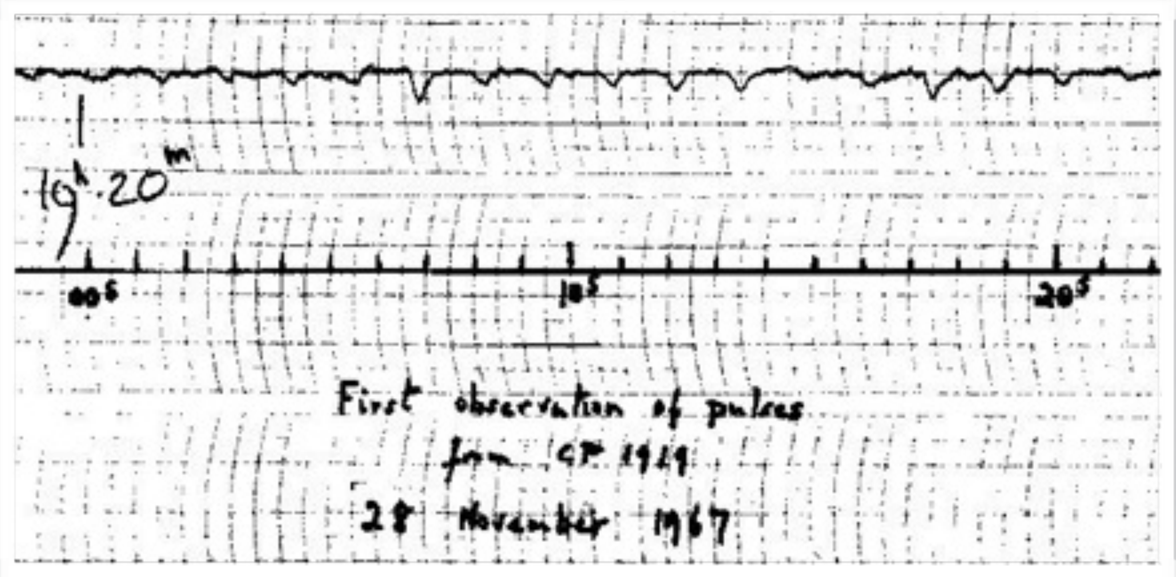
Fast Radio Bursts

Marta Burgay

INAF OAC Osservatorio Astronomico di Cagliari

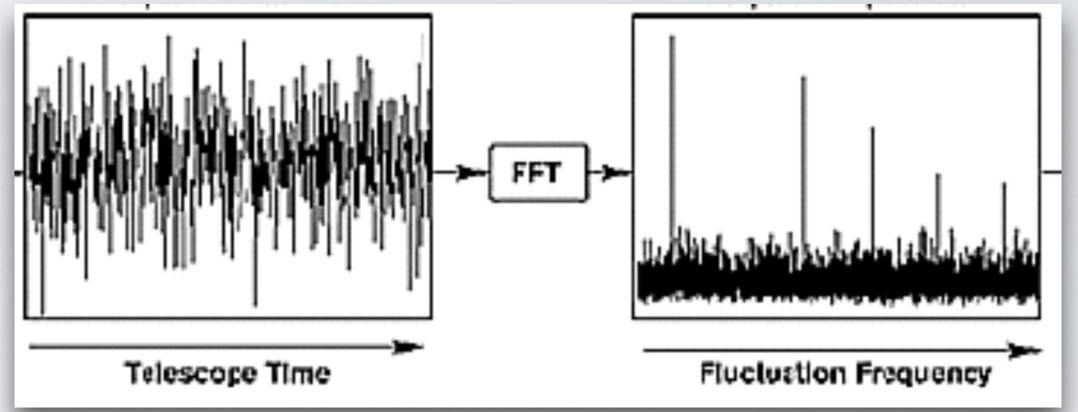
1967: THE FIRST 'FAST RADIO BURSTS'

Jocelyn Bell set the field going in 1967 by discovering pulsars through their time-variable bursts of emission



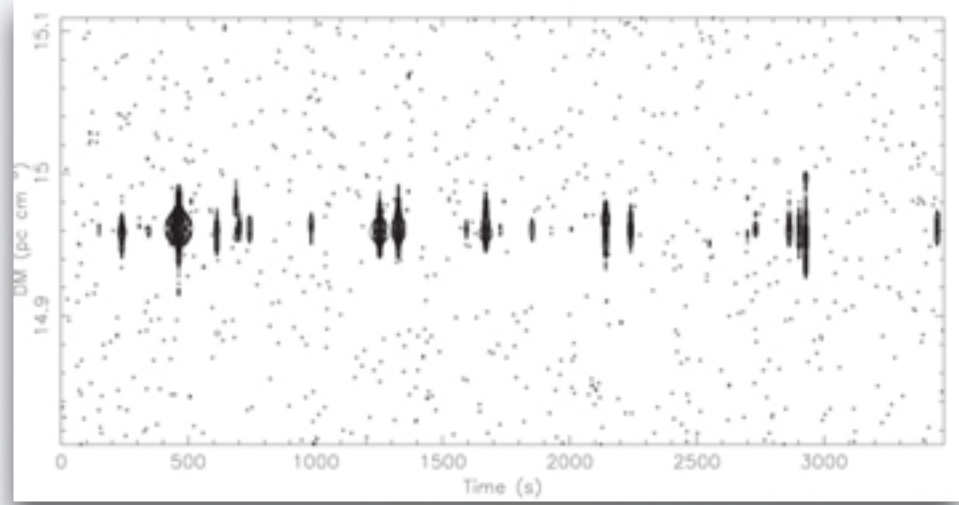
Searches for PSRs and Fast Transients

- Periodicity searches through FFTs



- Fast transient (single pulses) searches resumed only recently

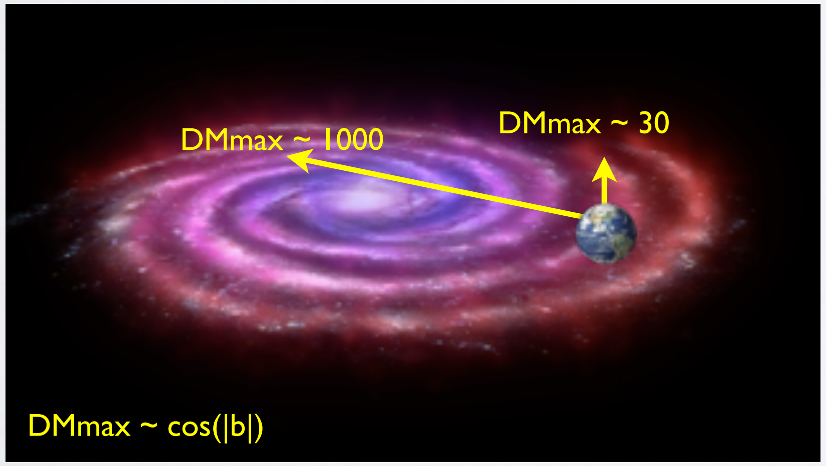
- Discovery of RRATs

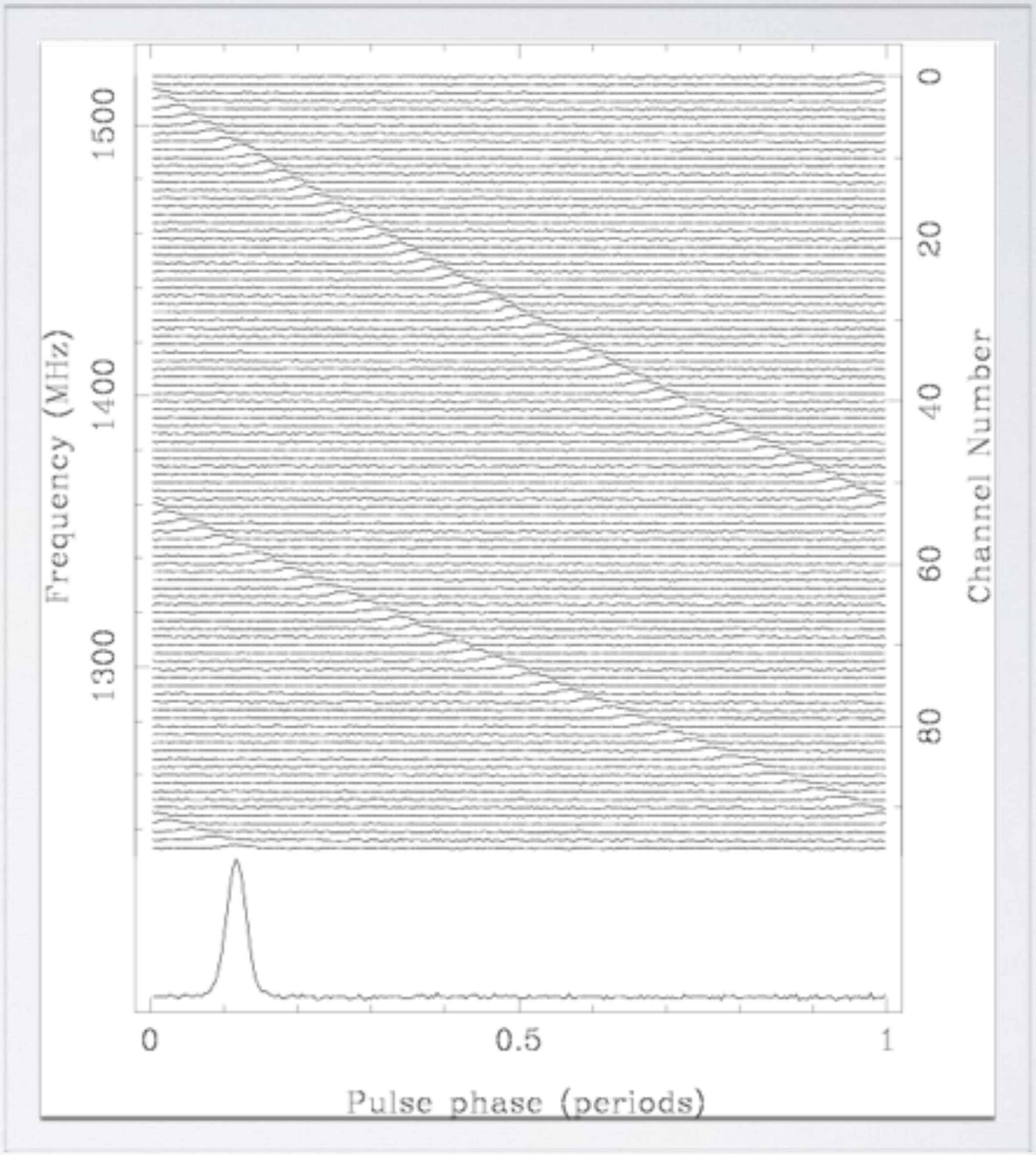


DISPERSION OF A RADIO SIGNAL

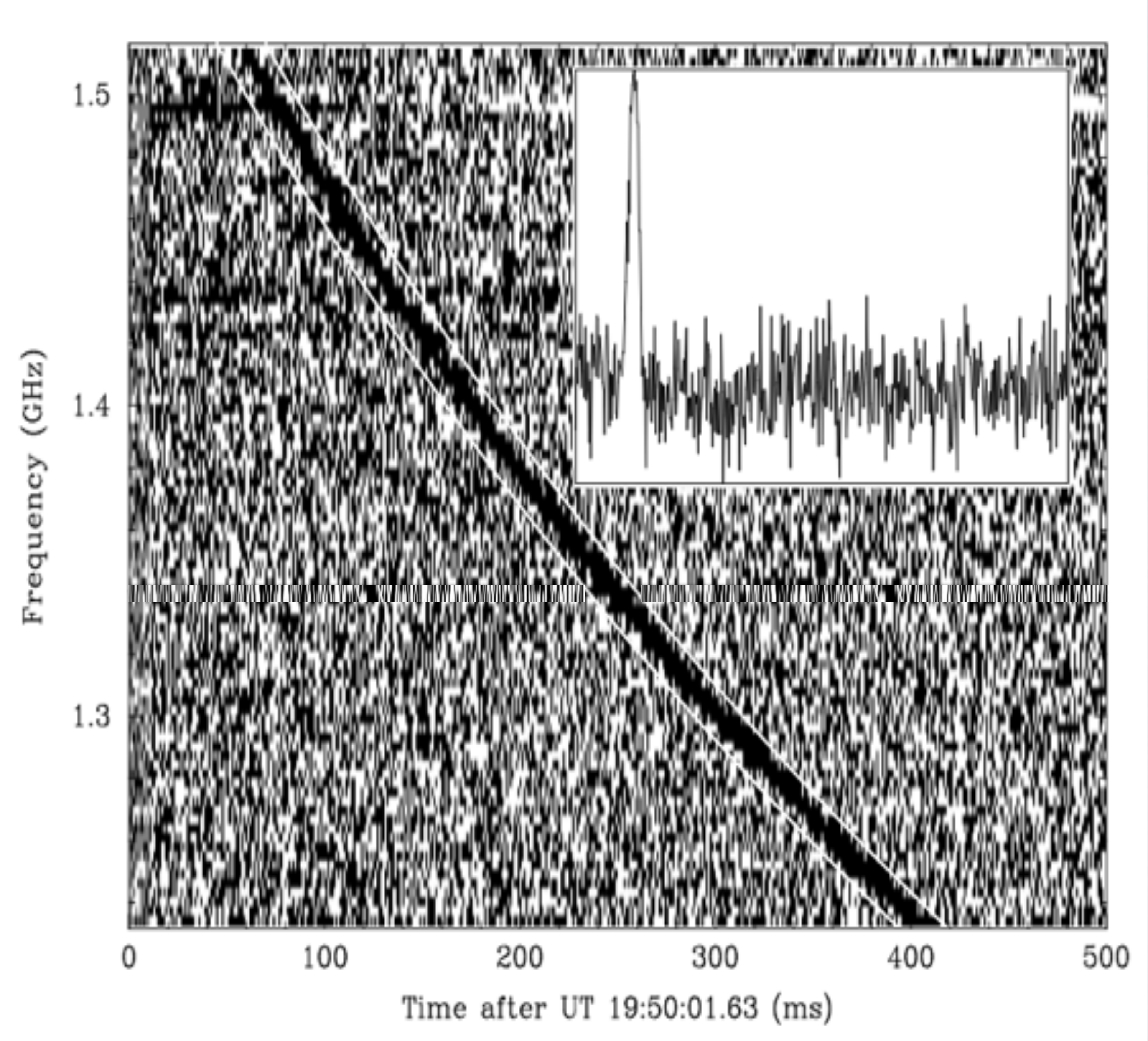
Travelling through an ionised medium, radio waves arrive earlier at higher frequencies.

$$DM = \int_0^d n_e \, ds$$





2007: The Lorimer Burst



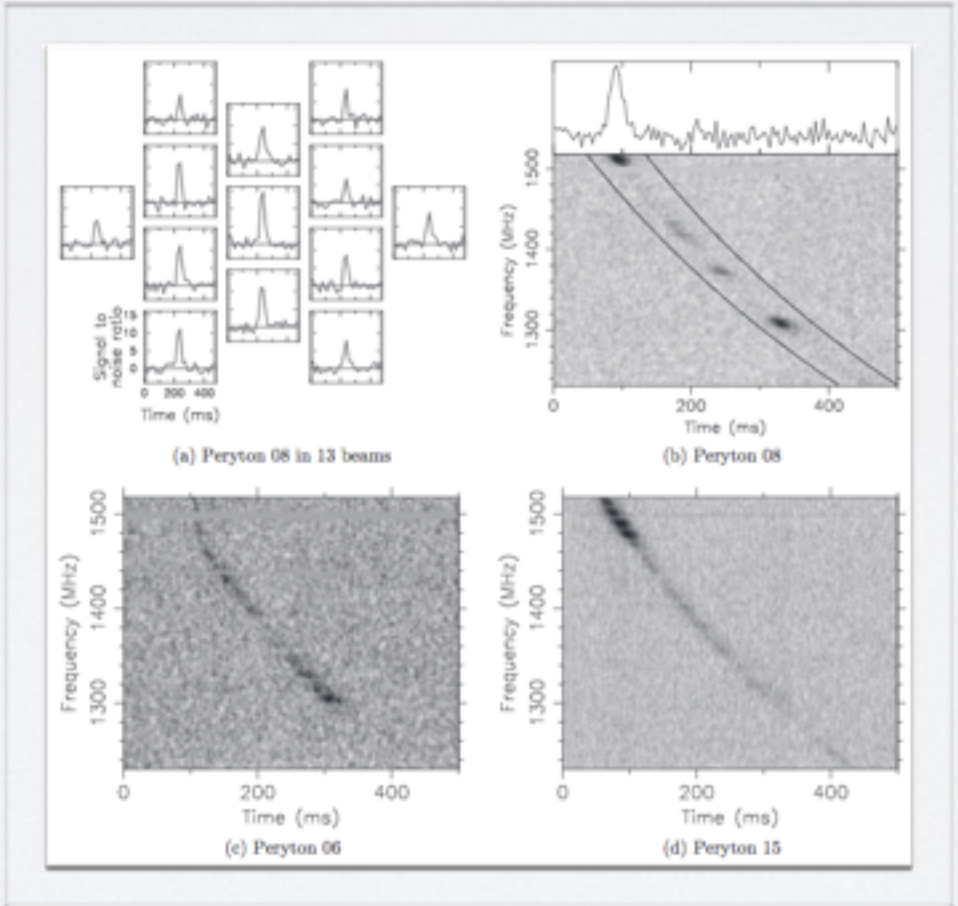
Lorimer et al 2007

First case of detection of an extragalactic (?) dispersed radio burst

2011: Perytons set back the field

Abstract:

frequency sweep with a shape and magnitude resembling the Lorimer Burst. These new events were detected in a sidelobe of the Parkes Telescope and are of clearly terrestrial origin, with properties unlike any known sources of terrestrial broadband radio emission. The new detections cast doubt on the extragalactic interpretation of the original burst, and call for further



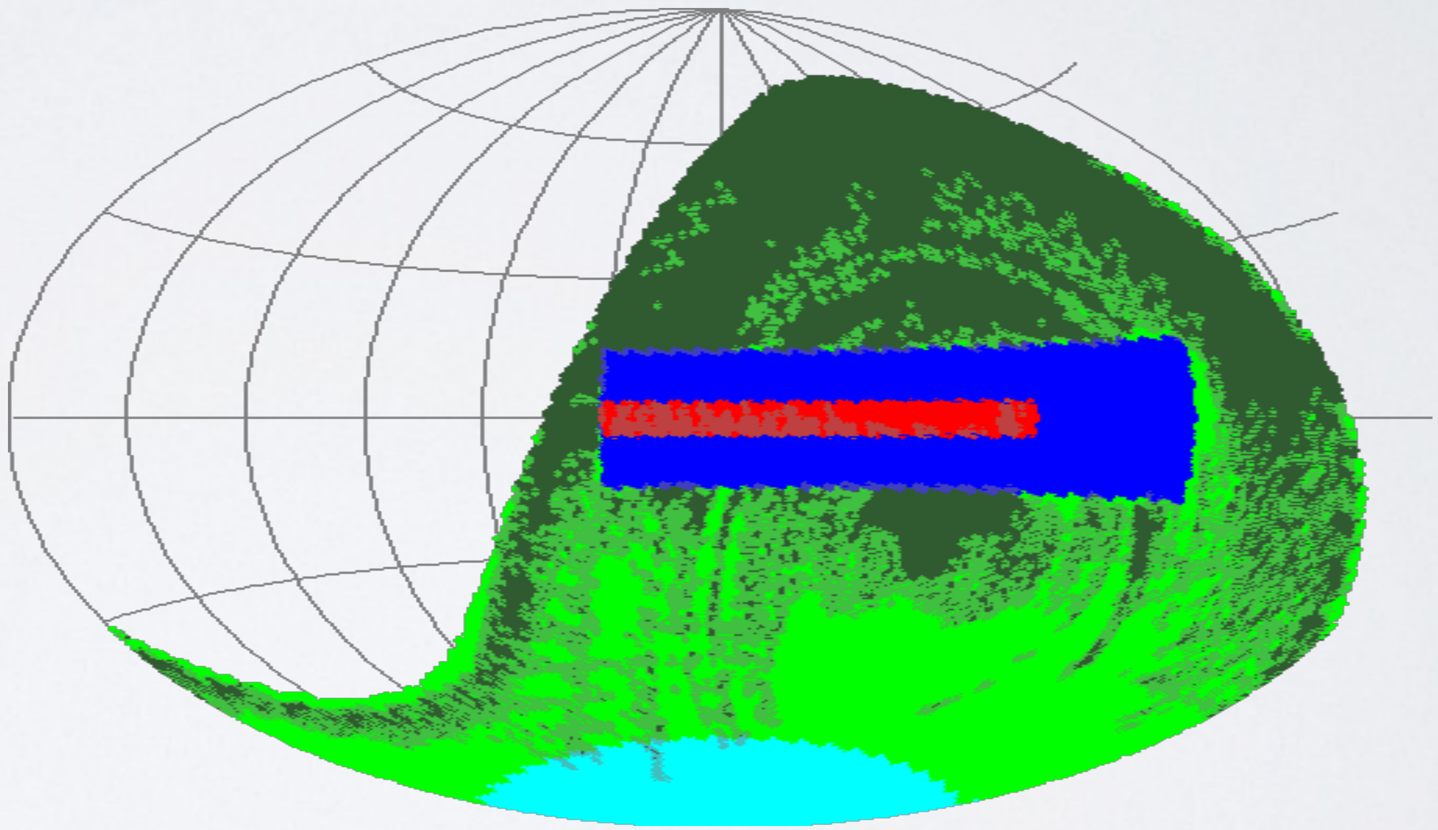
Burke-Spolaor et al. 2011. ApJ.

THE HIGH TIME RESOLUTION UNIVERSE SURVEY

Survey
1.4 GHz, 13 beams
400 MHz BW
1024 channels
64us sampling

Galactic Plane
70 min/pt
-80< gl <30
|gb|<3.5
1240 pointings

Intermediate
8.5 min/pt
-120< gl <30
|gb|<15
6690 pointings



Keith et al. 2010 (MNRAS)

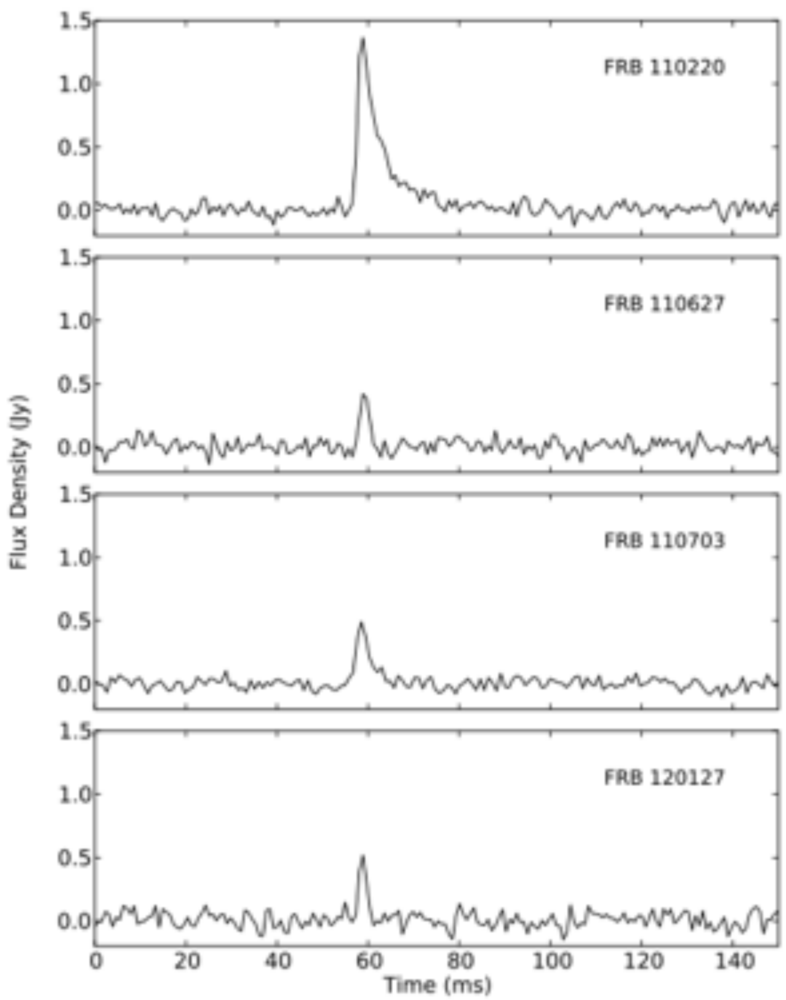
All Sky
4 min/pt
Southern sky
36450 pointings

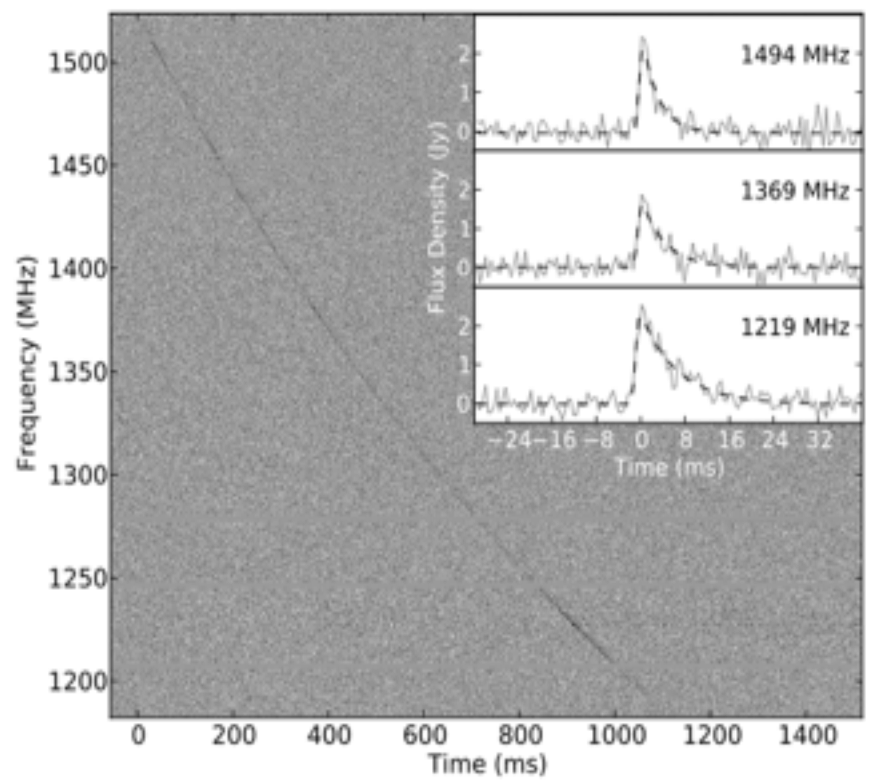
2013: The discovery of a Population of Fast Radio Bursts

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]

Published in *Science*, Vol. 340, Issue 6141 (5th July 2013)

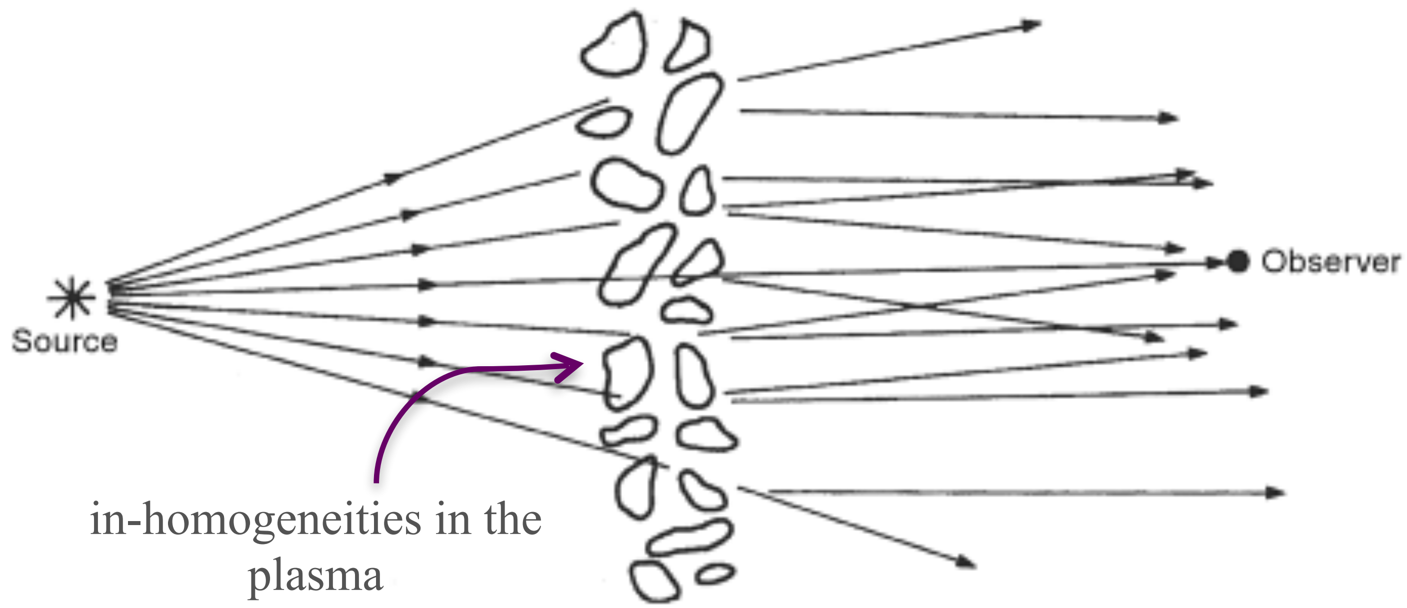


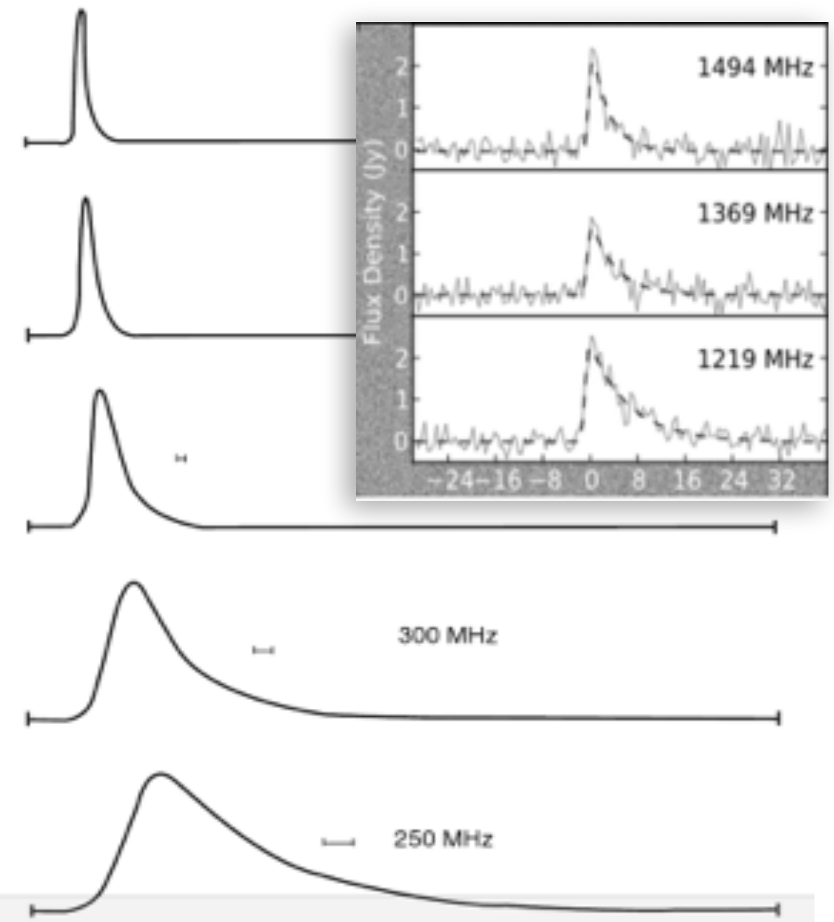


Clear signature of a signal undergoing "scattering" in FRB110220

THE IMPACT OF INHOMOGENEOUS PLASMA ON A RADIO SIGNAL

[from Graham-Smith & Lyne]

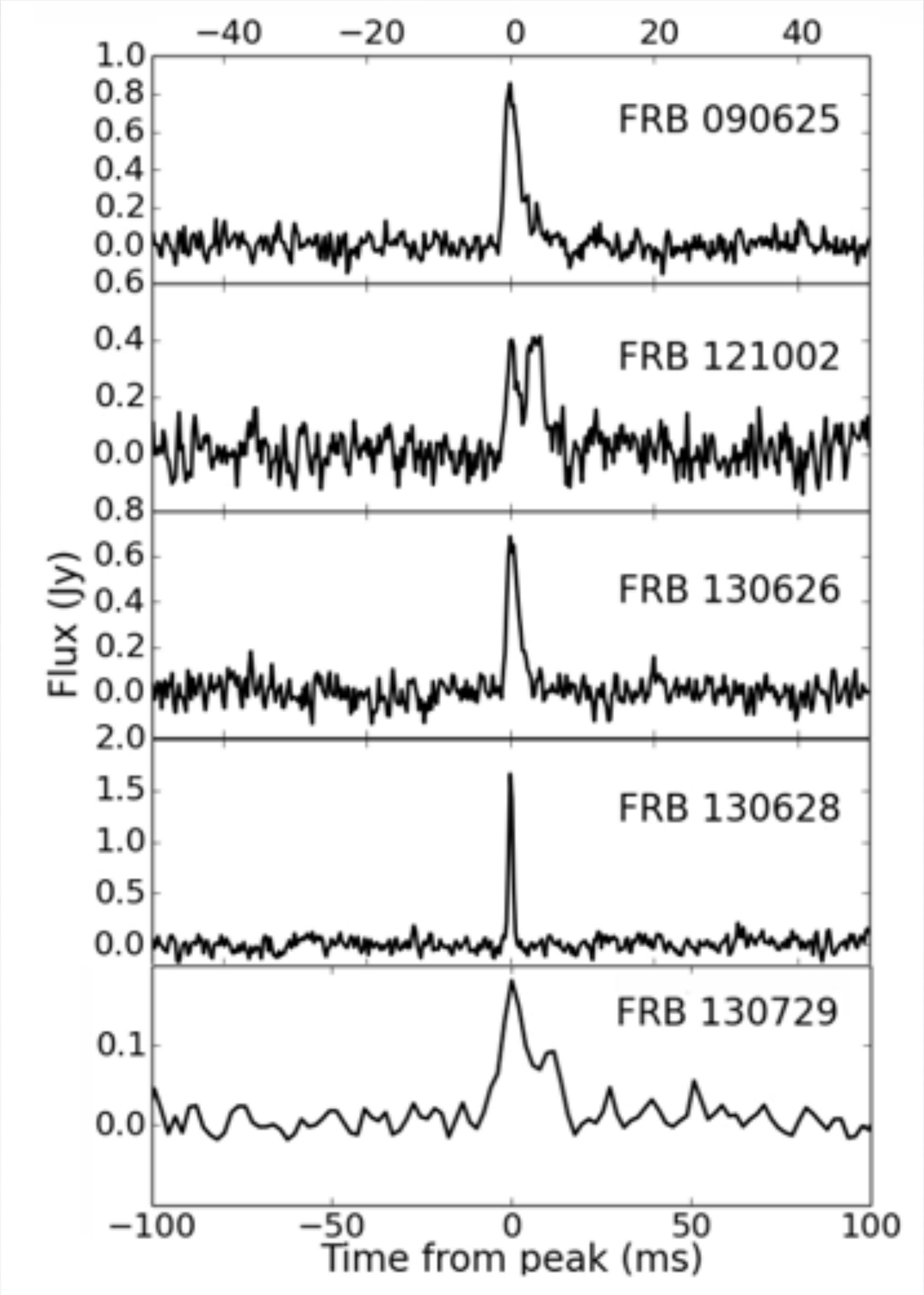




For a Kolmogorov spectrum of in-homogeneities, the scattering time τscatt , i.e. the e-folding time of the asymmetrical exponential tail, scales as

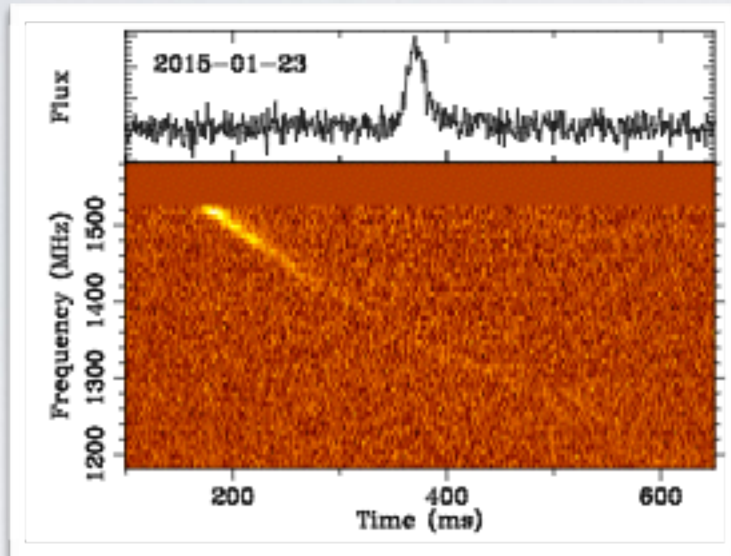
$\tau_{scatt} \cong \nu^{-4.4}$

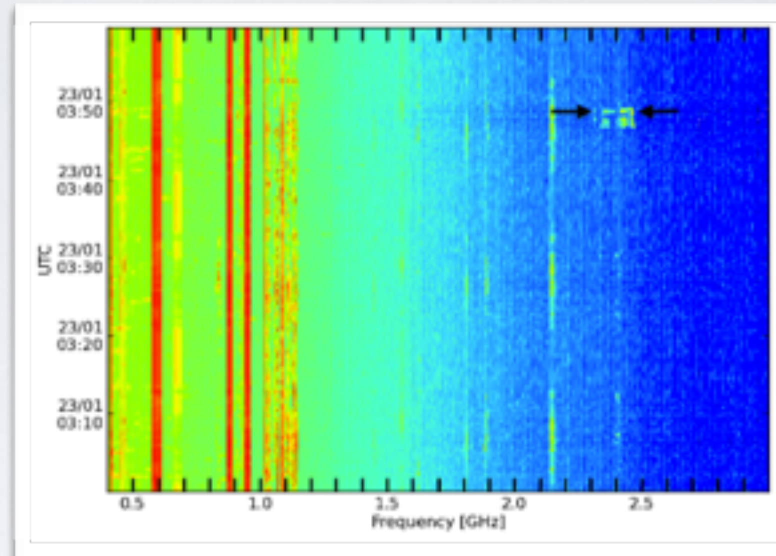
MORE HTRU FRBS



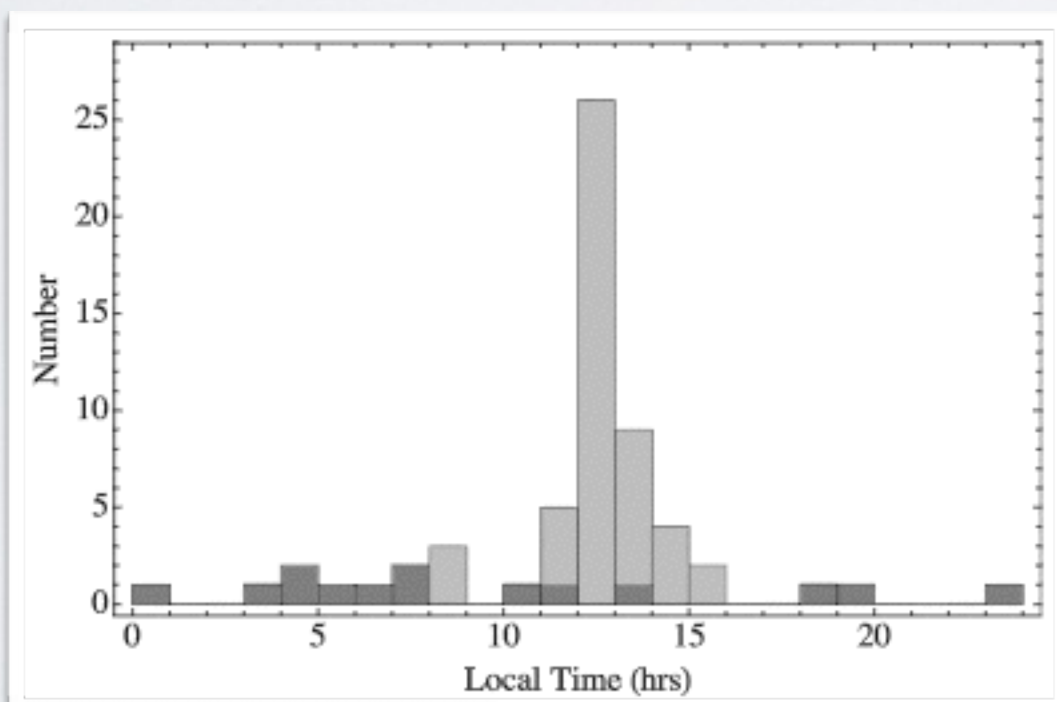
Champion et al. 2016. MNRAS.

2015: Perytons' mystery solved!

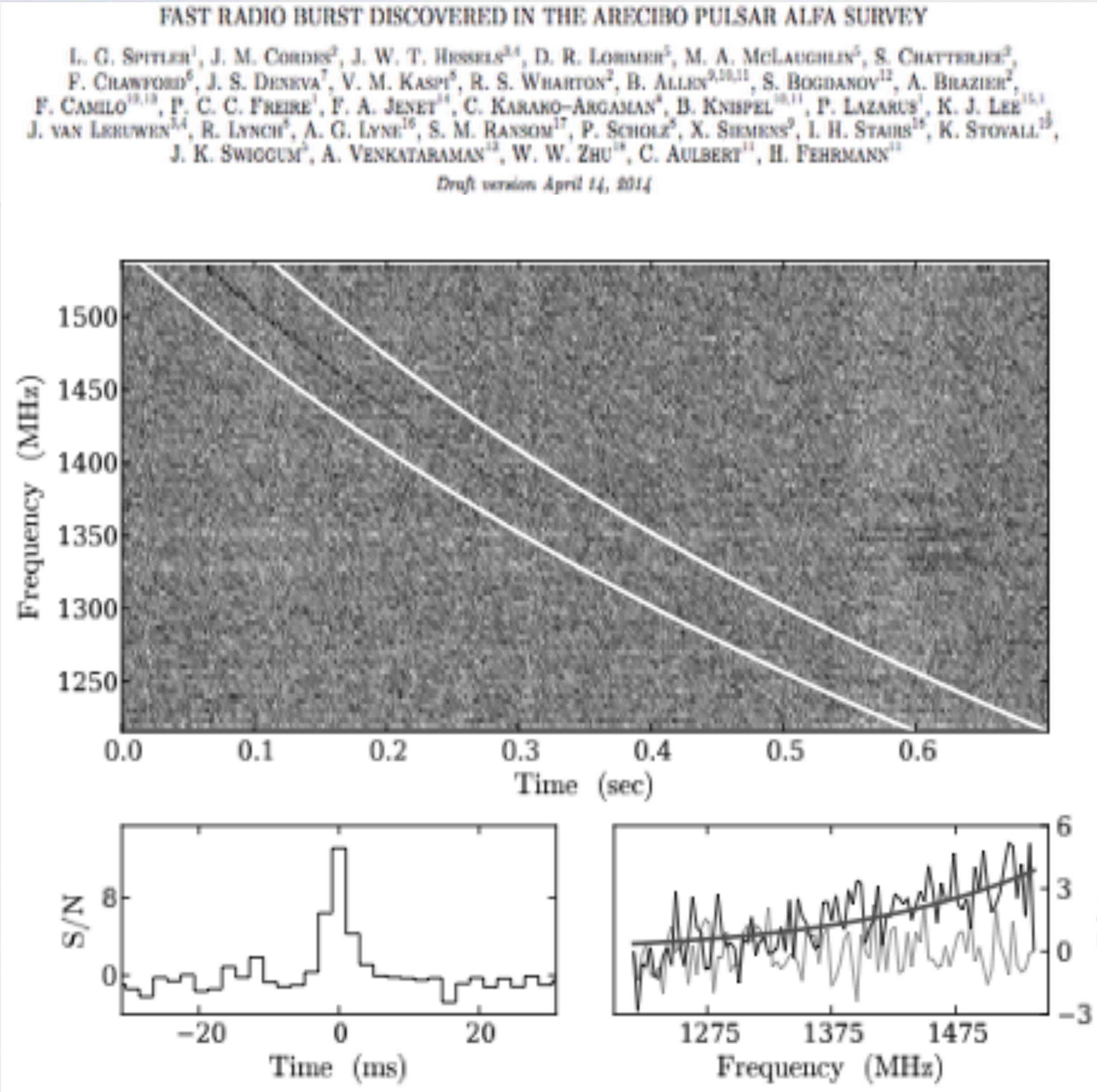


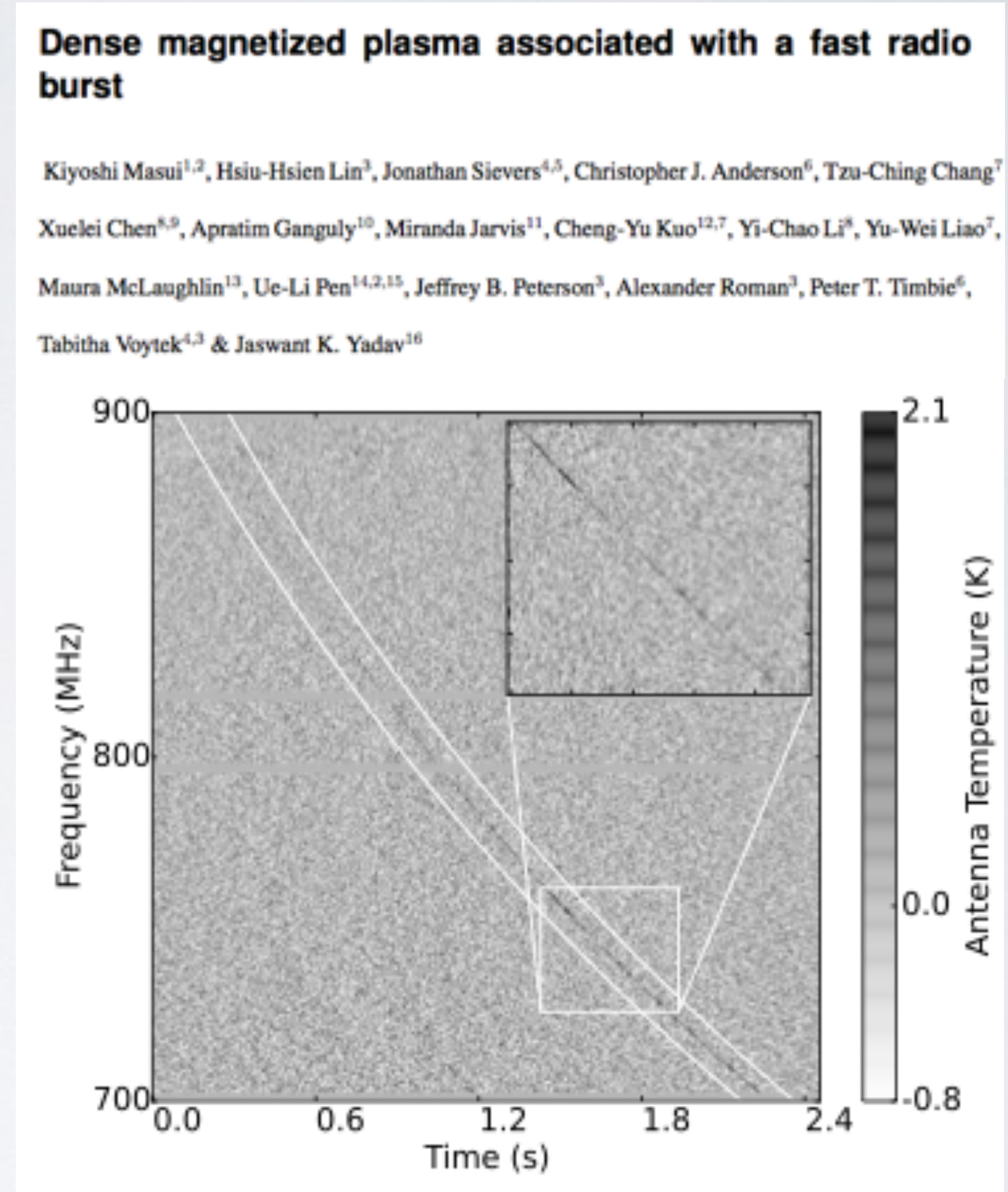


Petrof et al. 2015 (MNRAS)



FRBs at other telescopes and frequencies





The official catalogue of published FRBs

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/frbcat/).

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

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

Observational features

- Burst of $\approx$ millisecond duration
- Dispersion measure DM $>$ few $\times$ DM_{MW} (the expected Milky-Way contribution)
- Dispersion delay consistent with ν^{-2} (e,g. $\nu^{-2.003\pm0.006}$, $\nu^{-2.000\pm0.006}$, $\nu^{-1.998\pm0.003}$)
- When measurable, scattering time compatible with Kolmogorov (e.g $\nu^{-4.8\pm0.4}$, $\nu^{-4.0\pm0.4}$, $\nu^{-3.6\pm1.4}$)
- Peak Flux density at 1.4 GHz $\approx$ 0.1-10 Jansky
- Fluence at 1.4 GHz $\approx$ 0.1-10 Jansky $*$ ms

[Thornton et al 2013, Spitler et al 2014, Masui et al 2015, Keane et al 2016, Champion et al 2016, FRB catalogue]

FRBs Event Rates

Combining all Parkes surveys:

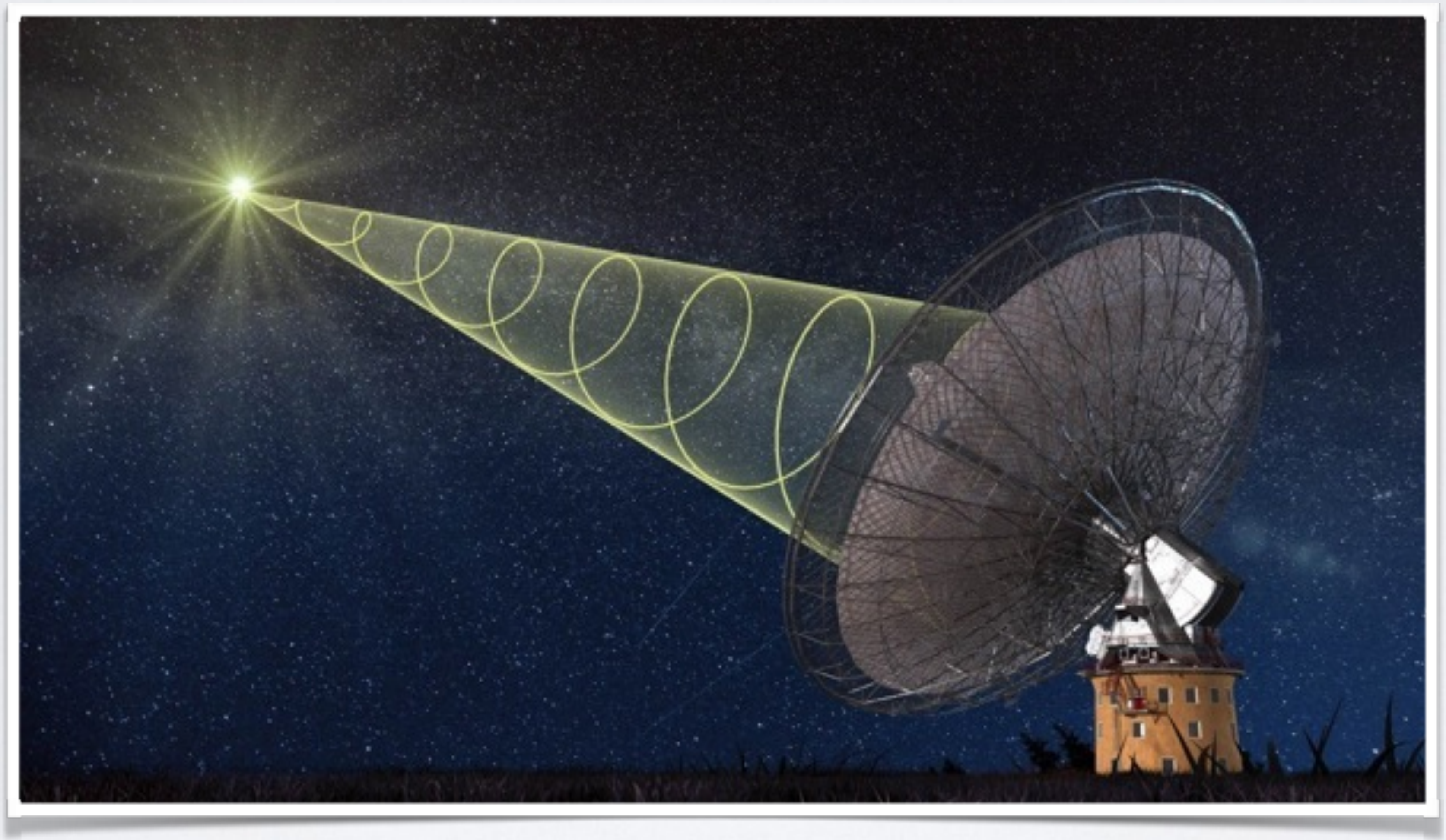
- [3÷10] × 10^3 sky/day [Champion et al 2016] for fluence > 0.13-5.9 Jy ∗ ms
- [1.3÷9.6] × 10^3 sky/day [Rane et al 2015] for fluence > 4.0 Jy ∗ ms
- ≈ 2800 sky/day [Keane & Petroff 2015] for fluence > 2.0 Jy ∗ ms
  where Parkes survey are basically "complete"

All calculations predict:
rate at 1.4 GHz ≈ $10^{-2} \div 10^{-3}$ per year in a MilkyWay-like galaxy

Open Questions

What are FRBs?

Can they be used as cosmological probes?

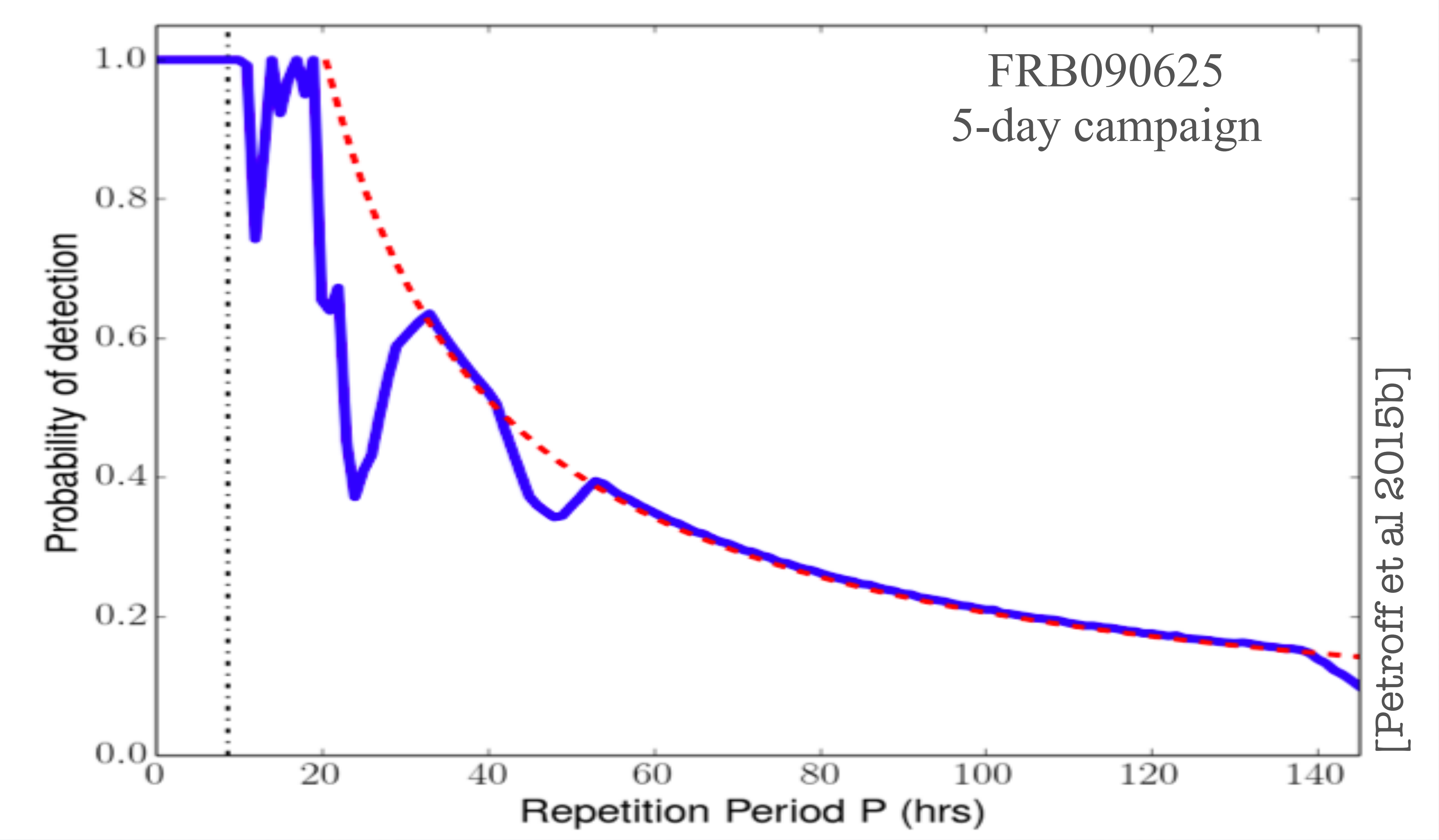


FRB Models

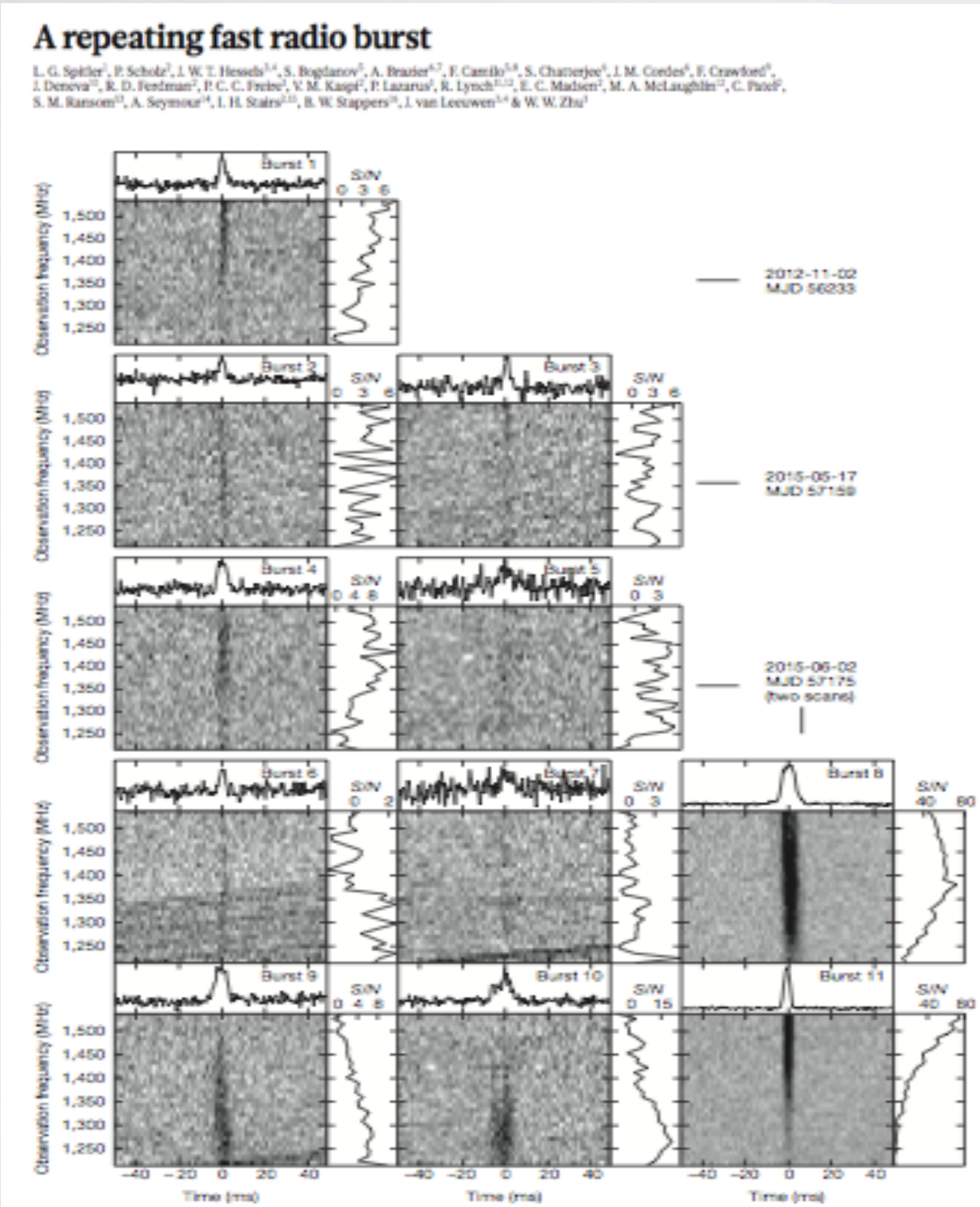
- Bursts from corona of very nearby flare stars [Loeb et al. 2013]
- Asteroid/Planet/WD magnetosphere interaction with the wind from a orbited pulsar/NS [Mottez & Zarka 2014]
- Core Collapse SuperNovae, [Thornton et al 2013]
- Binary WD merger to highly magnetic rapidly spinning WD [Kashiyama et al 2013]
- Binary Neutron Star merger; short hard GRBs [Keane et al. 2012, Totani et al 2013, Zhang et al 2014]
- Evaporating primordial BH [Keane et al 2012]
- BH to WH quantum transition [Haggard & Rovelli 2014]
- Collisions btw axion stars and neutron stars [Iwazaki 2014]
- Explosive decay of axion miniclusters [Tkachev 2014]
- Superconducting cosmic string (SCS) loops [Cai et al. 2012] oscillating in cosmic magnetic fields [Yu et al 2014]
- Blitzar: Collapse to BH of a supramassive NS [Falcke & Rezzolla 2014] from an original scenario of [Vietri & Stella 2000]
- Magnetar giant flares [Popov & Postnov 2010, Thornton et al 2013]
- Hyper Pulses from extra-galactic NSs [Cordes & Wasserman 2016]

LIMITS ON REPEATABILITY…

A survey of 110 hours over 6 months dedicated to re-observing the fields of 8 known FRBs
No repeat emission was detected from an FRB during this time



… BUT FOR FRB121102



Follow-up pointings with Arecibo (1.4 GHz) and Green Bank (2.0 GHz) telescope toward the position of FRB121102 [Spitler et al. 2014]

seen to repeat!
[Spitler et al. 2016]

The repeating bursts are resolved in time:
i.e. intrinsic timescale of ≈ ms
vs
often unresolved Parkes FRBs, never seen (so far) to repeat [Keane et al. 2016]

DISTANCE FROM THE DISPERSION DELAY

If the frequency dependent arrival time of the FRBs is due to dispersion in a cold plasma, it is possible to use the observed DM to constrain the distance of the source.

Building up on pioneering works of [Ioka 2003] and [Inoue 2004], one can write the relation between DM, the Luminosity Distance DL , the redshift z, the matter density parameter in the universe Ω_m, the mean number density n_0 of nucleons at z=0 and fe ≈ 0.88 at low redshift

[Zheng et al. 2014]

$$\mathrm{DM} \cong n_0 f_e D_L \left[1 + 0.932z + (0.16\Omega_m - 0.078)z^2\right]^{-0.5}$$

which has an accuracy $\lesssim 0.5\%$ for $0 < z < 3$ with $0.25 < \Omega_m < 0.35$

Derived Features for Cosmological FRBs

Given the observed parameters

Assuming that the extra-DM is mainly due to the Inter Galactic Medium, one can derive the following additional parameters:

- Red-shift $0.2 < z < 1.0$ (IGM from [Ioka 2003;Inoue 2004])
- Co-moving distance $1 < D$ (Gpc) < 3
- Isotropic emitted energy $10^{38} < E_{iso}$ (erg) $< 10^{40}$
- Brightness temperature $10^{33} < T$ (K) $< 10^{36}$

FRBs as Cosmological probes

If cosmological, with a series of independent z determinations (from the identification of the source at other wavelengths), one could

- measure the density of the ionised component of the IGM [Zheng et al. 2014]
- measure the missing baryonic matter in the Universe [MacQuinn 2014]]
- weight baryons in the IGM [Deng & Zhang 2014]
- constrain the EoS of the "dark energy" [Gao et al 2014; Zhou et al 2014]
- probe the era of Helium re-ionisation at $z \approx 3$ [Zheng et al. 2014]
- put constraints to fundamental quantities and laws [Wei et al 2015]
- put limits to the existence of floating MACHO-like objects in the IGM via gravitational lensing [Zheng et al. 2014]
- 3D clustering of the electrons in the Universe, with > 10000 FRBs, even without redshift [Masui & Sigurdson 2015]
- put limits to the fraction of "dark matter" in MACHO of $>20M_{\odot}$ via counting the number of echoes due to gravitational lensing [Munoz et al 2016]

SUPERB: SOLVING FRBS' MYSTERY

SUrvey for Pulsars and Extragalactic Radio Bursts

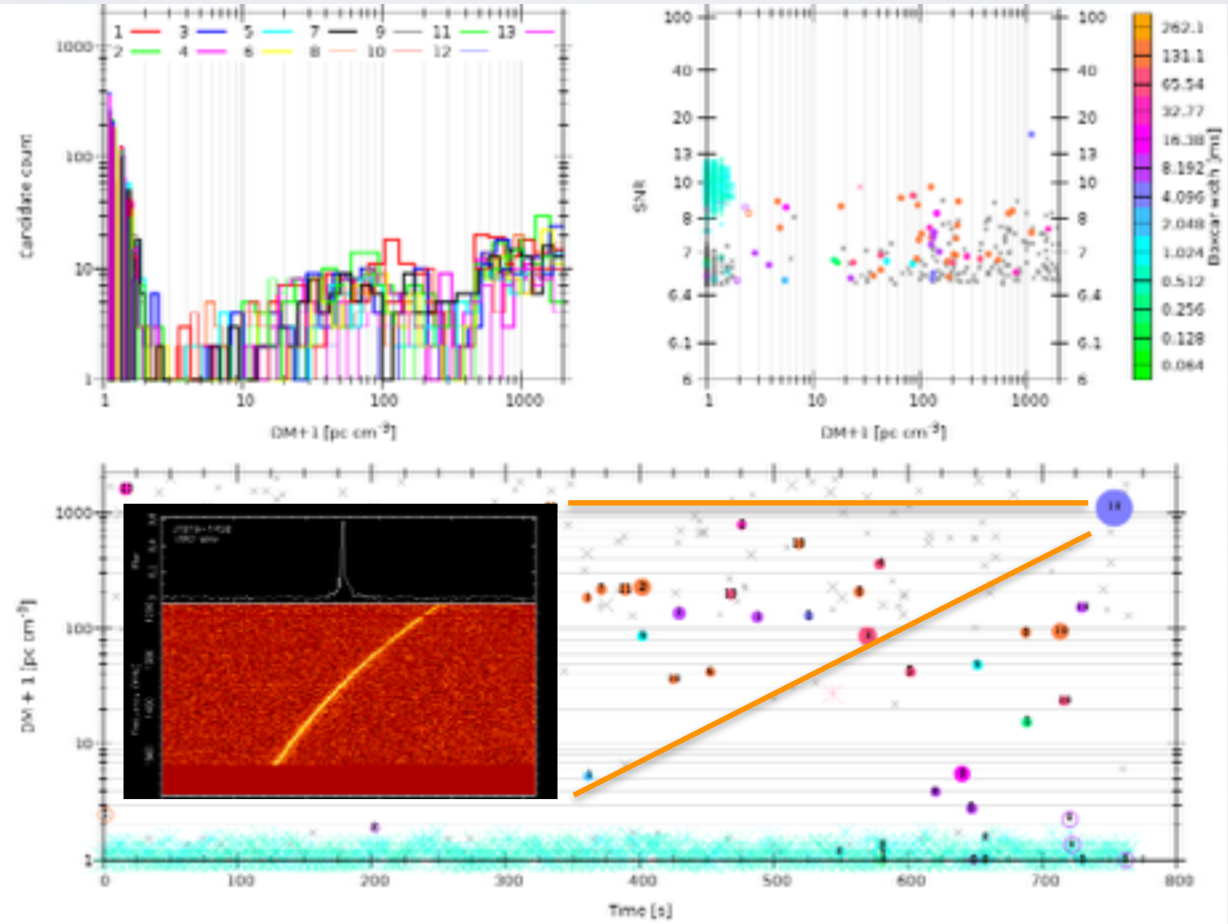
20cm, 13-beams receiver
-120 < l < 30; 15 < |b| < 25
30 < l < 50; |b| < 25

SUPERBx ongoing
|b| > 25º

Expected yield: ~10 FRBs (+ few tens of PSRs and MSPs)

SUPERB LIVE!

The FRB search is done in RAM "live" thus leading to real time discoveries



A trigger e-mail il sent to partners who signed an LoI with SUPERB to start multi-wavelength follow-up

SUPERB LIVE!

The FRB search is done in RAM "live" thus leading to real time discoveries

Name	Event date	Discovery date	Lag
FRB 010125 Burke-Spolaor/Bannister	2001	2014	13 years
FRB 010724 Lorimer	2001	2007	6 years
FRB 110220 Thornton	2011	2013	2 years
FRB 140514 Petroff	14 May, 2014 17:14:11 UT	14 May, 2014 17:14:30 UT	20 seconds

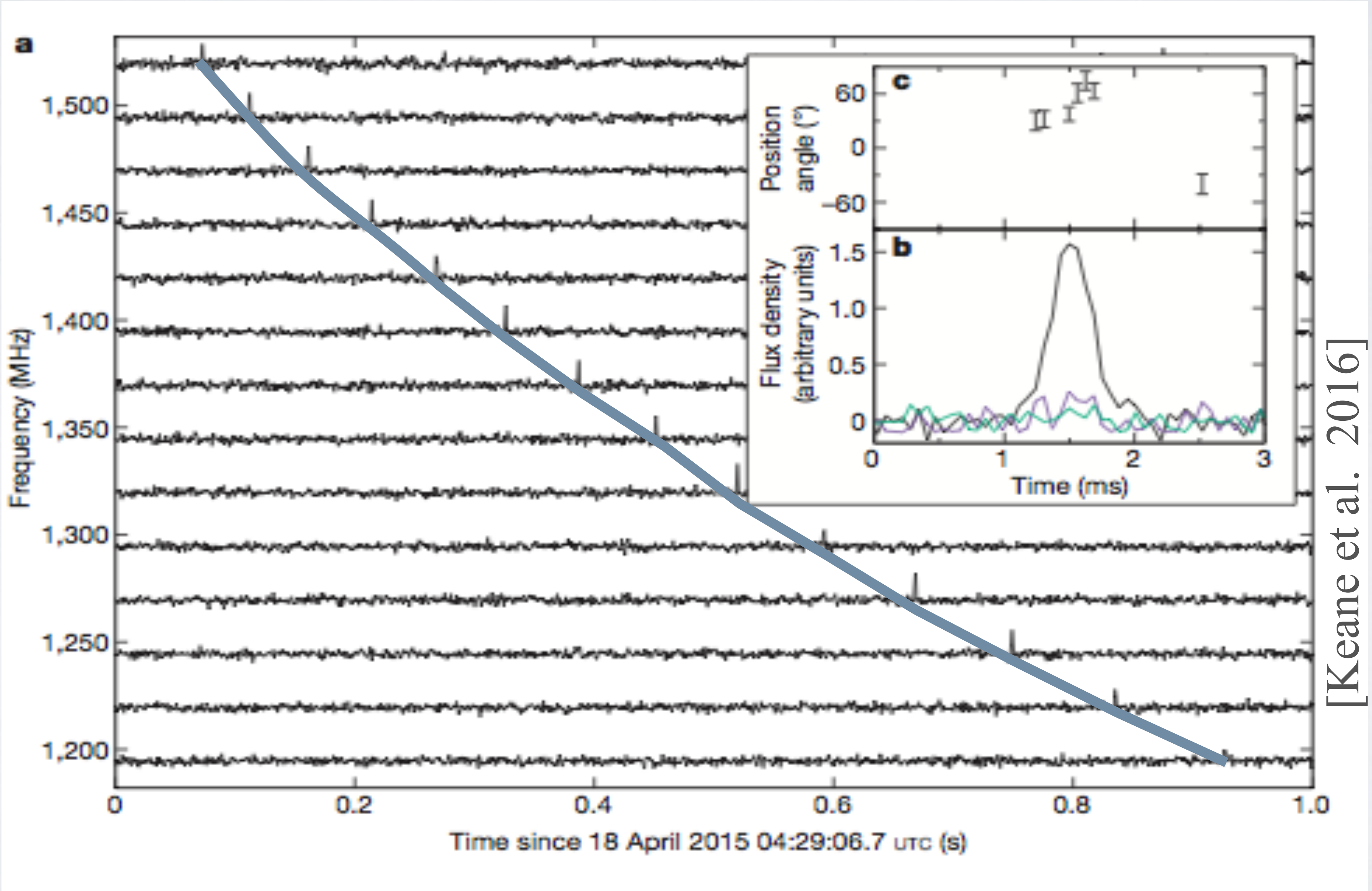
[Petroff et al 2015a]

A trigger e-mail il sent to partners who signed an LoI with SUPERB to start multi-wavelength follow-up

SUPERB FOLLOW-UP

FRB150418: a Rosetta stone ?

DM = 776 pc/cm3, unresolved 0.8 ms-wide pulse
Flux at peak = 2.2 Jy, ≈10% linear pol, no circ pol, no RM determined

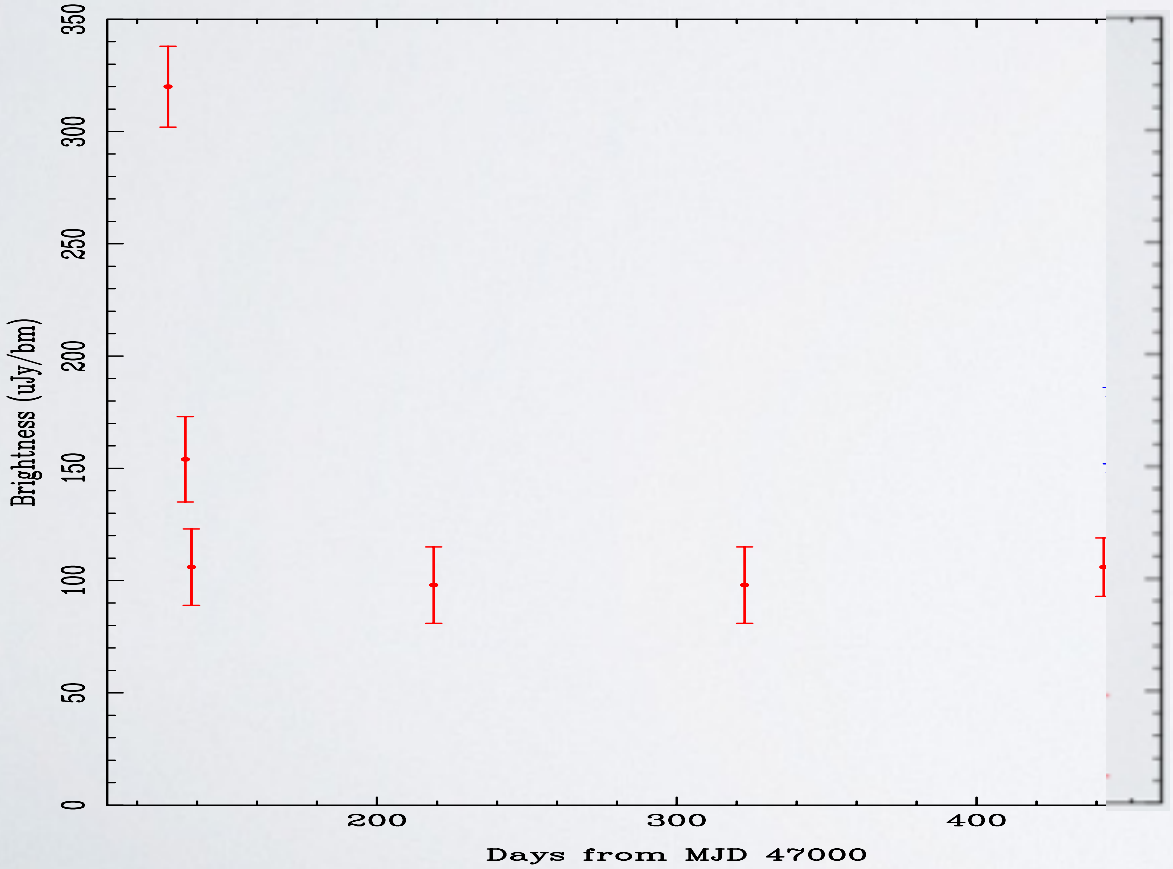


[Keane et al. 2016]

FRB150418: A Rosetta stone ?

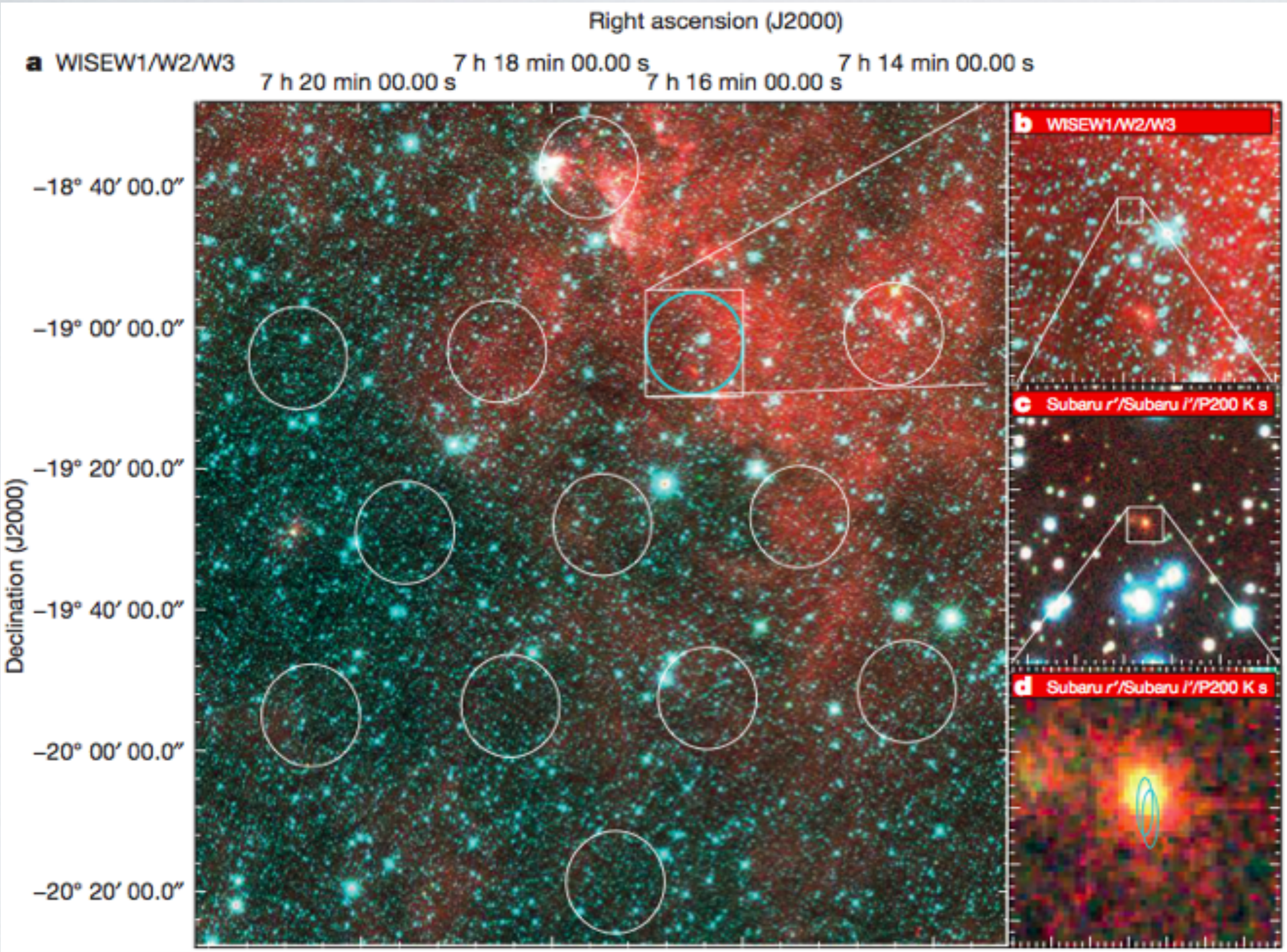
Radio interferometry with ATCA less than 2 hours after the detection at Parkes

Keane et al. Nature



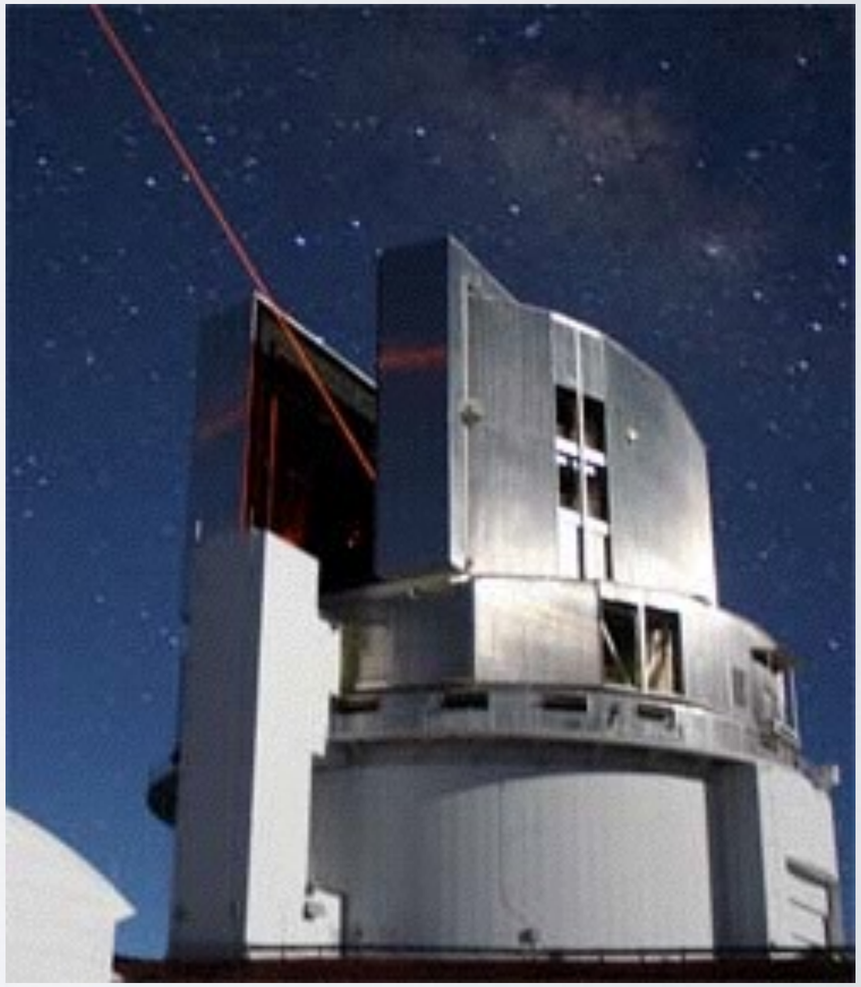
Observed a fading radio source in the uncertainty beam of the Parkes detection that showed a 3x flux variation in about 1 week

FRB150418: A ROSETTA STONE ?



[Keane et al. 2016]

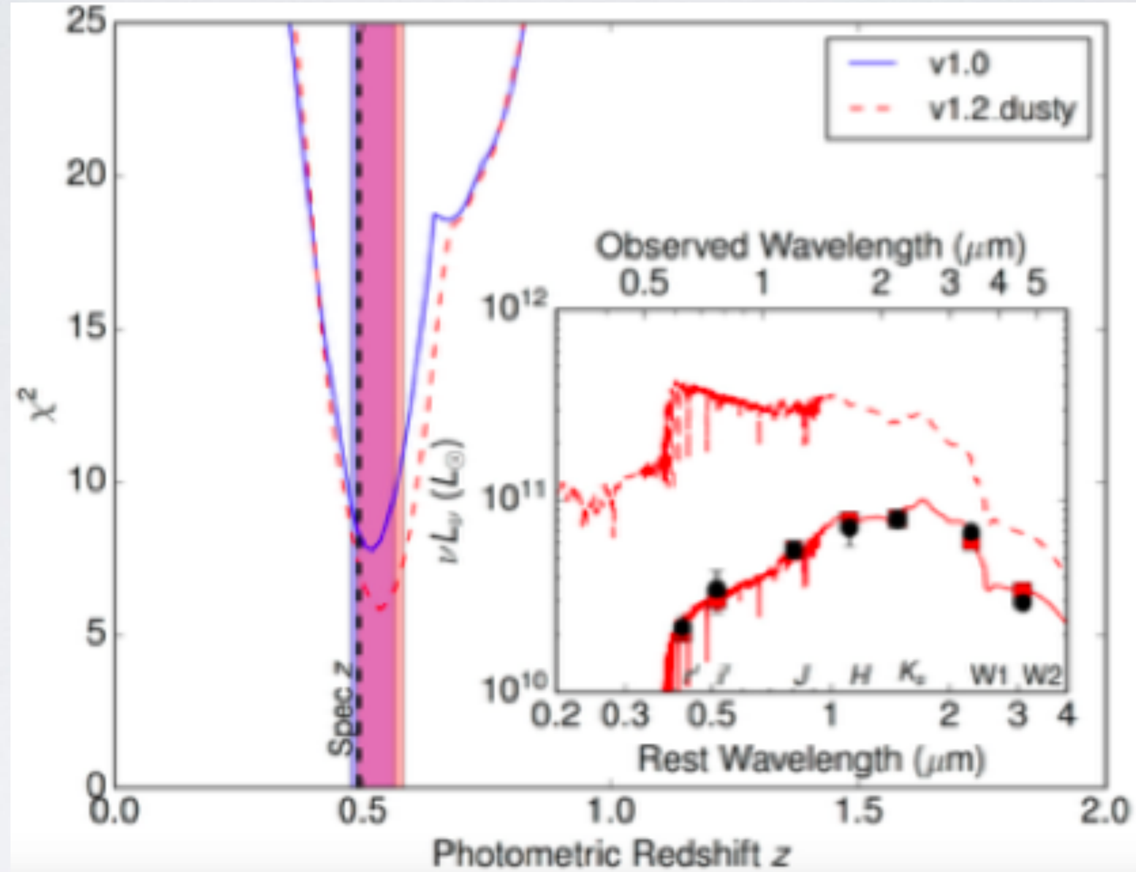
Detected an elliptical galaxy at the position of the fading source

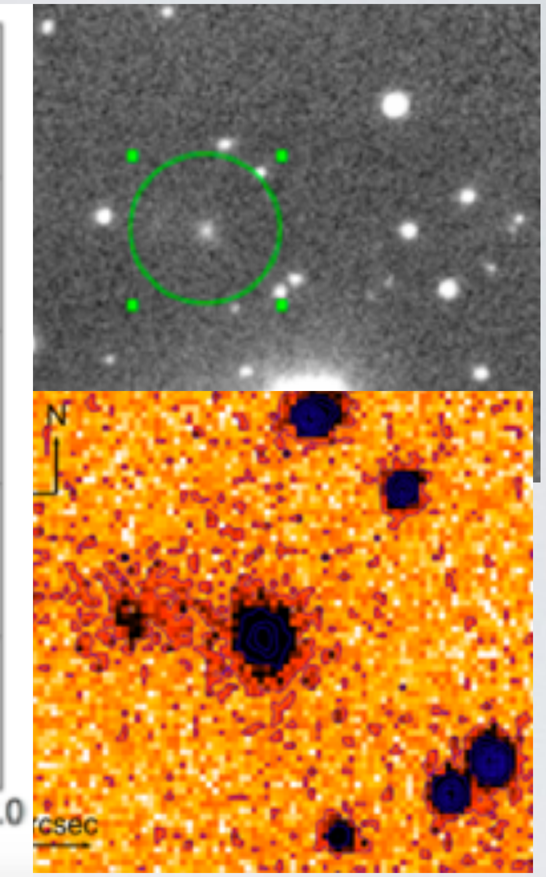


Performed optical observations with Subaru, 1 and 2 days after the detection of the FRB and again ~6 months later

FRB150418: A ROSETTA STONE ?

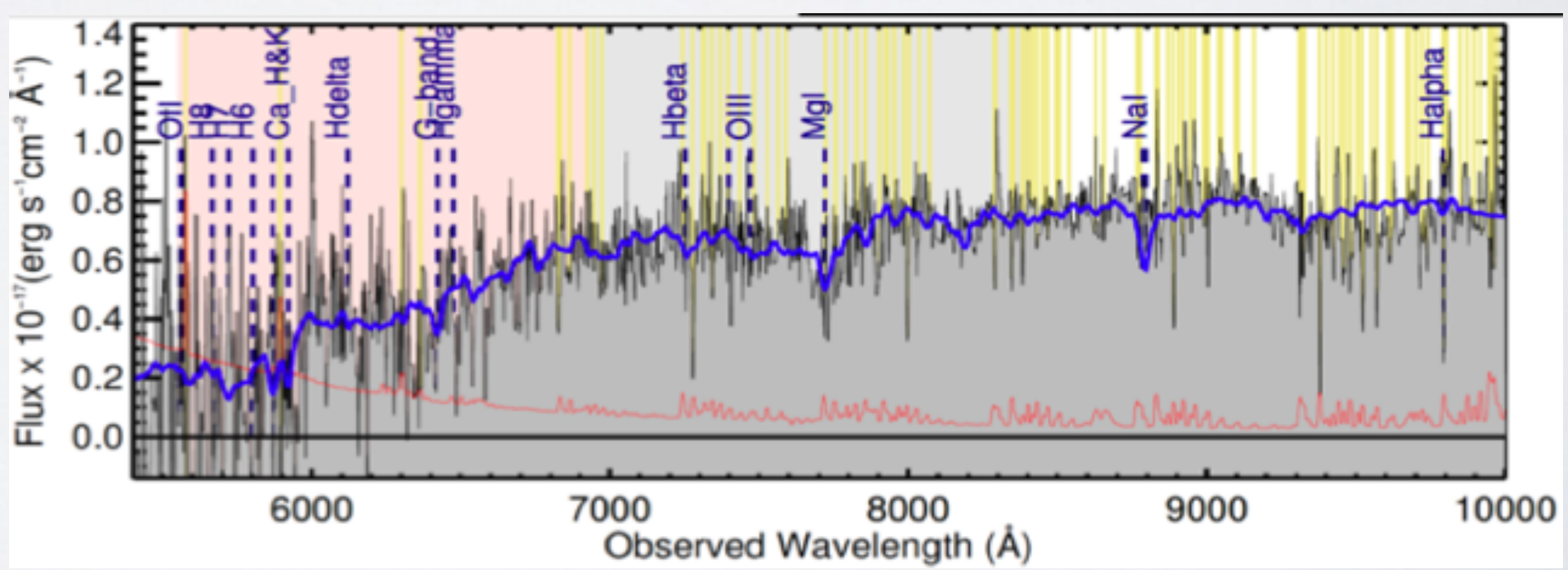
Photometric red-shift
z = 0.52±0.04



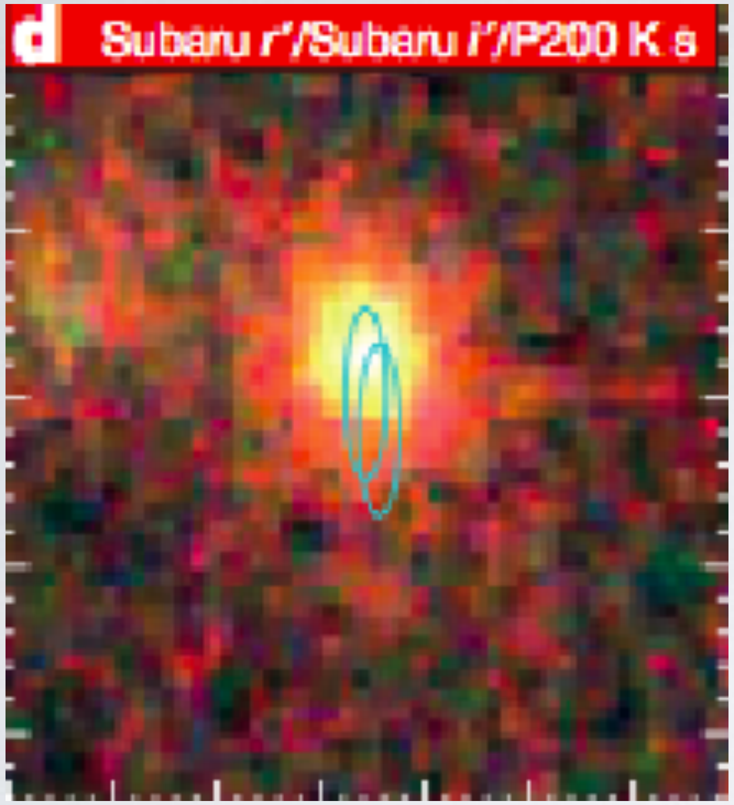


[Keane et al. 2016]

Spectroscopic red-shift
z = 0.492±0.008

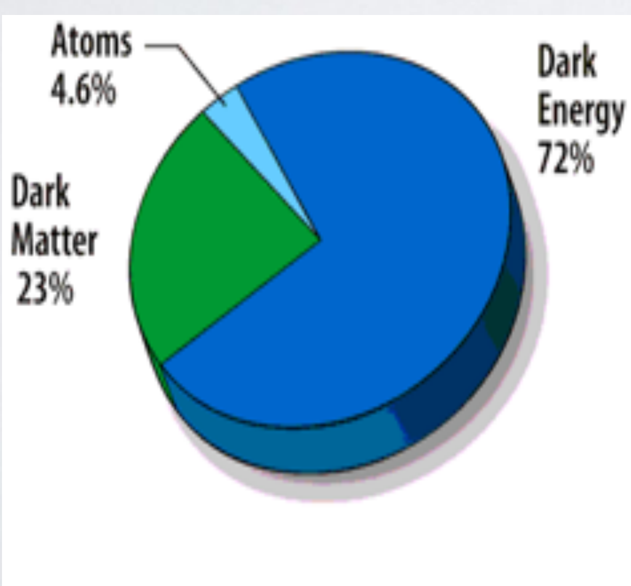


WEIGHTING THE MASS ALONG THE LINE-OF-SIGHT



From z and DM_{IGM}, for each given set of cosmological parameters H_0 , Ω_m and Ω_Λ, plus the fraction of ionized atoms f_e , one can get the baryon density along the line of sight Ω_{IGM}

$$DM_{IGM} = \frac{3cH_0\Omega_{IGM}}{8\pi G m_p} \int_0^z \frac{(1+z')f_e(z')dz'}{[(1+z')^3\Omega_m + \Omega_\Lambda]^{0.5}}$$



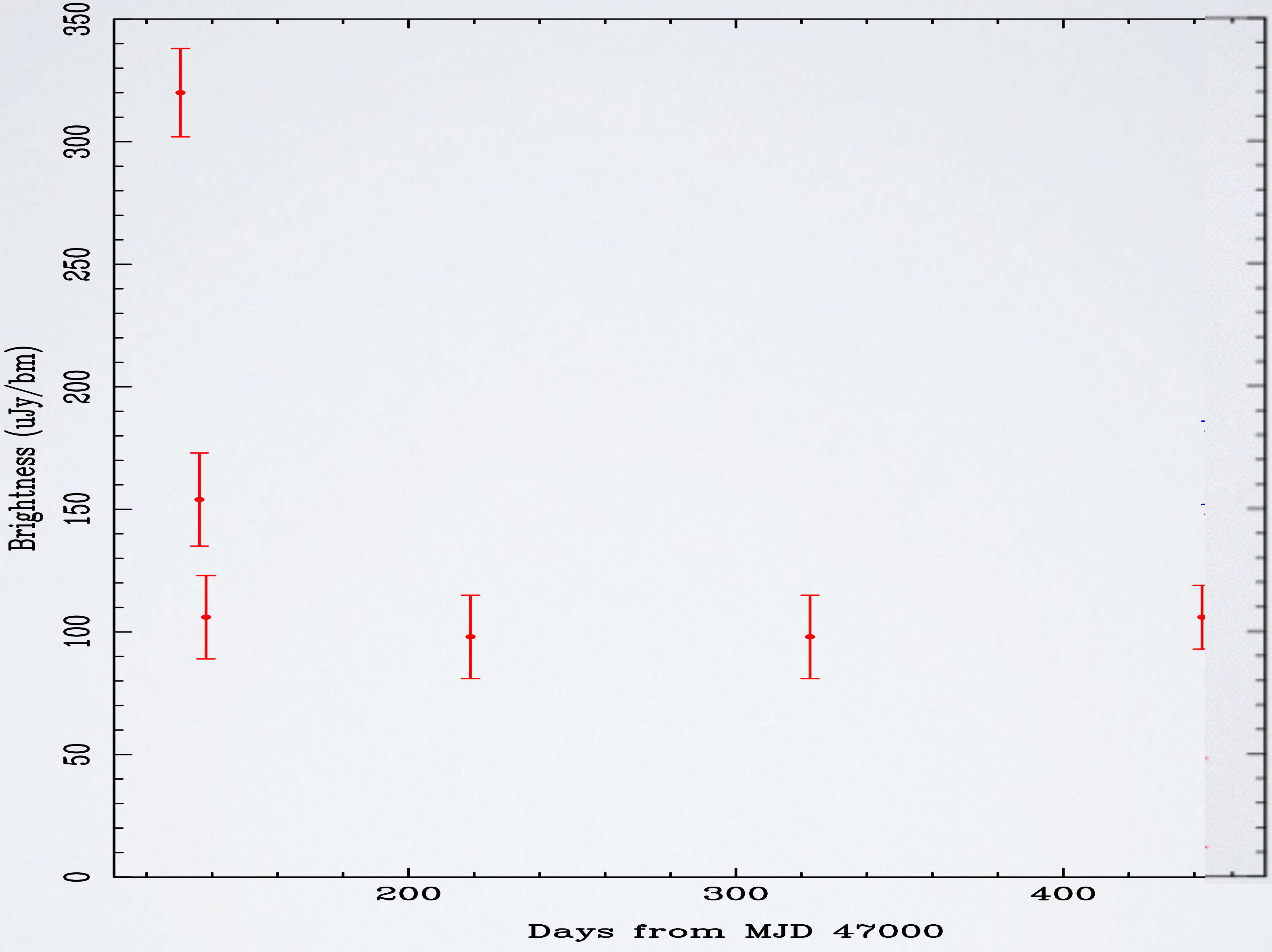
Ω_{IGM} = 4.9 % ± 1.3 %

In agreement with WMAP and other indirect determinations for ΛCDM cosmologies

So far, only 50% of the baryonic mass had been directly observed (i.e. the missing baryons issue)

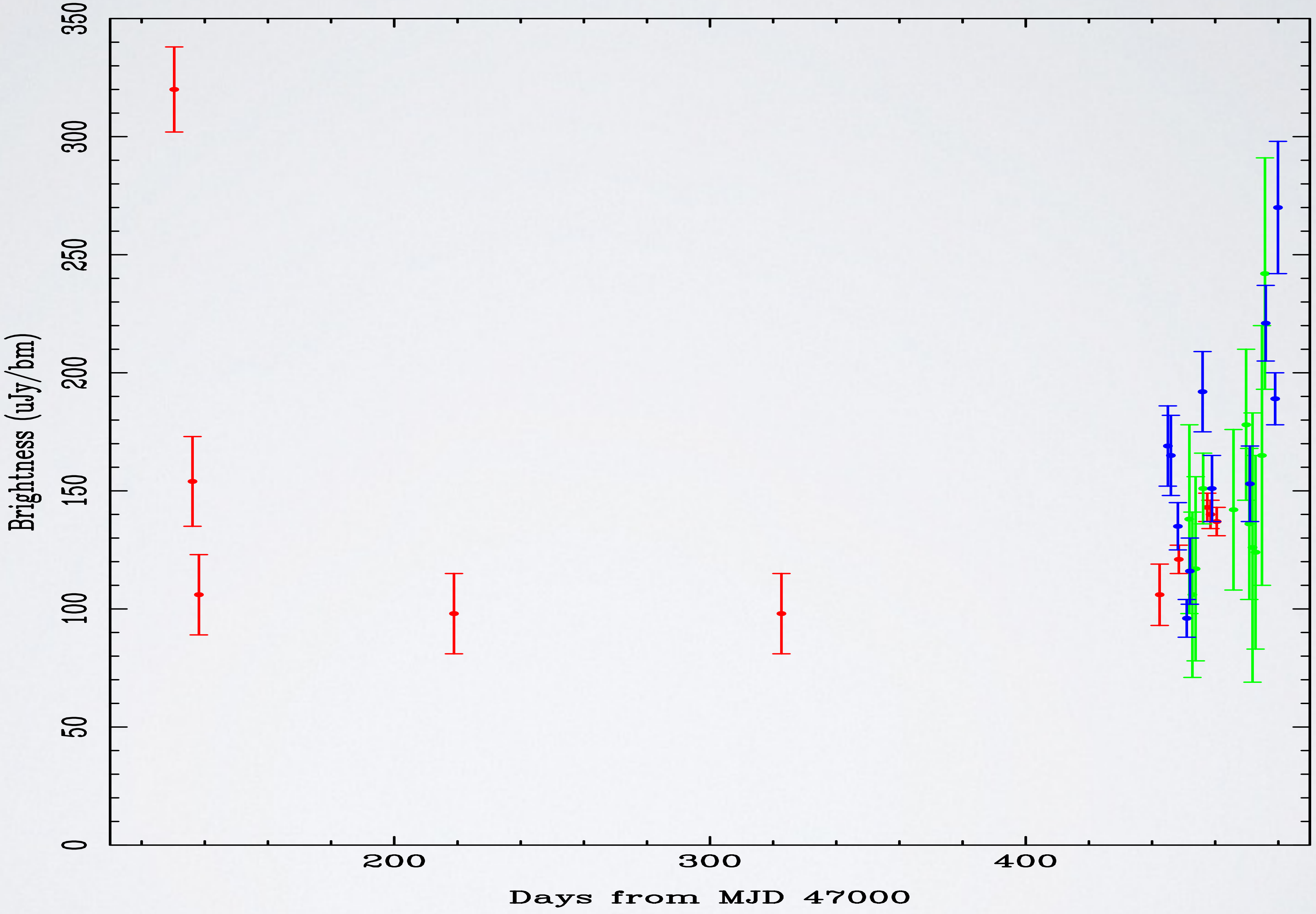
FRB150418: a Rosetta stone ?

Keane et al. Nature



FRB150418: A ROSETTA STONE ?

Johnston et al. MNRAS



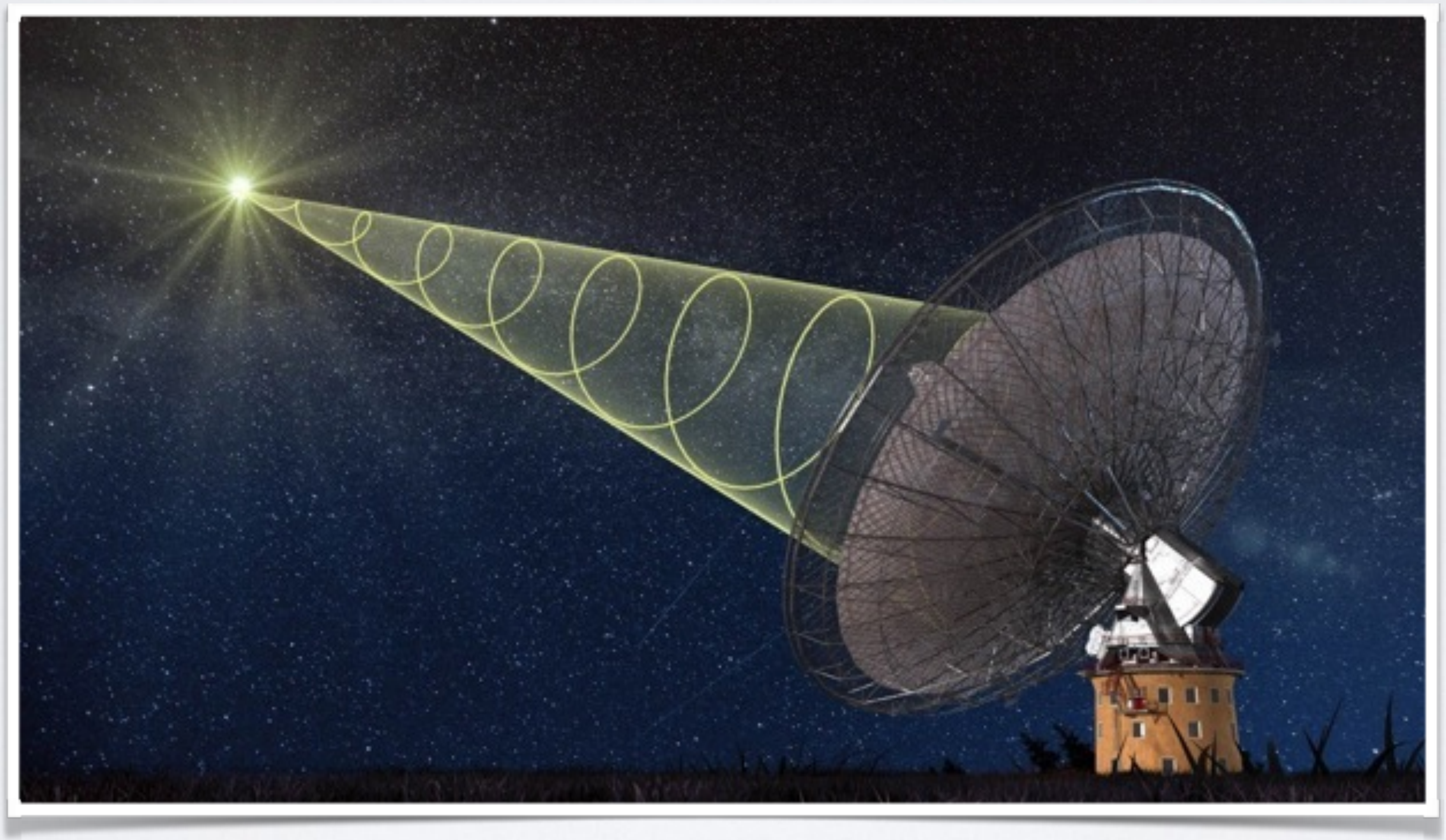
FRB150418: ASSOCIATED WITH THE VARIABLE SOURCE?

- CONS
  - Consistent with scintillation from the central AGN
  - The sky may be more variable at low flux levels
  - How to associate AGN with FRBs?
- PROS
  - Variable sources like this are rare, see for example Li & Zhang (2016), Mooley et al. (2016)
  - The first point is the brightest
  - The DM and the redshift “agree” with the models
  - FRB 131104 also could be coincident with an AGN flare!
  - Rumour: The repeating FRB has an AGN counterpart ??!!

Open Questions

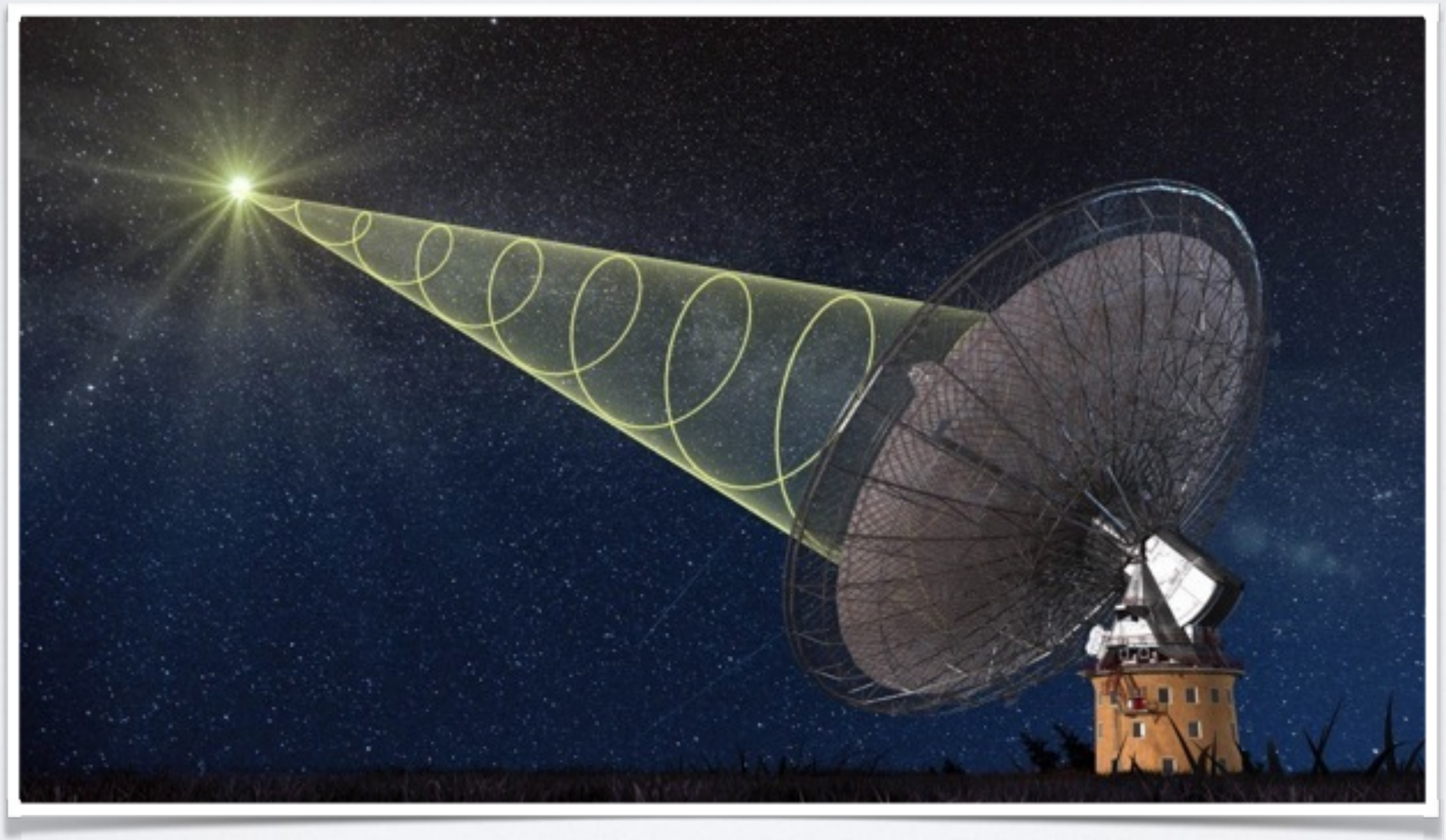
What are FRBs?

Can they be used as cosmological probes?

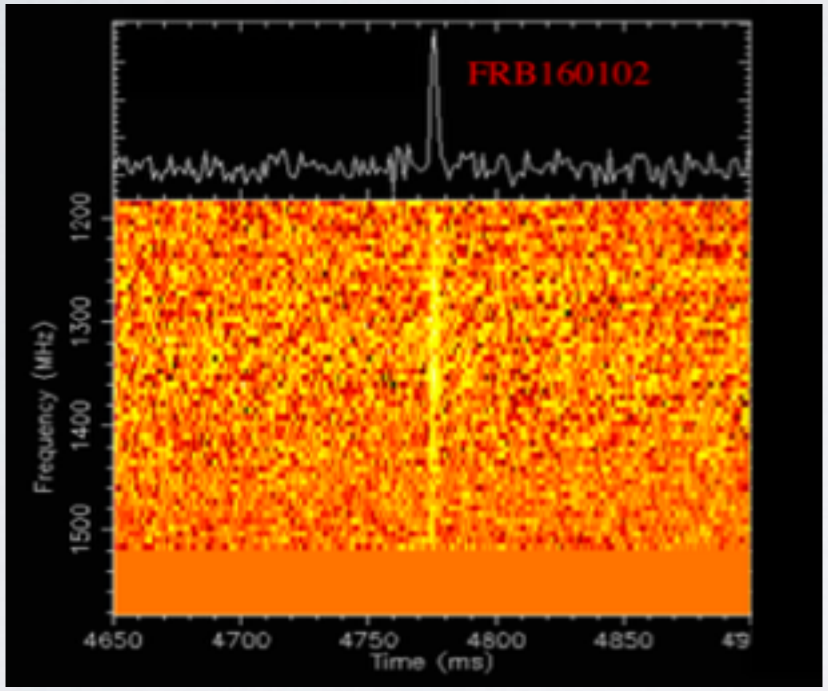


Open Questions

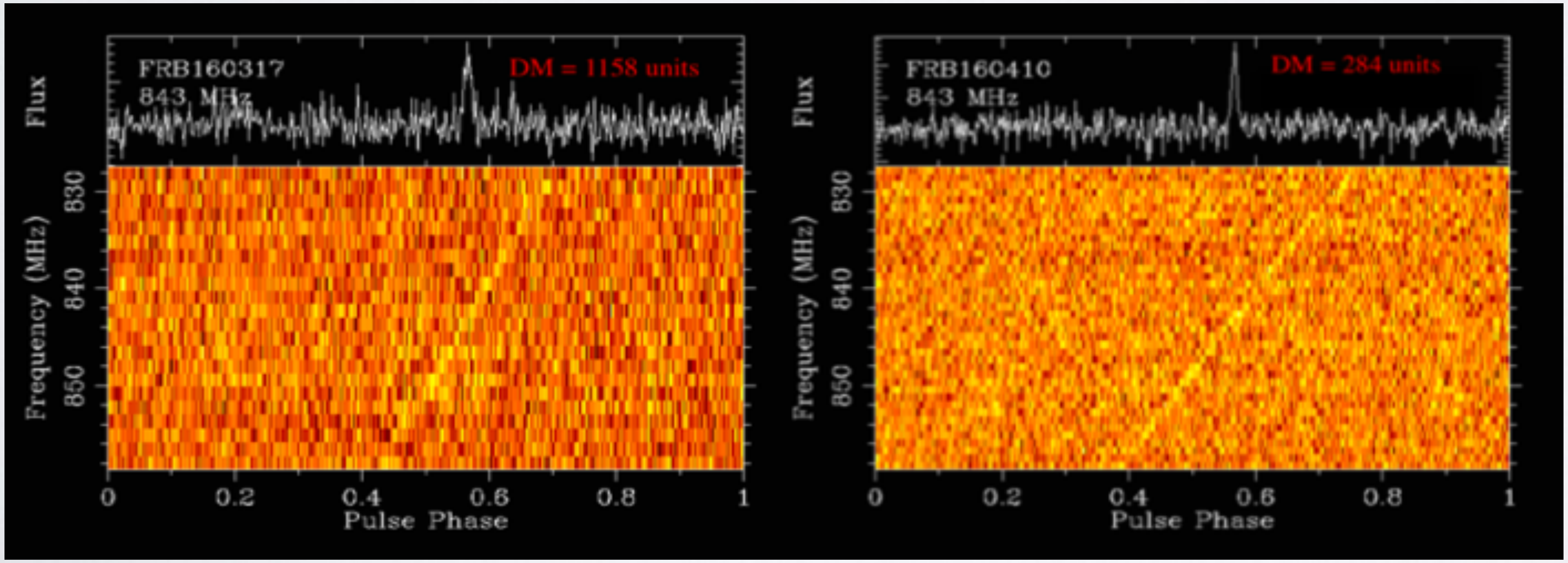
- Is the fading source seen by ATCA really associated to FRB150418 ?
- Are FRBs catastrophic or highly energetic but repeating events?
- Are there multiple classes of FRBs (à la GRBs) ?
- ... ?



NEW FRBS



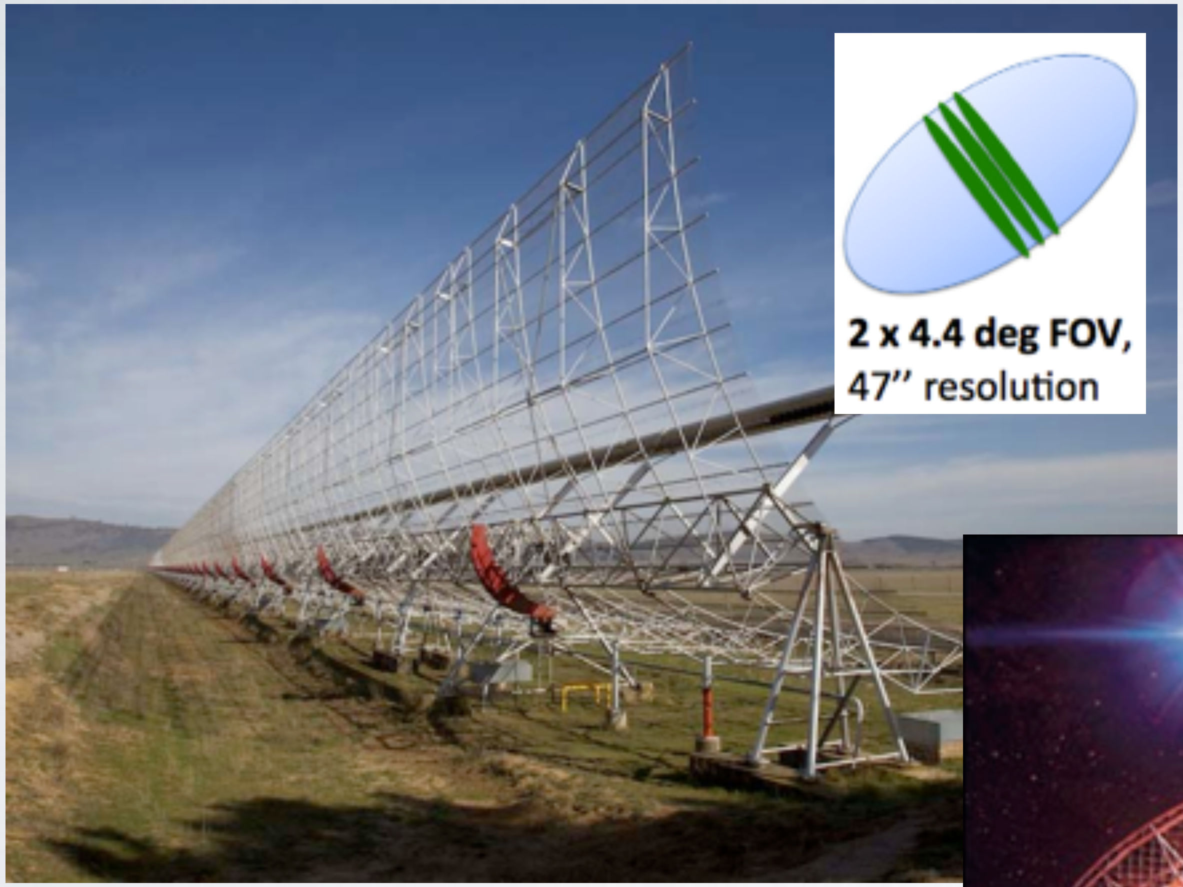
From SUPERB:
FRB160102
highest DM = 2593 pc cm^{-3}
implying a red-shift $z \approx 2$



The first two FRBs observed with a transit telescope: localised in at least one coord

SUPERB NEW OBSERVING RUN

NOW WITH MOLONGLO SHADOWING!



... STAY TUNED ...

THANKS !