LOFAR :

opening a window on the low frequency radio Universe

Goal in FP7 timeframe:

to evolve a unique national

into a unique

European research infrastructure

Developing the Science Case: workshops

2001
7-9 May, Dwingeloo, Netherlands

2002
21-25 January, Leiden, Netherlands
11-15 March, Austin, Texas USA
21-23 October, Washington DC USA

2004
27-28 January, San Diego USA
22-23 November, Växjö, Sweden
9 February, Bremen, Germany
19-22 March, Kahuku, Hawaii USA
22-23 April, Bonn, Germany
24-25 May, Dwingeloo, Netherlands

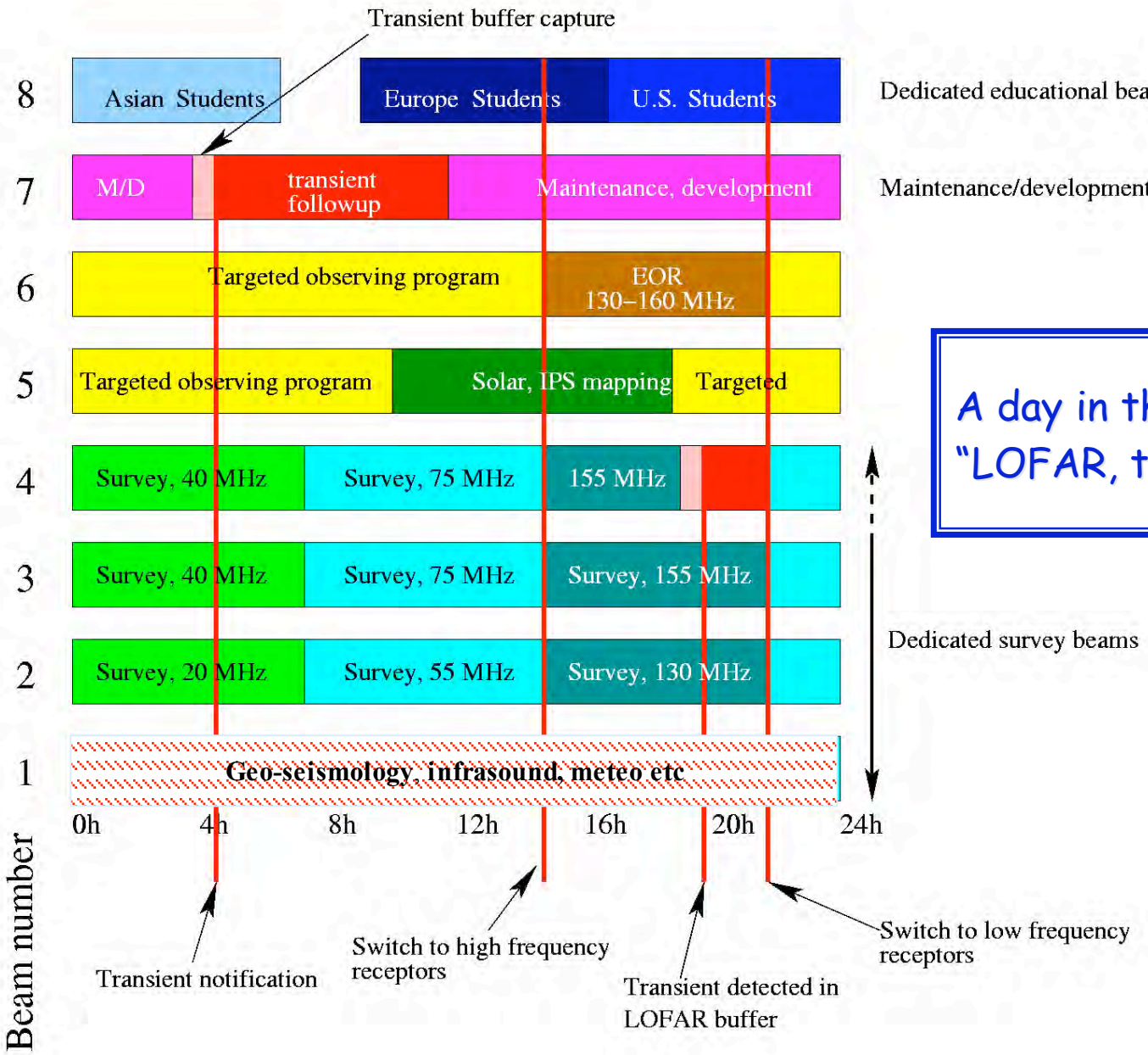
2005
1 February, Southampton, UK
3 March, Potsdam, Germany
16-18 March, Budapest, Hungary
22-23 March, Bremen, Germany
17-19 May, Zeuthen, Germany
27 June–1 July, Groningen, Netherlands
15-16 September, Bremen, Germany
27-30 September, Cologne, Germany
4-6 October, Zeuthen, Germany
11 October, Gran Sasso, Italy
24-28 October, New Delhi, India
15-16 December, Jülich, Germany

LOFAR

LOFAR : aperture synthesis interferometer

- Frequency range
  - f ~ 20 - 240 MHz (λ ~ 1.2 - 15m); FM-band excluded
- Unprecedented sensitivity
  - > 100x previous instruments: 0.03 – 3 mJy; 10^4 element antennas
- Angular resolution
  - ~ 100x previous instruments: ~ arcsec at 200 MHz; 160+ km array
- Temporal resolution
  - all-sky monitoring: $\Delta\tau$ ~ msec; signal buffer (sec)
- Frequency resolution, bandwidth
  - Δf ~ 1 kHz, 32 MHz instantaneous bandwidth
- Shared aperture multi-beaming
  - up to 8 independently pointable ‘software telescopes’

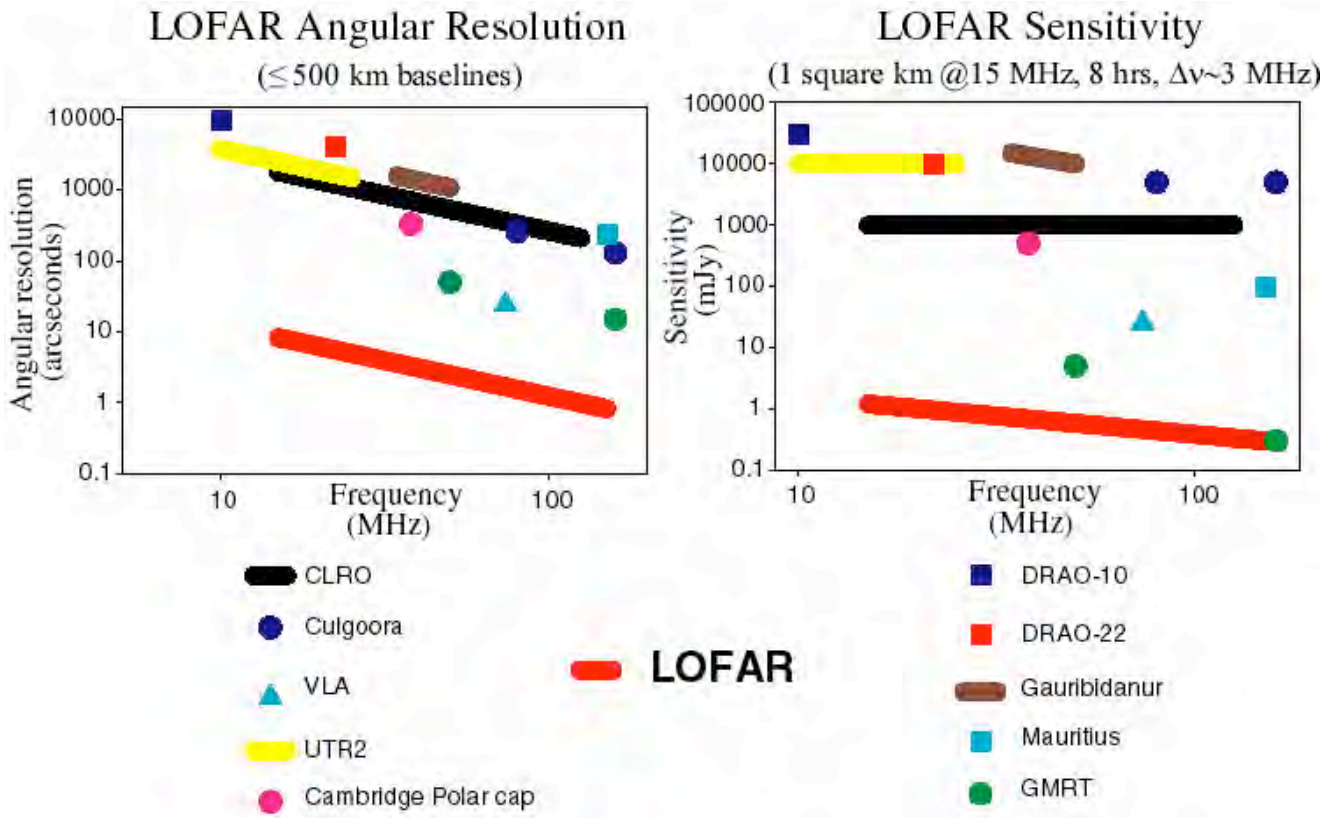
LOFAR



A day in the life of "LOFAR, the telescope"

LOFAR

Comparison to previous radio telescopes



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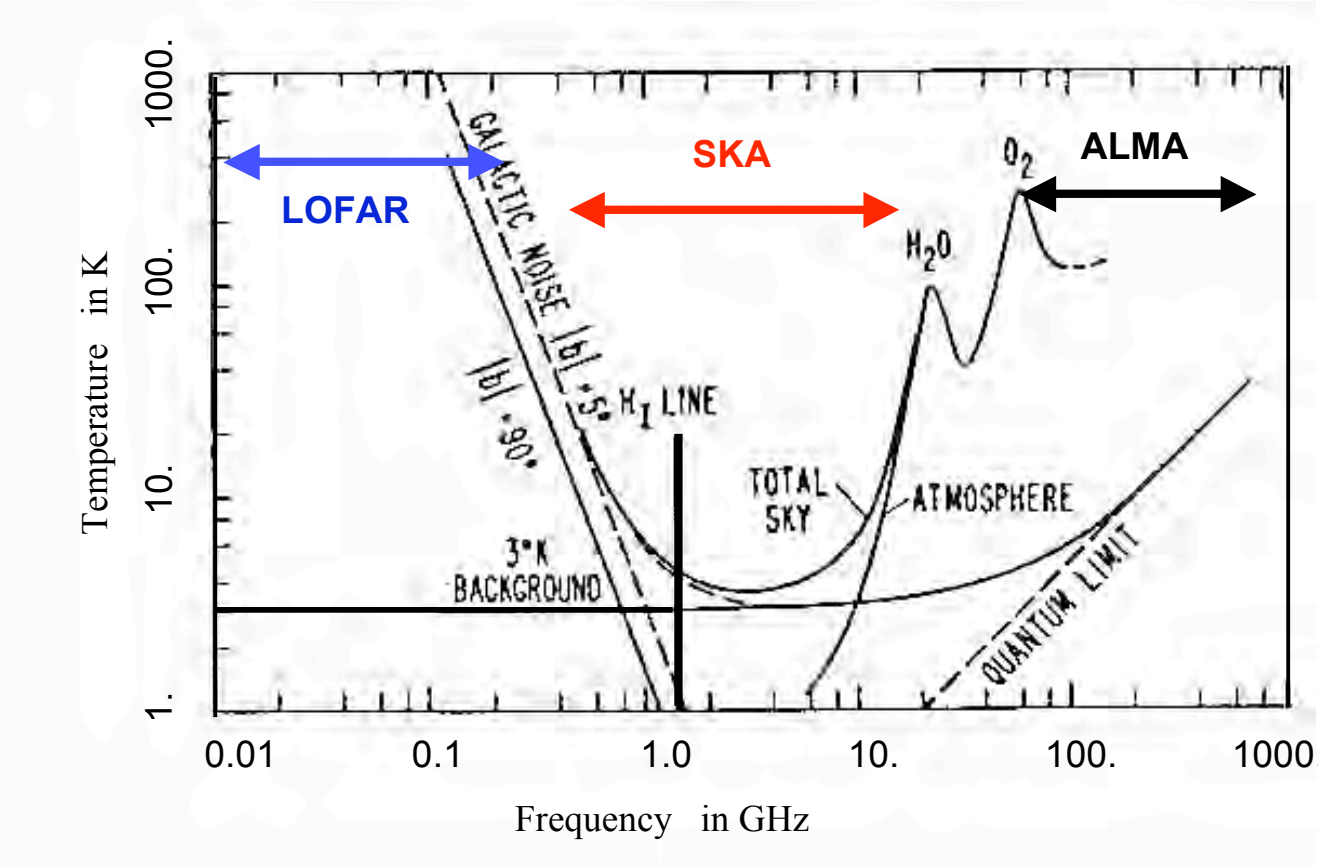
Comparison to future radio telescopes



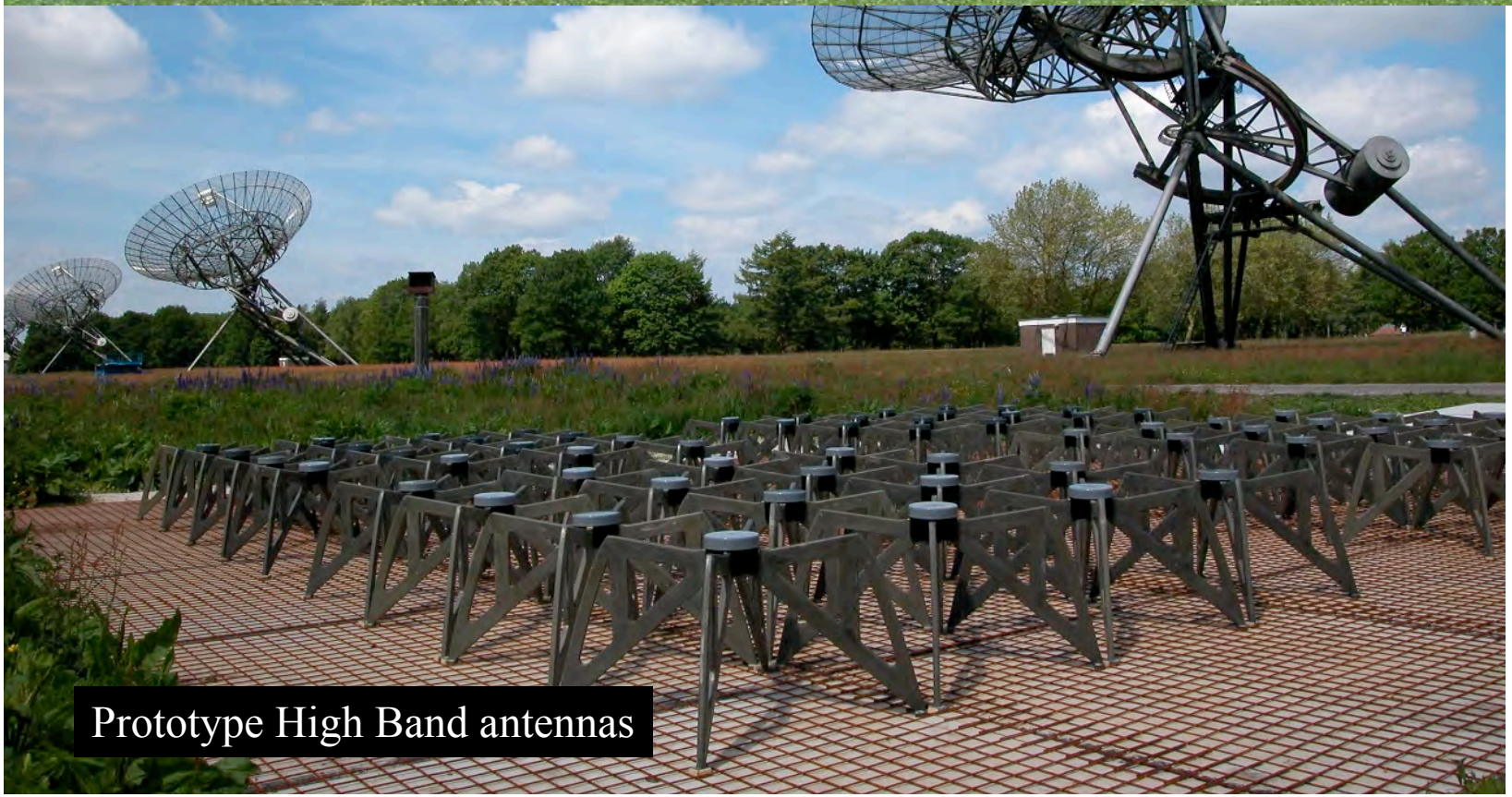
LOFAR

Project status

- Budget € 150M for development and construction in NL
- Critical Design Review in progress
  - 14 Sept – Antenna's, Receivers, ADCs
  - 30 Sept – Station digital processing
  - 12 Oct – Monitoring, Control, Specification, Scheduling
  - 19 Oct – Wide area network, Central Processor
  - 16 Nov – Calibration
  - 23 Nov – Key projects, User software
  - 2Q2006 – Final System Design Review
- Roll out starts summer 2006
- First operations beginning of 2007
- Full operations from 2008

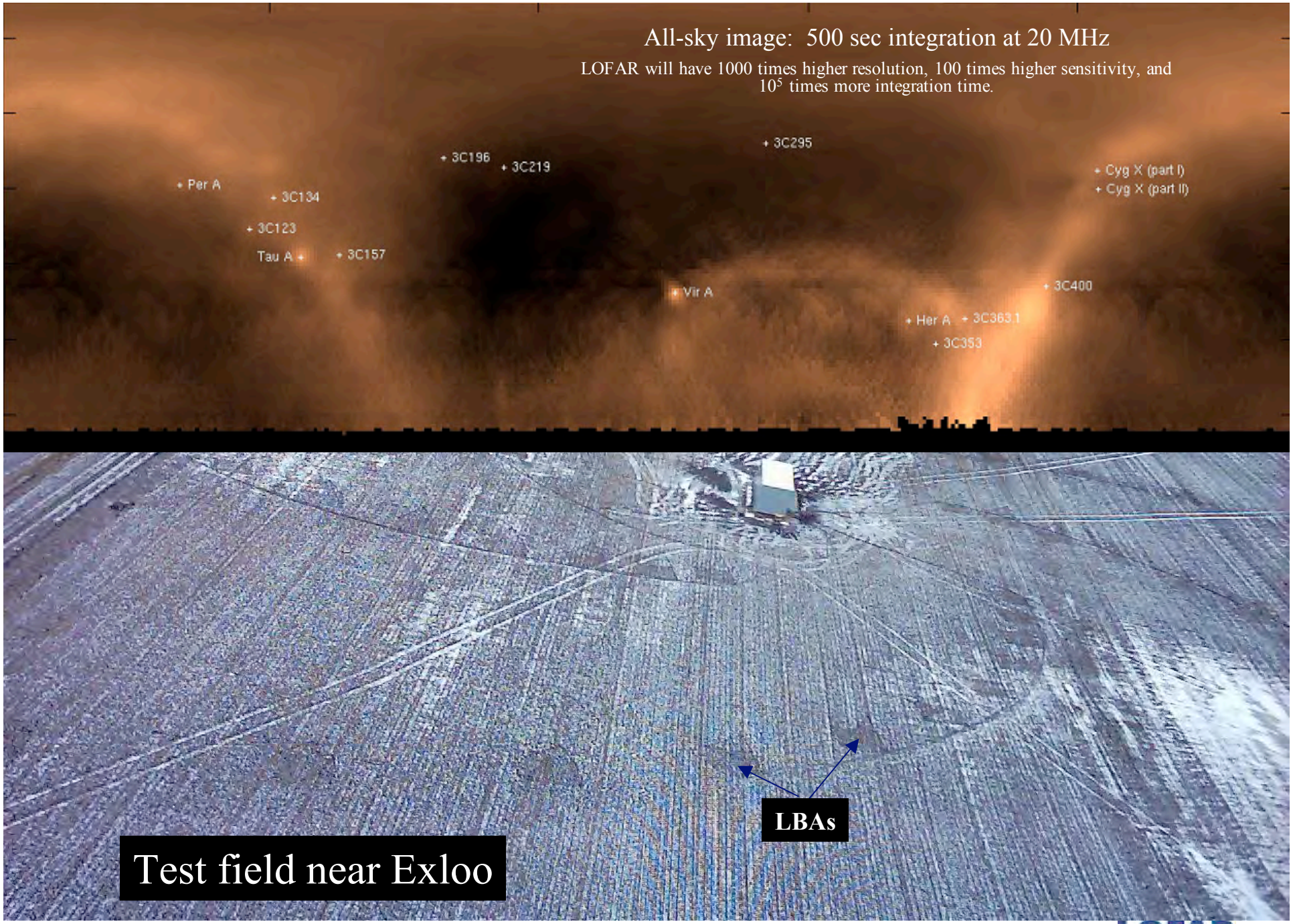
LOFAR

Prototype Low Band antennas



Prototype High Band antennas

LOFAR


All-sky image: 500 sec integration at 20 MHz
LOFAR will have 1000 times higher resolution, 100 times higher sensitivity, and 10^5 times more integration time.
3C295
3C196
3C219
Per A
3C134
3C123
Tau A
3C157
Cyg X (part I)
Cyg X (part II)
Vir A
3C400
Her A
3C363.1
3C353
LBAs
Test field near Exloo

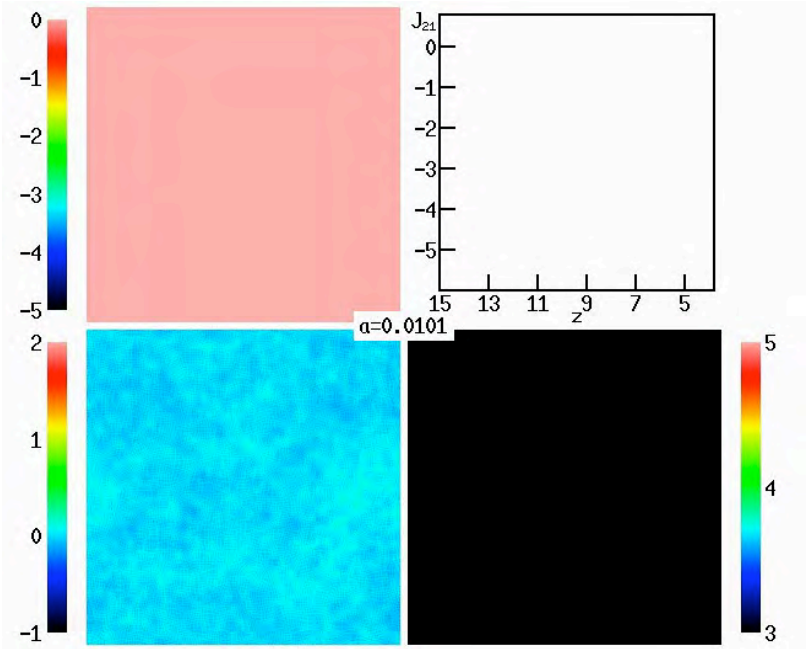
Science drivers

- Sky Survey at high (arcsec) resolution
  - sky at 30 - 50 MHz
  - high redshift Universe, fossil radio sources
  - complement, stimulate VLT, ALMA, JWST observations
- Detection of re-ionization signal
  - warm atomic hydrogen at $z \gtrsim 7$ (21cm → ~2m)
- Transient signals
  - new science: AGNs, pulsars, LIGO events, exo-planets
  - all-sky monitor, re-pointing after event
- Origin of Cosmic Rays
  - distribution in galaxies (see same electrons as γ-ray telescopes)
  - direct detection of the very highest energy particles
- Solar, space, atmospheric physics
  - solar physics
  - solar-terrestrial effects
  - turbulence, physics of lightning, ionospheric physics

LOFAR

Re-Ionization of the Universe

- After the big bang and recombination of elements the universe was neutral, matter and radiation decouple
- First luminous objects must have warmed the gas
- First Ly-α photons recouple matter and radiation
- 21cm line shifted to ~ 200 MHz is diagnostic of choice
- We expect clumpy neutral hydrogen emission from primordial matter at z ~ 6-10+



Gnedin (1999)

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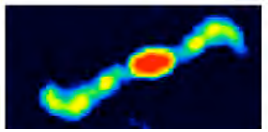
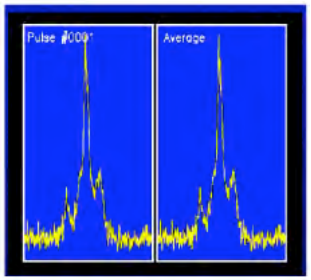
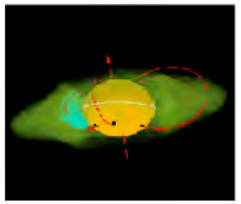
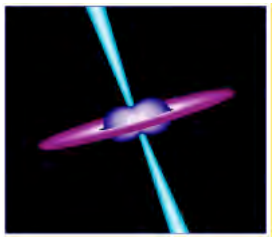
Transient Sources





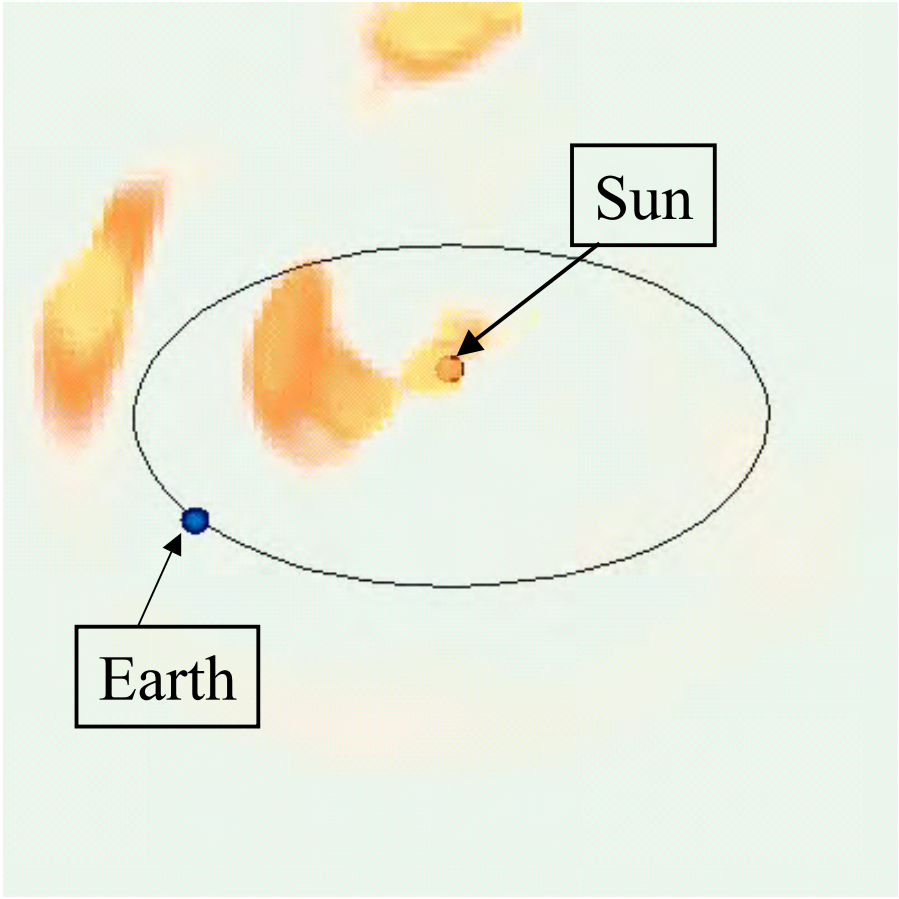




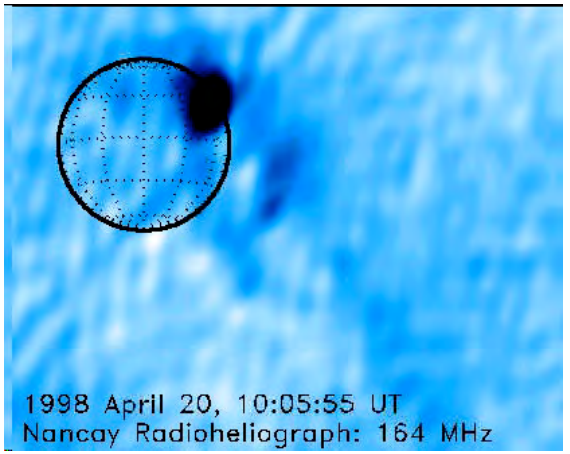
- X-ray Binaries (stellar mass black holes)
- AGN (supermassive black holes)
- Pulsars (neutron stars)
- CV's/Flare Stars
- LIGO Events (merging neutron stars)
- Supernovae
- Jupiter-like Planets
- Gamma-Ray Bursts (prompt emission and afterglows)
- Cosmic Rays & Neutrinos
- Meterorites
- … New sources …
  - Aliens, Airplanes, etc.

For the first time we will have an (almost) all-sky monitor of the radio sky!

LOFAR Studies of the Solar System: Space Weather

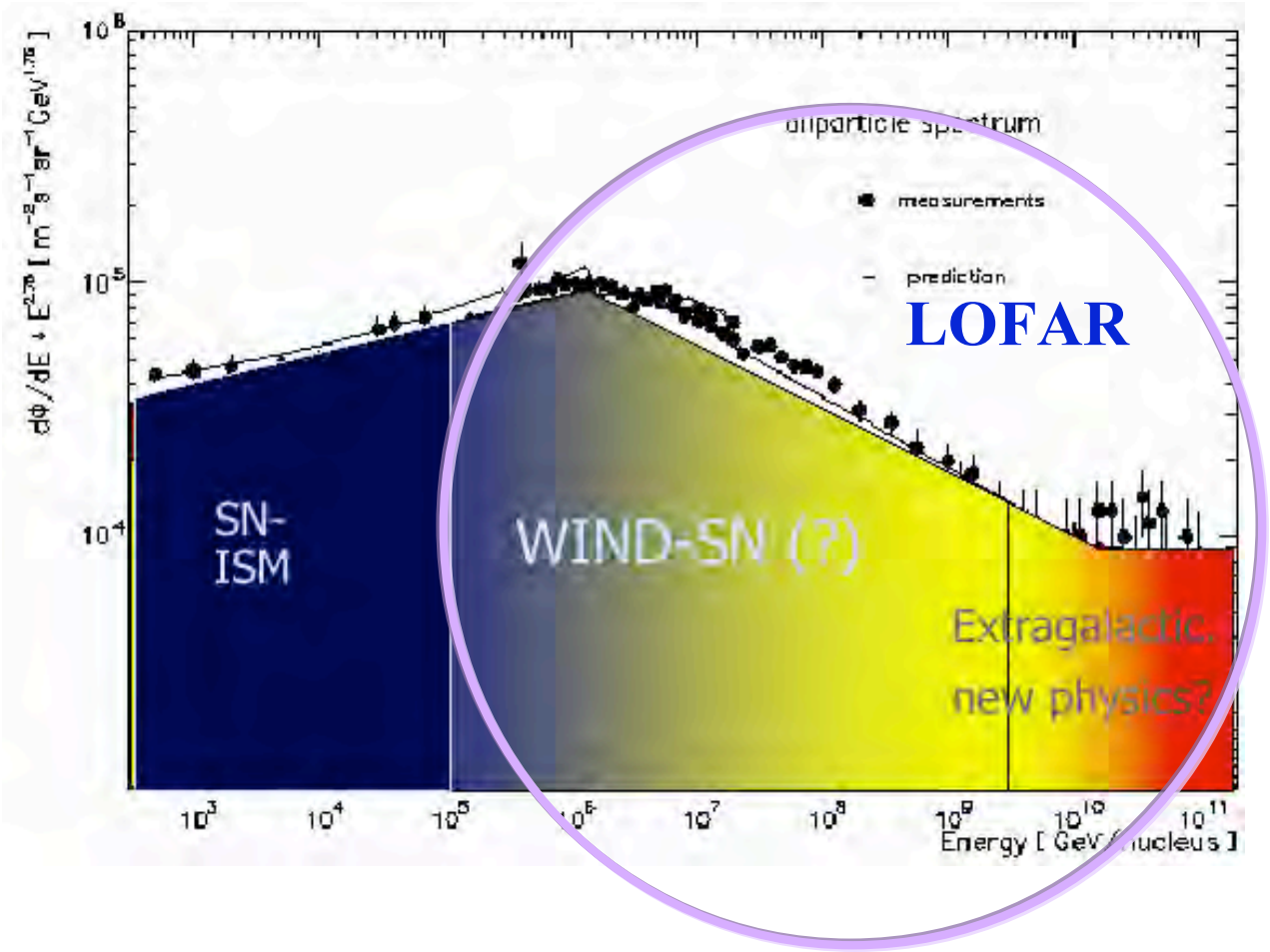


Solar Wind
observed via Radio Source Scintillation



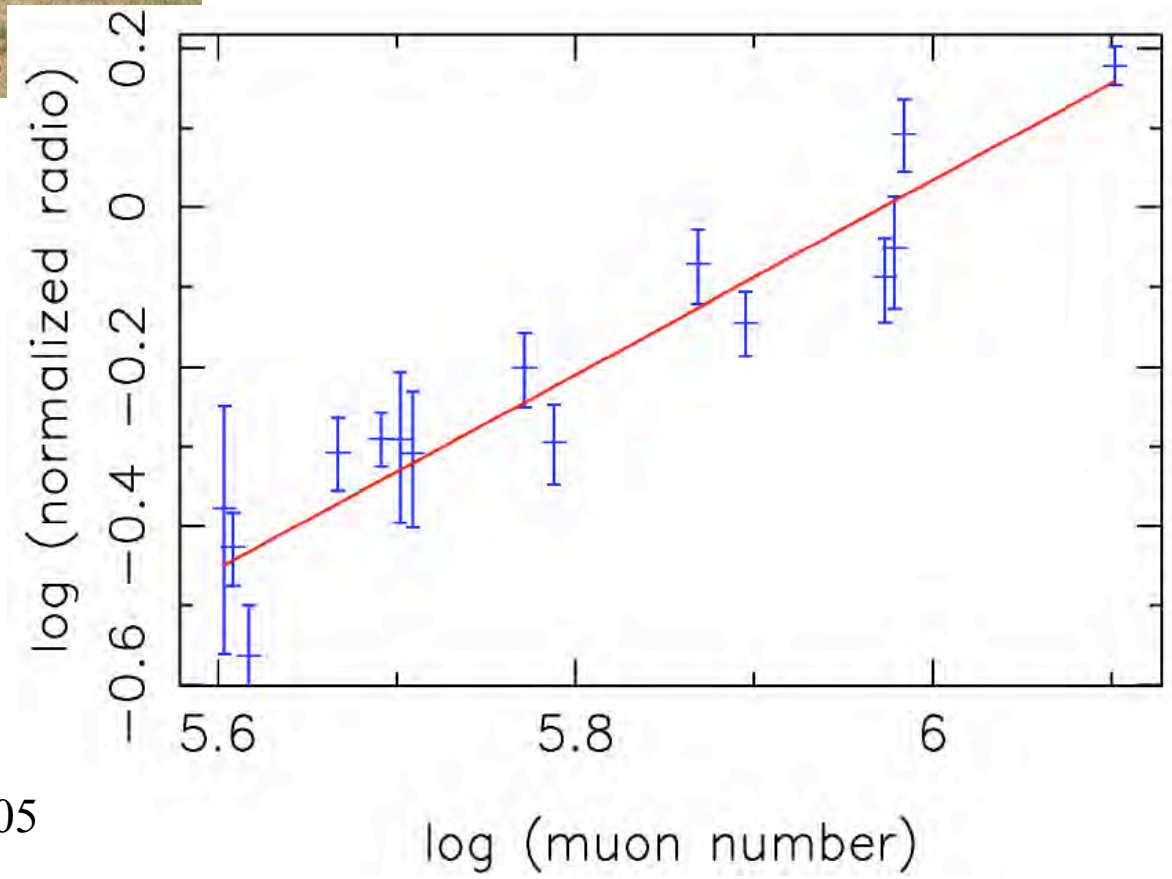
Animation LOFAR

LOFAR as Cosmic Ray detector



Prototype LOFAR Low Band antennas in Karlsruhe

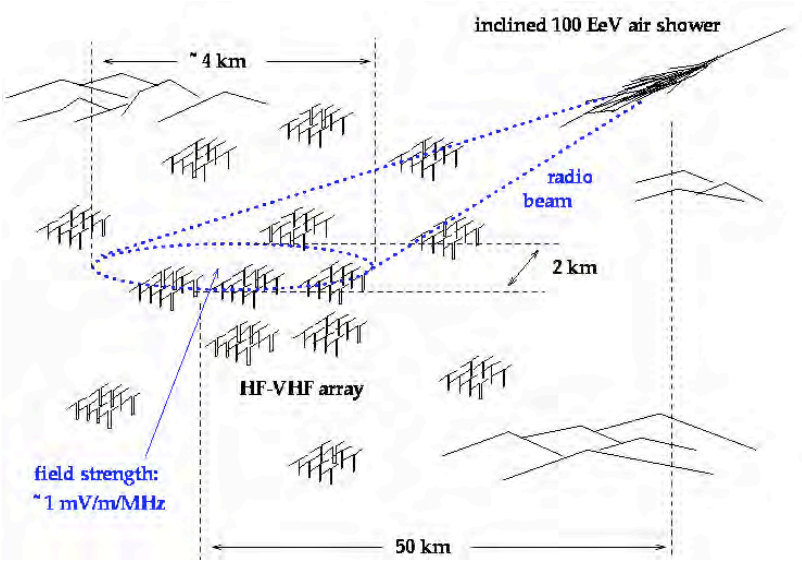
Demonstrated radio flashes from CRs are due to interaction with Earth's atmosphere and geomagnetic field



Flacke etal, *Nature*, 15 May 2005

Radio Emission from Ultrahigh-Energy Cosmic Particles

- Advantages:
  - Cheap detectors, easy to deploy
  - High duty cycle (24 hours/day)
  - Low attenuation (can see also distant and inclined showers)
  - Bolometric measurement (integral over shower evolution)
  - Very interesting for neutrinos



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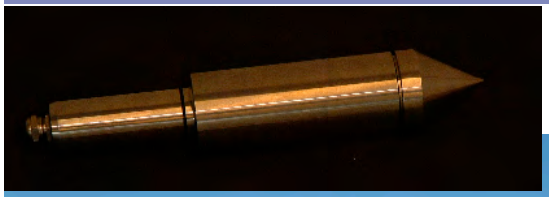
Non-astronomical research

Based on dynamic modelling guided by real-time sensing



Applications:

- Seismology
- Precision agriculture
- Infra-sound
- Wind energy
- Water management
- etc: e.g. lightning

e-IRG Road Map

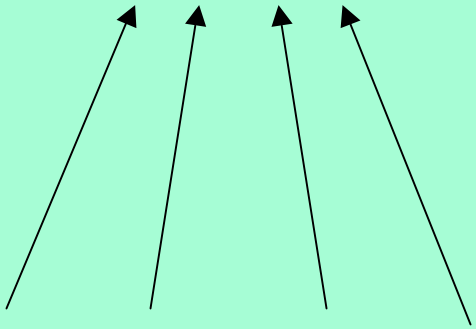
Conclusions

- Bright future for radio astronomy with ALMA, SKA, LOFAR
- Software telescopes will revolutionize low-frequency astronomy
- LOFAR will likely offer the single largest step forward that will be undertaken at any wavelength in the next decade
- LOFAR is a truly multi-disciplinary instrument
  - It will be a premier instrument from cosmology to climatology and astroparticle physics.
  - It is a research platform for sensor networks.
- LOFAR is extremely flexible: a lot is to be discovered!
- Next step: expand LOFAR across Europe

Consortium agreement LOFAR
LOFAR General Assembly

Stichting LOFAR:
"Beherend vennoot"

C.V.



"Commanditaire vennoten"

Development, construction and exploitation infrastructure

Research management Committee:

- Chairman
- 4 research program leaders
- Executive secretary

- Agriculture
- Astronomy
- Geophysics
- ICT

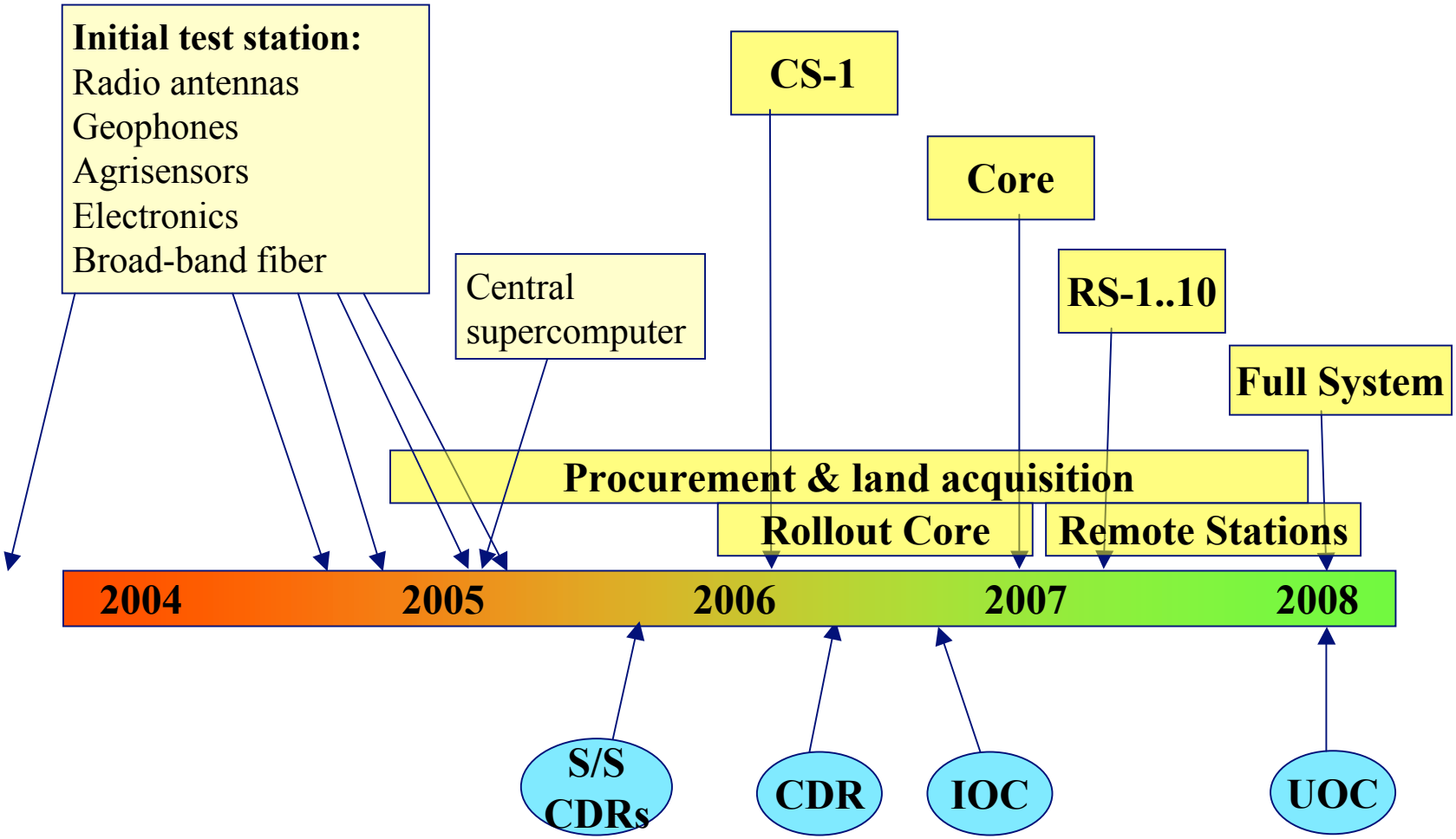
Research programs

LOFAR Organisation

- *Consortium 20 partners*
  - *6 universities, 2 technical universities, 5 knowledge institutes, 5 private companies*
  - *Of which 2 German and 1 Swedish partners*
  - *Interests: innovative instrumentation development, pre-competitive technology development, scientific use*
- *Limited partnership*
  - *Development, construction and operations of LOFAR*
  - *Transparency (separate from ASTRON), tax considerations*
- *Managing partner "LOFAR Foundation"*

LOFAR

Timeline Overall Development Plan



Costs, finance

- Dutch LOFAR costs to 2010: ~ € 150M
  - national, regional funds for economic structuring
  - universities, research councils, industry
- Single external antenna station: ~ € 0,6M + fiber connection
  - international partners to fund via national, regional sources
- Technical operations ~ € 7M per year
  - Dutch national, other national, international funds
  - excludes support for national computing, data transport infrastructure
  - excludes upgrades
- Science operations
  - Dutch, other national, local science system funding

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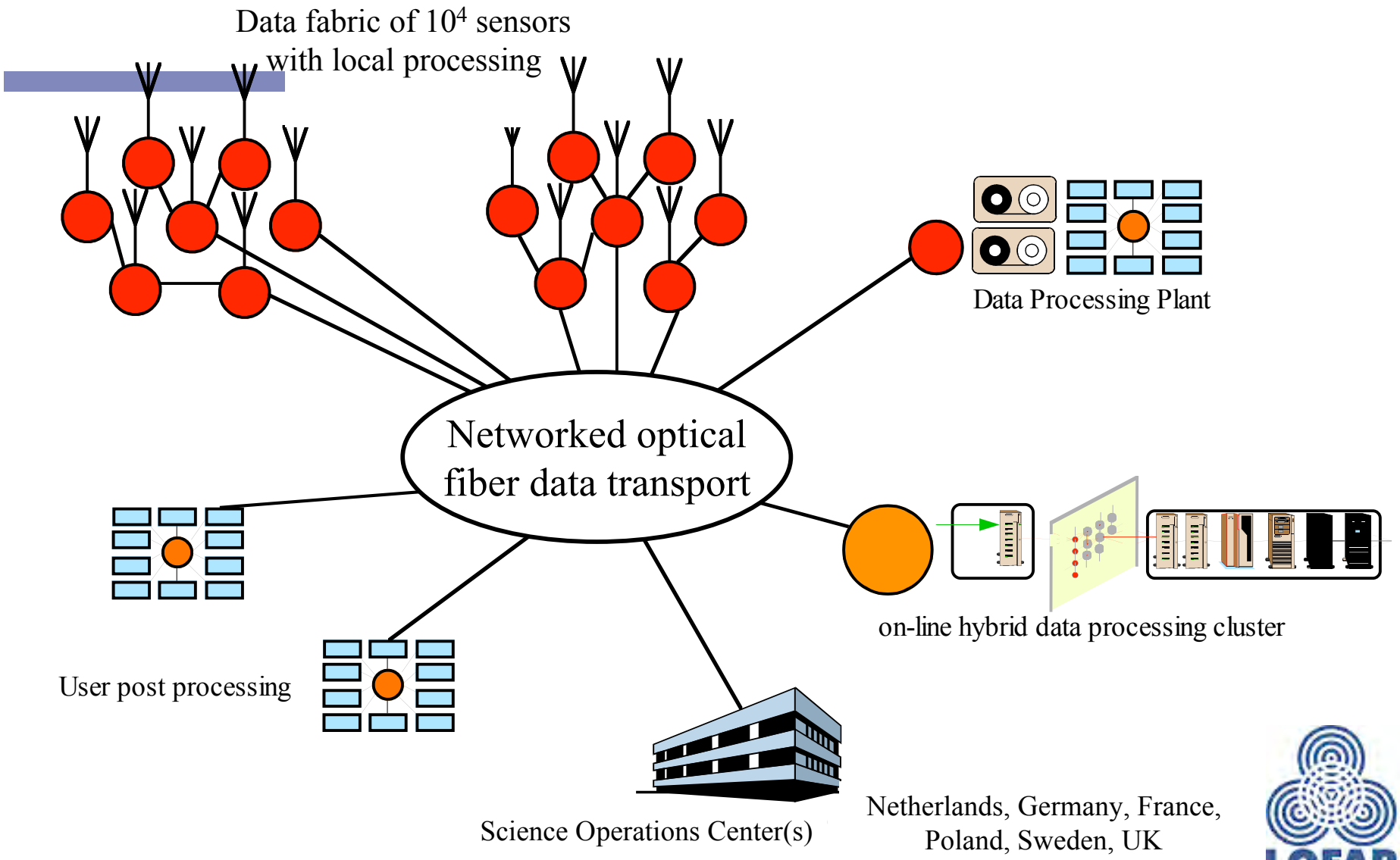
LOFAR operations



LOFAR Access

- *Guaranteed time (commissioning)*
  - *Key programs*
- *Scientific merit*
  - *Time allocation based on refereed proposals*
- *BUT: LOFAR paradigm shift*
  - *NOT limited by available telescope time per user*
  - *MORE LIKELY limited by user smartness & user software*

Success of LOFAR requires being open to many users

LOFAR

LOFAR Europeanisation

- *Interest in scientific and technological participations*
  - *Germany (GLOW consortium, FZ Jülich, …)*
  - *Sweden*
  - *U.K.*
  - *France*
  - *Italy*
  - *Poland*
  - *Etc.*

- *LOFAR is open to other participants in all relevant areas of science*
  - *Issues: financial (investment, operations), data rights, physical locations, broadband infrastructure*

LOFAR

LOFAR Europeanisation

- *LOFAR is ideally suited to becoming a European Research Infrastructure*
  - *Scientific interest in many countries*
  - *... across many scientific disciplines*
  - *... can accommodate several users at once*
  - *Technologically very challenging*
  - *Takes technology transfer very seriously*
  - *Interests parallel with other European priorities:*
    - *GMES*
    - *SKA*
    - *Geant (multi-gigabit pan-European data communications network)*
  - *Appealing to a wide community (including the public)*
  - *Draws young people to it*

LOFAR

LOFAR Europeanisation: What is needed?

- *What is not needed?*
  - *Interest at country level now starts bottom-up*
  - *Core infrastructure is already funded*
  - *Broad scientific use already guaranteed*

- *So, what is needed?*
  - *Expansion of infrastructure across Europe*
    - *Broadband fiber network, Stations, Expansion of central processing*
  - *Organization of integration in European programs*
    - *Astronomy, GMES, Meteorology, geophysics, particle physics*

LOFAR

Thank you

LOFAR Performance

Frequency (MHz)	A_{eff} (m^2)	T_{sys} (in K)	δS in 1s (mJy)	δS in 10h (mJy)	δS in 100h (mJy)
30	3.3×10^5	23k	68	0.35	0.11
75	5.2×10^4	2450	46	0.24	0.07
120	3.3×10^5	820	2.4	0.013	0.004

Approximate sensitivity per beam, with 4 MHz BW and for a single polarization

LOFAR

LOFAR Applicaties: Partners

RuG

TU Delft
Technische Universiteit Delft

Universiteit Leiden

Radboud Universiteit Nijmegen

TU/e

UvA

Uppsala Universitet

CWI

KNMI

TNO
Netherlands Institute of Applied Geoscience TNO
-National Geological Survey

WAGENINGEN UR
for quality of life

ORDINA

S&T

Dutch Space

Max-Planck-Institut für Radioastronomie

IUB

Geomatics Park

energy valley

AVEBE

RIZA

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