CAASTRO
ARC CENTRE OF EXCELLENCE FOR ALL-SKY ASTROPHYSICS

ICRAR International Centre for Radio Astronomy Research

Curtin University

THE UNIVERSITY OF WESTERN AUSTRALIA

Sub-arcsec Compact Source Properties using wide field interplanetary scintillation with the Murchison Widefield Array

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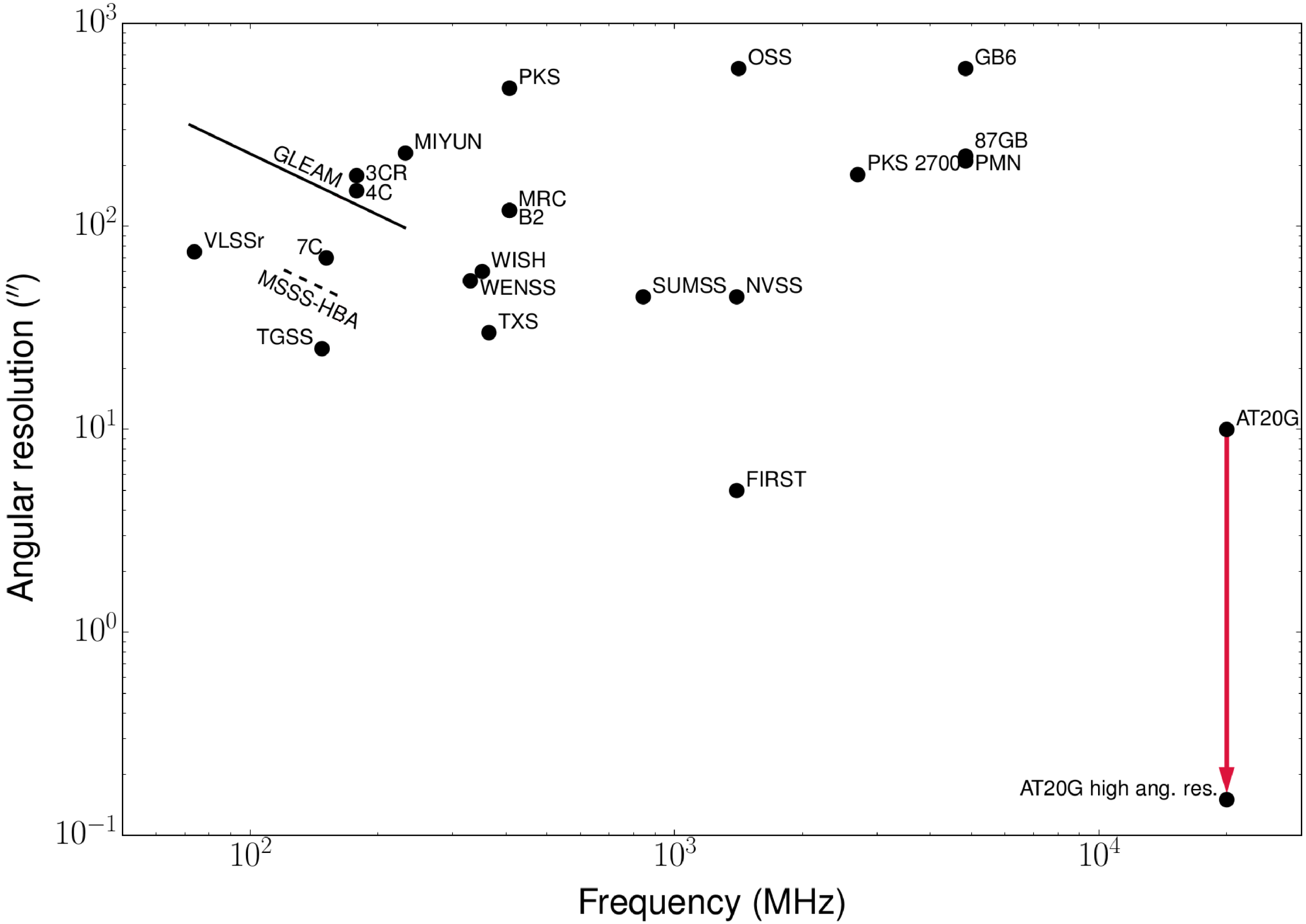
J-P Macquart (Curtin)
Ron Ekers (CASS)
Elaine Sadler (Usyd)
Marcello Giroletti (INAF)
Joe Callingham (ASTRON)

Australian Government
Australian Research Council

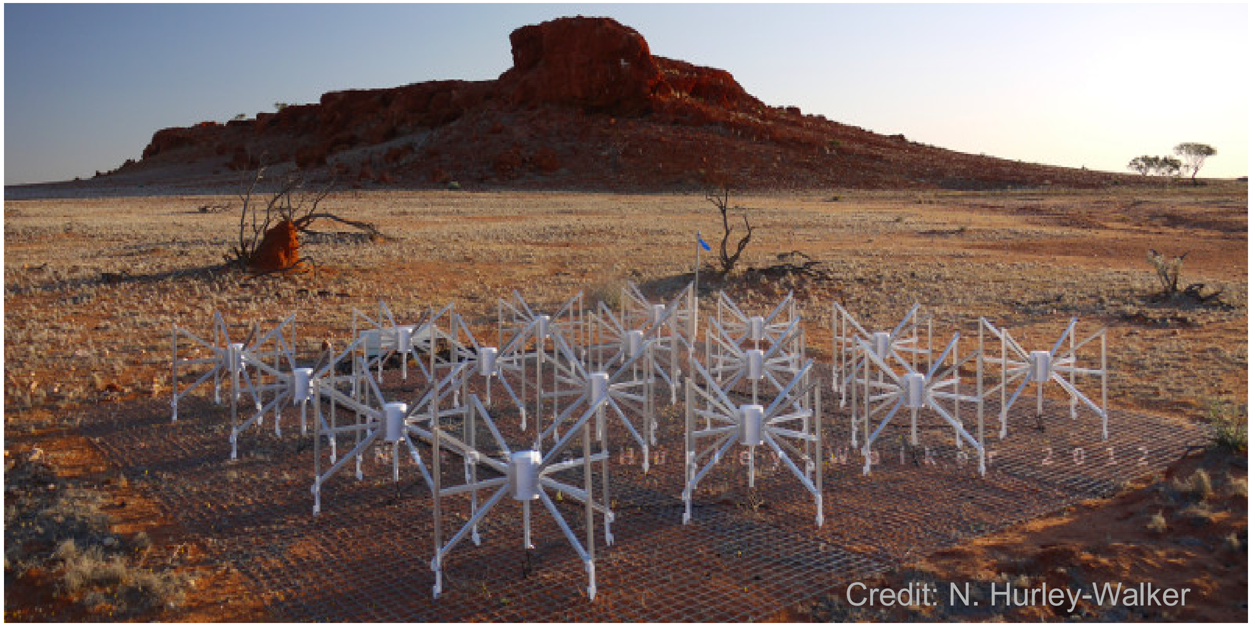
Large Area Surveys and Angular Resolutions



Credit: Joe Callingham

The Opportunity

The Murchison Widefield Array (Western Australia)
128 tiles with 2 x 16 dipoles each
Operating frequencies: 80 – 300 MHz
Bandwidth: 30.72 MHz



Typical MWA field

Angular resolution ~ 2'

MWA field in TGSS

Angular resolution ~ 25''

Current Low Frequency Instruments' challenge

Field of View: 15 – 50 degrees (200 – 2500 sq degrees)
Very large number of sources in the field of view
Angular resolution (3-km array) at 150 MHz > 2 arcmin

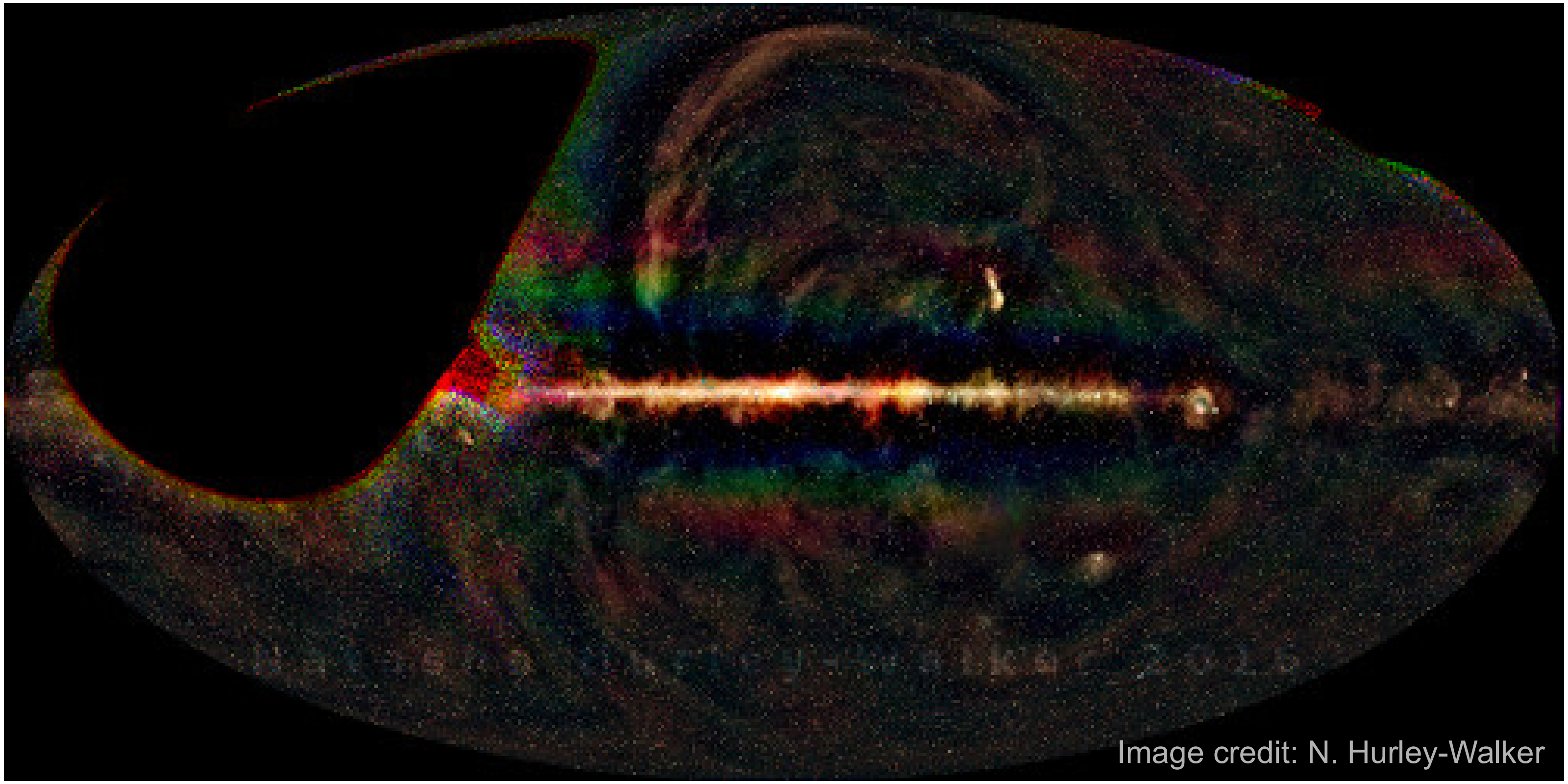


Image credit: N. Hurley-Walker

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The Low Frequency solution?

Field of View: 15 – 50 degrees (200 – 2500 sq degrees)
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VLBI

Networks and telescopes used for IYA2009 24hr e-VLBI. Image by Paul Boven <boven@jive.nl>. Satellite image: Blue Marble Next Generation, courtesy of Nasa Visible Earth (visibleearth.nasa.gov).

Image credit: EXPRes website

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VLBI

Time required

X

Very high number of sources

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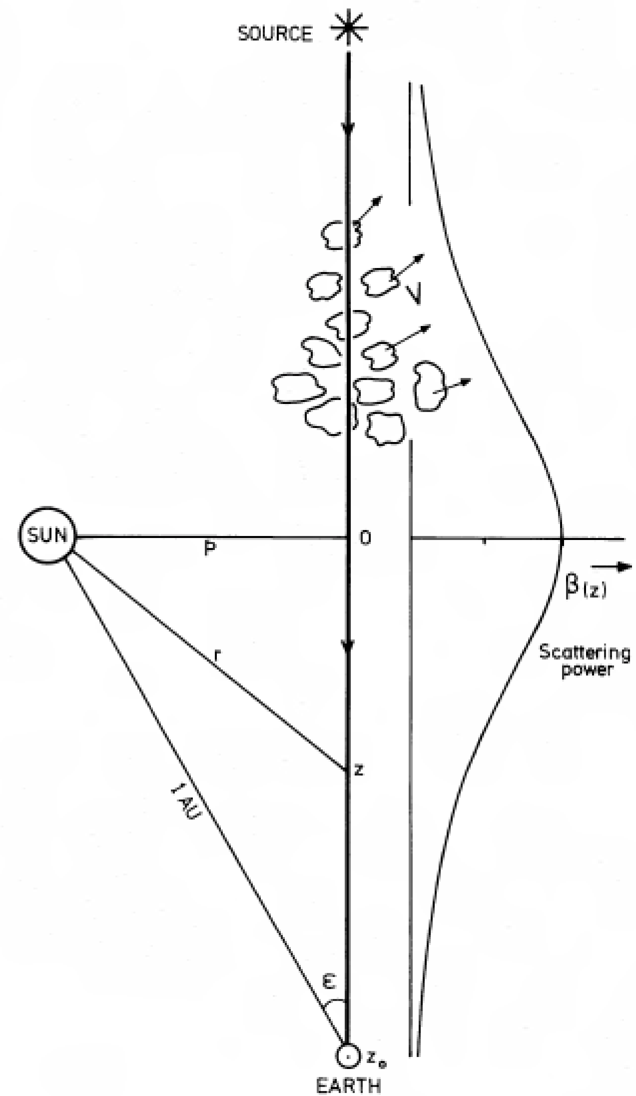
Is there an alternative?

Image credit: EXPRes website

Interplanetary Scintillation

Compact radio sources (< 1 arcsec)
+
Turbulence in interplanetary plasma

=
Scintillation effects
(random fluctuations in flux density)



Credit: Readhead+1978

Interplanetary Scintillation

Compact radio sources (< 1 arcsec)
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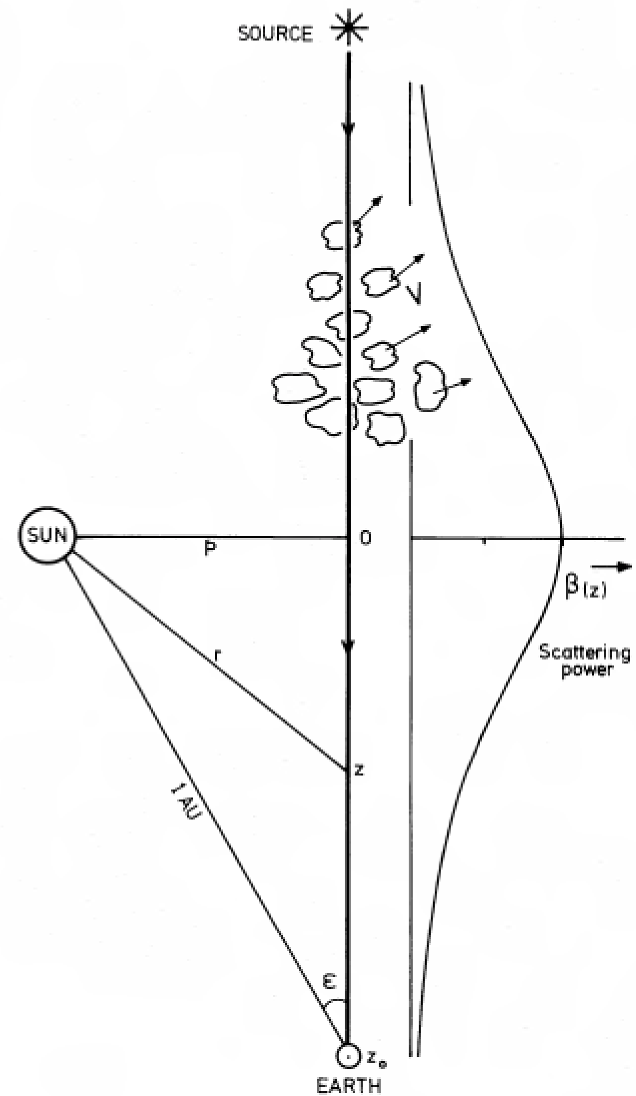
(random fluctuations in flux density)

Analogous to the effects of twinkling of stars in optical wavelengths



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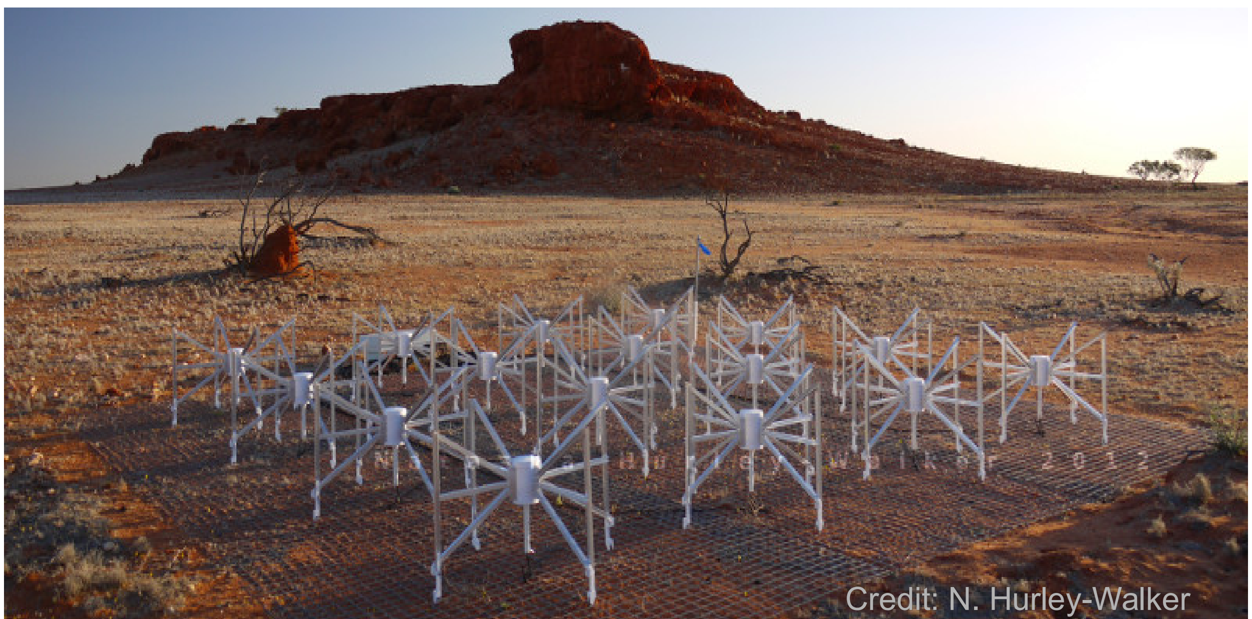
The Opportunity

The Murchison Widefield Array (Western Australia)
128 tiles with 2 x 16 dipoles each
Operating frequencies: 80 – 300 MHz
Bandwidth: 30.72 MHz

Field of View: 15 – 50 degrees (200 – 2500 sq degrees)
Temporal resolution: 0.5 sec
Excellent instantaneous UV coverage



Background on IPS with MWA

Kaplan et al. 2015 detected a night time IPS.

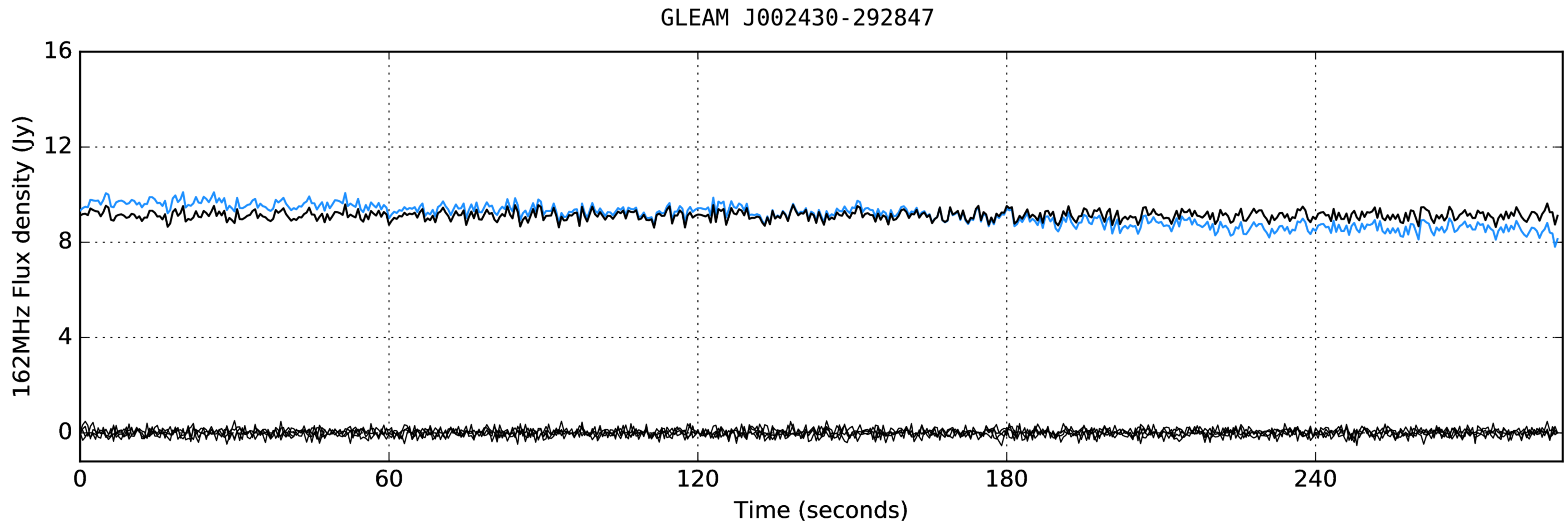
Pilot study on wide-field IPS by J. Morgan, Curtin University

Regular daytime observations (late December 2015 – July 2016)

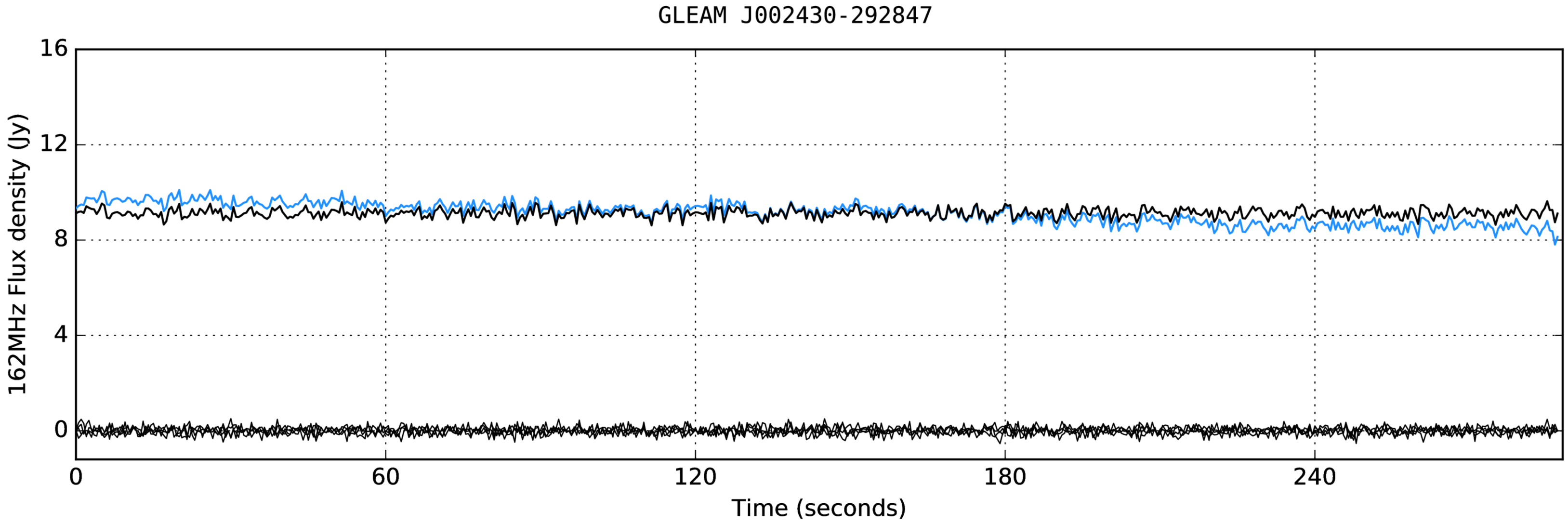
Observations at two bands 80 MHz & 162 MHz

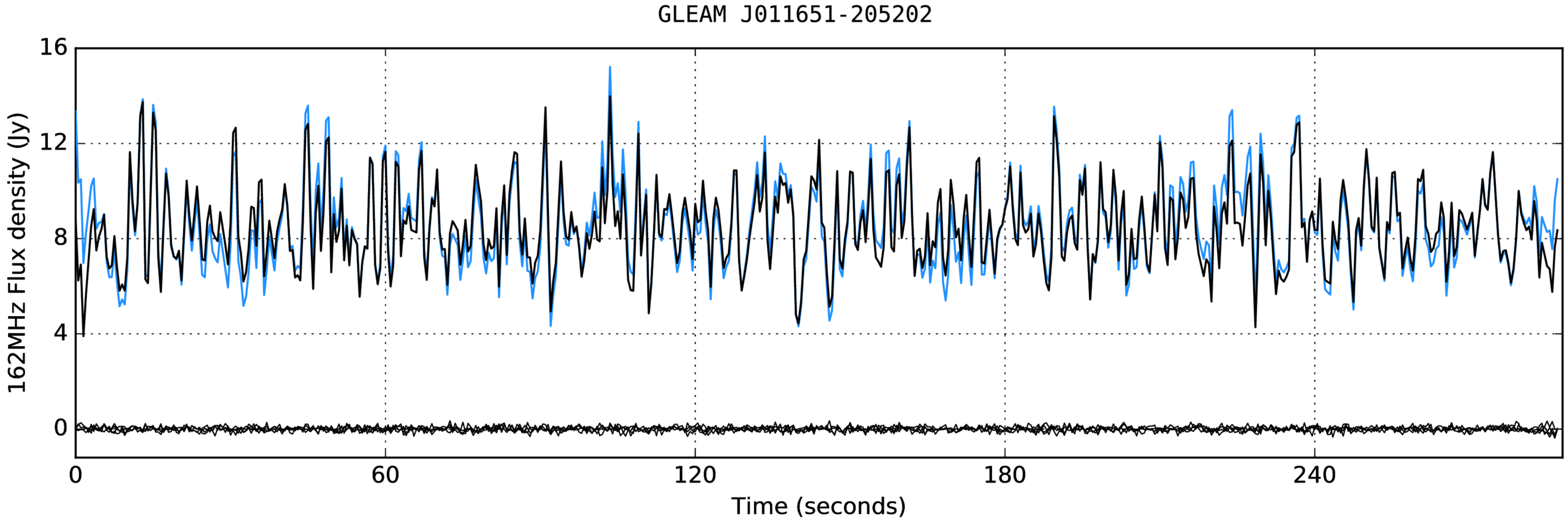
Over 4000 observations made of different parts of sky

Non-scintillators vs Scintillators



Non-scintillators vs Scintillators





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How do we do it?

Data processing

Image data as a continuum image

Image at 0.5 second integration in both frequency bands and polarisations

Produce variability (standard deviation) image across ~ 600 images

Run source finding script – Aegean (Hancock et al. 2012)

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Identify sub arcsecond compact components in variability image

~2500 objects in a field (in Stokes I image)

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~5 mintues of observation

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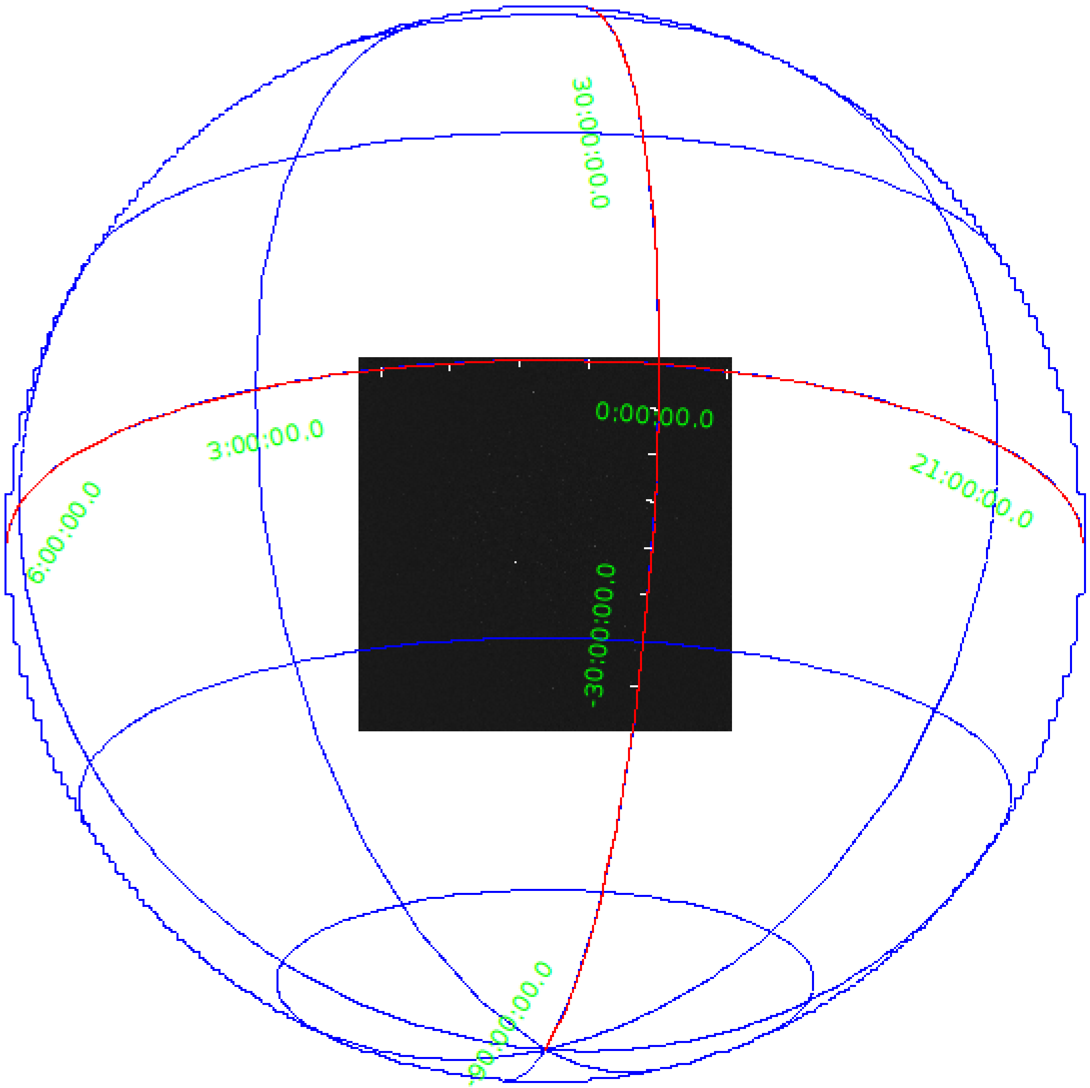
Publication

MNRAS 000, 1–?? (2017) Preprint 24 May 2017 Compiled using MNRAS LaTeX style file v3.0

Interplanetary Scintillation with the Murchison Widefield Array I: A sub-arcsecond Survey over 900 square degrees at 79 and 158 MHz

J .S. Morgan,[1*] J-P. Macquart,[1,2] R. Ekers,[3] R. Chhetri,[1,2]
M. Tokumaru,[4] P. K. Manoharan,[5] S. Tremblay,[1,2] M. M. Bisi,[6] and B. V. Jackson[7]

Typical MWA field



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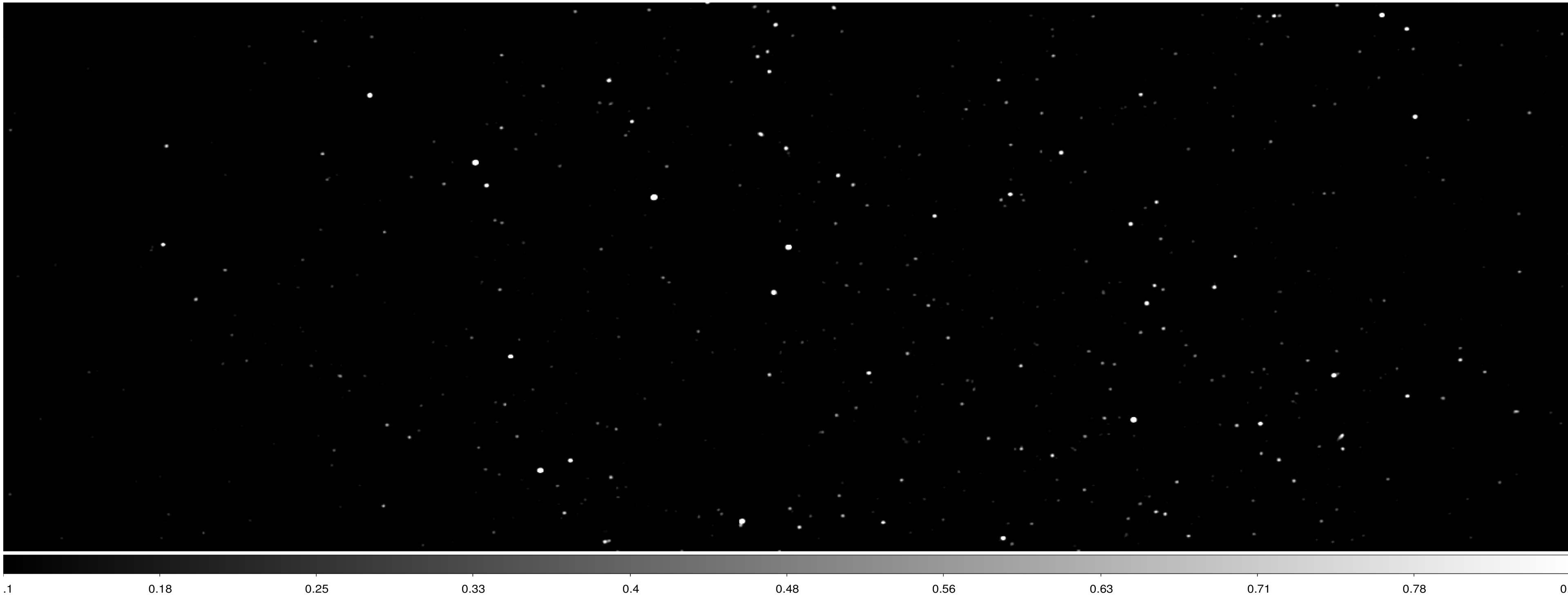
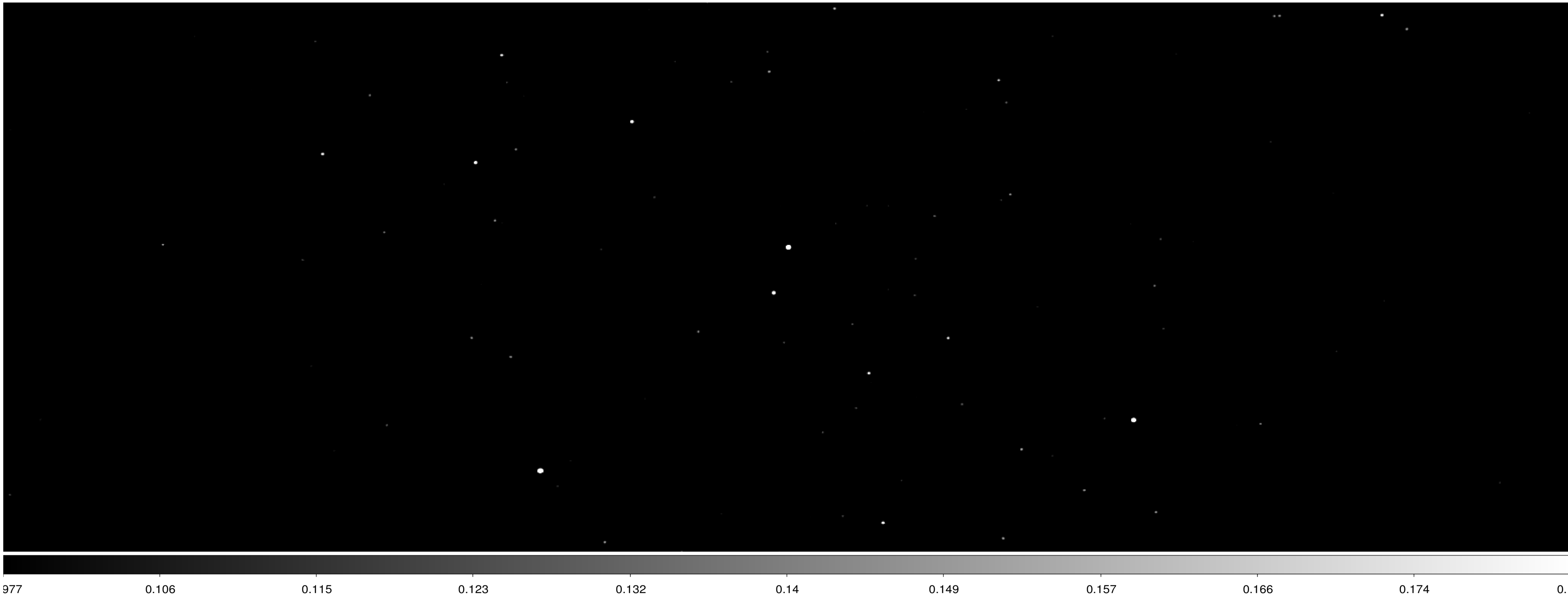


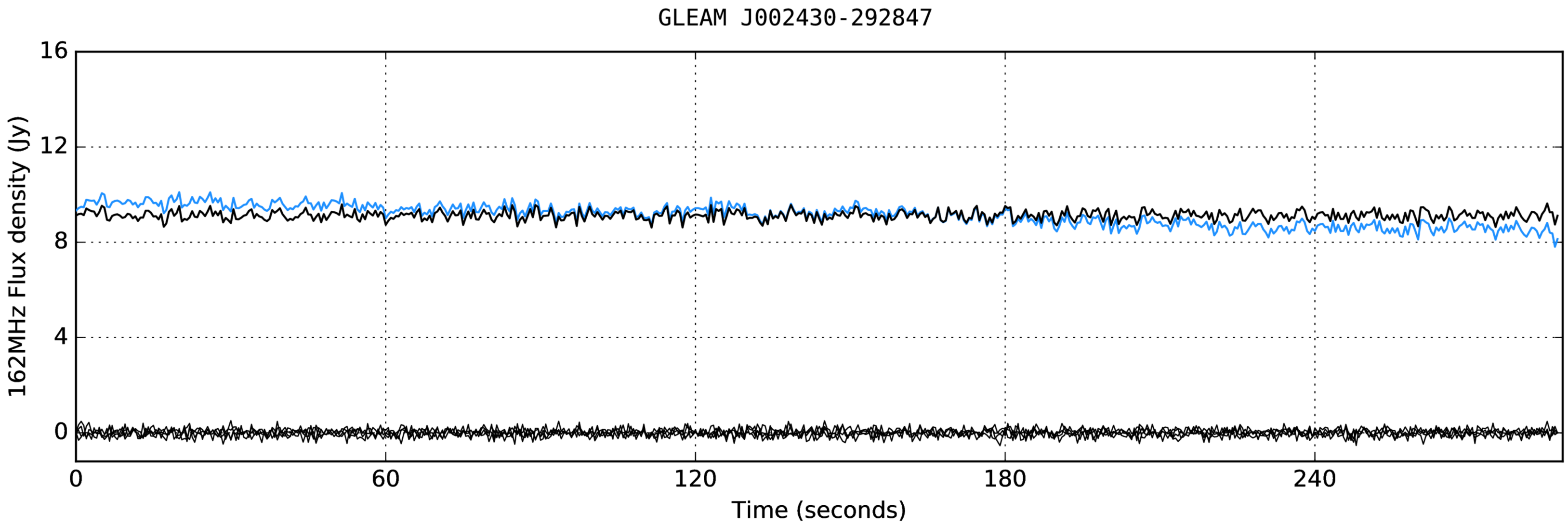
Field size: 23 x 8 sq degrees

Variability Image

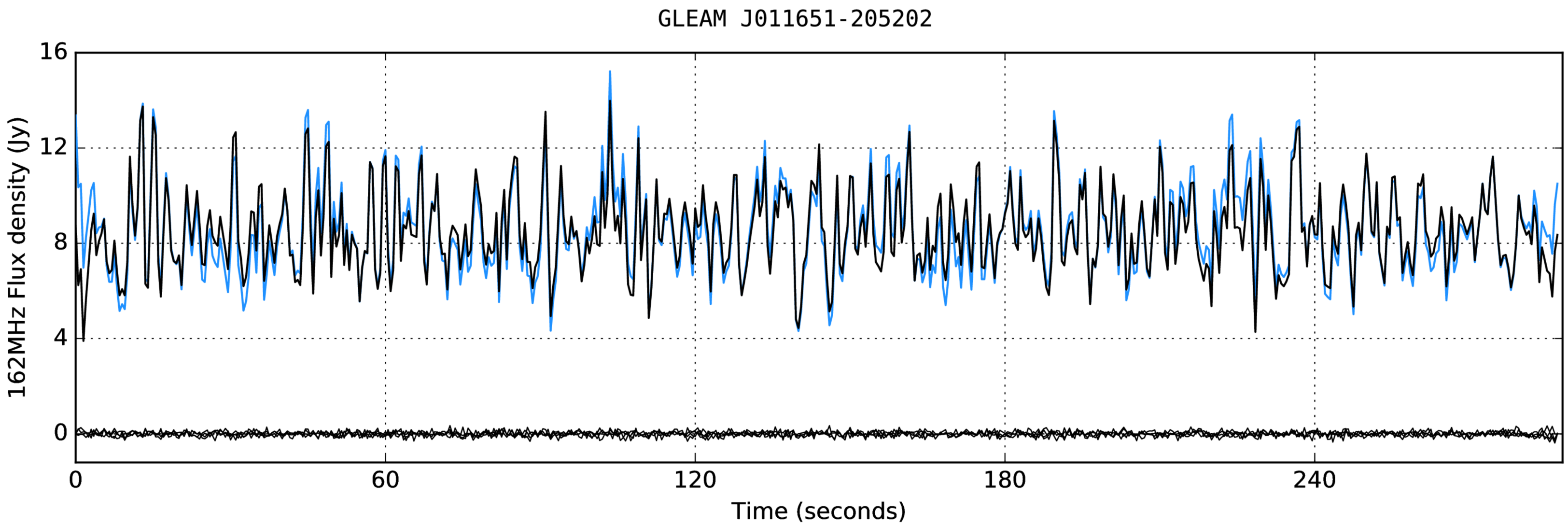


Field size: 23 x 8 sq degrees

Observable

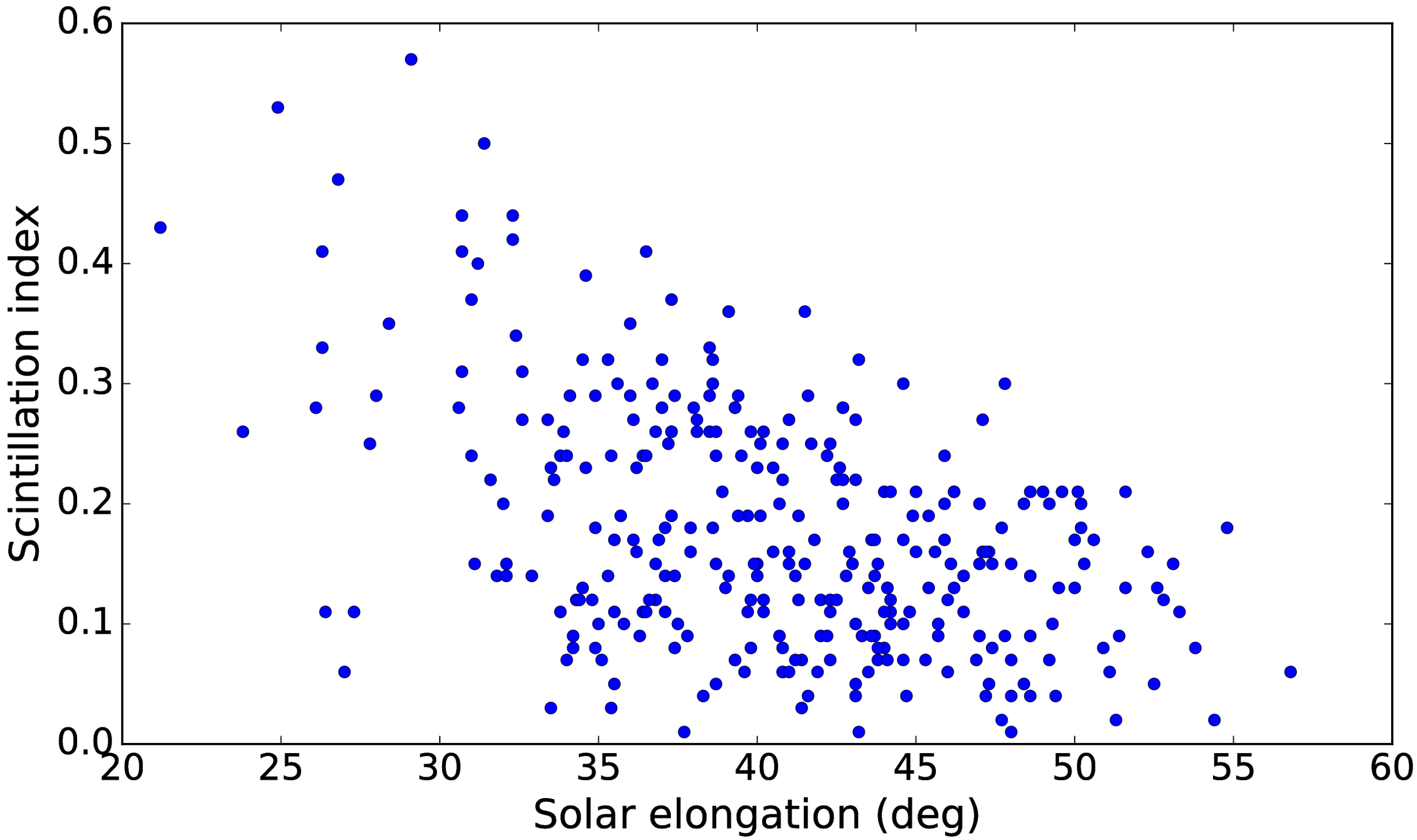


GLEAM J002430-292847
162MHz Flux density (Jy)
16
12
8
4
0
0
60
120
180
240
Time (seconds)



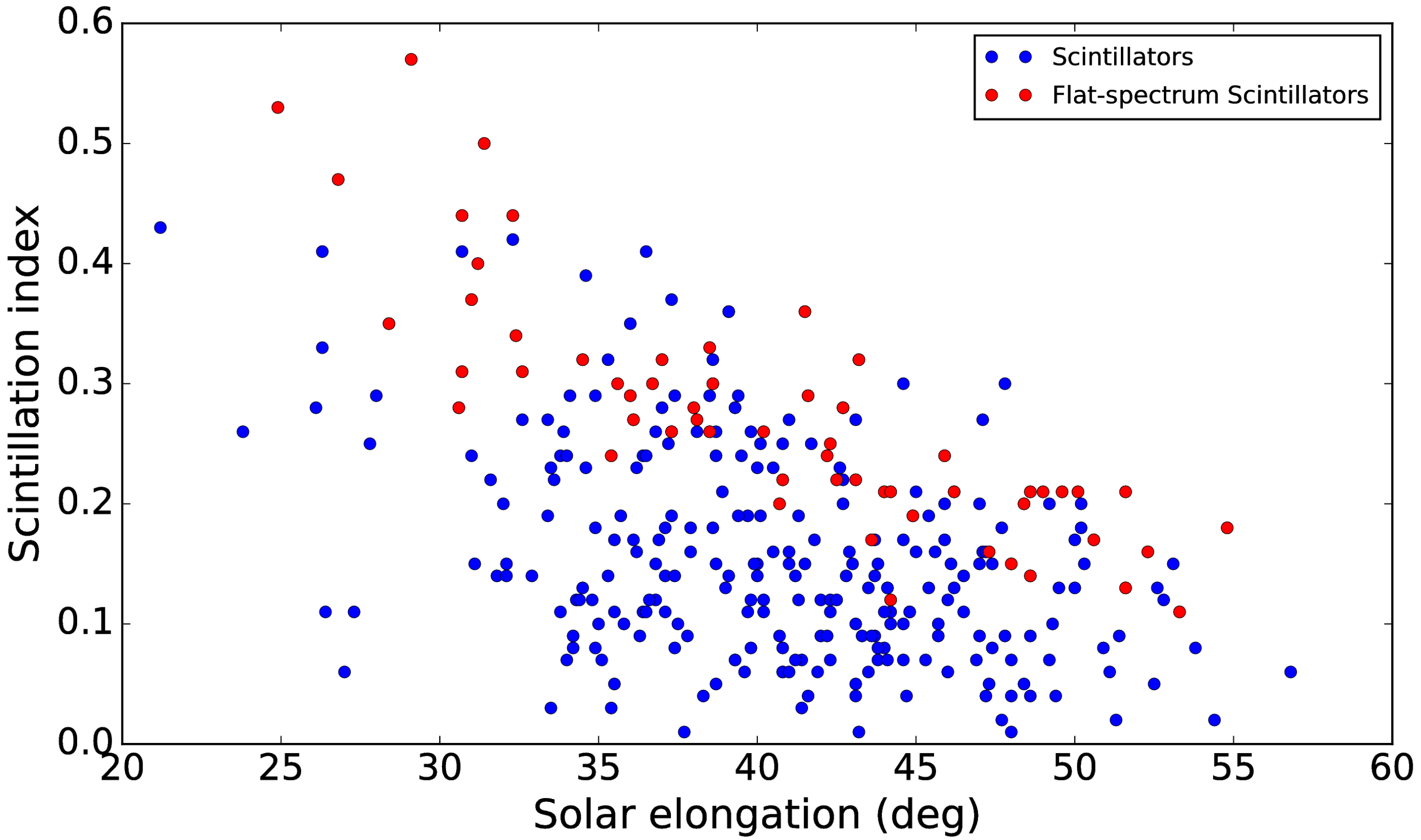
GLEAM J011651-205202
162MHz Flux density (Jy)
16
12
8
4
0
0
60
120
180
240
Time (seconds)

Observable



Detect scintillation on 302 out of 2550 objects (12%)

Observable



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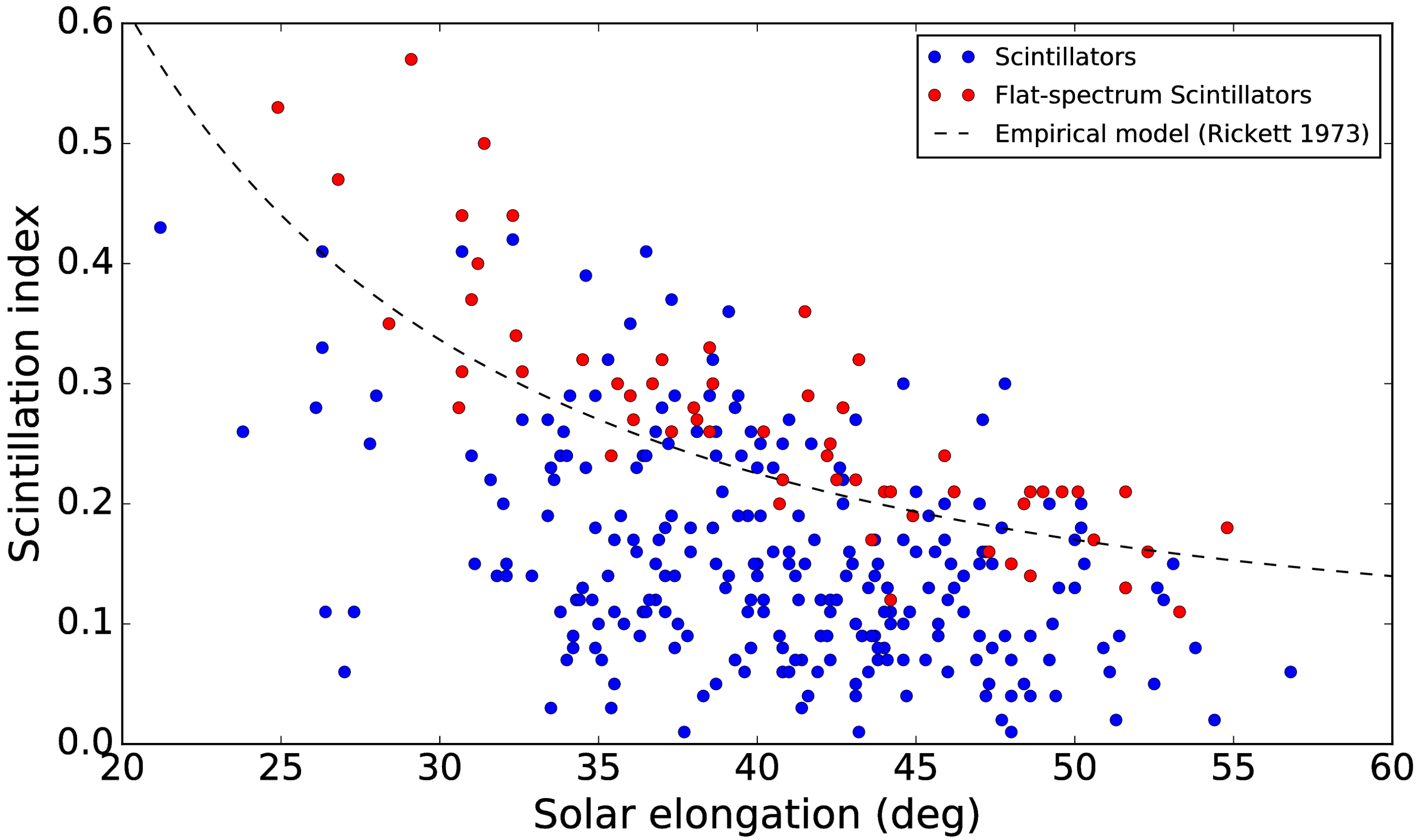

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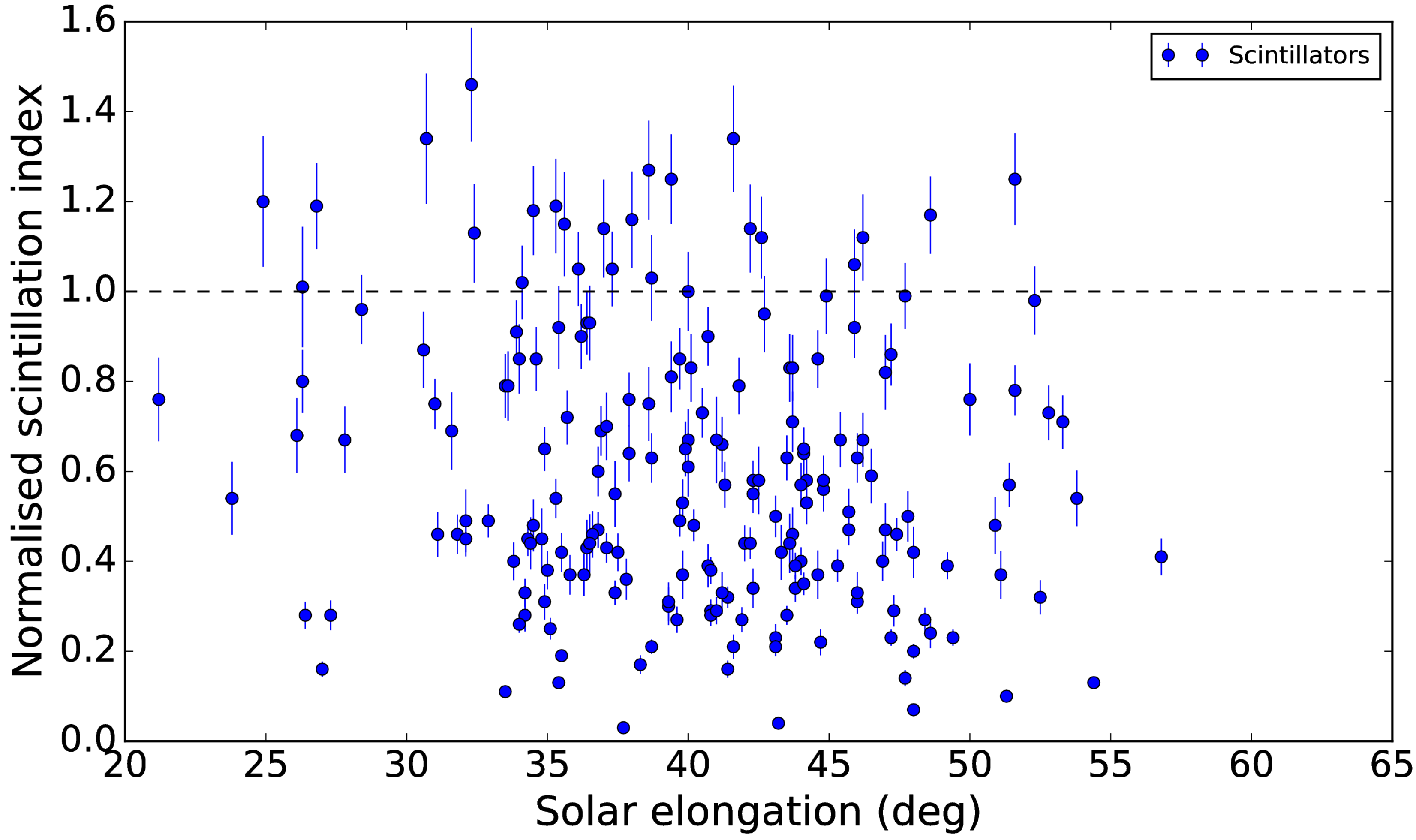
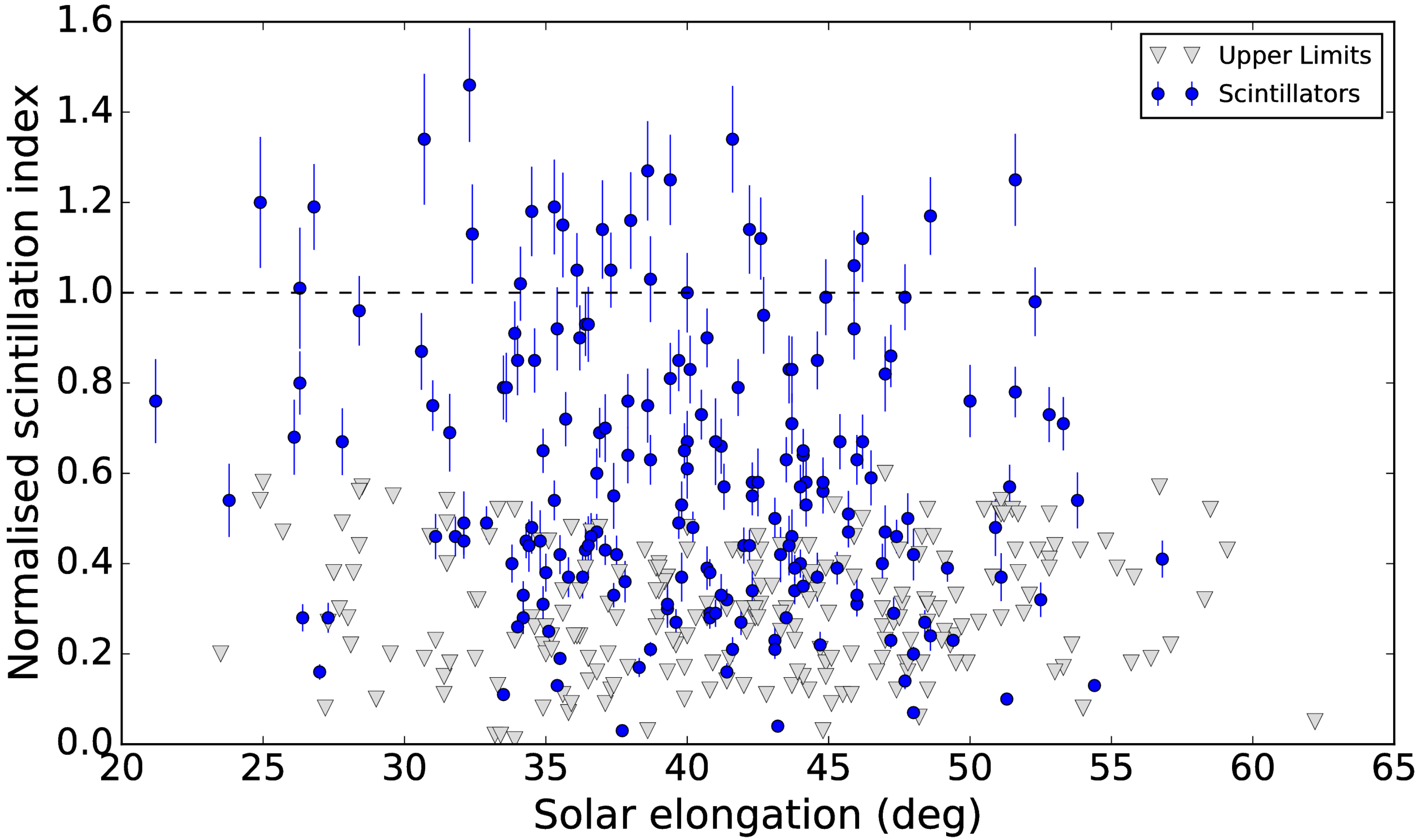


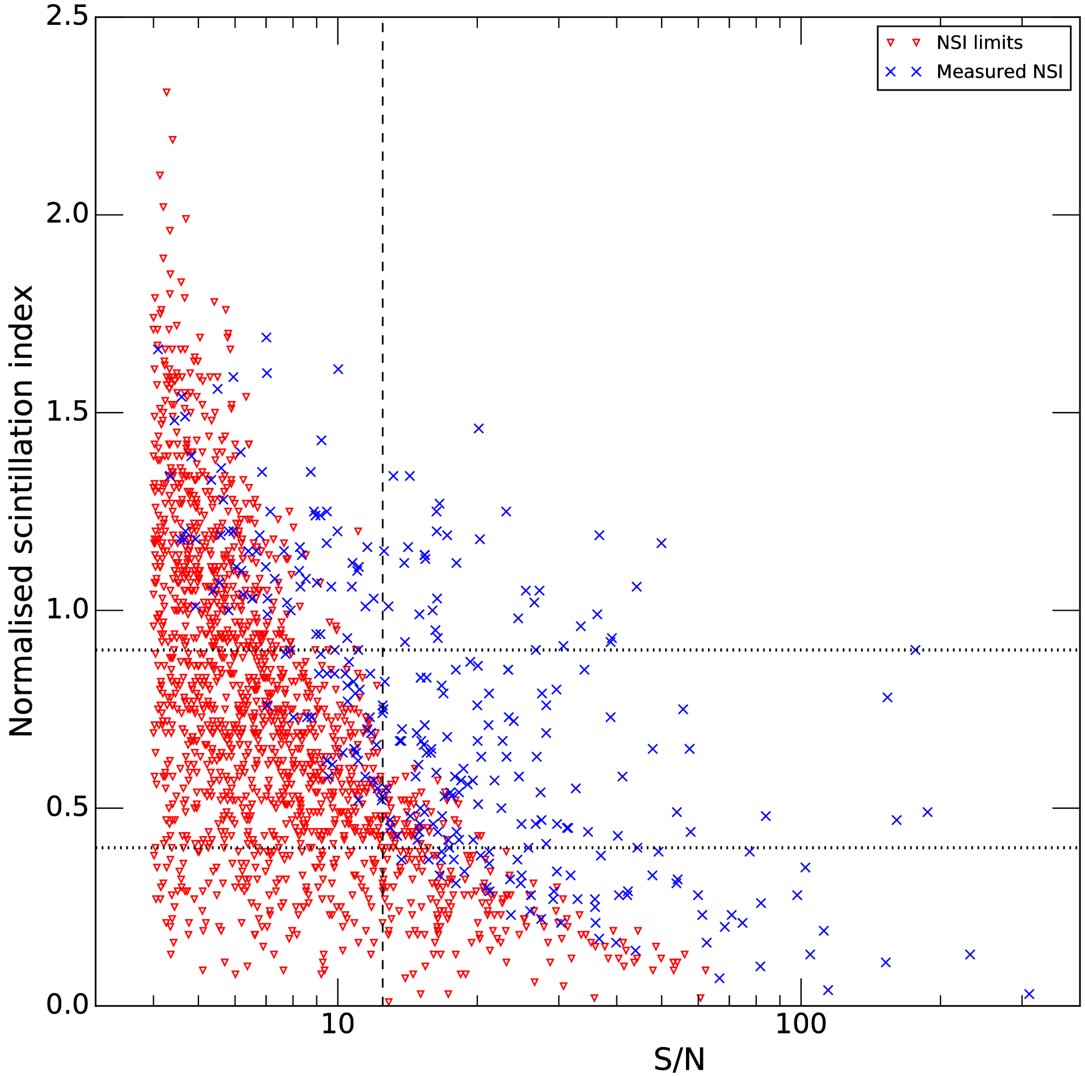
Scintillators
Normalised scintillation index
Solar elongation (deg)
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
20
25
30
35
40
45
50
55
60
65

Observable



Upper Limits
Scintillators
Normalised scintillation index
Solar elongation (deg)
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
20
25
30
35
40
45
50
55
60
65

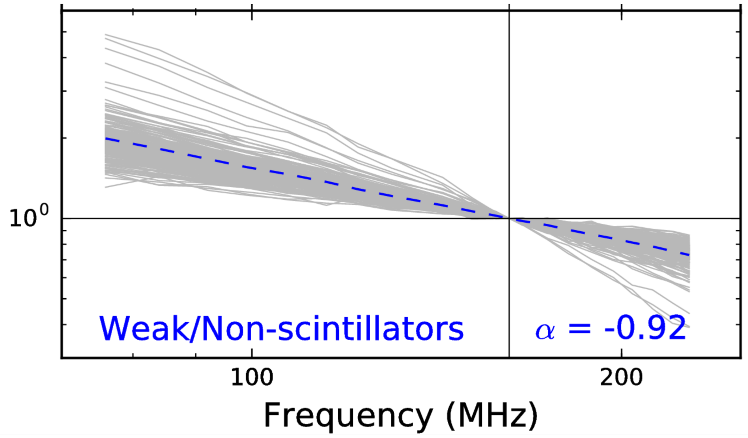
Detection Statistics



High S/N: 414 objects

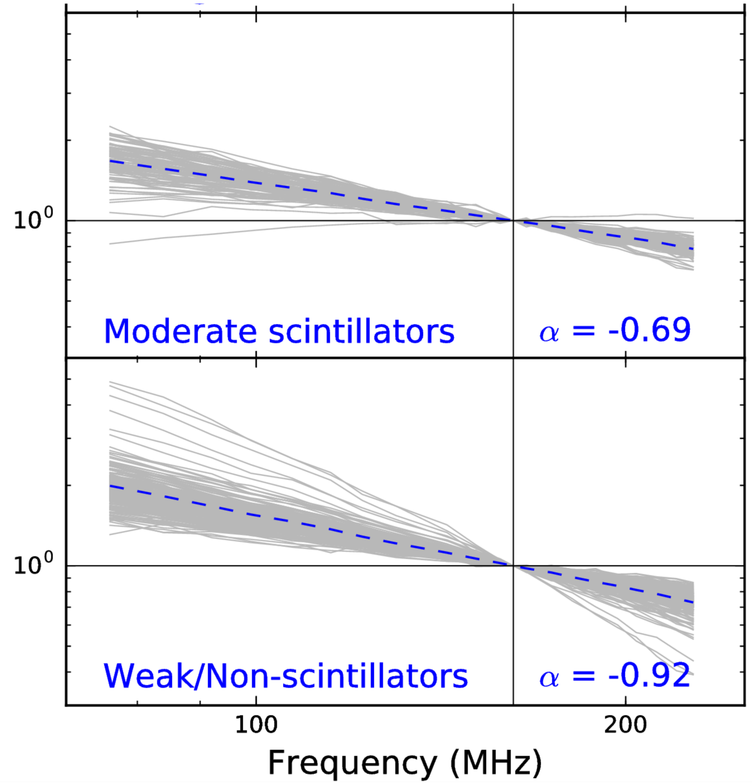
- **Strong Scintillators**
  (NSI ≥ 0.9)
  9%
- **Moderate Scintillators**
  (0.4 ≤ NSI < 0.9)
  23%
- **Weak/non Scintillators**
  (NSI < 0.4)
  53%
- Unrestrictive NSI limits
  All have NSI < 0.6
  14%

Properties of compact objects



Chhetri et al. 2017 in prep

Properties of compact objects



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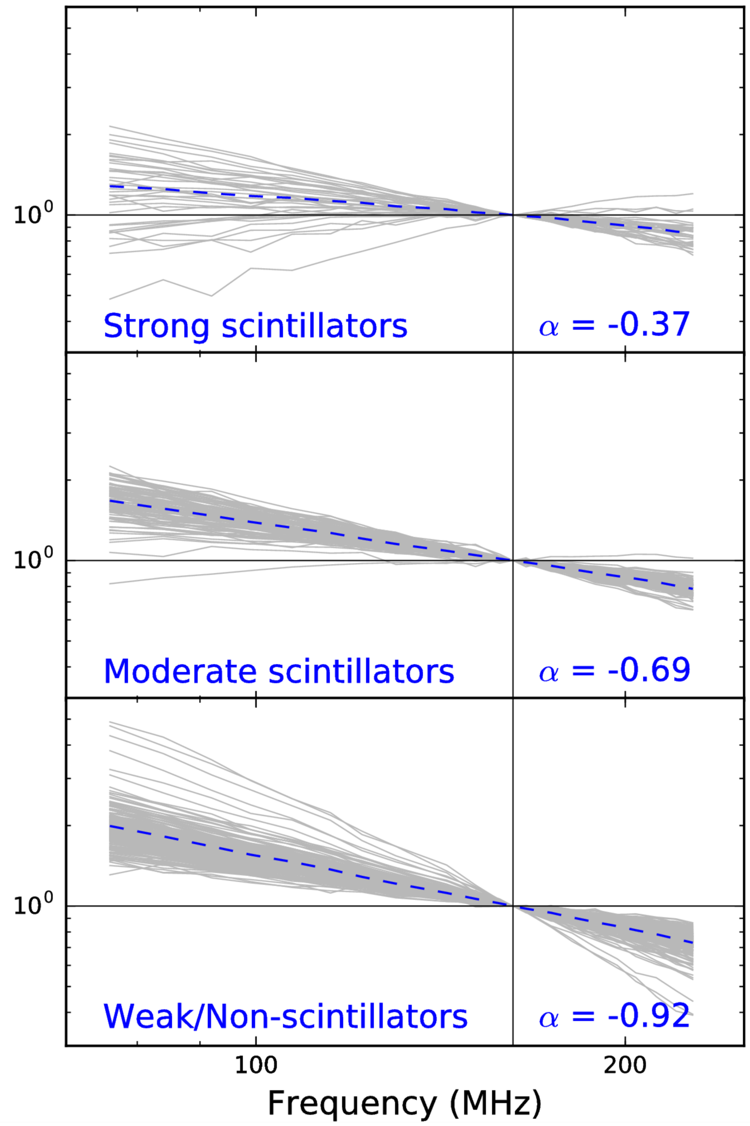
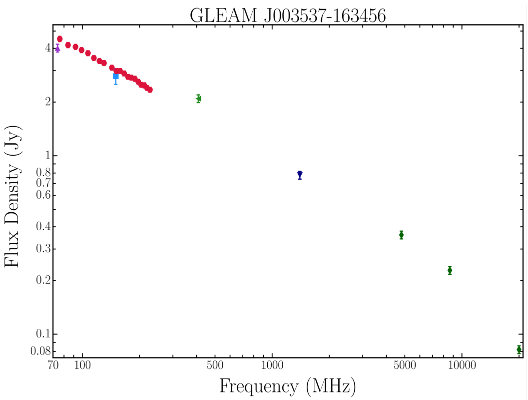
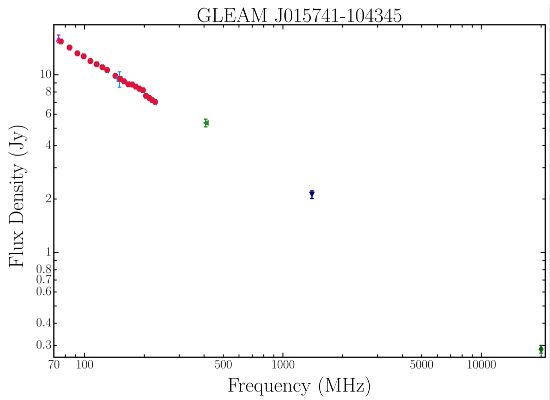


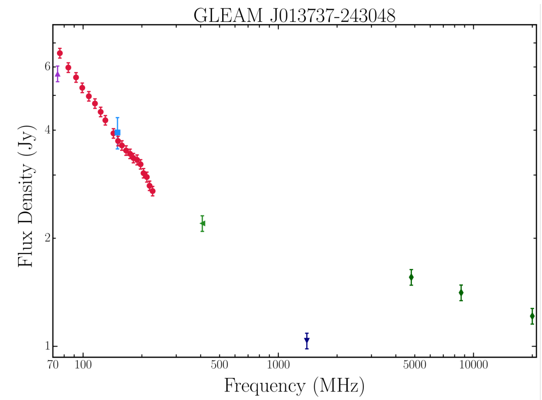
Chhetri et al. 2017 in prep

Typical SEDs

Weak Scintillators







SEDs Credit: Joe Callingham

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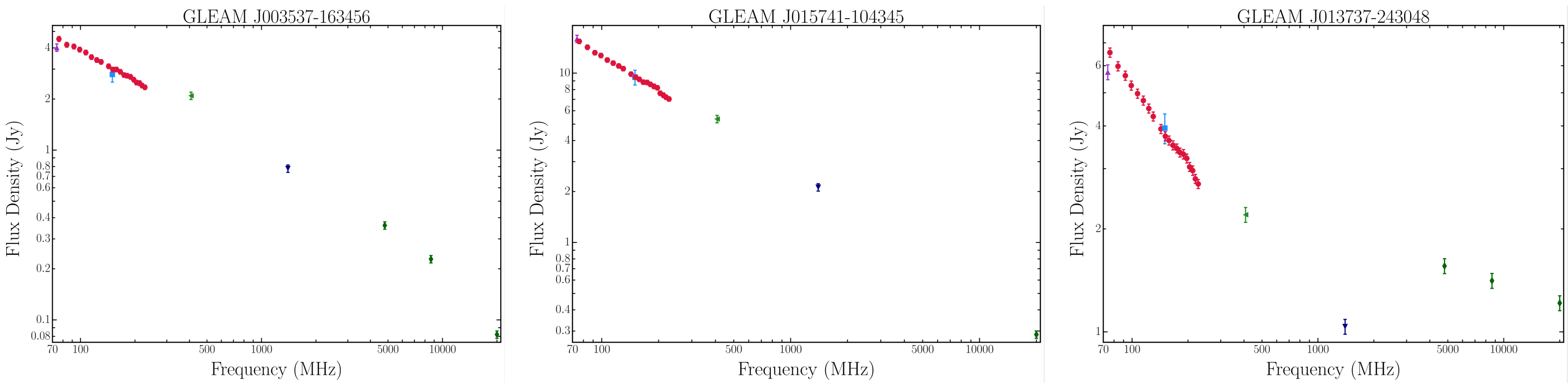
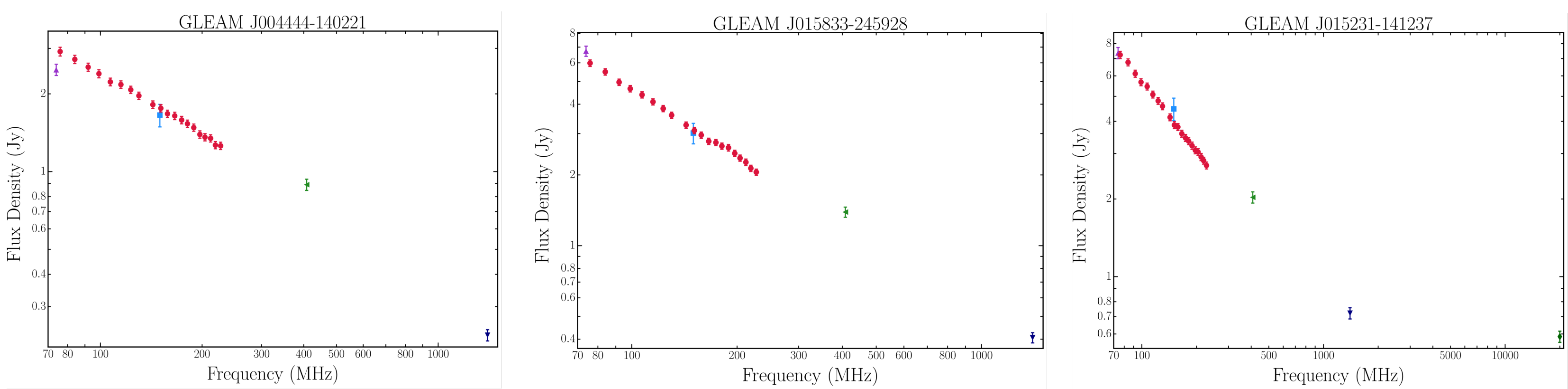


Moderate Scintillators



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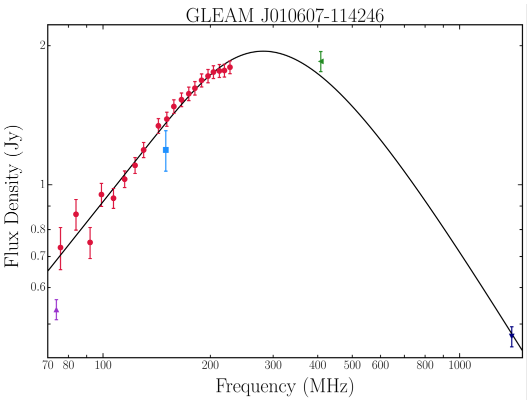

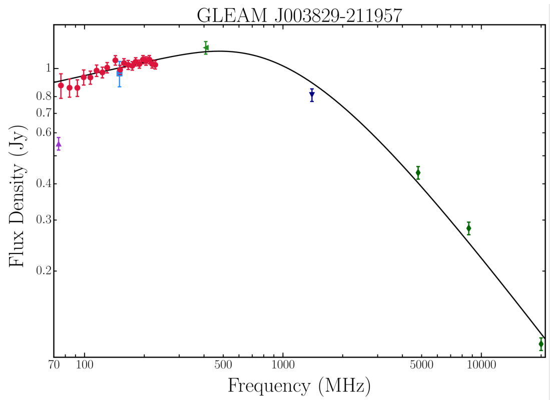

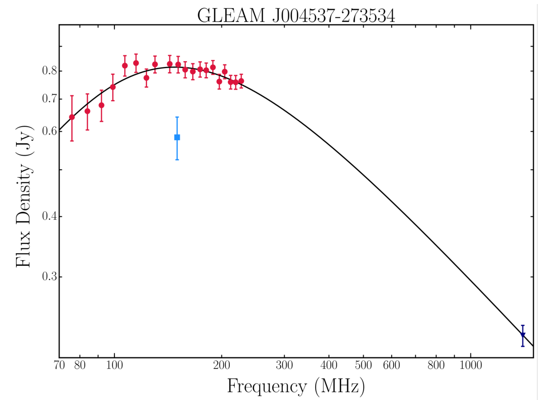

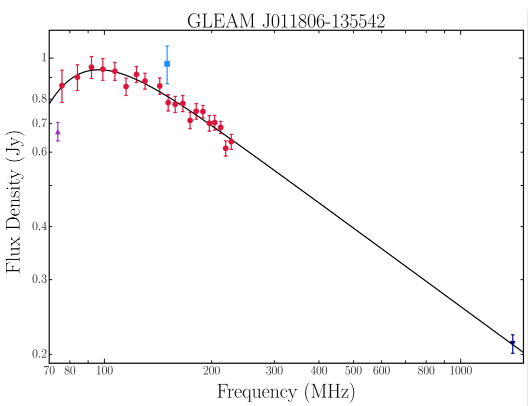

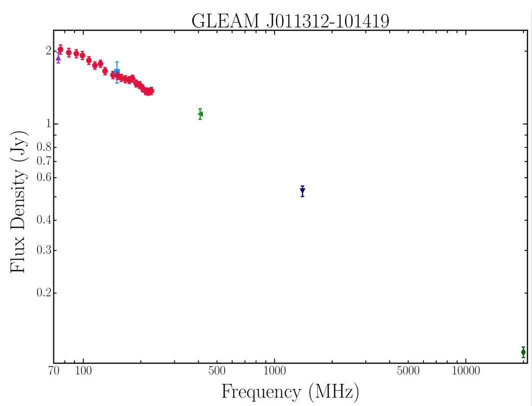

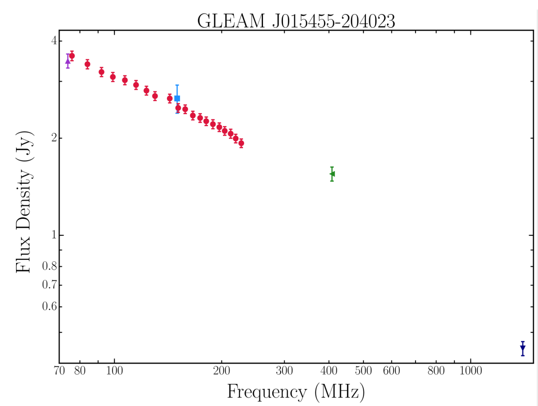

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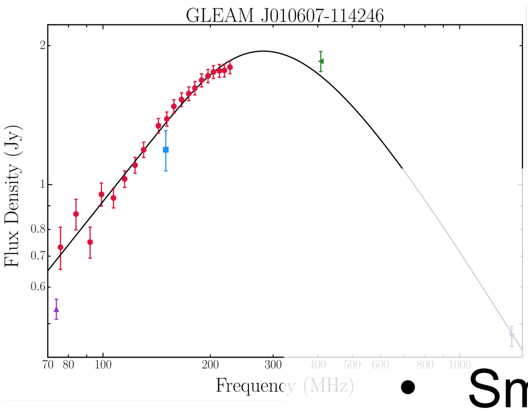
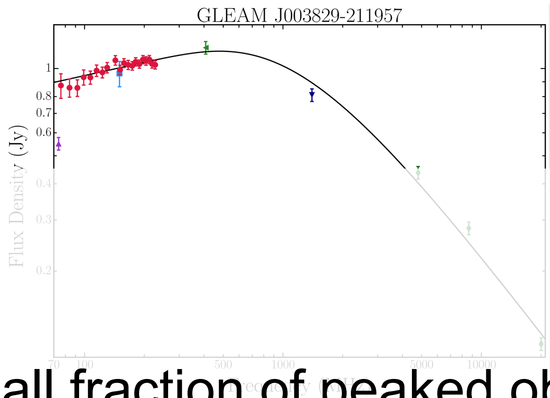
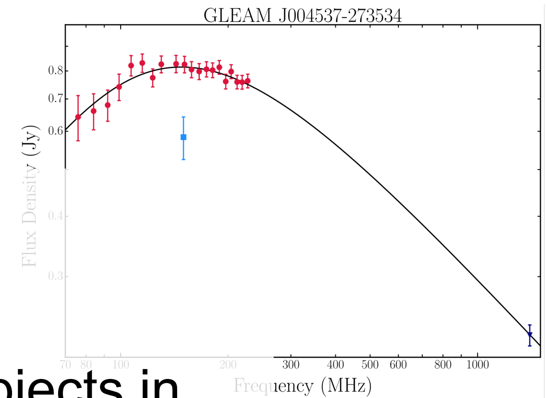
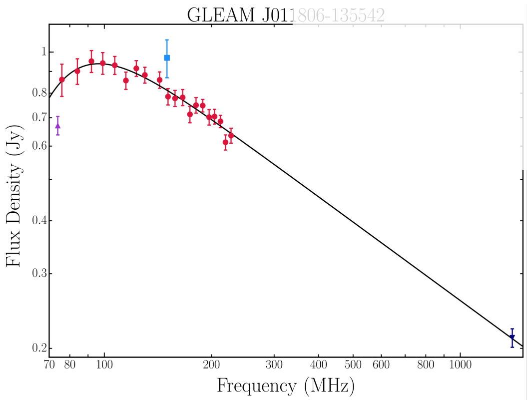
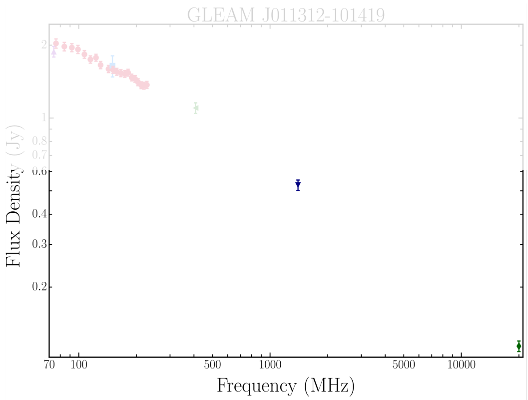


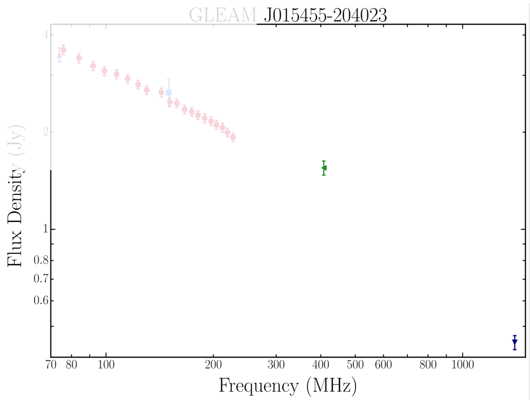




- Small fraction of peaked objects in GLEAM now a majority (46%)







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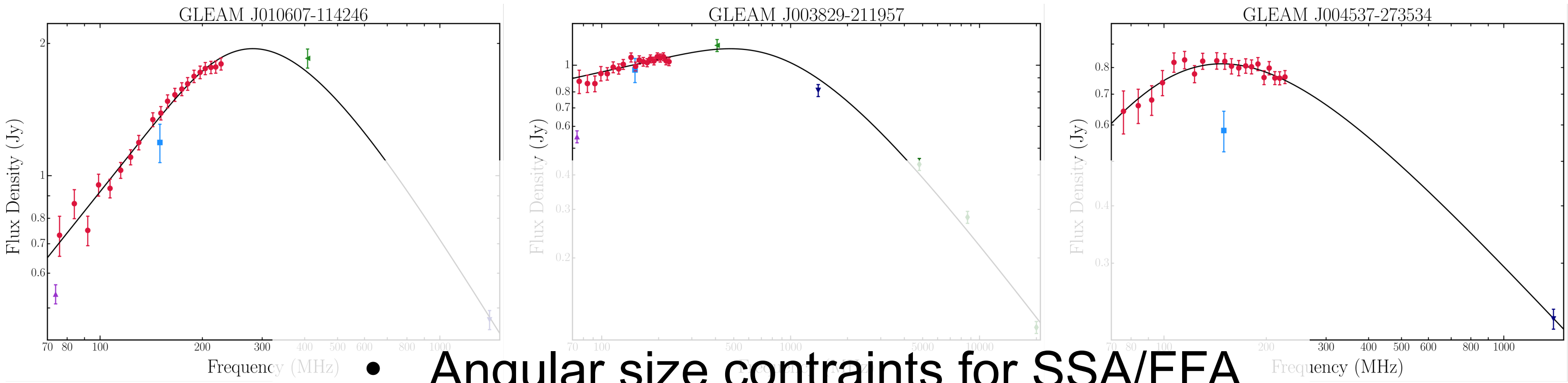
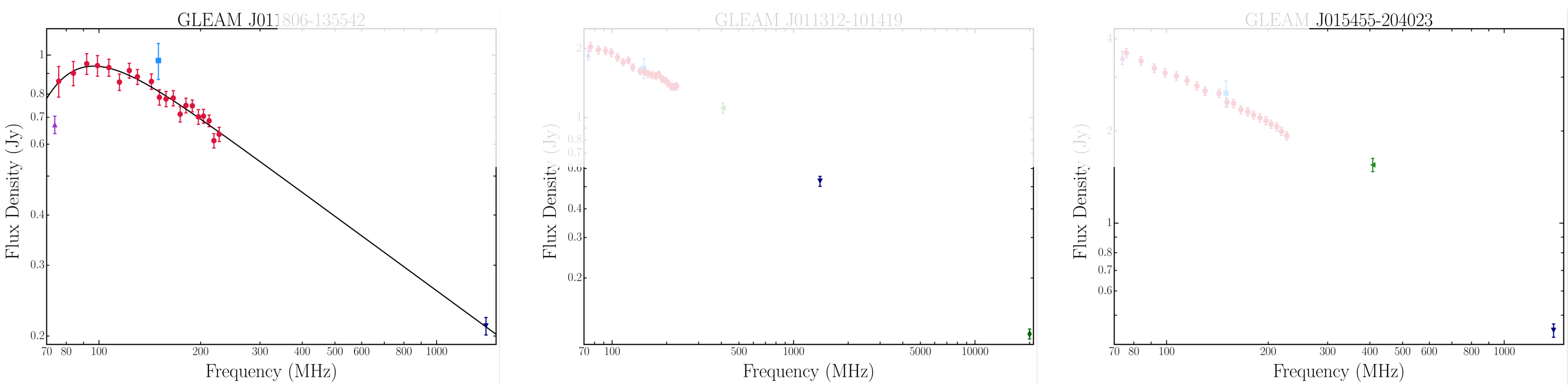


- Angular size contraints for SSA/FFA investigations



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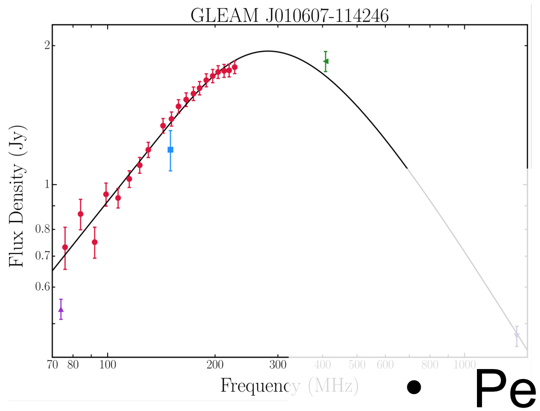
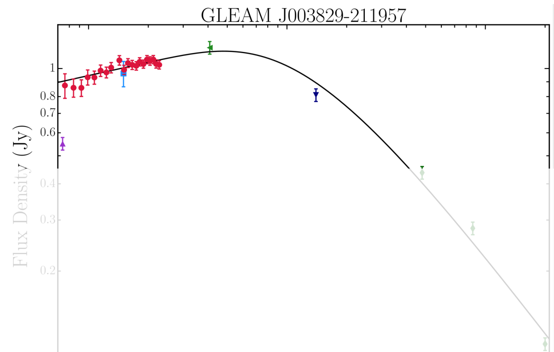
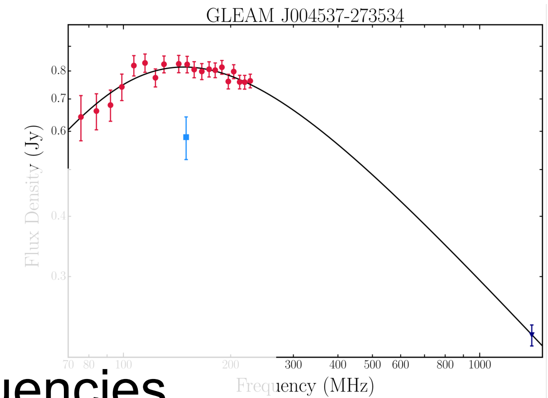
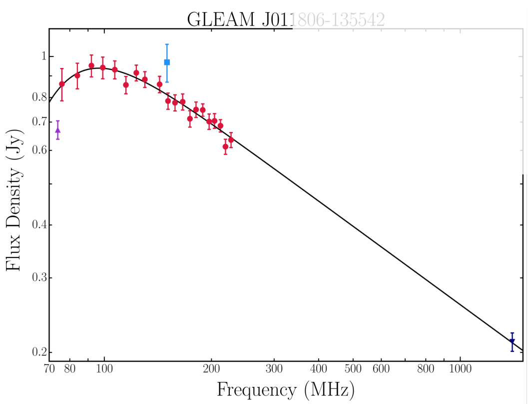
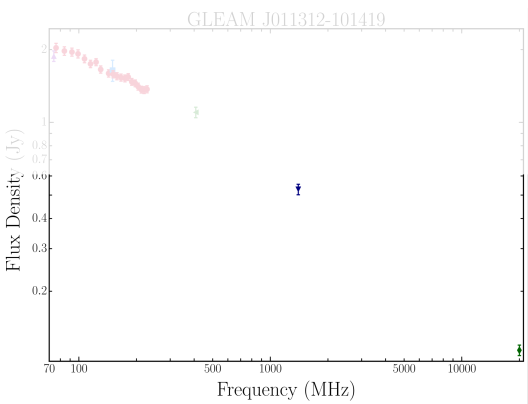


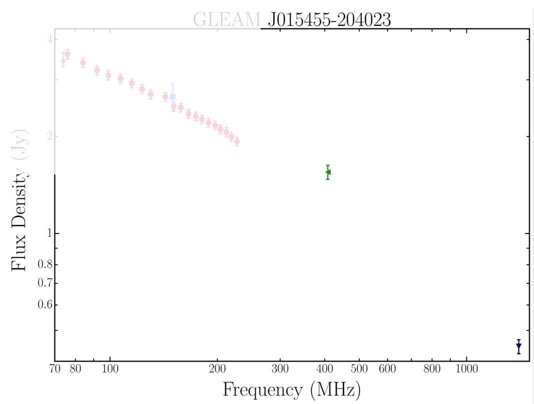




- Peaks below GLEAM frequencies, possible high redshift objects?







SEDs Credit: Joe Callingham

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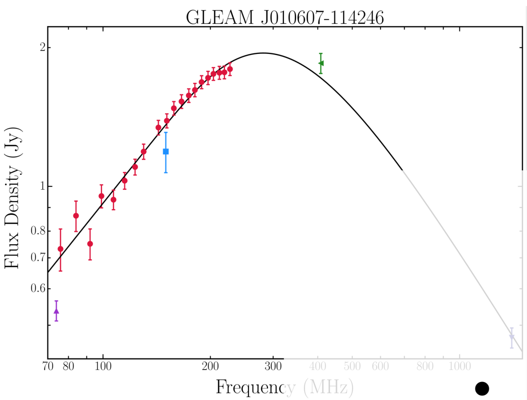
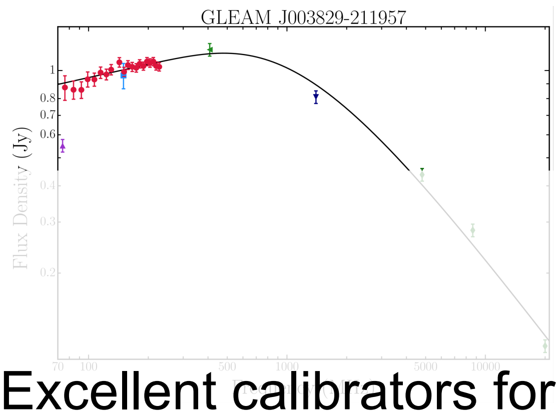
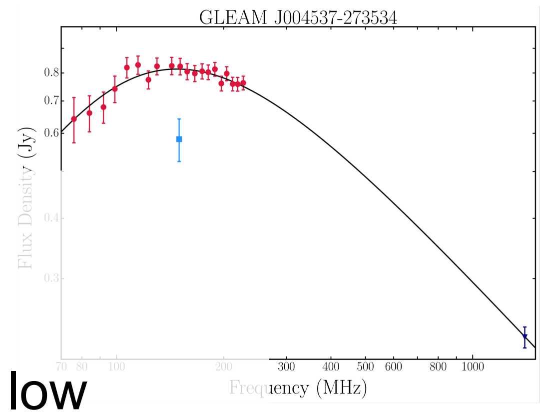
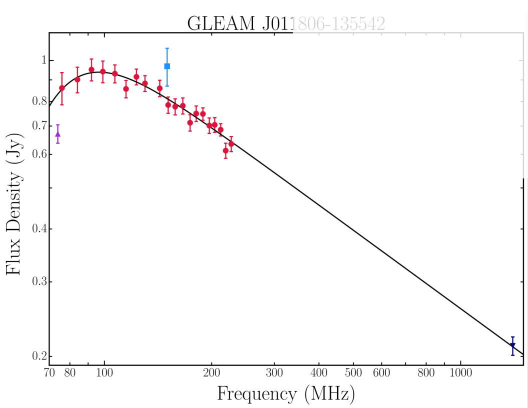
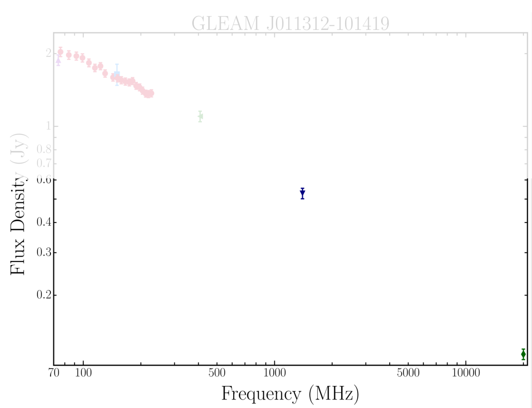


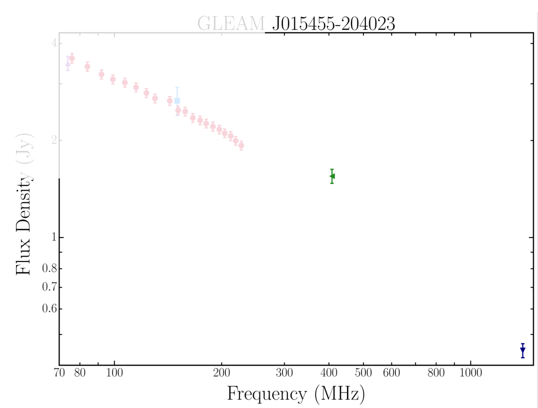




- Excellent calibrators for low frequency instruments

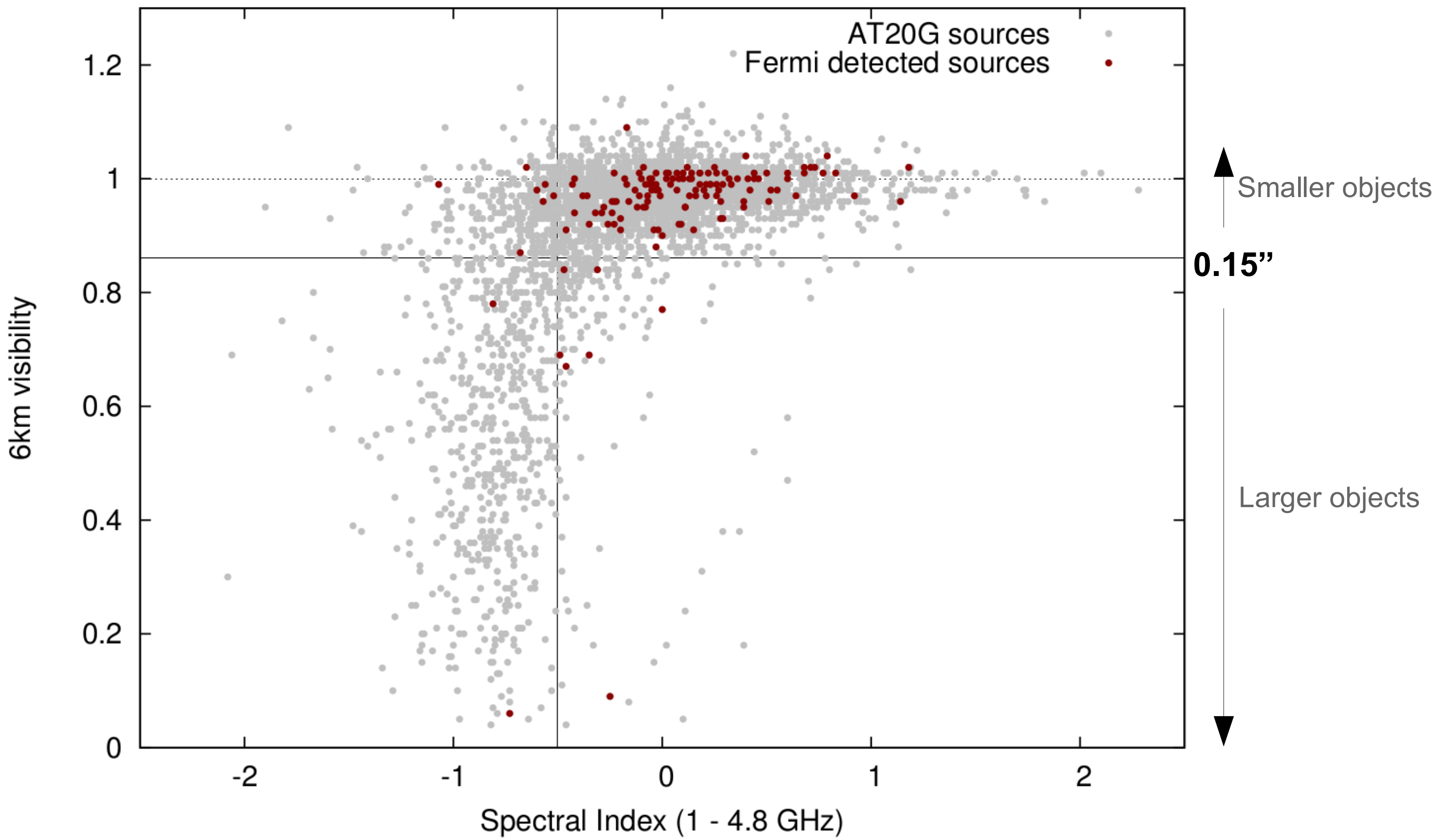




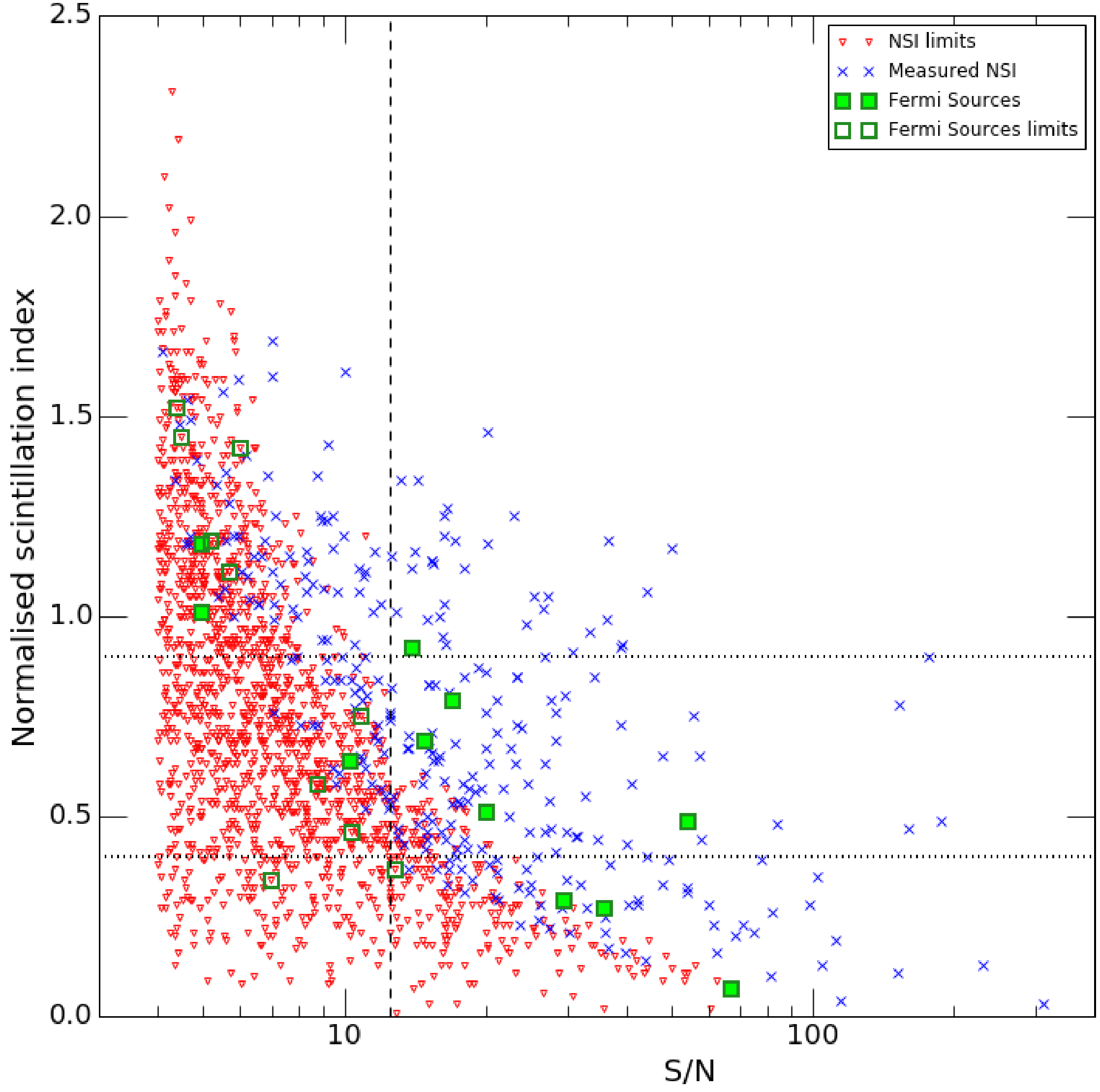


SEDs Credit: Joe Callingham

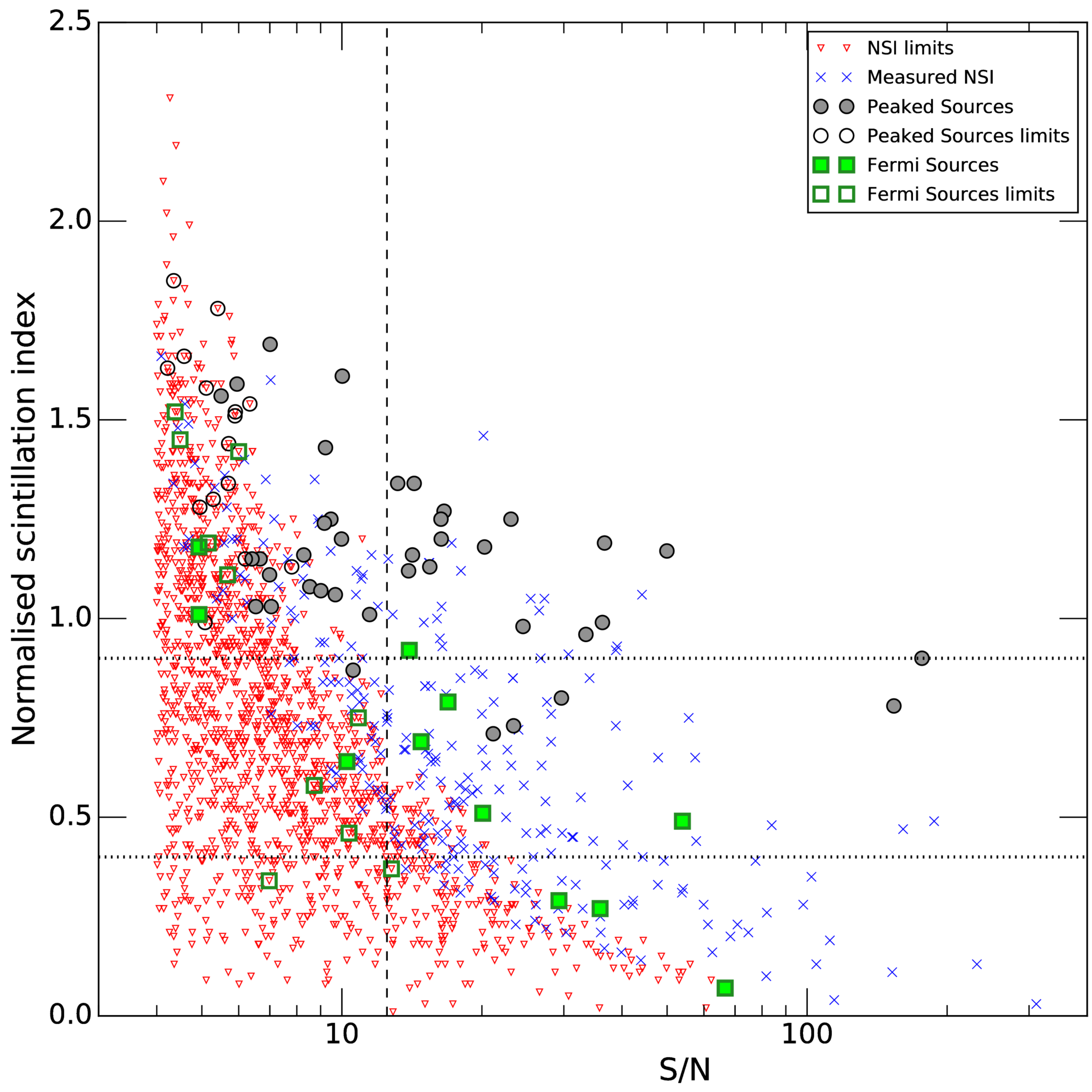
What about the high frequency subarcsecond objects?



High frequency subarcsecond objects in MWA



High frequency subarcsecond objects in MWA



Of Interest for Future

PSR J0034-0721

Detected with S/N of 4.6 in I image
5.6 in variability image

Normalised scintillation index 1.92+/-0.49
(Highest in the field)

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= candidate pulsars ~ 9%

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Normalised scintillation index 1.92+/-0.49
(Highest in the field)

- At the limits of sensitivity threshold for detection

- Technique can be applied to the sensitive SKA

Using IPS (NSI>0.9)
= candidate pulsars ~ 9%

+ spectra (< -0.7)
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CAASTRO ARC CENTRE OF EXCELLENCE FOR ALL-SKY ASTROPHYSICS

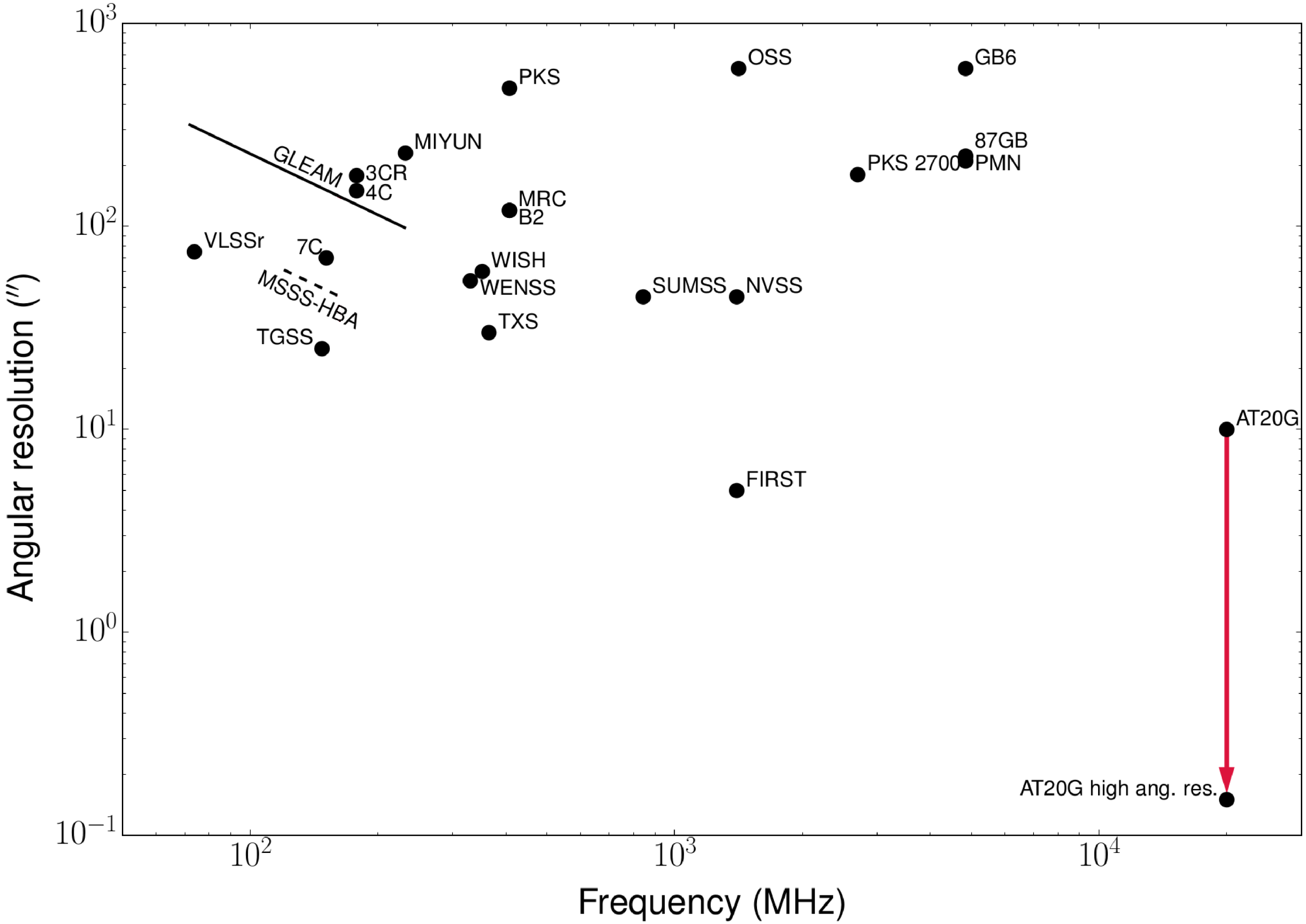
Publication

Mon. Not. R. Astron. Soc. **000**, 000–000 (0000) Printed 10 June 2017 (MN LaTeX style file v2.2)

Interplanetary Scintillation studies with the Murchison Wide-field Array II: Properties of sub-arcsecond compact sources at low radio frequencies

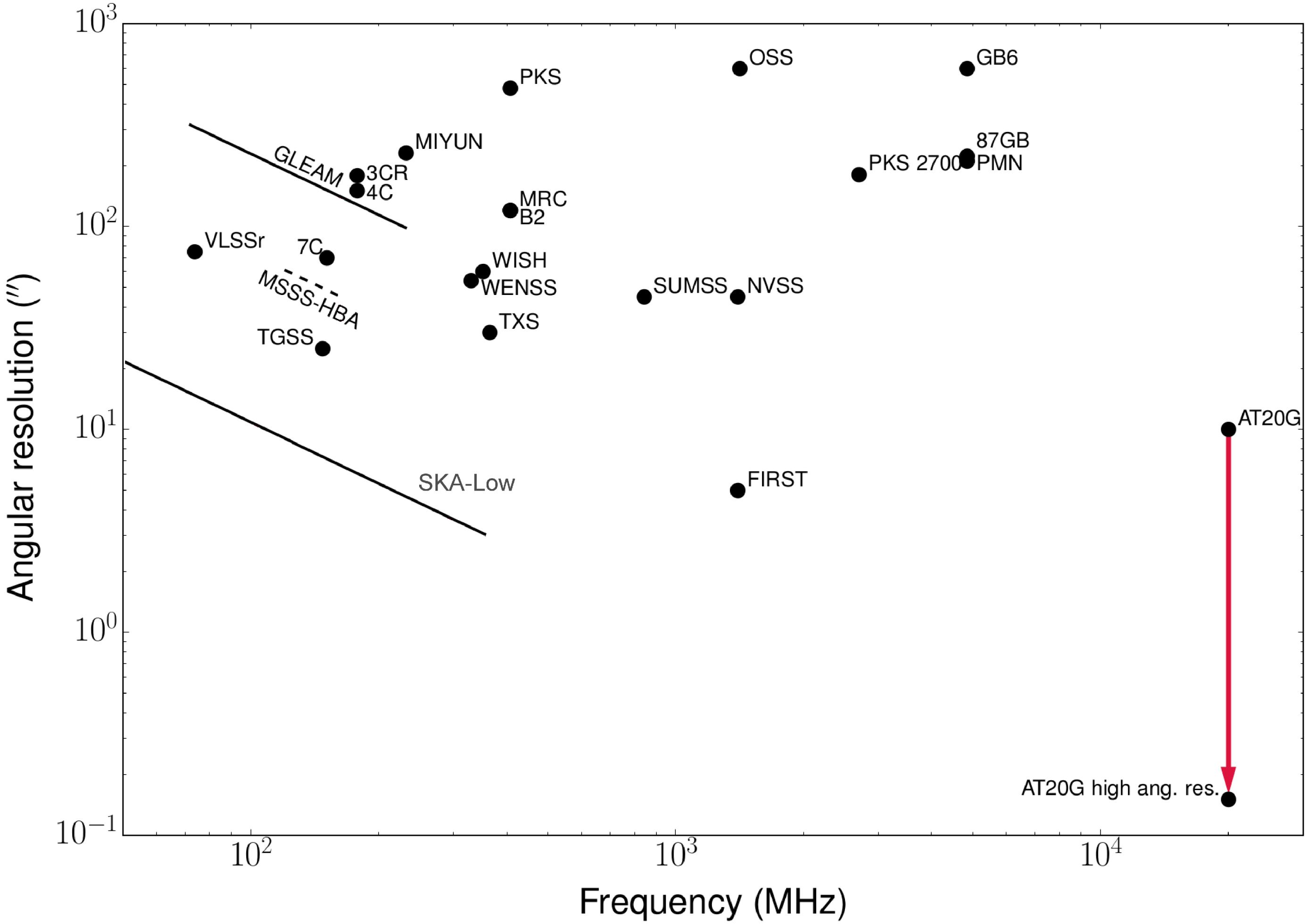
R. Chhetri,[1,2*] J. Morgan,[1] R. D. Ekers,[1,3] J-P Macquart,[1,2] E. M. Sadler,[2,4] M. Giroletti[5] and J. R. Callingham[6]

Large Area Surveys and Angular Resolutions



Credit: Joe Callingham

Large Area Surveys and Angular Resolutions



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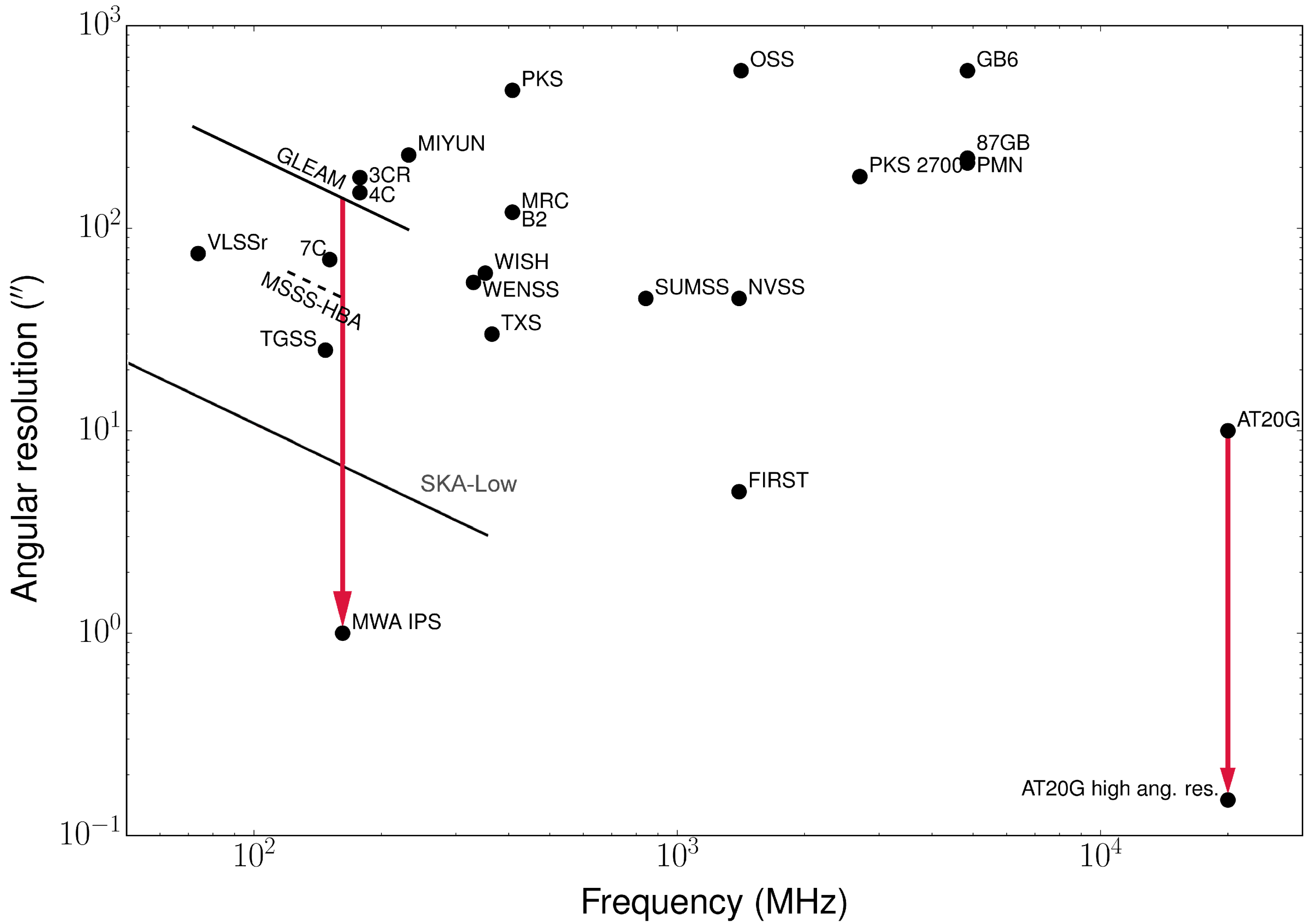

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Summary

Extremely efficient technique to search large parts of sky

- Pulsars (at the threshold of sensitivity)
- Subarcsecond extragalactic population (eg. AGNs)
- Calibrators for low frequency instruments

Technique can be implemented on SKA-Low for angular resolution gain

Low frequency compact population

- Dominated by a different (peaked) source population
- Enable tests for SSA vs FFA
- Compactness not an indicator source hosts blazar core

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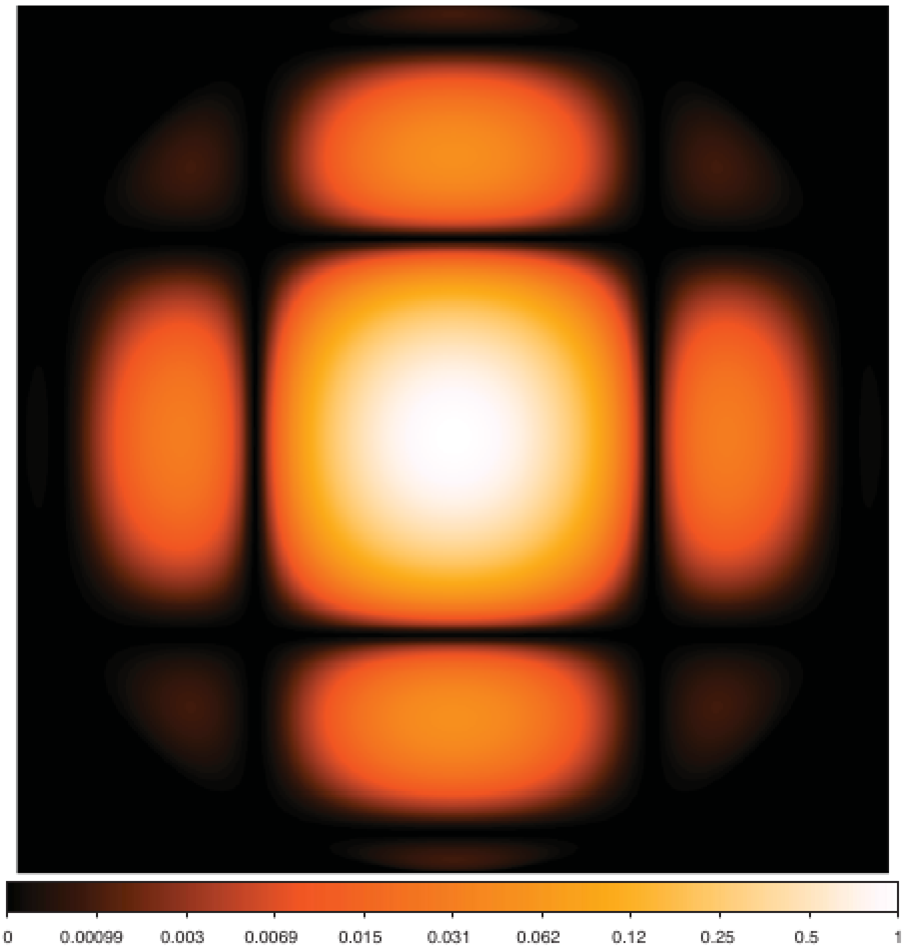
Thank you

IPS strategy with MWA

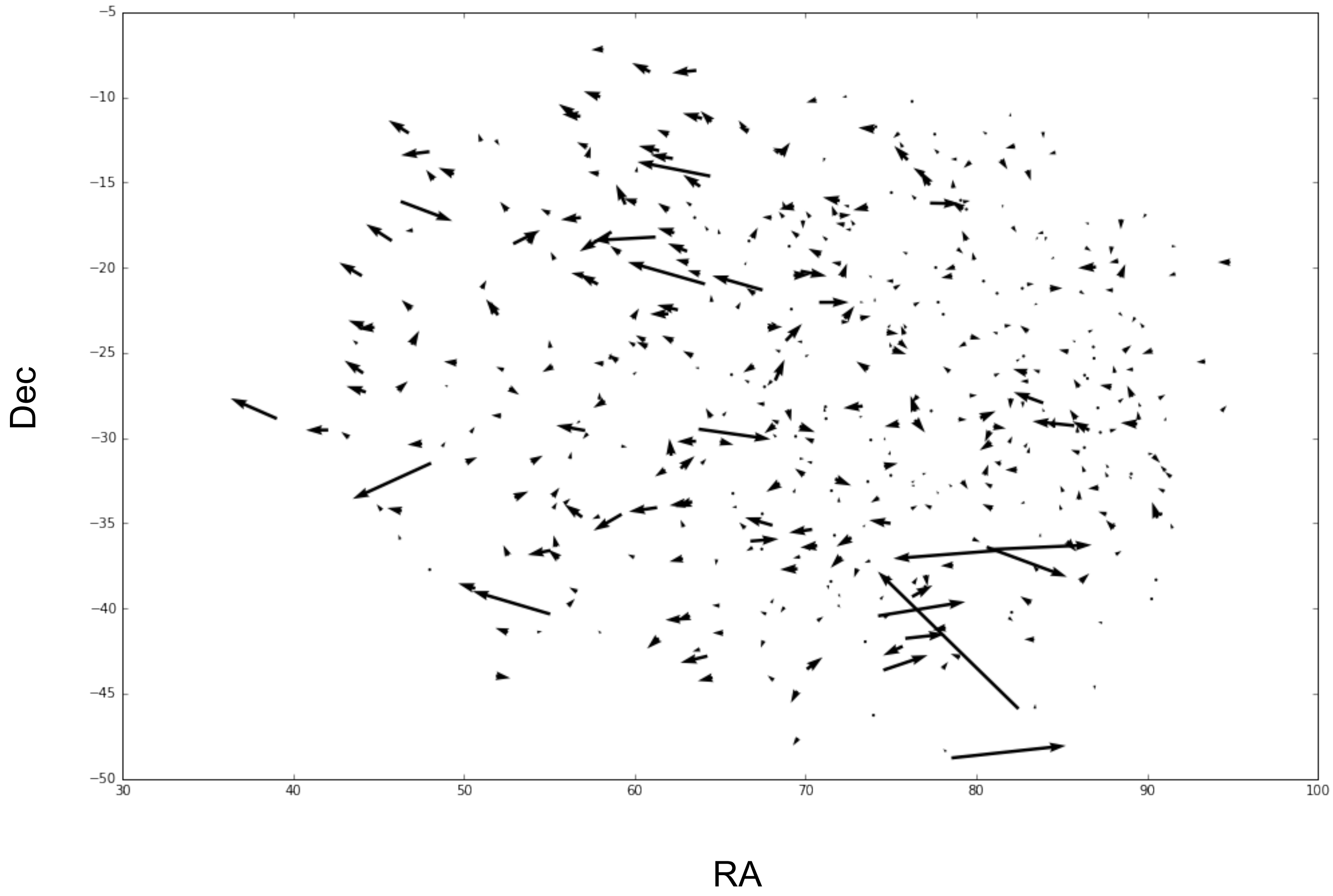
Simulated MWA beam at 150 MHz



Credit: Tingay et al. 2012

Ionospheric effects

IPS affected by ionospheric effects?



The visibility-spectra plot