More TRAnsients and Pulsars with MeerKAT

MANISHA CALEB

University of Manchester

On behalf of the MeerTRAP collaboration

MeerTRAP

European Research Council

Established by the European Commission

SKA AFRICA

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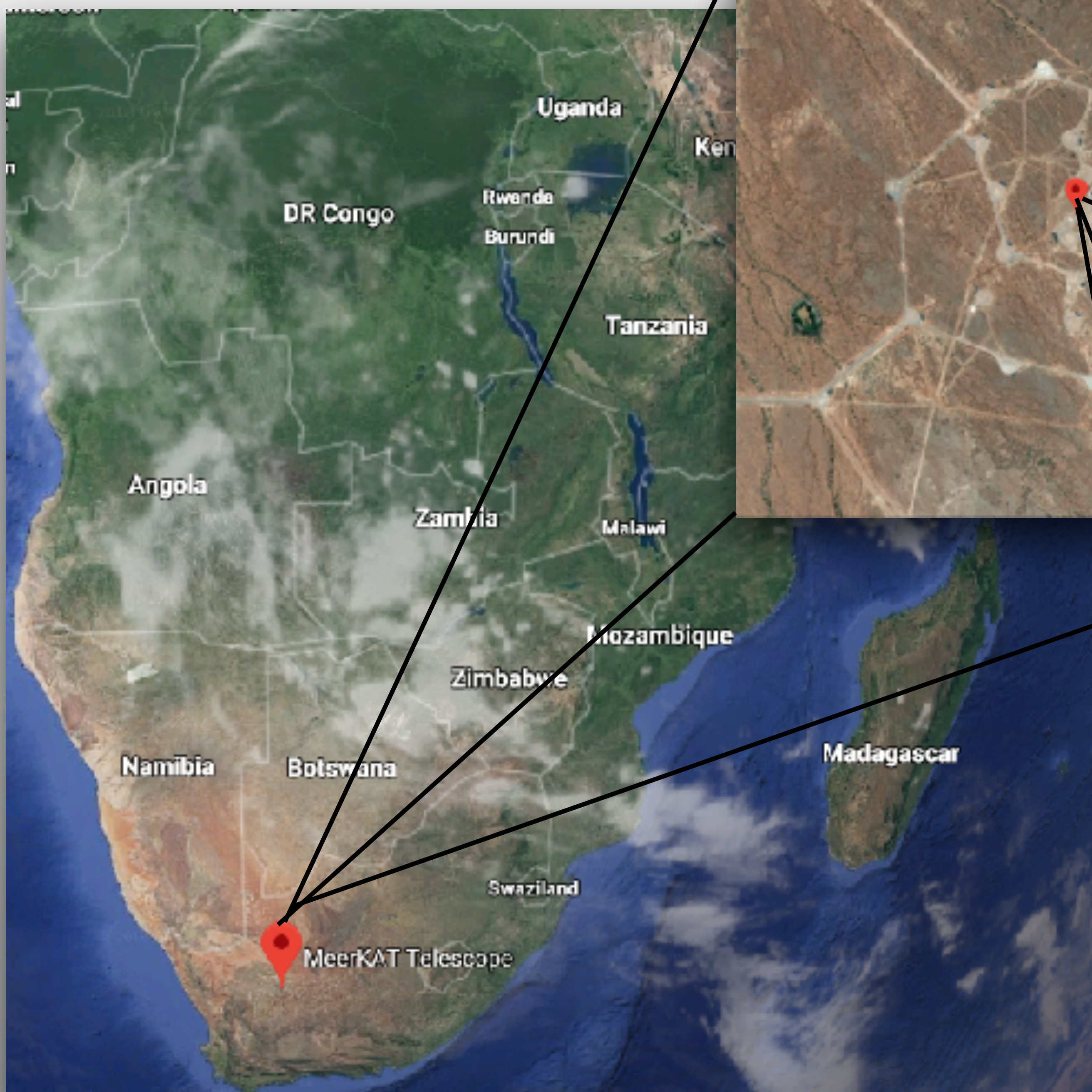
The University of Manchester

Overview

1. **The MeerKAT radio telescope**
2. **Why MeerKAT for FRBs?**
3. **The MeerTRAP project**
4. **Transient pipeline**
5. **The MeerLICHT optical telescope**
6. **Summary**

MeerKAT


Day 37:
They still do not suspect
I am a mere cat.


Uganda
DR Congo
Rwanda
Burundi
Tanzania
Angola
Zambia
Malawi
Mozambique
Zimbabwe
Namibia
Botswana
Madagascar
Swaziland
MeerKAT Telescope


22/11/2017 12:50
Google

MeerKAT

Dishes	64 (13.5m offset Gregorians)
Sensitivity	0.06 Jy
Frequencies	0.6-1.0, 0.9-1.7, 1.6-3.2 GHz
Bandwidth	300, 750, 1600 MHz
Incoherent FoV	~1.27 sq. deg
Coherent FoV	~0.1 sq. deg. (assuming 400 TBs)

AR-1: 16 receptor array
First light: 30 June 2016
L-band receivers only
ROACH-2 correlator/beamformer (CBF)

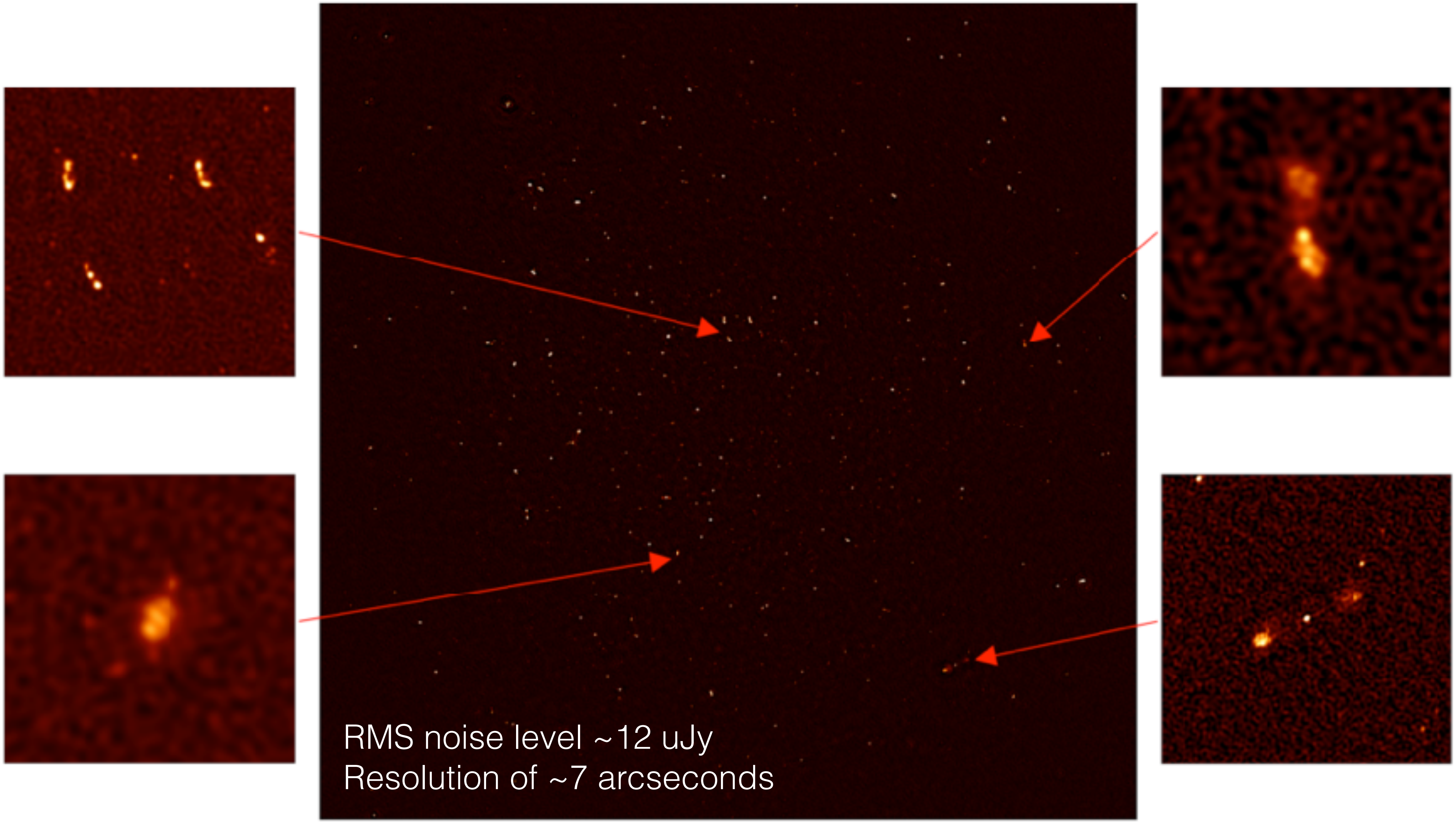
AR-2: 32 receptor array
32 single-polarisation inputs (ROACH-2 CBF)
32 dual-polarisation inputs (SKARAB CBF)

AR-3: 64 receptor array
Additional CBF functionality
64 dual-polarisation stations — L-band and UHF-band

AR 4,5,6 — further functionality like Fly's Eye modes

Tsys	~18 K
Gain	2.3 K/Jy for f = 0.7
Nchan	4096 MHz, 32768 MHz
Sample time	64 us
Sky coverage	< dec = +44
DM smear	~0.6 ms for 1000 pc/cc

MeerKAT



Montage of MeerKAT First Light radio image and four zoomed-in insets. The two panels to the right show distant galaxies with massive black holes at their centers. At lower left is a galaxy approximately 200 million light years away, where hydrogen gas is being used up to form stars in large numbers.

http://www.ska.ac.za/gallery/meerkat/

Why MeerKAT?

1. **Exceptional sensitivity**
   - Large collecting area
   - Wide bandwidths — good for studying the spectra, polarisation properties
2. **Wide-ish field of view**
   - Allow for “faster surveys”
   - Access through combination of coherent and incoherent beams
3. **Resolution**
   - Essential for accurate localisation of transients
   - Useful for searching diffuse high brightness temperature regions (e.g.: SNRs and the Galactic centre)
4. **Wide range of frequencies**
   - S-band for deep in the Galactic centre
   - L-band for intermediate Galactic latitudes
   - UHF band for wide area searches
5. **Flexibility and commensality**
   - Sub-arraying and piggyback observations
6. **Ideal for finding pulsars and fast transients**
   - FRBs
   - RRATs
   - Intermittent pulsars
   - Scintillating sources
   - Moding/Nulling sources
   - GW counterparts

MeerKAT Large Survey Projects (LSPs)

MLSPs

1. **MeerTIME:** Testing Einstein's theory of gravity and gravitational radiation - Investigating the physics of enigmatic neutron stars through observations of pulsars.

2. **LADUMA** (Looking at the Distant Universe with the MeerKAT Array) - An ultra-deep survey of neutral hydrogen gas in the early Universe

3. **A MeerKAT HI Survey of the Fornax Cluster** (Galaxy formation and evolution in the cluster environment).

4. **MeerKAT Absorption Line Survey** for atomic hydrogen and OH lines in absorption against distant continuum sources (OH line ratios may give clues about changes in the fundamental constants in the early Universe).

5. **MHONGOOSE** (MeerKAT HI Observations of Nearby Galactic Objects: Observing Southern Emitters) - Investigations of different types of galaxies; dark matter and the cosmic web.

6. **ThunderKAT** (The Hunt for Dynamic and Explosive Radio Transients with MeerKAT) - for example gamma ray bursts, novae and supernovae, plus new types of transient radio sources.

7. **MIGHTEE** (MeerKAT International GigaHertz Tiered Extragalactic Exploration Survey) - Deep continuum observations of the earliest radio galaxies.

8. **TRAPUM** (Transients and Pulsars with MeerKAT) - Searching for and investigating new and exotic pulsars.

What is MeerTRAP?

- An ERC funded collaboration (PI: Stappers) that aims to use MeerKAT to reveal numerous new pulsars and fast radio transients.
- Use these sources to improve our understanding of physics in extreme environments.
- **Fully commensal high time resolution survey that will piggyback all the MeerKAT Large Survey projects (MLSPs)**.
- It will allow a large sky coverage, multiple visits to the same field to search for repeats, and variable cadence observations.

Commensal observing

MeerTime	Matthew Bailes	L-band	4000h
LADUMA	Andrew Baker & Sarah Blyth	UHF-band, L-band	3500h
MALS	Neeraj Gupta	UHF-band, L-band	3500h
MHONGOOSE	Erwin de Blok	L-band	1700h
TRAPUM	Michael Kramer & Ben Stappers	L-band	1700h
FORNAX	Paolo Serra	L-band	900h
MIGHTEE	Matt Jarvis	UHF-band, L-band, S-band	2000h
ThunderKAT	Rob Fender	L-band	1900h

~ 20,000 hours of observing with MeerTRAP

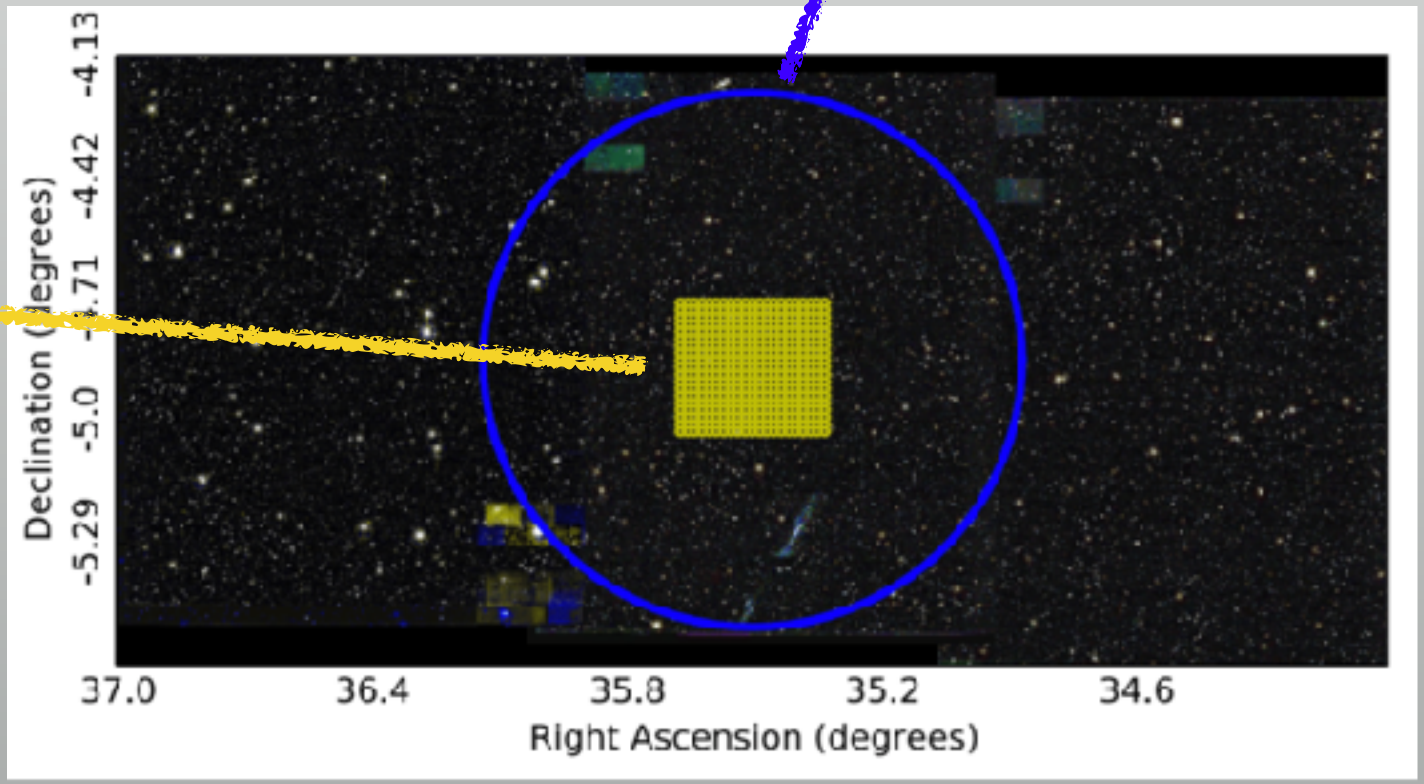
MeerTRAP Goals

1. Detect hundreds of Galactic and extragalactic short duration radio bursts from extreme and cataclysmic events.

2. Discover pulsars over an unprecedented range of possible search parameter space by covering variability on timescales from days to years, luminosity, spectral index and multiple systems.

Incoherent beam
~1.27 sq deg

Coherent beam
~0.1 sq deg



A 4.5 sq. deg. part of the XMMLSS field that will be observed by MIGHTEE

Who are we?

- Ben Stappers (PI)
  - Sotiris Sanidas
  - Kaustubh Rajwade
  - Fabian Jankowski
  - Laura Driessen (PhD)
  - Vincent Morello (PhD)
  - Manisha Caleb
  - + New PhD student
  - + New software engineer

9 members

Wanted - Software Engineer

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Software and Hardware Engineer (MeerTRAP project)

Tweet

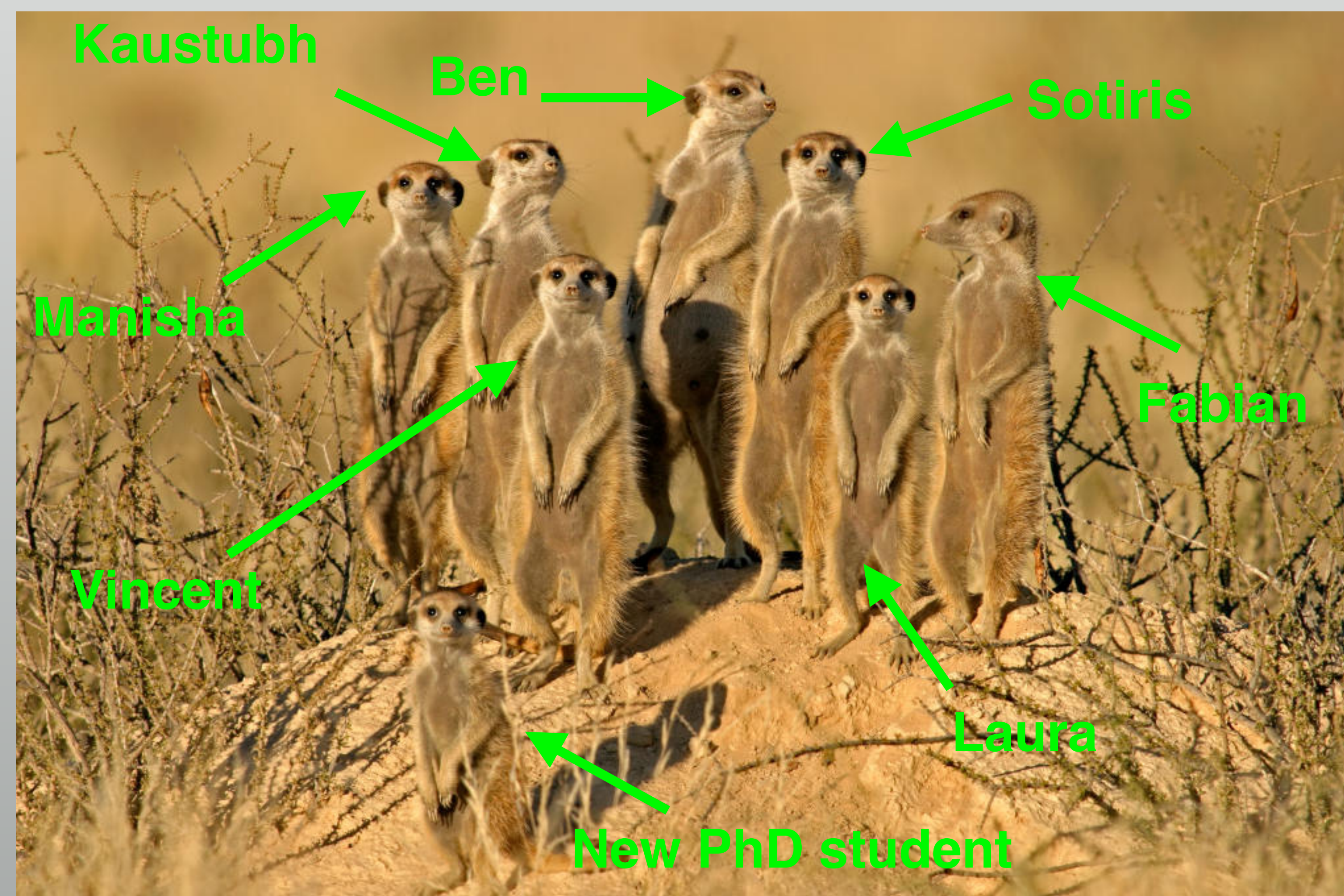
Ben Stappers
@bstappers

We are looking for someone to help us with the Hardware and Software for our MeerTRAP project on pulsars and fast radio bursts jobs.manchester.ac.uk/internal/displ...

9:00 am · 31 Jan 18

4 Retweets 6 Likes

MeerTRAP



MeerKAT Large Survey Projects (LSPs)

Radio Pulsar Timing: Testing Einstein's theory of gravity and gravitational radiation - Investigating the physics of enigmatic neutron stars through observations of pulsars.

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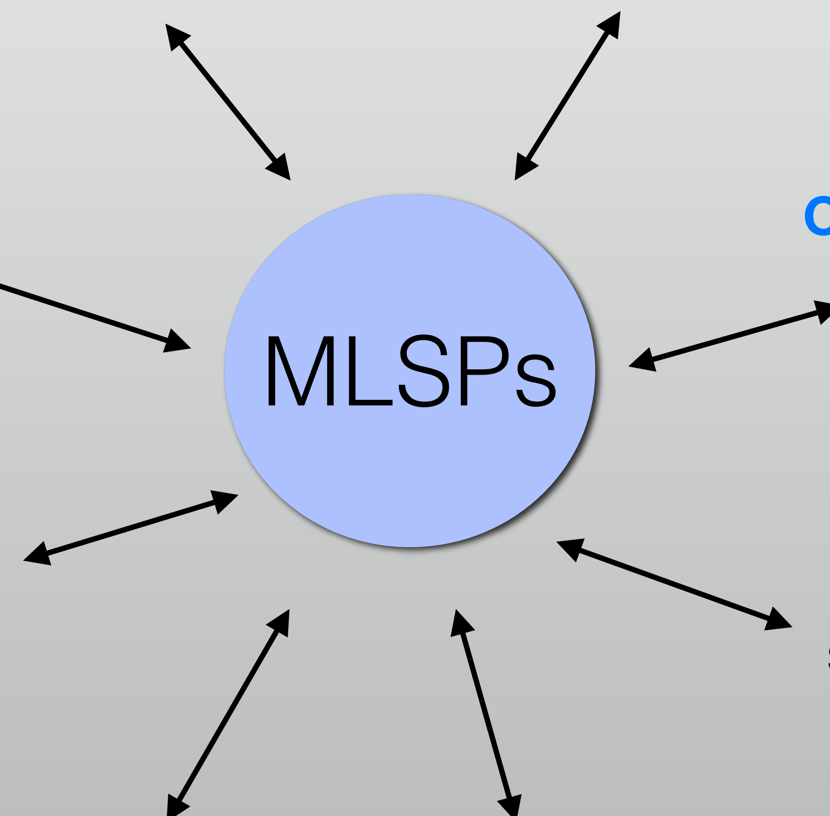

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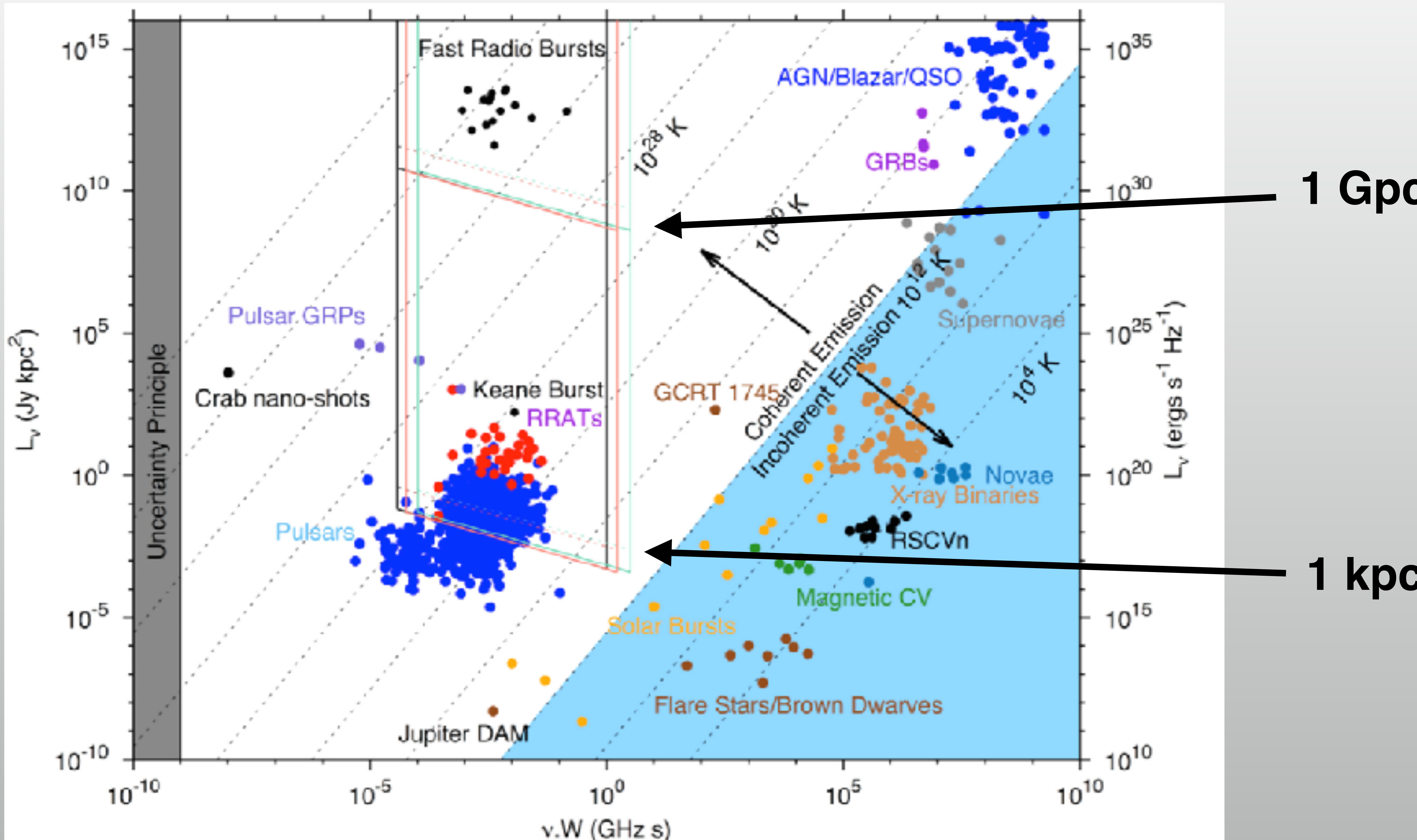
Transient phase space

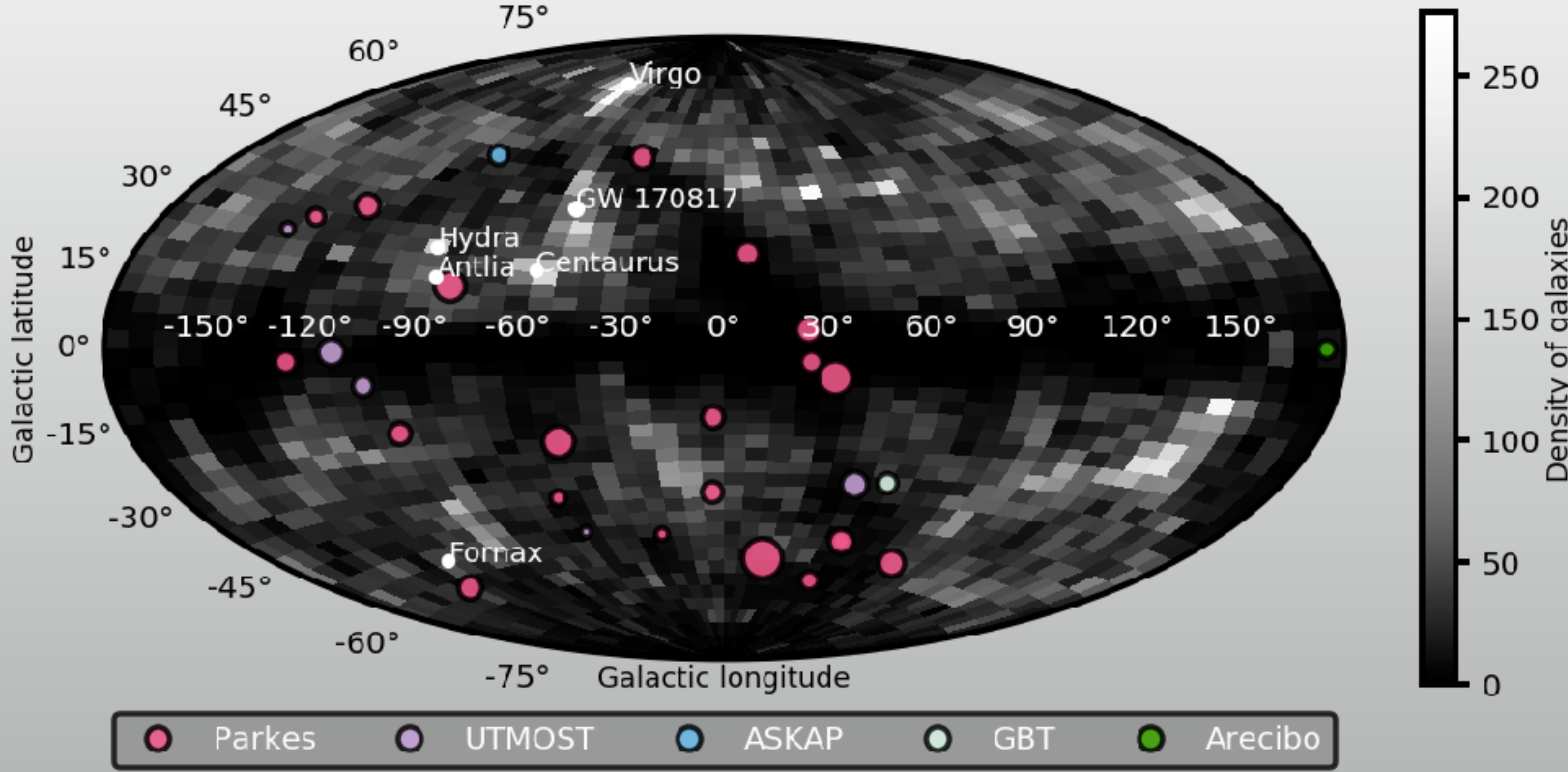


UHF-band, L-band, S-band

Incoherent (dashed), Coherent (solid)

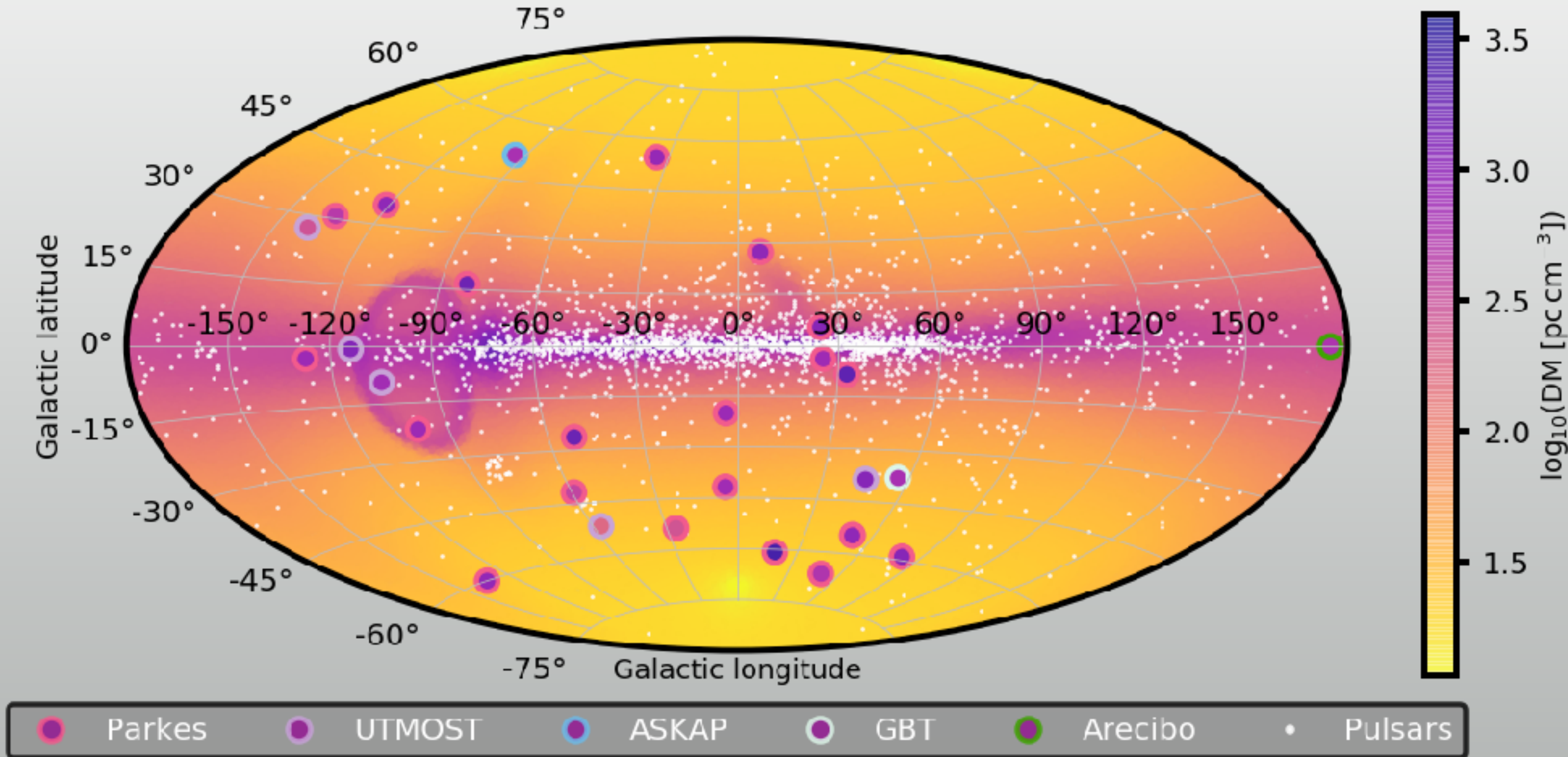
Credit: Evan Keane

Where are they?



Driessen & MeerTRAP

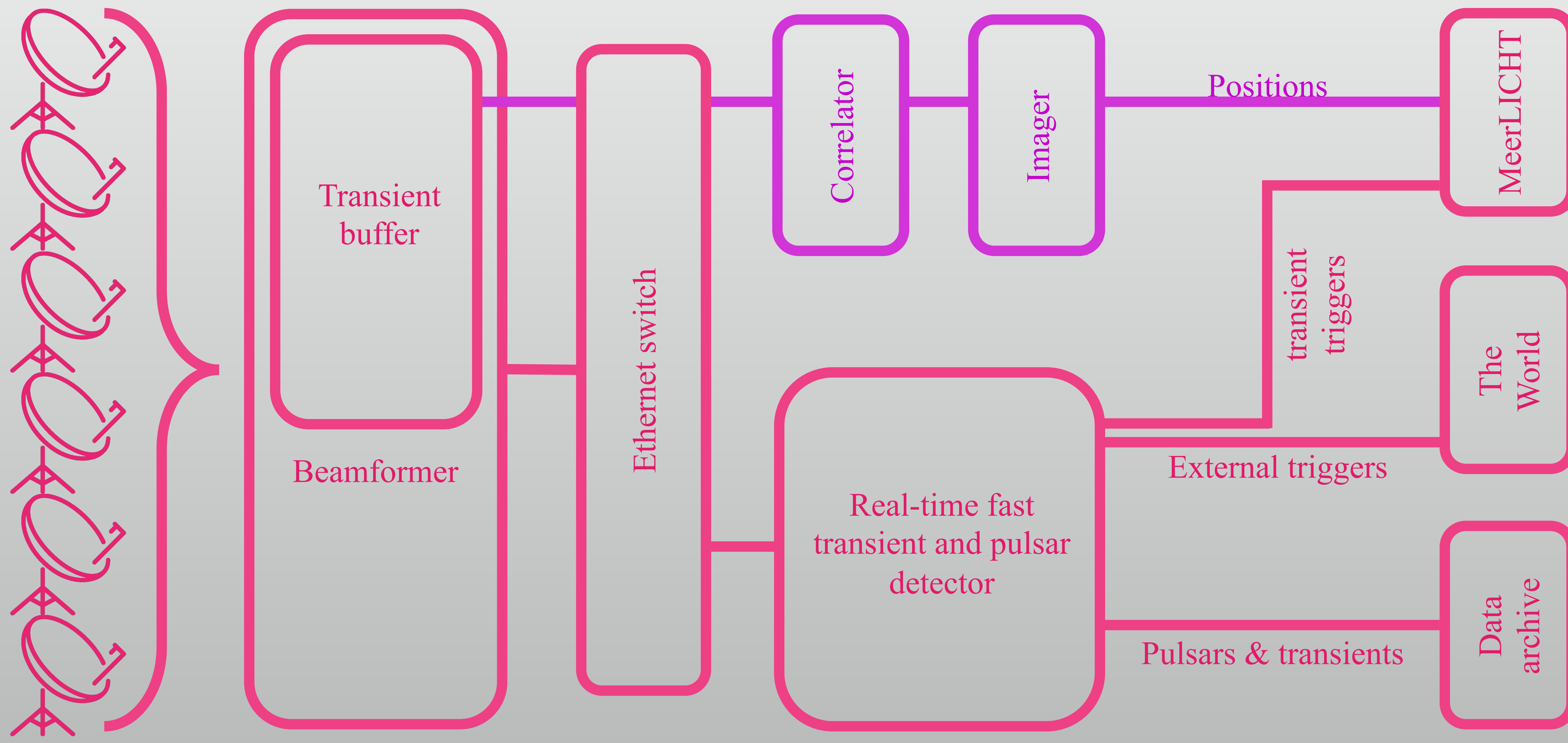
Extragalactic



Driessen & MeerTRAP

Beamforming and Processing

MeerTRAP



Driessen & MeerTRAP

Operate all of the beams in commensal mode on all LSP observing time, stowed time and where possible, open time.

Beamforming and Processing

Incoherent mode

- Total FoV of ~1.27 sq deg
- Uses 64 dishes but is a factor of 5 less sensitive than the coherent mode
- **Parkes like sensitivity**
- Expected to discover **1 FRB/week**
- Can use transient buffer to image after the fact for localisation

Coherent mode

- Total FoV of ~0.1 sq deg
- 400 tied-array beams in collaboration with MPIfR
- Uses 40 core dishes with much higher sensitivity
- Expected to detect **100 FRBs over 5 years**
- Good localisation from overlapping
- **GBT like sensitivity**

Transient buffers will provide:

- Localisation to sub-arsecond to allow host-id even if no multi-lambda counterpart
- Beam form post-facto for incoherent detections
- Reprocess data to correct for beam effects on flux and polarisation
- Also can coherently dedisperse to get intrinsic width (some unresolved)
- Instant afterglows in the radio.

Localisation I

- Localisation from coherent beams which provides a good initial position of ~1″
- Multiple beam detections and frequency-dependent beam shape can be used to refine position to arcseconds and even sub-arcseconds (Obrocka et al. 2015)
- Localisation from imaging the transient buffer data. Data will be immediately transferred to the realtime processing cluster for imaging.
- Voltages from all 64 dishes (longest baselines) can be combined coherently to increase the detection significance of the weaker bursts

Localisation II

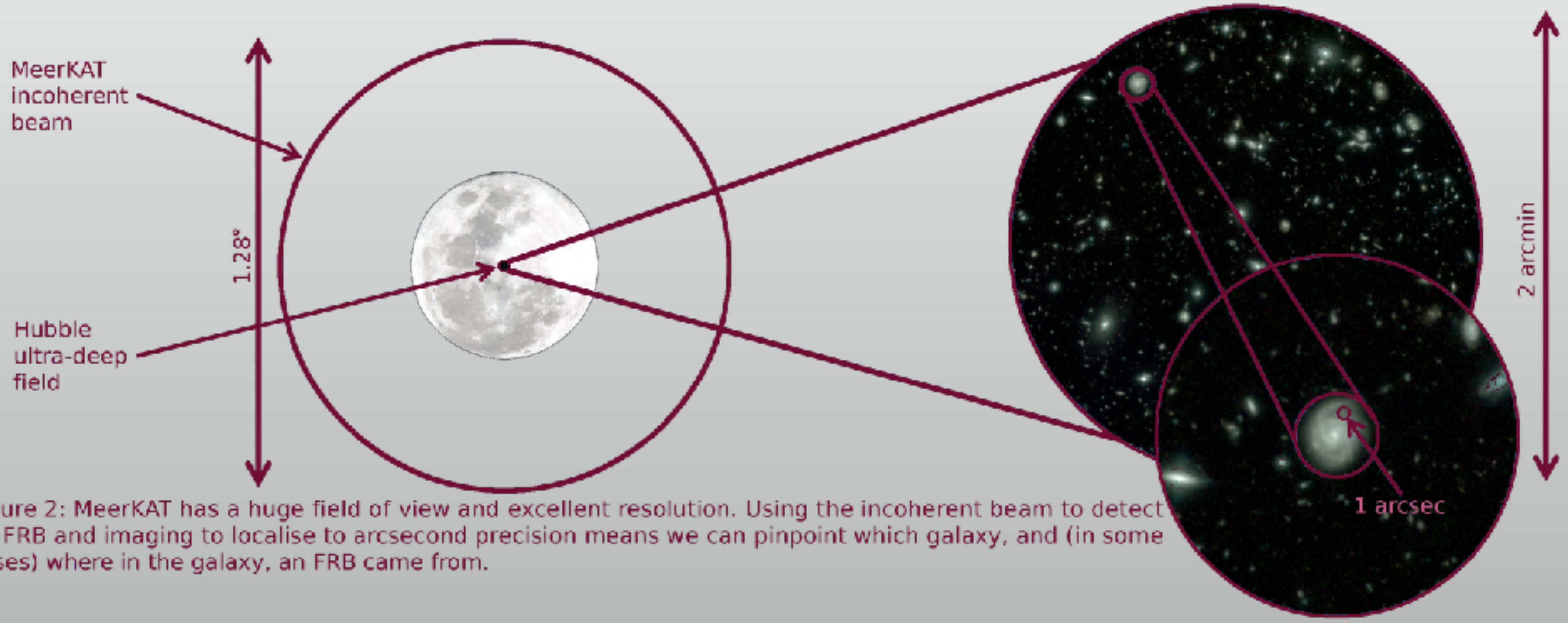


Figure 2: MeerKAT has a huge field of view and excellent resolution. Using the incoherent beam to detect an FRB and imaging to localise to arcsecond precision means we can pinpoint which galaxy, and (in some cases) where in the galaxy, an FRB came from.

MeerKAT's Fly's Eye - TRAPUM

- Can detect Lorimer-burst brightness (30 Jy) FRBs with this experiment
- Instantaneous coverage of 1.27*64 = ~81.3 sq. deg or ~0.002 of the sky
- Conservative assumptions on sensitivity and detection significance results in about 9 bursts of this brightness
- Assuming logN-logS = -1.5 results in a total of about 30 FRBs in 720 hours
- Crucial information on the luminosity distribution and potentially very useful probes of the local IGM and the host galaxy
- Localisation will be poorer but event rate will be higher

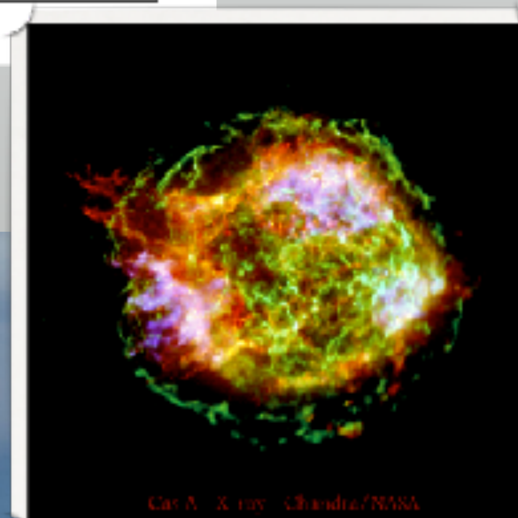
Targeted and Blind searches

- SNRs, PWNe, TeV and gamma-ray sources
- Globular clusters
- Extragalactic sources, Nearby galaxies
- Galactic Centre — S-band ++ to see in (and through)
- Galactic Plane — Large pulsar population
- Galactic Bulge — Fermi excess
- Plenty of Galactic pointings — probe the latitude dependence

Approximate fraction of observation time spent on each survey component.

Target	Fraction
SNRs,PWNe,TeV & γ-ray	10.6%
Globular Clusters	7.9%
Nearby Galaxies	5.5%
"Fly's Eye" Transients	17.8%
Repeat Fast Radio Bursts	4.9%
Galactic Census & Plane	40.7%
Follow up pulsar timing	12.4%

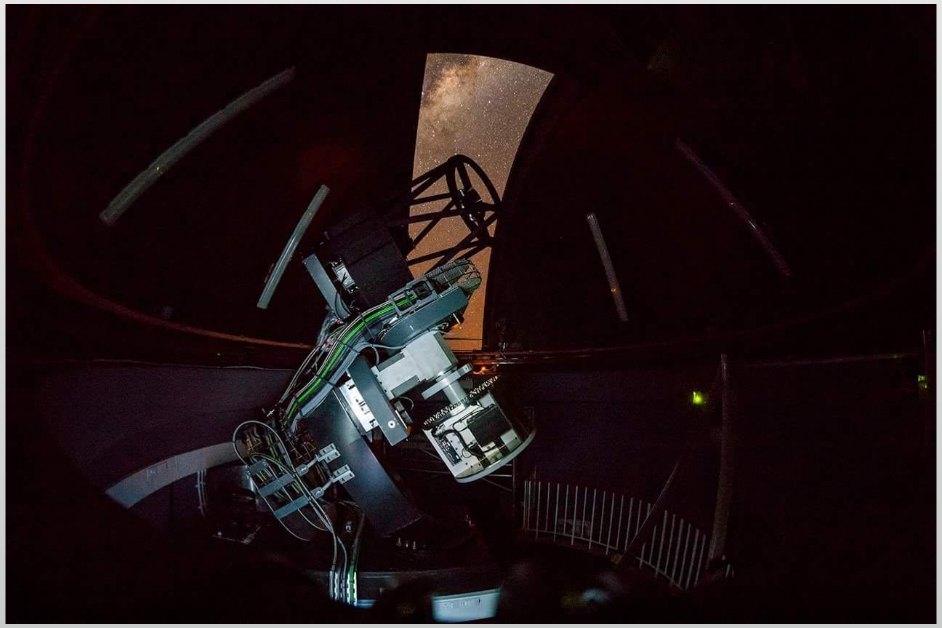
http://www.trapum.org/



The Cassiopeia A supernova remnant. (Chandra/NASA)

MeerLICHT

- MeerLICHT is a 65-cm fully robotic optical telescope that will co-point with MeerKAT to provide simultaneous optical and radio data on astronomical transient phenomena: cosmic explosions and outbursts.
- FoV of ~2.7 sq. deg. at 0.56 arcsec/pixel. CCD of 10560 x 10560 pixels.
- Basic integration time of 1 minute per exposure (but faster integrations are possible) reaching magnitude 20.5 in “g” in 1" seeing.



Filter	Wavelength range (nm)	Depth in 1 min ; 5 min (AB mag)
u	350 – 410	19.8 ; 20.9
g	410 – 550	21.9 ; 22.9
r	563 – 690	21.3 ; 22.3
i	690 – 840	20.7 ; 21.7
z	840 – 990	20.4 ; 21.4
vr	440 – 720	22.2 ; 23.2

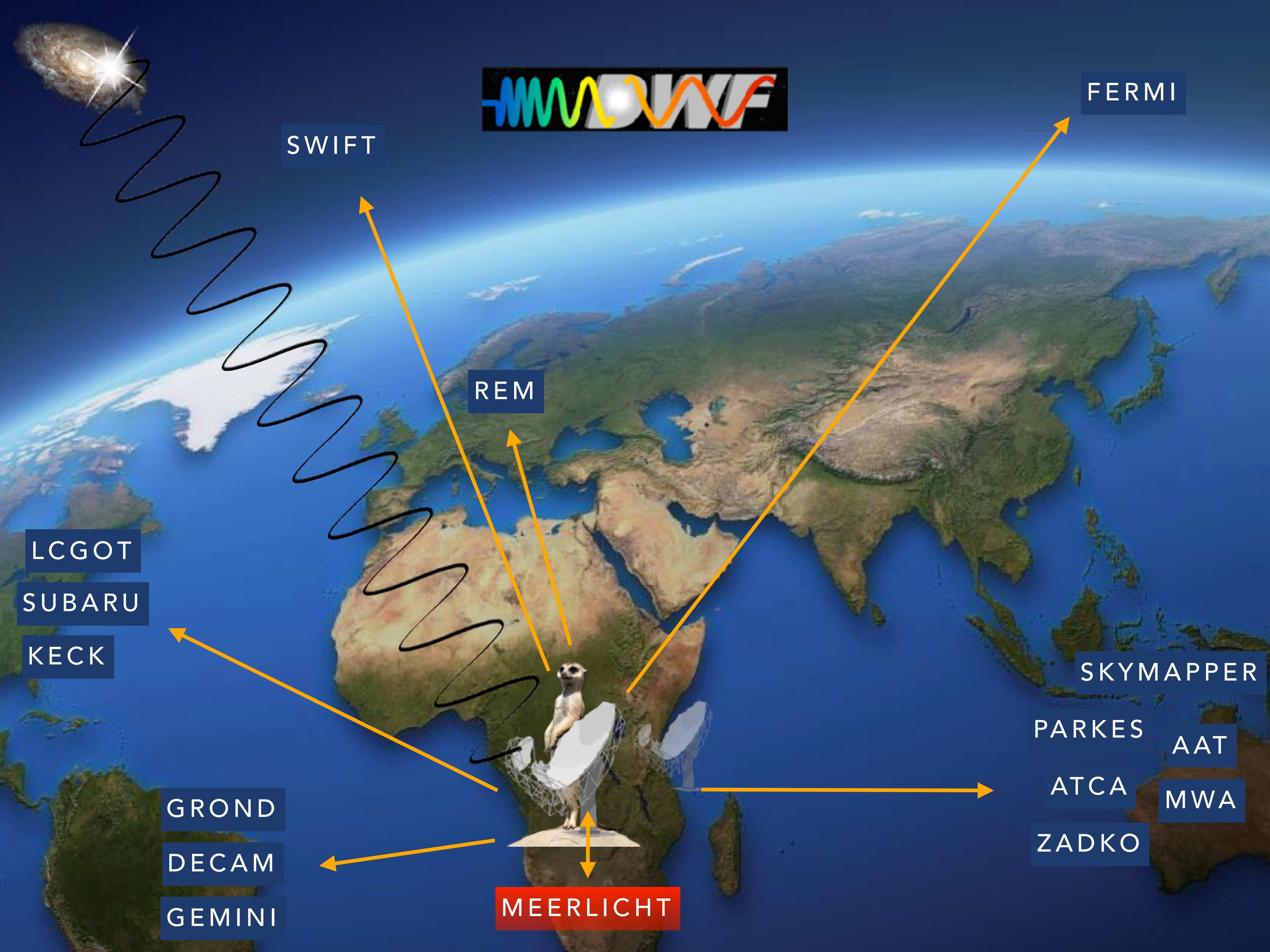
Bloemen et al. 2017

Present status

- Cheetah based single pulse search/periodicity search pipeline is under development
- Hardware tendered (procurement soon)
- On sky in the second half of the year

Where next?

- Definitely need to increase the population!!
- Is there more than one class of source population?
- What is their sky and luminosity distribution?
- Get host location, and even potentially location within host.
- Follow-up at multiple wavelengths.
- Can we use them as a cosmological probe?
- Independent distance estimation.
- MeerKAT can provide all of the above.


SWIFT
FERMI
REM
LCGOT
SUBARU
KECK
SKYMAPPER
PARKES
AAT
ATCA
MWA
ZADKO
GROND
DECAM
GEMINI
MEERLICHT

Summary

- MeerKAT is going to be an excellent instrument for pulsar and fast transient science.
- TRAPUM, the S-band system and MeerTRAP all combine to provide an excellent tool for FRBs and other fast transients too.
- The Fly's Eye mode of TRAPUM will find the very bright end of the luminosity distribution.
- The incoherent and coherent modes will probe different luminosity regimes.
- Total number of bursts of a couple of hundred with the majority with arcsecond or better localisation.
- Optical Monitoring with MeerLICHT.
- Follow-ups being set up across the spectrum.
- Measure accurate positions for the bursts to enable use as probes of IGM and for testing cosmological models.