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IBIS
instrumental characteristics and first results

F. Cavallini and K. Reardon

Istituto Nazionale di Astrofisica – Osservatorio Astrofisico di Arcetri, Largo E. Fermi 5, I-50125 Firenze, Italy e-mail: fabio@arcetri.inaf.it

Abstract. The Interferometric BIdimensional Spectrometer (IBIS) was installed in June 2003 at the DST/NSO, where it is used in conjuction with a high order AO system. IBIS has since proved to be a reliable and versatile instrument for performing high resolution observations in both the photosphere and chromosphere. We describe here the instrument and its performance characteristics especially with respect to the obtainable spectral, temporal and spatial resolutions, providing examples of the actual observations.

Key words. Solar physics – Solar instruments – Spectroscopic instrumentation

1. Instrumental characteristics

IBIS is a new instrument for imaging solar spectroscopy, which has been designed to allow high spectral ($\lambda/\Delta\lambda \geq 200\,000$), spatial ($\simeq$ 0".2) and temporal resolution (several frames s^{-1}).
It is essentially formed by two Fabry-Perot interferometers (FPI), used in classic mount and in axial mode, in series with a set of narrow-band interference filters. A single electronic shutter and two CCD cameras allow us to simultaneously take a monochromatic and a broad-band image (wavelength: 7200 Å, band-pass: 100 Å) of the same solar area.
The instrument has been operating since June 2003 at the Dunn Solar Telescope (DST) of the Sacramento Peak Observatory (USA - NM), where it is fed by a high order AO system (Rimmele et al. 2003).
The use of two FPI's has been imposed by the required instrumental characteristics. The required high spectral resolution implies a converse decrease in photon flux on the detector, requiring an increase in the exposure time so as to maintain the photometric precision. As a consequence, both the temporal and the spatial resolution decrease; in fact, when the exposure time exceedes some tens of milliseconds, the seeing cannot be frozen, producing a degradation of the *effective* spatial resolution.
On the other hand, by increasing the diameter of the telescope entrance pupil, both the collected photon flux and the spatial resolution increase, but the flux per resolved element does not change. Moreover, if the same field of view is wanted, the increased spatial resolution demands a larger number of detector pixels, entailing longer readout and storage times to the detriment of the temporal resolution.
The problem can only be mitigated by maximizing the flux transmitted by the spectrometric system. A good candidate for this purpose is the FPI; this device, as known, has a large throughput and a large transmittance, thanks to the low absorption coefficient of the mod-

Send offprint requests to: F. Cavallini

Table 1. IBIS instrumental characteristics

Wavelength range	5800 Å – 8600Å
Peak wavelengths of the available interference filters	5896 Å (FWHM: 3 Å) 6302 Å ” 7090 Å ” 7224 Å ” 8542 Å (FWHM: 5 Å)
Spectral resolving power	190 000 – 300 000
Wavelength drift	$\leq$ 10 ms^{-1} on 10 h
Field of view (circular)	80”
Wavelength setting time	$\simeq$ 20 ms
Minimum wavelength step	4.5 mÅ – 6.6 mÅ
Monochromatic camera	Roper PentaMAX 1317×1035 square pixels 6.8 μm in size. Dyn. range: 12 bits Data rate: 5MHz
Broad band camera	Dalsa CA-D7-1024T 1024×1024 square pixels 12 μm in size. Dyn. range: 12 bits Data rate: 10MHz
Image scale	0”.08 pixel^{-1} (2.4 – 3.6 pixels/r.e.)
Exposure time (S/N = 100 in the solar continuum)	27 – 50 ms
Acquisition rate including: wavelength setting, exposure, frame reading, storing	$\simeq$ 2.5 frames s^{-1} (1024×1024 pixels); $\simeq$ 4 frames s^{-1} (binning 2×2)

ern multi-layer dielectric coatings. Moreover, if a piezo-scanned interferometer is adopted, it also allows very short wavelength setting times (some milliseconds), further to the advantage of the temporal resolution.
The primary instrumental characteristics are reported in Table 1, showing that the spectral ($\lambda/\Delta\lambda \geq$ 190 000) and temporal (2.5 frame s^{-1} for 1024×1024 pixels) resolutions well satisfy the initial requirements. As far as the spatial resolution is concerned, the image scale ($\geq$ 2.4 pixels/resolved element) is such to warrant a good sampling, and the exposure time ($\leq$ 50 ms) is sufficiently short to mostly freeze the seeing. However, the *effective* spatial resolution also depends on at least two other conditions. Firstly, as AO is able to compensate for the seeing effects on small areas ($\simeq$ 10” in size), *post facto* techniques must be used, if high spatial resolution is wanted over all the available field of view (80” in diameter). In the second place, the spectrometer itself must not sensibly reduce the optical quality of the telescope.

2. Image restoration

Since only *single-frame* spectral series (one frame for each wavelength) have been acquired till now, to test the effectiveness of *post facto* techniques under our observing conditions, 16 broad-band frames have been used. These were taken simultaneously with monochromatic images during a spectral scan along the 7090 Å FeI line profile. The *Multi-Frame Blind Deconvolution* (MFBD) procedure (van Noort et al. 2005) has been used to obtain a single square restored broad-band image, 52” in size, with a spatial resolution very near to the diffraction limit of the telescope (see Fig. 1). On this image a large number of small bright points (*flux tubes*) are clearly visible, although these structures are generally observed around 4300 Å, where both the telescope spatial resolution and the photospheric contrast are higher, and often through a filter centered on the G-band, where they appear brighter. The smallest bright points in Fig. 1 are 2-3 pixels in size, corresponding to 100-150 Km on the solar surface, which represent both the typical dimen-

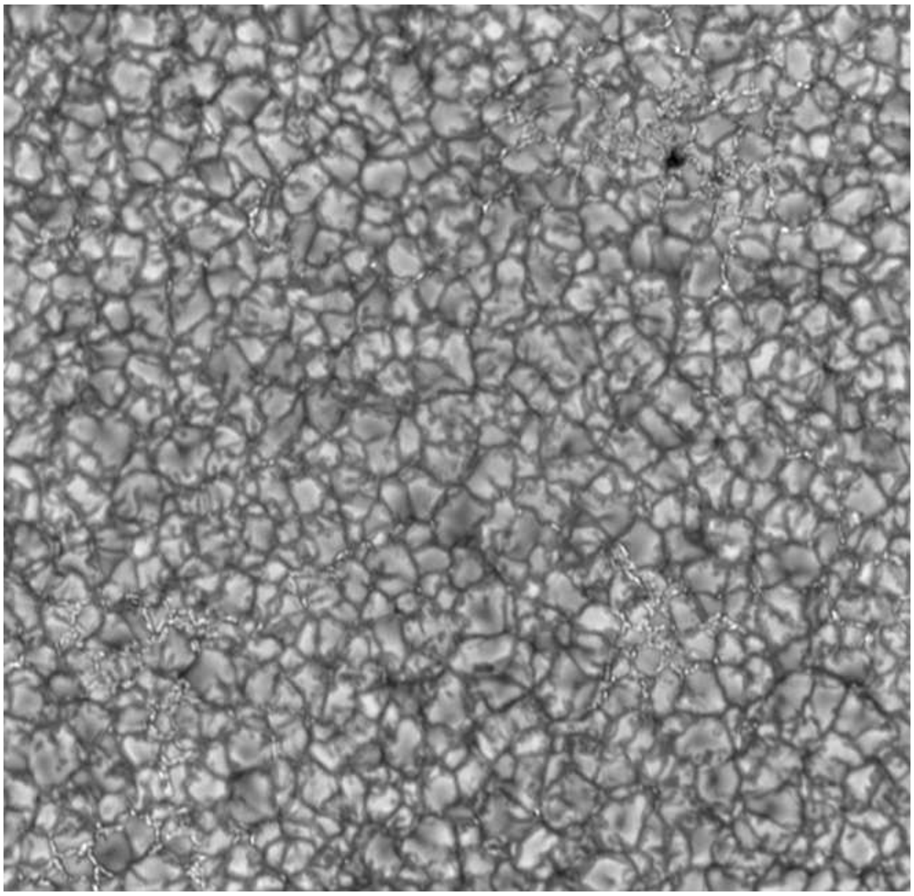

Fig. 1. Broad-band image (wavelength: 7200 Å; bandpass: 100 Å) obtained by IBIS at the disk center (June 2, 2004). The seeing effects have been corrected by the high order AO system of the DST/NSO telescope, and the MFBD technique applied to a sequence of 16 images. Size: 52”×52”; exposure time of each frame: 25 ms; diffraction limit of the telescope: 0”.24; image scale: 3 pixels/resolved element.

sion of these structures and the diffraction limit of the telescope at this wavelength (0”.24).

3. Image quality

To test how much the spectrometer affects the spatial resolution of the telescope, monochromatic images (bandpass: 24 mÅ), taken on the solar continuum near the 7090 Å FeI line, have been compared with simultaneous broad-band images. Since the spectral images have been acquired with a 2×2 binning, a similar binning has been performed on the broad-band frames. Then the same sub-region has been selected on a couple of images, where the seeing seems to be excellent (see Fig. 2). It may be seen that both frames show very similar contrast and resolution, although a greater noise is present on the monochromatic one. Unfortunately, due to the binning, the sampling is reduced to 1.5 pixels/resolved element. For the moment, we may only conclude, therefore, that a spatial resolution of at least 0”.32 can be achieved on the IBIS monochromatic channel, in comparison with a diffraction limit of the telescope of 0”.24.

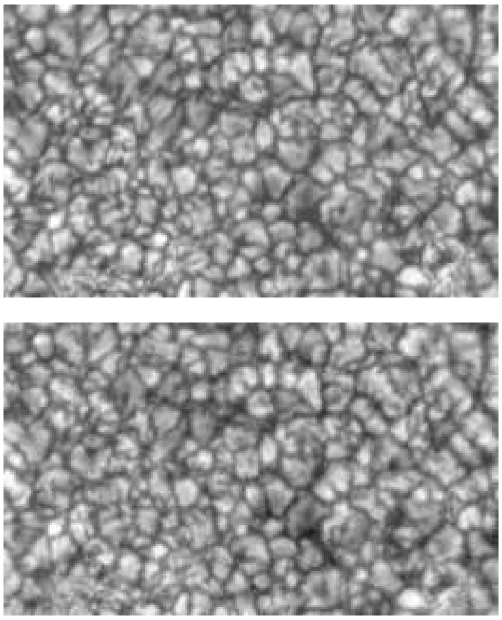

Fig. 2. Simultaneous images obtained by IBIS at the disk center (June 2, 2004). Size: 37”×22”; exposure time: 25 ms; diffraction limit of the telescope: 0”.24; image scale: 1.5 pixels/resolved element. *Top*: broad-band image (wavelength: 7200 Å; bandpass: 100 Å). *Bottom*: narrow-band image (wavelength: continuum near to the 7090 Å FeI line; bandpass: 24 mÅ).

4. Conclusions

Among the more relevant instrumental characteristics required for IBIS, the high spectral and temporal resolution have been obtained; the high spatial resolution, instead, deserves a careful analysis. As a matter of fact, if we want diffraction limited images, the spectrometer must not reduce the spatial resolution of the telescope and the seeing effects must be suitably corrected by both AO and restoring techniques. The results so far obtained suggest that we are able to achieve this goal.
However, all the spectral series acquired till now are *single-frame*, while the restoring techniques require a sequence of images to be efficiently used. Next observing runs have been therefore planned to take *multi-frame* spectral series (several frames at each wavelength), aimed to performe diffraction limited bidimensional spectroscopy.

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References

Rimmele, T.R. et al. 2003, Proc. SPIE 5171, 179

van Noort, M., Rouppe van der Voort, L., Lofdahl, M.G. 2005, Sol. Phys. (in press)