The African VLBI Network of telescopes

The African Very Long Baseline Interferometry Network (AVN)

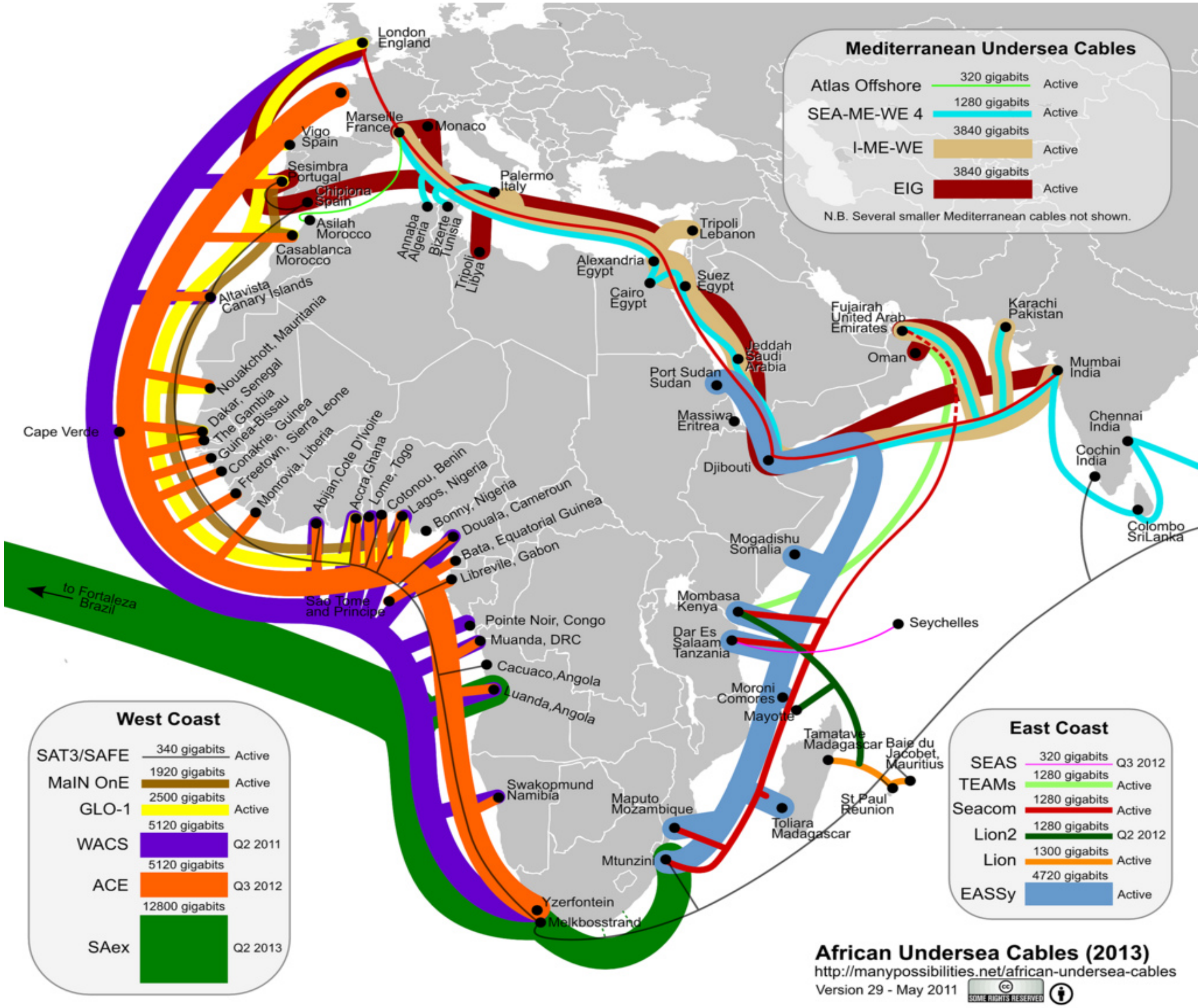
Radio astronomy at high angular resolution

The opportunity

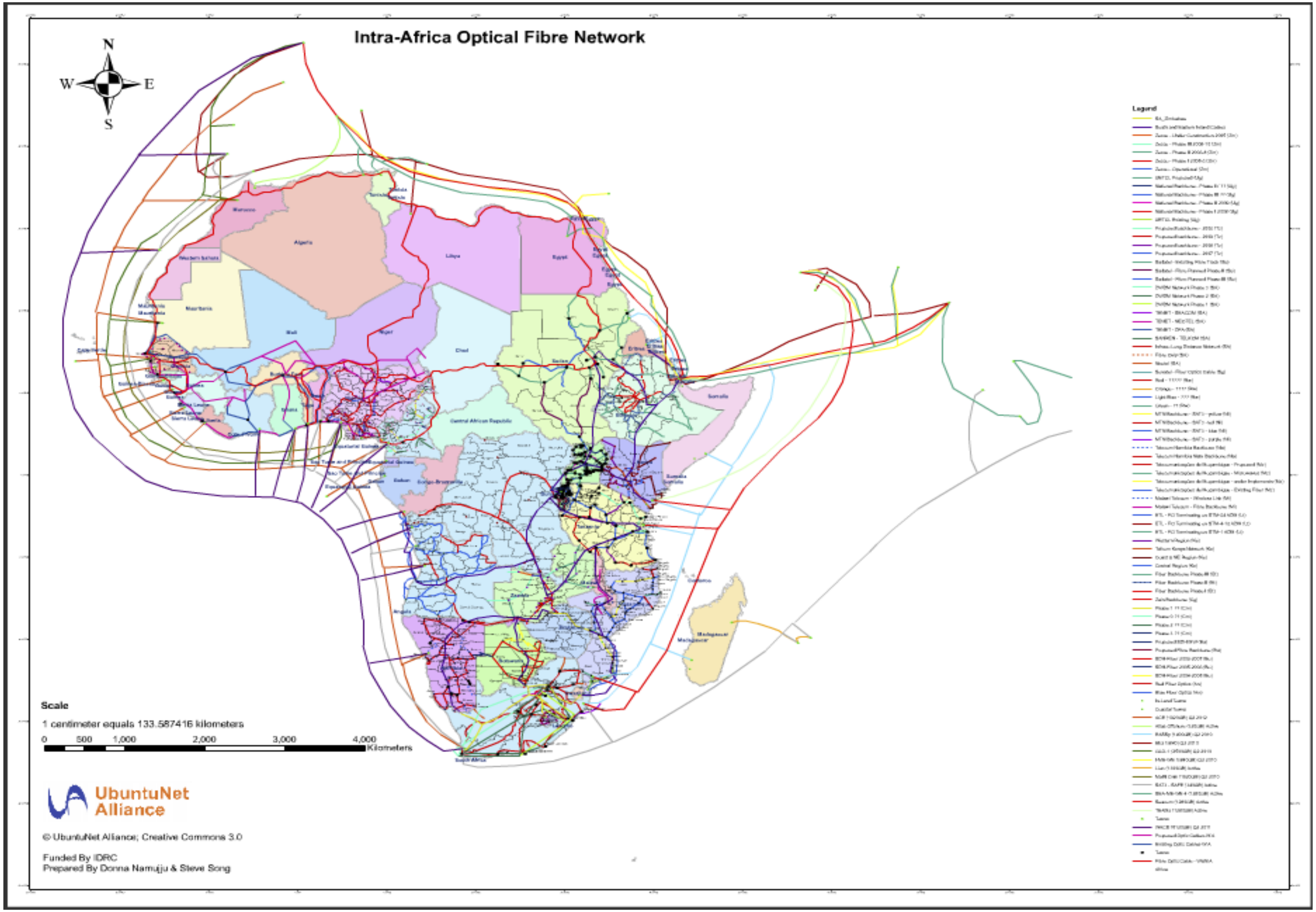
- There are many 30-m class satellite antennas in Africa that are becoming redundant because of the massive expansion of the undersea and terrestrial fibre data pipes.
- This pairing of redundant antennas and data pipes provides a perfect environment for creating a VLBI network in Africa.

30-m class antennas in Africa

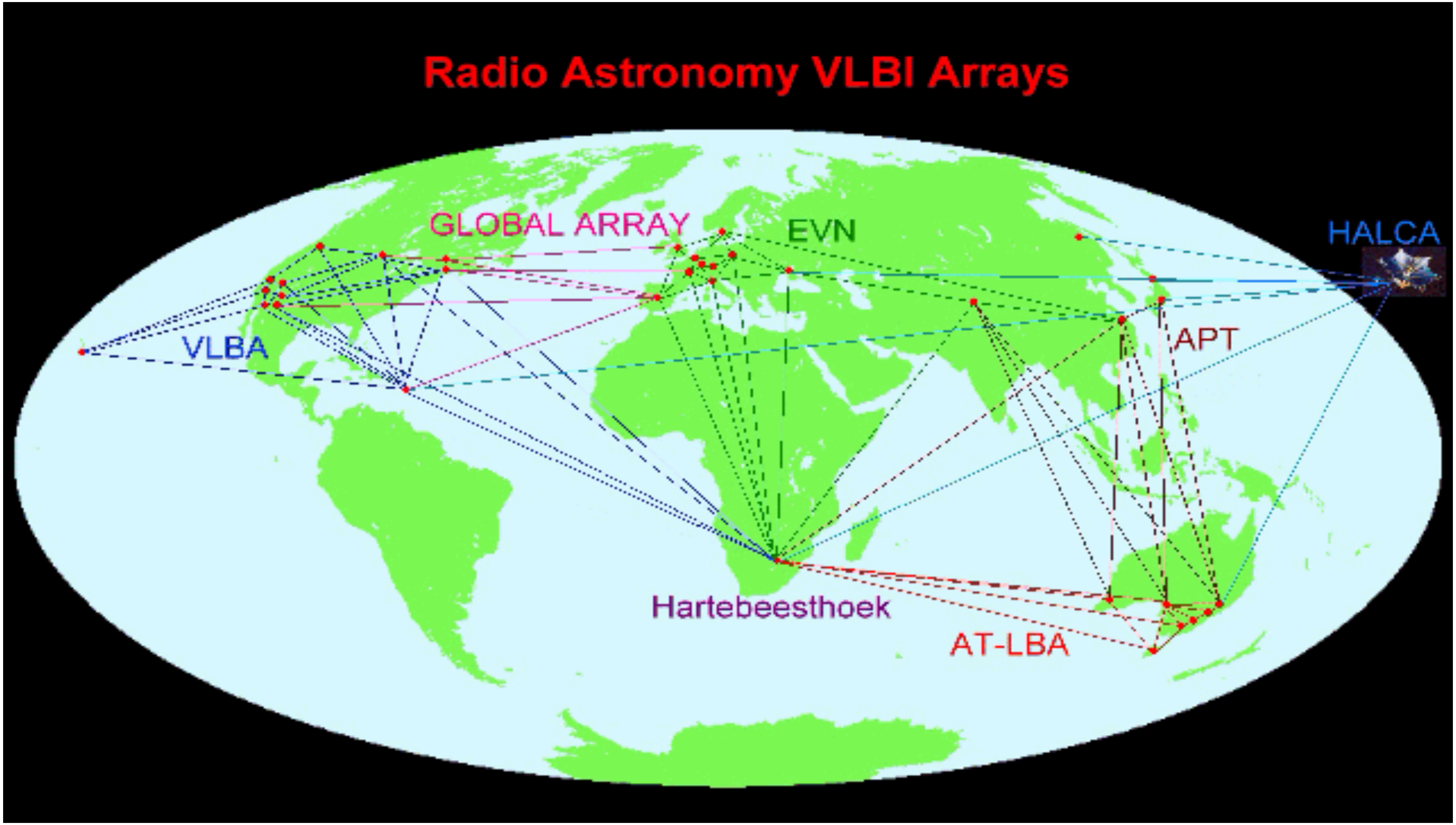
African Submarine Cable Systems



Africa Terrestrial Cable Systems



The need – the u-v gap

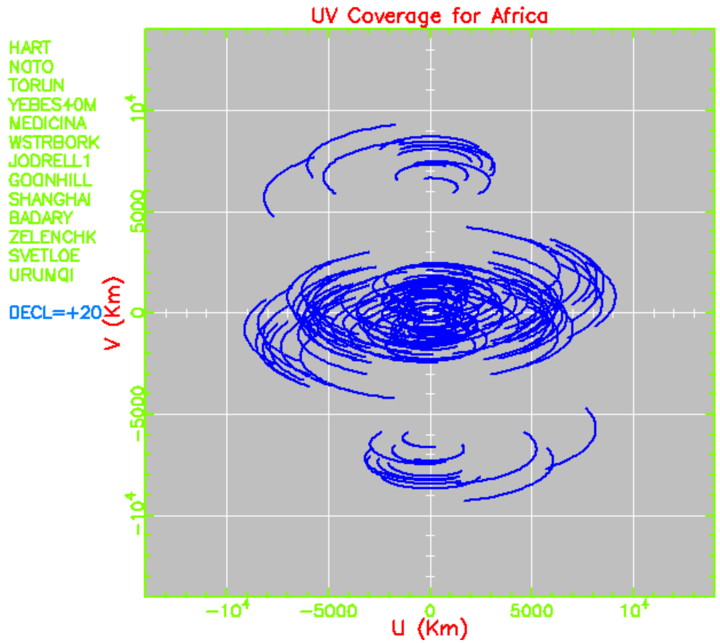


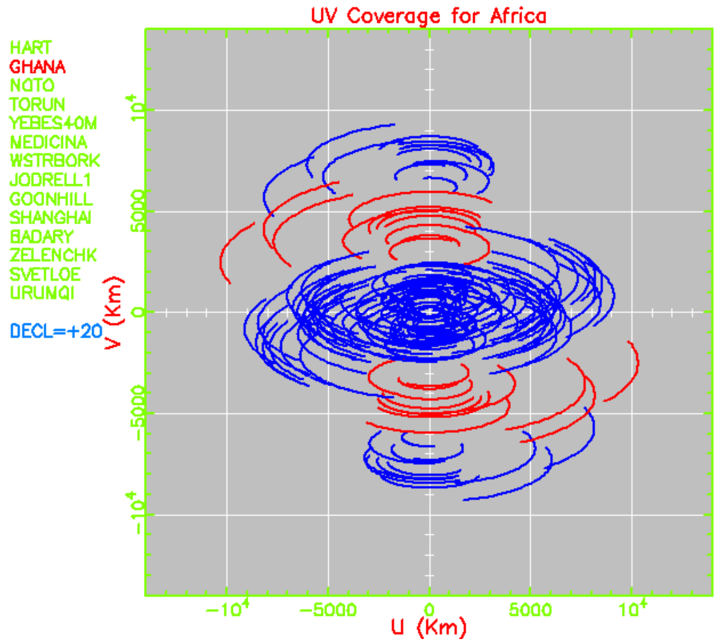
VLBI networks that could benefit from more radio telescopes in Africa

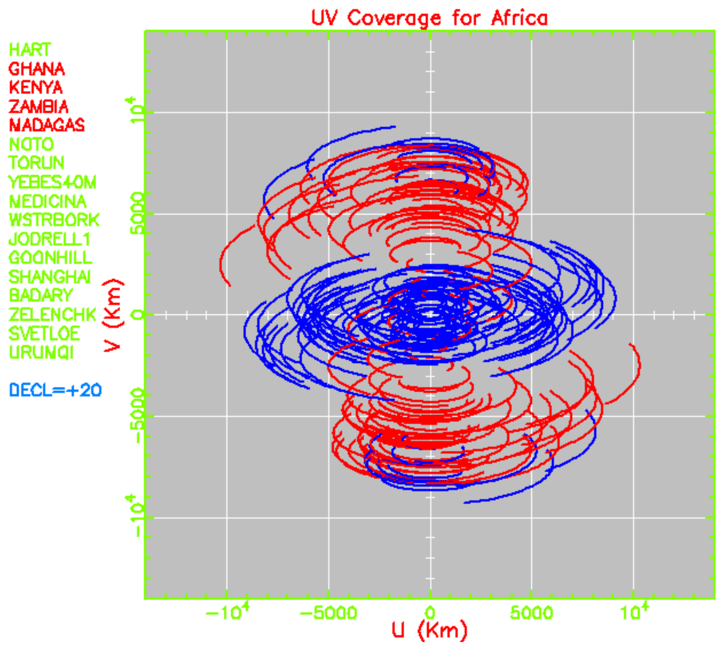
- European VLBI Network
- Global Array (EVN + US VLBA)
- Australia Telescope Long Baseline Array
- Astrometry and Geodesy Network (International VLBI Service for Astrometry and Geodesy (IVS))
- MeerKAT?
- SKA?

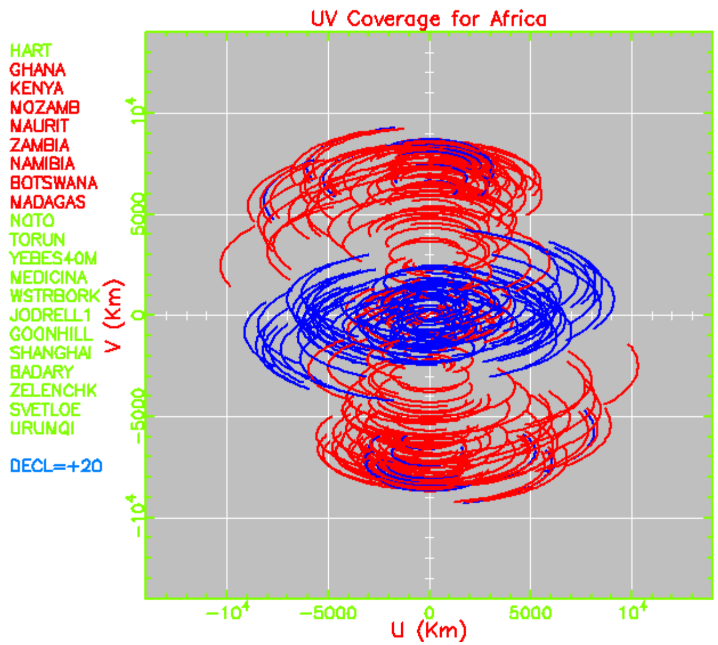
- **Astronomical VLBI as primary objective**
- **Astrometric and Geodetic VLBI as added functionality**
- **Geodesy as co-located facilities**

UV-coverage









UV+20 = +20 degrees declination (source 20 degrees north of the equator)

Primary objectives

- Generate a cadre of radio astronomers and engineers in Africa that can build, operate and use the SKA.
- Improve the u-v coverage of global VLBI networks.
- Establish infrastructure in the African partner countries that would support the SKA remote stations.
- Produce science outputs in the short term.

AVN telescope implementation options

- Countries with redundant large telecommunications antennas:
  - Telecomms facility donated for science use, convert the antenna to VLBI science instrument (preferably also include the technical staff working on the telecomms site);
  - (Ghana, Kenya, Zambia (?))
- Countries with no suitable antennas for conversion (require new-builds):
  - Option of new-build telescope system on a proposed SKA remote site location **OR**
  - Computing cluster at tertiary institute to develop skills in software engineering, data processing, data mining, etc.
  - (Namibia, Botswana, Mozambique, Madagascar, Mauritius)
- Training telescope (Mozambique)

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 opportunity examples:

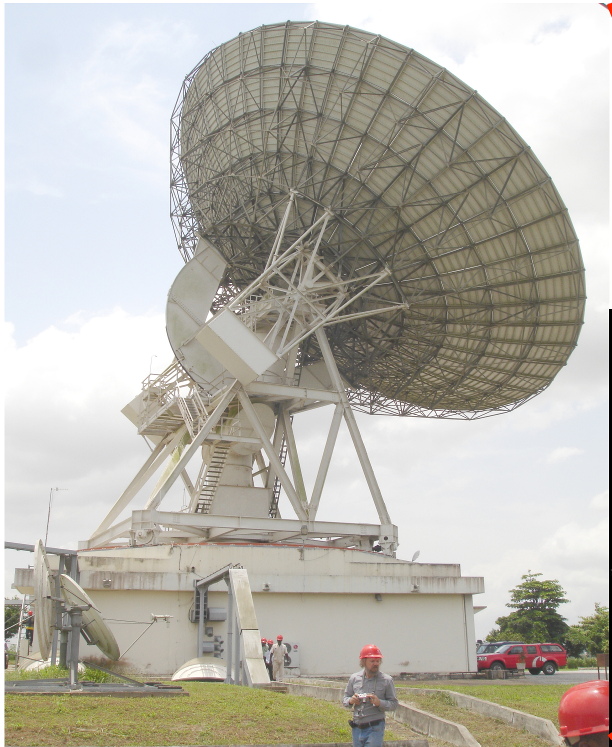
- Spectroscopy with narrowband multi-channel receiver:
  - Monitor masers in star-forming regions eg for periodic variations (methanol at 6668MHz, 12178MHz);
  - Survey formaldehyde absorption in Milky Way dark clouds (4829 MHz, 14488MHz).
- Pulsar observing with wideband multi-channel timer:
  - Monitor 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.

Science Objectives – VLBI Astronomy

Imaging with high angular resolution of compact, bright radio sources:

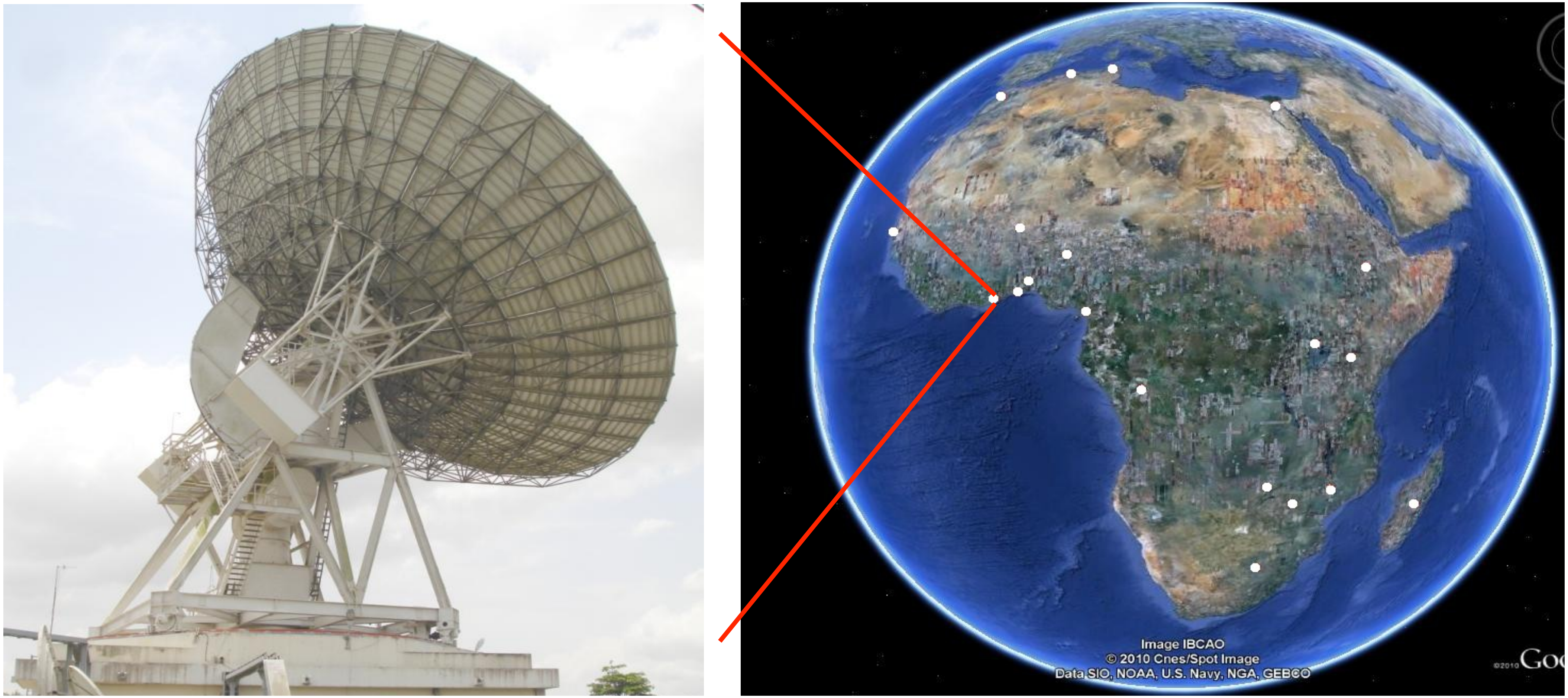
- Quasars – changes in jet structure, calibrators, astrometry, celestial reference frame;
- Gamma-ray flare source follow-up (HESS II in Namibia, FERMI-LAT, CTA);
- Masers – interstellar (e.g. methanol) – investigate variability / periodicity; measure maser spot movements; measure annual parallax to determine the distances to star-forming regions in the Milky and map the spiral arms;
- Pulsars – proper motions and distance determination through annual parallax, interstellar magnetic fields, interstellar scattering, emission region size;
- Transient radio source behaviour;
- Supernovae – behaviour of remnants of core-collapse supernovae;
- Interacting binary star behaviour e.g. Circinus X-1;
- E-VLBI and ToO VLBI through internet – rapid response to new events;
- Improve the Celestial Reference Frame for parallax determination and multi-wavelength astronomy.

Conversions: Ghana and Kenya



Ghana

- Beam waveguide optics, 32m diam dish at Kutunse, use existing feed for observations at 5 GHz, 6.7 GHz;
- Ambient temperature receiver system;
- Use as much control system hardware from C-Bass as possible;
- ROACH-based back-end supplied by AVN team (Cape Town).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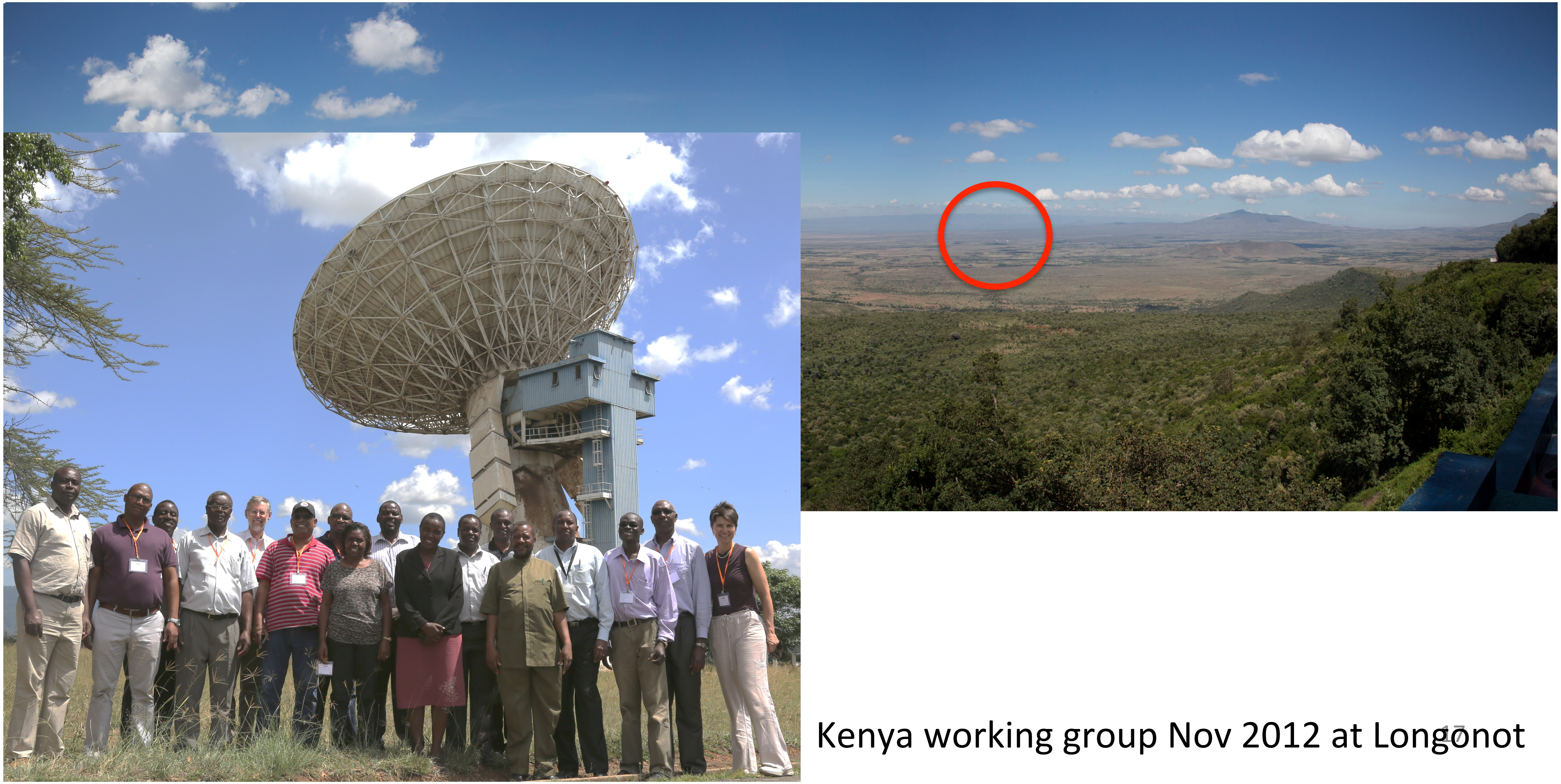
Kenya (Longonot)



Kenya working group Nov 2012 at Longonot

Conversions – Kenya

- Cassegrain optics, 30m diam dish at Longonot, 4.7-5.2 GHz, 6.6 to 6.8 GHz, 8.2-9 GHz;
- Cryogenic cooling with similar (if not same) solution as per Oxford for Goonhilly;
- Collaboration with Oxford (Mike Jones)
- LNA 6-month lead time, all other items expected to be COTS for signal chain;
- ROACH-based back-end supplied by AVN team (Cape Town).

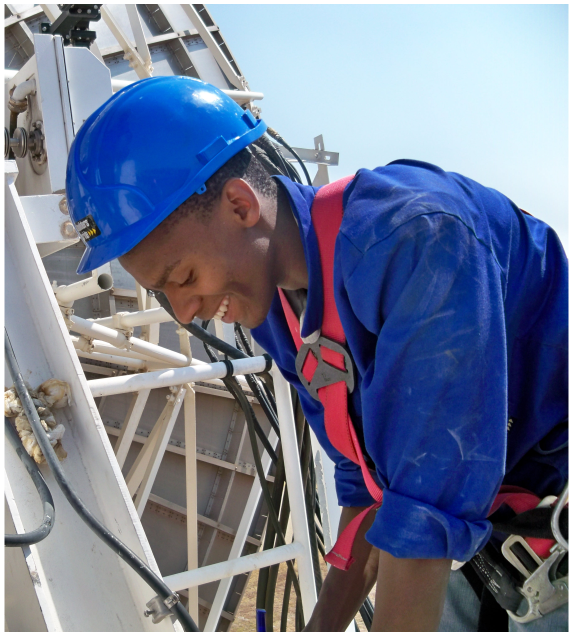
User requirements for new-builds

- **Low frequency limit:**
  - VLBI usually above 1 GHz (30cm wavelength)
  - Pulsars brightest below 1 GHz, but pulse broadening bad below 0.5 GHz
  - SKA dish lower limit is 0.45 GHz
  - **Target: 0.5 GHz** (60 cm wavelength)
- **High frequency limit:**
  - Water masers at 22 GHz could be top limit for SKA (currently 10 GHz)
  - But AGNs, astrometry, spacecraft at 32 GHz
  - **Target: 32 GHz** (1 cm wavelength)

Computing Clusters for interferometric data analysis – Big Data Africa

The Mozambique Training Telescope for Maluana Science Park

7.6m Antenna to be relocated to Mozambique



Science with MRAO system

- Feed / receiver solution:
  - S-band receiver as is (1950 – 2250 MHz) for radiometry and pulsar observation and radiometry (eg Vela);
  - Upper C-band retuned to include 6668 MHz for radiometry and spectroscopy (Methanol Maser)
    - Methanol masers are well established as signposts of the early stages of star formation.
  - Use both (circular) polarizations in each band to improve sensitivity;
  - Use uncooled LNAs with good noise figures.

Human Capital Development

- Establish suitably trained core teams in partner countries (both science and engineering);
- Ensure that Africans fully participate and proudly own facilities in their countries – especially for SKA;
- Link African facilities and user communities (scientists) into global networks of facilities and world-class science;
- Create platforms for co-location of other global research facilties (*eg* other radio telescope systems, GNSS stations, etc.).

ALL *implementation options will be done* ***WITH*** *a human capital development programme to develop all skills needed to operate established systems.*

Maser Research (Ghana)

Royal Society Grant (UK)

- Using existing data archives, 26m at HartRAO if available and Kutunse 32m antenna to do maser research (delays in Kutunse conversion);
- Carry out long term monitoring of around 100 methanol maser sources;
  - ✧ discover new periodic masers and characterise these;
  - ✧ propose and perform follow-up high resolution observations to determine their nature;
- Develop a pool of radio astronomy expertise that can carry out such observations and reduce and analyse the data.

- £180k award to fund:
    - a research programme
    - 1 PhD student in Ghana
    - a training programme
- The team providing the training:
    - Leeds University (UK), GSSTI (Ghana), SKA-SA

- Monitoring of methanol maser emission in regions where massive stars are forming
    - Looking for periodic flaring arising from close binary system
- The Royal Society funded project represents an excellent opportunity for young researchers to become part of the first generation of radio astronomers in Ghana
    - Potential to gain the experience necessary to win a PhD place overseas
    - Be well placed to take advantage and lead the exploitation of the new generation of world-class radio telescopes coming to Africa

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CELEBRATING 350 YEARS

Maser Research (Ghana)
Training programme

- The training programme in radio astronomy part time over a period of 1 year;
- The programme will be repeated 3 times;
- In the first year - train 10 students, the second 20, and final year 30;
- Training 8-10 weeks of lectures and workshops at GSSTI with an additional 5 weeks of observing experience on the telescope.

Duration	Training Topics
2 weeks	Astrophysics, Radio Astronomy Theory, Multi-wavelength Astronomy
1 week	Technical Training for Telescope & Receiver
2 weeks	Radio astronomy observation, Survey astronomy, Presentation skills
2 weeks	Data Reduction & Analysis, Telescope Time & PhD Application Writing Training
1 week	Satellite Telecommunications & Commercial Awareness Training
2 week	Visit of top 2 students to overseas observatory and potential PhD institutions

Teams to deliver the AVN

- South African team:
  - Joint SKA SA and HartRAO team;
  - Workgroups
    - Structural and Mechanical, Software and Data Processing, Science, Control and Monitoring, Signal Chain, *(Cluster Computing)*;
- Partner country teams (ideally):
  - Mirror the team structure in SA and establish the core of the Observatory Staff in partner country;
  - Build science capability in partner countries (start now!).
- Core Joint Working Groups with each country to inform all stakeholders and unlock bottlenecks (quickly)
  - Senior government officials, leaders of institutions and engineers.
- Crucial government-level support to ensure sustainability and remove obstacles speedily (eg visas, exports/imports, customs, etc.)

AVN technical teams