Research Infrastructure Investment

(African VLBI network and cooperation between African and European VLBI)

AERAP meeting

Brussels, Belgium

Anita Loots *Pr.Eng.* **(SKA SA)**

6 March 2013

Structure of presentation

- What is the AVN and the current status?
- Summary / Closure

Context – towards the SKA in (South) Africa

2012. AVN project started, partner countries buy-in to build in-house capacity to maximise SKA Phase 2 involvement and benefit.

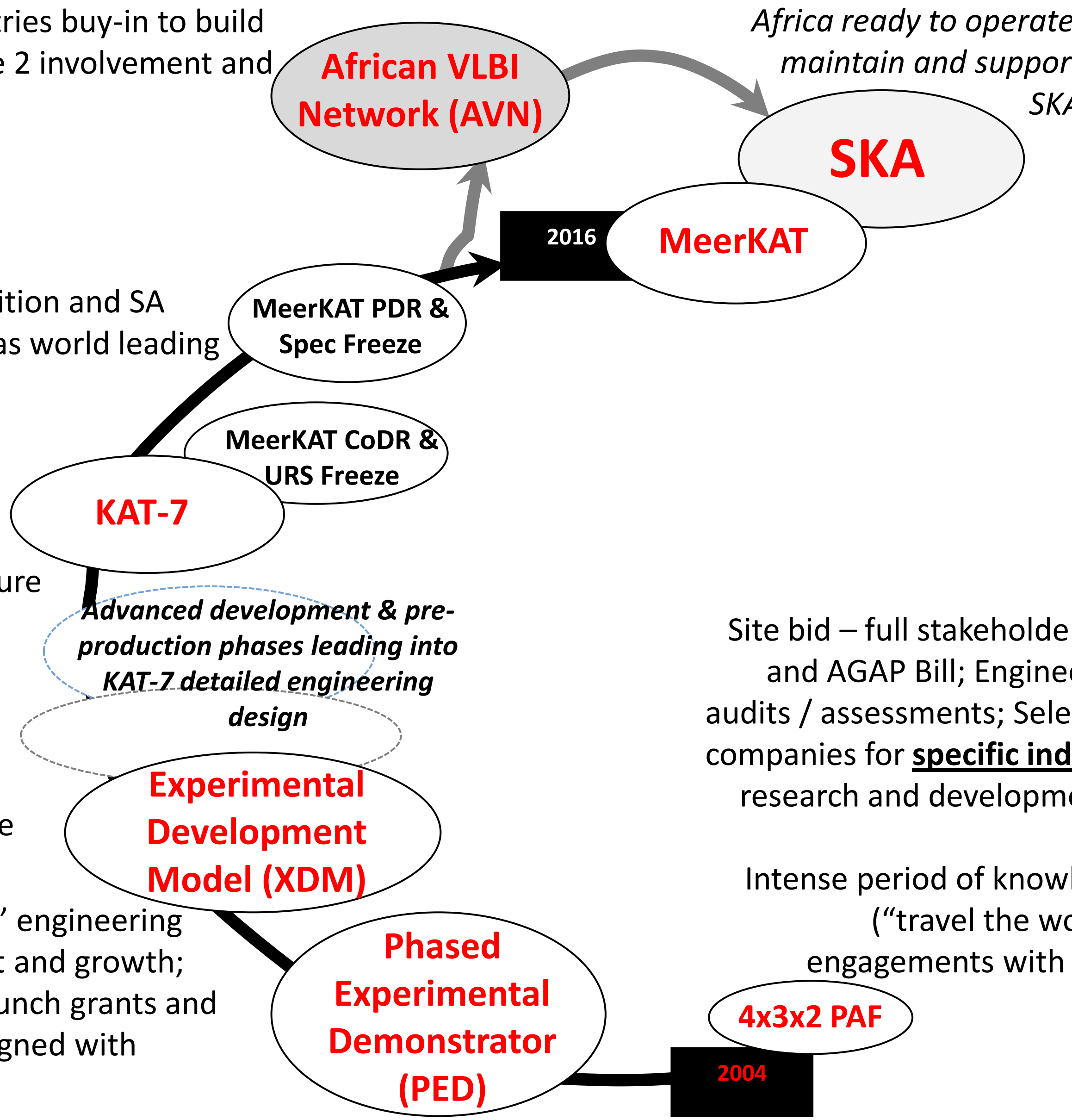
2010. SKA SA gaining international recognition and SA industry fully on board; some recognised as world leading

2009. MeerKAT science Call for Proposals issued and 9 key surveys selected. Global interest.

2006. SA industry contracts for infrastructure in the Karoo on proposed SKA core site; development of local communities to win contracts.

2006. First significant industry contracts – shared cost / shared risk model (composite antenna, feed cluster)

2005. Appoint first members of "in-house" engineering team; pick areas for industry development and growth; assume systems engineering approach; launch grants and bursaries with very specific focus areas aligned with project needs.



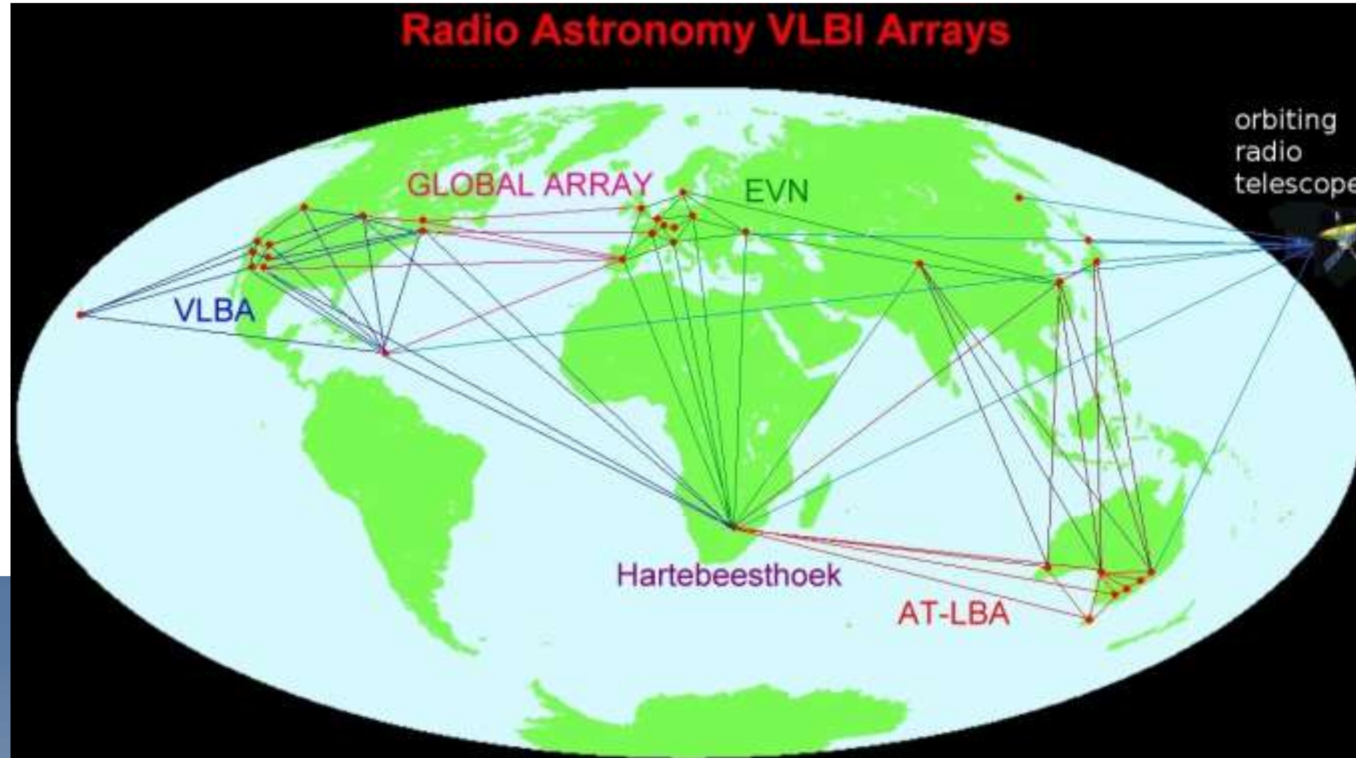
Site bid – full stakeholder involvement and AGAP Bill; Engineering industry audits / assessments; Select (hand-pick) companies for **specific individuals** to do research and development of specific **components**.

Intense period of knowledge transfer ("travel the world") through engagements with world leaders

Why an AVN?

- Important global science contribution by Africa – an "instrument" owned by Africa for global science;
  - The AVN project has caught the imagination of our African partners who are ready to play a role in the global science community (and ultimately the knowledge economy).
- An African Network as a stepping stone towards SKA:
  - SKA SA invested heavily in Human Capital Development to ensure suitable capacity for SKA;
  - To optimise benefit from SKA to Africa, we need to replicate this for the SKA partner countries and beyond.
- "General purpose" science instrument, broad science case.

Current VLBI-capable telescopes in Africa



VLBI - Very Long Baseline Interferometry

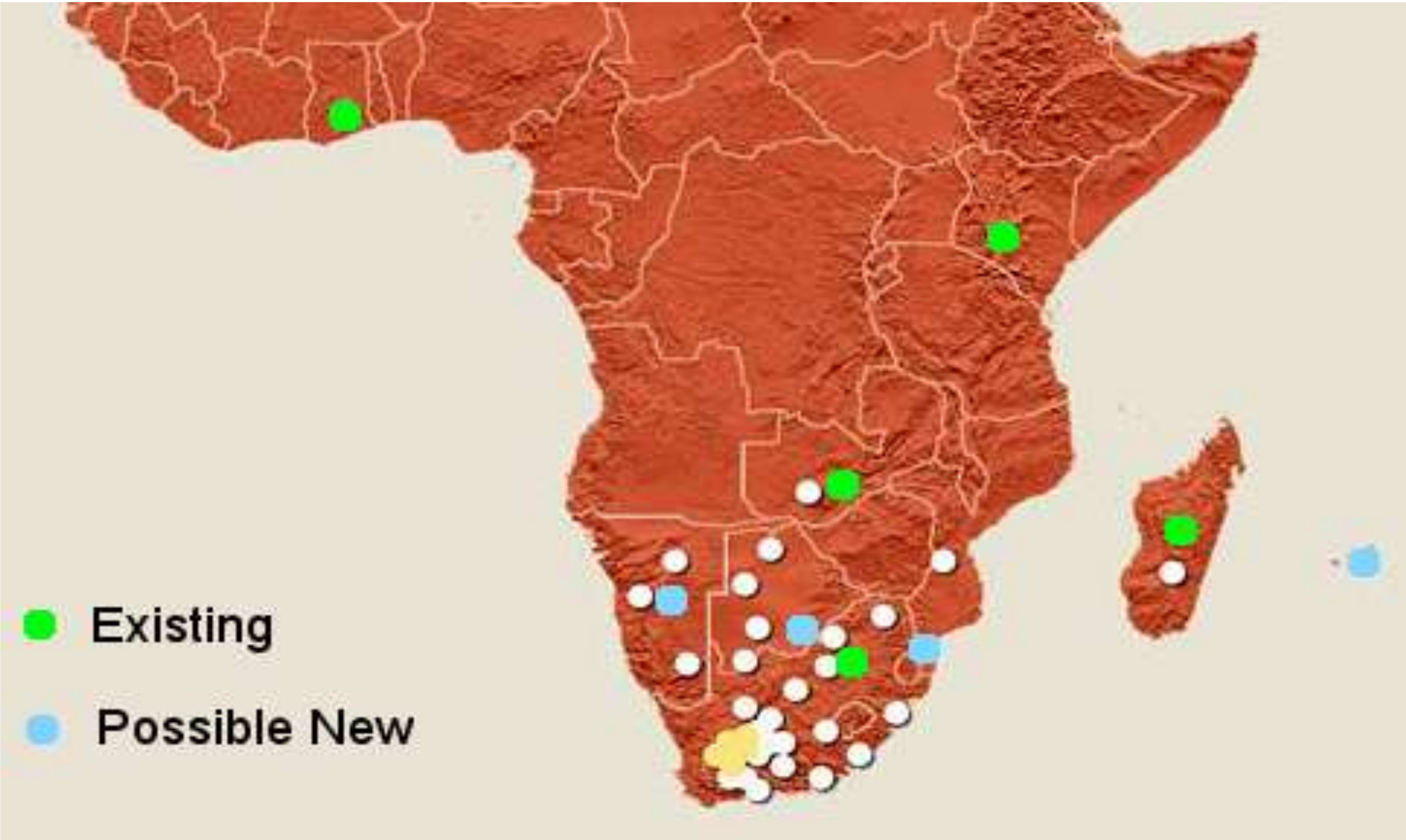
26m and 15m Radio Telescopes,
HartRAO, South Africa

VLBI networks that could benefit from more radio telescopes in Africa

- European VLBI Network
- Global Array (EVN + 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**

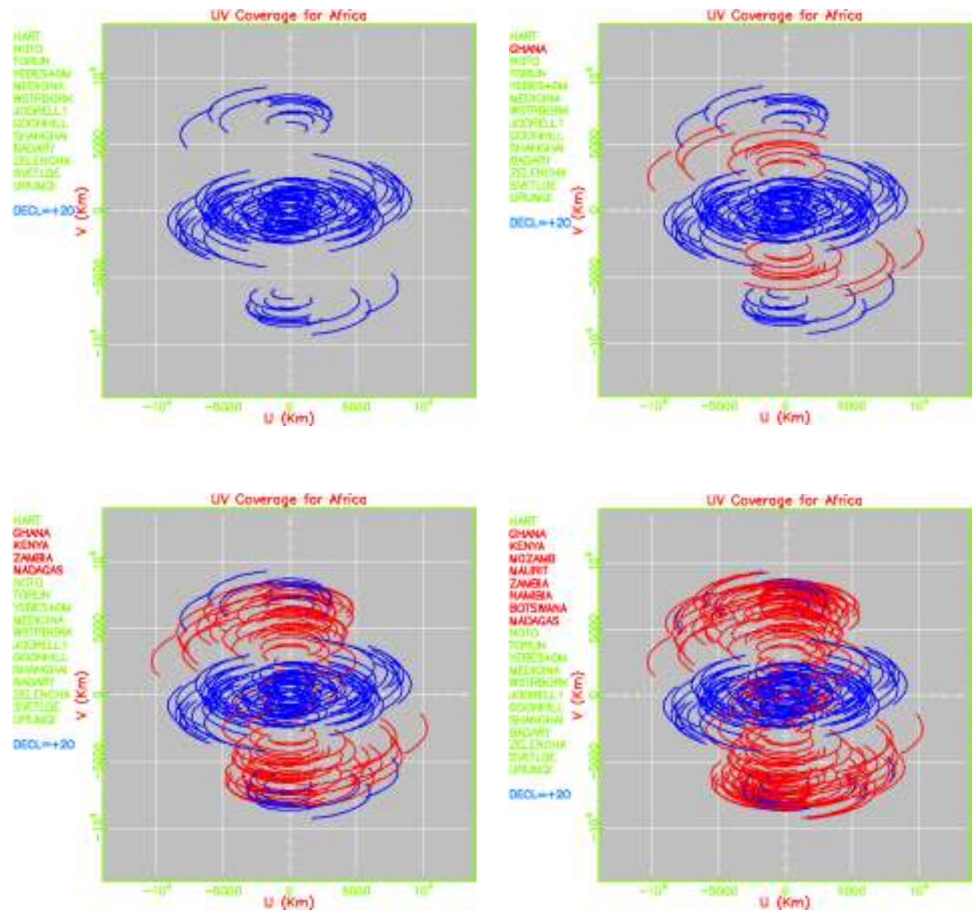
Existing and possible new antennas for AVN
(in SKA partner countries)



Can (this) AVN make a real difference?

(Importance of UV-coverage)

- The quality of a VLBI image is usually determined by the density and distribution of UV tracks in the UV-plane. These tracks are formed by the 2-D projection of the various interferometer baselines on a plane (the so-called "uv-plane") which is perpendicular to the source direction.
- Every pair of antennas makes a contribution to filling the UV-plane, and the design of a synthesis array is aimed at filling the UV-plane as completely as possible (**An Introduction to Radio Astronomy** by Bernard F. Burke, Francis Graham-Smith)
- Better UV coverage enables high dynamic range, milli-arcsecond resolution images of complex radio sources. "Snap-shot" observations of many sources can also take advantage of the dense UV coverage.



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

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 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 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.

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.

Co-location of science instruments

- An operational VLBI station with a wideband internet connection provides a valuable platform for co-locating other science equipment.
- Global Navigational Satellite System Receivers
  - If a geodetic quality dual-frequency GPS base-station is added, it would enable precise position measurement for the African Reference Frame project and the International Global Navigation Satellite Service;
  - These base-stations measure plate tectonic motion and local movements. In addition, the atmospheric water vapour and the total electron content of the ionosphere can be derived continuously and the data made available for global climate change monitoring, solar storm monitoring etc.
  - Receivers for other GNSS systems such as GLONASS (Russia), Beidou / Compass (China) and Galileo (EU) are now becoming available.

Space-based positioning techniques available to realise the International Terrestrial Reference Frame (ITRF)

(GPS, GLONASS, SLR, VLBI and DORIS sites in Africa)

NOTE:
Geodetic VLBI – needs to observe the same source simultaneously at 2.3GHz and 8.4GHz (either with one receiver to receive both frequencies or with a dichroic reflector system to direct the signals into two different receivers)

VLBI2010 – higher frequencies or two or more smaller fast slewing antennas)

Co-location of science instruments (2)

- Meteorological unit
  - The VLBI antenna needs a co-located meteorological recording system for air temperature, pressure and humidity.
- Further instruments that could be valuable additions are:
  - Seismometers;
  - Absolute and relative gravimeters;
  - Magnetometers.
- Partner countries encouraged to take the initiative to co-locate instruments but need to be aware of radio frequency interference that could harm the observatory.

e-VLBI for the AVN?

- Need an African network similar to GEANT or SANREN;
- European e-VLBI - Gigabit per second data transport links to JIVE;
- Need to connect AVN stations to backbone data transfer networks and negotiate affordable rates for data transfer (a SANREN or GEANT-type network for Africa?).

Types of projects & current funding

- Three types of projects in the AVN
  - Conversion projects through conversion of 30m-class antennas (Ghana, Kenya, Zambia, Madagascar?, Telkom?);
  - New-builds (Botswana, Mauritius, Namibia, Mozambique);
  - Training facilities through conversion of smaller antennas (Mozambique).
- Current funding (probably) sufficient for 4 conversions:
- One training facility funded (Mozambique);
- New-builds not funded – currently working towards a User Requirements Specification and potential / estimated costs;
- Infrastructure in partner countries (especially for new-builds) not funded;
- Correlator and e-VLBI not funded;
- Other countries (non-SKA partners) to join – model to be worked out.

High level current status, progress and the year ahead

2012 – AVN overall

- Significant strides in governance / institutional aspects of the project;
- Significant progress in technical work areas within control of SA team;
- Applications for capacity building projects funded by the EU (ACP proposal) incl UK, Portugal, SA, Kenya, Ghana;
- Somewhat slow progress in human capital development and technical programs / activities within partner countries;
- Somewhat slow progress in recruitment in SA and pressure on the technical teams at HartRAO and Cape Town.

2012 – Ghana

- Extensive progress on desk-top studies, analyses, design and evaluation of GAEC skills available to execute technical repair work on antenna structure;
- GDSatcom contract awarded to scope structural and mechanical repair work and derive high fidelity costing;
- Two feasibility "go" milestones since inception:
  - Mike Gaylard and others from HartRAO initial "approvals";
  - Justin Jonas further "reality check" and "approval";
  - GDSatcom to provide significant decision point that could be a "go/no-go" for the feasibility of conversions.

Ghana setting the pace and leading the way

Pictures 2 May 2012 and 3 Sept 2012

2012 – Kenya

- Initial visit to the Longonot site and inspection of the facilities:
  - Mike Gaylard, Anita Loots and VenKAT visit in November 2013;
  - Excellent political support amongst current office-bearers – elections;
  - Extensive "to do" list provided to Kenyan officials and telecomms company and regulator.
- No significant technical work until "to do" list has been completed / made satisfactory progress;
- Visits and presentations to various universities and institutions relevant to the project;
- International interest to collaborate on the Kenya conversion.

Great Rift Valley

2012 – Mozambique

- Secured the 7.6m Telkom antenna in SA and started technical work of the conversion;
- Agreed split of responsibilities and scope of work for foundations and related civil works (with MCT) at Maluana;
- Dynamic environment (politically) now settling;
- Identified possible trainees – in process of being contracted;
- Design review completed on 27 February 2013, conversion under way.

2013 - overview

- Set mid-year goals on technical aspects for SA AVN team:
  - Immediate focus on Ghana S&M, CAM and software and Mozambique 7.6m conversion;
  - Ensure adequate design and engineering review points on all technical programs;
  - Augment the team to be able to deliver when technical programs ramp up.
- Launch well packaged and thought-out training program as per schedule for first pilot group from Mozambique and Ghana;
- Ensure high-profile non-technical milestones that will enable AVN to secure longer term funding for new-builds and other infrastructure (eg correlator, training facilities etc.);
- Engage actively with the international community and have an AVN international "lekgotla" in June / July 2013.

Mid-year goals 2013: Ghana

- Structural and mechanical work program as per Systems Engineering Management Plan:
  - Contract with GDSatcom to be executed.
- First trainees selected and training starts;
- Institutional:
  - MOA contents agreed and signed in February 2013, includes agreement on bridging fund
  - Elevation of GSSTC from a “Centre” to an “Institute”.

Mid-year goals 2013: Kenya

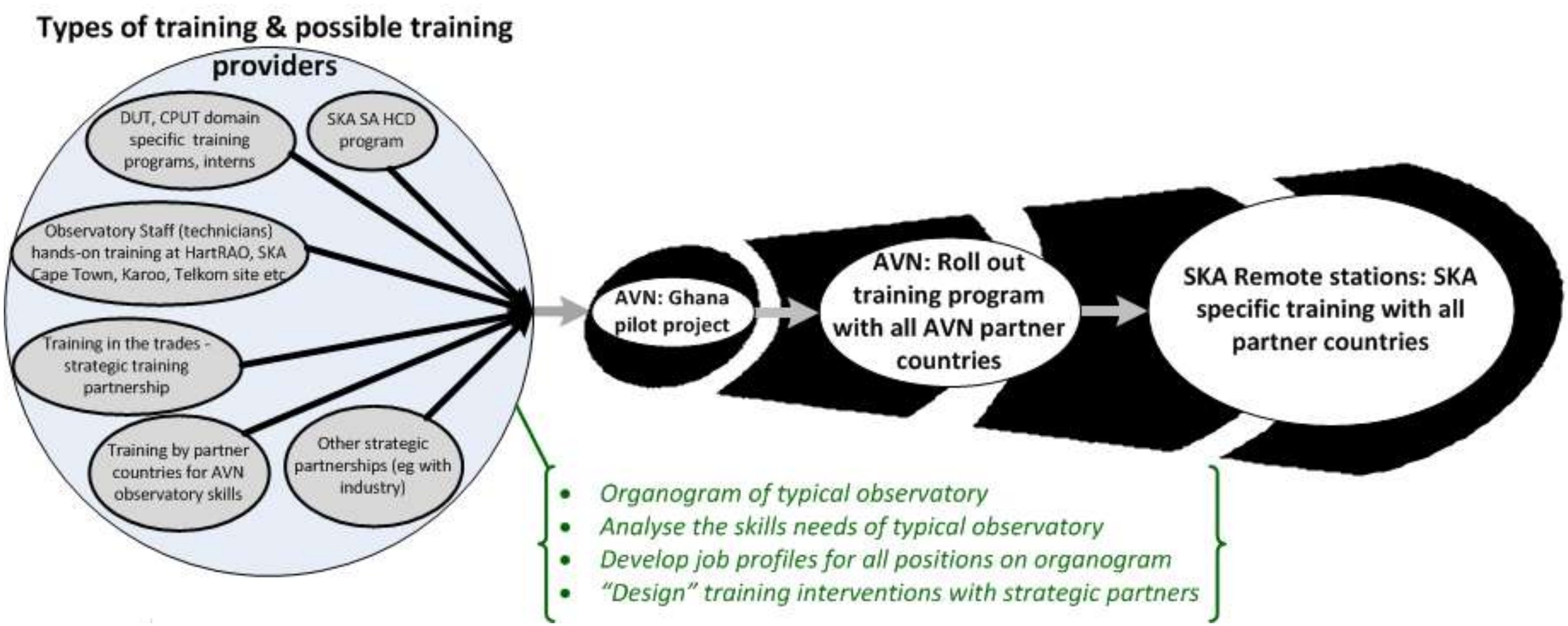
- Institutional:
  - Track progress of items on “to-do” list and support where needed;
  - Kenya to establish Kenya Space Science and Technology Centre;
  - Identification of skills as needed for the core team for the observatory.
- Training in use of SKA RFI measurement equipment (in SA) and possible measurement campaign at Longonot site by Kenyan regulator;
- Explore how to best involve interested collaborators.

Mid-year goals 2013: Moz

- Institutional:
  - Confirmed political buy-in to the Maluana project by new Minister and “re-started” activities in Mozambique;
  - Assist to establish the appropriate ownership and technical team in Mozambique;
  - Assist to deliver civil works contract as per agreed scope of work.
- First trainees to participate in 6-month program in SA;
- Convert system at Telkom site and package for transport;
- Help set up partnerships with Portuguese speaking collaborators.

Mid-year goals 2013: Training

- Training package for core teams under development:
  - Review of training package likely in April 2013.
- Launch training program, welcome first trainees:
  - Ghana and Mozambique.
- First trainees to participate in 6-month program in SA.



Mid-year goals 2013: Other

- Start building bigger VLBI science capacity in SA and then in partner countries;
- New-builds:
  - Has to be inclusive process involving partner countries on all activities
  - 2-day workshop with Mauritian Scientists and Engineers held (20-21 Sept 2012) to derive a “wish-list” for high-level system specification.

Summary

- The AVN will be an important global instrument that could contribute significantly to global knowledge;
- It will be important to find ways to collaborate with the international VLBI community to build the science capability on the African continent;
- The AVN project will be an important training ground to ensure maximum benefit for Africa from SKA;
- The AVN will identify and address all possible issues related to working in and with the SKA partner countries to ensure smooth roll-out of SKA Phase 2.

Closure

- Dependent on partner countries to establish appropriate HCD programs in to run observatories, do good science and establish track record of Africa as a destination for high impact global science;
- The experiences in Ghana and Mozambique are building strong relationships and foundations for productive collaboration in the future – not just in science communities but also with key stakeholders (eg government departments);
- Partnerships with EU collaborators will be important success factor.

Thank you!
Questions welcome

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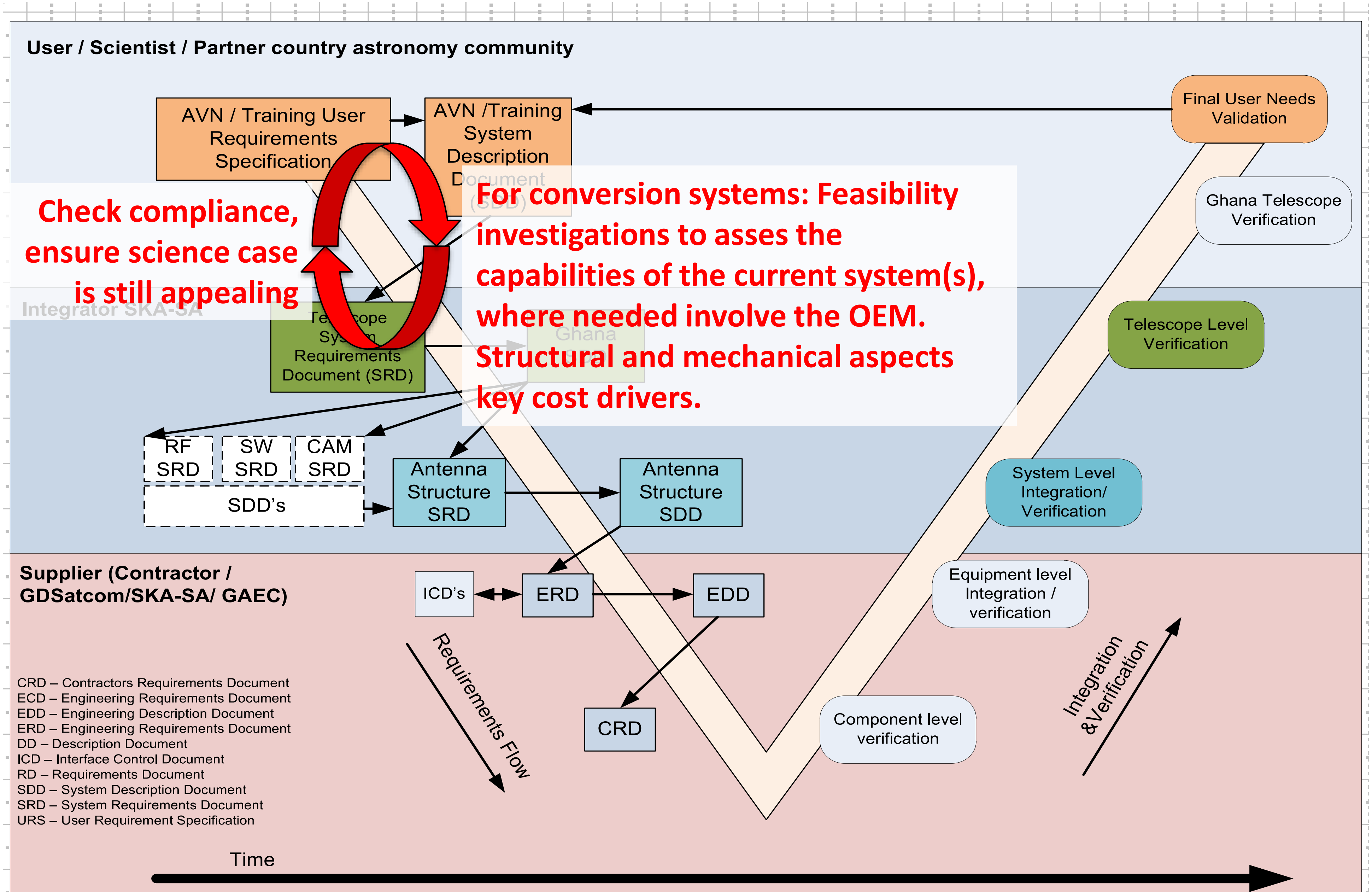
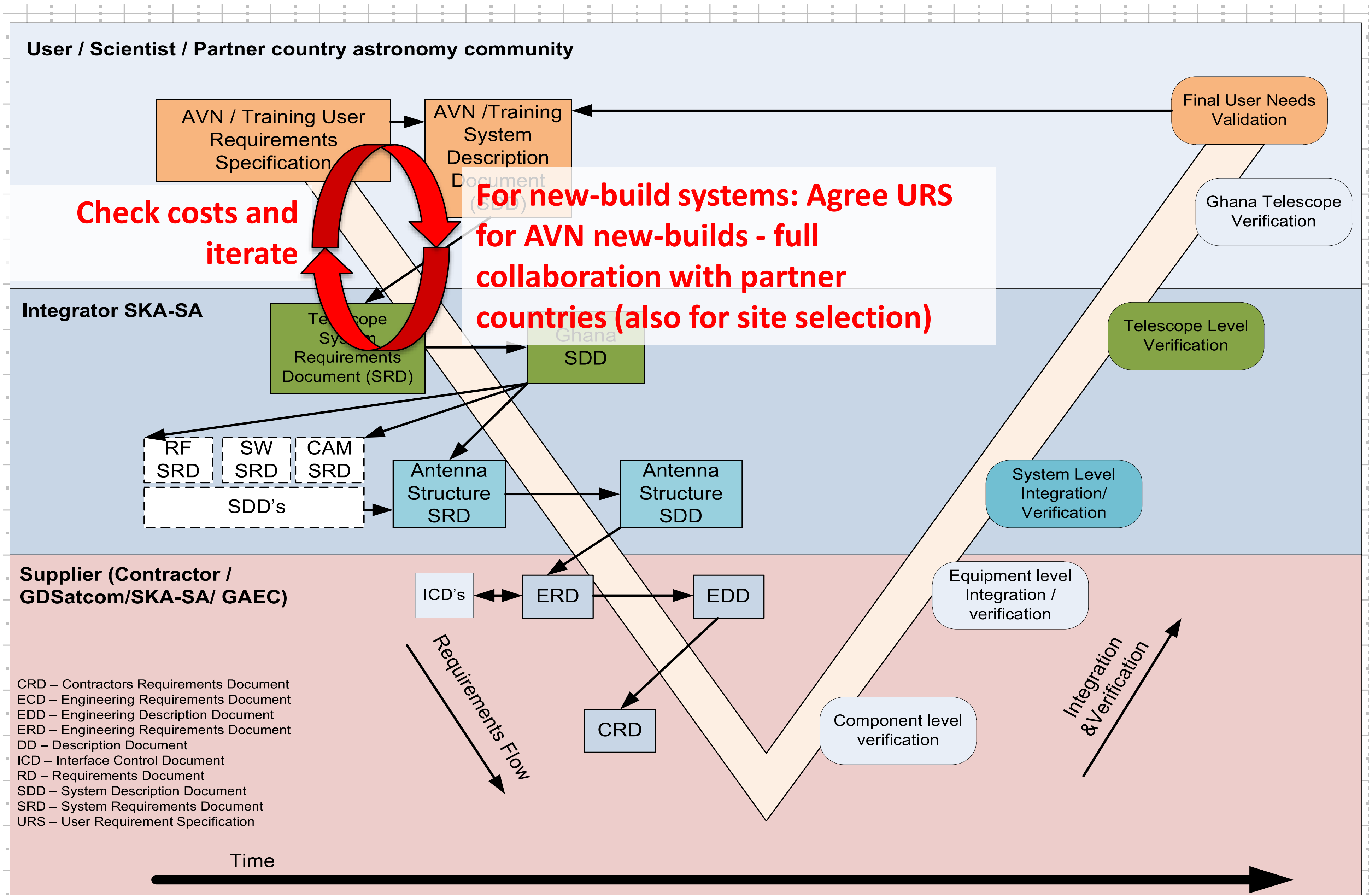
Extras

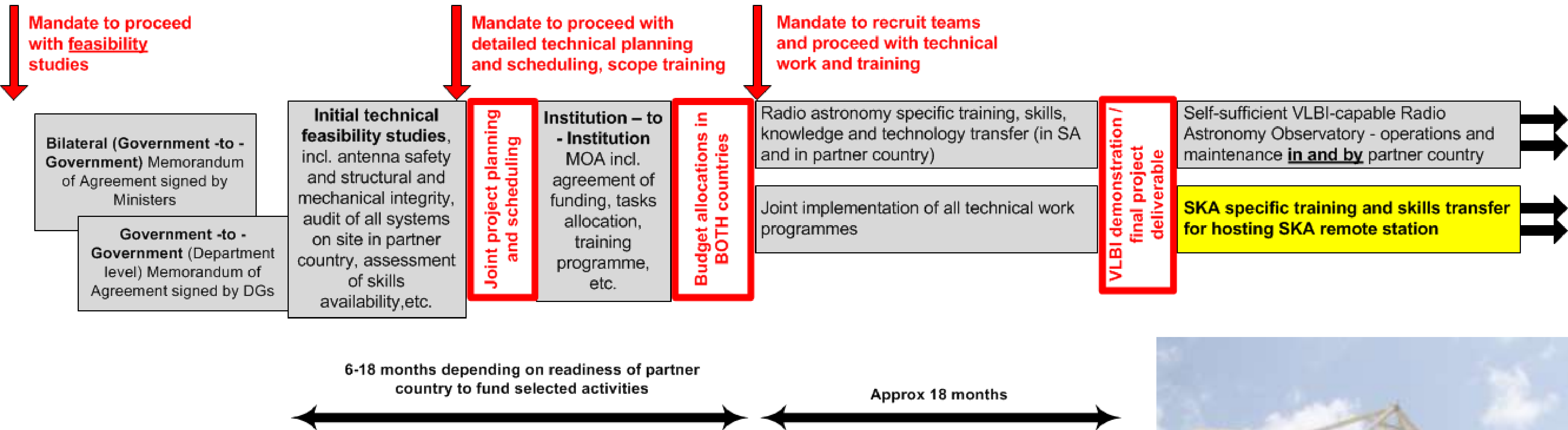
Pragmatic engineering processes (2)



Pragmatic engineering processes (3)

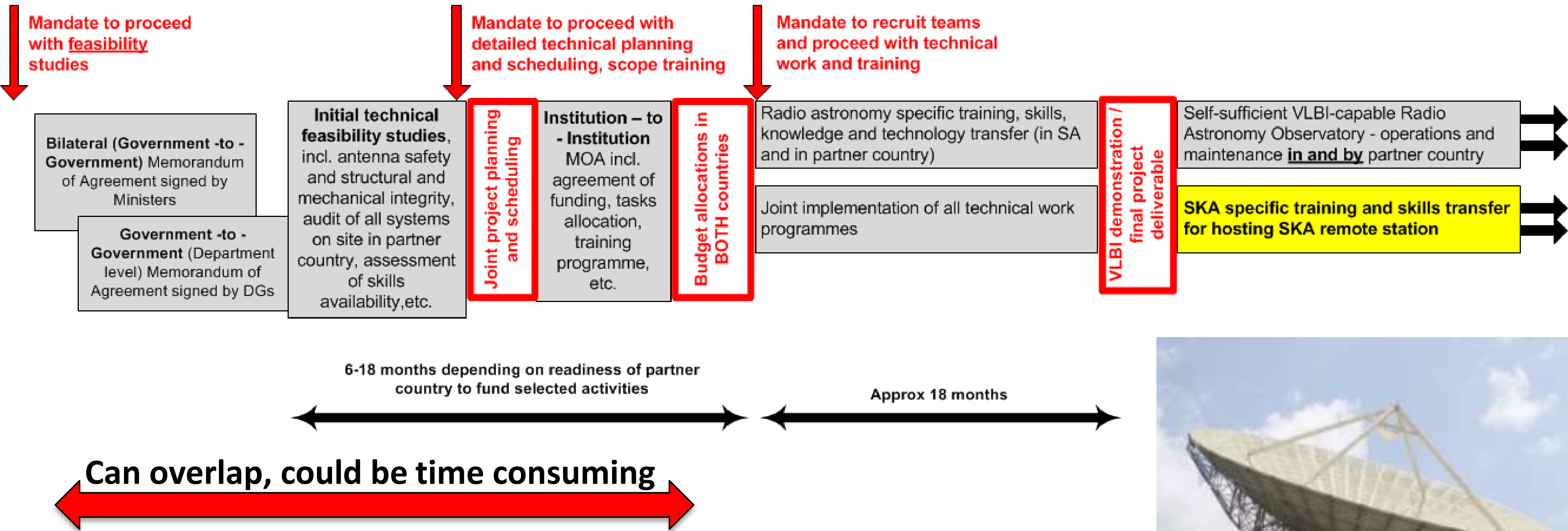


Process overview - Antenna conversion project(s)



Kutunse 32m antenna Ghana

Process overview - Antenna conversion project(s)

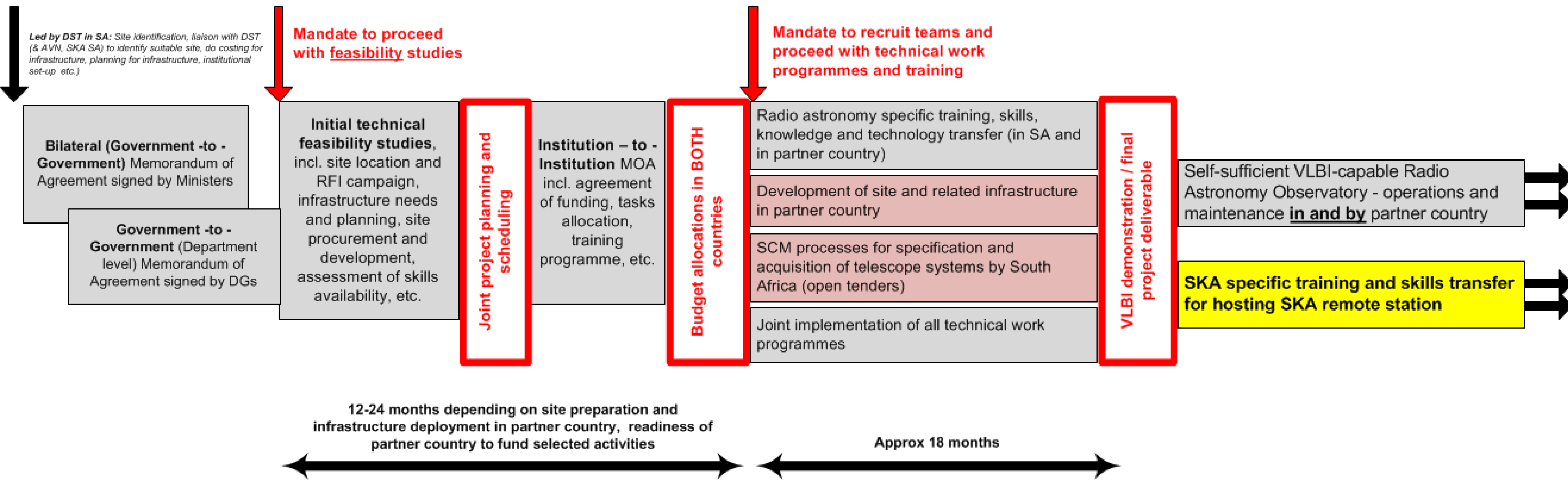


(First country (Ghana) to create a "model" which will hopefully lead to faster implementation for those that come next)

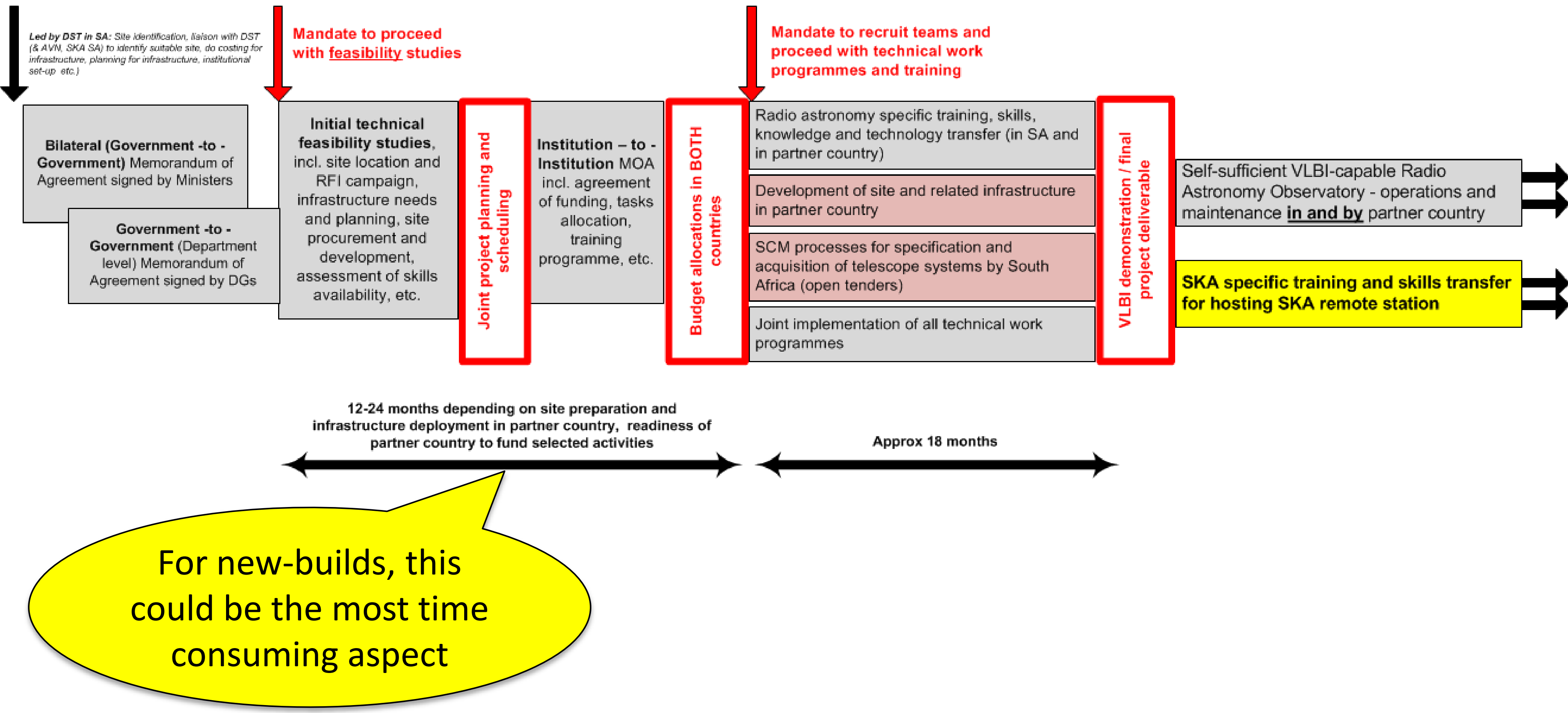
Starter recipe for conversions

- Initial audit and feasibility checks - evaluate structural, mechanical and electronic realities and needs for conversion;
- Carry out mechanical & control system upgrades for initial radio tests;
- 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;
- Evaluate options for operation at other frequencies;
- Implement multi-frequency option selected.

Process overview – possible new-build(s)



Process overview – possible new-build(s)



AVN Stations – new-builds

- 2-day workshop with Mauritian Scientists and Engineers held (20-21 Sept 2012) to derive a "wish-list" for high-level system specifications:
  - A figure for System Equivalent Flux Density[1] (SEFD) of *"much less than but not above"* 800 – a criterion for acceptance of the VLBI station into European VLBI Network (EVN);
  - Consider 22 to 32m diameter **single** dish OR an array of smaller dishes with equivalent collecting area;
  - Consider cryogenic state-of-the-art receivers with VLBI and non-VLBI (pulsar timing, spectroscopy) back-ends;

[1] The Source Flux Density in Jansky which doubles the system noise temperature – A figure of merit for sensitivity as used by VLBI Community

AVN Stations – new-builds (2)

- Consider initial operation in frequencies of:
  - 1.4-1.73 GHz;
  - 2.2-2.4 GHz;
  - 4.7-5.2 GHz;
  - 6.6 to 6.8 GHz and
  - 8.2-9.0 GHz
- Derive a site selection matrix considering RFI, soil studies, topography, approach roads, optical fibre connectivity, power, water, environmental (wind, humidity, temperature) etc.;
- "General purpose" as opposed to "special purpose";
- Consider linkages to SKA Phase 2 proposed sites in order to optimise infrastructure costs / investments?

Process overview – training facility

Bilateral (Government -to - Government) Memorandum of Agreement signed by Ministers

Government -to - Government (Department level) Memorandum of Agreement signed by DGs

Mandate to proceed with technical work programmes

Joint project planning, scheduling and task allocation (April 2012)

Formation of Radio Astronomy Institution in Mozambique (ownership of facility after commissioning) – including arrangements for operations and maintenance funding, training programmes, etc.

Identification of Mozambique team to be trained during the project conversion phase

AVN Team starts antenna development work at TELKOM site in SA

Mozambique team involvement in all aspects of developing and building the instrument at TELKOM site near HartRAO

Mozambique team executes site work at Maluana Science Park as per agreed scope of infrastructure and site investigations

Telescope system fully tested at Telkom site, containerised and transported to Mozambique

Telescope system unpacked, re-built on site in Mozambique, tested and commissioned by joint Mozambique / South Africa / team

Radio Astronomy demonstration, official opening of facility

Training facility established, operations and science programmes by Mozambique team

Ongoing radio astronomy specific training, skills, knowledge and technology transfer (in SA and in partner country)

Development of site and related infrastructure for Mozambique new-build (phase 2)

SCM processes for specification and acquisition of telescope systems by South Africa (open tenders) for new-build phase

Joint implementation of all technical work programmes

Radio Astronomy demonstration / final project deliverable

Self-sufficient Radio Astronomy Training Facility - operations and maintenance **in and by** partner country

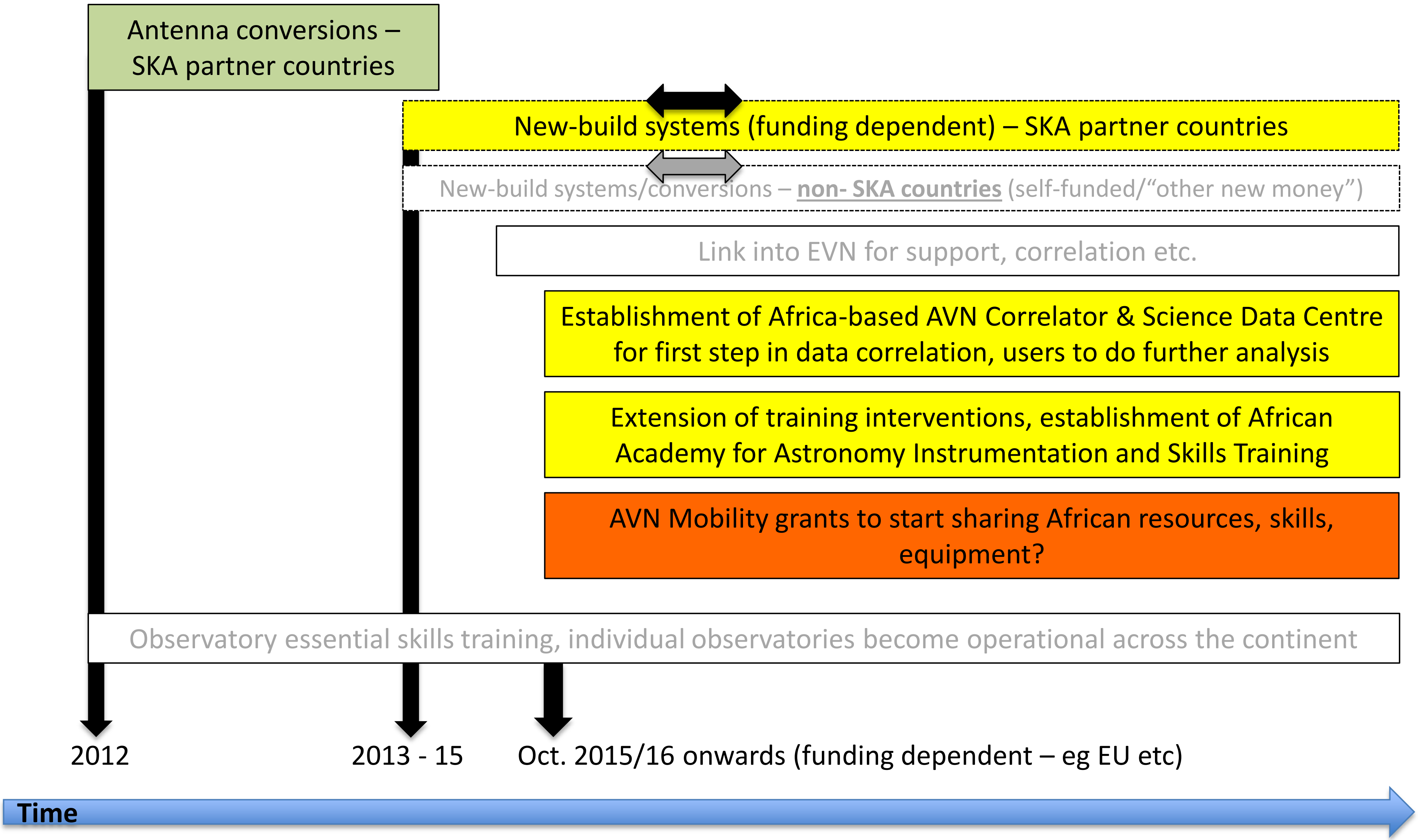
SKA specific training and skills transfer for hosting SKA remote station

Duration approximately 9 months. Already ± 6 months delay due to constraints in Mozambique

Approx 3 months

12-24 months depending on site preparation and infrastructure deployment in partner country, readiness of partner country to fund selected activities

Big picture of an AVN (conceptual / proposal)



Teams, training and processes

(the AVN as a stepping stone towards SKA)

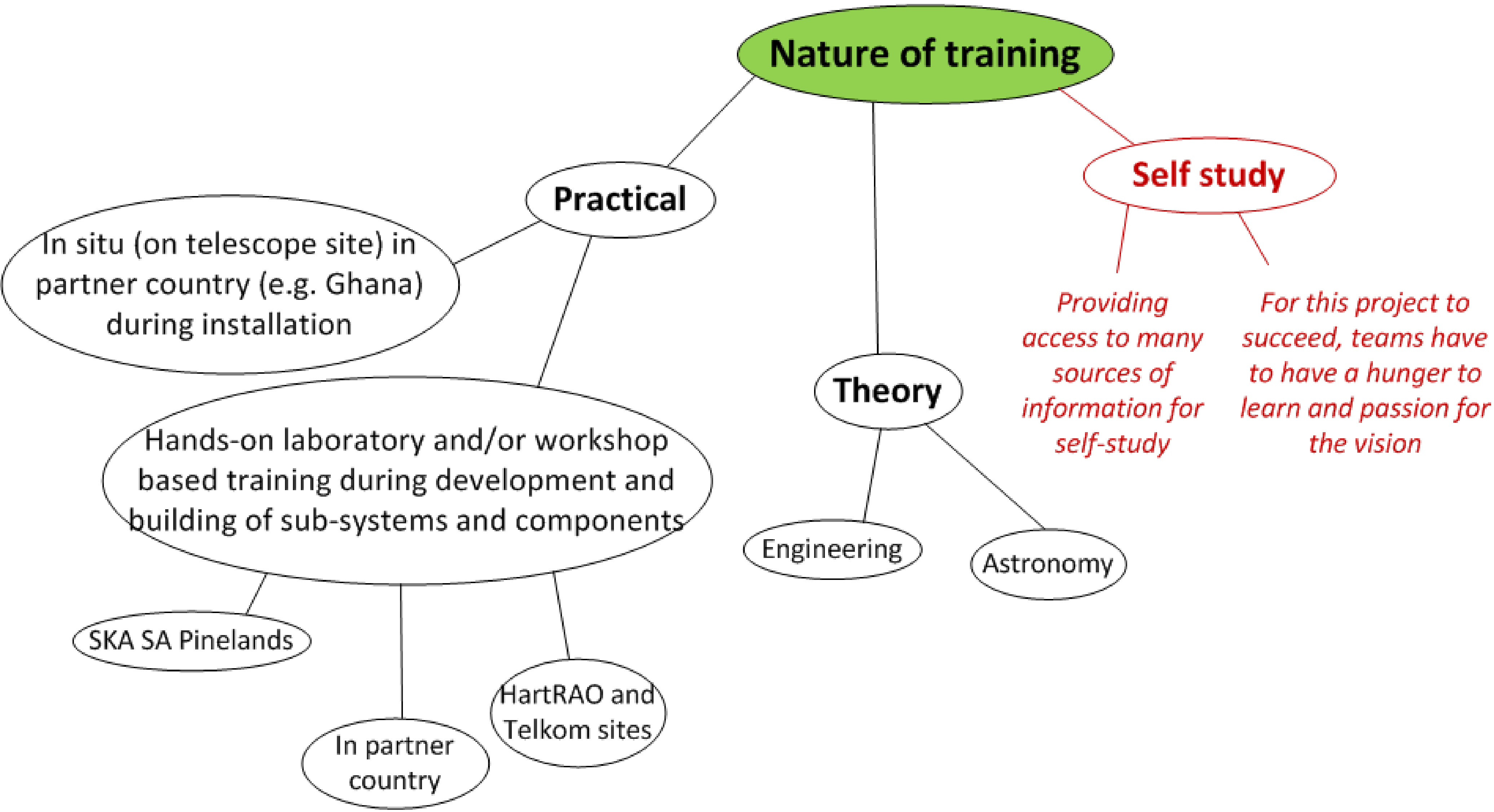
Teams to deliver the AVN

- South African team:
  - Workgroups (Structural and Mechanical, Software and Data Processing, Science, Control and Monitoring, Signal Chain).
- Partner country teams:
  - Mirror the team structure in SA and establish the core of the Observatory Staff in partner country;
  - Build science capability in partner countries (long term).
- 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 obstacles are removed speedily (eg visas, exports/imports, customs, etc.)

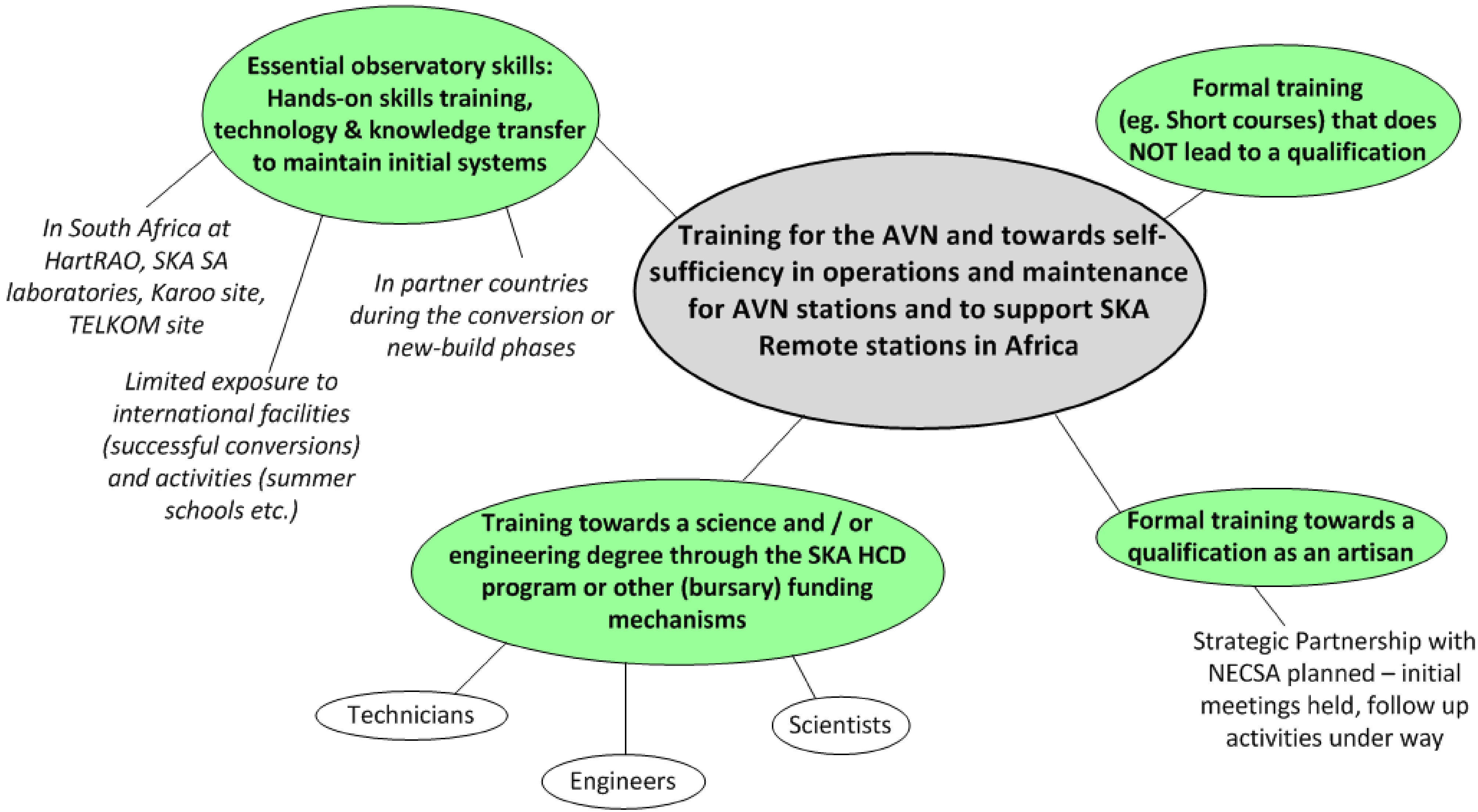
Human Capital Development - Rationale

- Establish suitably trained teams (human capital) in all partner countries as done in and for South Africa since 2005;
- Ensure that Africans fully participate and proudly own facilities in their countries;
- 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.).

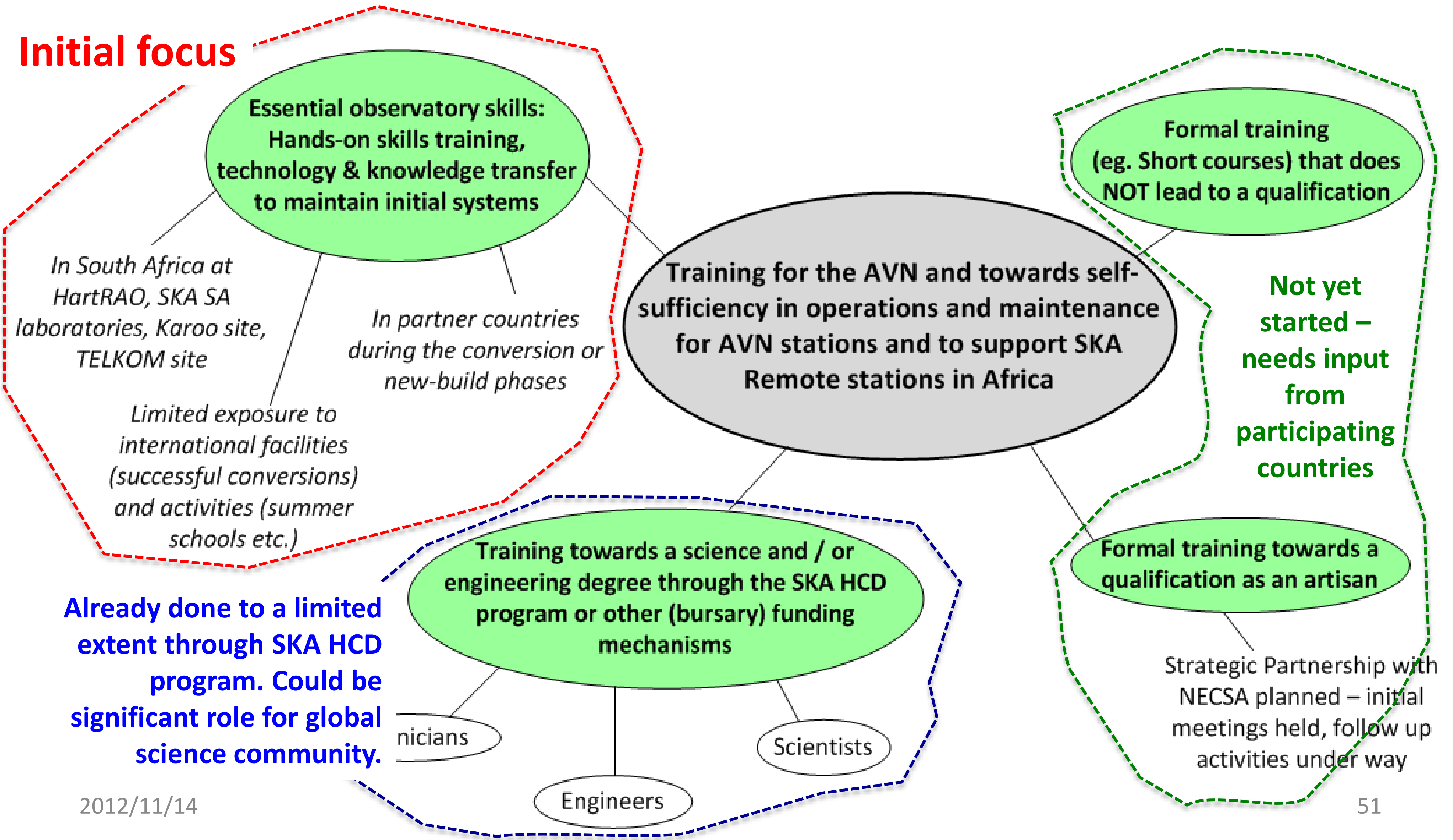
Nature of training



Types of training



Types of training



Training Pilot Program

Orientation -
Fundamentals in Radio Astronomy
(one week)

HartRAO

↓

Orientation -
Basic in systems engineering as relevant for AVN
(one week)

Cape Town

↓

Model-based learning -
Building a fully steerable training telescope
(five weeks – incl. mid-term evaluation)

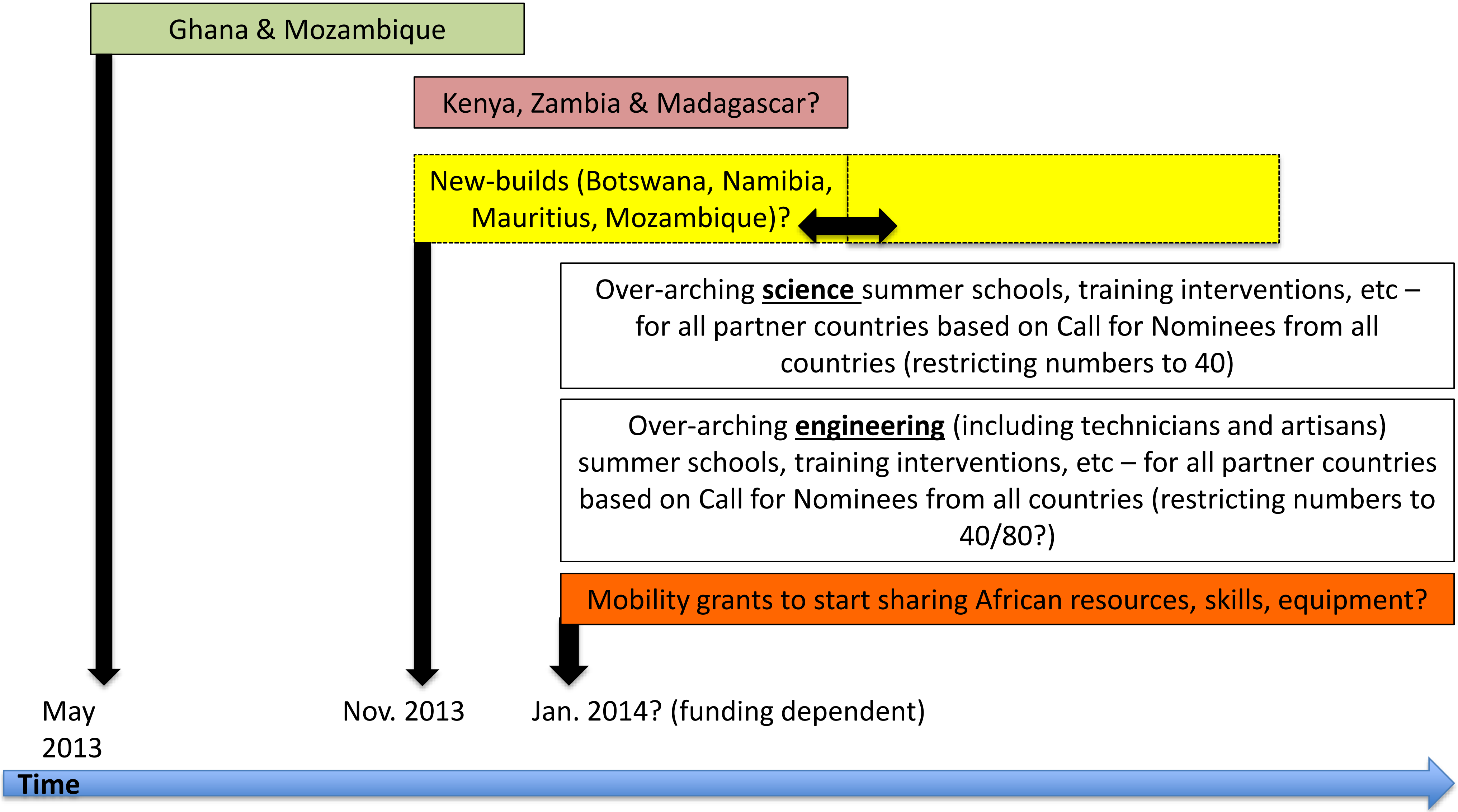
HartRAO +
Cape Town

↓

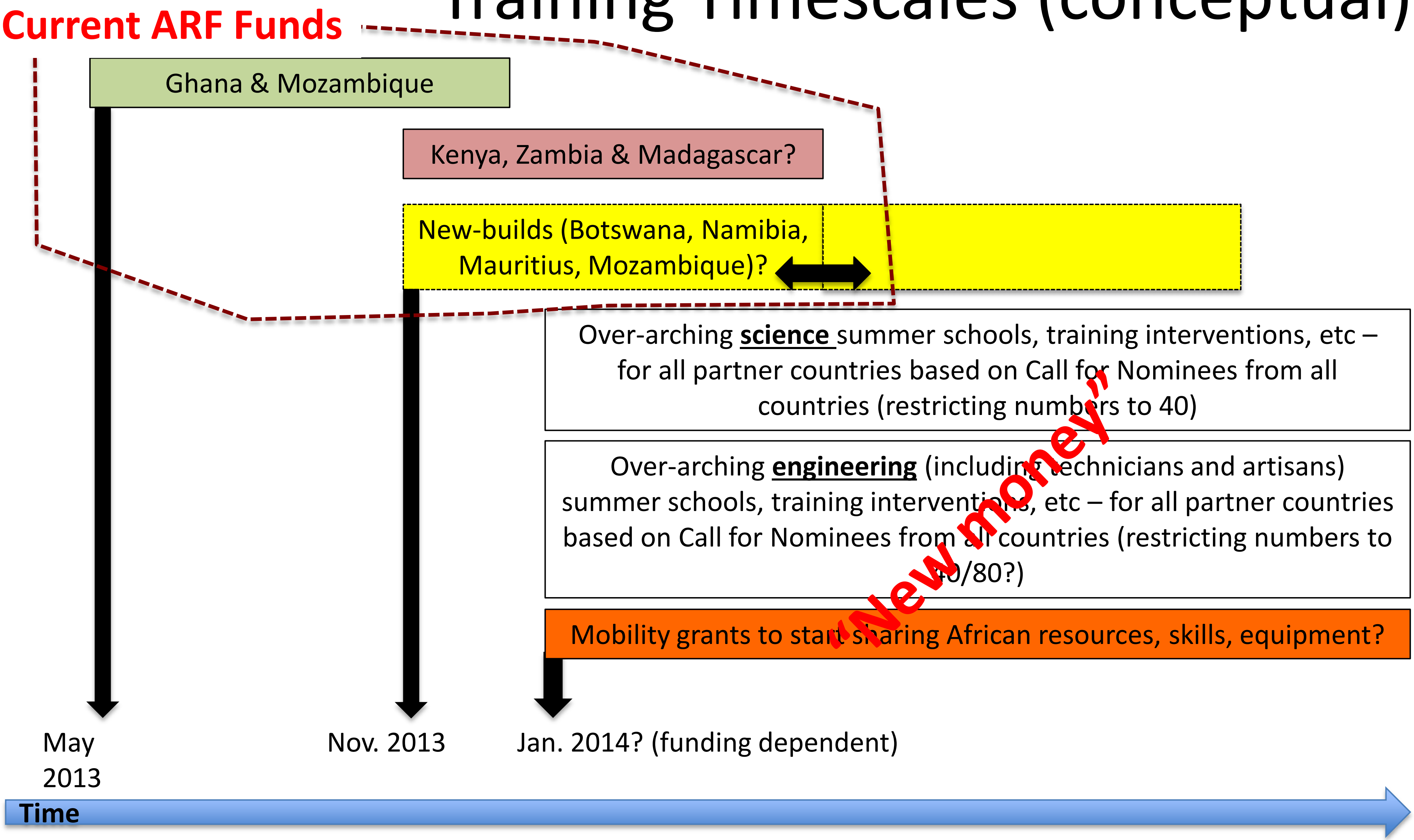
Domain-specific training –
(sixteen weeks – incl. final evaluation)

HartRAO +
Cape Town

Training Timescales (conceptual)



Training Timescales (conceptual)



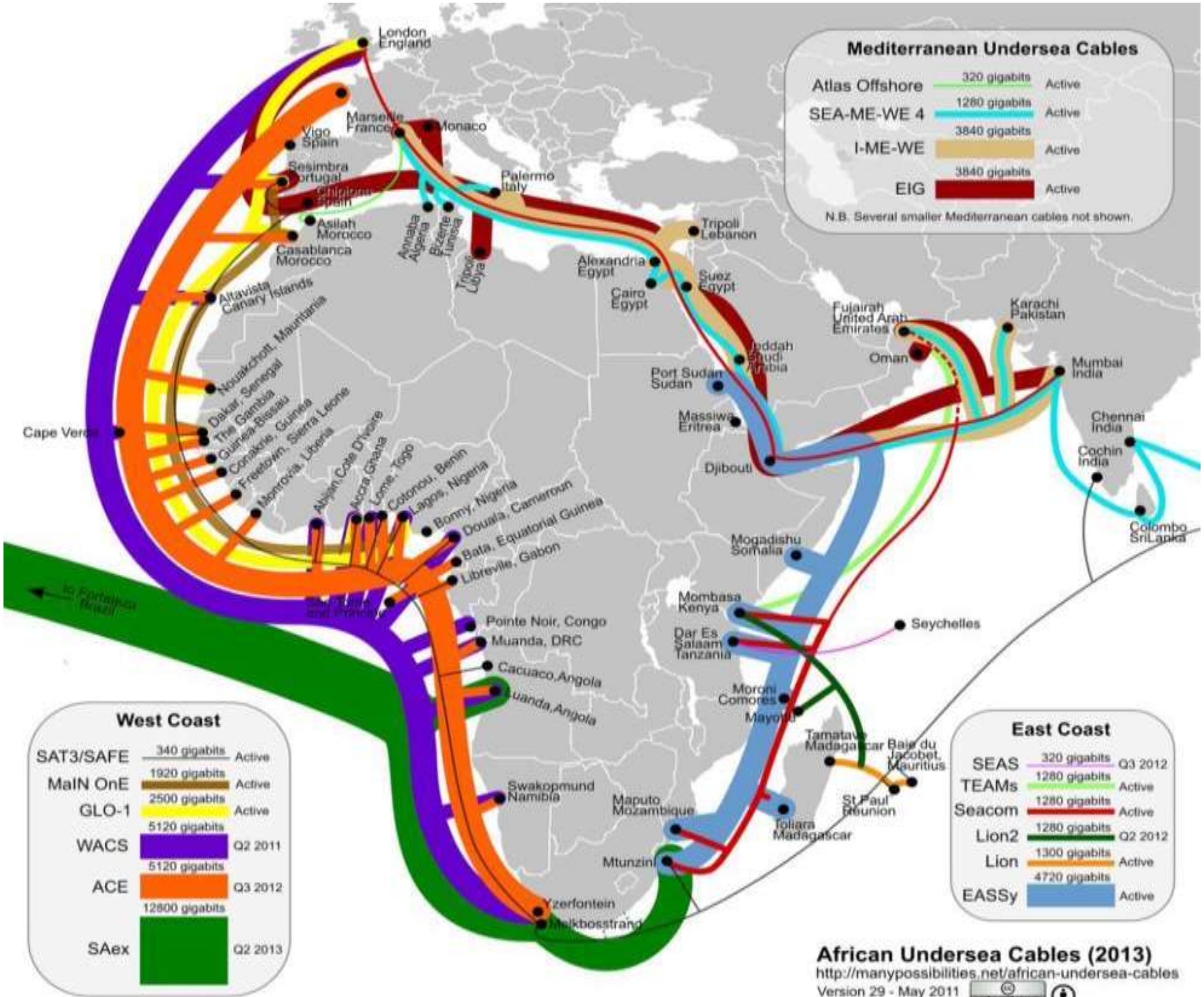
Summary - training

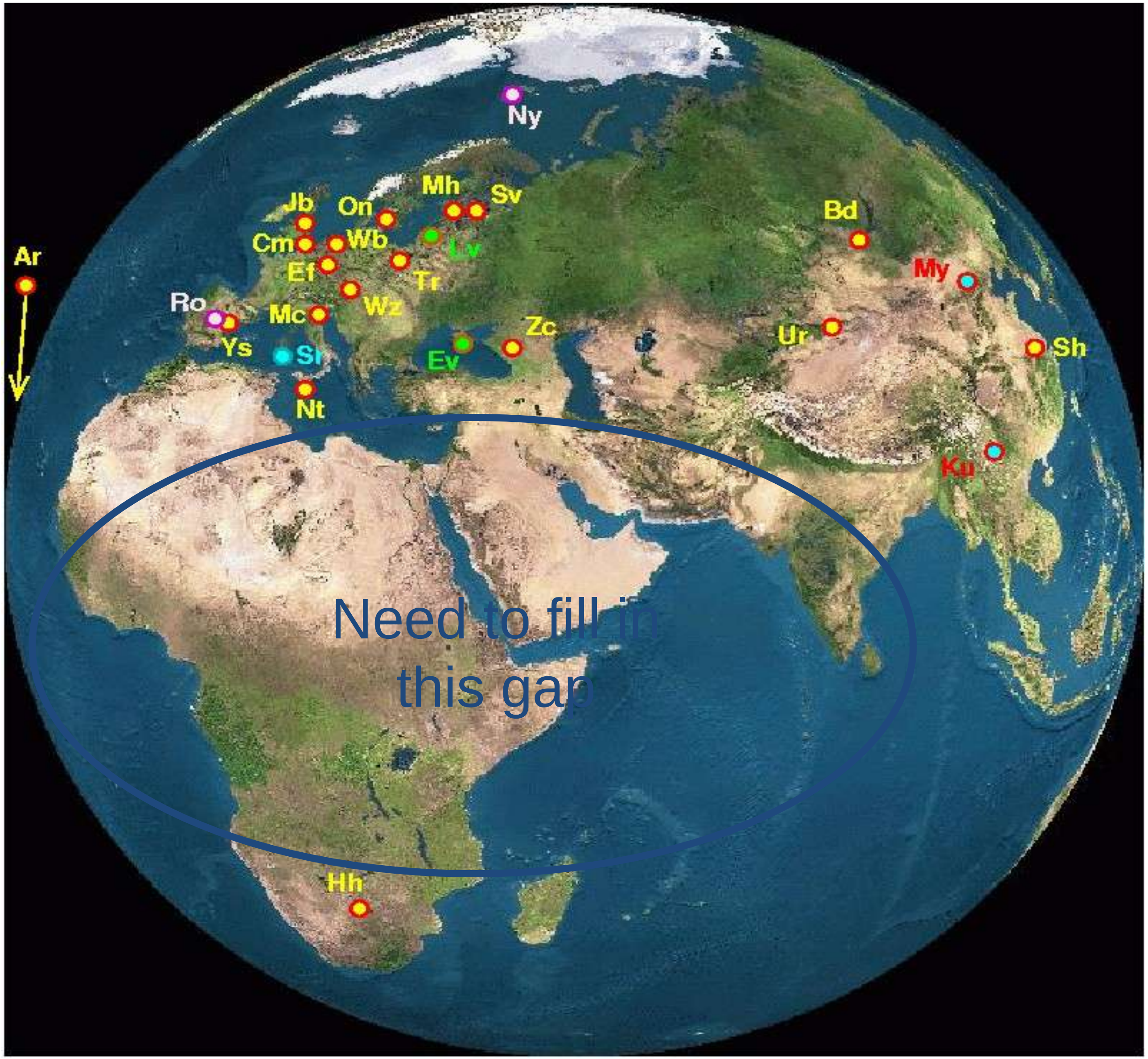
- The Training Programs are being developed for Ghana and Mozambique and will be adjusted based on feedback and new insights – and then implemented in other partner countries as their projects get off the ground;
- The success of AVN depends heavily on the motivation and involvement of the team members in partner countries, who need to be convinced that their participation is the start of a long career with good growth potential needing 100%+ commitment;
- It is imperative for the “system” in partner countries to provide such an environment.

Overview in pictures

African VLBI Network (AVN)

African Submarine Cable Systems

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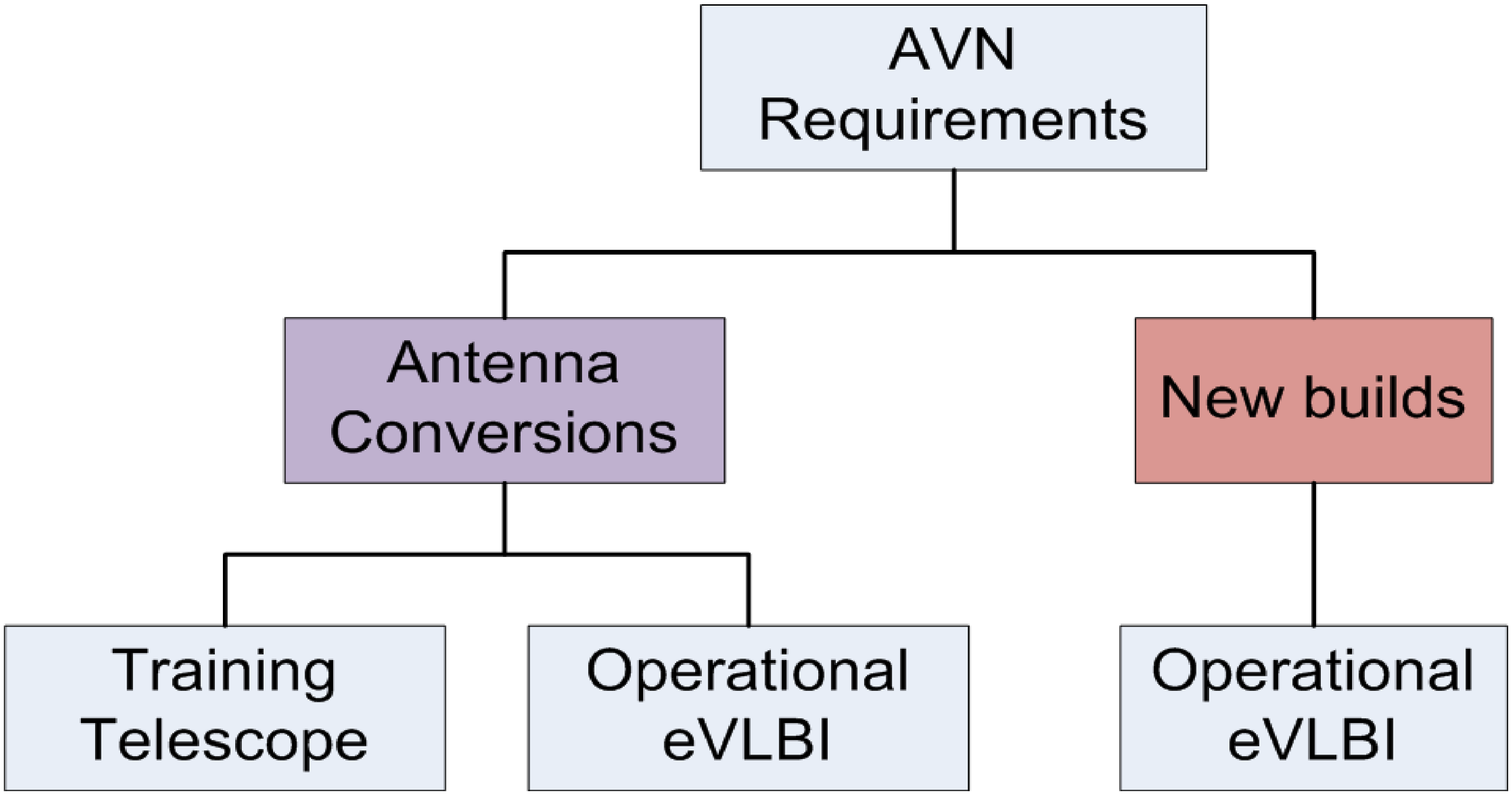
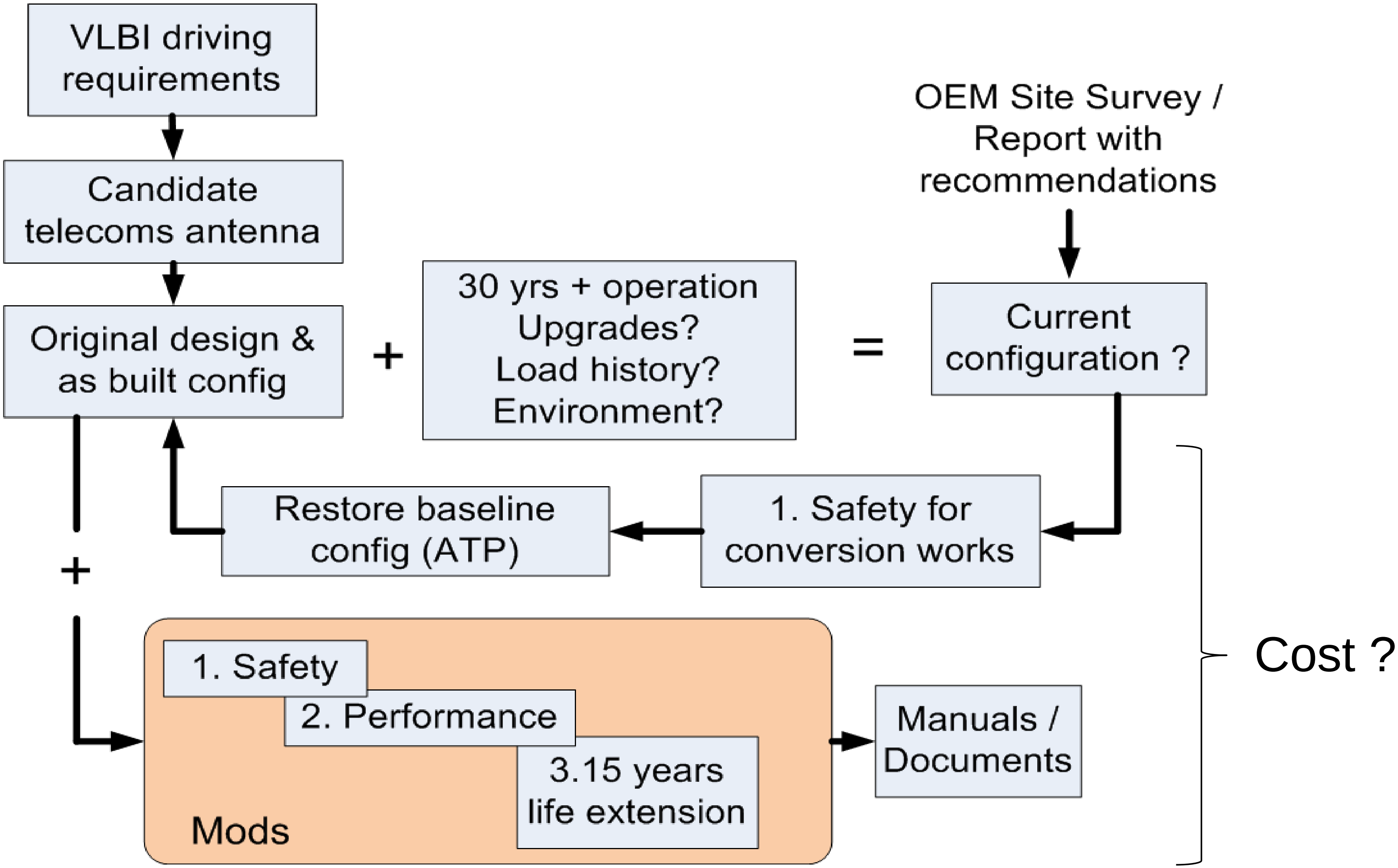

AVN Requirements
Antenna Conversions
New builds
Training Telescope
Operational eVLBI
Operational eVLBI


VLBI driving requirements
Candidate telecoms antenna
Original design & as built config
+
30 yrs + operation Upgrades? Load history? Environment?
=
OEM Site Survey / Report with recommendations
Current configuration ?
1. Safety for conversion works
Restore baseline config (ATP)
+
1. Safety
2. Performance
3.15 years life extension
Mods
Manuals / Documents
Cost ?

In Ghana

Das Bildelement mit der Beziehungs-ID rId4 wurde in der Datei nicht gefunden.

Cape Town, Telkom

HartRAO, Karoo

In Mozambique

Das Bildelement mit der Beziehungs-ID rId2 wurde in der Datei nicht gefunden.

HartRAO – AVN Ghana receiver

Antenna conversion examples

Top row are operational as radio telescopes:

Australia Ceduna

Japan

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


32m
32m
32m
11m
11m
11m
18m
18m

Benefits of antenna conversion for the host country

- Continued 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
  - Very Long Baseline Interferometry (VLBI) for high angular resolution imaging
- Create a pool of astronomers able to use current and future radio telescope arrays
- 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
- Create an organisation that could support an SKA outstation
- Requires the establishment of a supporting agency - Space / Astronomy Agency

SKA Long Baseline Science Case

Likely to be partly accessible to current VLBI (and the AVN), thus providing current research opportunities:

- Accurate pulsar distances from trigonometric parallax measurements, as well as pulsar proper motions
- Modelling the large-scale galactic magnetic field using pulsars – (rotation measure)
- Resolving AGN and star formation in galaxies
- Radio studies of high-redshift AGN jets
- Transients – long baselines provide discrimination against radio frequency interference (RFI)
- Binary supermassive black holes
- X-Ray binary systems and relativistic jets.

May be inaccessible to current VLBI / AVN:

- Strong field test of gravity - timing relativistic binary systems
- monitoring an array of millisecond pulsars to detect gravitational waves with nanoHertz frequencies
- Imaging protoplanetary disks at centimetre wavelengths
- The first generation of AGN jets
- CO Studies of high-redshift AGN jets.

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
- ROACH 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
- Evaluate structural, mechanical and electronic needs for converting the antenna for radio astronomy
- Carry out mechanical & control system upgrades for initial radio tests
- 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
- Implement multi-frequency option selected

Conversions of Large Satellite Antennas

- First stage receiver development:
- Use components from C-BASS antennas to create an uncooled receiver for C-band = 5 + 6.668 GHz to mount on existing 3.7 – 6.4 GHz feedhorn
- If (successful = aperture efficiency > 50%, to give SEFD < 800 Jy)
- Then
  - develop into initial VLBI-capable receiver
- Else
  - develop new feedhorn and receiver

- Second stage receiver development options:
- Add L-band e.g. 1.4 – 1.7 GHz receiver with folding tertiary reflector, at beam waveguide aperture (like Ceduna)
- Replace original feed with wideband feed eg 4 - 8 GHz (4.5 – 9 better)
- Remove feed below beam waveguide and add rotating tertiary mirror below beam waveguide to feed multiple receivers

Newbuild Telescope Options

- What is the level of our ambition:
- 1. Minimum size, to give acceptable SEFD < 800 Jy?
- Could clone 13.5m MeerKAT antennas, but not designed to survive cyclone wind speeds (Mozambique, Mauritius)

- 2. Minimum size but cyclone resistant, for 250 < SEFD < 800 Jy?
- Should be 20 – 22m to provide adequate performance
- Is there an existing design that could serve?

- 3. Provide international target VLBI SEFD < 250 Jy
- Clone VLBA 25m antennas (wind limit? St Croix – hurricane tolerant?)
- or relocate VLBA antennas that are taken out of service

- 4. Match size of redundant satellite dishes to provide uniform array
- Clone Medicina 32m design – radio telescope version of Ghana satellite dish (cyclone tolerant?) or other existing design providing required wind tolerance