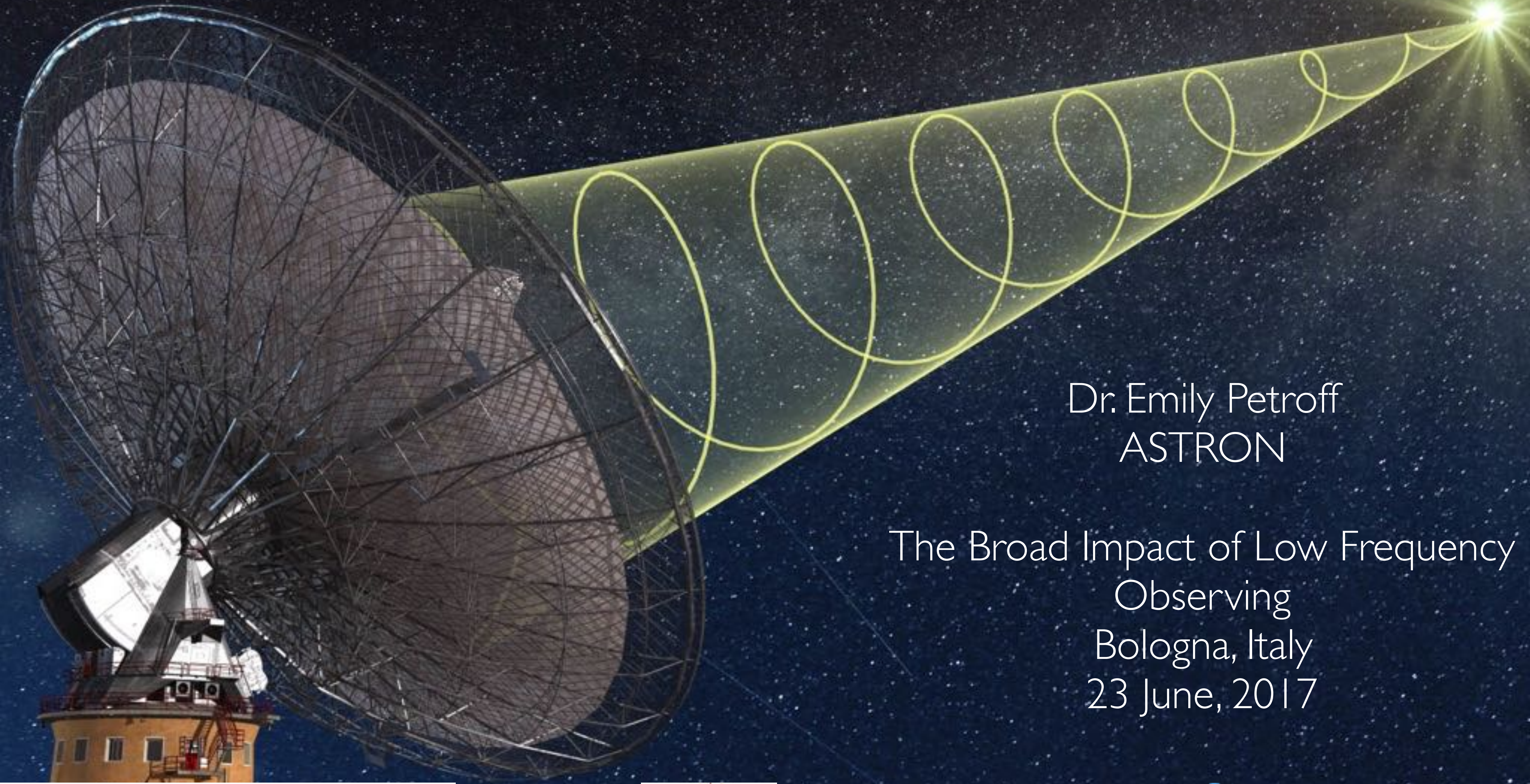
Fast Radio Bursts: Recent discoveries and future prospects



Dr. Emily Petroff
ASTRON

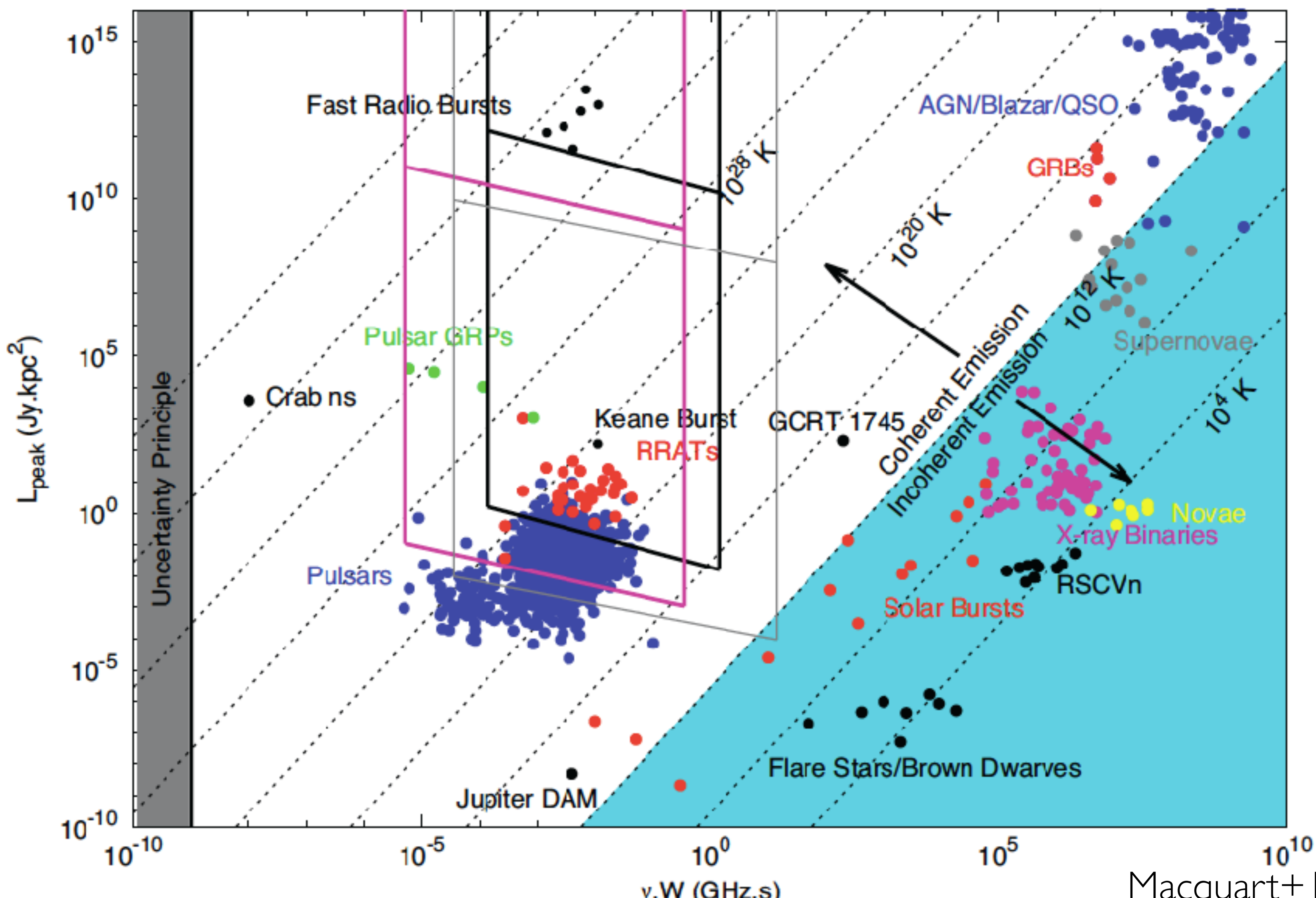
The Broad Impact of Low Frequency Observing
Bologna, Italy
23 June, 2017

ASTRON Netherlands Institute for Radio Astronomy

erc European Research Council

@ebpetroff
www.ebpetroff.com

Transient parameter space



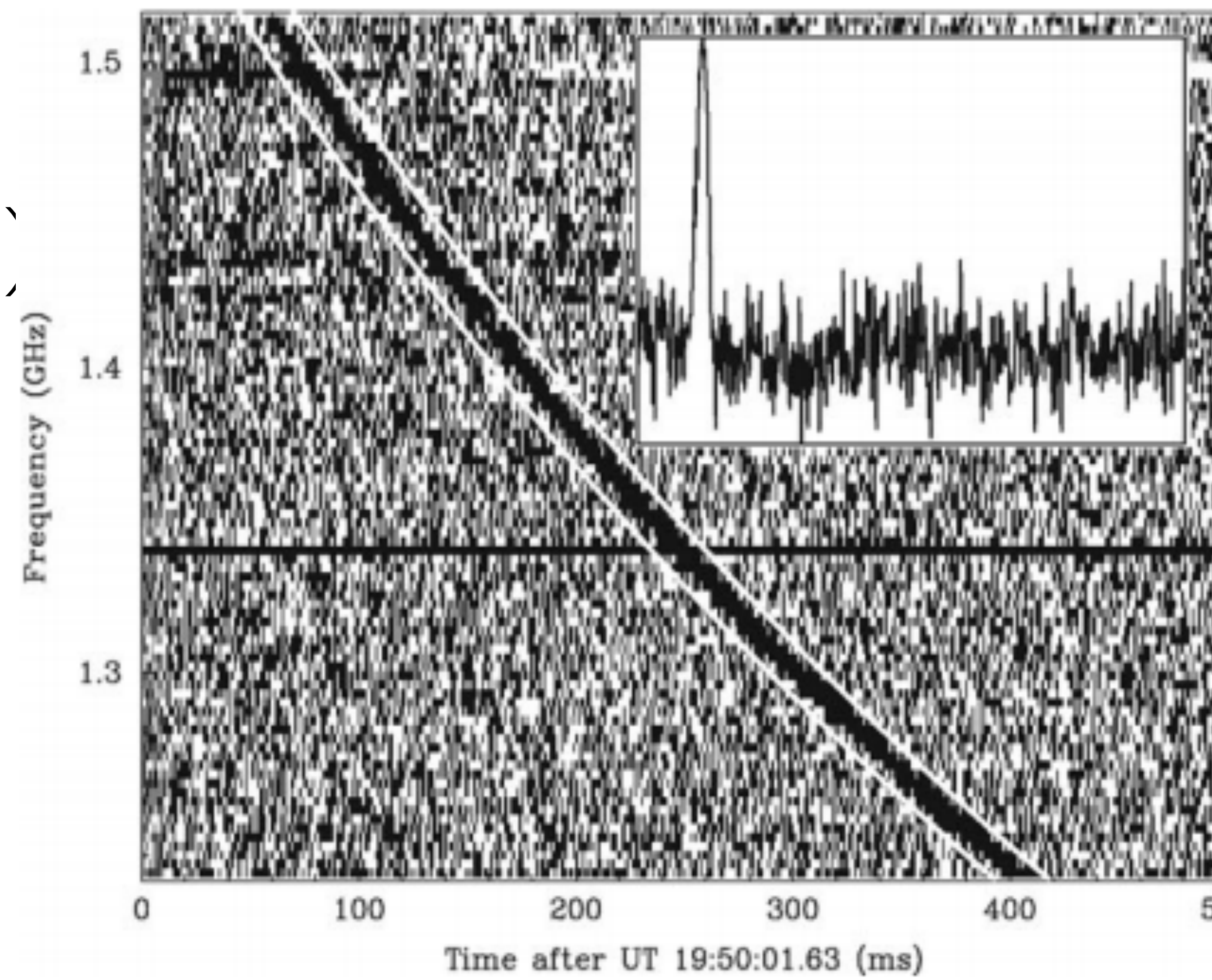
Macquart+15

What are fast radio burst and why are they cool?

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

$$\boxed{DM = \int_0^d n_e \, ds}$$

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



Lorimer et al 2007

- Hugely energetic, relatively common new transients

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} (above Parkes threshold)

Why are we so excited about FRBs?

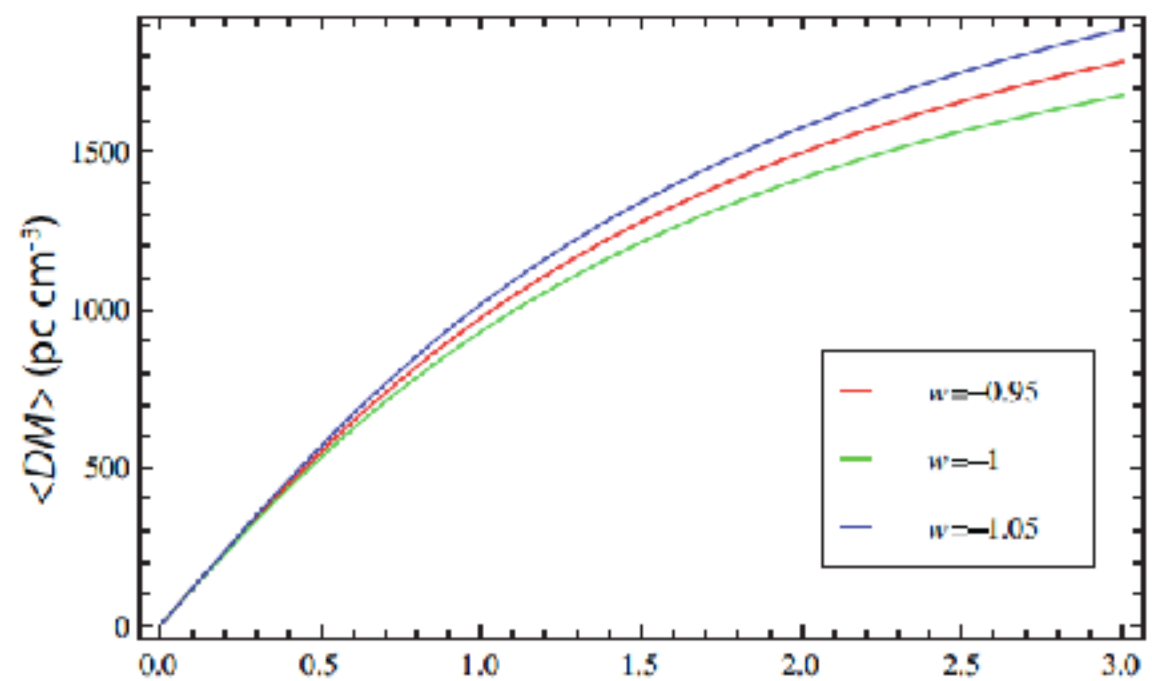
- Brand new transients! Extreme physics!
- Use FRBs as probes in interesting cosmological experiments
- Most exciting immediate prospect: probing the baryons in the IGM (and their magnetic field?)

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

$$\mathrm{DM_{FRB}} = \mathrm{DM_{Galaxy}} + \mathrm{DM_{anomaly}} + \mathrm{DM_{IGM}} + \mathrm{DM_{host}} + \mathrm{DM_{source}}$$

$$z \leq \frac{(\mathrm{DM_{tot}} - \mathrm{DM_{Galaxy}})}{1200 \ \mathrm{pc\ cm^{-3}}}$$

$$\mathrm{RM} = \frac{e^3}{2\pi m_e^2 c^4} \int_0^d n_e B_{\|} d\ell$$



Macquart+15

Progenitors of FRBs?

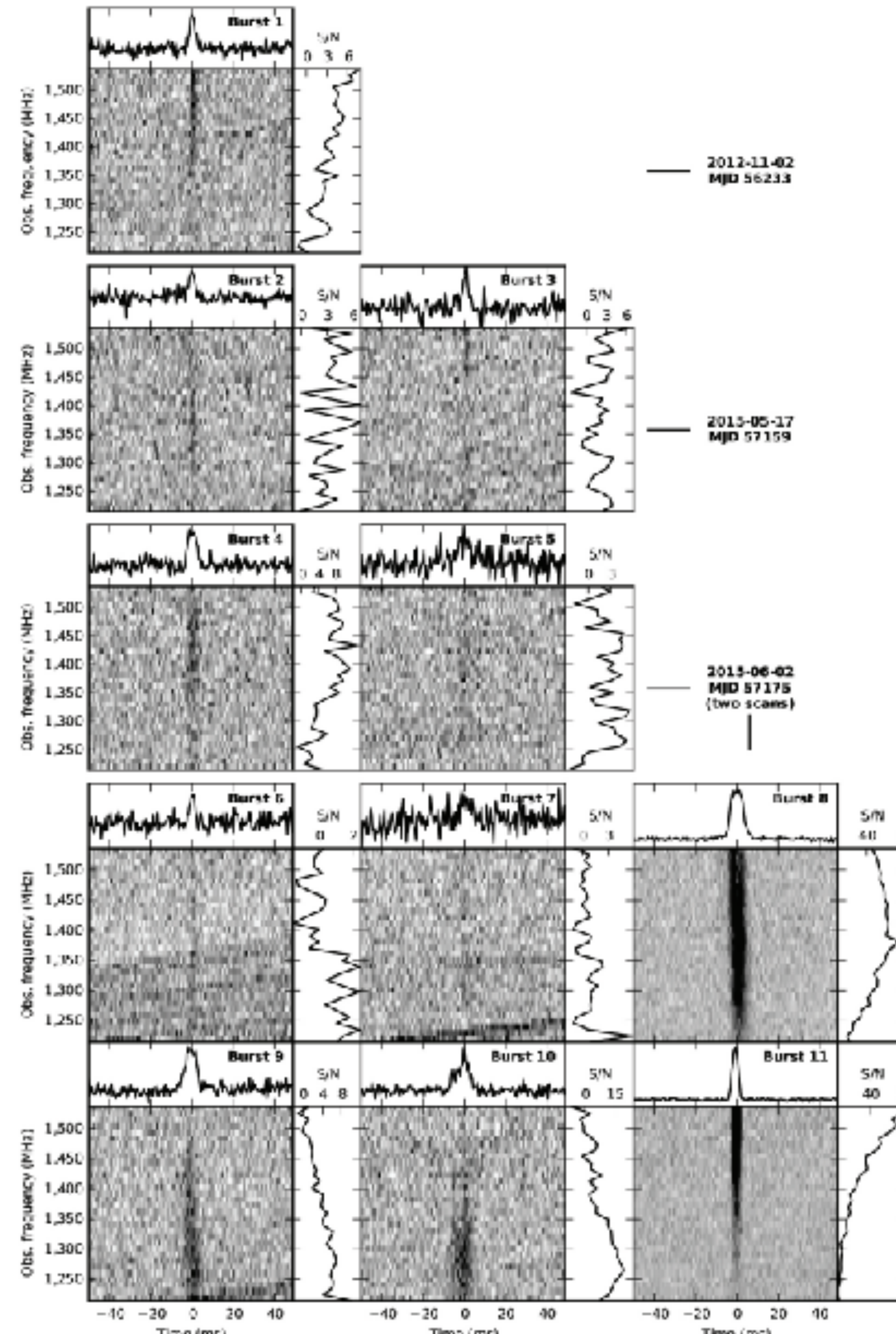
What could FRBs be?

- Neutron stars collapsing to black holes, ejecting "magnetic hair" (Falcke & Rezzolla '14; Zhang '14)
- Merger of charged black holes (Zhang '16; Liu et al. '16; Liebling & Panenzuela '16)
- Magnetospheric activity during neutron star mergers (Totani '13)
- Unipolar inductor in neutron star mergers (Hansen & Lyutikov '01; Piro '12; Wang et al. '16)
- White dwarf mergers (Kashiyama et al. '13)
- Pulses from young neutron stars (Cordes & Wasserman '15; Connor et al. '15; Lyutikov et al. '16; Popov & Pshirkov '16; Kashiyama & Murase '17)
- Magnetars (Popov et al. '07; Kulkarni et al. '14; Lyubarsky '14; Katz '15; Pen & Connor '15)
- Sparks from cosmic strings (Vachaspati '08; Yu et al. '14)
- Evaporating primordial black holes (Rees '77; Keane et al. '12)
- White holes (Barrau et al. '14)
- Flaring stars (Loeb et al. '13; Maoz et al. '15)
- Axion stars (Tkachev '15; Iwazaki '15)
- Asteroids/comets falling onto neutron stars (Geng & Huang '15)
- Quark novae (Chand et al. '15)
- Dark matter-induced collapse of neutron stars (Fuller & Ott '15)
- Higgs portals to pulsar collapse (Bramante & Elahi '15)
- Planets interacting with a pulsar wind (Mottez & Zarka '15)
- Black hole superradiance (Conlon & Herdeiro '17)
- Extragalactic light sails (Lingam & Loeb '17)
- Schwinger instability in young magnetars (Lieu '17)
- Neutron star-white dwarf binaries (Gu et al. '16)

Credit: Tony Piro

FRBs in 2016

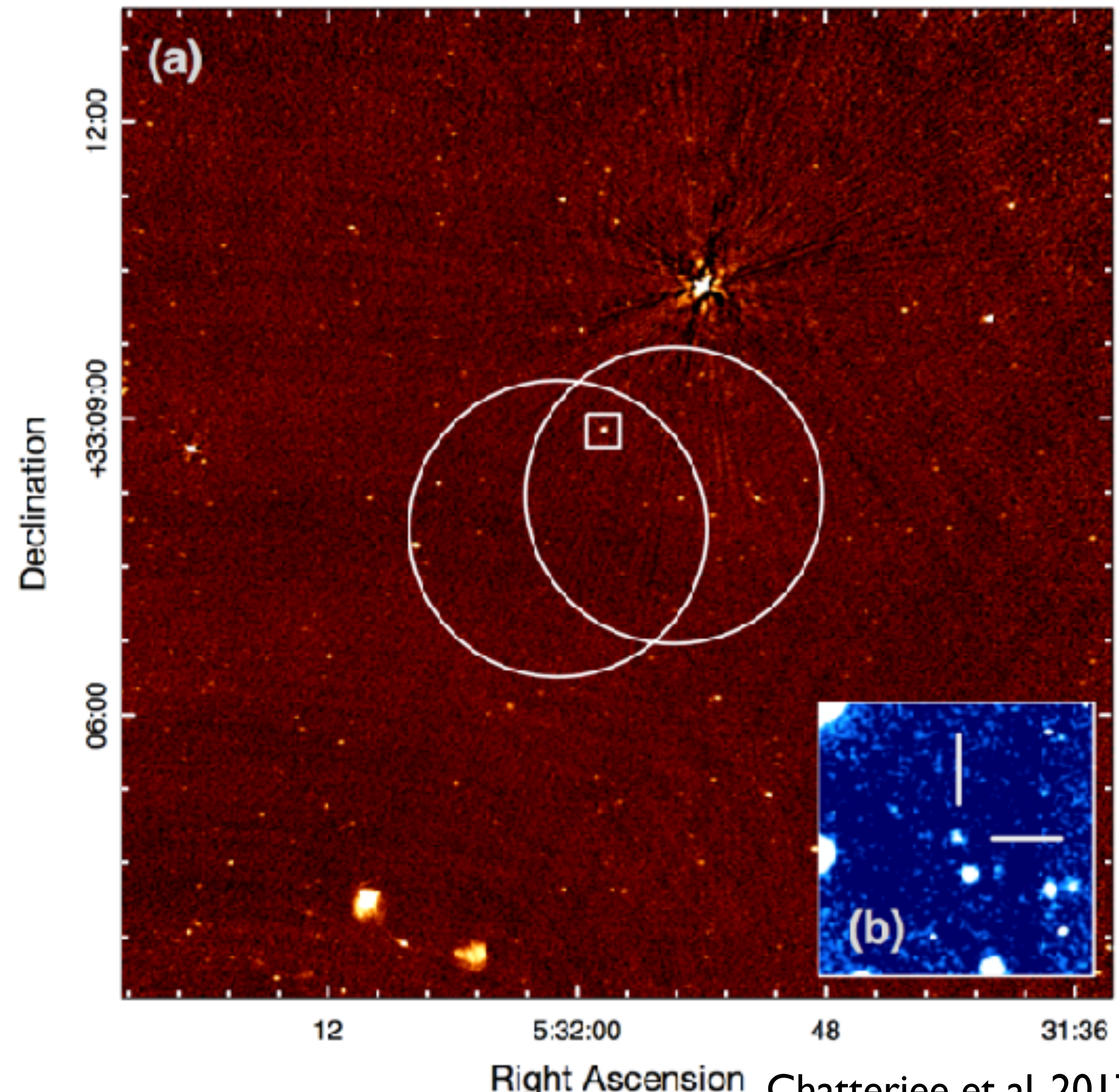
- Green bank telescope burst in January
- Parkes real-time detection in February
- **Repeat pulses seen from FRB 121102 in March**
- First interferometric detection with UTMOST in April
- Possible gamma ray counterpart to FRB 131104 in November
- Extremely bright low DM burst in November



Spitler et al. 2016

The first host galaxy

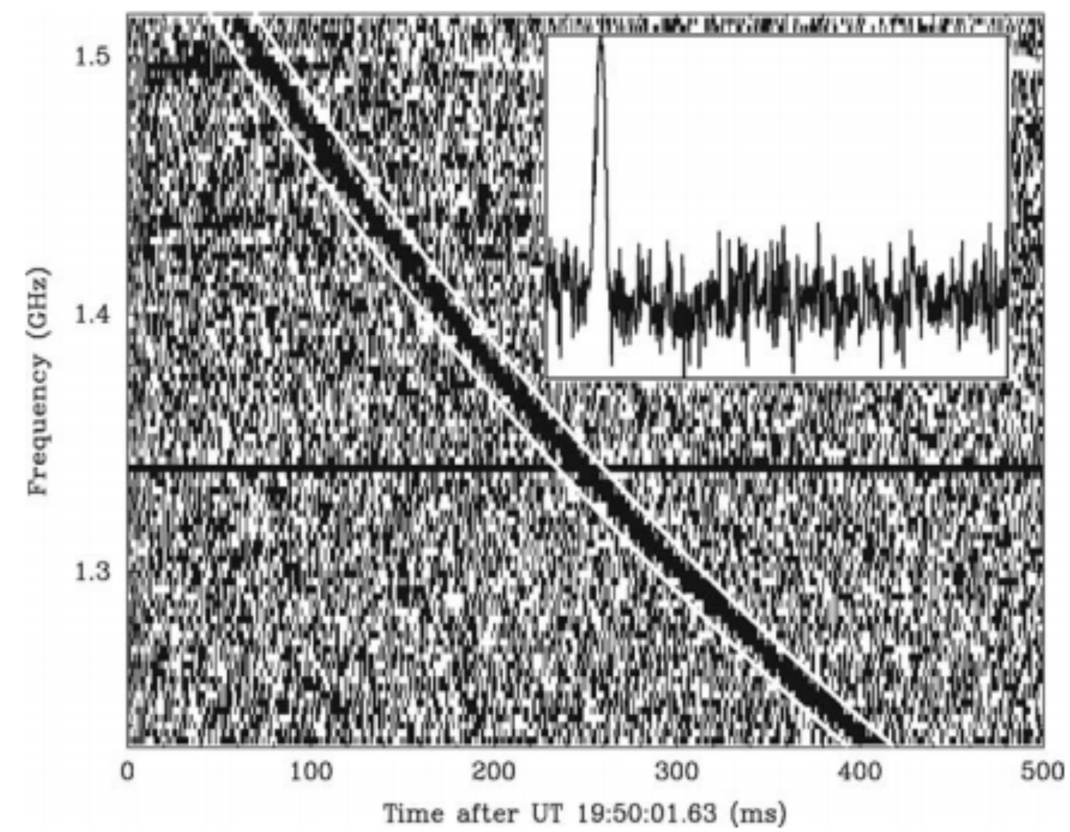
- Only one FRB seen t
- **Localized** through re
- Located in a dwarf ga
  - z = 0.19 (~1 Gpc a
- Co-located with pers
- Possible connection v
  - young magnetar wi



Chatterjee et al. 2017

Do all FRBs repeat?

- No other FRB seen to repeat
- Some observed for over 100 hours
- Possible interpretations:
  - Only very young or very extreme sources repeat often
  - Observed when it was "off"
  - Multiple progenitor populations

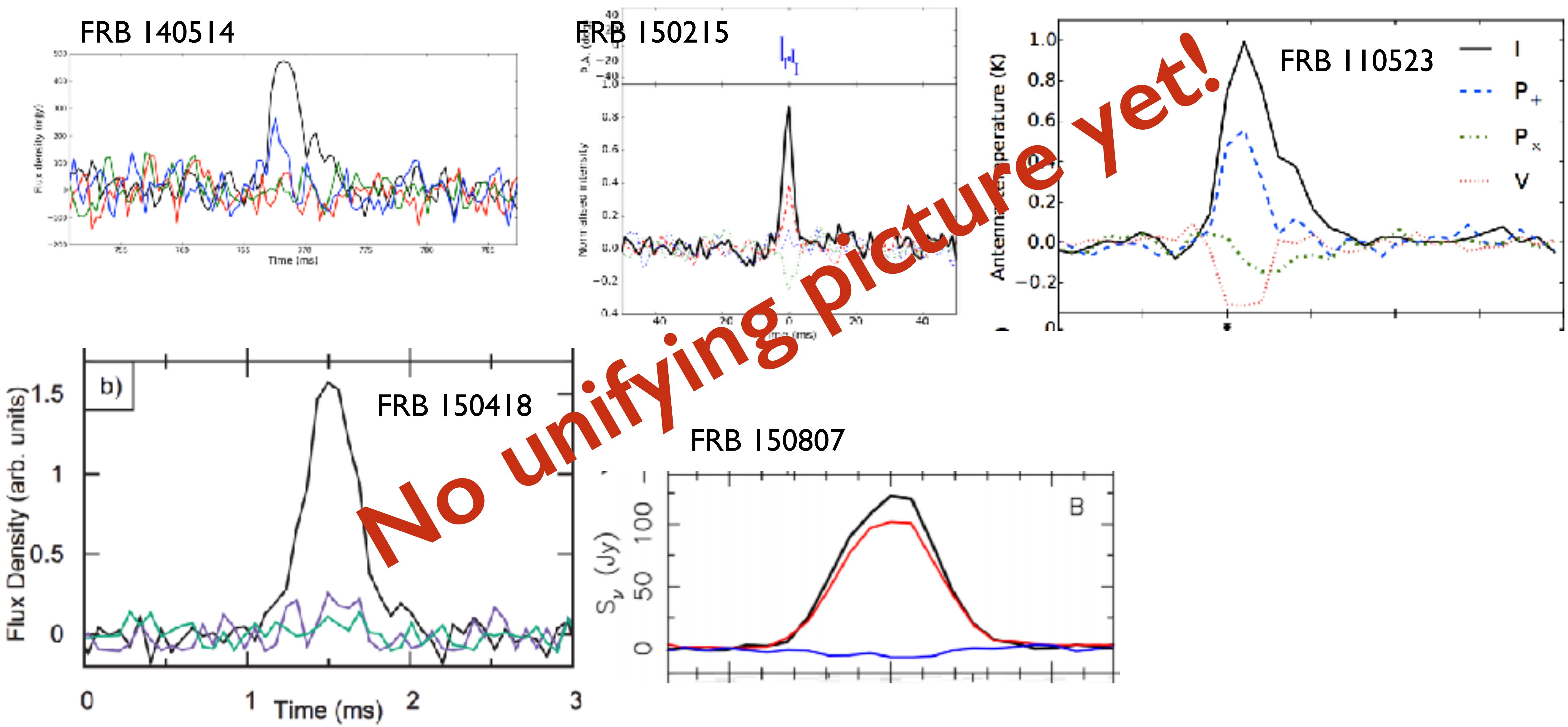


Lorimer et al 2007

- Still want to identify host galaxies for new FRBs and get the interesting science!

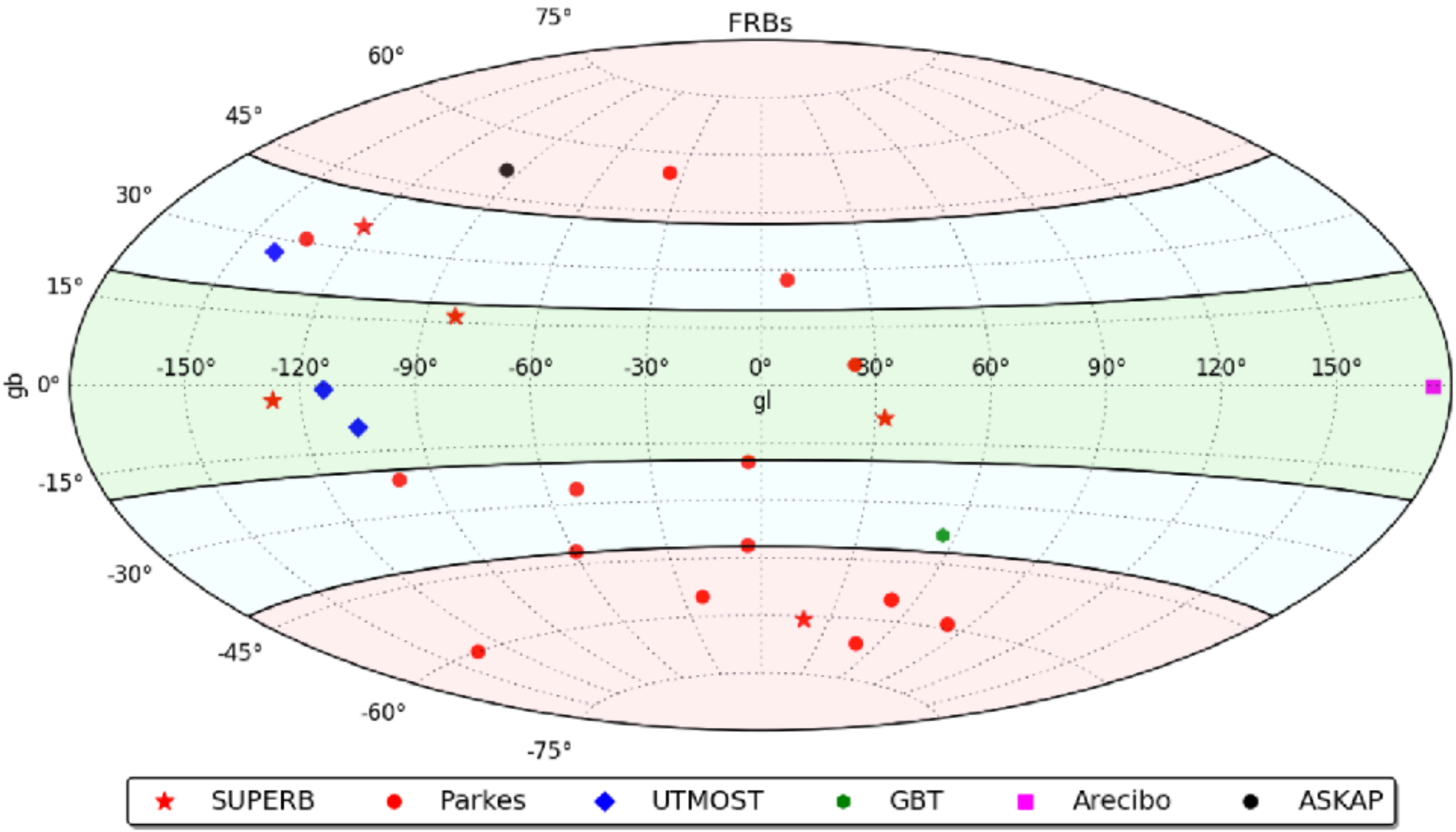
FRB Polarization and RM

- FRB polarization measurements: linear polarization suggests coherent emission (but we probably knew that already)



Many (many) open questions

- What progenitor(s) cause(s) FRBs?
- Are there multiple populations?
- What does the cosmological distribution look like?
- Can we use FRBs for cosmology?
- Can we probe magnetic fields at the progenitor?
- What is the true event rate?
- Do all FRBs repeat?
- Is there associated multiwavelength emission?
- How broadband is the radio emission?
- **Can we detect FRBs at low frequencies?**



All above 700 MHz

Looking for FRBs at low frequencies

Limits on Fast Radio Bursts at 145 MHz with ARTEMIS, a real-time software backend

A. Karastergiou[1,2,3], J. Chennamangalam[1], W. Armour[4], C. Williams[1], B. Mort[4], F. Dulwich[4], S. Salvini[4], A. Magro[5], S. Roberts[6], M. Serylak[3], A. Doo[7], A. V. Bilous[8], R. P. Breton[9], H. Falcke[8,10], J.-M. Grießmeier[11,12], J. W. T. Hessels[10,13], E. F. Keane[14], V. I. Kondratiev[10,15] M. Kramer[16], J. van Leeuwen[10,13], A. Noutsos[16], S. Osłowski[16,17], C. Sobey[10], B. W. Stappers[9], P. Weltevrede[9].

LOFAR SP search (Daniele Michilli)

The LOFAR Pilot Surveys for Pulsars and Fast Radio Transients★

Thijs Coenen[1,2], Joeri van Leeuwen[2**,1], Jason W. T. Hessels[2,1], Ben W. Stappers[3], Vladislav I. Kondratiev[2,4], A. Alexov[1,5], R. P. Breton[6], A. Bilous[7], S. Cooper[3], H. Falcke[7,2], R. A. Fallows[2], V. Gajjar[8,3], J.-M. Grießmeier[9,10], T. E. Hassall[6], A. Karastergiou[11], E. F. Keane[12,13], M. Kramer[14,3], M. Kuniyoshi[14], A. Noutsos[14], S. Osłowski[14,15], M. Pilia[2], M. Serylak[11], C. Schrijvers[16], C. Sobey[2], S. ter Veen[7], J. Verbiest[15], P. Weltevrede[3], S. Wijnholds[2], K. Zagkouris[11], A.S. van Amesfoort[2], J. Anderson[17,18], A. Asgekar[2,19], I. M. Avruch[20,21], M. E. Bell[22], M. J. Bentum[2,23], G. Bernardi[24], P. Best[25], A. Bonafede[26], F. Breitling[18], J. Broderick[6], M. Brüggen[26], H. R. Butcher[27], B. Ciardi[28], A. Corstanje[7], A. Deller[2], S. Duscha[2], J. Eislöffel[29], R. Fender[11], C. Ferrari[30], W. Frieswijk[2], M. A. Garrett[2,31], F. de Gasperin[26], E. de Geus[2,32], A. W. Gunst[2], J. P. Hamaker[2], G. Heald[2], M. Hoeft[29], A. van der Horst[1], E. Juette[33], G. Kuper[2], C. Law[34,1], G. Mann[18], R. McFadden[2], D. McKay-Bukowski[35,36], J. P. McKean[2,21], H. Munk[2], E. Orru[2], H. Paas[37], M. Pandey-Pommier[38], A. G. Polatidis[2], W. Reich[14], A. Renting[2], H. Röttgering[31], A. Rowlinson[1], A. M. M. Scaife[5], D. Schwarz[15], J. Sluman[2], O. Smirnov[39,40], J. Swinbank[1], M. Tagger[9], Y. Tang[2], C. Tasse[41], S. Thoudam[7], C. Toribio[2], R. Vermeulen[2], C. Vocks[18], R. J. van Weeren[24], O. Wucknitz[14], P. Zarka[41], and A. Zensus[14]

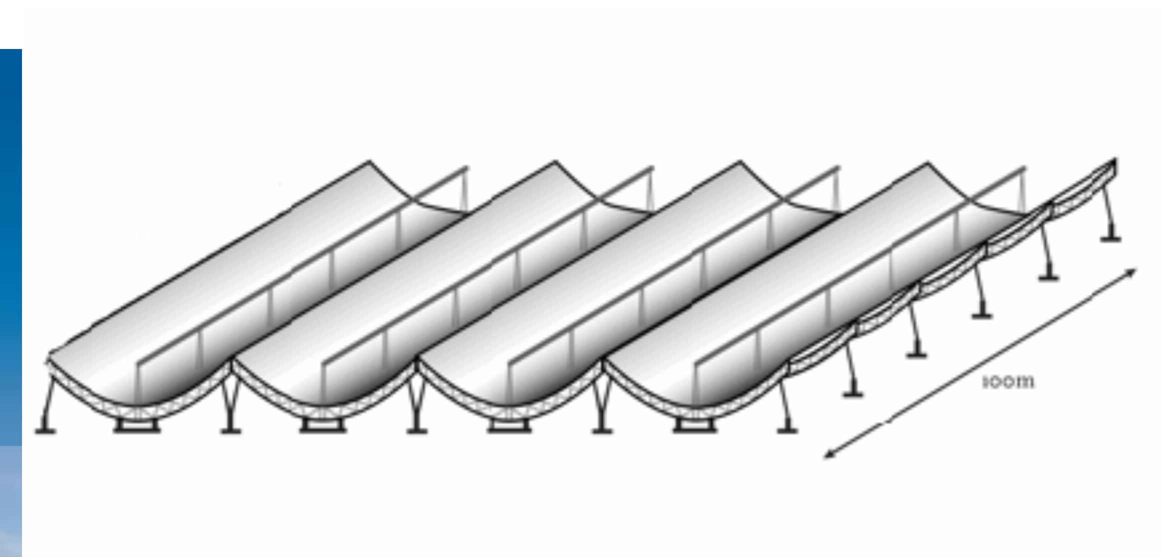
Effelsberg - LOFAR (Leon Houben)

Prospects for the Detection of Fast Radio Bursts with the Murchison Widefield Array

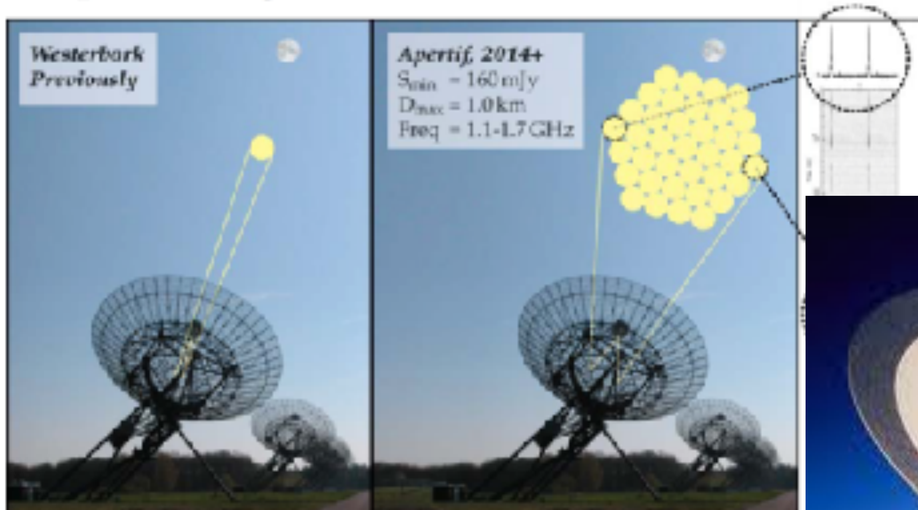
Cathryn M. Trott[1,2], Steven J. Tingay[1,2] and Randall B. Wayth[1]

The role of future surveys

- Entering the era of wide-field interferometers

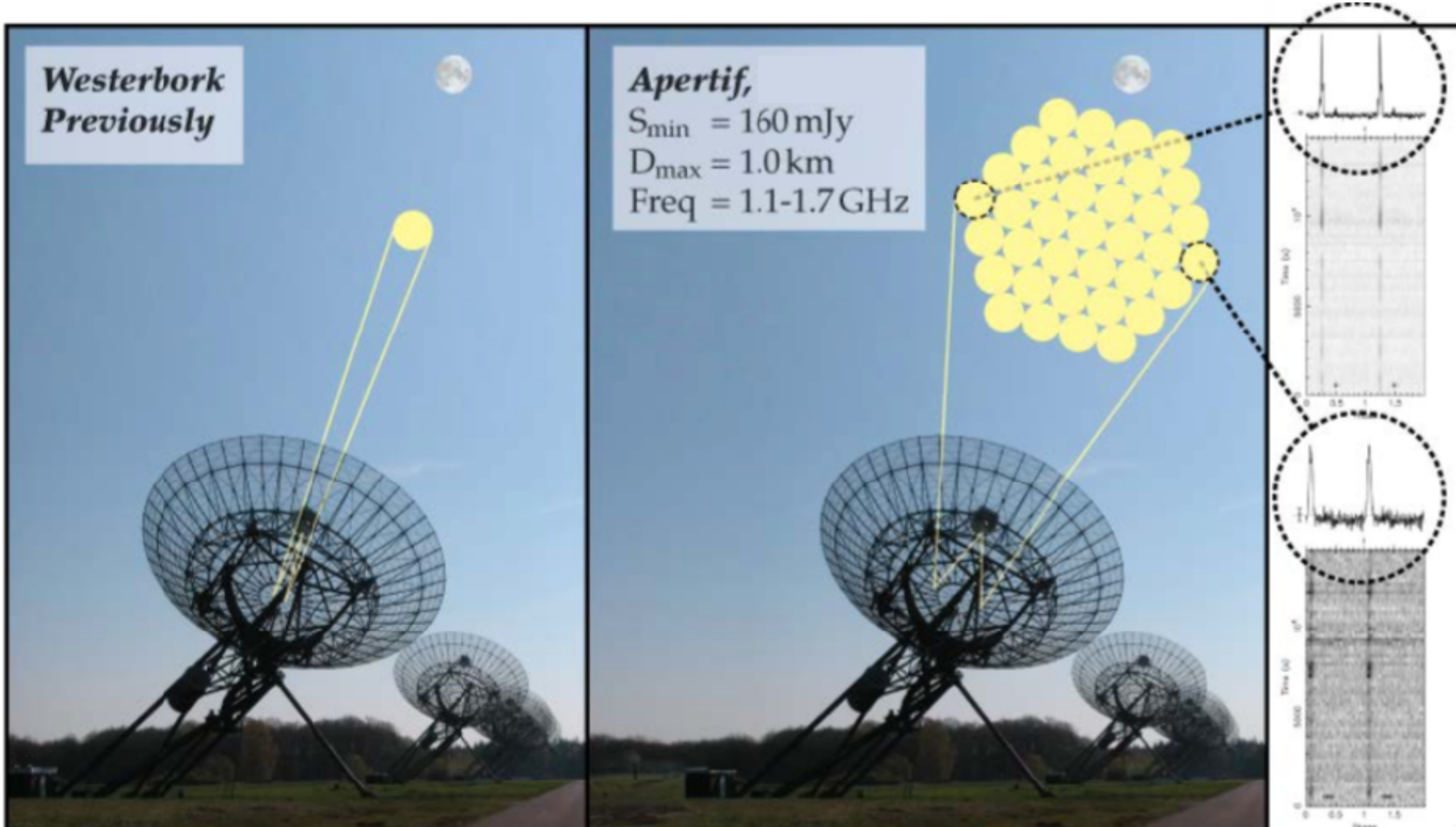


Apertif: 9 deg^2 field, 20 frames/ms (*PI*, 1.6 MEur)



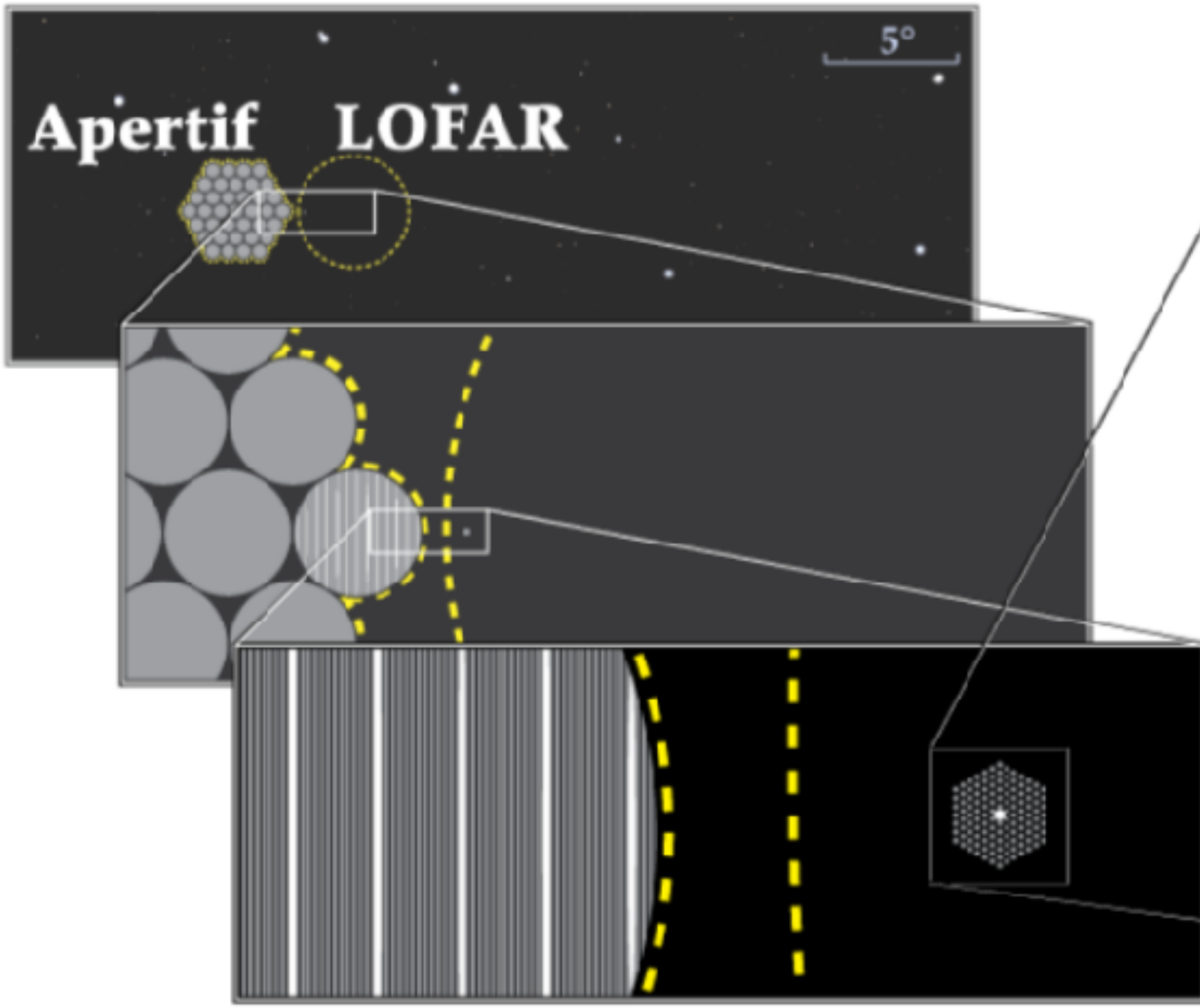
ALERT:

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

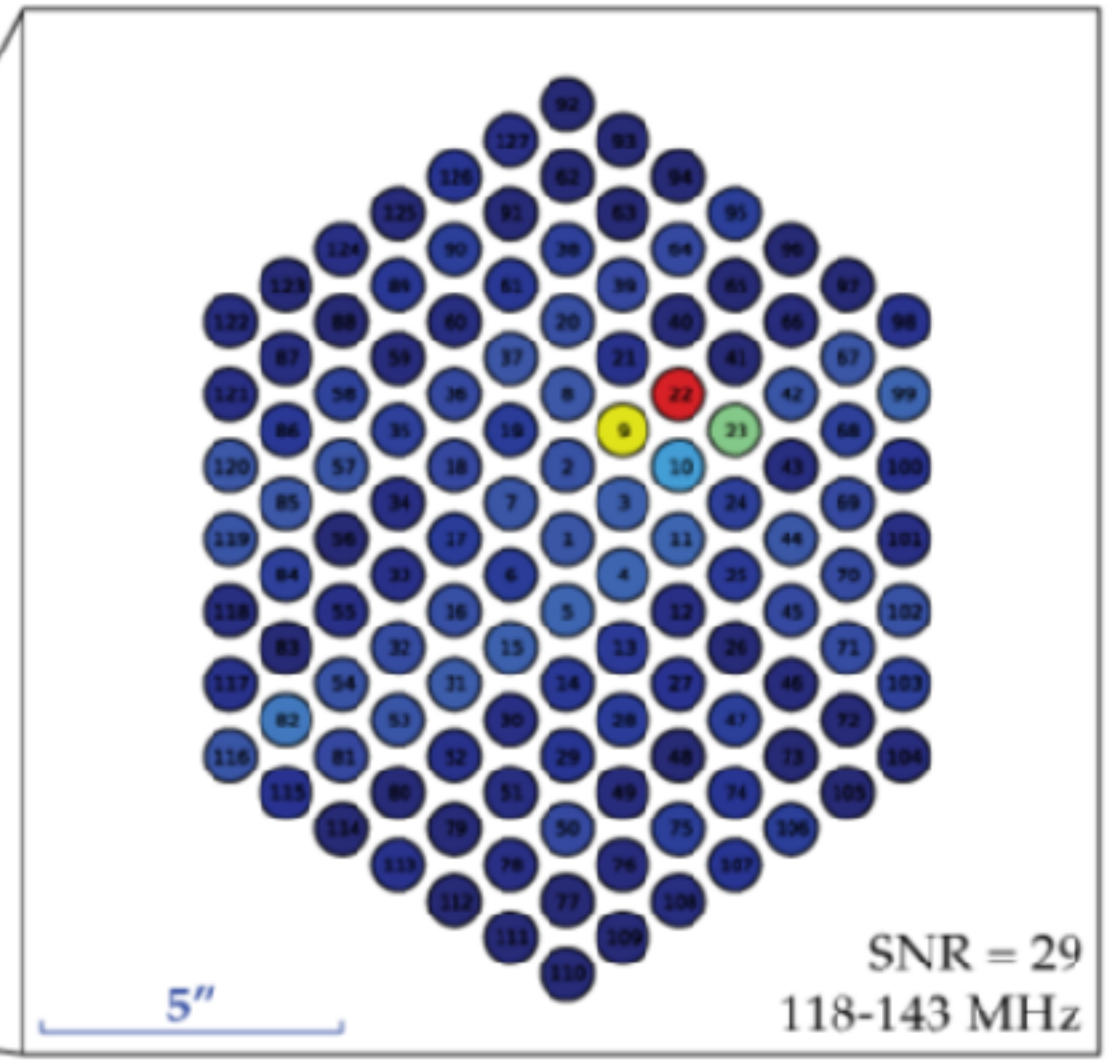


Expected rate: ~1-5 FRBs per week

ALERT:



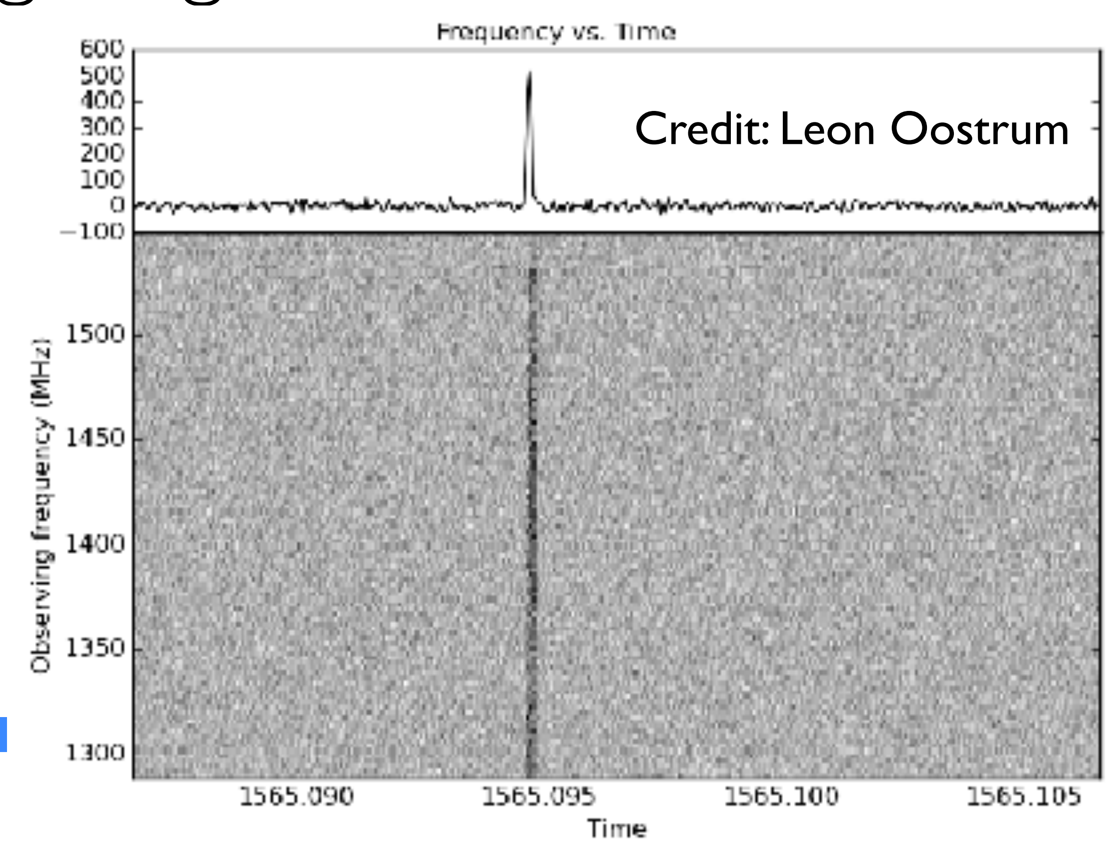
Real-life single pulse detection:



Localisation: arcsec²

ALERT Timeline

- July 2017: Incoherent search with subset of full telescope
- August 2017: GPU Processing cluster delivered
- September 2017: Begin coherent search commissioning
- January 2018: Coherent survey begins with WSRT
- 2018- : Commissioning LOFAR triggering mode
- 2018- : Profit (scientifically)



Credit: Leon Oostrum

VOEvent Standard for Fast Radio Bursts

Emily Petroff[*1,12], **Leon Houben**[2,3,12], **Oscar Martinez Rubi**[4], **Ronald van Haren**[4], **Joeri van Leeuwen**[1,5], **Casey Law**[6], **Sarah Burke-Spolaor**[7], **Aris Karastergiou**[8,9,10], **Michael Kramer**[2,11], **Duncan Lorimer**[7], **and Laura Spitler**[2]

[1]ASTRON Netherlands Institute for Radio Astronomy, Oude Hoogevensedijk 4, 7991 PD Dwingeloo, The Netherlands
[2]Max-Planck-Institut für Radioastronomie, Auf dem Hügel 69, D-53121 Bonn, Germany
[3]Department of Astrophysics, Radboud University Nijmegen, PO Box 9010, 6500 GL Nijmegen, The Netherlands
[4]Netherlands eScience Center, Address
[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
[7]Department of Physics and Astronomy, West Virginia University, P.O. Box 6315, Morgantown, WV 26506, USA
[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
[11]Jodrell Bank Centre for Astrophysics, University of Manchester, Alan Turing Building, Oxford Road, Manchester M13 9PL, United Kingdom
[12]The authors contributed equally to this work
[*]email: ebpetroff@gmail.com

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/

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/).

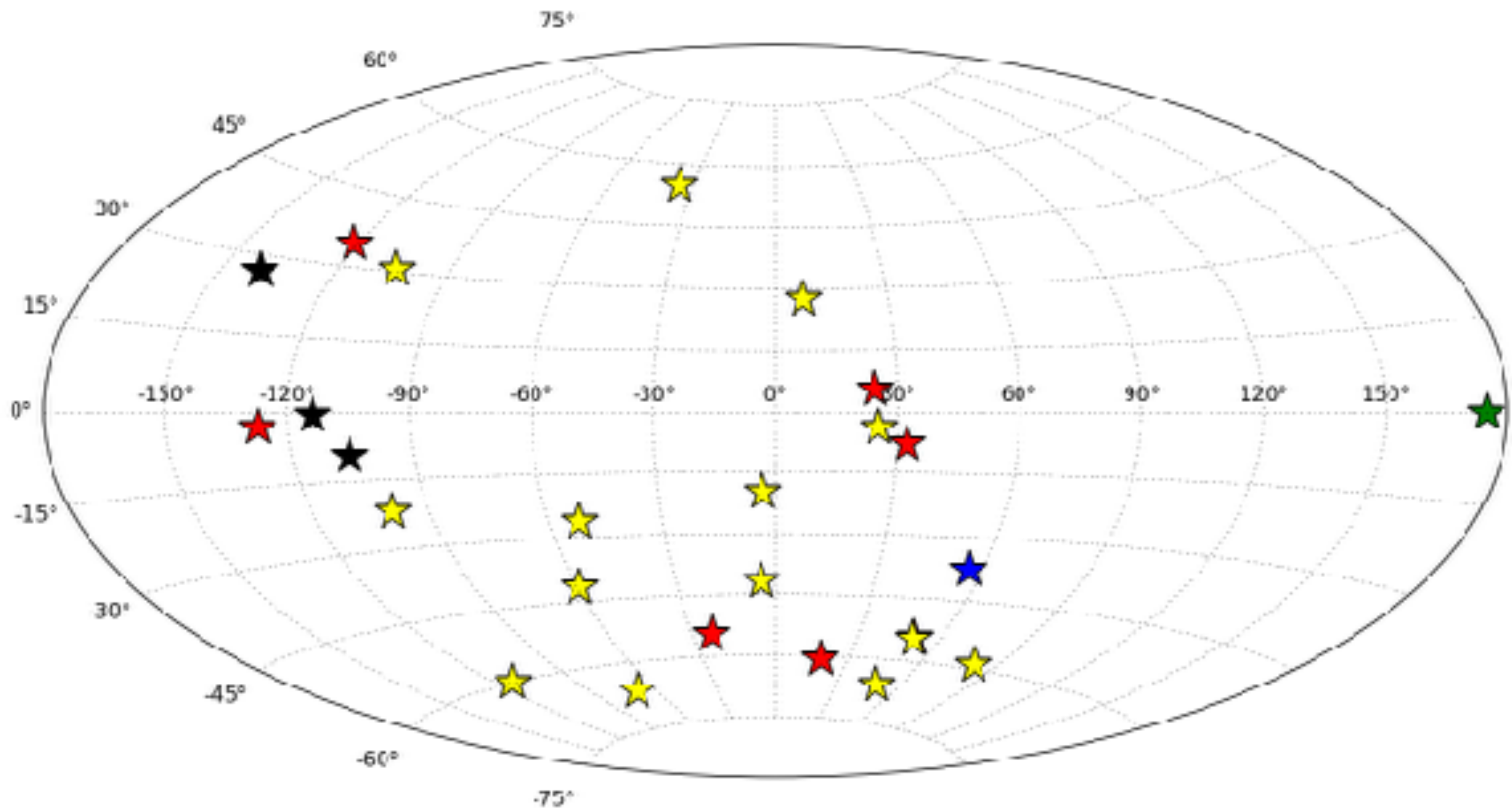
Catalogue Version 1.0

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)

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



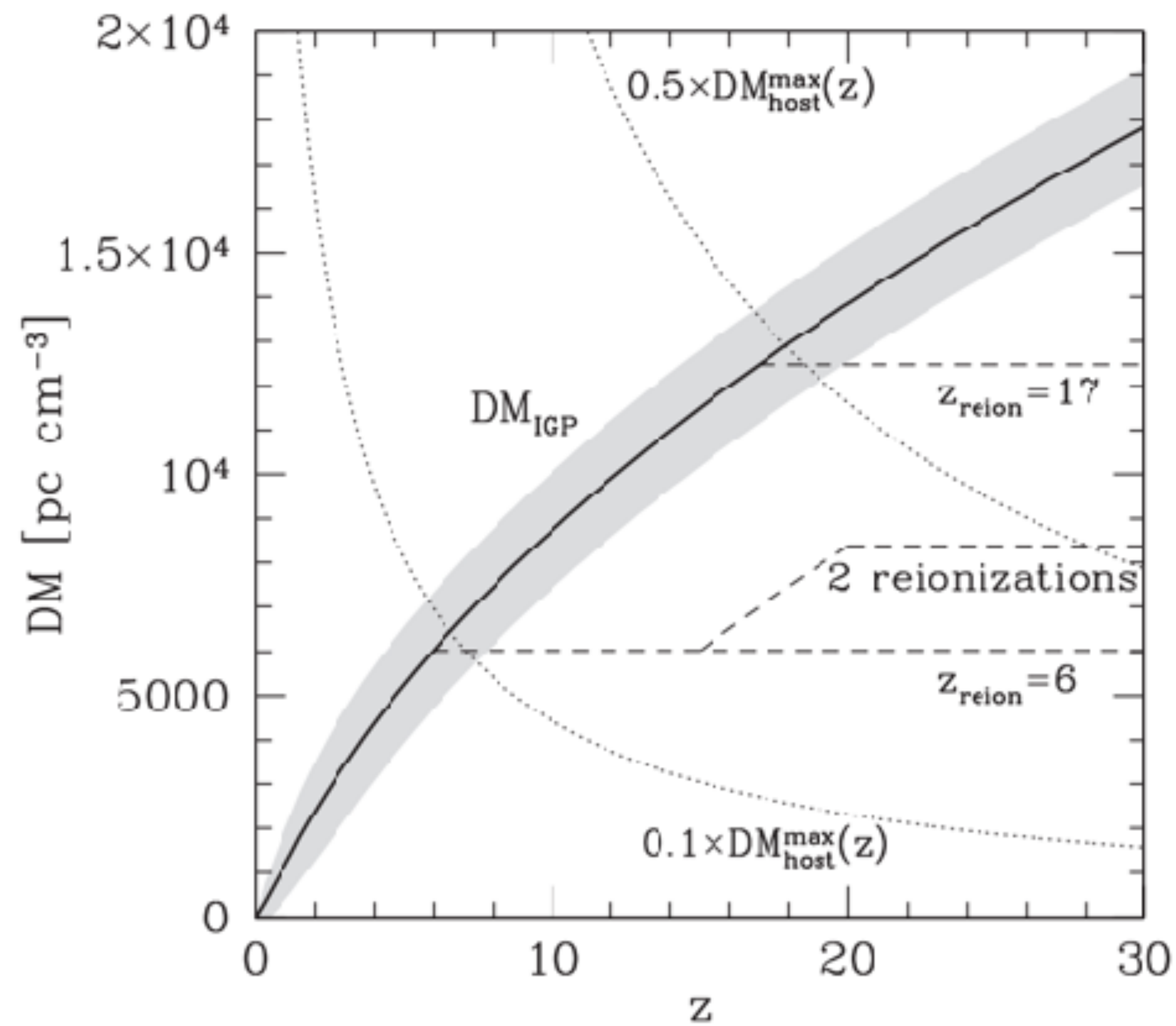
- Polarisation will become increasingly important and real-time detection and triggering will play a large role
- Still technically challenging to find FRBs at low frequencies, but detections may happen in the next few years!

Thank You!

ebpetroff@gmail.com

re: 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

re: Local magnetic field

- Two conflicting pictures

- FRBs 110523, 160102
  - High fractional linear polarization
  - RM much higher than estimated foreground
  - Ordered magnetic field local to progenitor or in host galaxy

- FRBs 150215, 150807
  - High fractional linear polarization
  - Low RM consistent with estimates of Galactic foreground
  - No ordered magnetic field in addition to Galactic contribution

RM may give greatest insights into local environment!