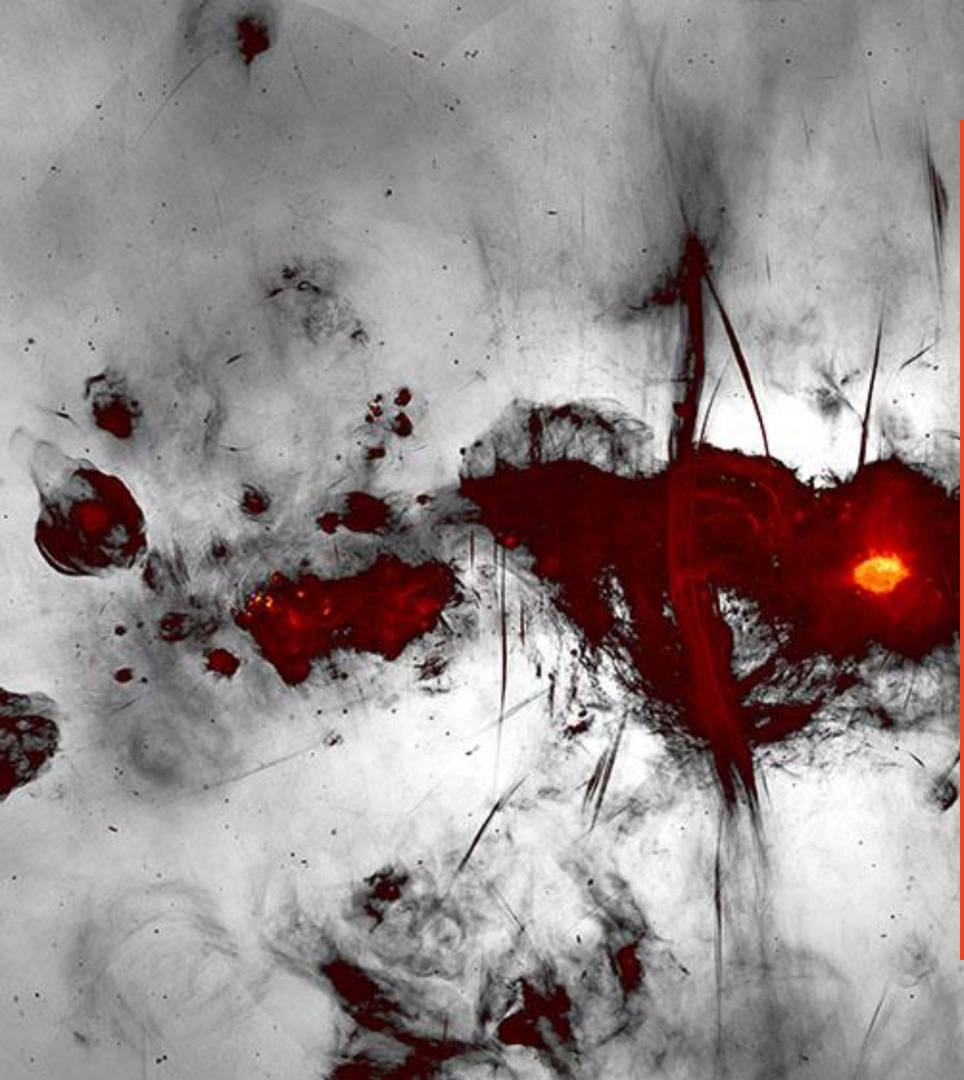

Radio transients and variables

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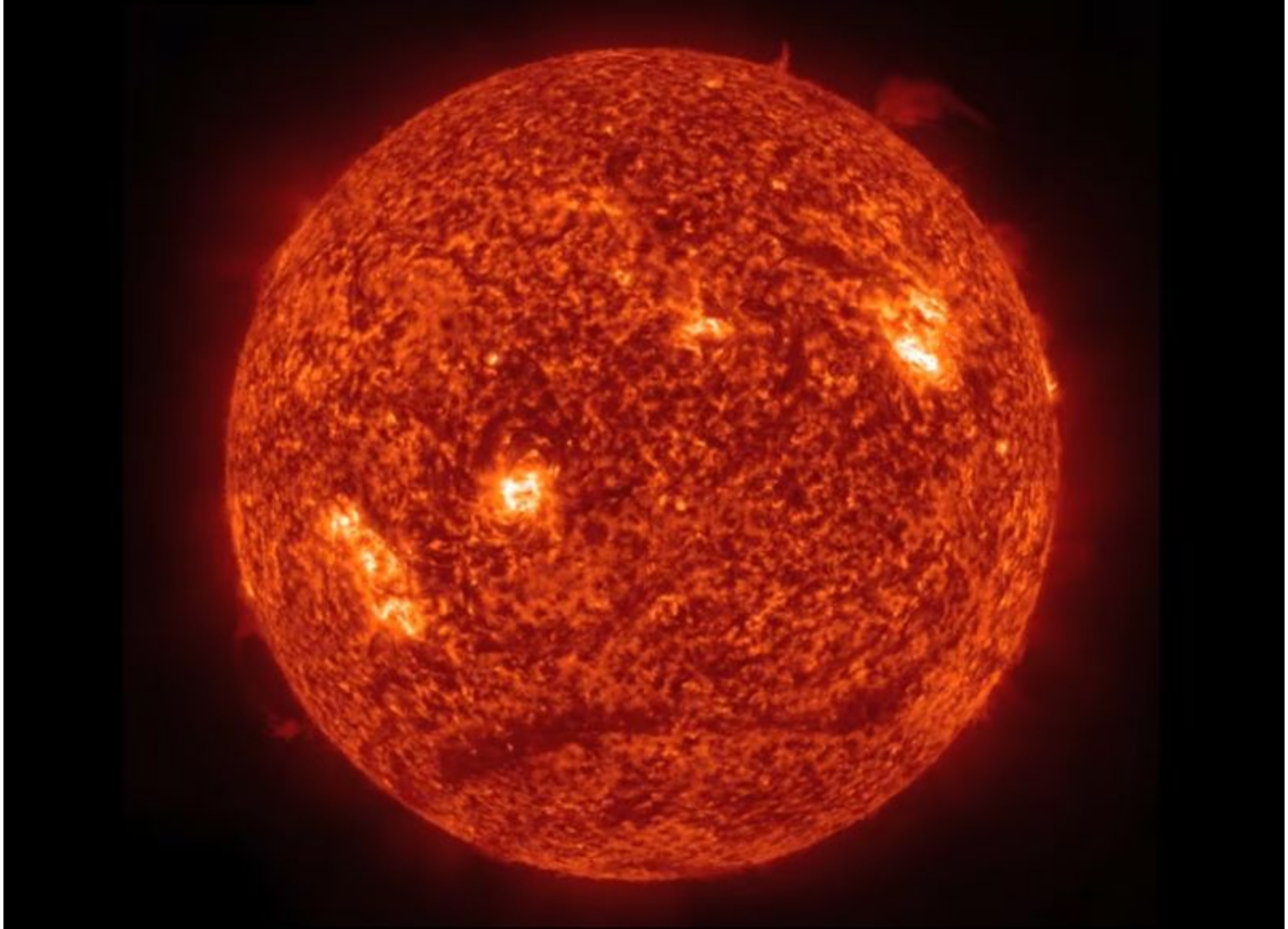
THE UNIVERSITY OF SYDNEY

Transients vs Variables

Transient: by nature it happens once and doesn't happen again. E.g. explosions (supernovae, GRBs)

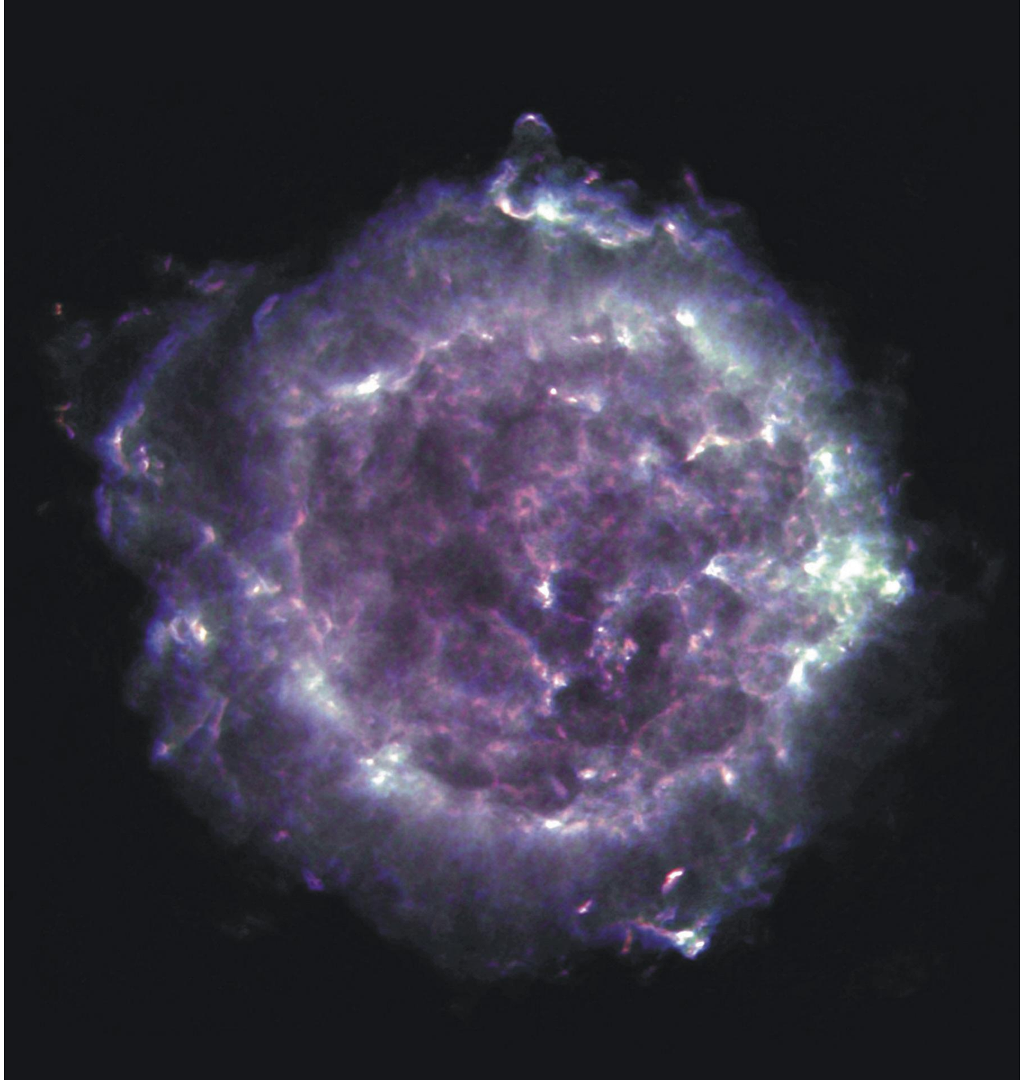
Variable: by nature can happen multiple times, periodically or otherwise. E.g. X-ray binaries (XRBs), novae, stellar flares

Credit: Shutterstock/Mik Ulyannikov



Hey 1946

Credit: NRAO
AUI
NSF



L. Rudnick, T. Delaney, J. Keohane & B. Koralesky, image composite by T. Rector (VLA)

Stellar radio flare (from YZ Canis Minoris) was observed by Sir Bernard Lovell in 1969 using the Mark I (now Lovell) telescope

It is fortunate that these records are of unusually high quality, and because the event occurred in the early hours of a Sunday morning they are completely free from any transient forms of terrestrial interference.

ν (GHz)	Area (deg^2)	Direction (deg)	$\Delta\theta$ ($''$)	N_{ep}	δt	Δt	rms (mJy)	Sources	Tran.	Var.	Reference
0.84	2776	$\delta < -30$	∼45	2	12 hr	1 day–20 yr	2.8	29730	2	∼100	Bannister et al. (2011)
1.4	0.22	$l = 150,\ b = +53$	4.5	3	6 hr	19 days, 17 months	0.015	...	0	2%	Carilli et al. (2003)
1.4	2.6	$l = 151,\ b = +24$	60	16	12 hr	1–12 days, 1–3 months	0.7	245	0	∼ 1%	Frail et al. (1994)
1.4	120	South Gal. cap	5	2	days	7 yr	0.15	9086	0	1.4%	de Vries et al. (2004)
1.4	2500	$b \geq 30$	45	2	days	∼years	0.45	7181	1	...	Levinson et al. (2002)
1.4	2870	$+32 > \delta > +42$	$24'' \times 2.4'$	∼1000	4 min	1 day	300	...	1	...	Aoki et al. (2014)
1.4	0.2	$l = 57,\ b = +81$	20	1852	minutes	1 day–23 yr	2	10	0	...	Bower & Saul (2011)
1.4	690	$l = 70,\ b = +64$	150	2	months	15 yr	3.94	4408	0	∼0.1%	Croft et al. (2010b)
1.4	690	$l = 70,\ b = +64$	150	12	> 1 day	days–months	38	4408	0	≲0.5%	Croft et al. (2011)
1.4	0.2	Phase calibration	...	151	5 min	days–years	∼1	...	0	...	Bell et al. (2011)
1.4	**8444**	**North Gal. cap**	**5.4**	**∼55000**	**11 yr**	**∼days–years**	**∼1**	**279407**	**...**	**1627**	**Thyagarajan et al. (2011a)**
1.5	**0.44**	$l = 237,\ b = +42$	**4.3**	**172**	**∼days**	**days–6 yr**	**0.001**	**2713**	**...**	**58**	**Sarbadhicary et al. (2020)**
1.4	**0.5**	**E-CDFS**	**∼3**	**49**	**3 months**	**1 day–3 months**	**0.003**	**736**	**0**	**1%**	**Mooley et al. (2013)**
1.4	**60**	**SDSS Stripe 82**	**5**	**3**	**21 yr**	**7 yr**	**0.15**	**1436**	**0**	**89**	**Hodge et al. (2013)**
0.86	**56**	**PSR J1107−5907**	**78**	**390**	**13 hr**	**2 min-13 hr**	**21**	**...**	**0**	**1**	**Hobbs et al. (2016)**
1.4	**5.97**	$l \approx 296,\ b \approx -70$		**6**	**8 yr**	**∼days–8 yr**	∼ 1	**∼500**	**1**	**8**	**Hancock et al. (2016)**
0.86	**150**	***Spitzer* SSDF**	**70**	**3**	**1 week**	**12 h–1 week**	**1**	**3722**	**0**	**1**	**Heywood et al. (2016)**
1.4	**30**	**NGC 7232**	**∼17**	**8**	**12 day**	**∼days**	**0.3**	**1653**	**0**	**9**	**Bhandari et al. (2018)**
0.95	**30**	$l = 40.5,\ b = -80$	**12**	**7**	**∼1 yr**	**minutes-1 yr**	**0.0.035**	**40859**	**0**	**6**	**Wang et al. (2021)**

Table 1.1: Summary of radio searches for variable and transient sources between 0.8 and 2 GHz, reproduced from Ofek et al. (2011a). Bold rows indicate surveys that were not included in Ofek et al. (2011a). ν is the central frequency of the survey; the area is the total area observed by the survey; $\Delta\theta$ is the FWHM of the primary beam of the instrument conducting the survey; N_{ep} is the number of epochs; δt is the time span over which each epoch was obtained; Δt is the range of separations between epochs; rms is the average root-mean-square (RMS) noise in the images; Sources is the total number of detected persistent sources; Tran. is the number of transient sources detected; Var. is the number or percentage of variable sources detected.

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1.4	0.2	Phase calibration	...	151	5 min	days–years	$\sim$1	...	0	...	Bell et al. (2011)
1.4	**8444**	**North Gal. cap**	**5.4**	**$\sim$55000**	**11 yr**	**$\sim$days–years**	**$\sim$1**	**279407**	**...**	**1627**	**Thyagarajan et al. (2011a)**
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Different types of radio variables/transients

Fast vs Slow

Fast = pulsars, rotating radio transients, magnetars, fast radio bursts

Slow = AGN scintillation, XRBs, stellar flares, novae, GRB afterglows, tidal disruption events and more

Fast vs Slow

Fast = pulsars, rotating ra[illegible] transients, magnetar[illegible]ast radio bursts

Slow = AGN scintillation, XRBs, [illegible]ellar flares[illegible]vae, GRB afterglows, tidal disruption events and more

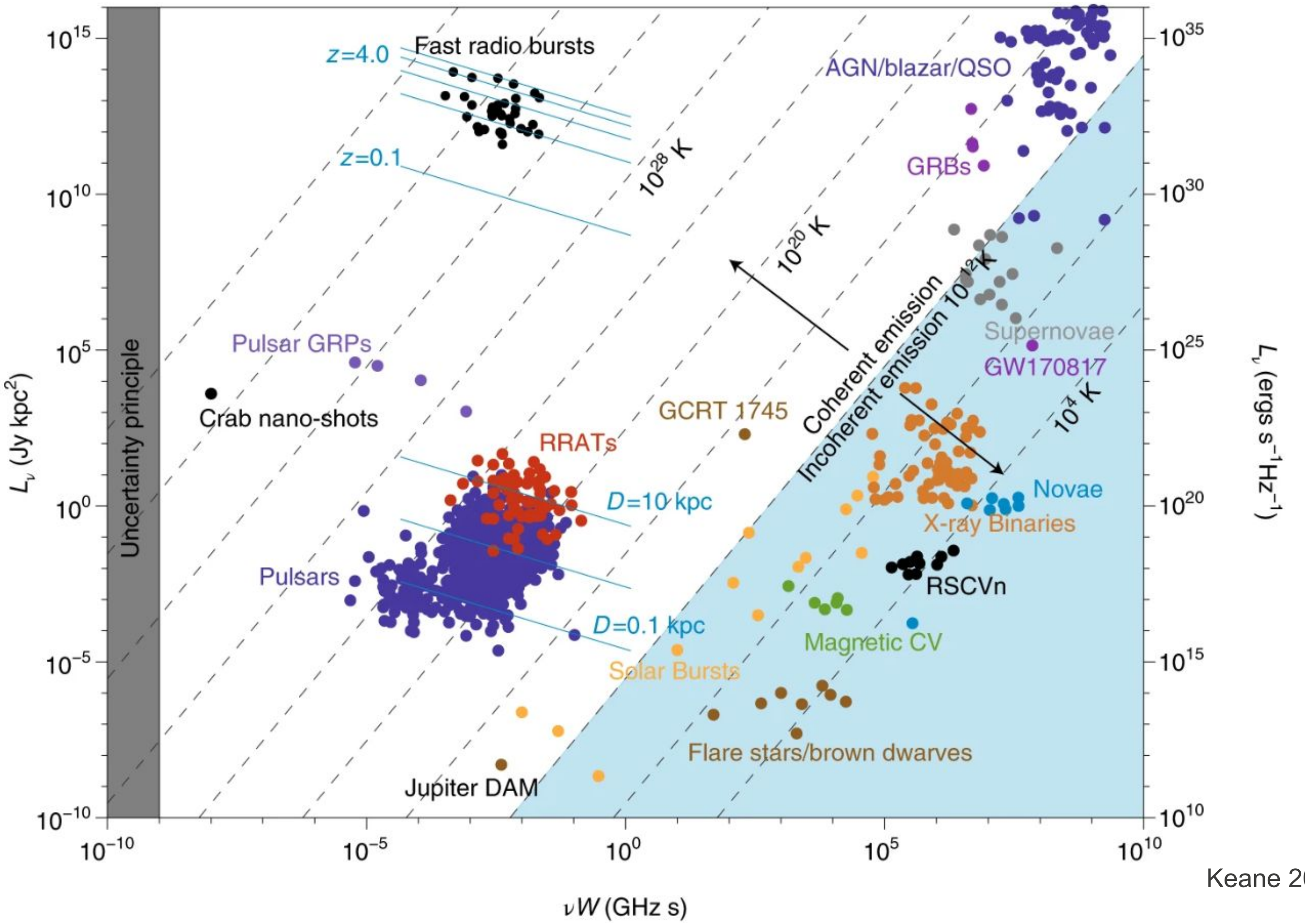
Fast vs Slow

Fast = pulsars, rotating radio transients, magnetars, fast radio bursts

Slow = AGN scintillation, XRBs, stellar flares, novae, GRB afterglows, tidal disruption events and more

- Doesn’t tell us any physical information about the sources
- Where do we draw the line? How fast is fast? How slow is slow?
- We can now make very short images and longer dynamic spectra, there’s no clear divide between the techniques anymore

Emission types: coherent vs incoherent



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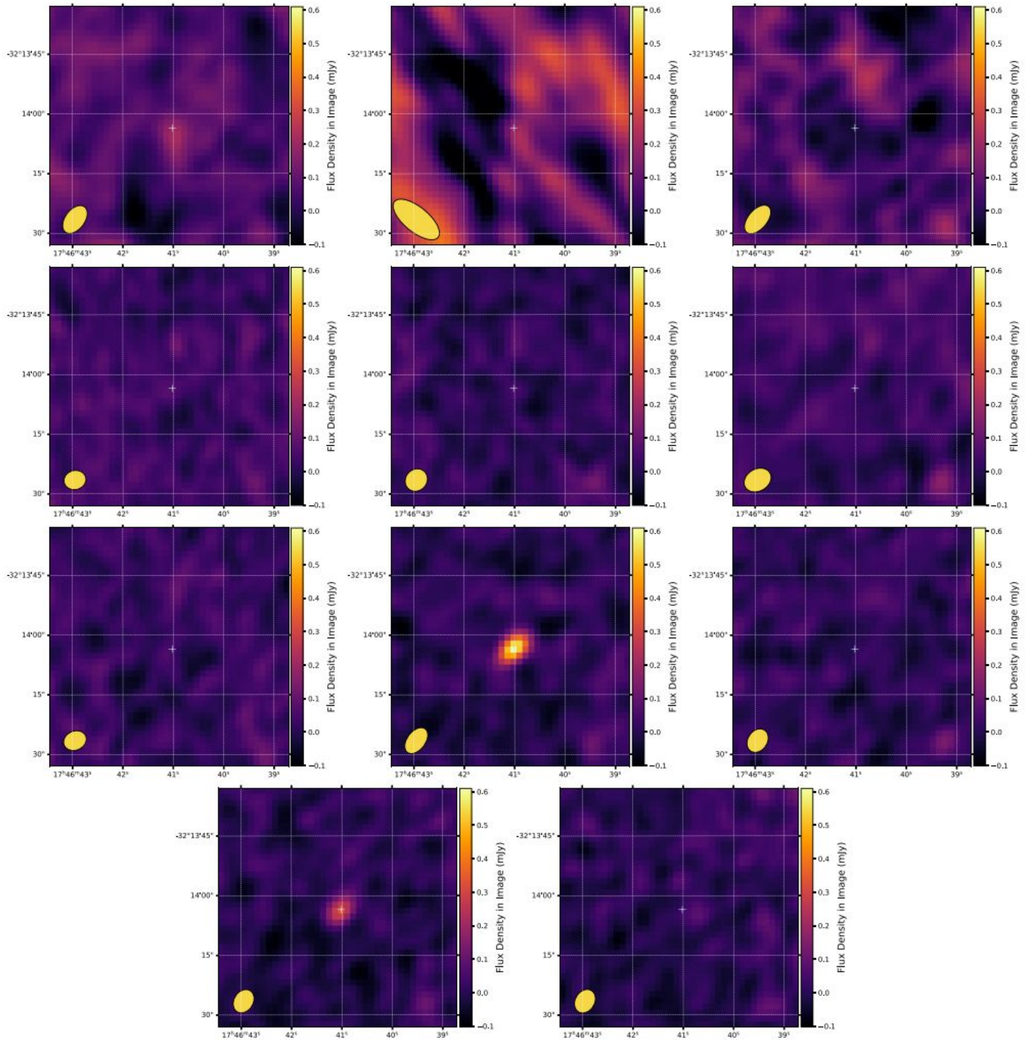
Keane 2018, Pietka et al. 2015,

Techniques: image-plane vs time-domain

Image-plane = searching in images of the radio sky

Time-domain = searching in the time-frequency-brightness domain (dynamic spectra)



Andersson et al. 2022

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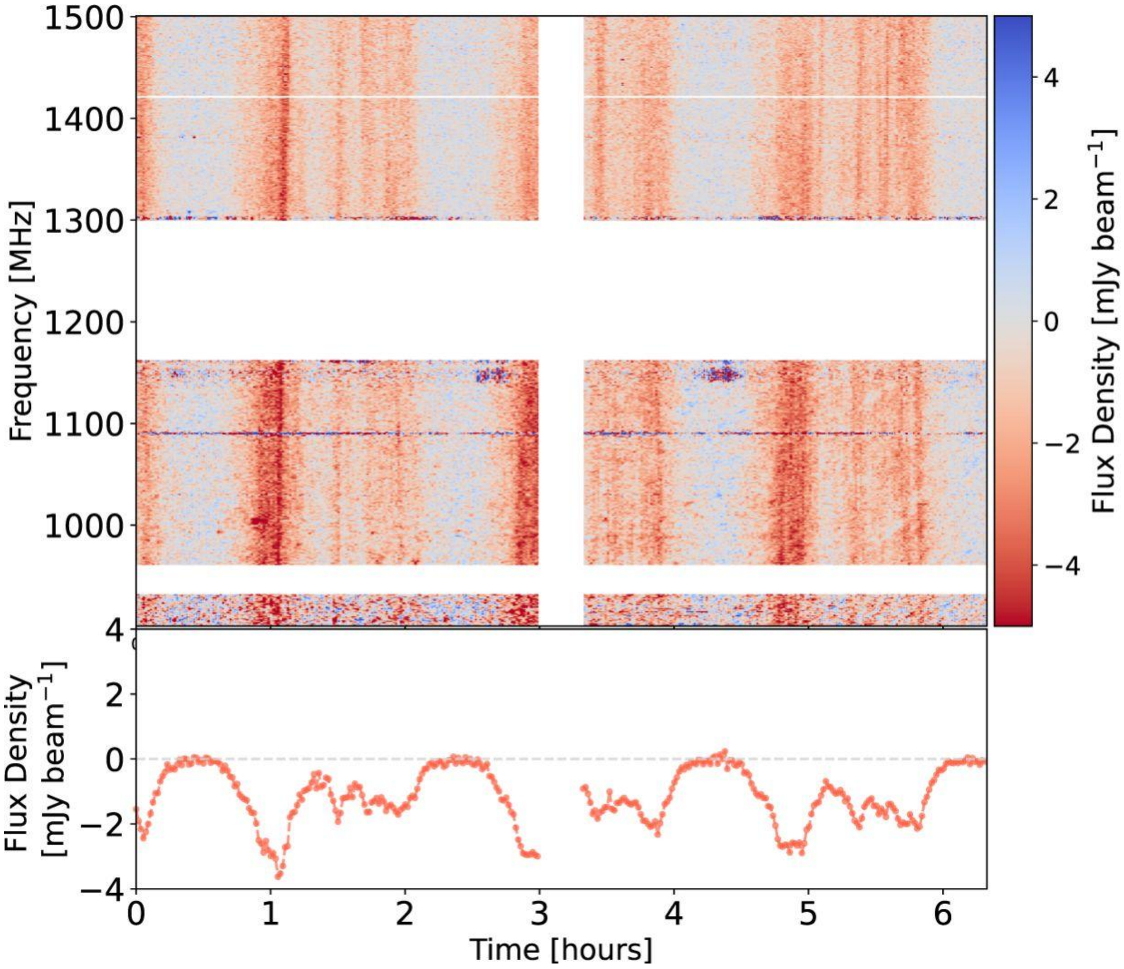


1500
1400
1300
1200
1100
1000
Frequency [MHz]
4
2
0
−2
−4
Flux Density [mJy beam^{-1}]
4
2
0
−2
−4
Flux Density
[mJy beam^{-1}]
0
1
2
3
4
5
6
Time [hours]

Techniques: image-plane vs time-domain

Image-plane = searching in images of the radio sky

Time-domain = searching in the time-frequency-brightness domain (dynamic spectra)

Techniques: image-pla… time-dom…

Image-plane = searching i… …ges of the radio

Time-domain = searching in the time-frequency-… …tness domain (dynamic spectra)

?

Techniques: image-plane vs time-domain

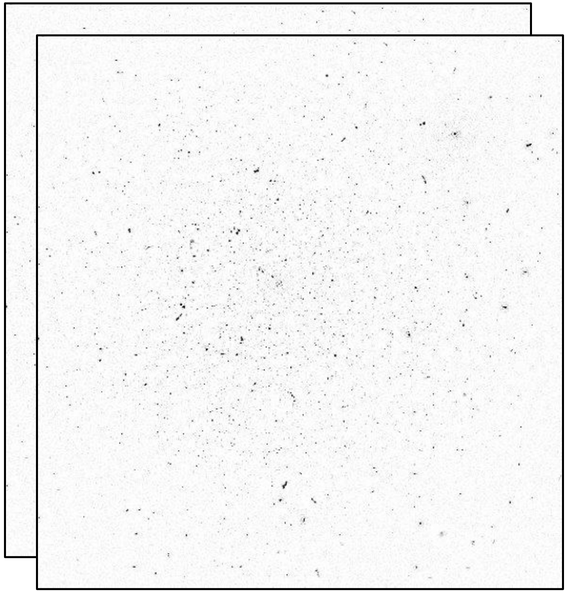
VAST
- ASKAP
- Image-plane source-tracking
- Visibility subtraction
- Untargeted

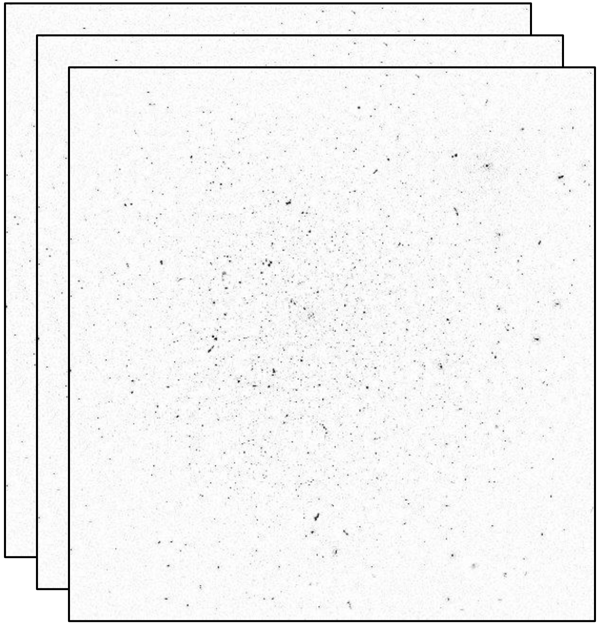
CRACO
- ASKAP
- Searching for “fast” transients in the visibilities (including de-dispersion)
- Untargeted

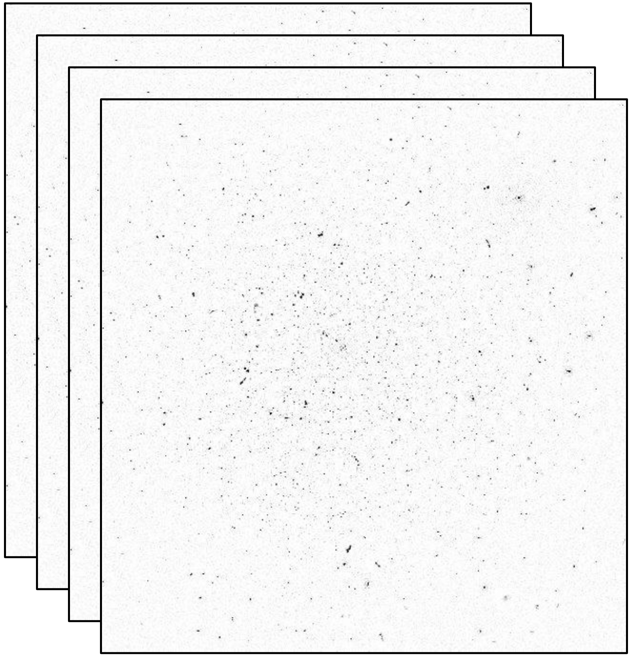
ThunderKAT
- MeerKAT
- Image-plane source tracking
- Exploring visibility subtraction
- Targeted and untargeted

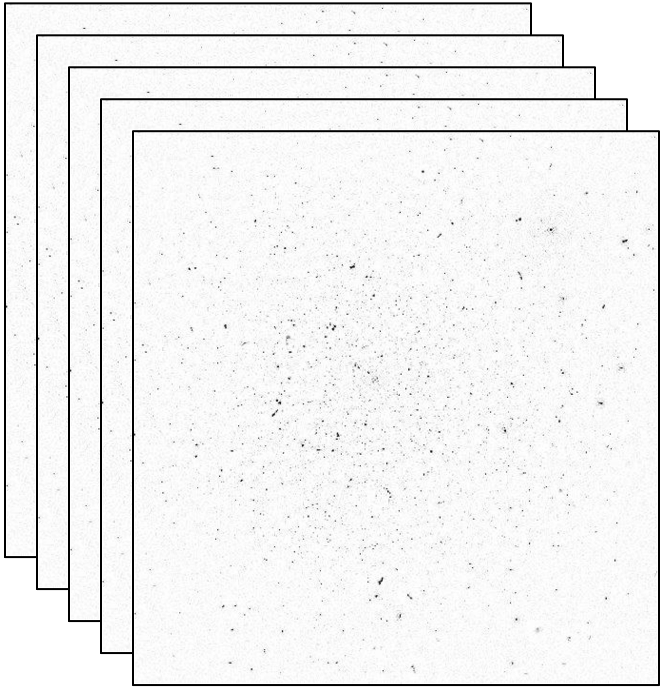
MeerTRAP
- MeerKAT
- Real-time single-pulse searching
- Imaging ms-long integrations to localise sources

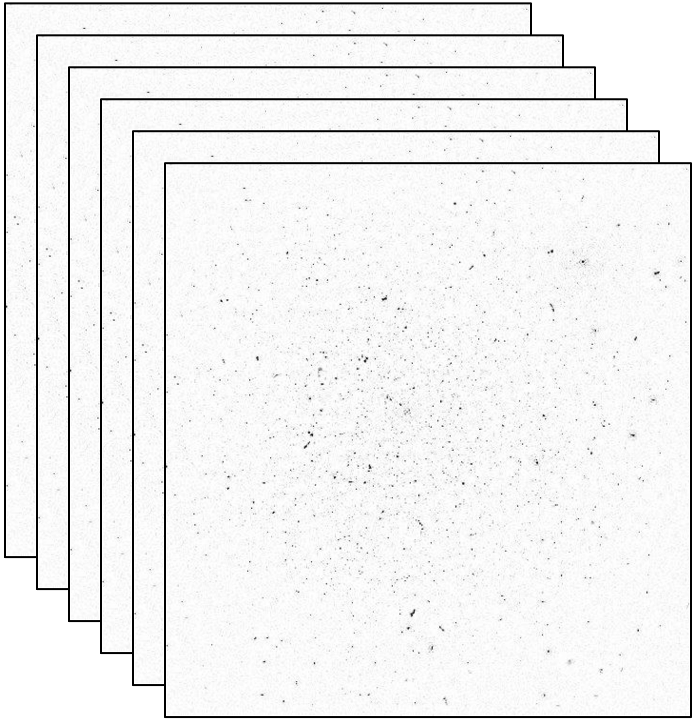
Image plane - source tracking

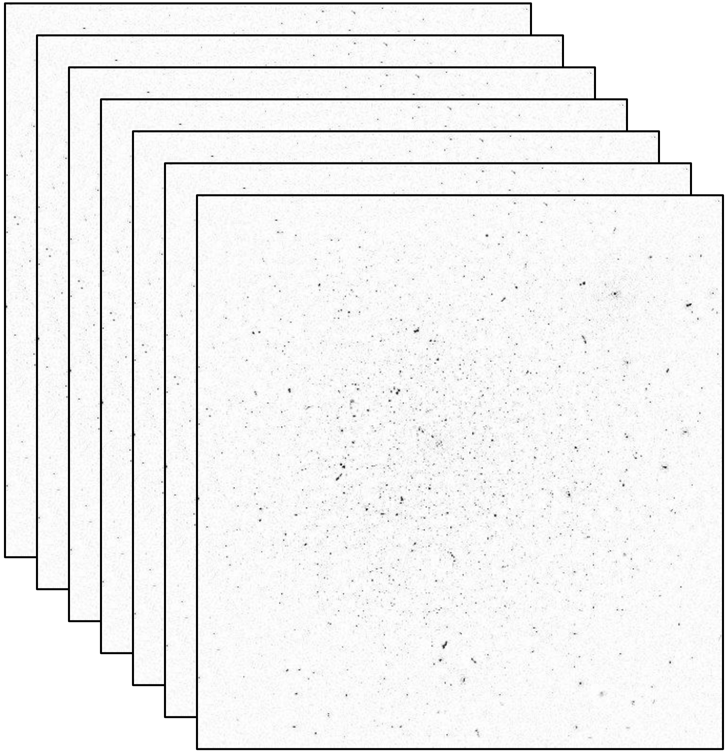


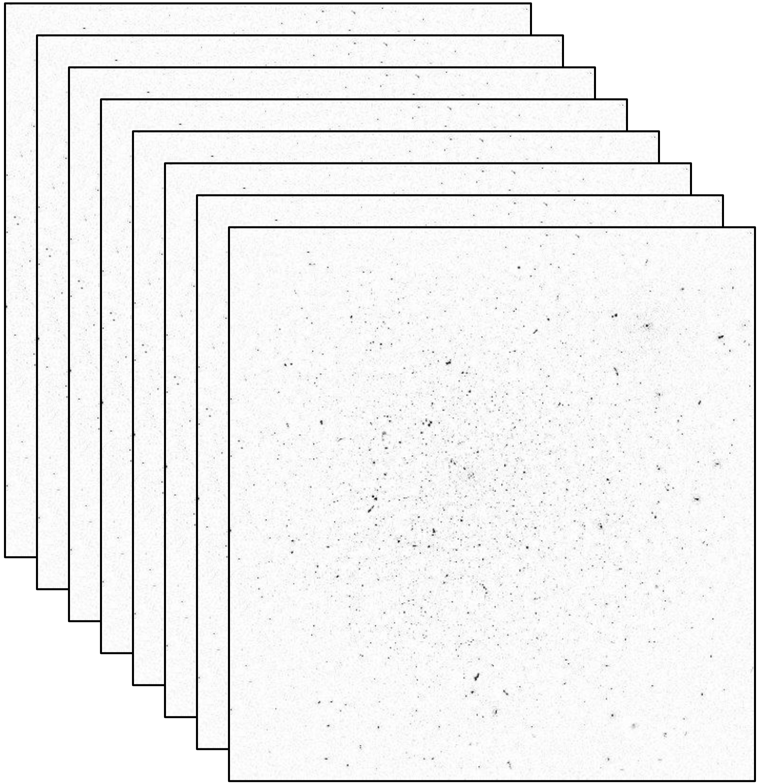


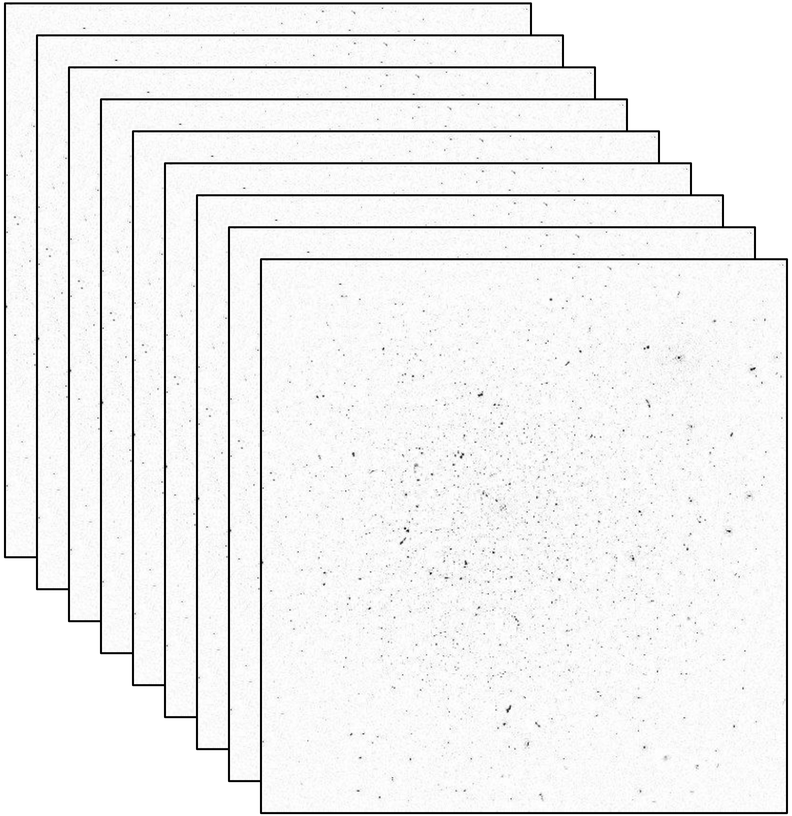


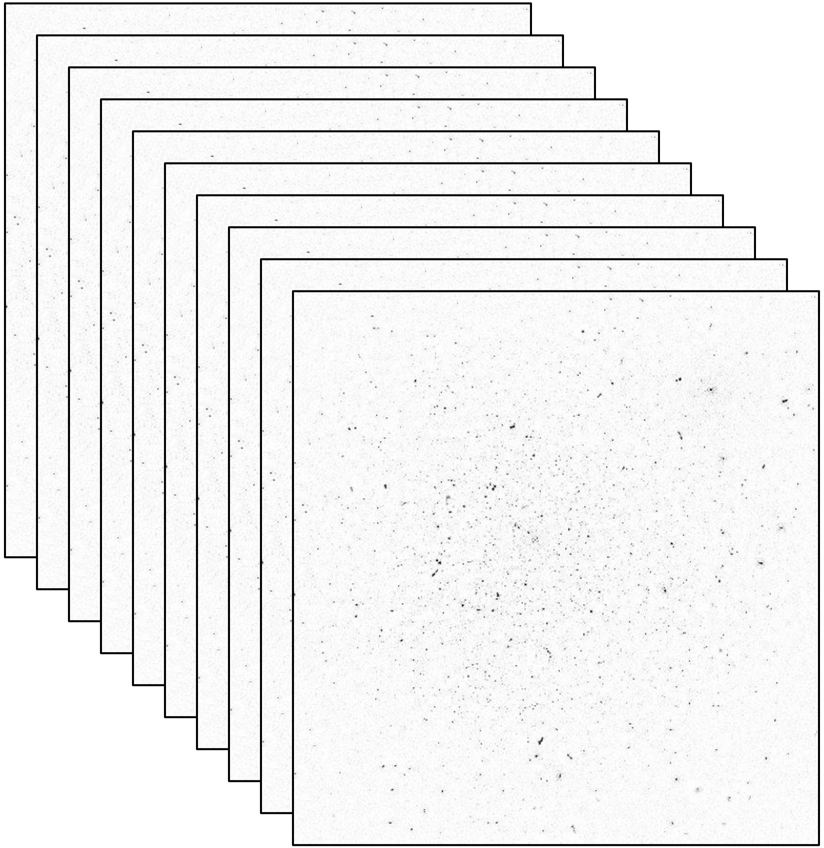


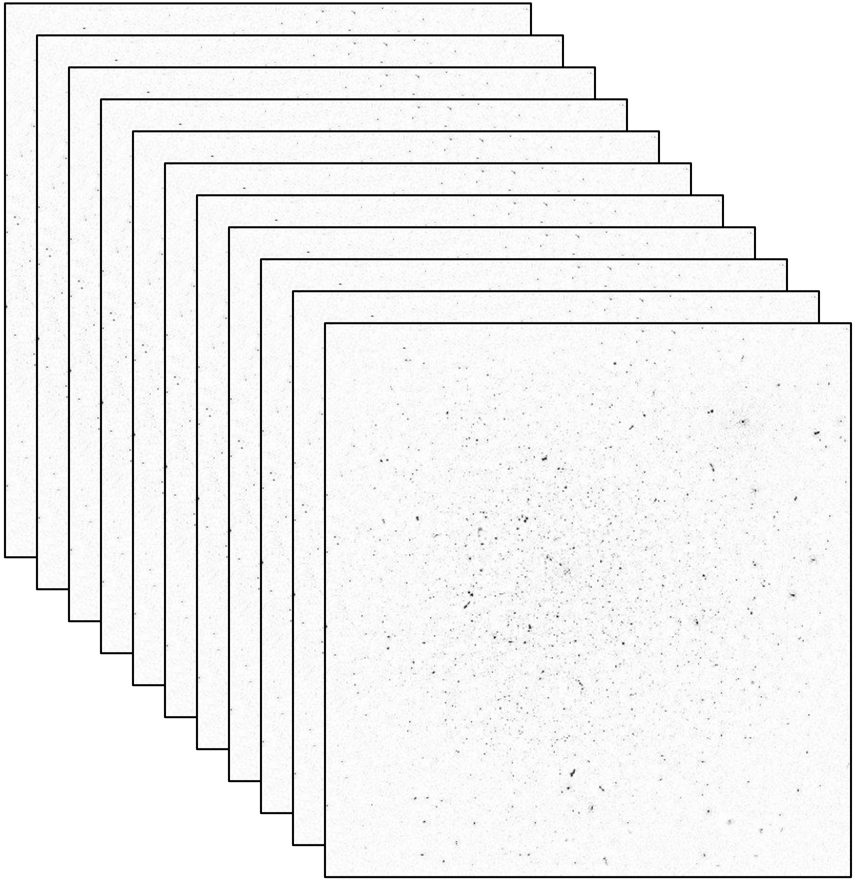


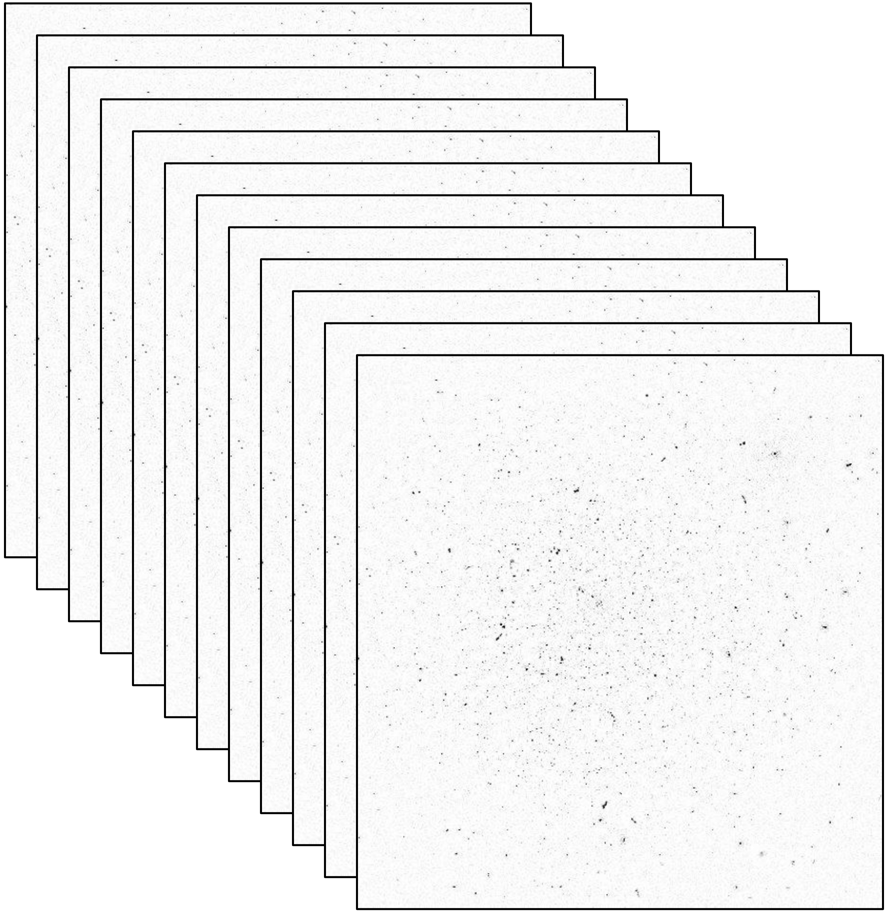


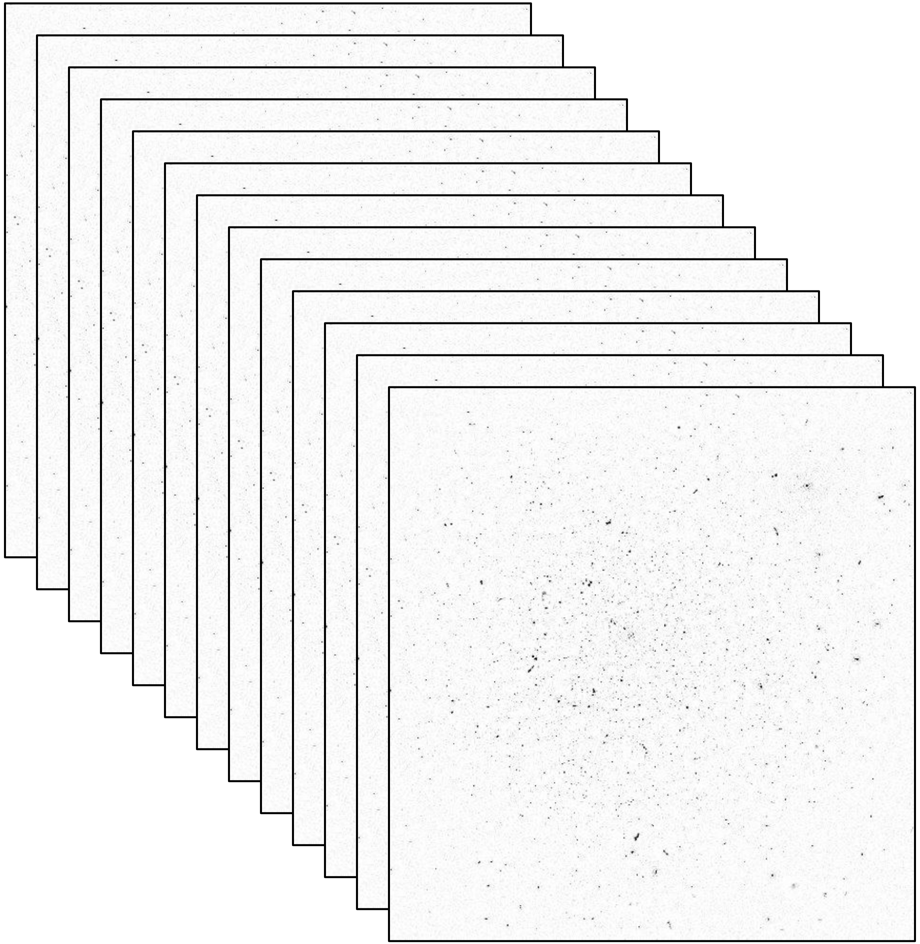


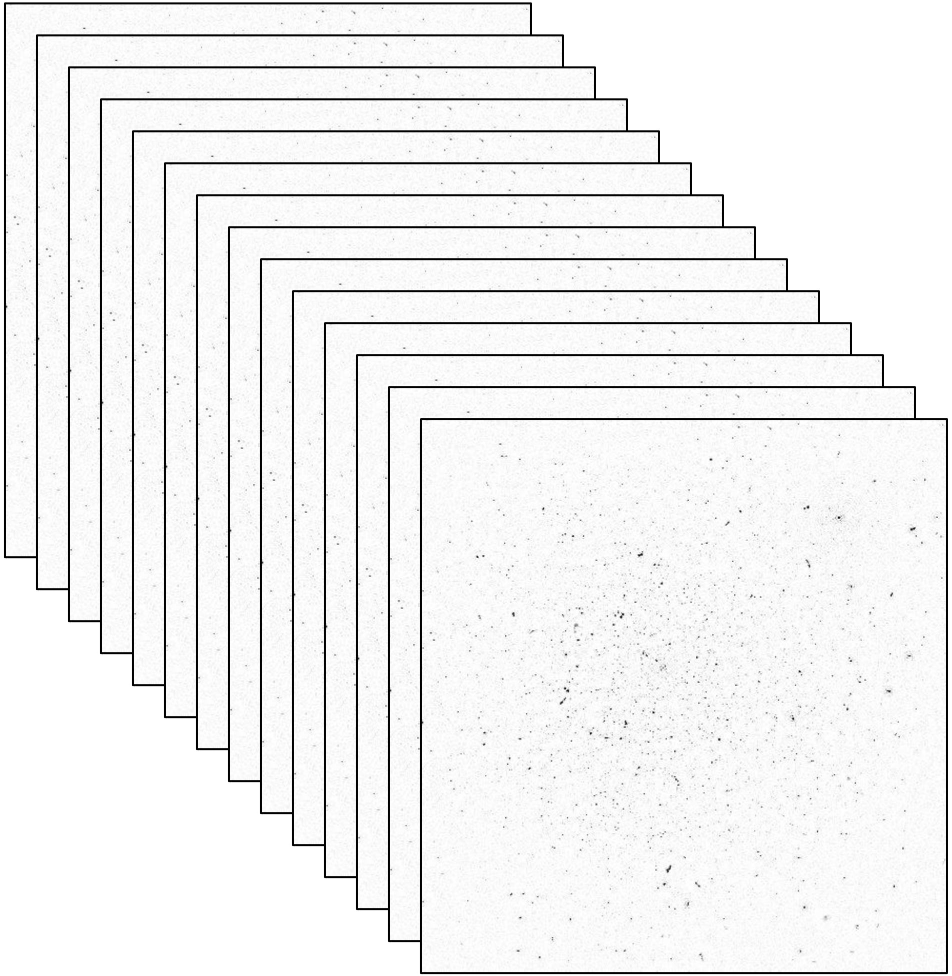


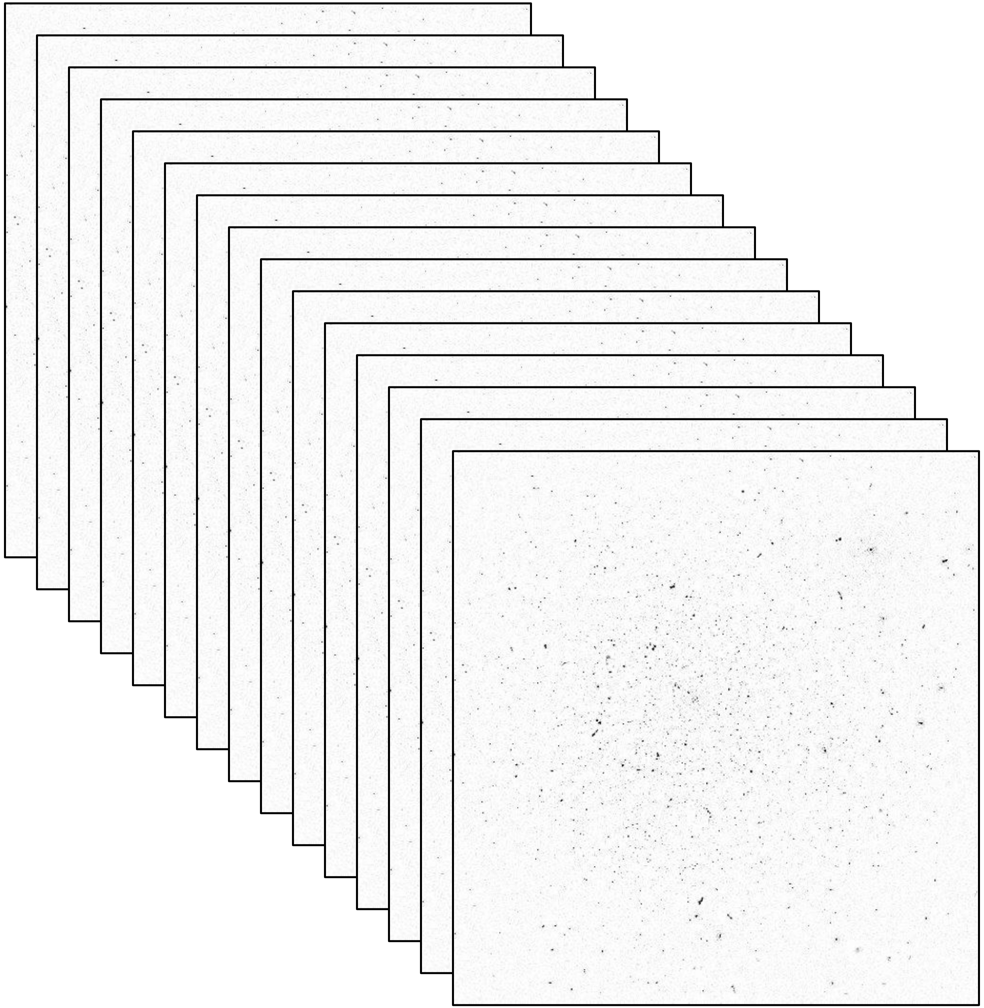


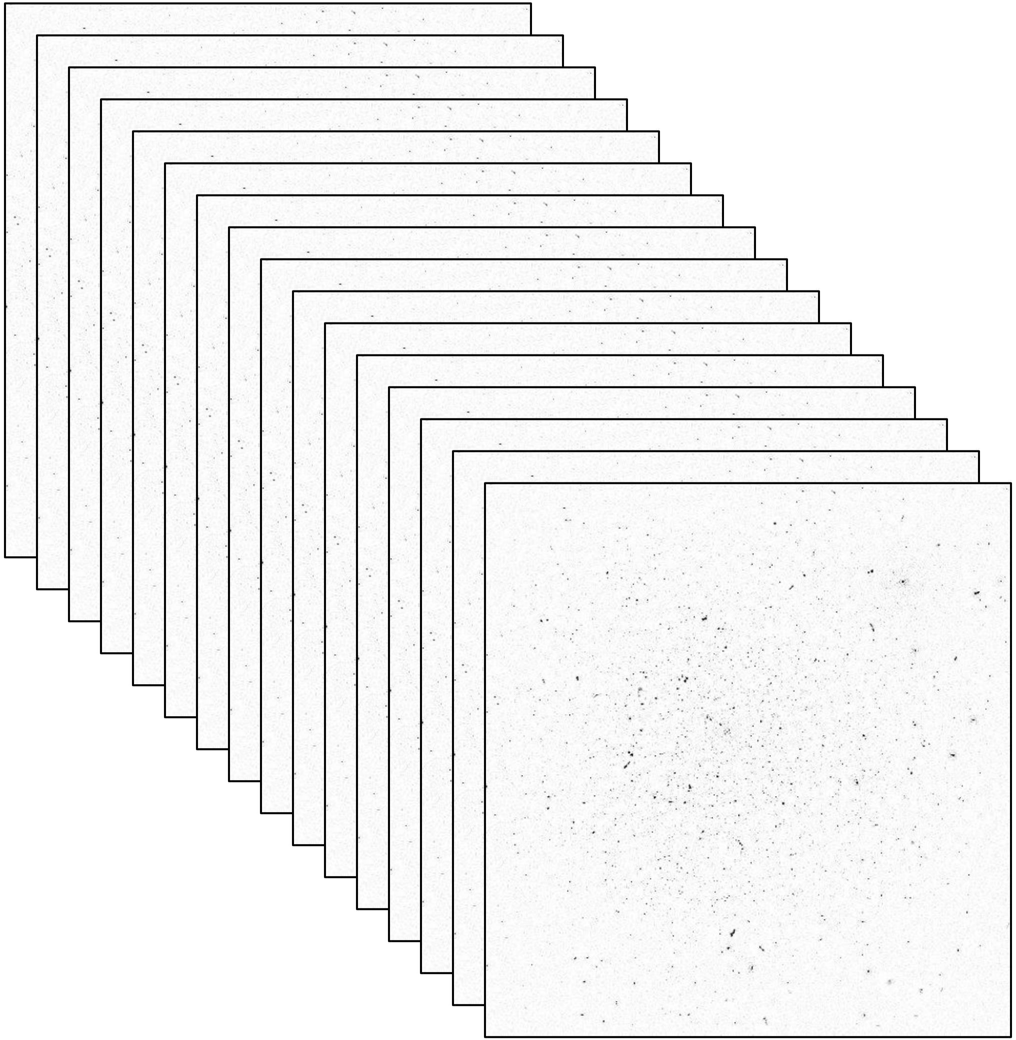










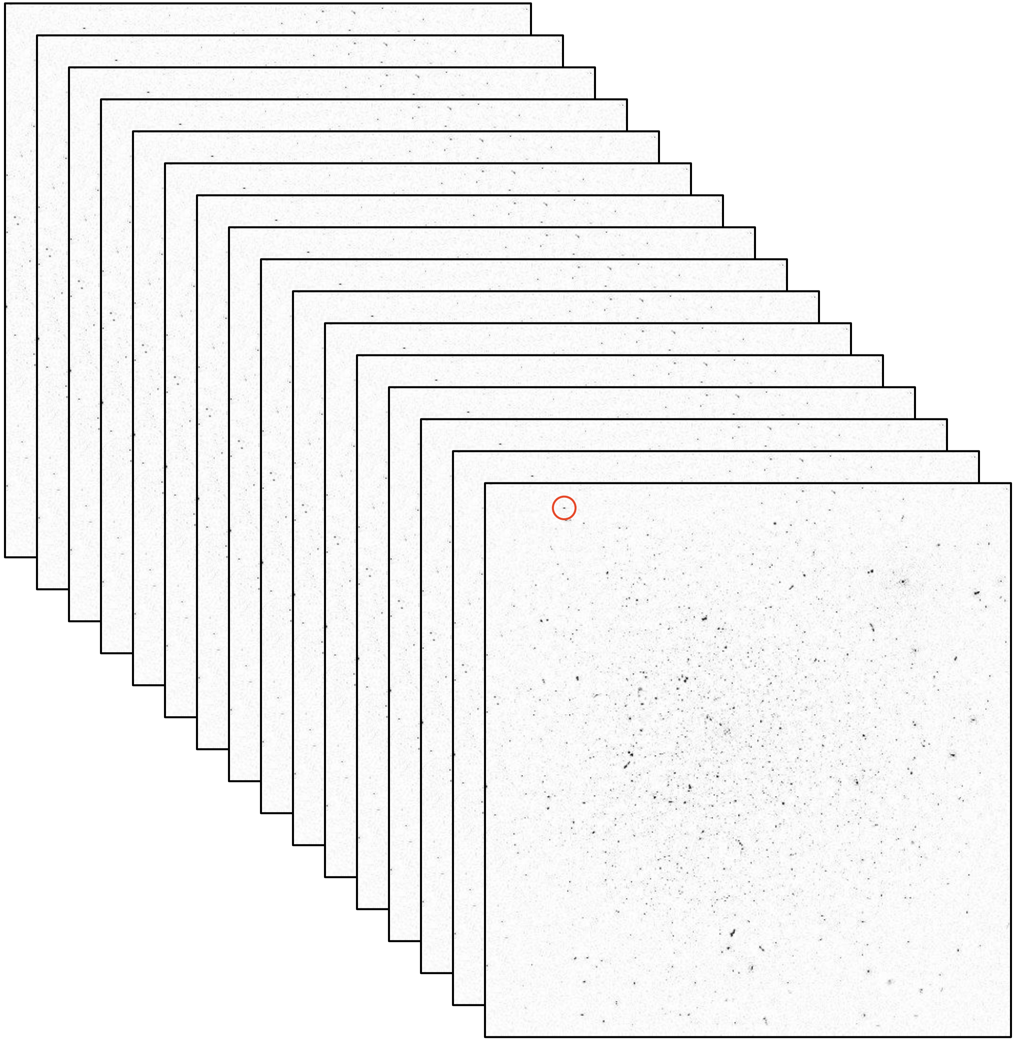


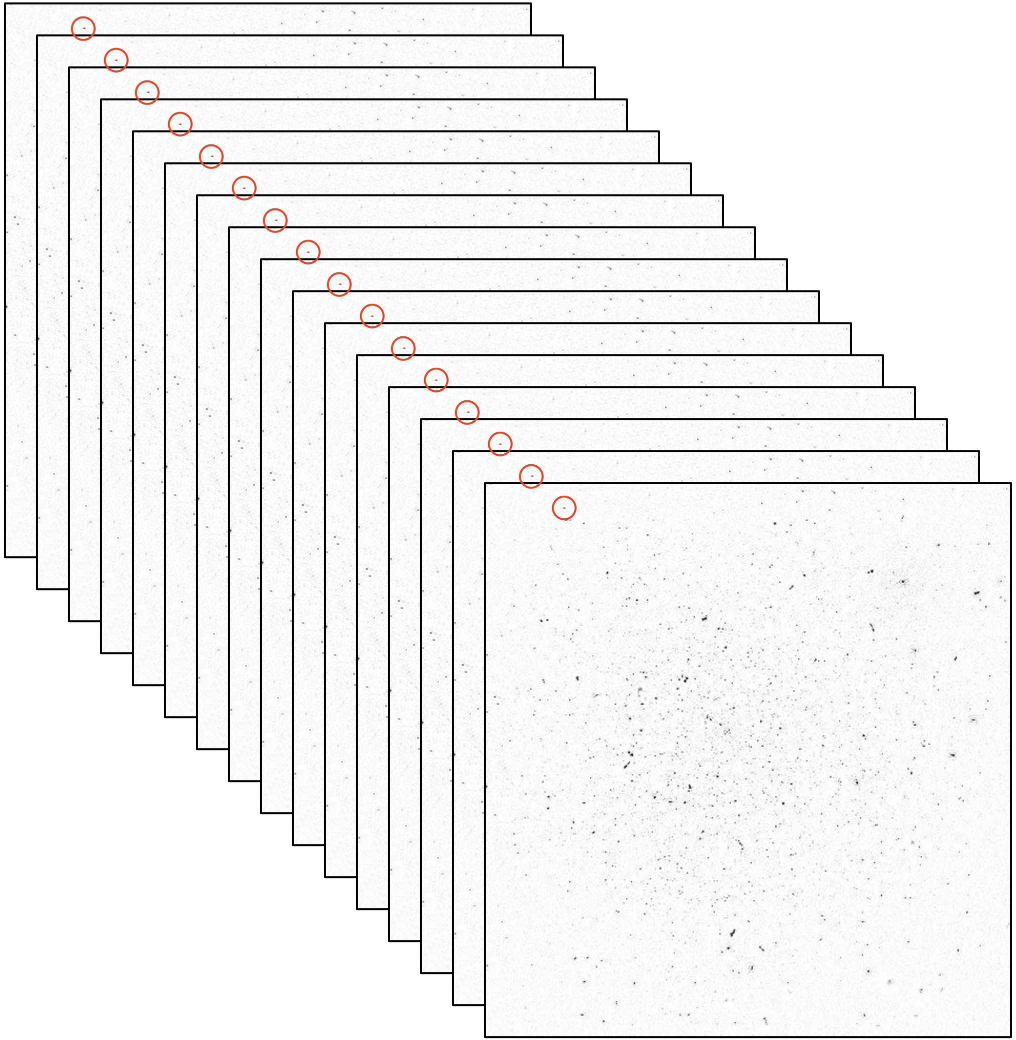
Why not do difference imaging?

- Optical astronomers do difference imaging
  - Make an average image
  - Subtract it from each individual image
  - See what's changed

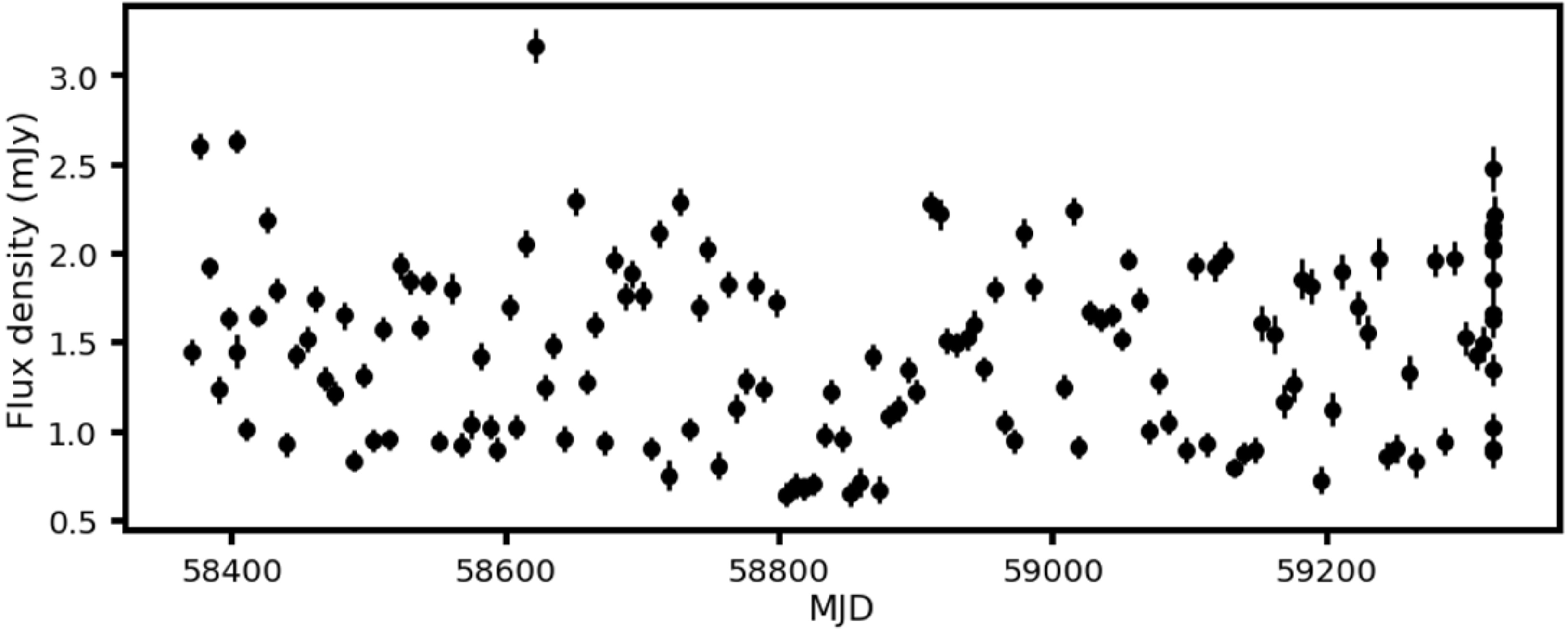
Why not do differe[illegible]e imaging?

- Optical astronomers [illegible] difference imaging
  - Make an average i[illegible]e
  - Subtract it from each [illegible]vidual ima[illegible]
  - See what’s changed

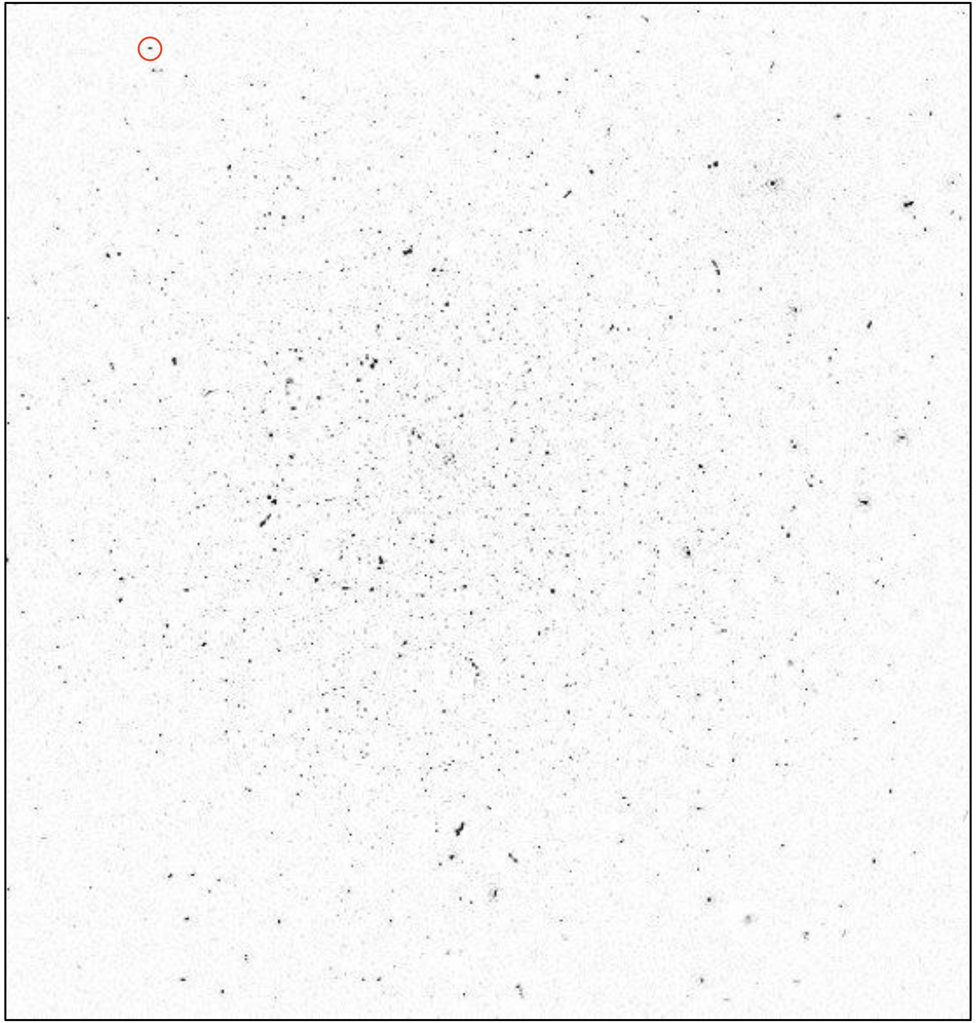




Light curve



Flux density (mJy)
3.0
2.5
2.0
1.5
1.0
0.5
58400
58600
58800
59000
59200
MJD



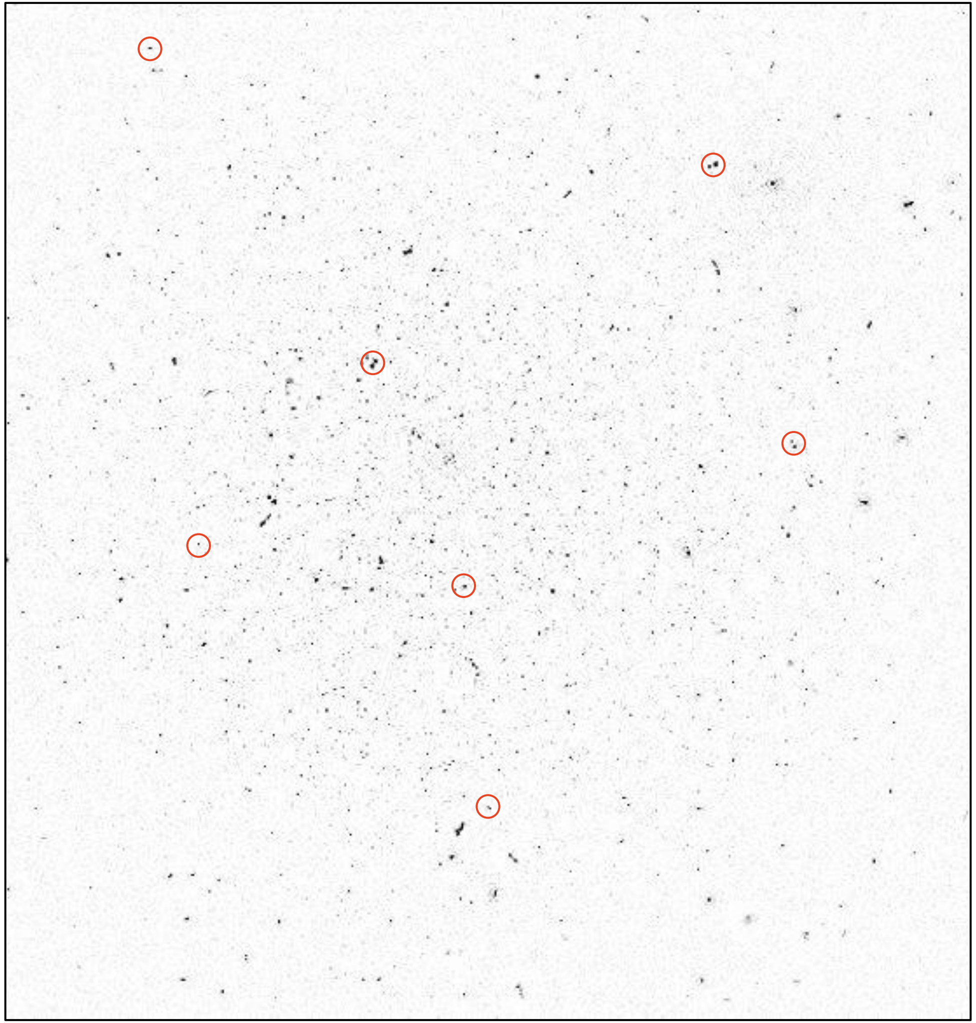


Image plane - variability parameters

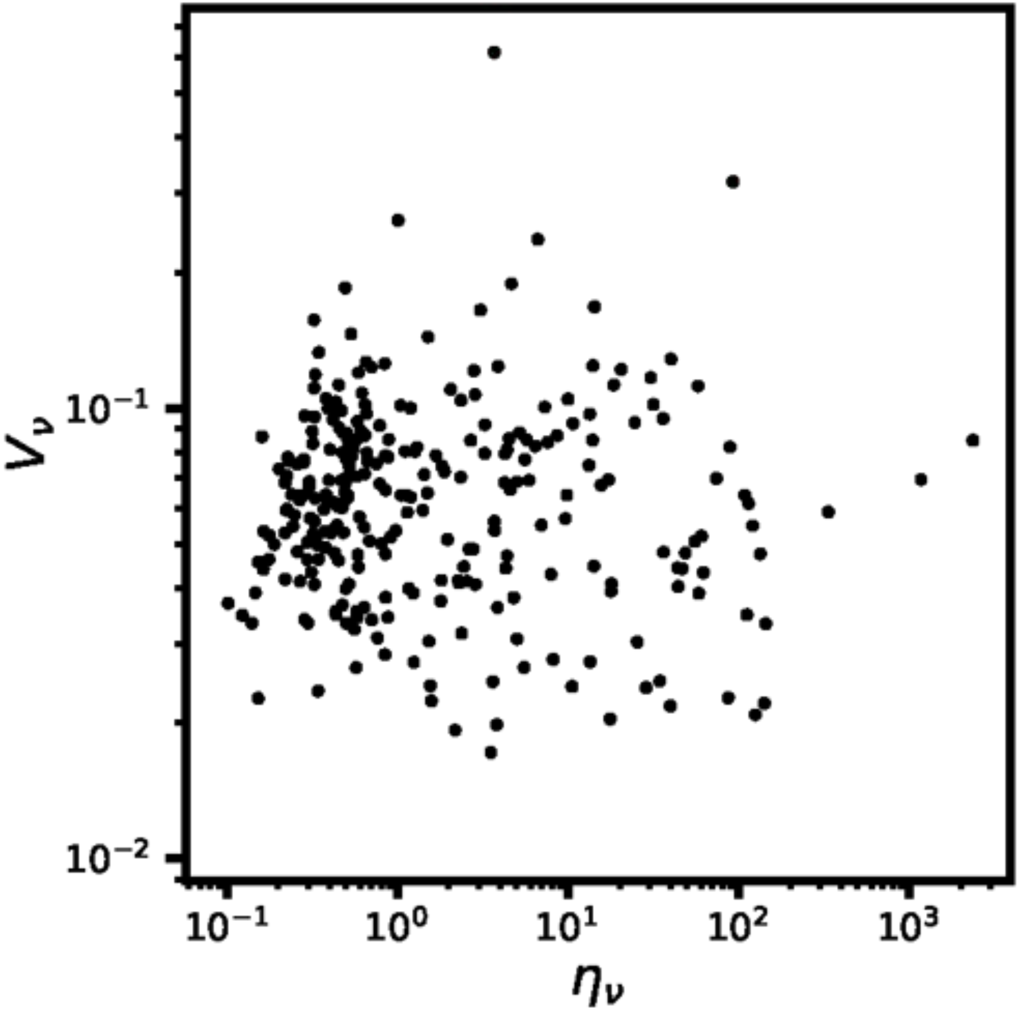
Variability parameters

- V_ν - modulation parameter
- η_ν - reduced chi-squared parameter

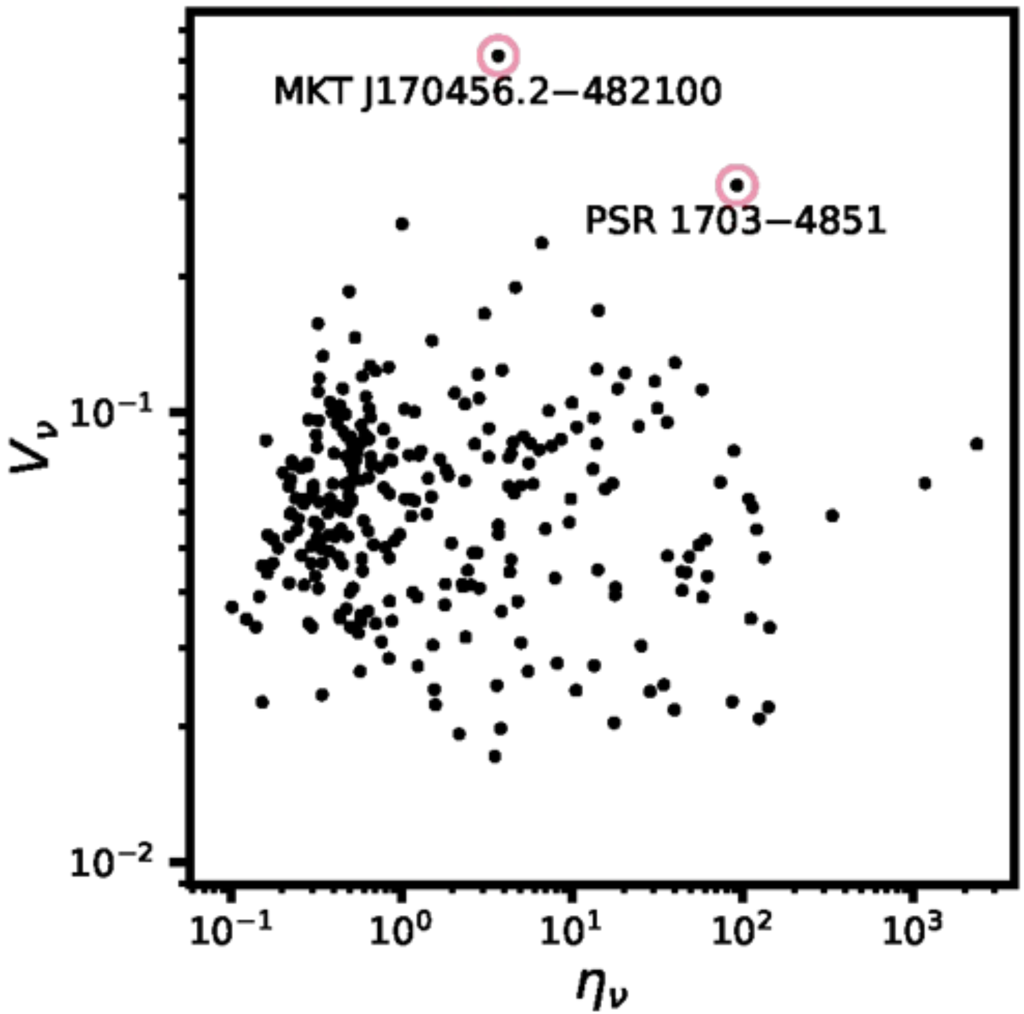
$$V_\nu = \frac{s}{\overline{I_\nu}}$$

$$\eta_\nu = \frac{1}{N-1}\sum_{i=1}^{N}\frac{(I_{\nu,i} - \overline{I_\nu})}{\sigma^2_{\nu,i}}$$

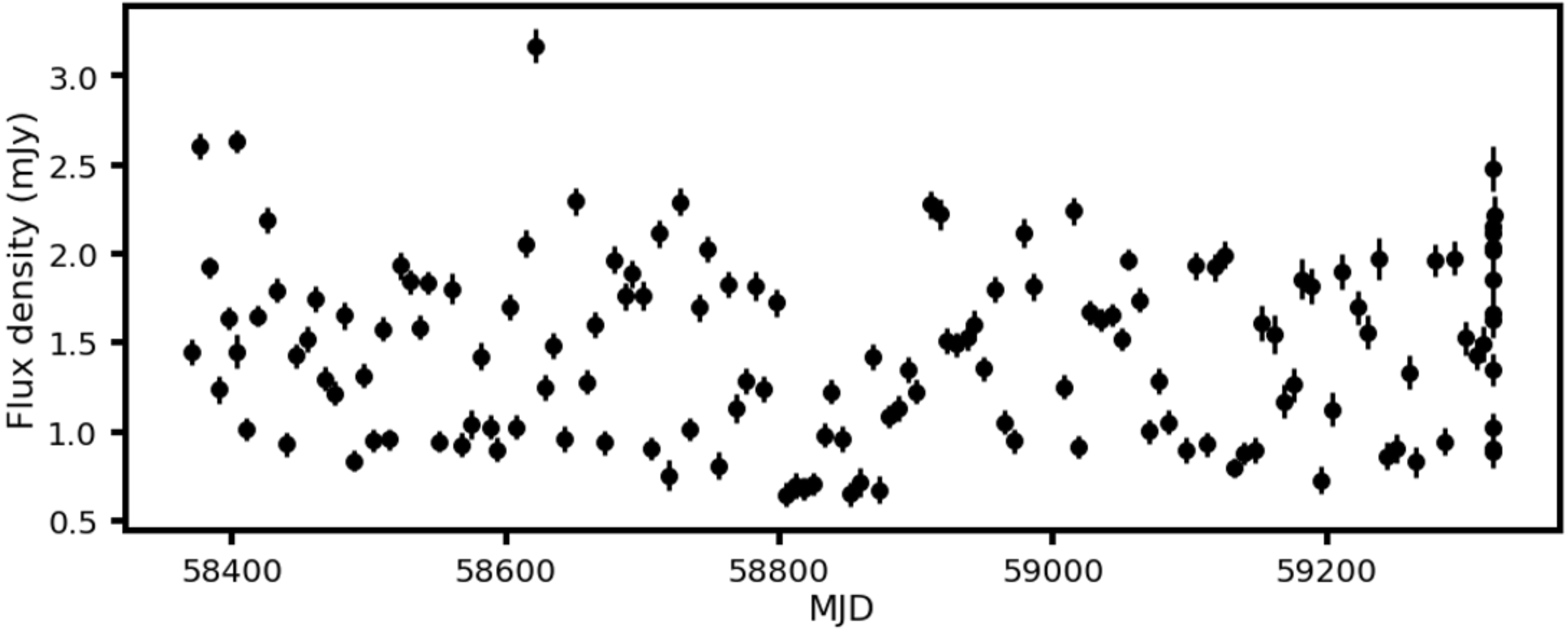
Variability parameters



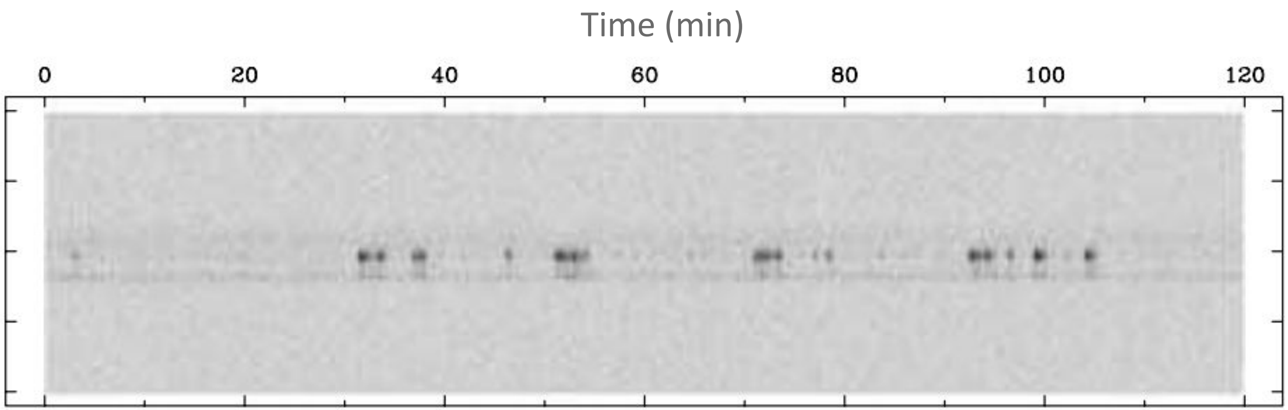
Variability parameters

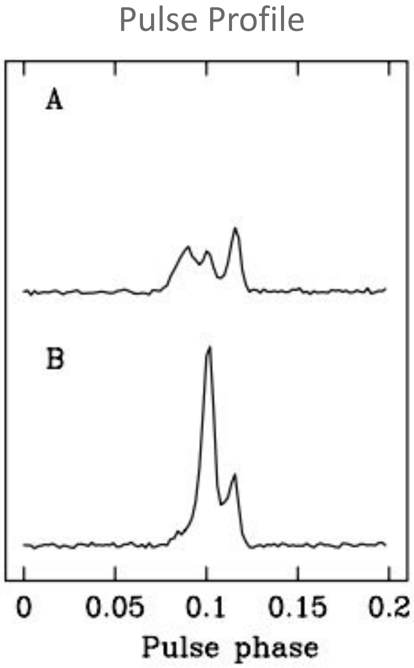


PSR J1703-4851



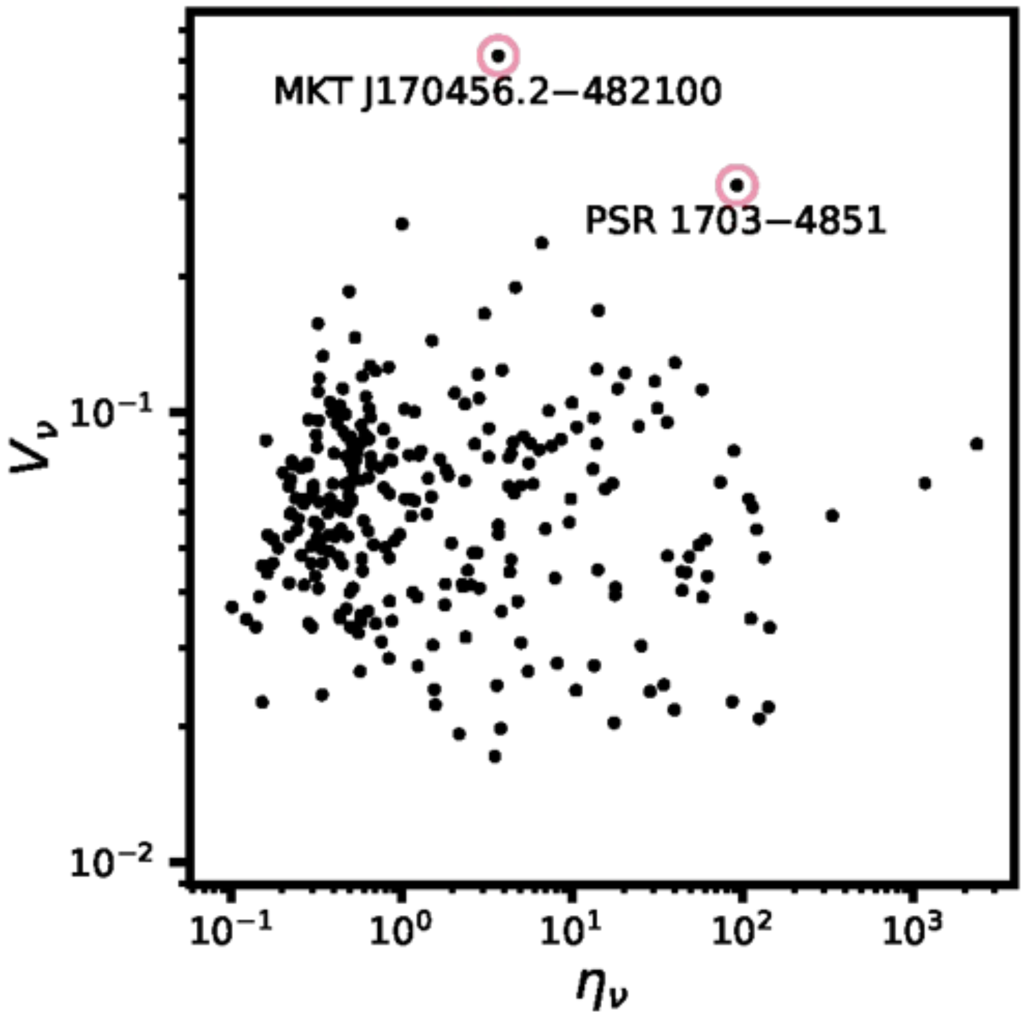
PSR J1703-4851



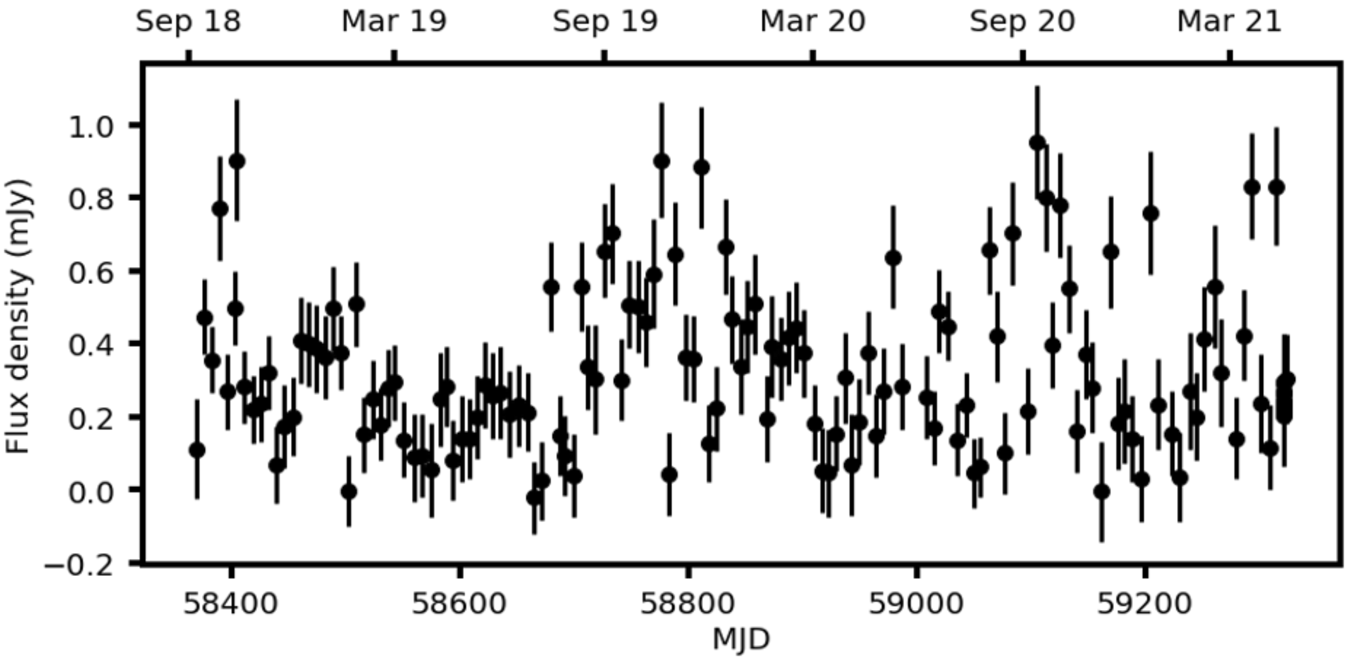


Wang, Manchester & Johnston 2007

Variability parameters

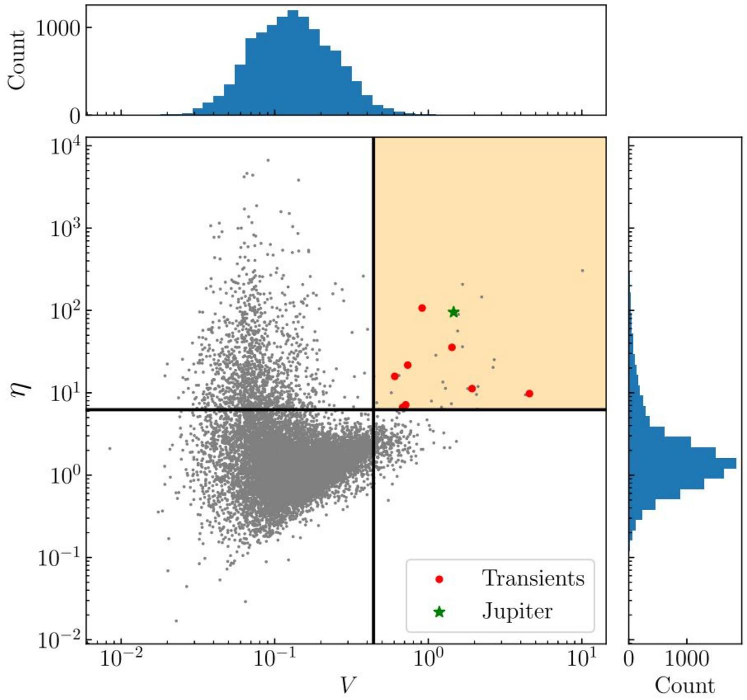


MKT J170456.2 – 482100



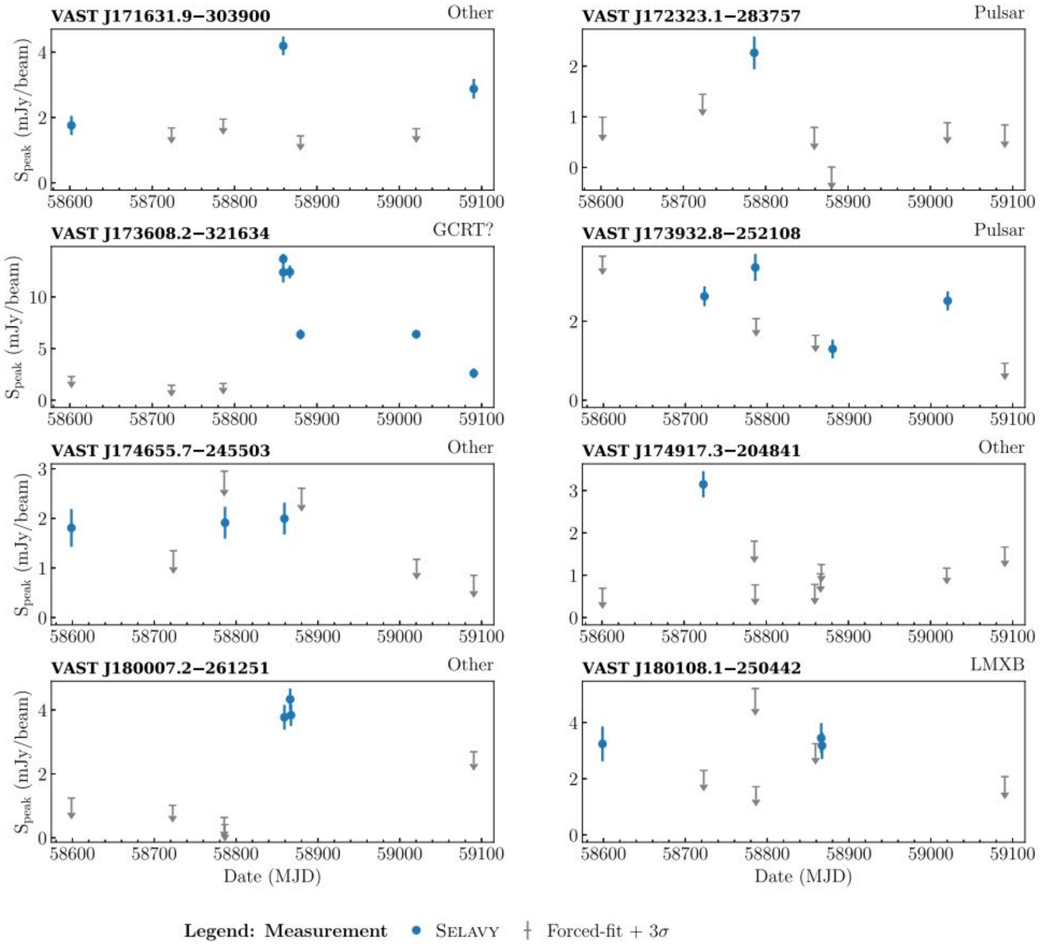
Driessen et al. 2020

ASKAP VAST - Galactic Centre Transients



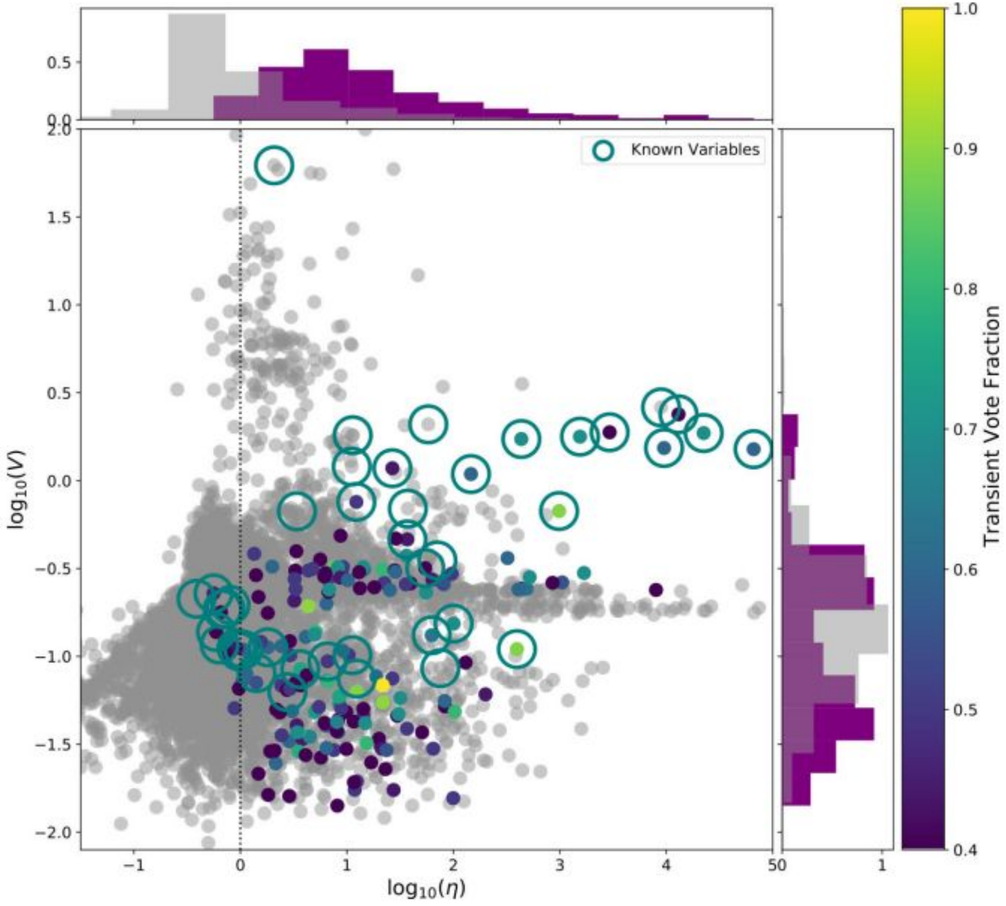
Wang et al. 2022

ASKAP VAST - Galactic Centre Transients



Wang et al. 2022

Bursts from space - radio transients with citizen science



Andersson et al. 2023

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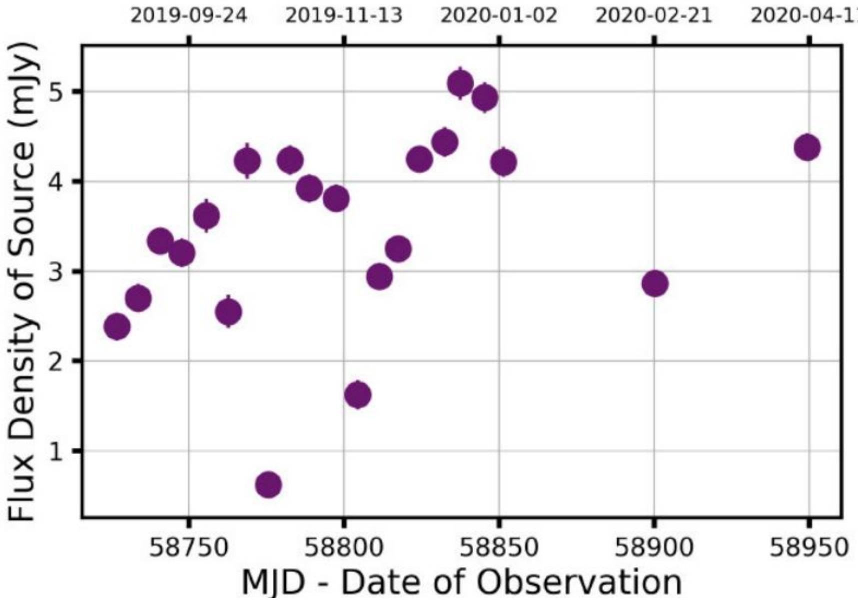
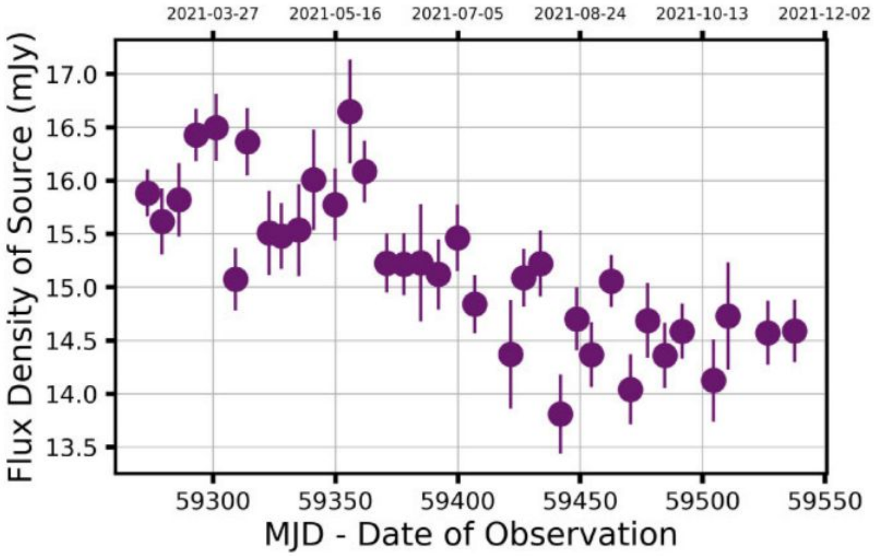
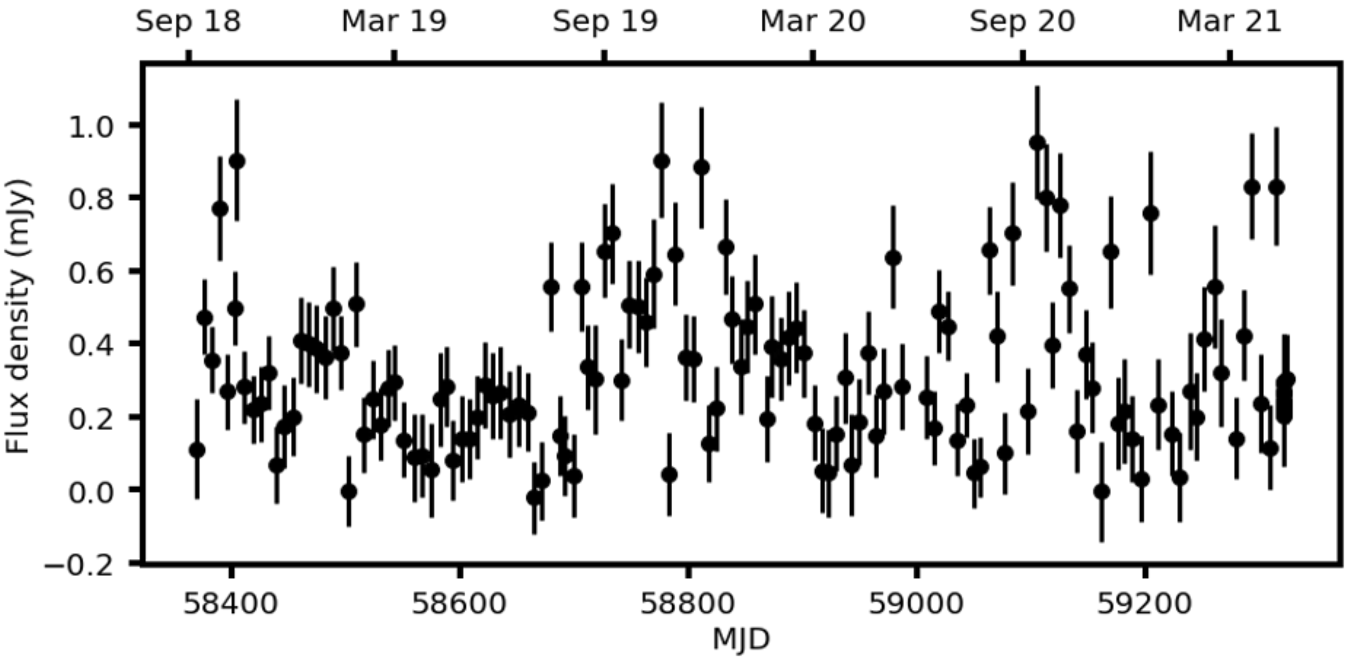




Andersson et al. 2023

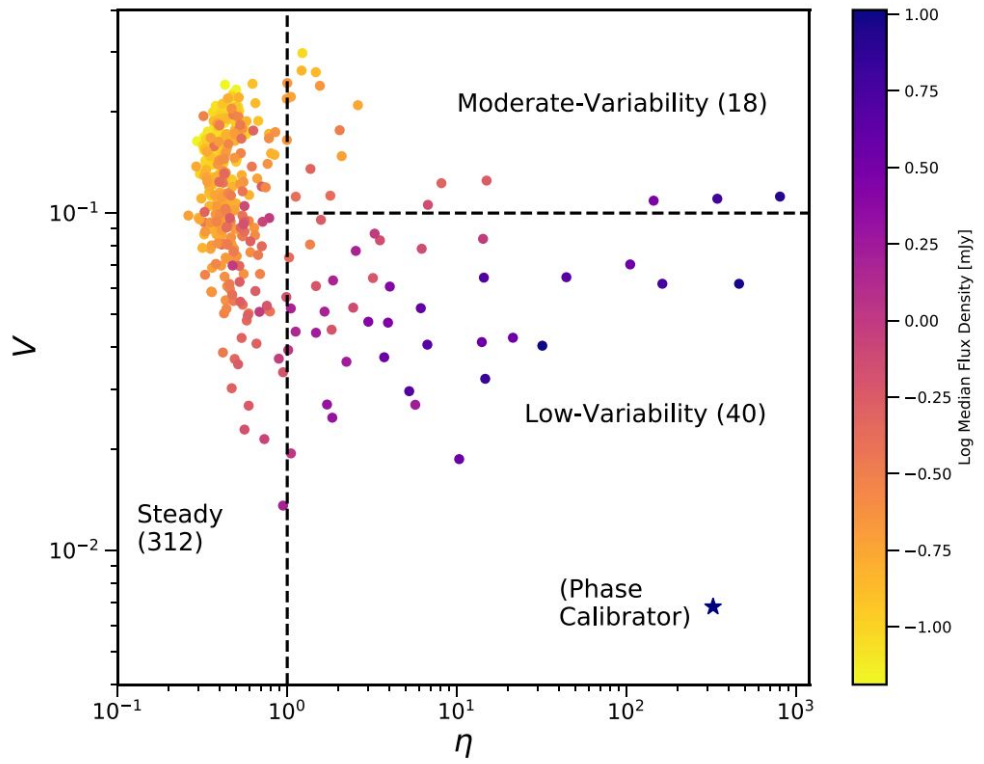
MKT J170456.2 – 482100

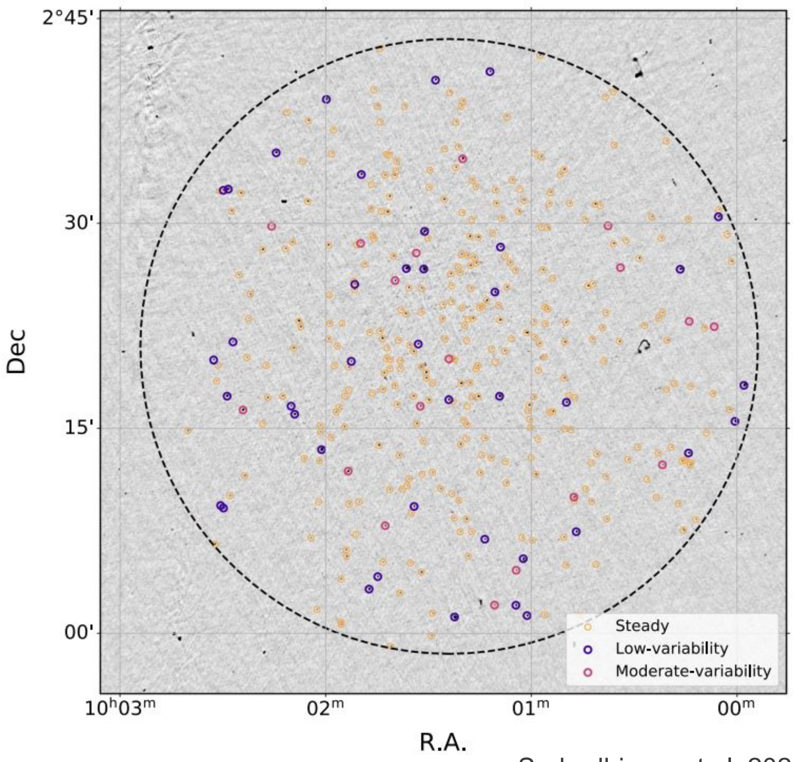


Driessen et al. 2020

Image plane - fun variables

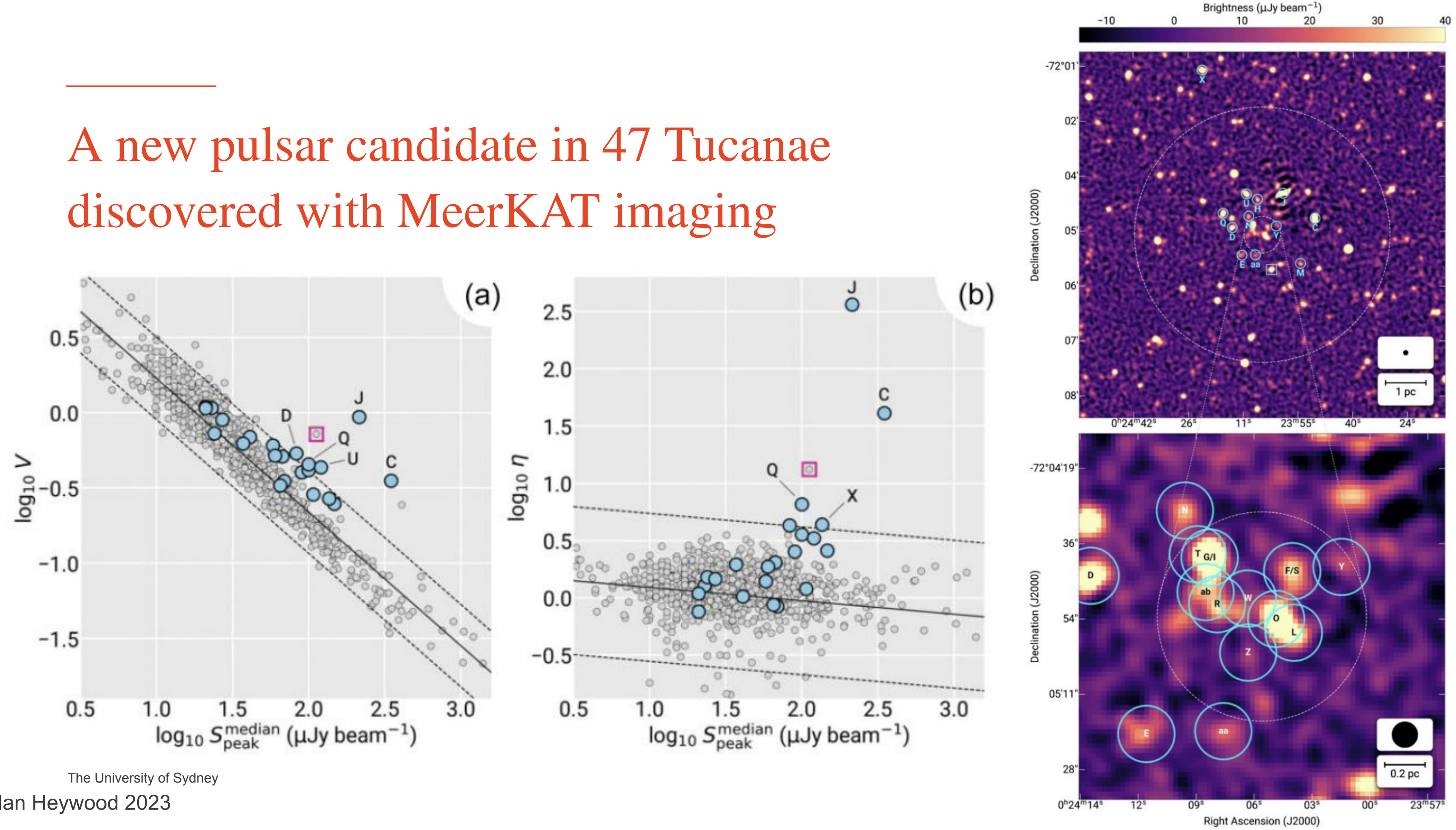
CHILES VERDES (VLA) - 370 (4.9%) variable candidates





Sarbadhicary et al. 2021

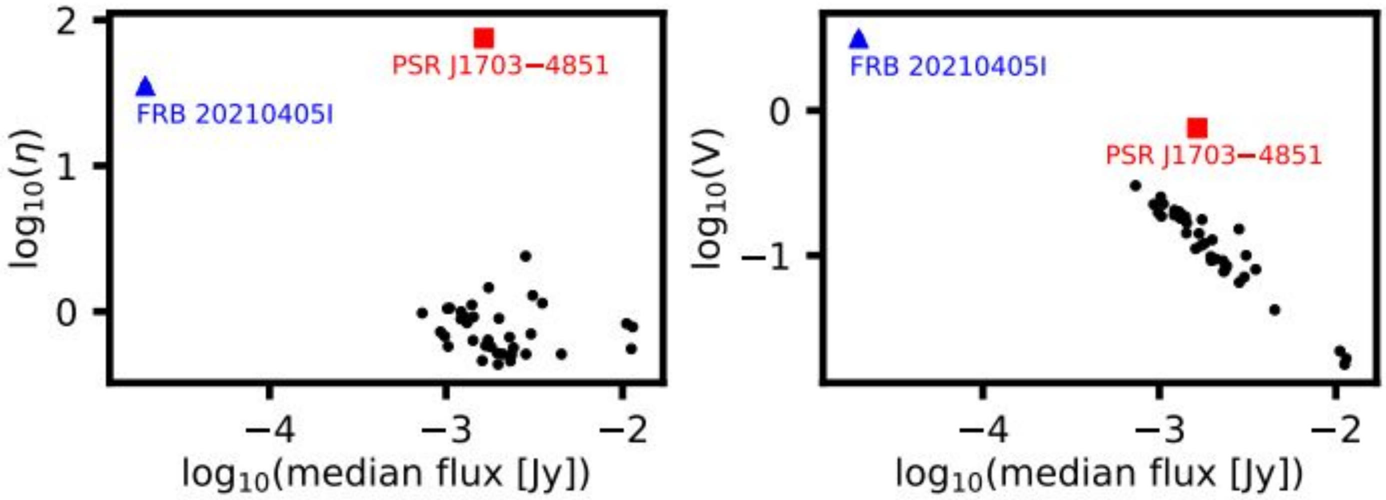
A new pulsar candidate in 47 Tucanae discovered with MeerKAT imaging



The University of Sydney

Ian Heywood 2023

The first localised MeerKAT Fast Radio Burst



Driessen et al. 2023

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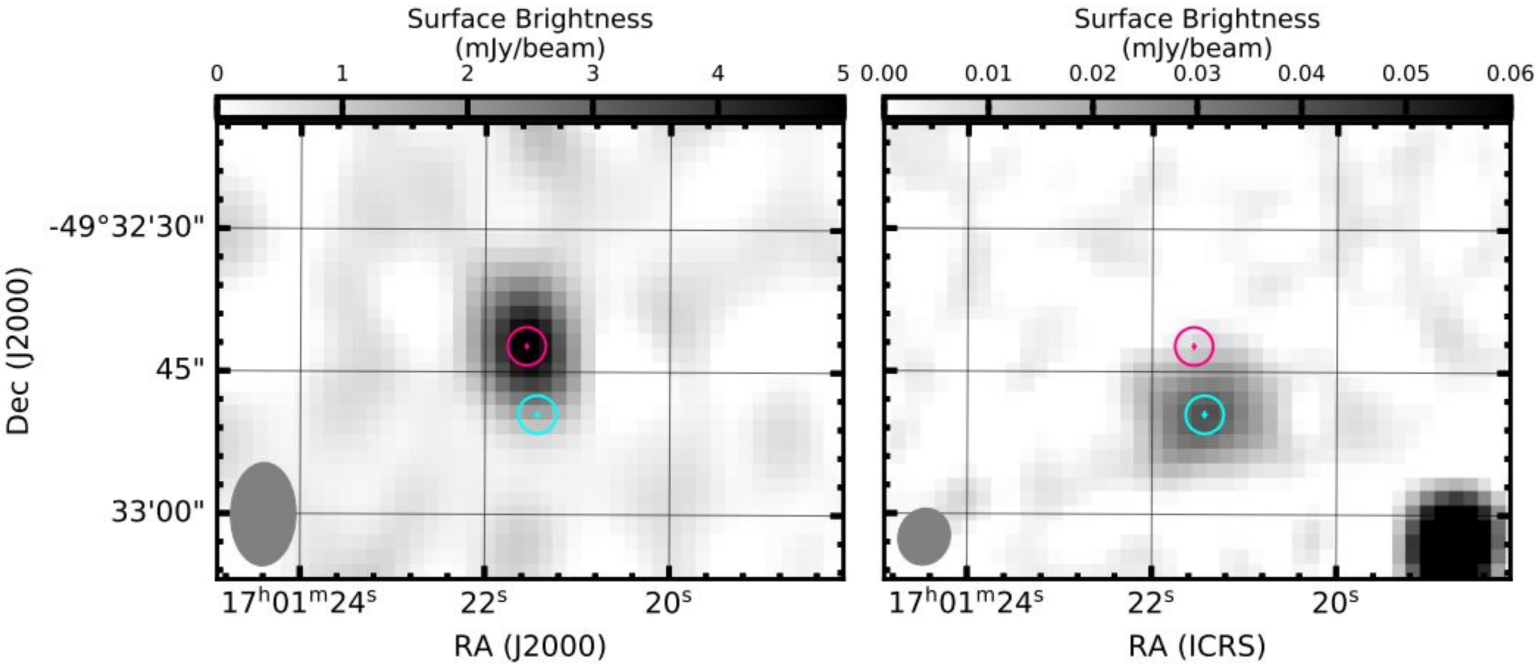

Driessen et al. 2023

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