ASTRON

Netherlands Institute for Radio Astronomy

Astronomy at ASTRON

George Heald

27 May 2011

Outline

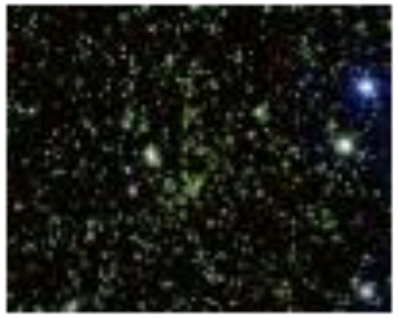
- Overview of ASTRON science, and why do radio interferometry?

- Science with WSRT: Highlight on nearby galaxies
  - Neutral hydrogen (HI): *cold atomic gas - fuel for star formation and an excellent kinematic tracer*
  - Magnetic fields: *weak magnets, but a high energy density!*

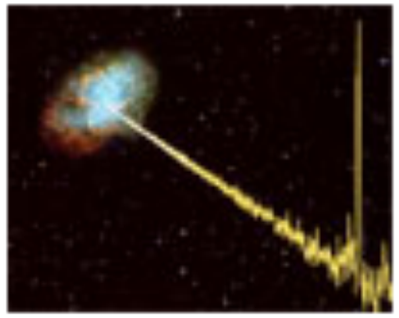
- LOFAR: what and where
- Science with LOFAR
  - Key Science Projects
  - Surveys and Cosmic Magnetism
  - Latest LOFAR images!

Astronomy at ASTRON

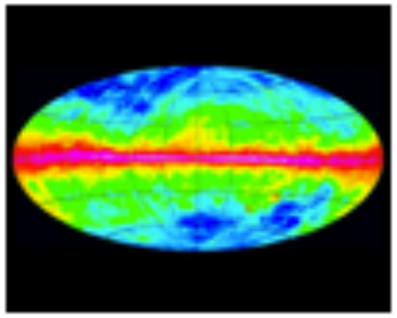
- Astronomers at ASTRON are working on many science topics:



DEEP FIELDS

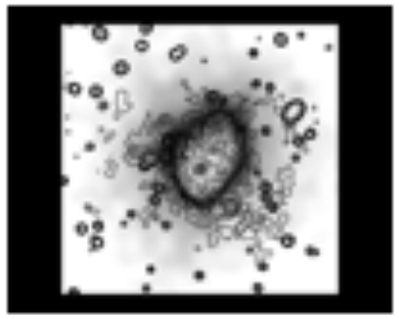


COMPACT OBJECTS



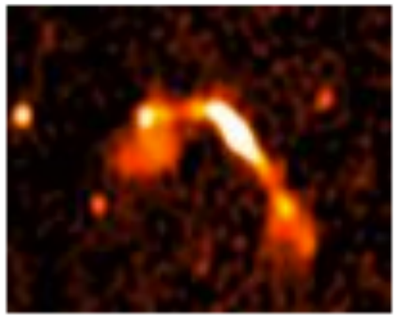
MILKY WAY ISM

NEARBY GALAXIES



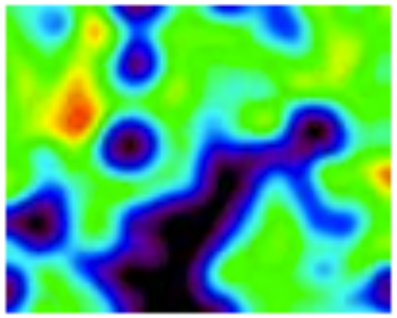
CLUSTERS

COSMIC MAGNETISM



AGNs

GRAVITATIONAL LENSES

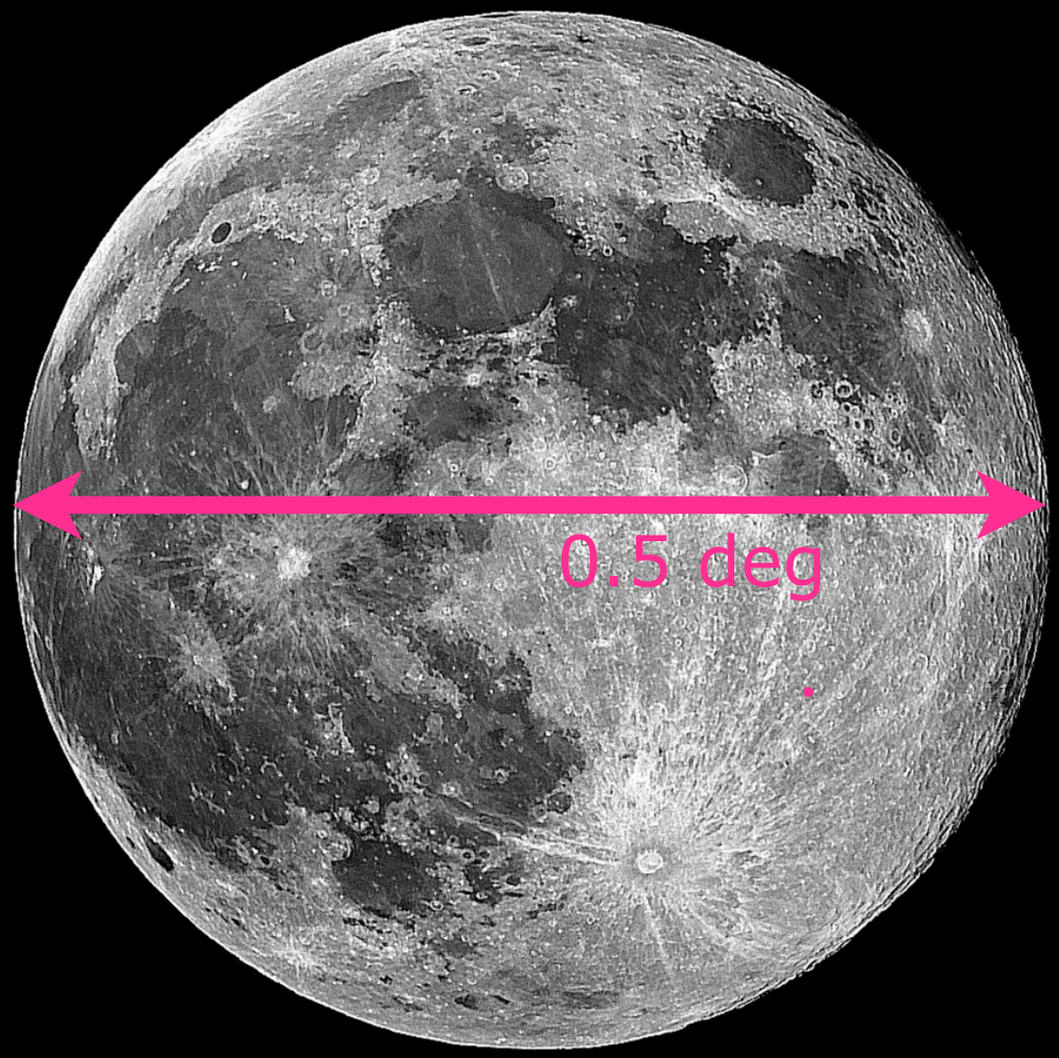


COSMOLOGY

Radio telescopes

- At ASTRON we observe mostly with radio telescopes, and especially *interferometers*
- These give us a sharp view of the sky, without building a huge, expensive dish!

$$\text{Resolution} \propto \lambda / D$$

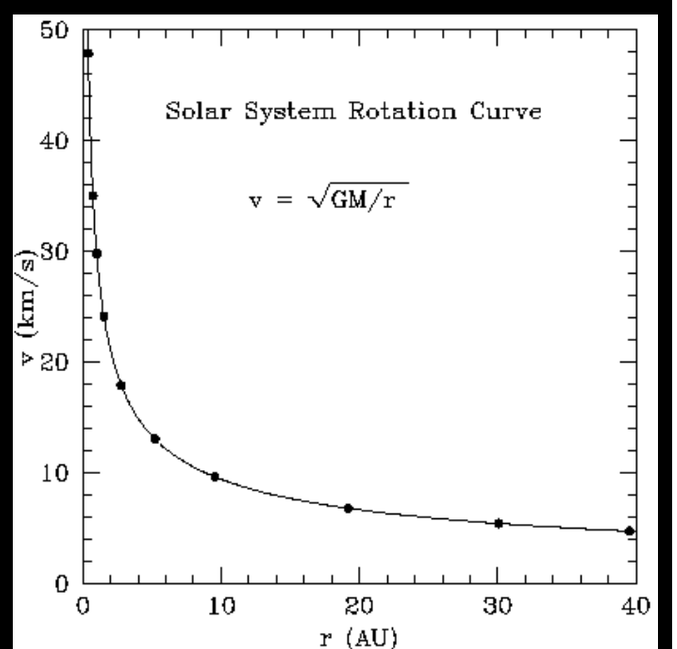


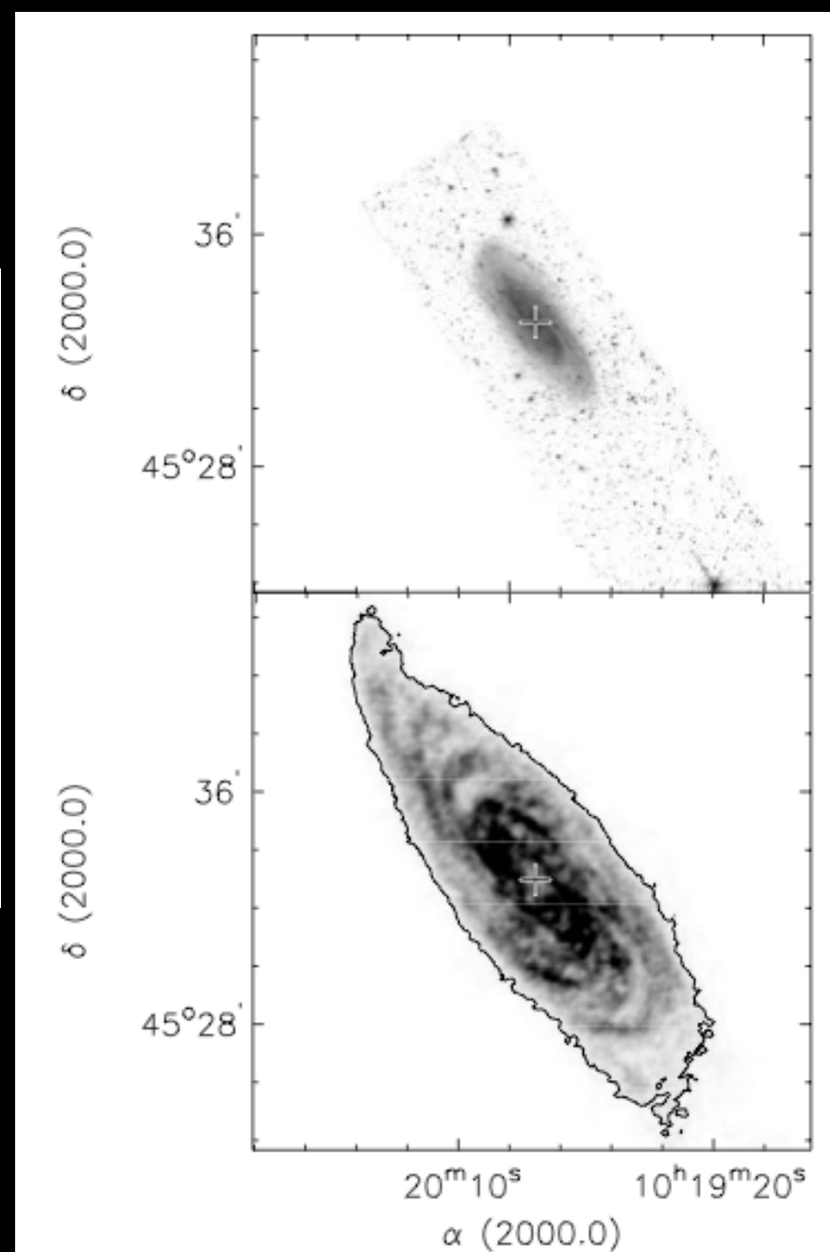
Nearby galaxies

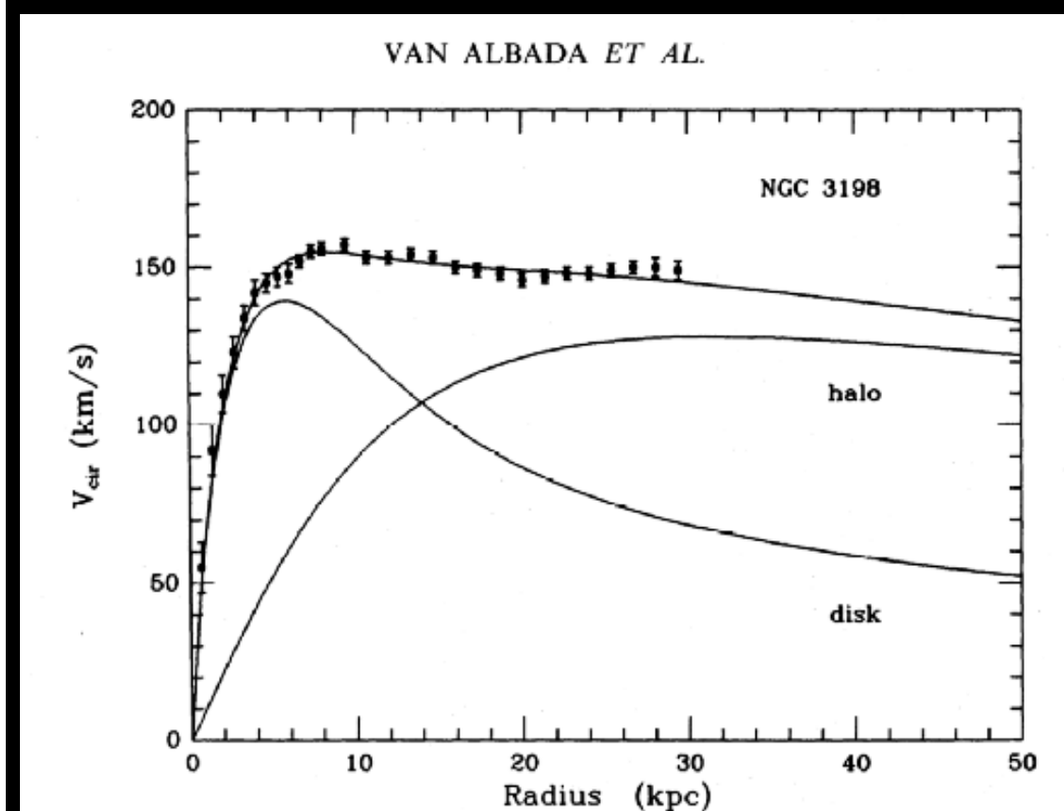
Hubble Heritage image
of M51 (the Whirlpool Galaxy)

Nearby galaxies with WSRT: HI

- HI traces material far out into the disk, often far beyond the optical light distribution
- Evidence for *dark matter*!



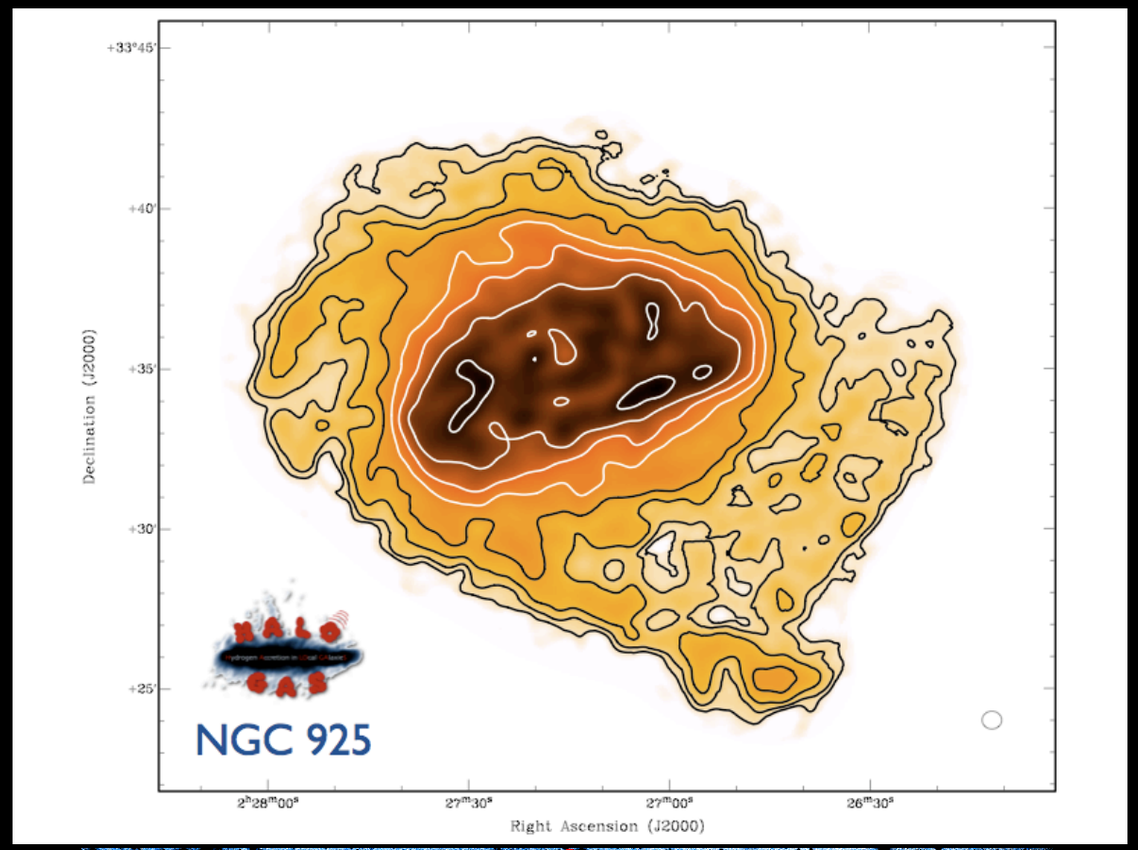


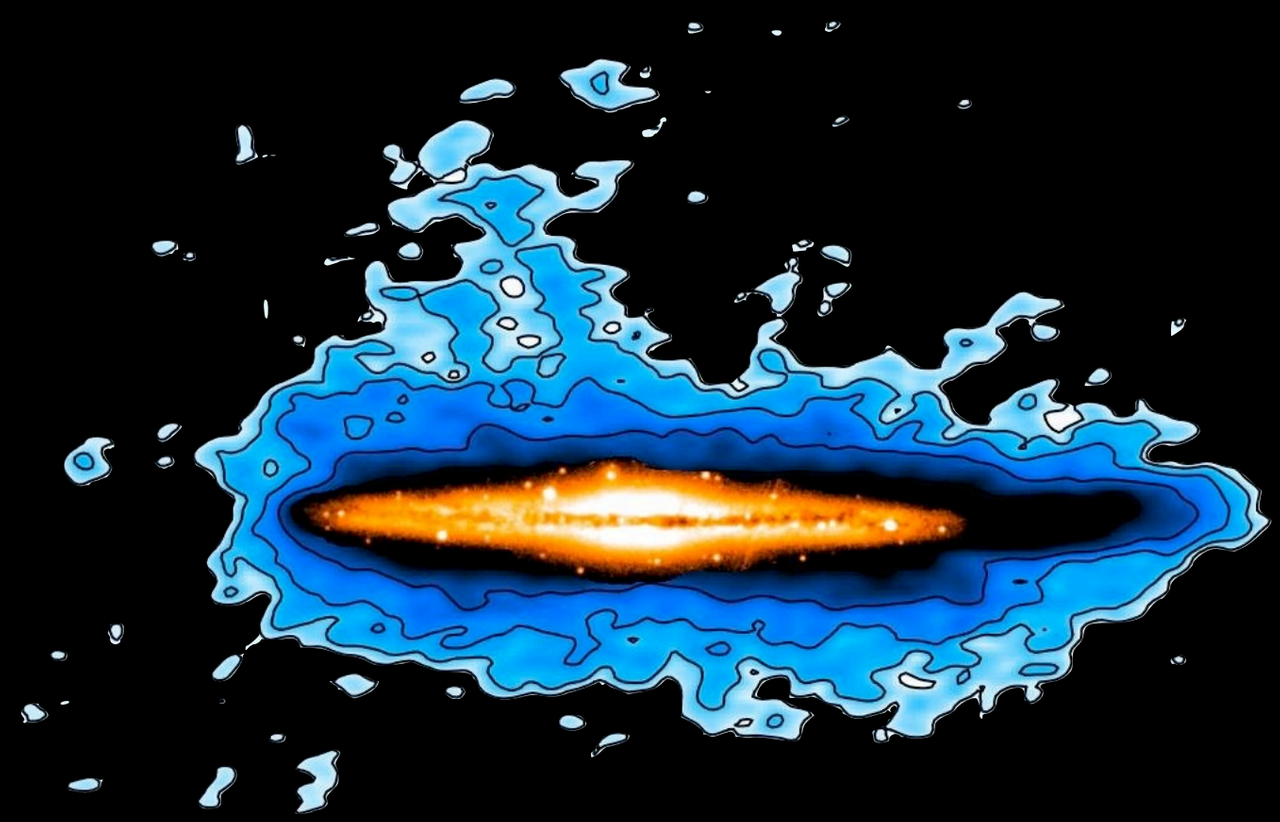


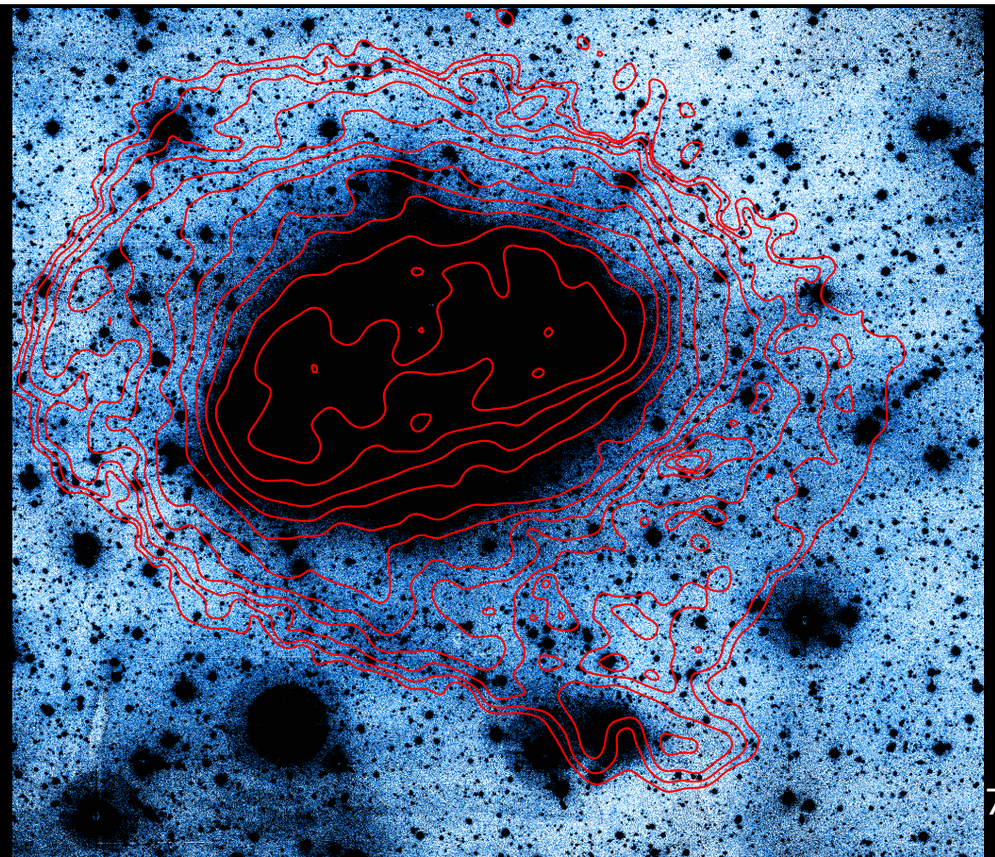
(maximum disk model)

Nearby galaxies with WSRT: HI

- HI is an excellent tracer of *cold gas accretion* in galaxies
- This process is important for maintaining star formation in galaxies (among other reasons)





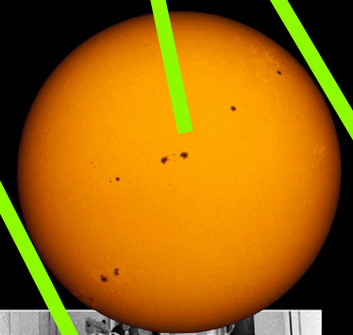


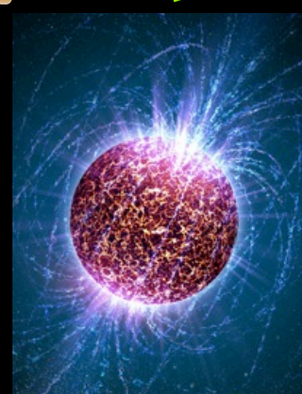
Nearby galaxies with WSRT: B-fields

- Spiral galaxies have magnetic fields with typical strengths of about 10 microGauss (~10,000 times weaker than the magnetic field used for cassette tapes!)

Magnetic field strength (Gauss)
(most numbers from wikipedia)

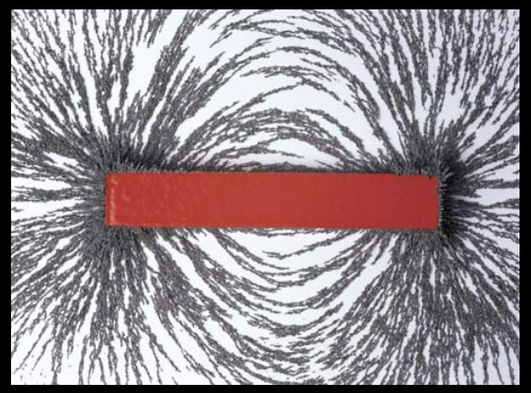
10^{-8} 10^{-5} 10^{-2} 10^{1} 10^{4} 10^{7} 10^{10}





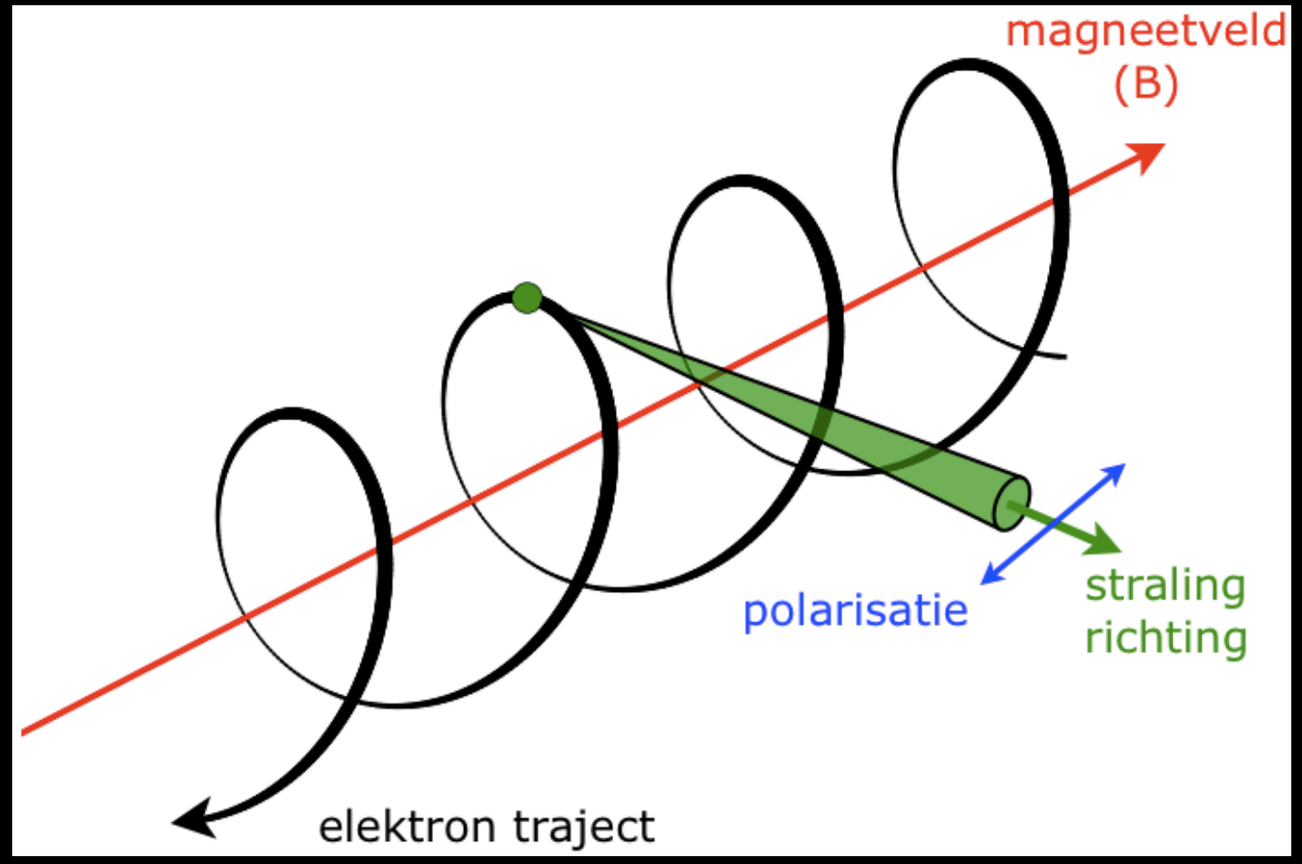
Nearby galaxies with WSRT: B-fields

- Magnetic fields are invisible ...

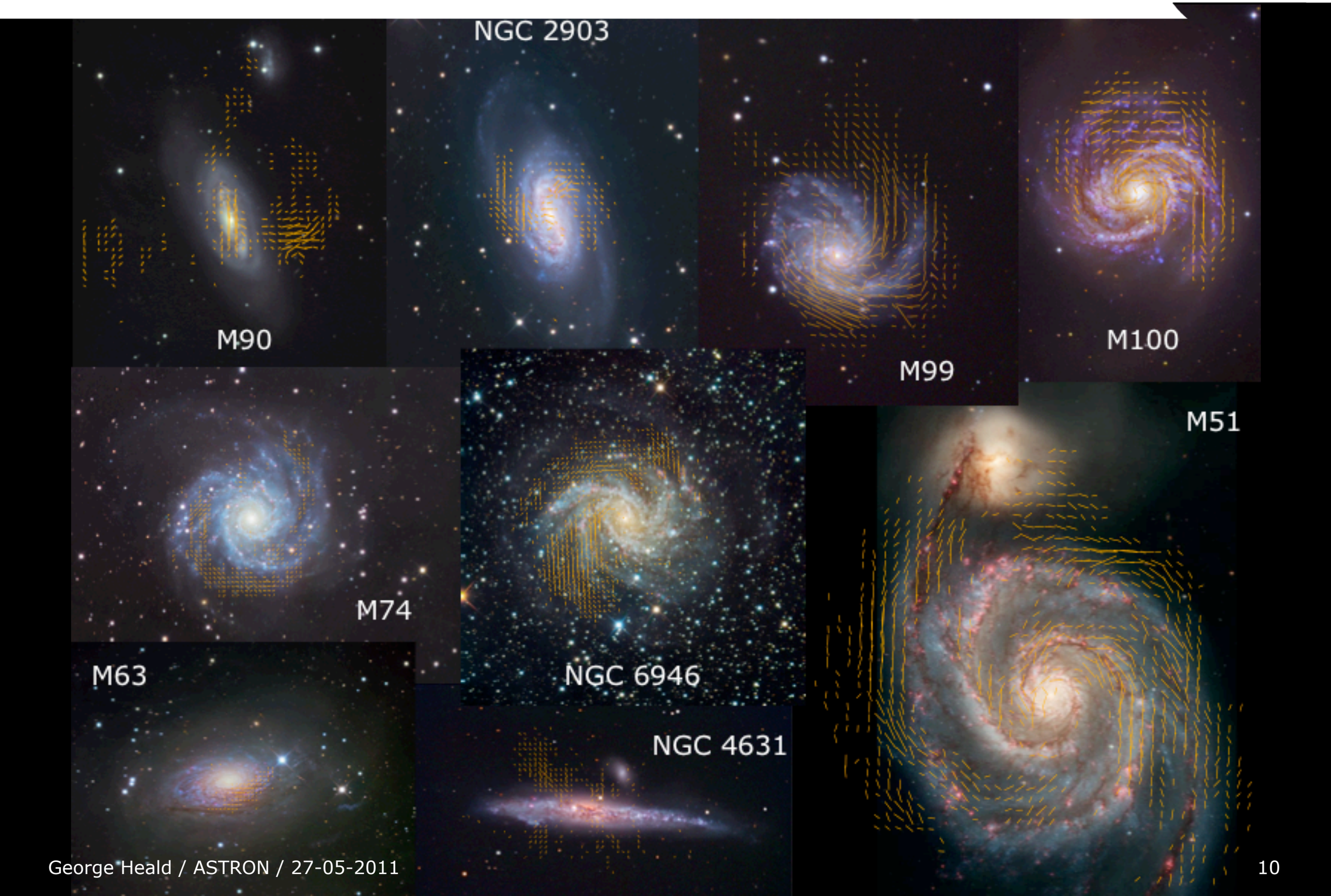


... so how do we see them?

- Relativistic cosmic rays are accelerated by magnetic fields, and therefore produce synchrotron radiation
- Synchrotron radiation is polarized - this gives us information about the orientation of the magnetic fields

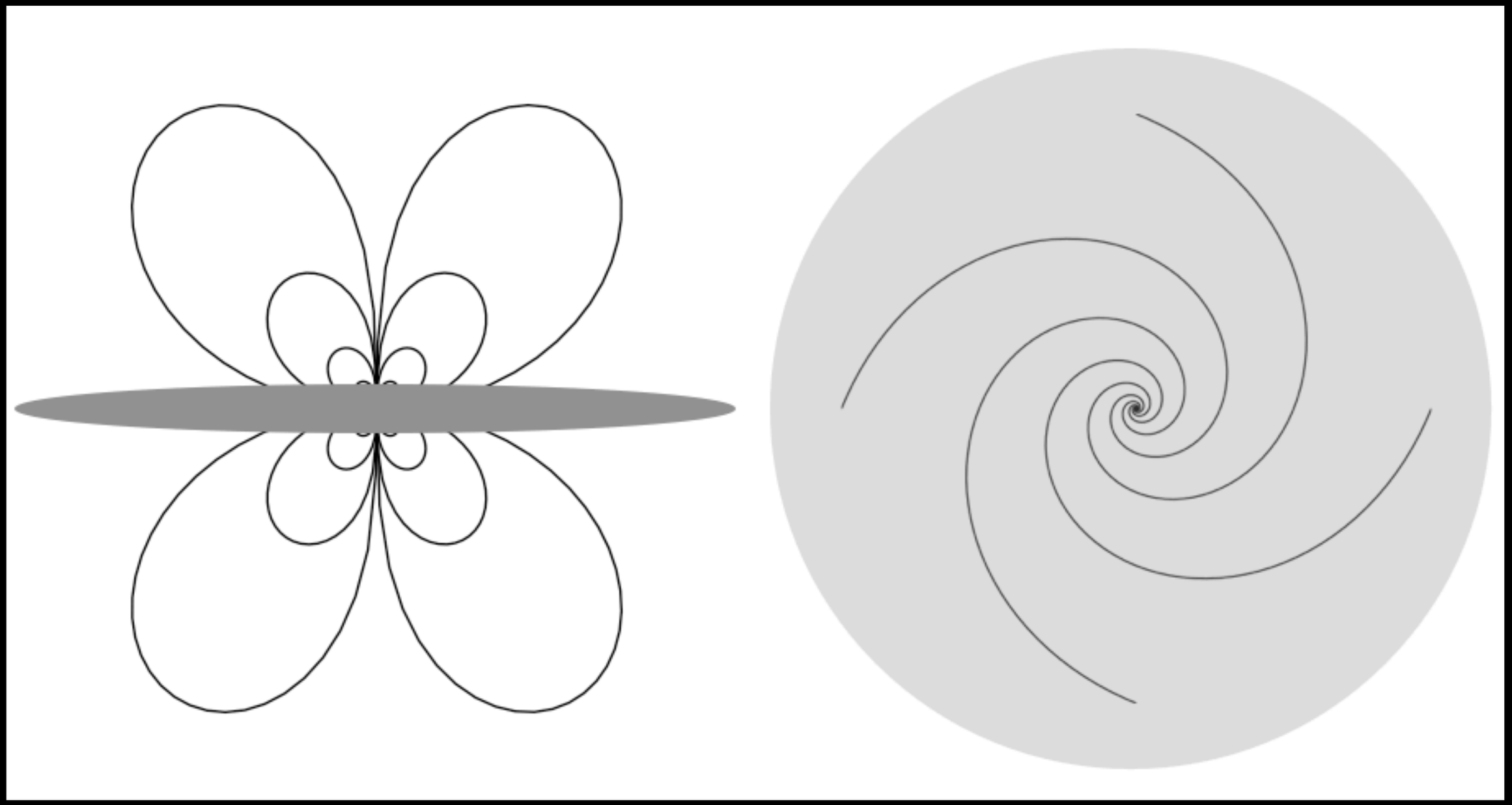


Nearby galaxies with WSRT: B-fields



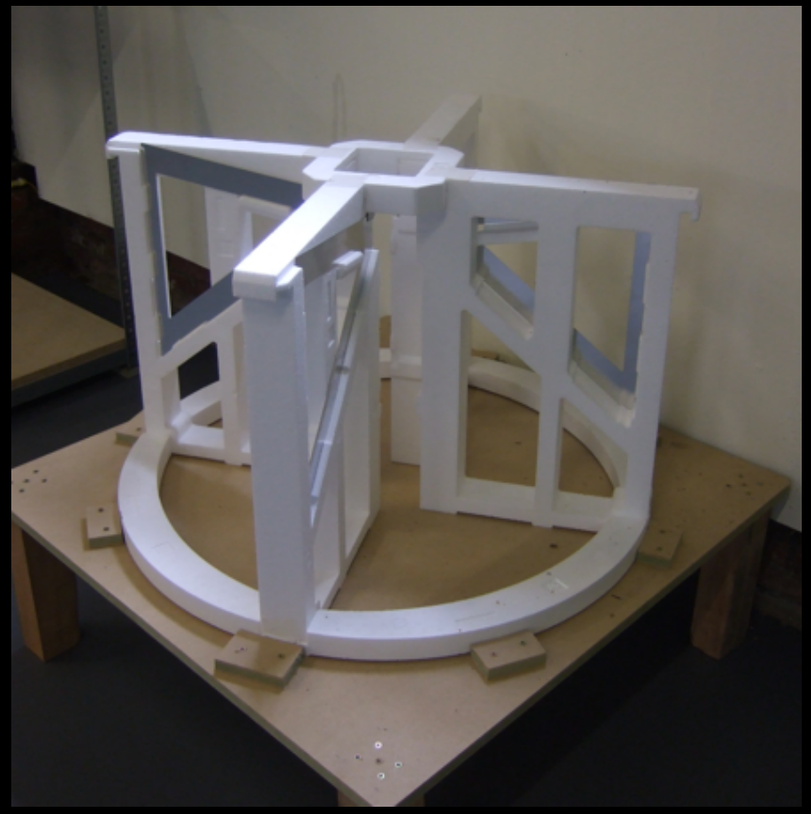
Nearby galaxies with WSRT: B-fields

- Spiral galaxies have spiral magnetic fields, with a vertical component (originating from a *quadrupolar* field)



LOFAR: what it's made of

- Two kinds of antennas: low-band (30-80 MHz) and high-band (120-240 MHz)



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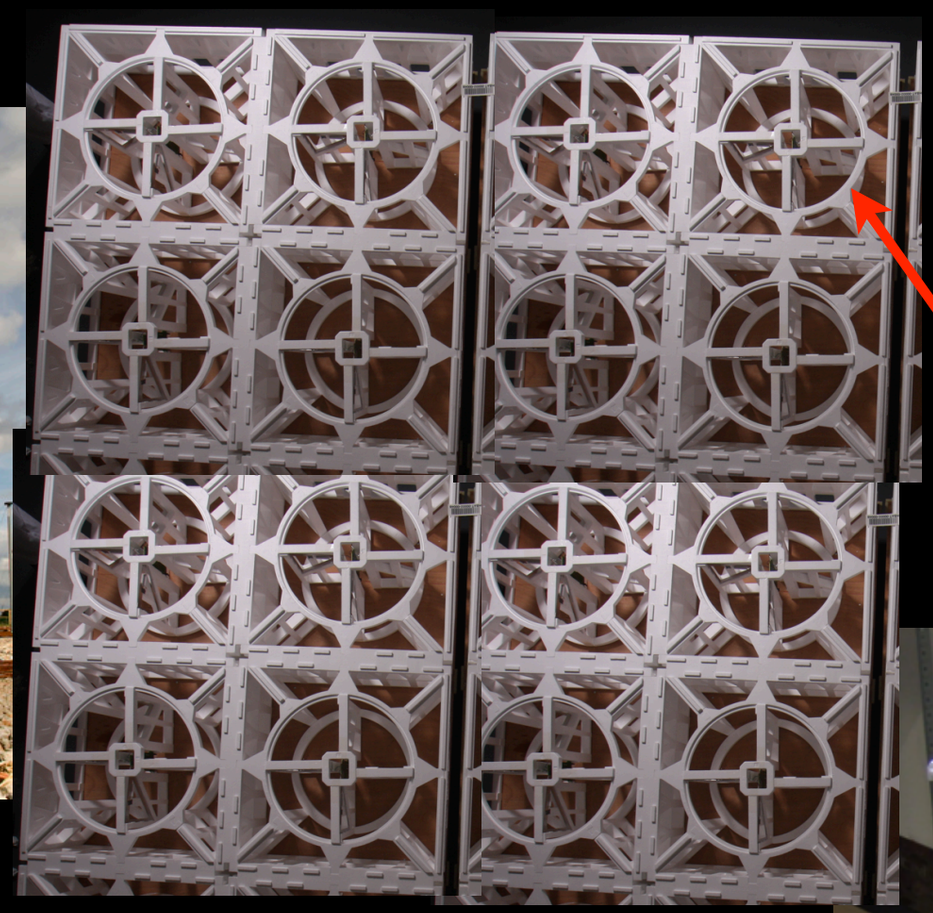

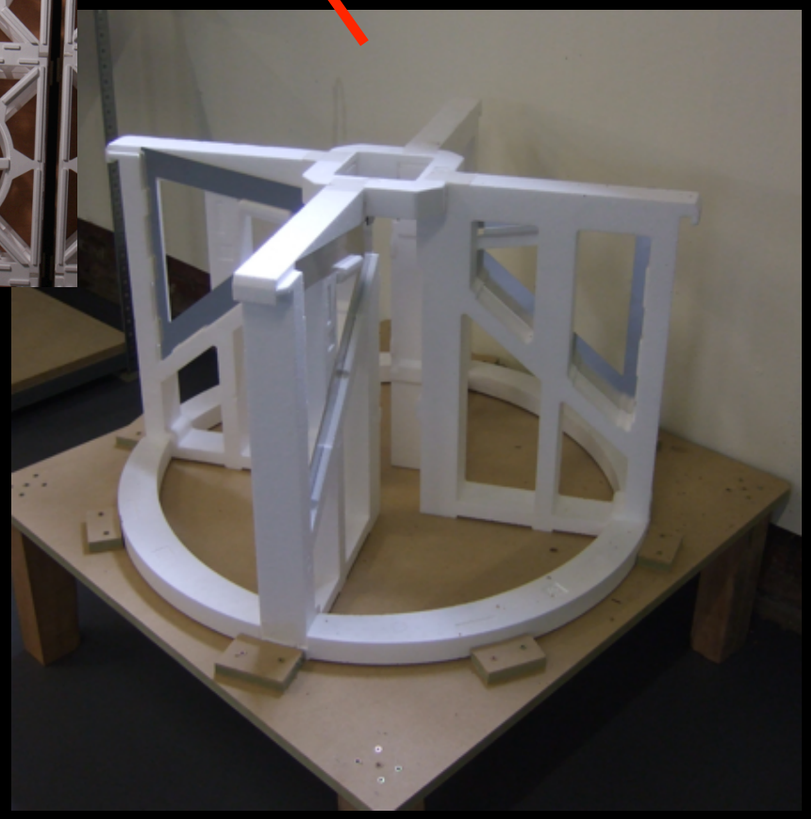

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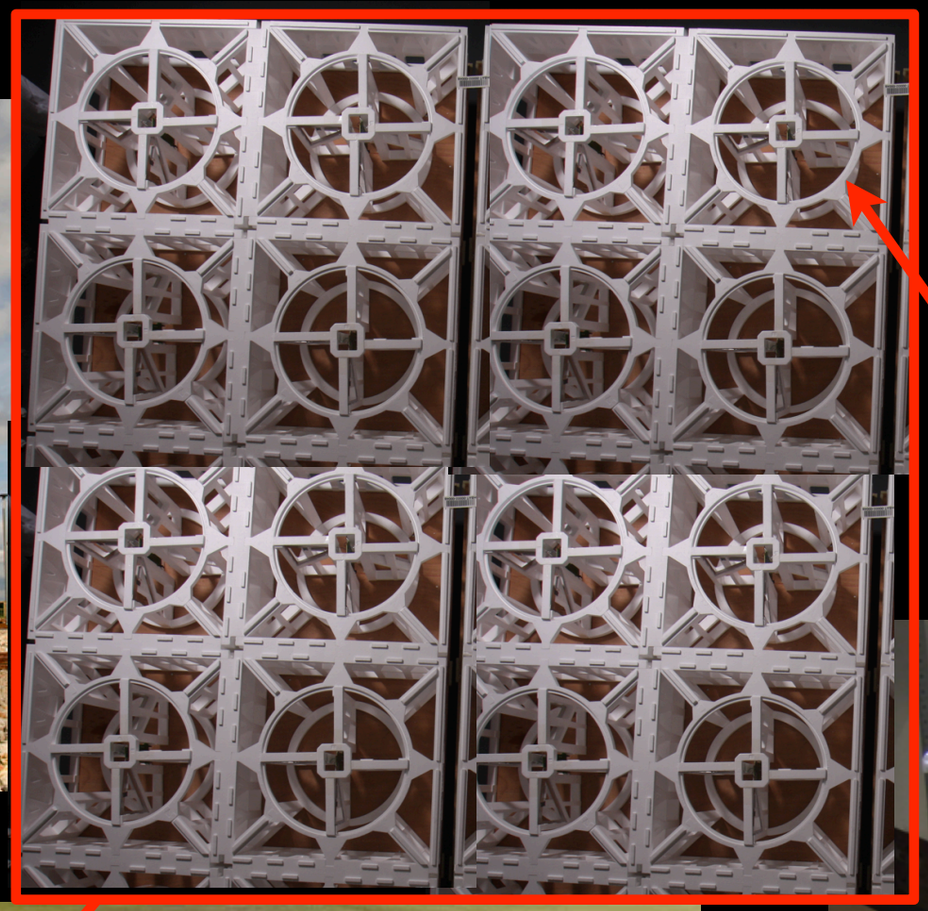
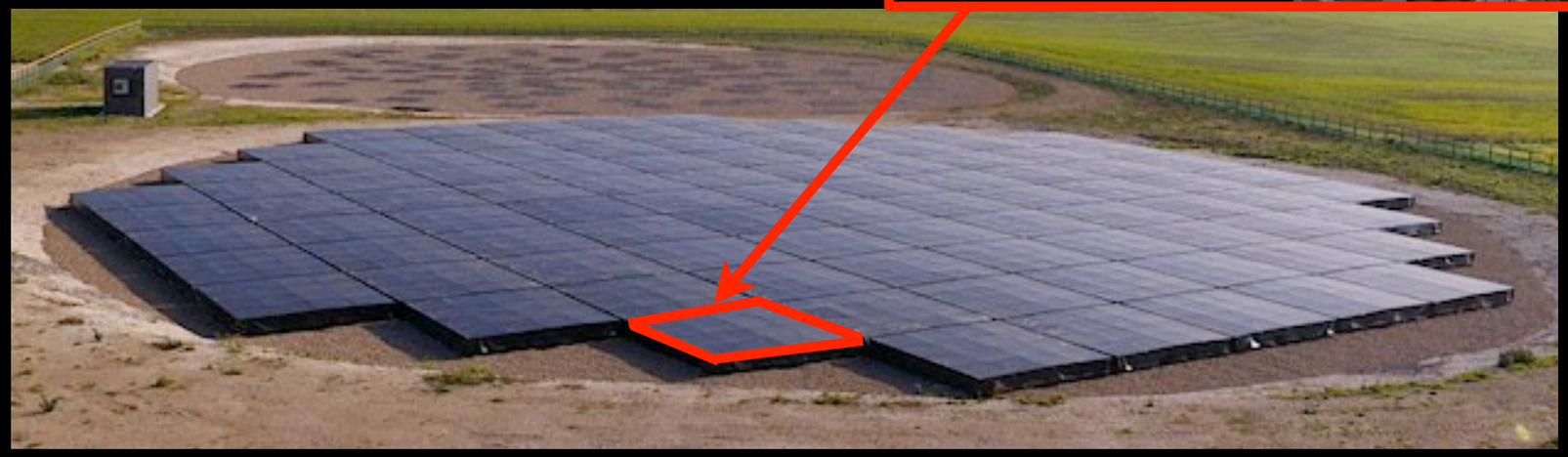
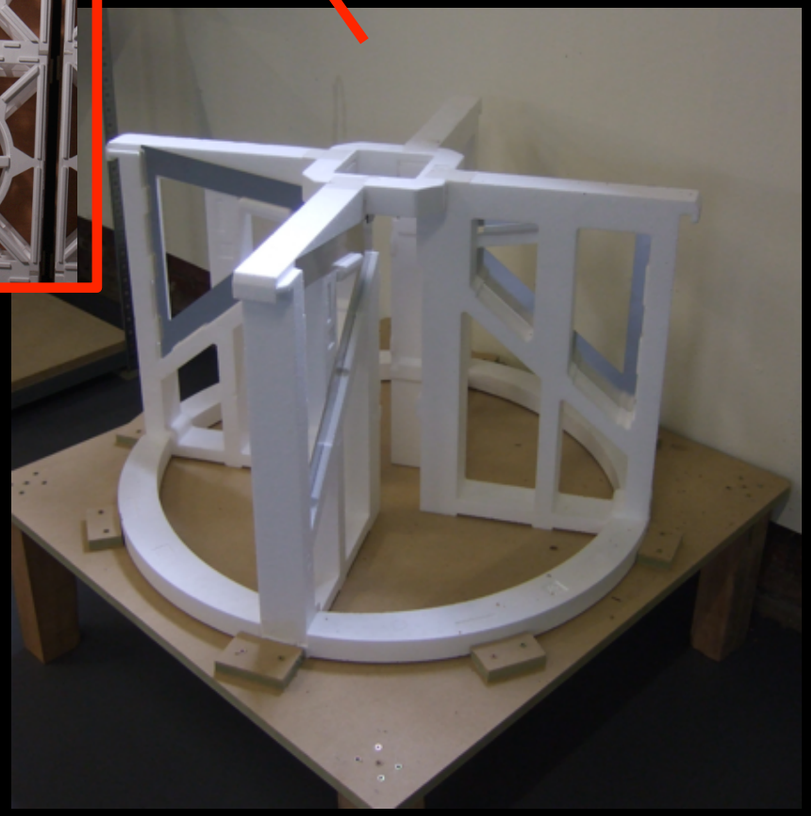
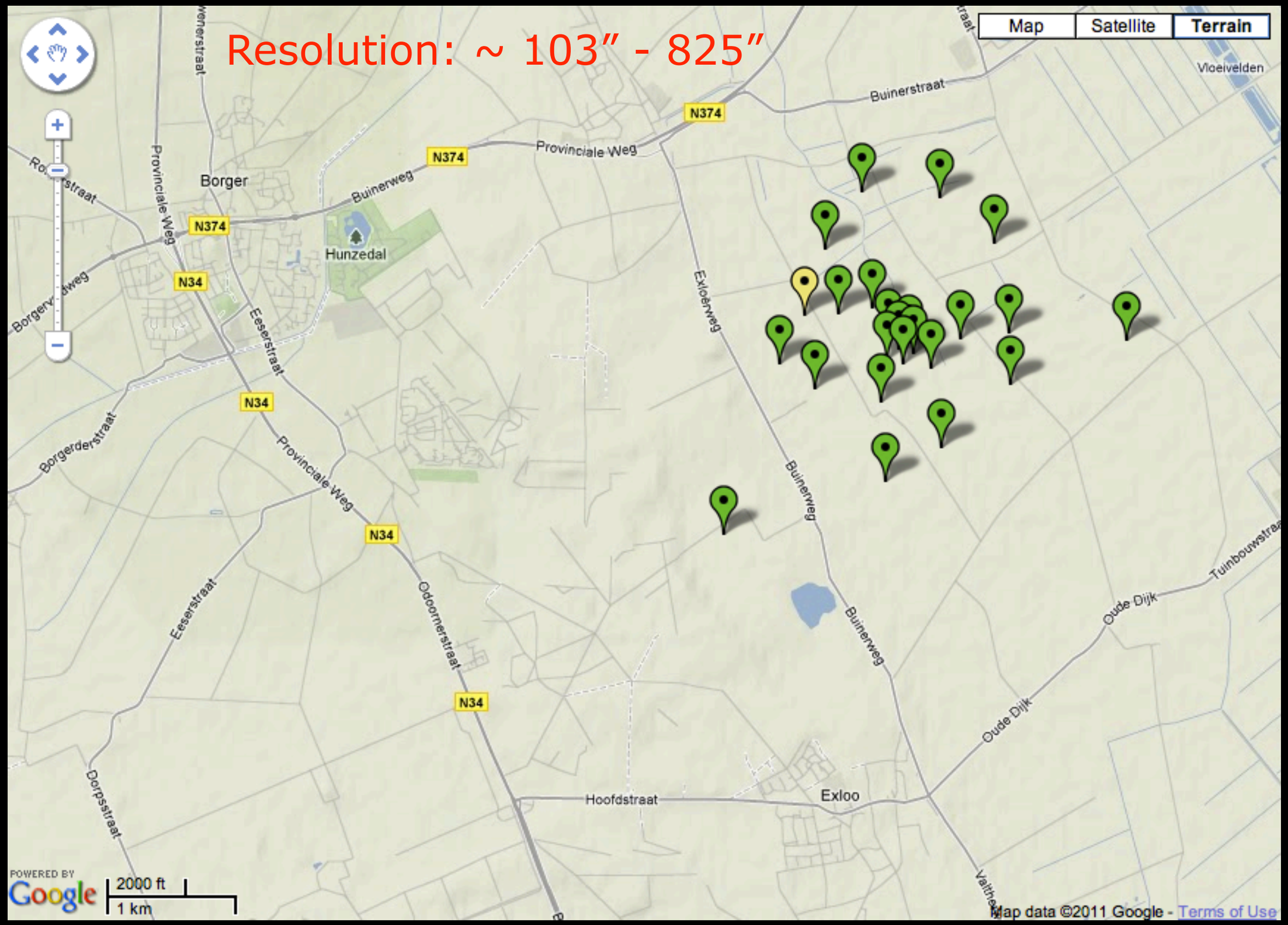






LOFAR: where it is



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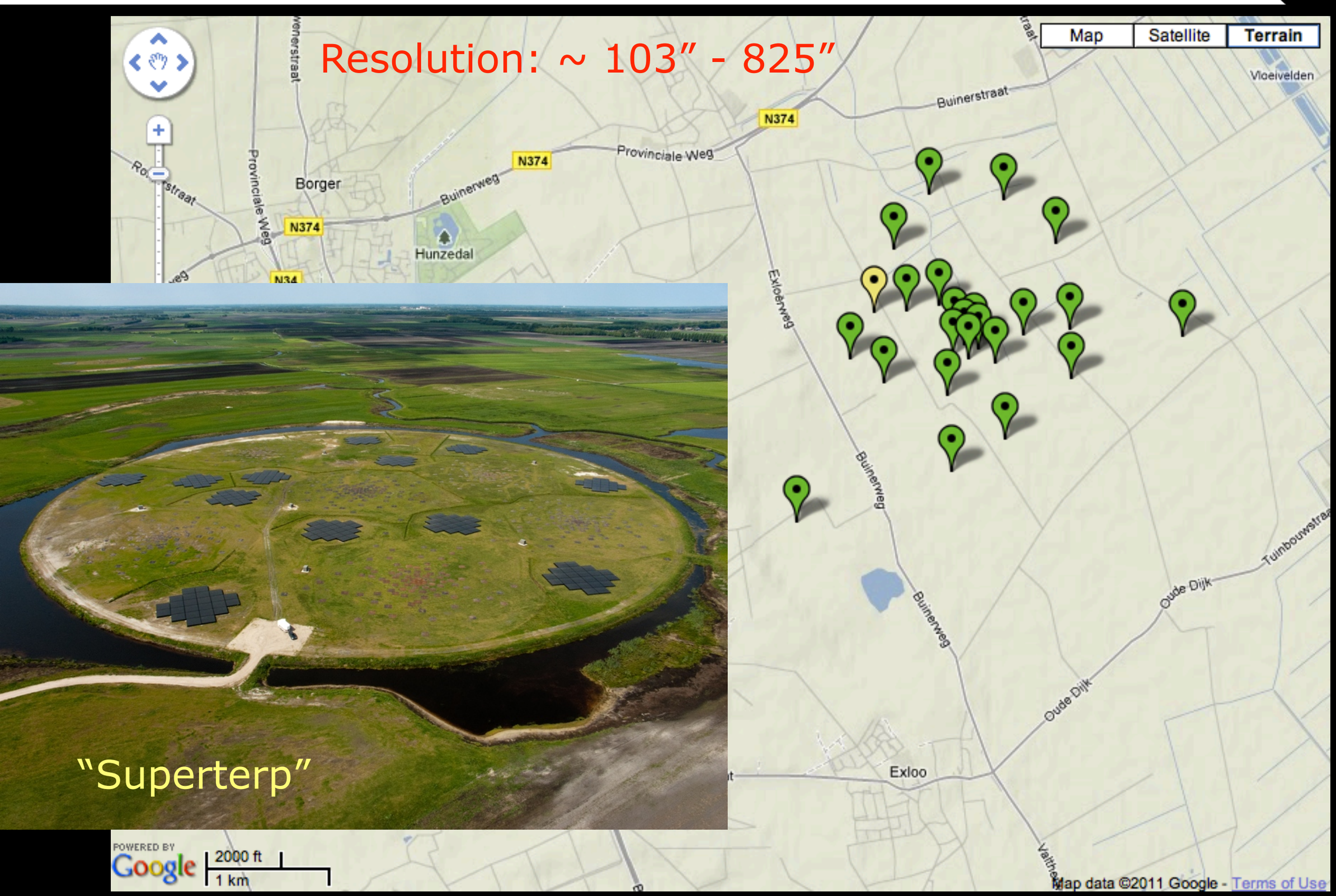

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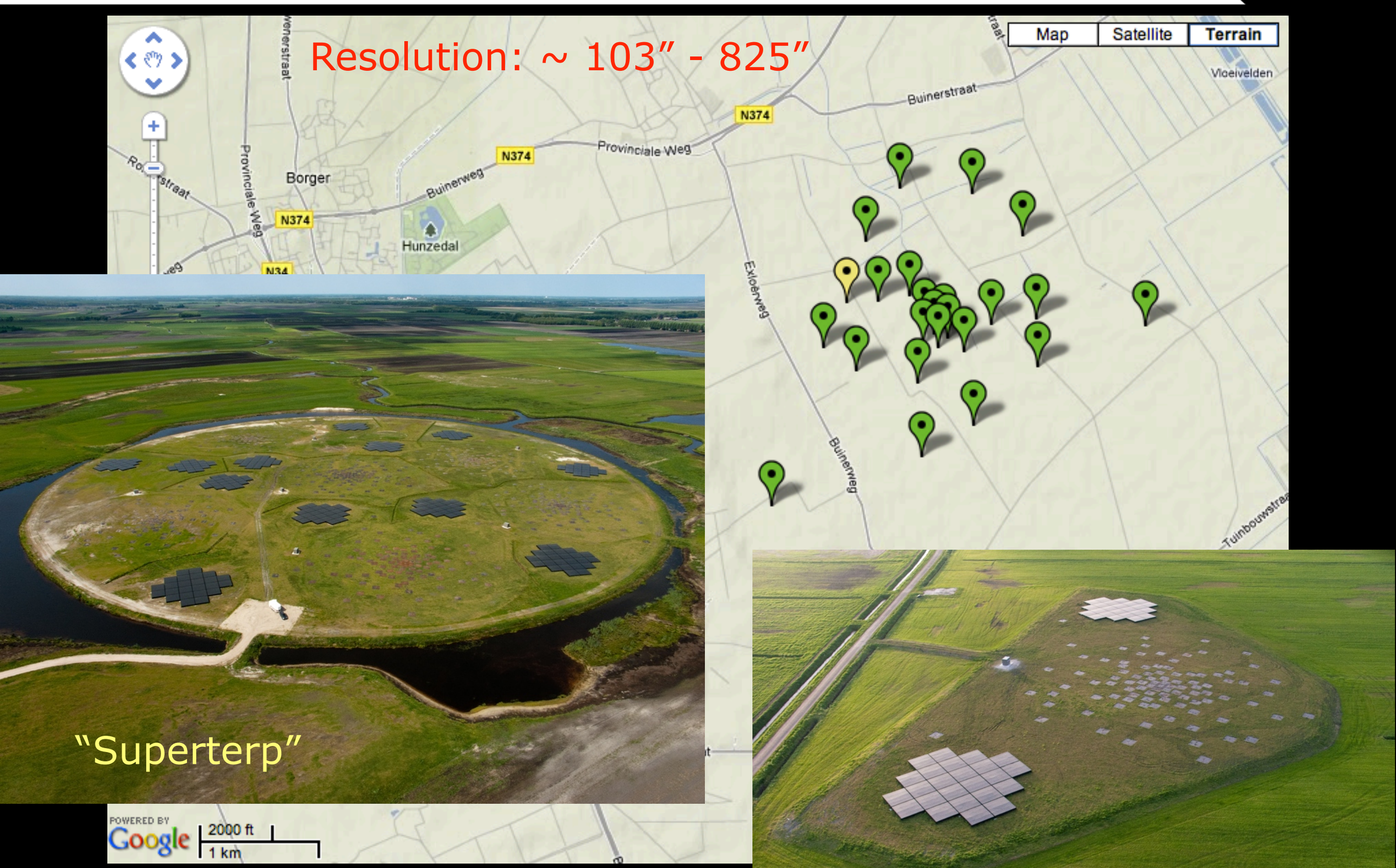

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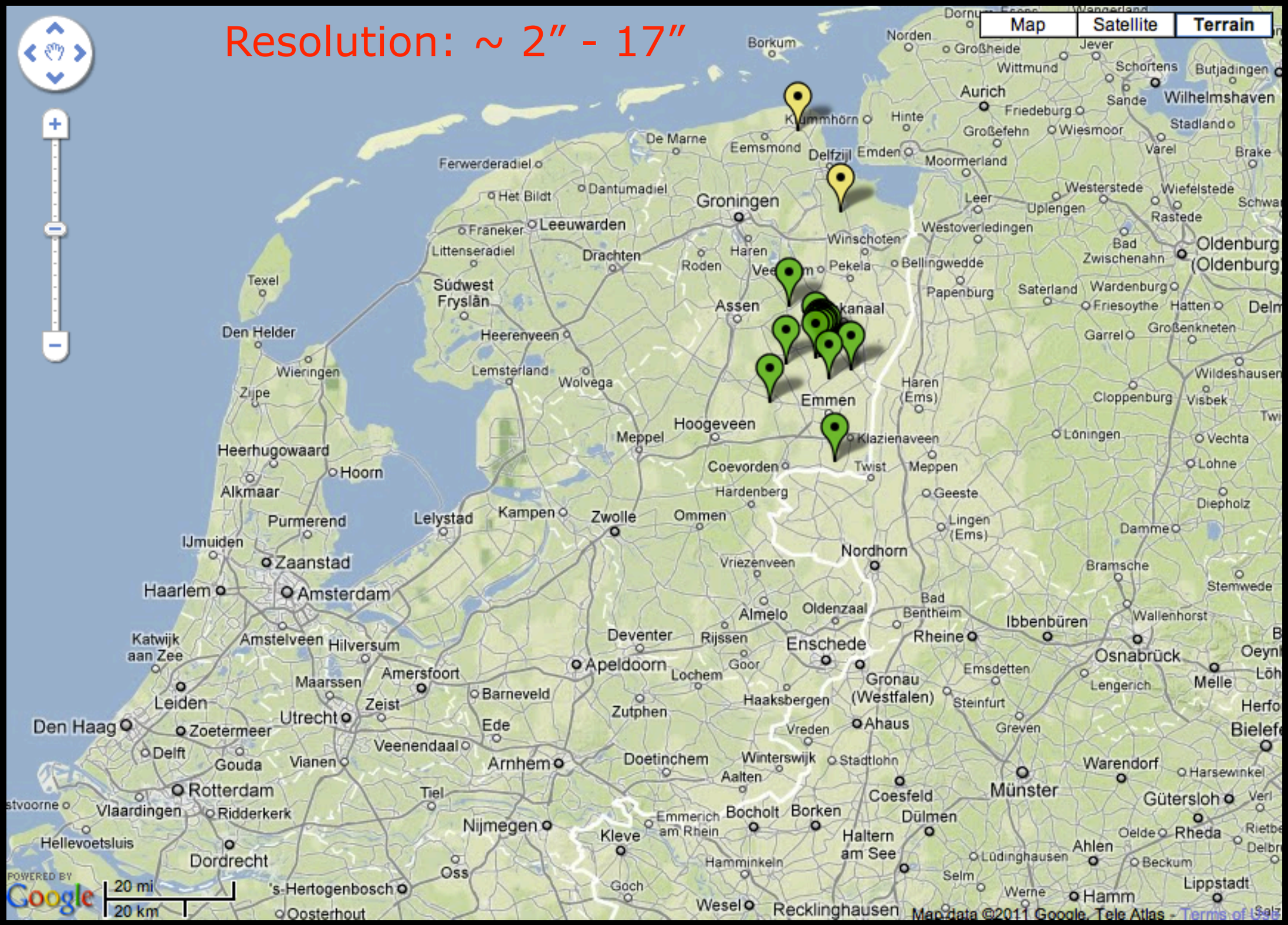

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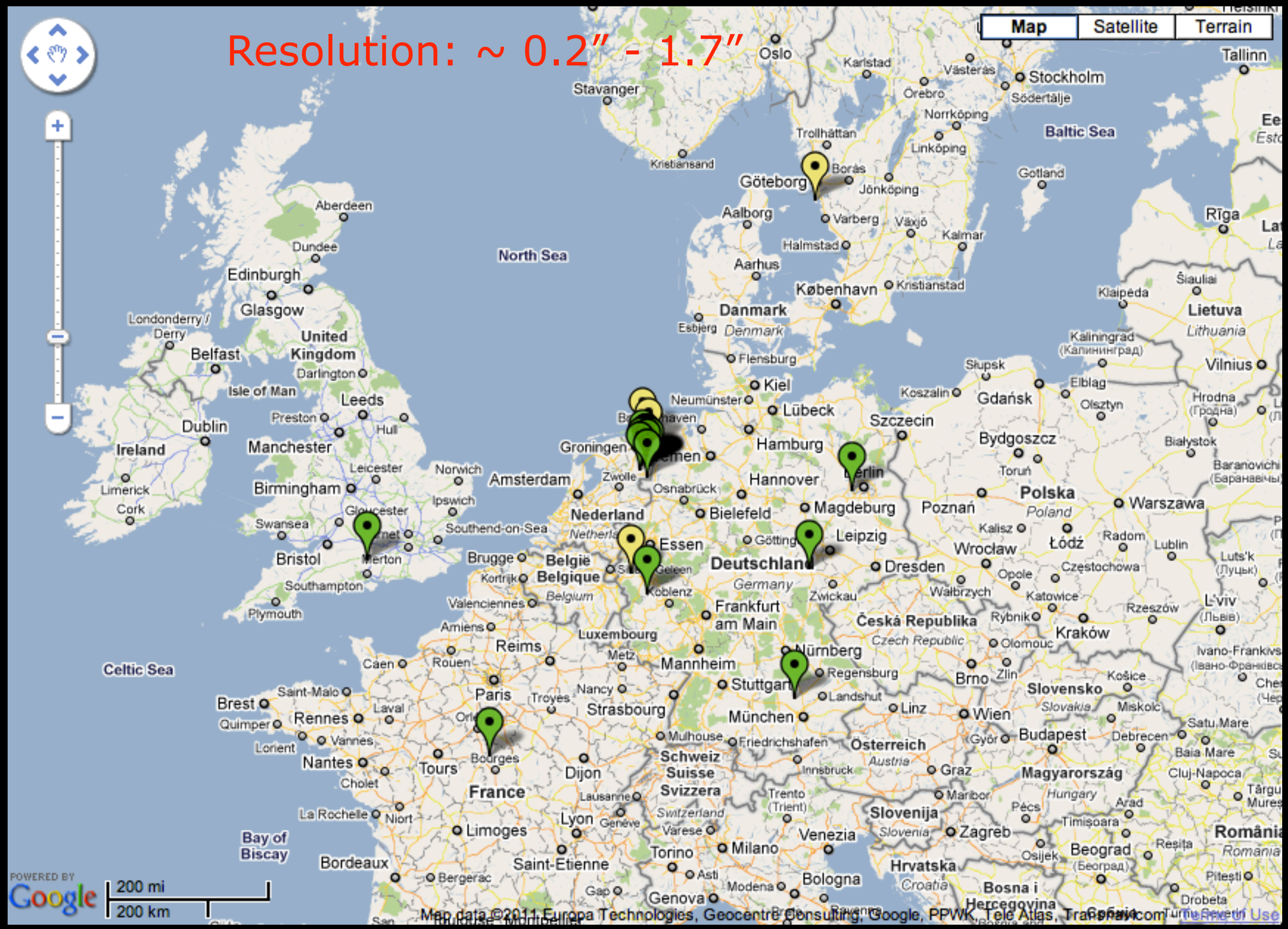


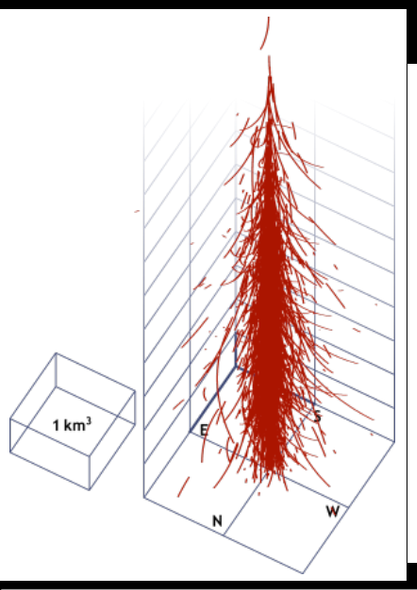
Resolution: ~ 0.2″ - 1.7″

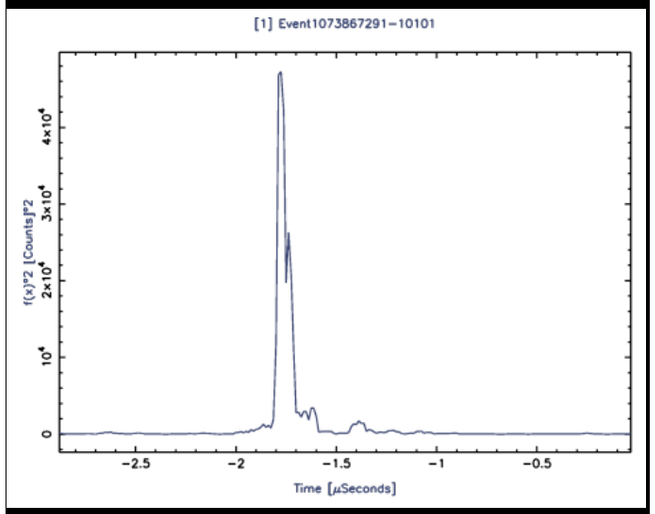
LOFAR Key Science Projects (KSPs)

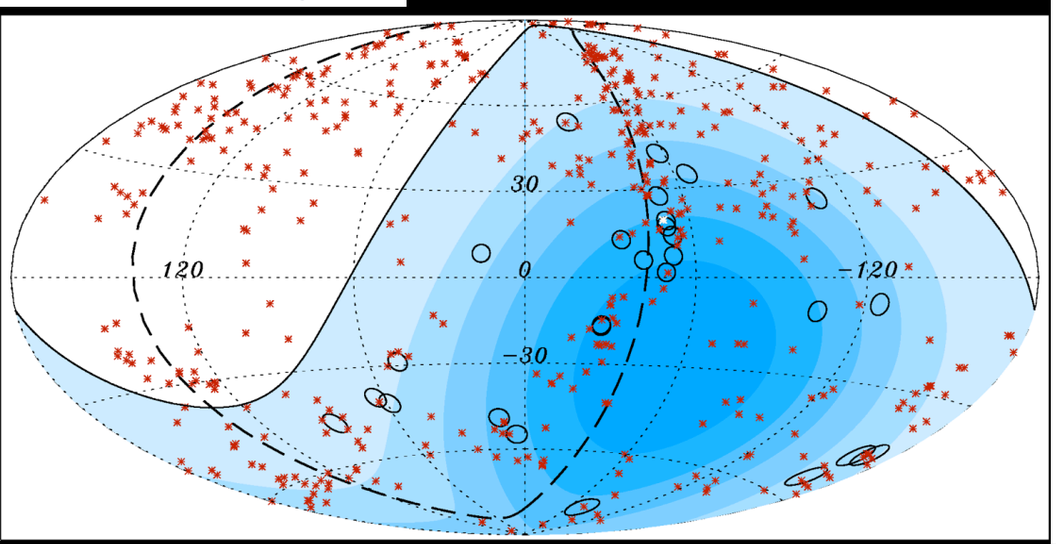
- Six KSPs drive the development of LOFAR:
  - High-energy cosmic rays (Nijmegen)
  - Epoch of Reionization (Groningen)
  - Transients (Amsterdam)
  - Solar Physics and Space Weather (Potsdam, Germany)
  - Surveys (Leiden)
  - Cosmic Magnetism (Bonn, Germany)

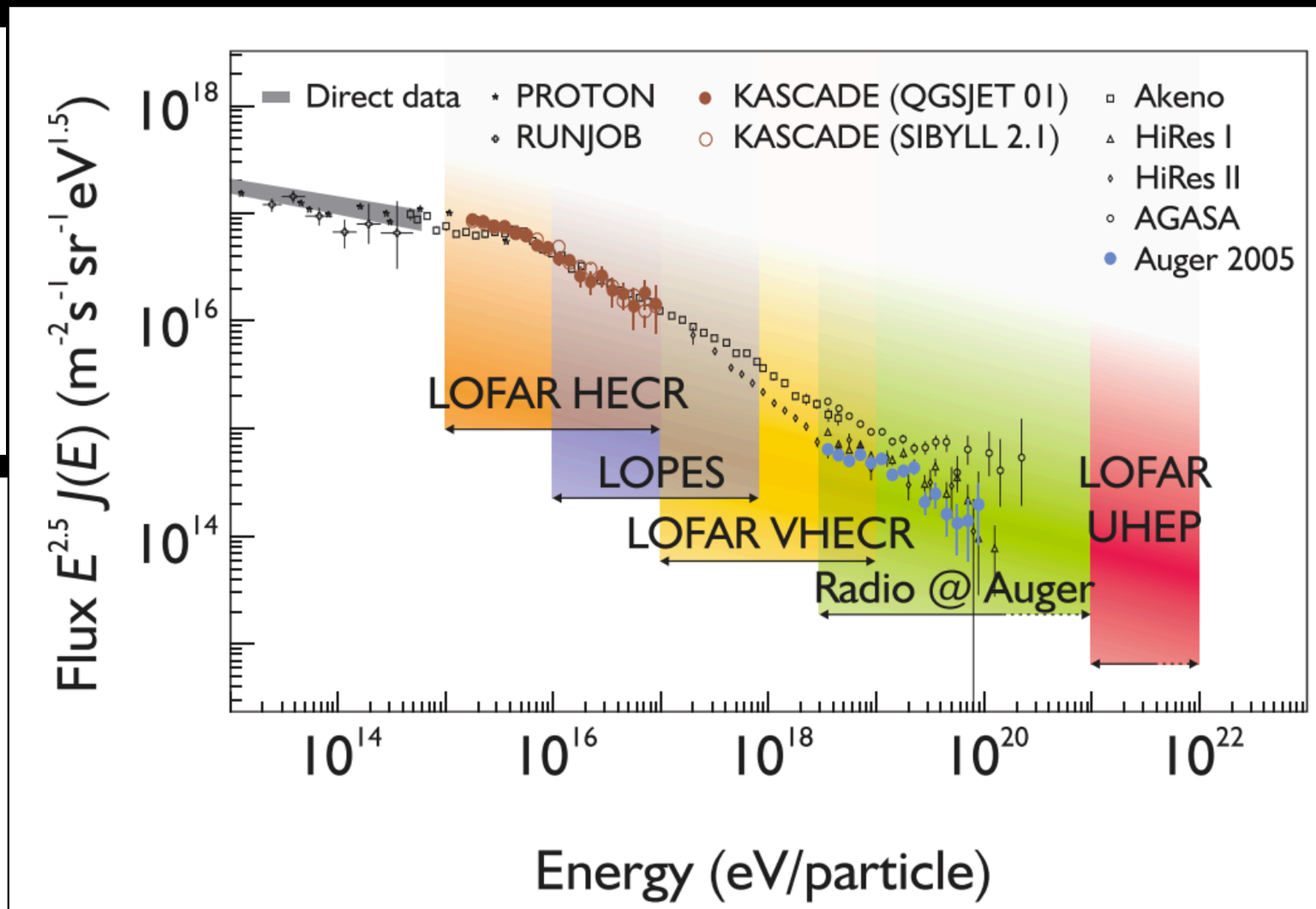
High-energy cosmic rays

- High-energy cosmic rays induce particle showers in the upper atmosphere; these are accelerated by the Earth's magnetic field and emit synchrotron radiation



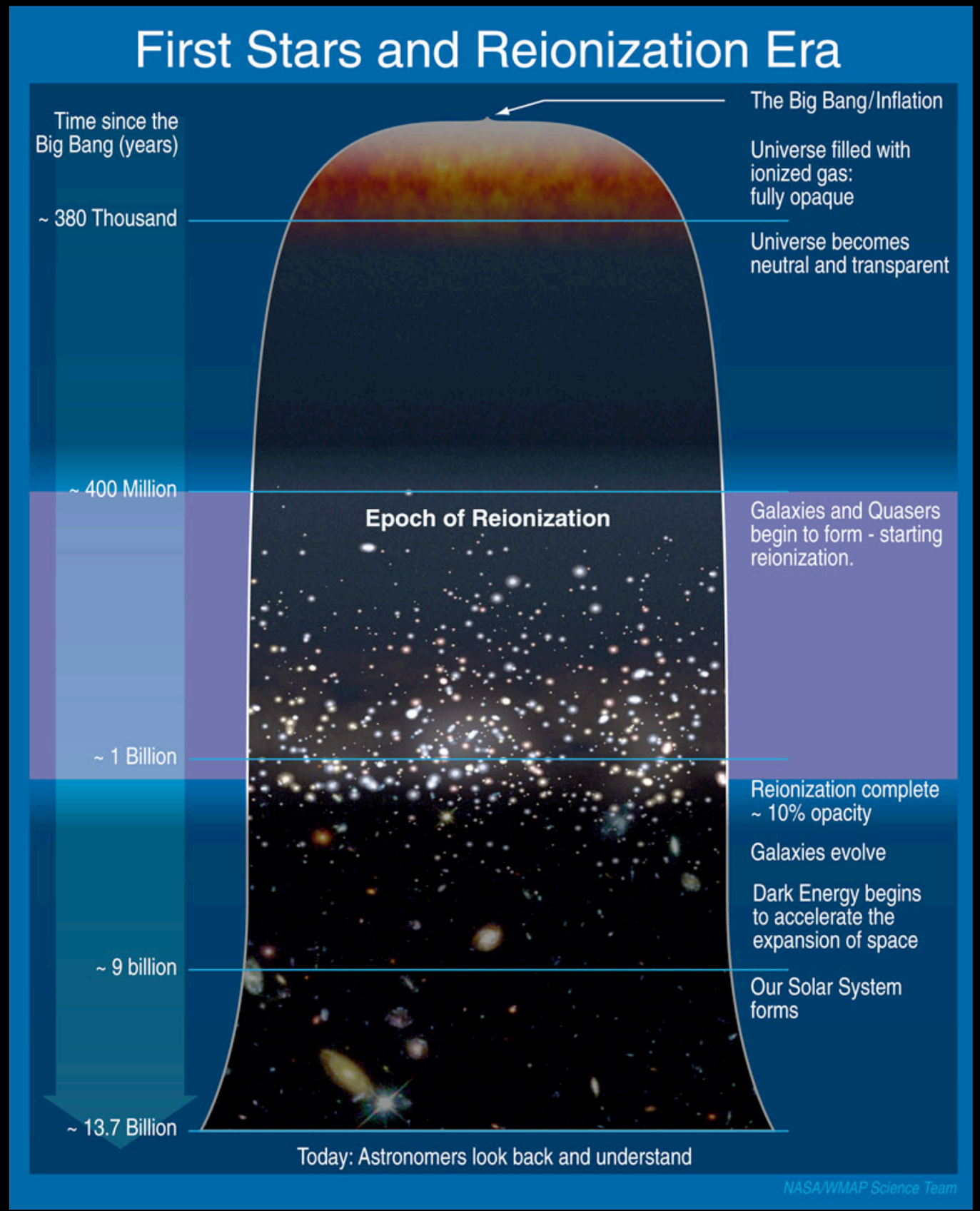




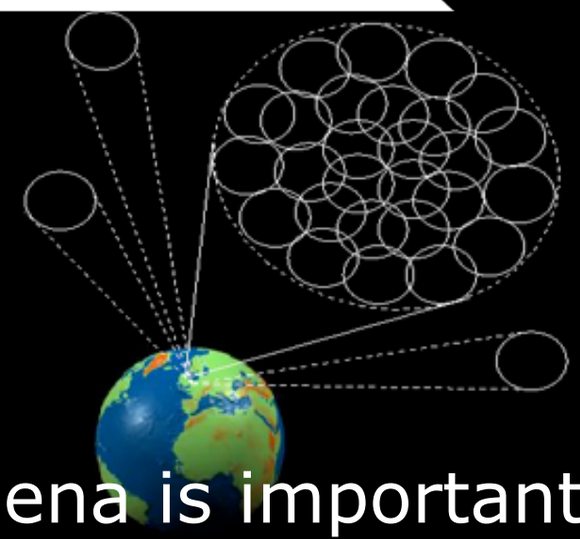


Epoch of Reionization

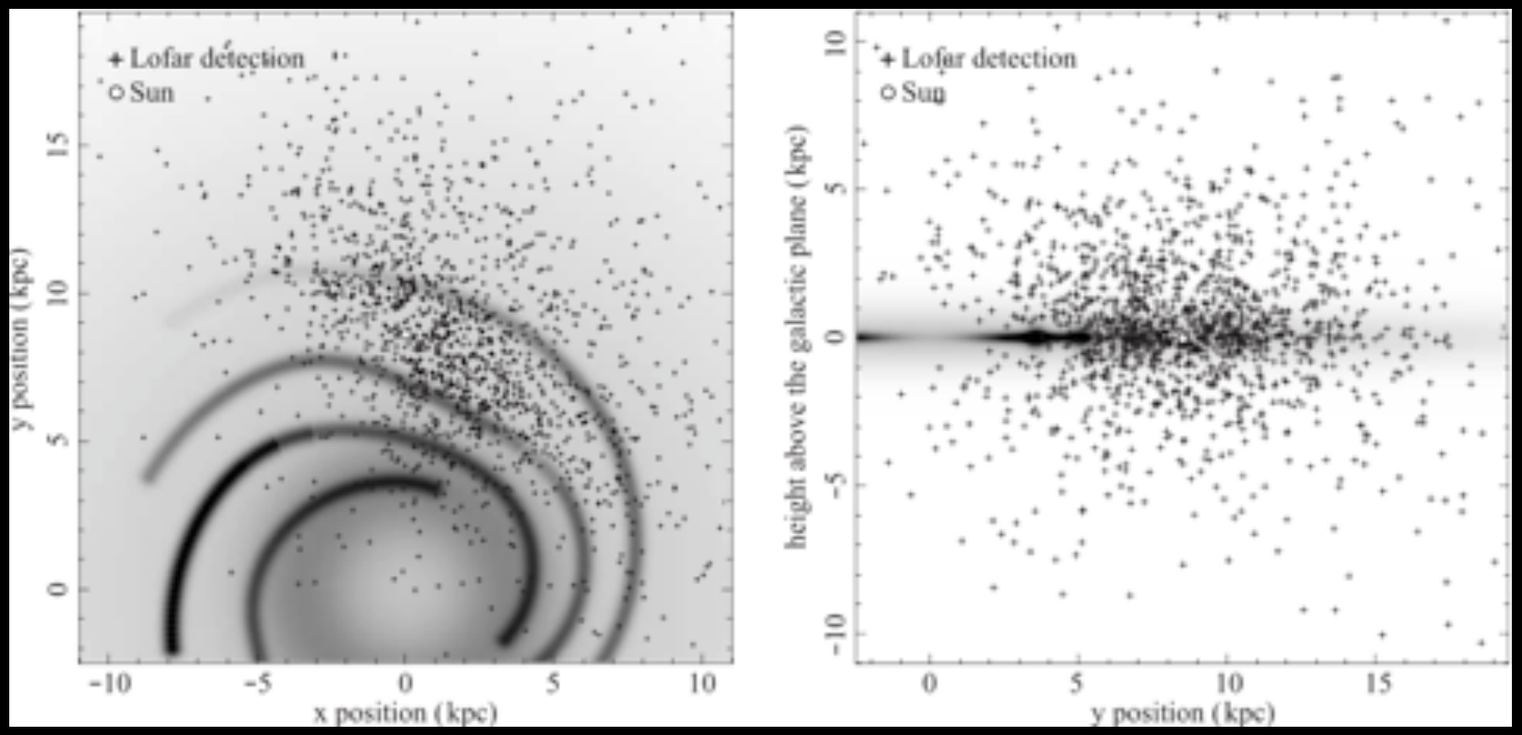
- Aims for statistical detection of high-redshift HI
- When did reionization happen?
- How fast did it happen?
- What were the sources of reionization (stars? galaxies?)

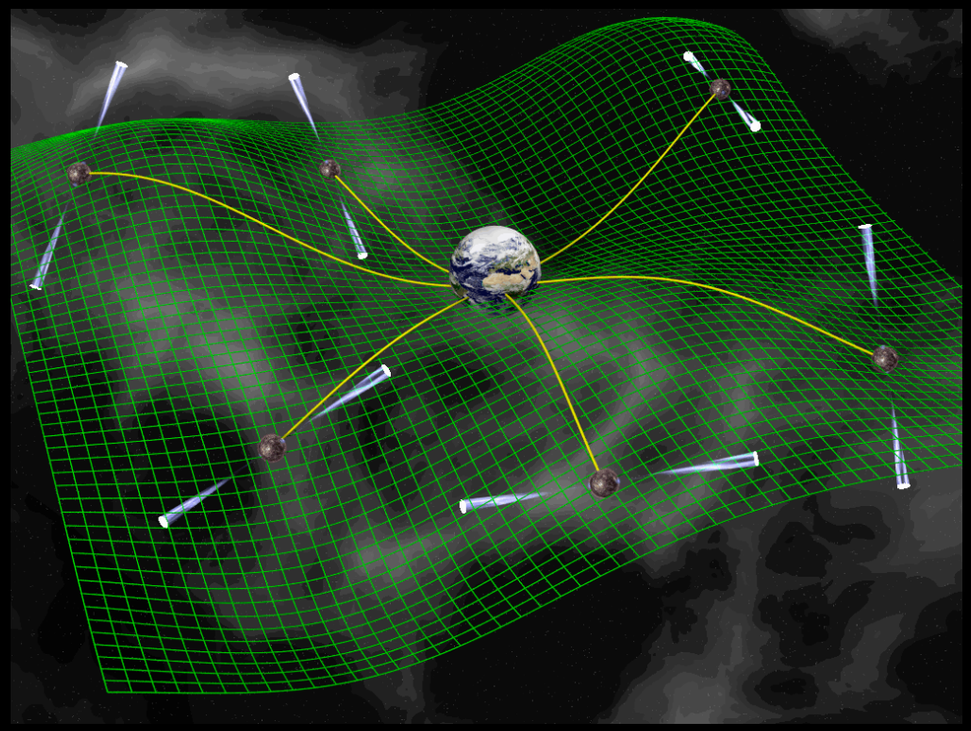


Transients and Pulsars



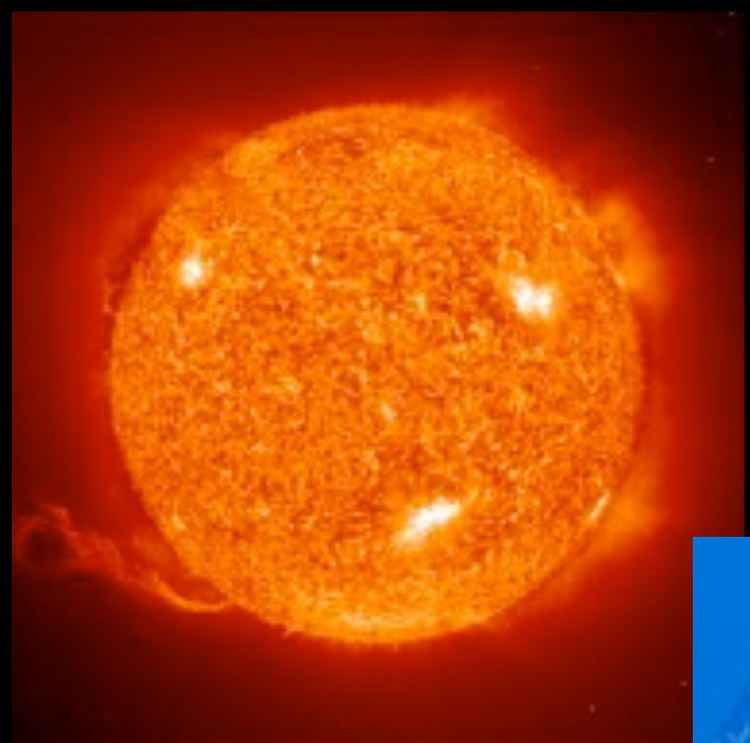
- Many sources in the sky are variable:
  - X-ray binaries, supernovae, GRBs
  - flare stars, brown dwarfs, planets
  - Studying these extremely energetic phenomena is important to understand how they affect their surroundings ...
- Pulsars (rapidly rotating neutron stars): cosmic metronomes

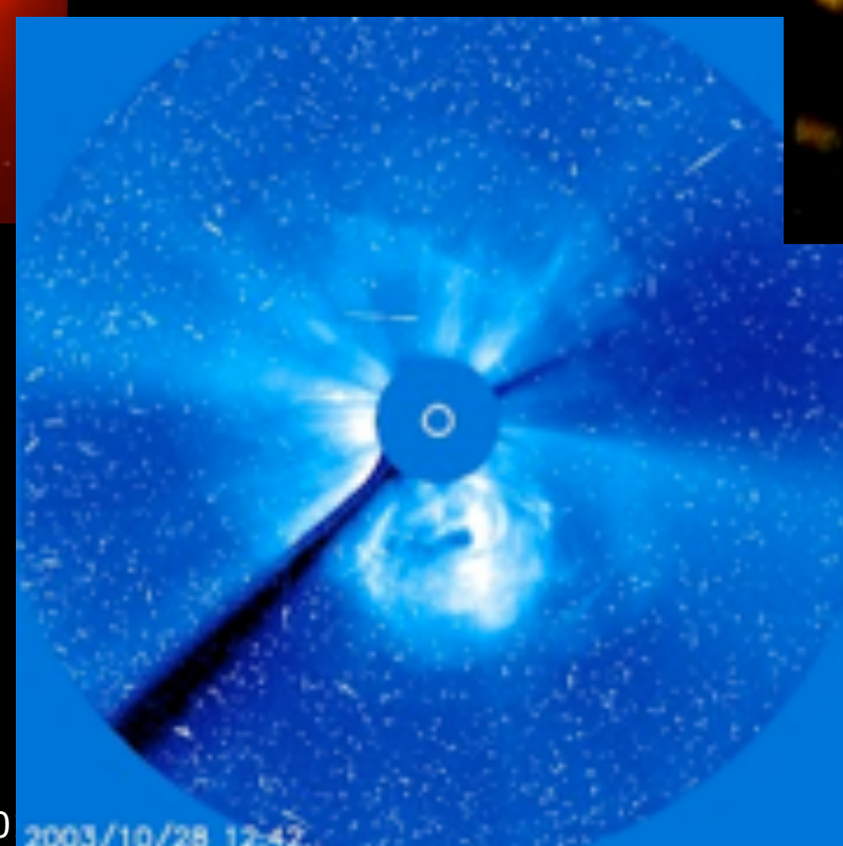


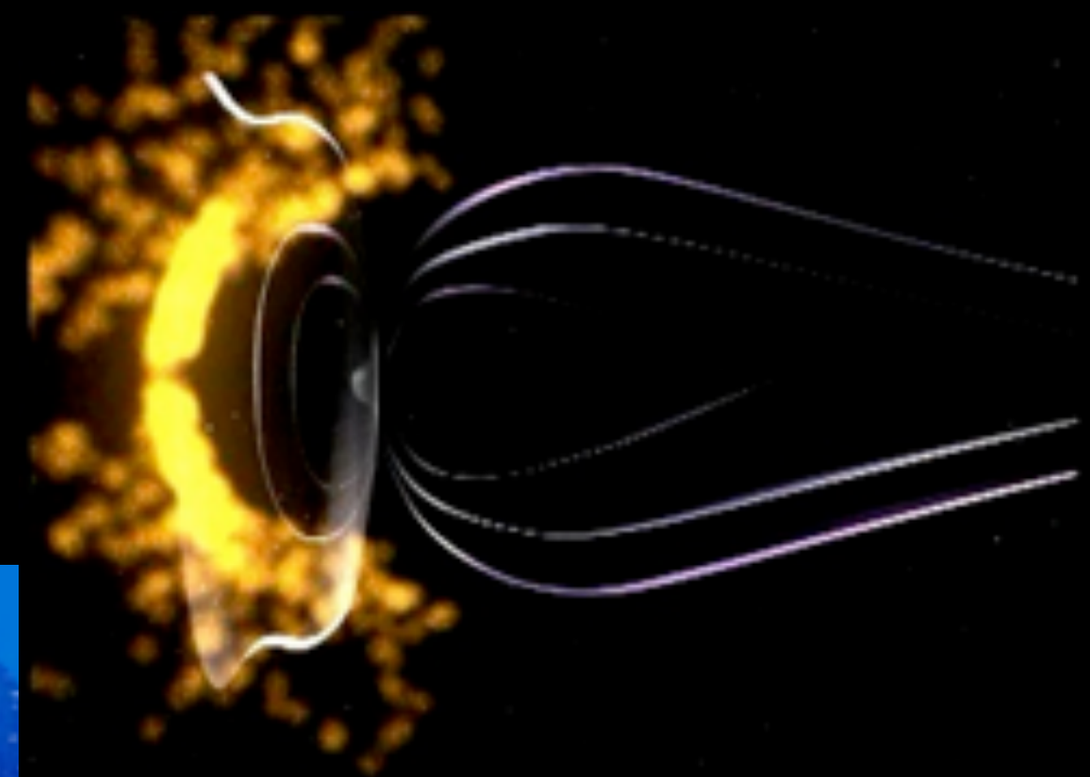


Solar Physics and Space Weather

- Study solar activity to better understand solar physics
- Monitor the Sun to minimize damage from CMEs







Surveys with LOFAR

- LOFAR's field of view is huge, and low frequencies have not been explored very much so far ....
- Main goals are to investigate
  - Formation of massive galaxies, clusters and black holes using $z \geq 6$ (age of Universe ~ 10^9 yr) radio galaxies as probes
  - Intercluster magnetic fields using diffuse radio emission in galaxy clusters as probes
  - Star formation processes in the early Universe using starburst galaxies as probes
  - Exploration of new parameter space for serendipitous discovery!

Surveys with LOFAR

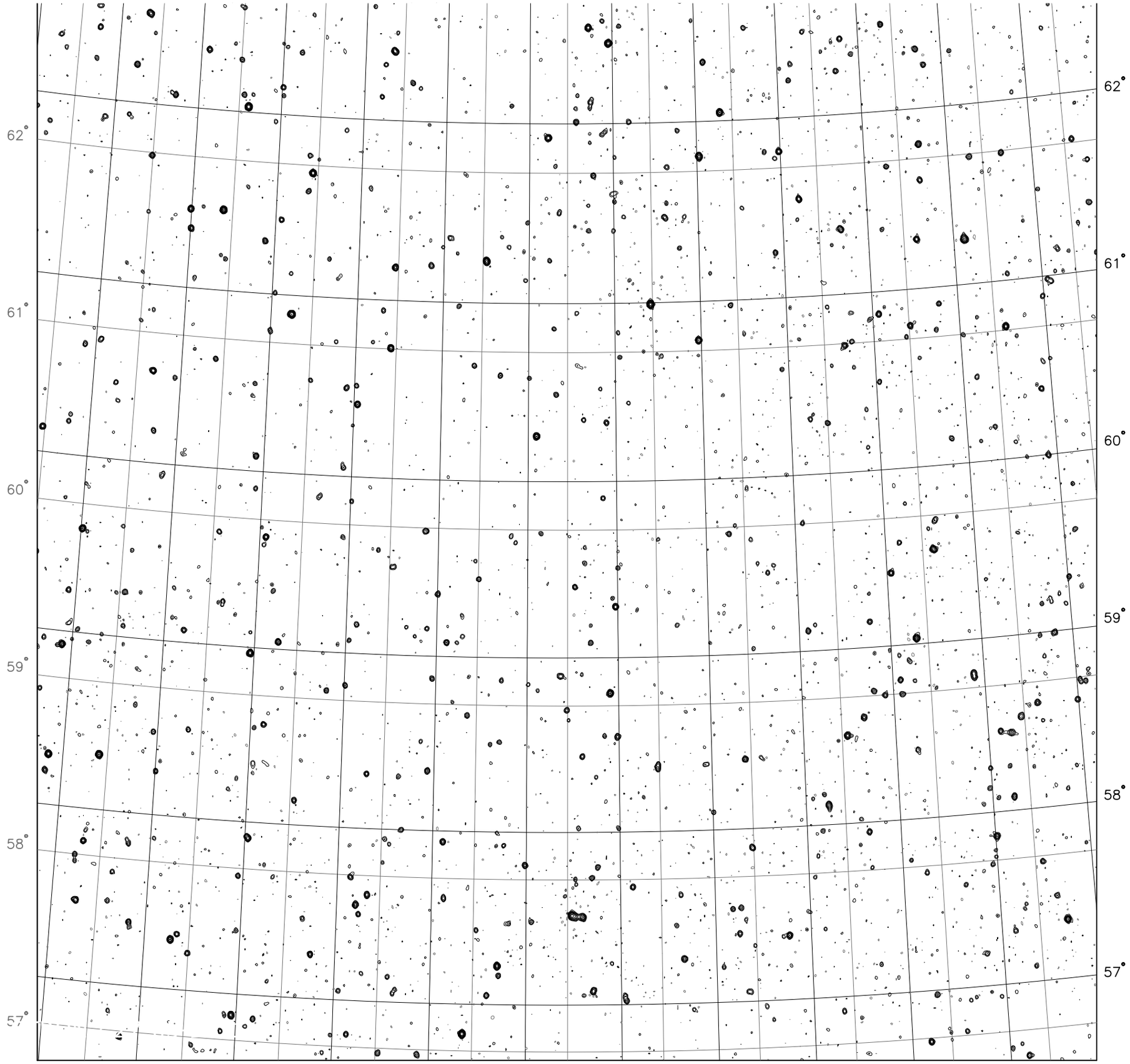
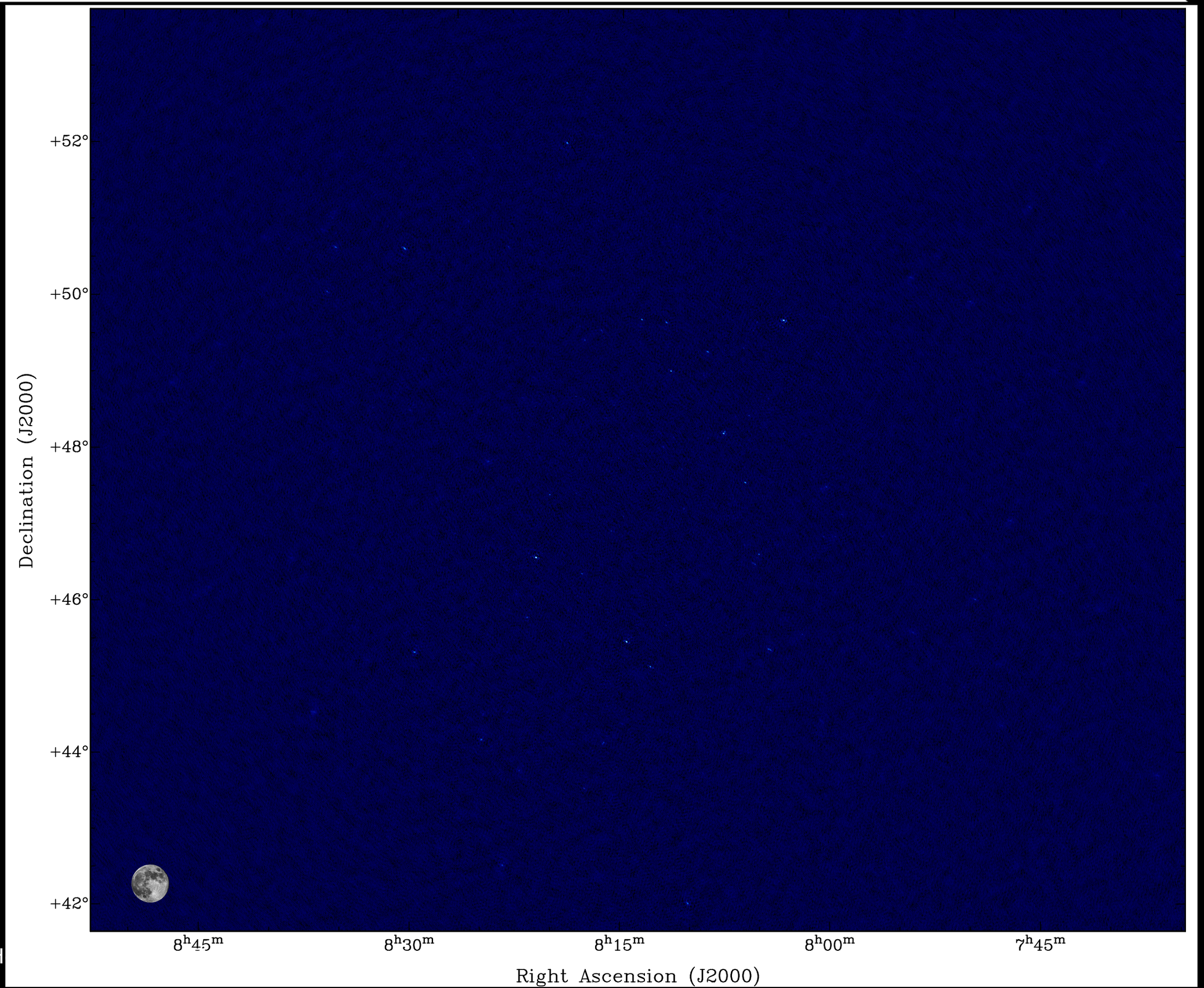


Image from WENSS

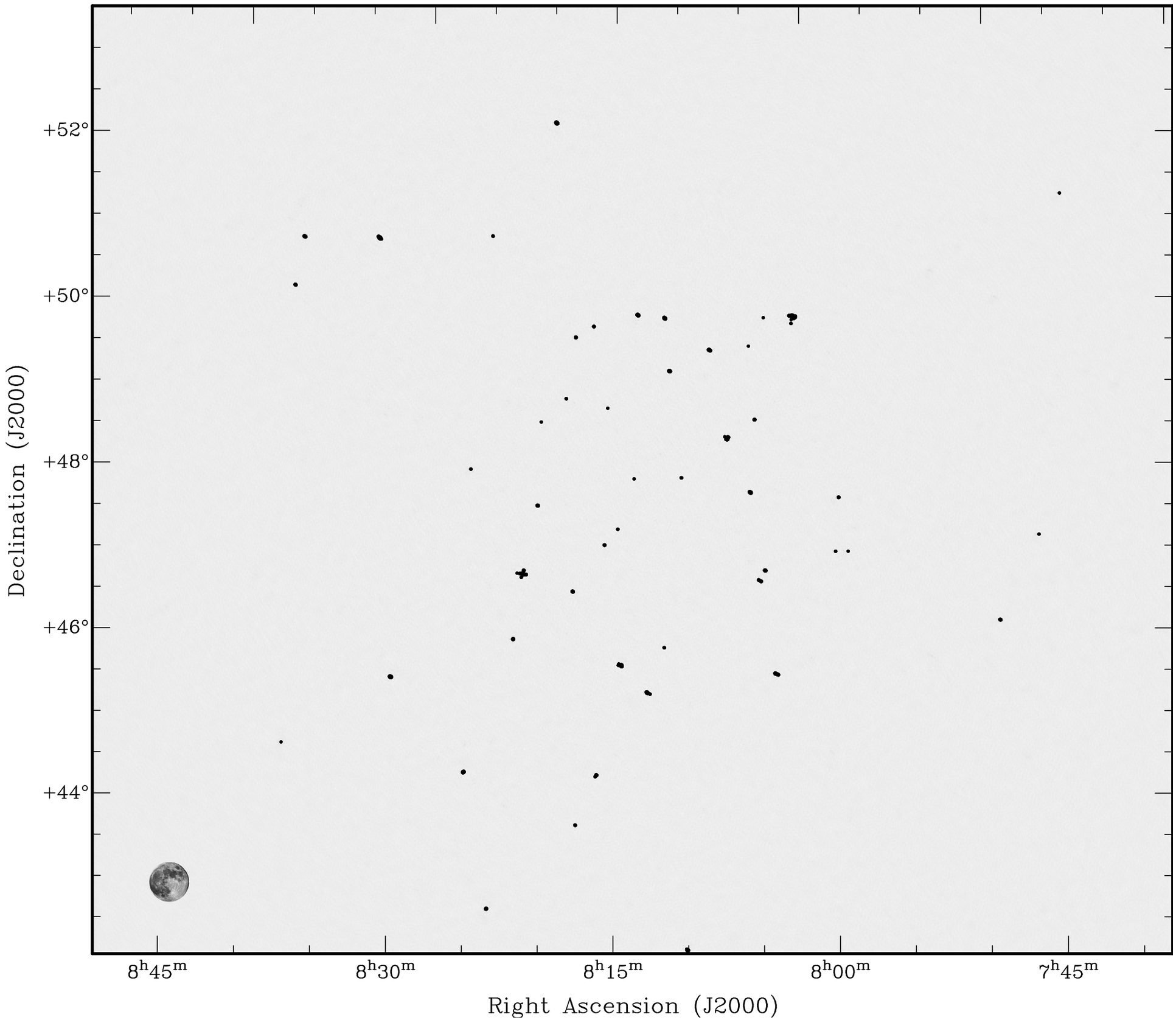
Cosmic Magnetism with LOFAR

- Big questions:
  - When were the first magnetic fields generated: in young galaxies, or are they relics from the early Universe before the galaxies were formed?
  - How were magnetic fields amplified and ordered during the evolution of galaxies?
  - Do magnetic fields exist only in the star-forming inner regions of galaxies, or do they extend out to intergalactic space?
  - How important are magnetic fields for the physics of galaxies, like the efficiency to form stars from gas, the formation of spiral arms, or the generation of gas outflows ("galactic winds")?

Recent LOFAR images



Recent LOFAR images



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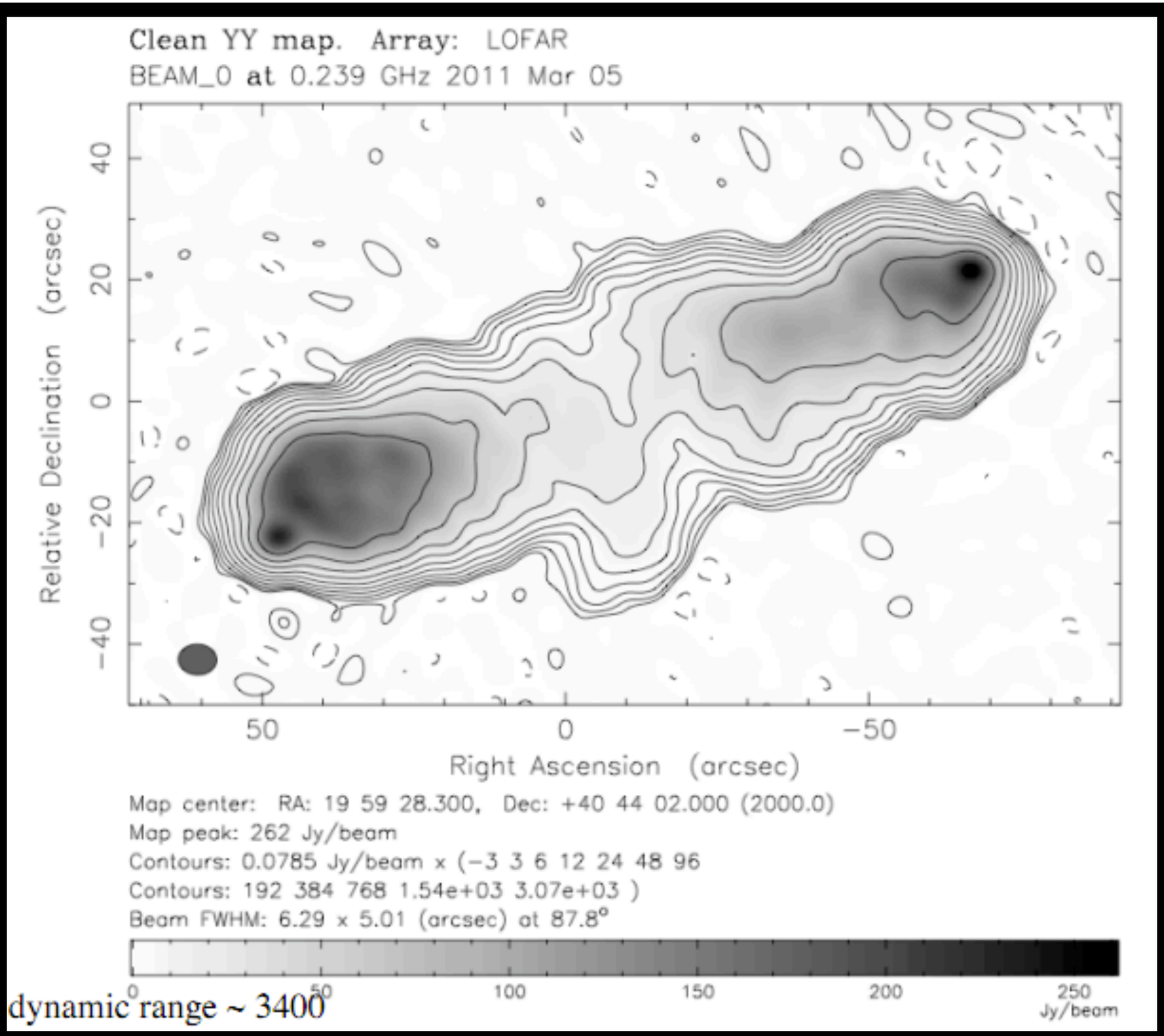
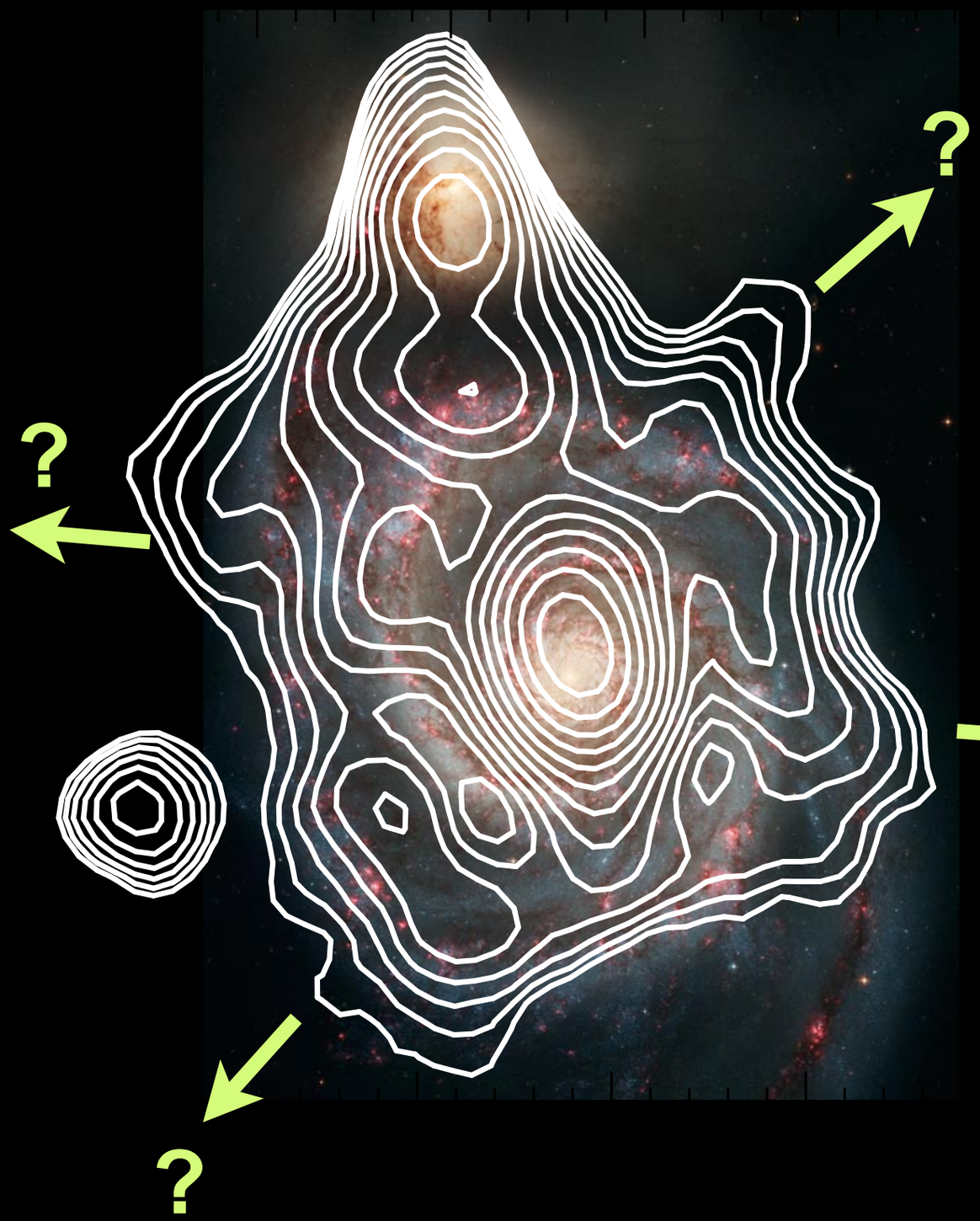
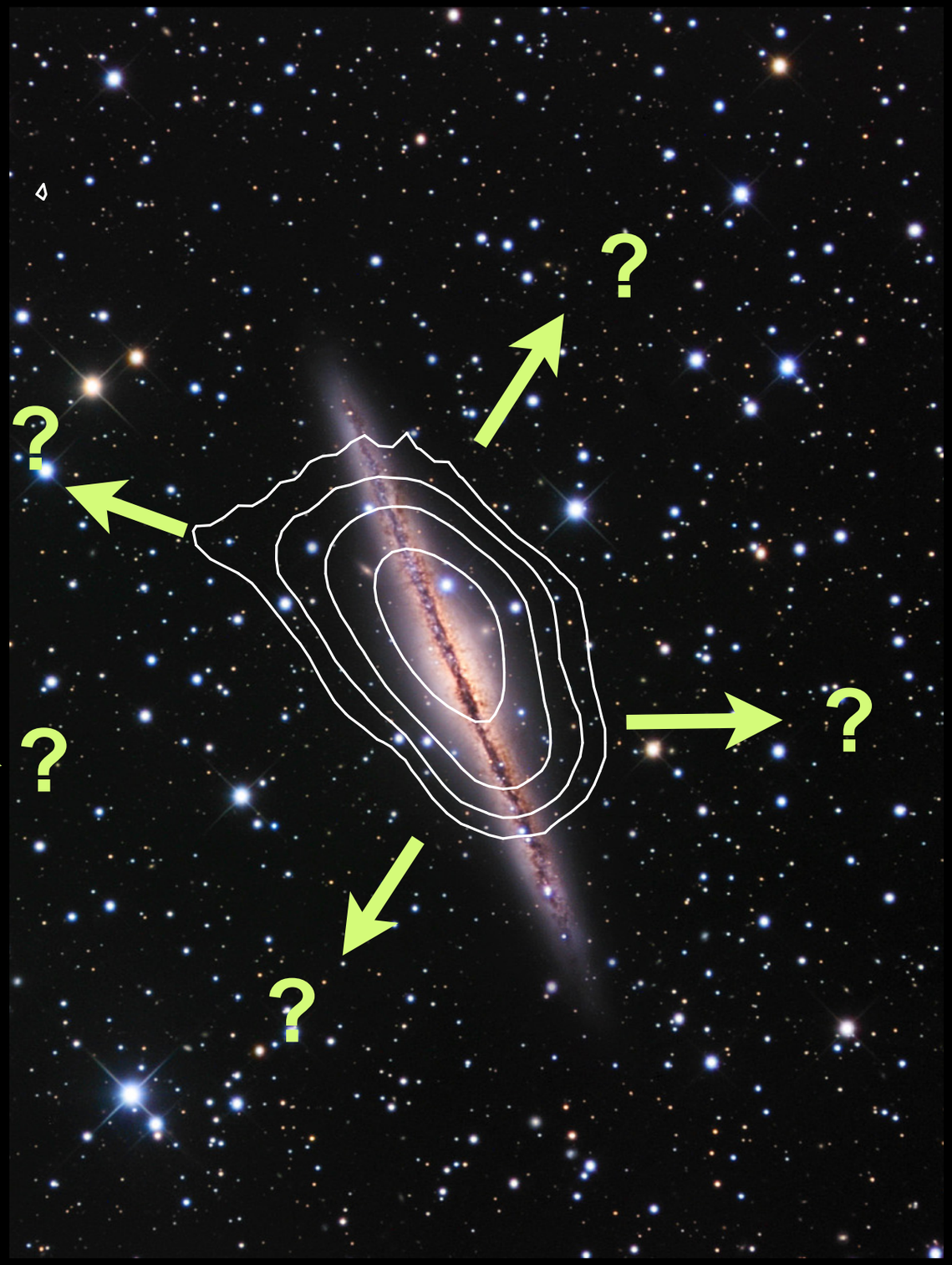


dynamic range ~ 3400

Recent LOFAR images





To the future ....

- Most of the science we are doing is leading toward the upcoming Square Kilometre Array (SKA)

Key Science Projects

2. Cradle of Life

T. J.W. Lazio, J.C. Tarter, D.J. Wilner – PDF

3. Strong-field tests of gravity using pulsars and black holes

M. Kramer, D. C. Backer, J. M. Cordes , T. J. W. Lazio, B. W. Stappers, S. Johnston – PDF

4. The origin and evolution of cosmic magnetism

B. M. Gaensler, R. Beck, L. Feretti – PDF

5. Galaxy evolution, cosmology and dark energy with the Square Kilometre Array

S.Rawlings, F.B. Abdalla, S.L Bridle, C.A.Blake, C.M. Baugh, L.J. Greenhill, J.M. van der Hulst – PDF

6. Probing the dark ages with the Square Kilometre Array

C. Carilli, S. Furlanetto, F. Briggs, M. Jarvis, S. Rawlings, H. Falcke- PDF