LAST RESULTS FOR TECHNOLOGICAL DEVELOPMENTS FOR ULTRA-LIGHTWEIGHT, LARGE APERTURE, DEPLOYABLE MIRROR FOR SPACE TELESCOPES

Lisa Gambicorti
for the LATT community

9th ICSO
International Conference on Space Optics
Ajaccio (France), October 9th – 12th, 2012
Credits

CNR-INO

F. D’Amato, L. Gambicorti, M. Pucci

CGS, Compagnia Generale per lo Spazio SpA

F. Duò

INAF, Arcetri Observatory

F. Lisi, A. Riccardi

ADS International S.r.l.

D. Gallieni

MICROGATE S.r.l.

R. Biasi

ESA / ESTEC

A. Zuccaro Marchi

J. Pereira Do Carmo
OUTLINE

✓ The 1st project (the “past”): summary of ALC (Advanced Lidar Concept)
  • Motivations and requirements
  • Active mirror concept

✓ The 2nd project: status of LATT
  ✓ The Optical Bread-Board (OBB)
    • The CFRP backplane
    • The Electrostatic Locking (EL)
    • The actuators
    • The deployment mechanism
    • The mirror manufacturing
    • The optical test
**MOTIVATION & REQUIREMENTS**

**ALC target**

*Characterise a space telescope for monitoring the atmospheric water vapour distribution with DIAL technique*

Telescope collecting area is KEY parameter, since laser power transmission is inversely proportional to aperture size

*Deployable structure (depending on launcher’s fairing)*

The large aperture primary mirror must therefore be lightweight

*(shape error sources: deployment, thermal deformation, any on-orbit disturbances)*

---

<table>
<thead>
<tr>
<th>Some Requirements</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength</td>
<td>935.5 nm</td>
</tr>
<tr>
<td>Field of View (FOV)</td>
<td>115 μrad</td>
</tr>
<tr>
<td>Obscuration</td>
<td>&lt; 5%</td>
</tr>
<tr>
<td>Effective aperture area</td>
<td>&gt; 7 m²</td>
</tr>
<tr>
<td>Mass/Area density of mirror</td>
<td>&lt; 20 Kg/m²</td>
</tr>
<tr>
<td>Wavefront error (rms)</td>
<td>&lt; ( \lambda / 3 )</td>
</tr>
<tr>
<td>Power dissipation</td>
<td>&lt; 40 W</td>
</tr>
</tbody>
</table>

ESA contract (ITT AO/1-4629/NL/CP Ref. 2053, “Advanced LIDAR Concept,” ALC)
ACTIVE MIRROR CONCEPT

Optical precision retrieved by active feedback control of the mirror surface:

1. Primary mirror is illuminated with a plane wave (light from emitter, retro-scattered by atmosphere).
2. Collected wavefront is analysed.
3. Aberrations are measured.
4. Aberrations are corrected by repositioning the actuators beneath the mirror.

Technology already in use in ground telescopes for atmospheric monitoring (i.e. LBT): kHz feedback loop ⇒ adaptive mirror.

In orbit: Hz feedback loop (< power required) ⇒ active mirror

Thin optical surface coupled to stiff lightweight support structure through array of actuators.
# THE OPTICAL BREADBOARD FOR LATT

**LATT: Large Aperture Telescope Technology**  
(Phase 2: ESTEC/Contract No. 4200022321 CCN1)

Demonstrate and manufacturing the critical technologies to increase the aperture of the telescope

<table>
<thead>
<tr>
<th>Component</th>
<th>Requirement</th>
<th>Expected value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary mirror</td>
<td>Wavefront error</td>
<td>&lt; $\lambda$ /6 rms</td>
</tr>
<tr>
<td></td>
<td>Mass areal density</td>
<td>&lt; 16 Kg/m²</td>
</tr>
<tr>
<td></td>
<td>Material</td>
<td>Zerodur®</td>
</tr>
<tr>
<td></td>
<td>Shape</td>
<td>Spherical (5 m curvature radius)</td>
</tr>
<tr>
<td></td>
<td>Diameter x Thickness</td>
<td>400 mm x 1 mm</td>
</tr>
<tr>
<td>Backplane (with EL)</td>
<td>Material</td>
<td>Carbon Fiber Reinforced Plastic + Aluminum</td>
</tr>
<tr>
<td></td>
<td>Main dimensions</td>
<td>400 mm diameter</td>
</tr>
<tr>
<td></td>
<td>EL axial, shear force</td>
<td>&gt; 400 N/m², &gt; 530 N/m²</td>
</tr>
<tr>
<td>Actuators</td>
<td>Quantity</td>
<td>19 (5 on the diameter)</td>
</tr>
<tr>
<td></td>
<td>Power consumption</td>
<td>&lt; 0.2 W /Actuator</td>
</tr>
<tr>
<td></td>
<td>Mass</td>
<td>&lt; 0.15 Kg</td>
</tr>
<tr>
<td></td>
<td>Stroke</td>
<td>1 mm (± 500 µm)</td>
</tr>
<tr>
<td></td>
<td>Accuracy</td>
<td>&lt; 200 nm rms</td>
</tr>
<tr>
<td></td>
<td>Resolution</td>
<td>&lt; 10 nm</td>
</tr>
<tr>
<td></td>
<td>Force</td>
<td>&gt; 0.6 N /Actuator</td>
</tr>
<tr>
<td></td>
<td>Closed loop bandwidth</td>
<td>&gt; 0.1 Hz</td>
</tr>
</tbody>
</table>

- **Lightweight**
- **1-mm thick Zerodur**
- **Electrostating Locking to the CFRP backplane during launch phase**
- for mirror alignment due to errors to guarantee the WF req.
OBB & DBB

OBB concept: the thin shell mirror surface, actuators glued at CFRP back-plane via EL subsystem

The OBB shall demonstrate:

- The wavefront correction associated with the primary mirror (RMS) < \lambda/6
- The Electrostatic Locking (EL) functionality (is considered as part of Backplane)
- The Mass Areal density of primary mirror < 16 Kg / m²

The Deployment Bread Board shall demonstrate:

the capability of the deployment mechanisms and kinematics to obtain the required positioning accuracy of the petals.
The average linear pitch is about 92-95 mm

With respect to the previous diamond shaped pattern in this case the 19 actuators are arranged on two rings having respectively: D1=371 mm D2=185 mm

OBB rendering

Backplane is slightly larger than the thin shell (440 mm with respect to 400 mm)

Out of the six flexure supports the three in foreground are also used to clamp the OBB during the vibration and optical tests
OBB & DBB

BP: the backbone structure where actuators are mounted on and which provides also the substrate to electrostatically constrain the mirror during launch.

CFRP has been chosen because of its low density, high stiffness, low CTE and high strength, vacuum compatible. Backplate material: M55J/epoxy

The Honeycomb Sandwich
Backplane structure

The actuator cup inserted from the rear side
ELECTROSTATIC LOCKING

- The back Zerodur thin mirror surface is Al coated.
- The front face of the Backplane has a conductive layer covered by an insulator (Mylar) with high dielectric constant.

![Diagram showing capacitor armatures, glass, Mylar, CFRP, and glue layer]

**Electrostatic Locking specimens tests**

- LATT-Zaot glass (2x) Al_SiO2
- ALC-CONF.7
- ALC-CONF.6
- CFRP - Glass with Al and SiO2 on both sides

![Graph showing normalized shear force vs. applied voltage]

- Fixed armature
- Sample mirror
- Shear force
The first resonant mode (278 Hz) when the OBB is attached to ground at the three aluminum supports.

Mode is clearly a global and uniform bending.
DEPLOYMENT

Petal deployment:
- End of deployment: stiffening strut latched with a latching device and a rod.
- Precision of deployment: due to hinges and latching device.
  - Error = ± 75.9 μm

- The Deployment Breadboard will be used to verify the repeatability and the accuracy of the latching device.
- The proposed latching device is effective if the differences in the readings of the comparator, with respect to the first reading, are within + 25.5 μm
Shell thermal deflections

Thermally induced deflection for the optical ground experiments

Displacements due to the flexure system for 10° C temperature variations PTV is about 11 micron

The Z direction displacement pattern caused by a -45° C temperature variation

The print through due to the magnets is very limited and the PTV deflection over the entire surface is smaller than 33.5 nm
Gravitational deformations in under launch

assess the safety of the thin Zerodur shell for the loads experienced during the launch phase

The deflections of the thin shell in the directions perpendicular to the optical surface

shell PTV deflection is about 0.42 micron before active compensation

Tensile stress in the glass

Maximum stress is about 6 MPa and remains below the admissible value for Zerodur, fixed at 30 MPa

Displacement of the thin shell (quilting) for a 100 g load.
The glass shell tends to fall inside the hole of the CFRP backplane by 16.8 micron

margin of safety for the 37g
Advantages of glass, e.g. Zerodur:

- Low, predictable strain relaxation during thinning process
- Easy to machine with proven technologies
- CTE as low as $10^{-8}$/K and constant all over the mirror body (no active thermal control requested for rigid M1)
- Very stable in time and under environment variation

The only drawback is intrinsic fragility, but the electrostatic locking shows the way to safe launch.

**Mirror fabrication: manufacturing procedure**

Manufacturing of two spherical glasses (one + backups)

- Material: Zerodur
- Diameter: 400mm
- Thickness: 1mm
- Curvature radius: 5000mm
OPTICS MANUFACTURING

1. Pre-manufacturing:
   piano convex & piano concave control forms;
   Aluminum support: for grinding & polishing procedures
2. Roughcasting concave part: with roughing tool
3. Grinding concave part: lapping machine with patina
   & Carborundum, to eliminate imperfections
3. Polishing concave part: similar to grinding, with Cerio oxide grain and
   pitch. Interferometric controls
4. Locking glass: gluing of glass to convex bad zerodur glass
5. Making thin glass: roughing tool to get 1.1 mm thick & concave-convex
   surface.
6. Grinding convex part: lapping machine with Carborundium to get 1-mm
   thickness.
7. Polishing convex part: similar setup using Cerio oxide; Interferometric
   check.
8. Unsticking glass: electric heating, fusing mastic.
   Observatory (LBT group)
OPTICS MANUFACTURING

40 cm diameter of diameter 1 mm of thickness shell manufacturing
OBB Test Design

- The Deformable Mirror can be tested in the lab with standard equipment.
- The gravity influence is controllable by actuators’ action up to a certain level (70mN Peak force), then it can be measured and subtracted (as a static bias) to get the required sensitivity of measurement; flattening is an iterative process, following LBT secondary mirror’s procedures.

OBB Test results

- Subtraction: piston, tip, tilt and focusing (4Z removed)
- Subtraction: 15 Zernike. WFE in nanometer RMS
- 2 pixel eliminated at diameter to calculate WFE
- Not considered actuators action
## TESTING M1/M2

<table>
<thead>
<tr>
<th>4z subtracted</th>
<th>15 z subtracted</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>WFE= 261 nm</strong></td>
<td><strong>WFE= 53 nm</strong></td>
</tr>
</tbody>
</table>

### M1, 4Z removed, WFE= 261 nm

![M1 image](image1.png)

### M1, 15Z removed, WFE= 53 nm

![M1 image](image2.png)

<table>
<thead>
<tr>
<th><strong>WFE= 527 nm</strong></th>
<th><strong>WFE= 90 nm</strong></th>
</tr>
</thead>
</table>

### M2, 4Z removed, WFE= 527 nm

![M2 image](image3.png)

### M2, 15Z removed, WFE= 90 nm

![M2 image](image4.png)
FINAL REMARKS

✓ OBB backplate:
  ➢ Design performed: structural verifications passed
  ➢ Manufacturing process
  ➢ Optimizations of the areal density (now ~ 18 Kg/m²)

✓ OBB actuator:
  ➢ Voice Coil Motor preliminary design performed. Advanced design on go
  ➢ Actuator mass to be optimized: 200 gr achievable, <150 gr goal

✓ Electrostatic Locking:
  ➢ Coating process to make the EL armature on the backplate has been implemented *Applicable to flat and/or curved surfaces*

✓ Mirror manufacturing and test:
  ➢ manufacturing procedures
  ➢ Preliminary test
This technological study was originated by a specific application: LIDAR for Remote Sensing.

The technological development of *actively controlled, large aperture, lightweight and deployable mirrors* is potentially applicable to a wide range of situations.

LATT demonstrates the technology; next step will be mirror space telescope!
THANKS!
OBB VOICE COIL ACTUATOR

Grand total = 230 gr, minor optimization to get 200 gr

- Fail-safe, do not lock in case of failure (vs. Piezo actuators)
- Long stroke (up to 1 mm), correct large deployment error (Piezo limited stroke: 100 μm)
- Accuracy (<200 nm rms)
- Compact, low weight
VOICE COIL MOTOR

Moving magnet concept:
NO moving wires!
… but higher moving mass

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Voice Coil Motor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency</td>
<td>Good at low-moderate force levels</td>
</tr>
<tr>
<td>Force constant</td>
<td>Almost constant</td>
</tr>
<tr>
<td>Hysteresis</td>
<td>Substantially absent</td>
</tr>
<tr>
<td>Complexity</td>
<td>Single coil, single drive</td>
</tr>
<tr>
<td>Mover mass</td>
<td>30g</td>
</tr>
</tbody>
</table>

Expected typical optical aberrations correction forces: 0.3mN!
(extrapolated from LBT data)

Higher mover mass is not an issue for the correction activity – low dynamic demand & mirror mass
OBB VOICE COIL ACTUATOR

SMART ACTUATOR

- Contactless Voice Coil Motor principle
- Coil current controlled from a MCU defines actuator force
- Force exerted on magnets glued on the back surface of the thin shell
- Principle already widely implemented in ground base telescopes (MMT, LBT, Magellan, VLT)
- Difference w.r.t. ground based is high stroke demanded by LATT (1.2 mm)
- Efficiency (and therefore motor constant) vs. gap not constant

POWER BUDGET

<table>
<thead>
<tr>
<th>Source</th>
<th>Power [mW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analog circuitry</td>
<td>6</td>
</tr>
<tr>
<td>Communication</td>
<td>9</td>
</tr>
<tr>
<td>Processing</td>
<td>10</td>
</tr>
<tr>
<td>Coil driver @ 28mN rms, 0.4N/√W efficiency</td>
<td>42</td>
</tr>
<tr>
<td>Coil @ 28mN rms, 0.4N/√W efficiency</td>
<td>5</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>72</strong></td>
</tr>
</tbody>
</table>

Mass BUDGET 14.85 gr without comm. cable
DEPLOYMENT

The Deployment Breadboard will be representative of the latching device that is needed to latch the petals at the end of the deployment.

The DBB is made of 4 main subsystems:
1. The Drive device (testing purpose);
2. The Latching device (flight like);
3. The Latching release device (testing purpose);
4. The Support Structure (testing purpose);

Task of the DBB:
• verify the deployment repeatability
• determine the force needed to unlatch the system.

Unlatched Configuration

Latched Configuration