Developing an African VLBI Network

Michael Gaylard

Hartebeesthoek Radio Astronomy Observatory (HartRAO)
P. O. Box 443, Krugersdorp 1740, South Africa
www.hartrao.ac.za
mike@hartrao.ac.za

The SKA is coming...

Africa
Phase 1: 0.45 – 3 GHz
Over 100 km
Phase 2: 0.45 – 10 GHz
Over 3000 km

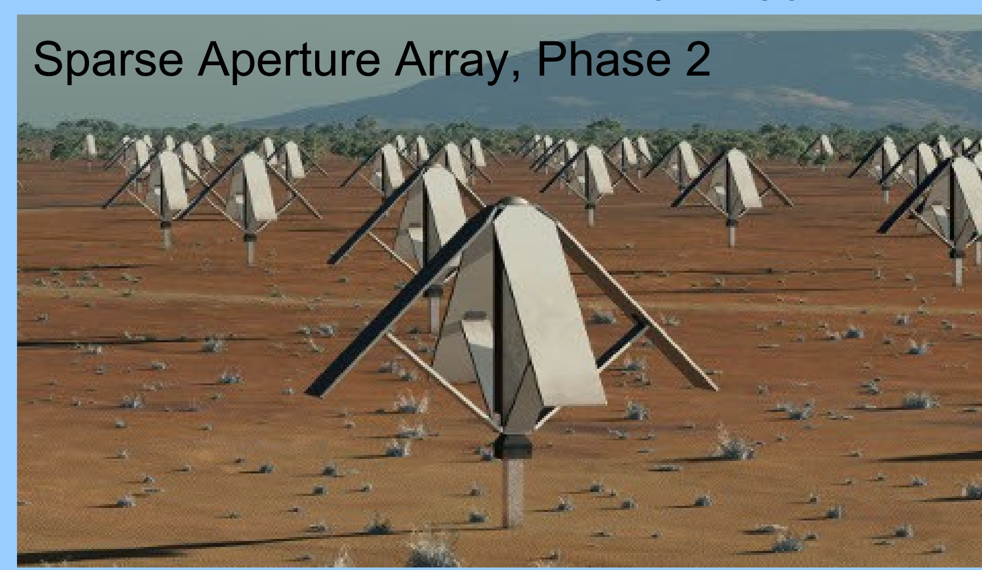
+ 64 MeerKAT dishes

Australia
Phase 1: 0.45 – 3 GHz
< 100 km

+ 36 ASKAP dishes

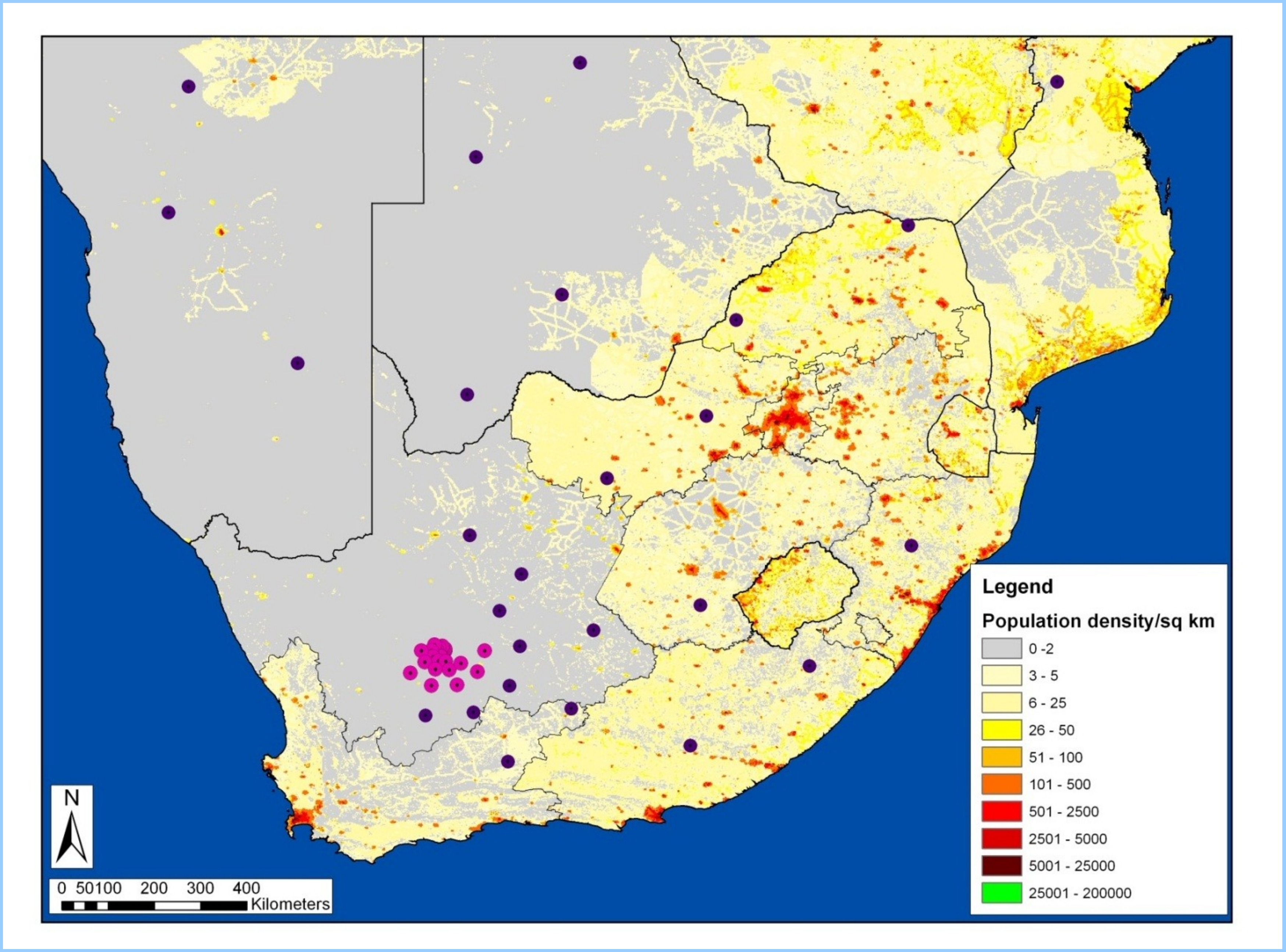
0.4 – 1.4 GHz

70 – 450 MHz

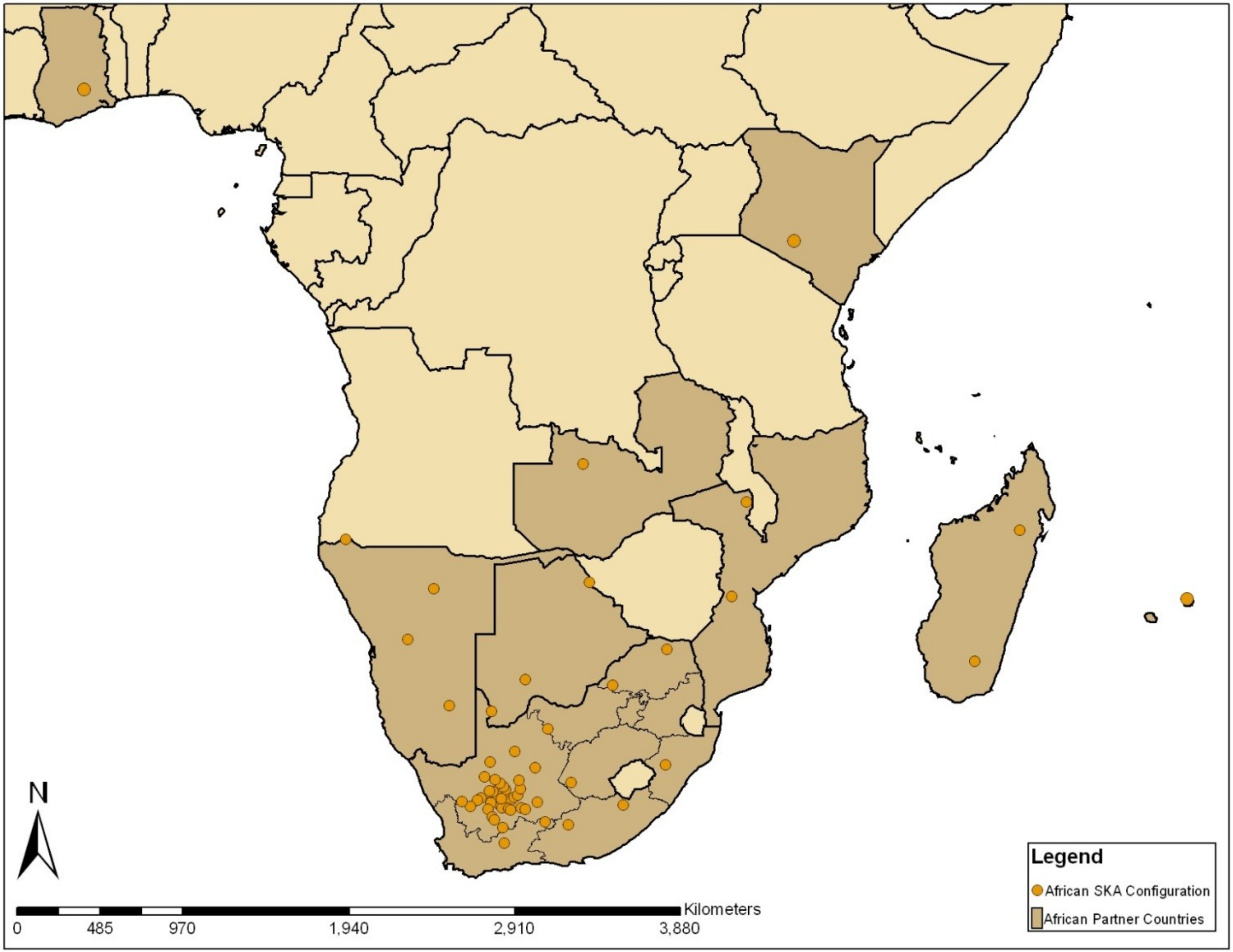


SKA-SA proposed siting – Southern Africa

Phase 1 **Phase 2**

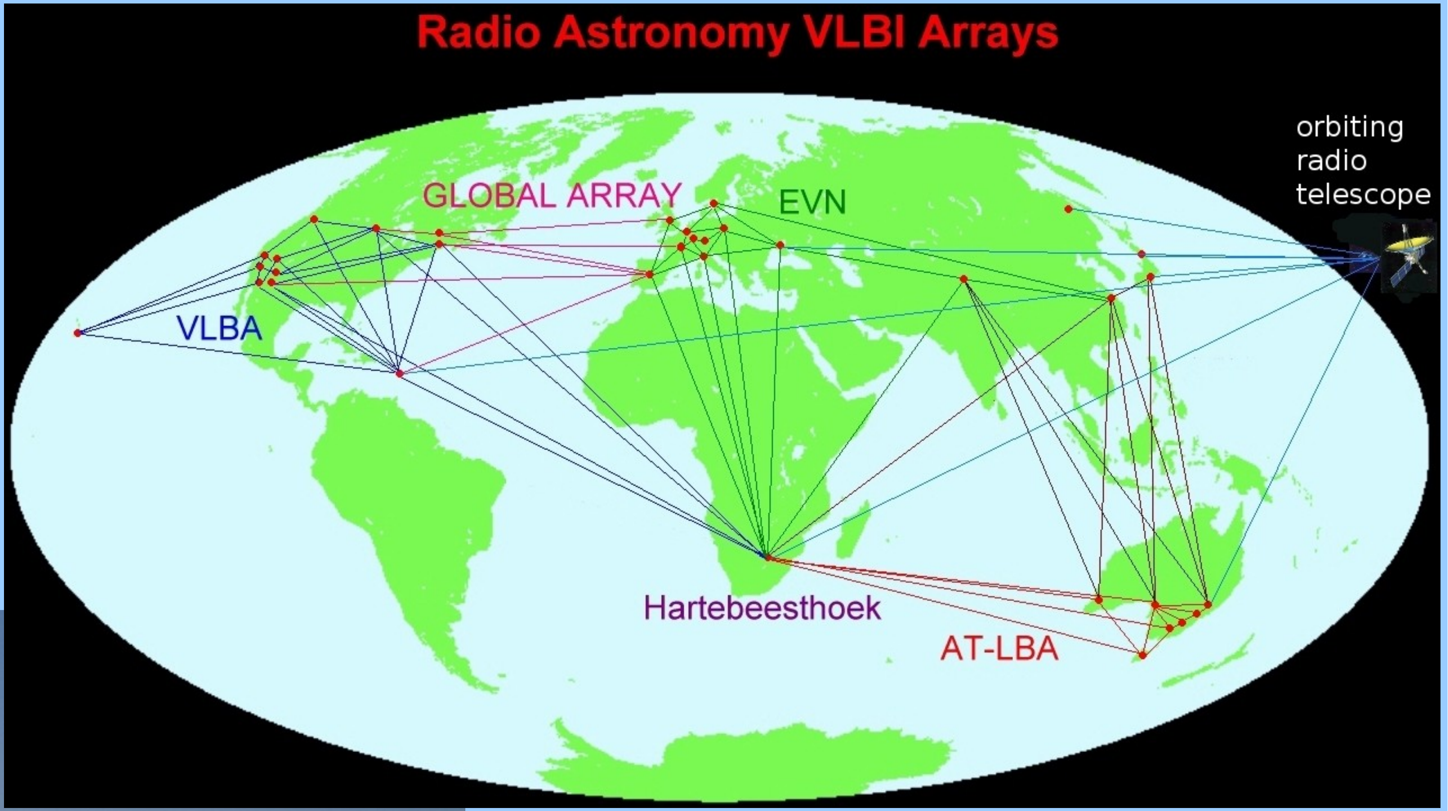


SKA-SA proposed siting - Africa



Contact:
Dr. Adrian Tiplady
SKA South Africa
17 Baker Street
Rosebank
2196
South Africa
Tel: +27 11 442 2434
Fax: +27 11 442 2454
Email: atiplady@ska.ac.za

Preparing for SKA Long Baselines: Current VLBI-capable Radio Telescopes in Africa



VLBI - Very Long Baseline Interferometry

26m and 15m Radio Telescopes, HartRAO, South Africa

Preparing African Partner Countries for SKA Long Baseline Stations - 1

- South Africa's Department of Science and Technology and SKA-SA have been working with partner countries:
  - Obtaining political buy-in
  - Obtaining infrastructure information
  - Identifying potential SKA outstation sites
  - Funding training in SA of students from partner countries as astronomers, engineers, technologists

Preparing African Partner Countries for SKA Long Baseline Stations - 2

- Capacity development:
    - Organisational structures to support outstation operation – visa facilitation, import/export of equipment
    - Availability of wideband internet connection at sites costed at academic rates
    - Availability of technical / engineering capability to support operations
    - Availability of electrical power to meet reliability requirement
    - Establishing benefits for the partner countries

Preparing African Partner Countries for SKA Long Baseline Stations - 3

- Benefits for partners – what is in it for them?
  - Participate in SKA science?
  - Participate in SKA development?
  - Development of internal capacity / capability?

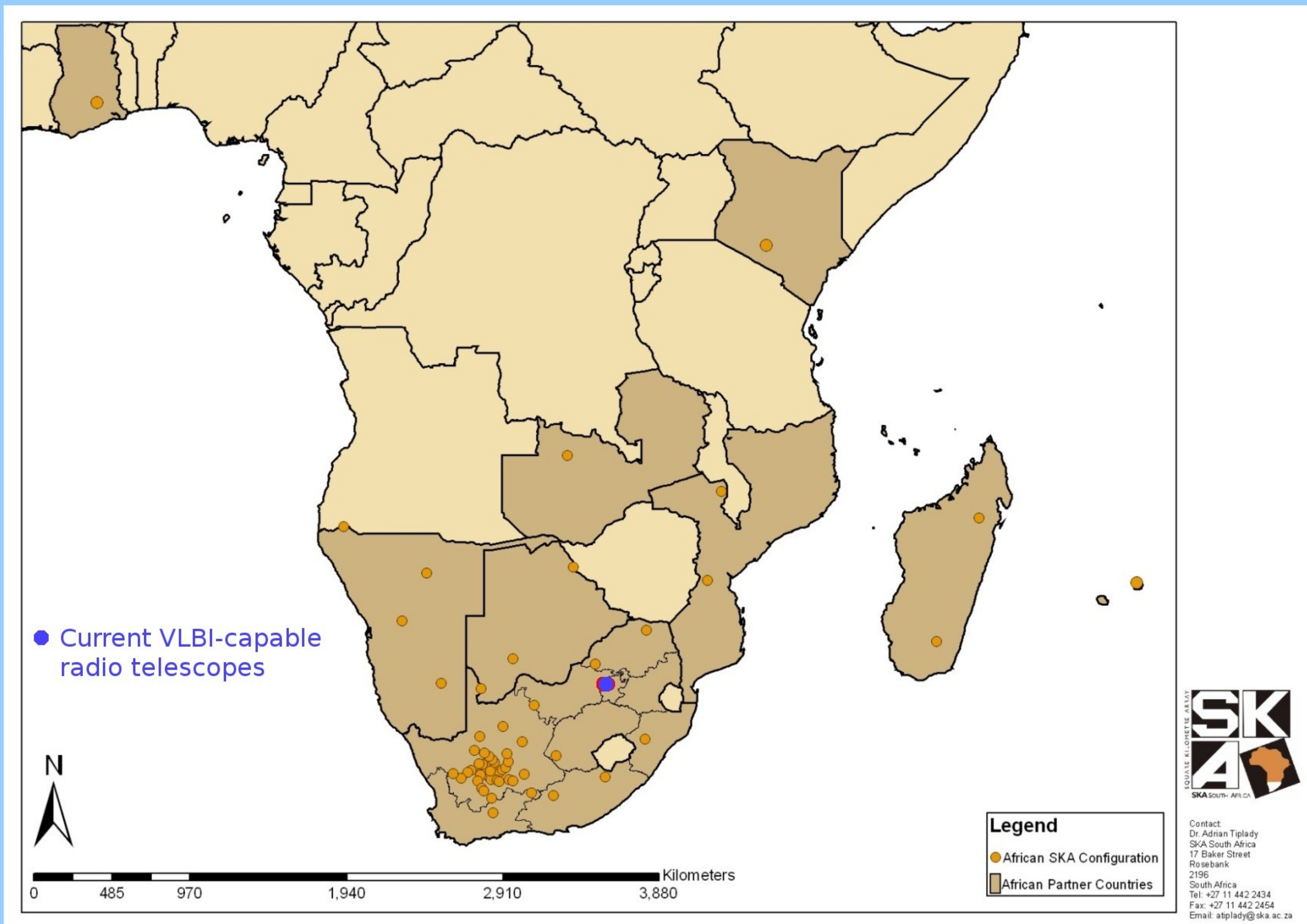
Preparing African Partner Countries for SKA Long Baseline Stations - 4

The best way to learn / prepare is by doing:

- Could we establish a VLBI-capable radio telescope in each country ahead of the SKA?
- What science could they do?
- Could they work with existing VLBI networks?
- Could a stand-alone VLBI capability be developed?
- DST proposal for the above was funded by SA's African Renaissance Fund and DST for ~$14m.

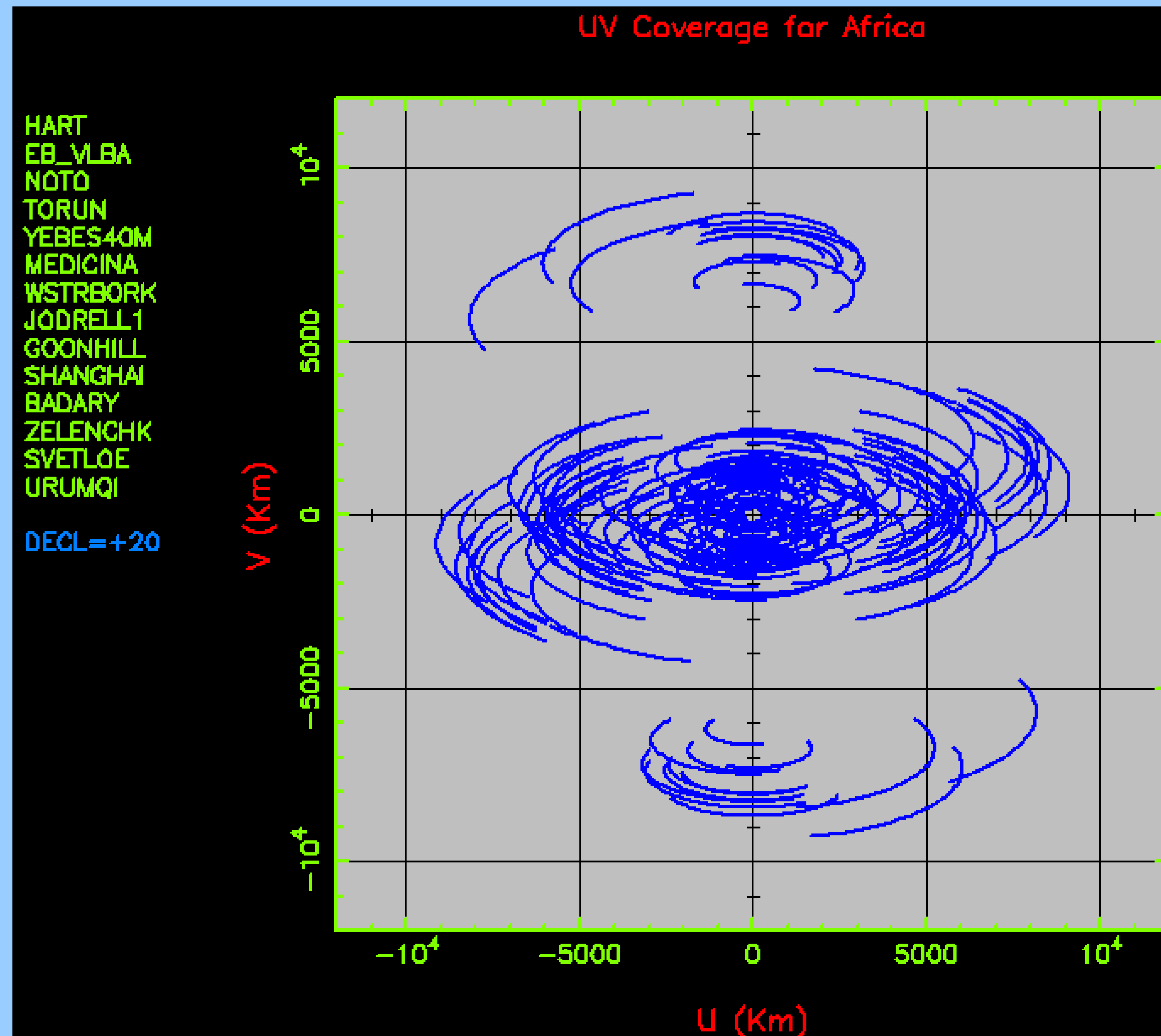
Preparing African Partner Countries for SKA Long Baseline Stations - 5

SKA-SA Africa bid participating countries



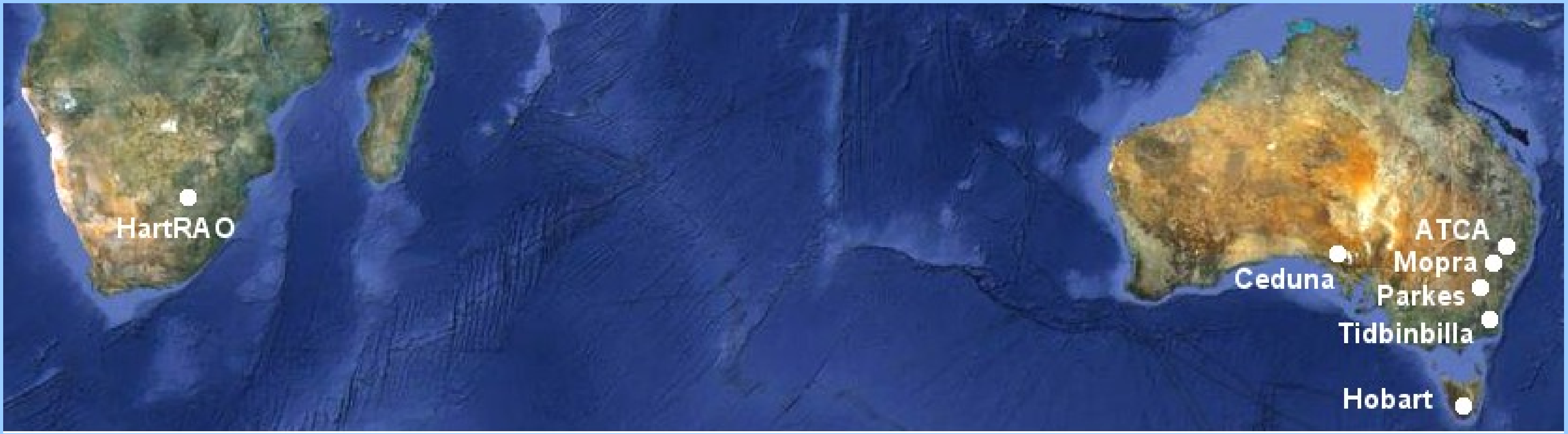
European VLBI Network + HartRAO UV-plot for source at Dec +20^{o}

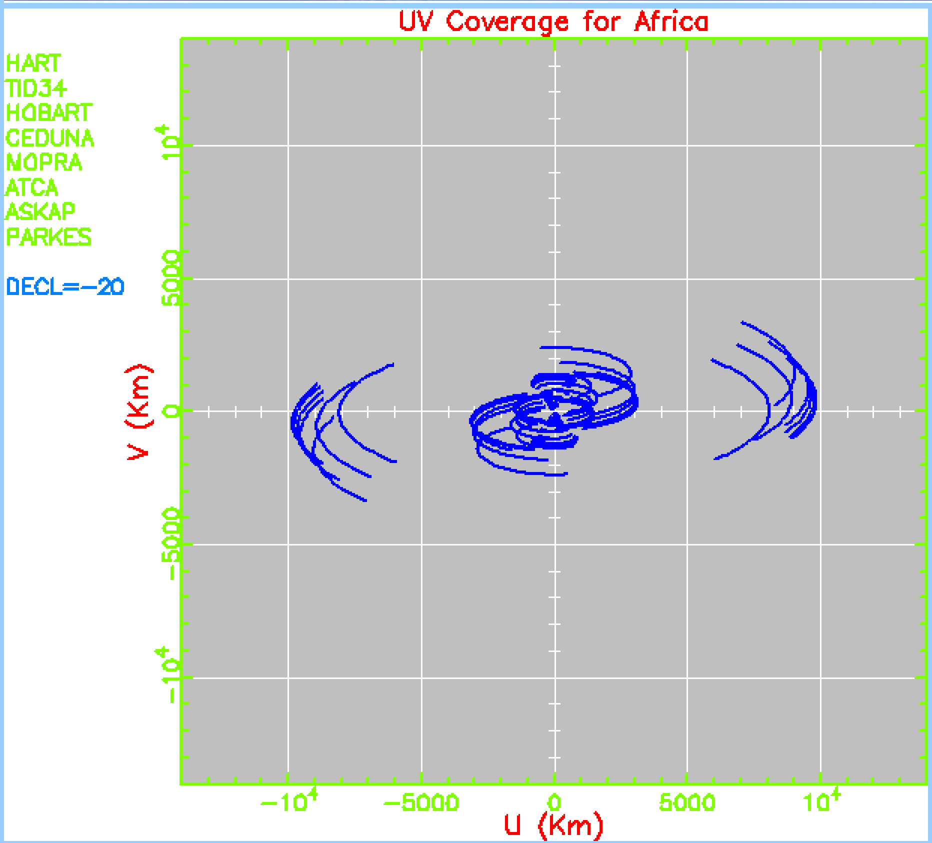
European VLBI Network



The large gap between Europe and South Africa leads to missing information and poor image quality

Australia Telescope Long Baseline Array + HartRAO





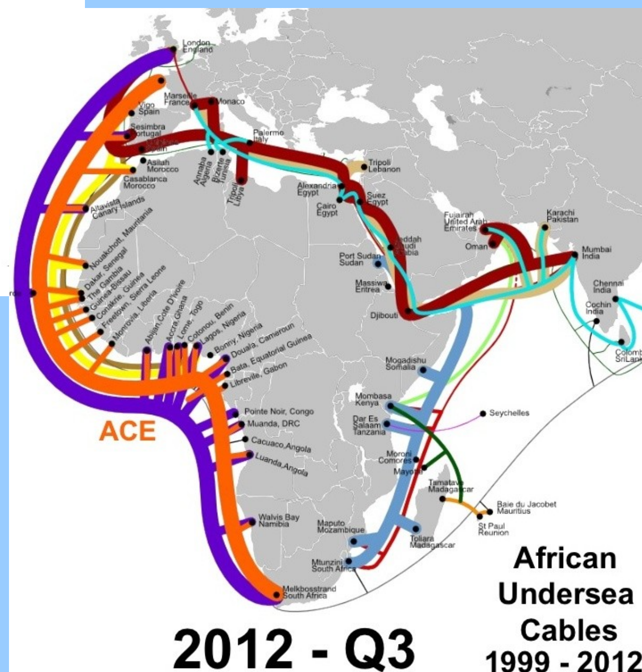
The long gap between the telescopes caused by the Indian Ocean means the “synthetic telescope” provided by Earth rotation has substantial missing information, reducing image quality

African Undersea Cables

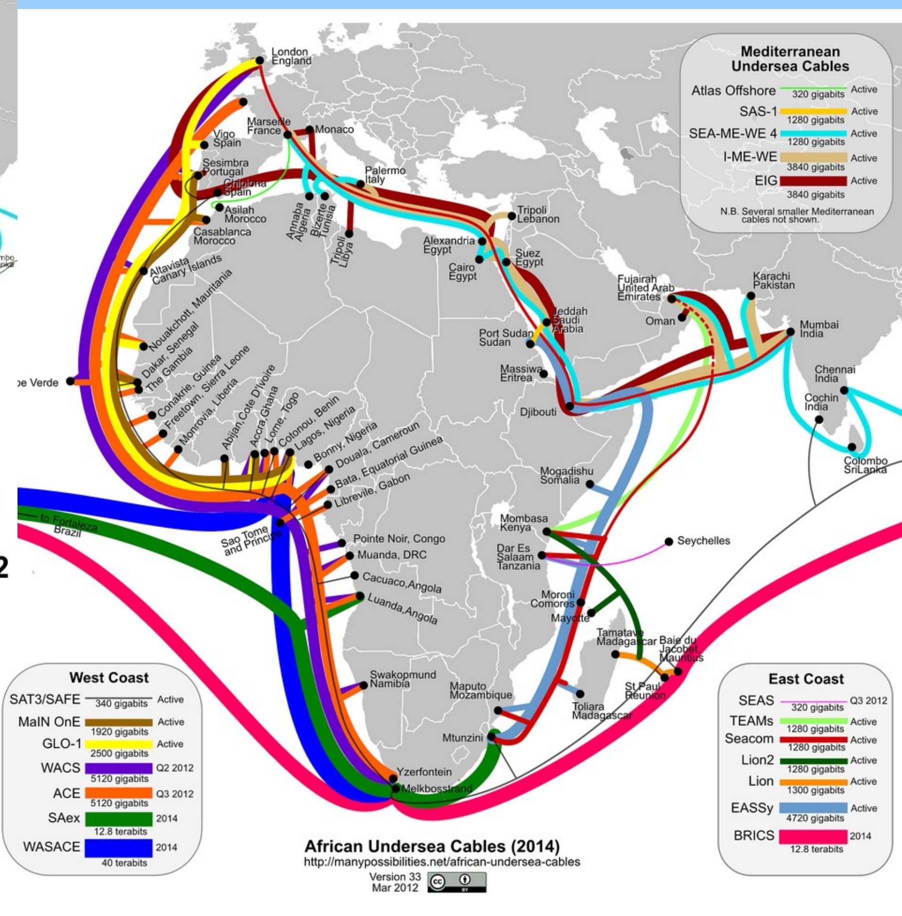
An enabling technology for the SKA in future,
And for long baseline radio astronomy now

The new technology is also making old, large satellite antennas obsolete

Hart - EVN
32 Mbps

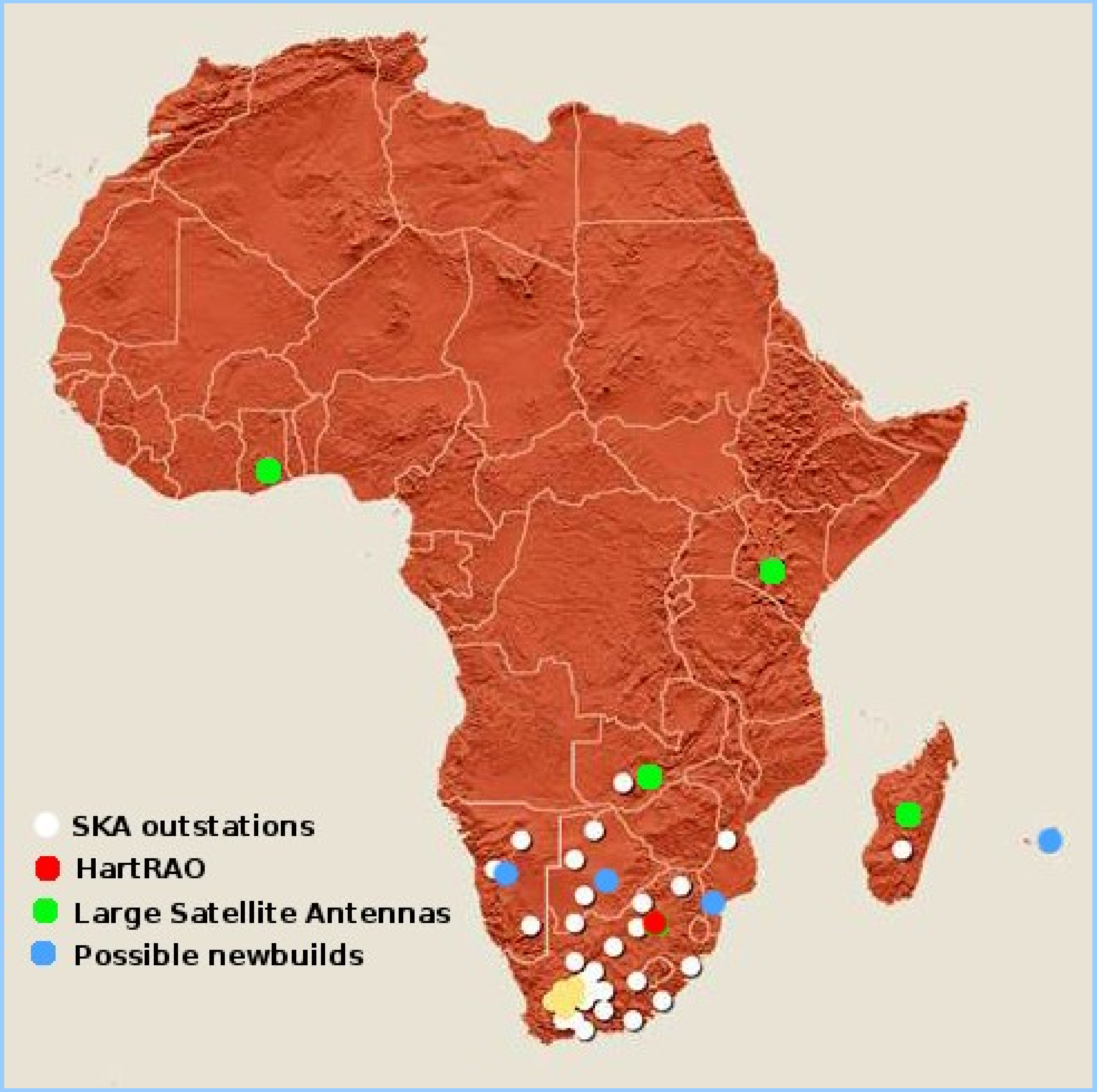


Hart – EVN
10 Gbps



Africa – Large Satellite Antennas

Existing and Possible New Antennas in SKA-SA partner countries



SKA-SA Partner Satellite Stations

Kenya
Longonot

Ghana
Kutunse

Madagascar
Tsirinana

Zambia
Mwembeshi

South Africa
Hartebeesthoek
Telkom

Networks that could benefit from more radio telescopes in Africa

European VLBI Network (EVN)

Global Array (EVN + US VLBA)

Australia Telescope Long Baseline Array (AT-LBA)

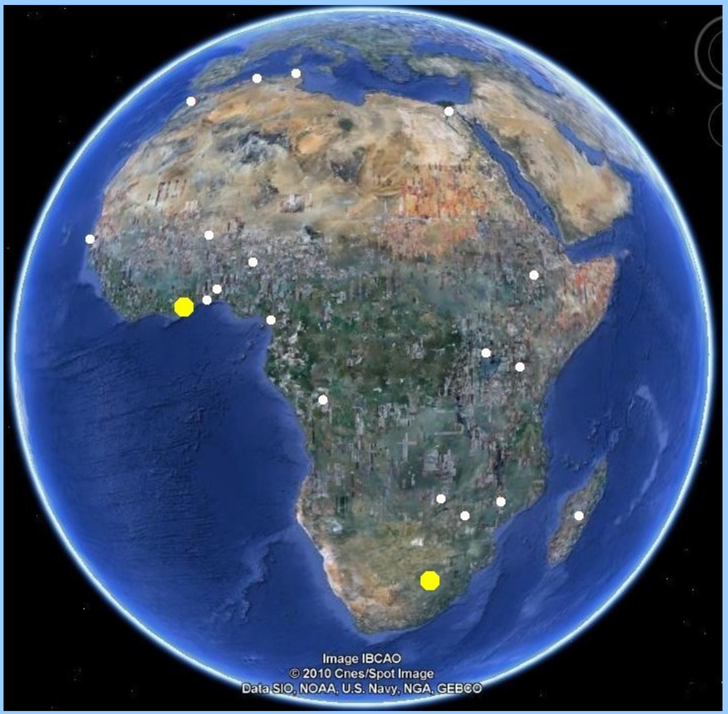
Astrometry and Geodesy Network (IVS)

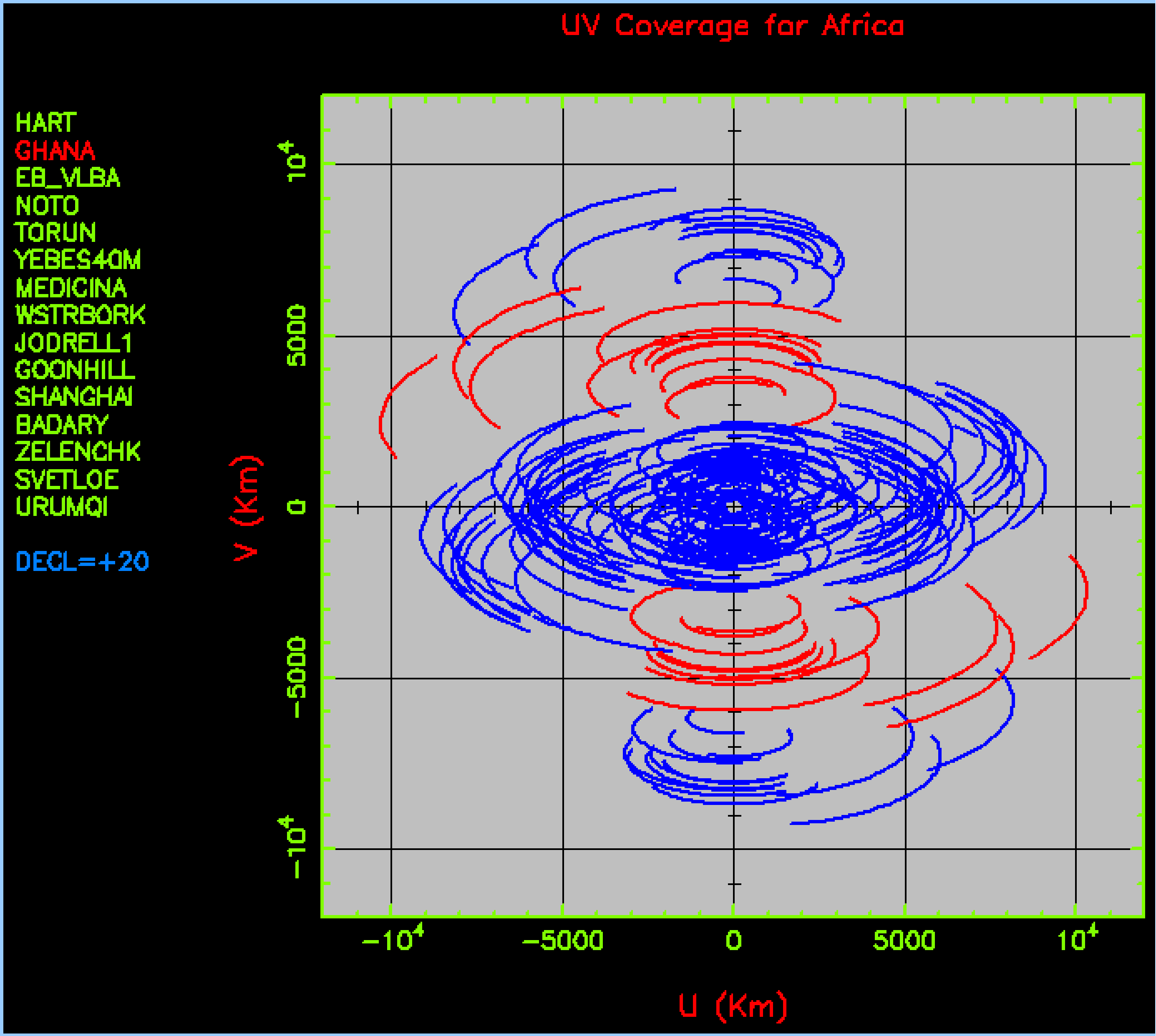
MeerKAT

SKA

An African VLBI Network: needs 4+ antennas for an independent imaging capability

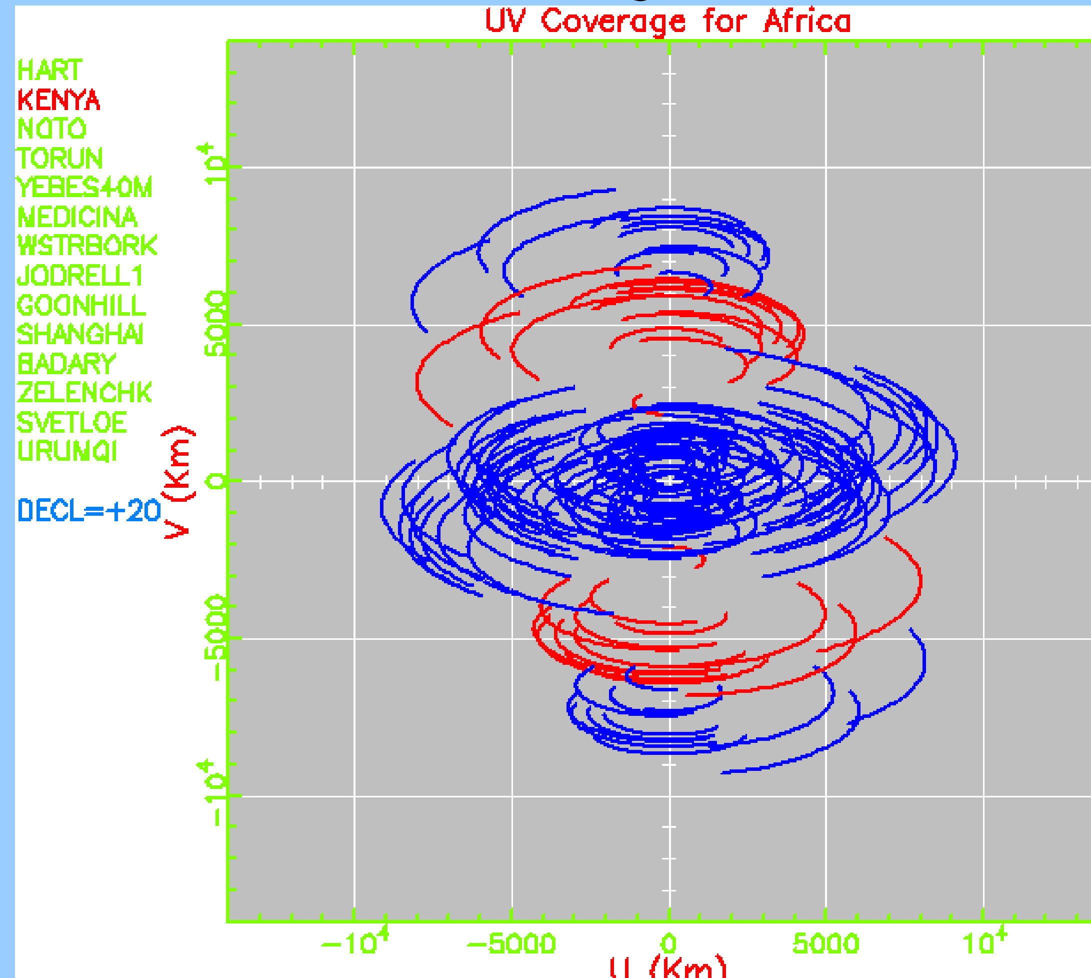
EVN with HartRAO + Ghana





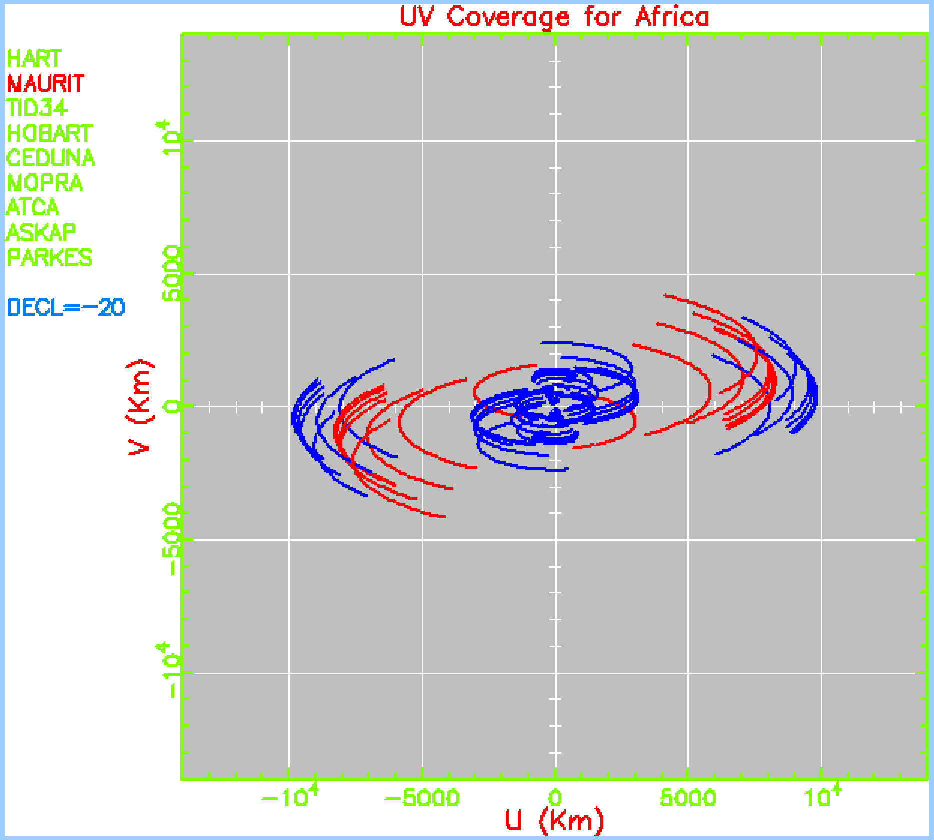
Filling the gap with Ghana or Kenya gives much superior imaging

EVN with HartRAO + Kenya



Longonot satellite station in Kenya – 1x30m out of use, 1x32m still in limited use
30m is similar to Goonhilly 3

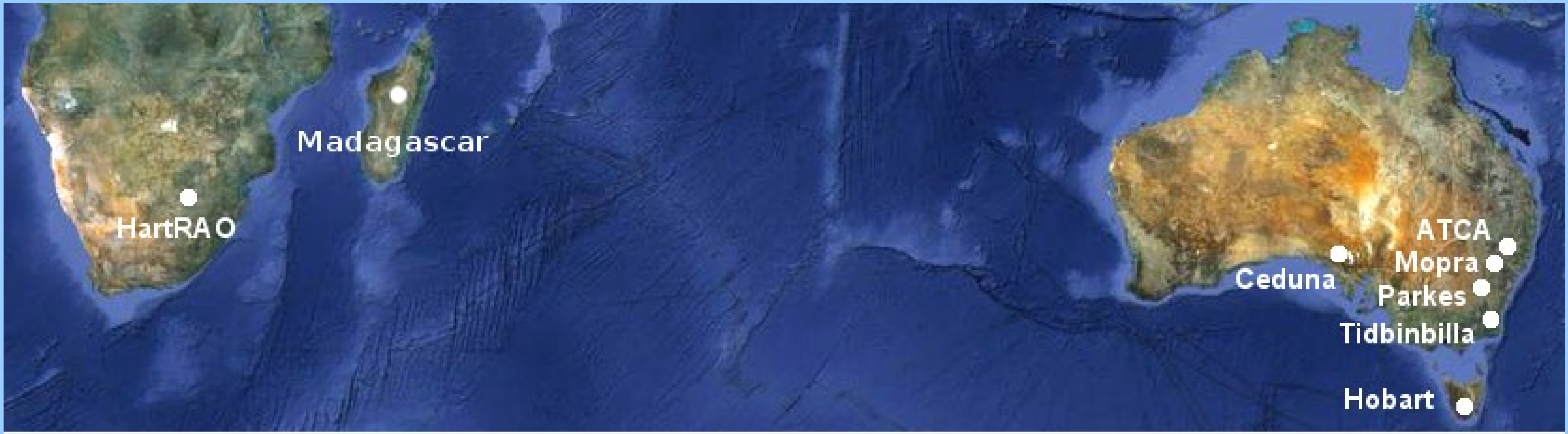
Australia Telescope LBA + HartRAO + Mauritius

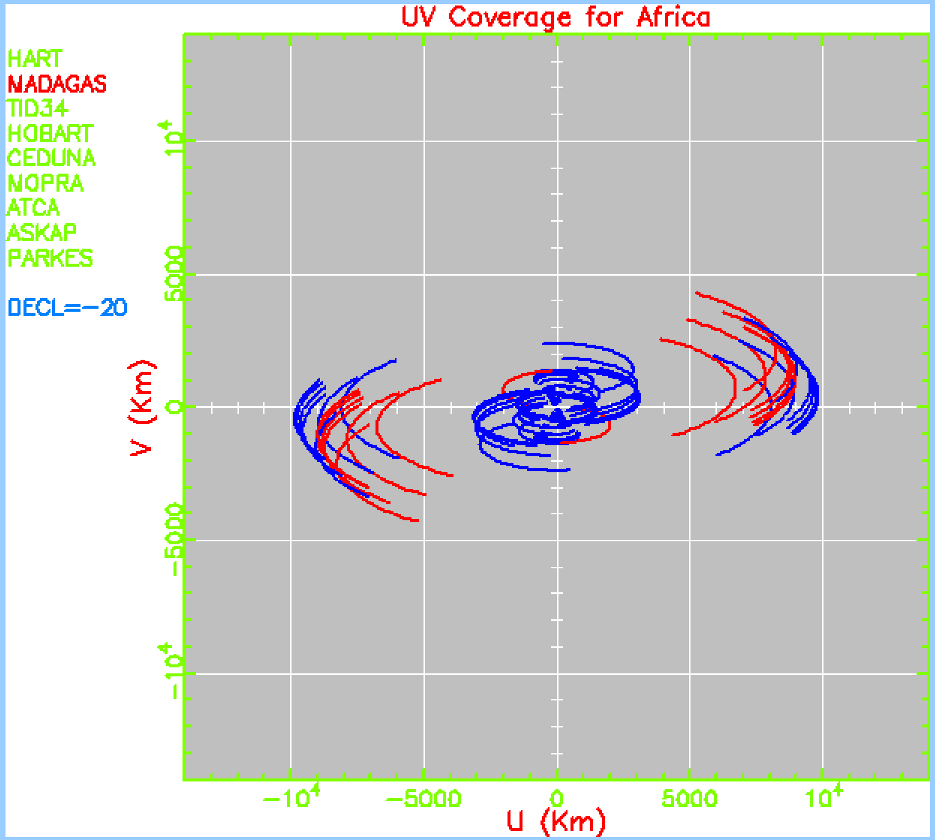


Having telescopes on the Indian Ocean islands would grealt reduce the gap and improve image quality.

There is no large satellite antenna available on Mauritius – a new large antenna would have to be built

Australia Telescope LBA + HartRAO + Madagascar





Madagascar has a large satellite antenna that could be converted for radio astronomy as its communications role diminishes or is no longer commercially viable. This would expected to be much cheaper than a newbuild of the same size.

Benefits of antenna conversion for the host country

- Re-use of an expensive installation that is now or is becoming redundant, at relatively low cost
- In country training in practical radio astronomy:
  - Single-dish research, student projects and practicals
  - Long baseline astronomy for high angular resolution imaging
- Create a pool of astronomers able to use current and future radio telescope arrays
- Create a pool of engineers and technicians able to support SKA outstations
- Stimulate fibre optic network development with spinoffs for the country
- Opportunities for training, research and development in engineering and technology:
  - advanced microwave feeds, low-noise amplifiers and receiver systems
  - analogue and digital electronics
  - digital signal processing
  - control and monitoring systems
  - software engineering
  - wide bandwidth communications networks
- Stimulate interest in science, engineering and technology through outreach programme
- Promote the establishment / development of a national Space / Astronomy Agency
- Establish other science instruments for multi-disciplinary science, eg:

  GPS base-station, gravimeter, seismometer, magnetometer

Science Objectives – VLBI Astronomy

Imaging with high angular resolution of bright radio sources of small angular size:

- **Quasars (AGNs)** – understanding jets, use as calibrators, references for parallaxes
- **Gamma-ray flare & burster** followup (HESS II in Namibia, FERMI-LAT, CTA)
- **Masers** – interstellar (e.g. methanol) – investigate variability / periodicity; measure maser spot movements; measure annual parallax to determine the distances to star-forming regions in the Milky Way and map the spiral arms
- **Supernovae** – behaviour of remnants of core-collapse supernovae, determine distances
- **Pulsars** – proper motions and distance determination through annual parallax, interstellar magnetic fields interstellar scattering, emission region size
- **Transient radio source** behaviour
- **Interacting binary star** behaviour e.g. Circinus X-1
- **Rapid response to new events** - E-VLBI and TOO VLBI through internet
- **Celestial and Terrestrial Reference Frames** development

Compare with SKA long baseline science case:

"*Memo 135 Very High Angular Resolution Science with the SKA*", L. Godfrey, H. Bignall, S. Tingay, May 2011, and summarised in "*Science at Very High Angular Resolution with the Square Kilometre Array*", E. H. Godfrey, et al., Publ. Astron. Soc. Australia, 2012, 29, 42–53.

Science Objectives – Single-Dish Astronomy

West African and Central African stations:

- Near equator so see more of the sky than any other similar radio telescope
- Can see the entire Milky Way Galaxy

Single dish research / training opportunity examples:

- **Spectroscopy** with narrowband multi-channel receiver
  - Monitor masers in star-forming regions eg for periodic variations (e.g. methanol at 6668MHz, 12178MHz)
  - Survey formaldehyde absorption in Milky Way dark clouds (4829 MHz, 14488MHz)
- **Pulsar** observing with wideband multi-channel timer
  - Monitor pulsars for glitches, long term behaviour, proper motion
  - Search / monitor for intermittent pulsars and transients (RRATs)
- **Radio continuum flux measurement** with wideband multi-channel radiometer
  - Monitoring of Gamma-ray flare sources
- FPGA-based board with suitable software can do all three of these tasks

Process for Conversions

- Assist in establishing organisation in host country to operate the facility
- Establish training of engineers, technicians, astronomers
- Evaluate structural, mechanical and electronic needs for converting the antenna for radio astronomy
- Carry out mechanical & control system upgrades as needed
- Test with simple 5 GHz receiver on existing 4 - 6 GHz feed, permitting basic single-dish & VLBI testing
- Build 5 + 6.7 GHz receivers for existing feed to develop an operational VLBI capability
- Commission for operational VLBI at 5 + 6.7 GHz, operation by host country
- Evaluate options for operation at other frequencies, e.g 1.4 – 1.7 GHz eg as Ceduna
- Implement multi-frequency option selected
- Upgrade to cryogenic receivers

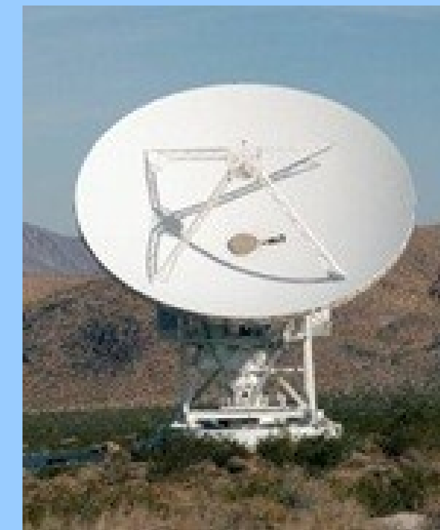
Antenna conversion examples

Top row are operational as radio telescopes:

Australia Ceduna

Japan Yamaguchi

Japan Ibaraki



USA NASA DSS28

Peru Sicaya – First light 2011/03

New Zealand Warkworth - handed over 2010/11

Ireland Elfordstown – handed over 2011/05

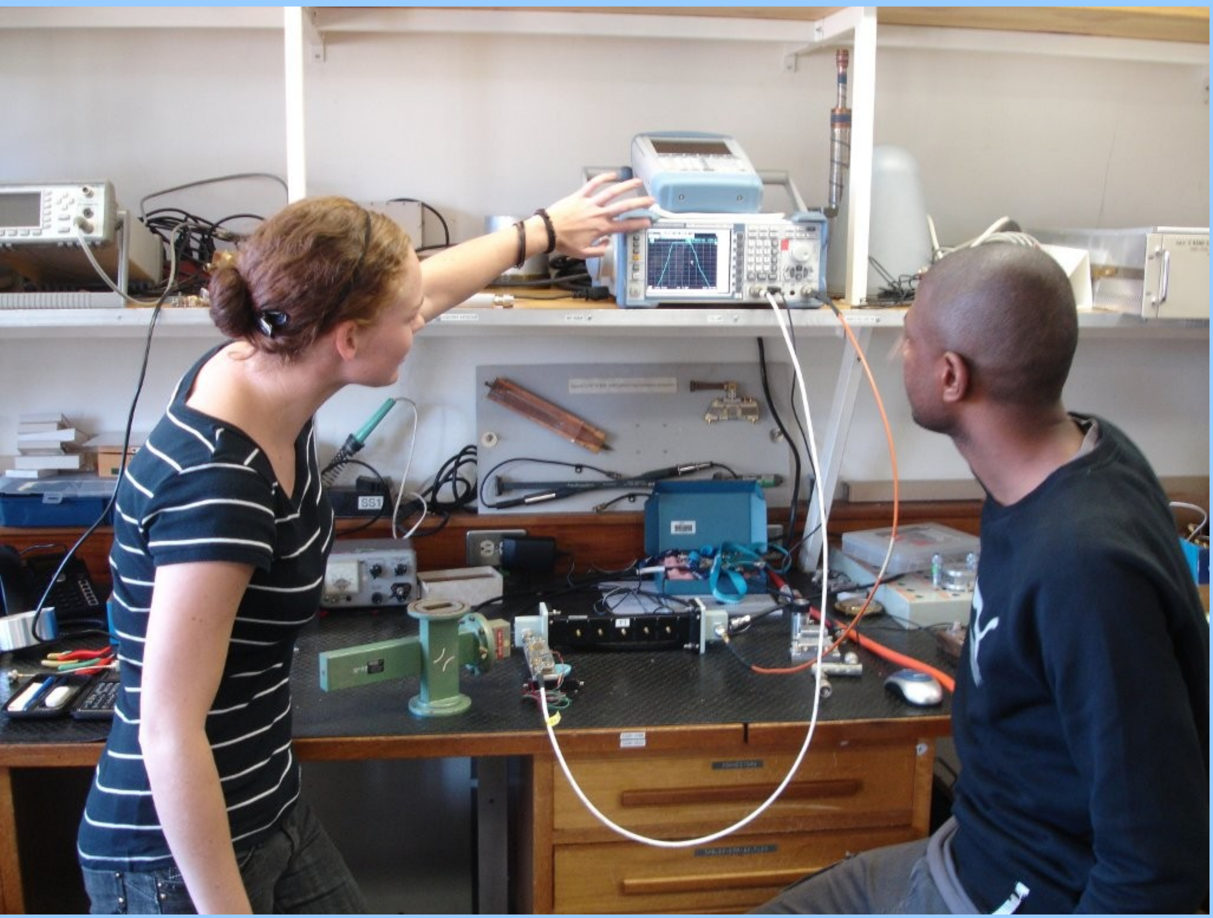
England Goonhilly – funded 2012

SA Development team

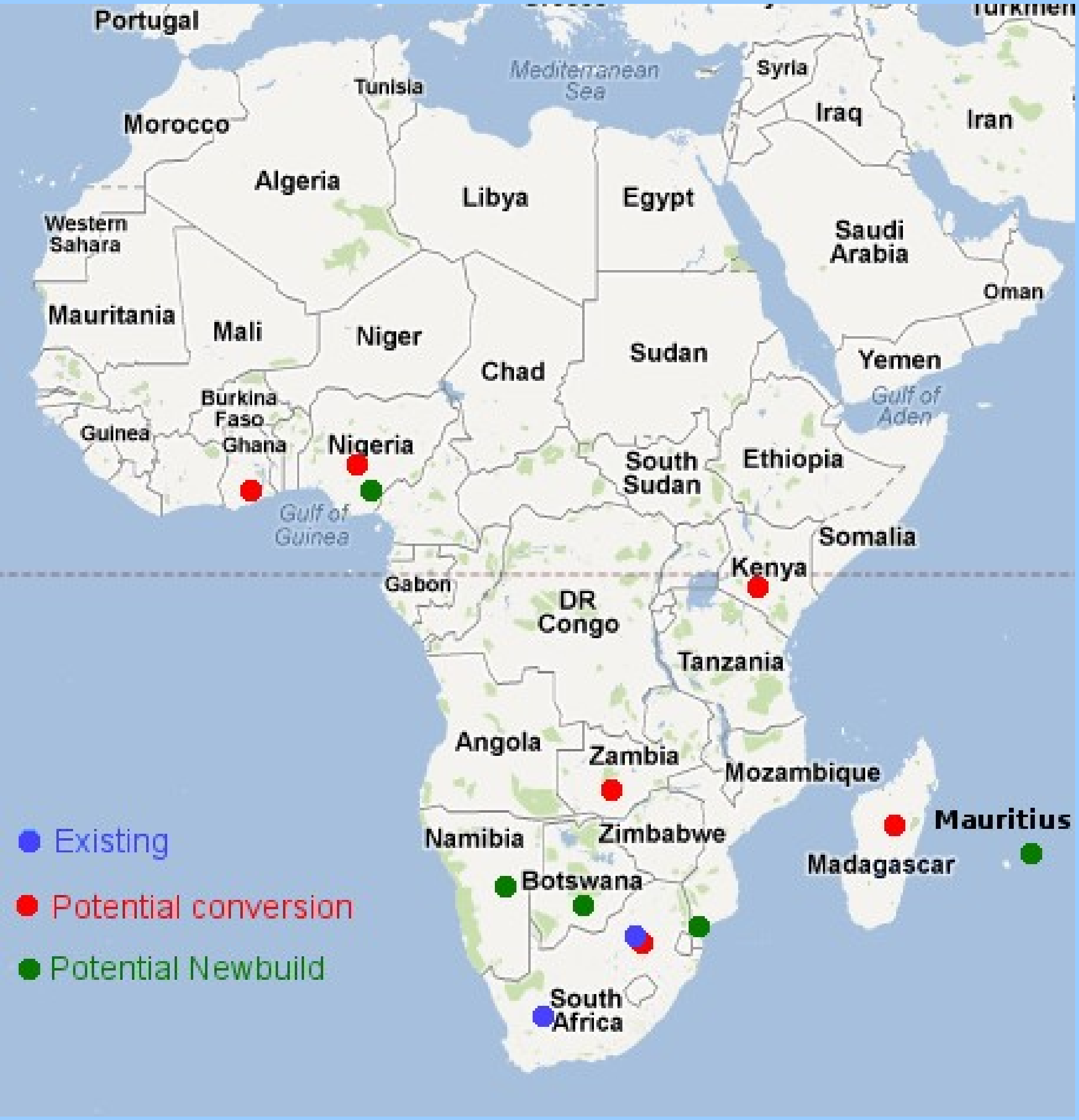
Development team has been established at SKA-SA offices in Cape Town and at HartRAO:

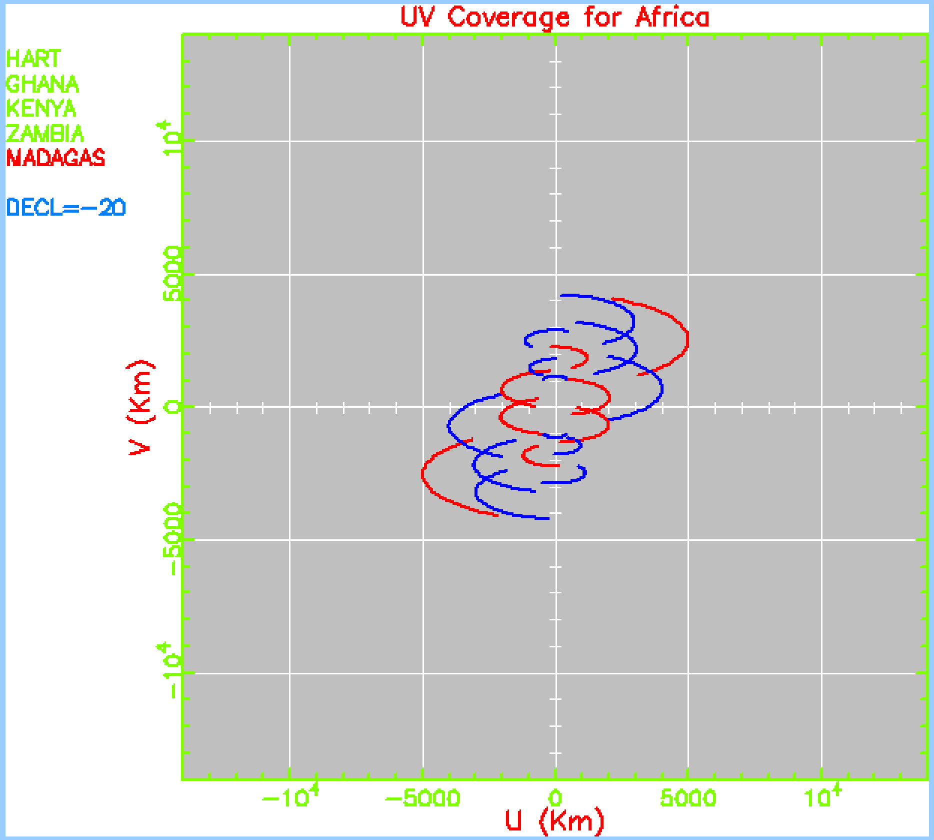
- Project Manager (engineer)
- Mechanical engineer and technicians
- Electronic engineer and technicians
- Software engineer and technicians
- RF engineer and technicians being recruited
- Systems test and verification engineer
- \+ part time commitments from HartRAO staff

First test receiver for Ghana antenna, in development at HartRAO



Expanding the African VLBI Network

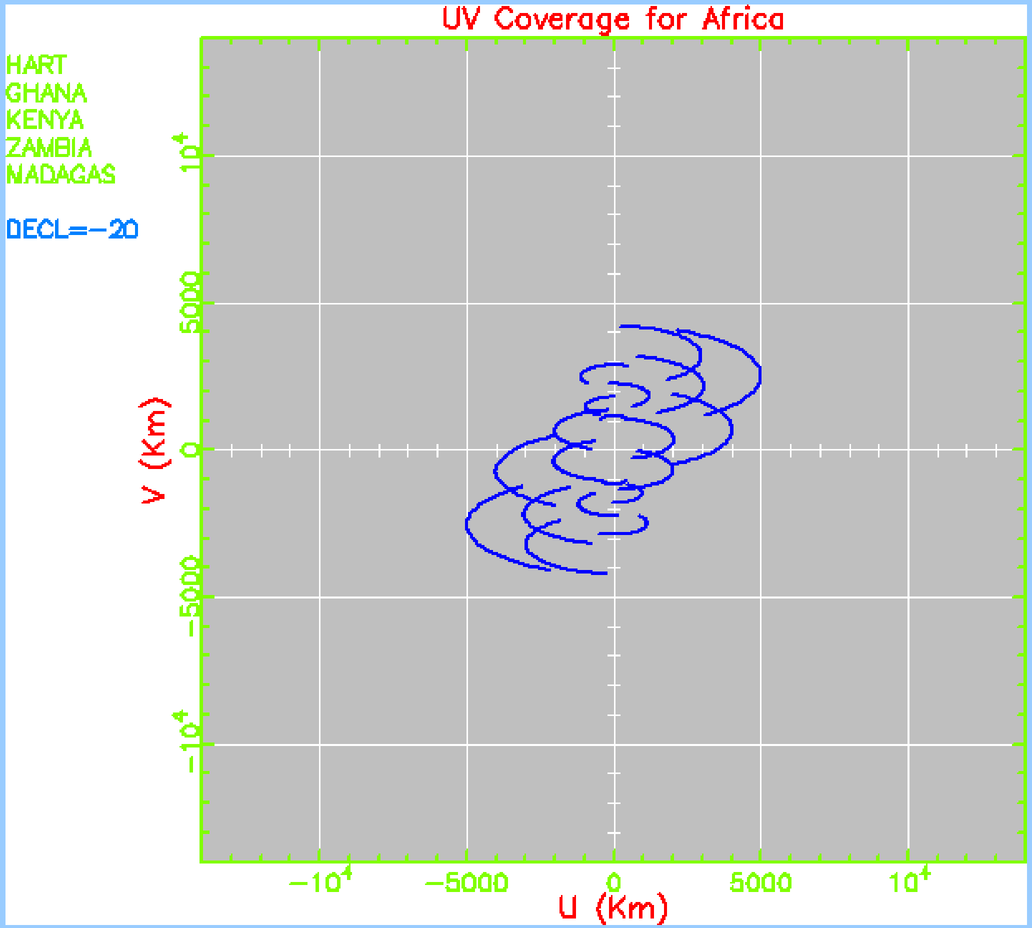




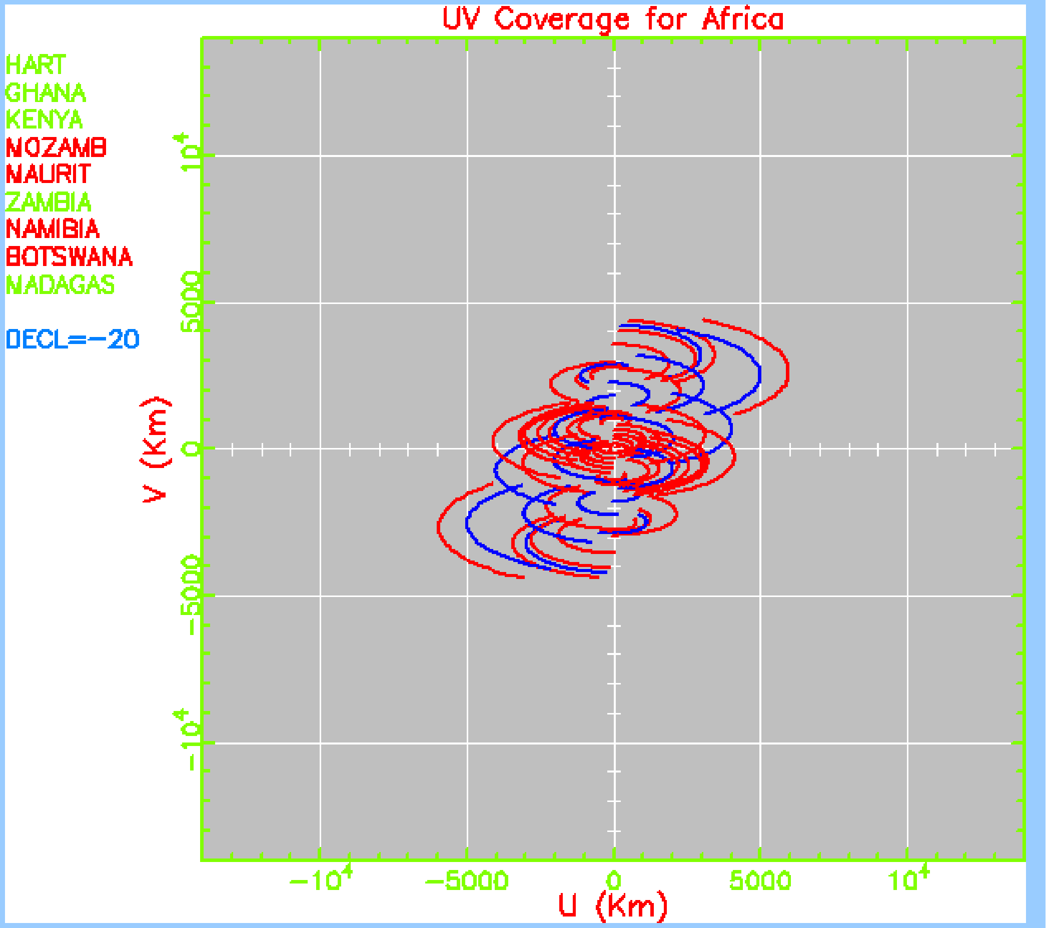
Importance of Madagascar in a network of converted large satellite antennas in filling gaps in coverage

Adding new-build telescopes would improve imaging capability

UV coverage with all large satellite antennas converted, for source at Dec -20



UV coverage with all large satellite antennas converted and four new-builds, for source at Dec -20



Potential New-Build Telescopes

SKA-SA Partner Countries:

Botswana, Mauritius, Mozambique, Namibia

Functions:

Training

Science

Compatibility with existing VLBI Networks

Enhance stand-alone AVN VLBI capability

Compatibility with MeerKAT

Compatibility with SKA

Key questions require investigation:

Location, Infrastructure cost, Radio emissions at potential sites, Antenna size, Frequency bands

Commenced design studies

Funding sources need to be identified for:

Infrastructure – optic fibre connection, power, water etc.

Telescope and associated equipment

Training

Operating organisation

Operating costs

System Equivalent Flux Density – Requirement for EVN acceptance

telescope	EVN code	Diameter (m)	SEFD_1.6GHz	SEFD_5GHz
EVN				
Jodrell Bank	JB-1	76	65	80
Jodrell Bank	JB-2	25	320	320
Cambridge	Cm	32	212	136
Westerbork (14)	Wb	25	330	760
Effelsberg	Eb	100	19	20
Medicina	Mc	32	700	170
Noto	Nt	32	784	260
Onsala	On-85	25	320	600
Shanghai	Sh	25	670	720
Urumqi	Ur	25	270	200
Torun	Tr	32	300	220
Yebes	Ts	40		160
Arecibo	Ar	305	3	5
Hartebeesthoek	Hh	26	430	650
Svetloe	Sv	32	360	250
Zelenchukskaya	Zc	32	300	400
Badary	Bd	32	330	200
SEFD (Jy)	**median**	**32**	**320**	**220**
VLBA (10)		25	303	210
AT-LBA				
ATCA (6)		22	282	420
Hobart		26	420	640
Ceduna		30		450

Antenna diameter required to give SEFD

Parameter	new 32m	new 25m	new 20m	new 15m	new 13.5m
antenna diameter (m)	32	25	20	15	13.5
physical area (m^2)	804.2	490.9	314.2	176.7	143.1
frequency (GHz) (not used in calculation)	5	5	5	5	5
aperture efficiency	0.65	0.65	0.65	0.65	0.70
gain in rcvr components ahead of LNA (dB)	**-0.4**	**-0.4**	**-0.4**	**-0.4**	**-0.4**
gain in rcvr components (linear)	0.91	0.91	0.91	0.91	0.91
loss in rcvr components	1.096	1.096	1.096	1.096	1.096
apparent efficiency with rcvr loss	0.593	0.593	0.593	0.593	0.638
physical temp. of lossy rcvr components (K)	**20**	**20**	**20**	**20**	**20**
noise temp contrib from lossy rcvr components (K)	2	2	2	2	2
T_cmb+T_atmos+T_spillover (K)	12	12	12	12	12
T_lna (K)	**15**	**15**	**15**	**15**	**15**
T_sys (K)	**29**	**29**	**29**	**29**	**29**
sensitivity (K_av/Jy_total)	**0.173**	**0.105**	**0.067**	**0.038**	**0.033**
System Equivalent Flux Density SEFD (Jy)	**167**	**274**	**429**	**762**	**874**

13.5m is the effective diameter of the MeerKAT antennas.
15m is the proposed effective diameter of the SKA dish antennas
20m is the diameter of the Japanese VERA VLBI network antennas.
25m is conventionally regarded as the entry level for VLBI antennas; = VLBA antenna size.
32m is the median EVN antenna size, and provides the most sensitivity (and highest cost!).

Optimum solution for 25m antenna: Cassegrain + Prime Focus Telescope?

Example: Italian Medicina and Noto 32m telescopes, f/D = 0.32
Subreflector slides down to uncover primary focus with three receiver bays; nine receiver bays at secondary focus
Antenna is semi-sister of Ghana Kuntunse satellite antenna
Positive: overcomes low frequency limitation of secondary focus
Negative: mechanical complexity of sliding subreflector

Newbuild Potential Receiver fit

- 4 – 8 GHz cryogenic wideband receiver
  - To cover first AVN bands = VLBI C-band and
  - 6.668 GHz methanol masers VLBI and single-dish
- 0.5 – 3 GHz cryogenic wideband receiver
  - To cover VLBI L-band, wideband for pulsar sensitivity
- 18 – 26 GHz cryogenic wideband receiver
  - To cover VLBI K-band, water masers
- 2.3+8.4+32 GHz cryogenic triband receiver
  - To cover astronomical + astrometric VLBI S+X+Ka bands

AVN Summary

This is a work in progress

Every country is different and will choose its level of participation

Other African countries want to participate e.g.

- Nigeria – radio astronomers seeking to take over redundant satellite antenna

Astronomy is growing in Africa:

- 2 x 1m optical telescopes in Ethiopia (with SAAO help)
- 1m optical telescope planned for Kenya (with SAAO help)
- Namibia is competing for the Cherenkov Telescope Array
- Namibia already hosts H.E.S.S. II successfully
- East African Astronomy Society is active
- SA's National Astrophysics and Space Science Programme includes significant participation from other African countries – producing PhDs