Optical design for the Giant Magellan Telescope Multi-object Astronomical and Cosmological Spectrograph (GMACS): design methodology, issues and trade-offs

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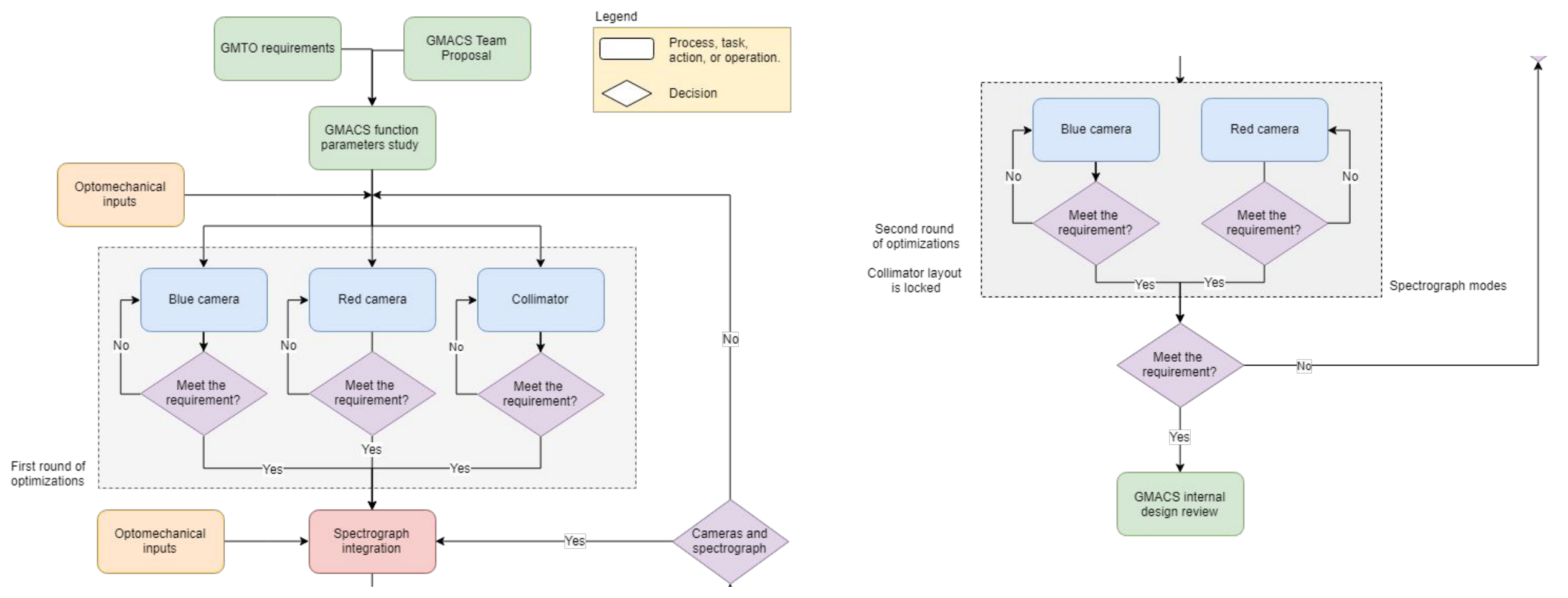
Abstract

We present the current optical design of GMACS, a multi-object wide field optical spectrograph being developed for the Giant Magellan Telescope, a member of the emerging generation of Extremely Large Telescopes (ELTs). Optical spectrographs for ELTs have unique design challenges and issues. For example, the combination of the largest practical field of view and beam widths necessary to achieve the desired spectral resolutions force the design of seeing limited ELT optical spectrographs to include aspheric lenses, broadband dichroics, and volume phase holographic gratings - all necessarily very large. We here outline details of the collimator and camera subsystems, the design methodology and trade-off analyses used to develop the collimator subsystem, the individual and combined subsystem performances and the predicted tolerances.

1. Introduction

GMACS is a first light instrument for the GMT. It will be capable of obtaining spectroscopy of ultra-faint targets that are currently identified only from broad-band imaging observations. High throughput, simultaneous wide wavelength coverage, accurate and precise sky subtraction, moderate resolution, multi-object capabilities, relatively wide field, and substantial multiplexing are crucial design drivers for the instrument. It is expected that GMACS will form one of the most important and heavily utilized scientific capabilities of the GMT.

2. Methodology



3. GMACS Requirements

Additional performance goals and practical constraints, such as throughput, large glass blank availability and standard detector dimensions will also guide the design process

Table 1. GMACS Requirements

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

4. Trade-off Analysis

4.1. Collimator architectures

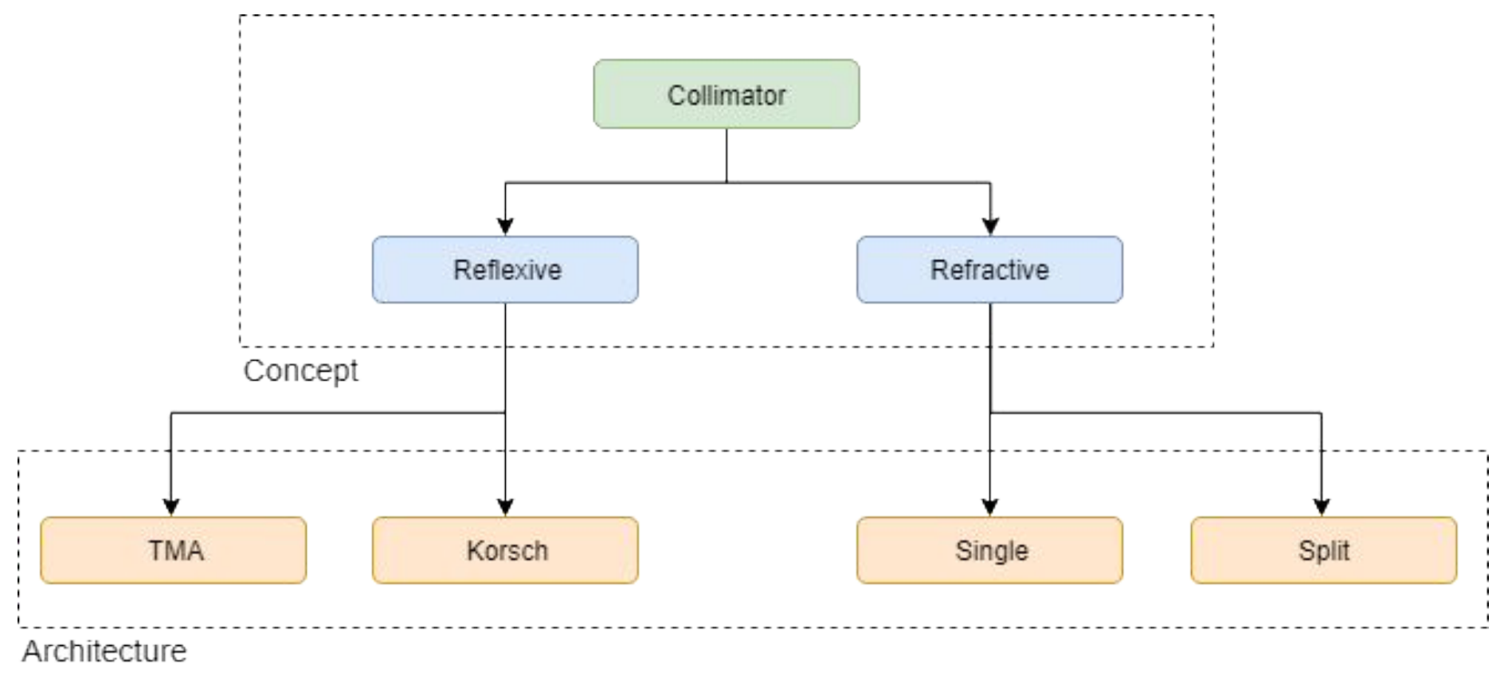

Collimator
Reflexive
Refractive
Concept
TMA
Korsch
Single
Split
Architecture

Table 2. Advantages and disadvantages for reflective collimators

	Obscured	Unobscured
Advantages	No wavelength dependence Good image quality High overall transmittance High UV-Blue transmittance	No wavelength dependence Good image quality High overall throughput High UV-Blue throughput
Disadvantages	Field vignetting Hard to design for large FoV (≈11°) Challenging alignment (and stability)	Size and packaging constraints Challenging alignment Large freeform mirrors

Table 3. Advantages and disadvantages for refractive collimators

Advantages	Large FoV Smaller packaging More degrees of freedom for optimization Straightforward to align
Disadvantages	Fewer glasses available for large optics Glass tends to absorbs UV-Blue

1.2. Refractive collimator architectures

Table 4. Refractive collimator architectures advantages and disadvantages

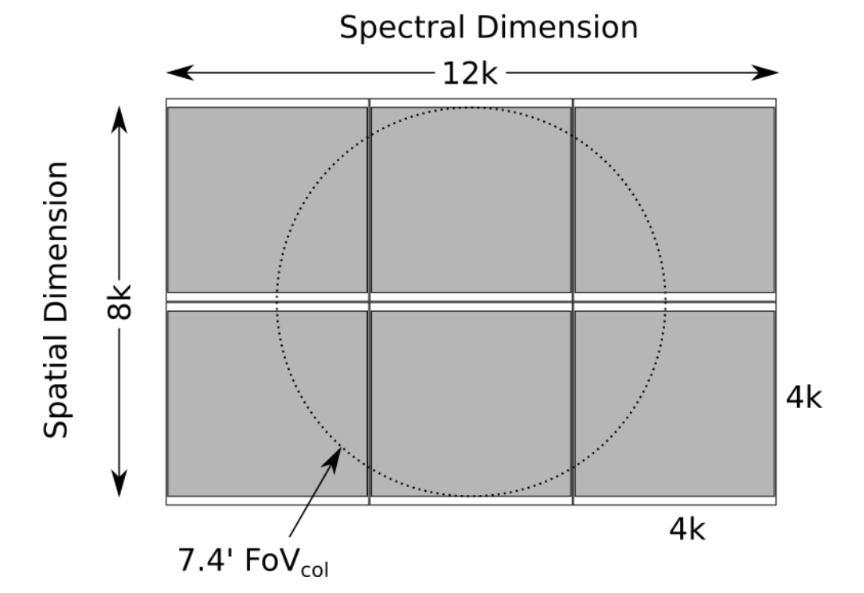
	Single Collimator	Split Collimator
Advantages	Simple design Fewer elements	Higher UV-blue throughput Better color correction Better exit pupil quality Reduced collimator eye relief (smaller optics)
Disadvantages	Large eye relief (large optics) Reduced UV-blue throughput	Astigmatism due to tilted dichroic in converging beam Additional mirror is required Larger mechanical packaging Envelope constraints for high mode resolution

1.2. Astigmatism compensator

- A compensator window tilted at an axis orthogonal to the dichroic;
- Cylindrical compensator or a dichroic with a cylindrical second surface;
- A wedge dichroic and compensator.

5. GMACS Optical Design

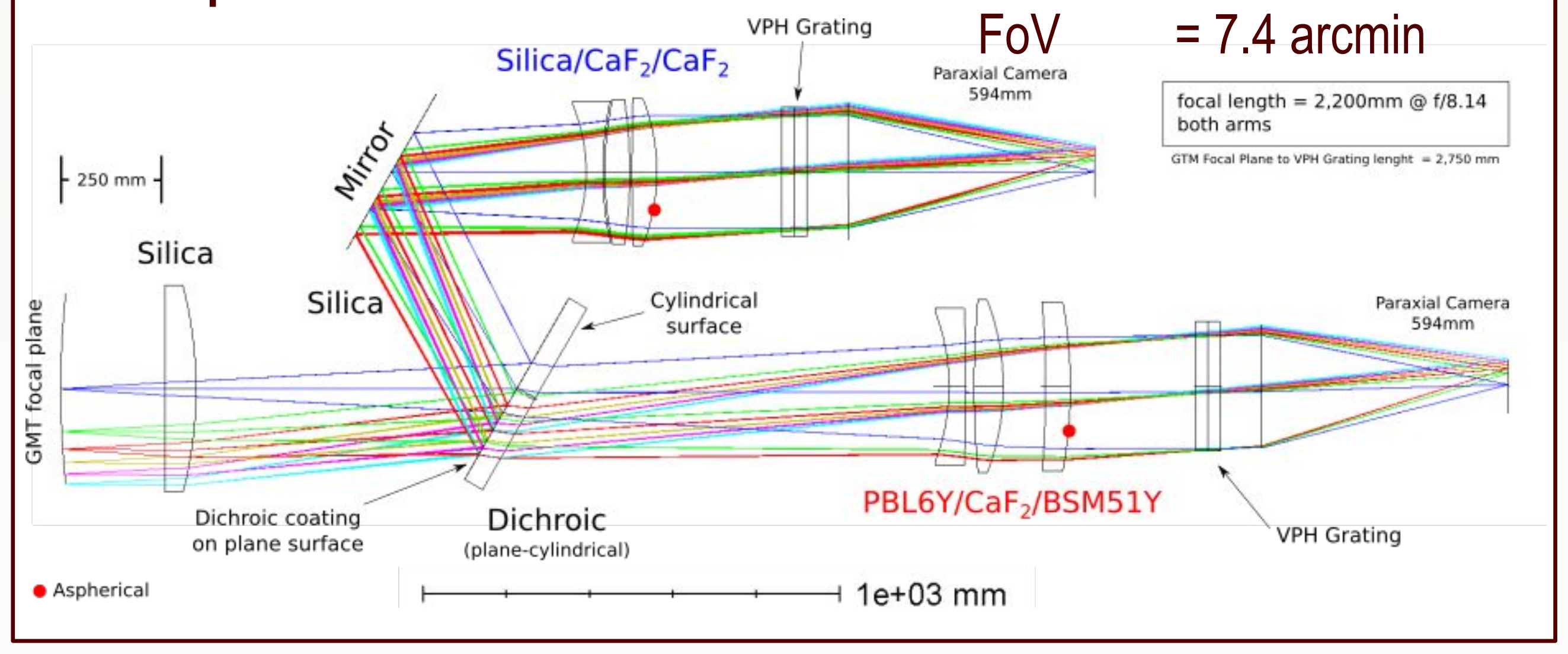
5.1. Detector

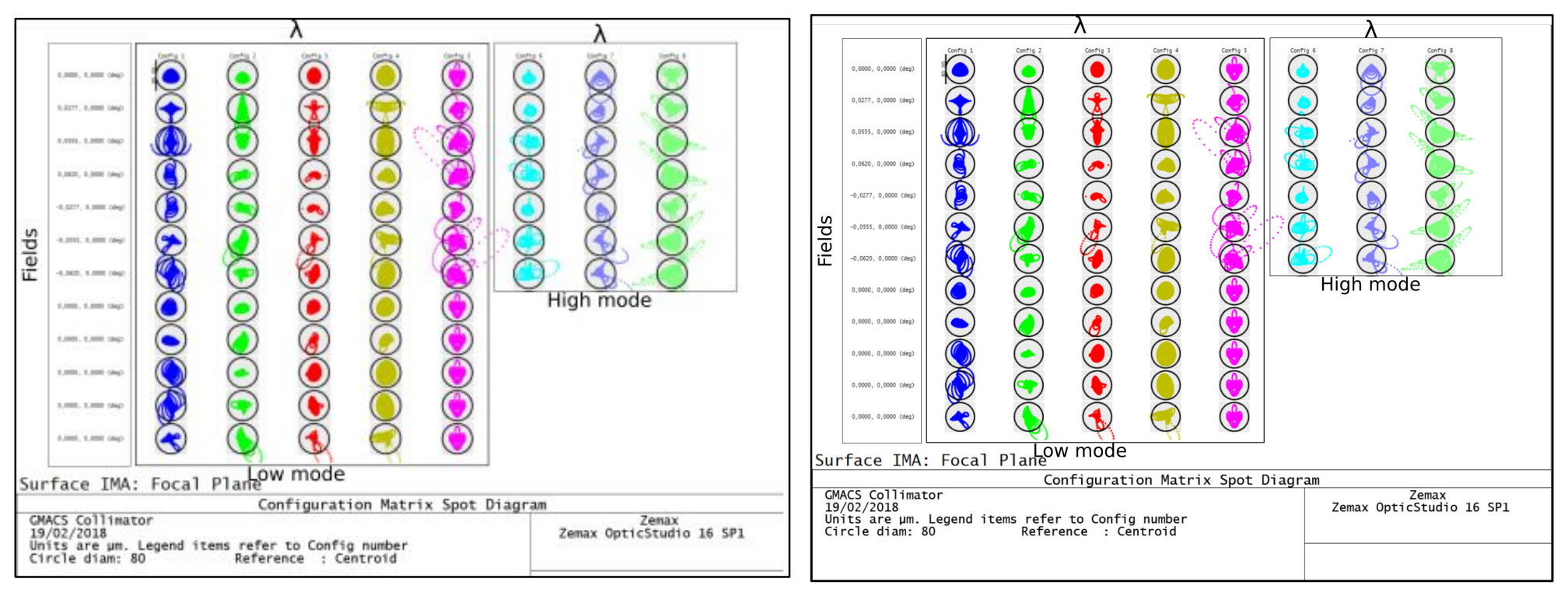


The focal plane is made of a two by three array of 4096 × 4096, 15 µm pixel CCD's for a total of 8k (spatial) by 12k (spectral) pixels.

1.2. Split Collimator

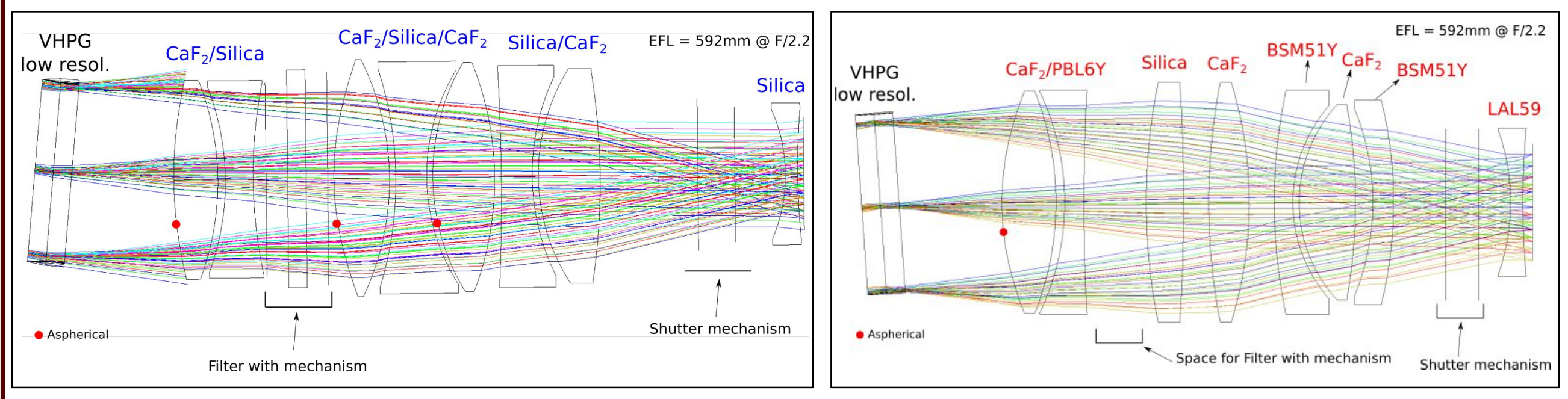
Exit pupil = 270mm
FoV = 7.4 arcmin



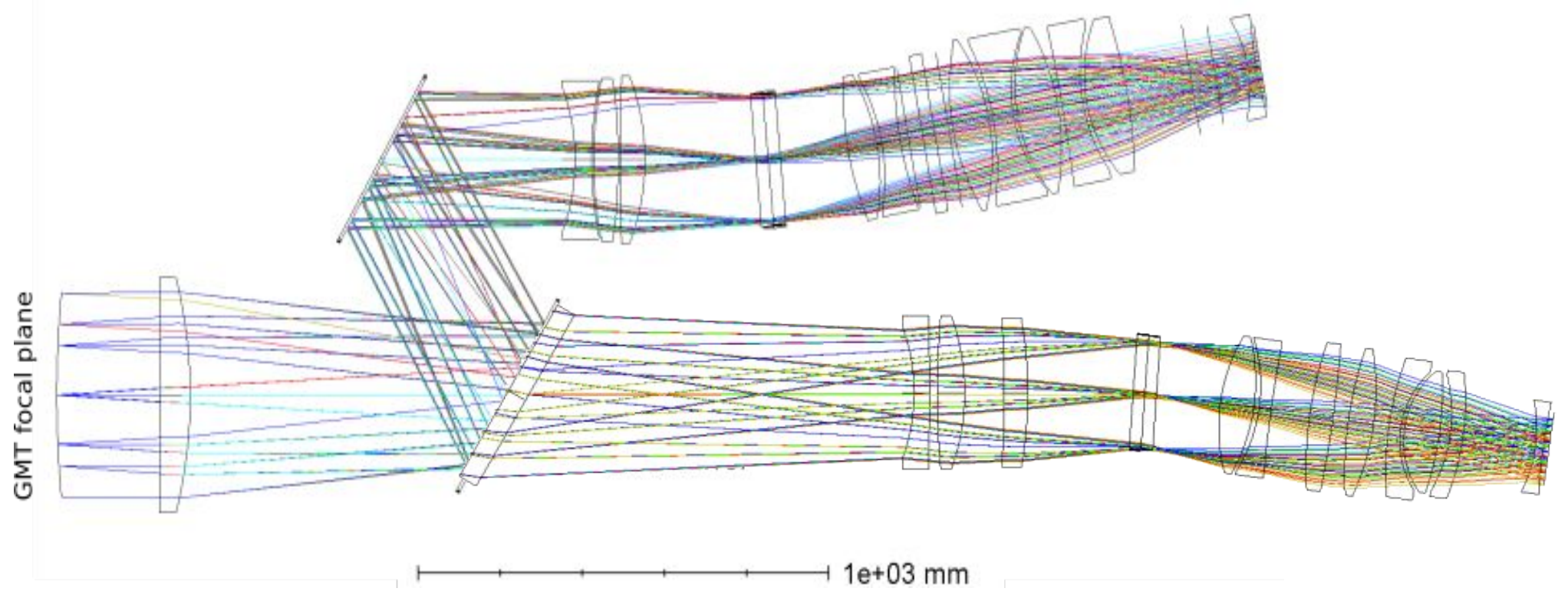


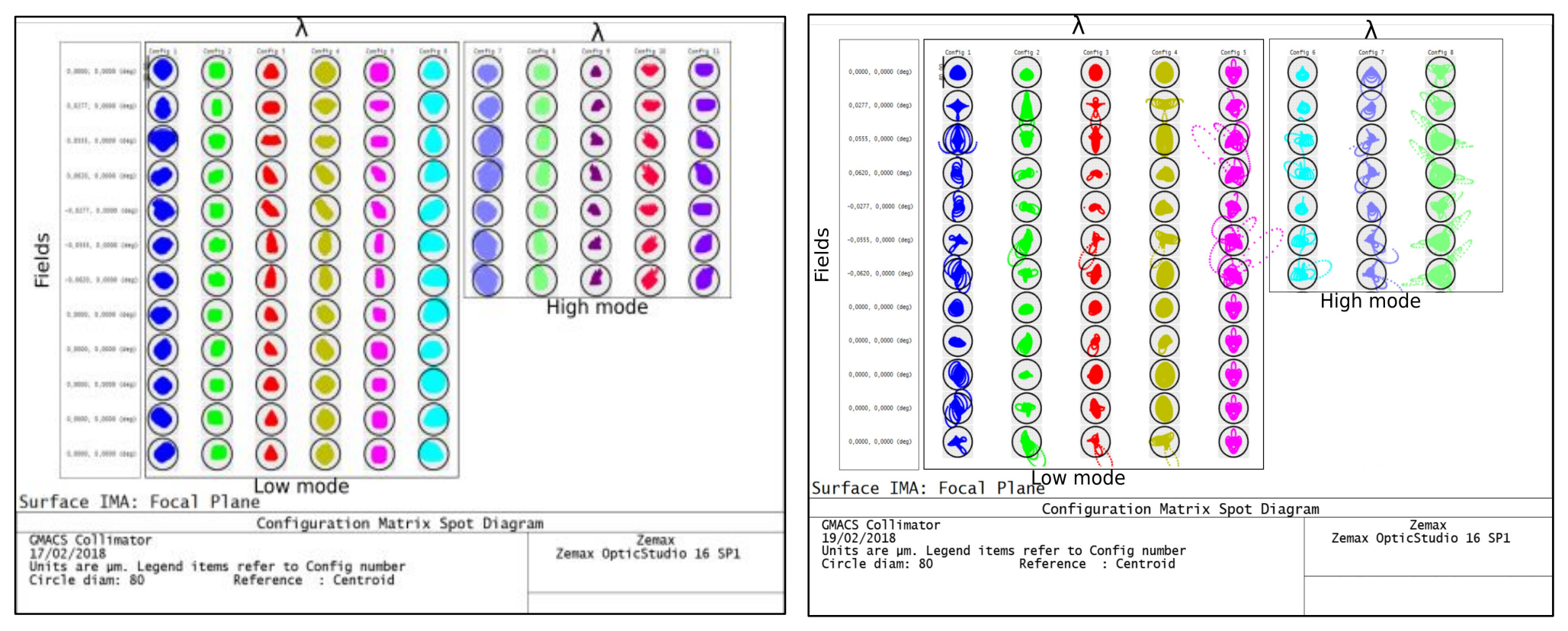
each circle is 0.3 arcsec diameter

1.2. Blue and Red cameras

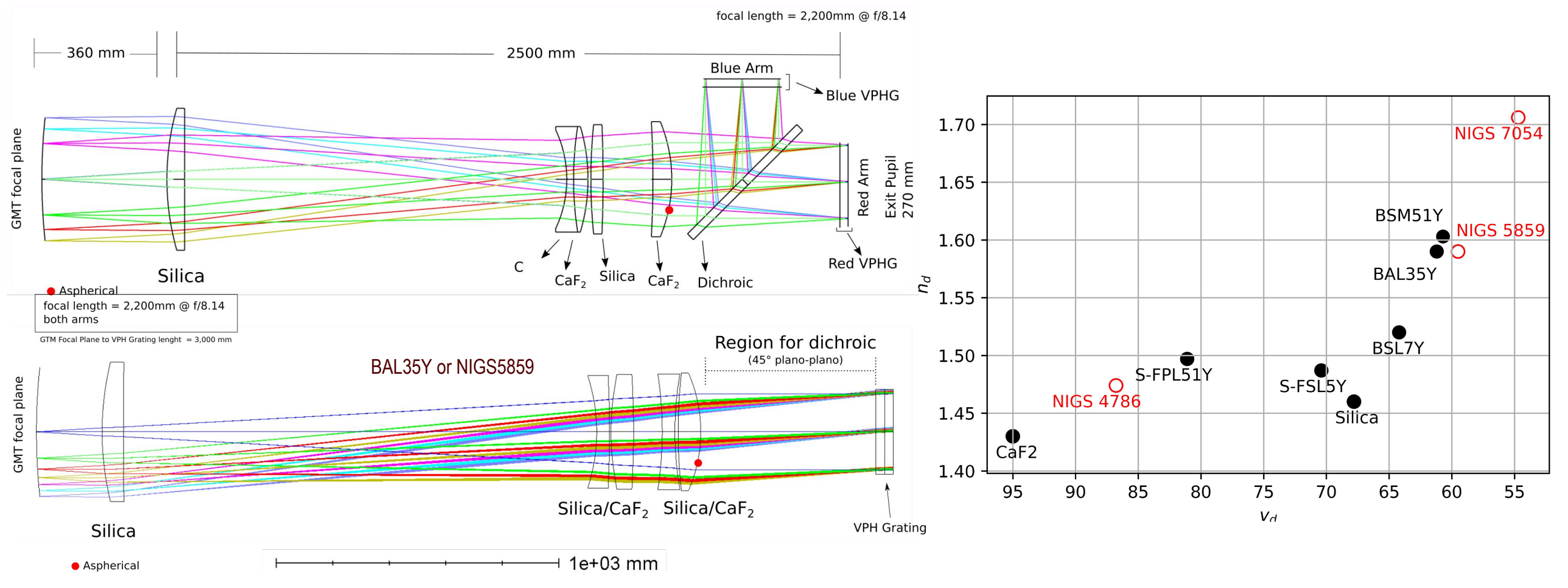


6. GMACS Operation modes - low and high resolution





7. Nikon Glass for single collimator architecture



8. Conclusion

GMACS is currently in conceptual design and will undergo a midpoint conceptual design review in July of 2018. However, the following improvements and proposed studies listed below already were identified and will be explored.

- Additional step in the second round of optimization of the design methodology;
- Split Collimator: wedge dichroic and compensator to correct the astigmatism
- Blue camera: both filter and its mechanisms will be moved next to the shutter and the focal plane;
- Red camera: field flattener will be changed to fused silica (LAL59 quality degradation under cosmic rays incidence)

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