The new giant radio telescope LOFAR and its Scandinavian outrigger LOIS

A transnational, cross-disciplinary initiative to build the world's largest and first fully digital radio observatory for astrophysics, space and earth sciences, and radio research

www.physics.irfu.se/LOIS

Bo Thidé
bt@irfu.se

Advanced Instrumentation and Measurements (AIM) graduate school
Uppsala University

and

Swedish Institute of Space Physics (IRF)
Uppsala

and

Department of Astronomy and Space Physics

Uppsala University

LOFAR/LOIS—a unique combination of radio facilities and IT infratructures for world-class astrophysics, space and earth sciences, and radio research

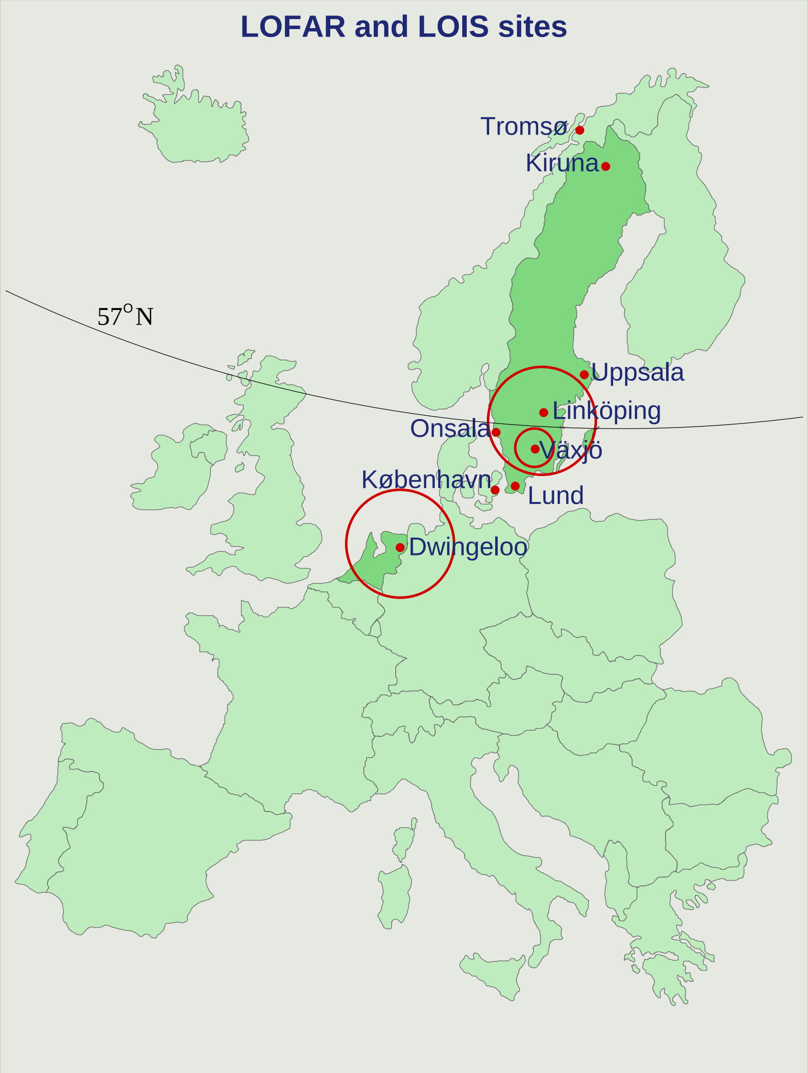
The European Low-Frequency Array (LOFAR) and the LOFAR Outrigger in Scandinavia (LOIS) will be a cross-disciplinary radio facility combo which will

- Allow astronomy, space, and environmental studies ranging from cosmology to climatology by using sofar largely unexplored low frequency windows (HF/VHF)
- Be the world's first major digital radio research facility operated entirely in software
- Be at least a hundred times larger and more sensitive than any other similar facility
- Consist of a huge scalable network of small, inconspicuous sensors and emitters
- Be connected on-line to DataGRID and other planned wideband networks
- Blur the line between radio research facility, sensor network, and computer
- Have public outreach and educational capabilities designed and built in already from the outset

LOFAR/LOIS siting and infrastructure

Modern approach with many small digital stations makes southern Sweden an almost ideal location for LOIS

- Sparsely populated region ($\sim$21/km^2) with an excellent IT infrastucture
- Low radio interference level (falls off in Europe as the local mean air temperature)
- Below the 57° N latitude so that ionospheric self-calibration can be used
- Excellent land communications with continental Europe thanks to the new Øresund Bridge
- Already existing EU interregional collaboration between Drenthe (LOFAR) and Kronoberg (LOIS)



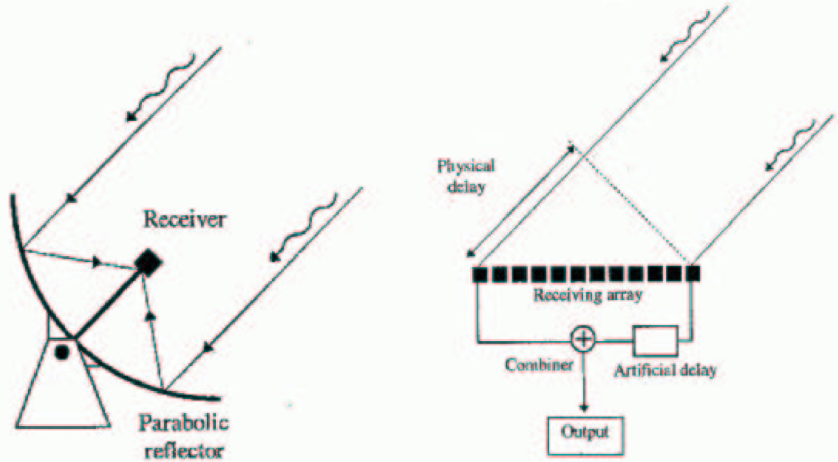
LOFAR/LOIS will address a wide range of outstanding scientific, technological, and political challenges

The LOFAR/LOIS software radio facility will be the first in astrophysics and space sciences which addresses such seemingly disparate scientific, technological, and political challenges as

- The current public concern about Earth and its space environment
- Man's existential questions about the origin and fate of the Universe
- The quest for better and more resource conserving information processing
- Closer collaboration between Academia, industry and society at large
- Bringing Europe to the absolute forefront in space sciences and technology
- Creating a research infrastructure beyond regional and national borders
- Total political openness and active involvement from the general public

A new paradigm in science methodology and outreach

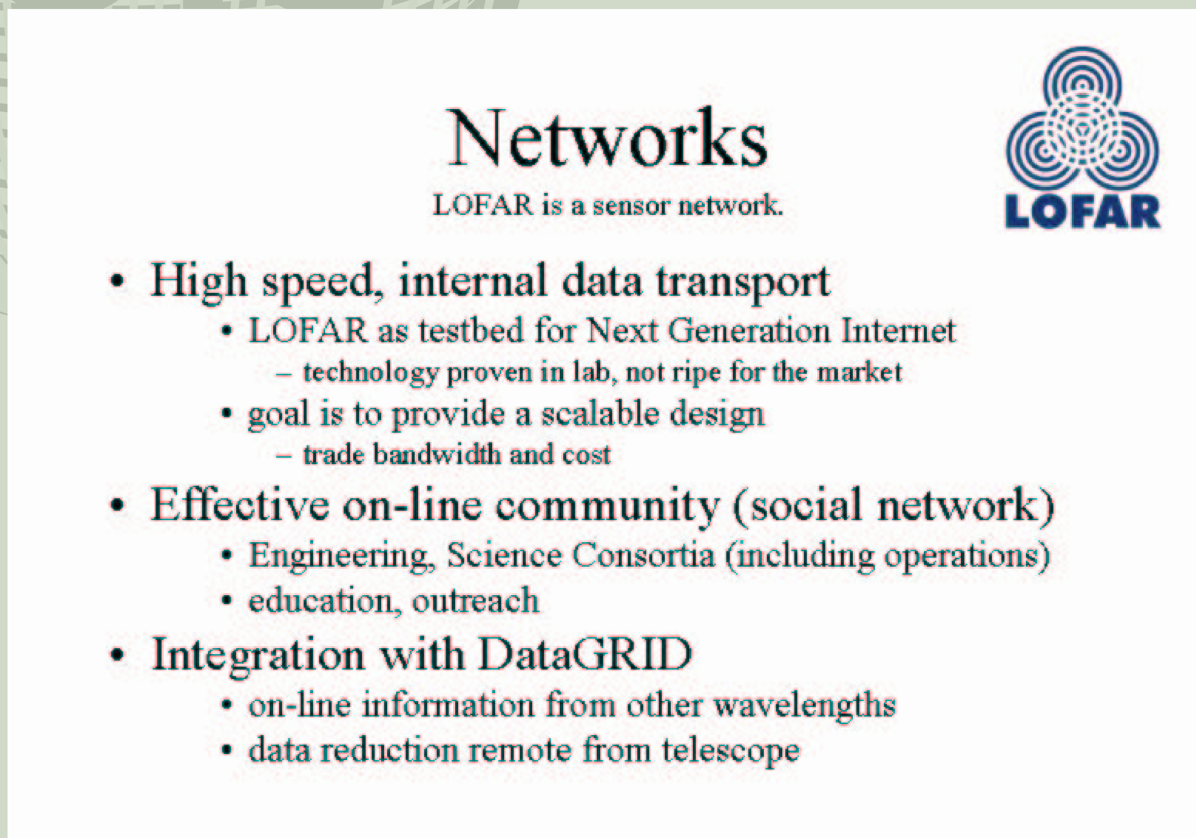
LOFAR/LOIS is best viewed as a huge, geographically distributed grid of electromagnetic sensors and emitters, fully digitised and operated entirely in software. The data from Earth's space environment and the Universe will be broadcast in real time over the World Wide Grid. This will be the first time that also the general public will have immediate, direct access to scientific data as they are produced.



A new generation of radio telescopes will
replace mechanical beam forming by fully electronic signal manipulation,
thereby enabling ***new functionality*** and
putting radio telescopes on ***favorable cost curve.***

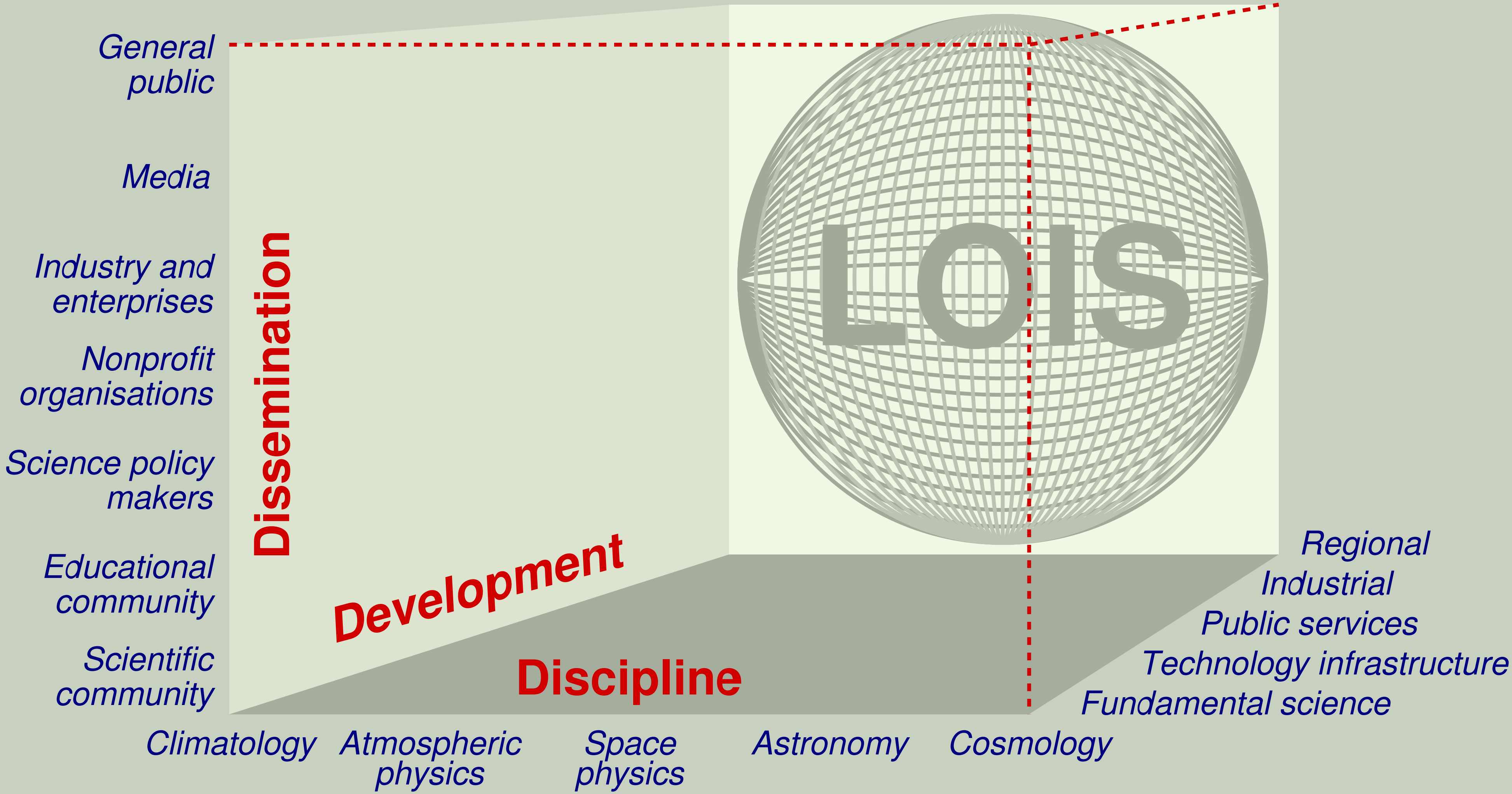
A huge digital sensor—and social—network

LOFAR and LOIS will be the world's first fully digital radio research facility operated entirely in software. It will be built like a huge, distributed network of sensors, supplemented by powerful computer soft- and hardware. Data rates up to tens of Tbits/s. Moore's law will have to be fully exploited.



Broad range of research Disciplines, extended Development sectors, and wide Dissemination of results

The LOIS 3D Cube



Examples of scientific challenges

Within the leading-edge scientific milieu which LOFAR/LOIS will constitute, a number of outstanding scientific and intellectual challenges can be attacked for the first time. These challenges span a broad range of space and earth sciences and include

- Interception and analysis of the extremely faint radio signals which were emitted from the first radiating hydrogen atoms in the Universe very soon after the "Big Bang". Will critically test competing theories on how the Universe was born.
- Actively probing dynamical processes further out in space than any existing radio facility for the earilest possible warning against particle storms which maybe harmful to man and disrupt and damage electric, electronic and communications systems.
- Detecting correlated transient phenomena, occurring at locations in space which may be vastly separated in distance and direction, for unprecedented cause-and-effect studies of Earth's space environment.
- Searching for new properties of radio signals from space which can be utilised for future research and communication purposes.

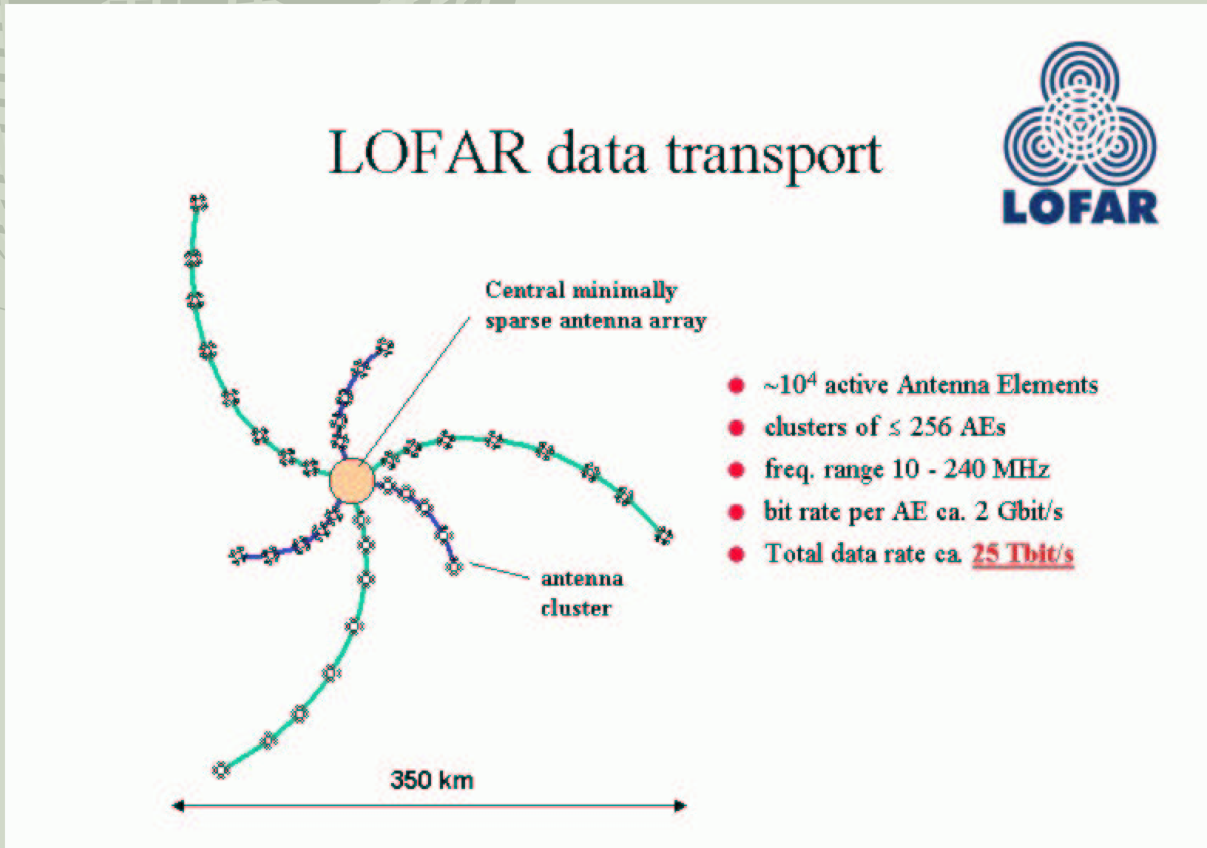
Examples of technological challenges

The scientific challenges give rise to a number of technological challenges, for instance

- Development of techniques for intelligent, resource conserving, large networks of sensors, analogous to the working of the human brain.
- Further development of smart antennas and radio systems which exploit the full three-dimensional electromagnetic field information in the radio waves and not just one or two field components or average intensity values.
- Develop the interface between the physical and the digital to facilitate immediate access to scientific primary data for scientists as well as the general public via the upcoming World Wide Grid.
- Investigate whether wireless communications from ground or satellites have any environmental impact on the Earth's atmosphere and ionosphere, and, if so, find remedies.

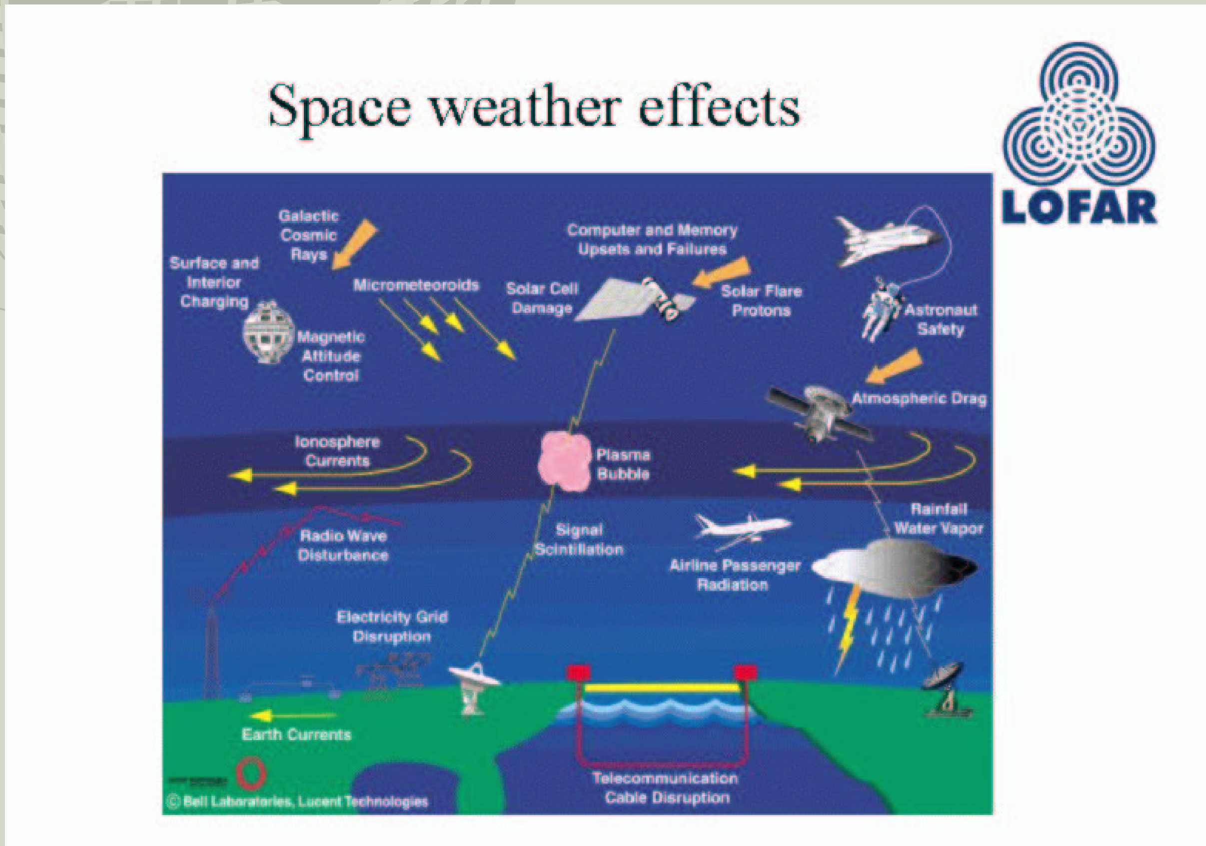
Scientific goals will push technology limits

The scientific goals of observing the very first radio emissions from hydrogen created in the Universe after the "Big Bang", and measuring space plasma dynamics on the Sun and in interplanetary space, will advance antenna, radio, detector, and data handling technologies beyond their current limits.



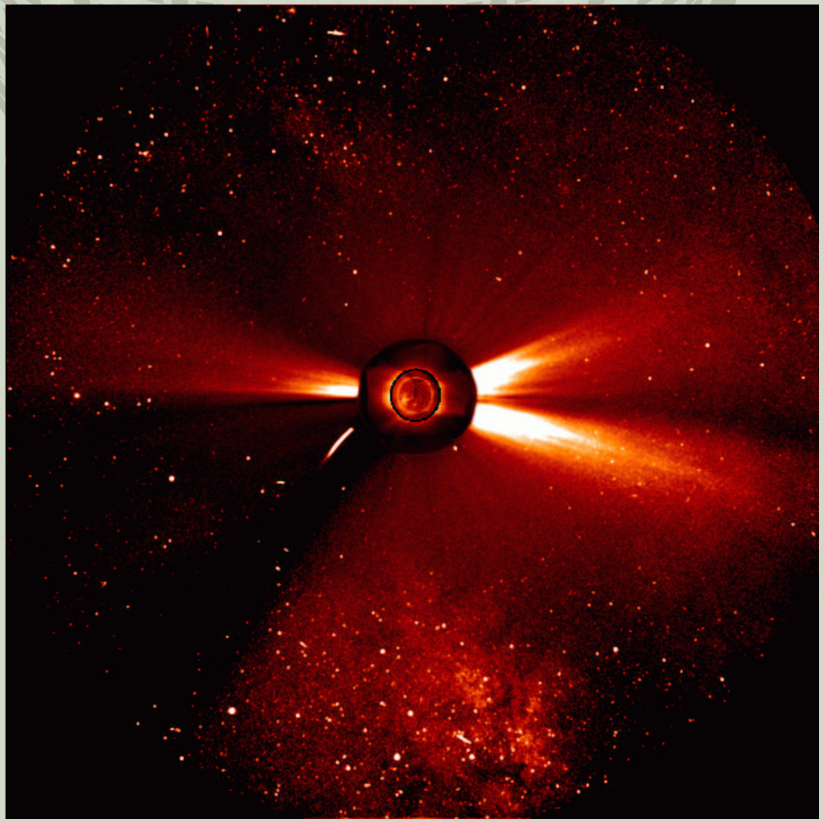
Modern technology is vulnerable

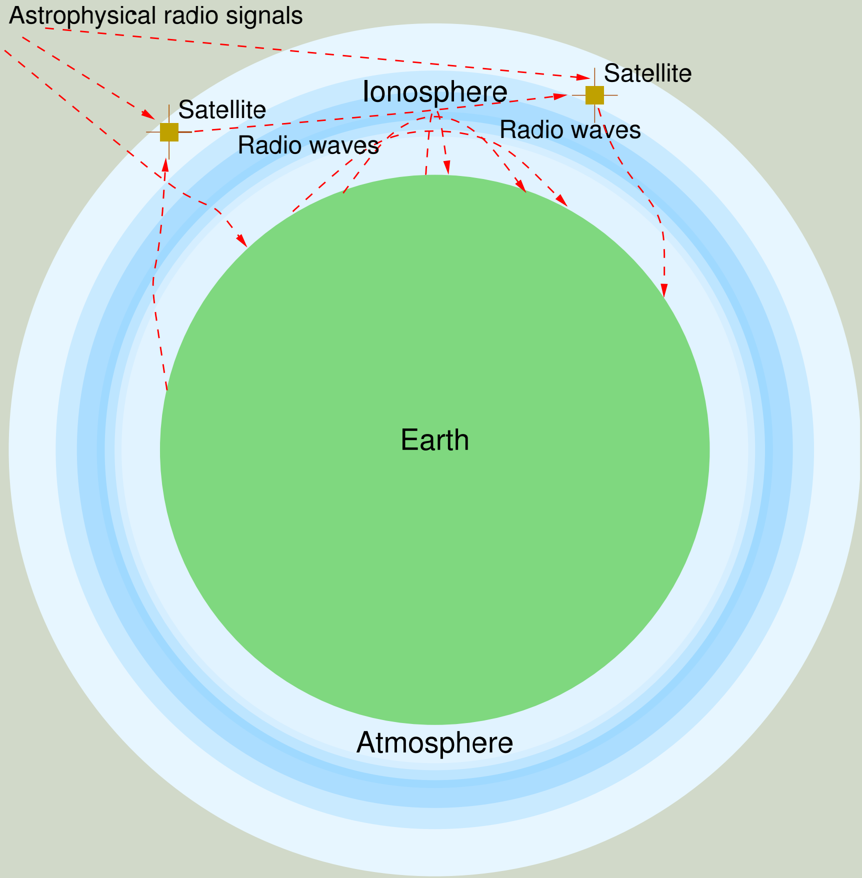
Modern electric, electronic and communications systems are very vulnerable to disruption and permanent damage due to solar storms and other natural phenomena occurring far out in space. Solution: more research and better diagnostics of space phenomena and space weather forecasting!



LOIS will add very early and accurate solar particle storm warning capability to LOFAR

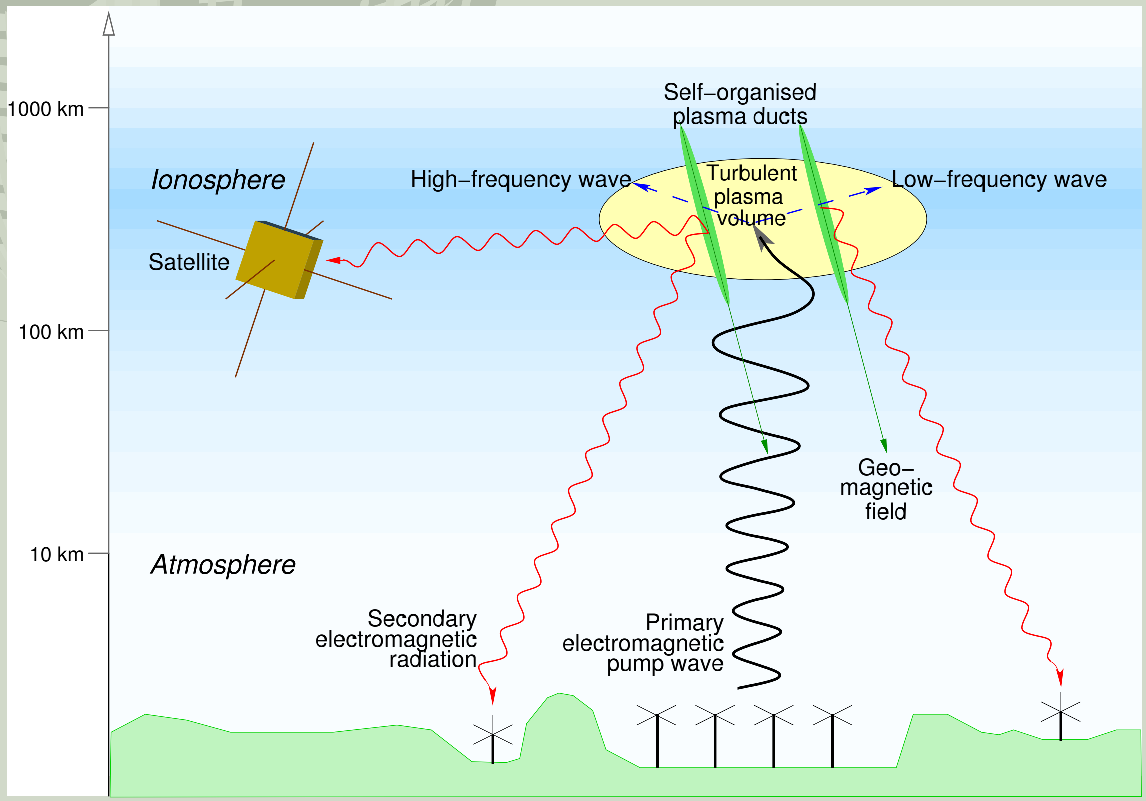
Solar particle storms may be hazardous to biological life and damage communication systems and power grids on Earth. Already after a few minutes the LOIS/LOFAR solar radar setup will detect the onset and *the direction of travel* of such particle clouds, thus providing early, accurate forecasts.





Ionospheric turbulence and associated radio noise

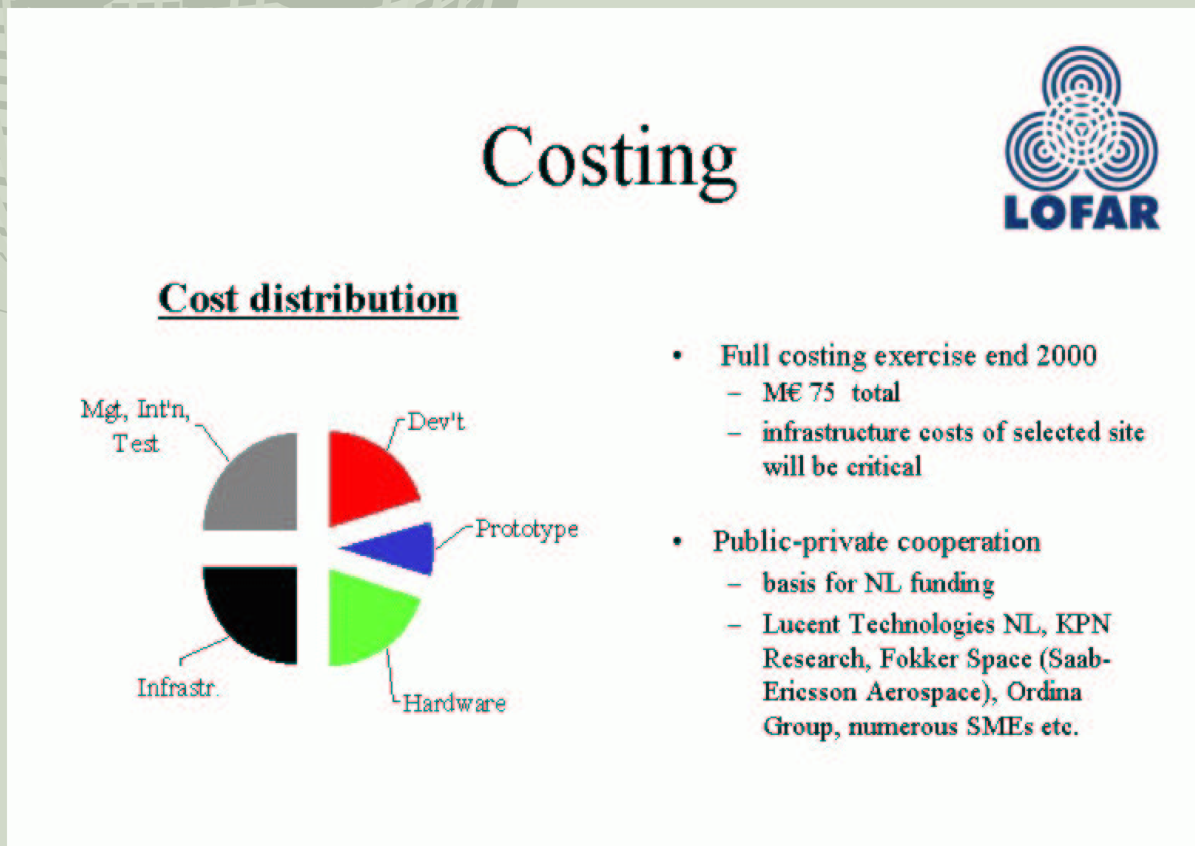
Radio waves from ordinary broadcast and other transmitters excite non-linear turbulence, irregularites, and secondary radio emissions in the ionosphere. This influences wireless communications, satellite positioning systems, and radio observations. LOIS will allow a systematic investigation of these newly discovered anthropogenic effects.



Stimulated Electromagnetic Emission (SEE); Beat-wave excitation.

Funding and procurement

On 26 April, 2001, a contract for the first 6.9 MEU funding of LOFAR from the EU/local political level in the Netherlands was signed. This supplements contracts of simliar size with industry. Further 10 MUSD will be provided by the US the coming winter. In September, 2001, the first Swedish funding (~0.7 MEU) for LOIS development was secured. A LOIS consortium is being set up.



Academia

An ad-hoc LOIS science group has been set up with members from

- Swedish Institute of Space Physics, Kiruna/Uppsala/Lund
- Växjö University, Växjö
- Uppsala University, Uppsala
- Advanced Instrumentation and Measurements (AIM) graduate school, Uppsala
- Onsala Space Observatory, Chalmers University, Göteborg
- ITN, Campus Norrköping, and National Supercomputer Centre, Linköping University, Linköping/Norrköping
- Theoretical Physics Department, Lebedev Institute, Moscow, Russia
- Arctic and Antarctic Research Institute, Saint Petersburg, Russia
- Radiophysical Research Institute, Nizhniy Novgorod, Russia
- Danish Meteorological Institute, København, Denmark
- Astrophysikalisches Institut, Potsdam, Germany

This list represents individuals involved in the discussions. Some of the organizations mentioned have now made committments.

Industry, agencies, authorities and organisations

- Kronoberg County Administrative Board, Växjö
- The Swedish Agency for Innovation Systems, VINNOVA, Stockholm
- Swedish Research Council, Stockholm
- AerotechTelub, Växjö
- SAAB Corporate, Linköping
- RemSpace Group, Linköping
- Ericsson Microwave Systems, Mölndal
- Ericsson Research, Kista
- IT Kronoberg, Växjö
- Teracom, Stockholm
- Racomna AB, Uppsala
- RedSnake Radio Technology, Stockholm

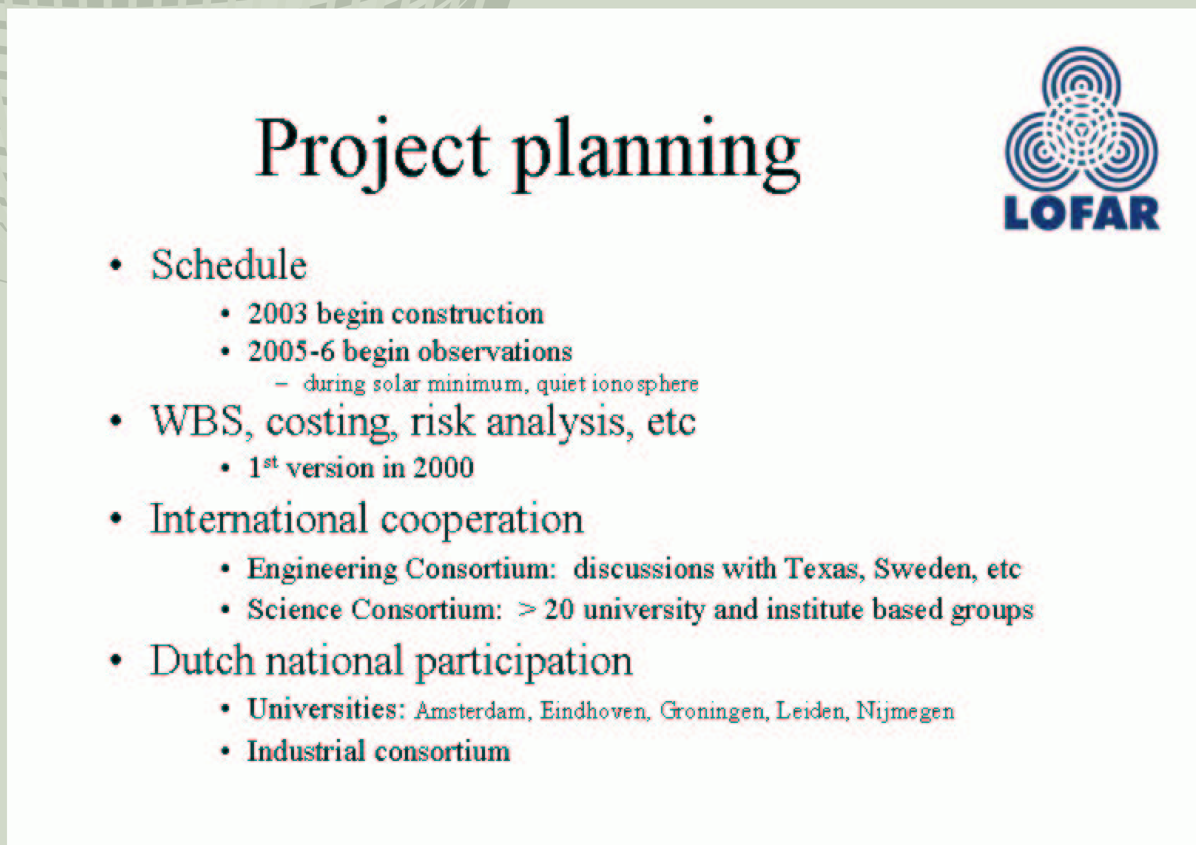
Several of the companies or agencies mentioned have now made committments.

Key features

- Challenging next generation communication and information technology. More than two orders of magnitude larger and more sensitive than any existing radio facility.
- Research of highest international class at the absolute forefronts of science and technology. First fully digital electromagnetic sensor-based radio observatory operated entirely in software.
- Extensive cooperation between Scandinavian universities, institutes, industry, and agencies.
- Science, technology, discipline, and culture frontier transcending.
- Major international impact and visibility.
- Will promote scientist mobility.
- Has potential of attracting more women into science.
- Technology areas: Antennas, sensors, high-frequency electronics, telematics, wireless communication, ultrahigh-speed networks.

Sweden as science and technology partner

For a giant radio and radar research project such as LOFAR, Swedish physics, technology and industry has a very interesting profile. Productive discussions on science and technology commenced in 1999. Talks with industry (Ericsson and others) were initiated in 2000 and have intensified and widened in 2001. First Swedish science/tecnology contracts obtained in late 2001.



LOFAR/LOIS—scientific and technological goals

Innovative methods, based on recent developments in radio astronomy, space physics, and electromagnetism as well as in radio, antenna, signal processing, and network technology, will be utilised at LOFAR and LOIS in order to achieve truly unique scientific and technological goals.