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A SOLAR INTERFEROMETRIC MISSION FOR ULTRAHIGH RESOLUTION IMAGING AND SPECTROSCOPY: SIMURIS

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ABSTRACT

SIMURIS is an interferometric investigation of the very fine structure of the solar atmosphere from the photosphere to the corona. It was proposed to ESA /1/, November 30 1989, for the Next Medium Size Mission — M2, and accepted in February 1990 for an Assessment Study in the context of the Space Station. The main scientific objectives will be outlined, and the ambitious model payload featuring the *Solar Ultraviolet Network* (SUN), a 2 m long monolithic array of 4 telescopes of Ø20 cm, and the *Imaging Fourier Transform Spectrometer* (IFTS), an UV and Visible Imaging Fourier Transform Spectrometer coupled to a Ø40 cm Gregory, described.

MISSION OBJECTIVES

SIMURIS, as a very complete Observatory Mission, will address most of the questions still, and often for long, left unanswered on the solar atmosphere. It will primarily use observations of the very fine structure, i.e. will get direct evidences of the structuring of the atmosphere by magnetic fields.

The solar atmosphere provides the primary astrophysical laboratory where non-equilibrium processes can be studied *at their process scales*. It is now abundantly clear that these scales are small, primarily due to the intricate structuring of the solar magnetic field into tiny intermittent concentrations of strong field modeled as 'tubes', 'sheets' and 'loops', rather than being configured as a weak-field dipole. High spatial resolution is the essential observational requirement to understand these structures and the processes they cause and represent. Resolving them at their own *physical scales* is feasible on the Sun but not elsewhere in the cosmos and is a must for interpreting dynamical phenomena observed throughout the universe with physical rather than phenomenological insight. As is well-known, these inhomogeneities have horizontal structural lengths much smaller than 1000 km. For example, detailed analysis of the transition region C IV lines /2/ led to anticipate single flux tubes radii in the range 3 to 30 km. And, though the ultimate gradient scale across a coronal loop might in principle be 25 cm (ion gyroradius), it will probably be smeared out by plasma micro-instabilities (such as drift waves), and the relevant minimum observable scale which justifies the current instrumental design of SUN is more realistically of the order of 10 km (which also corresponds to the photon mean free path in the chromosphere).

The high spatial and spectral resolutions of SIMURIS will enable us to observe structures and events associated with magnetic activity on various spatial, spectral and temporal scales and, thus, will significantly contribute to the understanding of : the physics of coronal loops, the plasma heating and thermal inputs of flares and microflares (flare kernels), the fine magnetic field structures in the UV and in the visible (flux tubes) and, also, the dynamics of granulation (e.g. magnetic vortex).

UV filtergrams of **0.01 arcsec** spatial resolution (**10 km** on the Sun) will be obtained with the *Solar Ultraviolet Network* (SUN) with 0.1 to 100 Å spectral bandwidth ; in the visible, spectral resolutions up to 60 mÅ allow to measure magnetic fields directly. The *Imaging Fourier Transform Spectrometer* (IFTS) will provide high spectral resolution simultaneously in selected UV or visible lines on a 10 x 10 arcsec field (and with 0.3 arcsec spatial resolution) : it will give 3D velocity fields information in the solar atmosphere.

The SIMURIS Mission is primarily intended to perform in the ultraviolet where most of the interesting lines of the high chromosphere, transition zone and corona are formed. As such it covers without interruption the UV range from the C III line at 1175 Å to the Magnesium line at 2803 Å. This range provides us also valuable physical diagnostics of the plasma density by use of line ratios (cf. Table 1). Both the major instruments, SUN & IFTS, also access the visible range for velocity diagnostics on the photospheric lines (in addition SUN measures directly the magnetic field in the Fabry Perot channel).

TABLE 1 Line pair examples for density and temperature diagnostic studies

Line	Wavelength (Å)	Ne (electrons/cm^3)	Te (K)
Si VIII	1445/1440	$1.0\ 10^7 - 1.0\ 10^9$	$7.9\ 10^5$
S X	1213/1196	$2.0\ 10^8 - 2.0\ 10^{10}$	$1.2\ 10^6$
C III	1247/1175	$1.0\ 10^9 - 1.0\ 10^{10}$	70 000
Si III	1312/1301	$1.0\ 10^9 - 1.0\ 10^{11}$	35 000
O IV	1407/1405	$3.0\ 10^9 - 3.0\ 10^{11}$	$1.2\ 10^5$

MISSION CONTEXT

SIMURIS, proposed to ESA in November 89, was accepted for an Assessment Study in February 1990, in the context of the Space Station program. It is intended to perform from the Space Station European Pointing System (EPS). The EPS (previously IPS, Instrument Pointing System, a 2 m in diameter pointed platform) has been flown on Spacelab2 with measured performances of pointing stability and accuracy at the 1 arcsec level /3/. Modifications to install it on the Space Station are currently addressed by ESA, and an improved electronics and control system is under study and development. The EPS on the Space Station should provide stability and accuracy performances of 0.35 arcsec or better.

One major advantage of the EPS which makes this platform unique for the SIMURIS Mission is its capacity to turn around its line-of-sight. Through a 180° rotation (3°/s rate), the EPS allows the SUN instrument to synthetize an image in 1 min. The EPS is currently the only planned large pointing system of the Space Station and ESA/NASA discussions are underway for its implementation as a join facility as soon as 1998.

In terms of mission requirements and resources, one could note that in addition of the EPS facility, the Space Station offers two significant advantages, i.e. : a 10 kW power supply, and an important 10 Mb/sec telemetry rate. For the complex SUN and IFTS instruments which require power and telemetry, but also for the complementary instruments which associate a large field of view with a high spatial resolution, these considerations are of prime importance.

MODEL PAYLOAD

The model payload is summarized hereafter, but more detailed presentations of the two major instruments (SUN & IFTS) can be found in this issue /4,5/ (a detailed description of SUN is also given in /6/). In Table 2 the instruments general characteristics are briefly indicated.

SUN is a fully stabilized interferometric concept in which both the pointing and the phase in between distant telescopes are controlled actively. The SUN telescopes are 20 cm in diameter, positioned non-redundantly such as to cover a 2 m baseline. The high resolution performances (**10 km - 0.01 arcsec** on a 4 x 4 arcsec^2 field on the Sun) are completed by an uninterrupted wavelength coverage from the C III line at λ 1175 Å to the near infrared at 9000 Å, thanks to a triple stage "double grating spectrometer" which, more simply, could be called a tunable UV monochromator. This quite complex focal instrument for the detection is imposed by the need to reconstruct images from interferograms by aperture synthesis, something impossible up to now in dispersed light, at least with the current available software from radio astronomy. An example of image reconstruction is reported in /3/. Specific to the optical domain is the photon noise and the large influence of the residual phase defects on the final image quality. The compact configuration selected for SUN allows a direct deconvolution, i.e. excellent imaging since the Optical Transfer Function of the system is without "holes" (it is continuous in the spatial frequencies domain allowing direct division without problems with "zeros"). This is a prerequisite for imaging of complex and extended objects such as the solar ones considered. As little as 100 to 1000 ph/pixel/s are necessary for very decent imaging with 0.01 arcsec resolution.

IFTS is a UV FTS intended to work from the far UV (Lyman α or C III line, alike SUN) to the visible, in two distinct channels accessible alternativelly by flip-in mirrors (for visible access). The IFTS system consists in a 40 cm Gregory telescope feeding a double grating pre-dispersive spectrometer (of the SUN type), before the collimated output can enter the Fourier Transform Spectrometer part. It provides, on a 10 x 10 arcsec field, a full spectrum with a minimum resolving power of 50000 in selected bandpass of 1 to several Å around selected lines or continua ; the spatial resolution is 0.3 arcsec. The major advantage of the IFTS compared to a classical grating spectrograph is the **axial symmetry** of the Michelson design allowing **an image to be formed**. The IFTS itself is of a classical design (cf. /7,5/ for further details on UV FTS design and performances) to the extent of its required precisions and optical components which have to be upgraded for far UV access.

The Complementary Instruments (Table 2) are now "classical" instruments of a solar physics payload, to the exception of the C IV Fabry Perot Imager which will need some further developments (which will be addressed during 2 accepted NASA Rocket flights in the frame work of the *Solar Plasma Diagnostics Experiment* program /8/). These instruments will complement global studies by their wide field of view, but they will also increase the temperature coverage up to the hot corona. They will benefit from the high telemetry rate of the Space Station and will therefore reach spatial resolutions of the order of one arcsec even though covering the full Sun at once.

CONCLUSION

SIMURIS will provide high spatial and spectral resolutions from the photosphere to the corona in order to address fundamental solar (and stellar) physics issues : plasma physics, magnetic field confinement, heating theories of the corona, flares and micro-flares, convection, etc... All the spatial scales of the observed solar structures are coupled to small scale processes linked to the discontinuities and constraints in the magnetic field. And from the understanding of the origin, evolution and decay of the hyperfine structure, we will be given to understand the larger scale phenomena, namely : active regions and coronal loops, flares, prominences, granulation, convection flows and shocks.

SIMURIS is indeed a complex payload which benefits from the latest available developments in electronics, active optics and detection techniques. These techniques are currently being investigated in laboratory with encouraging results /9,3/, and will soon be submitted to a test on the sky /10/.

TABLE 2 The SIMURIS Model Payload

SUN	UV section	Visible Section(s)
Spectral range	1175 — 2850 Å	250-480 ; 480-500 ; 500-900 (nm)
Spectral resolution	0.1 Å to 100 Å	0.12 Å (60 mÅ with added FP)
Spatial resolution	0.013 arcsec	0.03" (250nm) — 0.09" (900 nm)
Small field size (detector 1)	4 x 4 arcsec^2	4 x 4 arcsec^2
Large field size (detector 2)	30 x 30 arcsec^2	30 x 30 arcsec^2
Collecting area (4 teles. Ø20 cm)	1040 cm^2	1040 cm^2
Effective focal length	412 m	160 m
Detector 1 (minimum size)	540 x 110 (8.1 x 1.6 mm^2)	540 x 110 (20 x 4 mm^2)
Deterctor 2 (minimum size)	540 x 110 (12 x 2.4 mm^2)	540 x 110 (30 x 6 mm^2)

Optics : 4 Cassegrain telescopes + double grating spectrometer + Fabry Perot (visible channel)

IFTS		
Spectral range	1200 — 2800 Å	2500 — 5000 Å
Spectral resolution	$\lambda/\Delta\lambda \geq 50\,000$	$\lambda/\Delta\lambda \geq 10^5$
Spatial resolution	0.3 arcsec	0.3 arcsec
Field size	10 x 10 arcsec^2	10 x 10 arcsec^2
CCD detector	60 x 60 pixels	60 x 60 pixels
Collecting area (telescope Ø40 cm)	1180 cm^2	1180 cm^2

Optics : Folded Gregory telescope + double grating spectrometer + Fourier transform spectrometer

Complementary Instrumentation	Soft X-ray/EUV Multilayers Telescope (EMT)	Imaging Fabry Perot Interferometer (IFPI)	UV Filtergraph Camera (UVFC)
Spectral range	44, 130, 170, 195, 284, 304 Å	1533, 1550, 1580 Å	1216 — 2200 Å
Spectral resolution	$\lambda/\Delta\lambda \approx 20$—50	≤ 8 Å	$\lambda/\Delta\lambda \approx 25$
Spatial resolution	~ 1 arcsec	0.5 arcsec	~ 1 arcsec
Field of view	40 arcmin	20 arcmin	40 arcmin
Collecting area	45 cm^2	80 cm^2	80 cm^2
Effective focal length	2.5 m	2.5 m	2.5 m

Solar Interferometry, which was proposed to ESA for a Mission, has been accepted for an Assessment Study ; it has a tremendous potential of problem-solving and discoveries and we hope that the short description given will stimulate the solar physicists towards the new possibilities of ultrahigh resolution diagnostics they might not had even thought of before, and which could be reality by the end of this century.

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