MEGARA Optics Design

Multi Espectrógrafo en GTC de Alta Resolución para Astronomía

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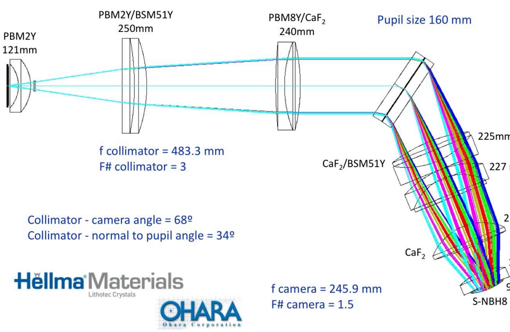
Abstract

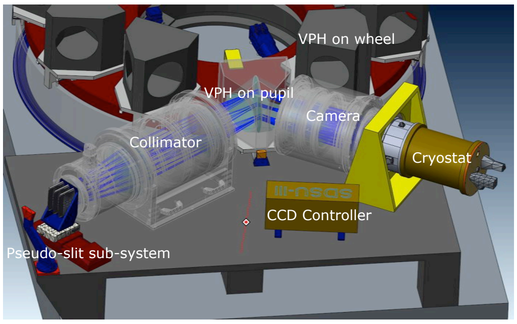
We summarizes the main aspects of the optics detailed design for MEGARA spectrograph. The spectrograph is a fully refractive system composed by a Pseudo-slit, where the fibers are placed like in a long slit and that it is mounted on a focusing mechanism; the Collimator, 1 singlet and two doublets; a set of 18 large and high-performance VPH-gratings at the 160mm Ø pupil position (11 of them being mounted simultaneously in the instrument); the Camera (two doublets and 3 singlets), with the last lens being the cryostat window; and the 4k x 4k Detector. The shutter and the order sorting filters, placed inside the collimator barrel, complete the optical system. MEGARA passed the Optics Detailed Design Review in May 2013, some of the blanks have been already ordered, and the Optics manufacturing phase has already started at INAOE and CIO in México.

Main optics: Collimator and Camera

The Optical CDR package has included all the analyses needed to proceed with MEGARA Optics fabrication. This includes the thermal analysis, ghost analysis, complete image quality evaluation; image stability, image quality and throughput error budgets and the production of the complete set of manufacturing drawings.



Optical Layout of MEGARA spectrograph



Collimator Optical Elements

Element	Material	R1 (mm)	R2 (mm)	Central Thick. (mm)	Blank ∅ (mm)
COLL-S1	PBM2Y	-91.0 (x)	-113.3	35.0	160.0
COLL-D2	PBM2Y	flat	-728.1	35.0	277.0
COLL-D3	BSM51Y	- 728.1	-398.8	35.0	277.0
COLL-D4	PBM8Y	+1259.9	+344.5	25.0	265.0
COLL-D5	CaF2	+344.5	-542.5	45.0	255.0

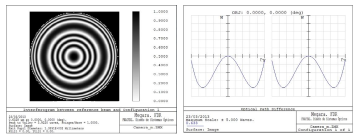
Camera Optical Elements

Element	Material	R1 (mm)	R2 (mm)	Central Thick. (mm)	Blank ∅ (mm)
CAM D-1	CaF2	+435.9	-231.7	60.0	241.0
CAM D-2	BSM51Y	-231.7	Flat	25.0	245.0
CAM D-3	BAL15Y	+269.2	+145.1	25.0	245.0
CAM D-4	CaF2	+145.1	Flat	60.0	225.0
CAM S-5	CaF2	+156	-1143	62.0	225.0
CAM S-6	S-LAH55V	+176.4	365.8	40.0	145.0
CAM S-7	S-NBH8	-162.5	219.5	30.0	115.0

Image Quality Error Budget Summary

ITEM	Σ (μm) MR-B	σ (μm LR-Z	σ (μm) LR-U	Comment
Nominal performance	**8.50**	**9.81***	**8.20***	Nominal design in one representative mode
Collimator fabrication (lens thickness, wedge, surface irregularity, curvature)	**2.26**	**2.03**	**1.86**	200 (PDR) and 1000 Monte Carlo runs in normal distribution, respectively.
Camera fabrication (lens thickness, wedge, surface irregularity, curvature)	**2.96**	**4.79**	**4.74**	200 (PDR) and 1000 Monte Carlo runs in normal distribution, respectively.
Collimator AIV (axial and lateral decentration, tilts).	**1.95**	**2.08**	**1.99**	200 (PDR) and 1000 Monte Carlo runs in normal distribution, respectively.
Camera AIV (axial and lateral decentration, tilts).	**3.10**	**3.98**	**3.11**	200 (PDR) and 1000 Monte Carlo runs in normal distribution, respectively.
Uncompensated	**3.60**	**2.18**	**3.02**	200 (PDR) and 1000 Monte Carlo runs in normal distribution, respectively.
Thermal	**2.10**	**2.10**	**2.10**	Worst case. Analytical model
Glass homogeneity	**3.60**	**3.60**	**3.60**	Analytical model
Pupil elements	**5.00**	**5.00**	**5.00**	Allocated Estimation
Detector Flatness	**1.32**	**1.32**	**1.32**	Considering flatness ± 5 μm
Pseudo-slit curvature	**3.20**	**3.20**	**3.20**	
Atmospheric Effect	**0.14**	**0.14**	**0.14**	Performance Difference between 0.77 and 1at
TOTAL (rms squared)	**12.92**	**14.23**	**13.05**	**Target value: 19.22**

Predicted values for the different Image Quality EB contributors at the time of optical CDR.



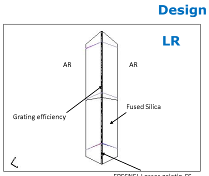
All the interferograms for final tests at the level of the collimator and camera have been simulated. The figure shows a nominal interferogram for central field (0º AOI), tilt/piston removed. The lower figure is the OPD plot.

Pupil Elements

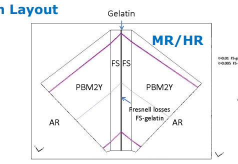
MEGARA gratings: scientific requirements

VPH Name	Setup	R_{FWHM}	λ_1-λ_2 (Å)	Λc (Å)	Δλ (@ λc), Å	Δv km/s	lin res Å/pix
VPH405-LR	LR-U	6028	3653 – 4386	4051	0.672	50	0.17
VPH480-LR	LR-B	6059	4332 – 5196	4800	0.792	49	0.20
VPH570-LR	LR-V	6080	5143 – 6164	5695	0.937	49	0.23
VPH675-LR	LR-R	6099	6094 – 7300	6747	1.106	49	0.28
VPH799-LR	LR-I	6110	7220 – 8646	7991	1.308	49	0.33
VPH890-LR	LR-Z	6117	8043 – 9630	8900	1.455	49	0.36
VPH410-MR	MR-U	12602	3917 – 4277	4104	0.326	24	0.08
VPH443-MR	MR-UB	12370	4225 – 4621	4431	0.358	24	0.09
VPH481-MR	MR-B	12178	4586 – 5024	4814	0.395	25	0.10
VPH521-MR	MR-G	12035	4963 – 5443	5213	0.433	25	0.11
VPH567-MR	MR-V	11916	5393 – 5919	5667	0.476	25	0.11
VPH617-MR	MR-VR	11825	5869 – 6447	6170	0.522	25	0.13
VPH656-MR	MR-R	11768	6241 – 6859	6563	0.558	25	0.14
VPH712-MR	MR-RI	11707	6764 – 7437	7115	0.608	26	0.15
VPH777-MR	MR-I	11654	7382 – 8120	7767	0.666	26	0.17
VPH926-MR	MR-Z	11638	8800 – 9686	9262	0.796	26	0.20
VPH665-HR	HR-R	18700	6445 – 6837	6646	0.355	16	0.09
VPH863-HR	HR-I	18701	8372 - 8882	8634	0.462	16	0.12

Design Layout

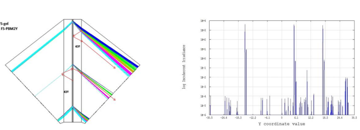


Model of R=5,500 type grating. The VPH hologram is sandwiched between two flat Fused Silica windows. INAOE will include specific coatings designed for each grating.



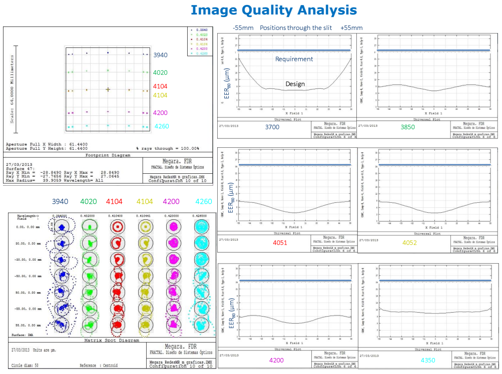
Model of an R(EED80) = 10,000 type grating and 20,000 type grating. The VPH hologram is sandwiched between two Fused Silica windows that are glued (with RTV141 silicon) to 2 prisms made of PBM2Y. INAOE will include specific coatings designed for each grating.

Ghost Analysis



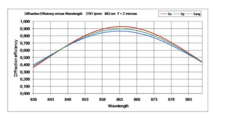
A complete ghost analysis for each pupil element has been carried out taken into account all relevant bounces among collimator, camera, detector and pupil elements. The baffle positions of all opto-mechanical elements have been set up. The figure shows the model for a MR grating. The ghost analysis including a 3 arcmin wedge window. The resulting ghost/image ratios are lower than $5x\ 10^{-5}$.

Image Quality Analysis

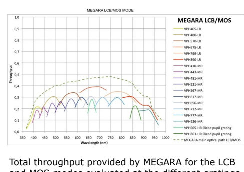


Throughput Analysis

We have carried out a detailed throughput Error Budget for each MEGARA set-up.



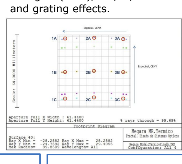
Diffraction Efficiency (by Wasatch) for VPH863-HR



Total throughput provided by MEGARA for the LCB and MOS modes evaluated at the different gratings.

Thermal Analysis

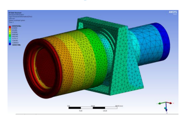
We have carried out a complete thermal analysis for collimator and camera separately to guarantee the optical performance between -4ºC to +20ºC (nominal range is -2ºC to +19ºC). The results have fed the opto-mechanical design. We have derived the image stability for each grating by measuring the change in the centroids position on the detector between -4º and 20ºC as shown in figure. This model contains collimator and camera changes (ROC), dn/dt, thickness and camera athermalization and grating effects.



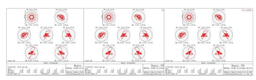
CENY(-4º) - CENY(20º) (mm)		
1A/2A/3A	1B/2B/3B	1C/2C /3C
-2	-2	-2
-3	-3	-3
-3	-3	-3

The main conclusion has been the introduction of a flat window between the prism and the hologram for MR and HR gratings.

Gravitational displacements analysis



Gravitational displacements. Camera-cryostat assembly



From left to right. Non-tilted camera (no mechanical deformation), LN2 empty and LN2 full. Circle is the fiber size. Each spot contains its centroid coordinates in x,y.

As expected, gravity deformation does not introduce degradation in image quality. The LN2 change does not introduce any relevant change in the centroids that might affect the instrument performance.

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