The MPIfR S-Band Rx for MeerKAT

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Motivation

Idea driven by various components: science, technology, engagement

- Science: - in many respects and for many projects, S-band is an ideal frequency (e.g. pulsar survey in inner Galaxy, high precision timing, spectroscopy (CH), magnetism and VLBI
- Challenges: for pulsars, flux decreased -> need larger bandwidth
  telescope beam reduced in size -> need 100+ beams
  overall processing requirements could be higher
- Technology: wide-band pixel feed receiver
  direct digitization (without causing RFI)
  large-scale beamforming
  data transport and analysis
- Engagement: being partner in MeerKAT, its people and science

MeerKAT – not only a SKA Precursor

- A telescope as sensitive and capable as VLA
- Most sensitive telescope in the Southern hemispehere – by far

Dishes „made in Germany“ by VERTEX (Duisburg) & Schauenburg (Mühlheim/Ruhr)

Approved MPG Funding Application

1.6-3.5 GHz-Empfängersystem für MeerKAT

Proposal for a MPG Großgeräteantrag

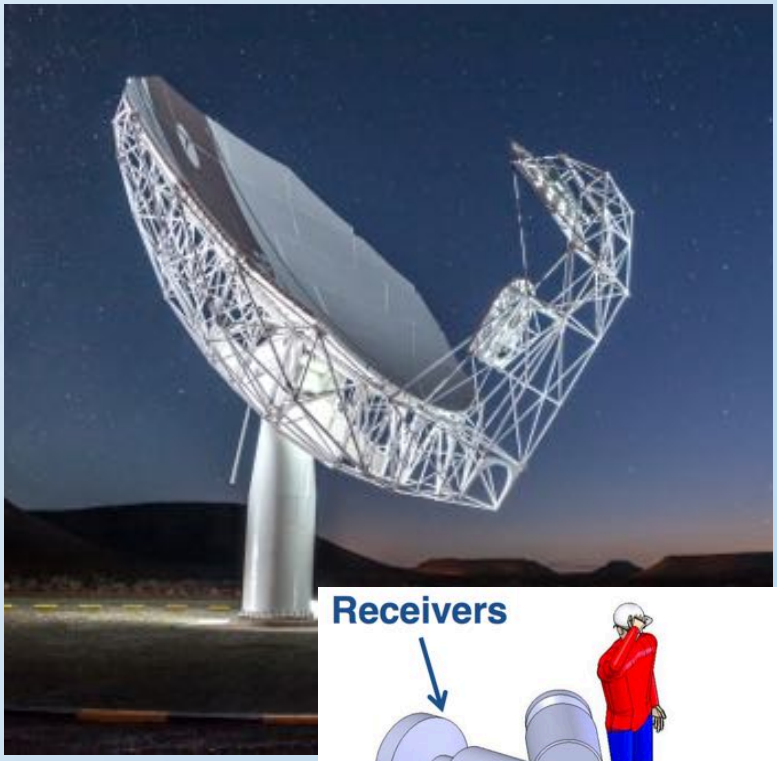
Michael Kramer, Karl Menten & Anton Zensus

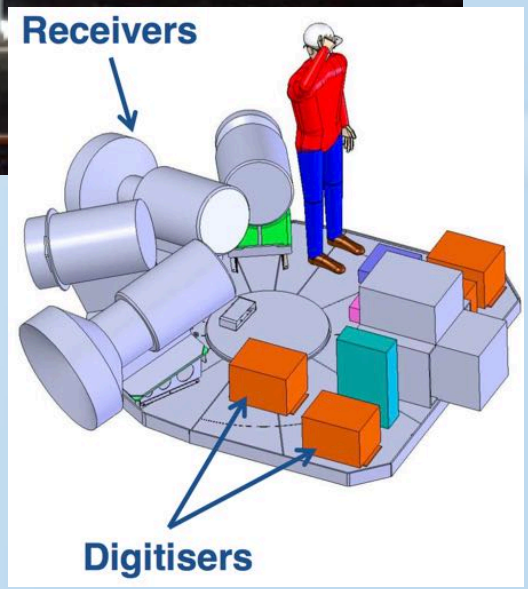
Max-Planck-Institut für Radioastronomie
Elektronik Abteilung
Auf dem Hügel 69
53121 Bonn, den 19.05.2014

- Project of about 11M Euro
- Complete receiver + backend system
- Main science drivers:
  - Pulsars
  - Transients
  - CH studies of ISM
  - S-Band VLBI (EVN & global)

MeerKAT Spec

Number of antennas	64 offset Gregorian
Dish diameter	13.5 m
Minimum baseline	29 m
Maximum baseline	8 km (Phase 1) 12 km (Phase 2 2018)
Frequency bands (receivers)	0.58 – 1.015 GHz 0.9 – 1.67 GHz 1.7 – 3.5 GHz 8 – 14.5 GHz
Continuum imaging dynamic range at 1.4 GHz	50 dB
Line-to-line dynamic range at 1.4 GHz	43 dB
Mosaicing imaging dynamic range at 14 GHz	27 dB
Linear polarisation cross coupling across -3 dB beam	-30 dB
Sensitivity (0.58 – 1.67GHz)	220 m^2/K
Sensitivity (8 – 14.5GHz)	200 m^2/K





It's happening...

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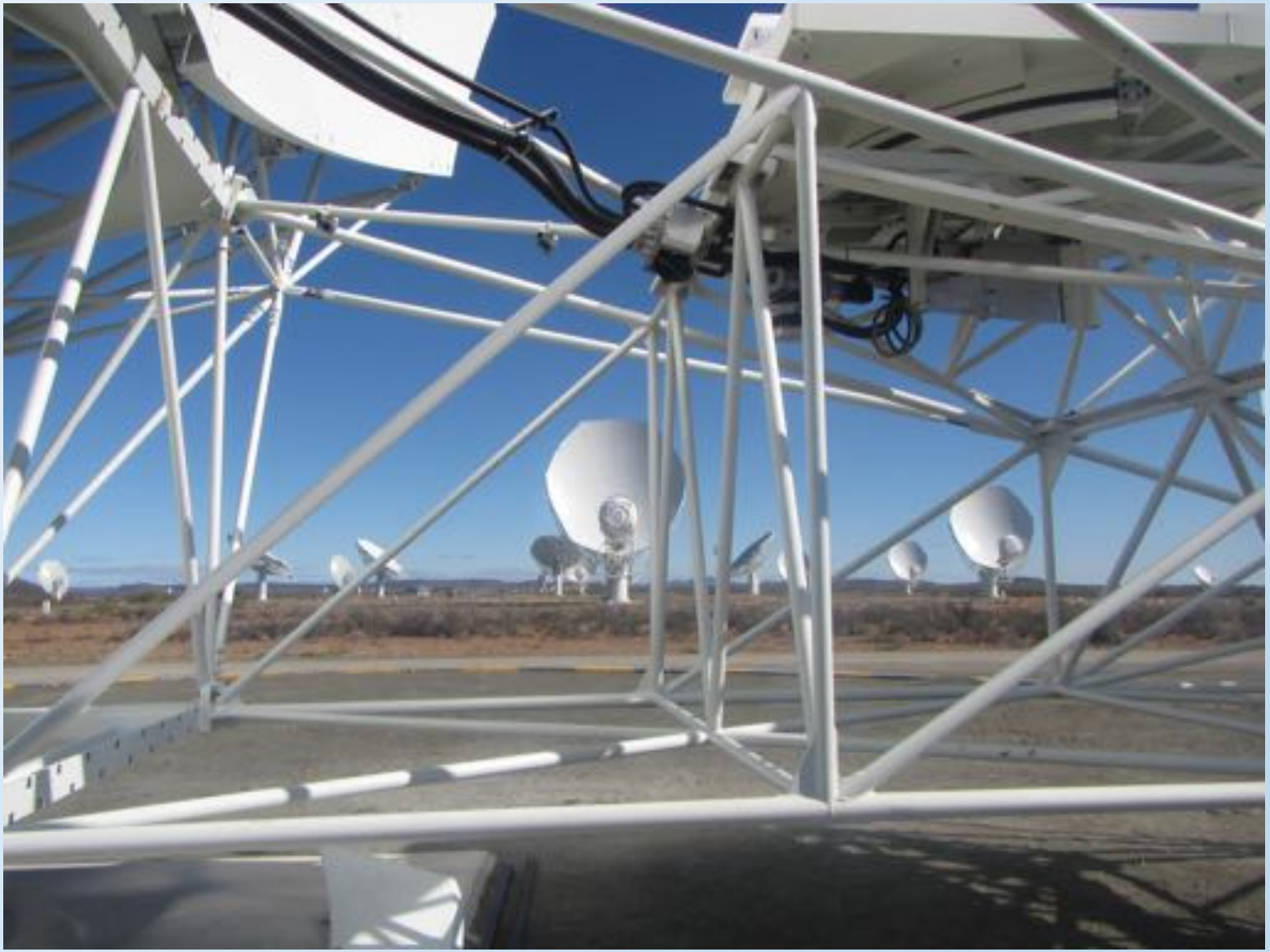
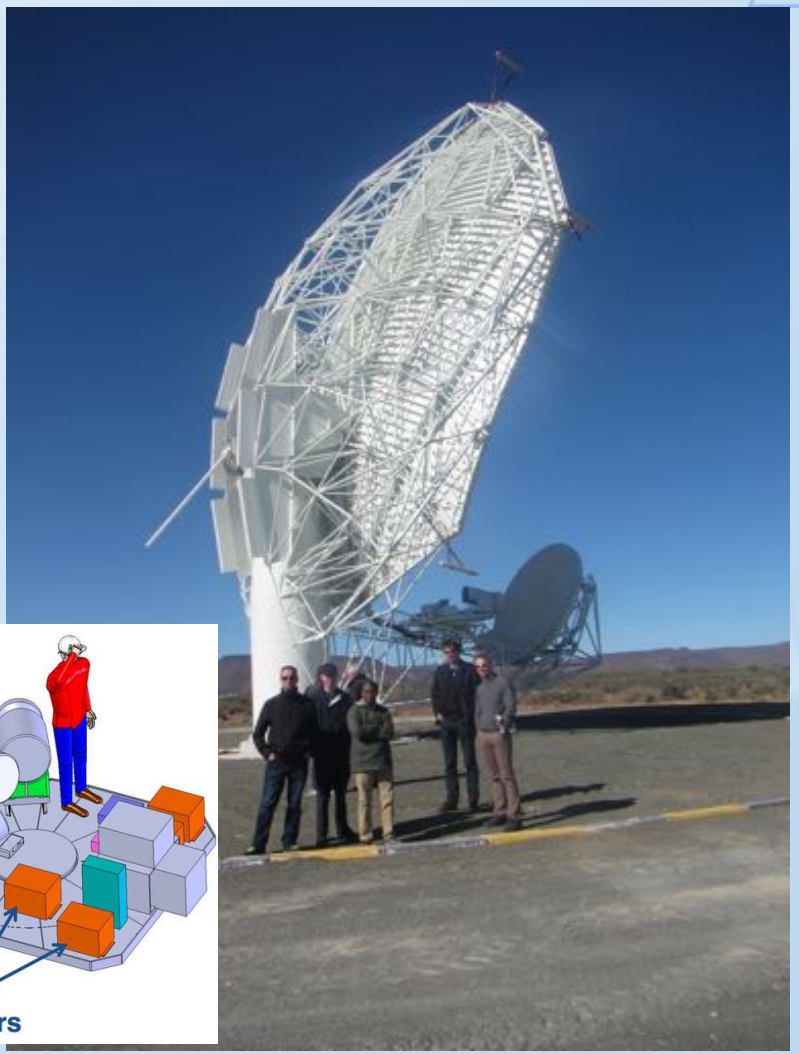


The system

More than a receiver:

- Frontend (64+2 receivers)
- new data transport system (digitzer + packetizer)
- 200/400 beam beam-former
- Compute cluster
- Storage



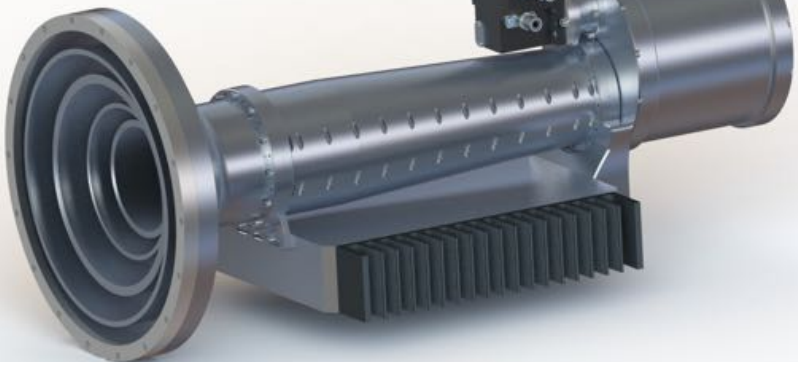
In close collaboration with our SA colleagues and Manchester & Oxford.

Idea: Provide it as facility instrument, even though it remains property of MPIfR

MPIfR MeerKAT S-Band System: Frontend

Number of Rx	2 Prototypen (Spare) 64 Produktion
Rx Bandwidth	1.75 – 3.50 GHz
Digitizer Bandwidth (Baseband Detection)	1.75 – 3.50 GHz (12Bit)
Sensitivity	T_{rec} < 25 K
Stabitlty	Spectroscopic Allan time$_{(1MHz\ Bandwidth)}$ > 1000 sec
Polarisation	H und V Polarisation Cross Coupling < 20dB
System Setup	cryogenic Dipole and LNA (@15Kelvin, GM cooler) baseband digitizing @ receiver
Time scale	prototype testing on MeerKAT Q3 2016 16 Rx release Q1 2017 32 Rx release Q3 2017 64 Rx release Q1 2018

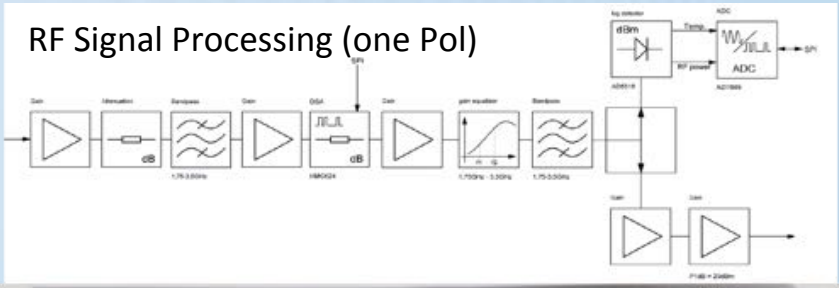
MPIfR S-Band Receiver

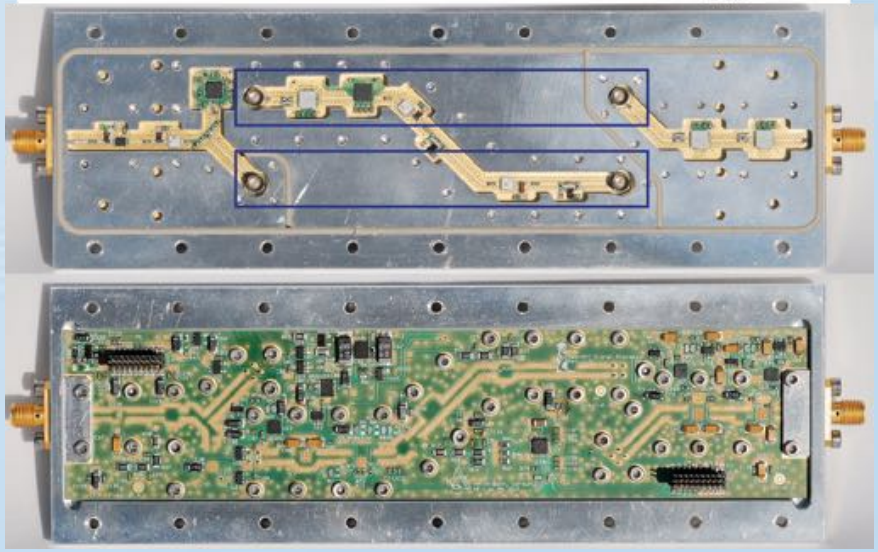


additional requirements

- highly reliable setup
- maintainability
- integration into MeerKAT infrastructure
- RFI requirement

RF Signal Processing (one Pol)

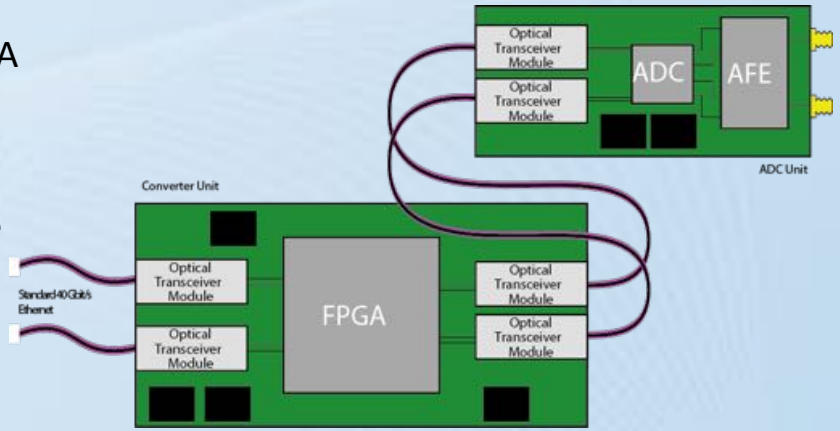




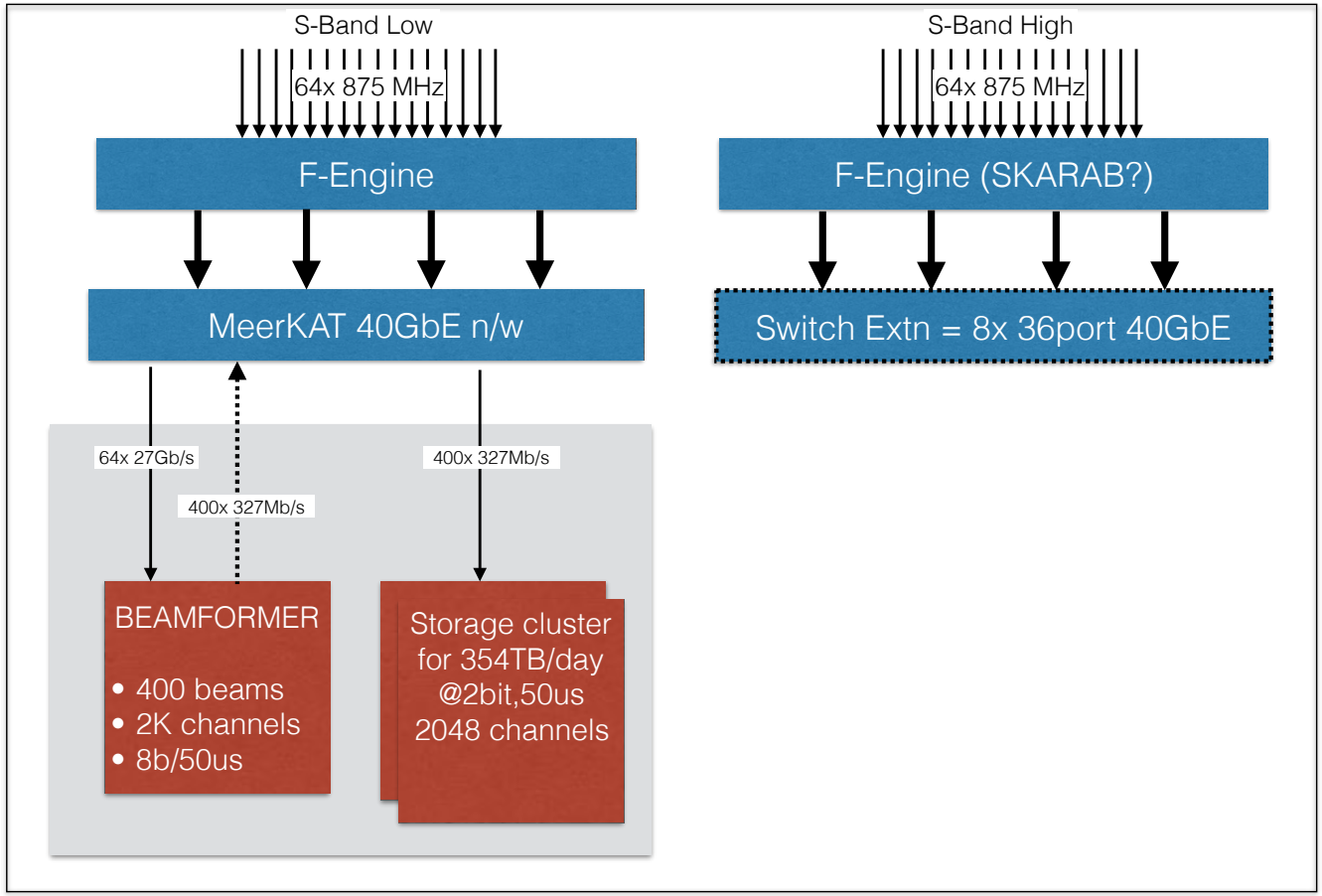
MPIfR MeerKAT S-Band System: Digitzer/Packetizer

- Electrical and spatial separation of ADC and FPGA
- integrating ADC in the Rx
- direct sampling 1.75 GHz bandwidth with 12Bit
- internal data reduction to 875MHz @10Bit to be compatible with MeerKAT Backend
- absolute time stamping in the Rx data stream

  -> timing limited by available time
- 2 x 40G/s Ethernet output total data stream up to 5400 Gb/sec (one output utilized for MeerKAT Backend)
- SPEAD – data protocol



MPIfR MeerKAT S-Band System
Beamformer & Backend System



Note: Phase I = standard BW of 875 MHz, Phase II = doubling to full bandwidth

Applications

- Spectroscopy (ISM studies via CH)
- VLBI
- Magnetism)polarisation surveys)
- ....
- Pulsar-related science:

Pulsar searching (extension of capabilities of TRAPUM)

- Probing inner Galaxy
- Deep Galactic plane searches for relativistic binaries

Pulsar timing (GR tests and GW detection)

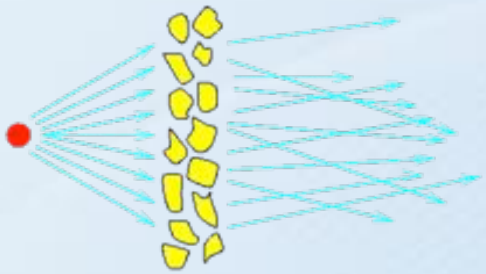
- Timing of newly discovered pulsars
- Removing ISM weather from PTA observations
- Combine with VLBI capability to measure parallax (GR tests)

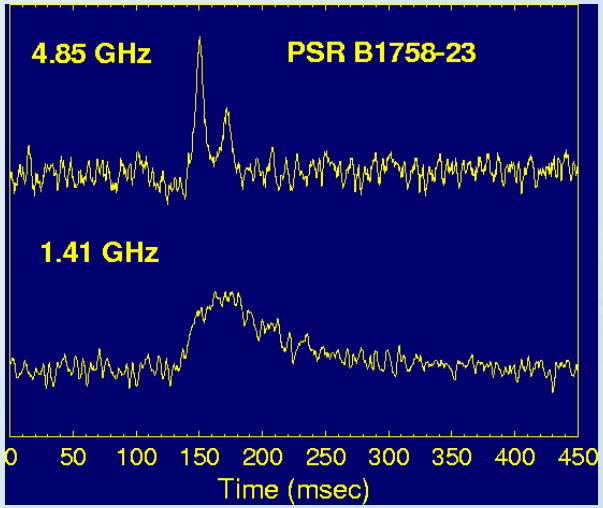
Transient detection and imaging (see MeerTRAP, PI Stappers)

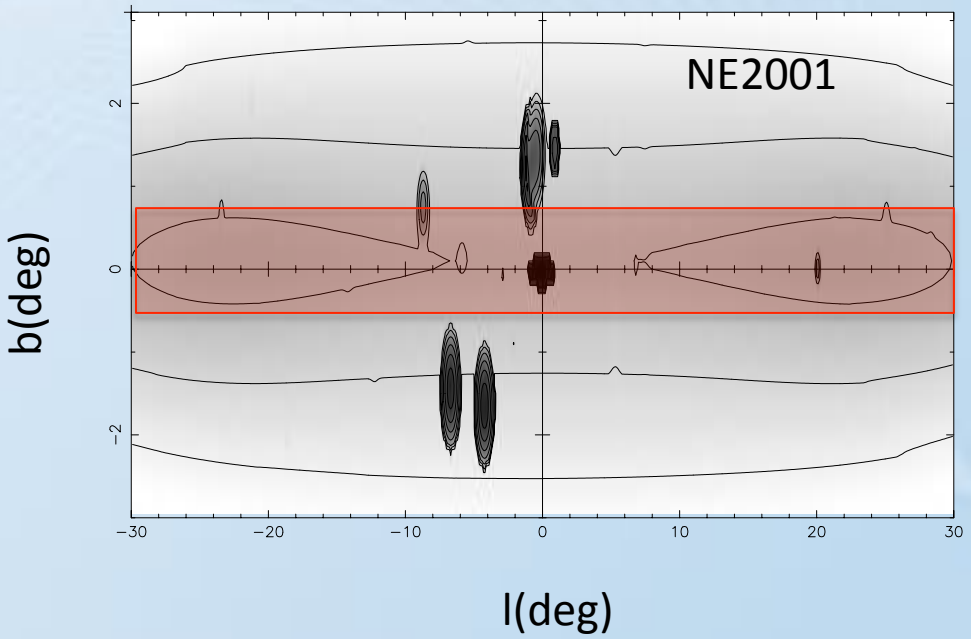
- Fast Radio Bursts (Detection & localisation)
- ??

Large-scale surveys

- L-band: deep survey for relativistic binary
- S-band: revealing population hidden by interstellar scattering:

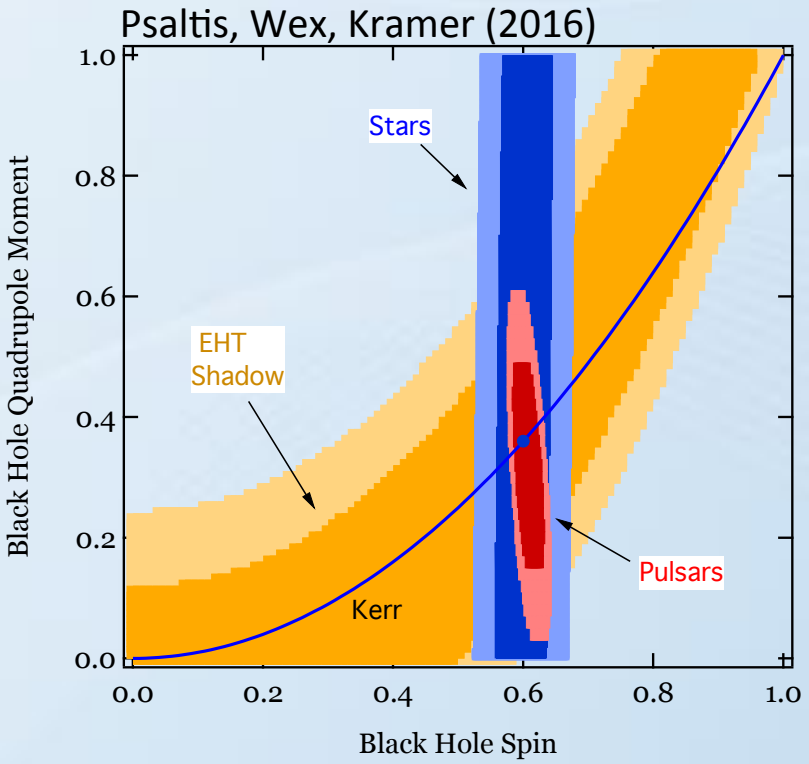




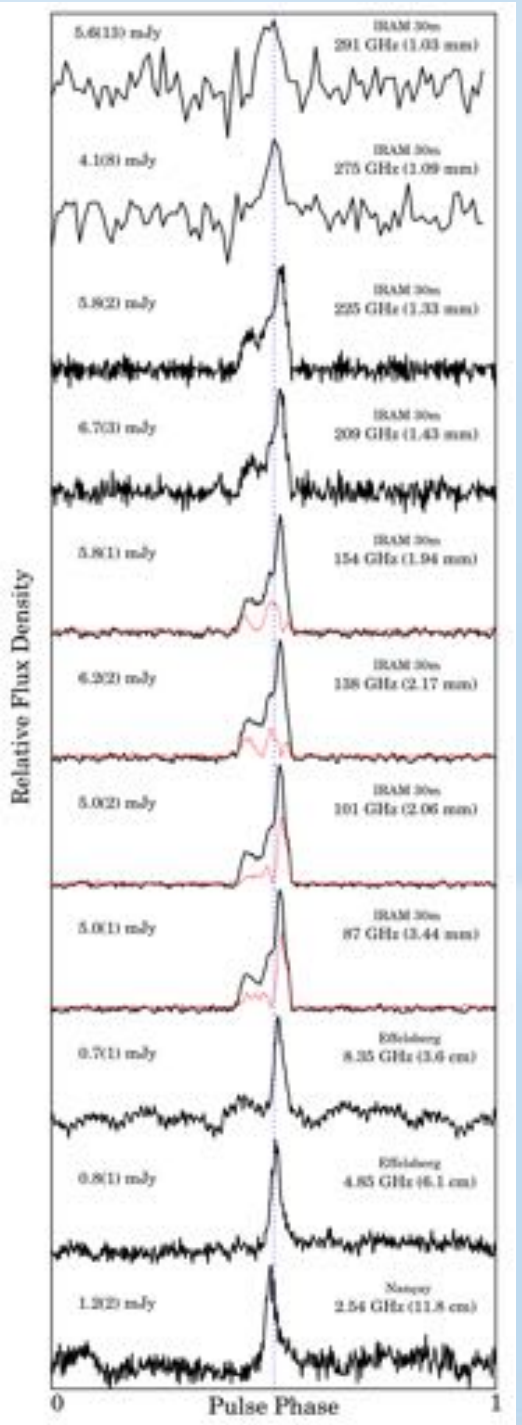


- Optimization of survey parameters still on-going,
- Current thinking: |l|<30 deg, |b|<0.5 deg
  Tobs = 5400 s
- Expected: >1100 detections, up to 750 discoveries
  few hundred millisecond pulsars
  exciting prospects for Galactic Centre!

Testing the no-hair theorem



Torne et al. (2016)



- A pulsar around Sgr A* will be superb probe for the BH
- We can measure mass (0.0001%), S (<0.1%) and Q (0.1%)
- Magnetar in Galactic Centre shows unexpected low scattering
- Chances to detect interesting pulsar even at lower frequencies
- Combine results from timing with EHT "shadow" image:

Combination will lead to uncorrelated measurement of spin and quadrupole moment and hence test of the no-hair theorem

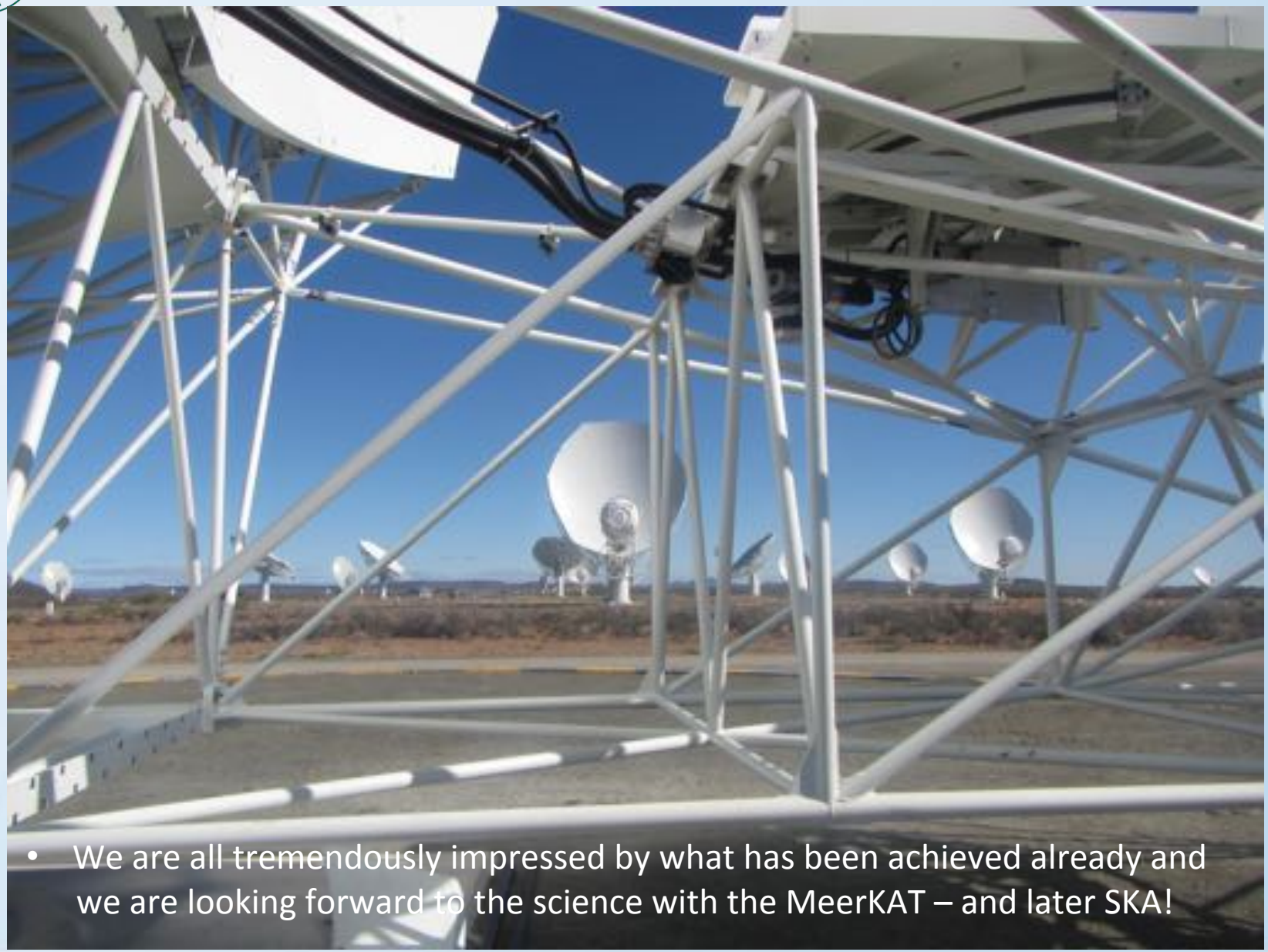
TRAPUM & MeerTRAP

- MPIfR search is complemented by TRAPUM
- "Transient and Pulsars with MeerKAT" at L-Band
- New: MeerTRAP ERC Advanced Grant to Ben Stappers:
  - upgrade: additional 200 beams to form 400 beams
  - online search & triggering to dump UV data for FRB localisation
  - commensal observations

Summary

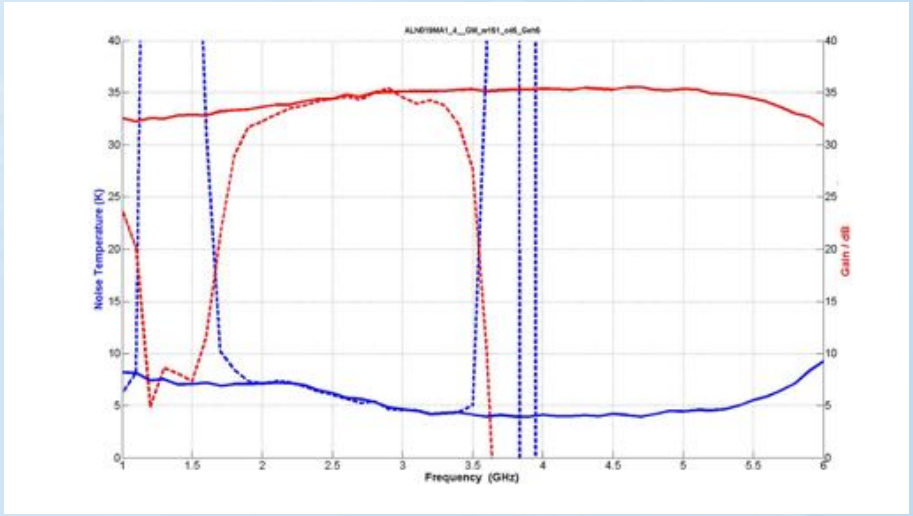
- S-band system extremely useful for variety of science questions
- Especially, excellent addition to TRAPUM & MEERTRAP
- Not only receivers but also data transport, beam former and compute/storage
- Available as facility instrument – with some caveats/rules attached
- Exploring LCT-satellite route to keep some data and to demonstrate application to remote sites in Africa

Summary



- We are all tremendously impressed by what has been achieved already and we are looking forward to the science with the MeerKAT – and later SKA!

MPIfR MeerKAT S-Band System Frontend (backup)



LNA noise tests
solid line: LNA
doted line: LNA incl. RF processor

stability RF processor and the digitizer