

**RESULTS FROM THE SHACK-HARTMANN TEST ON THE 1.9M
KOTTAMIA TELESCOPE PERFORMED IN FEBRUARY 1999
USING A NATURAL STAR**

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**Kottamia
11.2.99**

1. INTRODUCTION

In this document we present the results of the Shack-Hartmann test done on the 1.9m Kottamia telescope during the nights of 8-10 February 1999 using the Shack-Hartmann sensor Puntino of Spot s.r.l.

The aim of the tests was to evaluate the optical quality of the telescope, in particular to see its stability. This was necessary to check that the lateral pads glued by Zeiss again last August/September were indeed properly fixed. It may be recalled that some of the pads had become unstuck.

A sampling of 20x20 spots was used.

The various steps in the adjustment of the telescope have been reported in the respective tables for the days when the tests were conducted. In most cases, the steps are reported in the table for average frames.

Explanation of terms used in the document:

The values for the coefficients are given in nm when referred to the wavefront, and arcsecs, when referred to the focal plane. In the latter case, they denote the diameter in the focal plane containing 100% of the encircled energy due to that aberration alone.

1. **Coma:** Coefficient of coma. This aberration principally measures the misalignment of M_1 and M_2 , both decentering and tilt. It also measures the coma introduced by the supports. It is important to distinguish it from field coma.

Once the telescope is aligned, typically coma is about 0.2-0.3". It changes as the telescope is moved towards the zenith. The degree of change will depend on the telescope mechanics and the mounting of the mirrors, particularly M_2 .

2. **SA3:** Third order spherical aberration. This arises due to the wrong conic coefficients of M_1 and M_2 , as a result of faulty manufacturing. It also arises due to a choice of wrong focal plane for the telescope. This is the most difficult aberration to control during manufacture.

Acceptable values are about 0.15-0.2". This can change with temperature.

3. **Ast:** Third order astigmatism. This results from support errors during manufacture. At the telescope, it results from support problems of M_1 and M_2 .
4. **Tcoma:** Triangular coma. This usually results from the 3 fixed points. Typical values are 0.1-0.2".

5. **Qast:** Quadratic astigmatism. This can result from the four fixed points of M_1 .

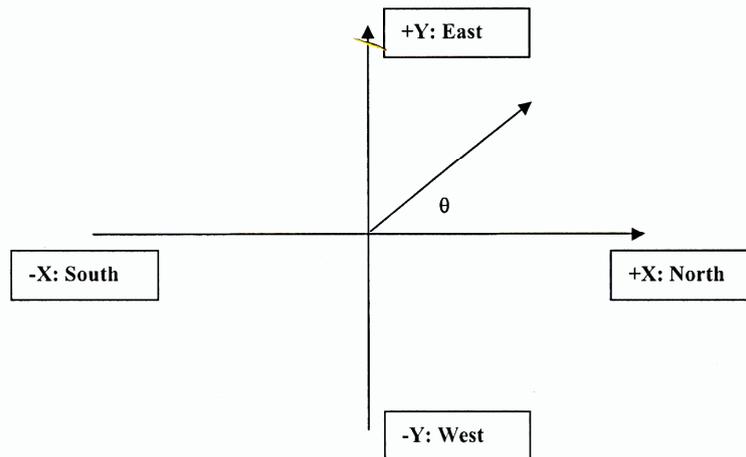
 Typical values are 0.1-0.2".
6. **AQ: Actual Quality:** Residuals remaining after subtracting out **defocus** and **tilt**. In some tables it is abbreviated as (A) instead of (AQ).
7. **PQ: Potential Quality:** Residuals after subtracting out 7 Zernike terms: defocus, tilt, coma, Ast, SA3, Tcoma and Qast. In some tables it is abbreviated as (P) instead of (PQ).
8. **D50:** Diameter containing 50% of the Encircled Energy.
9. **D80:** Diameter containing 80% of the Encircled Energy.
10. **Rms:** this value is obtained from the residuals of the SH spots. The mean is computed for all the residuals, and then the rms is computed using this mean. It is clearly a measure of the noise introduced by seeing. Typical values are in the range 0.08-0.4". The lower limit of 0.08" is obtained rarely, under conditions of exceptional seeing on the very best astronomical sites.

It is to be noted that all the above values obtained depend on the seeing. This term seeing is used here generically, and includes dome seeing, mirror seeing and external seeing.

All the above aberrations change with the direction in which the telescope is pointing.

2. Orientation of the contour plots of the mirror surface and the Zernike coefficients

The angles are measured counterclockwise, from the +x direction. The coordinate system is related to the direction on the sky (as determined from orientation frames taken with Puntino):



3. Results of Shack-Hartmann analysis for average of multiple frames

Night of 8-9 February

SET	POSITION OF TELESCOPE
MIR1-MIR5	NEAR ZENITH
MIR6-MIR10	STILL NEAR ENITH, AFTER 30 MINS
MIR11-MIR15	MOVED EAST (ALMOST HORIZONTAL), WEST AND BACK TO NEAR ZENITH
MIR16-MIR20	WEST,NORTH AND BROUGHT BACK
MIR21-MIR25	SOUTH, EAST AND BACK
MIR26-MIR30	45° SOUTH
MIR31-MIR35	70° SOUTH
MIR36-MIR40	80° EAST
MIR41-MIR45	80° WEST
MIR46-MIR50	25° NORTH

Table 1: The average Zernike coefficients in nm

Frame	Time	Coma	Angle	SA3	Ast	Angle	TComa	Angle	QAst	Angle
		nm	Deg	nm	nm	Deg	nm	deg	nm	deg
MIR1-MIR5	20:14:12	47±16	-144	18±16	56±17	-26	29±18	-15	23±14	-27
MIR6-MIR10	20:54:13	26±12	-134	32±12	100±15	-58	28±12	-0.1	17±	-14
MIR11-MIR15	21:15:46	33.5±19	-42	35±8	91±38	-50	22±11	9	22±2	-1
MIR16-MIR20	21:37:53	28±10	84	42±6	84±26	-54	33±13	-36	16±7	10
MIR21-MIR25	22:03:32	18±8	-45	28±8	91±45	-47	32±11	2	26±4	-32
MIR26-MIR30	22:58:06	29±10	-78	39±7	33±10	37	20±13	17	19	-2
MIR31-MIR35	23:24:37	26±17	-77	56±16	62±38	43	44±23	-32	27±9	-17
MIR36-MIR40	23:45:25	15±4	136	32±60	142±18	-40	28±17	-13	23±7	-34
MIR41-MIR45	00:13:25	39±12	-162	28±5	64±24	20	49±15	-48	40±14	-38
MIR46-MIR50	00:45:39	49±15	66	39	58±25	-49	24±18	-17	38±8	-22

Table 2: The average Zernike coefficients in arcsec

Frame	Time	Coma		SA3		Ast		TComa		Qast	
		C(")	Angle	C(")	C(")	C(")	Angle	C(")	Angle	C(")	Angle
MIR1-MIR5	20:14:12	0.26	-144	0.11	0.12	-26	0.11	-15	0.13	-27	
MIR10-MIR9	20:54:13	0.14	-134	0.20	0.21	-58	0.11	-0.1	0.09	-14	
MIR11-MIR15	21:15:46	0.19	-42	0.22	0.19	-50	0.08	9	0.12	-1	
MIR16-MIR20	21:37:53	0.15	84	0.26	0.18	-54	0.12	-36	0.08	10	
MIR21-MIR25	22:03:32	0.09	-45	0.17	0.19	-47	0.12	2	0.14	-32	
MIR26-MIR30	22:58:06	0.16	-78	0.24	0.07	37	0.07	17	0.10	-2	
MIR31-MIR35	23:24:37	0.15	-77	0.34	0.13	43	0.16	-32	0.15	-17	
MIR36-MIR40	23:45:25	0.09	136	0.20	0.30	-40	0.10	-13	0.13	-34	
MIR41-MIR45	00:13:25	0.21	-162	0.17	0.14	20	0.18	-48	0.22	-38	
MIR46-MIR50	00:45:39	0.27	66	0.24	0.12	-49	0.09	-17	0.21	-22	

Table 3- Encircled energy

Frame	Time	D50(A)	D80(A)	rms	D50(P)	D80(P)	rms
		"	"	"	"	"	"
MIR1-MIR5	20:14:12	0.45	0.83	0.33	0.45	0.81	0.32
MIR10-MIR9	20:54:13	0.41	0.73	0.29	0.39	0.66	0.27
MIR11-MIR15	21:15:46	0.45	0.77	0.32	0.43	0.70	0.30
MIR16-MIR20	21:37:53	0.44	0.71	0.29	0.39	0.65	0.27
MIR21-MIR25	22:03:32	0.45	0.75	0.29	0.45	0.71	0.28
MIR26-MIR30	22:58:06	0.45	0.74	0.30	0.42	0.70	0.29
MIR31-MIR35	23:24:37	0.43	0.74	0.29	0.40	0.63	0.26
MIR36-MIR40	23:45:25	0.40	0.72	0.29	0.34	0.64	0.26
MIR41-MIR45	00:13:25	0.51	0.82	0.35	0.48	0.78	0.33
MIR46-MIR50	00:45:39	0.44	0.75	0.32	0.43	0.66	0.30

Night of 9-10 February

SET	POSITION OF TELESCOPE
MIR1-MIR5	NEAR ZENITH
MIR6-MIR10	MOVED EAST, WEST, NORTH, SOUTH AND BACK
MIR11-MIR15	STILL NEAR ZENITH, BUT TELESCOPE TRACKS FOR 30 MINS
MIR16-MIR20	70° SOUTH
MIR21-MIR25	BROUGHT BACK TO NEAR ZENITH
MIR26-MIR30	70° EAST
MIR31-MIR35	70° WEST
MIR36-MIR40	NEAR ZENITH
MIR41-MIR45	EAST OF ZENITH
MIR46-MIR50	WEST OF ZENITH

Table 1: The average Zernike coefficients in nm

Frame	Time	Coma nm	Angle deg	SA3 nm	Ast nm	Angle deg	TComa nm	Angle deg	Qast nm	Angle deg
Good coefficients										
MIR1-MIR5	20:10:35	43±8	93	-3	93±7	-38	32±22	-33	12±7	-12
MIR10-MIR9	21:21:16	21±11	-21	35±3	118±16	-45	50±24	-33	37±14	-11
Coefficients almost the same as for the previous set										
MIR11-MIR15	21:46:33	18±3	32	20±18	91±27	-44	45±6	-32	36±10	-17
Coma, Ast3, Qast and Tcoma increase due to the extreme position of 70° south										
MIR16-MIR19	22:31:53	79±24	-124	5±22	112±76	-20	60±29	-0.4	47±22	16
Near zenith: values of coma decreases a bit										
MIR21-MIR25	23:07:14	44±17	-133	42±20	134±49	-54	44±20	9	40±5	-20
MIR26-MIR30	23:38:02	21±21	-29	36±18	100±50	-72	46±32	-14	36±20	-4
MIR31-MIR35	00:06:16	68±23	-130	20±8	164±76	-35	60±36	-27	60±14	-26
MIR36-MIR40	00:44:31	53±23	90	7±8	105±45	-43	78±22	-33	34±18	-20
MIR41-MIR45	01:16:55	44±18	86	9±18	98±62	-10	31±15	-6.4	25±16	-6
MIR46-MIR50	03:10:24	63±20	148	2±15	96±79	-50	57±19	-7	28±12	-22

Table 2: The average Zernike coefficients in arcsec

Frame	Time	Coma C(")	Angle	SA3 C(")	Ast C(")	Angle	TComa C(")	Angle	Qast C(")	Angle
MIR1-MIR5	20:10:35	0.24	93	-0.02	0.20	-38	0.12	-33	0.07	-12
MIR10-MIR9	21:21:16	0.11	-21	0.21	0.25	-45	0.18	-33	0.20	-11
MIR11-MIR15	21:46:33	0.10	32	0.12	0.19	-44	0.17	-32	0.20	-17
MIR16-MIR19	22:31:53	0.44	-124	0.03	0.24	-20	0.22	-0.4	0.26	16
MIR21-MIR25	23:07:14	0.24	-133	0.26	0.28	-54	0.16	9	0.22	-20
MIR26-MIR30	23:38:02	0.12	-29	0.22	0.21	-72	0.17	-14	0.19	-4
MIR31-MIR35	00:06:16	0.37	-130	0.13	0.35	-35	0.22	-27	0.33	-26
MIR36-MIR40	00:44:31	0.29	90	0.04	0.22	-43	0.29	-33	0.18	-20
MIR41-MIR45	01:16:55	0.24	86	0.06	0.21	-10	0.11	-6	0.14	-6
MIR46-MIR50	03:10:24	0.34	148	0.01	0.20	-50	0.21	-7	0.16	-22

Table 3- Encircled energy

Frame	Time	D50(A)	D80(A)	rms	D50(P)	D80(P)	rms
MIR1- MIR5	20:10:35	0.51	0.87	0.37	0.53	0.84	0.35
MIR10- MIR9	21:21:16	0.54	0.84	0.37	0.46	0.80	0.35
MIR11- MIR15	21:46:33	0.49	0.86	0.37	0.47	0.82	0.35
MIR16- MIR19	22:31:53	0.46	0.78	0.35	0.40	0.67	0.32
MIR21- MIR25	23:07:14	0.48	0.78	0.35	0.40	0.69	0.32
MIR26- MIR30	23:38:02	0.54	0.84	0.38	0.49	0.74	0.37
MIR31- MIR35	00:06:16	0.51	0.89	0.39	0.44	0.75	0.36
MIR36- MIR40	00:44:31	0.44	0.77	0.34	0.43	0.70	0.32
MIR41- MIR45	01:16:55	0.54	0.91	0.42	0.52	0.90	0.41
MIR46- MIR50	03:10:24	0.50	0.91	0.41	0.48	0.85	0.39

Comments

It can be seen from the above tables that the telescope is quite stable. This is shown both by tests done near the zenith, as well as those done far from the zenith. The increase of aberrations with zenith distance is within the limits of what is expected from a passive telescope.

Conclusions

Below we summarize the results obtained from the SH analysis.

The optical quality of the telescope:

The graphs in the previous sections demonstrate that after accounting for air effects, it can be stated that the telescope is functioning according to the contractual value imposed on Zeiss, that of $D80 < 0.35''$.

The stability of the telescope

After it was discovered that the pads had become unglued, it was necessary to check the stability of the telescope to ensure that the new gluing done by Zeiss was good. The exhaustive tests done by moving the telescope around in all the directions during the current run clearly demonstrate that both the primary and secondary mirrors are stable in their mounts.

Astigmatism

The level of astigmatism in the primary mirror was found to be around $0.25''$. This value is at the upper limit of what is found in most telescopes. Indeed, astigmatism is the most common error in mirrors, as it is easy to introduce due to any unbalance of the forces.

The value of astigmatism found by us is almost the same as that found in the test tower of Zeiss. Thus, it logically follows that in all probability M2 has a very small astigmatism.

Spherical aberration

The telescope had almost zero spherical aberration. This is an important result as it confirms that Zeiss has done a very good job of matching the shapes of the primary and secondary mirrors.

Alignment

It was noticed that the M2 drive motor is not aligned along the optical axis of the primary. This should be done in the future. The spiders of M1 and M2 also need alignment.

Tracking

The tracking needs to be improved.

CCD system for the guider

It will be very useful to have a CCD at the guider telescope for improving the efficiency of finding the stars. A Barlow lens can be used to increase the focal length of the guider to get a good scale.

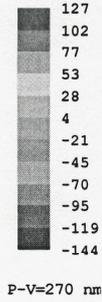
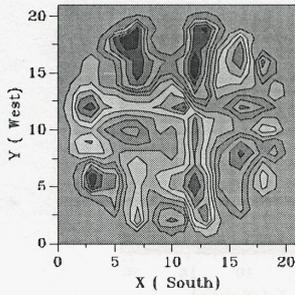
Appendix 1

In the following pages, the contour plots have been plotted both for AQ and PQ. They can be used to judge the effect of the supports in different directions

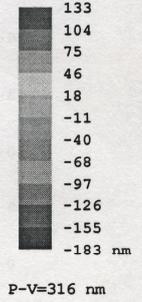
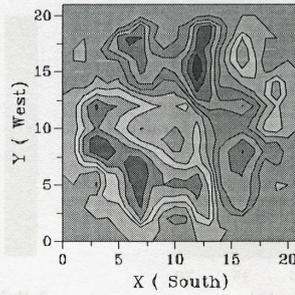
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Mir1-Mir5: telescope near zenith

Average of frames MIR1 to MIR5-Surface:RQ

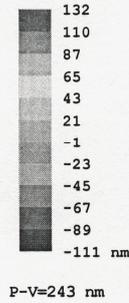
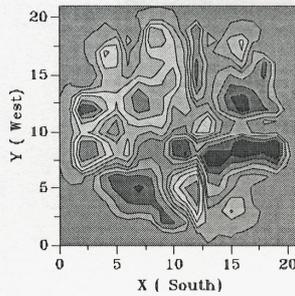


Average of frames MIR1 to MIR5-Surface:AQ

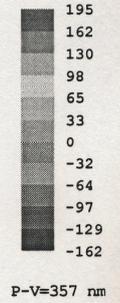
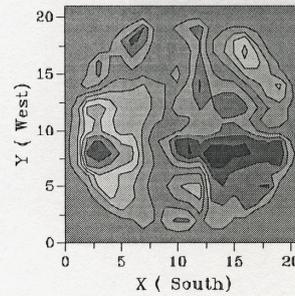


Mir6-Mir10: after about 30 minutes, telescope still near zenith

Average of frames MIR6 to MIR10-Surface:RQ



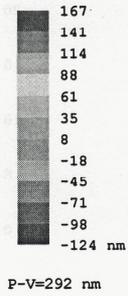
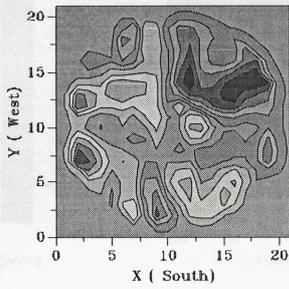
Average of frames MIR6 to MIR10-Surface:AQ



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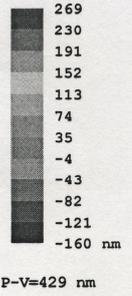
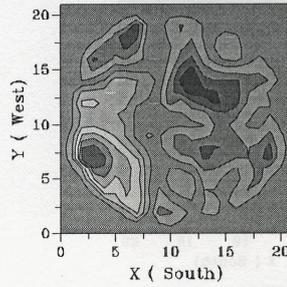
Mir11-Mir15: telescope moved east, north and back to zenith

Average of frames MIR11 to MIR15-Surface:RQ



P-V=292 nm

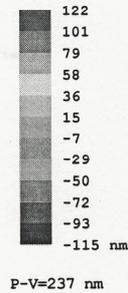
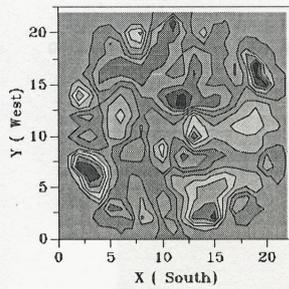
Average of frames MIR11 to MIR15-Surface:AQ



P-V=429 nm

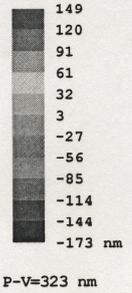
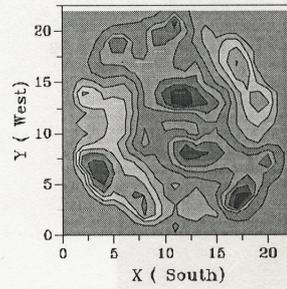
Mir16-Mir20: telescope moved west, north, and back to zenith

Average of frames MIR16 to MIR20-Surface:RQ



P-V=237 nm

Average of frames MIR16 to MIR20-Surface:AQ

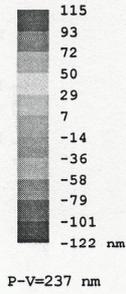
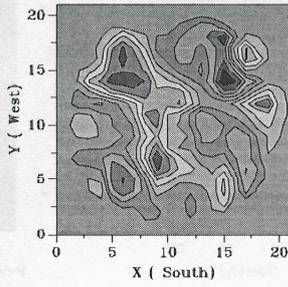


P-V=323 nm

8-9 February 1999

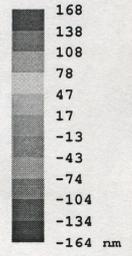
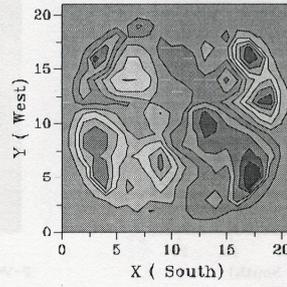
Mir21-Mir25: telescope moved south, east and back to zenith

Average of frames MIR21 to MIR25-Surface:RQ



P-V=237 nm

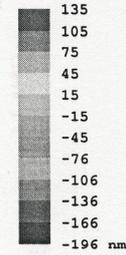
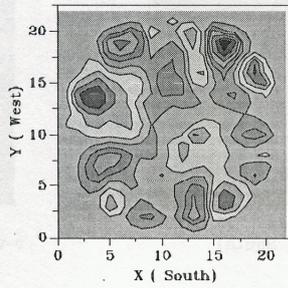
Average of frames MIR21 to MIR25-Surface:AQ



P-V=333 nm

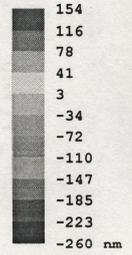
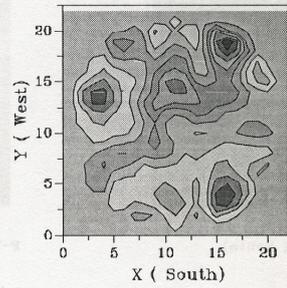
Mir26-Mir30: telescope moved 45° south

Average of frames MIR26 to MIR30-Surface:RQ



P-V=332 nm

Average of frames MIR26 to MIR30-Surface:AQ

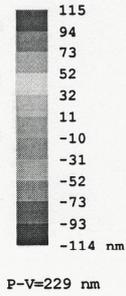
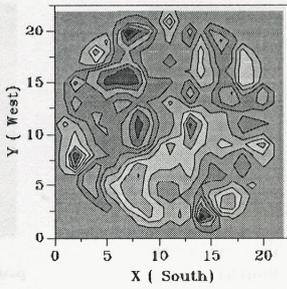


P-V=414 nm

8-9 February 1999

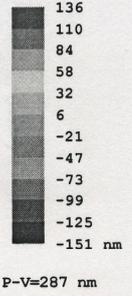
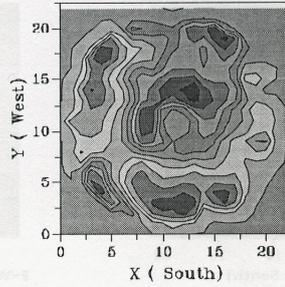
Mir31-Mir35: telescope moved 70° south

Average of frames MIR31 to MIR35-Surface:RQ



P-V=229 nm

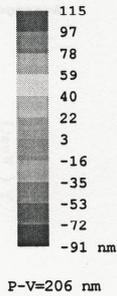
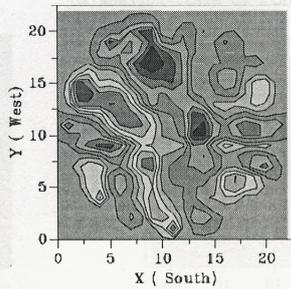
Average of frames MIR31 to MIR35-Surface:AQ



P-V=287 nm

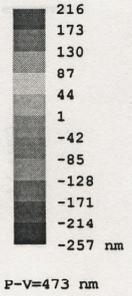
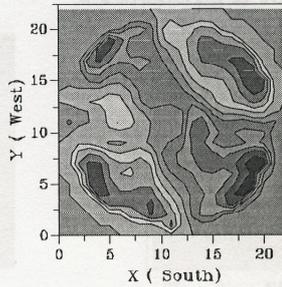
Mir36-Mir40: telescope moved 80° east

Average of frames MIR36 to MIR40-Surface:RQ



P-V=206 nm

Average of frames MIR36 to MIR40-Surface:AQ

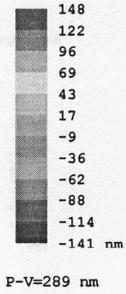
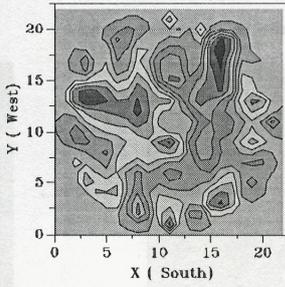


P-V=473 nm

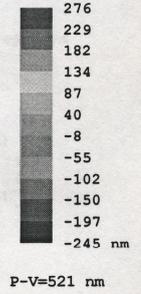
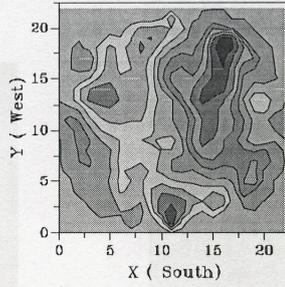
8-9 February 1999

Mir41-Mir45: telescope moved 80° west

Average of frames MIR41 to MIR45-Surface:RQ

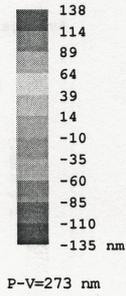
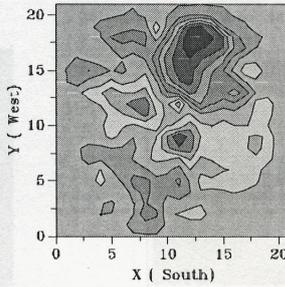


Average of frames MIR41 to MIR45-Surface:AQ

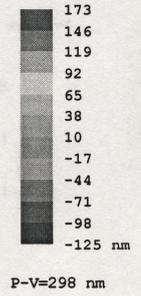
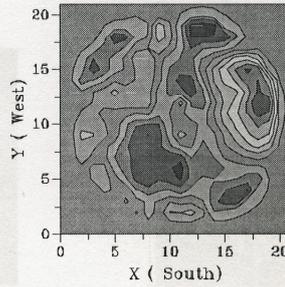


Mir45-Mir50: telescope moved 25° north

Average of frames MIR46 to MIR50-Surface:RQ



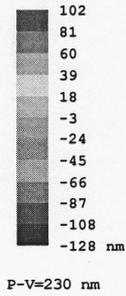
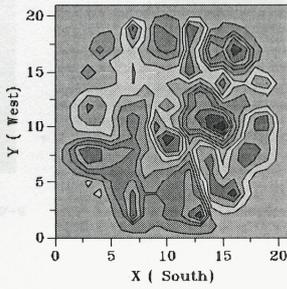
Average of frames MIR46 to MIR50-Surface:AQ



9-10 February 1999

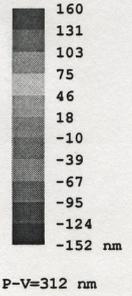
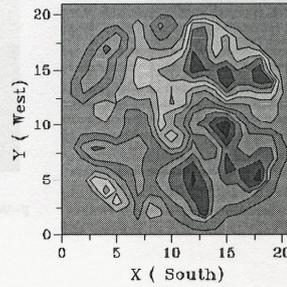
Mir1-Mir5: telescope near zenith

Average of frames MIR1 to MIR5-Surface:RQ



P-V=230 nm

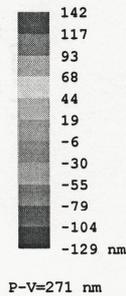
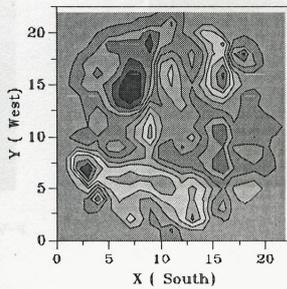
Average of frames MIR1 to MIR5-Surface:AQ



P-V=312 nm

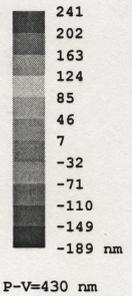
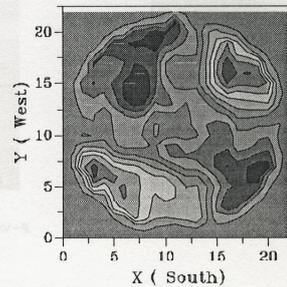
Mir6-Mir10: telescope moved east, west, north and back to zenith

Average of frames MIR6 to MIR10-Surface:RQ



P-V=271 nm

Average of frames MIR6 to MIR10-Surface:AQ

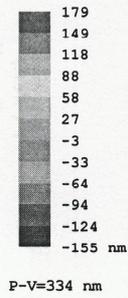
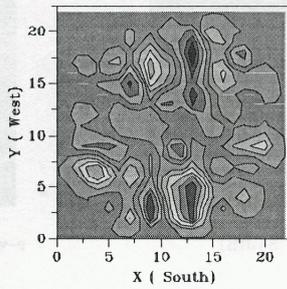


P-V=430 nm

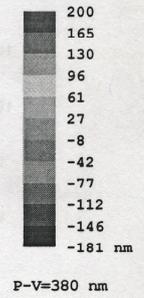
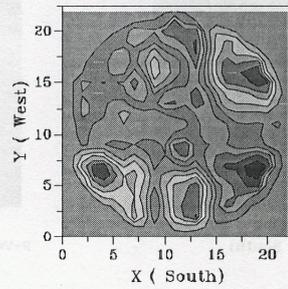
9-10 February 1999

Mir11-Mir15: telescope tracks for about 30 minutes near zenith

Average of frames MIR11 to MIR15-Surface:RQ

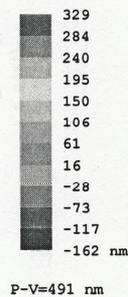
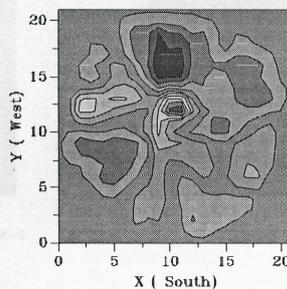


Average of frames MIR11 to MIR15-Surface:AQ

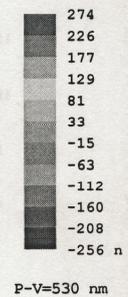
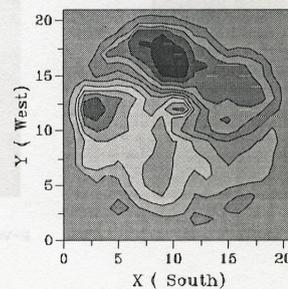


Mir16-Mir19: telescope moved 70° south

Average of frames MIR16 to MIR19-Surface:RQ



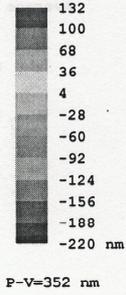
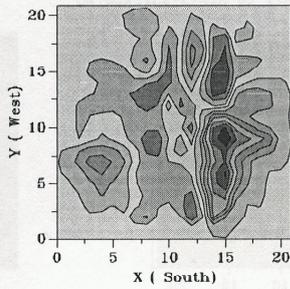
Average of frames MIR16 to MIR19-Surface:AQ



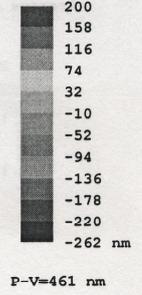
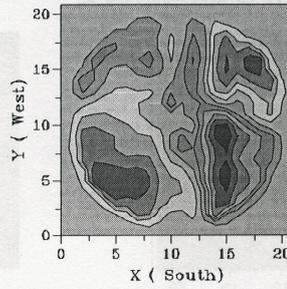
9-10 February 1999

Mir21-Mir25: telescope moved back to zenith

Average of frames MIR21 to MIR25-Surface:RQ

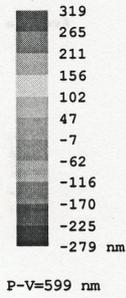
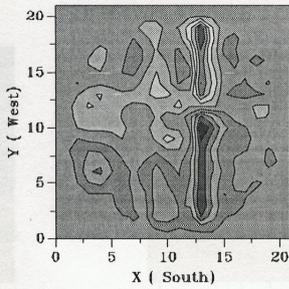


Average of frames MIR21 to MIR25-Surface:AQ

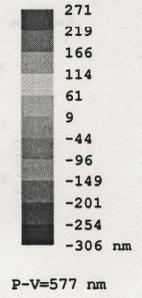
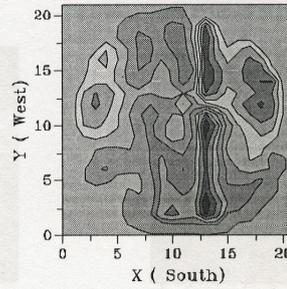


Mir26-Mir30: telescope moved 70° east

Average of frames MIR26 to MIR30-Surface:RQ



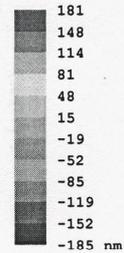
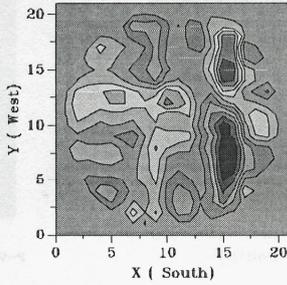
Average of frames MIR26 to MIR30-Surface:AQ



9-10 February 1999

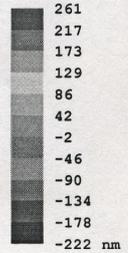
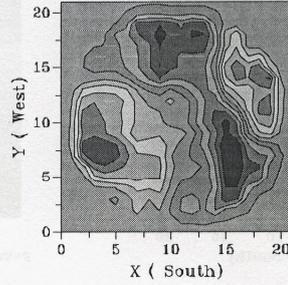
Mir31-Mir35: telescope moved 70° west

Average of frames MIR31 to MIR35-Surface:RQ



P-V=366 nm

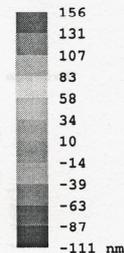
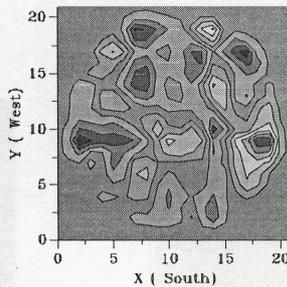
Average of frames MIR31 to MIR35-Surface:AQ



P-V=483 nm

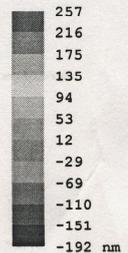
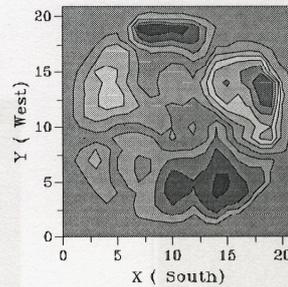
Mir36-Mir40: telescope moved to zenith

Average of frames MIR36 to MIR40-Surface:RQ



P-V=267 nm

Average of frames MIR36 to MIR40-Surface:AQ

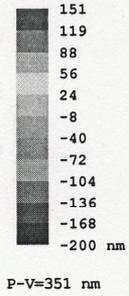
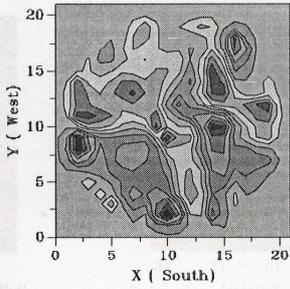


P-V=449 nm

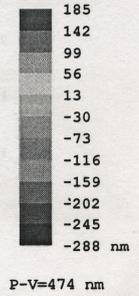
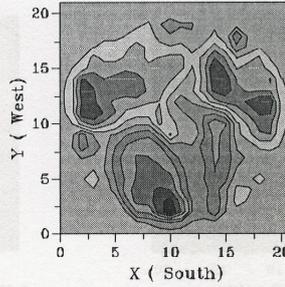
9-10 February 1999

Mir41-Mir45: telescope 1h east of zenith

Average of frames MIR41 to MIR45-Surface:RQ

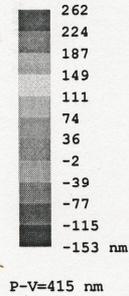
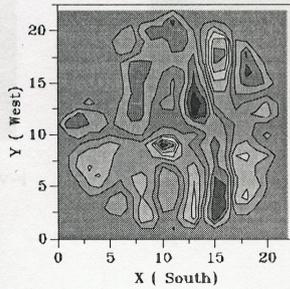


Average of frames MIR41 to MIR45-Surface:AQ



Mir46-Mir50: telescope now 1h west of zenith

Average of frames MIR46 to MIR50-Surface:RQ



Average of frames MIR46 to MIR50-Surface:AQ

