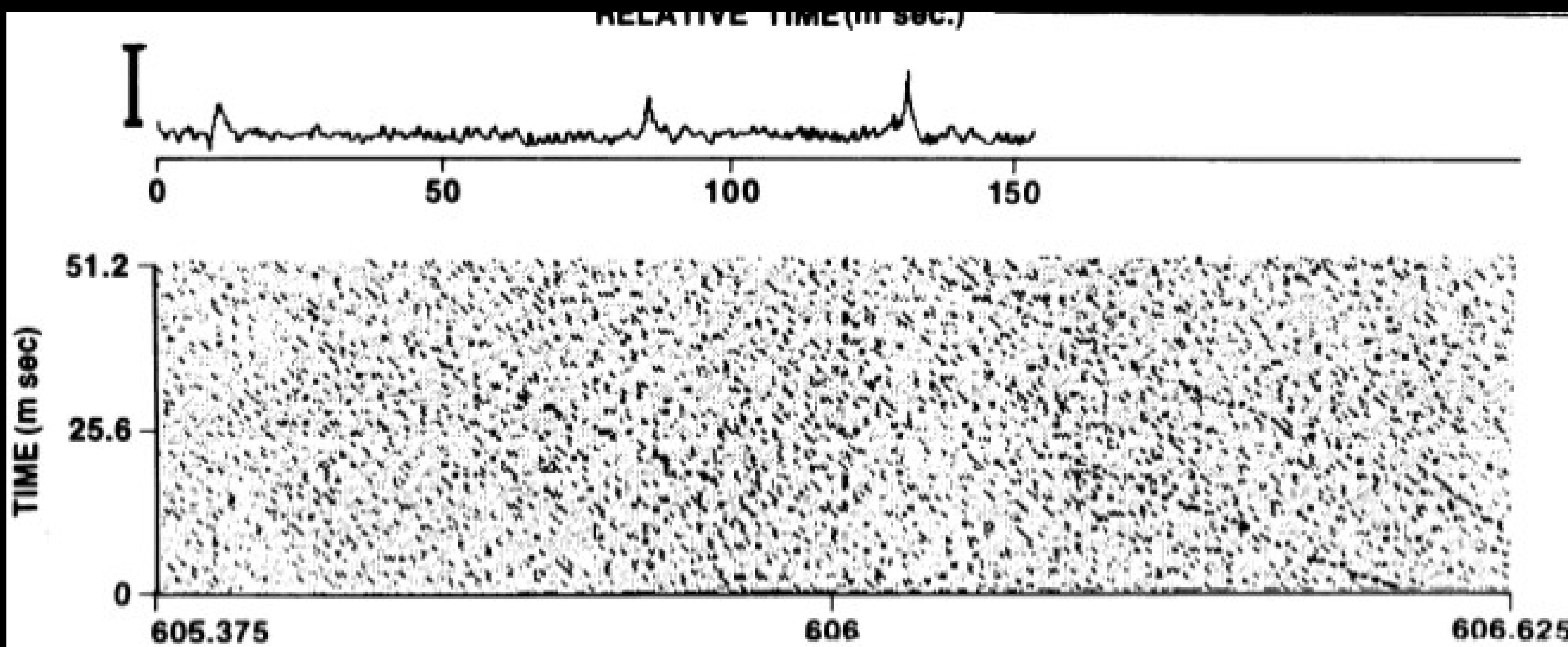
1979

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 $1–5 \times 10^3$ 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 $1\ s^{-1}$.



1979

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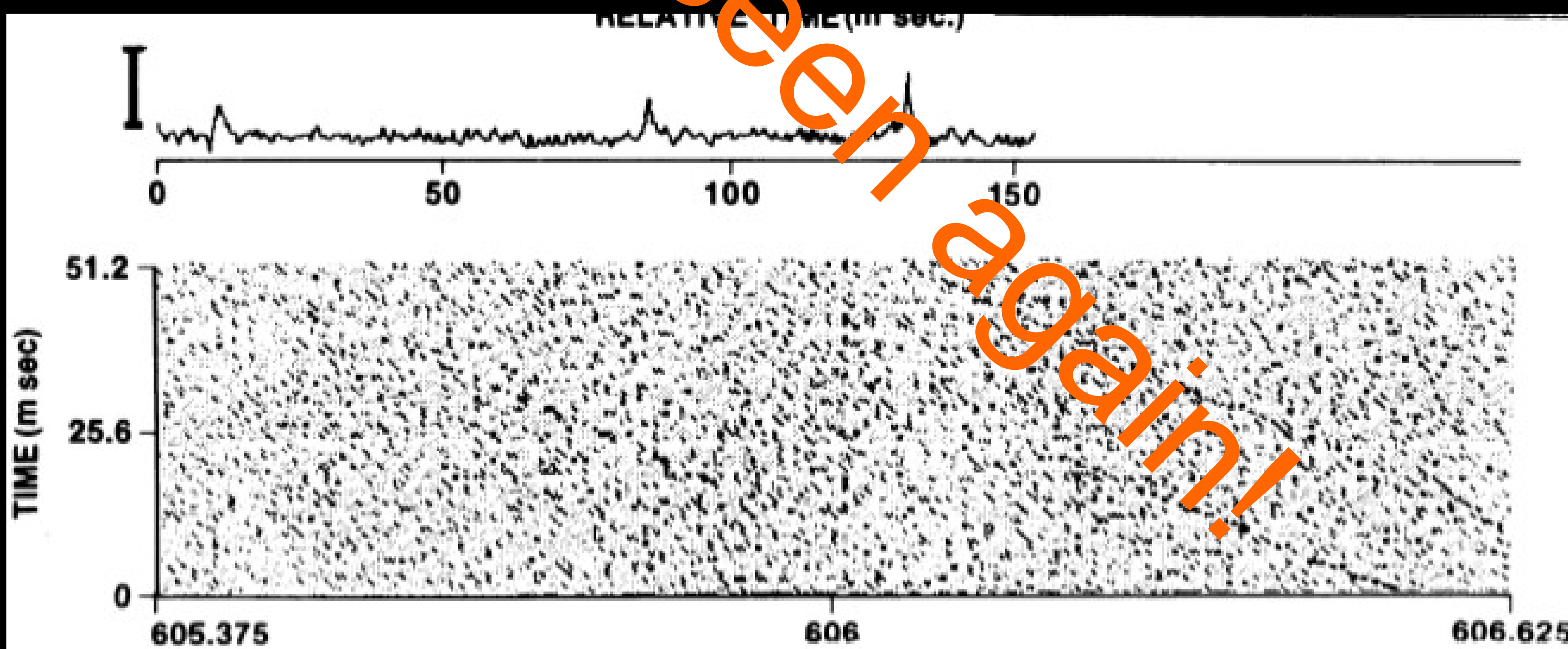
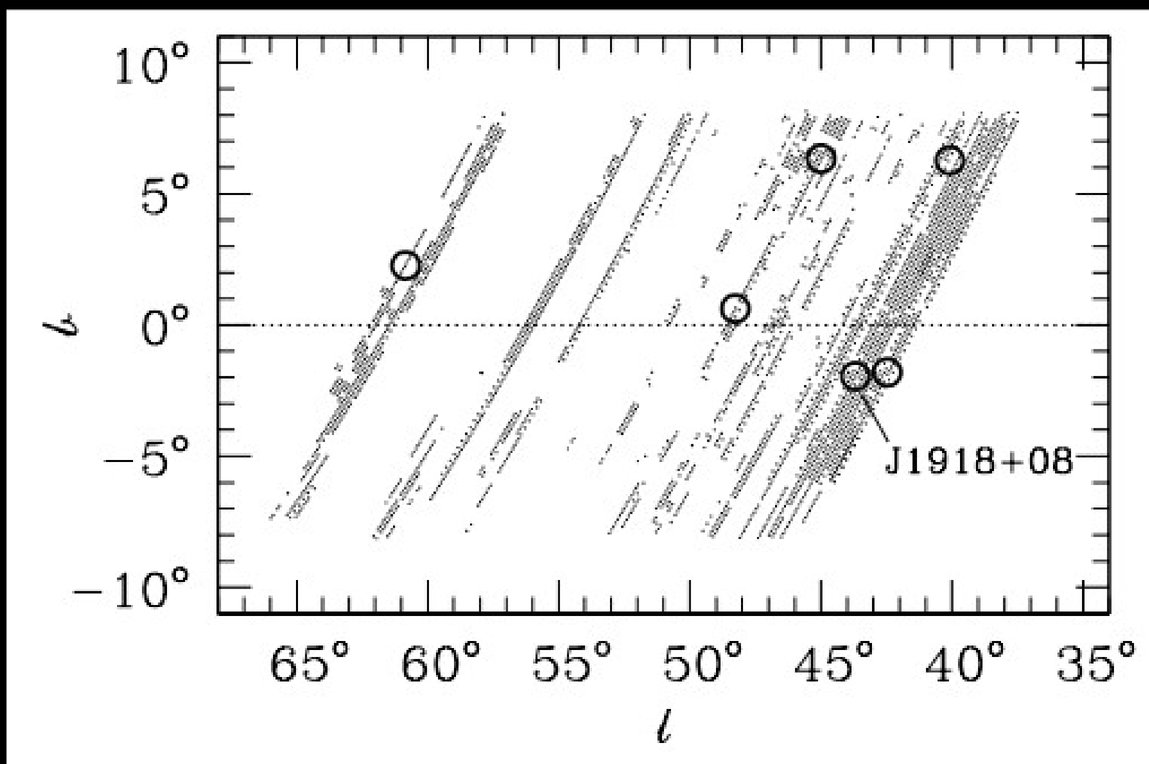
Never seen again!



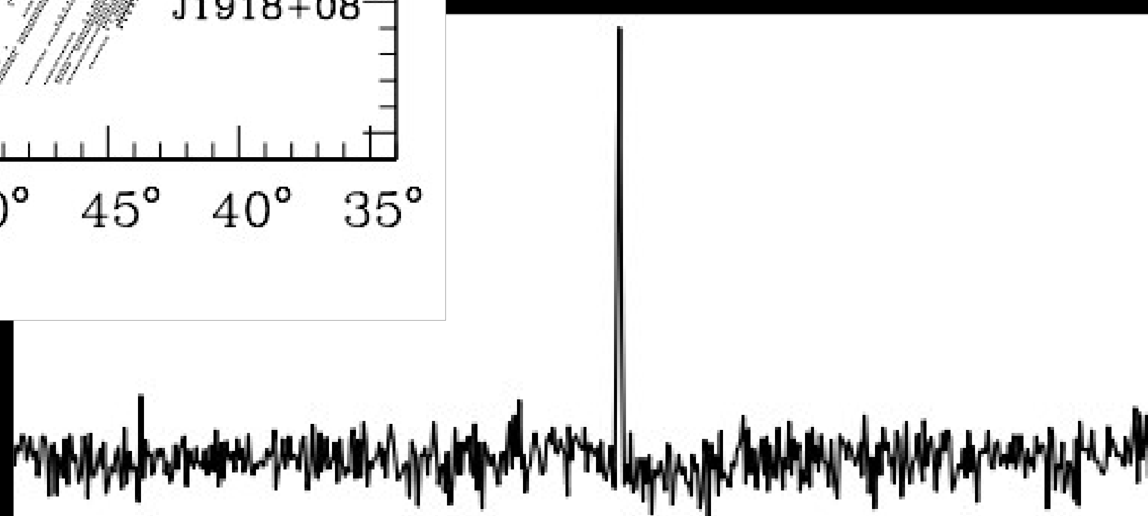
RADIO PULSES ALONG THE GALACTIC PLANE

DAVID J. NICE
Joseph Henry Laboratories and Physics Department, Princeton University, Princeton, NJ 08544

Received 1998 September 8 ; accepted 1998 October 19



1998



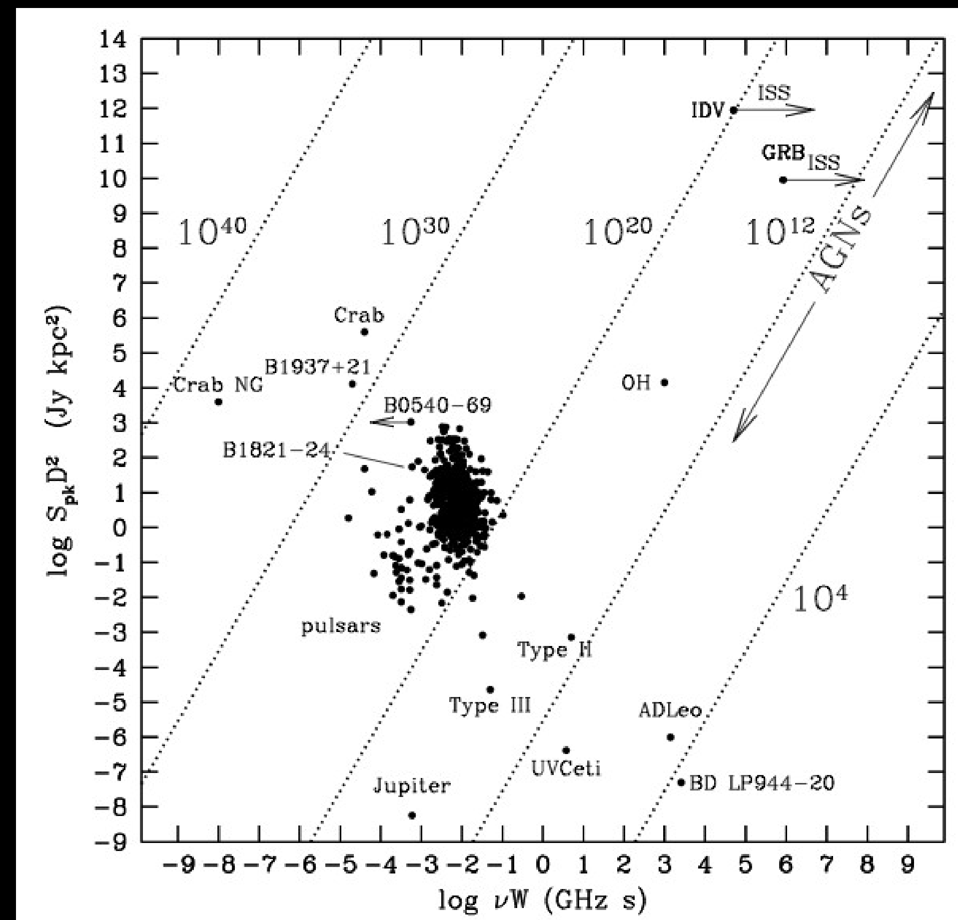
2003

SEARCHES FOR FAST RADIO TRANSIENTS

J. M. CORDES[1] AND M. A. MCLAUGHLIN[2]

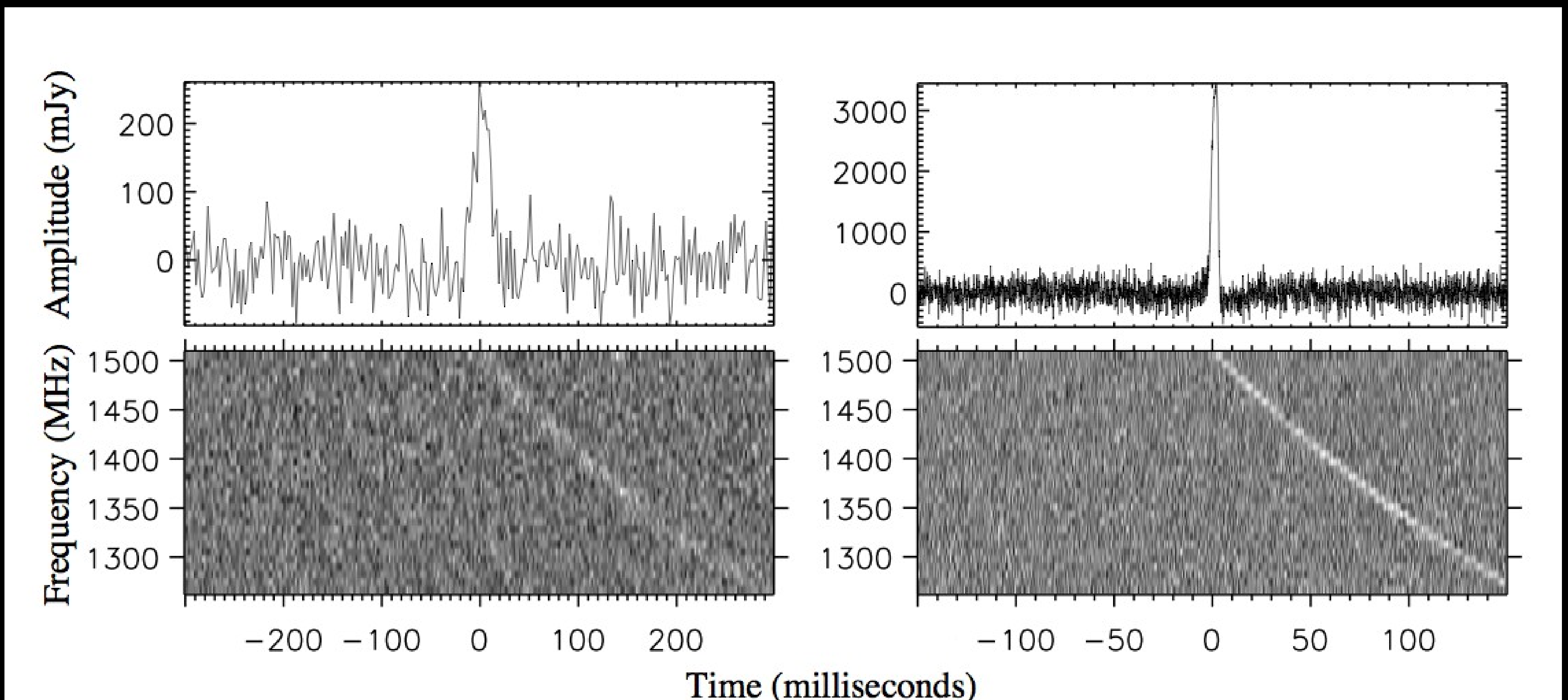
Received 2003 April 21; accepted 2003 July 2

"...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."



Rotating Radio Transients (RRATs; 2004)

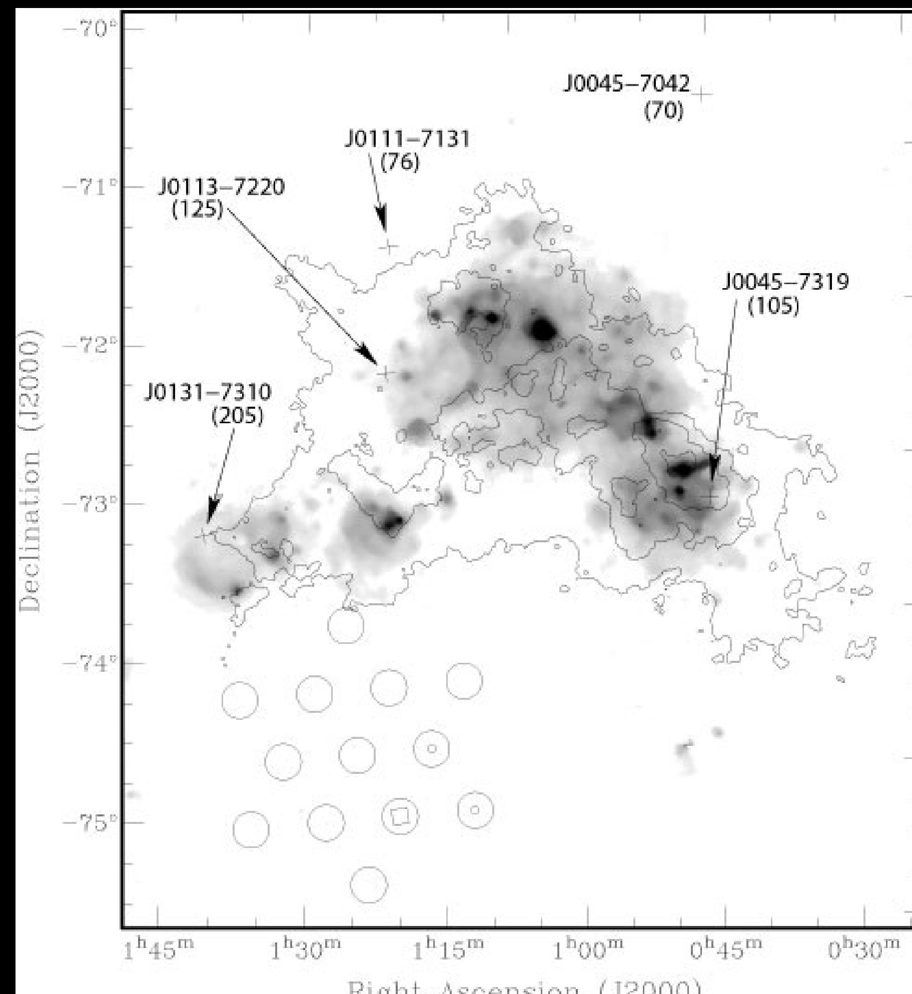

Transient radio bursts from rotating neutron stars
M. A. McLaughlin[1], A. G. Lyne[1], D. R. Lorimer[1], M. Kramer[1], A. J. Faulkner[1], R. N. Manchester[2], J. M. Cordes[3], F. Camilo[4], A. Possenti[5], I. H. Stairs[6], G. Hobbs[2], N. D'Amico[5,7], M. Burgay[5] & J. T. O'Brien[1]



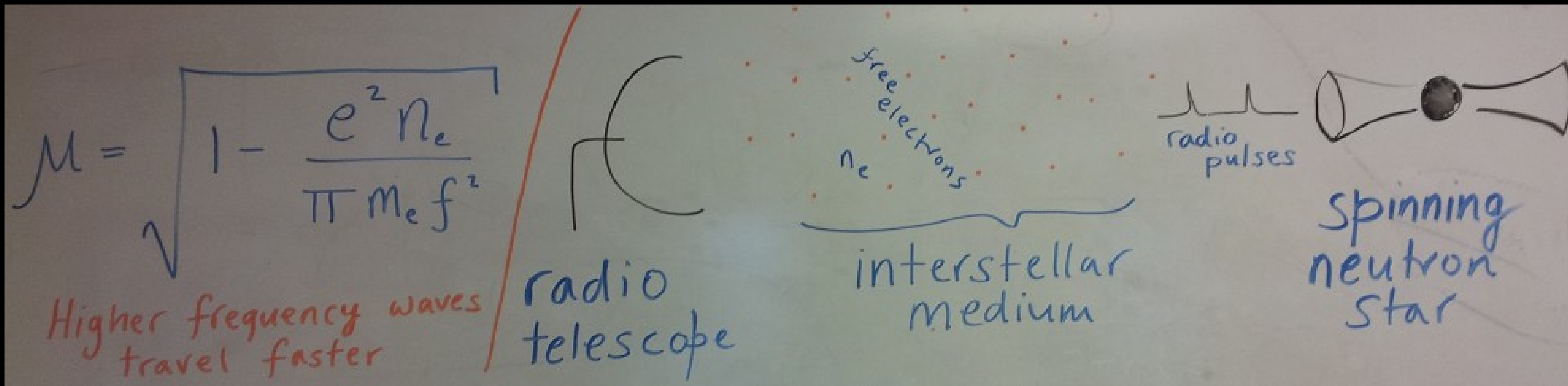
DISCOVERY OF 14 RADIO PULSARS IN A SURVEY OF THE MAGELLANIC CLOUDS

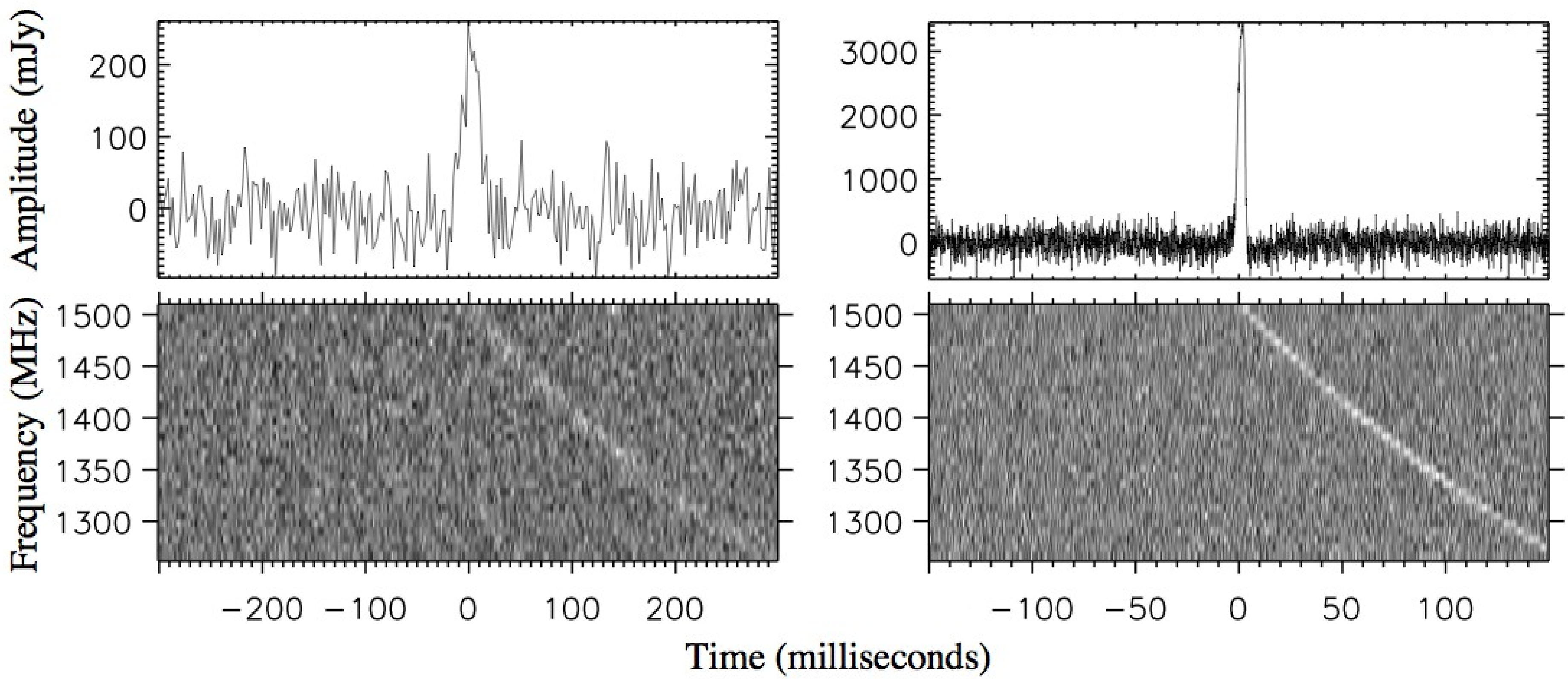
R. N. MANCHESTER,[1] G. FAN,[2,3] A. G. LYNE,[4] V. M. KASPI,[3] AND F. CRAWFORD[5]

Received 2006 February 23; accepted 2006 April 19



Credit: Froney Crawford

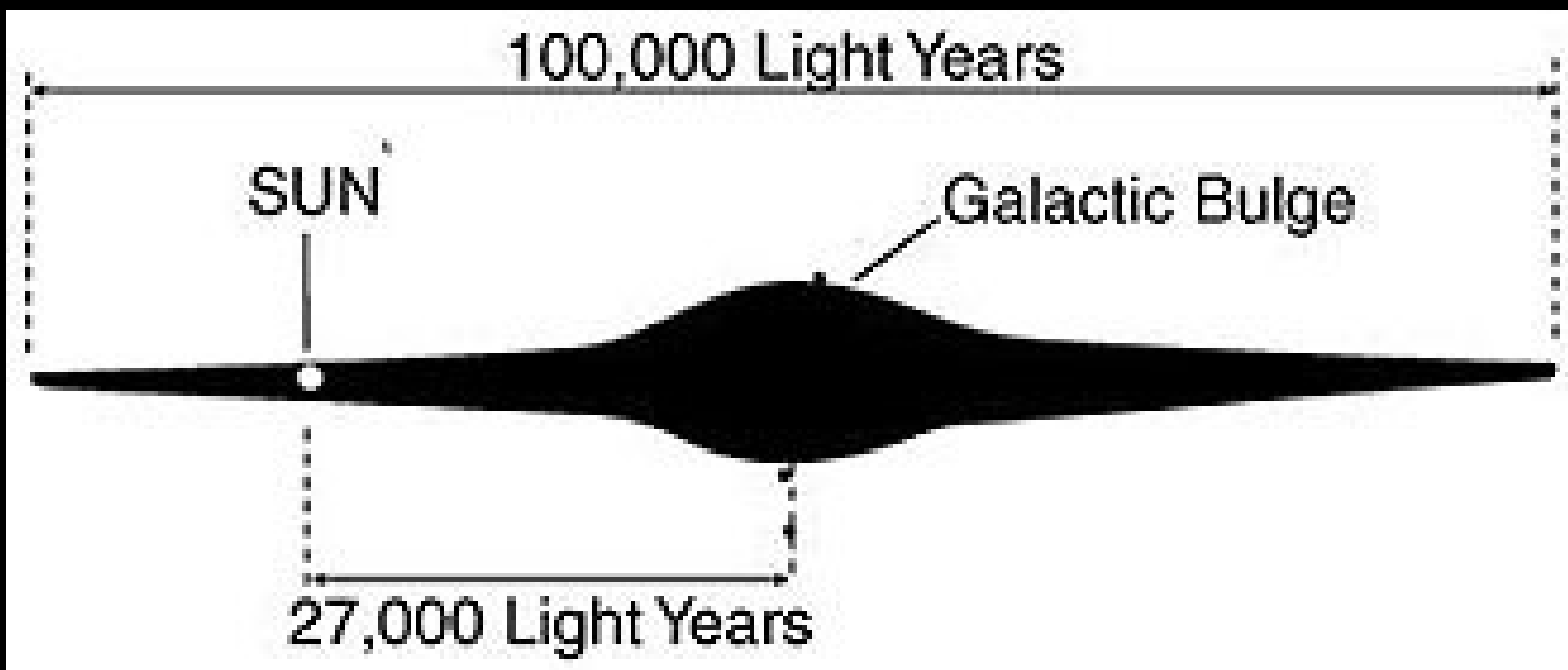




Credit: Maura McLaughlin

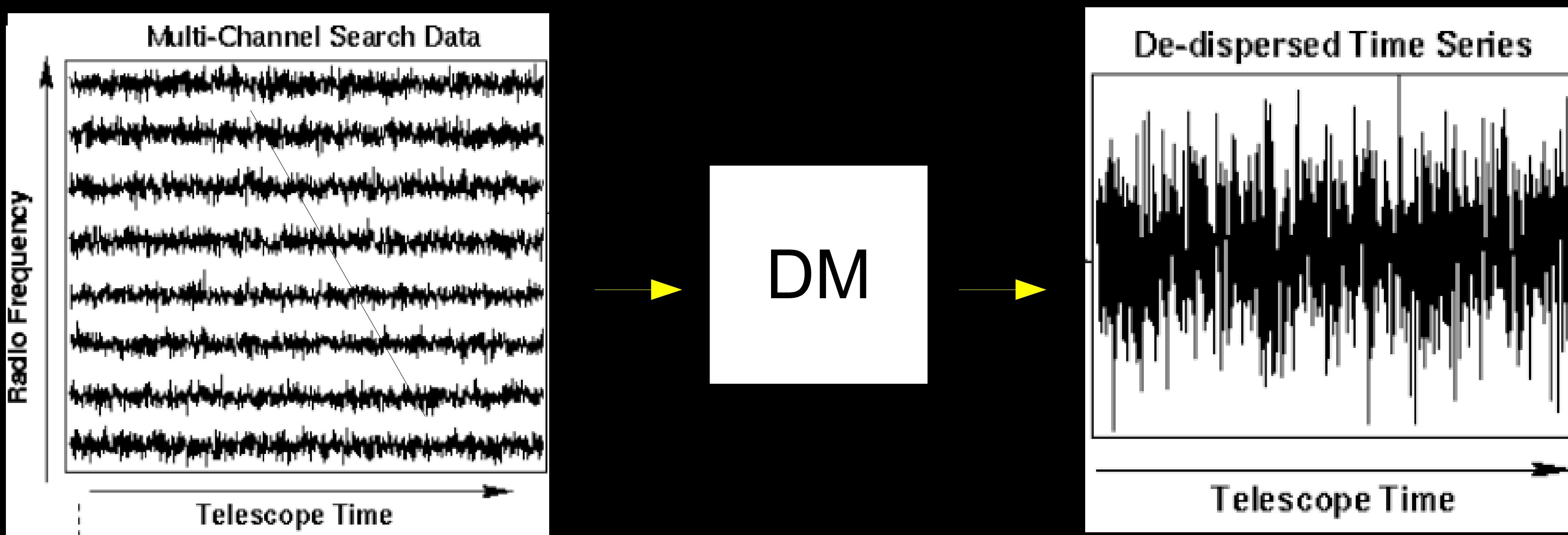
End up with a search over "DM"

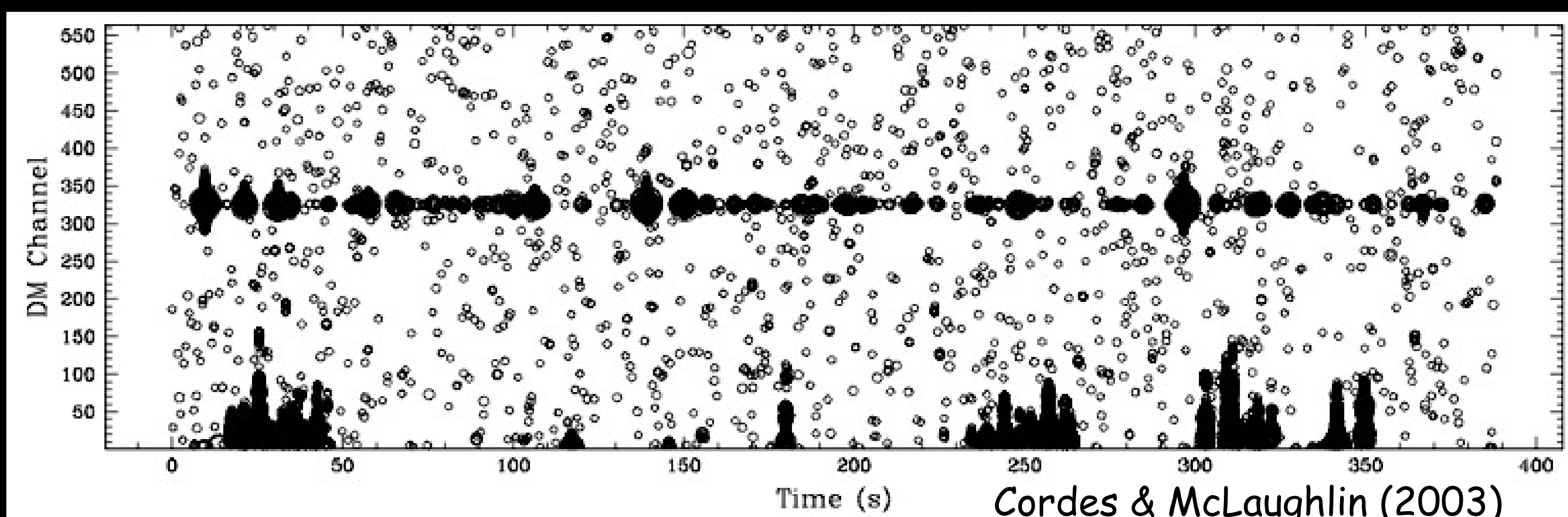
$$\mathrm{DM} = \int_0^D n_e dl \simeq \overline{n_e} D$$



Credit: fas.org

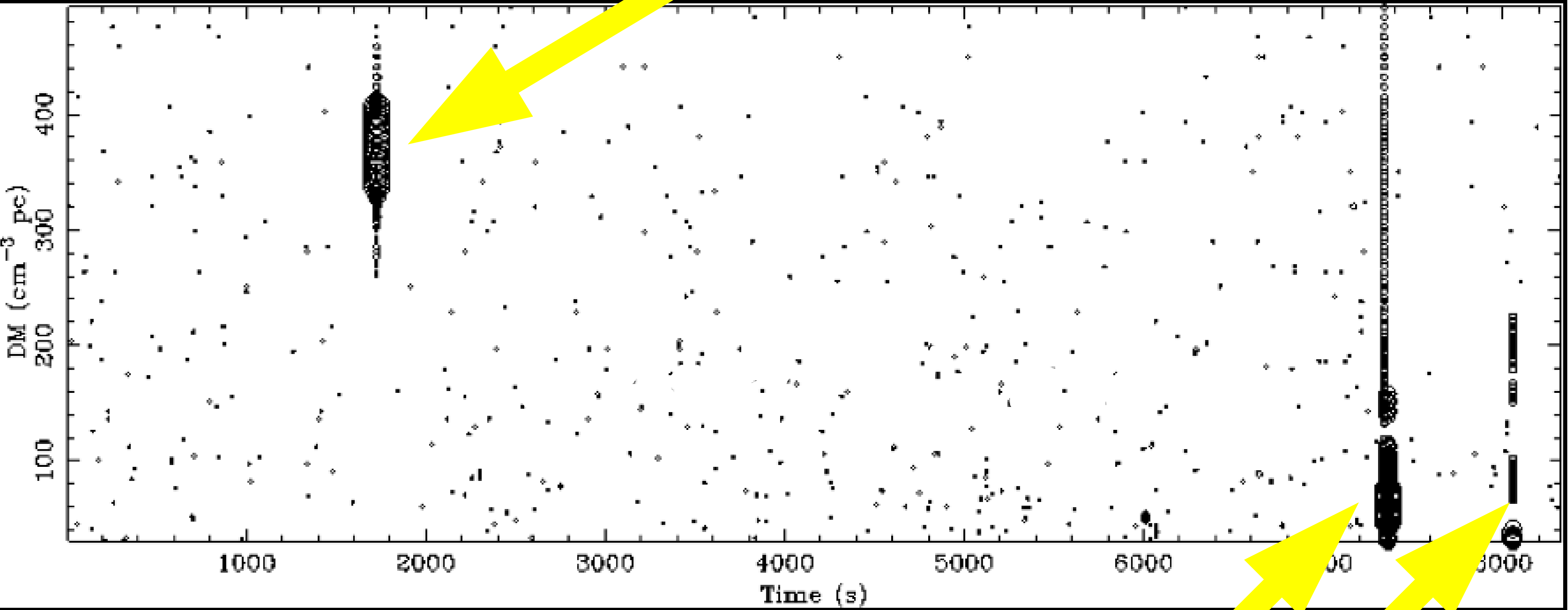
Single-pulse search pipeline





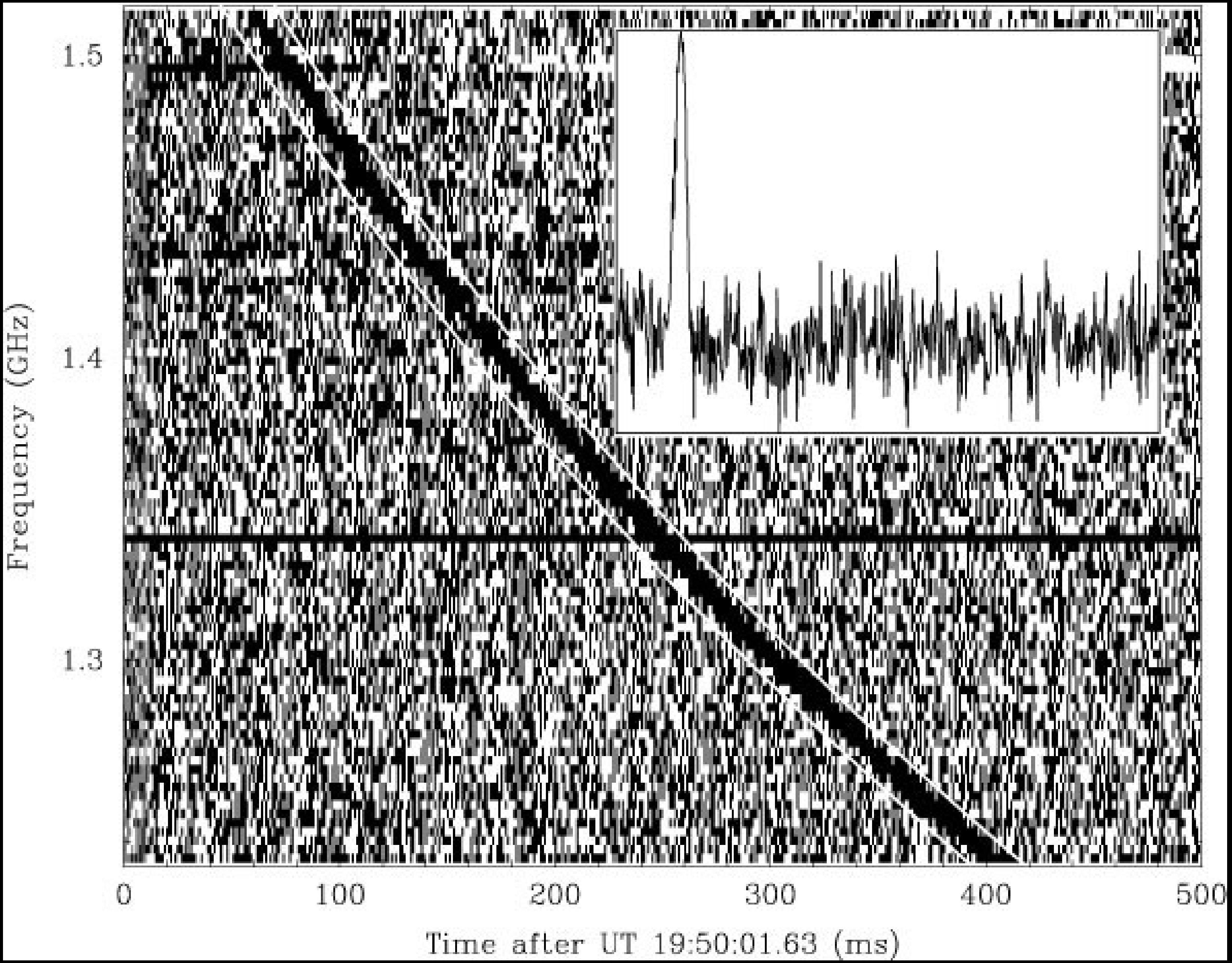
Cordes & McLaughlin (2003)

An unexpected signal!

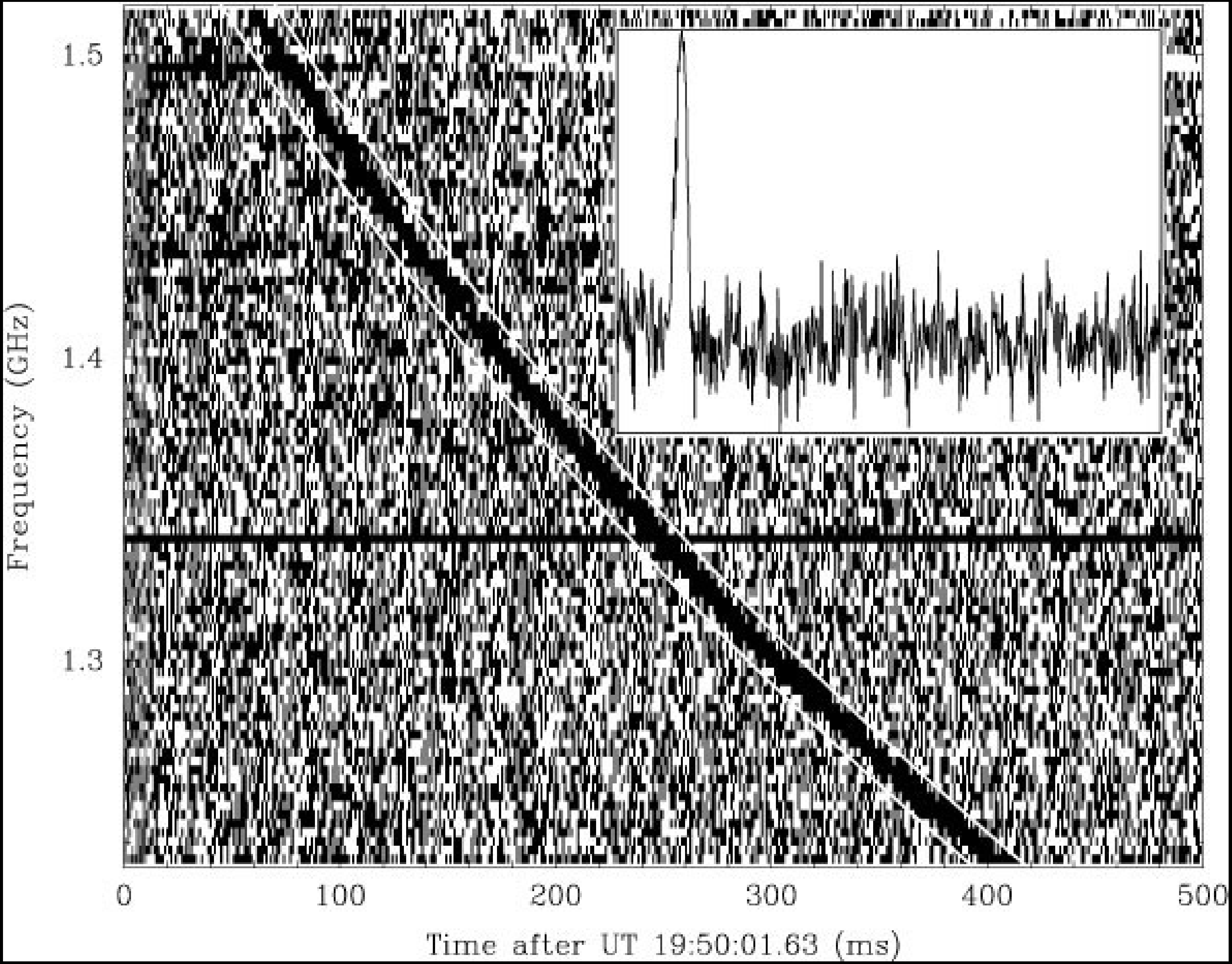


Interference

The “Lorimer” burst...



The “Lorimer” burst…



Listen to an audio version….

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.

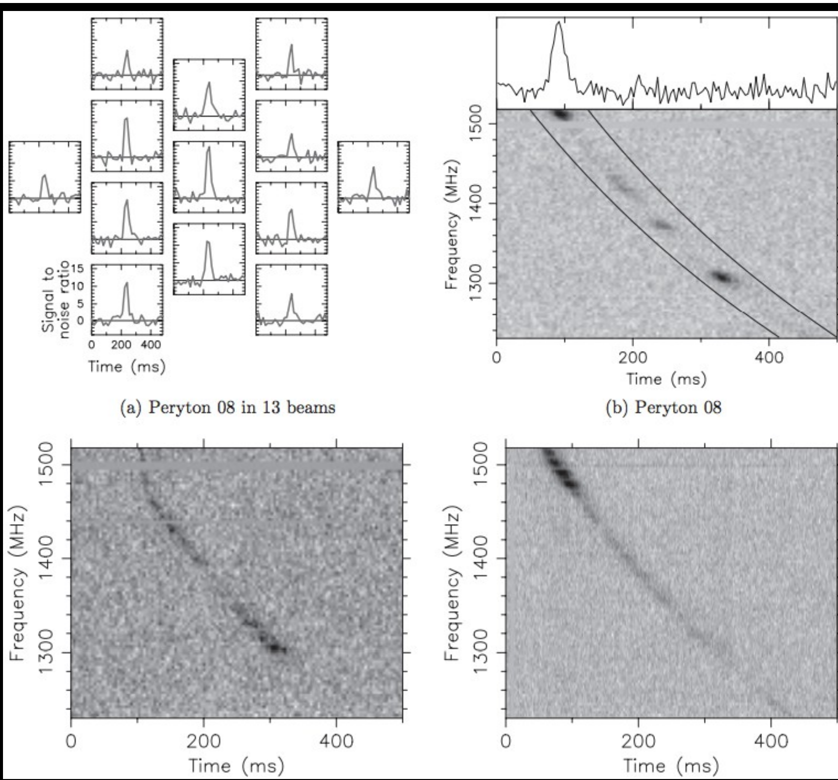
Questions:

* Why so bright?
* Why no weaker events?
* Detectable in other surveys?

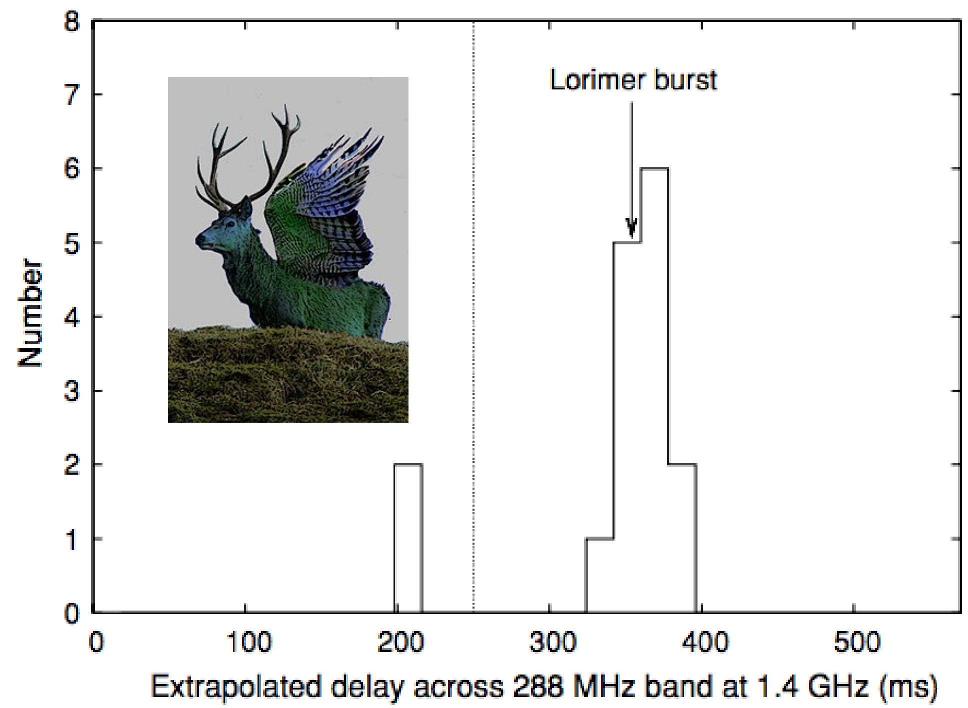
The Astrophysical Journal, 727:18 (5pp), 2011 January 20 doi:10.1088/0004-637X/727/1/18

RADIO BURSTS WITH EXTRAGALACTIC SPECTRAL CHARACTERISTICS SHOW TERRESTRIAL ORIGINS

S. Burke-Spolaor[1,5], Matthew Bailes[1], Ronald Ekers[2], Jean-Pierre Macquart[3], and Fronefield Crawford III[4]
[1] Centre for Astrophysics and Supercomputing, Swinburne University of Technology, Mail H39, P.O. Box 218, Hawthorn VIC 3122, Australia;
sburke@astro.swin.edu.au
[2] CSIRO Australia Telescope National Facility, P.O. Box 76, Epping NSW 1710, Australia
[3] ICRAR/Curtin Institute of Radio Astronomy, GPO Box U1987, Perth WA 6845, Australia
[4] Department of Physics and Astronomy, Franklin and Marshall College, Lancaster, PA 17604, USA
Received 2010 July 19; accepted 2010 October 29; published 2010 December 28



(a) Peryton 08 in 13 beams
(b) Peryton 08



Even my own wife begins to doubt…

A search for dispersed radio bursts in archival Parkes Multibeam Pulsar Survey data

Manjari Bagchi,[*] Angela Cortes Nieves and Maura McLaughlin[†]
Department of Physics, White Hall, West Virginia University, Morgantown, WV 26506, USA

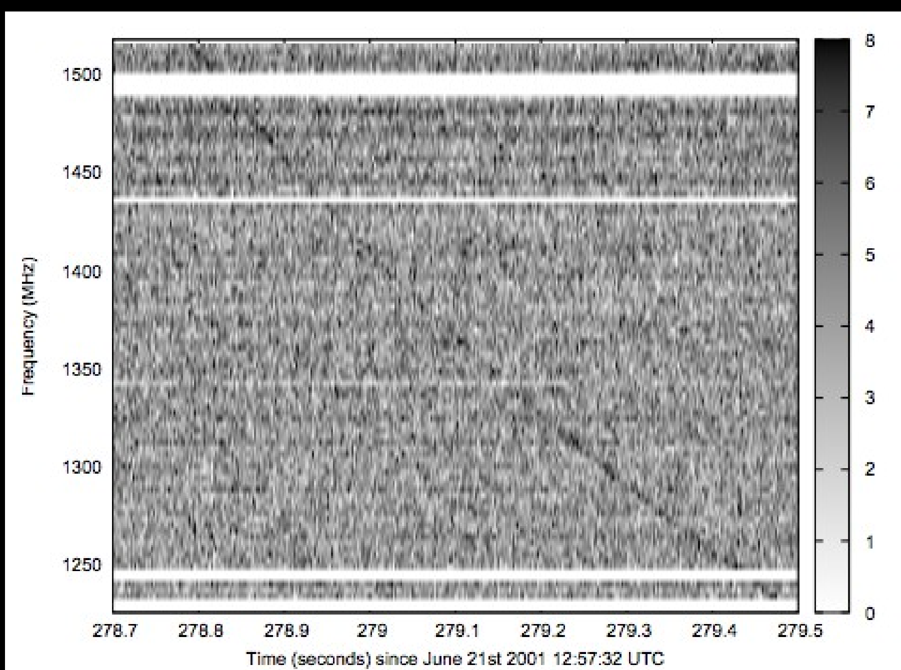
"Moreover, the lack of highly dispersed celestial signals is the evidence that the Lorimer burst is unlikely to belong to a cosmological source population."

…but then, in 2012, along came this

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."



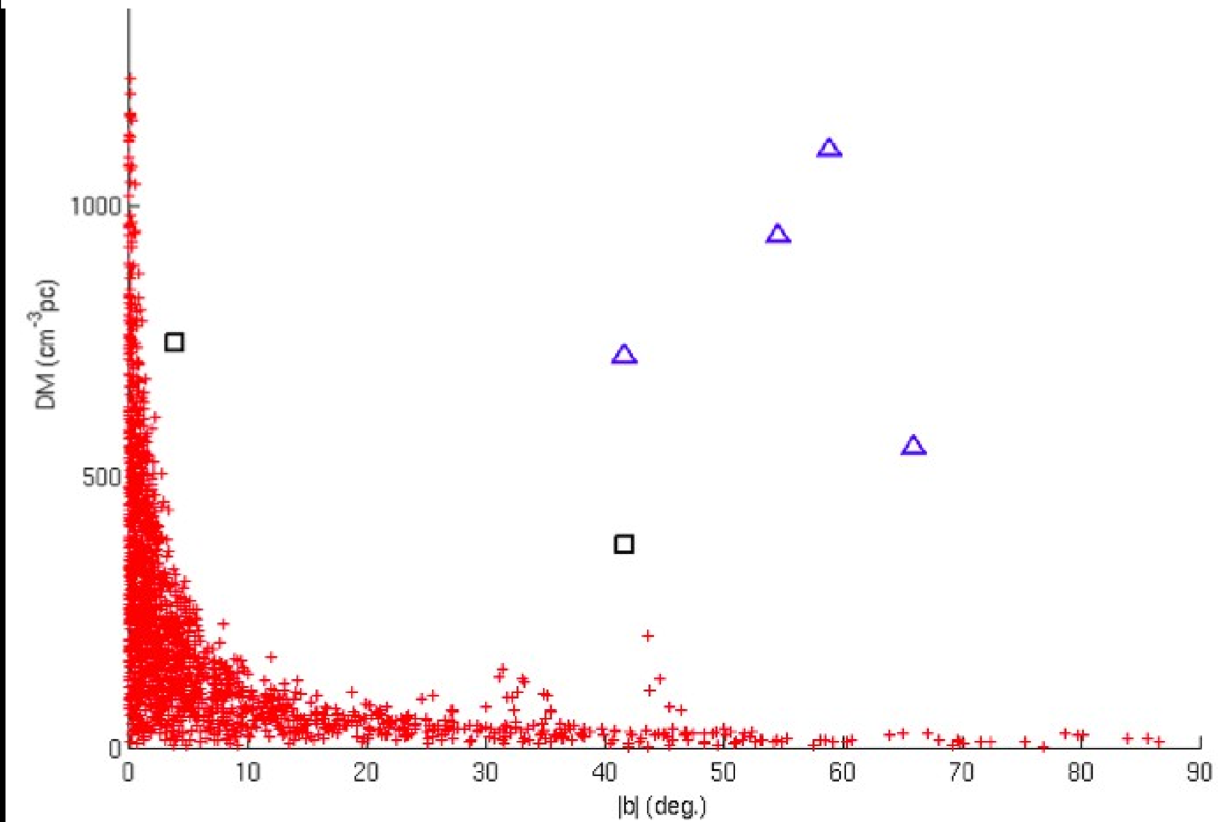
Credit: Keane et al. 2011/2012

DM = 746 pc/cc
W=8 ms

… more good news followed in 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]

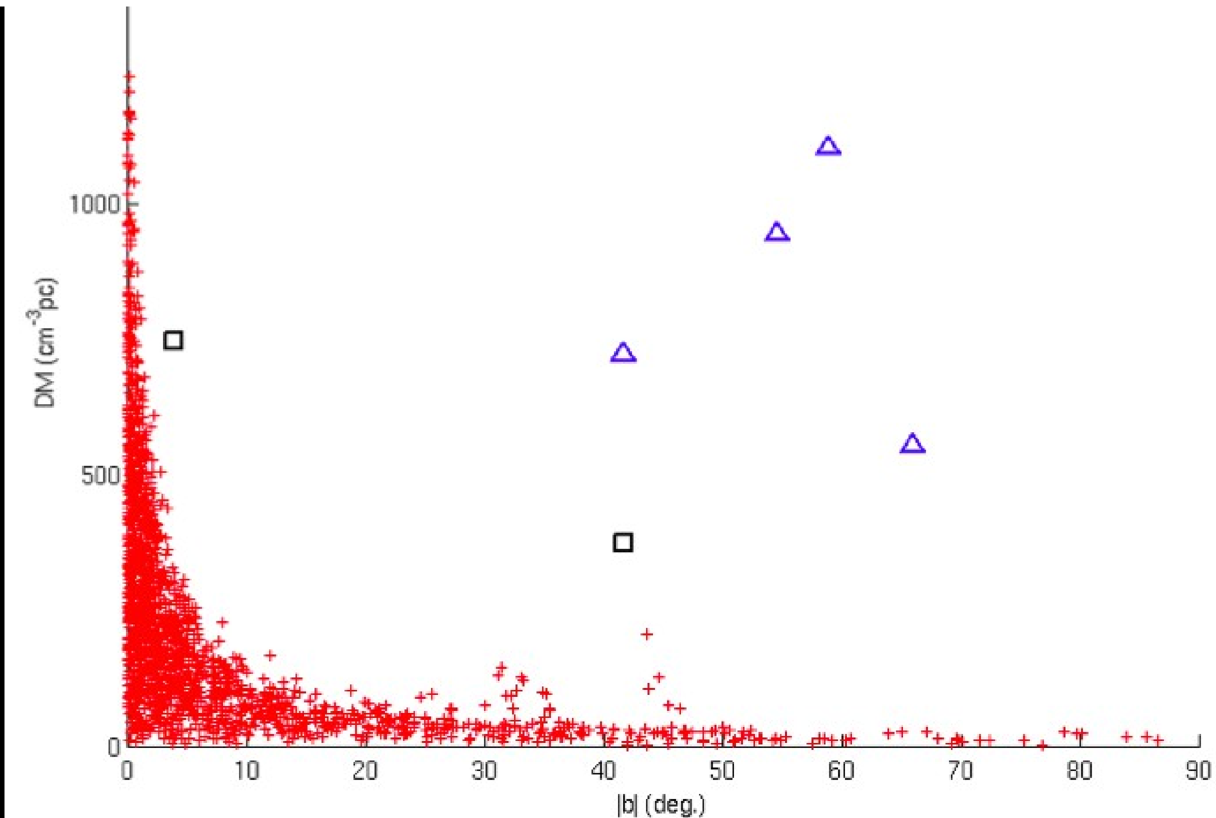


What should we call this new population of astrophysical sources???

… more good news followed in 2013

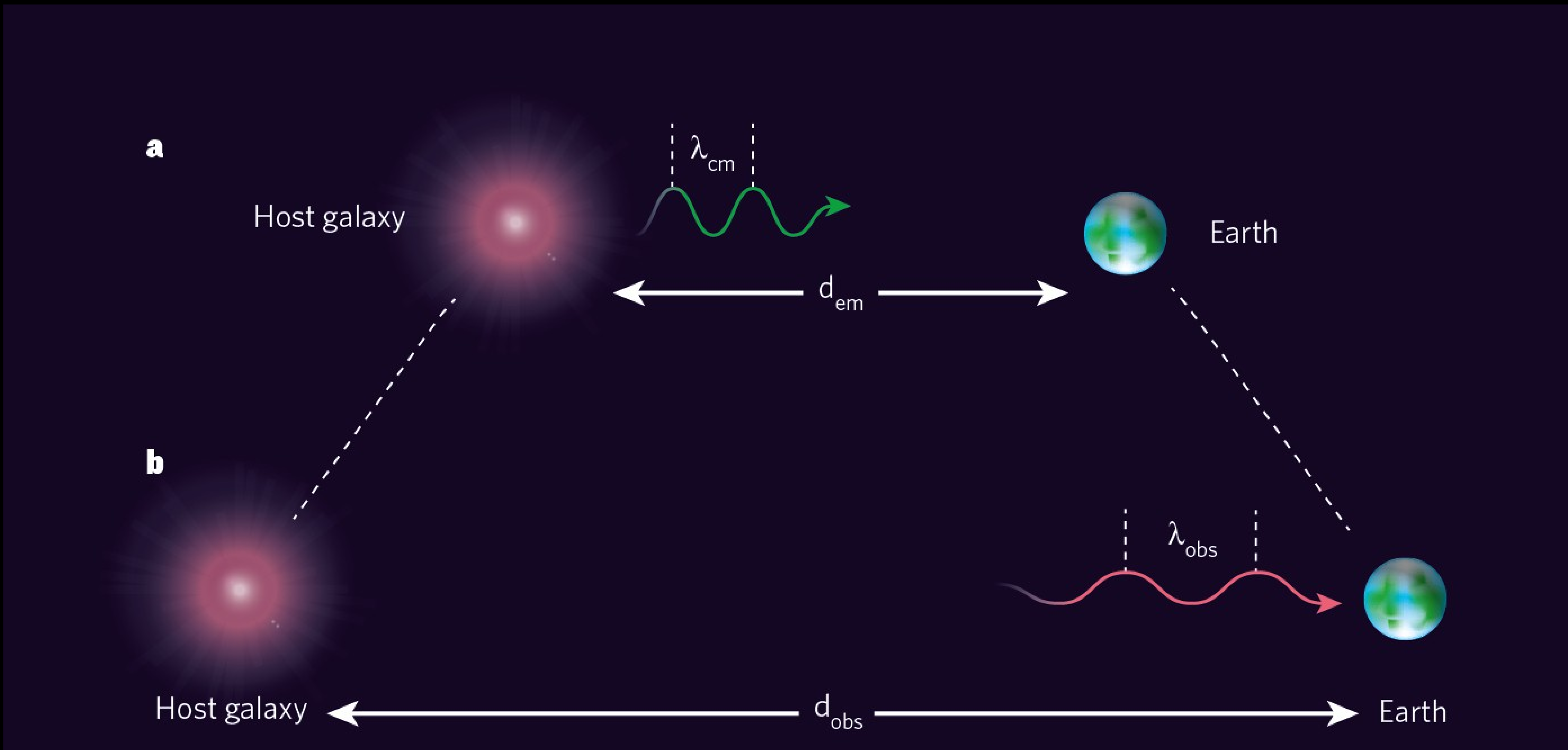
A Population of Fast Radio Bursts at Cosmological Distances

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]



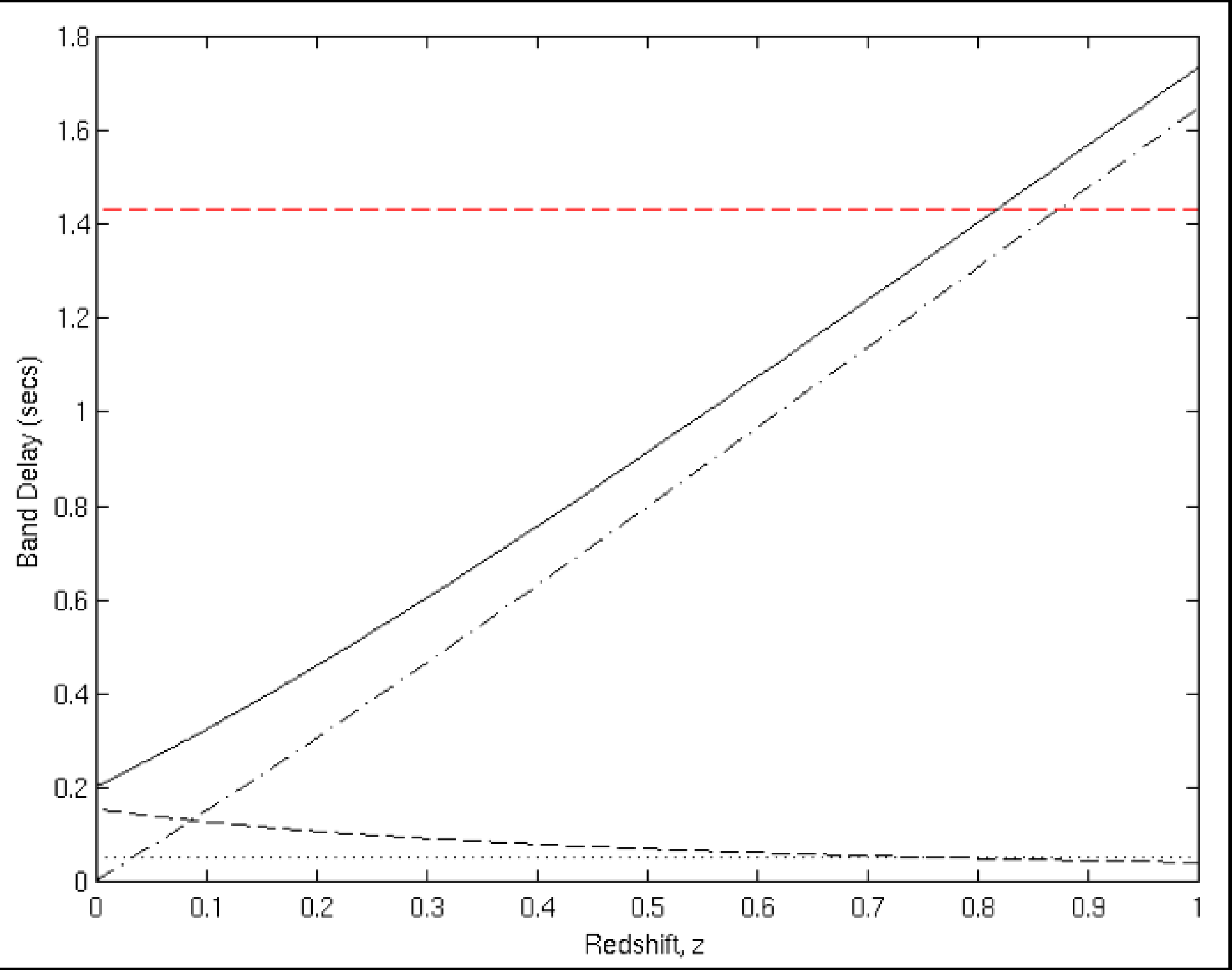
- Lorimer bursts?
- Sparkers?
- FARTS?
- FRBs

Cosmological redshift



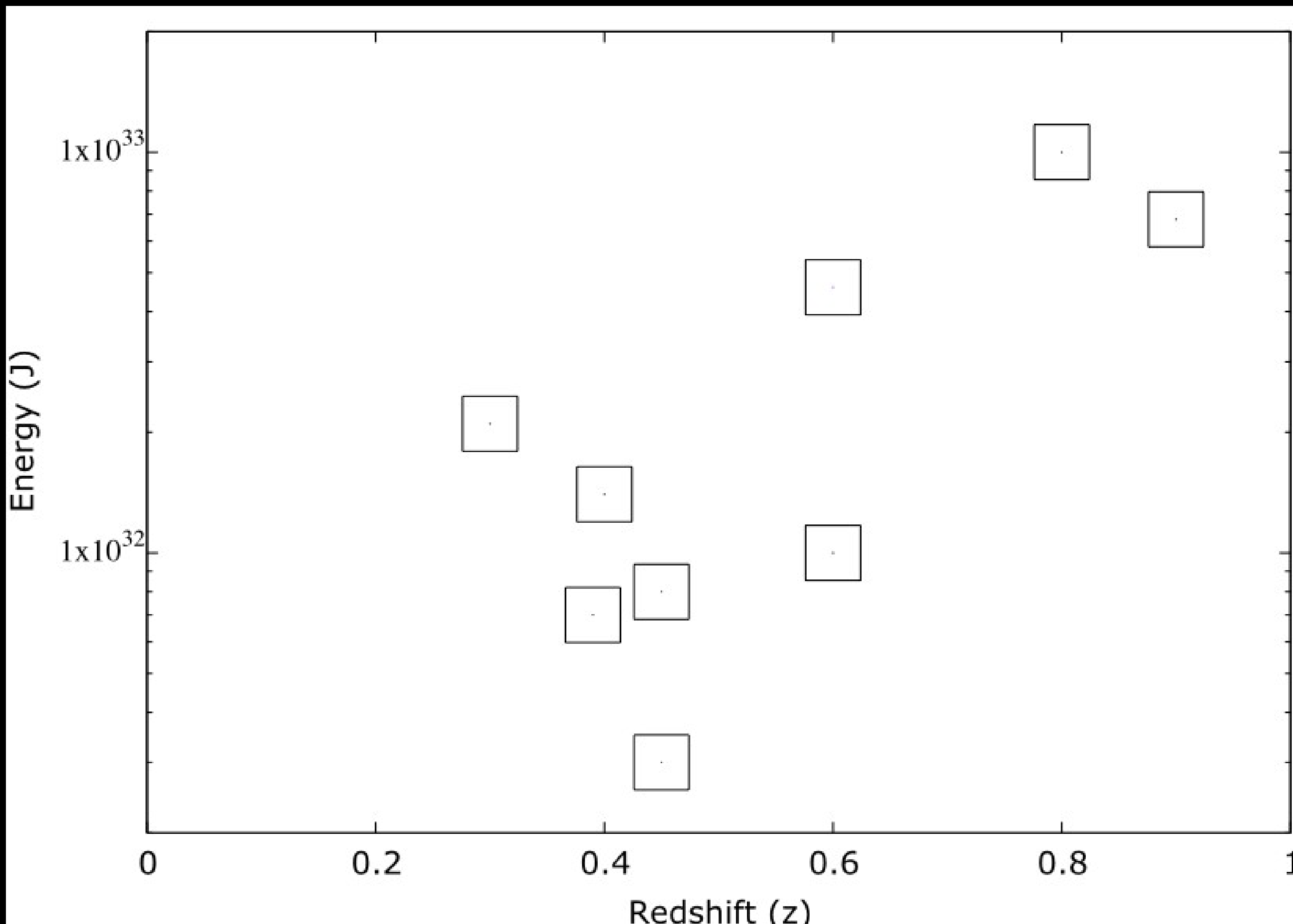
$$z = \frac{\lambda_{\text{obs}} - \lambda_{\text{emit}}}{\lambda_{\text{emit}}} \rightarrow (1+z) = \lambda_{\text{obs}}/\lambda_{\text{emit}}$$

DM delay in FRB 110220



Credit: Thornton et al. (2013)

Energy and redshift estimates



Inferred volumetric rates

"The most remarkable thing about FRBs is their event rate." – Shri Kulkarni

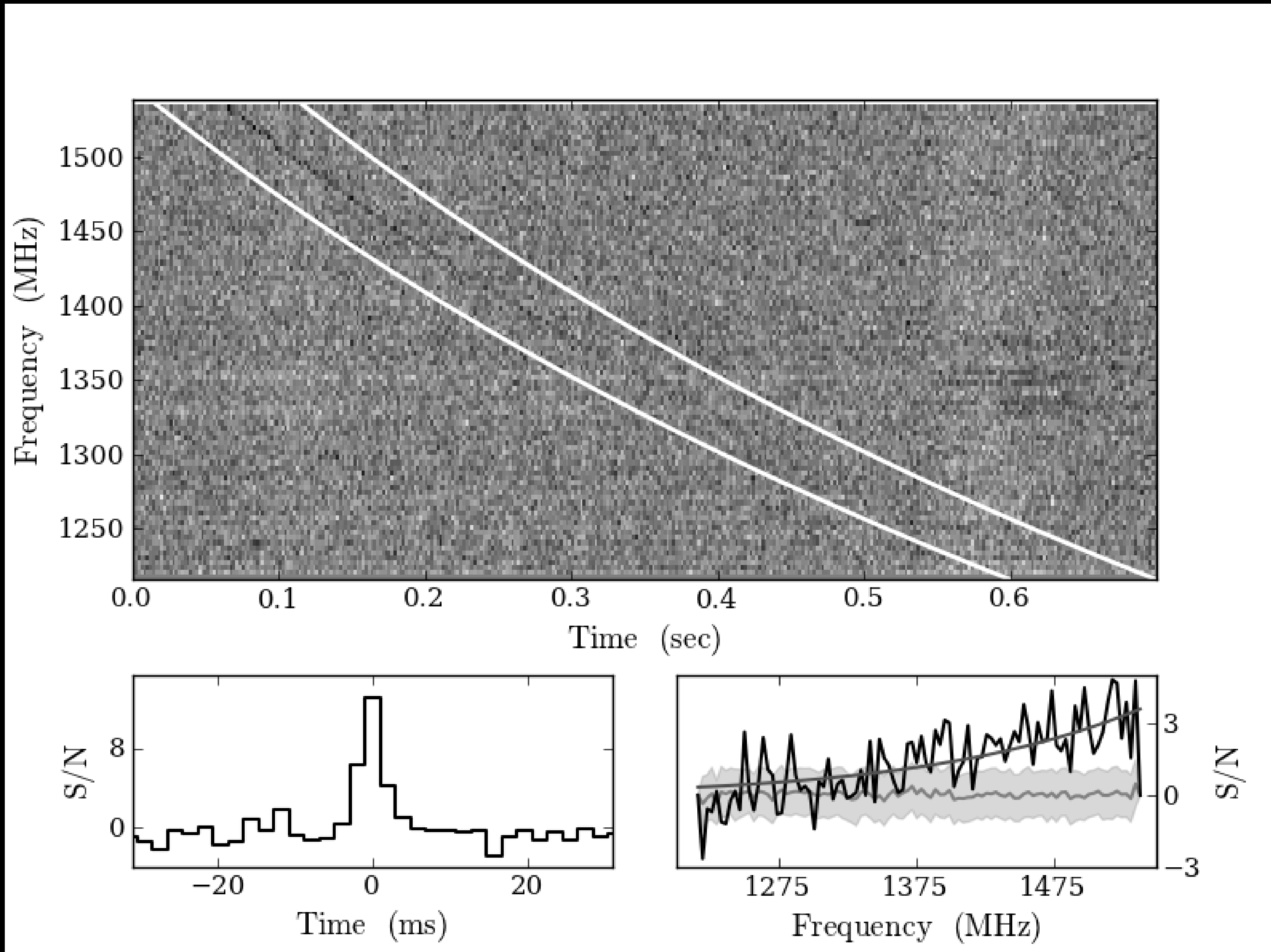
Kulkarni et al. (2014)

TABLE 2
VOLUMETRIC RATES OF SELECTED COSMIC EXPLOSIONS

Class	Type	Φ $\mathrm{Gpc}^{-3}\,\mathrm{yr}^{-1}$	Ref
LSB (low)	BC	100–1800	[1,2]
LSB (high)	Obs	1	[1]
	BC	100–550	[1]
SHB	Obs	> 10	[3a]
	BC	500-2000	[3b]
In-spiral	Th	3×10^3	[4]
SGR	Obs	$< 2.5 \times 10^4$	[5]
Type Ia	Obs	10^5	[6]
Core Collapse	Obs	2×10^5	[7]
FRB	Obs	$\approx 2 \times 10^4$	[8,9]

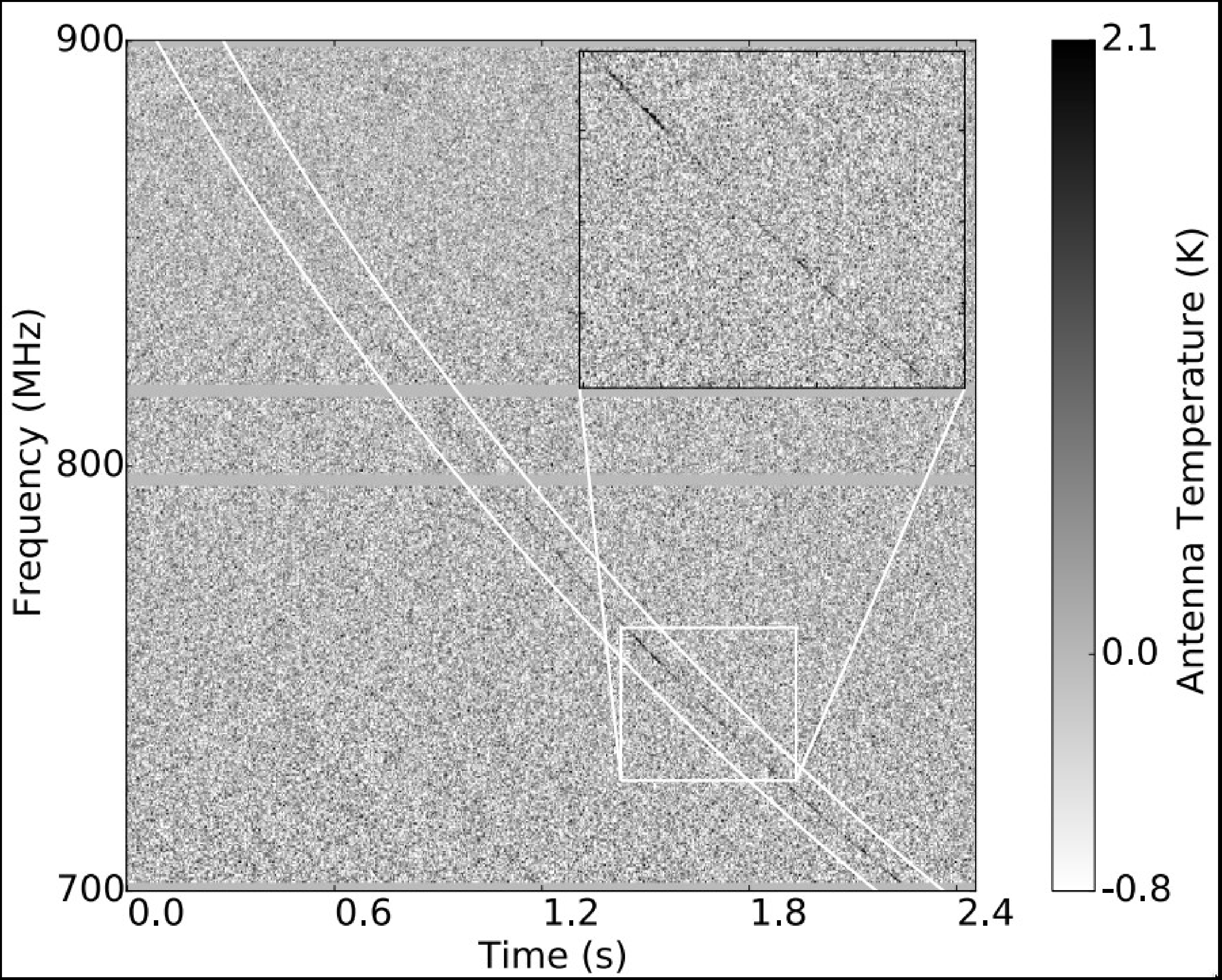
Notes: "Obs" is the annual rate inferred from observations. "BC" is the observed rate corrected for beaming. "Th" is the rate deduced from stellar models. LSB stands for GRBs of the long duration and soft spectrum variety. A gamma-ray luminosity of $10^{49}\,\mathrm{erg\,s^{-1}}$ divides the "low" and "high" subclasses (see Guetta & Della Valle 2007). SHB stands for GRBs of the short duration and hard spectrum class. SGR stands for Soft Gamma-ray Repeaters. Here we only include those giant flares with isotropic energy release $> 4 \times 10^{46}$ erg.
Refs: [1] Guetta & Della Valle 2007; [2] Soderberg *et al.* 2006; [3a] Nakar, Gal-Yam & Fox 2006; [3b] Coward *et al.* 2012; [4] Kalogera *et al.* 2004; [5] Ofek 2007; [6] Scannapieco & Bildsten 2005; [7] Li *et al.* 2011 [8] Lorimer *et al.* 2007; [9] Thornton *et al.* 2013.

2014: an FRB at Arecibo



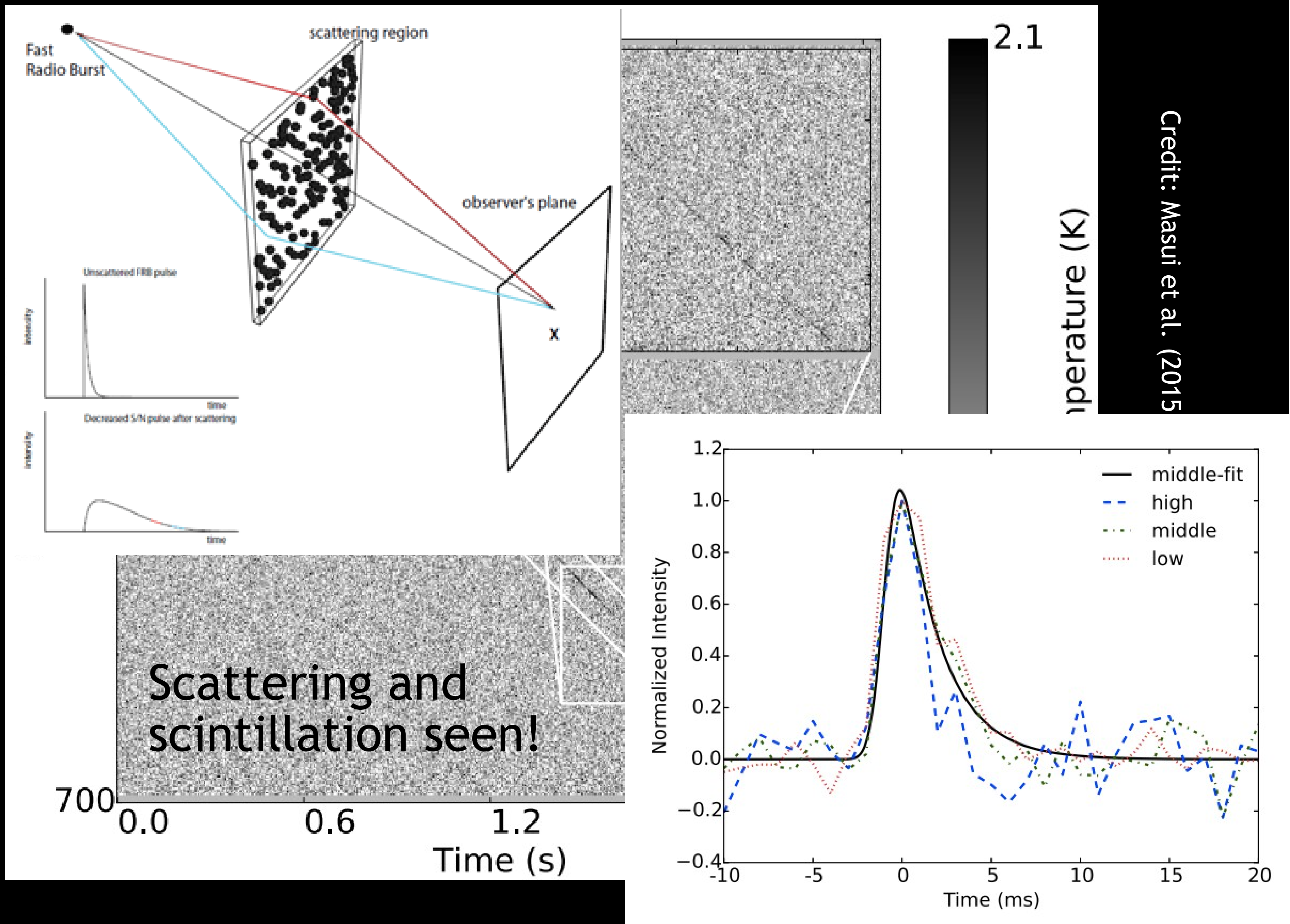
Credit: Spitler et al. (2014)

2015: an FRB at GBT

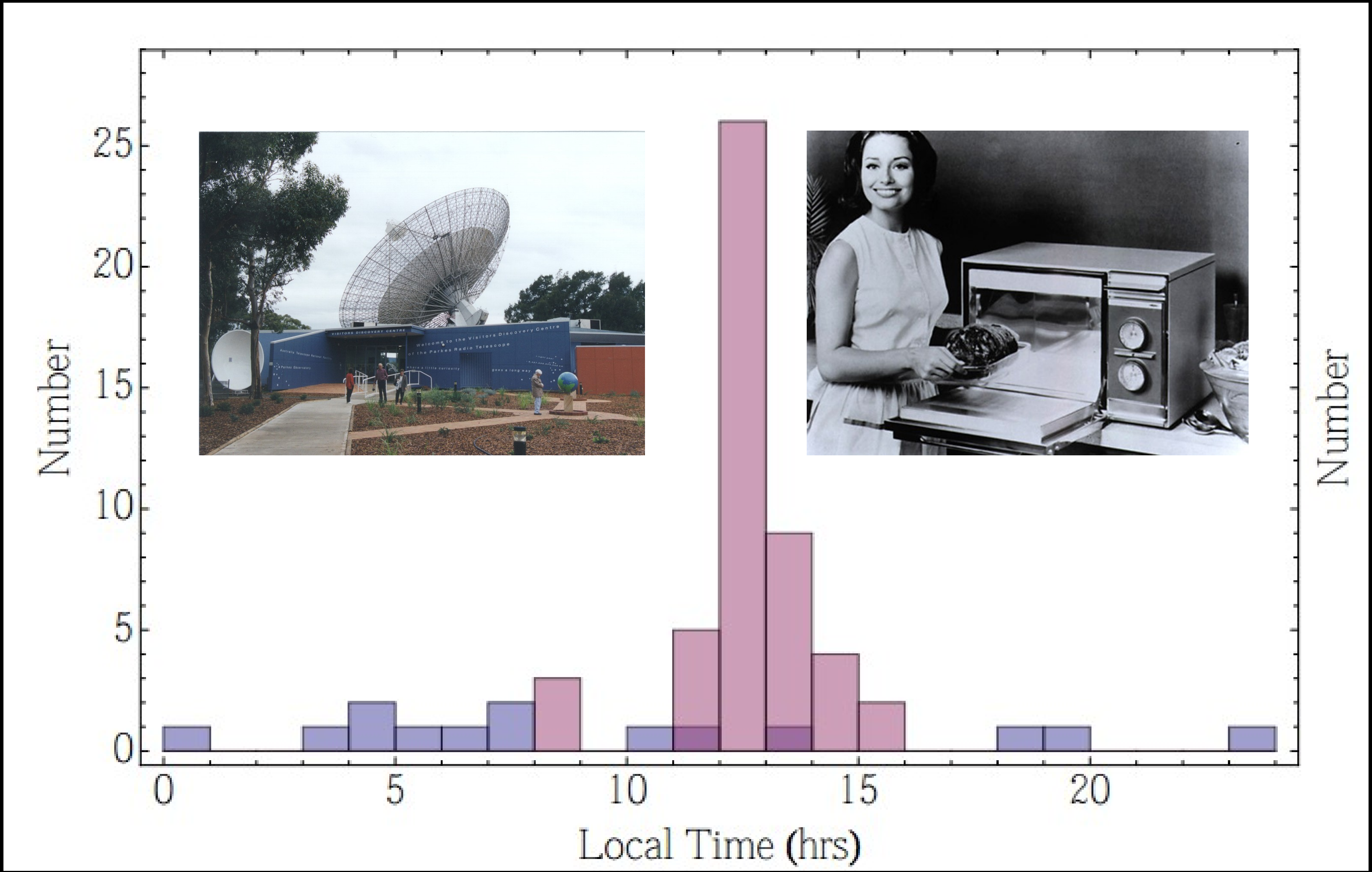


Credit: Masui et al. (2015)

2015: an FRB at GBT



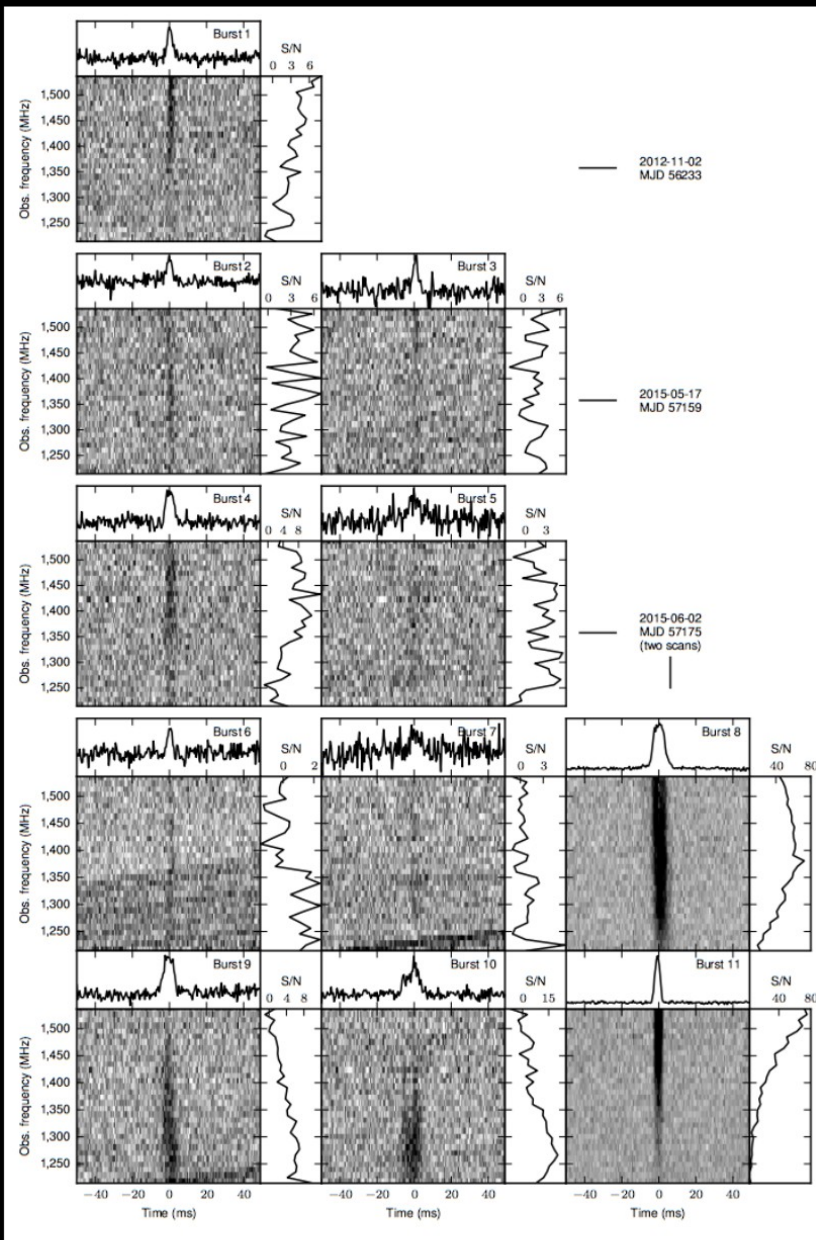
2015: Peryton mystery solved...

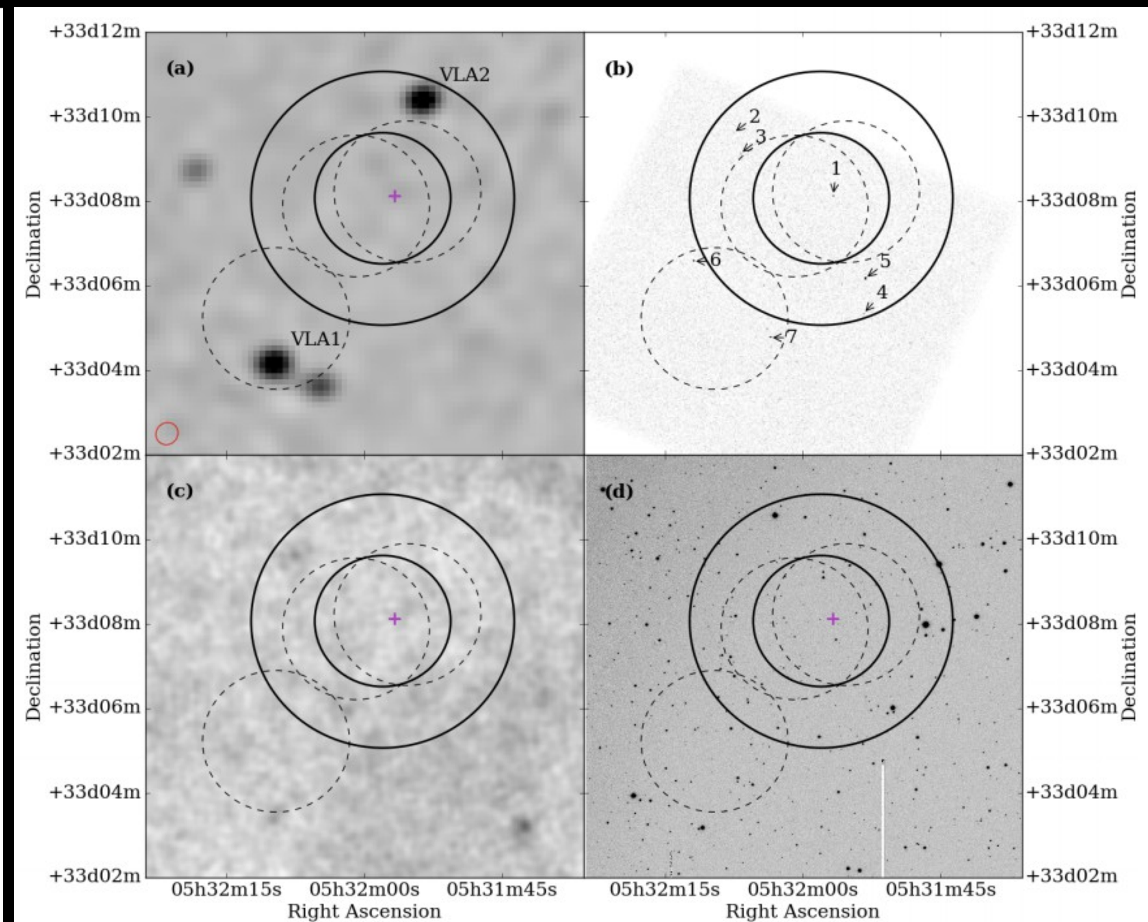


Credit: Petroff et al. (2015)

2016: Arecibo FRB repeats!

Credit: Spitler et al. and Scholz et al. (2016)

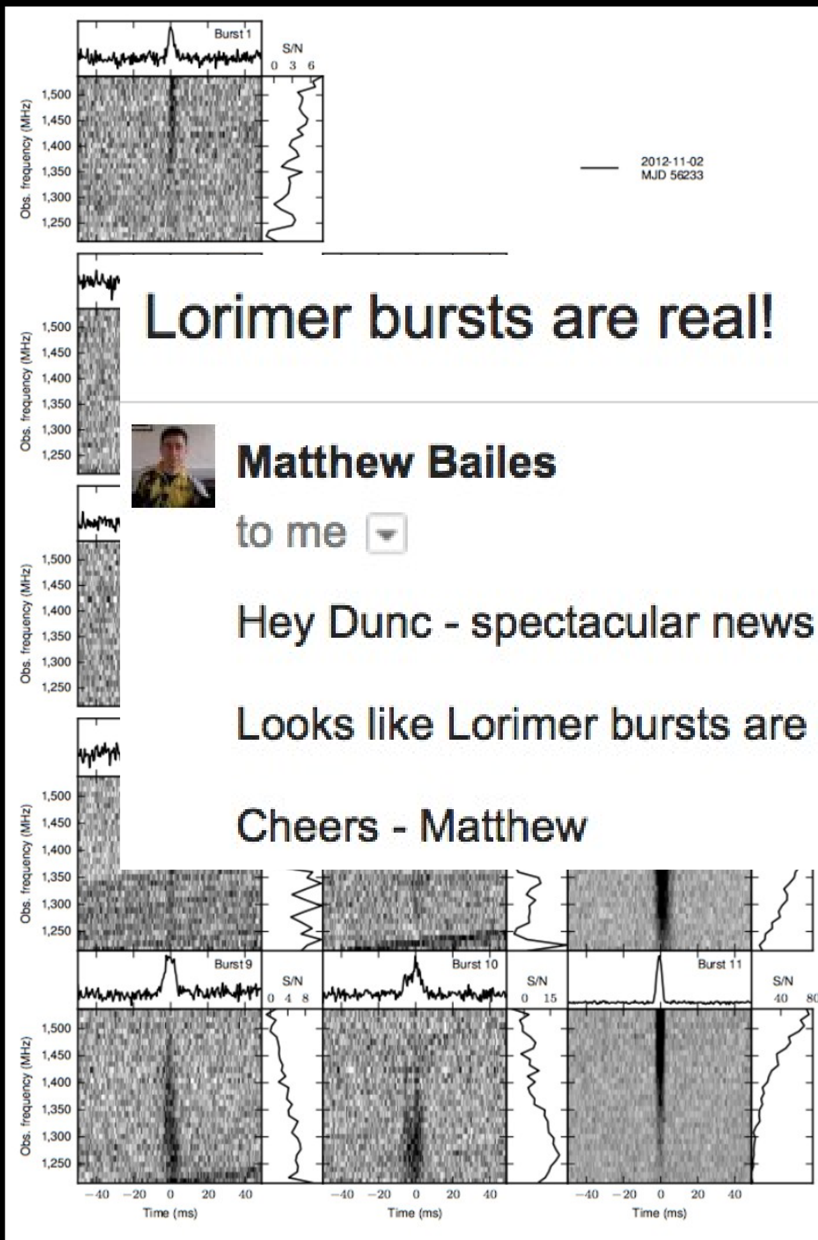


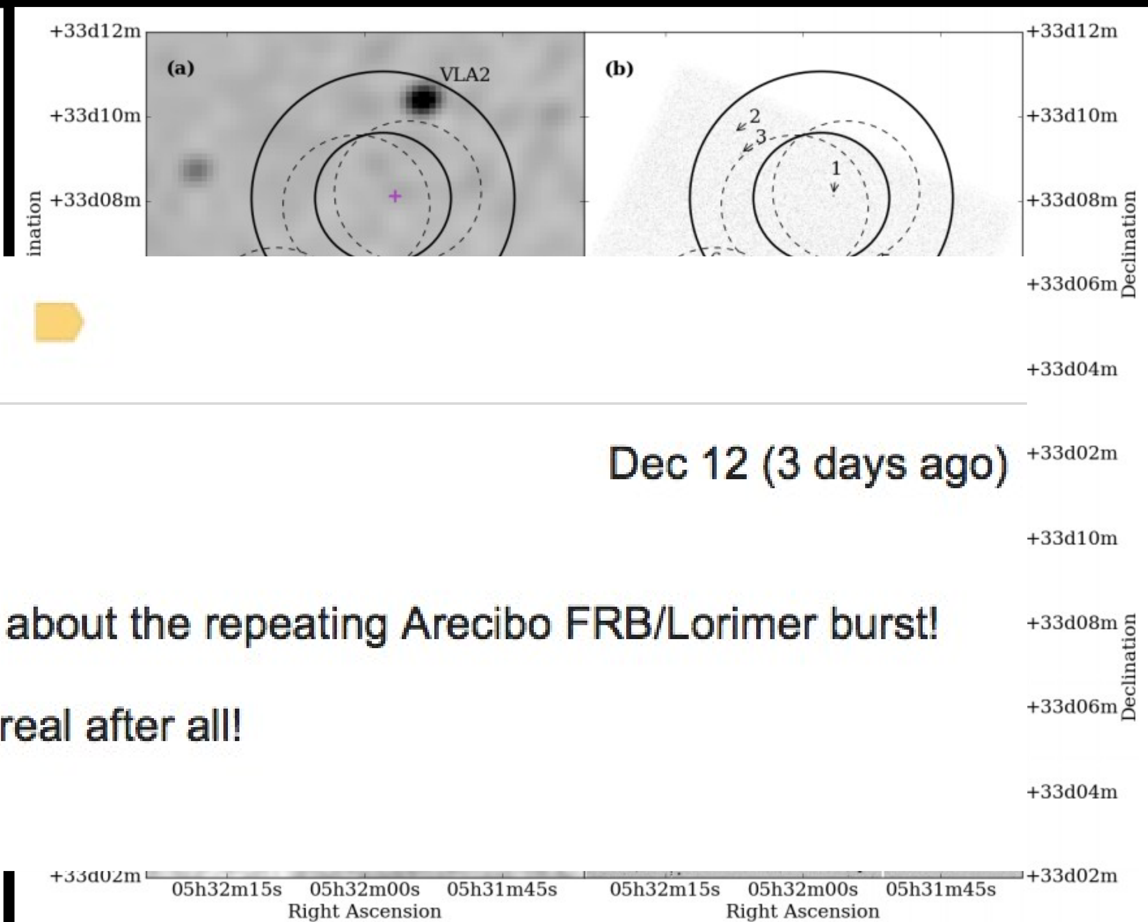


- No compelling counterparts
- No periodicity (so far)
- Widths broader than others?

2016: Arecibo FRB repeats!

Credit: Spitler et al. and Scholz et al. (2016)





Lorimer bursts are real!

Matthew Bailes Dec 12 (3 days ago)

to me

Hey Dunc - spectacular news about the repeating Arecibo FRB/Lorimer burst!

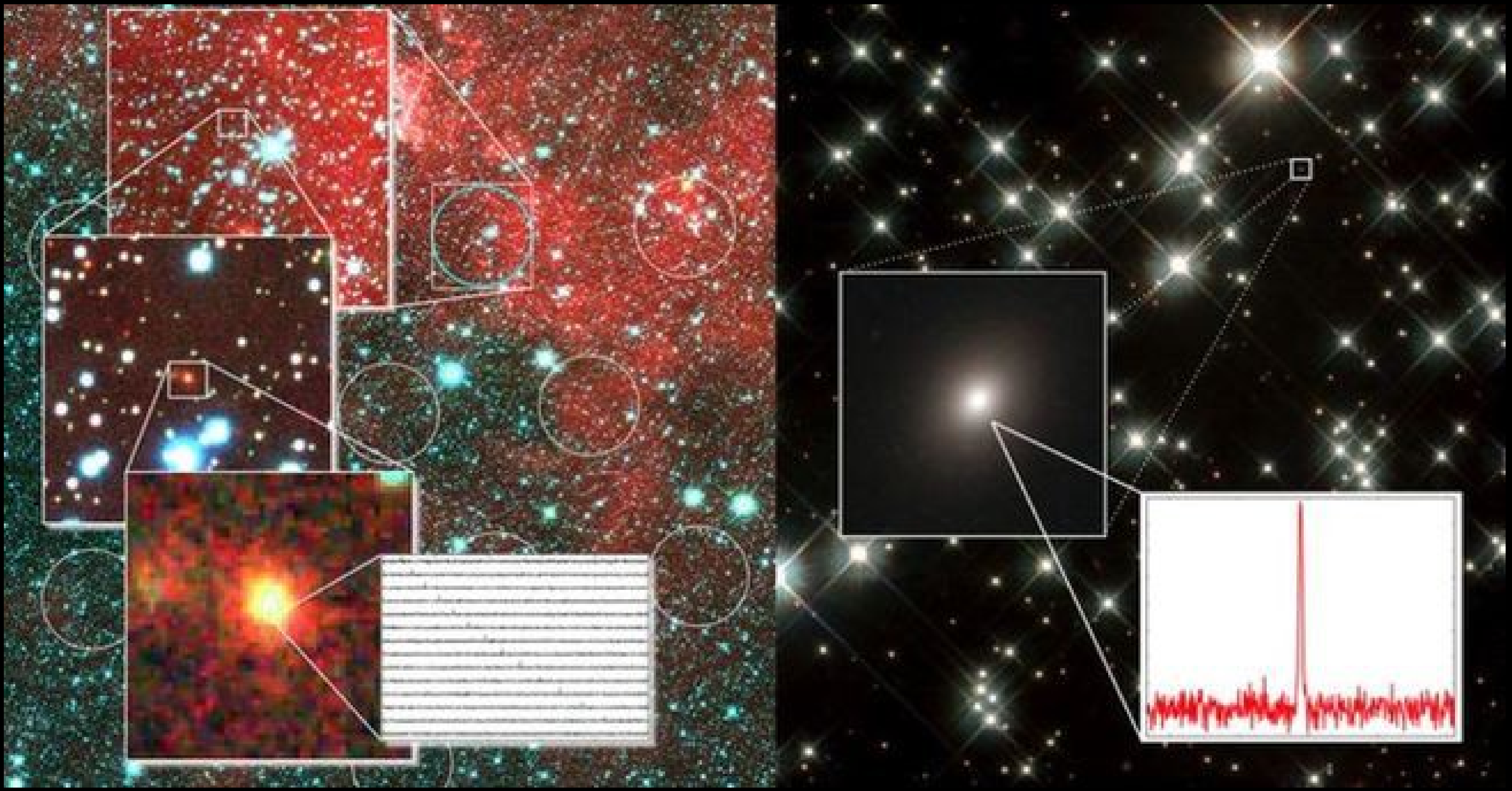
Looks like Lorimer bursts are real after all!

Cheers - Matthew

- No compelling counterparts
- No periodicity (so far)
- Widths broader than others?

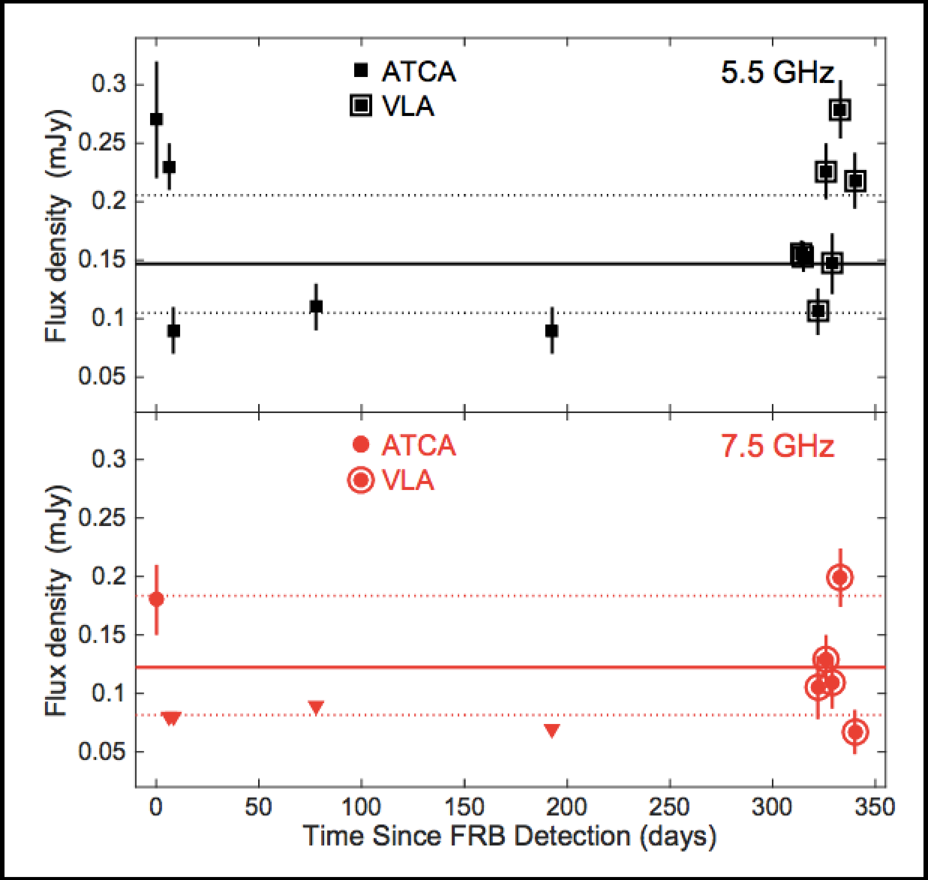
2016: FRB 150418 Counterpart?

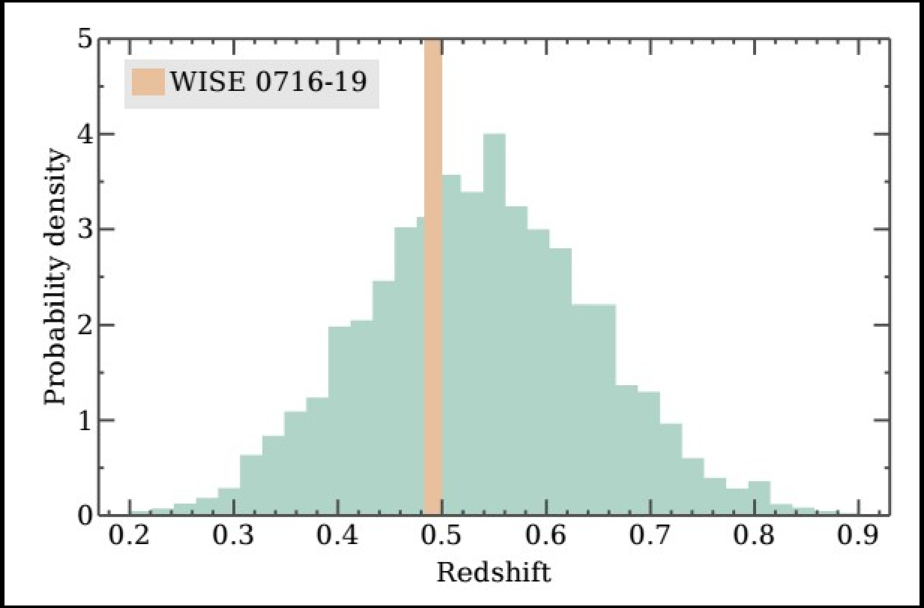
Credit: Kean et al. and Williams and Berger et al. (2016)



- Fading radio source
- Host galaxy found!
- DM – redshift connection …. missing baryons?!?!

2016: FRB 150418 Counterpart?





Credit: Kean et al. and Williams and Berger et al. (2016)

- The radio source reappeared!!!
- Variable AGN instead ▫ likely by chance
- DM – redshift connection gone… baryons still missing

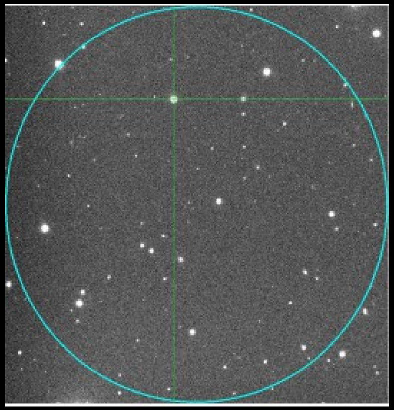
We still don't know what they are!

- Extra-terrestrial
  - Alien signals

    (Luan & Goldreich 2014)

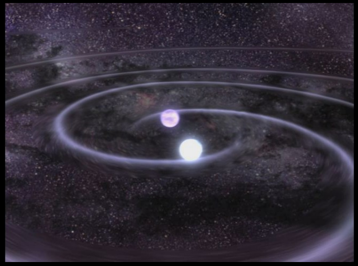
- Galactic
  - Flare stars

    (Loeb et al. 2014)



- Extragalactic
  - Favored cosmic catastrophe

    (Just about everybody 2014)

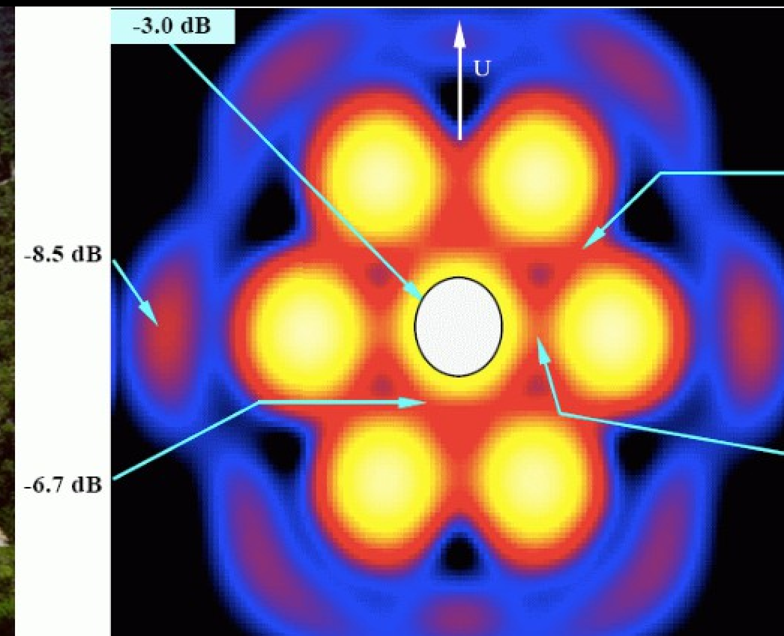


- Multiple FRB populations???
- More followup + counterparts
- My bias: pulsar/magnetar models

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
- Cosmic strings
- White holes

FRBs at Arecibo - ALFABURST



- 7 beams – commensal observing
- 56 MHz current bandwidth
- DM range out to 10,000 pc/cc
- Realtime pipeline (similar to Parkes)

FRBs at GBT - GREENBURST

- 1 beams – commensal observing
- Even when other feeds in use!
- 800 MHz current bandwidth
- DM range out to 10,000 pc/cc
- Realtime pipeline (similar to Parkes)

GBTrans [Ellingson et al.]

- 1.4 GHz / 50 MHz
- Realtime processing
- FRB rate ~1/month?
- Beginning “shadowing”
  - Swift
  - LIGO
  - Fermi
  - CHIMERA

(My) bold predictions

- 2016: counterparts found
  - Detection with VLA??
- 2020: 100s FRBs found
  - CHIME + others
- 2025: 1000s of FRBs known
  - SKA and its pathfinders
- 2030: FRBs essential cosmological tools
  - Many papers on this already!

Come to Aspen...

Aspen Center for Physics

Fast Radio Bursts: New Probes of Fundamental Physics and Cosmology

Conference Organizers:

Duncan Lorimer - West Virginia University
Edo Berger - Harvard University
Sarah Burke-Spolaor - National Radio Astronomy Observatory
Bing Zhang - University of Nevada, Las Vegas

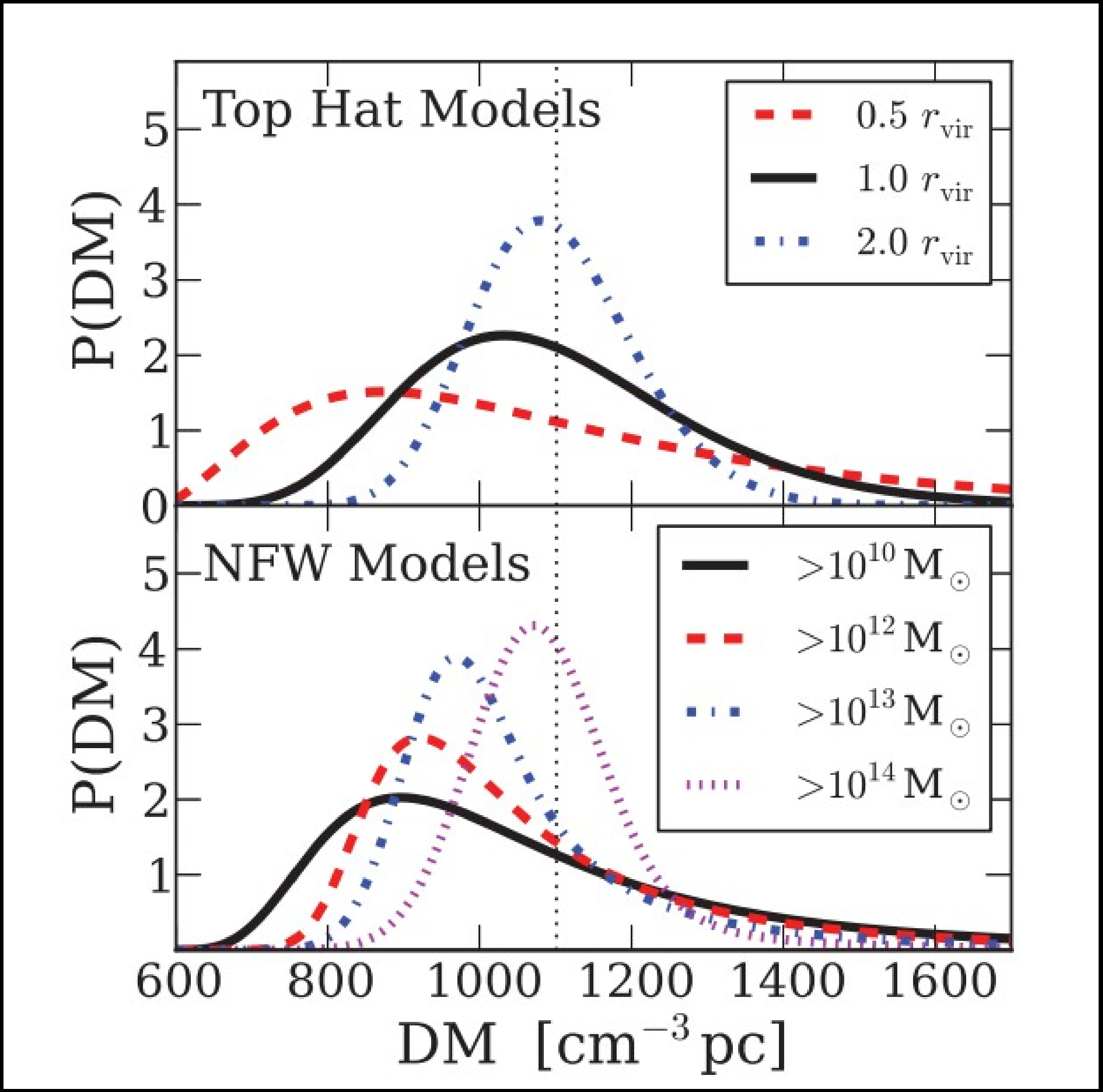
February 12 - 17, 2017

Meetings Sunday morning through Friday noon

This meeting marks the remarkable discovery and the first decade of study of Fast Radio Bursts (FRBs). We do not yet know what causes these enigmatic and extreme transient radio sources, and they pose many challenges for observers and theorists alike. FRBs appear to be at cosmological distances and show great promise as probes of exotic physical processes at their source, compact objects, and the ionized and magnetized plasma along the line of sight. The meeting aims to allow an essential convergence of data and theory at a time when FRB research is rapidly gaining momentum. The goals of the meeting are to: (i) identify and develop the most promising theories for the origins of FRBs based on the most recent observations; (ii) discuss how they can be used as astrophysical probes and tests of general relativity; (iii) advance progress on FRB discoveries via the exchange of technical expertise; (iv) organize and coordinate multi-wavelength follow-up strategies. Because of the many exciting developments in this field, FRBs are attracting a growing community of researchers with diverse backgrounds: including relativistic astrophysicists, machine learning and "big data" analysts, cosmologists, radio and time-domain astronomers, and engineers. We anticipate that this Aspen meeting will facilitate new collaborations and lead to further accelerated progress in this field.

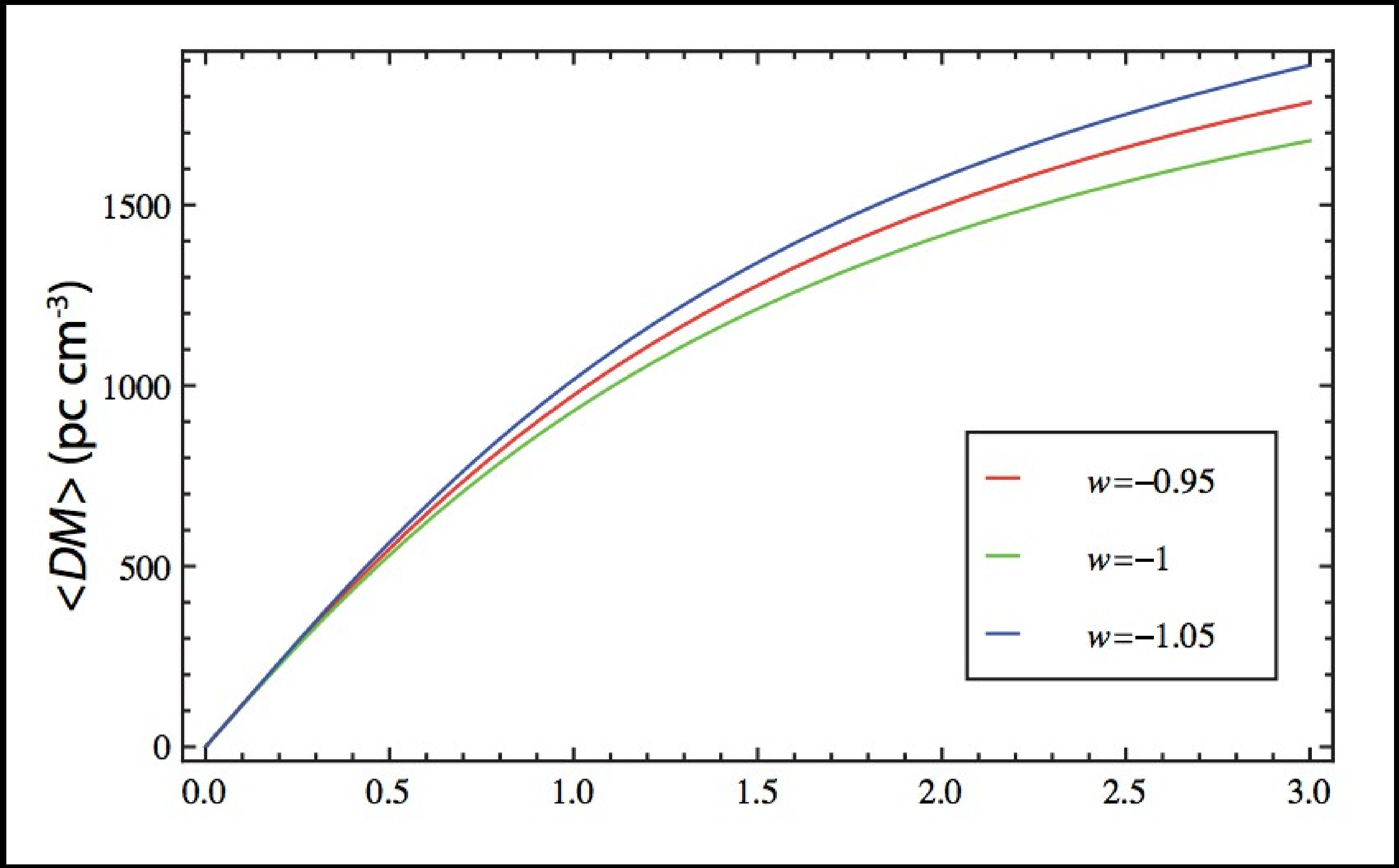
http://aspen17.phys.wvu.edu

Probing the missing baryons



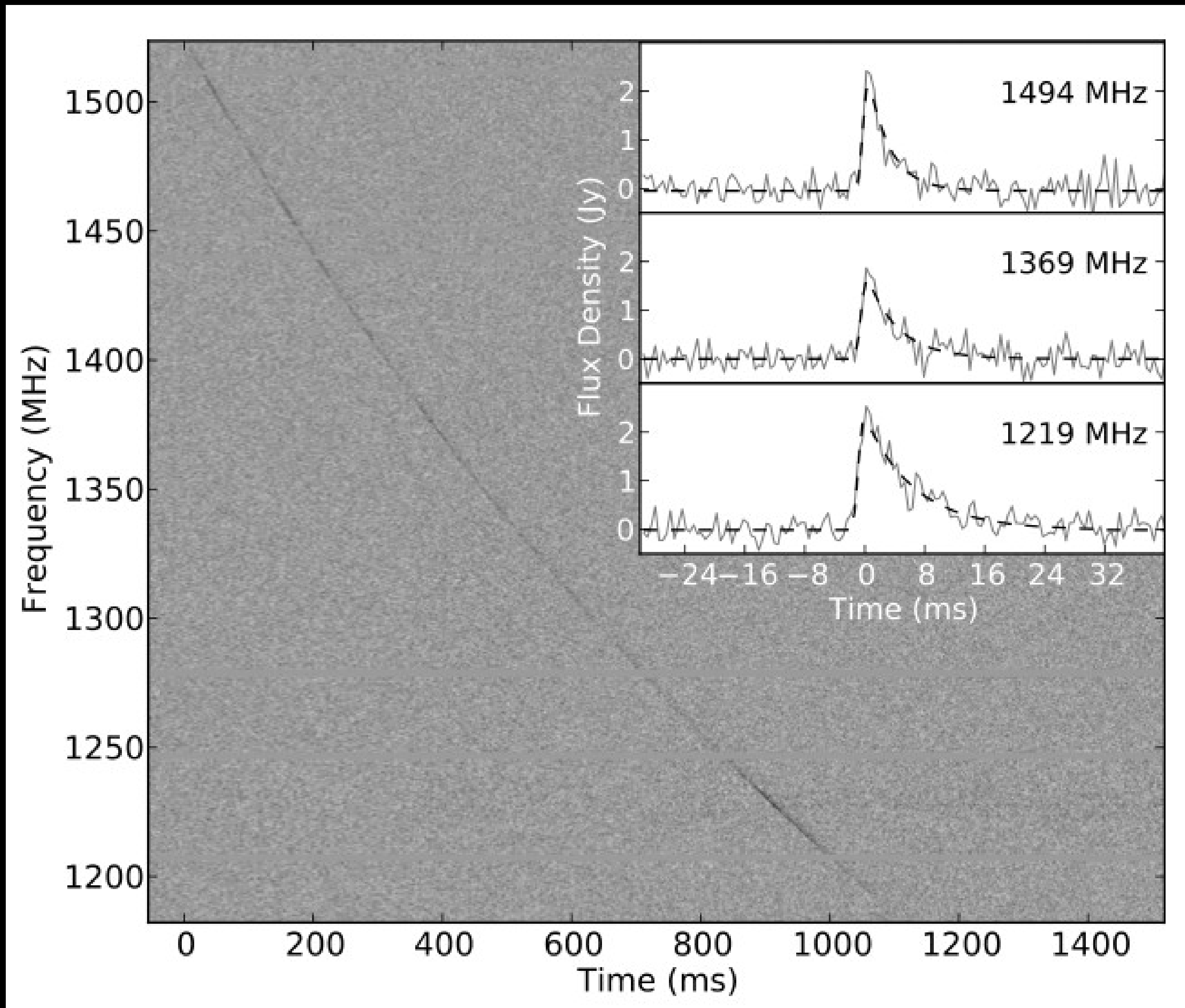
Credit: McQuinn (2014)

FRBs as cosmic rulers



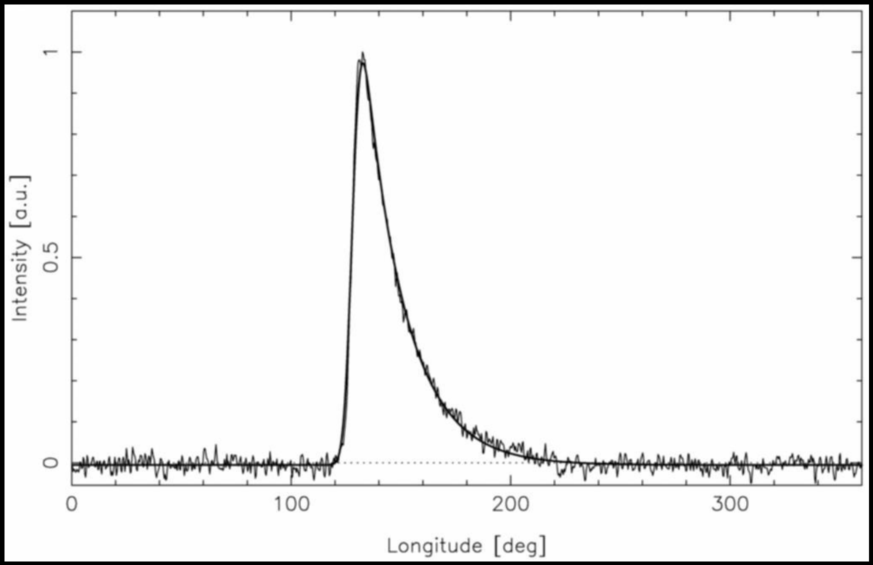
Credit: Zhou et al. (2014) and Macquart et al (2015)

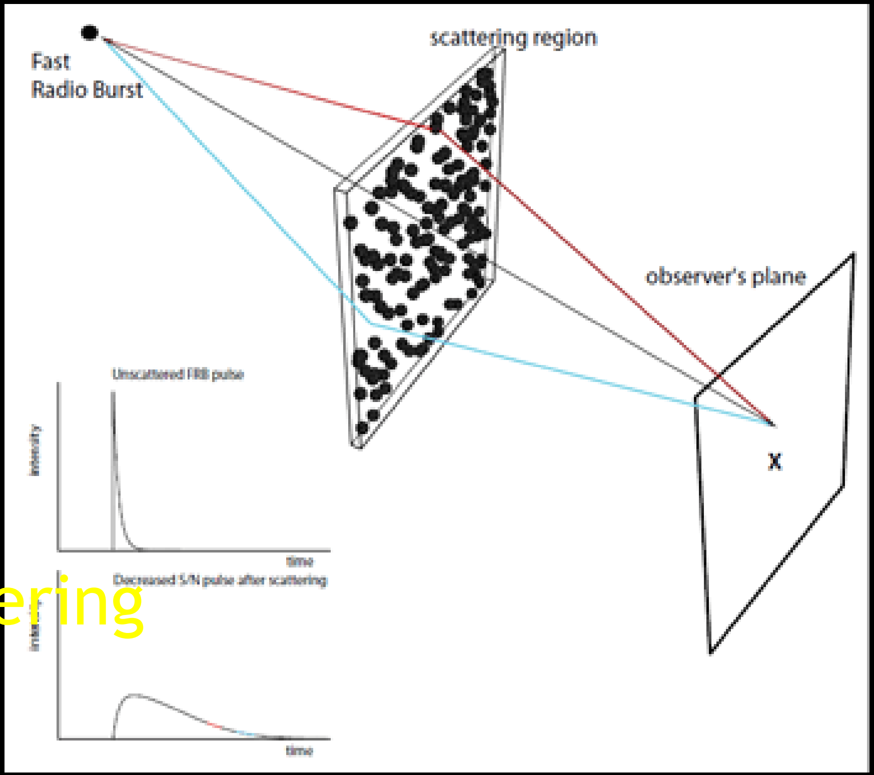
Scattering in FRB 110220



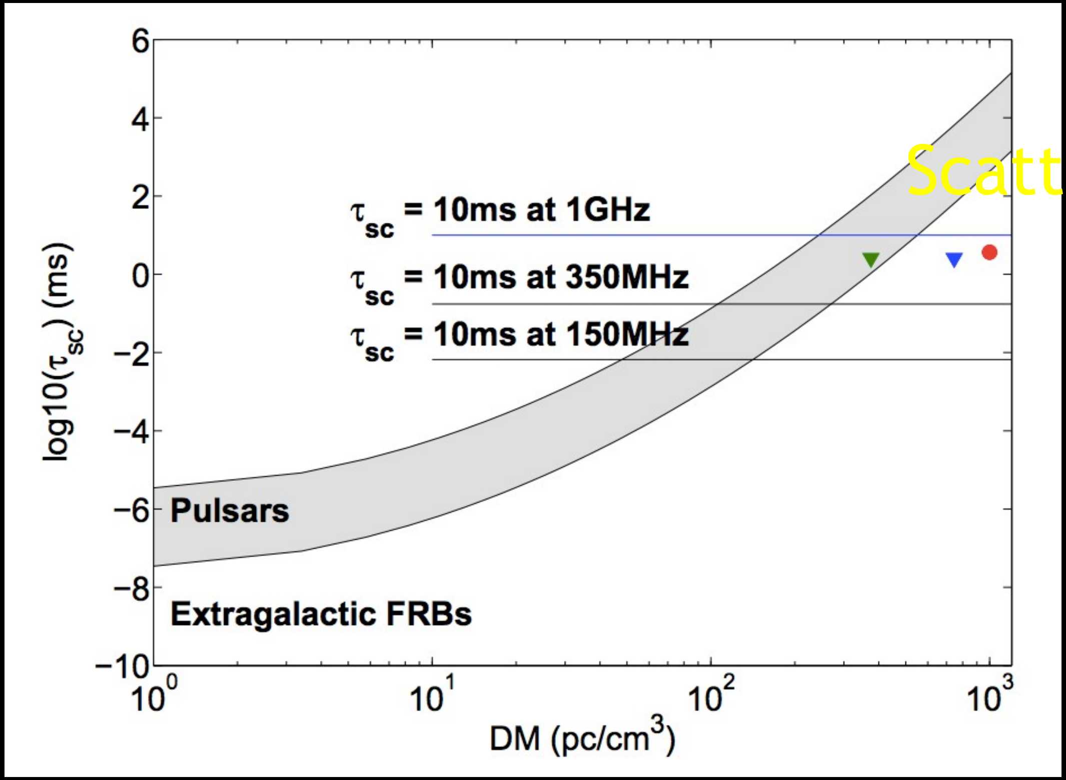
Credit: Thornton et al. 2013

Scattering in FRBs





Credit: J-P Macquart



Scattering

Scattering in FRBs is much lower than observed for Galactic pulsars