Hot Press Direct Slumping: an option to manufacture deformable optics

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Outline of the talk

- Brief overview of next giant telescopes

- The conventional technique for adaptive secondary mirror production

- A possible new technique: the Hot Press Direct Slumping concept

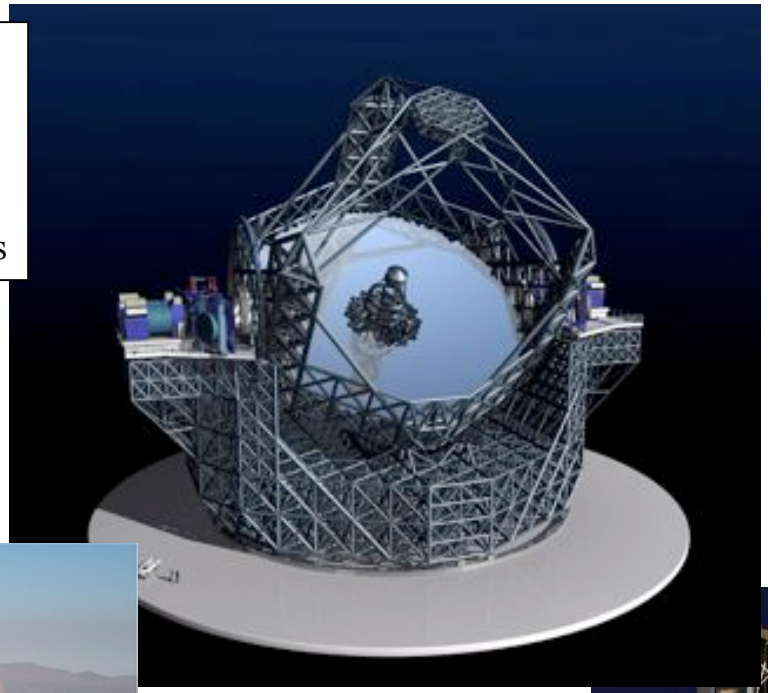
- Some problems related to slumping

- The state of the art:
  - tests on small diameter glass sheets
  - tests on 500 mm diameter glass sheets

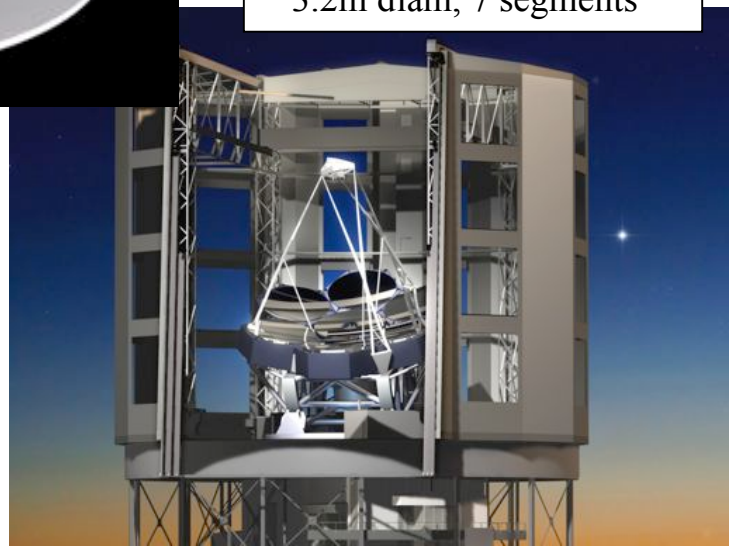
- Future work

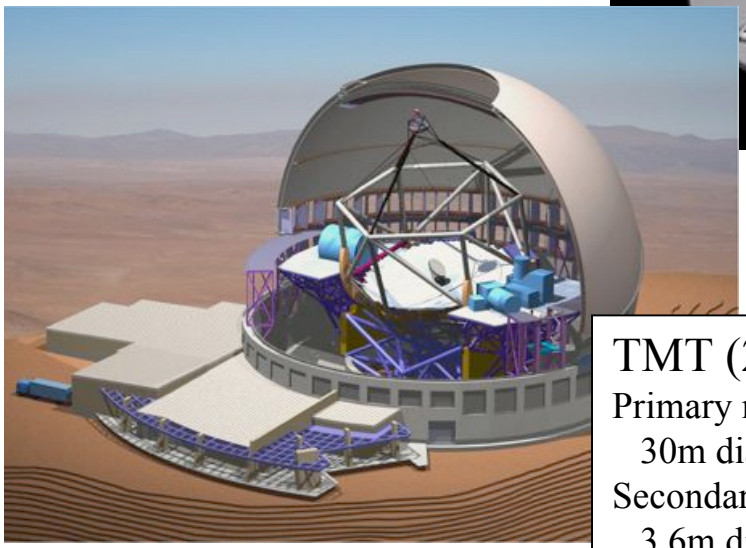
Future optical telescopes, ELT class

E-ELT (2017)
Primary mirror:
42m diam, 908 act. segments
Secondary mirror:
4.5m diam, 9 adaptive segments



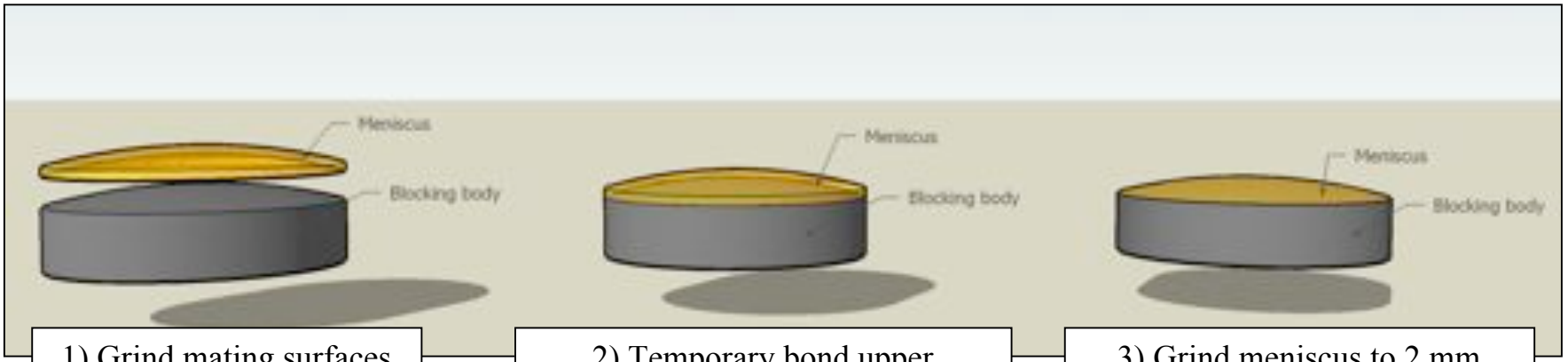
GMT (2016)
Primary mirror:
25m diam, 7act. segments
Secondary mirror:
3.2m diam, 7 segments





TMT (2015)
Primary mirror:
30m diam, 738 act. segments
Secondary mirror:
3.6m diam, adaptive

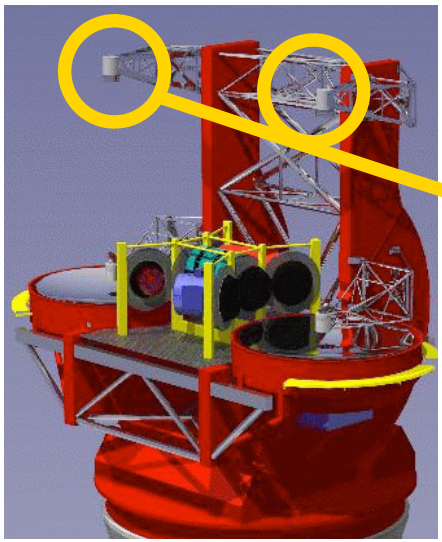
Conventional technique for ASM production



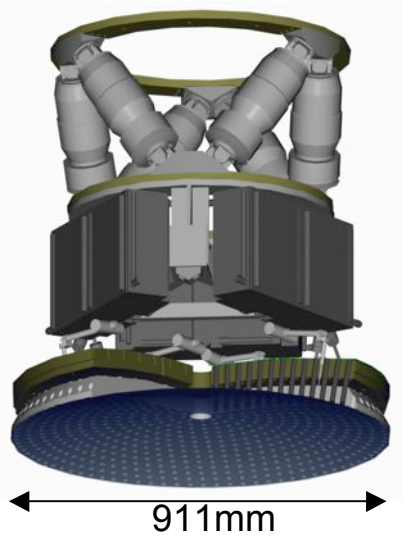
1) Grind mating surfaces to matching curvature

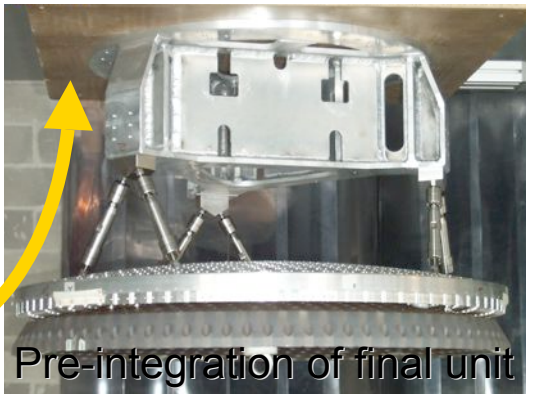
2) Temporary bond upper meniscus to lower blocking body

3) Grind meniscus to 2 mm thickness and polish



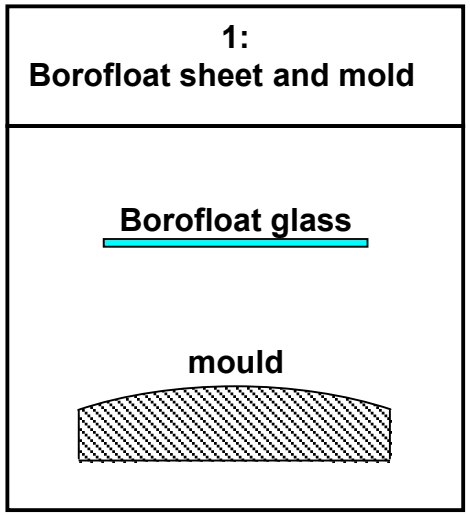
LBT (2 units):
ϕ = 911 mm
τ = 1.6 mm

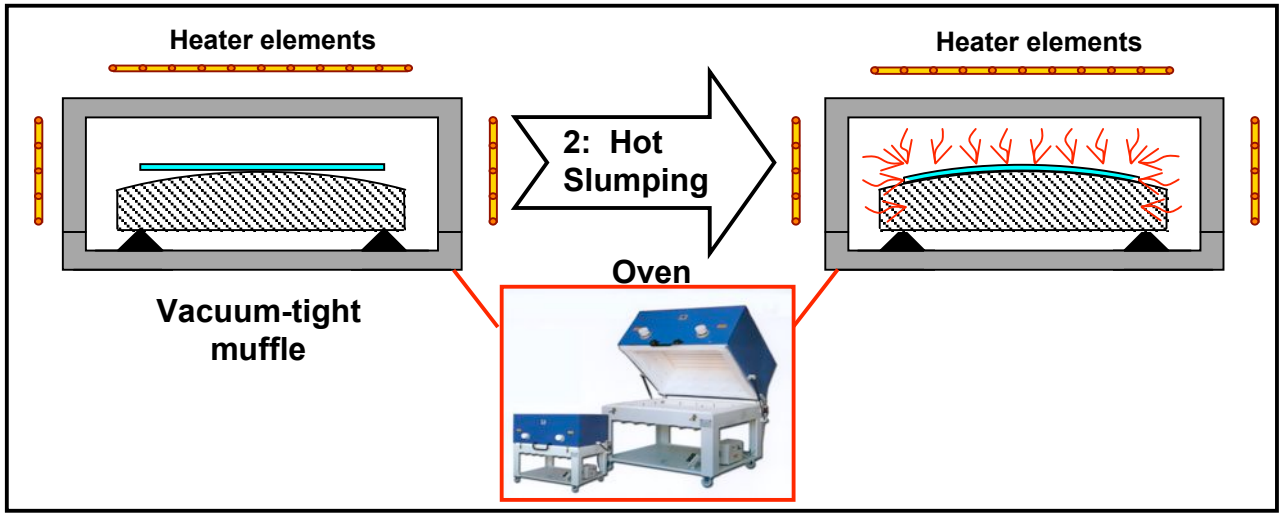


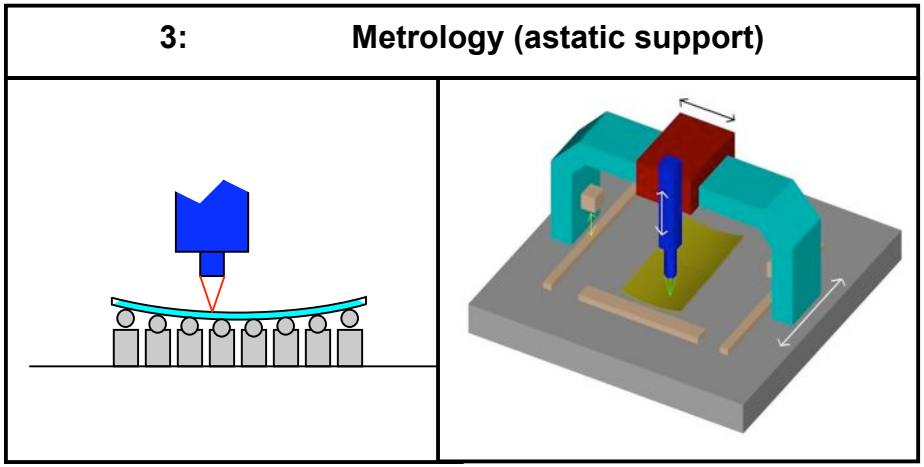


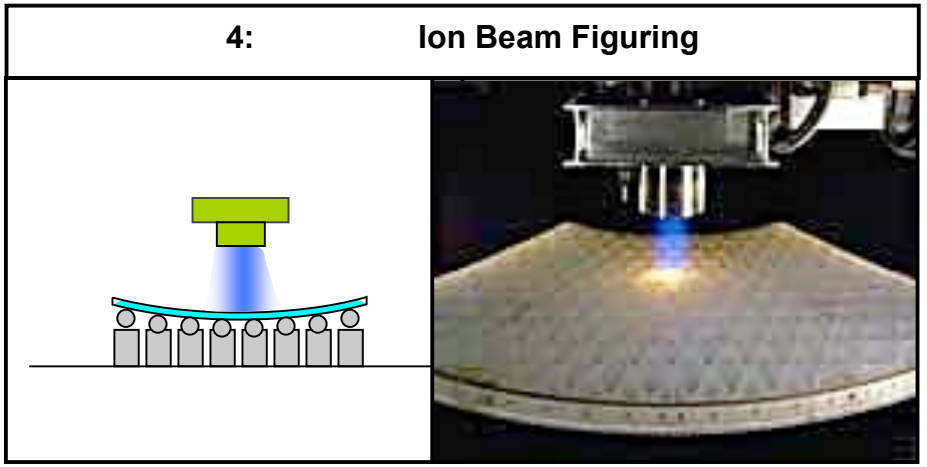
Hot Press Direct Slumping concept

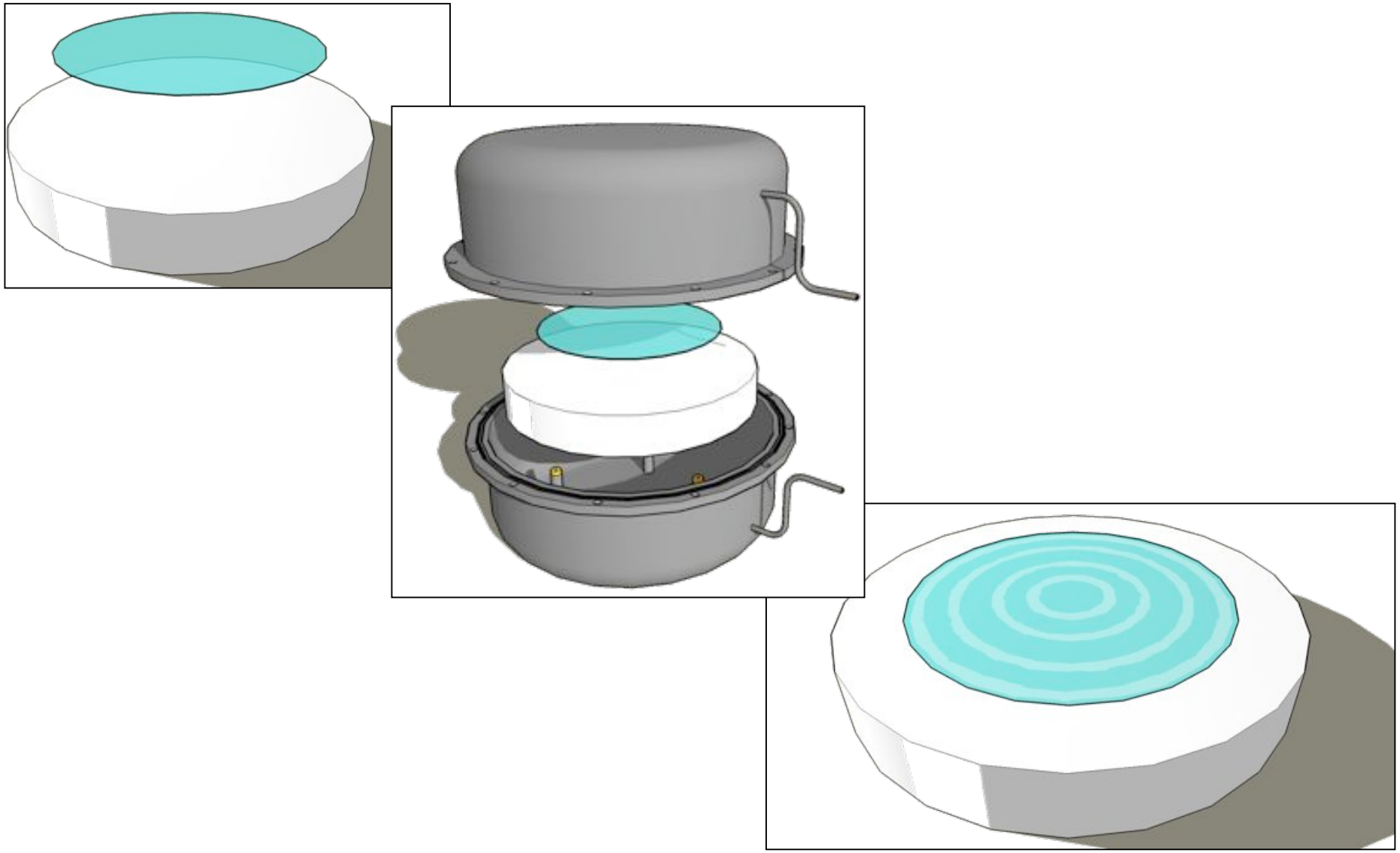
for thin mirror production



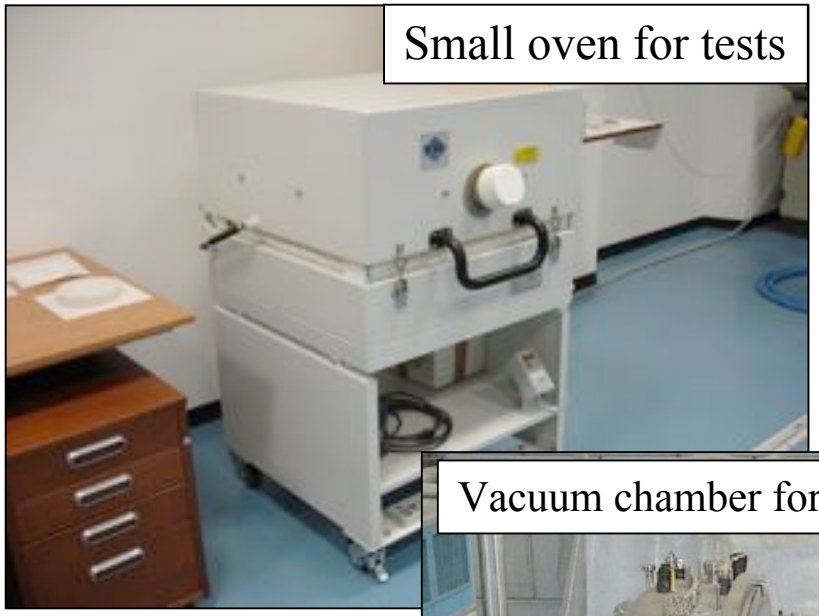




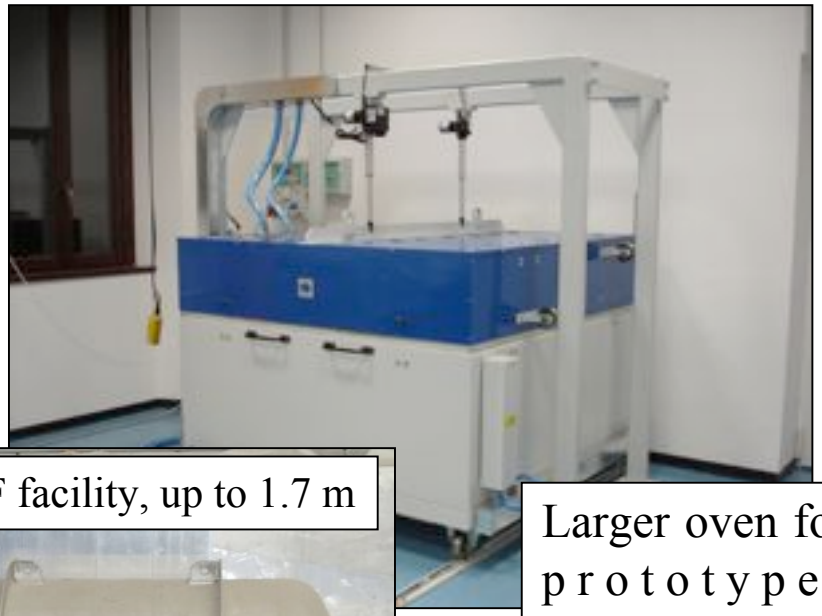




Facilities at INAF-OAB



Small oven for tests



Larger oven for prototypes production, up to 1 m diam

Vacuum chamber for IBF facility, up to 1.7 m

General considerations for a slumping process

The choice of the materials (mould + glass) must take into account a large number of properties that shall be properly weighted in a [illegible] function to reach an acceptable trade-off:

- Mechanical: Young's modulus, hardness
- Physical: CTE and CTE homogeneity, thermal conductivity, density, glass adhesion, transparency
- Structural: voids-inclusions, high temperature stability
- Fabrication: machinability, polishability, optical microroughness, characterization
- General: availability, costs

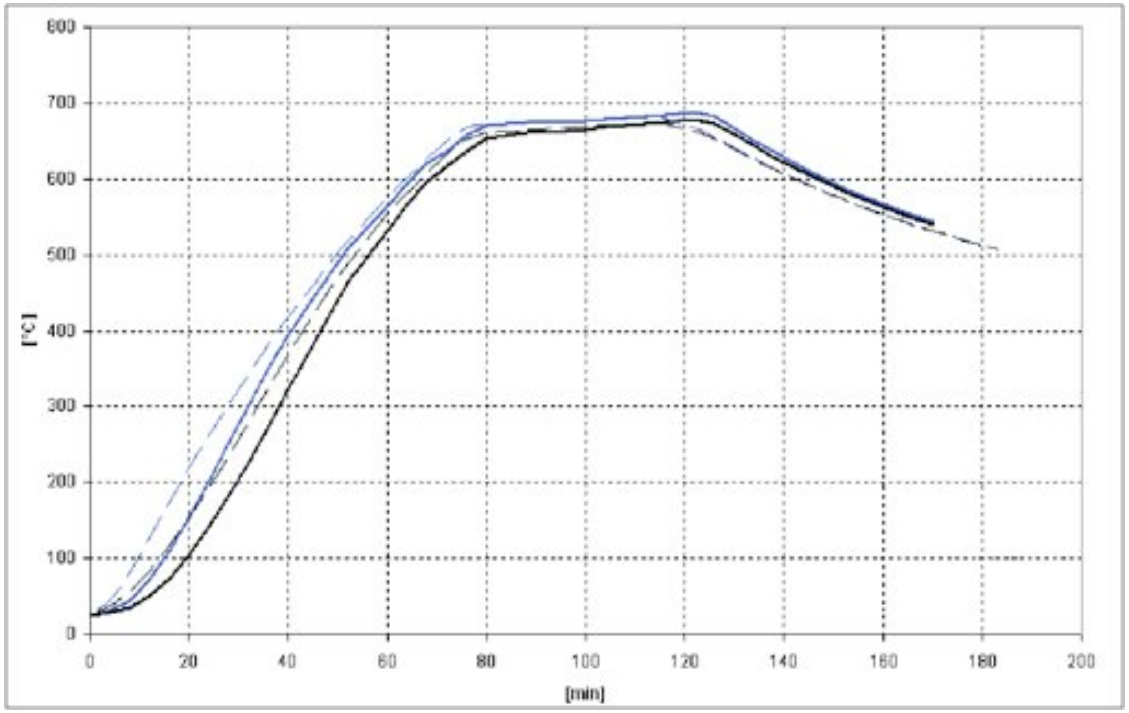
Our choice is Zerodur K20 for mould and Borofloat 33 glass

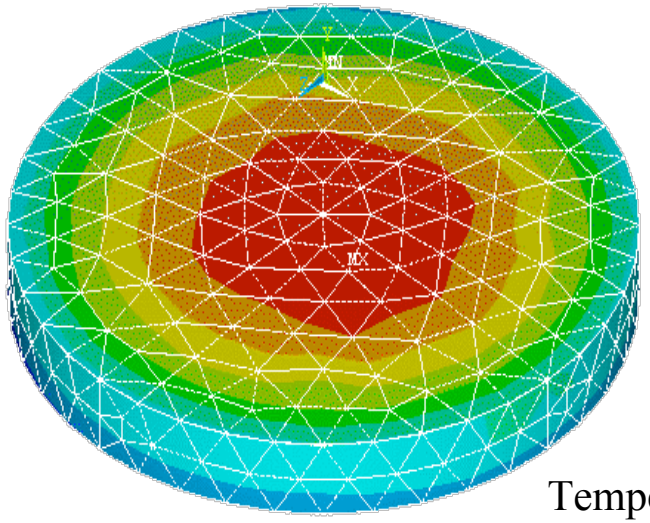
Definition of the critical aspects of the slumping procedure

- Thermal characterization of the oven
- Thermal characterization of mould and glass
- Thermal cycle optimization
- Set-up of a suitable slumping procedure

Oven characterization and thermal cycle optimization

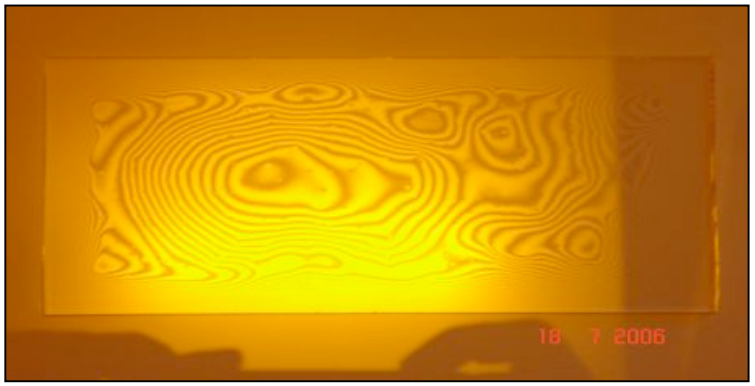
Measured and simulated thermal behavior of the small oven





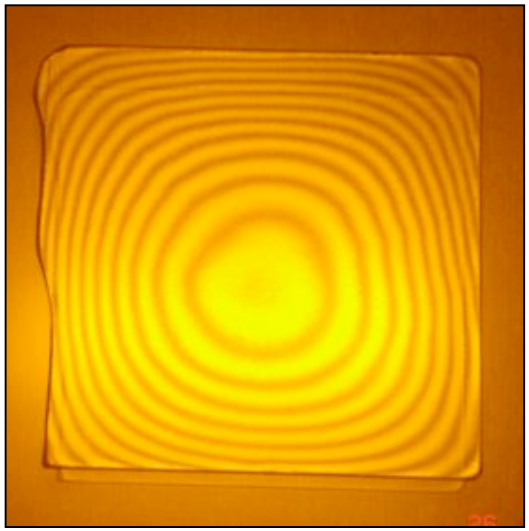
Temperature gradients on the mould must be avoided!

From concept to reality



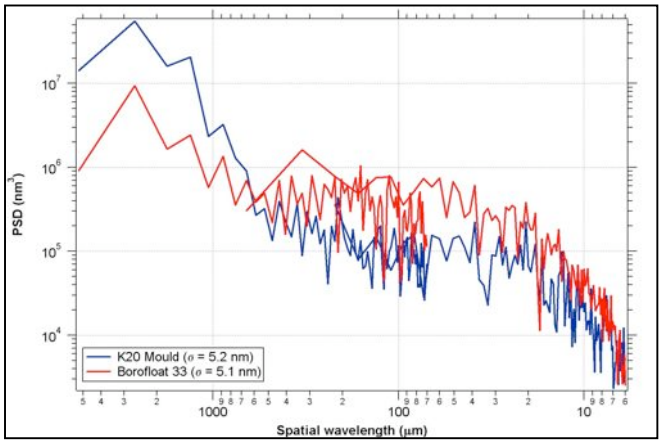
- Without vacuum
- Without deep cleaning
- Without pressure

- Presence of dust contamination
- Very irregular pattern of fringes
- Not slumped at the edge



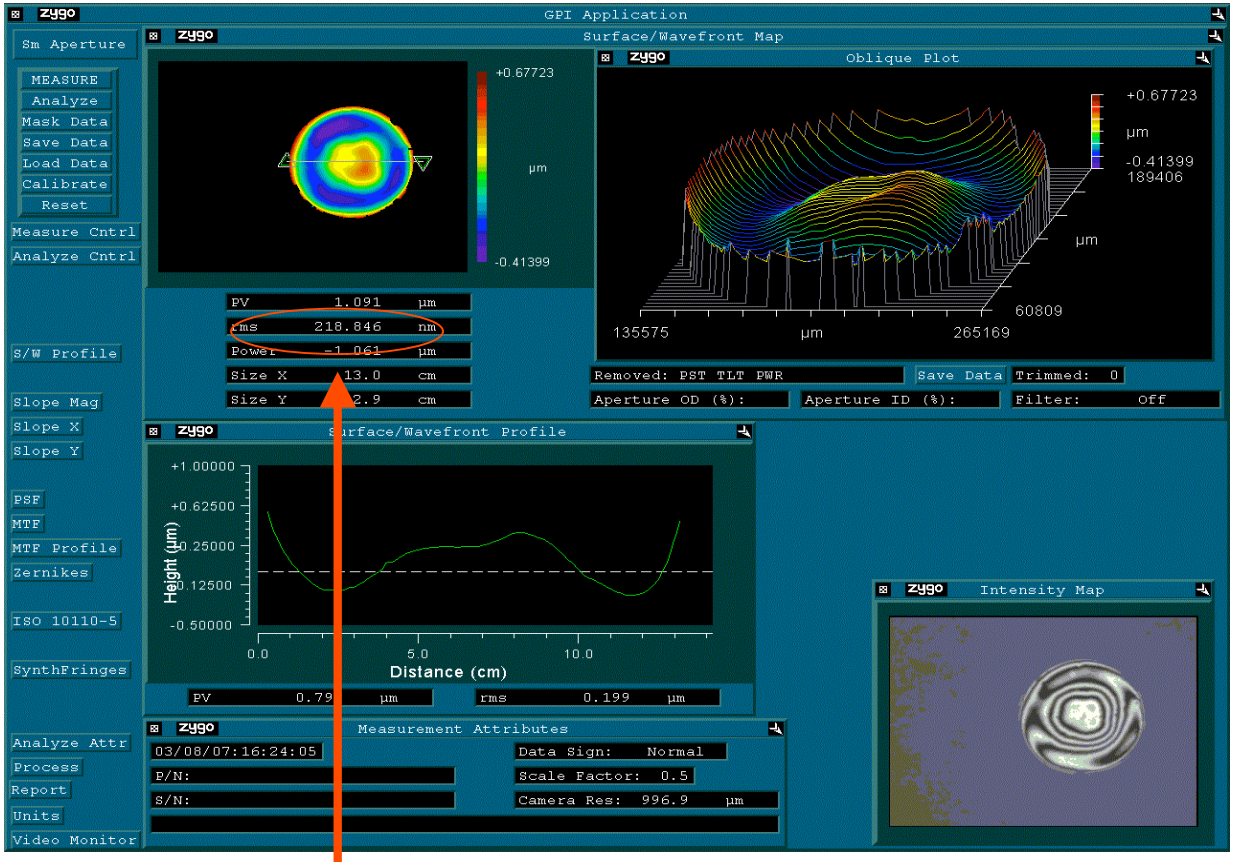
- With vacuum
- With deep cleaning
- With pressure

- No dust contamination
- Very circular pattern of fringes
- Slumped also at the edge
- Full copy of the mould



Some examples of thin slumped glass sheets

Interferometric measurement of a slumped glass shell having
radius of curvature of 4000 mm diameter of 130 mm and 2 mm thickness



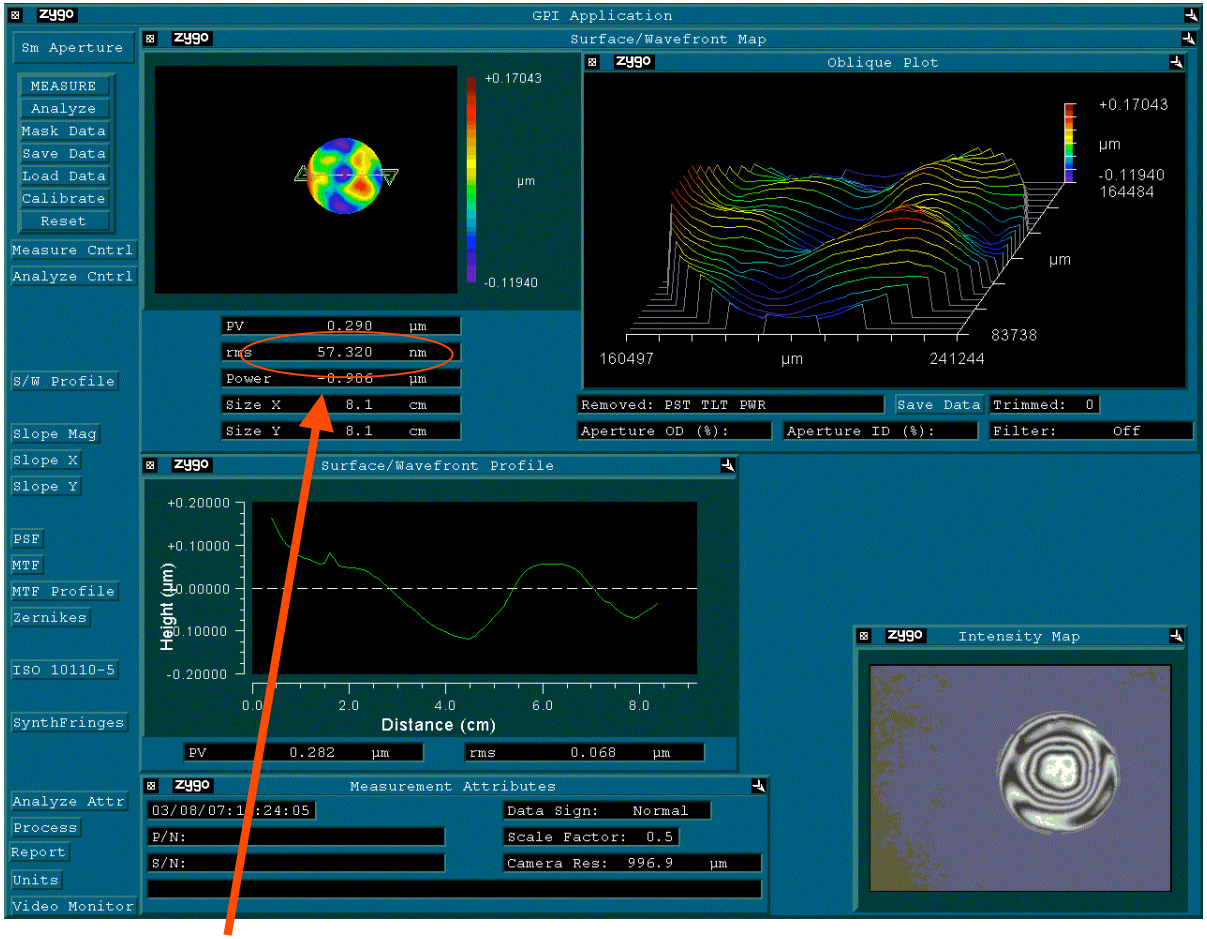
Fringes between mould and glass:

very circular and
without dust contamination

218 nm rms → λ/3 rms over 130 mm diam.

Some examples of thin slumped glass sheets

Same sample but measured on 80 mm diameter

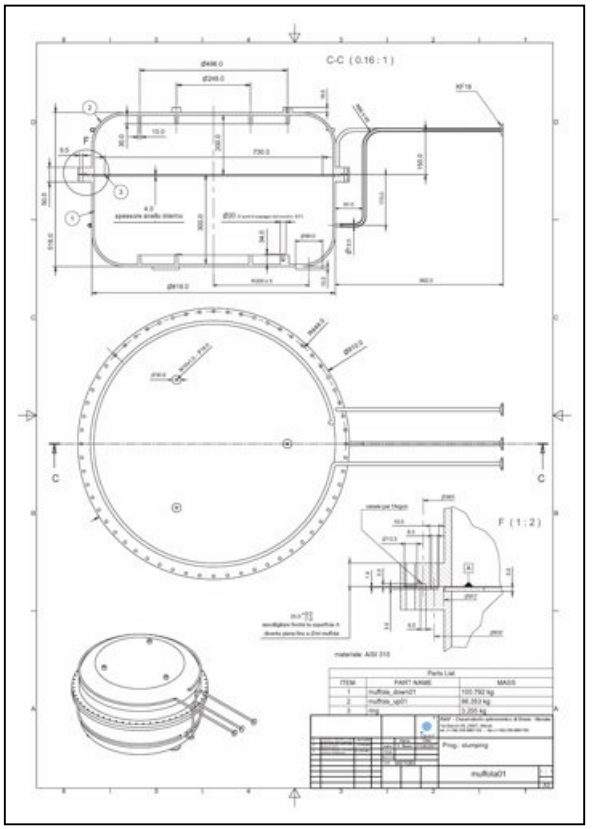


57 nm rms → λ/11 rms over 80 mm diam.

In all the small segments slumped it is visible a pattern of features that repeat itself with a good approximation indicating that the opposite of this pattern is very likely also present on the small mould used for these tests.

The process is able to deliver a good copy capability and the results till here obtained are limited from the quality of the mould optical surface and not from the slumped segments, that limit themselves to copy its surface.

Latest results: scale-up to 500 mm diameter



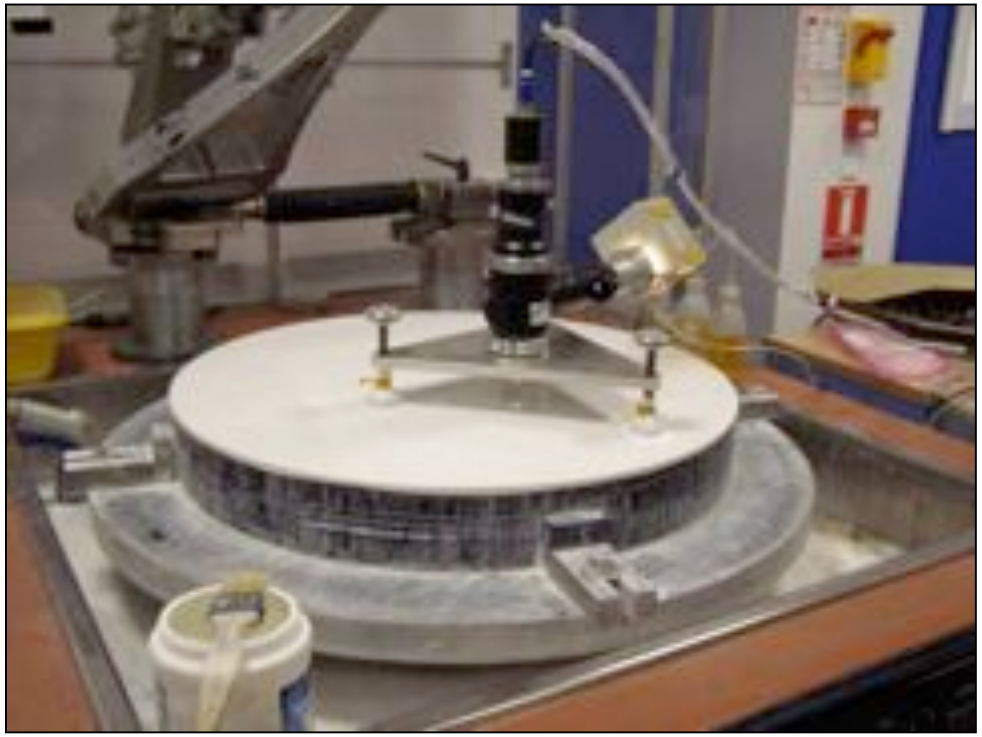
Muffle inside the large oven

Stainless steel AISI 310 Weight = 190 Kg

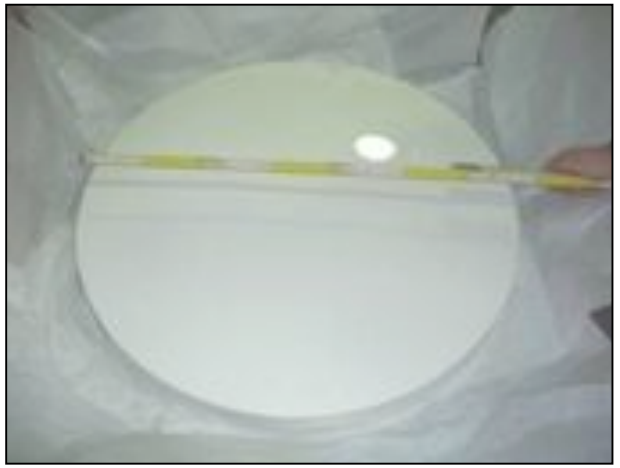
External Diam = 816 mm Height = 516 mm

Vacuum seal at about 650 °C

Latest results: scale-up to 500 mm diameter



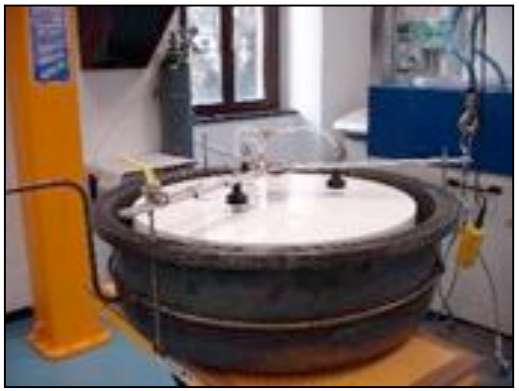
Polishing and characterization in SESO



K20 Mould in INAF-OAB

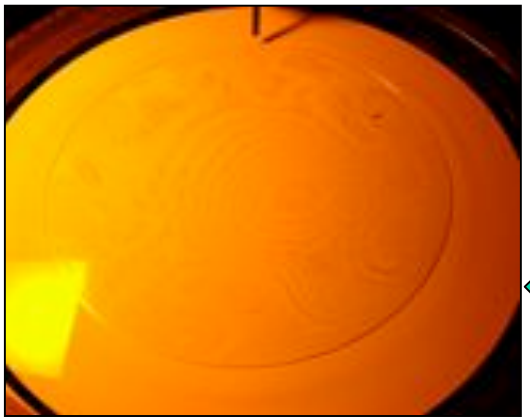
Latest results: scale-up to 500 mm diameter

In February we have started to use the 700 mm diameter mould to slump a full size segment and to tune the parameters of the scaled-up slumping procedure.
The initial results are very encouraging



Mould into the muffle

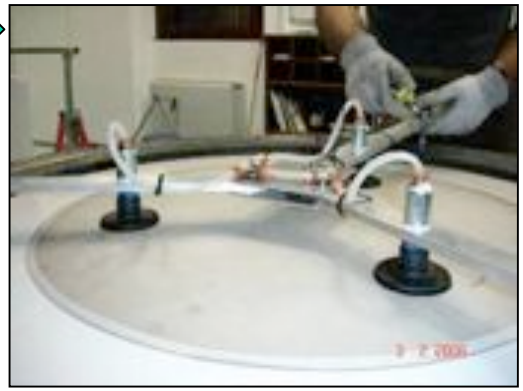
Segment suspended above the mould before the slumping



Segment on the mould and under sodium light.

10 fringes = PV 3μm or 2.5 arcsec of figure error

After the slumping, lift of the glass segment

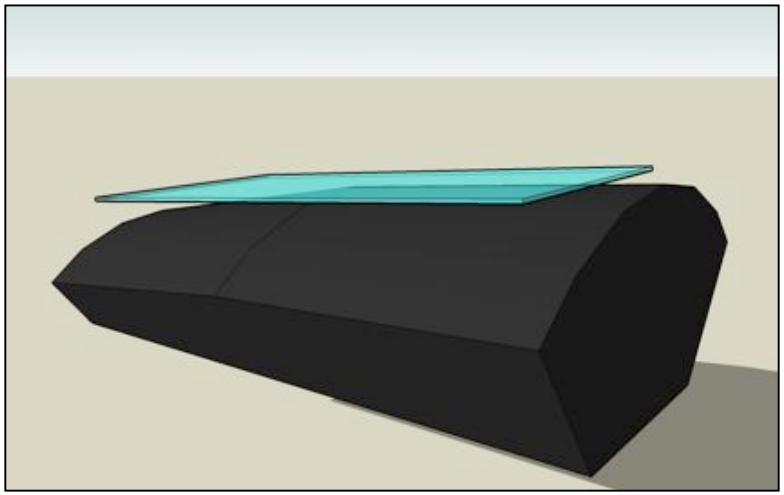


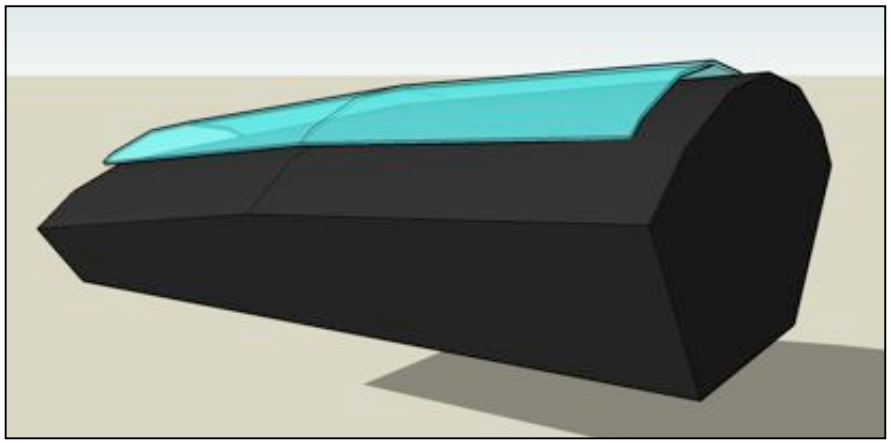
Future work…

- Further investigation of the hot slumping technique for adaptive optical segments;

- Study of a new hot slumping technique for the IXO-XEUS mission:

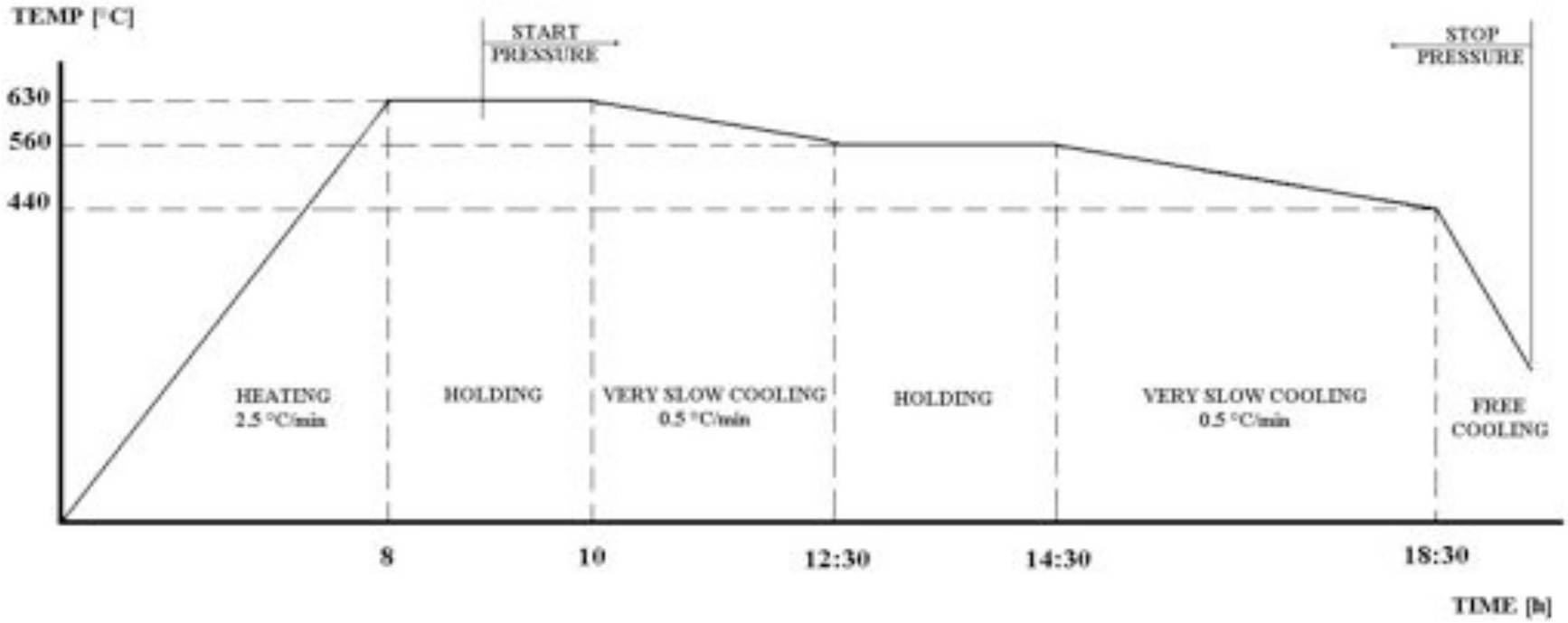
- new materials, procedure, thermal cycle;
- different characterization methods;
- integration and alignment of the shells





Thermal cycle for small diameter Borofloat33™ glass sheets

The results obtained with the slumping of small Borofloat33 disks have been obtained with the following thermal cycle, employing a vacuum muffle with the capability to apply on the glass a uniform controlled pressure (~150 g/cm^2)



For the slumping of a 500 mm diameter segment the thermal cycle foreseen is of about 4 days.

Some examples of thin slumped glass sheets

Spatial wavelength range [mm]	TEST 1	TEST 2	TEST 3	TEST 4
0-60	λ / 13	λ / 11	λ / 9.7	λ / 12.6
0-80	λ / 9	λ / 6	λ / 6.4	λ / 11
0-100	λ / 4.8	λ / 3	λ / 4	λ / 7.2
0-120	λ / 2.8	λ / 1.8	λ / 2.7	λ / 3.8
0-130	λ / 2.4	λ / 1.7	λ / 2.2	λ / 2.9

The shape of the small mould used in these tests has not yet been characterized (convex shape) and hence only a comparison in repeatability among slumped segments is possible.

The radius of curvature of the mould is 395 cm

1° Test	R = 398 cm	ΔR = 3 cm
2° Test	R = 400 cm	ΔR = 5 cm
3° Test	R = 390 cm	ΔR = -5 cm
4° Test	R = 394 cm	ΔR = -1 cm

List of publications

Development of lightweight optical segments for adaptive optics
*M. Ghigo, **R. Canestrari**, S. Basso, et al. **2007***

Lightweight optical segment prototype for adaptive optics manufactured by hot slumping
R. Canestrari**, M. Ghigo, S. Basso, L. Proserpio **2008

Investigation of a novel slumping technique for the manufacturing of stiff and lightweight optical mirrors
R. Canestrari**, M. Ghigo, G. Pareschi, S. Basso **2008

Glass panels by cold slumping to cover 100 m^2 of the MAGIC II Cherenkov telescope reflecting surface
*G. Pareschi, **R. Canestrari**, O. Citterio, M. Ghigo,et al. **2008***

Slumped glass option for making the XEUS mirrors: preliminary design and ongoing development
*M. Ghigo, S. Basso, **R. Canestrari**, O. Citterio, F. Mazzoleni, G. Pareschi, L. Proserpio **2008***

Wavefront corrective lens for the Subaru Laser Launching Telescope
*A. Novi, **R. Canestrari**, M. Ghigo,Y. Hayano **2008***

Correction of high spatial frequency errors on optical surfaces by means of ion beam figuring
*M. Ghigo, **R. Canestrari**, D. Spiga, et al. **2007***