Adaptive Optics Status & Roadmap

Norbert Hubin
Adaptive Optics Department
European Southern Observatory
November 2007
# The ESO Adaptive Optics Pipeline

## Analysis
- CASIS: VLT MCAO Imager
- NACO upgrade

## Study
- E-ELT AO Facility (SC-GLAO)
- E-ELT Large DM & Field stab. (M4, M5)
- EPICS Planet Finder Facility, Phase A
- EAGLE, Multi-Object AO Phase A
- MCAO Imager and multi spectro Phase A
- LTAO module Phase A

## Design
- FDR

## Development
- PAE
- AIT
- HOT (Lab demo)

## Commissioning
- Final AO Facility: GRAAL-HAWK-I
- M2 Adaptive (‘12)
- SPHERE Facility (‘11)

## Operation
- PAC
- NACO Facility (‘02)
- SINFONI Facility (‘04)
- MACAO-UT-1-2-3-4 (‘03-5)
- CRIRES-AO (‘06)
- SINFONI & NACO-LGS (‘07)
- MAD-CAMCAO Science Verification (07-08)

## Approval

## Papers

- 158 NACO-SINFONI
- 1 MAD
- 56 VLTI with AO

---

**Status: Nov. 07**

**Approval**

**Preliminary** GALACSI-MUSE ASSIST

**Final** GALACSI-MUSE ASSIST

**Papers**

- 158 NACO-SINFONI
- 1 MAD
- 56 VLTI with AO

---

Astro with LGS, Nov. 2007

AO roadmap, N. Hubin
Multi-Conjugate Adaptive Optics

- 1-2.5 μm
- 0.45-0.95 μm

- 8.5 Km conj. DM
- 1.5m

- F/15 VLT Focus
- Optical Derotator
- Ground conj. DM + TTM
- Turbulence Generator
- WFS Area

Astro with LGS, Nov 2007
AO roadmap, N. Hubin
Strehl Maps

Astro with LGS, Nov. 2007

AO roadmap, N. Hubin
M16 – Eagle Nebula

Seeing: 1.33"

τ₀: 1.6 ms

GL: 84%

T_{exp}: 1350s

K band

FWHM: 100mas

90 → 105mas
M16 – Eagle Nebula

FoV 7” x 7”

FWHM: 350mas

FWHM: 100mas
Omega Centauri

Field-1

Field-2

1 x 1 arcmin

200 arcsec
Omega Centauri

**Field-1**
- Seeing: 0.69"
- $\tau_0$: 3.1 ms
- GL: 58%
- $T_{\text{exp}}$: 600s
- FWHM: 98mas
- 87→107mas
- EE: 56% in 84mas
- K~20.5

**Field-2**
- Seeing: 0.94"
- $\tau_0$: 2.5ms
- GL: 74%
- $T_{\text{exp}}$: 1440s
- FWHM: 87mas
- 78→95mas
- EE: 60% in 84mas
- K~20.5
Omega Centauri

20 arcsec
Color-Magnitude Diagrams

- $m_k = 17.5$
- $m_B = 20$

Courtesy: G. Bono & A. Calamida

Astro with LGS, Nov. 2007

AO roadmap, N. Hubin
CASIS: Cassegrain AO Simultaneous Imaging System for the VLT (study)

- 1’ x 1’ FoV Simultaneous imaging from 0.6 to 5 μm with MCAO
- 5 channels: 0.6-1 μm, J, H, K, @15 mas, L&M band @ 30mas
- DM1: Adaptive Secondary
- DM 2: @ 12 km
diameter 42 mm
- DM 3: @ 5 km
diameter 42 mm
- FoV for NGS: 3’
- 4 LGS, 1.5’ off-axis
- 50-70% Sr(K)
2k actuator mini Piezo DM

- Pupil diameter: 49 mm
- 50x50 ~ 1900 actuators
- Max stroke: > 2.6 μm
- Individual stroke: > 1.2 μm
- Inter-actuator stroke: > 1.0 μm
- Freq.: > 30 kHz
- Voltage: ± 400 V
- Design on-going
**SHERE: VLT Planet Finder Science requirements**

- Gain up to 5 magnitudes in contrast compared to present instrumentation
  - Planet magnitude up to ~21-25
- Explore the separation range 0.1 – 3”
  - Planet distance 0.5 – 150 AUs
- Explore a large target sample, including low mass stars and young stars → mH < 8 (mV < 11)
  - Allow some spectral characterization
    - R > 50, range 0.96 – 2.32 microns
- Allow polarimetric measurements
High contrast detection capability
- Extreme AO (SR ~ 90% in H band)
- Coronagraphy (dynamics at short separation 0.1")
- Differential imaging (residual halo)
- System optimized to maintain the calibration

Characterisation
- Integral Field Spectroscopy

Visible Channel
- Imaging / Polarimetry (SR90% in H à 65% in R)
SPHERE: VLT Planet Finder design

Common path
Adaptive Optics

Differential Imager
IRDIS

Integral Field Spectrograph

Differential Polarimeter
ZIMPOL
High density DM & Fast readout low noise CCD

Fast readout low noise CCD 220

1370 actuator piezo DM

AO roadmap, N. Hubin
SPHERE three instruments

Differential imager

ZIMPOL

Integral Field Spectrograph
Very Large Adaptive Telescope

- E-ELT Path Finder
- Deformable M2 with 1170 actuators
- 4 Sodium Laser Guide Star
- GRAAL/Hawk-I: GLAO 10’ FOV NIR imaging
- GALACSI/MUSE:
  - GLAO 1’ FOV visible IFS
  - 7.5”diffraction limited IFS (LTAO)
- Option: Cassegrain 3DM MCAO imager
- Facility testing in Europe: ASSIST

Astro with LGS, Nov. 2007
AO roadmap, N. Hubin
VLT Deformable Secondary Mirror

- Focus, centering, tilt/chop (Hexapod, thin shell)
- 1170 voice coil act.
- Capacitive sensors; 80 kHz internal loop
- 1.12m; 2mm thin shell; 9kg w/ glued magnets
- 62 nm rms fitting error; 0.5msec rise time
- 39 DSP boards
- 1.47 kW power; No fans, totally liquid cooled
- Total weight: 1500 kg; I/F VLT Spider
- Integrated design, maintenance provisions
GRAAL & GALACSI design

GALACSI-MUSE: IFS 90k spaxels, 0.45-0.95µm
2xEE in 1’ FOV (650nm)
On-axis Diffraction (750 nm)

GRAAL-Hawk-I: Imager 4k², 1-2.5 µm
2xEE in 0.1”pixel in FOV 7.5’x7.5’
Uniform PSF over field

4 LGS off-axis
1 TT NGS
1’-8’ Science FOV

4 WFS with 32x32 subap.
1 TT sensor in VIS
Computer based on SPARTA
4 Laser Guide Stars
Deformable Secondary
The European Adaptive ELT

- Hyperbolic primary (42m)
- M5 - Field Stabilization (2.7m)
- Nasmyth Platform focus
- M4 - Adaptive Mirror (2.5 m)

- 6-9 LGSs
- SC-GLAO wavefront sensors
- Adaptive Relay Unit (~5600)
Large Deformable mirrors: from VLT to ELT

Hexapod for centring & fine focusing
Cold Plate; heat evacuation & act. attachment

2mm Thin Shell Reference body

VLT Deformable M2
- Ø 1.1m convex
- 1170 actuators
- 29 mm pitch
- 1 ms response
- Stroke 50 / 1.5 μm

ELT DM
- ~2.5 m flat
- ~5000 actuators
- 30 mm pitch
- 1 ms response
- Stroke 70-90μm
- Inter act: 2-3μm

• Microgate-ADS picture
Field Stabilization mirror 2.7 m

Tip-tilt stroke P-V required: 360µm

Seeing = 1.5 arcsec, wind speed = 18.5 m/s

Courtesy ONERA

NTE/CSEM/SAGEM picture
Single Conjugate AO @ E-ELT

- Visible Shack-Hartmann WFS
- 84 x 84 sub-apertures
- Low noise $504^2$ pixels CCD
- 700 Hz update frequency
- 83 x 83 actuators
- ESO internal development+MIDIR

From M5

150 mm

F/14.6

Pick-up dichroic

Mechanical derotator

Lenslet array

Pupil lens

ADC

---

ASTRO with LGS, Nov. 2007

AO roadmap, N. Hubin
Ground Layer AO @ E-ELT

- Laser Guide Stars: 4 - 6x visible Shack-Hartmann WFS (84 x 84), on 5'
- Low order WFS: 1x infrared Shack-Hartmann WFS (3 x 3)
- LGS WFS: low noise ~1700² pixels CCD
- ‘500-700 Hz update frequency
- ESO internal development
GLAO correction vs LGS number (42m)
GLAO correction vs FoV & 4 LGS positions (42m)

- 84x84 subapertures
- 500 frame rate (2 frame delay)
- Seeing 0.8, $\tau_0=3$ms
Ground Layer AO performance (NGS)

- **Seeing**: 1"
- **Gain in EE in 50 mas**: K, H, J
- **Photons/sub-aperture/frame**: mR<16, mR<17, mR<18, mR<19
- **Sky coverage (%)**:
  - $l=0^\circ$, $b=50^\circ$, 6' FoV
  - $b=90^\circ$, 6' FoV

Graphs showing the relationship between the number of natural guide stars and sky coverage for different conditions.
Laser Tomography Adaptive Optics

Seeing 0.8", Tau0: 3ms, 1kHz frame rate, theta0=2"

Call for proposal for Phase A Study to be launched soon
Adaptive Telescope & MCAO

- MCAO Module Phase A study launched: INAF Bologna-Arcetri-Padova-ONERA
- Laser Guide Stars: 6x visible Shack-Hartmann WFS (83²), on 2’
- M7 DM (~315mm, 88²) & M10 DM (~420mm, 108²) **NEW R&D FP6**
- IR Shack-Hartmann WFS (3 x 3) (TBC)
- LGS WFS: low noise ~1700² pixels CCD/CMOS
- 700-1000 Hz frame rate

![Diagram of Adaptive Telescope & MCAO system](image)
Combining GLAO-LTAO-MCAO & MOAO?
Combining GLAO-LTAO-MCAO & MOAO?


Diagram:
- Deformable Mirror
- Dichroic
- To wavefront sensor
- F/1.8 camera
  - (2k x 2k)
Combining GLAO-LTAO-MCAO & MOAO?
Adaptive E-ELT & EAGLE MOAO

- Ground layer AO correction provided by telescope over 5-6’
- Lower DM stroke in MOAO arm ➔ feasibility

T. Fusco
From SPHERE to EPICS

EPICS Phase A study launched: ESO, INSU, INAF, ETH, NOVA, MPIA

- XAO, Sr=90%, optional Starlight Halo Rejection
- J,H band spectro-imaging: R>30, R-band: Polarimetry
- I<8mag:
  - 30mas-100mas contrast H-band: 10^{-7} - 10^{-8}
  - 100mas-800mas: contrast H-band 10^{-8} - 10^{-9} - 10^{-10}
- I<10mag:
  - 30mas Contrast H band 10^{-6} - 10^{-7}
EPICS: E-ELT Planet Finder

Photon noise only!
Conclusions

- 1st generation AO for VLT completed
- MCAO demonstrated with MAD on-sky
- VLT Adaptive Optics Facility with two GLAO, one LTAO & 1.1m DSM ongoing
- SPHERE: VLT High contrast imager in design phase ➔ AO R&D ~ready
- European ELT
  - 2.5 m Deformable mirror with 5000-8000 actuators ➔ 3 designs & 3 proto
  - 2.7 m Field stabilization mirror ➔ 1 design & 1 proto
  - LGS fast detectors ➔ Feasibility studies ➔ next step expensive
  - Sodium pulsed laser ➔ feasibility to be launched soon
  - Real Time Computer and algorithms ➔ SPARTA & SPARTA + ➔ R&D on-going
  - Ground Layer and Single Conjugate AO being studied by ESO
  - EPICS: high contrast imager being studied by Consortium + ESO
  - Multi Conjugate AO module ➔ Phase A study with Consortium + ESO
  - Laser Tomography AO ➔ Phase A study ➔ Call for proposal
  - Multi Object AO: EAGLE ➔ Phase A study with Consortium + ESO