Fast radio bursts and their multi wavelength follow-ups

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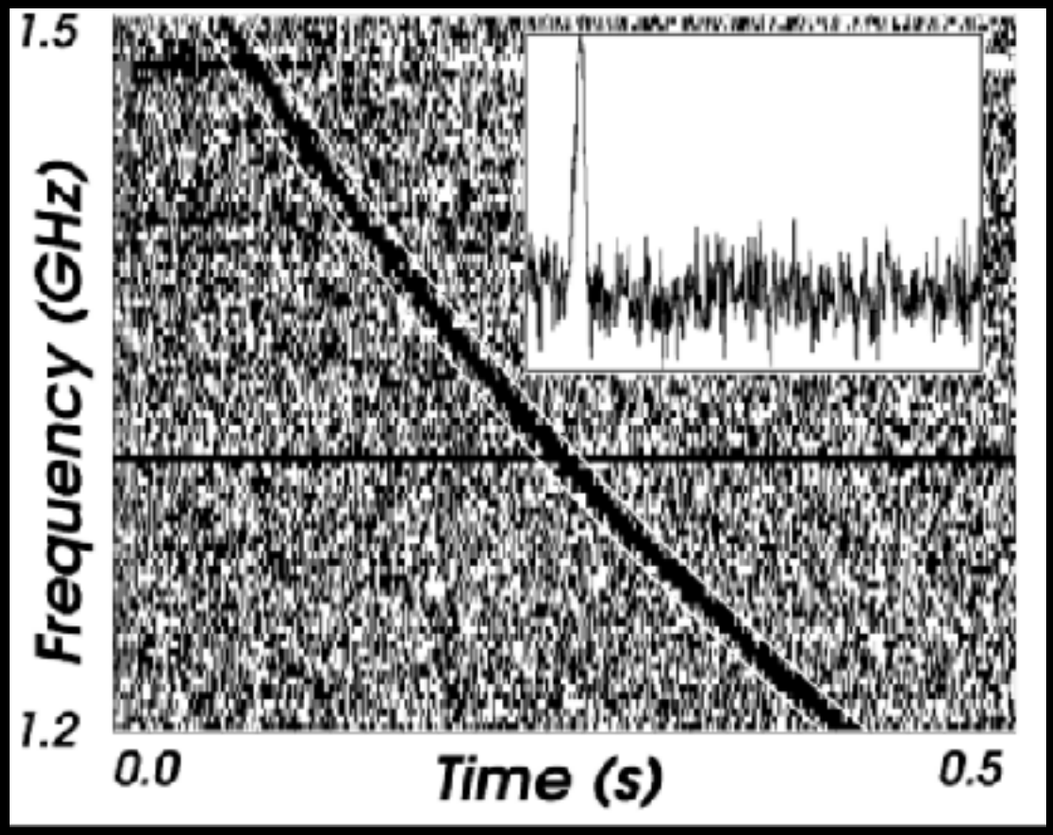
Research plus postdoctoral fellow
CSIRO/ATNF

The era of collaborative multi-wavelength and multi-messenger astronomy: science and engineering
22-24 October 2019, Firenze (Italy)

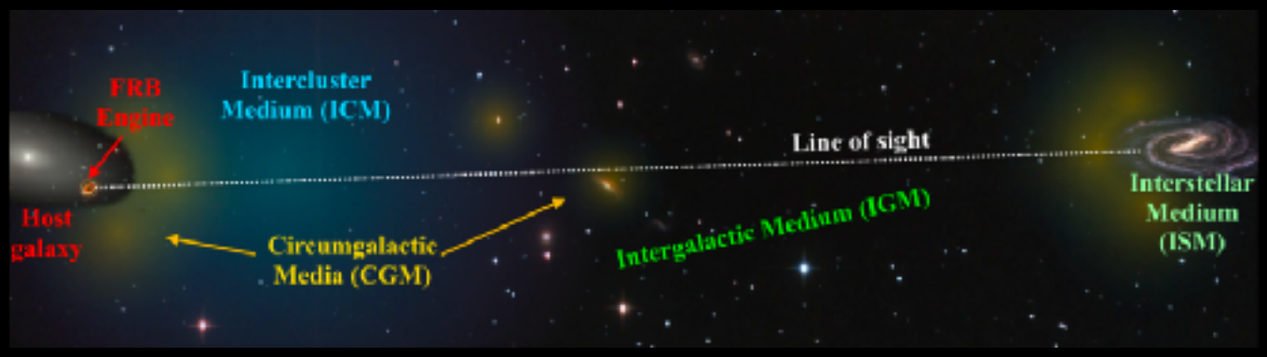
Fast Radio Bursts

What do we know about FRBs?

- Bright (few to ~400 Jyms) millisecond duration pulses of coherent ($T_b > 10^{35}$K) emission
- Observed DMs > Galactic DMs
- Observed high DMs (~100 to 2600 pc/cc) correspond to high inferred redshifts.
- 50+ progenitor theories (frbtheorycat)
  - ✳ Young magnetars
  - ✳ Compact binary mergers



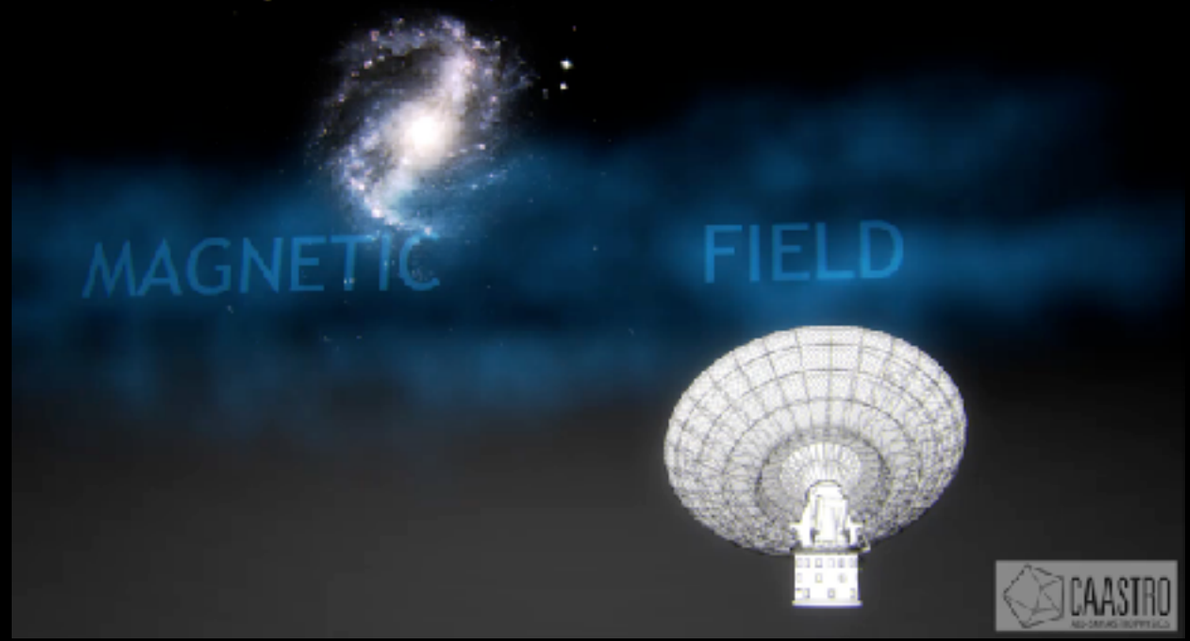
Lorimer+2007



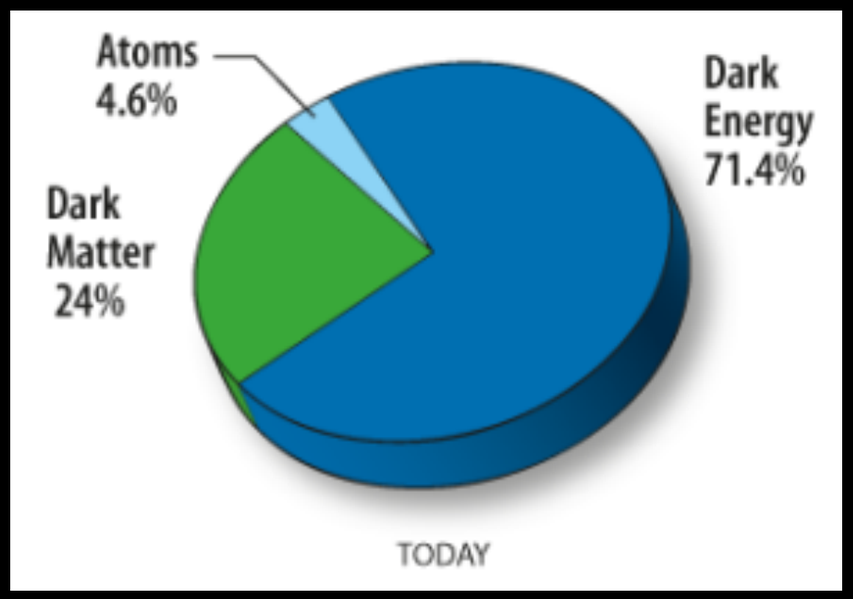
Ravi+19

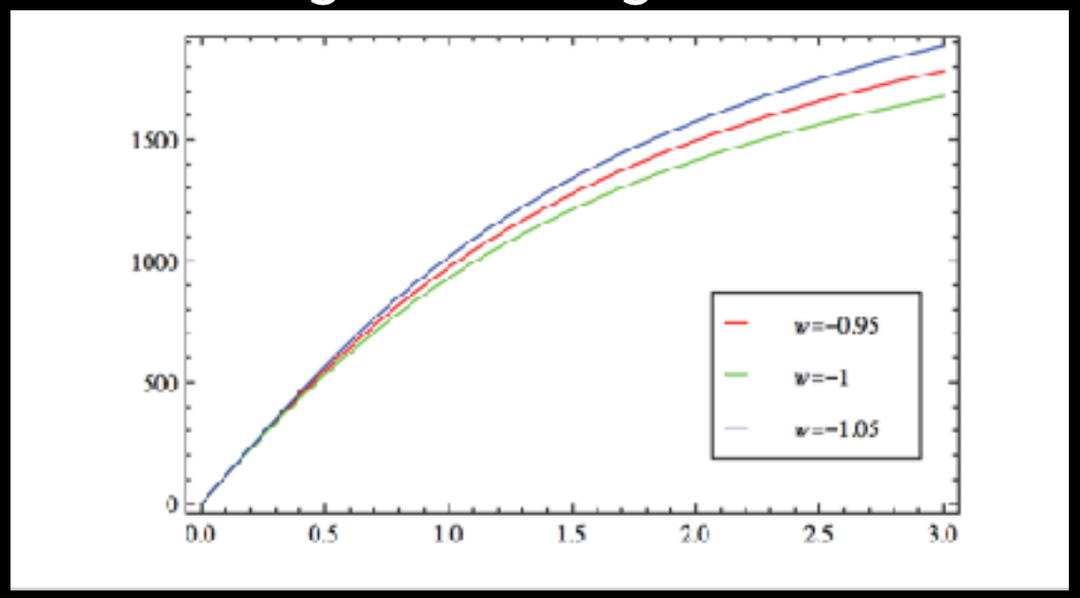
Cosmic Applications

Macquart+2015



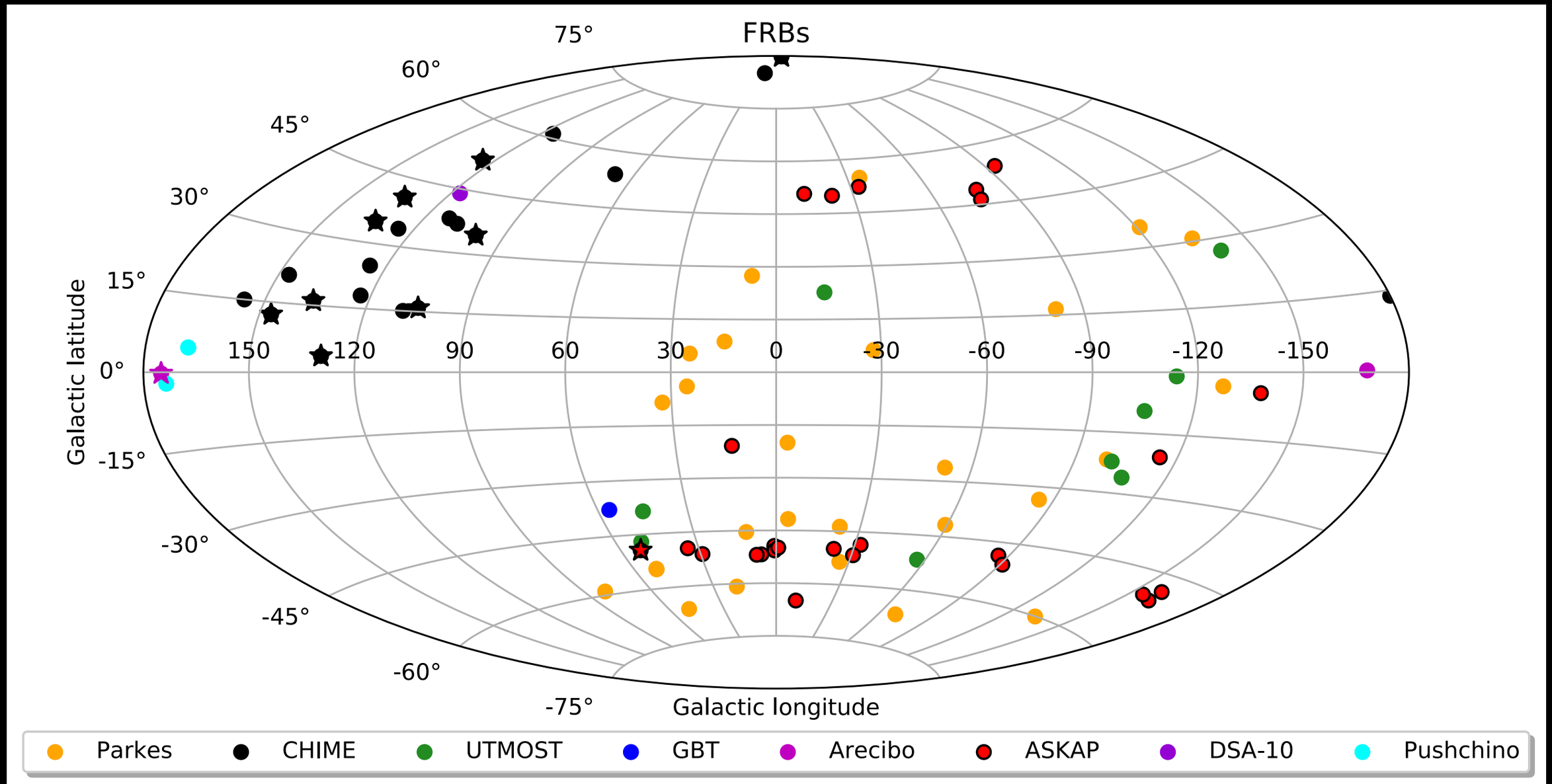
First measurements of
extragalactic magnetic fields





Independent measurement of the
dark energy equation of state

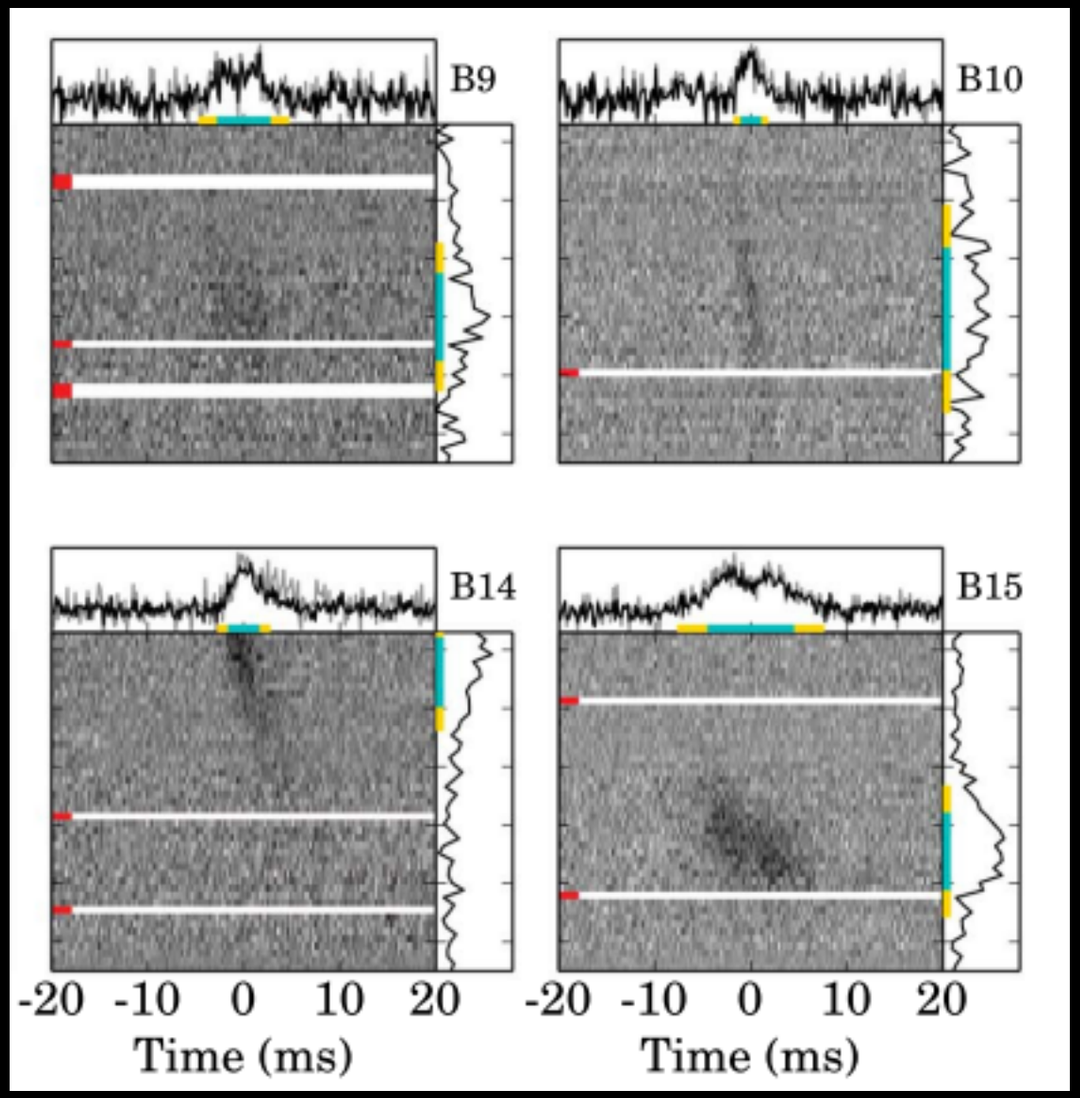
How many FRBs?



90 FRBs (published)

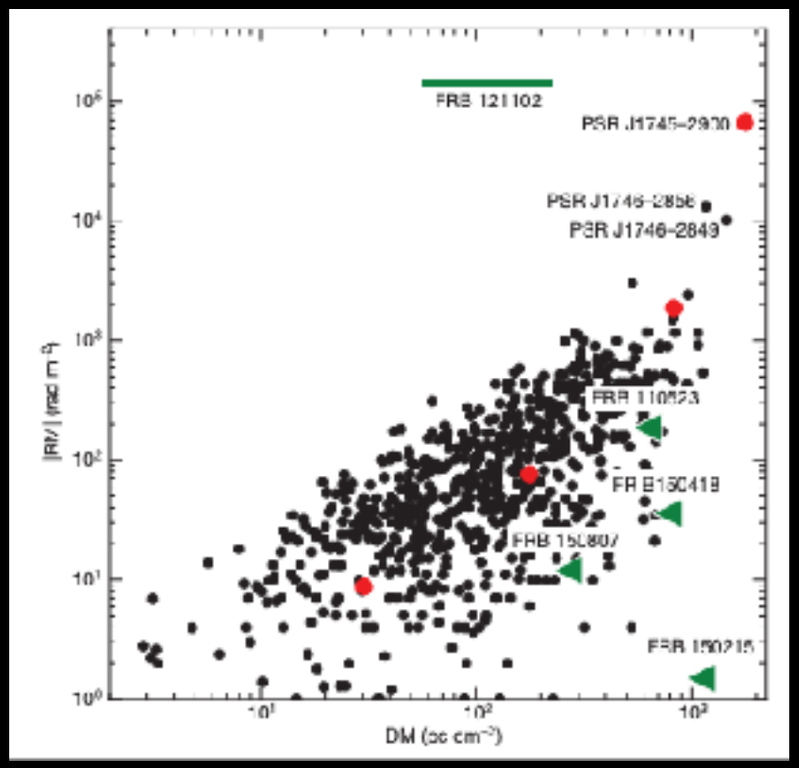
FRBCatalog
(Petroff+16)

FRB 121102
(Spitler et al 2016)

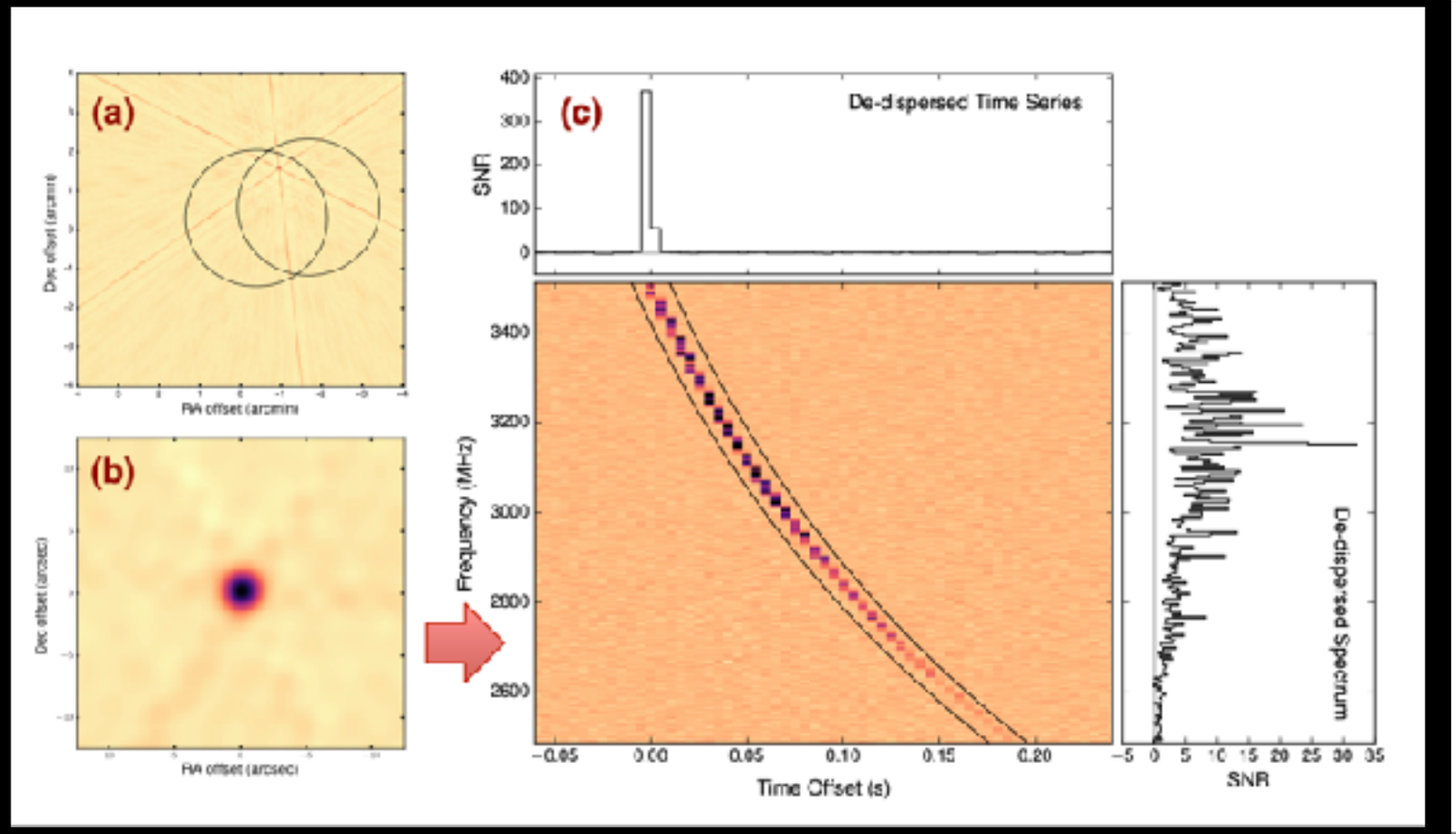


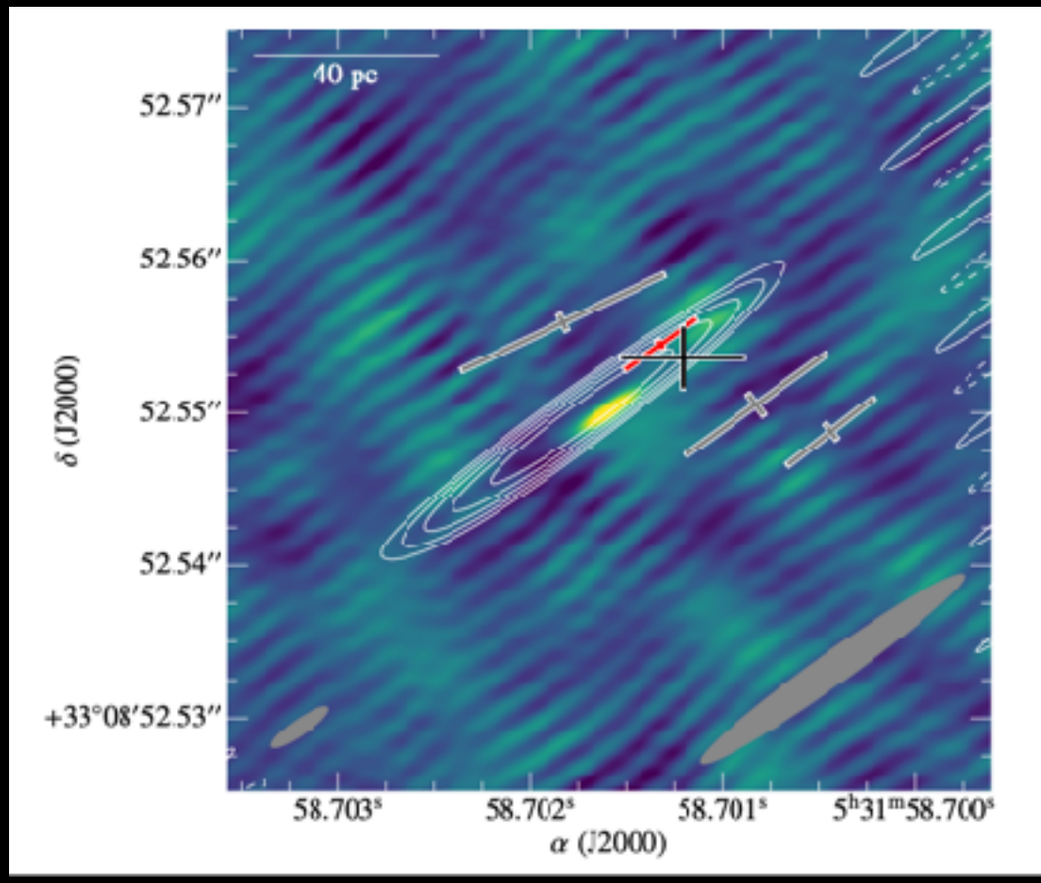
(Gourdjiet+2019)

- 50+ published repeats
- Aperiodic and mostly clustered in time.
- Source flips between active and dormant state
- Sub-pulse drifting in the dynamic spectrum
- High rotation measure ~10^5 rad m^{-2}
- Concordance picture: A flaring magnetar embedded in a magnetised ion-electron wind nebula (Margalit and Metzger 2018)



FRB121102 localisation



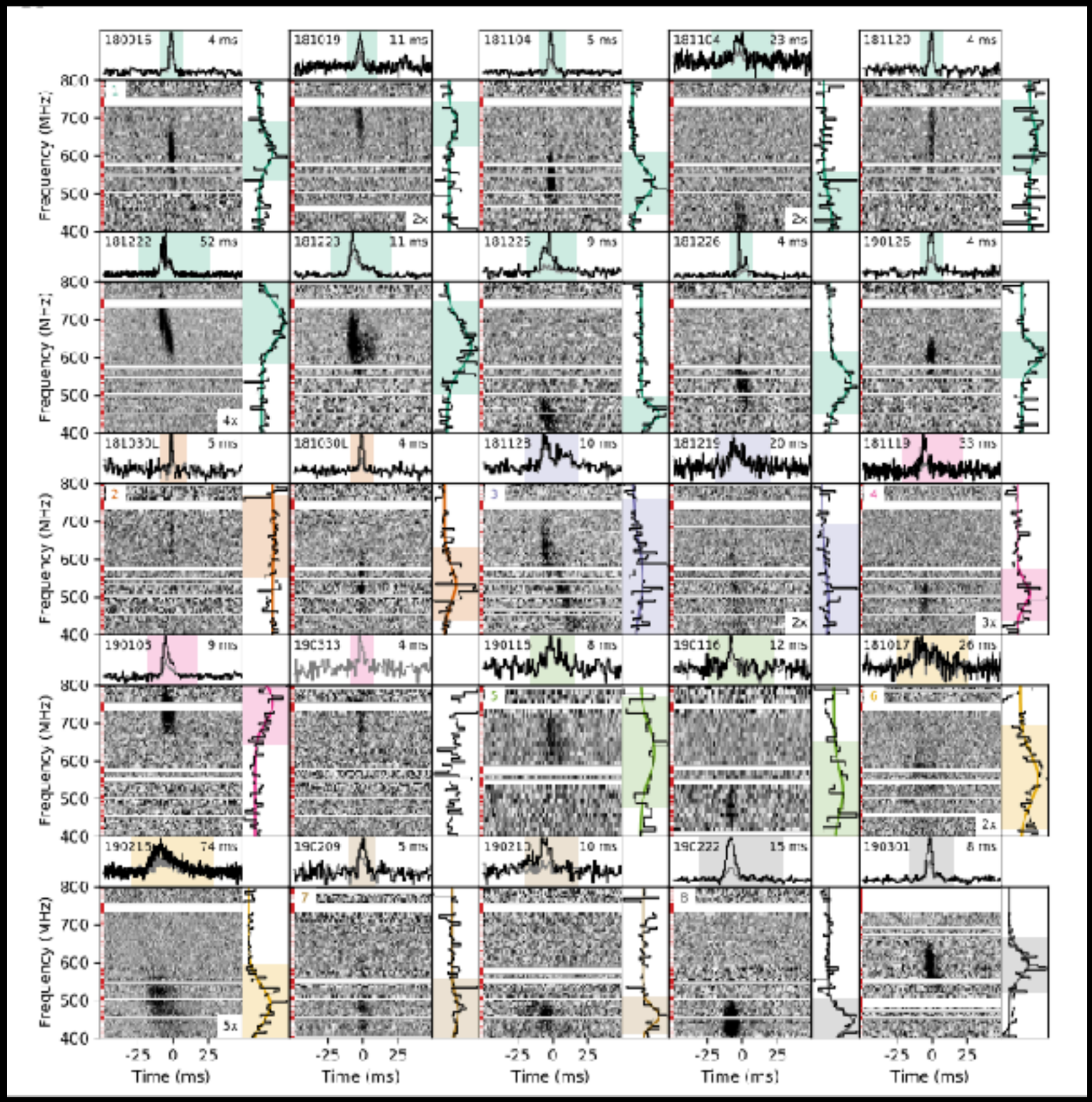


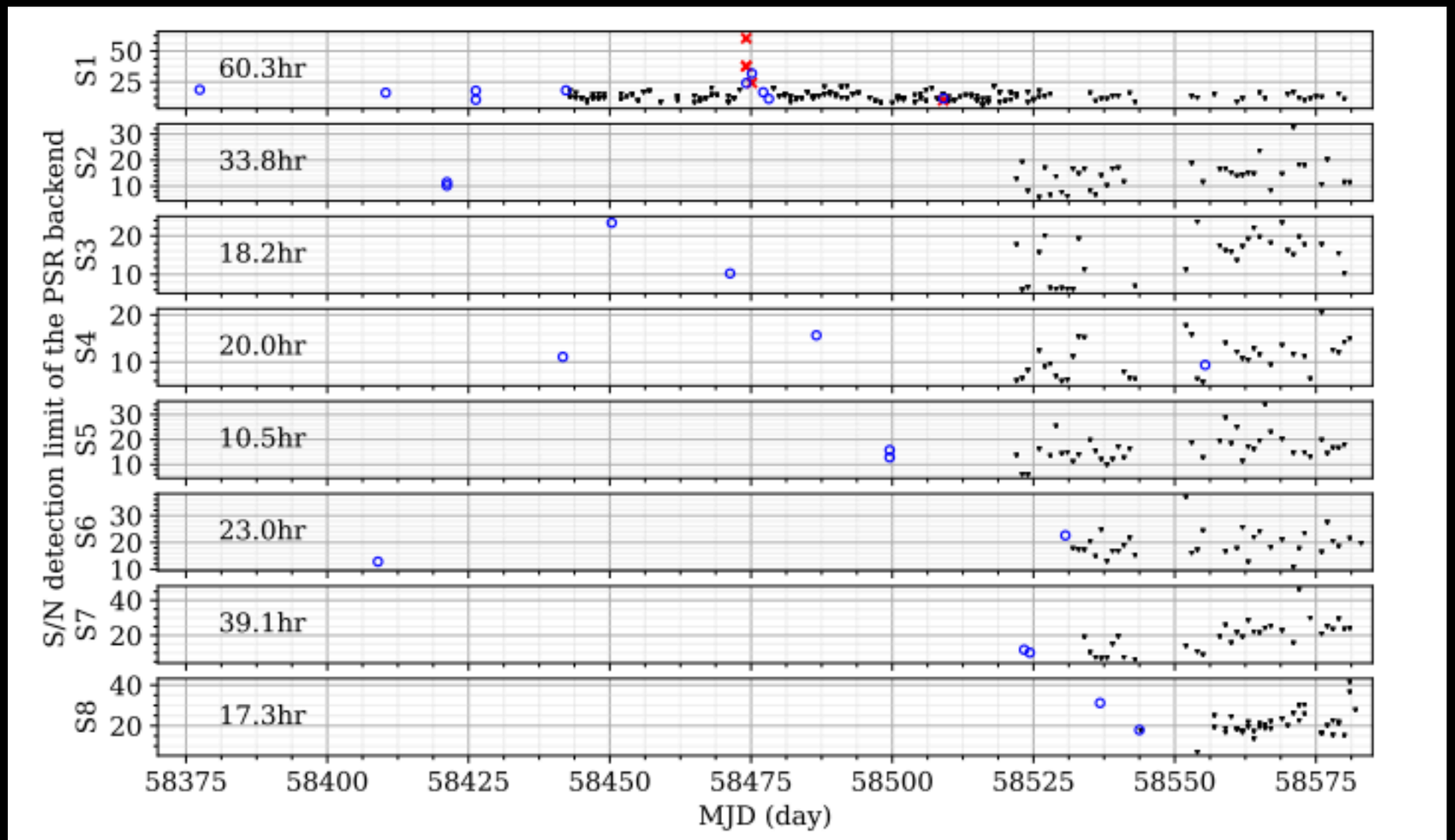
- Direct FRB localisation co-located with persistent radio source.
- Host galaxy is a star-forming dwarf at z = 0.192.

(Chatterjee+2017, Tendulkar+2017, Marcote +2017).

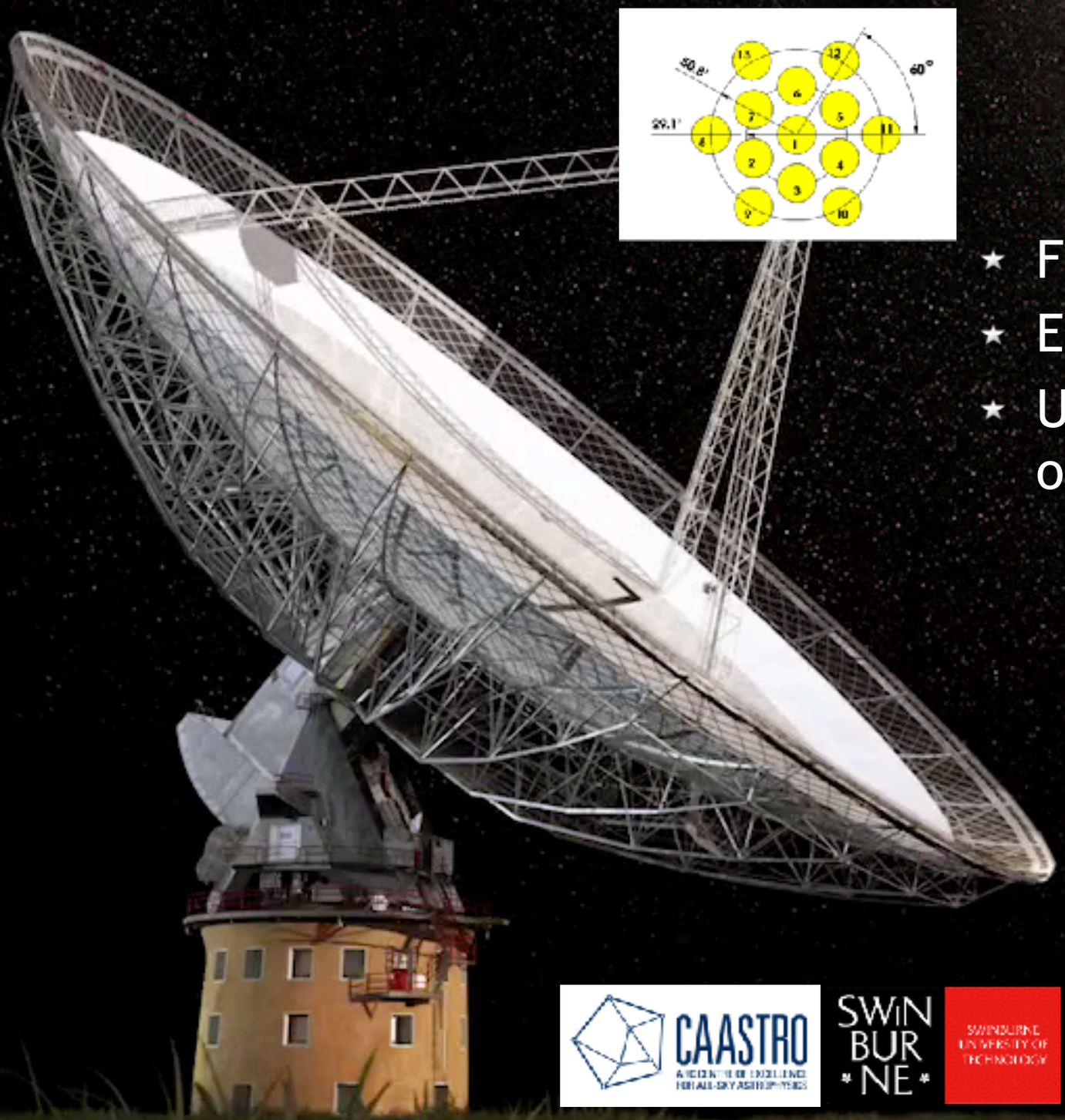
CHIME repeating FRBs

(The CHIME collaboration)




S1
60.3hr
50
25
S2
33.8hr
30
20
10
S3
18.2hr
20
10
S4
20.0hr
20
10
S5
10.5hr
30
20
10
S6
23.0hr
30
20
10
S7
39.1hr
40
20
S8
17.3hr
40
20
S/N detection limit of the PSR backend
58375
58400
58425
58450
58475
58500
58525
58550
58575
MJD (day)

SURVEY FOR PULSARS AND EXTRA GALACTIC RADIO BURSTS



SUPERB
Survey for Pulsars and Extragalactic Radio Bursts

- Finding FRBs in real time
- Effecting multi-wavelength follow-ups
- Understanding the nature and origin of FRBs

Bhandari+2018

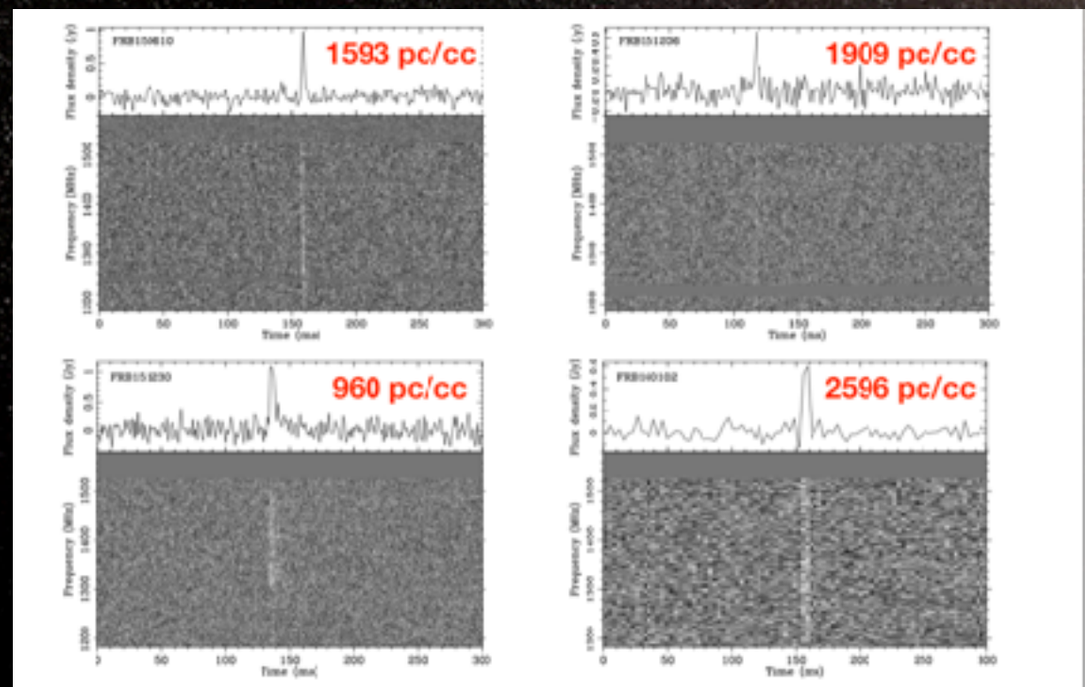


Figure 1. The pulse profiles of the four new FRBs de-dispersed to their best-fitting DM values: clock-wise from top left FRB 150610, FRB 151206, FRB 160102 and FRB 151230. The top panel shows the time series, frequency averaged to one channel and the bottom panel shows the spectrum of the pulse. The data have been time averaged to 1 ms, 0.6 ms, 0.8 ms and 0.5 ms per sample for FRB 150610 FRB 151206, FRB 160102 and FRB 151230 respectively. The flux density scale in the upper panel of individual pulses is derived from the radiometer equation. See table 1 for the dispersion smearing times within a single channel for each FRB.

CAASTRO
ARC CENTRE OF EXCELLENCE FOR ALL-SKY ASTROPHYSICS

SWINBURNE UNIVERSITY OF TECHNOLOGY

From: BPSR FRB Detector [Andrew.Jameson@atnf.csiro.au]
Sent: Saturday, 18 April 2015 2:29 PM
To: Andrew Jameson
Subject: New Detection: FRB150418

UTC START	2015-04-18-04:21:15
Source	G233.2-03.3_s
PID	P892
NE2001 DM	189.1684

FRB Detections

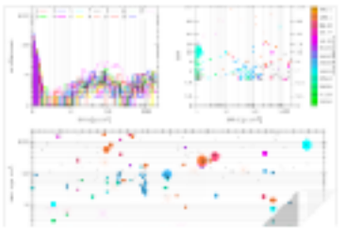
SNR	Time	DM	Length	Beam	Known Source(s)
29.5571	471.66	774.723	1.024	04	

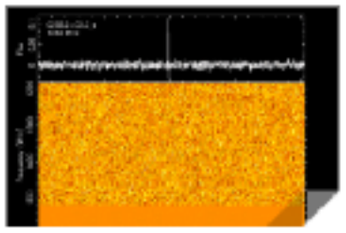
Beams Positions & Known Sources

Beam	RA	DEC	Gl	Gb
01	07:17:28.3	-19:28:08.7	233.16997547	-3.2600178939
02	07:16:22.4	-19:52:44.6	233.41381672	-3.6792507386
03	07:15:25.0	-19:26:58.0	232.92805616	-3.6803552890
04	07:16:30.9	-19:02:24.4	232.68442586	-3.2610104572
05	07:18:33.9	-19:03:31.4	232.92633778	-2.8407264687
06	07:19:31.6	-19:29:13.3	233.41169448	-2.839618867
07	07:18:25.0	-19:53:51.0	233.65552280	-3.2587968426
08	07:17:19.0	-20:18:51.5	233.90496614	-3.6809846212
09	07:14:17.4	-19:51:42.4	233.17191166	-4.1058511689
10	07:14:26.6	-19:01:00.3	232.43691718	-3.6843297815
11	07:17:36.5	-18:37:25.0	232.43560046	-2.8385186410
12	07:20:38.3	-19:04:22.7	233.1680439	-2.4141821187
13	07:20:30.0	-19:55:05.8	233.9024127	-2.835175025

Plots

2 Attachments



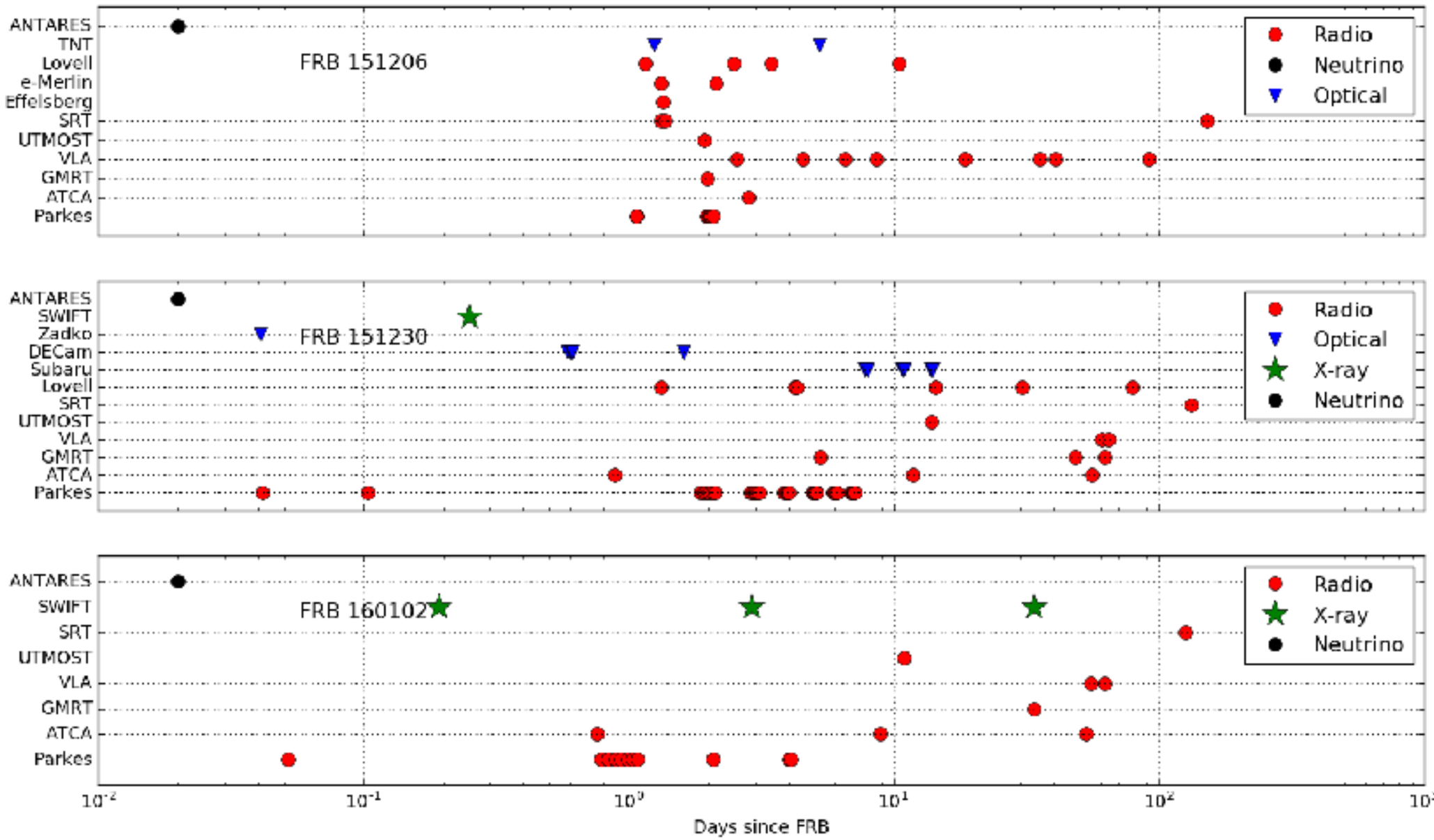


Multi-wavelength synergies

Multi-wavelength follow-up campaign

Image credit: NASA.

Follow-up campaign



< a day **10 days** **~ 3 months**

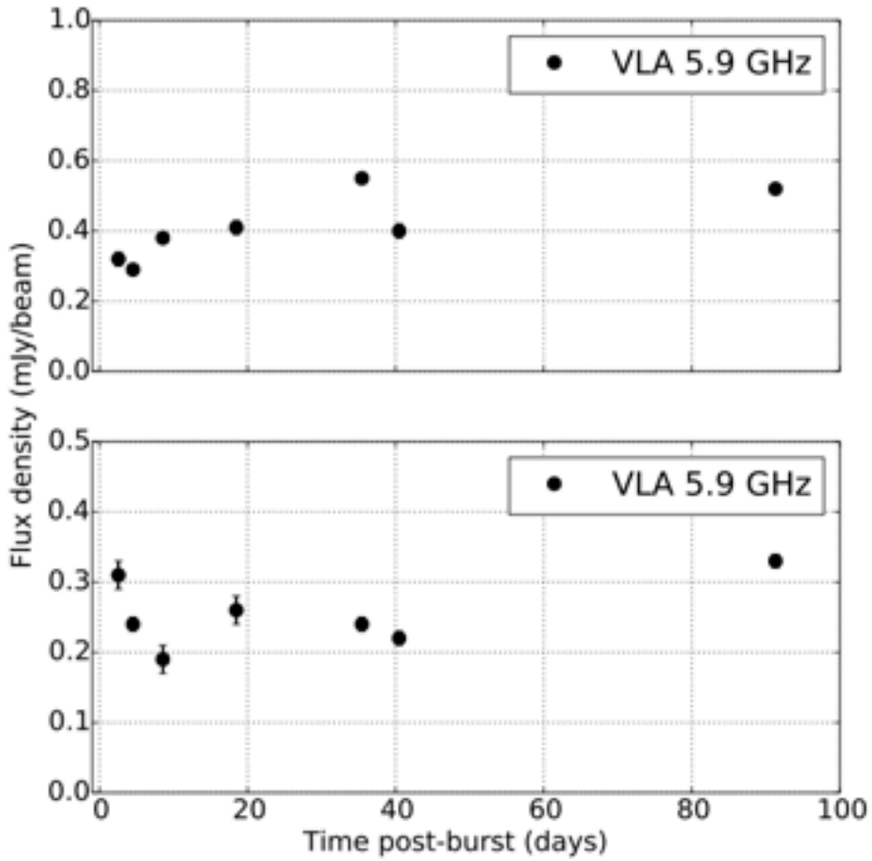
Bhandari+2018

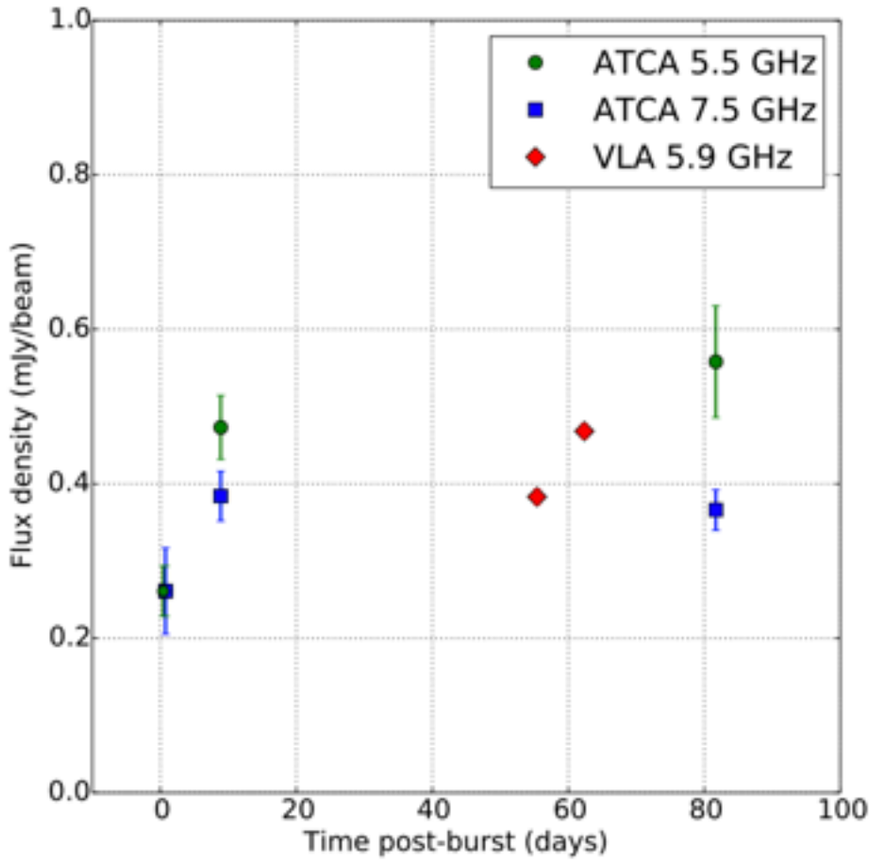
Any hints in radio follow-ups? Observations

- ATCA
  - 42 pointing mosaics encompassing Parkes 15’ FWHM
  - C band 2 IFs – center freqs : 5.5 GHz and 7.5 GHz
  - Best RMS ~ 40 μJy/beam
- GMRT
  - L band – center freq : 1.4 GHz
  - Best RMS ~ 30 μJy/beam
- VLA
  - 7 pointing mosaics encompassing Parkes 15’ FWHM
  - C band – center freq : 5.9 GHz
  - Best RMS ~ 10 μJy/beam

Image credit: NRAO.

Any hints in radio images ?

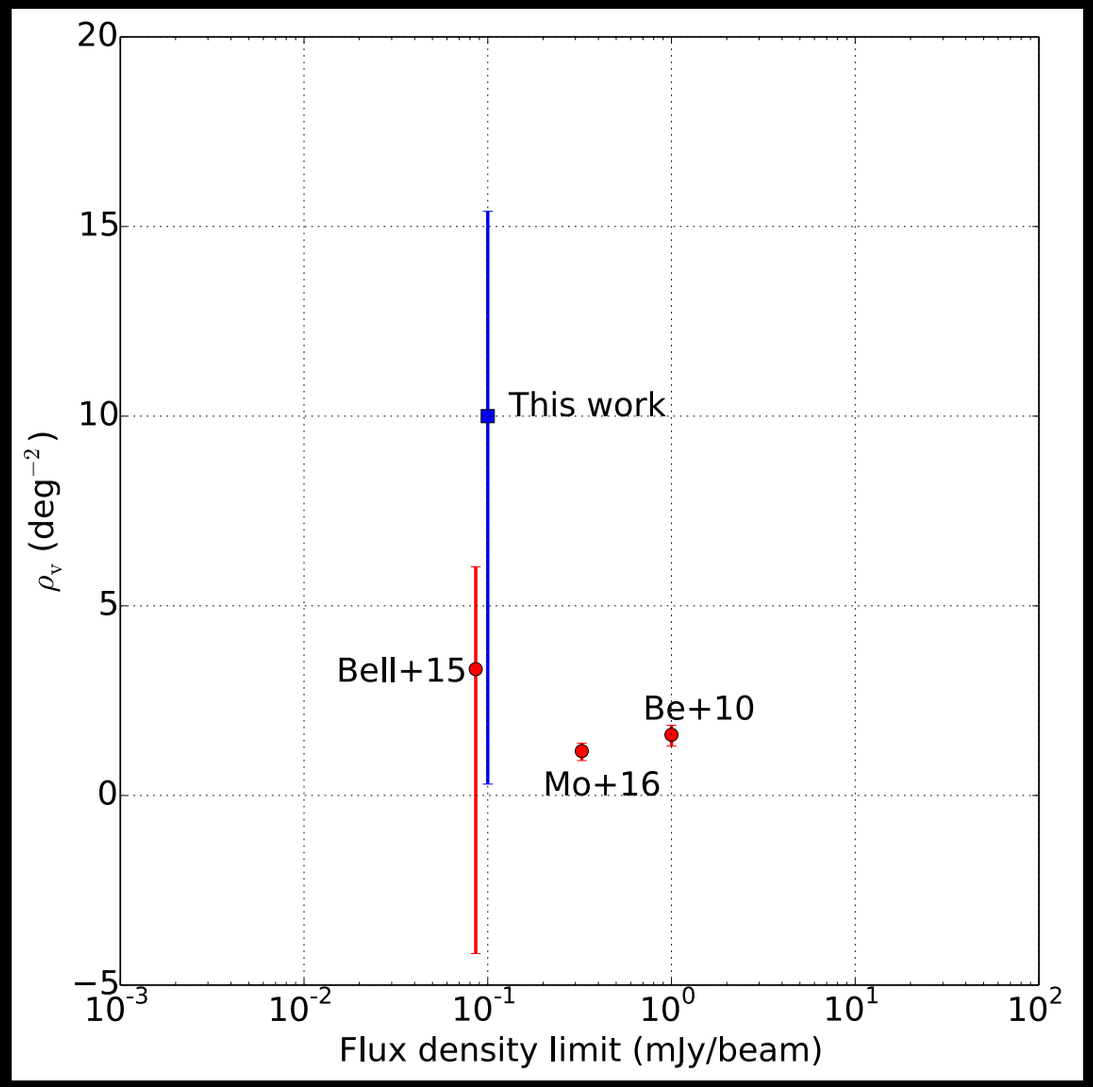


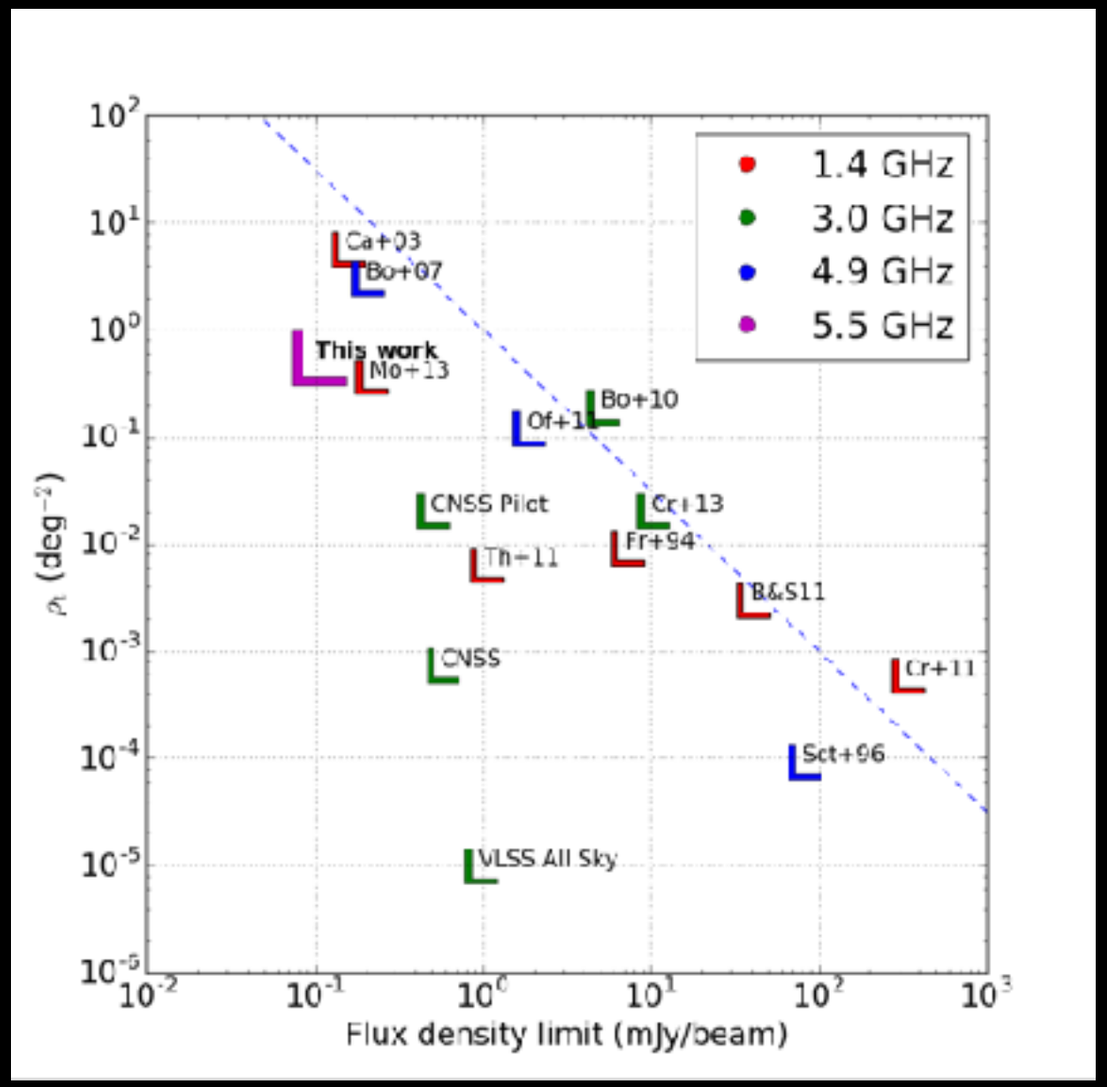


Significant variable sources in VLA images of FRB 151206 field

Significant variable source in ATCA image of FRB 160102 field

Does variability of sources lead to reliable host galaxy associations?





Not likely as the radio variability seen in FRB fields is consistent (within the uncertainties) with the variability in blind searches in literature.

Did FRBs repeat?

Thai National Telescope

Subaru Telescope

OPTICAL

FOLLOWUP

DECAM

Zadko Telescope

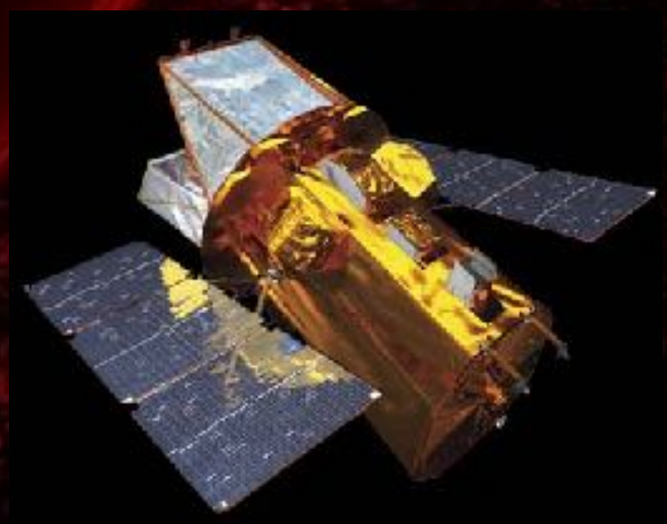
Optical follow-up results

- All variable sources attributed to
  - stellar variability
  - AGN variability
  - asteroids
- No optical afterglows/transients found to limiting magnitudes of
  - i-band ~ 25.0
  - r-band ~ 22.0
- Cadence range: minutes, days to weeks.

Credit: Gemini Observatory/AURA

X-ray follow-up

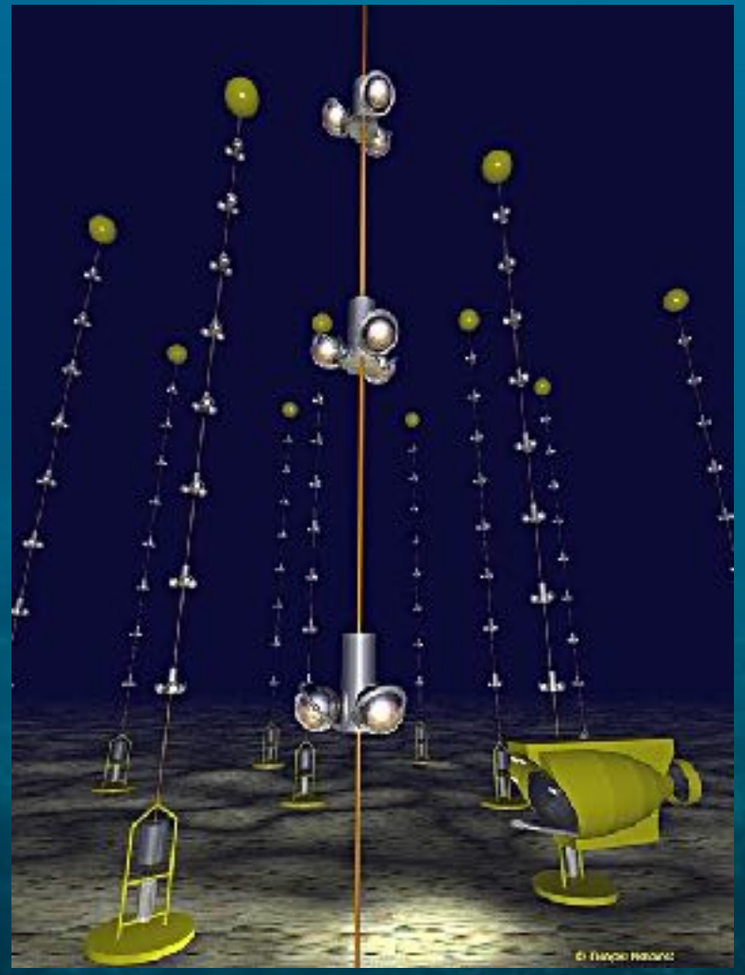
- Triggered for FRB 151230 and FRB 160102.
- FRB 151230
  - No sources detected above 3 sigma
  - limiting flux ~ 1.9E-13 erg/cm^2/s
- FRB 160102
  - No sources detected above 3 sigma
  - limiting flux ~ 1.4E-13 erg/cm^2/s



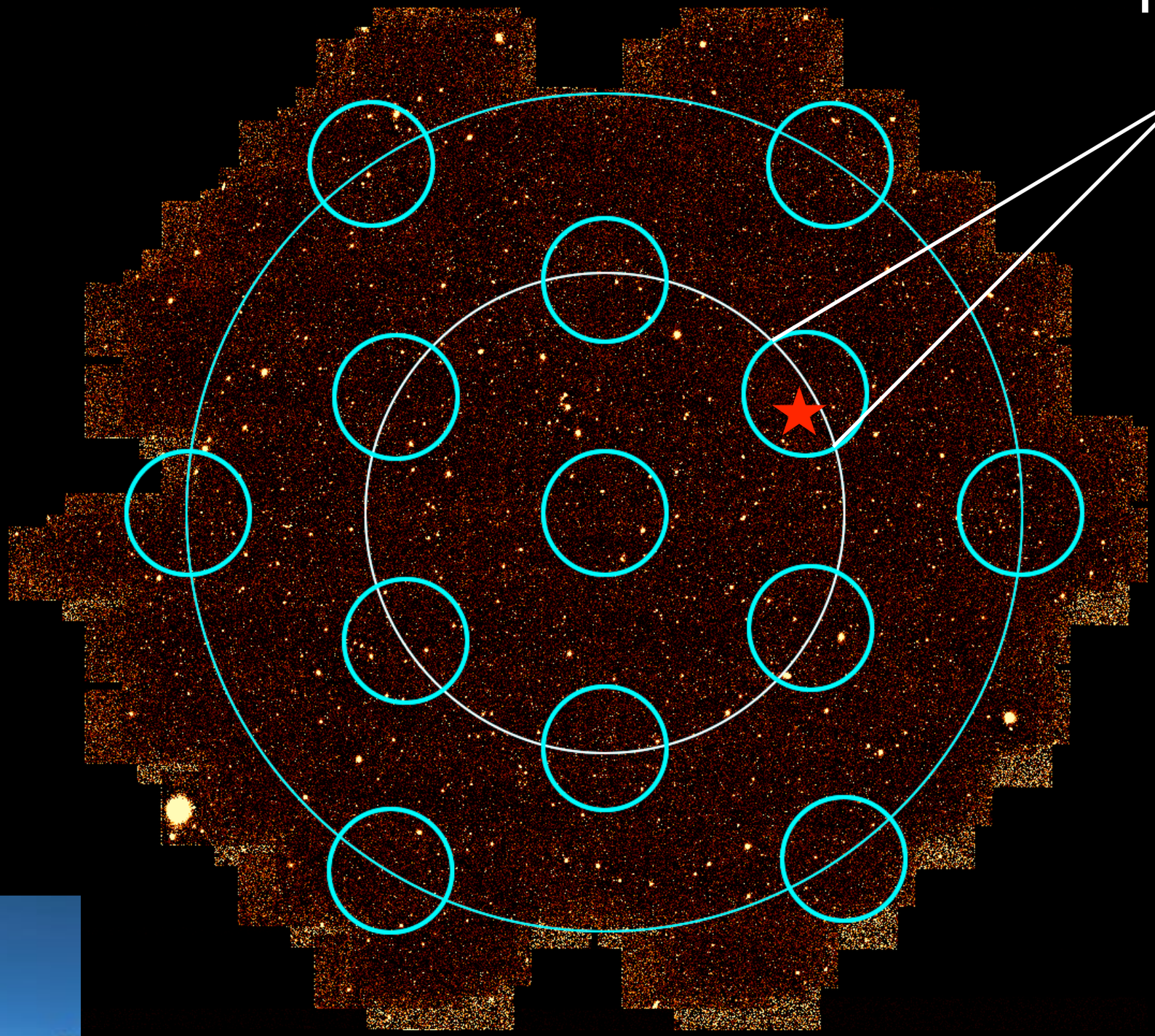
SWIFT

ANTARES

- ANTARES is a deep water neutrino detector.
- Aims to detect neutrino-induced muons (above 100 GeV) that produce Cherenkov light in the detector.
- Triggered at the time of FRB events to look for neutrino counterparts.
- No neutrino event was detected in correlation with FRB events.



Localisation with Parkes



Parkes beam overlaid on DECAM image.

Credits: Igor Andreoni

The Australian SKA Pathfinder (ASKAP)

- 36 antennas, each 12m in diameter.
- Frequency coverage: 700 MHz to 1.8 GHz
- 300 MHz instantaneous bandwidth
- 36 independent beams
- 30 square degree field-of-view at 1.4 GHz
- 6 km maximum baseline

The Commensal Real-Time ASKAP Fast Transients (CRAFT)

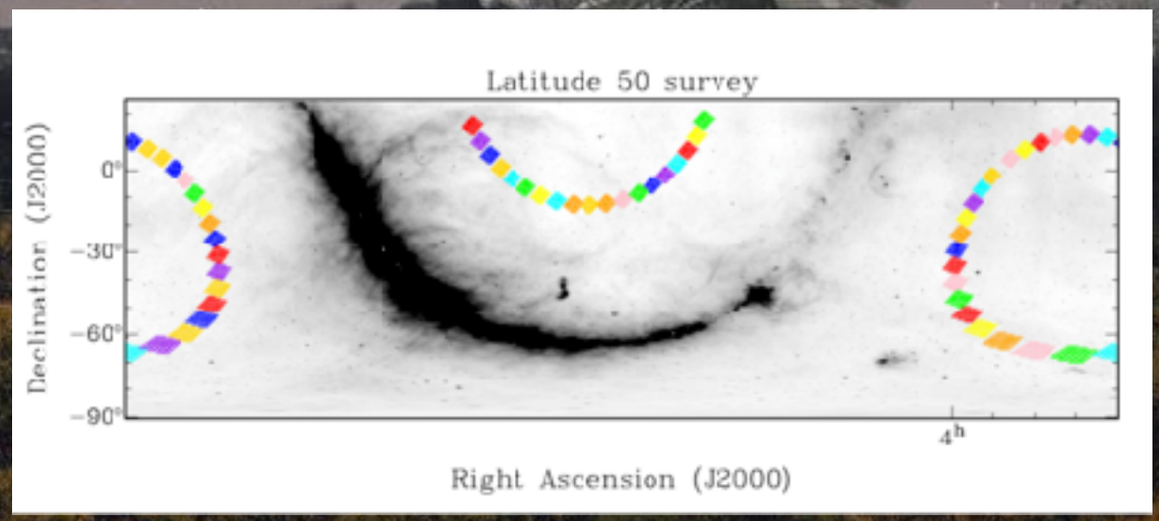
Letter | Published: 10 October 2018

The dispersion–brightness relation for fast radio bursts from a wide-field survey

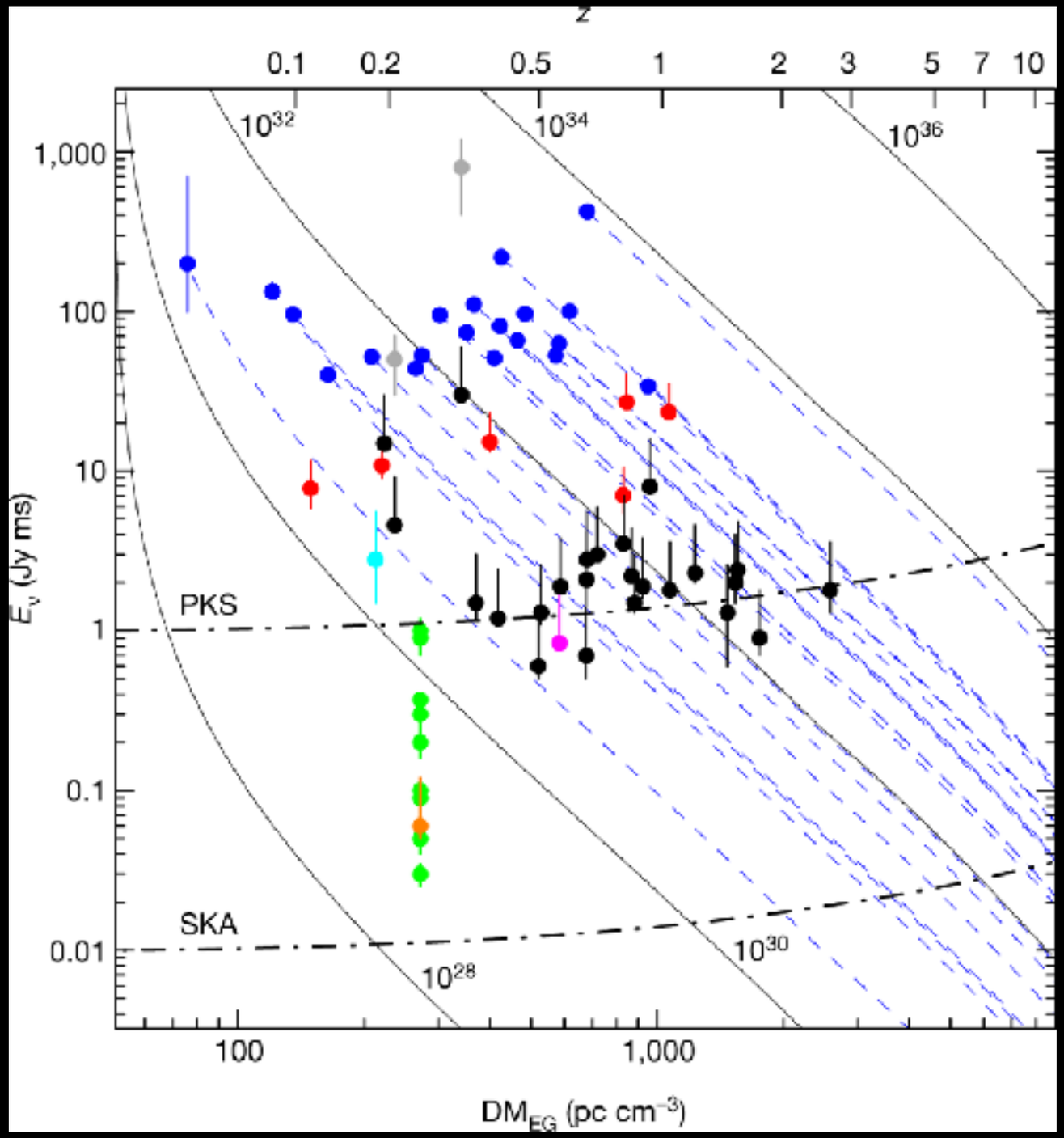
R. M. Shannon ✉, J.-P. Macquart ✉, […] C. J. Riseley

Nature **562**, 386–390 (2018) | Download Citation ↓

- Wide (exposure: 5.1e5 deg^2 hr) and shallow (26 Jy ms) Fly's eye survey
- 20 FRBs detected
- Bright FRBs exist (34 - 420 Jy ms)
- Lower DM sample than detected by Parkes (114-991 pc cm^{-3})
- No evidence for repetition in self-followup.



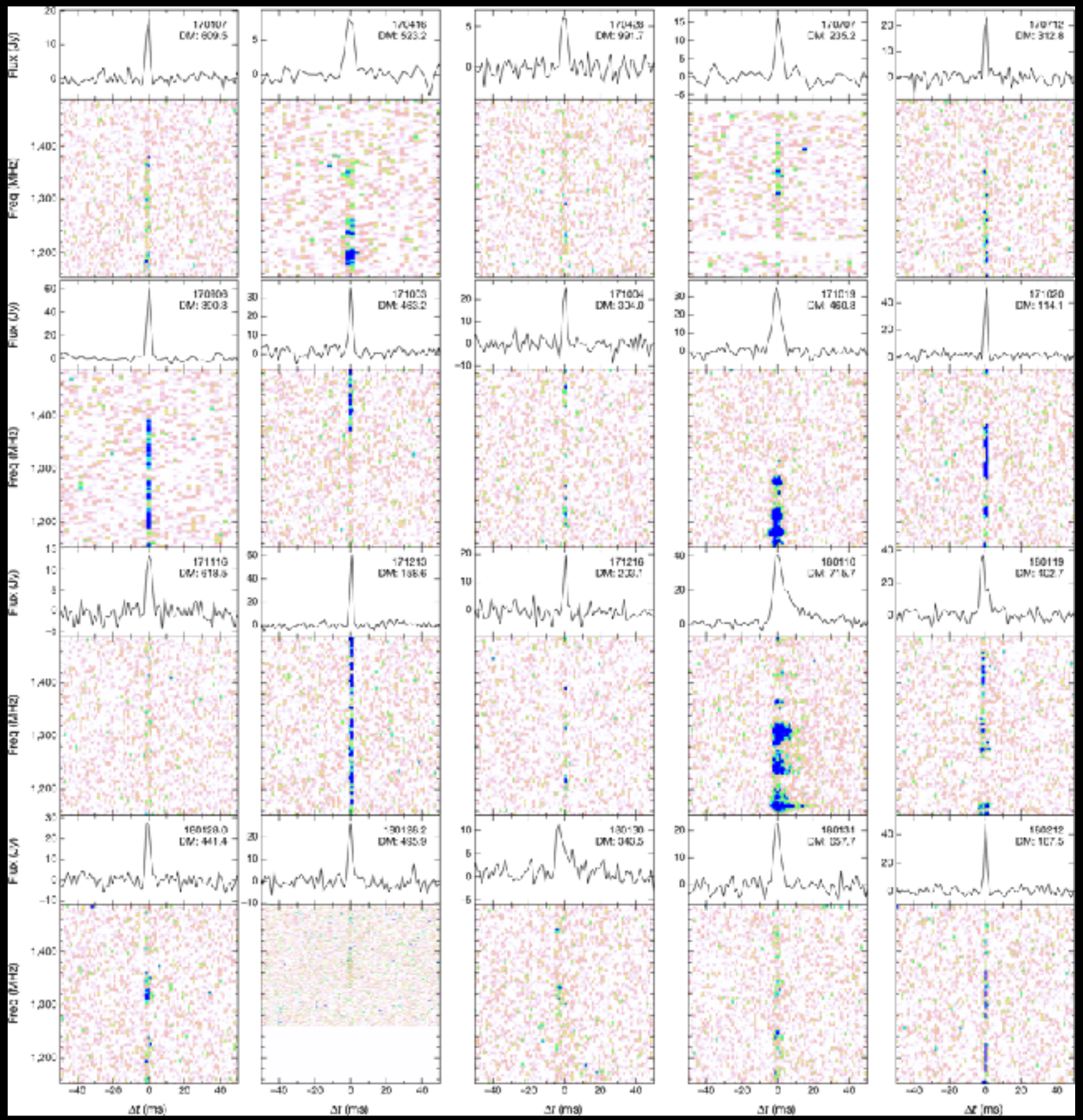
Dispersion-Brightness Relation



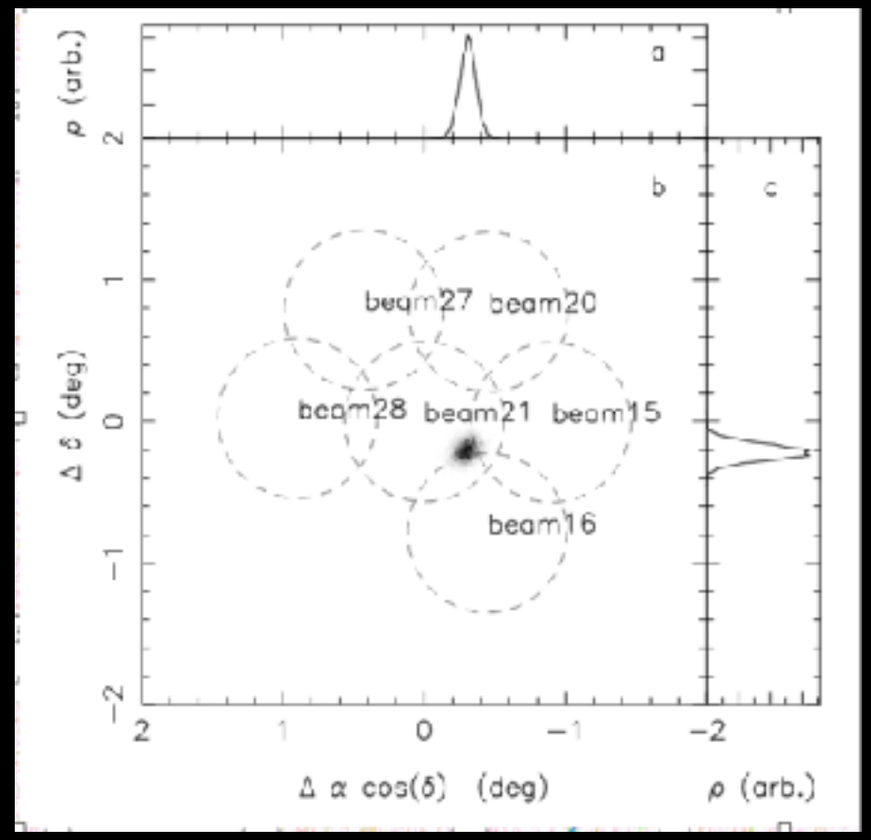
The high-fluence bursts are the nearby analogues to the more distant events.

Shannon+2018

ASKAP Fly's eye FRBs



10' localisation



Shannon+2018

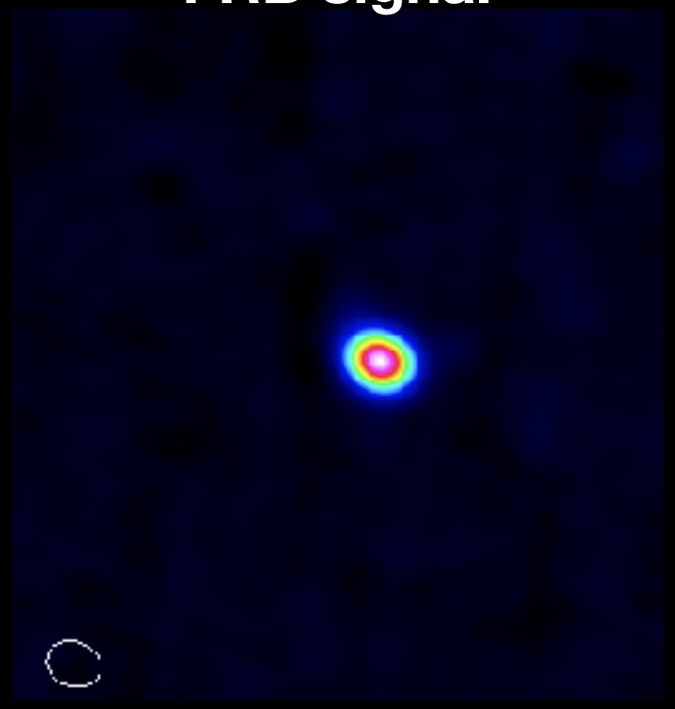
FRBs and Interferometry

Credits: NRAO

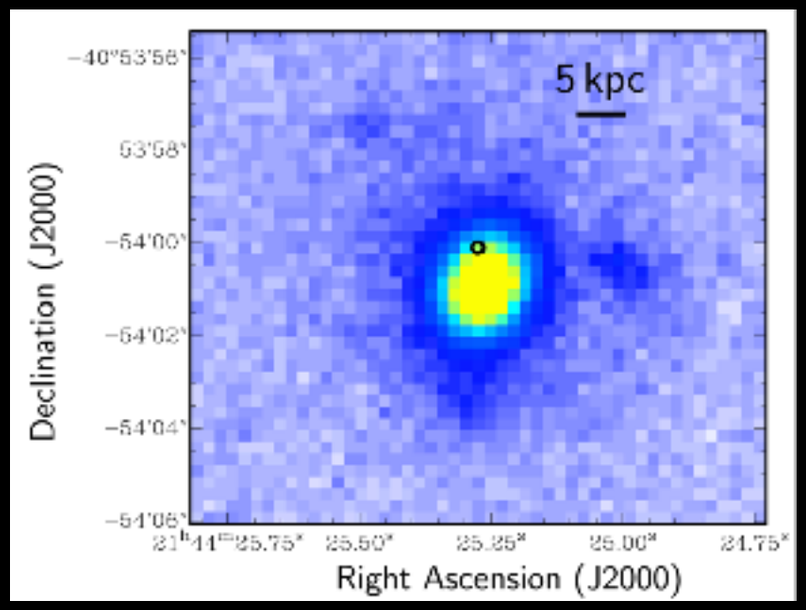
Find an FRB real-time

Localise using interferometry

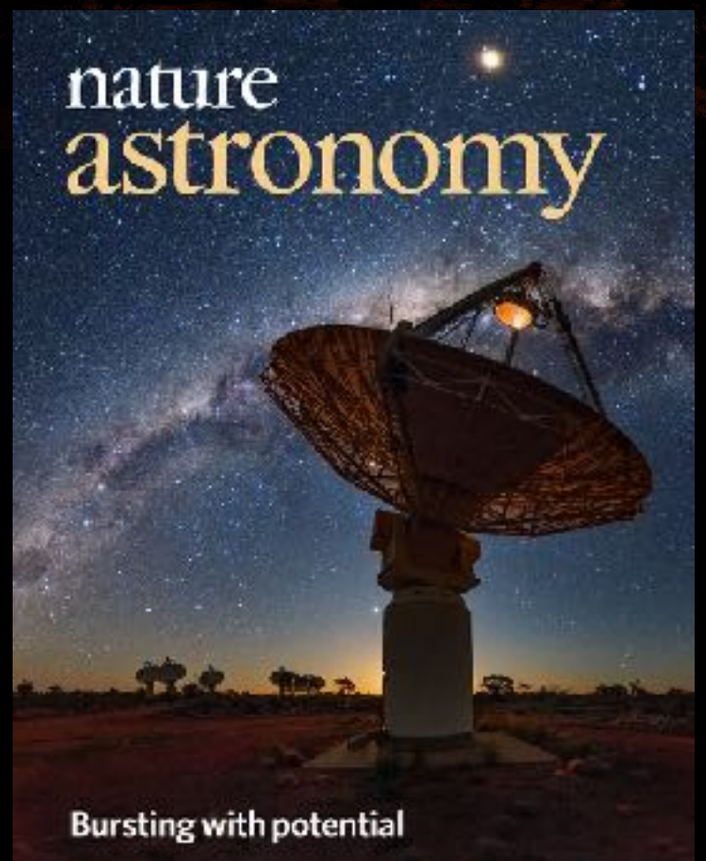
FRB signal

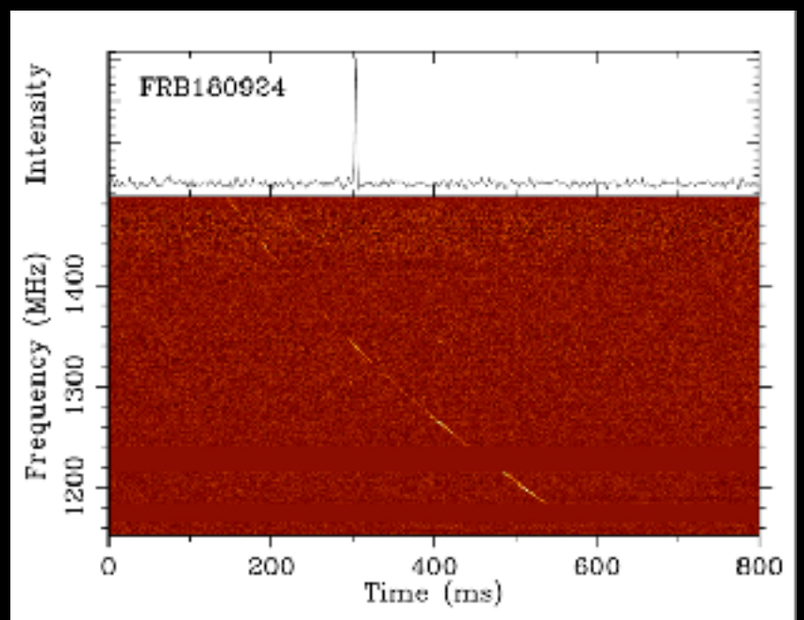


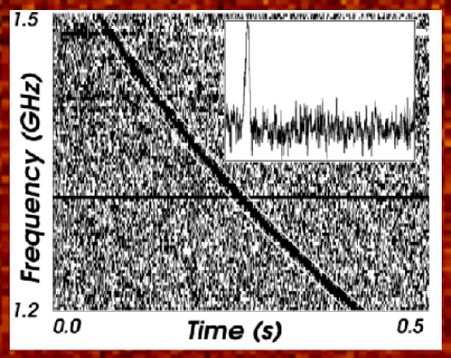
FRB host galaxy

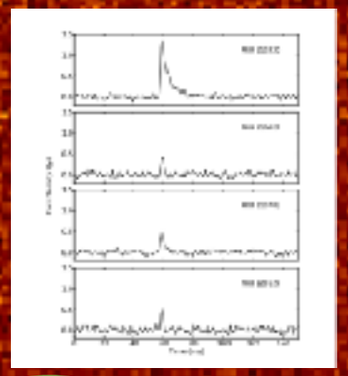


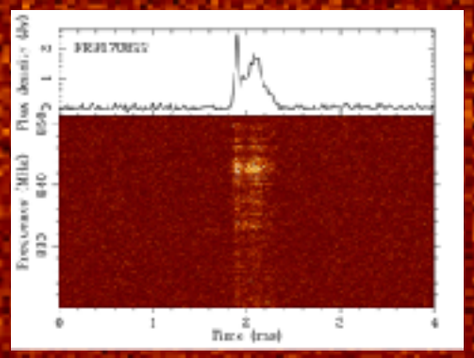
Do amazing Science

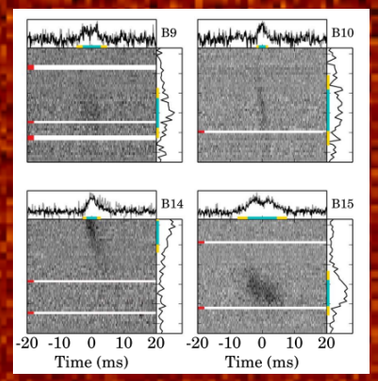












2007 Lorimer Burst

2010 First sample of FRBs

2013 Perytons

2014 Arecibo detection

2015 Real-time FRB

2015 GBT, Faraday rotation

2016 Repeating FRB

2016 Bright FRBs

2017 UTMOST

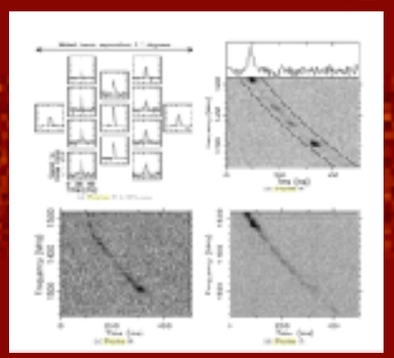
2017 Localisation repeater

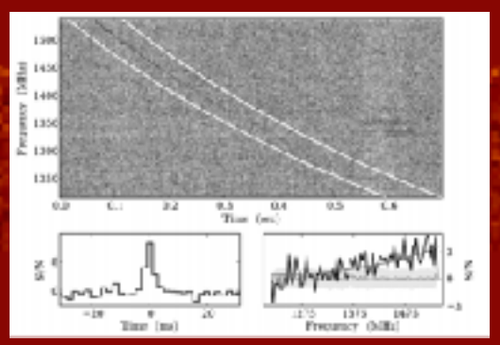
2018 Multi-wavelength campaign

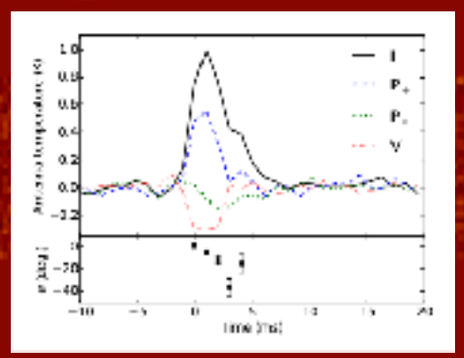
2018 ASKAP FRB population

2019 CHIME FRBs

2019 Single burst localisation







Lorimer+07, Burke-Spolaor+11, Thornton+13, Spitler+14, Petroff+15, Spitler+16, Ravi+16, Caleb+17, Farah+18, Chatterjee+17, Bhandari+18, Shannon+18, CHIME+19, Bannister+19, Ravi+19

Thank you

CSIRO Space and Astronomy Science
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More about ASKAP FRBs
See Stuart Ryder's talk