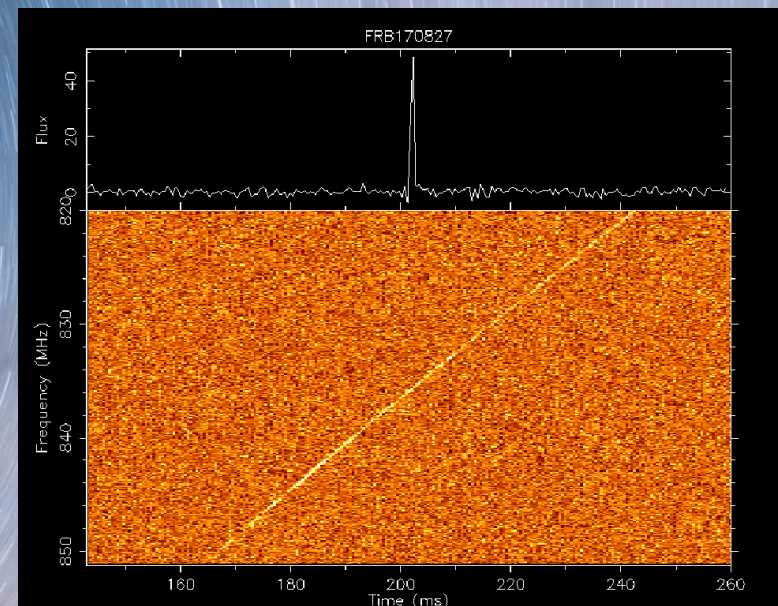
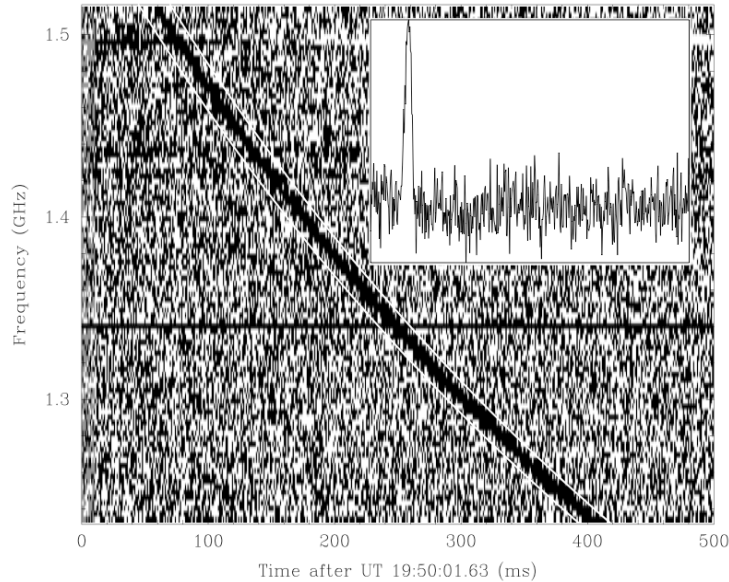


All the latest on Fast Radio Bursts



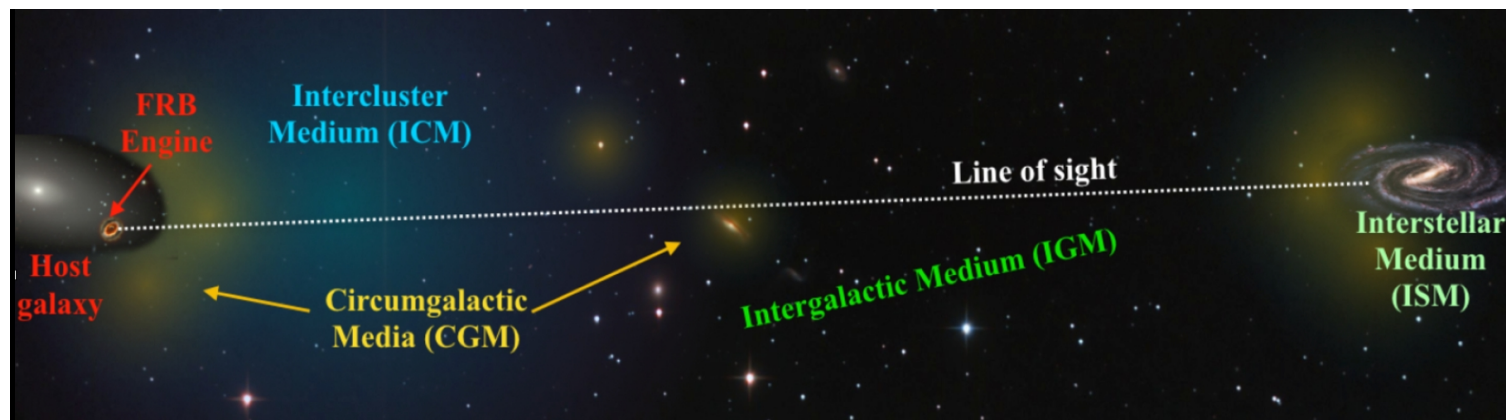
Chris Flynn for UTMOST and CRAFT - Adelaide CTA meeting Nov 2019

FRB basics



The LORIMER BURST (2001 data, published in Lorimer et al. 2007)

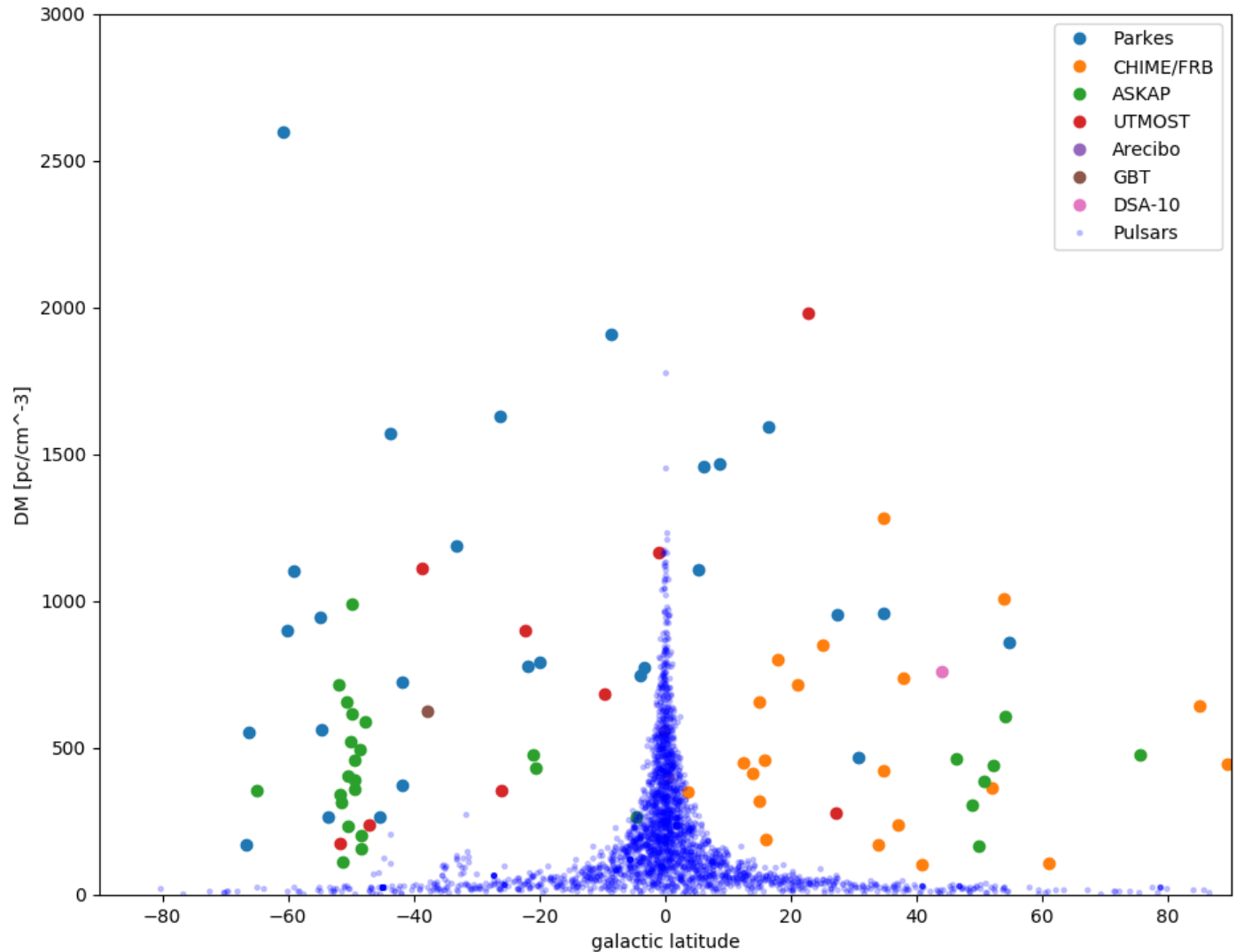
- First seen at Parkes in archival data from 2001
- Bright ms timescale radio bursts
- Highly time dispersed
- At cosmological distances
- ~ 3000 / sky / day at Parkes sensitivity
- Some FRBs repeat
- Not yet seen at other wavelengths
- >50 progenitor theories

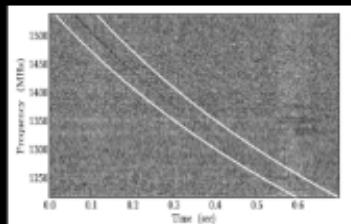


FRBs / pulsars

$$DM = \int_0^d n_e dl$$

Dispersion measure (DM) is the integrated column density of electrons along the line of sight



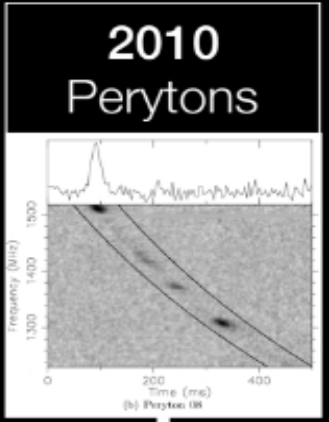
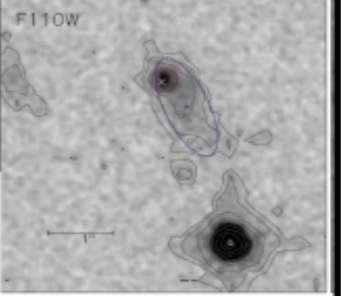


2014
Arecibo
detection

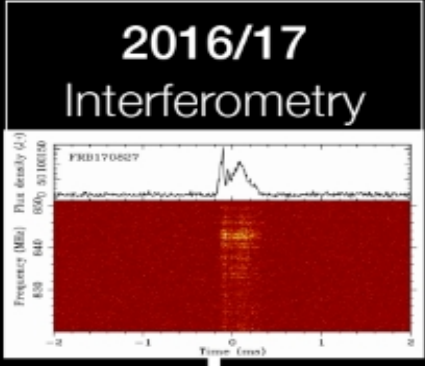
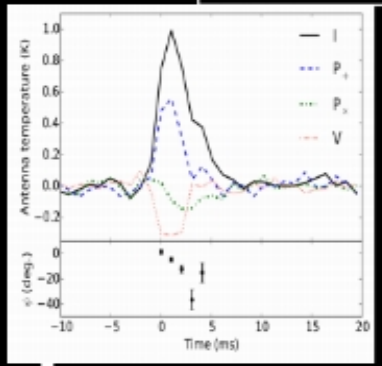
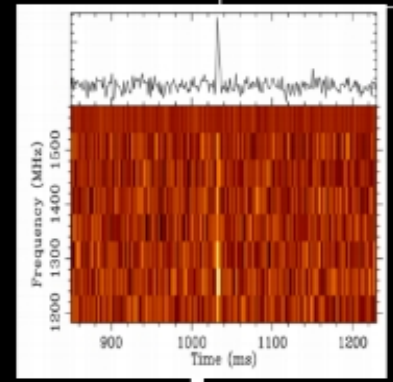
2015
Real-time
detection

2015
GBT, Faraday
rotation

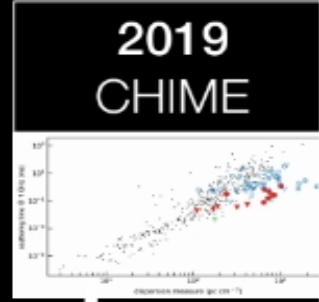
2017
Repeater
localization
2018
Environment



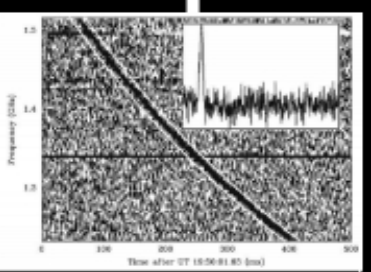
2010
Perytons



2016/17
Interferometry

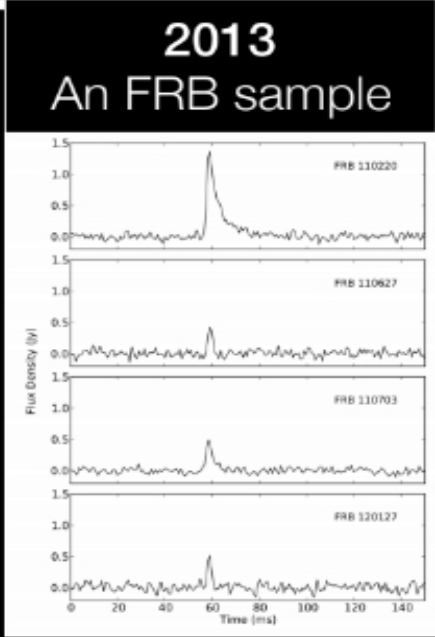


2019
CHIME

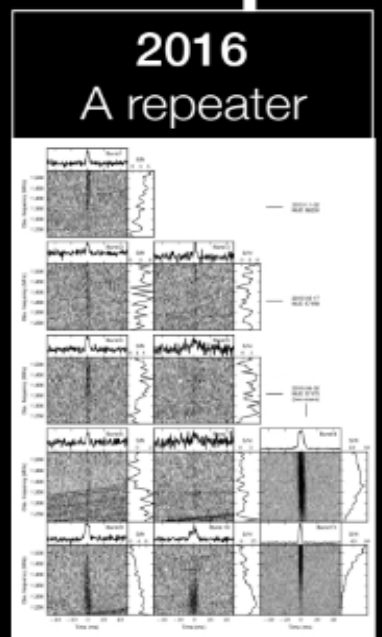


2007
The first FRB

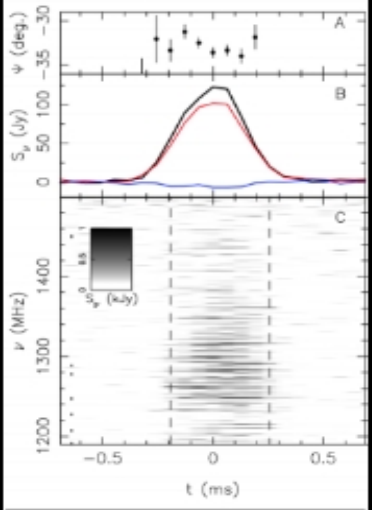
Primer+07, Burke-Spolaor+11,
Thornton+13, Spitler+14,
Petroff+15, Spitler+16, Ravi+16,
Caleb+17, Farah+18,
Chatterjee+17, Michilli+18,
Shannon+18, CHIME+19



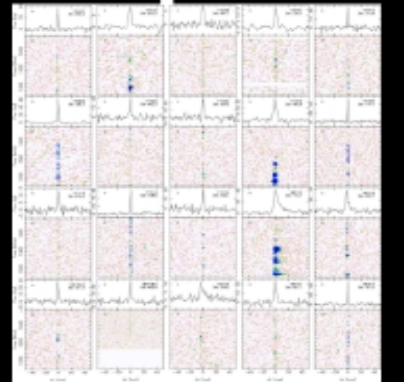
2013
An FRB sample



2016
A repeater



2016
Bright FRBs



2018
ASKAP FRB
population

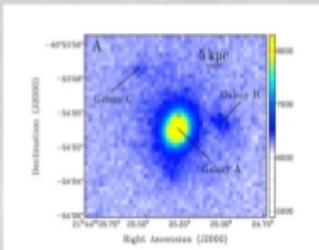
The FRB Times

27 NOV 2019

Host galaxy localised for the first time from a single FRB burst

By CRAFT TEAM

For the first time since FRBs were discovered, a host galaxy has been found from a single burst – all due to the radio collecting power of a telescope array in the remotest Australian Outback. And there are more coming!



~90 FRBs now published from Parkes, Arecibo, GBT, Molonglo, ASKAP, CHIME and DSA-10.

CHIME : ~250 FRBs announced Feb 2019, many repeaters. FRBs seen down to 400 MHz.

Three host galaxies from single FRB bursts localised mid 2019 (ASKAP, DSA-10)

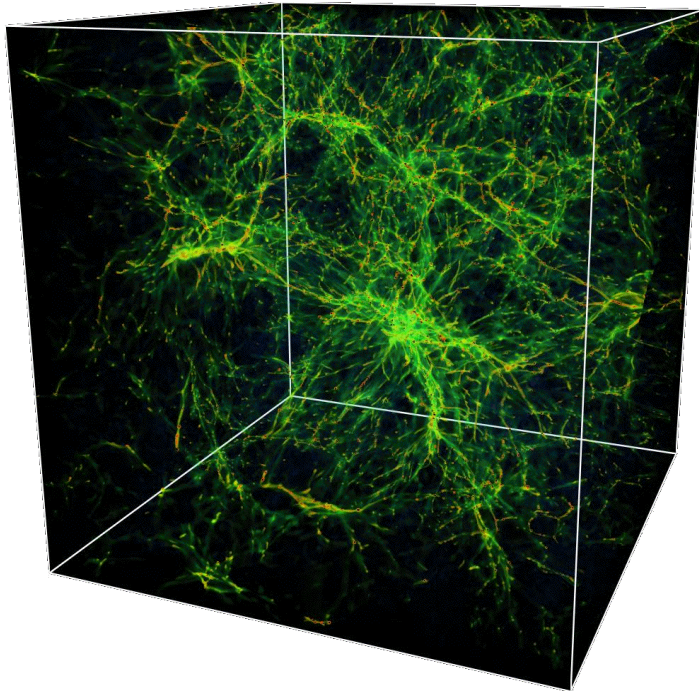
More host galaxies of FRBs localised by ASKAP – talk by Clancy James, this meeting.

The DM-z relation is emerging, in particular for $z < 1$.

First CRAFT repeating FRB has been found (Kumar et al in press).

Very high time resolution being achieved through "voltage capture" with live FRB detections at Molonglo and ASKAP.

FRBS probe the Intergalactic Medium



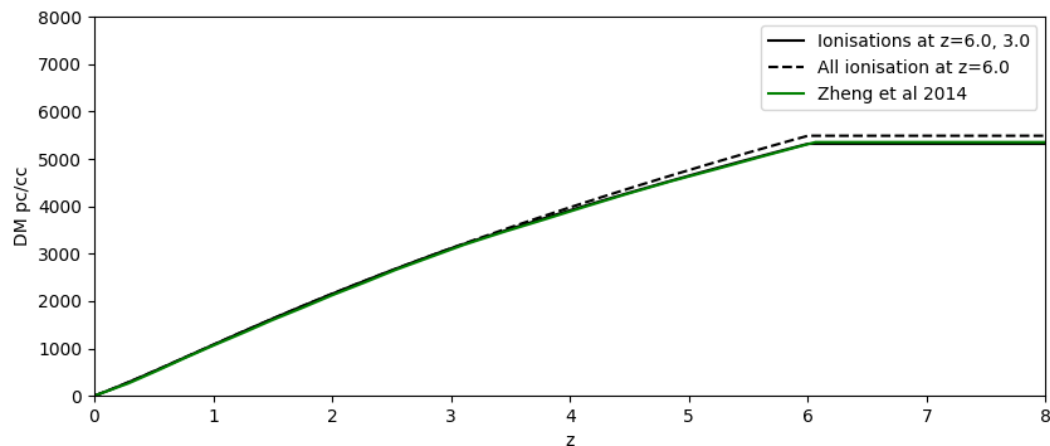
Use FRBs to:

Weigh the universe's baryons!

Probe ionisation state / magnetic fields, turbulence of the IGM

7 host galaxies have been found at latest count (Nov 19)

DM-z relation emerging at lowish redshift ($z < 1$) – Clancy James, this conference



Probing Helium reionization with FRBs
Caleb et al 2019

26 FRBS at Parkes – HTRU and SUPERB surveys

Bhandari et al 2018

New FRB discoveries and their follow-up

4 *S. Bhandari et al.*

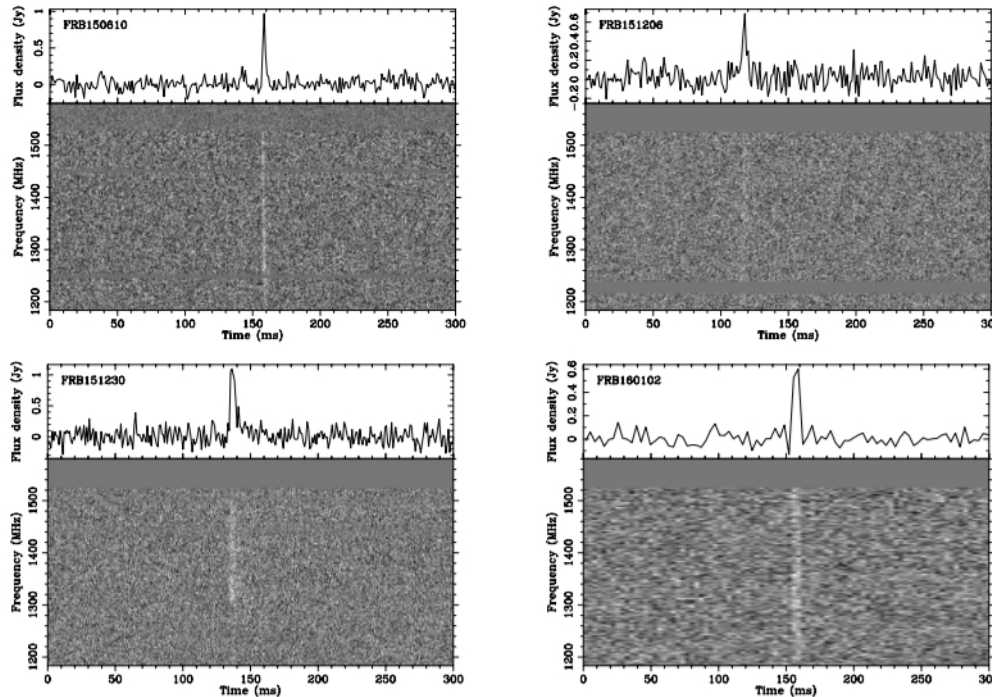


Figure 1. The pulse profiles of the four new FRBs de-dispersed to their best-fitting DM values: clock-wise from top left FRB 150610, FRB 151206, FRB 160102 and FRB 151230. The top panel shows the time series, frequency averaged to one channel and the bottom panel shows the spectrum of the pulse. The 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.

A handful of FRBs are possibly reaching beyond redshift 2

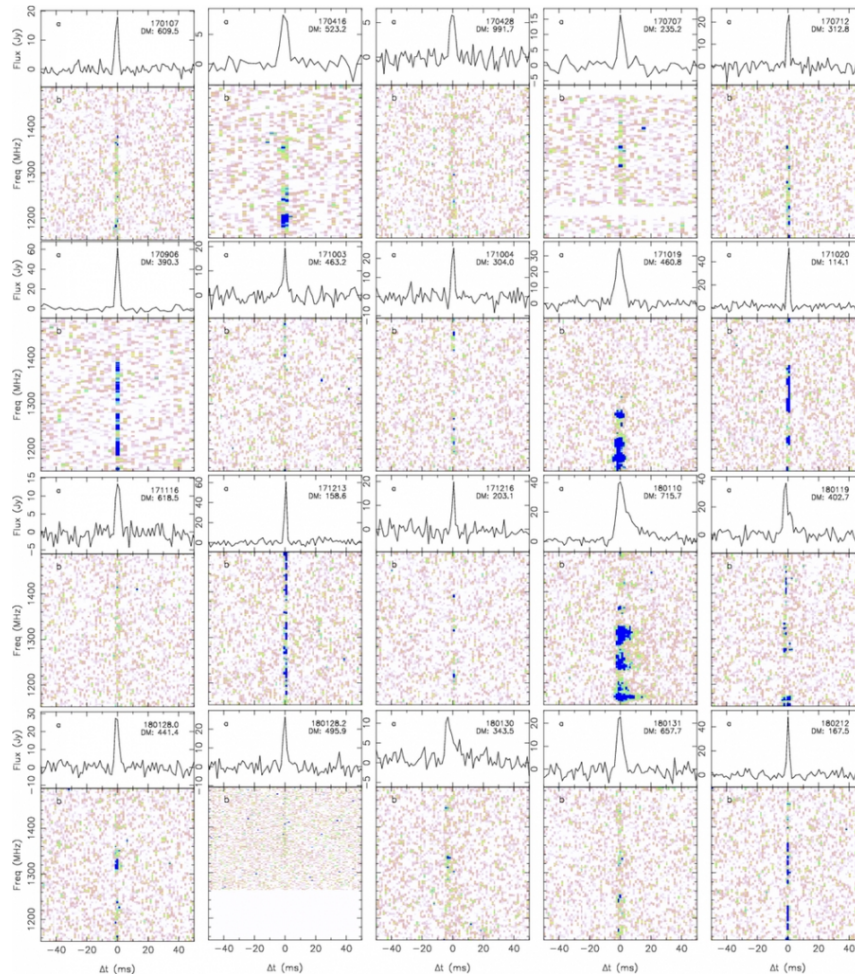
Great range of spectral and temporal properties

Energy at source $\sim 10^{34}$ Joules

Power 10^{36} W



22 ASKAP FRBs



Found in **fly's eye mode**

Same frequency as Parkes (L-band)

22 FRBs

Many are **patchy**

Rate ~ 30 sky/day

For fluence > 22 Jy ms

Shannon et al Nature 2018



CHIME – November 2018

Report 13 new FRBs

Seen down to 400 MHz

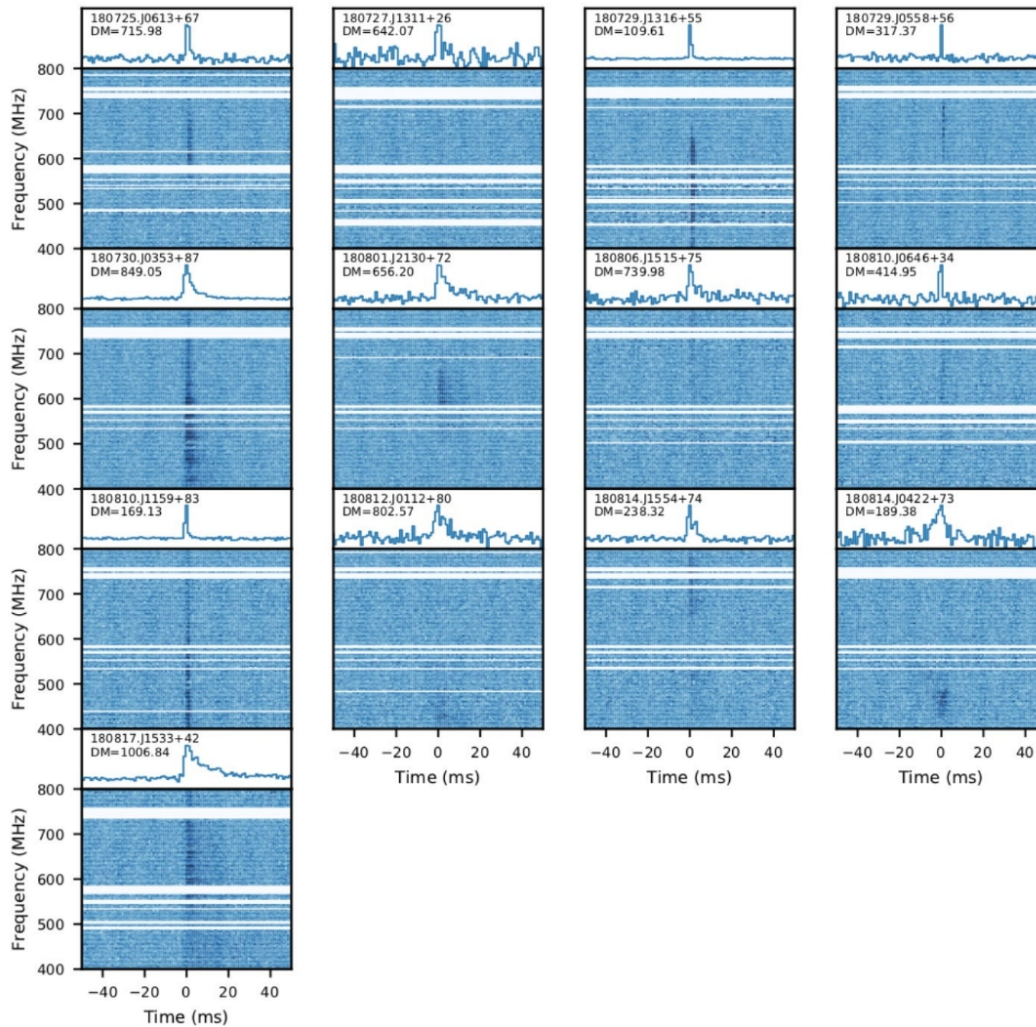
Patchy spectra

Some narrow even at 400 MHz

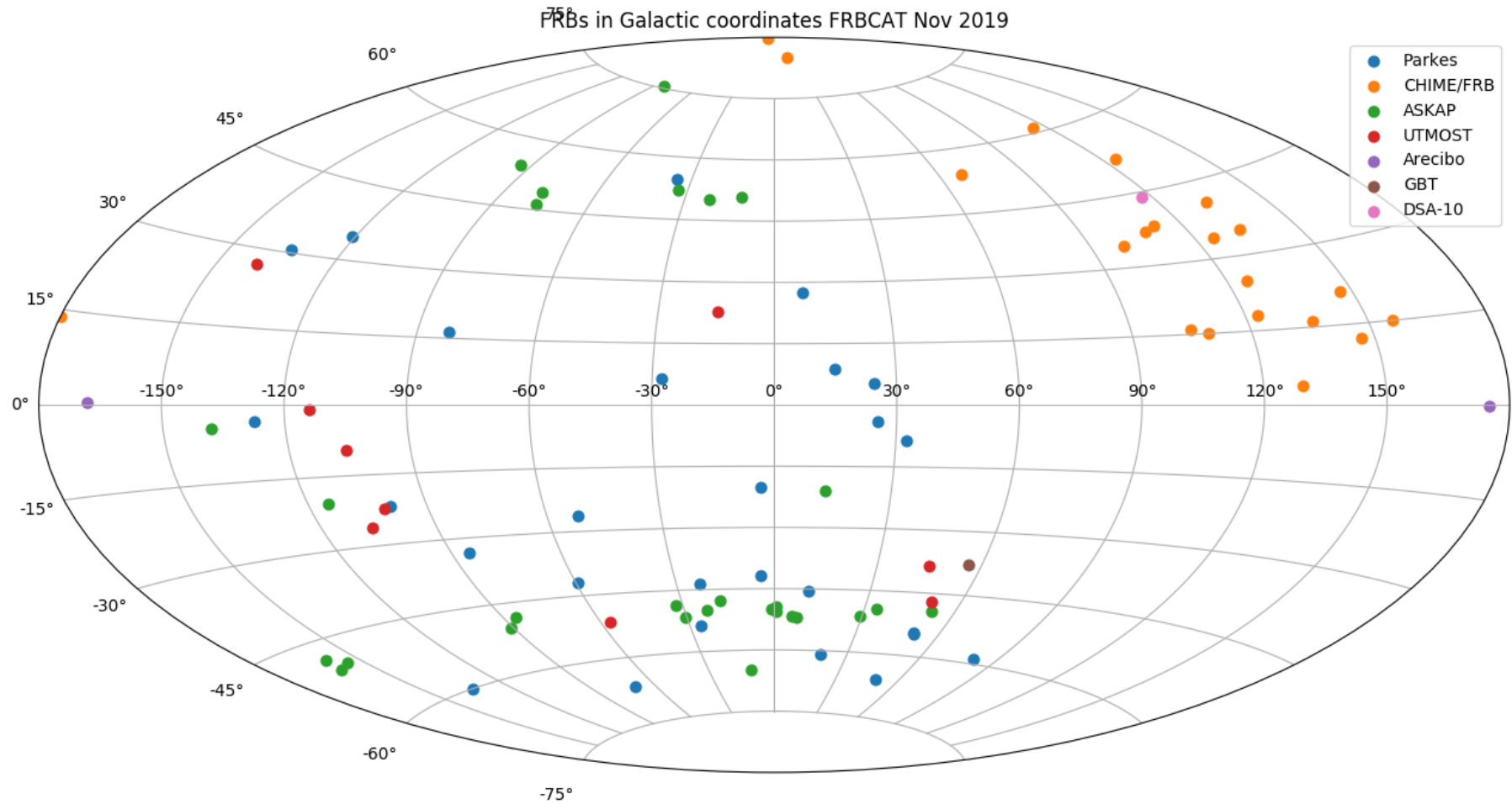
Very high discovery rate -
several per day

1 DM > 3000 p/cc

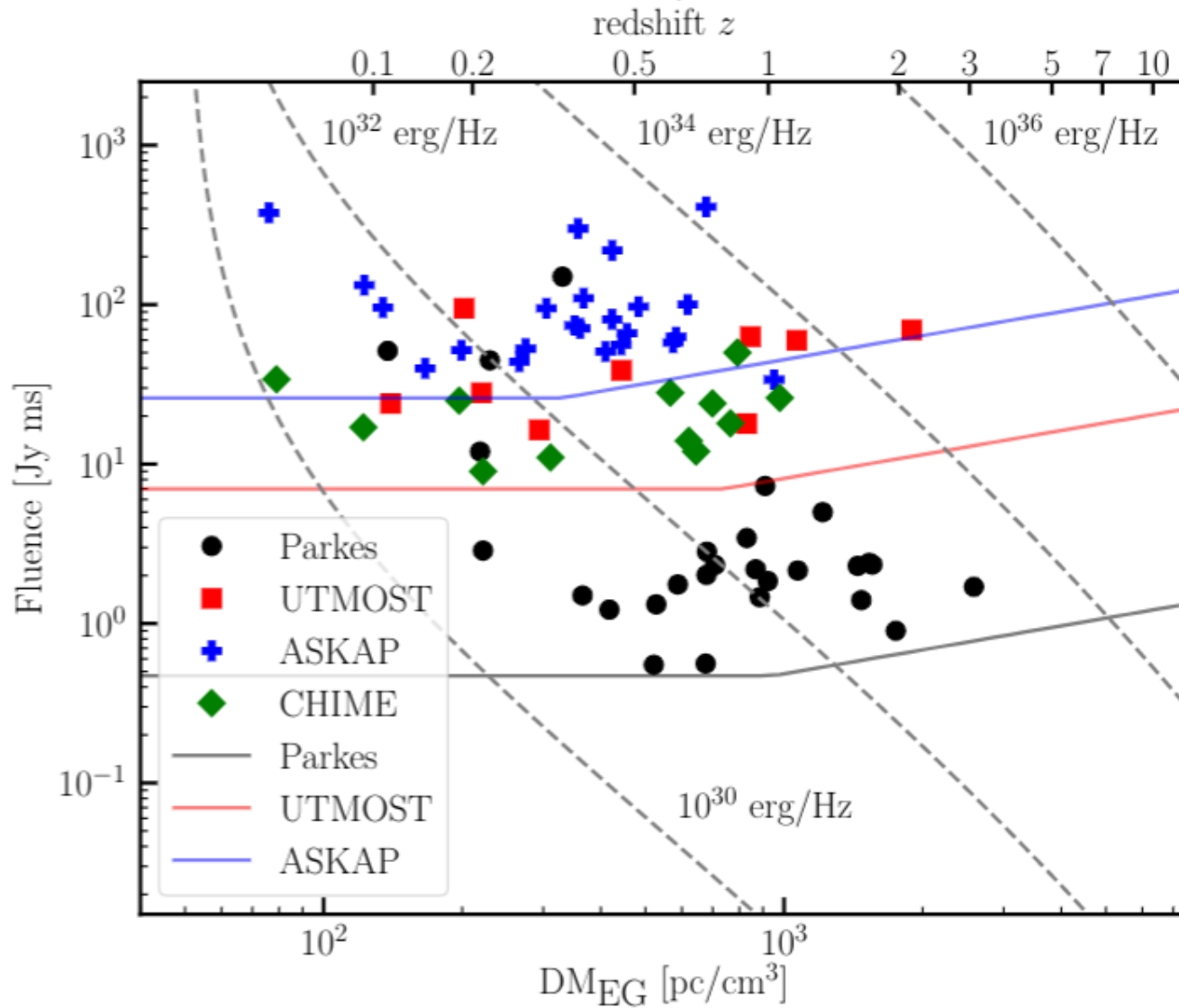
Feb 2019 – 250 FRBs
announced, and ~13
repeaters



FRB sky distribution is isotropic

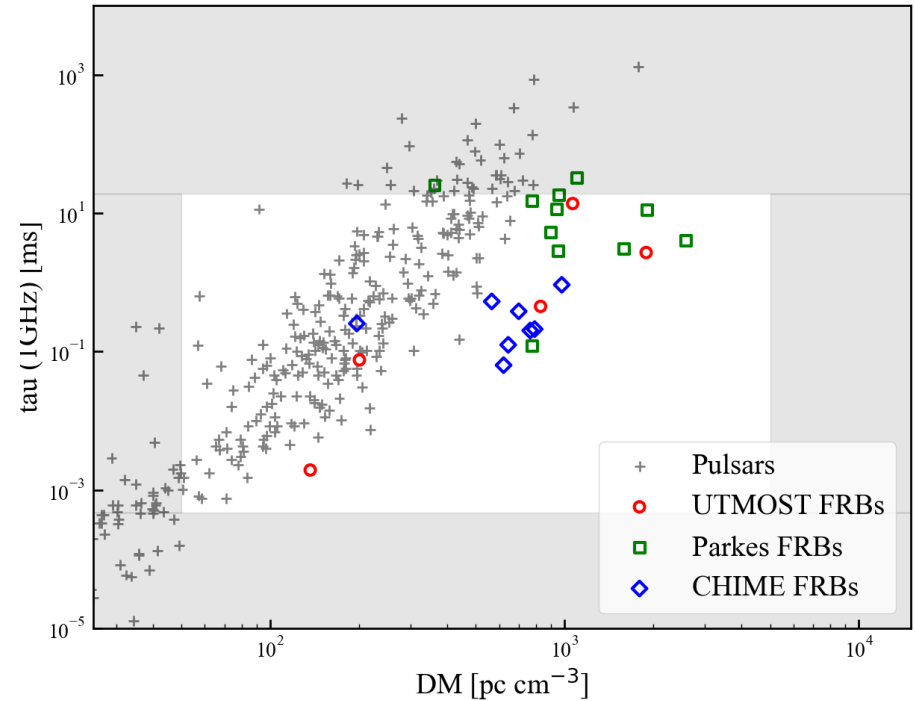
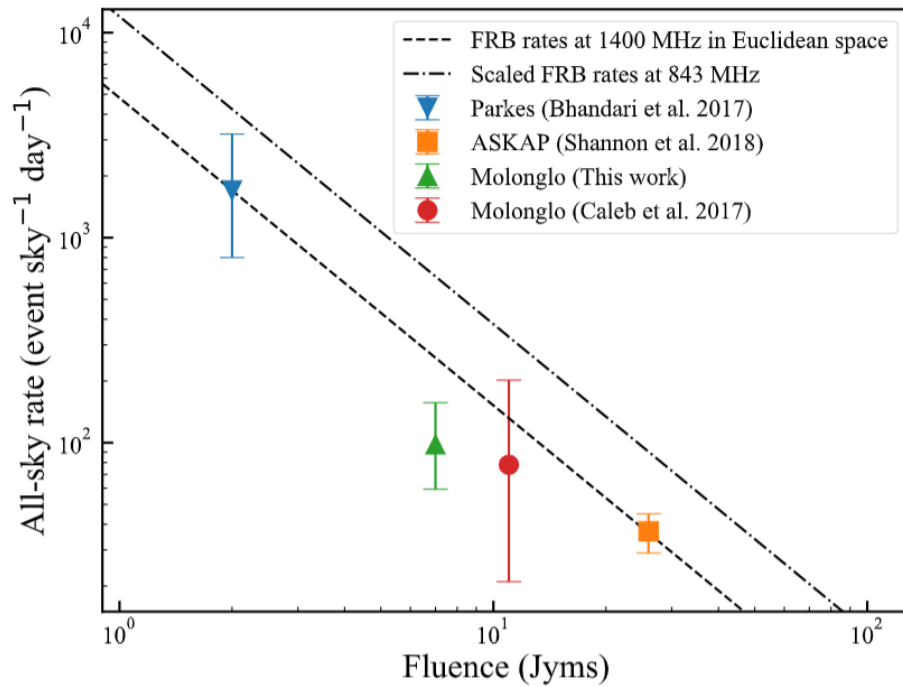


FRB luminosity DM relation



Farah et al 2019

FRB rates and FRB scattering



FRB rate appears low at 843 MHz

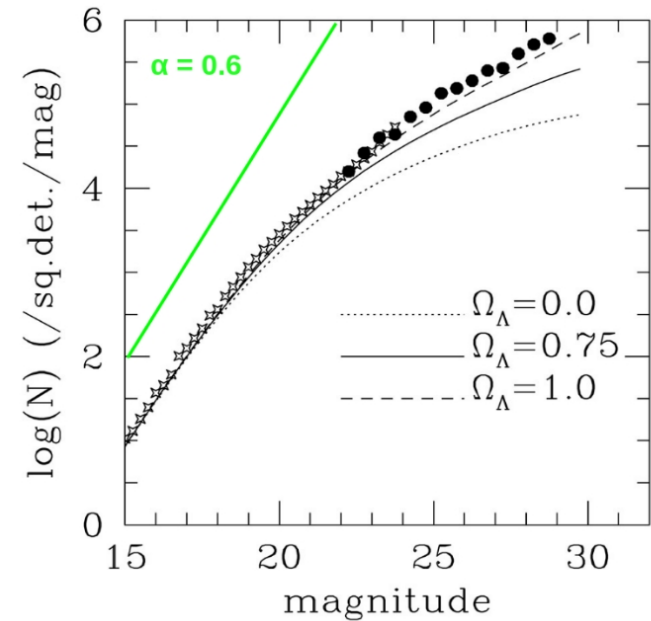
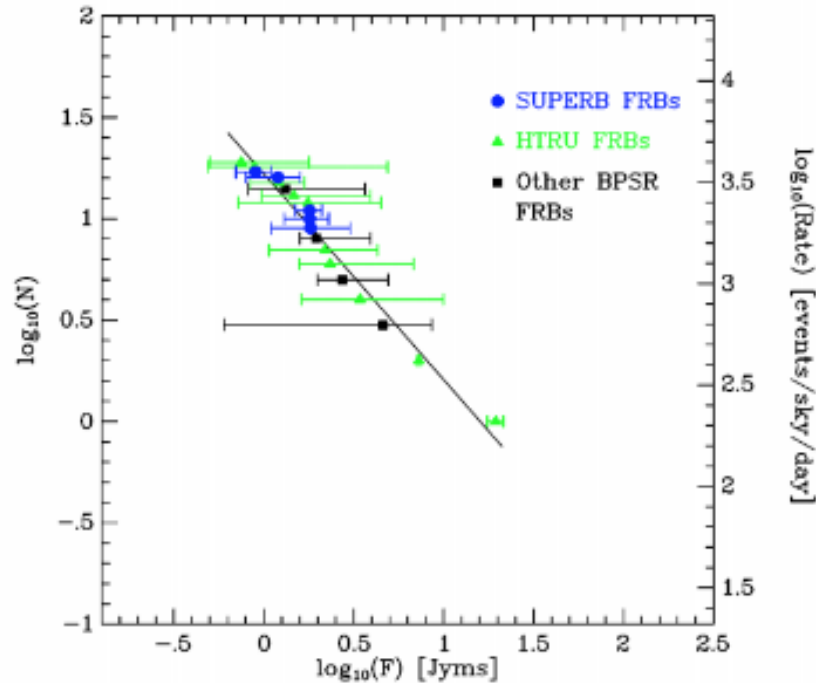
Do FRB spectra turn over at ~ 1 GHz?

Farah et al 2019



FRB source counts

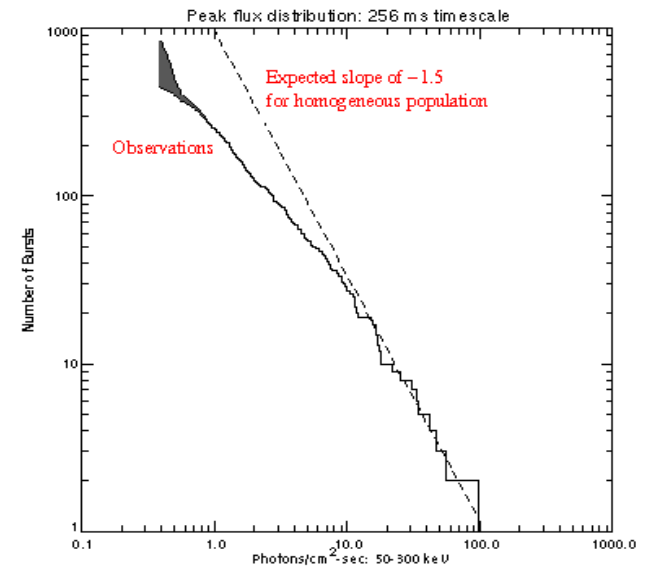
Bhandari et al 2017



Parkes FRBs counts consistent with "standard"-ish candles in LCDM

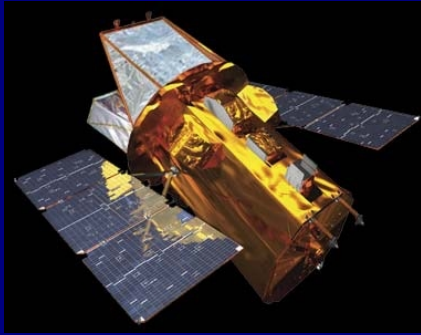
ASKAP FRBs are consistent with this view

Spectral properties are a problem

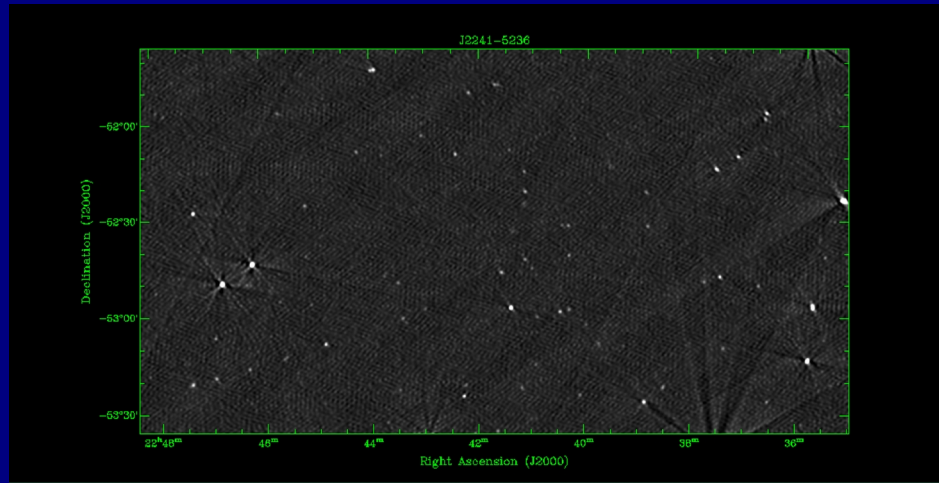


CHIME will clean up on logNlogS

Parkes real time FRB follow-ups



Subaru
Keck
GBT
SkyMapper
Arecibo
VLA
ATCA
Zadko
Swift
GMRT
Molonglo
IceCube



Shivani
Bhandari's
PhD

Now at CSIRO

Nothing at any other wavelength yet in followup:-(

Deeper Wider Faster might catch an FRB live



Single dishes mean poor FRB localisation on the sky - use telescope arrays.

Interferometers that are finding FRBs:

UTMOST – wide FoV, being upgraded to ~ arcsec localisation

VLA – mas localisation, tiny FoV

ASKAP – very wide FoV, sub-arcsec localisation

CHIME – huge FoV, few arcmin localisation

DSA-10 – few arcsec localisation, good FoV, low sensitivity

**Coming :
MeerKat, LOFAR**



Australian
National
University



THE UNIVERSITY OF
SYDNEY

The Australian Square Kilometre Array Pathfinder

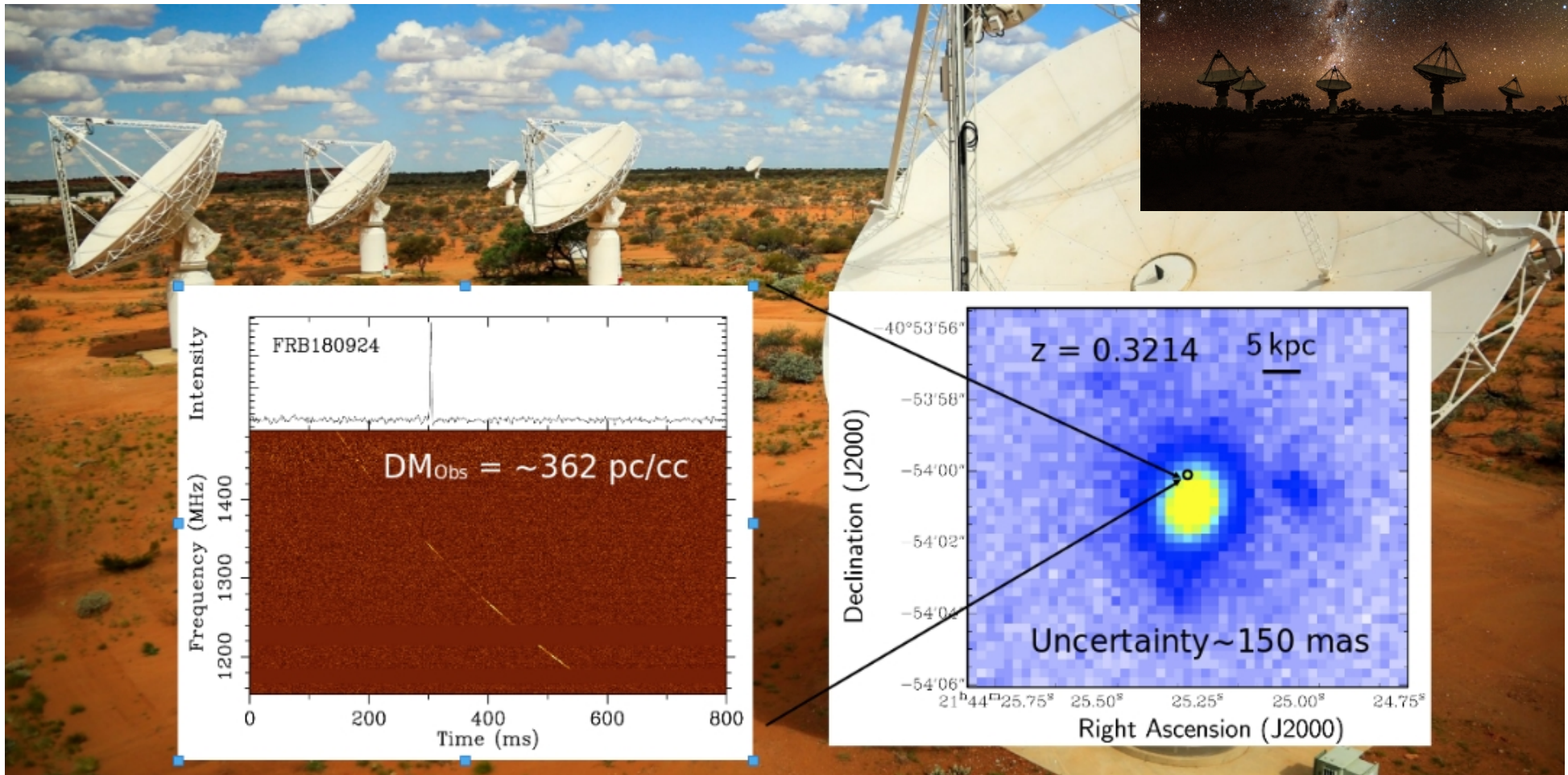
- ❖ 36 12-m dishes
- ❖ Max baseline: 6km
- ❖ Phased Array Feed (PAF)
 - ❖ 36 individual “beams” on the sky
- ❖ Field of View: 30 sq. deg
 - ❖ i.e., 100x the size of the full moon
- ❖ Location: MRO in WA
 - ❖ Radio quiet!



First single burst localised to a galaxy

28 ASKAP dishes

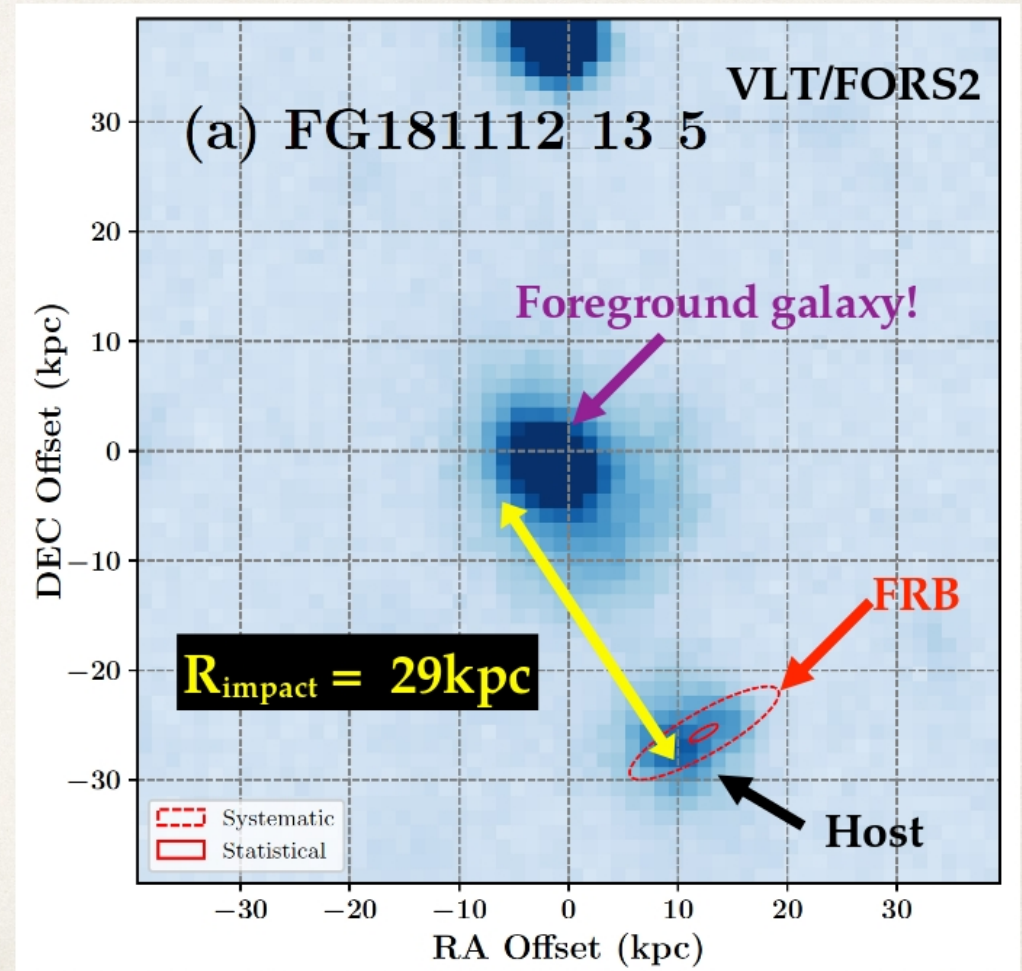
Early type, L^* galaxy redshift 0.32 low SFR



Bannister et al Science 2019

FRB 181112

- ❖ Astrometric precision \sim a few arcsec
- ❖ Host galaxy redshift = 0.4755
- ❖ The host is similar to FRB180924's host
 - ❖ One-off burst hosts different from repeater hosts?
- ❖ The burst travels through a foreground galaxy halo!
 - ❖ $z = 0.3674$
- ❖ Probing the CGM! On sub-ms scales!
- ❖ Very narrow despite all the propagation effects! Not much scattering....

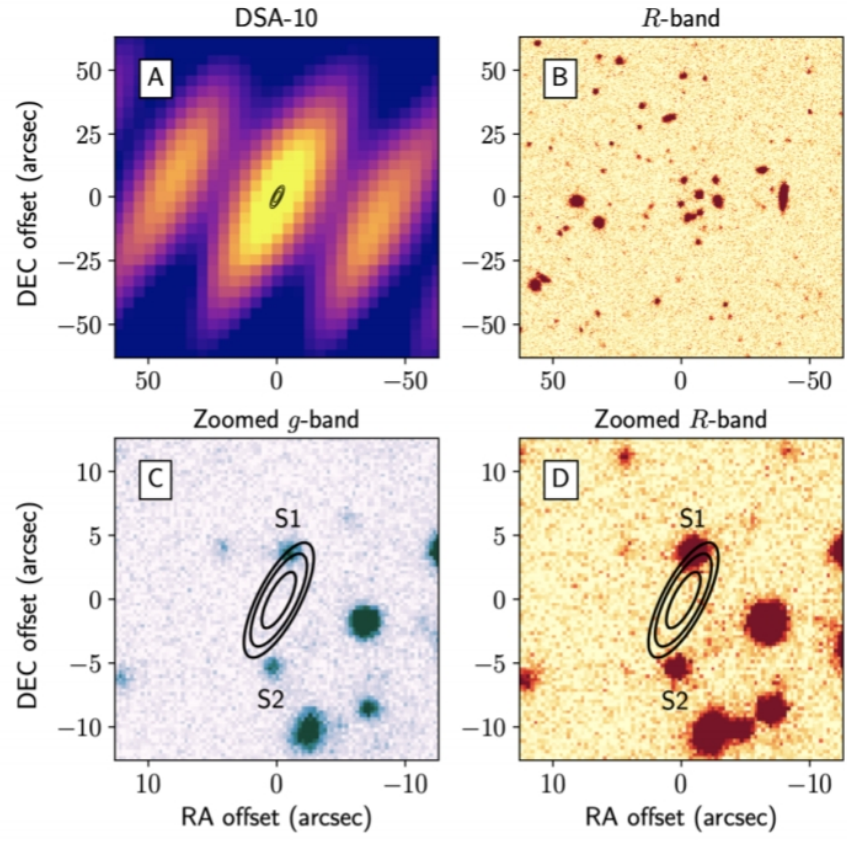
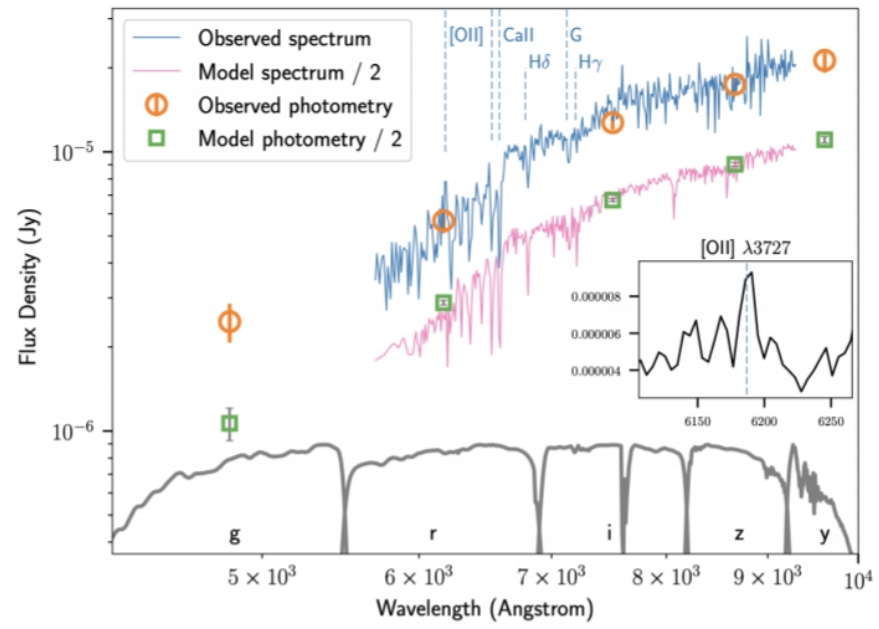
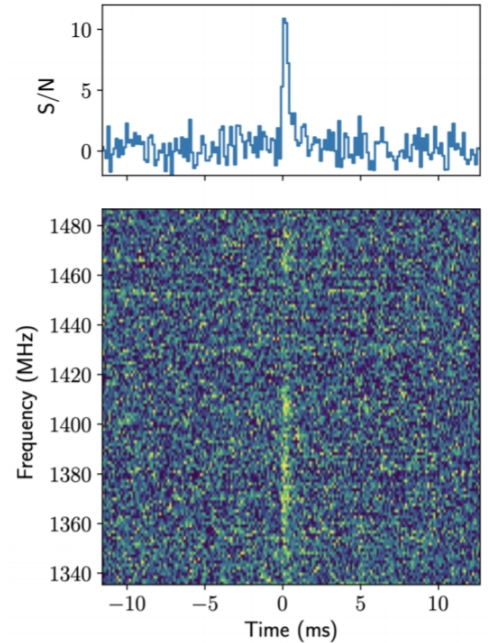


Prochaska et al. (submitted)

DSA-10 localised FRB host galaxy

Ravi et al
2019
Science

Massive
host
galaxy, old
stellar
population



UTMOST and UTMOST-2D

Mills cross

One operational arm

1.6 km x 12 m

843 MHz

31 MHz bandwidth

10 square degrees FoV

$S_{\text{lim}} \sim 7 \text{ Jyms}$

Live FRB detection

Voltage triggering

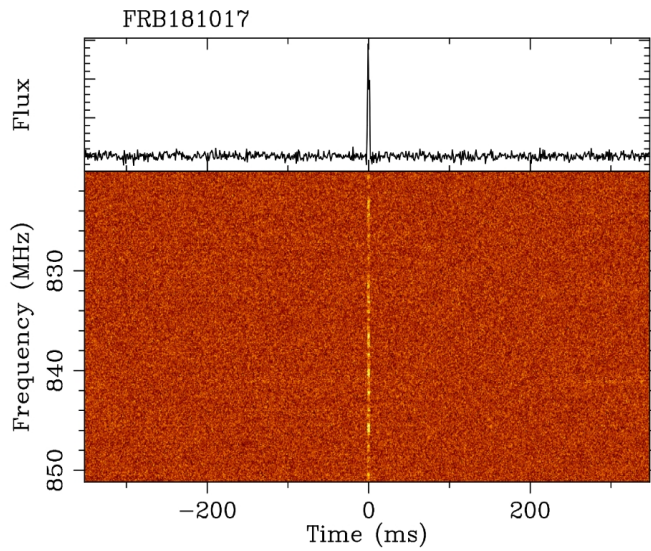
FRB candidates
require human
verification

Localisation
accuracy:

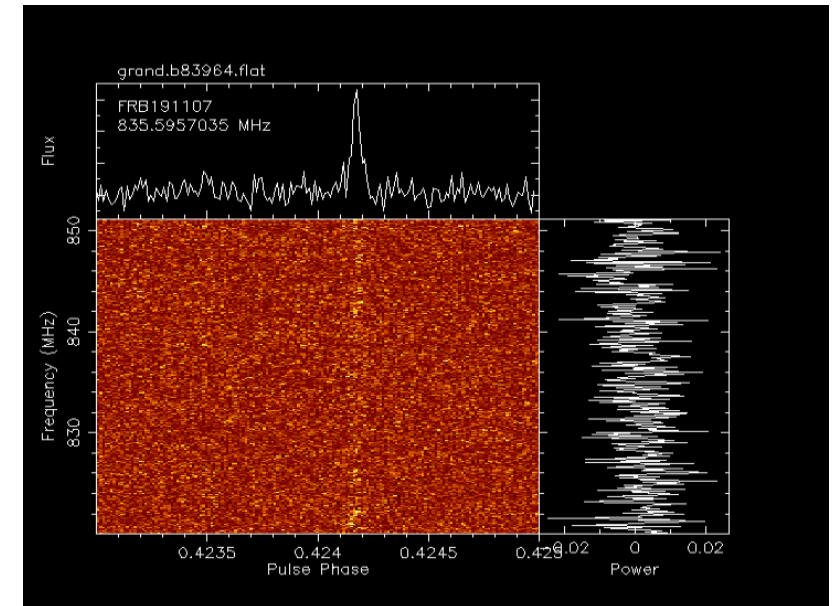
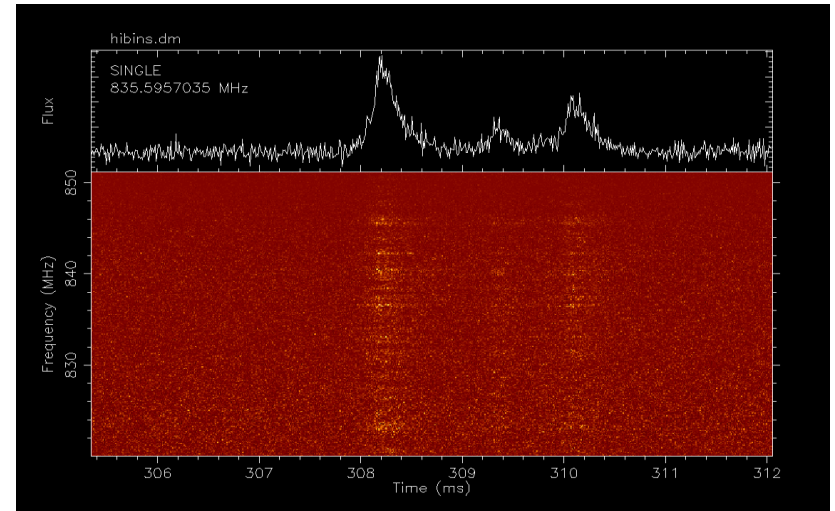
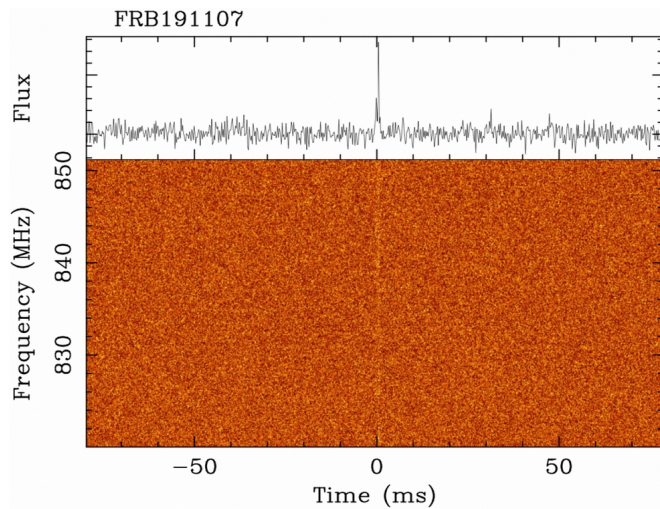
5 arcsec EW
2 degrees NS



Some UTMOST FRBs

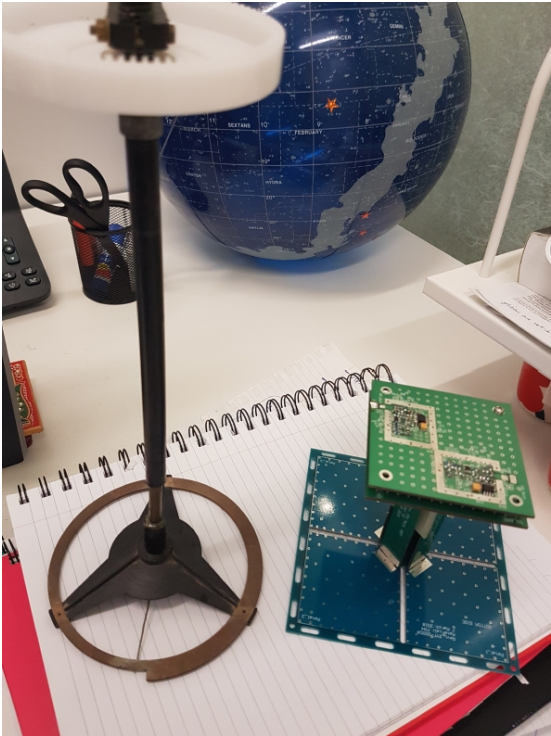
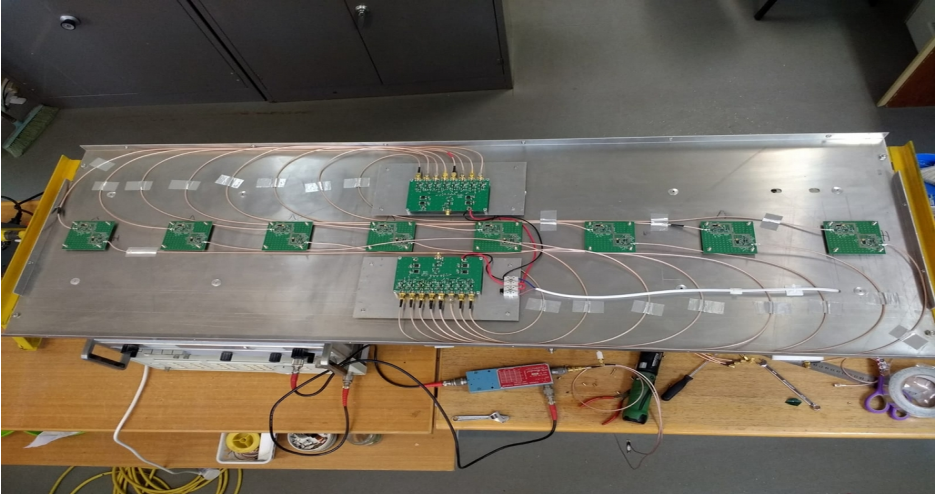


**High time
and
frequency
resolution**

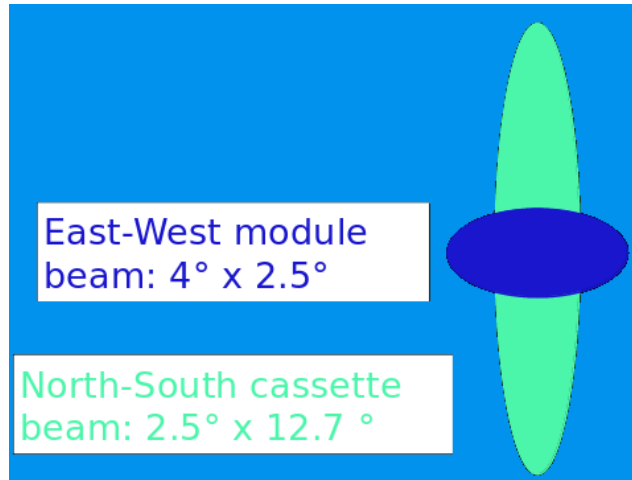


**Skinniest FRB yet – few x 10 usec
Triggered HESS followup a few hrs after the event
(human verification still needed)**

Refitting the Molonglo North-South arm



Refitting the Molonglo North-South arm



Triple our field of view

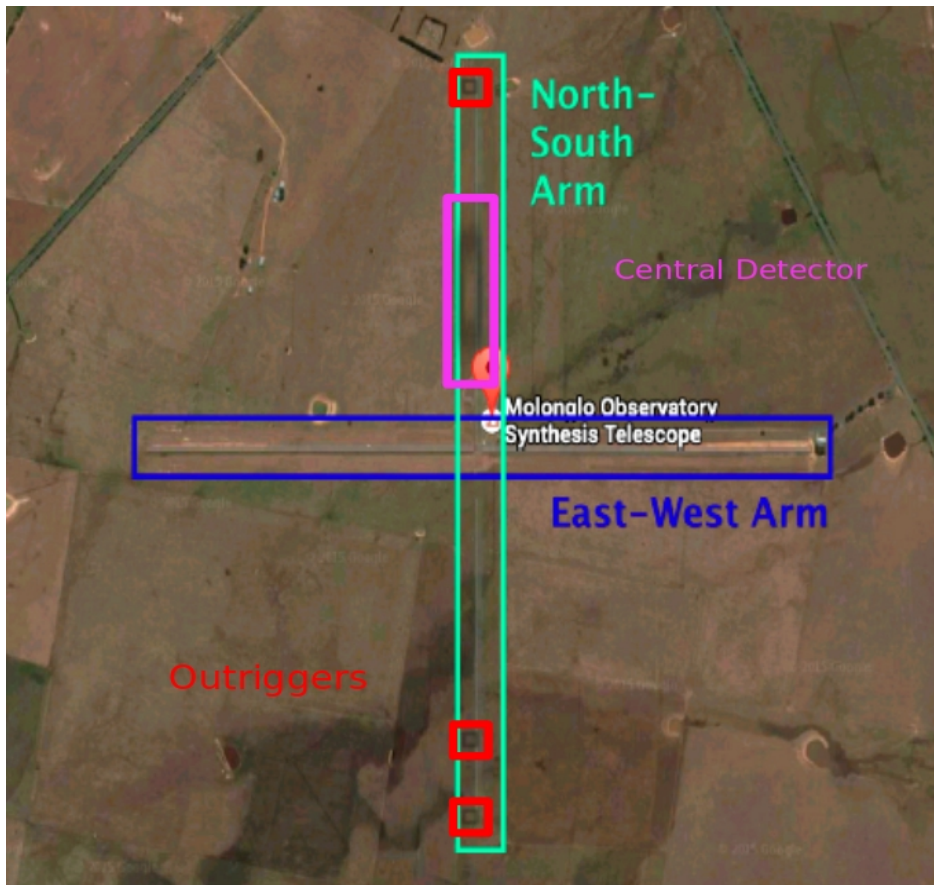
Triple our bandpass

Get both polarisations

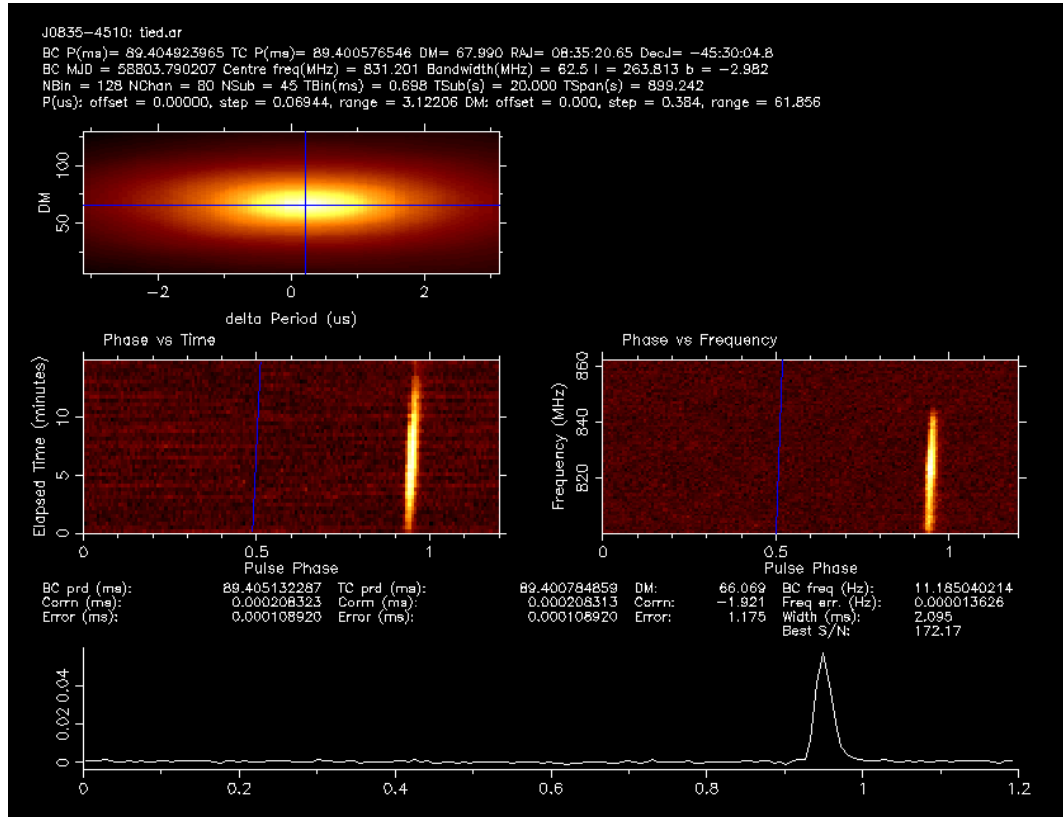
Reduced Tsys by factor of three

2 degree overlap region for localising FRBs

Localisation to a few arcsec



Refitting the Molonglo North-South arm



Nov 2019 : First observations operating as a (2-element) array.

This morning : first dual pole observations !



12 to 24 month prospects

Apparent luminosity counts distribution ($\log N \log S$)

Spectral index / average spectral properties of FRBs

10 – 20 host galaxies localised from single bursts

5 – 10 host galaxies of repeaters localised

DM-z relation – scatter, properties of IGM

Host galaxy properties – how important is the host ISM?

DM, RM of repeaters – behaviour on long timescales

High time and frequency resolution of FRBs – clues to progenitors

Properties of the IGM, CGM, galaxy halos

FRBs seen at other than radio wavelengths?