June 21, 1993

Atmospheric Dispersion Corrector for the 3.5 M WIYN Telescope

Introduction

Because of recent refinements in the WIYN instrument adapter, both the position and separation of the original atmospheric dispersion corrector (ADC) needed some adjustment. In addition, test results on the finished primary mirror are now available. The ADC has been re-optimized based on all the above changes. This report contains the new design, an image quality analysis, a tolerance calculation, and related discussions.

Design requirements:

The atmospheric dispersion corrector will be put into one of the two Nasmyth beams of the 3.5 meter WIYN telescope. From the optical design point of view this is identical to a Cassegrain focus. The design requirements are as follows:

1. The ADC should be able to compensate atmospheric dispersion from 0 to 65 degrees zenith angle over a wavelength band from 3500 A to 10140 A.
2. The ADC should provide a 30 arcminute full field of view and a flat focal surface.
3. The position of the focal surface remains unchanged with the ADC in or out of the beam. Defocusing between the two modes may only be adjusted by moving the secondary mirror position.

4. The mechanical arrangement requires that the distance from the first surface of the corrector to the focal surface can not be more than 512 mm. The total length of the ADC - the separation between the first and the last surface of the ADC - should be about 140 mm.
5. The image quality should not be significantly degraded compared to the original ADC design.

Design results

1) Interface with telescope.

The optical prescription of the WIYN telescope is given in Table 1, and a layout of the telescope is shown in Figure 1. The radius of the primary mirror was measured to be 3mm longer than in the original design. Figure 2 shows spot diagrams of the uncorrected RC optics on the curved Cassegrain focal surface located 2727.0212 behind the primary mirror vertex. This position will not change after the ADC is inserted and the telescope refocused.

Table 1.

(all the units of length are in mm)

	radius	separation	conic constant
primary	-12553		1.07085
secondary	-5332.25	-4201.2444	3.7316672
focus	-2142.8124	6928.2656	

2) The choice of glasses:

Two kinds of glasses are required for the ADC corrector. The glasses should have good transparency from 3500 A to 10140 A, have nearly the same refractive index at intermediate wavelengths, and should have large dispersion. After comparing many candidate pairs, we have chosen LLF1 and PSK3. Their refractive index, Abbe number v; transmittance through 25 mm thickness are listed in Table 2.

Table 2. Parameters of LLF1 and PSK3

	3500 A	4341 A	10140 A	v	transmittance 25 mm / 3500A
LLF1	1.58443	1.56333	1.53540	45.75	0.93
PSK3	1.57657	1.56303	1.54219	63.46	0.92

3) The structure of ADC.

The ADC corrector, shown in figures 3 and 4, is comprised of two cemented lensms (combination lens - prisms). The cemented surfaces are tilted to produce dispersion. The outer surfaces of the lensm are orthogonal with the axes. By counter-rotating the two cemented lensms, the ADC can compensate for atmospheric dispersion at different zenith distances.

When the ADC is inserted, the secondary mirror is moved about 1 mm away from the primary mirror to compensate for defocus, and the system focal length is 22450 mm.

The parameters of the ADC are listed in Table 3. This is a preliminary design and should be adjusted according to glass melt data and test plate fits.

Table 3. The parameters of the ADC corrector

(all the units of length are in mm)

	radius	separation	media.	others
primary	-12253			CC=-1.07085
secondary	-5332.25	-4202.2765	air	CC=-3.7316672
lensm 1	plane	6418.3415	air	
	plane	18	LLF1	tilt=2.9920
	-784.8752	28	PSK3	
lensm 2	-608.9496	63.9562	air	
	plane	15	PSK3	tilt=3.9
	plane	19	LLF1	
focus	plane	367	air	

System performance

1) Atmospheric dispersion compensation and residual errors:

Figure 5 shows atmospheric dispersion as a function of zenith distance for dry air at 760 mm Hg pressure and t=15° C. At the elevation of Kitt peak the pressure will be about 20% less with a corresponding reduction in dispersion. The calculated values were based on a formula from Astrophysical Quantities (C.W. Allen, 1973 third edtion). The figure shows that atmospheric dispersion is already more than one arcsecond at a zenith distance of 25°.

Each lensm in the ADC can produce 0.38 mm dispersion from 3500 A to 10140 A which is equal to about 3.5 arcsec in the telescope. The largest dispersion attainable by adding the dispersion of each of the two lensms is about 7 arcsec which compensates for atmospheric dispersion to a zenith distance of 70 degrees. Figure 6 shows spot diagrams with the ADC set to minimum dispersion. For minimum dispersion the lensms are oriented so that the surface normal vectors of the prisms are in the same plane as the optical axis and point to either side of the axis. In this position, no dispersion is produced and the ADC works as an ordinary corrector.

Figure 7 shows spot diagrams at a zenith distance of 45° on a curved Cassegrain focal surface with no ADC. Figure 8 shows spot diagrams for the same zenith distance with the ADC in.

Figure 9 and figure 10 show spot diagrams for 65° zenith distance with and without the ADC.

In Figures 8 and 10 we see that the dominant residual error is secondary spectrum which arises from differences between the dispersive properties of the glasses and the atmosphere. The magnitude of this error is proportional to the square of the wavelength band. If the wavelength band were reduced by half, this error will be reduced to one quarter.

2) Transmission characteristics:

Twenty-four rays were traced through the two lensms to calculate transmission characteristics. The average transmission values for each element are listed in Table 4. It is assumed that the outer surfaces of both lensms are coated with magnesium flouride antireflection coating optimised for peak transparency at 4341 A.

Table 4. The transmittance

		10140 A	4341 A	3500 A
lensm I	surface	.968	.990	.981
	LLF1	.996	.993	.950
	PSK3	.990	.989	.910
	surface	.968	.990	.981
lensm II	surface	.968	.990	.981
	LLF1	.994	.994	.949
	PSK3	.996	.992	.948
	surface	.968	.990	.981
	total	.857	.932	.777

3) Fabrication tolerances:

For purposes of tolerancing the ADC the telescope secondary mirror position is assumed to be a variable at the initial installation. Once the focal position has been established, it cannot change when the ADC is inserted. This requirement drove tolerances to be a little tighter than in an ordinary corrector. The criteria for tolerancing was that the image degradation not exceed 4% of the parent design rms image quality. Parametric tolerances are listed in the following table:

Table 5. The tolerances

	tolerance	secondary adjustment
radii	± 1 mm	± 0.02 mm
thicknesses	± 0.25 mm	± 0.07 mm
decenters	surface 5: 0.1 mm surface 6: 0.06 mm	
wedge angle	± 30 arcsec	

If the position of the second lensm can be adjusted at initial assembly, then the radius tolerances can be made larger. In this case the tolerances on the radii will be ± 2 mm. The required movement of the second lensm is less than ± 1 mm, and the piston adjustment of the secondary mirror still less than ± 0.02 mm.

4) Ghost image analysis

A ghost reflection analysis has been performed. The reflections between the cemented surfaces of the two prisms can form ghost images of about 1.9 mm diameter on the focal surface. Both reflections take place on the cemented surface, as shown in figure 11 and figure 12, where reflectivity is usually less than 1% so even at wavelength of 3500 A, the intensities of the ghost images are less than 8×10^{-8} of the mother image. Other reflections in the ADC form ghost images larger than 10 mm in diameter.

5) Weight

The weight of the four elements of the ADC are 2.8, 3.4,2.6 and 2.3 kg respectively. The total glass weight will be about 11.3 kg.

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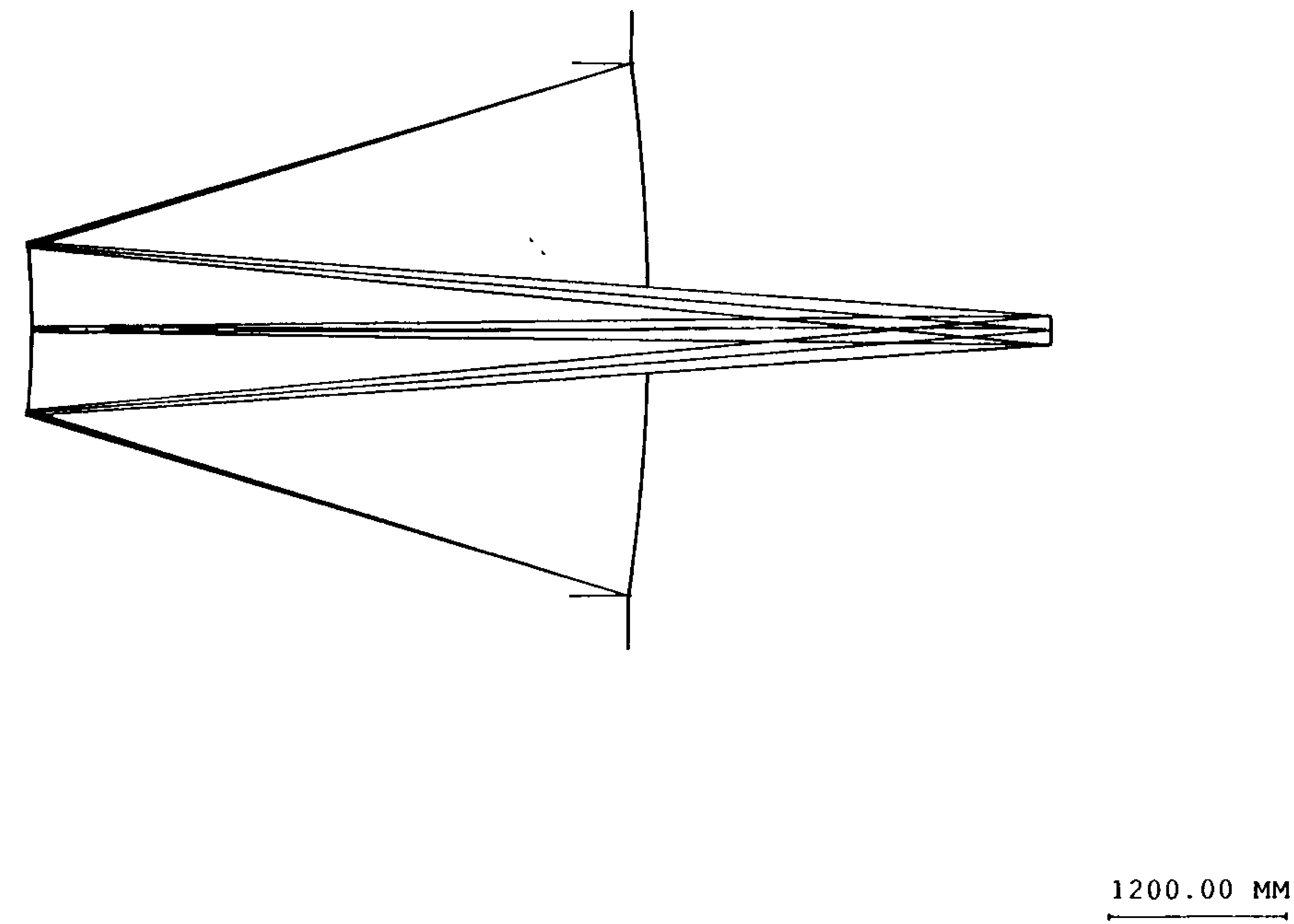

Figure 1. 3.5 meter WIYN telescope.

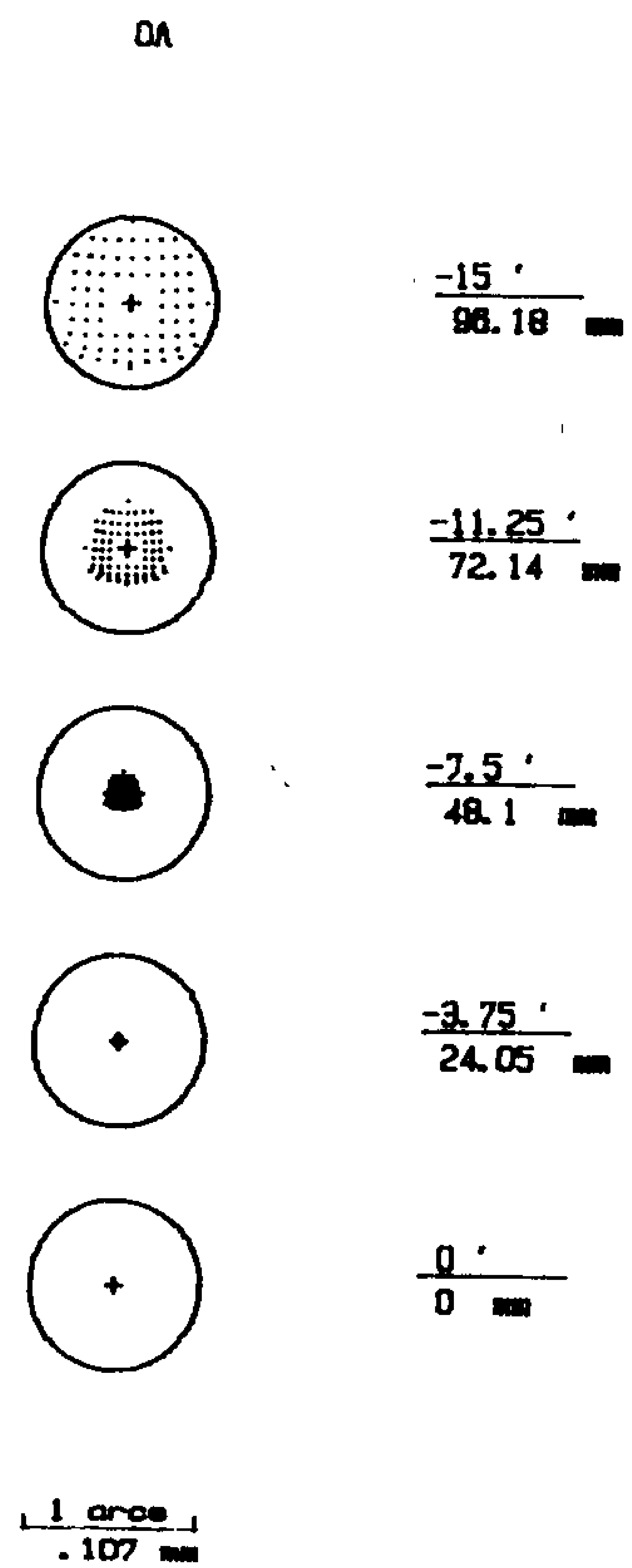

Figure 2. The spot diagrams at Cassegrain focal surface without ADC. The diameter of the circles around the spot diagrams are 0.107 mm, which subtend 1 arcsec to the sky. The data over the bars in the right collum are the field of view and the data under the bars are their height on the focal surface.

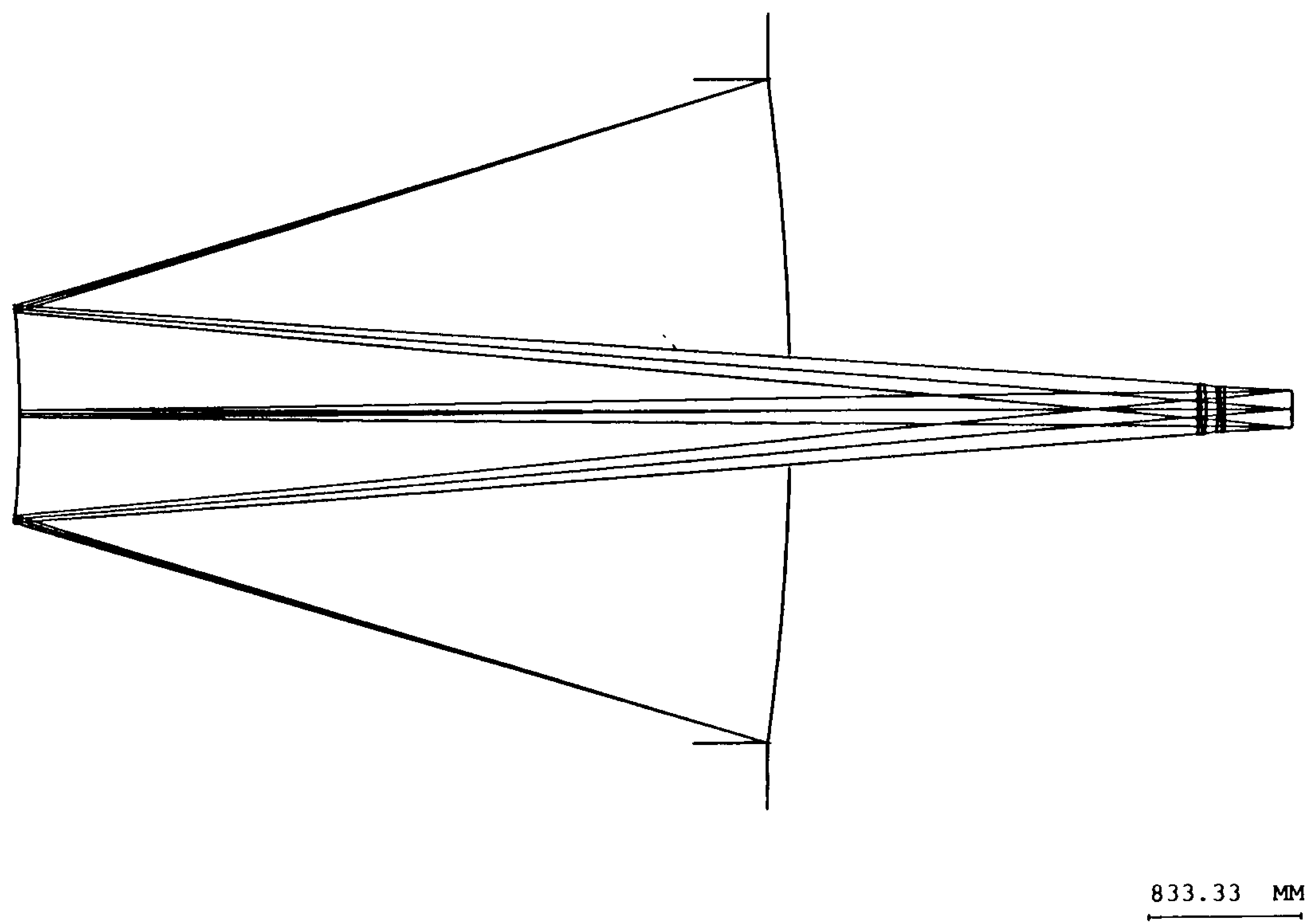

Figure 3. The telescope and the position of the ADC corrector.

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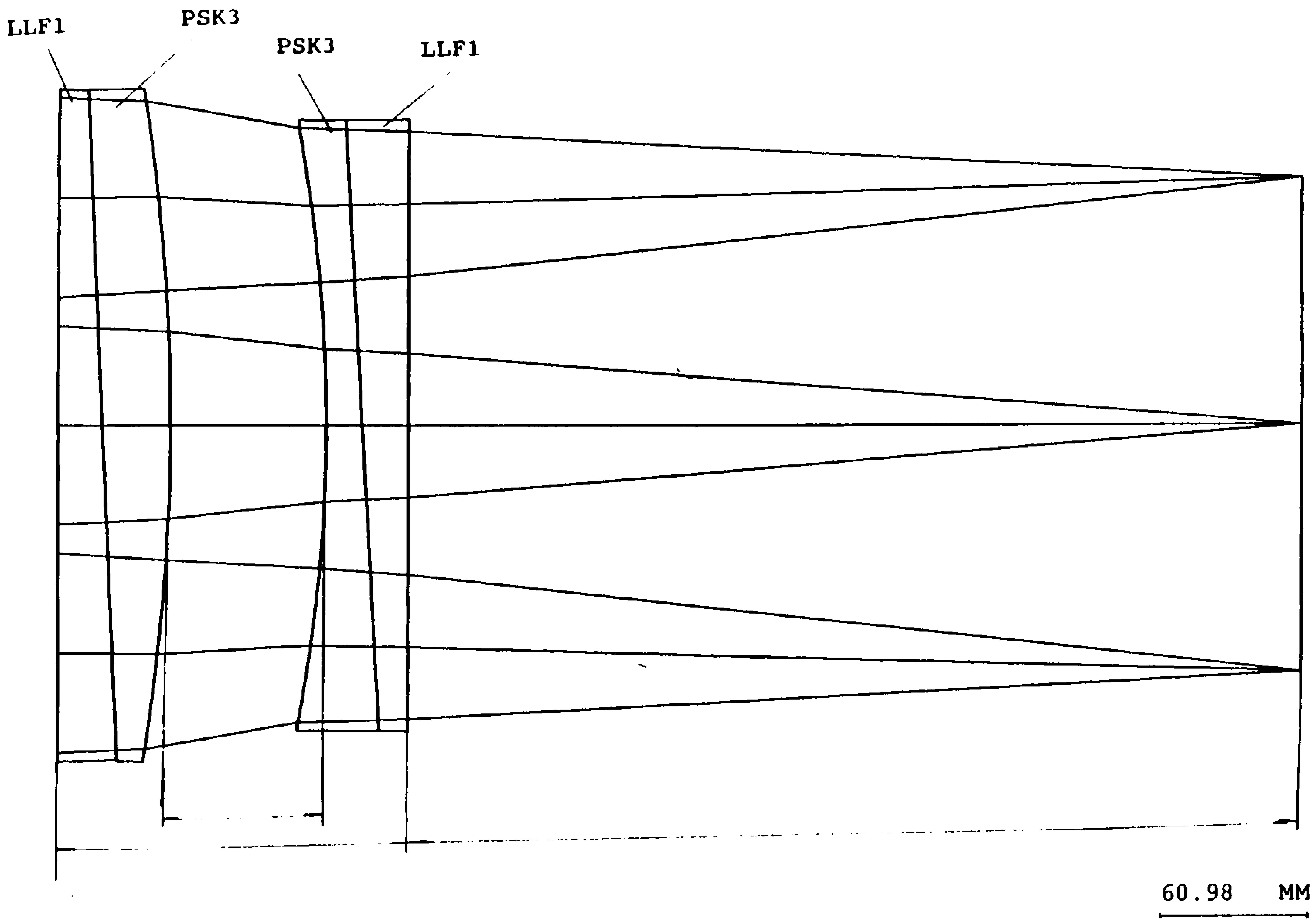

Figure 4. The ADC corrector.

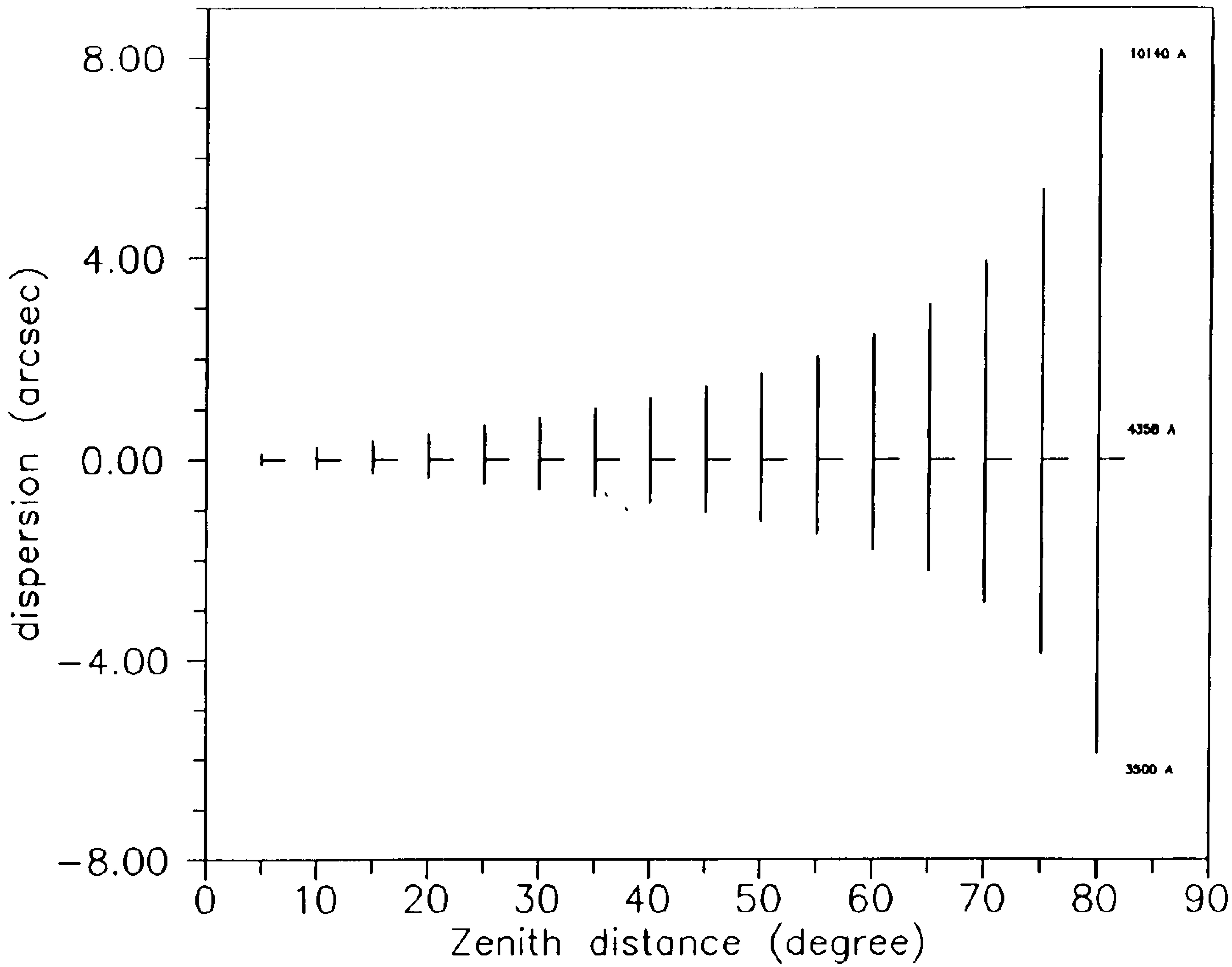

Figure 5. The atmospheric dispersion at different zenith distance. The wavelength bands are from 3500 A to 10140 A. The little center horizontal bars are the positions of 4358 A.

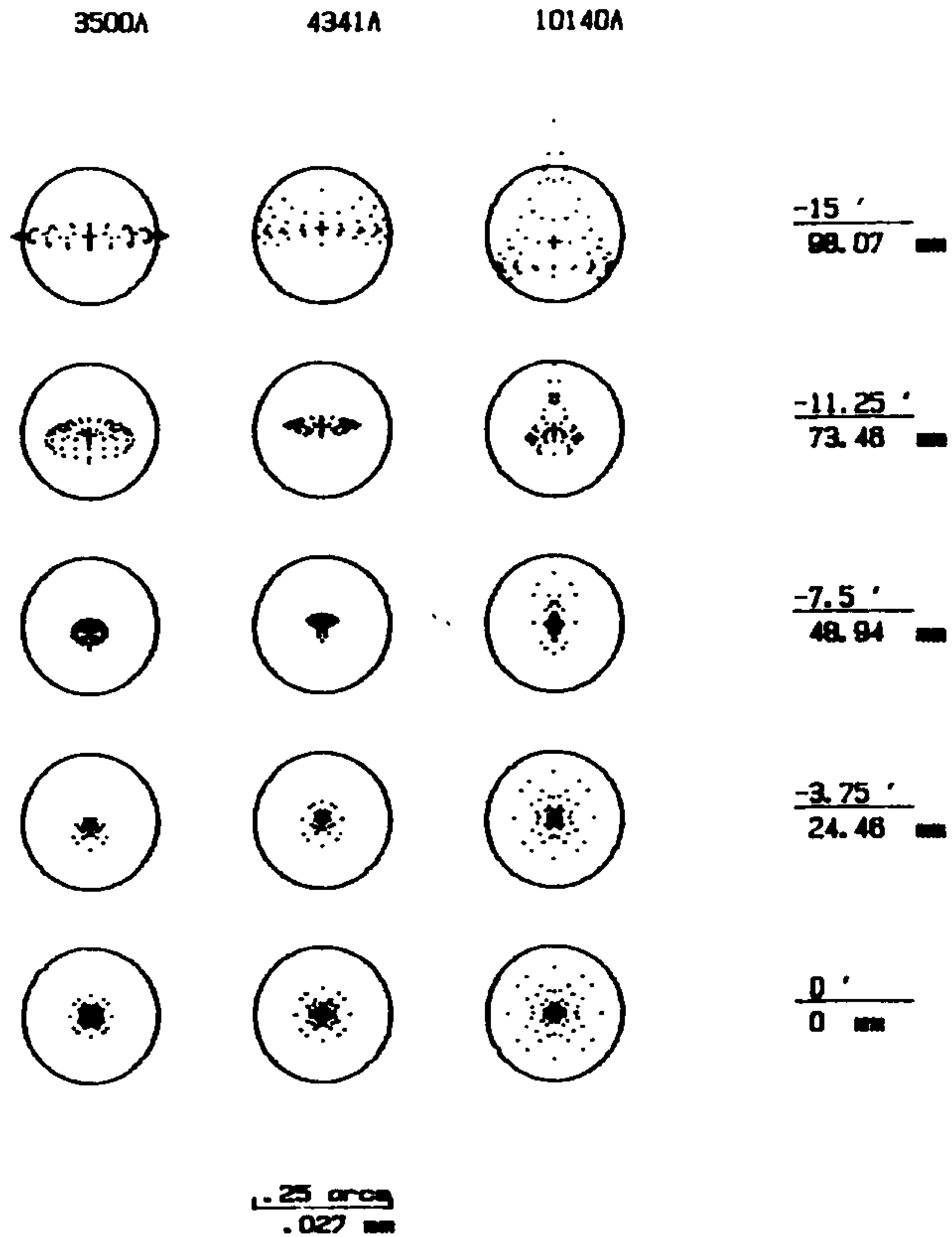

Figure 6. The spot diagrams for the ADC works at zenith position. The diameter of the circles around the spot diagrams are 0.027 mm, which subtend 0.25 arcsec to the sky. At this position, the rotating angles of the lensms are $\theta 1 = 90°$; $\theta 2 = 90°$.

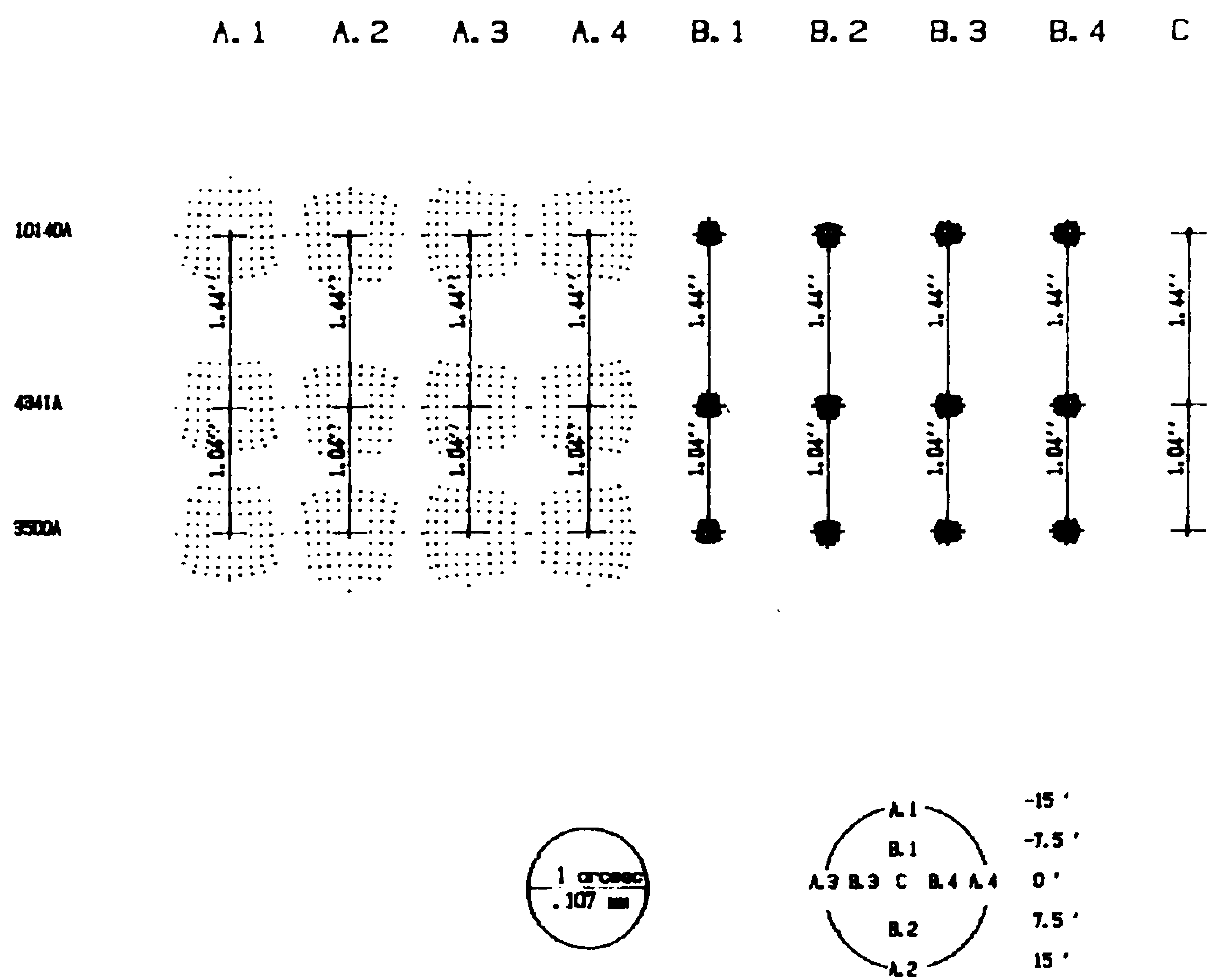

Figure 7. The spot diagrams for the telescope works at 45° zenith distance without ADC. The field positions are shown in the low right circle. The scale for the spot diagrams is shown in the low left circle. The dispersion size are marked at the left side of each dispersion line.

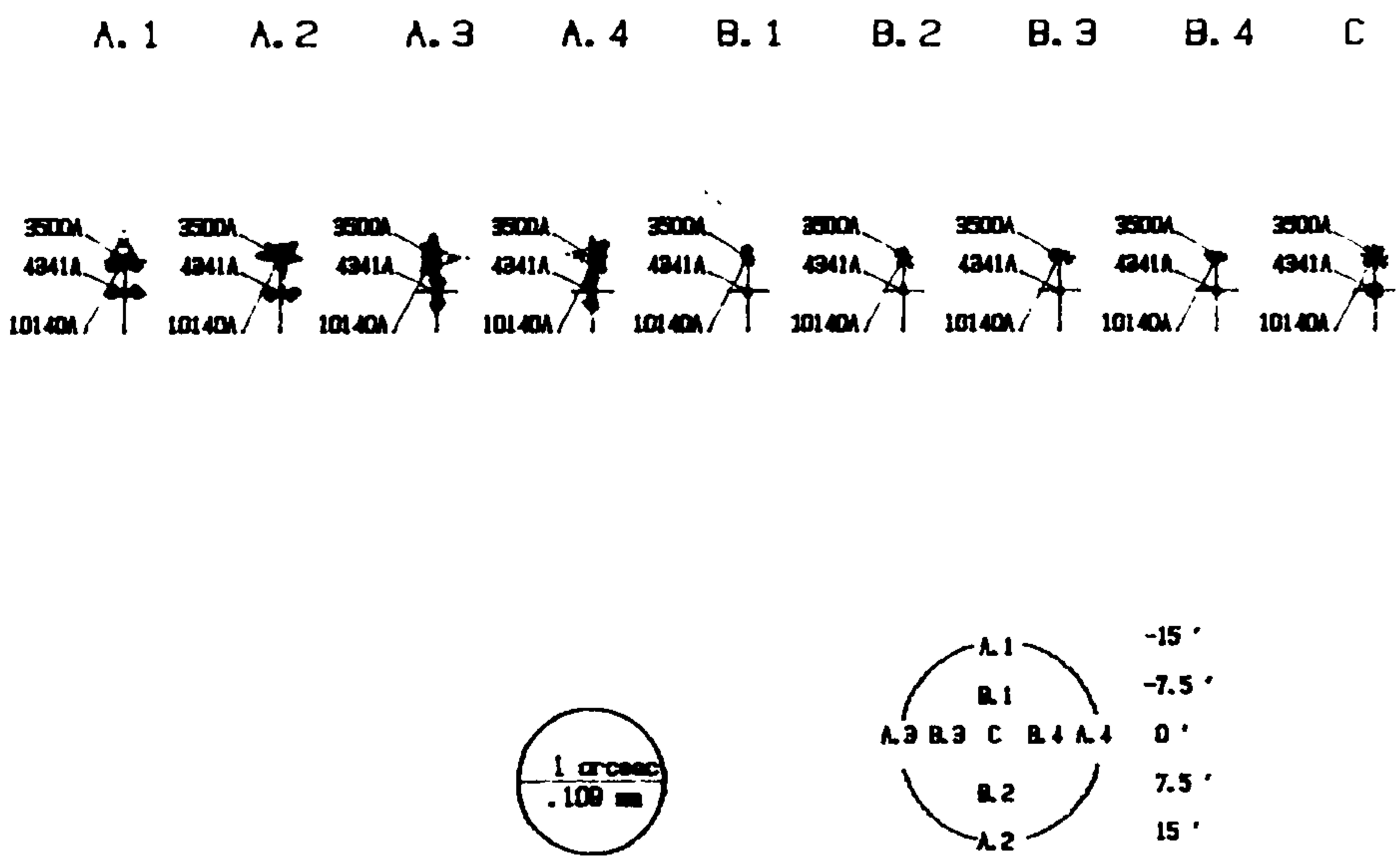

Figure 8. The spot diagrams for the telescope works at 45° zenith distance when ADC is put in. $\theta 1$ = 110.7°; $\theta 2$ = 69.3°The wavelength 3500 A and 10140 A are brought to the same point, the separation between this point and 4341 A is the compensation error.

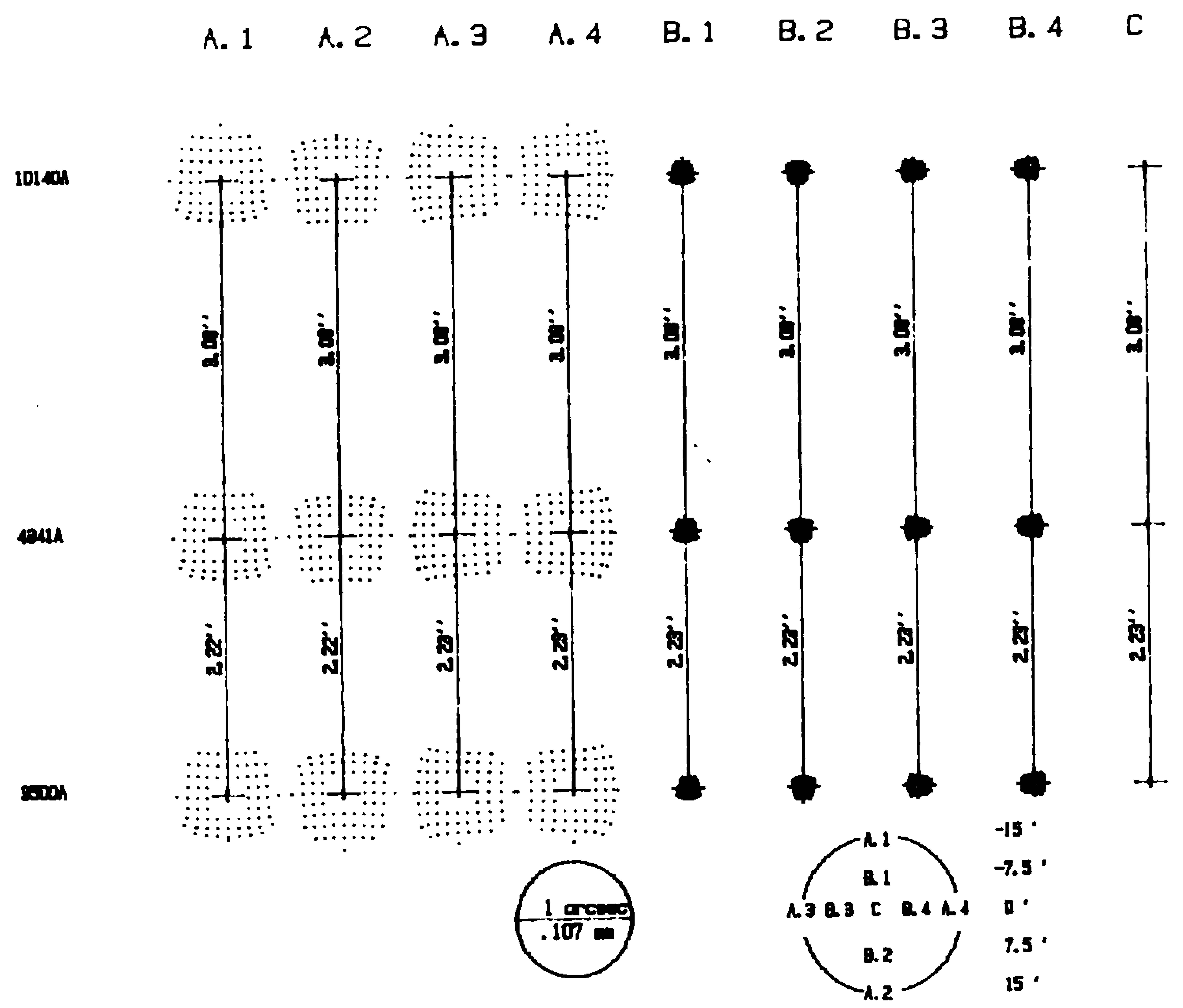

Figure 9. The spot diagrams for the telescope works at 65° zenith distance without ADC.

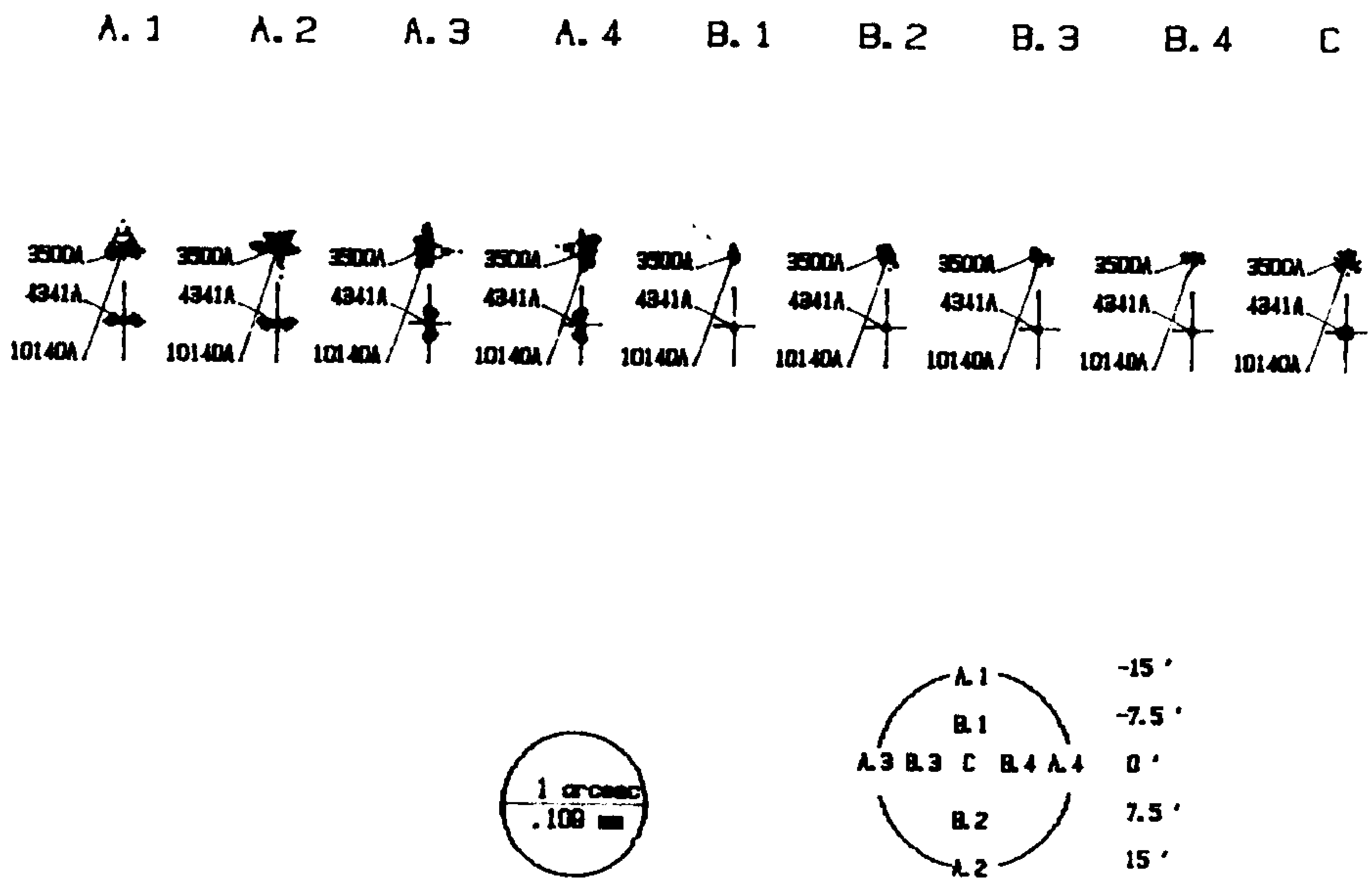

Figure 10. The spot diagrams for the telescope works at 65° zenith distance when ADC is put in. $\theta 1 = 139.4°$; $\theta 2 = 40.6°$At this position even the residual errors are already very large.

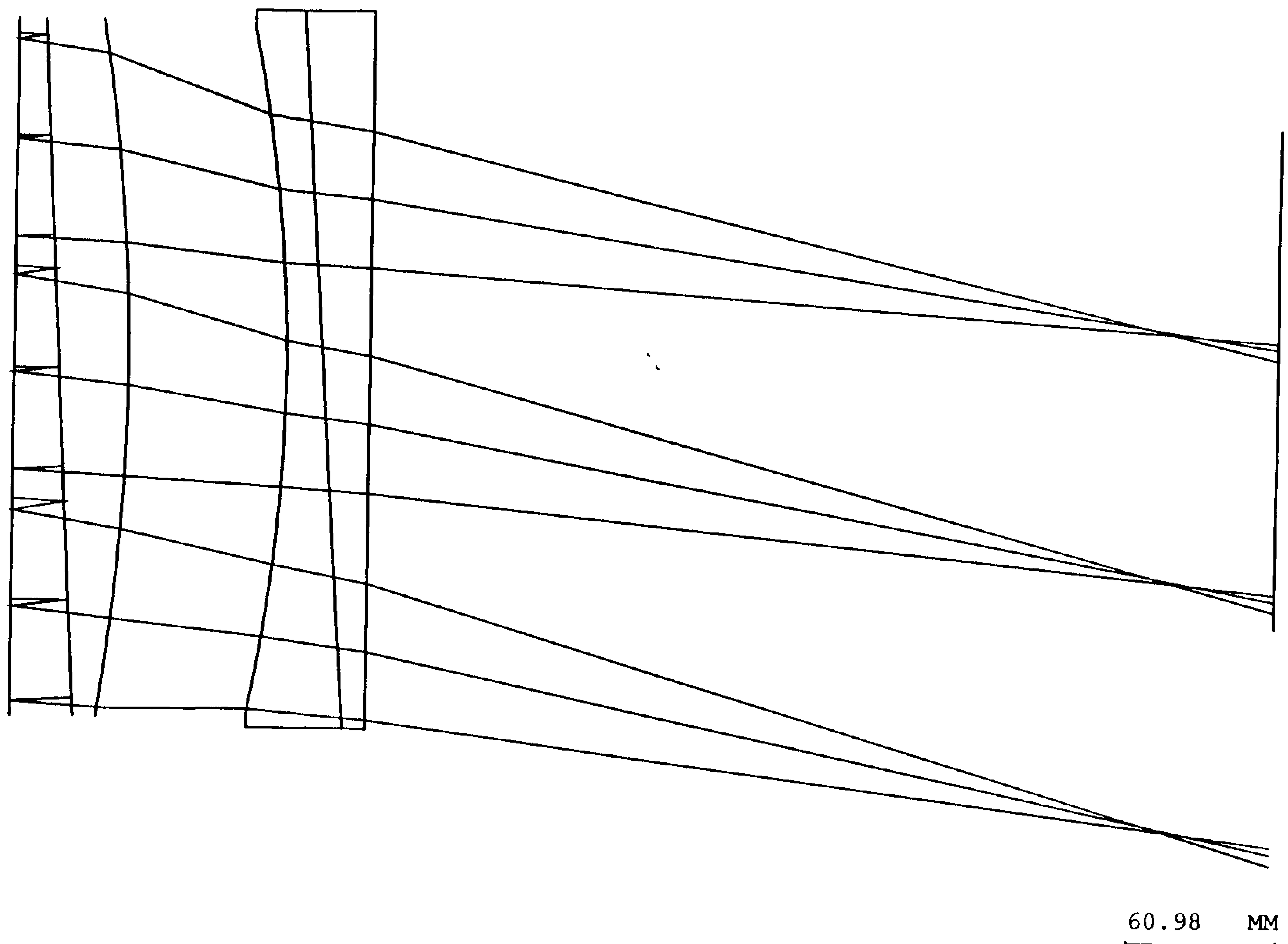

Figure 11. The ghost image produced from the reflection of surface 4 and 5.

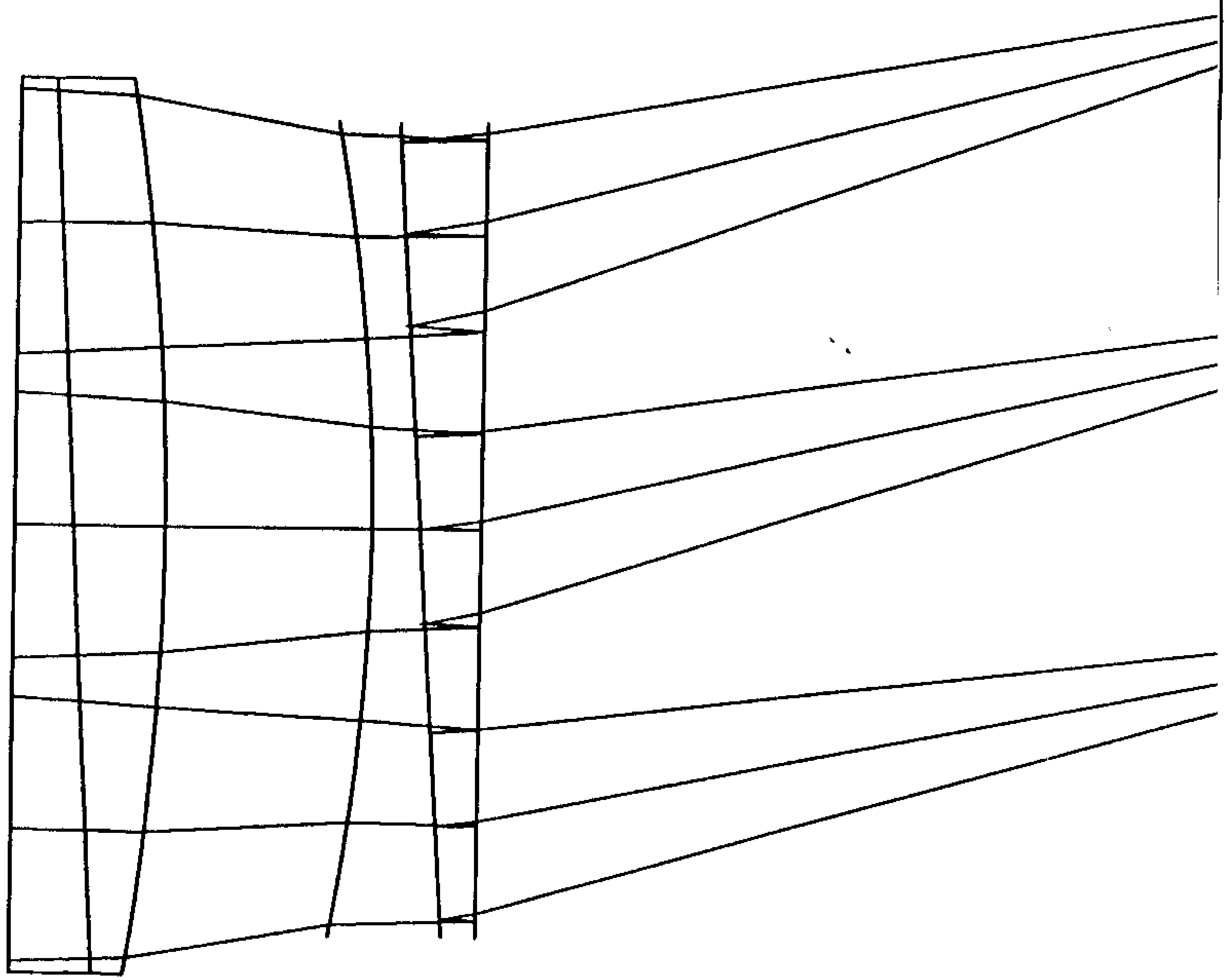

Figure 12. The ghost image produced from the reflection of s
8 and 9.