Euro-African cooperation in radio astronomy as seen from space: evolution toward SKA and beyond

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JIVE
JOINT INSTITUTE FOR VLBI IN EUROPE

TU Delft

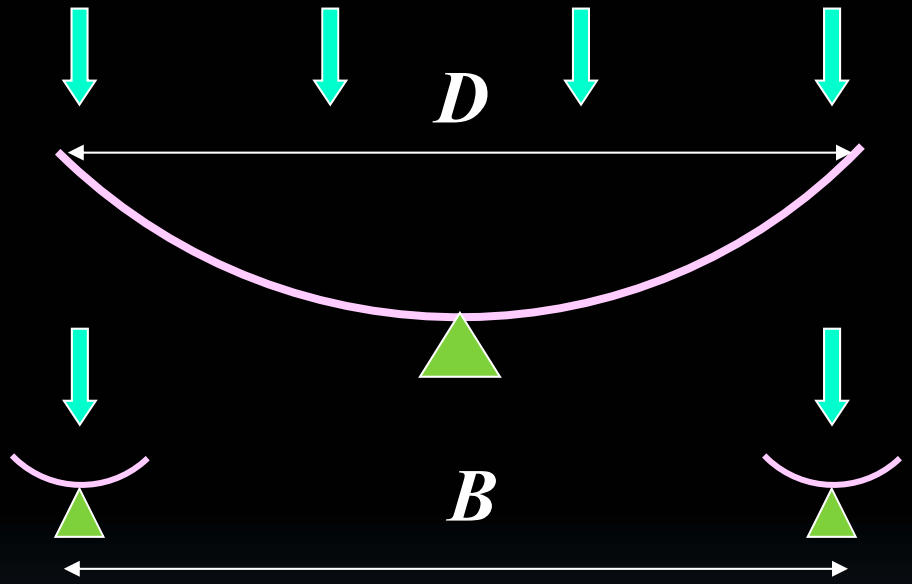
Why radio astronomy?

?

Dr. X.Y. *******
A former postdoc at MeerKAT,
awarded for *********

Radio interferometry: a one-slide tutorial

- Michelson & Young, 1890's: measurements of stars' diametres
- Synthesis of large apertures *(by poor and curious people)*



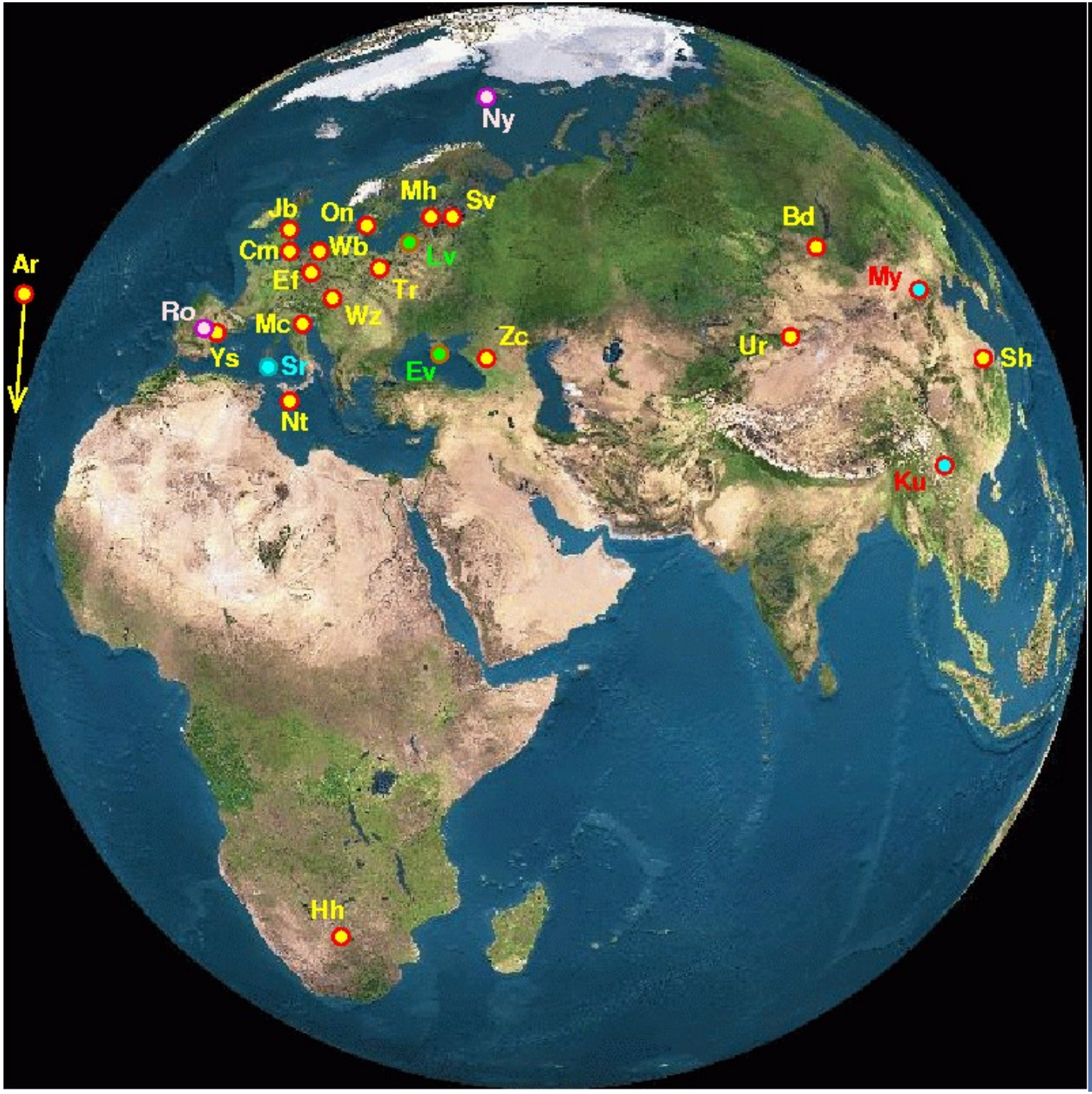
$$\vartheta = \frac{\lambda}{D}$$

Large aperture –
high sensitivity

$$\vartheta = \frac{\lambda}{B}$$

Large size –
high angular resolution

Very Long Baseline Interferometry (VLBI) - the ultimate angular resolution
- baselines up to 10,000 km



EUROPEAN VLBI NETWORK

Arguably, the most sensitive and "sharpest" VLBI network in the world

Delivers cutting-edge science

Open to world-wide users community

EVN today

- EVN consortium with 20+ radio telescopes
  - *Ef, Mc, On, Jb, Nt, Tr, Wb, Sh, Ur, Hh, Ar, Mh, Ys, Sv, Ro, Ku, My, Wz, Sm, Ny, Ka*
  - Ran by 14 different organisations
  - And 12 more antennas for "Globals" with NRAO

Widely international

- Covering range of frequencies
  - Workhorse frequencies 18, 6 cm,
  - Also available: 13, 5, 3.4, 1.3 cm
  - And at limited stations 90, 21, ~30, 50, 2, 0.7 cm

Covers two decades in wavelengths

- Reaching milliarcsecond (mas) angular resolutions
  - From 15 mas for 1.6 GHz EVN (can add MERLIN for brightness sensitivity)
  - To 1 mas at 5 GHz with Asian, African or American baselines

Offers sharpest view at the Universe

- Sensitivity of 5μJy in 8 hr at 1.6 GHz
  - Combination of Big Antennas and 1 Gbps bandwidth
  - Big antennas also vital for spectroscopy (mJy sensitivity)

Superb sensitivity

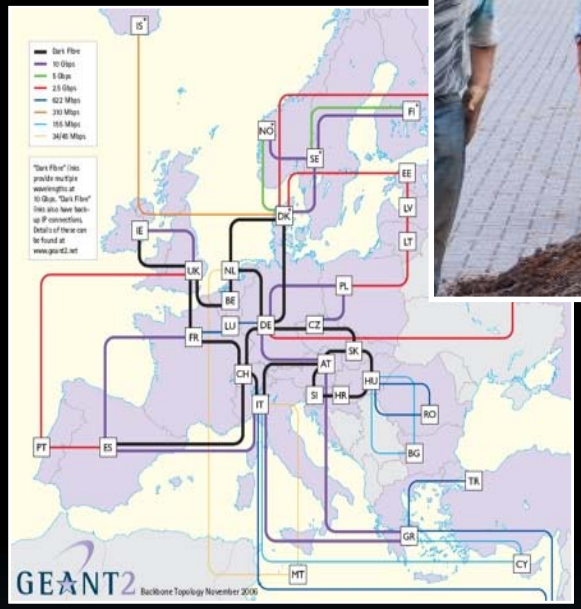
- Operational approximately 60 days/year
  - 3 sessions augmented with e-VLBI once a month

Co-exists with "domestic" operations

JIVE: the heart of EVN

From recording to real-time VLBI: e-VLBI

- In line with ICT developments
- Boosted with EC FP6 EXPReS
  - *…and now continues with FP7 NEXPReS*
  - *Help solve last mile problem at telescopes*
  - *Work with NRENs on robust connectivity*
  - *Push to 1 Gb/s/telescope and beyond*
  - *Transition from EVN to e-EVN*
- Now an operational facility
  - *Guaranteed 10 x 24 h per year*
  - *Flexible ways to get into e-VLBI*
  - *Request e-VLBI for fast response*
  - *Or for triggered proposals*
  - *Short requests <2hr*
  - *Targets of Opportunities*
  - *Produces excellent science!*
- e-EVN – an SKA pathfinder

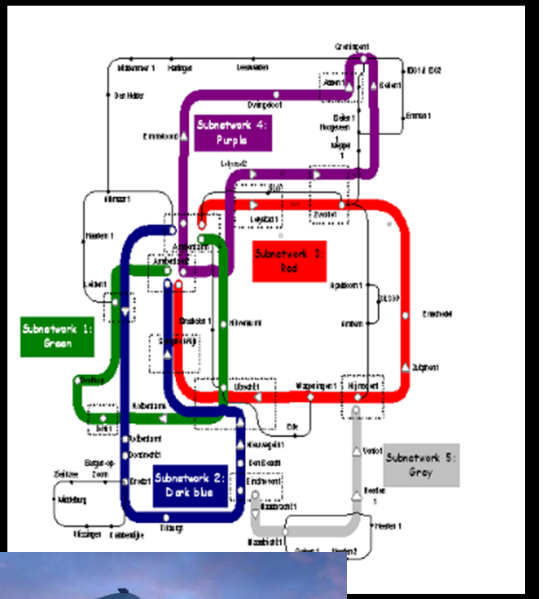


EXPReS

Express Production Real-time e-VLBI Service

e-VLBI: further progress

- **EC FP7 NEXPReS**
  - ***Novel EXplorations Pushing Robust e-VLBI Services***
  - Implementation since 2010
  - Focus at operations

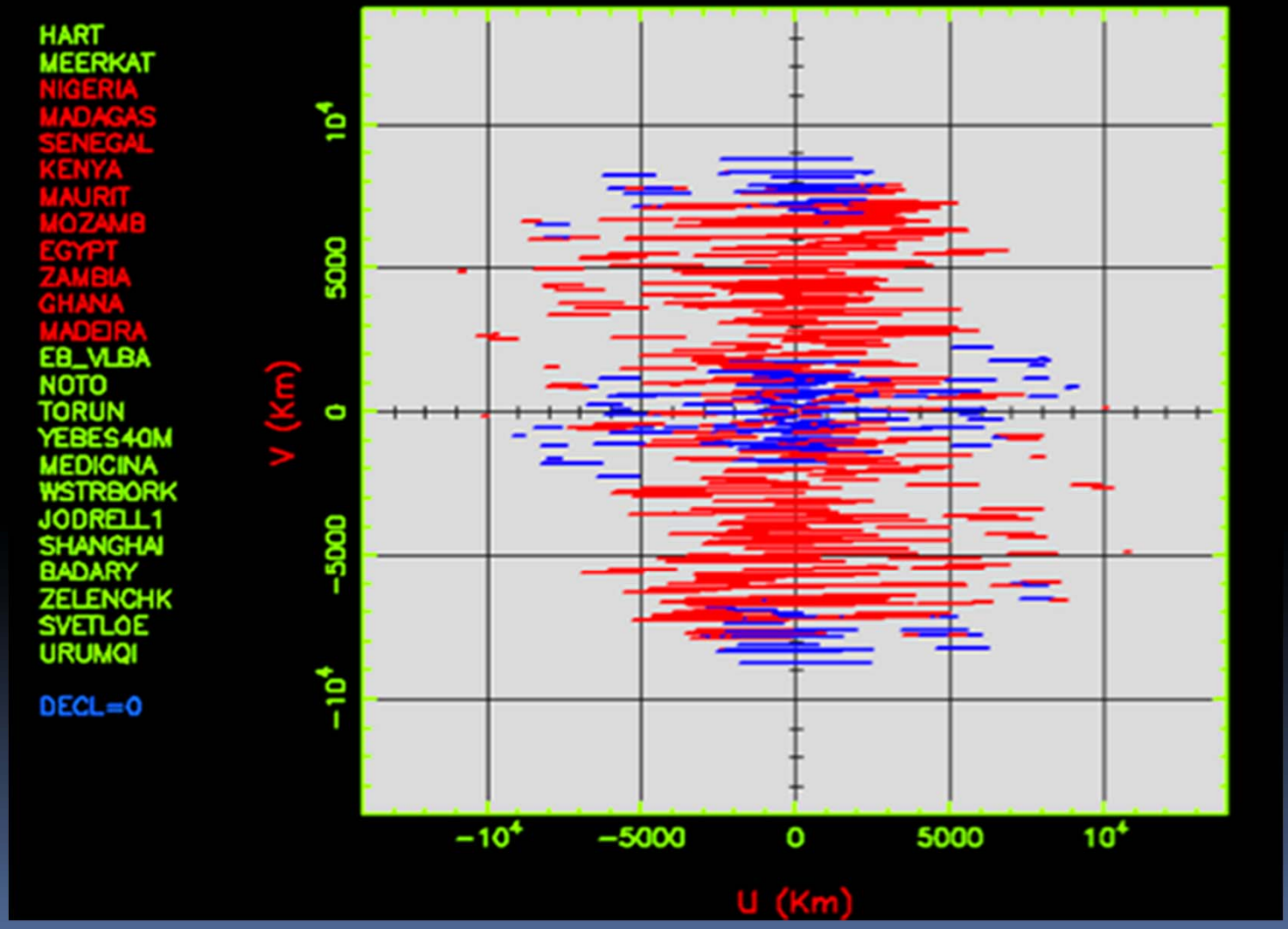


- Connectivity is more robust than shipping – ***the case for Africa***?

- Impressive 1 Gbps e-VLBI with HartRAO (2010, after the telescope repair)
- Next challenge: e-distribution of ultra-stable clock signal
- ***All the above: highly relevant for the SKA***

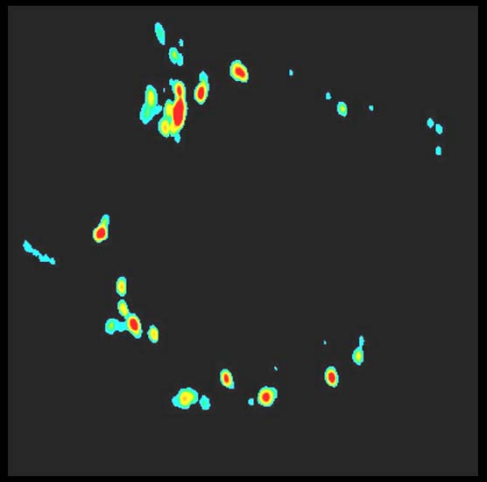
EVN + African VLBI Array: *fantastic!*

uv-Coverage: decl = 0° with Africa Array + EVN

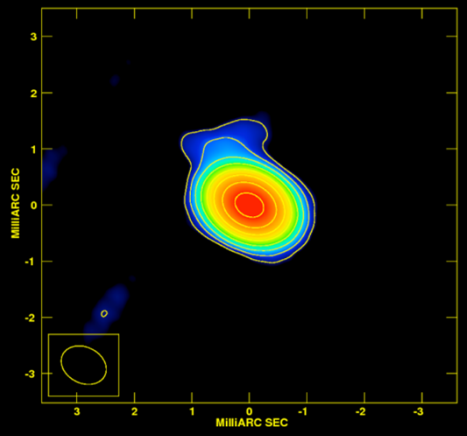


EVN image gallery

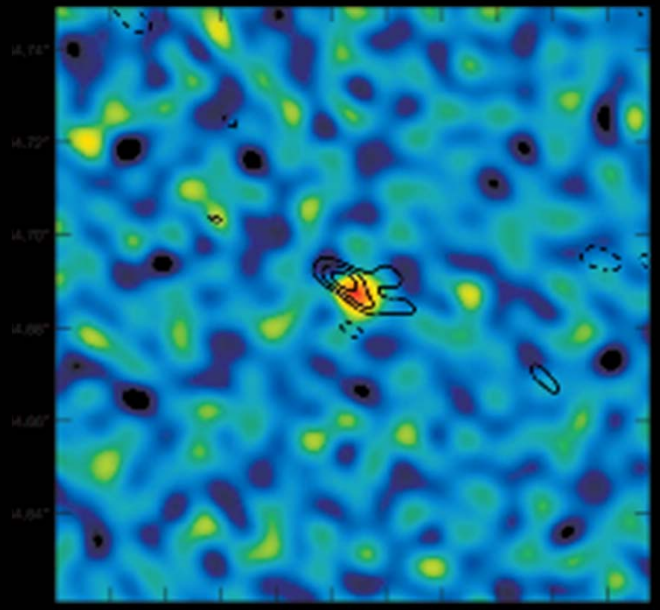
Methanol maser ring in G23.657-0.127 Bartkiewicz et al. 2005



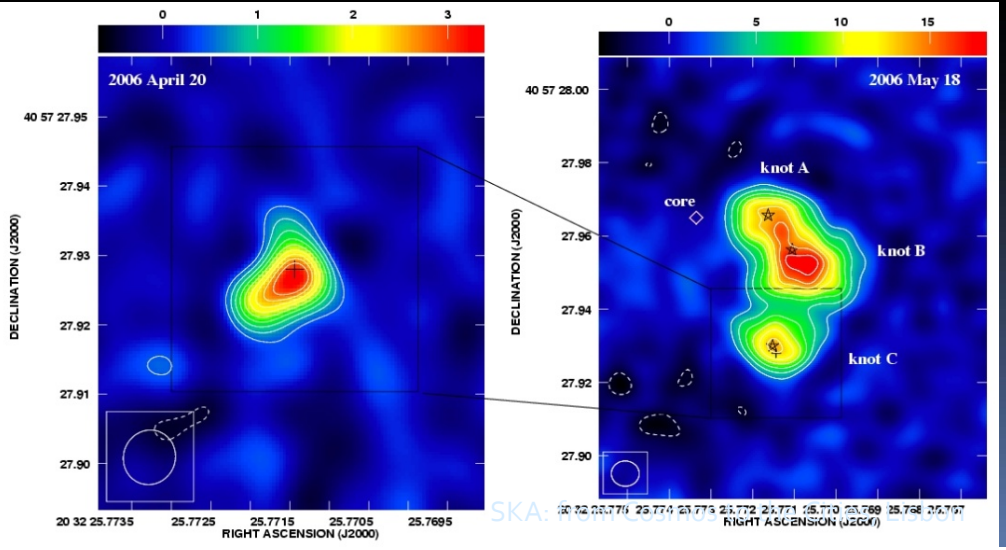
First Fermi-detected narrow-line AGN, Giroletti et bal. 2011

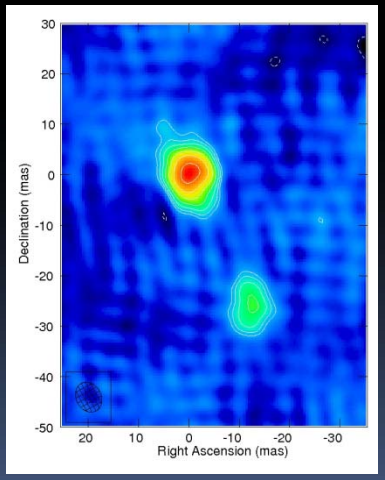


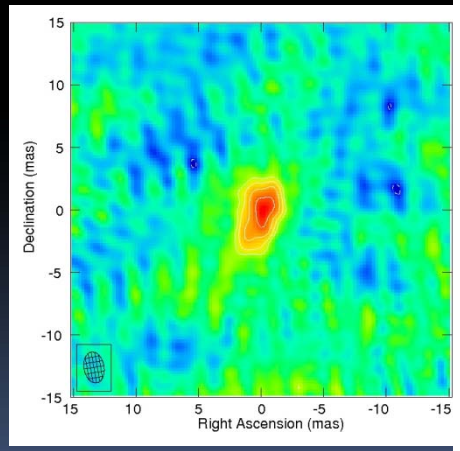
SN2007gr, Paragi et al., 2010 Nature, 463 516



e-VLBI images of Cygnus X-3, Tudose et al. 2007





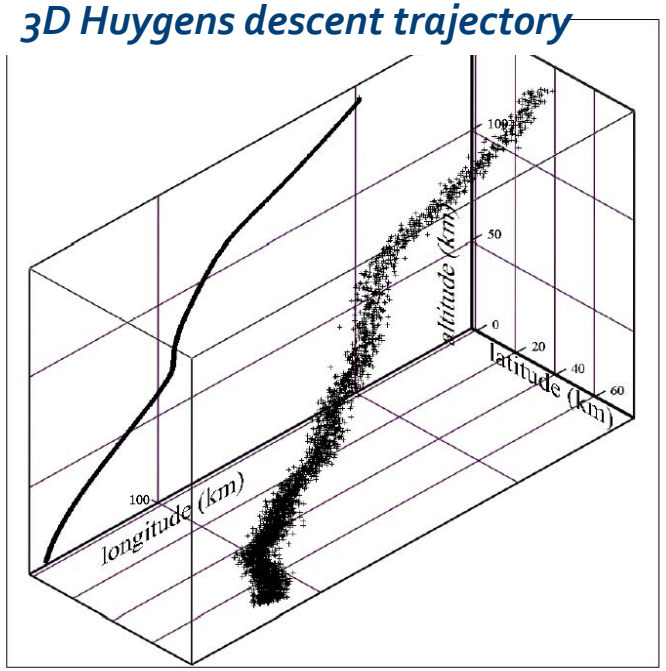


"Baby quasar" J1427+3312 near the edge of the visible Universe, Frey et al. 2008

Huygens VLBI heritage: 20 photons/dish/s

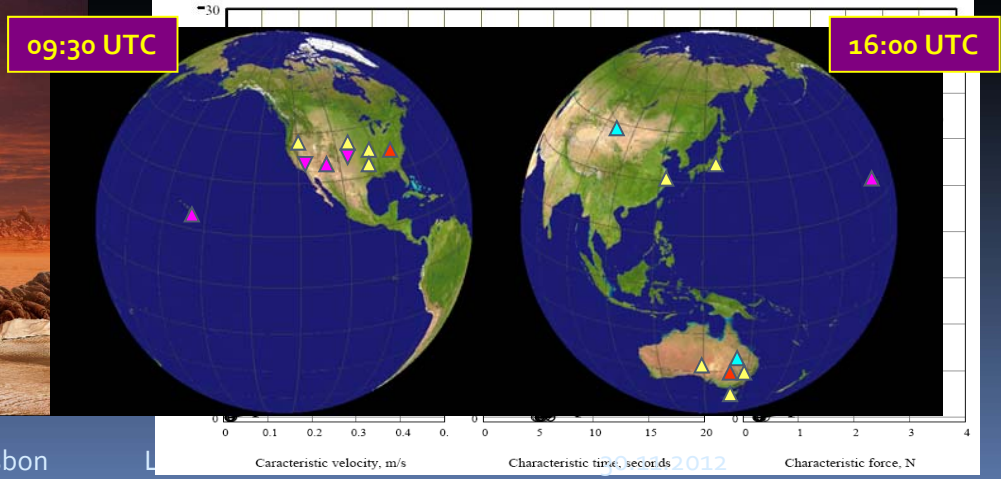
- Ad hoc use of the Huygens “uplink” carrier signal at 2040 MHz
- Utilised 17 Earth-based radio telescopes
- Non-optimal parameters of the experiment (not planned originally)
- Achieved 1 km accuracy of Probe’s descent trajectory determination
- Assisted in achieving one of main science goals of the mission – vertical wind profile

3D Huygens descent trajectory

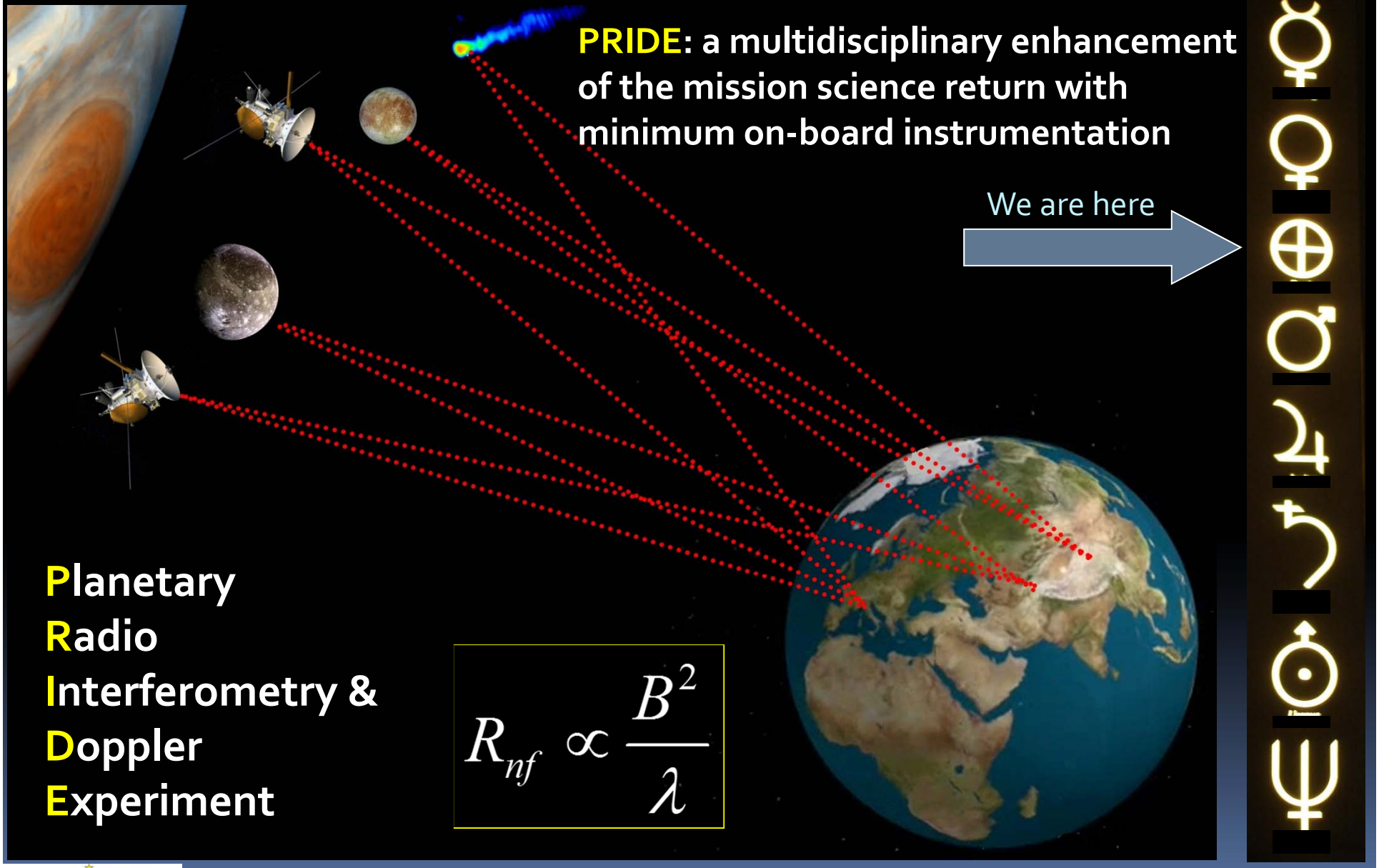


(Xp, Yp, Zp)

XY (Longitude/Latitude) Projection

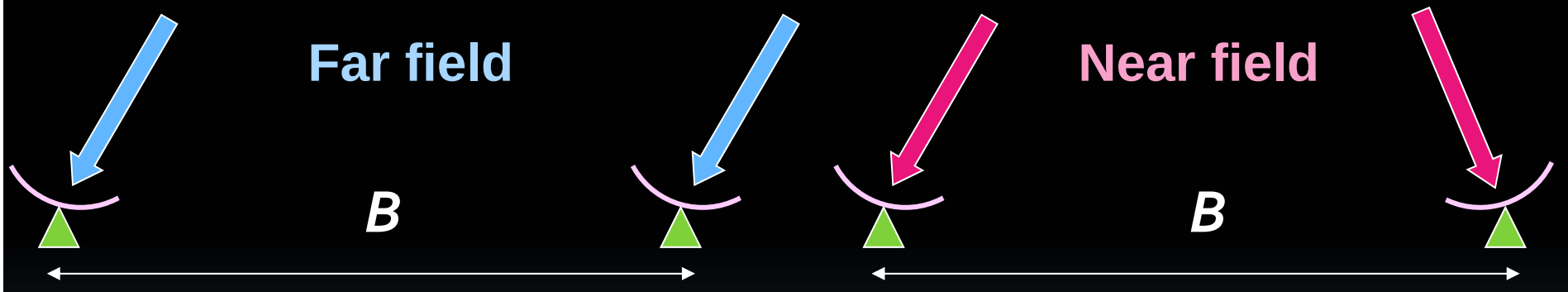


Generic PRIDE configuration



Working in the near field with PRIDE

While praying $\theta \propto \frac{\lambda}{B}$, let's not forget $R_{nf} \propto \frac{B^2}{\lambda}$

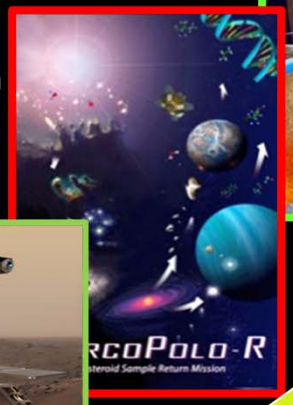


Baseline	100 km	1000 km	10^4 km
Facility	MERLIN	EVN_{WE}	EVN
λ = 3.6 cm *X-band*	2 AU	200 AU	0.1 pc
λ = 1 cm K_a-band	8 AU	750 AU	0.5 pc

ESA planetary science missions – VLBI “customers”

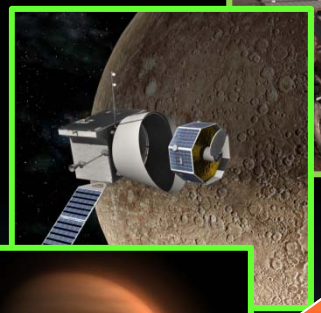
JUICE-Laplace

MarcoPolo-R ?
(asteroid sample return)



ExoMars

BepiColombo



2025

2020

2015

2010

SKA era

SKA pathfinders

VenusExpress &
MarsExpress

PRIDE-2011 vs Huygens VLBI tracking

Mission	Distance	Transmitter power/gain	Band	Time resolution	Delay noise	Positional accuracy (lateral)
	[AU]		*[GHz]*	*[s]*	*[ps]*	*[m]*
Huygens VLBI	8	3 W / 3 dBi	2.0 (S)	500	15	1000
PRIDE--2012	5	10 w / 6 dBi	2.3 (S)	100	5	120
			8.4 (X)	10	3	70
			32 (Ka)	10	1	23

GPS accuracy anywhere in Solar System

- **Conservative estimate, today's technology**
- **Minimal special requirements for the on-board instrumentation**

ESA: Jupiter Icy Satellites Explorer (JUICE)

Progressing from exploration to characterisation of habitable worlds

JUICE Science Themes

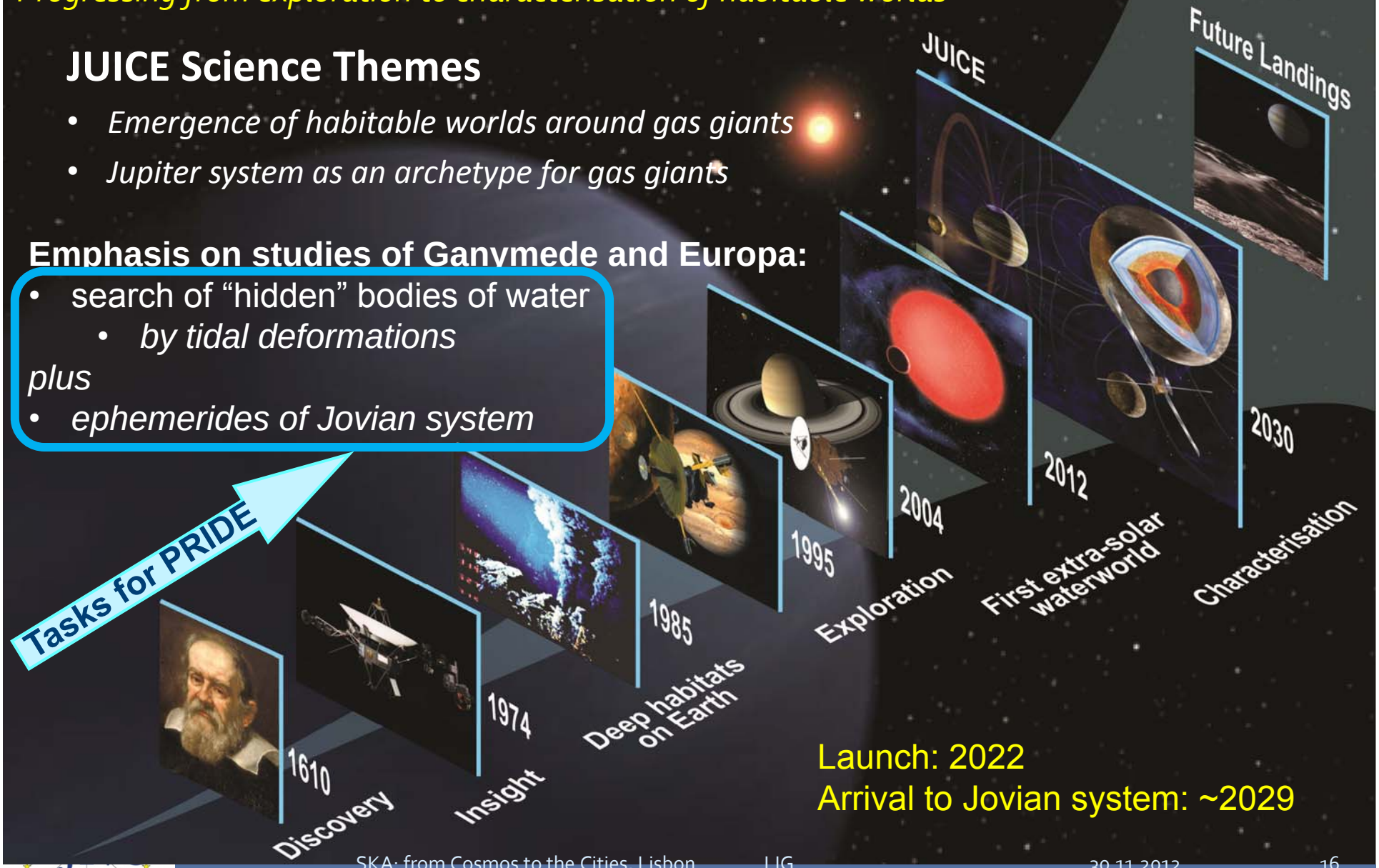
- *Emergence of habitable worlds around gas giants*
- *Jupiter system as an archetype for gas giants*

Emphasis on studies of Ganymede and Europa:

- search of "hidden" bodies of water
  - *by tidal deformations*

plus

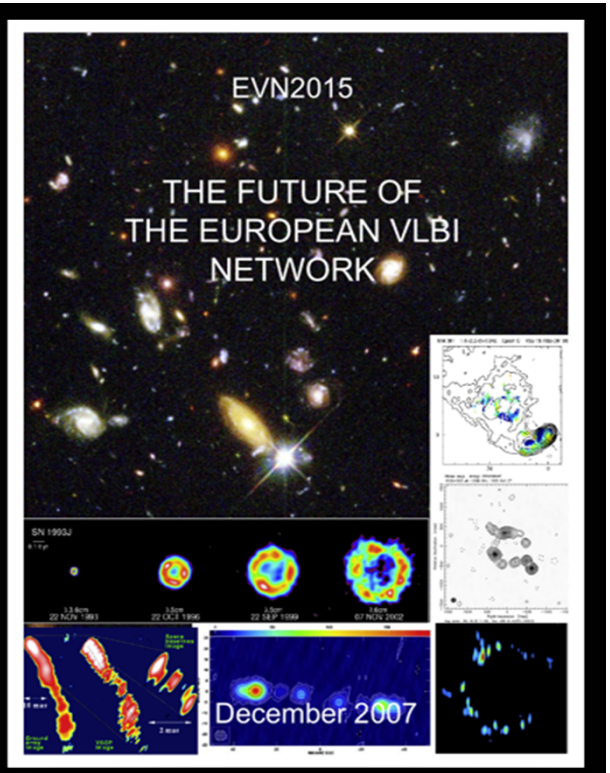
- *ephemerides of Jovian system*



Launch: 2022
Arrival to Jovian system: ~2029

VLBI Future

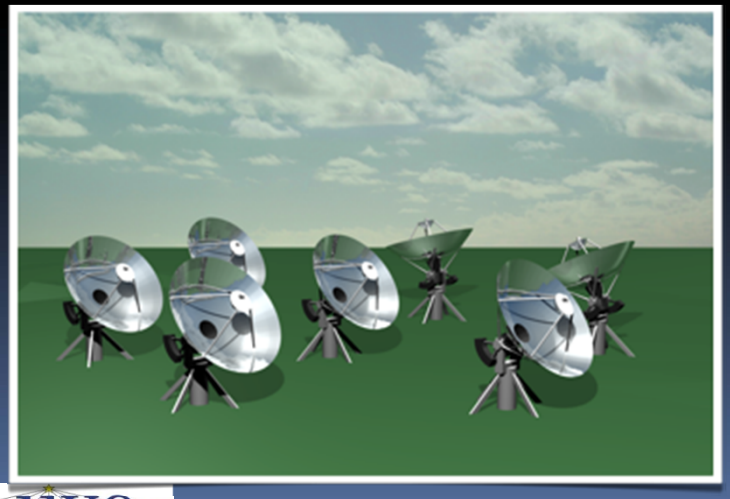
- Unique science
  - long baselines
  - wider range of frequencies
- Keeping up with EVLA/eMERLIN
  - Going for 4 Gbps in 2011
- Follow up LOFAR, MeerKAT science
  - especially in the SKA era
- Better images? More telescopes, new instrumentation!
  - *MeerKAT, African array, Madeira, Azores*
  - *100-fold bigger correlator*



Our Future: the SKA

- SKA Square Kilometre Array
  - Global radio-astronomy ambition
  - 10% in 2020...

- e-EVN is a SKA pathfinder
  - long-range connectivity,
  - real-time radio-astronomy
  - Shared technology interests:
    - *Digital processing (correlators)*
    - *Calibration pipeline*
    - *Cheap telescopes…*



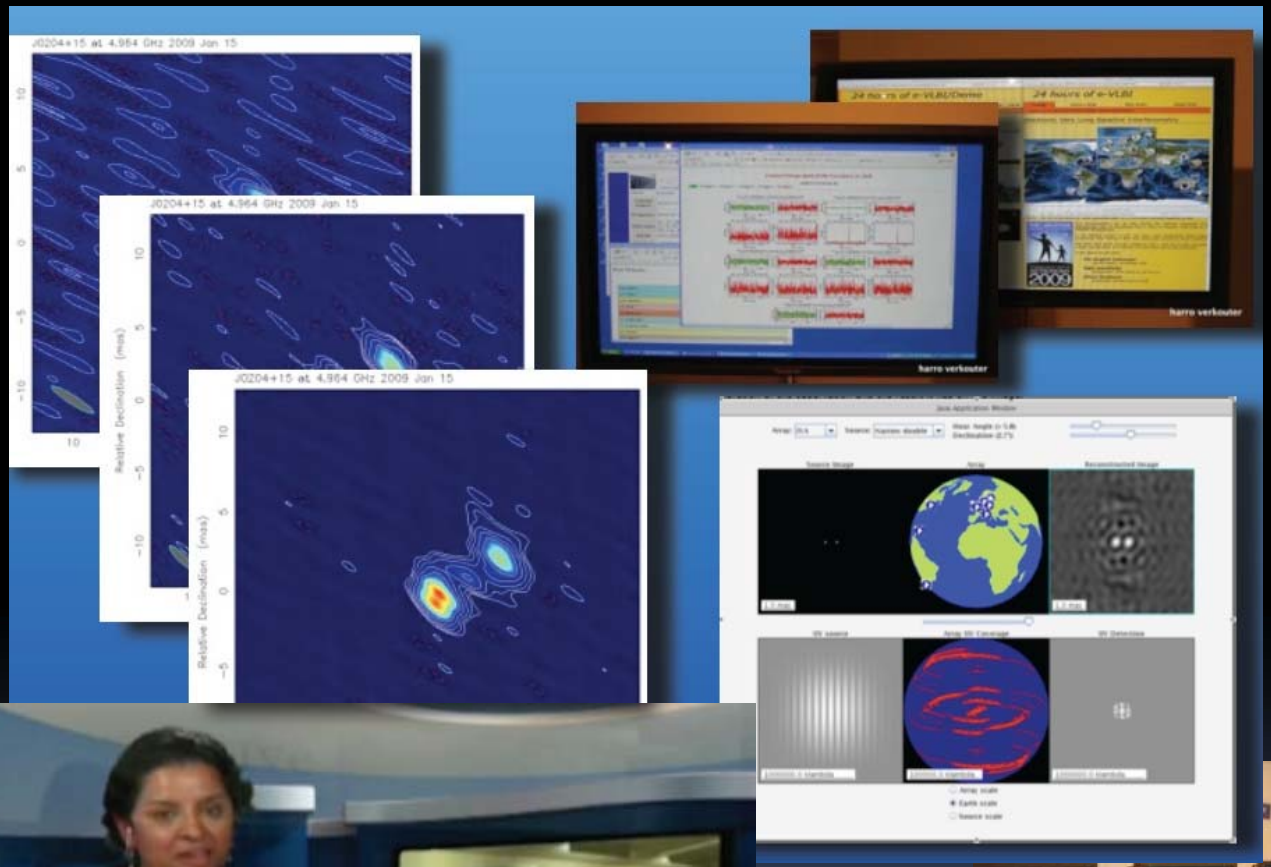
- **Data transport, compute and storage**
  - Will be overwhelming: ExaFlop scale
  - Energy bill will be the constraint

    - *SKA aims to be green facility*
    - *compute where it is cheap*

- **(e)-VLBI technology feed into SKA**

VLBI : outreach and education

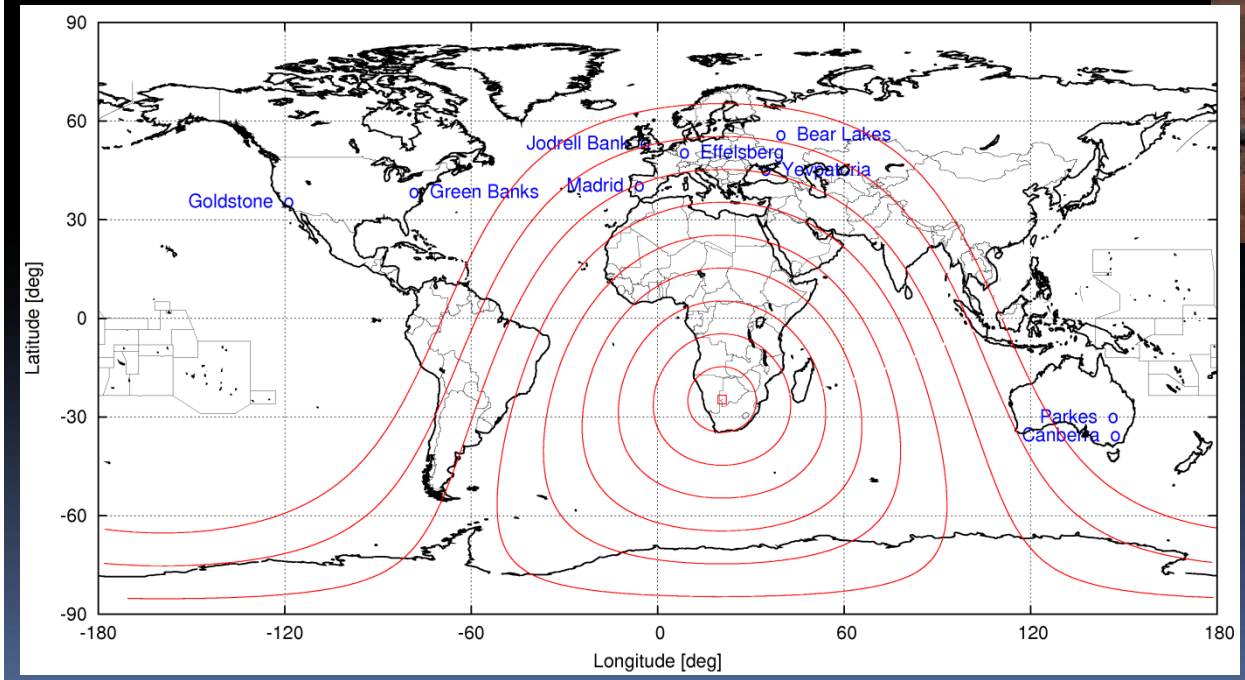
- Real-time e-VLBI demo at the IYA opening ceremony (Jan 2009)
- 100-hours astronomy web-cast



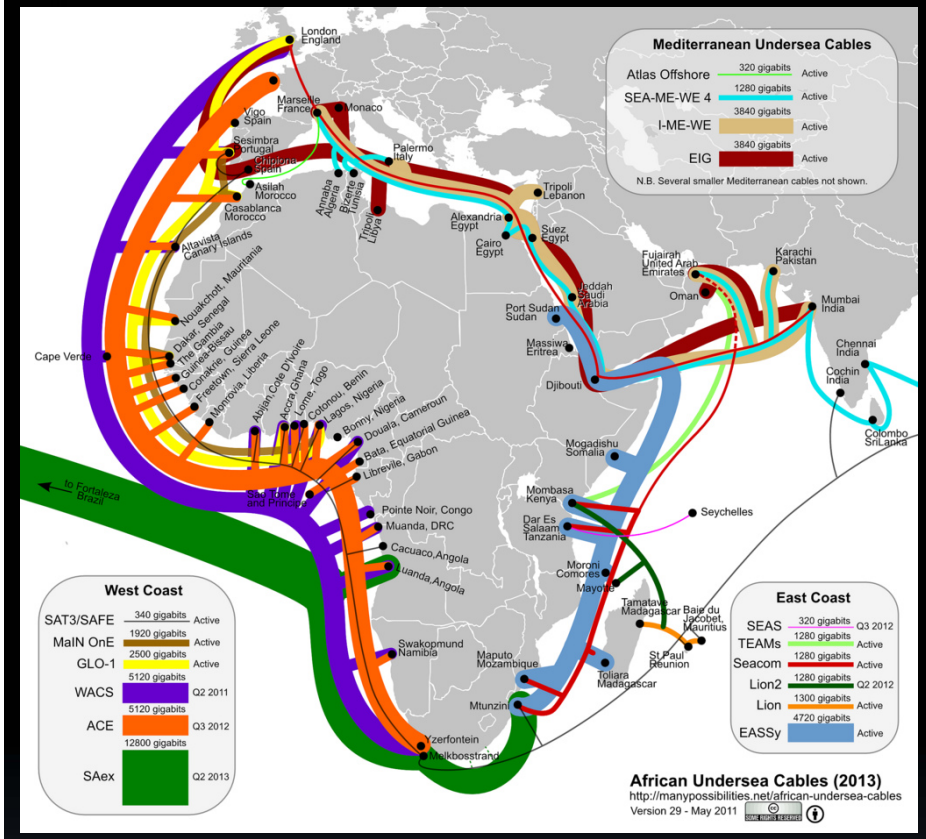
Huge educational potential!

Going Mars (side-story #1)

Request from ESA to consider radio astronomy support for ExoMars
(outcome of ESA Ministerial meeting Nov 2012)



Getting connected (side-story #2)



Lisbon, Portugal, 28 November 2012: DANTE, the operator of GÉANT, the pan-European research and education network; and UbuntuNet Alliance, the regional research and education network for Southern and Eastern Africa, today announce the launch of the UbuntuNet network, a high-speed Internet network connecting scientists and academics throughout Southern and Eastern Africa to peers in the region and to Europe, the first network of its kind in Africa.

Concluding remarks

Radio astronomy and space science are no longer about expenses, they are investments.

Rephrasing J.-J. Dordain, ESA DG, 2012