

LOIS — a LOFAR Outrigger in Sweden. Science and Technologies.

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

www.physics.irfu.se/LOIS

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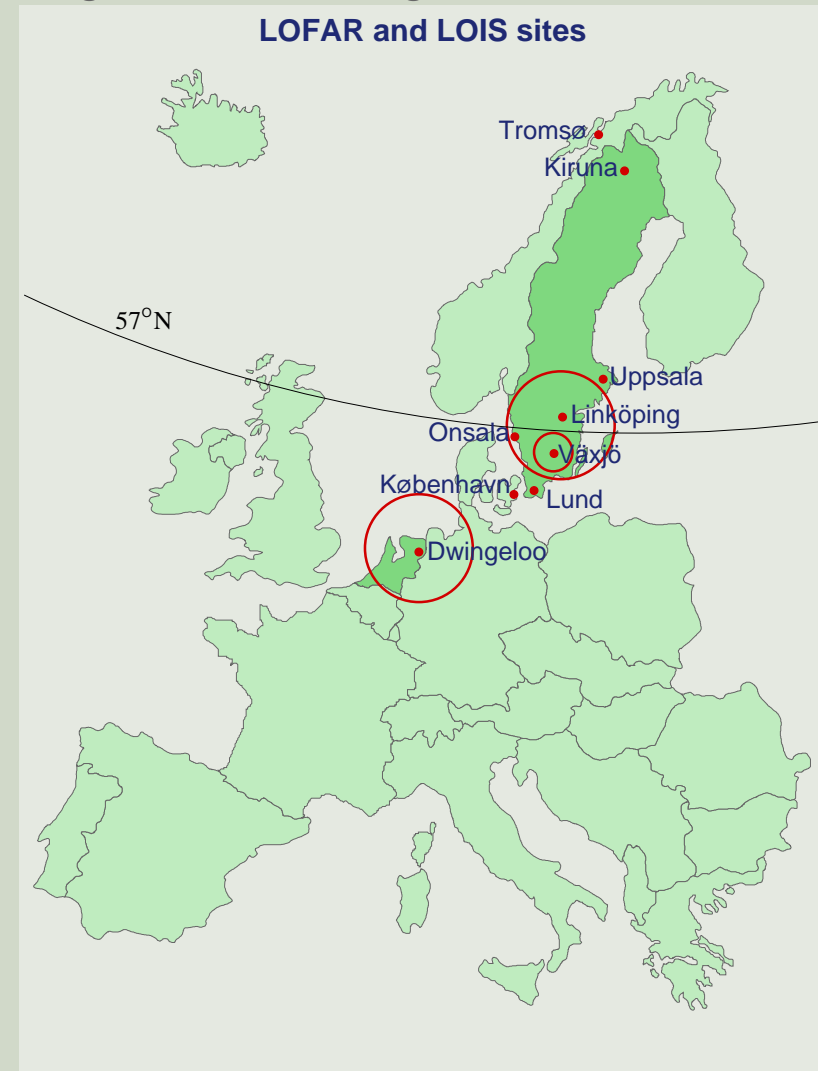
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Siting and infrastructure

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

- Sparsely populated region ($\sim 21/\text{km}^2$) with an excellent IT infrastructure
- 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)



Active applications

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
- Space plasma 'turbulence on demand' effects, including formation of self-organised temporal and spatial structures
- Anomalous tunneling of waves and turbulent transport in space plasma
- Nonlinear spectral and polarimetric 'colouring' of strong radio signals
- Radar detection of transient ionisation in the atmosphere due to cosmic particles
- Radio phase detection of gamma ray bursts from magnetars
- Test of Sagnac and general relativistic effects due to non-inertial frame properties

Near space 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 fluorescence 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



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
- Solar system objects, including planets and planetary topside ionospheres
- Transition layers in the magnetosphere
- The lunar regolith

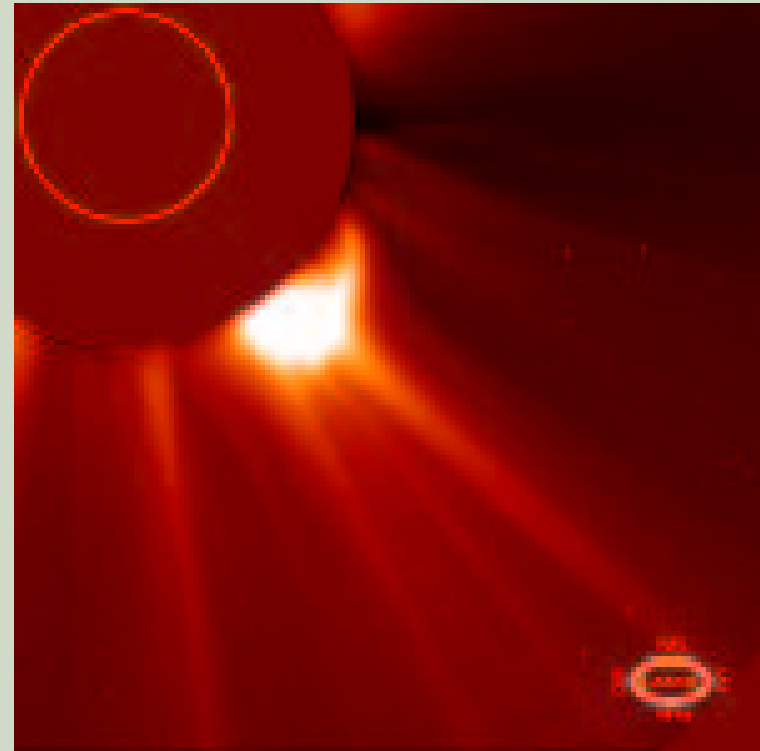
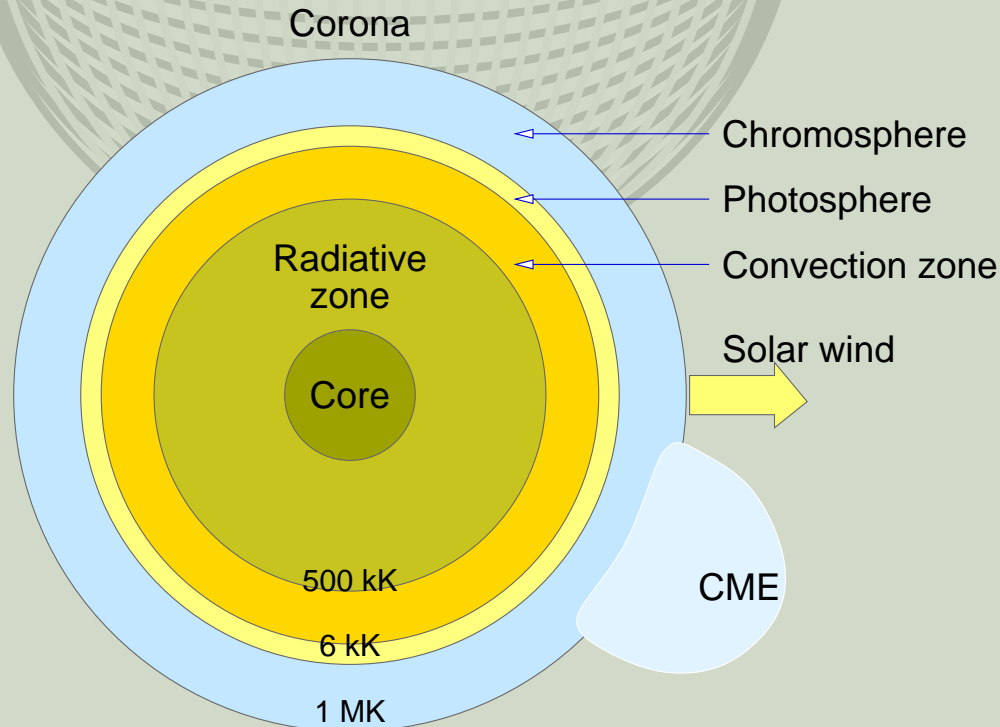
Solar Radar

- Want raw data recording for after-the-fact image forming. Can trade off resolution in the various dimensions to enhance the most interesting ones.
- Maximum sensitivity, determined by RX core area (within 10 km or so from the center [could be calculated more exactly]) and TX power
- Want the best possible instantaneous u-v plane coverage, *i.e.*, RX antenna element placement, for solar 'snapshot' images.
- Coded transmission needs at least one and preferably several samples per baud, saved as raw data. Baud lengths as short as 0.1 s or better (*James* down to at least 0.25 s). Bandwidth will be a much more stringent criteria for sampling speed. Want hundreds of kHz. Up to several MHz for multi-frequency observations.
- Time resolution better than 1 s (serendipity factor is high!). Angular resolution down to 1 arcmin. Frequency resolution 0.5 kHz. All Stokes parameters.

Coronal Mass Ejections (CMEs)

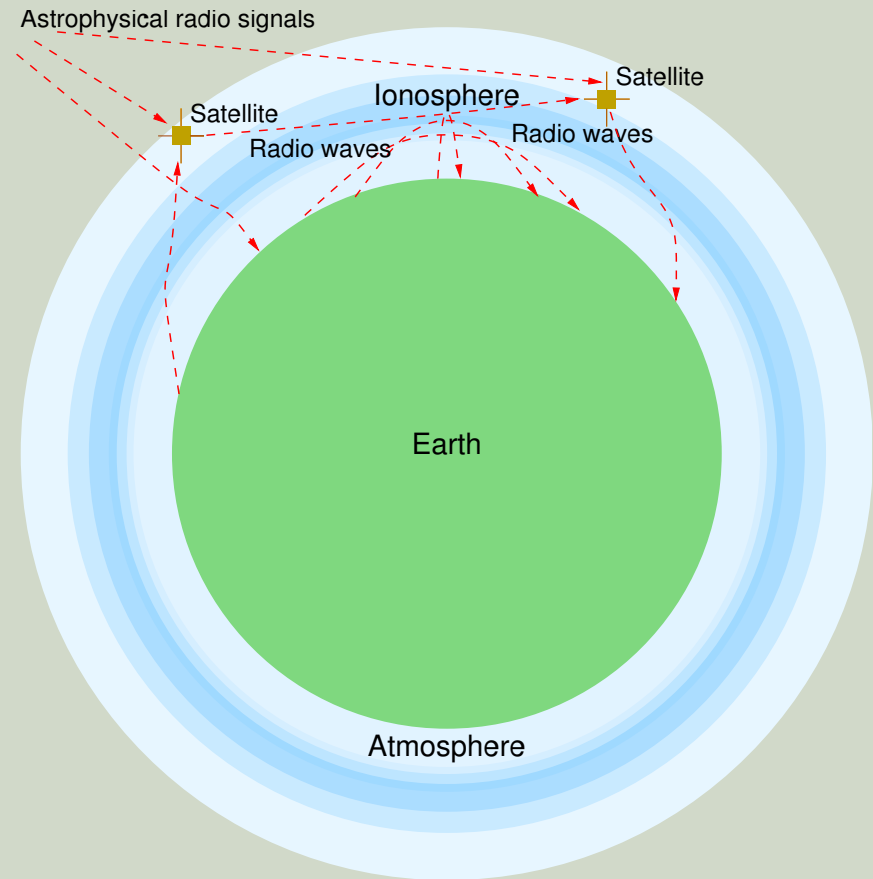
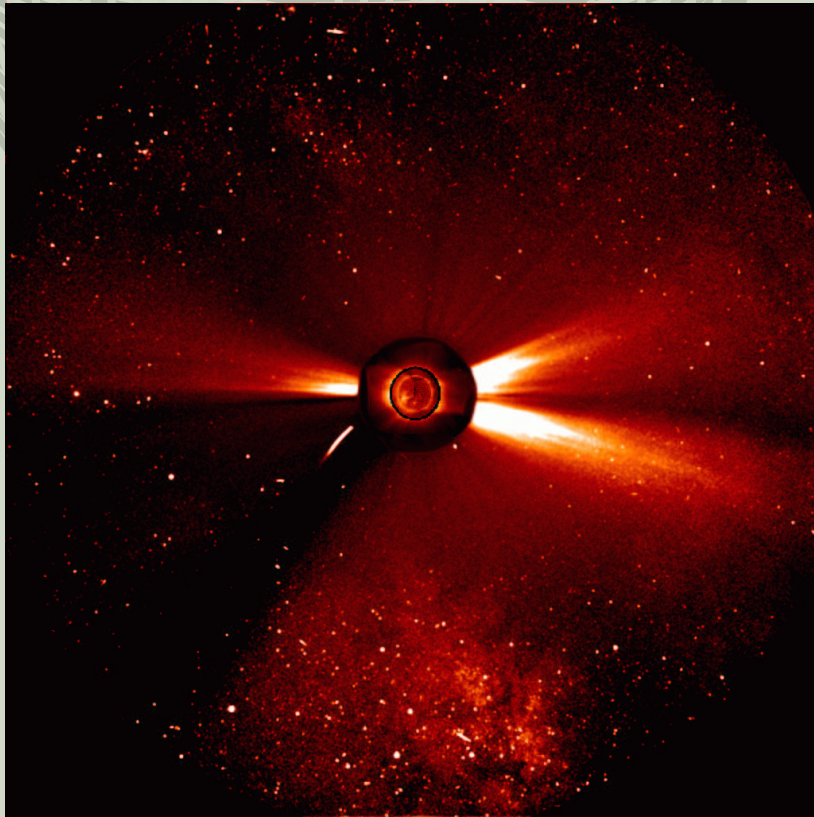
Dynamic solar events in which plasma initially contained in closed coronal magnetic field lines is ejected into interplanetary space

CMEs drive interplanetary shock waves and accelerate particles to relativistic speeds [Gosling et al. (1974), Rust (1983), Sheeley et al. (1985), Schwenn (1986), Cane et al. (1987), Feynman and Garrett (1987), Kahler (1994), Bravo and Perez-Enriquez (1994), McAllister et al. (1996a), Weiss et al. (1996), Reames et al. (1996)].



Early and accurate particle storm warnings

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 plasma bubbles, thus providing early, accurate forecasts.



Venus

Radar equation:

$$P_r = \frac{P_t G A \sigma_T}{(4\pi R^2)^2} = \frac{P_t A^2 \sigma_T}{4\pi \lambda^2 R^4}$$

where P_t is transmitted power, G antenna gain, $A = \lambda^2 G / (4\pi)$ antenna aperture, $\sigma_T \approx a |(\sqrt{\epsilon} - 1) / (\sqrt{\epsilon} + 1)|^2$ target radar cross section, and R the distance to the target.

Parameters:

$$R = 10^{11} \text{ m}$$

$$\sigma_T = 10^{13} \text{ m}^2$$

$$P_t = 10^6 \text{ W}$$

$$\lambda = 6 \text{ m (50 MHz)}$$

$$G = 10^5 \text{ (50 dB)}$$

$$A = \frac{\lambda^2}{4\pi} G = 10^8 \text{ m}^2$$

These numerical values give $P_r = \times 10^{-14} \text{ W}$

For a noise temperature of 10^4 K and a bandwidth of 2 kHz to allow for a range resolution of 75 km the system noise power is $P_n = \kappa T B = 1.38 \times 10^{-23} \times 10^4 \times 2 \times 10^3 = 2.8 \times 10^{-16} \text{ W}$ and the signal to noise ratio becomes

$$\left(\frac{P_r}{P_n} \right)_{50\text{MHz}} = 30 \tag{1}$$

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 engineering

- 3D polarimetry [$SU(2) \rightarrow SU(3)$ extension of Stokes parameters] with fully digital sensors/emitters and small, inconspicuous, 'smarter' antennas.
- High-performance GRID-enabled data management of (streaming) LOFAR/LOIS data.
- Efficient optimisation of antenna beam-forming using the full information in the 3D electric and magnetic field vectors.
- LOIS key project in Sweden's national and regional World Wide Grid efforts.
- Enhanced RFI mitigation by using the full 3D generalised Stokes parameter characterization of the signals.
- Provide communication links for the International Space Station.
- 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 3 cm.
- A full-fledged LOIS would add a sizeable extra receiving array
- 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.