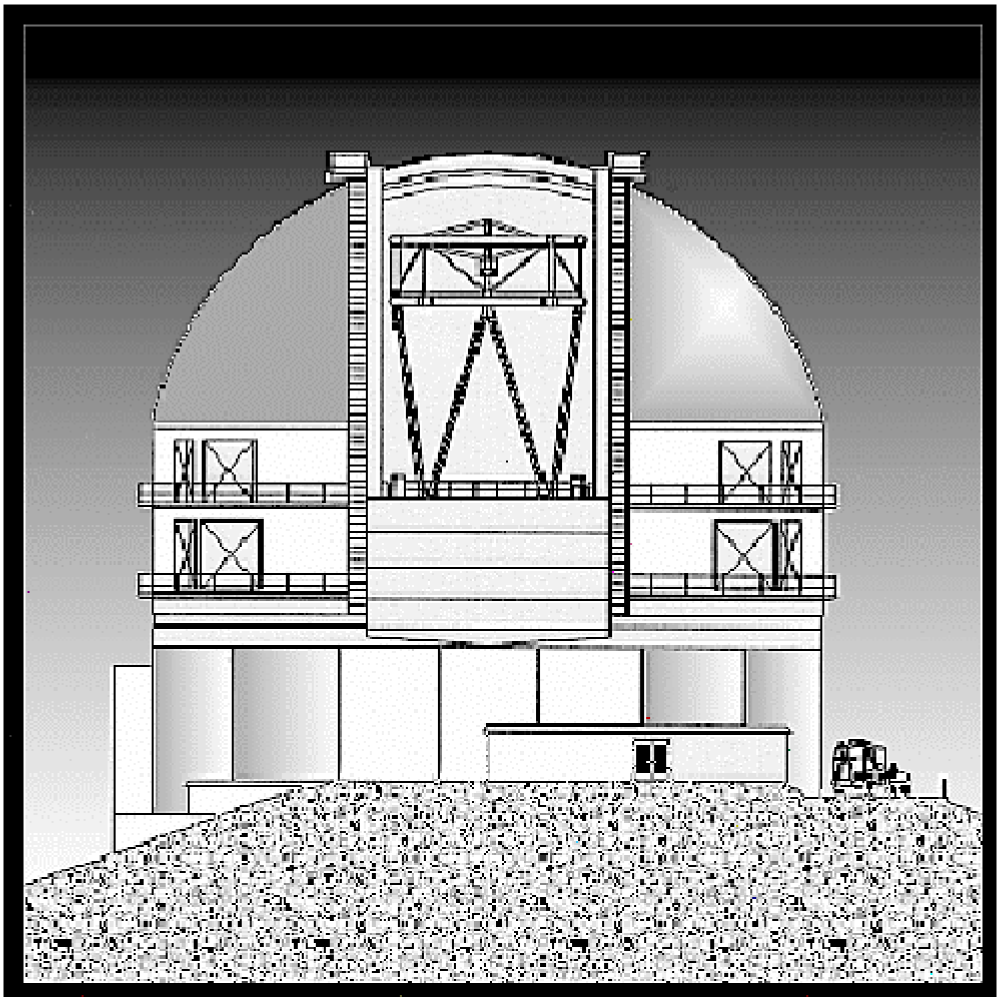
GEMINI
8-M Telescopes
Project

REV-I-G0094

Gemini High Resolution Optical Spectrograph Conceptual Design Review Final Report



December 30, 1996

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GEMINI HIGH RESOLUTION OPTICAL SPECTROGRAPH
CONCEPTUAL DESIGN REVIEW PANEL - FINAL REPORT

Review held at University College London on 21 and 22 November 1996
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SUMMARY

The panel recognized that the immersed echelle concept offers important advantages for HROS at the Cassegrain focus of Gemini-South but found that the team failed to prove the viability of their design in several crucial areas:

i) static flexure will probably exceed the range of possible active flexure control,
ii) thermal stability requirements for the cross-dispersion prism may be impossible to meet in practice,
iii) refractive index inhomogeneity integrated through 1.5-m of fused silica may lead to uncorrectable image errors which exceed the error budget,
iv) the on-axis camera design has a large central obscuration with potential operational, fiber-feed and up-grade problems, while the manual camera interchange is too inflexible operationally.

Items (i) to (iii) are considered 'show stoppers' which AURA should address immediately. For (iv) we suggest a single, or more operationally flexible dual, off-axis camera design which meets the science requirements.

We were confident that the design would meet its goals in terms of through-put, order separation, simultaneous wavelength coverage, and the lay-out and functionality of the slit area.

We believe that the multi-object capability described is very desirable and that a fiber or mirror fed high-stability mode should be investigated before PDR.

We are concerned that CCDs with sufficiently high QE and low fringing characteristics may not be available to cover the 300-1000 nm spectral range and we also suggest alternate lay-outs for CCDs in the camera focal plane.

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THE PANEL

Hans Dekker	ESO
Peter Hastings	ROE
Jeremy Allington-Smith	Durham
Bob Carswell	IoA Cambridge
Sam Barden	NOAO
John Glaspey	DAO
Vik Dhillon	RGO
Germano Quast	Brazil
Eli Atad	ROE

Richard Wade	Rutherford Lab
Gordon Walker (chair)	UBC

MEMBERS UNABLE TO ATTEND BUT WHO SUBMITTED COMMENTS

Mario Mateo	Michigan
Paul Felenbok	Meudon

OTHERS PRESENT AT CLOSED SESSIONS

Pat Roche	UKGPS
Adrian Russell	UKGPM
Ian Corbett	PPARC
Fred Gillett	IGPO PS
Doug Simons	IGPO
Rick McGonegal	IGPO

The panel received documentation from the HROS team one to two weeks before the meeting and exchanged comments and raised questions by e-mail exploder. A set of draft resolutions was discussed and drawn up after completion of the team presentations on 22 November and submitted immediately to AURA. Subsequently, these resolutions were reviewed and panel members have elaborated their concerns and comments through the exploder, senior members of the HROS team were included in all e-mail exchanges. In this report we incorporate our original resolutions, one of which has been modified.

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THE RESOLUTIONS

The HROS CoDR Panel was very impressed by several aspects of the review:

1. The analysis gave us confidence that the design would meet throughput goals
2. The order separation and simultaneous wavelength coverage meet requirements
3. The slit area design appears to satisfy many of the functional requirements and the arrangement for simultaneously imaging of the slit and field seems particularly innovative and attractive
4. The science cases were well presented and argued.

None-the-less, the Panel has serious Top Level Concerns.

While the HROS team has shown great skill in putting all of the optics within the space envelope this, unfortunately, places the 3 heaviest components close to the bottom of the structure and the panel was not convinced by the evidence presented that the stability requirement for the stellar spectrum can be met in the current design. The concerns fall into 2 categories:

1. Overall mechanical flexure and the method of compensation
2. The effect of thermal gradients in the X-dispersion and immersion prisms

These are potential "show stoppers" which must be addressed immediately. We therefore recommend:

1. That the HROS team provide a preliminary FEA taking into account the major components and likely support structure constrained by the mass and space envelopes.
2. An optical analysis of the prisms to establish limits to the temperature uniformity to meet the image quality and spectral stability specifications, before proceeding with the preliminary design stage.

The Gemini Project must be satisfied with these analyses before the concept can be considered viable.

On the assumption that the design IS shown to be viable we strongly recommend consideration of the following points:

Multi-Slit

The panel believes that a multi-object capability of the scope described (<10 slits with a 30x60 arcsec field) would be desirable. We suggest that an implementation which does not add significantly to the complexity around the slit area should be investigated.

Cameras

The panel is concerned about the need for 2 demountable cameras and has specific concerns about each of them. For the short camera these are:

1. The central obscuration is too large for a fiber-fed mode
2. Cooling the detector presents potential problems, e.g. is it possible to cool the mosaic with the cold finger? Can the whole package fit within the allotted area (the obscuration), and would an evacuated camera fit within the mass budget?

Other concerns are the operational impact of frequent camera interchanges (e.g. queue scheduling, stability, reliability, manpower, etc.).

The panel is concerned about the availability of thinned, red-optimized CCDs with sufficiently low fringing amplitude in the red. We encourage the teams to explore other options such as a pair of end-butted red CCDs (8096x2048) with a single UV CCD directly below it. Alternatively, the team could explore the possibility of providing both red and blue mosaics on a slide.

The preferred option to the interchangeable cameras is a single, off-axis camera with a large CCD mosaic which retains a slit-width resolution product of 30,000 and which still allows a 3-pixel sampled resolution of up to 120,000. Two permanent, off-axis, cameras with a simple optical switch would also be acceptable.

Fiber-fed High Stability Mode

The high stability mode fed by fiber optics or possibly by a mirror train to the spectrograph pier must be investigated by the IGPO with appropriate interactions with both the HROS and GMOS teams prior to the HROS PDR. The investigation and design should cover:

1. Overall efficiency of the fiber feeds with appropriate image slicing and iodine cell implementation
2. Trade-off study between fiber feeds and mirror train
3. Use of HROS as a pier mounted spectrograph and issues of instrumental stability when moved between Cassegrain and Pier (e.g. how long does it take to achieve stability?)

CCDs

The panel is concerned about the availability of CCDs that will have the spectral response characteristics needed to cover the 300-1000 nm range, i.e., that have both high QE and low fringing amplitude. Existing UV optimized CCDs show fringing of order 15% Peak-to-Valley with fine structure that could compromise radial velocity and line profile studies. The HROS team should investigate the performance specifications of the Gemini CCDs to demonstrate that there exist combinations of CCDs to place into mosaics that satisfy the science specifications. Also, can UV optimized CCDs provide the spatial resolution of the detector (MTF) required to match the spectral resolving power in the UV?

There is also concern that a small detector package embedded in the short camera could not be cooled sufficiently to meet dark current or low noise performance specifications. There could also be difficulties with condensation on the outer surface of the field flattener lens due to radiative cooling unless a dry atmosphere is maintained inside the camera.

The panel suggests that a different layout of CCDs in the camera focal plane be considered. Different orientations of the CCDs could minimize the CTE contribution to the effective scattered light of the spectrograph.

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INDIVIDUAL DETAILED COMMENTS [separated by -------]

FLEXURE

The major concerns about the mechanical engineering of HROS are :

1) That the static flexure of the instrument will greatly exceed the estimates in TN-PS-G0033 and will exceed the capacity of the active flexure correction (AFC) system to correct for it. In particular, the proposed AFC system provides no correction for rotations of the image on the detector - provision of such a capability (or the removal of the need for it by structural means) will prove to be difficult.
2) That the mass allowance in the budget for structure will prove insufficient to provide a structure which will safely meet the environmental requirements and give a suitably high first resonant frequency.
3) That the stated thermal performance of the enclosure (0.1 degrees C / hour) will prove to be impossible to meet within the mass budget.
4) That the mass and volume allocated for electronics will prove to be insufficient by a large margin.
5) That the conceptual layout concentrates so much mass so far from the ISS that a workable structural design may not be possible at all.

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(1) The whole concept of a Cassegrain-mounted HROS is predicated on the belief that flexure can be controlled to the tight levels required. The decision by the GEMINI project to remove the Nasmyth foci was also based, in part, on this belief. It is therefore essential that the HROS team demonstrate that it is justified. So far, this has not been done.

(2) The CoDR documentation claims that uncompensated flexure (slit-detector displacement) is ~10µm/90-deg (TN-PS-G0033). In what was acknowledged to be a preliminary analysis. If correct, open-loop compensation could be used to reduce the actual flexure to the required ~2µm/hr (assuming 20% non-repeatability). However, the panel strongly suspected that the real uncompensated flexure was likely to be much larger, perhaps by an order of magnitude!
If so, then closed-loop flexure compensation will not help.
    a) Tilting the collimator to maintain the image of a spectral feature on the same detector pixel changes the dispersion (as light now enters the disperser at a different angle). Thus, even though the center of the order is stabilized, the ends of the order experience a motion of roughly 10% of the uncompensated flexure. A closed loop system, in which the collimator tilt is altered, will not remove this.
    b) To reduce the flexure further presumably requires the active control of more than one optical component. But in closed-loop it is impossible to control multiple elements if only one parameter of the light is measured (e.g. displacement at the detector). How would movement be assigned to each active element? Such a system could only work (perhaps) in open-loop where non-repeatable effects are a problem or via some other system that senses the movement of the optics indirectly - which will introduce its own error.

(3) Therefore, some panel members felt that uncompensated flexure must be reduced to a level small enough for an *open-loop system* to reduce the actual flexure to the required level. This does not rule out a closed-loop system if there were other benefits (e.g. eliminate the need to generate and update look-up tables), merely that the passive performance of the system should be correctable in open-loop.
(4) The GMOS non-repeatable residual flexure is 3% for its main optical support structure (a relatively simple truss similar to the telescope for which this degree of hysteresis is well attested). The problem of variable dispersion implies a floor to the non-repeatability of 10% for HROS. It might be possible to remove this effect by making the detector the active component, as proposed for GMOS, but bearing in mind the complexity of the system, 10% may be a realistic minimum level.
(5) The performance of the flexure compensation system needs to be closely examined to see which elements need to be moved to provide the required correction over the entire field and to ensure that image quality remains within spec. These problems may not be significant if the uncompensated flexure is within the range of correction by an open-loop system.
(6) The bottom-line is that uncompensated flexure must be reduced to around 20μm /hr - and that this must be demonstrated clearly. If so, the problem of flexure compensation is probably tractable with a relatively simple open-loop system, with a consequent large reduction in system complexity. Although there are real worries that a structure with this performance may be impossible to achieve given the mass of optical components to be supported, some members of the panel are confident that the problem can be solved.

INHOMOGENEITY IN FUSED SILICA:

One of the main effects in degrading the performance of HROS is the inhomogeneity of the 1.5 m of fused silica in the beam. A first order calculation of this effect is to take the best inhomogeneity that the manufacturer can provide and a variation of the index of refraction of 1.e-6 and multiply that by 1.5 m to get the optical path difference (OPD) or the wavefront error; it is: 1.e-6*1500 = 1.5μm. At a typical wavelength of λ=0.5μm that means that the P-V error in the wavefront is 3*λ. The diffraction wavefront error is given by λ/4 P-V which means that the wavefront error introduced by inhomogeneity is 12 times bigger than the one introduced by diffraction. The FWHM spot from diffraction is given approximately by λ*fnumber=0.5*1.85=0.93μm for the short camera and 0.5*4.52=2.3μm for the long camera. The FWHM spot introduced by the inhomogeneity will be 12*0.93=11μm for the short camera and 12*2.3=28μm for the long camera.

THERMAL GRADIENT:

A simulation with Zemax has been made of a radial gradient across the first lens in the short camera with a parabolic function for the index of refraction: $n=n0+n*r^2+n2*z$ where r is the height of the ray in the lens and z is the thickness along the optical axis and dn/dt=9.8e-6. The total change from center to edge of lens is given by 9.8e-6*DT. A DT of 1 degC will degrade the spots by 20%. No degradation is expected for 0.1 degC.

This simulation should be done for the complete system, especially the immersed grating and the cross disperser prisms.

A few additional sensitivity calculations.

Taking the above wavefront error of 3 λ (λ = 0.6μm) due to glass inhomogeneity of $1\text{x}10^{-6}$ and assuming it occurs over 1/2 the pupil diameter of 160 mm, the associated wavefront slopes lead to a geometric spot size of 22μm with the short camera and 50μm with the long camera. This would be very noticeable, especially with the long camera.

So, the error budget contribution of the Silica should probably not be larger than 1/2 wave which points to a P-V "inherent" inhomogeneity of $1.5\text{x}10^{-7}$.

Temperature gradients must be limited to 0.025 degree in order to limit the "temperature-induced" inhomogeneity to the same value of $1.5\text{x}10^{-7}$ (assuming dn/dT = $9.8\text{x}10^{-6}$ per degree).

Remember that these are non-refocusable errors. A careful analysis should be made on the way contributions from the various prisms will sum up and on the remaining contributions that cannot be focused out.

HROS is a Cass instrument that changes its attitude whenever a new object is acquired and also during tracking, so it will never reach a stable temperature stratification. The effect of changing thermal gradients in the Silica on image motion is as follows. Assume a lateral temperature gradient change of 0.01 K/deg/h across a 20 cm beam traversing 1.5 m of Silica in front of the camera. This leads to a change in wavefront slope of 0.25 λ and an image motion of 1.5μm/h in the focal plane of the long camera. These motions will be slow and can be of course be taken care of by the flexure control system, but ONLY IF IT WORKS IN CLOSED LOOP.

Above computations are for the long camera and sensitivities are a factor 2.4 times less for the short camera.

ACQUISITION, FOCUSING AND GUIDING

A number of acquisition, focusing and guidance issues must be addressed before PDR. We need a document from the HROS team which details exactly how objects will be acquired, focused and guided on the HROS slit and how well these functions meet the requirements. Specifically,

(a) The current pixel scale of the HROS slit-viewer is 0.18 arcsec, probably insufficient to meet the guiding accuracy requirement of ~0.01 arcsec (which requires a pixel scale of ~0.1 arcsec, as modeled by Paolo on page 328 of the CoDR). The penalty of moving to a finer pixel scale is reduced field, which impacts on the number of guide stars available for differential flexure correction. But...

(b) Gemini will provide guiding accurate to 0.005 arcsec. With this accuracy, and the proximity (and hence rigidity?) of the slit unit with respect to the ISS, is guiding on the slit viewer to correct for differential flexure really necessary? If not, this eases the requirement to find a solution to problem (a).
(c) During the meeting, it was suggested that HROS would be used with the slit set at the parallactic angle to offset the effects of atmospheric dispersion. This implies that the Cassegrain derotator is immobilized, which means that off-axis guiding will have to cope with image rotation as well as the usual tracking errors. The ISS will provide such a facility, but it was suggested during the meeting that it might be difficult to implement such a function in the slit-viewing system.
(d) Acquisition and focusing of targets on the HROS slit will be provided by facilities in the ISS. Will the position of the HROS slit with respect to the focal point provided by Gemini be sufficiently stable to allow this to work? If not, the slit-viewing camera will have to be used to tweak the position of the object on the slit or the focus of the telescope on the slit. If it was necessary to do this, then problem (a) comes into play as the pixel scale will probably be too coarse to enable this.
(e) Details of how objects are to be acquired, focused and guided when using HROS in each of its multi-slit, image slicer, fiber PSF-scrambling (if implemented), polarimetric and high stability modes need to be described.
(f) The requirement for the post-slit exposure meter needs to be reviewed.

CAMERAS

Given that the OISWG declared 3-pixel resolutions of 50,000 and 120,000 to be of equal priority, we stress that any single camera design must attempt to achieve these resolutions while maintaining a slit-width resolution product of 30,000. We feel that spectral coverage could be sacrificed if necessary with the interval 370 to 670 nm covered in a single exposure being a goal. The panel also recognized that any compromises introduced by moving to a single or dual off-axis camera(s) will require a review of the scientific priorities for HROS.

Gordon A.H Walker
15 December 1996