FRBs, Perytons, and the hunts for their origins

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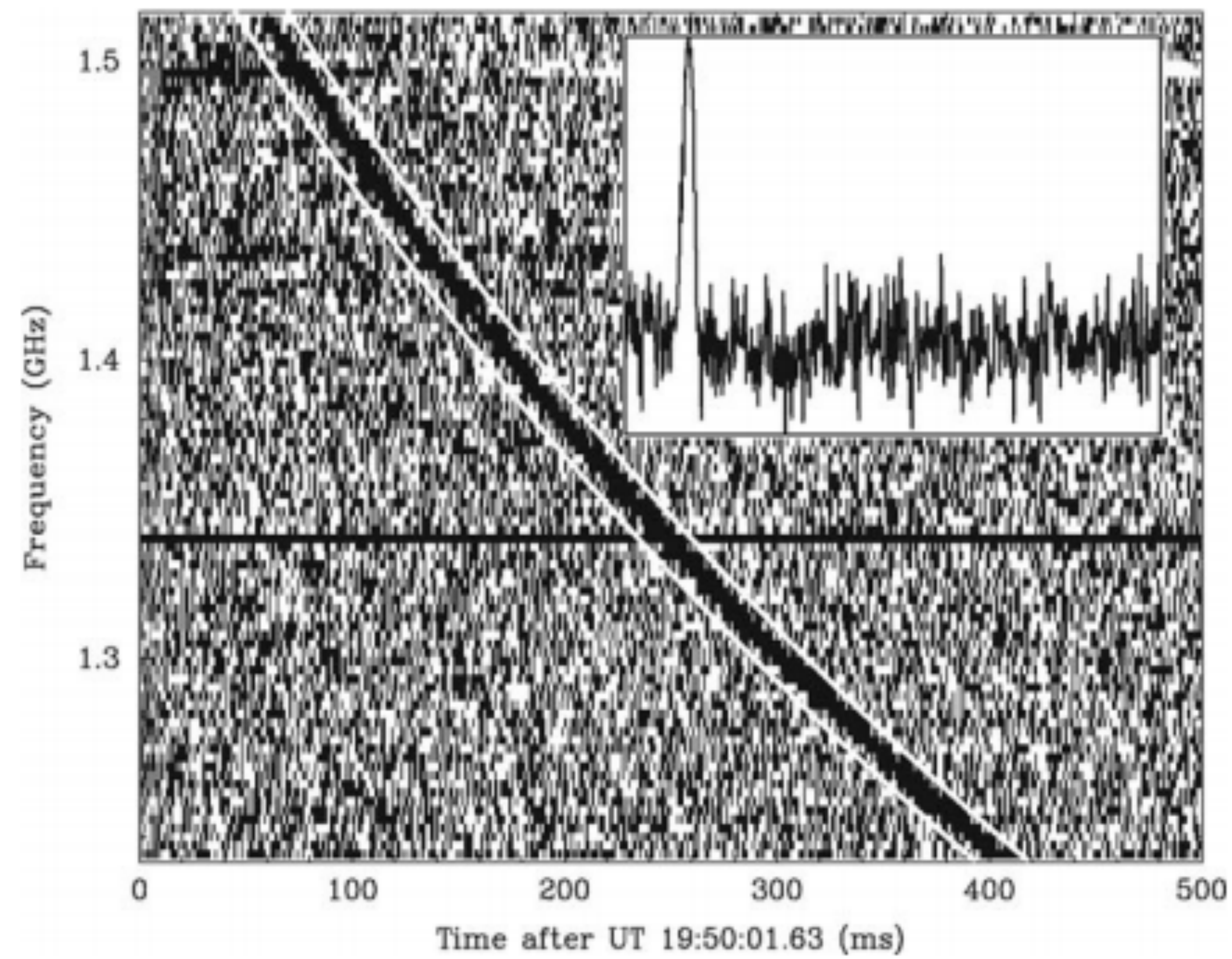
Introduction to FRBs

- Bright, short radio pulses
- High dispersion measure (DM)

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

- DM(FRB) ~ 10 x DM(MW)
- Originate extragalactically



Lorimer et al 2007

- Hugely energetic, relatively common new transients

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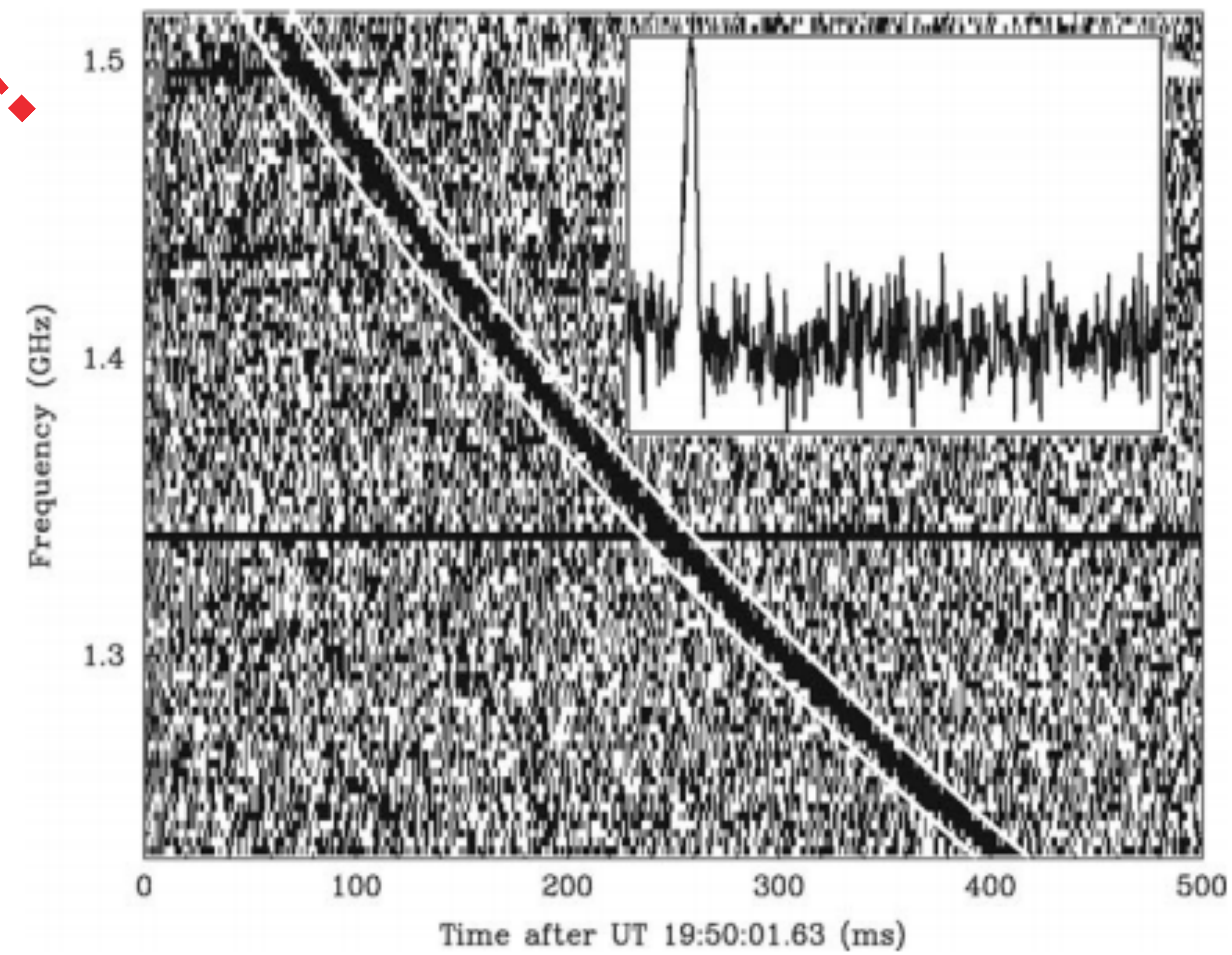


Lorimer et al 2007

We know already!

We know FRBs are interesting…

what do we do with them?

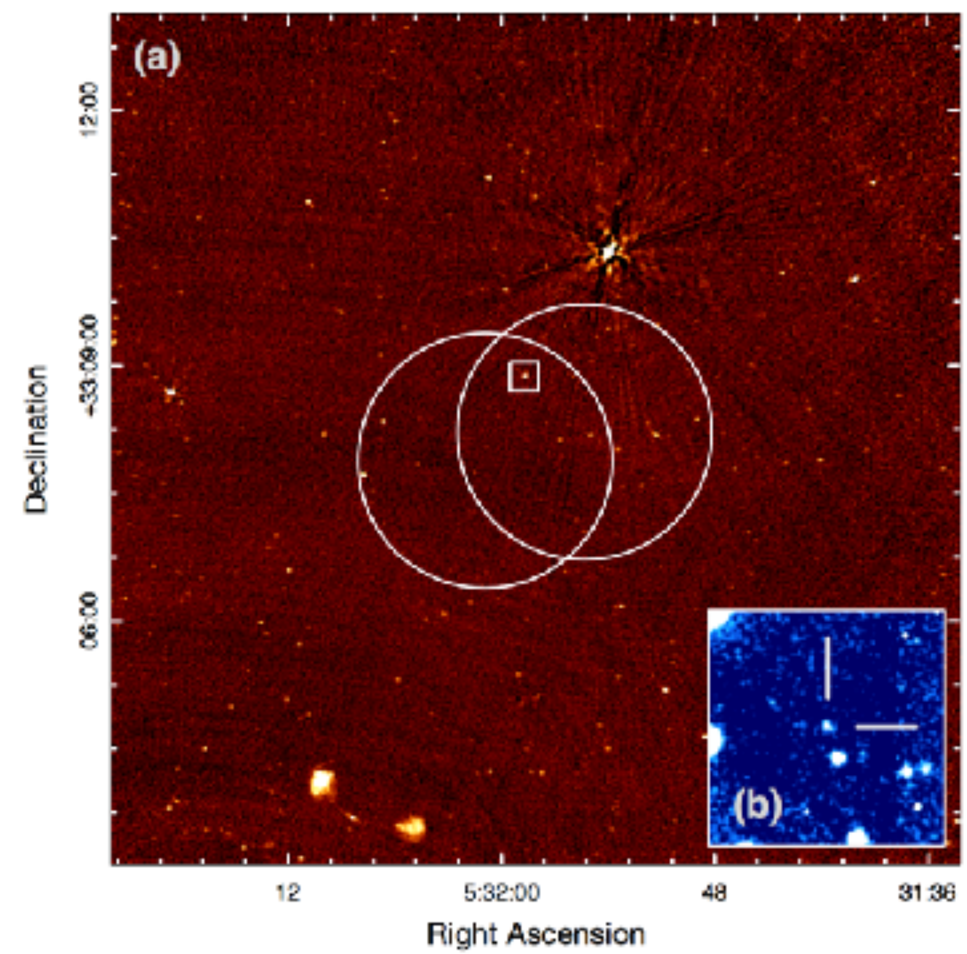
We know FRBs are interesting…

what do we do with them?

We would really like to know what they are first!

Learning more about FRBs

- If we understand more about their progenitors and where they come from we can:
  - Find more FRBs more efficiently
  - Find (and believe) unusual bursts
  - Identify host galaxies
  - Associate them with other astrophysical transients
  - Do the exciting science!



Finding the origins of FRBs

- Follow all possible leads that might give us an answer or a window on the population

- Design basic experiments to build up a complete picture of FRBs

Some simple checks

- Searches for similar local/terrestrial signals
- Searches for repeating pulses
- Searches at other wavelengths
- Searches in all directions
- Searches to the edge of the parameter space

Searches for Local/Terrestrial Signals

- 2010: S. Burke-Spolaor et al. "local FRBs"
- Perytons made people skeptical about the Lorimer burst
- 2013: D. Thornton et al. find more FRBs
- Continue to search Parkes data for FRBs *and* perytons
- 2015: ~10 FRBs, ~60 perytons

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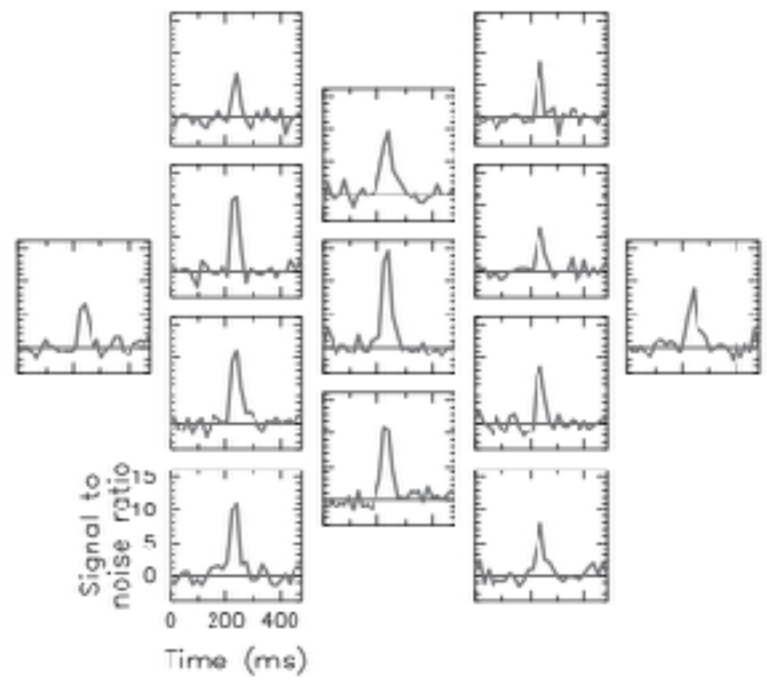

(a) Peryton 08 in 13 beams

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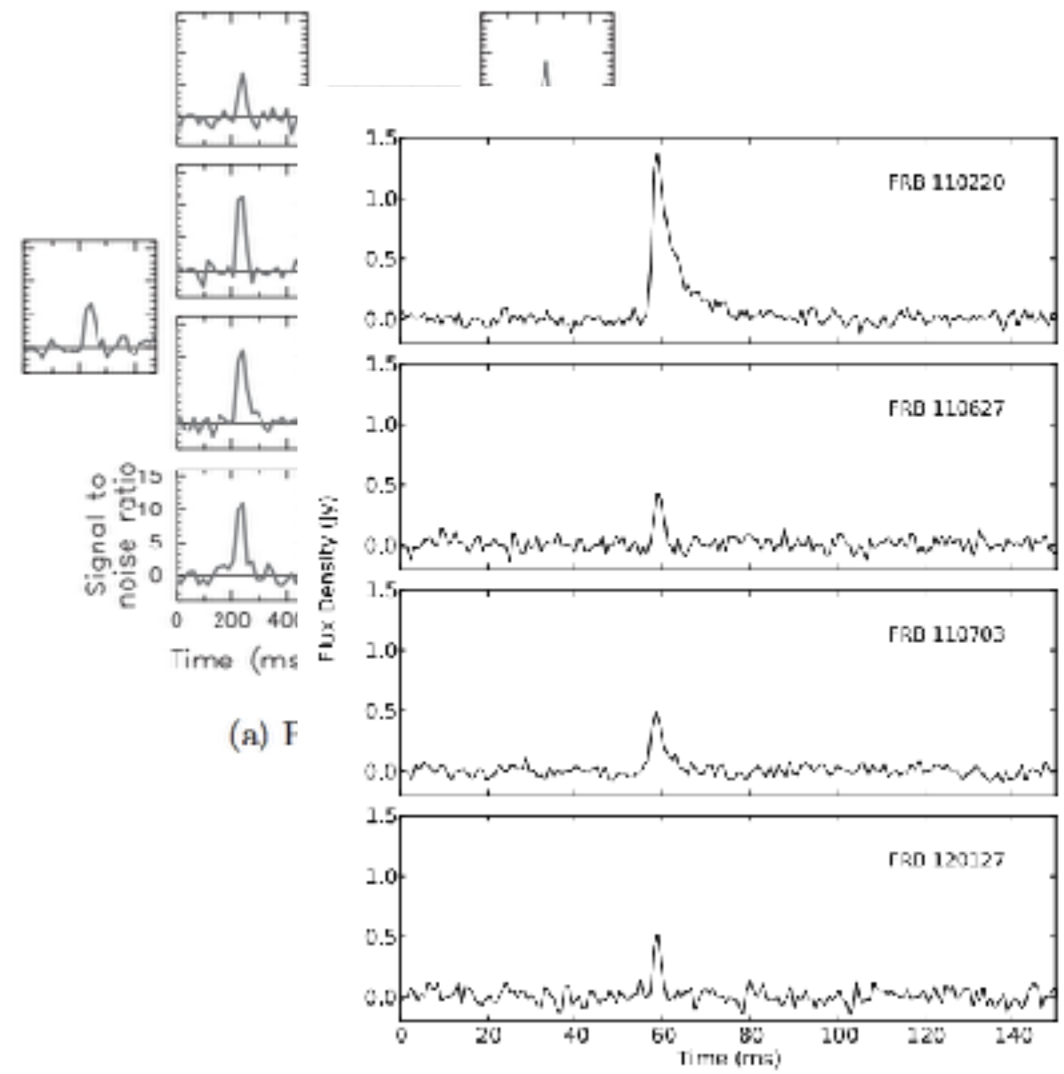

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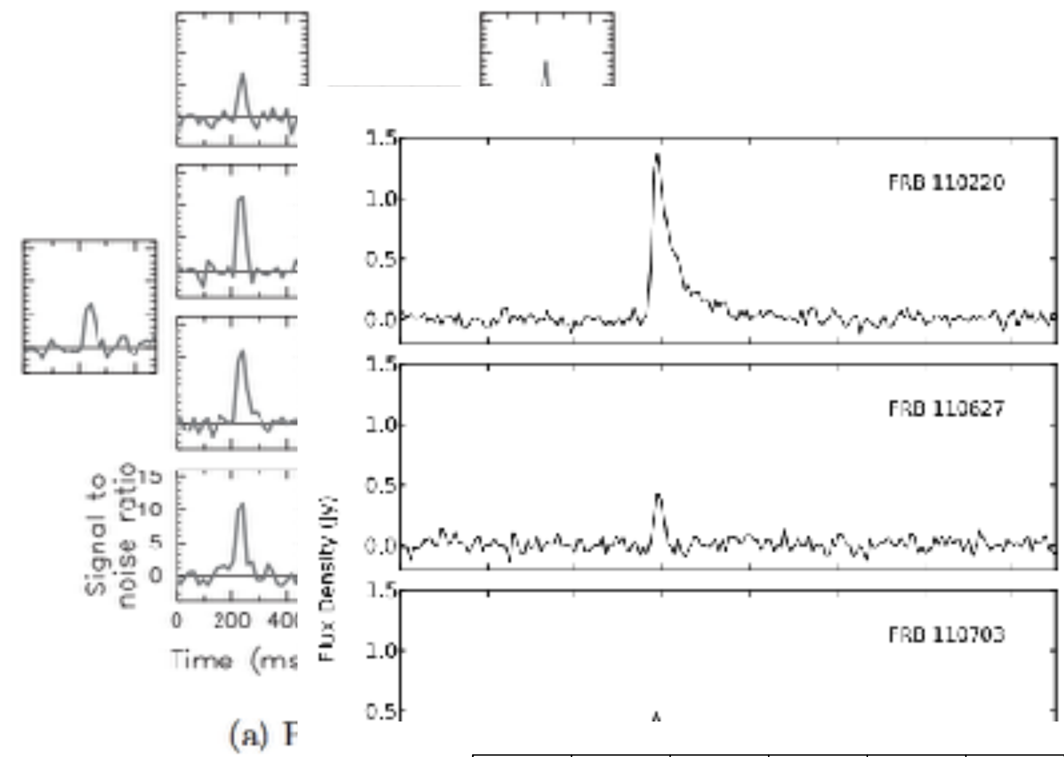

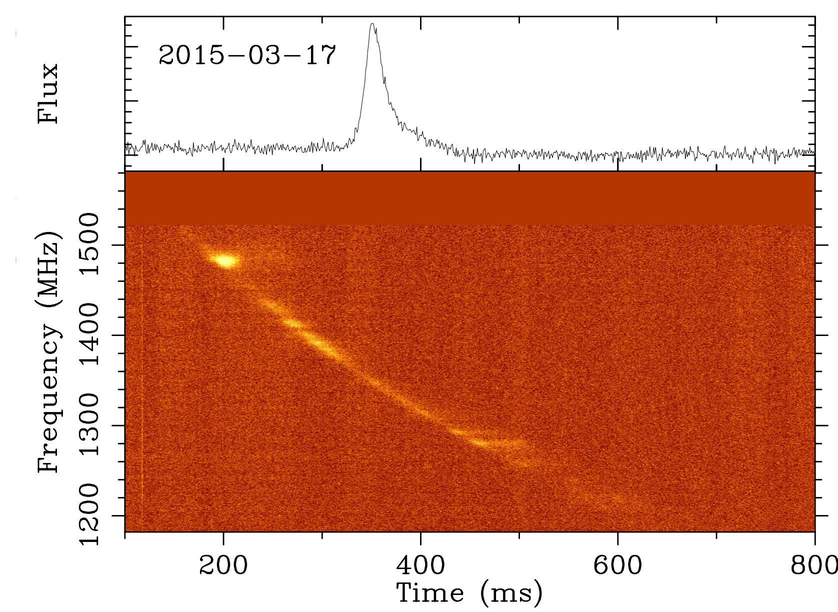

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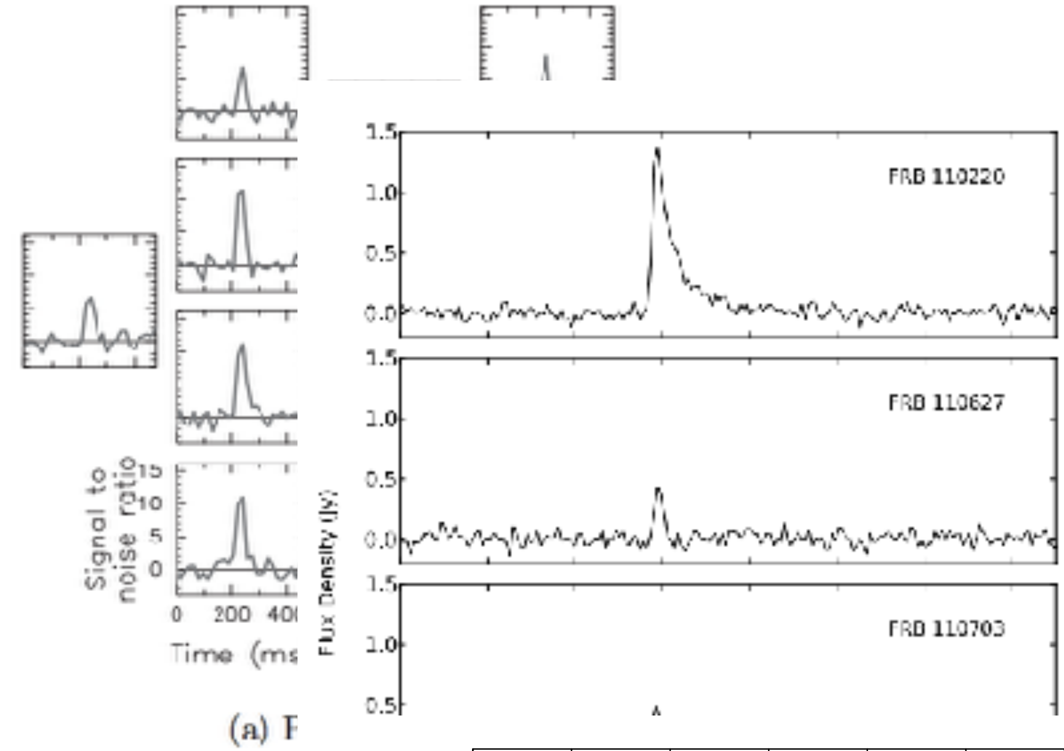

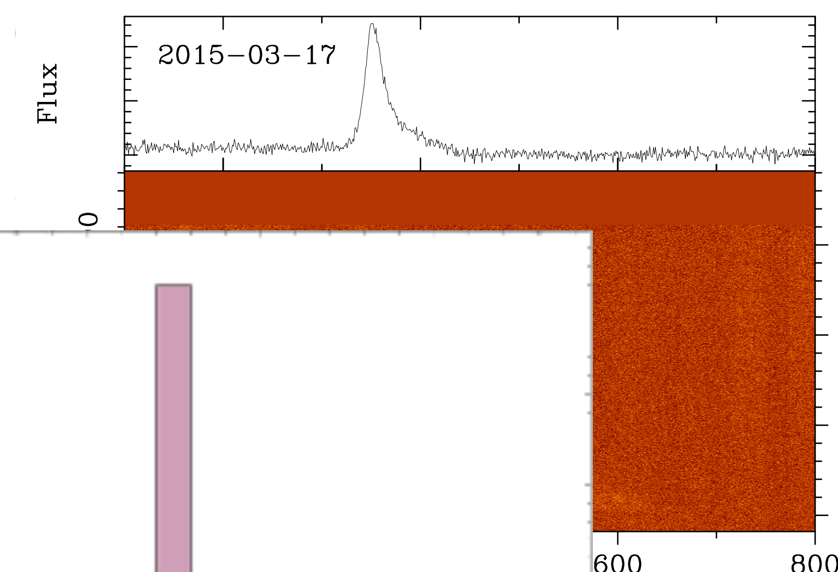

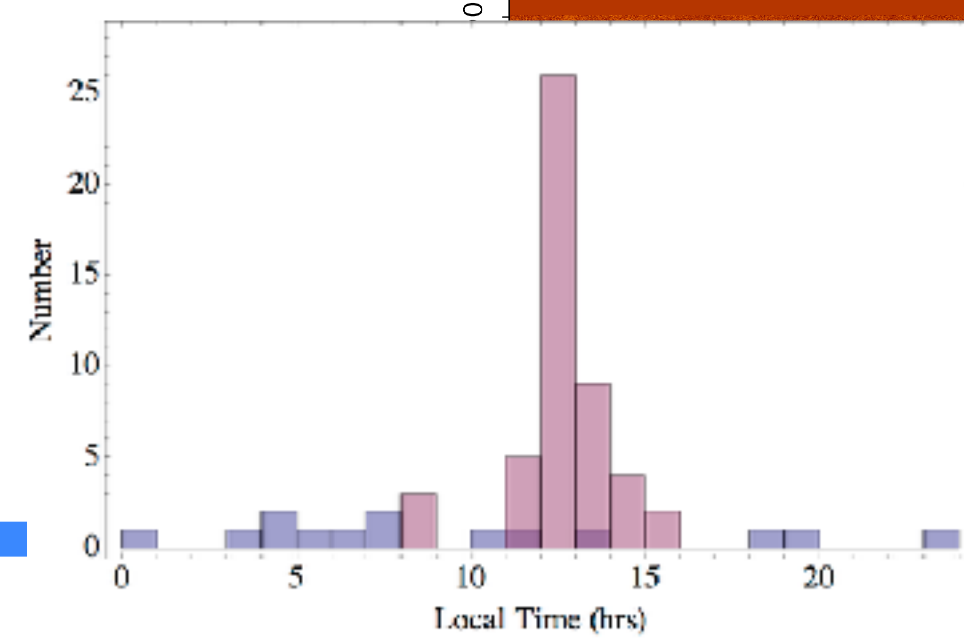

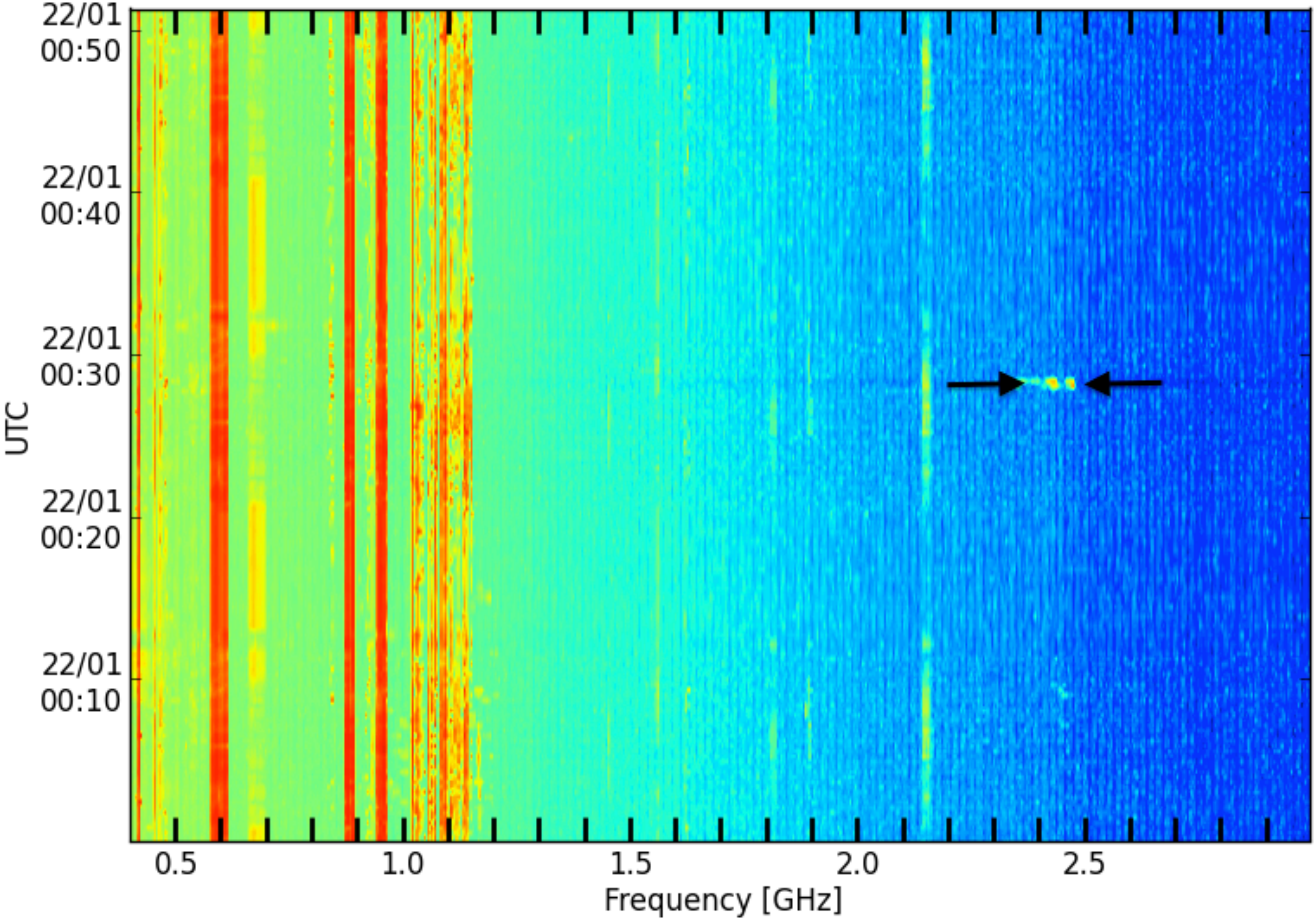
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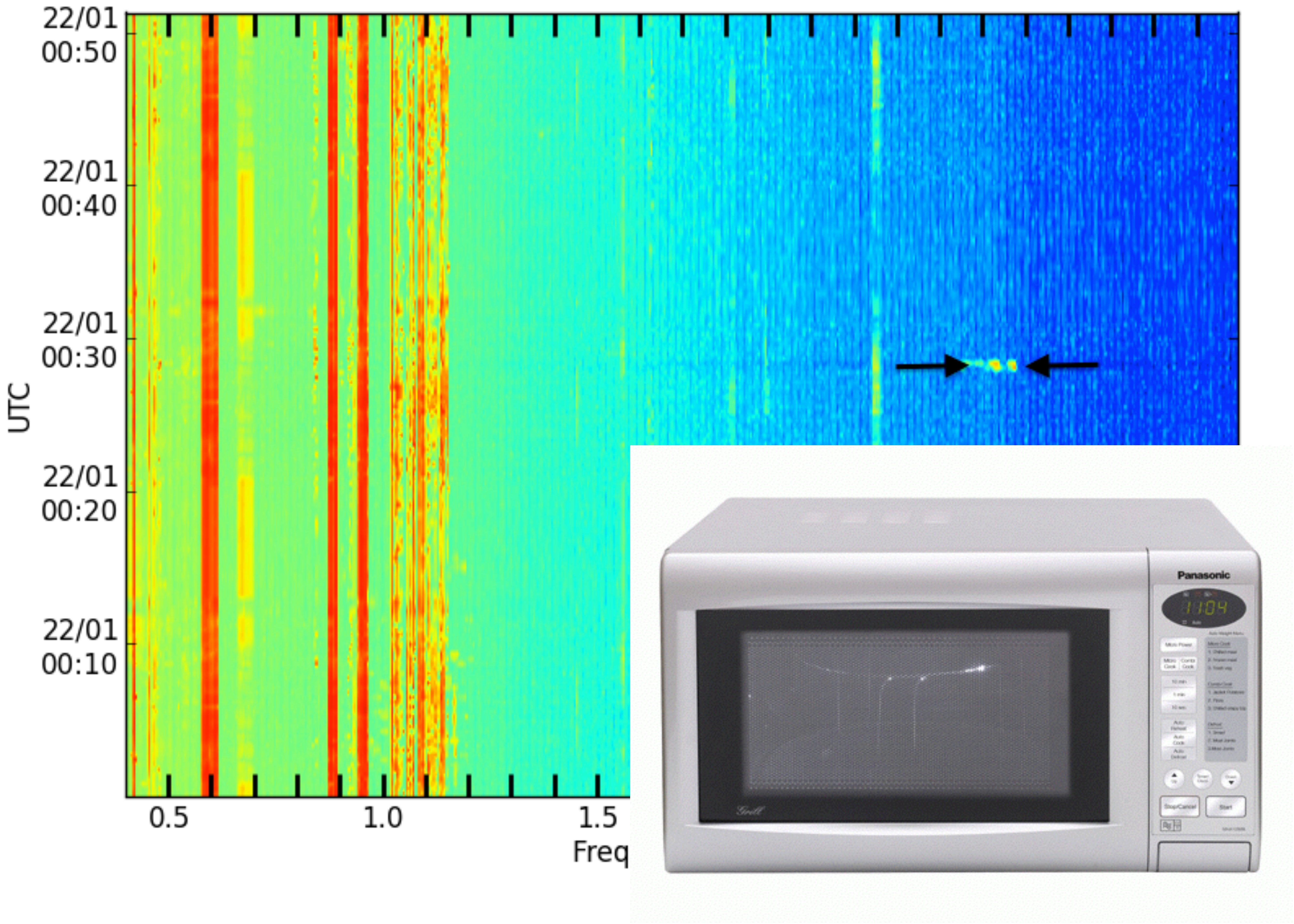
Frequency [GHz]



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Panasonic

Lessons from the perytons

- Let the microwave finish!
- Don't dismiss "spurious" signals off-hand
- Finding the source certainly helped, but gathering population data remained critical

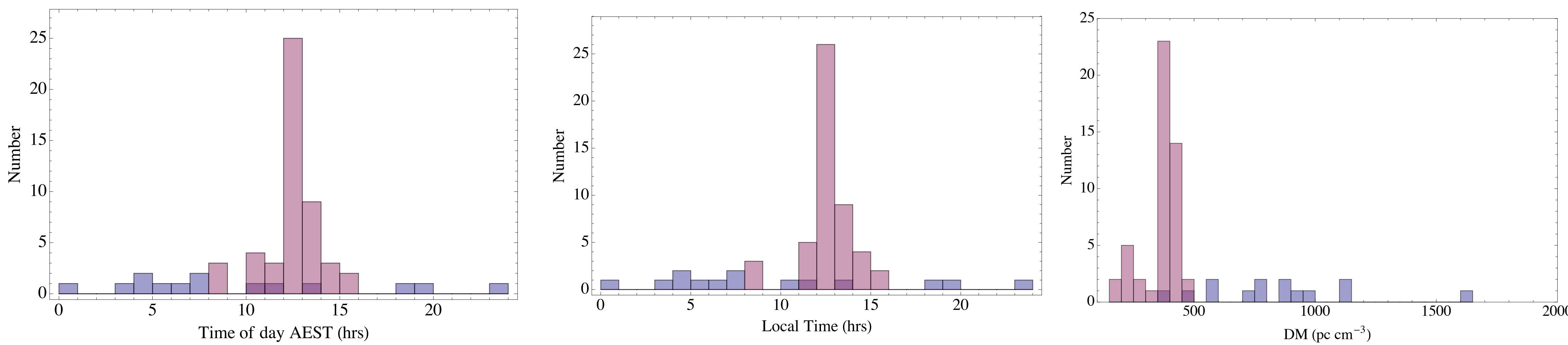
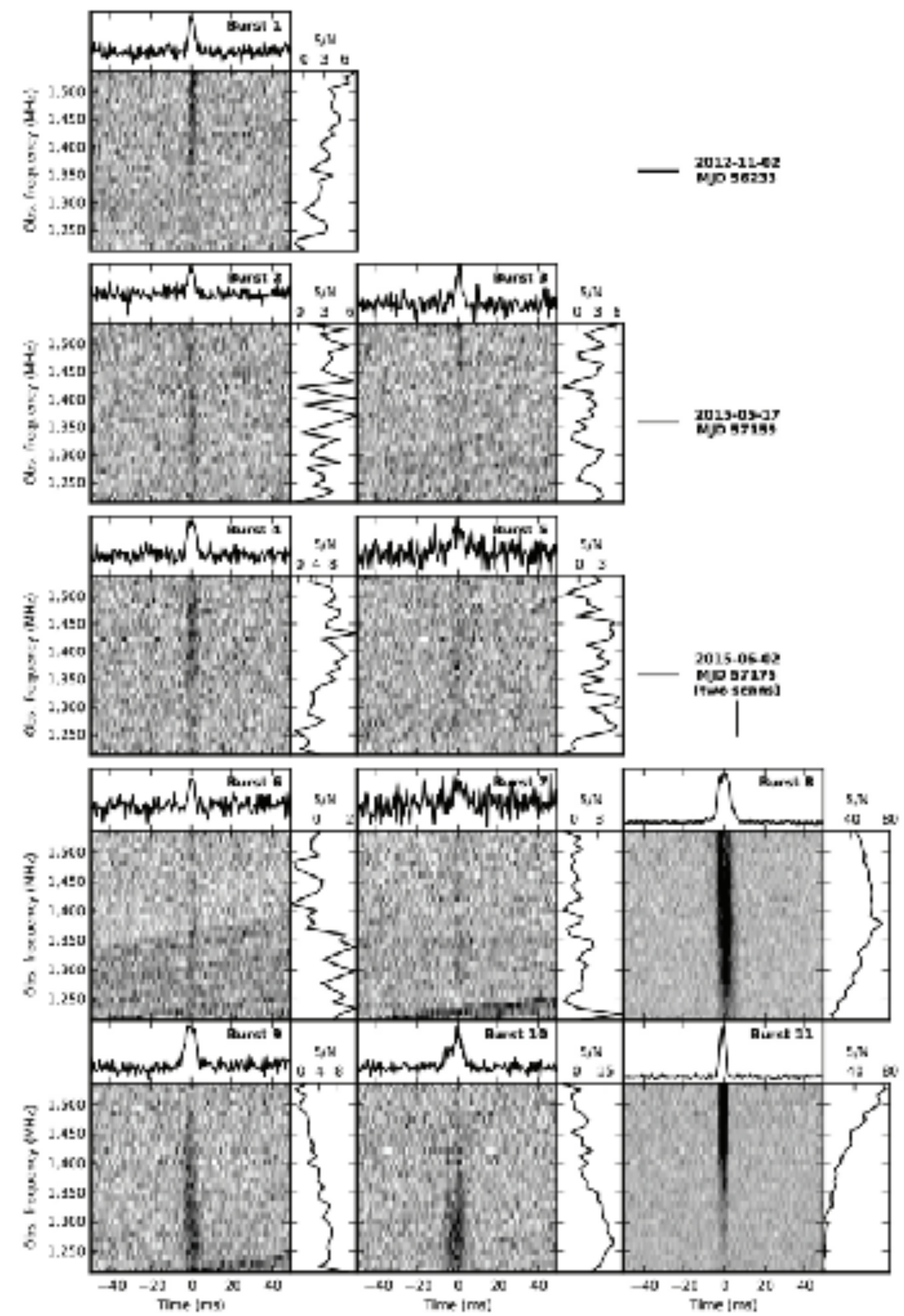


Figure 7. The overlaid FRB (dark) and peryton (light) distributions as a function of the local time with Australian Eastern Daylight Savings Time accounted for (top left), time in Australian Eastern Standard Time (top right) and as a function of DM over the entire range searched (bottom). Clearly the FRB distribution is uniform throughout the day, whereas the peryton signals peak strongly during office hours (particularly around lunch time). A random distribution would look approximately flat, with a slight dip during office hours where occasional maintenance is carried out. The bi-modal peryton distribution with peaks at ~ 200 and ~ 400 cm^{-3} pc is evident.

Searches for repeating FRBs

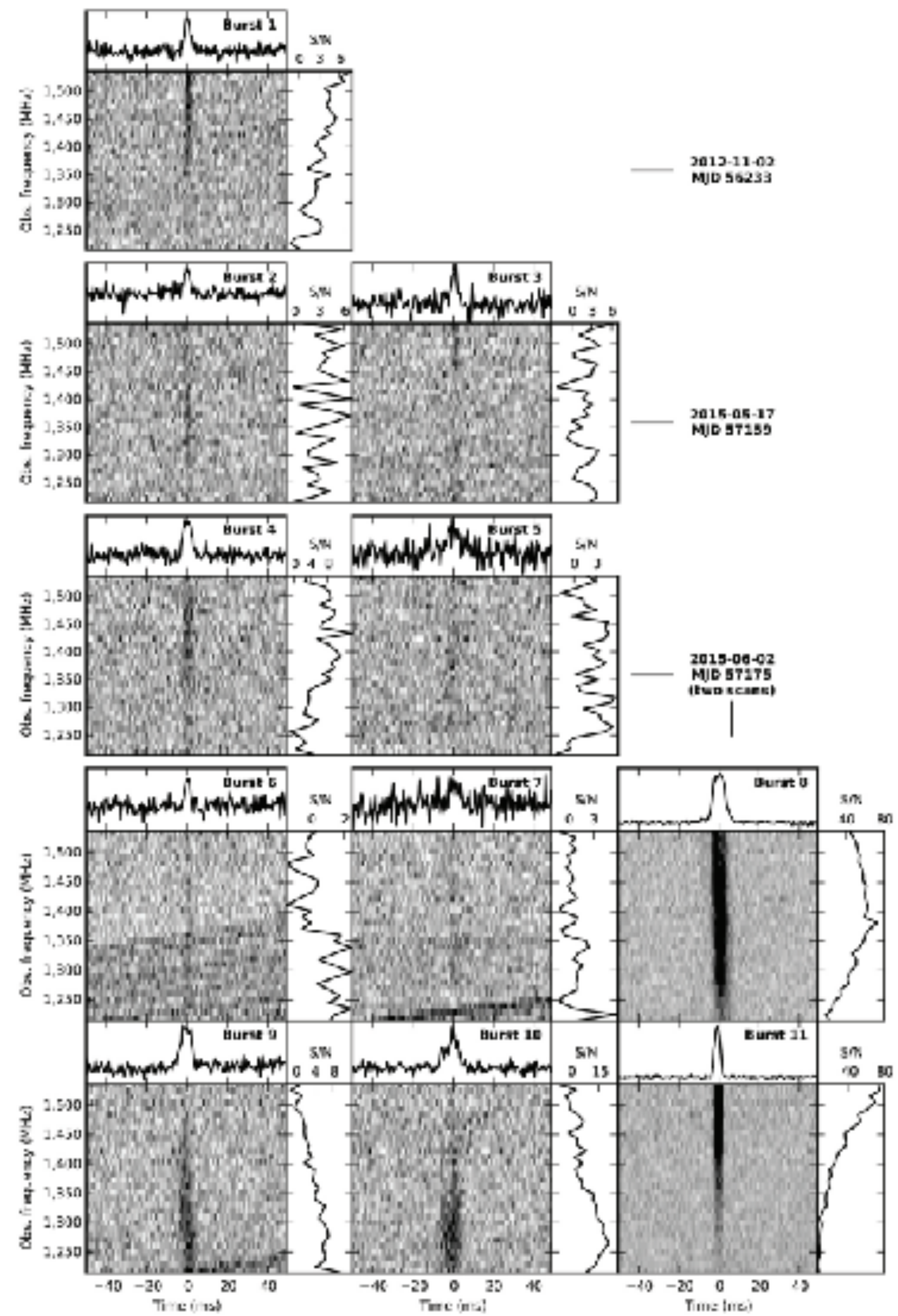
do FRBs repeat?

- YES! (but also no)
- FRB 121102 repeats a lot! (100s of pulses now)
- Some FRBs have been observed for 100s of hours without repeat pulses (particularly the brightest bursts at the lowest DMs)
- Still not clear if FRB 121102 is representative of the population



Lessons from the repeater

- Repeat pulses are clustered in time, non-periodic, and very unpredictable
- Very strange host/progenitor region properties
- All other FRBs may have been “off” when followed up
- Population of 31 FRBs: 1 repeats, 30 haven’t repeated yet
- Continued monitoring of FRBs is critical
- We need to find more FRBs that repeat!!



Searches at other wavelengths

- Is the radio pulse accompanied by multi-wavelength (or multi-messenger) signatures?
- Short prompt emission in X-rays or gamma rays, longer prompt emission in optical
- Longer-lived synchrotron afterglow emission in optical or radio
- Either shadow radio observations or trigger follow-up upon real-time detection

Multi-wavelength follow-up

- Only a handful of FRBs have been triggered on in real-time for follow-up
- Example: FRB 150215
- Triggered VHE gamma-ray, X-ray, optical, radio transient, radio imaging, neutrino telescopes
- Delayed trigger time (T+1 hour) meant slower response times

Telescope	Date Start time UTC	T+	Limits
Parkes	Feb 15 20:41:42	1 s	145 mJy at 1.4 GHz
ANTARES	Feb 15 20:41:42	1 s	1.4×10^{-2} erg cm^{-2} (E^{-2})
			0.5 erg cm^{-2} (E^{-1})
ATCA	Feb 16 01:22:26	4.6 h	280 μJy at 5.5 GHz
			300 μJy at 7.5 GHz
GMRT	Feb 16 06:36:00	8.9 h	100 μJy at 610 MHz
DECam	Feb 16 09:01:36	12.3 h	$i = 24.3$, $r = 24.8$,
			VR = 25.1
Swift	Feb 16 15:30:23	18.8 h	1.7e−13 erg cm^{-2} s^{-1}
ATCA	Feb 16 20:41:44	24 h	208 μJy at 5.5 GHz
			200 μJy at 7.5 GHz
ANTARES	Feb 16 20:41:42	1.0 d	1.4×10^{-2} erg cm^{-2} (E^{-2})
			0.5 erg cm^{-2} (E^{-1})
TNT	Feb 16 21:59:00	1.0 d	R = 21.3
GMRT	Feb 17 05:08:00	1.3 d	100 μJy at 610 MHz
Magellan	Feb 17 08:53:05	1.5 d	$J = 18.6$
Parkes	Feb 17 20:26:47	1.9 d	145 mJy at 1.4 GHz
Chandra	Feb 18 03:56:00	2.3 d	1e−14 erg cm^{-2} s^{-1}
Swift	Feb 18 04:44:58	2.3 d	2.4e−13 erg cm^{-2} s^{-1}
Magellan	Feb 18 08:59:44	2.5 d	$J = 19.1$
Parkes	Feb 18 20:04:25	2.9 d	145 mJy at 1.4 GHz
Swift	Feb 19 01:27:59	3.2 d	9.7e−13 erg cm^{-2} s^{-1}
ATCA	Feb 19 17:13:44	3.8 d	192 μJy at 5.5 GHz
			228 μJy at 7.5 GHz
GMRT	Feb 20 05:51:00	4.3 h	100 μJy at 610 MHz
Swift	Feb 20 12:36:58	4.6 d	2.1e−13 erg cm^{-2} s^{-1}
Swift	Feb 21 18:53:59	5.9 d	6.8e−13 erg cm^{-2} s^{-1}
H.E.S.S.	Feb 22 02:53:00	6.3 d	see text
Parkes	Feb 23 19:41:53	7.9 d	145 mJy at 1.4 GHz
H.E.S.S.	Feb 25 02:40:00	9.3 d	see text
DECam	Feb 28 08:13:46	12.5 d	$i = 24.3$, $r = 24.8$,
			VR = 25.1
DECam	Mar 1 08:59:45	13.5 d	$i = 24.3$, $r = 24.8$,
			VR = 25.1
VLA	Mar 1 13:59:46	13.7 d	7.92 μJy at 10.1 GHz
VLA	Mar 6 14:26:00	18.7 d	7.83 μJy at 10.1 GHz
VLA	Mar 9 15:02:34	21.7 d	164.5 μJy at 10.1 GHz
DECam	Mar 11 08:02:32	23.5 d	$i = 24.3$
VLA	Mar 17 12:34:56	29.6 d	5.95 μJy at 10.1 GHz
ATCA	Mar 18 18:44:14	30.9 d	240 μJy at 5.5 GHz
			200 μJy at 7.5 GHz
ATCA	Mar 19 18:44:14	31.9 d	200 μJy at 5.5 GHz
			200 μJy at 7.5 GHz
ATCA	Mar 24 18:13:44	36.9 d	220 μJy at 5.5 GHz
			220 μJy at 7.5 GHz
VLA	Apr 8 10:51:51	51.0 d	7.05 μJy at 10.1 GHz
TNT	Apr 14 21:07:54	58.0 d	R = 21.3
DECam	Apr 27 08:42:05	70.5 d	$i = 22.2$, VR = 21.3
VLA	Apr 28 10:53:20	71.6 d	8.67 μJy at 10.1 GHz
VLA	Apr 28 11:38:11	71.6 d	8.48 μJy at 10.1 GHz
VLA	Apr 28 12:23:04	71.6 d	7.23 μJy at 10.1 GHz
VLA	Apr 29 10:17:15	73.5 d	8.78 μJy at 10.1 GHz
Lovell	2016 Feb 14 12:31:58	364 d	168 mJy at 1.5 GHz
Lovell	2016 Feb 15 12:47:17	365 d	168 mJy at 1.5 GHz
Lovell	2016 Feb 19 10:32:25	269 d	168 mJy at 1.5 GHz
ATCA	2016 Feb 24 18:41:45	374 d	160 μJy at 5.5 GHz
			192 μJy at 7.5 GHz
Lovell	2016 Mar 10 09:11:15	398 d	168 mJy at 1.5 GHz
ATCA	2016 Mar 10 15:58:15	398 d	132 μJy at 5.5 GHz
			160 μJy at 7.5 GHz
Lovell	2016 Mar 19 01:20:44	407 d	168 mJy at 1.5 GHz
Lovell	2016 Mar 27 01:34:12	4.5 d	168 mJy at 1.5 GHz
Lovell	2016 Apr 06 08:42:45	4.6 d	168 mJy at 1.5 GHz
Lovell	2016 Apr 16 06:48:43	4.6 d	168 mJy at 1.5 GHz

Multi-wavelength follow-up

- Already ruled out standard SN, LGRB, SLSN models
- Most exciting theories are still in the mix
- Shadowing with optical and radio telescopes becomes an attractive option
- Faster triggering method needed to do real-time search with coordinated follow-up
- Currently developing a VOEvent standard for FRBs for automated triggering (white paper in progress)

VOEvent Standard for Fast Radio Bursts

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[3]Department of Astrophysics, Radboud University Nijmegen, PO Box 9010, 6500 GL Nijmegen, The Netherlands
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[5]Anton Pannekoek Institute, University of Amsterdam, Postbus 94249, 1090 GE, Amsterdam, The Netherlands
[6]Department of Astronomy and Radio Astronomy Lab, Univ. of California, Berkeley, CA, USA
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[8]Astrophysics, University of Oxford, Denys Wilkinson Building, Keble Road, Oxford OX1 3RH, UK
[9]Department of Physics and Electronics, Rhodes University, PO Box 94, Grahamstown 6140, South Africa
[10]Physics Department, University of the Western Cape, Cape Town 7535, South Africa
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[12]The authors contributed equally to this work
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ABSTRACT

Fast radio bursts are a new class of transient radio phenomena currently detected as millisecond radio pulses with anomalously high dispersion measures. As new radio surveys begin searching for FRBs a large population is expected to be detected in real-time, triggering a range of multi-wavelength and multi-messenger telescopes to search for repeating bursts and/or associated emission. Here we propose a method for disseminating FRB triggers using the Virtual Observatory Events (VOEvents) developed and used successfully for transient alerts across the electromagnetic spectrum and for multi-messenger signals such as gravitational waves. In this paper we outline a proposed VOEvent standard for FRBs including the essential parameters of the event and the structure of the event itself. We also discuss an additional advantage to the use of VOEvents for FRBs: new events can now be automatically ingested into the FRB Catalogue (FRBCAT) enabling real-time updates for public use. We welcome feedback from the community on the proposed standard outlined below and encourage those interested to join in the nascent working group forming around this topic.

Introduction

Fast radio bursts (FRBs) are one of the most exciting topics in modern astrophysics and their study is of intense interest to the transient astronomy community. FRBs are detected as millisecond radio pulses with a high dispersion measure, defined as

$$\mathrm{DM} = \int_0^D n_e \, d\ell \qquad (1)$$

where D is the distance between the source and the observer along some path ℓ, and n_e is the electron column density. Dispersion is seen in pulses from Galactic pulsars but the DMs of FRBs are up to 70 times greater than the DM expected along the line of sight in the Milky Way leading to energetic extragalactic progenitor theories such as binary neutron star mergers[1], collapses of neutron stars to black holes[2], extremely active young pulsars in nearby galaxies[3], and hyperflares from magnetars[4], to name a few. The designation of a bright single pulse as an FRB (as opposed to a bright single pulse from a Galactic pulsar) has been based on its DM. All known FRBs have DMs in excess of the modeled electron density contribution from the Milky Way, and all but one[5] have DMs $> 1.5 \times \mathrm{DM}_{\mathrm{MW_N E2001}}$ where $\mathrm{DM}_{\mathrm{MW_N E2001}}$ is the electron density contribution along the line of sight modeled by NE2001[6].

The first FRB was discovered in 2007 by Lorimer et al.[7], FRB 010724[*], and since then progress has increased rapidly. Eighteen FRB sources have been published[†] and one source, FRB 121102, has been seen to repeat[8]. Interferometric observations

[*]FRBs currently follow the date-based naming conventions for gamma-ray burst and gravitational wave events: FRB YYMMDD.
[†]All publicly available FRBs are included in the FRB Catalogue (FRBCAT); http://www.astronomy.swin.edu.au/pulsar/frbcat/

Searches in all directions

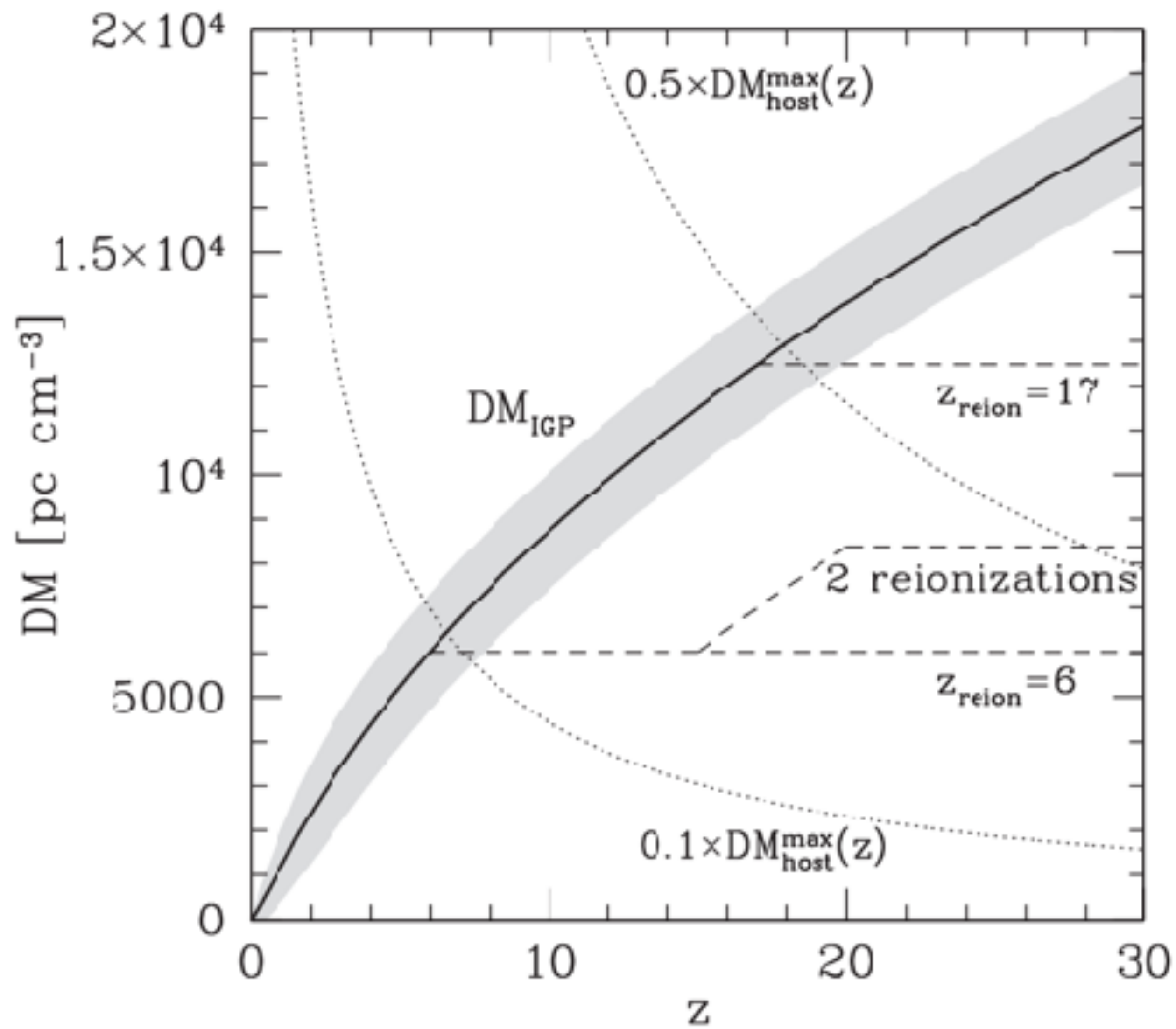
	HTRU int	HTRU high	RRATs	FRB follow up	SUPERB	P574	Total	N FRBs
0 - 19.5	1157	402	483	0	700	281	3024	4
19.5 - 42	0	942	28	50	1115	10	2145	5
42 - 90	0	982	39	60	907	9	1998	10

Searches to the edge of the parameter space

- Searches to high and low DMs
- Searches for multi-component bursts
- Searching for bursts with spectral cutoffs
- Searching for weird signatures

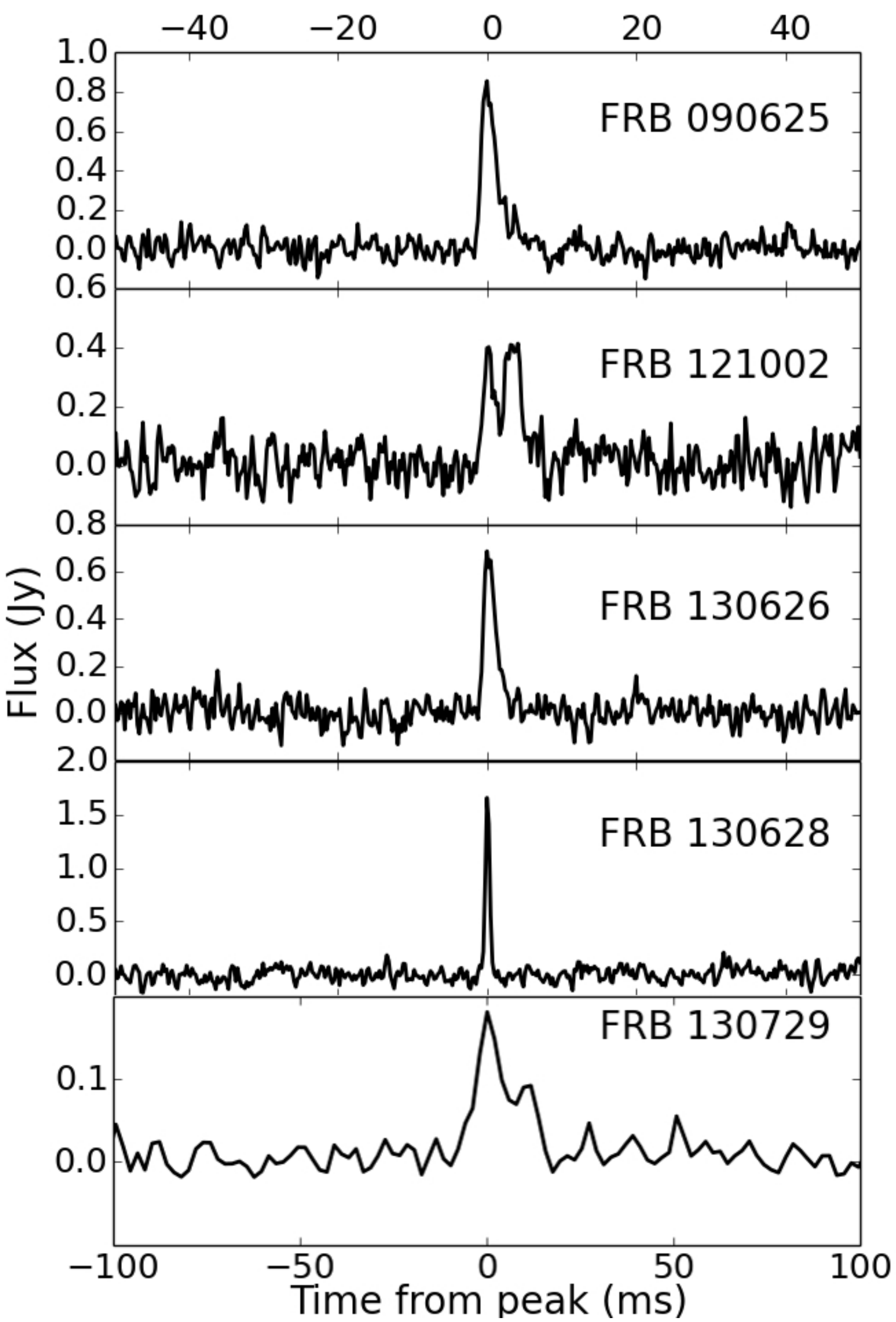
DM and redshift

- Looking at the FRB DM excess
- $z \leq DM_{excess}/1200$
  - Very basic, lots of assumptions, for IGM after He re-ionization ($z < 3$)
- No precise relation, but some indication of path of FRB
- Using DM as an indicator for distance:
  - $0.05 < z < 2.1$
- Heavily depends on density of progenitor region and models for DM-redshift relation



Ioka 2003

Pulse variety



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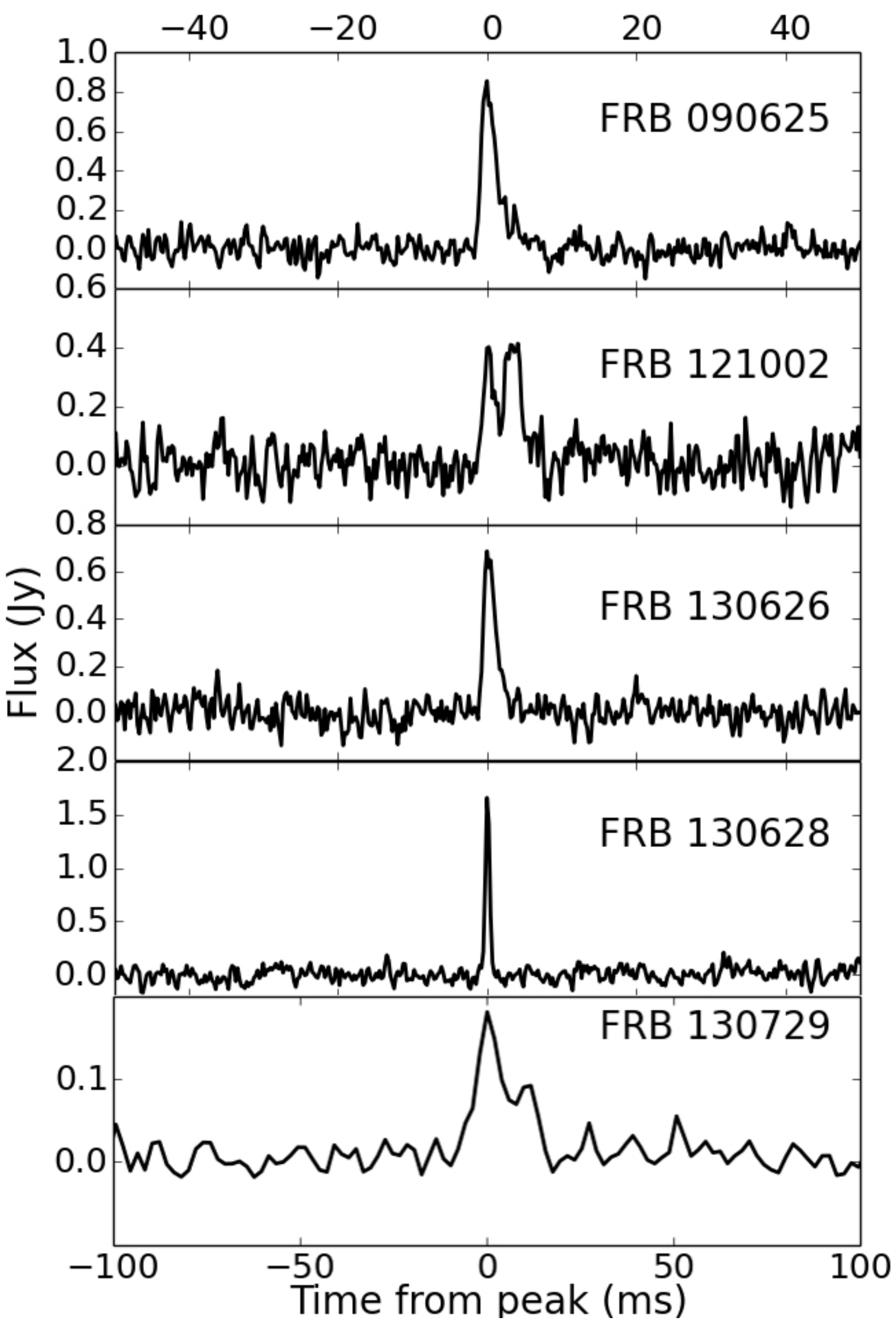

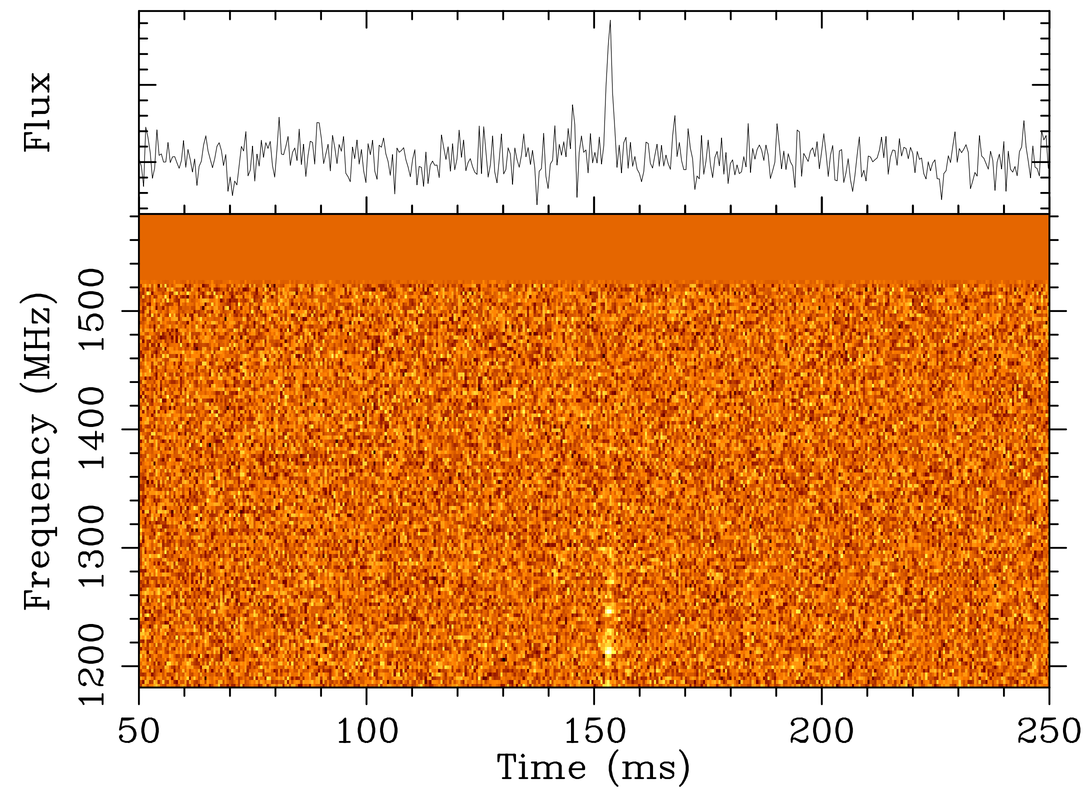

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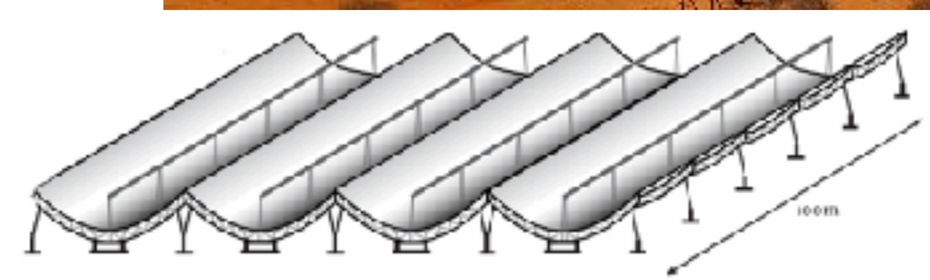
Inconclusive conclusions

- We still don't know the source of FRBs, but we have many avenues to pursue that might give us answers



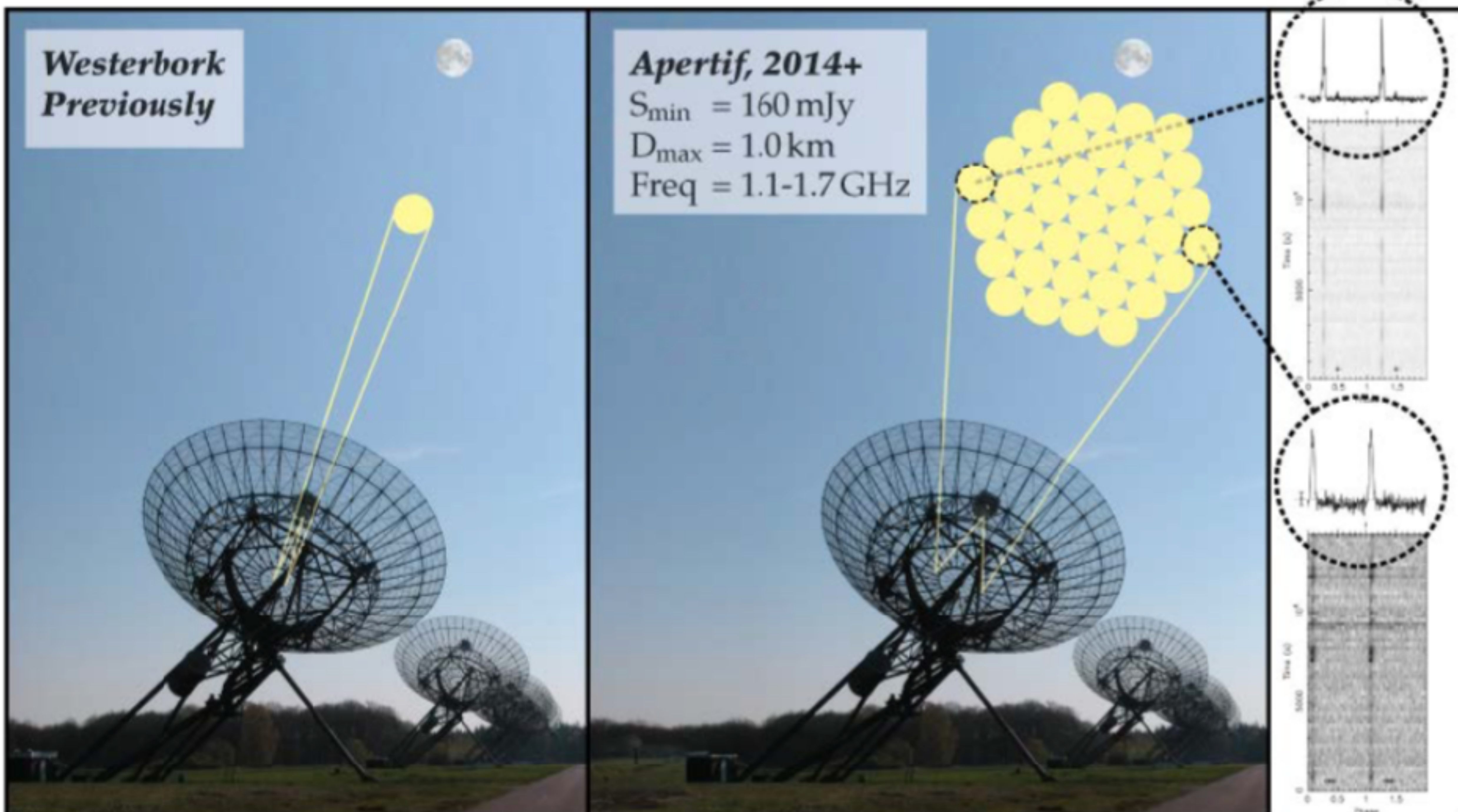
- Highest priority in the near future is understanding the population(s) and progenitor(s)

- Enormous progress expected with wide field interferometers (Apertif, ASKAP, CHIME, UTMOST) and real-time or near real-time searches

- Other checks we should be doing? Negative DMs? etc.

ALERT:

Apertif: 9 deg^2 field, 20 frames/ms (*PI*, 1.6 MEur)



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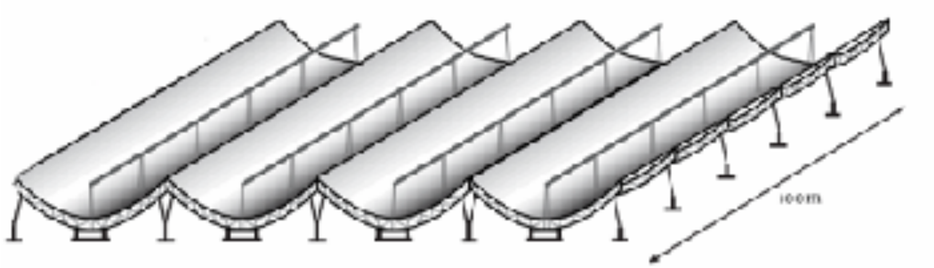

FRB Catalog (FRBCAT)

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

Swinburne Pulsar Group

@FRBCatalogue

> Swinburne Pulsar Group > FRBCAT

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	$5.44^{+3.50}$	$0.43^{+0.33}$	$2.34^{+4.46}$	4

Petroff et al. (2016)

Thank You!

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