ADAPTIVE TELESCOPE PATHFINDERS FOR THE ELTs: MMT, LBT, MAGELLAN AND VLT

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INAF – Osservatorio Astrofisico di Arcetri
80s: the tech jump of Active Telescopes

- NOT First-light 1988
- NTT First-light 1989
Y2K: tech jump of Adaptive Telescope

- Integration of AO in the telescope optics
  - Reduced Mid Infrared emissivity
  - Increased transmissibility
  - Common DM for all the focal stations
A single corrector serves all the focal stations.

- Less surfaces: increased transmissibility.
- Less warm surfaces: K and MIR optimization.
  - Shorter exp. time [1]: K band: 2-3, L-M band: 3-5 (8/10m-class tel’s).
- More compact WFS module and optics. Closer to the instrument beam-splitter: reduced non common path aberrations.

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- More compact MCAO module at the focal station
A STUDY OF AN ADAPTIVE SECONDARY MIRROR

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Abstract
We report the study of an adaptive secondary mirror providing high order correction of the wave front perturbed by propagation through the atmosphere (up to approximately 1000 degrees of freedom). The device, based on electromagnetic actuators and capacitive position sensors, can also provide chopping with simultaneous correction of the induced coma, and can be used statistically for correcting low order aberrations (active optics). We discuss the characteristics of the most important components, such as actuators, sensors, and the ultra thin mirror, and report the expected performances in the three above mentioned modes of operation (adaptive, chopping, and active).

| Rms wf (axial and lateral gravity) | ≤ 10 nm |
| One hour rms stability (single actuator) | ≤ 10 nm |
| Settling time (single actuator) | ≤ 1 ms |
| Tip–tilt amplitude | ≥ 2 arcsec (on sky) |
| Tip–tilt settling time | ≤ 1 ms |
| Chopping throw | ≥ 20 arcsec (on sky) |
| Chopping settling time | ≤ 5 ms |
| Number of actuators | ≈ 1000 |
| Mirror thickness | ≈ 2 mm |
| SR @ λ = 2 μm (average seeing, mirror only) | ≥ 0.9 |

Table 1: Design Goals.

Figure 1: The conceptual Scheme of the Adaptive Secondary Unit.

Figure 3: Electronics Layout of the A/S Unit.
Y2K: tech jump of Adaptive Telescope


- Voice-coil technology with capacitive sensor internal metrology:
  - Large stroke (~100µm): TTM+DM+chopper+FS functionality in a single device
  - No-contact technology: robust in case of actuator failure: 5% increase of fitting error rms in case of 10% not working randomly distributed actuators [1]
  - Internal metrology: No hysteresis

Development partners

Original Concept. System Level Development, Test and Commissioning

Mechanical design, manufacturing and integration

Electronic design, Electronic manufacturing integration and test

Optical components: thin shell and refplate (MMT, LBT and Magellan)

Optical components: thin shell (VLT)

Optical components: light-weighted reference plate (VLT)

Control design and control simulations
Development history: done!

MMT: 1stLight Nov 2002
MMTAO (SH 12x12)
Convex, 2mm thick
642mm diam
336 acts, 30mm/act
Proj. on M1: 30cm/act
$\sigma_{fit} = 84\text{nm rms WFE}$
(0.8as seeing@V)

LBT1: 1stLight Mar 2010
LBT2: 1stLight Sep 2011
FLAO, LBTI (PWFS 30x30)
(Convex, 1.6mm thick
911mm diam
672 acts, 30mm/act
Proj. on M1: 27cm/act
$\sigma_{fit} = 75\text{nm rms WFE}$
(0.8as seeing@V)

Magellan: 1stLight Nov 2012
MagAO (PWFS 30x30)
(Convex, 1.6mm thick
850mm diam
585 acts, 30mm/act
Proj. on M1: 23cm/act
$\sigma_{fit} = 66\text{nm rms WFE}$
(0.8as seeing@V)

See talks:
Hinz, today, 16:40
Posters:
Raab, ARGOS
Busoni, ARGOS
Hill, LBT&LBTI

See next talk by L. Close

AO4ELT3 - Firenze 26-31 May 2013
Development history: close to be done!

AO4ELT3 - Firenze 26-31 May 2013

VLT: 1stLight End 2014
AOF (SCAO end 2017)

Convex, 2mm thick
1120mm diam
1170 acts, 29mm/act
Proj. on M1: 21cm/act
\( \sigma_{fit} = 66 \text{nm rms WFE} \)
(0.8as seeing@V)

SUBARU: WF GLAO
Oya et al., SPIE 8477, 3V (2012)

GEMINI: interest

See next talks:
Hubin, Monday on AOF
Gallieni, Thursday 11:50
Briguglio, Thursday 12:10

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Why attractive for ELTs: LO stabilization

- Seeing limited observations require Adaptive Optics capability (temporal bandwidth): requirement for all focal stations
- GMT (TT+HO) [1]:
  - ~120um stroke (~1” on-sky)
- E-ELT:
  - M5 (TT) [2]: 1 on-sky-arcsec rms, 10Hz BW
  - M4 (TT+HO) [3]:
    - typical 19um stroke (operational)
    - up to 80um stroke (functional, ~0.4” on-sky)

GLAO and Etendue (AΩ): wo Adaptive Telescope larger incidence angle on DM or longer relay system, increasing AO module size
- GMT: 6.5 arcmin, up to 20 arcmin FoV [1]
- E-ELT: 5-10 arcmin FoV (Optimos) [2]
- TMT: constrained GLAO w AM2 (WFOS before 2006)[3]

[1] Bouchez et al., this conference on Monday
Etendue problem with ELT GLAO

\[ A \theta^2 = \text{const} \]

33°

10'

40m

20cm

Optical reduction factor: 200

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Adaptive Telescope Mirrors on ELTs

Talks:
Hubin, Thursday 8:30
Vernet, Thursday 11:10

Talk:
Bouchez, Monday

Poster:
Gallieni & Biasi, WFC session

4326 actuators

7x672 act segments (tot:4700)

(courtesy Microgate/ADS)
How AdSec is made: LBT example

Hexapod

Interface flange and structural support
How AdSec is made: LBT example

- Interface flange and structural support
- 3 cooled electronics boxes
- Cold-plate and actuator support
- Thick Zerodur reference-plate
- 1.6mm thick deformable Zerodur shell
How AdSec is made: LBT example
The control problem

First hundreds of modes have $\nu_{res} < 1kHz +$ local control
Phase lag of 180deg for $\nu > \nu_{res}$ if low damping $\rightarrow$ unstable
High damping (18Ns/m => 40µm gap) + local control PD
Control implementation

Command vector from rec. $c_i(t)$

Feed-forward force $\sum F_{ik} \Delta c_k$

$\int$

Control loop of $i$-th actuator

$\Sigma F_{ik} \Delta c_k$

$G$

$e(t)$

$p(t)$

$K \frac{d}{dt} v(t)$

$\Sigma F_{ik} \Delta c_k$

$\int$

DAC

Delay

<11\mu s

90kHz

56kHz @-3dB

Current Driver and coil

Mirror Shell

Capacitive Sensor

Dyn FF, see talk: Gallieni/Biasi, Thursday 11:50

90kHz

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Step responses MMT, LBT and VLT

- **MMT**: 50um gap, 1.5ms settling time, Natural damping
- **LBT**: 60um gap, 1.0ms settling time, Digital damping
- **VLT**: 70um gap, 0.7ms settling time, Digital damping, Dynamical Feed-forward

**MODE #3** (3.0E-004 N/µm)

**Mode #0** - Settling: 0.721 [ms] - Oversh: 3.5%

**Mode #501** - Settling: 0.672 [ms] - Oversh: 0.1%

**Mode #101** - Settling: 0.721 [ms] - Oversh: 5.7%
Optical calibration

- Calibration of optical flattening command
- Calibration of AO interaction matrix
- Need of optically coupling the WFSs with the “remote” Adaptive Mirror: large optical systems
  - Convection instability
  - thermal drift
  - on-telescope calibration (issue for convex or large flat mirrors)
Concave shells: LBT, Magellan, GMT

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4DTechnology Interferometer

Retro-reflecting optics holder
Shell figuring: Zerodur thin shells

PtV = 932 nm, Rms = 44 nm

Expected flat residual, RMS = 21nm

OPD@FD RMS = 28nm, 4 terms removed

See talk about DSM optical test: Briguglio, Thursday 12:10
Synthetic interaction matrix

H band PSF on IRTC (10 mas/pix)

Synthetic IM
SR = 92%

Standard IM
SR = 93%

Observing conditions
Guide star          R  = 7.1
Seeing              Good
Elevation           70°-75°

Loop parameters
Frequency           990Hz
WFS sampling        30x30 SA
Pyr. Modul.         +/- 3 λ/D
Modes               400

Uncorrected turbulence
Synthetic IM
Standard IM

Pinna et al., SPIE 8447, 2012
On-sky measured interaction matrix

H band PSF on IRTC (10 mas/pix)

Standard IM
SR = 74%

On-sky IM
SR = 68%

Observing conditions
Guide star          R = 8.8
Seeing               Median
Elevation           70°-80°

Loop parameters
Frequency           990Hz
WFS sampling   30x30 SA
Pyr. Modul.        +/- 3 λ/D
Modes               400

Pinna et al., SPIE 8447, 2012
LBT-FLAO results (bright end)

HD 175658, $M_R=7.2$, Seeing 0.8-0.9 arcsec (DIMM measurement), wind speed at $M2=1\text{m/s}$
WFS: 1kHz loop, 30x30 subaperture, 500 KL modes corrected (June 2010)

What happens when a Pyramid wavefront sensor is coupled with an AdSec

No evidence of static speckles

$>80\%$ SR in H, 20sec

AO4ELT3 - Firenze 26-31 May 2013
Contrast at 0.4arcsec: $10^4$

HD 175658, $M_R=7.1$, Seeing 0.8-0.9arcsec (DIMM measurement)

>80% SR in H
Robustness on actuator failures

31 of 672 actuators are not working (5%)
Conclusions

- 4 adaptive secondary mirrors have been tested on-sky with high strehl and contrast (2xLBT and Magellan in combination with PWFS)
- LBT ASMs are permanently on-telescope: LBT is the real first adaptive telescope
- New control implementation on VLT-DSM showed the ability to manage the large stroke required for ELT specs
- High quality Shell production both in US and EU
- On-telescope AO calibration is possible even for convex shells (Synthetic or on-sky measured IMs)
- Ready step for ELT adaptive telescopes
Open position for an experienced Post-Doc. Duration 2y in Arcetri

NGS Pyramid wavefront sensing for E-ELT (SysEng)

Reference person: Simone Esposito

Application dead-line:
- 30 June 2013
- Visit “Job Opportunities” section in the AO4ELT3 site for more info (tomorrow)