UNIVERSITY OF HAWAI'I AT MĀNOA

Institute for Astronomy

Pan-STARRS Project Management System

The PS-1 Telescope Non-ADC Optical Design

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Revision History

Version/Revision	Date	Comments
DR	27/12/04	Creation of report
00	6/1/05	Release of report
01	3/29/05	Fix minor inconsistencies with ADC version

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1 Scope of Document

This document describes the non-ADC optical design for the Pan-STARRS prototype telescope, PS-1.

2 Referenced Documents

PSDC-330-005-00, The PS-1 Telescope ADC Optical Design, Morgan.

3 Introduction

This design was designated as the baseline optical design of the telescope on 16 December 2004. It is anticipated that this will be the optical layout of the telescope when it sees first light in January 2006. As soon as it is available it is planned that the L1 corrector in this design will be replaced by an Atmospheric Dispersion Corrector (ADC). This replacement is a “drop-in” design in the sense that all other optical elements and their positions are unchanged with the installation of the ADC. The ADC version of the optics is given in PSDC-330-005-00.

The description of the optical layout of the PS-1 telescope is available as a Zemax design file. This design is given in the file NOADC-M-1.0.ZMX. The design ADC-M-1.0.ZMX is the ADC version of the PS-1 optical design.

This design was derived by Ed Mannery from an initial optical design which was done by Klaus Hodapp. The Hodapp design from which this layout was derived can be found in the Zemax file ADC-H-1.0.ZMX. This design differs from the Hodapp design in that it has two aspheric surfaces in the corrector optics rather than one, it has a shorter back focal distance, and the corrector optics are more compact, extending only about 0.1 m in front of the M1 vertex.

4 The PS-1 non-ADC Optical Design

4.1 The Optical Layout

Figure 1 shows the layout of the non-ADC optical design for the Pan-STARRS prototype telescope, PS-1. The telescope is a Cassegrain design with a three element corrector, 10 mm thick filters, and a 1.5° field of view. The primary and secondary mirrors are labeled M1 and M2, respectively. The refractive corrector optics are labeled L1 through L3, with L3 forming the window of the CCD dewar window. This design requires the presence of the filters to achieve proper focus. The filter mechanism for PS-1 will have 3 layers of filters. Only a single filter will be in the optical path at any given time. The approximate locations of the filters in each layer are given by F1 through F3 in Figure 1.

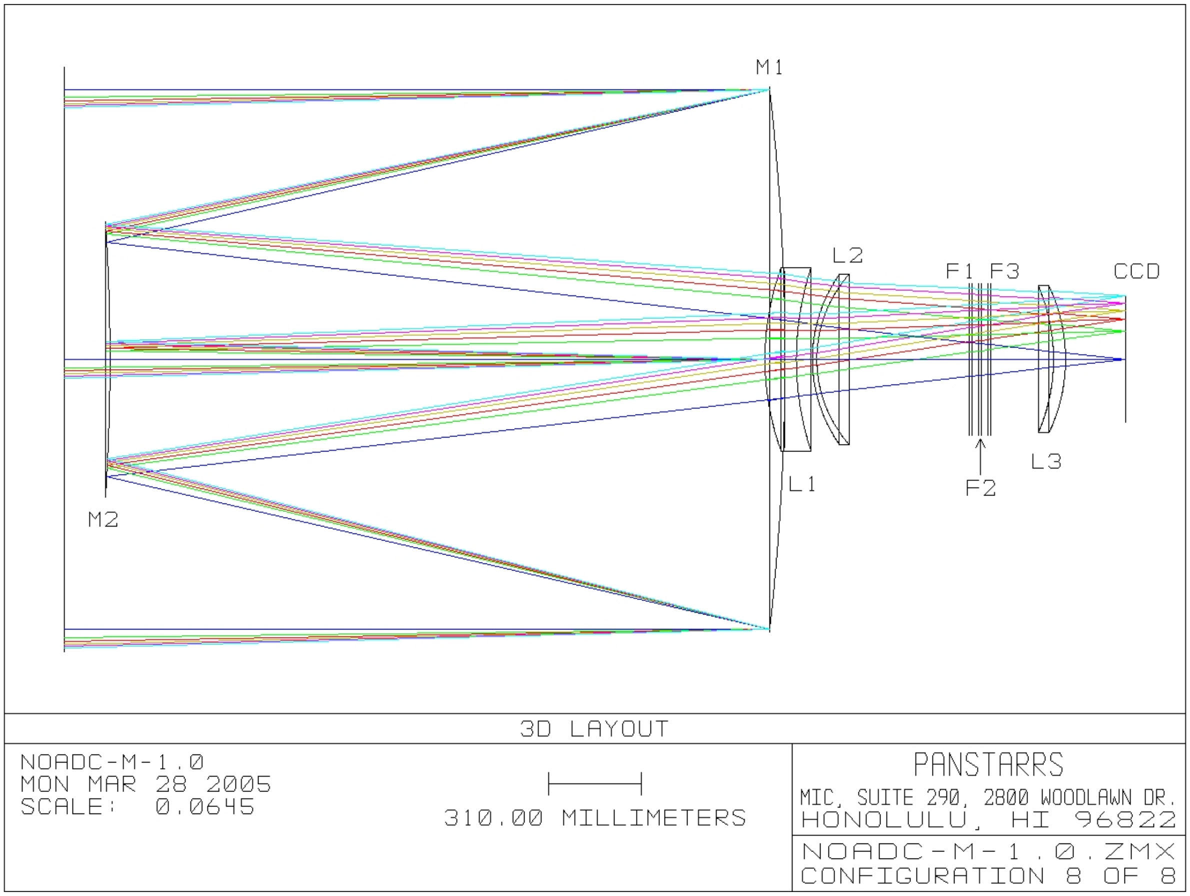

Figure 1 The layout of the baseline optical design for the PS-1 telescope.

4.2 Basic Optical Parameters of this Design

For the equations in this section we adopt the following nomenclature:

- R_1 = the radius of curvature of M1
- K_1 = the conic constant of M1
- R_2 = the radius of curvature of M2
- K_2 = the conic constant of M2
- f_1 = focal length of M1 = R_1 /-2
- f_2 = focal length of M2 = R_2 /2
- f = telescope focal length
- d = distance between M1 and M2

We also adopt the following standard nomenclature for the paraxial normalized telescope parameters:

- k = ratio of secondary to primary marginal ray heights.
- $\rho = R_2 / R_1$ = the ratio of secondary to primary radii of curvature.
- m = transverse magnification of the secondary, also = $f/ f_1 = \rho/(\rho - k)$.

- β = the telescope back focal distance normalized to f_1, i.e., the distance from the vertex of the primary to the telescope focal plane is given by βf_1. β = k(m + 1) – 1.
- (1 – k) = distance between M1 and M2 normalized to f_1, i.e., the distance between M1 and M2 is given by $(1 - k)f_1$

By specification for the Pan-STARRS telescope design we have f = 8000 mm. Given that R_1 = -7876.2 mm and R_2 = -6769.1, we have

$f_1 = R_1/-2 = -7876.2 / -2 = 3938.1$ mm

$m = f / f_1 = 8000 / 3938.1 = 2.0314$

$\rho = R_2 / R_1 = -6769.1 / -7876.2 = 0.8594$

$k = \rho(m - 1) / m = 0.8594(2.0314 - 1) / 2.0314 = 0.4364$

$\beta = k(m + 1) - 1 = 0.4364(2.0314 + 1) - 1 = 0.3228$

$d = (1 - k)f_1 = (1 - 0.4364)3938.1 = 2219.5$ mm

The Ritchey-Chretien (RC) values of the conic constants for this design are given by

$$K_1 = -1 - \frac{2(1+\beta)}{m^2(m-\beta)} = -1.375$$

$$K_2 = -\left(\frac{m+1}{m-1}\right)^2 - \frac{2m(m+1)}{(m-\beta)(m-1)^3} = -15.208$$

A comparison between these constants and those used in the Pan-STARRS design shows considerable differences, which illustrates that this design is not a classical RC Cassegrain telescope. This is obvious from the presence of the corrector optics. But this comparison emphasizes that the corrector optics are critical for the suppression of all three of the major aberrations in the system (spherical, coma, and astigmatism).

If we denote a differential movement of the secondary from the primary by ds_2 and if ds_2' is the motion of the focal plane induced by ds_2, the relationship between these two parameters is given by the equation

$$ds_2' = -(m^2+1)ds_2 = -5.126\, ds_2$$

This shows that for a 1 mm change of the distance between M1 and M2, the position of the telescope's focal surface changes by 5.13 mm.

There is a very small curvature to the CCD focal surface on this design. The sag of this surface, x, is given by

$$\boldsymbol{x = R - \sqrt{R^2 - y^2}}$$

where R is the radius of curvature and y is the radius of the chord associated with x. The optimal focal plane radius of curvature is 2.4×10^5 mm. At the edge of a 1.5° field of view, y = 210.53 mm and x = 92 µm. Note that the sag in the ADC design is approximately one half of this (47 µm). The direction of the curvature for the non-ADC design is illustrated in Figure 2. However, for simplicity, we have decided to keep the focal plane curvature the same between the ADC and non-ADC designs. Using 4.7×10^5 mm (the radius of curvature for the ADC design) causes only minor degradation to the image PSF.

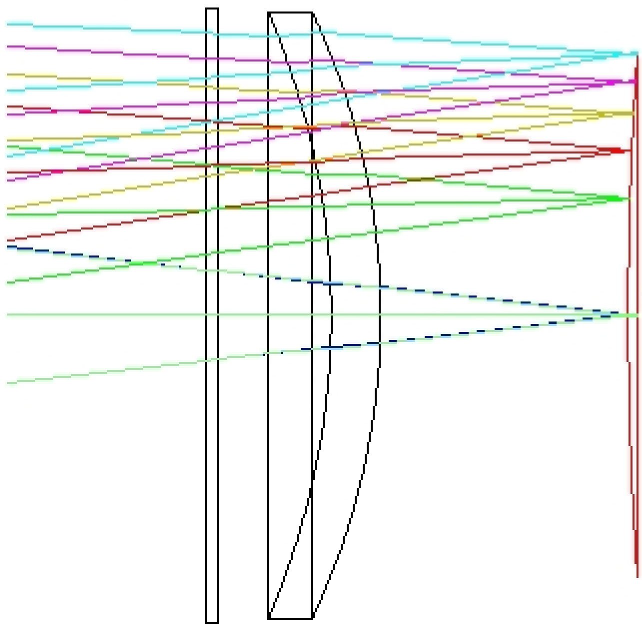

Figure 2 Focal Plane Curvature in the non-ADC Pan-STARRS optical design, NOADC-M-1.0. The curvature shown in the figure has been magnified by a factor of 2000 to make it visible in the figure. A filter and L3 are shown to the left of the curved focal plane. The ray traces show spots out to a field angle of 1.5°.

Figure 3 shows a spot diagram from the design NOADC-M-1.0 through the w filter band-pass at zenith with an assumed focal plane radius of curvature of 4.7×10^5 mm. Chromatic aberrations dominate this design at large field angles. This design does not meet the image budget for the PS-1 telescope at all zenith angles of operation. At zenith angles greater than about 10° atmospheric dispersion dominates the size of the telescope PSF. For example in the w filter, at 10° the telescope PSF RMS radius increases from 6.14 µm to 7.42 µm, an increase of 21%. This is the driving motivation for the ADC design. The band pass of operation for this design is between 0.402 µm and 1.10 µm. With a focal length of 8 m, the plate scale on the camera is 8000 mm/radian = 38.8 µm/arcsecond.

Figure 3 A spot diagram from the design NOADC-M-1.0 through the w filter band-pass at zenith.

5 System/Prescription Data for NOADC-M-1.0

The following tables give the optical prescription for the NOADC-M-1.0 design. They are derived from the ZEMAX prescription report. Note that this document does not include tolerance information. This type of information can be found in the polishing specifications for each optic (e.g. PSDC-330-003-01 gives the polishing specifications for M1 and M2), in the system image budget (PSDC-300-011-00), and in the specialized tolerance ZEMAX file ADC-M-1.0 tol.ZMX. In Table 3 only the first filter layer (F1) is given a glass type. In this way, the other filters (F2-F3) are only placeholders in the optical prescription and have no influence on the optical ray trace.

Table 1. General Lens Data

Data Type	Data Value
Surfaces	21
Stop	3
System Aperture	Entrance Pupil Diameter = 1800
Glass Catalogs	INFRARED MISC HODAPP
Ray Aiming	Off
Apodization	Uniform, factor = 0.00000E+000
Temperature (C)	0.00000E+000
Pressure (ATM)	6.16000E-001
Effective Focal Length	8003.797 (in air at system temperature and pressure)
Effective Focal Length	8003.797 (in image space)
Back Focal Length	200.0634
Total Track	3536.198
Image Space F/#	4.446554
Paraxial Working F/#	4.446554
Working F/#	4.44627
Image Space NA	0.11174
Object Space NA	8.999998e-008
Stop Radius	900
Paraxial Image Height	209.5868
Paraxial Magnification	0
Entrance Pupil Diameter	1800
Entrance Pupil Position	2350
Exit Pupil Diameter	1170.035
Exit Pupil Position	-5202.562
Field Type	Angle in degrees
Maximum Field	1.5
Primary Wave	0.818
Lens Units	Millimeters
Angular Magnification	1.538415

Table 2. Fields

Field Number	X-Value	Y-Value	Weight
1	0.0000	0.0000	3.0
2	0.0000	0.67078	2.0
3	0.0000	0.94860	1.3
4	0.0000	1.16187	1.0
5	0.0000	1.34159	1.0
6	0.0000	1.50000	3.0
7	1.5000	0.0000	3.0
8	-1.5000	0.0000	3.0

Table 3. Surface Data Summary

Surf	Type	Comment	Radius	Thickness	Glass	Diameter	Conic
OBJ	STANDARD		Infinity	Infinity		0	0
1	ATMOSPHR	ATM+M2 BAFFEL	Infinity	0		1939.074	0
2	STANDARD	SPIDER	Infinity	0		1939.074	0
STO	STANDARD	M1 PUPIL	Infinity	51.763		1800	0
4	EVENASPH	M1	-7876.185	-2248.489	MIRROR	1816.023	-1.592048
5	COORDBRK	M2 FOC CONTROL	-	-0.251	-	-	-
6	EVENASPH	M2	-6769.096	0.251	MIRROR	916.9247	-20.41155
7	COORDBRK	M2 FOC	-	2248.489	-	-	-
8	STANDARD	M1 VERTEX	Infinity	-66.816	-	588.5316	0
9	STANDARD	L1-A	891.9184	104.571	F_SILICA	588.5316	0
10	EVENASPH	L1-B	977.1177	53.43		558.939	0
11	STANDARD	L2-A	491.2228	14.71	F_SILICA	541.6477	0
12	STANDARD	L2-B	427.4985	507.01		529.4379	0
13	STANDARD	F1-A	Infinity	10	F_SILICA	488.748	0
14	STANDARD	F1-B	Infinity	21		488.0839	0
15	STANDARD	F2-A	Infinity	10		486.0559	0
16	STANDARD	F2-B	Infinity	21		485.0902	0
17	STANDARD	F3-A	Infinity	10		483.0622	0
18	STANDARD	F3-B	Infinity	209.53		482.0964	0
19	EVENASPH	L3-A	-610.5099	40	F_SILICA	465.9881	0
20	STANDARD	L3-B	-568.6764	200		472.3189	0
IMA	STANDARD	CCD-ARRAY	470000	--		421.0716	0

Table 4. Surface Data Detail

Surface	Surface Name	Surface Type	Surface Feature	Value
1	ATM+M2 BAFFEL	ATMOSPHR	Aperture	Circular
			Minimum Radius	530
			Maximum Radius	975
			Atmosphere	Refraction
			Zenith Angle	0
			Height (m)	4205
			Temperature (K)	273
			Pressure (mb)	616
			Humidity (rel)	0.3
			Latitude (deg)	19
2	SPIDER	SPIDER	Number of vanes	4
			Vane thickness	25
3 (Stop)	M1 PUPIL	STANDARD	Aperture	Circular
			Minimum Radius	0

Surface	Surface Name	Surface Type	Surface Feature	Value
			Maximum Radius	900
4	M1	EVENASPH	r^6 Coefficient	1.845611e-021
5	M2 FOC CNTL	COORDBRK	-	-
6	M2	EVENASPH	r^6 Coefficient	4.4772746e-019
7	M2 FOC	COORDBRK	-	-
8	M1 VERTEX	STANDARD	--	--
9	L1-A	STANDARD	Aperture	Circular
			Minimum Radius	0
			Maximum Radius	306
10	L1-B	EVENASPH	r^4 Coefficient	8.6773906e-012
			r^6 Coefficient	-1.1255523e-016
			Aperture	Circular
			Minimum Radius	0
			Maximum Radius	306
11	L2-A	STANDARD	Aperture	Circular
			Minimum Radius	0
			Maximum Radius	283
12	L2-B	STANDARD	Aperture	Circular
			Minimum Radius	0
			Maximum Radius	283
13	F1-A	STANDARD	Aperture	PAN-STARRS_FILTERS.UDA
			Aperture Scale	25.4
14	F1-B	STANDARD	Aperture	PAN-STARRS_FILTERS.UDA
			Aperture Scale	25.4
15	F2-A	STANDARD	Aperture	PAN-STARRS_FILTERS.UDA
			Aperture Scale	25.4
16	F2-B	STANDARD	Aperture	PAN-STARRS_FILTERS.UDA
			Aperture Scale	25.4
17	F3-A	STANDARD	Aperture	PAN-STARRS_FILTERS.UDA
			Aperture Scale	25.4
18	F3-B	STANDARD	Aperture	PAN-STARRS_FILTERS.UDA
			Aperture Scale	25.4
19	L3-A	EVENASPH	r^4 Coefficient	-2.3377101e-011
			r^6 Coefficient	2.3449778e-015
			Aperture	Circular
			Minimum Radius	0
			Maximum Radius	245
20	L3-B	STANDARD	Aperture	Circular
			Minimum Radius	0
			Maximum Radius	245
21	CCD ARRAY	STANDARD	--	--