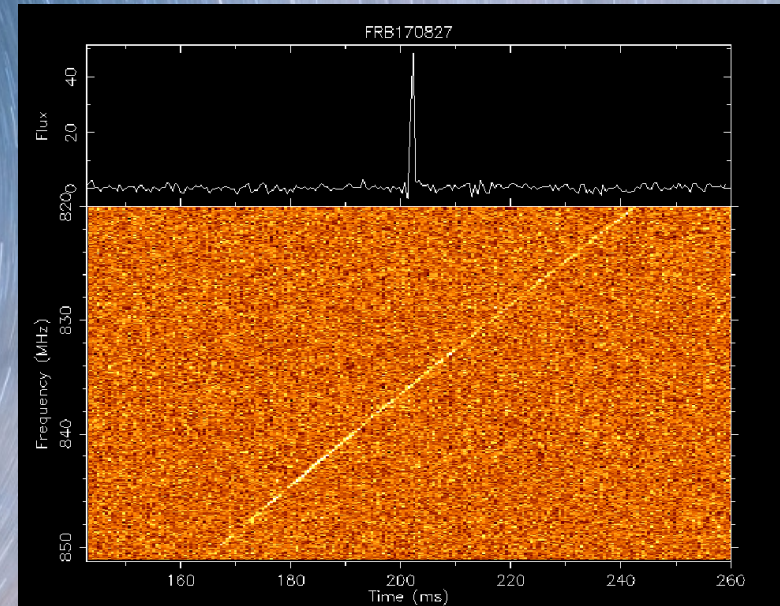


# Fast Radio Bursts

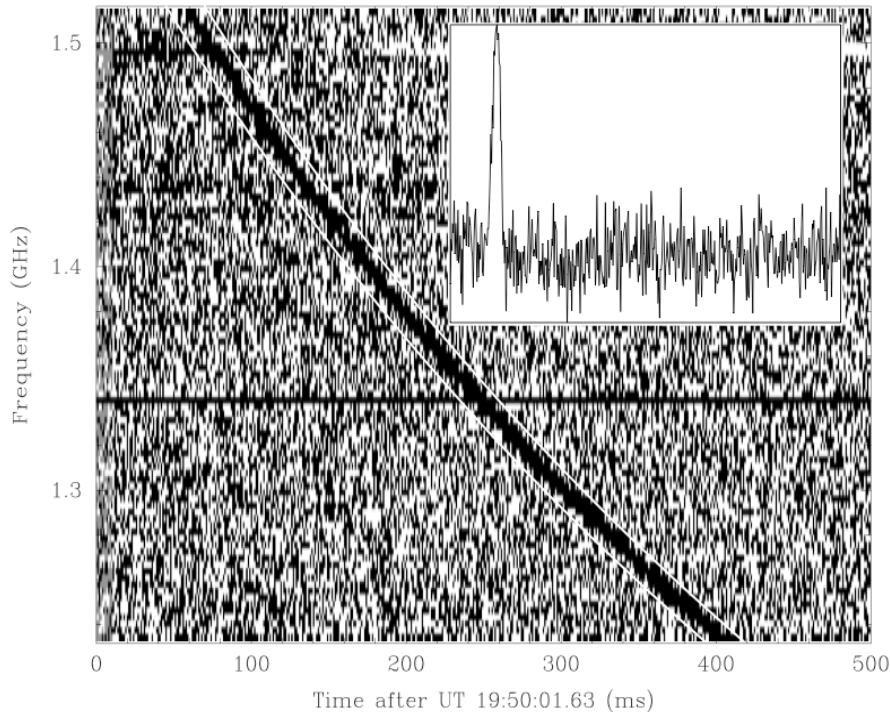


Chris Flynn for Team UTMOST - Sydney CTA meeting April 2019



# FRB basics

- First seen at Parkes in archival data from 2001
- Bright ms timescale radio bursts
- Highly time dispersed
- Of cosmological origin
- ~ 3000 / sky / day at Parkes' sensitivity
- Some FRBs repeat

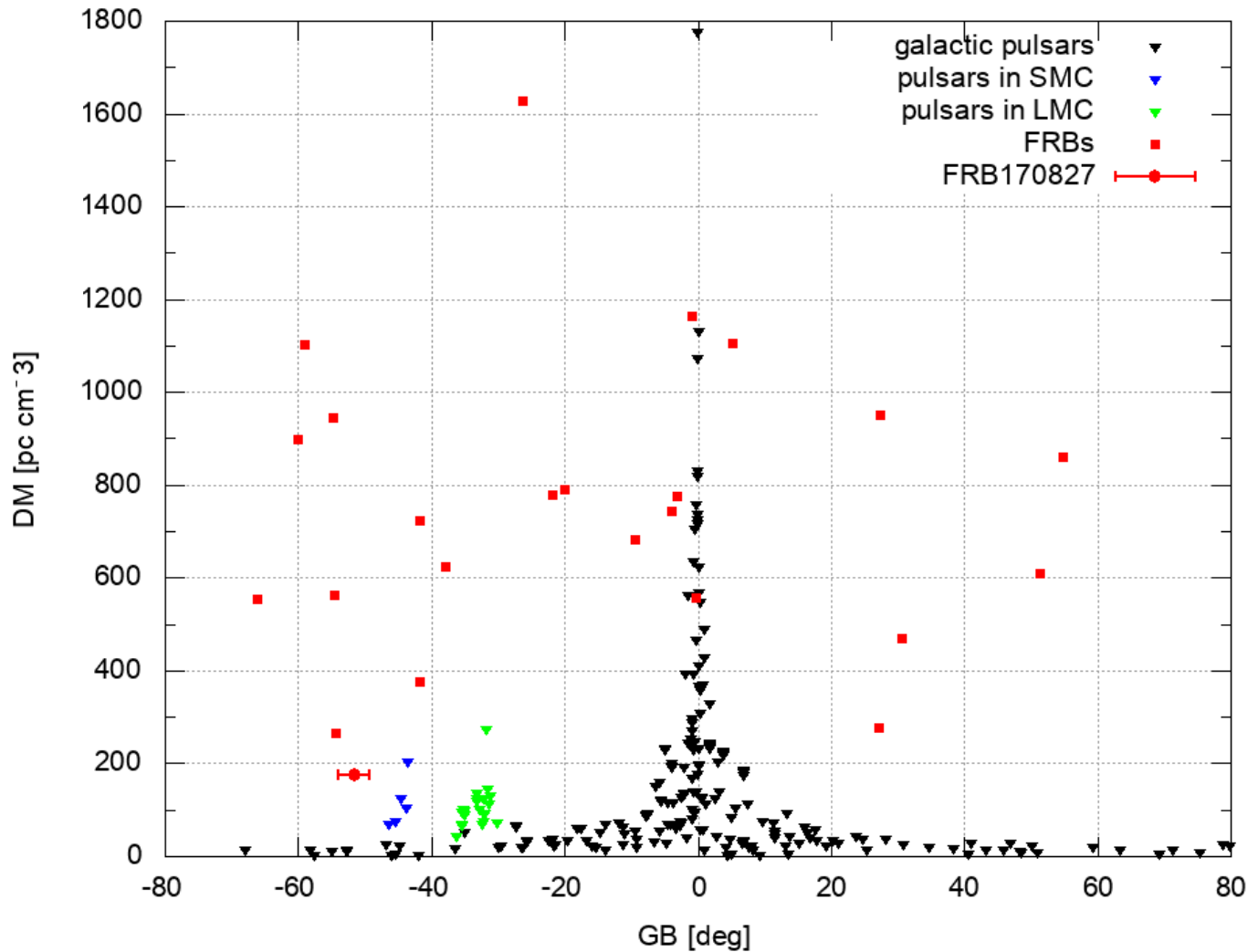


The LORIMER BURST (2001 data, published in Lorimer et al. 2007)

# FRBs / pulsars

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

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



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# Some basics

Sky rate at Parkes ~2500 / sky / day with fluence >2 Jyms

Range of dispersion measures from few 100 to 2500 pc/cc

Occasionally resolved in time with a scatter tail

Two FRBs repeat - **UPDATE Feb 2019 – 13 repeating FRBs**



# Recent developments

~70 FRBs known from Parkes, Arecibo, GBT, Molonglo, ASKAP, CHIME

2018 - 22 FRBs found at ASKAP – Shannon et al, Nature

Coming : ASKAP host galaxies localised – Clancy James, this meeting

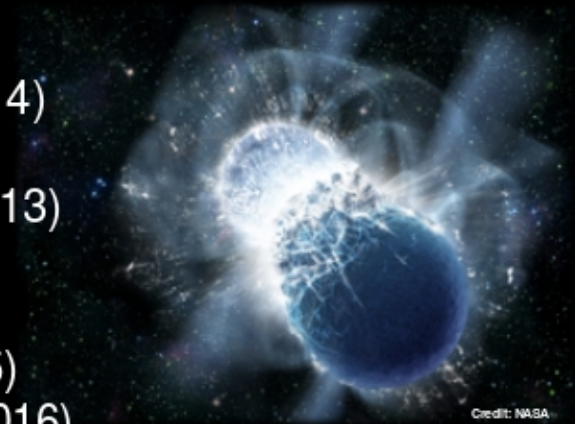
**CHIME : seen down to 400 MHz - 250 FRBs announced Feb 2019**





# Possible Progenitors?

- Collapse of supra-massive neutron stars (Falcke & Rezzolla 2014)
- Merger of binary white dwarfs (Kashiyama et al 2013)
- Merger of two neutron stars (Hansen & Lyutikov 2001, Totani 2013)
- Superconducting cosmic strings (e.g. Vachaspati 2008)
- Evaporating primordial black holes (Rees 1977)
- Dark matter-induced collapse of neutron stars (Fuller & Ott 2015)
- Magnetospheric collapse of a Kerr-Newman black hole (Liu et al. 2016)



## Cataclysmic

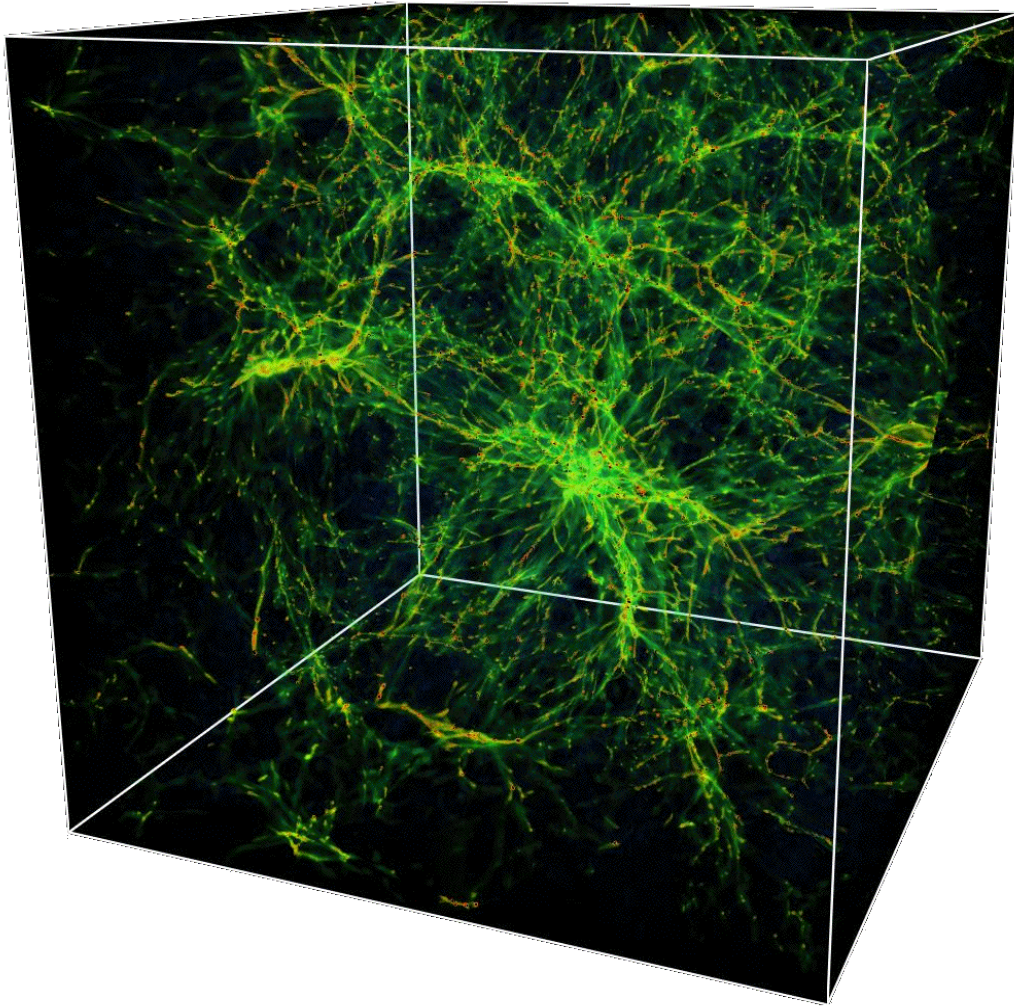
Volumetric Rate  $\sim 10^3$  to  $10^4$  / Gpc<sup>3</sup> / yr



- Flaring stars (e.g. Loeb et al 2013)
- Magnetar radio bursts (e.g. Popov 2007, 2013; Lyubarsky 2014)
- Supergiant pulses from NSs (e.g. Cordes and Wasserman 2016, Lyutikov 2016)
- Pulsar + planet (Mottez & Zarka 2014)
- Pulsar in asteroid field (Dai et al 2016)
- Mass transfer in a WD-NS system (Gu et al 2016)

## Non-Cataclysmic

# Probe of the Intergalactic Medium



**Use FRBs to:**

**Weigh the universe's baryons!**

**Probe ionisation state / magnetic fields, turbulence of the IGM**

**But to do so we need to find host galaxies**



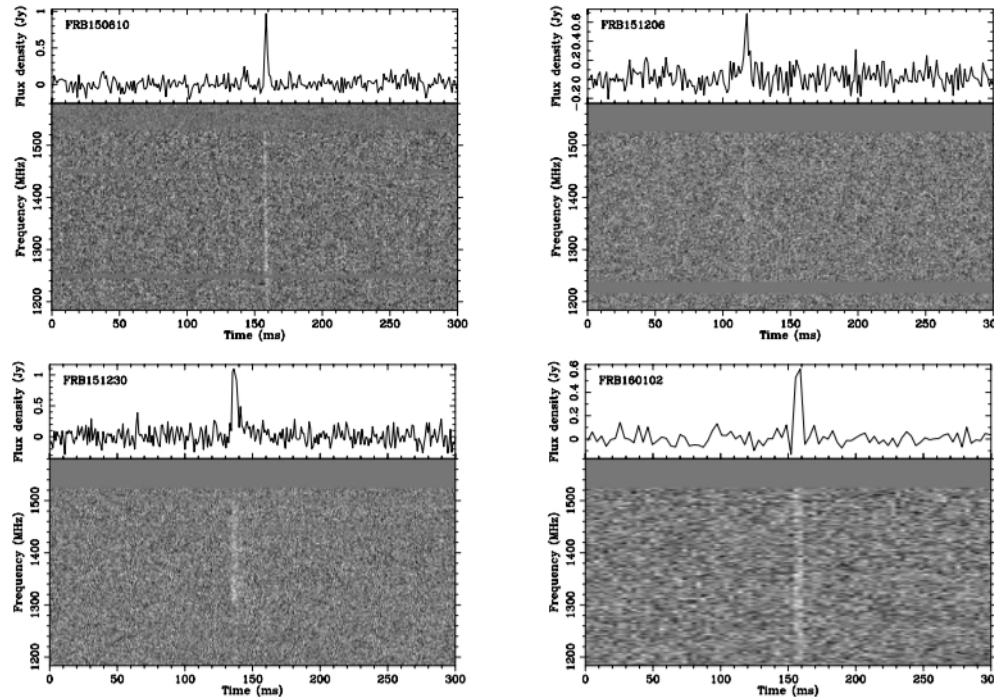


# 26 FRBS at Parkes – HTRU and SUPERB surveys

**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.

**Latest 4 FRBs at Parkes**

**One set the DM record – so potentially at a redshift of  $z > 2$ .**

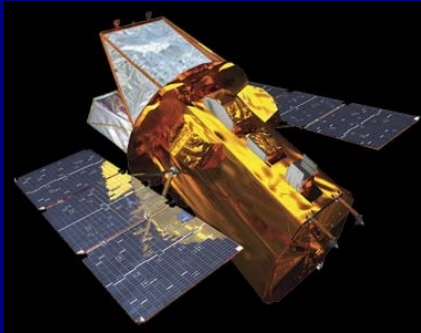
**Great range of spectral and temporal properties**

**Energy at source ~  $10^{34}$  Joules**

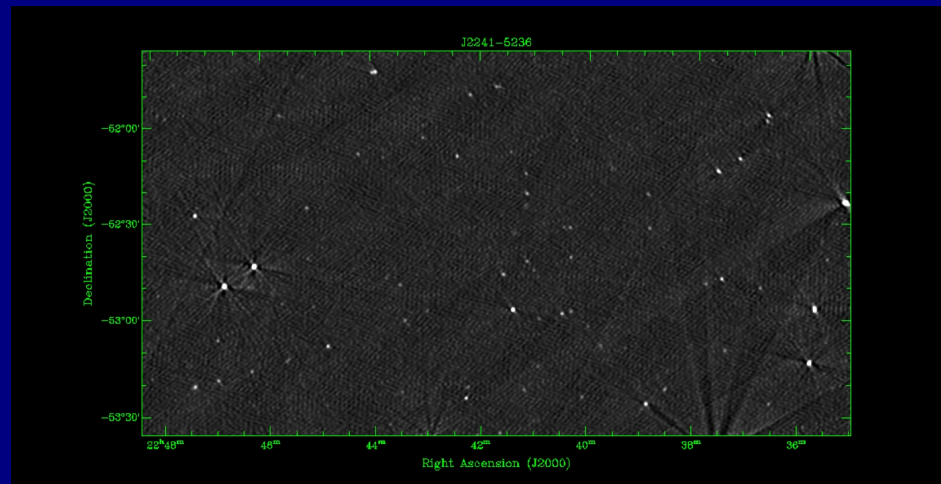
**Power  $10^{36}$  W**



# 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



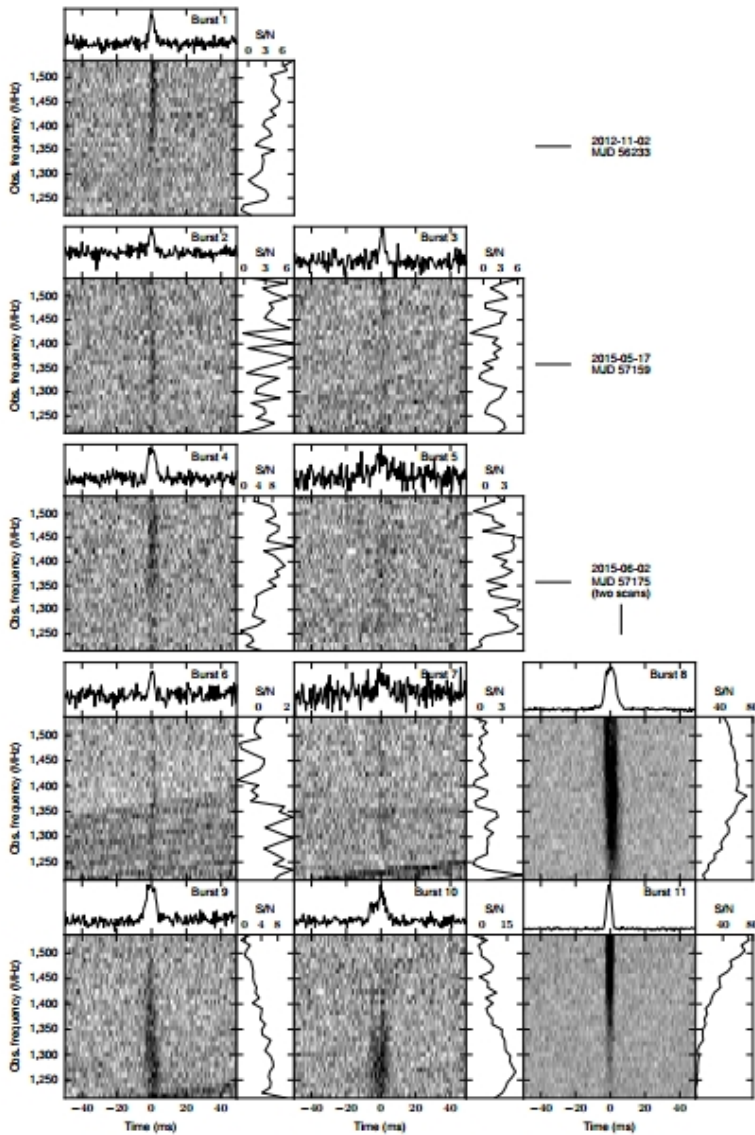
# The "Repeater"

Eleven repeats of the FRB in observations at Arecibo reported in Spitler et al 2016, Nature

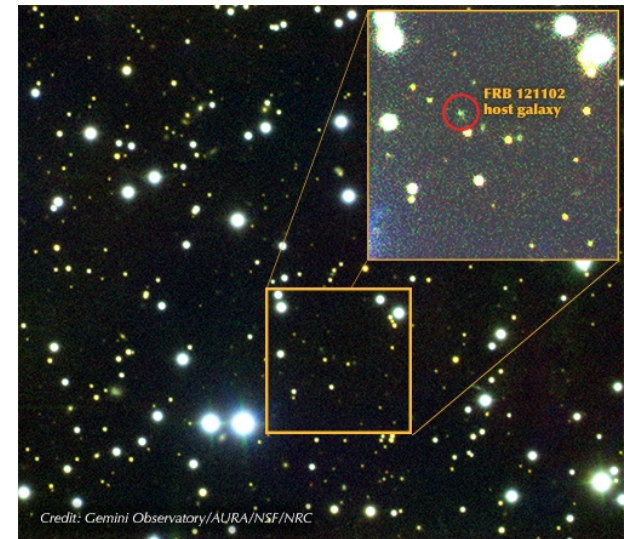
Dwarf host galaxy at  $z \sim 0.19$

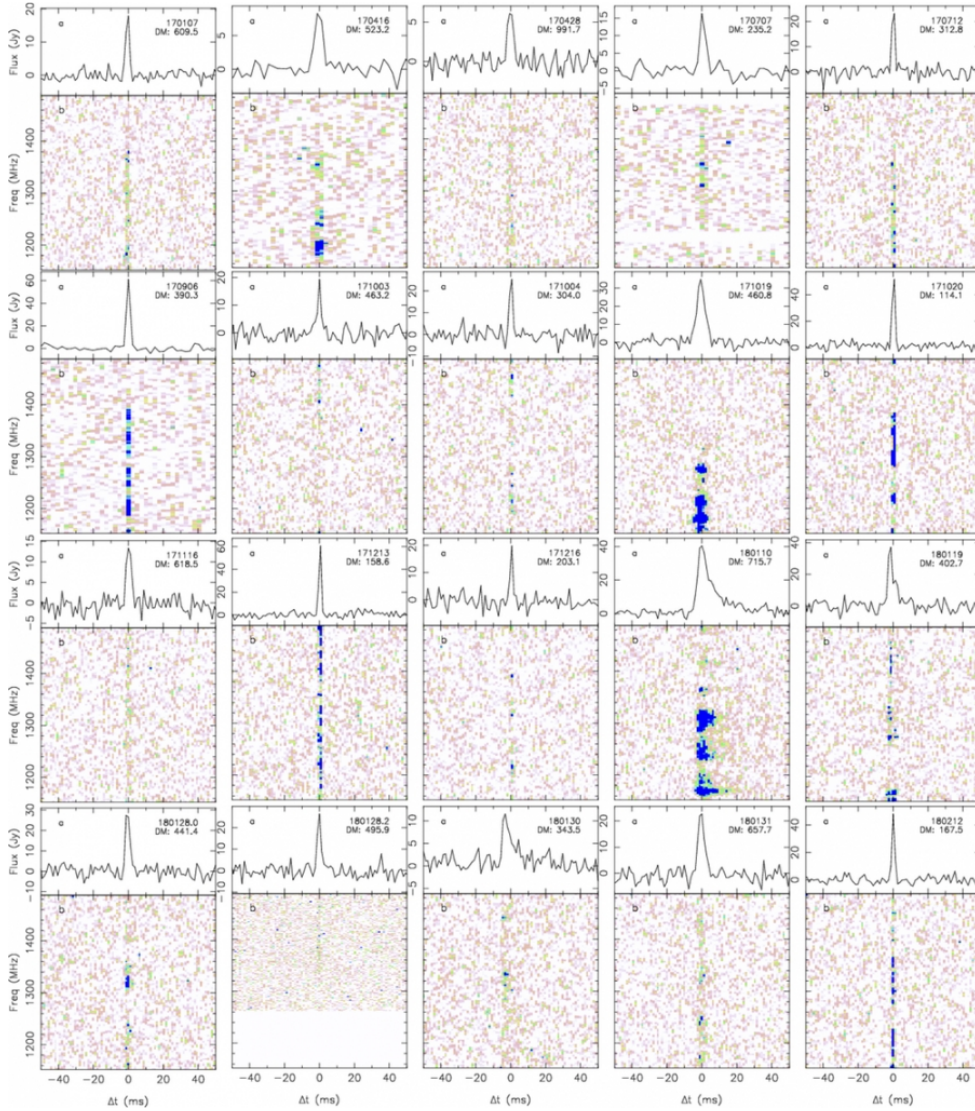
>250 repeats now known

Considerable internal structure in bursts



Localised by the VLA





# ASKAP FRBs



Found in fly's eye mode

Same frequency as Parkes (L-band)

22 FRBs – probably cosmological

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

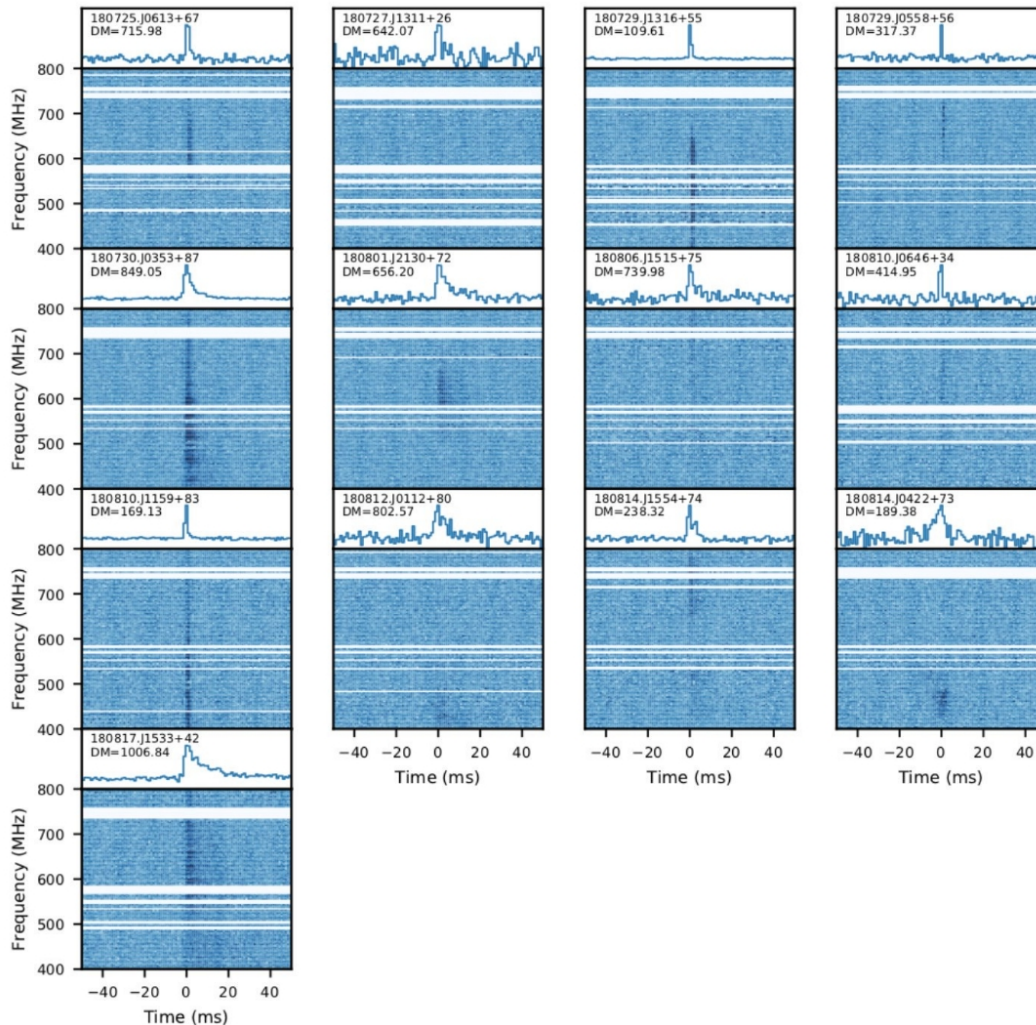
Patchy spectra

Some narrow even at 400 MHz

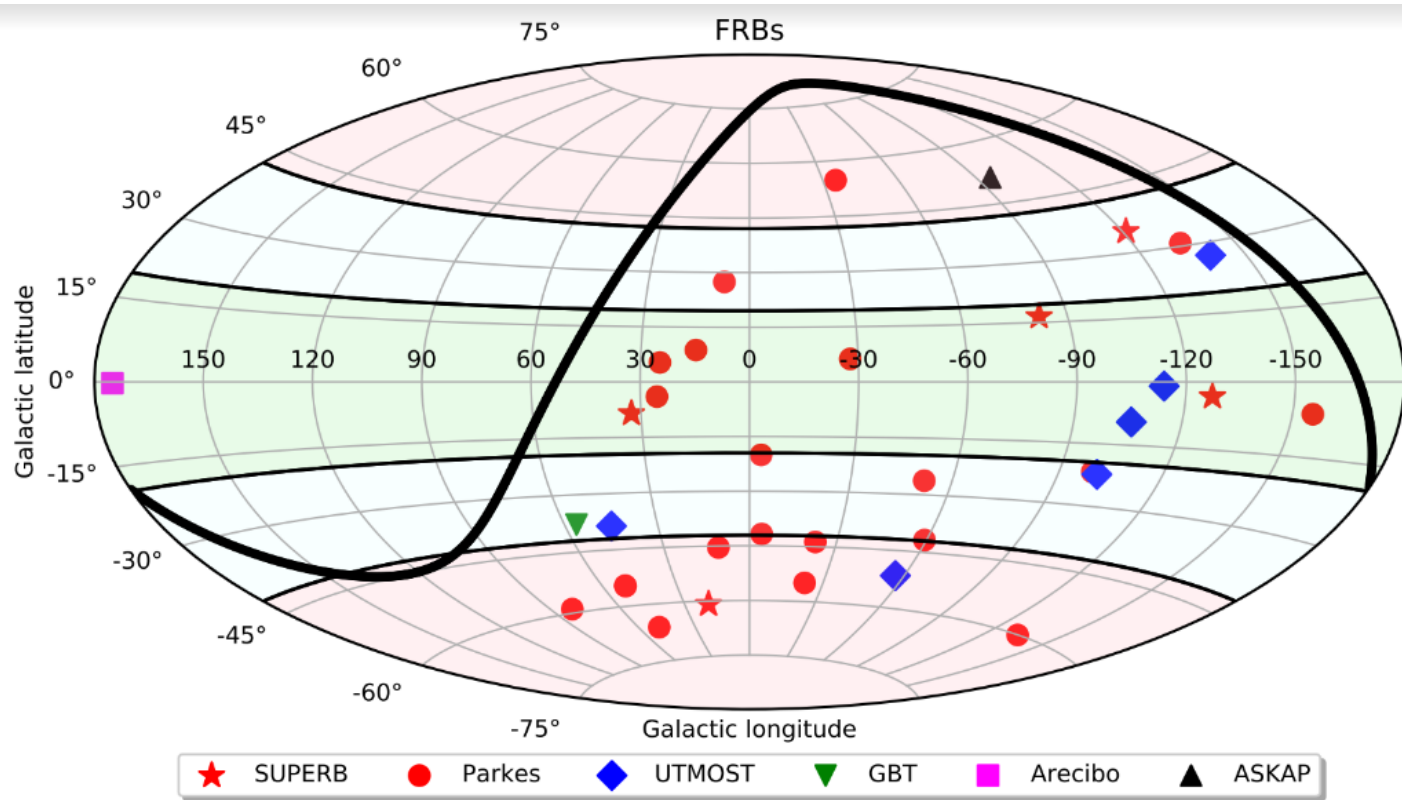
Very high discovery rate -  
several per day

1 DM > 3000 p/cc

Feb 2019 – 250 FRBs  
announced, and ~13  
repeaters



# Sky distribution is isotropic



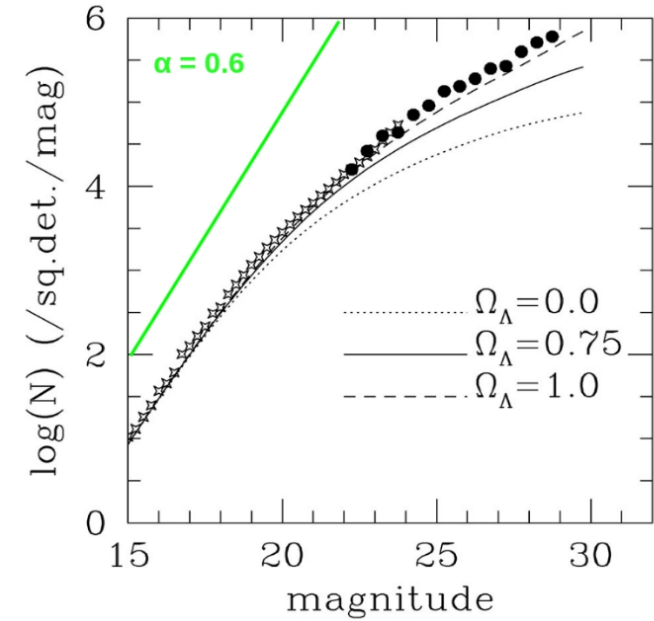
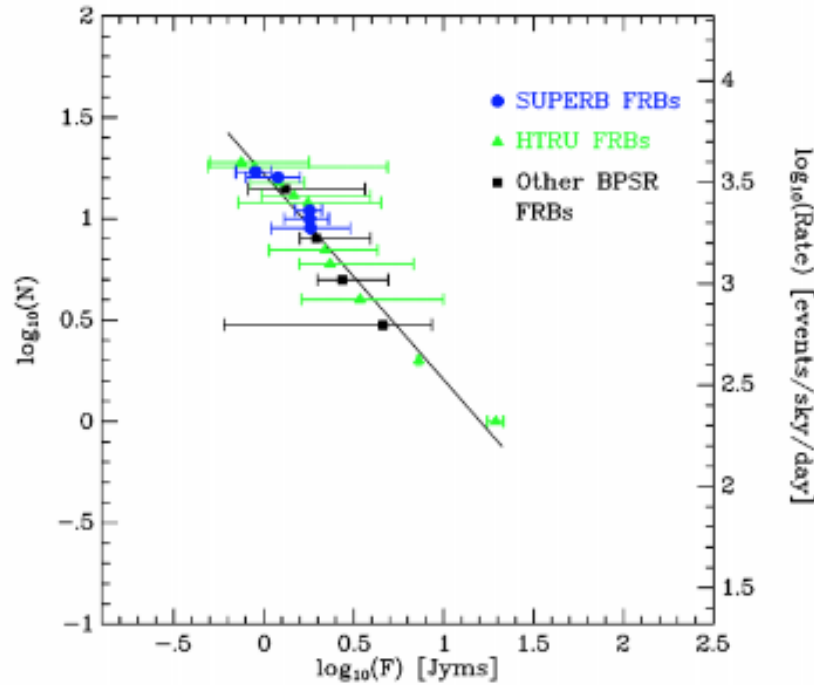
26 Parkes  
6 Molonglo  
1 GBT  
1 Arecibo  
1 ASKAP





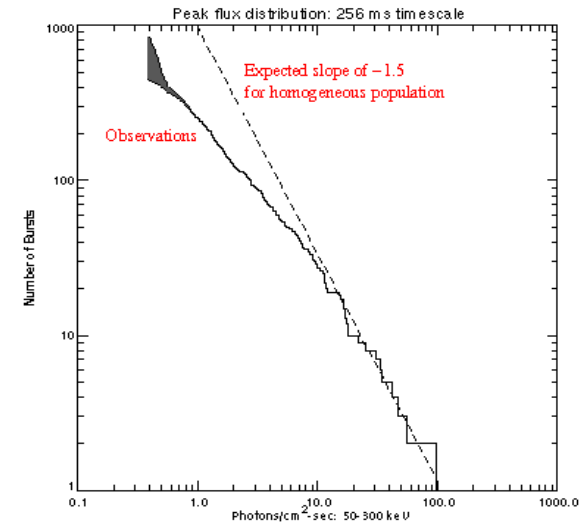
# FRB source counts

Bhandari et al 2017



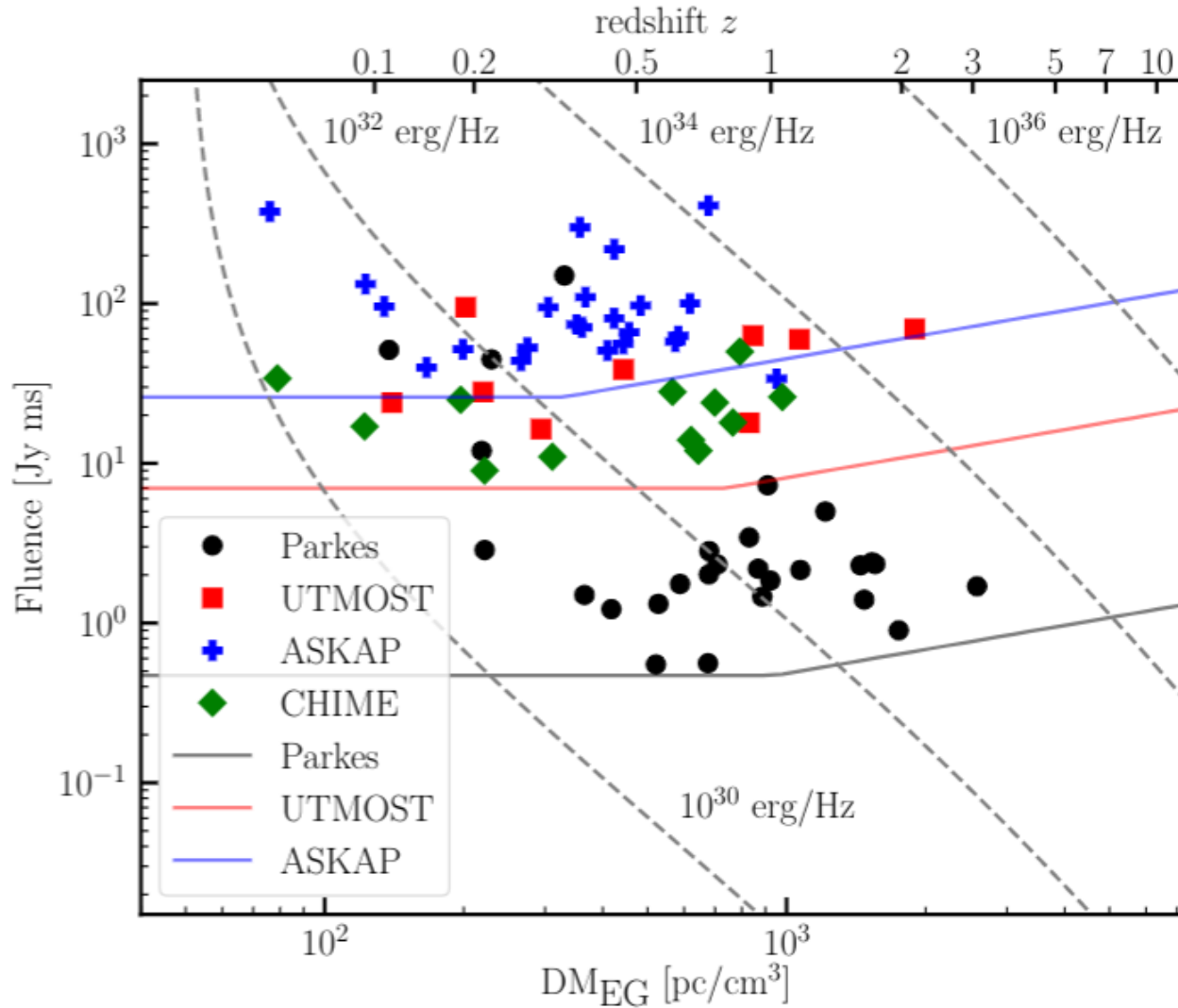
Consistent with "standard"-ish candles in LCDM

**CHIME will clean up!**



# FRB luminosity DM relation

PRELIMINARY



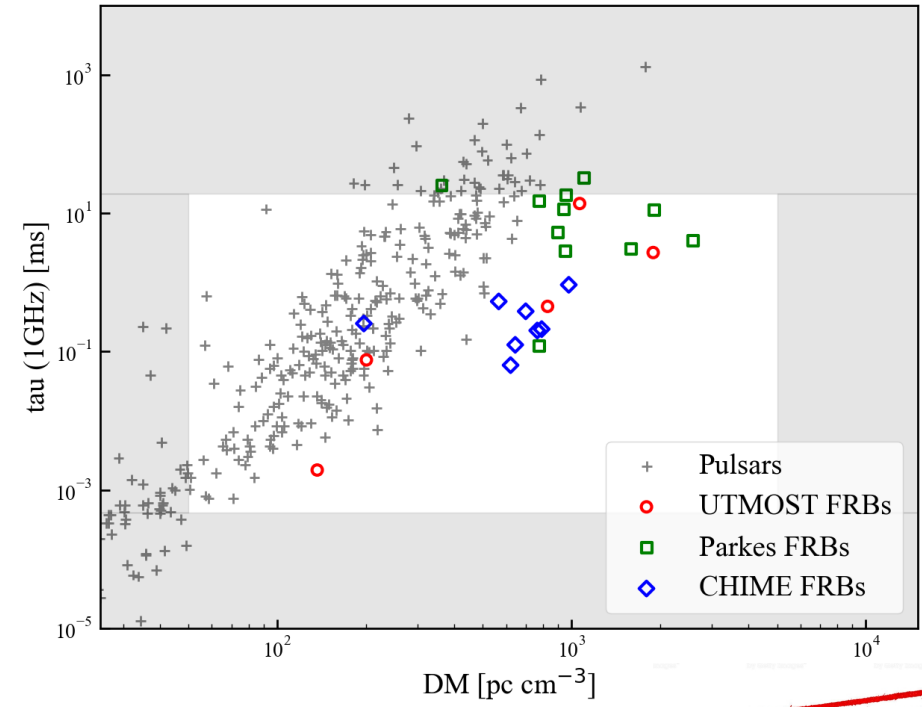
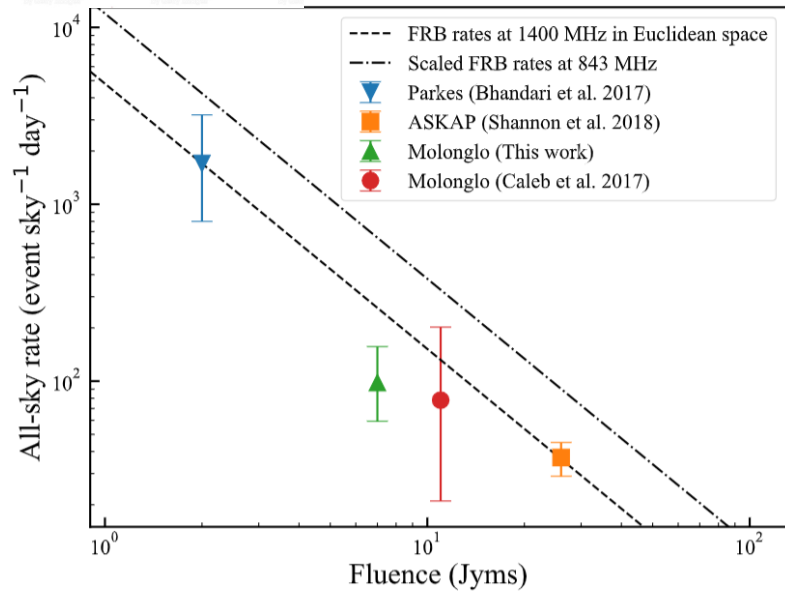
Farah et al 2019 in prep





# FRB rates and FRB scattering

**PRELIMINARY**



**PRELIMINARY**

FRB rate appears low at 843 MHz

Do FRB spectra turn over at ~ 1 GHz?

Farah et al 2019 in prep



# 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

**All hunting host galaxies**

Coming :  
MeerKat, LOFAR



Australian  
National  
University



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SYDNEY



# 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









# The first 3 UTMOST FRBS - Caleb et al 2017

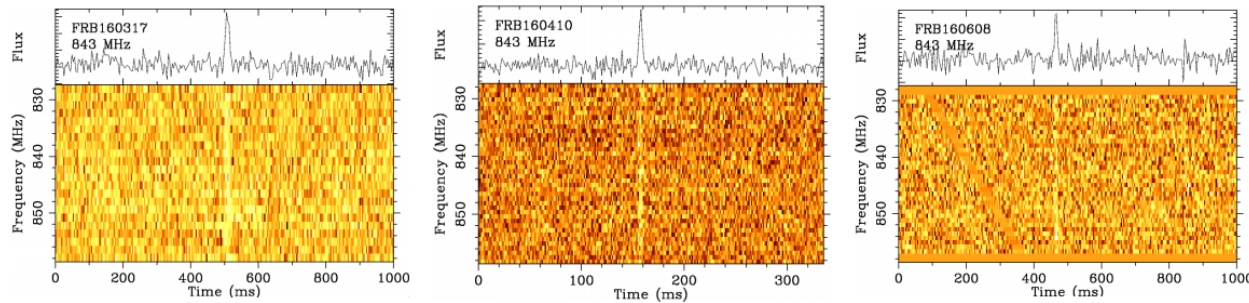


Figure 1: Frequency vs time plots of FRB160317, FRB160410 and FRB160608 detected at UTMOST with the effects of dispersion removed assuming DMs of  $1167 \text{ pc cm}^{-3}$ ,  $284 \text{ pc cm}^{-3}$  and  $684 \text{ pc cm}^{-3}$ .

Manisha Caleb's  
PhD project

Now at Manchester  
University



## March-May 2016 – three FRBs at Molonglo

Detections with an interferometer

>10000 km away (Fresnel limit)

Barely or not time resolved due to smearing across our 0.75 MHz channels

Discovery rate :

~ 1 every 60 days

Sky rate :

~75 sky/day fluence >11 Jyms



# Live FRB detections began April 2017

Trained on 1000s of pulsar pulses and RFI

> 250,000 pulses seen from 135 different pulsars

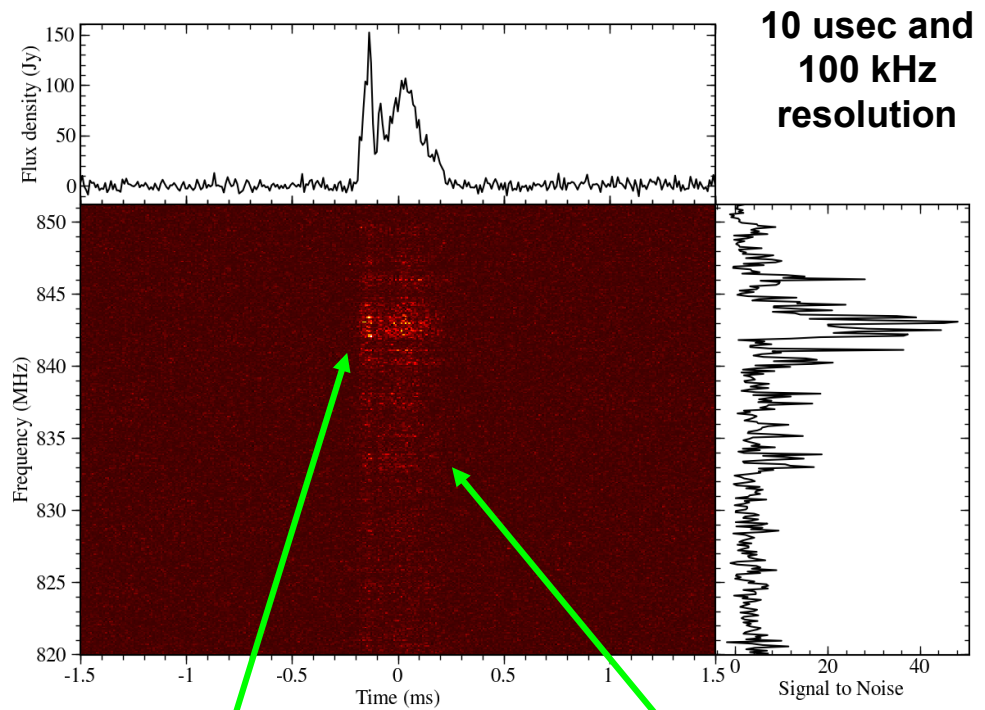
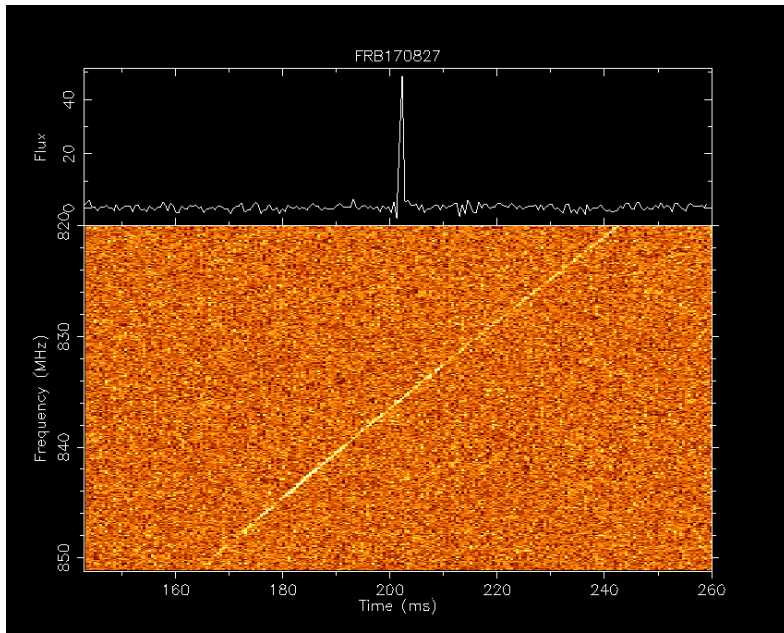
Voltage dumps on FRB candidates < 10 sec



Wael Farah  
PhD student  
Swinburne



# First live FRB



**FRB170827**

**DM = 176 pc/cc**

**Detected and email alert in < 10 seconds**

**Published as Farah et al 2018**

**Scintillation scale consistent with the Milky Way's ISM**

**Scintillation scale within 100 Mpc of host galaxy... possibly due to IGM, or host galaxy, or intrinsic to FRB**



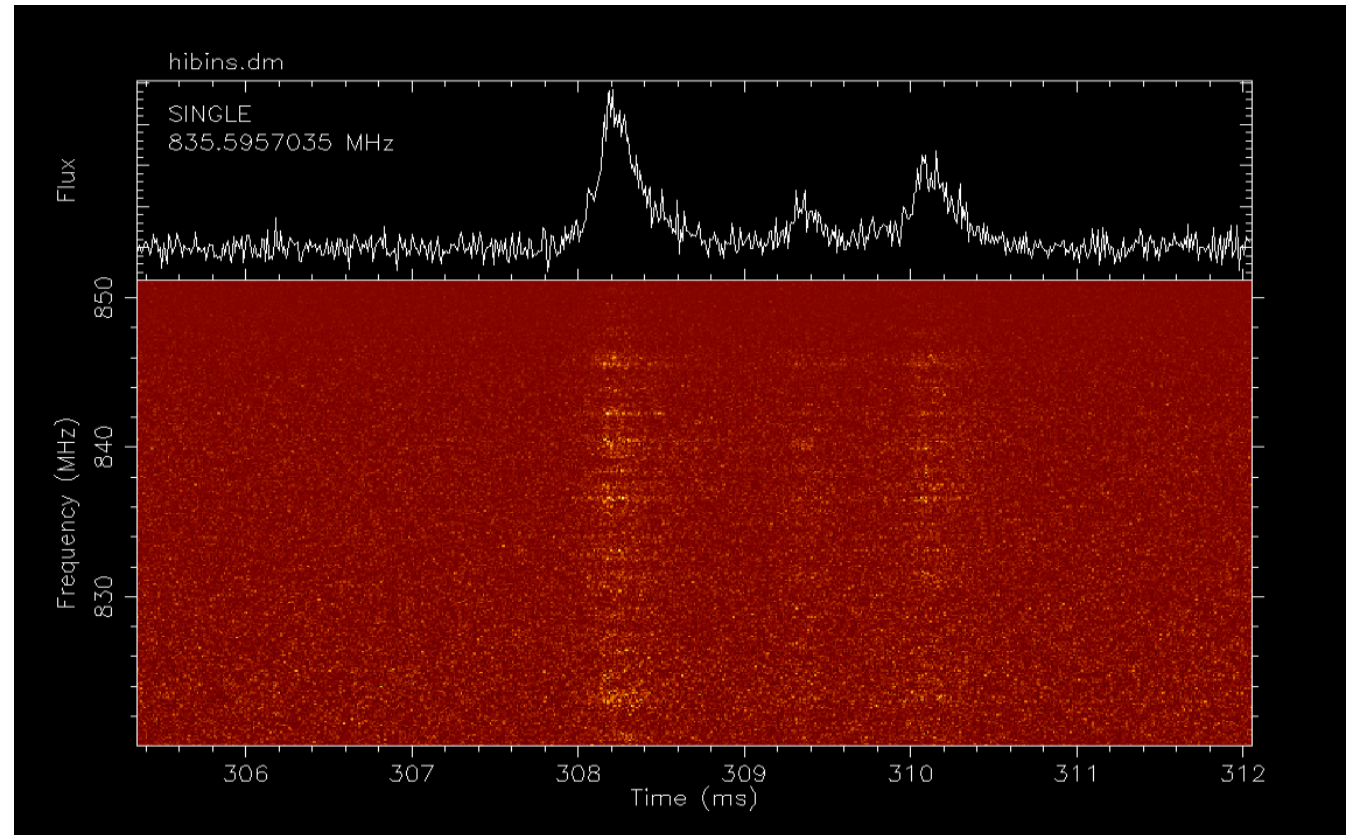
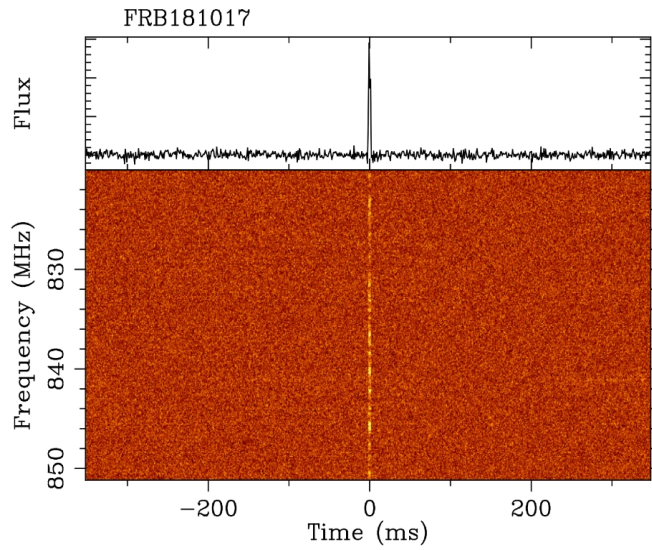
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# FRB181017



**Striking triple peaked structure**

**Scint bands similar across the peaks**

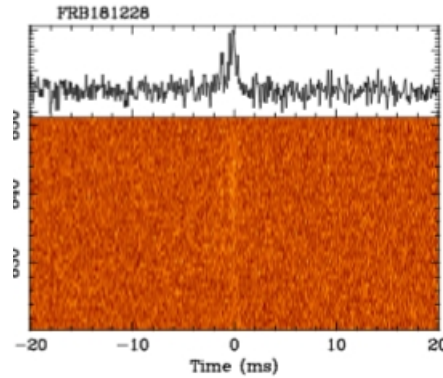
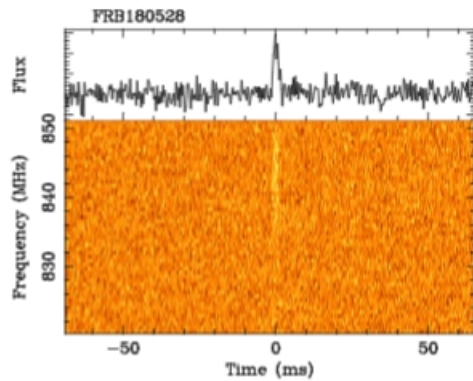
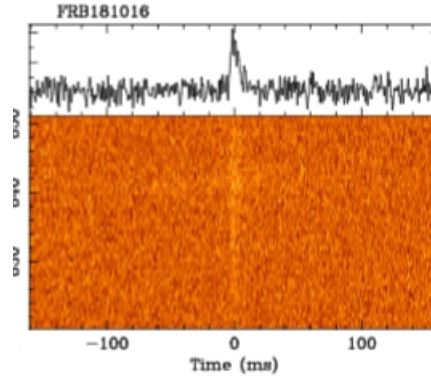
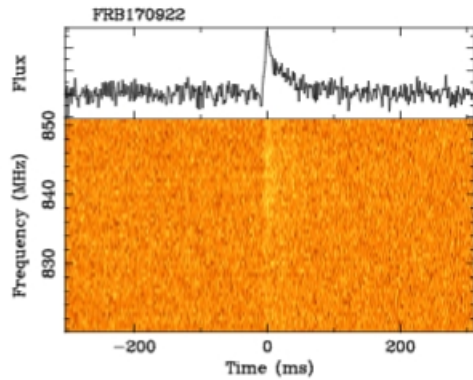
**10 usec and  
100 kHz  
resolution**



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National  
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## Six new UTMOST FRBs

All but one have **voltage dumps**

10 usec, 100 kHz resolution

## DMs

**FRB 170922 1111 pc/cc**

**FRB 180528 899 pc/cc**

**FRB 181016 1984 pc/cc**

**FRB 181228 354 pc/cc**

FRB170922 **had** longest scattering tail to date – 29 ms

FRB181016 equal highest energy to date ~  $5E42$  erg



# Furbies – inserting mock FRBs

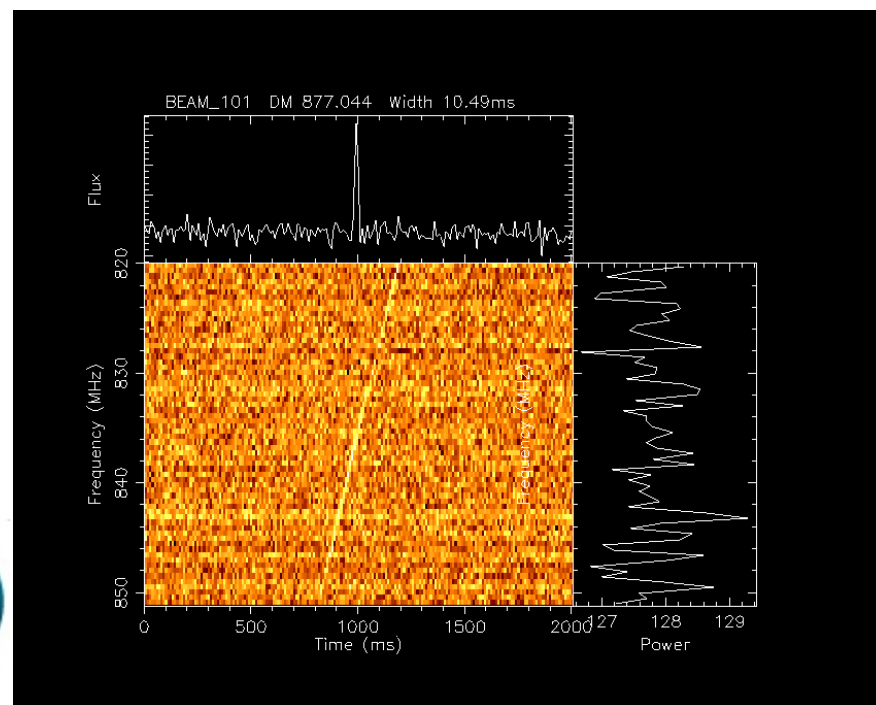
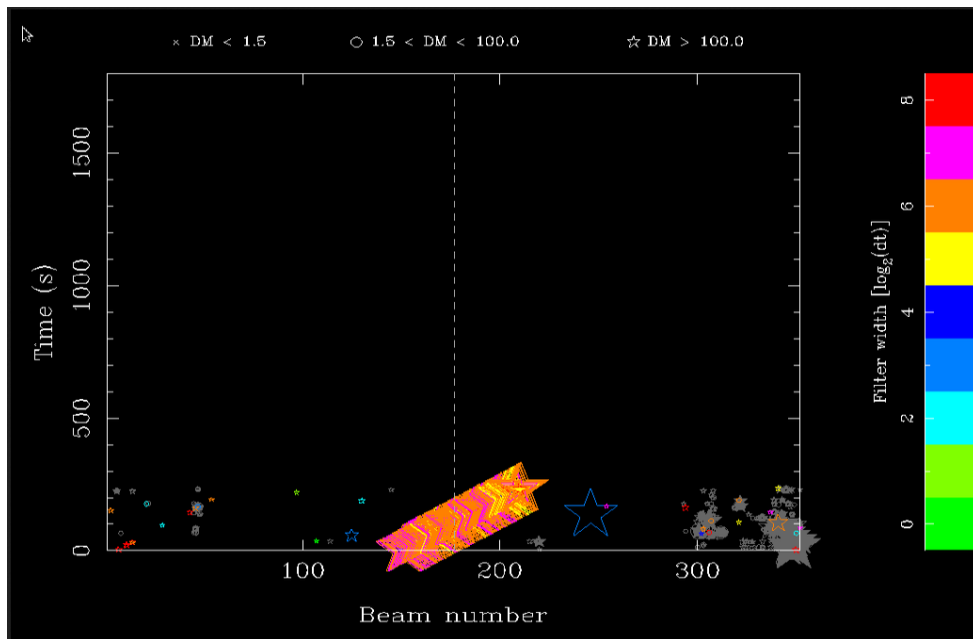
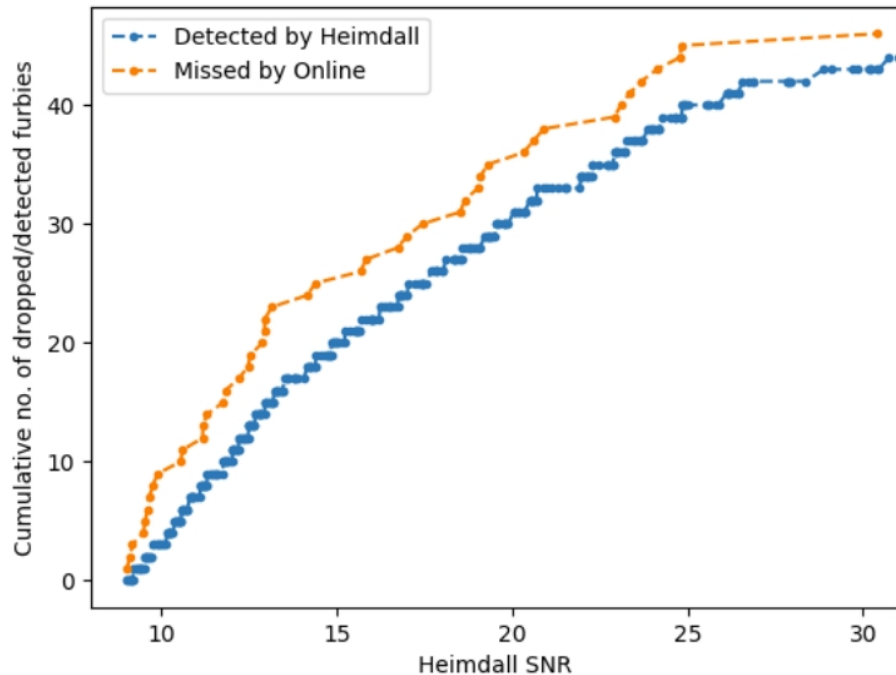


PhD student Vivek Gupta

600 mock FRBs injected live

>90% recovery of mock FRBs

Range of widths, DM, S/N, spectral properties







- Virtual Observatory Events: framework for automated information exchange between observatories
  - Simply a raw xml packet conforming to a standard schema (FRBs: Petroff et al. 2017)
- Already used widely: NASA-GCN, ASAS-SN, GAIA-alerts
- UTMOST VOEvents available via 4pisky (manually vetted; minute to hour delay)

```
<?xml version='1.0' encoding='UTF-8'?>
<voe:VOEvent xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xmlns:voe="http://
www.ivoa.net/xml/VOEvent/v2.0" xsi:schemaLocation="http://www.ivoa.net/xml/VOEvent/
v2.0 http://www.ivoa.net/xml/VOEvent/VOEvent-v2.0.xsd" version="2.0"
role="observation" ivorn="ivo://au.edu.swin/utmost#FRB1802210215/58170.09386343">
  <Who>
    <AuthorIVORN>ivo://au.edu.swin/cflynn</AuthorIVORN>
    <Date>2018-02-21T02:15:09</Date>
    <Author><contactEmail>cflynn@astro.swin.edu.au</
contactEmail><contactName>Chris Flynn</contactName></Author>
  </Who>
  <What>
    <Group name="observatory parameters">
      <Param dataType="float" name="beam_semi-major_axis"
ucd="instr.beam;pos.errorEllipse;phys.angSize.smajAxis" unit="MM" value="75"/>
      <Param dataType="float" name="beam_semi-minor_axis"
ucd="instr.beam;pos.errorEllipse;phys.angSize.sminAxis" unit="MM" value="0.35"/>
      <Param dataType="float" name="beam_rotation_angle"
ucd="instr.beam;pos.errorEllipse;instr.offset" unit="Degrees" value="0.0"/>
      <Param dataType="float" name="sampling_time" ucd="time.resolution"
```

Molonglo\_FRB\_voE.xml

# Current UTMOST Localisation

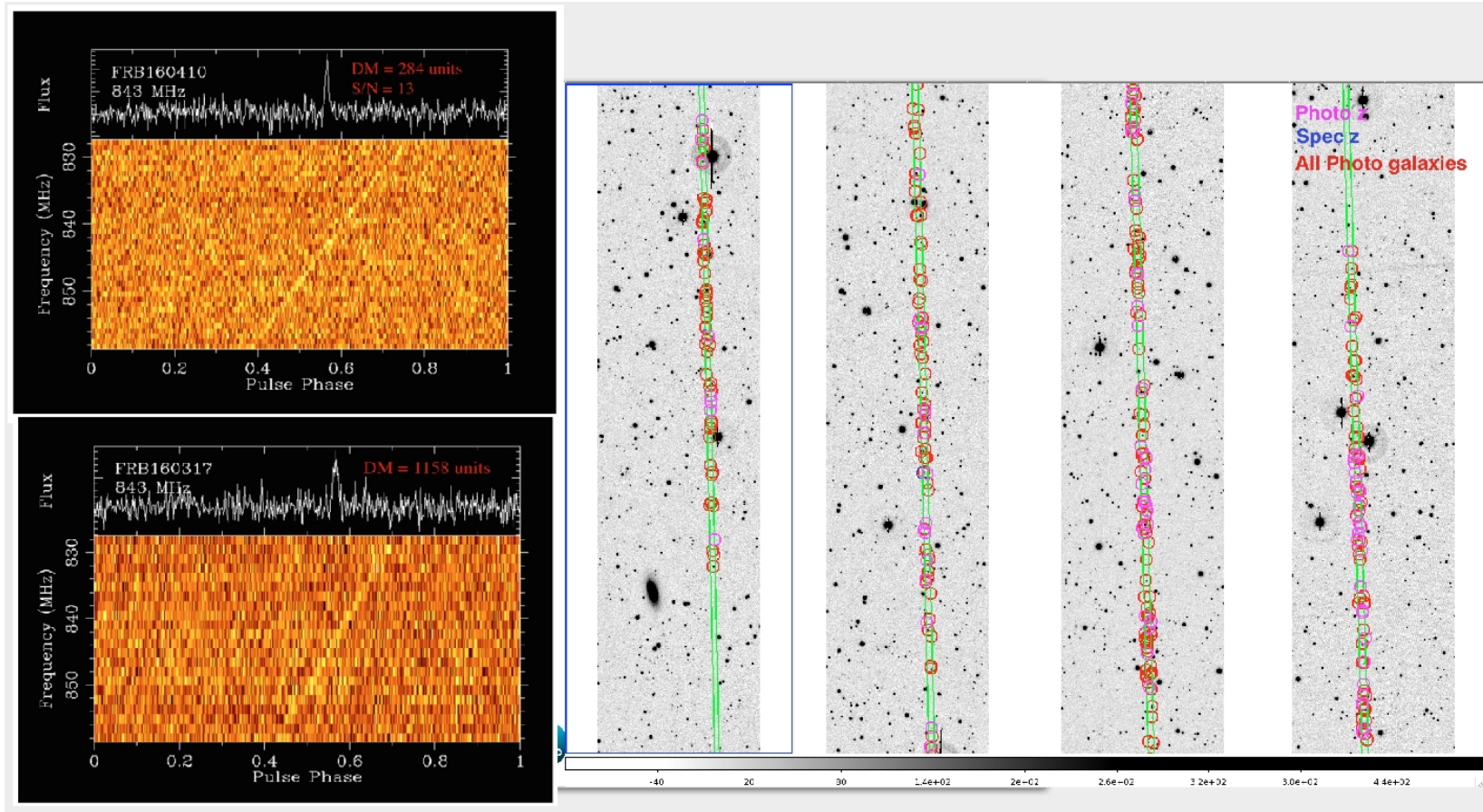


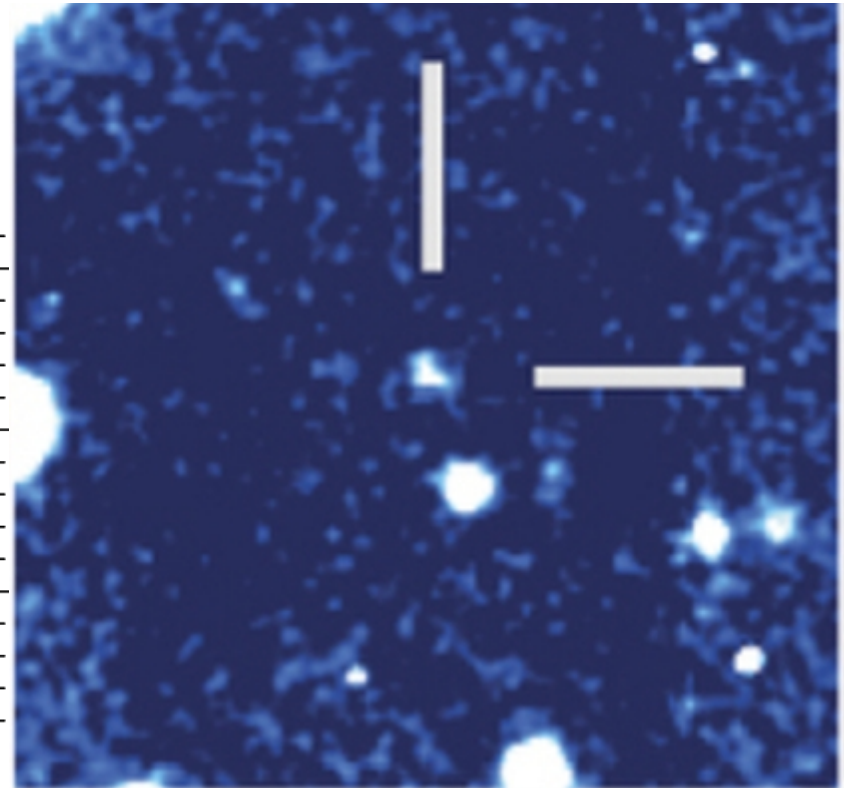
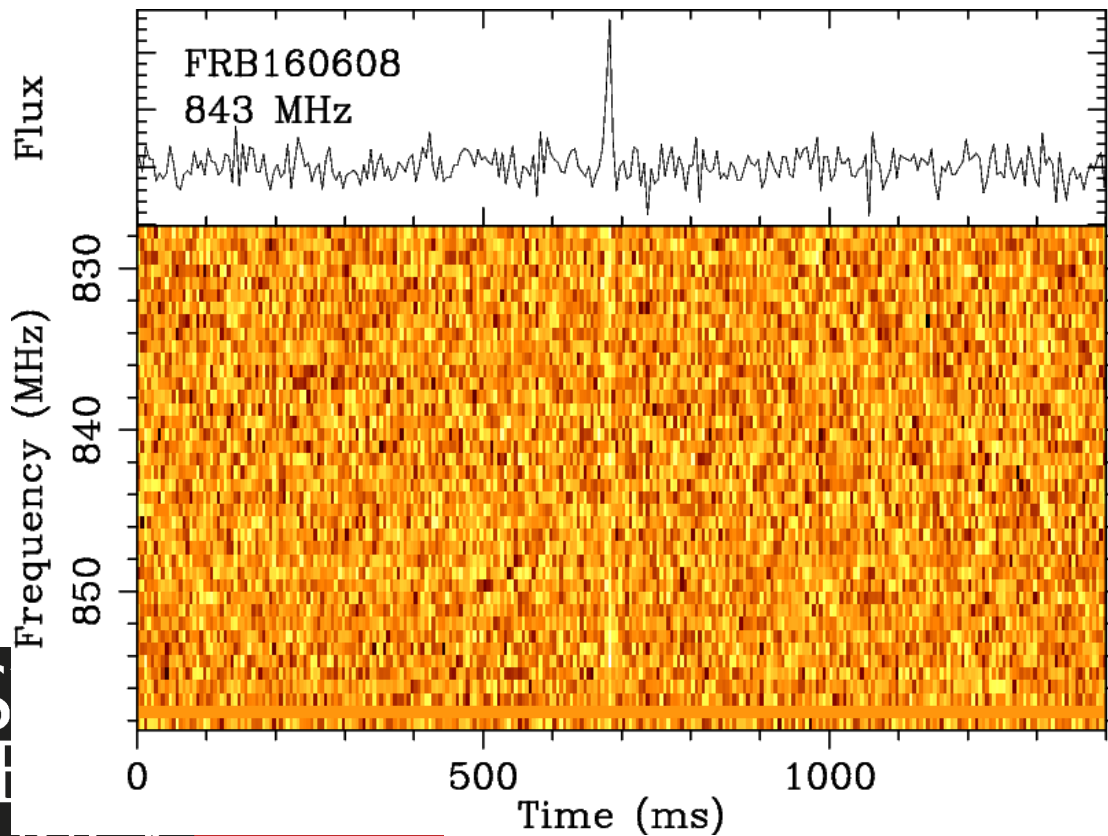
Image credit : Fang Yuan / SkyMapper

3-sigma localisation : 15 " x 6 degree arc on sky

Hundreds of SDSS galaxies in these error arcs



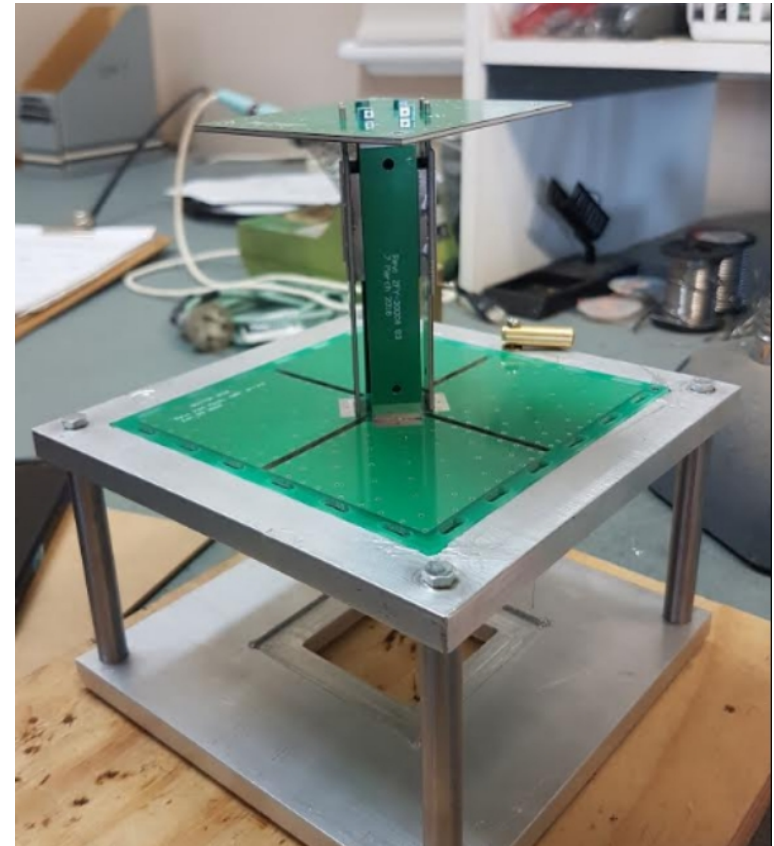
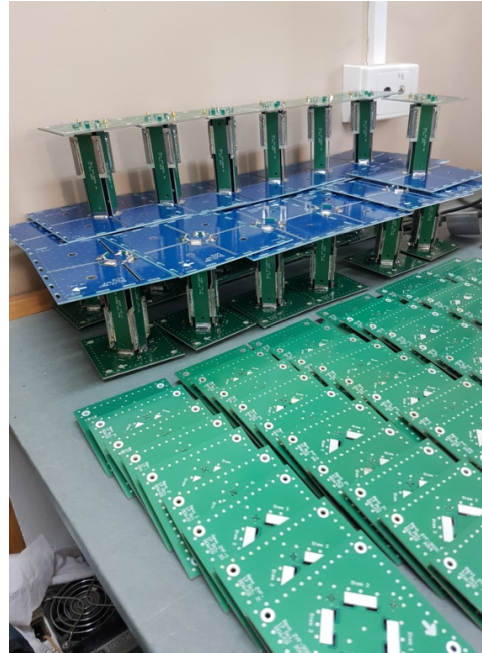
# UTMOST transforms from an FRB-finder to an FRB-localiser





**Bring back the North-South arm – localisation to ~ few arcsec**

**Hunting host galaxies of FRBs**

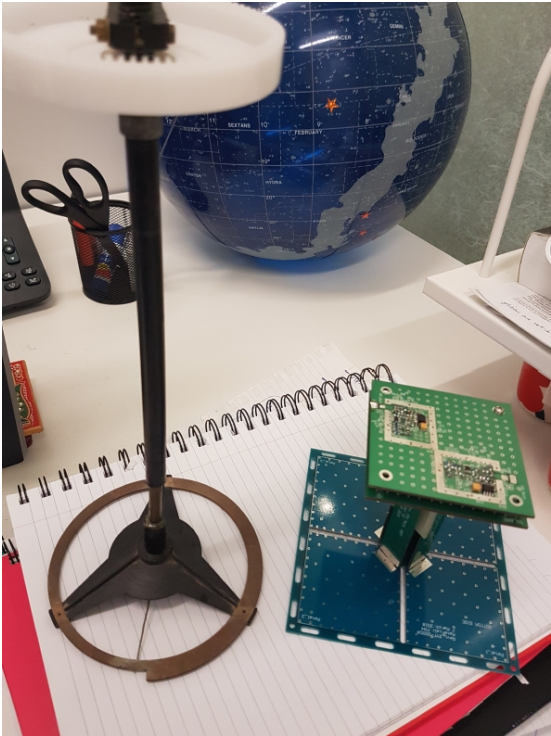
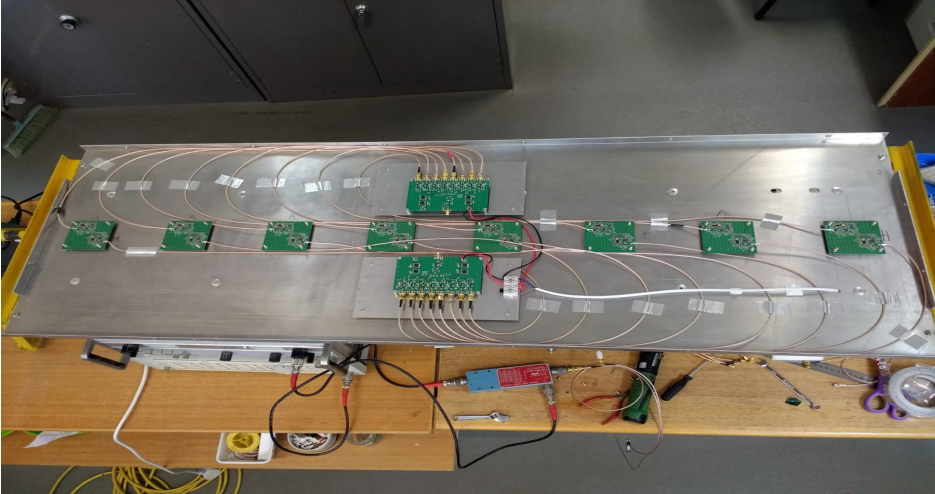


**PhD student Cherie Day building her antenna design (Dec 2018)**



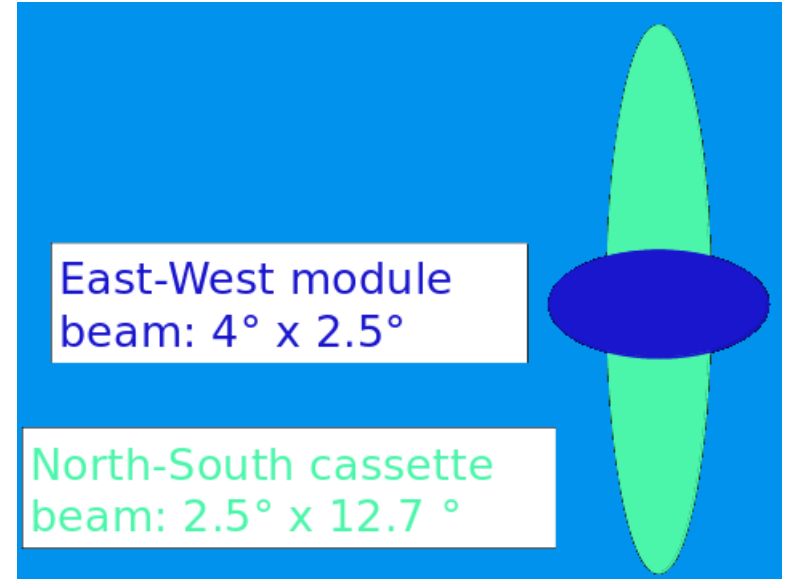
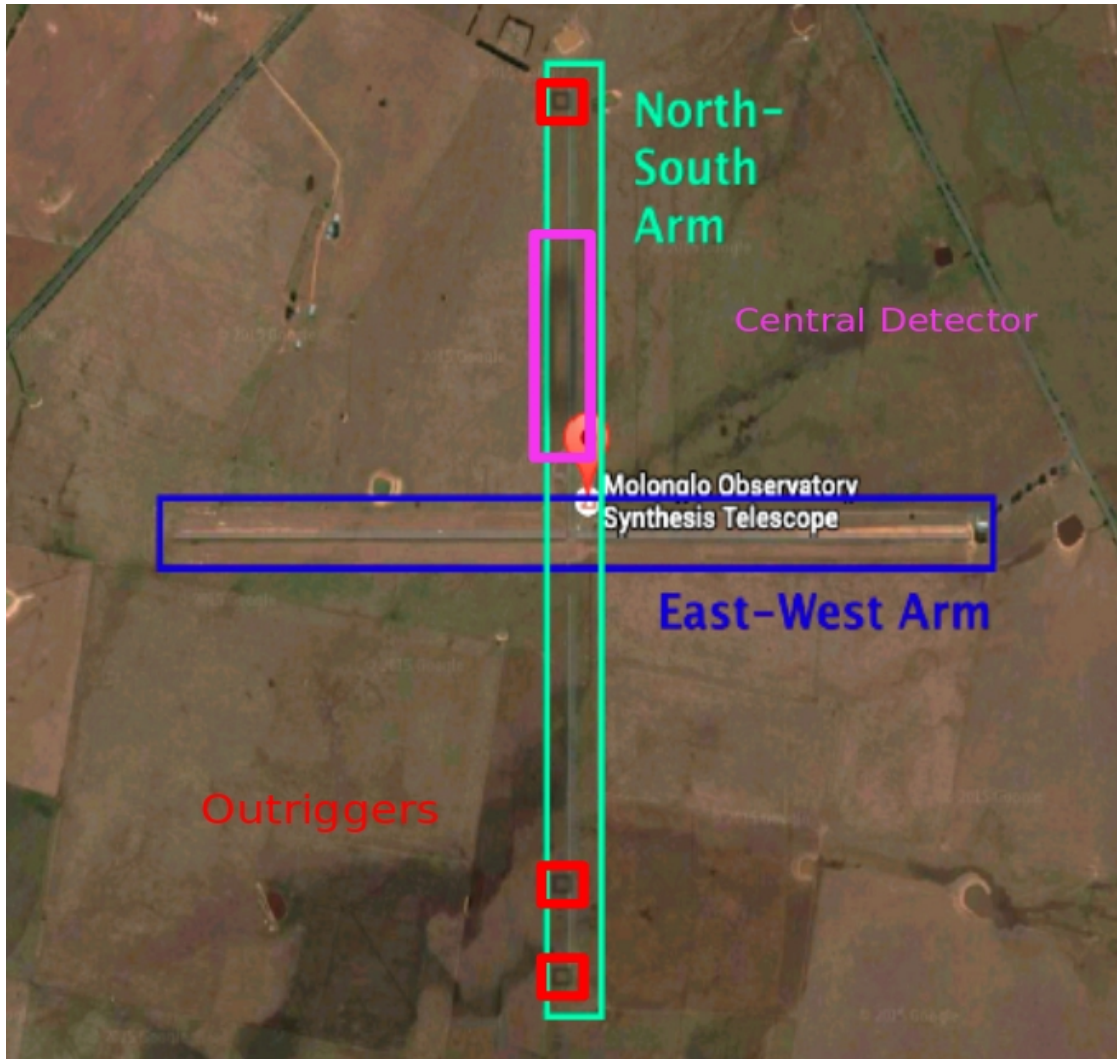


# Refitting the Molonglo North-South arm





# Refitting the Molonglo North-South arm



Triple our field of view

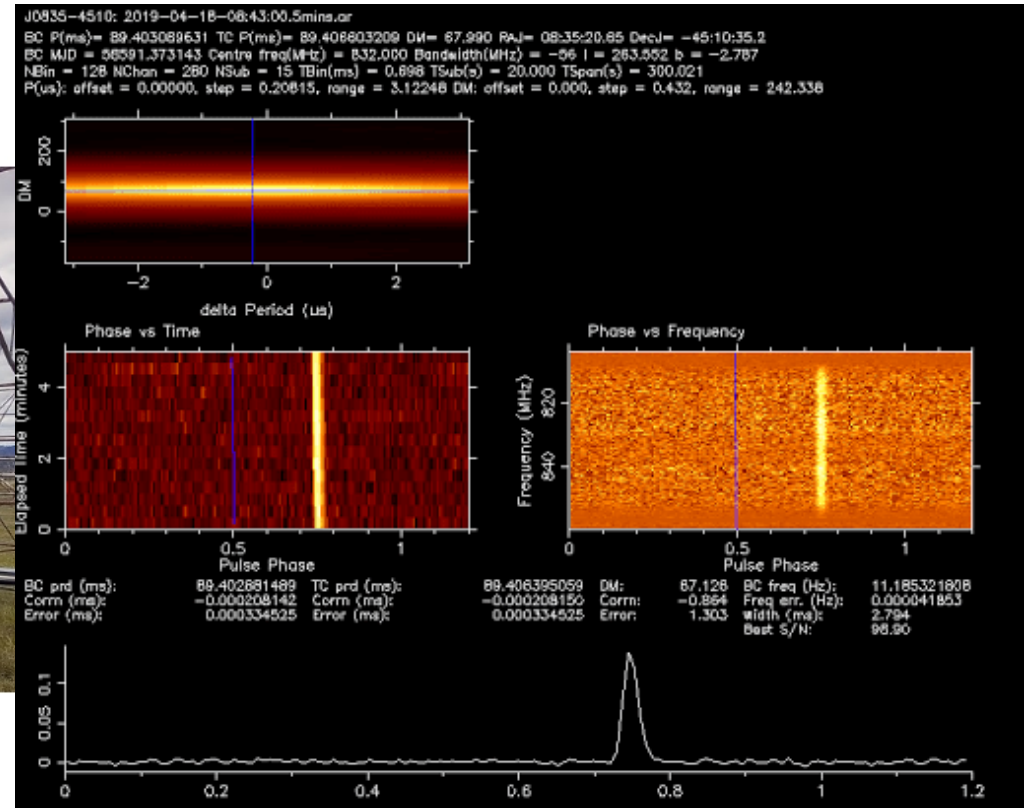
2 degree overlap region for localising FRBs

**Localisation to a few arcsec**





# Refitting the Molonglo North-South arm



**Dec 2019 : First light on North-South arm (after 42 years!)**

**First use of RFoF / SAW filters to remove mobile phone RFI**

**18/04/19 – best S/N yet during commissioning**

**Digitization with SNAP boards**



## 12 to 24 month prospects

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

Spectral index / average spectral properties of FRBs

5 – 10 host galaxies localised from single bursts

5 – 10 host galaxies of repeaters localised

DM-z relation starts to emerge

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?

