JIVE

VLBI networks

Paco Colomer

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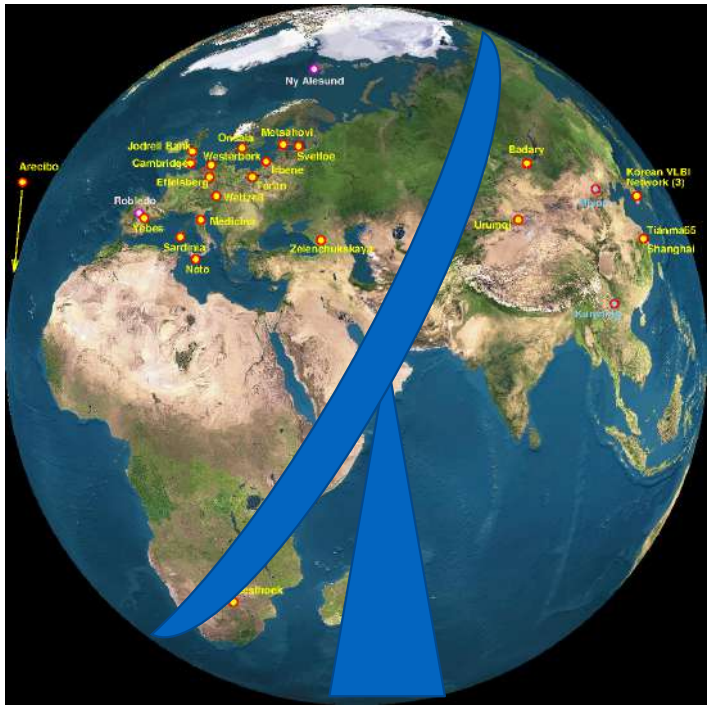
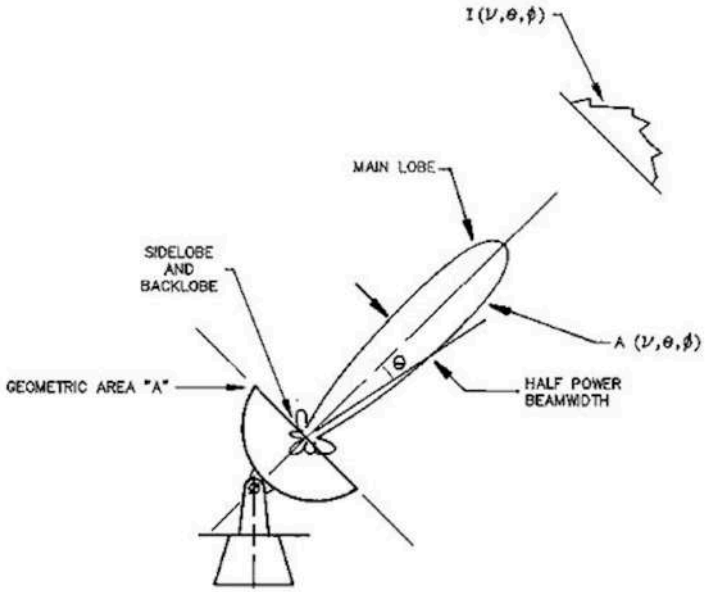
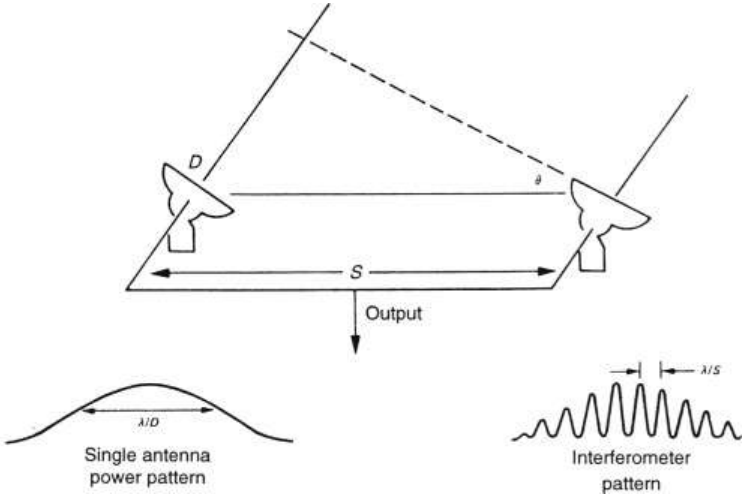
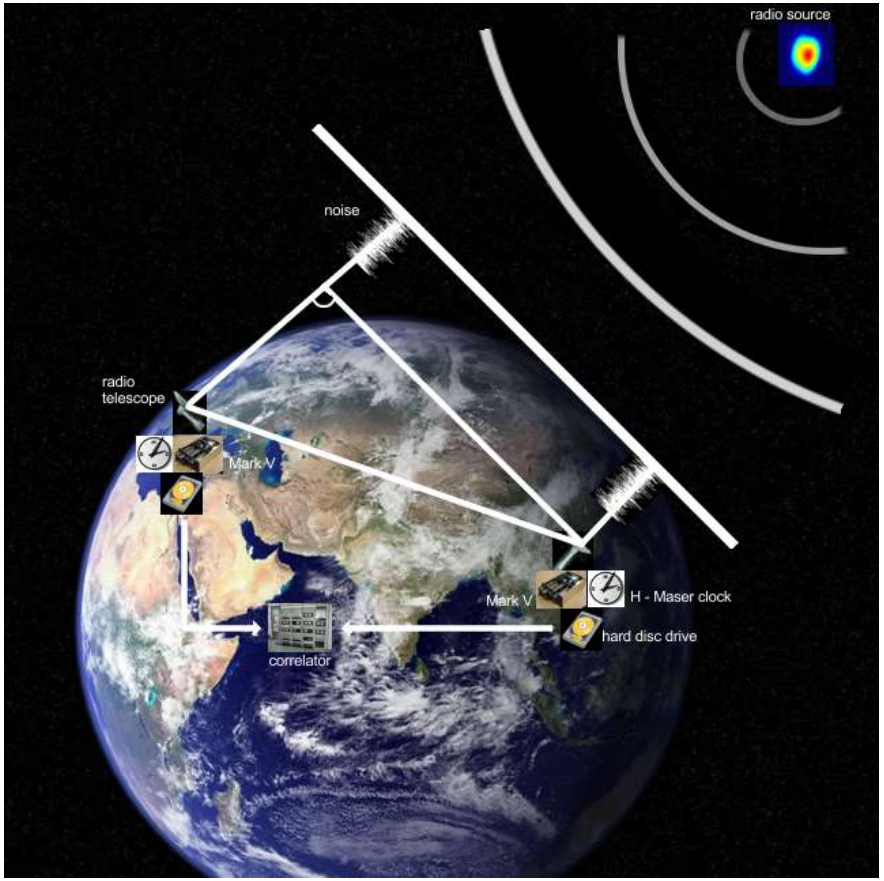


The quest for VERY HIGH angular resolution





The VLBI instrument – basic definitions (I)



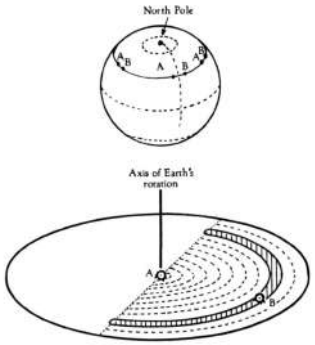
VLBI models the signal delay:

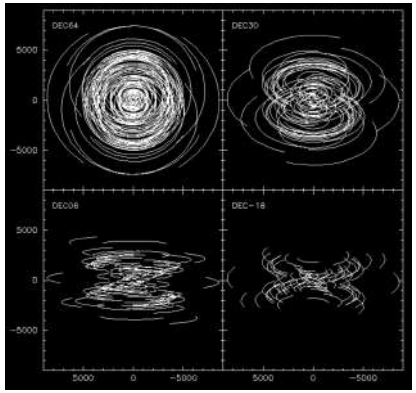
- Depends on cosmic source structure, array geometry, atmosphere (ionosphere, troposphere), instrumentation (antenna, frontends/receivers, IFs, backends, cables), etc.
- Needs very accurate clocks at each VLBI station

$$\phi_{\text{meas}} = \phi_{\text{vis}} + \phi_{\text{inst}} + \phi_{\text{pos}} + \phi_{\text{ant}} + \phi_{\text{atmos}} + \phi_{\text{ionos}}$$

and measures "visibilities":

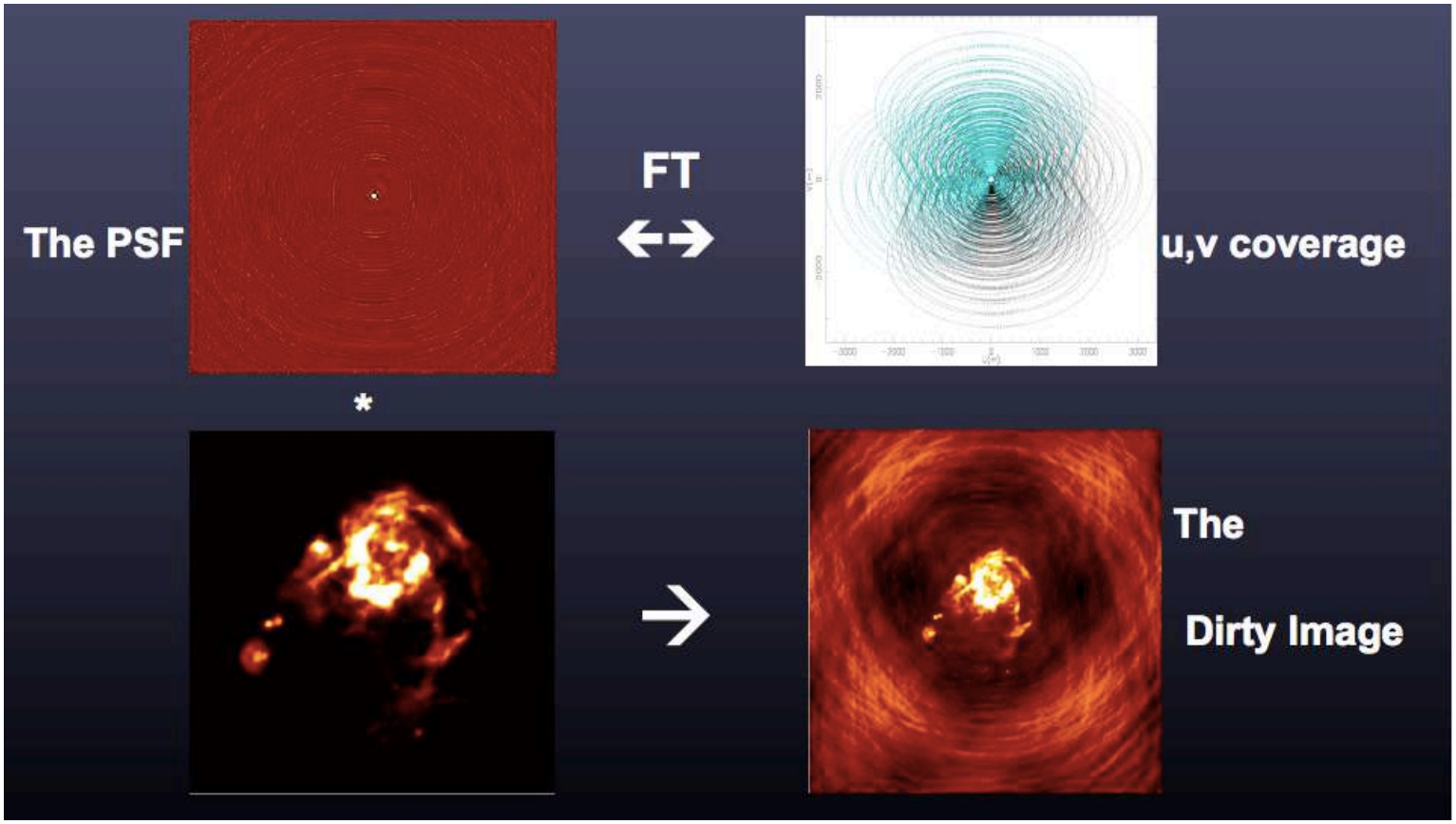
$$V_\nu(u,\mathrm{v}) = \iint I(l,m) e^{-i2\pi(ul+vm)}\, dldm \qquad I_\upsilon(l,m) \Leftrightarrow V_\upsilon(u,\mathrm{v})$$





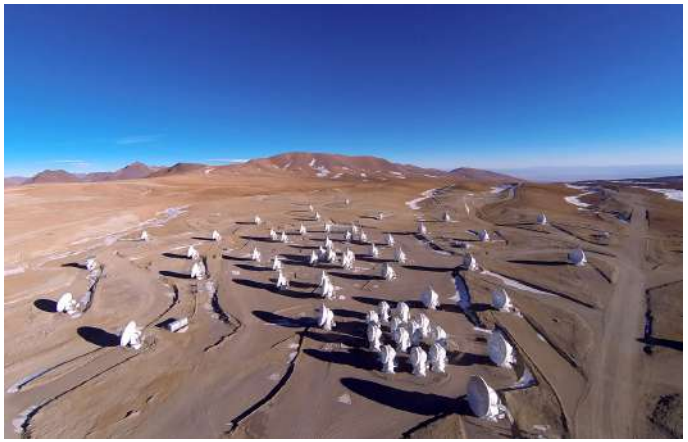
The VLBI instrument – basic definitions (2)

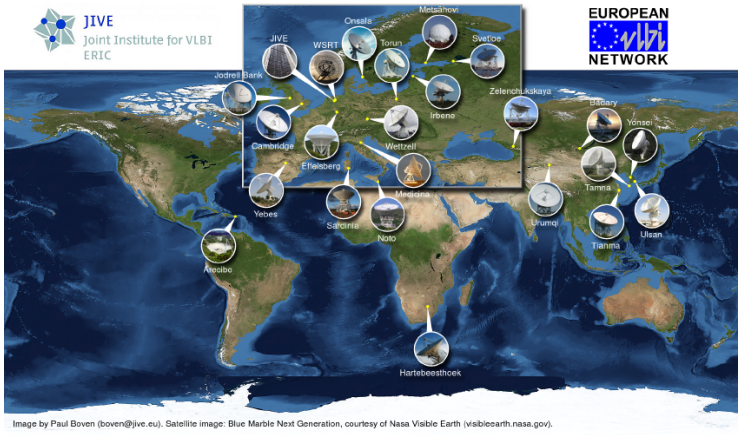
uv coverage -> Interferometer PSF or "dirty" beam -> "dirty" image



What is VLBI?

Very Long Baseline Interferometry – How long is "very long" ?





Not very long
(10^2-10^4 m)

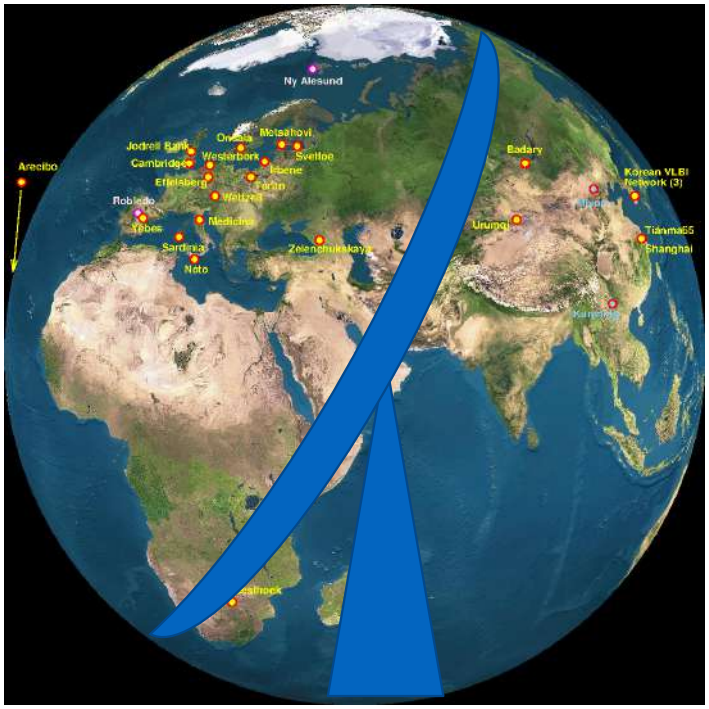
Very long
(10^5-10^7 m)

Space
(> 10^7 m)

What is VLBI?

- ***VLBI is the highest resolution astronomical technique that exists !***
- There is NO fundamental difference between VLBI and regular interferometry - only technology, convenience and convention.
- One potential (but not useful) distinction: independent antenna electronics; i.e., anything that's not "connected element".
- Angular resolution will be very high:
  - At 1.4 GHz (21cm), an array of maximum baseline 8,000 km will have a resolution of ~ 7 milli-arcseconds
  - At 43 GHz (7 mm), the same array will have a resolution of 200 microarcseconds!
  - At 230 GHz (1mm): 30 microarcseconds!
- The collecting area can also be very large so point source sensitivity can be excellent (think Arecibo + GBT + Effelsberg + FAST + ...).
- BUT: if the object is larger than your synthesized beam, emission from different regions will interfere destructively and the source will be *"resolved out"* ! So: **VLBI provides a tool to study mas-level structure in radio sources.**

VLBI networks



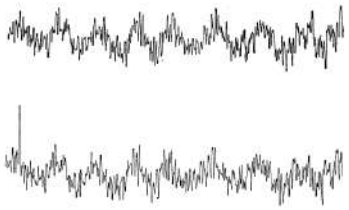
Global VLBI Alliance:

@globalvlbi

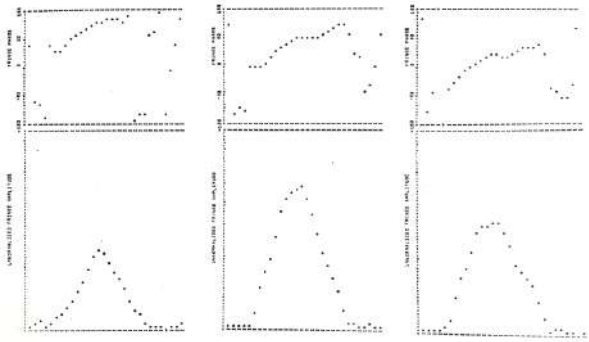
- http://www.gvlbi.org/
- https://www.iau.org/science/scientific_bodies/commissions/B4/

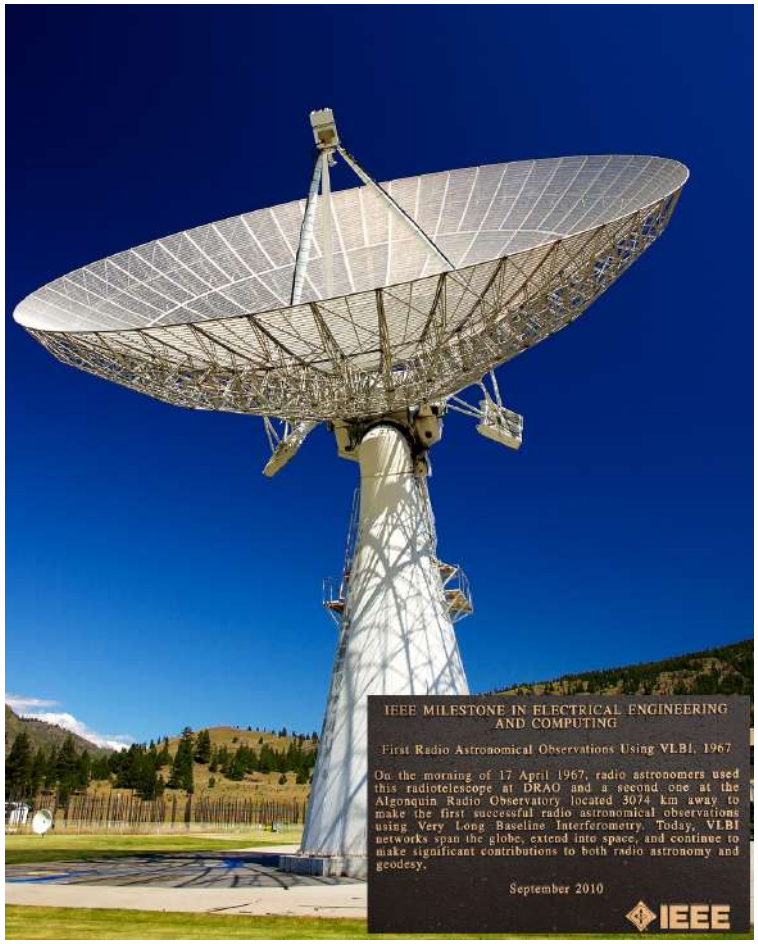
Brief history of VLBI

- VLBI fringes on 3C 294 (short baselines), technology demo (Broten et al. 1967, Science)



- VLBI detections (OH) Haystack–NRAO, observed 1967.06.08 (Moran 1968, PhD thesis, MIT)



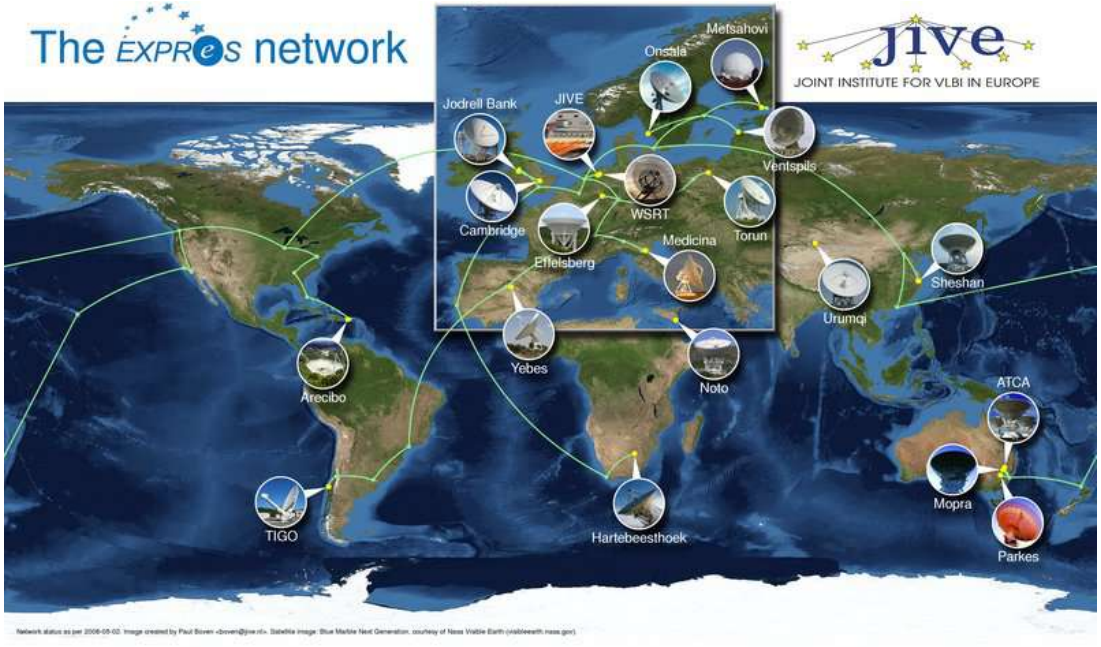


Early VLBI systems

- MKI, II, III, IV…

Modern VLBI recording systems

- MK5 and MK6, DifX, SFXC, Flexbuff, fibre…



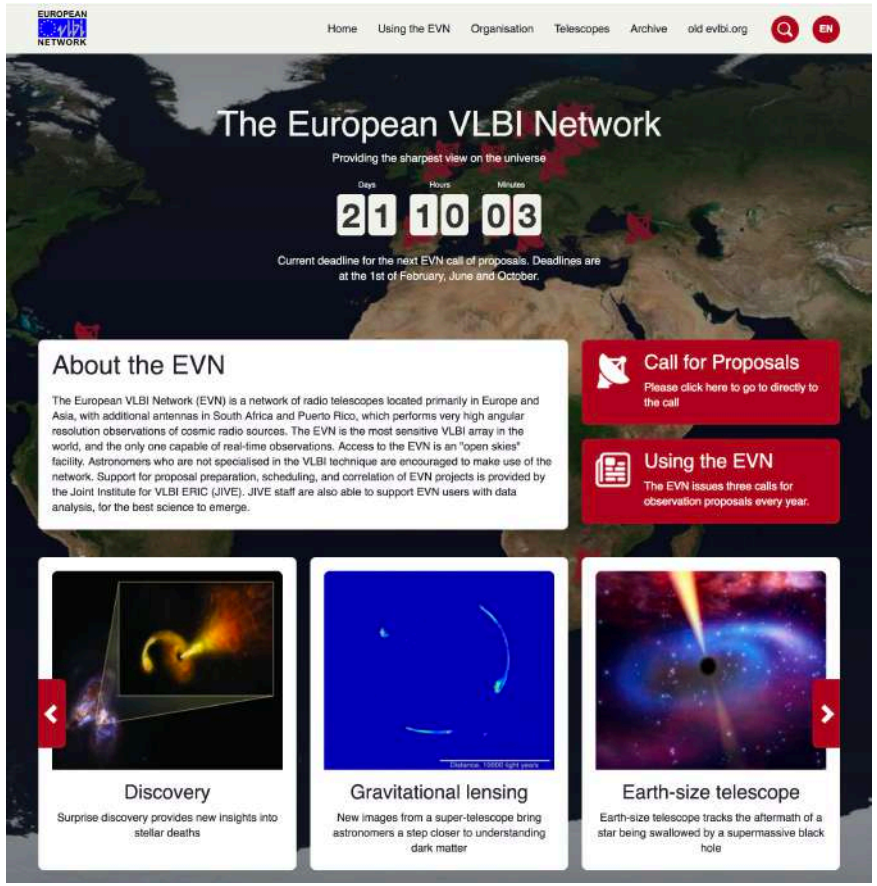
Main cm-wave VLBI networks

- The European VLBI Network (EVN) + eMERLIN
  - Joint Institute for VLBI ERIC (JIVE)
- Very Long Baseline Array (VLBA)
- Long Baseline Array (LBA)
- East Asian VLBI Network (EAVN)
  - VLBI Exploration in Radio Astronomy (VERA)
  - Korean VLBI Network (KVN)
- African VLBI Network (AVN)
- Space VLBI telescope “RadioAstron”

European VLBI Network

- Up to 22 radio telescopes, worldwide
- Operating from 1.4 GHz to 45 GHz
- Disk recording at 2 Gbps (testing 4 Gbps)
- **Real-time (eEVN)** at 2 Gbps.
- 3 sessions per year of ~3 weeks duration
- **Open Sky" policy**, based on proposal merit and technical feasibility.
  - Proposal submission by *NorthStar*
- The **Joint Institute for VLBI ERIC (JIVE)** correlates the EVN data and provides expert support to EVN users.
  - SXFC data processor

http://www.evlbi.org/



European VLBI Network

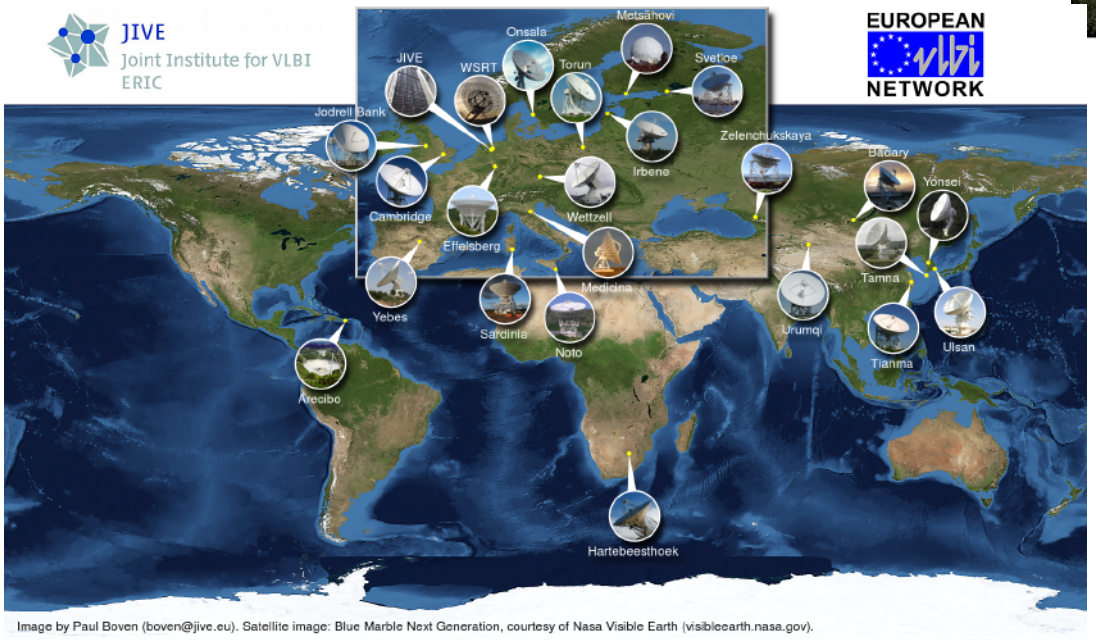
- Call for proposals to EVN: **deadlines on Feb/June/Oct 1st !**

  https://www.jive.eu/proposals *Check EVN Newsletter !*

- Proposals active for 1 year, data proprietary for 1 year*.

Effelsberg 100m (Germany)

Westerbork 14x15m (the Netherlands)



Jodrell Bank 76m (UK)

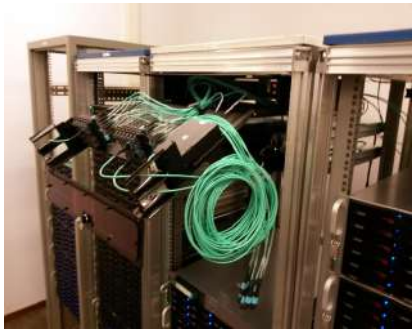
Yebes 40m (Spain)

Sardinia 64m (Italy)

Tianma 65m (China)

Joint Institute for VLBI ERIC (JIVE) - I

- An European Research Infrastructure Consortium (ERIC)
  - 7 partner countries: NL (host), FR, ES, UK, SE, LV, IT
  - 3 associated institutions: NRF (SA), MPIfR (DE), NAOC (Cn)
- Supports the European VLBI Network
  - operations
  - correlation
  - data acquisition
- Research & development
  - Software (CASA-VLBI)
  - hardware
  - e-VLBI



http://www.evlbi.org/

Joint Institute for VLBI ERIC (JIVE) - II

- Science support
- Training
- Outreach

Multi-Element Radio-Linked Interferometer (*e*-MERLIN)

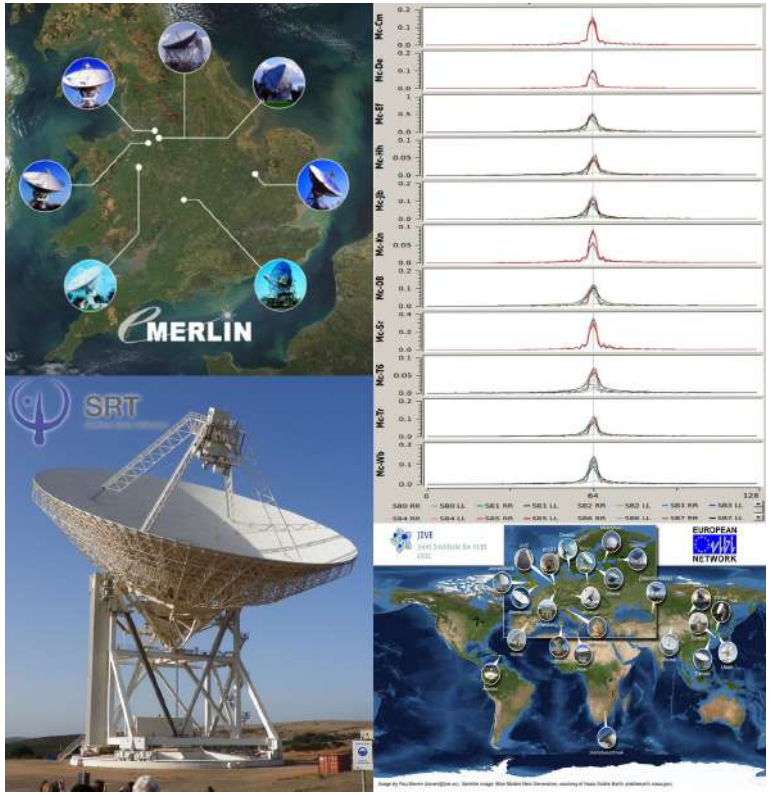
- 7 radio telescopes, including Lovell 76m @ JBO near Manchester, UK
- Network span up to 217 km
- Frequencies: 1.3-1.8 GHz, 4-8 GHz, 22-24 GHz
- Resolution of 12 mas at 22 GHz.
- Two calls for proposals per year
- Proposal submission by *NorthStar*

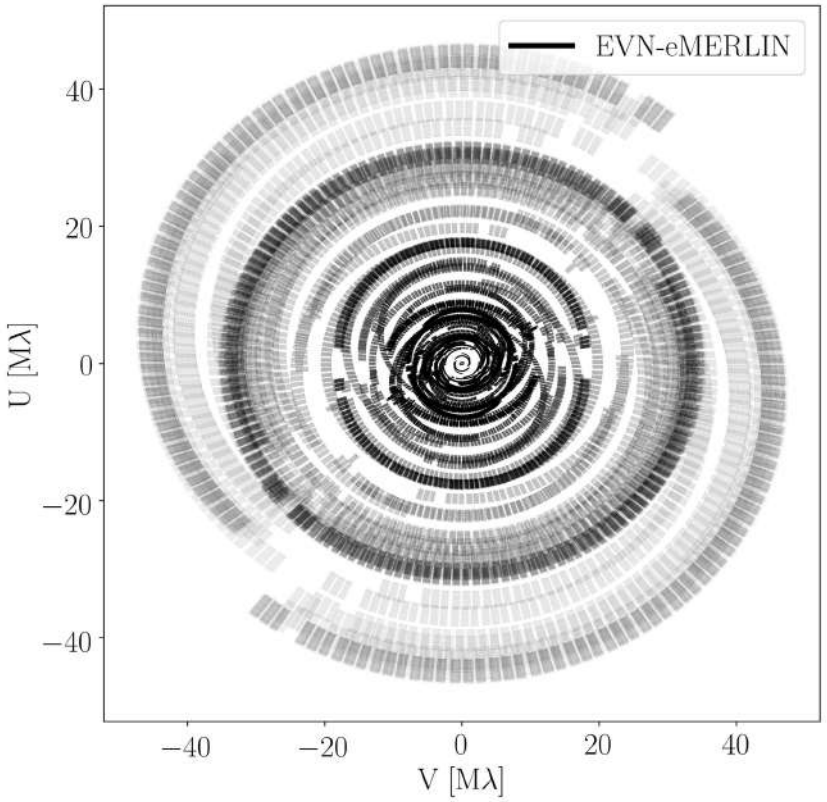
Jodrell Bank 76m (UK)

http://www.e-merlin.ac.uk/

eEVN+MERLIN

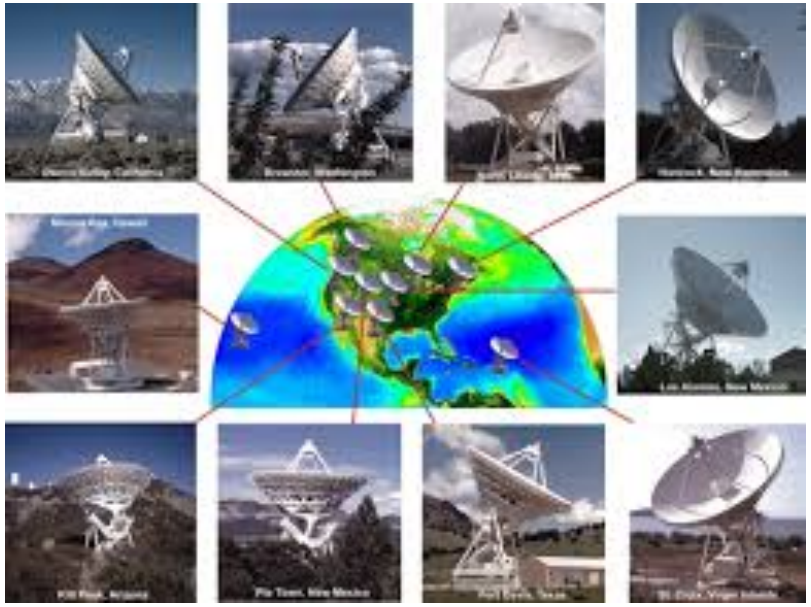
- High sensitivity, excellent uv-coverage !
- Also in real time !





Very Long Baseline Array (VLBA)

- 10 identical 25m antennas in USA
- Continuous operation (24x7)
- Dynamical scheduling
- Frequencies 1.2 to 92 GHz
- Disk recording up to 4 Gbps (MK6)

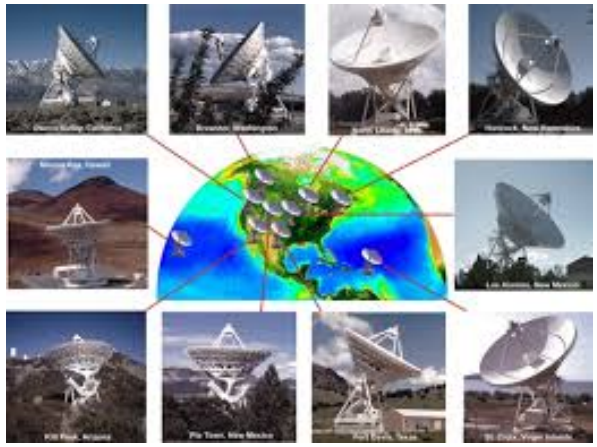


https://public.nrao.edu/telescopes/vlba/

High Sensitivity Array (HSA)

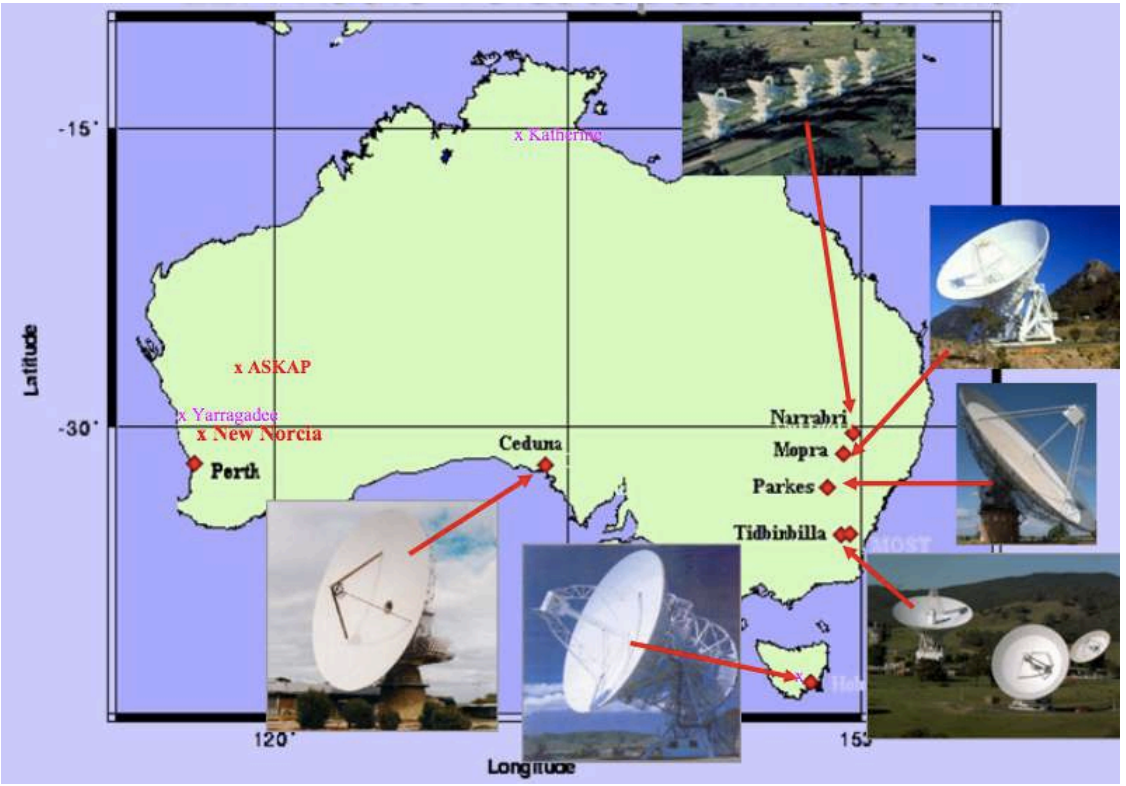
- VLBA + Phased VLA + ~~Arecibo~~ + Green Bank + Effelsberg
- HSA sensitivity is 5xVLBA
- Available 100h / 4 months
- Frequencies as VLBA (but Ar < 10 GHz)

https://science.nrao.edu/facilities/vlba/HSA



Southern Hemisphere Long Baseline Array (LBA)

- LBA utilizes the ATNF telescopes (Parkes, ATCA and Mopra), and the Hobart and Ceduna antennas operated by the University of Tasmania
- And HRAO in South Africa
- Frequencies: from 1.4 to 22 GHz
- DifX correlation
- Unique for sources at large south declinations

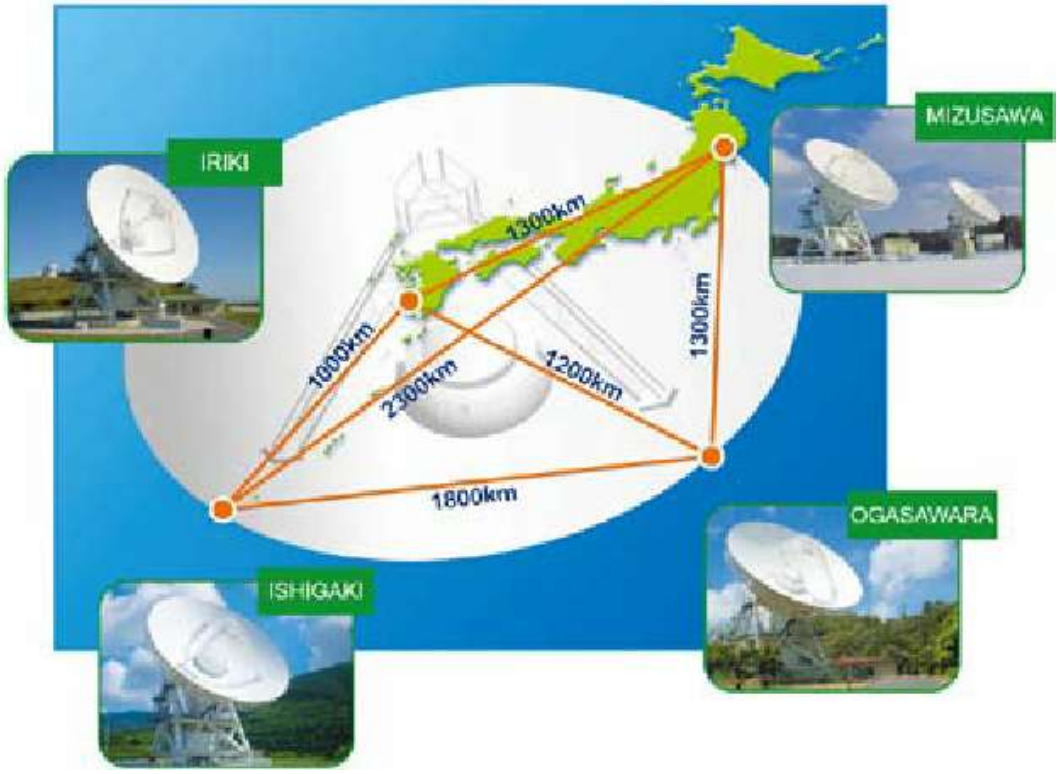


http://www.atnf.csiro.au/vlbi/

VLBI Exploration of Radio Astrometry (VERA)

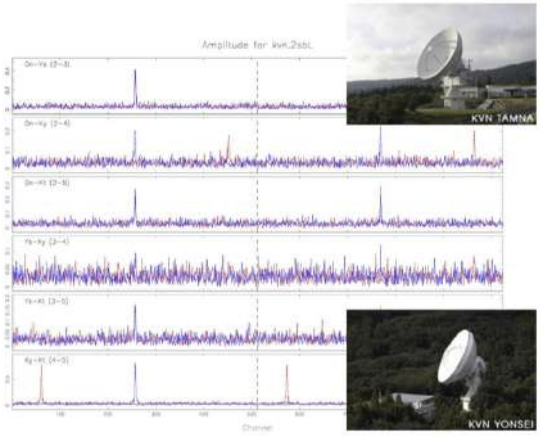
- Explores the 3-D structure of the Milky Way Galaxy based on high-precision astrometry of Galactic maser sources.
- 4 x 20m antennas in Japan, baselines up to 2000 km
- “Dual beam” unique capability
- Frequencies: K and Q bands (C)
- Recording up to 4 Gbps
- Also with Nobeyama 45m and/or NICT 34-m telescopes
- Call for proposals by semester

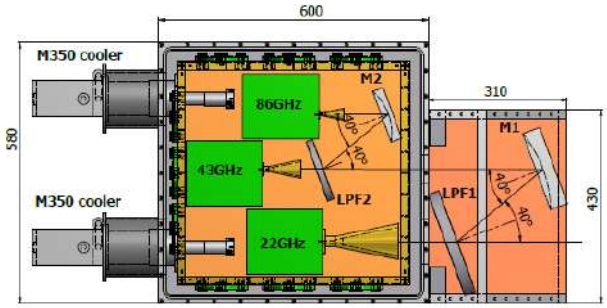
http://veraserver.mtk.nao.ac.jp/

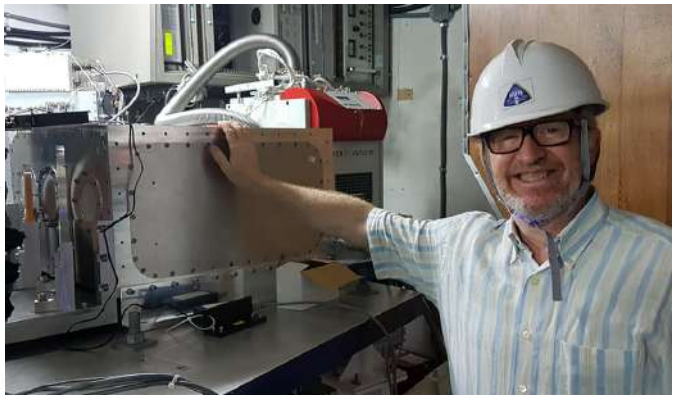


Korean VLBI Network (KVN)

- 3 x 21m stations, baselines < 500 km
- Frequencies (simultaneous):
  - K band (22 GHz)
  - Q band (43 GHz)
  - W band (86 GHz)
  - Mm band (129 GHz)
- Observes regularly with EVN
  - Development of compact KQW receiver

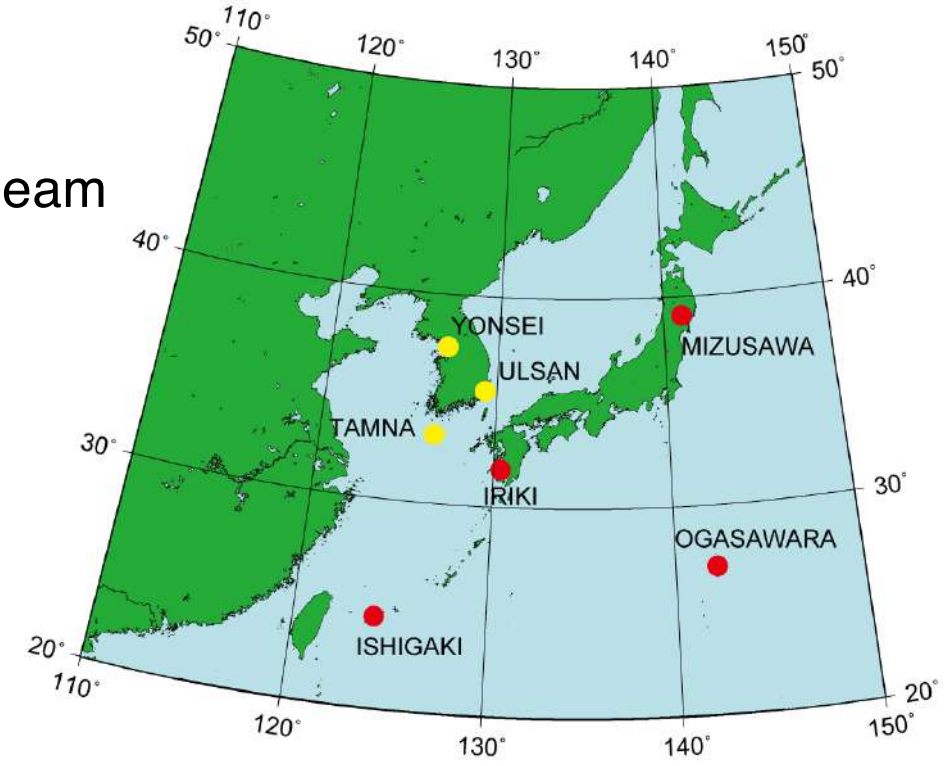






KaVa

- Joint observations of VERA + KVN since 2010
- “Open skies” at 22 and 43 GHz (but avoid conflict with KVN Large Programms)
- 500 h/yr, maximum 100h per proposal
- Combines some multi-frequency and dual beam capabilities.



http://kava.kasi.re.kr

East Asia VLBI Network (EAVN)

- Up to 21 radio telescopes (incl. 6 in China, 12 in Japan, and 3 in Korea)
- 15 telescopes for open use
- Offers 500 h (twice)/yr
- Frequencies: 22 and 43 GHz, 1 Gbps
- Yearly EAVN Scientific workshops

https://radio.kasi.re.kr/eavn/

VLBI networks comparison (I)

VLBI Network	Access	Proposals Types	Proposals tool and deadlines	Projects active period	Observing Cycles	Scheduling	Proprietary period
EVN	Open sky Scientific merit and technical feasibility	Regular (disk, e-VLBI, trigger, out-of-session & globals); ToO; Short observations Joint observations for global VLBI	EVN NorthStar February, June & October ToO & short (and manual triggers) any time by e-mail to PC chair	1 year (9m automatically triggered e-VLBI projects)	3 observing sessions (3-4 weeks each) 10 e-VLBI sessions (24h each) 10 out-of-session (144h/yr)	Fixed dates Dynamic for automatically triggered e-VLBI, 10min response	1 year from data release ToO 6 months
EAVN	Open-use on share-risk basis Scientific merit and technical feasibility	Regular, Large Projects, ToO (trigger and DDT)	EAVN website in latex format June & November	1 year for triggers	2 semesters: (500h/yr) A=mid-Jan / mid-Jun B=Sep/mid-Jan	Fixed dates	18 months from data release Raw data deleted 1 month after correlation

VLBI networks comparison (II)

VLBI Network	Access	Proposals Types	Proposals tool and deadlines	Projects active period	Observing Cycles	Scheduling	Proprietary period
VLBA	50% open sky Scientific merit and technical feasibility GBT time and VLA time very limited, well justified.	Regular; Large; Triggered; Directors' Discretionary Time (DDT, 5% of total) for a ToO or Exploratory Time Joint programmes with XMM, Chandra, FERMI, Swift and HST	NRAO PST or EVN NorthStar for VLBI Global February & August DDT any time using PST	1 year	2 semesters: A=Feb/end-Jul B=Aug/end-Jan	Dynamic Fixed dates for Global VLBI	1 year from last observation ToO 6 months

VLBI networks comparison (III)

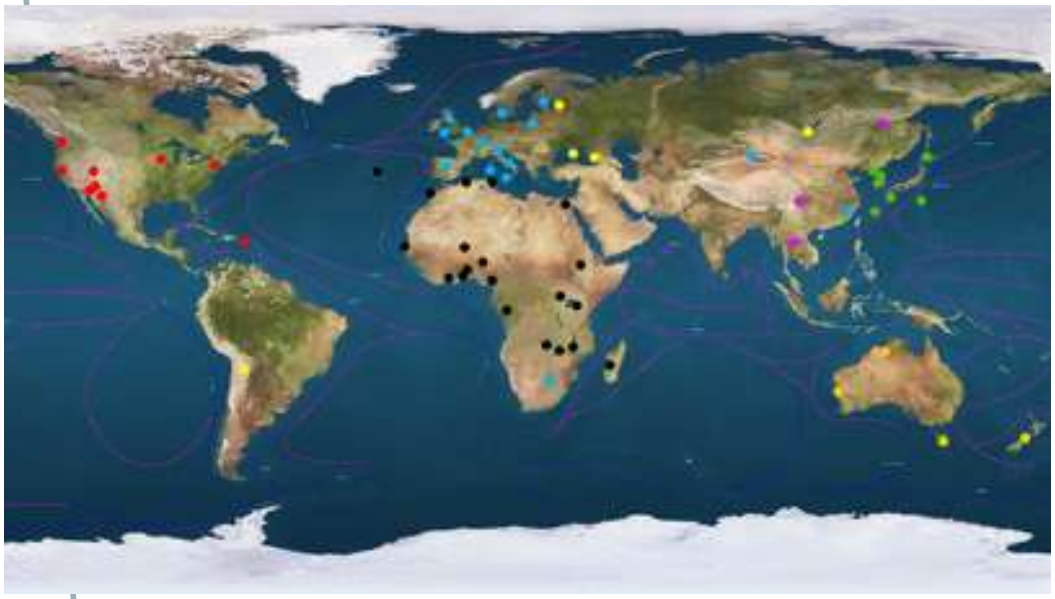
VLBI Network	Access	Proposals Types	Proposals tool and deadlines	Projects active period	Observing Cycles	Scheduling	Proprietary period
LBA	Open sky but limited number of VLBI sessions (plus ATCA & Parkes private projects) Scientific merit and technical feasibility	Standard; Time critical (ToO and triggered NAPA); Director's time	ATNF OPAL Mid-Dec & Mid-June ToO (and Director's) any time by e-mail to ATNF Alert group	1 year	2 semesters: (21 days/yr) I=Apr/end-Sep II=Oct/end-Mar	Fixed dates For ToO and NAPA no fast response Time lost due to overrides or failures to be replaced	18 months ToO additional rules: publish results 1 week after observation to retain data rights Approved proposals coversheet and targets list made public

D10.2 - Operational plan for inclusion of SKA in Global VLBI

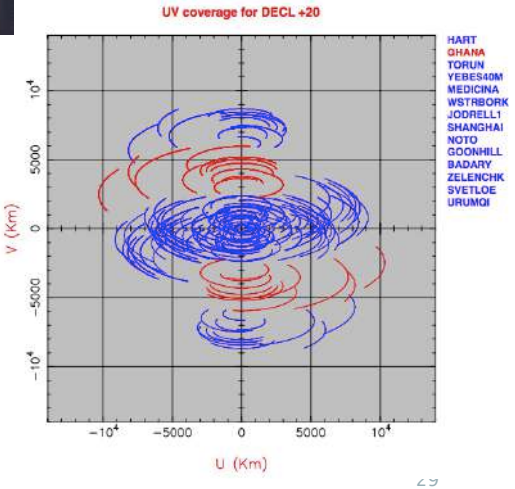
http://jumping.jive.eu/exec/d10.2.pdf

African VLBI Network (AVN)

- Many training activities (DARA, JUMPING JIVE)
- Ghana Radio Astronomical Observatory first VLBI in 2017.



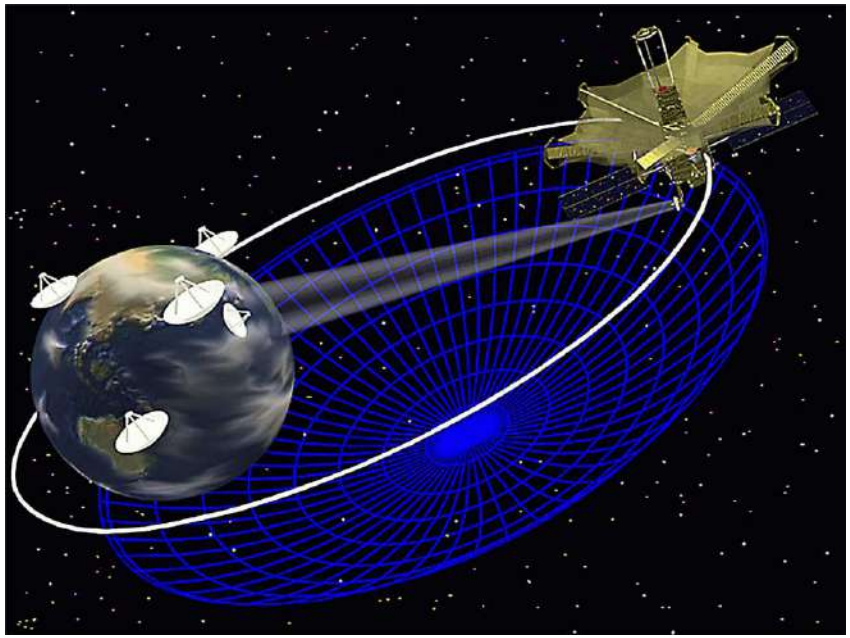
DARA
DEVELOPMENT IN AFRICA WITH RADIO ASTRONOMY



https://www.ska.ac.za/science-engineering/avn/

Space VLBI telescope “RadioAstron”

- Launched in 2011, and operational till January 2019.
- Baseline extends up to 300.000 km ! But imaging is limited.
- Frequencies: 18 and 5 GHz (22 GHz failed)
- World-wide co-observing with ground stations



Assembling of the SRT at Pushchino, December 2003

http://www.asc.rssi.ru/radioastron/

VLBI at other frequencies / fields

- Global Millimeter VLBI Array (GMVA)
- Event Horizon Telescope (EHT)
- International LOFAR Telescope (ILT)

- VLBI with the Square Kilometer Array (SKA-VLBI)

- International VLBI Service for Geodesy and Astrometry (IVS)

- Towards a “Global VLBI Alliance”

Global Millimeter VLBI Array (GMVA)

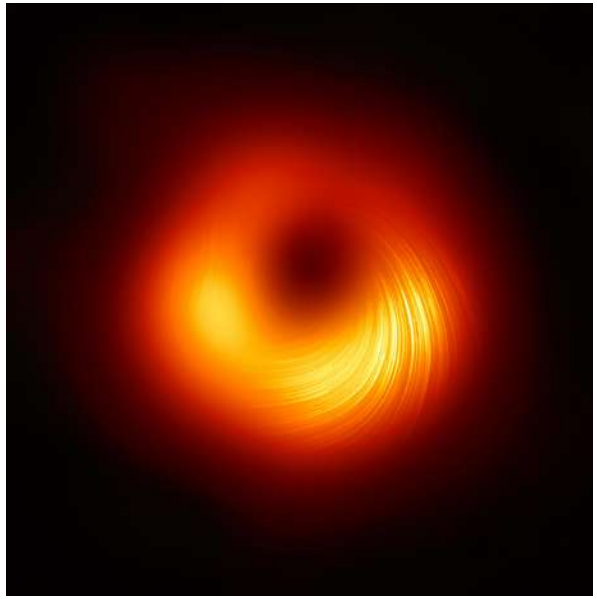
- Operates at 3mm wavelength (86 GHz)
- High resolution (45 μas)
- High sensitivity
- Operates twice per year (april/october)
- Proposal deadlines on Feb 1 / Aug 1, reviewed by NRAO and participant stns
- Correlation at MPIfR (Bonn)

https://www3.mpifr-bonn.mpg.de/div/vlbi/globalmm/

Event Horizon Telescope (project)

- International collaboration
- Operates at 230/345 GHz
- Up to 64 Gbps
- One observing campaign per year

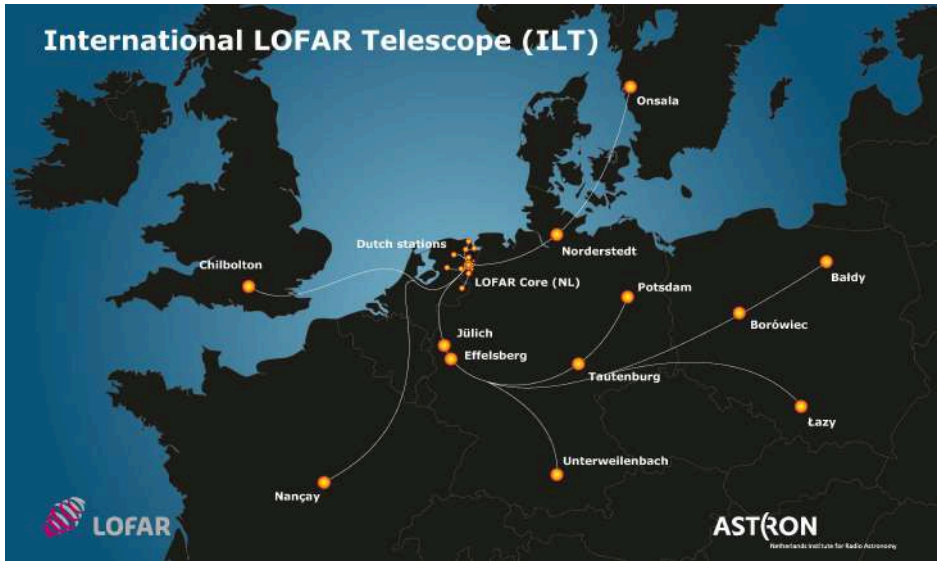
- Produced the first-ever image of the environment around a supermassive black hole, in M87
- Other results are expected (e.g. Sgr A*)

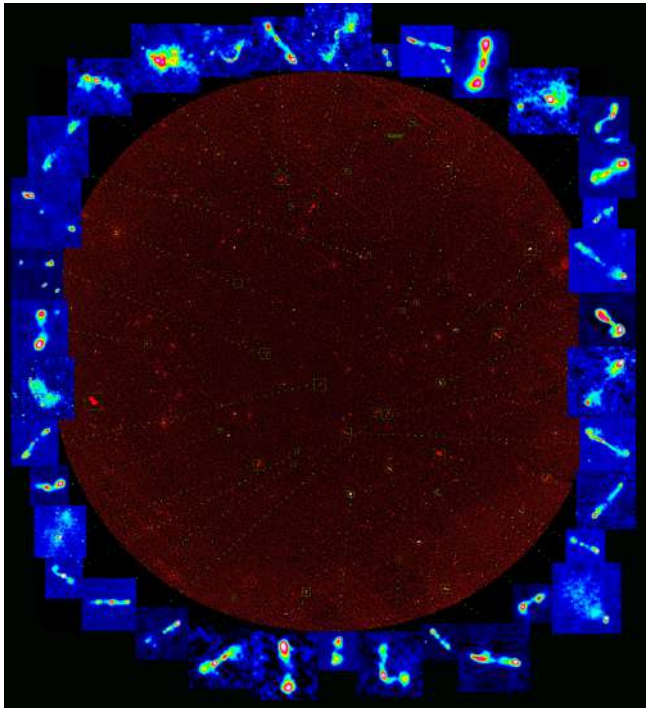


https://eventhorizontelescope.org/

The International LOFAR Telescope (ILT)

- LOw Frequency ARray (LOFAR) developed by consortium led by ASTRON (NL)
- Real time instrument, LBA: 10 - 90 MHz, HBA: 110 - 250 MHz
- Applications in astronomy, geosciences, agriculture, space weather…
- Synergies with EVN

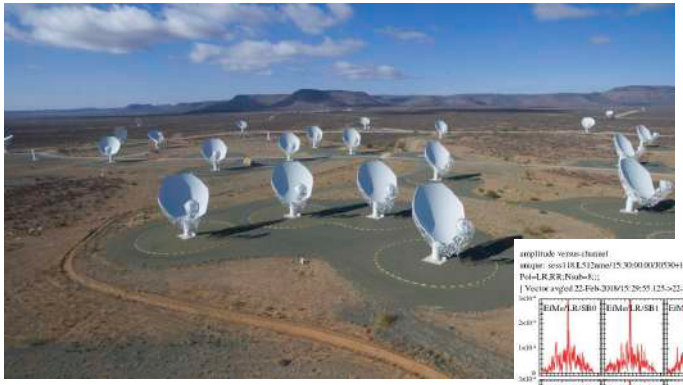


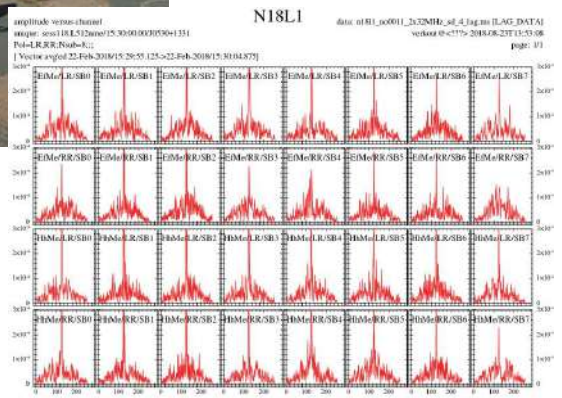


https://www.astron.nl/telescopes/lofar/

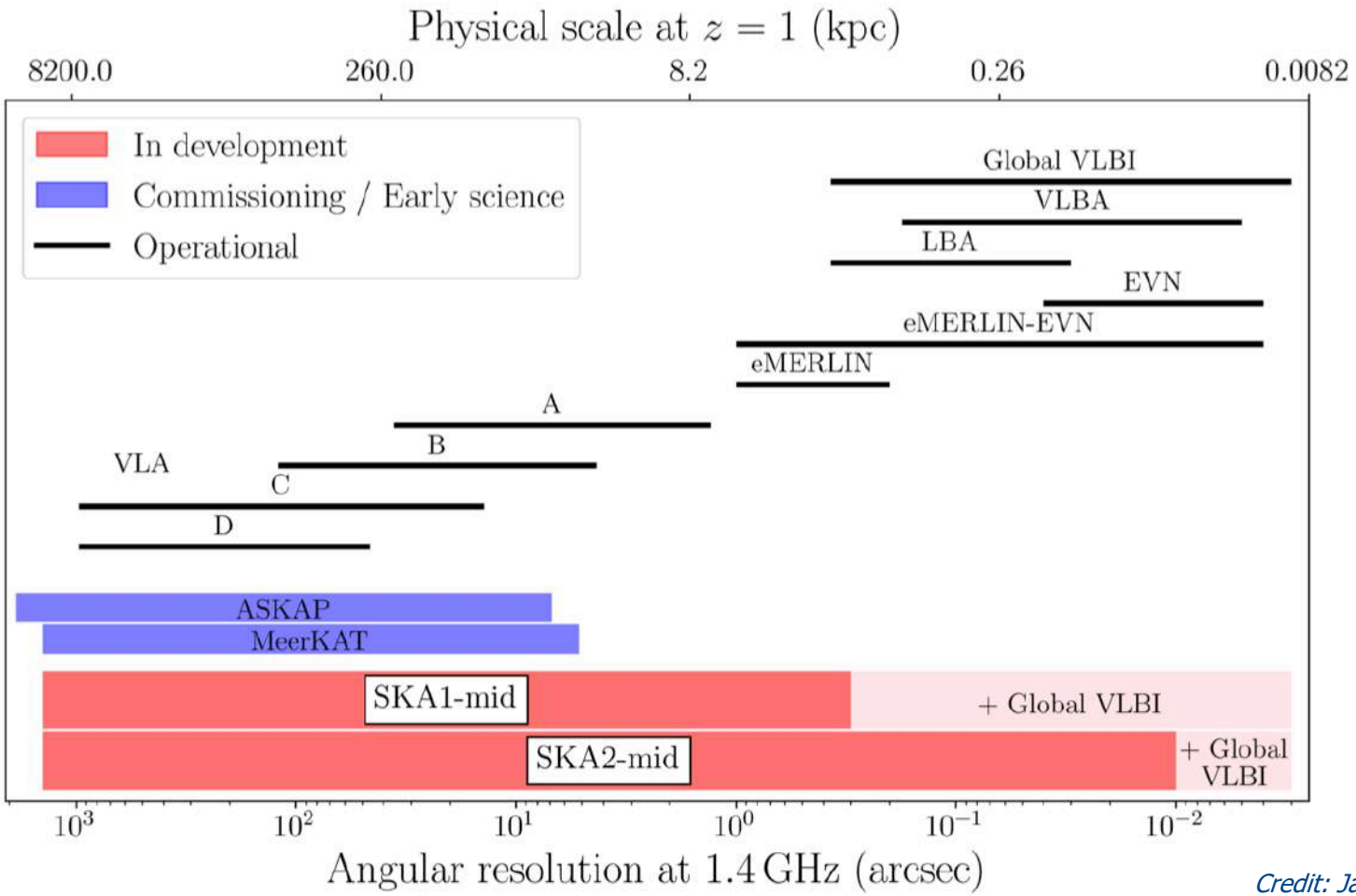
SKA-VLBI

- The Square Kilometer Array (SKA) will be built in two phases.
- SKA-1 is 10% of the full SKA, and will lack very long baselines, which are provided by VLBI.
- Preliminary tests with SKA-MID pathfinder MeerKAT





Complementarity of instruments



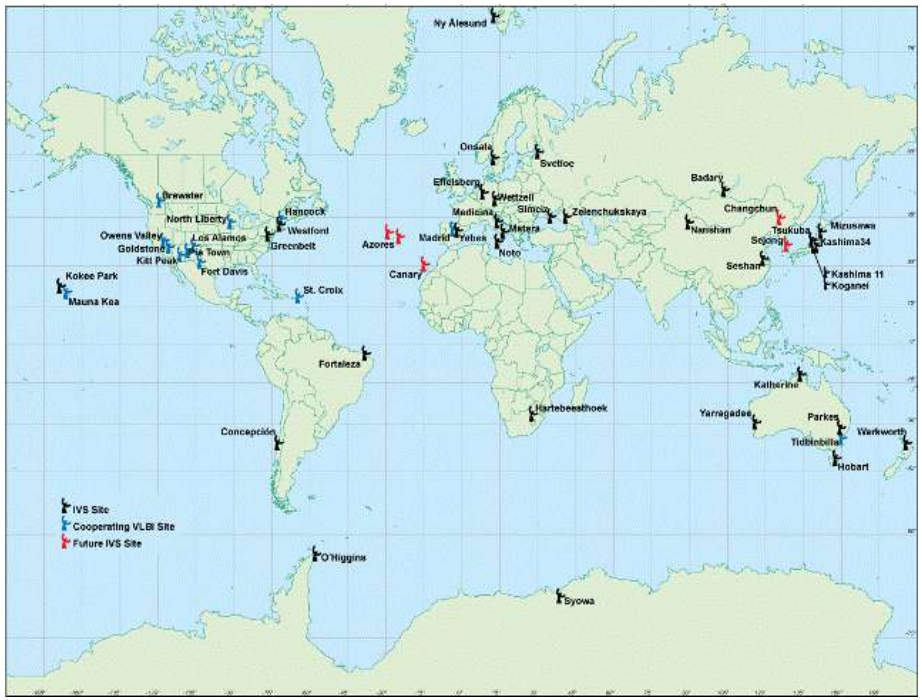
Credit: Jack Radcliffe

International VLBI Service (IVS) for Geodesy and Astrometry

- International collaboration provides a ***service*** to support geodetic, geophysical, and astrometric research and operational activities.

- Provides data and products such as a terrestrial reference frame (TRF), the international celestial reference frame (ICRF), and Earth orientation parameters (EOP).
  - **All IVS data and products are archived and publically available.**

- Essential to measure UT1.



https://ivscc.gsfc.nasa.gov/ and https://vlbi.org/

The “Global VLBI Alliance”

Global VLBI Alliance:

@globalvlbi

- http://www.gvlbi.org/
- https://www.iau.org/science/scientific_bodies/commissions/B4/

Contact

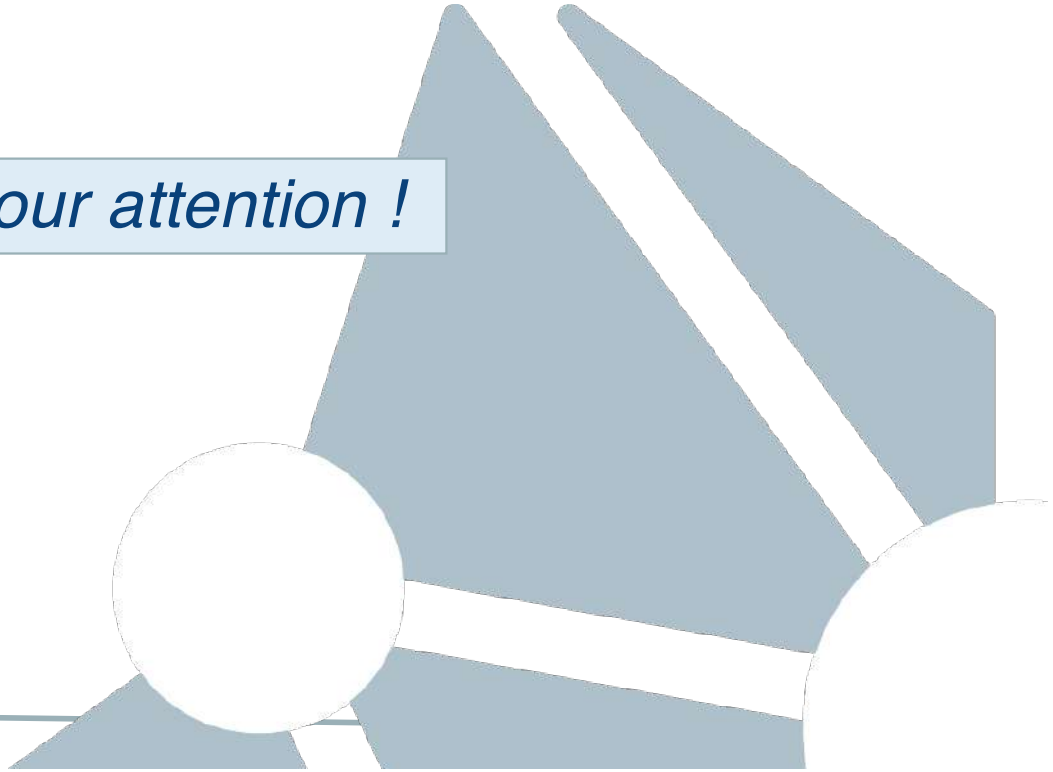
colomer@jive.eu

www.jive.eu

@jivevlbi / @jivedirector

@JIVERIC

Thank you for your attention !



Some important VLBI-related events

- Scientific conferences
  - Symposium of the European VLBI Network and users' meeting
  - East Asian VLBI workshop (EAVW)
  - Young European Radio Astronomers Conference (YERAC)
  - IVS General Meeting
- Technology meetings
  - EVN Technical Operations Group (TOG)
  - IVS Technical Operations Workshop (TOW)
- Schools
  - European Radio Interferometry School (ERIS)
  - NRAO Synthesis Imaging Workshop
  - IVS training school