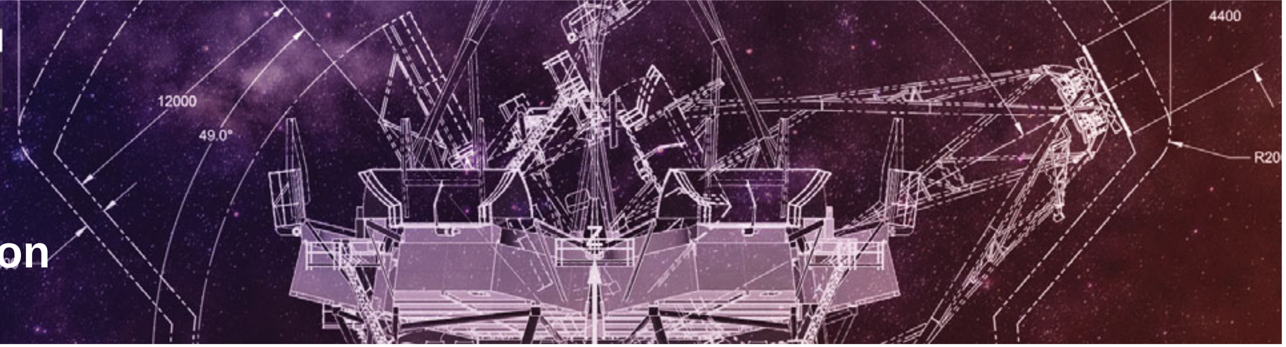
GIANT MAGELLAN TELESCOPE

XVIII IAG/USP Advanced School on Astrophysics



INSTITUTO DE ASTRONOMIA, GEOFÍSICA E CIÊNCIAS ATMOSFÉRICAS

GMACS Brief Project Status
- Optical System description -

Rafael Ribeiro
Ph.D. Student (Optical Designer)
Department of Astronomy

Advisor: Profª. Drª. Claudia de Oliveira

São Paulo, March 1, 2018
Instituto de Astronomia, Geofísicas e Ciências Atmosféricas
Universidade de São Paulo

McDonald Observatory
The University of Texas at Austin

Munnerlyn Astronomical Instrumentation Lab
Texas A&M University

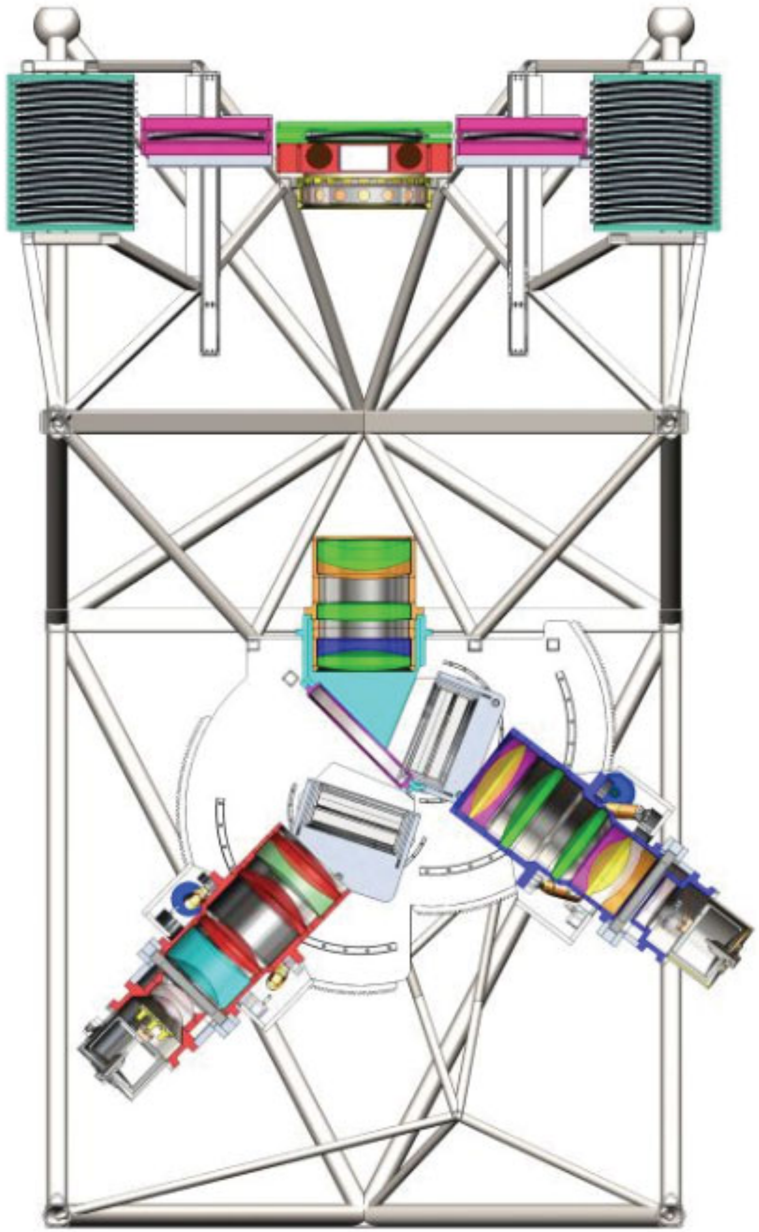
FAPESP

KYUNG HEE UNIVERSITY

Summary

1. GMACS Description
2. Science and Instruments requirements
3. Optical Design
   - Methodology
   - Trade-off case study

GMACS Acronym



Giant Magellan Telescope

Multi-Object

Astronomical and

Cosmological

Spectrograph

GMACS Design Drivers

- High throughput;
- Simultaneous wide wavelength coverage;
- Accurate and precise sky subtraction;
- Moderate resolution;
- Wide field (for an extremely large telescope)
- Optical spectral range.

A spectrometer operating in the visible spectrum (0.32 µm to 1µm) with the capability to observe multiple targets simultaneously is *critical to our goals in the areas of star formation, stellar populations and most extragalactic science* (GMT Science Requirement Book)

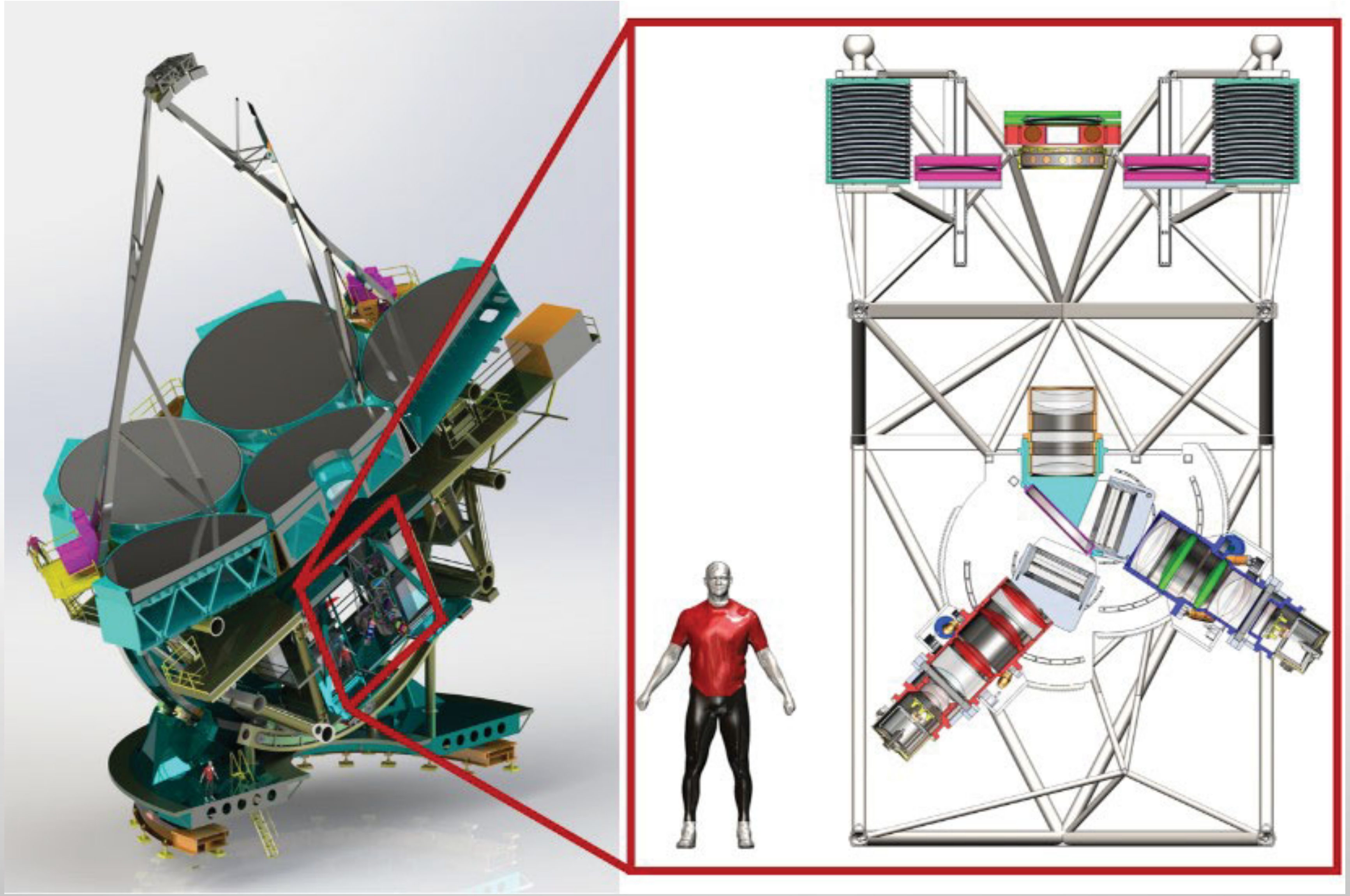
GMACS Science

- The evolution of the distribution of cold gas around galaxies from z=2 to z=4
- Measuring the evolution of the Lyman alpha emission fraction in galaxies at $z < 7.4$
- Census of the Local Group Dark Matter Mass Function and the Dark Matter profiles of dwarf galaxies
- Constraining the Galactic Halo and Galactic Center through spectroscopy of Galaxy Halo and Hypervelocity Stars
- The end of the stellar mass function: Identifying brown dwarfs and subdwarf cool stars.
- Measuring the Faint End Slope of the Lyman alpha Luminosity Function at $z \sim 6$
- White Dwarfs as a Probe of Stellar Evolution
- Surface composition of Kuiper Belt Objects
- A Measurement of the Galaxy Power Spectrum at $z > 2.5$

GMACS Conceptual Design Report 2014

Avaliable at http://instrumentation.tamu.edu/gmacs.html

GMACS in the GMT



GMACS will be mounted in the Gregorian Instrument Rotator

GMACS Principal Functional Parameters

INSTITUTO DE ASTRONOMIA, GEOFÍSICA E CIÊNCIAS ATMOSFÉRICAS

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

First Order Parameters Study

- Telescope *f/#*
- Maximum pupil size
- Resolution 1000-6000

→

Collimator Focal Length
~2000-2500mm

First Order Parameters Study

- Telescope *f/#*
- Maximum pupil size
- Resolution 1000-6000

→ Collimator Focal Length ~2000-2500mm

- Spectrograph FoV
- Detector aspect ratio
- Typical camera designs

→ Camera FoV ≤22°

First Order Parameters Study

- Telescope *f/#*
- Maximum pupil size
- Resolution 1000-6000

→ Collimator Focal Length ~2000-2500mm

- Spectrograph FoV
- Detector aspect ratio
- Typical camera designs

→ Camera FoV ≤22°

- Physical size of detector array
- Camera FoV

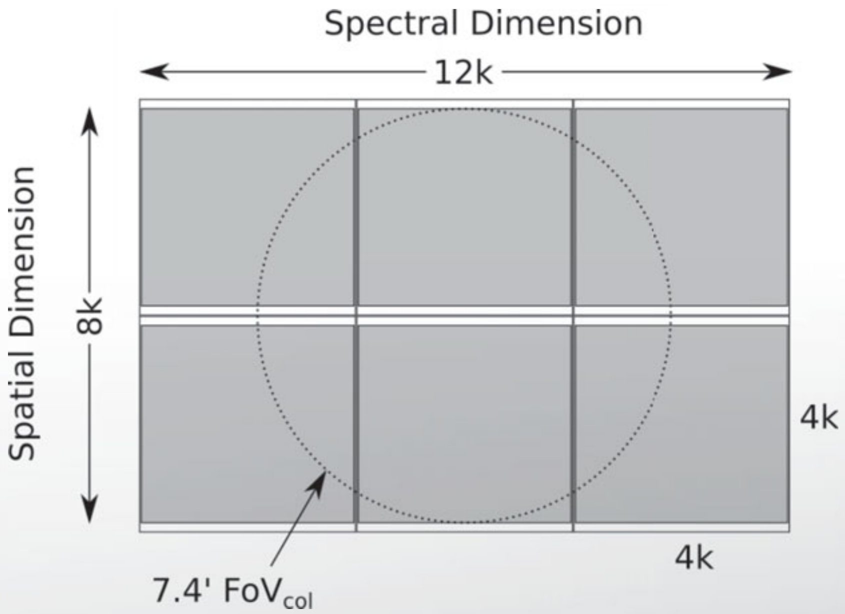
→ Camera Focal Length ~500-700nm

GMACS High Level Description

- Dual-beam VPHG CCD spectrograph;
- On-axis single collimator (until Sept 2017);
- High throughput
- Articulated cameras;
  - Dichroic & VPHG
    - 320nm-550nm (blue spectrum)
    - 550nm-1000nm (red spectrum)
- CCD camera

GMACS Optical Parameters

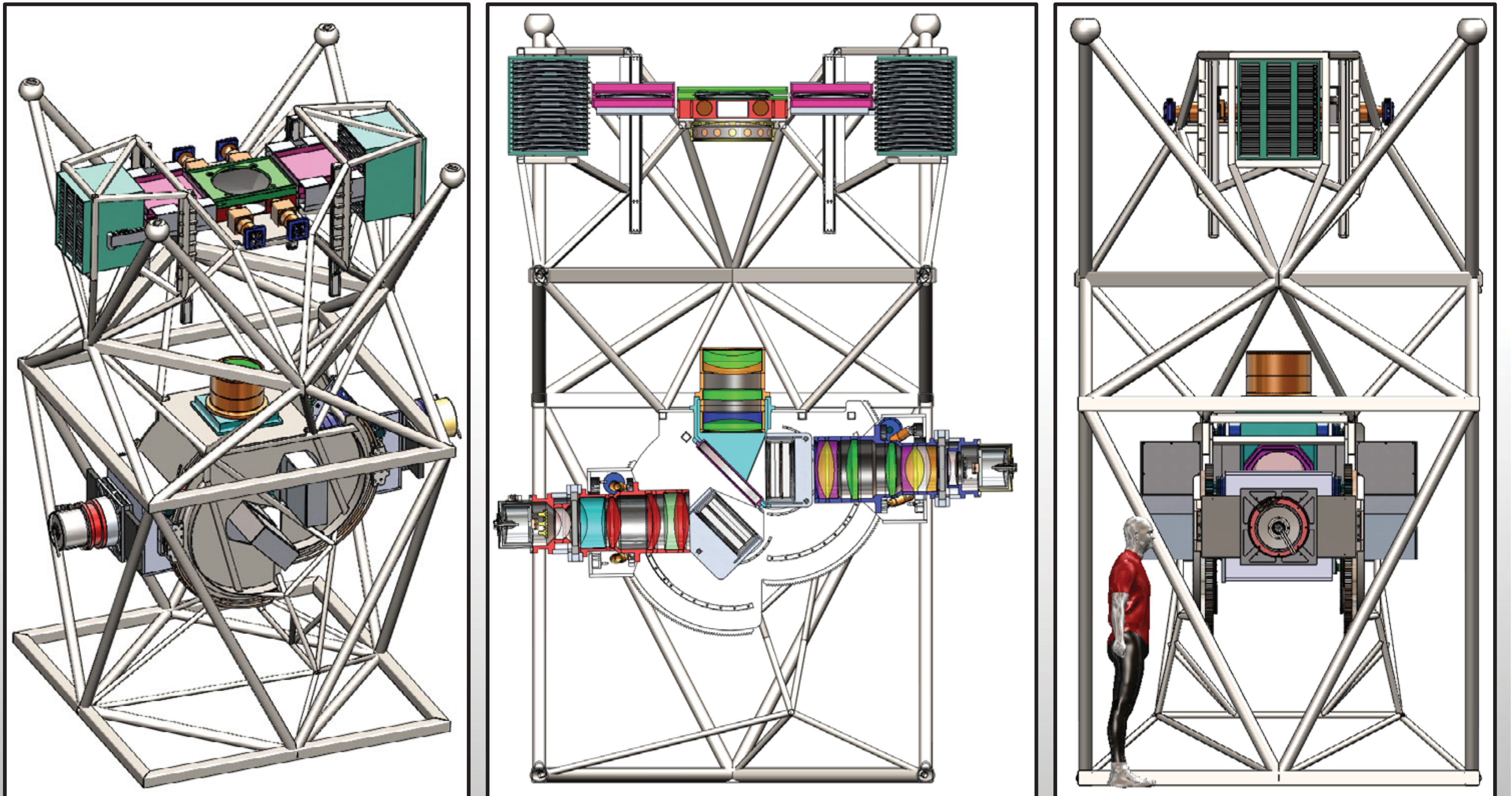
- Collimator focal length = 2,200mm @ F/8.1 (full GMT aperture)
- Cameras focal length = 592mm (F/2.2)
- Exit Pupil = 270mm
- Slit:
  - Length is 7,4 arcmin (42 arcmin²)
  - Width is 0.7 arcsec ≈ 190μm on detector plane (linked to MANIFEST)
- Detector format 2-by-3 of 4k² CCDs @15 μm



Example of reconfiguration options

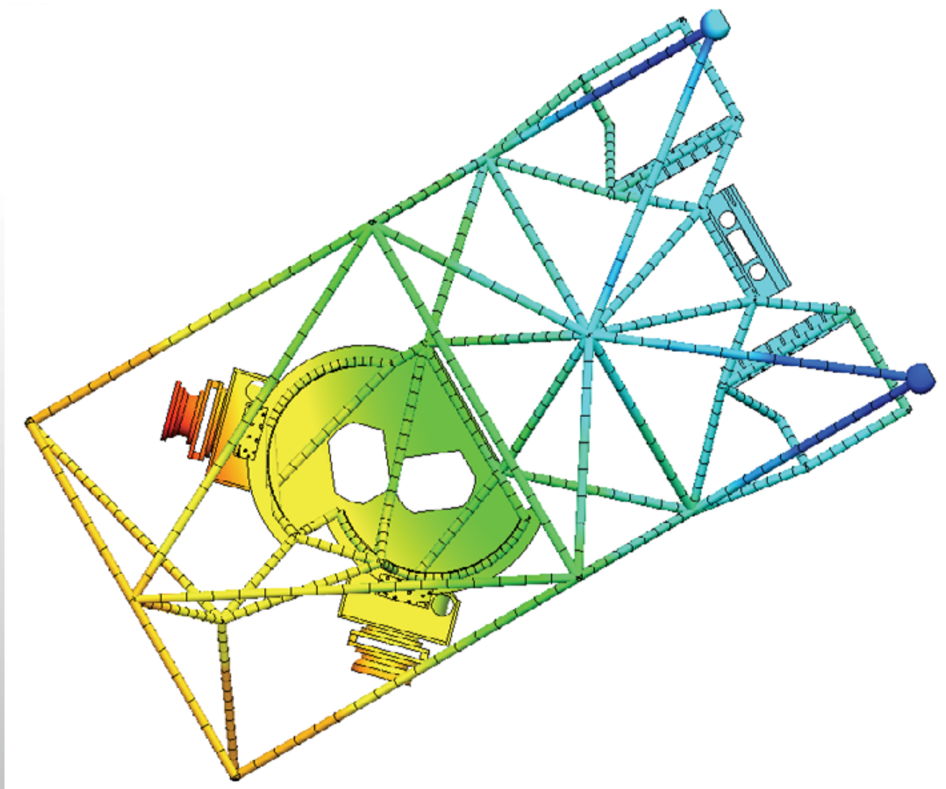
- Wide range of VPH gratings
- VPHG + narrow band filter allows for highly multiplexed observations of narrow spectral features (single/multiple spectral lines of many targets)
- Replace grating with prism, very high throughput, R~50 spectra of very faint targets
- Narrow band image mode (20-30nm) for all GMACS spectral range

GMACS Views – on-axis collimator

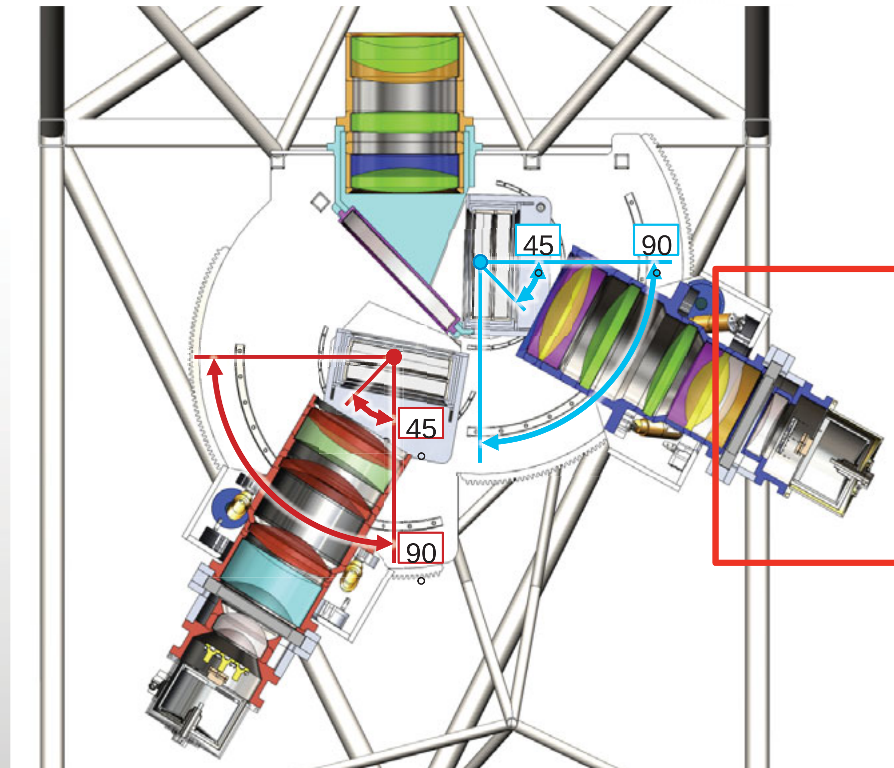


Structure: FEA & Configuration

Gravity & thermal induced deflection & stress

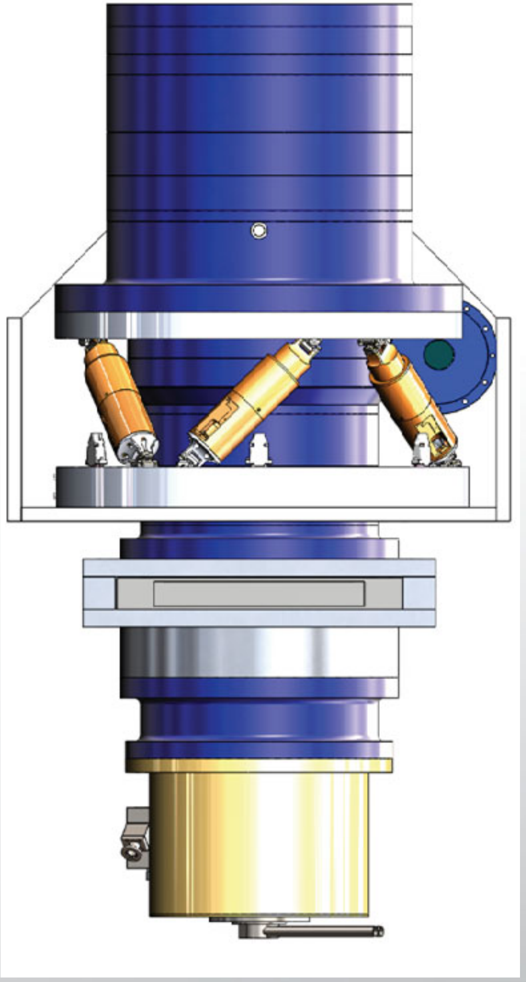


Combinations of instrument configuration and gravity vector

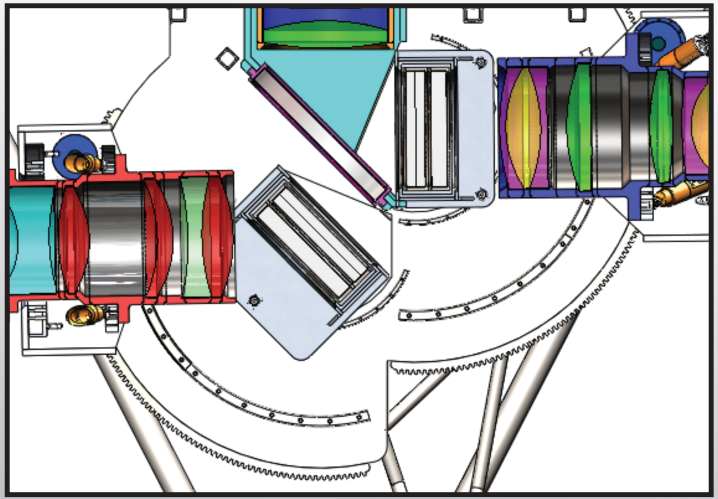


Mechanisms

Shutters



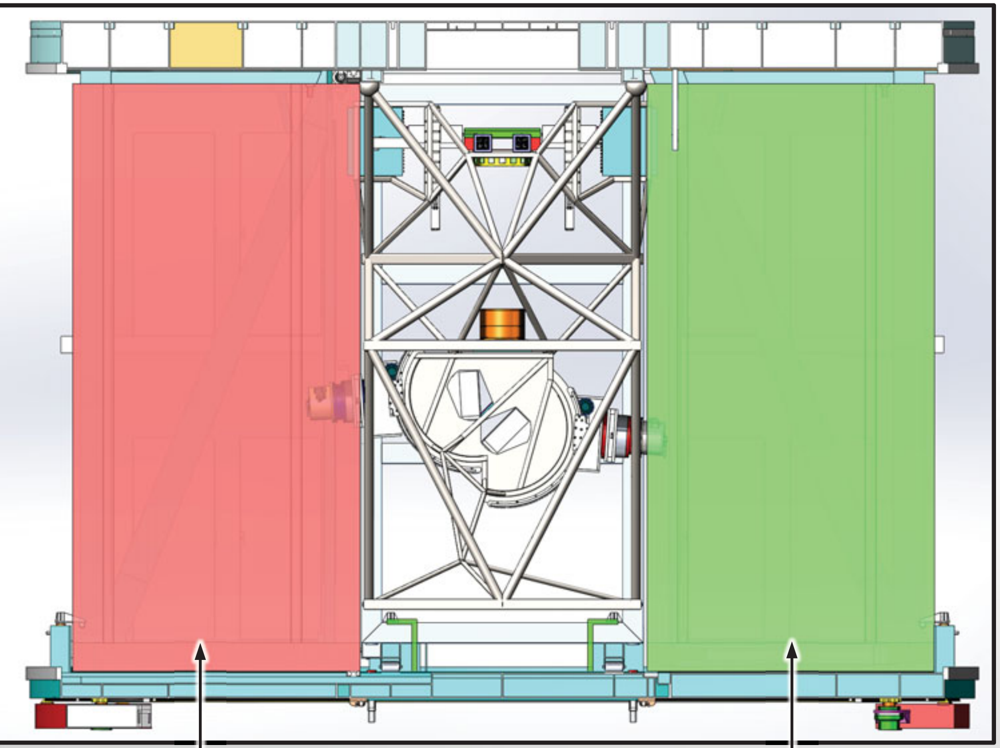
Hexapods



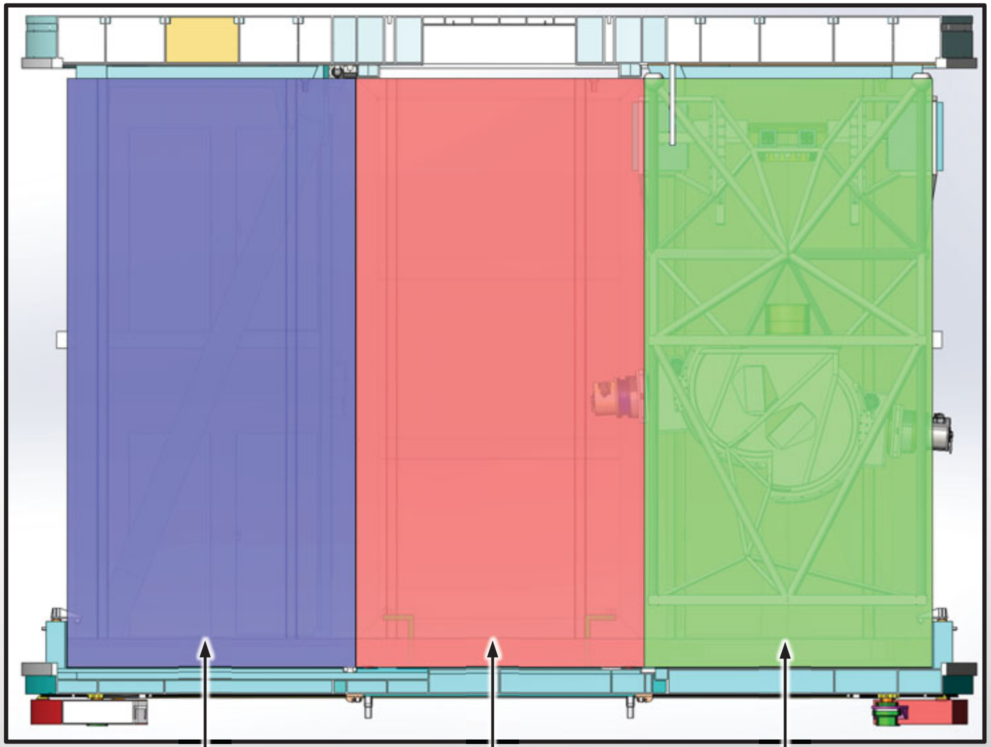
Camera & Grating Articulation

Base configuration with MANIFEST

GMACS in DG Position



GMACS fed by MANIFEST



GMACS Principal Functional Parameters

From the Optical Design Perspective

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

GMACS Principal Functional Parameters

Focal length
Field angle or field size
F/number
Numerical aperture
Wavelength and spectral range
Magnification
Magnification range
Type of lens
Back focus
Front focus
Pupil locations
Illumination
Irradiance uniformity
vignetting
transmission

ptical Design Perspective

	Requirement	Goal
	30 arcmin sq.	50 arcmin sq.
	350-950nm	320-1000nm
	Blue: 1000-6000 Red: 1000-6000	Blue: 1000-6000 Red: 1000-6000
	80% EE at 0.30 arcsec	80% EE at 0.15 arcsec
	0.3 spectral resolution elements/hour	0.1 spectral resolution elements/hour
Number of Gratings	2	≥2
Slit Mask Exchange	12	≥20

GMACS Principal Functional Parameters

Focal length
Field angle or field size
F/number
Numerical aperture
Wavelength and spectral range
Magnification
Magnification range
Type of lens
Back focus
Front focus
Pupil locations
Illumination
Irradiance uniformity
  vignetting
  transmission

Ghost images
Distortion
Variation with conjugates
Variation with spectral region
Size and configuration
Folding components
Interference with optical path
Zoom range
Zoom mechanization
Focus mechanization
Image quality
  Aberrations
  Resolution
  OTF
  MTF
  Energy concentration
  Effect of aperture stop

…erspective

		Goal
		50 arcmin sq.
		320-1000nm
		Blue: 1000-6000 Red: 1000-6000
		80% EE at 0.15 arcsec
		0.1 spectral resolution elements/hour
Number of Gratings	2	≥2
Slit Mask Exchange	12	≥20

GMACS Principal Functional Parameters

Focal length
Field angle or field size
F/number
Numerical aperture
Wavelength and spectral range
Magnification
Magnification range
Type of lens
Back focus
Front focus
Pupil locations
Illumination
Irradiance uniformity
vignetting
transmission

Ghost images
Distortion
Variation with conjugates
Variation with spectral region
Size and configuration
Folding components
Interference with optical path
Zoom range
Zoom mechanization
Focus mechanization
Image quality
Aberrations
Resolution
OTF
MTF
Energy concentration
Effect of aperture stop

Scattered light
Polarization
Veiling glare
Light baffling
Off-axis rejection
Field stop definition
Diffraction effects
Tolerances
Depth of focus
Interface with variable aperture
Interface with autofocus system
Image quality at various apertures
Cost of design
Cost of prototype
Cost of production
Schedule and delivery time
Optical interfacing with instrument
Materials
Availability
Cost

Number of Gratings	2
Slit Mask Exchange	12

GMACS Principal Functional Parameters

Focal length
Field angle o
F/number
Numerical a
Wavelength
Magnificatio
Magnificatio
Type of lens
Back focus
Front focus
Pupil locatio
Illumination
Irradiance w
vi
tr

Numbe
Slit Mas

Environmental considerations
Hazardous materials
Environment
Temperature range
Storage conditions
Atmospheric pressure
Humidity
Vibration and shock
Availability of subcontractors
Level of technology
Coatings
Transmission
Reflectivity
Absorption
Availability
Risk
Environmental effects
Weight
Moment about mounting
Producibility
Manufacturability

s
th conjugates
h spectral region
iguration
onents
vith optical path
iization
iization
ns
n
ncentration
iperture stop

Scattered light
Polarization
Veiling glare
Light baffling
Off-axis rejection
Field stop definition
Diffraction effects
Tolerances
Depth of focus
Interface with variable aperture
Interface with autofocus system
Image quality at various apertures
Cost of design
Cost of prototype
Cost of production
Schedule and delivery time
Optical interfacing with instrument
Materials
Availability
Cost

GMACS Principal Functional Parameters

Focal length
Field angle o
F/number
Numerical a
Wavelength
Magnificatio
Magnificatio
Type of lens
Back focus
Front focus
Pupil locatio
Illumination
Irradiance w

Environmental considerations
Hazardous materials
Environment
Temperature range
Storage conditions
Atmospheric pressure
Humidity
Vibration and shock
Availability of subcontractors
Level of technology
Coatings
Transmission
Reflectivity
Absorption
Availability
Risk
Environmental effects
Weight
Moment about mounting
Producibility
Manufacturability

Mounting procedures
Mounting interfaces
Mechanical interface with instrument
Detector
Photographic
Sampling array
Signal to noise
Surface finish, cosmetics
Beam parameters
Radiation damage
Irradiance damage
Prior experience
Track record
Prior art
Patentability
Patent conflict situation
Competitive situation
Marketability

Availability
Cost

GMACS Principal Functional Parameters

Focal length
Field angle o
F/number
Numerical a
Wavelength
Magnificatio
Magnificatio
Type of lens
Back focus
Front focus
Pupil locatio
Illumination
Irradiance w
vi
tr

Number
Slit Mas

Environmental considerations
Hazardous materials
Environment
Temperature range
Storage conditions
Atmospheric pressu
Humidity
Vibration and shoc
Availability of subcon
Level of technology
Coatings
Transmission
Reflectivity
Absorption
Availability
Risk
Environmental effects
Weight
Moment about mounting
Producibility
Manufacturability

s
th conju
perture s

Lifetime of product
Rate of production
Environmental hazards
Liability issues
Delay to market
Timing of disclosure
Integration with products
Customer view of product
Styling
Financial viability
Investment requirements
Investment risk

Mounting procedures
Mounting interfaces
Mechanical interface with instrument
phic
array
noise
, cosmetics
eters
mage
mage
nce
tability
t conflict situation
Competitive situation
Marketability
Availability
Cost

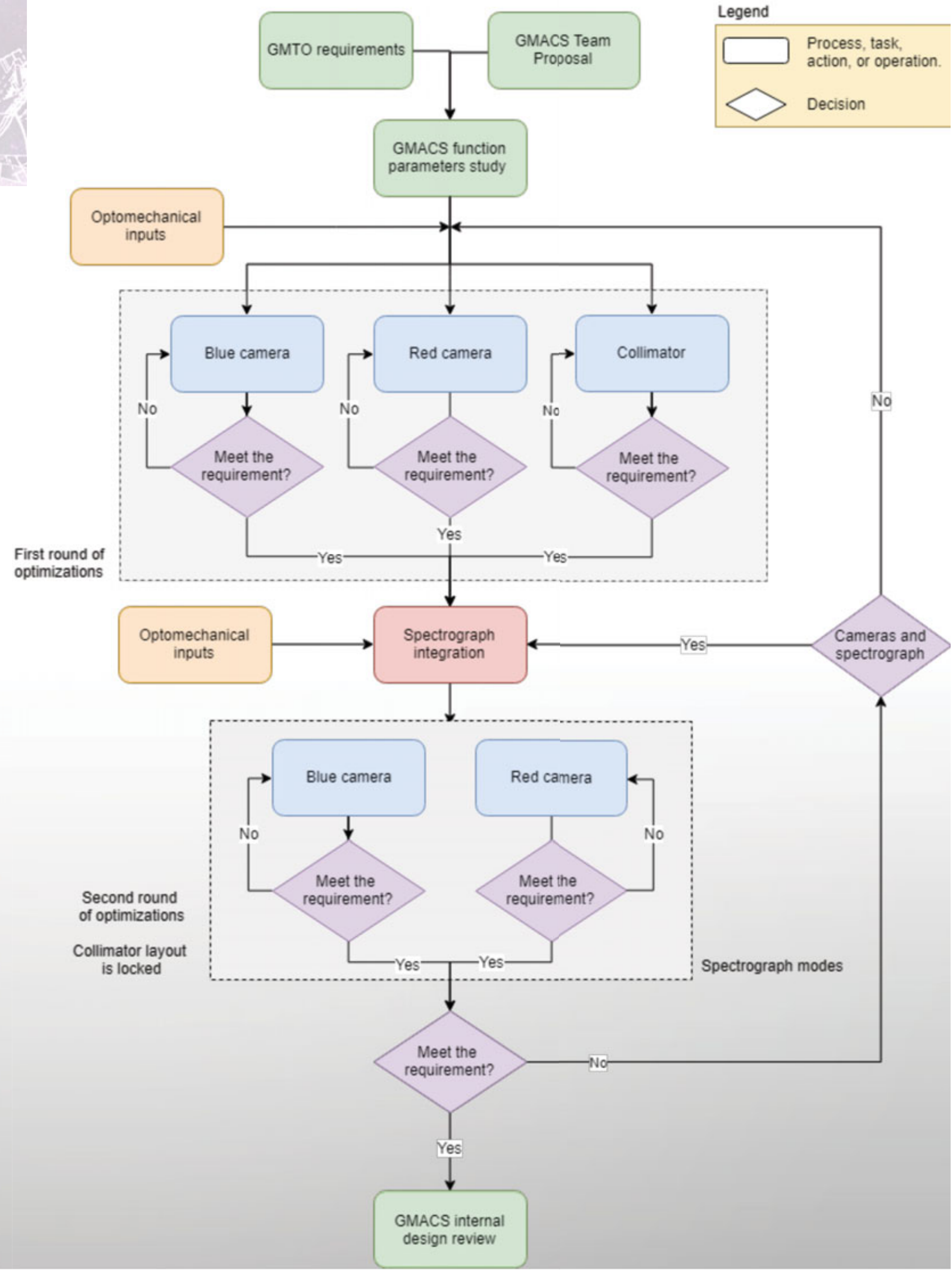
ture
stem
ertures
trument

GIANT MAGELLAN TELESCOPE

Methodology

GMACS Optical System

- Subsystem optimizations
  - Intermediates specifications
- Optomechanical inputs
- Integration and spectrograph mode optimizations



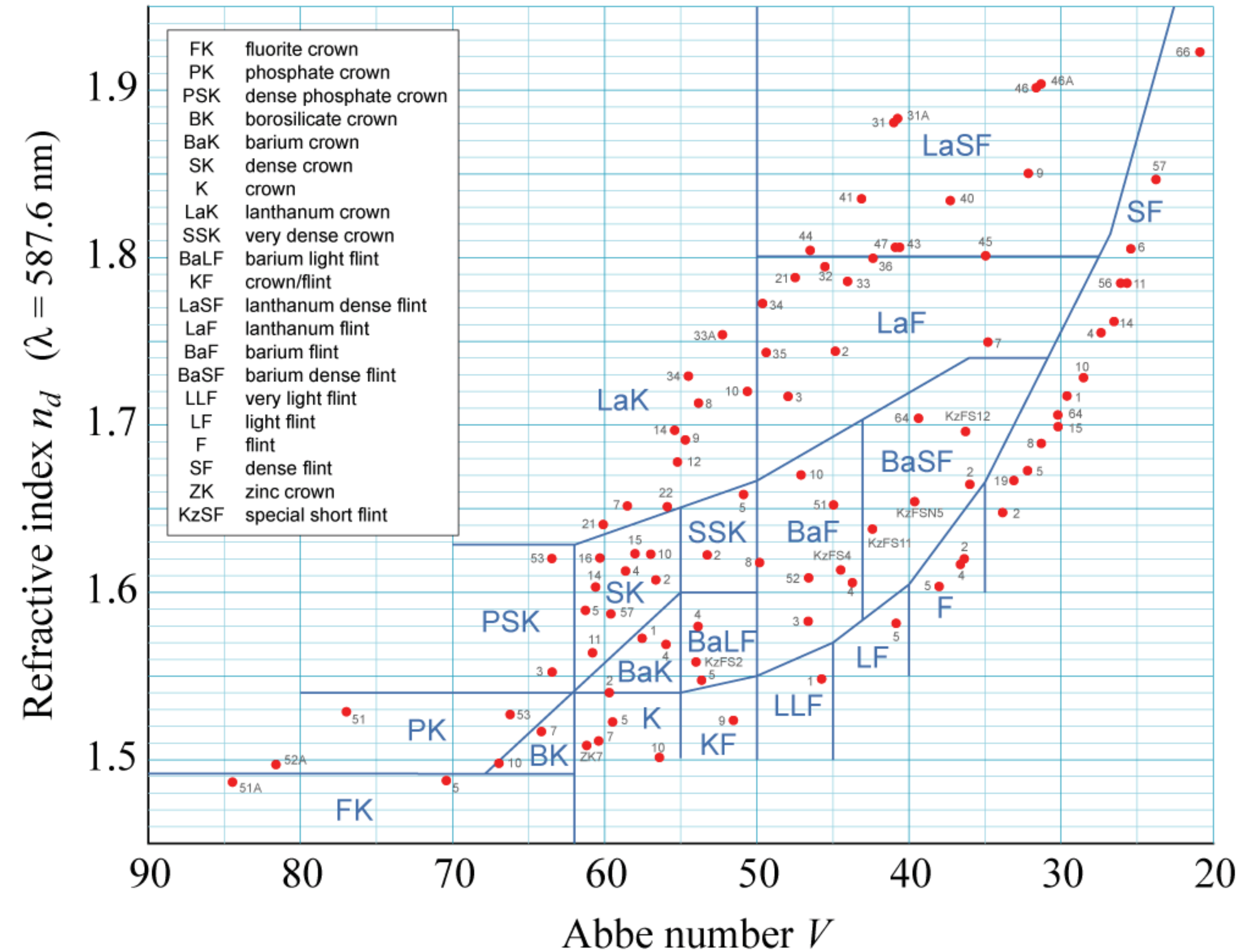
Case Study: UV cut-off wavelength

Small changes in requirements can cause huge effect on the optical design

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

Optical Design Constraints

vd is Abbe Number (dispersion: higher dispersion for lower vd)

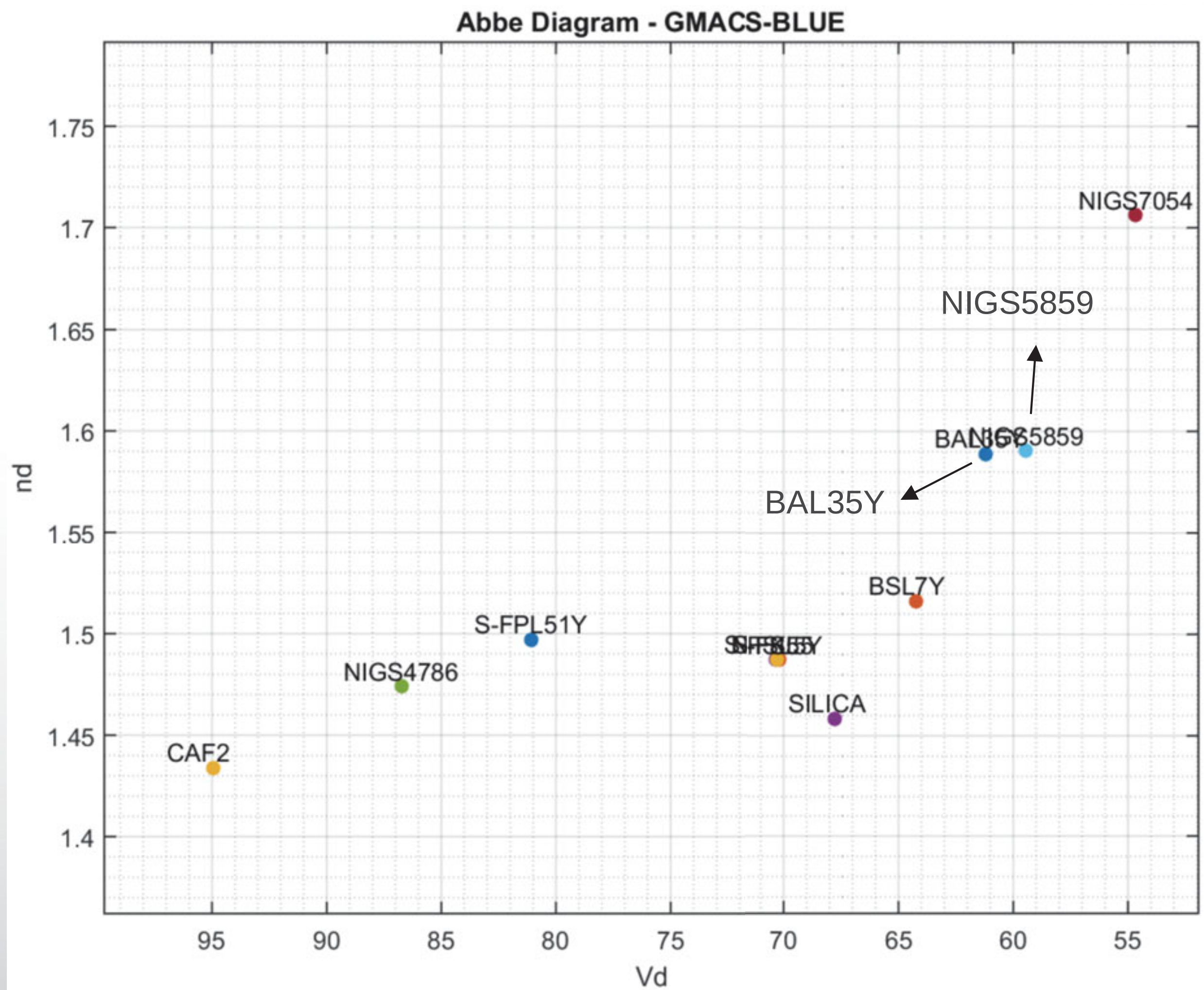


Optical Design Constraints

vd is Abbe Number (dispersion: higher dispersion for lower vd)

Glass choice:

- Large blanks;
- Internal transmittance



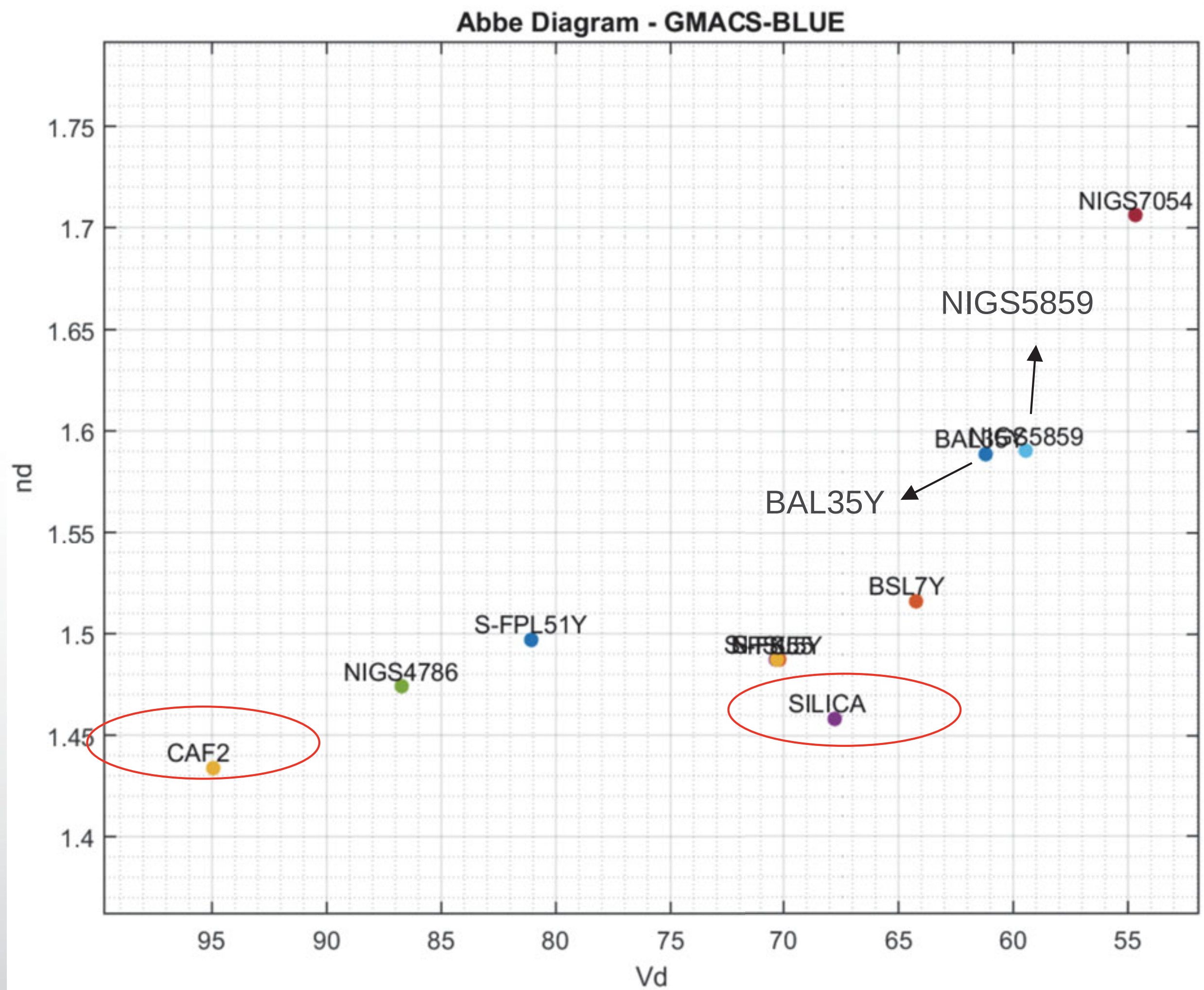
Optical Design Constraints

vd is Abbe Number (dispersion: higher dispersion for lower vd)

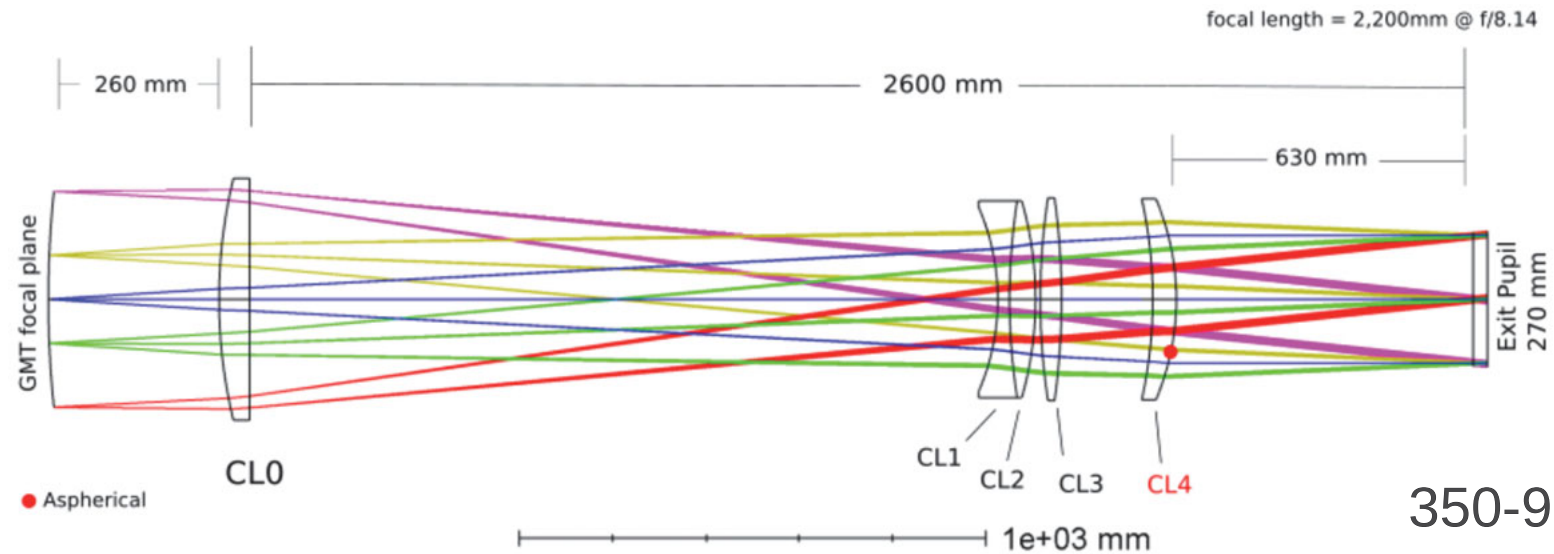
Glass choice:

- Large blanks;
- Internal transmittance

- **320nm internal transmittance only for FS and CaF_2**

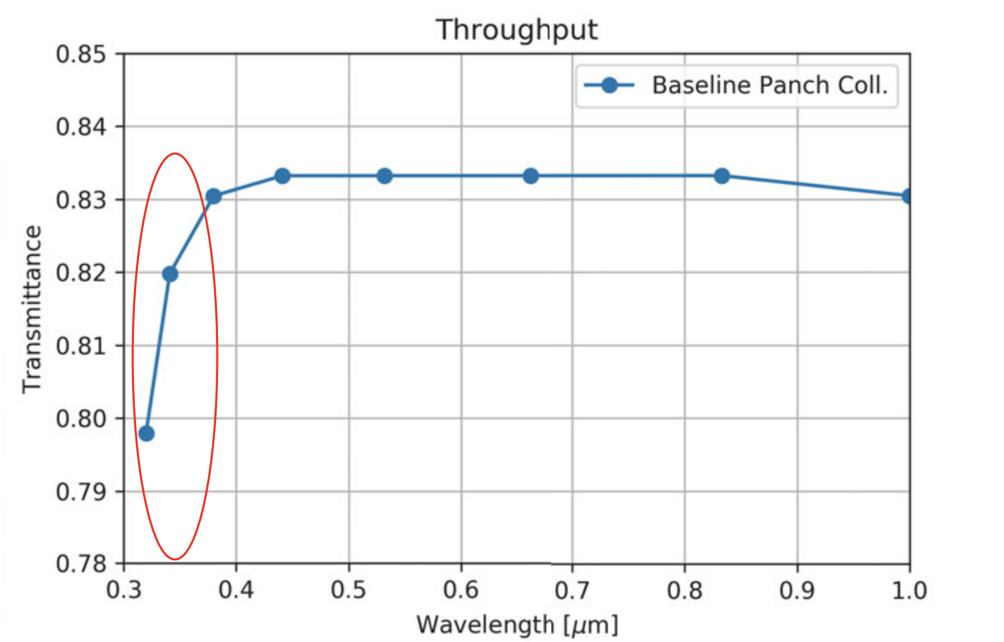


Panchromatic Collimator – On axis

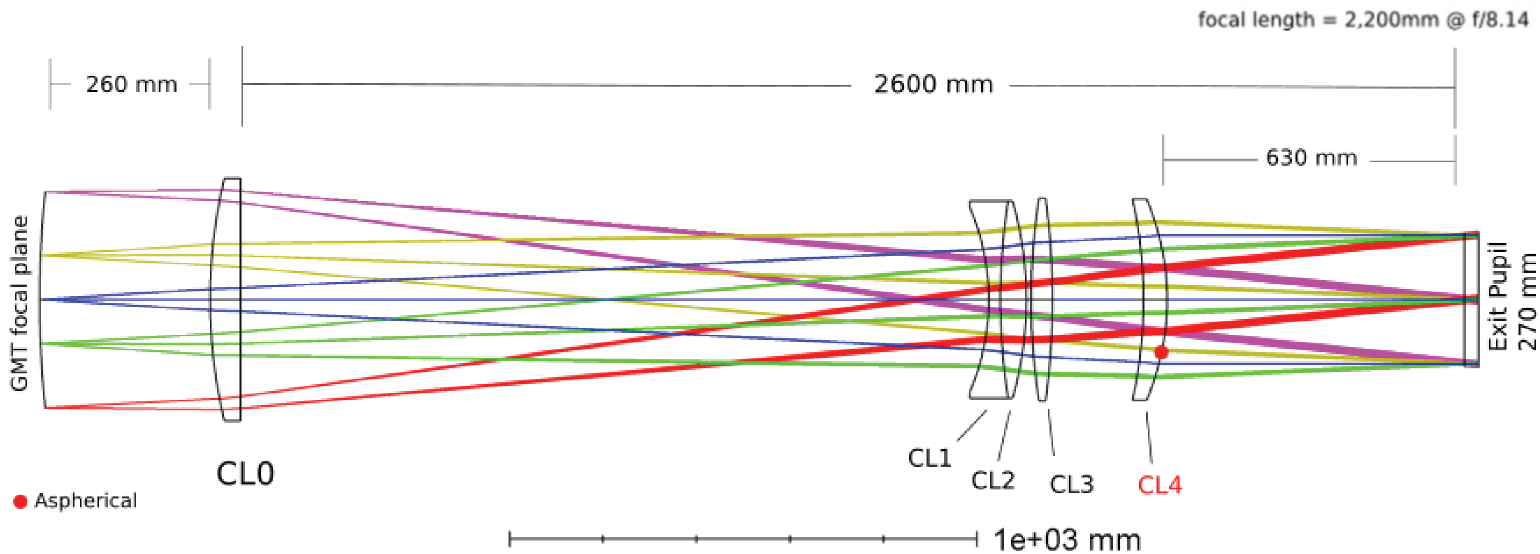


FS
NIGS5859/CaF2
Silica
CaF2

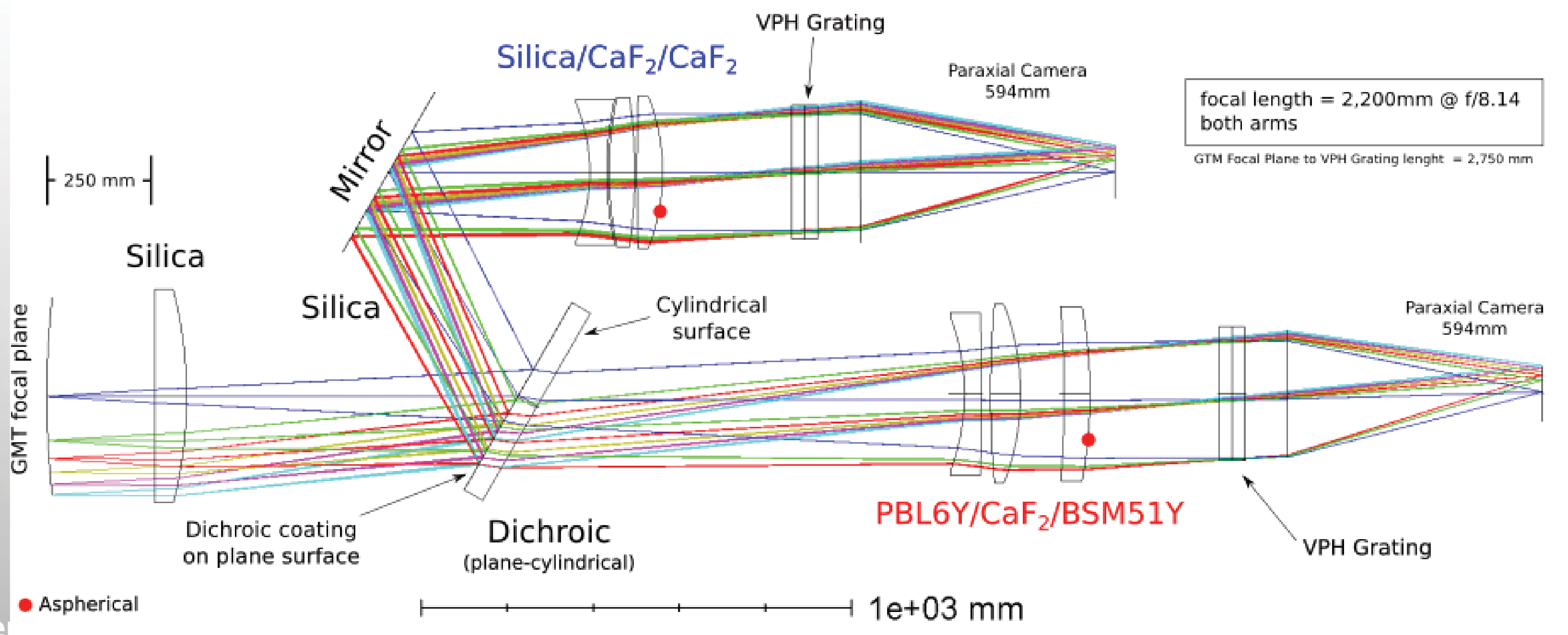
350-950nm



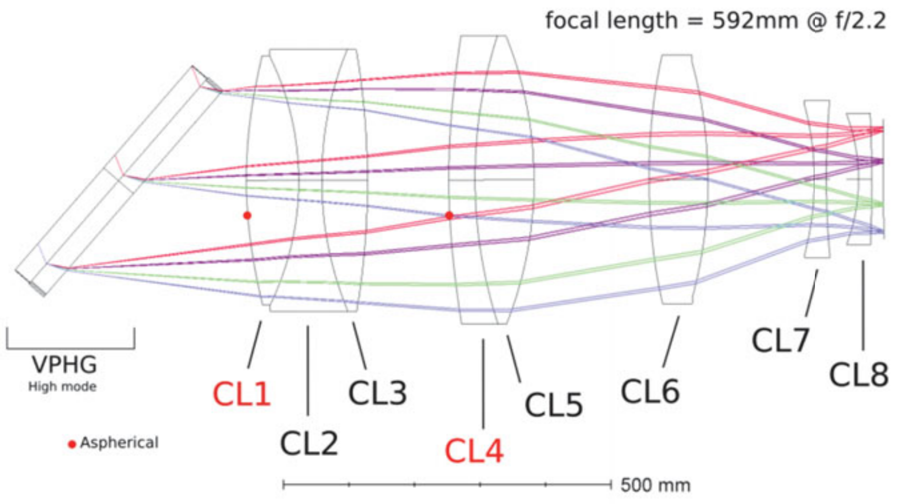
On Axis and Split Collimator Architectures

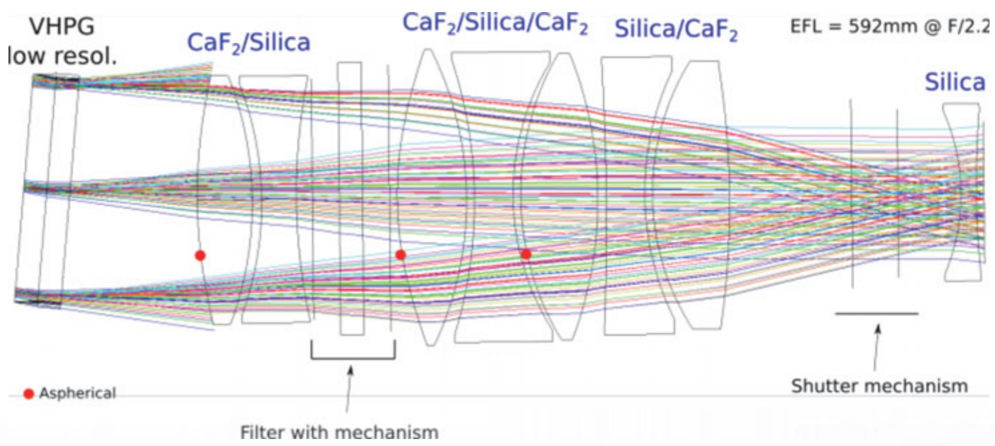


FS
NIGS5859/CaF2
Silica
CaF2



Respective Blue Cameras





	ID	Glass Material	Opt. Diameter[mm]	Asp. surf.\BFSD
TP1	CL1	CaF_2	350	1st/340μm
	CL2	NIGS5859	360	-
	CL3	NIGS4786	185	-
DB1	CL4	Silica	430	1st/340μm
	CL5	CaF_2	430	-
	CL6	CaF_2	380	-
	CL7	Silica	240	-
	CL8	Silica	220	-

Other constraints were included:

- Avoid glass interfaces with CaF_2
- Mechanical space for filter (with mechanism) and shutter
- Vignetting

Conclusion

GMACS project is in progress.

Current work on optical design:

- Trade-off analysis (Reflexive vs refractive optics, collimator architecture, dichroic transition wavelength, vignetting on camera, TCA effects on the spectra etc.).
- GMACS optical system for Split collimator is ready for optomechanical pre-design – flexure analysis.

All GMACS Team representatives will be at next SPIE Conference

Austin, Texas, United States
10 - 15 June 2018

SPIE. ASTRONOMICAL TELESCOPES + INSTRUMENTATION

rafael.alves.ribeiro@usp.br

Thank you!