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Preliminary NGST IFS Concept

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Preliminary Concept for the NGST Integral Field Spectrograph

1 Reference Documents

RD-1 “NGST Science Instrument Recommendations”, 10 January 2000, John Mather, Peter Jakobsen, Simon Lilly, Peter Stockman.

RD-2 “A Solid Block Image Slicer for NGST, E. Harvey Richardson

2 ASWG Recommendation

The NGST Science Instrument Recommendations of the Ad-Hoc Science Working Group (ASWG) (RD-1), called for an Integral Field Spectrograph (IFS) as a candidate for the fourth instrument of the NGST complement. The following IFS specifications are proposed:

Wavelength Coverage	1 - 5 μm
Spectral Resolution	< 5000
Field of View	2" x 2"
Spatial Resolution	<0.1"

3 Proposed IFS Configuration

The Integral Field Spectrograph will consist of an integral field unit which reformats a square field of view into a long slit and a spectrograph with a common collimator, beamsplitter, two fixed gratings, two collimators and two focal plane arrays.

3.1 The Integral Field Unit

EHR Optical Systems has developed an imager slicer solution for the NGST IFS which reformats a 2.2" x 4" section of the focal plane into 22 4" long slits each 0.1" wide (RD-2). With 0.5" spacings between the slits, the overall length of the exit slit is thus 99mm.

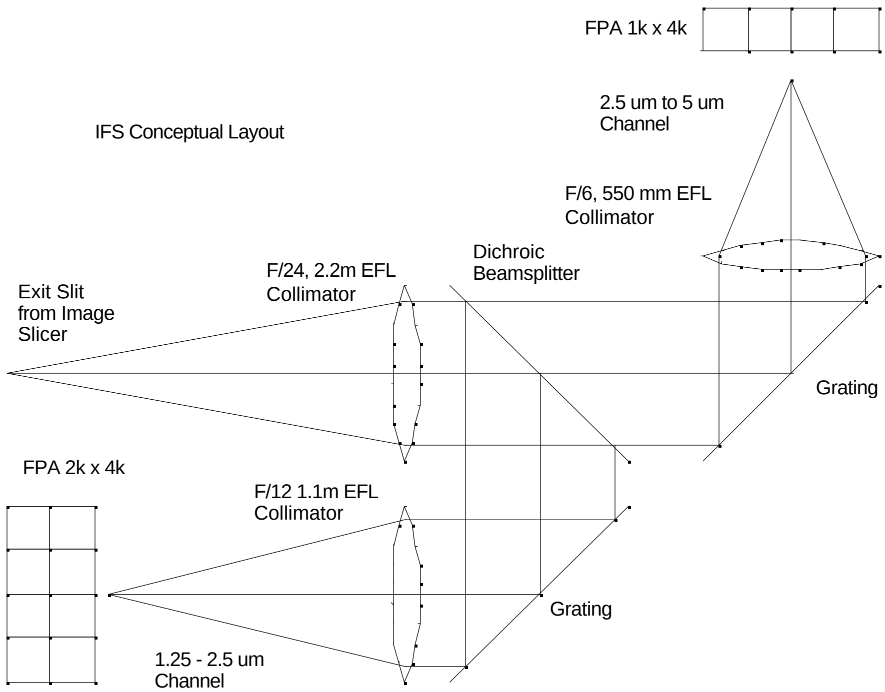
This all refractive image slicer is composed of a solid CaF_2 block into which the slit mirrors, re-imaging mirrors and two fold mirrors are formed with external metalization. All reflections are internal and the exit slit can be arranged to be in the same plane as the original focus.

It is not clear that the design feature of preserving the focal plane location will need to be retained. Eliminating it will simplify the design by eliminating the two plane surface internally reflecting folds. Also other options, such as an all reflective image slicer should also be considered.

Detailed drawings of the IFU can be found in the Appendix

3.2 Spectrograph

The conceptual layout of the spectrograph is shown below.



The exit slit of the image slicer will form the entrance slit to the spectrograph. The spectrograph will consist of three collimators, a beamsplitter, two fixed gratings and two focal plane arrays. The beamsplitter will be designed to reflect 1.25 μm to 2.5 μm and transmit 2.5 μm to 5 μm. Since the transition will not be a step function, some 2nd order contamination near 1.25 μm will occur. It is expected that this contamination can be subtracted during post-processing using the spectral information from the short wavelength end of the long wavelength spectrograph.

The magnifications of the two channels will be set to optimize the spatial sampling along the slit length for the wavelength range of interest. The short wavelength channel will remap the IFU's 99 mm long exit slit to 55.3 mm at the short wavelength FPA. This will correspond with the 2048 27 μm pixels of the standard NGST NIR Camera InSb detector. Two of these detectors, which may actually take the form of 2x2 1k buttable detector arrays, are the baseline for the short wavlength channel. This gives 49 mas spatial sampling for this channel.

The long wavelength channel will remap the IFU exit slit to 27.6 mm, corresponding to the width of a detector array with 1024 27 μm pixels. Four of these 1k x 1k detectors will form the focal plane array for the long wavelength channel.

One of the implications of this type of configuration is that the highest sensitivities will be at the short wavelength ends of both spectrographs since the energy encircled by a pixel will be a maximum at these locations.

Shown in section 5 are a number of views of a possible layout of the instrument. Each of the collimators is a three mirror design. The optical design is realistic and provides adequate images. Due to the magnifications, the short wavelength channel runs at f/12 while the long wavelength channel runs at f/6. The latter channel has large optical elements as a result. In this case a more compact solution may be a refractive one. The magnification could be reduced by requiring a wider detector. For sensitivity reasons bigger individual detectors would be desirable, but in practical terms a larger number of ~27 μm or so detectors is more likely. Note that a ~100 mm pupil image near the beamsplitter and grating was assumed for this design, other pupil sizes are possible. The size of the optical elements will scale with different pupil sizes and their distance from the pupil.

For ease of packaging, a transmission grating is baselined for the long wavelength channel. Since this element will not have optical power, no changes in optical characteristics, other than perhaps a spectral shift will result due to fabrication at room temperture and operation at ~30K. Other spectrograph configurations are possible, including the use of a prism as the dispersive element. There does not appear to be significant disadvantages to the prism approach and there may be a benefit if a wider spectral coverage is desired. For example, a prism disperser could be used in a channel covering from < 1 μm to 2.5 or 3 μm, without any second order contamination.

The gratings have not yet been selected, but the optical concept developed allows small angles between the incident and reflected light from the grating ($<30^o$) so that efficiency can be maximized. The goal is to maintain a resolution ($\lambda / \Delta\lambda$) of close to 3000 for the entire wavelength range of both spectrographs.

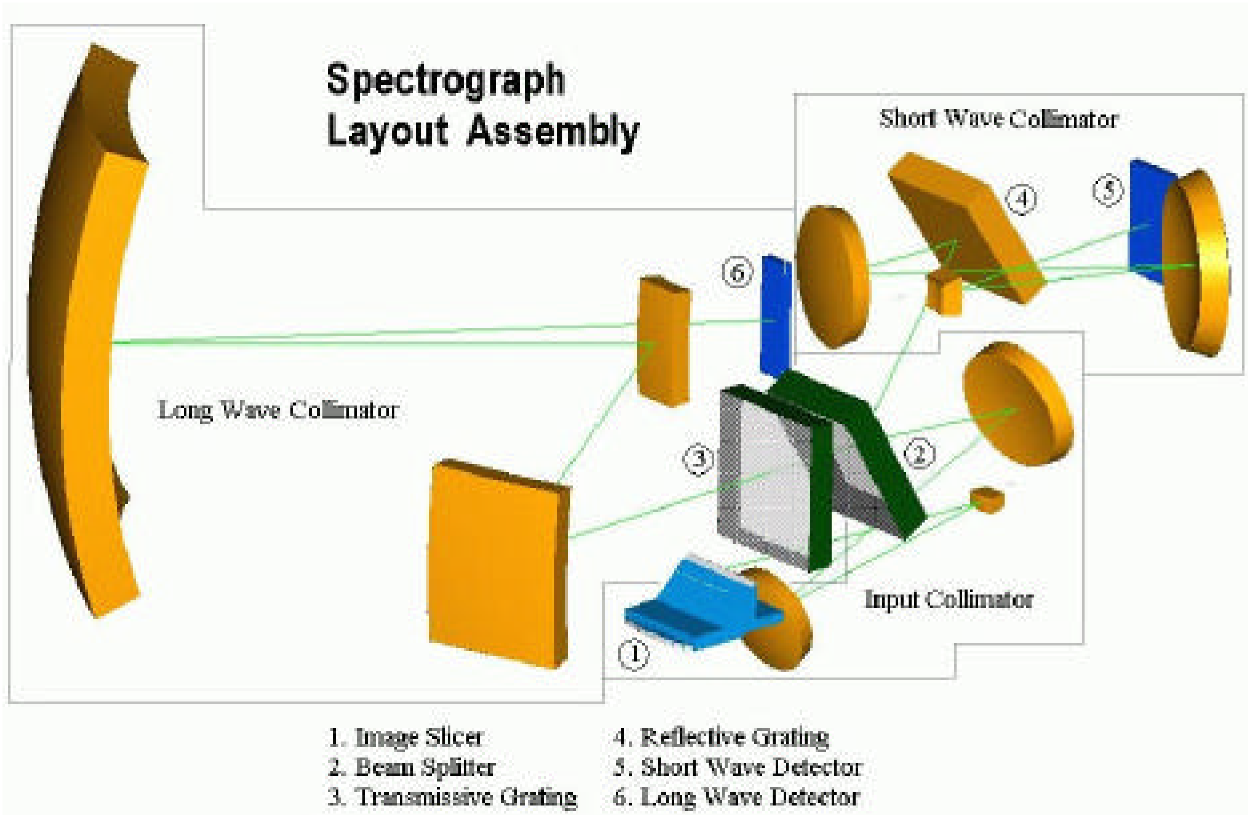
The table summarizes the basic parameters of the proposed IFS, in comparison with the ASWG Recommendation

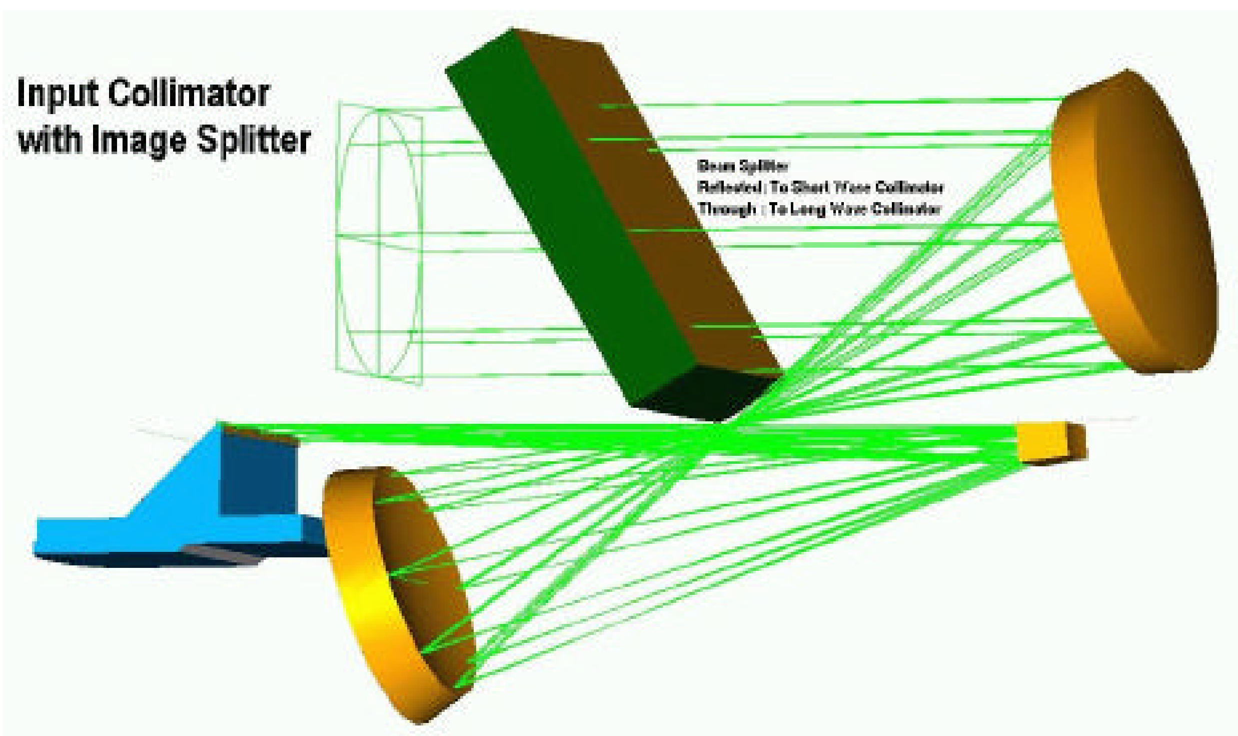
	Short Channel	Long Channel	ASWG
Wavelength Coverage	1.25 - 2.5 μm	2.5 - 5 μm	1 - 5 μm
Spectral Resolution	~3300	~ 3300	< 5000
Field of View	2.2" x 4"	2.2" x 4"	2" x 2"
Spatial Sampling	0.049"	0.098"	<0.1"

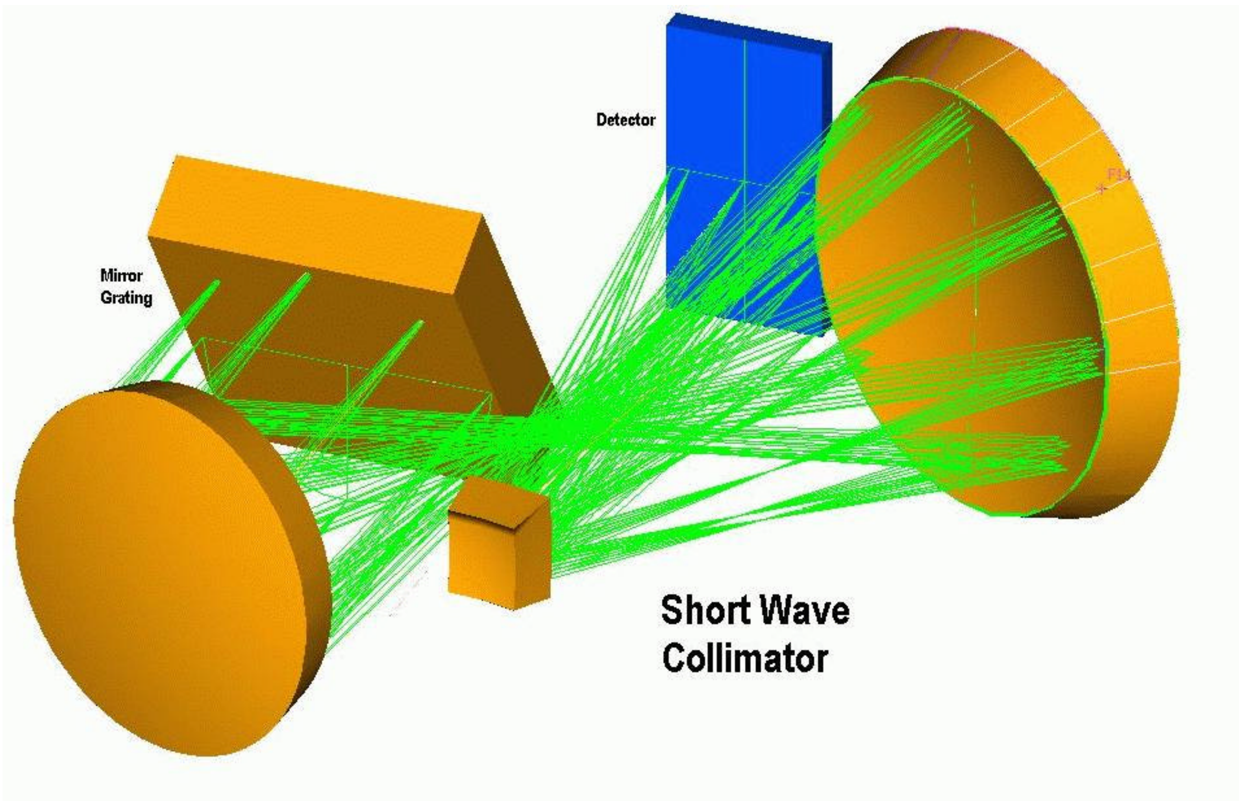
4 Calibration

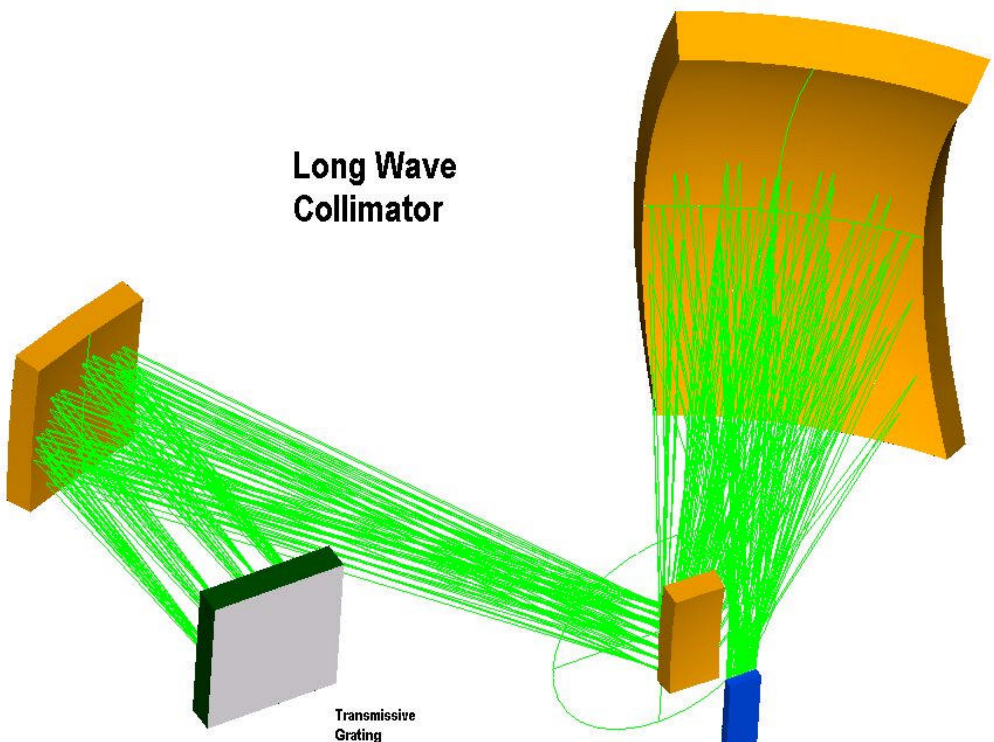
Spectral calibration, radiometric, flat field and dark calibration data call all be collected during astronomical observations. Since it is desirable to avoid mechanisms, calibration via targeting of known objects is to be preferred. It may be possible to perform a relative spectral calibration without mechanisms if a spectral source can be arranged to illuminate a slit adjacent to the image slicer. When on this source would then produce a known spectrum across all detectors which is offset from the spectra of astronomical objects by an amount known via ground calibration.

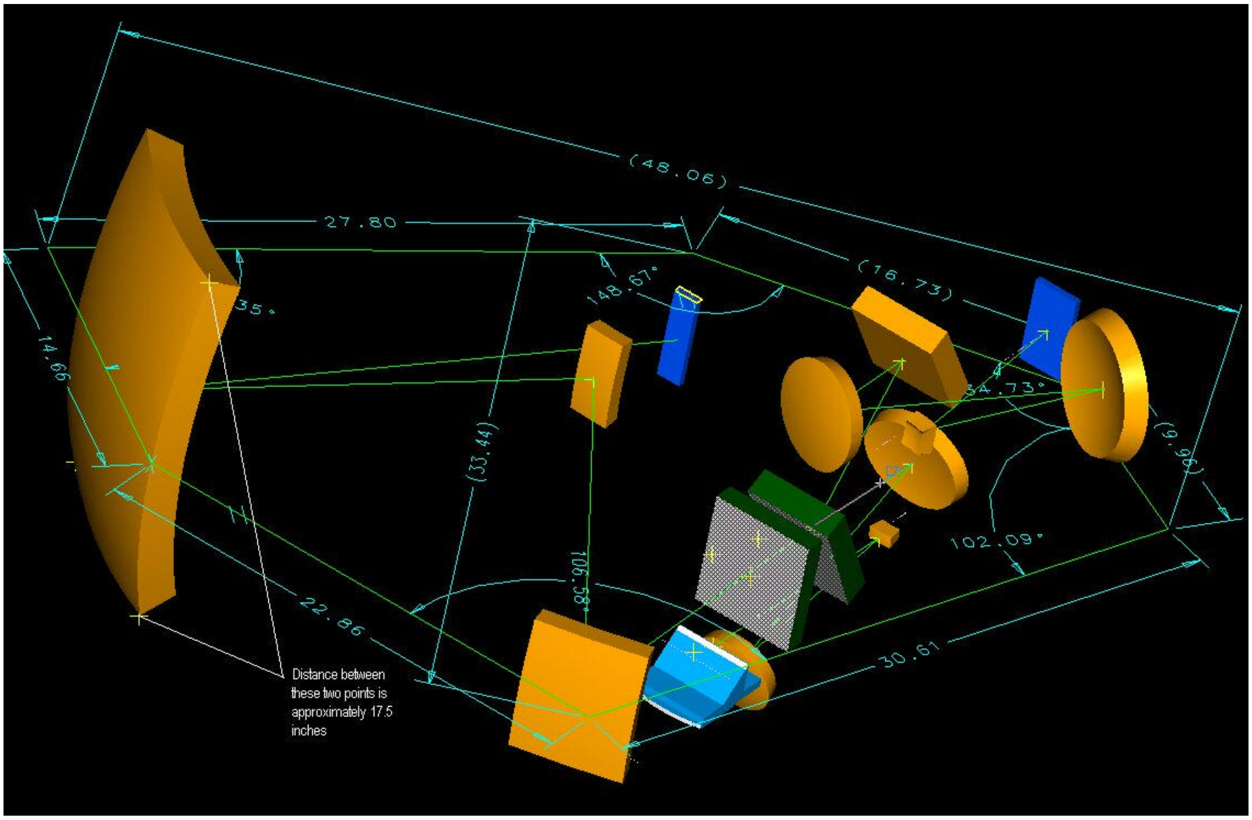
5 Spectrograph Layout Views






Detector
Mirror
Grating
Short Wave
Collimator


Long Wave
Collimator
Transmissive
Grating
Detector



The view above includes dimensional information. The largest (diagonal) dimension is 1.2m while longest side is 0.77 m. The largest optic (the rightmost mirror in the long wavelength channel) is 44 cm on a side

6 Costing

6.1 Model Philosophy

It is proposed that rather than follow the simple STM, EM (bench level), PFM model philosophy suggested by the NASA proposal that a more conservative approach be taken with respect to the “Optical Head” (all the equipment to be housed on the cold side of NGST). It is recommended that the EM of the Optical Head be enhanced sufficiently such that the Qualification of the structural design can be completed prior to CDR. This will allow the optical head of the Flight Model to be Acceptance tested only and thus subject to the minimum levels of stress possible. It is felt that this approach, whilst making the first two years of the project more difficult will retire a significant amount of risk on the design of the optical head.

It is proposed that the EM electronics be limited to an electrically representative version only, ASICs being implemented by FPGAs etc. It is felt that because of the relatively benign environment on the warm side of the spacecraft that this is an acceptable risk.

Given a successful Phase A/B & C1 a two year Phase C2/D to provide a PFM model electronics unit and FM Optical Head seems a reasonable proposition. Ultimately success will depend on good communications within the instrument team and spacecraft teams and effective definition of interfaces and software. This will be especially true if the proposed level of instrument integration within the ISIM.

This instrument model philosophy is consistent with a better, cheaper, faster solution in that no hardware is delivered before the final flight set. The approach adopted is slightly more conservative than the NASA suggested basline but it allows significant risk retirement.

6.2 Costing Assumptions

General

Phase A has not been costed due to uncertainties in the scope of the programme between now and the 2002 date currently presented by NASA as the date for the selection of instruments.

The programme from 2001 has been made to fit the schedule assuming a flight item delivery in 2005. This allows approximately 4.5 years for instrument development, qualification and flight build.

It has been assumed that the whole package will be provided by a single contractor. If the various elements are to be split up then a cost increase is to be expected as certain tasks will have to be completed for each unit and increased effort will be required to manage the interfaces.

The costing has been done in first quarter 2000 dollars. Fee is included but the estimate does not include inflation.

Product Assurance

It is assumed that this mission will only require EEE parts screened to MIL-STD-883/B, with no Destructive Parts Analysis (DPA). No special provisions for optical cleanliness have been assumed beyond that needed for typical optical products (star-trackers class 10,000 conditions)

Requirements for redundancy have not been considered.

System Engineering

It is assumed that a significant amount of the required preliminary study work will have been undertaken prior to the NASA start date of 2002.

The systems engineering package includes all of the co-ordinating work associated with each of skill areas. A Flight Operations Manual has not been included in this costing as the scope of this will not be known until close to delivery.

Opto-Mechanical Elements

This estimate includes the specific design related to the provision of the hardware.
A full flight spare set of mirrors and gratings for the IFS have been assumed along with a flight spare IFU block.

Detector Assembly

Assumes that detector development is funded by NASA. Assumes that the basic detector packaging issues are also funded by NASA and that the basic FPA is assembled by the supplier and provided to the instrument fabricator at the reecurring price. It is assumed that the spectrometer will require two FPAs, one with four 1k x 1k detectors and the other as two 2k x 2k modules (which themselves might by four 1k x 1k mosaics).

The detectors have been priced at Cdn $600 K for flight and Cdn $400 K for EQM standard devices for the 2k x 2k modules. . It has been assumed that there will be 2 flight spare devices, one 2k x 2k module and two 1k arrays. The latter are assumed to be $100K each.

Optical Calibration Sources

This is an indicative cost to allow for the inclusion of a simple on-board calibration source.

Structures

An all aluminum structure and mirrors for the spectrograph have been selected at this stage to allow for room temperature assembly and alignment. This covers basic enclosures for the electronics and a support frame for the optics

Electronics

A cost is estimated for both the warm and cold electronics. It is assumed that the IFS has its own independent controller, despite the likelihood that NASA will supply all the warm electronics.

Flight Software

A basic software development package is assumed. The proposed instrument should not require any exotic or complex software.

Instrument Assembly

Assumes five people completing instrument assembly (duration 2 months) given the inputs of ;

Integrated & Aligned IFU,
Integrated Space Frame, finished optical compenents & mechanism
Integrated Detector Modules & cold electronics
Integrated Electronics Unit,

Optical Ground Support Equipment

Two sources have been assumed, point source and diffuse source These will be NGST specific. Other optical equipment will also be required to test the performance of the instrument this has been included in the estimate.

Electrical Ground Support Equipment

This provides a basic computer with I/O cards and user test software.

Mechanical Ground Support Equipment

This provides basic handling jigs, fixtures, and transportation packaging.

Instrument Testing

It is assumed that the instrument will be tested both for normal spacecraft environmental levels and also optically tested. Instrument characterization is assumed to be performed by the Science Team following instrument delivery. Costs associated with this are not included here nor is any industrial support to such activities. It has been assumed that the environmental testing will be performed at the CSA David Florida Laboratories (facility rental has been estimated)

Optical testing to verify performance will be undertaken by the development team, it has been assumed that this will take place at DFL . It has been assumed that the facility and support staff costs will be supplied by CSA they have not been included in this synthesis.

Engineering Redesign for FM

The covers the cost of the incorporation of miscellaneous ECNs into the flight build from EQM for the Camera portion and for problems with the PFM approach on the Electronics Unit.

FM Flight Integration Support

This is the assumed level of support required by the spacecraft contractor during the integration process. It has been assumed that a level of support of 3 people for 4 months with travel to the US will be appropriate. This could increase substantially, depending upon the level of integration of the ISIM.

Travel and Living

The travel and living line reflects the estimated cost for approximately 8 visits to DAO and 2 visits to NASA per year. If the instrument package becomes divided between two or more partners then the travel and living cost might rise substantially.