EUROPEAN SOUTHERN OBSERVATORY

VLT REPORT No. 61

VLT OPTICS
DESIGN OF COUDÉ OPTICS

WP:T170

Status: October 1990

Prepared by G. Avila, B. Delabre, D. Enard and F. Merkle

Very Large Telescope Project

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Contents

1 Introduction

Each unit telescope of the VLT will be equipped with a coudé focus. There are two symetrical optical trains: one for the visible and one for the infrared wavelength range. Both trains will be fed via the Nasmyth beams. A flat mirror will be placed infront the Nasmyth focus in order to deflect the beam into the coudé train.

Each coudé train consists of 5 mirrors: three flats and two concaves. The concave ones will be large off-axis ellipsoidal mirrors. If the manufacturing and the sensitivity for adjustments are too critical, there is an alternative solution with on-axis toroidal mirrors at expenses of a slight degradation of the image quality.

The last mirror in the train will be the deformable mirror for adaptive optics for real-time seeing compensation.

The light beams will be protected by metal tubes for shielding and baffelling. They are designed to withstand vacuum in case air turbulences would degrade seriously the optical transmission inside the tubes.

Some of the mirrors of the train will be equipped with translation and tilt actuators for alignment. Some of these movements may be remotely controlled.

Because of the large number of mirrors of the coudé trains, high efficiency coatings are mandatory.

The incoherent and coherent combined foci of the VLT will be fed via these coudé beams by introducing a flat dichroic mirror and deflecting the beam towards the combinnig optics trains.

2 Coudé Optics

The optics of the coudé trains is shown in the Figure 1. Only one of the two symetrical beams per telescope (visible and infrared) is represented. The second is symetrical with respect to the optical axis of the telescope. It is switched from one train to the other by rotation of the Nasmyth mirror M3 of the telescope.

In the coudé configuration, the Nasmyth focus is situated at 700 mm below of the M4 flat mirror. The M5 concave mirror will produce an intermediate image between M6 and M7 (Figure 1). This image shows a high degree of astigmatism and it will be accessible only for alignments purposes.

Table 1 shows the main specifications for the coudé focus.

Table 1: SPECIFICATIONS FOR THE COUDÉ FOCUS

F/#	F/49.9
Scale	1936μm/arcsec
Field of view	2 arcmin 232.3mm
Focal length	399m

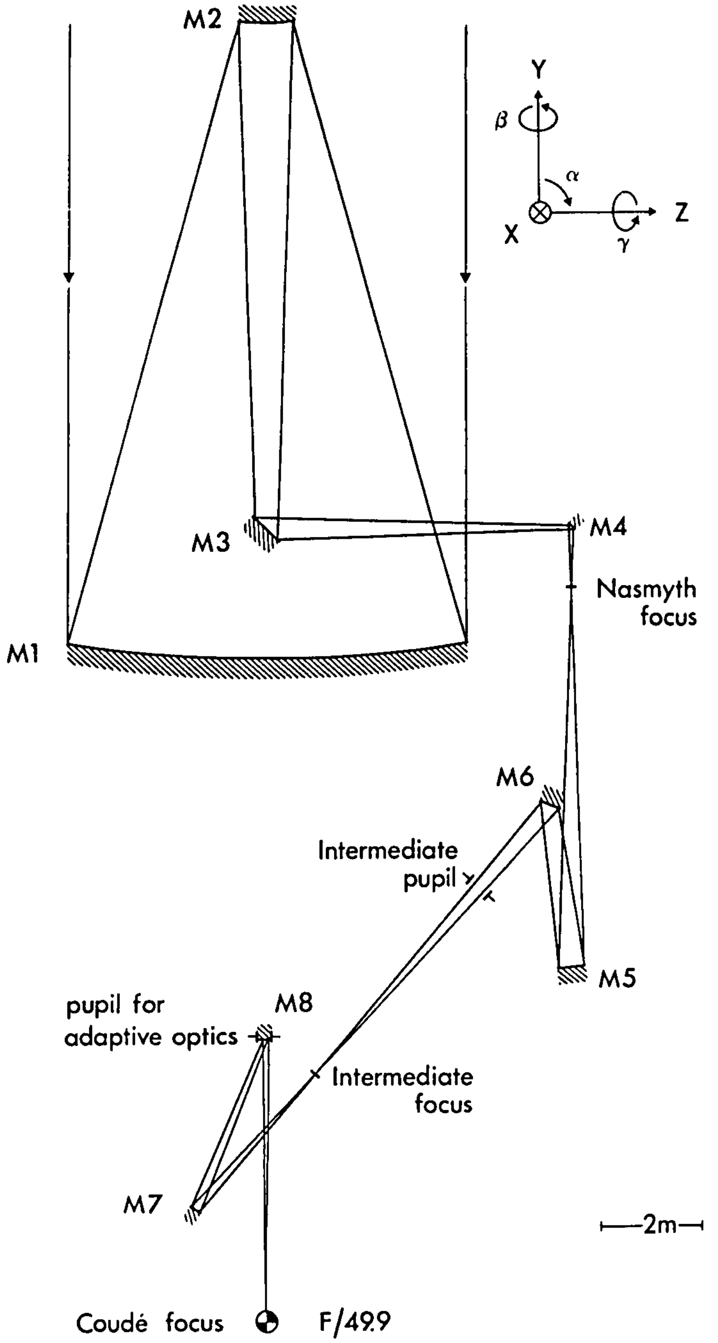

Figure 1: Optical lay-out of the coudé train

3 Foci and Pupils Location

3.1 Foci location

Table 2 gives the locations and characteristics of the Nasmyth, intermediate and coudé foci.

Table 2: FOCI LOCATION AND SPECIFICATIONS

FOCUS	LOCATION	F/#	SCALE ($\mu m/arcsec$)	PROJECTED FOV (2 arcmin)
Nasmyth	700mm below M4	F/15	582	69.84
Intermediate	7057mm from M6	F/19.5	757	91
Coudé	5556mm from M8 and 13060 below the center of M1	F/49.9	1936	232.3

3.2 Pupil location

The pupil is defined by the secondary mirror of the telescope, its intermediate image due to M5 is located between M6 and M7 at 2162 mm from M6 (Figure 1) and its diameter is 252 mm. The same as the intermediate foci, this intermediate pupil will be accessible only for alignment purposes. The exit pupil is located on M8 (the deformable mirror for adaptive optics) with a diameter of 110 mm.

4 Optical Quality of the Coudé Focus

The optical quality of the image at the coudé focus is given by the spot diagrams shown in the Figure 2 for a flat field. The astigmatism is pretty good corrected and only remains a small amount of residual coma.

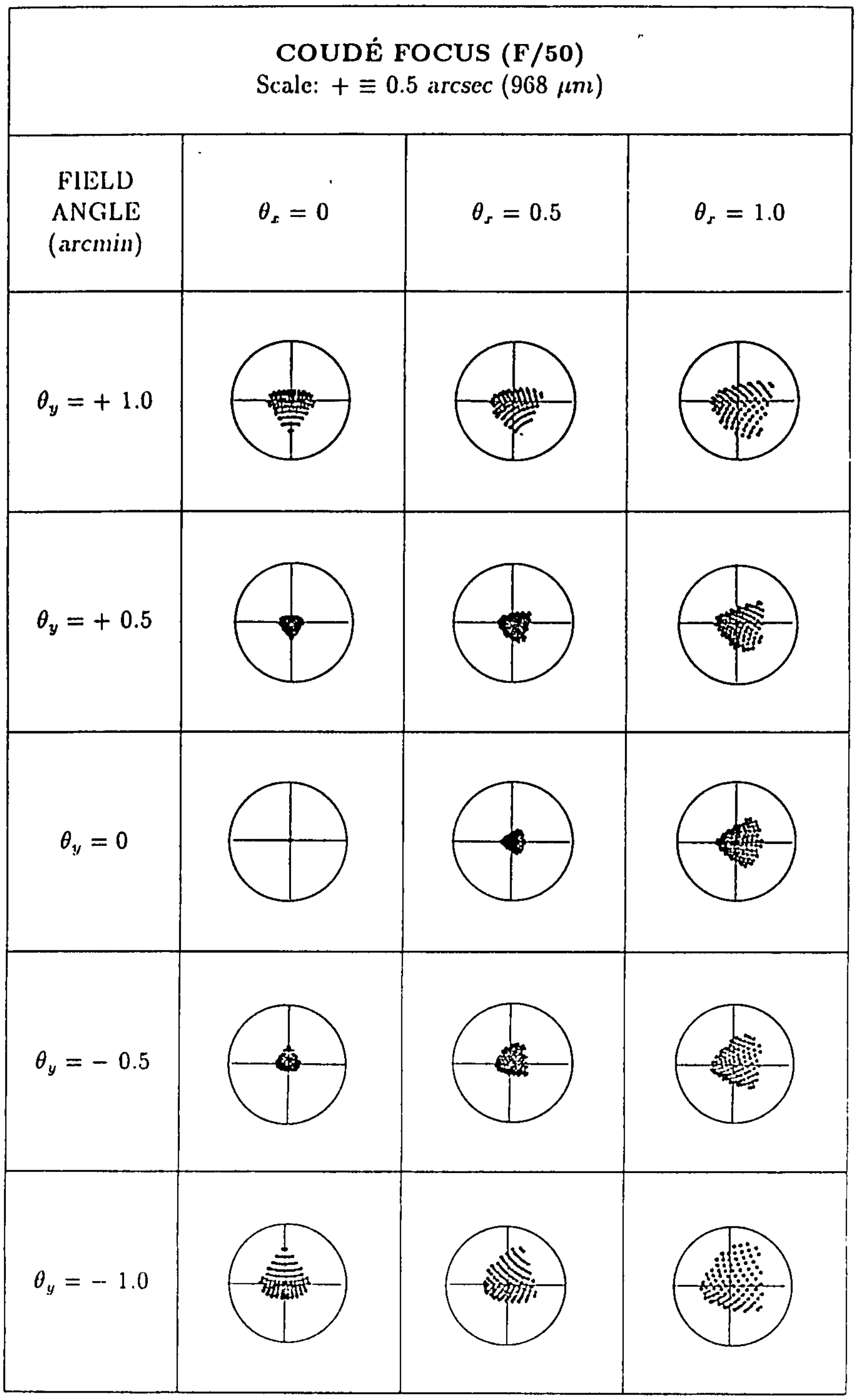

Figure 2: Spot diagrams at the coudé focus. M5 and M7 are on-axis elliptical mirrors.

5 Mirrors

Tables 3 and 4 summarizes general characteristics and specifications of the mirrors.

Table 3: OPTICAL DESIGN CHARACTERISTICS OF THE MIRRORS

MIR-ROR	SURFACE PROFILE	SIZE* (mm)	SHAPE	THICK. (mm)	MATE-RIAL	MASS (kg **)
M4	Flat	164 X 115	Elliptical	20	Zerodur	0.75
M5	Ellipsoidal or Toroidal	640	Circular	91	Zerodur	74
M6	Flat	450 X 405	Elliptical	61	Zerodur	22
M7	Ellipsoidal or Toroidal	350	Circular	50	Zerodur	12
M8	Flat (Adaptive)	118 X 115	Elliptical	≈ 1	Silica(?)	21g
*Useful areas **Diameter-thickness ratio = 7:1						

Table 4: COORDINATES AND TILTS OF THE MIRRORS

MIRROR	Z* (mm)	Y* (mm)	Tilt (deg)	Beam Incidence Angle (deg)	Distance center-center between two mirrors
M1	0	0	0	0	
M4	6100	2500	-135	45	M3-M4 6100
M5	6100	-6097	-3.99	3.99	M4-M5 8597
M6	5654	-2928	-163	25.0	M5-M6 3200
M7	-1446	-10815	32.8	9.21	M6-M7 10612
M8	0	-7503	-168.2	11.8	M7-M8 3614
Focus	0	-13060	-	0	M8-CF 5556
*The coordinate system is the same defined for the Telescope and described in §10 of the Design of Telescope Optics report, VLT Report No. 58 June 1989.					

5.1 M4 and M6 Flat Mirrors

The M4 mirror will be retractable: it will stay in park position out of the Nasmyth field-of-view when the Nasmyth focus is in operation. When the coudé focus is required, the mirror will be put in position on the optical axis to fold the beam 90° towards the coudé train. M4 is a small flat mirror which will be integrated in the adaptor at the Nasmyth focus.

M6 is a large flat mirror (450 × 405 mm useful dimensions). Because the mirror stays very close to the beam coming from M4, a special support system has been foreseen in order to avoid vignetting.

5.2 M5 Elliptical Mirror

Table 5 summarizes the main characteristics and specifications of the mirror.

Table 5: CHARACTERISTICS OF THE M5 ELLIPTICAL MIRROR

Useful diameter	640 mm
Radius of curvature (primary)	8880 mm
Conic constant (primary)	-0.0216934

5.3 M7 Elliptical Mirror

Table 6 summarizes the main Characteristics and specifications of the mirror.

Table 6: CHARACTERISTICS OF THE M7 ELLIPTICAL MIRROR

Useful diameter	350 mm
Radius of curvature (primary)	-4990 mm
Conic constant (primary)	-0.214687

5.4 Mirror M8 (Deformable Mirror for Adaptive Optics)

This mirror together with a wave sensor located at the coudé focus and a control unit, will provide compensation for atmospheric turbulence on the incoming wavefront. There will be also equivalent flat mirrors for both coudé trains when the adaptive mirror is not in operation.

Table 7 summarizes the main characteristics and specifications of the mirror.

Table 7: OPTICAL DESIGN CHARACTERISTICS OF THE M8 MIRROR

Useful diameter	118 × 115 mm
Number of actuators	≈ 250
Stroke per actuator	$\approx \pm 5\mu m$

6 Alternative solution with toroidal mirrors

There exists an alternative design with toroidal mirrors which can replace the elliptical ones in case of major manufacturing difficulties.

The optical quality of the image at the Coudé focus is illustrated by the spot diagrams of Figure 3. The astigmatism is only partially compensated. Nevertheless, it is interesting to note that the image quality can much improve if the image plane is tilted with respect to the optical axis of 26° (Figure 4). This tilt angle is the sum of all off-axis angles of the beam.

Tables 8 and 9 summarizes the main characteristics and specifications of the M5 and M7 toroidal mirrors.

Table 8: CHARACTERISTICS OF THE M5 TOROIDAL MIRROR

Useful diameter	640 mm
Radius of curvature R_y*	8900 mm
Radius of curvature R_x**	8943.5 mm
* R_y on the figure plan ** R_x on the perpendicular plan	

Table 9: CHARACTERISTICS OF THE M7 TOROIDAL MIRROR

Useful diameter	350 mm
Radius of curvature R_y*	-5050.00 mm
Radius of curvature R_x**	-5182.45 mm
*R_y on the figure plan **R_x on the perpendicular plan	

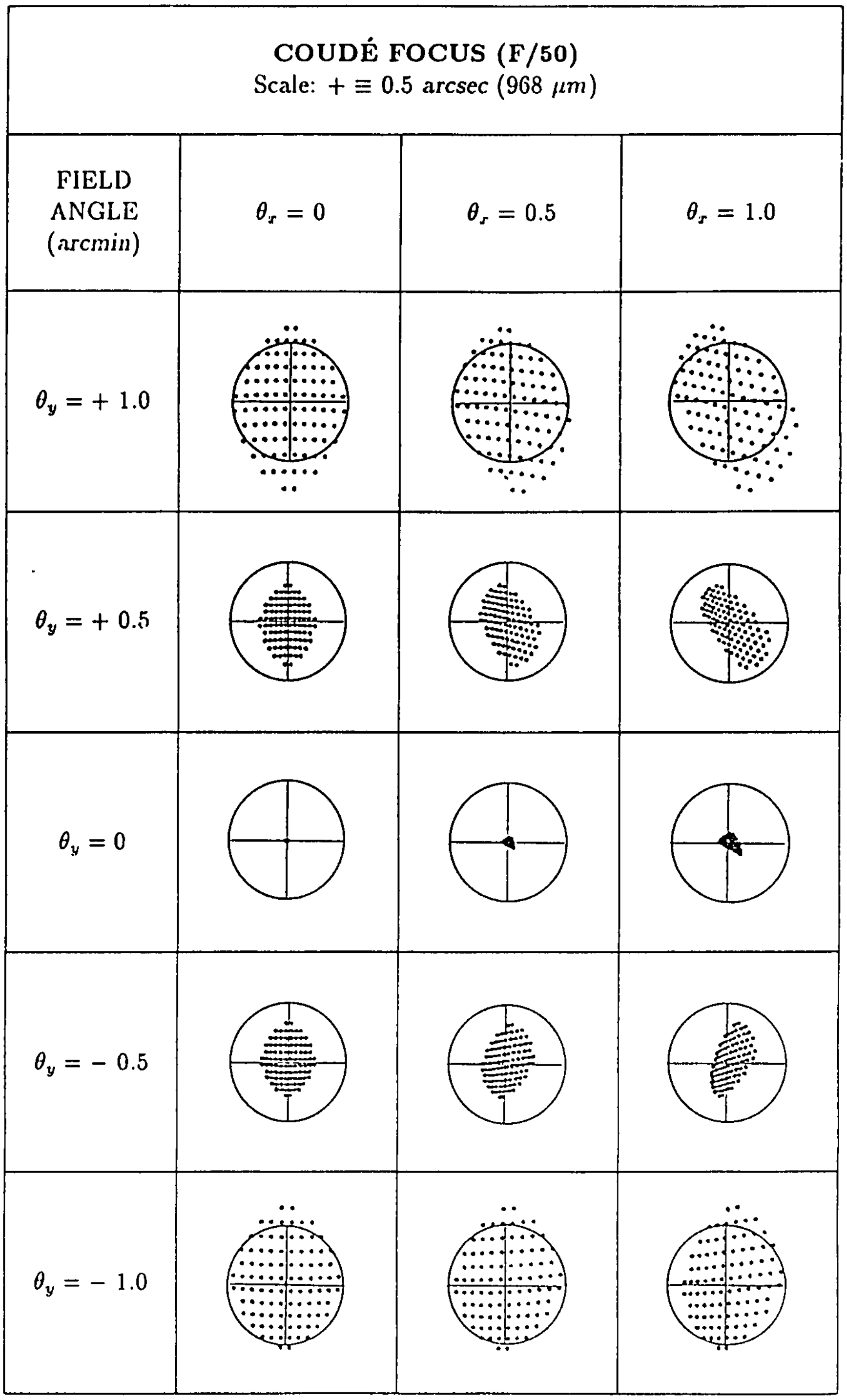

Figure 3: Spot diagrams at the coudé focus. M5 and M7 are on-axis toroidal mirrors. The image plane is perpendicular with respect to the optical axis.

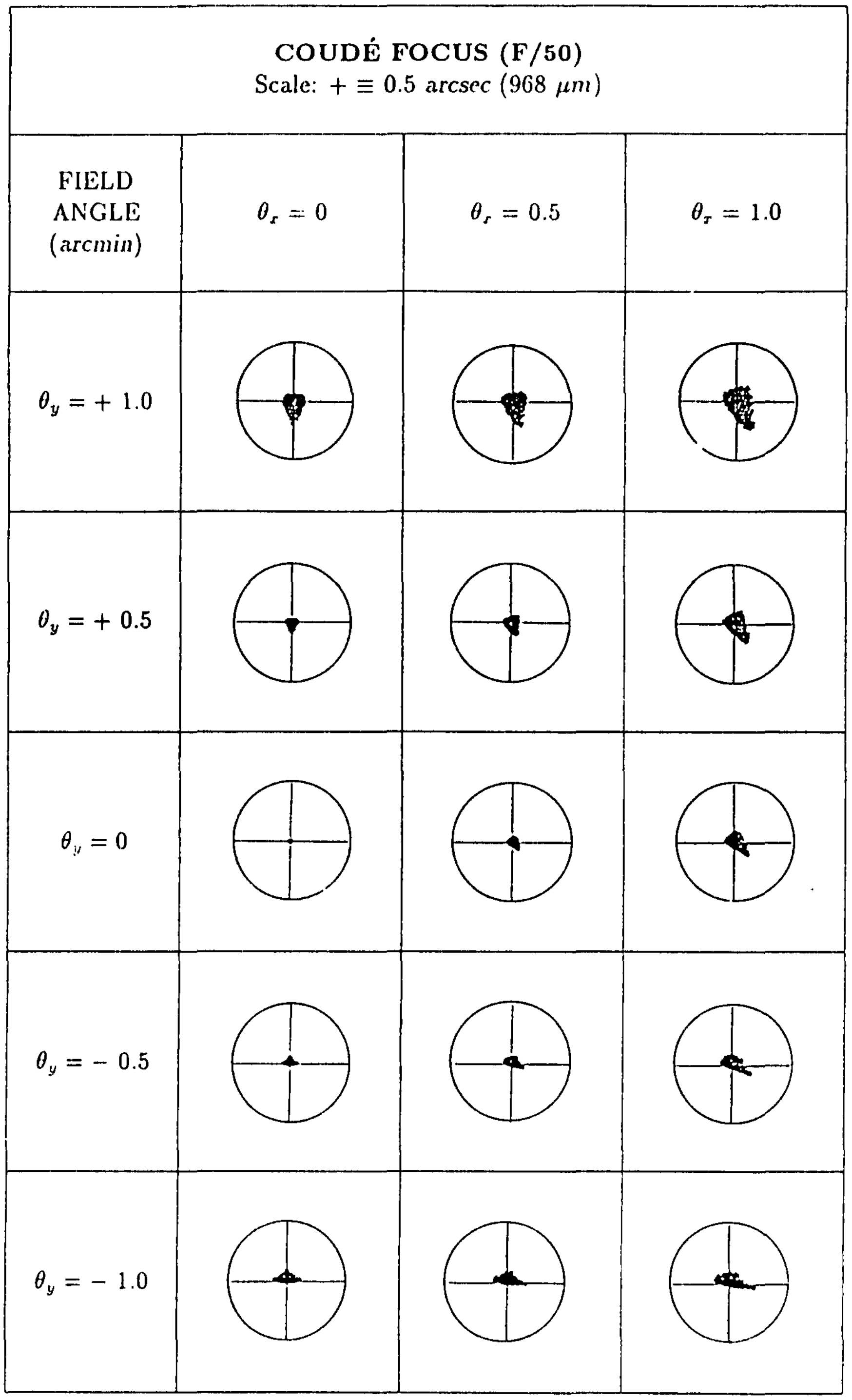

Figure 4: Spot diagrams at the coudé focus. M5 and M7 are on-axis toroidal mirrors. The image plane is tilted of 26^o with respect to the optical axis.

7 Sensitivity of the Coudé Image

The sensitivity of the optical system with respect to tilts and displacements of the individual components is given in Table 10. The same coordinate system as for the telescopes will be applied. $d\alpha, d\beta$ and $d\gamma$ are the mirror tilts (in armin) around the x, y and z axis respectively, dx, dy and dz the mirror displacement (in mm). The coordinate system is indicated in Figure 1.

Table 10: SENSITIVITY OF THE COUDÉ IMAGE

	MIRROR						IMAGE		
	Tilt (arcmin)			Displacement (mm)			Displacement (mm)		Defocusing (mm)
	$d\alpha$	$d\beta$	$d\gamma$	dy	dx	dz	dz	dx	dy
M1	+1						-233		
			+1					-233	
				+1					+765
					+1			-27.7	
						+1	-27.7		
M2	+1						+32.4		
			+1					+32.4	
				+1					-777
					+1			-24.4	
						+1	+24.4		
M3	+1						-13.2		
		+1						+6.6	
			+1					-6.5	
				+1			+3.33		+11.1
						+1	+3.33		+11.1
M4	+1						-1.35		
		+1						-0.66	
			+1					+0.65	
				+1			-3.34		+12.80
						+1	+3.44		-12.74
M5	+1						-15.7		
		+1						+1.1	
			+1					+15.6	
				+1			-0.14		-17.76
					+1			-5.92	
						+1	-5.90		+2.51
M6	+1						+10.8		
		+1						+5.3	
			+1					+8.2	
					+1		-1.83		+10.8
						+1	+1.18		-6.96
M7	+1						+5.43		
		+1						+4.18	
			+1					-3.36	
				+1			-2.59		-4.81
					+1			+3.58	
						+1	+2.41		-5.98
M8	+1						-3.3		
		+1						-0.67	
			+1					+3.16	
				+1			-0.4		+1.92
						+1	-0.4		+0.08

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