TSPM Optical configurations

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Issue	Date	Section	Page	Change description
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Applicable and Reference Documents

Nº	Document Name	Code
R.1	TSPM High Level Requirements	TSPM/HLREQ-001
R.2	f/5 Wide Field Corrector Manual (D. Fabricant 2003)	EXT/MMT/010
R.3	Optical Specifications for the MMT Conversion (D. Fabricant 1999)	EXT/MMT/009
R. 4	TSPM Optical performance and Error Budget for f5 Cassegrain	TEC/TSPM-PDR-OP/001
R. 5	TSPM focal plane distortion Error Budget for f5 Cassegrain	TEC/TSPM-PDR-OP/003
R. 6	TSPM Cassegrain focal plane baffle study	TEC/TSPM-PDR-OP/004
R. 7	TSPM Coordinate systems	TEC/TSPM/007
R. 8	Summary of Magellan Wide Field Corrector Optical Fabrication Metrology (2004)	EXT/SAO/001
R.9	TSPM: List of acronyms and abbreviations	TEC/TSPM/001
R.10	TSPM: Glossary	TEC/TSPM/006

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1. SCOPE

The goal of this document is to provide a summary of the optical elements, optics performance and the main characteristics of the day-one configuration of the 6.5 m Telescopio San Pedro Mártir (TSPM project). Namely:

- The day-one configuration of TSPM will be the f/5 Cassegrain and is the only one that is fully defined. Other configurations are mentioned only as possible upgrade paths mainly to ensure that the mechanical design of the telescope permits future implementation of this sort.
- TSPM, MMT and Magellan have nominally identical primaries, f/5 secondaries and WFCs, in optical terms.
- The base design will be assembled with M2 and WFC imported from Magellan.
- The f/5 science instruments are imported from the Magellan and MMT facilities.

At the end of this document (Section 7) information about extreme configurations is included. This information has been used to limit the mechanical design of the telescope, the enclosure and the dimensions of the tertiary mirror (M3).

2. RELEVANT HIGH-LEVEL REQUIREMENTS

In the same way as in the "TSPM High Level Requirements" (R1), the word "shall" is to be taken as indicating a requirement and "should" as indicating a guideline. Requirements are mandatory and guidelines are not mandatory, although their fulfillment should be pursued.

This section summarizes the requirements that apply to the day-one optical configuration of the TSPM. These HLR define the path in the development of the different error budgets related with optical aspects of the project. There are other HLR related with extreme configurations but they are excluded from this list to avoid confusion.

3.	**GENERAL REQUIREMETS RELATED TO OPTICAL DESIGN**
3.1	Project Development
RQ/TSPM/001	The TSPM project shall construct a new 6.5-m telescope at SPM. TSPM shall be suitable for general science projects. TSPM shall use the existing 6.5-m primary mirror owned by INAOE and UA. *Rationale: By "suitable for general science projects" it is understood that TSPM should have comparable flexibility to facilities such as MMT, Magellan, Keck, Gemini, VLT, and GTC, and not be a single-purpose facility such as LSST, Pan STARRS, and VISTA.*
RQ/TSPM/003	TSPM shall minimize risks by following existing and proven reference designs (e.g., the MMT and Magellan) where appropriate and possible.
RQ/TSPM/004	The TSPM primary mirror shall be manufactured and polished to the same optical

	specifications as the MMT and Magellan primaries. *Rationale: This is to exchange secondaries, field-correctors and science instruments with these facilities as well as to facilitate its polishing and to minimize fabrication and testing risks.*
3.2	Wavelength range, image quality and background
RQ/TSPM/011	TSPM shall be optimized from the near ultraviolet to the near infrared (0.35 -2.5 μm).
RQ/TSPM/012	The effective thermal emissivity of the telescope shall be less than 10% of that from a blackbody at the ambient temperature (goal 7%) at the Cassegrain.
RQ/TSPM/013	The delivered image quality of TSPM Cassegrain f/5 at the imaging mode shall allow a 12% degradation of the 10th-percentile seeing reported by Skidmore et al. (2009, PASP, 121, 1151). The reported 10th-percentile seeing is 0.5" at 5000Å. The tolerances for active optics and telescope alignment for imaging mode shall be derived from this budget and shall also be applied to the spectroscopy mode. ***The analyses of the optical performance for the TSPM F5 Cassegrain imaging and spectroscopy configuration is available in the document (R. 4)***
RQ/TSPM/014	The telescope background shall be at most 5% of the expected minimum atmospheric and astronomical backgrounds.
RQ/TSPM/015	The maximum differential image distortion at the edge of the spectroscopy FOV shall be a 2.5% of the nominal plate scale (i.e., a maximum displacement of ± 0.15"). ***The analysis about the image distortion is available in the document (R. 5)***
RQ/TSPM/016	A fully baffled system in the 1º FOV shall be provided. ***A detailed design for a full 1º focal plane baffling is available in the document (R. 6)***
3.3	**Plate Scales and Focal Stations**
RQ/TSPM/021	TSPM shall start operations with an f/5 secondary and a wide-field corrector at a Cassegrain station
RQ/TSPM/022	TSPM shall use the existing secondary and wide-field corrector now in operation at Magellan.
RQ/TSPM/023	TSPM shall permit upgrades to provide other focal ratios that are compatible with those presently at Magellan and MMT, namely classical f/9 and f/15.
3.4	**Science Instruments**
RQ/TSPM/031	The TSPM f/5 Cassegrain station shall permit the use of at least the following science instruments presently in use at or under construction for the f/5 Cassegrain stations of MMT and Magellan: MEGACAM, MMIRS, BINOSPEC, SWIRC and MAESTRO.
RQ/TSPM/032	TSPM shall be commissioned and initially operate with the following f/5 Cassegrain instruments: MEGACAM and MMIRS.
RQ/TSPM/033	TSPM shall not exclude future instruments that maintain it at the frontier of competitive astronomical research.
6.	**VERIFICATION**
	The fulfillment of the high level requirements of the TSPM will be verified along the Project on a distributed basis. It will be performed mainly by means of: Validation of the TSPM subsystems, through design reviews and inspection and testing of products. Every subsystem must include a verification section describing the plan to verify the requirements.

Table 1. *High level requirements applicable to the f/5 Cassegrain optical configuration.*

3. TSPM F/5 CASSEGRAIN CONFIGURATION

The TSPM project corresponds to a classical Cassegrain configuration with a parabolic primary mirror and a hyperbolic secondary mirror. This configuration provides geometrically perfect on-axis images. The HLR define the off-axis image quality for the day-one (base) configuration, TSPM via:

- Use an existing 6.5 meters honeycomb primary mirror (M1) cast by the UA Mirror Lab and polished to the same prescription and specifications as the primaries of the MMT and the Magellan telescopes.
- Adopt the existing f/5 secondary from the Magellan telescope, together with its WFC and ADC.
- Start operations at least with a set of f/5 instruments either in use or already under construction for the MMT or the Magellan observatories. Currently, the instruments that are foreseen to be available for Day 1 are MEGACAM and MMIRS, although other instruments could be also received as commented at section 4.

System Aperture: Entrance Pupil Diameter	6502
Temperature (C)	2.00000E+001
Pressure (ATM)	1.00000E+000
Effective Focal Length	33463 (in air at system temperature and pressure)
Back Focal Length	8028.84
Image Space f/#	5.146254
Working f/#	5.158399
Entrance Pupil Diameter	6502
Entrance Pupil Position	0
Exit Pupil Diameter	1913.374
Exit Pupil Position	-9846.708
Primary Wavelength	0.4775 µm

Table 2: *f/5 Cassegrain Optical Prescription.*

The optical design of the f/5 Cassegrain configuration is already fixed, and although the TSPM M1 is yet to be polished, it has to be figured within the same optical specifications as the MMT and Magellan primaries. The TSPM f/5 Cassegrain optical configuration, being an exact copy of Magellan, is a fully proven design.

3.1 Primary mirror main characteristics

The following table summarizes the optical parameters of the TSPM primary mirror (M1) and its differences and similarities with respect to the MMT and Magellan primary mirrors.

	TSPM	MMT	Magellan I & II

Diameter	6512.56 +/- 0.5 mm (6500 optical)	6512 Overall 6502 Optical	6502.4
Outer Clear Aperture	6478	6435	6478
Focal Length	8128 mm	8127.75 +/- 0.15	
Conic Constant	-1.0000	-1.0000 (+0.0001,-0.0004)	
Central Aperture Diameter [mm]	889 +/- 0.5 (top) 940 +/- 0.5 (bot)		970
Inner Clear Aperture	967-923	967	923
Thickness	711 +/- 2 mm (max) 391 +/- 2 mm (min)	711	710
Faceplate thickness	27.9 +/- 1 mm	32.4+/-0.7 mm	
Bottom plate thickness	25.4 +/- 1 mm		
Wall thickness	15 +/- 2 mm		
Cast Figure	f/1.25 parabola		
Material	E6 borosilicate (O'Hara)		
Structure	Honeycomb about 20% solid density (1020 cells)		
Casting date	2002	1992	1994
		2% heavier	
Weight [kg] w/loadspreaders hardpoint blocks	9364	7735 (glass) 9318	9670 & 9005

Table 3: *TSPM Primary mirror parameters.*

3.2 f/5 Secondary

TSPM will adopt the existing secondary at Magellan. It was constructed to the same optical design and specifications as the secondary for the MMT, but they are not identical and they have slightly different as-built characteristics.

3.2.1 f/5 Secondary as design

The Magellan f/5 secondary (M2) was fabricated according to the Optical Specifications for the MMT Conversion (Fabricant, McLeod & West, 1999), the optical characteristics of the secondary are:

Secondary vertex radius	Secondary conic	Secondary clear aperture
-5150.974	-2.6946	1692mm

Material	Zerodur (Schott)
Edge thickness	133 mm
Central thickness	206 mm
Glass weight	288 kg (R.4 for MMT), 316 kg

Table 4: *TSPM M2 parameters.*

3.3 Wide Field Corrector

The bare telescope optics corresponds to a classical Cassegrain design. The coma aberration quickly dominates the off-axis images.

The f/5 wide field corrector reduces the off-axis aberrations of the bare configuration. Therefore, the wide-field instruments must use the WFC or incorporate their own field corrector.

TSPM telescope will adopt the existing WFC at Magellan telescope. It was constructed to the same optical design and specifications as the WFC for the MMT, but has slightly different as-built characteristics.

3.3.1 Imaging and Spectroscopic Plate scales

The wide-Field Cassegrain Foci							
f/#	Configuration	FOV	ADC	Scale (mm/arcsec)	Distortion (%)	Focal surface radius(mm)	Focal surface conic
5.36	Imaging	0.5°	No	0.169	1.0	Flat	
5.29	Spectroscopy	1.0°	Yes	0.167	1.8	3404	-665

Table 5: *Imaging and Spectroscopy mode characteristics.*

The f/5 corrector has two configurations, sharing two lenses between them, the imaging and the spectroscopic modes offering an image plane with a field of view of 0.5° and 1°, respectively. The two modes have different image quality specifications given by the science requirements. The plate scale is different in the two configurations, as summarized in the following table. A field-flattener in imaging mode permits a flat focal surface for direct imaging while, in spectroscopic mode, the focal surface is curved and well characterized by a conic.

3.3.2 Imaging Mode Prescription

The whole optical prescription for the imaging mode is given in the following table. In this mode, there is no ADC on the WFC, but a field-flattener and a filter glass is inserted after the first three lenses of the WFC.

Surface data summary					
Surface	**Radius (mm)**	**Thickness (mm)**	**Glass**	**Diameter (mm)**	**Conic**
Primary	-16255.3	-6184.11	Mirror	6502.4	-1
Secondary	-5150.890	6184.11	Mirror	1714.50	-26947
Air space		29.382		621.755	
L1	604.737	73.288	SIL5C	831.44	
	694.826	80.085		831.44	
L2	1012.496	46.741	SIL5C	797.03	
	577.816	325.001		797.03	
L4	-8055.3	66.097	SIL5C	523.950	
	-2020.77	1044.671		523.950	
Dewar Window		8.467	S-TIL1	365.153	
		38.1		364.341	
Field flattener	-1134.801	48.260	SIL5C	360.848	
	-4097.612	52.445		360.794	
Image plane	infinity			258.573	

Table 6: *TSPM imaging mode prescription.*

The reader can see in section 5, Figure 5-2 shows WFC in imaging mode.

3.3.3 Spectroscopic Mode Prescription

The TSPM spectroscopic mode requires the modification of the imaging corrector (4 lenses) by removing the field flattener (fourth lens) and changing the third lens. The nominal telescope has strong field curvature, as is expected for this design. The whole optical prescription (including telescope) in the spectroscopic mode of the WFC is given in the following table.

Surface	Radius (mm)	Thickness (mm)	Glass	Diameter (mm)	Conic
Primary	-16255.3	-6184.652	Mirror	6502.4	-1
Secondary	-5150.890	6184.652	Mirror	1714.50	-26947
Air space		29.382		621.755	
L1	604.737	73.288	SIL5C	831.44	
	694.826	80.085		831.44	
L2	1012.496	46.741	SIL5C	797.03	
	577.816	171.250		797.03	
L3	-5983.1	49.108	SIL5C	767.410	
	-2104.29	53.828		767.410	
Coordinate break*	Tilt about z 90°				
Prism		25.4	SFSL5Y_5C	748.92	
Cement		0.127	CAF2P20	748.92	
Prism		15.24	PBL6Y_5C	748.92	
		25.705		748.92	
Coordinate break*	Tilt about z -180°				
Prism		15.24	PBL6Y_5C	748.92	
Cement		0.127	CAF2P20	748.92	
Prism		25.4	SFSL5Y_5C	748.92	
		699.754		748.92	
Coordinate break*	Tilt about z 90°				
			SIL5C	648.479	
		52.445		647.780	
Image plane	-3404			611.131	-665
*A "*coordinate break*" indicates a change respect to the main coordinate system, in this case a rotation of the element, It is a term used in optical design software (ZEMAX)					

Table 7: *Surface data summary spectroscopic mode*

The reader can see in section 5, Figure 5-1 shows WFC in Spectroscopic mode.

3.3.3.1 ADC Prisms

In the spectroscopic mode, the pair of double prisms of the ADC replaces the field flattener of the imaging mode. The ADC is a significant issue for spectroscopy with optical fibers. The differential dispersion between 0.37 and 0.76 μm is about 1.4" at a zenith distance of 45° (1.4 air masses) and about 2.5" at a zenith distance of 60° (2 air masses). This would cause significant light loss with 1.5″ diameter fibers if it were not corrected with the Atmospheric

Dispersion Compensation (ADC) prisms built into the wide-field corrector. The angles of the ADC prims are specified as single Zernike term as follow:

ZEMAX – FZERNSAG*, Maximum rad aperture: 2540						
Surface	11	12	13	16	17	18
Zernike term 3	4.0744902	-44.694627	-44.694615	4.2296588	50.624257	50.624252
* "*FZERNSAG*" is a tool in the optical design software (ZEMAX) to model elements in term of the Zernike polynomials						

Table 8: *ADC specifications. Prism angles*

The reader can see in section 5, Figure 5-1 shows WFC with ADC in Spectroscopic mode.

3.4 TSPM Telescope Error Budget

In this section we summarize the error-budget and the image quality of the TSPM f/5 Cassegrain station. The error budget was based on the concept used in the document "MMT Conversion Specifications" (D. Fabricant, 1999) that, together with "f/5 Wide Field Corrector Manual" (D. Fabricant, 2003), summarizes the design and performance of the MMT f/5 system.

3.4.1 TSPM Image Quality

The average image quality is presented in Table 9; These values indicates the nominal performance of the configuration and they are the starting points in the development of the error budget.

Configuration	FOV	Plate scale	Image Quality	Wavelength range	Focal curv.
Imaging	0.5º	170 μm/"	0.12" average	0.33 - 1.00 μm	flat
Spectroscopy	1º	170 μm/" average	0.36" average	0.33 - 1.00 μm	3404 mm

Table 9: *Image quality and configurations*

The document TEC/TSPM-PDR-OP/001 (R.4) presents the TSPM error-budget. In that document a comprehensive error budget regarding the optical performance is provided in order to define the mechanical requirements and a full picture of the expected performance. Both this document and the document Distortion-EB (R.5) should be read.

3.4.2 f/5 Imaging Mode Error-Budget

The imaging mode error budget summary is given in Table 11. Although the grand total budget is given in terms of FWHM in arc seconds, different budget pieces are allocated through another specification, in particular RMS spot radius and Fried parameter, r_0. (see R. 4)

ITEM	FWHM	RMS (µm)	R0 (cm)	Comment
Nominal performance	0.121	8.6		Nominal design F5 Cassegrain Imaging mode 0.5º FOV
M1 manufacturing, surface irregularity with AO	< 0.184		> 91	Based on UA contract spec Kolmogorov structure function
M1 manufacturing, CC and ROC	0.022	1.54		Based on 100 MC and contract spec.
M1 manufacturing, CC and ROC uncertainties	0.059	4.22		Measurement uncertainties provided by UA. Based 100MC
M2 manufacturing, CC and ROC uncertainties	0.020	1.42		Magellan M2 as built. Mirror uncertainties measure.
M2 manufacturing, surface irregularity, curvature	0.040		253	Specs for the MMT telescope. Apply to Magellan (TBC)
Corrector fabrication	0.065			MMT document
Telescope alignment (active optics)	0.045	3.2		200 Monte Carlo runs in normal distribution
M2 hexapod residuals	0.025	1.8		100 Monte Carlo runs in normal distribution
Thermal	0.047	3.4		Operation temperature ranges shall be introduced
Guiding	0.030			Based on TSPM requirement
TOTAL (Rms squared)	0.254			Full budget

***Table 10:** Image error budget summary table (see R.4).*

3.4.3 f/5 Spectroscopic Mode Error-Budget

The error budget summary is given in Table 12. Some of the budgeted items are the same as for imaging mode and are not repeated here. As in the imaging mode, the total budget is given in terms of FWHM in arc seconds, though different budget pieces are allocated through another specification, in particular RMS spot radius and Fried parameter, r_0 (see R.4).

ITEM	FWHM	RMS (μm)	r0 (cm)	Comment
Nominal performance	0.36	25.8		Average
M1 manufacturing, surface irregularity with AO	<0.184		> 91	Based on UA contract spec Kolmogorov structure function
M1 manufacturing, CC and ROC	0.060	4.3		200 Monte Carlo runs in normal distribution
M1 manufacturing, CC and ROC uncertainties	0.079	5.6		Measurement uncertainties provided by UA. Based 100MC
M2 manufacturing, CC and ROC uncertainties	0.028	2.0		200 Monte Carlo runs in normal distribution
M2 manufacturing, surface irregularity, curvature	0.040		253	Same as imaging.
Corrector fabrication	0.220			MMT document
Telescope alignment (active optics)	0.17	12.3		200 Monte Carlo runs in normal distribution
M2 hexapod residuals	0.036	2.6		200 Monte Carlo runs in normal distribution
Thermal	0.069	4.9		Operation temperature ranges shall be introduced
Guiding	0.03			Based on TSPM requirement
TOTAL (rms squared)	0.512			Full budget

Table 11: *Spectroscopic error budget summary table (see R.4).*

4. SCIENCE INSTRUMENTS

As established in the HLR document (R. 1), the TSPM f/5 Cassegrain station shall permit the use of at least the following science instruments presently in use at or under construction for the f/5 Cassegrain stations of MMT and Magellan: MEGACAM, MMIRS, BINOSPEC, SWIRC and MAESTRO. TSPM shall be commissioned and initially operate with the following f/5 Cassegrain instruments: MEGACAM and MMIRS. The information about the instruments designed for MMT and Magellan is given in Table 13.

Instrument	Type	Spectral Range	Resolution/ Scale	Field	Considered for SPMT
Hectochelle	Optical fibre-fed multi-object echelle spectrograph	3800 - 9200Å	R = 32,000 - 40,000	1 deg 240 fibers	Yes
Hectospec	Optical fibre-fed multi-object spectrograph	3650 - 9200Å	R = 1000 - 2500	1 deg 300 fibers	Yes
Binospec	MOS/Long-Slit/Imager 2-arms, 4 gratings	3900-10000Å g, r, i,z	R = 1200 - 10000 0.24”/px	2 x 8’x15’ (MOS)	Yes
Megacam	Wide-field optical imager	3200 - 8300Å	0.08"/pix	24' x 24'	Yes
SWIRC	Wide-field IR imager	0.84 - 1.8um	YJH 0.15"/pix	5.12' x 5.12'	?
MAESTRO	Single-slit echelle spectrograph	3185 - 9850Å	R = 28,000 - 93,000 0.154”/px	4” Single object Single & dual slit	?
MMIRS	IR multi-object spectrograph & imager	0.9 - 2.5um	R = 1200 – 3000 0.2"/pix	7' x 7'	Yes

Table 12: *Potential science instruments for the TSPM.*

5. AS BUILT ELEMENTS

The document “EXT/SAO/001 - Summary of Magellan Wide Field Corrector Optical Fabrication Metrology (2004)” presents a review of the final metrology data for the fabrication of the Clay telescope wide field corrector (WFC) optics from the manufacturer Goodrich, Danbury. A similar document for the f/5 TSPM secondary is the “EXT/MAG/008 Test Report for the Magellan f/5 Secondary Mirror”. In this section is presented the optical prescription for the Imaging and spectroscopic modes including the as built parameters.

5.1 f/5 Imaging as Built Optical Prescription

	Surf	Type	Radius	Thickness	Glass	Diameter	Conic	Comment
	OBJ	STANDARD	Infinity	Infinity		0	0	
	STO	STANDARD	-16256	-6184.224	MIRROR	6502.4	-1	PRIMARY VERTEX
	2	SZERNSAG	-5151.64	6184.224	MIRROR	1714.5	-2.695	SECONDARY VERTEX
A	3	STANDARD	Infinity	28.7909		621.7846	0	TO L1
B	4	STANDARD	604.318	73.658	SIL5C	831.44	0	L1 FRONT
C	5	STANDARD	694.351	77.22816		831.44	0	L1 BACK
D	6	STANDARD	1015.136	49.717	SIL5C	797.03	0	L2 FRONT
E	7	STANDARD	577.621	325.968		797.03	0	L2 BACK
F	8	STANDARD	-8525.325	66.11981	SIL5C	523.95	0	L4 FRONT
	9	STANDARD	-2054.696	0		523.95	0	L4 BACK
G	10	STANDARD	Infinity	1043.812		518.898	0	TO FILTER
H	11	STANDARD	Infinity	8.467	S-TIL1	365.2322	0	FILTER
I	12	STANDARD	Infinity	38.1		364.4218	0	TO FLATTENER
J	13	STANDARD	-1134.801	48.26	SIL5C	360.939	0	FLATTENER FRONT
K	14	STANDARD	-4097.612	52.445		360.9028	0	FLATTENER BACK
	IMA	STANDARD	Infinity			358.7092	0	FOCAL PLANE

Table 13: *Imaging as-built optical prescription.*

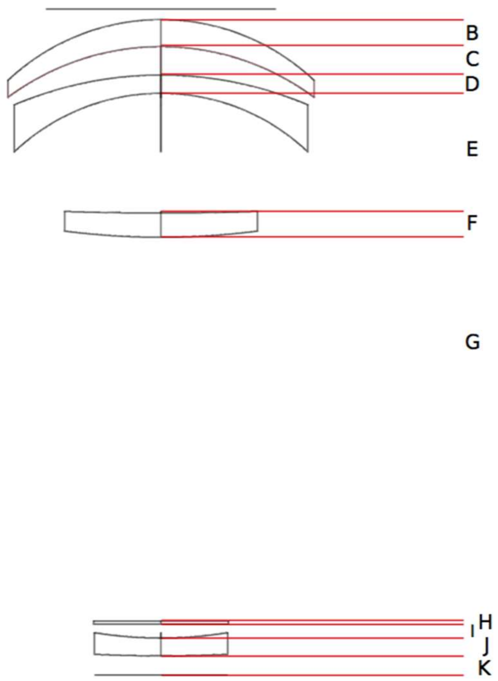

Figure 5-1. *WFC, Imaging mode.*

5.2 f/5 spectroscopy As Built Optical Prescription

	Surf	Type	Radius	Thickness	Glass	Diameter	Conic	Comment
	OBJ	STANDARD	Infinity	Infinity		0	0	
	STO	STANDARD	-16255.3	-6184.356	MIRROR	6502.4	-1	PRIMARY VERTEX
	2	SZERNSAG	-5151.64	6184.356	MIRROR	1714.5	-2.695	SECONDARY VERTEX
A	3	STANDARD	Infinity	28.7909		818.5846	0	TO L1
B	4	STANDARD	604.318	73.658	SIL5C	831.44	0	L1 FRONT
C	5	STANDARD	694.351	77.22816		831.44	0	L1 BACK
D	6	STANDARD	1015.136	49.717	SIL5C	797.03	0	L2 FRONT
E	7	STANDARD	577.621	171.8327		797.03	0	L2 BACK
F	8	STANDARD	-6469.1	49.318	SIL5C	767.41	0	L3 FRONT
	9	STANDARD	-2159.4	0		767.41	0	L3 BACK
G	10	STANDARD	Infinity	53.32		714.7365	0	
	11	COORDBRK	-	0		-	-	ROTATE ADC
H	12	FZERNSAG	Infinity	25.208	SFSL5Y_5C	748.92	0	FRONT PRISM FRONT
I	13	FZERNSAG	Infinity	0.127	EPOXY	748.92	0	FRONT PRISM BOND
J	14	FZERNSAG	Infinity	14.936	PBL6Y_5C	748.92	0	
K	15	STANDARD	Infinity	25.685		748.72	0	FRONT PRISM BACK
	16	COORDBRK	-	0		-	-	UNROTATE TO BACK
L	17	FZERNSAG	Infinity	15.001	PBL6Y_5C	748.92	0	BACK PRISM FRONT
M	18	FZERNSAG	Infinity	0.127	EPOXY	748.92	0	BACK PRISM BOND
N	19	FZERNSAG	Infinity	25.481	SFSL5Y_5C	748.92	0	
Ñ	20	STANDARD	Infinity	700.211		748.92	0	BACK PRISM BACK
	21	COORDBRK	-	0		-	-	UNROTATE
O	22	STANDARD	Infinity	12.7	SIL5C	648.0988	0	HECTO WINDOW FRONT
	23	STANDARD	Infinity	471.551		647.3988	0	HECTO WINDOW BACK
P	24	STANDARD	Infinity	0		612.9424	0	FOCUS BIT
	IMA	STANDARD	-3404			610.8025	-665	FOCAL PLANE

Table 14: *Spectroscopic as-built optical prescription.*

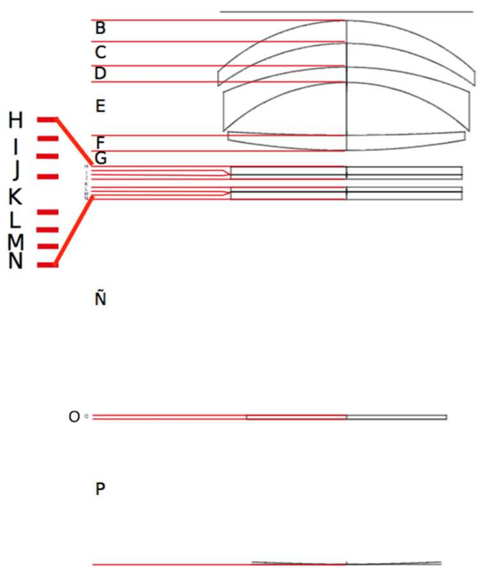

Figure 5-2. *WFC, Spectroscopic mode.*

6. REFERENCE NODES FOR THE OPTICAL ELEMENTS

Throughout the whole project is necessary to define coordinate systems and reference nodes for many reasons, one of those reasons is the error budget. The reference nodes define where the optical elements are with respect to the mechanical elements. The document "Coordinate systems" presents the coordinate system and reference nodes used for part of the tolerance analysis in the documents image quality error budget (TEC/TSPM-PDR-OP/001) and differential distortion (TEC/TSPM-PDR-OP/003) The Figure 6-1 summarizes the information to describe the different configurations and the relation between them and the mechanical elements in a general way. It should be noted that the horizontal lines are common to Figures 6-1, 6-2, 6-3, 7-1, and 7-2.

The reference nodes shown in the Figure 6-1 are:

- RN-M2 coordinate system is defined at the intersection of the telescope optical axis and the plane defined by the upper face of the Top Ring of the TSPM structure.
- RN-M1 vertex: X = 0, Y = 0, Z = - 1006.3 mm in the Tube coordinate system
- RN-M3: X = 0, Y = 0, Z = 0 mm in the Tube coordinate system.
- RN-INST-C: X = 0, Y = 0, Z = -2484 mm in the Tube coordinate system.
- RN-WFC-C: X = 0, Y = 0, Z = -1531 mm in the Tube coordinate system.
- RN-WFC-NA: X = +3930 mm, Y = 0, Z = 0 at the Telescope mount coordinate system.
- RN-INST-NA: X = +4287 mm, Y = 0, Z = 0 at the Telescope mount coordinate system.

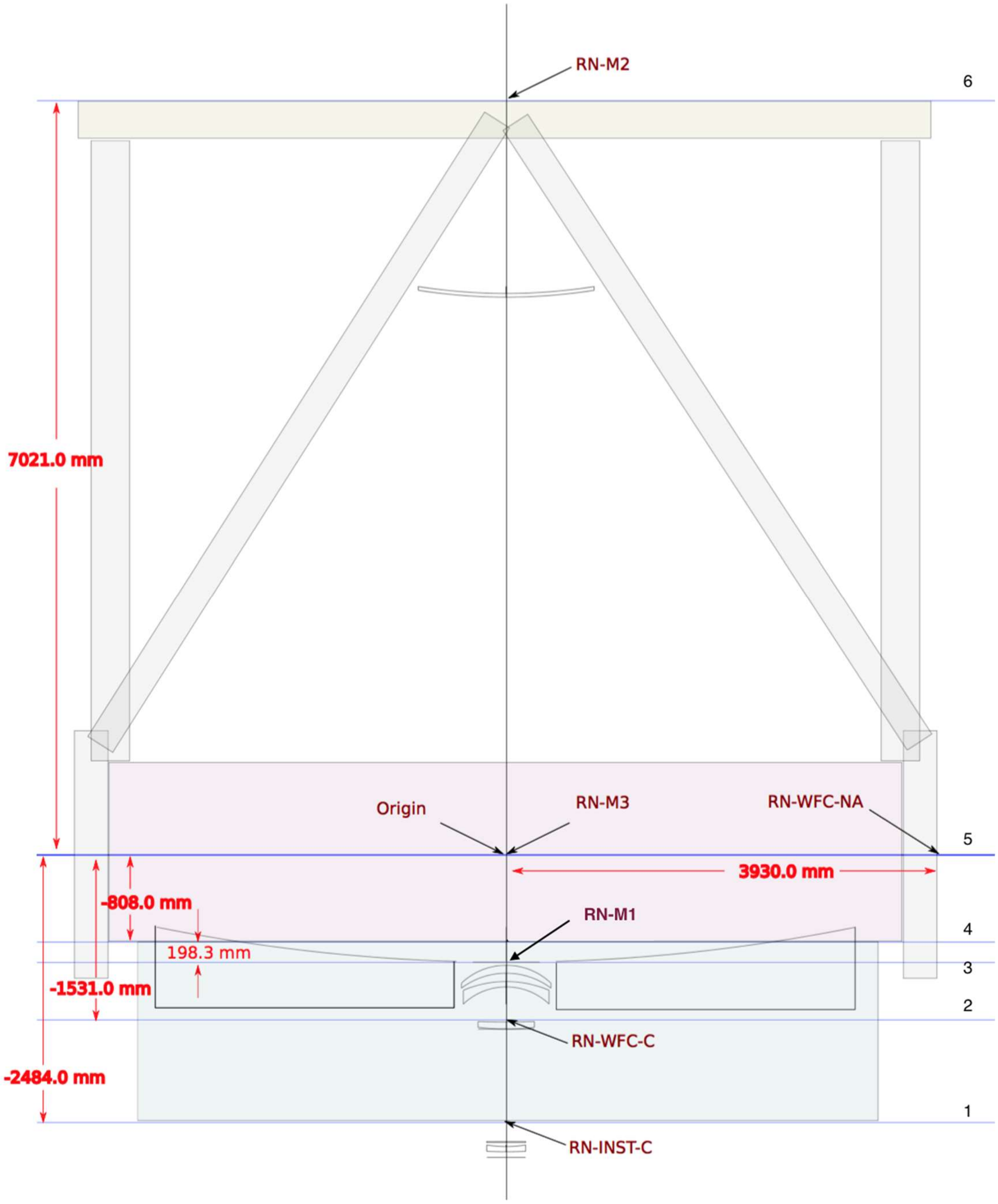

Figure 6-1: Reference nodes and their positions on the telescope structure. The lines 1-6 are 1: Plane defined by the lower face of the mirror cell (RN-INST-C), 2: Plane defined by the internal face of the mirror cell, where the WFC is joined (RN-WFC-C), 3: Vertex of the primary mirror, (RN-M1), 4: Plane defined by the upper face of the mirror cell, 5: Reference to the Tube coordinate system (0,0,0) and Nasmyth optical axis, 6: Plane defined by the upper face of the Top Ring of the TSPM structure.

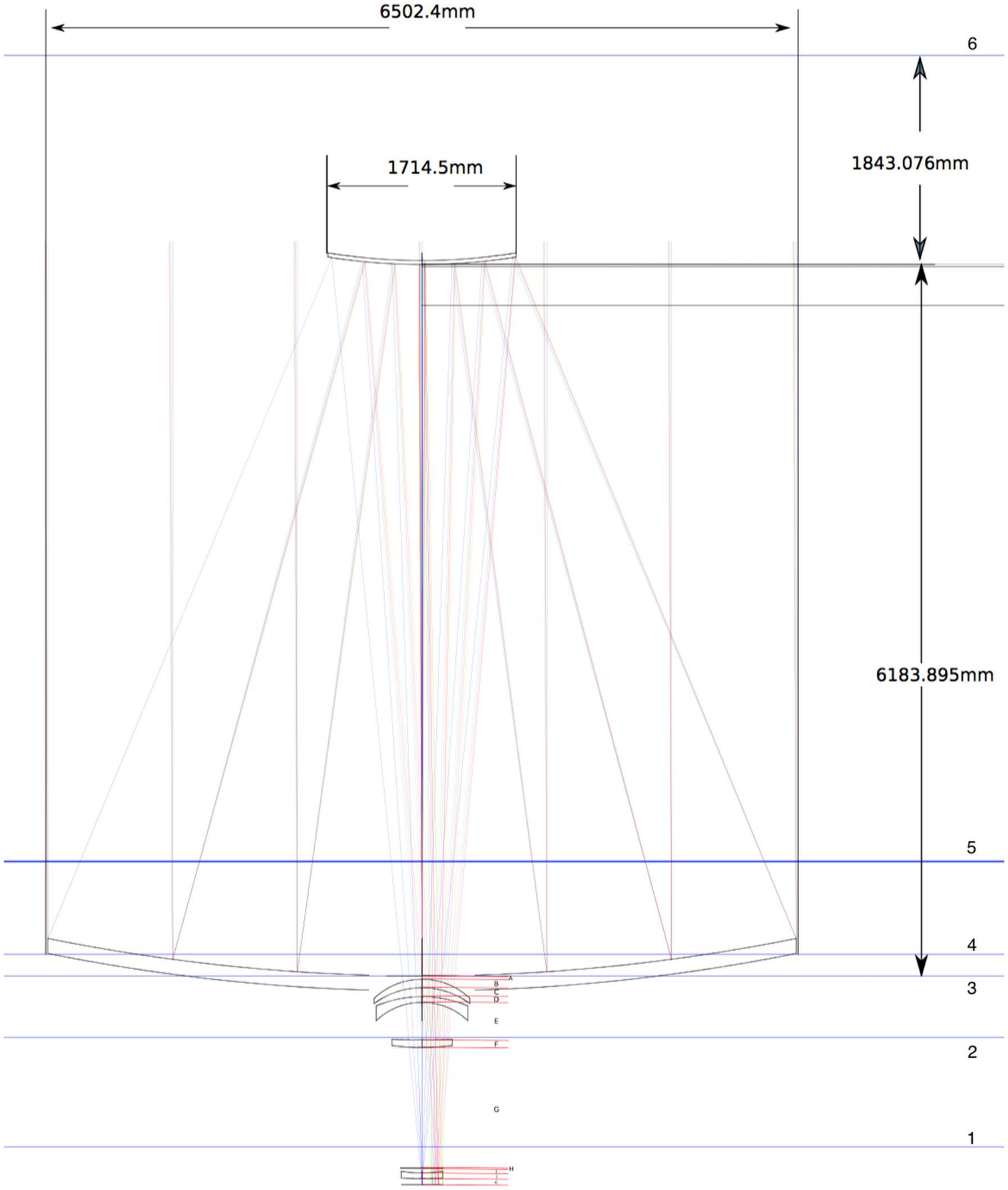

Figure 6-2: *Reference nodes and the imaging configuration. Lines 1-6 are described in Figure 6-1.*

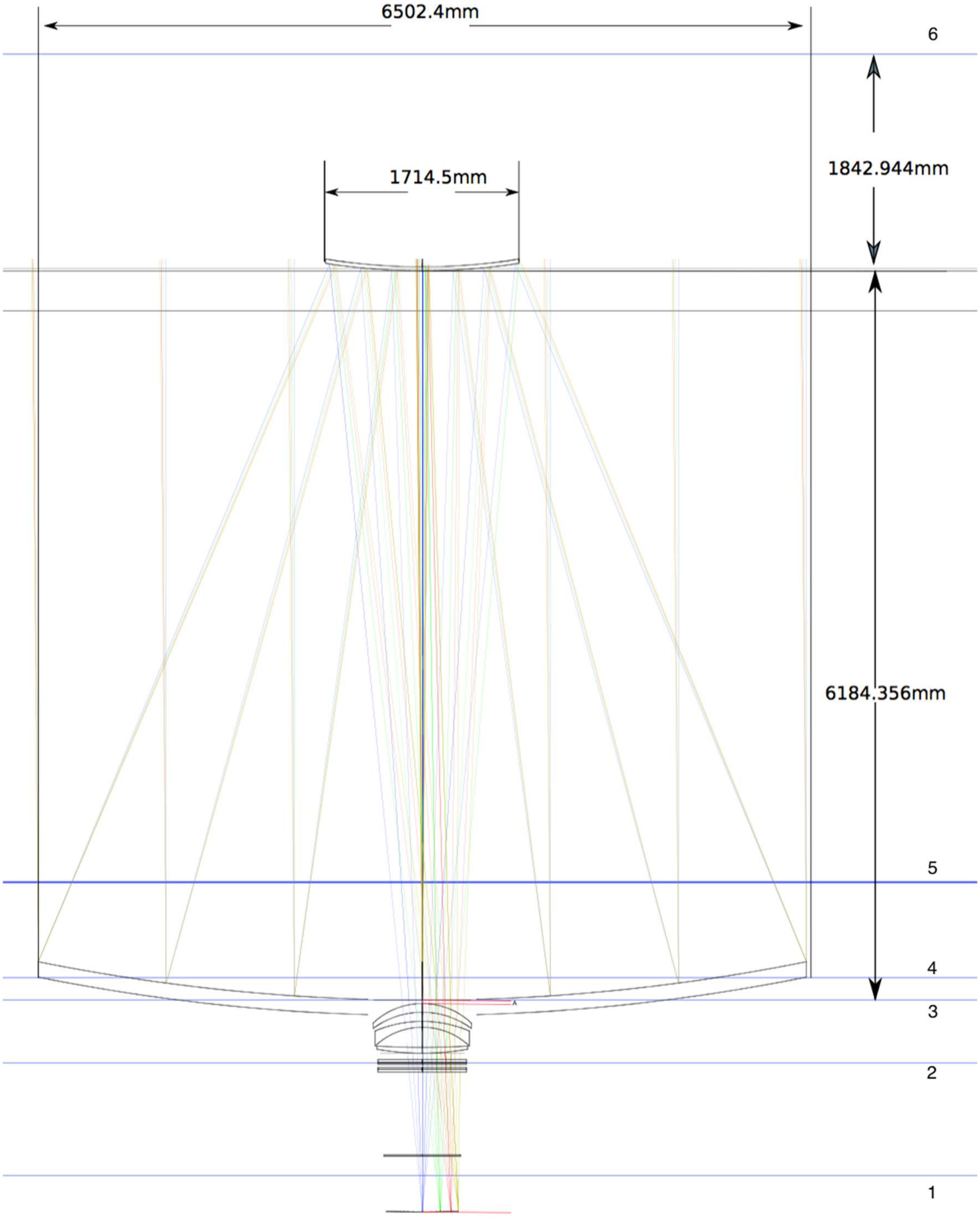

Figure 6-3: *Reference nodes, f/5 spectroscopic configuration. Lines 1-6 are described in Figure 6-1.*

7. TSPM NASMYTH EXTREME CONFIGURATIONS

To limit the mechanical design of the telescope, the enclosure, and the dimensions of the tertiary mirror (M3), two extreme Nasmyth configurations have been defined:

- An f/5 Classical Nasmyth configuration with a 1° diameter field of view (FoV).
- An f/11 Gregorian Nasmyth configuration with a 0.5° diameter FoV.

It is important to realize that in TSPM the f/5 Cassegrain and Nasmyth stations require different secondary, since these stations have very different back-focal distances.

These particular f/11 Gregorian and f/5 Classical Nasmyth configurations are not expected to be constructed for Day 1, nevertheless we expect to complete a preliminary design in the near future, including specifications endorsed by manufacturers for M2, M3, WFC and ADC.

It is worth to mention that if the designs of the telescope structure and enclosure are compatible with the above extreme configurations (f/11 Gregorian and f/5 Classical Nasmyth), they should also be compatible with the f/9 and f/15 classical configurations requested at the High-level requirements. For this reason, we do not consider them further.

7.1 f/11 Gregorian

The design of the TSMP f/11 Configuration is based on the Magellan Gregorian system. The main differences from Magellan are:

- TSPM has a higher elevation axis (1 m form M1 vertex)
- TSPM requires Wider FoV in Nasmyth, about 0.5° (f/11) or 1° (f/5) in diameter. This implies a slightly larger secondary.
- This also implies a much larger M3 (f/5 1° FoV at Nasmyth)
- Given the bigger tertiary mirror, it would inconvenient to mount the WFC close to M3 for mechanical and operational reasons. Therefore, a similar WFC-ADC system is designed for TSPM, but placed closer to the focal plane, inside the Nasmyth rotator.
- A disadvantage of this choice of WFC position is that each port needs its own corrector. On the other hand, an advantage is that the WFC can be optimized for each instrument.

7.1.1 f/11 Nasmyth, Optical Prescription

Surf	Type	Radius	Thickness	Glass	Diameter	Conic	Comment	
OBJ	STANDARD	Infinity	Infinity		0	0		
STO	STANDARD	-16255.3	-9671.613	MIRROR	6502.4	-1	PRIMARY	
2	STANDARD	2777.35	9671.613	MIRROR	1308.207	-0.6388845	SECONDARY	
3	STANDARD	Infinity	-1000		789.7359	0		
4	COORDBRK	-	0		-	-		
5	STANDARD	Infinity	0	MIRROR	1190.491	0	Tertiary	
6	COORDBRK	-	-1000		-	-		
7	STANDARD	Infinity	-2360		789.7359	0		
8	STANDARD	-2657.677	-40	N-PK52A	640	0	WFC - L1	Wide field corrector
9	STANDARD	3465.898	-24.88	K10	640	0	WFC - L2	
10	STANDARD	Infinity	-5		640	0		
11	STANDARD	-1413.836	-25.04	K10	600	0	WFC - L3	
12	STANDARD	-2179.47	-25.04	N-PK52A	600	0	WFC - L4	
13	STANDARD	-892.3095	-1620.264		600	0		
IMA	STANDARD	-1214.336			633.9675	1.004471		

Table 15: *Extreme configuration f/11 Nasmyth.*

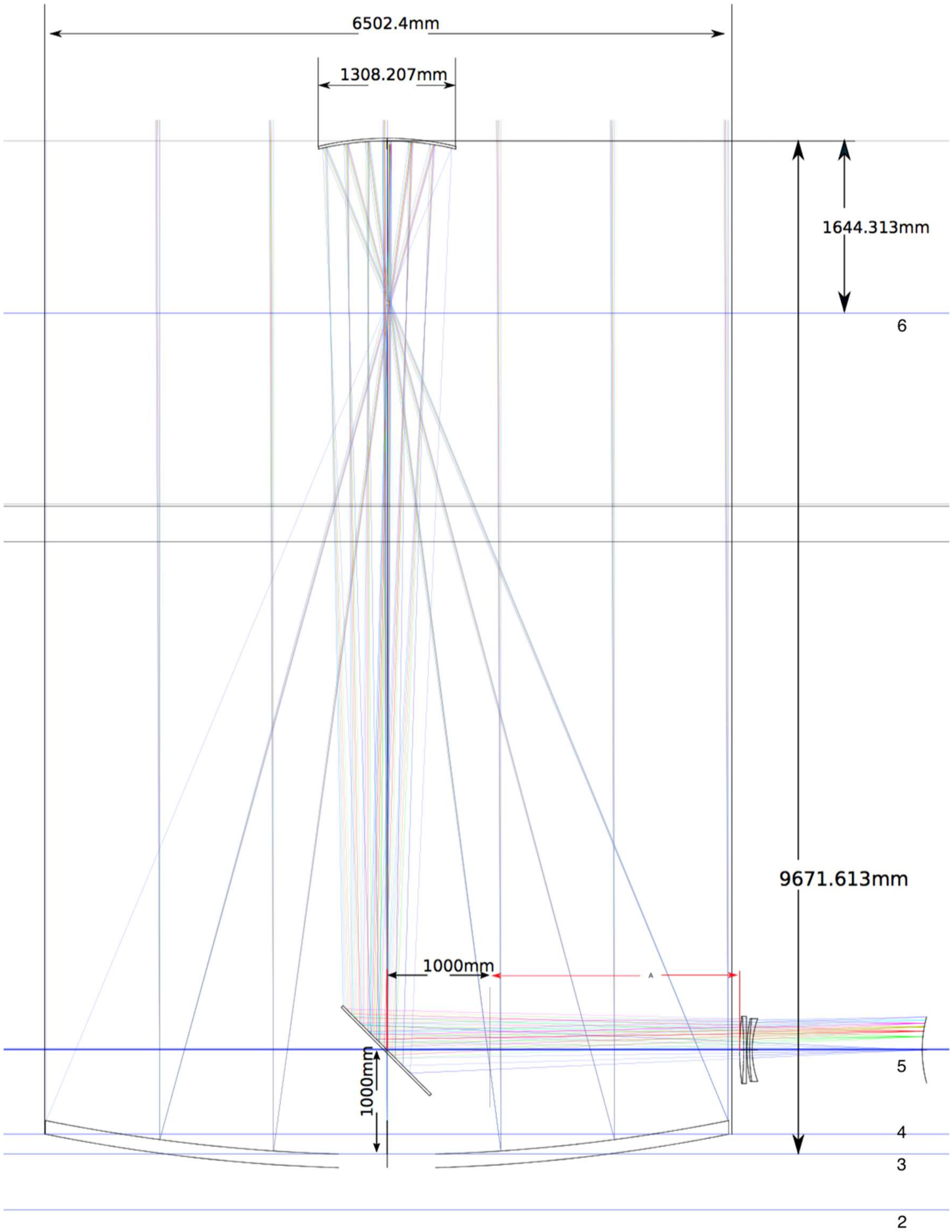

Figure 7-1: *Extreme f/11 configuration of TSPM. The size of M2 is a bit larger than in Magellan, to accommodate the same physical field as the f/5 configuration that, given the 2.08 factor given by the ratio of the effective lengths, is close to 0.5 degrees in diameter. Lines 2-6 are described in Figure 6-1.*

7.2 Nasmyth f/5 configuration

The extreme f/5 Nasmyth configuration of TSPM is defined to be equivalent to the f/5 Cassegrain. The schematic design has a similar corrector, yielding the same plate scale and field of view. The f/5 WFC is more complex and massive than the f/11 Nasmyth WFC so, unlike Magellan it is not located close to M3, but much closer to the focal plane within the Nasmyth rotator. As in the case of the f/11 Nasmyth configuration, this configuration will not necessarily be constructed, but is presented to limit the size of the tertiary as well as the mechanical design. In particular, this extreme Nasmyth configuration drives the size of M3. The indicative f/11 Gregorian and f/5 classical configurations at Nasmyth define the largest M1-M2 separation and of the larger secondary respectively, and set the physical limits of any final configuration the TSPM decides to construct: from an f/5 classical configuration and slower systems up to a prime focus and Gregorian systems slower than about f/11.

7.2.1 f/5 Nasmyth, Optical Prescription

Surf	Type	Radius	Thickness	Glass	Diameter	Conic	Comment
OBJ	STANDARD	Infinity	Infinity		0	0	
STO	STANDARD	-16256	-5824.393	MIRROR	6502.4	-1	PRIMARY
2	STANDARD	-6045.714	5824.393	MIRROR	1966	-2.615194	SECONDARY
3	STANDARD	Infinity	-1000		1138.69	0	
4	STANDARD	Infinity	0		1278.787	0	
5	COORDBRK	-	0		-	-	
6	STANDARD	Infinity	0	MIRROR	1690.089	0	Tertiary
7	COORDBRK	-	-1000		-	-	
8	STANDARD	Infinity	-2360		1278.787	0	
9	STANDARD	-2388.479	-73.288	SILICASCHOTT	831.44	0	WFC - L1
10	STANDARD	25827.91	-107.5751		831.44	0	
11	STANDARD	-2011.661	-46.741	SILICASCHOTT	797.03	0	WFC - L2
12	STANDARD	-744.8416	-80		797.03	0	
13	STANDARD	-2186.196	-49.108	SILICASCHOTT	767.41	0	WFC - L3
14	STANDARD	-5402.545	-53		767.41	0	
15	COORDBRK	-	0		-	-	
16	FZERNSAG	Infinity	-25.4	S-FSL5Y	748.92	0	ADC_PRISM1
17	FZERNSAG	Infinity	-0.127	CAF2SCHOTT	748.92	0	
18	FZERNSAG	Infinity	-15.24	PBL6Y	748.92	0	ADC_PRISM2
19	STANDARD	Infinity	-25.705		748.92	0	
20	COORDBRK	-	0		-	-	
21	FZERNSAG	Infinity	-15.24	PBL6Y	748.92	0	ADC_PRISM3
22	FZERNSAG	Infinity	-0.127	CAF2SCHOTT	748.92	0	
23	FZERNSAG	Infinity	-25.4	S-FSL5Y	748.92	0	ADC_PRISM4
24	STANDARD	Infinity	-523.7979		704.8809	0	
25	COORDBRK	-	0		-	-	
26	STANDARD	Infinity	-12.7	SILICASCHOTT	649.1717	0	
27	STANDARD	Infinity	-477.487019		654.0544	0	
IMA	STANDARD	5482.72			611.354	-490.3231	

Wide field corrector (surfaces 8–24)

Table 16: *Extreme configuration f/5 Nasmyth.*

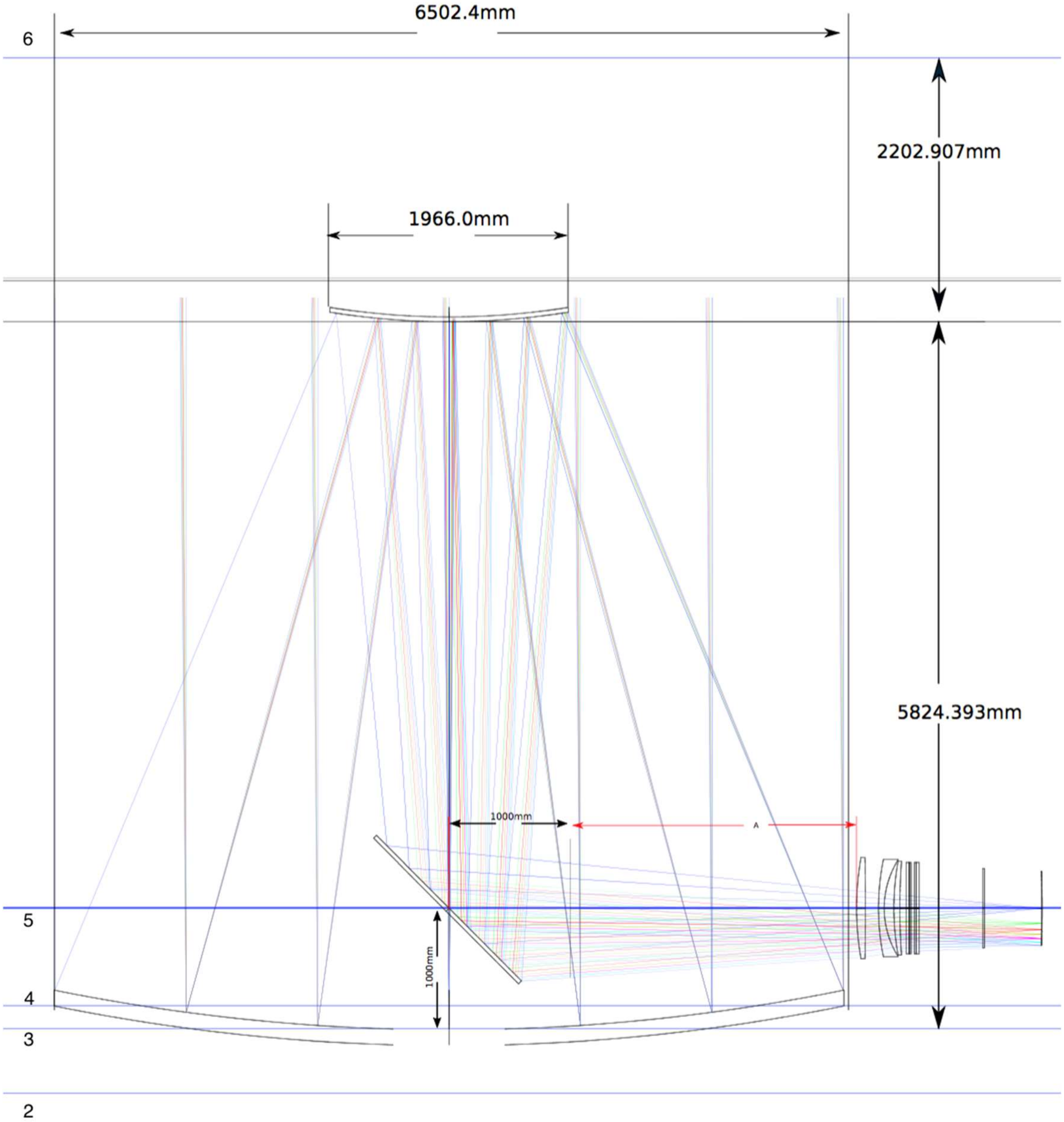

Figure 7-2: *Optical layout of the TSPM extreme f/5 Nasmyth configuration. The indicative system has the same field of view and plate scale as the base f/5 Cassegrain system, setting important limits for the configurations TSPM may eventually construct, such as the size of M3, the widest un-obstructed aperture and the largest M2, among others.*

8. TSPM OPTICAL CONFIGURATIONS SUMMARY

Figure 6-3 presents the three TSPM optical configurations discussed. The base f/5 Cassegrain configuration is the only one that will be constructed initially. The other two configurations are indicative designs to limit the size of the building, the top-end of the telescope dimensions and rigidity, the size of the tertiary mirror, the clear apertures and overall dimensions of the Nasmyth rotators and platforms. In particular, the f/5 Nasmyth configuration drives the size of M3 and the telescope rigidity required to support its M2 while the f/11 Gregorian drives the height of the dome.

The following table summarizes the main characteristics of the TSPM optical configurations discussed in this document.

	f/5 Cassegrain	**f/5 Nasmyth****	**f/11 Nasmyth****
Primary Mirror (M1)	Diameter=6502mm, Rc=16255.3 mm, Conic=-1.0000		
Elevation Axis	1,000 mm above M1		
Eff. focal length [mm]	34372.5	34358.8	71524
FoV [degrees]	0.5 Ima-1.0 Spec	1.0	0.45
M1-M2 distance [mm]	6184.356	5824.4	9671.6
M2 Diameter/Rc [mm]	1714.5 / 5151.64	1966 / 6045.7	1308 / 2777.4
M2 conic	-2.6950	-2.61519	-0.63888
M3 Location* [mm]		0, -46.23, -46.23 (65.38 mm disp)	
M3 Aperture [mm]		1830x1300 ellipse	
WFC concept	3-elements +2-doublet ADC		2-doublet ADC system
WFC 1st-surf Loc* [mm]	0, 0, 1029.4	0, 3360, 0	0, 3360, 0
WFC 1st-surf D/Rc [mm]	831.4 / 604.7	831.4 / 2388.5	640 / 2657.7
ADC last-surf Loc* [mm]	0, 0, 1529.4	0, 3877, 0	0, 3480, 0
ADC last-surf D/Rc [mm]	704.9 / flat	704.9 / flat	600 / -892.3
Focal Surface Loc* [mm]	0, 0, 2713.4	0, 4885, 0	0, 5100, 0
Focal Surface D/Rc [mm]	611.3 / -3404	611.3 / 5278	611.3 / -1214
* Locations are relative to the reference node (RN-M3), Section 6. ** These optical prescriptions are schematic, to define the extremes of the mechanical design. They will be refined after definition of future science cases and instrumentation.			

Table 17: *TSPM configurations summary.*

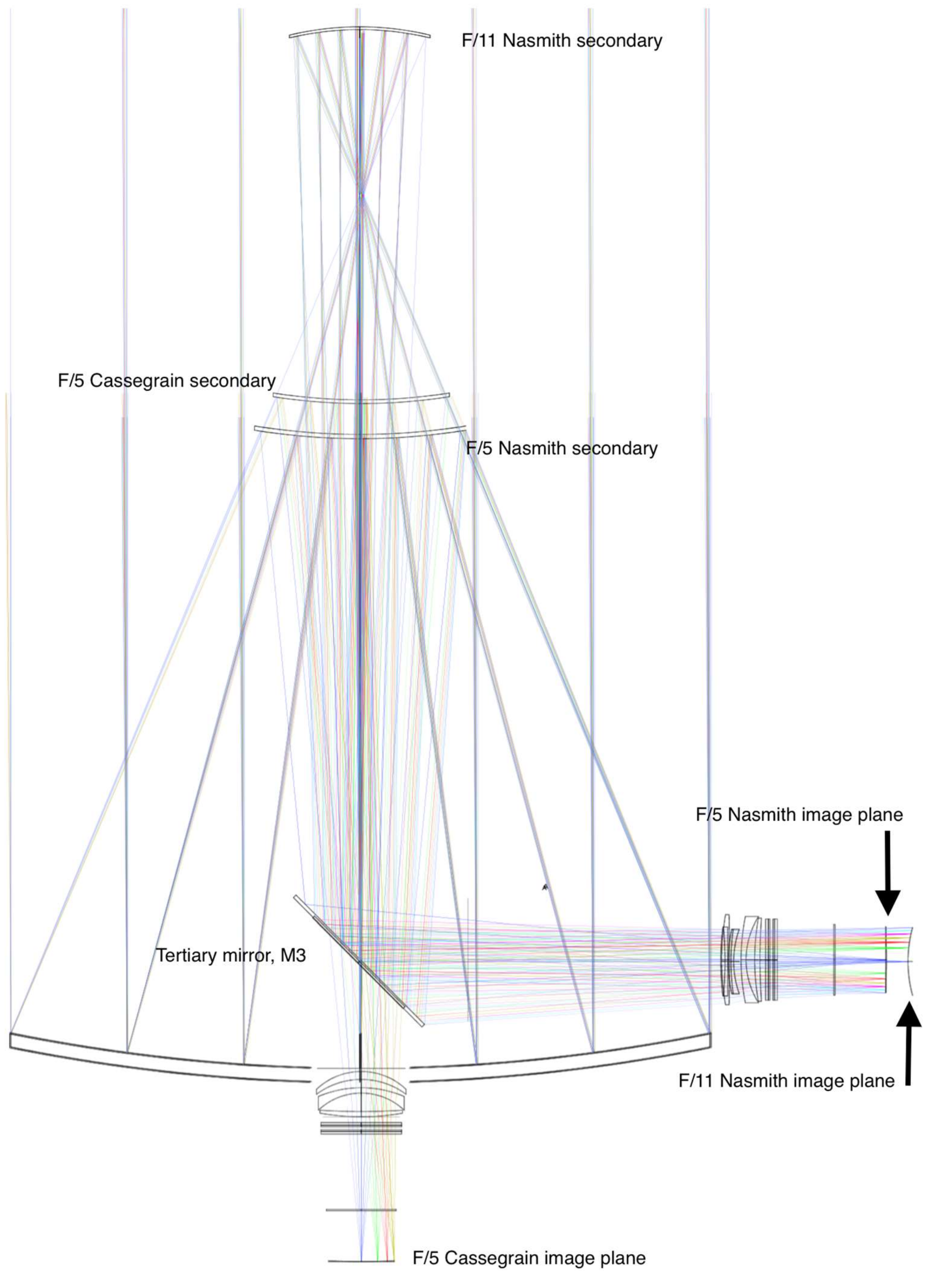

Figure 8-1: *Optical layout of the TSPM configurations.*