SOLAR TELESCOPES - II

Instrumentation

Adaptive optics

The recent development of real-time adaptive optics systems to measure and stabilize image motion and to compensate low- and high-order image aberrations led to a major breakthrough in the spatial resolution of solar observations. To date, several telescopes of the 70 – 100 cm class are equipped with adaptive optics systems. These systems can correct atmospheric disturbances with a bandwidth of up to 100 Hz and are capable of correcting the dominant aberration modes caused by the turbulent Earth atmosphere and the instrument itself. The number of aberration modes that can be corrected grows with the number of sub-apertures of the wave-front sensor. The typical size of sub-apertures of a high-order adaptive optics is about 8 cm. This is small enough to account for the anisoplanatism of the day-time atmosphere, but also large enough to resolve the solar photospheric granulation. The area that can be corrected with adaptive optics is very small, only a few arcseconds in diameter. In order to overcome this limitation, multi-conjugated adaptive optics systems are presently under development. Theses systems use several deformable mirrors to correct the wavefront deformations that occur in different heights above the telescope.

The importance and the complexity of adaptive optics for solar observations grows rapidly with increasing telescope aperture. The achievable spatial resolution of the planned telescopes in the U.S. and Europe with apertures in the order of 4 meters will depend critically on the quality of their adaptive optics systems. A high-order system will require wave-front sensors with about 2000 sub-apertures – quite a technical challenge. Fortunately, computing power has grown more rapidly than the size of telescopes, therefore such high-order systems are nowadays within reach.

Filtergraphs

Observations of the smallest details on the Sun, near the diffraction limit of the telescope are made with broad-band imagers. They may consist of a filter to select the wavelength band, and a suitable digital detector, e.g. a CCD camera. Thanks to the high light level, exposure times of a few milliseconds are sufficient. This allows collecting bursts of images in rapid sequence and then selecting the very best ones afterwards, or use the full burst for post-facto image restoration using techniques based on multi-frame blind deconvolution or speckle interferometry. These techniques allow the study of the morphology of the solar photosphere and the evolution of large- and small-scale objects on time scales of a seconds, minutes or longer. Without image restoration, the high-quality field of view of filtergrams is limited by the corrected field (isoplanatic area) of the adaptive optics. However, in practice the full field of view of the available CCDs can be restored to homogeneous quality.

Spectroscopic instruments

Spectroscopic instruments are needed to obtain physical parameters, such as temperature, magnetic field, or flow speed. These measurements are multi-dimensional: two spatial dimensions, wavelength, and time. At present, detectors can only record two dimensions at a time. There are two different solutions to obtain spectroscopic data: filter instruments that record two-dimensional images at a fixed wavelength, and long-slit spectrographs that record one spatial dimension and a certain wavelength range. Both types of instruments have obvious advantages and also disadvantages, and it depends on the scientific topic, which one is preferred. Some solar observatories therefore provide both instruments.

Filter spectrometers record (nearly) monochromatic images. They use tunable narrow-band filters to select the wavelength. Spatial and wavelength information is recorded by taking a sequence of monochromatic images with varying wavelength. Tunable filters can be Lyot filters, or Fabry-Pérot Interferometers or Michelson Interferometers. With a combination of two or three tunable high-quality Fabry-Pérots, a spectral resolution of 2.5 pm can be obtained. The global tuning range is around 300 nm. Due to the small free spectral range, the spectral coverage for an individual measurement is limited to 0.3 nm. Filter spectrometers are often equipped with an additional broad-band channel that takes images in a fixed wavelength band, and simultaneous with the narrowband images. The broad-band sequences are then used for post-facto reconstruction of the data. A typical data set with a field of view of about one arc minute squared and 15 wavelength positions across a spectral line can be taken in a few seconds. The spatial resolution of such a measurement depends on the size of the telescope and the image scale on the detector. Different parts of the spectral line are measured at different times. During times of variable seeing, the shape of the line profile may become distorted. Several Fabry-Pérot instruments are available at the high-resolution solar telescopes mentioned above.

Long-slit grating spectrographs provide instantaneous information about a certain wavelength range and one spatial dimension (along the slit). The spectral resolution depends mainly on the (illuminated) area of the diffraction grating and the focal length of the instrument. Compact spectrographs have a resolution of 2.5 pm (Resolving power of 250.000), similar to the best filter spectrometers. Spectrographs with large gratings and long focal lengths, like the Echelle spectrograph of the German VTT, have a theoretical resolving power of 1.000.000. Slit spectrographs record one or several spectral lines at a time. This is important for the investigation of the shape of line profiles, because they are not distorted by possible changes in the Earth atmosphere. Two-dimensional spatial information is collected by moving the solar image across the slit. The time needed to cover a certain area depends on the desired spatial resolution, i.e., the slit width and the step size. Fast cadences with high spectral resolution and coverage are possible for small scan areas. Grating spectrographs cover a large range of wavelengths, typically from 380 to 2200 Nanometers.

Spectro-polarimeters are used for the measurement of magnetic field in the solar atmosphere. They exist as combination of filter spectrometers or long-slit spectrographs with suitable polarization modulation components. Since the fraction of polarized light from the Sun is often very small, the needed accuracy of polarimetric measurements is very high. The magnetic signal is obtained by measuring the Stokes parameters that provide information about the total intensity, the circular and two orthogonal states of linear polarization. The polarization modulation is performed either with rotating retarding wave plates, or with modern tunable liquid crystal retarders. A single magnetic field measurement requires at least four different images at different settings of the polarization modulator. In order to minimize the influence of variable seeing conditions, these images have to be taken in rapid sequence. In addition, precise calibrations of the polarization properties of the telescope and the spectro-polarimeter itself are necessary, to guarantee high polarimetric accuracy of the data. The best instruments have an accuracy of 1 part in 10,000.

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