PROSPECTS WITH SIMURIS

L. Damé[1] and R.J. Rutten[2]

[1] Service d'Aeronomie CNRS, BP N^o 3, F–91371 Verrières-le-Buisson Cedex, France
[2] Sterrekundig Instituut, Postbus 80 000, NL–3508 TA Utrecht, The Netherlands

ABSTRACT

We give an introductory overview of the SIMURIS payload by briefly presenting its goals and concepts.

Keywords: solar physics, astrophysics, interferometry, space research.

1. INTRODUCTION

SIMURIS ("Solar, Solar System and Stellar Interferometric Mission for Ultrahigh Resolution Imaging and Spectroscopy") is described in detail in a recent ESA study report[1] by Coradini et al. [1].

SIMURIS is a payload proposal to study the Sun and other nearby objects at very high spatial resolution, using both imaging and spectrometry simultaneously in the ultraviolet and the visible. The Study Report is the result of assessment by a team set up jointly by ESA's Science Directorate and its Directorate of Space Station and Microgravity. SIMURIS is a proposal of interest to both directorates, being a scientific mission which may fruitfully utilize Space Station Freedom facilities.

SIMURIS' major goal is to achieve solar physics at unprecedented image resolution, sufficiently high to resolve the fine structuring governed by basic magnetohydrodynamical and plasma physics processes. In meeting this goal, to be achieved with new interferometric techniques, SIMURIS also furnishes research capabilities of interest to solar system science and galactic astrophysics, and may be seen as a precursor to future developments in the context of understanding astrophysical processes and in the context of developing space interferometry at short wavelengths.

[1]Copies available from Dr. M. Coradini, ESA Headquarters, Paris, and from Dr. H. Olthof, ESTEC, Noordwijk.

2. SIMURIS SCIENCE GOALS

The emphasis of the SIMURIS proposal is on furnishing high spatial resolution in solar imaging and solar spectrometry, simultaneously for the photosphere, the chromosphere and the transition region, with additional larger-field reference imaging at various wavelengths.

SIMURIS aims to obtain the measurement capability needed to accomplish the transition from studying *phenomena* to studying *physical processes*. Making this transition is a quest of astrophysics in general. In many areas of modern astrophysics, the nature of the physics underlying observed patterns comes under scrutiny, rather than just the patterns. The questioning evolves from asking *how* things are to asking *why* they are so. Solar astrophysics is in a prime position to achieve this transition because the Sun is sufficiently close that basic physical scales such as density scale height and photon mean free path are in reach of observation. In angular measure, these scales are a million times smaller for other stars; thus, solar physics requires only a millionth of the baseline needed for other astrophysical objects.

The Sun represents an astrophysics laboratory of huge interest. The solar photosphere is the only place where stellar convection can be observed in detail; the outer atmosphere, pervaded and finely structured by highly intricate magnetic fields, provides a tremendous array of plasma processes, offering much to learn to plasma physicists and astrophysicists alike. Solar physics topics of obvious interest for SIMURIS are (cf. Study Report, Chapt. 1):

– *MHD configurations:* fluxtubes, canopies,

Science Requirements

- very high spatial resolution
  ultraviolet (thin): $\approx 0.01''$ $\propto$ 10 km
  visible (thick): $\approx 0.05''$ $\propto$ 40 km
- multiband observation
  X-ray: corona
  UV: chromosphere & transition region
  visible — near infrared: photosphere
- narrow-band imaging
  UV: emission lines
  visible: absorption lines
- broad-band line selection
  velocities
  temperature & density diagnostics
  height resolution
- two-dimensional spectrometry
  magnetic & velocity mapping
- photon usage versatility
  spectral line selection
  time resolution ⇔ spatial resolution
  time resolution ⇔ field dimensions
  time resolution ⇔ spectral resolution

loops;

- *structure and evolution of magnetic patterns:* umbrae, penumbrae, plage, network, grains, fibrils, spicules, prominences;
- *instabilities and eruptive phenomena:* jets, bullets, explosive events, flares, microflares;
- *radiation hydrodynamics:* granulation, oscillation grains, shocks, extreme limb,

plus probably quite a number of structuring agents and dynamical processes that aren't known yet, at scales below the few 100 km resolution presently obtainable at best.

The variety of solar research topics is very large (see illustration above). Nevertheless, they may be grouped together in a single theme, which is defined as the complex entity constituted by a magnetically-active star's outer envelope. In the lower atmosphere, the transition from convective to radiative energy transport causes detailed structuring of the surface layers accessible in the visible part of the spectrum; in the structuring and energy balance of the outer solar atmosphere, a very dynamic plasma best observed in the ultraviolet down to the soft X-ray domain, magnetic fields play a dominant role.

In a wider context, SIMURIS' solar physics topics are part of general space science. Magnetic fields present riddles in objects as diverse as planetary magnetospheres, accretion disks, galactic jets and terrestrial plasma machines; time-dependent MHD and plasma processes are essential to many areas of astrophysics and solar system science. Obtaining high spatial and temporal resolution and appropriate spectral diagnostics is a prerequisite to such studies, the more so since current numerical simulation capabilities (now turning astrophysics from a conceptual into an experimental science) already permit and seek detailed comparisons with structural observables.

In a more direct context, SIMURIS brings also promising capabilities to non-solar studies requiring high spatial resolution. SIMURIS' photon gathering capacity is modest, but one should note that the Sun is as dim per *resolved* pixel as any other cool star, specific intensity being the signal measure for image elements rather than irradiance. The Study Report (Sects. 1.4 & 1.5) lists a large number of solar-system and galactic studies of interest, worth further feasability study.

3. SIMURIS CONCEPTS

3.1 SIMURIS model payload

SIMURIS' model payload, as reported in the Study Report, is summarized in the table above.

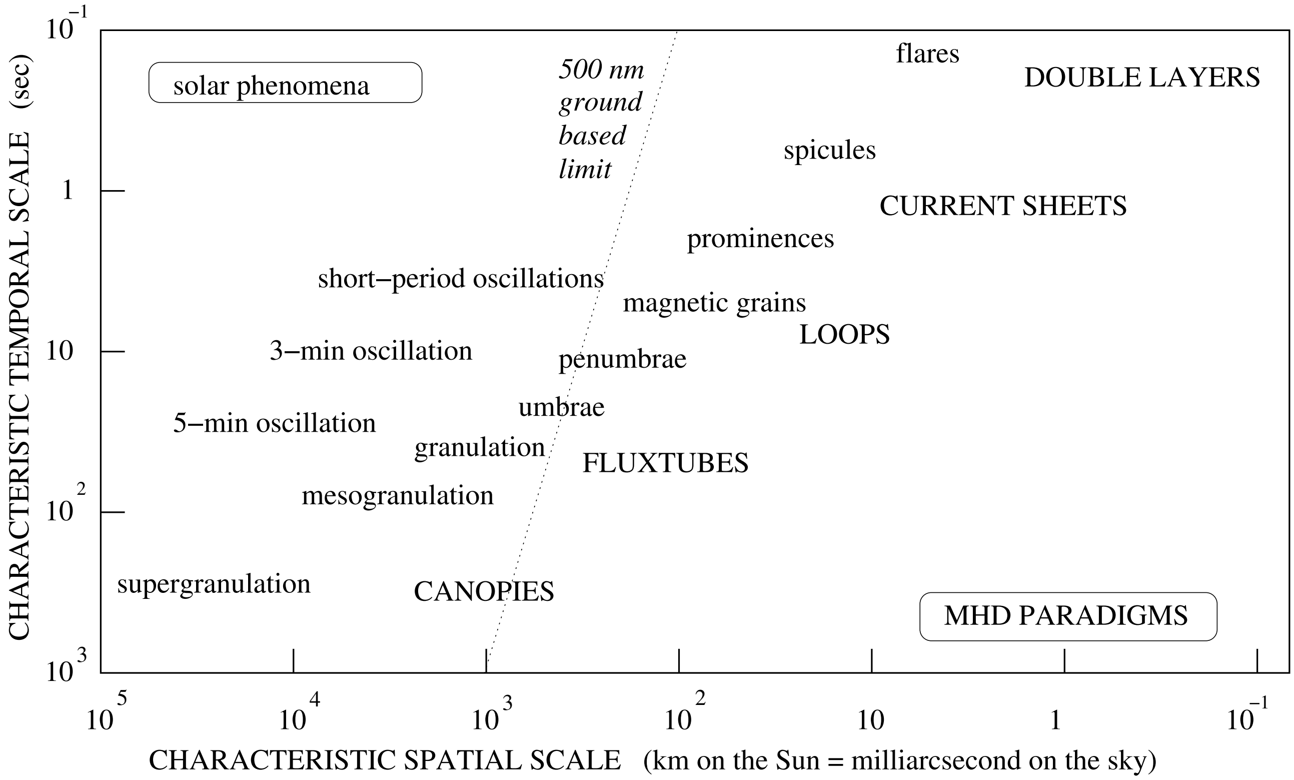
The main instruments are the Solar Ultraviolet Network (SUN) and the Imaging Fourier Transform Spectrometer (IFTS). In addition, there are multilayer narrow-band imagers (EUVT), Ly-α and 1600 Å continuum imagers (UVC) and a He II 304 Å imager (HLT).

SUN is the primary imager, giving very high spatial resolution with moderately wide spectral bandpasses. IFTS furnishes higher spectral resolution at lower spatial resolution. Both instruments work simultaneously in the UV and the visible up to the near-infrared.

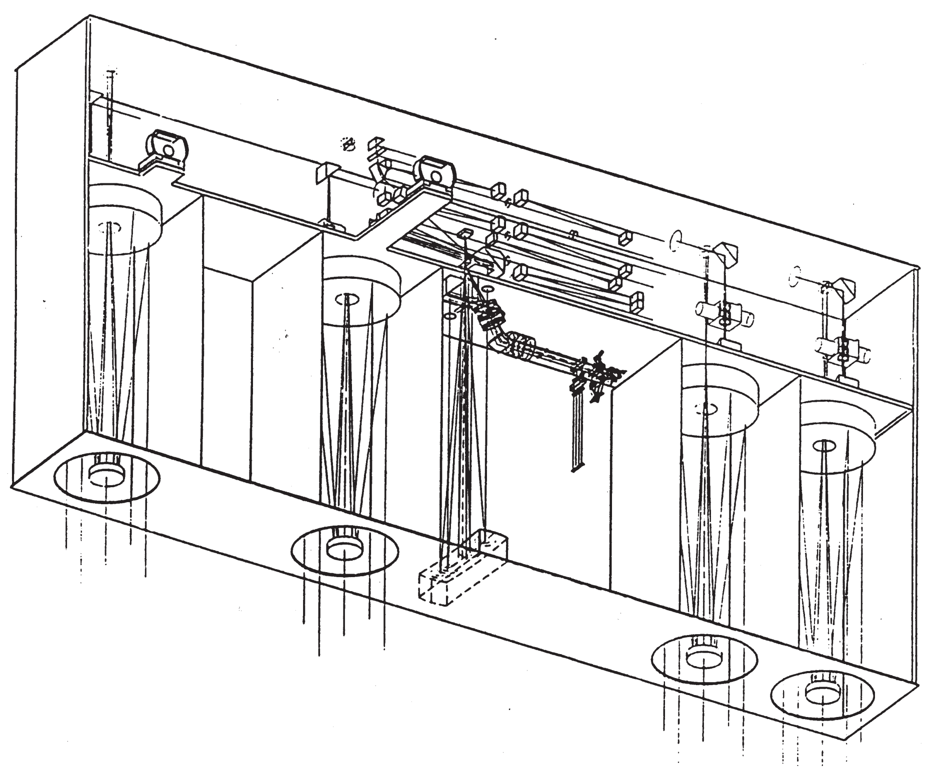
3.2 SUN: the Solar Ultraviolet Network

SUN has been designed from the following concepts:

- *aperture.* A linear array of 2 m baseline consisting of four separate 20 cm telescopes. The main reasons not to aim at a filled 2 m aperture (using either a rigid mirror or an actively-controlled one) are, first, that the cost of high-quality telecopes increases very rapidly with their size, and second, that large telescopes of even the best quality do



Spacetime resolution characteristics of solar phenomena (small print) and solar-inspired paradigms of magnetohydrodynamics (capitals). Abscissa: characteristic sizes in km. Ordinate: charasteristic lifetime in s. The dotted line is the ground-based resolution limit including present image-restoration developments. One arcsecond measures 725 km kilometer on the Sun. Note that many structures (e.g., granules, spicules, filaments) contain smaller fine structure. The largest-scale phenomena are set by radiation hydrodynamics (oscillations and granulation at different scales); in all others, magnetic fields are important.



Optical layout of the SUN interferometer. Below the four telescopes are the cophasing system and the three-stage subtractive double monochromator.

not necessarily reach their diffraction limit. For example, the original design specification for the Hubble Telescope remained below the diffraction limit of a 2.4 m telescope by an order of magnitude. For solar observing, on-off solar heating cycling poses additional problems. Adaptivity may work but at the cost of enormous complexity. Utilizing four small diffraction-limited telescopes permits SUN to reach 2 m baseline resolution; configuring them into a simple linear array keeps the cost relatively low.

Adding a perpendicular baseline would not result in full field coverage, only in a factor two speed gain. Good instantaneous coverage of the two-dimensional (u, v)–plane actually requires an excessive number of small telescopes. The concept of rotational tomography employed by SIMURIS (similar, but not identical to rotational aperture synthesis), ensures that two-dimensional imaging is supplied — although for fast-evolving structures, "snapshot" viewing with high spatial resolution along only one axis will often be preferable.

The chosen configuration is compact and non-redundant, an important property for the subsequent image restoration because it produces a modulation transfer function with optimum spacing coverage and without zeroes, thus enabling "linear" first-order restoration through division in the Fourier domain.

– *interferometry.* SUN is an interferometer just as any other telescope is an interferometer. It projects an image on a focal plane detector. The interferometry is achieved by the photons themselves before detection, not by measuring separate signal phases and subsequent correlations the way radio astronomers work; nor are the interference fringes in SUN's image measured directly. Because of the four-telescope aperture, the image is not made up of Airy disks per picture elements, but of elongated fringes with elongated side lobes, together forming the "dirty beam". They are taken out in the subsequent processing.

– *real-time co-phasing.* Fringe measurement is, however, an important ingredient of SUN because it is employed in the alignment and co-phasing system. The four telecopes of SUN are dynamically guided, aligned and co-phased with a hierarchical system described in Sect. 4.3 of the Study Report. In brief, wide-band visible radiation (4000 Å bandwidth) is employed to adjust the four telescopes in pair-wise combinations into a coherent array by acquiring and stabilizing their interference fringes in real time, using delay-line optical balancing to provide equal path lengths. These white-light fringes are measured from a small field on the solar disk, near the area of study (which may be off-limb.) At the same time, the solar limb is used as an off-set reference source for alignment and guiding. Diasporameters consisting of optical wedges maintain co-alignment while the telescope array is rotated in the course of tomography.

– *image restoration.* Image restoration is an important part of the concept. The fringe visibility is very low because signals with low spatial frequencies dominate when the object is an extended source. Nevertheless, they are present; it is important to note that the imaging is narrow-band (see monochromator below) so that fringes do not disperse and can be taken out. The MTF restoration is also aided by the smallness of temporal variations due to the real-time co-phasing and pointing stabilization (making MTF variations much smaller than for the Hubble Telescope where they pose large problems to image restoration). The real-time co-phasing minimizes MTF variation even during rotational tomography; it also allows for temporal integration by which sufficient signal can be reached to permit stable restoration. It is important to note that restoration stability and dynamic range is not determined by detector noise but by photon shot noise at optical and shorter wavelengths; depending on the object and scientific goals, longer integration may be employed to obtain preciser imaging.

– *subtractive double monochromator.* SUN requires narrow-band imaging of fully two-dimensional fields. This is accomplished with a triple-stage subtractive double monochromator, analogous to the MSDP spectrometer developed by P. Mein *c.s.* at Meudon and in use at various solar telescopes. Each stage employs a grating to disperse a solar field in wavelength; a mask is employed for spectral-band selection; another grating pass converges the dispersed wavelengths back to the original field. This is an all-reflective way of obtaining narrow-band images, a must in the ultraviolet where birefringent filtering is no option. SUN uses three such monochromators to provide a choice of six passbands from ultraviolet to near-infrared; one of the visible channels may feed an additional Fabry-Perot to obtain higher spectral resolution.

IFTS: Concepts

- Fourier spectrometry
  two-dimensional field
  ultraviolet — near infrared
  time resolution ⇔ spectral resolution
  time resolution ⇔ spatial resolution
- subtractive double monochromator
  spectral-line selection masks
- two simultaneous output beams
  UV: chromosphere / transition region
  visible: photosphere
- Doppler mapping
  $\lambda/\Delta\lambda \approx 10^5$
- polarimetry
  Stokes V, Q & U modulation
  masked-CCD pixel-shift

4. SIMURIS REQUIREMENTS

The need to achieve high-resolution solar physics with appropriate diagnostics makes for a specification list of hard-to-meet requirements:

– *very high spatial resolution.* The basic scales at which processes are observable is set for the solar photosphere by the photon mean free path, because in optically thick conditions photon travel lengths set the smallest scale at which the emergent radiation is coded by structuring in state parameters. The basic resolution element one aims for in optically-thick observing therefore measures a few tenths of kilometers. This applies to the visible and near-infrared parts of the spectrum, in which the emergent radiation comes from the photosphere.

For the tenuous outer atmosphere, the situation is very much different because it contains structures that are optically thin in many lines, Lyα being the major exception. In optically thin conditions, the emergent radiation (or absorption) scales with the local extinction and is therefore encoded by structuring at any length scale. The basic physical resolution is therefore set by the actual plasma-physics processes occurring within MHD structuring. This applies to the ultraviolet and X-ray regimes.

The outer-atmosphere structuring is dominated by magnetic fields. These are organized in three basic MHD entities which are paradigms of solar modeling. At photospheric levels, the field consists primarily of tiny kilo-Gauss *magnetic fluxtubes*. They are clustered into the magnetic network, with intermediate field-free areas ("cell interiors") underlying the *magnetic canopies*, into which the outward expanding fluxtubes combine together in the low chromosphere. At larger height, tube ensembles join in *magnetic loops*. These have large lengths but contain very steep gradients across magnetic field lines. The latter are a source of a multitude of fine-scale plasma processes which define the structuring to be resolved in ultraviolet and X-ray imaging, at kilometer scales or even smaller characteristic lenghts. Current ultraviolet and X-ray imaging and spectrometry just about show that MHD loops exist, at 1 arcsec or 700 km resolution; to achieve kilometer-scale plasma-physics resolution requires orders of magnitude improvement.

– *multiband observation.* The split between the photospheric regime observed in the visible and the outer atmosphere observed at shorter and longer wavelengths requires simultaneous observing in different spectral domains. The photosphere and outer atmosphere must be observed together because of the interplay between them: the structuring and processes in the nonthermal outer atmosphere are to a large extent constrained by the configuring impressed by the convective and oscillatory motion patterns in the photosphere and the sub-surface layers — where the mass is.

Choosing the ultraviolet over the sub-mm and the X-ray over the radio domains is obviously dictated by the much larger resolution obtained per baseline at short wavelengths, the much larger choice of spectral line diagnostics at short wavelengths, and the much clearer signatures of temperature and density structuring at shorter wavelengths.

– *narrow-band imaging.* In the ultraviolet, all emission is concentrated in lines which must be separated. In the visible, imaging bands must be sufficiently narrow to isolate specific layers of the photosphere.

– *broad-band line selection.* Different ultraviolet emission lines and visible continuum bands supply signals of differing information content, for example supplying height resolution in temperature, density and velocity information. Diagnostic application requires that the wavelength bands in which images are obtained are freely choosable throughout the spectrum.

- *two-dimensional spectrometry.* Measuring physical state parameters (temperature, density, velocity, magnetic field) requires the use of spectral line diagnostics. In particular, precise Doppler and magnetic field mapping requires measurement of detailed line profile shape variations. Such measurement must be achieved with full two-dimensional resolution.

- *photon usage versatility.* The large variety of solar phenomena, structures and processes requires large versatility in using spectral imaging and imaging spectrometry. Many small structures evolve very fast, requiring instantaneous imaging; many have linear geometry, however, so that limited field coverage may suffice. For other processes, good signal to noise capability is adamant, requiring longer integration times. Sometimes spatial resolution must be traded for speed; spectral resolution should also be an adaptable parameter.

These requirements can only be met by space observation. Of course, the ultraviolet is only accessible from space; in addition, in space the isoplanatic patch is essentially infinite, providing accessibility to off-set reference sources such as the solar limb.

SUN: Concepts

- aperture
  2 m baseline
  4 separate 20 cm telescopes
  non-redundant compact array
  rotational tomography
- interferometry
  no fringe measurement but co-phased "image"
  time integration ⇔ S/N
- real-time co-phasing
  offset reference (solar limb)
  white-light fringe acquisition & tracking
  delay-line optical path balancing
  diasporameter telescope pointing & alignment
- image restoration
  no zeroes in MTF
  narrow-band image fringes
  photon noise
- subtractive double monochromator
  2D monochromatic field
  three channels UV — near-IR
  different spectral bandwidths
  visible: Fabry-Perot

5. SIMURIS CONCEPTS

5.1 SIMURIS model payload

SIMURIS' model payload, as reported in the Study Report, is summarized in the table above.

The main instruments are the Solar Ultraviolet Network (SUN) and the Imaging Fourier Transform Spectrometer (IFTS). In addition, there are multilayer narrow-band imagers (EUVT), Ly-α and 1600 Å continuum imagers (UVC) and a He II 304 Å imager (HLT).

SUN is the primary imager, giving very high spatial resolution with moderately wide spectral bandpasses. IFTS furnishes higher spectral resolution at lower spatial resolution. Both instruments work simultaneously in the UV and the visible up to the near-infrared.

5.2 SUN: the Solar Ultraviolet Network

SUN has been designed from the following concepts:

- *aperture.* A linear array of 2 m baseline consisting of four separate 20 cm telescopes. The main reasons not to aim at a filled 2 m aperture (using either a rigid mirror or an actively-controlled one) are, first, that the cost of high-quality telecopes increases very rapidly with their size, and second, that large telescopes of even the best quality do not necessarily reach their diffraction limit. For example, the original design specification for the Hubble Telescope remained below the diffraction limit of a 2.4 m telescope by an order of magnitude. For solar observing, on-off solar heating cycling poses additional problems. Adaptivity may work but at the cost of enormous complexity. Utilizing four small diffraction-limited telescopes permits SUN to reach 2 m baseline resolution; configuring them into a simple linear array keeps the cost relatively low.

  Adding a perpendicular baseline would not result in full field coverage, only in a factor two speed gain. Good instantaneous coverage of the two-dimensional (u, v)–plane actually requires an excessive number of small telescopes. The concept of rotational tomography employed by SIMURIS (similar, but not identical to rotational aperture synthesis), ensures that two-dimensional imaging is supplied — although for fast-evolving structures, "snapshot" viewing with high spatial resolution along only one axis will often be preferable.

  The chosen configuration is compact and non-redundant, an important property for the subsequent image restoration because it produces a modulation transfer function with optimum spacing coverage and without zeroes, thus enabling "linear" first-order restoration through division in the Fourier domain.

- *interferometry.* SUN is an interferometer just as any other telescope is an interferometer. It projects an image on a focal plane detector. The interferometry is achieved by the photons themselves before detection, not by measuring separate signal phases and subsequent correlations the way radio astronomers work; nor are the interference fringes in SUN's image measured directly. Because of the four-telescope aperture, the image is not made up of Airy disks per picture elements, but of elongated fringes with elongated side lobes, together forming the "dirty beam". They are taken out in the subsequent processing.

- *real-time co-phasing.* Fringe measurement is, however, an important ingredient of SUN because it is employed in the alignment and co-phasing system. The four telecopes of SUN are dynamically guided, aligned and cophased with a hierarchical system described in Sect. 4.3 of the Study Report. In brief, wide-band visible radiation (4000 Å bandwidth) is employed to adjust the four telescopes in pair-wise combinations into a coherent array by acquiring and stabilizing their interference fringes in real time, using delay-line optical balancing to provide equal path lengths. These white-light fringes are measured from a small field on the solar disk, near the area of study (which may be off-limb.) At the same time, the solar limb is used as an off-set reference source for alignment and guiding. Diasporameters consisting of optical wedges maintain co-alignment while the telescope array is rotated in the course of tomography.

- *image restoration.* Image restoration is an important part of the concept. The fringe visibility is very low because signals with low spatial frequencies dominate when the object is an extended source. Nevertheless, they are present; it is important to note that the imaging is narrow-band (see monochromator below) so that fringes do not disperse and can be taken out. The MTF restoration is also aided by the smallness of temporal variations due to the real-time co-phasing and pointing stabilization (making MTF variations much smaller than for the Hubble Telescope where they pose large problems to image restoration). The real-time co-phasing minimizes MTF variation even during rotational tomography; it also allows for temporal integration by which sufficient signal can be reached to permit stable restoration. It is important to note that restoration stability and dynamic range is not determined by detector noise but by photon shot noise at optical and shorter wavelengths; depending on the object and scientific goals, longer integration may be employed to obtain preciser imaging.

- *subtractive double monochromator.* SUN requires narrow-band imaging of fully two-dimensional fields. This is accomplished with a triple-stage subtractive double monochromator, analogous to the MSDP spectrometer developed by P. Mein *c.s.* at Meudon and in use at various solar telescopes. Each stage employs a grating to disperse a solar field in wavelength; a mask is employed for spectral-band selection; another grating pass converges the dispersed wavelengths back to the original field. This is an all-reflective way of obtaining narrow-band images, a must in the ultraviolet where birefringent filtering is no option. SUN uses three such monochromators to provide a choice of six passbands from ultraviolet to near-infrared; one of the visible channels may feed an additional Fabry-Perot to obtain higher spectral resolution.

IFTS: Concepts

- Fourier spectrometry
  two-dimensional field
  ultraviolet — near infrared
  time resolution ⇔ spectral resolution
  time resolution ⇔ spatial resolution
- subtractive double monochromator
  spectral-line selection masks
- two simultaneous output beams
  UV: chromosphere / transition region
  visible: photosphere
- Doppler mapping
  $\lambda/\Delta\lambda \approx 10^5$
- polarimetry
  Stokes V, Q & U modulation
  masked-CCD pixel-shift

5.3 IFTS: the Imaging Fourier Spectrometer

- *Fourier spectrometry.* The primary reason to opt for Fourier spectrometry is again that it permits analysis of two-dimensional fields; all previous ultraviolet spectrometers (including the SOHO instruments) employ slits and therefore allow one-dimensional spatial resolution only. Furthermore, spatial resolution, spectral resolution and temporal resolution can freely be traded for each other in Fourier spectrometry, per individual observing program: the absence of a slit implies no instrumentally fixed relation between these domains of resolution. Each program may therefore employ optimum settings.

- *subtractive double monochromator.* An important problem, just as for imaging interferometry, is that not detector noise but photon noise dominates at short wavelengths. In Fourier spectrometry the noise is therefore set by the total flux reaching the detector. It is essential to limit its size to only those photons that are of interest, i.e., the spectral lines to be employed as diagnostics. The latter should be freely chosen. The IFTS achieves such selected-line tuning with a prefilter consisting of another subtractive double monochromator. It has masks in the intermediate stage between dispersion and convergence to select the spectral line(s) of interest, limiting the photon flux to just those.

- *two simultaneous output beams.* The IFTS produces two output beams so that simultaneous spectrometry in the ultraviolet and the visible (up to the near infrared) is supported. Typically, the former wil be used to supply density and temperature diagnostics of the outer atmosphere, the latter for Doppler and magnetic field mapping.

- *Doppler mapping.* The IFTS supplies a spectral resolution of up to $\lambda/\Delta\lambda \approx 10^5$, sufficient for Doppler mapping using narrow photospheric lines.

- *magnetic mapping.* The Zürich group has proposed extensions to the IFTS by which Stokes polarimetry may be achieved employing lines in the visible (cf. paper by Stenflo & Solanki in this volume). Their proposal envisages modulation with piezoelectric crystals to encode Stokes V, Q & U information, and demodulation with a scheme in which CCD pixel charges are shifted between image and masked columns at the modulating frequencies.

6. COMPLEMENTARY INSTRUMENTS

The three additional instruments are part of the auxiliary instrumentation but constitute quite interesting science experiments in their own right. They bring additional information, employing plasma diagnostics which differ in characteristic formation temperature. They provide wider fields than SUN and IFTS in order to relate the high-resolution strctures seen by the latter instruments to the larger-scale magnetic field patterns around the small fields. Their larger fields make them also useful to more global research topics, with large-scale topologies and their evolution as research goals in survey programs. The three instruments are:

- *UltraViolet Camera UVC.* A small telescope providing images of $2.5' \times 2.5'$ in Lyα, the C IV lines near 1550 Å, and the 1600 Å continuum which arises from the temperature minimum region between photosphere and chromosphere. The spatial resolution will be $0.6''$.

- *He II Telescope HLT.* Full-Sun imager in the He II 304 Å line, with a resolution of a few arcsec.

- *Extreme Ultraviolet Telescopes EUVT.* One or more small multi-layer telescopes providing EUV images of $5' \times 5'$ with sub-arcsec resolution. Multi-layer techniques have recently resulted in beautiful imaging (e.g., NIXT rocket experiment, see Golub's article in these proceedings). They are highly suited to provide additional EUV diagnostics from higher temperature domains ($10^6 - 10^7$ K).

7. SIMURIS DESIGN STUDIES

In addition to the Study Report (reference [1]), there is a large number of studies concerning SIMURIS instrumentation by Estec, TPD, MBB and other institutions. For example, optical designs, tolerance analyses, mechanical structuring, thermal response etc. have all been addressed in detail already. References are listed in Damé's paper on the SUN instrument in these proceedings; copies of these studies are available from L. Damé.

8. SUN-SV

A proposal related to SUN has been forwarded to ESA in connection with the COLUMBUS precursor program. It embodies a smaller and simplified test version of SUN for technology assessment. Copies of this proposal are also available from L. Damé.

REFERENCES

[1] Coradini, M., Damé, L., Foing, B., Haskell, G., Kassing, D., Olthof, H., Mersch, G., Rutten, R. J., Thorne, A. P. & Vial, J.-C. 1991, Simuris — solar, solar system and stellar interferometric mission for ultrahigh resolution imaging and spectroscopy, *ESA SCI*, (91) 7, 1–115 ("Study Report").