



The development of global VLBI

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director of JIVE*



Acronyms/Organizations involved

- **VLBI: Very Long Baseline Interferometry**
 - A radio-astronomical technique with telescopes thousands kilometres apart to obtain highest possible resolution
- **EVN: European VLBI Network**
 - Consortium of (European) Telescopes
 - 30 year of collaboration, open to global collaborations
- **AVN: African VLBI Network**
- **JIVE: Joint Institute for VLBI in Europe**
 - Funded by radio-astronomy institutes and research councils
 - NWO (NL), ASTRON (NL), STFC (UK), INAF (IT), ICN-IG (ES), OSO (SE), CAS (CN), CNRS (FR), MPG (DE), NRF (ZA)
 - Promote the use and advance of VLBI (for astronomy)
 - Central correlation; User services; Network support; Innovation R&D
 - Exemplary science; EC liaison/representation
 - With ambition to become ERIC (European Research Infrastructure Consortium)



Hartebeesthoek a very valued member of the EVN

- Now with 2 antennas on site
- North-south sensitivity on long baselines



South-Africa's NRF joined JIVE foundation on May 10

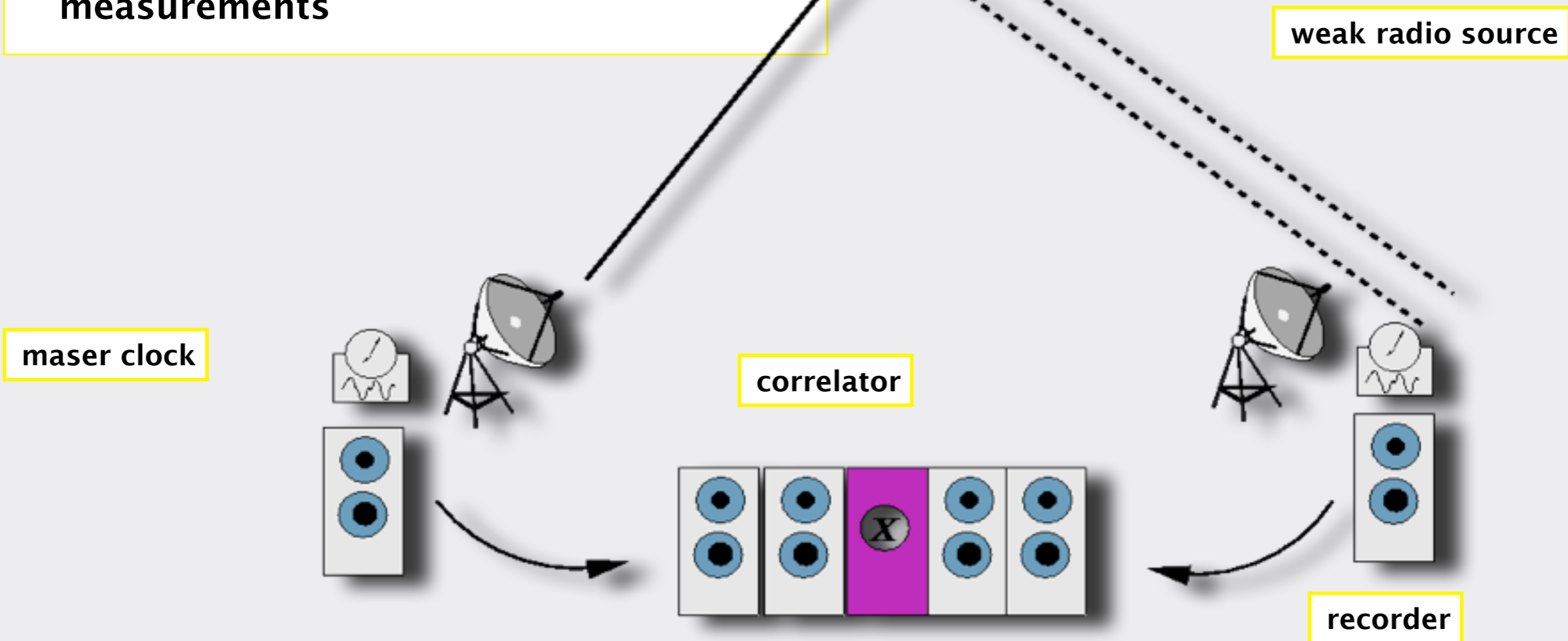
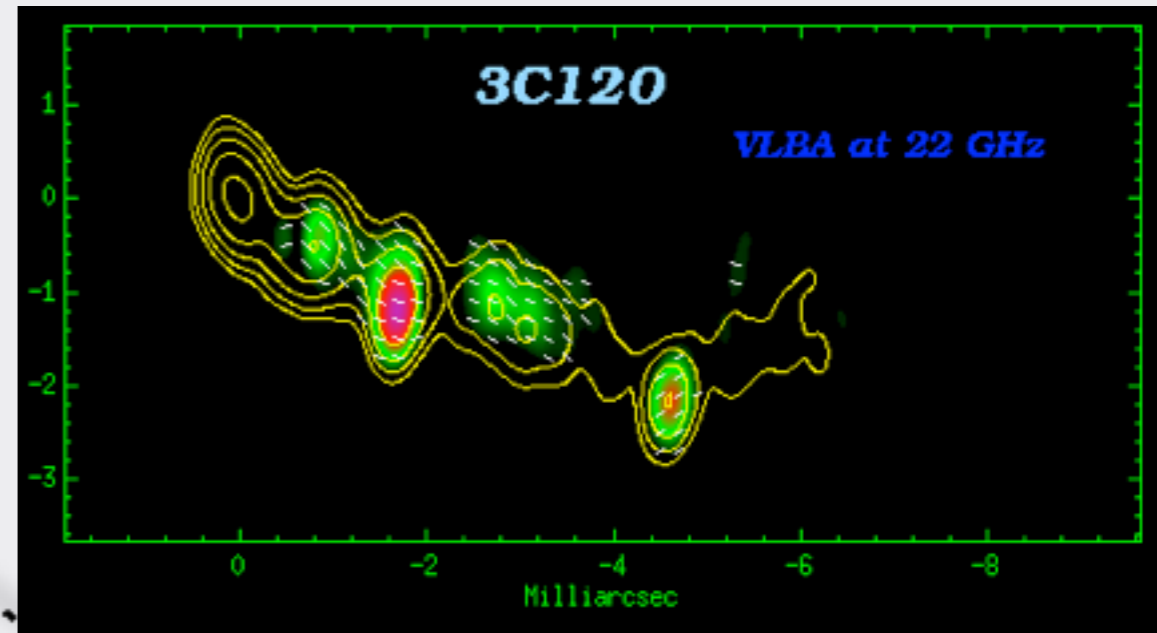


Recognizing a joint interest:

- VLBI with KAT7 and MeerKAT
- The potential of the AVN
- Human capacity building

VLBI: make a giant telescope

- Radio interferometry measures Fourier components of sky
- Atmosphere transparent for radio emission 100M - 100GHz
- Big telescopes more sensitive, long baselines high resolution
- Sample, digitize and record and tag very accurate time
- Send to correlator, measure interference
- Compute image back from measurements



The European VLBI Network

- **Big telescopes in number of European countries**
 - Run by national agencies
- **Important partners outside EC countries**
- **Network defines telescope:**
 - Resolution of astronomical picture depends on baseline length
 - Sensitivity depends on telescope size and digital equipment
 - Image quality on number and distribution of receptors
- **Arranged in Consortium**
 - No exchange of funds
 - Except central operations of JIVE



Irbene LV

3 telescopes in Russia

Sardinia 64m

Arecibo, Puerto Rico

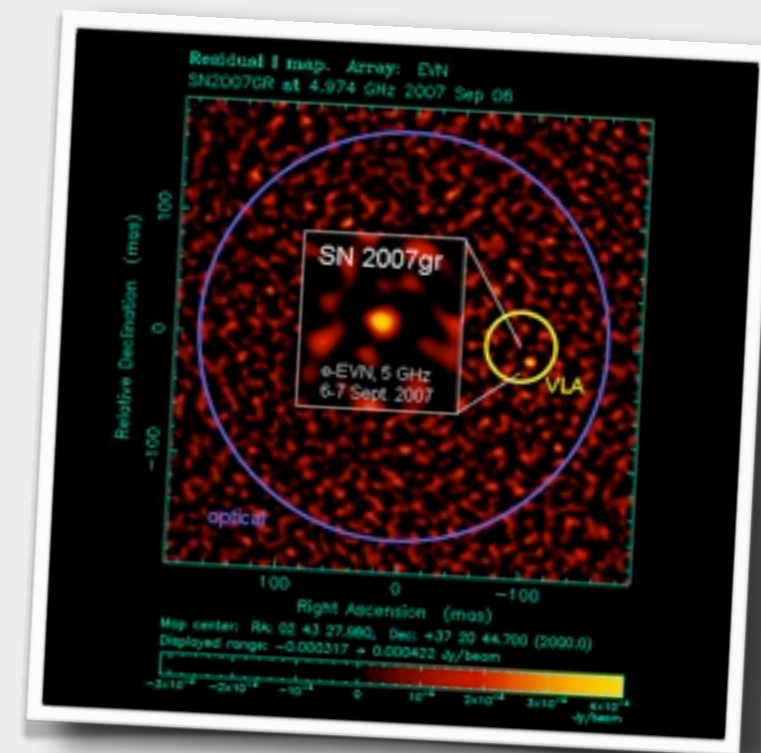
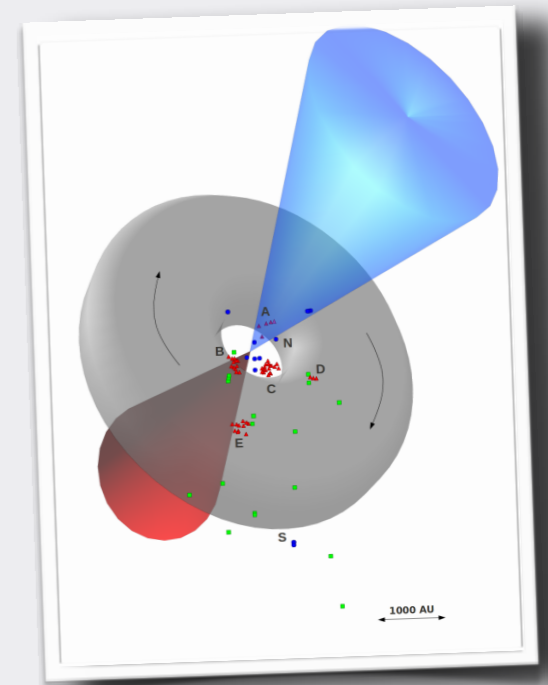
Hartebeesthoek, South Africa

4 telescopes in China



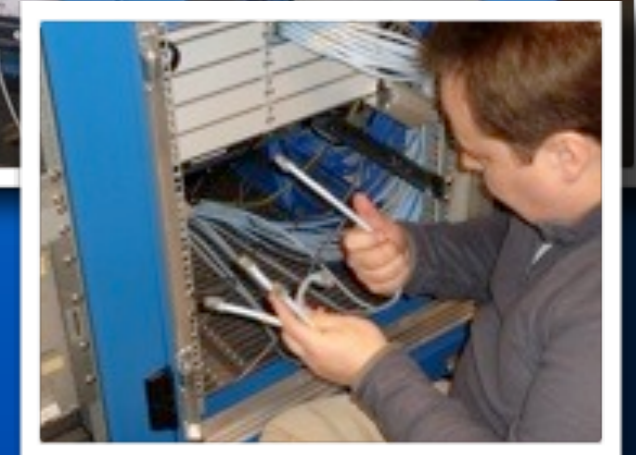
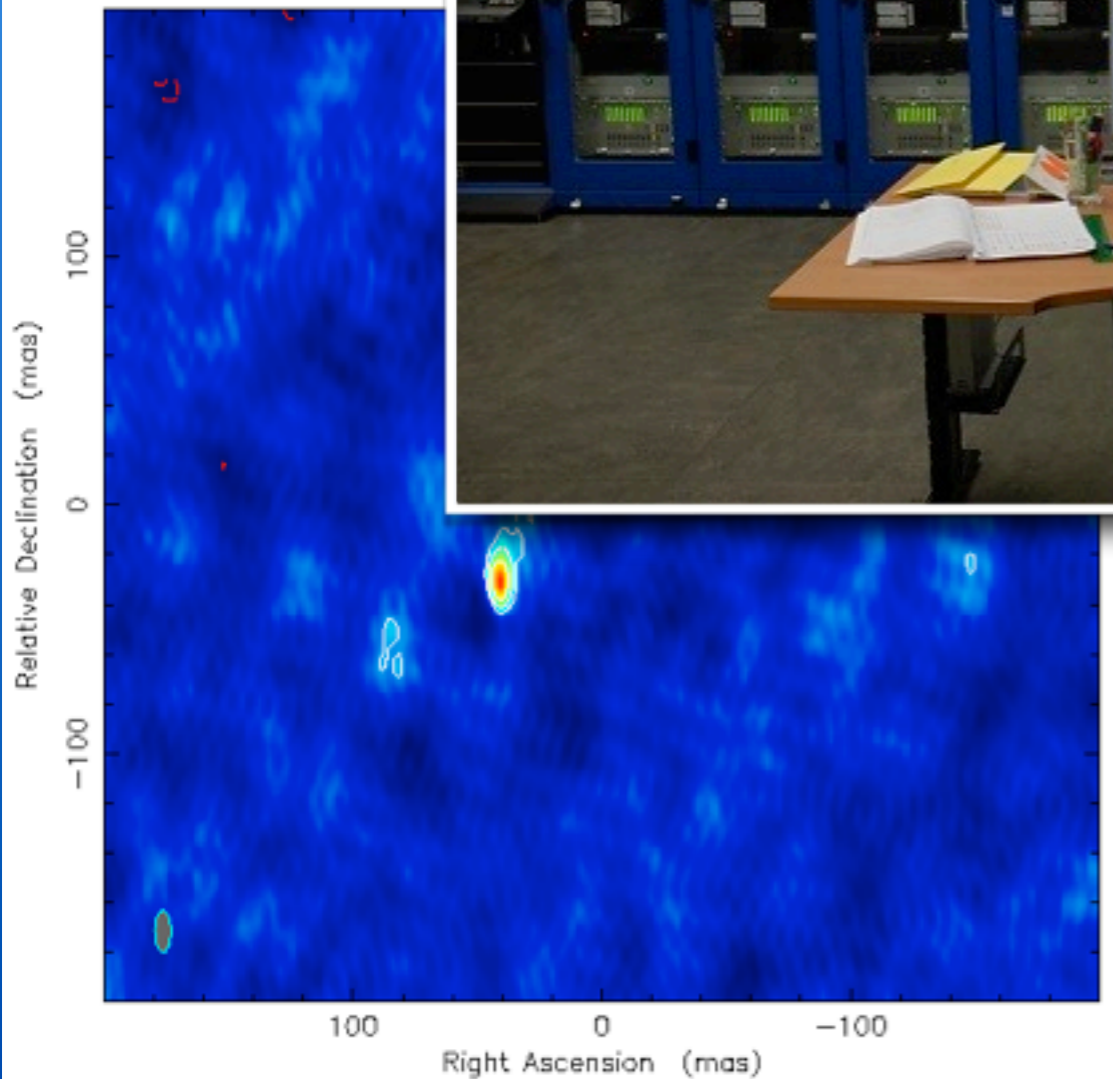
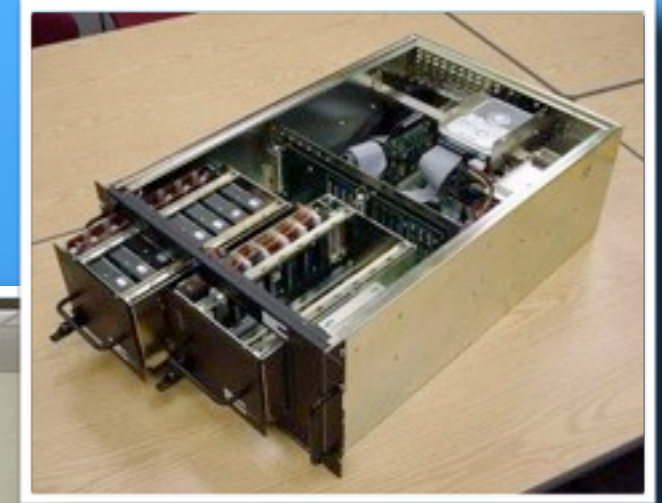
The EVN in numbers

- **EVN consortium with 20+ possible antennas**
 - Ef, Jb, Cm, Wb, On, Mc, Nt, Tr, Ys, Ur, Sh, Hh, Mh, Ar, Sv, Zc, Bd, Wz, Ro, Km, My, Ny, Ma, Sm
 - Ran by up to 14 different organizations
 - And 12 more antennas for “Globals” with NRAO
 - + other DSN (Go, Ti), Japanese (Ka, Ym, Vm, Vs), & Australian (Pa, Ho, At, Mp, Cd)
- **Covering range of frequencies**
 - Workhorse frequencies 18cm, 6cm, 5cm
 - Also available: SX, 1.2cm
 - And at limited stations 90cm, 50cm, UHF, 21cm, 2cm, 0.7mm
- **Reaching mas resolutions**
 - From 15mas for 1.4 GHz EVN (can add MERLIN for sensitivity)
 - To 1 mas at 5GHz with Asian, African or American baselines
- **Sensitivity of 5 μ Jy in 8hr at 1.4 GHz**
 - Combination of Big Antennas and 1 Gbps bandwidth
 - Big antennas also vital for spectroscopy (mJy sensitivity)
- **Operational approximately 75 days/year**
 - 3 sessions augmented with e-VLBI once a month
- **Typically 80 experiments per year scheduled**
 - Quite competitive at factor 2 oversubscription
 - Serves European community and beyond (open skies)
 - Access for non-specialist through EC-funded RadioNet



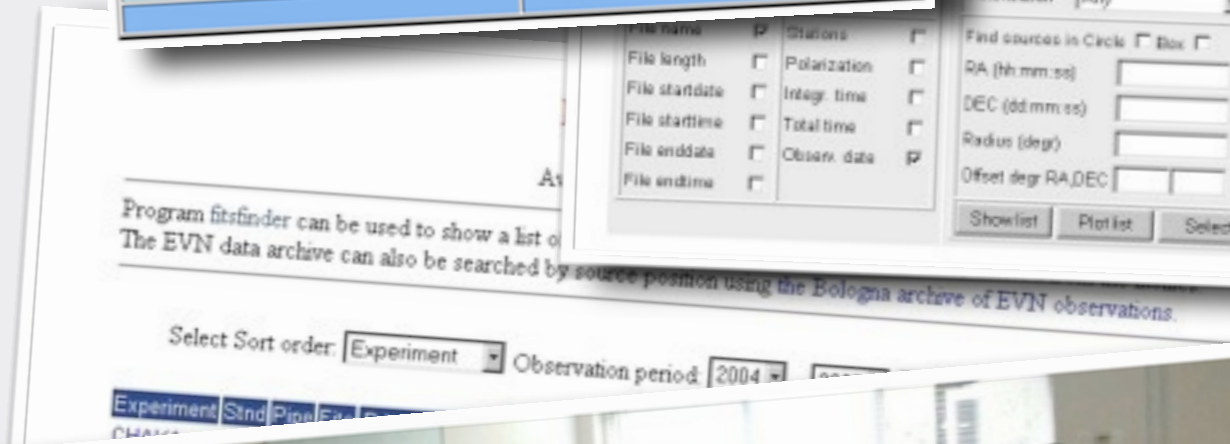
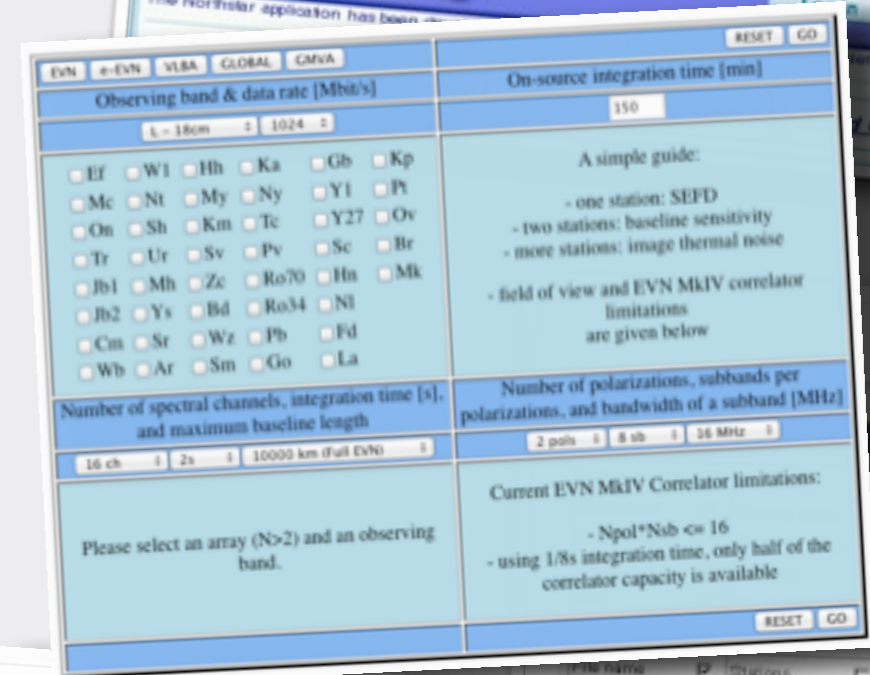
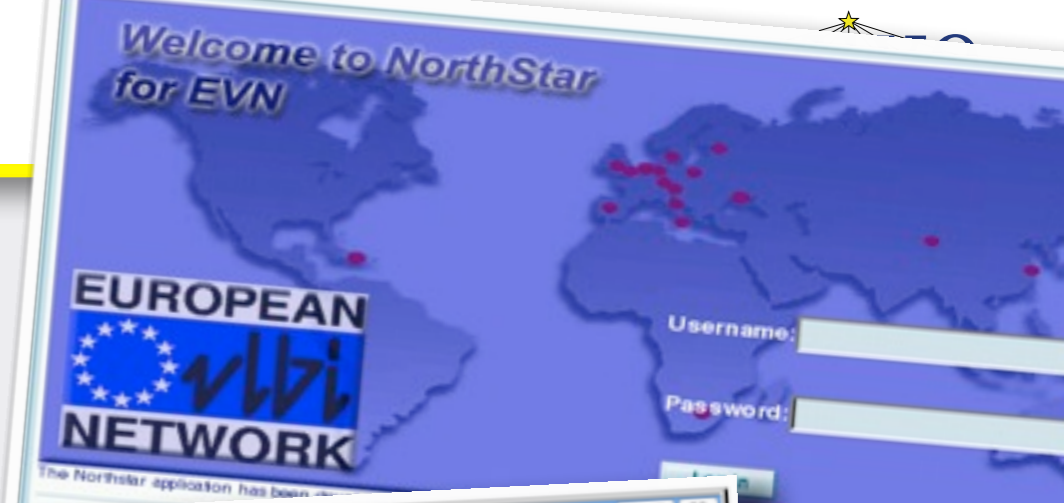
- **Requires correlators at JIVE**

- Dedicated supercomputer form 90s
- Recently developed software correlator



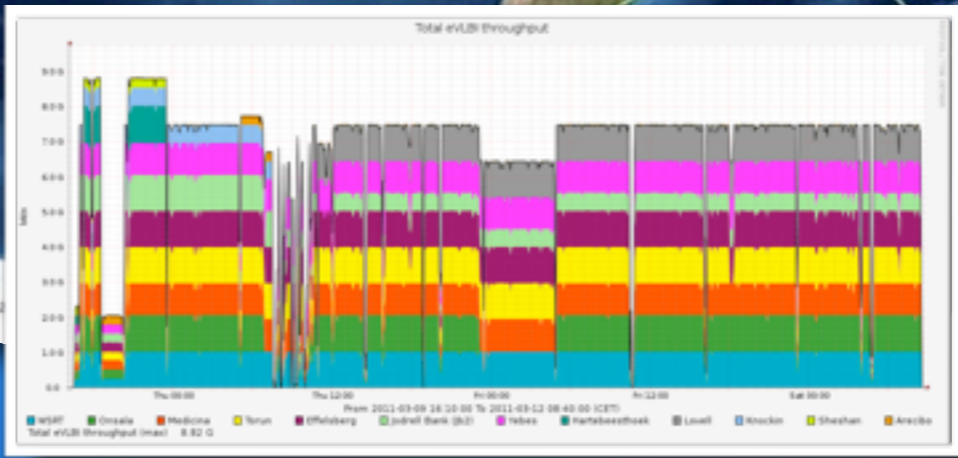
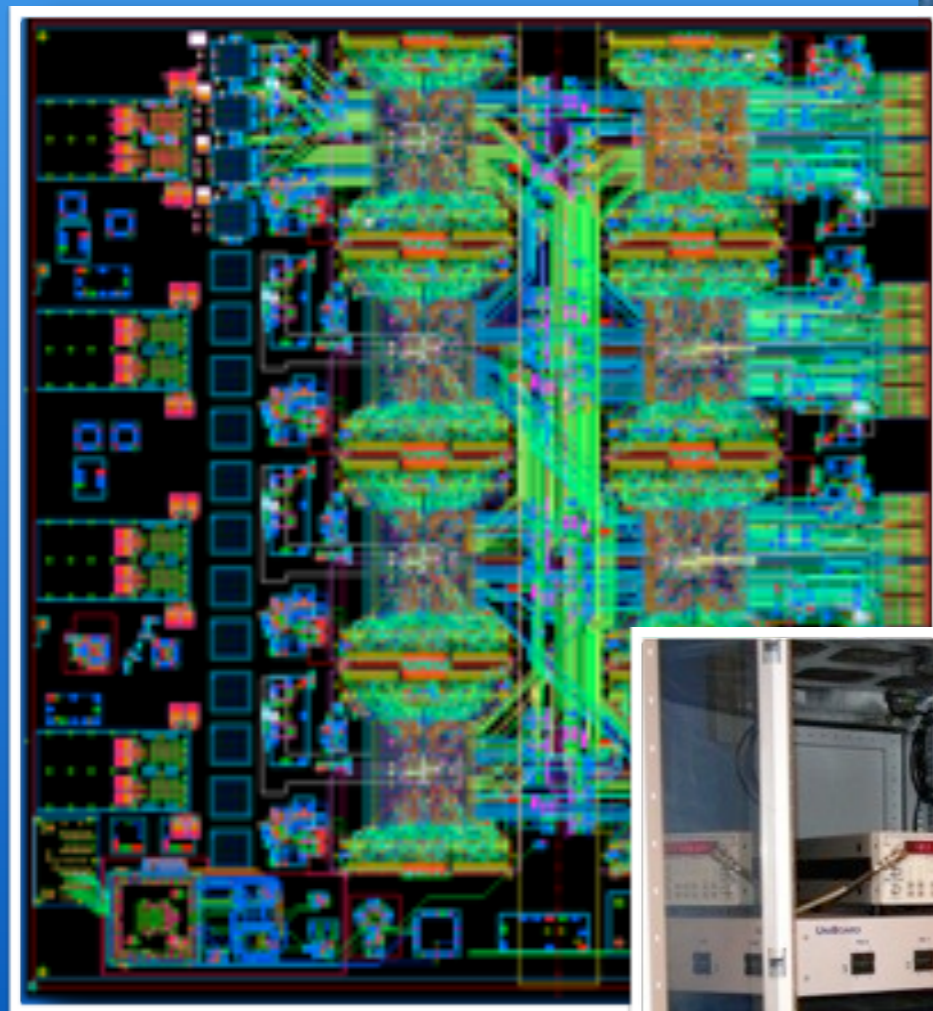
JIVE: User hub of EVN

- User interfaces
 - Proposal tool
 - Sensitivity calculator
 - EVN observation scheduling
 - Data product
 - And related software interfaces
 - Archive
 - proprietary for one year after observation
 - Pipeline: calibration info & preliminary images
- User support
 - Offer help in all stages
 - Check the correlation of all user data
 - Pipeline calibration and imaging
 - Visitor facilities
 - EVN TransNational Access programme
 - Open for user visits
 - Point of contact various RadioNet funds
- Telescope support
 - Feedback on performance



Considerable R+D effort

- for VLBI innovations
- with important EC support
- together with (EVN) partners

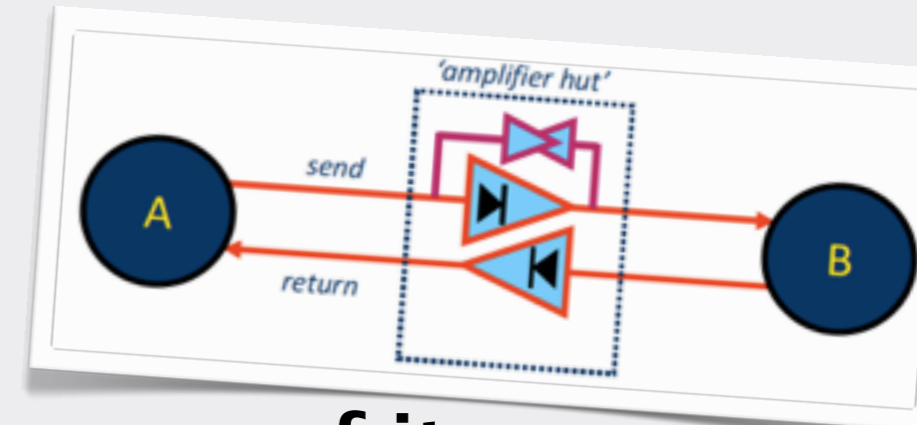


Enhancing global e-VLBI

Defining many-station, large-bandwidth, economic correlators

- **The e-EVN is a recognized SKA pathfinder**

- For long-haul connectivity (on public fibre)
- For real-time operations and science exploitation
- For distributed computing issues



- **Feeding into SKA technology and making use of it**

- Correlator programme (RadioNet)
 - also for Aperture Array beam-formers
- Computing and data distribution (NEXPreS)

- **Scientific synergy with other pathfinder**

- Follow-up large scale surveys (cosmology, pulsars)
- Transient science
- Space applications

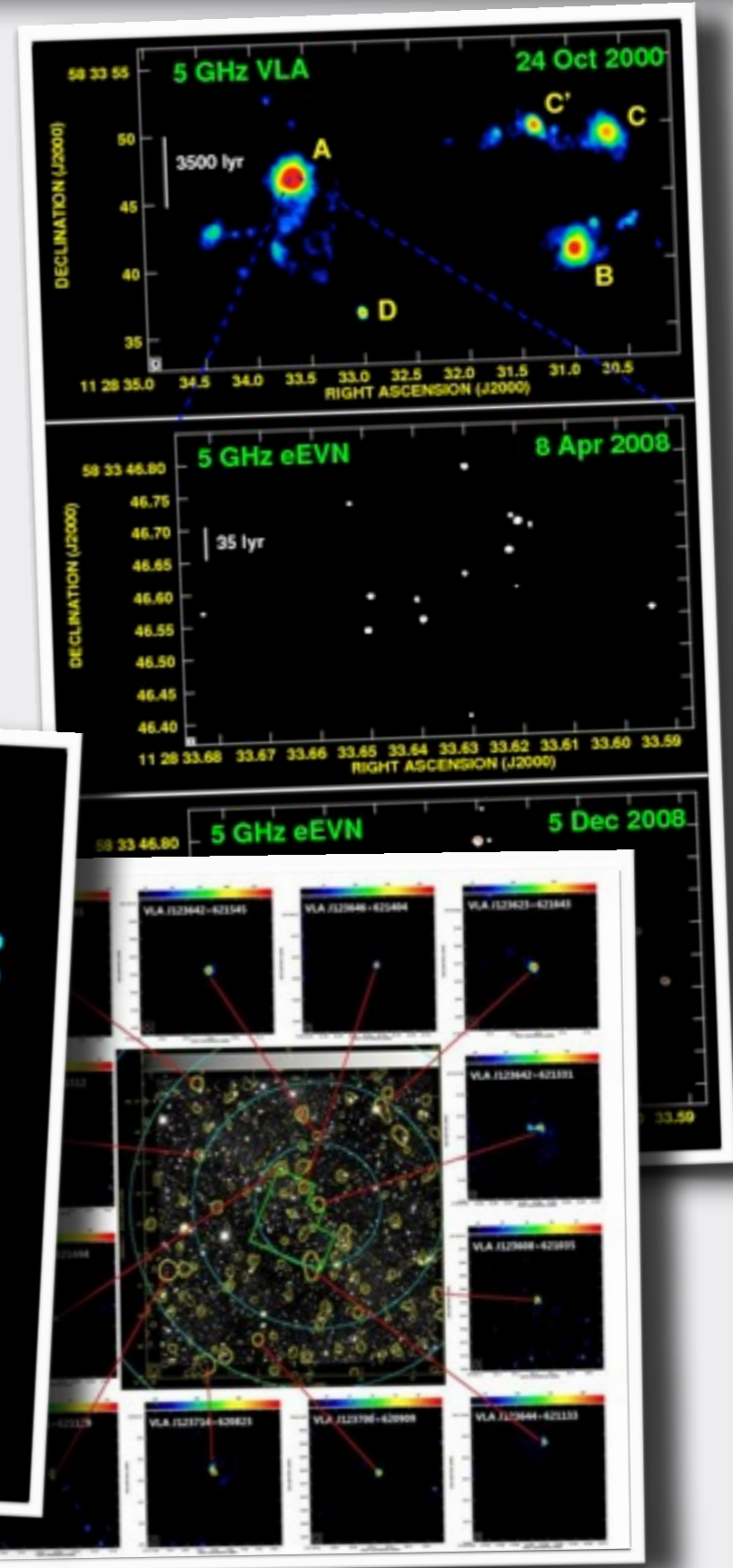
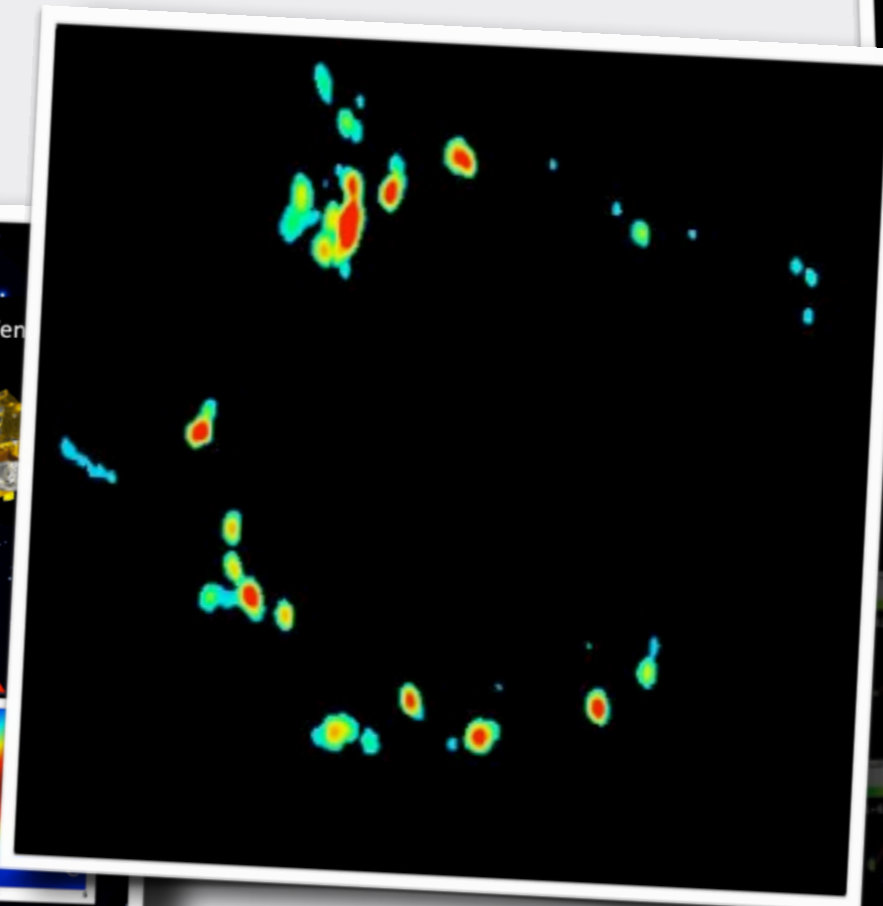
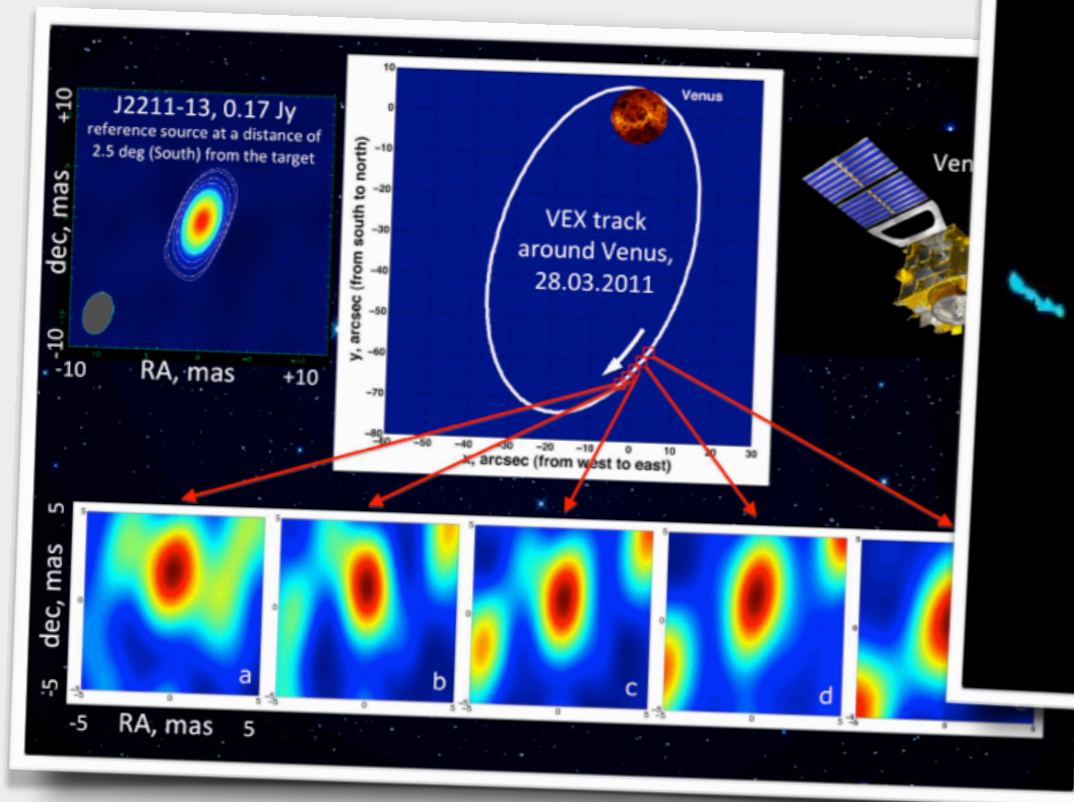
- **Training and outreach, capacity building**

- Scientists and engineers for SKA era (RadioNet)
- Educating general public about (radio) astronomy
 - Operational telescopes in populated regions



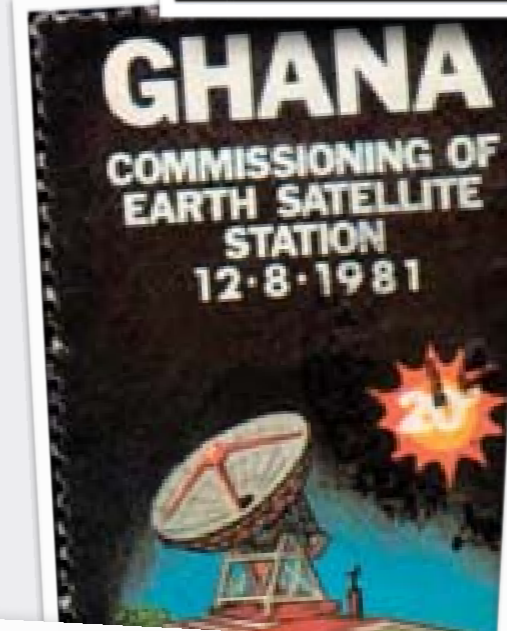
VLBI science case

- Recently reviewed
 - Review of JIVE
 - ASTRONET radio panel
- Recognized science priorities
 - Extremes of the universe
 - Evolution of Galaxies
 - Birth of stars and planets
 - How do we fit in



Opportunities for VLBI

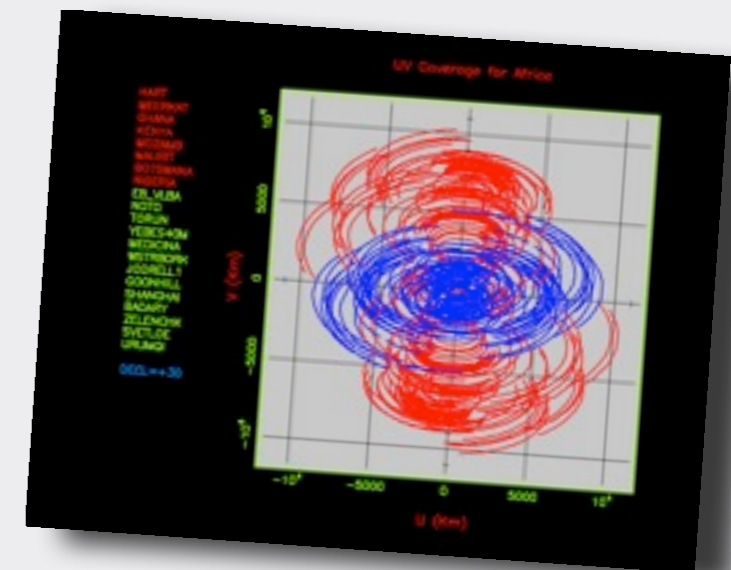
- **Science case calls for enhancements**
 - Increase sensitivity
 - more digital bandwidth
 - Go to higher frequencies
 - Double number of stations
 - Joint observations with e-MERLIN
 - Others: Goonhilly, Portugal, Ireland, Ukraine, Brasil....
 - Preferably connected in real-time
- **Stations in African VLBI Network Very relevant for this!**
 - And MeerKAT connection too
- **Science synergy with new technology (survey) instruments**
 - e.g. Transients from LOFAR
 - or Pulsars from Apertif
 - MeerKAT Galactic surveys



Target AVN:

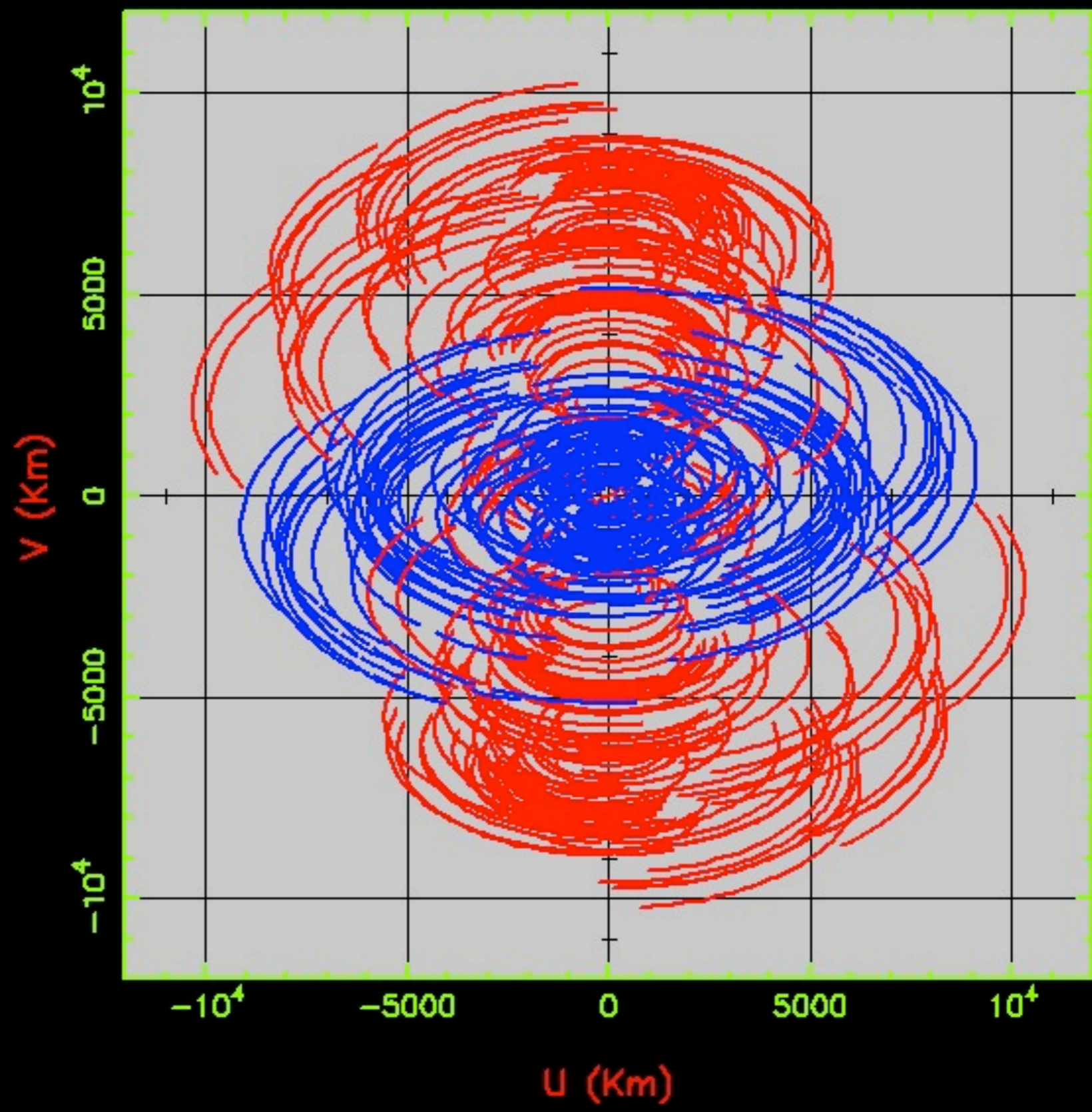
Necessary ingredients for VLBI:

- **A telescope**
 - They are already there!
 - Being retrofitted by African collaboration (?)
 - Including receivers for common frequencies
- **VLBI instrumentation**
 - Increasingly off-the-shelf, but compatibility required
 - Maser clock, digitization equipment, recorder, interface computer
- **Competent staff (technical & scientific)**
 - Training through workshops and exchange programmes
 - Means to operate
 - Man station, but also consumables (power, disks, connectivity, logistics)
- **Possibility for a win-win-win situation**
 - Attract local talent for science and engineering
 - Get everybody ready for SKA (involve Africans)
 - Enhance the scientific potential of the European research infrastructure



UV Coverage for Africa

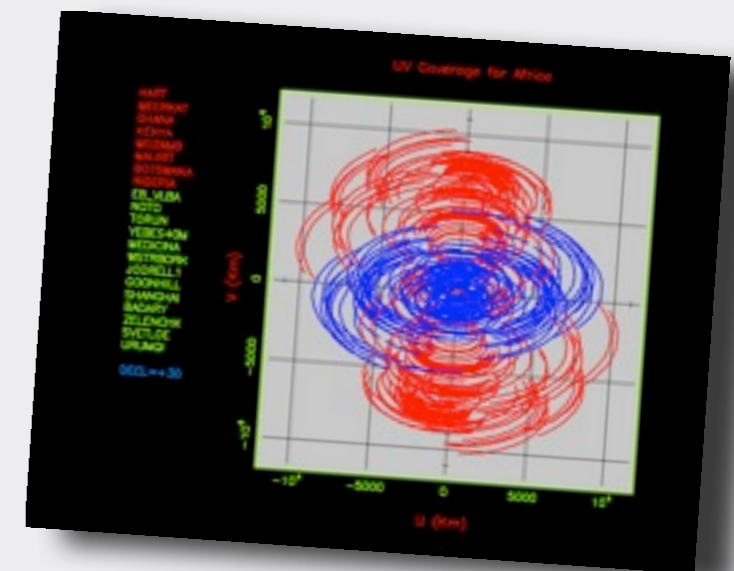
- HART
 - MEERKAT
 - GHANA
 - KENYA
 - MOZAMB
 - MAURIT
 - BOTSWANA
 - NIGERIA
 - EB_VLBA
 - NOTO
 - TORUN
 - YEBES40M
 - MEDICINA
 - WSTRBORK
 - JODRELL1
 - GOONHILL
 - SHANGHAI
 - BADARY
 - ZELENCHK
 - SVETLOE
 - URUMQI
- DECL=+30



Target AVN:

Necessary ingredients for VLBI:

- **A telescope**
 - They are already there!
 - Being retrofitted by African collaboration (?)
 - But SKA programme also offers dish technology
 - Including receivers for common frequencies
- **VLBI instrumentation**
 - Increasingly off-the-shelf, but compatibility required
 - Maser clock, digitization equipment, recorder, interface computer
- **Competent staff (technical & scientific)**
 - Training through workshops and exchange programmes
 - Means to operate
 - Man station, but also consumables (power, disks, connectivity, logistics)
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Opportunity for collaboration

- **EVN has expertise for this process**
 - May offer partnership in commissioning VLBI elements
 - Has worked for China, Latvia
 - Training events already in place
 - Exchange programmes could be implemented
 - Advice on compatible equipment and components
- **JIVE can assist**
 - Correlation is the ultimate test
 - User training/schools/exchanges
 - Project coordination
 - EC funding?
 - Central equipment purchases
 - Science programmes
- **VLBI offers a growth path**
 - Complementary science to pathfinders
 - Partnership in all areas
 - Science and operations
 - Technology development



The future of VLBI in the SKA era

- **Siting decision much welcomed**
 - Allows for Africa-Europe synergy
- **Global array with African dishes in SKA-1 era**
 - Already ~10% of SKA-2 sensitivity
 - **Complements SKA-1**
 - with sensitive long baselines
 - at high frequencies
 - **Team up with SKA-2**
 - Joint operations/user support
- **VLBI offers a growth path**
 - Complementary science to pathfinders
 - Partnership in all areas
 - Science and operations
 - Technology development
- **European radio astronomy**
 - Has an open structure
 - RadioNet platform





**Full information available,
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