





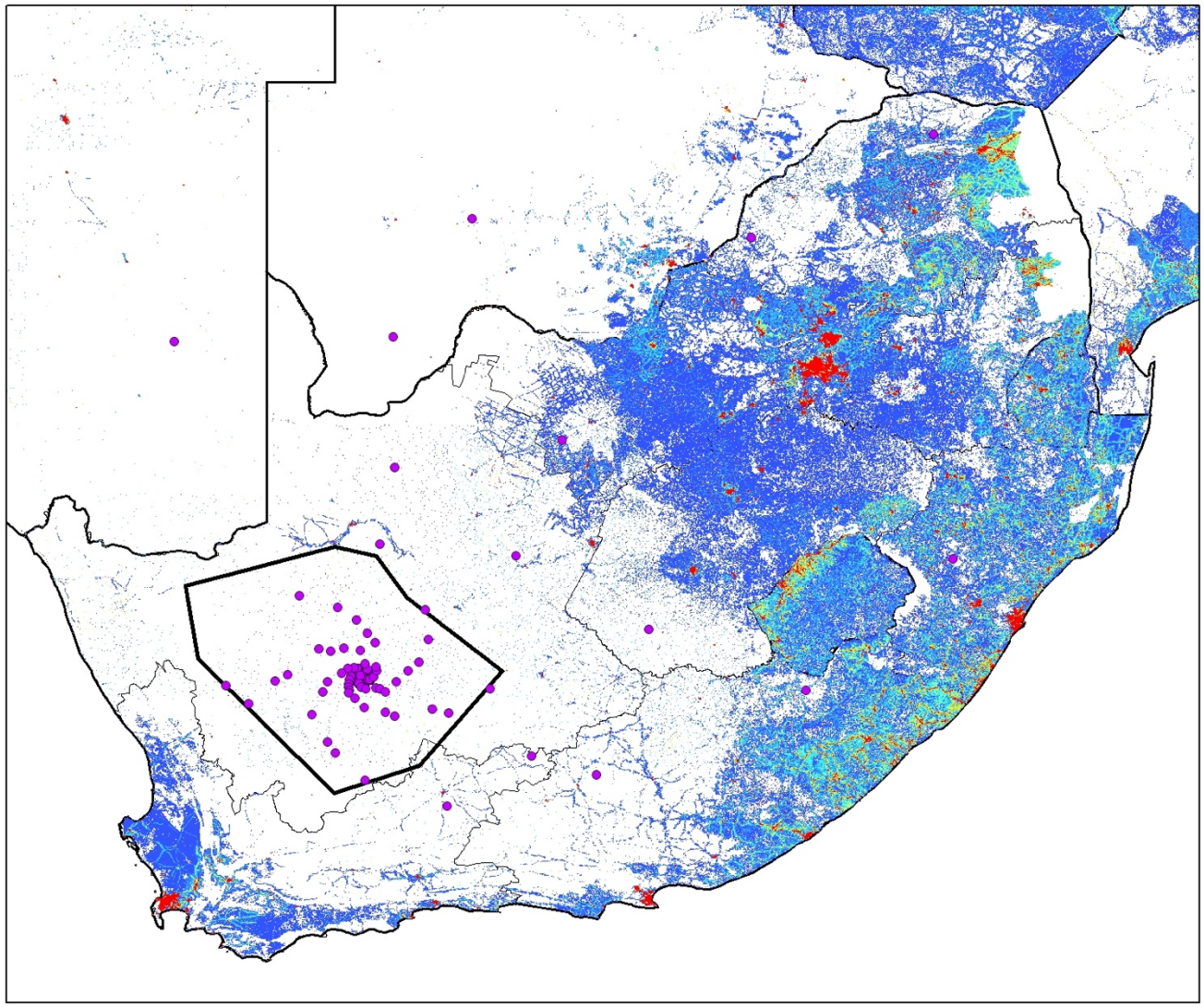

The MeerKAT Radio Telescope

National Research Foundation | SARAO | South African Radio Astronomy Observatory

IUCAF Summer School
STIAS Stellenbosch – 2nd March 2020

Justin Jonas
Chief Technologist: SARAO
Director: RATT, Rhodes University

SKA/MeerKAT site (& HIRAX & C-BASS & HERA)



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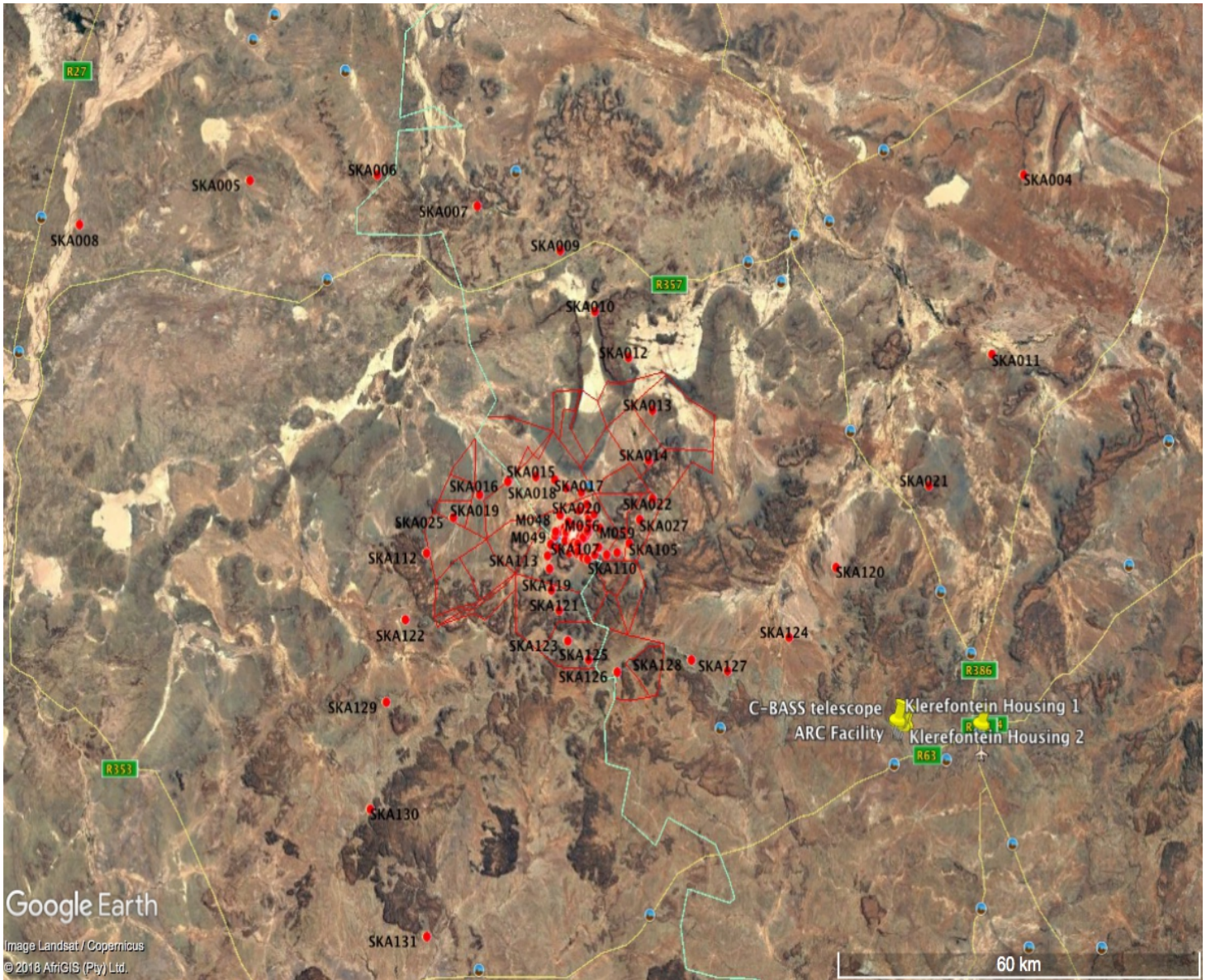
RFI Survey with ICASA


Dave Drew - ICASA

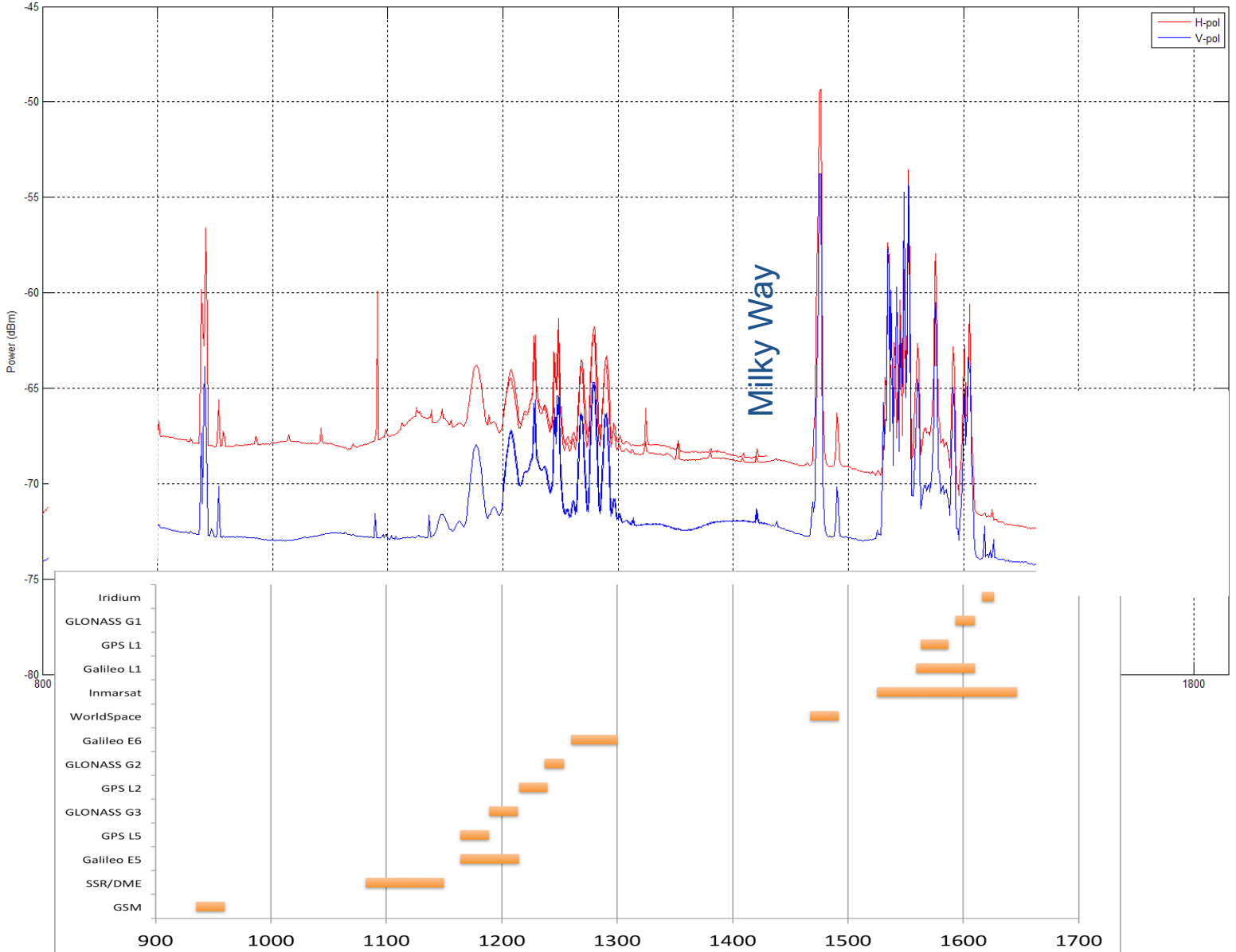
SKA1-mid and 120 000 ha



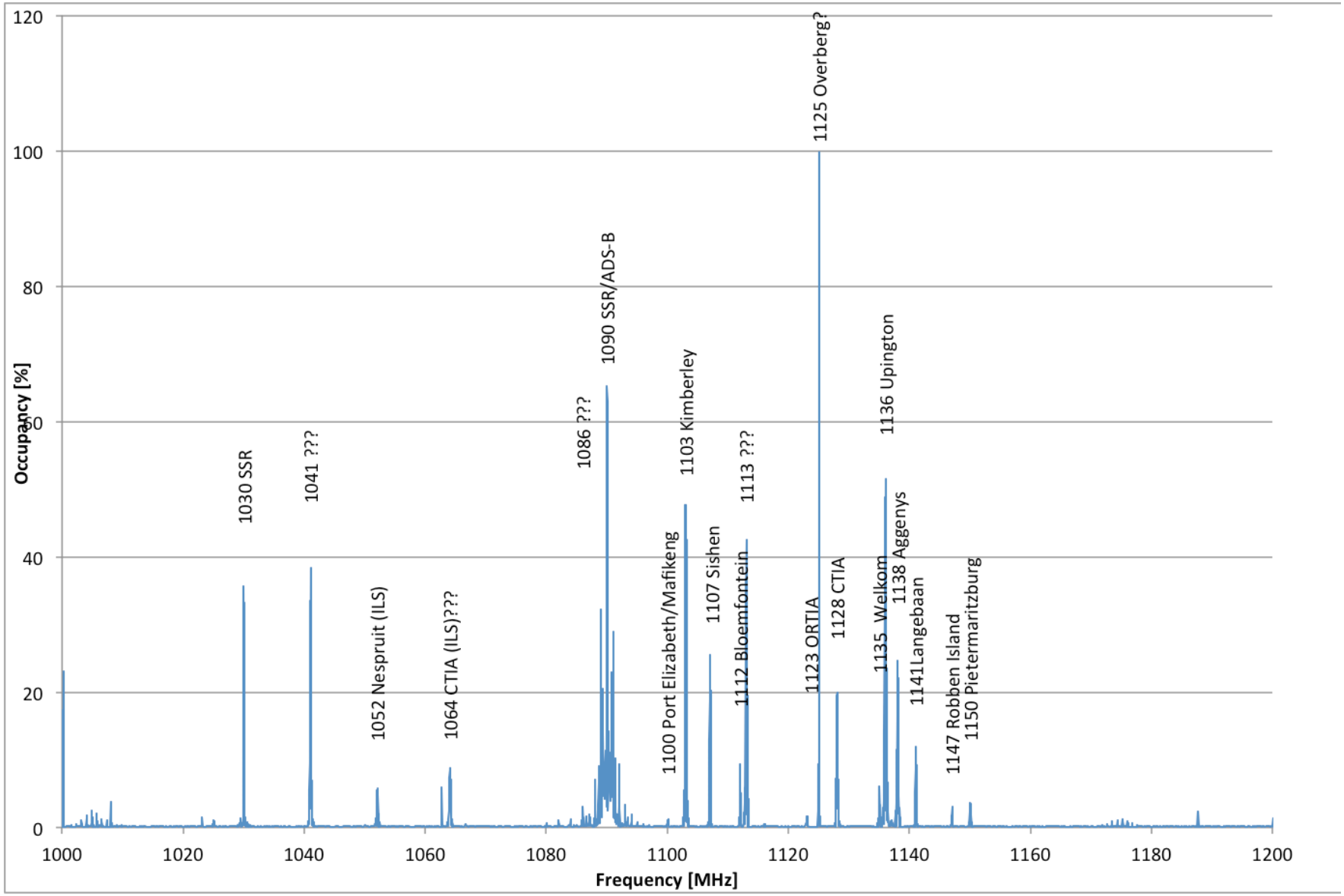
Meerkat National Park

South African
NATIONAL PARKS

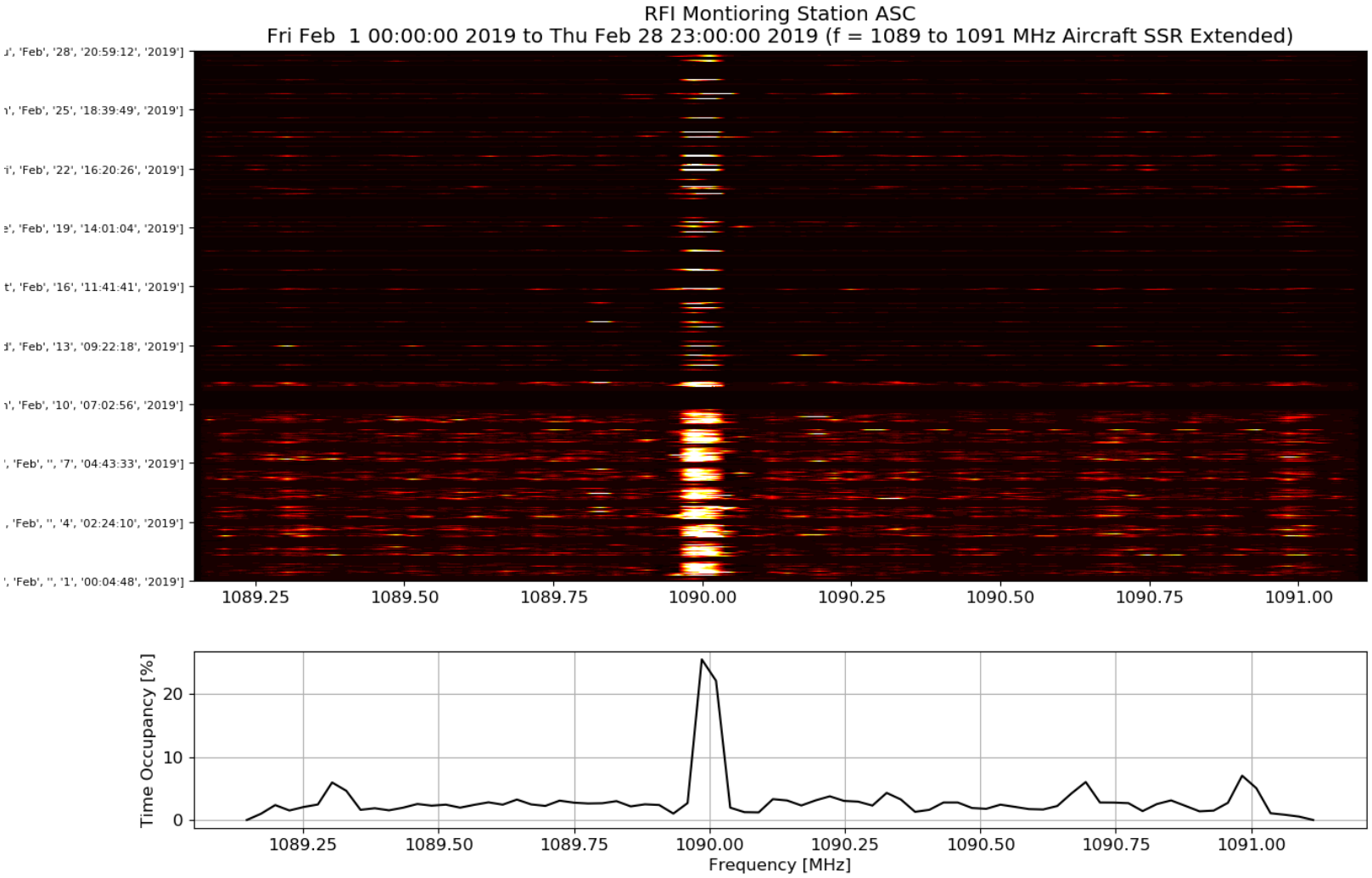
L-band RFI


H-pol
V-pol
Power (dBm)
-45
-50
-55
-60
-65
-70
-75
-80
Milky Way
800
1800
Iridium
GLONASS G1
GPS L1
Galileo L1
Inmarsat
WorldSpace
Galileo E6
GLONASS G2
GPS L2
GLONASS G3
GPS L5
Galileo E5
SSR/DME
GSM
900
1000
1100
1200
1300
1400
1500
1600
1700

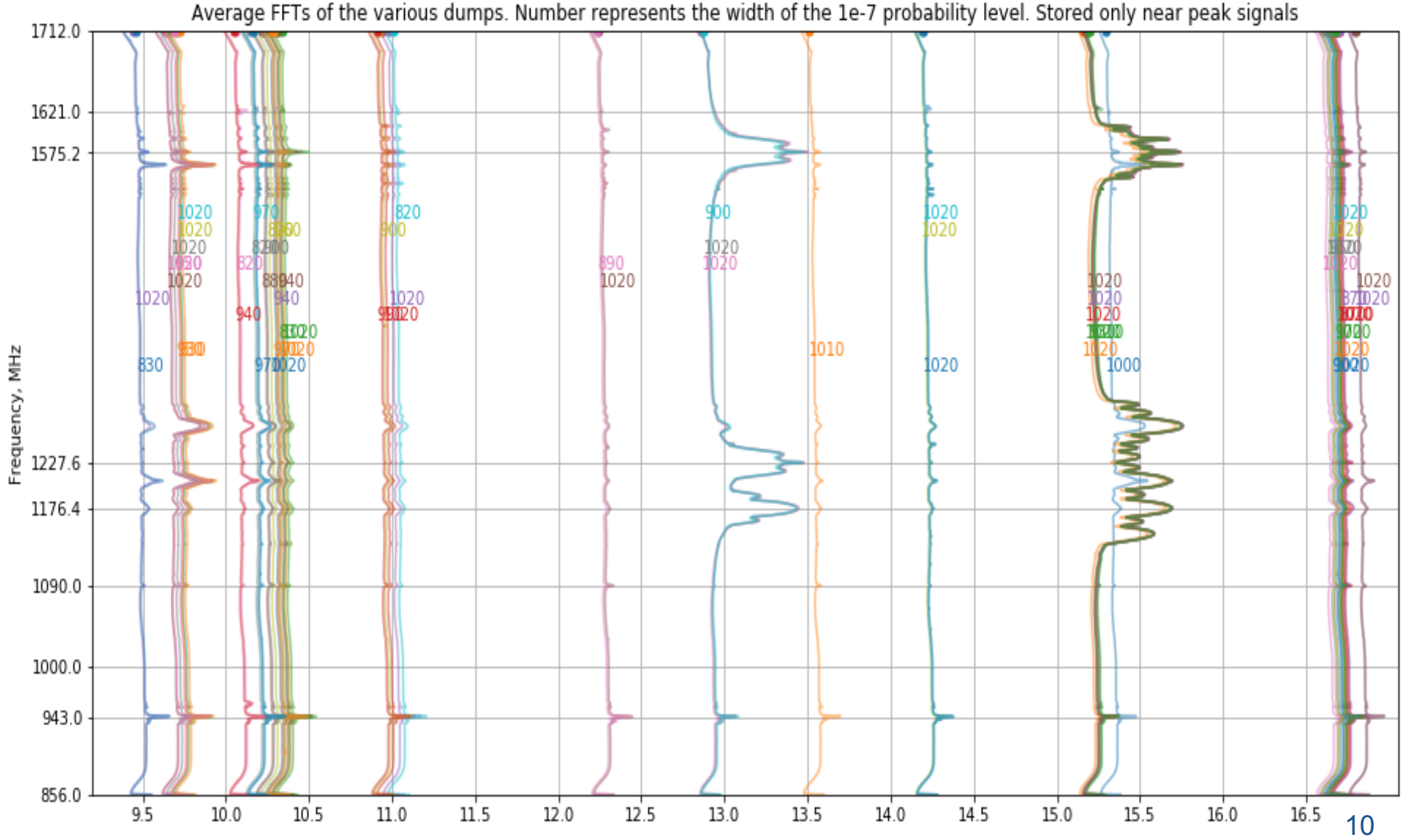
L-band Avionics



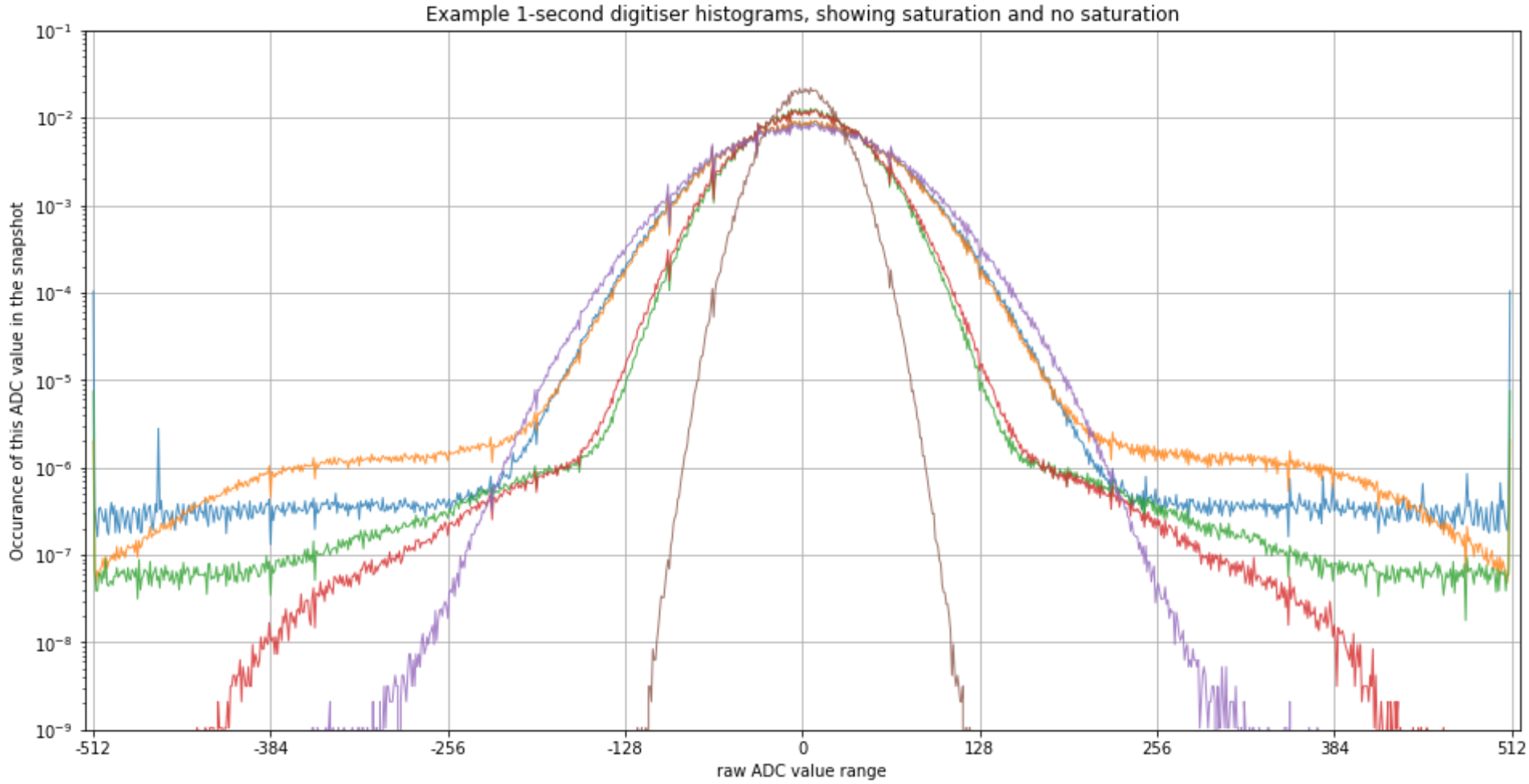
SSR & ADS-B


RFI Montioring Station ASC
Fri Feb 1 00:00:00 2019 to Thu Feb 28 23:00:00 2019 (f = 1089 to 1091 MHz Aircraft SSR Extended)
1089.25
1089.50
1089.75
1090.00
1090.25
1090.50
1090.75
1091.00
Time Occupancy [%]
0
10
20
Frequency [MHz]

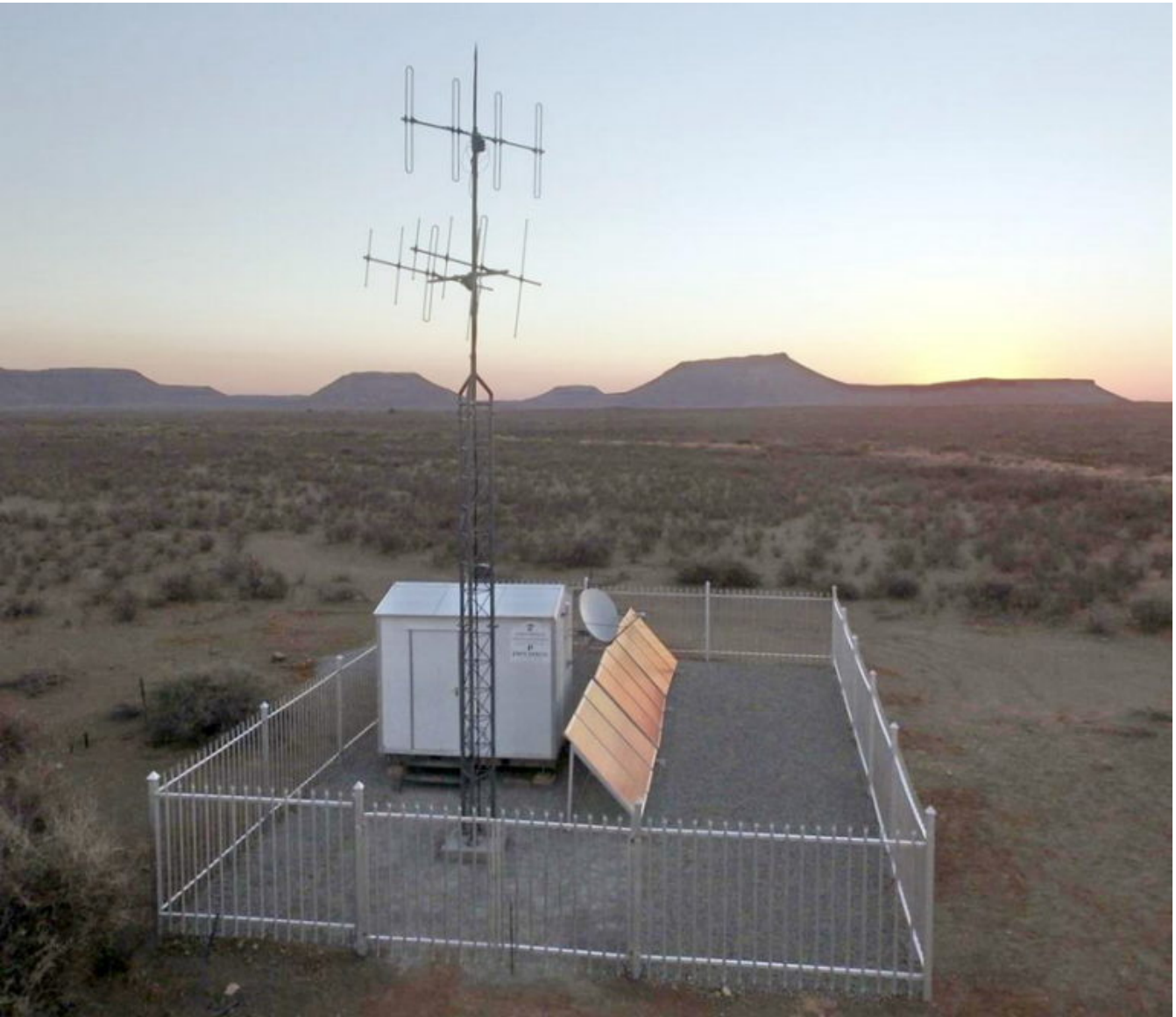
L-band RFI – GNSS & Avionics



Avionic & GNSS signals



COMRAD Passive Radar



SKARAB

So how did we get here?

- The MeerKAT Challenge
  - Build a world leading radio telescope
    - for a fixed cost
    - within a fixed schedule.
  - Be an SKA ***precursor*** telescope.

Design Parameter Space

- Requirements
  - Sensitivity
  - Field of View
  - Angular resolution
  - Instantaneous bandwidth
  - Dynamic range
    - Stable and smoo
      instrumenta
  - RFI/EM
  - Re ility
- Constraints
  - Capital
  - P ption
    cost
    transport cost
    Data storage cost
  - Maintenance cost

Systems Engineering

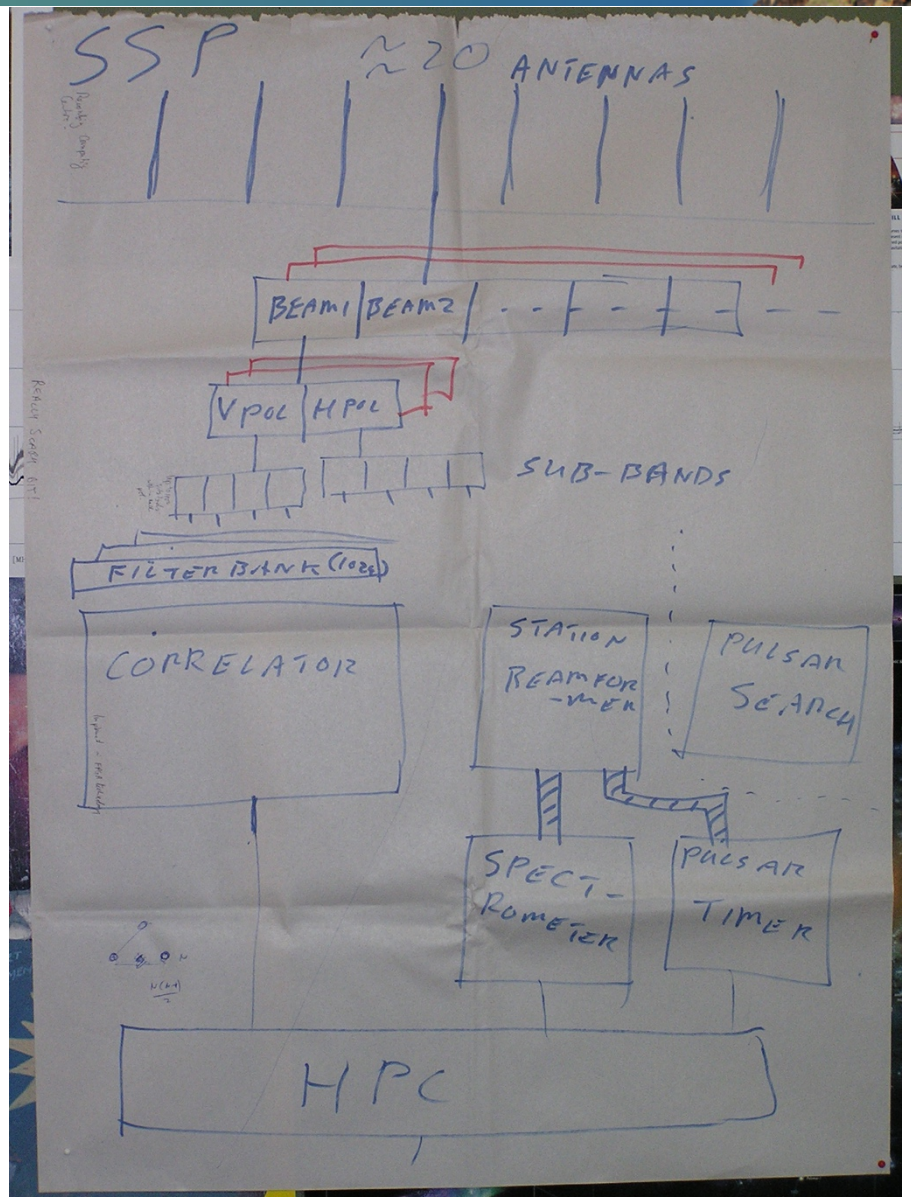
oncept Exploration to fully sample this
r space and perform trade-off studies against constraints.

Validate cost and performance using ***Prototypes***.

In the beginning there was KAT

~ 2003

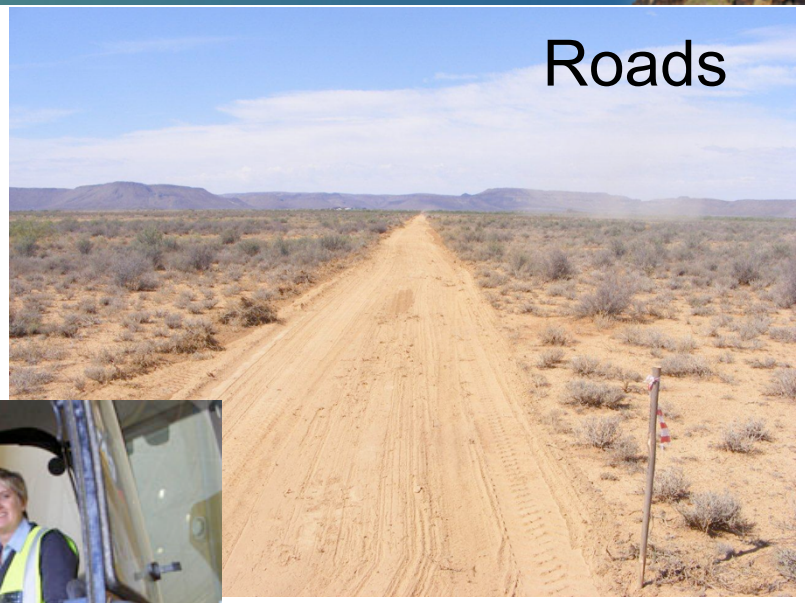
SKA technology pathfinder with high risk options



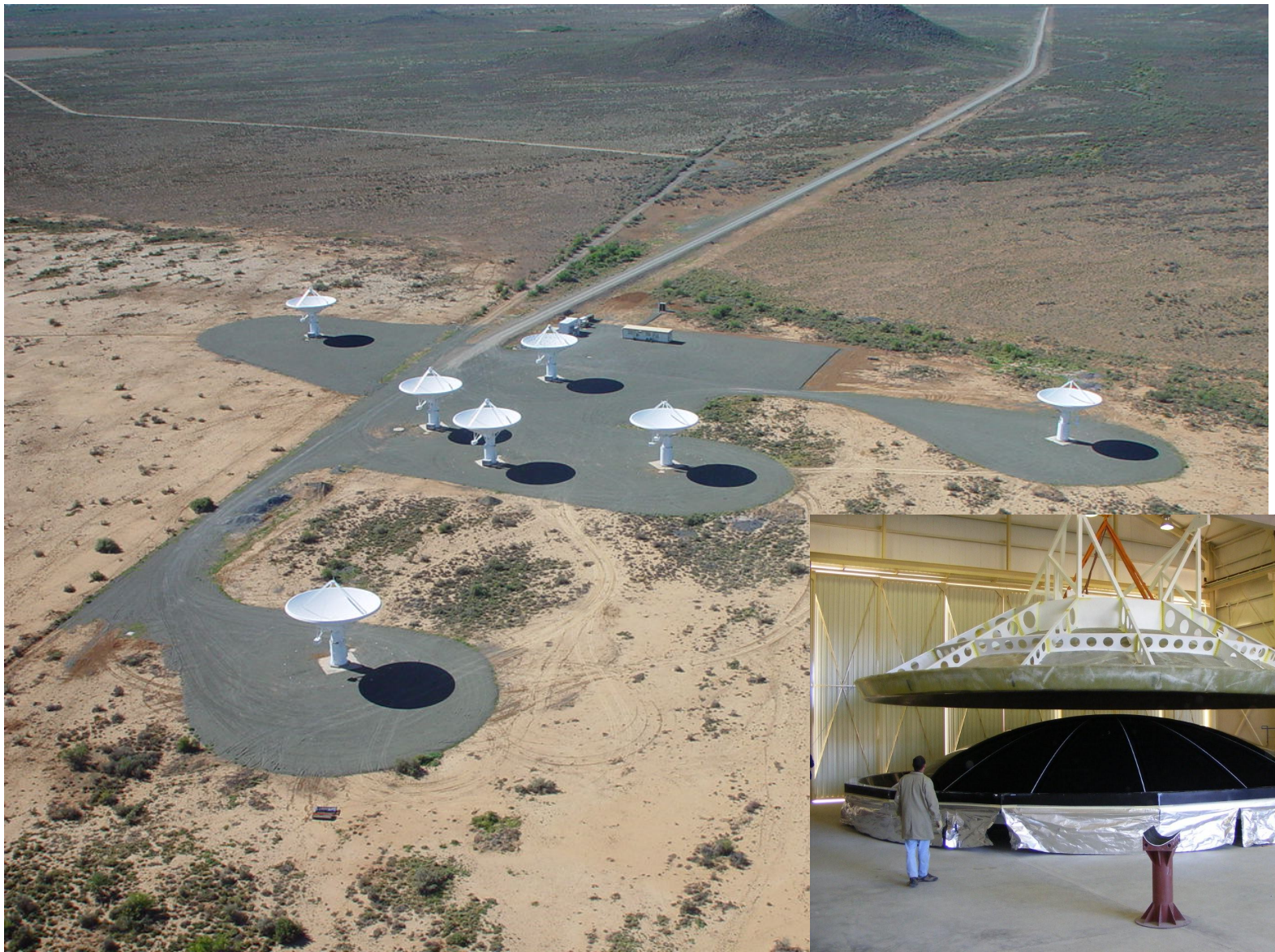
XDM 15-m composite & PAFs

HartRAO 26-m & XDM 15-m

Establishing the Karoo site



KAT-7 12-m



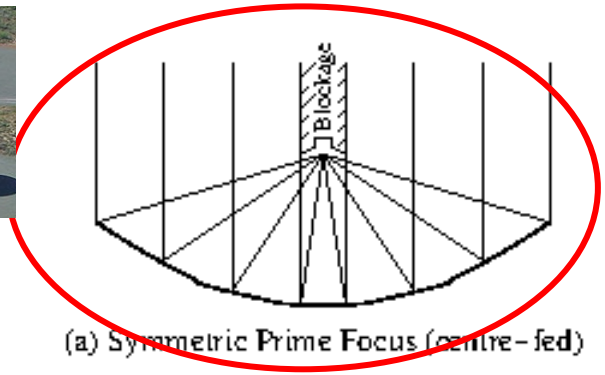
Design Parameter Space

- Sensitivity
- Field of View
- Angular resolution
- Instantaneous bandwidth
- Sky coverage
- Dynamic range
- Stability
- RFI/EMC
- Reliability/availability

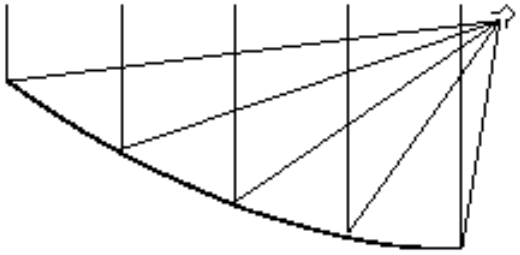
- Capital cost
- Power consumption
- Compute cost
- Data transport cost
- Data storage cost
- Maintenance cost

Need to do a thorough Concept Exploration to fully sample this parameter space and perform trade-offs.

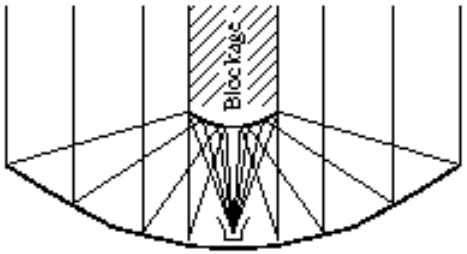
Dish Optical Configurations



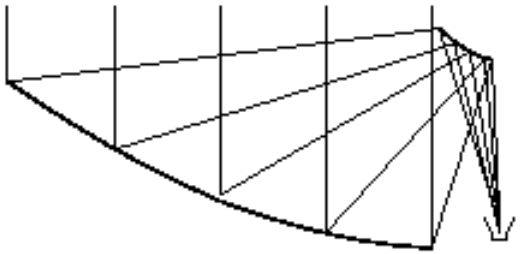
(a) Symmetric Prime Focus (centre-fed)



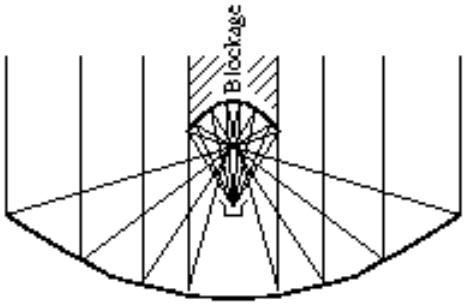
(b) Offset Prime Focus



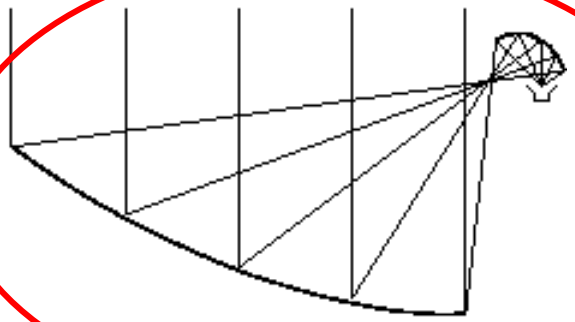
(c) Symmetric Cassegrain



(d) Offset Cassegrain

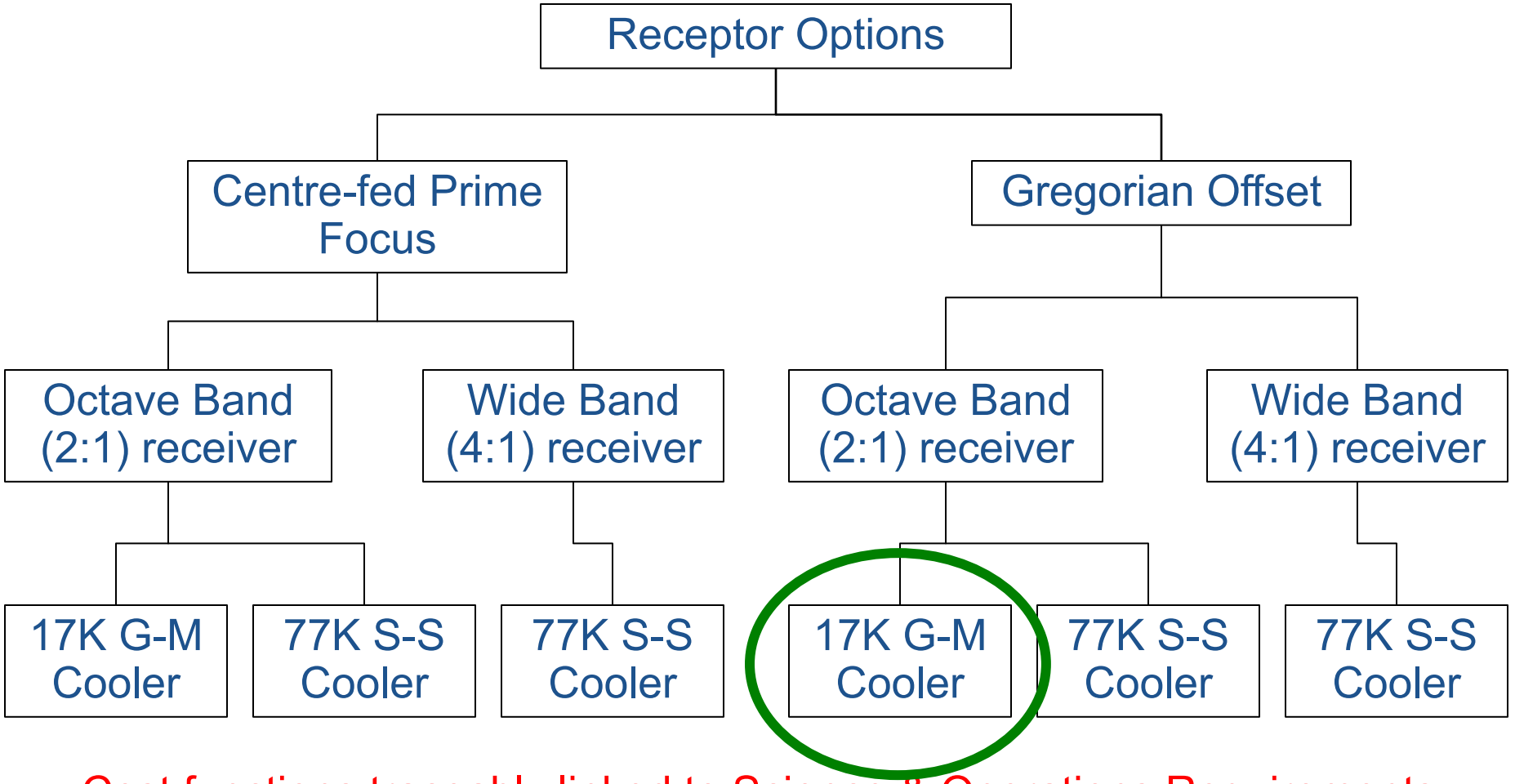


(e) Symmetric Gregorian



(f) Offset Gregorian

Example of CoDR Study: Receptor

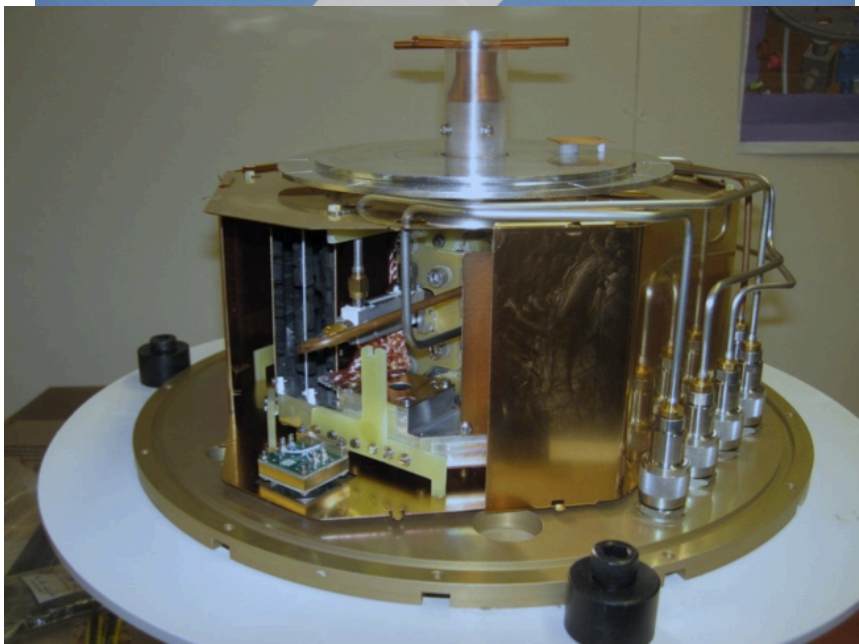


Cost functions traceably linked to Science & Operations Requirements

NOT post-facto justification for technology choice

KAT-7 – (not a MeerKAT prototype…)

- Symmetric centre-fed dish
- Wide flare corrugated horn
- Compact OMT
- Stirling cycle cryogenics
- Water cooling
- Ion vacuum pump
- RF-over-fibre
- Heterodyne Rx
- Casper/Roach DSP



Costs more, but:

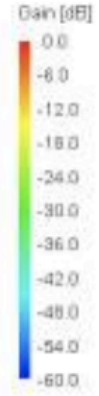
Unblocked aperture.
"Good" beam and
Aperture efficiency.

Large volume for multiple receivers and associated services.
Easy access.

Low ground spillover.

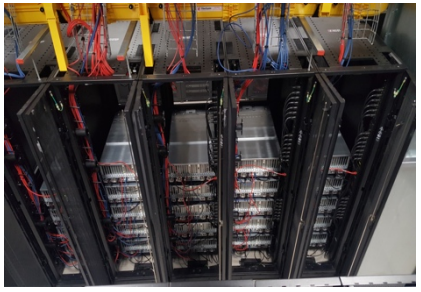
Comparison of beam patterns

Satellite
RFI

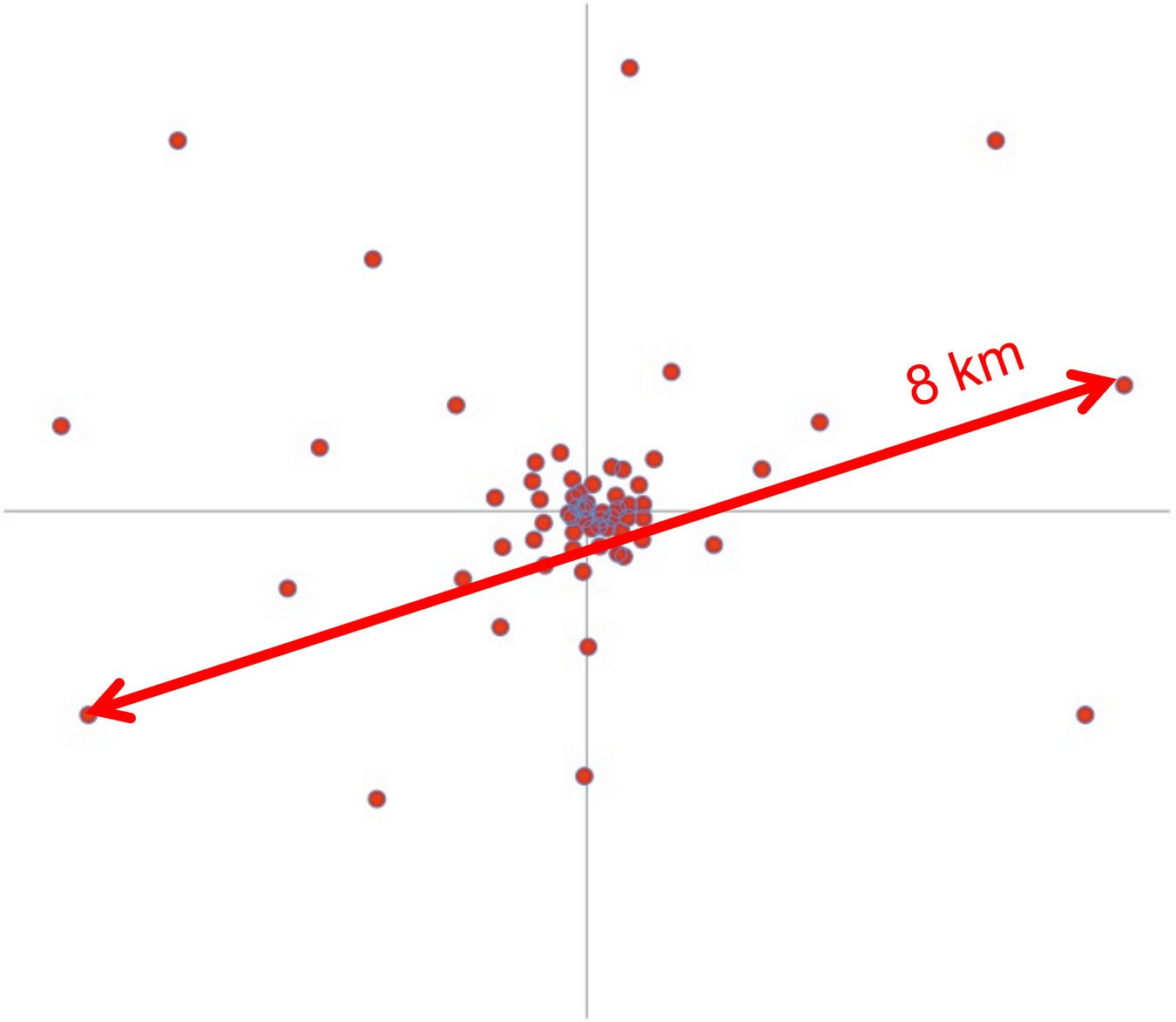


High Level Description

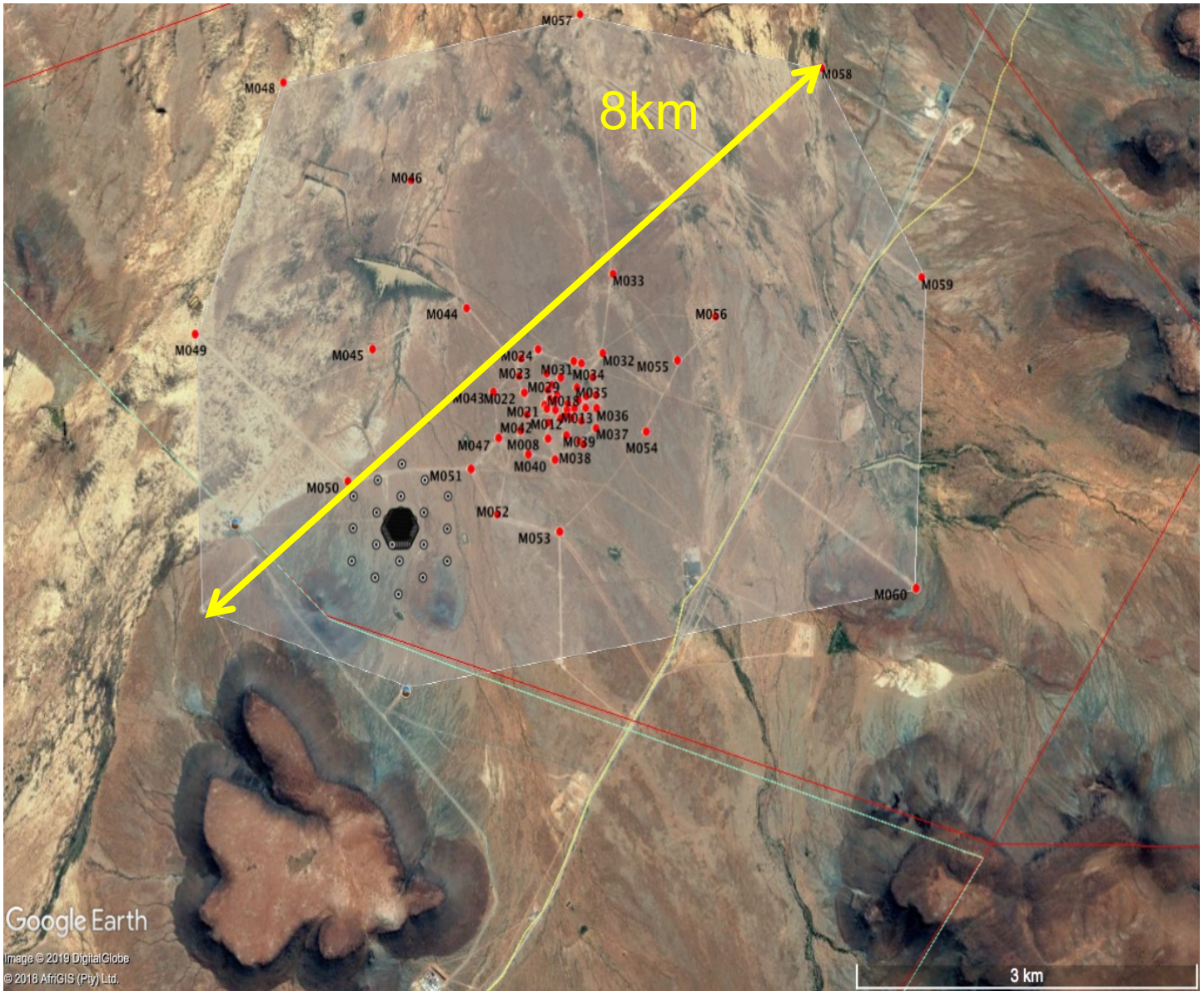
- 64 x 13.5 m offset Gregorian antennas
  - Compact core (1 km diameter)
  - 8 km maximum baseline
- 3 cryogenic single pixel receivers
  - UHF 0.580-1.015 GHz
  - L-band 0.9-1.67 GHz (T_{sys}~15K)
  - S-band (MPIfR) 1.75-3.5 GHz
  - ~~X-band 8-14.5 GHz~~
- Channelization
  - 1k wideband (pulsars)
  - 4k wideband (continuum)
  - 32k wideband (spectral line)
  - 32k narrowband (BW=$F_{samp}/2^N$ spectral line)
- Correlator/Beamformer
- User supplied backends
  - PTUSE (MeerTIME)
  - FBFUSE+APSUSE+TUSE (TRAPPUM)
  - BLUSE (Breakthrough Listen)
- Science Data Processing and Archive
- MeerKAT Extension



MeerKAT Configuration (64 antennas)



MeerKAT-64 Configuration



Dish panel factory

Carbon-fibre Subreflector

Pedestal fabrication & integration

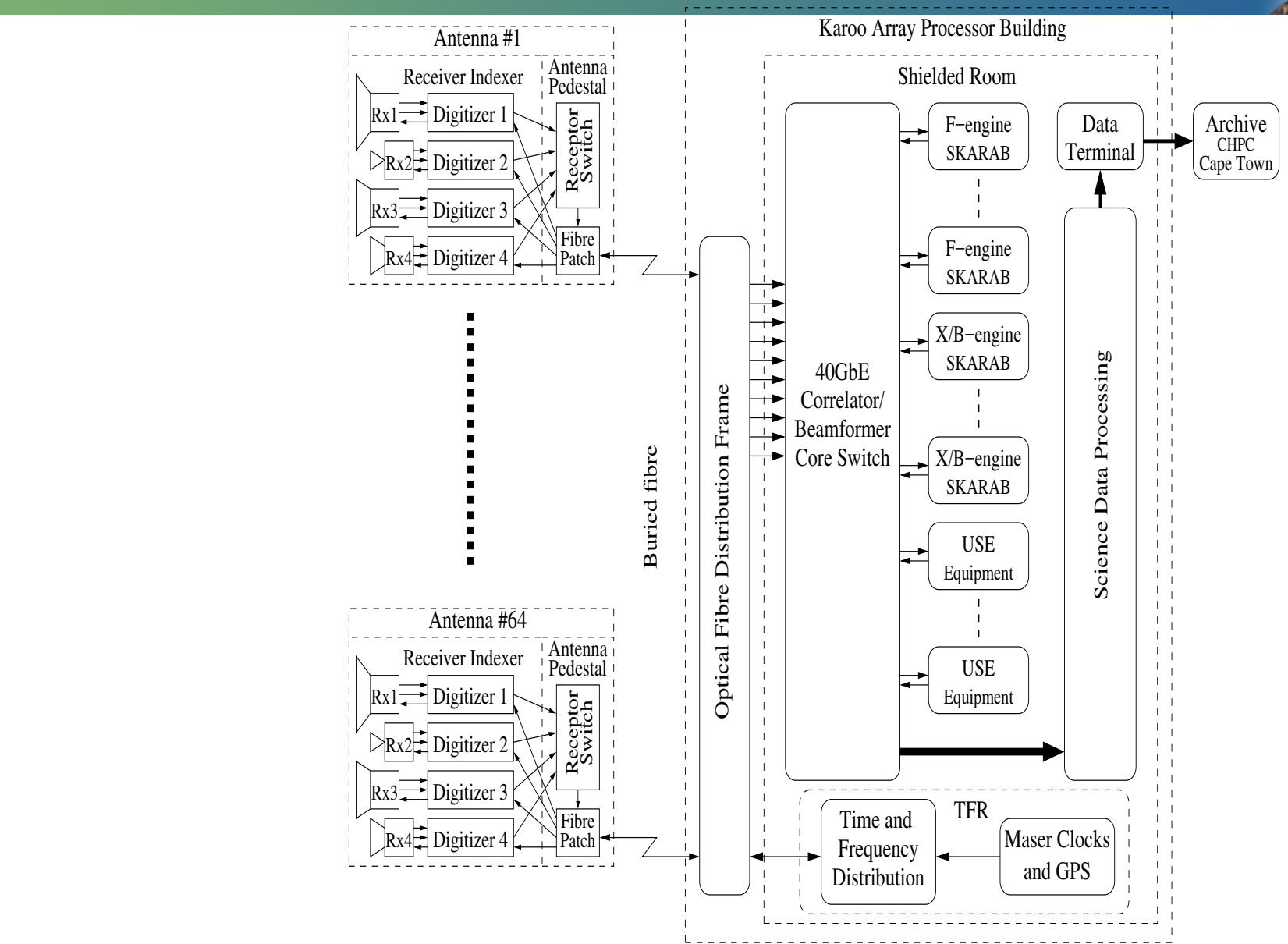
Off and on-site production line

“Traditional” paneled dish

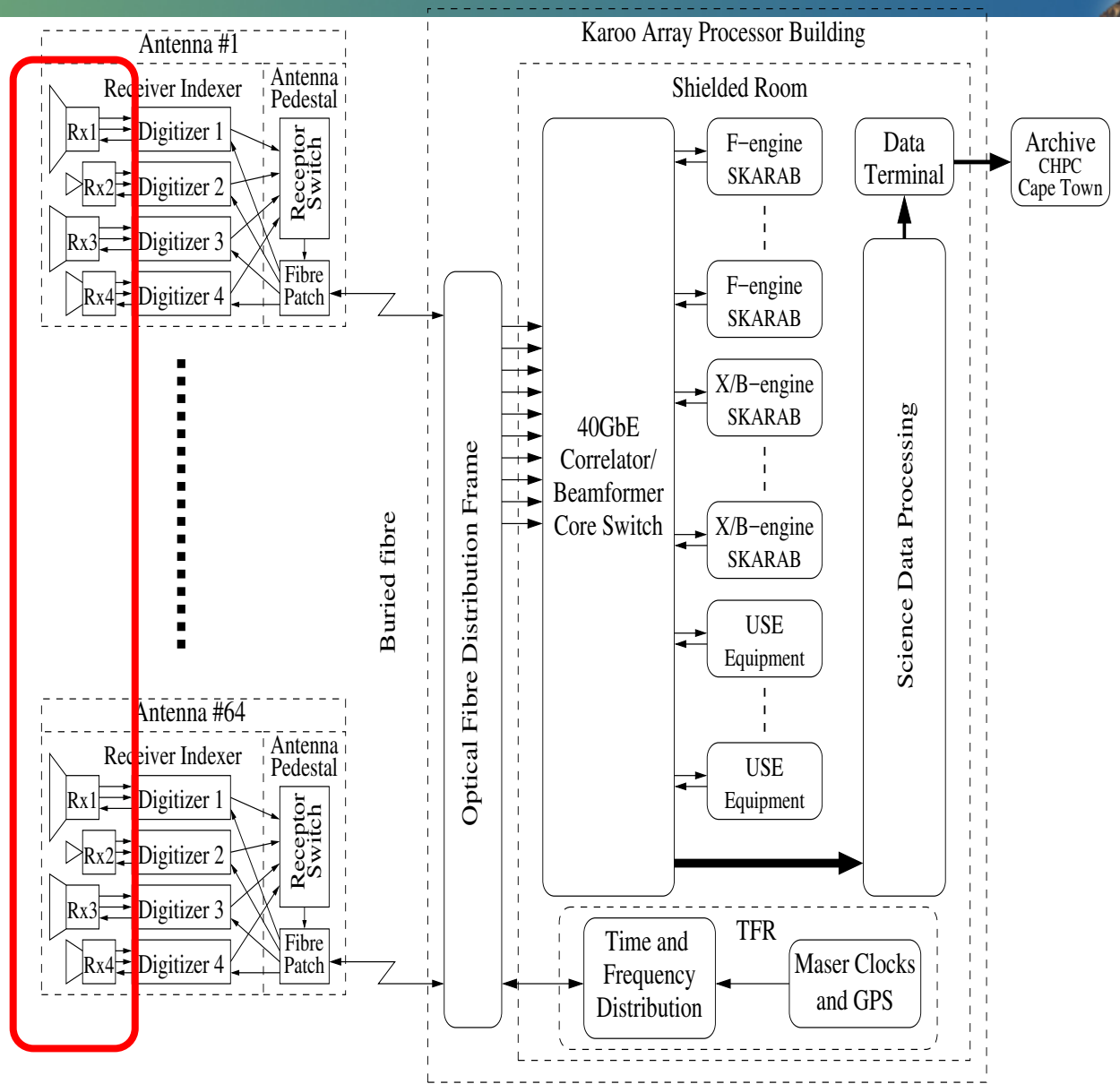
In silicon and in the Karoo

MeerKAT core antennas

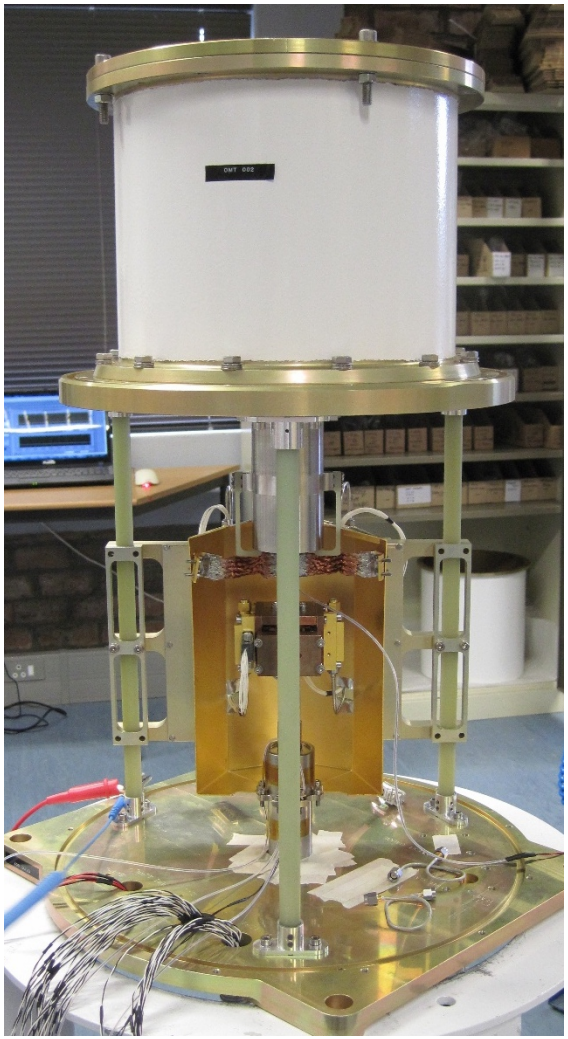
System Architecture

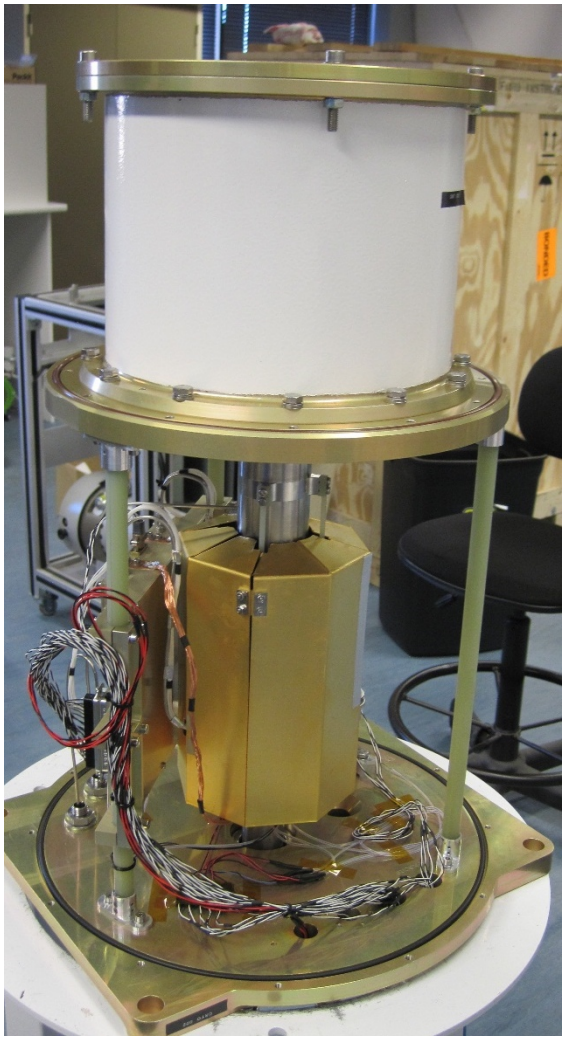


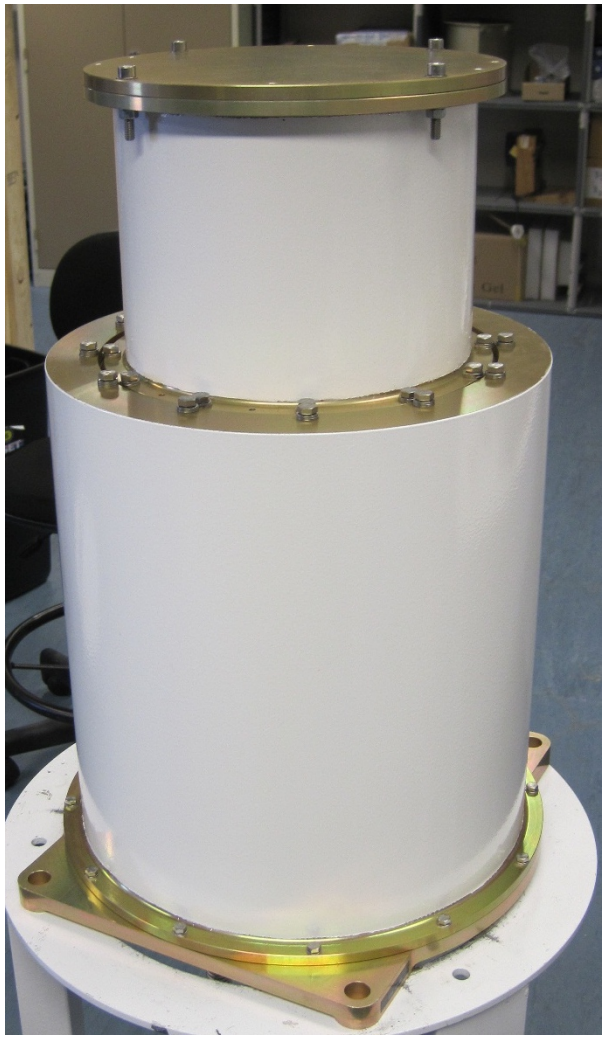
Receivers


Antenna #1
Receiver Indexer
Antenna Pedestal
Rx1
Rx2
Rx3
Rx4
Digitizer 1
Digitizer 2
Digitizer 3
Digitizer 4
Receptor Switch
Fibre Patch
Antenna #64
Receiver Indexer
Antenna Pedestal
Rx1
Rx2
Rx3
Rx4
Digitizer 1
Digitizer 2
Digitizer 3
Digitizer 4
Receptor Switch
Fibre Patch
Buried fibre
Optical Fibre Distribution Frame
Karoo Array Processor Building
Shielded Room
40GbE Correlator/ Beamformer Core Switch
F−engine SKARAB
F−engine SKARAB
X/B−engine SKARAB
X/B−engine SKARAB
USE Equipment
USE Equipment
Science Data Processing
Data Terminal
Archive CHPC Cape Town
TFR
Time and Frequency Distribution
Maser Clocks and GPS

Cryogenic, 1.85:1 bandwidth Rx

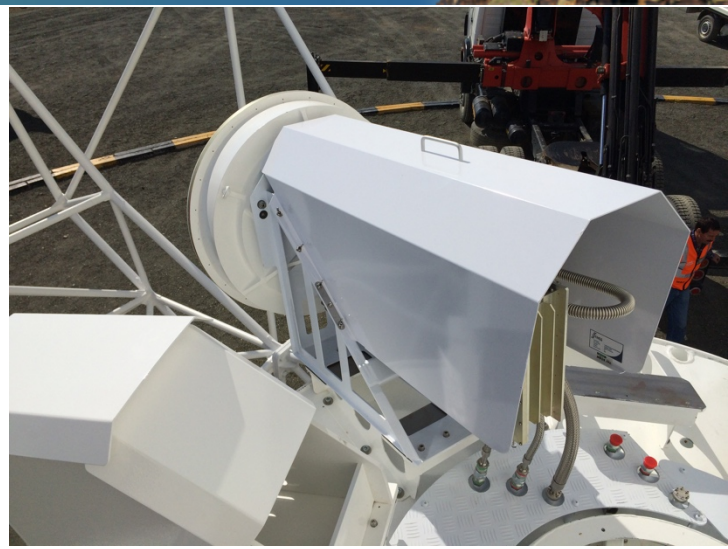


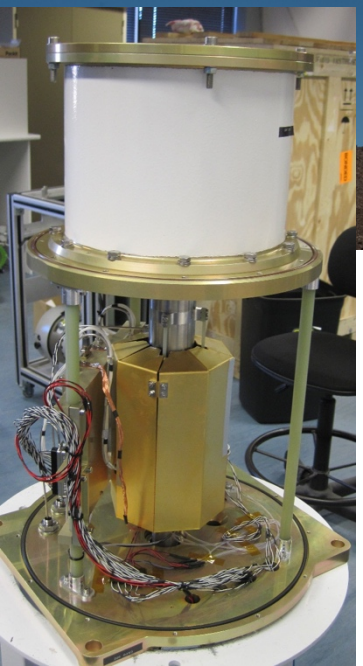




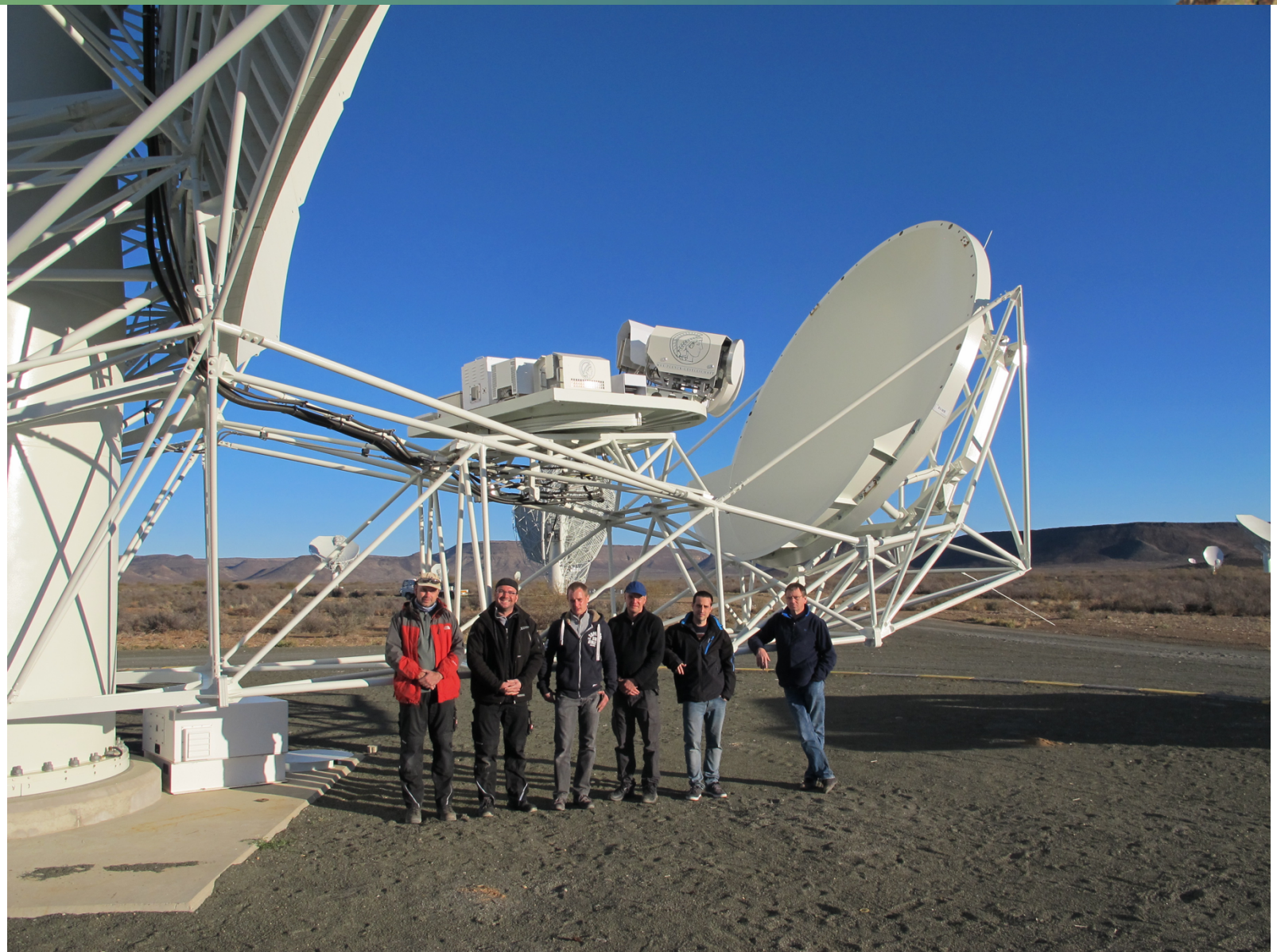
T_{rec}~7K

Cryogenic Receivers & Services



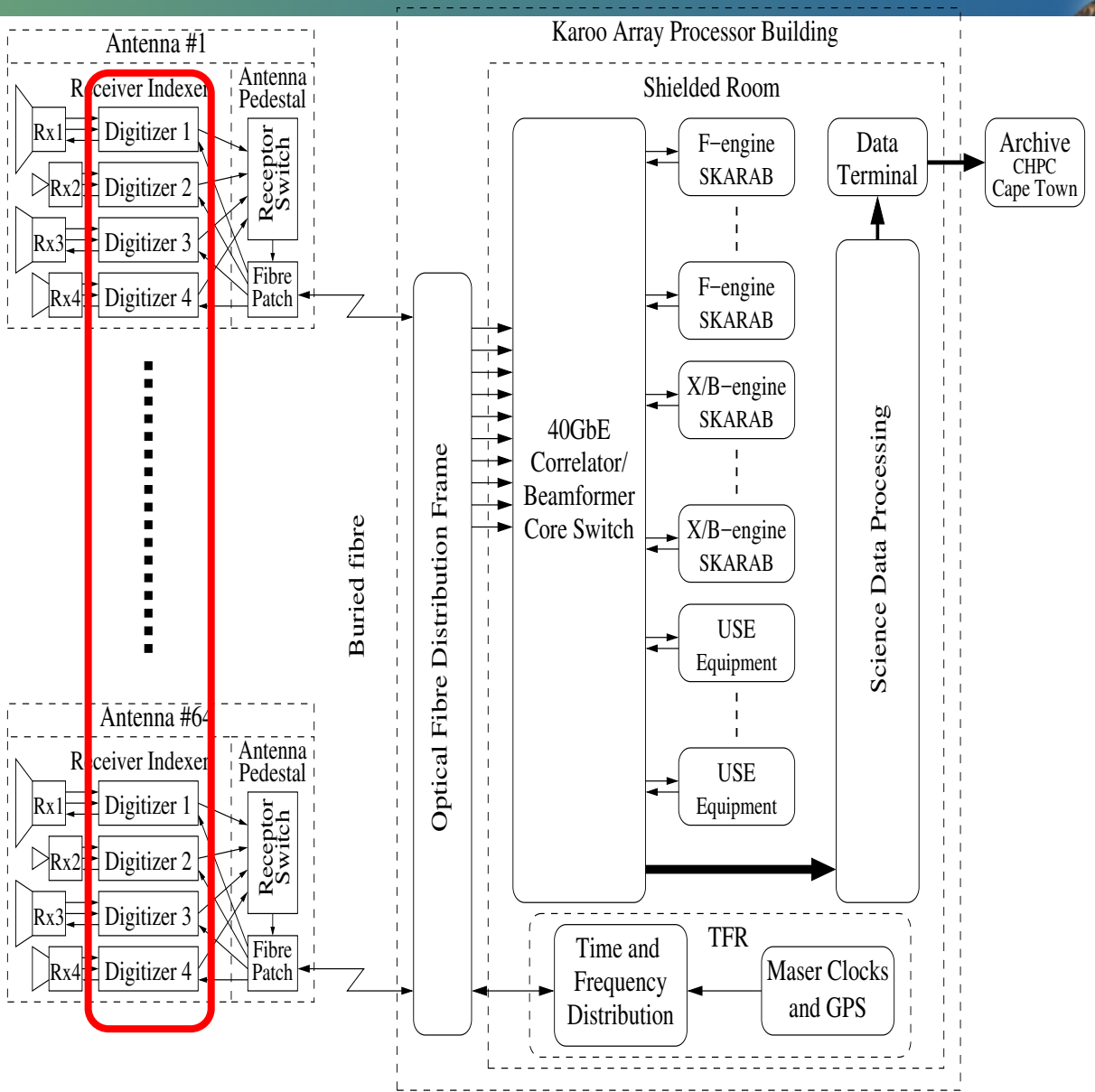


MPIfR S-band receiver



Rx horns are close to the ground

Digitizers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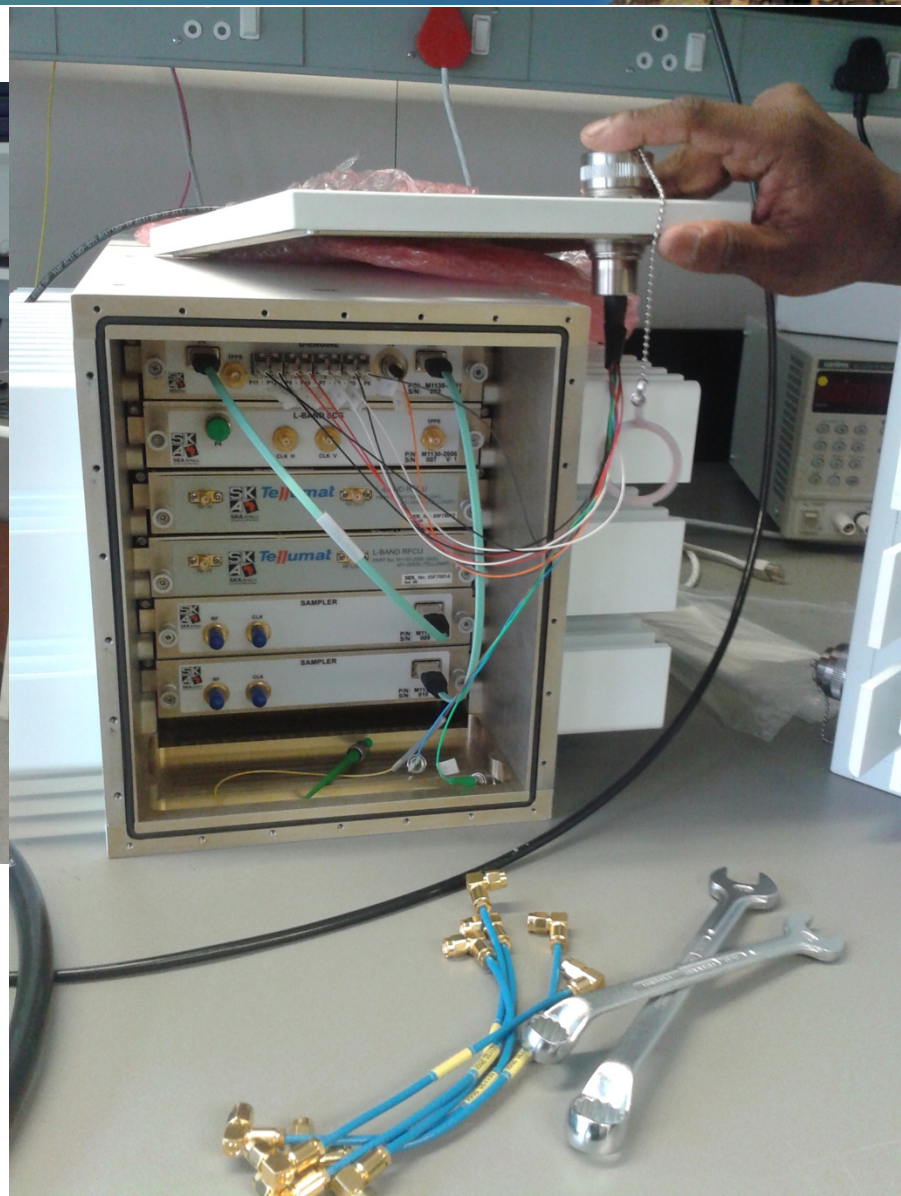
Maser Clocks and GPS

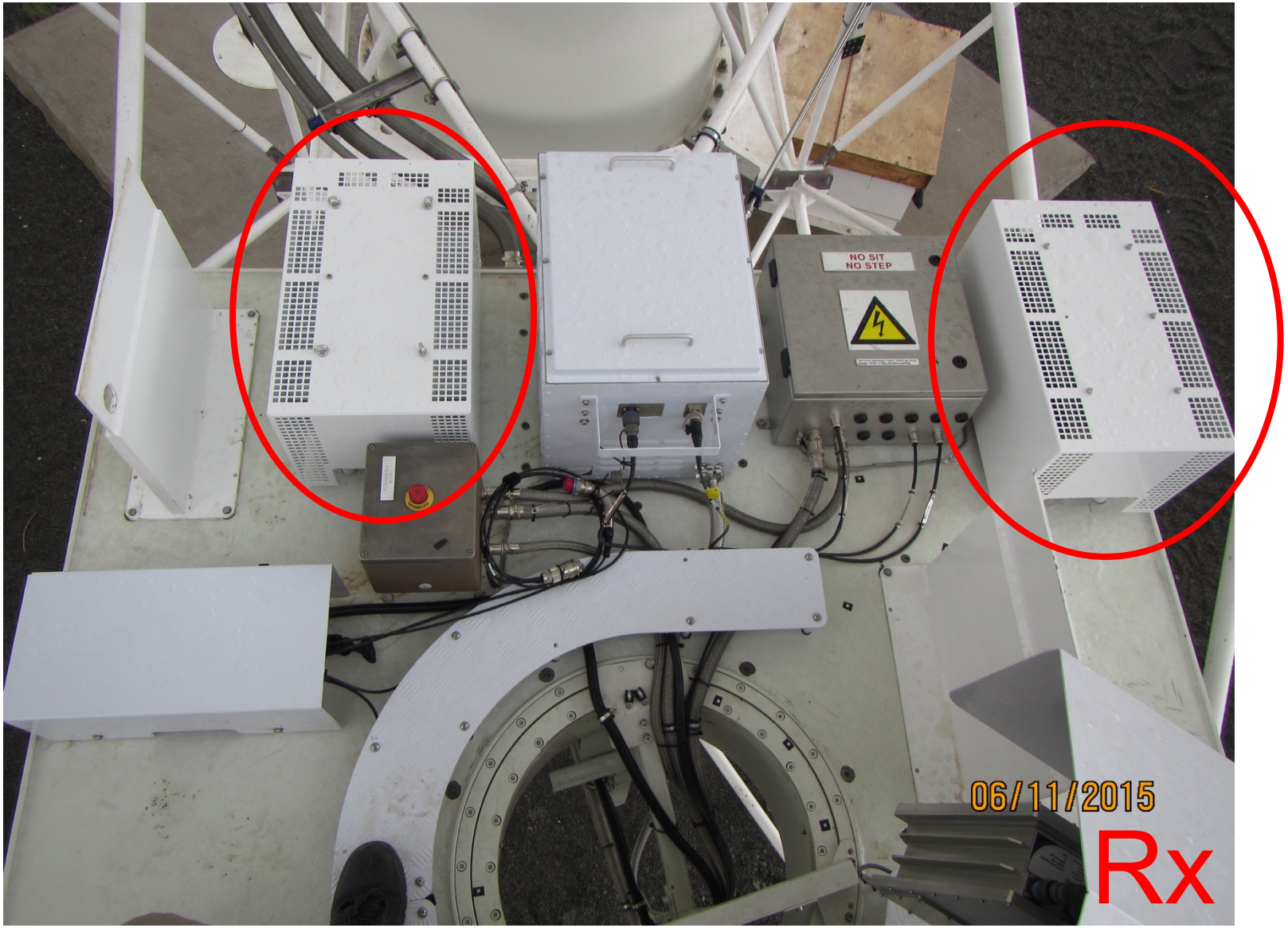
Digitizer Assembly

10 bits × 2 pol × 1712 Msamp/s

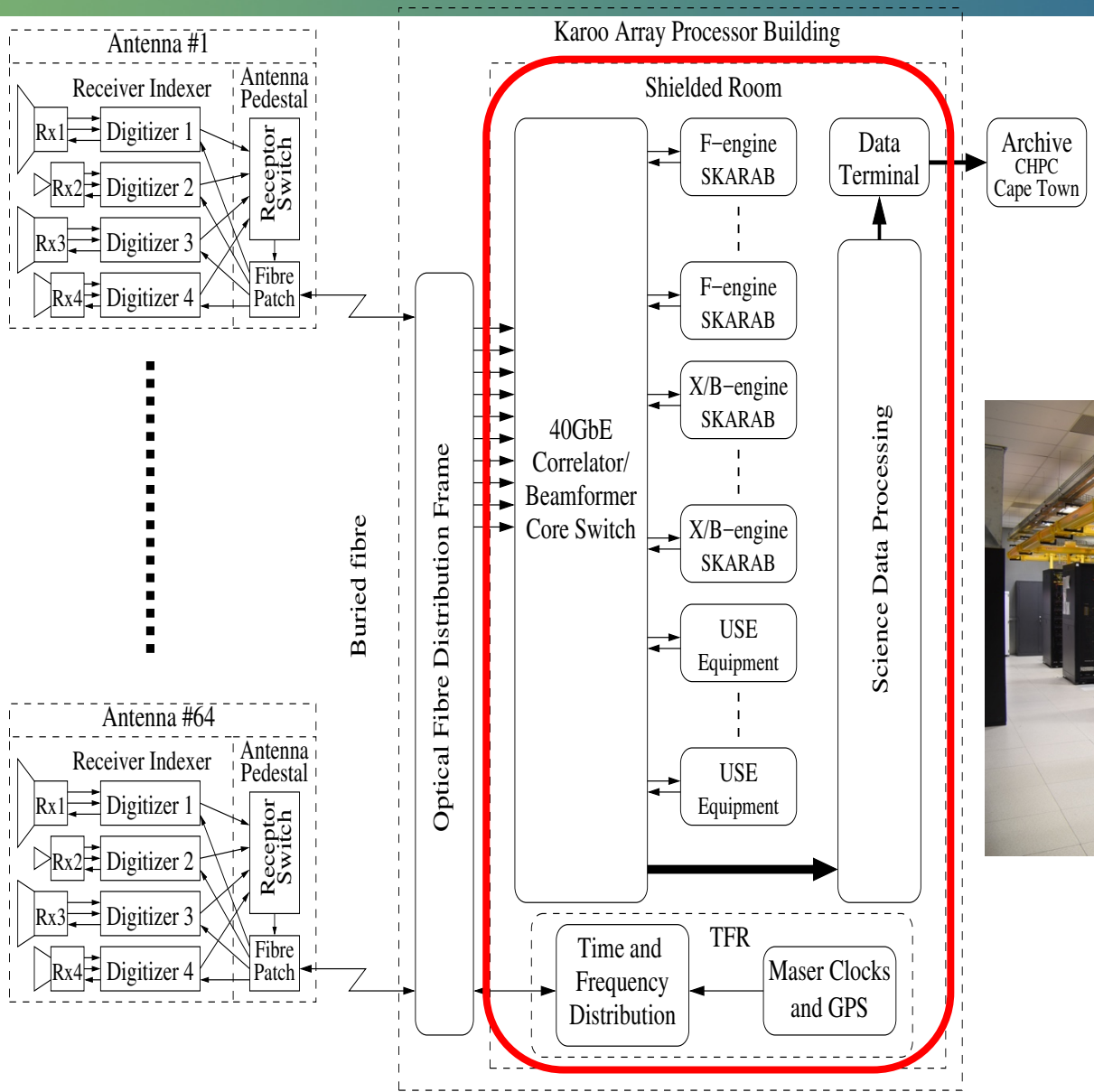


- ~1 DVD per second per antenna
- Array would produce a 12 km high stack of DVDs per day

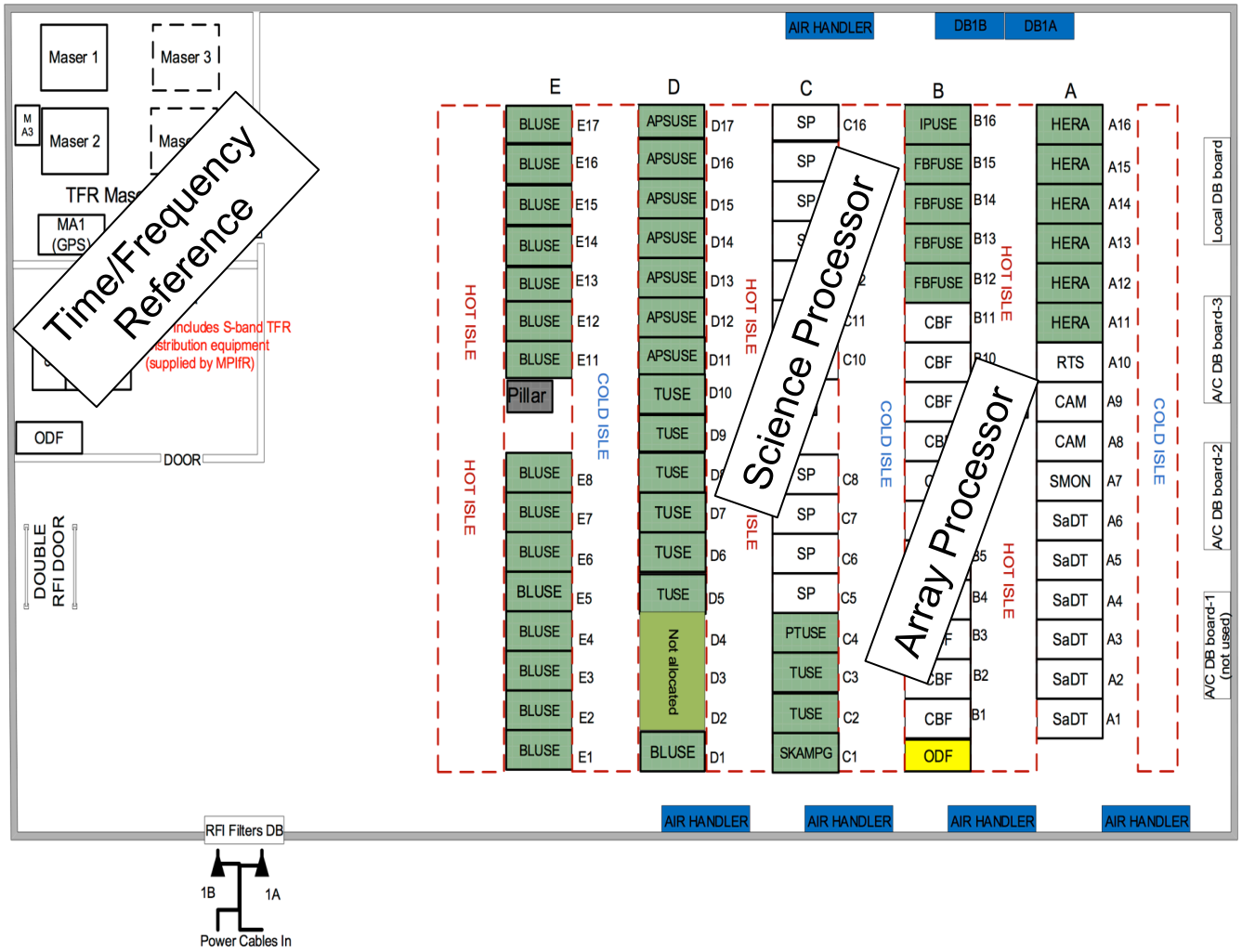
Close to receiver horns



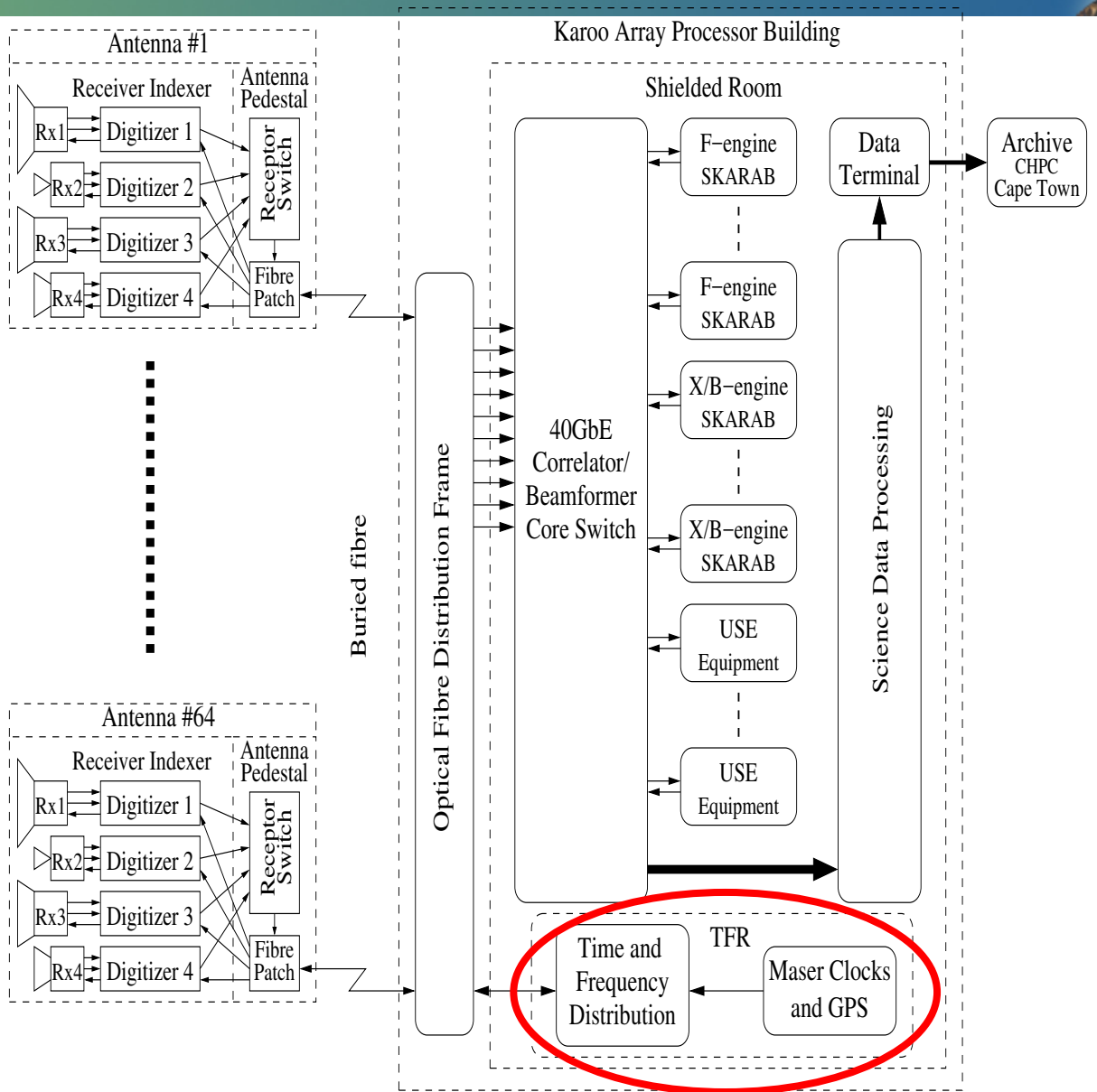
Shielded Equipment Room



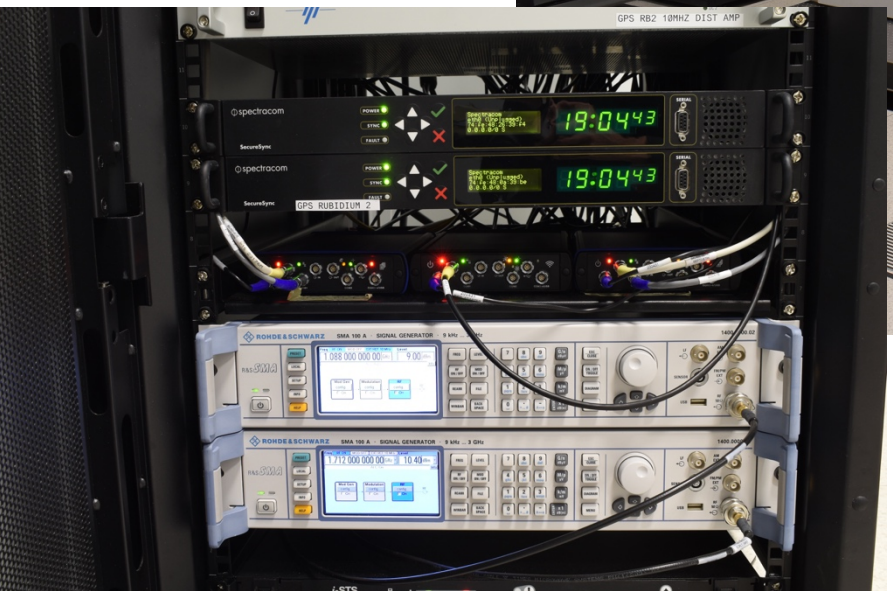
Shielded Data Rack Room



Time and Frequency Reference

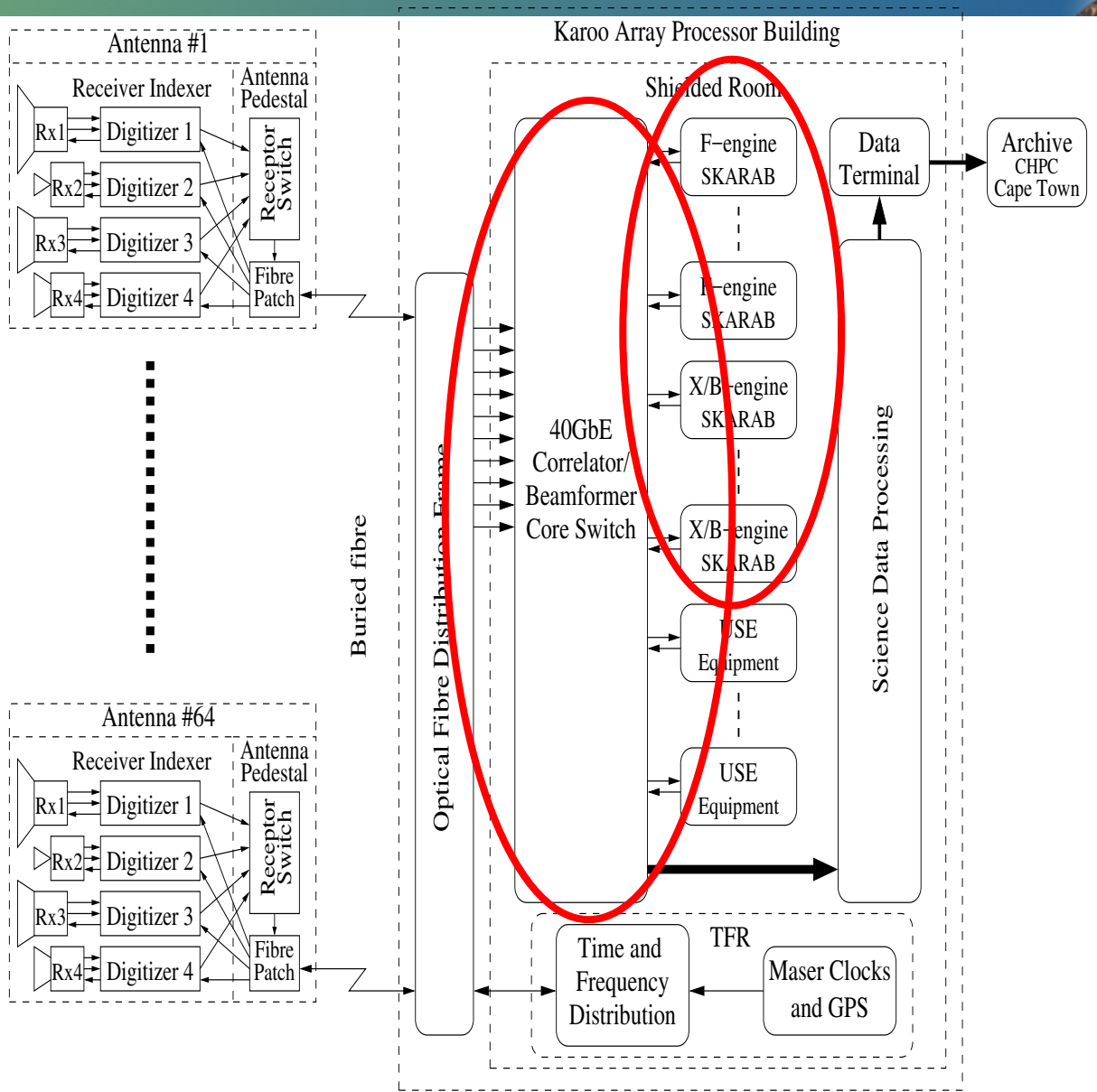


Time and Frequency Reference



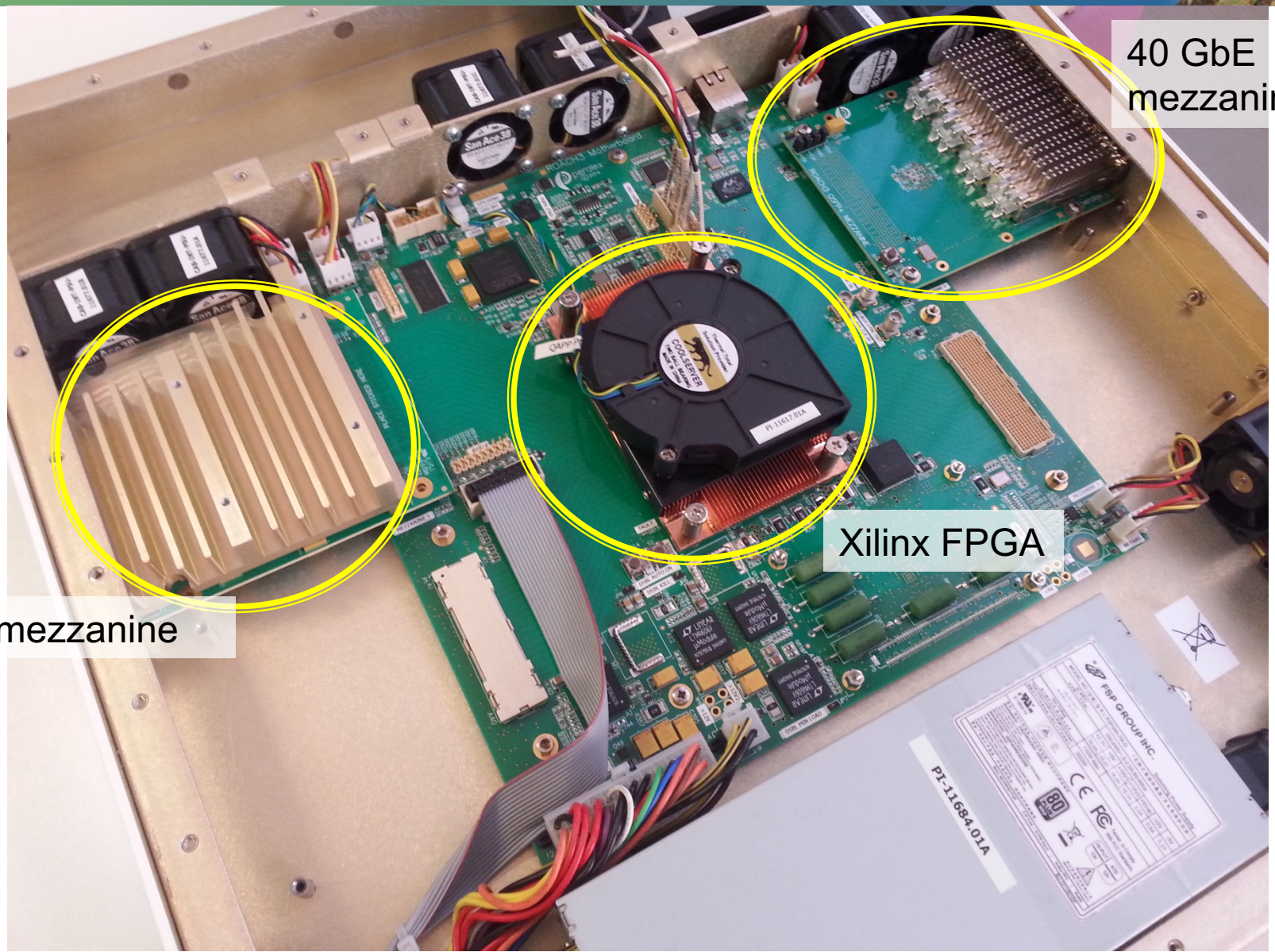
GNSS Common View UTC transfer

Correlator/Beamformer

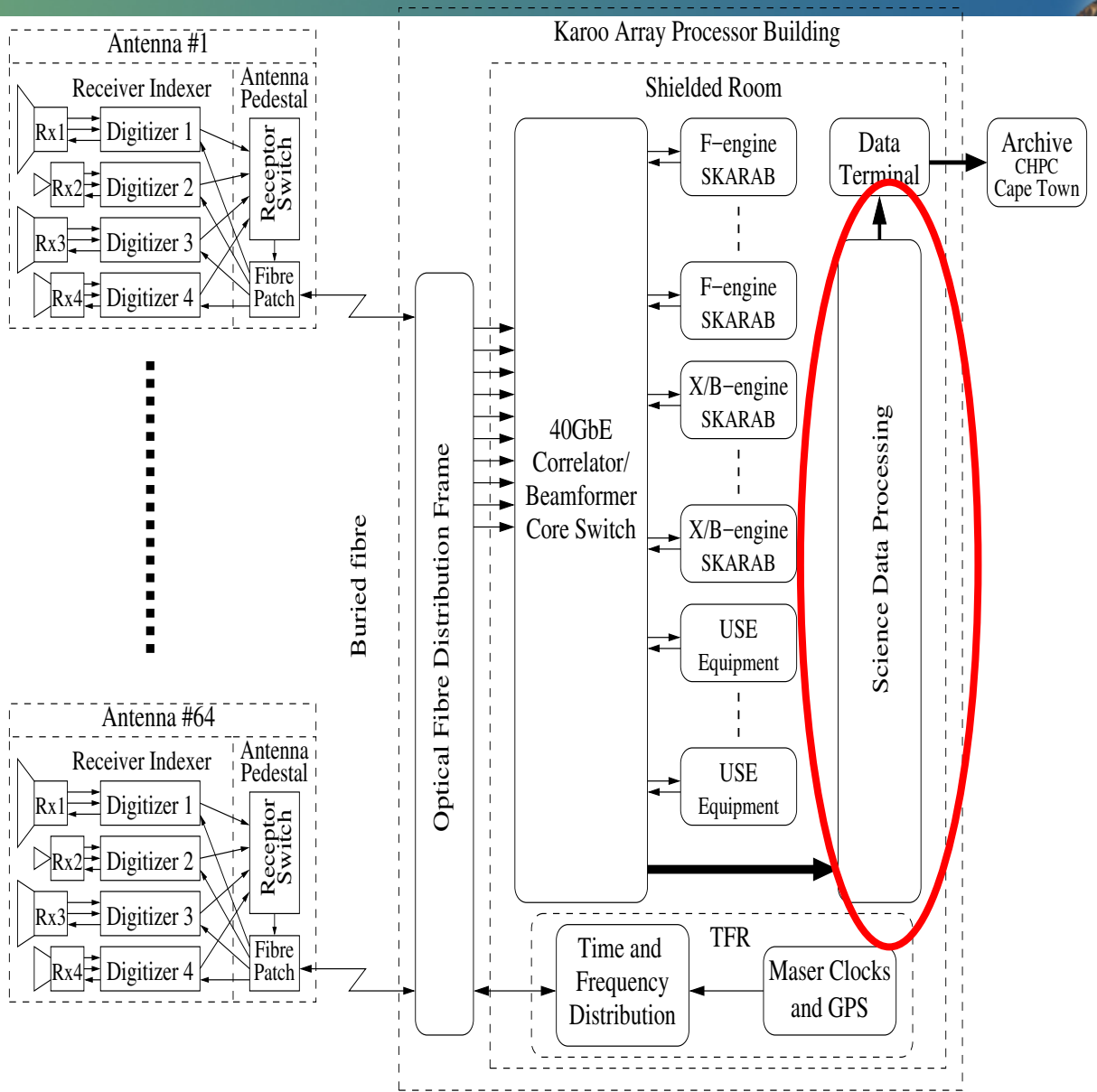


SKARAB Correlator/Beamformer

SKARAB



Science Data Processing



Deployed Infrastructure (as at Oct 2018) – 1st Tier

Realtime Mesos Cluster : Ingest + Cal

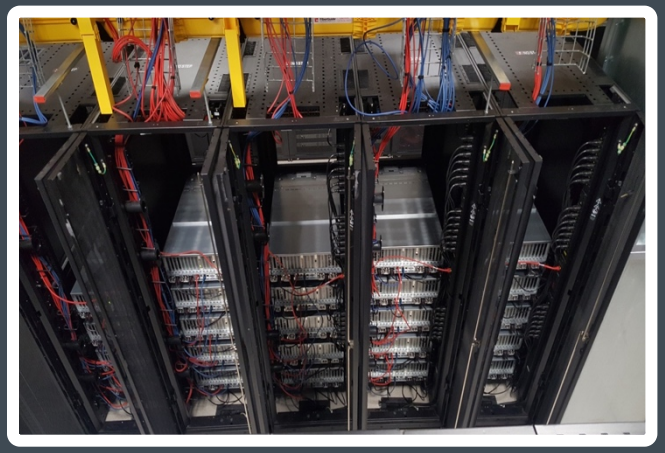
100 TFLOPs, 6TB RAM

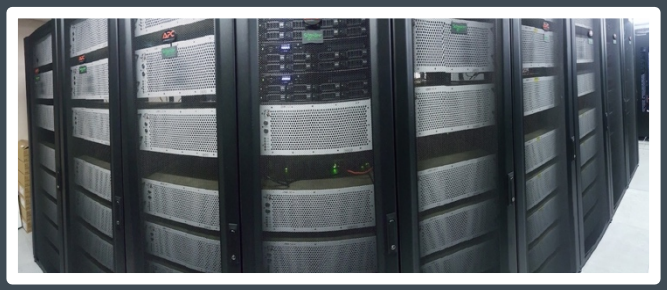
Batch Cluster : Spectral + Continuum Imaging

1.5 PFLOPs, 4TB RAM, 1 PB scratch

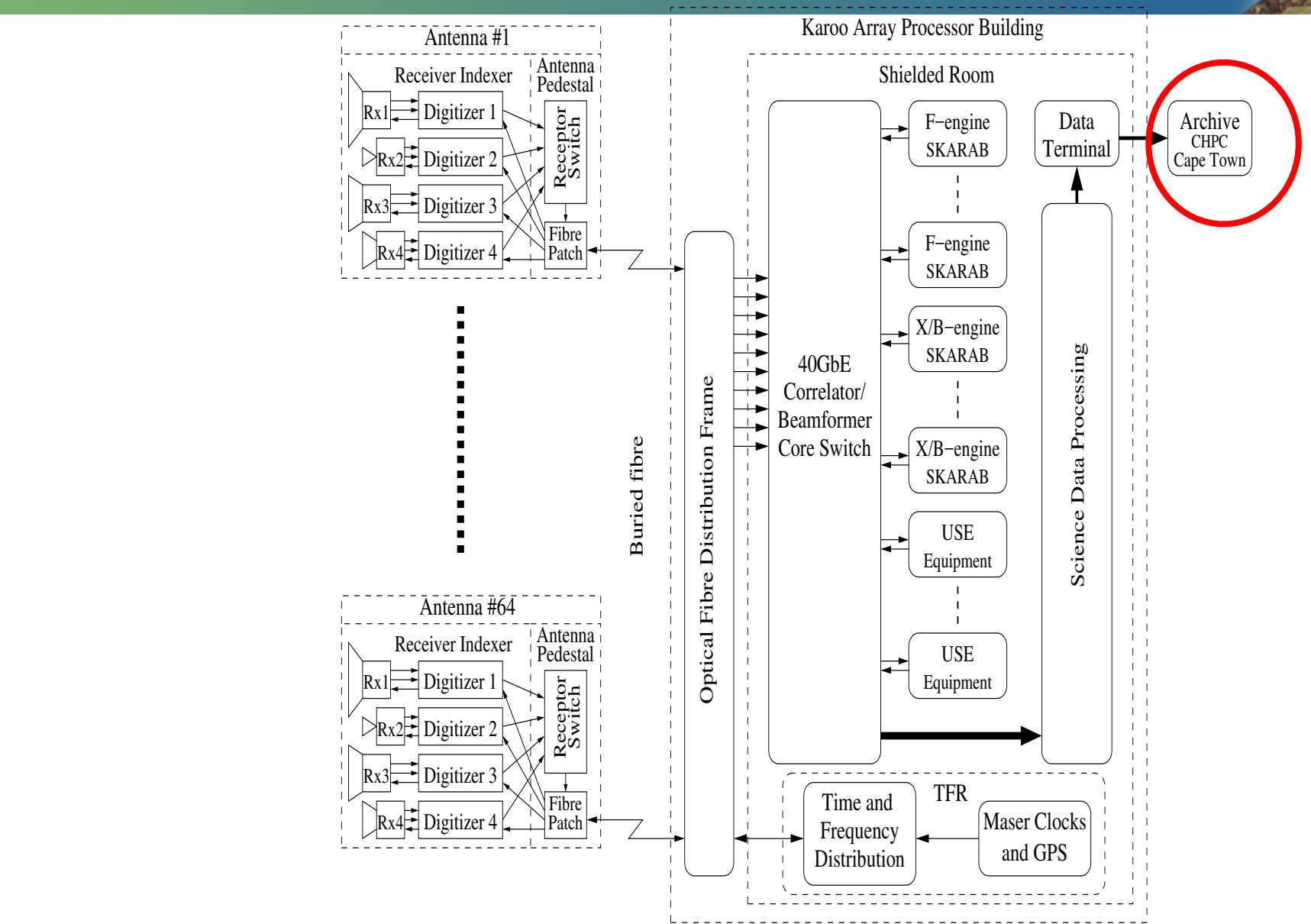
Object Storage : Vis Data + Science Products

cluster1: 5.4 PiB – production – 1 PiB used
cluster3: 12.2 PiB – ready for production



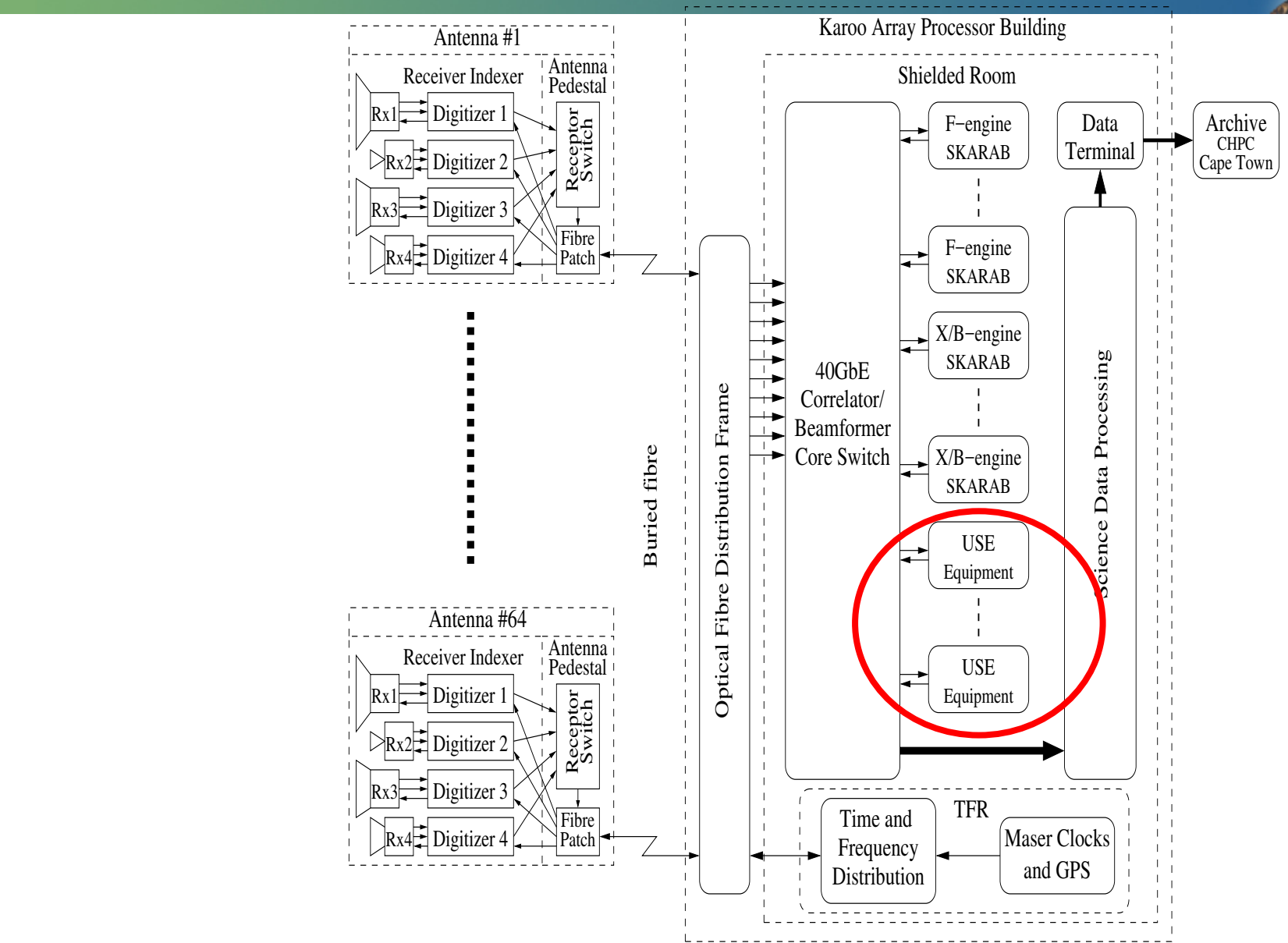


Archive at CHPC in CT

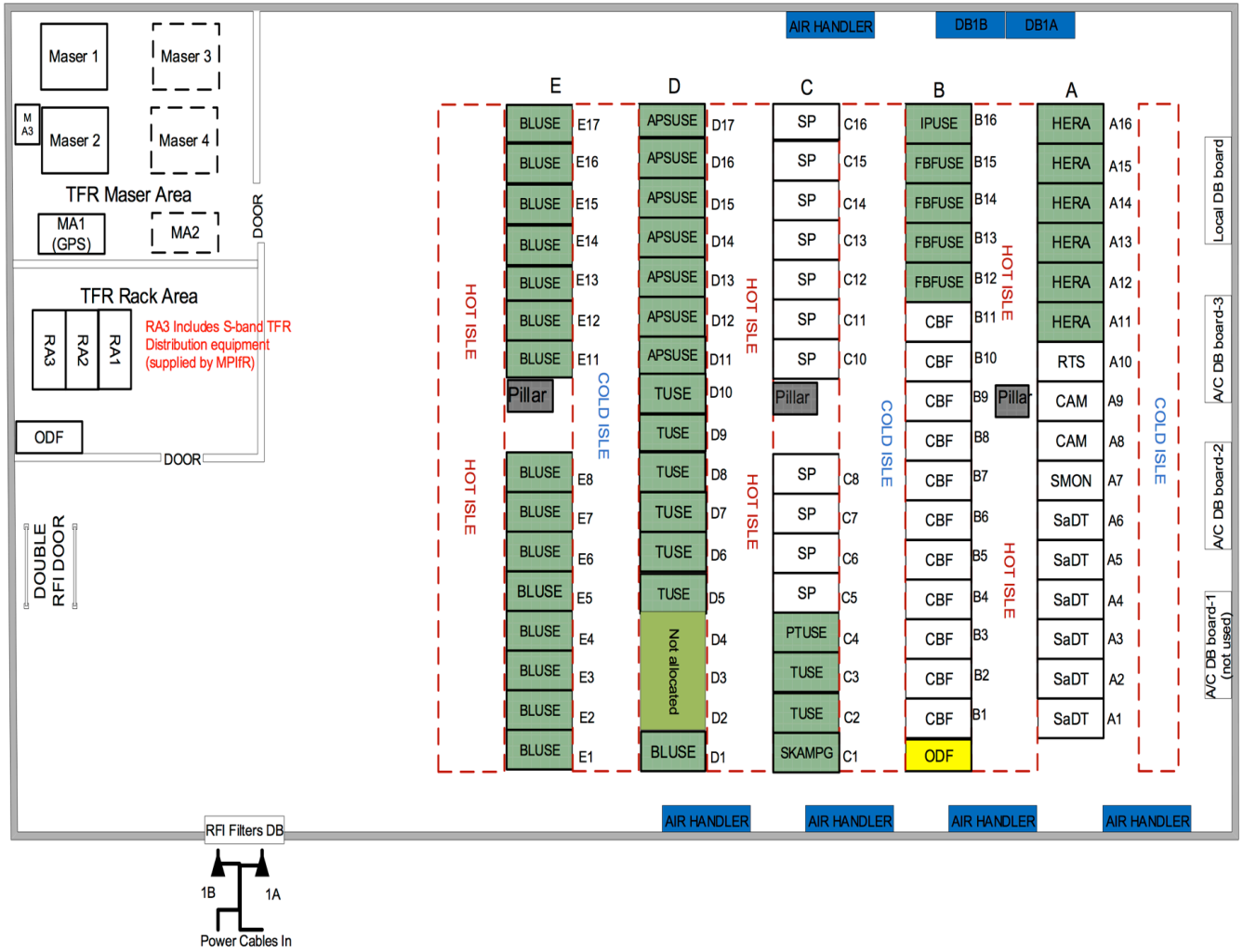


CEPH Archive and Tape Library at CHPC

User Supplied Equipment



User Supplied Equipment

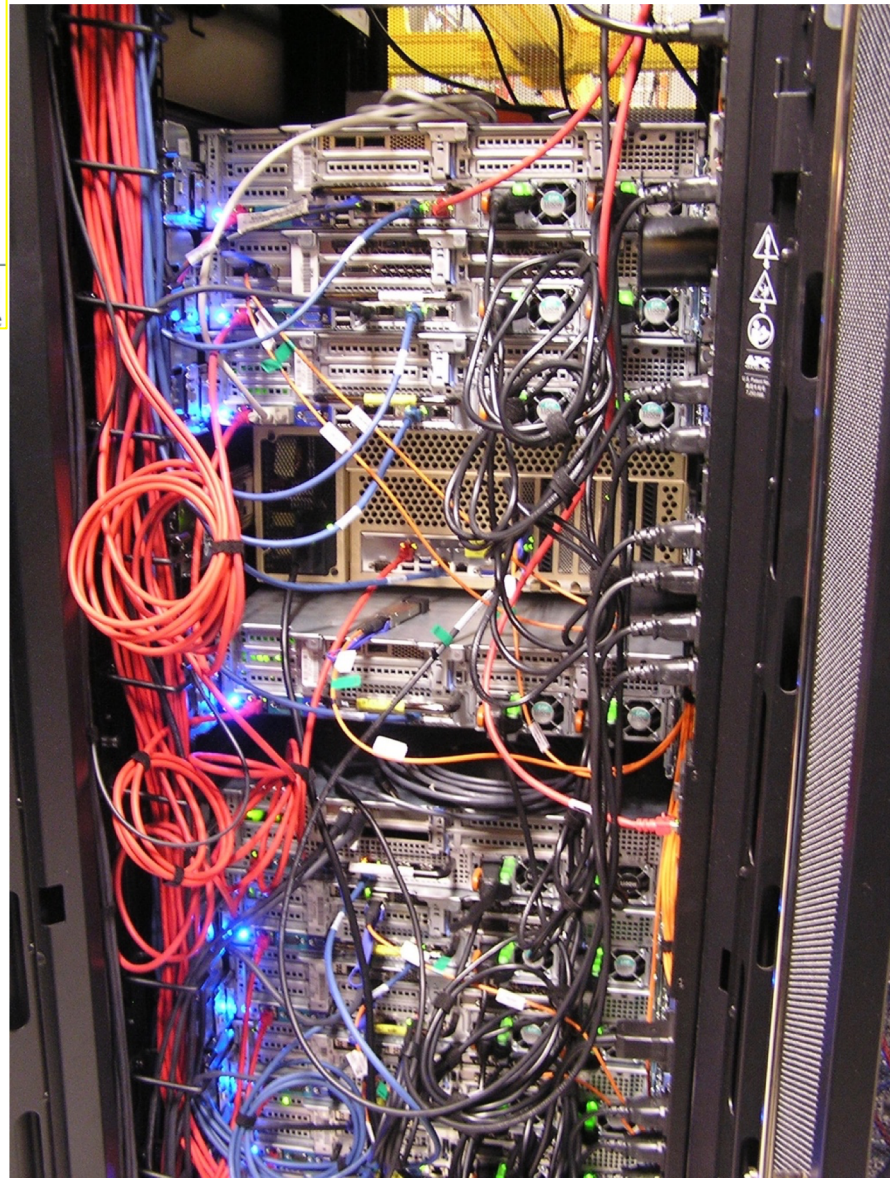


User Supplied Equipment (USE)

- **BLUSE**
  Breakthrough Listen (formerly SETI)
- **FBFUSE**
  Filter Banked Beamformer (MPIfR)
- **APSUSE**
  Accelerated Pulsar Search (MPIfR)
- **TUSE**
  MeerTRAP (Manchester)
- **PTUSE**
  Pulsar Timing (Swinburne)

FBFuse, APSuse, Tuse & PTuse

Max-Planck-Institut
für Radioastronomie



Breakthrough Listen - BLuse

New Partnership Between SKA Precursor Telescope MeerKAT & SETI Programme Breakthrough Listen

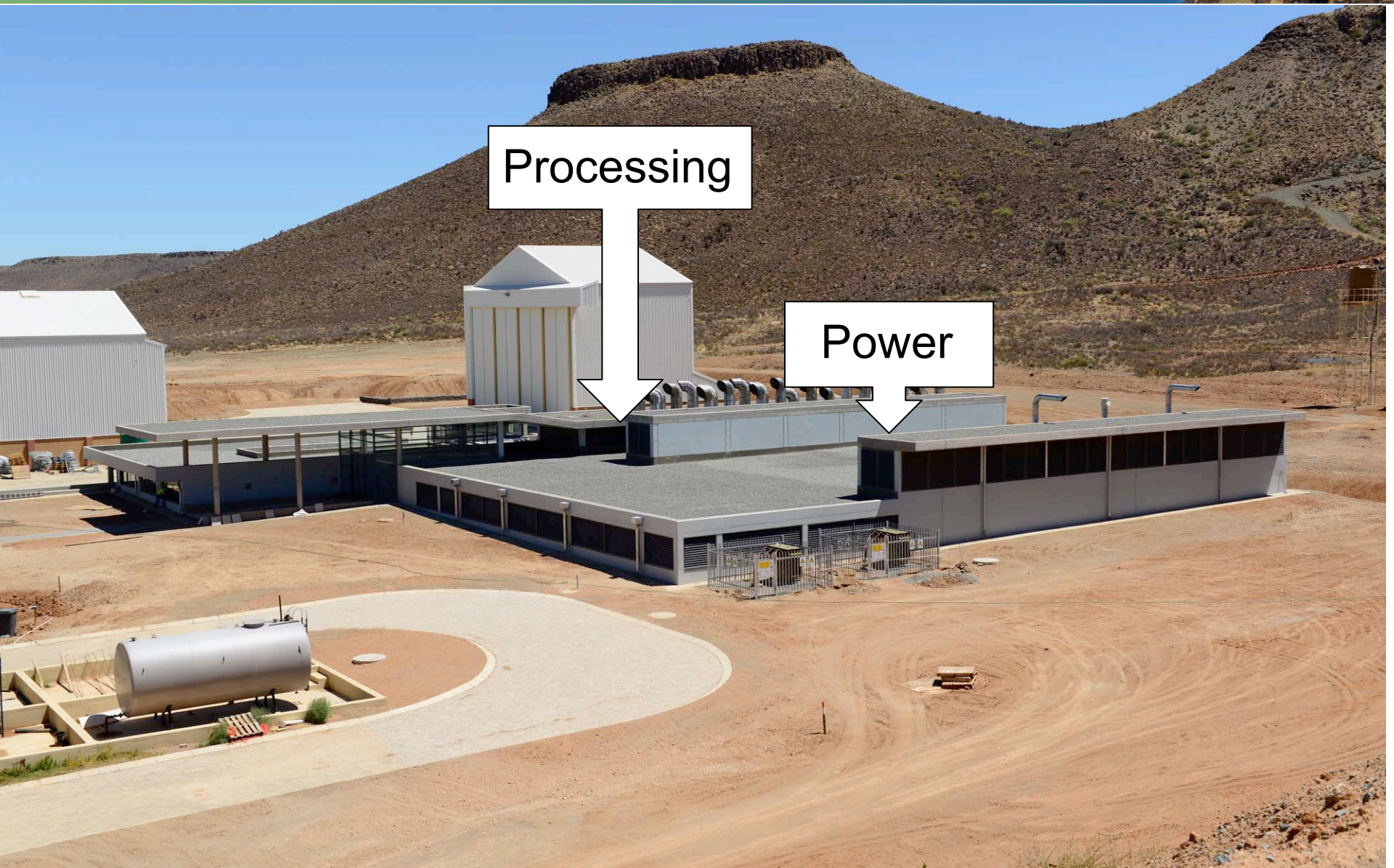
Bremen, Germany – October 2, 2018 – Breakthrough Listen, the global initiative to seek signs of intelligent life in the universe – announced today at the International Astronautical Congress the commencement of a major new programme with the MeerKAT telescope in partnership with the South African Radio Astronomy Observatory (SARAO).

Breakthrough Listen's MeerKAT survey will examine a million individual stars – 1,000 times the number of targets in any previous search – in the quietest part of the radio spectrum, monitoring for signs of extraterrestrial technology. With the addition of MeerKAT's observations to its existing surveys, *Listen* will operate 24 hours a day, seven days a week, in parallel with other surveys.

Observations will occur in a *commensal mode* – at the same time as other astrophysics programs. Using sophisticated processing, *Breakthrough Listen* scientists will digitally point the telescope at targets of interest. This means that the *Breakthrough Listen* instrument at MeerKAT will be operating almost continuously, scanning the skies for signs of intelligent life.

"Collaborating with MeerKAT will significantly enhance the capabilities of *Breakthrough Listen*", said Yuri Milner, founder of the Breakthrough Initiatives.

Bunker – RFI & temperature



Transformer, Switchgear & DRUPS


Transport instructions
TRANSFORMER 1
ABB


MAX SWL 9000KG

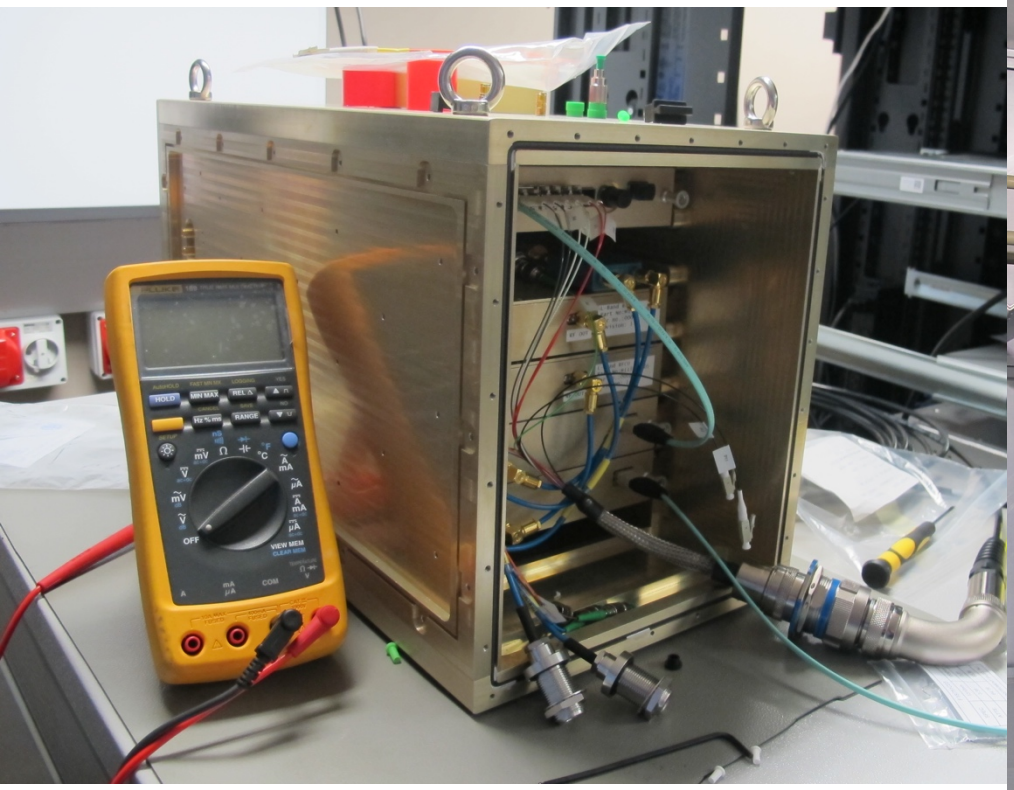

ABB
ZX0.2
J01
INCOMER TX1 2.5MVA
J02
INCOMER TX2 2.5MVA
J03
FEEDER DRUPS
J04
ESKOM B PASS
J05
BYPASS RISER
J06
FEEDER MEERKAT RING 1


TEST-JOINT
TEST-JOINT

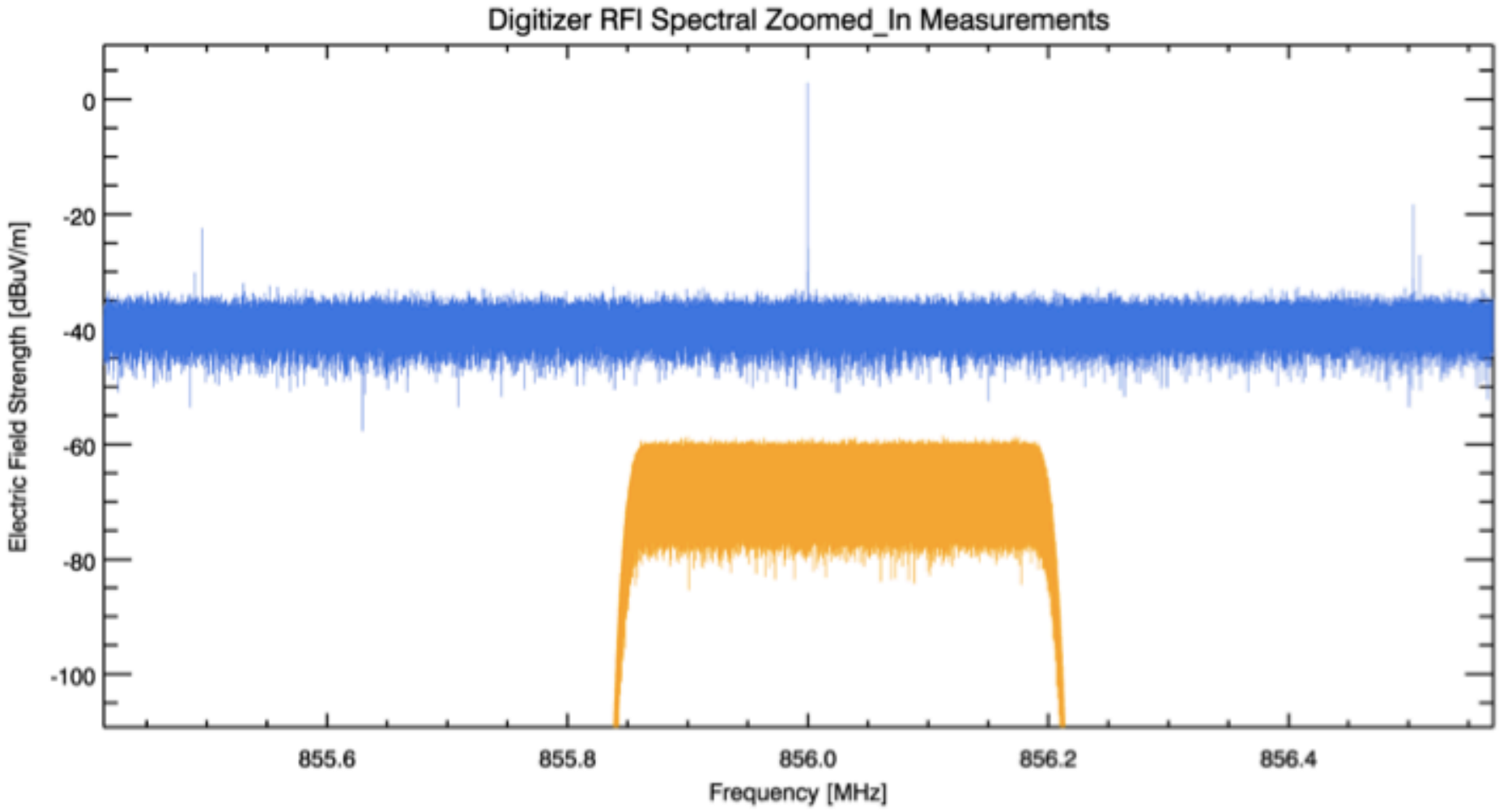
Shielded room


FiberGuide
CAUTION:
OPTICAL FIBER
E17
E16
APC

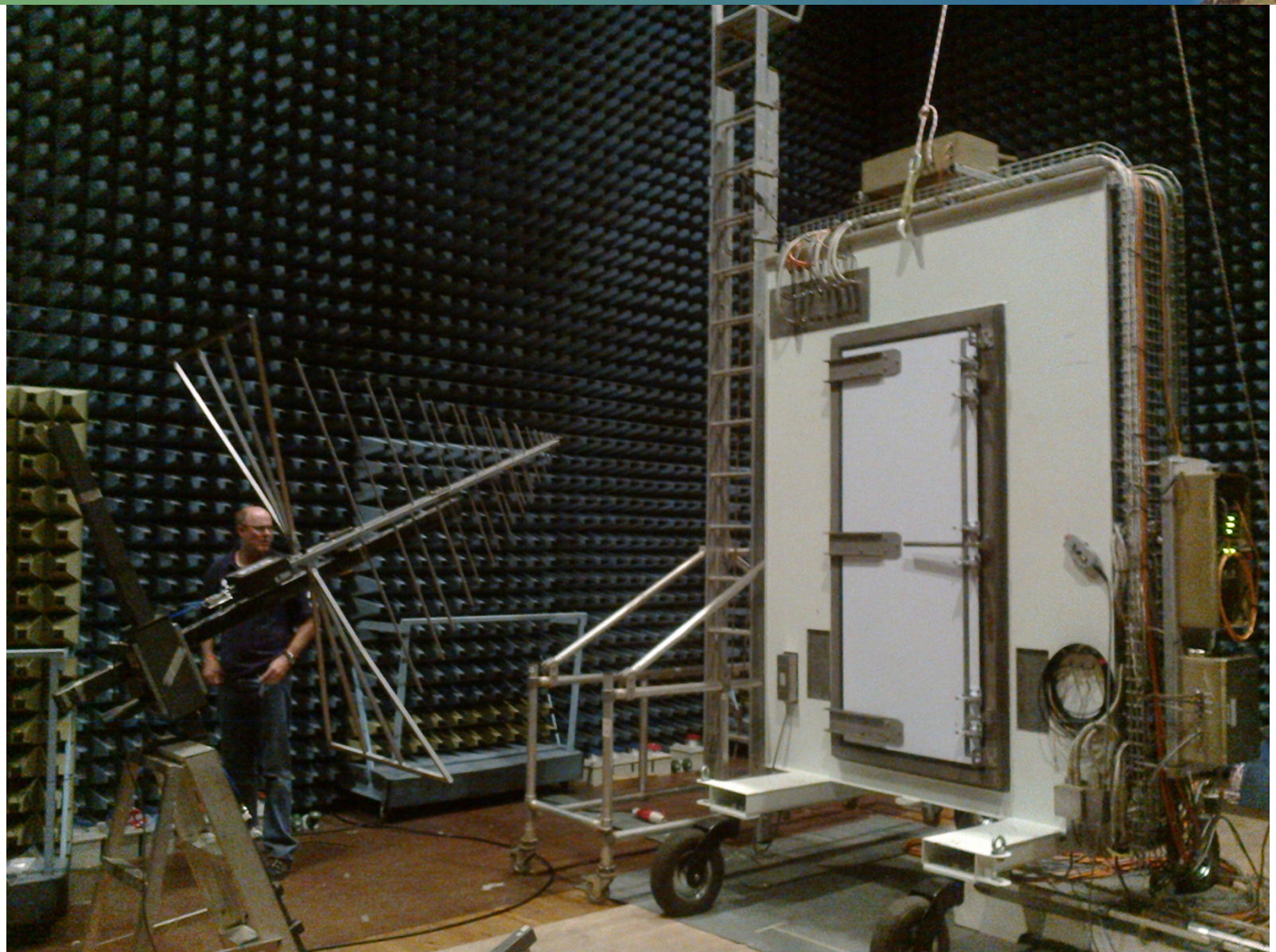
Digitizer in reverb chamber



Zoom in on culprits



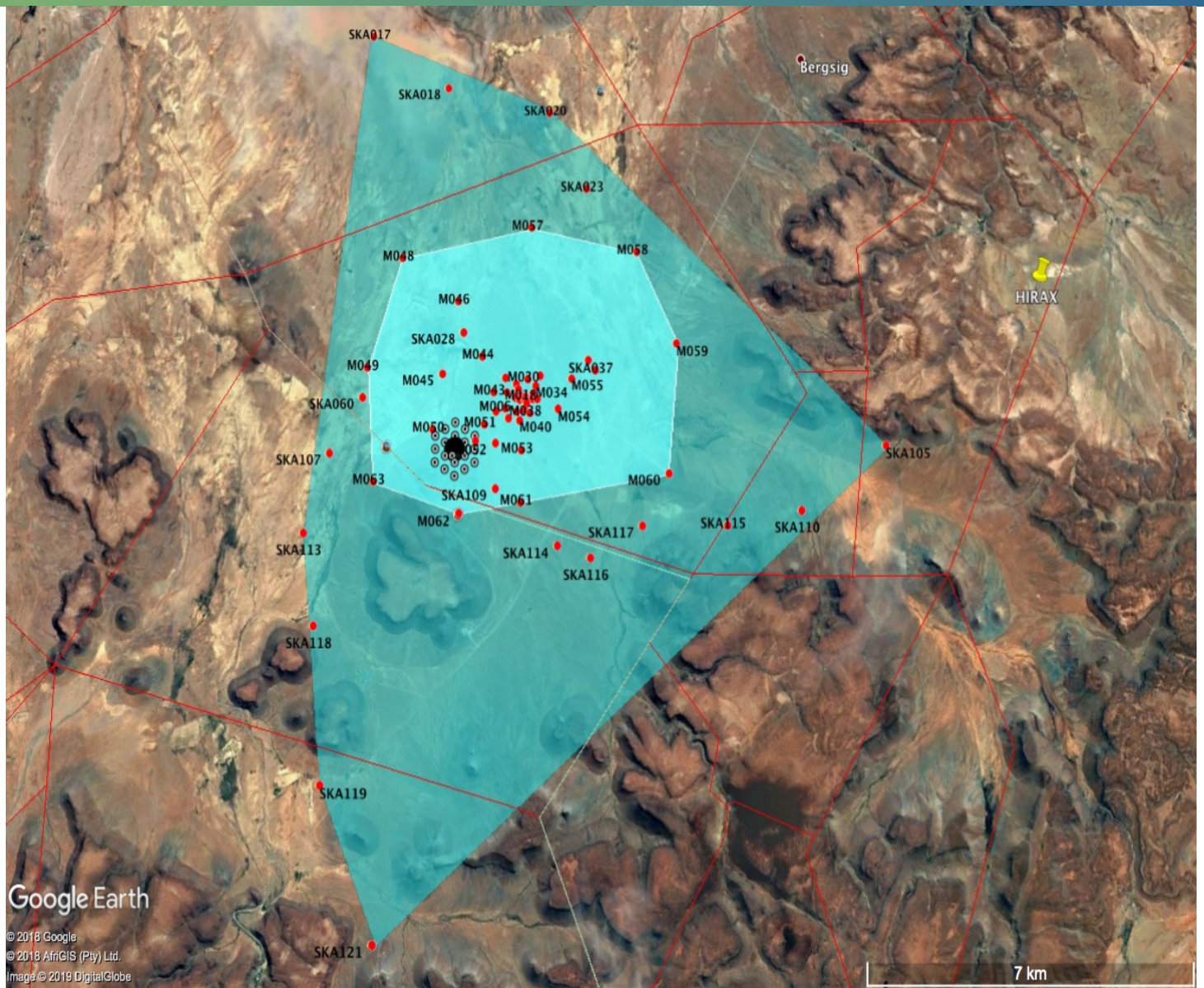
SDC test jig at Houwteq



HERA


TANDEM
CRANES

MeerKAT extension



Add 20 SKA dishes at SKA-mid locations out to where buried cable reticulation ends.

MAX-PLANCK-GESELLSCHAFT