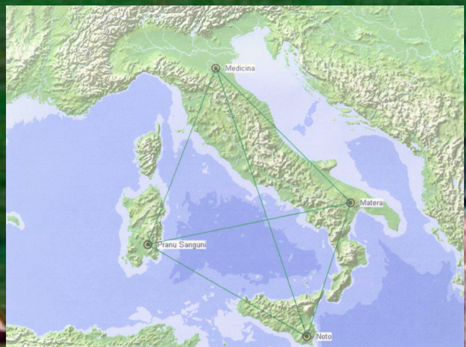
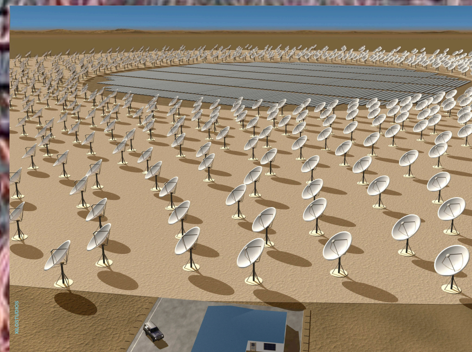
Technical developments at IRA-INAF

A mirror of the future of radio astronomy





Karl –Heinz Mack
Istituto di Radioastronomia – INAF
Via P. Gobetti 101
I-40129 Bologna

Some telescope characteristics

Sensitivity $\propto D^2$

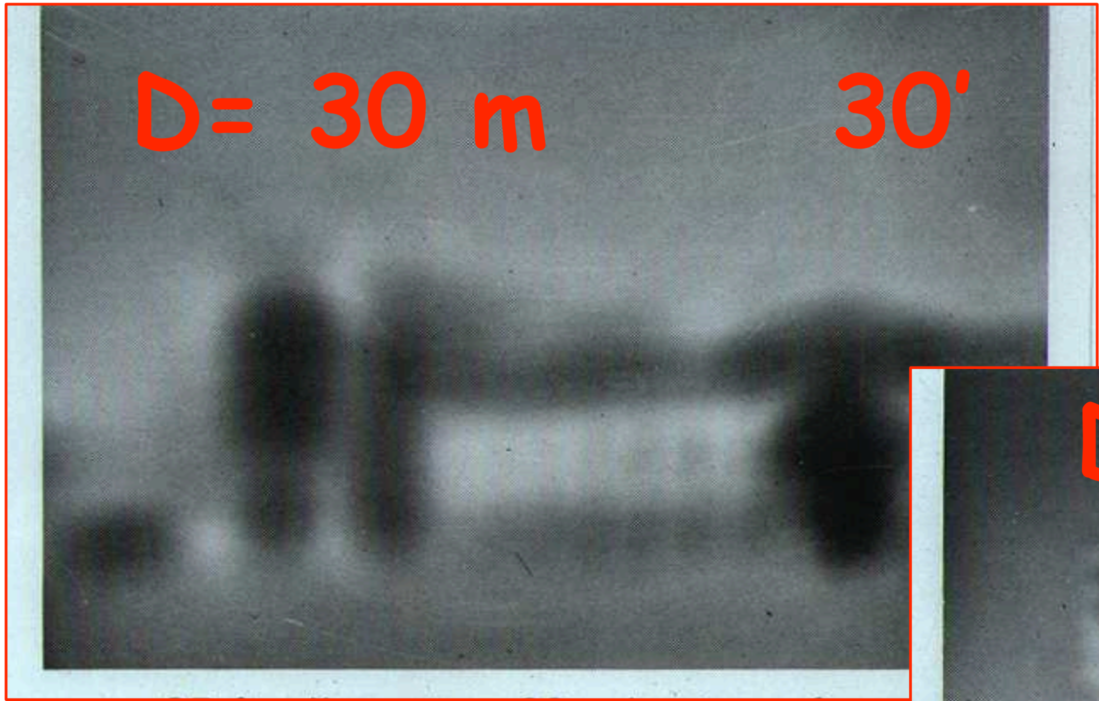
Resolution $\propto \lambda/D$

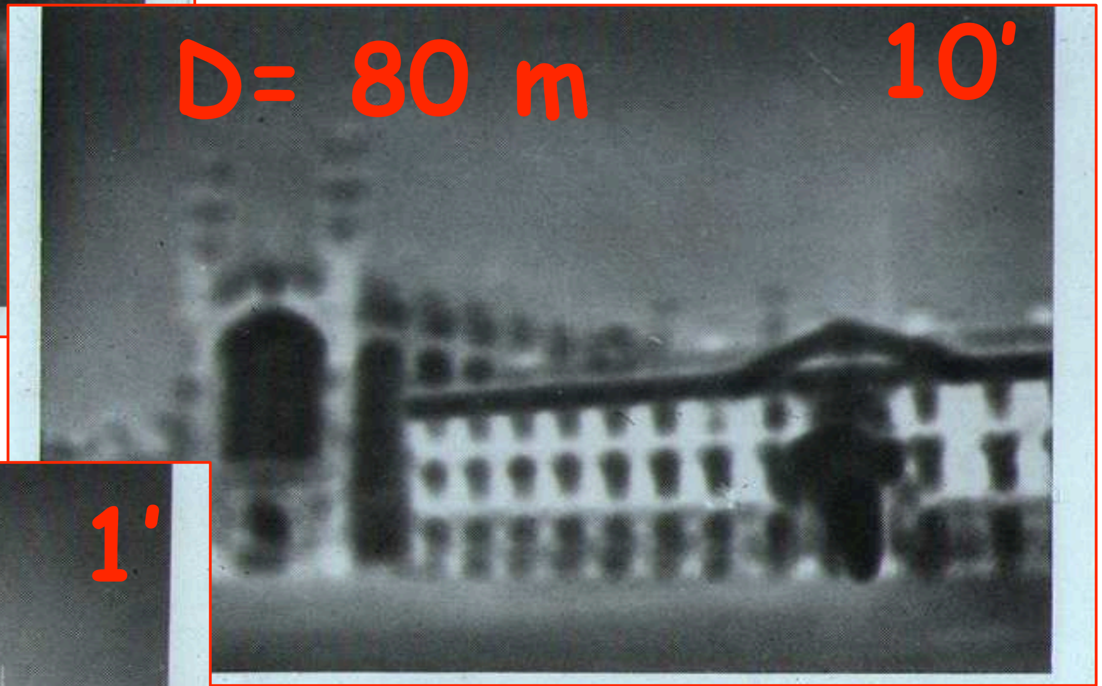
Human pupil: $\lambda \sim 10^{-3}$ mm
D = 5 mm

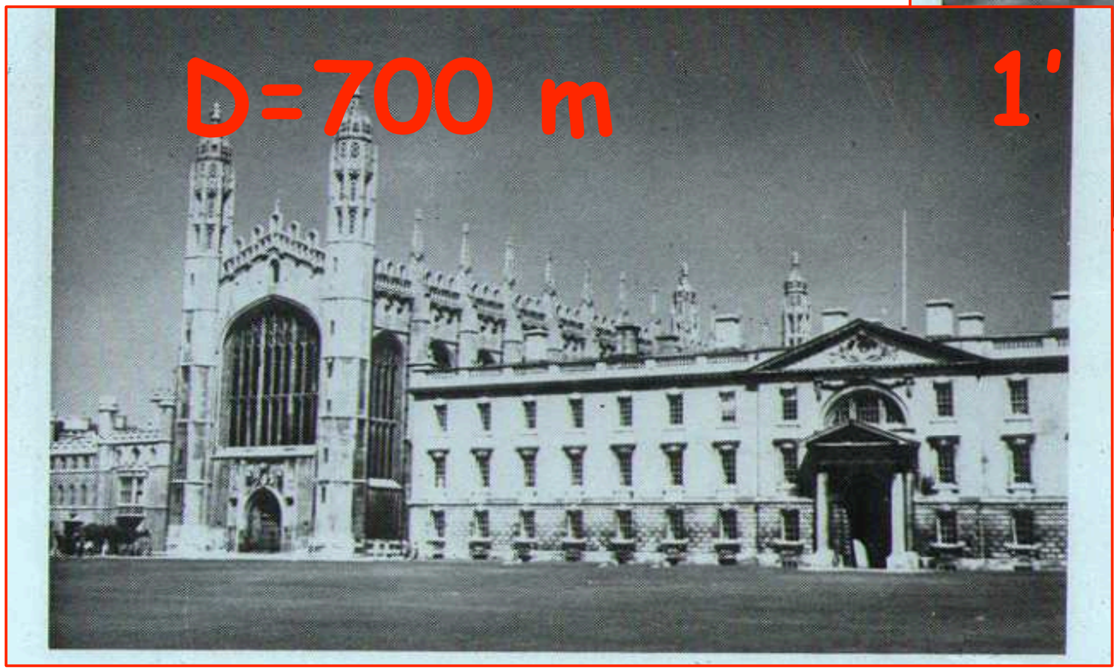
⟷ **1′**

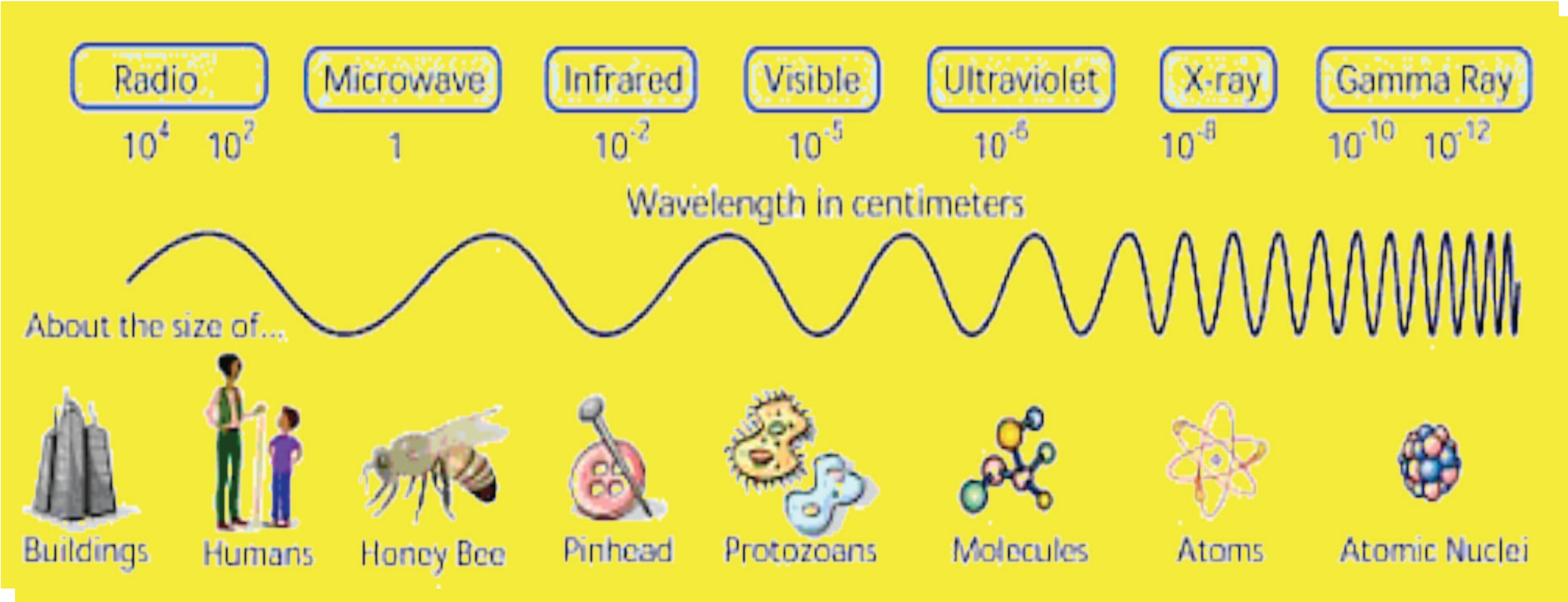
Radio band:

λ = 20 cm



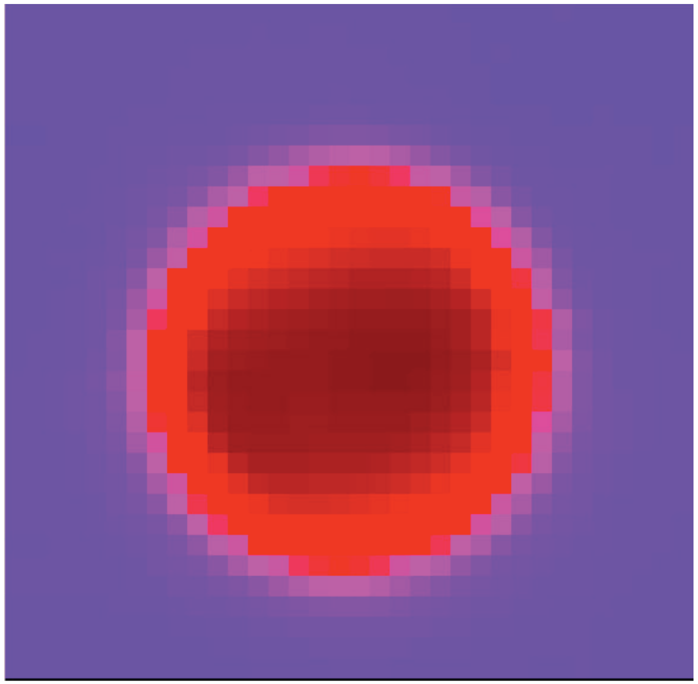






Visible wavelengths:
Reflected sunlight
⇒Lunar phases
“natural” colours

Radio wavelengths:
Thermal black body radiation (200 K)
⇒ No lunar phases
false colours



Birth of a new science

Bell Labs, Holmdel, NJ:
20.5 MHz rotable antenna:
1) static from nearby thunderstorms
2) static from distant thunderstorms
3) faint steady hiss of unknown origin

Karl Jansky
(1905 – 1950)

Birth of a new science

May 5, 1933

"All the News That's Fit to Print"

The New York Times.

LATE CITY EDITION

NEW RADIO WAVES TRACED TO CENTRE OF THE MILKY WAY

BIG NEW INVASION PLANNED BY JAPAN

ROOSEVELT ASKS PAY RISE FOR WORKERS; PROMISES TO HELP BUSINESS END CHAOS; HE SENDS RAILROAD BILL TO CONGRESS

Features of Railroad Bill

FARM BILL CLAUSE BLOCKS AGREEMENT

KIDNAPPERS URGED TO ANSWER PLEAS

BRITISH DEMANDING TARIFF SAFEGUARDS

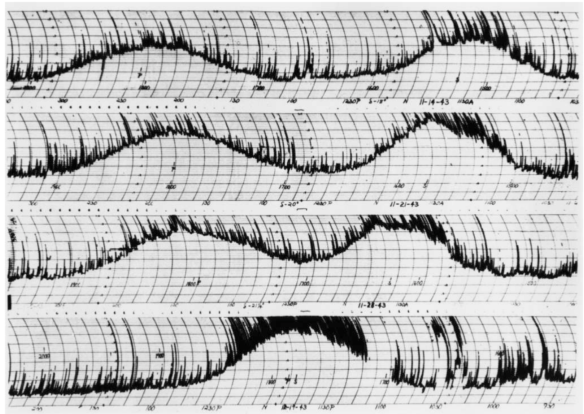
ITALIANS NOW BACK BRITISH ARMS PLAN

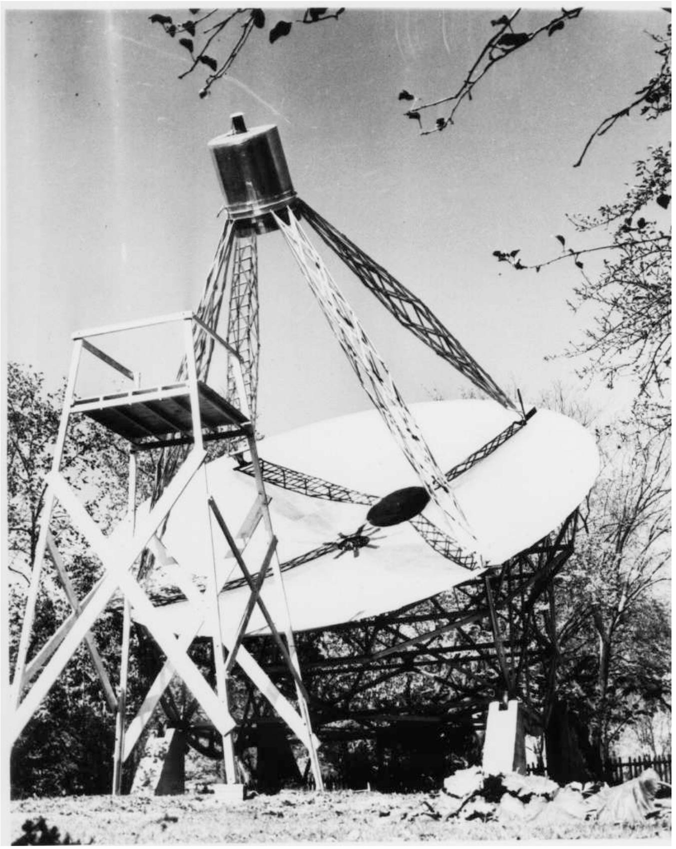
Karl Jansky
(1905 – 1950)

The first scientific results

Grote Reber (1911 – 2002)

(W9GFZ)





Wheaton, IL: 10-m antenna

1) detected 160-MHz from Milky Way in 1938
2) Discrete sources: Cas A, Cen A

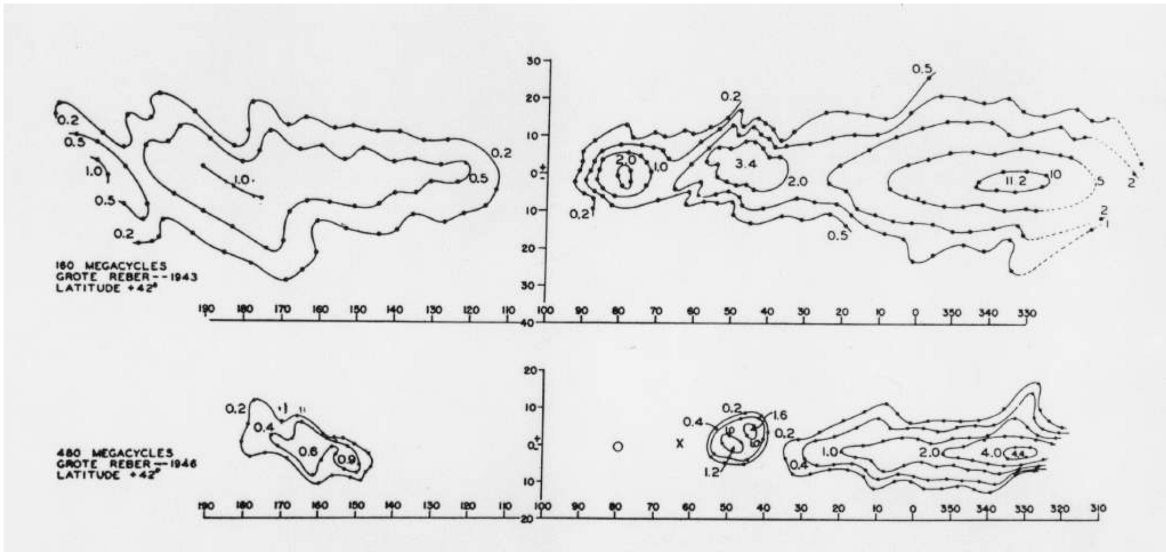
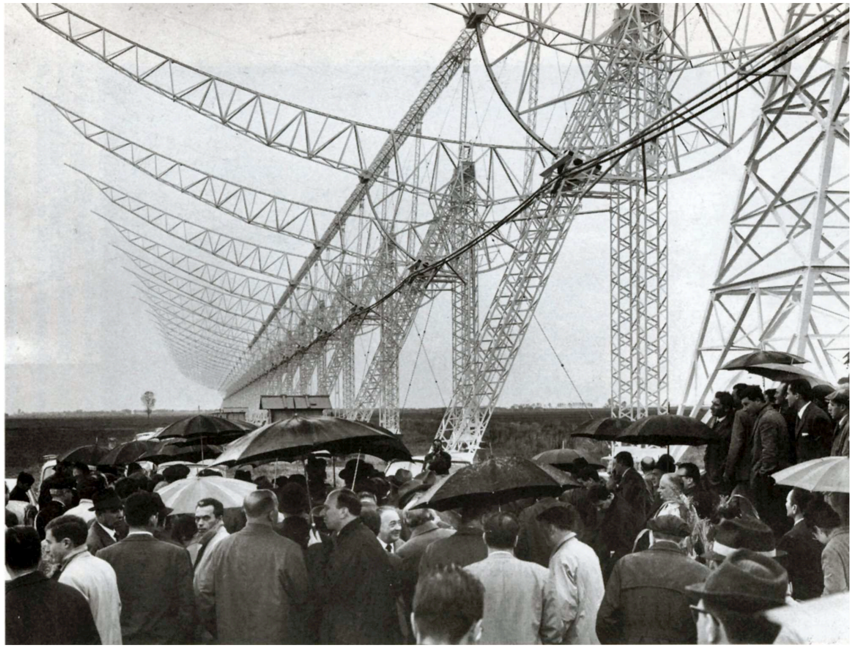
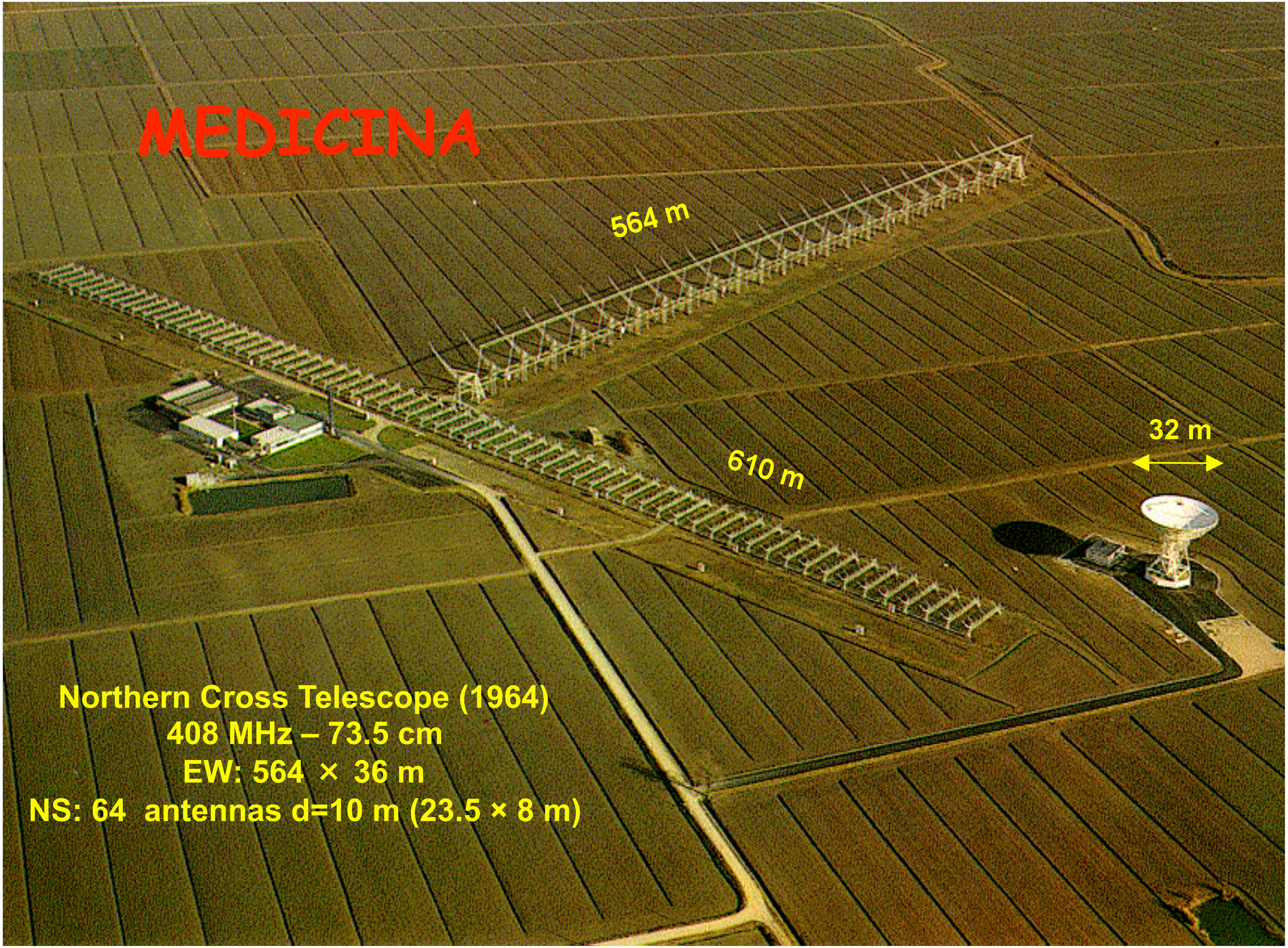


FIG. 7—Contours of constant intensity at 160 MHz and 480 MHz, taken at Wheaton, Illinois.

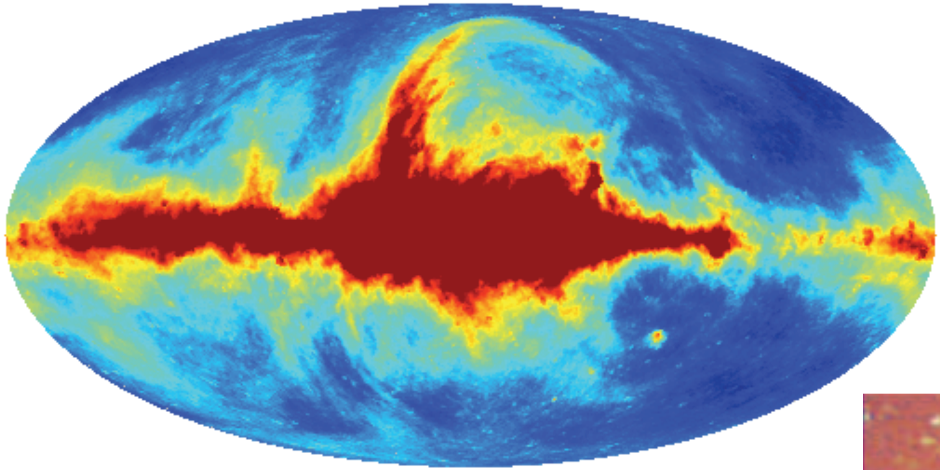
Radio Astronomy in Italy

In the plane north of Medicina (Bo), close to the village of Fiorentina , the Northern Cross telescope (Croce del Nord), the biggest transit instrument in the Northern hemisphere, was inaugurated on Oct 24, 1964.

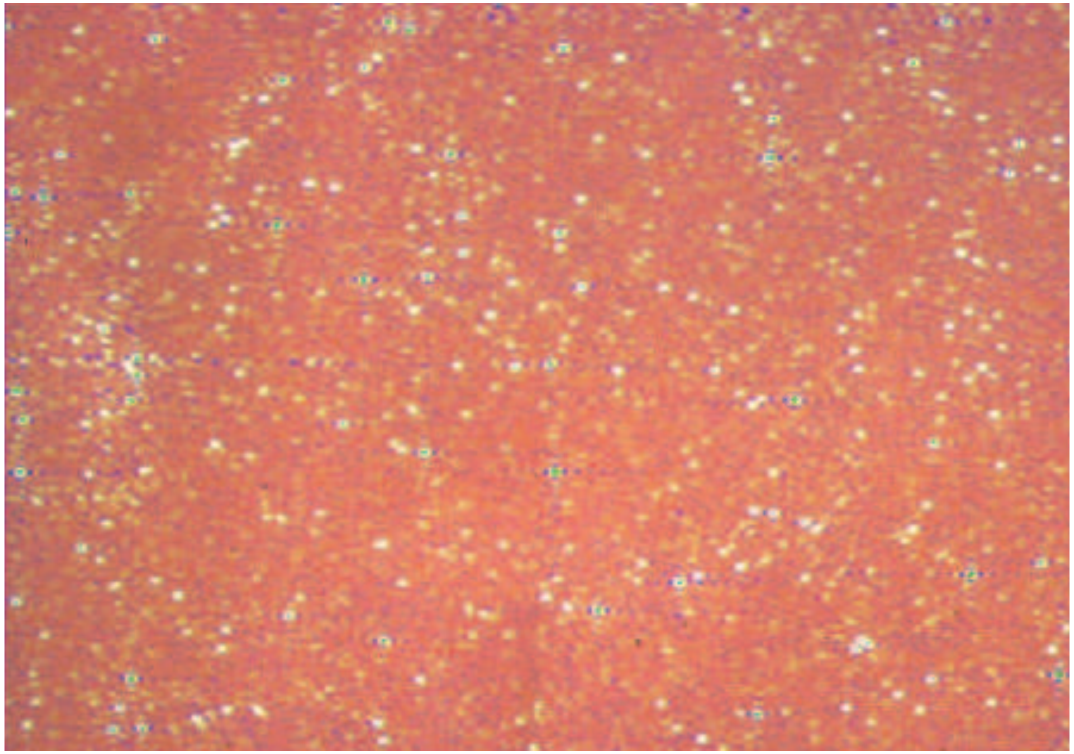



MEDICINA
564 m
610 m
32 m
Northern Cross Telescope (1964)
408 MHz – 73.5 cm
EW: 564 × 36 m
NS: 64 antennas d=10 m (23.5 × 8 m)

How does the radio sky look like? Where are the radio sources?
=> Large-area surveys: 3C, 4C, … B2, B3

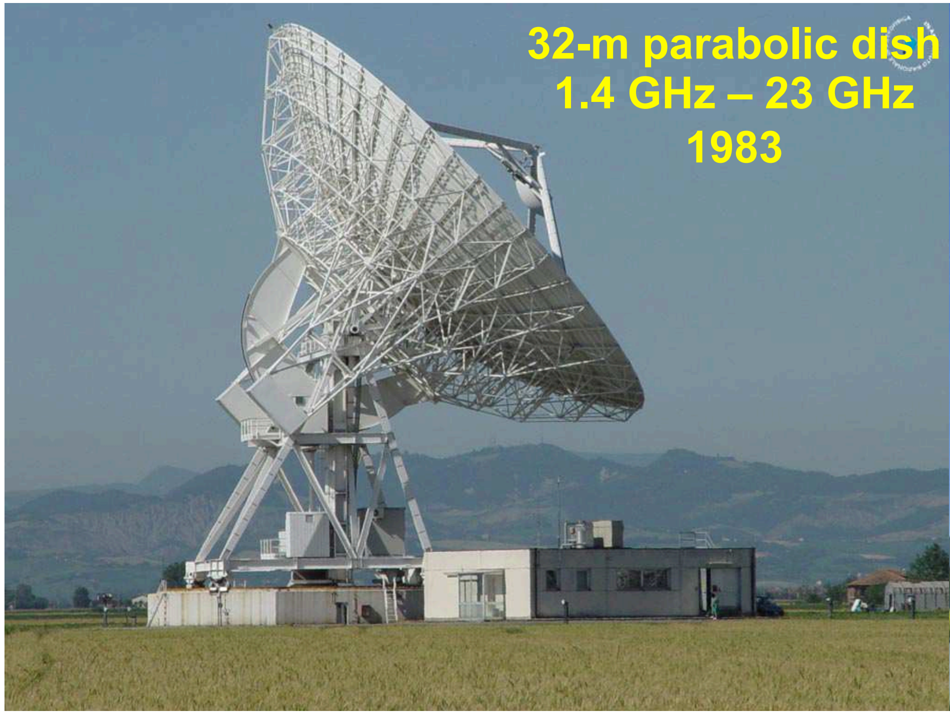


408 MHz all-sky survey (100-m Effelsberg, 70-m Lovell, 64-m Parkes)
Resolution ≈ 1°
Haslam et al. (1982)



408 MHz large-area survey
(Medicina Northern Cross Telescope)
Resolution: 2.6′ × 4.8′
Ficarra et al. (1985)

Medicina (Emilia-Romagna)



Noto (Sicily)

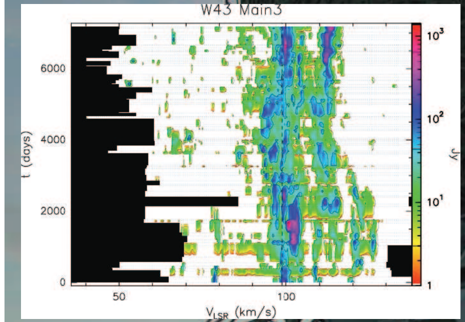
Medicina (Emilia-Romagna) Noto (Sicily)

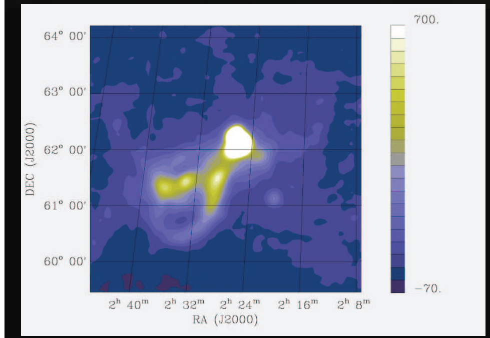
Medicina:
frequency agility (1.4 – 23 GHz)
(as first single-dish antenna in Europe)

Noto:
active primary surface (0.33 – 43 (86) GHz)
(unique in Europe)

Results of single-dish observations

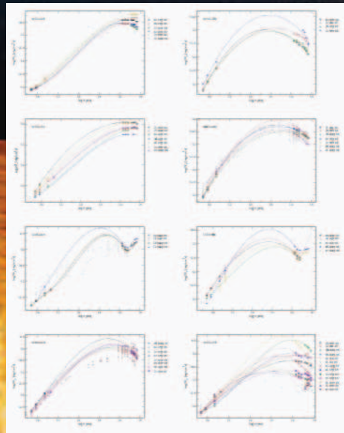
Long-time (>20 y) monitoring of $H2O$ masers in star-forming regions

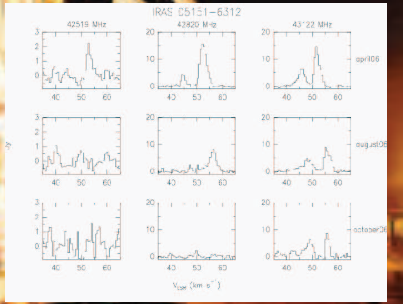




Large-area high-frequency Continuum mapping

Coordinated multi-frequency monitoring of variable Active Galactic Nuclei





Search for new SiO masers

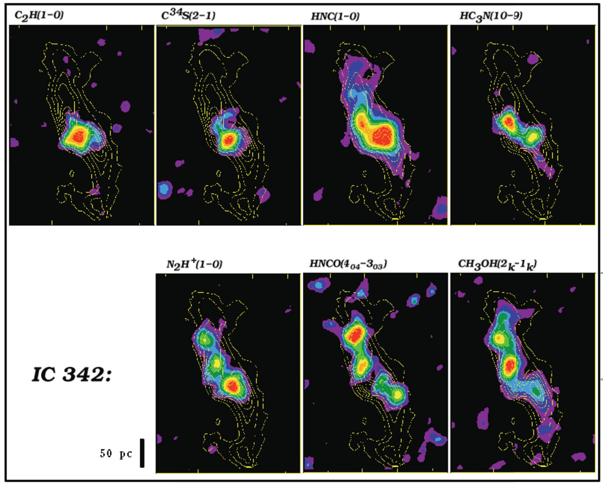
San Basilio (Sardinia)

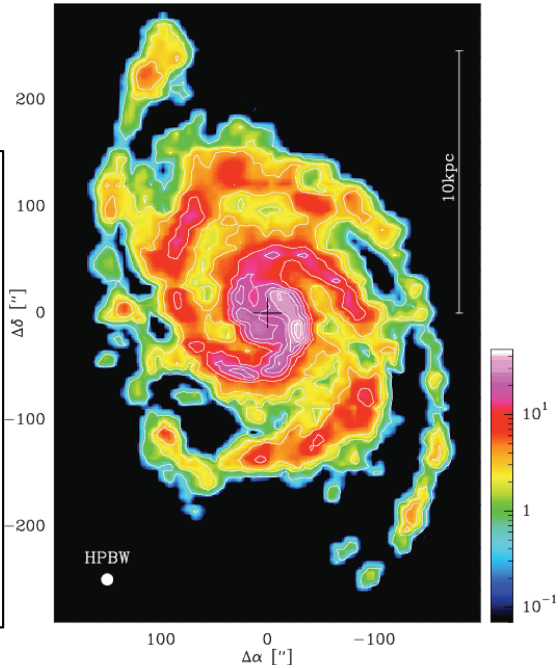
Site: Pranu Sanguni (35 km north of Cagliari)
Low RFI level
Low wind ($\langle v_w \rangle$ 4 m/s)
Suited for 100-GHz observations

- 64-m; general purpose
- 3 focus positions
- Complete frequency coverage (300 MHz - 100 GHz)
- Frequency agility
- Active primary surface
- Surface accuracy 220 μm RMS
- Shaped surface; diminish standing waves for high-frequency spectroscopy
- Transmission capability

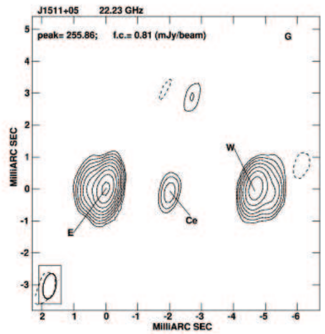
Single-Dish Science with the SRT

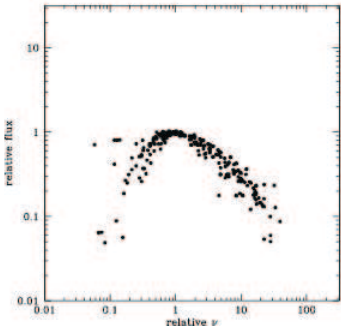
Astrochemistry

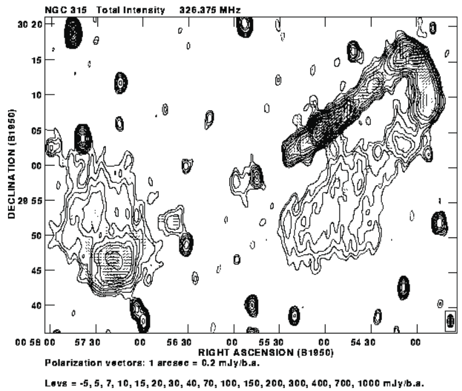


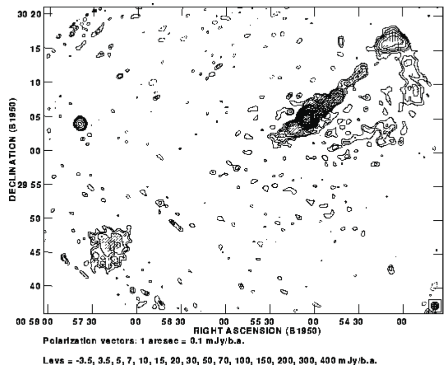


High-frequency continuum

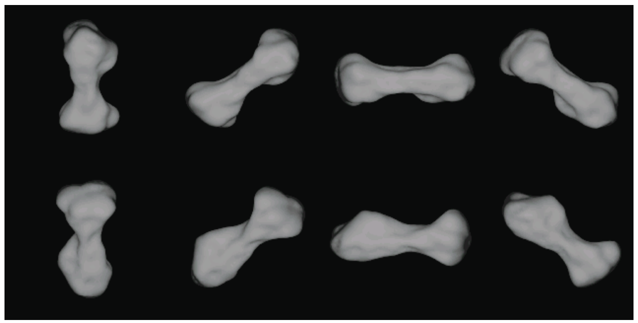


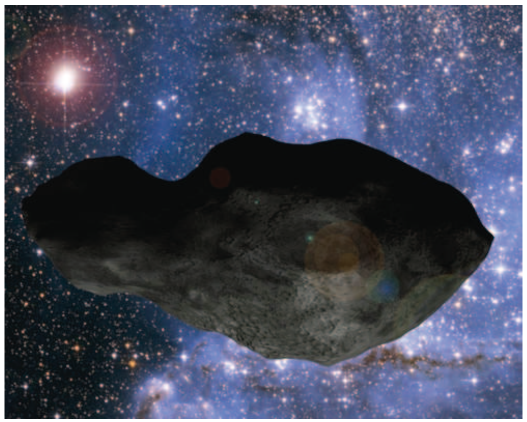


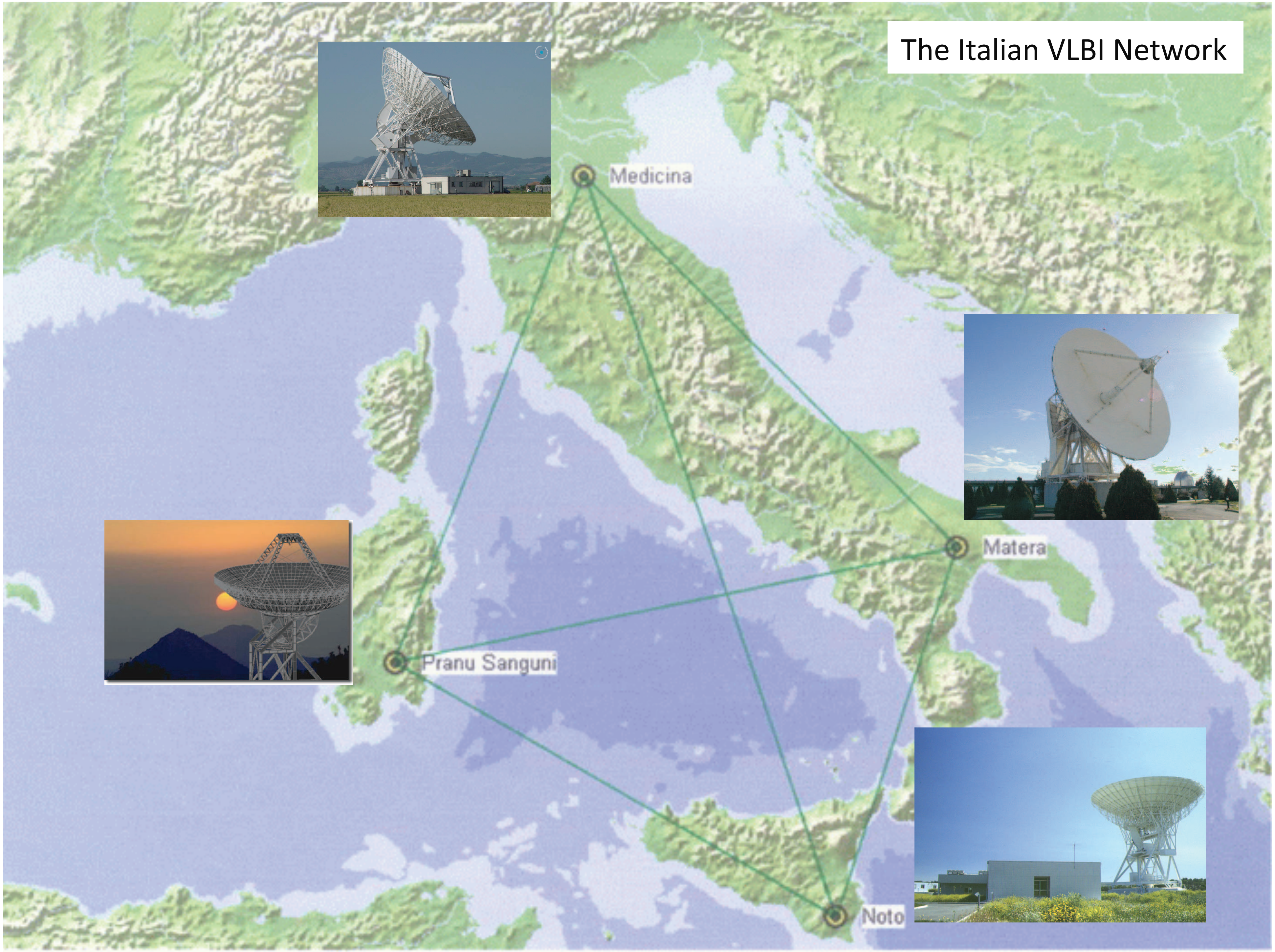


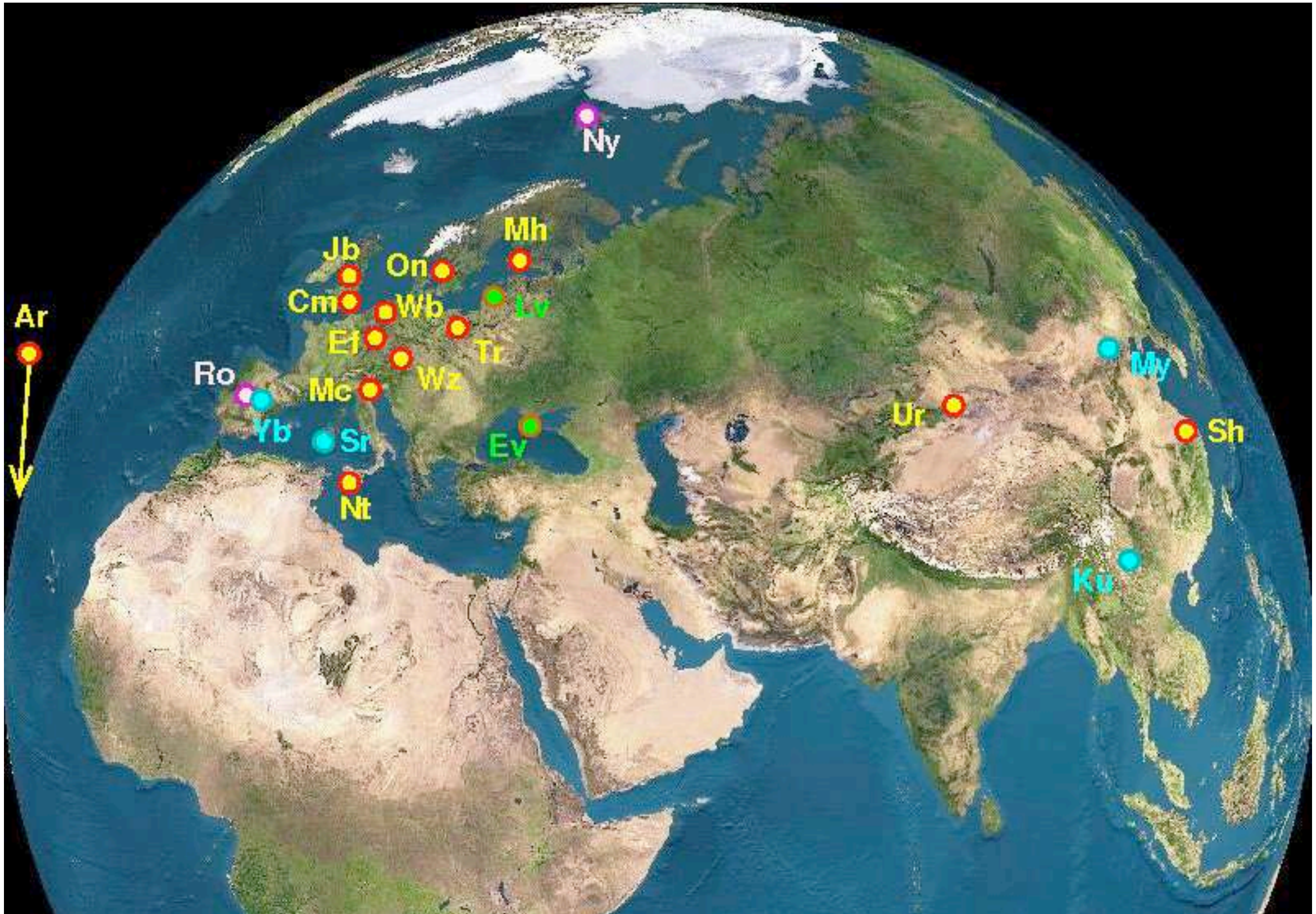


Radar Transmission






The Italian VLBI Network
Medicina
Matera
Pranu Sanguni
Noto



EUROPEAN vlbi NETWORK

18 telescopes (2008)

Several telescopes currently being built

Stations outside Europe

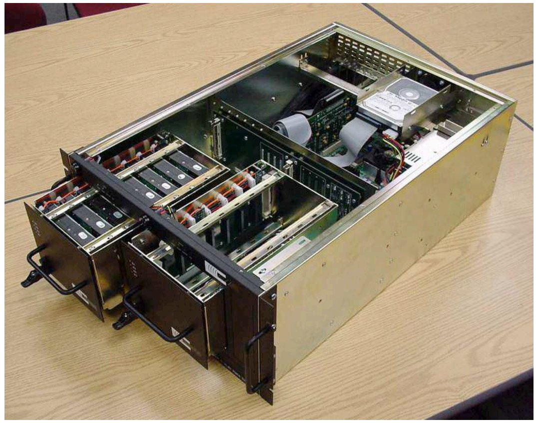
Several of the world's largest telescopes

Observing wavelength 92 cm – 1.3 cm

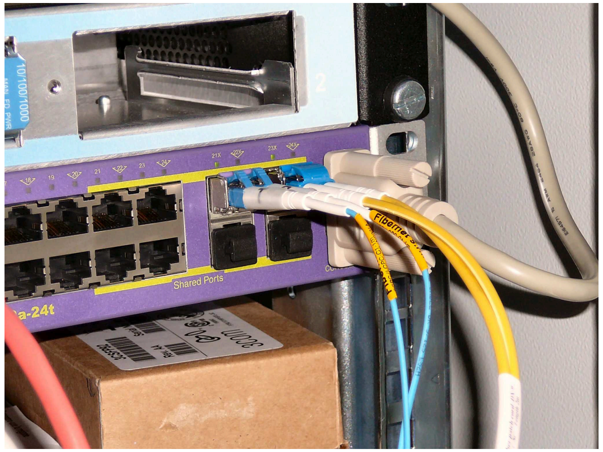
Data correlator at JIVE (NL)

Data transport in VLBI

- Observing mode VLBI Mk 4
  - Registration velocity 128-256 Mbit/s
  - Capacity 0.7 Terabytes (4-12 hours)



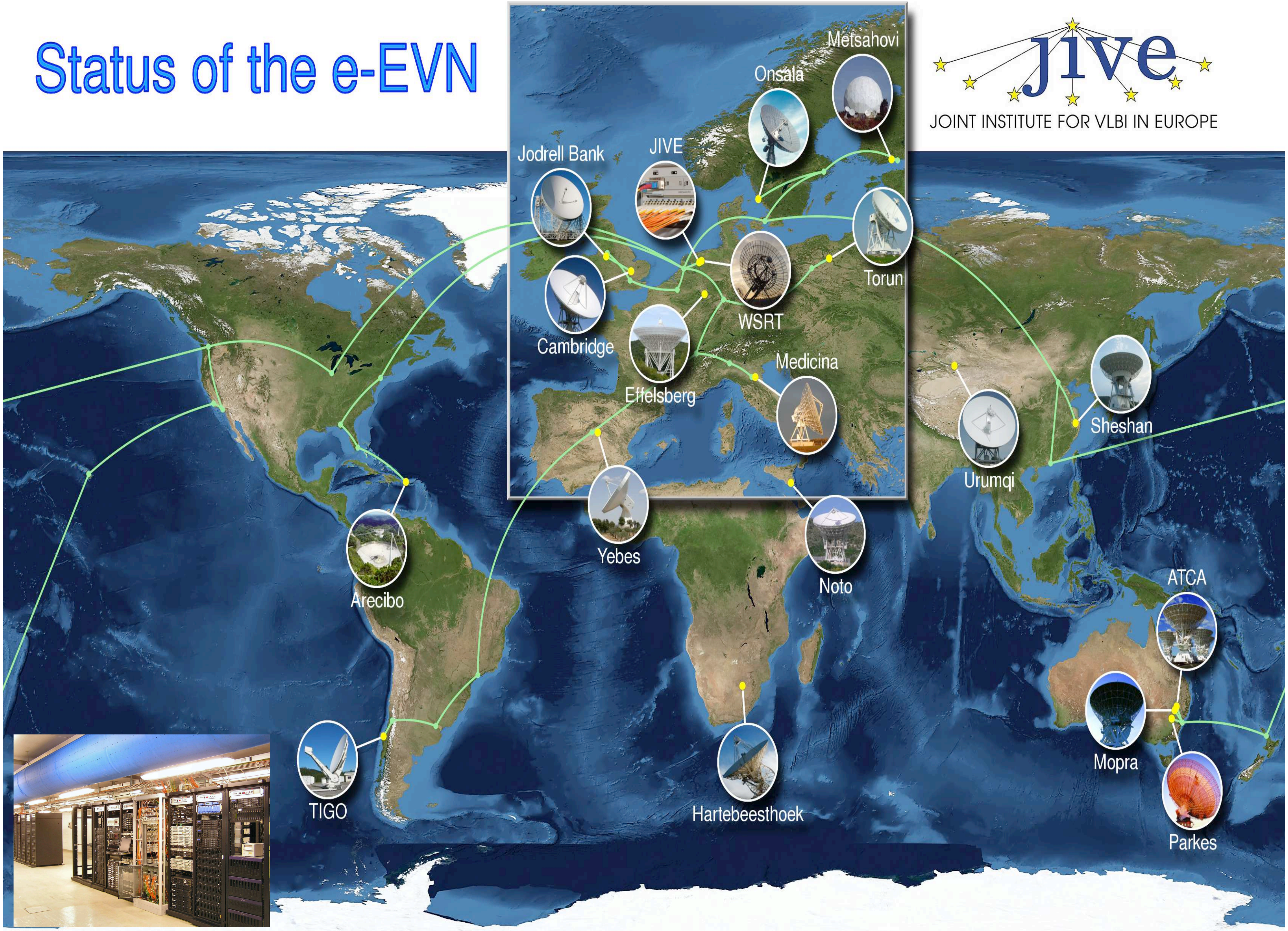
- Observing mode VLBI Mk 5
  - Registration velocity 512 Mbit/s
  - Capacity 2 Terabytes (6 hours)



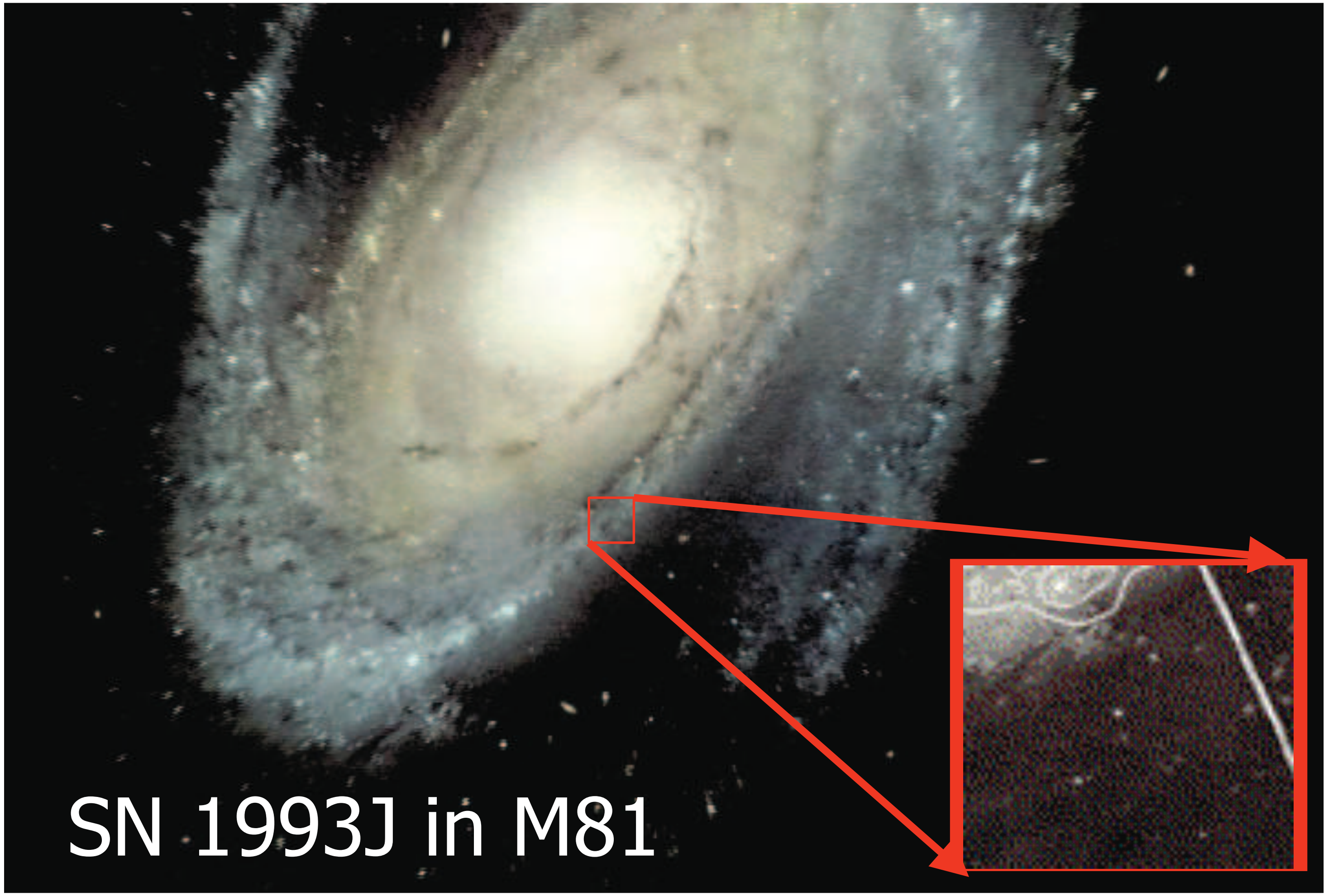
- Observing mode e-VLBI
  - Registration velocity ≈ 10 Gbit/s
  - Capacity unlimited

Status of the e-EVN

jive
JOINT INSTITUTE FOR VLBI IN EUROPE

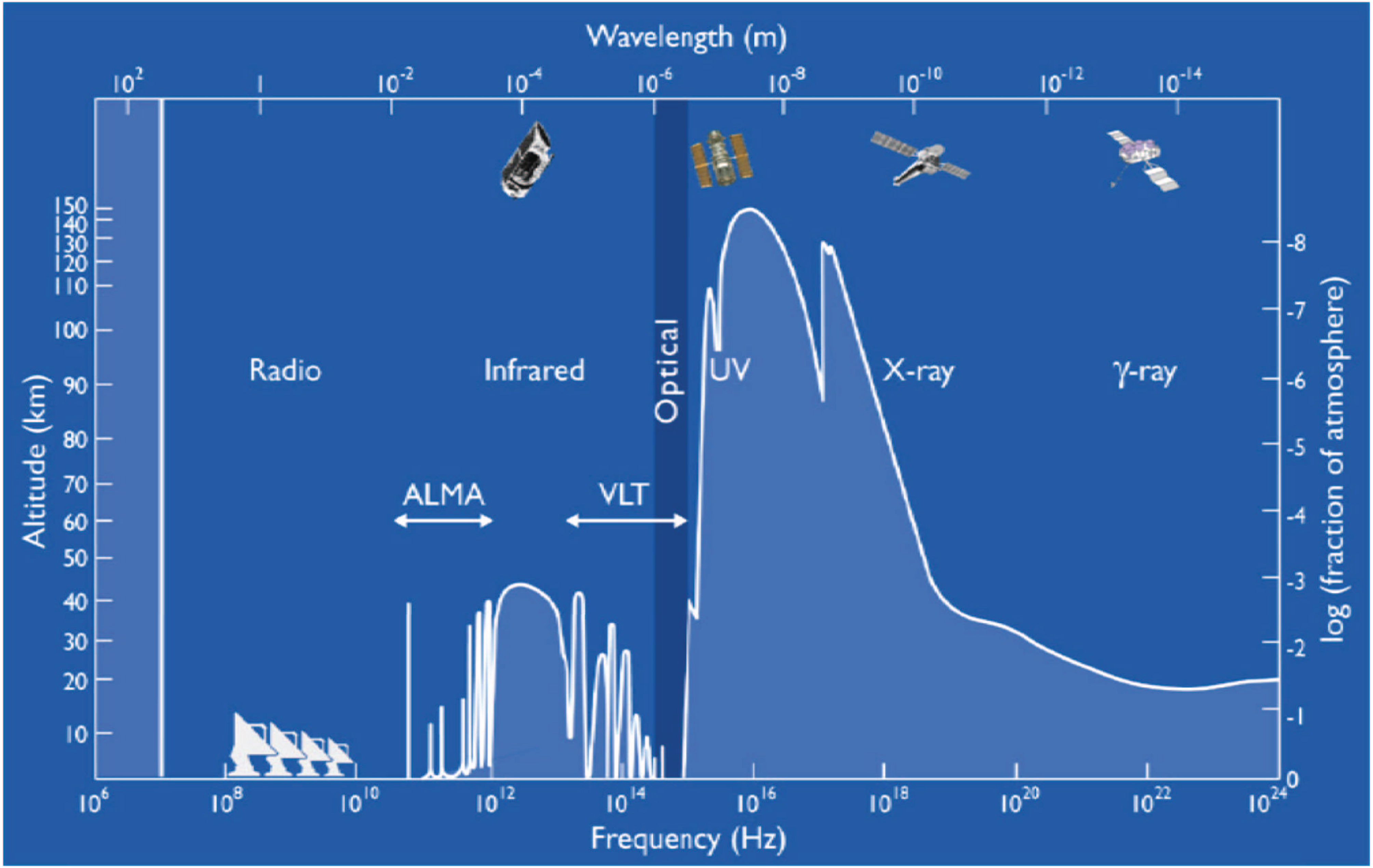


Network status as per 2007-08-21. Image created by Paul Boven <boven@jive.nl>. Satellite image: Blue Marble Next Generation, courtesy of Nasa Visible Earth (visibleearth.nasa.gov).

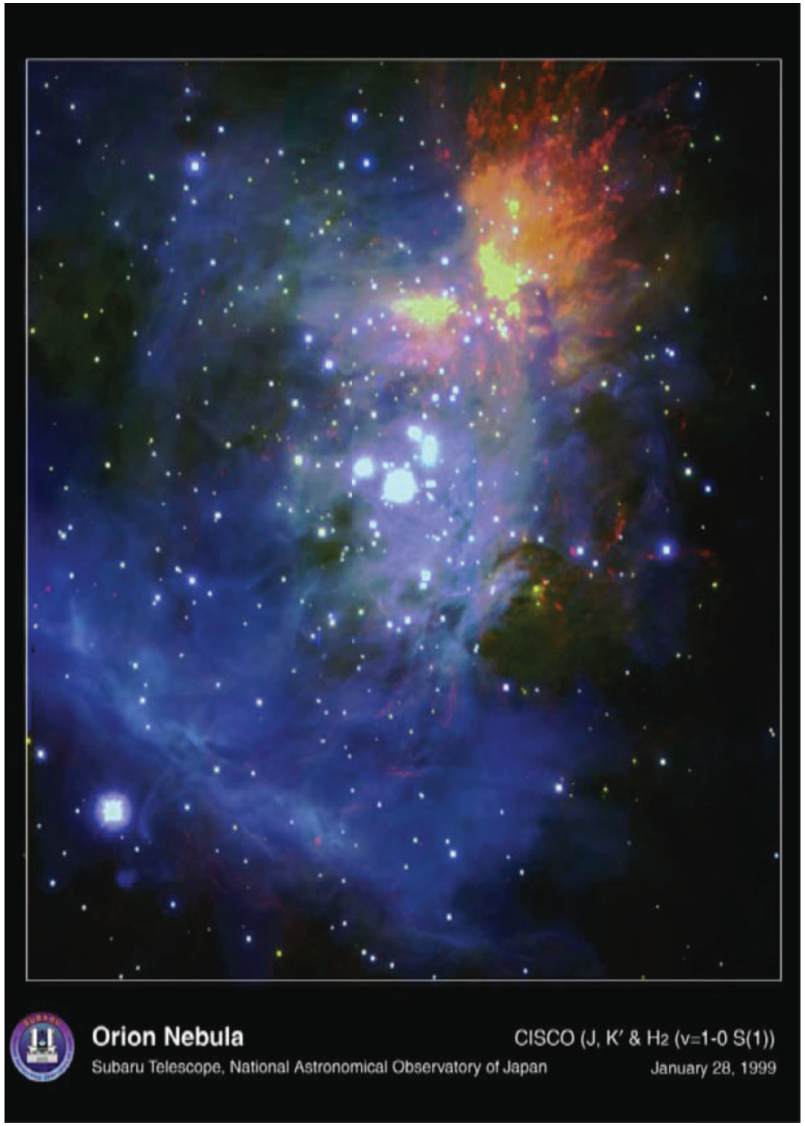


VLBA :
Mar 17 1993 – Feb 25 2000
→ V ~ 15.000 km/s

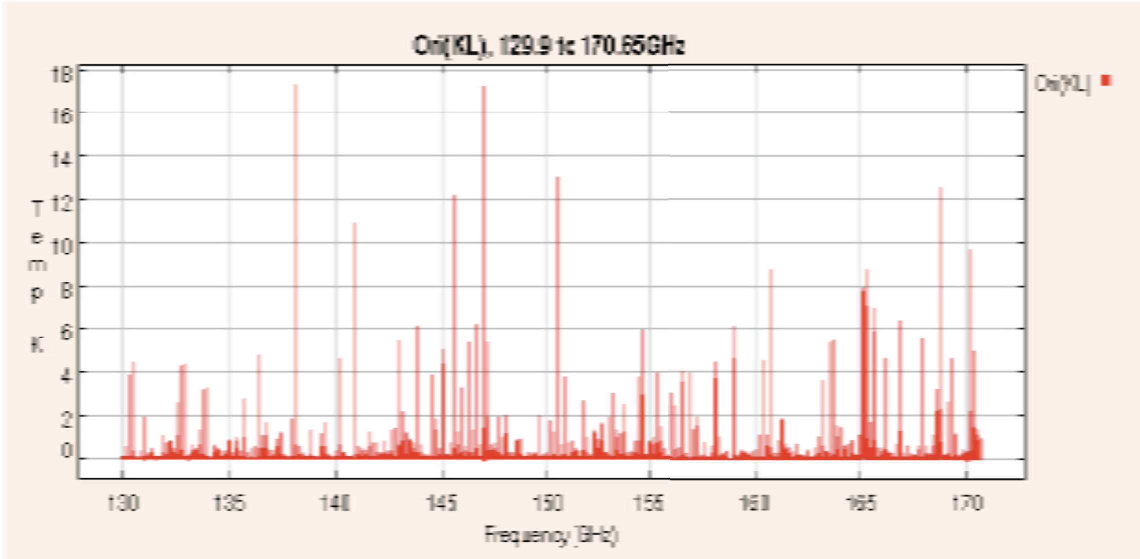
Atmospheric transmission for electromagnetic radiation



Astrochemistry



17,000 lines are seen in a small portion of the spectrum at 2 mm of the Orion Nebula

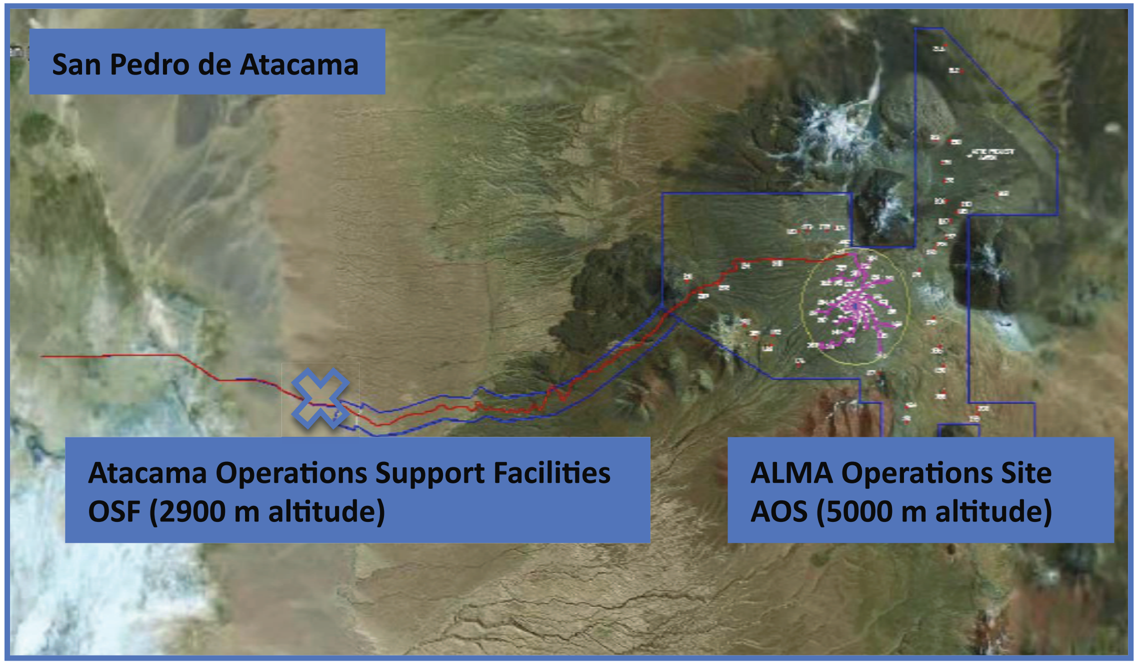


Millimeter/submillimeter spectral components dominate the spectrum of planets, young stars, many distant galaxies

Most of the observed transitions of the 125 known interstellar molecules lie in the mm/submmm spectral region

The ALMA site in Northern Chile

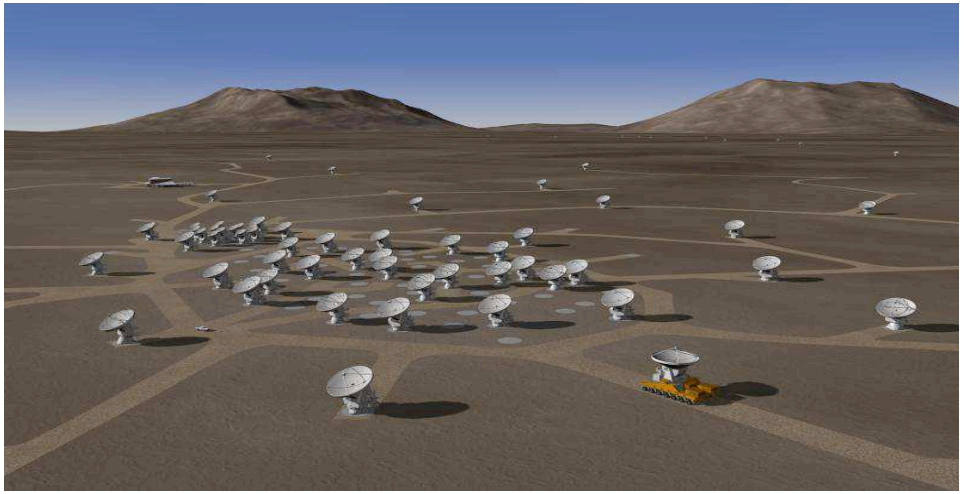
ALMA



Altoplano de Chajnantor
Atacama Desert 5000 m a.s.l.

ALMA Operation Site (AOS) 43 km distant
from closest public road

Operation Support Facilities (OSF) on 2900 m



AOS (artist’s impression)

Three different antenna types (Mitsubishi, Vertex, AEC) …

4 × 12 m 12 × 7 m	25 (32) × 12 m	25 (32) × 12 m

25 μm surface accuracy; 100 tons total weight

… moved between 168 different bases by two unique machines

Most compact configuration:
All antennas within 160 m × 250 m

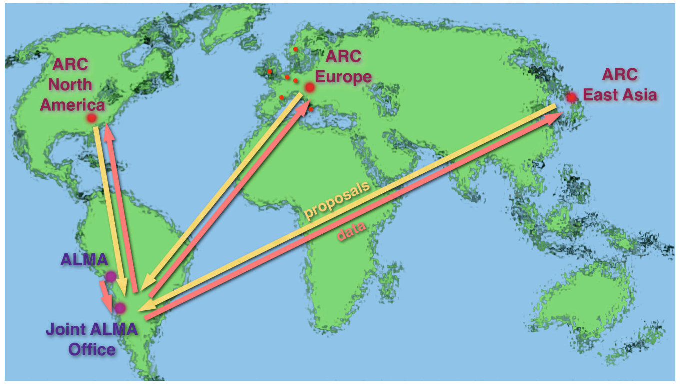
Most expanded configuration:
≈15 km

The ALMA Antenna Transporter

ESO Press Photo 45b/07 (5 October 2007)

Transport vehicles (Lise & Otto)
1400 horsepowers (at OSF level)
10 m × 15 m × 6 m
≈ 150 tons

The 'Camera' Goal



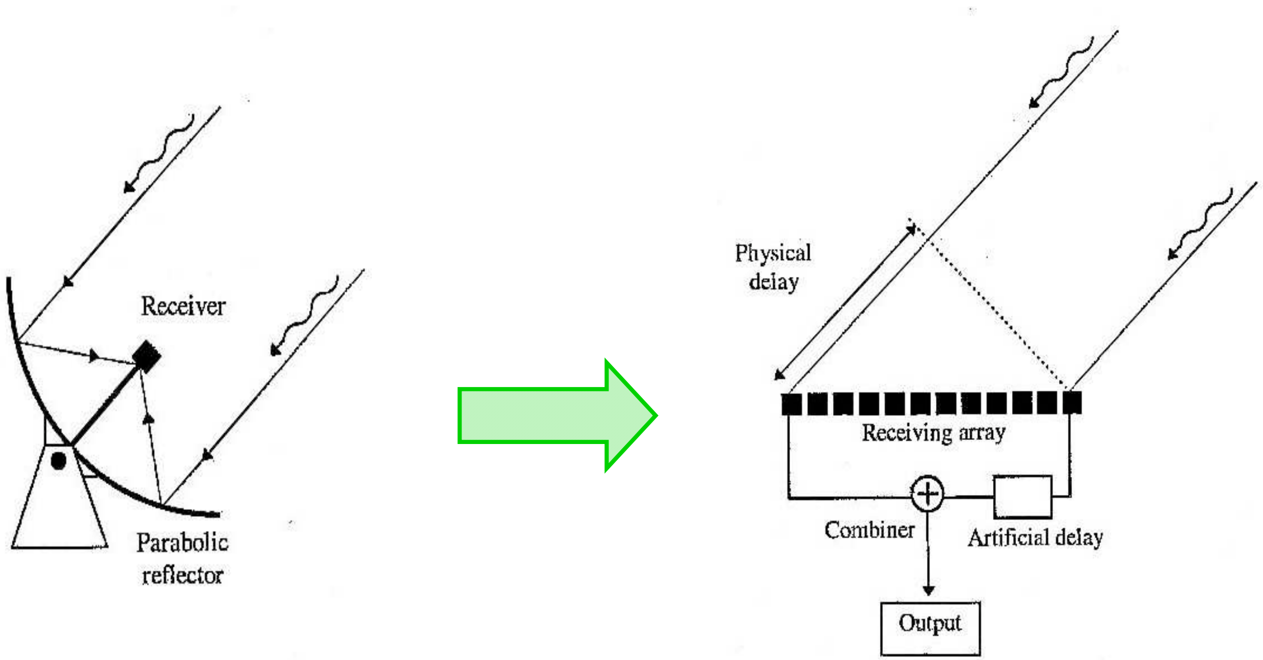
- ALMA delivers images
- The astronomer specifies the science requirements
  - angular resolution
  - Field of view
  - Image fidelity
  - Spectral configuration and calibration precision
- Full service observing with dynamic scheduling
- The ALMA imaging pipeline ensures optimal (within current knowledge) data processing to produce the image

Remaining difficulties for Astronomers

- A minimum understanding of interferometry may still be important
- High fidelity, very wide-field images or full polarisation imaging may require post-processing
- Special observations (e.g. moving targets)

➢ **ALMA Regional Centres**

Cost is driving a shift in design approach



Principile:

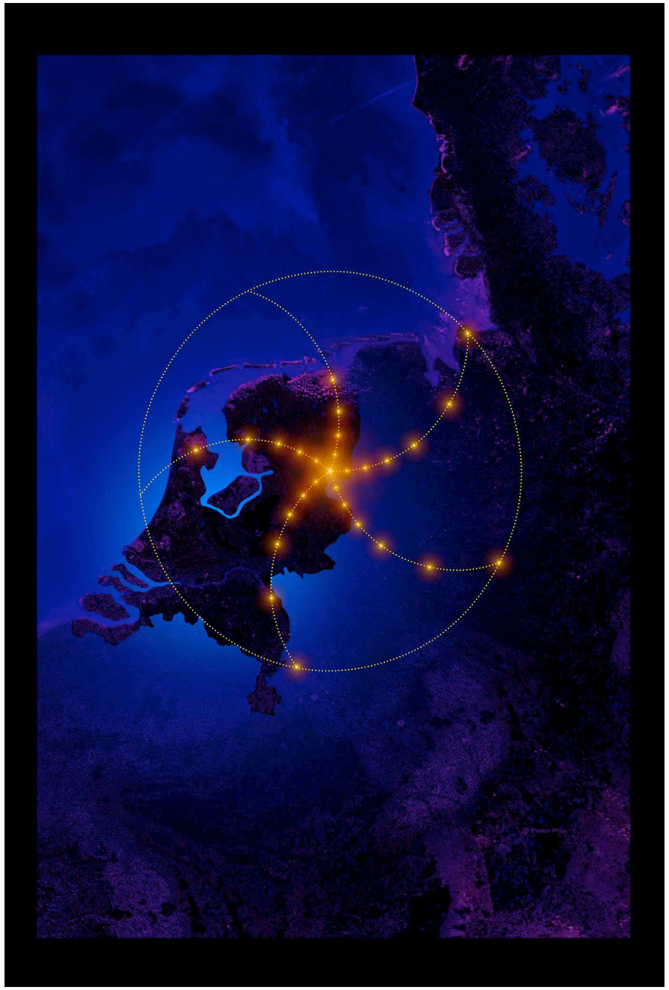
E is detected, interference can be performed (off-line) in computer

Consequences:

a) Can replace mechanical beam forming by electronic signal processing
b) Put the technology of radio telescopes on *favorable cost curve*
c) Also: multiple, independent beams become possible

LOFAR

- Interferometer for the frequency range of 10 - 240 MHz
- Array of up to 100 stations of 100 dipole antennas
- Baselines of 10 m to at least 350 km
- Fully digital: received waves are digitized and sent to a central computer cluster



Lofar Low-band antenna element

- Optimised for 30 -80 MHz with sharp cut-off filter above 80 MHz

- Separate filter for observations below 30 MHz

- Usable down to 30 degrees elevation

- dual-polarisation dipole
- height 1.40 m
- dipole arms 1.00 m
- wire-mesh groundplane for shielding

Lofar Low-band antenna element

• Optimised for 30 -80 MHz with sharp cut-off filter above 80 MHz

• Separate filter for observations below 30 MHz

• Usable down to 30 degrees elevation

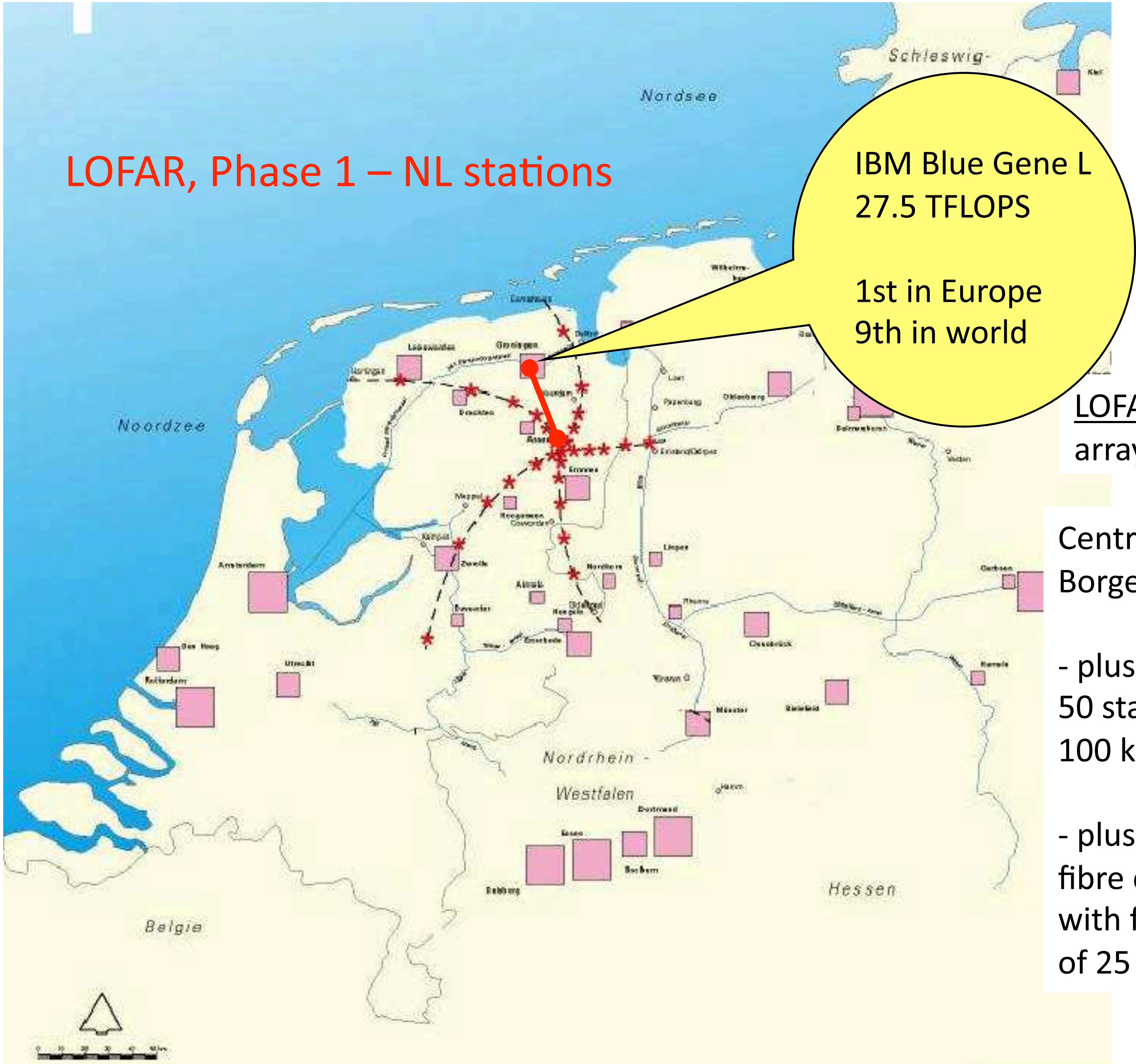
• dual-polarisation dipole
• height 1.40 m
• dipole arms 1.00 m
• wire-mesh groundplane for shielding

Lofar High-band antenna element

- used between 120 – 240 MHz
- FM band suppressed in the antenna amplifier

- Compound antenna: 4 × 4 dual-polarisation dipoles
- Height = 60 cm
- Dipole arms = 70 cm

LOFAR, Phase 1 – NL stations



<u>LOFAR</u>
array configuration

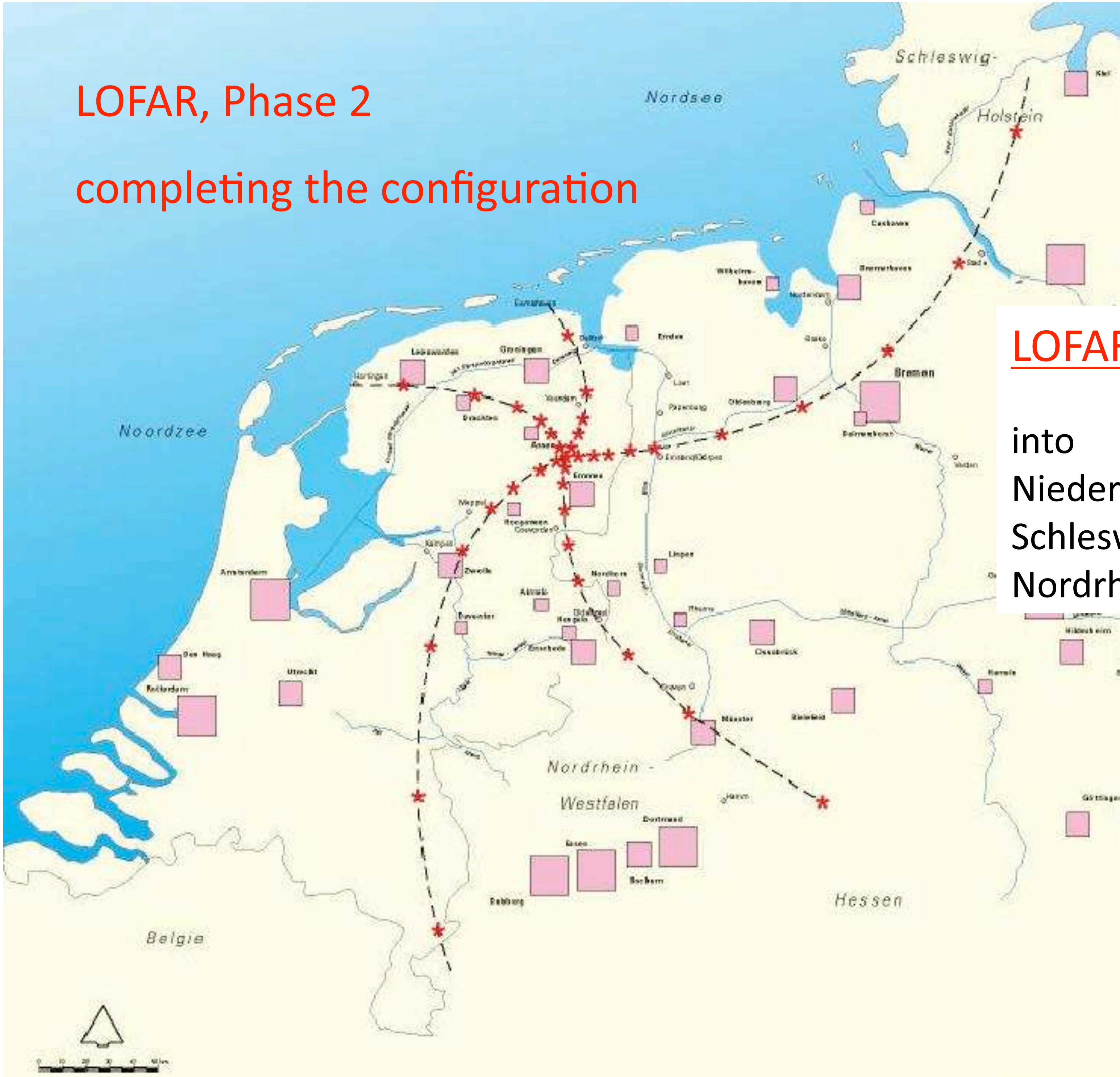
Central ITS Core at
Borger-Odoorn

- plus -
50 stations
100 km max baseline

- plus -
fibre connectivity
with future capacity
of 25 Tbps

LOFAR, Phase 2

completing the configuration



LOFAR

into
Niedersachsen,
Schleswig-Holstein,
Nordrhein-Westfalen

LOFAR, Phase 3

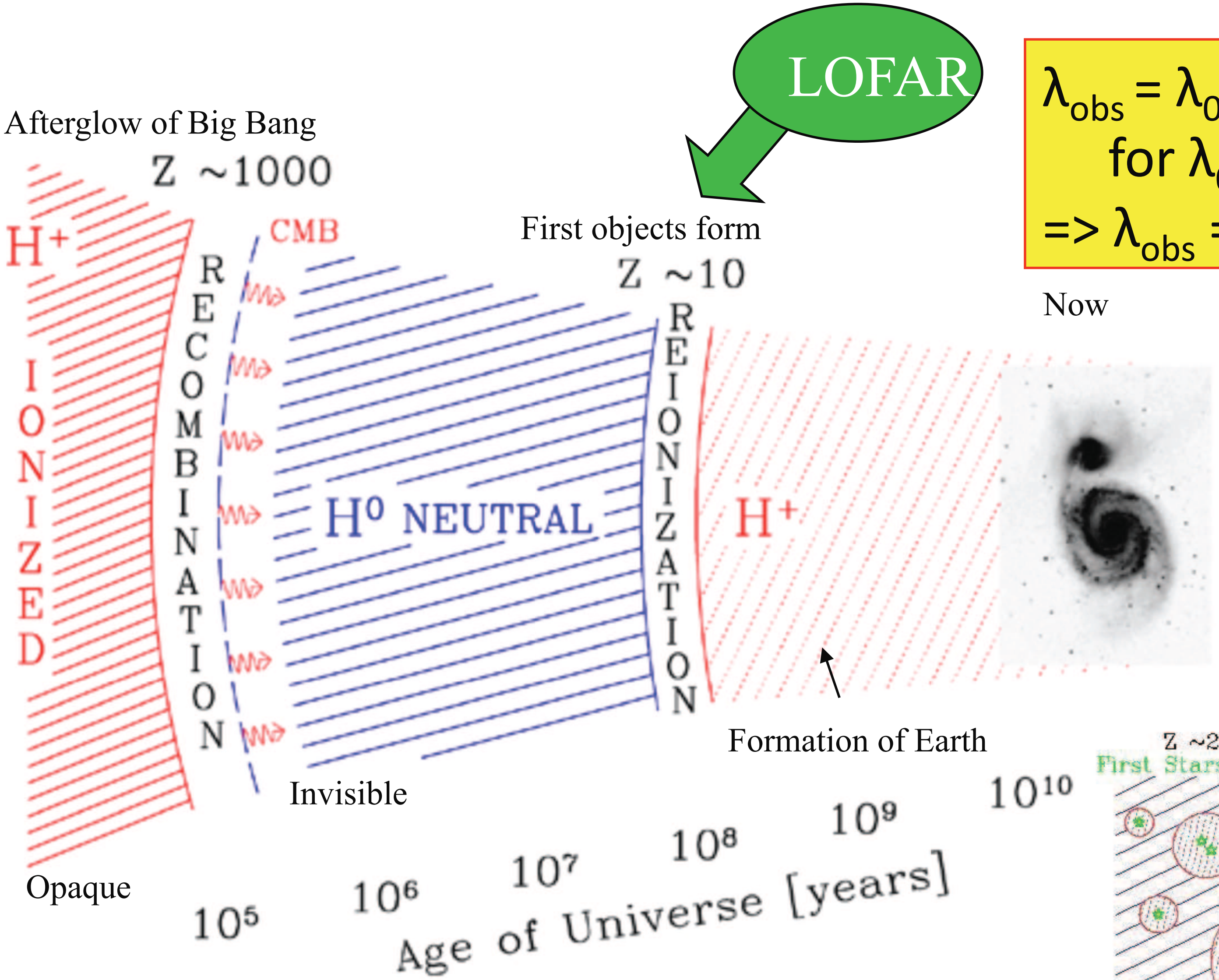
adding international stations

Ultimate LOFAR configuration

Onsala SE
Växjö SE
Cambridge UK
Oxford UK
JBO UK
Potsdam DE
Effelsberg DE
Nançay FR
Yebes ES
Toruń PL
Kraków PL
Bologna IT
etc...

History of the Universe

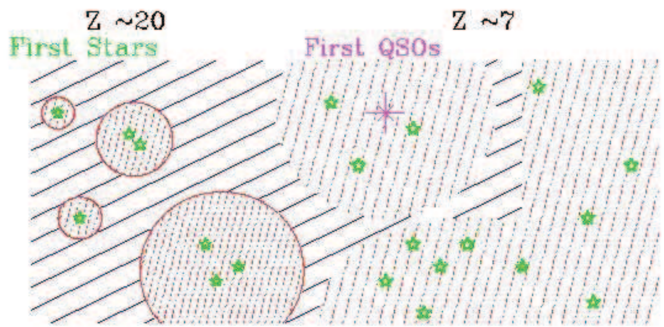
(condensed version)



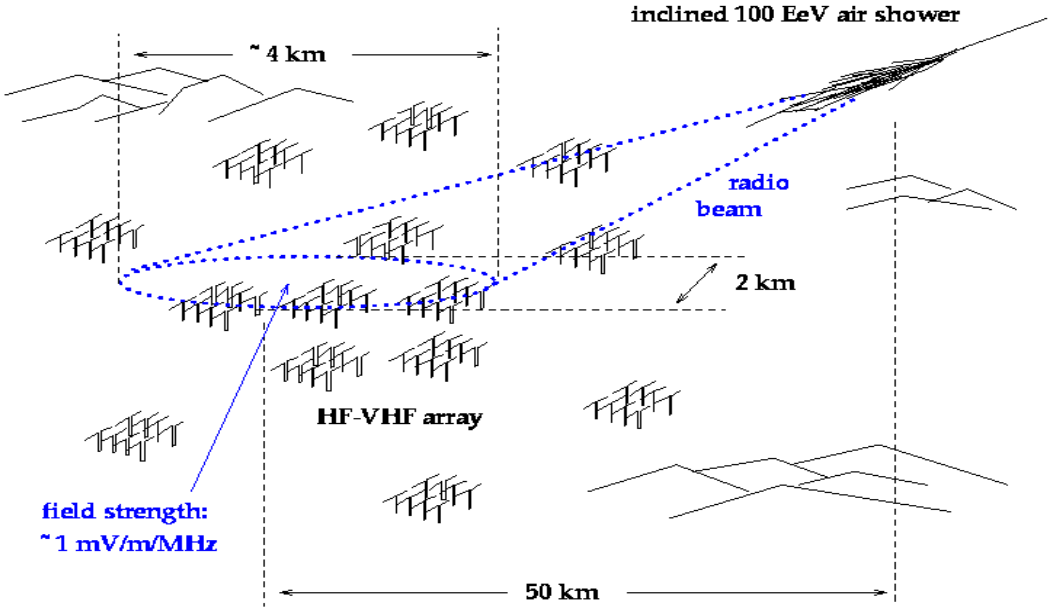
$\lambda_{obs} = \lambda_0\,(1+z)$

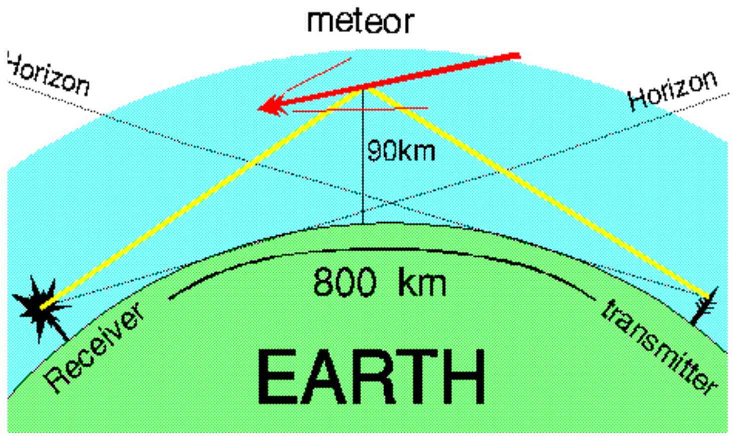
for λ_0 = 20 cm; $z \approx 10$

=> λ_{obs} = 220 cm: 136 MHz



Detecting particles in Earth's atmosphere

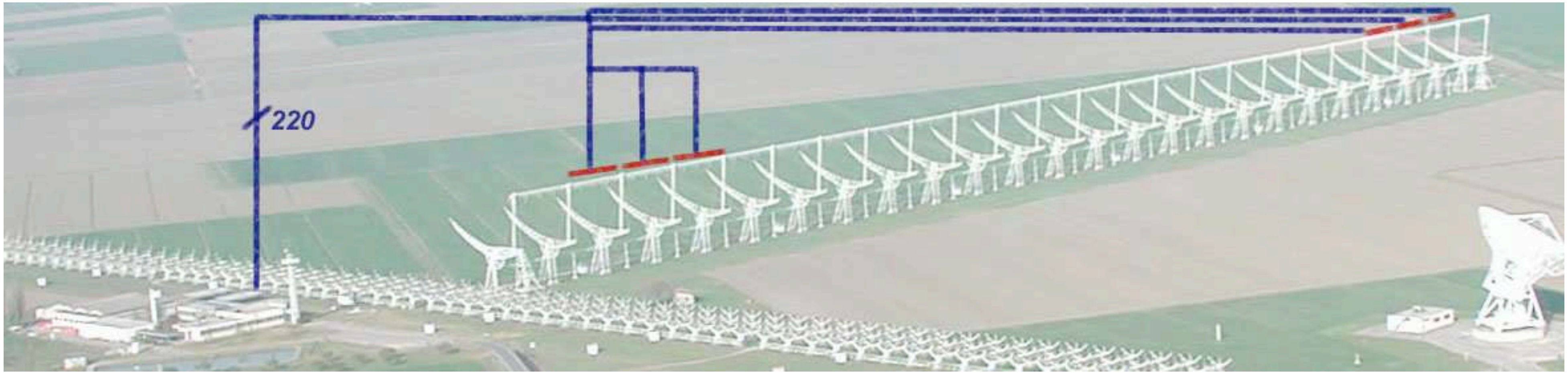




Cosmic Ray events using intrinsic coherent emission

Meteor events using radar (30 – 100 MHz)

LOFAR at Medicina



ν = 120 – 620 MHz ν_{inst} = 10 MHz

A_{eff} > 2000 m^2 (5000 m^2)

Fundamental Questions in Physics and Astronomy

“What are the basic properties of the fundamental particles and forces?”

Neutrinos, Magnetic Fields, Gravity, Gravitational Waves, Dark Energy

“What constitutes the missing mass of the Universe?”

Cold Dark Matter (e.g. via lensing), Dark Energy, Hot Dark Matter (neutrinos)

“What is the origin of the Universe and the observed structure and how did it evolve?”

Atomic hydrogen, epoch of reionization, magnetic fields, star-formation history……

“How do planetary systems form and evolve?”

Movies of Planet Formation, Astrobiology, Radio flares from exo-planets……

“Has life existed elsewhere in the Universe, and does it exist elsewhere now?”

SETI

Square Kilometre Array

~ 1 km^2 **collecting area** in an interferometer array

sensitivity ≈50 × EVLA

10000 × faster than EVLA

- wide frequency range: **0.1 – 25 GHz**
- configuration: **longest baselines > 3000 km;**

  50% collecting area < 5 km
- wide field of view: **50 sq. degree at < 1 GHz** (250 × moon)
- total cost 1 B€; operating costs 70 M€/year

SKADS (at Medicina)
1% demonstrator for SKA technology