Using the Fermi Treasure Map to Find Pulsars with MeerKAT

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Jodrell Bank Centre for Astrophysics
The University of Manchester

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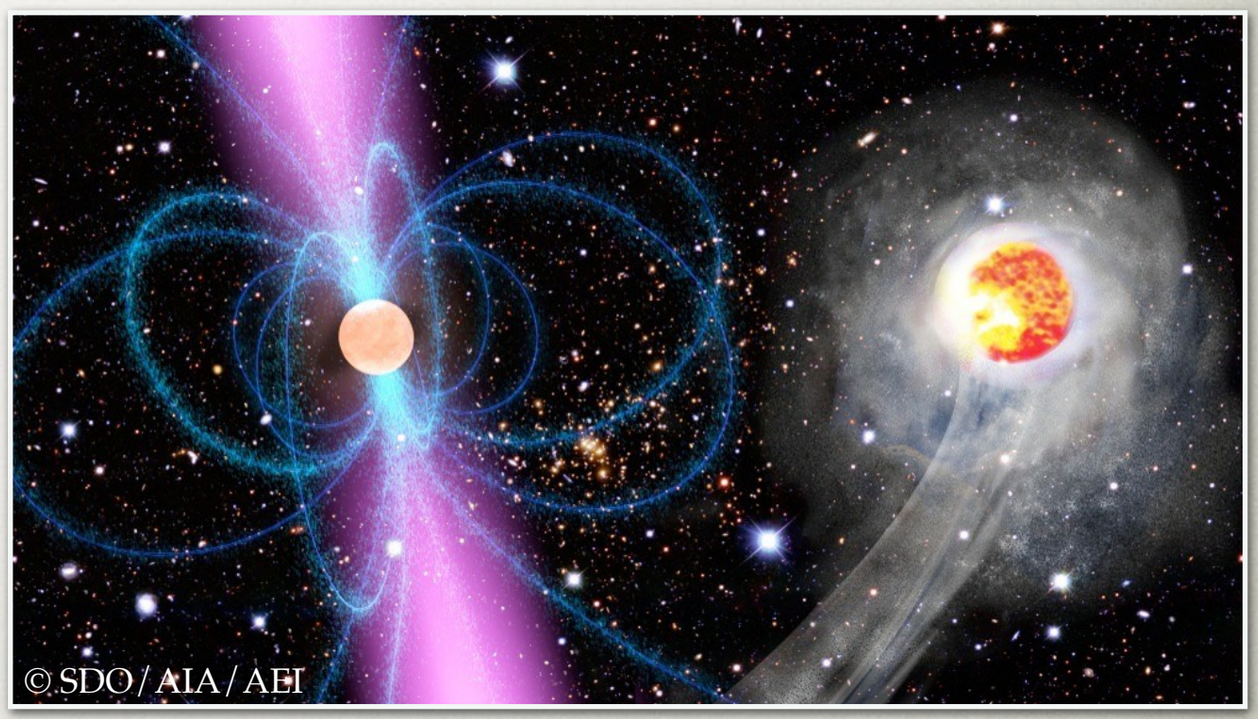
On behalf of the TRAPUM Collaboration

http://trapum.org



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Spiders

erc
European Research Council
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TRAPUM
Transients and Pulsars with MeerKAT

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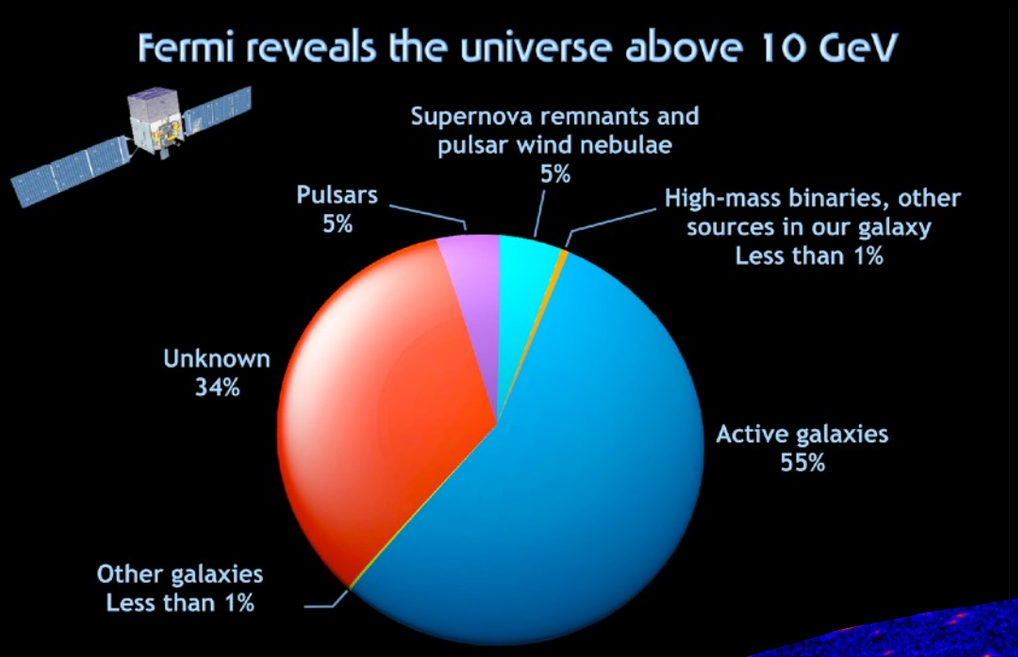
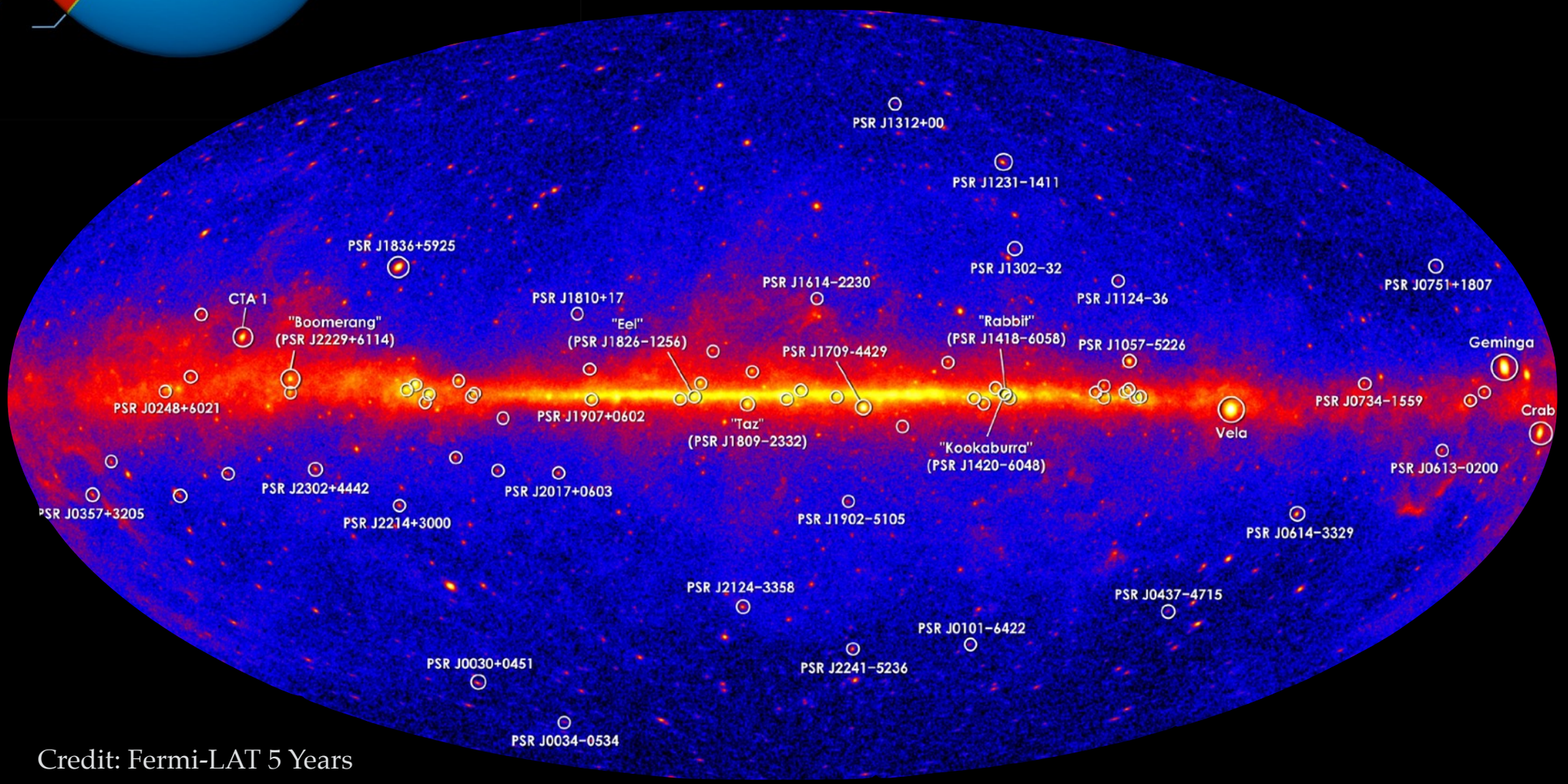
The Fermi Treasure Map



Number of known spider pulsar binaries (in the Galactic field)

- Pre-Fermi: ~4
- Now: ~80



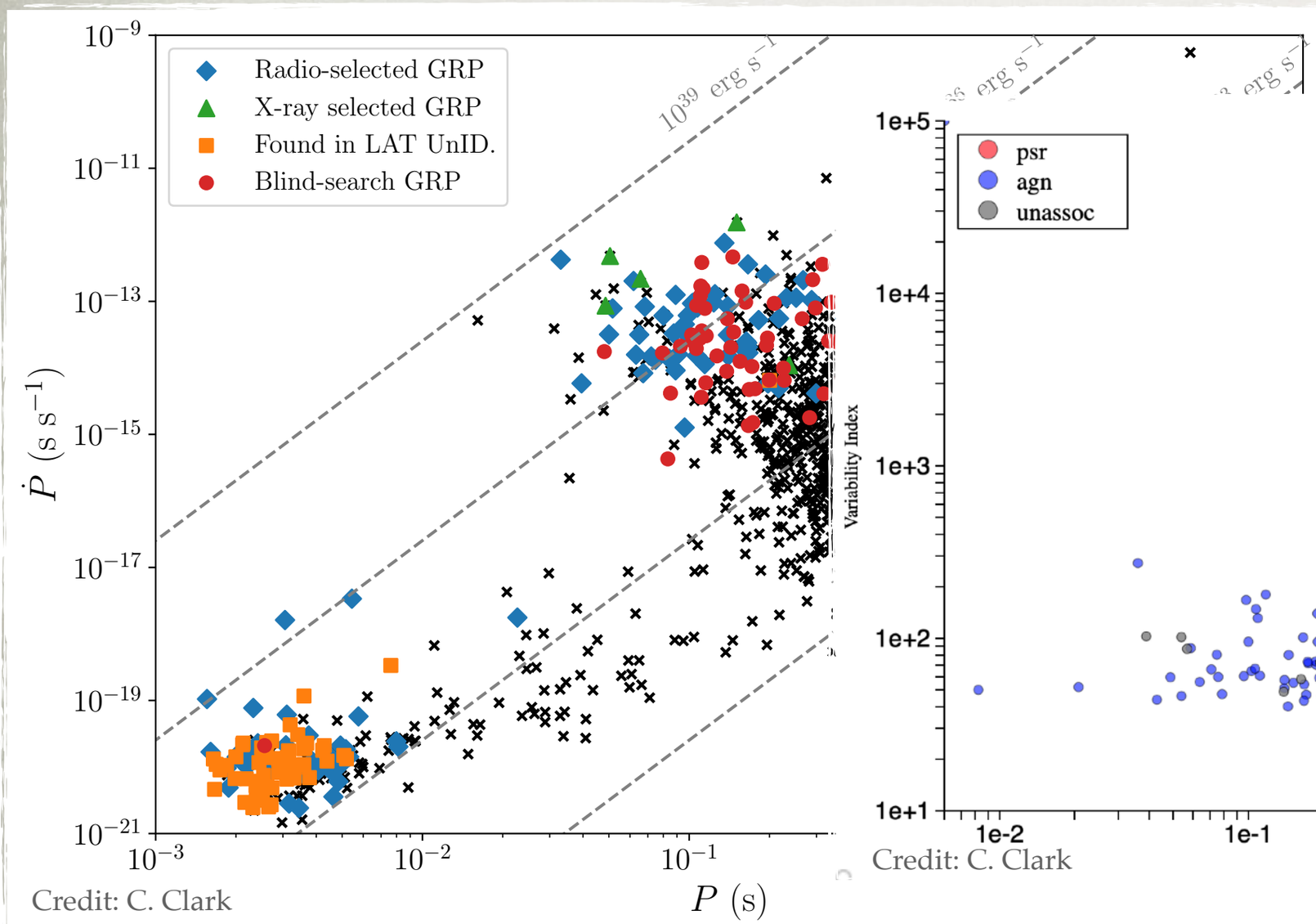
Credit: Fermi-LAT 5 Years

The Fermi Treasure Map

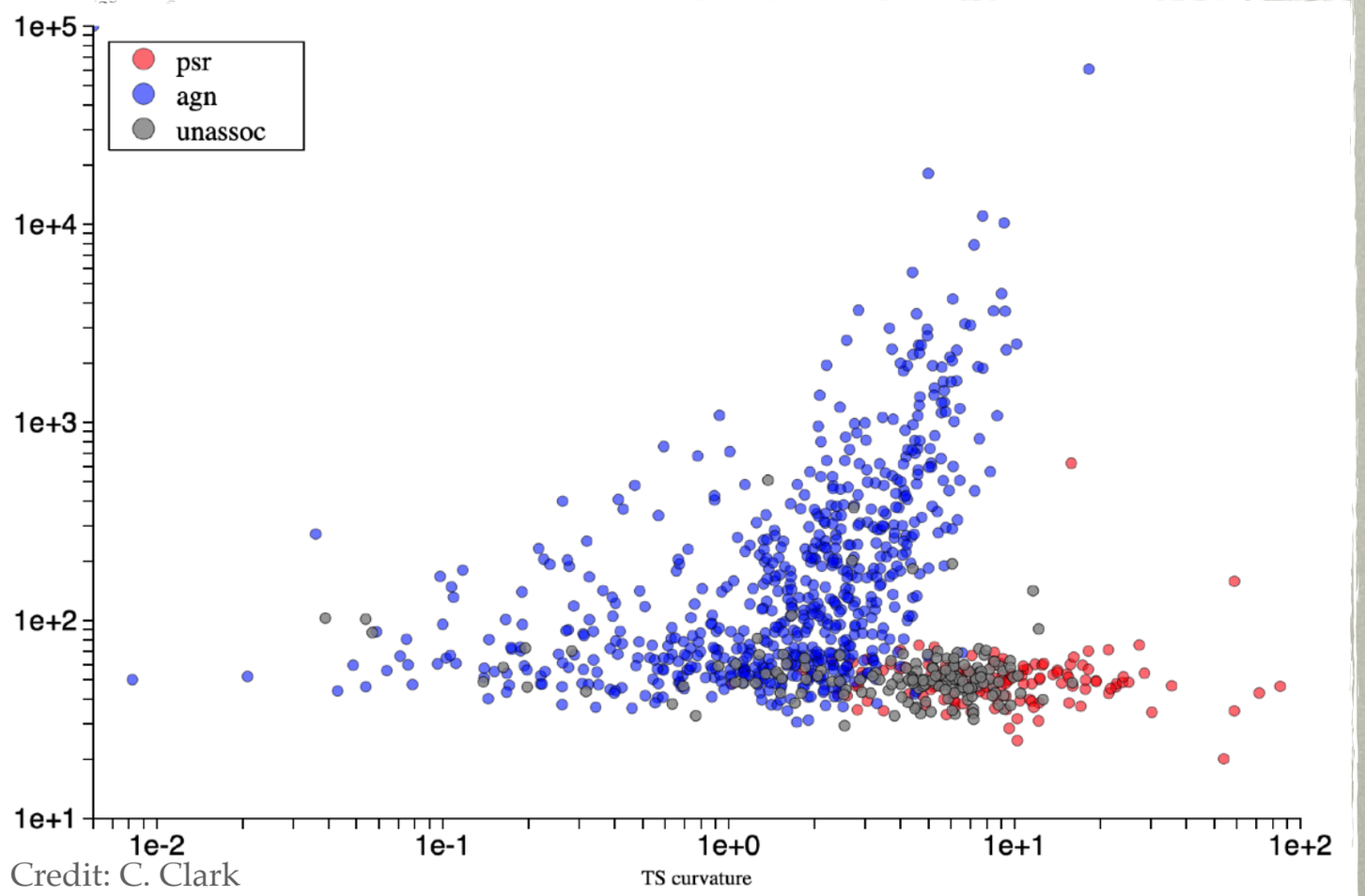
Energetic young pulsars and MSPs detected by Fermi

1. Detection of known pulsar (folding ephemeris) => see M. Kerr's talk
2. Direct detection of new gamma-ray pulsar => Clark et al. (2018)
3. Targeted radio search (with #1 after) => Camilo et al. (2015)
4. Optical detection of companion (with #2 or #3 after) => Nieder et al. (2020)

Pulsars have a 'typical' gamma-ray signature



Credit: C. Clark

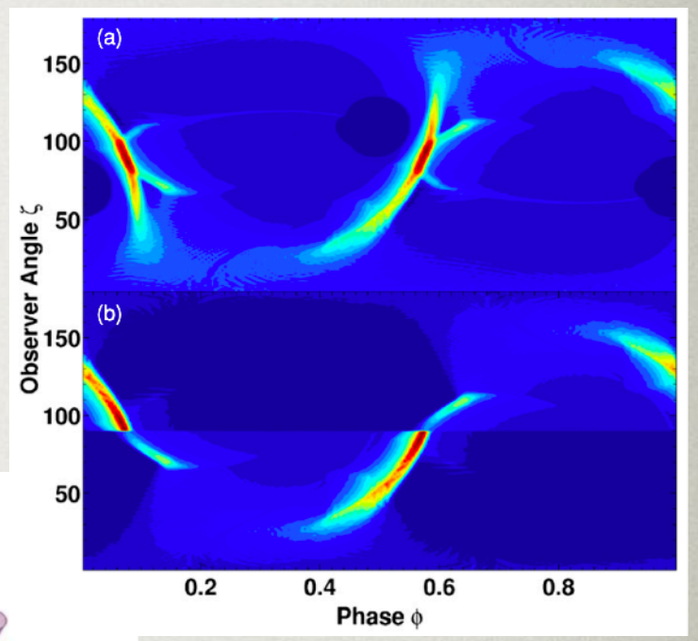


Credit: C. Clark

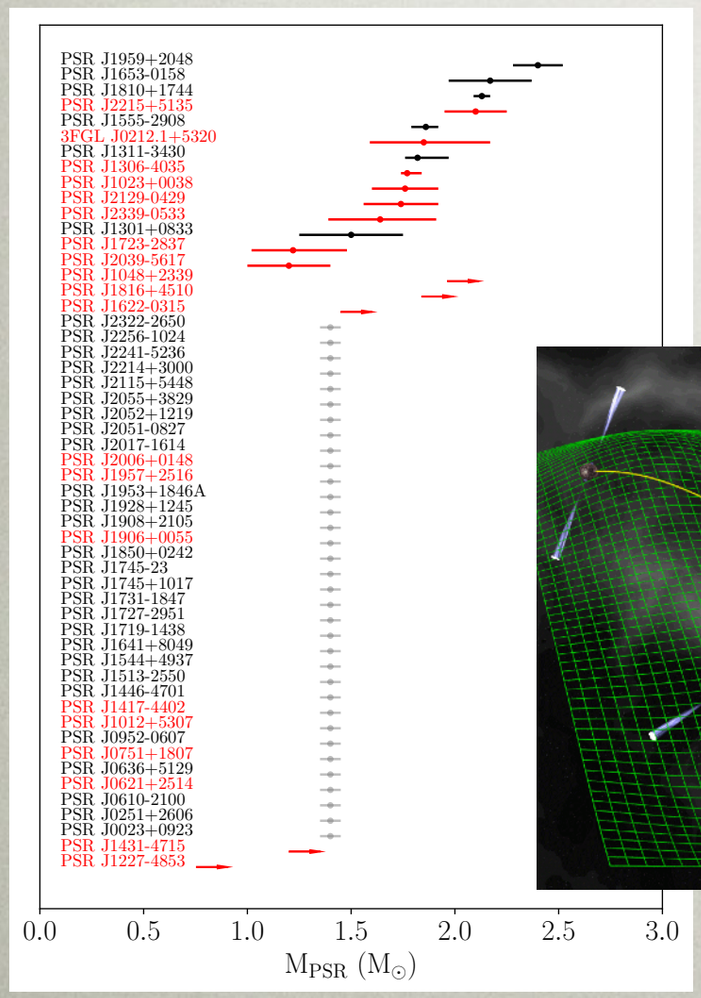
Why 'Stamp' Collecting Fermi Pulsars?

Finding energetic pulsars (typical young or MSP)

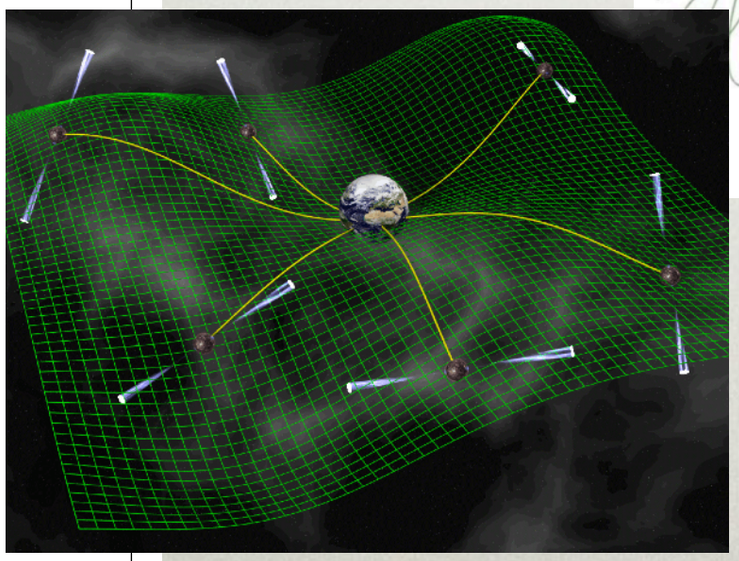
- Emission mechanism (see A. Harding & C. Venter's talks)
- Radio quiet population
- Pulsar timing array
- Pulsar mass measurement
- Pulsar binary evolution/interactions



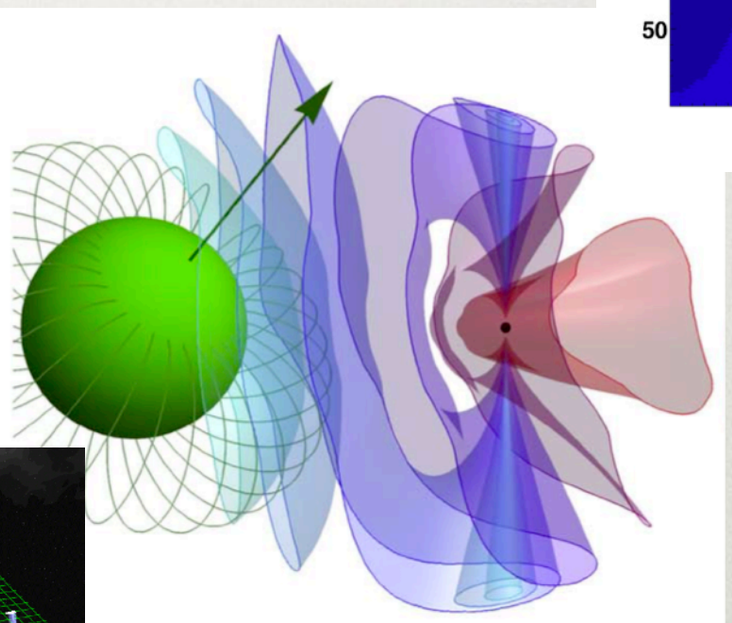
Credit: Venter et al. (2009)



Credit: M. Kennedy



Credit: D. Champion

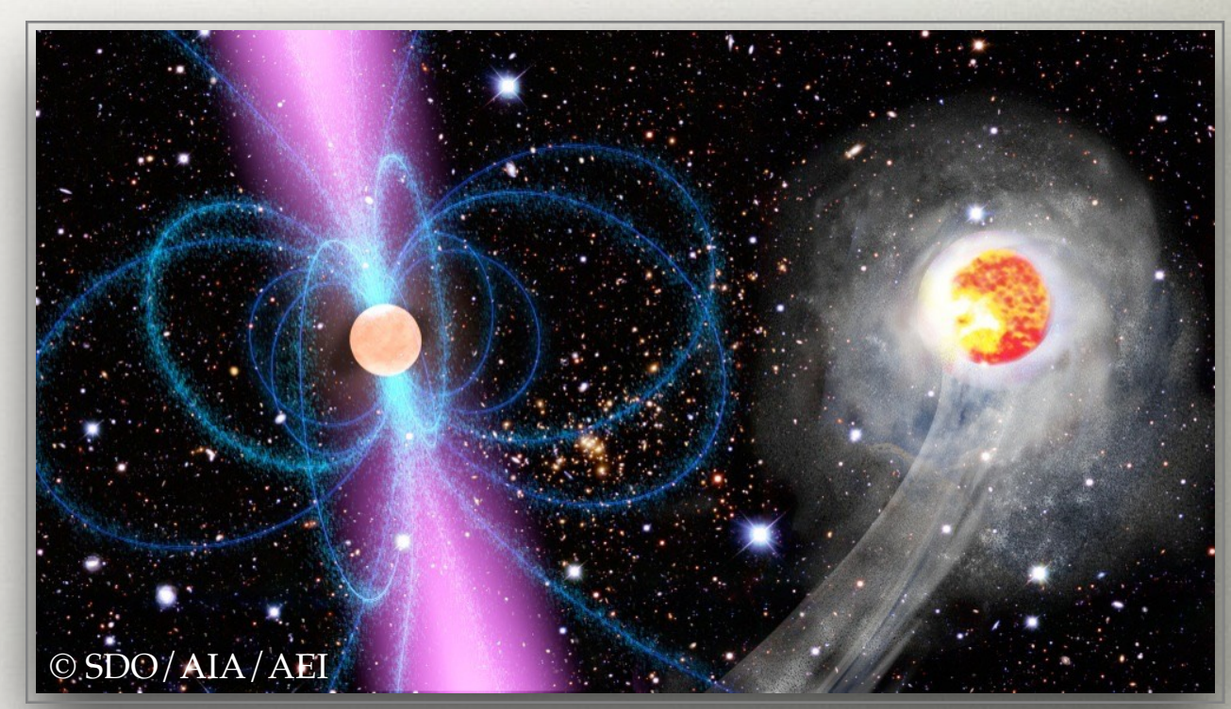


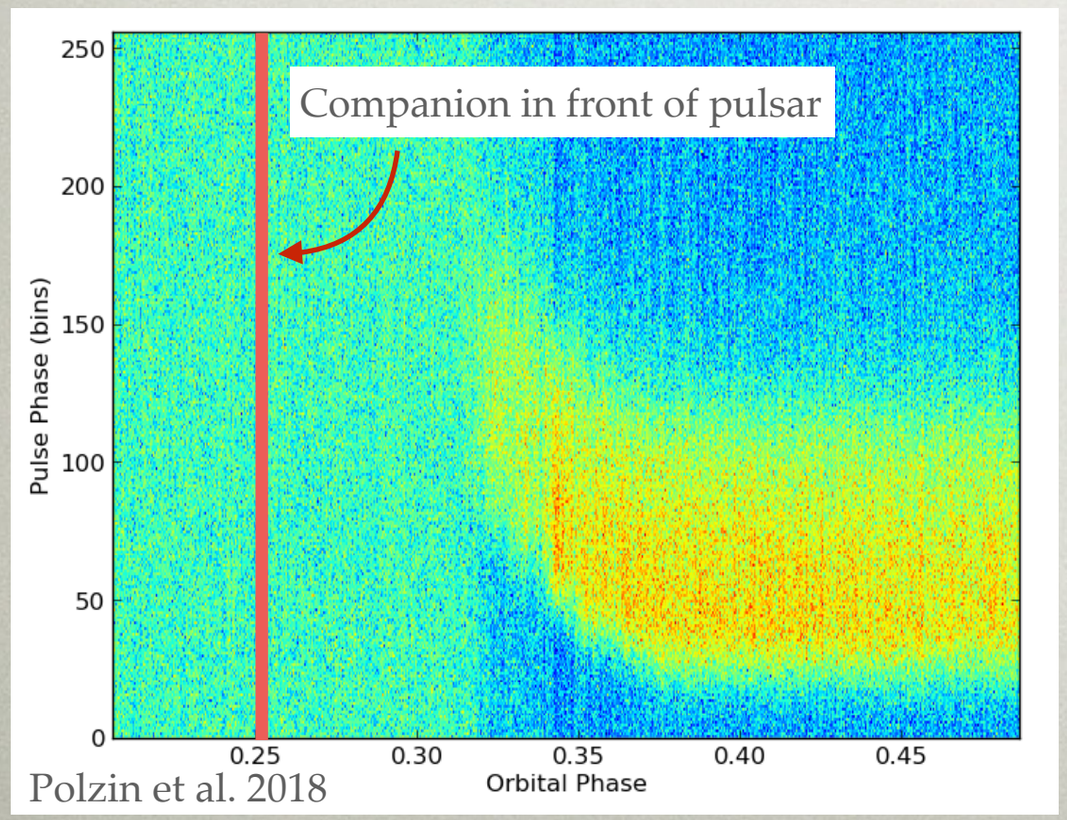
Credit: Wadiasingh et al. (2018)

Hunting for 'Spider' Pulsar Binaries

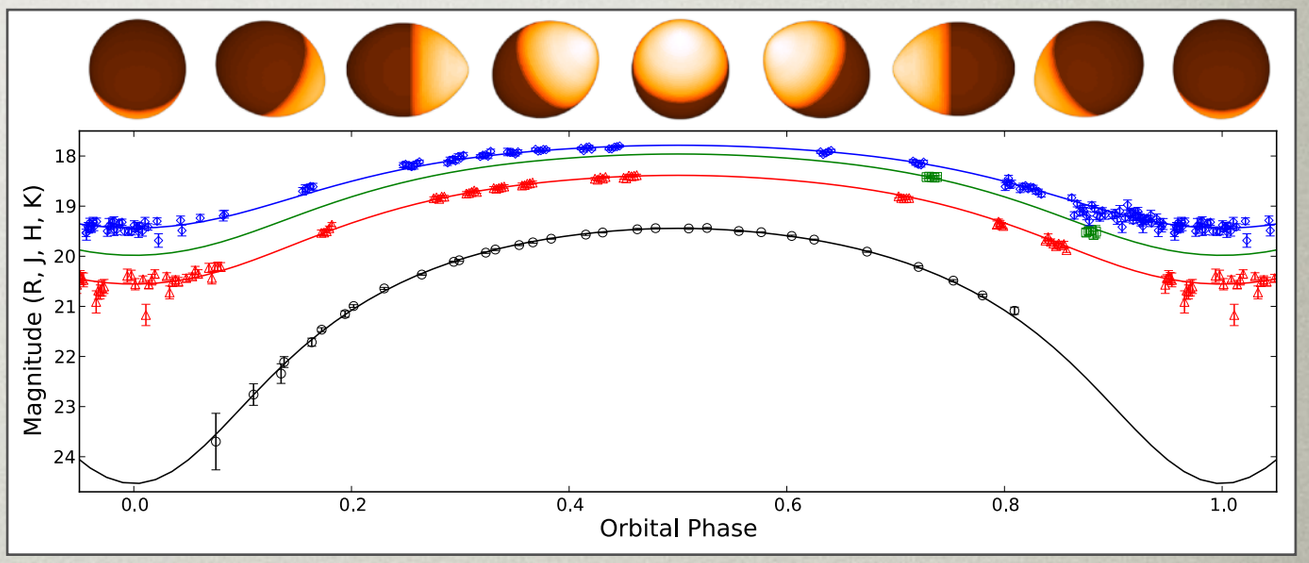
Spiders are binary MSPs:

- Compact orbit (~hour to ~day)
- Low mass companion
  - Black widow: ~0.01-0.05 Msun
  - Redback: ~0.2-0.5 Msun
- Irradiated/evaporating companion
  - Pulsar radio eclipses
  - Companion optical orbital variability
  - X-ray intra-binary shock



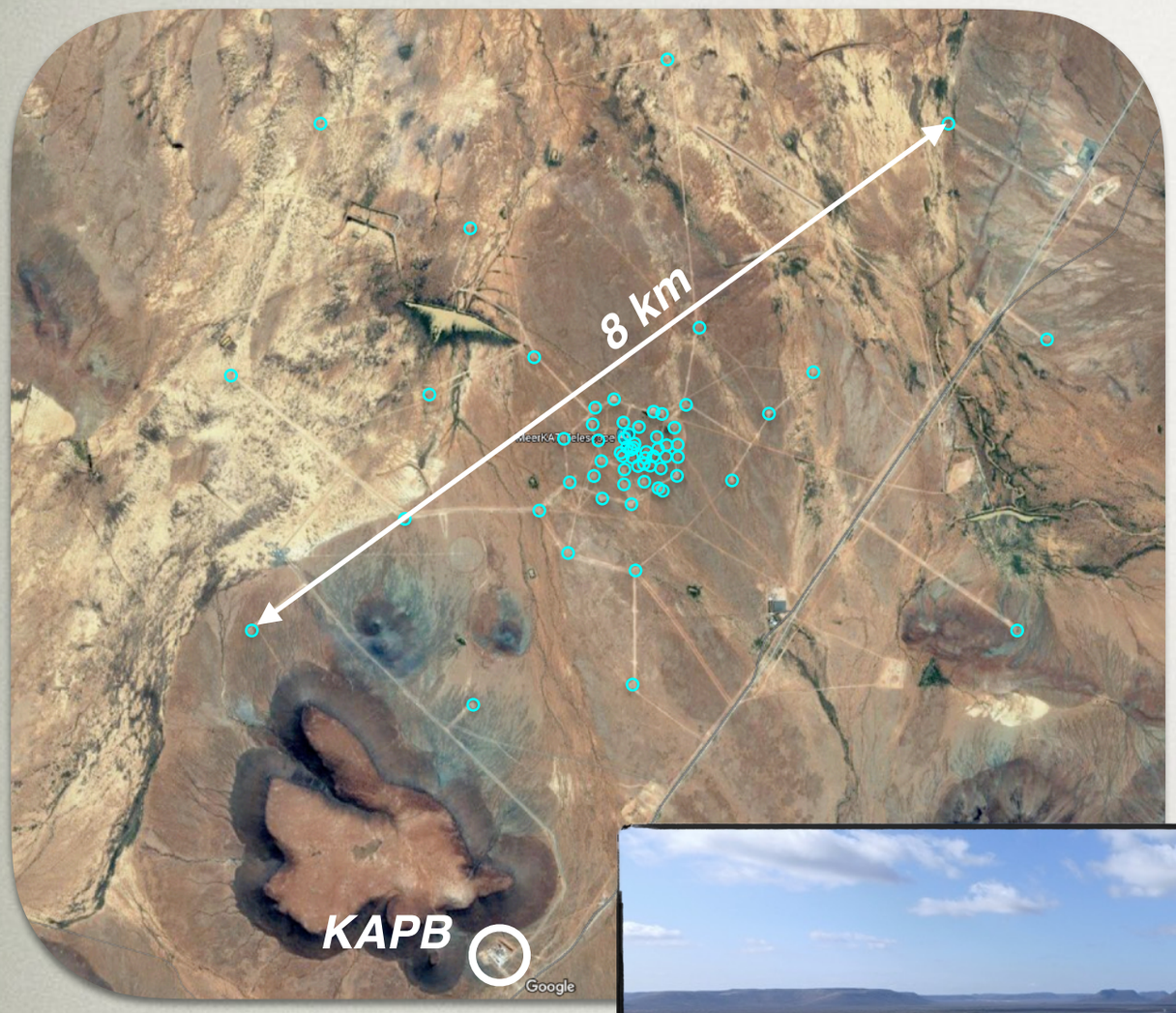


Polzin et al. 2018



Kennedy et al. (in prep)

MeerKAT, the Telescope



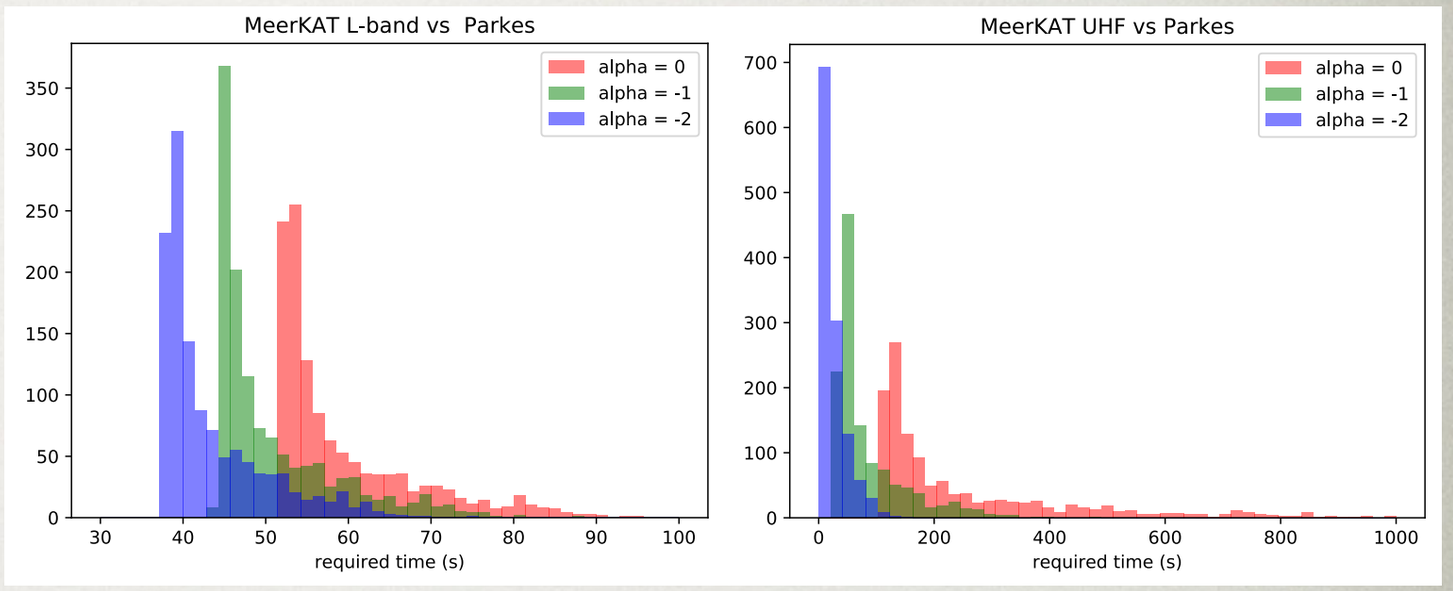
Number of antennas	64
Dish diameter	13.5 m
Minimum baseline	29 m
Maximum baseline	8 km
Frequency bands	544 – 1088 MHz (UHF-band) 856 –1712 MHz (L-band)
Instantaneous bandwidth	544 MHz (UHF-band) 856 MHz (L-band)
Gain 64 dishes (0.58 - 1.67GHz)	2.75 K/Jy

Survey Capabilities: Sensitivity

MeerKAT: very competitive sensitivity compared to major historical surveys of Fermi UNIDs

10 minutes is sufficient to match or improve

Parameter	Parkes	GBT	Arecibo	Effelsberg	MeerKAT
T_{rec} (K)	25	18	64	25	25
Gain (K/Jy)	0.735	2	10	1.5	2.75
t_{obs} (min)	60	45	76	76	10
Frequency (MHz)	1390	820	327	1360	1284 / 816
Bandwidth (MHz)	256	200	68.75	240	856 / 544



Credit: T. Thongmeearkom

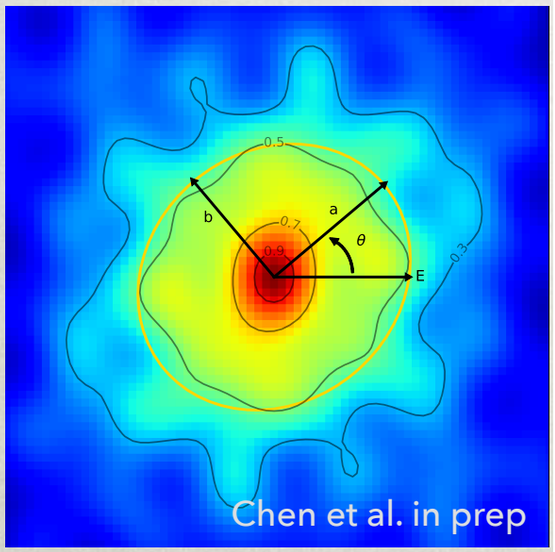
Survey Capabilities: Interferometry

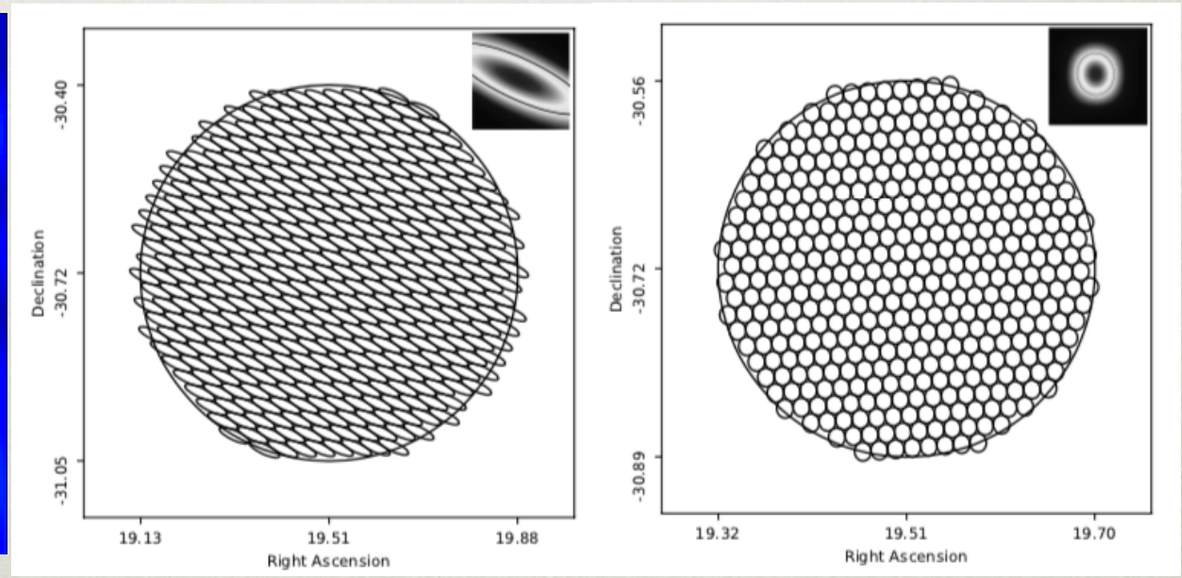
MeerKAT is an interferometer:

- Small dishes => large FoV
- Tied-array beams tiling
  - 480 coherent beams (tuneable)
  - RFI robustness
  - RFI mitigation
  - Localisation

Parameter	Parkes	GBT	Arecibo	MeerKAT
Frequency (MHz)	1390	820	327	1284 / 816
FoV @ survey (arcmin)	11	12	11	53 (0.09 for TAB)

Can tune observing elevation to adapt the beam shape and cover larger areas





Coverage of entire $r_{95\%}$ region for several Fermi UNIDs in a single pointing

Survey Capabilities: Interferometry

MeerKAT is an interferometer:

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Coherent beam "naturally" filters some of the RFI

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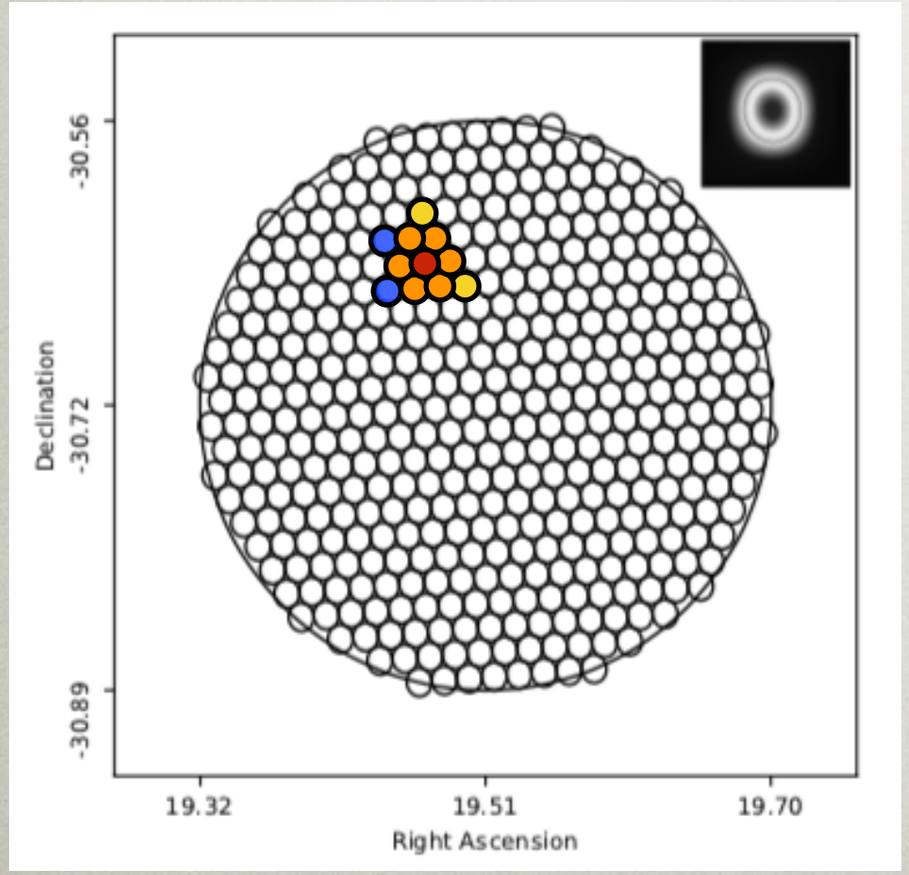

Credit: Chen et al. (in prep)

Pulsars should be detected in a few beams, with a predictable S/N.

RFI might be in all beams, or in a single beam only (noise too)

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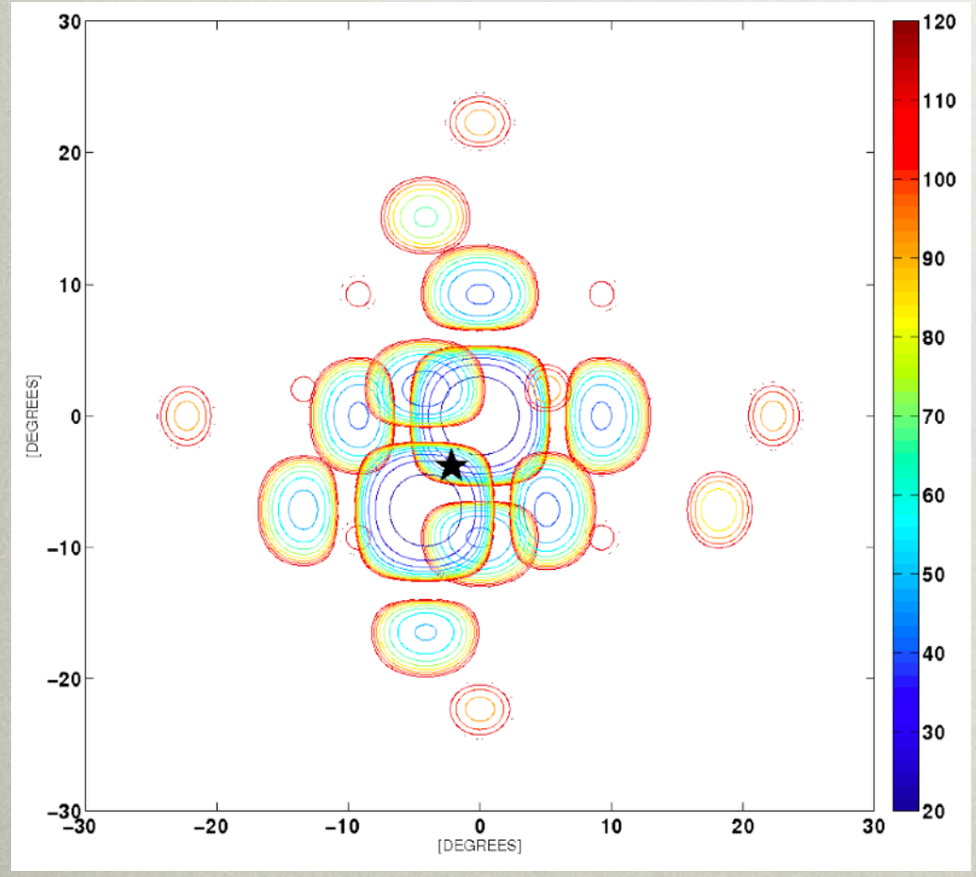

Credit: Obrocka et al. (2015)

Pulsars should be detected in a few beams, with a predictable S/N.

Credit: T. Bezuidenhout

RFI might be in all beams, or in a single beam only (noise too)

Fermi UNIDs 'Shallow' Survey

a.k.a. the "perfect" survey (Clark et al. in prep)

- t_{obs}
  - Minimise acceleration
  - Number of sources
  - Processing (46-71 TB/hr)
- 2 passes
  - Eclipsing binaries
  - Scintillation
- Dual band (L-band + UHF)
  - Radio spectrum
  - Eclipsing binaries

Parameter	Parkes	GBT	Arecibo	Effelsberg	MeerKAT
T_{rec} (K)	25	18	64	25	25
Gain (K/Jy)	0.735	2	10	1.5	2.75
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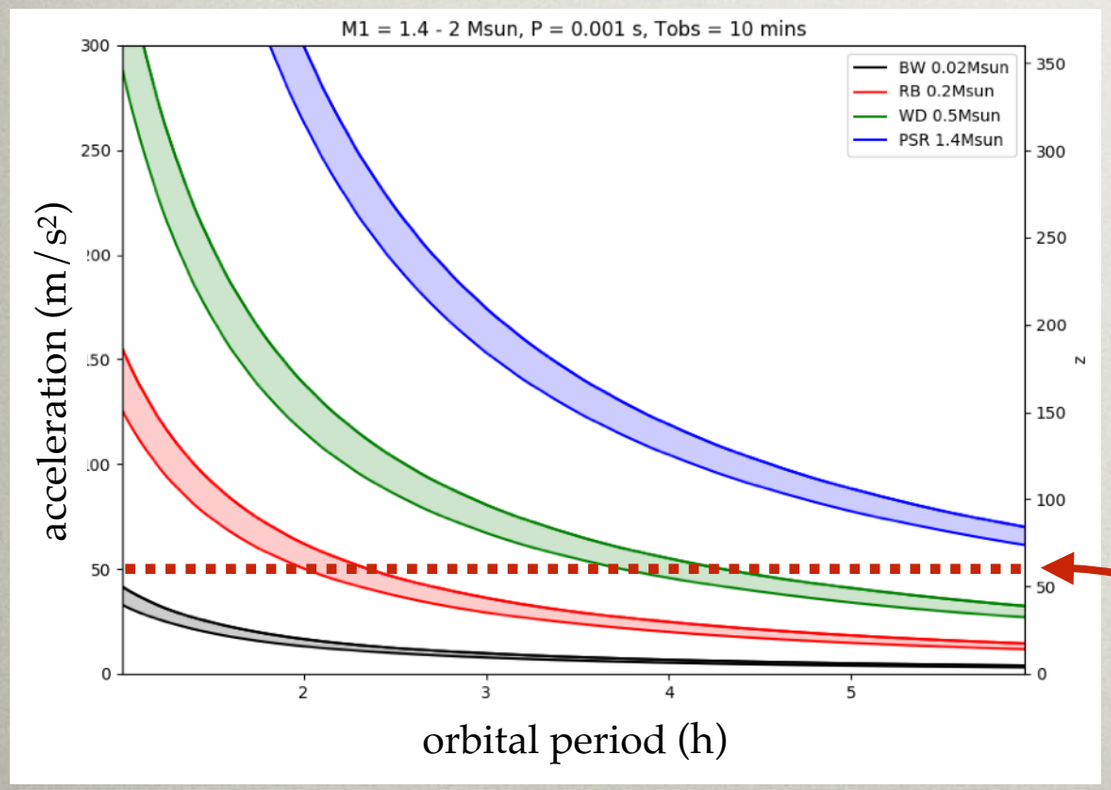
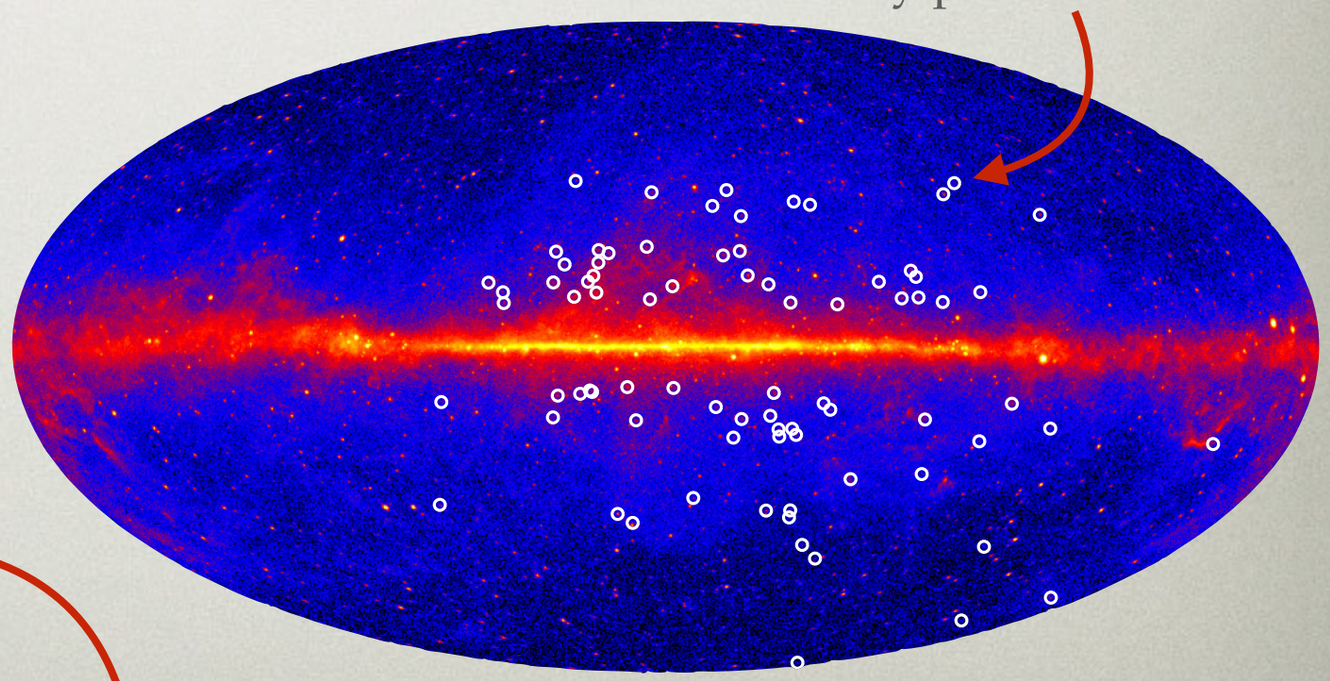


Credit: T. Thongmeearkom

79 sources for the first survey phase



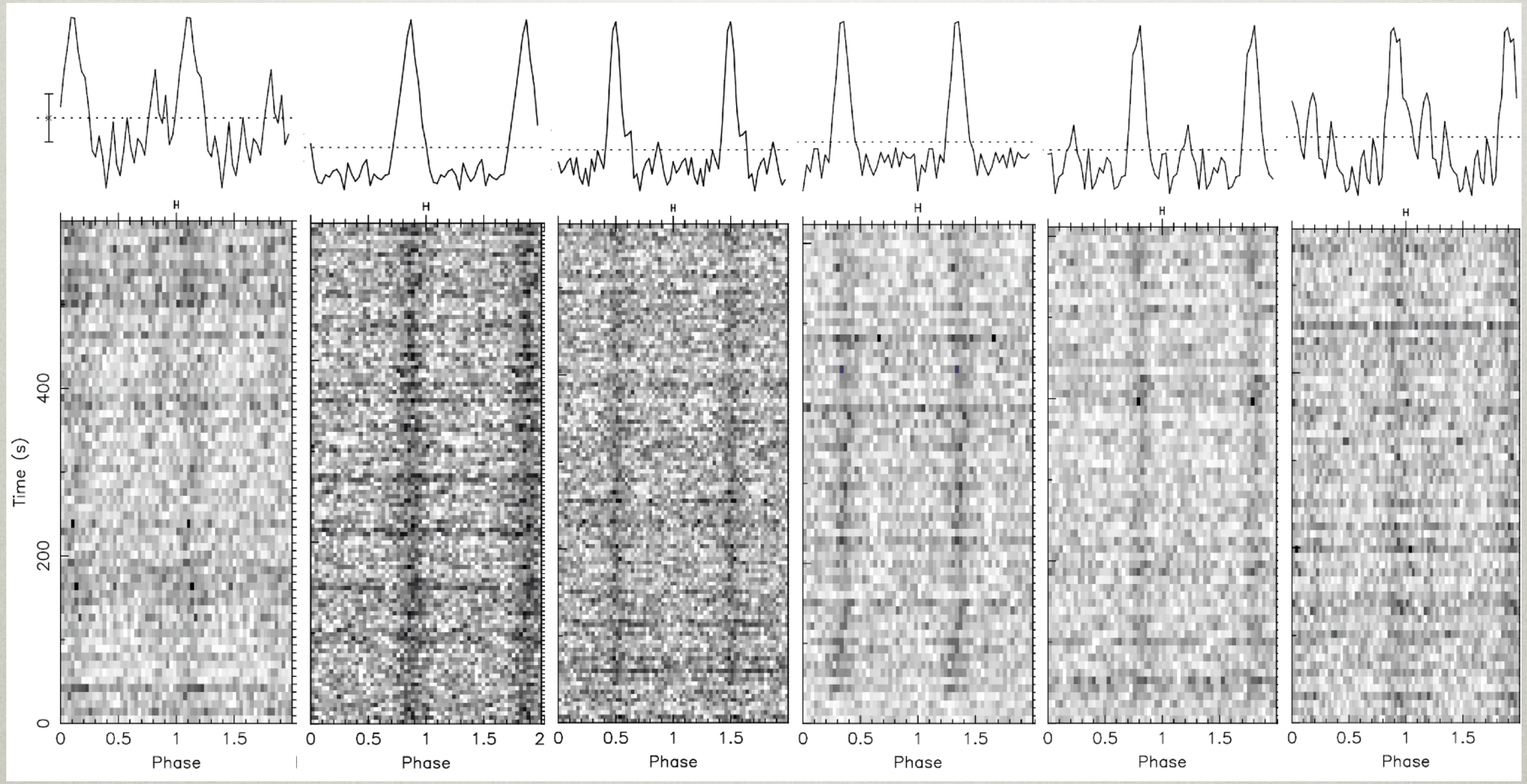
Credit: Clark et al. (in prep)

Search range limit

Shallow Survey Results

8 new discoveries + 1 independent co-discovery

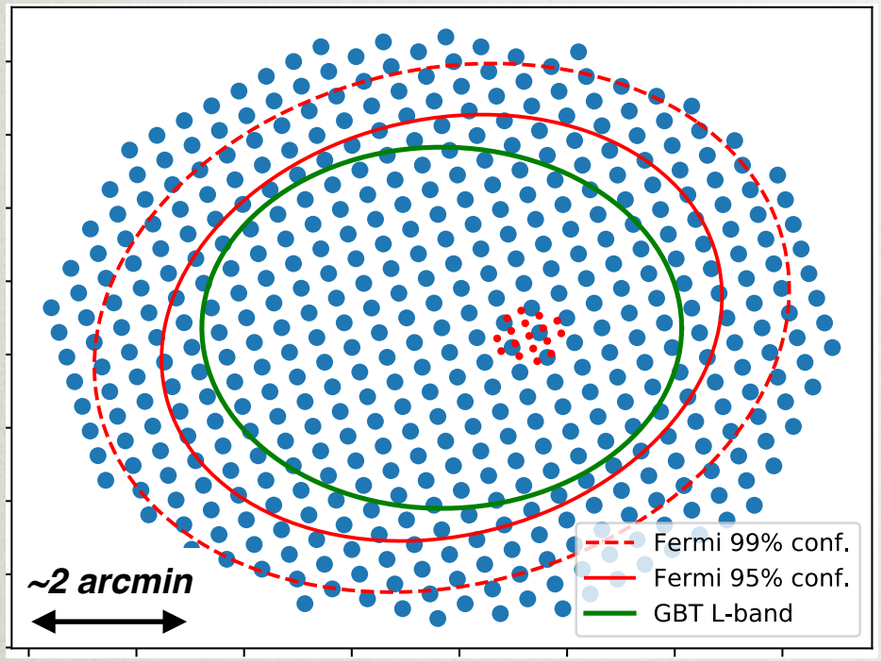
J1526–2744	J1623–6936	J1757–6032	J1823–3543	J1858–5422	J1906–1754
2.49 ms	2.41 ms	2.91 ms	2.37 ms	2.36 ms	2.88 ms

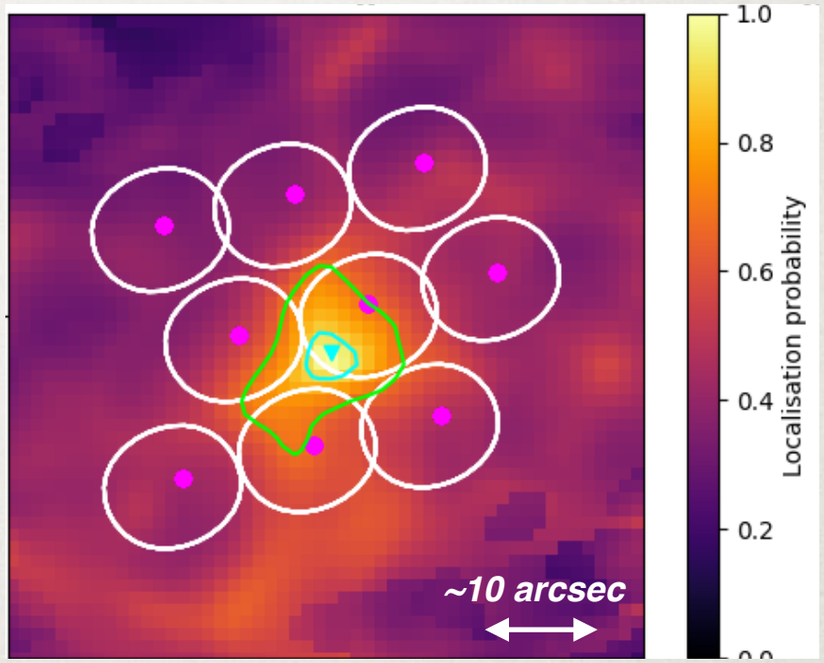


Credit: Clark et al. (in prep)

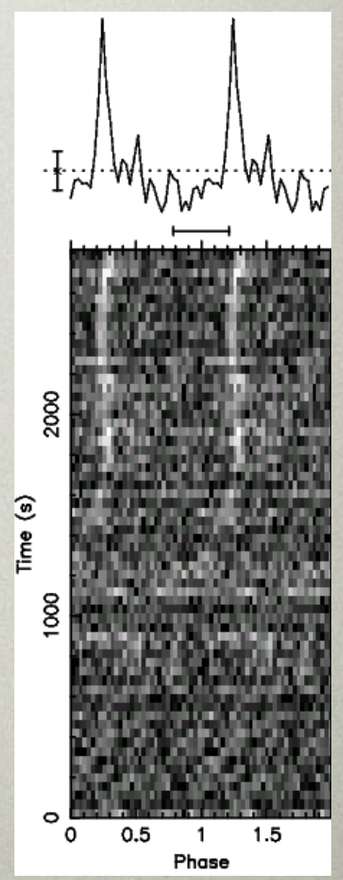
Follow-up Studies

MeerKAT confirmation observations and accurate relocalisation





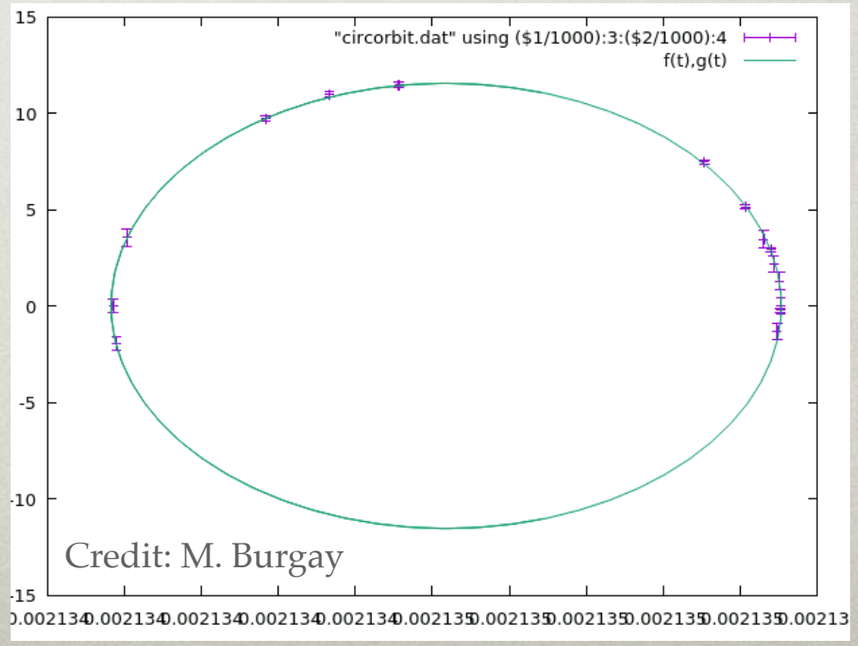
Credit: T. Thongmeearkom & T. Bezuidenhout



Parkes timing programme (+ optical underway)

J1803-6707, confirmed redback

- 2.13 ms
- P_{orb} ~ 9 hr
- M_{comp} ~ 0.3 Msun

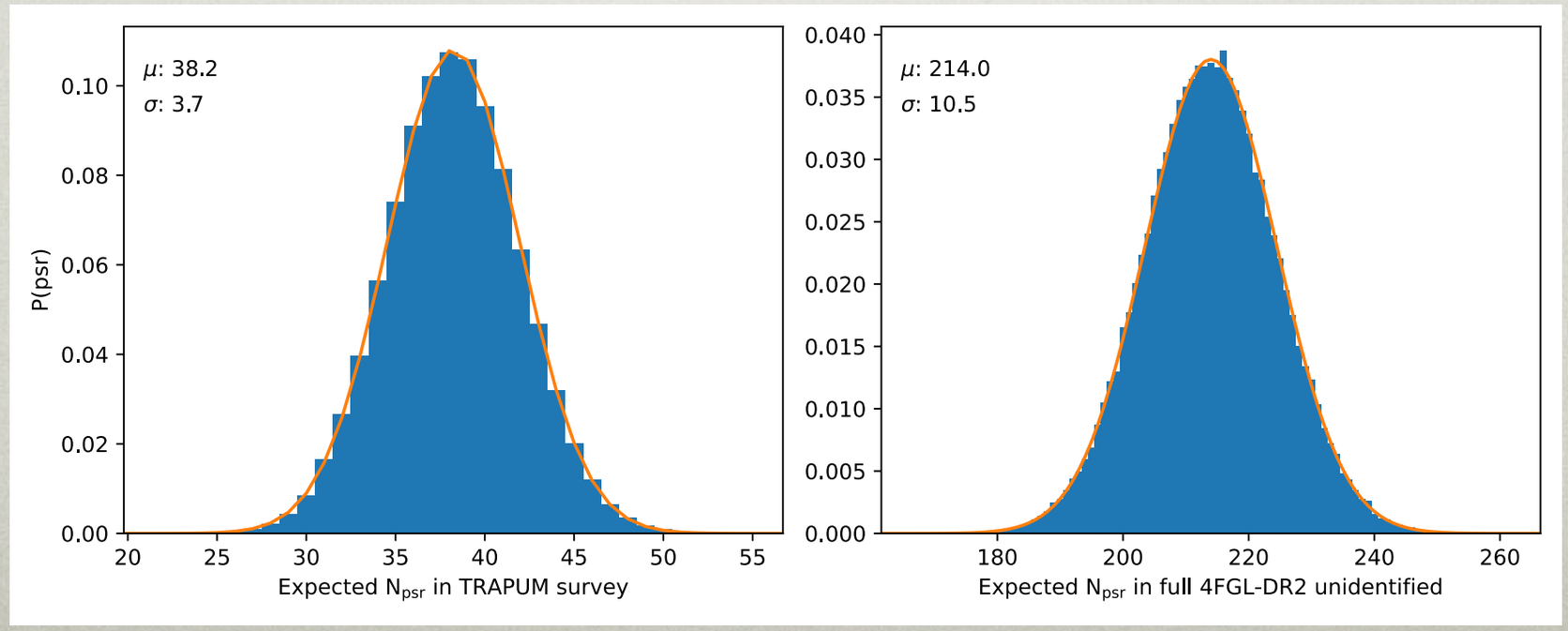


Credit: M. Burgay

Summary

- MeerKAT
  - Step change in surveying capabilities
    - Sensitivity
    - Interferometry

- TRAPUM Fermi WG's 'Shallow Survey'
  - L-band so far
  - 79 sources
  - 8 new discoveries + 1 independent co-discovery
    - All MSPs
    - At least one redback

- Coming up
  - 'Shallow Survey' at UHF-band
  - Phase 2 of 'Shallow Survey' with new sources
    - Aim to cover 'all' credible candidates from 4FGL+
  - Targeted survey of redbacks
    - Already underway

How many of Fermi UNIDs will turn out to be pulsars?