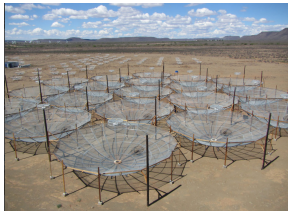






SKA AFRICA
SQUARE KILOMETRE ARRAY

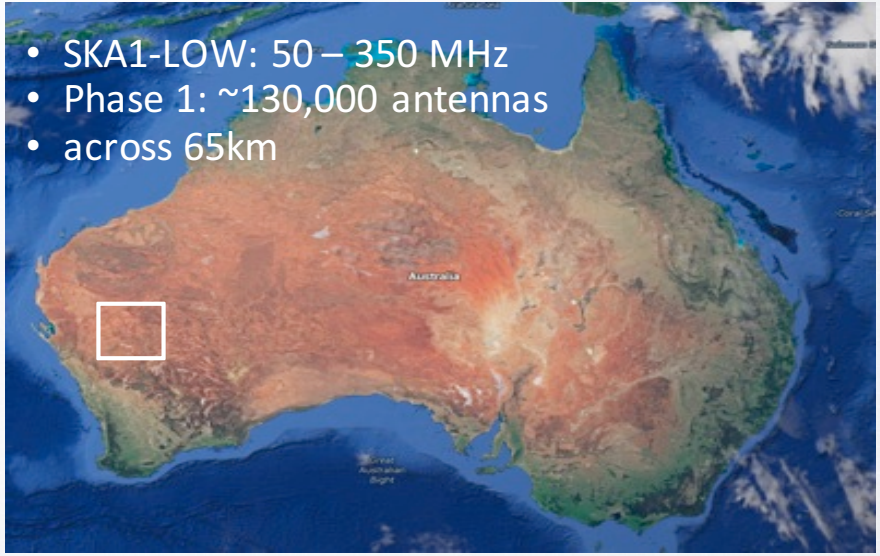
MeerKAT: Progress and Plans

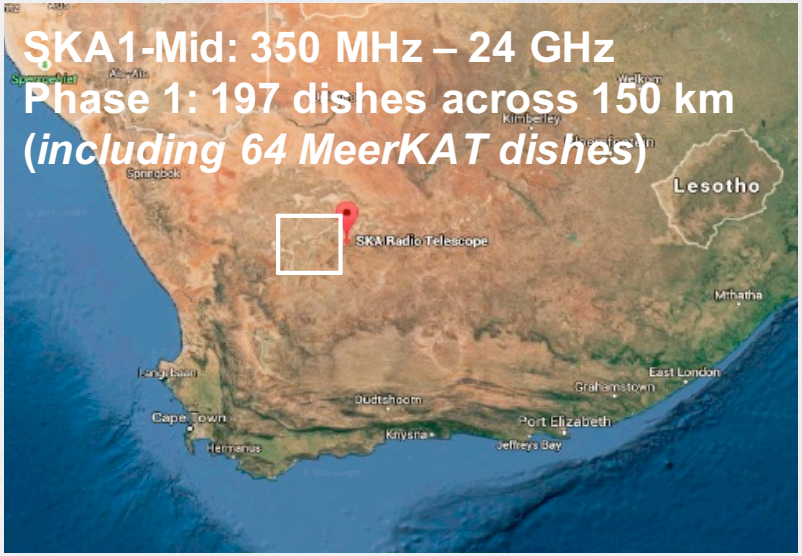
SWISS SKA DAYS: 11 JUNE 2018

Oleg Smirnov
(on behalf of SKA South Africa team)

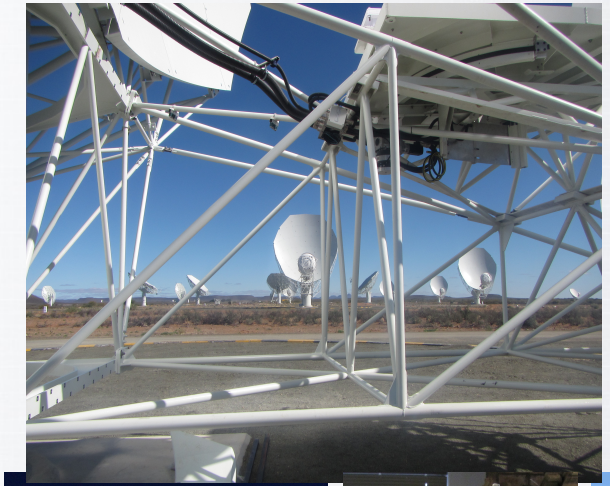
The Square Kilometre Array (SKA)

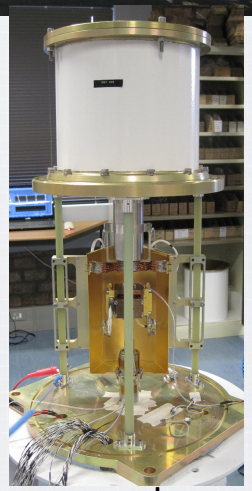
HQ in UK; telescopes in AUS and RSA





MeerKAT in the Karoo: SKA precursor under construction



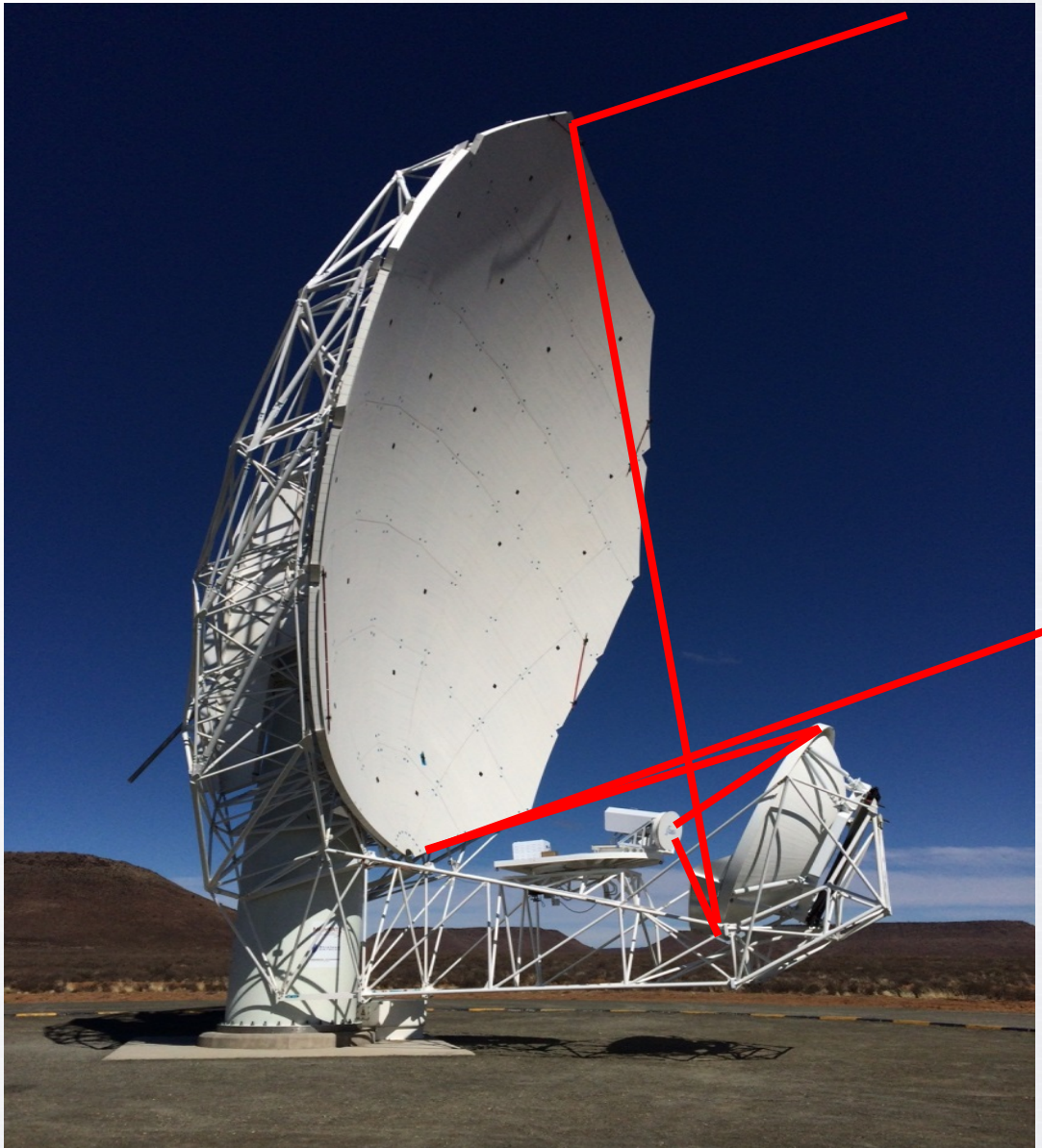


64 x 13.5-metre highly efficient offset Gregorian dishes spread over 8 km (~75% within ~1km diameter); superb L-band receivers (0.9–1.67 GHz); also UHF (0.58–1.0 GHz) and S-band (1.75–3.5 GHz – by MPIfR).

The view through an ordinary telescope…

Visible light image of
“Centaurus A” galaxy

The receptors

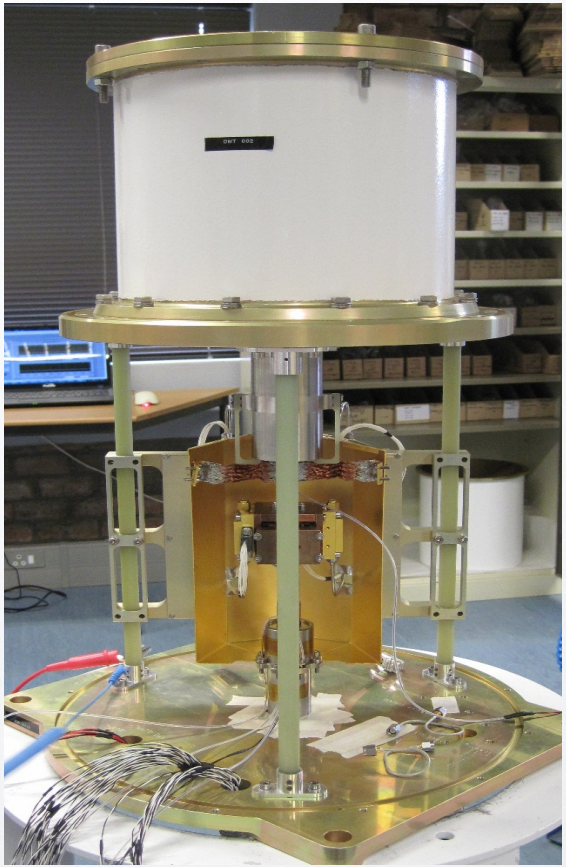


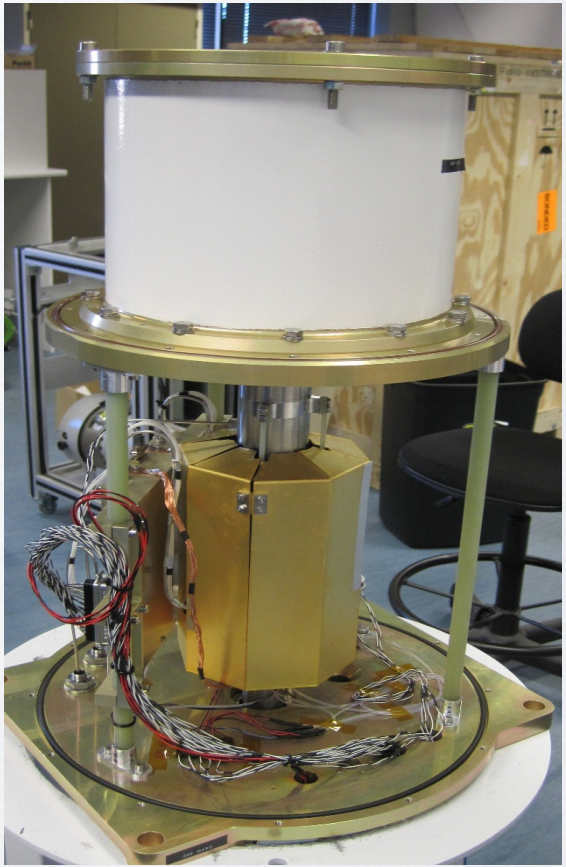
Unblocked Aperture, high effective aperture

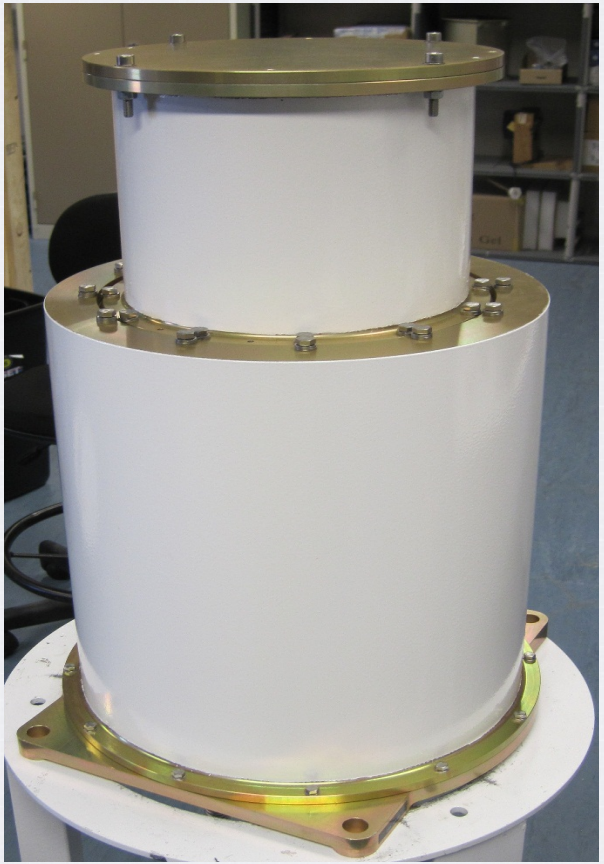
Large volume for multiple receivers and associated services

Low ground spillover

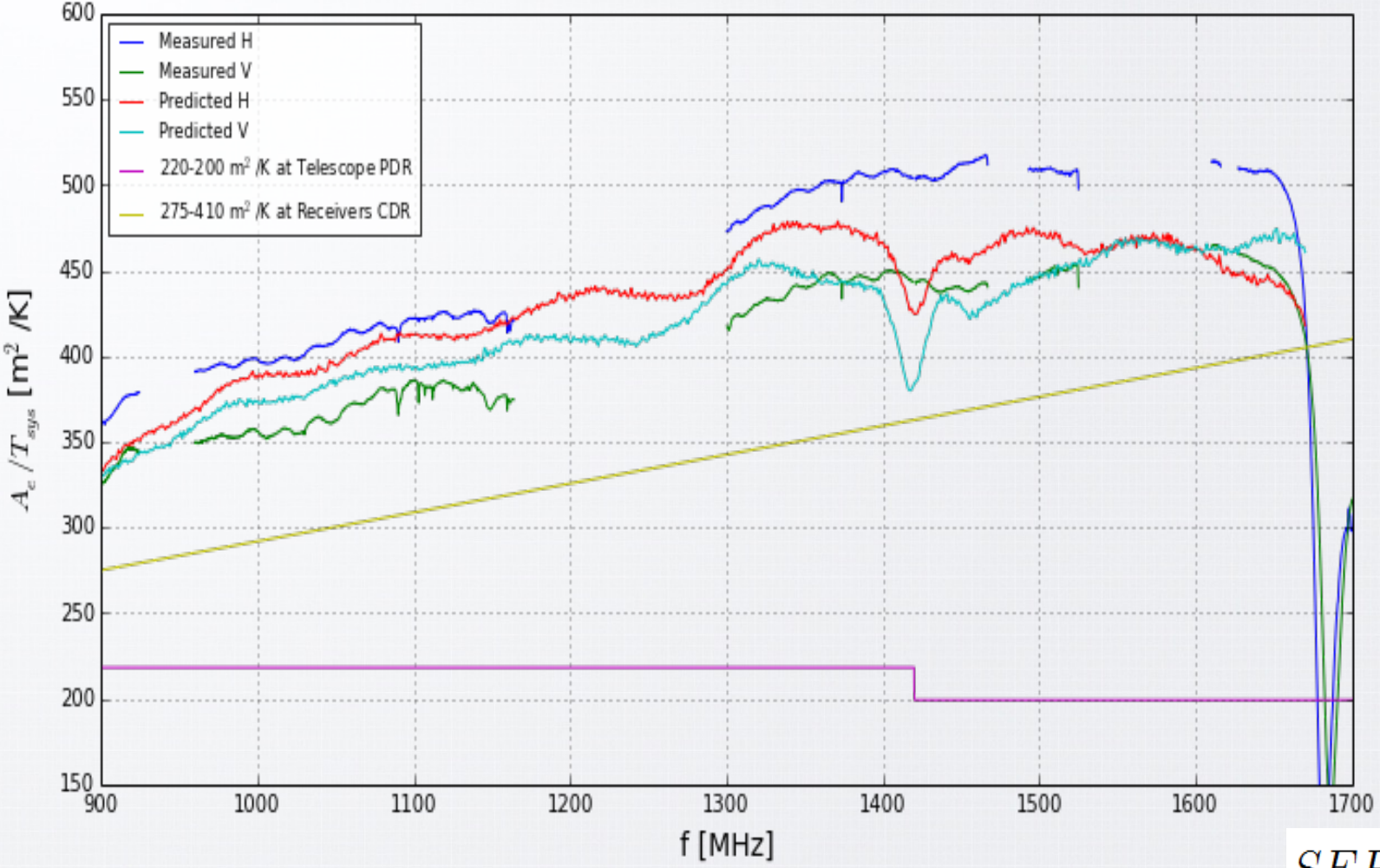
Superb cryogenic receivers (built at EMSS, South Africa)







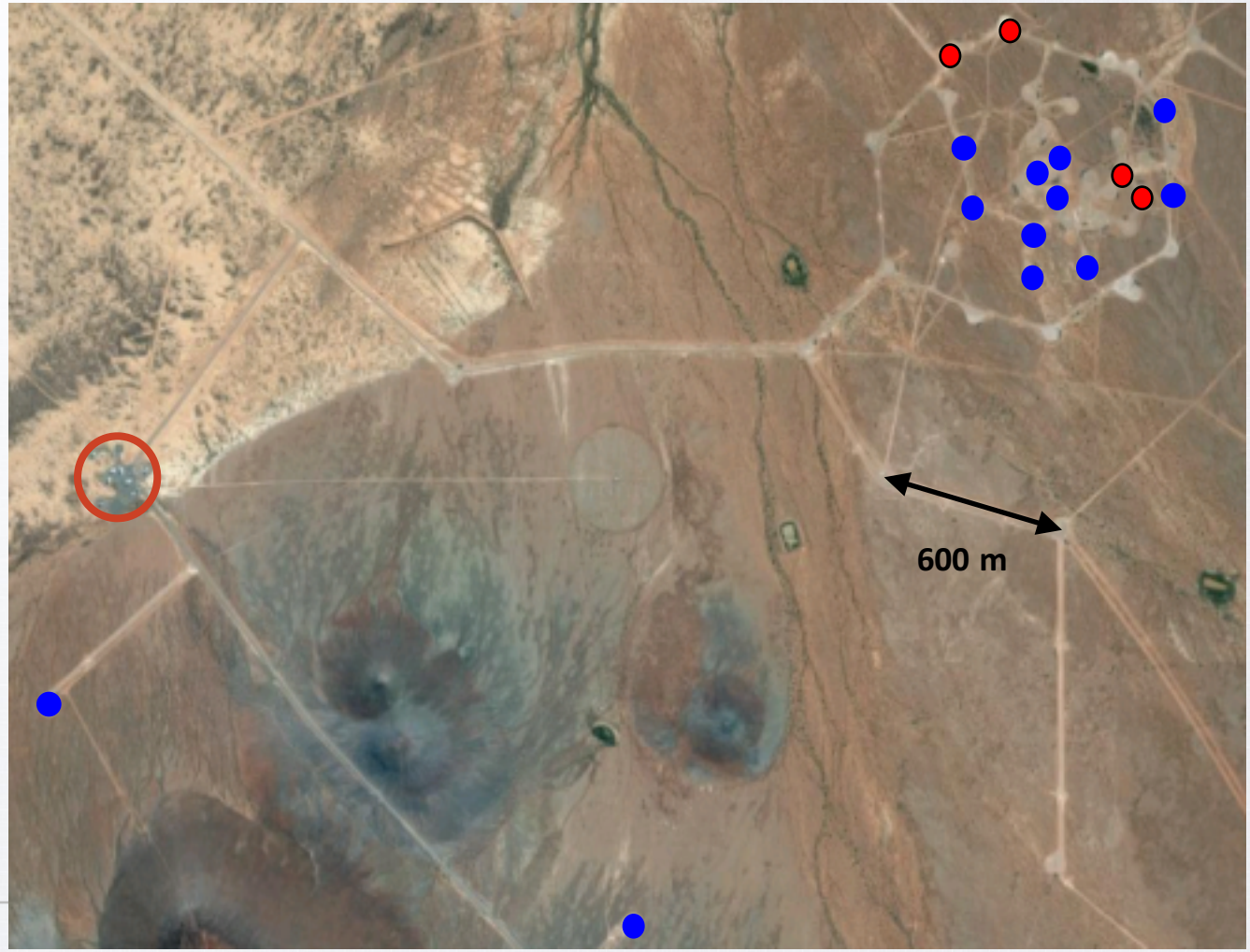
Extremely good L-band performance



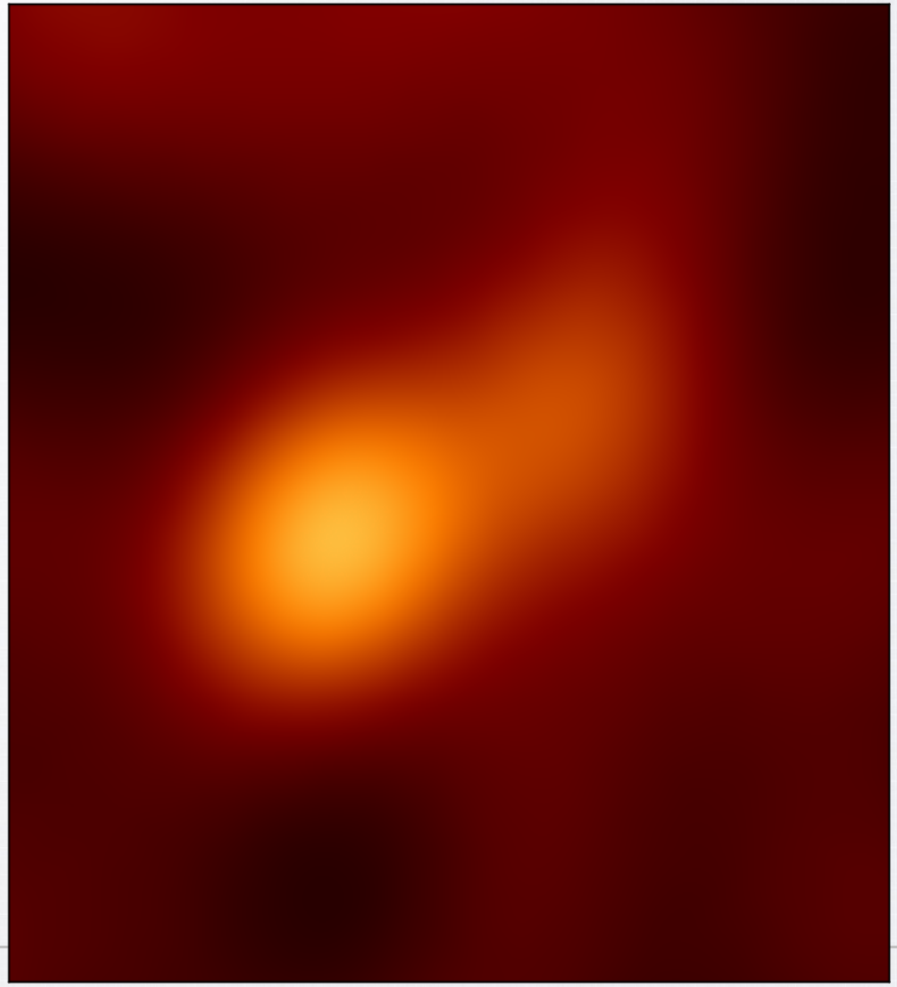
SEFD comparable to that of a VLA 25m antenna!

$$SEFD = \frac{2kT_{sys}}{\eta_a \frac{\pi}{4} D^2}$$

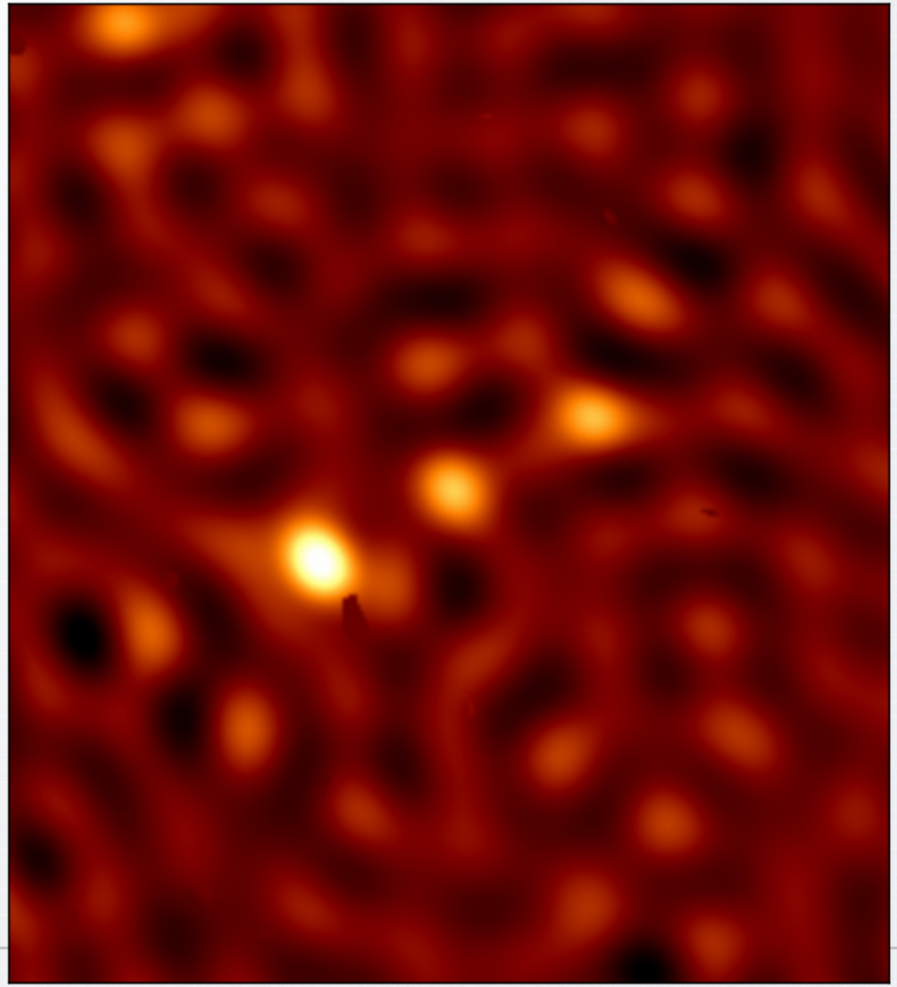
The SKA South Africa Karoo site: ever improving radio telescopes



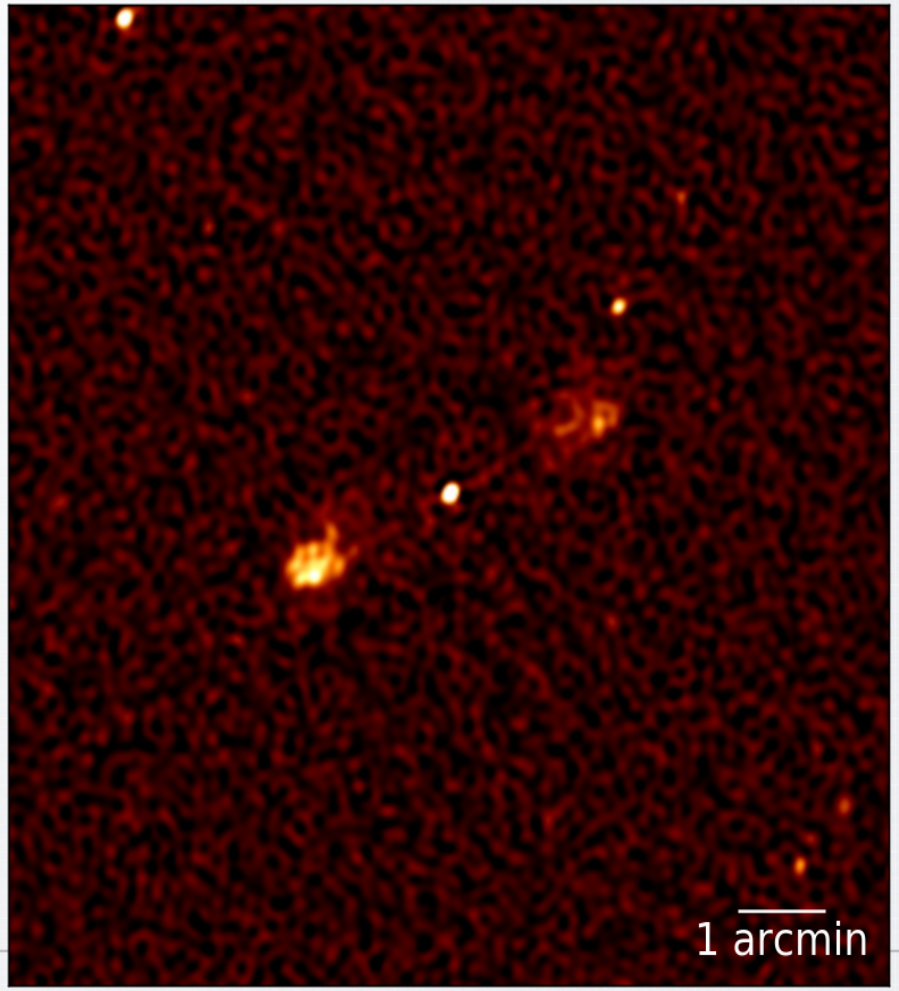
KAT-7 (engineering testbed) image in 2012



4-dish MeerKAT in May 2016 (commissioning)

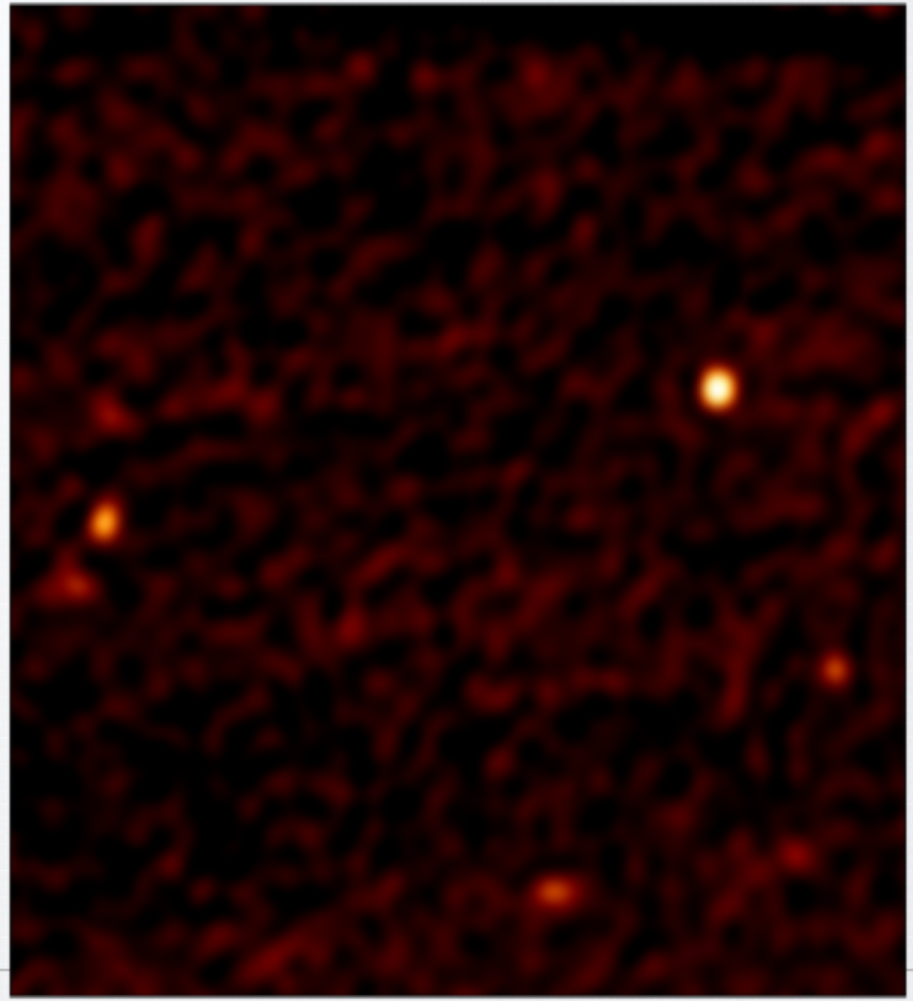


16-dish MeerKAT in June 2016 (“Array Release 1”)

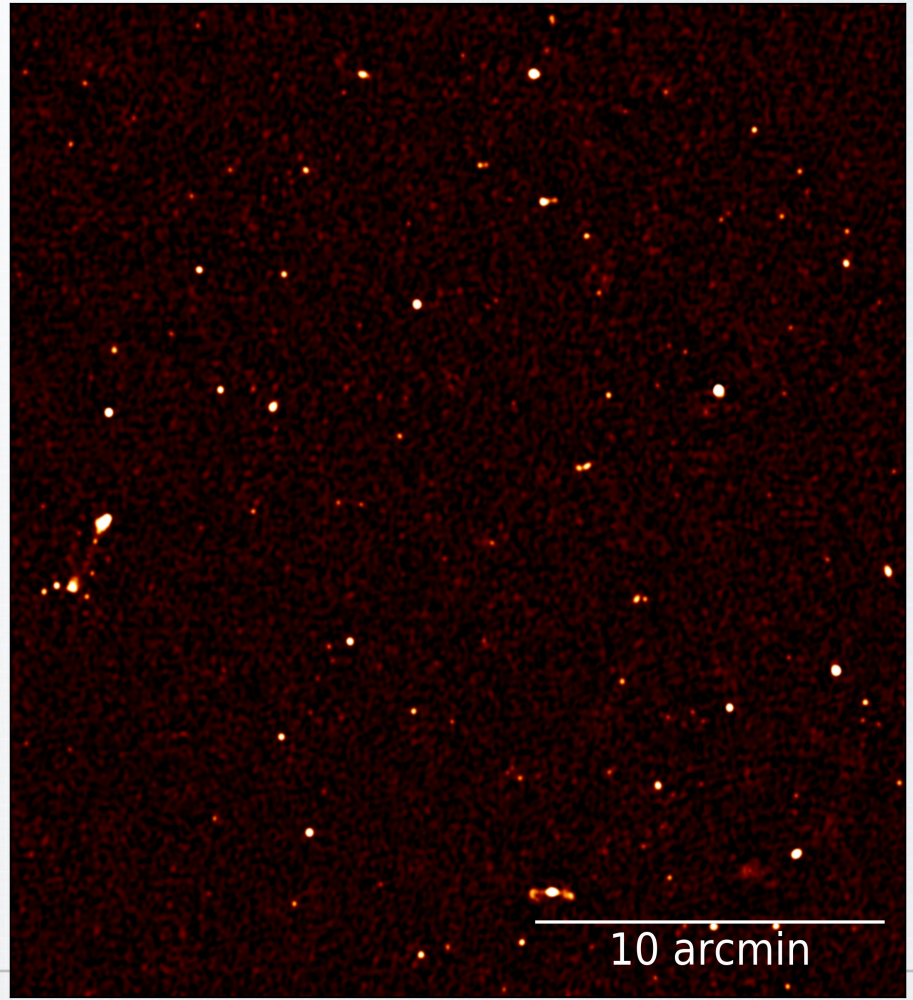


1% of First Light image

Best image of this patch of sky before MeerKAT

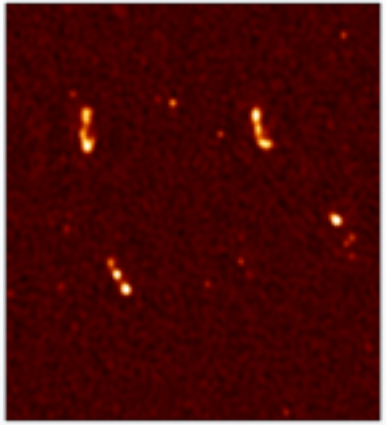


The MeerKAT sky

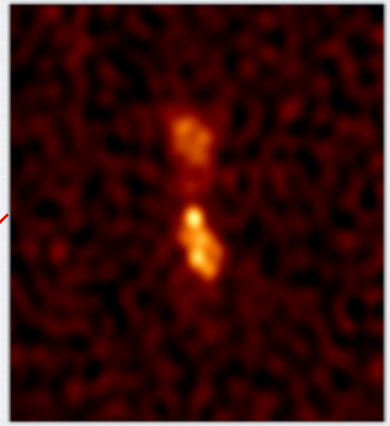


10% of First Light image (radio frequency range: 0.9–1.67 GHz)

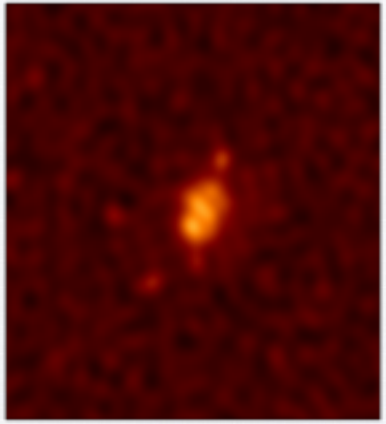
MeerKAT First Light



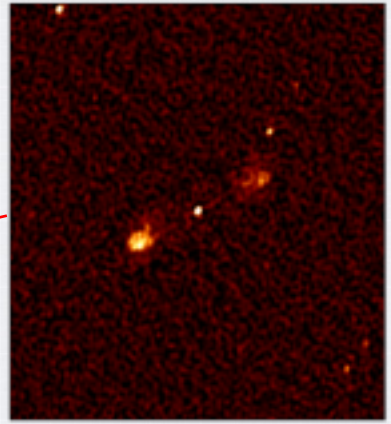
?



FR1 radio galaxy



Star forming galaxy



FR2 radio galaxy

The MeerKAT science programme

- 2010: call for scientific proposals by SKA SA results in 10 approved “Large Survey Projects” (LSPs, requiring more than 1000 hours of MeerKAT observing time over 5 years)
- Leads to strong support and interest in MeerKAT, including international investment
- 2016: MeerKAT is a different telescope than planned in 2010, and science has evolved
- SKA SA requested 8 approved LSPs to submit revised project plans; reviewed in 2017
- ~2/3 of telescope time to be used by LSPs, remaining “open time” for other programmes; strong focus on South African participation at all levels (starting in early 2019)
- 64 dishes operational as of April 2018 (plus continued development of capabilities)
- Eventually, MeerKAT will be integrated into the SKA telescope

MeerKAT science: LSPs approved in 2010

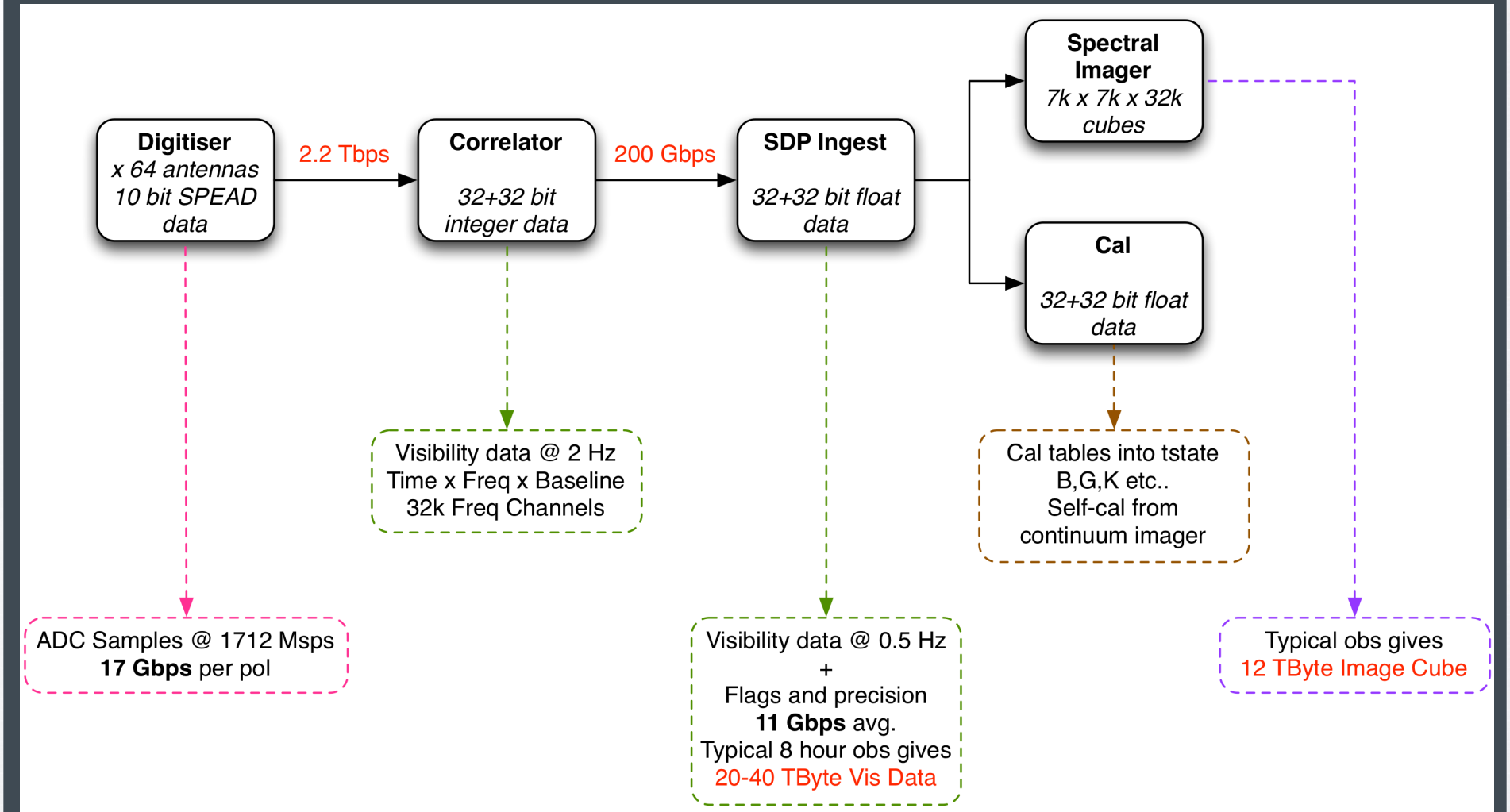
Radio Pulsar Timing	Bailes (AU)	7860 h
Testing Einstein's theory of gravity and gravitational radiation - Investigating the physics of enigmatic neutron stars through observations of pulsars		
LADUMA	Blyth, Holwerda, Baker (SA,NL,US)	5000 h
An ultra-deep survey of neutral hydrogen gas in the early universe		
MESMER	Heywood (UK)	6500 h
Searching for CO at high red-shift (z>7) to investigate the role of molecular hydrogen in the early universe		
MeerKAT Absorption Line Survey	Gupta, Srianand (NL, IN)	4000 h
Survey for H and OH lines in absorption against distant continuum sources; OH line ratios may give clues about changes in the fundamental constants		
MHONGOOSE	de Blok (NL,SA)	6000 h
Investigations of different types of galaxies; dark matter and the cosmic web		
MeerKAT HI Survey of Fornax	Serra (NL)	2450 h
Galaxy formation and evolution in the cluster environment		
MeerGAL	Thompson, Goedhart (UK,SA)	3300 h
Galactic structure and dynamics, distribution of ionised gas, recombination lines, interstellar molecular gas and masers		
MIGHTEE	Jarvis, van der Heyden (UK,SA)	1950 h
Deep continuum observations of the earliest radio galaxies		
TRAPUM	Stappers, Kramer (UK, DE)	3080 h + **commensal (timing)**
Searching for, and investigating new and exotic pulsars		
ThunderKAT	Woudt, Fender (SA,UK)	3000 h + **commensal (imaging)**
Study of explosive radio transients with MeerKAT; accretion-induced outflow from compact stellar remnants, e.g. relativistic jets and (super)novae		

Approved MeerKAT LSP program

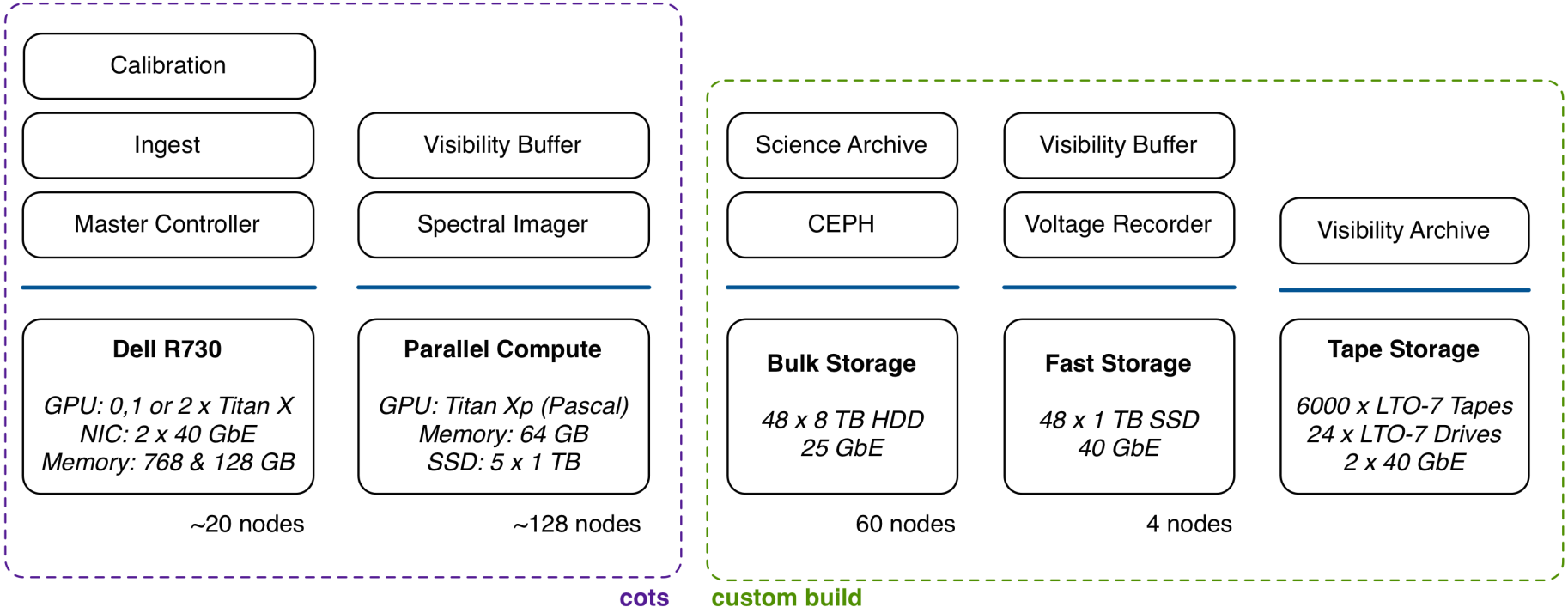
- 17,200 (rank-ordered) hours approved for scheduling (highest priority science objectives)
- (28,000 hours submitted for review; SKA SA Chief Scientist and Science Committee managed review process)
- External review panel emphasized that most of these are key science projects on the way to SKA1 – these *are* the science projects that this mid-frequency SKA1 precursor was built for

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 Data Rates



MeerKAT SDP Hardware Landscape



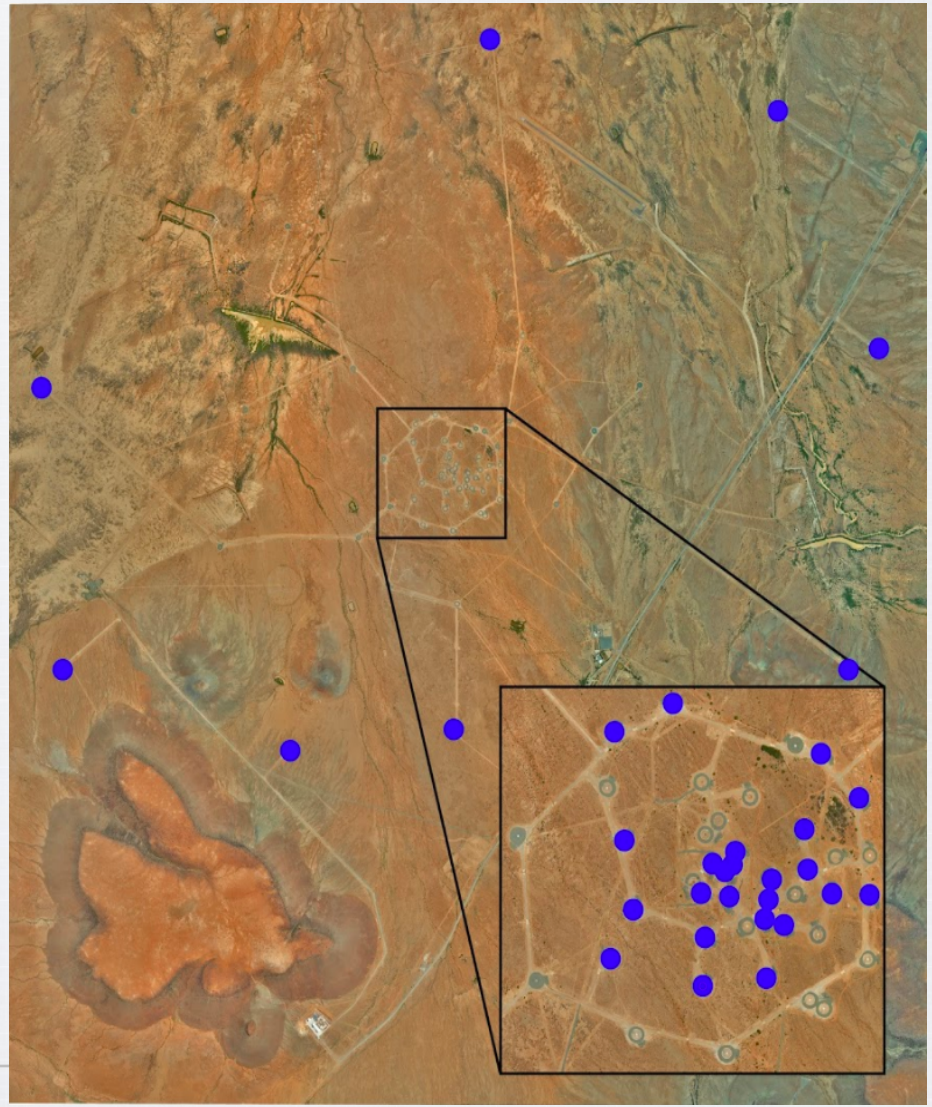
1.6 PFLOPs (GPU)

23 PBytes (Disk - CEPH)

40 PBytes (Tape)

Array configuration in April 2017

- 32 dishes available (*square surrounding core is 1.2 km on the side*)
- Commissioning continues concurrently with construction



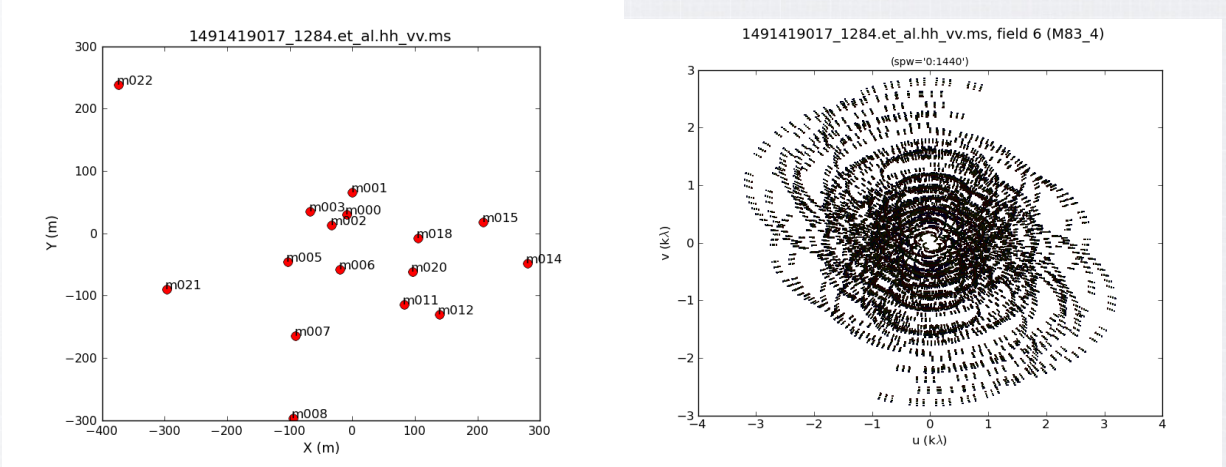
Commissioning in April 2017, up to 32 antennas

(*but only 32 inputs into ROACH2 correlator*; each antenna provides Horizontal + Vertical polarizations, so that commissioning observations typically continue with 16 dishes, selected from 32 available)

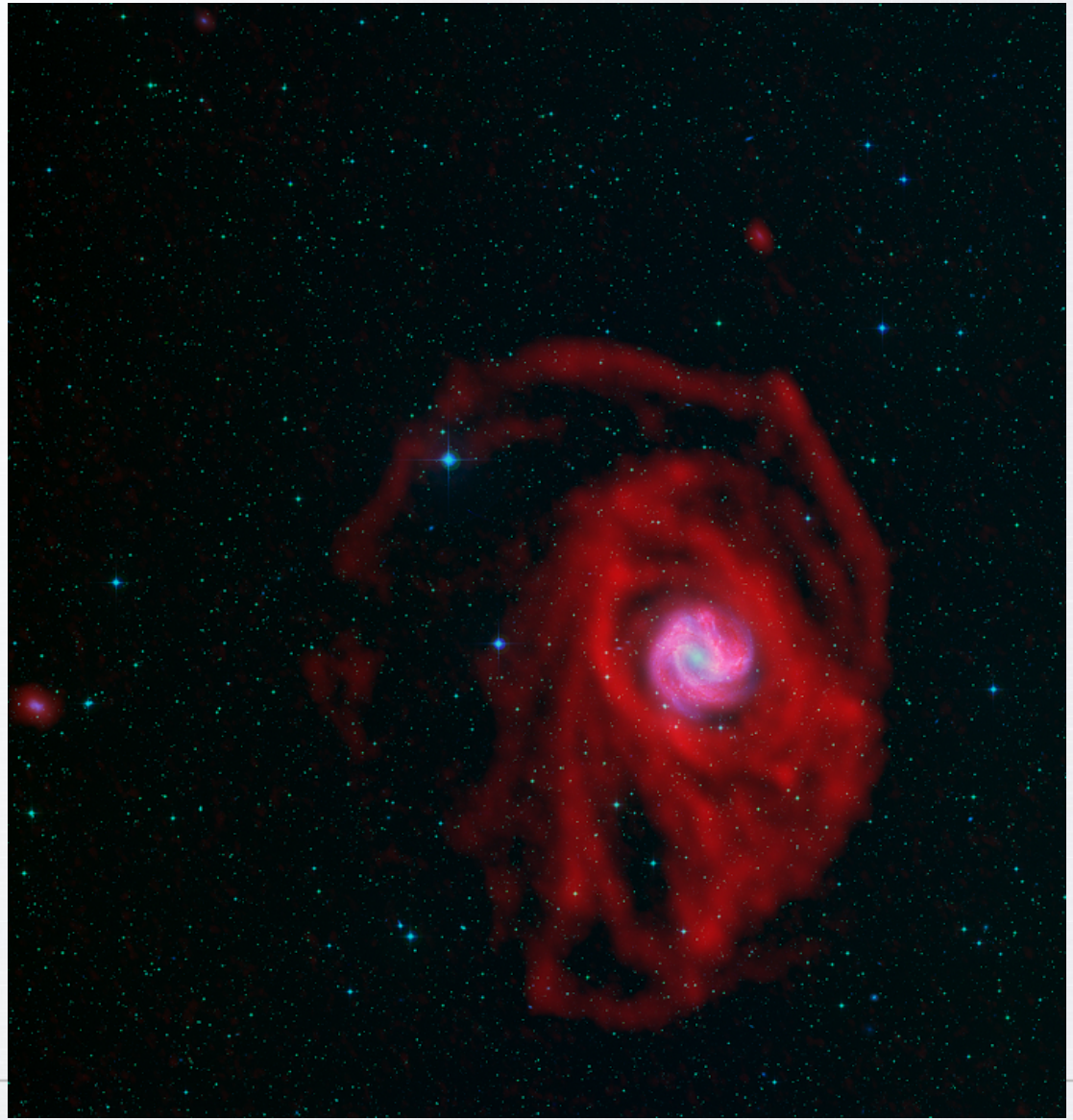
HI (neutral atomic hydrogen) emission in M83

(Spiral galaxy at 5 Mpc discovered in Cape Town in 1752 by Louis de La Caille)

- 32K channels (140 imaged)
- *16 core antennas*
- 9 hour track, 2017-04-05
- Mosaic: 7 pointings
- ~50 minutes per pointing
- Min baseline (projected): 16 m
- Max baseline: 711 m
- Beam 90x70 arcsec
- Measured rms 2.9 mJy (emission-free channel) vs 2.1 theoretical (40% off; looking into this)
- Reached this depth is *much* less time than with previous telescopes

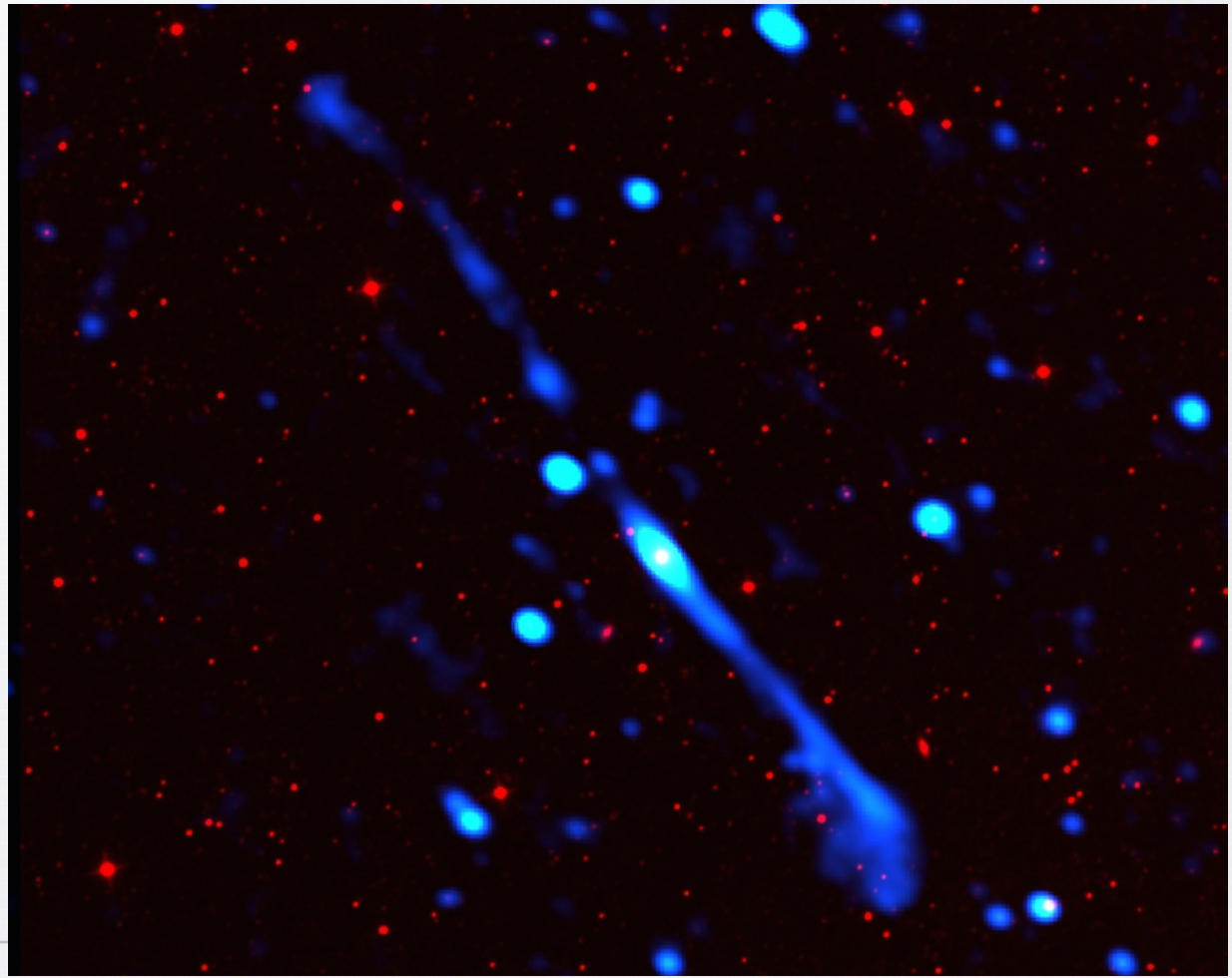


M83



A MeerKAT discovery: newly identified Giant Radio Galaxy

- Hint of extended source in SUMSS survey
- 7-point MeerKAT mosaic
- Radio source (blue) angular size = 0.8 deg; elliptical galaxy (red/IR) at z = 0.02; linear size = 1.2 Mpc: GRG



Update as of November 2017

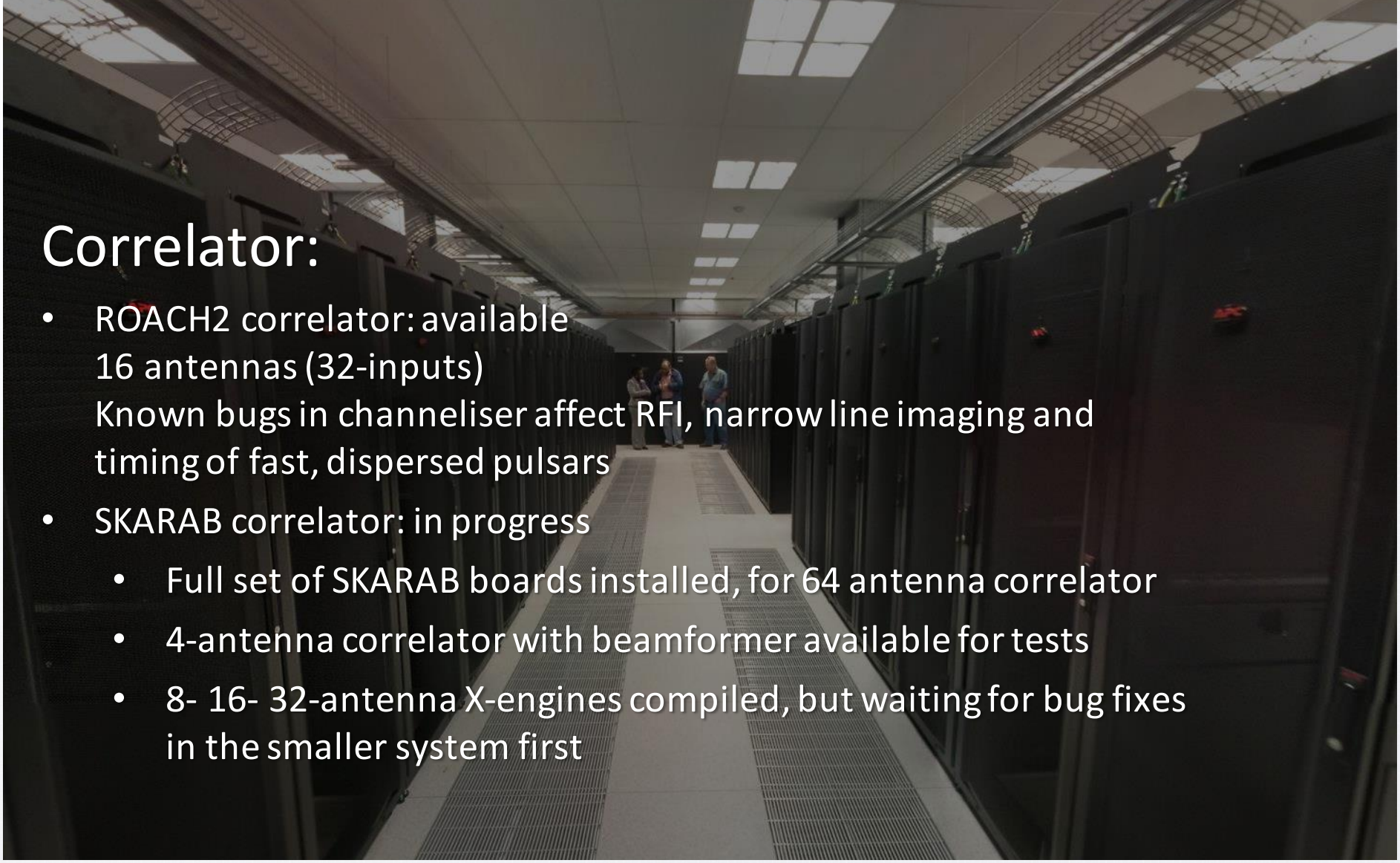
Antennas:

All hardware on site, 64 dishes lifted, >57 L-band receivers installed

Two receptors with UHF receivers and digitisers. Two being used for S-band receiver qualification

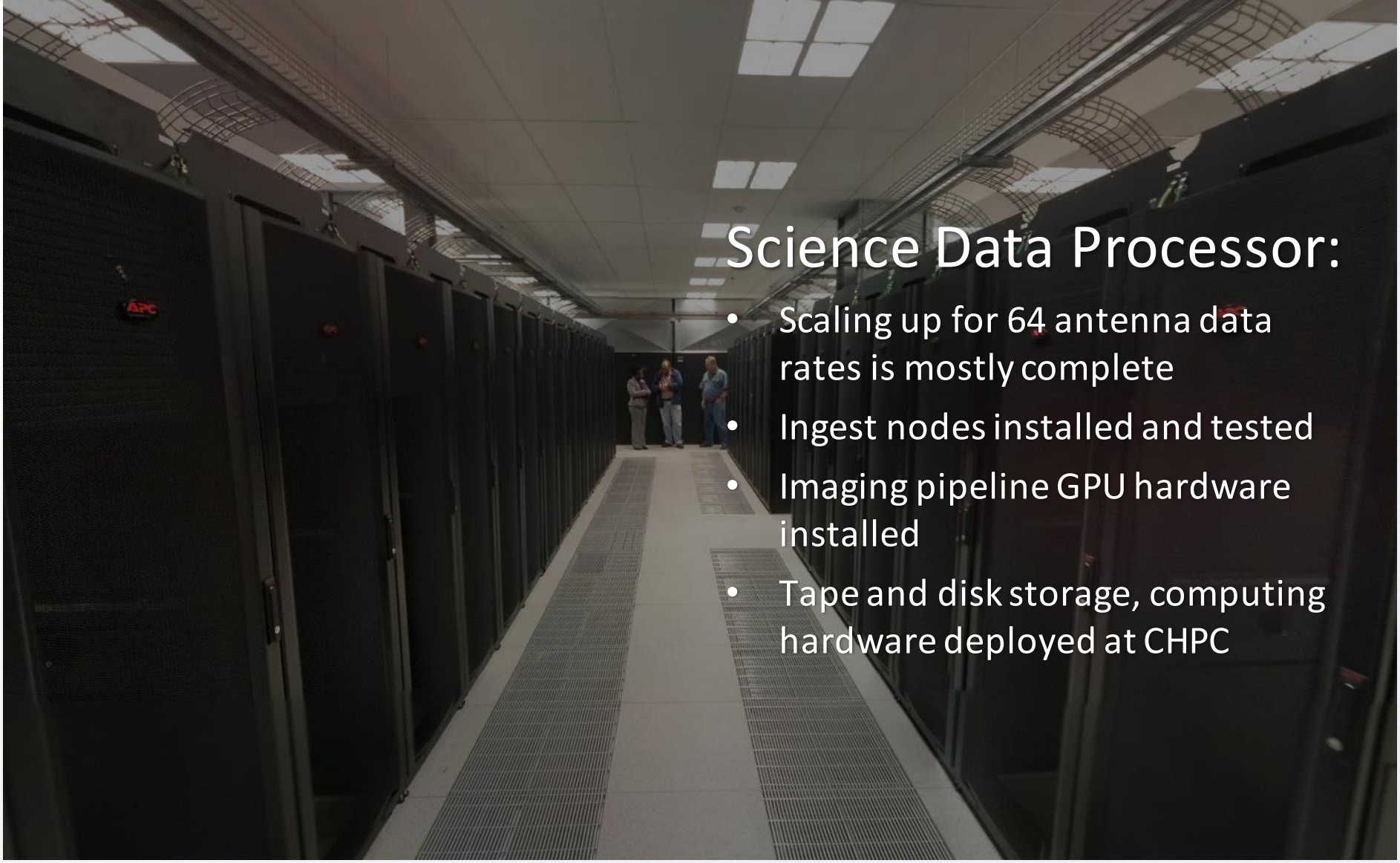
All antennas planned to be integrated by March 2018


Lifting of the 64th dish
(October 2017)



Correlator:

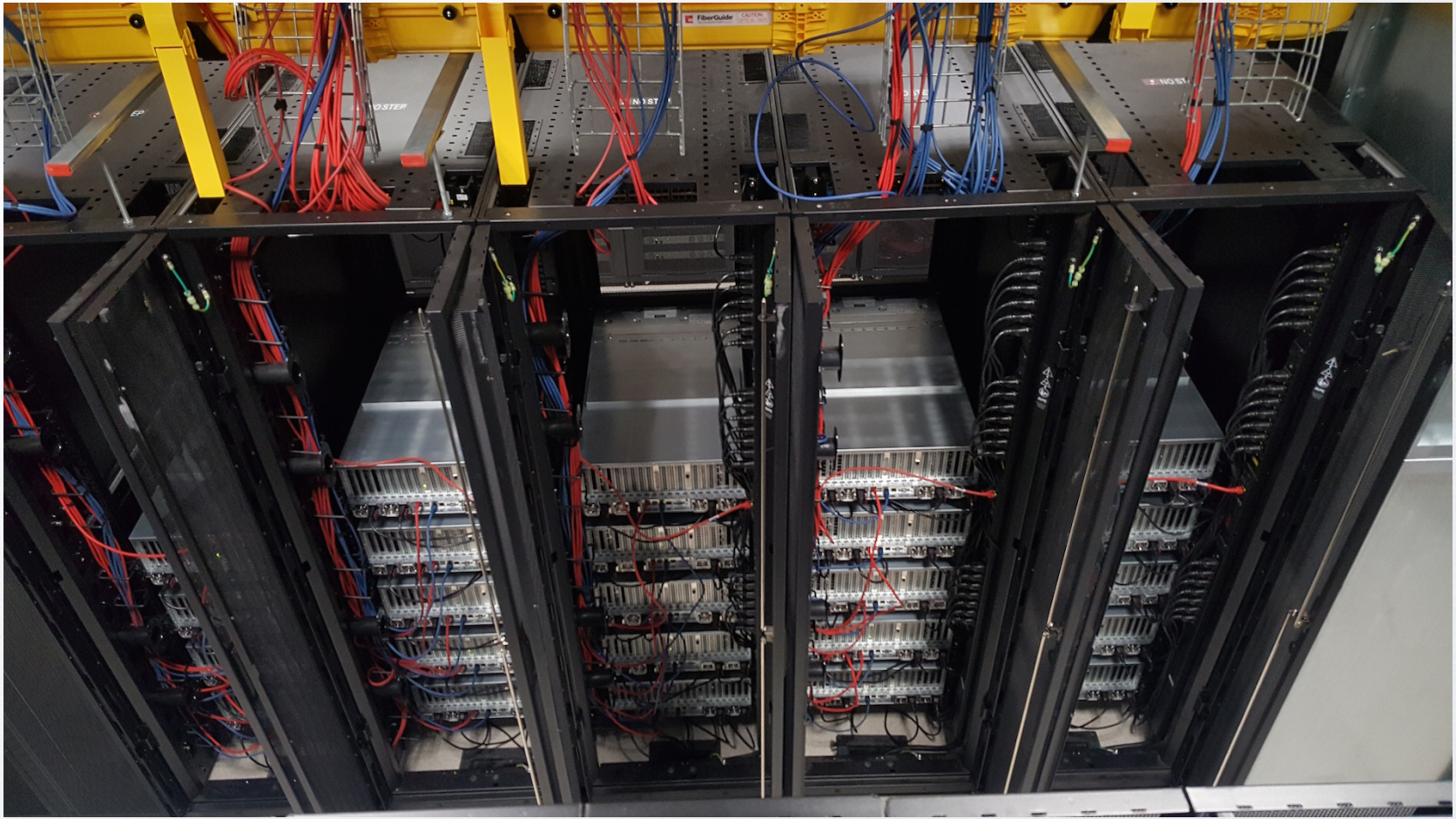
- ROACH2 correlator: available
  16 antennas (32-inputs)
  Known bugs in channeliser affect RFI, narrow line imaging and timing of fast, dispersed pulsars
- SKARAB correlator: in progress
  - Full set of SKARAB boards installed, for 64 antenna correlator
  - 4-antenna correlator with beamformer available for tests
  - 8- 16- 32-antenna X-engines compiled, but waiting for bug fixes in the smaller system first

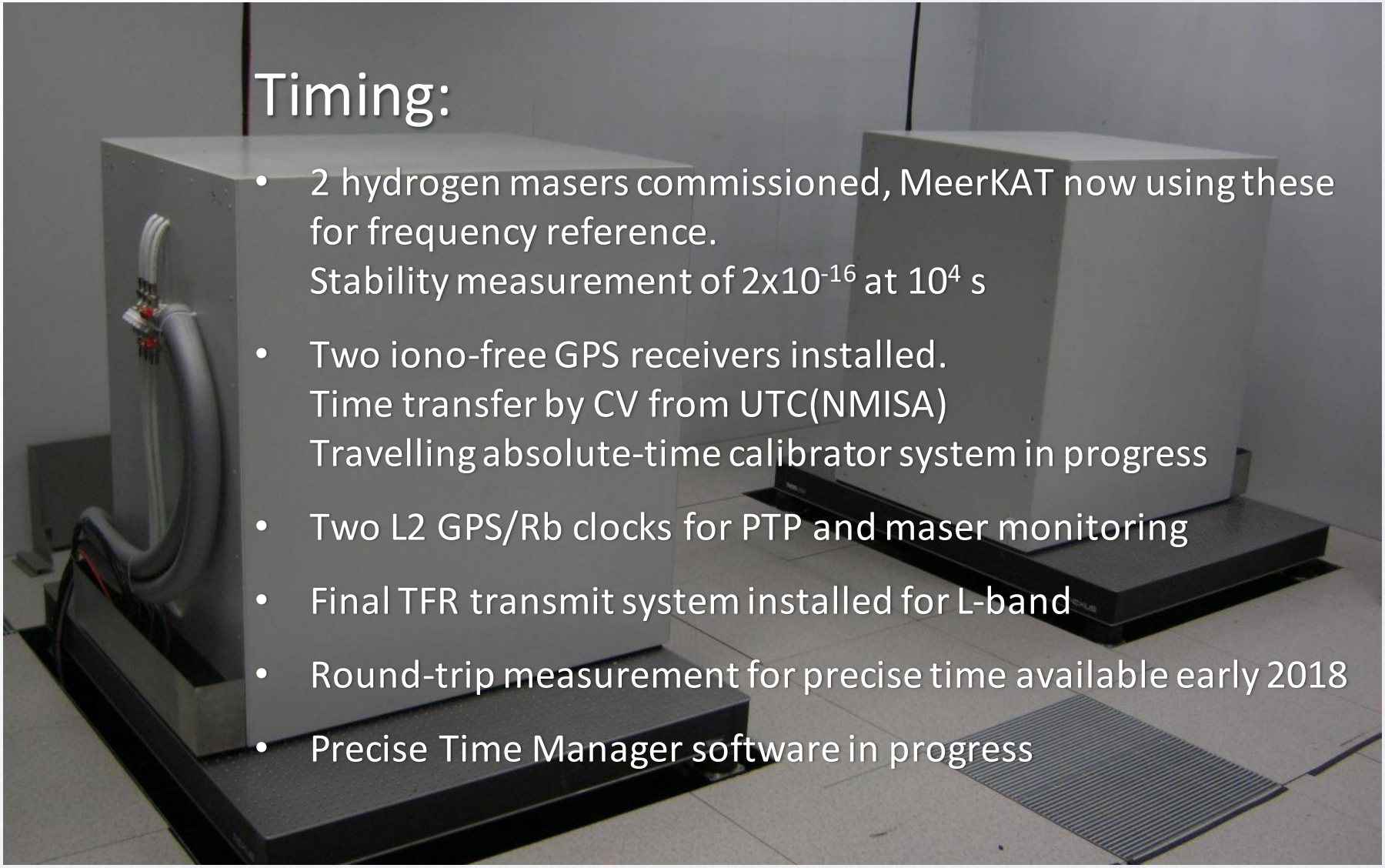


Science Data Processor:

- Scaling up for 64 antenna data rates is mostly complete
- Ingest nodes installed and tested
- Imaging pipeline GPU hardware installed
- Tape and disk storage, computing hardware deployed at CHPC

SDP: 1.1 PFLOPS in Karoo (+0.4 PFLOPS @CHPC)





Timing:

- 2 hydrogen masers commissioned, MeerKAT now using these for frequency reference.
  Stability measurement of 2×10^{-16} at 10^4 s
- Two iono-free GPS receivers installed.
  Time transfer by CV from UTC(NMISA)
  Travelling absolute-time calibrator system in progress
- Two L2 GPS/Rb clocks for PTP and maser monitoring
- Final TFR transmit system installed for L-band
- Round-trip measurement for precise time available early 2018
- Precise Time Manager software in progress

First science publications using MeerKAT data

REVIVAL OF THE MAGNETAR PSR J1622−4950: OBSERVATIONS WITH MeerKAT, Parkes, *XMM-Newton*, *Swift*, *Chandra*, AND *NuSTAR*

Published April 2018: ApJ, 856, 180

F. Camilo,[1] P. Scholz,[2] M. Serylak,[1,3,4] S. Buchner,[1] M. Merryfield,[2,5] V. M. Kaspi,[6] R. F. Archibald,[6,7] M. Bailes,[8,9] A. Jameson,[8] W. van Straten,[8,10] J. Sarkissian,[11] J. E. Reynolds,[12] S. Johnston,[12] G. Hobbs,[12] T. D. Abbott,[1] R. M. Adam,[1] G. B. Adams,[1] T. Alberts,[1] R. Andreas,[1] K. M. B. Asad,[1,13,3] T. Baloyi,[1] E. F. Bauermeister,[1] T. Baxana,[1] T. G. H. Bennett,[1] G. Bernardi,[13,14] D. Booisen,[1] R. S. Booth,[15] D. H. Botha,[16] R. Brederode,[1] J. P. Burger,[1] T. Cheetham,[1] J. Conradie,[16] J. P. Conradie,[16] D. B. Davidson,[17] G. de Bruin,[1] B. de Swardt,[1] C. de Villiers,[1] W. de Villiers,[16] C. de Waal,[1] M. A. Dikgale,[1] G. du Toit,[16] L. J. du Toit,[16] S. W. P. Esterhuyse,[1] B. Fanaroff,[1] A. R. Foley,[1] G. Foster,[18,
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C. C. Julius,[1] F. Kapp,[1]
E. C. Knox-Davies,[16] D
R. Lehmensiek,[16] D. Liebe
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C. Tasse,[13,28] G. Taylor,[1] I. P.
T. van Balla,[1] L. van den H
J. P. van Staden,[16] V. van To

The Astrophysical Journal Letters, 848:L12 (59pp), 2017 October 20

https://doi.org/10.3847/2041-8213/aa91c9

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Multi-messenger Observations of a Binary Neutron Star Merger

LIGO Scientific Collaboration and Virgo Collaboration, Fermi GBM, INTEGRAL, IceCube Collaboration, AstroSat Cadmium Zinc Telluride Imager Team, IPN Collaboration, The Insight-Hxmt Collaboration, ANTARES Collaboration, The Swift Collaboration, AGILE Team, The 1M2H Team, The Dark Energy Camera GW-EM Collaboration and the DES Collaboration, The DLT40 Collaboration, GRAWITA: GRAvitational Wave Inaf TeAm, The Fermi Large Area Telescope Collaboration, ATCA: Australia Telescope Compact Array, ASKAP: Australian SKA Pathfinder, Las Cumbres Observatory Group, OzGrav, DWF (Deeper, Wider, Faster Program), AST3, and CAASTRO Collaborations, The VINROUGE Collaboration, MASTER Collaboration, J-GEM, GROWTH, JAGWAR, Caltech-NRAO, TTU-NRAO, and NuSTAR Collaborations, Pan-STARRS, The MAXI Team, TZAC Consortium, KU Collaboration, Nordic Optical Telescope, ePESSTO, GROND, Texas Tech University, SALT Group, TOROS: Transient Robotic Observatory of the South Collaboration, The BOOTES Collaboration, MWA: Murchison Widefield Array, The CALET Collaboration, IKI-GW Follow-up Collaboration, H.E.S.S. Collaboration, LOFAR Collaboration, LWA: Long Wavelength Array, HAWC Collaboration, The Pierre Auger Collaboration, ALMA Collaboration, Euro VLBI Team, Pi of the Sky Collaboration, The Chandra Team at McGill University, DFN: Desert Fireball Network, ATLAS, High Time Resolution Universe Survey, RIMAS and RATIR, and SKA South Africa/MeerKAT
(See the end matter for the full list of authors.)

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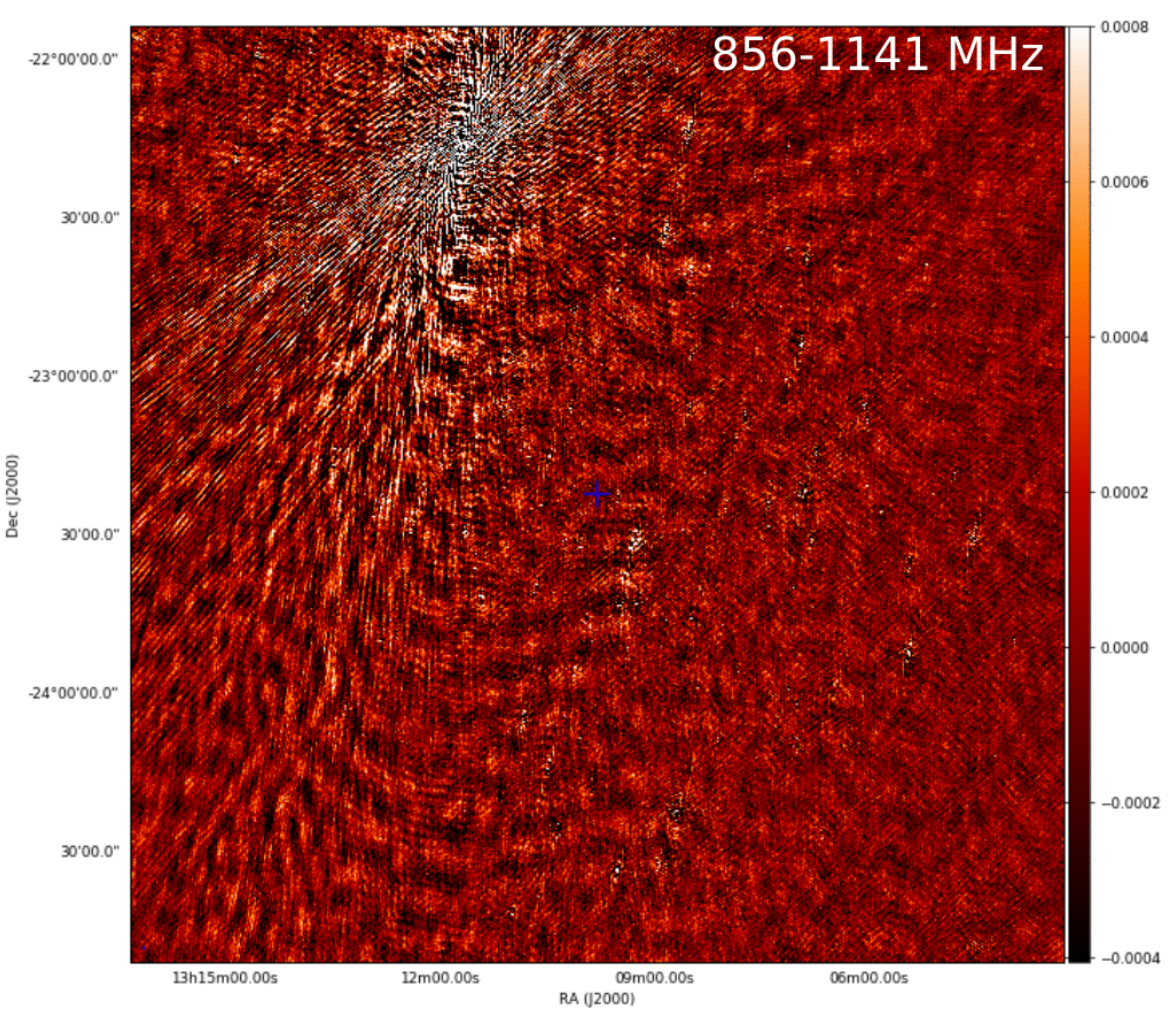
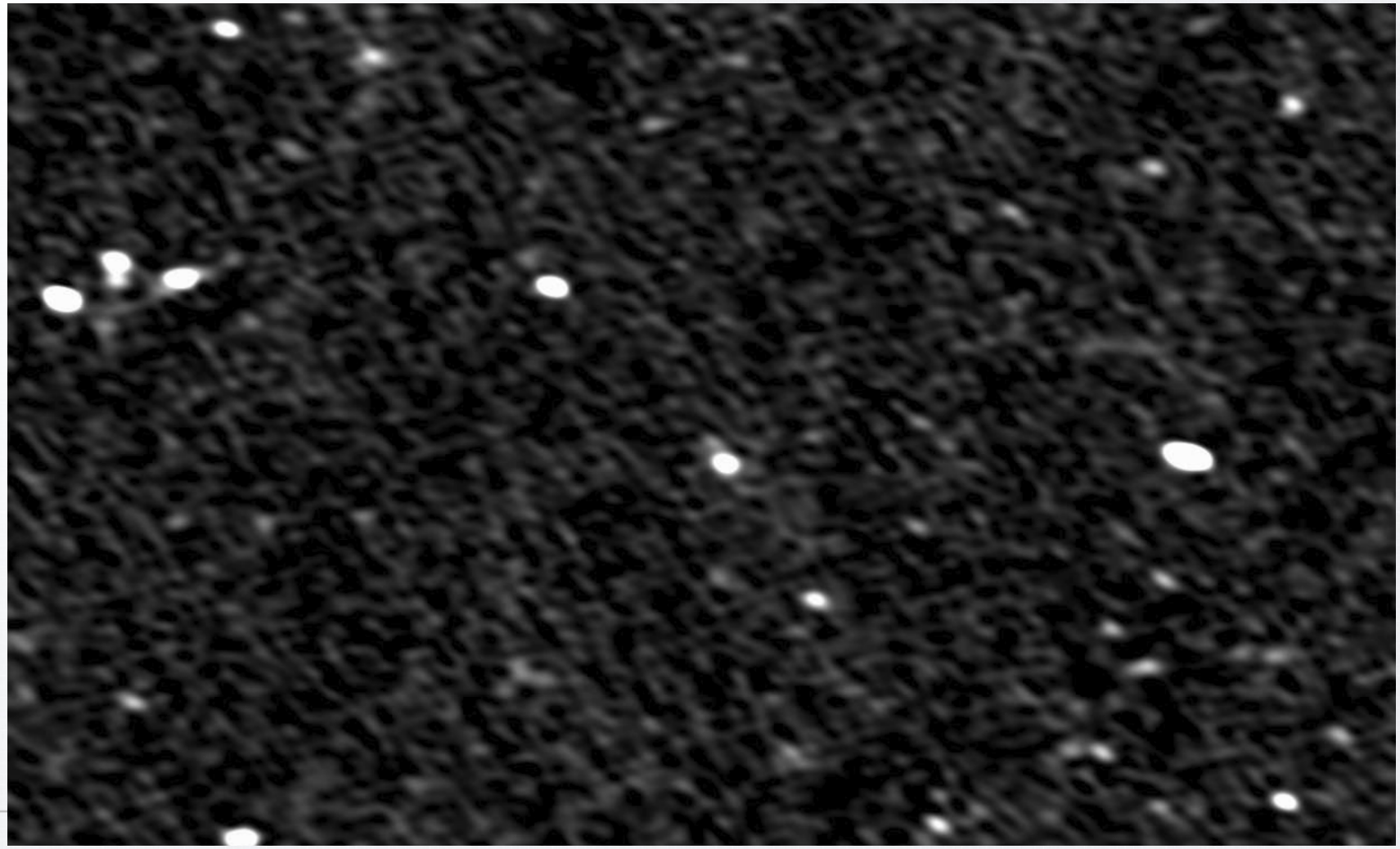
More science, and interesting challenges… MeerKAT and GW170817

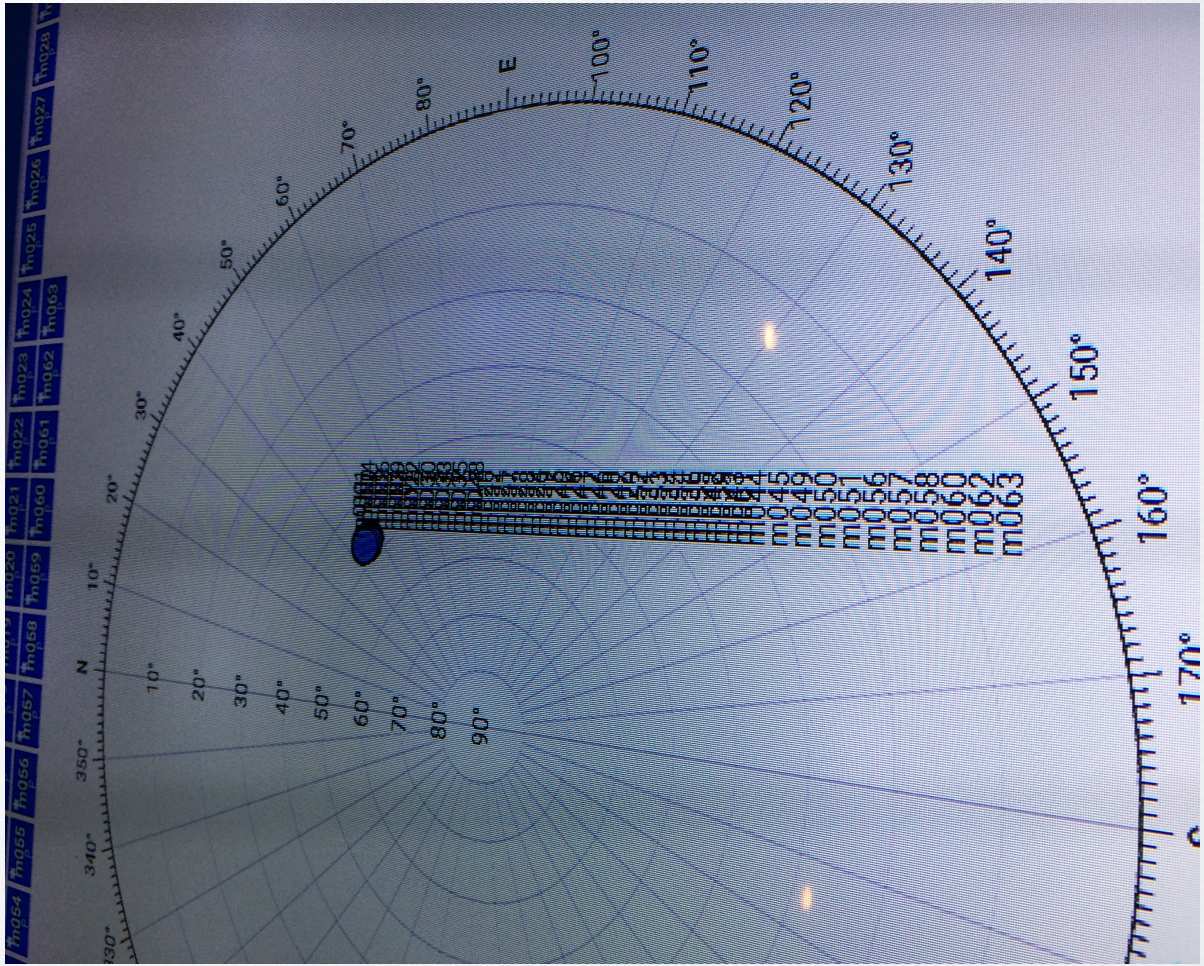


GW170817 field with MeerKAT after a lot of work

~4 sigma (100 uJy) detection 11” NE of NGC 4993 (day 107)

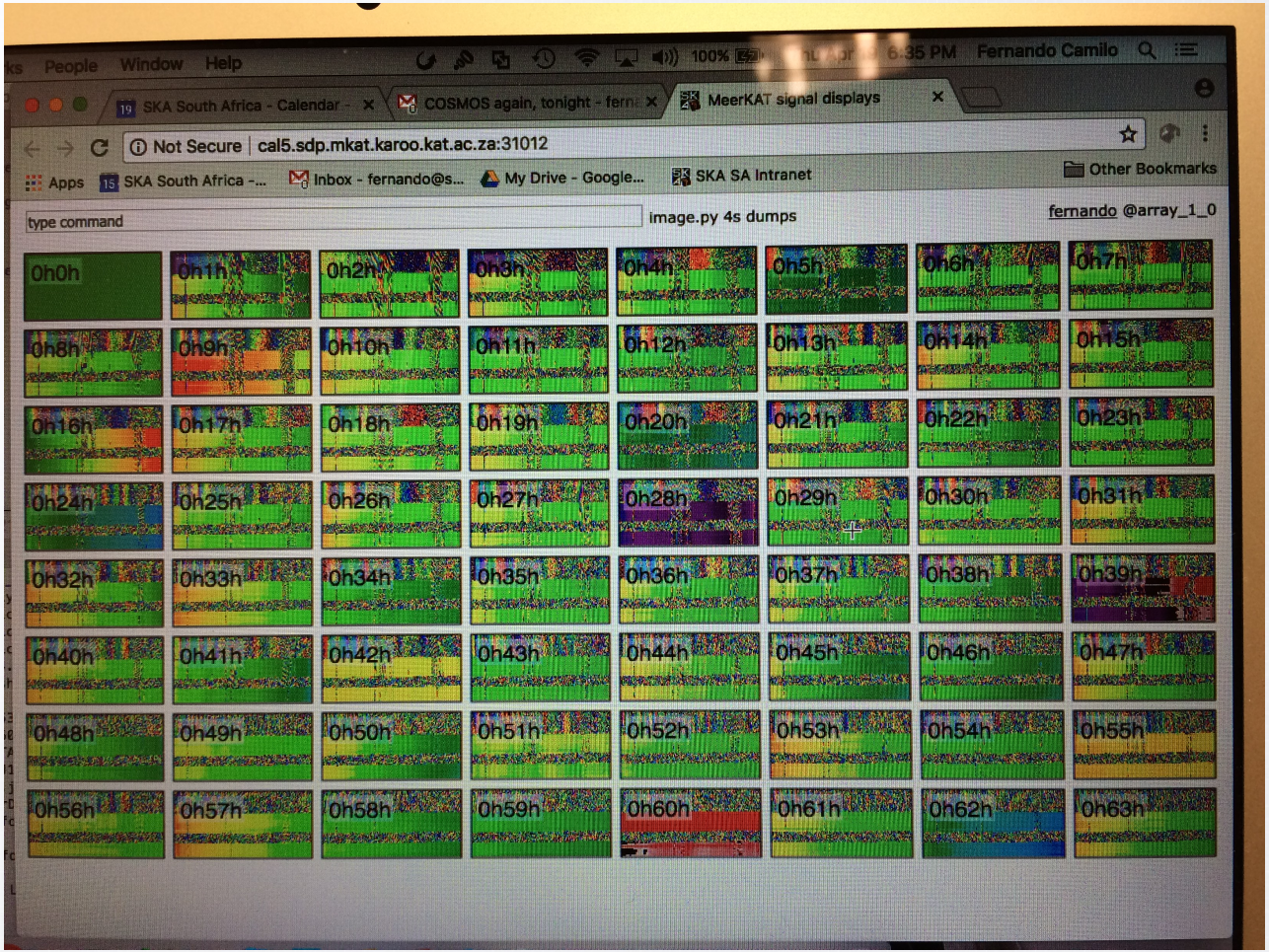


Finally, in April 2018: first ever MeerKAT-64 observation!



64 dishes pointing in the same direction

Fringes from 64 MeerKAT antennas!



MeerKAT status as of June 2018

- Two Large Survey Projects have started collecting science data
- Additional correlator modes are being developed (pulsar timing, 32K wideband and “zoom”)
- Development continues on a variety of “guest instruments”
- Telescope will be officially inaugurated later in 2018
- First call for “Open Time” observing projects is expected in late 2018

SKA South Africa, a Business Unit of the National Research Foundation, is supervising South Africa's involvement in the SKA on behalf of the Department of Science & Technology.

Thanks