IMACS:
The Inamori Magellan Areal Camera and Spectrograph

System Specifications
DRAFT
Version 1.3

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1 Overview

The Inamori Magellan Areal Camera and Spectrograph (IMACS) is a multi-mode imaging and wide-field multi-object spectrograph for the Magellan I telescope. The instrument is mounted on the right Nasmyth instrument rotator, where it operates in the f/11 Gregorian telescope configuration.

2 Reference Documents

1. System Spec. for the 6.5-Meter Magellan Telescope, 22 March 1996
2. CCD detector mosaic specifications (Thompson, Burley) date xxxxxx
3. TV Guider System Spec. (Thompson, Burley) 19 March 1998
4. “Preconstruction Optical Designs for Broad-Passband 22.46-inch f/2.24 and 14.00-inch f/1.49 Camera Lenses for the Inamori Wide Field Spectrograph” (Epps, 9/5/97)
5. “Preconstruction Optical Design for a Broad-Passband 25.2675-inch f/2.66 Camera Lens Alternative for the Inamori Magellan Areal Camera and Spectrograph (IMACS)” (Epps, 1/21/98)

3 Instrument Science Rationale

Even as observational astronomy has broadened to span the full electro-magnetic spectrum, optical imaging and spectroscopy has remained the crucial method of studying the wide range of astrophysical phenomena, particularly for understanding the discoveries in other wave-bands. It can be argued, then, that the most important of the first scientific instruments for Magellan will be IMACS, a combination wide-field imager and versatile low-to-medium dispersion spectrograph. The first Magellan telescope is being fitted with an f/11 Gregorian secondary mirror specifically designed to feed this instrument, by which it achieves excellent image quality and transmission. The on-axis optical performance, for small fields or single objects, will rival the best available at any telescope. However, it is the exceptionally wide field of 1/2 degree that distinguishes this instrument, making feasible two kinds of projects: (1) studies of rare objects, for example, photometric/spectroscopy searches for the lowest-metal-abundance halo giants or high-redshift AGN, and (2) gathering large samples, for example, measuring the colors, redshifts, and star formation rates of thousands of faint field galaxies at $z \gtrsim 1$, or collecting many hundreds of radial velocities for globular cluster stars with a broad range in mass. With its wide field, multi-slit masks, and an 8K x 8K pixel CCD detector, IMACS will be able to image large sky areas and acquire spectra of hundreds of such objects simultaneously, at resolutions running from a fraction of an angstrom to several angstroms, with many thousand pixels devoted to each spectra.

The following sections offers a sampling of some of the currently active fields of study where IMACS will make important contributions.

3.1 Studies of Faint Galaxies and Exotic Objects

The IMACS instrument will be well suited to studies of galaxy evolution, in particular, the detection, photometry, and spectroscopy of faint galaxies at high redshift. With the discovery of starforming systems at redshifts $z > 2$, the way is now open for comprehensive redshift surveys back to a billion years of the Big Bang, to identify and analyze the early generations of star formation and the structures by which modern galaxies have been built. The Southern Hemisphere will provide many opportunities for this kind of research. The southern Hubble Deep Field (and flanking regions) is available for studies of the redshift and evolutionary state of galaxies with $r < 25$. Although the smaller aperture compared to the Keck 10-m telescopes means that integration times of a factor of 2 longer will be necessary, the Magellan Imaging Spectrograph will produce comparable or better results than Keck + LRIS in its ground-breaking study of the northern Hubble Deep Field, and other faint galaxy samples. The principal questions include: what is the earliest epoch of star formation? how did the presently observed metal abundances of galaxies evolve? when did galaxy-sized structures first emerge? What is the large-scale structure of galaxies at these early epochs?

Supernovae, specifically SNeIa, have emerged as the most promising tool to measuring the geometry of the universe, the characterization of the cosmological model that describes how the universe evolves. The method relies on these intrinsically bright sources attaining a predictable luminosity; present data indicate that this can be done reliably over wide range of cosmic time. The wide field of IMACS as a imaging camera will allow the discovery of such supernovae to very great distance, $z \gtrsim 1$, and the efficient spectrograph mode will enable spectra to be taken that will confirm their identifications as SNeIa. Follow-up photometry will be done with IMACS and Hubble Space Telescope.

Because of its exceptionally wide-field coverage and versatility in terms of wavelength coverage and resolution, IMACS will have applicability to a very broad range of programs relating to the early universe, galaxy formation and evolution, and the nature of exotic objects, Continued observations of distant galaxies with the Hubble Space Telescope, and faint mid-IR imaging from SIRTF (time frame 2001), and cluster and AGN samples from AXAF (time frame 1999) will provide a rich collection of targets for IMACS spectroscopy.

3.2 The Cosmological World Model

Measurement of the matter and energy density of the universe is a fundamental goal of cosmology. Through Einstein's theory of General Relativity these quantities predict the future of the expansion of the universe. Moreover, the theory relates these quantities to the geometric curvature of the universe, which is also directly measurable (using techniques such as the SNeIa discussed above) to provide a test of this profound application of Einstein's ideas. The density of Cold Dark Matter in the universe is now widely believed to be in the range of 10-30% of the value required for a "flat" universe. The physical motivations for a flat universe are sufficiently strong that they have inspired considerable effort to measure the universe's curvature to see if there is a Ω_Λ which would provide the other 70-90% of the energy density required to make a flat universe. Aside from the awesome implications of these cosmological parameters, they are necessary quantities to convert everyday measurements of distant objects into physical sizes, luminosities and masses.

Early results from two groups of researchers have provided tantalizing evidence that the world model does, in fact, contain a large Ω_Λ term and that $\Omega_\Lambda + \Omega_{matter} = 1.0$. If true, this is strong evidence for some sort of inflationary period (or several) in the universe's history; in particular, the universe would be in an accelerating period at the current epoch – cause unknown. This result, then, is extremely important for our understanding of physics at a fundamental level.

IMACS will be a powerful tool for precision measurement of the parameters of the cosmological world model. It will efficiently gather large, homogeneous, data samples over a large redshift range allowing the measurement of the density of dark matter to be refined and making several new measurements from which the geometry of the universe will be inferred. Confirmation of the proposed model with $\Omega_\Lambda + \Omega_{matter} = 1.0$ is perhaps best accomplished by carrying the measurements of SNeIa beyond $z = 1$. The expected decline of the Ω_Λ term and rise of Ω_{matter} to ~ 1.0 would be an unmistakable signature of the correctness of this surprising cosmological model, distinctive from other systematic or evolutionary effects in the brightness of supernovae with greater look-back time.

3.3 Evolution of Large-Scale Structure

The best test of any theory for the evolution of structure in the universe is to observe the changes of structure with time. This is a formidable problem for which IMACS is uniquely suited. This problem requires large samples of faint galaxies, which means that the figure of merit for the telescope is the squared product of the telescope aperture and the spectrograph field. On this basis, the combination of Magellan and IMACS exceeds all existing and planned instrument by a factor of two or more in its capabilities.

- Large-Scale Structure is indeed large, with the biggest structures being 100 Megaparsecs across or more. Even as far away as redshift one, this size subtends about six degrees on the sky.

- We use galaxies to trace the properties of the universe. The existence of a relation between galaxy morphology and the density of the surroundings (an effect investigated by Dressler since 1979) means that galaxies of different types give somewhat different measurements of the clustering in the universe. The procedures to disentangle the galaxies from the dominant underlying dark mass distribution are gradually being devised and tested, but will require large samples to implement.

- The surprisingly rapid evolution of galaxies at low redshift (first seen in clusters, via the "Butcher-Oemler" effect) poses two problems. First, it has to be understood at a statistical level so that same population of galaxies can be identified at two redshifts to measure evolution. Second, the physics which causes this evolution remains a fundamental problem in galaxy evolution. The combination of Magellan spectroscopy and imaging (and du Pont imaging as well) to measure many physical parameters of individual galaxies in samples which contain a wide range of cosmic structures should lead to an empirical resolution of this puzzle.

The combination of Magellan and IMACS has the capability to efficiently study galaxies and large scale structure from redshifts as low as 0.1 up to redshift 3 and is expected to be a premier instrument exploring the evolution of cosmic structure over this redshift range.

3.4 History of Star Formation in the Milky Way and Its Neighbors

Extrapolation from experience with the LCO 2.5-m and CTIO 4-m telescopes indicates that it will be possible to obtain spectra with S/N=25 and R 12000 to V=19 in one night, and as faint as V=22 if four nights of integration on 40 similar stars (with 3 electron readout and on-chip extraction) are co-added. We enumerate three important initial projects that can be pursued with these capabilities of the spectrograph:

- SNeI and SNeII nucleosynthetic yields from first generation stars in Carina et al

  By the time Magellan comes into operation a CaII K-line interference filter survey conducted at LCO by McWilliam will have identified the numerous stars with $[Fe/H] < -3$ that must be present among the thousands of red giants in Carina and other dwarf spheroidals. Co-added spectra of stars binned by [Fe/H] can be used to investigate the ubiquity of abundance-dependent yields for Cr, Mn, and Co and the enormous dispersion in r-process yields found in Milky Way red giants (McWilliam et al 1995). These are basic constraints for theory of supernova nucleosynthesis.
- Calibration of SNeI timescale from [/Fe] versus [Fe/H] relations derived from:
  - globular clusters in LMC with 10 Gyr age-spread.
  - star bursts in Carina dwarf spheroidal (Smecker-Hane et al 1994) with 10 Gyr age- spread. This calibration, never performed heretofore and a prerequisite for believable modeling of chemical evolution, is a natural for the spectrograph. The observations will also test the dogma that a sequence of starbursts is accompanied by a monotonic increase in metallicity.
- Use of thorium chronometers to derive the age and its dispersion of the Galactic Bulge

  A CaII K-line interference filter survey conducted at LCO by Preston, Shectman & Thompson will permit a follow-on search with intermediate resolution for r-process rich stars among those with $[Fe/H] < -3$. A search for thorium among such objects with the higher resolution of the Magellan Echelle Spectrograph will permit multiple estimates for the age and its dispersion in the central region of the Milky Way (Cowan et al 1996).

4 Science Requirements

The general requirements on image quality and image stability are that the optical system not degrade the median seeing at Las Companas (0.6 arc-sec FWHM) by more than 10%. The general image stability requirement is that gravity and thermally induced flexures be limited to 0.1 pixels a 15 degree rotation of the instrument about the Nasmyth optical axis.

5 Optical Design

The design parameters for the Magellan f/11 configuration can be found in telescope System Specification. The important parameters are repeated here in the table below.

primary diameter:	6.5 m	(255.9 inches)
focal length:	71526.4 mm	(2816 inches)
plate scale:	346.77 microns/arc-sec	
	2.88 arc-sec/mm	
	(0.01365 in/arc-sec)	(73.2474 arc-sec/in)
field of view:	30 arc-min dia.	
	1800 arc-sec dia.	
field area:	706.8 arc-min^2	
	2.54E6 arc-sec^2	
focal surf. rad. of curv.:	-1231.74 mm (convex)	(48.49 inches)
focal surf. diameter	620 mm	(24.42 inch dia.)
focal surf. sagitta:	39.7 mm	(1.56 inches)

5.1 Field Lens

There is a field lens located immediately following the f/11 focal surface. The lens is approximately 625 mm (25”) in diameter, and made of fused silica.

5.2 Collimator

The f/11 configuration of the telescope and refracting collimator design were defined together to provide a 30 arc-min, well-corrected field of view for imaging and multi-object spectroscopy. The current collimator design consistd of a field lens and 4 collimating elements. The design parameters for the collimator are:

focal ratio	f/11	
focal length	1648.46 mm	(64.90 inches)
output beam diameter	150 mm	(5.9 inches)
number of elements	4 (all-spherical)	
max. fused silica dia.	323 mm	(12.7 inches)
max. CaF_2 dia.	250 mm	(9.84 inches)

5.3 Long Camera

The long camera provides a field of view of 15 x 15 arc-min^2, at a plate scale of 9 pixels/arc-sec, or 0.111 arc-sec/pixel. The camera consists of six all-spherical elements, arranged in a [1-3-1-1] grouping. The design parameters for the long camera are:

field of view	21.48 arc-min dia.	362 arc-min^2
focal length	641.79 mm	(25.2675 inches)
scale	0.111 arc-sec/px	9 px/arc-sec
	0.0074 arc-sec/micron	135 microns/arc-sec

number of elements	6	
number of CaF_2	2	
max. CaF_2 dia.	300 mm	(12 inches)

5.3.1 Imaging Mode

In the long camera imaging mode, a folding flat is placed at the re-imaged telescope pupil by the disperser carousel, which folds the collimated beam back to the camera. A full description of the performance of the long camera is contained in the report by Epps (1/21/98).

In general, this camera (independently) produces images with 22.3 ± 3.8 microns (at 135 microns/arc-sec) averaged over all field angles and wavelengths within the 0.365-1.00 micron spectral range (without refocus). Table 1 show the RMS image diameters for five pass-bands and four field positions.

Field	mod U	B band	V band	R band	I band
on axis	0.07	0.05	0.10	0.12	0.15
50%	0.11	0.05	0.10	0.10	0.14
80%	0.13	0.06	0.11	0.10	0.17
full field	0.14	0.10	0.16	0.14	0.20

Table 1: Long camera image diameters (arc-sec) for 5 pass bands

5.3.2 Grating Mode

In the long camera spectrographic mode, a grating is placed at the re-imaged pupil, and the diffracted beam is directed into the camera. The gratings are mounted in frames which are in turn are mounted to grating tilt mechanisms. There are four grating mount positions for 154 mm x 206 mm gratings on the carousel. One is reserved for the folding flat and is fixed in angle. The initial grating selection is intended to include the gratings shown in Table 2.

Spectronics Part. #	Rulings gr/mm	Nom. λ (Littrow)	Nom. Blaze Angle	Ruled Area (mm)
35-53-*-270	300	500 nm	4.3^o	154 x 206
35-53-*-260	600	500 nm	8.6^o	154 x 206
35-53-*-350	600	750 nm	13.0^o	154 x 206
35-53-*-280	1200	500 nm	17.5^o	154 x 206
35-53-*-360	1200	750 nm	26.7^o	154 x 206

Table 2: Initial grating compliment.

5.4 Short Camera

The short camera provides a field of view of 27 x 27 arc-min^2, at a plate scale of 5 pixels/arc-sec, or 0.200 arc-sec/pixel. The camera consists of 9 elements, including three aspheric surfaces, arranged in a [2-1-3-2-1] grouping. The design parameters for the short camera are:

field of view	27 x 27 arc-min	729 arc-min^2
focal length	355.6 mm	(14.00 inches)
scale	0.200 arc-sec/px	5 pixels/arc-sec
	0.0133 arc-sec/micron	75 microns/arc-sec
number of elements	9	
number of aspheres	3	
number of CaF_2	3	
max. CaF_2 dia.	312 mm	(12.27 inches)

5.4.1 Imaging Mode

In the short camera imaging mode, the unobscured position in the disperser carousel is placed at the pupil, and the collimated beam passes straight through to the camera.

The short camera re-images a 27 x 27 arc-min field of view at a plate scale of 0.200 arc-sec/pixel. This camera produces images with an RMS diameter of 24.4 ± 6.9 microns (at 74.80 microns/arc-sec) averaged over all field angles and wavelengths within the 0.39-105 micron spectral range (without refocus). Table 3 show the RMS image diameters for four pass-bands and four field positions.

Field	mod-U	B band	V band	R band	I band
on ax.	***	0.12	0.22	0.31	0.31
50%	***	0.16	0.21	0.21	0.17
80%	***	0.26	0.24	0.20	0.20
full f.	***	0.43	0.27	0.25	0.32

Table 3: Short camera image diameters (arc-sec) for 4 pass bands

5.4.2 Grism Mode

In the short camera spectrographic mode, a grism is positioned at the pupil by the disperser carousel. The grisms are mounted in frames which are in turn attached to the disperser carousel. There are three grism mounting positions for 150 mm diameter grisms. The initial grism selection is intended to include the following:

6 Functional Requirements

The following sections describe the functions of the various instrument sub-systems, roughly in the order seen by photons traversing the instrument optical path.

6.1 Instrument Hatch

There will be an air-powered hatch located at the entrance to the instrument. The hatch serves two purposes: first, it provides a dust-tight seal to keep the instrument clean; second, the hatch provides a light-tight seal, and the interior side of the hatch is painted with a diffusive coating to allow internal wavelength calibrations.

6.2 Guiders

There will be three CCD guider cameras located behind the hatch, and in front of the f/11 focal surface. The CCD cameras and controllers will be designed and fabricated by Thomson and Burley at OCIW. (See the TV Guider specification for details of the camera and controller designs.)

As used in IMACS, each guide camera will image an 105 arc-sec field of view at 0.10 arc-sec/pixel, re-binned 2x2 for 0.20 arc-sec/pixel. Each guider will include an infrared filter that will allow the guider to be used during considerable moonlight. This and other possible filters will be focus-compensated by a glass dummy filter when no filter is desired, so that the camera requires no refocusing mechanism after its original setup. (The focus of the telescope is held fixed to the focal plane where the apertures are installed.)

6.2.1 Principal Guider

This principal guider will intercept the edge of the field before the focal surface. The camera and feed optics will mounted so as to allow it to traverse a 45 degree sector of the field of view, will move only in the angular coordinate so as to maintain focus for all positions, and will be tilted so as to be tangent to the focal surface at the position. The sampled area of $\sim$ 15 arc-min^2 is sufficient to find at least one R=19 mag star, even at the Galactic poles, for guiding at approximately 1 Hz.

6.2.2 Shack-Hartman Guider

The Shack-Hartmann Guider will access an angular sector like that of the Principal Guider, but directly opposite. In addition to providing directing imaging capability, the S-H guider will be used to provide feedback to the active optical system for the primary mirror support, by performing a low-order Shack-Hartmann test (focus, spherical aberration, astigmatism,...). Unlike the Principal Guider, the S-H must move radially by up to one field diameter, so that the acquired star can be centered on the aperture of the Shack-Hartman sensor, to an accuracy of 0.2 arcsec. Linear displacements of the Shack-Hartman spots will be used to provide feedback for de-rotation correction of the

Prism mat'l	Rulings gr/mm	Nominal λ 1st. O. (Littrow)	Nominal Blaze Angle	Prism angle
F. Silica	150	2000 nm	8.6	8.6
F. Silica	300	2000 nm	17.5	17.5
F. Silica	600	1600 nm	28.7	28.7

Table 4: Initial grism compliment

instrument on the Nasmyth rotator bearing. The mode of operation of the S-H Guider will be to integrate for ~30-60 seconds in order to collect enough light for a low-order correction of the primary mirror support system and the secondary mirror collimation. This is sufficiently frequent to update the field rotation correction.

6.2.3 Center-Field Guider

The Center-Field guider will be used for bright target acquisition and in fixed-slit operating mode. The fixed-slit will be multi-width (from 0.5 to 2.0 arcsec, each section 20 arcsec long. The fixed-slit will be flanked by reflective surfaces that will, through transfer optics attached to the slit-assembly, direct the beam to a fixed camera mounted outside the field. The Center-Field Guider will provide a mode of rapid acquisition, on-field guiding for relatively bright, single objects. (Alternatively, the Principal Guider can be used; use of the S-H Guider will be required to control the primary mirror support and secondary mirror collimation.)

Long-slit observing, with single width and/or longer slits, will be accomplished through use of specially fabricated multi-slit masks. Field acquisition and guiding will be accomplished as in multi-slit mode

6.3 Calibration

6.3.1 Internal

The instrument will have internal lamps – quartz-halogen, helium, neon, and mercury, for approximate calibration of the instrument. These will be viewed by the instrument from reflection off the instrument hatch. These internal flats are necessary for instrument setup when the telescope will be set up for other instruments or unavailable to the astronomer.

6.3.2 External

External lamps of quartz-halogen, helium, neon, and mercury, will be mounted at the end of the telescope for projection against a screen on a screen mounted below the secondary mirror. The flats and calibrations taken in this way will be the normal mode of calibration, although flat-fields taken in twilight and night-sky exposures will be preferred when possible.

6.4 Slit-Masks

An automated slit-mask handling system allows selection from a minimum of five masks (6 goal) to be used during a single loading of the handler. The design parameters for the f/11 focal surface are:

plate scale	346.77 microns/arc-sec	2.88 arc-sec/mm
field of view	27 arc-min dia (620 mm) 1800 arc-sec dia.	(24.42 inch dia.)
field area:	706.8 arc-min^2 2.54E6 arc-sec^2	

focal surface R_c	-1231.74 mm (convex)	(48.49 inches)
sagitta	39.7 mm	(1.56 inches)

6.4.1 Slit-Mask Characteristics

The slit mask handler (below) will install several different types of masks, including long slits, 5 arc-min multi-slit masks (flat), and 27 arc-min dia. multi-slit masks (spherical shells). Long slits of various widths will be available on one of the long slit frames, and four 5 arc-min multi-slit masks will be loaded on each of the frames dedicated to them.

A minimum of 100 full-s mask blanks will be provided. It is anticipated that the mask blanks will be stamped or pressed into the spherical shape, and then mounted in frames. The frames will carry kinematic features which engage on the machine tool which cuts the slits into the masks. A minimum of 10 prefabricated frames will be provided.

Unless slit masks are made of low-CTE material, masks will be cut at ambient temperature to minimize thermal scale changes. The time required to machine a set of four masks should not exceed 8 hours.

6.4.2 Slit Dimensions

The narrowest slits are to be a maximum of 0.5 arc-sec (150 microns or 0.006") wide, with a width variation of less than 10% over the slit length. The longest slits in a multi-slit mask will be approximately 20 arc-sec (6.9 mm or 0.27") long. The longest slit in single slit mode will be 5 arc-min (104 mm or 4"). Multi-slits will be located to relative to each other by better than 0.10 arc-sec (35 μm or 0.0013") across the full 27 arc-min field of view.

6.4.3 Slit-Mask Handler

The slit mask handler carries a cassette of up to 6 masks which will be added and removed individually from the cassette. Kinematic holding fixtures locate the mask repeatably to $\pm 25\mu$m (0.001") in all directions at the focal surface, and flexure between the Principal Guider will be held under 0.10 arcsec for exposures of two hours or less.

6.4.4 Integral Field Units

Although not currently included in the scope of the project, provisions for addition of integral field units (IFU) will be made. It is expected that two IFU's would be installed, one for the science field and one for sky subtraction. The IFU field of view should be 5 x 5 arc-min, with a sampling of 0.2 arc-sec/fiber, corresponding to 600-plus fibers.

6.5 Field Lens

The field lens is a large fused silica element located immediately behind the focal surface. The lens will be mounted in a statically athermal cell. The lens/cell unit is removable for re-coating. The lens cell will include features to simplify removal and re-installation. The cell will be kinematically attached to the instrument structure for stress isolation, and to simplify collimation.

The field lens design parameters are:

diameter	635 mm	(25 inches)
thickness	85 mm	(3.35 inches)
material	fused silica	

6.6 Collimator

The collimator is an all-spherical refracting design as described above. The collimator focus may change with temperature, and consequently must be capable of focus correction. This may be achieved by passive compensation, by moving some part of the collimator, or by focus of the collimator assembly as a unit. If focus is done actively, it will be motor-driven, with a range sufficient to correct for thermal focal errors. The collimator assembly is kinematically mounted to the structure to avoid stressing the optics and to simplify alignment. The collimator assembly includes features to simplify removal, re-installation, and re-alignment. The lenses are removable from the barrel for re-coating.

6.7 Flexure Control

The primary requirement for the flexure control system, if it is found to be necessary, is that it limit image motion to 0.1 pixels rms over a one hour exposure.

Translation of the detector array will be the principal means of flexure correction, and will require precision translation stages, either inside or external to the evacuated CCD enclosure. (Alternately, tip/tilt motion of the collimator barrel, or a subset of the collimator optics, could provide the flexure correction.)

The flexure control system may operate in an open-loop mode, with corrections based on a look-up table of flexure versus instrument rotation angle. Alternately, a closed-loop control system, based on error signals from additional flexure control CCDs in the focal plane, could be used. In either case, separate control systems would be required, depending on which camera was in use.

6.8 Focus Control

Focus control that is not accomplished through passive means within the collimator and camera cells will be accomplished through a motion stage carrying the CCD detectors. Corrections will be made through focus-sequence exposures with IMACS in direct mode, and/or through open loop corrections responding to changes in instrument temperature, which will be monitored.

6.9 Disperser Selector

The disperser selector will provide three positions for gratings with their mounts and tilt assemblies, three grisms and their mounts, a flat mirror for the long camera imaging mode, an open position for the short camera imaging mode, and provision for mounting a

Fabry-Perot etalon. The selector will consists of a frame, a drive assembly, and a carriage which carries the various optics and mounts.

The general requirement for removal and replacement of a dispersing element is that any spectral feature returns to within 5 pixels (1 pixel goal) after transfer. Flexure of the disperser relative to the CCD focal plane should be less than 0.5 pixels (0.1 pixel goal) over a 1 hour exposure.

6.9.1 Grating Mounts

Gratings will be kinematically mounted in cells to avoid thermal or gravity induced deformations of the grating by its cell. The grating cells will attach to the grating tilt mechanisms. Grating mounts may be exchanged on the tilting mechanisms to accommodate additional gratings not included in the initial compliment.

6.9.2 Grating Tilt

Grating tilt angles will be adjusted automatically by grating tilt mechanisms, one per grating. The tilt mechanisms will carry the gratings in their mounts, and must limit image motion errors according to the image motion requirements above. Grating exchange out of tilt mechanisms will not be automated, but must be accessible while the instrument is installed. The minimum tilt range required is ±4 degrees for the 300 line/mm grating, and ±12 degrees for the 1200 line/mm grating. Grating tilt must be sensed at the 0.1 arc-sec level to maintain grating angle.

6.9.3 Grisms Mounts

Grisms will be attached kinematically to mounts, to prevent thermal or gravity deformations of the grisms. There will be three positions for grism mountings on the disperser selector. Grism mounts will attach kinematically to the selector carriage to simplify collimation and removal/installation. There will be no automated motion of grism mounts. Grism mounts must limit image motion according to the image motion requirements.

6.9.4 Imaging Mirror

There will be a single, fixed position for the long camera imaging flat. The flat and mount should limit image motion to less than 0.1 pixel rms over a one hour exposure. The flat and its cell will attach kinematically to the selector carriage.

6.9.5 Fabry-Perot Etalon

There will be a mounting position for a Fabry-Perot etalon on the selector carriage.

6.10 Long Camera

The optical design parameters of the long camera are described above. The long camera consists of lens elements mounted in bezels which are in turn mounted in a barrel assembly. The lenses must be removable for re-coating. The camera barrel is kinematically attached to the instrument mainframe, and includes features for alignment and removal/installation. The barrel assembly will be temperature controlled to minimize thermal stresses and changes in focus and scale. The camera barrel carries the focus mechanism, shutter, and filter changer.

6.10.1 Focus

Camera focus may change with temperature and consequently must be remotely controlled. Long camera focus will be by motion of a single lens or lens group within the camera barrel, which may be done by passive compensation. If active compensation is required, focus will be motor driven. The focus range must accommodate the range of thermal focus errors.

6.10.2 Shutter

A shutter will be located inside the camera barrel for precise control of exposure time. The shutter will use two blades to insure constant exposure time across the detector. The shutter may be removed/installed without removing the camera barrel from the instrument. The minimum shutter exposure will be 2 seconds (1 second goal) with 1% linearity over the duration of the exposure.

6.10.3 Filters

Provision will be made for installing filters inside the camera barrel. There will be spaces for 15 filters in the filter server mechanism. A motor/gear train and motion stage will position the filters, with filter exchange taking less than 30 seconds. Filters will reposition to 25 microns (0.001") (goal 10 microns).

6.11 Short Camera

The optical design parameters of the short camera are described above. The short camera consists of lens elements mounted in bezels which are in turn mounted in a "drop-in" type barrel assembly. The lenses must be removable for re-coating. The camera barrel is kinematically attached to the instrument mainframe, and includes features for alignment and removal/installation. The barrel assembly will be temperature controlled to minimize thermal stresses, and changes in focus and scale. The camera barrel carries the focus mechanism, shutter, and filter changer.

6.11.1 Focus

Camera focus may change with temperature and consequently must be remotely controlled. Long camera focus will be accomplished by passive compensation through the motion of a single lens or lens group within the camera barrel, or by active compensation through means of a motor/gear mechanism. The focus range is must accommodate the range of thermal focus errors.

6.11.2 Shutter

A shutter will be located inside the camera barrel for precise control of exposure time. The shutter will use two blades to insure constant exposure time across the detector. The shutter may be removed/installed without removing the camera barrel from the instrument. The minimum shutter exposure will be 2 seconds (1 second goal) with 1% linearity over the duration of the exposure.

6.11.3 Filters

Provision will be made for installing filters inside the camera barrel. There will be spaces for 15 filters in the filter server mechanism. A motor/gear train and motion stage will position the filters, with filter exchange taking less than 30 seconds. Filters will reposition to 25 microns (0.001") (goal 10 microns).

6.12 Dewar and CCD Array

6.12.1 Dewar

The dewar carries the CCD array, local electronics, and kinematic features for connecting the dewar to the cameras. Removal and replacement of the dewar is a daytime operation, and will not occur during the course of a night's operation.

The dewar will use cryo pumps or carry enough liquid nitrogen to operate 24 hours between fills.

6.12.2 CCD Array

The detector arrays consists of (8) 2048 x 4096 pixel CCDs, arranged in a 2 x 4 array, to give a square detector area of 8192 pixels by 8192 pixels. The individual CCDs are three-side buttable.

- CCD and array flatness requirements:
  ± 15 microns over the entire focal surface (goal)
  40 microns P-V over each detector (SITe specification)
- Gap requirements:
  short side gap req.: < 0.5 mm
  long side gap req.: < 0.5 mm
- Read noise requirements:
  2 e^- goal (at XXX kpix/sec TBD)
  4 e^- required (at XXX kpix/sec TBD)
- Dark current requirements:
  < 3 elec/pix/hr at -100C (SITe specification)
- Spurious charge injection requirements:
  TBD
- Fringing requirements:
  less than 1% (goal) at 0.9 microns
  less than 3% (req.) at 0.9 microns
- Anti-reflection coatings:
  TBD

6.12.3 Kinematic Mount

The kinematic mount for the dewar will provide a repeatable, stress-free connection between the dewar and the camera barrels. Flexures or ball-and-vee joints may be used at the interface. Removal and replacement of the CCD array is required to be repeatable to ± 25 microns (± 0.001").

6.13 Instrument Structure

The main function of the instrument structure will support the various components of the instrument such that the optical design is satisfied, both statically and dynamically. The primary requirement for the structure is the image motion requirement of 0.1 pixel per hour be upheld. The structure will provide mounting points for the optical and mechanical sub-assemblies, and the mechanical connection to the telescope.

6.13.1 Interface to Telescope

There will be several interfaces between the telescope and instrument. The details of the interfaces are to be determined. The interfaces include:

- Mechanical - attachment to Nas. rotator bearing, Nas. deck.
- Electrical - power, voltages, currents, connectors
- Fiber-Optic -
- Video -
- Coolant Supply - pressure, flow-rate, connectors
- Air Supply - pressure, flow-rate, connectors

6.13.2 Mainframe

The mainframe is defined to be the central of the structure that supports the optical subassemblies, including the guiders, slit mask, field lens, collimator, dispersers, and cameras. The mainframe is attached to the telescope by the Nasmyth Instrument Rotator (NIR) bearing flange, and at a secondary support point near the instrument center of gravity. The secondary support point provides a single degree of freedom constraint in the direction opposite to gravity.

6.13.3 Optical Support Structure

Angular errors between the collimator, dispersers, and cameras must be minimized in order to maintain the 0.1 pixel rms image stability requirement. One way to accomplish this may be to mount those assemblies on a sub-structure. The optical support structure would provide the rigid base for the main optics, and would be attached to the mainframe.

6.13.4 Instrument Carriage

The instrument carriage is a structure which supports the mainframe when it is not installed or attached to the telescope. The carriage also supports other systems not attached to the mainframe, including remote electronics enclosures, spare slit-masks, spare filters, dispersers, etc. The carriage will have lifting points and/or wheels which are used to help move the instrument. The carriage may include mechanisms for transferring the mainframe supports from the carriage to the telescope.

6.13.5 Electronics Enclosures

Many of the instrument electronic components (motion controllers, power supplies, dewar electronics, guider electronics) will be local to the instrument, but may not need to rotate with the mainframe. These components will be housed in temperature-controlled enclosures which are attached to the instrument carriage. Wiring will pass through a cable wrap to the mainframe and through connectors to the telescope.

6.13.6 Instrument Enclosure

The instrument enclosure will provide a light-tight, dust-tight, and thermally insulated housing for the rotating part of the instrument. The enclosure will consist of insulated panels attached to the mainframe structure. The panels will be attached with quarter-turn fasteners which allow quick removal of the panels for access to the instrument.

6.13.7 Thermal Control

Electronics both on-board the mainframe and on the cart will require cooling to avoid dissipating heat into the instrument and dome, and to maintain components within specified operating temperature. Cooling will be provided by heat exchangers supplied with telescope glycol coolant. Fans will be cycled to control the amount of heat transfered at each exchanger.

7 Instrument Electronics

7.1 System Architecture

There is an overall architecture for the various electronic subsystems which provides integrated control and information exchange between the subsystems, instrument computer, and user. The system architecture is TBD.

7.2 Instrument Computer

The instrument computer provides a user interface to the instrument, controls the instrument configuration, starts and stops exposures, collects and stores images, communicates with the telescope, monitors instrument and telescope conditions and status (temperatures, flow-rates, humidity, dome conditions), and operates the TV guiders.

7.3 Instrument Network

The CCD controller, TV guider controllers, and instrument computer communicate via an instrument network. This network will be compatible with the telescope network infrastructure.

7.4 CCD Controllers

The CCD controllers provide driving signals to the CCDs and return images to the instrument computer. The CCD controllers are provided with the dewar and CCD array. See the CCD array specification by Thomson and Burley.

7.5 TV Guiders

The three TV guider cameras are described in section 6.2. See the TV guider specification by Thomson and Burley.

7.6 Motion Control

Motion control for linear and rotation stages may be provided by DC servo systems (Galil, Compumotor, Other), stepper motors, and/or AC synchronous motors. The motion control components will be compatible with those used in the telescope whenever possible. Final details of motors, encoders, power supplies, amplifiers, wiring harnesses, fiducials, limit switches, etc. are TBD.

7.7 Air Control

Motion control for simple binary operations (hatch open/close, latch on/off, filter in/out, etc.) may be provided by air cylinders. The state of air-powered stages will provided by limit switches.

7.8 Uninteruptable Power Supply

An Uninteruptable power supply (UPS) may be provided, and might be located on the instrument carriage. The UPS would provide enough battery power to complete and readout an exposure in the event of a power outage. Requirement for the UPS, and its specifications are TBD.

7.9 Environmental Sensing

The telescope and instrument environments will be monitored to avoid overheating, condensation, and to control thermal flexure.

Potential conditions and status items to monitor:

1. Thermal
    - Coolant supply temp.
    - Coolant return temp.
    - Dewar level

   - Dome ambient temp.
   - Dome relative humidity
   - Instrument ambient temp.
   - Instrument relative humidity
   - CCD crate temp.
   - Motion controller rack temp.
   - TV controller temps.
   - Structure temp. (XX locations)

2. Observatory Services
   - Air supply pressure
   - Power supply voltage
   - Coolant supply pressure
   - Coolant supply flow

3. Instrument Status
   - CCD crate fan on/off
   - Motion controller rack fan on/off
   - Ion pump
   - Lamp name
   - Lamp on/off
   - TV camera on/off (3)
   - TV controller fan on/off (3)

7.10 Thermal Control

The thermal control system will use temperature data from various sensors as inputs to a control system which toggles fans on and off to maintain temperature set points.

7.11 Cable Wrap

A cable wrap feeds wiring from the fixed cart to the rotating mainframe. The (removable) angular rotation limits for the Nasmyth rotator are ± 179.5 degrees. The cable wrap is a chain-type with a storage tray (Igus, etc.).

7.12 Wiring Harness

Wiring harnesses exist for the motion control system, the detector array and controllers, the TV guiders, and the environmental sensors. Motion stage wiring includes disconnects (AMP, etc) at the stage and at the controller. Dewar wiring must accommodate installation at both the long and short cameras. Cable assemblies should be interchangeable wherever possible to simplify trouble-shooting and sparing.

8 Instrument Software

There is a large compliment of software required for control of the instrument. The functional requirements for the software are to be determined. The general areas requiring software effort include:

- System architecture
- Target selection tools
- Slit mask design
- Slit mask fabrication
- Instrument configuration and performance simulator
- User interface (GUI)
- Air-stage control
- Servo-stage control
- Stepper stage control
- AC synch. motor control
- Flexure control
- Thermal control
- TV guiders (Thomson/Burley)
- CCD array (Thomson/Burley)
  - exposure control
  - data pipeline
  - data display
  - data reduction
  - data archiving

8.1 Control Functions

There are automated features in the instrument which are either motor-driven or toggled by air cylinders. Table 5 lists the automated functions and the numbers of motor/encoder units, high-resolution (HR) encoders, air cylinders, fiducials, limit switches, and the type of motion required to provide those functions.

Stage	Mot/Enc	HR Enc	Air Sol	Fiducial	Limits	Motion
Hatch			1		2	op/cl
Pr. TV scan	1			1	2	cont.
Pr. TV filter			1		2	in/out
S-H TV scan	1			1	2	cont.
S-H TV insert	1			1	2	in/out
S-H TV filter			1		2	in/out
S-H Direct/S-H			1		2	in/out
C-F TV filter			1		2	in/out
Mask select	1			1	2	cont.
Mask insert			1	1	2	in/out
Mask lock			1		6	on/off
Dewar Focus	1			1	2	cont.
Flexure contr.	1 + 2 PZT			1	2	cont.
Disperser Sel.	1			1	2	cont.
Grating Tilt 1	1	1		1	2	cont.
Grating Tilt 2	1	1		1	2	cont.
Grating Tilt 3	1	1		1	2	cont.
Filt select (2)	2			2	4	cont.
Filt insert (2)			2		4	in/out
Shutters (2)			4		8	op/cl
Totals	13	3	13	14	52	

Table 5: Instrument control functions.

8.2 Function Descriptions

- Hatch position is open or closed. Limit switches indicate status. Default state is closed.
- Principal Guider scan traverses the edge of the focal surface, over a range of plus/minus 22.5 degrees. Fiducial indicates center of travel and default position. Limit switches indicate extremes of range.
- Principal Guider filter is in or out. Only one filter (at a time) available. Out position includes a glass window to maintain camera focus. Limit switches indicate status. Default state is filter out.
- Shack-Hartmann Guider scan traverses the edge of the focal surface, over a range of plus/minus 22.5 degrees. Fiducial indicates center of travel and default position.

Limit switches indicate extremes of range.

- Shack-Hartmann Guider insert moves the pick-off assembly continuously by up to one field diameter. Fiducial indicates center of travel and default position. Limit switches indicate extremes of range.
- Shack-Hartmann Guider filter is in or out. Only one filter (at a time) available. Out position includes a glass window to maintain camera focus. Limit switches indicate status. Default state is filter out.
- Center-Field Guider filter is in or out. Only one filter (at a time) available. Out position includes a glass window to maintain camera focus. Limit switches indicate status. Default state is filter out.
- Mask select scans the slit mask cassette to choose one of five (5) slit masks. Motion is continuous. A fiducial indicates the center of travel and default position. Limit switches indicate the extremes of the travel range.
- Mask insert moves the selected mask from the cassette to the operation position at the telescope focal surface. Motion is between in - out positions. A fiducial indicates the parked (out) position of the insertion mechanism. Limit switches indicate the state of the insert mechanism, in or out.
- Mask lock locates the slit mask frame in kinematic defining points at the focal surface. Motion is on or off, with the default position being unlocked. Limit switches indicate the state of the locks, on or off.
- Collimator focus is continuous over a fixed range. A fiducial indicates the default position at the center of the focus range. Limit switches indicate the extremes of the focal motion.
- Flexure control is continuous over a fixed range. A fiducial indicates the default position at the center of the travel range. Limit switches indicate the extremes of the focal motion.
- Disperser select scans the disperser wheel to choose one of three gratings, three grisms, an imaging mirror, or an open position. A fiducial indicates the default open position. Rotation is limited to less than one revolution by the grating tilt cable wrap. Limit switches indicate the extremes of rotation.
- Grating tilt (1,2,3) tilts the grating to given angular position. A fiducial indicates the default position at the center of the tilt range. Limit switches indicates the extremes of the tilt range.
- Dewar focus is continuous over a fixed range. A fiducial indicates the default position at the center of the focus range. Limit switches indicate the extremes of the focal motion.
- Filter select scans the filter cassette to choose one of twelve (12) filters. Motion is continuous. A fiducial indicates the center of travel and default position. Limit switches indicate the extremes of the travel range.

- Filter insert moves the selected filter from the cassette to the working position in the camera. Motion is between the in or out positions. Limit switches indicate the state of the insert mechanism, in or out.

- Shutter begins or ends an exposure. The two positions are open and closed. Default position is closed. Limit switches indicate the state of the shutter blades. Shutters are internal to the two cameras.