Australian searches for FRBs: ASKAP, Molonglo, and Parkes

Stefan Osłowski
with slides by
C. Flynn, S. Bandhari, K. Bannister, R. Shannon

SWINBURNE UNIVERSITY OF TECHNOLOGY

Australian Government
Australian Research Council

Postdoc position in FRBs

- Interested in cutting edge Astronomy and Astrophysics?
- Find Fast Radio Bursts and pinpoint their location?
- Join internationally-renowned CSIRO Astronomy and Space Science

- https://jobs.csiro.au/
- https://jobregister.aas.org/job_view?JobID=60720

Early days

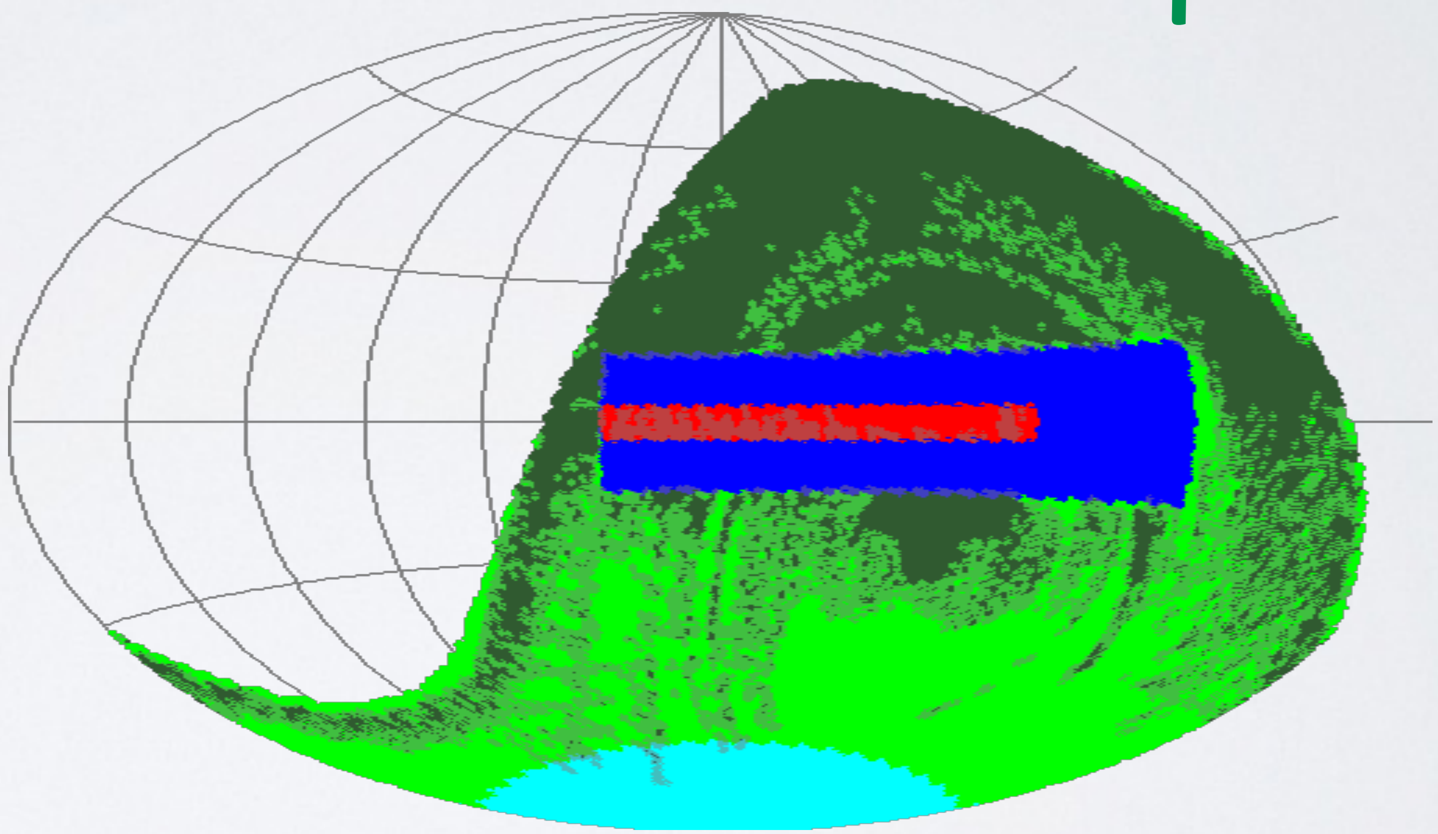
The High Time Resolution Universe Survey

Survey
1.4 GHz, 13 beams
400 MHz BW
1024 channels
64us sampling

see papers by
Thornton et al.
Champion et al.

Galactic Plane
70 min/pt
-80< gl <30
|gb|<3.5
1240 pointings

Intermediate
8.5 min/pt
-120< gl <30
|gb|<15
6690 pointings



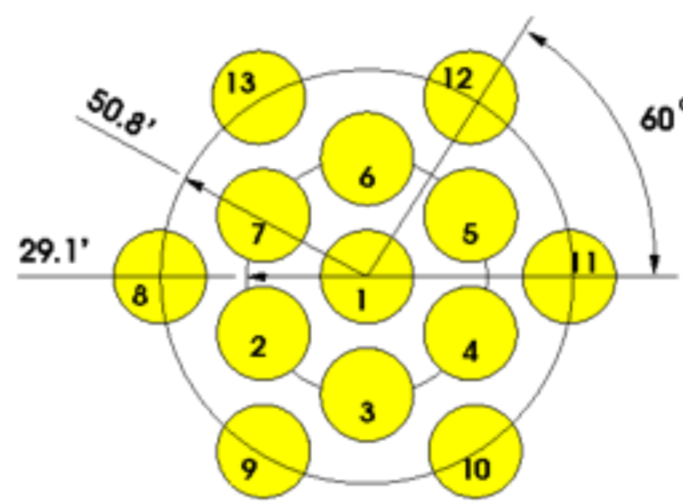
Keith et al. 2010 (MNRAS)

All Sky
4 min/pt
Southern sky
36450 pointings

SURVEY FOR PULSARS AND EXTRA-GALACTIC RADIO BURSTS

- Find FRBs in real time
- Effect multi-wavelength follow-ups
- Understand the nature and origin of FRBs

Credits: SKA Organisation



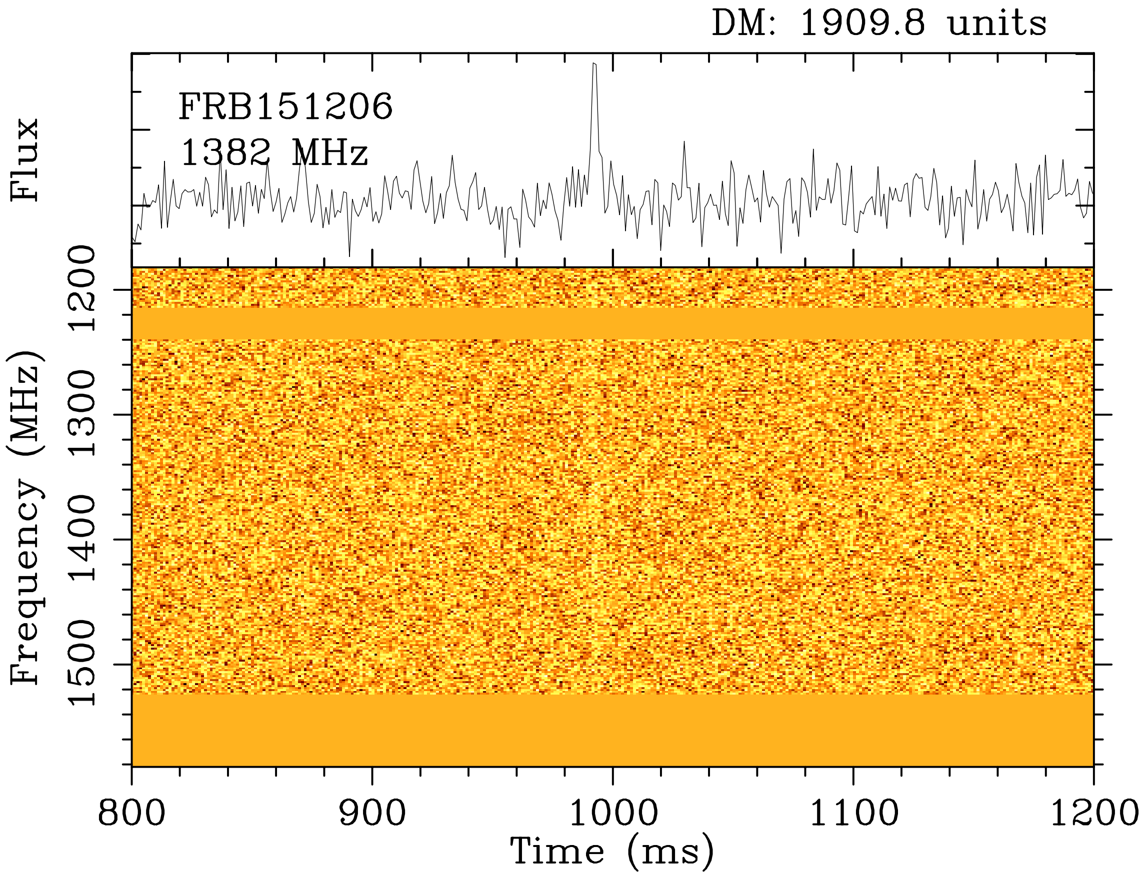
Credits : CSIRO/ATNF

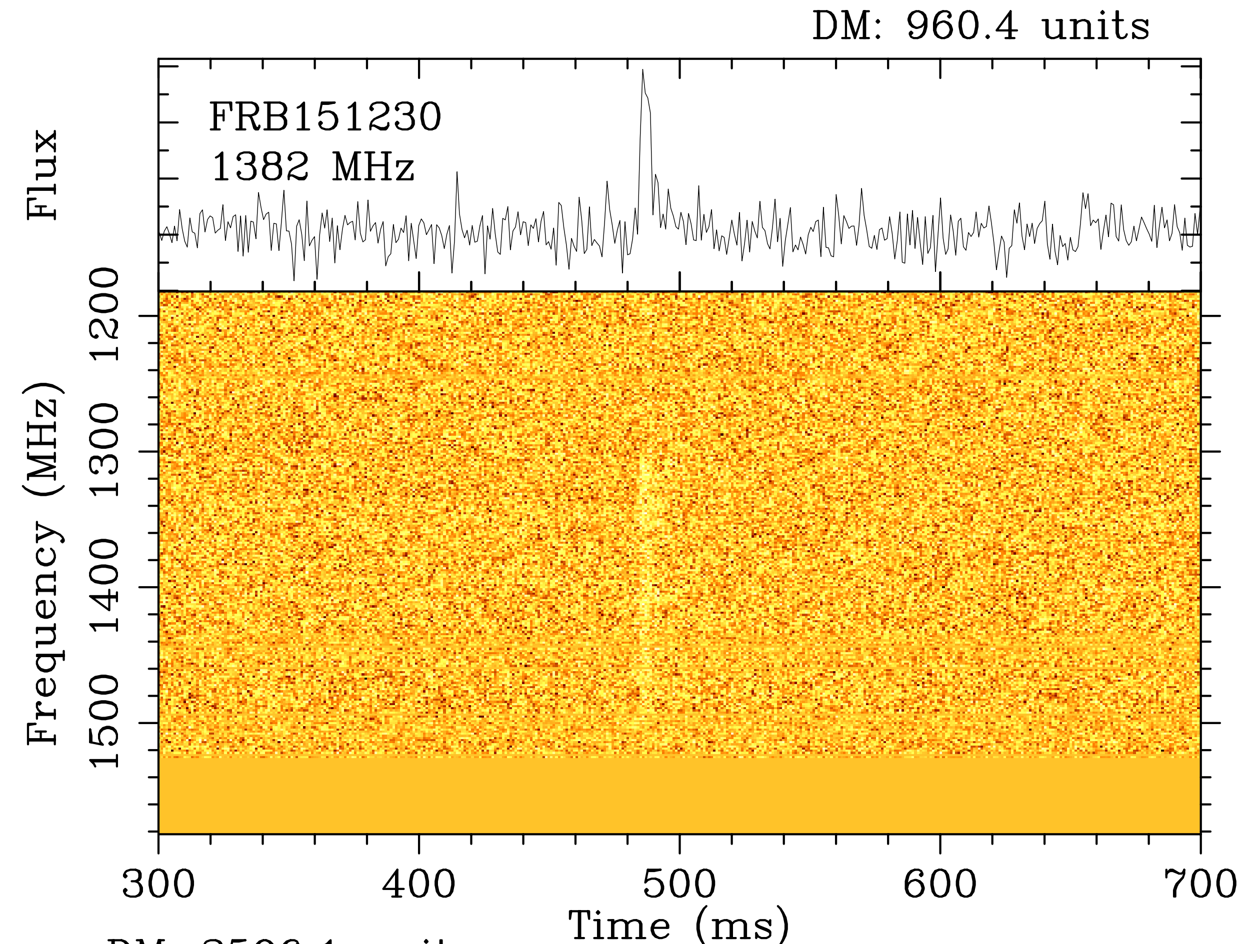
SUPERB

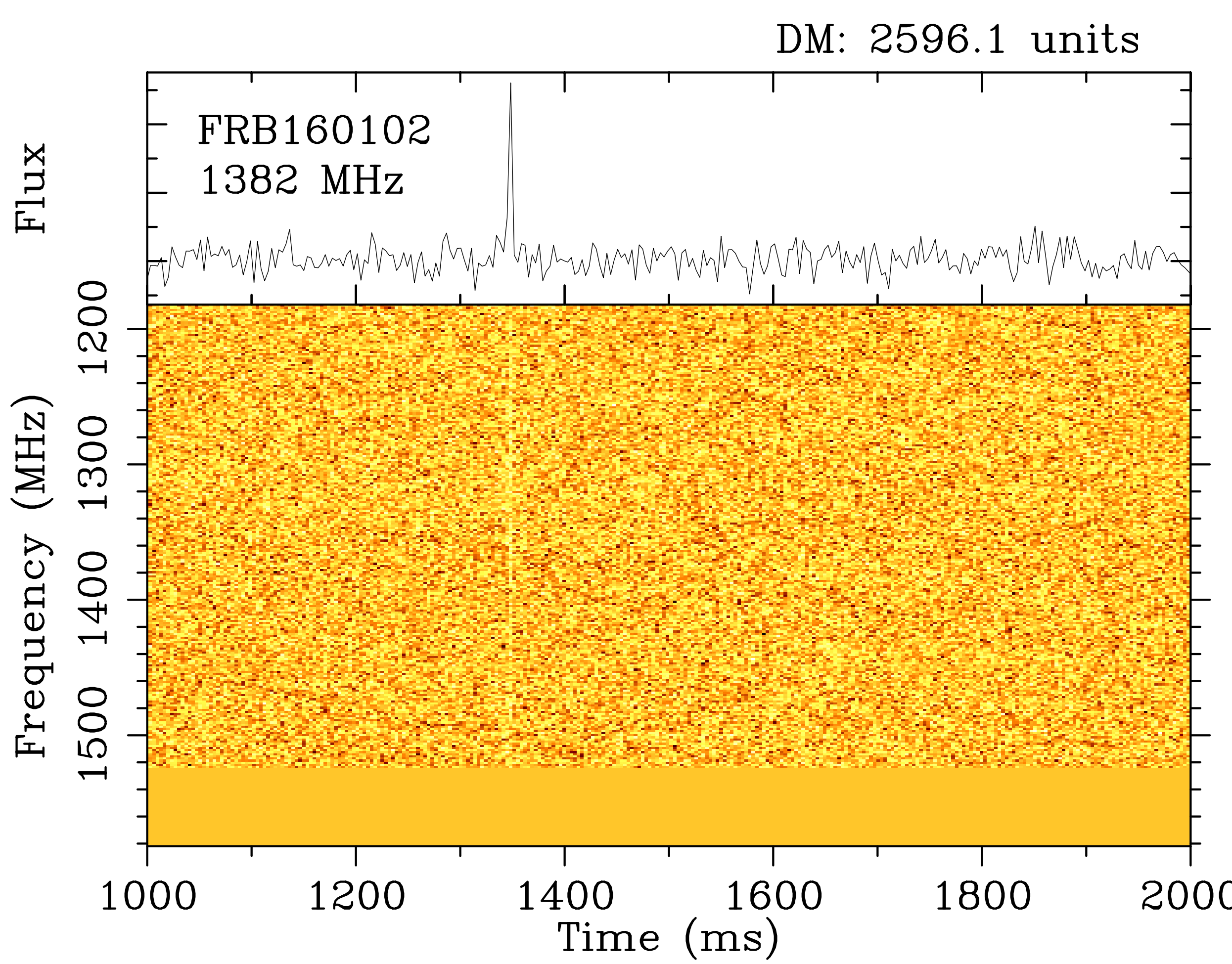
Survey for Pulsars and Extragalactic Radio Bursts

Multi-wavelength synergies

SUPERB FRBs

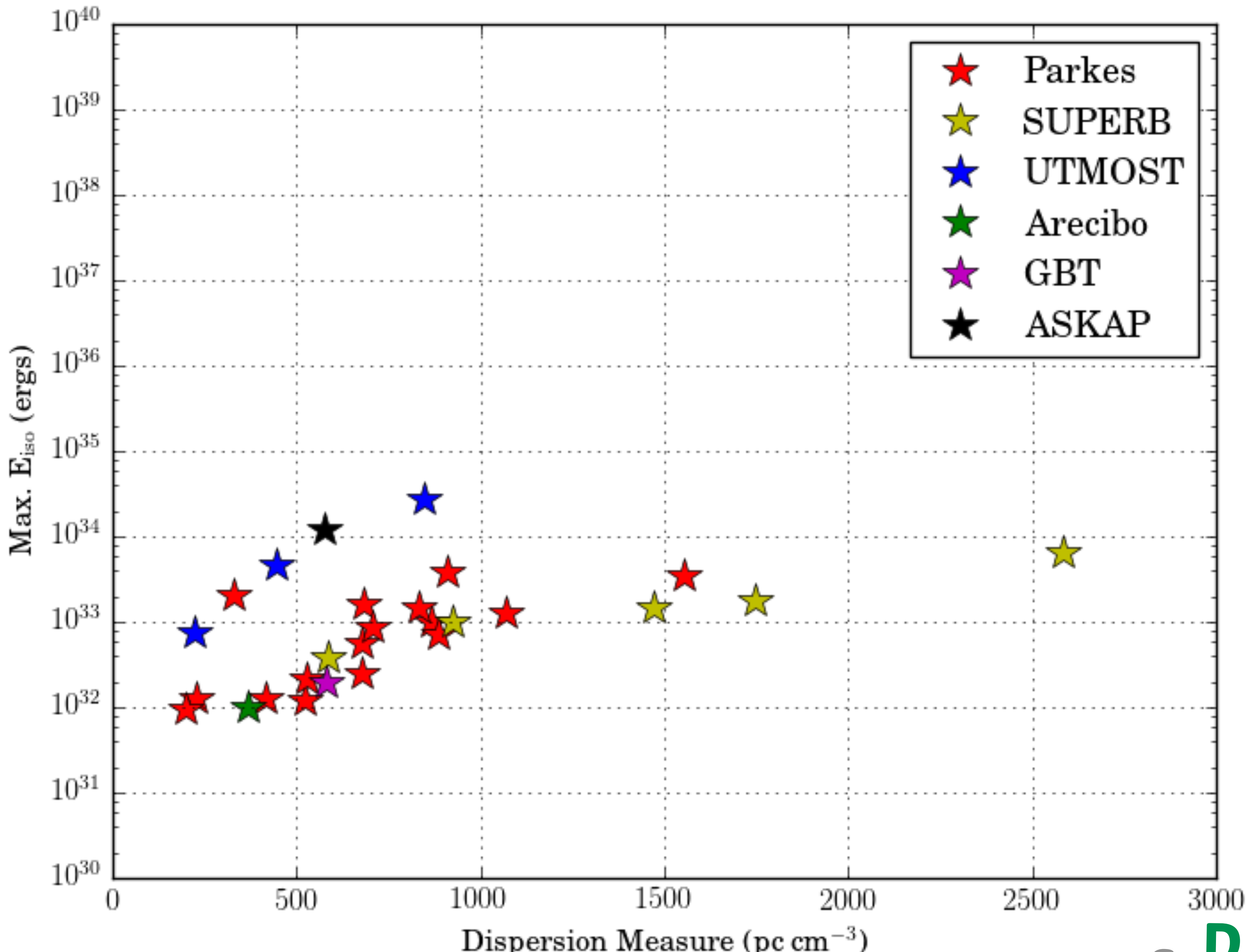




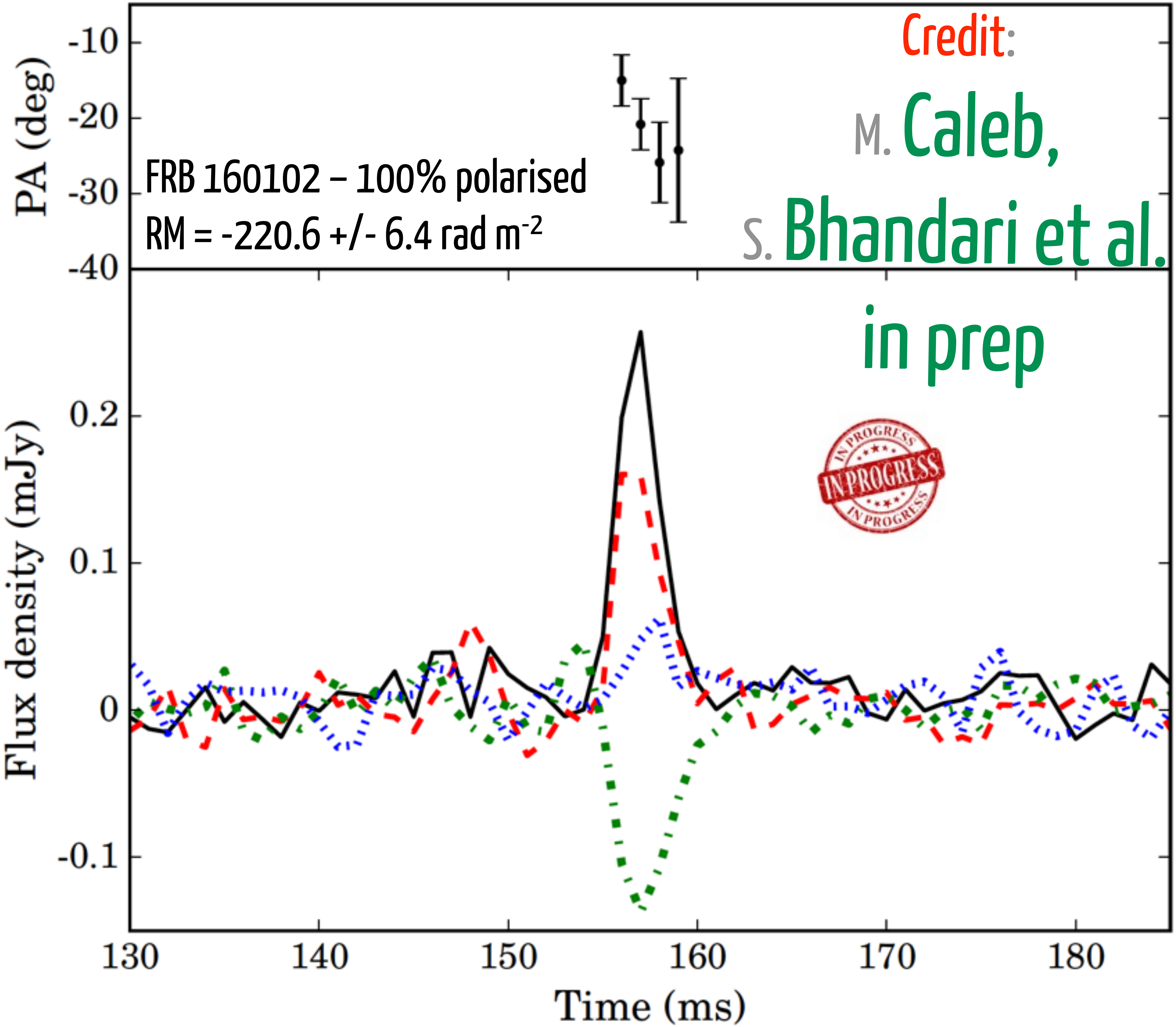


Credit:

Bhandari et al., 2017 in prep

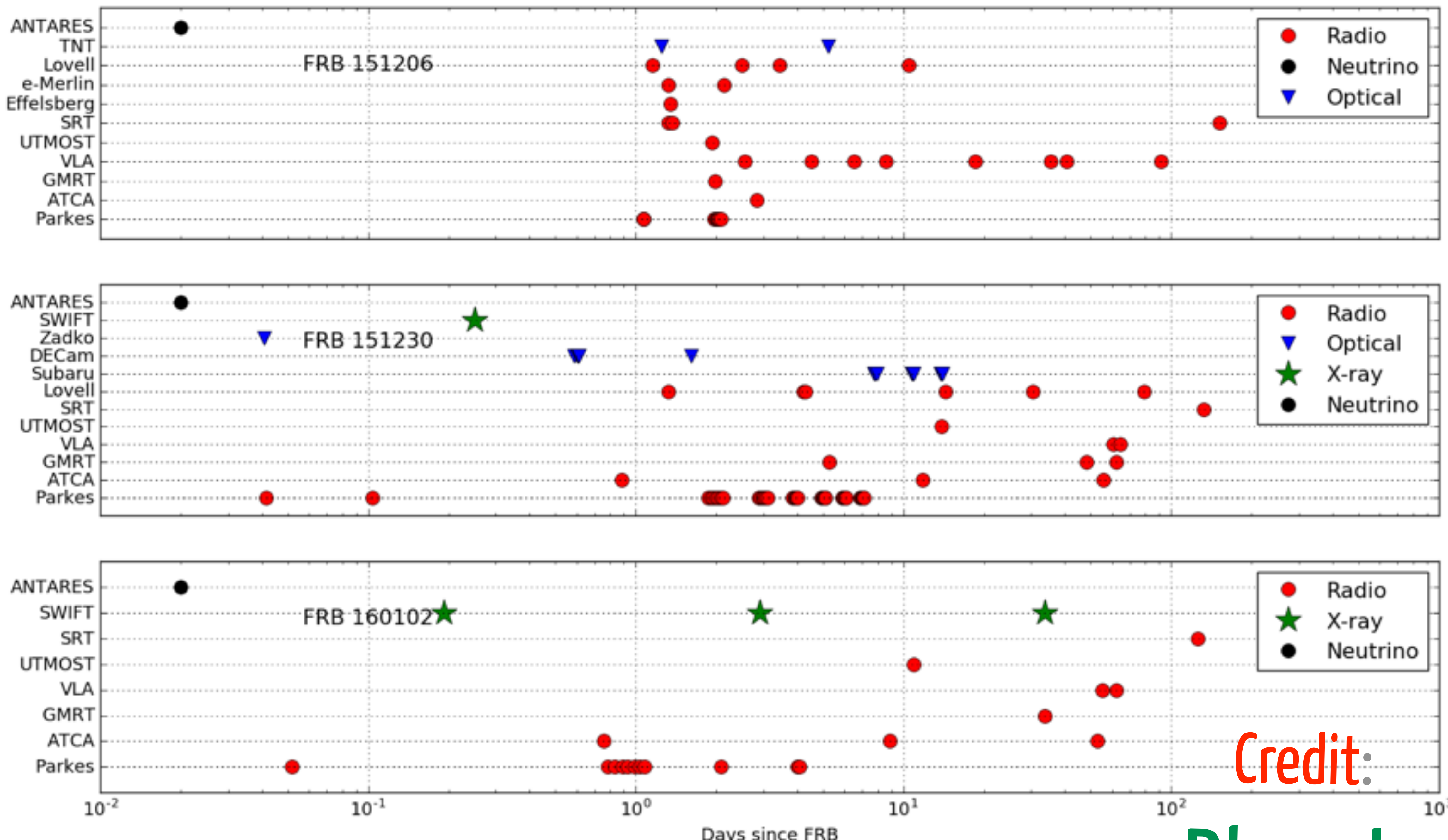


Credit: S. Bhandari



FRB 160102 – 100% polarised
RM = -220.6 +/- 6.4 rad m-2
Credit:
M. Caleb,
S. Bhandari et al.
in prep
IN PROGRESS
PA (deg)
-10
-20
-30
-40
Flux density (mJy)
0.2
0.1
0
-0.1
130
140
150
160
170
180
Time (ms)

Follow-up campaign



Credit:

S. Bhandari

Did FRBs repeat?

Optical follow-up results

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

Credit: Gemini Observatory/AURA

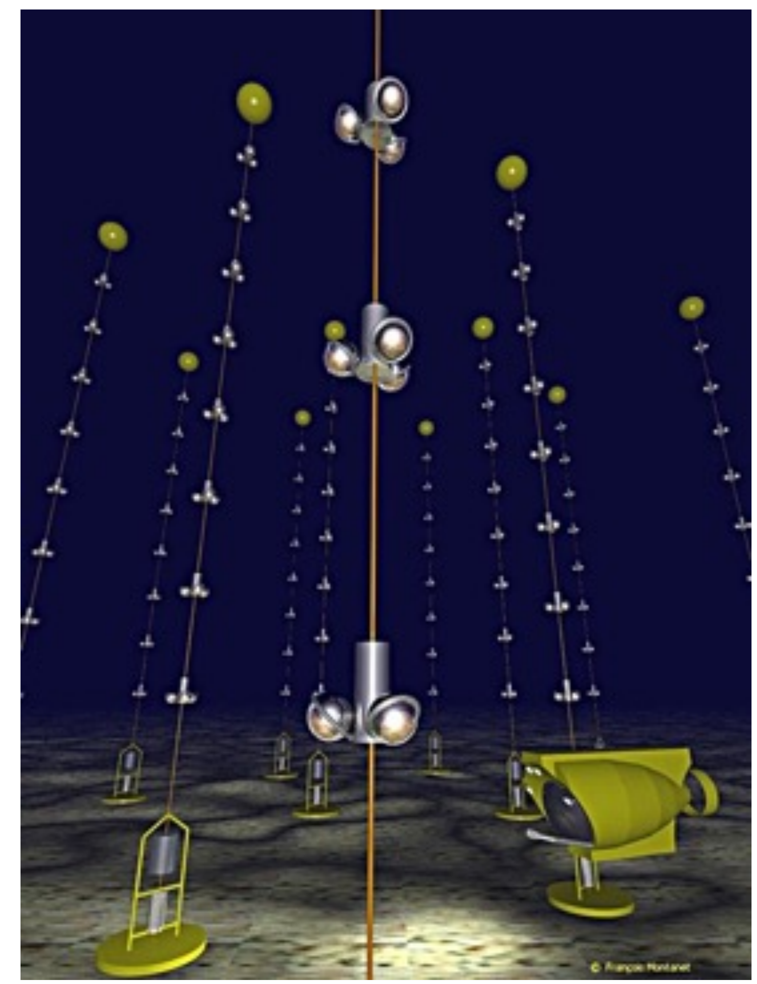
X-ray follow-up with SWIFT

Triggered for FRB 151230 and FRB 160102.

- FRB 151230
  - 1 epoch
  - No sources detected above 3-sigma
  - limiting flux on FRB afterglow ~ 1.9E-13 erg/cm^2/s
- FRB 160102
  - 3 epochs
  - No sources detected above 3-sigma
  - limiting flux on FRB afterglow ~ 1.4E-13 erg/cm^2/s

ANTARES

- ANTARES is a deep water neutrino detector.
- Aims to detect Cherenkov light from neutrino-induced muons (above 100 GeV).
- No neutrino event was detected in correlation with all FRB events.

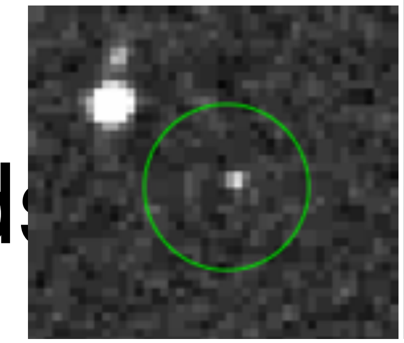


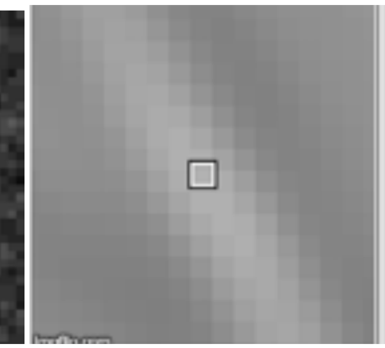
Any hints in radio follow-ups?
Imaging Observations

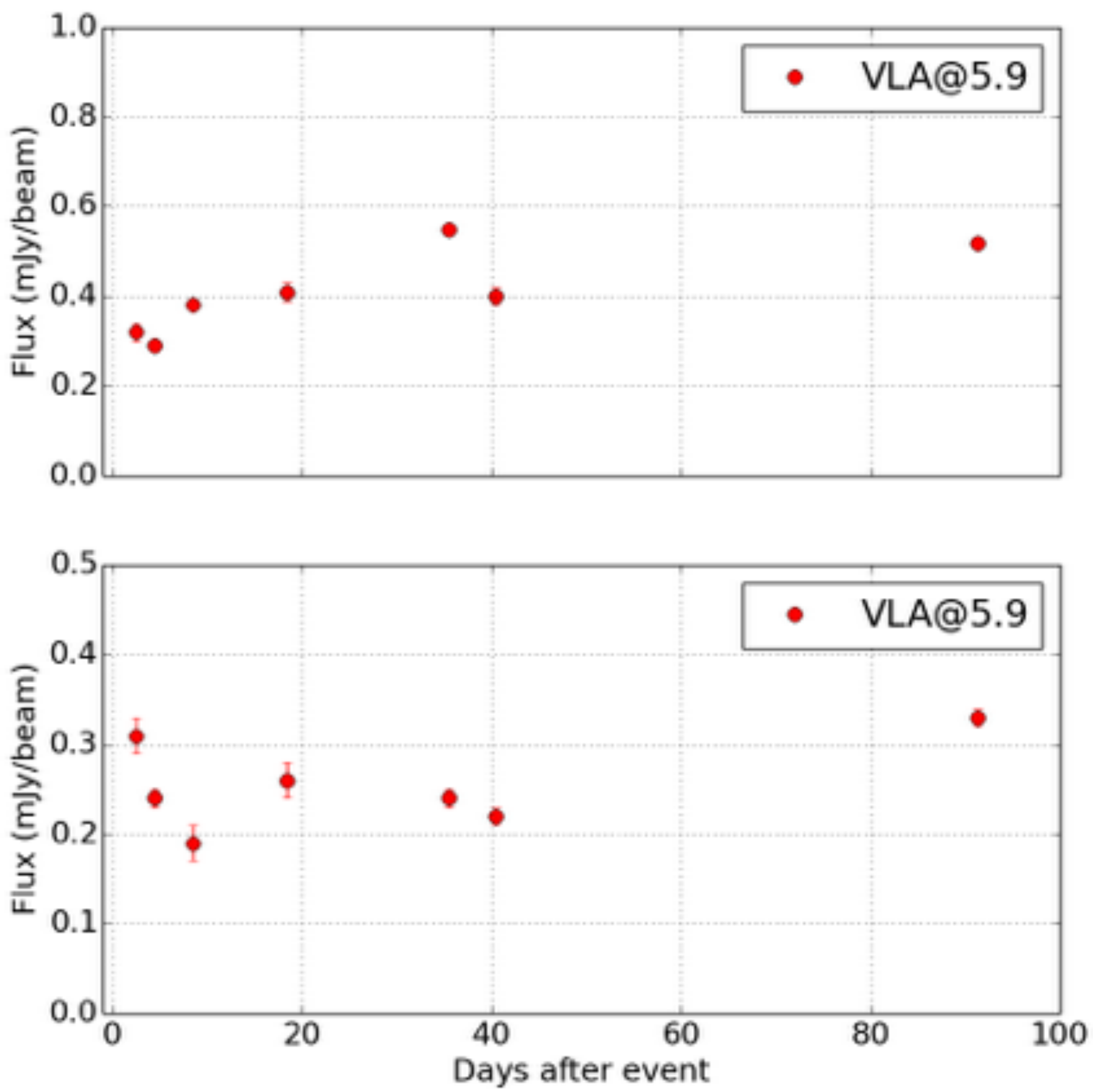
- ATCA
  - 42 pointing mosaics encompassing Parkes 15’ FWHM.
  - C band at center freqs : 5.5 GHz and 7.5 GHz.
  - High sensitivity (RMS ~ 40 μJy/beam).
- GMRT
  - L band at center freq : 1.4 GHz.
  - High sensitivity (RMS~ 30 μJy/beam).
- VLA
  - 7 pointing mosaics encompassing Parkes 15’ FWHM.
  - C band –at center freq : 5.9 GHz.
  - Very high sensitivity (RMS ~ 10 μJy/beam).

Image credit: NRAO.

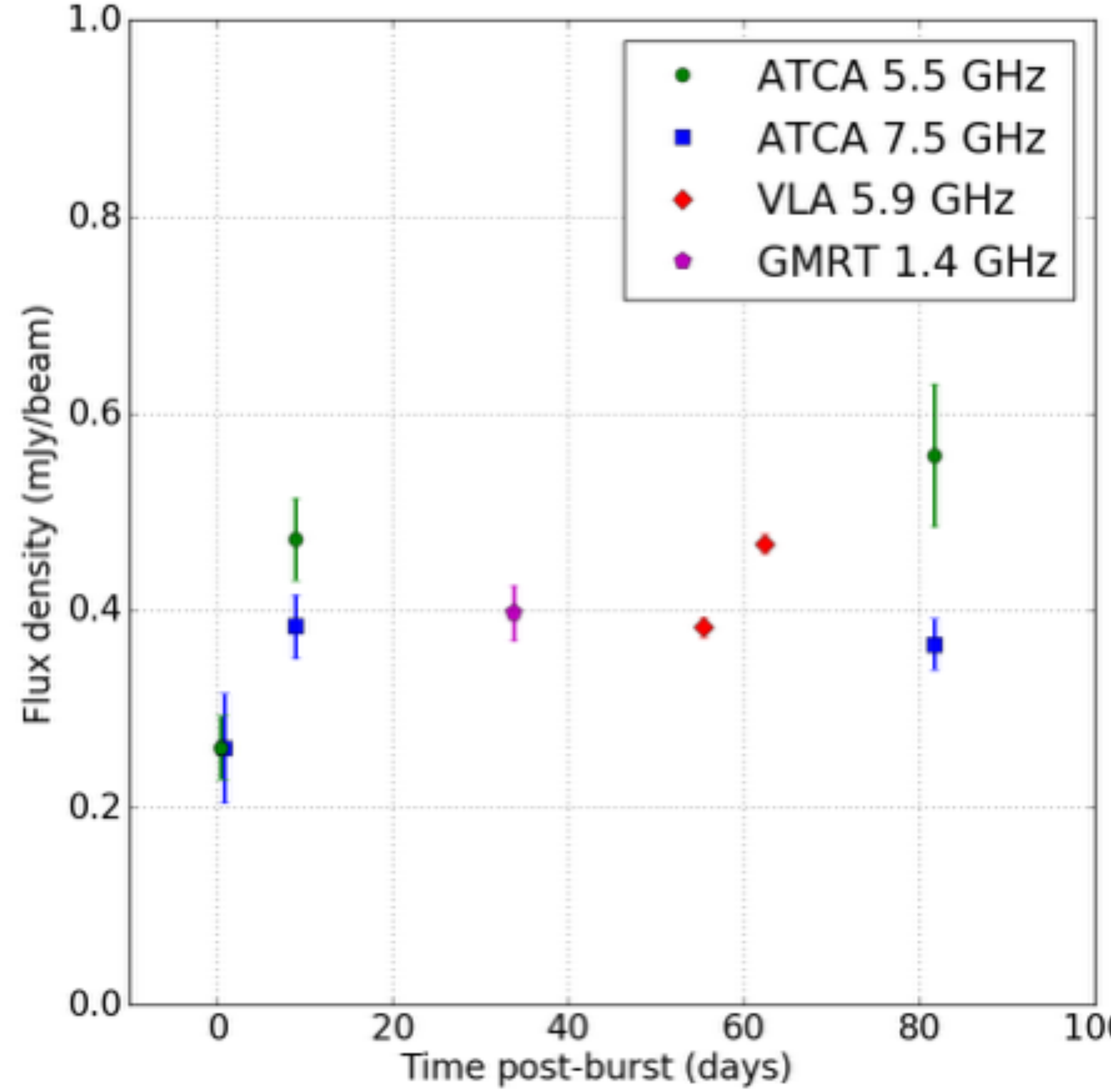
Radio variable sources in FRB fields







Significantly variable sources in VLA images of FRB 151206 field



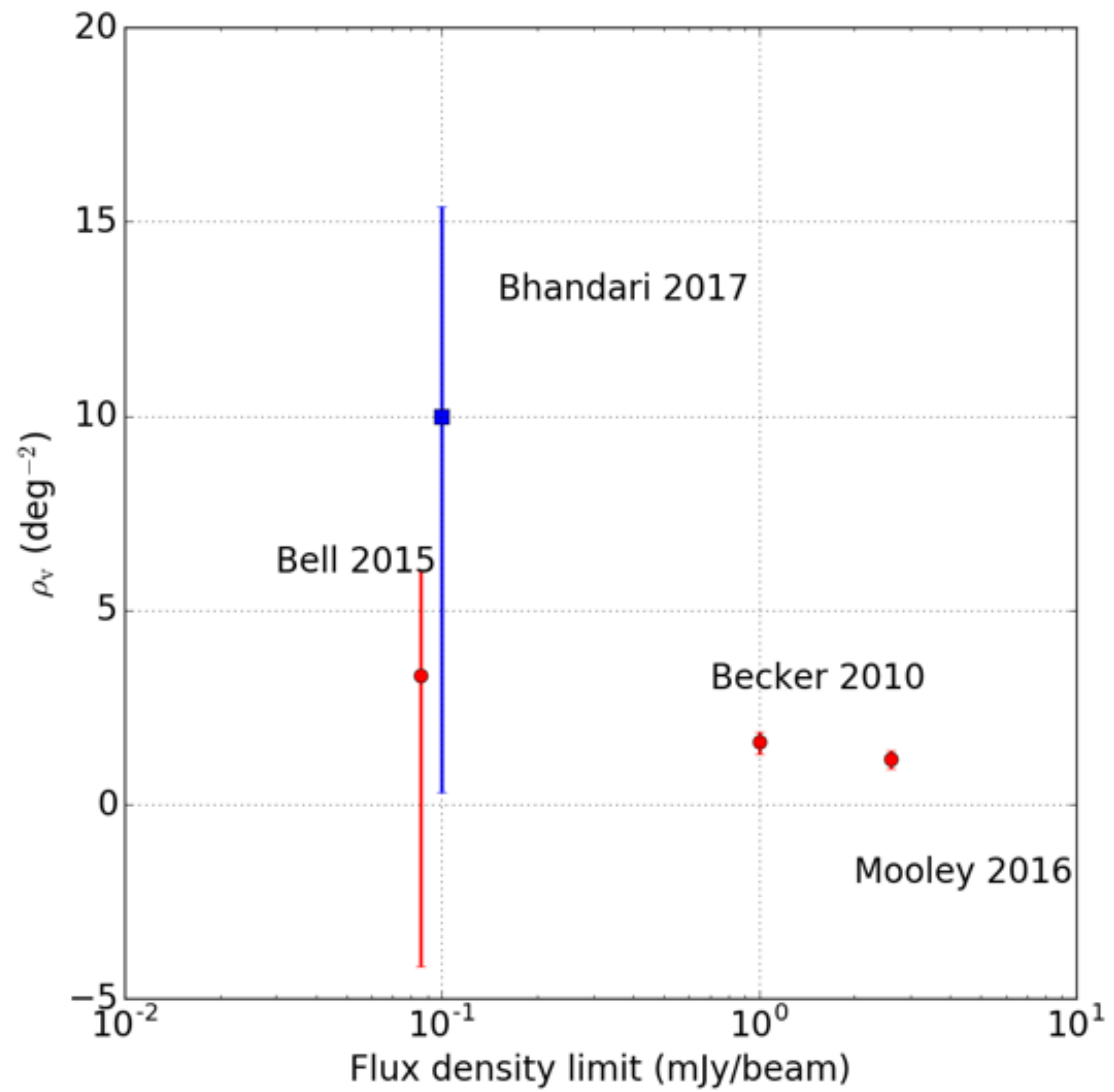
Significantly variable source in ATCA image of FRB 160102 field

Variability results

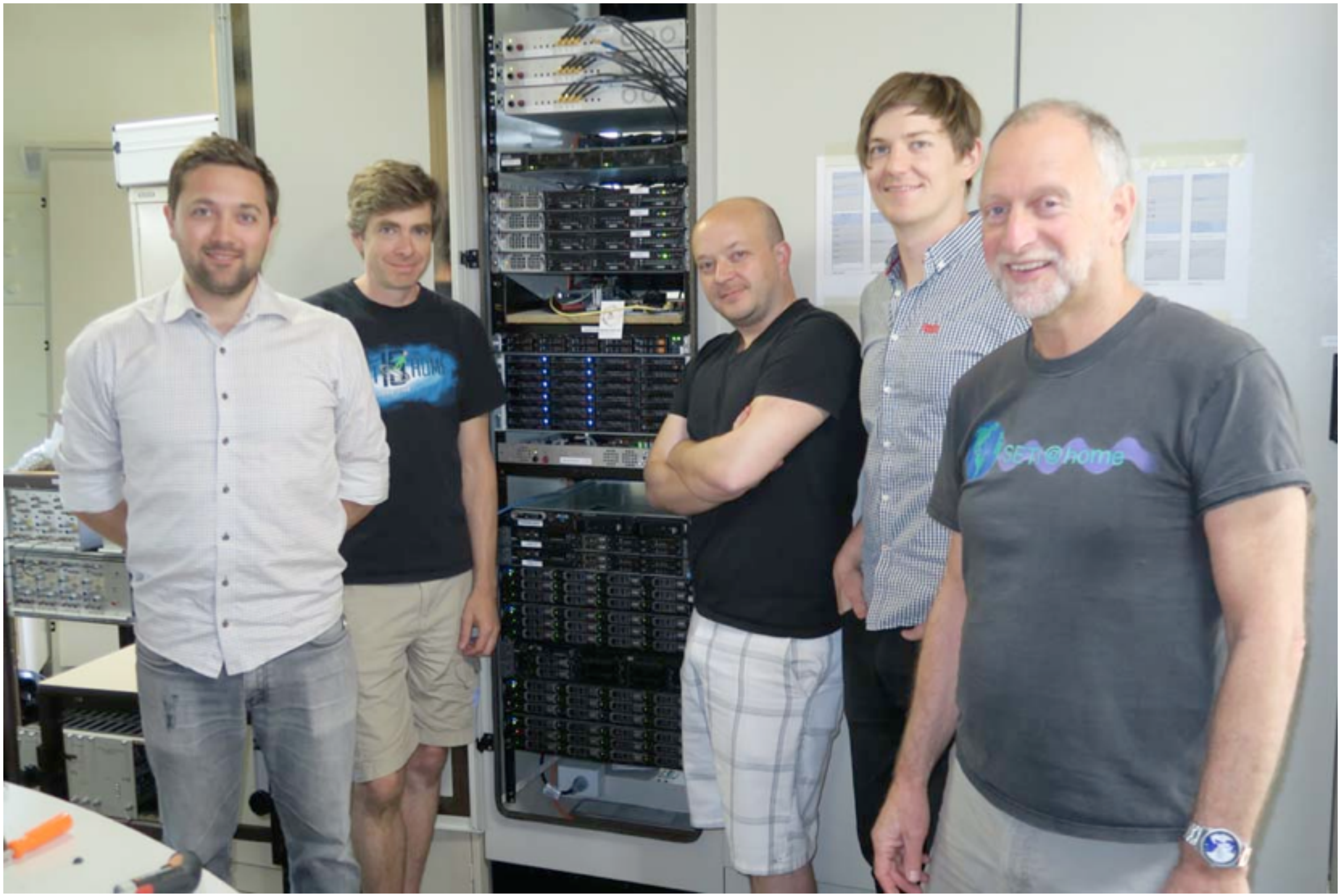
- Targeted
  - FOV
  - Flux
  - Signi (1-sigma poisson error)

- Comparir 5
  - FC
  - Fl
  - Sig (1-sigma poisson error)

Nun s



BREAKTHROUGH INITIATIVES



Credit: CSIRO

PPTA

~36 hours every ~fortnight

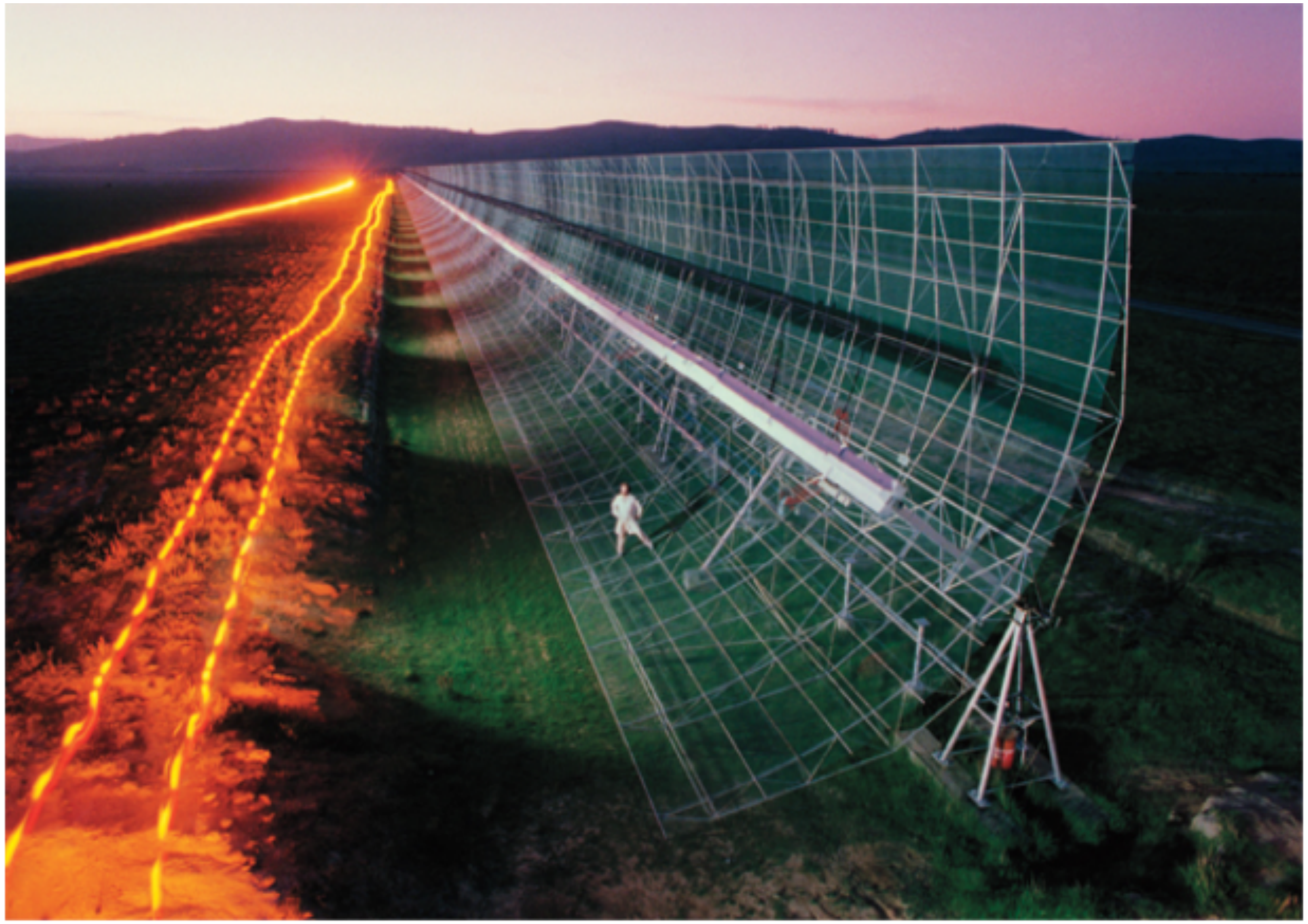
Australian National University

CAASTRO
ARC CENTRE OF EXCELLENCE FOR ALL-SKY ASTROPHYSICS

CSIRO

THE UNIVERSITY OF SYDNEY

SWIN BUR NE



Phased array

1.6 km x 12 m

7744 antennae

352 modules (i.e. telescopes)

EW arm of cross

843 MHz

15 MHz bandwidth

10 ns sampling

Australian National University

CAASTRO
ARC CENTRE OF EXCELLENCE FOR ALL-SKY ASTROPHYSICS

CSIRO

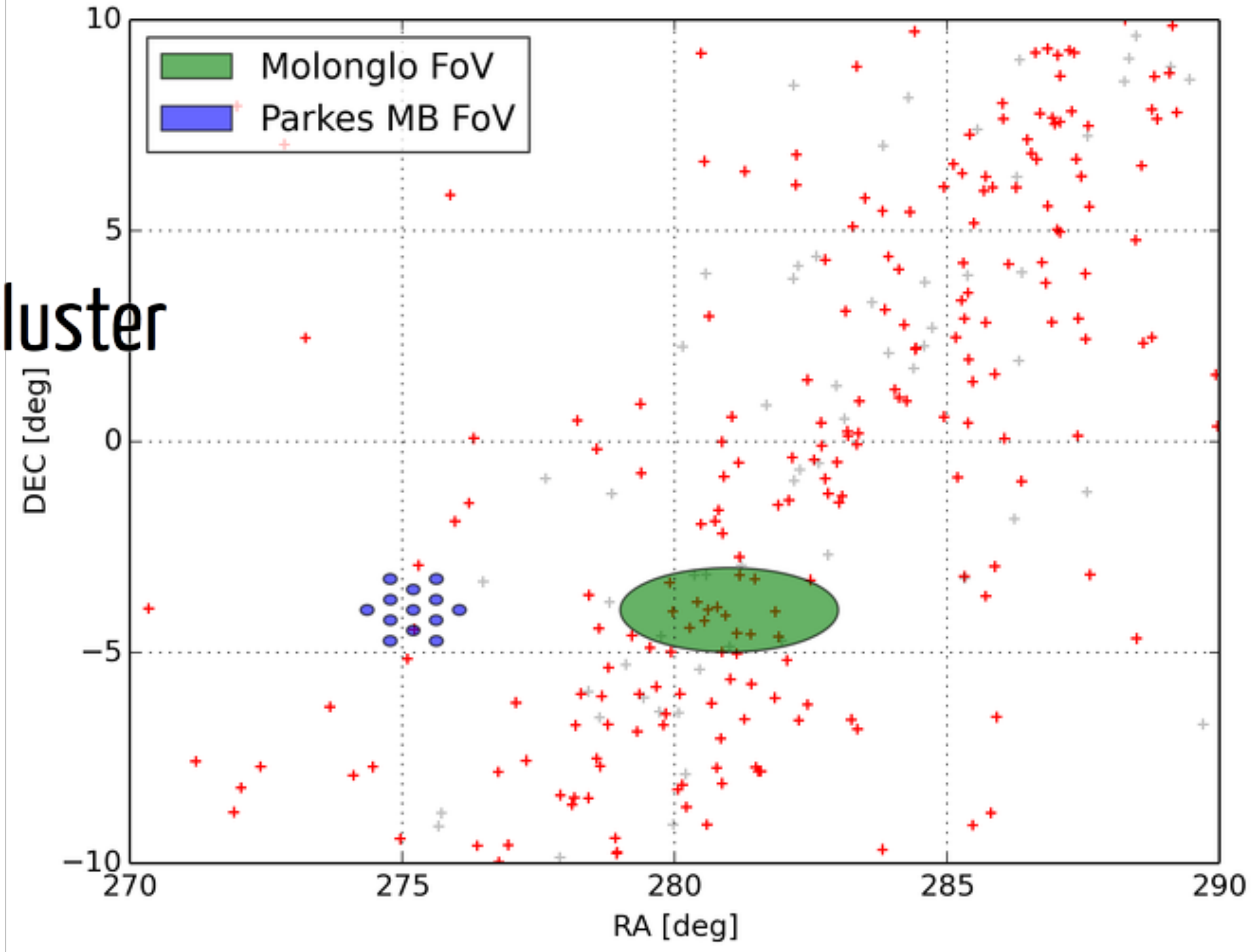
THE UNIVERSITY OF SYDNEY

SWIN BUR NE

Field of View currently tiled with 352 "fanbeams"

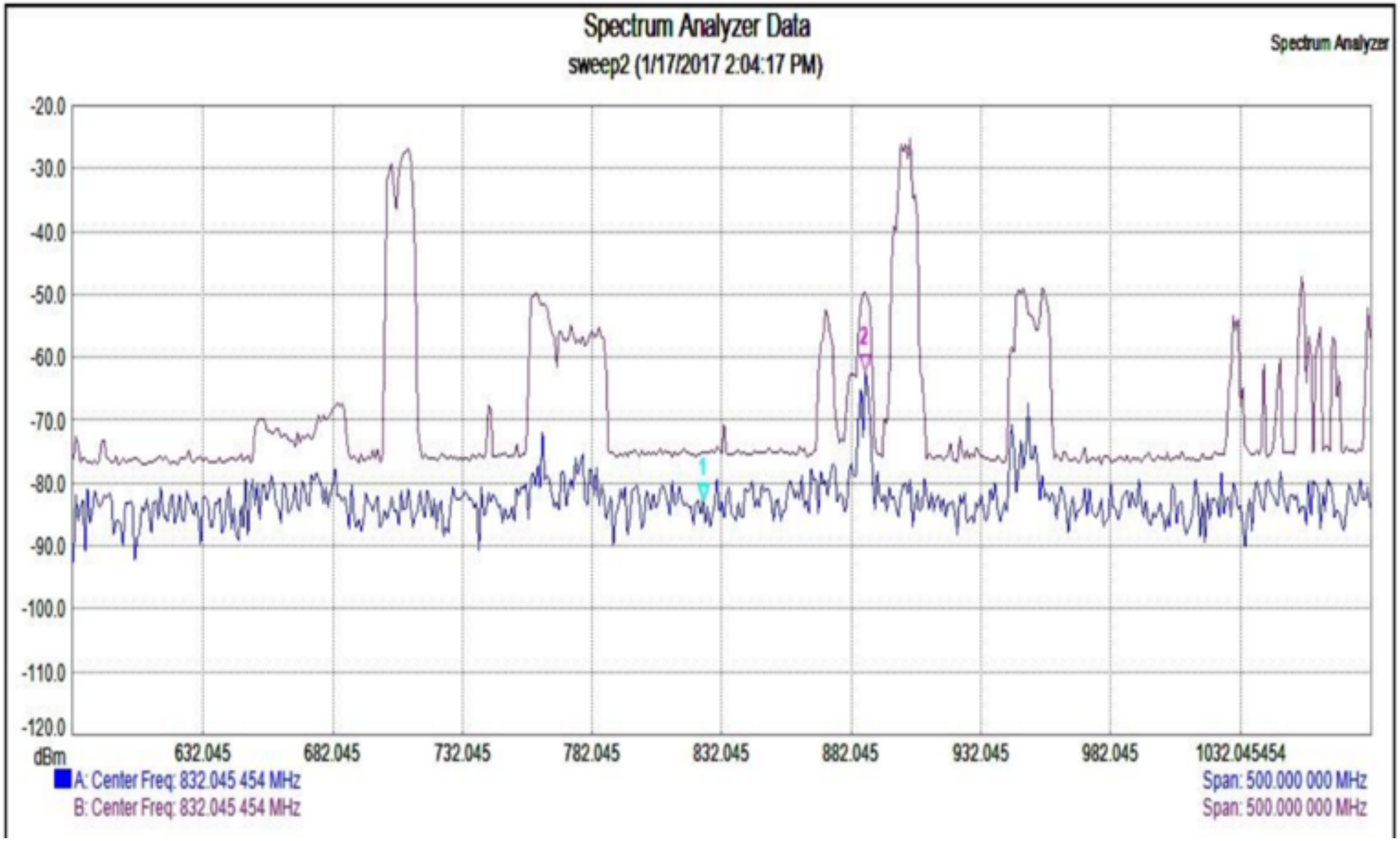
46" x 2 deg

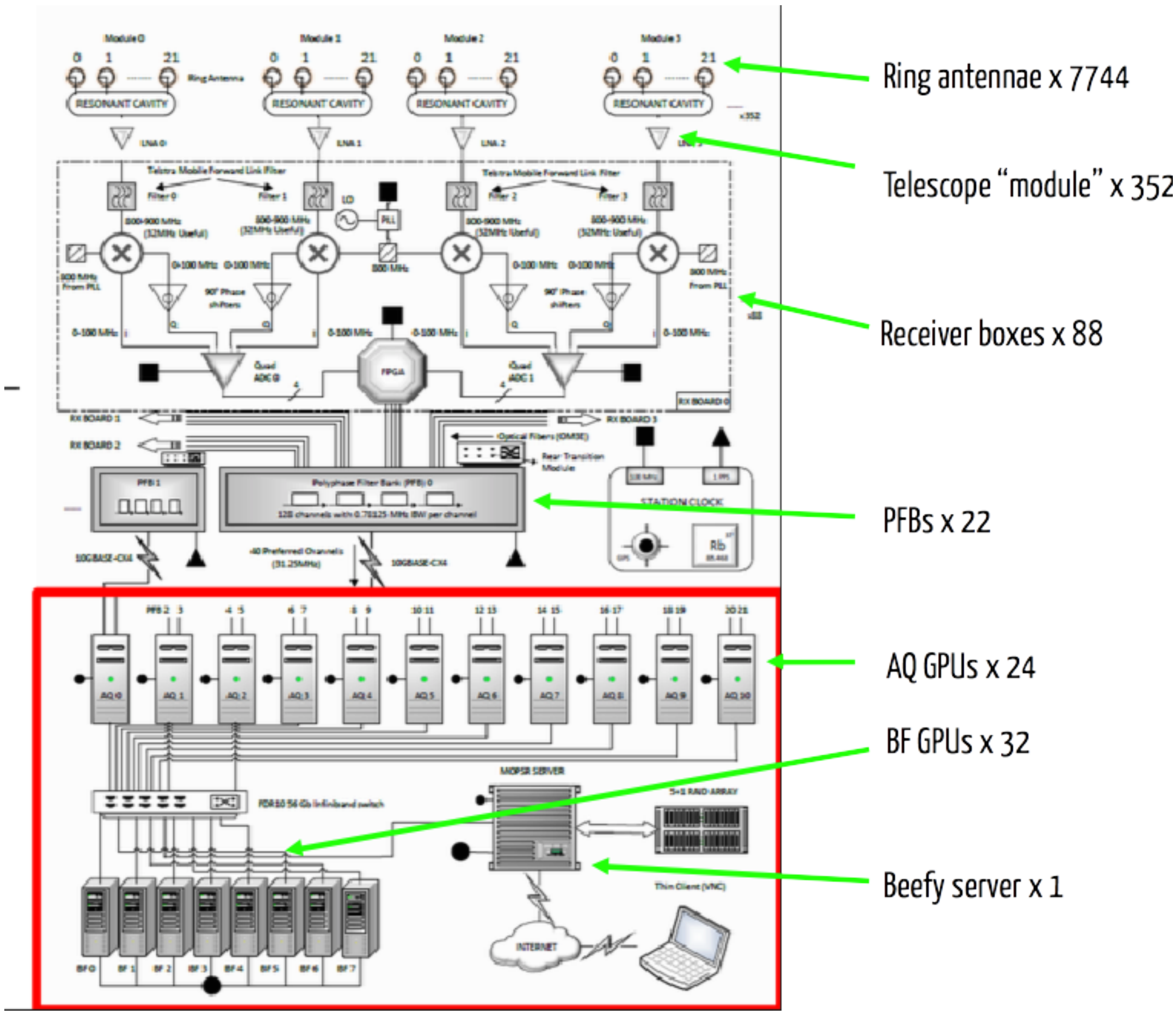
Twice this number sustainable by GPU cluster



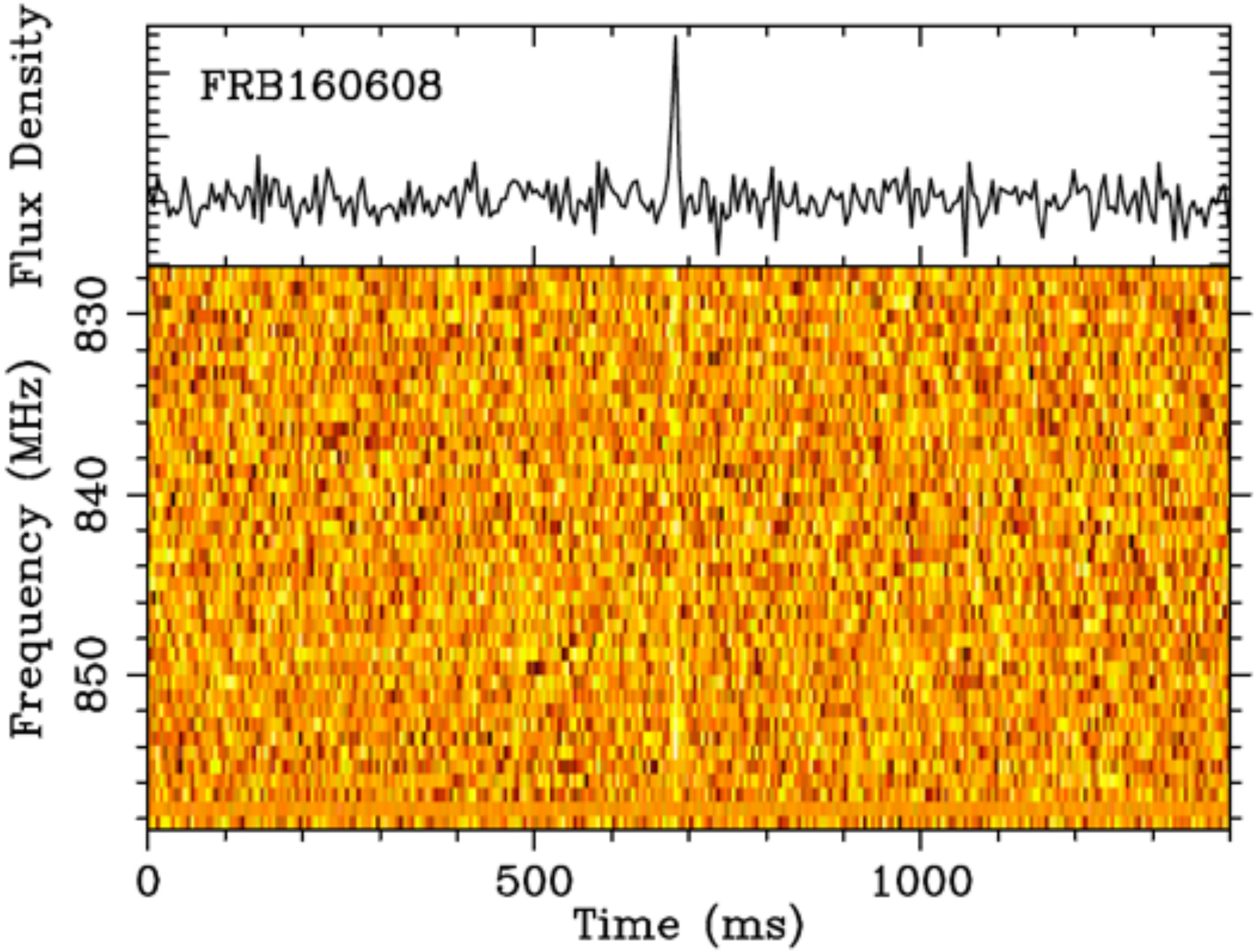
What are the challenges?

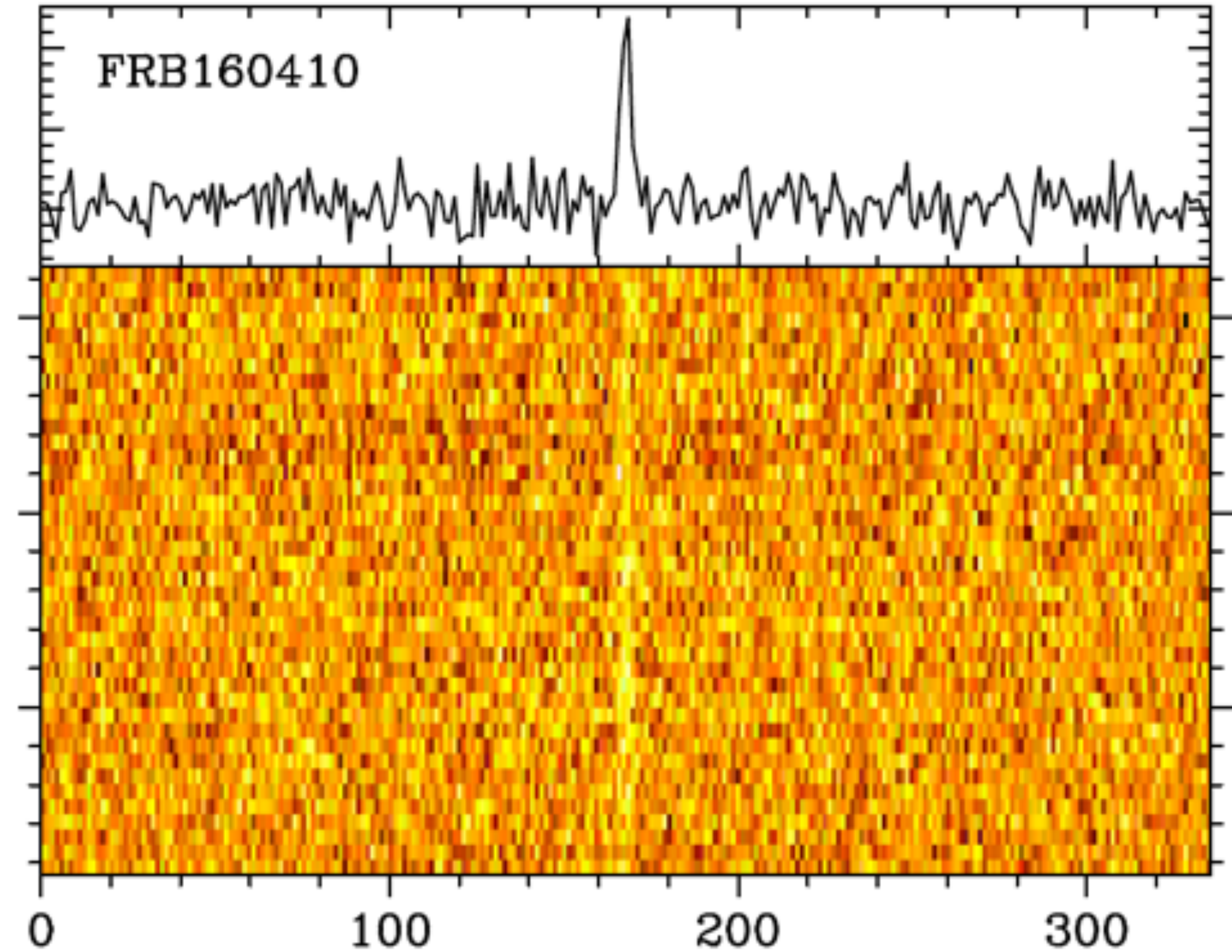
- RFI on-site

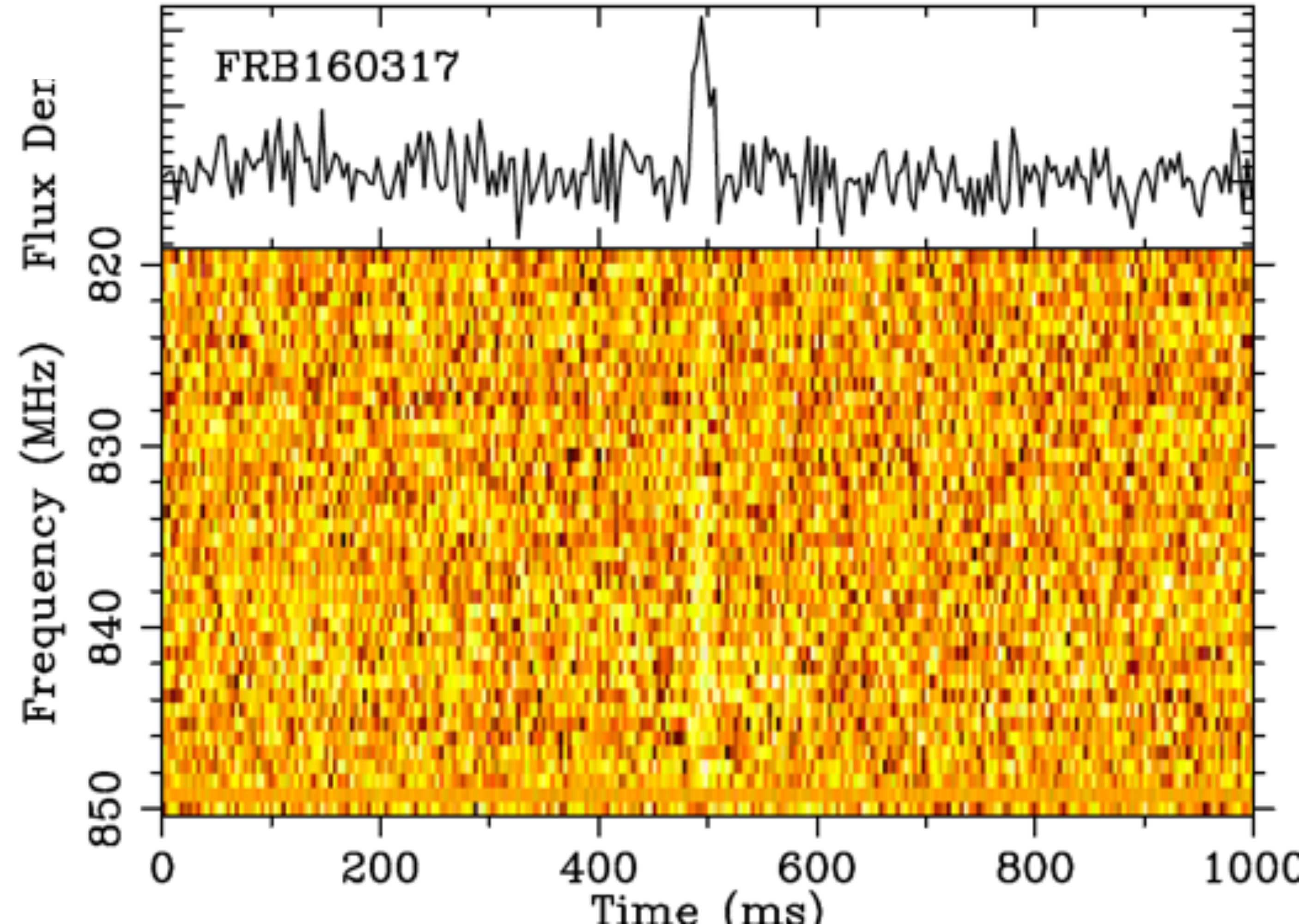




Ring antennae x 7744
Telescope "module" x 352
Receiver boxes x 88
PFBs x 22
AQ GPUs x 24
BF GPUs x 32
Beefy server x 1
RESONANT CAVITY
STATION CLOCK
INTERNET

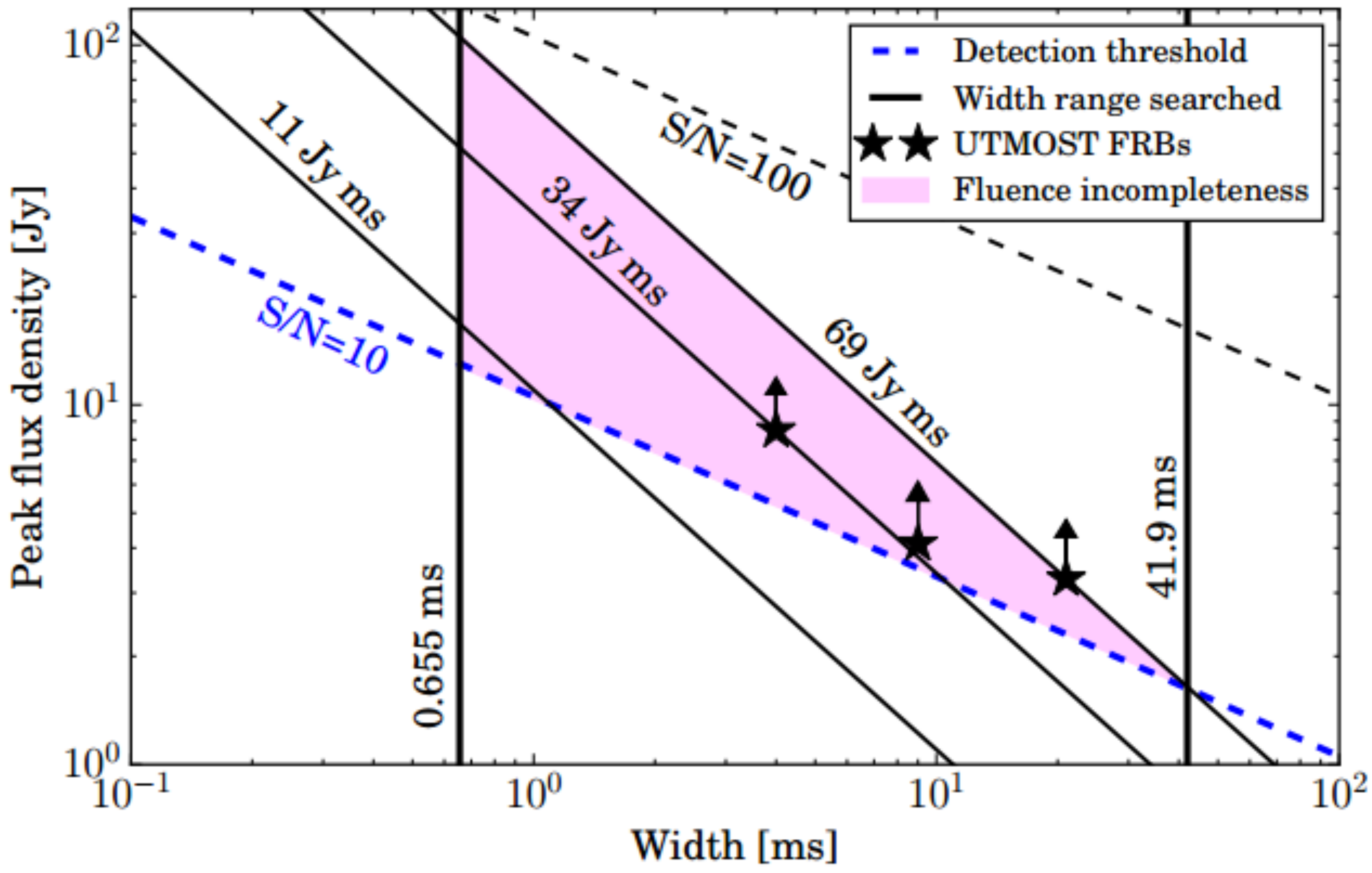






Credit:

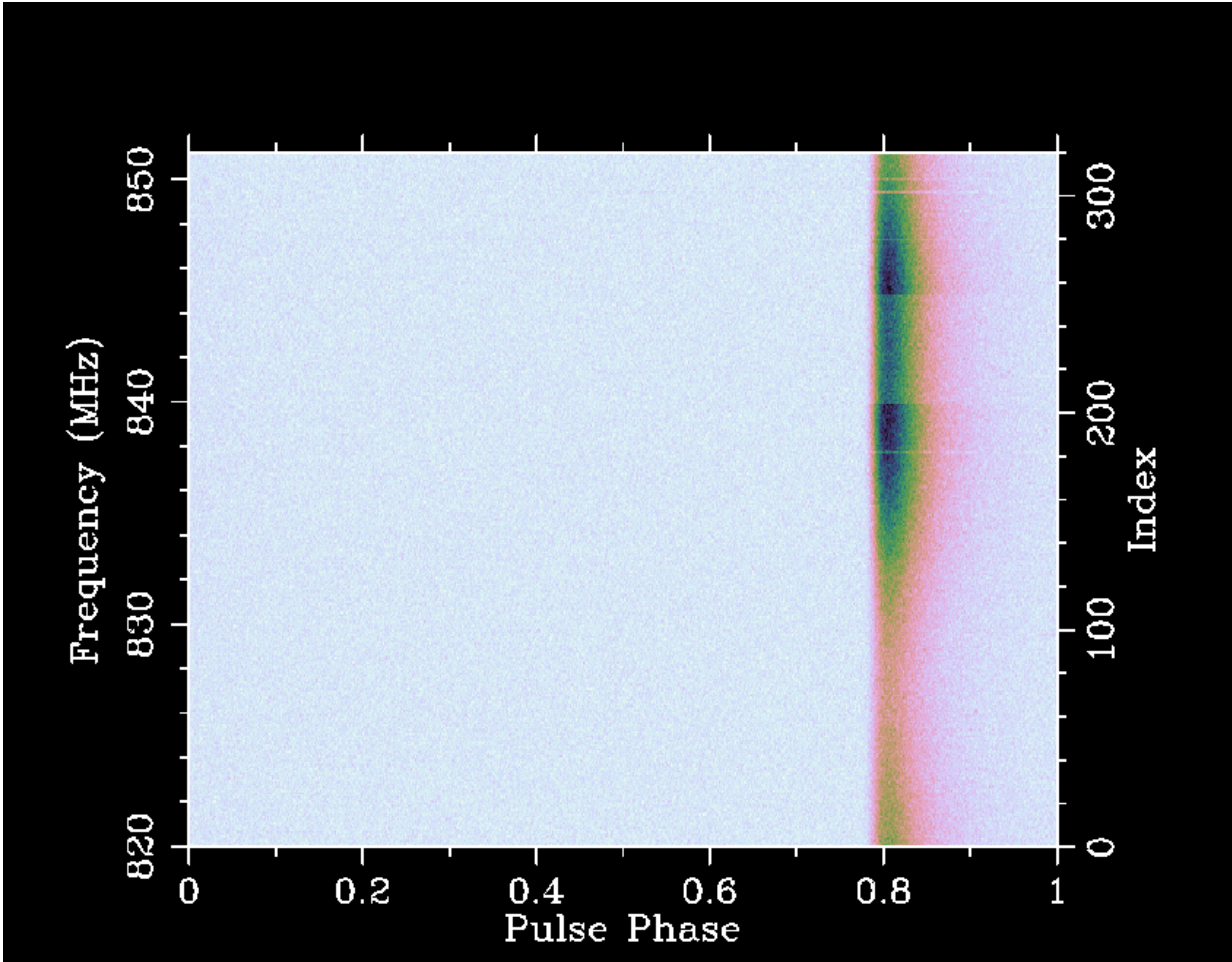
Caleb et al., 2017

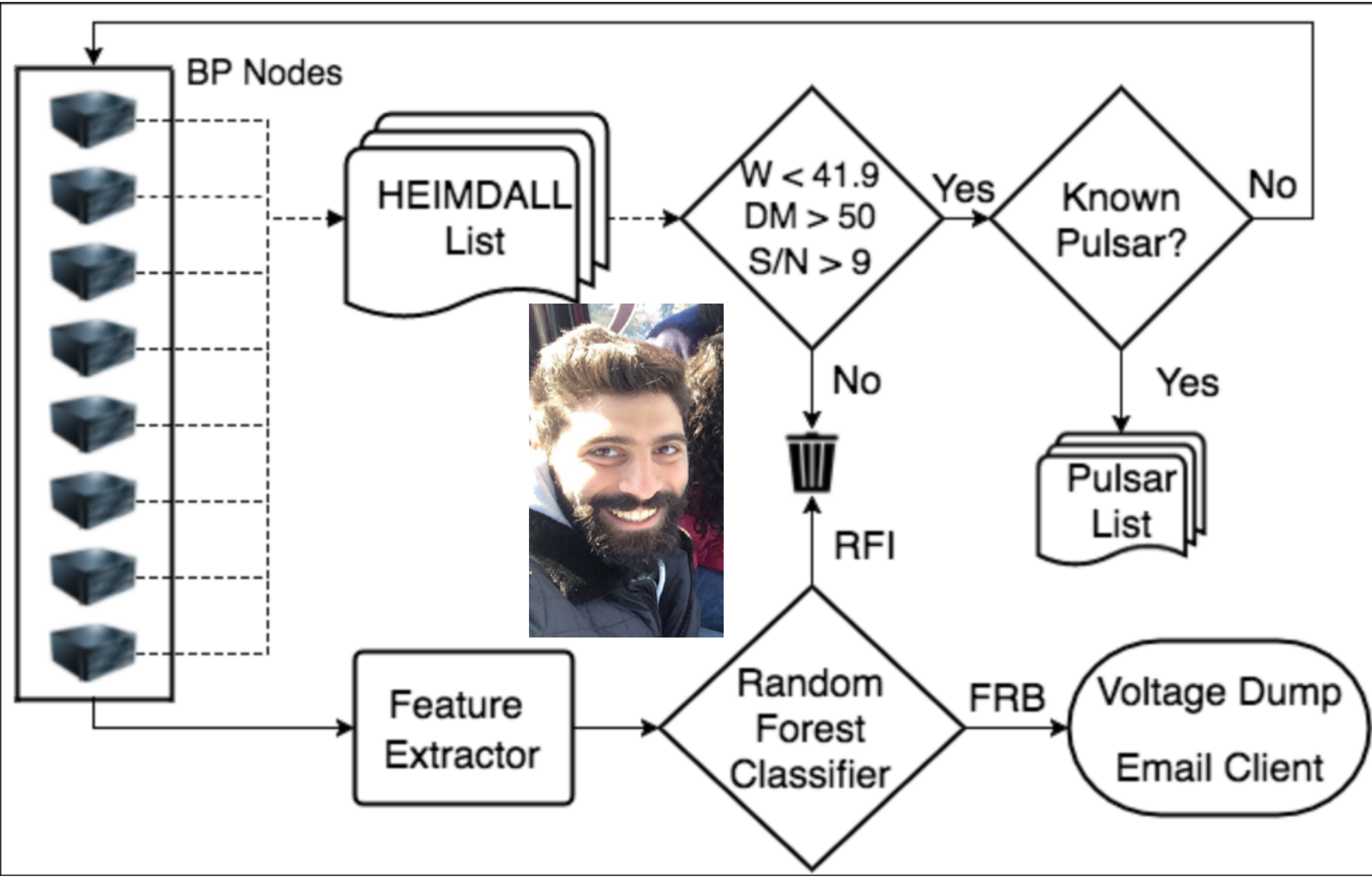


Credit:

Caleb et al., 2017

Backend improvements




BP Nodes
HEIMDALL List
W < 41.9
DM > 50
S/N > 9
Yes
Known Pulsar?
No
No
Yes
Pulsar List
RFI
Feature Extractor
Random Forest Classifier
FRB
Voltage Dump
Email Client

UTMOST FRB Detector noreply@utmost.usyd.edu.au via utu.fi — 03:35 (27 minutes ago)

to Andrew, Adam, bateman.tim, Timothy.Bateman, Christopher, fjankowsk, Jr-Wei, kaplant, manisha.caleb, Mattl

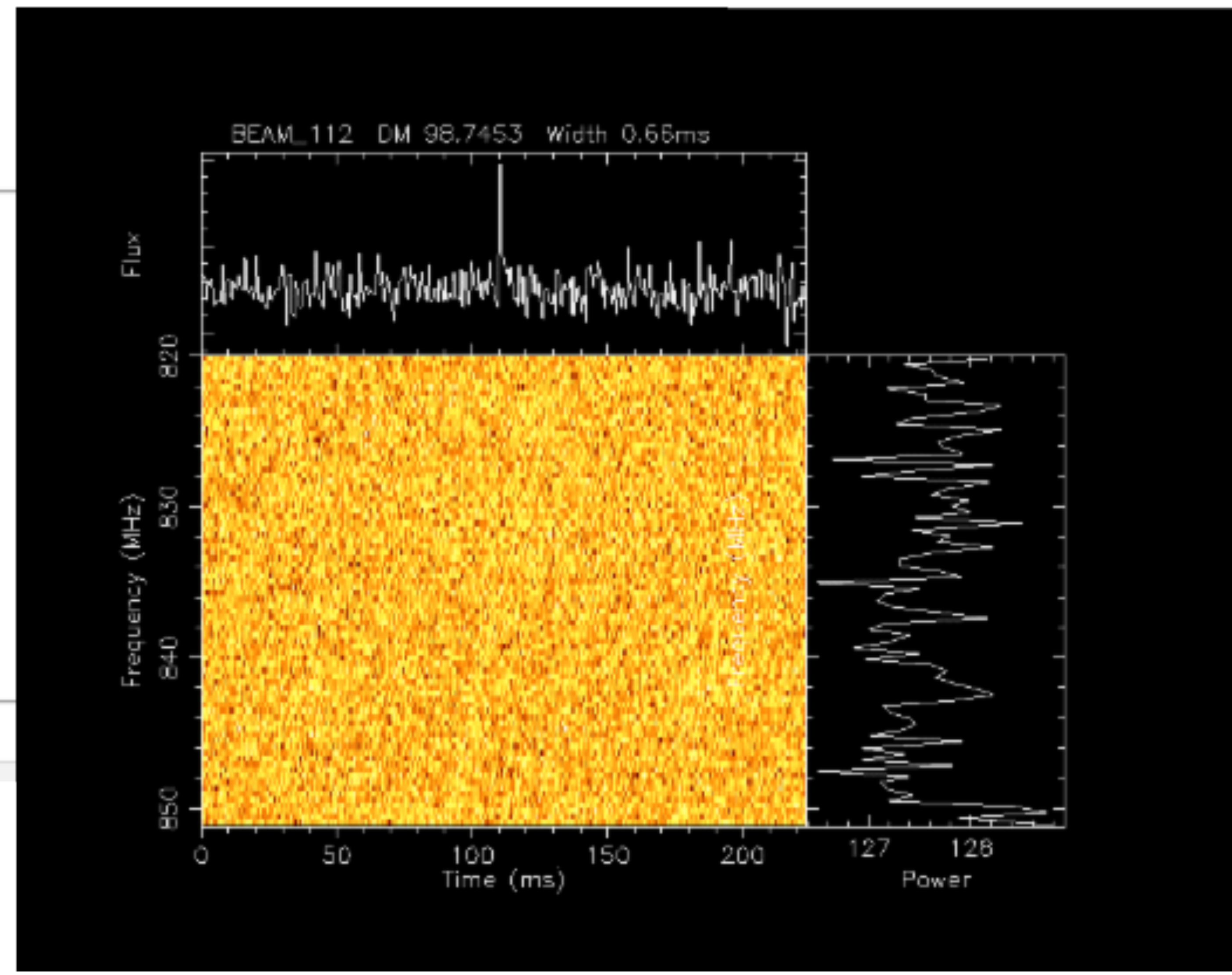
Candidate

UTC	2017-02-16-16:35:00.3
SNR	9.27441978455
DM	98.7453
Width	0.655 ms
Probability	[0.8167431]

Observation

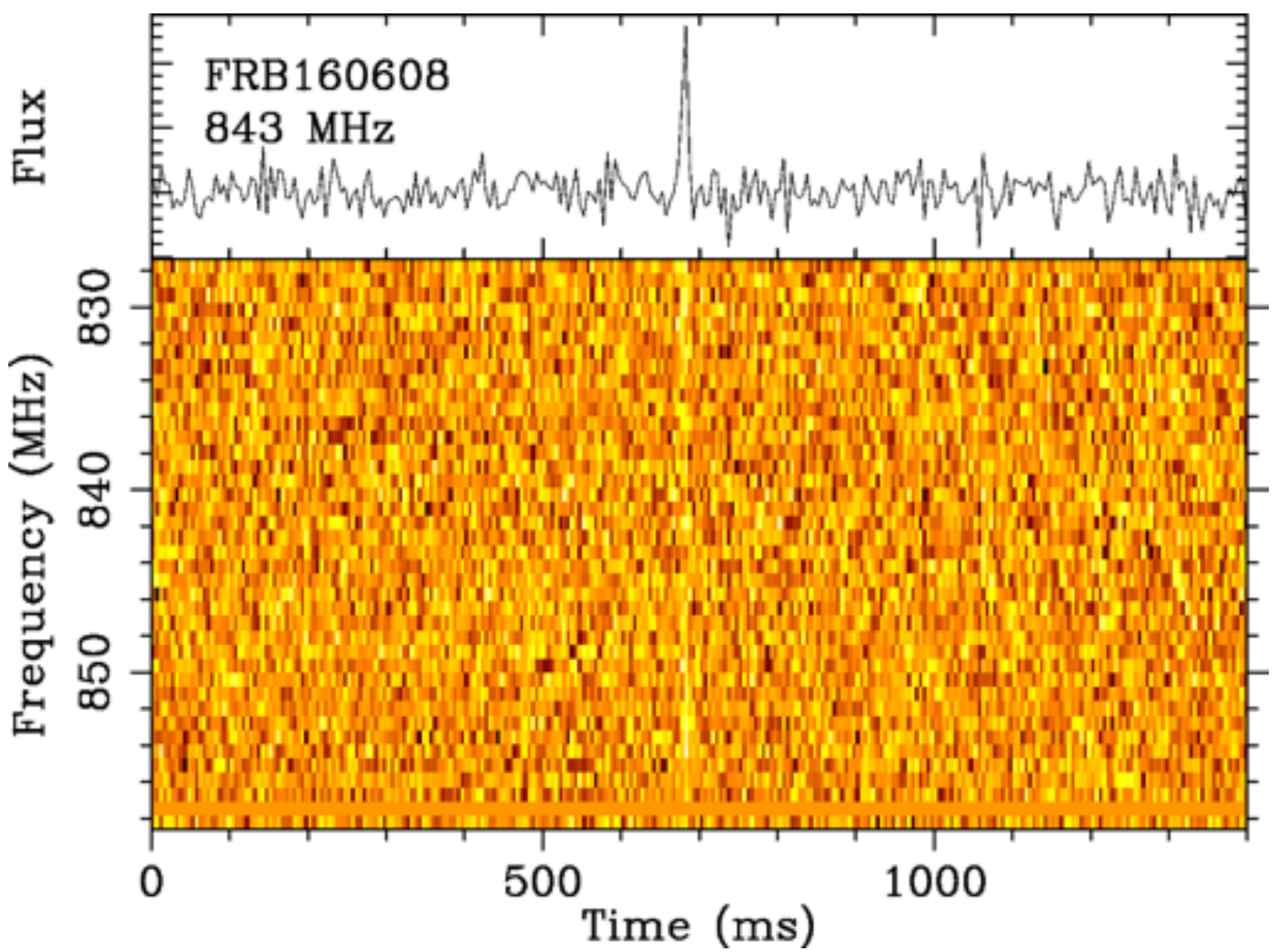
UTC START	2017-02-16-15:53:09
Beam	112
MD Offset	-0.752137 degrees
Total Beams	352
PID	P000
Voltage Dump	true
Dump Start	2017-02-16-16:35:00.2
Dump End	2017-02-16-16:35:00.5

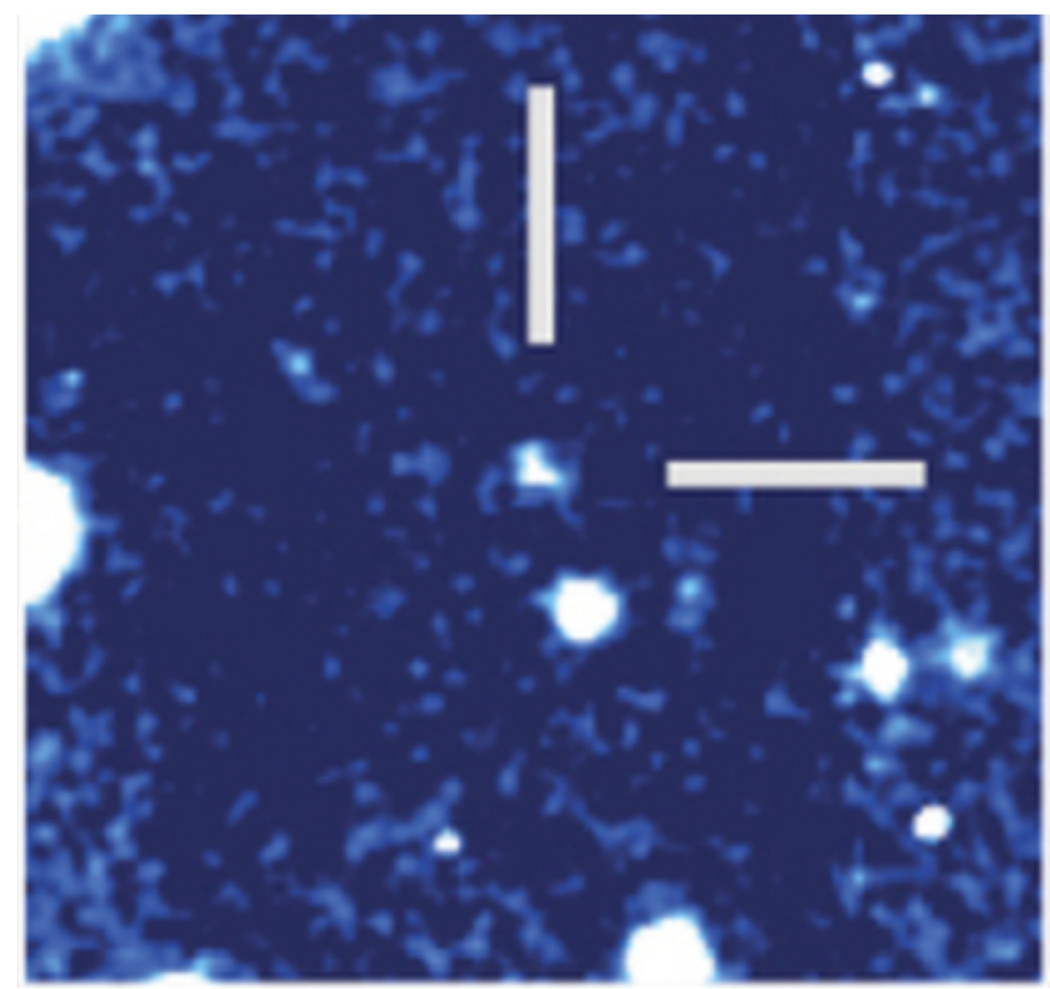
Boresight Properties



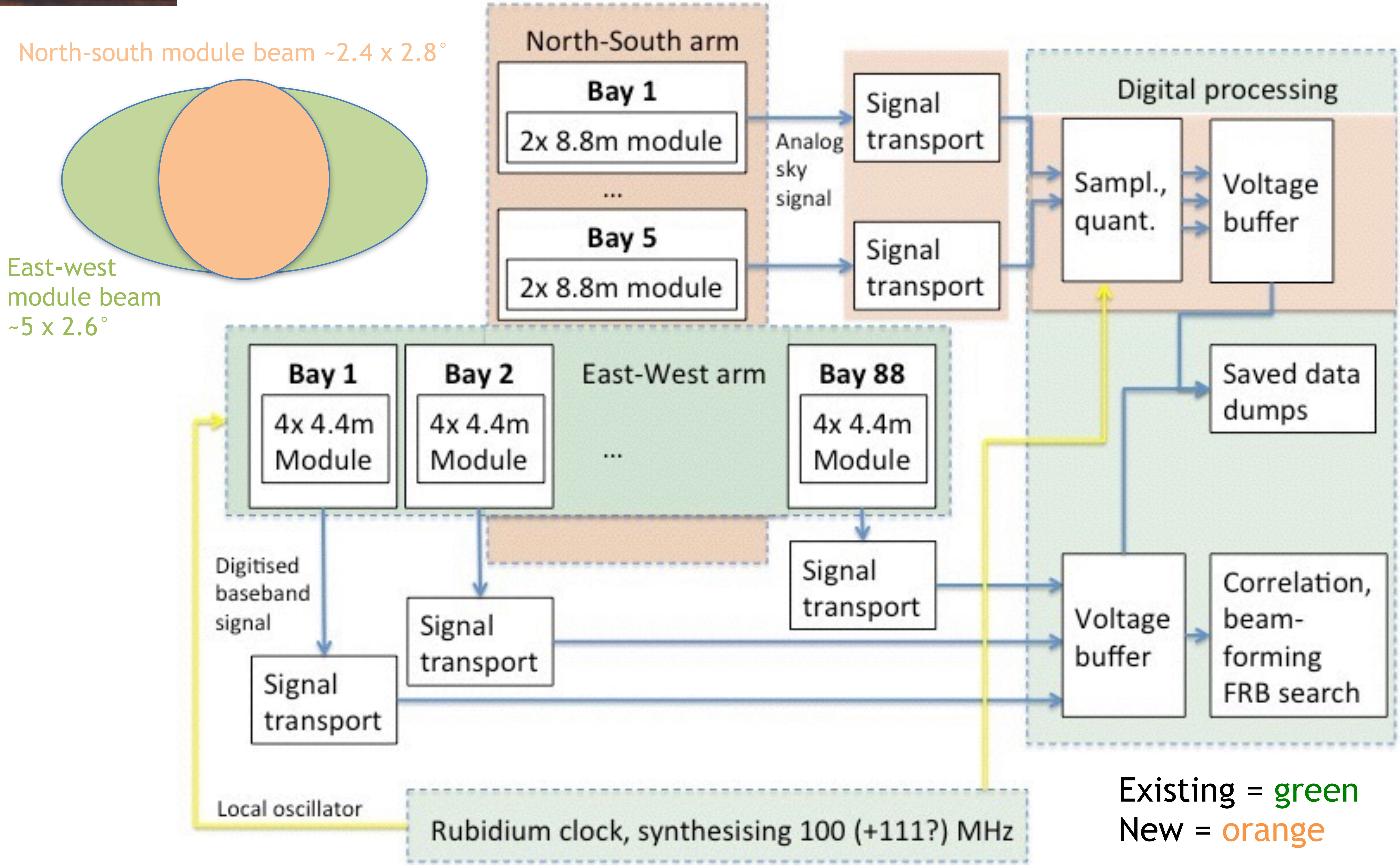
UTMOST-2D: What is it?

A project to get dozens of FRB host galaxies
(>40% of the FRBs detected by UTMOST)



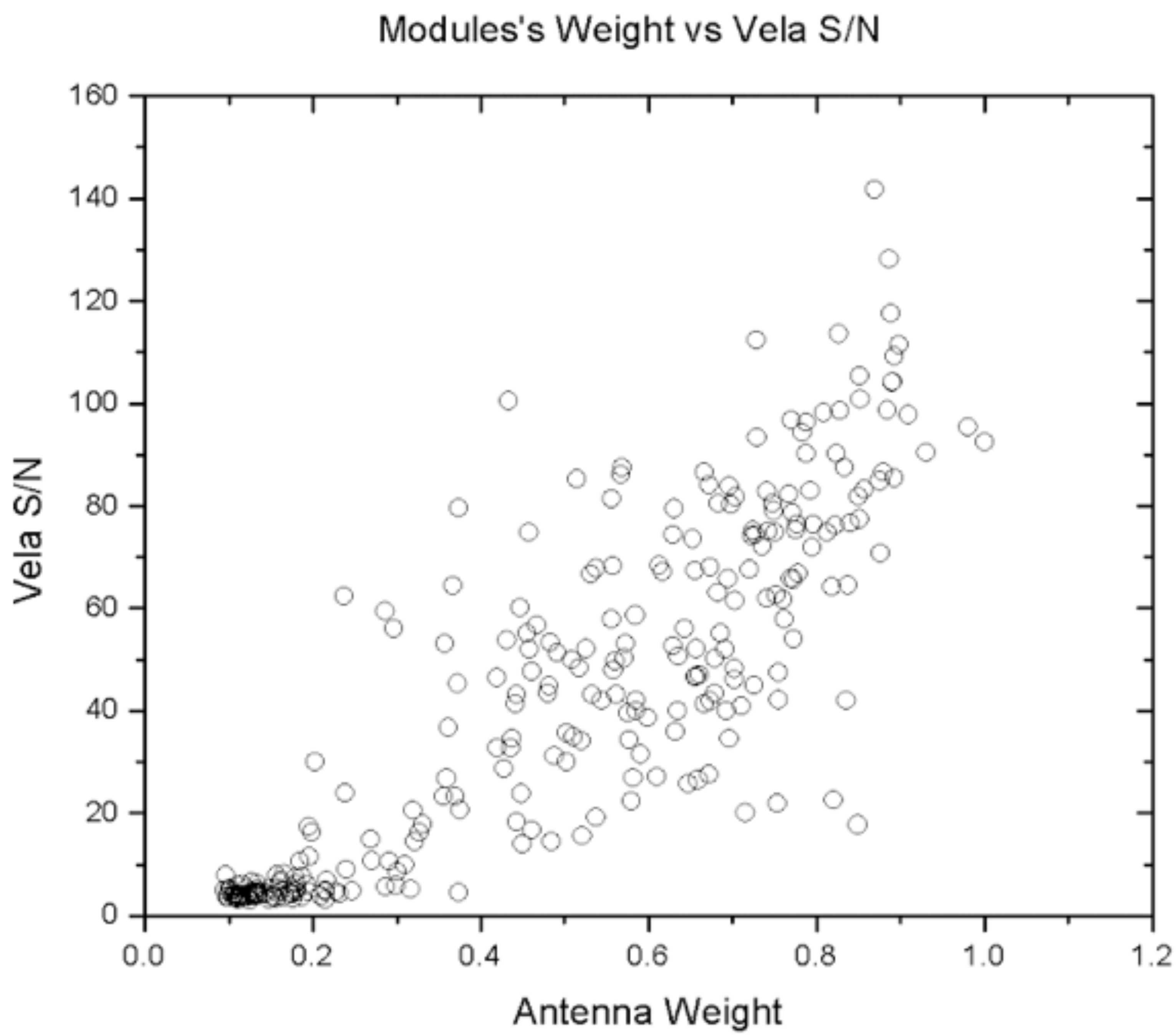


How will it localise FRBs?



What are the challenges?

- RFI on-site
- RF engineer time
- UTMOST sensitivity



What are the challenges?

What are the challenges?

Timeline

- Project commenced: October 2016
- Requirements: Q4 2016
- Component design: Q1, Q2 2017
- Manufacturing / prototyping: Q3 2017
- Module testing: Q4 2017
- Science commissioning: Q1 2018

CRAFT

Thanks!

PI: Keith Bannister (ATNF)

- Andrew Brown (ATNF)
- John Tuthill (ATNF)
- Aidan Hotan (ATNF)
- Maxim Voronkov (ATNF)
- Ryan Shannon (ATNF/Curtin)
- J-P Macquart (Curtin)
- Wayne Arcus (Curtin)
- Stefan Oslowski (Swinburne)
- Morgan O'Neill (Swinburne)
- Andrew Jameson (Swinburne)

ASKAP will be...

- 36 antennas
- Each antenna: 36 beams = ~ 30 deg^2
- Tuning: 0.7-1.8 GHz
- 336 x 1 MHz channels (only 300 MHz for interferometry)
- Search with autocorrelations (incoherent sum): ~@ 1ms & 1 MHz
- Triggered voltage transient buffer for interferometric localisation
- ~7” synthesised beam at 1.4 GHz

ASKAP is (May 2016)

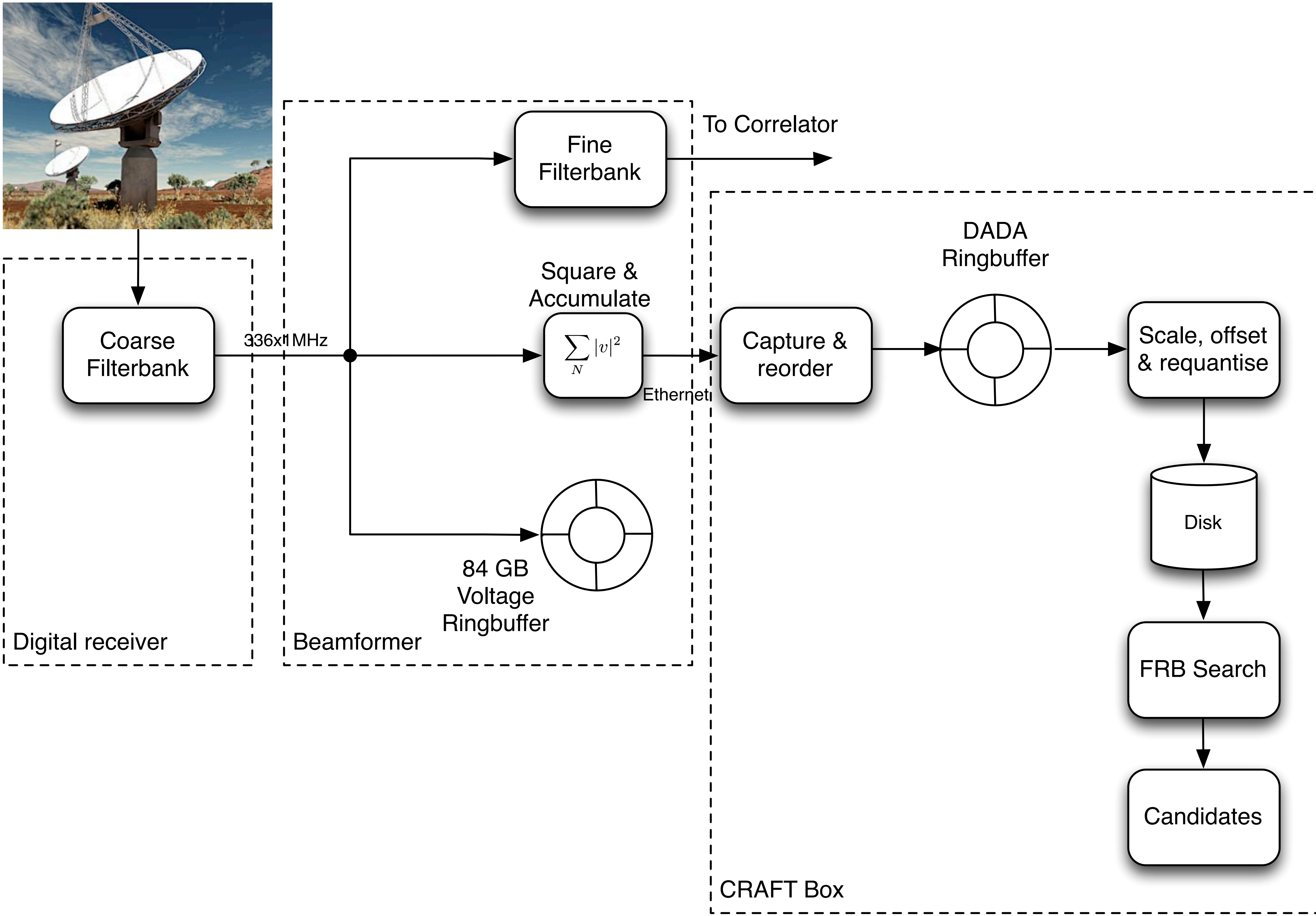
- 17 antennas with all equipment, connected to the correlator - “the array”
- A “commissioning array” of ~6 antennas (increasing by the day), used for single-dish work only.
- Operational FRB search mode with 15 antennas, offline processing

FRB Sensitivities

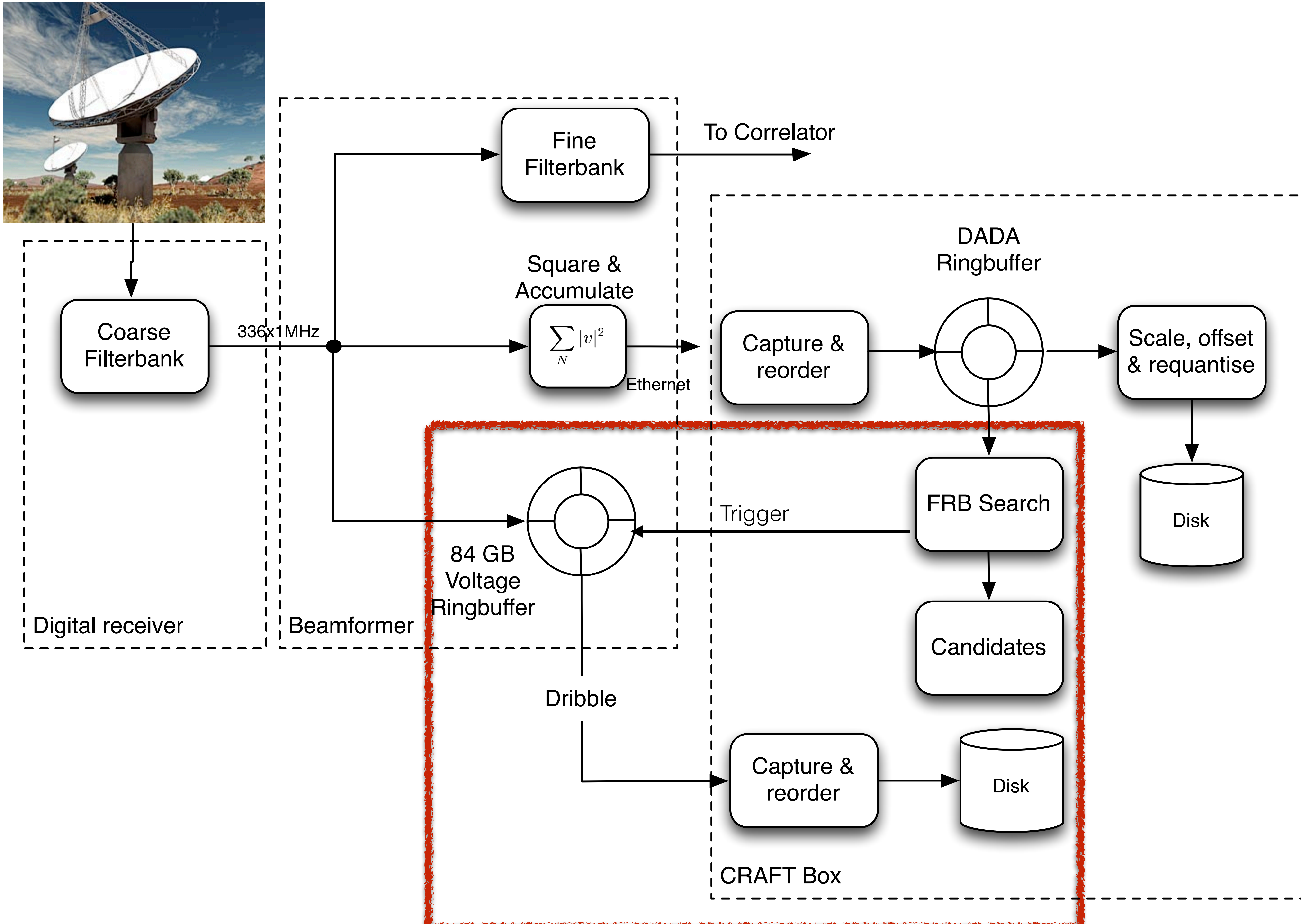
Nant	Date	Fly's Eye				Incoherent sum = Commensal		
		Sensitivity 1ms, 8σ (Jy)	FoV (deg^2)	Nbeams	Normalised FRB rate	Sensitivity 1ms, 8σ (Jy)	FoV (deg^2)	Normalised FRB rate
12	Dec 2016	25	360	432	1	7.2	30	1
15	April 2017	25	450	540	1.2	6.4	30	1.2
24	?	25	720	864	2	5.1	30	2
36	?	25	1080	1296	3	4.1	30	3

Assumptions: SEFD=1800 Jy, bandwidth=336 MHz, euclidian source counts, no flagging

CRAFT - now


To Correlator
Fine Filterbank
DADA Ringbuffer
Square & Accumulate
$\sum_N |v|^2$
Coarse Filterbank
336x1MHz
Ethernet
Capture & reorder
Scale, offset & requantise
Disk
84 GB Voltage Ringbuffer
Digital receiver
Beamformer
FRB Search
Candidates
CRAFT Box

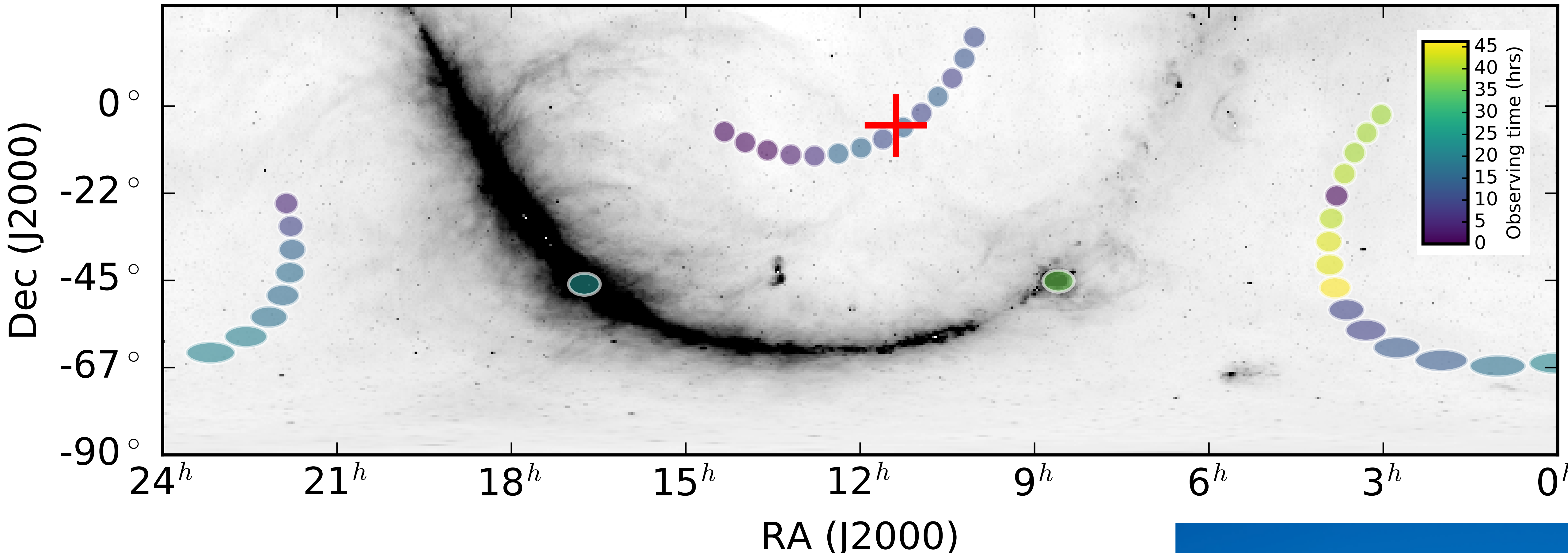
CRAFT - the next step



Capabilities - May 2017

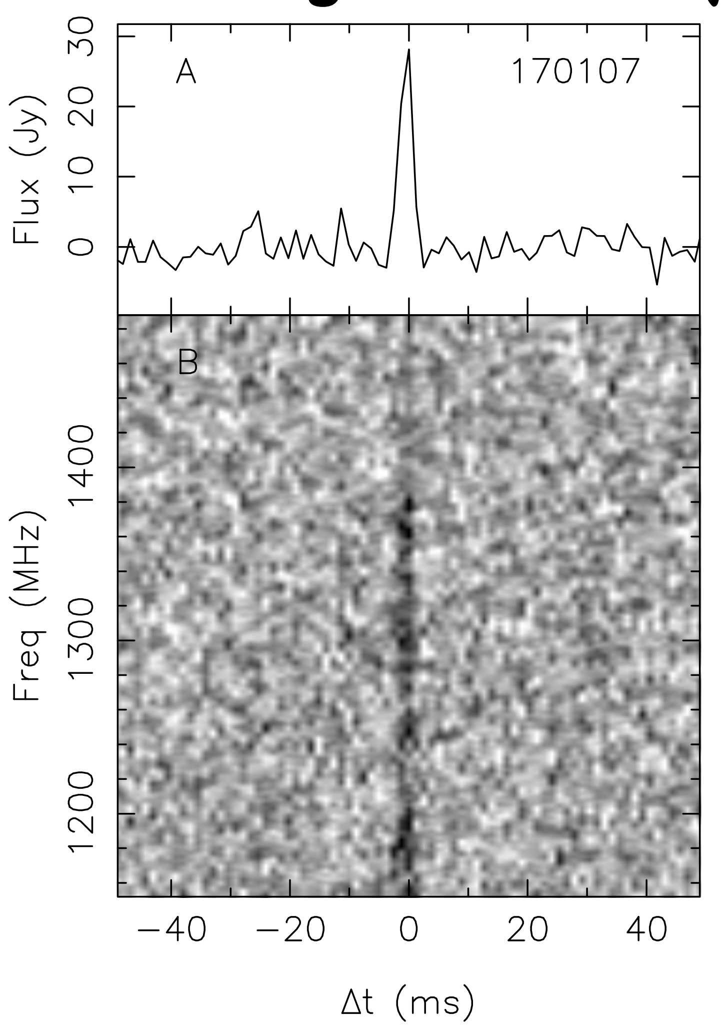
Spectra capture to disk	15 antennas/336 MHz/1ms/36 beams/polsum/8bits = 145 MB/sec = 13 TB/day
Transfer to Pawsey	100 MB/sec ~ real time for 12 antennas
Offline processing on Galaxy (64 x NVIDIA K20X)	36 beams @ 7x real time / GPU
On-site processing hardware (2x NVIDIA GTX 1070)	~ real time for 15 antennas 24TB disk, 32 GB RAM
Check CRAFT is commensal	Checked OK Dec 2016
Astronomer-friendly monitoring	OK - Grafana
Astronomer-friendly control	No: GNU screen/bash/Python
Rapid response to GCN triggers	Planned for June 2017 if "commissioning array" available
Voltage trigger & download	Firmware available Initial commissioning started
Real-time FRB search	Planned for June 2017
Calibration & Imaging pipeline	Planned for Sep 2017

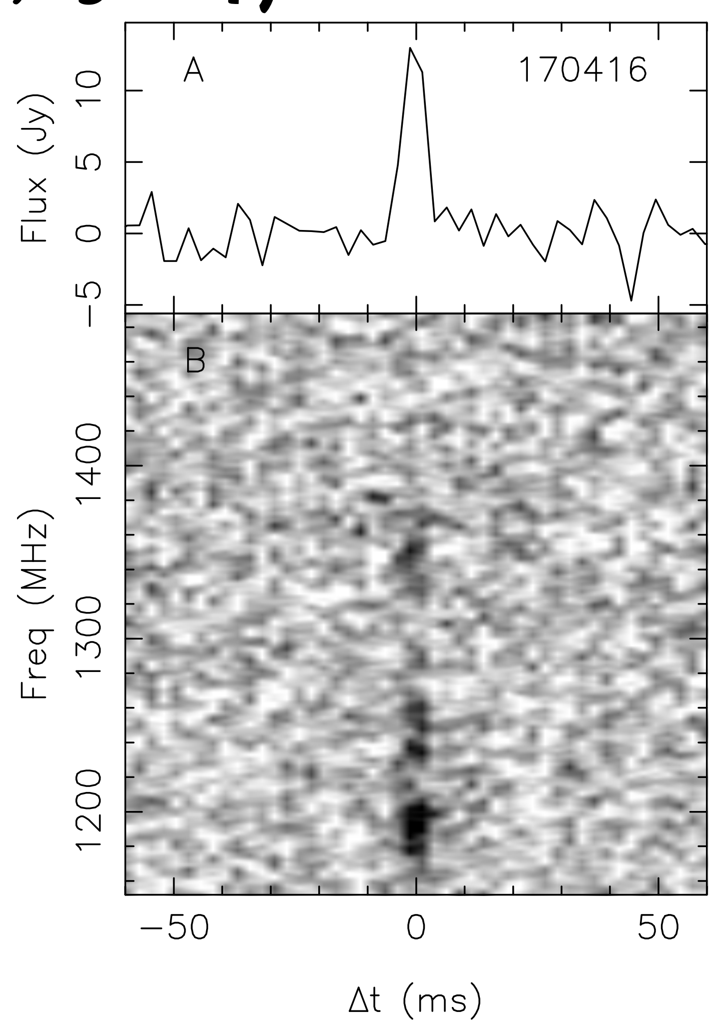
Flye's-eye observing @ |b|=50

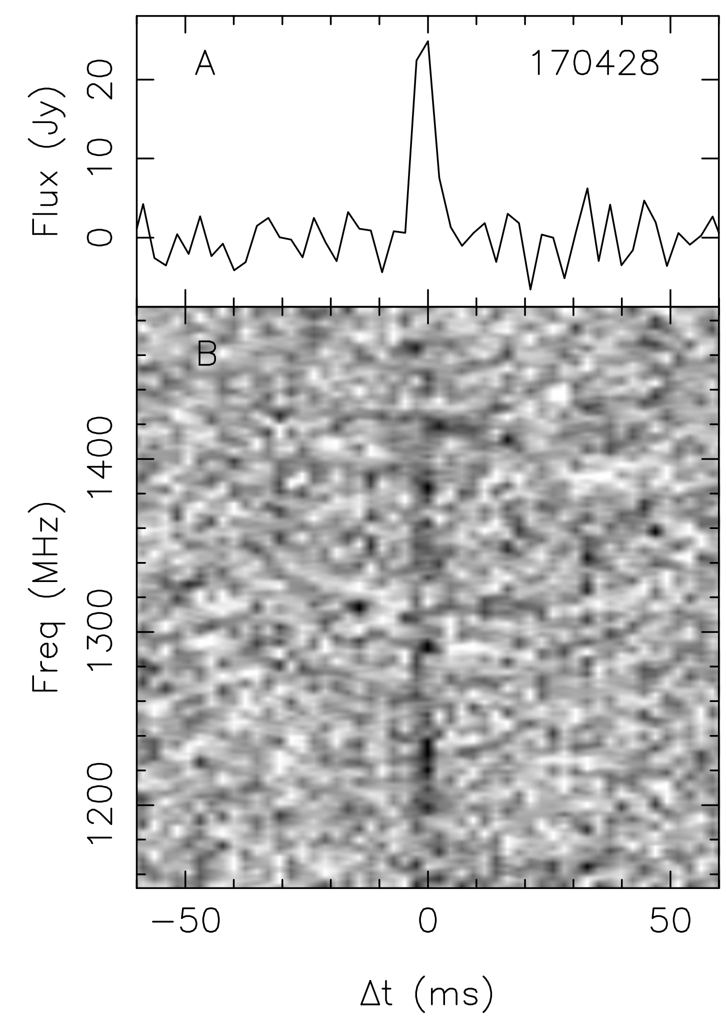


ASKAP-CRAFT Fast Radio Bursts

- Use ASKAP in "fly's" eye mode: point antennas in different direction
- PAFs: very wide and shallow search
- **Bright FRBs exist (Lorimer, 150807)!**



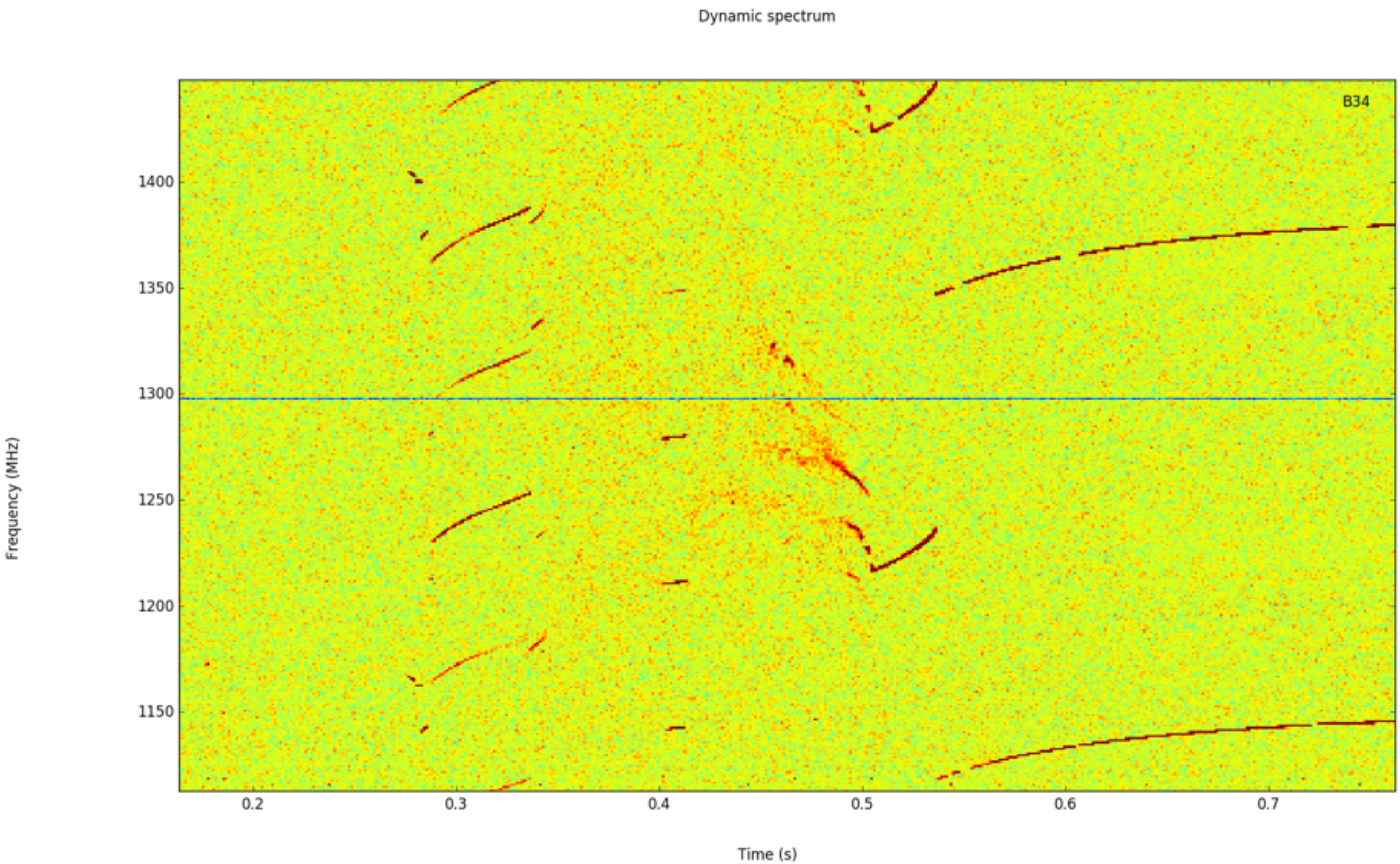




FRB 170107
DM: 609.5 pc cm^{-3}

FRB 170416
DM: 523.2(2) pc cm^{-3}

FRB 170428
DM: 991.7(8) pc cm^{-3}

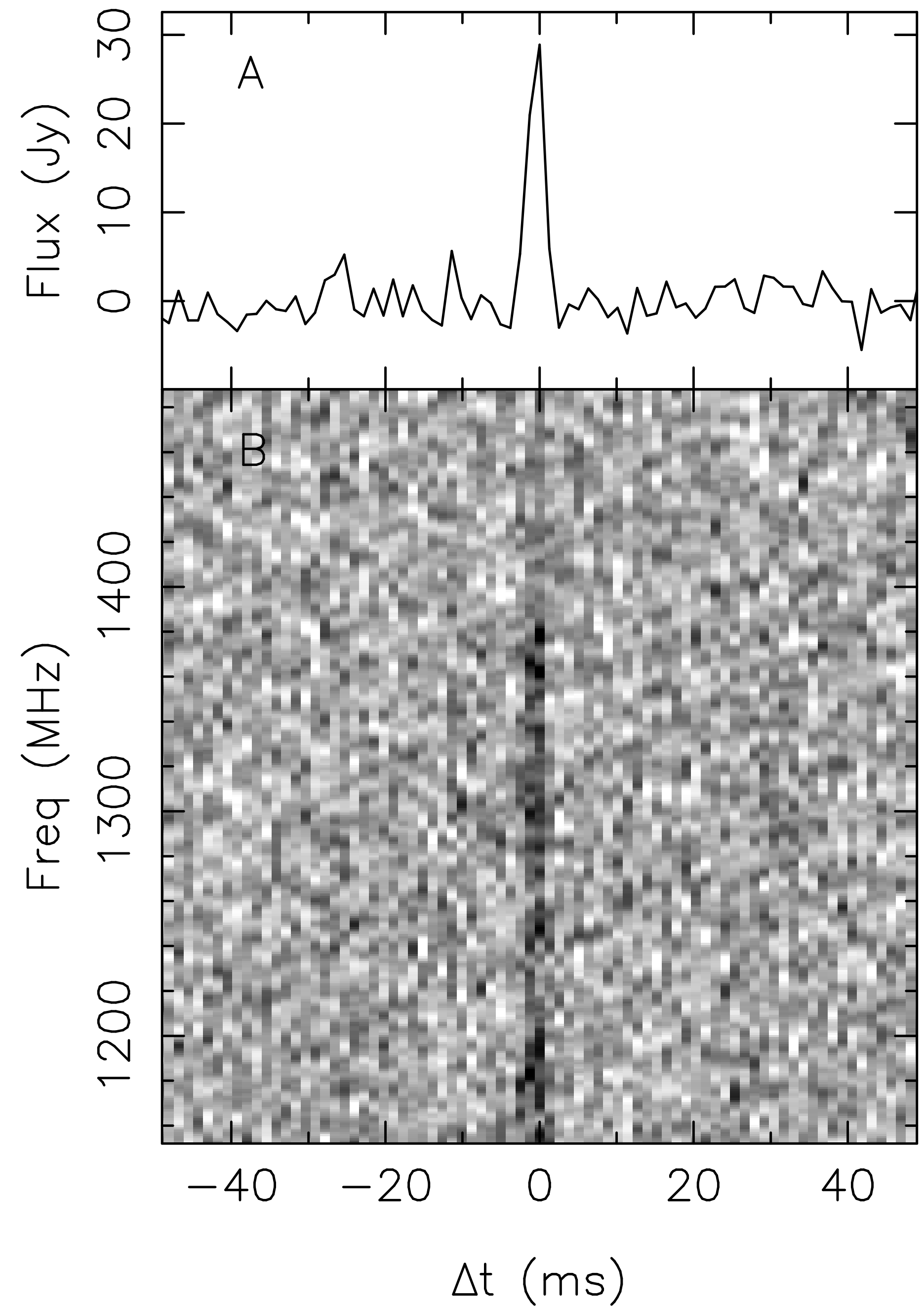


AK30 - zoom in

7th & 8th harmonic of a ~200 MHz signal

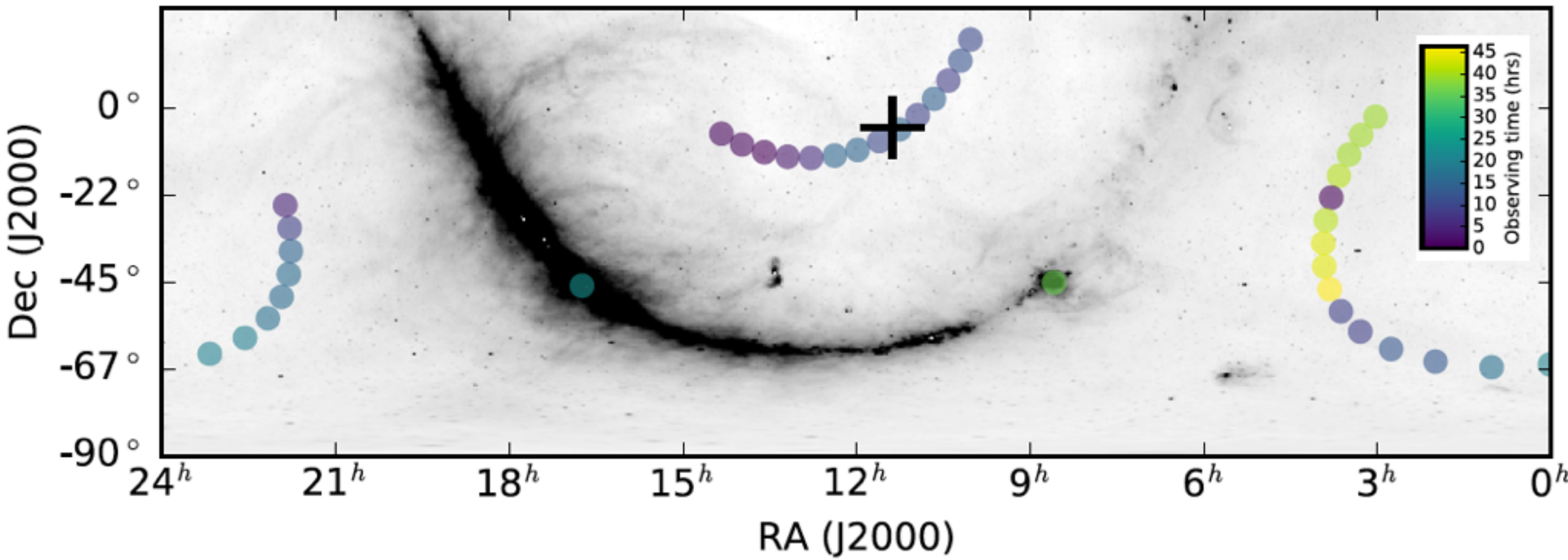
Next steps

- Measure logN-logS with ~50 FRBs
- Commission real-time search, voltage capture and interferometry



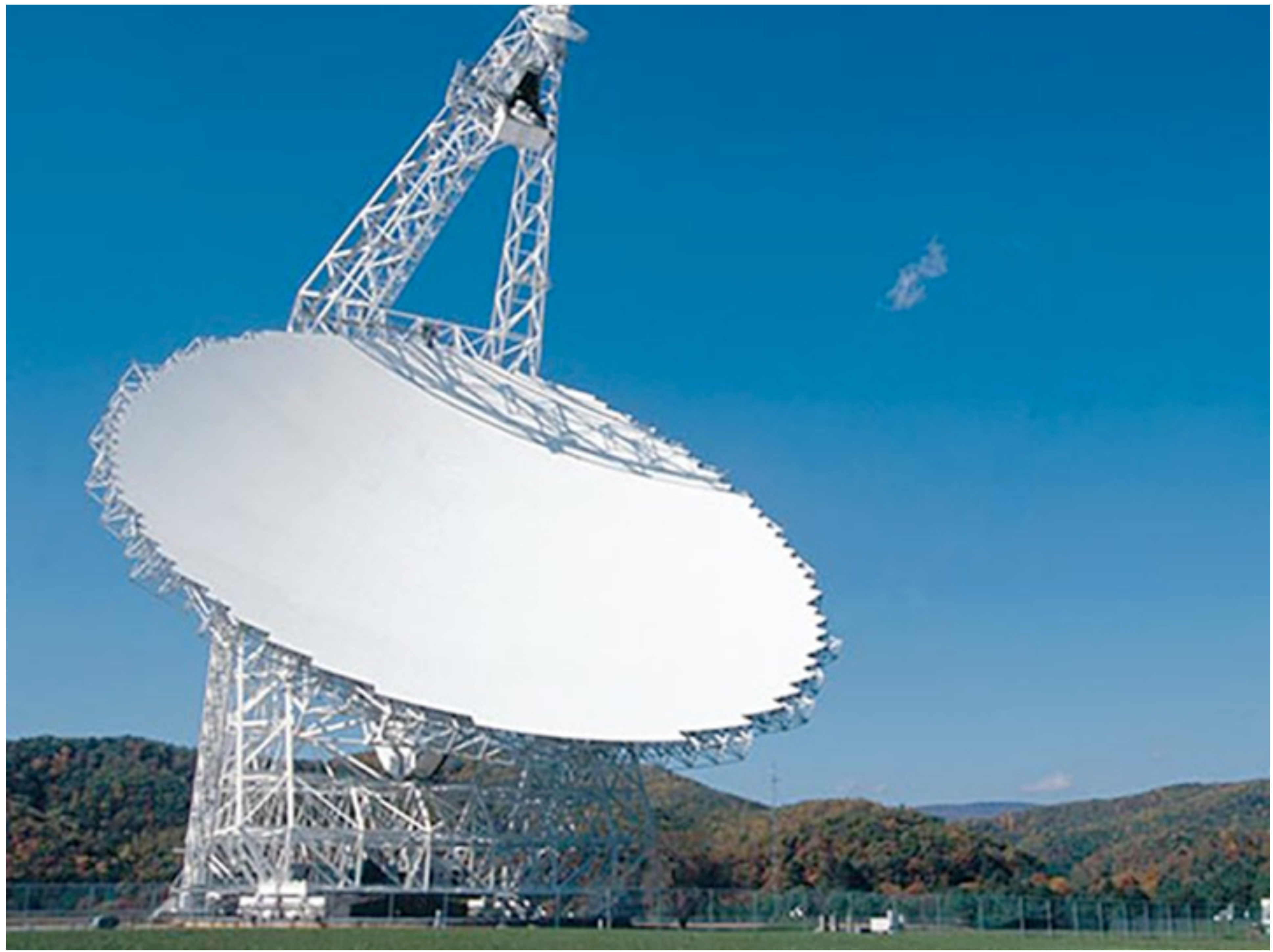
Next steps

- Find more FRBs
- Automate MWA shadowing



Next steps

- Follow up

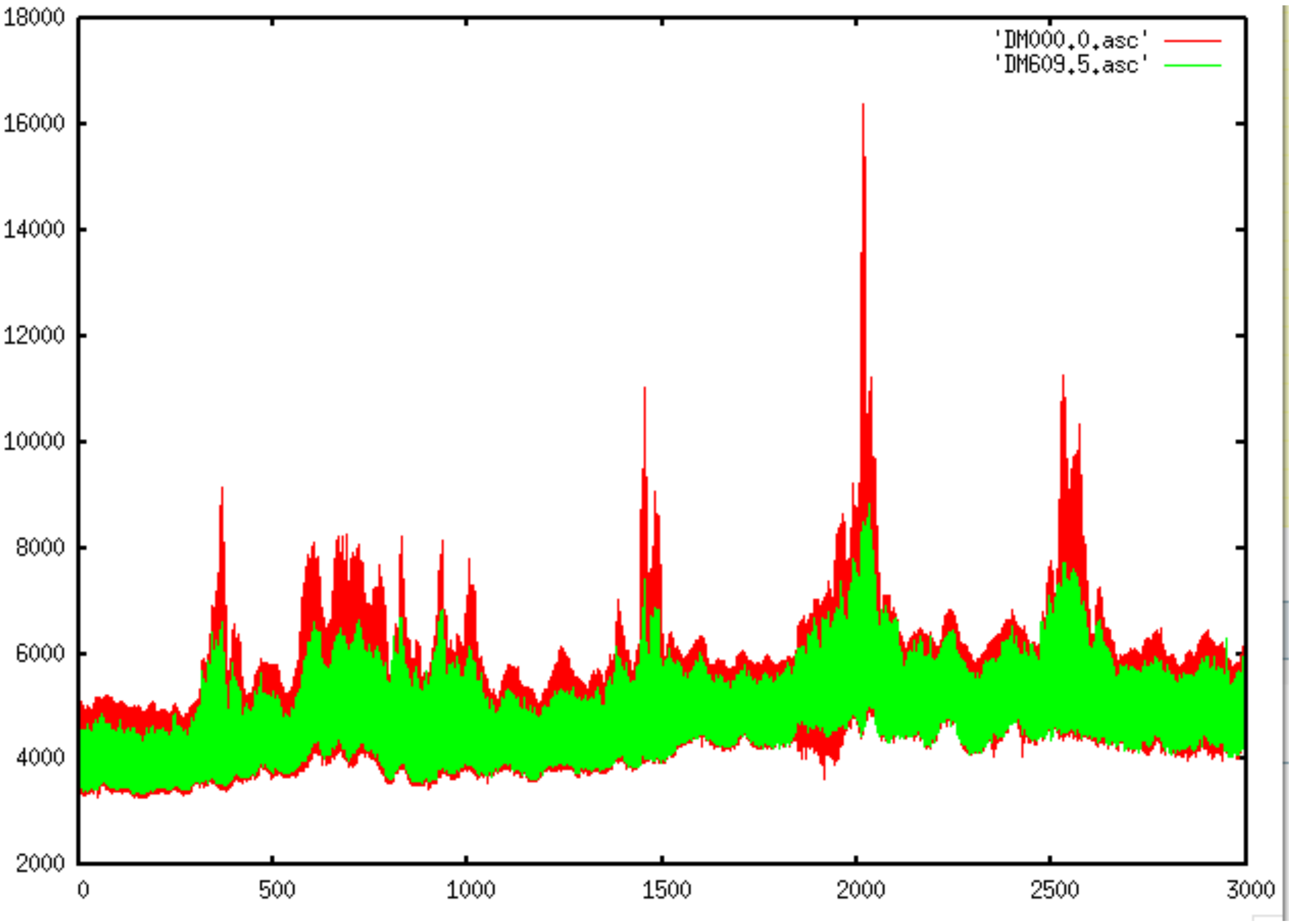


Next steps

- Follow up

Credit:

Lorimer



Next steps

- Follow up

the Deeper Wider Faster program

PI Jeff Cooke

No more classical "reactive" follow up of FRBs

A **proactive** approach to discover FRBs

Perform observations that are:

- Coordinated (simultaneous with multiple telescopes)
- Multi-wavelength
- High-cadence
- Real-time analysis with radio, optical, high energy telescopes

Deeper, Wider, Faster

PI: *Jeff Cooke [1]*

Radio: *Emily Petroff [2], Chris Flynn [1], Manisha Caleb [1,3], Shivani Bhandari [1], Evan Keane [4], Stuart Ryder [5], Wael Farah [1], Vivek Venkatraman Krishnan [1], Stefan Osłowski [1], Aditya Parthasarathy [1], Renee Spiewak [1], Sarah Burke−Spolaor [6], Casey Law [6]*

Optical: *Tyler Pritchard [1], Tim Abbott [7], Chris Curtin [1], Stephanie Bernard [8], Chuck Horst [9], Mansi Kasliwal [10], David Coward [11], the SkyMapper team, the Zadko team, and the Gemini−South and SALT support astronomers*

UV/x−ray/gamma−ray: *Tyler Pritchard [1], Igor Andreoni [1], Amy Lien [12], Neil Gehrels*

Real−time processing: *Igor Andreoni [1], Tyler Pritchard [1], Armin Rest [12,14], Phil Cowperthwaite [14], Chuck Horst*

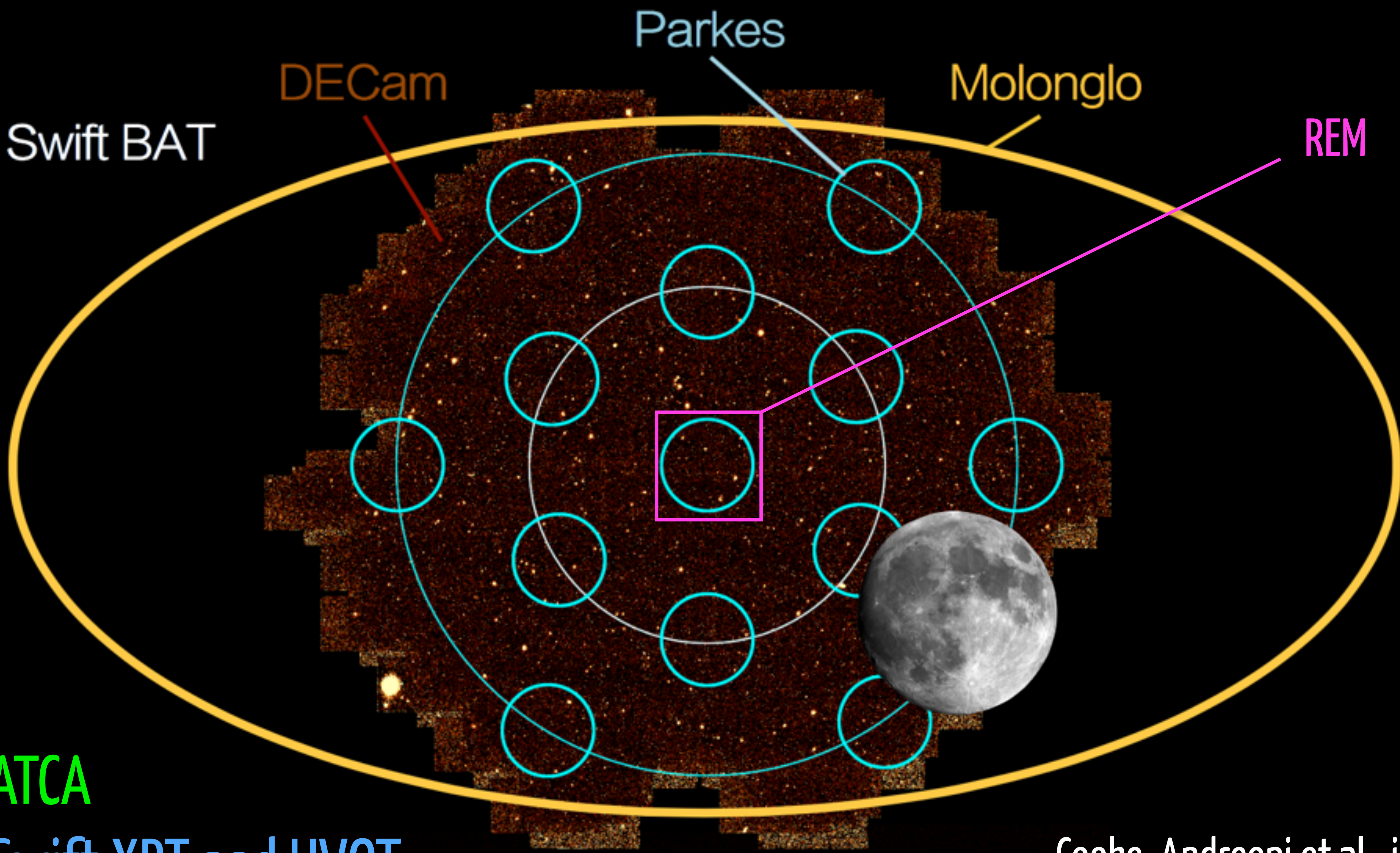
Data Science: *Dany Vohl [1], Colin Jacobs[1]*

Visualization: *Bernard Meade [8], Chris Fluke [1], Dany Vohl [1], Sarah Hegarty [1]*

Real−time data Inspection and Analysis: *Uros Mestric [1], Chuck Horst [9], Garry Foran [1], Stephanie Bernard [8], Rebecca Allen [1], Michael Murphy [1], Katie Mack [8], Srdan Kotus [1] Albany Asher [1], Bernard Meade [8], Shivani Bhandari [1], Chris Curtin [1], Wael Farah [1], Sarah Hegarty [1], Eric Howell [11], Colin Jacobs [1], Fabian Jankowski [1], Regina Jorgenson [16], Vivek Venkatraman Krishnan [1] Aditya Parthasarathy [1], Tristan Reynolds [8], Geoff Bryan [1], Frederic Robert [1], Themiya Nanayakkara [1], Fanual Rumokoy [8], Luciana Sinpetru [16], Cameron van der Veldon [8], Ibnul Hussaini [8], Pamela Bain, Dany Vohl [1], SAO students [1]*

[1]Swinburne [2]ASTRON/NIRA [3]ANU [4]University of Manchester/SKAO [5]AAO [6]NRAO [7]CTIO/NOAO [8]University of Melbourne [9]San Diego State University [10]Caltech [11]UWA [12]STScI [13]NASA/GSFC [14]Harvard University [15]University of Bonn [16] Maria Mitchell Observatory [17] University of Edinburgh

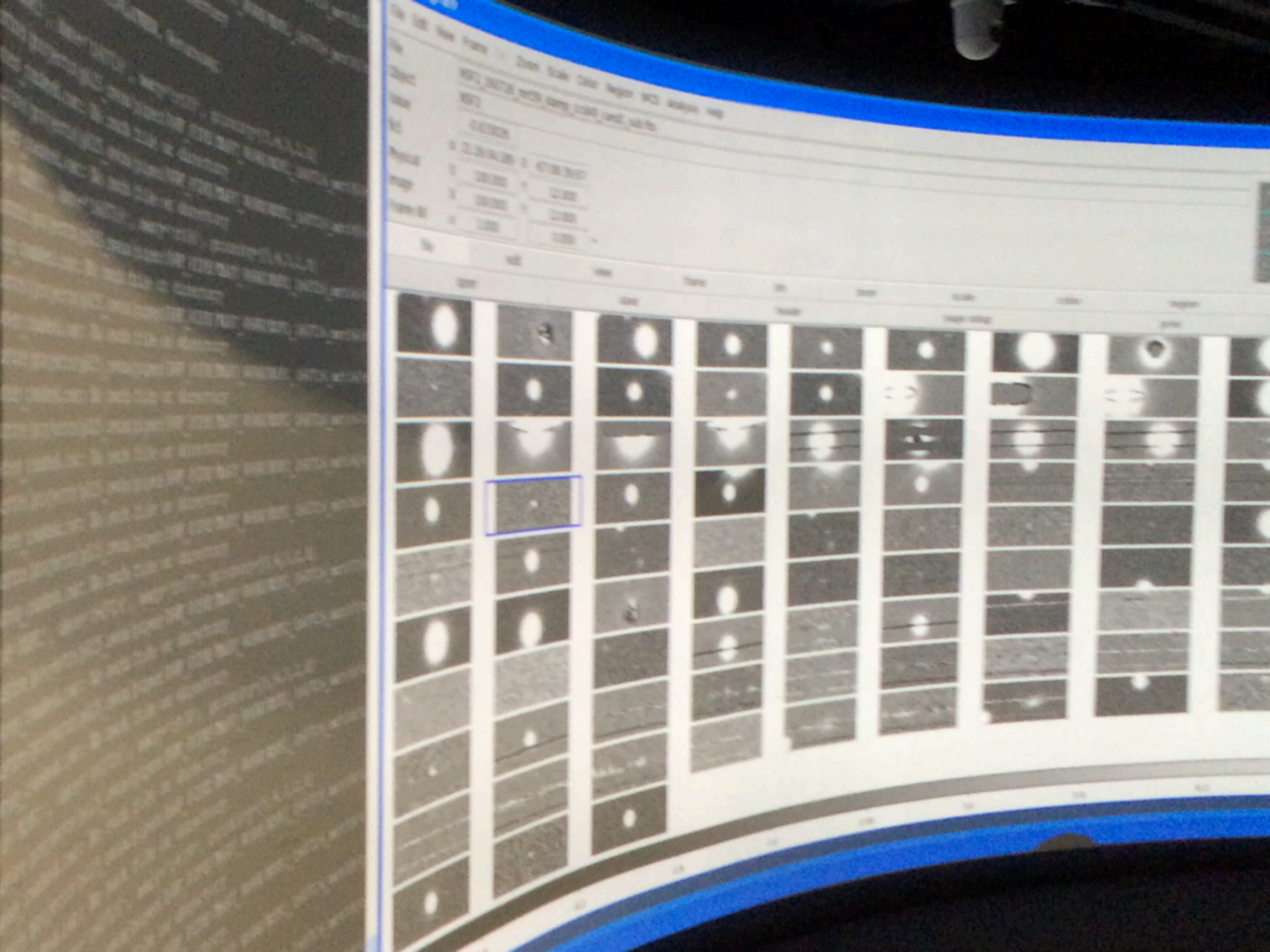
Simultaneous observations



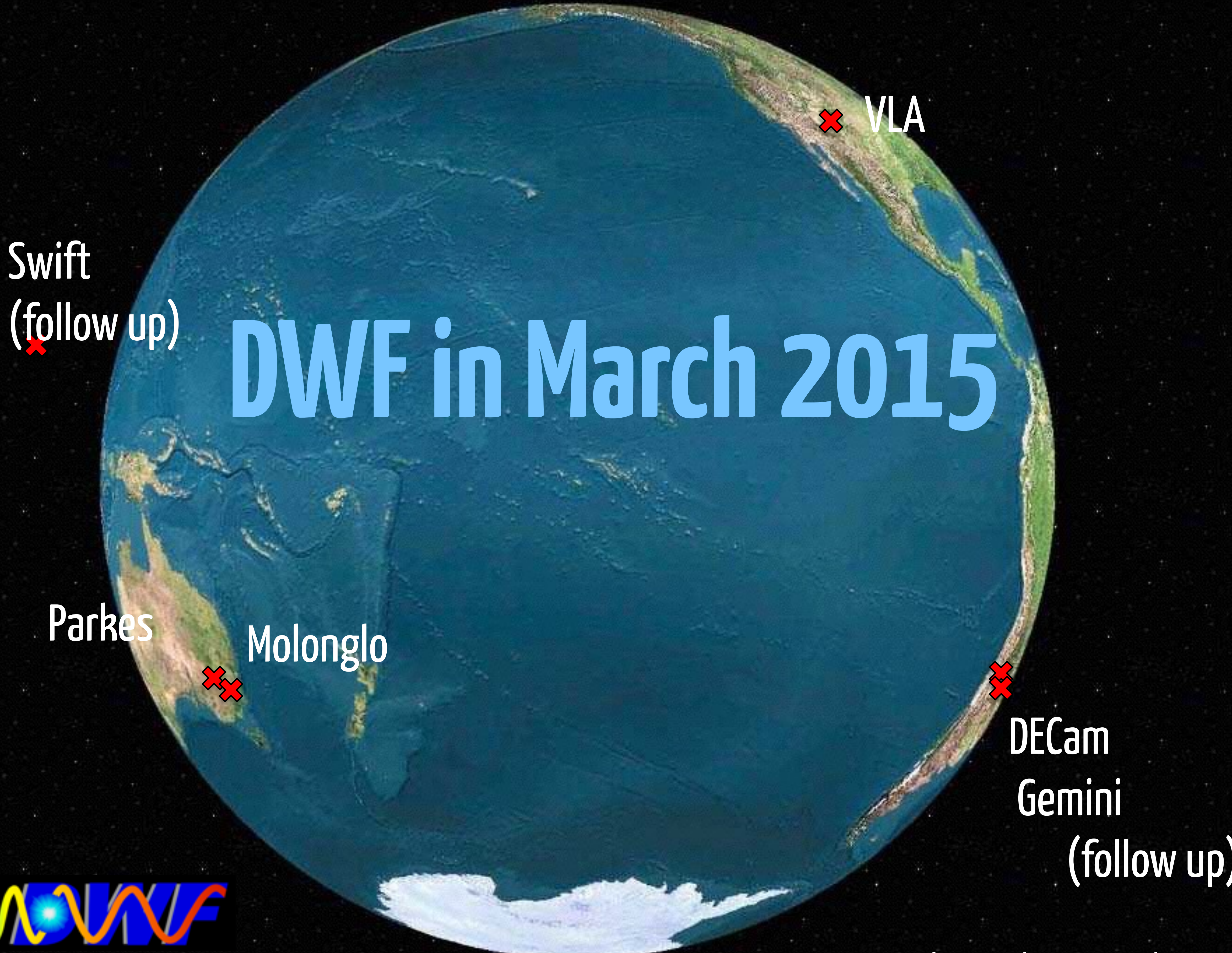
+ATCA

+Swift XRT and UVOT

Cooke, Andreoni et al., in prep


File Edit View Frame Zoom Scale Color Region WCS Analysis Help

DWF in March 2015



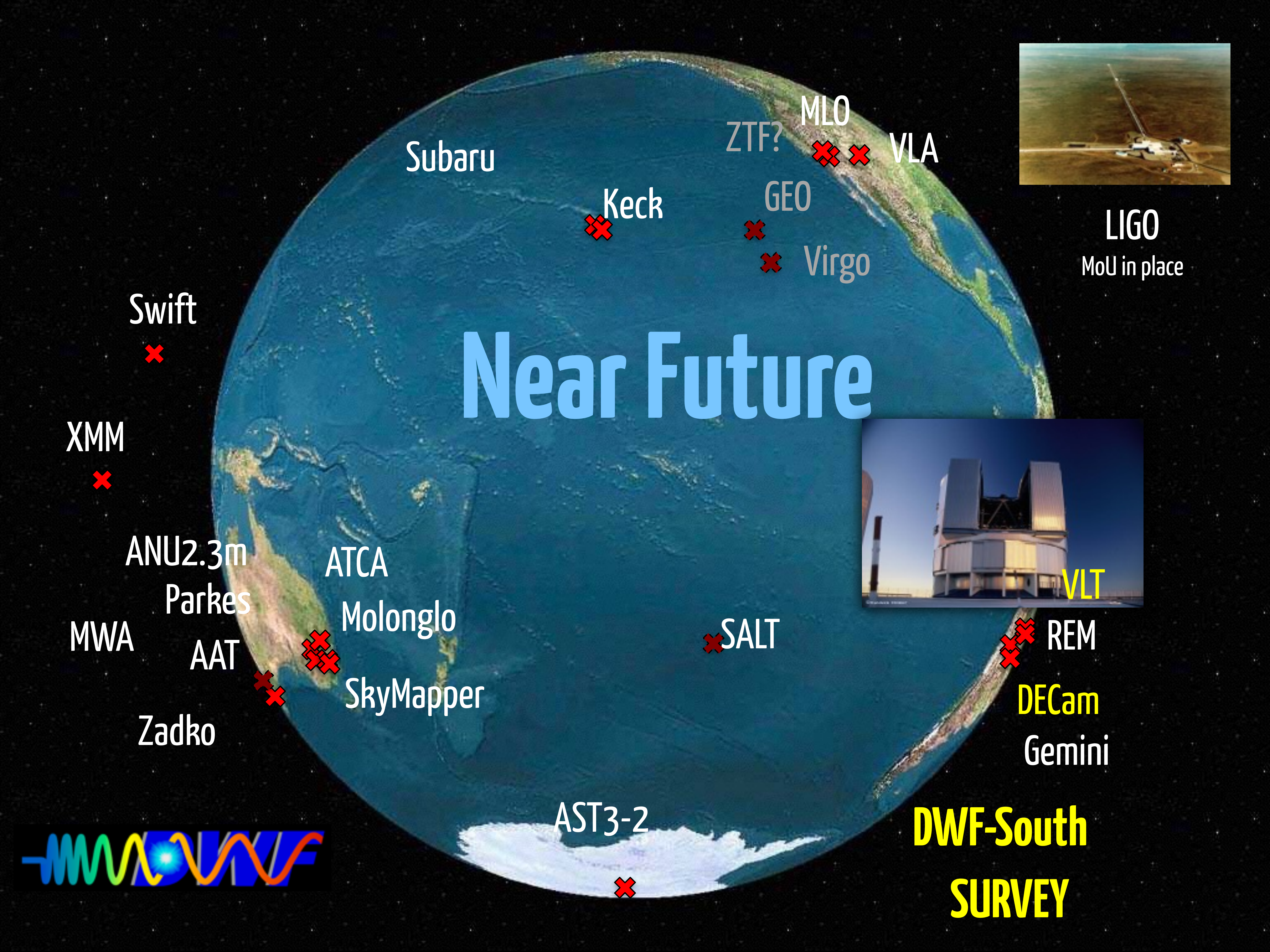
Cooke, Andreoni et al., in prep


DWF in February 2017
MLO
VLA
Keck
GEO
Virgo
LIGO
MoU in place
Swift
XMM
ANU2.3m
Parkes
MWA
AAT
Zadko
ATCA
Molonglo
SkyMapper
SALT
VLT
REM
DECam
Gemini
AST3-2
Cooke, Andreoni et al., in prep


MADE ACTIVE
DWF in February 2017
MLO
VLA
Keck
GEO
Virgo
LIGO
MoU in place
Swift
XMM
ANU2.3m
Parkes
MWA
AAT
Zadko
ATCA
Molonglo
SkyMapper
SALT
VLT
REM
DECam
Gemini
AST3-2
DWF
Cooke, Andreoni et al., in prep

DWF-North

Cooke, Andreoni et al., in prep


Near Future
Subaru
Keck
ZTF?
MLO
VLA
GEO
Virgo
LIGO
MoU in place
Swift
XMM
ANU2.3m
Parkes
MWA
AAT
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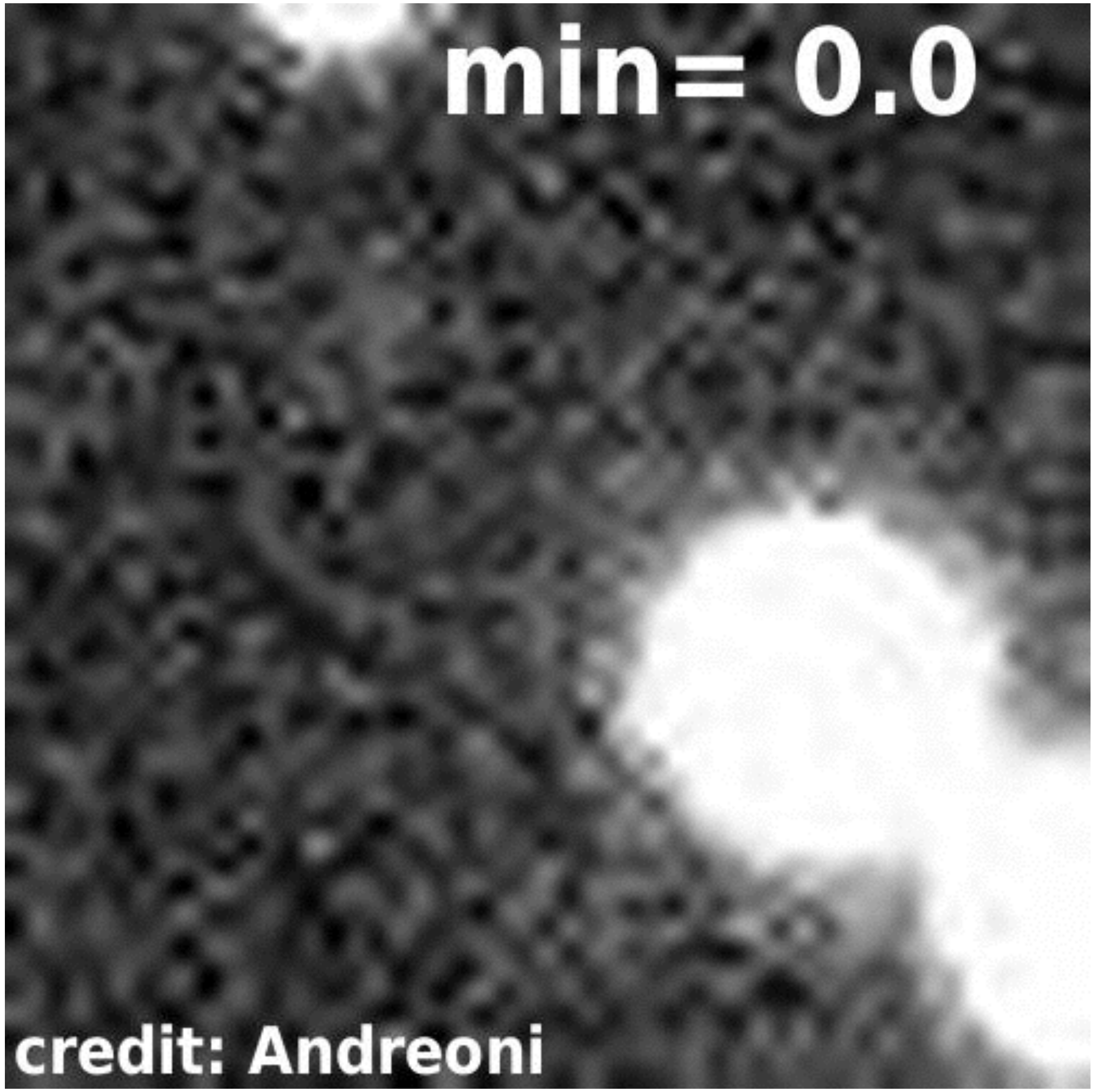
AST3-2
DWF-South
SURVEY



See also ATELs 10072 & 10078

Thank you