

IMACS, the multi-object spectrograph and imager for Magellan: a status report

Bruce C. Bigelow and Alan Dressler

Observatories of the Carnegie Institution of Washington,
813 Santa Barbara St., Pasadena, CA 91101

ABSTRACT

The Inamori Magellan Areal Camera and Spectrograph (IMACS) will soon be one of the three first-generation instruments for the Magellan 6.5m telescopes. This instrument drove the specification and design of the f/11 Gregorian focus on Magellan, which it uses to feed an all-spherical, refracting wide-field collimator with a 30 arcmin field of view. Two Epps cameras are used to re-image the field of view for imaging and spectroscopy. The aspheric, f/2 ("short") camera images a field of 27 x 27 arcmin at 0.2 arcsec/pixel, and produces 0.32 arcsec images averaged over all field positions across the 0.39 – 1.05 micron bandpass. The all-spherical f/4 ("long") camera images a field 15 x 15 arcmin at 0.11 arcsec/pixel, and produces 0.16 arcsec images averaged over all field positions across the 0.365 – 1.0 micron bandpass. This paper describes the final specifications for the multiple spectrographic and imaging modes, and provides a status report on the current state of the instrument project.

Keywords: MOS, spectrographs, optics, cameras, opto-mechanics, flexure control,

1. INTRODUCTION

The IMACS (Inamori Magellan Areal Camera and Spectrograph) is the principal multi-object spectrograph and imager for the 6.5m Magellan I telescope. The five year, five million dollar project to build the instrument is in its final stages at the instrument laboratories of the Carnegie Observatories in Pasadena, Ca. This paper provides a status report for the instrument, and describes some of its features. See additional papers in these proceedings by Dressler¹ (target science for IMACS), Epps² (the optically athermalized f/2 camera), Bigelow³ (the CCD detector and dewar system), and Sutin⁴ (echellette mode). Concurrently, the Observatories are in the final stages of construction for the telescopes and the first generation of optical and infrared instrumentation. See Shectman⁵ for report about telescope project progress, and Bernstein⁶ for a description of the MIKE double-echelle spectrograph.

IMACS mounts at the Nasmyth focus of the Magellan I telescope. Fed by the f/11 Gregorian configuration (which will soon include an integral ADC and field corrector mounted at the tertiary mirror), the transmitting, all-spherical collimator produces a well corrected, unvignetted field of 24 arcmin in diameter, and a full 30 arcmin in diameter with slight vignetting. Two cameras are used to re-image the 150mm-diameter collimator exit pupil at 0.111 and 0.201 arcsec/pixel. The all-spherical, f/4 Epps "long" camera can directly image a 15 x 15 arcmin field of view (FOV), or spectroscopically image a 15 arcmin long slit with a variety of standard 150 x 200 mm diffraction gratings. The aspheric, f/2 Epps "short" camera can directly image a 27 x 27 arcmin FOV (with slight vignetting), or spectroscopically image a 27 arcmin long slit with a variety of 150mm-aperture grisms. Both cameras feed a single 8192 x 8192 CCD mosaic. A general summary of the instrument specifications is shown in Table 1.

2. SPECIFICATIONS

IMACS images with two optical systems which can operate in either imaging or spectrographic modes. The specifications for each camera are shown in table 1.

Feature	F/4 "Long" Camera	F/2 "Short" Camera
Focal length	641.8 mm	355.6 mm
Focal ratio	f/4.3(imaging), f/2.66 (anamorphic)	f/2.38 (imaging), f/1.47 (ana.)
Field of view	15.46 arcmin X 15.46 arcmin	27.2 arcmin X 27.2 arcmin
Vignetting	None	None below 24 arcmin radius
Total area	239 square arcmin	635 square arcmin
Pixel scale	9.0 pixels/arcsec	5.0 pixels/arcsec
Design wavelength range	0.365 – 1.0 microns	0.390 – 1.05 microns
Allow wavelength range	0.330 – 1.1 microns	0.390 – 1.1 microns

Table 1. IMACS camera specifications.

Spectroscopy with the long camera uses reflection gratings. Table 2 shows the current selection of gratings and their operating parameters.

Ruling	Blaze angle	Order	Wavelength range	Dispersion	Dispersion
Lines/mm	Degrees		Microns	R/0.5 arcsec slit	Angstroms/pixel
300	4.3	1	0.365-0.974	2162	0.743
600	8.63	1	0.365-0.675	3491	0.378
600	13.0	1	0.684-1.000	6117	0.387
1200	17.45	1	0.365-0.523	6542	0.194
1200	26.7	1	0.846-1.000	20693	0.188
1200	26.7	2	0.365-0.443	15740	0.096
1200	26.7	2	0.482-0.557	28082	0.092

Table 2. Gratings and dispersions.

Spectroscopy with the short camera is accomplished with grisms. Table 3 shows the current selection of grisms and their operating parameters.

Ruling	Blaze angle	Order	Central Wavelength	Dispersion
Lines/mm	Degrees		Microns	Angstroms/pixel
200	15	1	0.66	2.037
300	17.5	1	0.67	1.341
600	34.0	1	0.77	0.583

Table 3. Grisms and dispersions.

In general, the image quality target for both cameras is to limit image motion (flexure) to 0.1 pixel for typical 1-hour exposures. This specification places tight constraints on tilts and deflections of all of the instrument optical components and support structures. Detailed error budgets for static (alignment) and dynamic (exposure) image quality have been used to direct the design of the opto-mechanical systems.

3. OPTICAL SYSTEM

There are four main lens groups in the IMACS optical system, and these are shown in figure 1. From telescope focus to science array focus, the groups include a singlet field lens, a four-element, all-spherical refracting collimator, a six element, all refracting "long" camera, and an 8-element aspheric "short" camera. Not shown in the figure are the pupil elements, which include imaging mirrors, gratings, and

grisms, which are installed at the intersection of the main and long camera optical axes. The original concept for the field lens and collimator were developed by Sheckman [7], and the final designs for the collimator and both cameras were designed by Harland Epps [2,8].

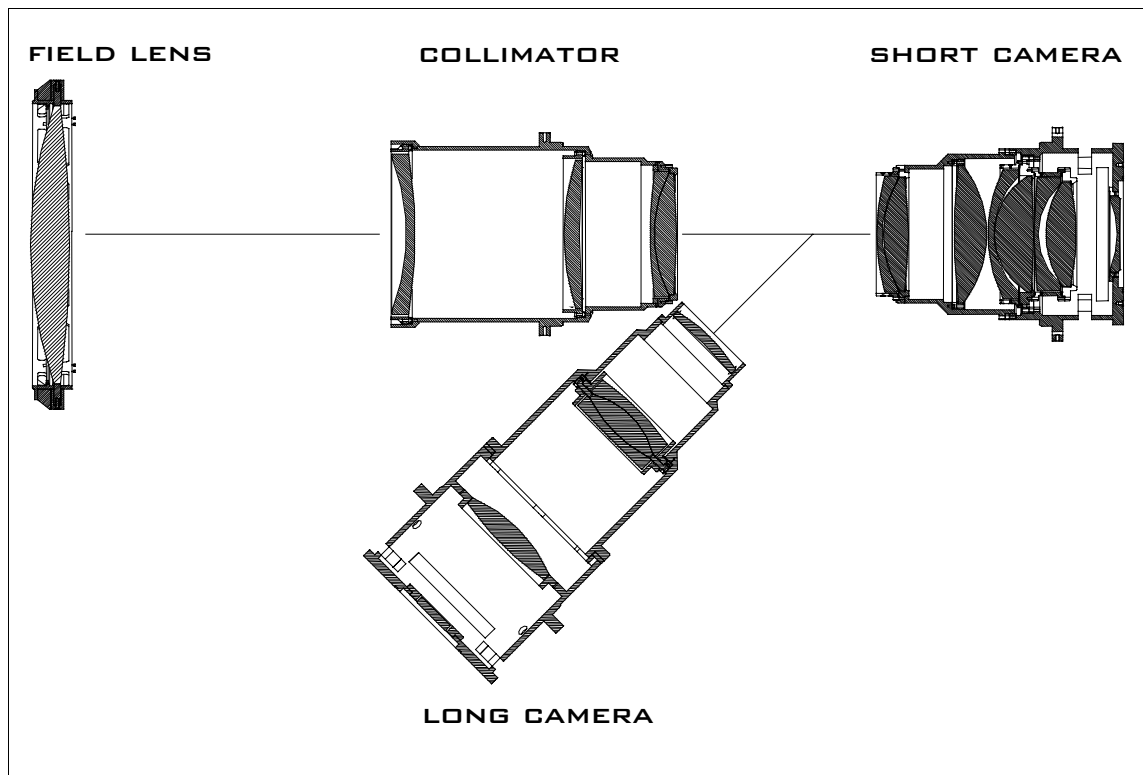


Figure 1. Schematic of the IMACS main optical systems

3.1 Field Lens

The field lens is a singlet fused silica lens, 650 mm in diameter, which weighs 34 Kg. The lens blank was provided by Dynasil (West Berlin, NJ), at an approximate cost of \$14,220. Brashears LP (Pittsburgh, PA) polished the lens, at an approximate cost of \$55,870. Finally, the polished optic was sol-gel coated by Cleveland Crystals Inc (Highland Heights, OH) for approximately \$34,770, which included tooling and shipping fixtures.

3.2 Collimator

The collimator consists of four lenses in three groups (two singlets and a doublet), as shown in Figure 1. The materials, in order of occurrence in the optical path, are Dynasil 1100 fused silica, Ohara S-FSL5Y (Rancho Santa Margarita, CA), Ohara BSM51Y, and Optovac (North Brookfield, MA) calcium fluoride (CaF₂). Note that the optical glasses were selected from the Ohara I-Line catalog for high transmission in the near ultra-violet (UV). The total glass and crystal cost for the collimator was about \$55,000. Tucson Optical Research Corp. (Tucson, AZ) polished the lenses at a cost of about \$26,180. Following polishing, the three glass lenses were sent to Newport Thin Films Labs (NTFL, Chino, CA) for anti-reflection (AR) coating. Ultimately, elements C02 and C03 were coated by NTFL, while C04 and C05 were later coated by Spectrum Thin Films Labs (STFL, Knickerbocker, NY), with a total coating cost of about \$23,500 for six surfaces. The collimator doublet was coupled with Cargille 5610 laser liquid (Cargille Labs, Cedar Grove, NJ).

3.3 F/4 Camera

The f/4 camera uses six lenses in four groups (singlet-triplet-singlet-singlet). The materials, from entrance to focus, are Ohara FPL51Y, Ohara BAL15Y, Optovac CaF2, Ohara S-LAL7, CaF2, and BSM51Y. Note that, as in the collimator, all optical glasses are from the Ohara I-line catalog, and were selected for high transmission in the near ultra-violet. The approximate total cost of the long camera lens materials was \$87,500. After polishing by TORC, at cost of \$39,000, all of the lenses except L03 were sent to STFL for AR coating, at a cost of \$33,300. L03 is embedded in a triplet, and is coupled to its neighbors with Cargille 5610 laser liquid.

3.4 F/2 Camera

The f/2 camera uses eight lenses in four groups (doublet-singlet-quartet-singlet). The materials are S-LAL7, CaF2, CaF2, BSM51Y, CaF2, BSM51Y, S-FPL51Y, and S-LAL7 with the same material suppliers as in the collimator and long camera. Total cost of the optical glasses and CaF2 crystals was \$183,250. Two of the short camera lenses have aspheres on one side – elements 1 and 7. Tinsley Optical Labs (Richmond, CA) polished the aspheric lenses, at a cost of \$133,000 (for two lenses). The remaining lenses were polished by TORC, at a cost of \$39,000, and AR coatings were again provided by STF for \$52,750 (8 surfaces). One interesting feature of the short camera design is the focus and scale athermalization is provided by “oil lenses” formed by the elements in the quartet and the oil couplant. See Epps[2] in these proceedings for a full description of the short camera optical design and optical athermalization.

3.5 Diffraction Gratings, Grisms, and Miscellaneous Optics

The gratings in Table 2 were purchased from Thermo/RGL (Rochester, NY). Brian Sutin designed the grisms. The grism materials for the 15°, 17.5°, and 34° grisms are Ohara BSL7Y, S-LAL12, and PBH53W respectively. The prisms are being cut and polished by Harold Johnson Optical Labs (Gardena, CA), and Thermo/RGL will apply the rulings. The remaining optics include two imaging mirrors, one aluminized and one silver coated. The mirrors were polished and coated by Custom Scientific (Phoenix, AZ). The guide camera optical systems were designed by Brian Sutin, and use Canon (Lake Success, NY), Edmund Industrial Optics (Barrington, NJ), and Adaptive Optics Associates (Boston, MA) components.

As of late July, 2002, all of the optics are polished, coated, and mounted, except for the short camera lenses, the last of which (aspheres) are due at the end of July, and the grisms, all of which are in various stages of prism cutting and polishing.

4. DETECTOR SYSTEMS

IMACS uses two locally designed detector controller systems; one design for the Magellan guide cameras, and a second, related design for the science mosaic. Both systems were designed by Greg Burley and Ian Thompson of OCIW. The guide camera detectors are EEV CCD47-20 devices, and the science detectors are SITE ST002AB1-0 devices. Only the guide cameras are discussed here. See Bigelow¹ in these proceedings for details and status of the dewar and detector systems.

4.1 Guide Cameras

The Magellan guider camera design was developed to be used in a number of instruments, as part of the Nasmyth guider system, and as part of the telescope active optics system. In operation, the guide cameras support a full-frame imaging mode, a fast sub-raster imaging/centroiding mode for rapid guiding, and a Shack-Hartmann wavefront-sensing mode. A frame transfer architecture was required to allow the guide star to be almost continuously monitored, and to provide shutter-less operation. Other requirements included simple calibration of the device and a versatile package for integrating into the various optical systems. The in-house design was carried through to fabrication, and approximately 30 of the cameras have been assembled, several of which are currently operating on the telescopes. As of late July 2002, the three guide cameras for IMACS are ready for installation in the guider motion stages.

5. OPTO-MECHANICS

The opto-mechanical systems in IMACS include 19 lenses in the collimator and cameras, as well as multiple gratings, grisms, and mirrors. With the exception of the 600mm-diameter field lens, all the lenses are elastomerically mounted. Except for the field lens and (current) grating cell design, all of the remaining optics are kinematically mounted in a variety of cell designs, not all of which will be discussed here.

5.1 Field Lens Cell

The field lens is a fused silica singlet, 650mm in diameter, 91 mm thick, weighing 34 Kg. The lens is mounted in a thermally compensated radial support, consisting of a steel cell and 12 delrin posts. The posts are mounted in pockets around the circumference of the cell, and were machined to fit the lens diameter at assembly. Axial support is provided by three rigid defining points, spaced equally over 360 degrees, and three spring plungers directly opposite the defining points.

5.2 Elastomeric Mounts

The 19 lens mounts in IMACS face a stringent list of constraints. The mounts must locate and support the lenses under a variety of gravity orientations and temperatures, while maintaining the optical figures and alignment. The thermal environment dictates operation over a temperature range from 0 to 20C, and survivability range from -10 to 30C. Science requirements dictate that image motion stability be held to 0.1 pixels over the course of a typical exposure, for all gravity and thermal conditions. In all three optical trains, oil coupling and/or oil lenses add hydraulic forces to the list of loads. In order to meet all of the often-conflicting requirements, elastomeric mounts were chosen for the radial and axial support of all the lenses.

An elastomeric mount in this case refers to a room temperature vulcanizing (RTV) rubber ring, which is cast in place between a lens and its cell. The width, depth, and material of the ring can be varied in each case to meet the lens support requirements (in terms of radial, axial, and tilt stiffness) while maintaining low-stress support across the operating temperature range. A sequential process was used to design the width and thickness of each RTV ring. First, spreadsheet calculations were used to estimate width and thickness combinations, using approximations for changes in the effective elastic modulus and coefficient of thermal expansion of the RTV due to constraints on the surfaces of the ring (see Fata⁹). Finally, multiple load cases for each design were examined with finite element analysis to check for stiffness in various gravity cases, thermal stress, and multiple hydraulic loads as appropriate.

In keeping with the general philosophy to minimize the number of parts in the instrument, a minimalist approach was used in the design of the cells and barrels. Rather than designing in features that would allow for individual alignment of each lens or group within a barrel, and each barrels within the instrument, the cells and barrels designs were kept simple, and held to tight tolerances. The only degree of freedom left for final assembly was group spacing, which could be adjusted by changing the thickness of group spacers. When assembled, the cells and barrels were toleranced such that the sum of the fabrication and assembly errors would still meet the alignment error budget allowances.

5.3 Oil Couplant and Lenses

The collimator and long camera contain one oil-coupled doublet and one oil-coupled triplet respectively. The short camera has four oiled gaps that vary in thickness and radius, thus forming oil lenses. The oil in all cases is Cargille 5610 laser liquid, a silicon-based index-matching oil. Cargille publishes a list of materials known to be either compatible or incompatible with the oil, and this list was used in the selection of all materials that would come into contact with the oil. Additionally, sample of each material were immersed in the oil and checked periodically for reaction in either the oil or the material. Due to the oil's high coefficient of thermal expansion, each oiled multiplet has a small volume compensator, which accommodates oil volume changes with temperature.

5.4 Lens and Cell Assembly

The lenses in the collimator and both cameras are mounted and assembled using the same procedures. In each case, the design locations of the vertices of each lens are known relative to the mounting surface of the cell. An assembly plate mounted on a rotary table carried three tooling balls of known radius, angular position, and height relative to the base plate. With the dimensions and positions of the tooling balls known, the location of the lens vertices and the cell mounting surface relative to the base plate were calculated. Precision gauge blocks were then used to support each cell at the proper height relative to its lens. A dial gauge was used to center the lens and cell on the base plate, typically to better than 15-microns runout. Once the positions of the lens and cell were verified, a variety of casting dams were assembled to contain the liquid RTV during casting. A small portion of RTV was mixed and de-gassed, and then poured into the lens-cell cavity to seal the cavity. After 24 hours of curing time, additional layers of RTV were poured until the required bond depth was achieved. Each pour was allowed to cure for at least 48 hours.

The error budgets for the collimator, f/4, and f/2 cameras were all very similar, with allowances for assembly errors of +/- 0.5 arcmin for tip/tilt, +/- 50 microns for radial position, and +/-75 microns for axial position. Dynamic error budget allowances were typically +/- 2 arcsec for tip/tilt, +/- 3 microns for radial position, and +/- 5 microns for axial position. During assembly, lens positions in the barrels, and lens motions in their cells, were measured and verified to meet the requirements.

5.5 Collimator Cells and Barrel

The four collimator lenses are mounted in three groups in a single barrel. Each lens is bonded to its own cell, with spacers to control the axial position of two of the groups and the location of the barrel on the instrument structure. These are the only adjustable elements in the collimator assembly. Upon final assembly, the four lenses in the collimator were measured to be within 75 microns of their nominal positions, and hence no changes to the spacers were required.

5.6 F/4 Camera Cells and Barrels

The six f/4 camera lenses are mounted in four groups and carried in two barrels. Each lens is bonded into its own cell, and two spacers are used to control the axial position of the triplet in the front barrel, and the camera in the instrument structure. Temperature changes which impact the lens dimensions and refractive indices are uncorrected in the f/4 camera. In order to compensate for thermally induced changes in magnification and focus, the large CaF₂ singlet in the f/4 camera was articulated. Initially, a single actuator was envisioned for changing the axial position of the lens with temperature, but difficulties in meeting the tight position tolerances with an all-mechanical solution lead to a three-actuator system, which as a side benefit allows tip/tilt control of the lens for flexure compensation. The articulated cell is located in its plane by three titanium flexures, which are stiff in the planar directions, but flexible in tip, tilt, and piston. Three Physik Instrumente (Tustin, CA) M-230.10 actuators with 10mm of stroke constrain the remaining degrees of freedom.

The f/4 camera barrel is split into front and rear sections, with the front section carrying the first two groups and the rear section carrying the remaining two. Spacers for the triplet, and between the two barrel sections provide the only adjustable dimensions in the f/4 camera. On assembly, the triplet spacer was increased in thickness to account for minor fabrication errors in the triplet optics. The remaining lenses were measured to be within 75 microns of their nominal positions.

5.7 F/2 Camera Cells and Barrels

Unlike the f/4 camera, the design for the f/2 camera was optically athermalized by the use of couplant oil "lenses" in the coupling cavities (see the paper by Epps[2] in these proceedings for details of the f/2 camera design). Therefore, no provision for thermal focus or scale corrections was made. As with the f/4 camera,

the f/2 camera barrel is split into front and rear sections, with the front section carrying the first two groups and the rear section carrying the remaining two. Spacers for the CaF₂ singlet, the quartet, and between the two barrel sections provide the only adjustable dimensions within the f/2 camera.

As of late July 2002, all of the opto-mechanics are complete and have been assembled on the instrument structure and tested, with the exception of the short camera and the grisms. Assembly of short camera opto-mechanics is scheduled to begin in September 2002. Assembly of the grisms will also begin in the fall of 2002.

6. MOTION STAGES

Many functions in IMACS are automated to allow for instrument configuration changes. Slit masks, filters in both cameras, and dispersing elements can all be changed between exposures. The following sections describe the features of the various motion stages.

6.1 Center Field Guider Stages

The IMACS slit area includes three positionable guide cameras for guiding, Shack-Hartmann testing of the Magellan primary mirror, and rotation control of the Nasmyth Instrument Rotator (NIR) on which IMACS connects to the telescope. The center-field guider moves from a stowed position to the center of the 30-arcmin field under software control. A stepper-motor driving a THK KR series linear actuator provides position control. An air-powered stage allows for the optical system to toggle between imaging and Shack-Hartmann modes. A two-position air-powered slide allows selection of two filters.

6.2 Principal Guider Stages

The principal guide camera operates at the edge of the 30-arcmin field of view. The principal guider can provide the primary guide signals to the telescope, or rotation feedback for the NIR. The principal guide camera is mounted on a pair of arc-shaped THK bearings, and positioned by a chain drive with a stepper-motor-gearbox combination which allows the camera stage to traverse a 45-degree angular range. A home switch and limit switches at both ends of the motion range complete the control loop. The principal guider uses the Magellan standard CCD guide camera, and a two-position, air-powered filter slide.

6.3 Shack-Hartmann Guider Stages

Like the principal guide camera, the Shack-Hartmann (SH) guide camera can provide either direct guiding signals, or rotational feedback for the NIR. The SH guide camera can also provide Shack-Hartmann testing of the primary mirror over a range of radial and azimuthal positions on the focal surface. The first SH guider stage is carried by arc-shaped THK bearings, and is positioned by a stepper-motor with a similar chain drive. A second motion stage, uses a THK LM series actuator to provide motion in the radial direction. The SH guider has two sets of optics which can be automatically switched to toggle between guiding and Shack-Hartmann testing modes, and a two-position filter slide.

6.4 Slit Mask Server System

The slit mask server system allows for automated installation of slit masks and other focal surface items (aperture masks, integral field units). The mask changing system includes two sub-systems – a shuttle stage for selecting from 8 mask positions, and an insertion mechanism that draws a mask from the shuttle into the focal area. The shuttle and insertion mechanisms are loosely based on a similar system designed for the GMOS instrument (see Murowinski¹⁰). The shuttle positioner is based on a Daedal 412000 series linear motion stage, and driven by a Mycom stepper motor. An encoder provides position feedback, while limit switches and a home sensor completes the control loop. Masks are held in the shuttle by latches that are released by an air cylinder located in the insertion plane. Keyways in the masks allow the latch release mechanism to engage whichever mask is currently in the insertion position. The insertion mechanism uses a similar keyway system to extract the active mask. A single Bimba air cylinder carrying a round key engages whichever mask is located by the shuttle in the insertion position. Limit switches on the air

cylinder and proximity sensors on the shuttle and insertion mechanisms provide the logic required for avoiding collisions between the two motion systems. Testing of insertion mechanism indicates that mask location at the focal surface is functional, stable and repeatable to 25 microns regardless of gravity orientation.

6.5 Disperser Server System

Providing the ability to automatically change gratings, grisms, imaging mirrors, and other pupil plane accessories was one of the central challenges in the design of IMACS. The tightest error budget allowances in the instrument apply to the stability of gratings during an exposure, and the 0.1-pixel image stability requirement depends in part on the disperser server system (DSS).

The heart of the grating changing system is a Hirth coupling made by Matrix International. Hirth couplings, often used in machine tools for rotary indexing, consist of two rings with gear-like teeth cut in their mating faces. The angular spacing of the “teeth” provide a repeatable mating interface, and set the number of angular positions provided. In the DSS, the angular indexing feature is not used. Instead, the multiple sets of mating gear teeth act like an array of single degree-of-freedom kinematic couplings, which provide a massively over-constrained joint. It is that extreme over-constraint which makes the Hirth coupling a rigid, stable, and repeatable mounting for pupil elements in the DSS. One face of the Hirth coupling attaches to the instrument structure, and provides the base for the installed grating (or grism, or mirror). A seven-position wheel (one position open for imaging with the f/2 camera) carries grating, grism, and mirror cells, each with their own half of the coupling. The two halves of the coupling are clamped in the active position by four air-powered latches. To change dispersers, the latches are released, and the disperser (with its half of the coupling) is drawn back by springs on to guide pins attached to the wheel. A new disperser is then rotated into position, the latches are reactivated, the cell completely disengages from the wheel, and the new disperser is clamped in position. The clamping action is completed in under a second, so that grating change time is limited mainly by the time required to rotate the DSS wheel.

6.6 Grating Tilt Mechanisms

There are four grating tilt mechanisms, three of which can be mounted in any one of the seven positions on the DSS wheel at a given time. Grating tilt is driven by a stepper-motor-gearbox combination, through a cable drive. Position angle feedback is provided by a Renishaw (Hoffman Estates, IL) optical encoder. A home sensor and limit switches at each end of the travel range complete the control loop for grating tilt.

6.7 Filter server systems

There are filter server systems (FSS) for both the f/4 and f/2 cameras, each of which can carry a maximum of fifteen 165-mm square filters. A clear, anti-reflection coated “dummy” filter is included in each changer for maintaining focus if a color filter is not used. The filter changing system is very similar in concept and execution to the mask changing system. Again, a Daedal linear motion stage carries the 15-position filter cassette. Filters can be individually added or removed from the FSS cassette by releasing a latch. A separate, two-stage, air-powered insertion mechanism uses a key and keyway on the filter frames to engage them for insertion. A retaining bar and pre-loading magnets keep the filters in the inactive positions on the cassette. The filter frames have vee-shaped edges which ride on vee-rollers as a filter travels from the cassette to the active position in the camera. Magnets and the insertion actuator hold the filter in the active position inside the camera.

6.8 Shutters

The requirement to provide 1-sec exposures with 1% linearity drove the IMACS shutter design away from air power to servo-motor control. The shutter apertures are approximately 175x175-mm, and the shutters are located in the rear barrels of each of the two cameras. Power for the shutters is provided by two Linmot (Delavan, WI) linear servomotors. The motors attach to the trailing edges of two aluminum shutter blades. Shutter operation is sequential and bi-directional. An exposure is initiated by extracting one

shutter blade from the optical path and ended by drawing the second blade into the aperture. The next exposure is a mirror image of the first. The one second and 1% linearity exposure requirement was tested and demonstrated. Sub-second exposures can be accomplished by scanning a slit formed by the two shutter blades through the shutter aperture. If the shutter were located at the detector focus, the shutter could sequentially expose different parts of the detector array, although this is not practical with the shutter location in the IMACS cameras.

As of late July 2002, all of the motion stages are complete, tested, and operational, with the exception of the grating tilt stages, the DSS wheel drive, and the instrument hatch. Those last three systems are scheduled for completion and testing in the fall of 2002.

7. SLIT MASKS

The Magellan telescopes, at their f/11 focus, produce well corrected, unvignetted fields with a diameter of 24 arcmin (498 mm), and slightly vignetted out to 30 arcmin (623mm). The sagitta of the focal surface is 40mm, and curved with its convex vertex nearest to the telescope, due to the Gregorian secondary mirror. Two challenges in the IMACS project were how fabricate blank slit masks, and how to cut hundreds of finely finished slits at any location on the spherical mask.

7.1 Slit Mask Blank Fabrication

There are a variety of processes for forming large shallow dishes in stainless steel, but most press and forming companies contacted recommended hydroforming for the IMACS mask blanks. Hydroforming presses operate by first clamping a blank of material in a tool in the press, and then inflating an oil-filled bladder against the tool to shape the material. California Hydroforming (City of Industry, CA) did the development work for the IMACS masks and produced the first batch of 100 masks.

7.2 Slit Mask Laser

The goal for slit mask cutting production was to be able to cut a 300-aperture mask in under an hour, so that a full complement of 8 masks could be produced during a day shift. Slit requirements include the ability to produce 0.5 arcsec wide slits (170 microns) with smoothness and straightness of less than 1% of the slit width. After reviewing the technologies that could potentially result in acceptable slits (micro-machining, chemical etching, EDM, water-jet, and laser), laser cutting was chosen as the most robust option. Convergent/Prima (Sturbridge, MA) has a standard line of laser machining centers, including the Gemini system. A slightly modified version of a standard Gemini system (30" motion tables, capacitive auto-focus system) and a Coherent Diamond 64 250 W CO₂ laser was ordered at a total cost of \$280,000. The laser cuts both the slits and alignment star holes, as well as mask mounting holes. Acceptable cut quality has been demonstrated at 8-mm/sec, which suggests that typical masks with 300 slits can be cut in approximately 10-15 minutes.

7.3 Slit Mask Frames

Once the laser has cut the masks, they are loaded into frames for installation on the instrument. The frames have three dowel pins which index with three slots on the masks, so that masks and frames can be interchanged, and masks can be repeatably mounted in frames. The frames include V-shaped rails and keyways which are engaged by the mask insertion mechanism for mask changing.

As of late July, 2002, the Gemini mask cutter is installed in Chile, tooling is installed for cutting IMACS and LDSS2 masks, and production mask cutting for LDSS2 will start in late summer, 2002.

8. STRUCTURE AND ENCLOSURE

The IMACS instrument structure includes three components; a carriage that supports the instrument structure on the Magellan 1 West Nasmyth platform, the instrument structure mainframe, which carries the optical system and related motion stages, and a thermal enclosure. The carriage consists of a welded steel frame, and four castering roller assemblies that constrain four of the structure's six degrees of freedom. The telescope's Nasmyth Instrument Rotator (NIR) constrains the remaining two degrees of freedom – translation along the optical axis, and rotation about the optical axis. The NIR provides the torque for de-rotating the instrument for field rotation. The instrument carriage, structure, and enclosures were designed by Steve Gunnels of Paragon Engineering (Tehachapi, CA).

8.1 Instrument carriage

The Magellan telescopes provide instrument rotators at the Nasmyth and Cassegrain foci, but the diameter of the NIR was judged to be undersized for an efficient connection to the IMACS structure. Consequently, the structure design concept was extended to include a carriage. Detail design of the carriage was provided by Steve Gunnels of Paragon Engineering (Tehachapi, CA), and fabrication of the carriage was carried out by Rettig Machine Inc. (Redlands, CA). The carriage consists of a large square steel weldment, and four caster-roller assemblies. The roller assemblies are mounted on flexures, and allow the two discs on the mainframe to rotate about the optical axis with very low friction, and without depending on precise alignment to avoid scrubbing between the roller and the discs. The carriage has turned out to be very useful for testing and integration of the instrument. A temporary drive assembly was added to the carriage to allow computer control of instrument rotation, which has enabled extensive and realistic testing of the instrument in Pasadena.

8.2 Instrument Structure

The detailed design and analysis of the structure, like the carriage, was provided by Steve Gunnels. All fabrication and assembly work for the structure was carried out by Martinez and Turek (Rialto, CA). The mainframe of the structure consists of a main optical support structure (MOSS), a 100" diameter disc for the MOSS (MOSS disc), a 100" diameter forward optical support structure (FOSS) disk, and a ten-element truss which connects the two discs. The core of the mainframe is the MOSS, which carries the collimator assembly, both camera assemblies, both camera filter servers, and the disperser server. The MOSS is a single weldment of mainly 4.75-mm thick steel plates, with heavier plates used for the "wings" and at the mounting locations for each sub-system. The FOSS and MOSS discs were both fabricated from 4.76-mm thick mild steel plate, except for the outer rims and stage mounting pads. Following pre-machining, both discs were mounted on a vertical lathe, indexed to their proper positions, and then joined together with the ten truss elements. The completed structure weighs approximately 1400 Kg.

The support and drive of the structure is (at least in theory) kinematic, in that the structure has six degrees of freedom as a rigid body, and exactly six constraints (mounting or contact points) locate the structure in space. The castering roller assemblies together constrain translations perpendicular to the optical axis, and rotations about those two axes. A spring-loaded flexure assembly connects the structure to the NIR. The flexure is stiff only in the tangential direction, and it provides the torque required to rotate the instrument about the optical axis for field de-rotation. The spring-loaded link constrains the structure to the NIR along the optical axis. The link remains rigid along its axis unless forces or accelerations (i.e. an earthquake) move the structure away from the telescope at more than 1g. If such a force occurs, the springs temporarily "decouple" the link, and allow the telescope to move without drawing the instrument along with it.

8.3 Instrument Enclosures

The detailed design and fabrication of the IMACS instrument enclosures was provided by Steve Gunnels and Paragon Engineering. There were several requirements to meet with the enclosure design. First, for ease of access for routine servicing and repairs, the instrument structure is intentionally very "open", and does not shield the optical systems from stray light. Thus an enclosure was required to provide a light-tight



Figure 2. A recent image of IMACS partially assembled. The carriage, roller assemblies, DSS wheel, structure, and testing drive assembly can be seen.

seal around the optics. Second, observatories tend to be windy, dusty places, and an enclosure was required to keep dirt, dust, insects, falling wrenches, etc. from hitting the instrument. The enclosure will be lightly pressurized to assist dust rejection. Finally, diurnal temperature swings in the summer at Las Campanas Observatory can approach 20C. For this reason, a thermal enclosure was considered essential to insulate the optical systems from large temperature changes over short time scales.

The IMACS enclosures consist of three sets of ten flat panels each, split into front, middle, and rear sections. The panels are laminated structures with inner and outer aluminum skins sandwiching a 24mm sheet of CMI "Divinacell" foam insulation. The front panels are completely supported by the FOSS disc, and include lip seals against the telescope elevation structure. The middle panels span the gap between the FOSS and MOSS discs, and attach to flanges on the discs with quarter-turn fasteners. The rear panels are carried by flanges and truss work on the back of the MOSS disc, again attaching with quarter-turn latches. Access doors allow servicing of slit masks, filters, dispersers, and for exchange of the detector system between the f/4 and f/2 cameras. Finally, the rear enclosure panels also carry the instrument utility wrap, a serpentine IGUS system which carries air, coolant, and Cryotiger braided hoses, as well as fiber-optic links and all of the wiring for sensing and control of the instrument electronic systems. The instrument computers and electronics chassis are mounted in liquid-cooled enclosures that sit with the instrument on the Nasmyth platform.

The instrument carriage and structure were installed in the Pasadena facility in the first quarter of 2002. The front and middle enclosure panels were completed and delivered (except for minor modifications pending) in June 2002. The rear panels and utility wrap are scheduled for delivery in August 2002.

9. INSTRUMENT ELECTRONICS AND SOFTWARE

IMACS has approximately 30 computer-controlled motion functions, most of which are operated by air cylinders, steppers, or servomotors. Additionally, there are stand-alone closed-loop control systems (Physique Instrumente piezo and servo stages), and approximately 25 temperature, pressure, and flow sensors, all of which are powered by two racks of electronics and controlled by software. Detailed descriptions of the electronic and software systems are beyond the scope of this paper. As of July 2002, virtually all of the instrument control electronics are operational (with the exception of the DSS grating tilt and wheel drive systems) and are at least occasionally installed in the two electronics enclosures. The primary outstanding electronics work remaining is the fabrication and mounting of the instrument utility and cable wraps, which is scheduled for completion in the fall of 2002. All of the software components are currently operational, and many of the engineering GUIs are in regular use during final testing and integration of the instrument. Although the GUIs will continue to evolve, even beyond the ship date for the instrument, the instrument software programs for mask cutting, motion control, guiding, and exposure control are all functional.

CONCLUSIONS

A comprehensive report on the status of the IMACS project has been presented. Barring any unforeseen disasters, the instrument is currently scheduled for completion in late 2002.

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