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HIRDLS — TC-HIR-32

High Resolution Dynamics Limb Sounder

Originator: Ian A J Tosh — **Date:** 31st October 1995

Subject/Title: Optical System Specification Document

Description/summary/contents:

This document describes the nominal optical system upto the level which has been currently analysed.

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Rutherford Appleton Laboratory
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EOS

Change History:

This is the first issue of this document.

It includes all of TC-RAL-33D which has been modified to accommodate the change in filter thicknesses. The design was re-optimised by varying the air gaps, keeping the overall length, distortion, image quality and pupil aberrations to be very similar to TC-RAL-33D

Related Documents :

TC-RAL-33D	Baseline Optical description
TC-RAL-046A	Scatter measurements and analysis of lens and filter coatings
TC-RAL-047 AND 47A	Ghost analysis
TC-RAL-048B	Diffraction analysis
TC-RAL-049A	Criteria for aperture sizes
TC-RAL-055	IFOV performance
SP-HIR-13	Instrument Technical Specification

General:

The layout is that of an off-axis Gregorian telescope with a lens relay system after the second image plane to give the correct image scale and aberration control (fig 1,2,3).

The optical system was optimised for good image quality and small ILS to SAS pupil aberrations, consequently neither can be changed without due regard to the other.

The telescope has an entrance pupil diameter (EPD) of ~160mm on-axis.

The geometrical image scale is such that a 1km object height (at 3000km object distance) subtends 0.0818mm at the focal plane on axis. The effects of diffraction, aberrations and distortion will spread the resulting IFOV for each channel.

There are two sets of spectral filters. The set at the second image plane define the spectral shape of each channel and the set adjacent to the final image plane reduce the out-of-field signal reaching the detectors.

The apertures described in this document are a consistent and related set as used in TC-RAL-48. No individual aperture can be changed in isolation without due regard to the effect of stray light and the requirements on the other aperture sizes.

The plane of the chopper blade is close to the first image plane.

The fold mirror after the second lens is [TBD] but it's position and orientation doesn't significantly impact on the optical design.

The ZnSe dewar window also provides additional long wave blocking.

The reflections from the refractive components contribute to an out-of-field problem, consequently there is a requirement of low reflection from these surfaces.

The wavelength used for each channel is the centre of the 50% passband (in cm^{-1}) as defined in SP-HIR-13M table 3.4.1-1.

The data in this document is taken from the higher accuracy CodeV model.

Optical Components: (Refer to Figs 1,2,3)

- **Scan Mirror (FM0).**
  A flat mirror whose centre of rotation is 550.000mm from the parabolic segment.
  The nominal angle of the normal to the on axis chief ray is 25.3deg.
  Minimum clear aperture size [TBD]

- **Primary Diffraction Baffle (PDB).**
  Positioned 250mm from the scan mirror.
  Circular aperture radius 90.000mm.

- **Parabolic Primary Mirror (M1).**
  Positioned 300mm from the PDB
  Radius of curvature at the pole of the parent = 860.0mm.
  The used portion is 187.0mm off-axis.
  Minimum clear aperture size [TBD]

- **First Field Stop (PFM).**
  Positioned at the focus of the paraboloid and normal to the on-axis chief ray.
  It is a 10x10mm square aperture aligned with the image of the detectors.

- **Chopper Plane**
  [TBD]

- **Ellipsoidal Secondary Mirror (M2).**
  One of the foci of the ellipsoid is coincident with the focus of the paraboloid.
  The major axis of the ellipsoid is inclined by 3.2° (See fig 1 for direction) to the axis of the paraboloid.
  Conic Constant (k) = -0.25
  Radius of curvature at the pole = 195.0mm
  Minimum clear aperture size [TBD]

- **Intermediate Lyot STOP (ILS)**
  Positioned at 111.823mm from the used portion of the ellipsoidal secondary mirror, normal to the on axis chief ray.
  Circular aperture radius 18.250mm.

- **Warm Filters (WF1 thro' 21)**
  (Narrow Spectral Band-Pass)
  The 'equivalent Ge' thickness of the filter and substrate is 0.9mm.
  The front surface of the filter is positioned at the second image plane and normal to the on-axis chief ray and 273mm from the ILS.
  There is a field mask on the ellipsoid side of the filters, each aperture is placed at the geometrical image of the detectors and sized 5.96mm x 2.56mm

- **First Ge Lens (L1).**
  Ge lens 85.305mm from the back of the secondary filters
  Front surface radius of curvature = -52.343mm
  Conic constant of front surface = +0.20
  Back surface radius of curvature = -48.902mm
  Centre Thickness = 3.500mm
  Minimum clear aperture size [TBD]

- **Fold Mirror (FM4).**
  Position and alignment [TBD].
  Used to align the image plane with the detectors on the optical bench.
  Minimum clear aperture size [TBD]

- **Aperture STOP (SAS).**
  233.810mm from the first lens.
  Circular aperture radius 10.690mm

- **Second Ge Lens (L2).**
  Ge lens 20.466mm from the aperture STOP.
  Front surface radius of curvature = -36.427mm
  Back surface radius of curvature = -55.384mm
  Conic constant of front surface = -0.610
  Centre Thickness = 3.000mm
  Minimum clear aperture size [TBD]

- **Dewar Window (W1).**
  Flat ZnSe window 2.0mm thick.
  5.744mm from the back of the lens.
  Minimum clear aperture size [TBD]

- **Cold Filters (CF1 thro' 21).**
  (Wide Spectral Band)
  The back of the filters are 25.4mm from the back of the dewar window.
  Table 1 gives their optimised values.
  Minimum clear aperture size [TBD]

- **Anti-Reflection Coatings.**
  Anti-reflection coatings are required on all Ge and ZnSe surfaces.
  Reflection is required to be <2.7% between 6..18μm at each surface (ref ITS).

- **Detector Positions**
  The detectors are 0.100mm from the back of the focal plane filters.

Table 1 : Filter Thicknesses Required at the Detector Plane

Channel	Wavelength (nm)	Optimised Focal Plane Filter Thicknesses (mm)
1	17376	0.405
2	16461	0.397
3	16000	0.402
4	15552	0.413
5	14981	0.419
6	12070	0.418
7	11848	0.411
8	11331	0.406
9	10822	0.418
10	10000	0.429
11	9713	0.436
12	8850	0.418
13	8264	0.429
14	8035	0.436
15	7880	0.450
16	7761	0.451
17	7427	0.467
18	7092	0.479
19	7097	0.486
20	6748	0.496
21	6219	0.519

1. **Notes :**
   All thicknesses are for an 'equivalent Ge' thickness
   (i.e. NOT the total physical thickness of the substrate and the multilayer stacks).

Table 2 Refractive Index Data

Channel	Wavelength	Ge @ 293K	Ge @ 65K	ZnSe @ 293K
1	17376	4.0007	3.9257	2.3396
2	16461	4.0009	3.9259	2.3510
3	16000	4.0010	3.9260	2.3563
4	15552	4.0011	3.9260	2.3613
5	14981	4.0012	3.9262	2.3673
6	12070	4.0022	3.9270	2.3931
7	11848	4.0023	3.9271	2.3948
8	11331	4.0026	3.9273	2.3985
9	10822	4.0029	3.9275	2.4020
10	10000	4.0036	3.9281	2.4072
11	9713	4.0038	3.9283	2.4089
12	8850	4.0046	3.9290	2.4137
13	8264	4.0055	3.9296	2.4167
14	8035	4.0058	3.9299	2.4178
15	7888	4.0061	3.9301	2.4185
16	7761	4.0063	3.9303	2.4191
17	7427	4.0069	3.9309	2.4206
18	7092	4.0077	3.9315	2.4221
19	7097	4.0076	3.9315	2.4220
20	6748	4.0085	3.9321	2.4235
21	6219	4.0101	3.9334	2.4256

Notes :

1. Ge Data from H.H. Li paper , J. Phys Chem. Ref. Data Vol. 9, No 3,1980
   Data @ 65K is extrapolated from 100K.
2. ZnSe data from CodeV data base.
3. Refractive indices converted to their vacuum values

Fig 1: Optical System Layout (Not to scale - for reference only)

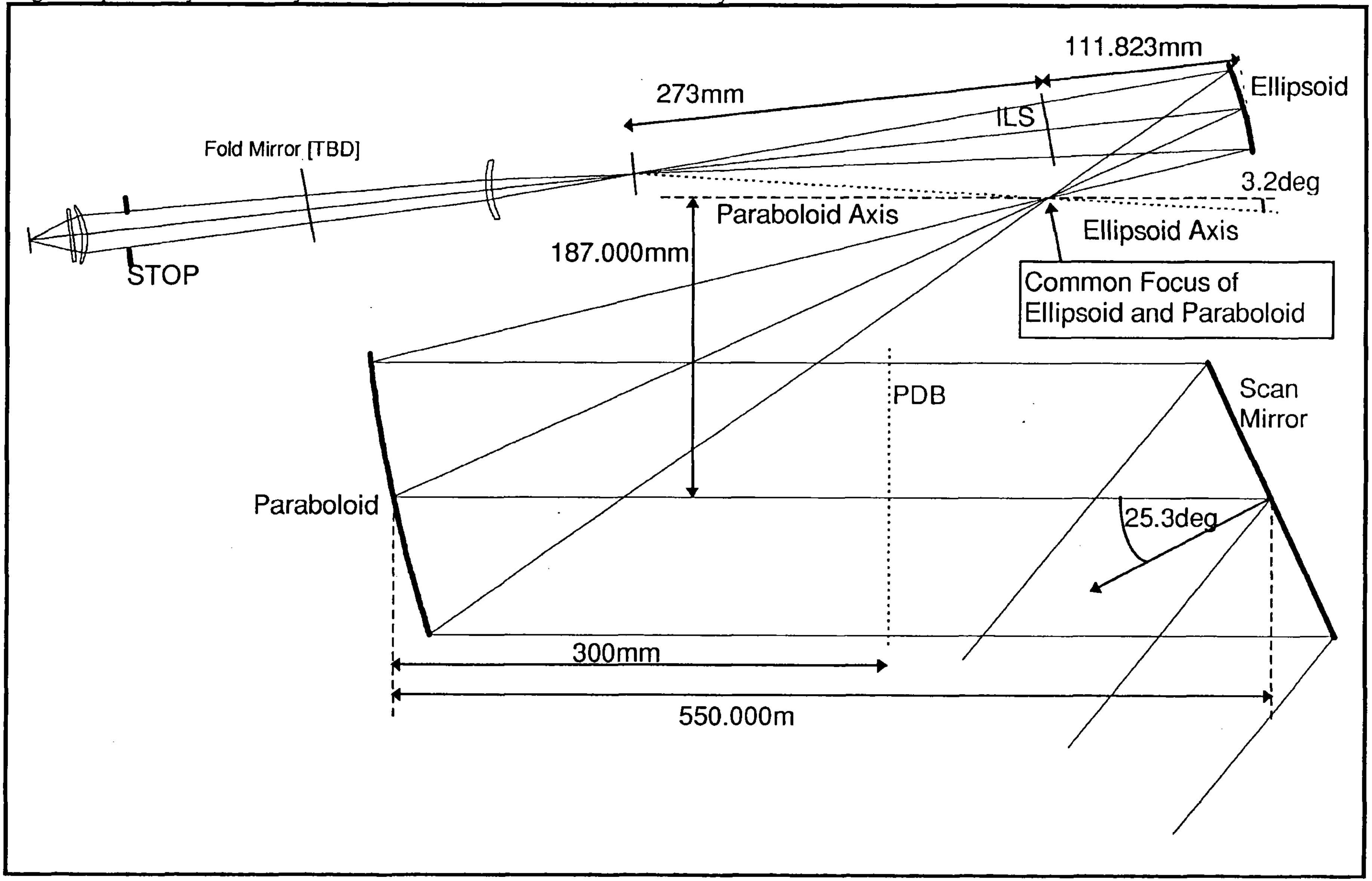

Fig 2 Optical System after the second image plane.
(Not to scale - for reference only)

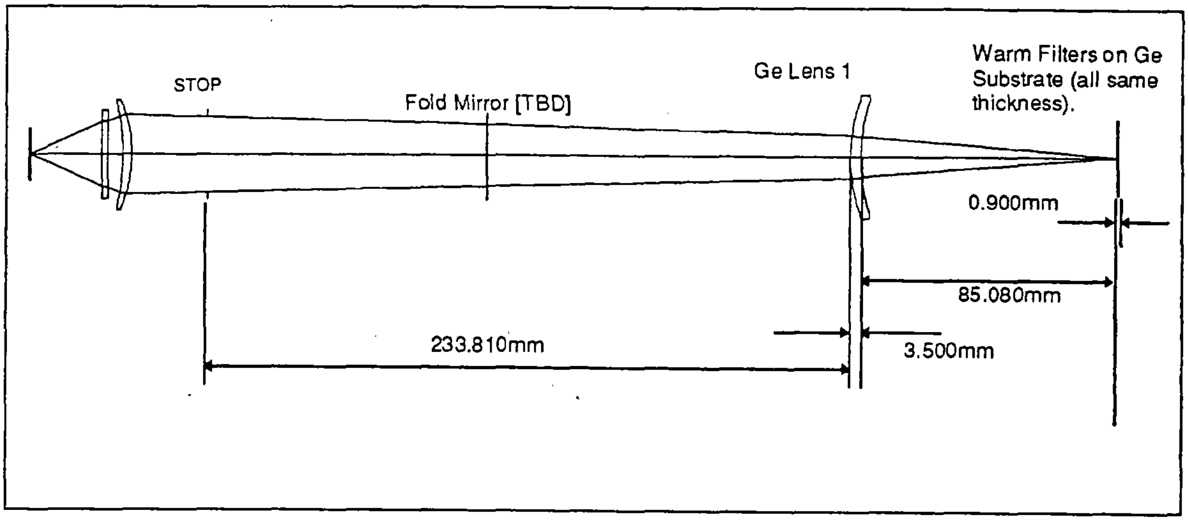

Fig 3 STOP to Detector Layout
(Not to scale - for reference only)

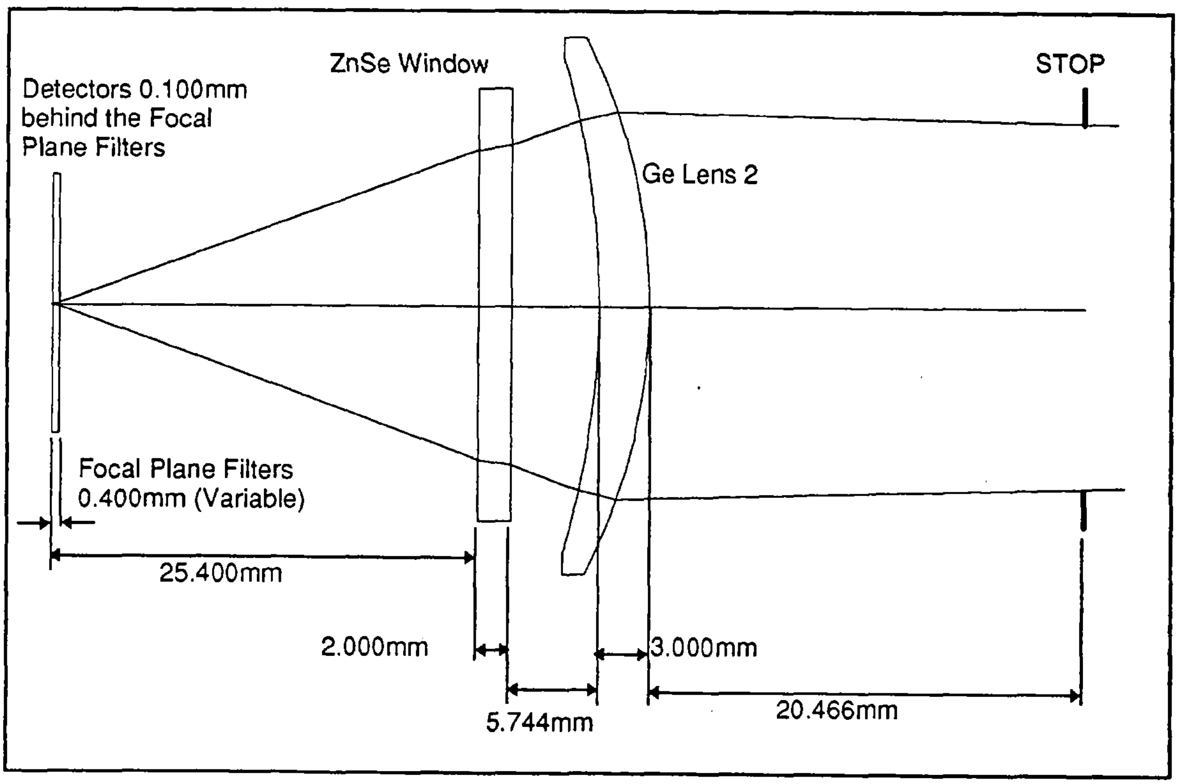

Fig 5 Global Co-ordinates Reference Axes.
(Not to scale - for reference only)

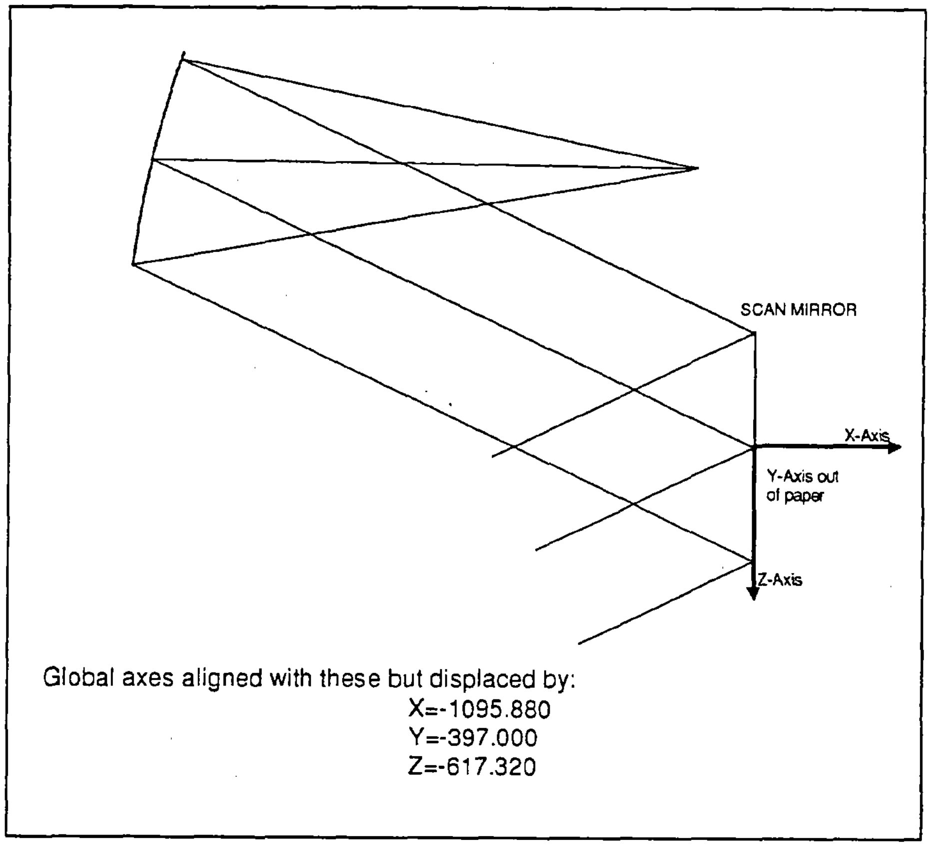

Table 3: Global System Co-ordinates for the Pole of Each Component.

Surface	X-Coord	Y-Coord	Z-Coord	L-Dir Cosine	M-Dir Cosine	N-Dir Cosine
Scan Mirror	1095.880	397.000	617.320	1.0000	0.0000	0.0000
PDB	869.859	397.000	510.481	0.9041	0.0000	0.4274
Paraboloid	660.170	397.000	204.521	0.9041	0.0000	0.4274
First image plane normal	1048.925	397.000	388.285	0.9999	0.0000	0.0133
Ellipsoid	1163.172	397.000	450.316	0.8788	0.0000	0.4772
ILS	1078.417	397.000	353.515	0.9450	0.0000	0.3271
Second Image plane and Warm Filter Front	820.433	397.000	264.224	0.9450	0.0000	0.3271
Warm Filter Back	819.582	397.000	263.929	0.9450	0.0000	0.3271
Lens 1 front	739.182	397.000	236.102	0.9450	0.0000	0.3271
Lens 1 back	735.875	397.000	234.957	0.9450	0.0000	0.3271
STOP	514.925	397.000	158.484	0.9450	0.0000	0.3271
Lens 2 front	495.584	397.000	151.790	0.9450	0.0000	0.3271
Lens 2 back	492.749	397.000	150.809	0.9450	0.0000	0.3271
Window Front	487.321	397.000	148.930	0.9450	0.0000	0.3271
Window Back	485.431	397.000	148.276	0.9450	0.0000	0.3271
Cold Filter Front	461.806	397.000	140.099	0.9450	0.0000	0.3271
Cold Filter back	461.428	397.000	139.968	0.9450	0.0000	0.3271
Final Image plane	461.333	397.000	139.935	0.9450	0.0000	0.3271

Note : Cold Filter Plane Front is variable

Table 4 Global system Co-ordinates of the Surface Intersection with the On-axis Chief Ray

Surface	X-Coord (mm)	Y-Coord (mm)	Z-Coord (mm)	Distance from last surface (mm)
Scan Mirror	1095.880	397.000	617.320	-------
PDB	869.859	397.000	510.481	250.000
Paraboloid	598.635	397.000	382.273	300.000
First image plane normal	1048.925	397.000	388.285	450.331
Ellipsoid	1184.090	397.000	390.090	135.177
ILS	1078.417	397.000	353.515	118.823
Second Image plane and Warm Filter Front	820.433	397.000	264.224	273.000
Warm Filter Back	819.582	397.000	263.929	0.900
Lens 1 front	739.182	397.000	236.102	85.080
Lens 1 back	735.875	397.000	234.957	3.5000
STOP	514.925	397.000	158.484	233.810
Lens 2 front	495.584	397.000	151.790	20.466
Lens 2 back	492.749	397.000	150.809	3.000
Window Front	487.321	397.000	148.930	5.744
Window Back	485.431	397.000	148.276	2.000
Cold Filter Front	461.806	397.000	140.099	25.000
Cold Filter back	461.428	397.000	139.968	0.4000
Final Image plane	461.333	397.000	139.935	0.1000

Note : Cold Filter Plane Front is variable

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  Circular aperture radius 90.000mm.

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  The used portion is 187.0mm off-axis.
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  It is a 10x10mm square aperture aligned with the image of the detectors.

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- **Ellipsoidal Secondary Mirror (M2).**
  One of the foci of the ellipsoid is coincident with the focus of the paraboloid.
  The major axis of the ellipsoid is inclined by 3.2° (See fig 1 for direction) to the axis of the paraboloid.
  Conic Constant (k) = -0.25
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  Front surface radius of curvature = -52.343mm
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  Centre Thickness = 3.500mm
  Minimum clear aperture size [TBD]

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  Circular aperture radius 10.690mm

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  Ge lens 20.466mm from the aperture STOP.
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  Minimum clear aperture size [TBD]

- **Dewar Window (W1).**
  Flat ZnSe window 2.0mm thick.
  5.744mm from the back of the lens.
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  (Wide Spectral Band)
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  Table 1 gives their optimised values.
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21	6219	4.0101	3.9334	2.4256

Notes :

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   Data @ 65K is extrapolated from 100K.
2. ZnSe data from CodeV data base.
3. Refractive indices converted to their vacuum values

Fig 1: Optical System Layout (Not to scale - for reference only)

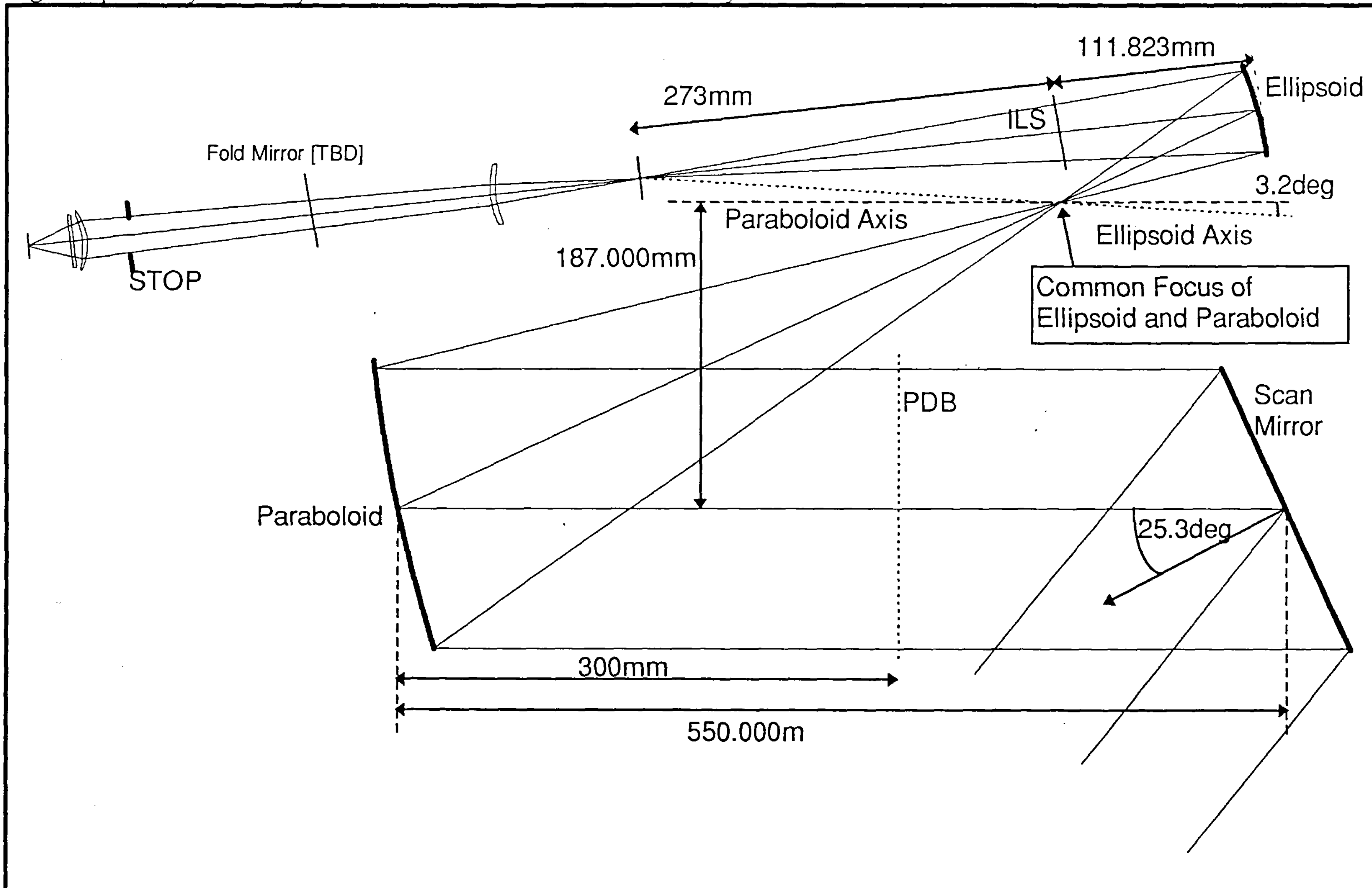

Fig 2 Optical System after the second image plane.
(Not to scale - for reference only)

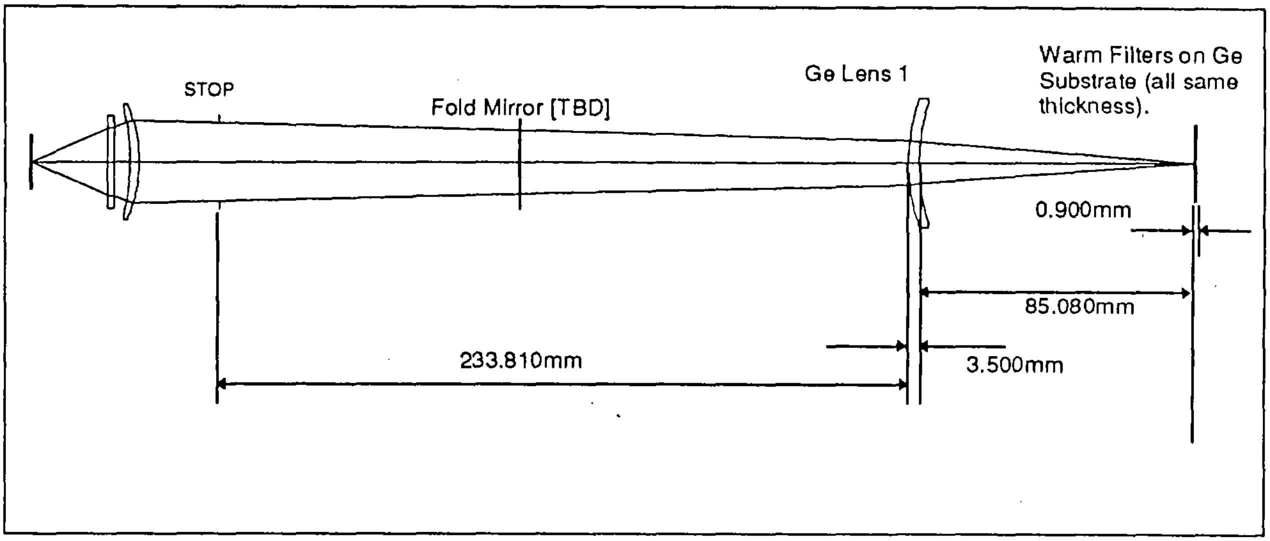

Fig 3 STOP to Detector Layout
(Not to scale - for reference only)

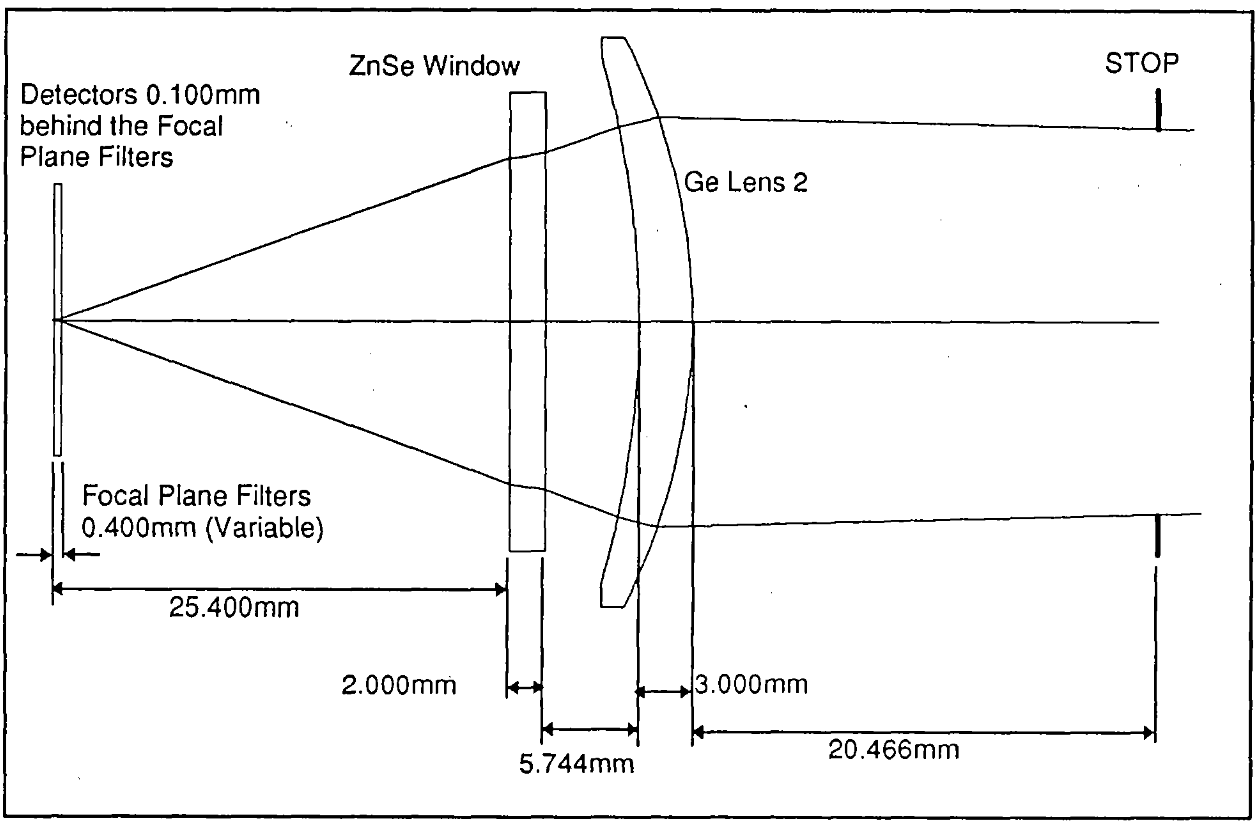

Fig 5 Global Co-ordinates Reference Axes.
(Not to scale - for reference only)

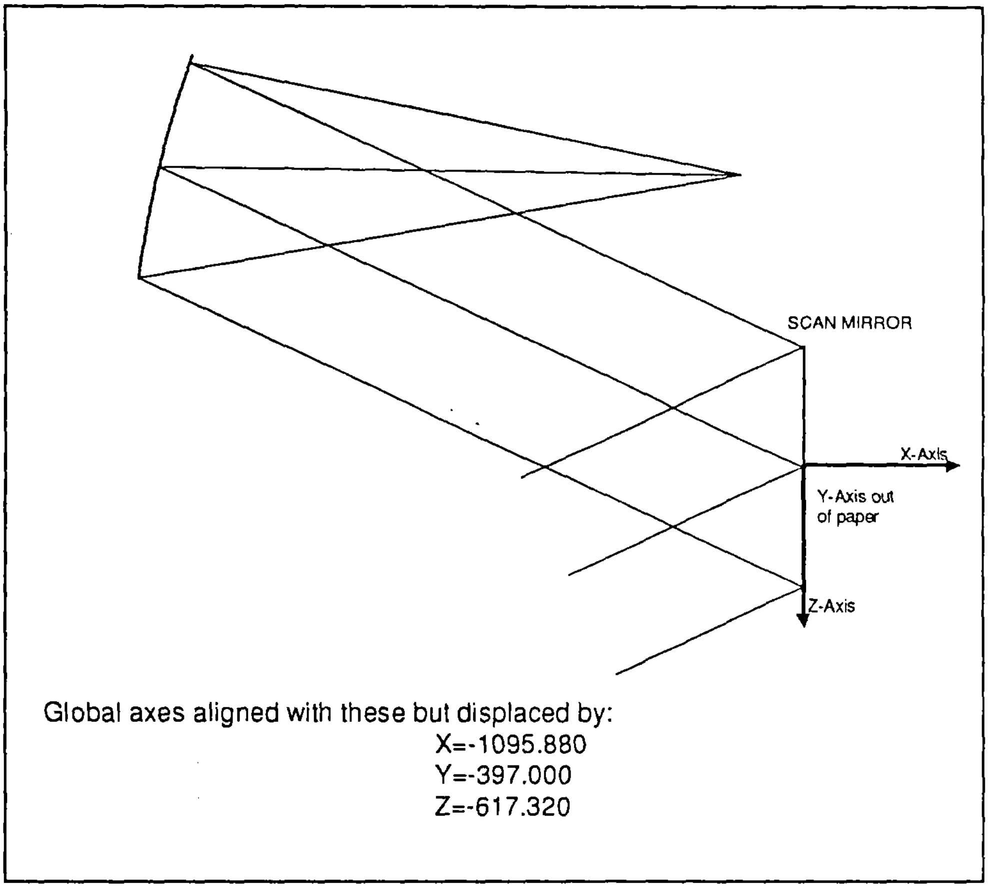

Table 3: Global System Co-ordinates for the Pole of Each Component.

Surface	X-Coord	Y-Coord	Z-Coord	L-Dir Cosine	M-Dir Cosine	N-Dir Cosine
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First image plane normal	1048.925	397.000	388.285	0.9999	0.0000	0.0133
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Lens 2 front	495.584	397.000	151.790	0.9450	0.0000	0.3271
Lens 2 back	492.749	397.000	150.809	0.9450	0.0000	0.3271
Window Front	487.321	397.000	148.930	0.9450	0.0000	0.3271
Window Back	485.431	397.000	148.276	0.9450	0.0000	0.3271
Cold Filter Front	461.806	397.000	140.099	0.9450	0.0000	0.3271
Cold Filter back	461.428	397.000	139.968	0.9450	0.0000	0.3271
Final Image plane	461.333	397.000	139.935	0.9450	0.0000	0.3271

Note : Cold Filter Plane Front is variable

as "Rear Mask"

Table 4 Global system Co-ordinates of the Surface Intersection with the On-axis Chief Ray

Surface	X-Coord (mm)	Y-Coord (mm)	Z-Coord (mm)	Distance from last surface (mm)
Scan Mirror	1095.880	397.000	617.320	-------
PDB	869.859	397.000	510.481	250.000
Paraboloid	598.635	397.000	382.273	300.000
First image plane normal	1048.925	397.000	388.285	450.331
Ellipsoid	1184.090	397.000	390.090	135.177
ILS	1078.417	397.000	353.515	118.823
Second Image plane and Warm Filter Front	820.433	397.000	264.224	273.000
Warm Filter Back	819.582	397.000	263.929	0.900
Lens 1 front	739.182	397.000	236.102	85.080
Lens 1 back	735.875	397.000	234.957	3.5000
STOP	514.925	397.000	158.484	233.810
Lens 2 front	495.584	397.000	151.790	20.466
Lens 2 back	492.749	397.000	150.809	3.000
Window Front	487.321	397.000	148.930	5.744
Window Back	485.431	397.000	148.276	2.000
Cold Filter Front	461.806	397.000	140.099	25.000
Cold Filter back	461.428	397.000	139.968	0.4000
Final Image plane	461.333	397.000	139.935	0.1000

Note : Cold Filter Plane Front is variable

Marked-up for errors, etc

HIRDLS SP-HIR-32

High Resolution Dynamics Limb Sounder

Originator: Ian A J Tosh **Date:** 2nd January 1995

Subject/Title: Optical System Specification Document

Description/summary/contents:

This document describes the nominal optical system upto the level which has been currently analysed.

Keywords: Optics, Telescope, Lens, Baseline

Purpose of this Document:
(20 Characters Maximum)

Reviewed/approved by: Date:(day-mon-yr):			

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EOS

Change History:

This is the first issue of this document.

It includes all of TC-RAL-33D which has been modified to accommodate the change in filter thicknesses. The design was re-optimised by varying the air gaps, keeping the overall length, distortion, image quality and pupil aberrations to be very similar to TC-RAL-33D.

Related Documents :

TC-RAL-33D	Baseline Optical description
TC-RAL-046A	Scatter measurements and analysis of lens and filter coatings
TC-RAL-047 AND 47A	Ghost analysis
TC-RAL-048B	Diffraction analysis
TC-RAL-049A	Criteria for aperture sizes
TC-RAL-055	IFOV performance
SP-HIR-13	Instrument Technical Specification

General:

The layout is that of an off-axis Gregorian telescope with a lens relay system after the second image plane to give the correct image scale and aberration control (fig 1,2,3).

The optical system was optimised for image quality and stray light performance, consequently the layout cannot be modified until the analysis of both aspects has shown the changes are acceptable.

The telescope has an entrance pupil diameter (EPD) of ~160mm on-axis.

The geometrical image scale is such that a 1km object height (at 3000km object distance) subtends 0.0818mm at the focal plane on axis. The effects of diffraction, aberrations and distortion will spread the resulting IFOV for each channel.

There are two sets of spectral filters. The set at the second image plane define the spectral shape of each channel and the set adjacent to the final image plane reduce the out-of-field signal reaching the detectors.

The apertures described in this document are a consistent and related set as used in TC-RAL-48. No individual aperture can be changed in isolation without due regard to the effect of stray light and the requirements on the other aperture sizes.

The plane of the chopper blade is close to the first image plane.

The fold mirror after the second lens is [TBD] but it's position and orientation doesn't significantly impact on the optical design.

The ZnSe dewar window also provides additional long wave blocking.

The reflections from the refractive components contribute to an out-of-field problem, consequently there is a requirement of low reflection from these surfaces.

The wavelength used for each channel is the centre of the 50% passband (in cm^{-1}) as defined in SP-HIR-13M table 3.4.1-1.

The data in this document is taken from the higher accuracy CodeV model.

Optical Components: (Refer to Figs 1,2,3)

- **Scan Mirror (FM0).**
  A flat mirror whose centre of rotation is 550.000mm from the parabolic segment.
  The nominal angle of the normal to the on axis chief ray is 25.3deg. O/C
  Minimum clear aperture size [TBD]

- **Primary Diffraction Baffle (PDB).**
  Positioned 250mm from the scan mirror. O/C
  Circular aperture radius 90.000mm.

- **Parabolic Primary Mirror (M1).**
  Positioned 300mm from the PDB
  Radius of curvature at the pole of the parent = 860.0mm. OK
  The used portion is 187.0mm off-axis.
  Minimum clear aperture size [TBD]

- **First Field Stop (PFM).**
  Positioned at the focus of the paraboloid and normal to the on-axis chief ray. OK
  It is a 10x10mm square aperture aligned with the image of the detectors.

- **Chopper Plane**
  [TBD] OK

- **Ellipsoidal Secondary Mirror (M2).**
  One of the foci of the ellipsoid is coincident with the focus of the paraboloid.
  The major axis of the ellipsoid is inclined by 3.2^{o} (See fig 1 for direction) to the axis of the paraboloid.
  Conic Constant (k) = -0.25 OK
  Radius of curvature at the pole = 195.0mm
  Minimum clear aperture size [TBD]

- **Intermediate Lyot STOP (ILS)** correct
  Positioned at 111.823mm from the used portion of the ellipsoidal secondary mirror, OK
  normal to the on axis chief ray.
  Circular aperture radius 18.250mm.

- **Warm Filters (WF1 thro' 21)** .25 mm from
  (Narrow Spectral Band-Pass)
  The 'equivalent Ge' thickness of the filter and ~~substrate~~ is 0.9mm. X
  The front surface of the filter is positioned ~~at~~ the second image plane and normal to the on-axis chief ray and 273mm from the ILS.
  There is a field mask on the ellipsoid side of the filters, each aperture is placed at the geometrical image of the detectors and sized 5.96mm x 2.56mm
  7.4 x 2.8 in SPLOC139 X

wrong

- **First Ge Lens (L1).** 85,305 + .9 = 86,205 from FS2 X
  Ge lens 85.305mm from the back of the secondary filters 85.9793 from FS2 in OPTIMA
  Front surface radius of curvature = -52.343mm
  Conic constant of front surface = +0.20
  Back surface radius of curvature = -48.902mm See Fig 2: 85.980 OK (But corrected in 2 other places)
  Centre Thickness = 3.500mm
  Minimum clear aperture size [TBD] {Code 5 85.0797+.9=85.9797} See Table 4: 85.080 +.9 85.980 OK

- **Fold Mirror (FM4).**
  Position and alignment [TBD].
  Used to align the image plane with the detectors on the optical bench. OK
  Minimum clear aperture size [TBD]

- **Aperture STOP (SAS).**
  233.810mm from the first lens. 233.6739 is 33Q value OK
  Circular aperture radius 10.690mm .1361 error in OPTIMA

- **Second Ge Lens (L2).**
  Ge lens 20.466mm from the aperture STOP.
  Front surface radius of curvature = -36.427mm
  Back surface radius of curvature = -55.384mm X
  Conic constant of front surface = -0.610 +.61 Back X
  Centre Thickness = 3.000mm
  Minimum clear aperture size [TBD]

- **Dewar Window (W1).**
  Flat ZnSe window 2.0mm thick.
  5.744mm from the back of the lens. X
  Minimum clear aperture size [TBD]
  6.090 in SPLOC139

- **Cold Filters (CF1 thro' 21).** 33.144 should be specified from the back of the lens L2
  (Wide Spectral Band)
  The back of the filters are coplanar and 25.4mm from the back of the dewar window. X
  Table 1 gives their optimised values.
  Minimum clear aperture size [TBD]

- **Anti-Reflection Coatings.**
  Anti-reflection coatings are required on all Ge and ZnSe surfaces. OK
  Reflection is required to be <2.7% between 6..18μm at each surface (ref ITS).

- **Detector Positions**
  The detectors are 0.100mm from the back of the focal plane filters. OK

Table 1 : Filter Thicknesses Required at the Detector Plane

Channel	Wavelength (nm)	Optimised Focal Plane Filter Thicknesses (mm)
1	17376	0.405
2	16461	0.397
3	16000	0.402
4	15552	0.413
5	14981	0.419
6	12070	0.418
7	11848	0.411
8	11331	0.406
9	10822	0432
10	10000	0.418
11	9713	0.429
12	8850	0.436
13	8264	0.450
14	8035	0.451
15	7880	0.459
16	7761	0.465
17	7427	0.467
18	7092	0.479
19	7097	0.486
20	6748	0.496
21	6219	0.519

1. **Notes :**
   All thicknesses are for an 'equivalent Ge' thickness
   (i.e. NOT the total physical thickness of the substrate and the multilayer stacks).

Table 2 Refractive Index Data

Channel	Wavelength	Ge @ 293K	Ge @ 65K	ZnSe @ 293K
1	17376	4.0007	3.9257	2.3396
2	16461	4.0009	3.9259	2.3510
3	16000	4.0010	3.9260	2.3563
4	15552	4.0011	3.9260	2.3613
5	14981	4.0012	3.9262	2.3673
6	12070	4.0022	3.9270	2.3931
7	11848	4.0023	3.9271	2.3948
8	11331	4.0026	3.9273	2.3985
9	10822	4.0029	3.9275	2.4020
10	10000	4.0036	3.9281	2.4072
11	9713	4.0038	3.9283	2.4089
12	8850	4.0046	3.9290	2.4137
13	8264	4.0055	3.9296	2.4167
14	8035	4.0058	3.9299	2.4178
15	7888	4.0061	3.9301	2.4185
16	7761	4.0063	3.9303	2.4191
17	7427	4.0069	3.9309	2.4206
18	7092	4.0077	3.9315	2.4221
19	7097	4.0076	3.9315	2.4220
20	6748	4.0085	3.9321	2.4235
21	6219	4.0101	3.9334	2.4256

Notes :

1. Ge Data from H.H. Li paper , J. Phys Chem. Ref. Data Vol. 9, No 3,1980
   Data @ 65K is extrapolated from 100K.
2. ZnSe data from CodeV data base.
3. Refractive indices converted to their vacuum values

Fig 1: Optical System Layout (Not to scale - for reference only)

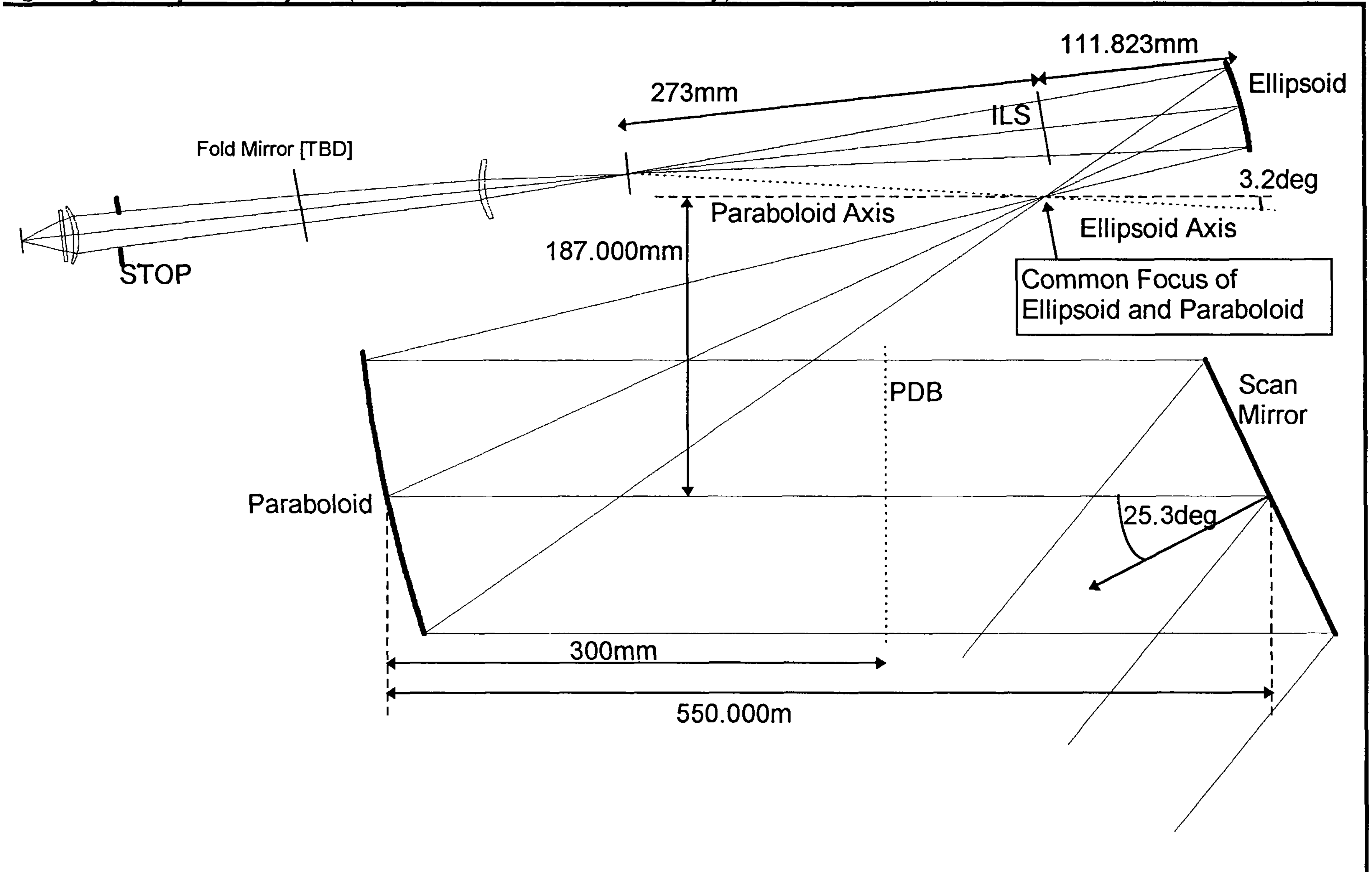


Fig 2 Optical System after the second image plane.
(Not to scale - for reference only)

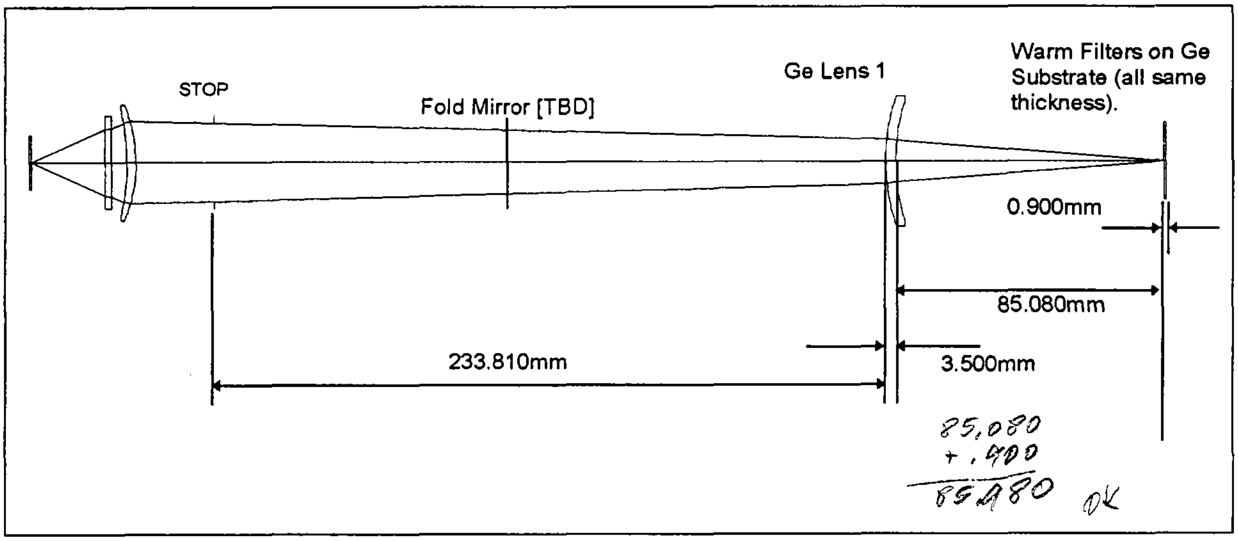


Fig 3 STOP to Detector Layout
(Not to scale - for reference only)

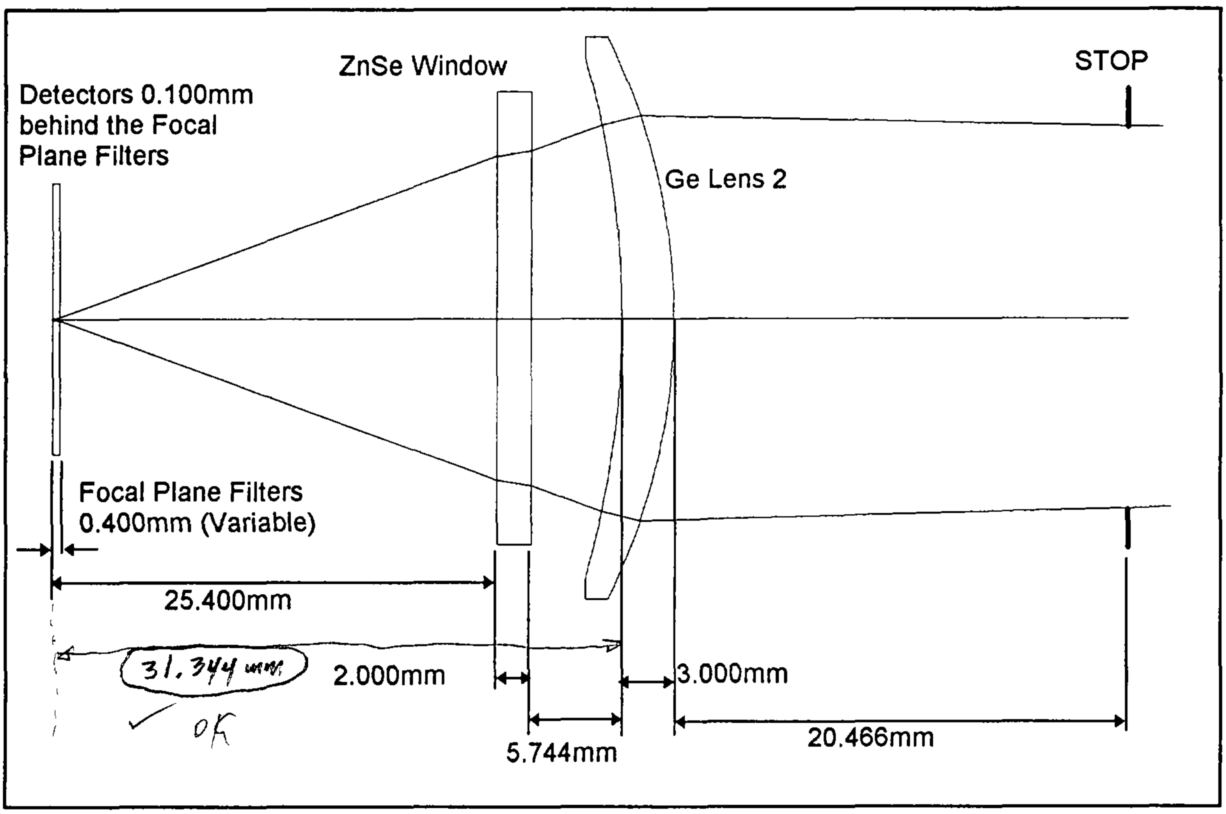
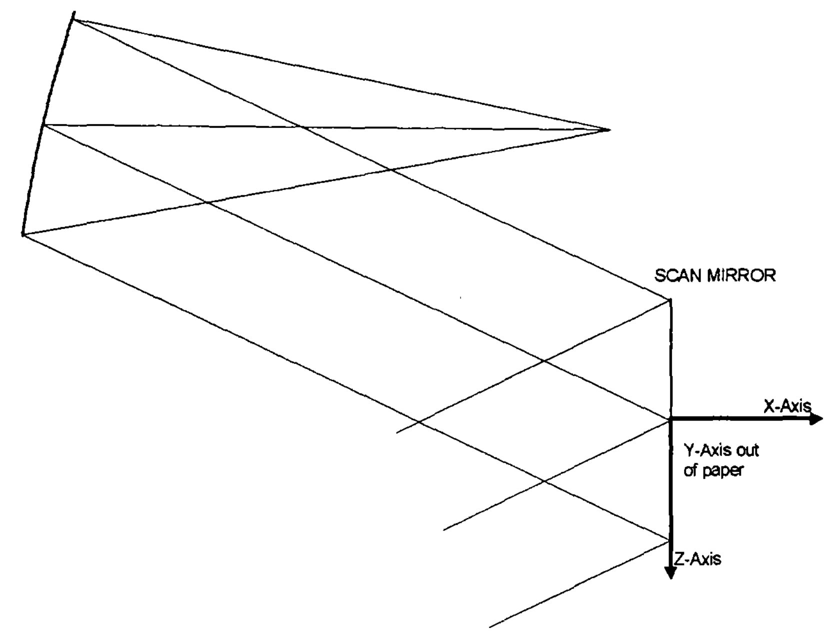


Fig 5 Global Co-ordinates Reference Axes.
(Not to scale - for reference only)



Global axes aligned with these but displaced by:
X=-1095.880
Y=-397.000
Z=-617.320

Table 3: Global System Co-ordinates for the Pole of Each Component.

Surface	X-Coord	Y-Coord	Z-Coord	L-Dir Cosine	M-Dir Cosine	N-Dir Cosine
Scan Mirror	1095.880	397.000	617.320	1.0000	0.0000	0.0000
PDB	869.859	397.000	510.481	0.9041	0.0000	0.4274
Paraboloid	660.170	397.000	204.521	0.9041	0.0000	0.4274
First image plane normal	1048.925	397.000	388.285	0.9999	0.0000	0.0133
Ellipsoid	1163.172	397.000	450.316	0.8788	0.0000	0.4772
ILS	1078.417	397.000	353.515	0.9450	0.0000	0.3271
Second Image plane and Warm Filter Front	820.433	397.000	264.224	0.9450	0.0000	0.3271
Warm Filter Back	819.582	397.000	263.929	0.9450	0.0000	0.3271
Lens 1 front	739.182	397.000	236.102	0.9450	0.0000	0.3271
Lens 1 back	735.875	397.000	234.957	0.9450	0.0000	0.3271
STOP	514.925	397.000	158.484	0.9450	0.0000	0.3271
Lens 2 front	495.584	397.000	151.790	0.9450	0.0000	0.3271
Lens 2 back	492.749	397.000	150.809	0.9450	0.0000	0.3271
Window Front	487.321	397.000	148.930	0.9450	0.0000	0.3271
Window Back	485.431	397.000	148.276	0.9450	0.0000	0.3271
Cold Filter Front	461.806	397.000	140.099	0.9450	0.0000	0.3271
Cold Filter back	461.428	397.000	139.968	0.9450	0.0000	0.3271
Final Image plane	461.333	397.000	139.935	0.9450	0.0000	0.3271

Note : Cold Filter Plane Front is variable

Table 4 Global system Co-ordinates of the Surface Intersection with the On-axis Chief Ray

Surface	X-Coord (mm)	Y-Coord (mm)	Z-Coord (mm)	Distance from last surface (mm)	
Scan Mirror	1095.880	397.000	617.320	-------	
PDB	869.859	397.000	510.481	250.000	
Paraboloid	598.635	397.000	382.273	300.000	
First image plane normal	1048.925	397.000	388.285	450.331	
Ellipsoid	1184.090	397.000	390.090	135.177	
ILS	1078.417	397.000	353.515	118.823	111.823 (correctly stated on P. 4)
Second Image plane an Warm Filter Front	820.433	397.000	264.224	273.000	
Warm Filter Back	819.582	397.000	263.929	0.900	85.980 agrees with 9PLOC139
Lens 1 front	739.182	397.000	236.102	85.080	
Lens 1 back	735.875	397.000	234.957	3.5000	
STOP	514.925	397.000	158.484	233.810	
Lens 2 front	495.584	397.000	151.790	20.466	
Lens 2 back	492.749	397.000	150.809	3.000	
Window Front	487.321	397.000	148.930	5.744	sum = 33.244 (agrees with 9PLOC139)
Window Back	485.431	397.000	148.276	2.000	
Cold Filter Front	461.806	397.000	140.099	25.000	
Cold Filter back	461.428	397.000	139.968	0.4000	
Final Image plane	461.333	397.000	139.935	0.1000	

Note : Cold Filter Plane Front is variable