Integral Field Units for SPIRAL and COHSI

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ABSTRACT

We discuss the design and construction techniques of the Integral Field Units (IFU's) for SPIRAL and COHSI (Cambridge OH Suppression Instrument). The design for both is similar and we explain our reasons for adopting our particular approach. Both IFU's have been used on telescopes and found to perform very well. Finally, our plans for future instruments which will use the same techniques are briefly discussed.

Keywords: spectrographs, optical fibres, integral field spectroscopy, lens arrays

1. INTRODUCTION

SPIRAL and COHSI are two separate fibre-fed spectrographs. SPIRAL[1] is an optical (450-900μm) spectrograph for use at the Anglo-Australian Observatory (AAO). The spectrograph was built by the AAO and the IFU was built in Cambridge. COHSI[2,3] is private instrument belonging to the Institute of Astronomy and is an infra-red (J and H band) low resolution spectrograph. So far it has been used once on UKIRT (United Kingdom Infra-Red Telescope). Both are capable of performing bi-dimensional spectroscopy using IFU's which incorporate lens arrays of close packed hexagonal lenslets. The techniques developed from the construction of the SPIRAL IFU were repeated and further developed in the construction of the IFU for COHSI. The specifications of the two IFU's are summarized in the table below.

IFU Specifications

IFU	Number of lenslets	Physical size of each lenslet	Fibre core diameter	Physical size of lens array	Lenslet size on sky	Lens array size on sky (arcsec)
SPIRAL Phase A	37	4mm across flats	50μm	20×20mm	0.5 arcsec	hexagonal field 3 arcsec across
COHSI	100	2.6mm across flats	110μm	16.5×41.5mm	0.66 arcsec or 0.33 arcsec	10.4×4.0 or 5×2

2. IFU DESIGNS INCORPORATING MACRO-LENS ARRAYS

IFU's are image reformatting devices that take pixels from a two-dimensional region of night sky and rearrange them to form a single line of pixels suitable for input to a spectrograph. The ability of optical fibres to carry light to any chosen point makes them ideal for the construction of such reformatters. However, the simplest fibre based IFU's are inefficient because the circular geometry and the optical cladding of fibres reduce the packing fraction. The solution to this problem is to use a close packed array of lenses in front of the fibre array. In this case the incident light from the full face of each lens is focused in to each fibre.

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For SPIRAL and COHSI we do not simply place the lens array directly in the focal plane (FP) of the telescope. Instead we use two lenses (the fore-optics) that enlarge the plate scale by a large factor and use much larger lenslets (a few mm across) in a larger lens array.

The advantages of using a macro lens array with fore-optics rather than a micro lens array directly at the telescope focal plane are:

- Lenses of the highest optical quality can be used including achromatic doublets
- Excellent AR coatings can be used
- Focal ratio degradation (FRD) due to non-telecentricity is eliminated
- The alignment of each fibre with its lens can be individually controlled and done with very high precision
- Changing the simple fore-optics allows various image scale options and allows the instrument to be readily moved to alternative telescopes

Placing a micro-lens array in the focal plane of the telescope minimizes the number of surfaces, but micro-lens arrays are difficult to manufacture. Optimal spatial sampling is achieved when the seeing is matched to two spatial resolution elements (lenslets). For Cassegrain foci on 4-8m telescopes with ~0.4 arcseconds seeing, the lenslet size has to be on the order of 50-200 microns across.

Although microlens arrays are commercially available their surface quality is not optimal. For example, the manufacturing method may leave surface scratches and the line between lens edges is prone to scattering incident light within the array. Fabrication of high quality lens arrays is still under development. Recent tests[4] have shown some micro-lens arrays to have losses on the order of 20%. On the other hand, lenses larger than ~2mm can made using traditional polishing methods. In the case of SPIRAL and COHSI we assemble the lens array ourselves from individually manufactured hexagonal lenses and we check each lens for scratches and imperfections, rejecting any that are below specification. The lens arrays for both SPIRAL and COHSI are AR coated.

Using optic fibres greatly simplifies the design of image reformatters, but FRD must be accounted for in the design. FRD is inherent to all fibres and causes the output beam to be slightly faster (i.e. more spread out) than the input beam. For both COHSI and SPIRAL, FRD is allowed for by making the lens array feed the light in to the fibres at a slightly larger f-ratio than the f-ratio of the collimator. In the case of SPIRAL the fibres receive an f/5 beam from the lens array and the collimator in the spectrograph is f/4.8. For COHSI the lens array feeds the fibres at f/6 and the suppressor collimator is f/5.5. Both instruments are designed to be exclusively fibre-fed which is why the collimators work at a fast enough f-ratio to ensure that the amount of FRD is small.

When the size of the lenslet in the lens array is comparable to the diameter of the fibre, extreme rays from the edge of the lenslet can enter the fibre at a much steeper angle than rays entering at the centre of the fibre (see figure 1). This lack of telecentricity in the lens array has the same effect as FRD and for very small lenslets can be a significant problem.

With micro-lens arrays it is extremely difficult to individually position fibres on the back of the lens array with high precision. In this case the fibres are first arranged into a pattern that matches the lens array and this unit is then glued onto the back of the lens array. Random errors in the lens and fibre arrays lead to misalignments of individual lens/fibre pairs. With much larger lenslets the fibres can be individually aligned with their lenses using a micrometer stage by back-illuminating the fibre and using a TV camera. In this way centre-to-centre errors in the lens array manufacture can be made very small.

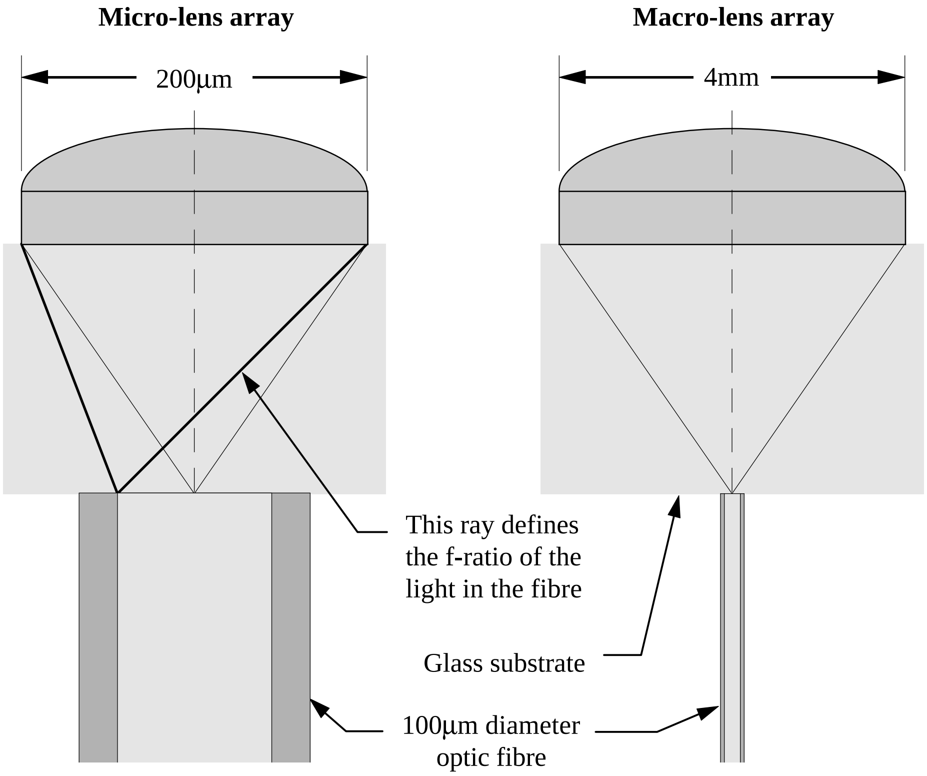

Figure 1: Non-telecentricity in micro-lens arrays. The left-hand diagram shows a microlens on a substrate with the fibre glued on the back, in the focal plane of the lenslet. Although the on-axis rays enter the fibre at the correct f-ratio, some of the rays entering the fibre near the cladding (shown as thicker rays) enter at extreme angles so the effective f-ratio into the fibre is lower. With the millimeter-sized lens on the right, this problem is virtually eliminated.

3. SPIRAL PHASE A

The SPIRAL phase A spectrograph was commissioned in February and November 1997. The total throughput at 6750Å, from the top of the atmosphere (at zenith) to detected photons is 11.8%. This value is an average for all the fibres, but for some of the fibres the system throughput is as high as 15%.

As discussed above, during manufacture each fibre is individually fixed in place with UV-curing optical cement. The fibres have stainless steel ferrules which provide a large enough surface area for bonding. After all the fibres are fixed to the back of the lens array a soft polyurethane potting compound is poured between and around the fibres. This provides mechanical strength and protection from the environment for the fibres. For SPIRAL A it was very difficult to properly cure the UV cement because the transmission of the lens array substrate is very low in the UV. This problem was overcome for the COHSI IFU (see below).

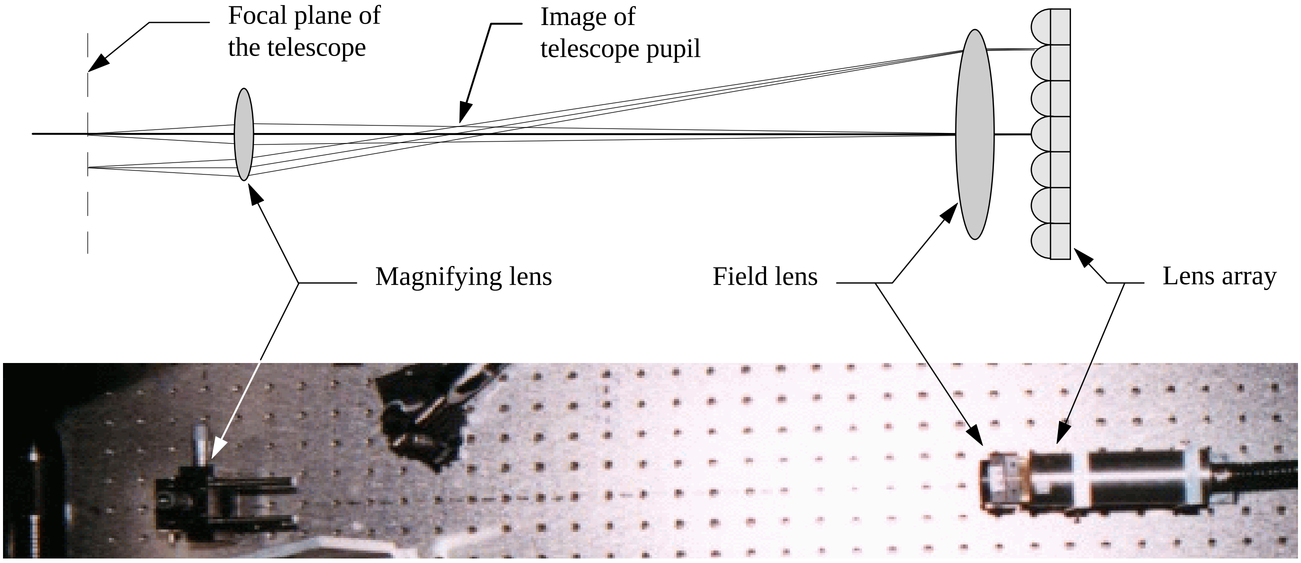

Figure 2: The SPIRAL Phase A fore-optics arrangement. The schematic drawing above shows the two lenses used to enlarge the plate scale of the telescope. A magnifying lens enlarges the field by a factor of 60 in the case of the AAT to produce a scale of 0.125”/mm corresponding to 0.5” per lenslet in the IFU. When the fibres are back-illuminated the field lens superimposes the images of all the fibres at the position of the image of the telescope primary mirror.

4. THE COHSI IFU

SPIRAL Phase A was a very successful prototype. However, its construction pointed the way to significant improvements in the techniques for manufacturing the lens array and the fibre alignment process and these were used for the COHSI IFU[5]. One of the major differences was the construction of a detachable lens array allowing UV light to be exposed directly onto the fibre faces during manufacture. Having a detachable lens array also, in principle, allows several fibre bundles of different fibre types (e.g. different core diameters, high OH, low OH etc.) to be used separately with the lens array. The registration of the lens array with the fibre array is achieved using dowels. XY misalignments are not a problem as this simply results in a shift of the common fibre pupil which is easily fixed by realigning the telescope pupil with the fore-optics. Rotation of the lens array results in a spreading of the individual fibres images at the pupil and therefore has be avoided. The repeatability of the dowels in the COHSI IFU is excellent and the fibre/lens array alignment is maintained with very high accuracy.

We were able to position all 100 of COHSI’s fibres to within 5μm of their optimal position. The design of the fore-optics on UKIRT projected an image of the telescope pupil (the secondary) which slightly under-fills the fibre faces, giving us a margin of error of 10μm. Effectively, the COHSI IFU (see figure 3) has no geometrical losses whatsoever, and preliminary examination of the fibre flat fields obtained from the March 1998 commissioning run on UKIRT shows a considerably more uniform flat field than that obtained from SPIRAL.

5. FUTURE PLANS

The success of SPIRAL phase-A and the COHSI IFU indicates that using macro-lens arrays and fore-optics is an extremely viable alternative to focal plane micro-lens arrays, ensuring optimum fibre alignment, allowing the best lenslets to be used and offering considerable versatility. We intend to use this method in building the SPIRAL B IFU and the IFU for a future IR spectrograph (CIRPASS - Cambridge IR PAnoramic Survey Spectrograph) both of which will use ~500 fibres/lenslets.

The proposed geometry of the lenslets is similar to the COHSI IFU configuration (see figure 4). Following on from the successful SPIRAL A results, the AAO is considering the possibility of using SPIRAL B as a common-user spectrograph replacement for the RGO spectrograph. The current SPIRAL spectrograph was used with the new 2K×4K MIT/Lincoln Laboratories CCD in the November 1997 run and already has the capability to be fed by 500 fibres.

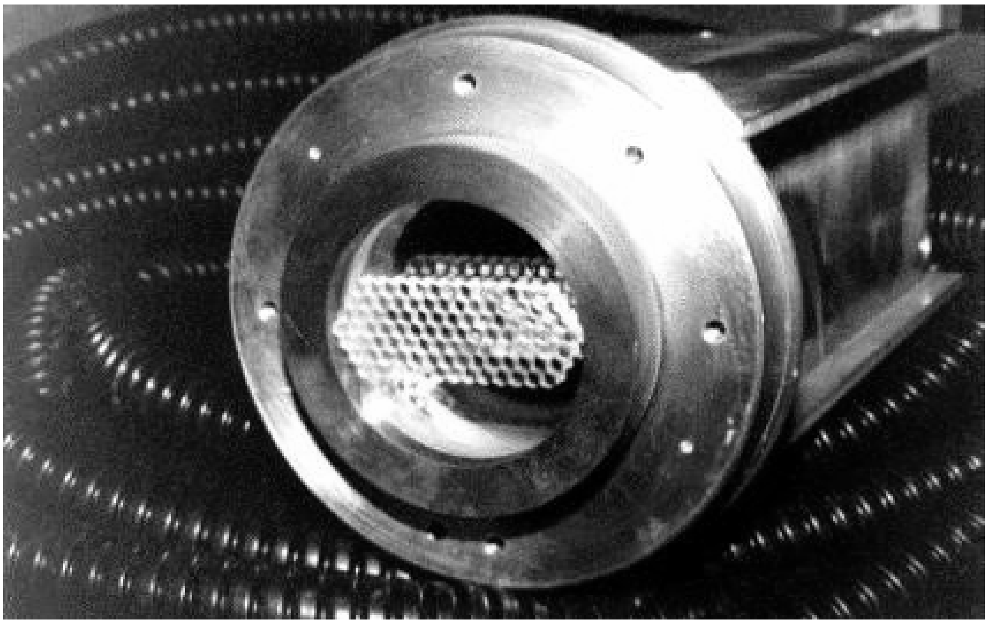

Figure 3: Picture of the finished COHSI integral field unit. The IFU is sitting on the coiled steel conduit that contains 12 metres of optical fibre.

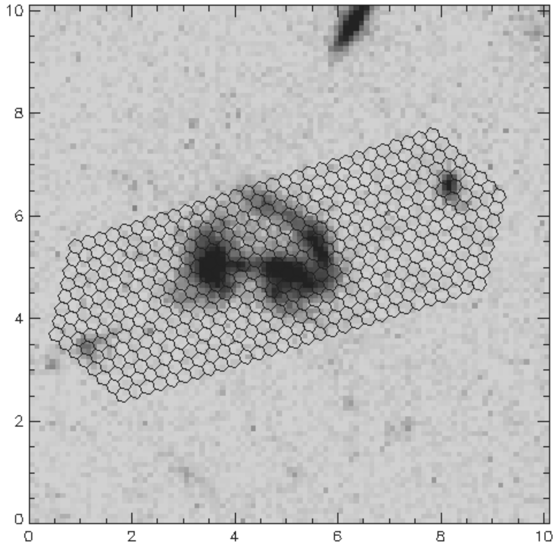

Figure 4: The proposed geometry of the CIRPASS/SPIRAL Phase B lens array. Here the lens array with its 499 lenses is superimposed on an HDF galaxy merger called CFRS 14.1129. The image scale is 0.25” per lenslet. Image courtesy of Jarle Brinchmann.

6. REFERENCES

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