LINC-NIRVANA

The **L**BT **IN**terferometric **C**amera and
Near-**I**nfra**R**ed / **V**isible **A**daptive
i**N**terferometer for **A**stronomy

A collaborative project of the MPIA Heidelberg, INAF-Arcetri,
Universität zu Köln, and MPIfR Bonn

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Warm Optics

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	Name	Date	Signature
Prepared	P. Bizenberger	12 May 2005	P. Bizenberger
Approved	Emiliano Diolaiti	19 May 2005	Emiliano Diolaiti
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1 Scope

This document describes the warm optics of LINC-NIRVANA, including the collimator optics and the so-called FP20 optics. The FP20 optics focus the collimated light to the Mid and High Level Wavefront Sensors. Also, the tolerancing and the thermal compensation is described. Chapters for melt data adaptation and test plate fitting are prepared but will be done after the FDR.

2 Applicable documents

No.	Title	Number & Issue
AD1	Design report (from Winlight)	LN-MPIA-FDR-OPT-001-APP_A
AD2	IR beam combining optics	LN-MPIA-FDR-OPT-002
AD3	K-mirror	LN-INAFA-FDR-AO-004
AD4	Piston mirror unit	LN-MPIA-FDR-MECH-002
AD5	Interface to telescope	LN-MPIA-FDR-INT-002
AD6	Technical Specifications	LN-MPIA-FDR-OPT-001-APP_B
AD7	List of science filters and dichroics	LN-MPIA-TN-OPT-003

3 External Interfaces

Item	Short descrition
Telescope optics	The telescope optics are input to the collimator

4 Acronyms and abbreviations

DM	Deformable Mirror
MHWS	Mid and High layer Wavefront Sensors
NIR	Near Infra Red
PDR	Preliminary Design Review
FP20	F/20 focal plane for the wave front sensors

5 Introduction

The optical design of the warm optics covers the design of the collimator and of the FP20 camera, as well as the tolerancing and the compensation for thermal effects. The design is done assuming a modified telescope design (shifted focal plane by modifying the secondary shape), which is identical for both arms. Since LINC-NIRVANA is fed by both telescopes, the collimator and the FP20 optics will be built twice. The design is identical and, of course, only one of each is described.

The collimator feeds the NIR science channel and the wavefront sensor channel, split by a warm dichroic mirror. Visible light is used for wavefront sensing and NIR is used for science observations. The collimator is folded by 2 plane mirrors, which are in the final LINC-NIRVANA set-up two deformable mirrors per side. These mirrors are conjugated to certain layers in the atmosphere. The collimator forms a pupil which is close to the center line of the two telescopes. The two pupils of the two collimators must be homothetic i.e. the diameter and separation ratio must be identical to the ratio of telescope entrance pupil diameter to telescope separation. These two pupils are forming the interface to the cold beam-combining optics. The light for wavefront sensing is split just before the cryostat windows to the FP20 optics. The FP20 optics focus the full 2 arcmin field of view to an image plane, which is the interface to the MHWS. In order to compensate the field rotation, an optical field rotator is included in the FP20 optics.

6 Functions

The main functions of the optical design are:

- Collimator optics,
  forming a constant envelope for the DMs and a collimated beam in the pupil. The collimator also places the DMs in a conjugated plane for the required altitude of the turbulence layers in the atmosphere.
- Cold pupil,
  including the piston mirror which bends the beams to form a homothetic pupil, the warm dichroics and the vacuum windows.
- FP20 optics,
  which generate a F/20 focal plane for each side.
- Temperature compensation,
  in order to handle the relatively large temperature range for the long optical path.
- Tolerance analysis,
  for manufacturing and assembly.
- LBT optical modifications,
  which means modification to the secondary mirror shape in order to shift the focus.

7 Collimator optics

7.1 Purpose

Note: The DMs are numbered starting at 2 because in the LINC-NIRVANA nomenclature, the secondary mirror of the LBT is DM 1.

The collimator optics must generate a homothetic pupil i.e. at a certain position and with a certain diameter. In addition, the optics must be folded in order to accommodate one or two deformable mirrors at certain conjugated positions. The DMs have a fixed diameter and to use as many actuators of the DM as possible, the beam for a certain field should have a constant outer diameter i.e. the two DMs are fully illuminated.

In front of the telescope focus, an annular mirror is placed to reflect the fields form 2 arcmin to 6 arcmin diameter to the ground level wavefront sensor. The central 2 arcmin are pass through a central hole in the mirror.

7.2 Requirements

Item	Value
Input	LBT optics, modified
Wavelength range	0.6 µm to 2.4 µm
Field of view	2 arcmin diameter
Collimation	The 2 PSF must overlap better than 1/10 of a PSF diameter
Pupil position	Pupil behind a bending mirror i.e. minimum 2 * beam diameter clearance after the last lens
Intermediate beam for DMs	Approximately constant envelope of ~ 140 mm
DMs conjugated altitudes	4 km , 8 km, adjustable by a moving stage up to 15 km.
Blur of meta pupils	≤ 0.7 mm
Temperature range	-15°C to +25°C

Table 1: Requirements for the collimator optics

7.3 Parts

- 2 x Annular mirror
  Elliptical mirror with a central hole for the inner 2 arcmin.
- 2 x Lens group I consisting of 3 lenses
  forming the constant envelope beam.
- 2 x DM 2 & 3 which are assumed as flat mirrors for the optical design.
- 2 x Lens group II consisting of 3 lenses
  collimating the beam.

7.4 Layout

The annular mirror is not shown in the layout, since it does not affect the collimator optics.

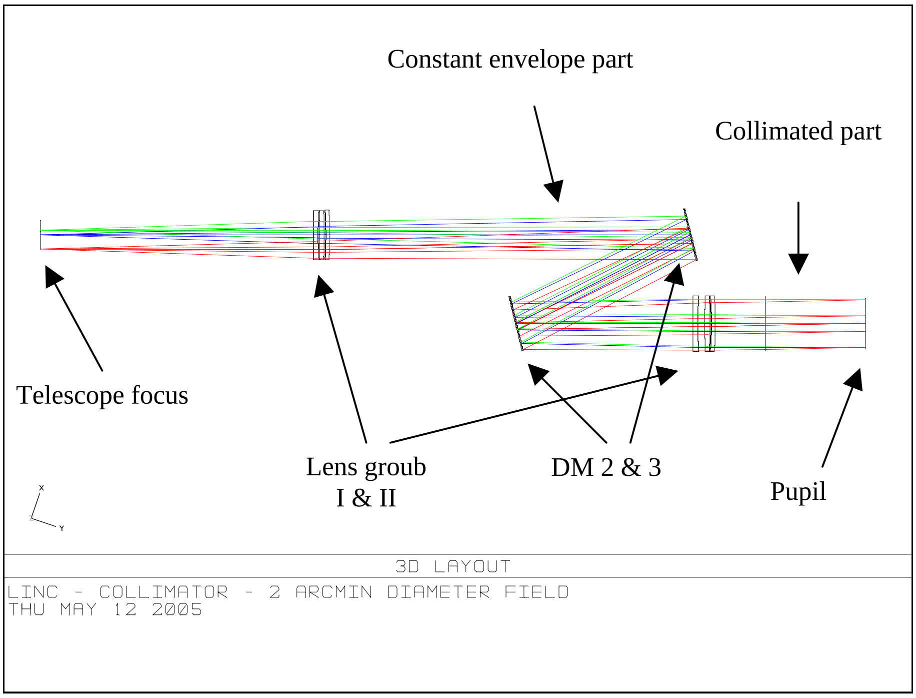

Figure 1: Layout of the collimator optics.

7.5 Functionality

7.5.1 Interfaces

The collimator has three optical interfaces, where two are basically identical. The LBT optics, operated in a modified mode, define the input beam. The homothetic pupil, generated by both collimators, is the interface to the NIR optics. A single pupil in reflection of the dichroic mirror is also the interface to the FP20 optics, described later in this document.

7.5.2 Constant envelope of intermediate beam

To fully cover the actuators of the DMs, the beam diameter for all fields should be constant on both DM positions. Therefore, the envelope of the intermediate beam between the two lens groups is designed to be constant. This is done with the first lens group.

7.5.3 Homothetic pupil & collimated beam

For the beam combining optics, the beams must be well collimated in order to avoid a PSF separation in the common focal plane of the two arms. The pupil geometry must be homothetic to guarantee zero OPD across the field.

7.5.4 Focus and thermal compensation

The first lens group must be motorized to adapt the focal length of the two arms to be identical. Also, the thermal compensation must be done by moving the this lens group. Details pending.

7.5.5 Fields

The fields used for the design are:

X field [deg]	Y field [deg]
0	0
0	0.01178
0	0.0166667
0.0166667	0

Table 2: Fields for the collimator optics.

7.5.6 Wavelengths

Waves [µm]	comments
0.6	Primary wave
0.7	
0.8	
0.95	
1.25	
1.65	
2.0	
2.4	

Table 3: Wavelengths for the collimator optics

The primary wavelength is used take to calculate the Airy disc diameter, diffraction limit, etc..

7.6 Specification

The detailed lens specification is given in AD6.

7.7 Capability

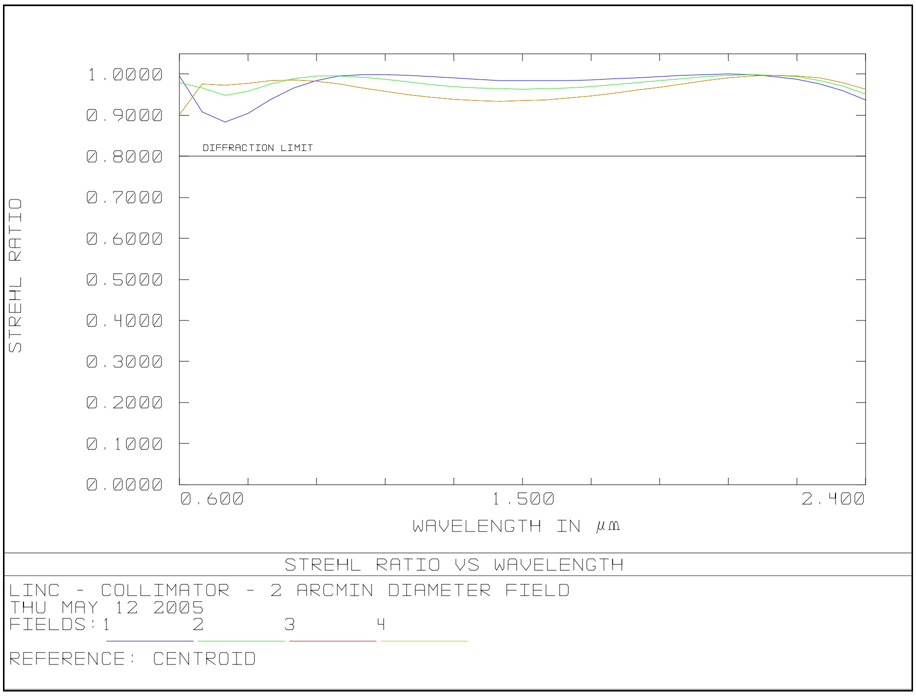

Figure 2: Strehl plot of the collimator optics.

The atmospheric layers at 8 km and 4.2 km are conjugated to the plane mirror positions in the collimator optical design. This is demonstrated in Figure 3 and Figure 5. The beams are focused at the conjugated planes.

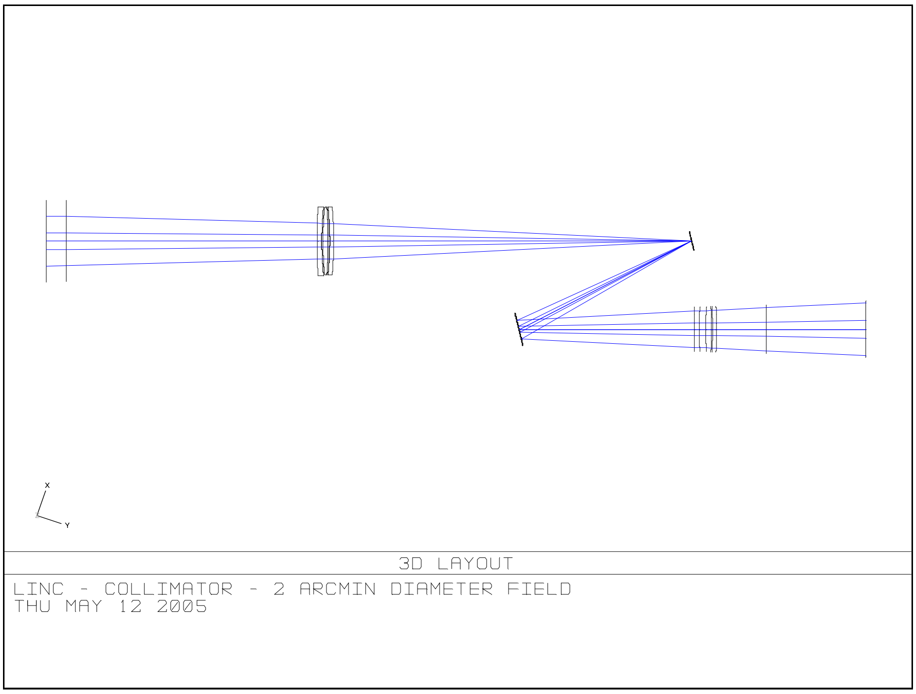

Figure 3: Image of a object (atmospheric layer) at 8 km distance

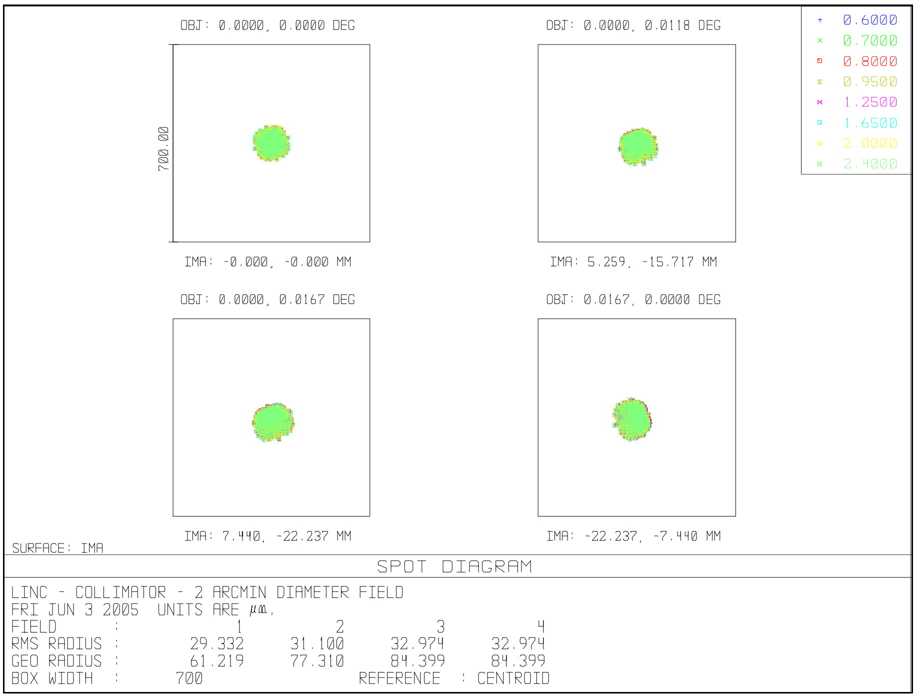

Figure 4: Spot diagram at the DM conjugated to 8 km distance.

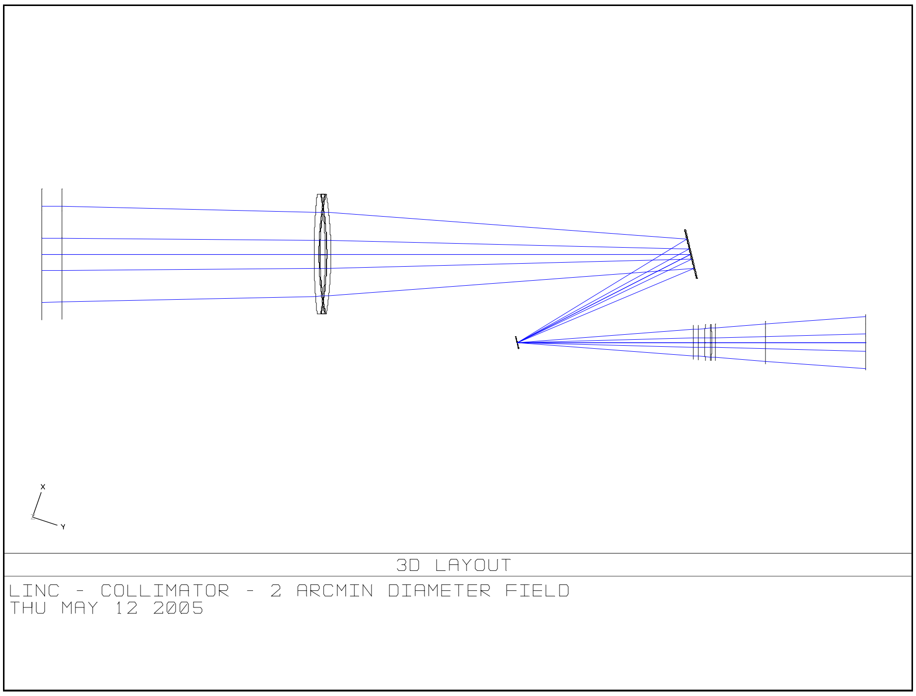

Figure 5: Image of a object (atmospheric layer) at 4.2 km distance.

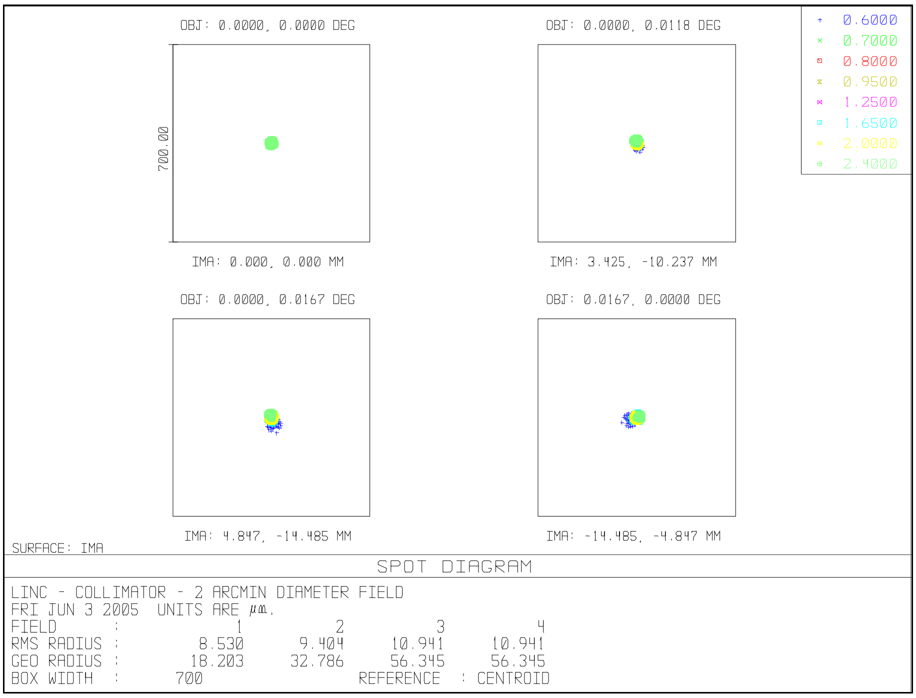

Figure 6: Spot diagram at the DM conjugated to 4.2 km distance.

The boxes in the spot diagrams indicate the requirement for the meta pupil blur given in Table 1.

7.8 Availability

The lenses have already been ordered from Winlight, France. Collimator lenses are already adapted to test plate list. The Collimator lenses are in production. The FP20 lenses will be adapted when the collimator lenses are finished. Coating will be done for all lenses together. The lens mount is designed (AD1) and will be manufactured when the ‘as built’ re-optimization is done and the final air spacing is defined. Complete delivery is scheduled for fall 2005.

8 Cold pupil

8.1 Purpose

The pupil of the beam combining optics must be inside the cryostat in order to reduce thermal background to the IR detector.

The collimator optics will not be changed in this step of the design, the optics are already defined in the previous section. This section only calculates the lateral and axial shift of the cold pupil and defines the exact position in order to achieve a homothetic pupil.

8.2 Requirements

Item	Value
Distance window – pupil	min. 30 mm
Pupil distortion	< 50 µm
Collimation of one field for both arms	< 0.1 PSF width
Wavelength range	1.0 µm to 2.4 µm
Field of view	1 arcmin diameter
Temperature range for operation	-15°C to +25°C

Table 4: Requirements for the cold pupil design.

8.3 Parts

Additional to the collimator:

- 1 x Piston mirror
  bends the beams into vertical direction, defines the pupil separation. The piston mirror is one unit with two reflecting surfaces.
- 2 x Dichroic mirror
  reflecting the visible 0.6 µm to 0.9 µm and transmitting the NIR 1.0 µm to 2.4 µm
- 2 x Vacuum window
  as part of the cryostat.

8.4 Layout

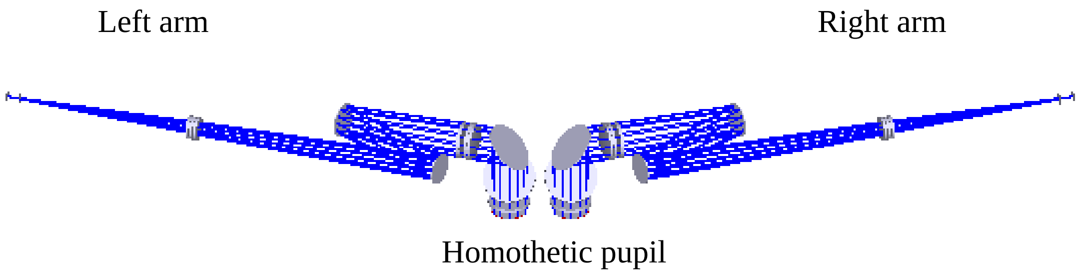

Figure 7: Both collimator arms with the cold pupils.

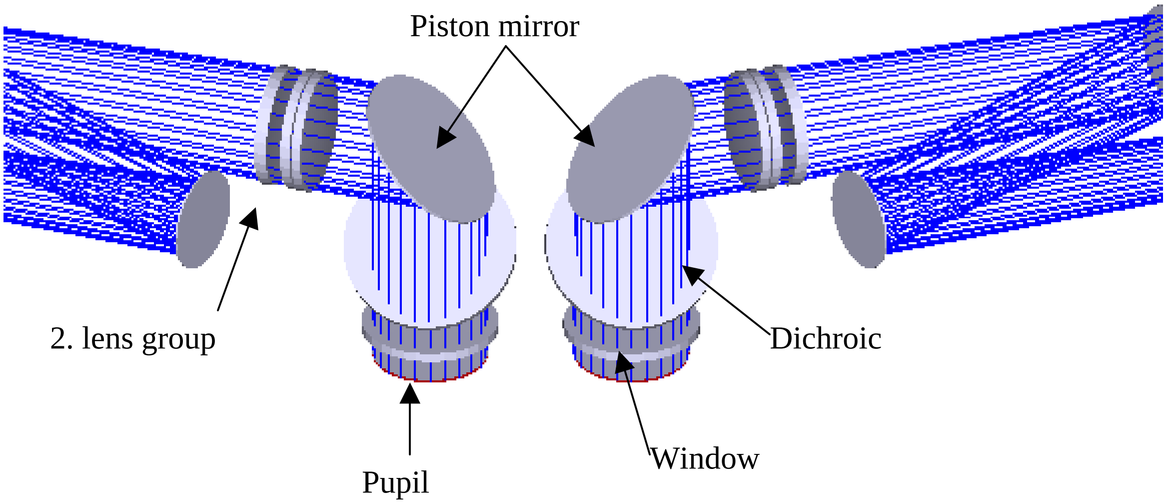

Figure 8: Zoom of the previous figure.

8.5 Functionality

8.5.1 Cold pupil

The pupil shifts laterally due to the tilted dichroic and axially due to the window. This must be considered in the calculations for the homothetic pupil. Chromatic aberrations are introduced. The windows are also bent due to the pressure difference

8.5.2 Fields

X field [deg]	Y field [deg]
0	0
0	0.0058333
0	0.008333
0.008333	0
	-0.008333
-0.008333	

Table 5: Fields for the cold pupil design.

8.5.3 Wavelengths

Waves [µm]	comments
0.9	Primary wave
1.75	
2.4	

Table 6: Wavelengths for the cold pupil design.

The primary wavelength is taken to calculate the Airy disc diameter, diffraction limit, etc..

8.6 Specification

8.6.1 Piston mirror

Detailed specifications for the piston mirror are given in AD4.

8.6.2 Dichroic mirrors

Item	Value
Material	Fused silica (IR grade)
Thickness	10 mm
Edge shape	Elliptical
Clear apperture	200 mm x 145 mm
Surface figure	TBD
Wedge	TBD
Coating	See AD7

Table 7: Dichroic mirror specifications.

8.6.3 Vacuum windows

Item	Value
Material	Fused silica (IR grade)
Thickness	10 mm
Dimensions	Round
Clear apperture	140 mm diameter
Surface figure	TBD
Wedge	TBD
Coating	AR 1.0 µm to 2.4 µm on both sides

Table 8: Vacuum window specifications.

9 FP20 optics

9.1 Purpose

The visible light reflected from the dichroic which is located after the collimator in the collimated beam, enters the FP20 camera. These optics provide a telecentric F/20 beam as input to the medium and high layer wavefront sensor, covering the full 2 arcmin field of view delivered by the collimator.

For compensating field rotation, an optical field rotator is included. This field rotator is built as a K-mirror design.

9.2 Requirements

Item	**Value**
Wavelength range	0.6 µm to 0.9 µm
Blocking	all wavelengths < 0.6 µm
Field of view	2 arcmin diameter
Field curvature	flat
Strehl ration	> 0.9
F/#	F/20 ± 0.1
Non telecentric angle	< 0.014°
Total length	< 2300 mm
Temperature range for operation	-15°C to +25°C

Table 9: Requirements for the FP20 camera

9.3 Parts

The lens groups of the FP20 optics are numbered starting at 3 because the lens groups are counted for the collimator and the FP20 camera together (all ‘warm’ optics).

- Lens group III consisting of 2 lenses
- K mirror
- Lens group IV consisting of 1 lens
- Filter for blocking TBD
- Lens group V consisting of 1 lens

9.4 Layout

One of the two FP20 optics arms is shown. The filter is not shown.

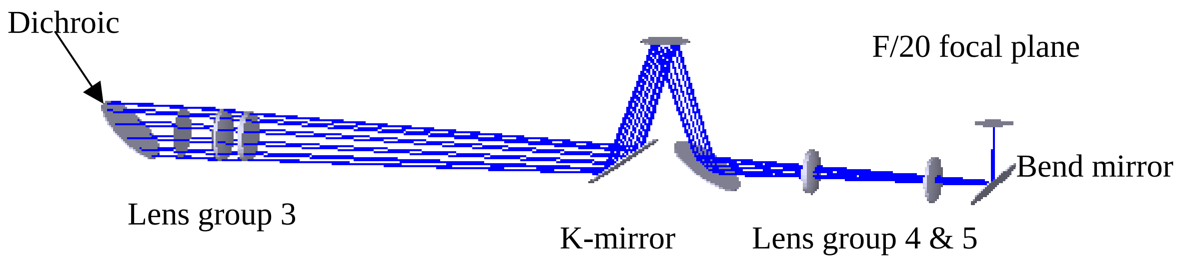

Figure 9: Layout of the FP20 optics

9.5 Functionality

9.5.1 F/20 focus

The three lens groups do the focusing of the beams with the required optical correction. The glass selection is from only one manufacturer (Ohara).

A filter limits the wavelength range of the FP20 camera, because the optics are not corrected for short wavelengths, which still can be detected by the wavefront sensor and the patrol camera. The position of this filter is in the converging beam between the 4th and 5th lens groups.

9.5.2 K-mirror

The field rotation will be compensated by a motorized K-mirror arrangement. These mirrors are all flat and have no optical power. The position of the K-mirror is defined in a global sense due to mounting requirements (clear space and potential vignetting). See AD3 for more information about the K-mirror.

9.5.3 Focus and thermal compensation

The last lens group must me motorized in order to compensate for temperature and for final focusing to the MHWS. Details pending.

9.5.4 Fields

X field [deg]	Y field [deg]
0	0
0	0.01178
0	0.0166667
0.0166667	0
	-0.0166667
-0.0166667	

Table 10: Fields for the FP20 design.

9.5.5 Wavelengths

Waves [µm]	comments
0.6	Primary wave
0.7	
0.8	
0.9	

Table 11: Wavelengths for the FP20 desgin

The primary wavelength is taken to calculate the Airy disc diameter, diffraction limit, etc..

9.6 Specification

9.6.1 Lenses

See AD1 and AD6 for details.

9.6.2 K-mirror

See AD3 for details.

9.6.3 Filter

Details pending

9.7 Capability

The following data reflects the current status of the design i.e. no melt data adaptation and no test plate adaptation. This will be done when the collimator is finished in order to include all possible constrains.

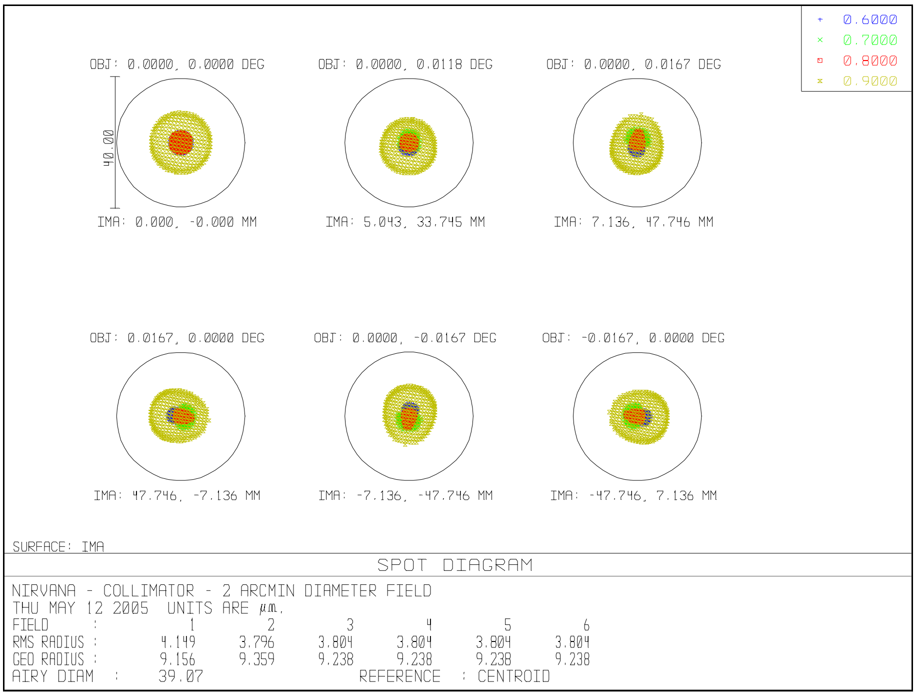

Figure 10: Spot diagram of the FP20 optics.

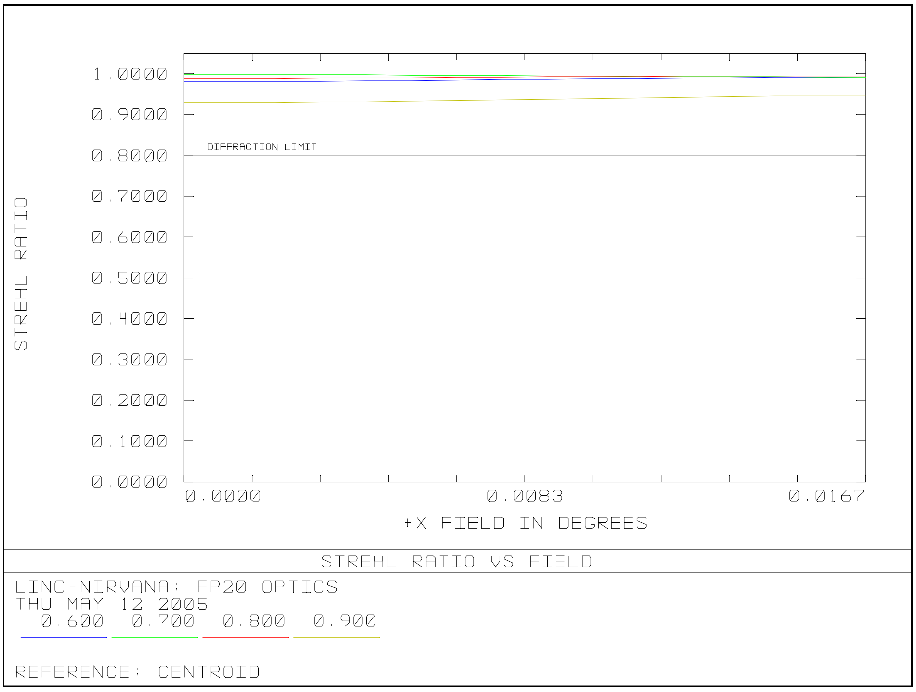

Figure 11: Strehl ratio plot of the FP20 optics.

9.8 Availability

The lenses are already ordered from Winlight, France. The lenses were ordered including the AR coating and the mounting, which interfaces to the mechanics designed by MPIA which will be mounted to the bench. The delivery is scheduled for summer 2005.

See AD3 for details of the K-mirror.

10 Tolerancing

Tolerancing details and results are given in AD6.

11 Temperature compensation

11.1 Collimator

By moving the first lens group of the collimator optics. Details pending.

11.2 FP20 optics

By moving the last lens group of the FP 20 optics. Details pending

12Tolerance analysis

12.1 Collimator

See AD1 for details.

12.2 FP20 optics

See AD1 for details.

13 LBT optical modification

The LBT is not operated in the nominal configuration when LINC-NIRVANA is in use. The LINC-NIRVANA input focus is 300 mm behind the nominal telescope focus, due to limitations in the optical design of the collimator and the desire to work at the offset, bent focus. The design of the collimator would not haven been feasible for the nominal mode with the performance of the current design. Moving the focus 300 mm towards the center line is well within the adjustment range of the secondary mirror. The shift is achieved by changing the conic constant and the position of the secondary.

See AD5 for details.

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