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Basic principles of integral field spectroscopy

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Abstract

The basic principles of integral field spectroscopy (IFS) are reviewed using a figure of merit, the specific information density, as an objective means of comparison. This shows that the best method in theory is image slicing, especially as implemented in the advanced image slicer (AIS) design used in the IFU of the Gemini near-infrared spectrograph (GNIRS). However an alternative, a hybrid of lenslet array and slicer techniques, may offer a better compromise between theoretical performance and practicality for panoramic spectroscopic surveys requiring millions of spatial elements. The role of anamorphism in enhancing the performance of image slicers is presented. Finally, the importance of multiplexed IFS to extremely large telescopes (ELTs) is discussed.

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1. Integral field spectroscopy and 3D instrumentation

The term 3D spectroscopy is often used, perhaps erroneously,[1] to indicate any technique that produces

[1] Of course it should either be *2D spectroscopy* or perhaps *3D imaging*.

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spatially-resolved spectra over a two-dimensional field. Integral field spectroscopy is that subset of "3D spectroscopy" in which all the data for one pointing of the telescope is obtained simultaneously. The other methods, such as Fabry–Perot Interferometry (FPI) and imaging Fourier transform spectroscopy (IFTS), use the time domain to step through wavelength space (or a Fourier conjugate). This leaves them potentially sensitive to changes in the instrumental or sky background, but allows a wide field to be covered in one pointing. In contrast, IFS encodes all the spectral and spatial information in the same exposure resulting in a smaller field of view for a given detector format. This conference is aimed mainly at IFS but the important contribution played by non-IFS 3D instrumentation must be acknowledged. Radio astronomers were making 3D spectral imaging observations long before it was adopted seriously in the optical regime and FPI and IFTS have an illustrious history that predates most IFS work and are well-suited to many areas of investigation.

All 3D techniques produce a datacube of a scalar quantity related to flux density as a function of spatial coordinates in the field and wavelength. To first order, the efficiency of all 3D techniques is the same. For example, an IFTS may provide a large number of spatial samples (spaxels) at one time but require a large number of timesteps to scan through the spectrum. An IFS may produce all the spectral information in one exposure, but its field of view is necessarily limited so that a number of exposures with different pointings must be mosaiced to produce the same number of volume resolution elements (voxels). The same argument applies to stepped-longslit spectroscopy: each position provides full spectral information for a 1D line of spaxels but a number of separate exposures must be combined to cover the same 2D field as the other techniques discussed. To second order, the relative efficiency of the techniques differs, depending on the details of how data from different exposures are combined, the variability of the background compared to fixed noise sources and the nature of the required data product.

3D techniques are generally preferable to slit spectroscopy for a number of reasons: (a) slit losses are eliminated; (b) accurate target acqusition is not required; (c) the actual target position can be recovered from the data by reconstructing an image – also an aid to accurate mosaicing; (d) errors in radial velocity due to differences in the barycentre of the slit illumination obtained from the object and from reference sources can be eliminated; (e) the global velocity field is recovered without bias imposed by the observer's choice of slit position and orientation; (f) atmospheric dispersion effects can be corrected without loss of light by manipulation of the datacube; (g) in poor or variable seeing, IFS is always optimally matched to the object PSF.

2. A comparison of the different methods of IFS

Fig. 1 summarises four techniques of IFS. The first three are explained in more detail in Allington-Smith and Content (1998), while the fourth is a more recent idea proposed by Content (2005a) as a means to provide ~1 million spaxels to search for primaeval galaxies. Here we summarise the different ways in which they sample the sky and identify the key technological issues.

It is useful to define a figure of merit referenced to the number of detector pixels since this still dominates the hardware costs of instruments. The specific information density (SID) is

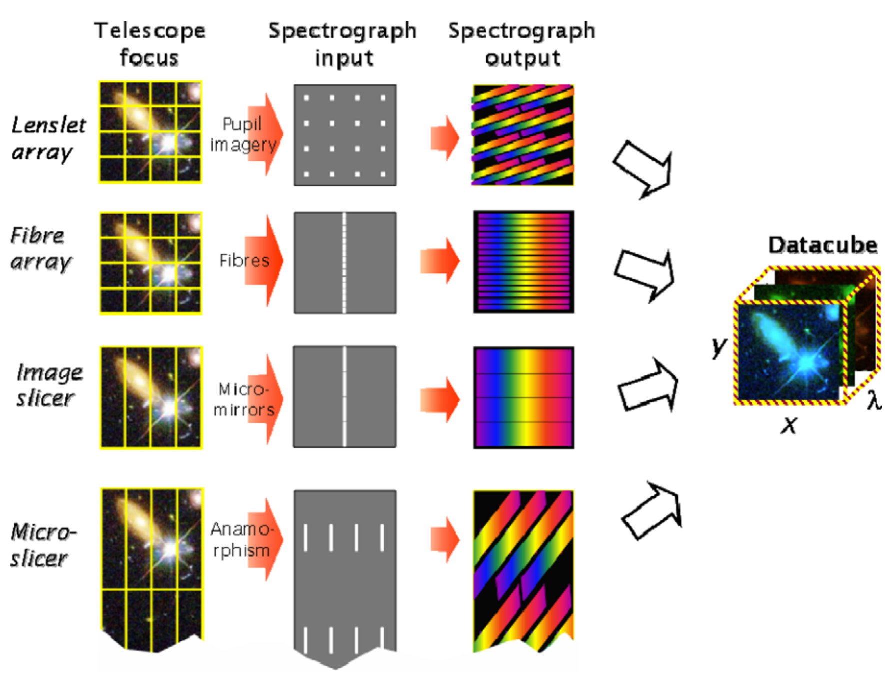

Fig. 1. A summary of the four main techniques of integral field spectroscopy.