SKA AFRICA
SQUARE KILOMETRE ARRAY

LESSONS LEARNED

FROM THE INTEGRATION OF MEERKAT ARRAY RELEASE 1

SKA Engineering Meeting October 2016

PRESENTER: **Thomas Abbott**

Agenda

- **Story of MeerKAT AR1 integration**
- MeerKAT AIV plan
- Tools
- Lessons Learned

The story of MeerKAT integration

- Integration started in June 2015
- AR1 system was integrated and working by ~ May 2016
- Scaled up and bugs fixed for our AR1 release in June 2016

2015 – Early integration is hard

January 2015: Receptor Test System is working. RTS is a small correlator, a previous-generation telescope manager, and two receptors.

9 June: We connect up a complete copy of the MeerKAT signal path in the integration lab. It's expected to work in a few weeks.

June: Lab Integration effort: twice-a-week sessions start

July: Lab Integration effort, first file is recorded from a signal generator

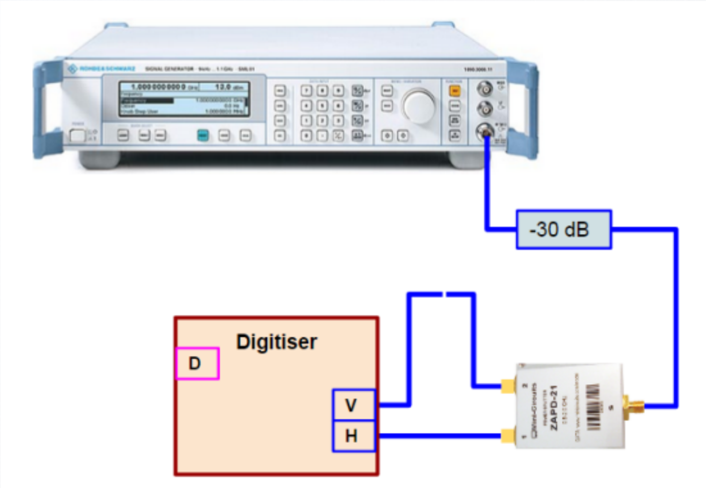
August: Lab integration continues

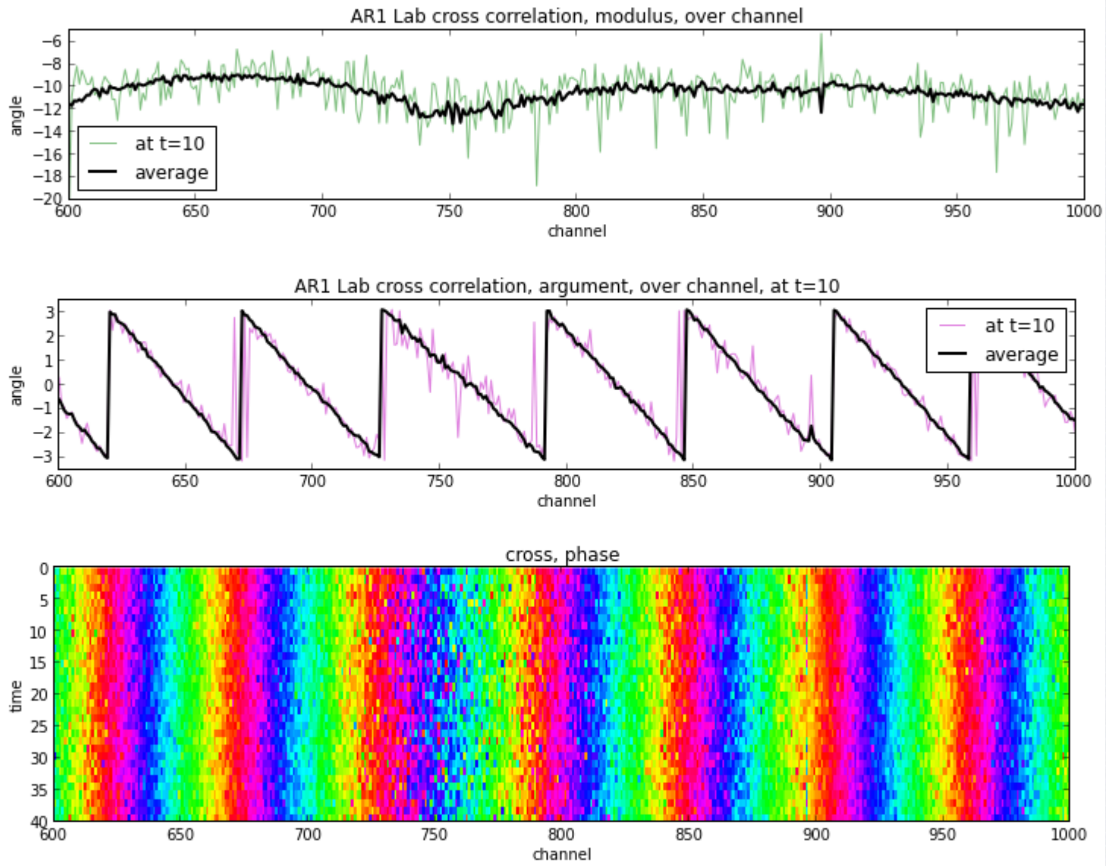
Sept: Lab integration continues. System now starts up and runs observations

Oct: Lab integration continues. Lab verification starts.

July 2015

First file recorded in lab : (cross-correlation of the signal generator noise only)





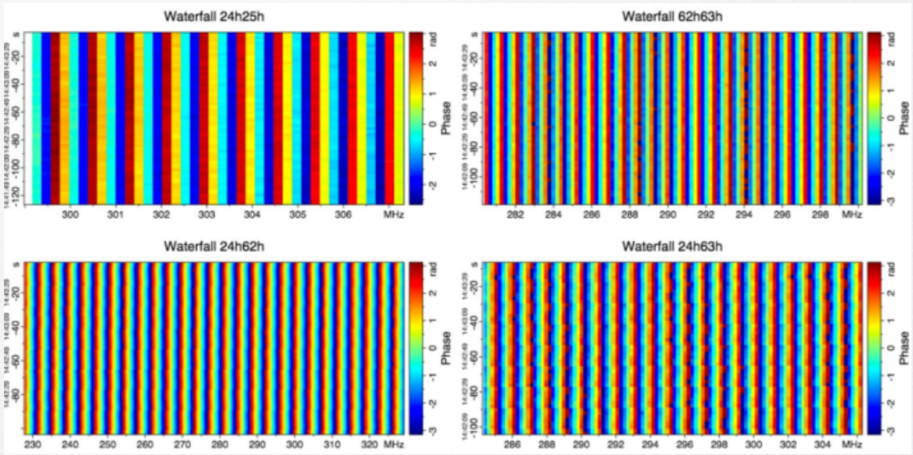
Connecting receptors

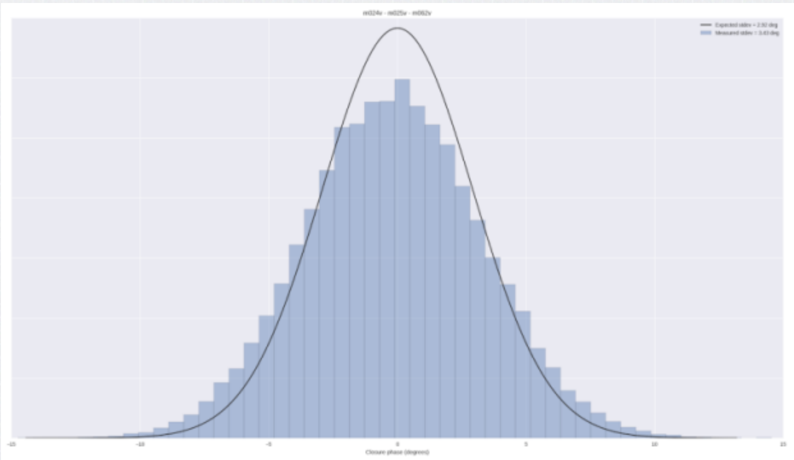
July-October 2015: Back-end is installed on site.

Nov 2015: First receptor is released from RTS.

Integration of site correlator with receptor.

Late Dec 2015: Four receptors connected to AR1 to attempt to form a first image before the end of the year. System is not stable enough, but we get:



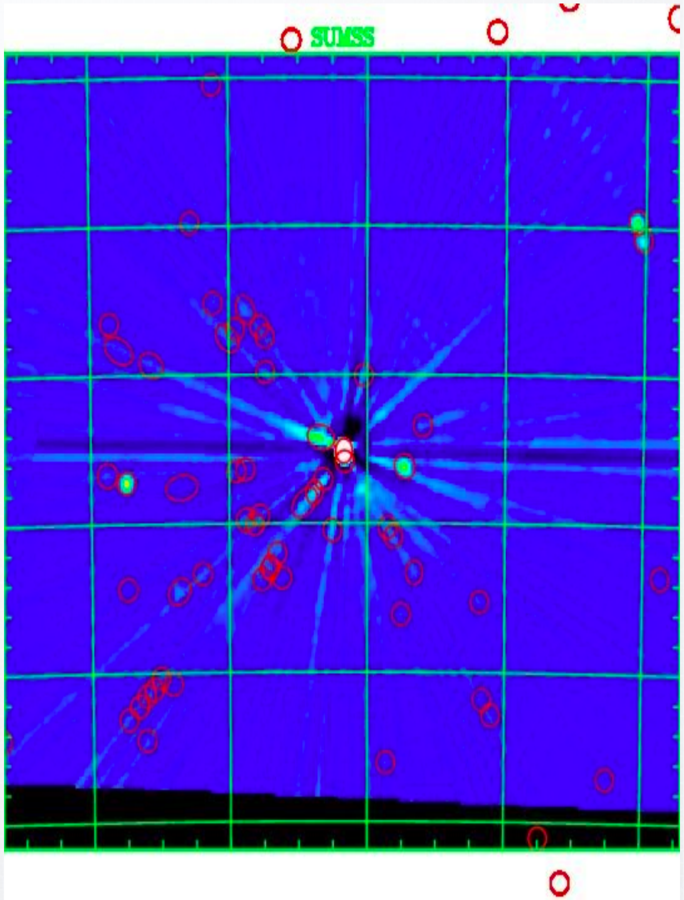


Jan 2016: Back to two receptors as RTS continues on the second pair

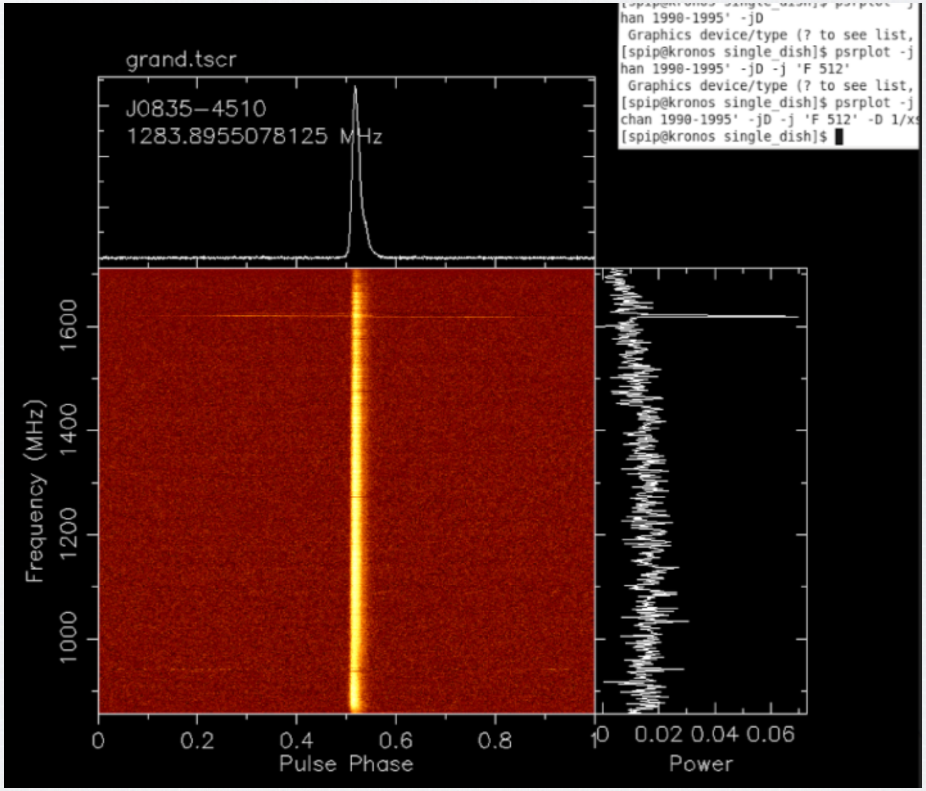
March and April 2016

March: Four receptors connected

First rough image formed

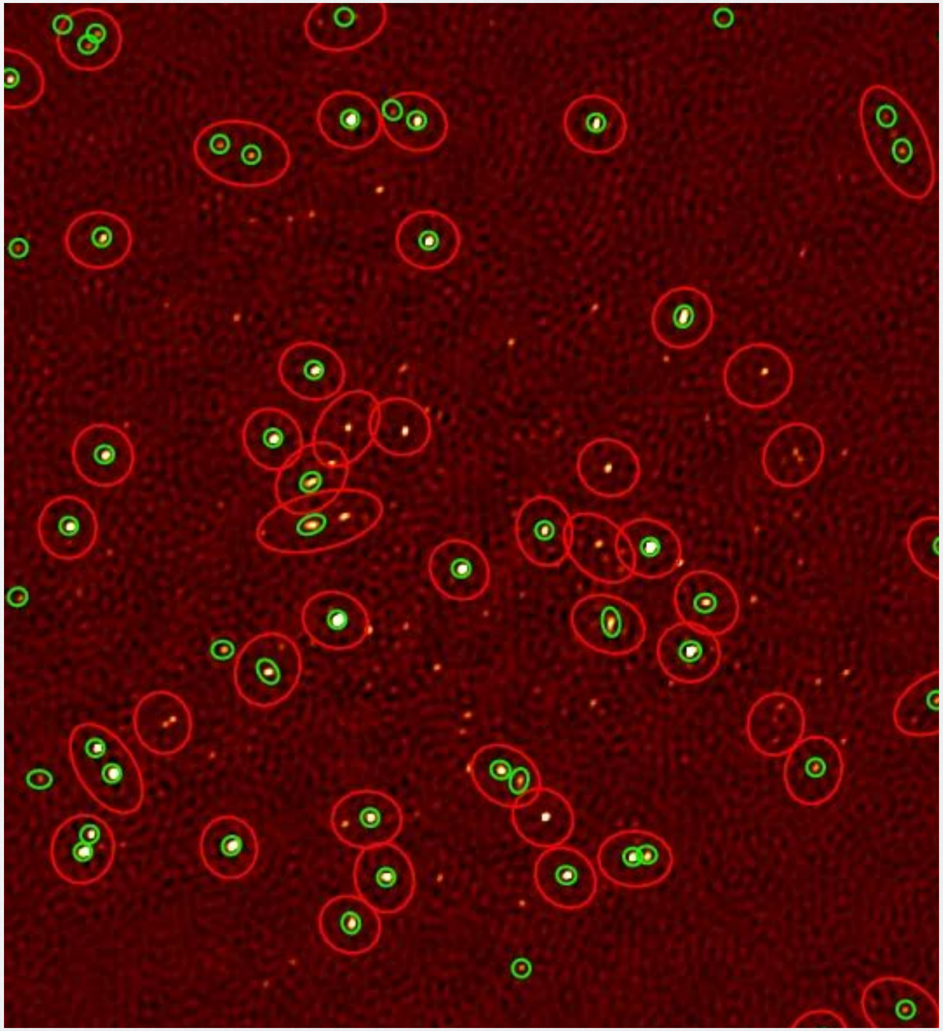


April: First beamformer observation and offline reduction of a pulsar



20 May 2016

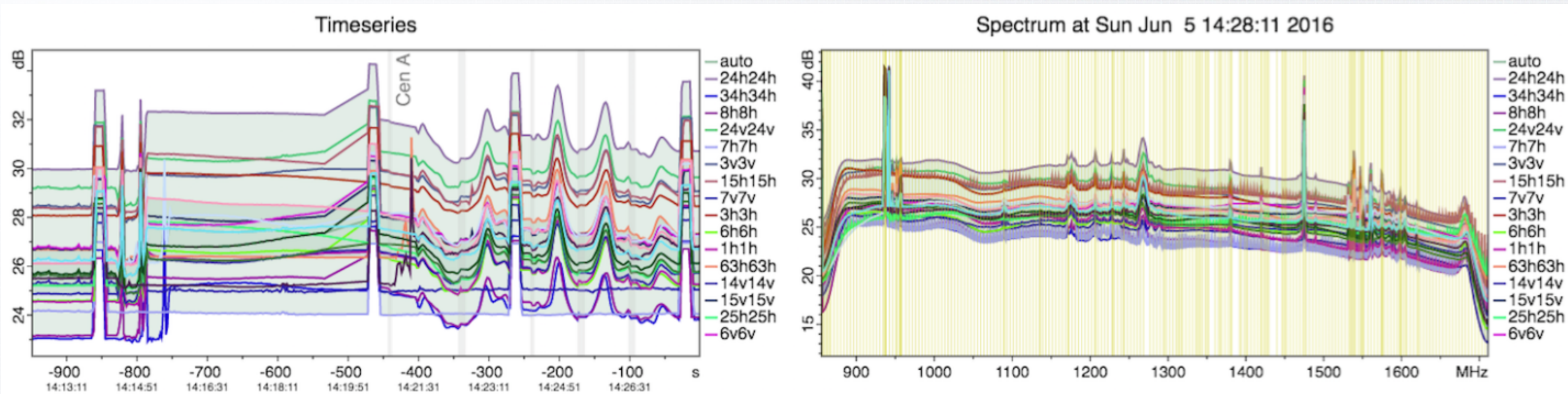
First image created with a 12-hour observation on 4 antennas – three in the core and one 4 km away. Comparison to earlier surveys shows the high resolution of MeerKAT.



20 May: 8-antenna correlator runs for the first time

5 June 2016

16-antenna correlator runs for the first time, 11 receptors



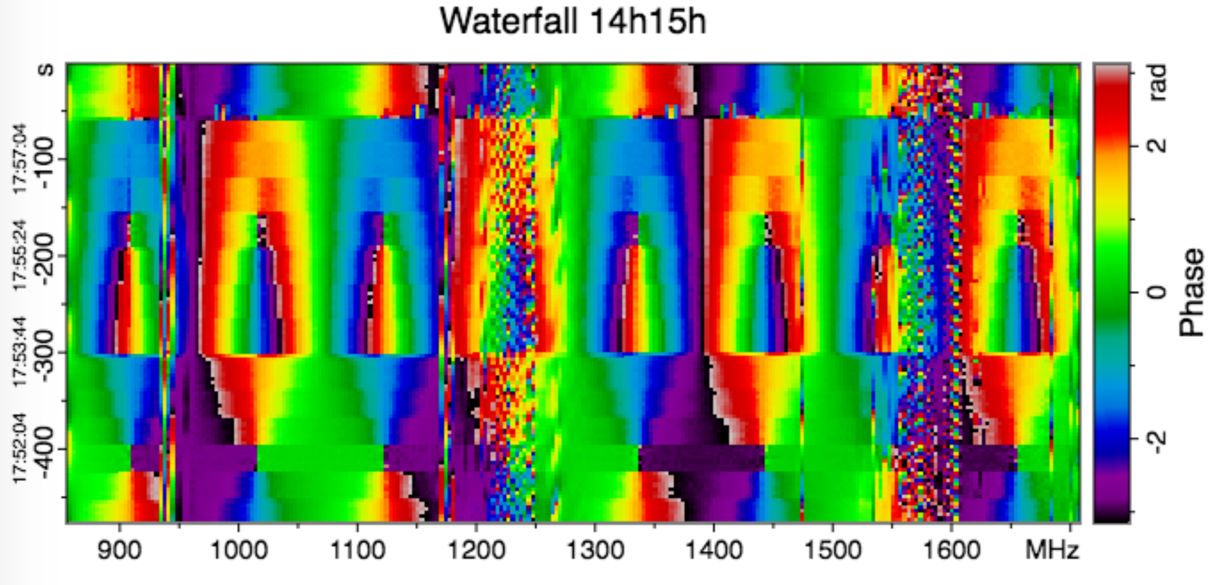
10 June 2016

10 June: 16th receptor connected accepted and integrated
(but we have one failure, so we need a 17th receptor)

The 17th receptor is connected a week later

16 June 2016

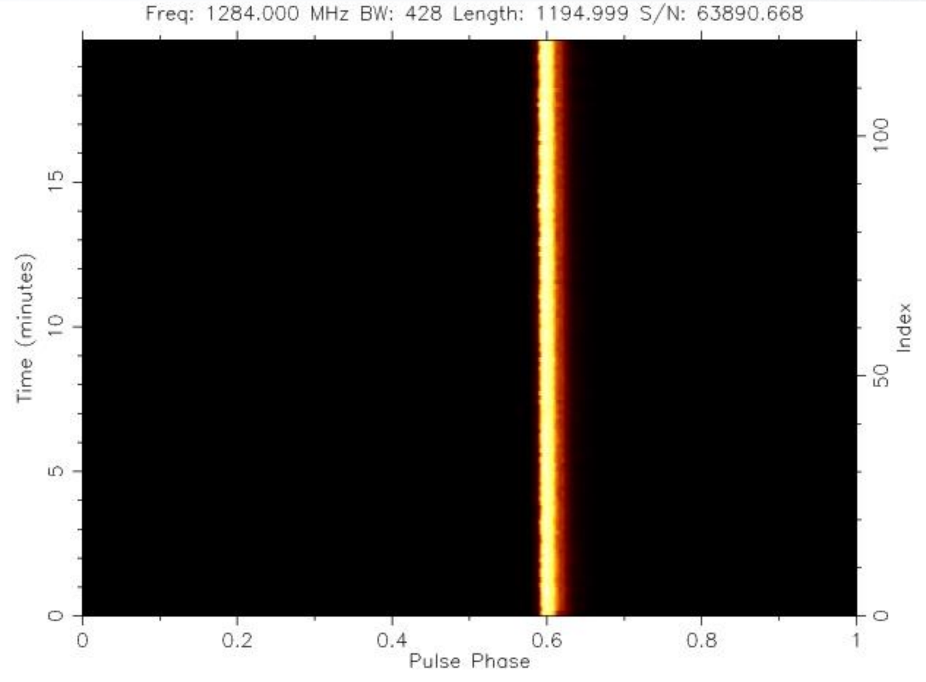
Disaster! A bug in the delay tracking system surfaces, where some delays are not correctly applied by the correlator.

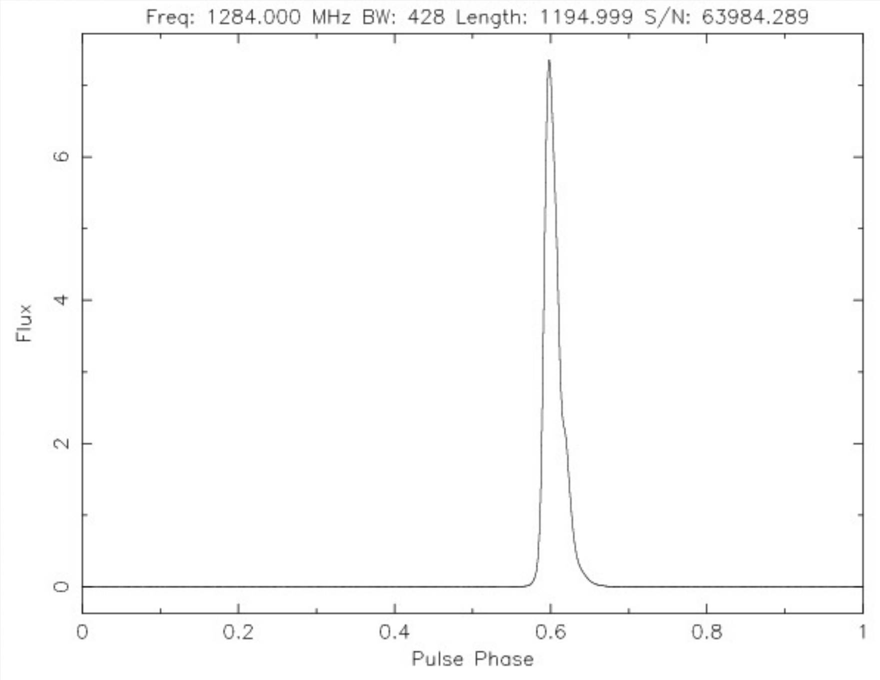


Saturday 18 June, 9 am, a new version of the correlator has been compiled and tested. The weekend's observing starts...

17 June 2016

Successful pulsar observations

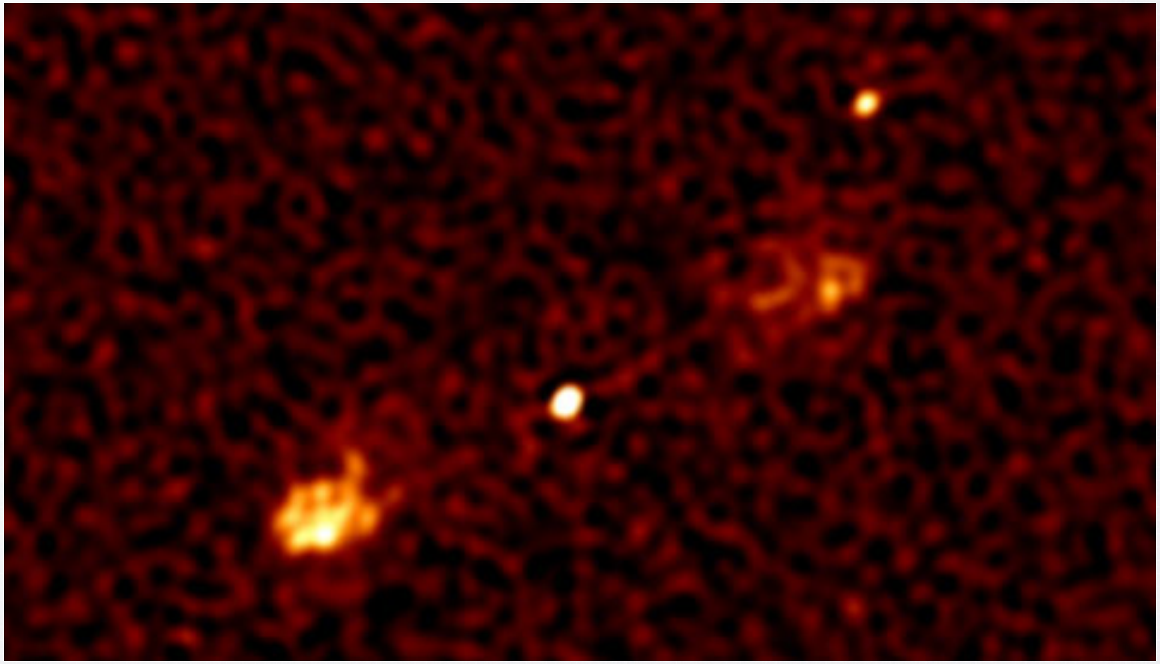




19 June 2016

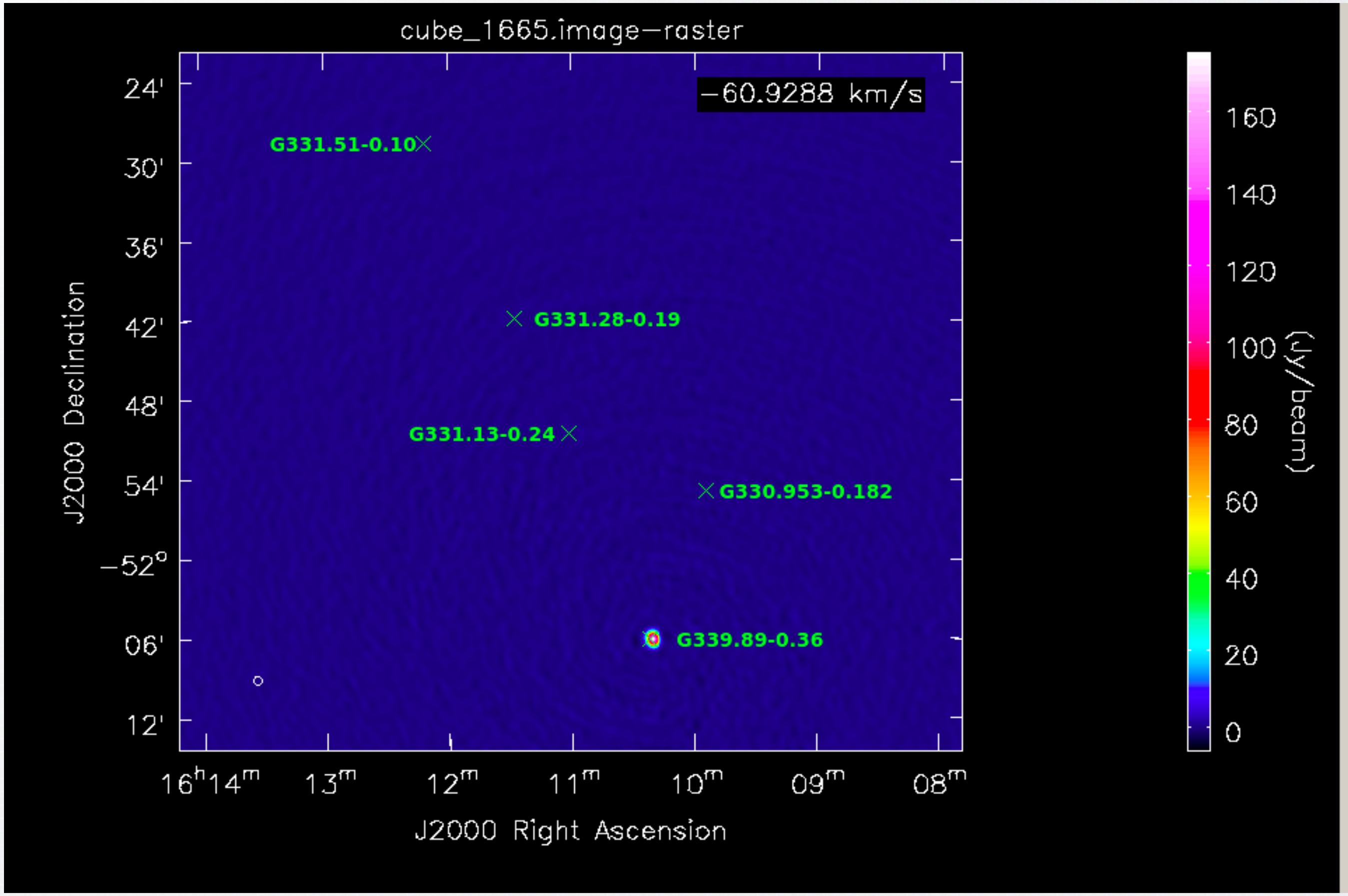
Successful continuum observations of our DEEP2 field

Reduced over the following week to form the image



20 June 2016

Successful spectral line observation of a maser calibrator



16 July 2016

First light press release

Agenda

- Story of MeerKAT integration
- **MeerKAT AIV plan**
- Tools
- Lessons Learned

MeerKAT Integration and Verification

- Array releases
- I&V plan
- Verification
- Tools

Array releases

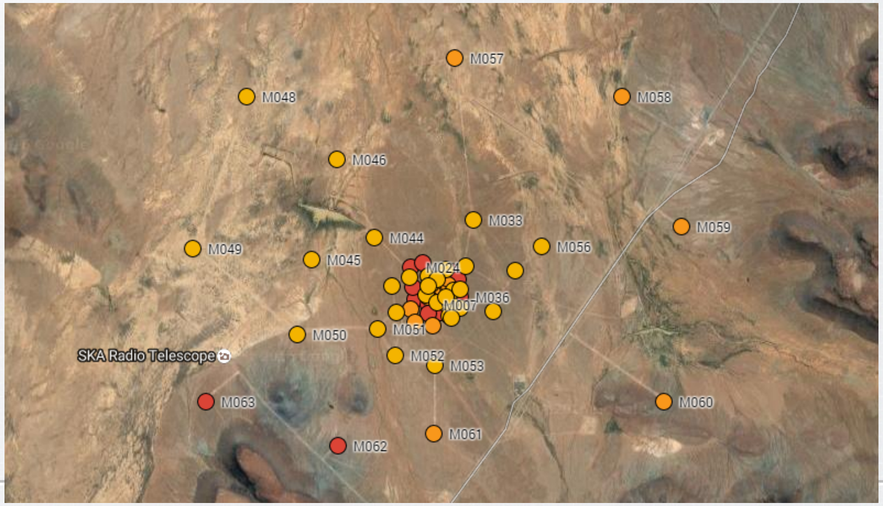
Defined in the MeerKAT Integration and Verification Plan

Staged release of functionality and scale:

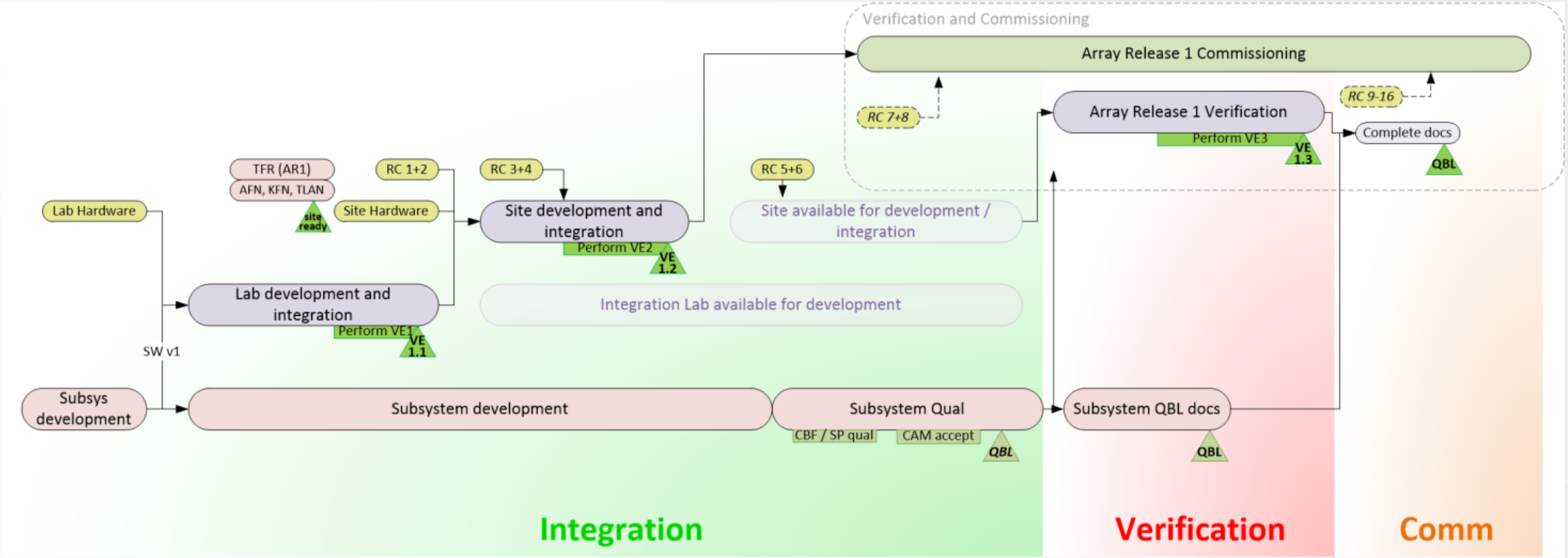
1. Receptor construction schedule
2. Scale of CBF and SDP
3. Functionality of CAM
4. Functionality releases for CBF and SP

Array releases

AR1	AR2	AR3	Later releases
16 receptors	32 receptors	64 receptors	64 receptors
Correlator 4k & 32k	Correlator 4k & 32k	Correlator 4k & 32k	Correlator 1k, 4k & 32k
Offline imaging	Offline imaging	Pipeline imaging	Pipeline imaging
1 beam	1 beam	1 beam	4 beams
			Narrowband modes
			Transient modes
			VLBI



AR1 Integration and Verification plan



AR1 Verification

AR1 has three system-level verification events defined:

- **VE1**: Lab event, testing most basic functionality
- **VE2**: First site verification. Essentially the same features as tested in VE1, but now on the site system with real receptors and sky signals.
- **VE3**: Complete AR1 verification on site system, with at least 6 receptors.

Subsystems each qualified according to own development plan

Agenda

- Story of MeerKAT AR1 integration
- MeerKAT AIV plan
- **Tools**
- Lessons Learned

Tools

- Receptor Test System
- Integration Lab in Cape Town
- Management Tools

Receptor Test System

First antennas are delivered and integrated before the telescope back-end is ready.

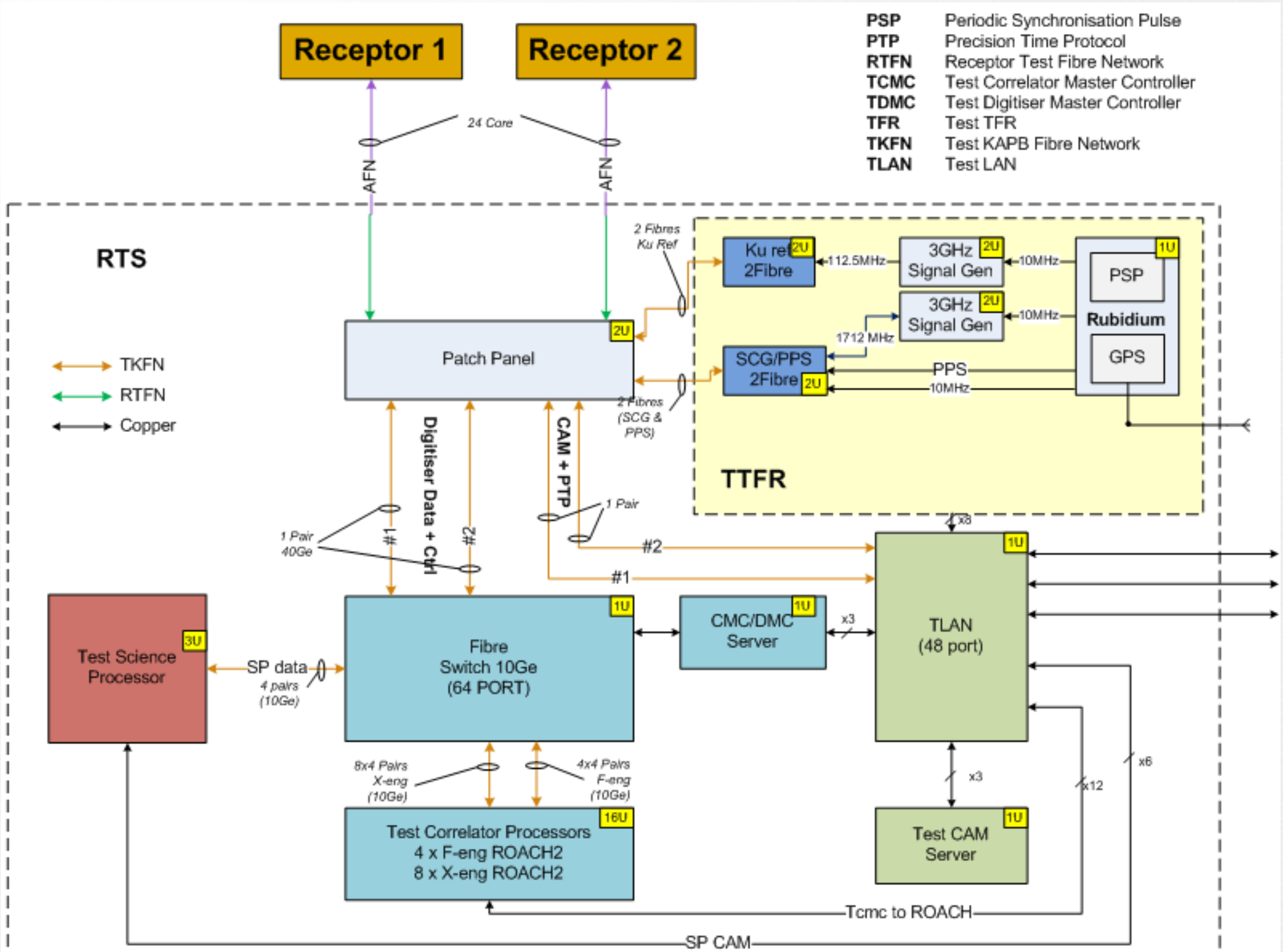
In short you need a Telescope to test a Receptor

Enter Receptor Test Systems (RTS)

To test the emergent properties of a Receptor we need:

- Control interface (CAM)
- Network transport of data and control (LAN/Fibre)
- Time and frequency reference (TFR)
- Correlator (CBF)
- Signal processing and reduction (SDP)
- Specialised Test receivers (Ku RX)

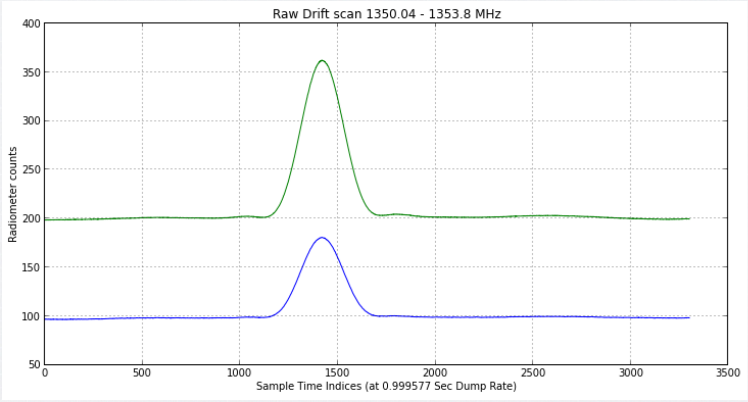
Receptor Test System



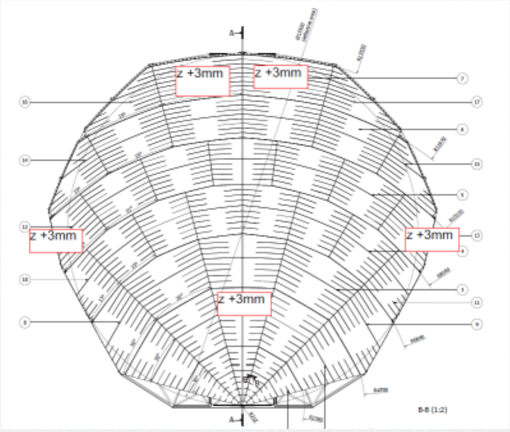
Receptor Test System

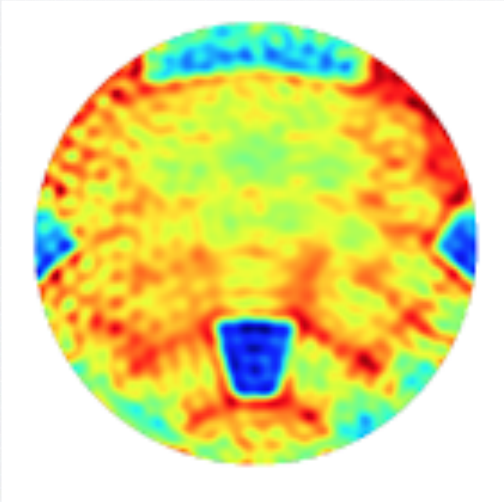
Test system (RTS) needs qualification as well

- Drift scan



- Ku Holography





Receptor Test System

L-band testing

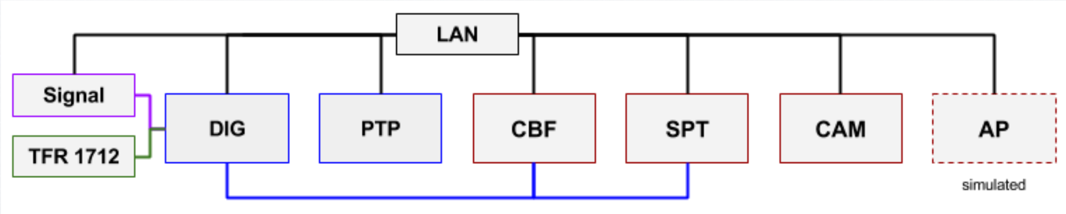
- Single dish:
  - Nominal input (wide band gain)
  - Tsys and Tnoise diode
  - Tipping curve
  - Gain stability
  - Linearity
  - Spectral baseline
- Interferometric:
  - Reflector efficiencies
  - Phase stability
  - Beam shape and sidelobe levels
  - Polarisation

Ku-band testing

- Single dish
  - Gain curve
  - Pointing
- Interferometric
  - Aperture phase efficiency
  - Gain curve
  - Error beam

Integration Lab

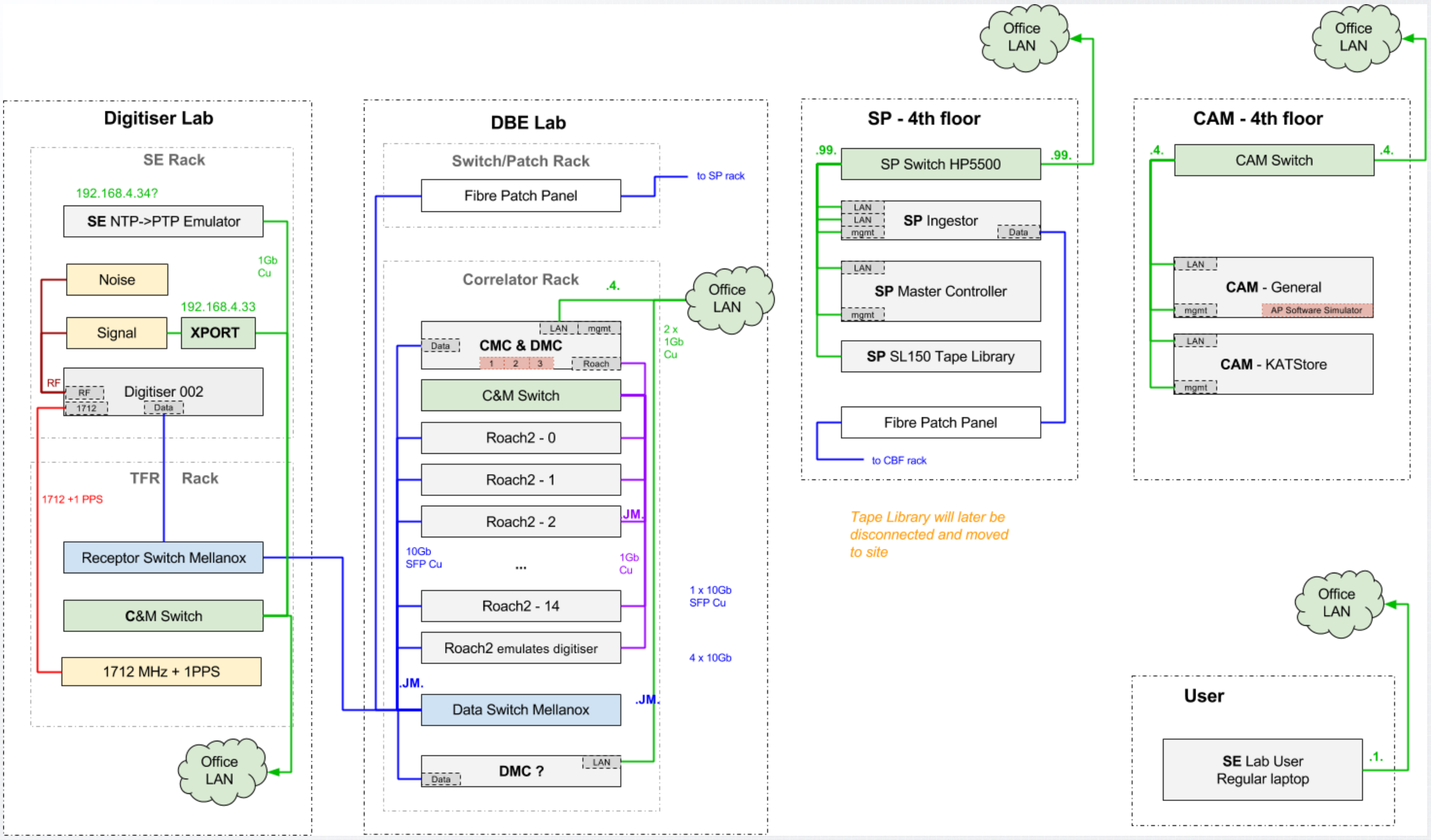
A simple Integration Lab allowed early integration to be done long before the system on site was ready.



Our lab consisted of:

- 2 x 40 Gbps inter-office LAN
- Signal generator and noise source
- Simulated Antenna Positioner
- 8-input correlator: 12 Roaches. Correlator master controller
- One digitiser and pedestal switch. Digitiser master controller
- Control and Monitoring system, one (virtualised) server
- Science processor ingest node
- Regular MeerKAT science archive
- General-purpose time and frequency reference system

Integration Lab



Management tools

VITECH CORE for modelling of the system.
Requirements specifications and verification plans are printed directly from CORE

We use JIRA extensively in all teams for managing week-to-week tasks and reporting bugs and feature requests

Primavera project planning software for high level project plans and reporting

Agenda

- Story of MeerKAT AR1 integration
- MeerKAT AIV plan
- Tools
- **Lessons Learned**

Lessons Learned

- Prototyping
- Lab integration
- Early integration
- Subsystem Involvement
- Integration team
- System stability – emergent behaviour
- Real-time communication
- Cameras
- RFI

Prototype Everything

“To measure is to know” -- Lord Kelvin

Individual subsystems all built mockups, models, or prototypes

- Don’t believe everything you read on a product’s specification sheet. Test it in your setup!
- CBF spent two years with seven network switch vendors. All had absolute confidence in their product, but none managed to make it operate as advertised, without some rework.

- At the system level, MeerKAT prototyping started with XDM and KAT-7.

Lab Integration

Before the site system was available, the Lab was used for:

- Nearly three months of integration work between CAM, CBF and SP subsystems
- Characterisation of digitiser, Correlator PFB leakage problem
- Substantial development and testing of correlator gateware
- Discovered a time offset between polarisations in digitiser, now improved.
- Correlator F-engine non-linearity.
- Being used to hunt a delayed-packet bug
- Integration tests with Pulsar-timing user

During site testing, the Lab was used for:

- Release testing of new CBF, SP and CAM software

Ongoing application

- Evaluation of sub-channel PFB effects
- Integration efforts with USE – Pulsar Timing, MeerTRAP
- Digitiser and Correlator gateware testing

Early integration

Integration is much harder than expected

- All subsystems perform very careful, thorough verification independently.
- Still, there are interfacing niggles only exposed during integration.
- Best to find these early while it can be corrected without impacting system schedule or budget.
- As described earlier, it took us several months to integrate three systems and get them to talk and work normally.

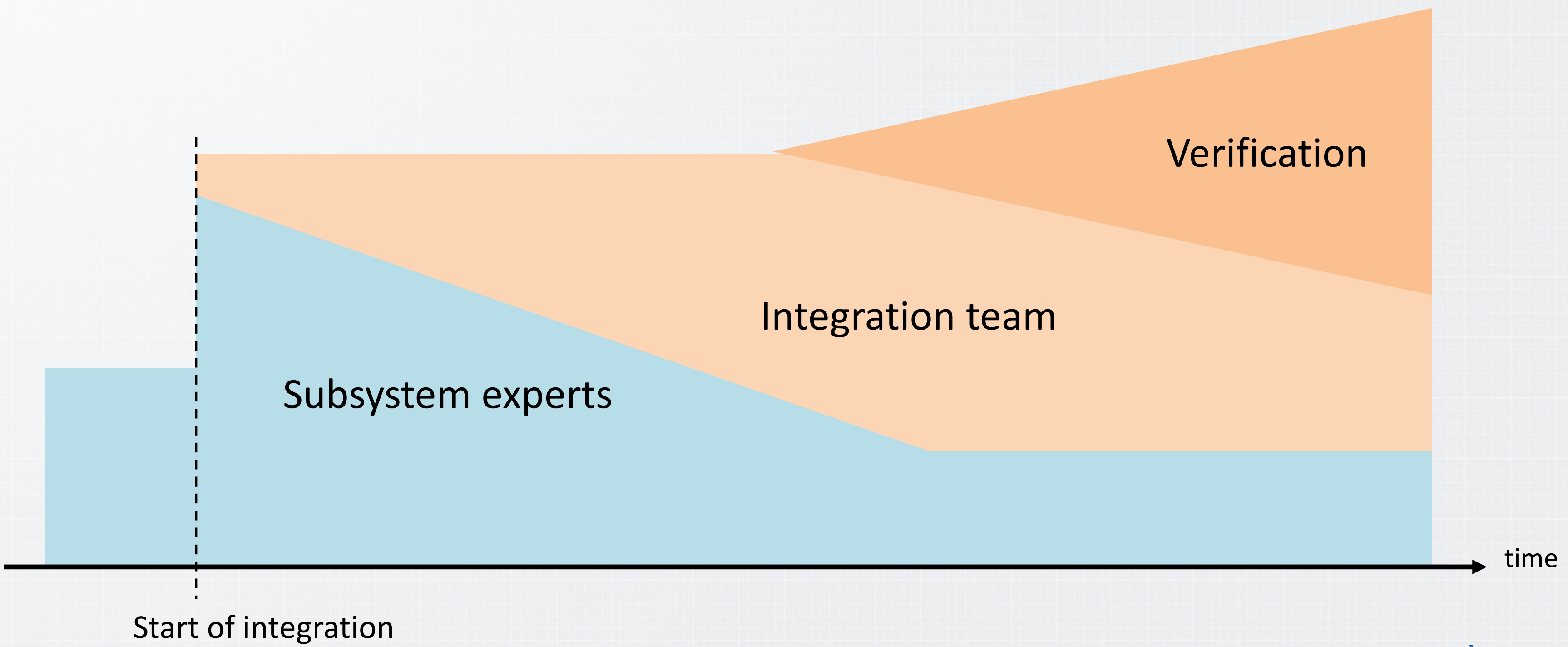
The lab environment enabled this early integration.

Subsystems should bring a reduced-functionality version of their system to the integration lab, 6 months before the full-functionality release.

Subsystem Involvement

Subsystem people need to be involved

- Integration cannot be done by the integration team alone.
- Initially, subsystem experts will do the bulk of the integration work
- Later, the integration team will be able to take over some functions



Strong Integration Team

A strong integration team is required for the later stages of the integration effort.

The first half can run almost entirely on people from subsystems, and as they're responsible for the problems, they're the best people to solve them.

Later when system behaviour becomes the main problem, the integration team needs several independent experts as well as the subsystem team members.

Involve telescope operators early. The telescope requires babysitting all night, the technical team leads can't keep this up for months.

System stability - emergent behaviour

Overall system stability is an elusive goal, much more difficult than getting it to work once. It takes an obsession for quality in all parts, not simply getting it to work.

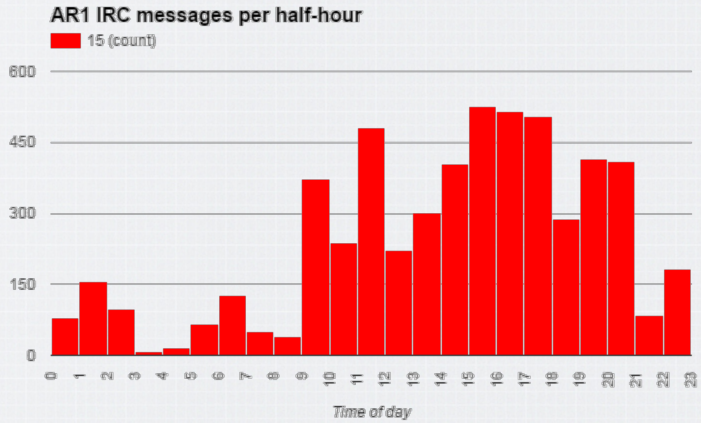
To achieve a system that works 95% of the time, every part must work at 99% of the time.

Stability problems were mostly emergent behaviour, new effects that cropped up during integration, or even once it had been working for a while.

Real-time communication

The integration team used IRC to communicate between various floors, offices and site.

It also worked well on a computer plugged into any receptor

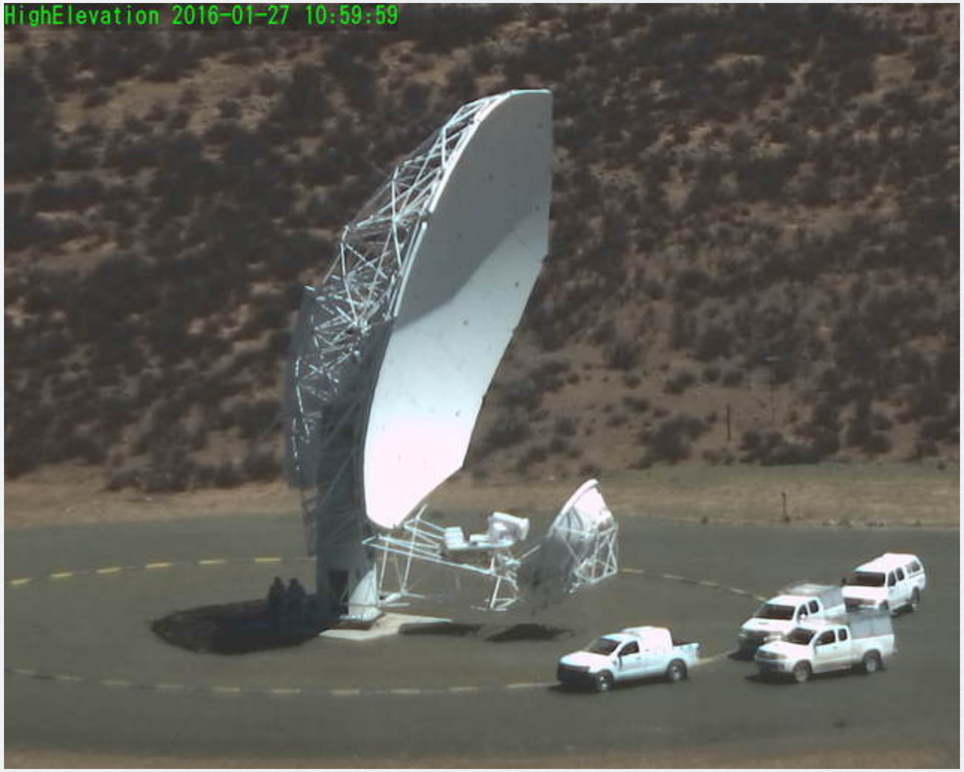


Communication to site was a problem, with the RFI restrictions. No cellphones or satellite phones. We have a few IP phones in some receptors.

Cameras for site visibility

The high elevation camera was very useful for observing things on site. Without being able to call people there, it was good to be able to watch and see.

Surveillance cameras foster a sense of closeness to the action in the Karoo. Consider having cameras in the control room, and major integration sites, for others to see who's there and what's happening.



Do Not Underestimate RFI challenges

This is an ultrasonic wind speed and direction transducer.

Qualified for use on KAT-7 and installed for years on site.

During RFI qualification of the MeerKAT WSS we discover that this sensor fails the new limits by 20 dB

Summary

- Story of MeerKAT AR1 integration
- MeerKAT AIV plan
- Tools
- Lessons Learned
- **Questions**

SKA South Africa, a Business Unit of the National Research Foundation.

We are building the Square Kilometre Array radio telescope (SKA), located in South Africa and eight other African countries, with part in Australia. The SKA will be the largest radio telescope ever built and will produce science that changes our understanding of the universe

Contact information

Thomas Abbott

MeerKAT Systems Engineer

Email: tabbott@ska.ac.za