Optical design concept for the Giant Magellan Telescope Multi-object Astronomical and Cosmological Spectrograph (GMACS)

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Abstract

We present a preliminary conceptual optical design for GMACS, a wide field, multi-object, optical spectrograph currently being developed for the Giant Magellan Telescope (GMT). We include details of the optical design requirements derived from the instrument scientific and technical objectives and demonstrate how these requirements are met by the current design. Detector specifications, field acquisition/alignment optics, and optical considerations for the active flexure control system are also discussed.

Requirements

Table 1.

Parameter	Requirement	Goal
Field of View	30 arcmin sq.	50 arcmin sq.
Wavelength Coverage	350-950nm	320-1000nm
Spectral Resolution	Blue: 1000-6000, Red 1000-6000	Blue: 1000-6000, Red 1000-6000
Image Quality	80% EE at 0.30 arcsec	80% EE at 0.15 arcsec
Spectral Stability	0.3 spectral resolution elements/hour	0.1 spectral resolution elements/hour
Number of Gratings	2	≥2
Slit Mask Exchange	12	≥20

Table 1 gives the GMACS principal functional requirements. Additional performance goals and practical constraints, such as throughput, large glass blank availability and standard detector dimensions will also guide the design process.

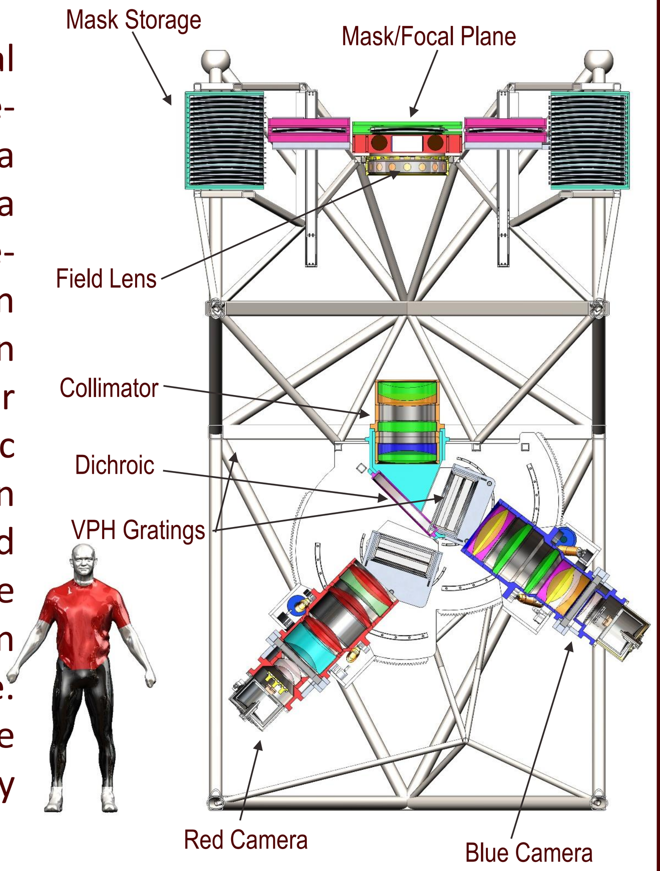

Figure 1. The new opto-mechanical design concept[1] for the GMACS double-beam optical spectrograph consists of a common pan-chromatic collimator, a dichroic beam-splitter, a set of volume-phase holographic transmission gratings (VPHGs) as the dispersion elements, a set of passband filters for both direct imaging and spectroscopic waveband selection, feeding twin articulating red and blue optimized *f*/2.2 CCD cameras. The cassette style slit mask exchangers can be seen on either side at the top of the image. The telescope focal plane and mask are located in the thin green box directly above the large field lens.

Optical Design

Prior to the detailed optical design process, a functional parameter study was performed. Using the stated requirements and the optical design of the GMT, a range of possible spectrograph parameters were determined. This included the number of pixels (15µm) along a slit that covers the full diameter of the field of view (FoV), different aspect ratios for the detector, and requirements for collimator focal length, pupil diameter and camera focal length. The camera FoV required to capture a continuous spectrum at the desired resolutions was also determined. Difficulties in designing and building very fast cameras (~*f*/1) or wide FoV cameras, as well as physical constraints on pupil (and therefore grating) size determined the starting point for the design presented here. The collimator and camera were optimized separately before combining them for complete system optimization. Tolerance analysis will take place as the design process progresses.

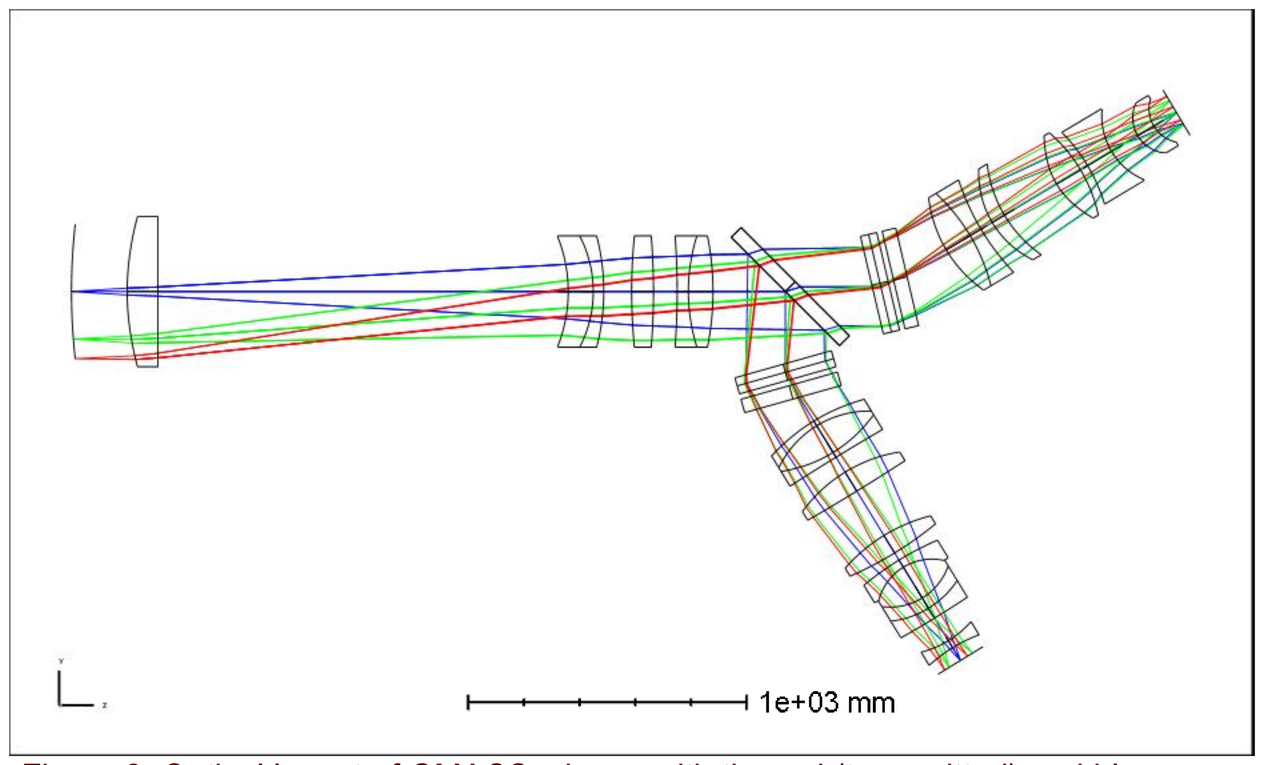

Figure 2. Optical layout of GMACS, shown with the red (transmitted) and blue (reflected) cameras. Gratings are shown articulated for the low resolution mode. The red camera is still in early stages of development.

Collimator

The current design of the collimator consists of four elements: a silica field lens immediately behind the telescope focus; two doublets and a singlet, which reimage the telescope aperture onto the central plane of the volume-phase holographic grating (VPHG). The 2200mm focal length collimator produces a 270mm diameter exit pupil approximately 520mm beyond the vertex of the last lens.

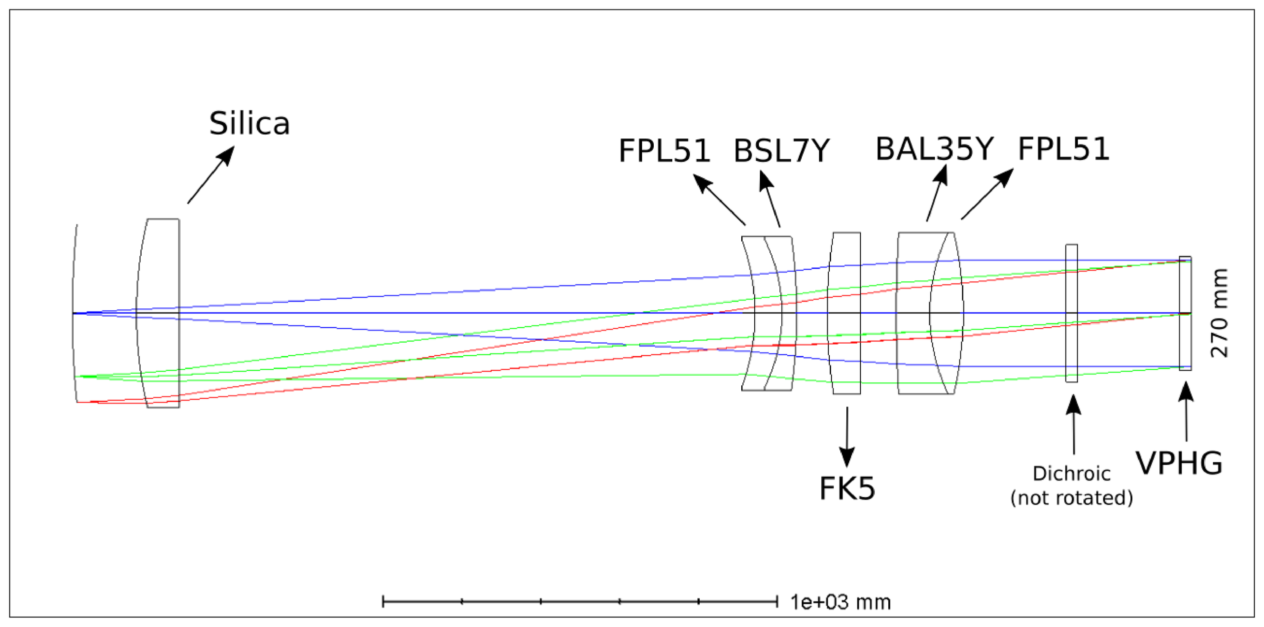

Figure 3. Optical layout of the GMACS collimator.

Blue Camera

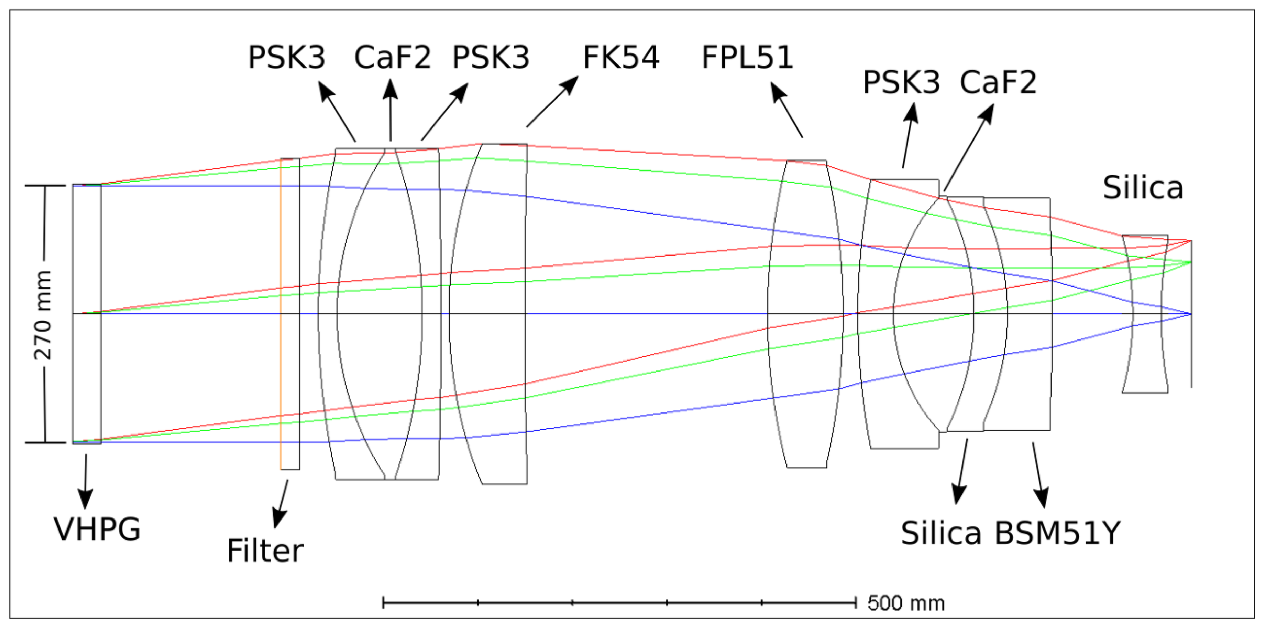

Figure 4. Optical layout of the GMACS blue camera.

The blue camera layout is illustrated in Figure 4. In imaging mode, this f/2.2 camera creates a 0.3 arcsec RMS image over a ~7.5 arcmin FoV, equivalent to a 14° diameter field. The space between the FK54 and FPL51 singlets is required to accommodate a shutter mechanism. The back focal distance of the camera is about 34 mm. The focal plane is made of a two by three array of 4096 × 4096, 15 µm pixel CCD's for a total of 8k (spatial) by 12k (spectral) pixels.

Performance

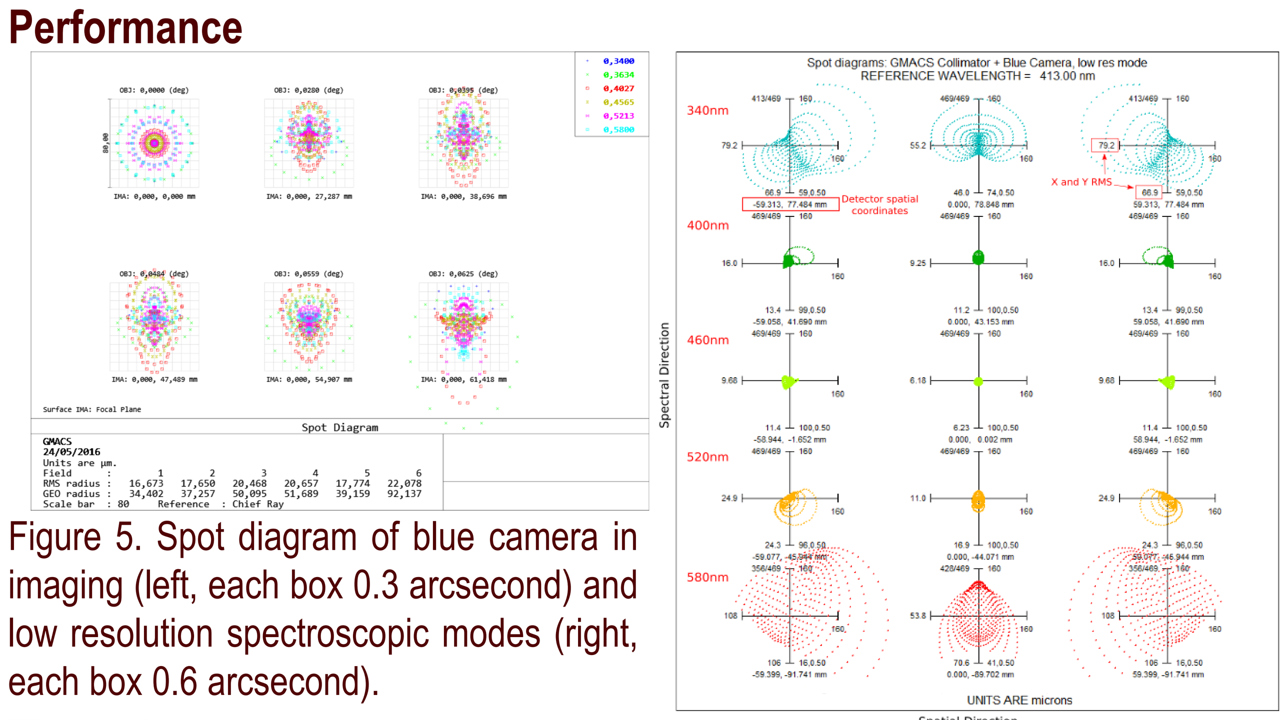

Figure 5. Spot diagram of blue camera in imaging (left, each box 0.3 arcsecond) and low resolution spectroscopic modes (right, each box 0.6 arcsecond).

Throughput

Figure 6 shows the throughput when considering the influence of the collimator and camera. We included a quarter wave MgF_2 coating on all surfaces. Given that there is no vignetting in the image mode, the throughput can be considered constant as a function of FoV. Throughput is highly dependent on glass absorption in the UV-blue spectral region. A small thickness reduction during optimization or a glass replacement will have a strong effect on the UV throughput. It is noted that it is practically impossible to have a reasonable throughput at 320nm with a 10 element refractive camera.

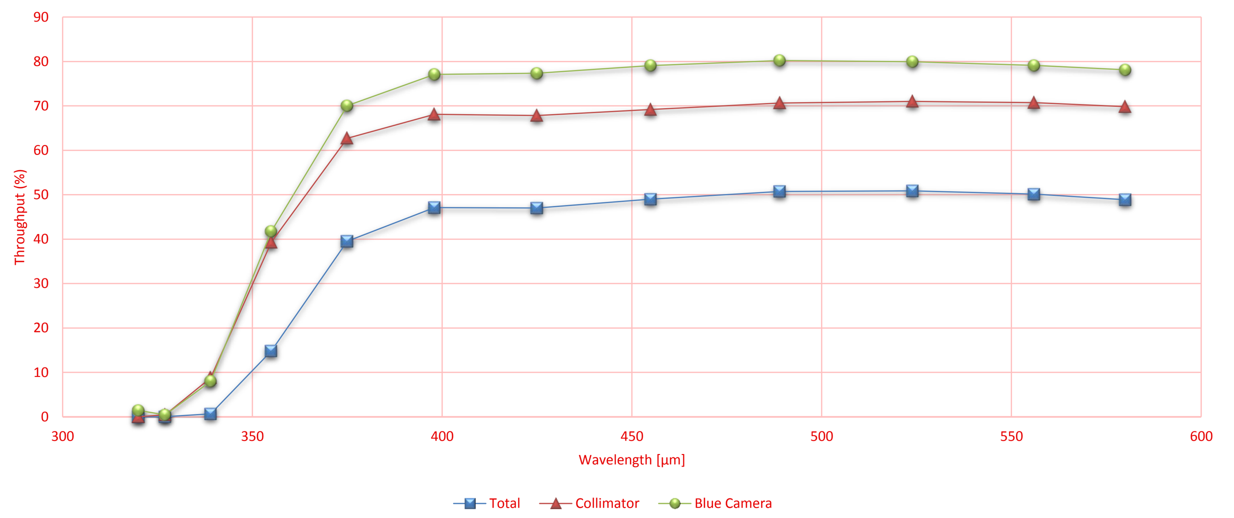

Figure 6. Throughput as a function of wavelength for collimator, blue camera, and combined collimator and blue camera.

Auxiliary Systems

We have started development of a guide and acquisition system located at the GMACS slit mask. Our current concept has several fixed cameras and a single camera that can move under the mask to confirm target object placement on the slits. The size and weight of GMACS will require flexure compensation. We plan to develop a closed loop system to track and correct any gravitationally induced flexure.

MANIFEST[2] is a 'starbug" based facility fiber positioner for GMT that will interface with GMACS and allow for multiplexed observations over the entire 20 arcmin GMT FoV. We are working with the MANIFEST team to develop the interface between these two instruments.

Future Work

As we continue development of the optical design we will investigate faster camera designs, a potential operational mode to swap the detector spatial and spectral axes for increased multiplexing at the expense of spectral coverage, and a catadioptric ~*f*/1 solution for the UV/blue arm where internal detector vignetting losses are less than transmission losses in the current lens only design.

References

[1] Prochaska et al. "Optomechanical design concept for the Giant Magellan Telescope Multi-object Astronomical and Cosmological Spectrograph (GMACS)" Proc. SPIE 9908, Ground-based and Airborne Instrumentation for Astronomy VI, 9908375 (June 30, 2016)

[2] Lawrence et al. "The MANIFEST prototyping design study" Proc. SPIE 9908, Ground-based and Airborne Instrumentation for Astronomy VI, 9908358 (June 30, 2016).

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