Final optical design of PANIC, a wide-field infrared camera for CAHA

M. C. Cárdenas, J. Rodríguez Gómez, R. Lenzen, E. Sánchez-Blanco and the International PANIC team

Abstract We present the Final Optical Design of PANIC (PAnoramic Near Infrared camera for Calar Alto), a wide-field infrared imager for the Ritchey-Chrtien focus of the Calar Alto 2.2 m telescope. This will be the first instrument built under the German-Spanish consortium that manages the Calar Alto observatory. The camera optical design is a folded single optical train that images the sky onto the focal plane with a plate scale of 0.45 arcsec per 18 μm pixel. The optical design produces a well defined internal pupil available to reducing the thermal background by a cryogenic pupil stop. A mosaic of four detectors Hawaii 2RG of 2kx2k, made by Teledyne, will give a field of view of 31.9 arcmin x 31.9 arcmin.

1 Introduction

In 2005, the German-Spanish Observatory of Calar Alto (CAHA) changed its administrative status, and since then Germany and Spain have given financial support in equal shares for the development of new instrumentation for the observatory through their institutions Max-Planck-Gesellschaft (MPG) and Consejo Superior de Investigaciones Científicas (CSIC). In the frame of this agreement, the idea of building a new infrared camera for the 2.2 m telescope (T2.2), as the first instrument of the consortium, was suggested by both astronomical communities, supported by the Scientific Advisory Committee and approved by the Executive Committee. The schedule of the design and construction of the camera is following the next mile-

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stones: Kick-off, in October 2006, Preliminary Design Review (PDR), in November 2007 and Optics Final Design Review (FDR), in September 2008, both successfully completed, and, in the third quarter of year, for the other work packages; finally first light at telescope during 2011. The PANIC optical design and its expected performances are presented hereafter. The camera will have a field of view (FOV) of 31.9'x31.9', with a diameter only one arcmin smaller than the largest non-vignetted FOV that the T2.2 allows without field corrector. Several scientific cases require a plate scale of 0.45"/pix and therefore a mosaic of four detectors of 2k x 2k pixels is envisaged. Others scientific projects, which require smaller plate scale, drive the study of the camera for the 3.5m telescope (T3.5), where the FOV is 16.4'x16.4' with 0.23"/pix.

2 Instrument parameters

The general requirements for PANIC from the start are: work at the T2.2 Ritchey-Chrétien (RC) focus; the detector size is 4096x4096 pixels; the spectral range Near Infrared (minimum YJHK); and the image scale 0.45"/pix. These basic requirements have direct consequences on the design of PANIC. The instrument must not exceed the limits set by the telescope in size, weight and envelope at the RC focus of the CAHA T2.2 ([1], [3], and [4]). While designing PANIC, several additional features were proposed which go beyond the basic requirements. The ones we followed up are: extend the spectral range to 0.82 ?m, in order to cover all spectral bands from Z to K; the use of narrow band (bandwidth=1% of central wavelength) filters; and the possibility to move occasionally PANIC to the T3.5 of CAHA, which represents a factor 2 in scale and will allow higher spatial resolution, very useful under good seeing conditions. Table 3-2 summarizes the general specifications for PANIC established and/or imposed by the scientific goals and the technical requirements that derivate of the operational conditions and design choices. We have studied different alternatives for the optical design to make the most of the RC focus capabilities.

3 Optical design

The camera optical design ([3]) is a single optical train that images the sky onto the focal plane at an optical speed of f/3.74, with a plate scale of 0.45"/pix. Fig. 1 shows the optical straight layout (1890 mm long), the folded solution, as well as the cold stop masks for each telescope. The complete status of the optics can be found in the Optics document of the FDR ([4]). The camera consists of one field lens, L1, close to the RC telescope focus; and two separate groups of lenses, one before the cold stop masks (L2-L5), and another after them (L6-L9). The packaging solution adopted introduces three folding flat mirrors in the optical path between L1 and L2, and it has not effect from the optical performance point of view. The mirrors

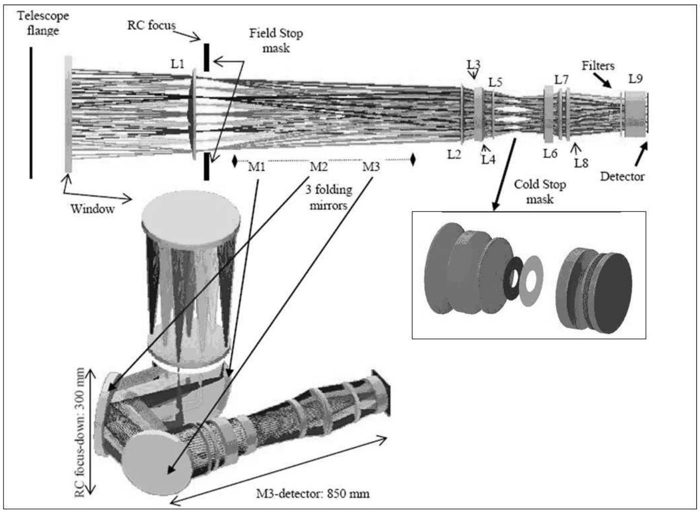

Fig. 1 PANIC optics layout, including the unfolded layout.

positions have been optimized for avoiding interference and vignetting, in order to reduce the cold volume of the whole system.

The optical design has been modeled for cryogenic temperatures and vacuum using a glass catalogue of the infrared materials working at 80 K produced for that

Element	Curvature radius		Center Thickness	Edge Thickness	Material	Optical Aperture	Full ∅
	Front face	Rear face					
Cryostat window	Infinity	Infinity	20.00	20.000	IR FS	287.90	330.00
L1	443.727	Infinity	25.20	6.488	IR FS	247.56	255.00
Field stop	Infinity	--	--	--	--	--	--
M1	Infinity	--	28.4 (TBC)	-=-	FS	275.90	284.00
M2	Infinity	--	26.0 (TBC)	-=-	FS	252.26	260.30
M3	Infinity	--	23.5 (TBC)	-=-	FS	226.78	234.80
L2	436.174	-256.647	31.91	8.435	CaF2	170.77	178.87
L3	-176.964	-436.765	10.00	21.552	S-FTM16	150.93	158.94
L4	-146.739	-140.799	13.00	11.790	IR FS	152.31	160.00
L5	290.075	Infinity	16.75	6.489	BaF2	145.12	152.92
Cold stops	Infinity	--	--	--	--	--	--
L6	419.552	137.827	10.00	26.150	S-FTM16	113.85	152.95
L7	157.962	-1319.326	25.52	6.485	BaF2	129.47	142.95
L8	290.988	Infinity	16.40	6.569	IR FS	130.52	150.00
Filter	Infinity	Infinity	8.30	8.300	IR FS	104.43	125.00
L9	-116.309	251.758	30.80	59.194	IR FS	108.80	130.00

Table 3-1. Prescriptions data of the optical system at its nominal design temperature, 80 K. All the units are in mm. The optical clear aperture is oversized by +5%.

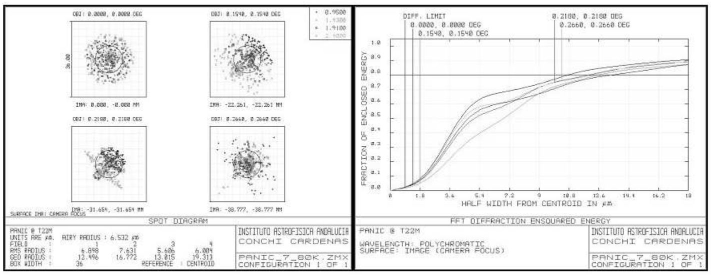

Fig. 2 Polychromatic EE and spot diagram for PANIC at the T2.2. Boxes are 2x2 pixels.

purpose. The optical prescription of the system at its working temperature is listed in Table 3-1. For manufacturing and assembly, those parameters have to be replaced by warm parameters, using coefficients of thermal expansion calculated from room temperature to 80 K.

The filters will be placed in the convergent beam between the L8 and L9, which is the most favorable position for the interference filters in PANIC. For the narrow band filters, because of the non collimated condition, we have to calculate carefully the effect on the filter performance to specify them to the manufacturers. Due to the constraints imposed during the optical design we do not expect any problem with this, even for %1 narrow band filters.

The FOV has been sampled and optimized from the centre to the external field in a radial configuration, following the equal area rule to cover the complete detector surface and the spectral band from 0.95 to 2.45 μm. Table 3-2 lists a summary of the characteristics that describe the optical performance of PANIC at the T2.2 and the T3.5. The image quality of the instrument is specified in terms of the 80 % Ensquared Energy (EE80). For simplicity, the polychromatic EE and spot diagrams are presented in Fig. 2 and Fig. 3. Better figures are obtained when the system is refocused in the photometric bands. All the bands are within requirements (EE80$\leq$2 pixels for the T2.2 and EE80$\leq$3 pixels for the T3.5) including the Z band.

The optical design is baffled with the two natural stops: a field and a pupil stop. PANIC only needs one field stop to work in both telescopes and it is placed at the

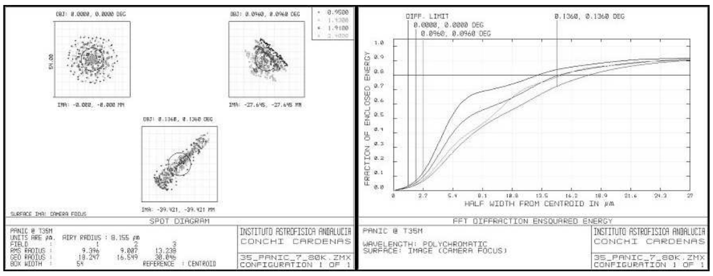

Fig. 3 Polychromatic EE and spot diagram for PANIC at the T3.5.

CAHA Telescope	@ 2.2 m RC focus	@ 3.5 m RC focus
Optics	Ritchey-Chrétien	Ritchey-Chrétien
Aperture, ∅ S1	2.2 m	3.5 m
Focal ratio	f/8	f/10
HFOV (not vignetted)	0.276°	0.245°
∅ Cassegrain focus	33' = 170 mm	29.5' = 300 mm
Scale at Cass. focus	11.7 "/mm	5.89 "/mm
PANIC performances	Optimized for this telescope	Evaluated at this telescope
Direct imaging	Over the whole FOV	Idem
FOV	31.9' x 31.9'	16.4' x 16.4'
Scale at detector	0.45 "/px	0.23 "/px
f/#	3.744	4.674
Pupil image mechanism	Mechanically available, Optimized for T2.2	Mechanically available, Optimized for T3.5
Wavelength range	Optimized: 0.95 – 2.5 µm Good transmission from 0.8 µm and IQ	Idem
Image Quality, EE80	1.5 pix.=26.4 µm= 0.66" max. (≤ 2 pixels=36µm=0.90")	2.0 pix.=35.5 µm = 0.45" max (≤ 3 pixels=54µm=0.69")
Distortion	< 1.4 % max. (corner)	Idem
Transmission	~ 57.3 % (window+9 lenses+3gold mirrors)	Idem
IR Detector	4 K x 4 K	Idem
Operating temperature	80 K	Idem
Gap between detectors	167 pixels (minimum) = 75"	40"
Filters	Broad band: ZYJHK, Narrow band ~1%	Idem

Table 3-2. General capabilities of the T2.2 and T3.5 RC foci and summary of the PANIC general specifications.

position of the RC focal plane between L1 and M1. The entrance pupil has been placed at the telescope primary mirror (S1) which gives the maximum light collecting power and achieves maximum background suppression, especially in the K band. The optical design provides a mechanically accessible pupil image with a good image quality of the S1 in the middle of the optical track for both telescopes. As a result of the Non-Sequential Components ghost analysis done we have confirmed the complete fulfillment of the ghost requirements (negligible on the image quality -IQ-) and we have a baffling proposal to minimize the contribution due to ghosts. In order to minimize the stray light, all the lenses and mirrors have been over dimensioned to avoid stray light coming from the lens edges and the folded mirrors are gold coated on glass substrate to reduce imaging errors and scattered light. In addition, the opto-mechanical design uses a light tight optical labyrinth between the optical assemblies. The whole system is encapsulated to minimize stray light effects [1].

4 Tolerance analysis and AIV

The PANIC performance has to be guaranteed after fabrication and assembly, considering all the possible error sources which could produce degradation of the ideal instrument or seeing profile: the nominal design, the optical manufacture, the position accuracy during integration/assembly of the instrument, the material inhomogeneities, the temperature effects and the motion effects. The tolerances need to be defined for the optical manufacturing, for the position accuracy during assembly and for the stability during operation. For this purpose we have done the analysis of the tolerances and the complete image quality error budget for the system. The results feed the opto-mechanical design and alignment strategy of the instrument. It has been decided to establish some compensators to relax critical values in tolerances. A preliminary optical assembly, integration and verification (AIV) plan has been made for the PANIC instrument covering three main categories related to the optical integration process: components manufacturing and tests; barrel integration (subassemblies) and tests; and system integration and final engineering tests.

5 Conclusions

The optical design meets the desired performance criteria and is feasible from the point of view of manufacture and integration. To achieve this, a specific control plan during the integration phases is foreseen. It has been iterated with several optical manufacturers and the mechanical designers. An error budget and a compensators strategy have been done. The feasibility of PANIC to work at both telescopes, the T2.2 and the T3.5, has been confirmed.

The most important achievements have been the correction of off-axis aberrations due to the wide-field available, the correction of chromatic aberration because of the wide spectral coverage, and the introduction of narrow band filters (1%) in the system minimizing the degradation of the filter pass-band. The design contains only spherical surfaces (i.e. no conic or aspheric surfaces) and special care has been taken in the selection of the lens materials, to include all the photometric bands, even the Z band, in the system, and to maximize the system throughput. A crucial point has been the production of the internal cold stop with good optical quality, which reduces the background, especially in the K band.

6 References

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