Spectrographs Part 2:

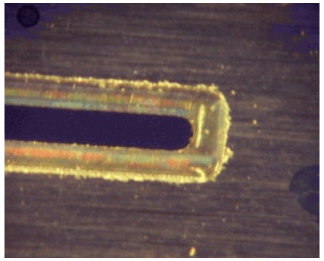
Multi-Object Spectroscopy
and
3D spectroscopy

ATI 2014 Lecture 11
Kenworthy and Keller

Multi-Object Spectrographs

Multi Object Spectrographs - drilled spectro slits

DEIMOS slit masks milled with 0.015 inch diameter bits



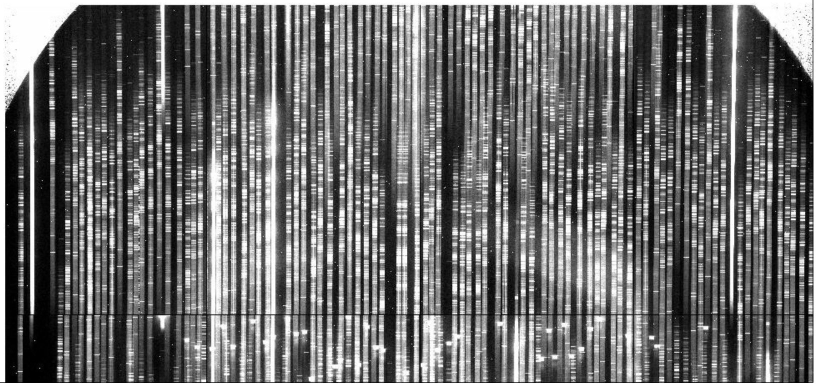
http://www.ucolick.org/~phillips/deimos_ref/masks.html

Multi Object Spectrographs - laser cut slits

IMACS on the Magellan 6.5m telescope

First spectrum with 240 slits

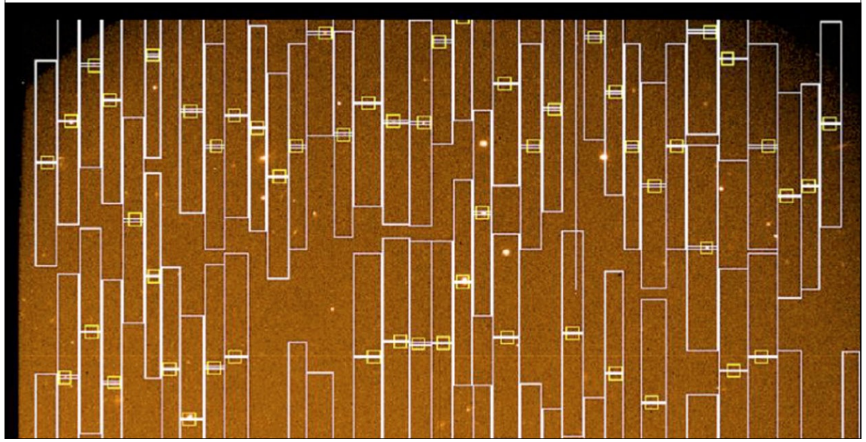
http://www.lco.cl/telescopes-information/magellan/instruments/imacs/



Multi Object Spectrographs - laser cut slits

VIMOS on the VLT telescopes

You decide where to put the slits on the science field
Can take up to two weeks to manufacture

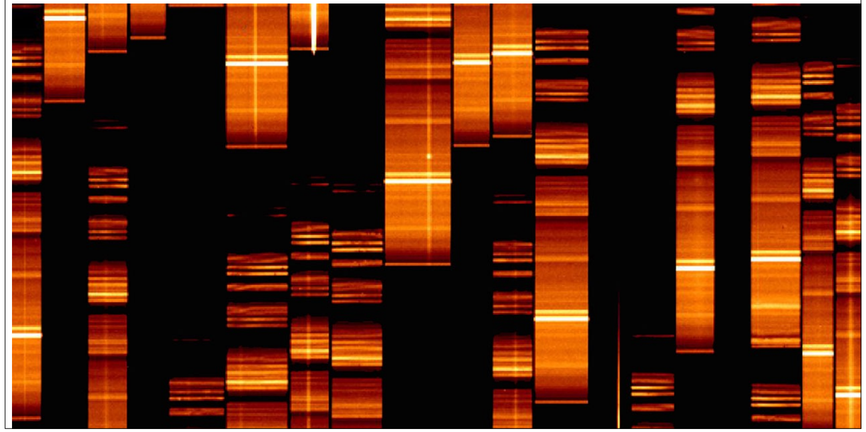


Multi Object Spectrographs - laser cut slits

VIMOS on the VLT telescopes

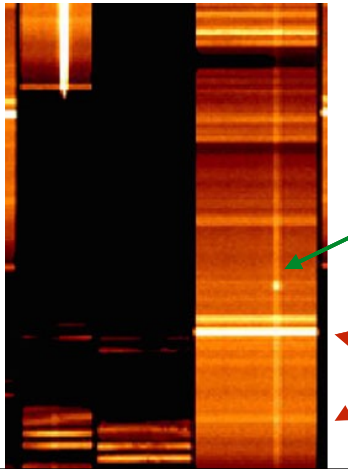
Number of spectra limited by sky coverage

http://www.eso.org/public/news/eso0209/



Night sky emission lines in NIR

VIMOS on the VLT telescopes



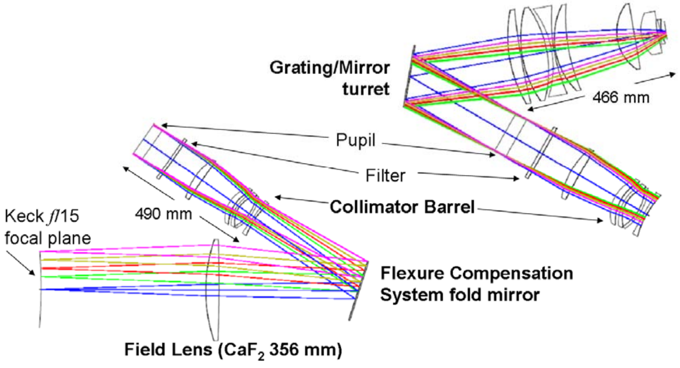
http://www.eso.org/public/news/eso0209/

Spectrum of galaxy

Night sky emission lines

Configurable slits on MOSFIRE (Keck)

NIR multi-object spectrograph

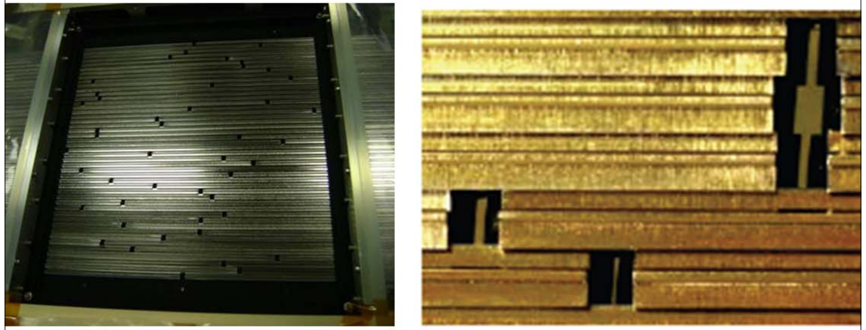


Field Lens (CaF$_2$ 356 mm)

McLean 2012

Configurable Slit Unit (CSU)

Cryogenic slits can be reconfigured in cold and in vacuum dewar!



McLean 2010

Configurable slits on MOSFIRE (Keck)

Adjustable mechanical slits allow for much faster configuration

McLean 2012

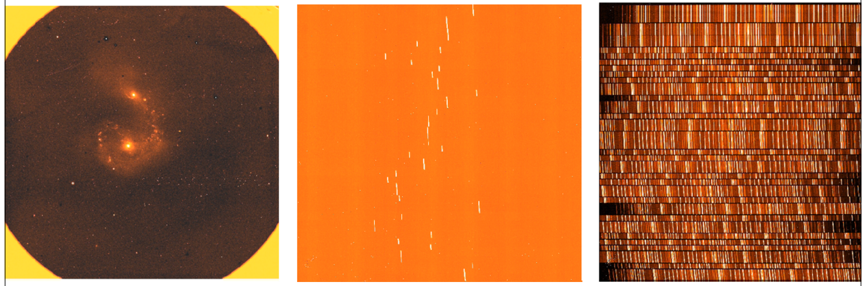
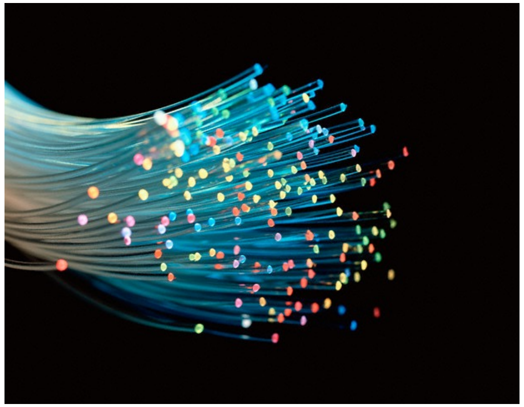
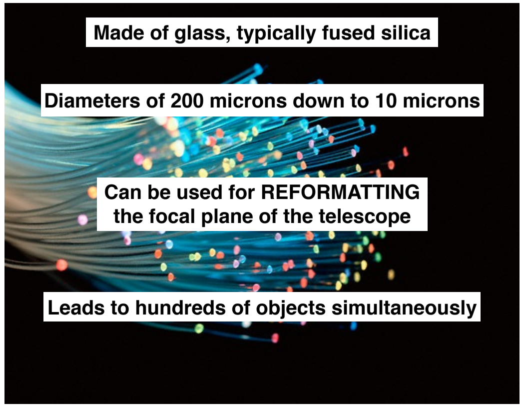


Figure 7. On the left is the layout of the MOSFIRE field on the sky with a 58s J-band image of The Antennae galaxies. The middle image is of a slit mask and the right image is the night sky emission with this mask in H-band.

Fibre Optics



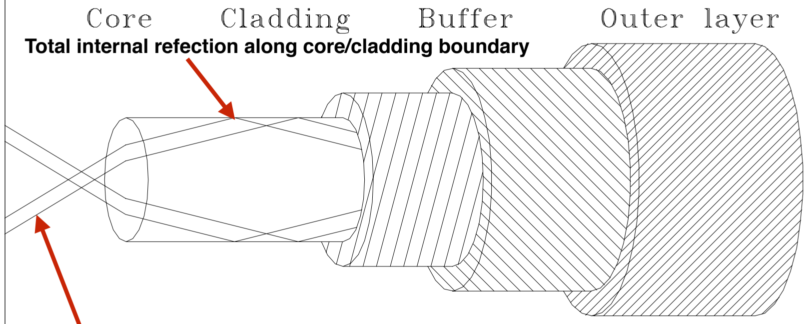
Fibre Optics



- Made of glass, typically fused silica
- Diameters of 200 microns down to 10 microns
- Can be used for REFORMATTING the focal plane of the telescope
- Leads to hundreds of objects simultaneously

Structure of an optical fibre

Cladding has higher refractive index than core material



Total internal refection along core/cladding boundary

Largest acceptance angle dependent on core and cladding refractive indices

Everything is big when you are 100 microns in size

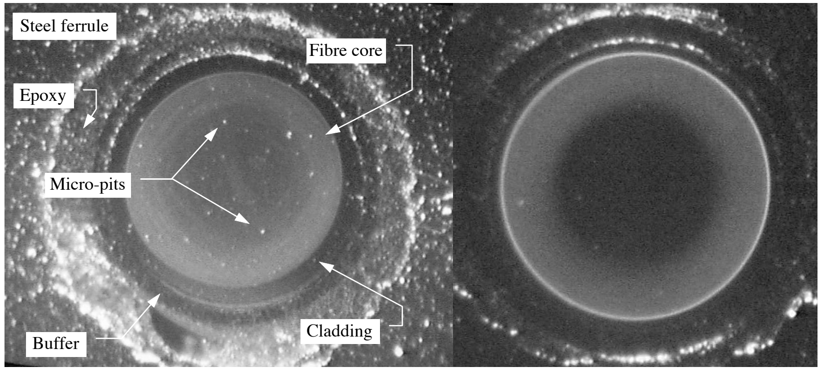
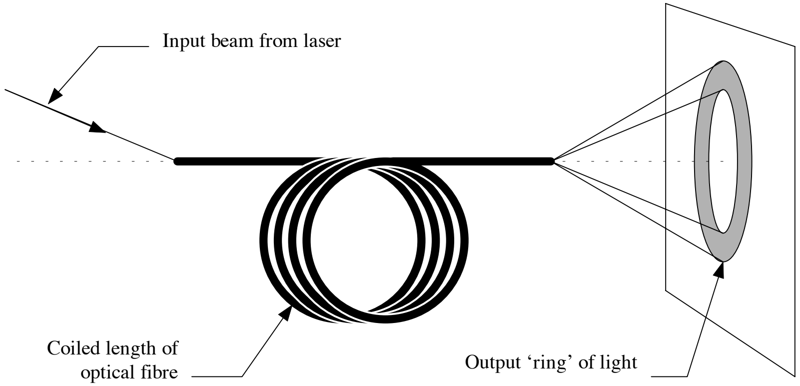


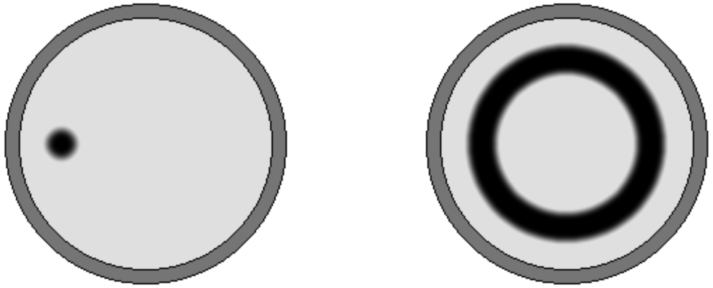
Figure 2-14 *Examining the fibre faces*. On the left the fibre face is checked for micro-pits - several can be clearly seen. On the right the back-illuminated fibre shows a clean ring of light across the face of the fibre.

Optical Fibre - azimuthal scrambling



Thousands of internal reflections from curved interface

Optical Fibre - azimuthal scrambling

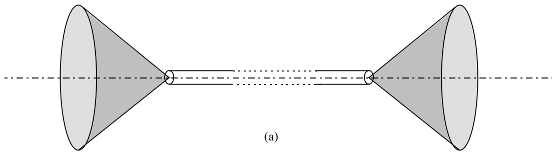


Input fibre face

Output fibre face

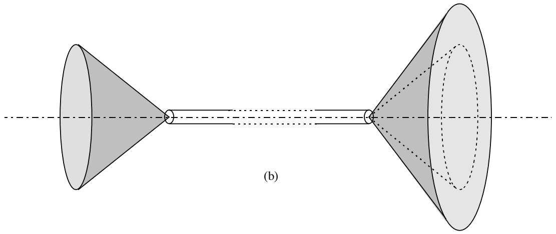
Looking down on the end of the polished fibre end

Optical Fibre - Focal Ratio Degradation



(a)

Ideal preservation of input beam angle and output beam angle



(b)

Deformation and stress causes light to ‘spread’ in output angle cone

Loss of flux from FRD if you don’t make the output optics bigger in size

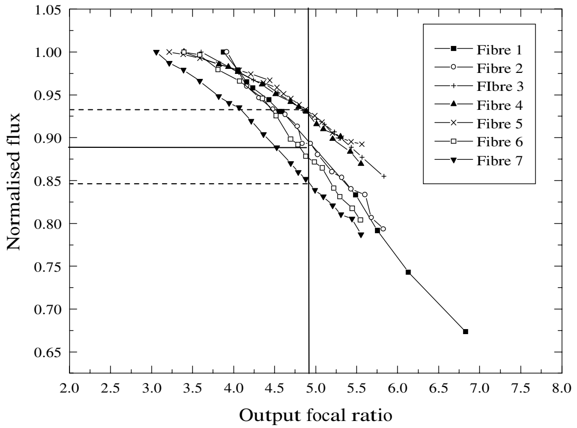
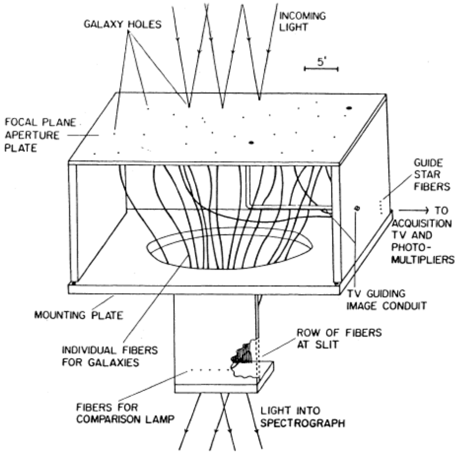


Figure 2-19 *FRD test results for seven SPIRAL fibres*. This is for a 16m length of Polymicro 50/70/90/110μm fibre measured at 600nm.

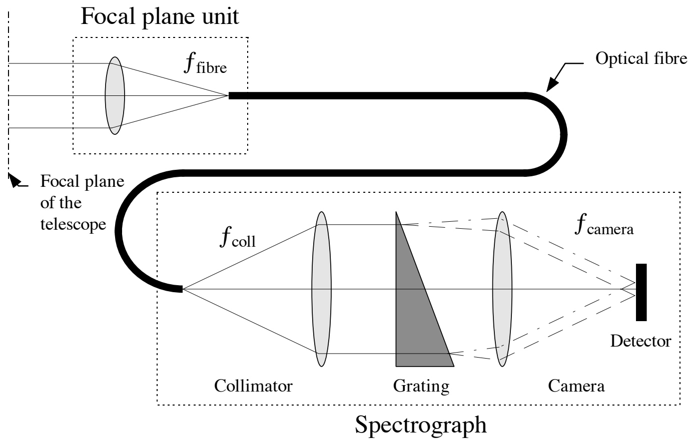
Plug plates drilled manually to match target fields



Hill 1988 ASPC

Figure 2. Schematic drawing of the aperture plate nucleus of the MEDUSA spectrograph.

Optical Fibre Spectrograph



Gluing optical fibres onto a glass plate(!)

The fine plate-scale (67 arcsec/mm) meant that drilling holes in brass plates was not an option for fibre positioning, due to thermal and other considerations. The required positioning accuracy for the fibres was 10 µm over the whole field (think of sticking a pin in a cricket pitch with a precision of 1 mm). It was one of the editors of these proceedings who suggested a viable alternative. Tacking the fibres directly onto transparent star and galaxy images on a positive copy of the target field using UV-curing cement seemed like a blindingly obvious solution to David Malin, with his background in photography and polymer chemistry.

Unlikely as it sounds, this technique worked rather well when it was tried out late in 1983. It required a special plate-holder to support the glass positive plate and bend it to the focal curvature. This had the same dimensions as the photographic plate-holders, so it could be loaded via the existing elevator, and was built for the project by UKST technicians Eric Coyte and Magnus Paterson (Fig. 3). It was another nine months before the necessary components for a fibre acquisition system had been built, but by October 1984, sets of stars spread over the full 6.5 degrees square field of the telescope were being simultaneously acquired. By then, too, the system had a name—FLAIR, for Fibre-Linked Array Image Reformatter. What else?

Fred Watson

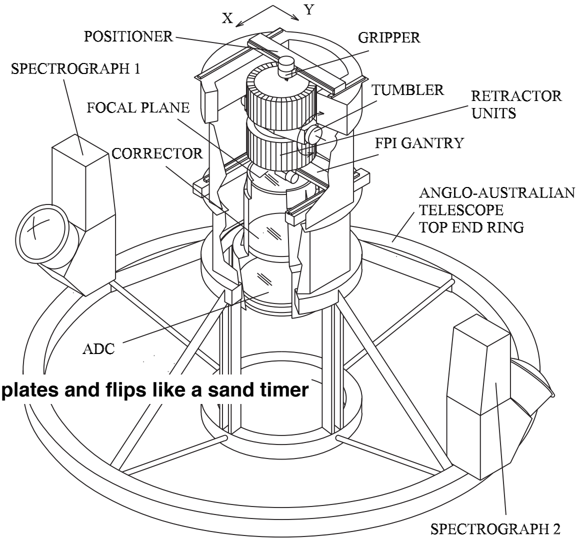
Robotic positioners - 2dF

Sits at prime focus of 4m Anglo-Australian Telescope

400 fibres positioned whilst other 400 are observing!

Diameter of 140 microns (2.1 arcsec on the sky)

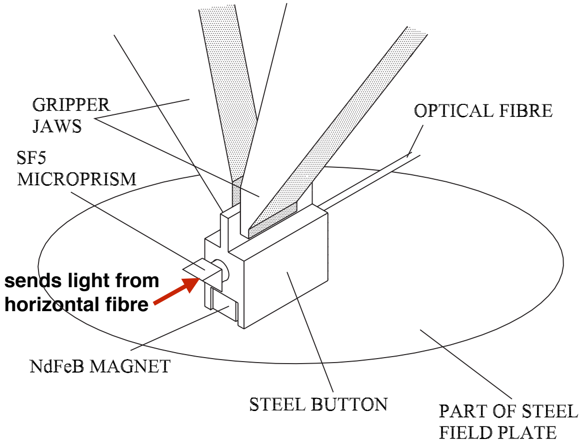
Robotic positioners - 2dF



Tumbler has two plates and flips like a sand timer

Lewis (2002)

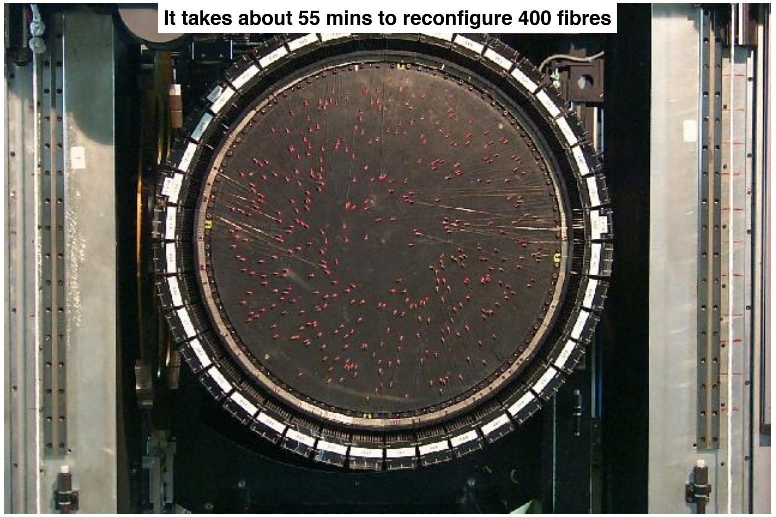
Robotic positioners - 2dF



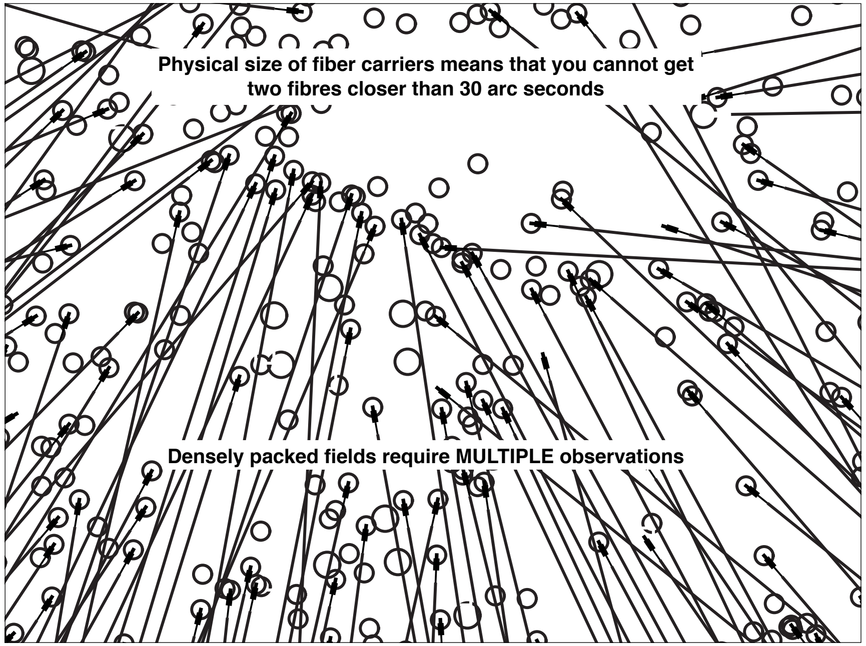
1.2mm prism sends light from vertical into horizontal fibre

Lewis (2002)

Robotic positioners - 2dF



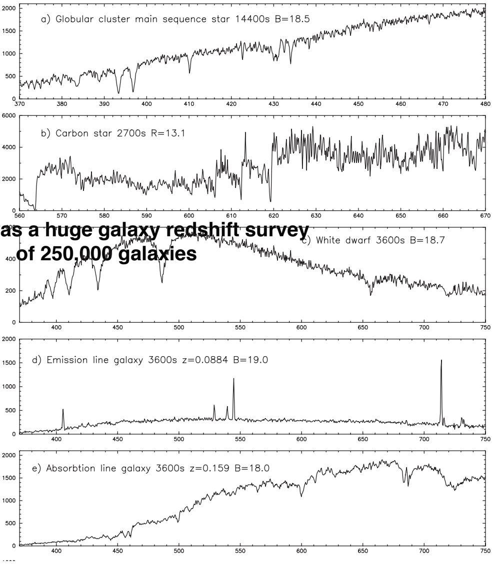
It takes about 55 mins to reconfigure 400 fibres



Physical size of fiber carriers means that you cannot get two fibres closer than 30 arc seconds

Densely packed fields require MULTIPLE observations

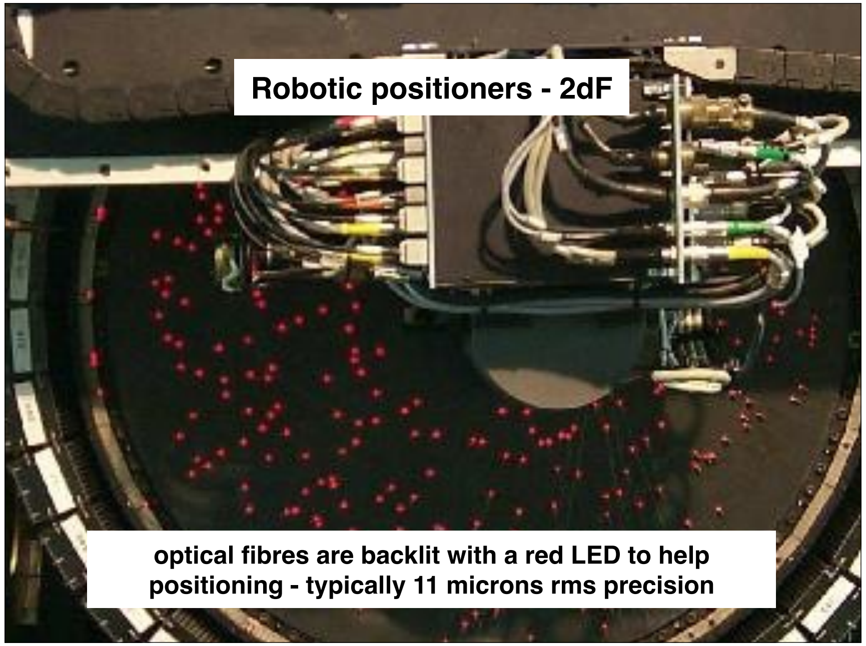
Robotic positioners - 2dF



Science was a huge galaxy redshift survey of 250,000 galaxies

Lewis (2002)

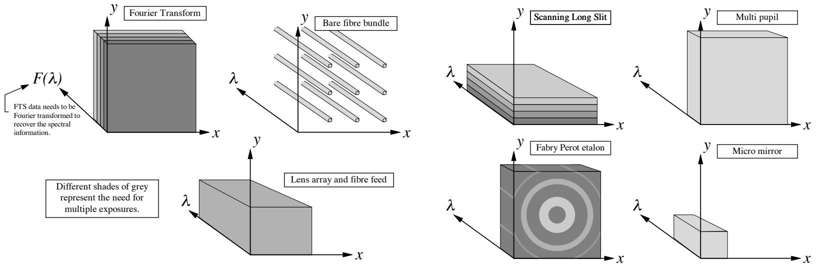
Robotic positioners - 2dF



optical fibres are backlit with a red LED to help positioning - typically 11 microns rms precision

3D Spectroscopy

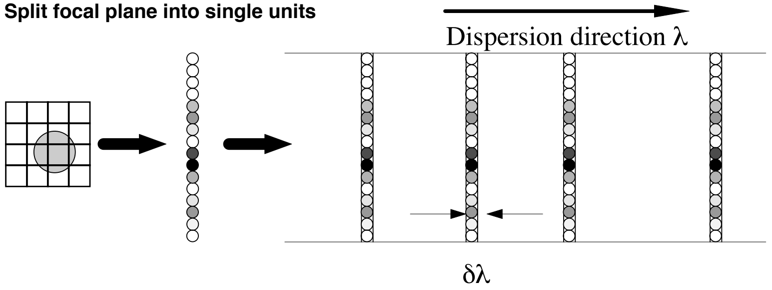
3D spectroscopy



Optical Fibre Image Reformatter

Use the flexibility of fibres to reformat the 2D sky into a 1D entrance slit

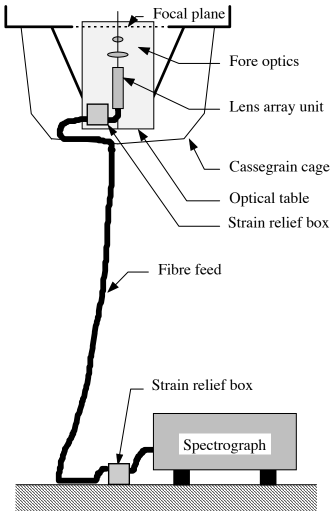
Split focal plane into single units

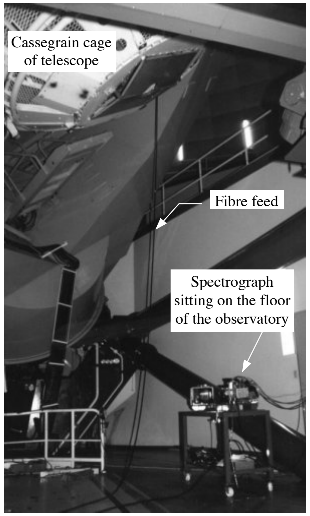


Fibers take light from telescope focus to the spectrograph

Spectrograph disperses the light

Spectrograph can sit on floor of the observatory instead of at the focus





Optical Fibre

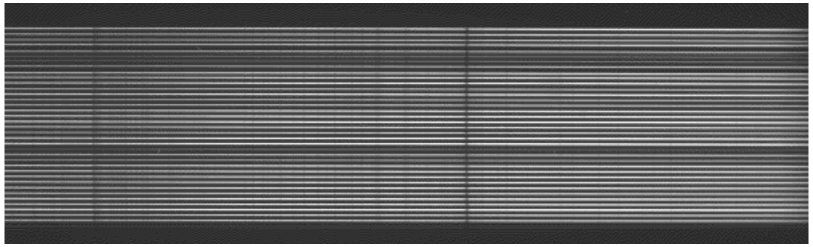


Figure 6-1 *A raw IFS data frame*. In this data frame from SPIRAL the dispersion axis is across the page and the 37 separate fibre tracks can be seen. This is a twilight sky exposure, clearly showing absorption features in the atmosphere and the variation in throughput between fibres.

Hexagonal lenslets on the sky

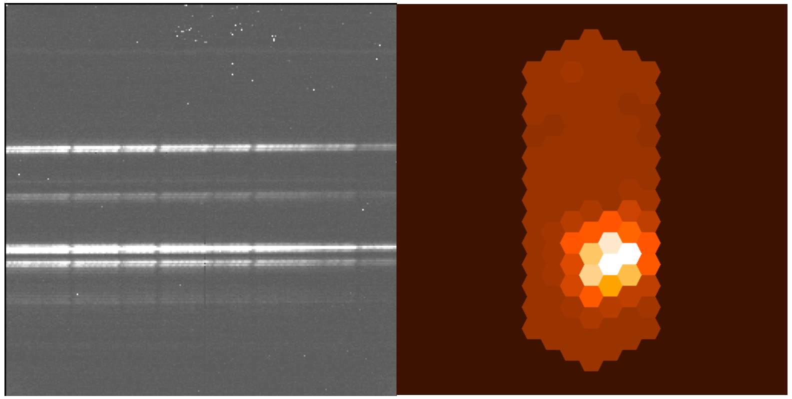
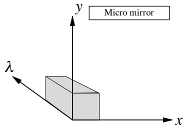
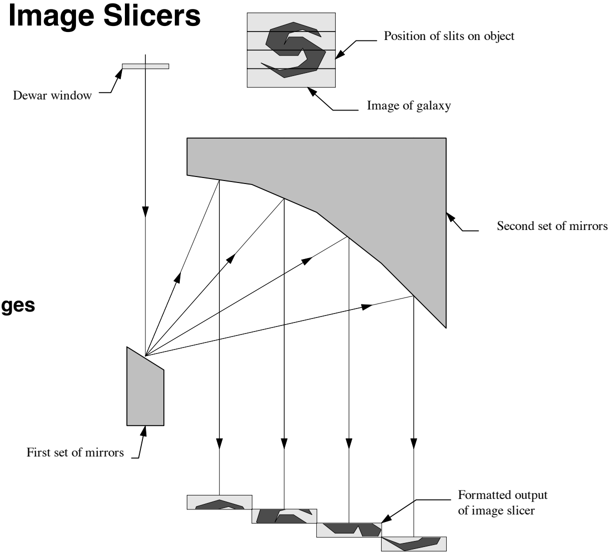


Figure 9-1 *Image reconstruction using the LDISPLAY software*. The image of the left is a raw image from the COHSI spectrograph. By knowing the relation between fibres on the sky and fibres in the slit an image can be reconstructed (right-hand panel).

Image Slicers

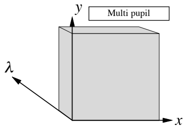


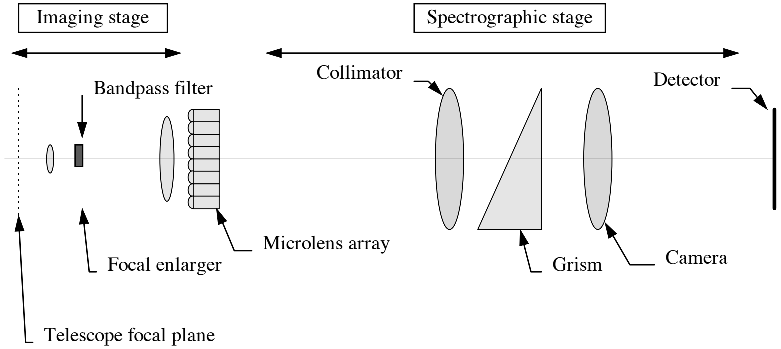


Small field of views

Large wavelength ranges

Multi pupil reimagers

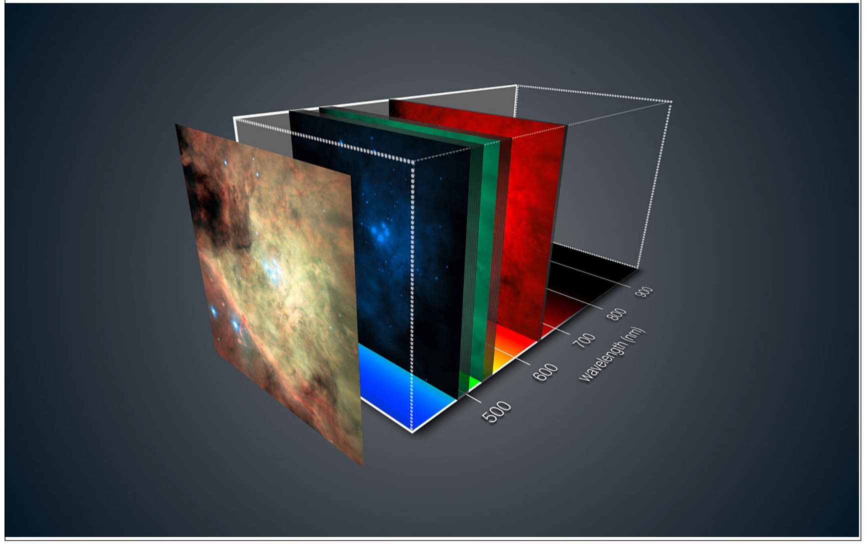




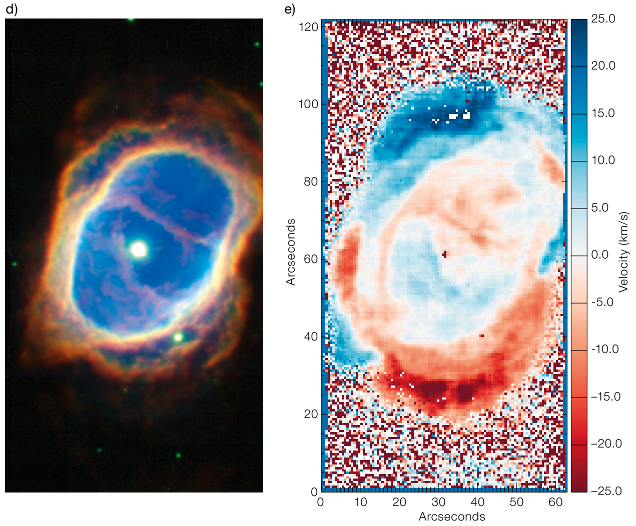
Microlenslet array cuts focal plane into tiny images

Disperse these images into short spectra -> limited wavelength range

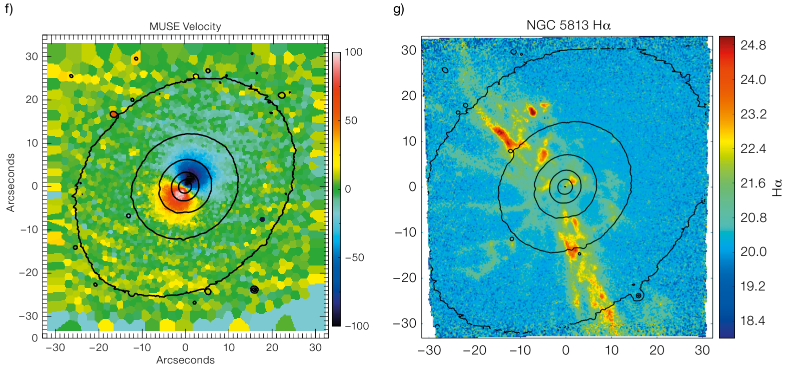
MUSE on VLT - 24 Integral Field Spectrographs



MUSE velocity fields



Complete wavelength coverage gives both abundances, velocity fields of different species of atomic transition



MUSE on VLT - 24 Integral Field Spectrographs

www.eso.org