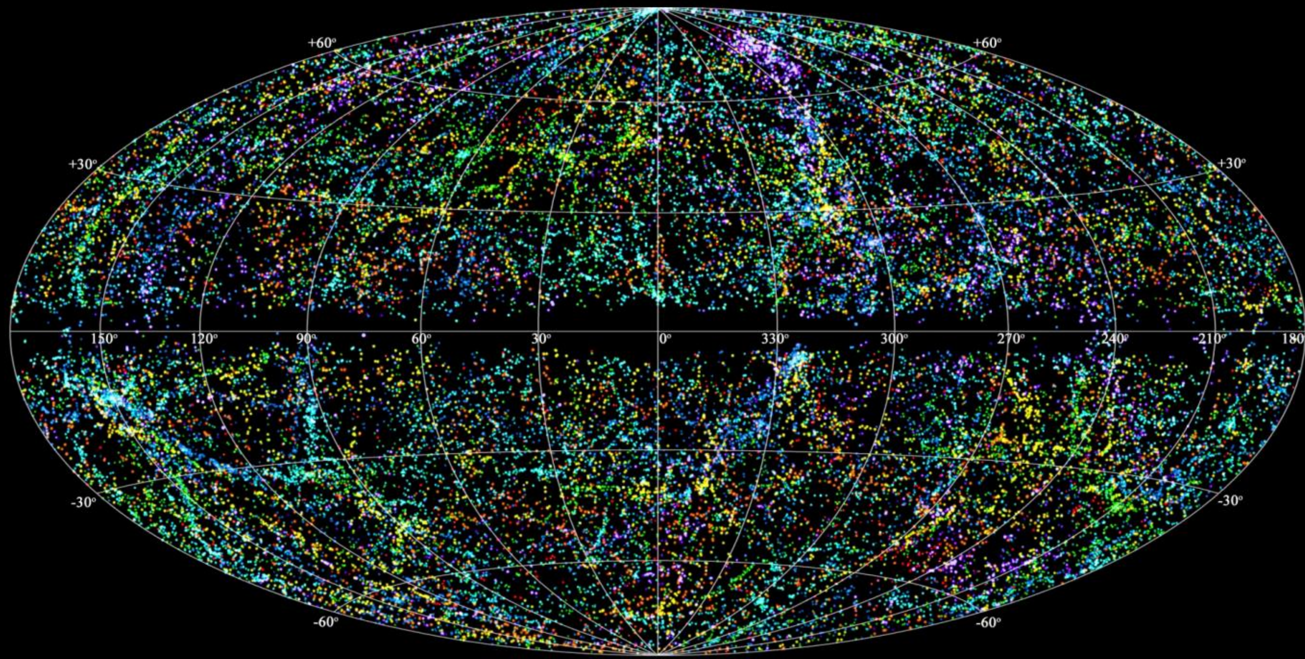
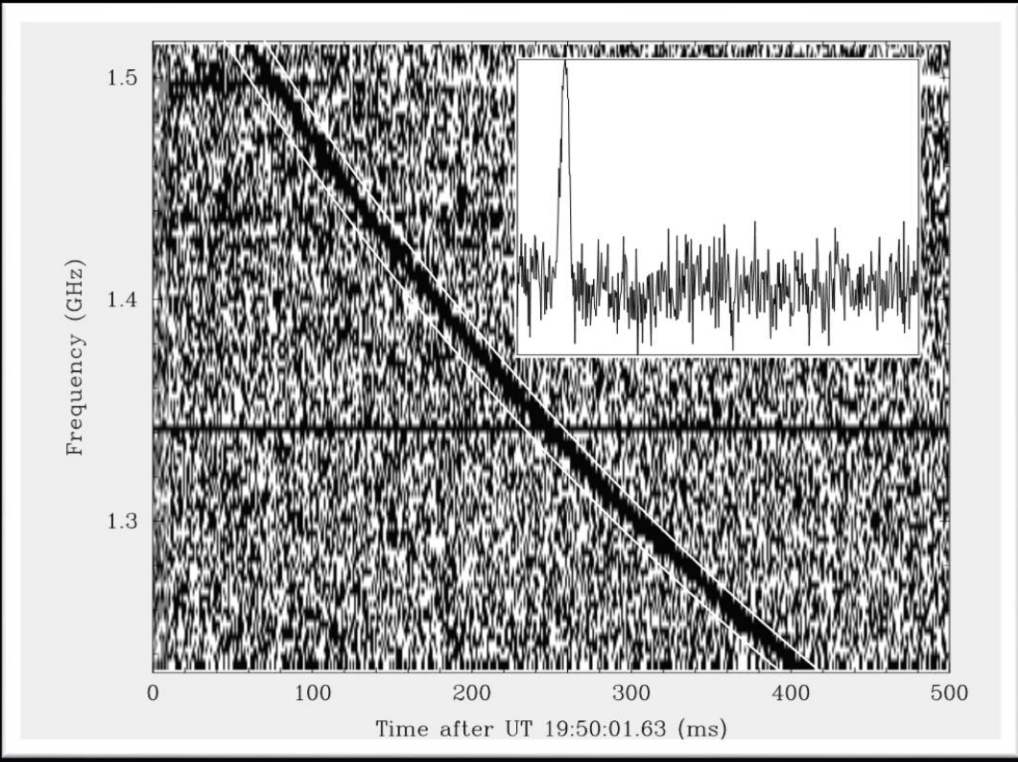


Fast Radio Bursts

Vicky Kaspi
Dept of Physics & McGill Space Institute
McGill University, Montreal, Canada
TeVPA Ohio State University Aug 8, 2017

Fast Radio Bursts

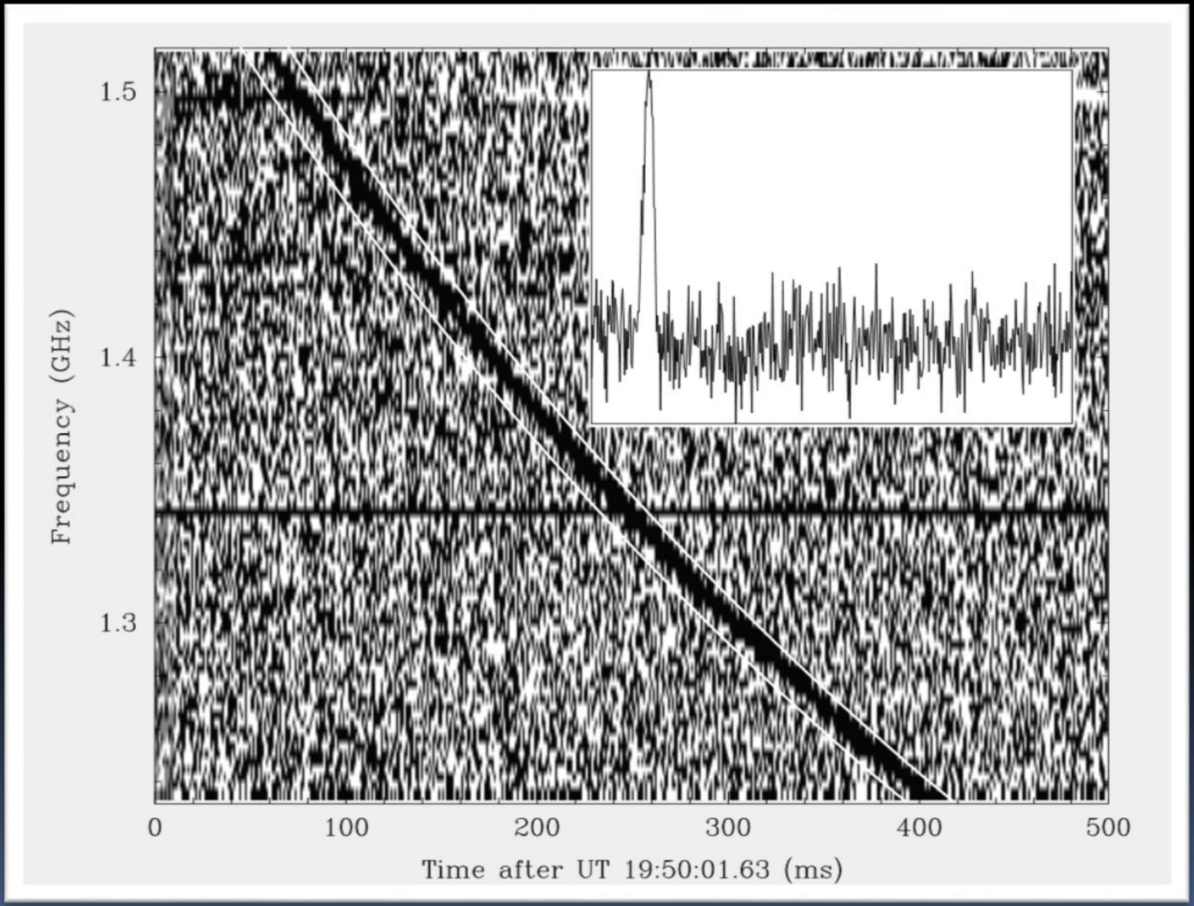
- Brief (~ms) radio bursts
- Likely cosmological
- 1st : Lorimer et al. 2007 using Parkes @ 1.4 GHz
- Today: ~23 known
- Estimated rate: ~1,000 /sky/day @ 1.4 GHz
- ORIGIN UNKNOWN!



Parkes Telescope, Australia

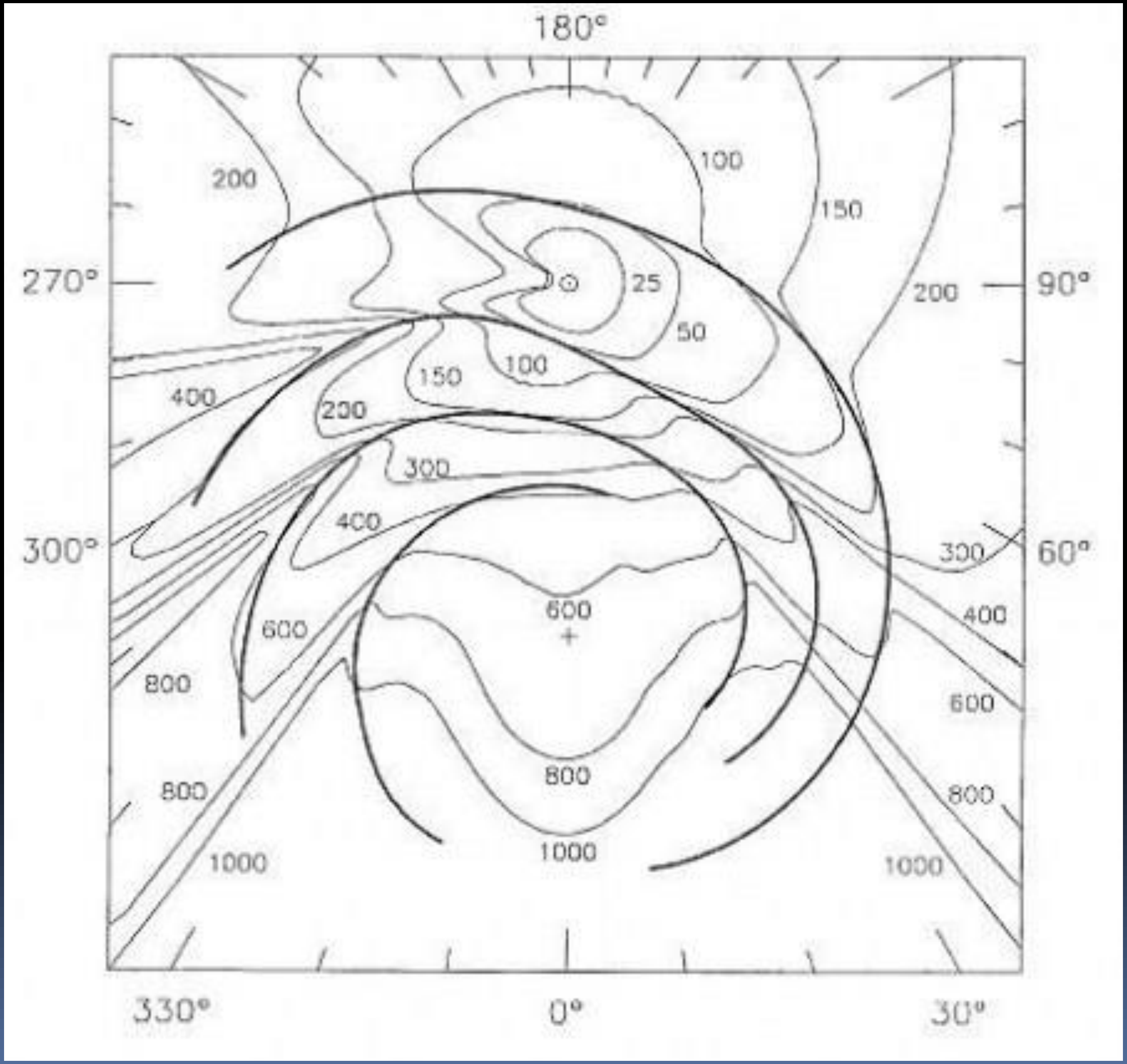
Dispersion of Radio Waves

$$t_2 - t_1 = DM\,(1/f_2^2 - 1/f_1^2)$$



$$DM \propto \int n_e \, dl$$

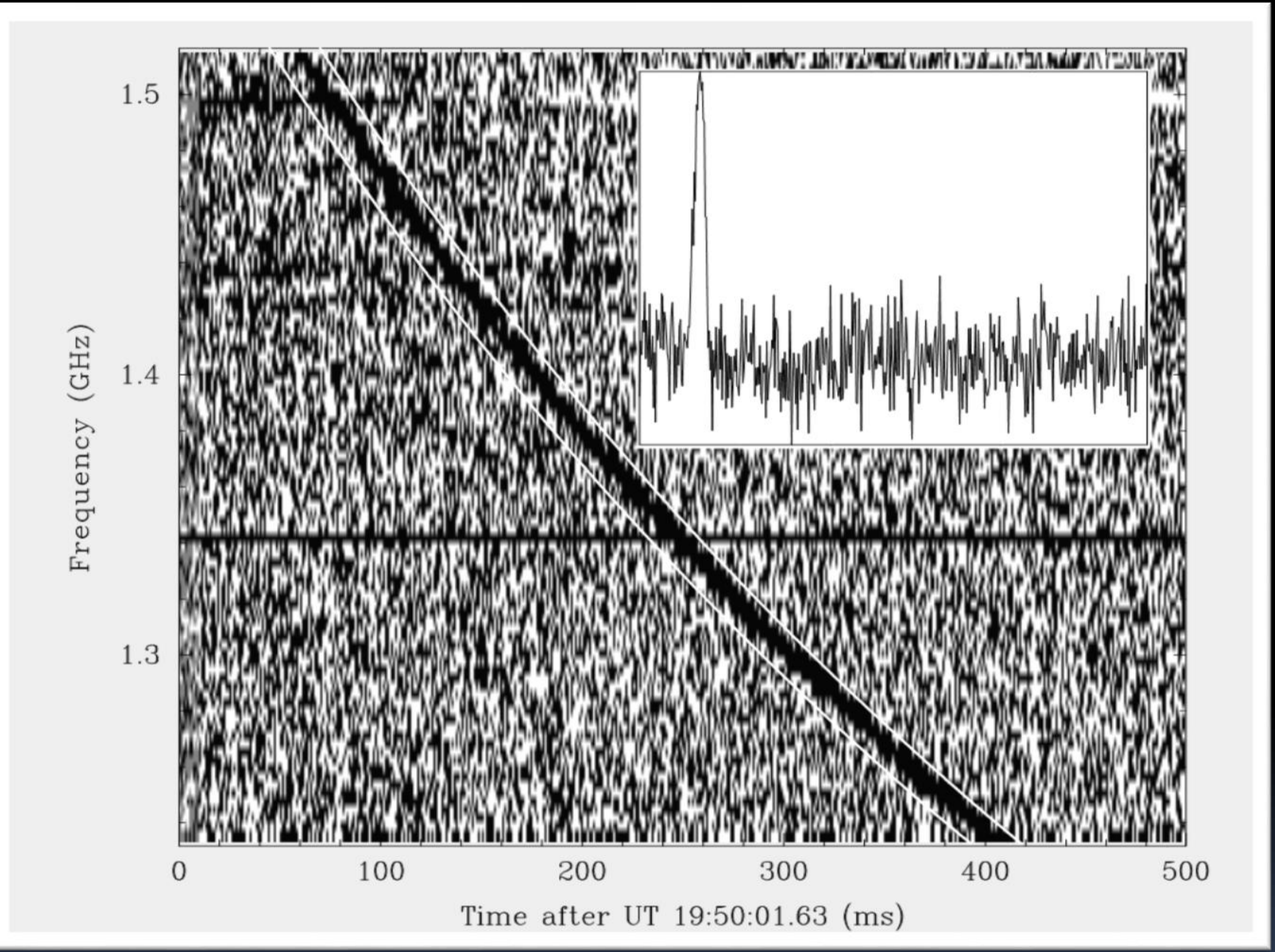
Free Electron Distribution



Milky Way Model: Contours of constant free electron column density

Cordes & Lazio 2002

“The Lorimer Burst”



DM_{max} = 25 pc/cm^3

DM_{burst} = 375 pc/cm^3

!!!!!

Lorimer et al. 2007, Science

Cosmological Distance?

- IGM Models: DM = 1200 z pc/cm^3
- Implies z=0.3 for Lorimer burst
- Corresponds to ~1 Gpc… really far!
- BUT: likely upper limit
  - some DM may be in host galaxy:

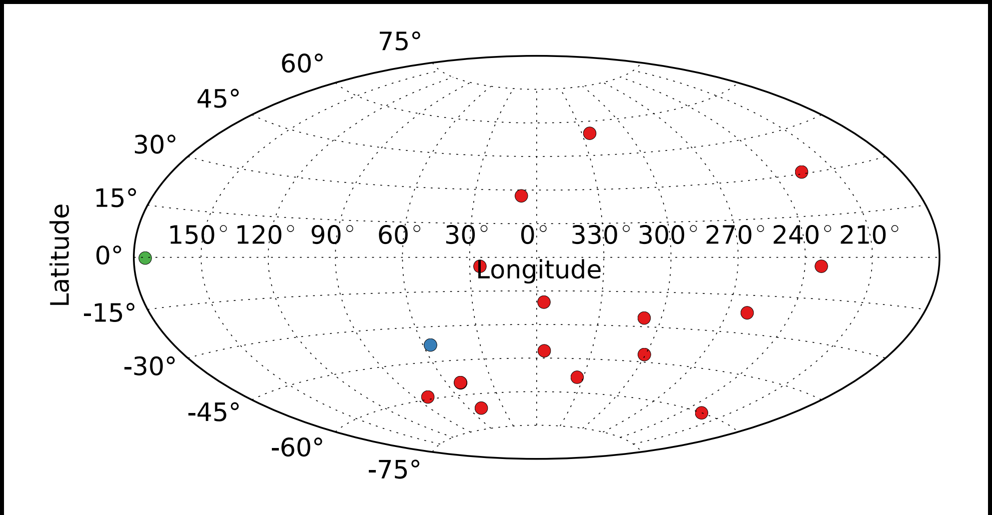
$$DM_{tot} = DM_{MW} + DM_{IGM} + DM_{host}$$

- For d=500 Mpc radio energy ~ 10^{40} erg

Corresponds to 10^{36} Watts = 10^{10} Suns!

Cosmological Distances to FRBs?

- Roughly isotropic sky distribution
- Dispersion of radio waves strongly suggests extragalactic
- Standard models of intergalactic medium suggest cosmological distances
- FRBs could make excellent cosmological probes! (e.g. Ravi et al. 2016)



Courtesy Ziggy Pleunis

FRB Catalogue

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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
FRB090625	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	50.828	-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	GBT	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	49.287	-66.203	0.25	553.3(3)	11	1.10	0.50	0.55	5
FRB121002	parkes	308.219	-26.264	0.25	1629.18(2)	16	$5.44^{+3.50}_{-1.20}$	$0.43^{+0.33}_{-0.06}$	$2.34^{+4.46}_{-0.77}$	4
FRB121102	arecibo	174.950	-0.225	0.05	557(2)	14	$3.00^{+0.50}_{-0.50}$	$0.40^{+0.40}_{-0.10}$	$1.20^{+1.60}_{-0.45}$	7
FRB130626	parkes	7.450	27.420	0.25	952.4(1)	21	$1.98^{+1.20}_{-0.44}$	$0.74^{+0.49}_{-0.11}$	$1.47^{+2.45}_{-0.50}$	4
FRB130628	parkes	225.955	30.655	0.25	469.88(1)	29	$0.64^{+0.13}_{-0.13}$	$1.91^{+0.29}_{-0.23}$	$1.22^{+0.47}_{-0.37}$	4
FRB130729	parkes	324.787	54.744	0.25	861(2)	14	$15.61^{+9.98}_{-6.27}$	$0.22^{+0.17}_{-0.05}$	$3.43^{+6.55}_{-1.81}$	4
FRB131104	parkes	260.549	-21.925	0.25	779(1)	30	2.08	1.12	2.33	8
FRB140514	parkes	50.841	-54.611	0.25	562.7(6)	16	$2.80^{+3.50}_{-0.70}$	$0.47^{+0.11}_{-0.08}$	$1.32^{+2.34}_{-0.50}$	9
FRB150418	parkes	232.665	-3.234	0.25	776.2(5)	39	$0.80^{+0.30}_{-0.30}$	$2.20^{+0.60}_{-0.30}$	$1.76^{+1.32}_{-0.81}$	10
FRB150807	parkes	336.709	-54.400	0.25	266.5(1)		$0.35^{+0.05}_{-0.05}$	$128.00^{+5.00}_{-5.00}$	$44.80^{+8.40}_{-7.90}$	11

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FRB Models

- More models than events!
- Energy not that constraining…gamma-ray bursts can have isotropic E ~ 10^{53} erg
  - No GRB/FRB coincidences (Tendulkar, VK, Patel 2016)
- For FRBs, easily enough energy in cataclysmic events
  - Supernovae
    - Need free-free opacity low…difficult!
  - Neutron star/black hole or neutron star/neutron star mergers…but rate too low!
- Radiation mechanism must be coherent:
  - Brightness temperature $T_b = I_\nu c^2/2k\nu^2 = 10^{34}$ K!
    - Same as in radio pulsars
    - Strong magnetic field?
  - Source size < ct = 300 km
    - Compact object?

Searching for FRBs: PALFA

- Pulsar Arecibo L-Band Feed Array (PALFA)
  - 305-m telescope in Arecibo, PR
  - Survey of Galactic Plane with 7-beam PALFA receiver
  - Center freq 1.4 GHz, BW 300 MHz,
  - ~1 Petabyte
  - HPC job!

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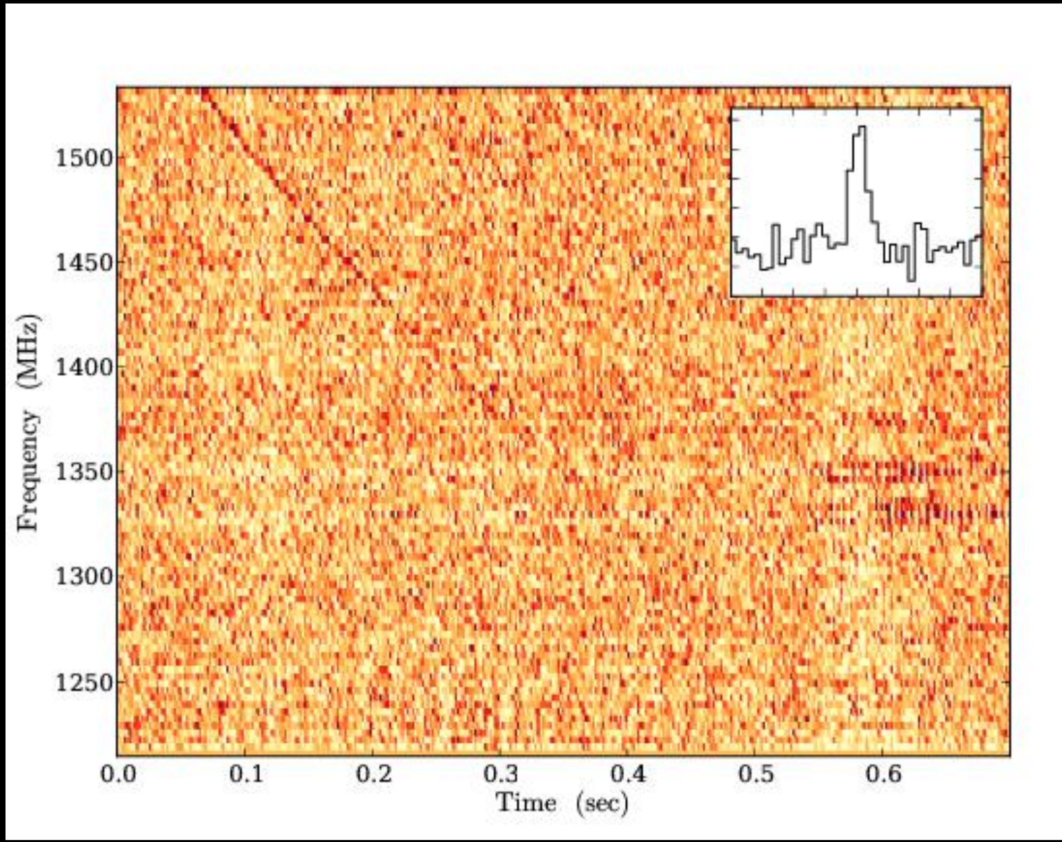
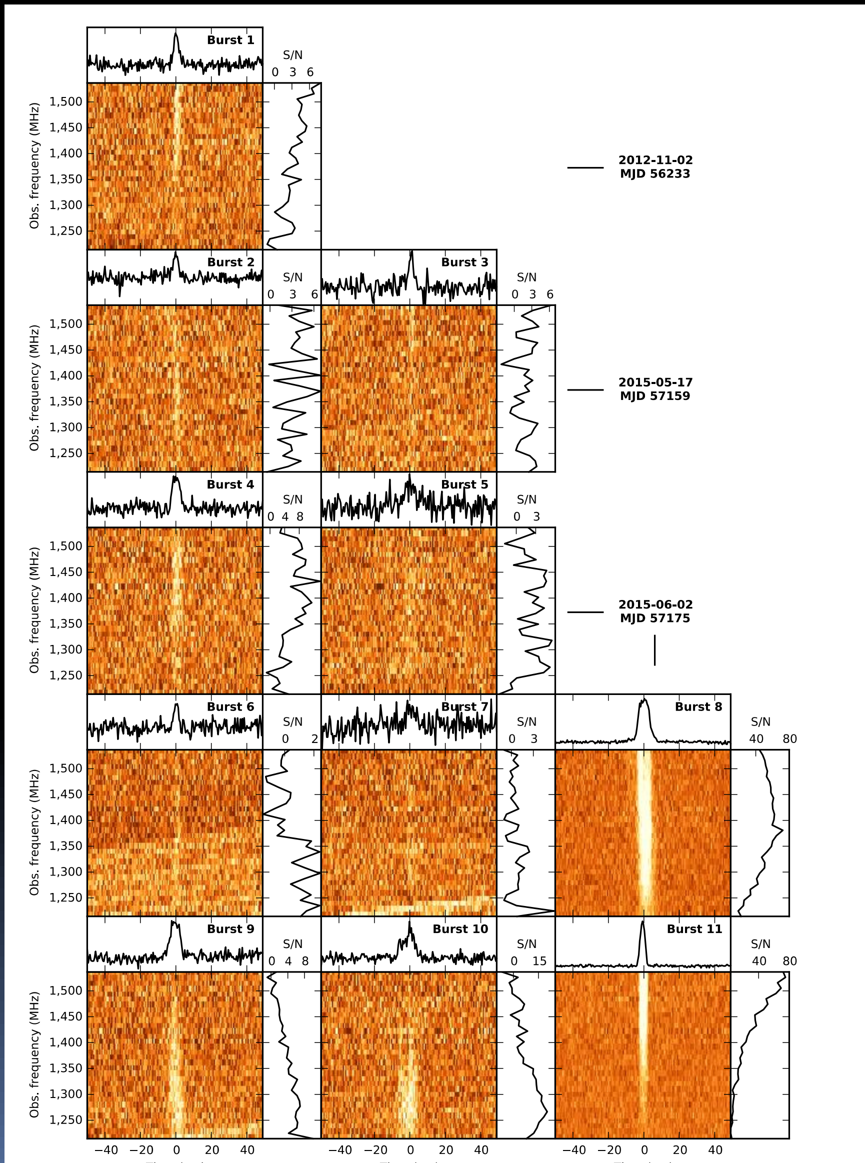
FRB 121102

- Found at Arecibo
- First non-Parkes FRB
- DM = 558 pc/cm^3 = $3DM_{max}$
- Note unusual spectrum
  - Spectral index ~+9!
- Assumed due to offset from beam centre

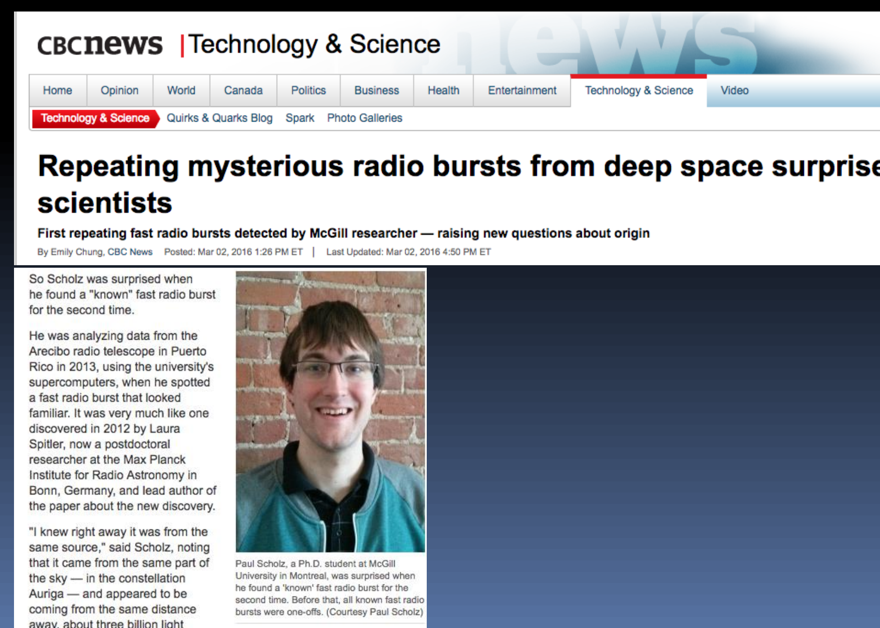


Spitler et al. 2014

Arecibo FRB Repeats!



- >10 more bursts detected
- Spitler et al. 2016 Nature; Scholz et al. 2016 ApJ
- Hugely varying spectra
- Bursts come in clusters



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Repeating mysterious radio bursts from deep space surprise scientists

First repeating fast radio bursts detected by McGill researcher — raising new questions about origin

By Emily Chung, CBC News Posted: Mar 02, 2016 1:26 PM ET | Last Updated: Mar 02, 2016 4:50 PM ET

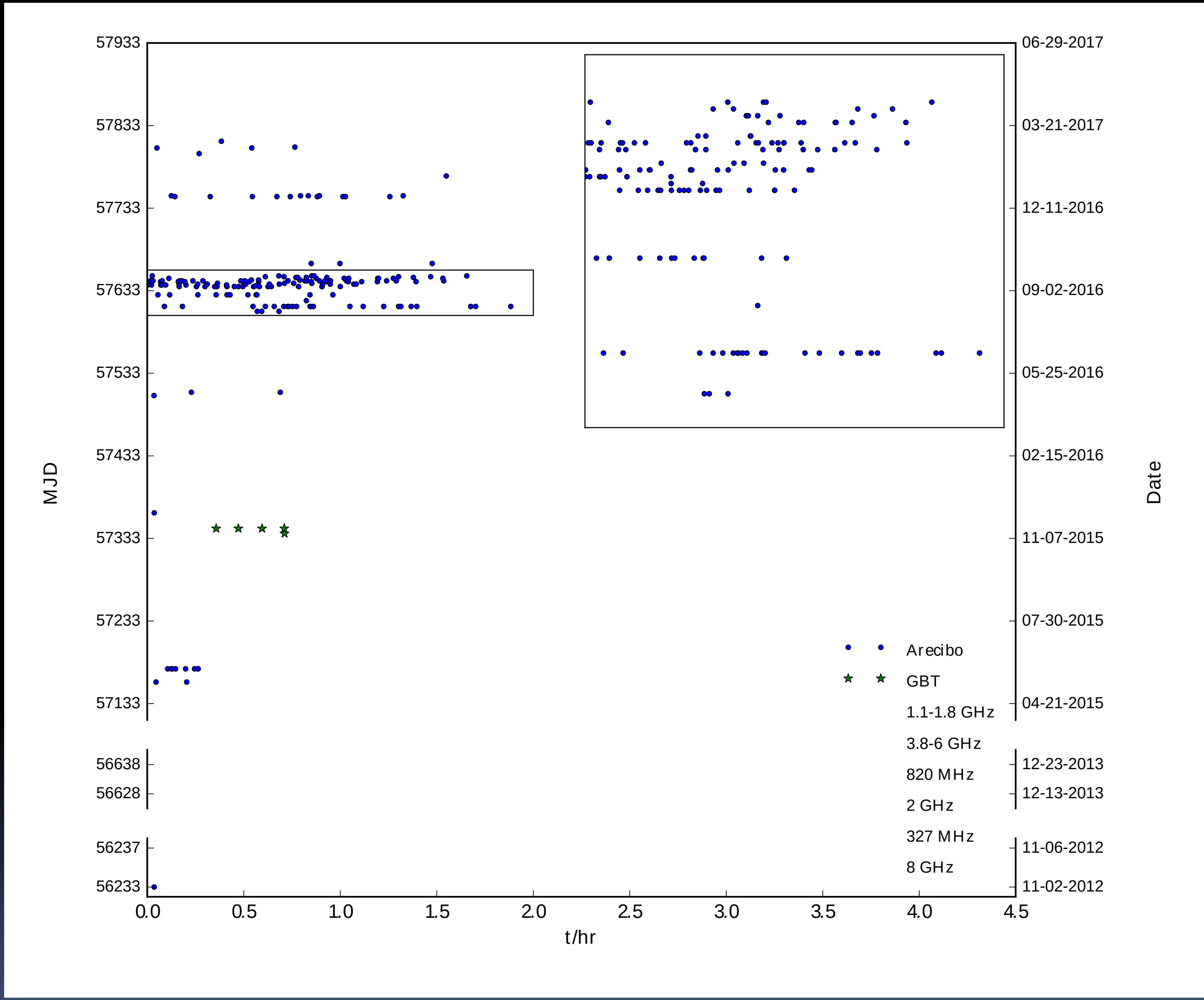
So Scholz was surprised when he found a "known" fast radio burst for the second time.

He was analyzing data from the Arecibo radio telescope in Puerto Rico in 2013, using the university's supercomputers, when he spotted a fast radio burst that looked familiar. It was very much like one discovered in 2012 by Laura Spitler, now a postdoctoral researcher at the Max Planck Institute for Radio Astronomy in Bonn, Germany, and lead author of the paper about the new discovery.

"I knew right away it was from the same source," said Scholz, noting that it came from the same part of the sky — in the constellation Auriga — and appeared to be coming from the same distance away, about three billion light

Paul Scholz, a Ph.D. student at McGill University in Montreal, was surprised when he found a 'known' fast radio burst for the second time. Before that, all known fast radio bursts were one-offs. (Courtesy Paul Scholz)

Repeats Highly Clustered!



Hessels et al. in prep.

Plot courtesy:
S. Ocker,
K. Gourdjii
L. Spitler
J. Hessels
Others…

Why Only 1 Repeater?

- Different classes of FRBs?
  - Some cataclysmic, some not?
- BUT coincidence that of 23 known, only repeater is also only Arecibo FRB??
  - Maybe no, as repeat bursts generally too faint for Parkes
- What could repeater be? We don't know.
  - Rotation-powered pulsar giant pulses?
  - Magnetar giant flares?

Crab-like Giant Pulses?

Max $L \sim 10^{35}$ erg/s

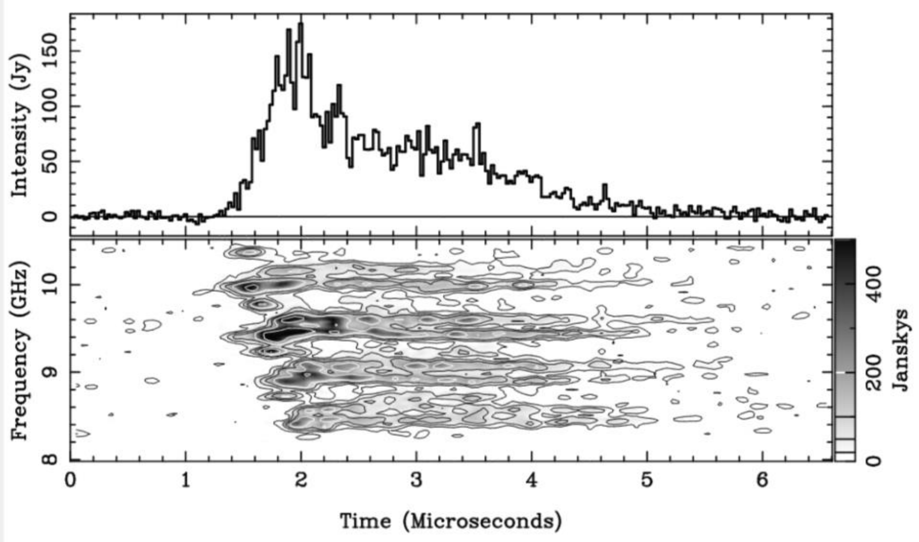


Fig. 6.— A typical interpulse, observed 12 minutes after the main pulse shown in Figure 2, and processed identically. The later arrival of bands at lower frequency implies that this pulse is more dispersed than the main pulse in Figure 2. The spectrum contour levels are 20, 50, 100, 200, 500 Jy. Total intensity time resolution is 51.2 ns; dynamic spectrum resolution is 51.2 ns, 19.5 MHz.

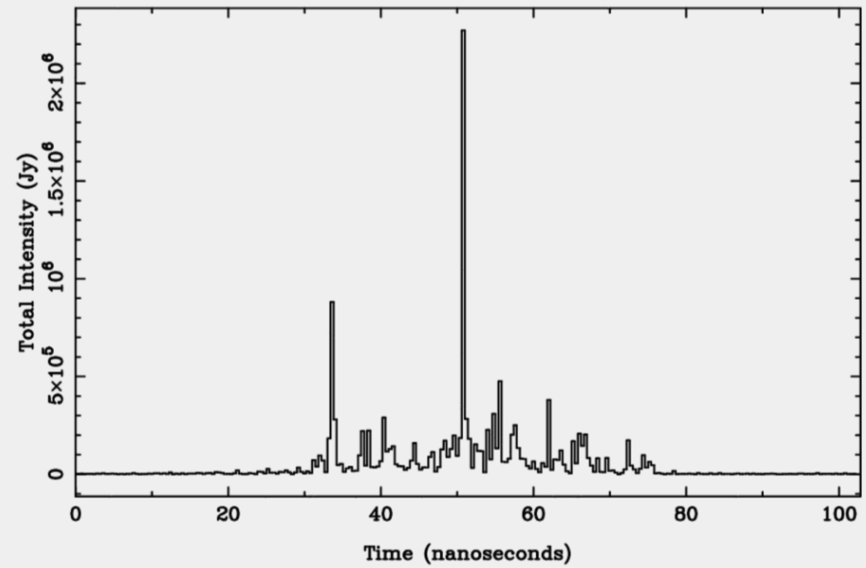
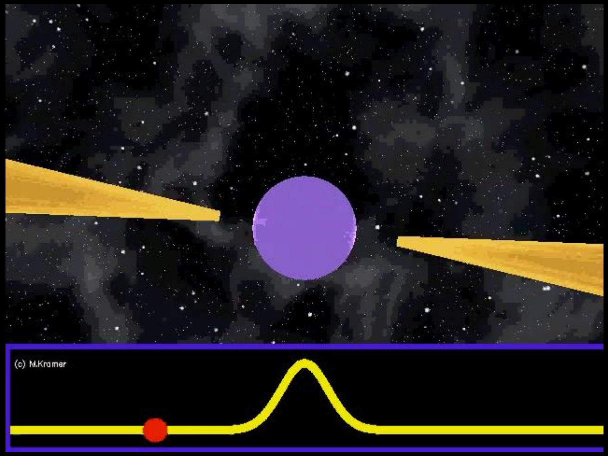


Fig. 5.— A single main pulse recorded at 9.25-GHz center frequency over a 2.2-GHz bandwidth and optimally dedispersed. The nanopulse shown is unresolved with the 0.4-ns time resolution afforded by our system. Despite the high peak intensity of this pulse, it is unlikely that it saturated the data acquisition system. The dispersion sweep time across the bandwidth is about 1.5 ms, so as sampled by our data acquisition system, the dispersed pulse energy is spread over $\approx 7.5 \times 10^6$ samples.

Hankins & Eilek 2007

Radio Pulsar Energetics: Spin-down

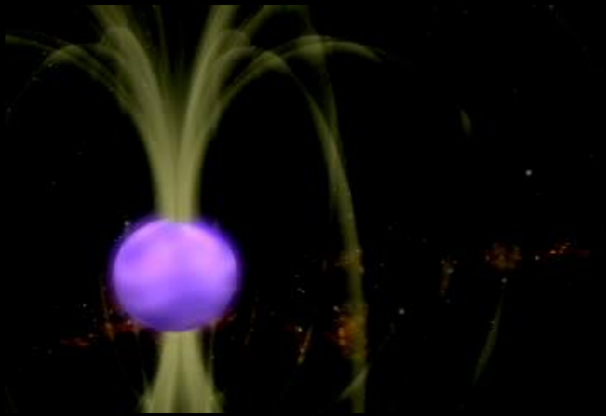


$$\dot{E} = \frac{d}{dt}\left(\frac{1}{2} I\omega^2\right) = I\omega\dot{\omega} = 4\pi^2 I \frac{\dot{P}}{P^3}$$

Crab pulsar: P = 33 ms, dP/dt = $4\text{x}10^{-13}$, E=$5\text{x}10^{38}$ erg/s

See Lyutikov (2017)

Pros of FRBs as Magnetars



- Magnetar Giant Flares have few ms peaks in X-rays
- 3 since 1979 → ~0.1 /MW/yr but FRBs ~10^{-3} /galaxy/yr
  - We must be sensitivity limited for FRBs
- Magnetars have sufficient energy: ~10^{47-49} erg
  - Even for repeating FRB? Depends on activity life time
  - Cannot be for more than ~100 yr

JVLA observes FRB 121102

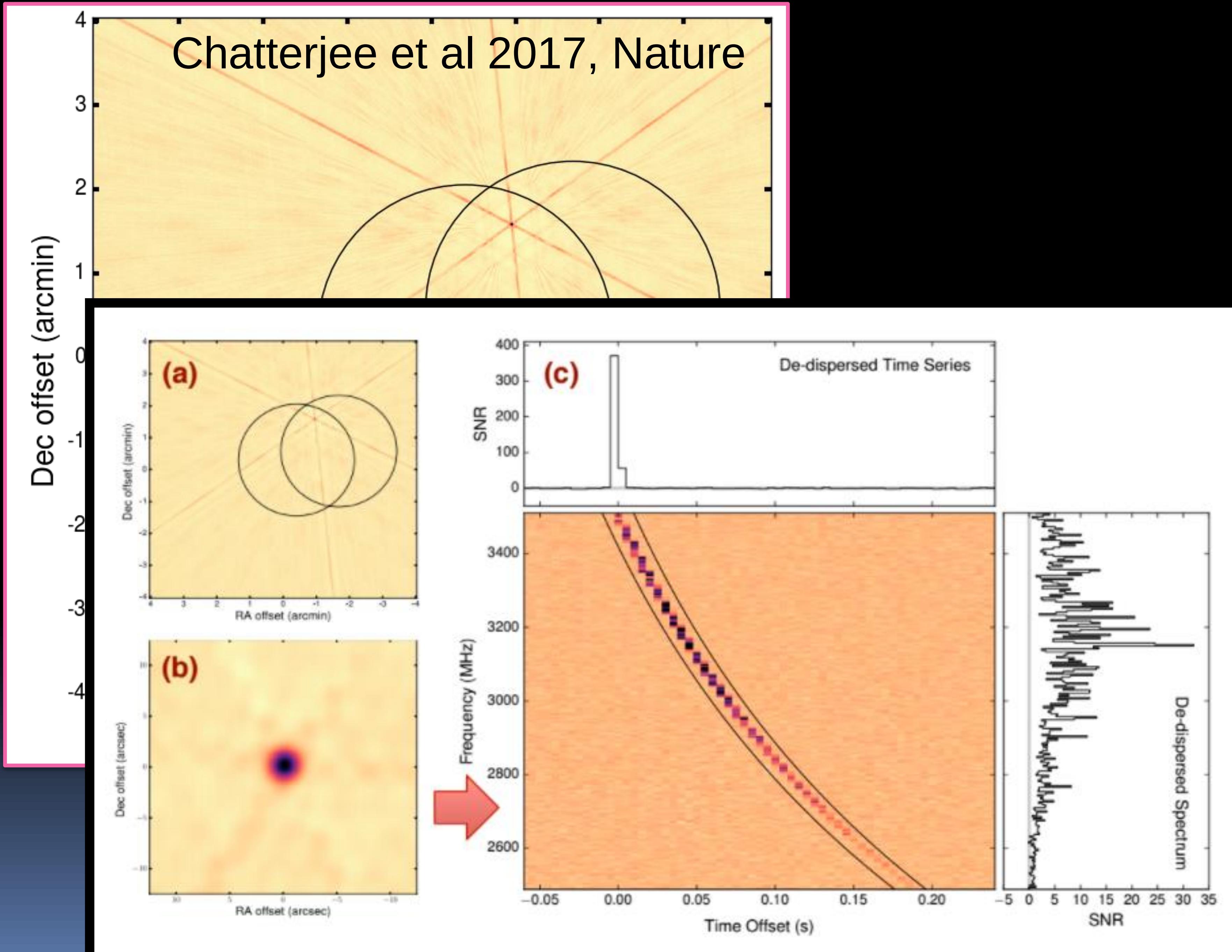
Computationally demanding!

(Law et al 2015)

Fast imaging of FRB 121102:

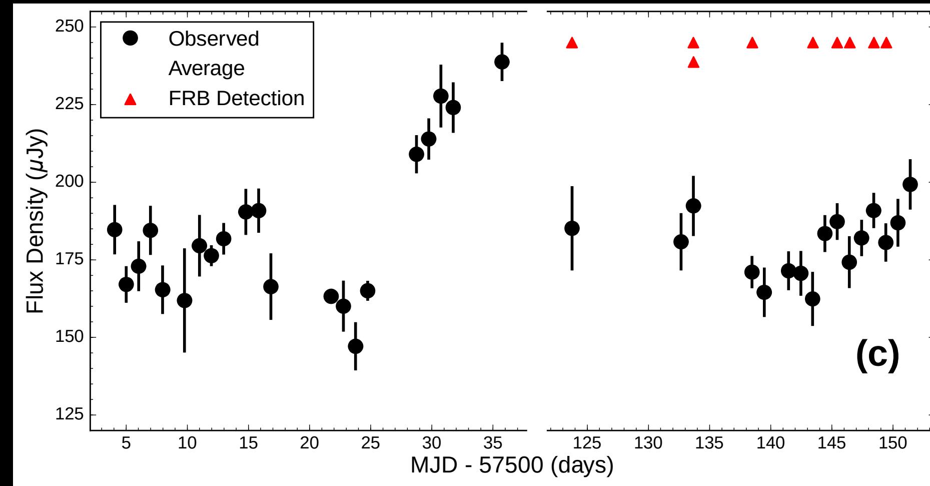
- Fall 2015, 10 hours: no detection
- Spring 2016, 40 hours: no detection
- Fall 2016, 40 hours
  - In the first hour of a test observation…

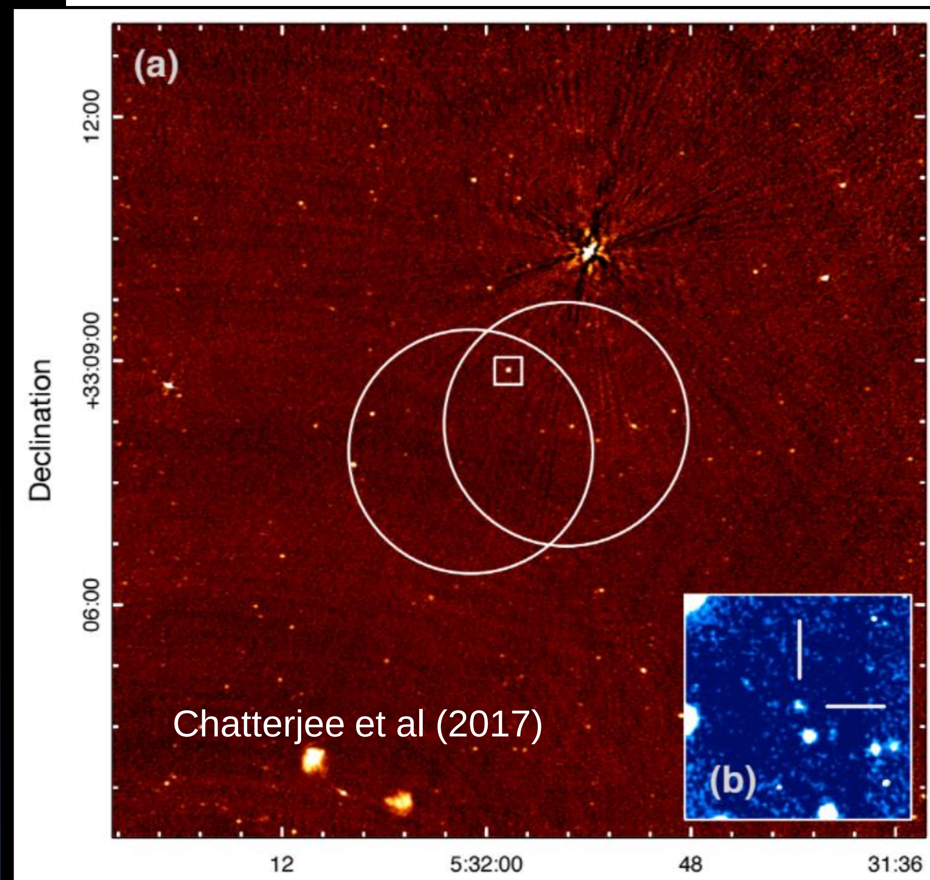
Chatterjee et al 2017, Nature



JVLA Detections

- 9 bursts in Fall 2016
- Location to 0.1 arcsecond
- Persistent radio source – 200 μJy!
  - 30% variability
- Optical counterpart 25th mag

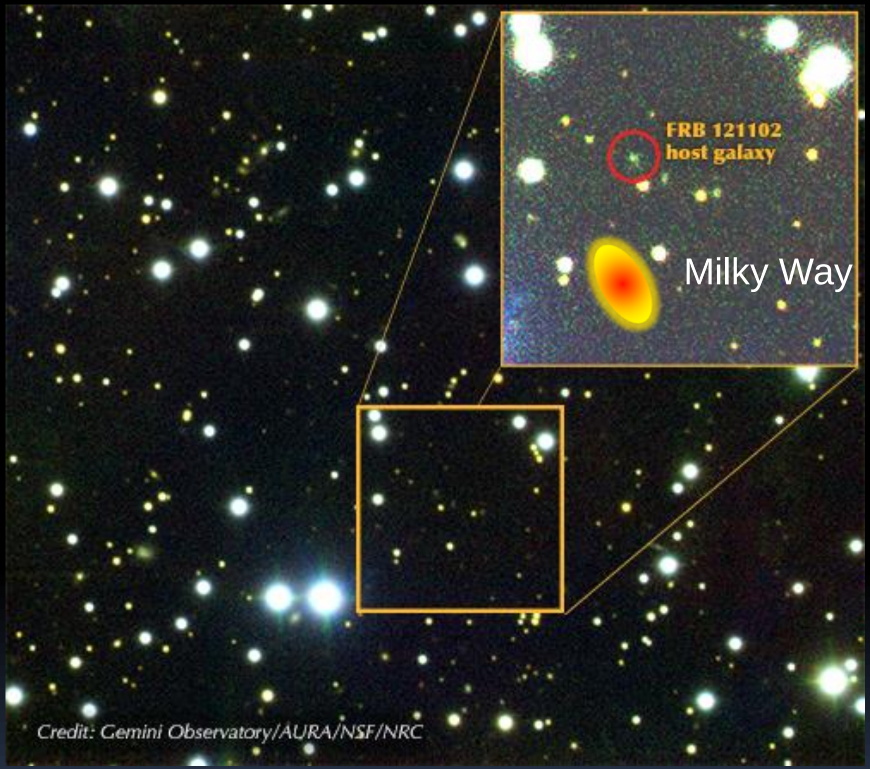




Deep VLA 3 GHz image and Gemini r-band image

Optical counterpart: a Dwarf Galaxy

- z=0.19273(8)
- Distance 972 Mpc
- Mass 5×10^7 M_{sun}
  - MW is 10^{12} M_{sun}
- Star forming
  - 0.5 M_{sun} / year
- Low metallicity
  - Affects stellar characteristics



Tendulkar et al (2017)

FRBs: Where do we stand?

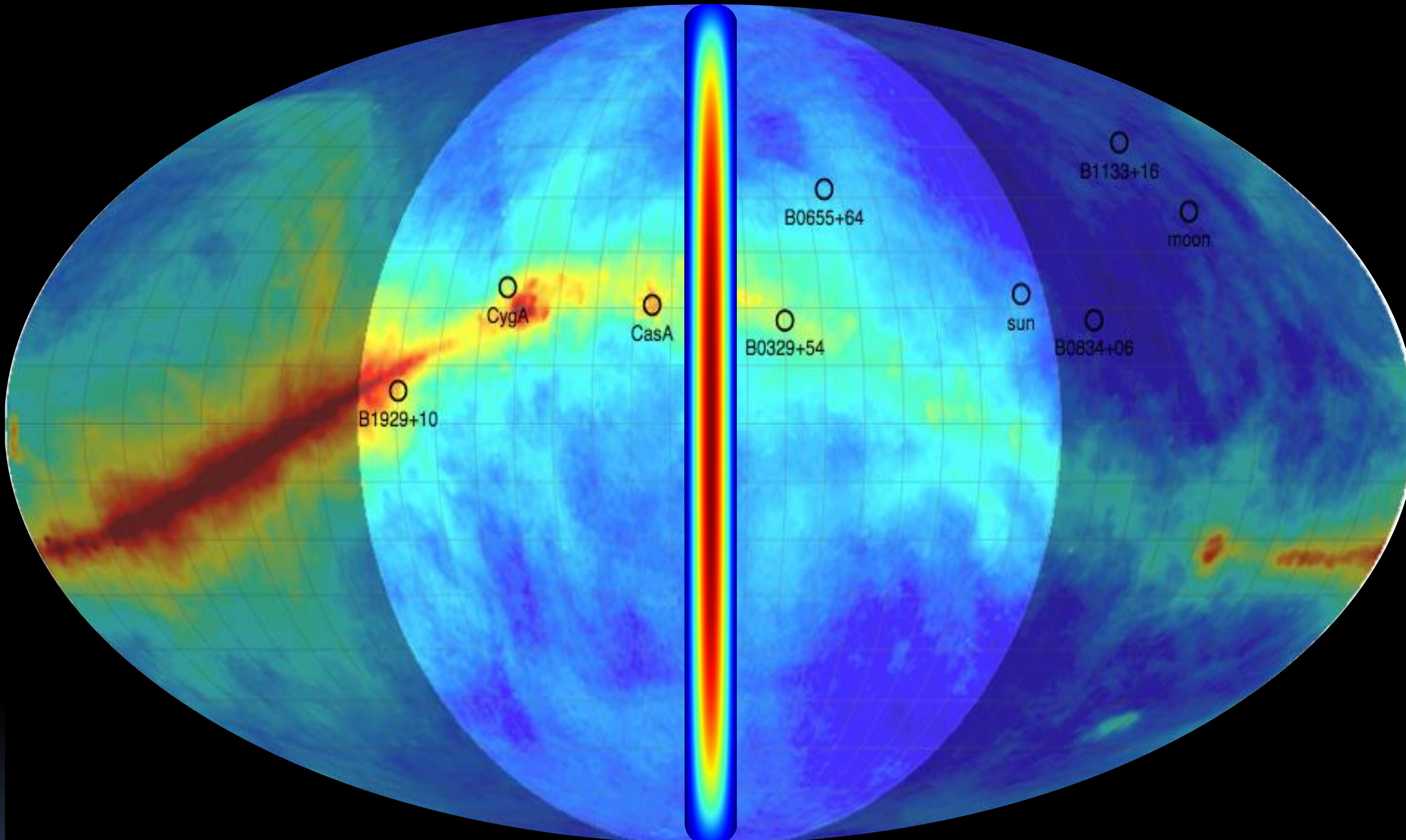
- At least one FRB repeats and is definitely cosmological!

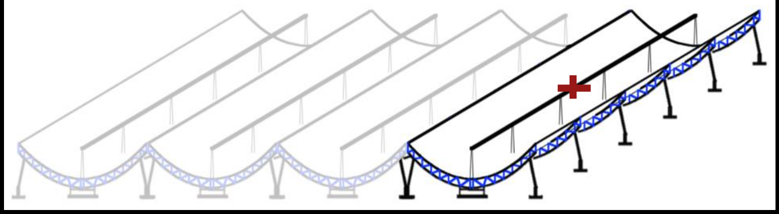
- Open questions
  - Is this representative?
  - What is the burst source?
  - What is the persistent source?
  - Is it related to SLSNe?

CHIME: Canadian Hydrogen Intensity Mapping Experiment

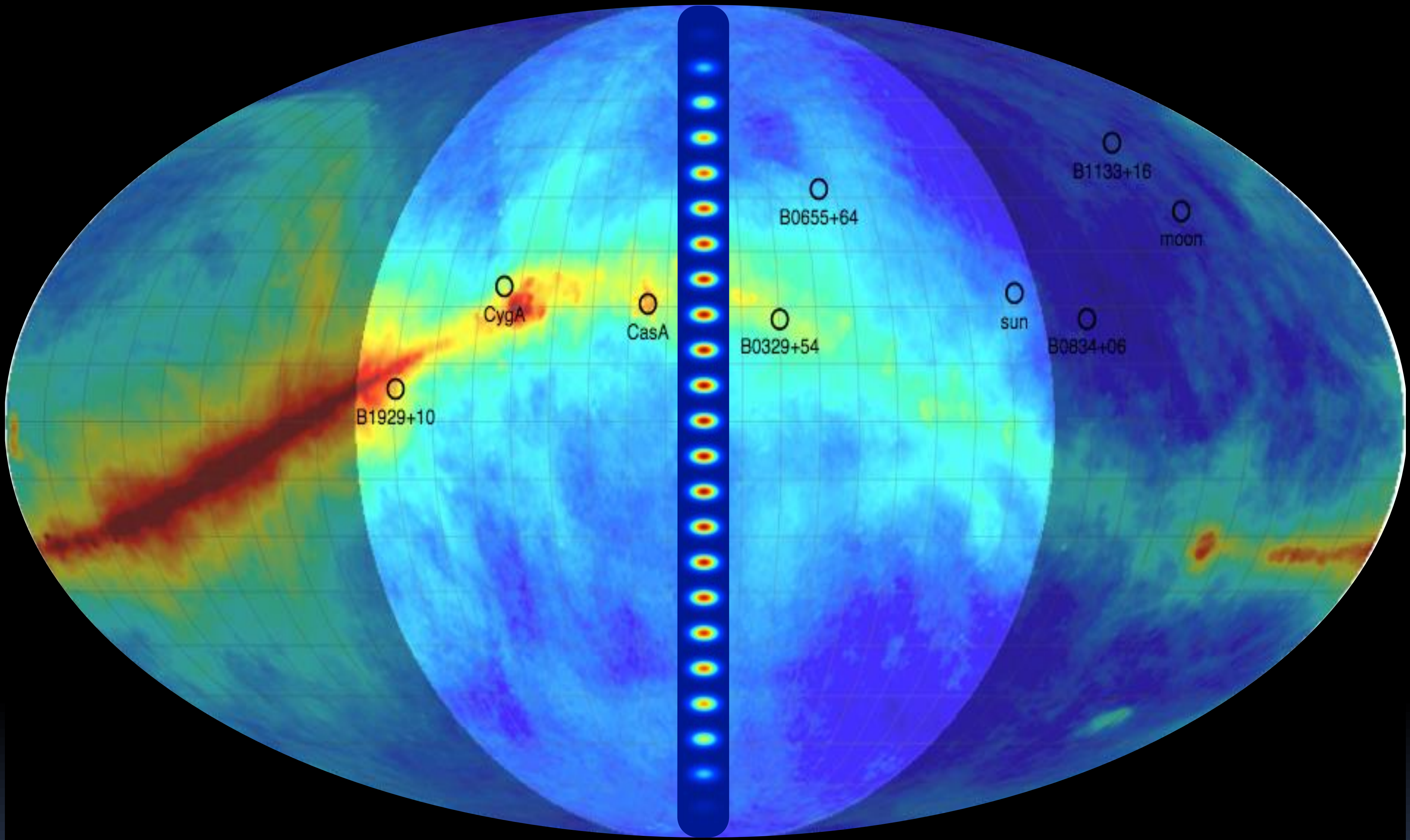
- Penticton, BC at DRAO
- 4 20 m x 100 m cylinders
- Transit telescope
- 256 dual-pol feeds per axis, 2048 input signals
- 400-800 MHz
- FOV: E-W 2.5^{o}-1.3^{o},
  N-S ~120^{o}
- Beam size 0.5^{o}-0.3^{o}
- CFI-funded $16M CDN: McGill, UofT, UBC

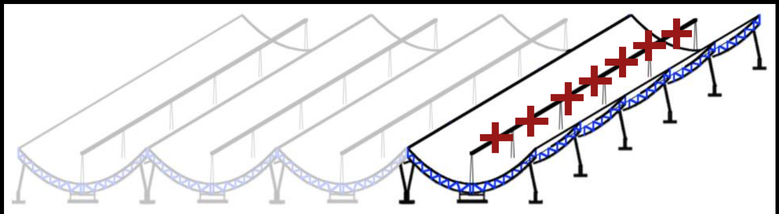
10 Terabits/s!



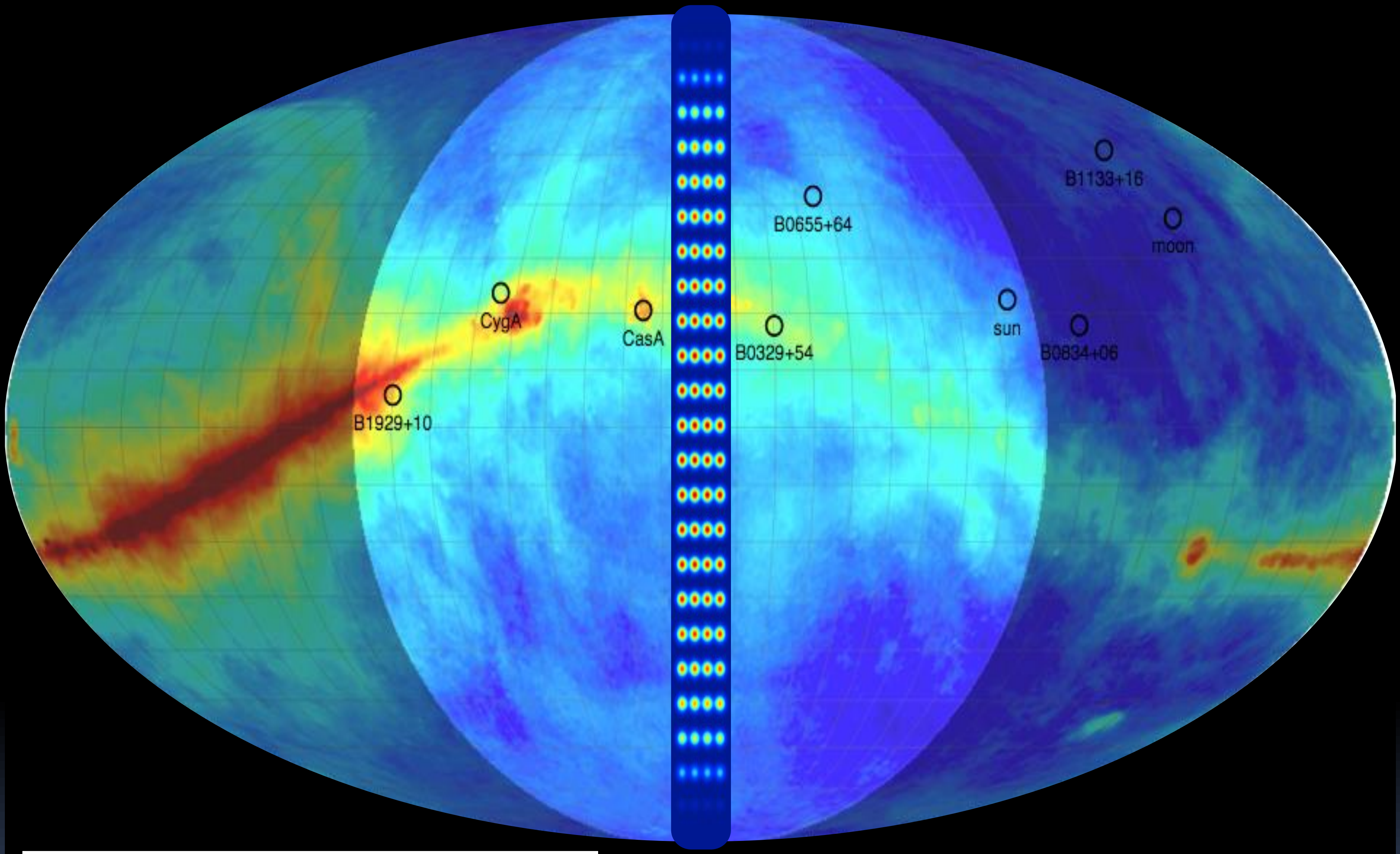


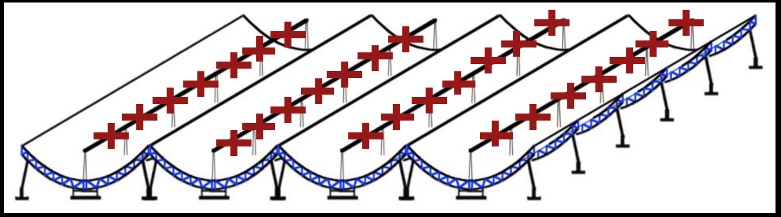
- Cylinder focuses light only in EW direction
- Gives us large FOV





- FFT telescope in NS direction
- 256 beams per cylinder





- 1024 beams from full 4-cylinder CHIME

CHIME & FRBs

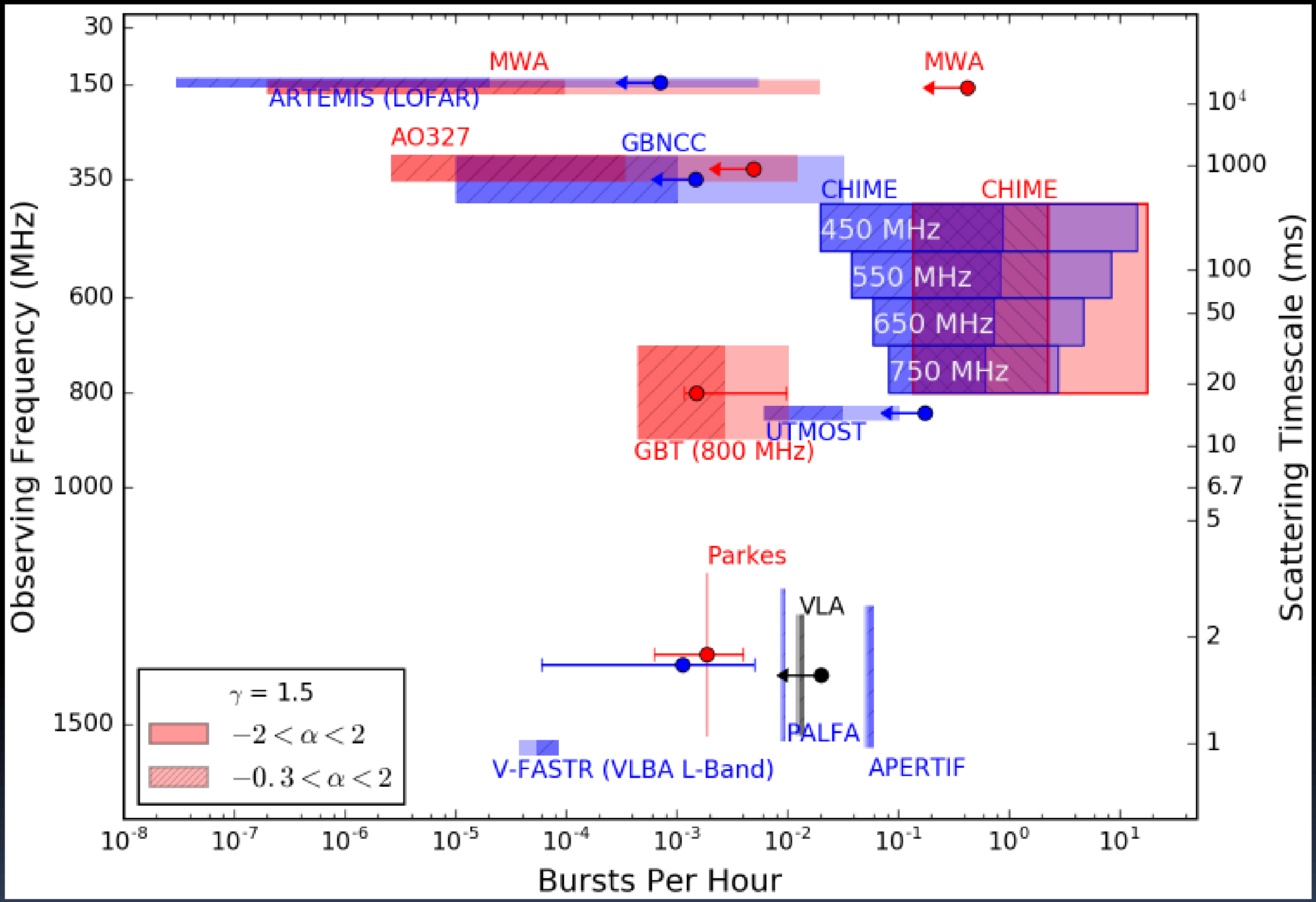
CHIME's

* 220 sq deg field-of-view

* wide 400-800 MHz Bandwidth

* Large collecting Area

mean it will detect <u>several FRBs per day!</u>



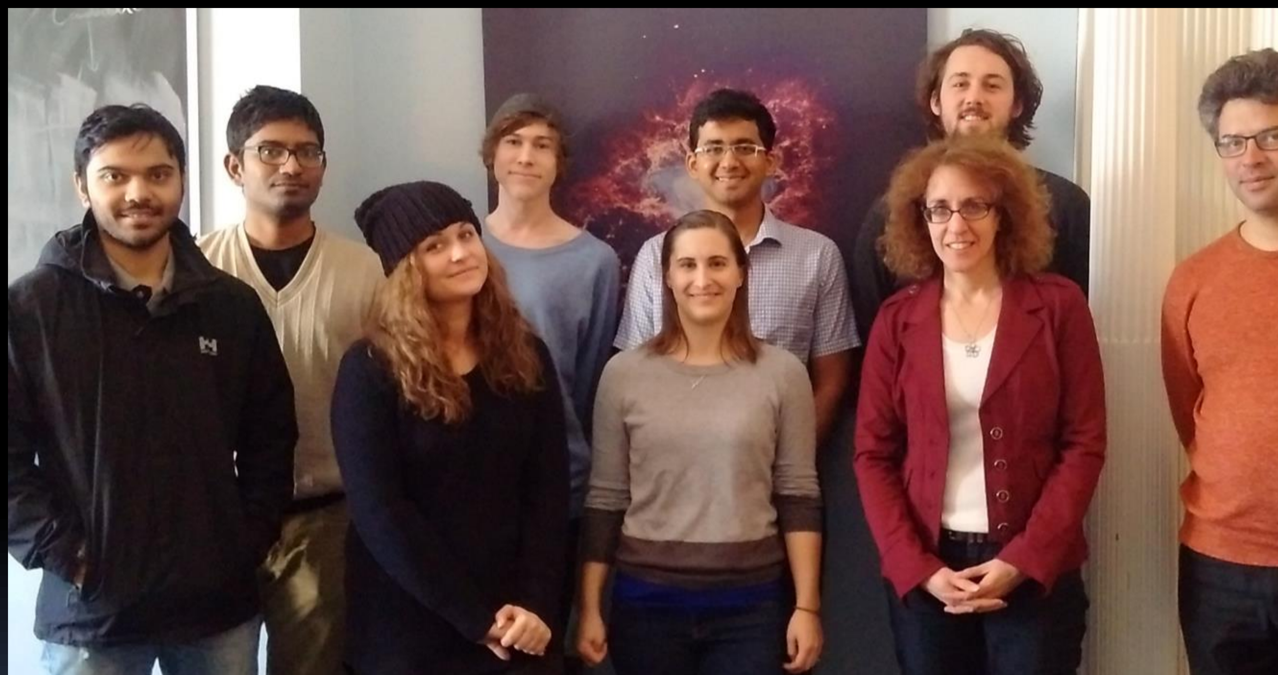
Chawla et al. 2017

Conclusions

- FRBs are here to stay
- Origin remains unknown
- Perhaps all repeat?
- First localization accomplished
  - Cosmological distance confirmed!
- CHIME will be a great FRB machine!

Thanks to…

CHIME Team



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McGill Space Institute

NSERC CRSNG

Fonds de recherche Nature et technologies Québec

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