

STELLAR OBJECTIVES OF SIMURIS

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Abstract. The *Solar Interferometric Mission for Ultrahigh Resolution Imaging and Spectroscopy* (SIMURIS) has recently completed an ESA Assessment Study (Coradini *et al.*, 1991). SIMURIS is a project for *Space Station Freedom* which major aims is to image the Sun with 0.01" resolution in the ultraviolet, and 0.05" resolution in the visible, employing full-field diagnostics, Doppler velocity mapping and Stokes polarimetry. SIMURIS is a solar mission but it has wider astrophysical interest. Implicitly because the Sun is the only star for which resolution at process scales is feasible with modest baseline; explicitly because SUN/SIMURIS will resolve nearby galactic objects. At 0.01" resolution, the intensity of many stars is larger than solar fluxes available per 0.01x0.01" pixel — the Sun being a cool star — and thanks to its active cophasing, SUN/SIMURIS should actually reach better resolution than the Hubble even after its repair. SIMURIS is therefore a precursor for future long-baseline space interferometry and this paper gives a brief, non-exhaustive, overview of the galactic astrophysics programs possible which could be addressed.

1 Introduction

SIMURIS represents the first space interferometry project at short wavelengths. Space interferometry is obviously needed on the long run in many fields of astrophysics. Going to long baselines is required to keep observations abreast of the increase in detailedness which computer simulations bring to interpretation; going to space is required since long-baseline interferometry is virtually impossible at the bottom of the atmosphere for the visible and totally impossible in the ultraviolet. ESA has reported on various options for space interferometry proposing a 100 m-class interferometer, to be launched around 2005 and, on a longer time scale (2015-2020), moon-based interferometry with much longer baselines... Obviously, SIMURIS is a precursor to such far-reaching endeavors. It is the only space interferometry project in Europe in which detailed designs are already prepared by industry and which has reached assessment phase scrutiny. The principles of the SUN/SIMURIS solution — a fully cophased array approach — to achieve faint-object interferometry, with the additional complexity of doing aperture synthesis on an extended rather than a point object, evidently pose valuable precedents for any other space interferometry scheme. Solar physics has often led general astrophysics in developing new instrumental techniques; SIMURIS will do the same in the important area of obtaining high resolution, at short wavelengths, and on faint objects using nearby referencé objects (planets or stars).

SIMURIS employs advanced interferometric techniques. The payload includes two major instruments which are the *Solar Ultraviolet Network* (SUN), an interferometric array of four 20-cm telescopes on a 2-m baseline, and the *Imaging Fourier Transform Spectrometer* (IFTS) which uses light from a 40-cm Gregory telescope. Both instruments have active pointing capabilities of 3 milliarcsec stability, and SUN has, in addition, an active cophasing

control to 1/50th of a wavelength. EUV multilayer telescopes complete the payload for diagnostics of the very high temperature plasma.

The diffraction limited use of the SUN instrument 2-m baseline provides an unprecedented ultrahigh resolution of 0.01" in the UV (at Lyman Alpha, $\lambda 120$ nm), and the focal plan instrumentation (a double monochromator) gives a tunable access simultaneously to several channels from the UV to the near infrared. At the same time the IFTS instrument provides velocity and magnetic maps of the solar region under study with a 0.1 arcsec resolution and a variable spectral resolution of 50 000 to 100 000.

2 Scientific Objectives

Why and how can SIMURIS address non-solar objects? For nearby stars which have an angular diameter of the order of the resolution of SUN, the flux per pixel is similar to what is achieved for solar observations. Active stars are brighter by factors 10-100 in the ultraviolet lines compared with the quiet Sun. Longer stellar exposure times can give the necessary information on large scale stellar structures (hours and days) or on energetic fast phenomena (minutes and hours), while time scales of a few seconds are expected for small-scale phenomena. The observation of non-solar objects requires stability of pointing, guiding and cophasing of stellar sources. This is possible provided the object itself or a nearby source has magnitude brighter than 9.

2.1 Stellar Structure, Hydrodynamics and Evolution

Modeling stellar structure and evolution is fundamental for understanding many ingredients of astrophysics from the history of our own Sun to the evolution of galaxies. Stellar modeling has progressed with advances in nuclear physics theories, stellar opacities, treatment of equation of states, boundary conditions, and the use of advanced computer evolution codes. Current stellar evolution theories characterize a star by its mass, initial He and metallic fraction, age and mixing length. Asteroseismology will provide for a few stars a number of observable quantities for constraining the models, but complementary parameters are necessary (such as luminosity, mass, age, chemical composition) independently (Gough, 1987). SIMURIS can measure a few angular diameters, binary separations. An ingredient not accounted for in giant and supergiant evolution is the mass-loss history by lack of relevant observations. Fundamental data will be obtained such as distances (from parallaxes or from resolved binary systems), and masses (from binary systems). Interferometric astrometric measurements can help determining these parameters (distances, velocities, masses, periods) for a large range of stars over the HR diagram, and at distances beyond HIPPARCOS possibilities.

2.2 Stellar Magnetic and Plasma Phenomena

As well as on the Sun, stellar observations at high resolution permit studying hydrodynamic and plasma phenomena: the convection which, coupled with rotation, controls the emergence of magnetic field from stellar surfaces, the interaction of magnetic fields with fluids non-thermal plasma processes, *etc...* Such observations allow diagnosis of the conversion of magnetic energy to thermal energy and the generation of magnetic fields in turbulent fields in different contexts. Stellar activity phenomena occur when strong magnetic fields perturb the structure and energy balance (Linsky, 1985). Non-thermal energy deposition occurs in the chromosphere, transition region and corona. Also, active magnetic regions appear with an excess emission in the core of strong lines such as Ca II H and K lines (Rebolo *et al.*, 1989), the infrared triplet of Calcium (Foing *et al.*, 1989), Mg II and H alpha in the chromosphere, or Ly α ,

C IV in the transition region, and up to coronal lines. Observations from Einstein X-ray satellite showed the presence of coronae in most of the convective stars. Also, the IUE satellite allowed to diagnose the properties of solar-like chromospheres and transition regions.

In solar-like stars, it has been invoked (Parker, 1979) that the dynamo effect regenerates the magnetic field, from the coupling between convective motions and the differential rotation. Also, the modulation of the stellar flux and of some chromospheric indicators of activity along the stellar rotation indicates the presence of photospheric spots and chromospheric active regions. The appearance of spots is attributed to intense sub-photospheric magnetic fields which inhibit the convective energy transport towards the surface. Long term periodical variations indicate solar-like activity cycles (Wilson, 1978) on late-type stars. Empirical relations were established (Mangeney and Praderie, 1984; Noyes *et al.*, 1984) between the coronal or chromospheric activity and the rotational velocity through the Rossby number, suggesting that the heating is related to the production of magnetic energy through a dynamo mechanism. In close binary systems, it is likely that the synchronization of short period binaries enforces dynamo effect and thus the activity.

Sunspots, plages, flares, and non-radiatively heated chromospheres and coronae all owe their existence to the presence of magnetic fields. Similar phenomena in late-type stars, in close binaries in particular, indicate that a substantial amount of magnetic flux exists in their photospheres (see Linsky, 1985). However, the detailed physics behind the fundamental role of magnetic fields in these phenomena is still unknown and the actual distribution of magnetic fields and activity phenomena on these stellar surfaces poorly determined. Recent global magnetic field measurements (Saar *et al.*, 1986) have allowed to start deriving mean magnetic intensities and surface filling factor for active solar-type dwarfs. Also, only a few dMe stars (Saar and Linsky, 1985) and RSCVn stars (Giampapa, Golub and Worden, 1983; Donati *et al.*, 1990) have been detected. Yet due to their high activity, they hold the keys to understanding the extremes of stellar magnetic phenomena. Magnetic field strengths (B) scale with photospheric pressure, a finding which is consistent with the modeling of solar-like flux-tubes, and surface filling factors (f) seem proportional to stellar angular velocity, saturating at small periods (Saar, 1987). Measurements of B and f on rapidly rotating solar-like stars (e.g. BY Dra and RS CVn stars) will help verifying these relations. A crucial issue is the spatial distribution of phenomena associated with these magnetic fields on different spatial and time scales, in order to test flux tube models, coronal loops models, dynamo models, empirical activity theories (e.g. Vilhu, 1984), heating theories for stellar outer atmospheres, and rotational evolution theories.

Flares are the most complex and violent phenomena occurring on solar-type, dMe, T-Tauri or active close binary stars. Fundamental issues for flare research concern the energy transport mechanism: particle beam vs heat conduction, the atmospheric response to flares; mass motions, ejected components and momentum balance; microflaring, flaring and the heating of coronae; statistics and recurrence of flares and relevant stellar flare spectroscopic diagnostics (Foing, 1989). On dMe stars, flare events have typical timescales of 10 s for rise and 10^3 s for decay. Simultaneous photometry and spectroscopy of flares have shown emission line enhancements of different species to take place as the response of the stellar atmosphere to the flare energy release (Houdebine, 1991).

3 Brief Overview of Galactic Astrophysics Programs of Interest

3.1 Fundamental Stellar Parameters

Stellar angular diameters. In principle, diameters (FWHM of a stellar image) down to 0.1 marcsec can be measured with 2500 counts/30 mn. The pointing stability is 3 marcsec and a calibration of the total point spread function is required.

Binary star separations. We can measure angular separations smaller than the Rayleigh criterion for binary systems whose components have very different colors; the cooler star will dominate the light in the visual, and the hotter one in the UV, and the relative shift in the centroid of UV and visual image will directly give the binary separation (goal is separation ≤ 0.3 marcsec with accuracy ≤ 0.03 marcsec).

3.2 Stellar Magnetic Activity Phenomena

Stellar active structures. The observation of solar-like activity phenomena has suggested the existence of solar-like activity cycles in stars (spots, plages filling factors and modeling); resolution has to be improved using interferometry in addition to Doppler imaging to detect smaller spots to increase our knowledge of the geometric distribution of activity phenomena on stars, to understand the differences with their solar equivalent, to model the active and quiescent atmospheric regions, to study the correlation between the structures observed at different heights, and to monitor the changes associated with active region behavior, cyclic activity, dynamo phenomena and differential rotation.

Tomographic, Doppler and interferometric imaging methods. To complement interferometric imaging — which is limited to the angular resolution of the maximum baseline — indirect imaging techniques using rotational modulation give a one dimensional projection in longitude of the surface structures, allow to reconstruct the spatial distribution of surface activity over active stars (with constraints from the velocity dimension, in addition to the photometry).

3.3 Interest of SIMURIS for Close Active Binaries

Spatial and velocity separation of close binaries. Two stars being highly unresolved, a way to determine their angular separation is the wavelength dependence of the centroid of the image using a weighted mean of the centroids of the binary components' images; interesting aspect for close binaries with orbital velocity separation up to 20 km/s, is that they can be separated by using the 0.1 Å resolution of the SUN double monochromator.

RS CVn systems. Study of the quasi-sinusoidal distortion of the lightcurve due to the rotational modulation of a non-uniform distribution of photospheric spots (observed in chromospheric emission lines too).

3.4 Energetic Phenomena and Circumstellar Studies

Stellar flare studies. Flares can be observed over a large range of wavelengths from EUV to the near infrared; they can be studied spectroscopically and located on the star where they occur with an accuracy down to a fraction of marcsec in solar-like stars of spectral types F to K, on young T-Tauri or post-T Tauri, dMe stars and close active binaries (RS CVn, Algols, W UMa systems). Aims are to determine what is the energy budget for a typical sample of flares, what are the respective roles of radiation from the corona (as shown in X rays),

conductive losses through the transition region (EUV) and expansion (from velocity fields measurements, temperatures, densities and volumes of the hot flaring plasma).

Extended coronal loops and condensations. Active regions at chromospheric and coronal heights can be studied through rotational modulation or eclipse studies of observed fluxes.

Circumstellar environments of young and evolved stars. The young stages of stellar evolution can be investigated making use of the imaging spectroscopic facilities of IFTS over a large field to map the fluxes, velocities, profiles of H II compact regions in stellar formation regions; the near environment (processes of excitation and destruction of circumstellar constituents) of the hot exciting stars can be studied with SUN.

Mass transfer and accretion in binaries. SUN allows to study departure from spherical symmetry for close binaries, when the evolved star is filling its Roche lobe, or in the case of contact binaries, in the nearest prototypes (such as Algol), and to determine the effect of this surface distortion on the variation of the equivalent separation and centroid positions along the orbital phase.

4 Conclusion

Even though of limited collecting area and of moderate baseline, the SIMURIS interferometric mission provides access to valuable stellar programs since capable of diffraction-limited observations in the UV (0.01") and of long-time integration (30 minutes to hours) thanks to its stabilized/cophased approach.

5 References

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