IMAGING SPECTROSCOPY ON VERY LARGE TELESCOPES.

Paul Atherton
Kapteyn Laboratorium,
University of Groningen.

Introduction:

Imaging Spectroscopy is a technique in which a spectrum is obtained for each spatial resolution element across a wide field. The data is essentially 3-D, and may be viewed as a series of monochromatic images, or as a two dimensional array of spectra. A device generating such data may be called an imaging spectrometer. In a previous paper (Atherton, 1983 SPIE 445, 535) three different imaging spectrometers - based on grating, Fabry-Perot and Fourier Transform devices - were compared in terms of their ability to obtain spectral and spatial information over a wide field and broad band, to the same spectral resolution and S/N ratio, using the same detector array. From such a study it is clear that interferometer based devices are significantly faster than conventional grating spectrographs.

However, the Fabry-Perot and Fourier Transfer interferometers have a spatial multiplex, imaging the whole field onto the detector, but no spectral multiplex (in the photon noise limited case)essentially acquiring spectral elements sequentially. Thus when working on point sources the slit spectrograph has the advantage of sampling all spectral elements simultaneously. On a VLT image- slicers or fibre optics can be used to feed the light from one seeing disk into the narrow slit. Clearly for extended sources this is not possible. Furthermore the information of interest in the spectrum of an extended source is not spread uniformly through the spectrum, but is concentrated in regions around emission and absorption lines e.g. [OII], H,K, HeII, Hβ, [OIII], MgB, NaD, [OI], Hα, [NII], [SII].

For work on emission line (and narrow absorption line) objects such as galaxies, HIII regions, SNR's, planetary nebulae, globular clusters, etc. imaging through Fabry-Perot interferometers is rapidly becoming a widely accepted technique, with clear advantages over more conventional methods of getting velocity-field information at high spectral resolution over a wide field (e.g. Taurus-Atherton et al. 1982, MNRAS 201, 661; Cigalle-Boulesteix et al. SPIE, 445, 37; Roesler et al. 1982, Ap. J. 259, 900). Within the next two or three years it is expected that most major observatories will have systems of this kind, using servo stabilized Fabry-Perots and Image Photon Counting Systems.

An Imaging Fourier Transform Spectrometer (IFTS)

An alternative configuration, an IFTS, has advantages which begin to be realised when using telescopes of 15 metres aperture:

Firstly, since each pixel in the detector sees the whole spectrum (as defined by some prefilter) all the time, even working in narrow band the sky back

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ground overcomes the detector noise very quickly. Thus we can use high quantum efficiency, high readout noise detectors (e.g. CID's, RCA CCD's) effectively, and in a regime where charge transfer efficiency is relatively unimportant.

Secondly, with an IFTS it is possible to use a second input beam, pointing at a blank area of sky, to cancel out the Fourier components of the nightsky spectrum in the source input beam (i.e. background suppression).

Thirdly, using a broad band beam splitter (e.g. inconel) one can use the same instrument to modulate all wavelengths over the range 0.35 - 3 μm, using dichroics to separate the output beams into blue, red and infra-red channels, imaging onto blue CCD's, red CCD's and IR arrays simultaneously or feeding into slit spectrographs to increase the spectral multiplicity at the expense of the spatial multiplicity.

Figure 1 shows, schematically, a rough outline of a design for a wide-field high-resolution, broad-band Imaging Fourier-Transform Spectrometer:

The light from a 5 arc minute field is collimated and fed into the IFTS. A beamsplitter (inconel or optimized dielectric) separates two beams which are fed to cube corner retro reflectors mounted on Inch-Worm actuators (100 mm range) with a commercial laser position servo. The sky channel from a nearby blank field is fed into the complementary input to suppress the background (Fellgett 1957, Bellevue), Zehnpfennig 1979, App. Optics 18, 12). The cube corners allow separation of both (complementary) output beams, which are imaged onto different parts of the same detector. Dichroic beam splitters are used to separate blue, red and IR parts of the spectrum which are imaged separately onto blue (IPCS or CCD), red (CCD) and IR arrays. At the detector we see two images of the source - one from each beam -modulated by the concentric $cosine^2$ interference fringes of the interferometer. At zero path difference the white light fringe gives us the broad band image (through the prefilter) of the source. The sky signal from the complementary input gives a modulation which is out of phase with the sky signal modulation in the source beam, cancelling it out optically. A series of images are taken, each at a different path difference. Thus the 3-D data cube has coordinate axes of α, δ, path difference. Fourier transformation of the intensity as a function of path difference for a particular α, δ gives the input spectrum.

As we scan to larger path differences, so the spectral resolution increases and the width of the fringes on the detector decreases. The field on the sky is limited when the fringewidth approaches the pixel size. The smaller the pixel size the larger the field at a particular spectral resolution. For a 5 arc minute fields and 20 μm pixels we have a limiting R of 10^5. Transparency variations during a scan are removed by normalizing each scan using the complementary output. Summation of both outputs should be a constant. Seeing variations during a scan represent the biggest potential problem. At low spectral resolution, where

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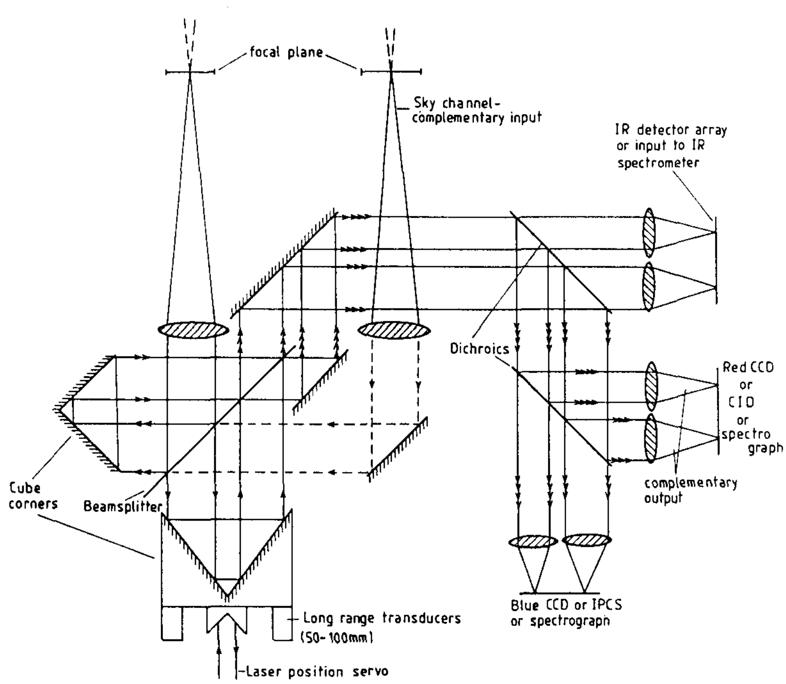
the seeing disk is only a small fraction of a fringewidth this is not a serious matter. However, at higher spectral resolution the seeing fluctuations can feed through into the spectral domain and produce spurious artefacts in the Fourier Transform. This effect can be drastically reduced by rapid scanning: since with an IFTS our signals are almost always greater than the readout noise, we can read out the CCD very rapidly - say once per second - and complete a scan of several hundred steps in a few minutes. Thus over a period of an hour we can average the seeing over many scans. The present Taurus data acquisition package works in this manner, although at a slower speed (~ 3 secs per step), and the seeing disk in each image, when averaged over 10 or 20 scans, is accurately aligned, and the same shape (within the S/N). Data transfer at this rate is within the capacity of a dedicated micro driving a Winchester disk. Data reduction is within the capacity of a dedicated mini-computer, and the data processing load is similar to the output of the VLA.

Using a GEC chip in the blue channel during dark time on a 15m telescope, with a 180Å band filter, and assuming reasonable values for the efficiency, then the sky signal alone dominates the readout noise in 1 second. One might expect that an instrument such as this would be used mainly in grey or bright time, where the sky subtraction capacity gives it a great advantage over other configurations. In such a case, even working in a narrow band on one line, read out noise is not a problem, instead rapid read out of the CCD is required to reduce dead-time.



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