MeerKAT: a South African star

Fernando Camilo
South African Radio Astronomy Observatory

SKA Days
19 June 2019

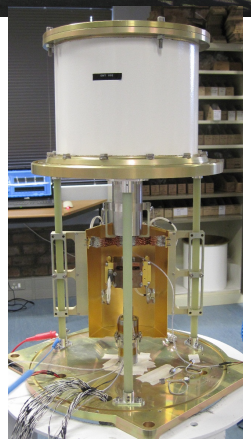


MeerKAT in the Karoo: SKA precursor





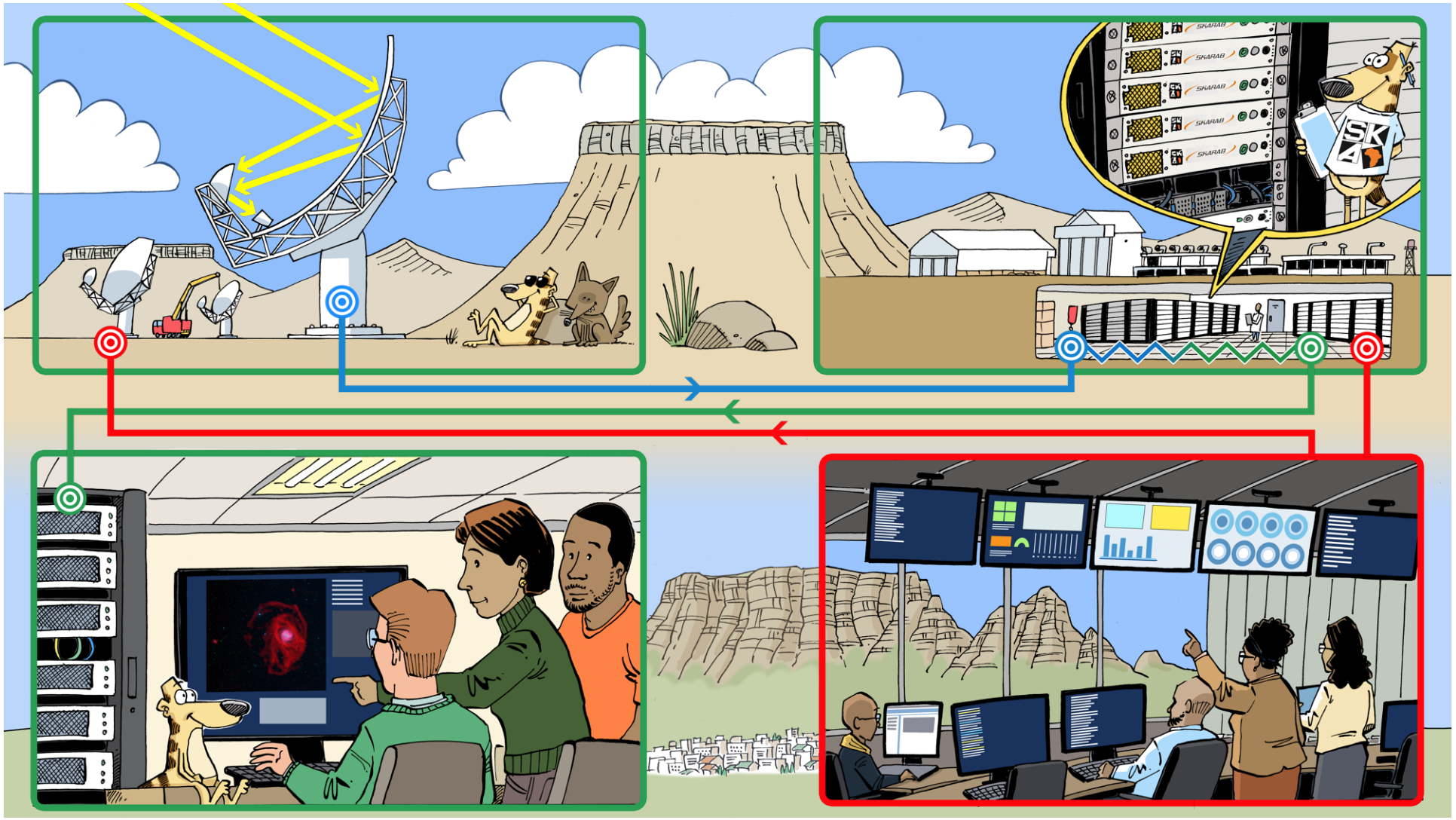





64 x 13.5-metre highly efficient **offset Gregorian dishes spread over 8 km** (~75% within ~1 km diameter); superb L-band receivers (**0.9–1.67 GHz**); also UHF (**0.58–1.0 GHz**) and S-band (**1.75–3.5 GHz** – by MPIfR)






SKARAB
SKARAB
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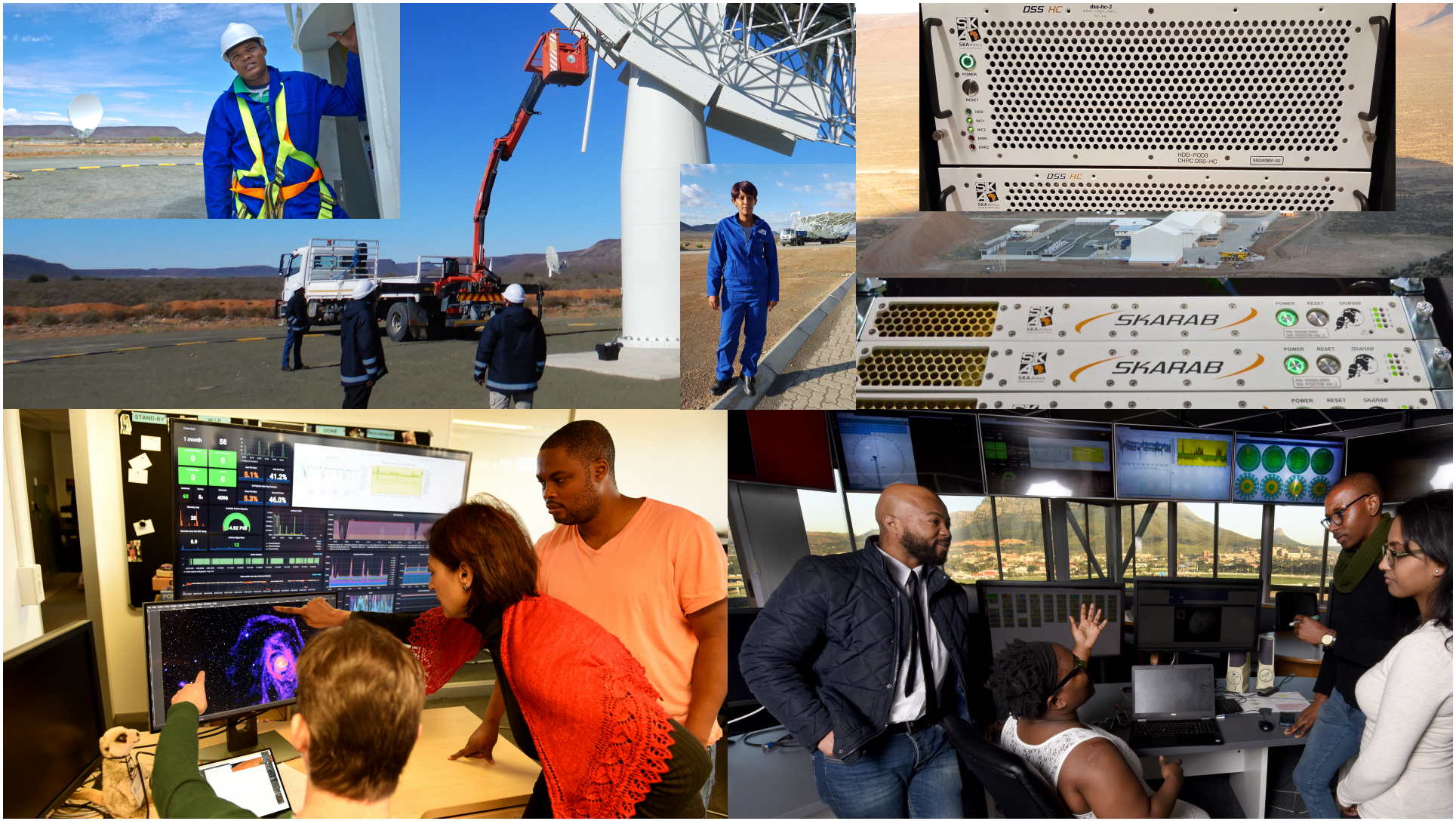
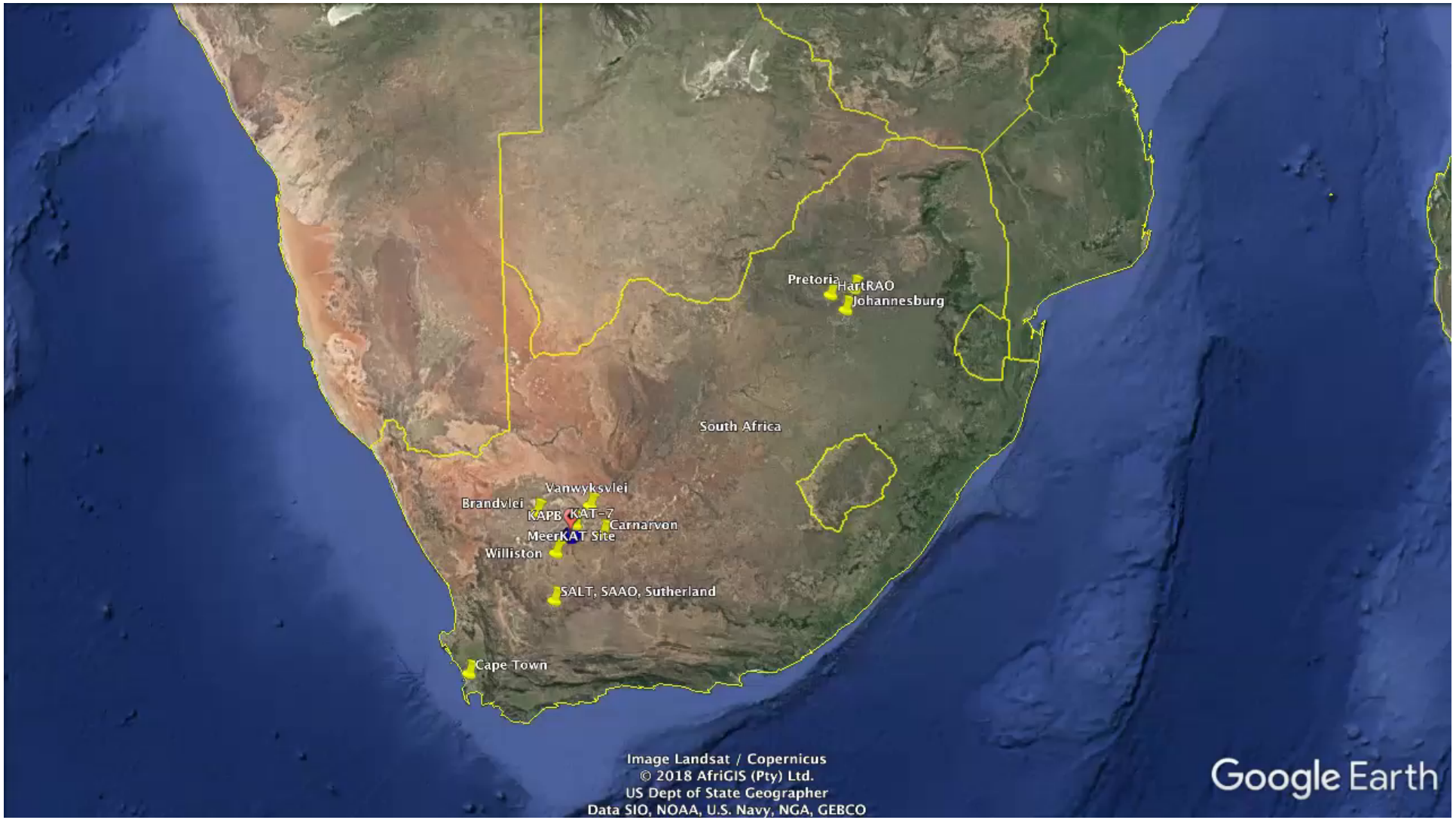
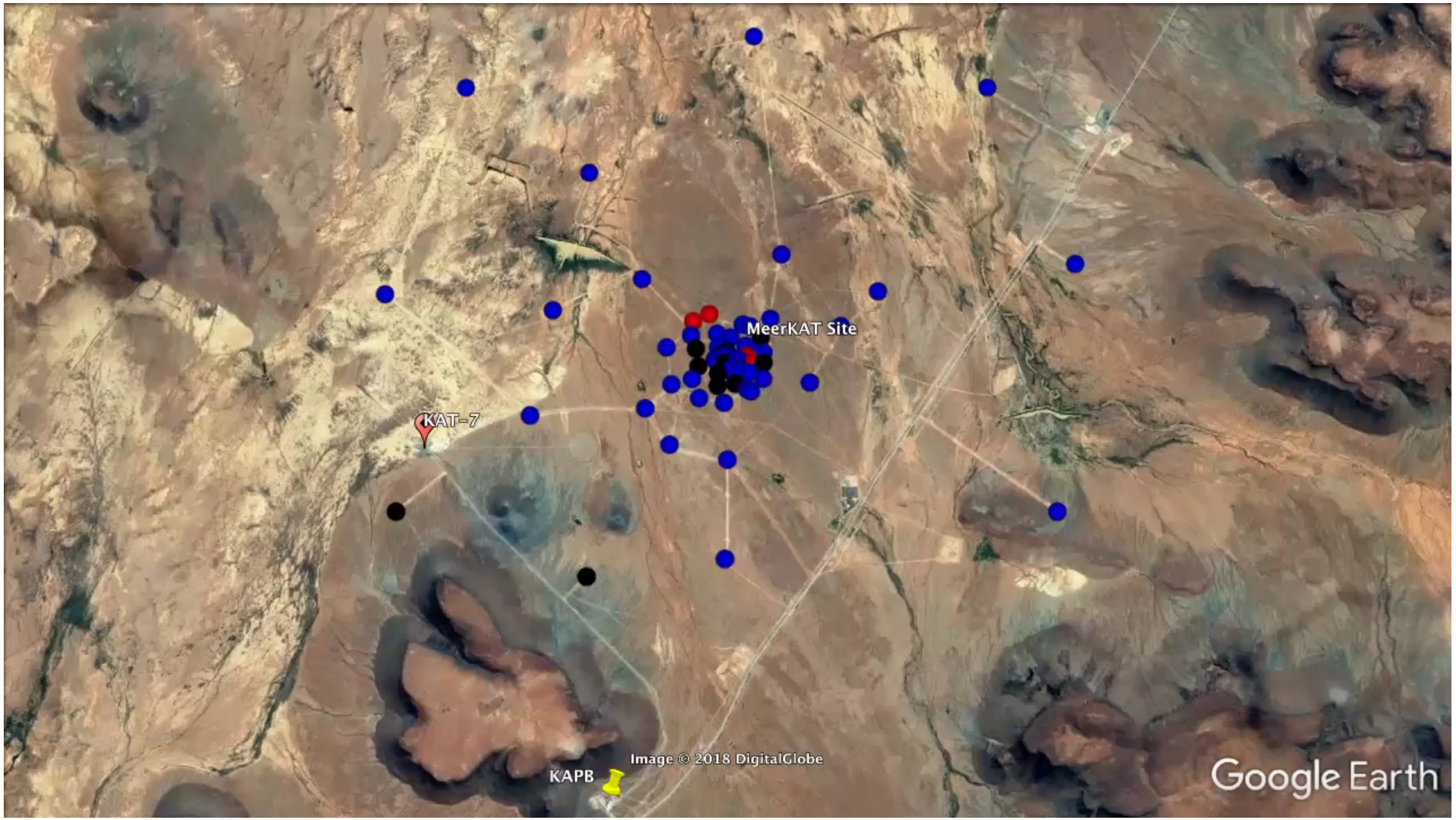
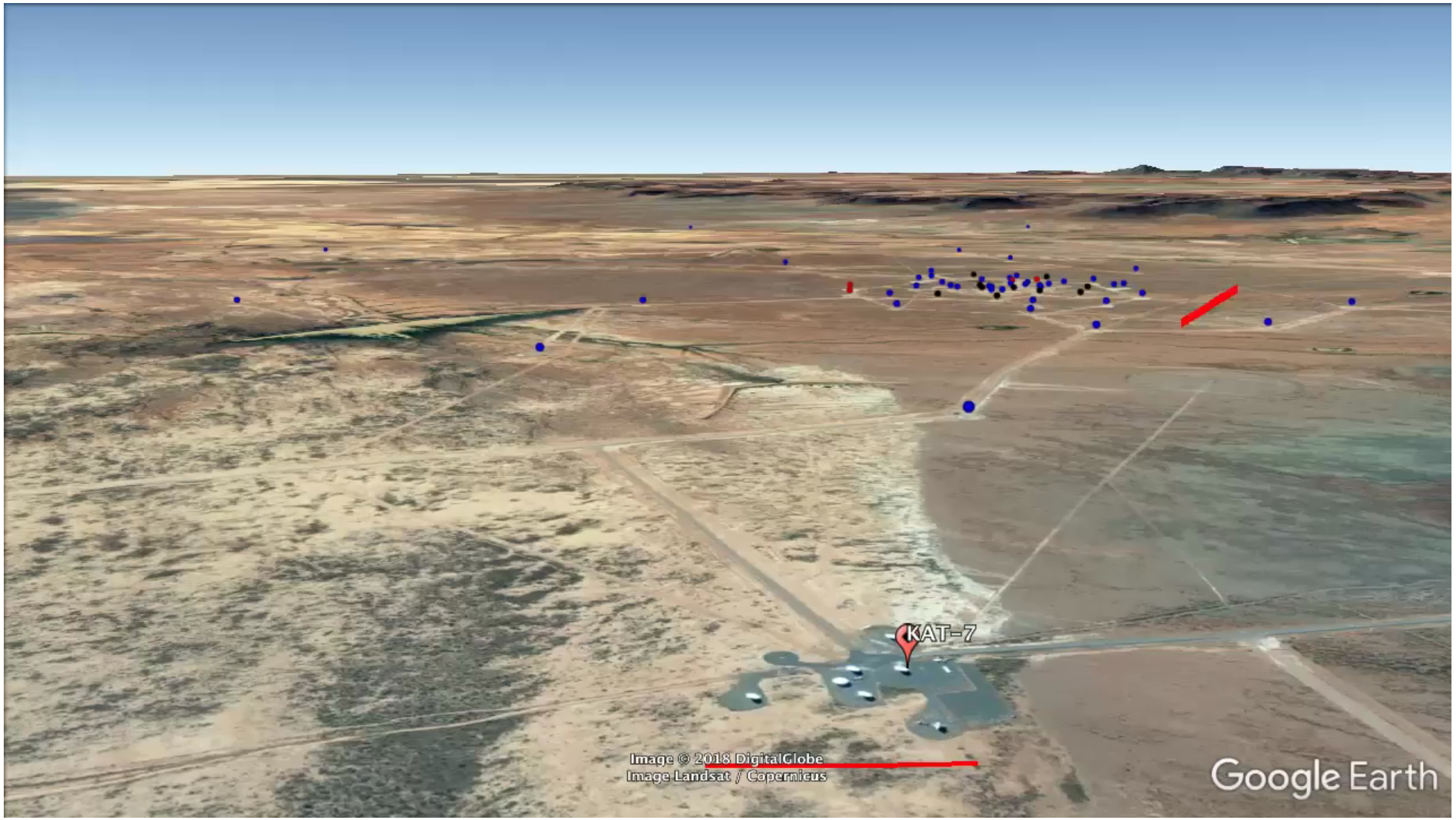
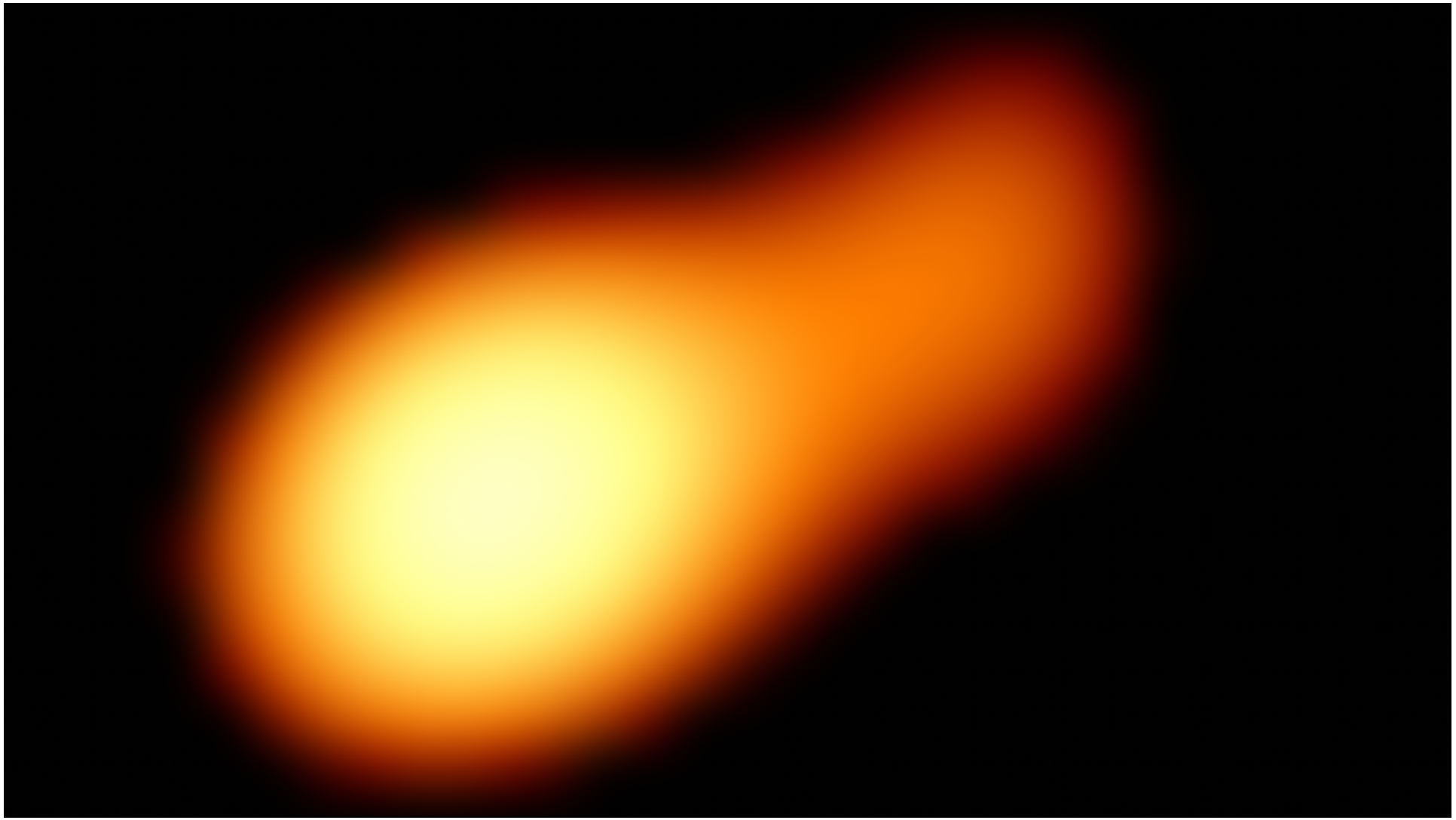
SKA

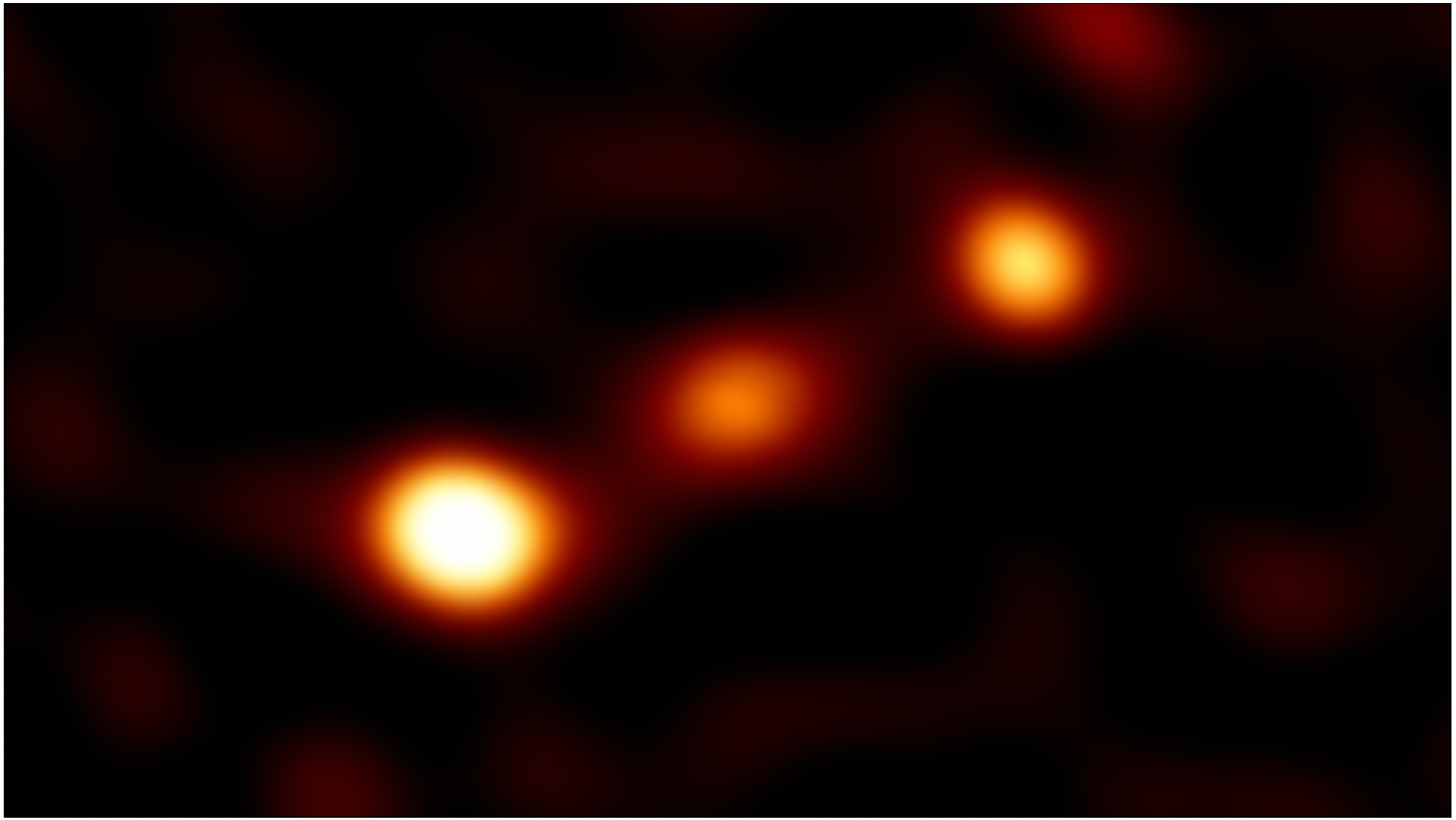

DSS HC
SKARAB
SKARAB
STAND-BY

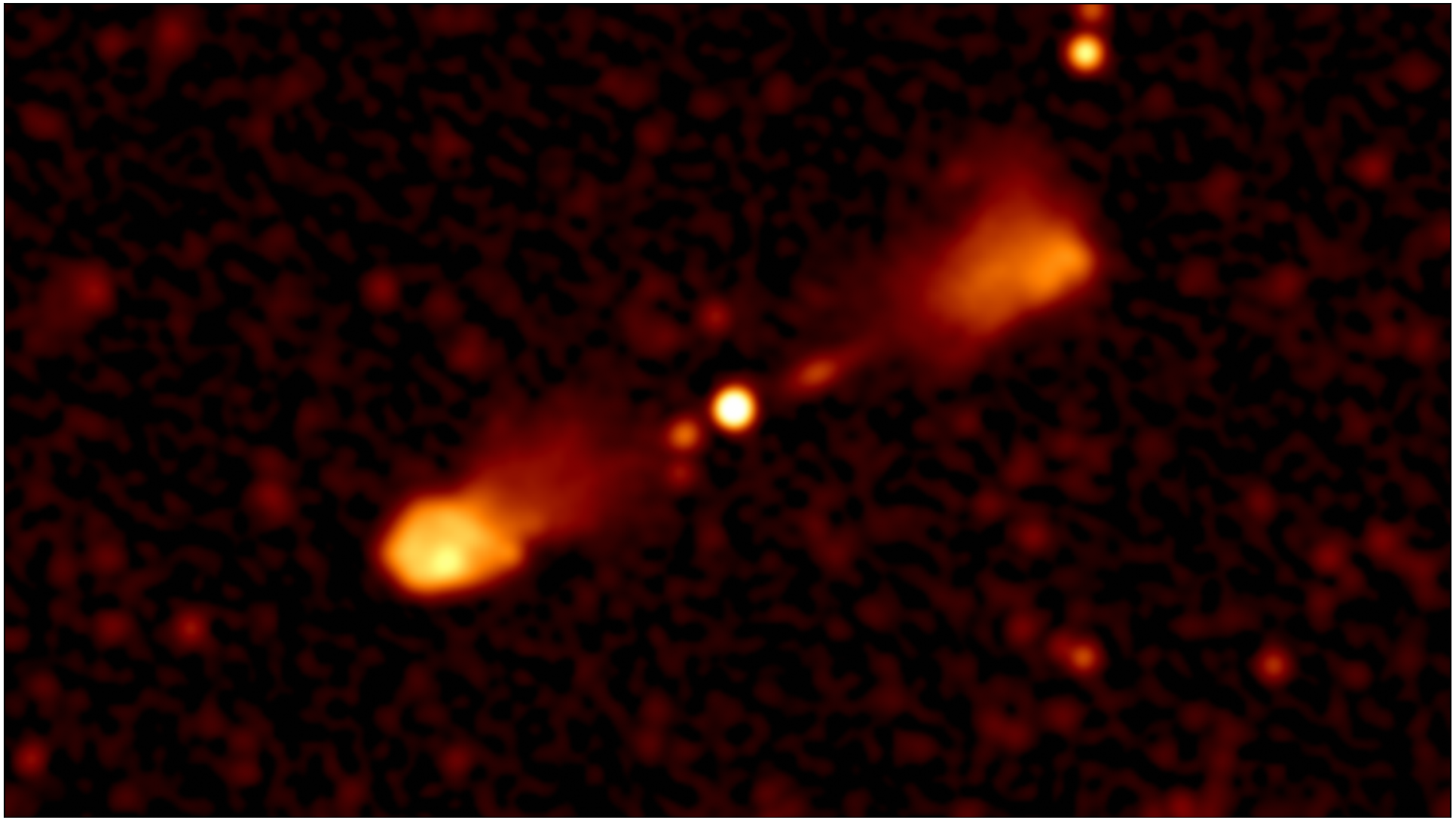

Pretoria
HartRAO
Johannesburg
South Africa
Vanwyksvlei
Brandvlei
KAPB
KAT-7
Carnarvon
MeerKAT Site
Williston
SALT, SAAO, Sutherland
Cape Town
Image Landsat / Copernicus
© 2018 AfriGIS (Pty) Ltd.
US Dept of State Geographer
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Google Earth

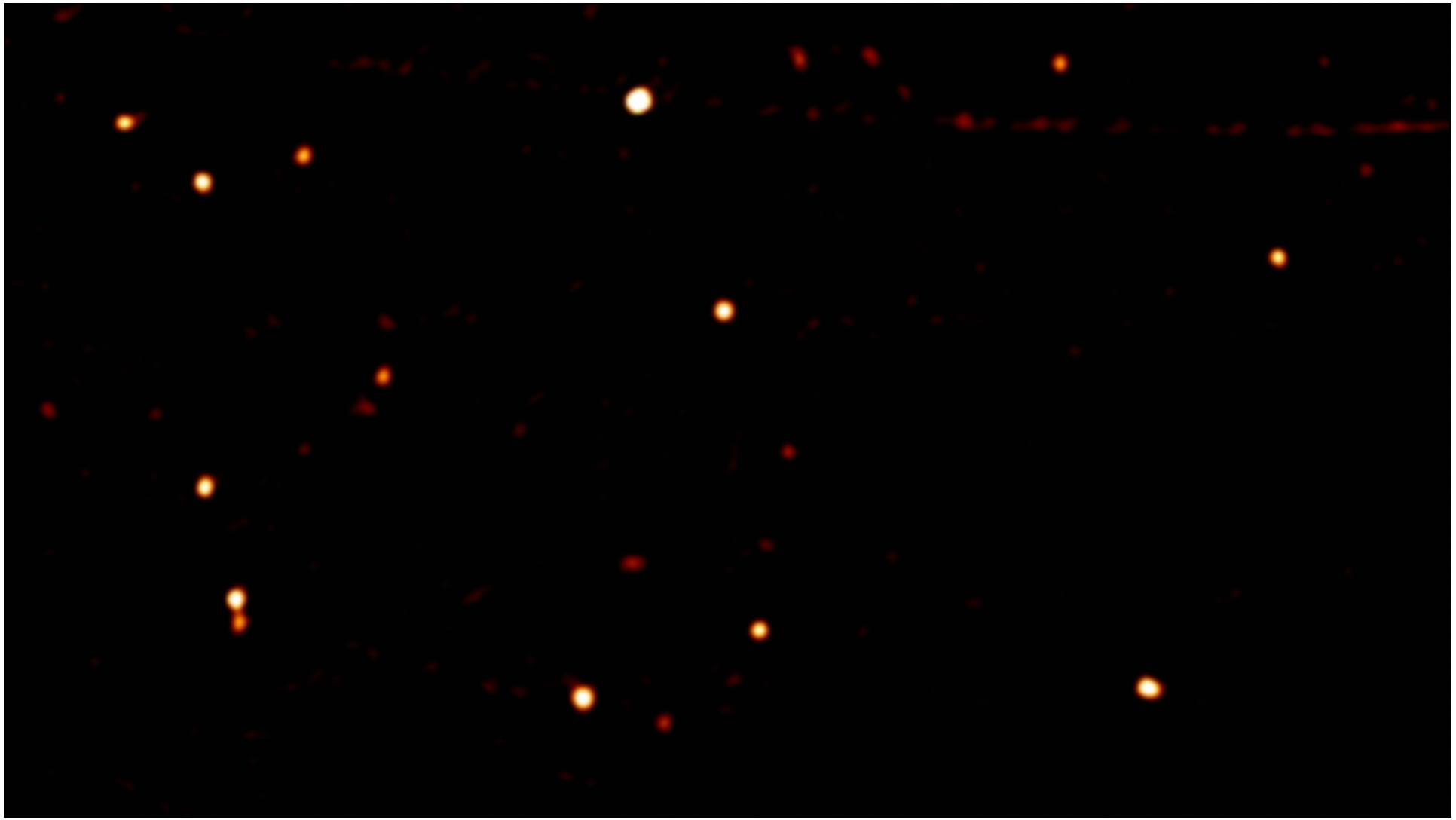

MeerKAT Site
KAT-7
KAPB
Image © 2018 DigitalGlobe
Google Earth

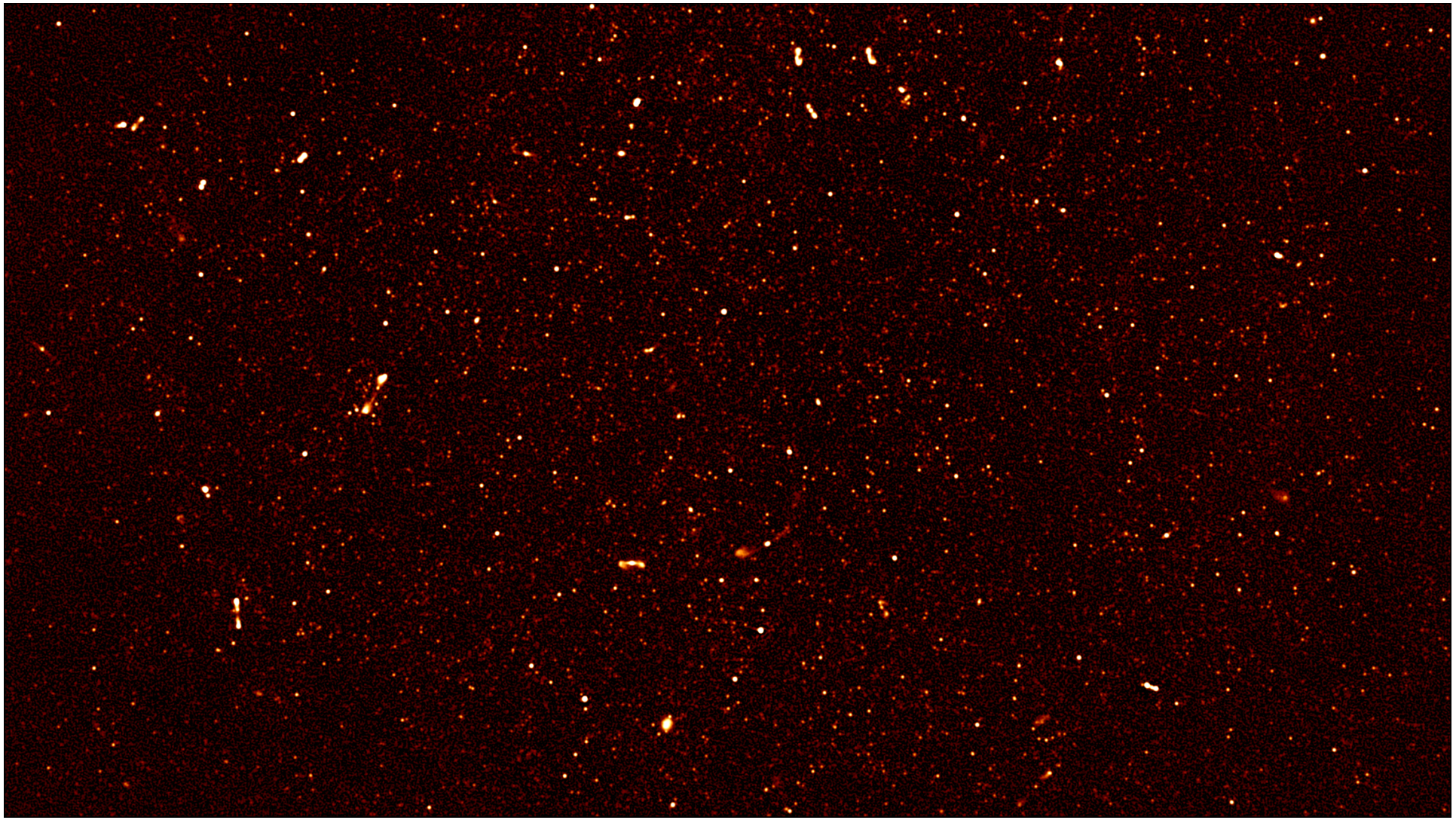

KAT-7
Image © 2018 DigitalGlobe
Image Landsat / Copernicus
Google Earth



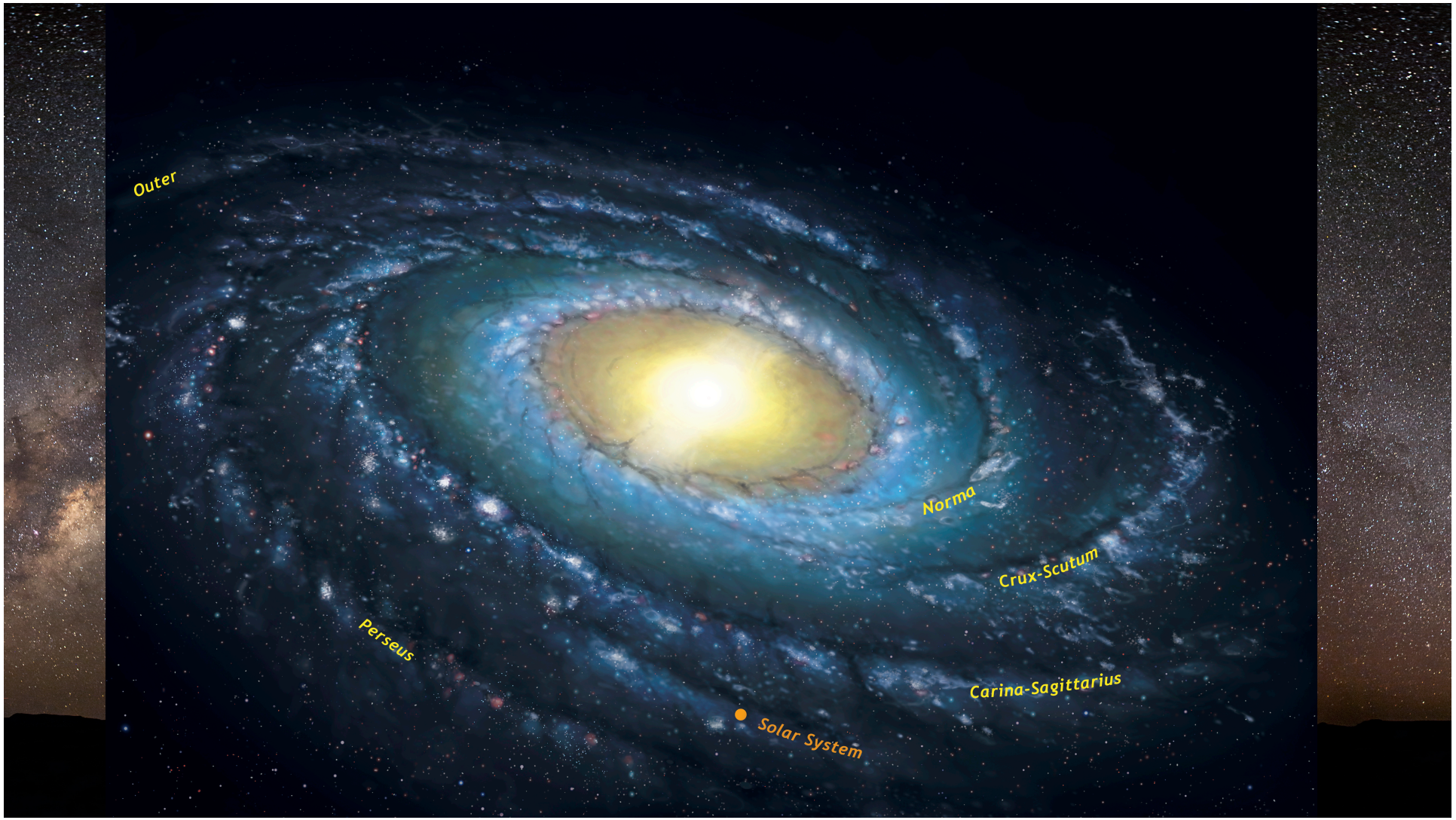


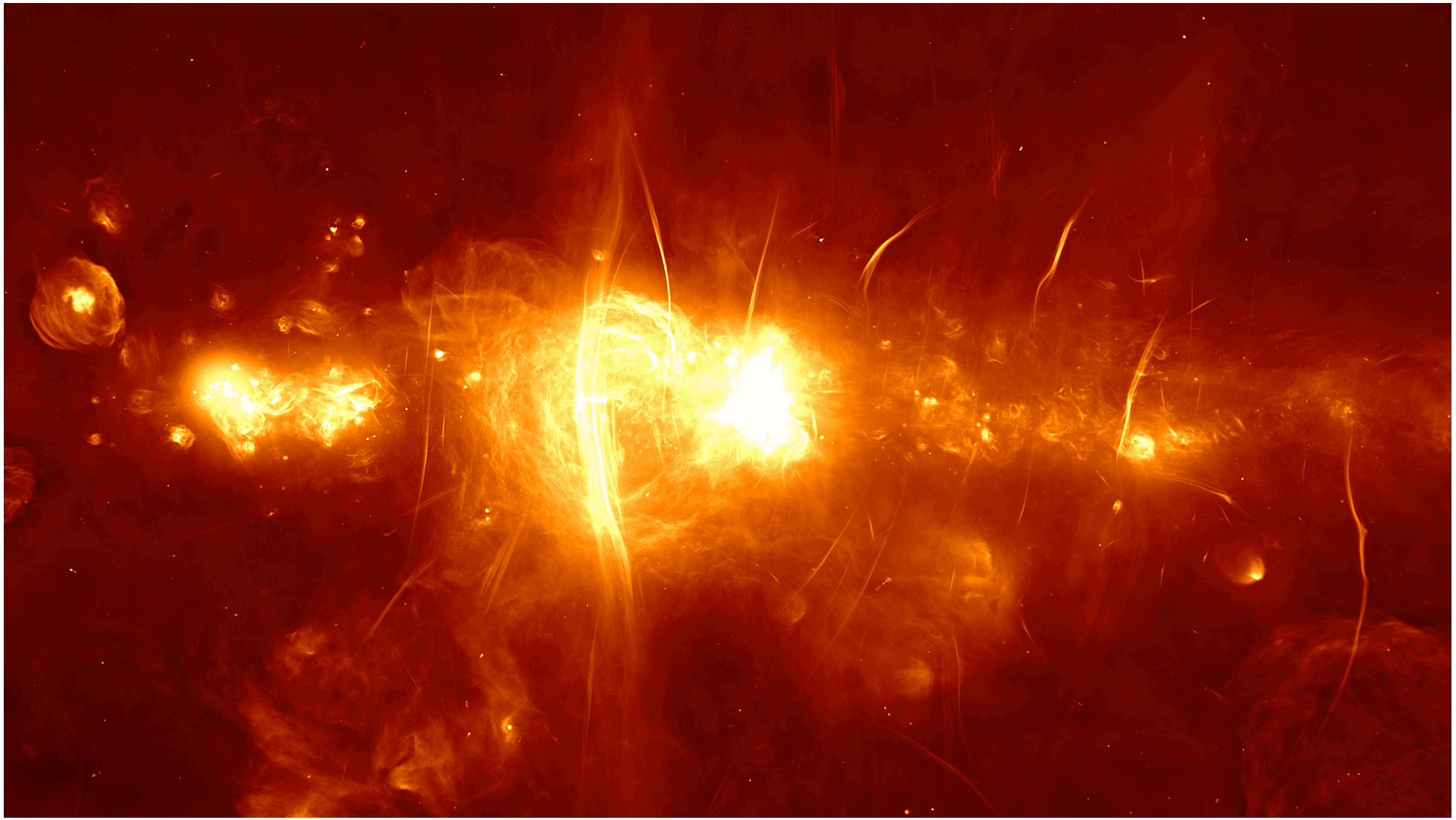


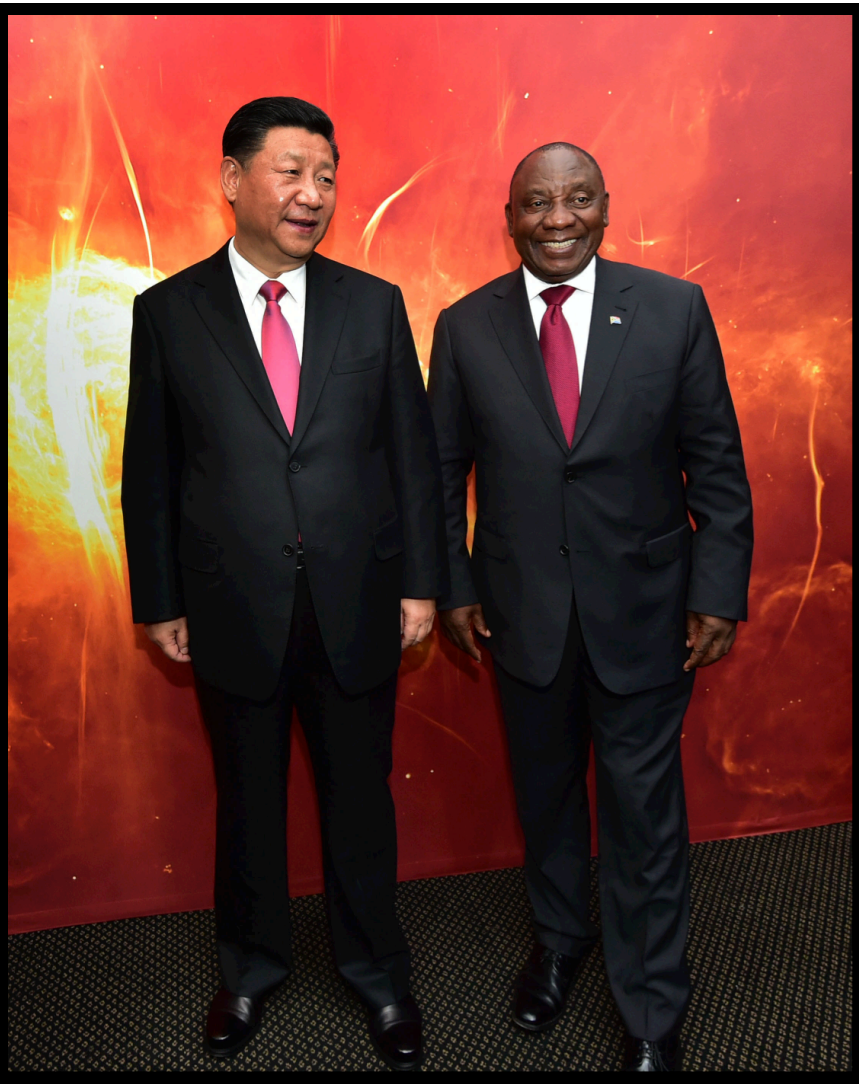


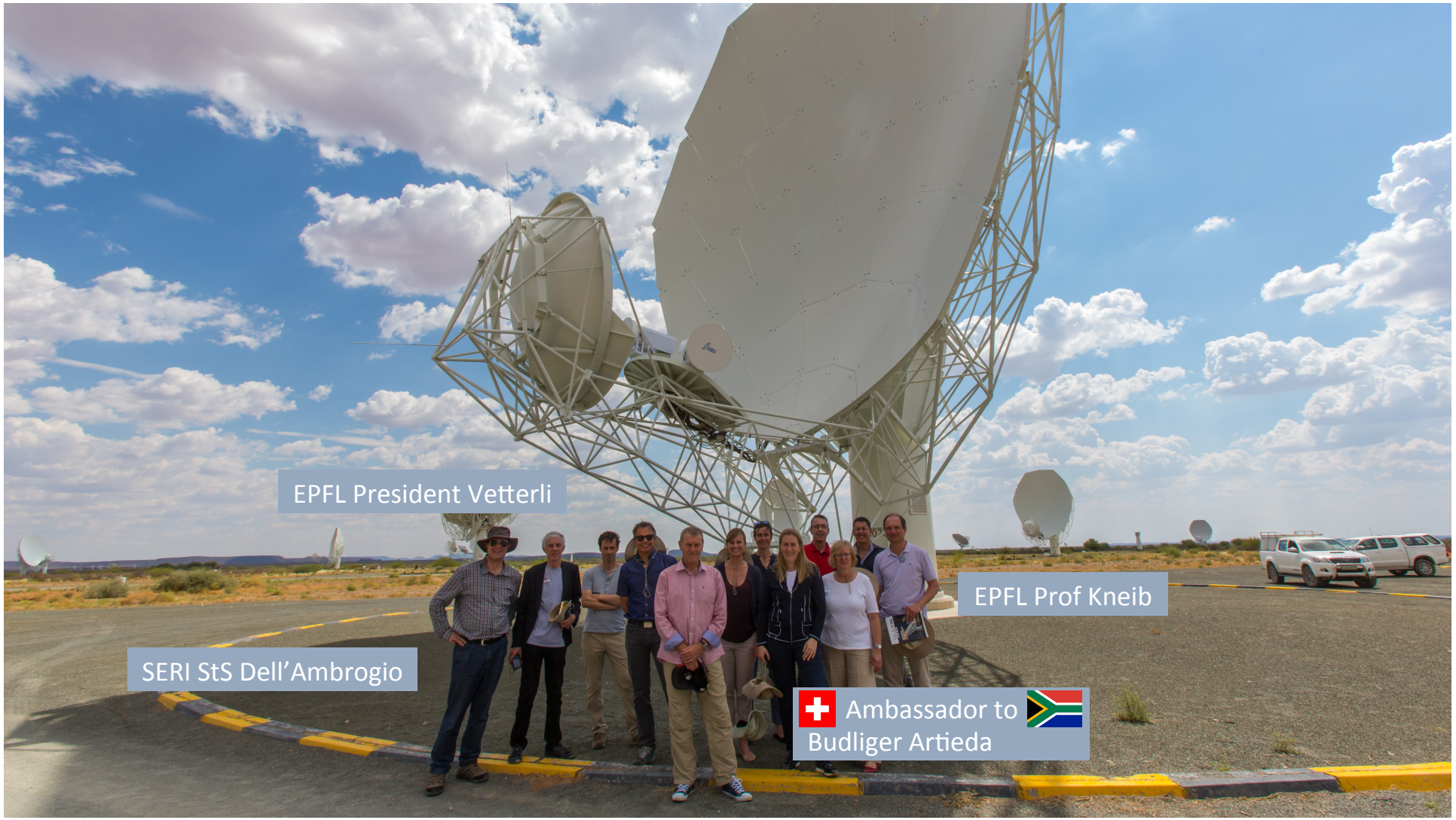




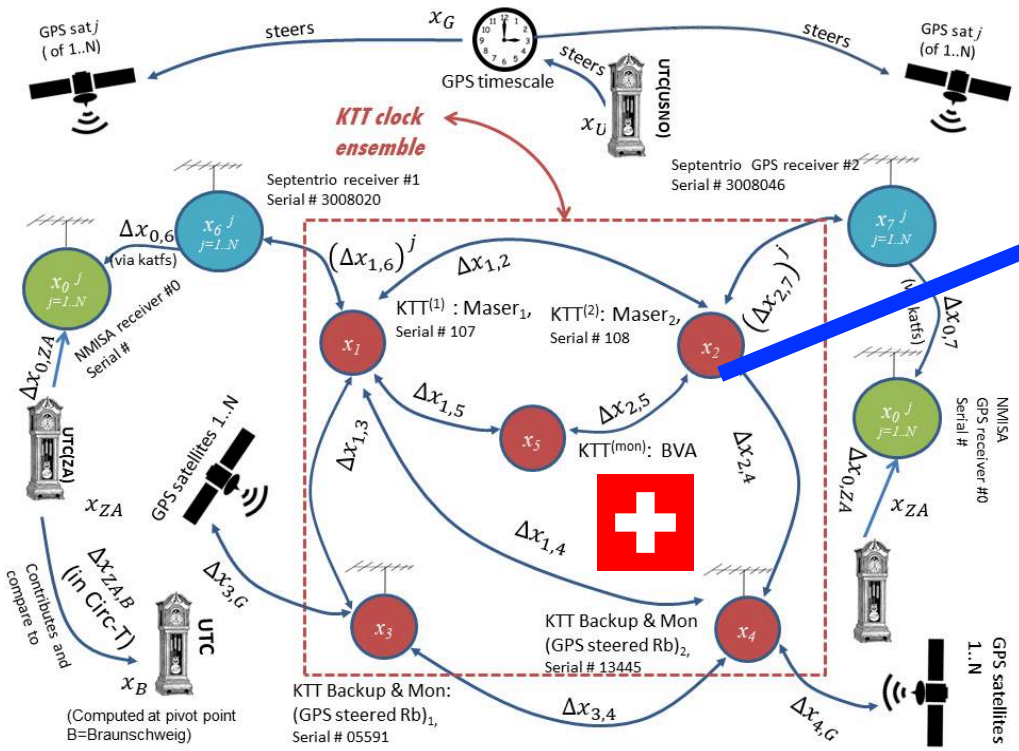

Outer
Norma
Crux-Scutum
Perseus
Carina-Sagittarius
Solar System

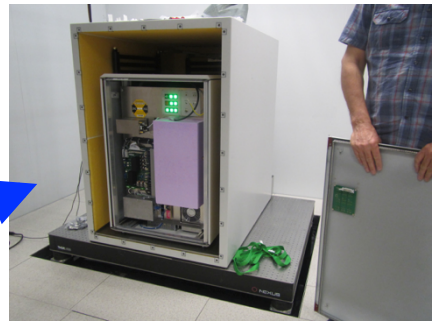





EPFL President Vetterli
EPFL Prof Kneib
SERI StS Dell'Ambrogio
Ambassador to
Budliger Artieda

Neuchâtel technology: key role in timing science – Karoo Telescope Timescale (KTT)





- Atomic clock ensemble: used to time events over 10+ years to ns level, and give pure sinewave to digitisers
- *T4Science* maser clocks: low vibration temperature controlled units – predictable drift, lowest phase noise clocks in the world?

Possibilities for SKA-MID era

KTT timescale uses 2 masers:

- Space for 4 masers
- Two *fully* redundant timescales?
- (Minimum of 3 called for in SKA-MID design)
- T4 designs compatible with infrastructure constraints



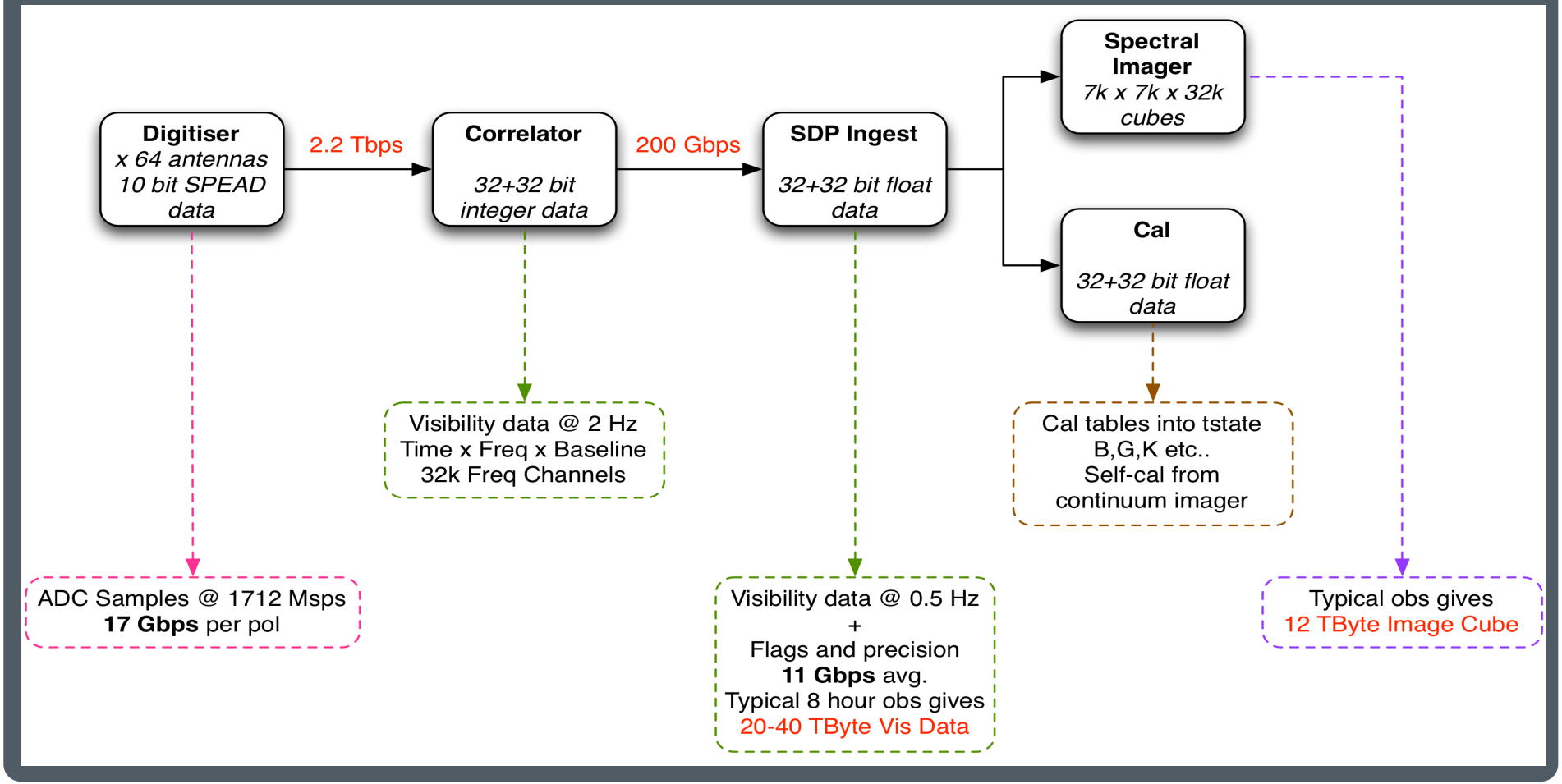
Specialized infrastructure for housing atomic clocks; time and radio frequency transmitting apparatus



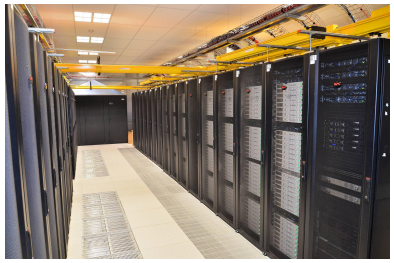


- SKA-MID design calls for antennas to receive approximation of UTC (Coordinated Universal Time)
- Swiss femtostepping technology can be used to provide simplest realization of ~UTC to telescope
- Compatible with 10 MHz used in KTT/MeerKAT

MeerKAT data rates



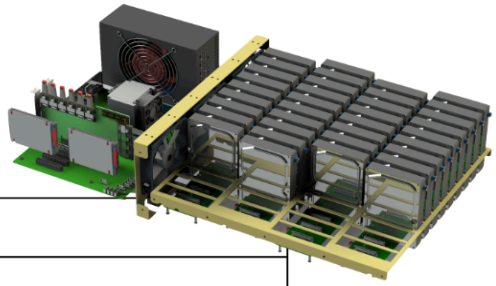
The MeerKAT correlator (SKARAB)





- Realtime DSP: fully reconfigurable Software Defined Radio (capable of concurrent full-band + ‘zoom’ correlation + beamforming on multiple subarrays)
- Uses 288 Xilinx 690T Virtex-7 FPGAs: processing elements (‘network attached accelerators’) reprogrammed and chained dynamically to form pipelines as required by science needs
- Processing elements interconnected using 40 Gb Ethernet (648-port full-mesh Mellanox crossbar switch; Clos architecture with 1U units)
- *All data multicast on network: any device can subscribe to any product*
- MeerKAT invites users to supply their own processing hardware, and interface to our Ethernet network (e.g., pulsar / transient searches, SETI)

Scale Challenge – Storage money



SP4000C	
KEY FEATURES	• 25 GbE (SFP+) • x48 SAS 3 connectivity
PROCESSOR	• Haswell-EP 4C Intel Xeon 4 core 3.7 GHz
MEMORY	• 64 GB per node
NETWORKING	• Mellanox Network Interface Card, 25GbE, Single-Port
DRIVE CONFIG	• 48 x 8TB HDDs • 2 x 512 GB nvme SSDs
FORM FACTOR	• 4U with 1500W PSU



Scale Challenge – Storage humans



3 tons of drives

Storage

Visibility data + Science products

Object store (CEPH): 20 PiB

Tape: 19 PiB

24 TiB image every 8 hours



5,760 screws to install

Consul

Prometheus

Grafana

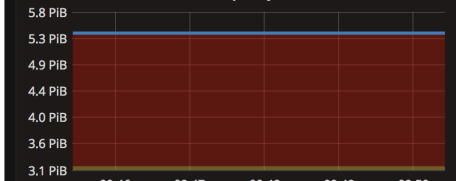


Status	Monitors In Quorum	Pools	Cluster Capacity	Used Capacity	Available Capacity
HEALTHY	3	11	5.42 PiB	2.241 PiB	58.62%

OSDs IN	OSDs OUT	OSDs UP	OSDs DOWN	Agerage PGs per OSD	Agerage OSD Apply Latency	Agerage OSD Commit Latency	Average Monitor Latency
777	8	777	8	100	755 µs	755 µs	N/A

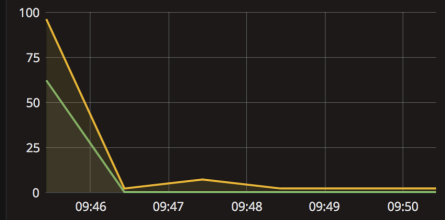
CLUSTER

Capacity



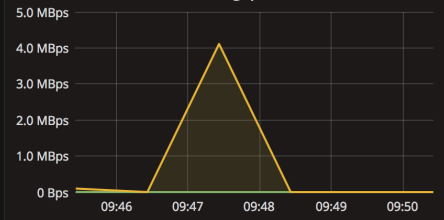
	min	max	avg	curr
Available	3.175 PiB	3.175 PiB	3.175 PiB	3.175
Used	2.241 PiB	2.241 PiB	2.241 PiB	2.241
Total Capacity	5.415 PiB	5.415 PiB	5.415 PiB	5.415

IOPS



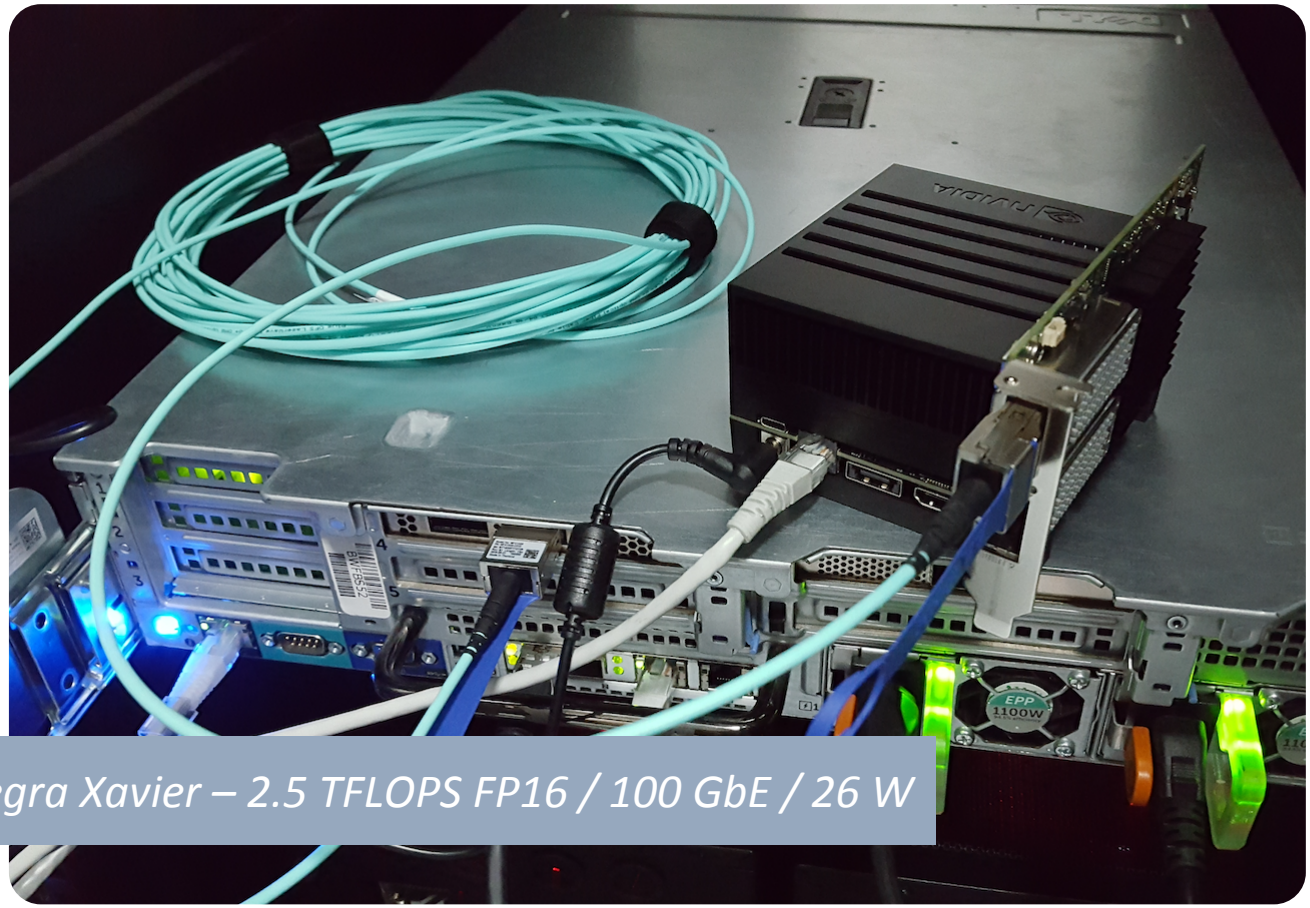
	min	max	avg	current
Write	0	62	10	0
Read	2	96	19	2

Throughput



	min	max	avg	current
Write	0 Bps	0 Bps	0 Bps	0 Bps
Read	839 Bps	4.110 MBps	702 kBps	1 kBps

Future Challenge – Power



Tegra Xavier – 2.5 TFLOPS FP16 / 100 GbE / 26 W

Future Challenge - Convergence

4 x 100GbE + FPGA = NIC is the Correlator





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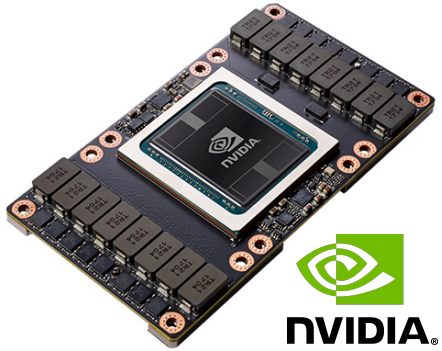
(?)



2 x 100GbE + GPU = NIC is the Imager

The MeerKAT science programme

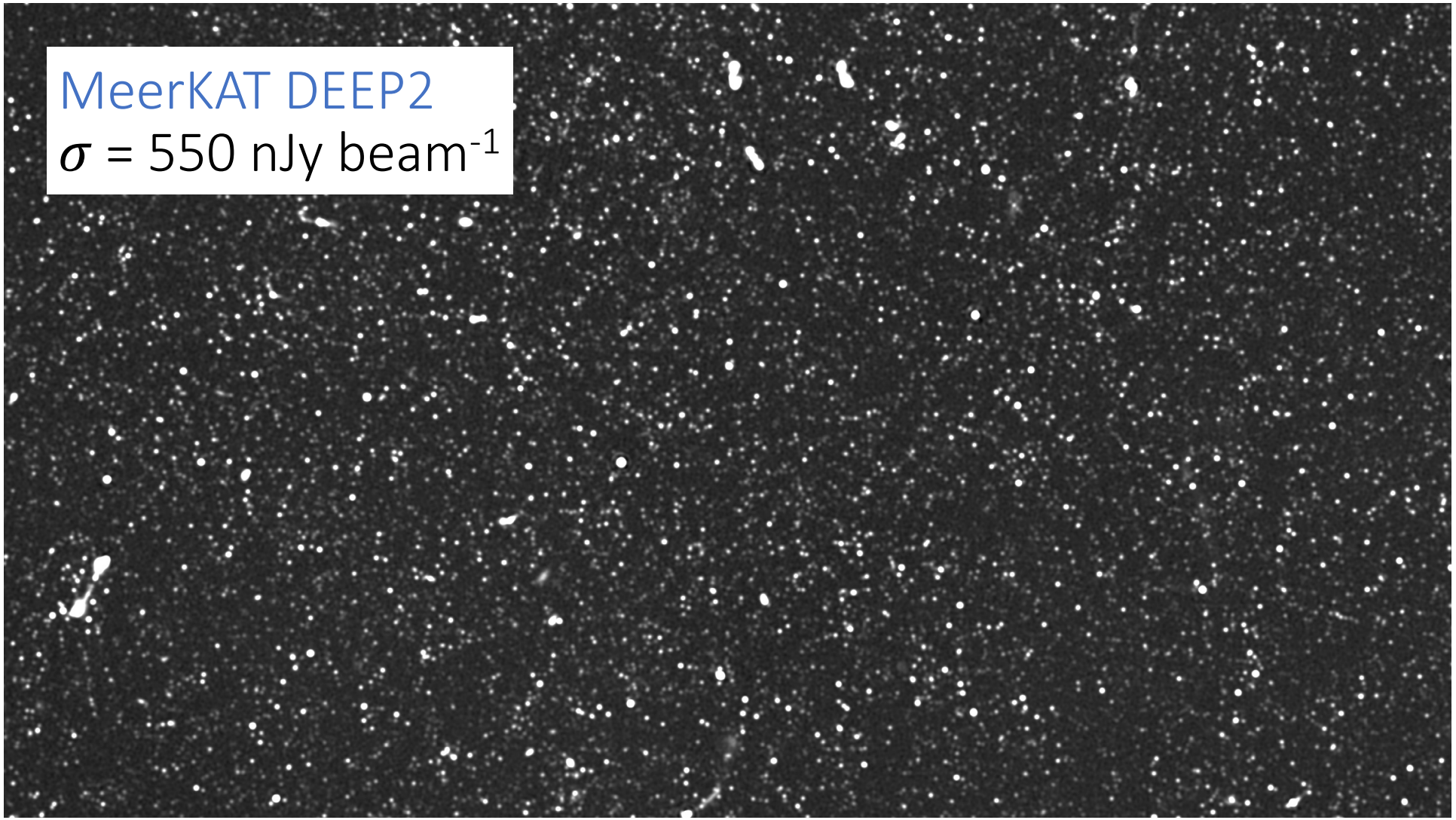
- 2010: Call for scientific proposals by SKA South Africa results in 10 approved “Large Survey Projects” (LSPs, requiring >1000 hours of MeerKAT observing time over 5 years)
- 2016: MeerKAT is a different telescope than planned in 2010, and science has evolved
- SKA SA requested 8 LSPs to submit revised project plans; reviewed in 2017
- 64 dishes operational since April 2018 (plus continued development of capabilities)
- 2/3 of telescope time to be used by LSPs, remaining “open time” for other projects (2019: 1st Open Time call resulted in 38 approved SA-led proposals)
- Eventually, MeerKAT will be integrated into the SKA-MID telescope



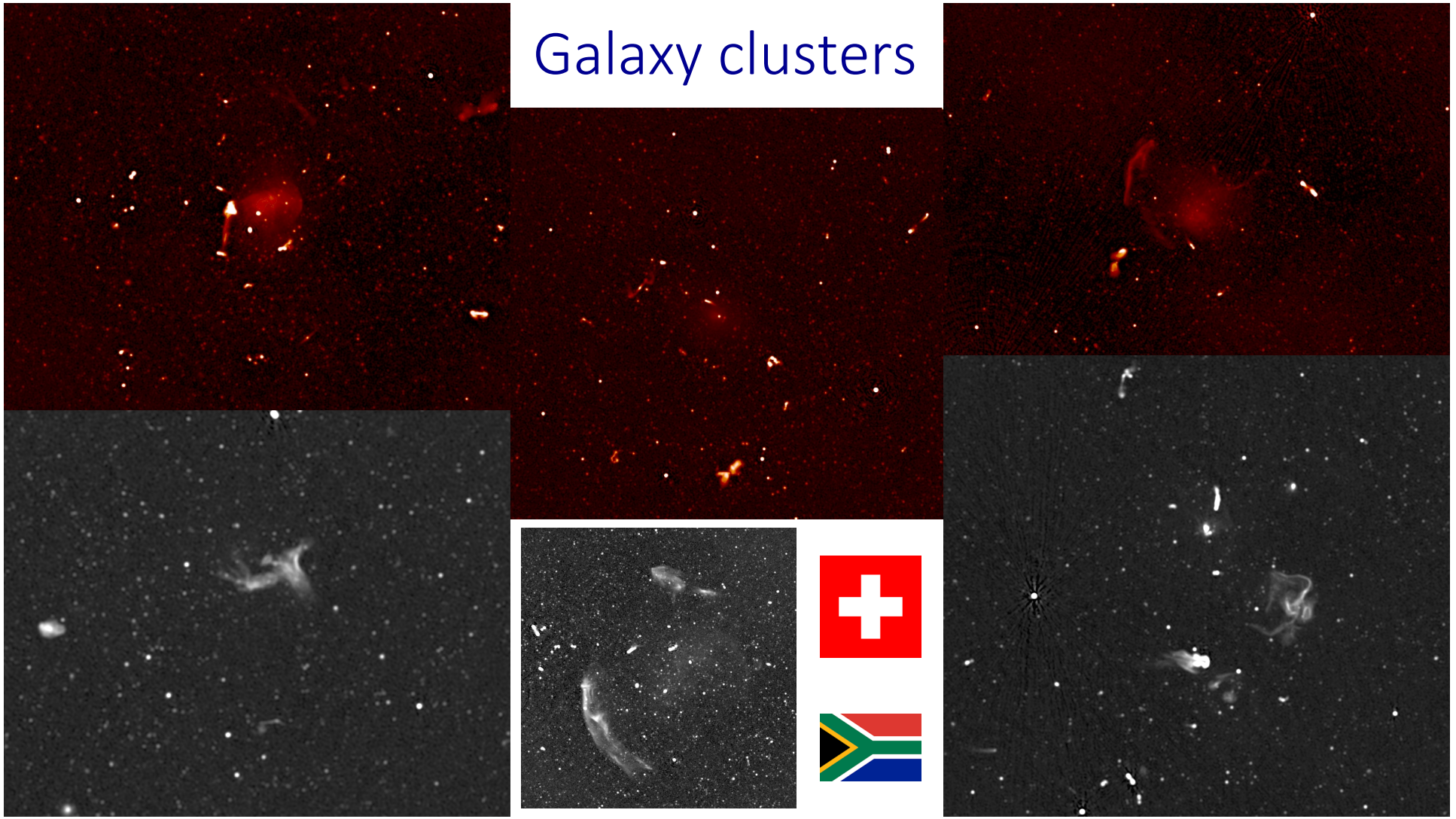
Approved MeerKAT LSP programme

- Pulsar timing
- Deep neutral hydrogen (HI) studies in 30 isolated nearby galaxies; and in Fornax cluster
- Ultra-deep HI survey
- Pulsar searches
- Explosive / accreting transient studies
- Deep continuum / polarimetry survey in 4 fields
- Absorption line survey

MeerTIME Binary	1440
MHONGOOSE	1650
MeerTIME MSP	2160
LADUMA: L-band ECDFS	333
LADUMA: UHF ECDFS	3091
FORNAX Fornax	900
TRAPUM Fermi sources	338
MeerTIME 1000 PSR array	720
ThunderKAT CVs	250
MIGHTEE ELAIS-S1	134
MIGHTEE XMMLSS	384
MIGHTEE COSMOS	19
MIGHTEE ECDFS	442
ThunderKAT GRBs	330
MeerTIME Globular clusters	1080
MALS UHF	858
MALS L-Band	794
TRAPUM: nearby galaxies	226
TRAPUM: GCs	320
TRAPUM: SNR PWN TeV Galactic Centre	92
ThunderKAT: SNe Ia	200
MIGHTEE: Sband COSMOS	306
MIGHTEE: Sband ECDFS	642
ThunderKAT: (XRBs)	500
Total	**17209**

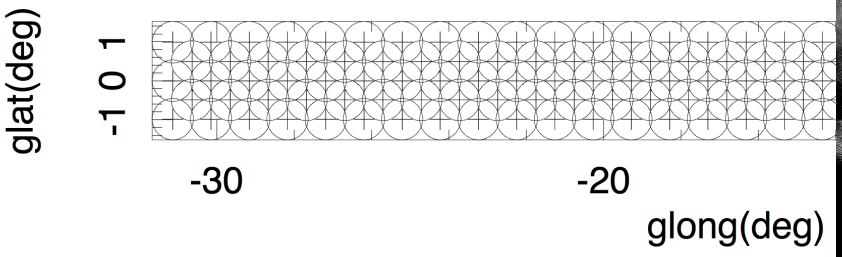

MeerKAT DEEP2
σ = 550 nJy beam^{-1}

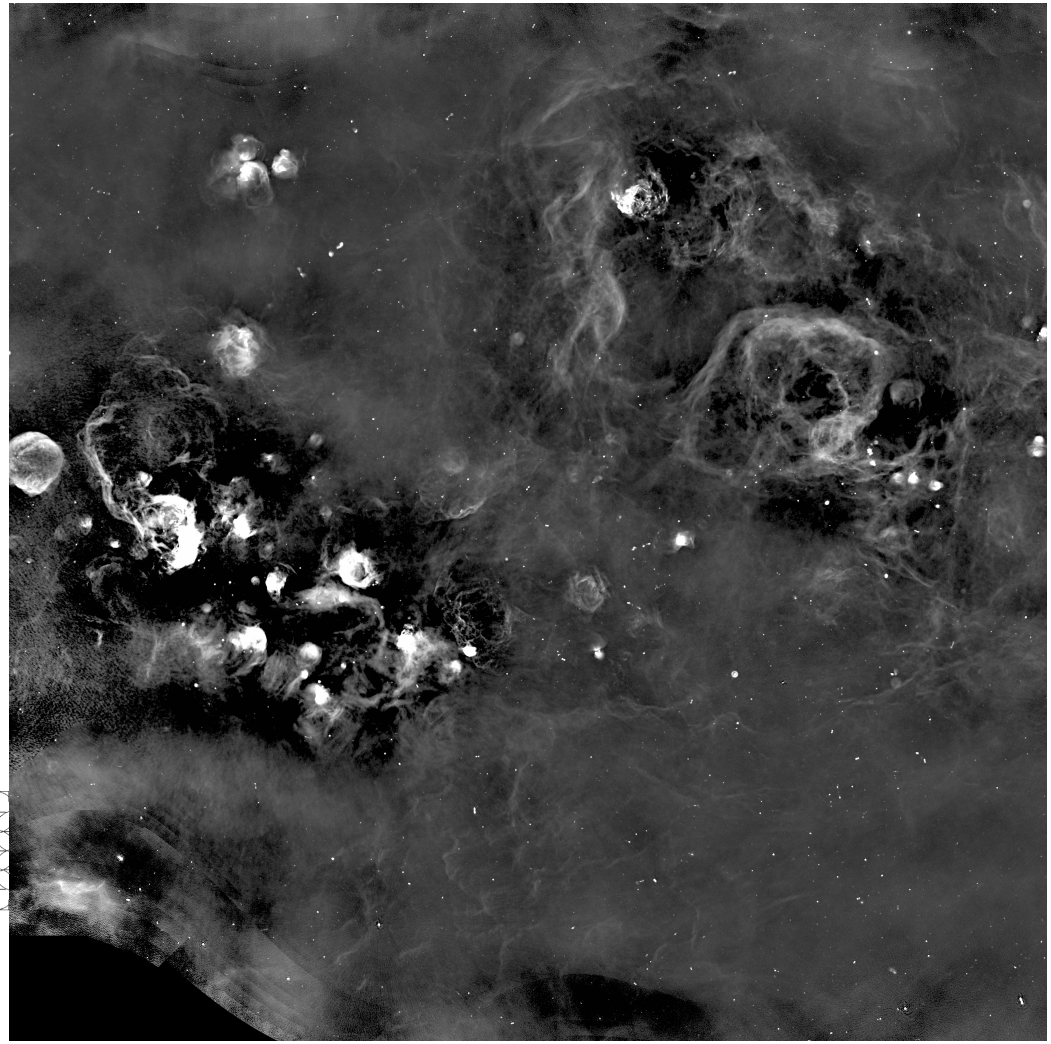
Galaxy clusters

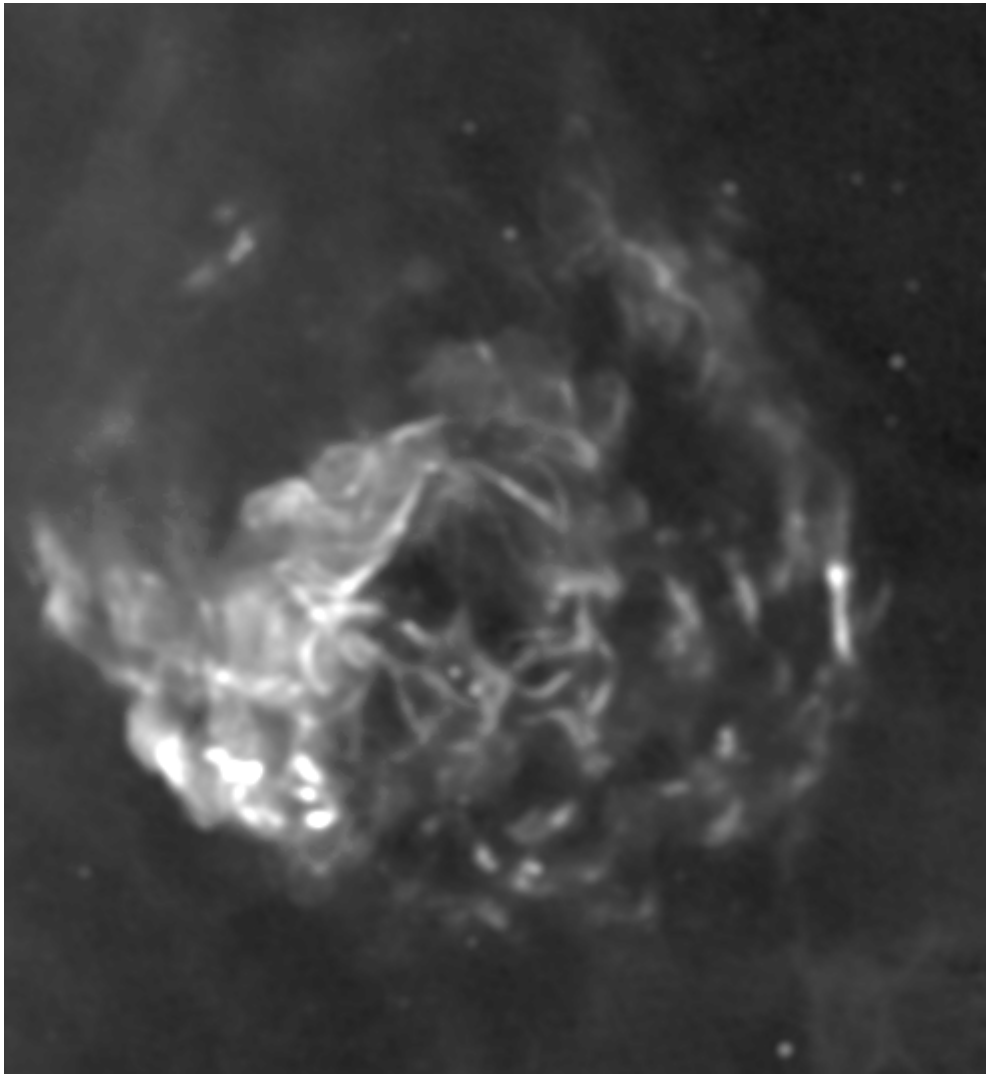


Galactic plane survey

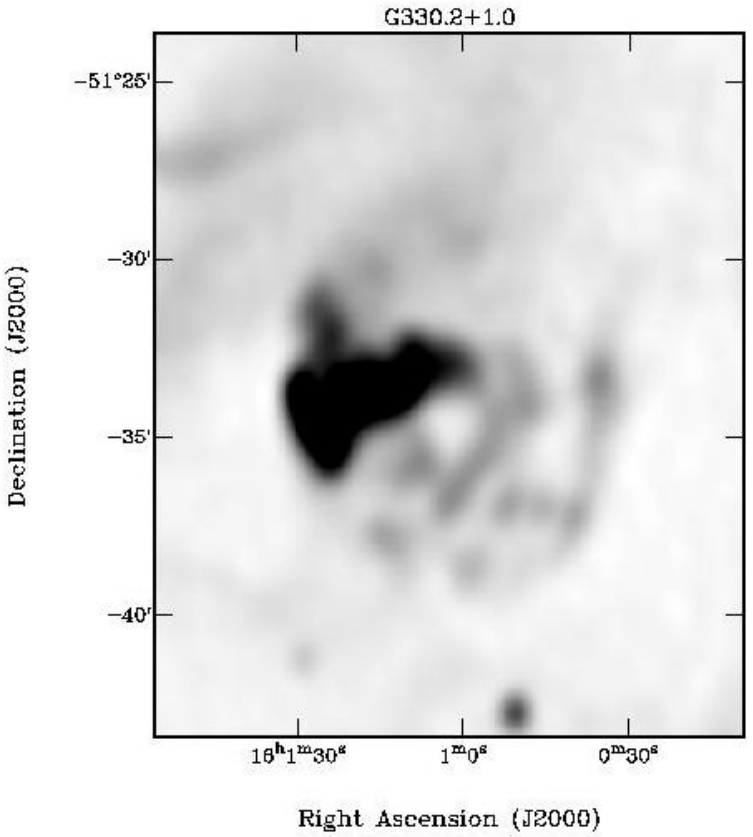
- 4th quadrant, |b|<1.5 deg
- 9-point mosaic observing
- ~1 hour on source per position
- Stitched in 3x3 deg^2 images
- *Excellent to develop imaging s/w and also for Galactic science*

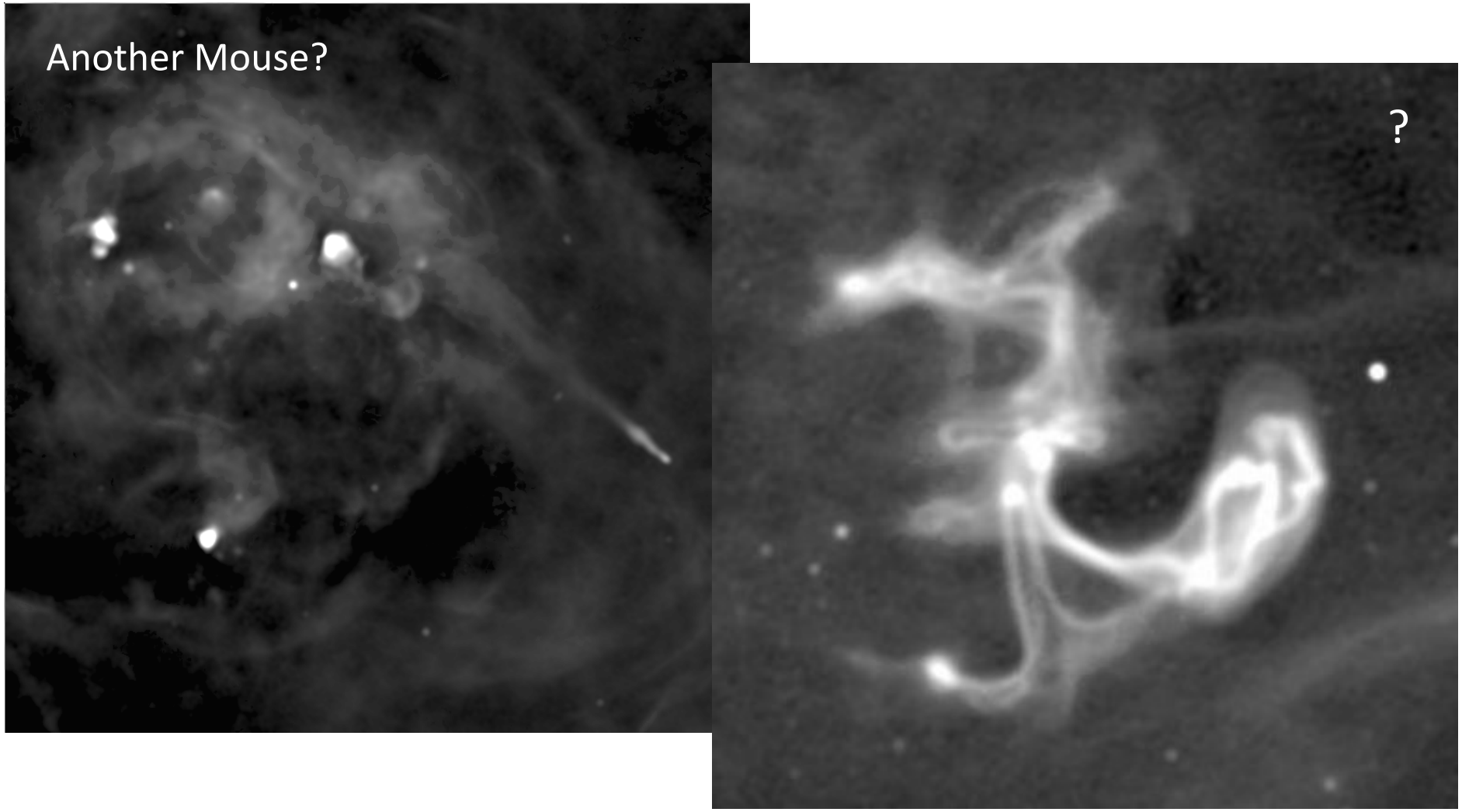






MOST Supernova Remnant




Another Mouse?
?

In conclusion

- MeerKAT is operational, doing initial science
- Lots of work remains to be done, to develop new capabilities
- MeerKAT has significant Swiss content
- Opportunities for increased interactions, both technical (timing, DSP / storage, SRCs) and scientific (multi-wavelength observing projects, data science)
- All of this on the way to SKA…

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science & technology

Department:
Science and Technology
REPUBLIC OF SOUTH AFRICA



SARAO
South African Radio Astronomy Observatory



Thank you

Grazie

Engraziel fetg

Merci

Danke