TRSS: A Three Reflection Sky Survey at Dome-C with active optics modified-Rumsey telescope

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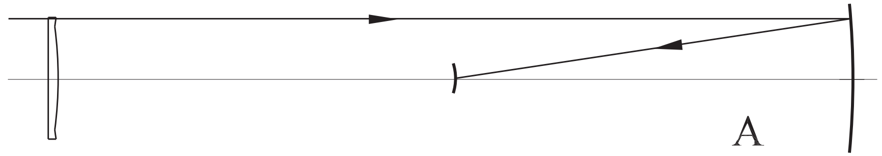
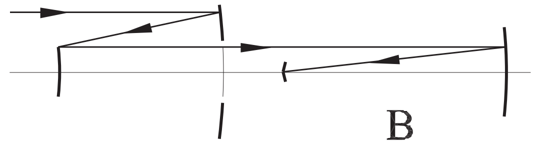
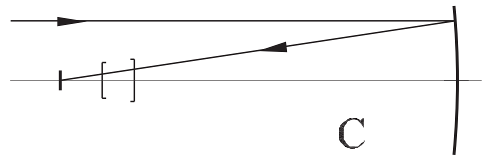
1. Comparison of Wide Field Telescopes for Astronomical Surveys



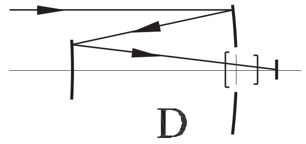
(**A**) Schmidt with refractive corrector - convex FOV,
1 aspheric, length $\simeq 2F$, **3 polished surfaces**.



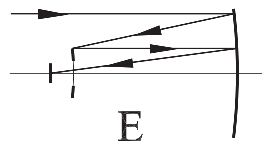
(**B**) Mersenne-Schmidt by Willstrop - concave FOV,
2 aspherics, length $\simeq F$, **3 polished surfaces**.



(**C**) Paraboloid and triplet-lens corrector - flat FOV,
1 aspheric, length $= F$, **7 polished surfaces**.



(**D**) Ritchey-Chrétien + doublet corrector - flat FOV,
2 aspherics, length $\simeq F/2$, **6 polished surfaces**.



(**E**) Modified-Rumsey continuous M1-M3 - flat FOV,
3 aspherics, length $\simeq F/2$, **2 polished surfaces**.

Fig. 1 - Telescopes with identical input beam aperture, focal length and field of view.

EXISTING SURVEY TELESCOPES :

- SDSS - Sloan Digital Sky Survey : Design (**D**) = 6 opt. surf., $d_1 = 2.5$ m, f/5, FOV $2.0 \times 1.5°$.
- VST - VLT Survey Telescope : Design (**D**) = 6 opt. surf., $d_1 = 2.6$ m, f/5, FOV $1.0 \times 1.0°$.
- CFHT with Megacam : Design (**C**) = 7 opt. surf., $d_1 = 3.6$ m, f/4, FOV $1.0 \times 1.0°$.
- Converted-MMT + Megacam : Design (**D'**) = 6 opt. surf., $d_1 = 6.5$ m, f/5, FOV $0.5 \times 0.5°$.

PRESENTLY PROPOSED SURVEY TELESCOPE :

→ Design (**E**) = 2 opt. surf. to polish

→ R&T results of a prototype : MINITRUST

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2. Optical Design of a Modified-Rumsey : MiniTrust-1 and -2

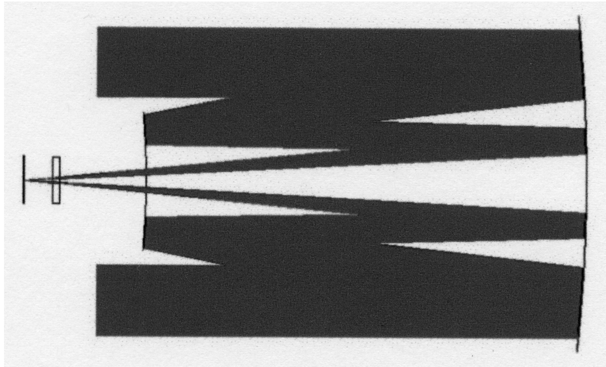


Fig. 2 - Optical scheme (on-axis beams).

Table 1. MiniTrust optical design – Aperture 450 mm – f/5 – 1.5 × 1.5° FOV – λλ [380 - 900 nm]

Surface	R	z	A_4	A_6	Clear Aperture	(κ ($\star$))
Primary	-2208.0	-630.000	$6.3905\,10^{-12}$	$3.1327\,10^{-19}$	450	(-1.5503)
Secondary	-1096.0	630.005	$2.7995\,10^{-10}$	$-2.4184\,10^{-16}$	Stop 200	(-3.9485)
Tertiary	-2197.2	-763.403	$7.5810\,10^{-11}$	$-6.9152\,10^{-17}$	180	(-7.4332)
Filter +	∞	-10.000			59×59	
fused silica	∞	-25.000			58×58	
Focus	∞				56×56	

Mirrors : $z = (1/2R)\,r^2 + A_4 r^4 + A_6 r^6$. ($\star$) Equivalent conic constant ($\kappa = -1$ paraboloid).

Sag and slope continuities of M_1 - M_3 at $d_{3\,max} = d_{1\,min} = 180$ mm. Dimensions: [mm]

Barr = 20μm

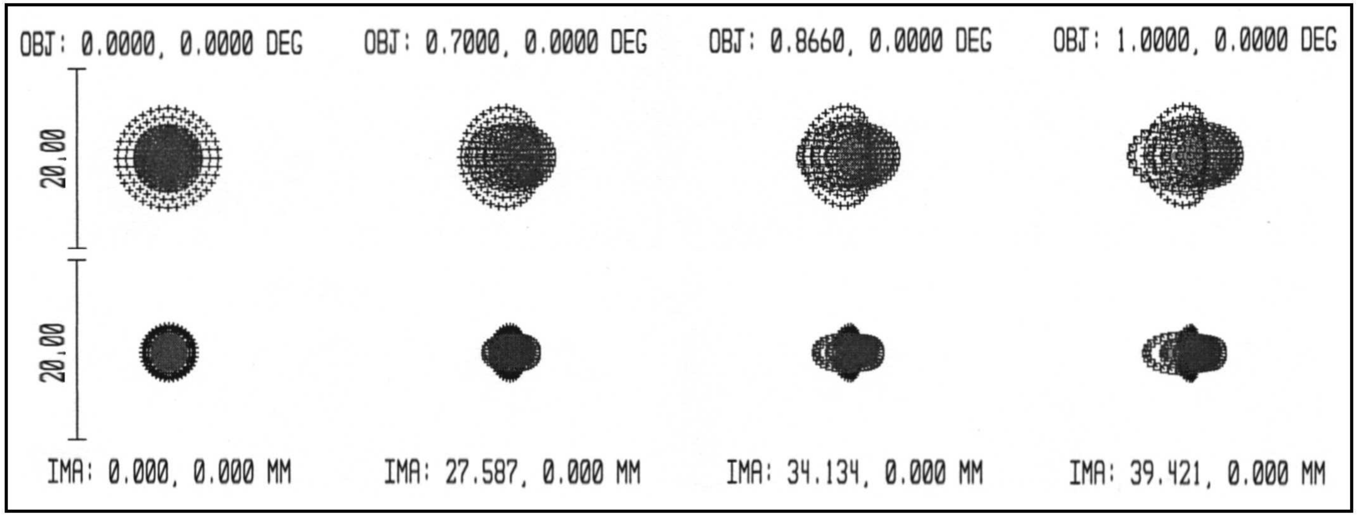


Fig. 3 - RESIDUAL BLUR IMAGES from Table 1 parameters (2° diagonal FOV).

(*Up*) Thickness of (filter + detector window) = 10 mm. RMS diameter of blur images $\leq 9\,\mu$m.

(*Down*) Thickness of (filter + detector window) = 5 mm. RMS diameter of blur images $\leq 5\,\mu$m .

$\rightarrow$ Sphero-chromatism of (filter + detector window) dominating.

3. Active Optics Methods

Advantages of Active Optics :

→ **generate smooth** and **accurate** optical surfaces with elastic linear materials (Hooke's law).

→ **avoid the slope discontinuities** of the optical surface i.e. cancels the high spacial frequency errors.
(inherent to local polishing tools)

→ **generate non-axisymmetrical** and **variable-shape** optics.[1,2]
(vase form, meniscus form, tulip form, cycloid-like form, ...)

→ **provide optics of the highest intrinsic quality**, then recommended for a site with excellent seeing.

FIELD DEVELOPMENTS OF ACTIVE OPTICS :

1 - Large amplitude aspherization of optics by **stress polishing** and/or by **in situ stressing**.

Stress polishing → Schmidt plates, Keck segments, Cassegrain secondaries (THEMIS), etc
In situ stressing i.e. aspherization at the telescope → (M_2-TEMOS, M_1-segments LAMOST)

2 - **In situ compensation** of large telescope mirrors due their deflection in field gravity (M_2-CFHT, M_1-VLT).

3 - **Variable asphericity mirrors** for multi-focii telescopes selected by focus interchange (VLT Cass.–Nasmyth).

4 - **Variable curvature mirrors** for field compensation and cophasing of optical telescope arrays (VLTI, GI2T).

5 - Segments and diffraction gratings aspherized by **replication techniques** from **active submasters**.

Aspherized gratings of many spectrographs (SOHO MISSION, OSIRIS OBSERVER)

6 - Mirror **concept** with the superposition capability of aberration modes for **adaptive optics systems.**

4. Vase Form Mirrors and the Theory of Shells

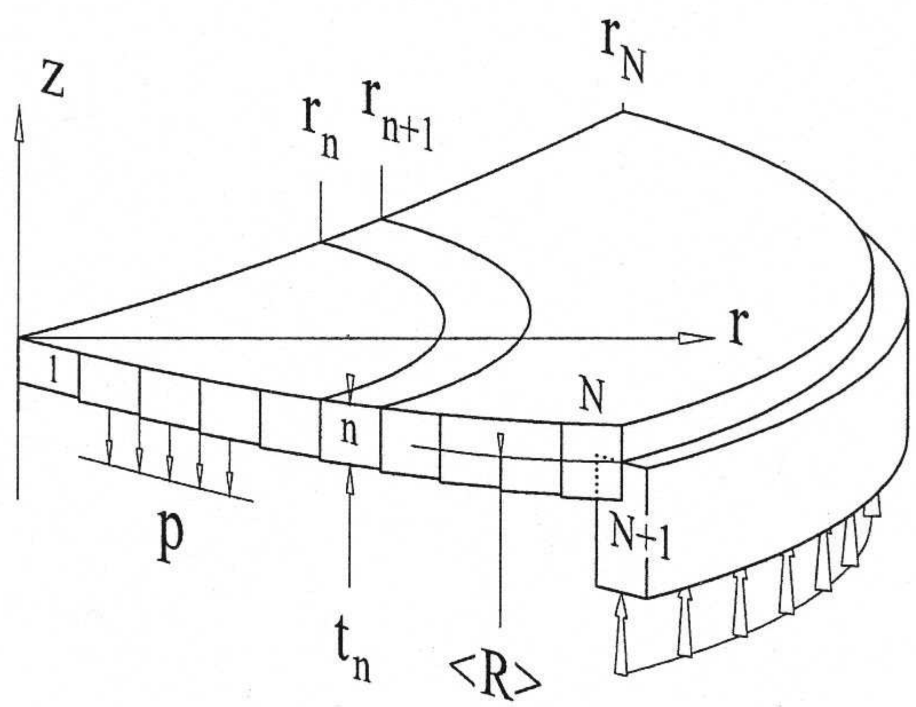


Fig. 4 - THEORY OF SHELLS: Geometrical parameters of element rings.

$$z_{\text{Optic}} = z_{\text{Sphere}} + z_{\text{Flexure}}$$

UNKNOWNS : z_{Sphere}, z_{Flexure}, $t\,(r)$ and p .

5. Elasticity Design of MiniTrust M_1-M_3 Substrate

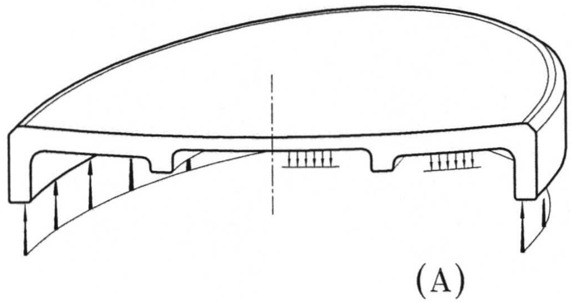
Table 2 - Thickness distribution $t(r)$ of M_1 - M_3 substrate - DOUBLE VASE FORM.

Zerodur : $\nu = 0.240$, $E = 920\,10^3\,\text{kgf/cm}^2$. Load $p = -0.8\,\text{kgf/cm}^2$. Dimensions [mm]

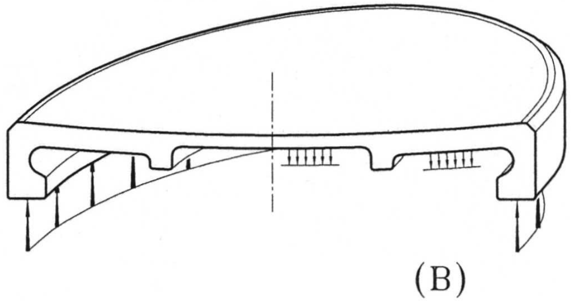
r	0	18	36	45	54	63	72	81	90^-	
$t(r)$	12.042	12.044	12.053	12.061	12.070	12.082	12.096	12.112	12.130	
r	90	110	110^+	132	154	176	198	220^-	220	240
$t(r)$	30.190	30.183	20.317	20.402	20.502	20.617	20.741	20.868	68	68

Fig. 5 - ALTERNATIVE GEOMETRIES for M_1 - M_3.

Design **A** : with cylindric outer ring



Design **B** : with L-shaped outer ring



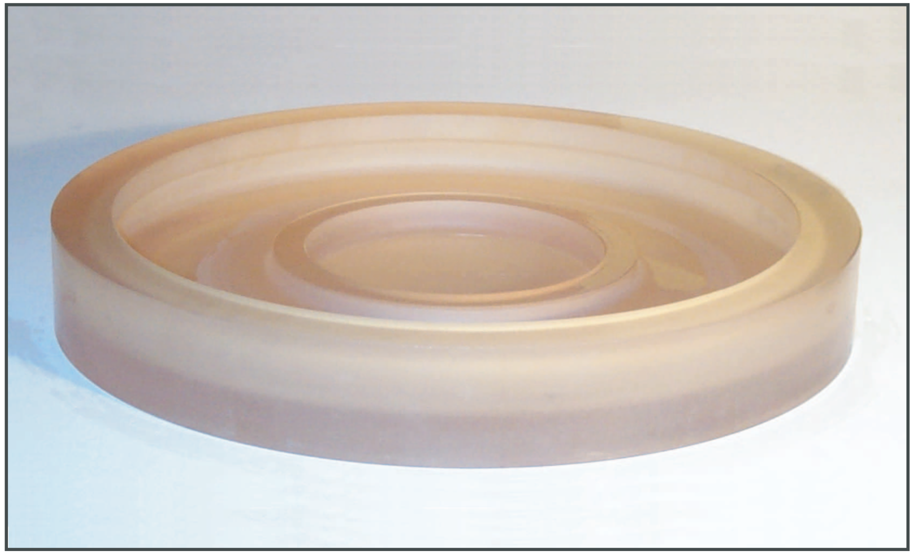


Fig. 6 - REAR VIEW OF M_1-M_3 SUBSTRATE.

Fig. 7 - IN-SITU STRESSING - He-Ne Fizeau interferograms of M_1 and M_3.

Autocollimations achieved at $\sqrt{3}/2$ of clear aperture radius r_{max} with respect to a sphere. Aperture radii: $r_{1max} = 220$ and $r_{3max} = 90$ mm. From M_1 interferogram, the source is moved of 13.32 mm towards the substrate to get M_3 interferogram.

6. Elasticity Design of M_2 Substrate by Stress Polishing

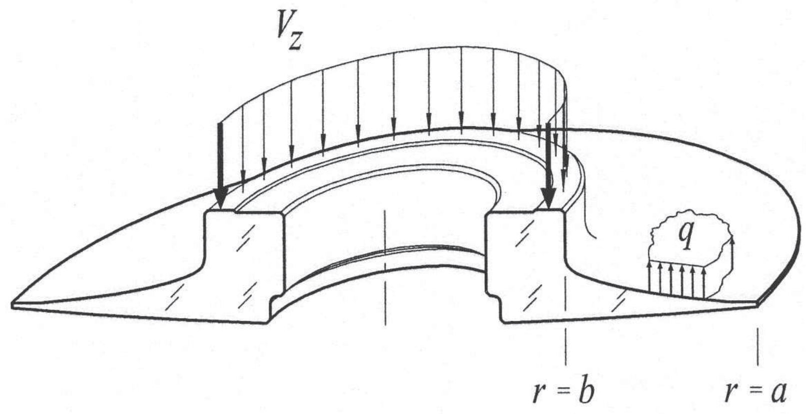


Fig. 8 - TULIP FORM elasticity design of M_2 substrate.

Table 3 - Thickness distribution $t(r)$ of M_2 substrate – TULIP FORM.

Zerodur : $\nu = 0.240$, $E = 920\,10^3\,\mathrm{kgf/cm^2}$. Load $p = -0.8\,\mathrm{kgf/cm^2}$. Dimensions [mm]

Clear aperture radii $50 \leq r \leq 100$. Outer edge $r_{\mathrm{ext}} = 103$. Stress $\sigma_{max} = 64\,\mathrm{kgf/cm^2}$.

r	30	50	50^+	60	70	80	85	90	95	100	103
$t(r)$	32.000	31.273	14.343	9.997	7.108	4.896	3.926	2.999	2.069	1.042	0.308
z_B (⋆)			9.318	5.471	3.173	1.641	1.044	0.512	0.200	0.000	0.000

(⋆) z_B represents the shape of rear surface when not stressed. This surface ends flat at the edge.

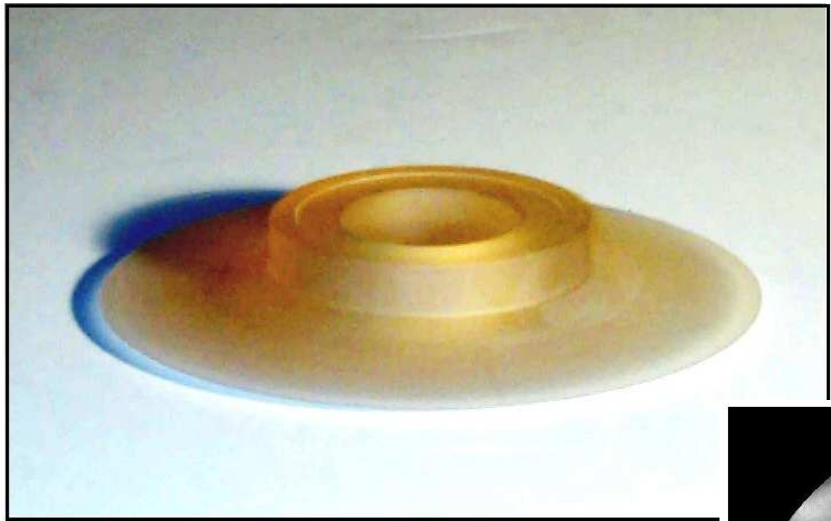


Fig. 9 - Rear View of M_2 Mirror.

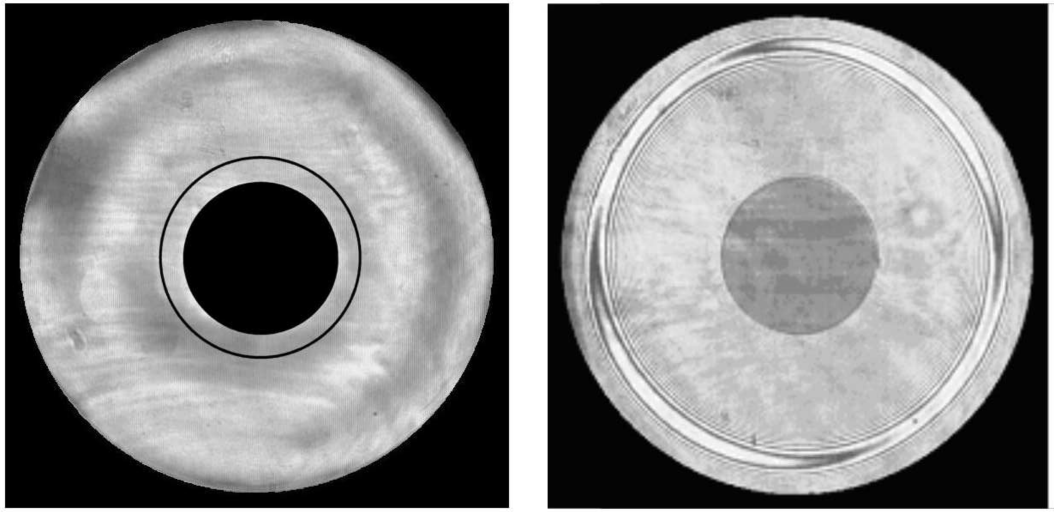


Fig. 10 - Stress Polishing - He-Ne Fizeau interferograms.

[*Left*] Mirror shape during stressing.

[*Right*] Shape after elastic relaxation.

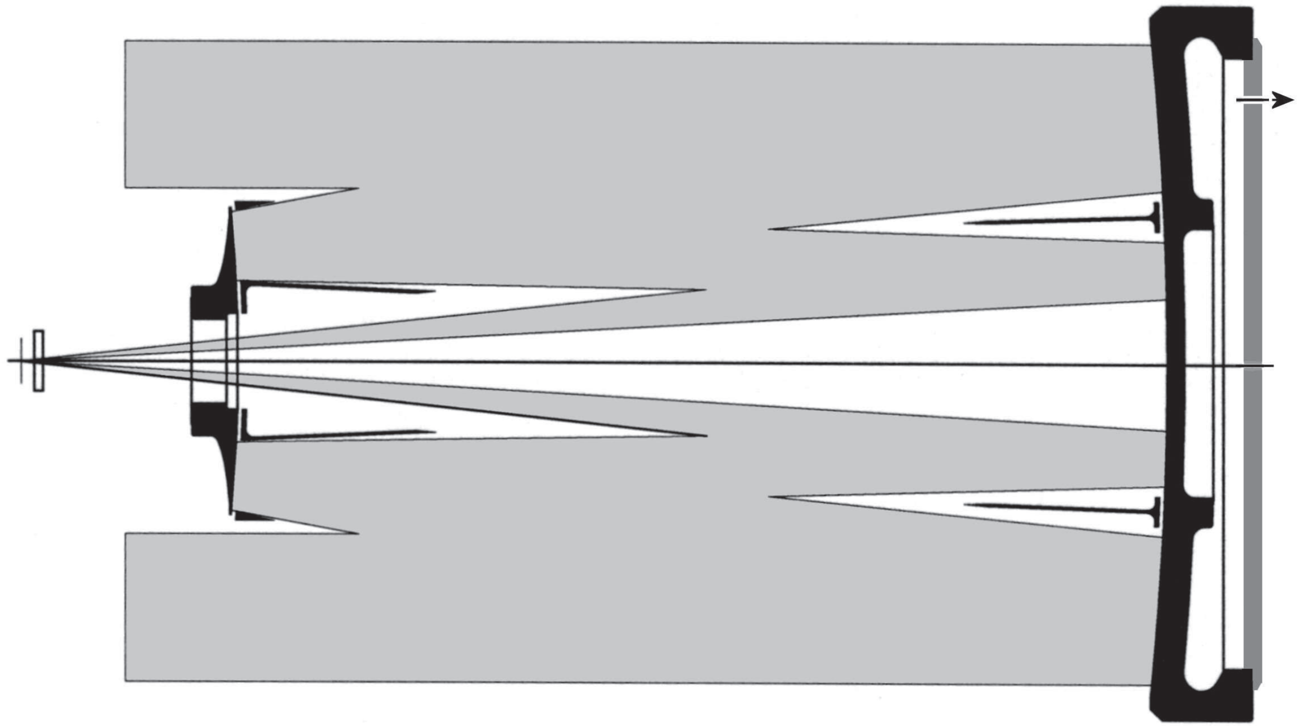


Fig. 11 - MiniTrust Final Design.

Entrance pupil on M_2 - Substrates - On-axis beam - Baffles.

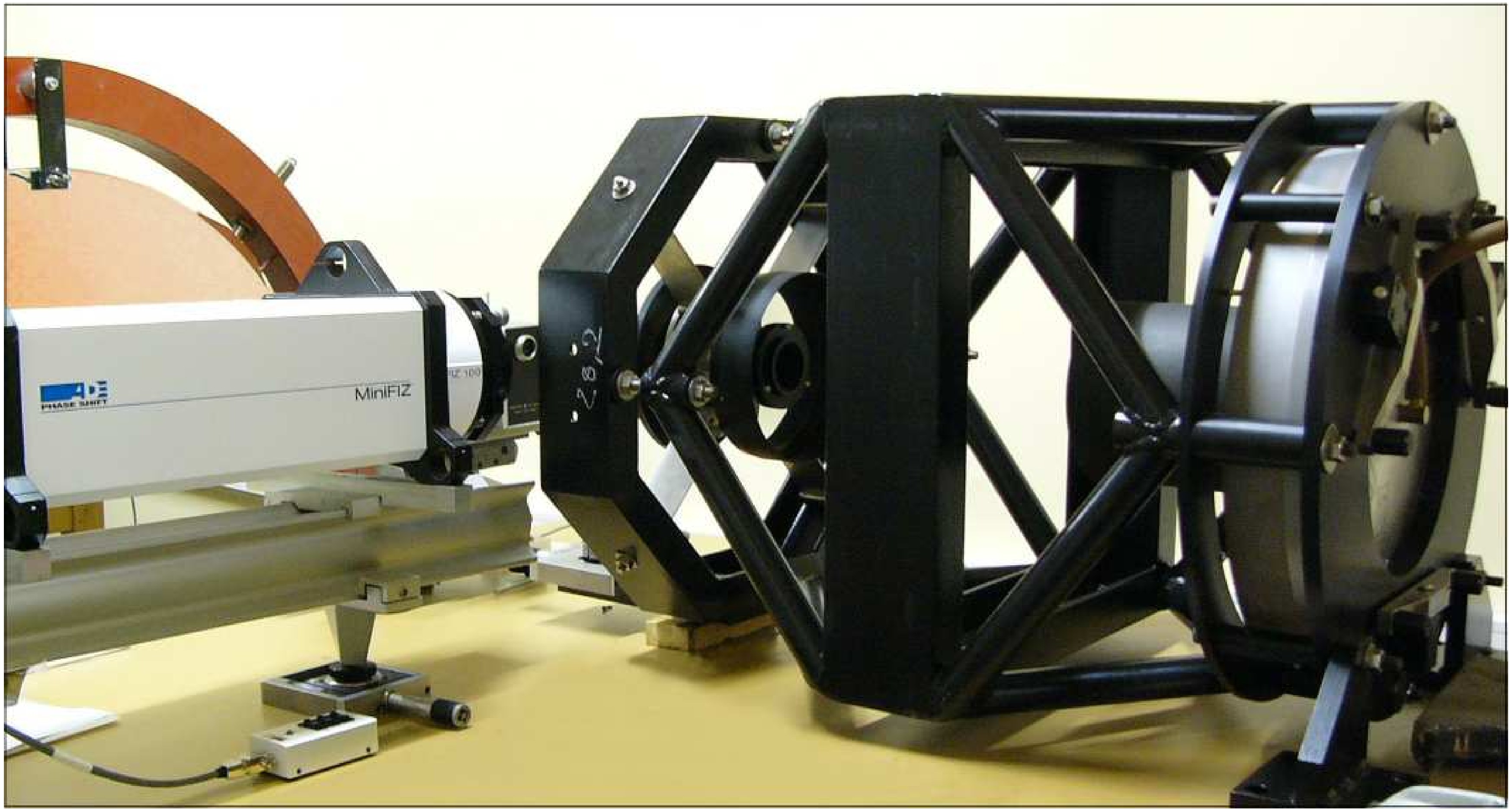


Fig. 12 - VIEW OF MINITRUST-1.

Alignment and double-pass testing by auto-collimation on a plane mirror.

7. Interferometric Results from MiniTrust-1 Integration

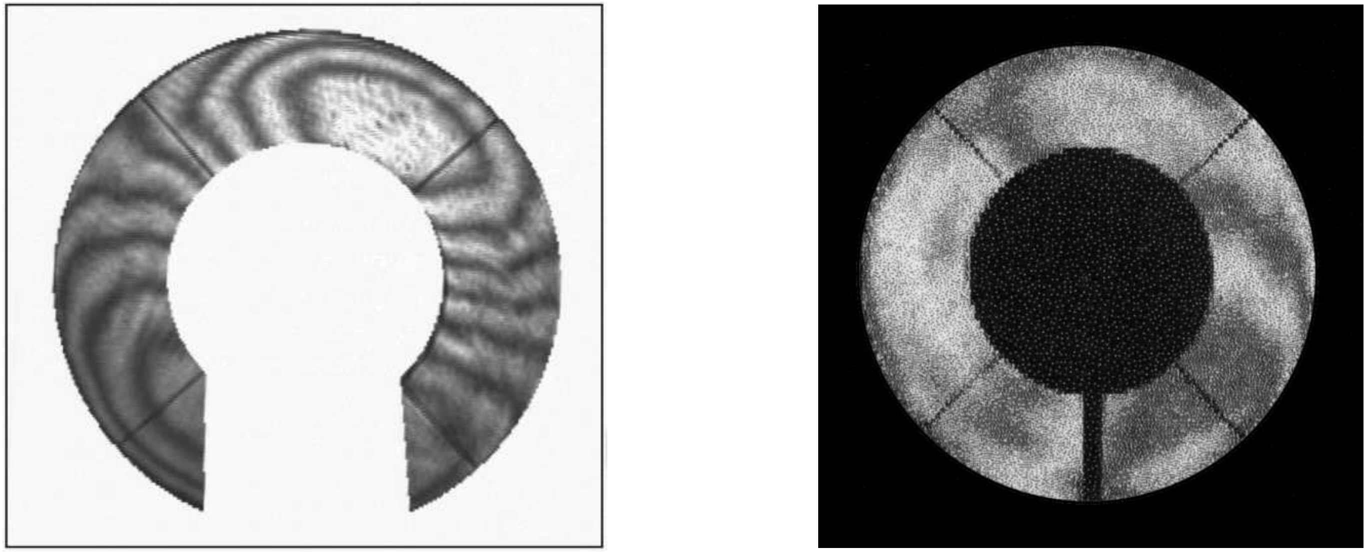


Fig. 13 - MINITRUST-1 OPTICAL TESTS: He-Ne wavefronts after double pass.
Left: Decentering coma before M_2 set up. *Right*: Wavefront after M_2 set up.

FINAL DATA REDUCTION FROM MINIFIZ PHASE-SHIFT INTERFEROMETER.

Residual PtV onto the wavefront issued from double pass:

$$Sphe\,3 = 0.06\,\lambda, \quad Coma\,3 = 0.07\,\lambda, \quad Astm\,3 = 0.42\,\lambda.$$

Must be divided by two for a wavefront from a star $\rightarrow$ Sum including all aberrations:

$$\mathbf{0.280}\,\lambda_{\mathrm{He-He}}\ \mathbf{PtV} \quad \Leftrightarrow \quad \mathbf{0.048}\,\lambda_{\mathrm{He-Ne}}\ \mathbf{RMS.}$$

8. TRSS Proposal : A Three Reflection Sky Survey at DOME C

2-Meter Modified-Rumsey Telescope – f/ 5 – 2° diagonal FOV

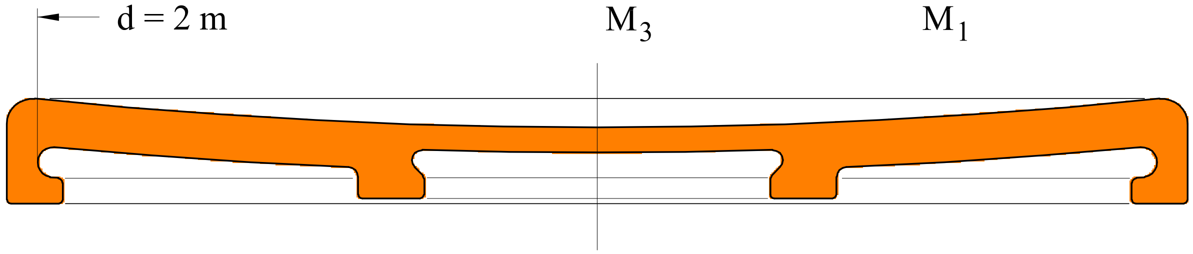


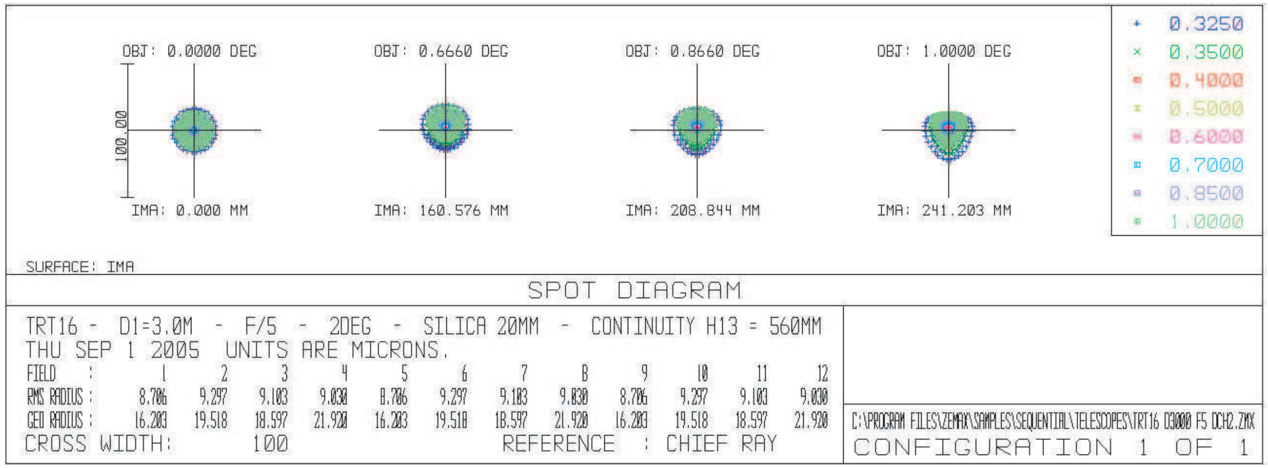
Fig. 14 - Elasticity Design of M_1 - M_3 Substrate

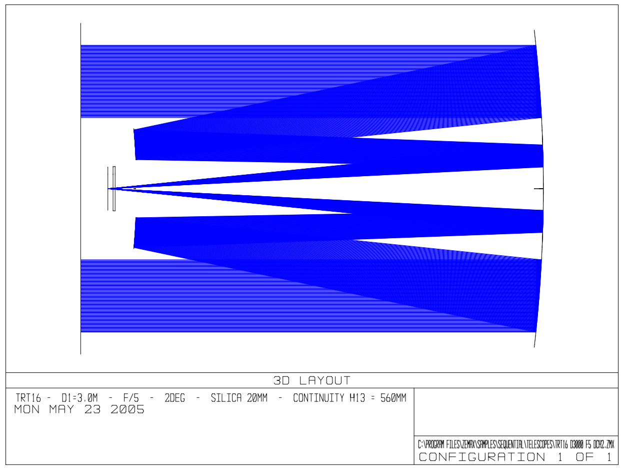
Table 4 - Optical design of a 3-Meter Modified-Rumsey Telescope.

f/5 – 2° diagonal FOV – $\lambda\lambda\,[300 - 1000\,\text{nm}]$ – M_1-M_2 continuity of slopes and sags at $r = 560$ mm.

Surface	R	z	A_4	A_6	Clear Aperture	(κ)
Primary	-13298.8	-3936.356	$2.4238\,10^{-14}$	$5.674\,10^{-23}$	3000	(-1.452)
Secondary	-6577.6	3936.398	$1.4074\,10^{-12}$	$-3.208\,10^{-20}$	Stop 1140	(-4.204)
Tertiary	-13204.3	-4142.356	$4.5446\,10^{-13}$	$-5.116\,10^{-21}$	1100	(-9.370)
Filter +	∞	-20.000			348×348	
window	∞	-50.000			346×346	
Focus	∞				341×341	

Equation of mirrors: $z = (1/2R)\,r^2 + A_4\,r^4 + A_6\,r^6$. Dimensions: [mm]





RMS diameter of blur images : 18 μm $\equiv$ **0.25 arcsec** $\rightarrow$ **excellent site**

9. Conclusions with a TRSS Telescope

Telescope features: → **compact, minimum number of optical surfaces (3)**

Telescope throughput: → **optical coatings of only 2 surfaces**

Completely achromatic: → **superiority in image quality from UV to IR,**
RMS blur images = 1/4 arcsec = Excellent Site

Telescope optics set up: → **no off-centering of M_3 with M_1**

Supporting of optics: → **perimeter points of M_1-M_3 substrate on M_3 edge**

Gravity compensation: → **small uniform load all over M_1-M_3 substrate**

Active optics aspherization: → **all optics with only 2 spherically polished surfaces,**
i.e. Minimum Cost

→ **the best intrinsic image quality**

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