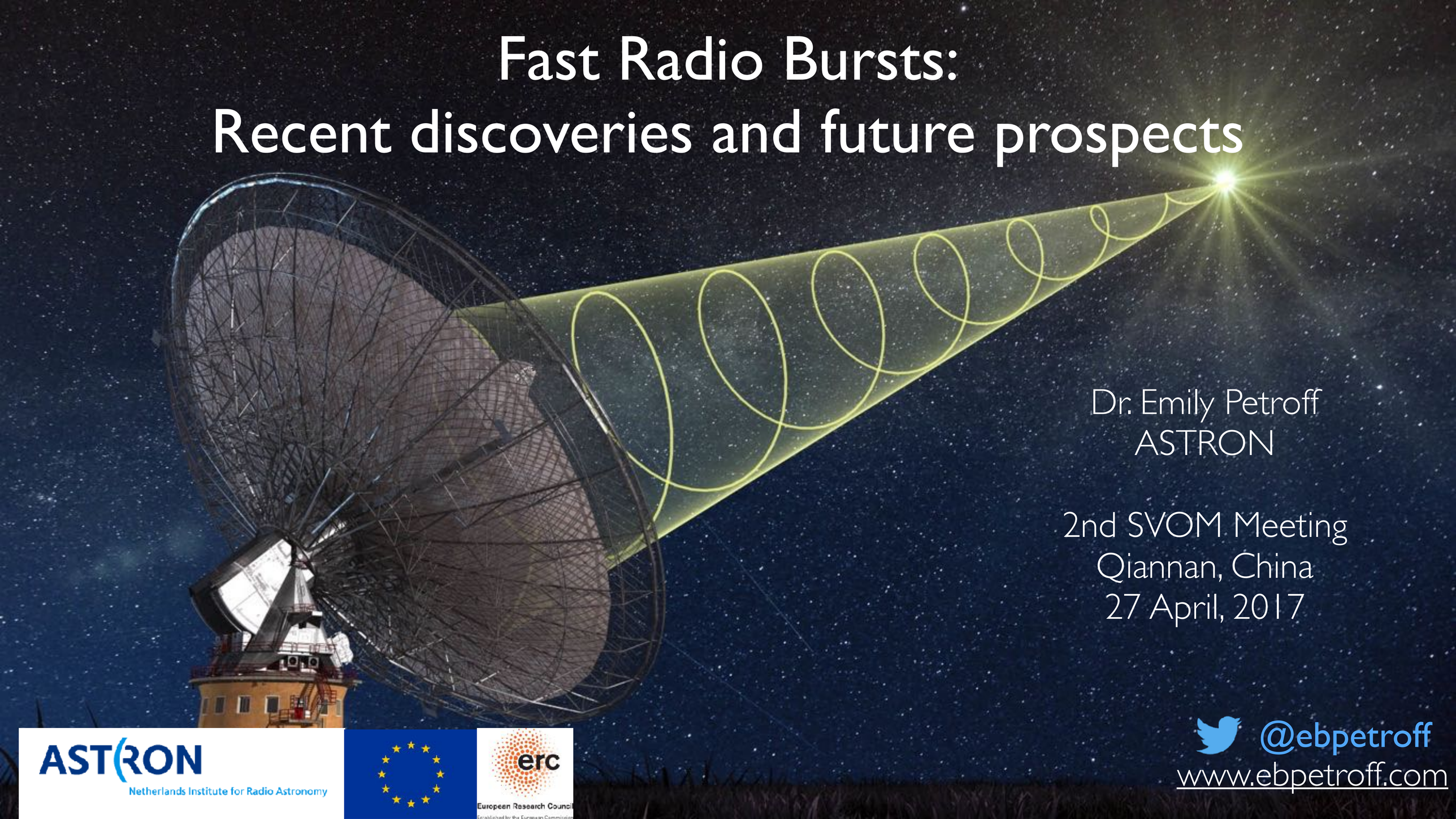
Fast Radio Bursts:
Recent discoveries and future prospects



Dr. Emily Petroff
ASTRON

2nd SVOM Meeting
Qiannan, China
27 April, 2017

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Netherlands Institute for Radio Astronomy

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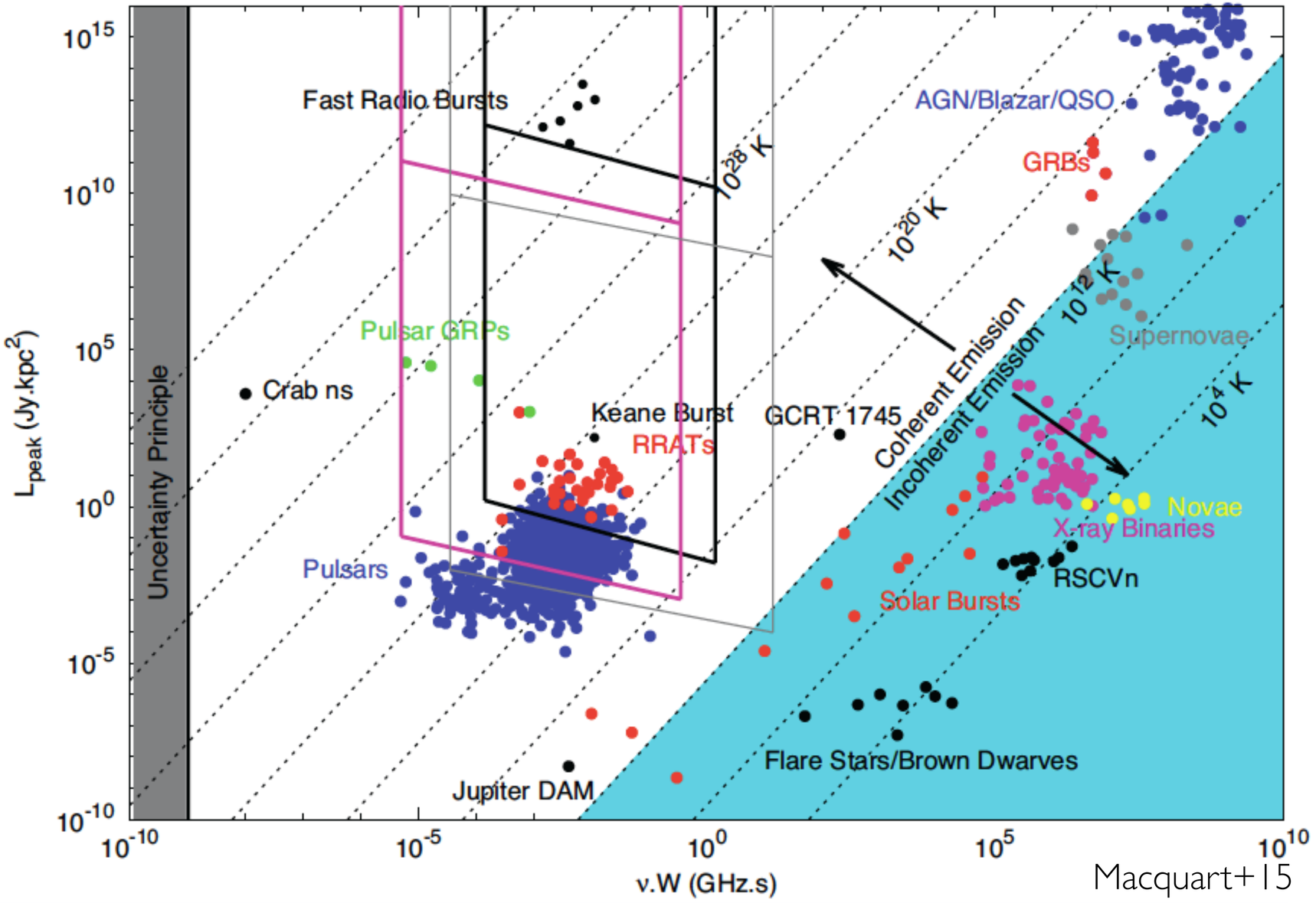
European Research Council

Transient parameter space



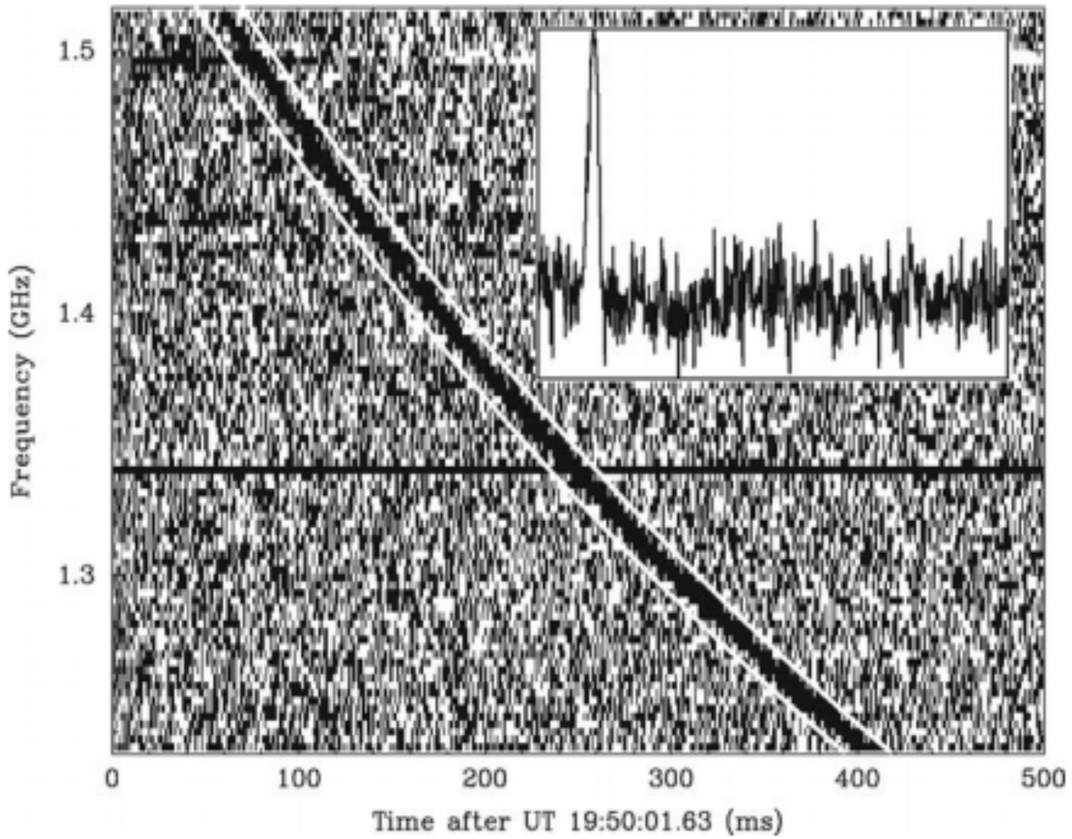
Macquart+15

What are fast radio burst and why are they cool?

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

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

- DM(FRB) ~ 10 x DM(MW)
- Originate extragalactically
- Hugely energetic, relatively common new transients



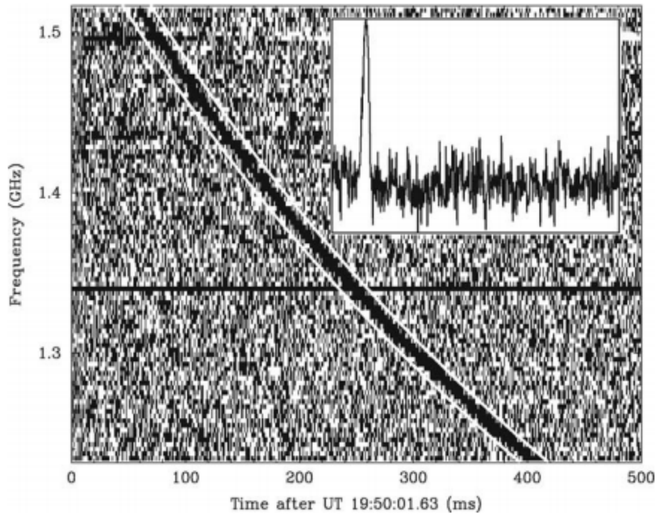
Lorimer et al 2007

Introduction to fast radio bursts

- Some or all excess DM may come from IGM
- Sources outside the Galaxy (at least some are cosmological)
- Rate ~ 5,000 sky^{-1} day^{-1}
- Possible progenitors:
  - GPs from young pulsars
  - Young magnetar
  - BNS merger
  - NS collapse

FRB History lesson

- Searches through more parameter space
- 2007: Discovery of Lorimer Burst
- 2010: Concern about strange interference (“perytons”)
- 2013—2016: 25 more FRBs found in old and new data:
  - 4 different telescopes
  - first real-time detection in 2014
  - first interferometric detection in 2016



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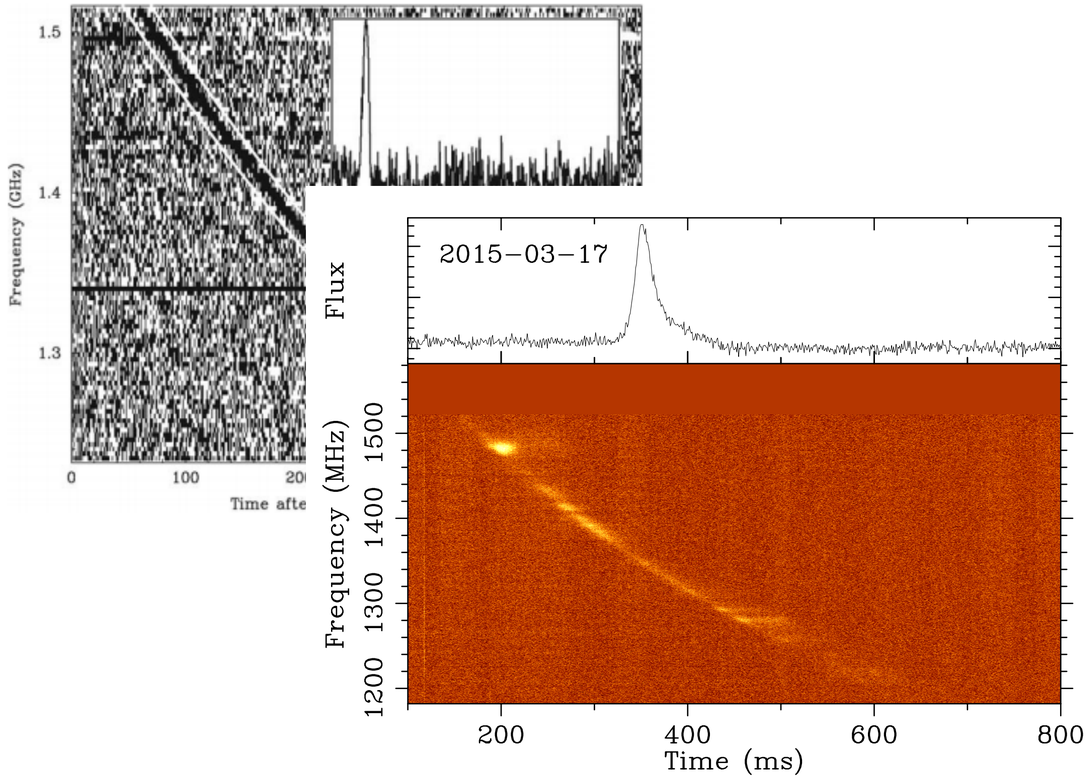

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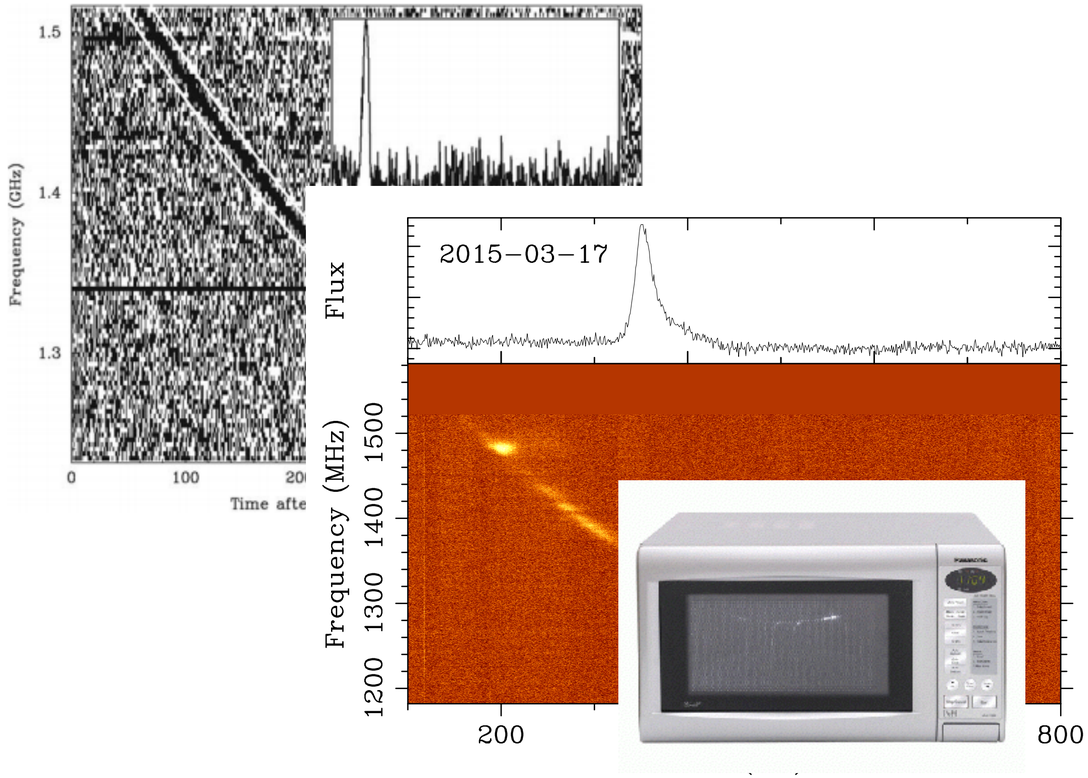

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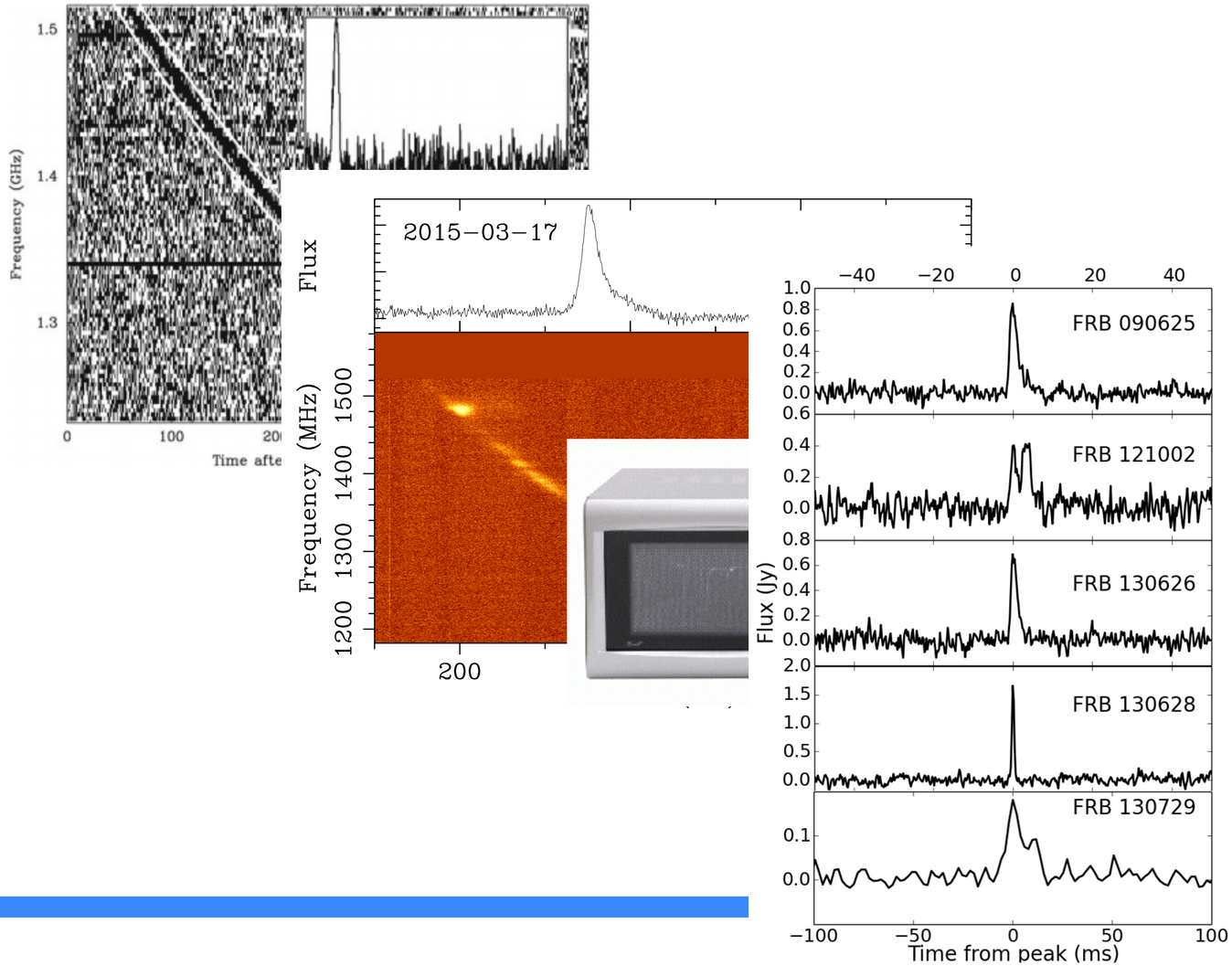

FRBs in 2016

- Green bank telescope burst in January
- Parkes real-time detection in February
- Repeat pulses seen from FRB 121102 in March
- First interferometric detection with UTMOST in April
- Possible gamma ray counterpart to FRB 131104 in November
- Extremely bright low DM burst in November

FRBs in 2016

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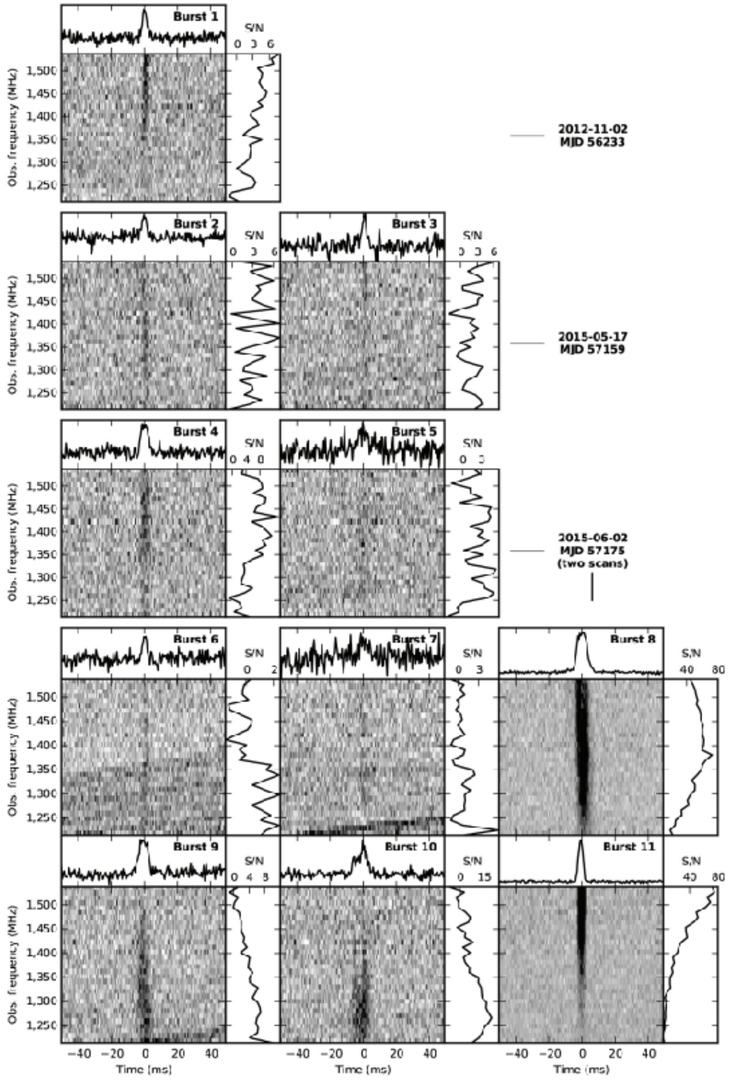
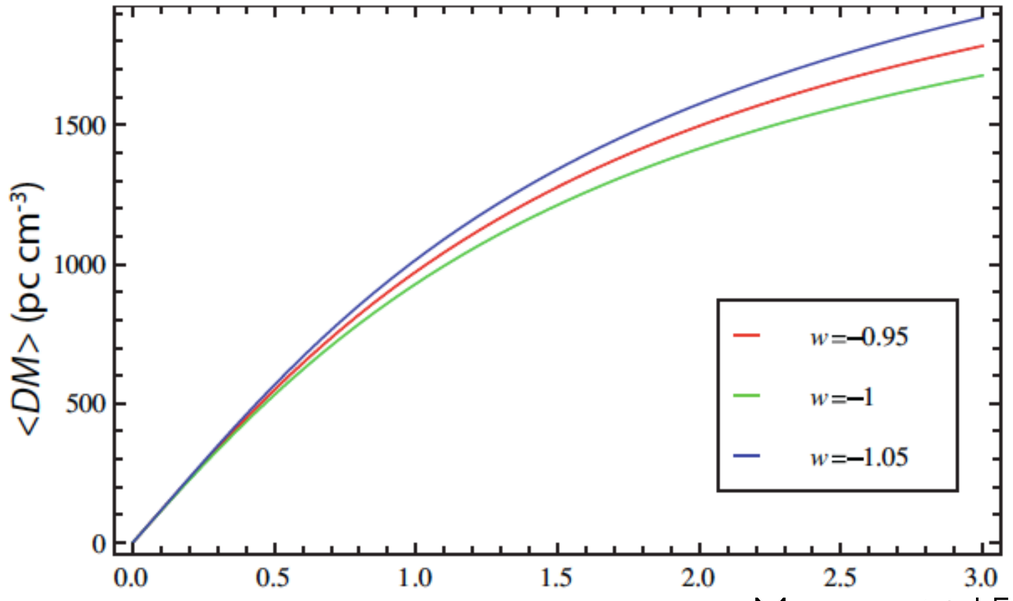


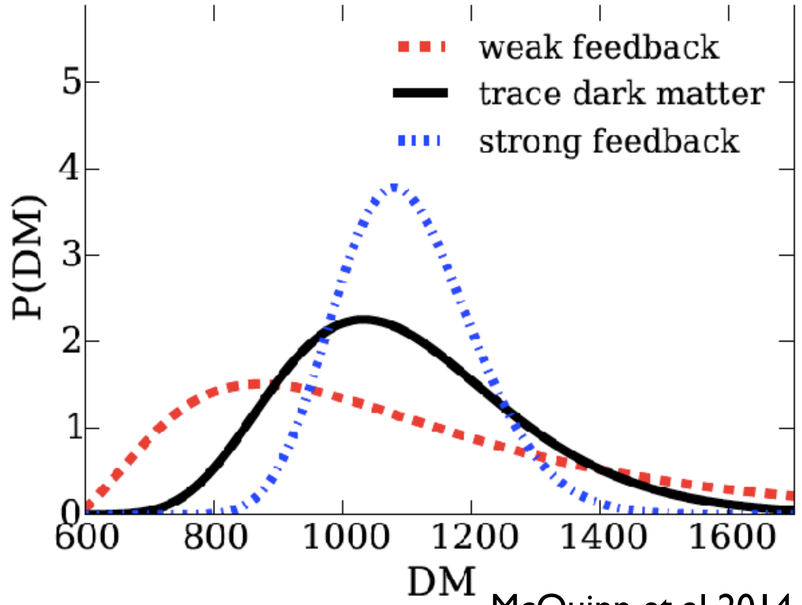
Spitler et al. 2016

Why are we so excited about FRBs?

- Brand new transients! Extreme physics!
- Use FRBs as probes in interesting cosmological experiments
- Most exciting immediate prospect: probing the baryons in the IGM



Macquart+15

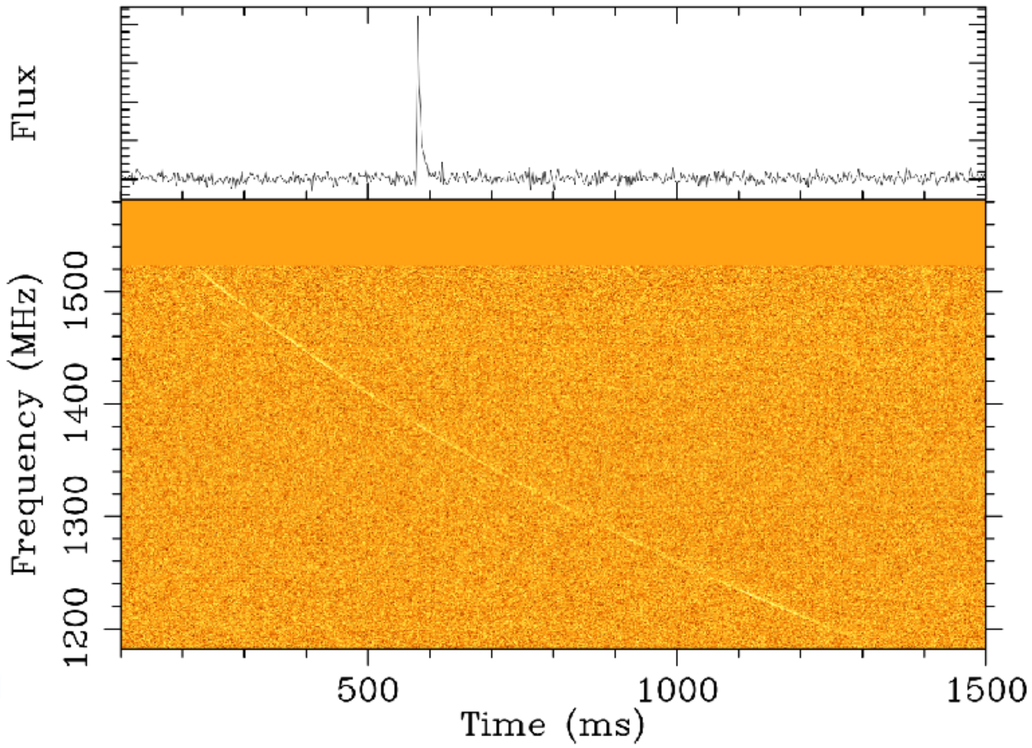


McQuinn et al 2014

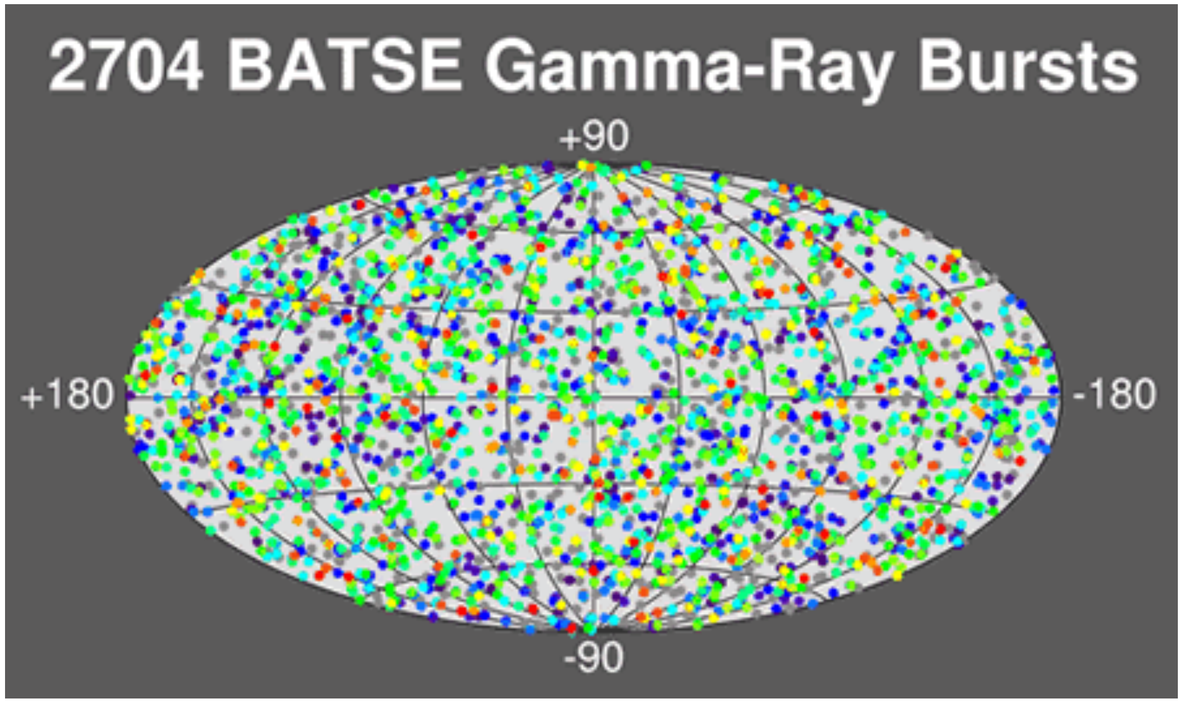
Probing the baryons

- n_e is the integrated *electron* column density
- probing the Warm Ionized Medium along the line of sight
  - ISM (also covered by pulsars)
  - IGM
  - intervening halos
  - host galaxy
  - progenitor region

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



Probing the baryons



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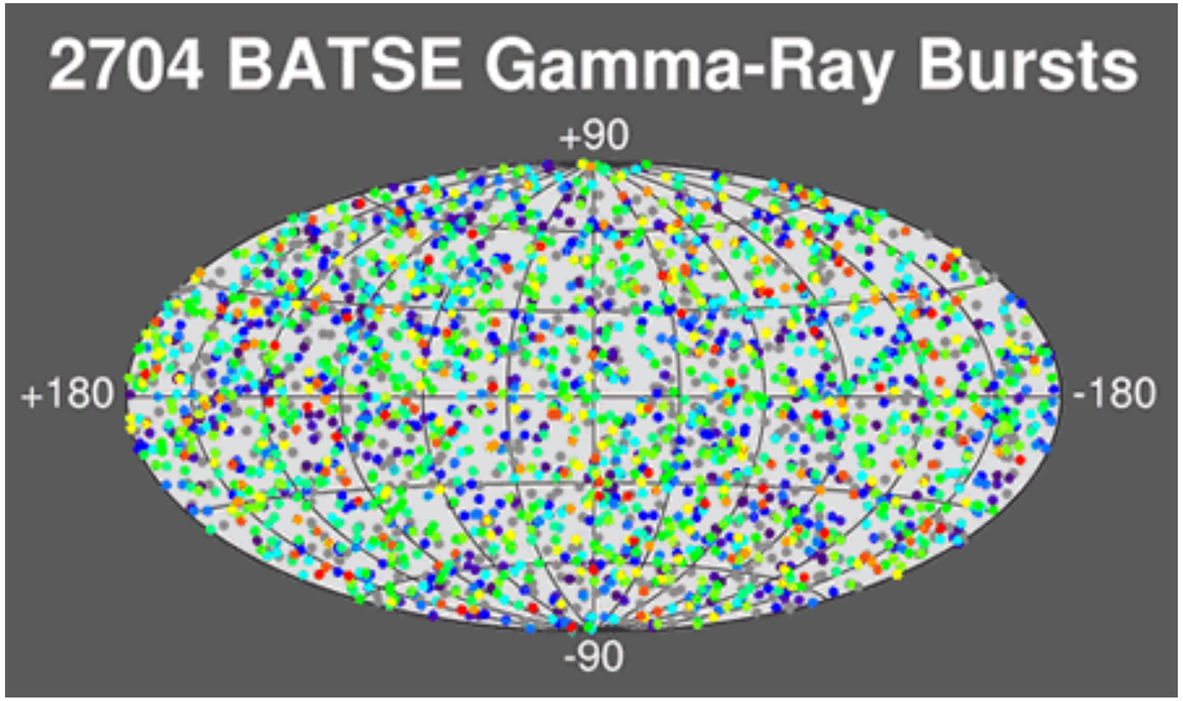
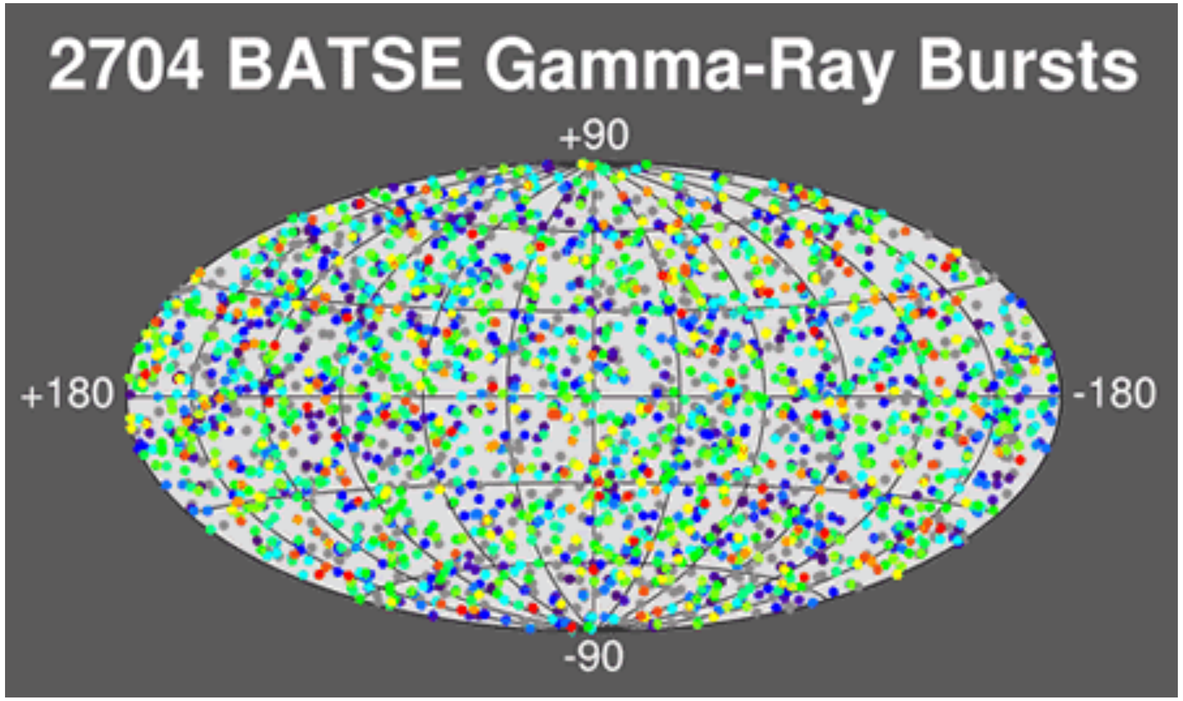


$R_{FRB} \sim 5000\ \text{sky}^{-1}\ \text{day}^{-1}$

(Champion, Petroff, et al., 2016)

Probing the baryons



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Brand new window on the WHIM and missing baryons

Probing the baryons

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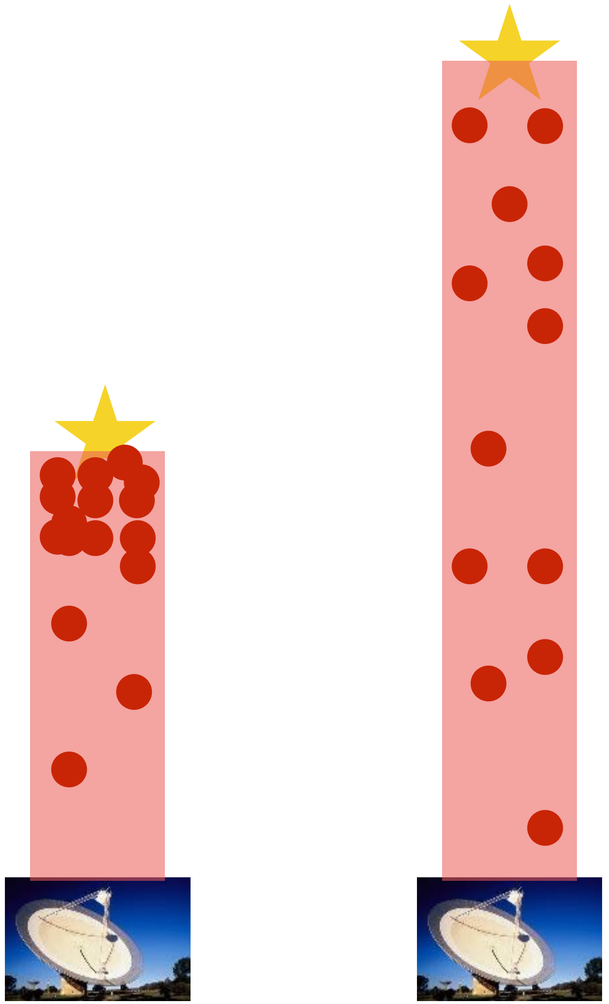

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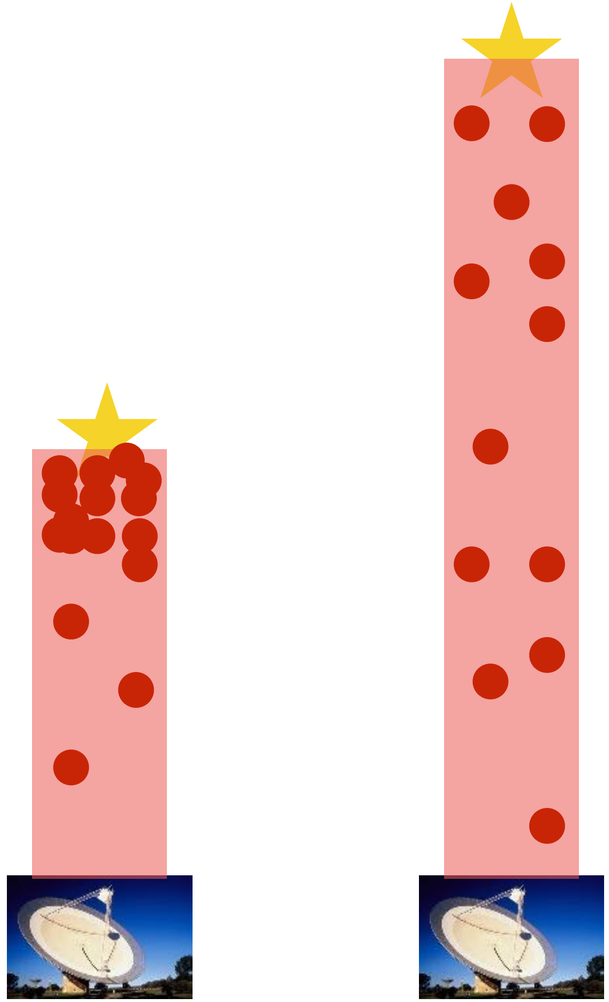
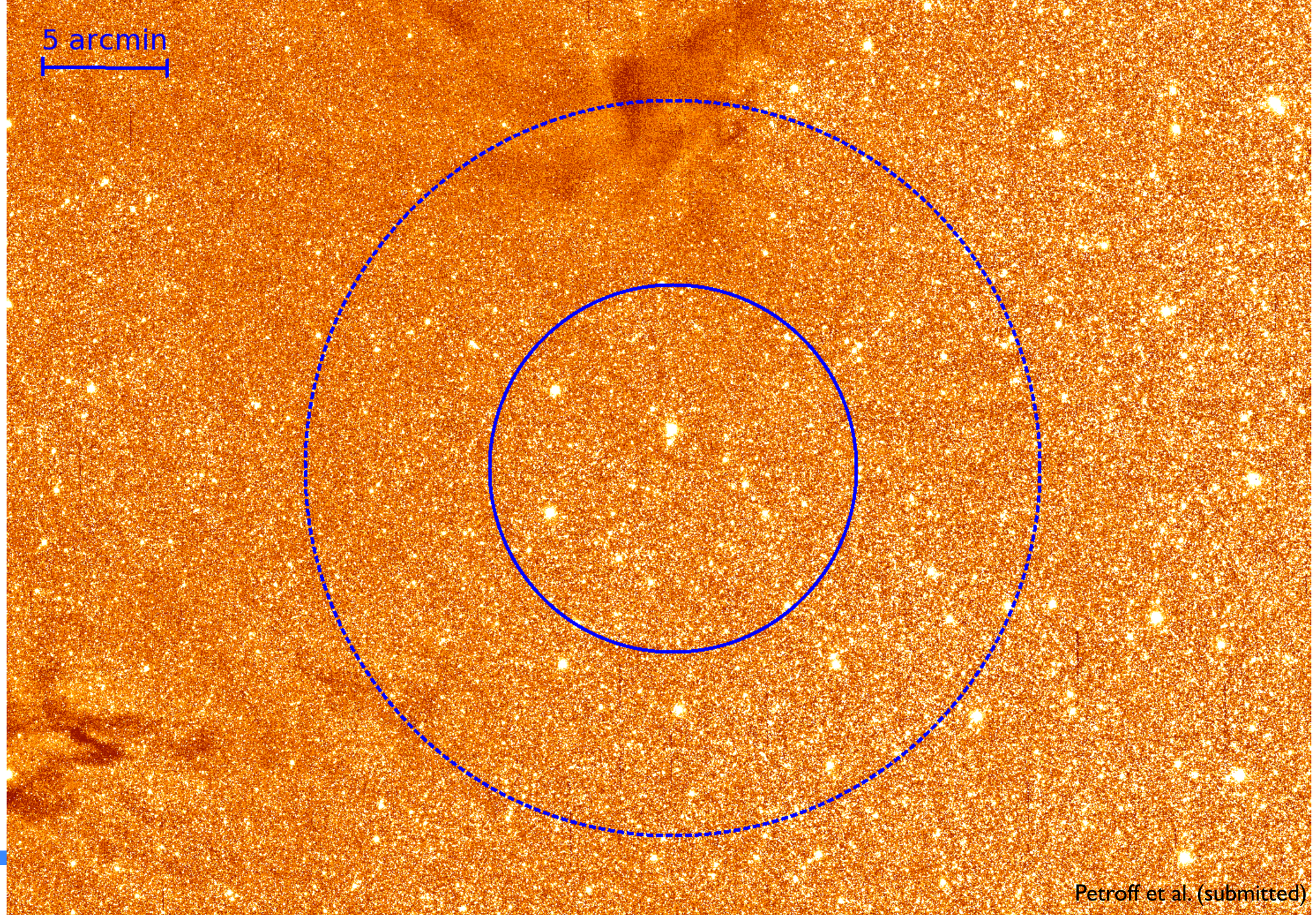




Petroff et al. (submitted)

Most promising new avenues

The first FRB host galaxy

Rapid multi-wavelength/multi-messenger follow-up

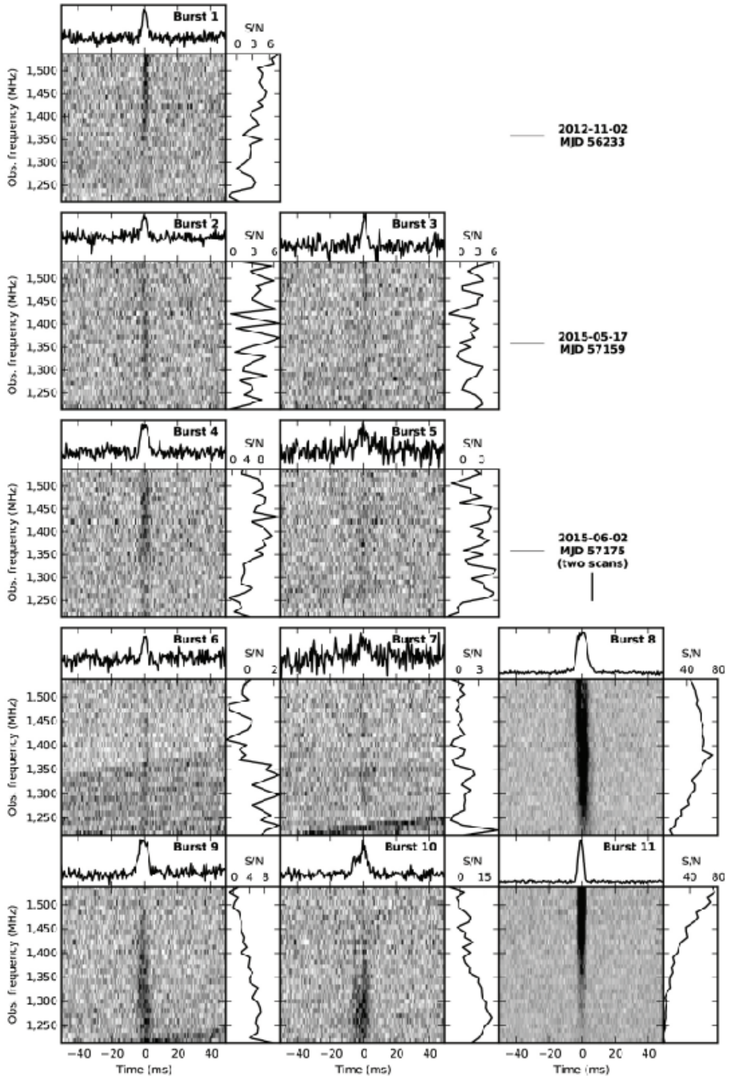
Studying the emerging population

New searches with wide-field interferometers

Other fun stuff

The first host galaxy

- Only one FRB seen to repeat (FRB 121102)
- **Localized** through repeating pulses with the VLA
- Located in a dwarf galaxy
  - z = 0.19 (~1 Gpc away)
- Co-located with persistent radio source
- Possible connection with **long GRBs** and **SLSNe**
  - young magnetar with dense PWN?



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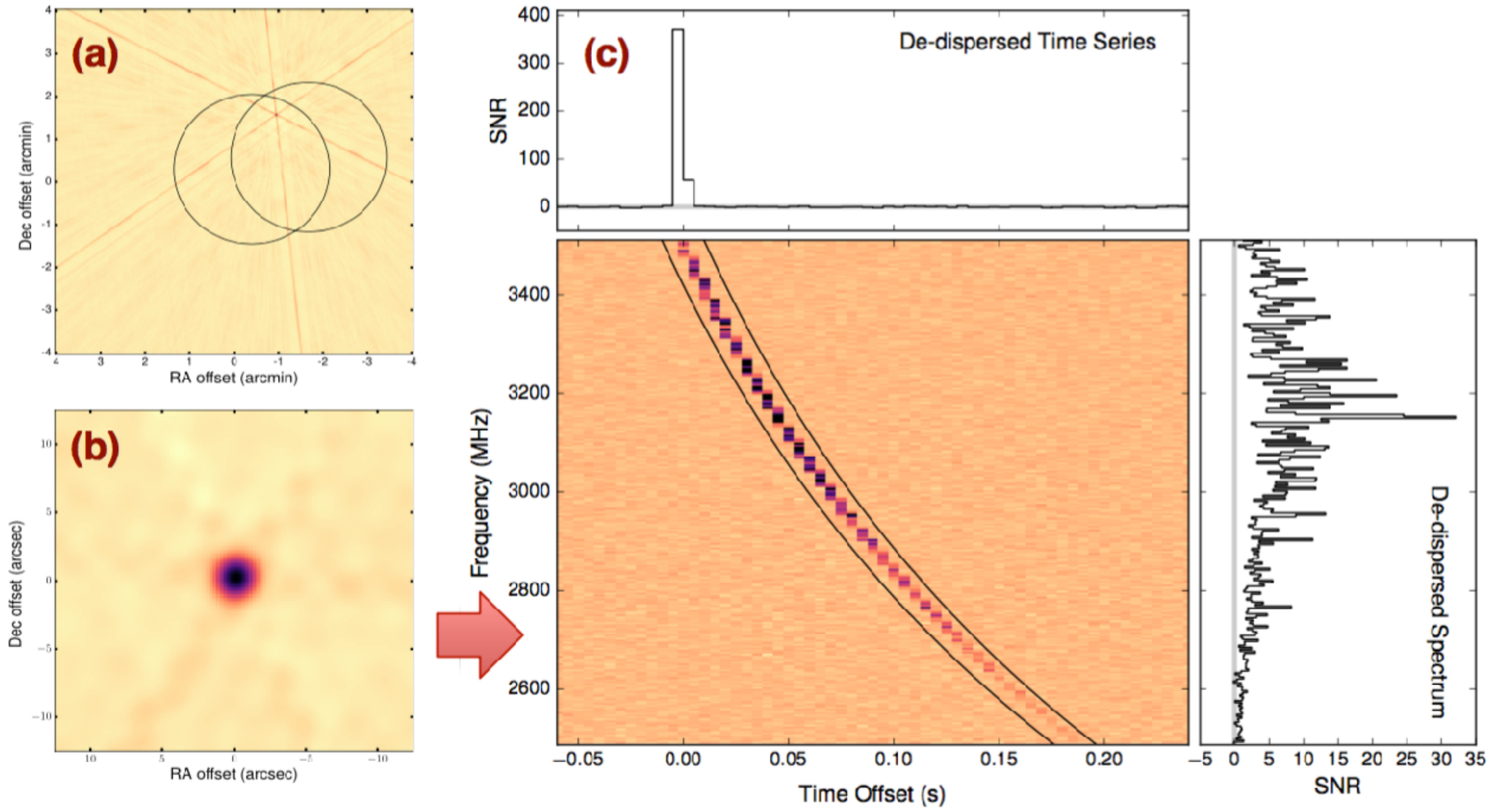

Chatterjee et al. 2017

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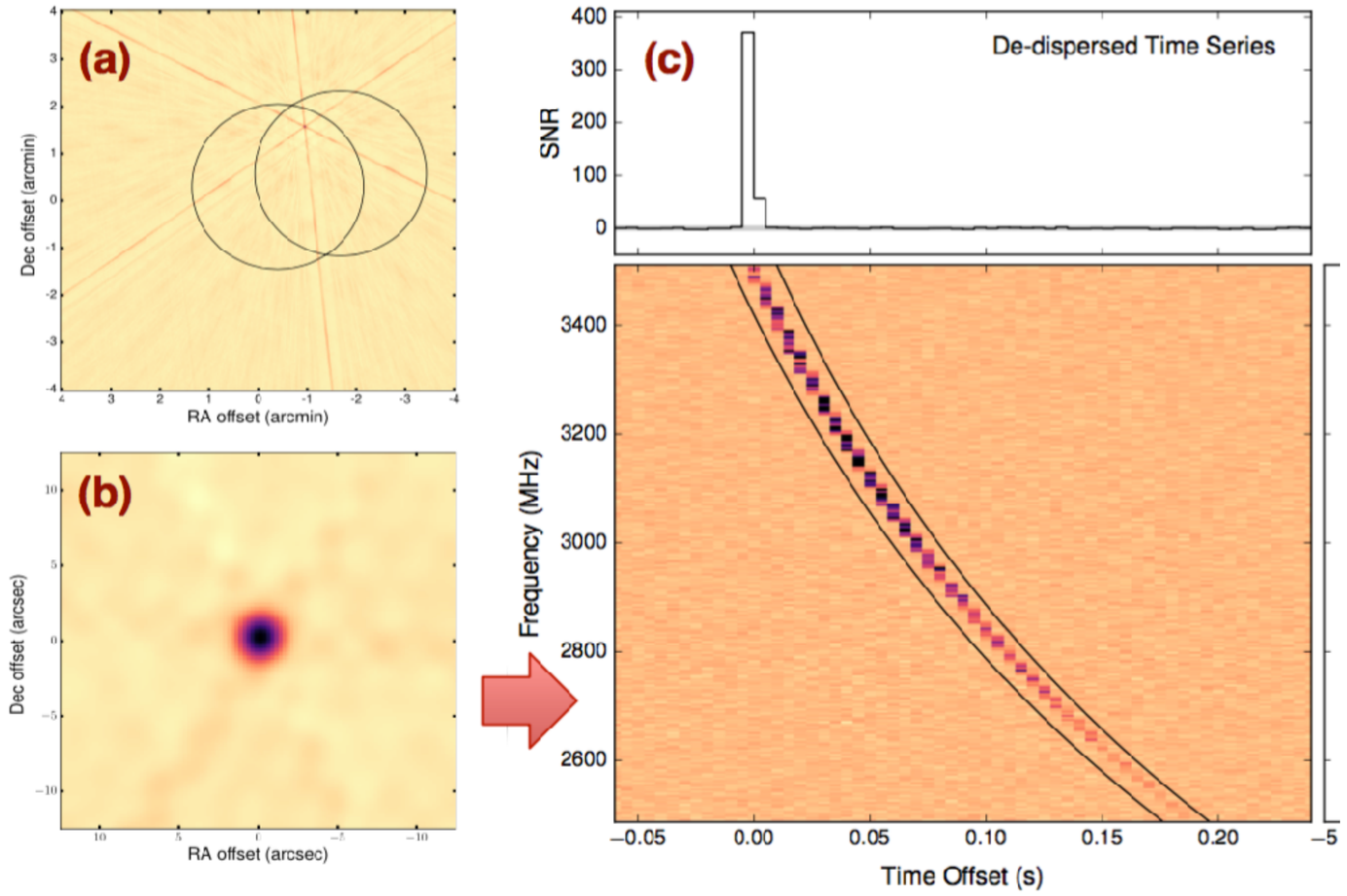
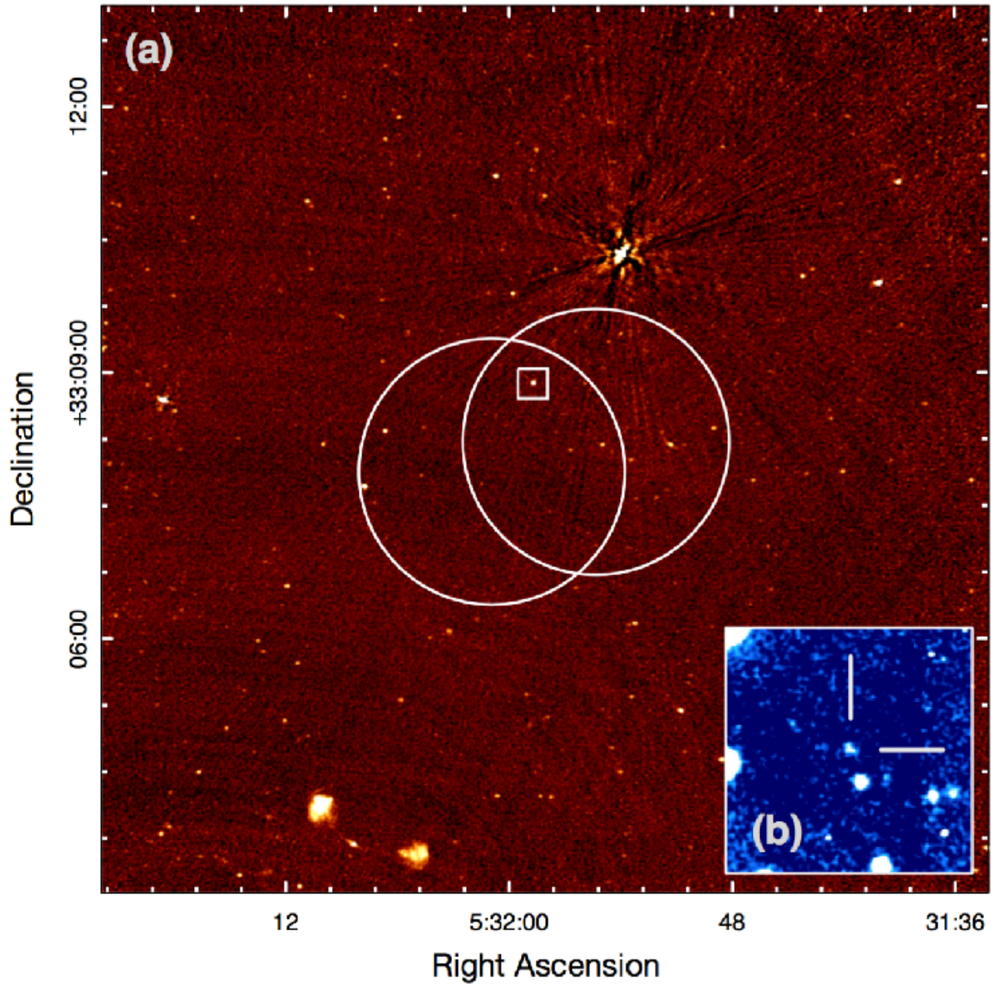
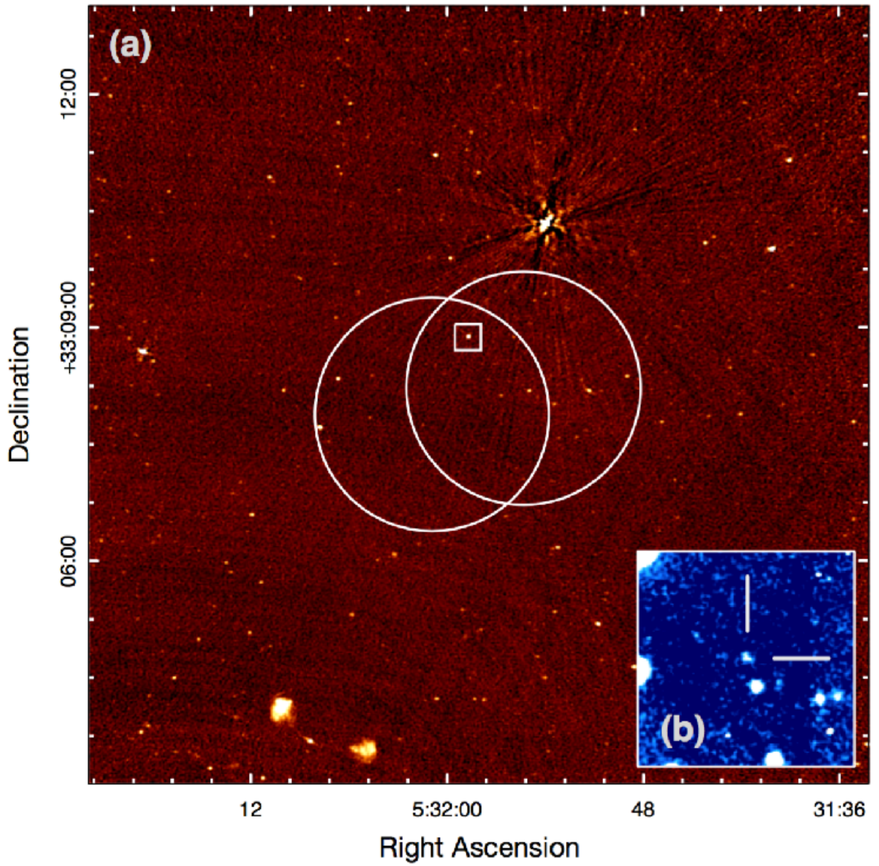




Chatterjee et al. 2017

Conclusions from the first host galaxy



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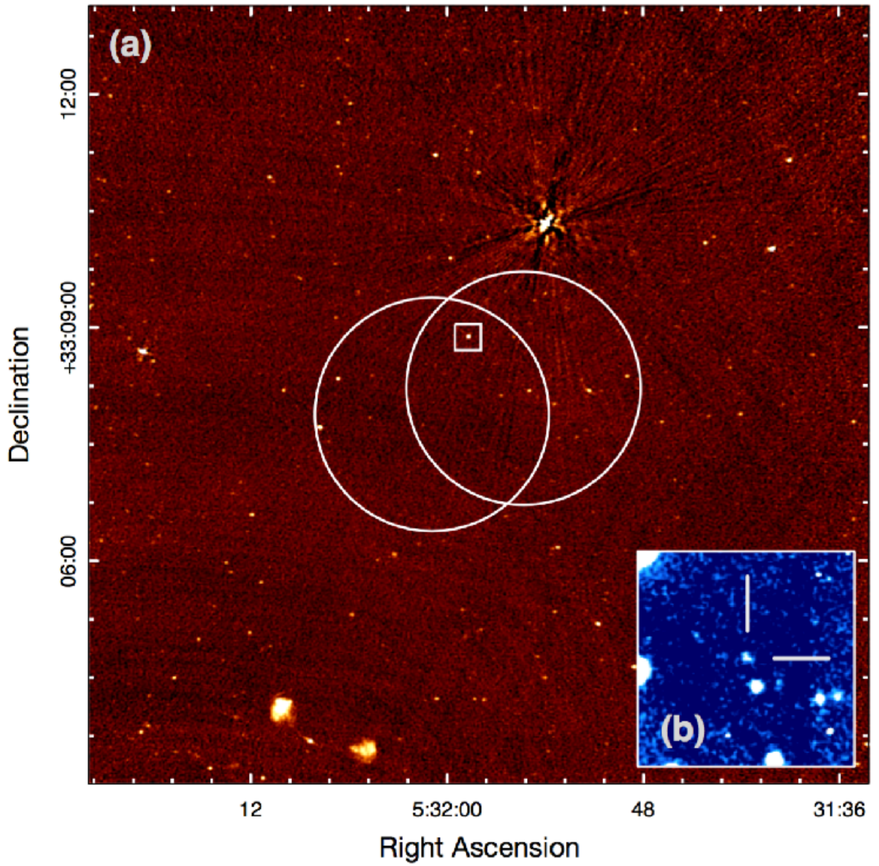

Conclusions from the first host galaxy

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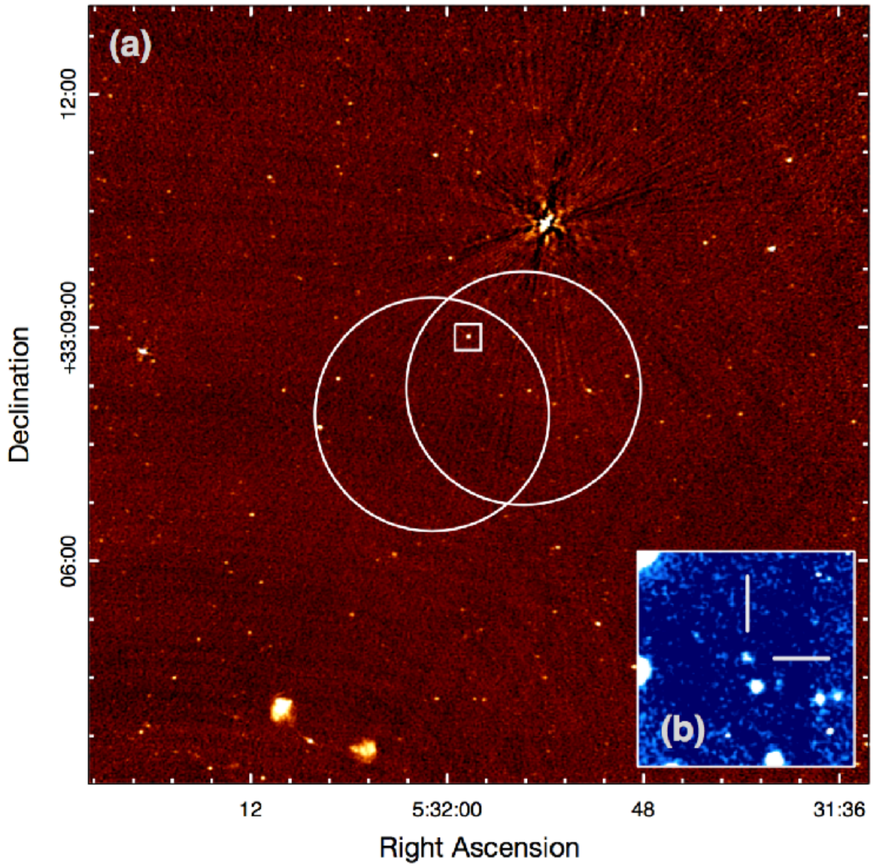

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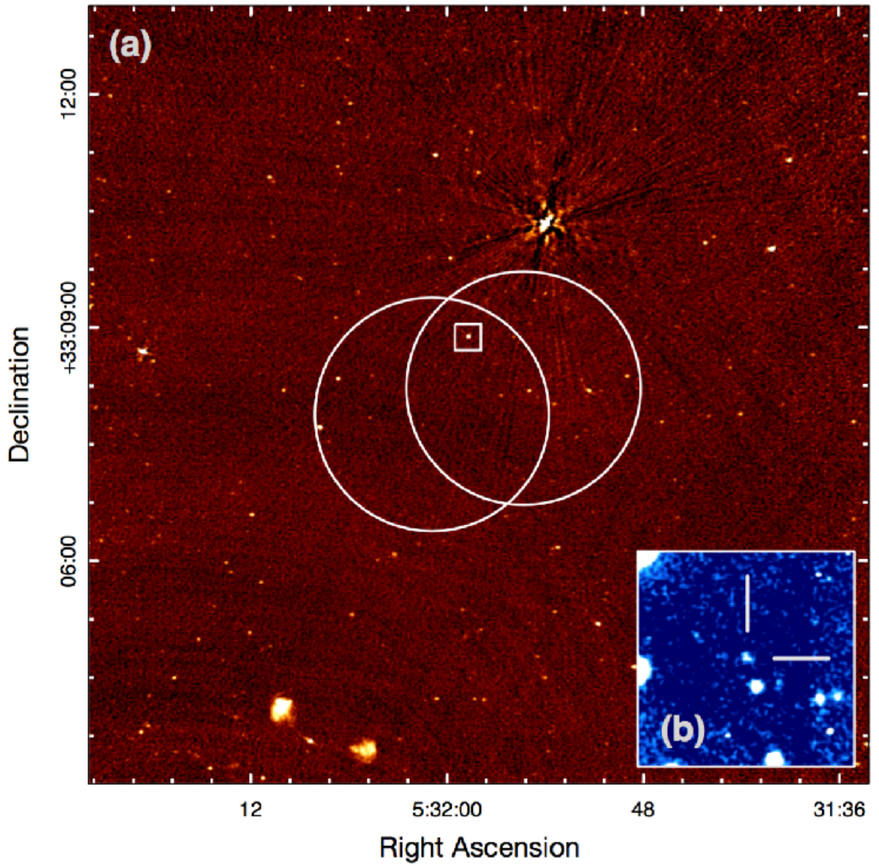

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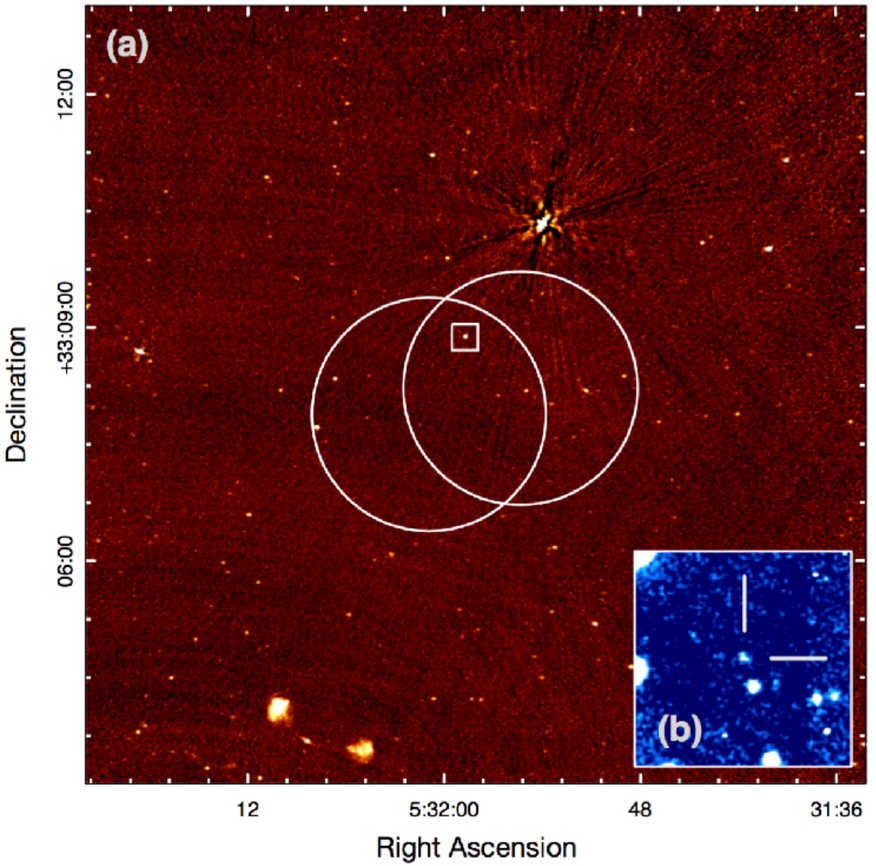

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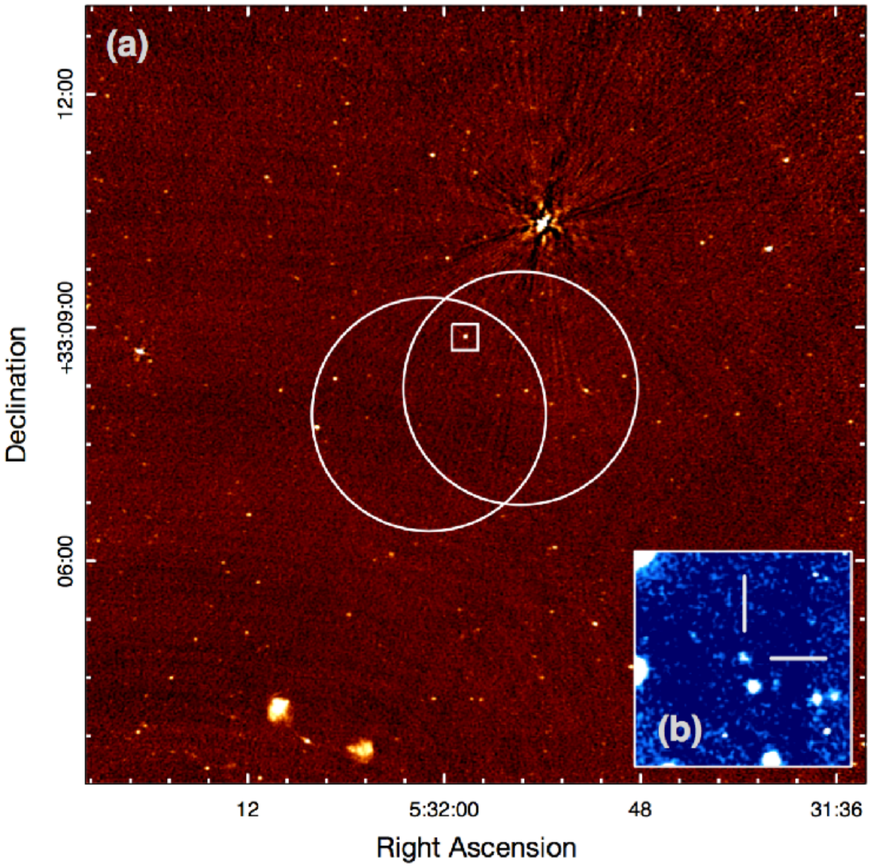
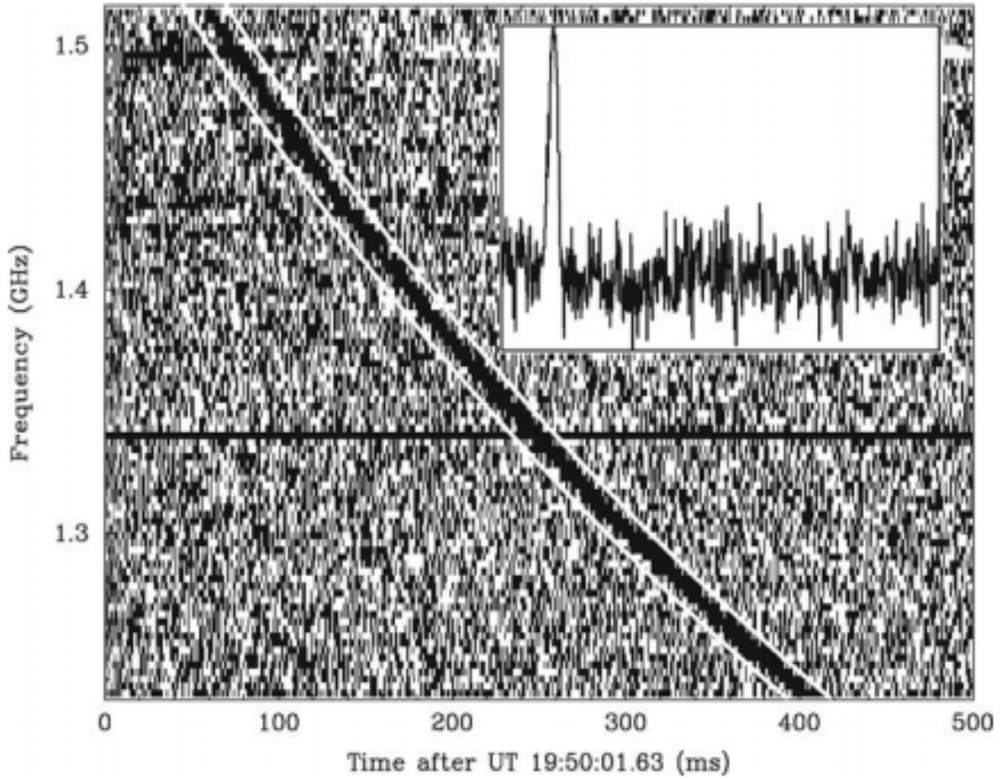
- Disentangling the local contribution is very hard
- The same for all FRBs?



Do all FRBs repeat?

- No other FRB seen to repeat
- Some observed for over 100 hours
- Possible interpretations:
  - Only very young sources repeat often
  - Observed when it was "off"
  - Multiple progenitor populations
- Still want to identify host galaxies for new FRBs and get the interesting science!



Most promising new avenues

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Rapid multi-wavelength/multi-messenger follow-up

Studying the emerging population

New searches with wide-field interferometers

Other fun stuff

Real-time detection and multi-wavelength follow-up

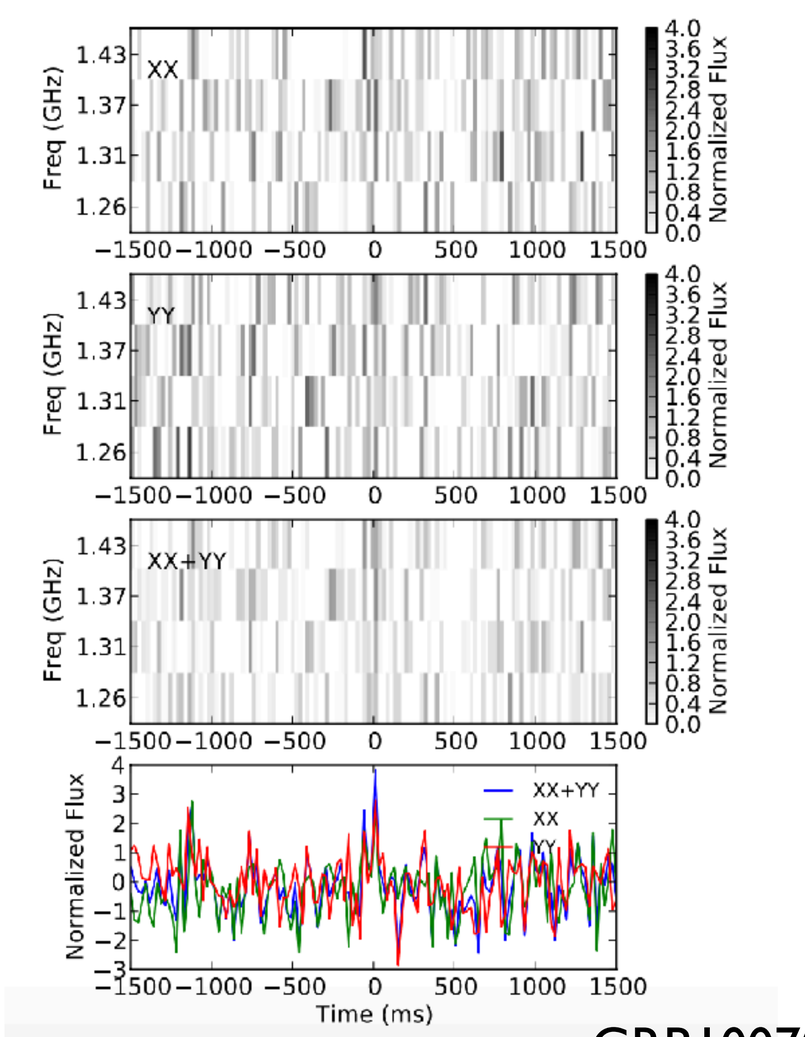
- Transient science requires fast responses:
  - trigger on a discovery
  - alert others for follow-up
  - preserve as much raw data as possible
- Finding FRBs and pulsars in real-time (*within 16s)
- Still limited by beam size at Parkes
- Aim: find associated emission
- Still unknown what type of associated emission may exist

Multi-wavelength/multi-messenger follow-up

- At Parkes: trigger a wide range of complementary facilities across all wavelengths (+ neutrino + GW)
- Searching for longer-lived prompt emission and/or afterglow
- Unlikely that millisecond prompt emission extends above radio regime
- Searching for connections with other types of transients

SUPERB
Survey for Pulsars and Extragalactic Radio Bursts

Possible gamma ray connection?



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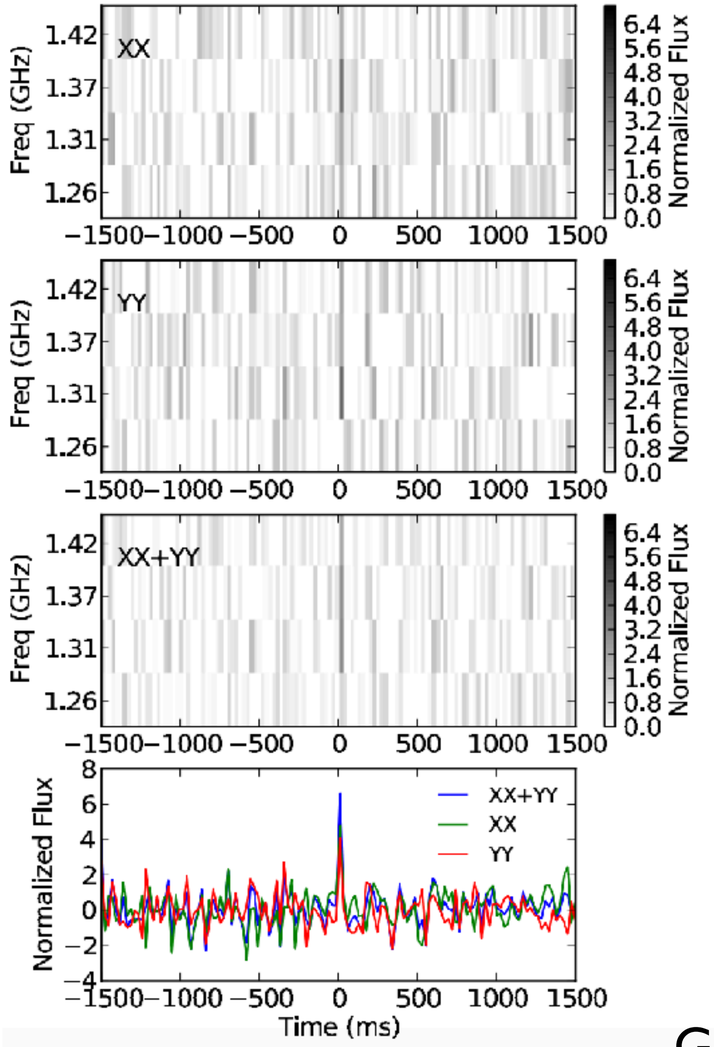

GRB101011A

Bannister et al. 2012

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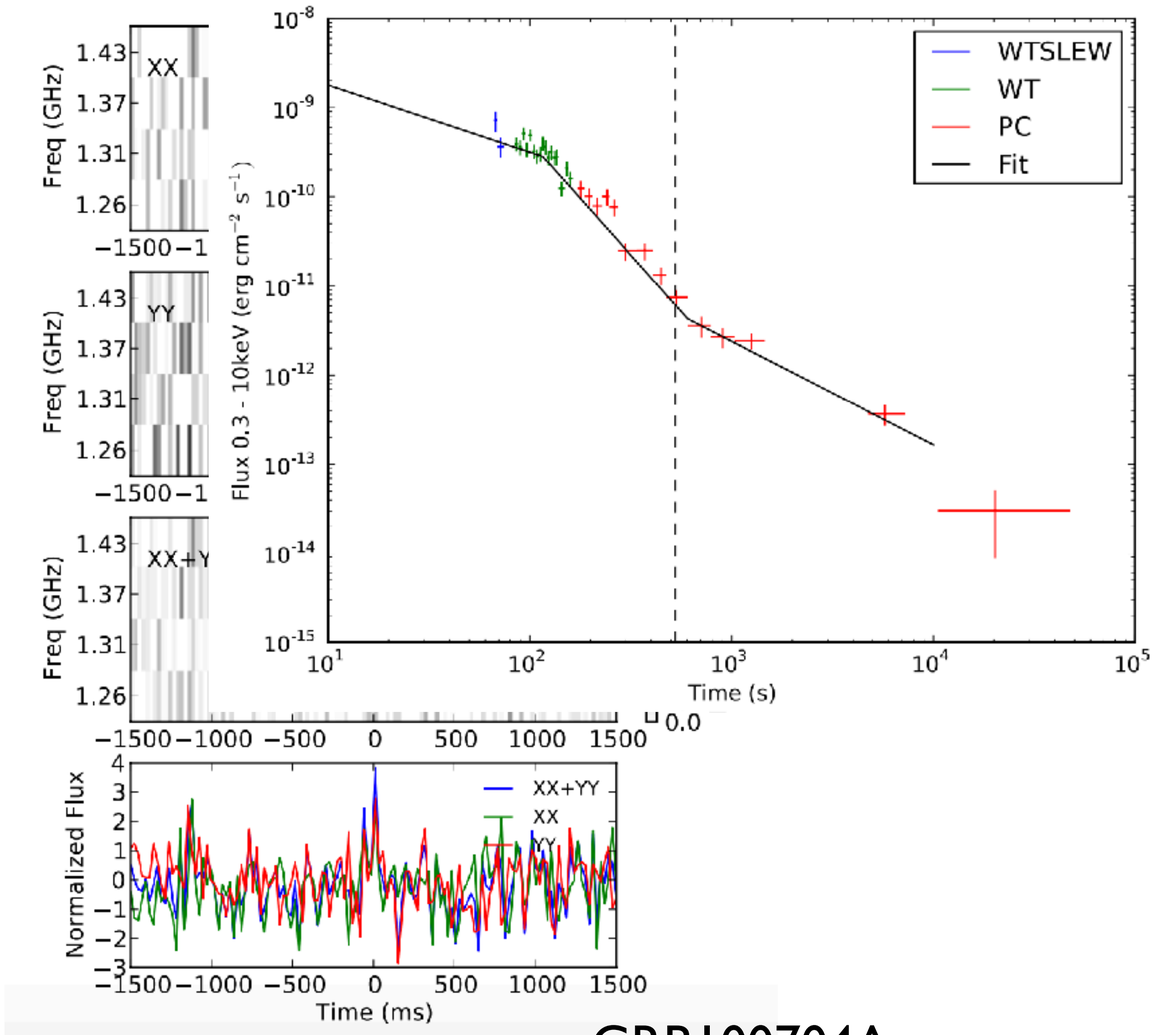

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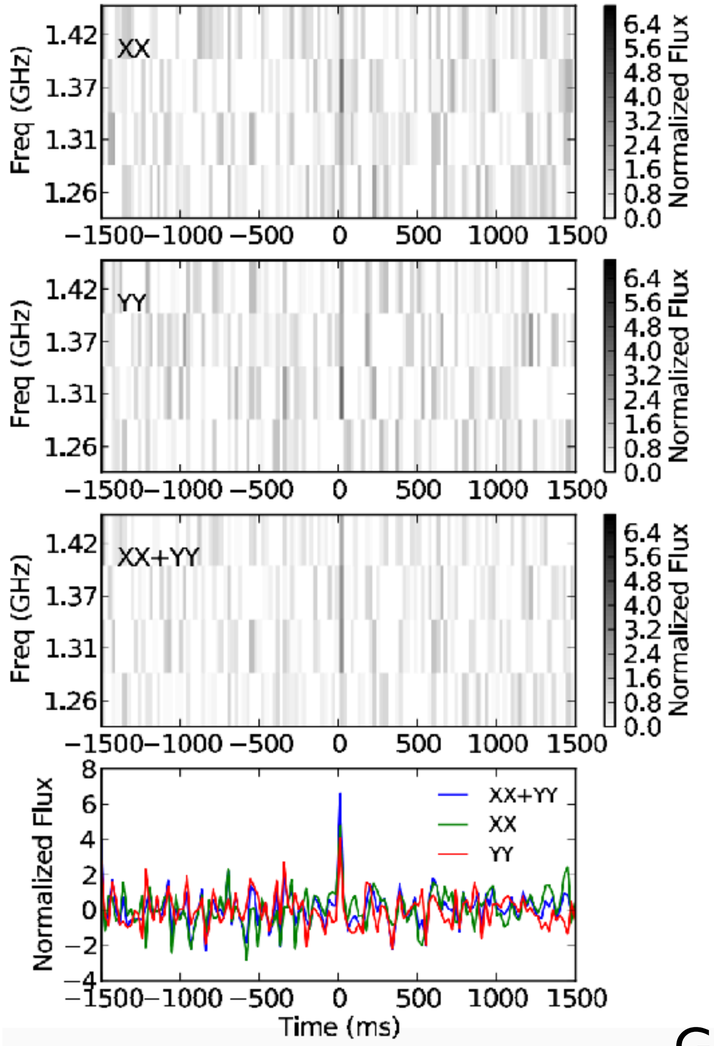

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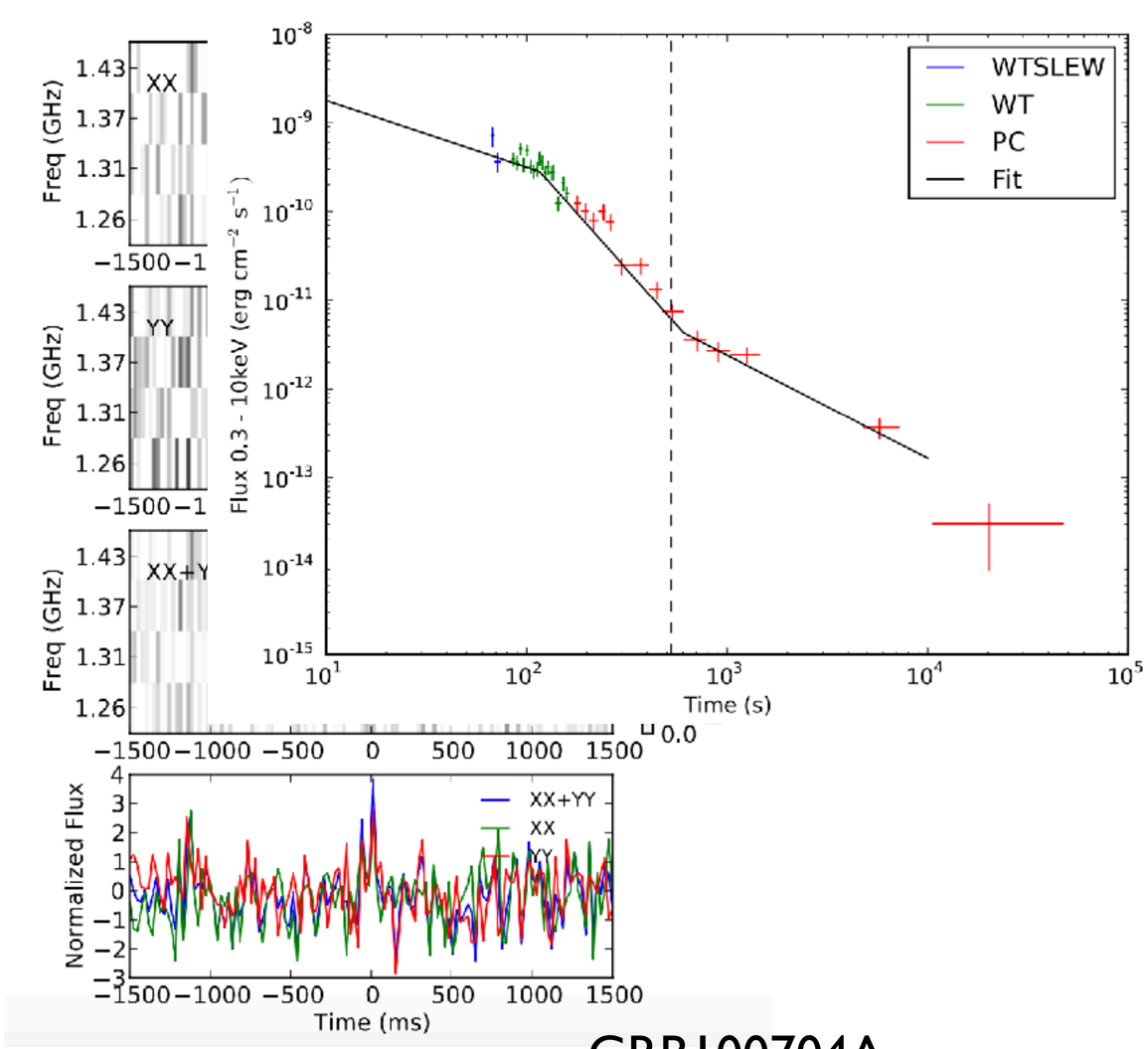

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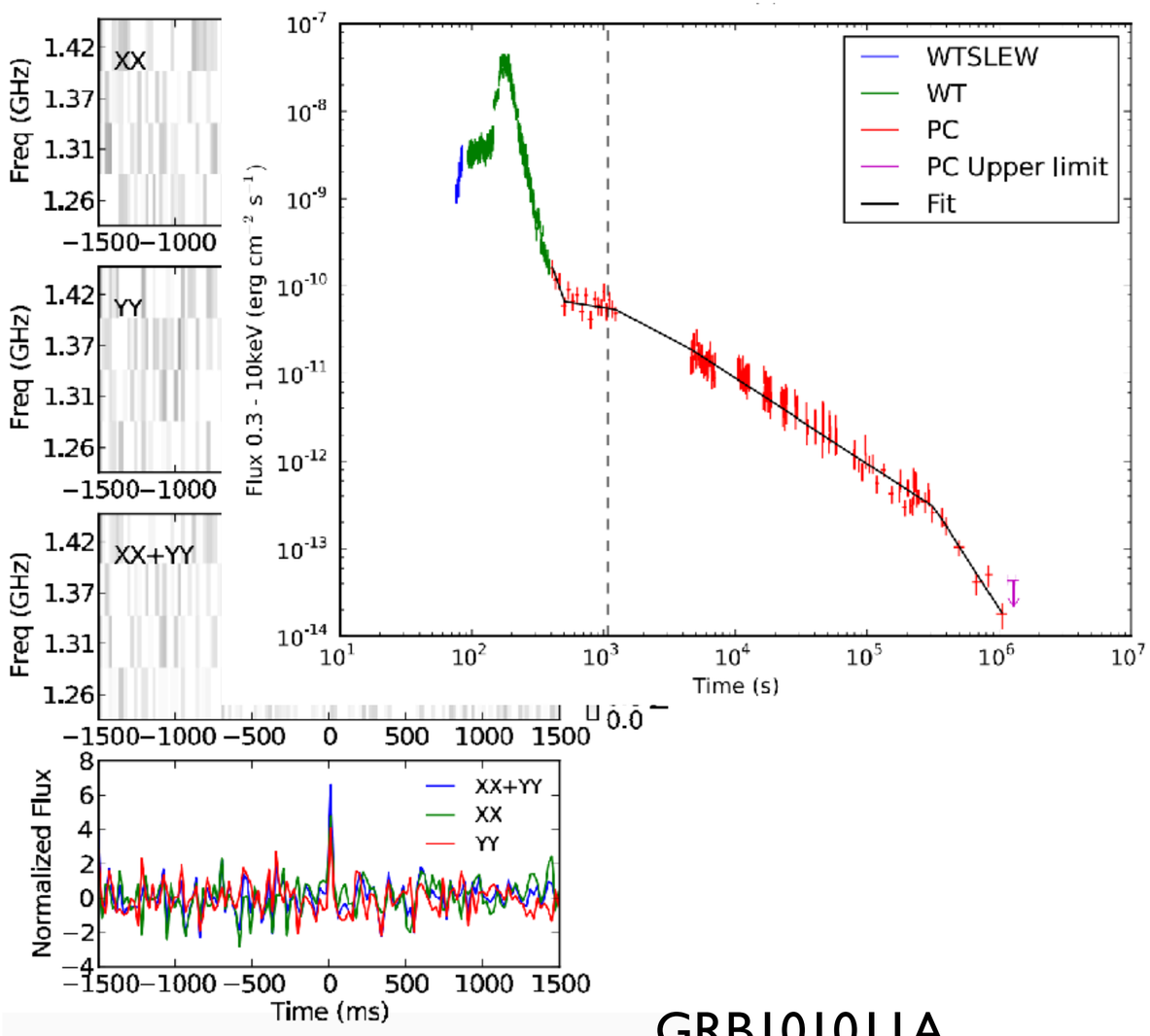

GRB101011A

Bannister et al. 2012

Multi-wavelength counterparts

- No conclusive multi-wavelength counterpart yet identified
- May require future surveys or smarter follow-up strategy
  - shadowing of radio telescope
  - radio telescope shadowing higher energy transient searches
  - targeted observations of fields/galaxies

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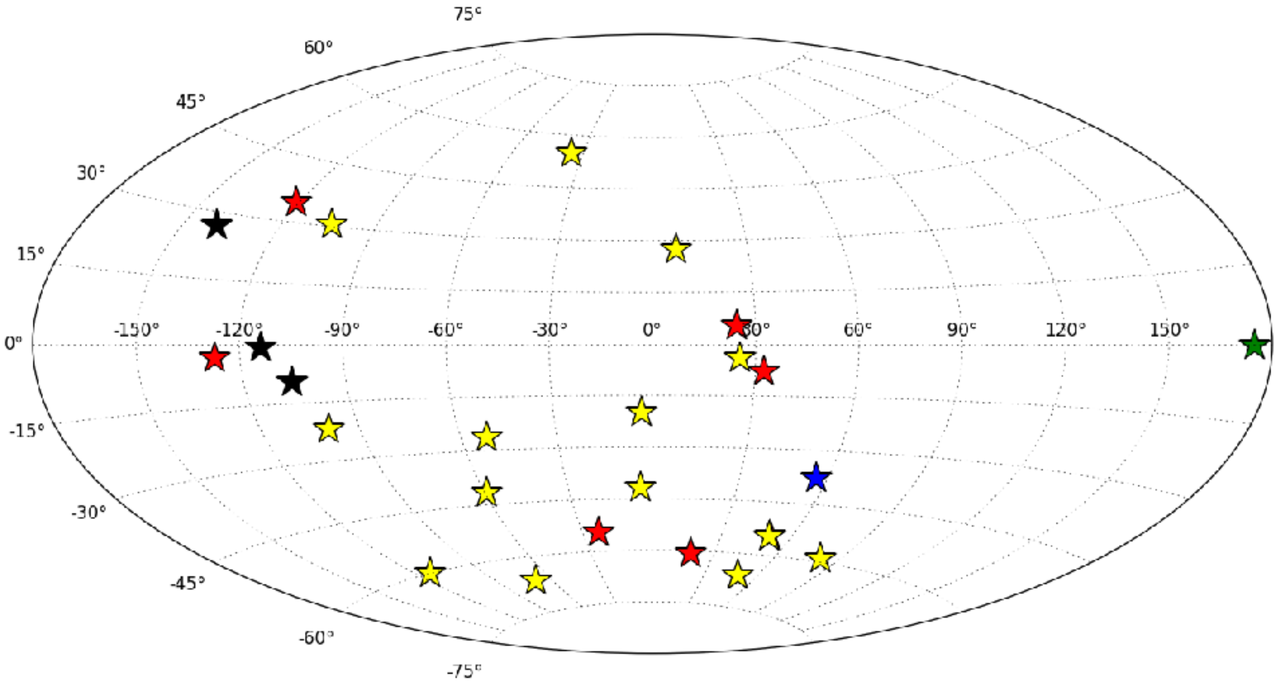
Other fun stuff

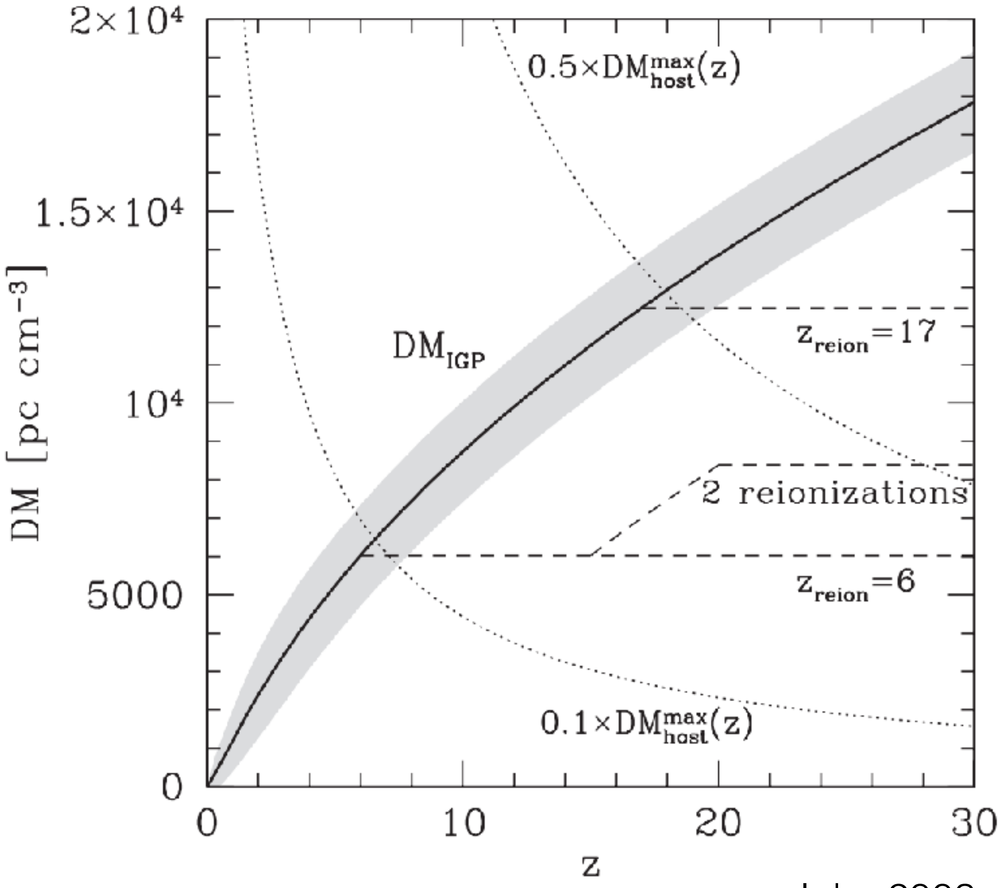
Studying the emerging population

- Outliers and individual FRBs of interest may give insights into the population
- FRBs at low and high DMs to look at possible redshift distribution
- Polarization and rotation measure properties



FRB DMs 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
- Constrain bounds of population with both high and low DM FRBs



Ioka 2003

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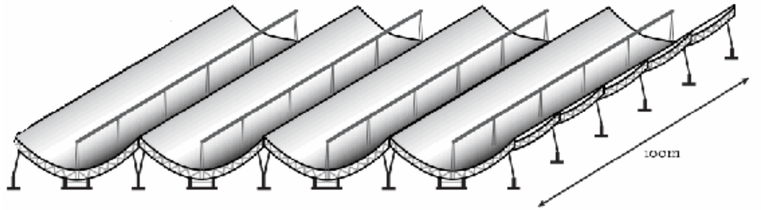
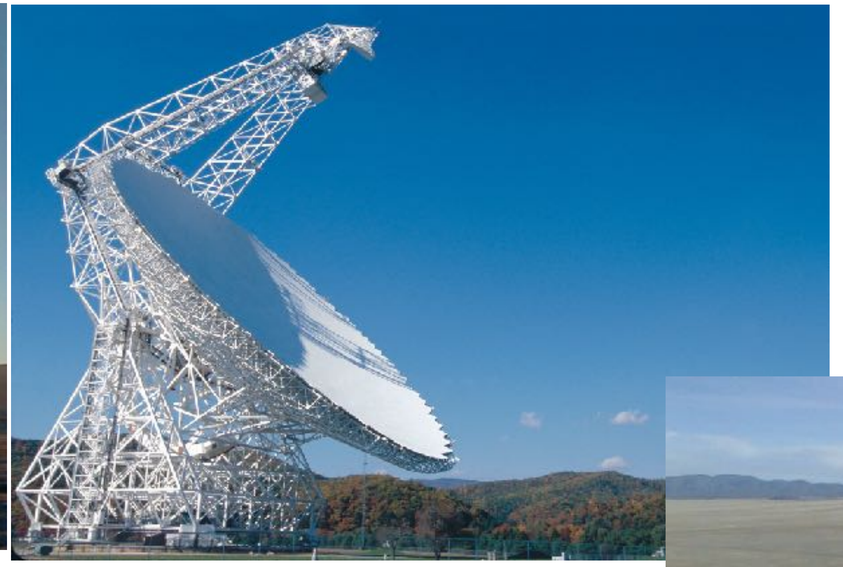
Wide-field interferometers

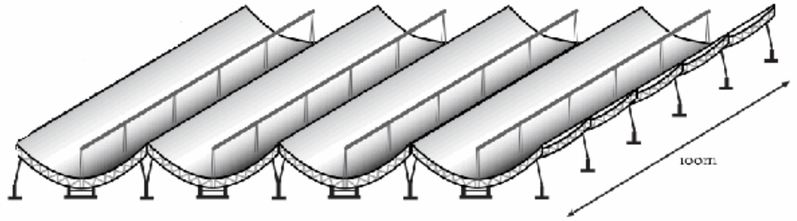
- Important improvements:
  - Localization
  - Lower (and higher?) frequencies
  - Larger bandwidth
- Be able to look at each FRB more often to search for repeats
- Larger FoV means more efficient shadowing of telescopes like SVOM at other wavelengths



Entering the era of wide-field interferometers

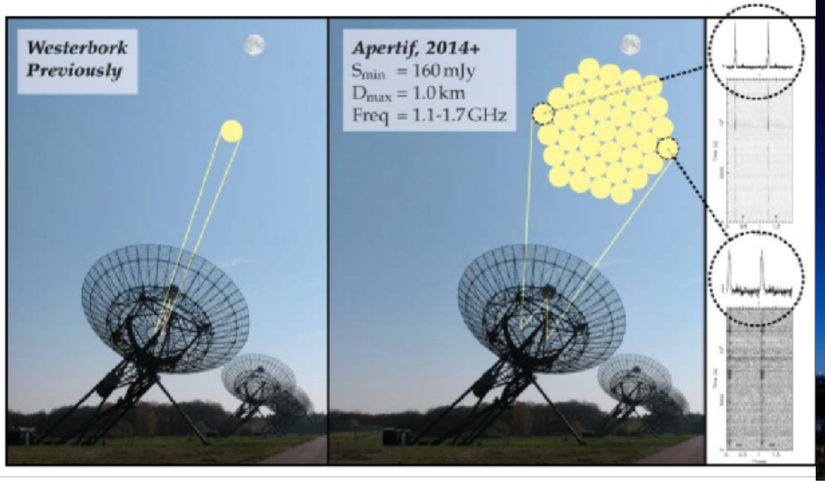
and BIG telescopes





ALERT:

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



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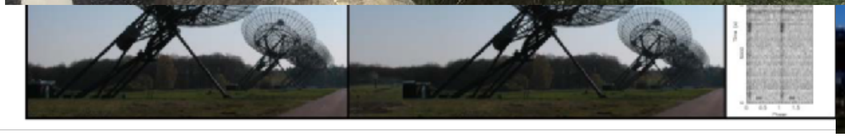
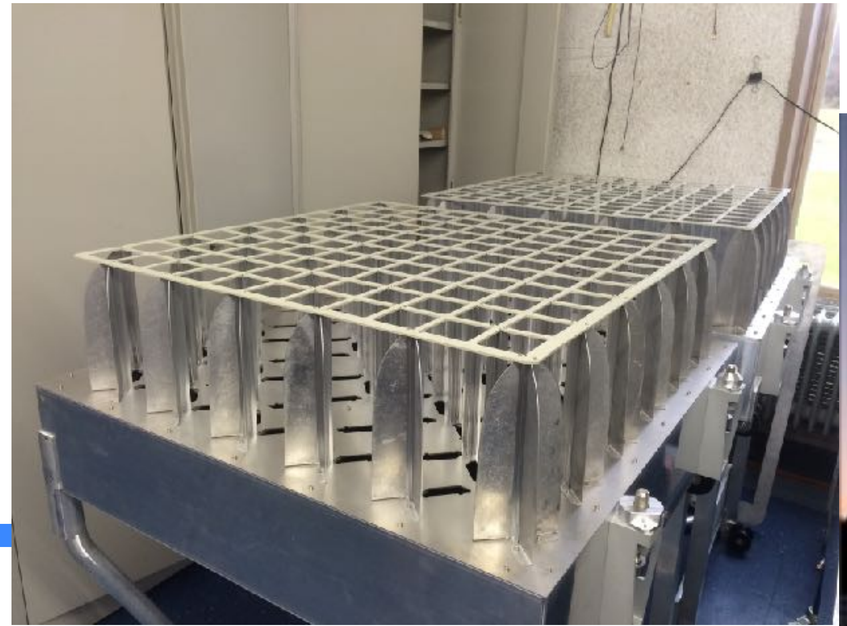


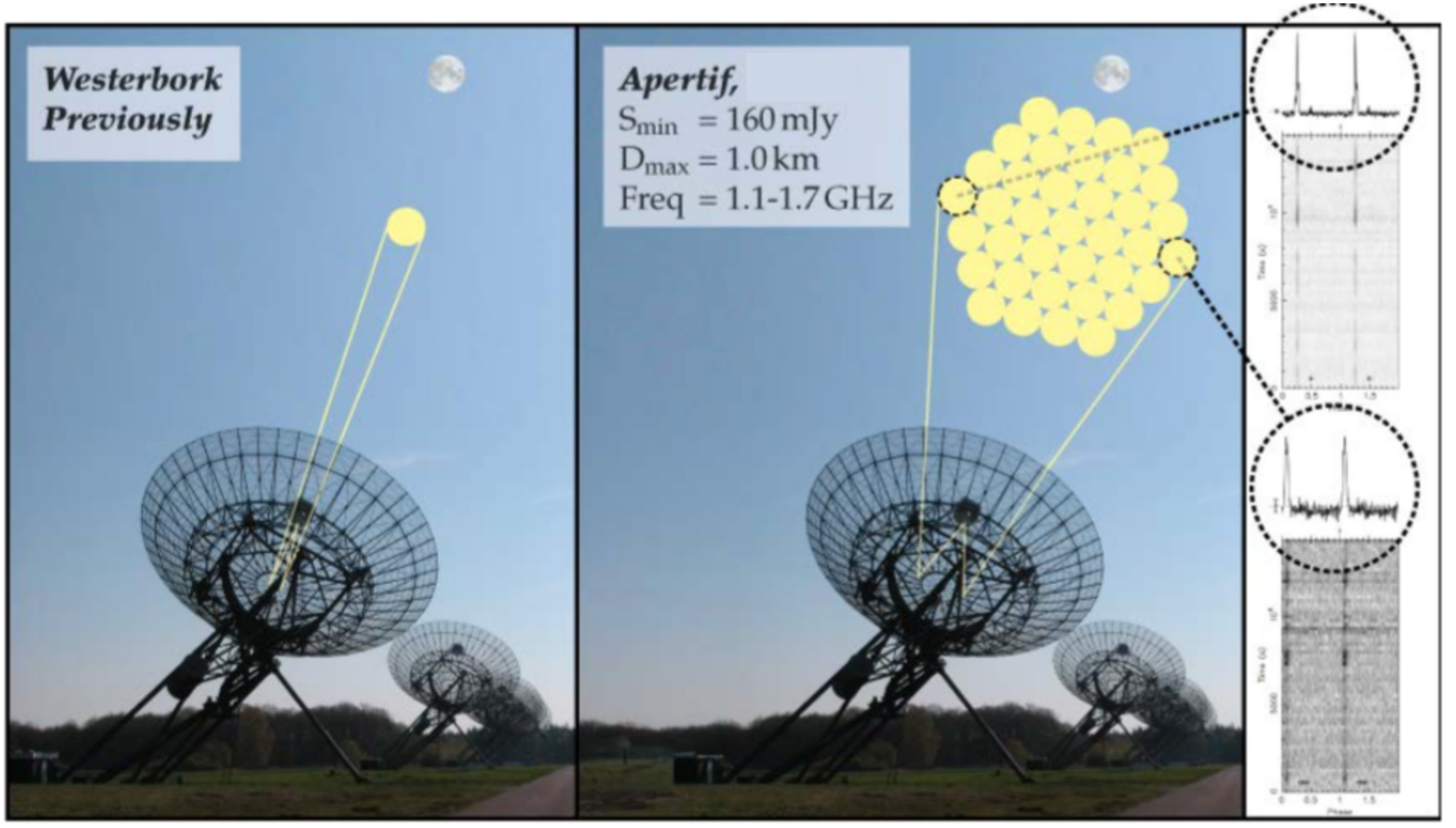
Apertif & ALERT

- Upgrade of Westerbork: 12 telescopes equipped with phased array feeds (1.4 GHz)
- ALERT: Apertif LOFAR Exploration of the Radio Transient Sky
  - searching for FRBs and pulsars over a large FoV with high sensitivity



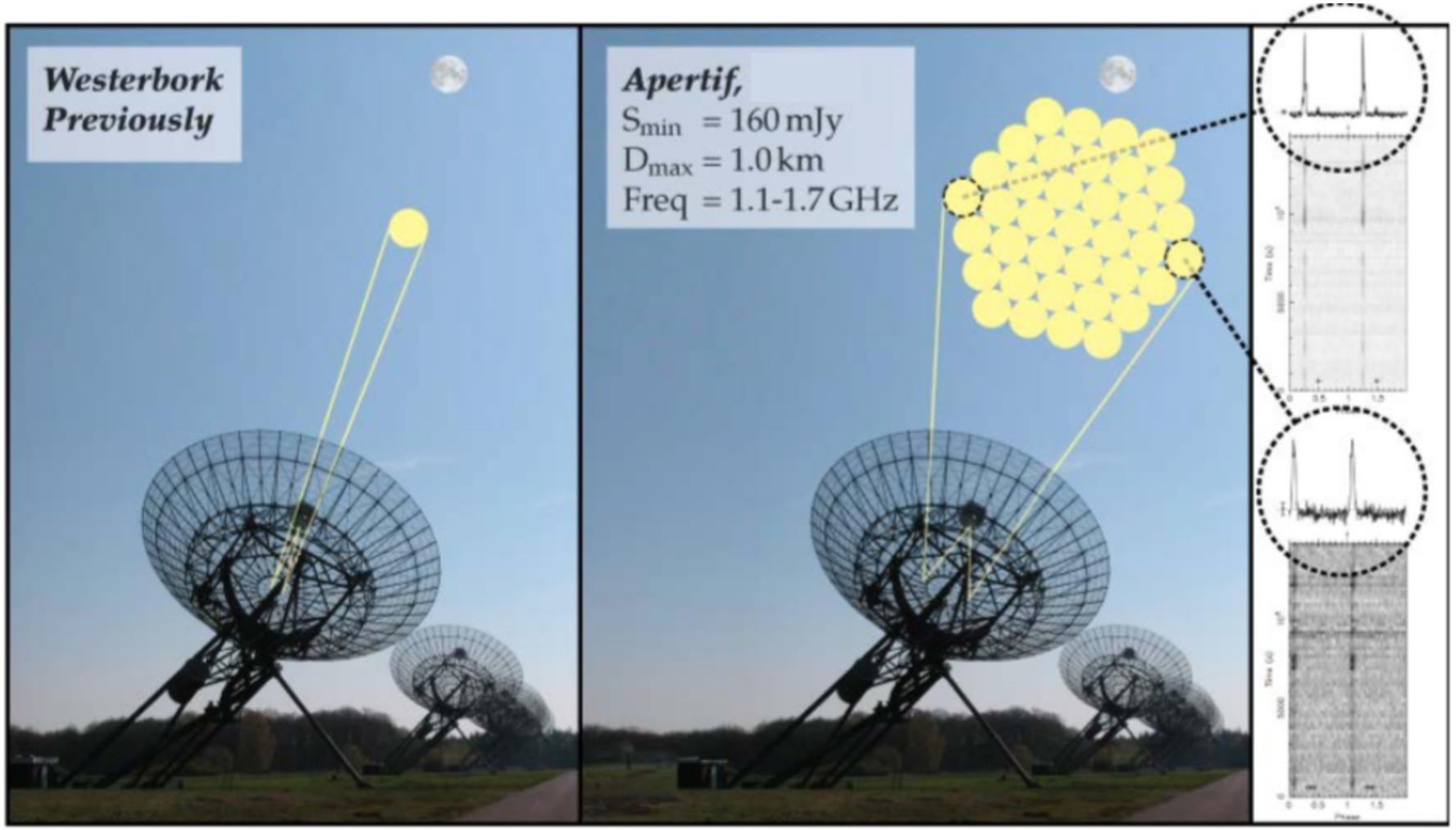
ALERT:

Apertif: 9 deg^2 field, 20 frames/ms



ALERT:

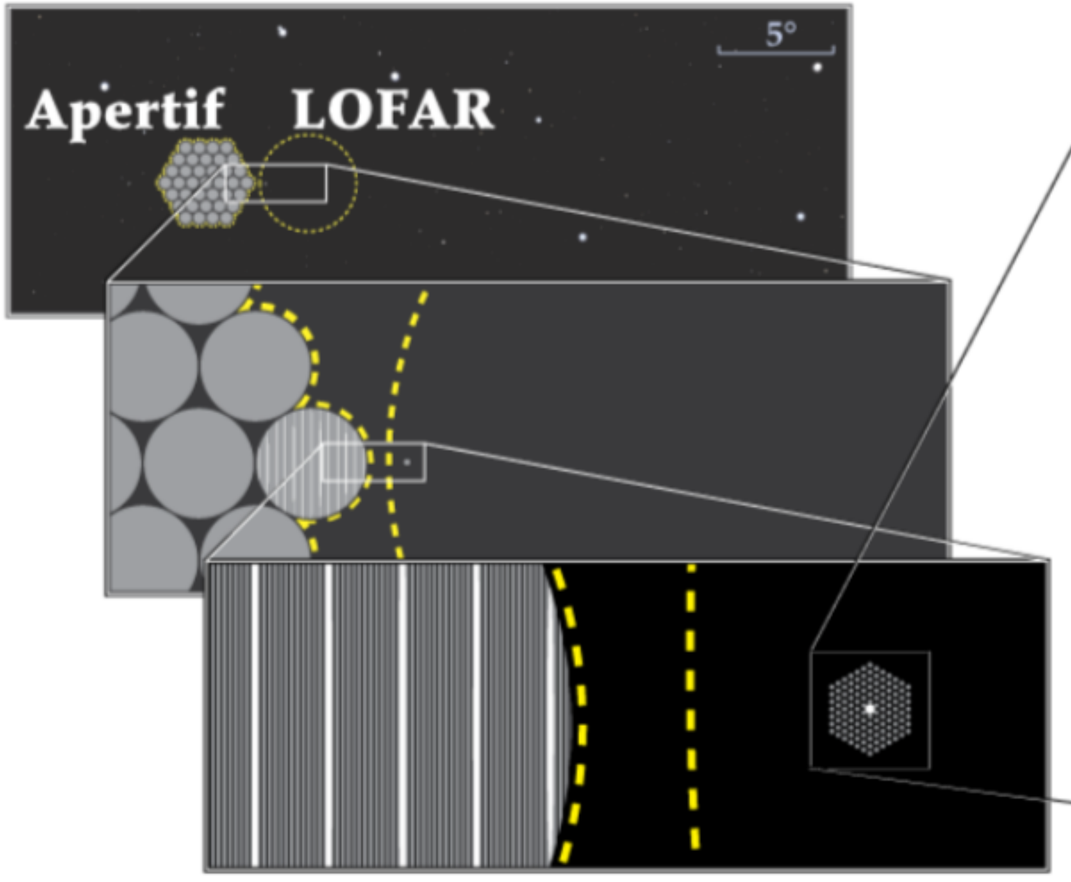
Apertif: 9 deg^2 field, 20 frames/ms



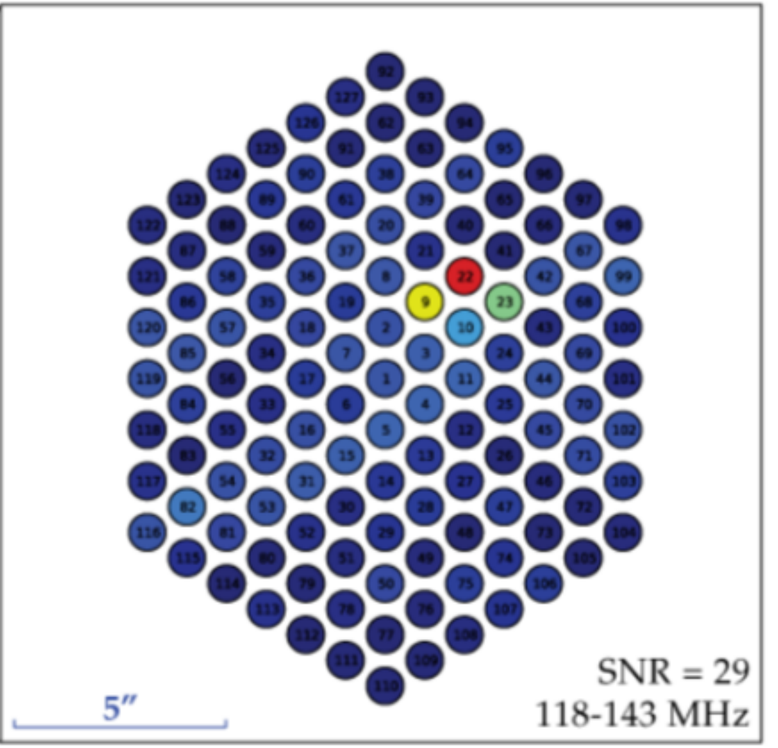
Expected rate: ~1-5 FRBs per week

ALERT:

Localise extragalactic bursts, *for the first time*



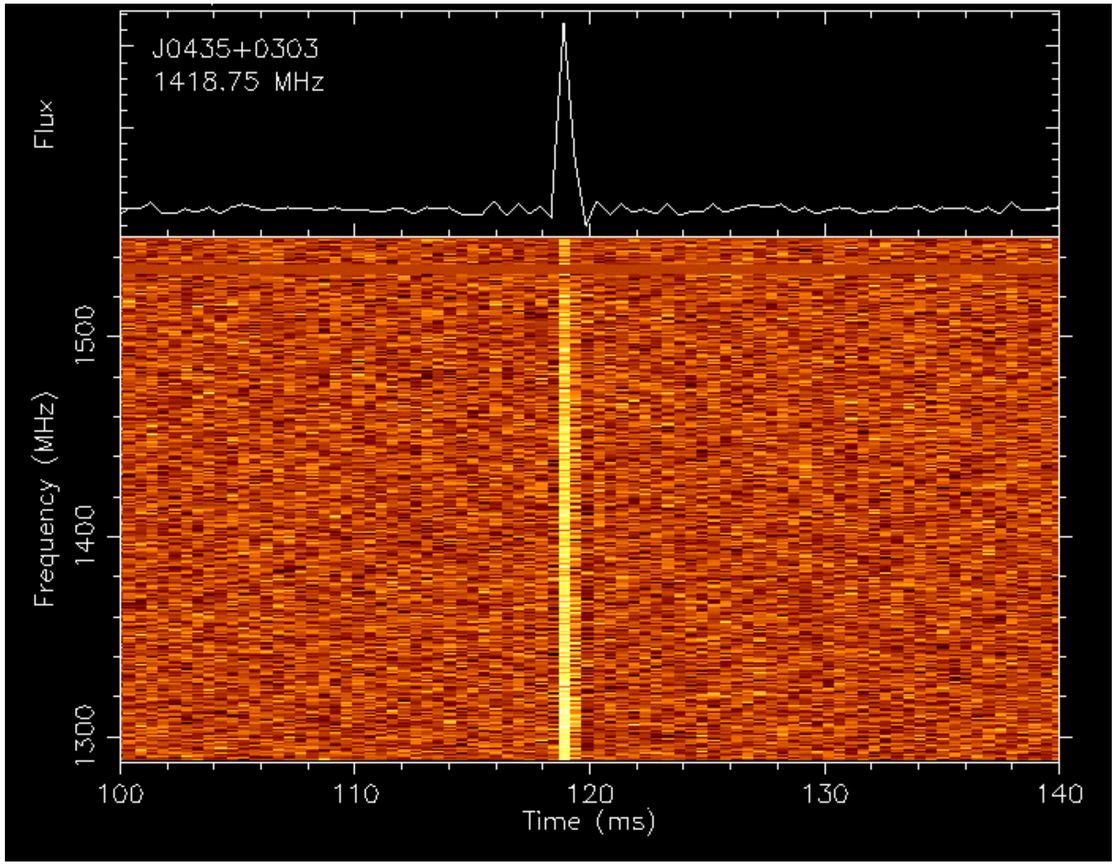
Real-life single pulse detection:



Localisation: arcsec^2

ALERT status

- Detecting single pulses from pulsars!
- Beginning search with incoherent beams (lower expected rate)
- Full GPU cluster delivered in July
- Full FRB search commissioning begins August 2017
- First FRBs soon after!



Most promising new avenues

The first FRB host galaxy

Rapid multi-wavelength/multi-messenger follow-up

Studying the emerging population

New searches with wide-field interferometers

Other fun stuff

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	309.219	-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)

A VOEvent standard for FRBs

- VOEvents: contain essential information about a transient
- Sent over the VO Network to listening observatories
- Enables rapid follow-up if people know what to listen for
- Requires a standard or set of standards
- First pass at an FRB VOEvent presented at an FRB meeting in February
- International working group to develop this idea

VOEvent Standard for Fast Radio Bursts

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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

$$\mathrm{DM} = \int_0^D n_e d\ell \tag{1}$$

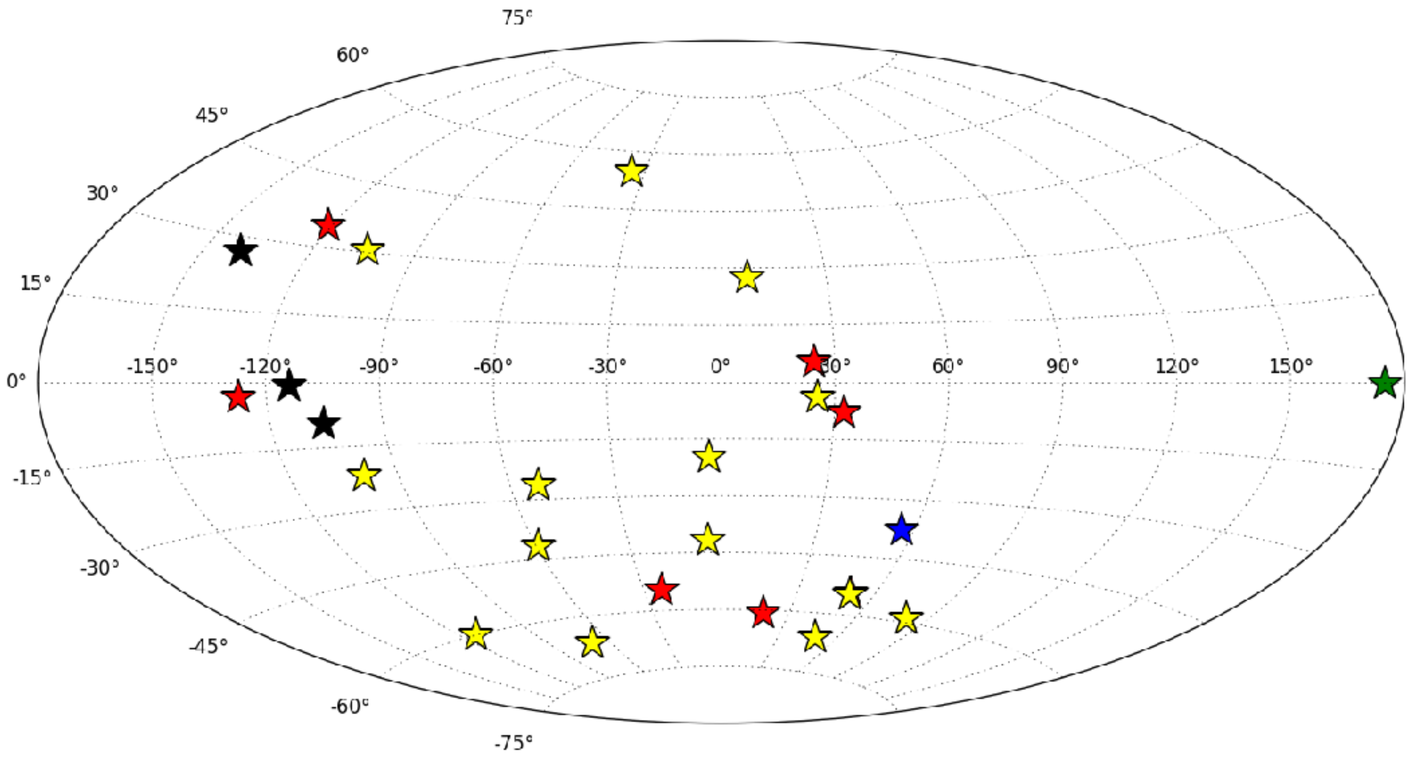
where D is the distance between the source and the observer along some path ℓ, and n_e is the electron column density. Dispersion is seen in pulses from Galactic pulsars but the DMs of FRBs are up to 70 times greater than the DM expected along the line of sight in the Milky Way leading to energetic extragalactic 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 $> 1.5 \times \mathrm{DM}_{\mathrm{MW_NE2001}}$ where $\mathrm{DM}_{\mathrm{MW_NE2001}}$ 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/

Closing remarks

- FRBs are extragalactic
- Have potential to be used as cosmological tools
- Need to localize a large number of FRBs and ID host galaxies
- Real-time detection and triggering, polarization, and wide-field telescoeps will play a large role
- Synergy with upcoming gamma ray transient missions



Thank You!

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