Developments on the UK FMOS project for the Subaru telescope

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ABSTRACT

We describe the UK participation in the FMOS project to provide multi-object IR spectroscopy for the Subaru telescope. The UK is working on the design of an OH suppression IR spectrograph, this work comprises the optical design, the opto-mechanical layout, spectrograph thermal environment and cryogenics and detector control system. We give a progress report on the current design work.

Keywords: IR Spectrograph, OH suppression, Subaru prime focus

1. INTRODUCTION

The UK FMOS project is part of a joint Japanese, Australian and UK initiative to provide the prime focus of the Japanese Subaru telescope with a 400 optical fibre multi-object capability in the near Infra-Red part of the spectrum (specifically the z, J and H bands). Detailed overviews of the FMOS project are given by Maihara et al[1] and Kimura et al[2]. The FMOS instrumentation consists of a new prime focus unit with IR corrector and a 400 optical fibre multi-object feed[3,4], this work package is a collaboration between the Japanese project staff and the AAO, Australia. The fibre feeds[5] are being built in at the University of Durham and the two near Infra-Red spectrographs are being built jointly in the UK (Oxford University and RAL) and Japan (Kyoto). In this paper we briefly describe some of the detailed work being undertaken in the UK towards the design of a cooled OH suppression spectrograph for the z, J and H bands.

2. OPTICAL DESIGN

The optical design of the FMOS spectrographs is being developed in the UK at the Rutherford Appleton Laboratories. The starting point was a design based on work by Ian Parry on the CIRPASS instrument[6]. The basic premise of the optical design is a moderate resolution spectrograph ($R=3200$) forming a high resolution spectral image on a mask mirror. The mask mirror can have regions masked out in the proximity of the night sky OH lines to avoid these intense sky lines propagating through the optical system any further. This image then may be re-imaged using a further pass through the spectrograph collimator and the camera optics onto a HAWAII-2 detector. The spectrum can be imaged either in four sections at high resolution (as in CIRPASS) or by inserting a Volume Phase Holographic (VPH) grating to reduce the dispersion of the light so that the whole of the 0.9-1.8μm spectrum may be imaged at low resolution.

The fibre slit unit is approximately 120mm long and formed by aligning the polished fibre ends in a pseudo-slit. More detail on the construction of the fibre feed and slit unit is given in Murray et al[3]. The light from the fibres is reflected for the first time from the collimator mirror (1.4m spherical honeycomb mirror from Hextek, Tucson) through a fold mirror (F1), through a Schmidt corrector (S1) and onto a high dispersion reflection grating (G1). This grating is a custom surface ruled reflection grating with 500 lines/mm with a Zerodur substrate and gold surface coating. The dispersed image is reflected back through the Schmidt corrector and fold mirror back onto the collimator mirror for the second time and forms a spectral image on a spherical surface adjacent to the slit unit. The image of the J band spectrum is located to one side of the slit unit and the image of the H band spectrum to the other side of the slit unit. The slit unit itself is located at the part of the spectral image corresponding to the 1.4μm atmospheric absorption feature between the J and H bands.

The mask mirrors are located at the exact focus of the high dispersion spectral image and have small gaps in the gold reflective material to allow the atmospheric OH lines to pass into the glass mirror material and to be absorbed. The rest of the spectral image is reflected back off the mask mirror back to the collimator mirror for the third time then through a second Schmidt corrector (S2). In the high dispersion mode the collimated light beam is them brought to a focus using an all Silica camera. To image the whole J and H band it is necessary to move the camera to 4 positions. In the low dispersion mode the collimated beam passes through a VPH grating to un-disperse the light and the same camera optics can re-image the whole of the J and H band spectrum in a single shot. An optical layout of the low dispersion mode is shown in figure 1.

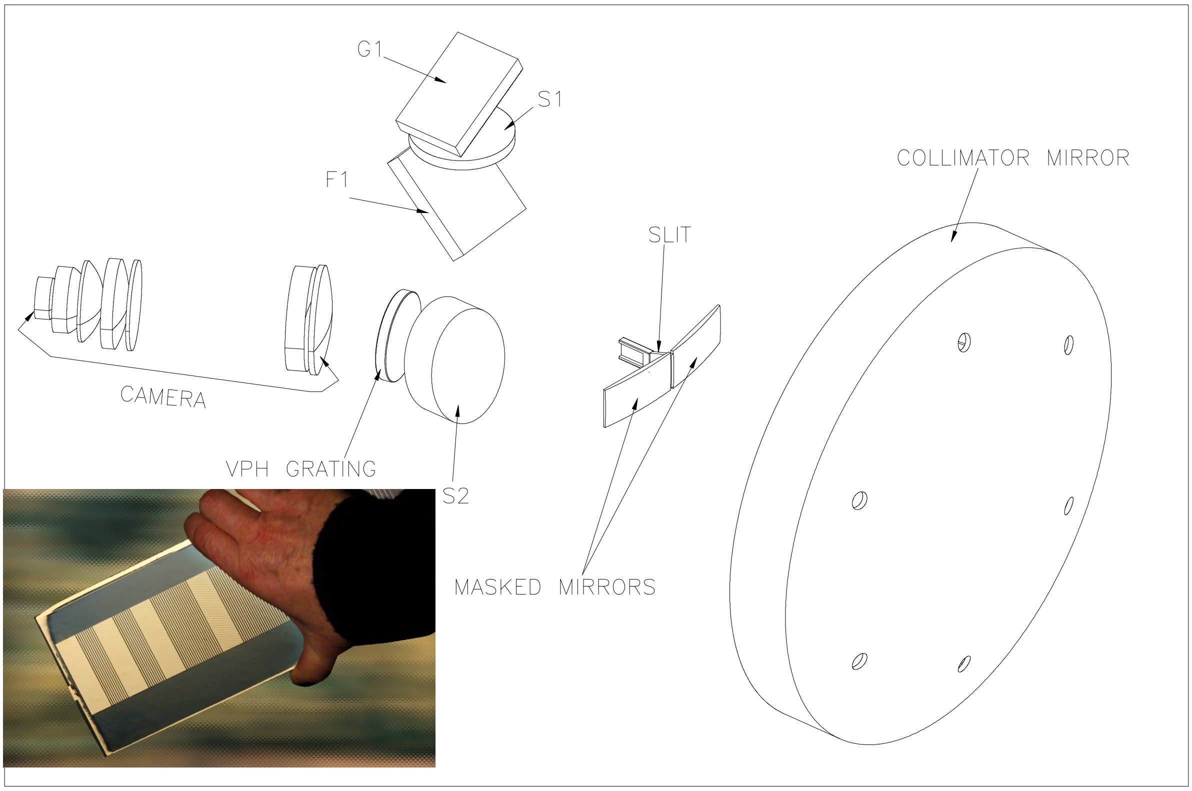

Fig 1. Low resolution mode optical layout showing the main optical elements, inset photograph shows a test sample of plate glass after AR coating, gold plating then etching away unprotected gold as described in section 3.

As well as normal optical alignment adjustments, the slit may be ‘nodded’ in the wavelength direction to shift the image of the spectrum on the mask mirror. This has the effect of moving the OH lines away from their normal location and out of the non-reflective area. The OH lines may then be imaged normally in a short exposure allowing for the relative fibre transmissions to be measured. The default slit position is always with the OH lines located at the non-reflective areas.

The reflection grating (G1) has a similar nodding mechanism to allow the image of the fibre slit to be shifted by a few pixels in the spatial direction to allow resampling of the spectrum image using different detector pixels.

The VPH grating has already been received and is currently undergoing extensive testing both at ambient and cryogenic temperatures at a purpose designed facility at Durham.

3. MASK MIRROR MANUFACTURE

The pair of mask mirrors are made from ClearCeram low thermal expansion glass and ground and polished to the required spherical shape. The technique for forming the reflective mask is performed in house at Oxford using the services of the photo-fabrication and coating units. Firstly a single layer AR coating tuned to either the J or H band is applied to the mirror surface, next a chromium followed by a gold coating are deposited over the AR coating. A photo-sensitive resist material is then applied over the gold surface and allowed to dry. A mask template of the OH lines is generated using a very high quality (10,000 dpi) printer and is placed in contact with the gold surface and the whole assembly exposed to UV light. The photo-sensitive resist is then developed to remove the unexposed material. The unprotected gold is then etched away using a saturated solution of Potassium Iodide in Iodine followed by removal of the chromium layer with a solution of Ceric Ammonium Nitrate. Finally the photo-sensitive resist is washed off leaving either a reflective gold mirror or bare glass with an AR coating. OH lines that hit the mask in the non-reflective areas will pass straight into the mask material and be absorbed at the rear face, the J and H band continuum will be reflected back from the gold surface into the spectrograph. The inset in figure 1 shows a test sample with gold coating after the etching process.

4. THROUGHPUT MODEL

By making a realistic assessment of the throughput of each optical element as a function of wavelength we can model the expected system throughput. We have used data from glass and fibre manufacturers, grating manufacturers, multi-layer coating design results together with standard atmosphere models.

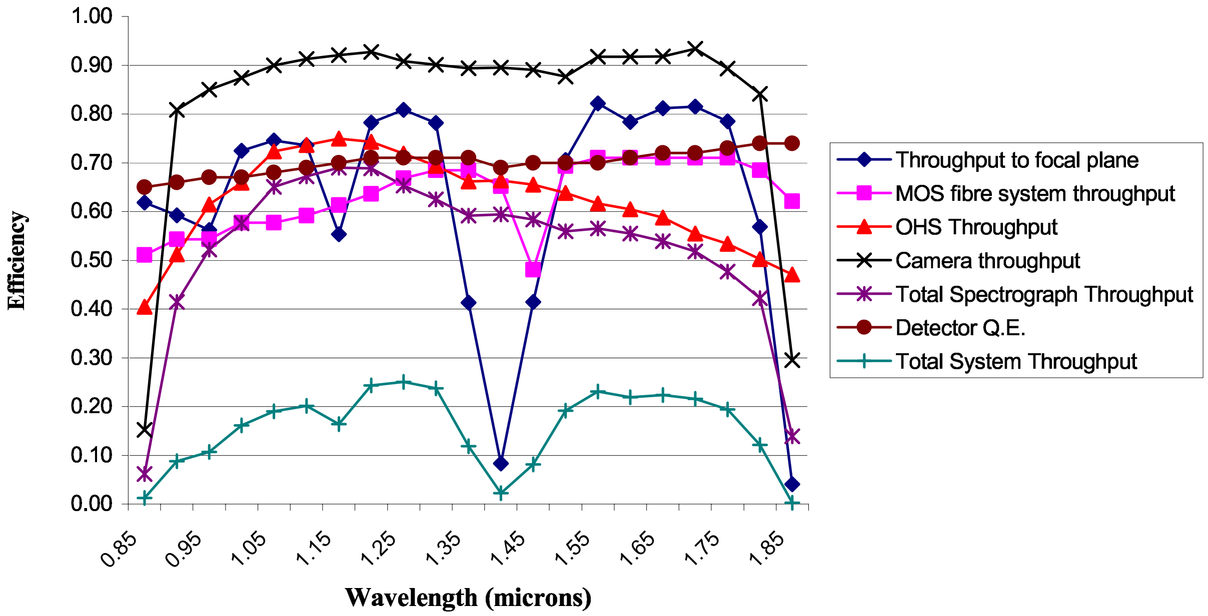

Fig 2. Graph showing efficiency by subsystem and total system efficiency.

The graph in figure 2 shows the model results by sub-system and the total system throughput for the high resolution mode, the low resolution mode will have lower efficiency due to the addition of the VPH grating. This single element should peak at better than 80 per cent at blaze. The overall efficiency of the OH suppression spectrograph is dominated by the blaze efficiency profile of the reflection grating (G1). The other major influences are the atmospheric loss at 1.4μm and the fibre losses due to the 50m length required.

5. MECHANICAL LAYOUT

The two spectrographs are located in a specially designed room above the Naysmyth platform of the Subaru telescope. Over 50m of optical fibre are required to reach from the prime focus unit to the spectrograph location. The spectrographs are floor mounted and therefore suffer from no gravitational stability issues.

The main part of the spectrograph is maintained at 200K to reduce the thermal background. Therefore the entire optical bench is contained within a thermal enclosure. The main optical elements of the spectrograph are mounted on the optical bench including the Collimator mirror, the slit and mask unit, the fold mirror, both Schmidt plates, and reflection and VPH gratings. See figure 3 for details.

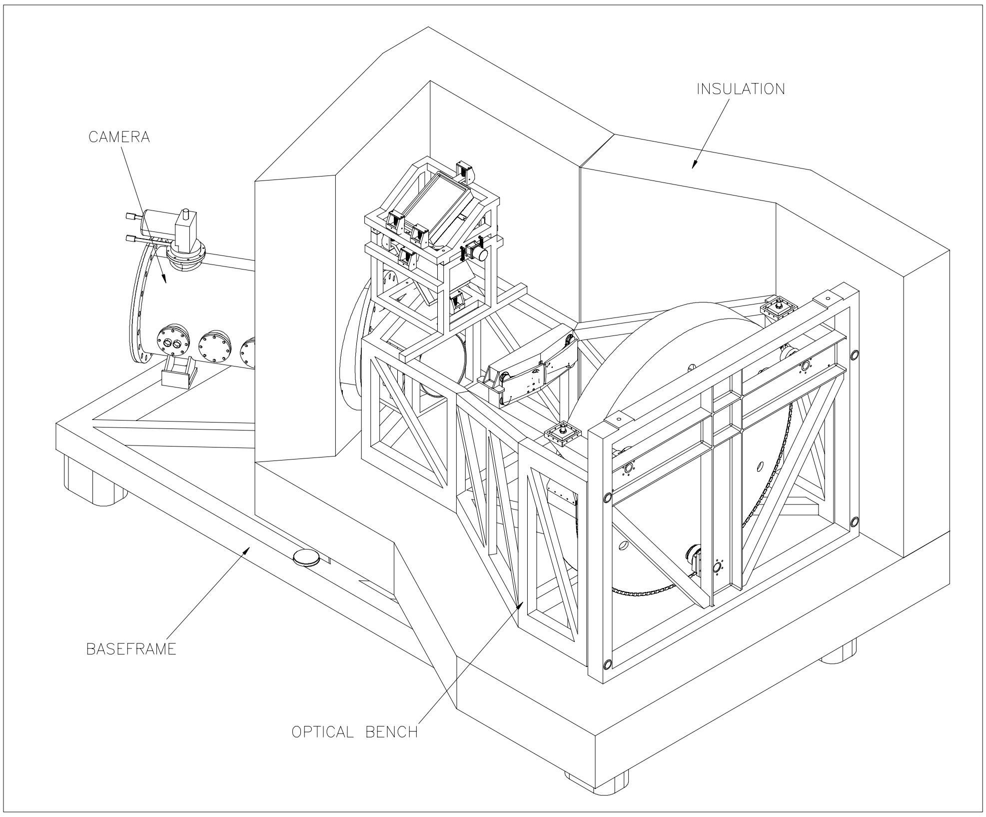

Fig 3. Opto-mechanical layout showing the OH suppression spectrograph in its thermal enclosure and the cryogenic camera.

The optical bench is supported on an instrument base frame using four flexible long thermal path legs. These allow the optical bench to contract as the instrument is cooled to 200K whilst the base frame remains at ambient temperatures. The collimator mirror is supported by a stainless steel band around the periphery of the front and back face. This band takes the weight of the mirror and positions the mirror perpendicular to its optical axis. The axial control of the mirror position is performed by three adjustable mounting points which float in a direction perpendicular to the axis of the mirror to allow the mirror and mounting frame to expand and contract during the cooling process. This mirror support design has been subjected to extensive finite element analysis to investigate the optical effects of supporting a honeycomb mirror vertically on its edge.

The camera unit contains the camera optics, blocking filter (thermal background and optical) and the detector assembly in a cryogenic dewar assembly. The camera is mounted on the ambient temperature base frame to allow it to be moved to select the observed wavelength. The camera aperture protrudes through a hole in the insulated enclosure of the main spectrograph assembly.

6. INSTRUMENT COOLING SYSTEM

The camera detector and optics are cooled by a Leybold Coolpower 150 chiller unit with the detector expected to reach 70K. Within the rest of the dewar the camera optics behind the thermal blocking filter are maintained below 150K and those in front of the blocking filter are maintained below 200K. The front window element of the camera optics is fixed at 200K by the internal temperature of the spectrograph enclosure. To aid the thermal cycling process, a liquid nitrogen precool is used to aid the cooling of the camera internal structure and heaters are available to ensure a swift warmup process.

The spectrograph structure is enclosure by 300mm thick insulating walls and is maintained at 200K using a cold air plant. The entire enclosure is servoed at a very slight overpressure relative to atmospheric pressure to avoid warm moist air escaping into the cold enclosure. The cooldown process is initiated by flushing dried air through the enclosure until the dewpoint of the air is below 230K, this is to avoid unnecessary icing up of the cooling system. Once the air is dry enough the air chiller is started and recycles cold air continuously through the enclosure with the final temperature being servoed at 200K. Thermal modelling of the spectrograph environment indicates that we expect to be at a stable operating temperature within 24 hours of starting cooling, this could be reduced but we wish to avoid inducing large thermal shocks to the optics, particularly the large collimator mirror.

The spectrograph thermal environment is controlled by a stand-alone PLC with battery backup to control the internal pressure of the enclosure in case of a mains power failure and an unplanned warmup occurring. A block diagram of the environmental control system is shown in figure 4.

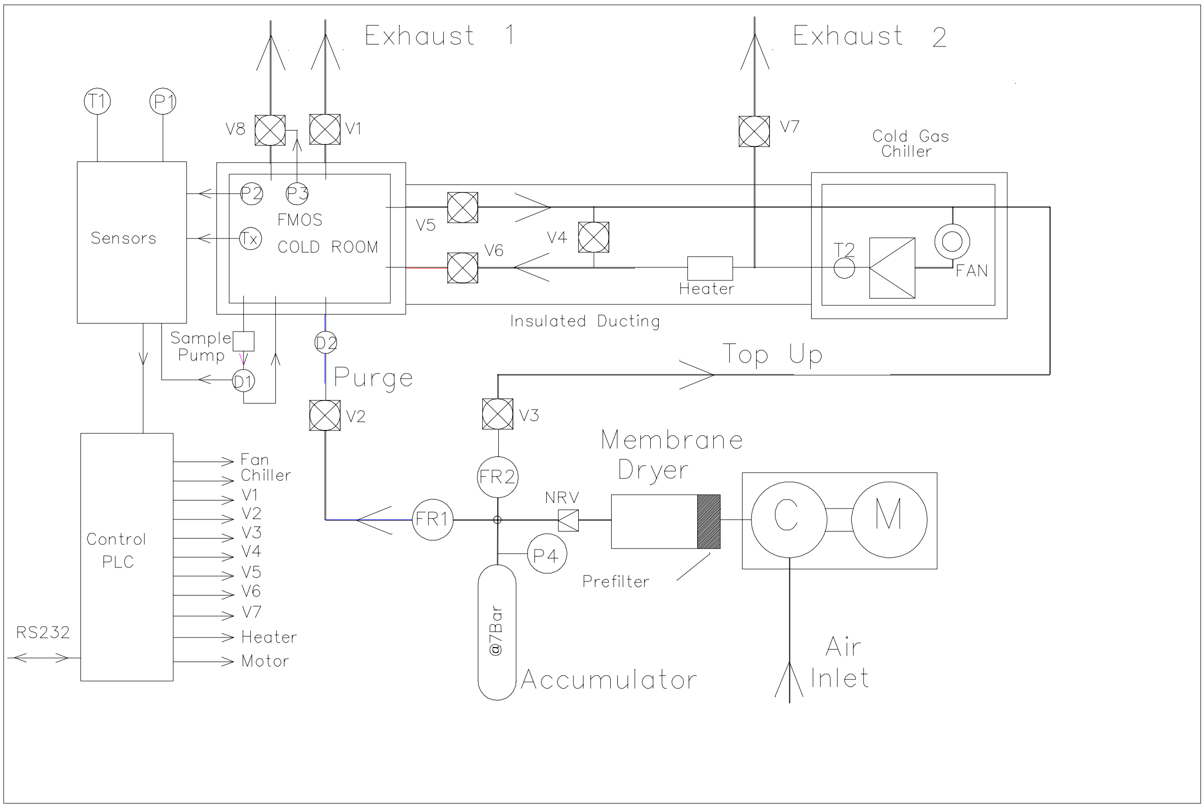

Fig. 4 Block diagram for the spectrograph environmental control system.

7. DETECTOR SYSTEMS

The detector for each of the two spectrographs will be a Hawaii-2 2048 square array with a SDSU IR controller system with software running under Linux. The detector control system will be fully integrated with the rest of the instrument control system and the observatory control system using standard Subaru software interfaces. Figure 5 shows the relationship between the detector and instrument control systems and also between the FMOS spectrographs and the Echidna fibre positioner and telescope software.

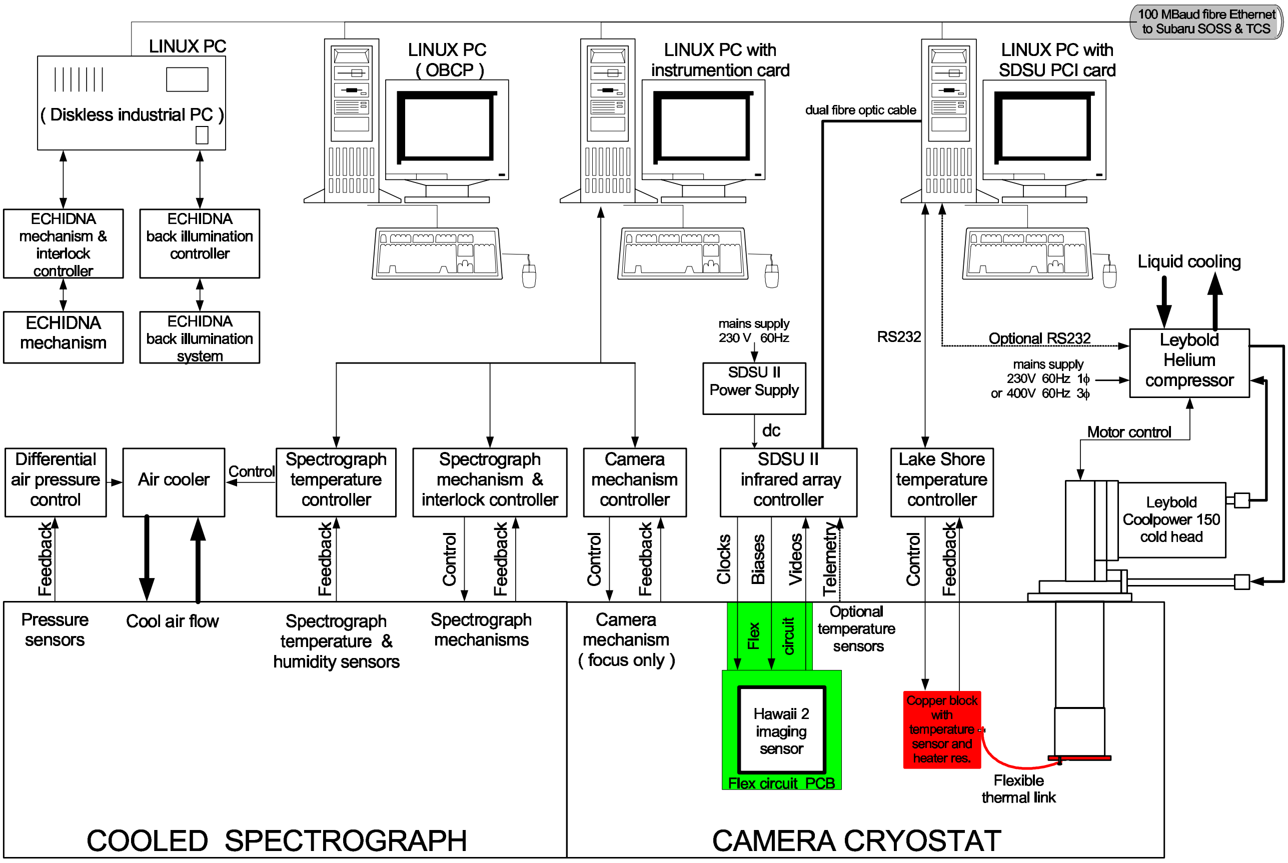

Fig. 5 FMOS detector and instrument control system block diagram

8. SUMMARY

We have described a near IR fibre fed OH suppression spectrograph design currently being built for the Subaru telescope. This work is currently approaching preliminary design review stage with construction expected to start in early 2003. The instrument is scheduled for first light in early 2005.

ACKNOWLEDGEMENTS

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