LOIS — An HF/VHF Deep-Space Radar Supplement to the LOFAR Telescope

LOIS, a Scandinavian initiative to build a LOFAR subfacility, including a software radar and first-class infrastructure, to enhance the space physics capability of LOFAR and to add some new technologies.

www.lois-space.org

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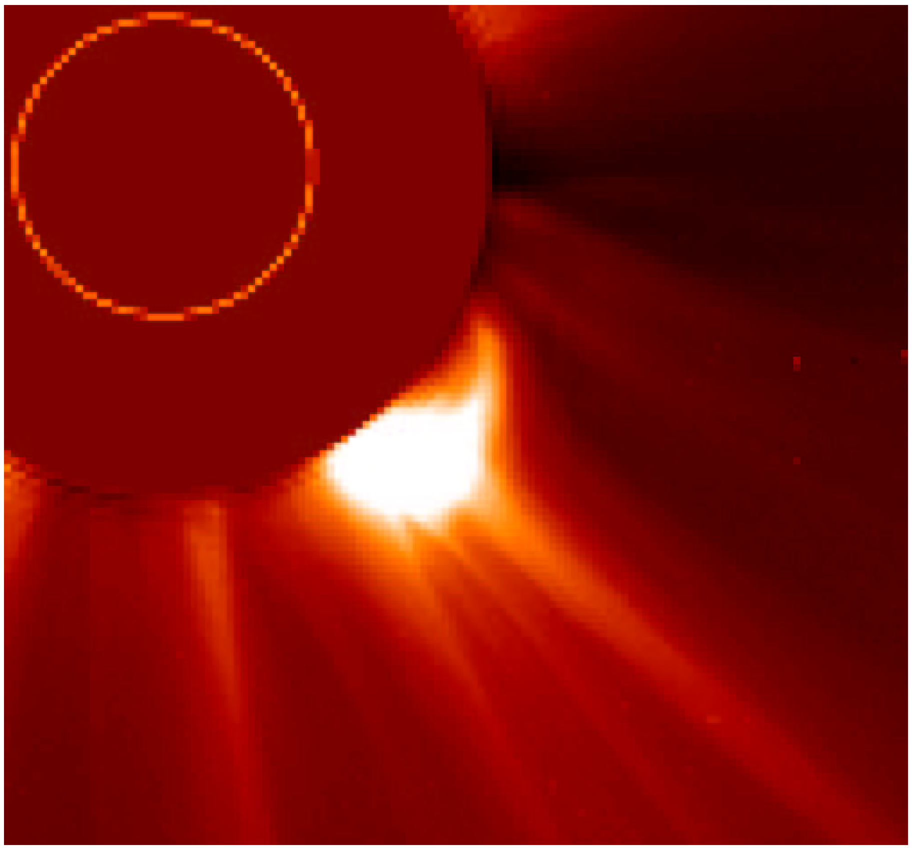
Deep space probing

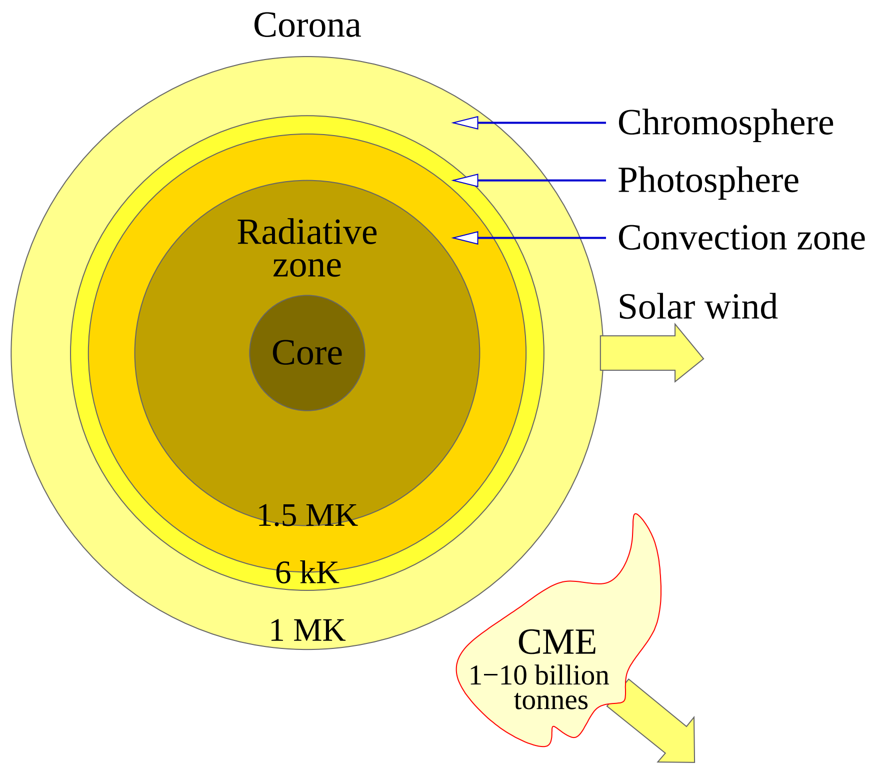
Active radio probing deep into space for studying the properties of

- Solar atmosphere dynamics including coronal mass ejections (CMEs)
- Solar wind ion-acoustic turbulence
- Transition layers in the magnetosphere
- The lunar regolith
- Solar system objects, including planets and planetary topside ionospheres

Coronal Mass Ejections (CMEs)

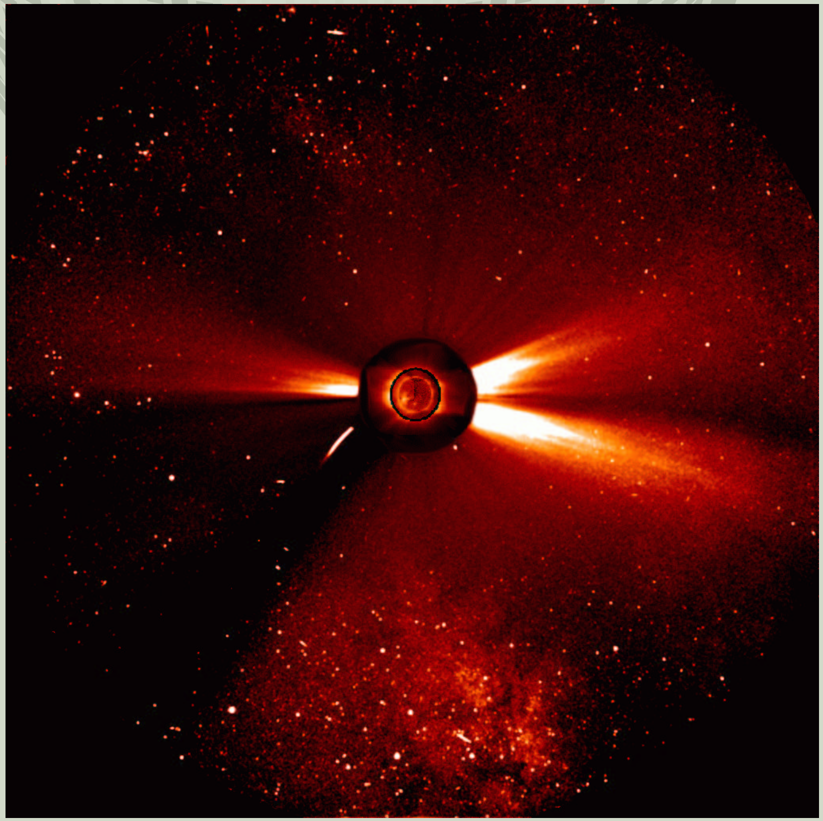
CMEs are dynamic solar events in which plasma initially contained in closed coronal magnetic field lines is ejected into interplanetary space.

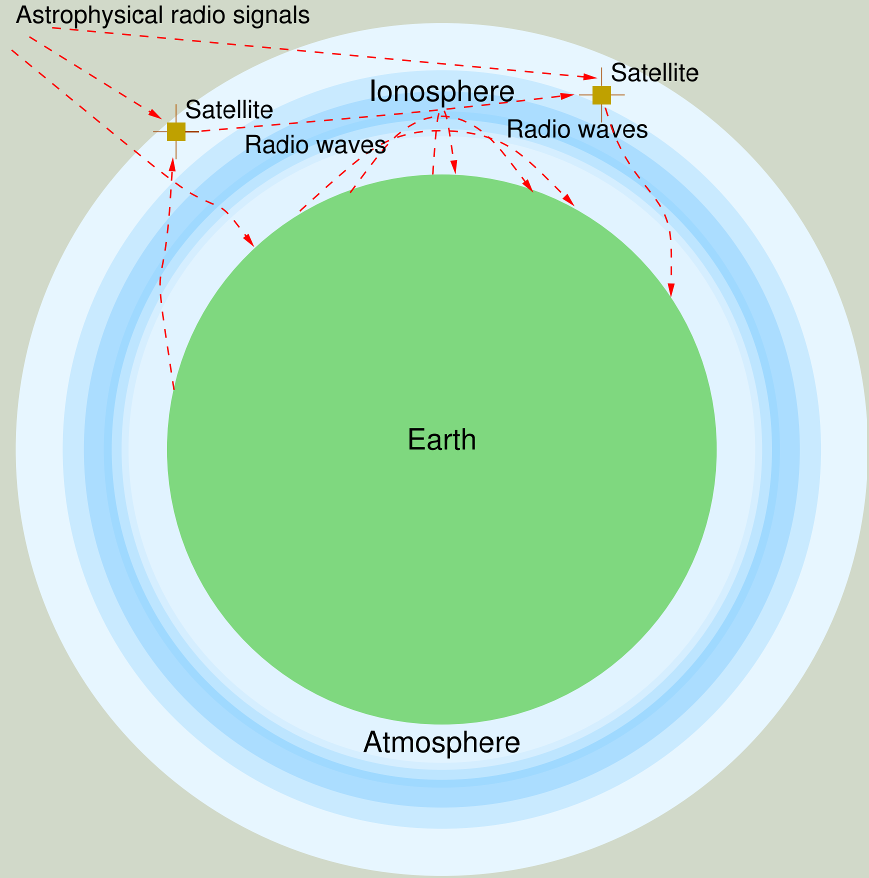




Early and reliable particle storm forecasts

Already after a few minutes a LOIS/LOFAR solar radar combo should be able to make radar detections of the onset and *the direction of travel* of CMEs, thus improving the possibilities to produce early, reliable particle storm forecasts.





Solar radar history

1. In 1959, *Eshleman et al.*, detected the corona at 25.6 MHz. The point of reflection was determined at 1.7 photospheric radii from the solar centr.

2. From 1961 to 1969 *James* observed the corona at local noon using a 38.25-MHz radar system at El Campo, TX. Echoes were typically blue-shifted.

3. In the mid-1960s, *Campbell and Parrish* detected the corona using a 40-MHz transmitter at Arecibo. Confirmed *James'* results but were severely limited by the 40-MHz Arecibo system sensitivity.

4. In 1977 and 1978 *Benz and Fitze* failed to observe scatter from Langmuir waves in the corona with the Arecibo S-band radar.

5. From 1996 to 1998 Russian/Ukrainan groups made solar radar experiments at 9 MHz with Sura and the UTR-2 radio telescope in a bistatic mode. Marginal detection of the corona with a Doppler bandwidth of about 40 kHz. Monostatic data analysis is in progress.

Why reopen the solar radar field of research?

Factors which were not available in earlier solar radar research and which are a strong motivation for reopening the field of fundamental solar radar research at this point in time are

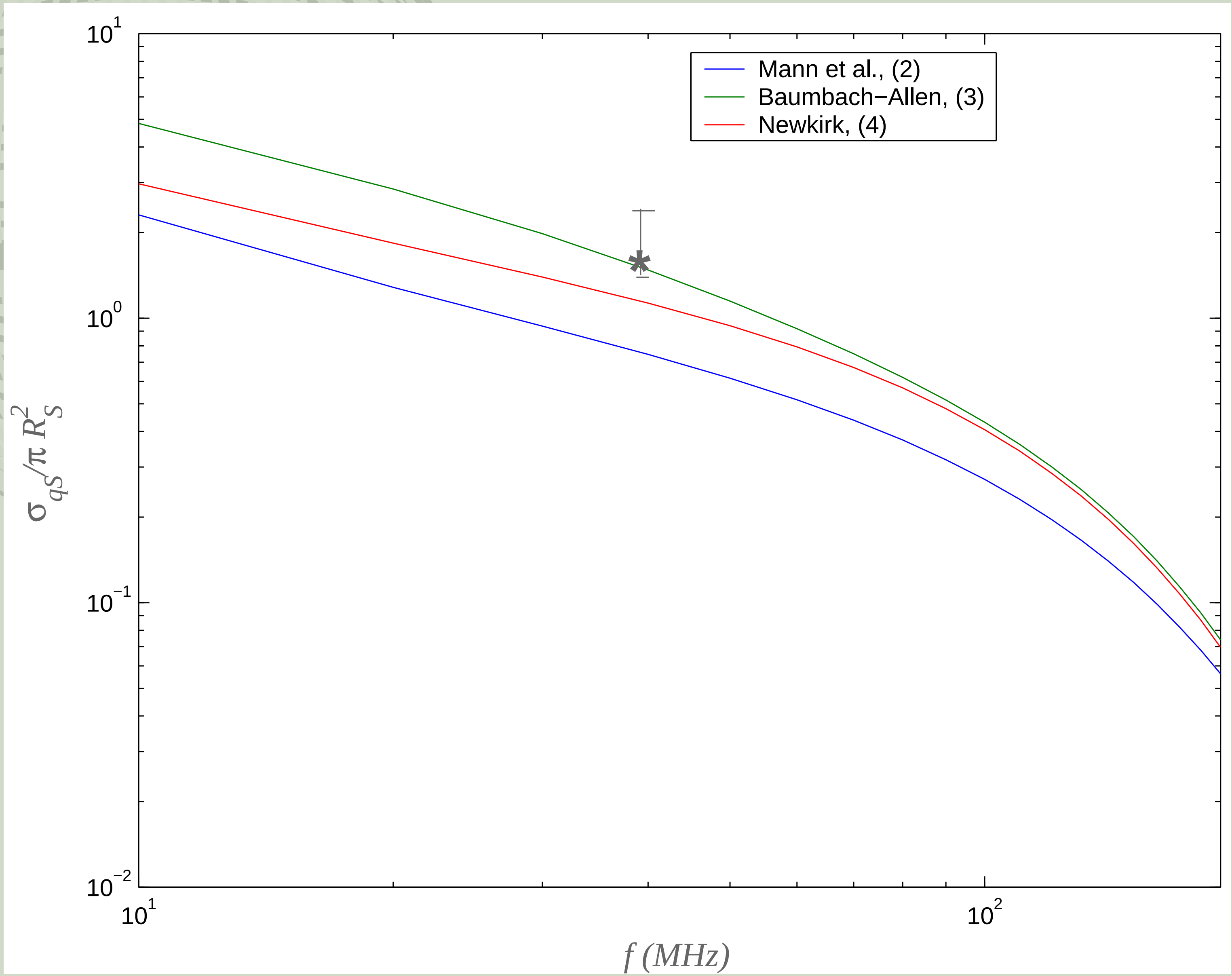
- Correlative observations from *Solar and Heliospheric Observatory (SOHO)*, *Transition Region and Coronal Explorer (TRACE)*, *WIND*, *Ulysses*, and other existing or upcoming spacecraft, as well as modern ground-based solar observatories.
- New radar, radio, and polarimetric techniques.
- Multi-frequency, multi-polarisation radar technologies.
- Improved general knowledge of the corona.
- Dramatically improved modelling and computing ability.

Radar probing of the quiet Sun

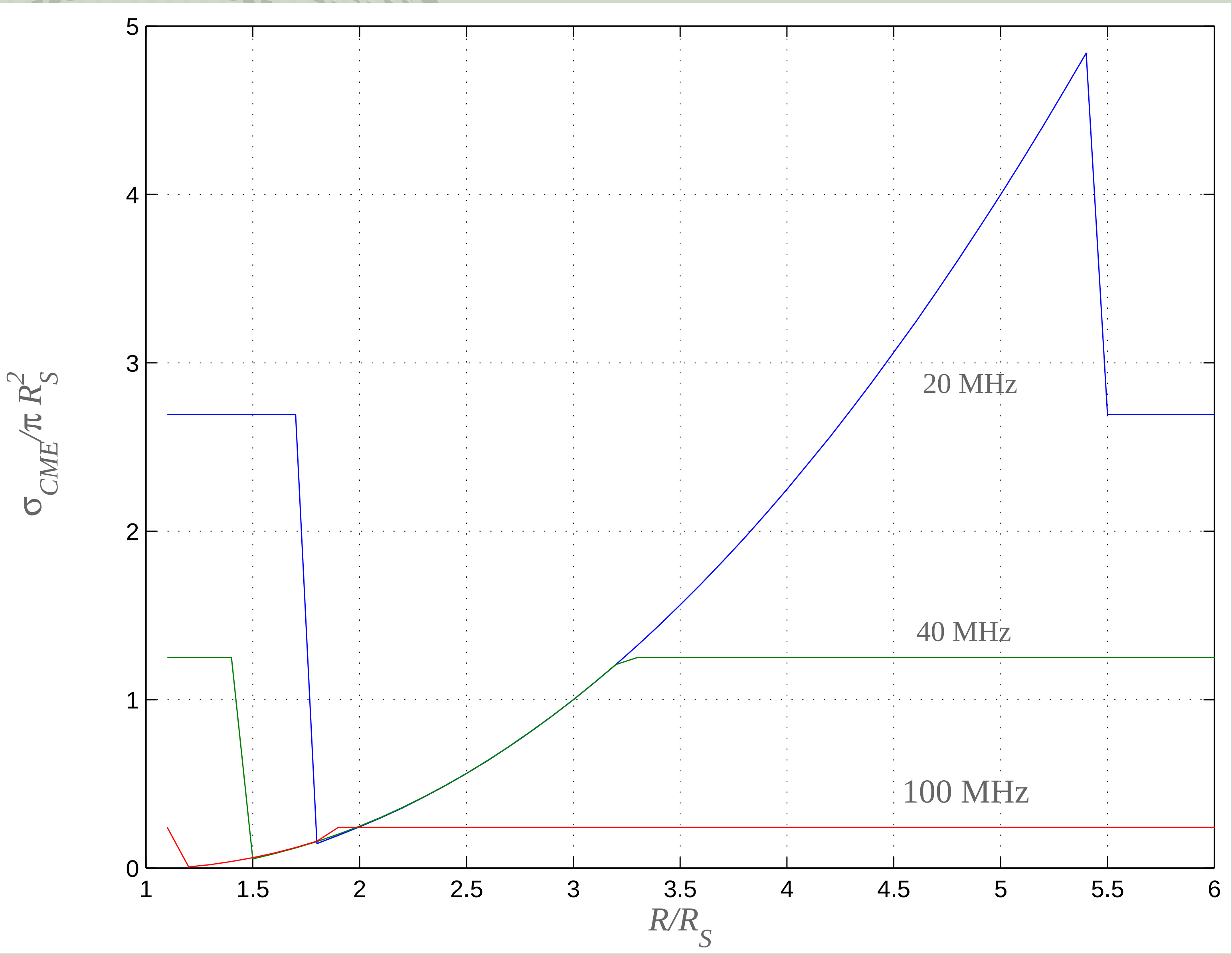
The solar atmosphere optical depth formula $I(\omega) = I_0 \times \exp[-\int \kappa(\omega) dz]$, where the absorption index $\kappa(\omega)$ exhibits an ω^2 dependence limits the frequency range for a solar radar to below 100 MHz or so.

The ionosphere sets a lower limit of the radar to 5–10 MHz. Even for frequencies above this cut-off, corrections for the ionospheric distortions on both the transmitted and received radar signals must be made with self-calibration techniques or similar.

Radar cross section for the quiet Sun



Radar cross section for a CME event



Active experimentation in geospace

Using geospace as a model space laboratory for systematic, repeatable, active radio investigations of fundamental aspects of

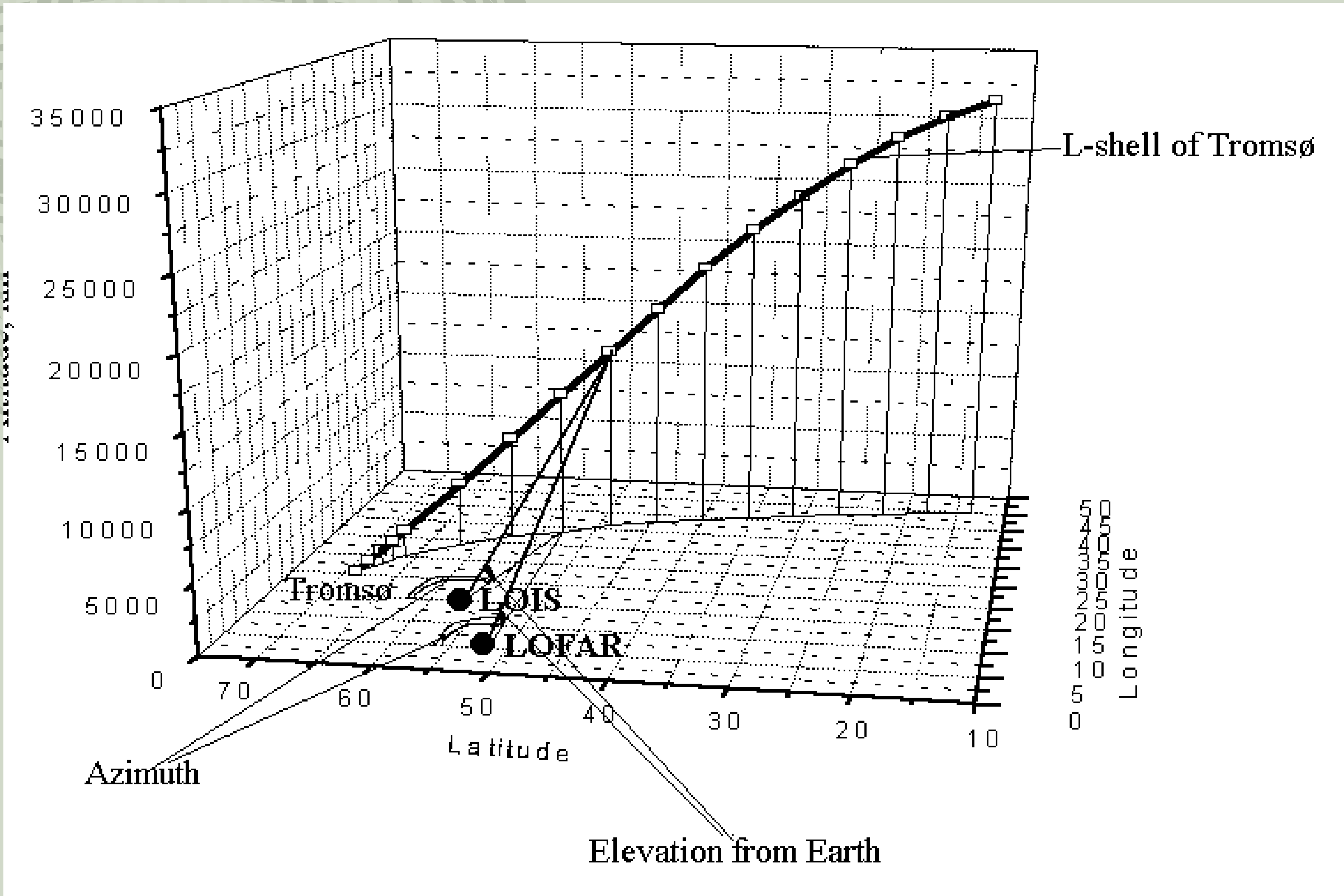
- Wave propagation and coupling (Raman, Mandelshtam-Brillouin) in the underdense, inhomogeneous ionosphere
- Verification of resonant beat-wave excitation (Manley-Rowe) and its utilisation in radio probing of space
- Nonlinear spectral and polarimetric ‘colouring’ of strong radio signals
- Radar detection of transient ionisation in the atmosphere due to cosmic particles
- Radio detection of gamma ray bursts from magnetars
- Test of Sagnac and general relativistic effects due to non-inertial frame properties

Near space radio probing

Improved active diagnostics of Earth's space environment by

- High spatial and temporal resolution of the local magnetic field and transport coefficients in the ionosphere via nonlinear EM radiation spectroscopy
- Radio-induced flouresence of chemical constituents in the upper atmosphere as a means of detecting possible pollutants with the help of optical subsystems
- Simultaneous multibeam, multilocation ionospheric sounding to map out dynamical structures
- Interaction of EM waves with free energy sources in the ionospheric-magnetospheric system to investigate the triggering of large-scale energy flows.
- Routine 'coherent' and 'incoherent' radar probing at lower frequencies and further out into space than before
- Geographically extended mesospheric-stratospheric-tropospheric 'weather' radar studies of atmospheric turbulence and front dynamics

Tromsø flux-tube experiments



Passive applications

- Low-frequency coronal radio emissions from the Sun with high resolution
- Low-frequency radio emissions from planetary surroundings
- Radio pulses from the lunar regolith (Askaryan effect)
- Cyclotron harmonic radiation from the perturbed ionosphere
- Radio pulses (Vavilov-Čerenkov radiation) from atmospheric showers
- Correlated observations of radio emissions from thunderstorms and lightning-induced sprites in the ionosphere
- Verification of feasibility of low-frequency reception within the 37.75–38.25 MHz band (reserved for radio astronomy) for future imaging relative ionospheric opacity (riometer) measurements

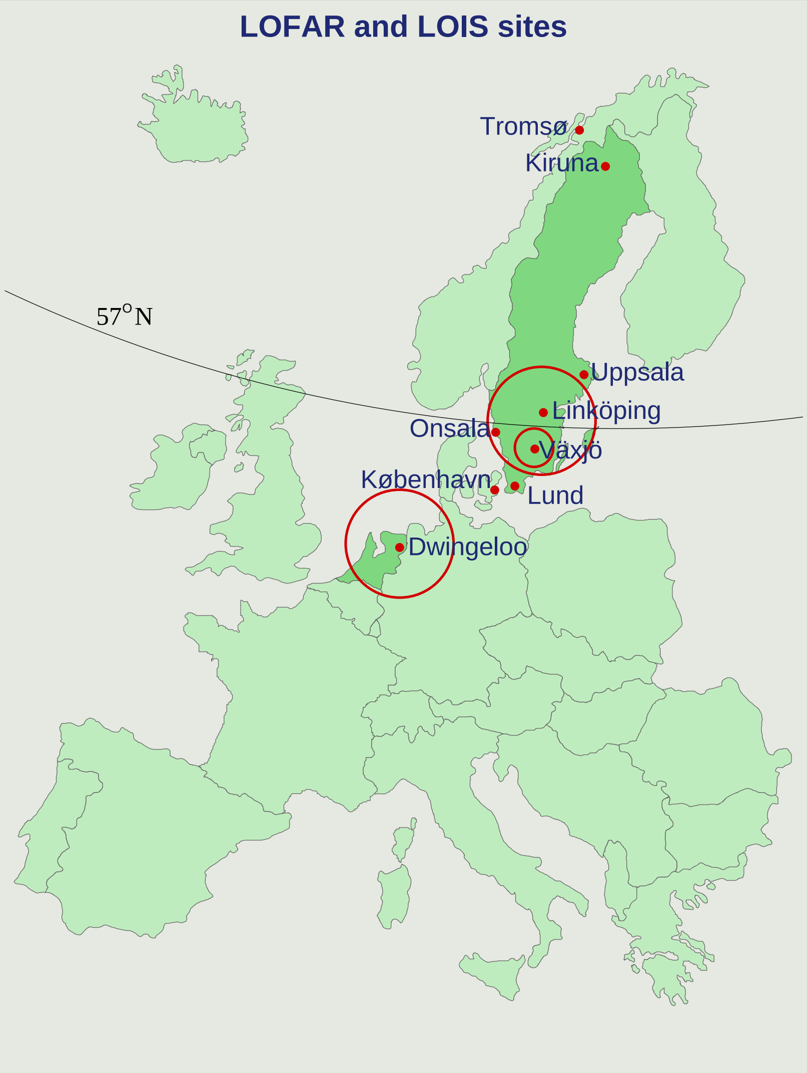
Technologies and techniques

- 3D polarimetry [SU(2)→SU(3) extension of Stokes parameters] with fully digital sensors/emitters and small, inconspicuous, 'smarter' antennas.
- Enhanced RFI mitigation by using the full 3D generalised Stokes parameter characterization of the signals.
- Efficient optimisation of antenna beam-forming using the full information in the 3D electric and magnetic field vectors.
- High-performance Grid-enabled data managment of streaming data. (LOIS key project in Sweden's national and regional World Wide Grid efforts. One Grid node already up and running in Uppsala.)
- Low-orbit satellite for measurements *in situ* of ionospheric radiation and turbulence as input to self-calibration.
- Geodetic charting underway. Will yield fix points accurate to typically 1 cm. Galileo will be used.
- Team members with long and solid experience in designing, constructing, running and maintaining huge, ground-based, multi-station sensor networks of the LOFAR/LOIS type.

Siting and infrastructure

Southern Sweden is an almost ideal location for huge distributed digtal radio observatories

- 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)



Bistatic geometries

RX	θ_{RX}	φ_{RX}	α
Tremsdorf, Germany	52.3° N	13.1° E	4.6°
Dwingeloo, Netherlands	53.0° N	6.5° E	6.2°
Nançay, France	48.4° N	2.2° E	11.4°
Kharkov, Ukraine	50.0° N	36.2° E	14.3°
Vasil'sursk, Russia	56.2° N	46.0° E	17.0°
Northern Kenya	2° N	37° E	57.5°
Arecibo, Puerto Rico	18.3° N	66.8° W	70.3°
El Campo, Texas	26.2° N	96.3° W	76.4°
Socorro, New Mexico	34.1° N	107.6° W	77.0°
West Texas	31° N	104° W	78.3°
Southwestern Australia	30° S	120° E	122.8°

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