



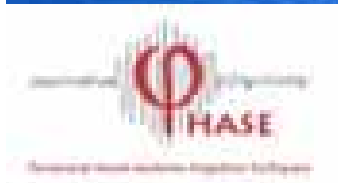
Optique adaptative pour l'astronomie

Développements en cours et à venir à l'ONERA

T. Fusco,
et l'équipe HRA du DOTA



r e t u r n o n i n n o v a t i o n



Plan de l'exposé

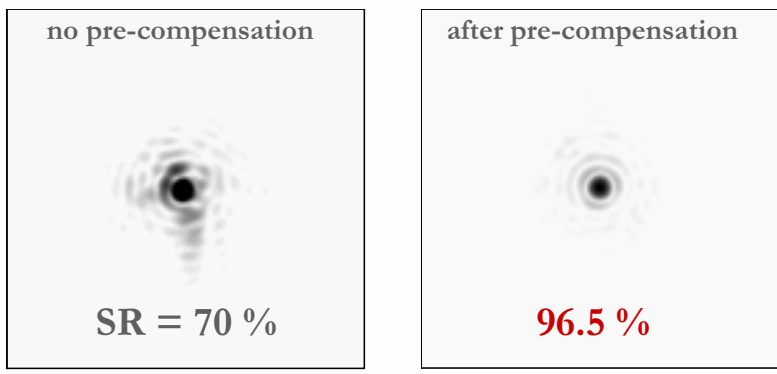
- Les thèmes de recherche
- Les moyens expérimentaux
- Les projets
 - Optique adaptative et VLT
 - NAOS
 - SPHERE / SAXO
 - Optique adaptative et ELT
 - OA intégré dans le télescope (M4)
 - MCAO module
 - MOAO (EAGLE)

Les thématiques en OA

- Etudes systèmes
 - Définition,
 - Intégration
 - Validation et tests

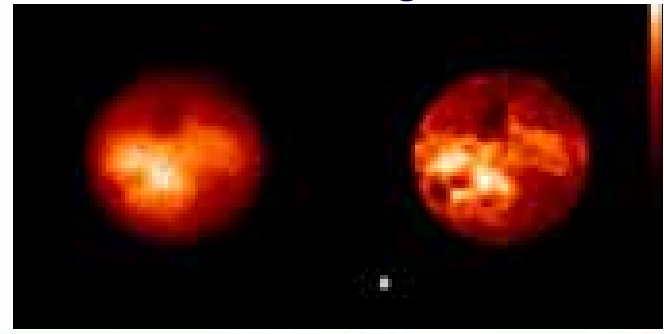
COME-ON
COME-ON+
NAOS
SPHERE

- ASO

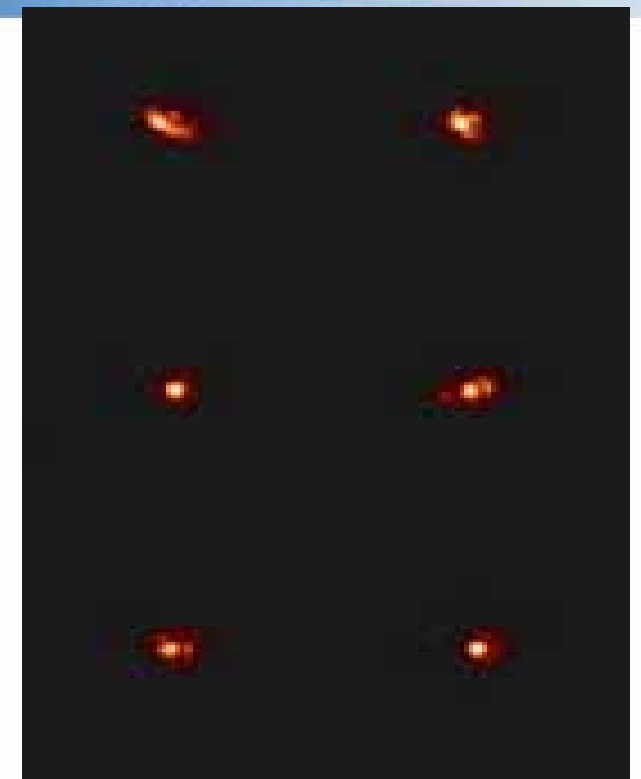


- Commande

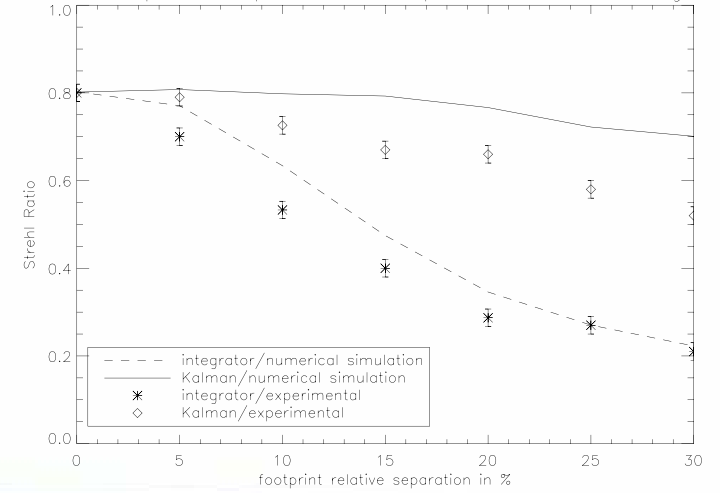
- Traitement du signal et des images



On-Axis Star Off-Axis Star



closed-loop off-axis performance of optimal control versus integrator



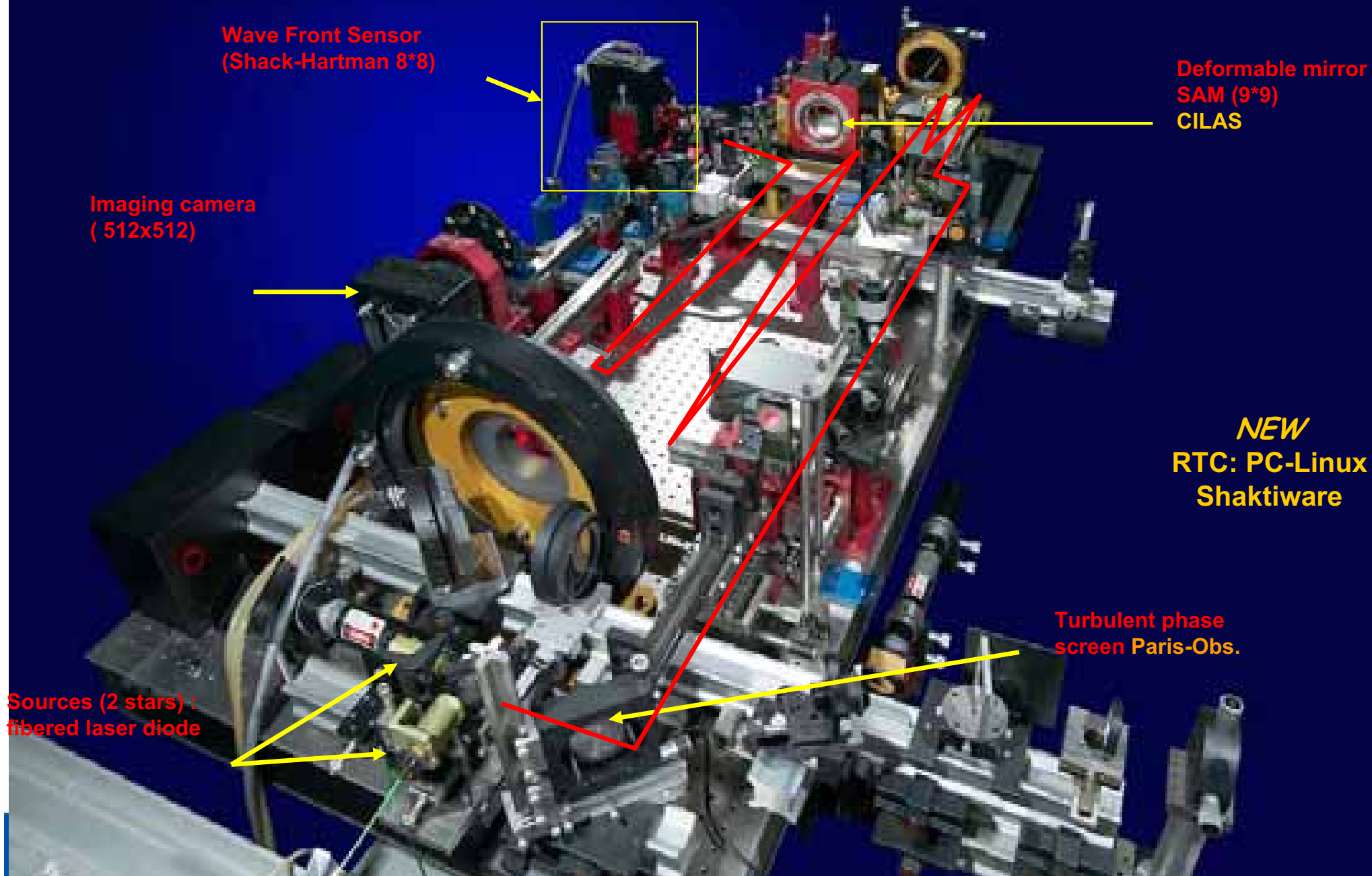
Les moyens expérimentaux (I)

- BOA : *systeme complètement intégré, optimisé ET évolutif*

- **OA classique et extreme**
- **Nouveaux concepts d'analyse**
 - WCoG
 - SH filtré
 - Diversité de phase
- **Nouveaux concepts de commande**
 - Prediction / Kalman (filtrage de Vibration)
 - OA hors axe
- **Nouveaux composants**
 - EMCCD
 - Miroir déformable (ALPAO)

- J.-M. Conan et al “Myopic deconvolution of AO images by use of object and PSF power spectra “ Appl. Optics
- C. Dessenne et al., “Predictive control laws”, Opt. Letters
- C. Petit et al. “ Optimal control law for multiconjugate AO“, CR Phy., 2005
- T. Fusco et al., “Closed loop experimental validation of the Spatially Filtered SH “, Opt. Letters , 2006
- L. Mugnier et al. “MISTRAL, a myopic edge preserving image restoration method “ JOSAA, 2004
- J.-F Sauvage et al. “ “, JOSAA
- C Petit et al. “First laboratory validation of vibration filtering with LQG control“ Opt. Express
- T. Fusco et al. “Closed loop experimental validation of the WCoG concept using EMCCD“ (en prep.)

BOA



Les moyens expérimentaux (II)

- HOMER (Hartmann-Oriented MCAO Experimental Resource) :
 - MCAO
 - GLAO
 - LTAO
 - Woofer / Tweeter
 - Commande – tomography – MCAO open et closed loop
 - Concept d'analyse de front d'onde (MFoV)
 - Multi-stage AO

Integration OK
Boucle fermée OA OK
Fermeture GLAO/MCAO (fin 07)

MCAO laboratory test bench at ONERA HOMER

[Hartmann Oriented Multiconjugate ao Experimental Resource]

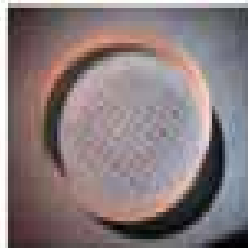
WFS and imaging
at visible wavelengths

October 2007



RTC-Linux
ShaktiWare

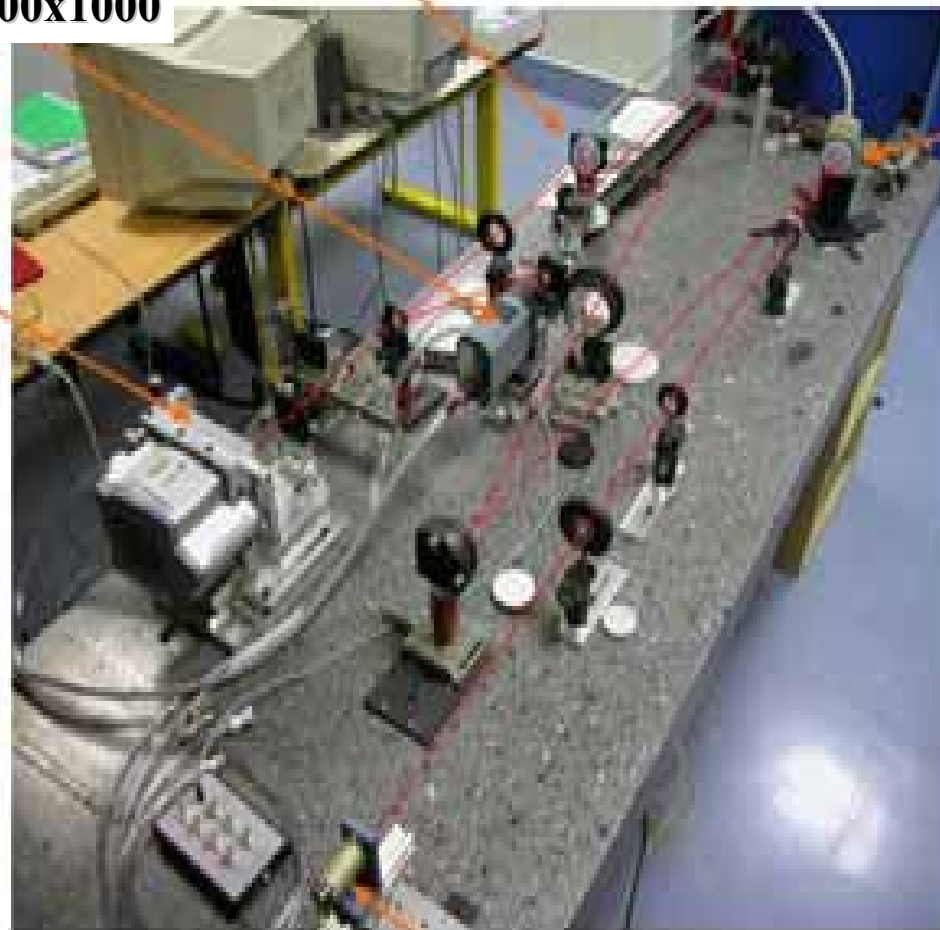
DM2 DM88 ALPAO



Imaging camera
ANDOR CCD 1000x1000

WFS

Onera micro-lens
ANDOR EM CCD 1000x1000



DM52 ALPAO

DM1



Source

**System integrated – aligned
Loop closed in classical AO**

Réalisation pour le VLT – NAOS (I)



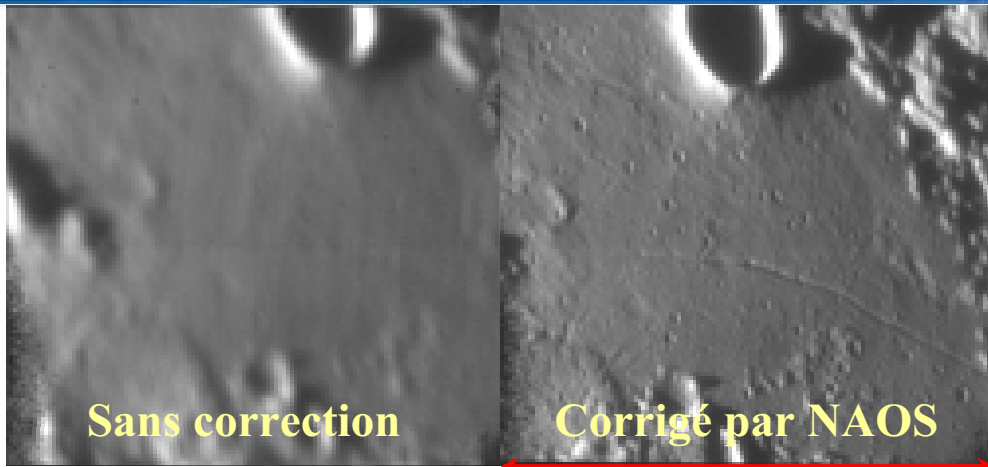
- 800 kg
- Supporte la caméra CONICA
- Derotation de champ
- DM: 185 actionneurs
- TTM rapide
- Freq max = 500 Hz
- 2 ASO (14x14 – 7x7)
 - Visible
 - IR
- RTC optimisé
- Préparation des observations



ONERA
LAOG
LESIA
+ ESO



Réalisation pour le VLT – NAOS (II)



26" = 45 km



HST (1 μ m)



NAOS (2.2 μ m)



Genzel et al.



NACO image of the Brown Dwarf Object 2M1207 and GPOC

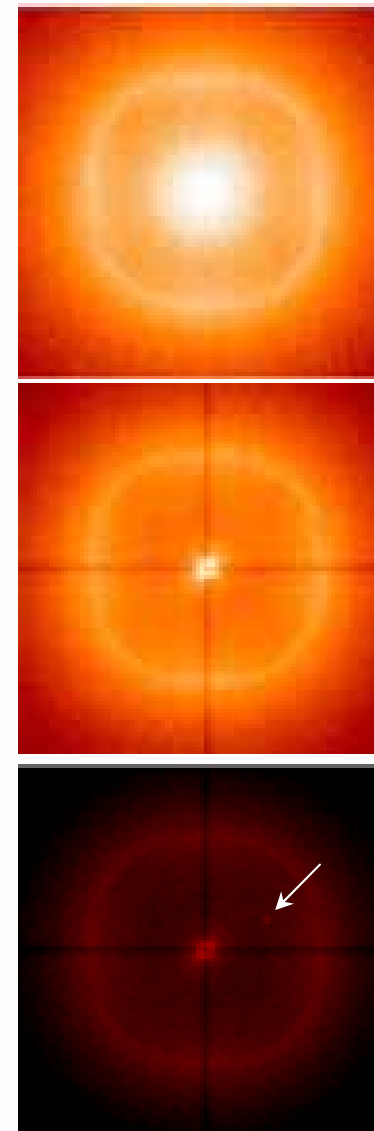
Chauvin et al.

Réalisation pour le VLT – SPHERE / SAXO

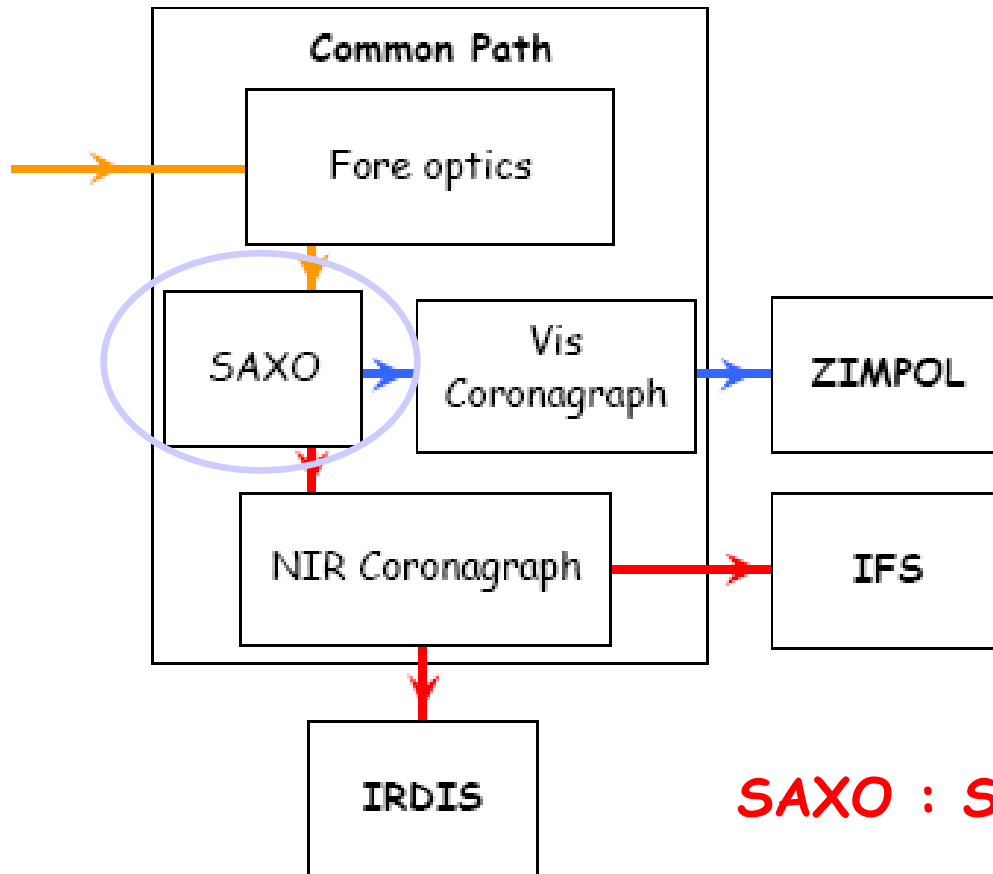
Direct detection : *small separation (1-100 AU)*

Large magnitude difference $\Delta m > 15$

- High contrast capability
 - *Extreme AO (turbulence correction)*
 - Feed coronagraph with extremely well corrected wavefront
 - *Coronagraphy (removal of diffraction pattern)*
 - dynamics at short separation < 0.1"
 - *Differential imaging (removal of residual defects)*
 - Calibration of internal system defects
 - Calibration of non common path aberrations
 - Pupil and Field stability
 - Smart post processing imaging tools
- High sensitivity
 - *Optimal correction up to $V_{mag} \sim 10-11$*
 - Large number of target



The SPHERE instrument and the SAXO system



SPHERE

3 Focal plane instruments

- NIR differential imaging (IRDIS)
- Integral Field Spect. (IFS)
- Polarimetric differential imaging (Zimpol)

Coronagraphic capabilities (VIS and NIR)

Extreme AO system

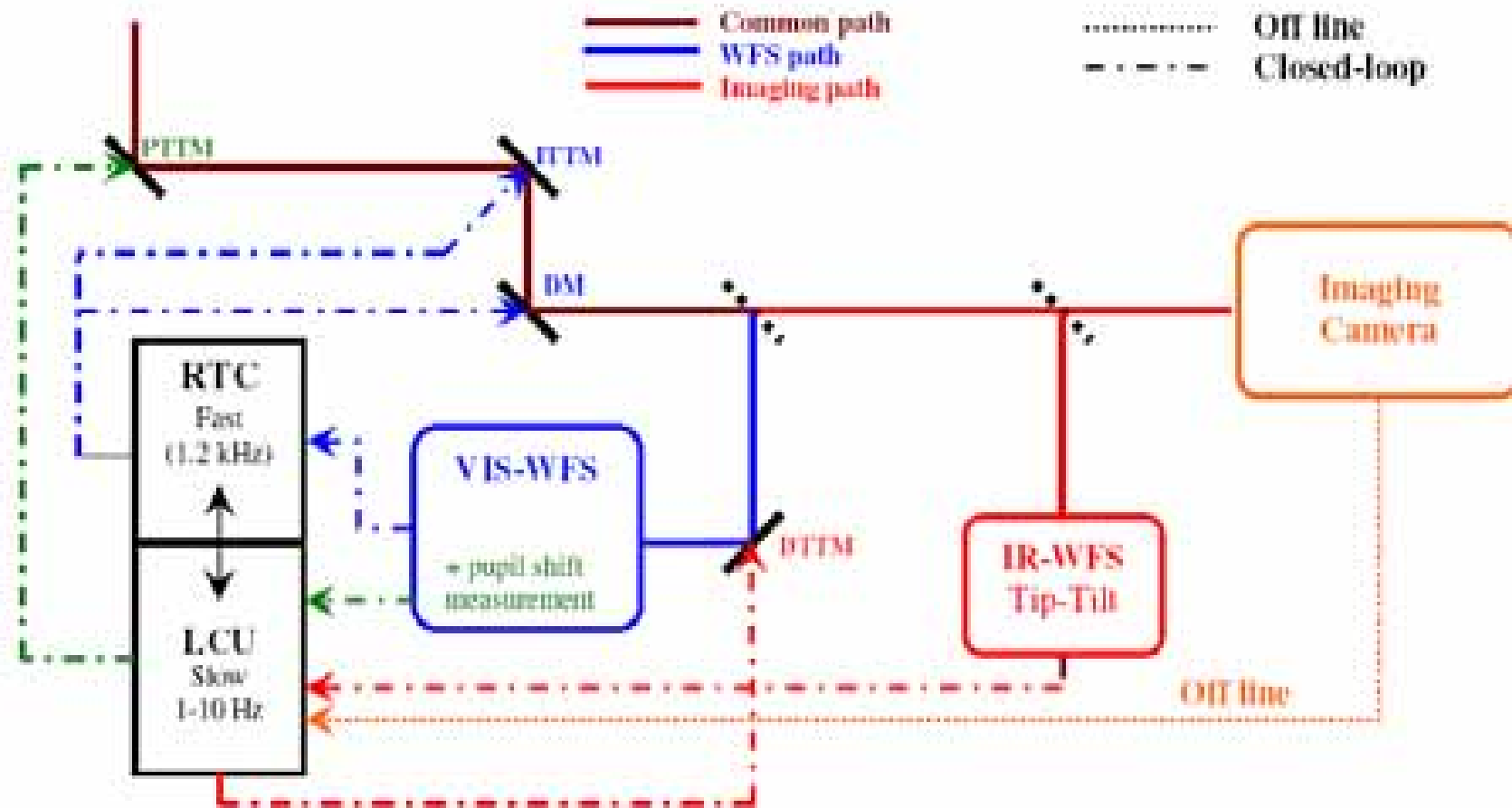
SAXO : Sphere AO for eXoplanet Observation

- To correct for turbulence and system defects
- To ensure system stability
- To provide useful data for post-processing

SAXO schematic view

3 Loops:

- main AO loop (~ 1.2 kHz) \longrightarrow Smooth halo reduction
 - IR Auxilliary sensor for fine centering (~ 10 Hz)
 - Pupil sensor for pupil stabilisation (~ 0.1 Hz)
- \longrightarrow Persistent speckle reduction



SAXO: the challenges

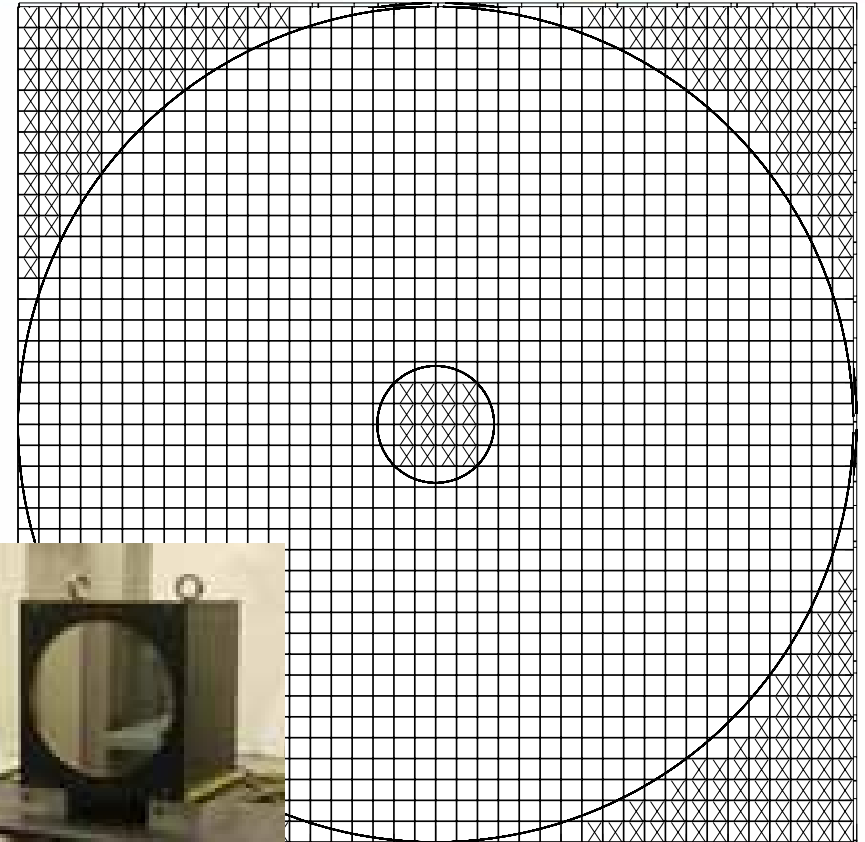
1 order of magnitude better than existing AO systems

✓ New technologies :

- DM : 200 ⇒ 1370 actuators
- CCD : 500 ⇒ ~ 1500 Hz
- $\sigma = 5e-$ ⇒ $\sigma < 1e-$
- RTC : > x200

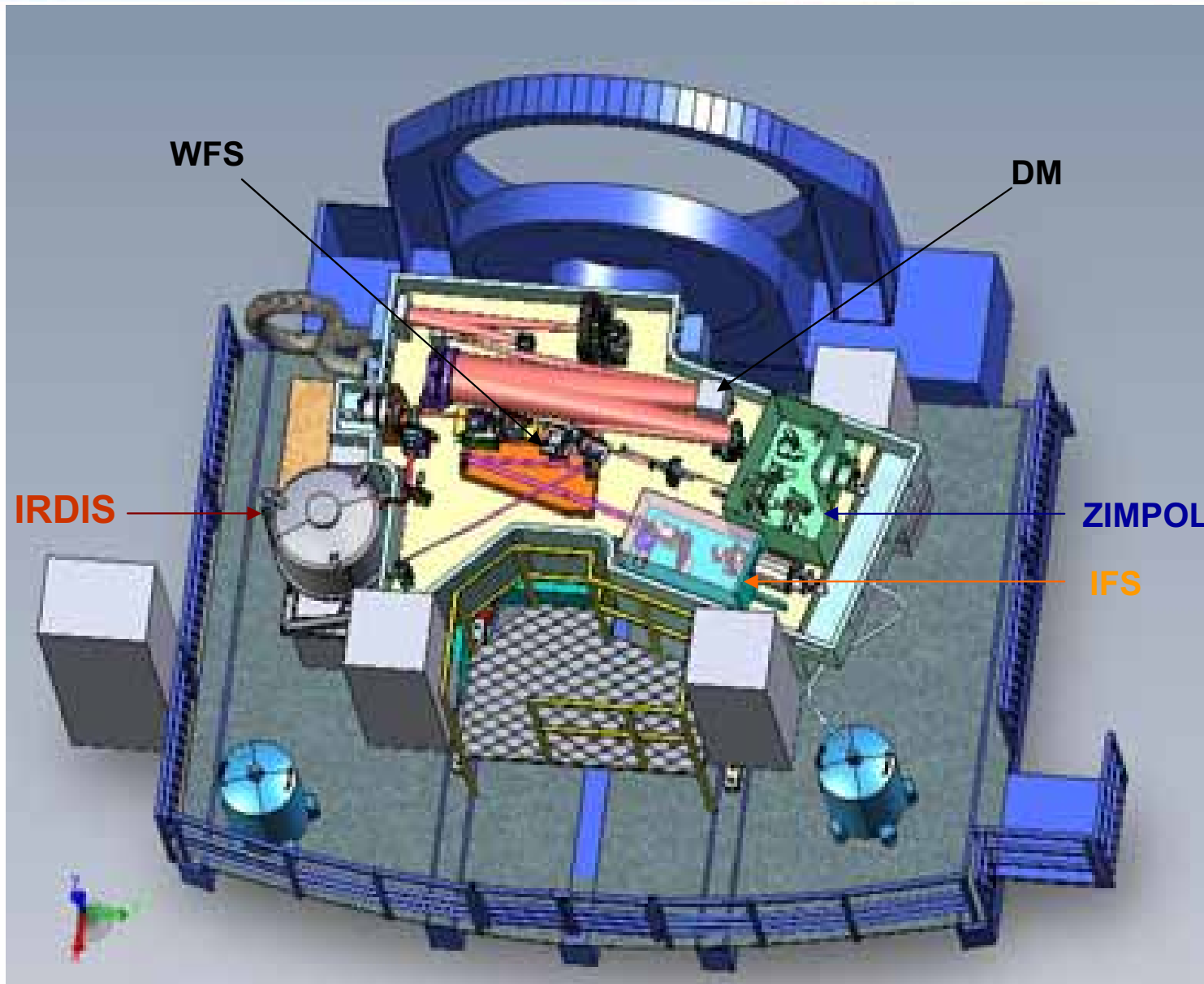
✓ System aspect:

- Control of 1300 actuators
- System calibration
- Filtered-SH and pupil stabilisation
- Dedicated Tip-Tilt sensor at the level of the coronagraphic mask
- Differential aberration calibration



SPAOSRE

Implementation @ Nasmyth



LAOG (PI)

LAM
LESIA
ONERA
LUAN

Univ. de Padoue

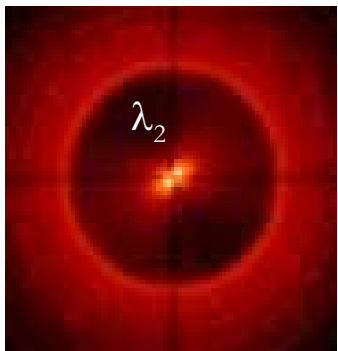
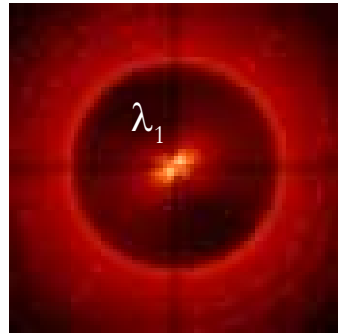
UTH Zurich
Obs de Genève

MPIA Heidelberg

Univ Amsterdam
ASTRON

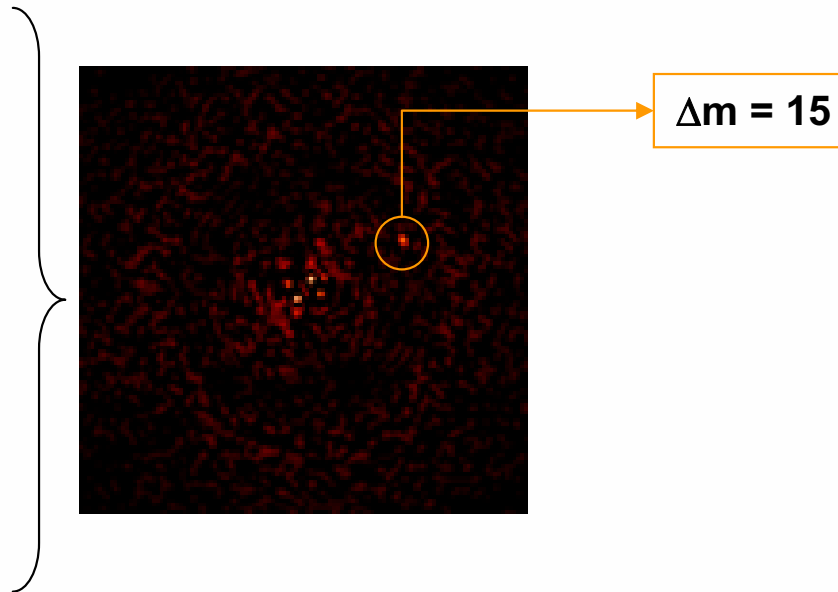
Phase de réalisation – Sur le ciel fin 2010

SPHERE – post processing & expected performances



+ calibration

- Reference star
- WFS data



➤ Assumed Defects (conservative):

- ⇒ Seeing variation (obj/ref) = 10 %
- ⇒ Reference decentering
- ⇒ Reference Pupil shift = 0.6%
- ⇒ Diff WFE = 10 nm
- ⇒ Additional non turbulent jitter = 3 mas

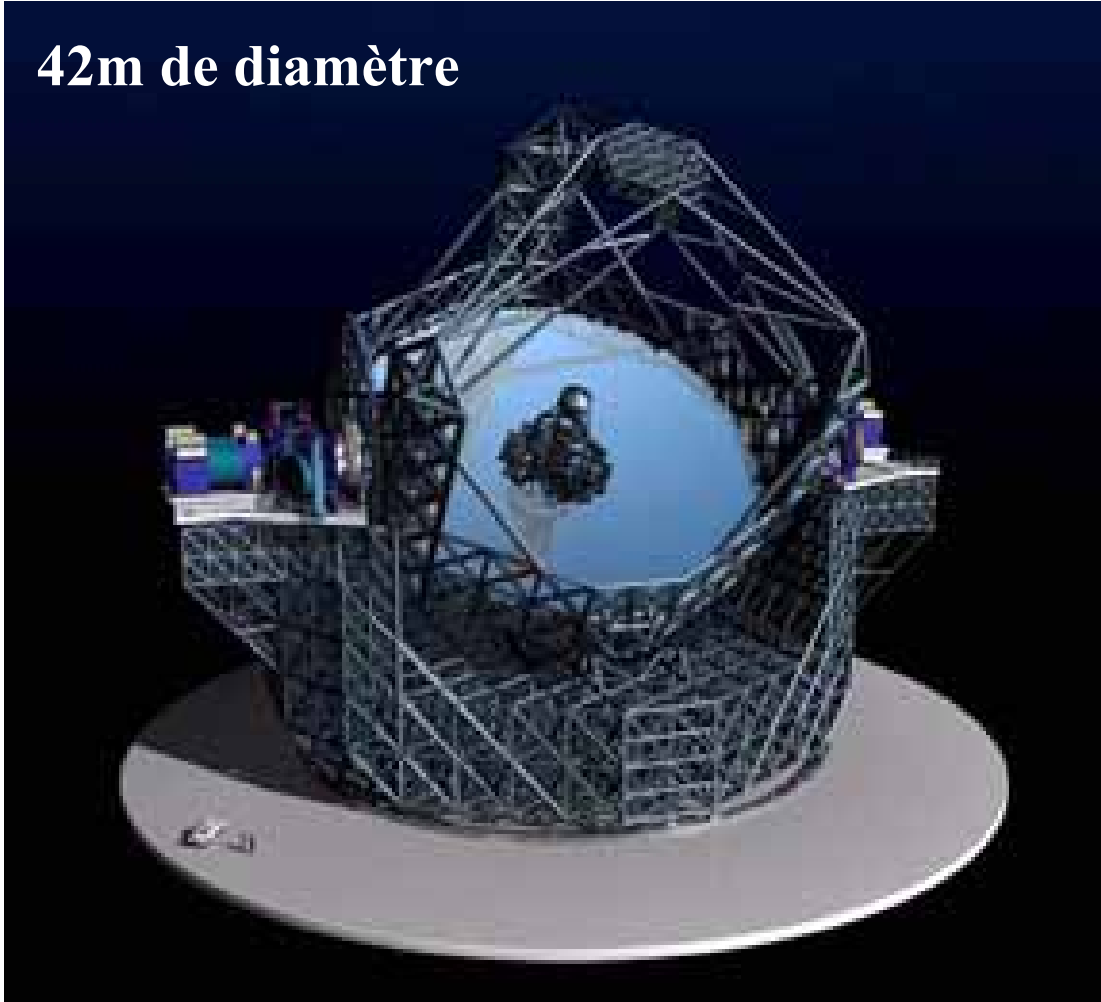
= 0.5 mas

- Detection up to 100 pc (depending on age and type)
- Masses > Jupiter
- Distance star-planet > 0.1"
⇒ > 1 AU a 10 pc

Etudes pour le télescope géant européen (E-ELT)

Le télescope géant européen: E-ELT

42m de diamètre



- Étoiles artificielles
 - ⇒ Système laser
- Segmentation du miroir de 42 m
 - ⇒ Cophasage
- Miroirs déformables
 - ⇒ Grands miroirs
 - ⇒ Micro-miroirs
- Analyse de front d'onde
 - ⇒ Algorithmes
 - ⇒ Détecteurs visibles et infrarouges
- Calculateurs temps réels
 - ⇒ Algorithmes
 - ⇒ Architecture
- Traitement de données
 - ⇒ Calibration
 - ⇒ Restauration d'images

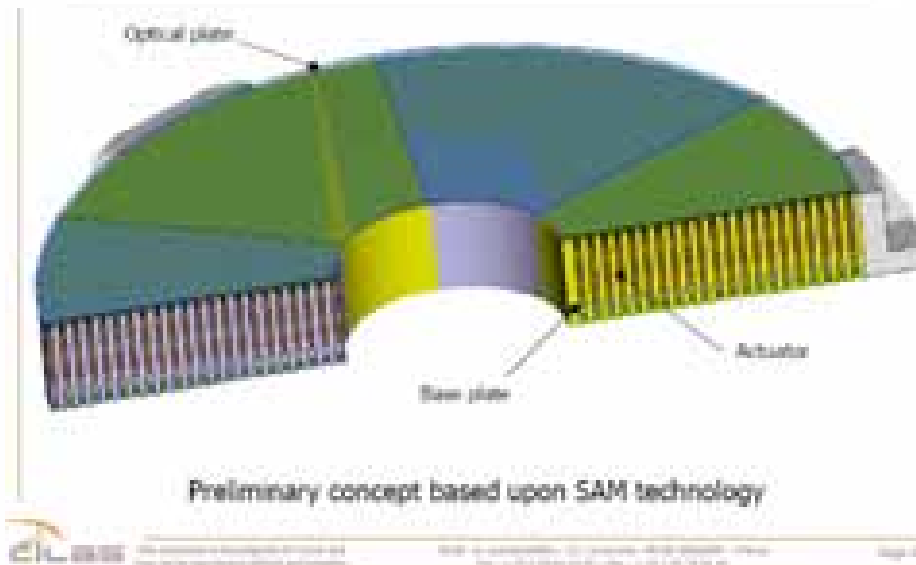
*Systeme
Instrumentation associée*

Etudes pour le ELT

- M4 adaptatif

Cilas

- 2.5 m
- > 5000 actionneurs
- BP > 500 Hz



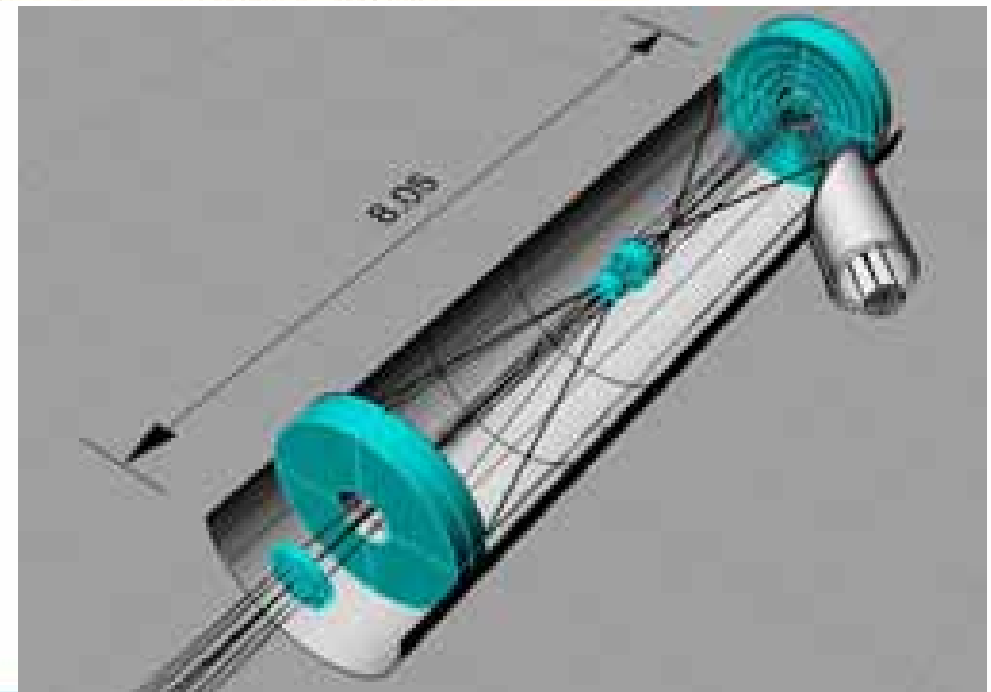
- MCAO module

INAF - ONERA

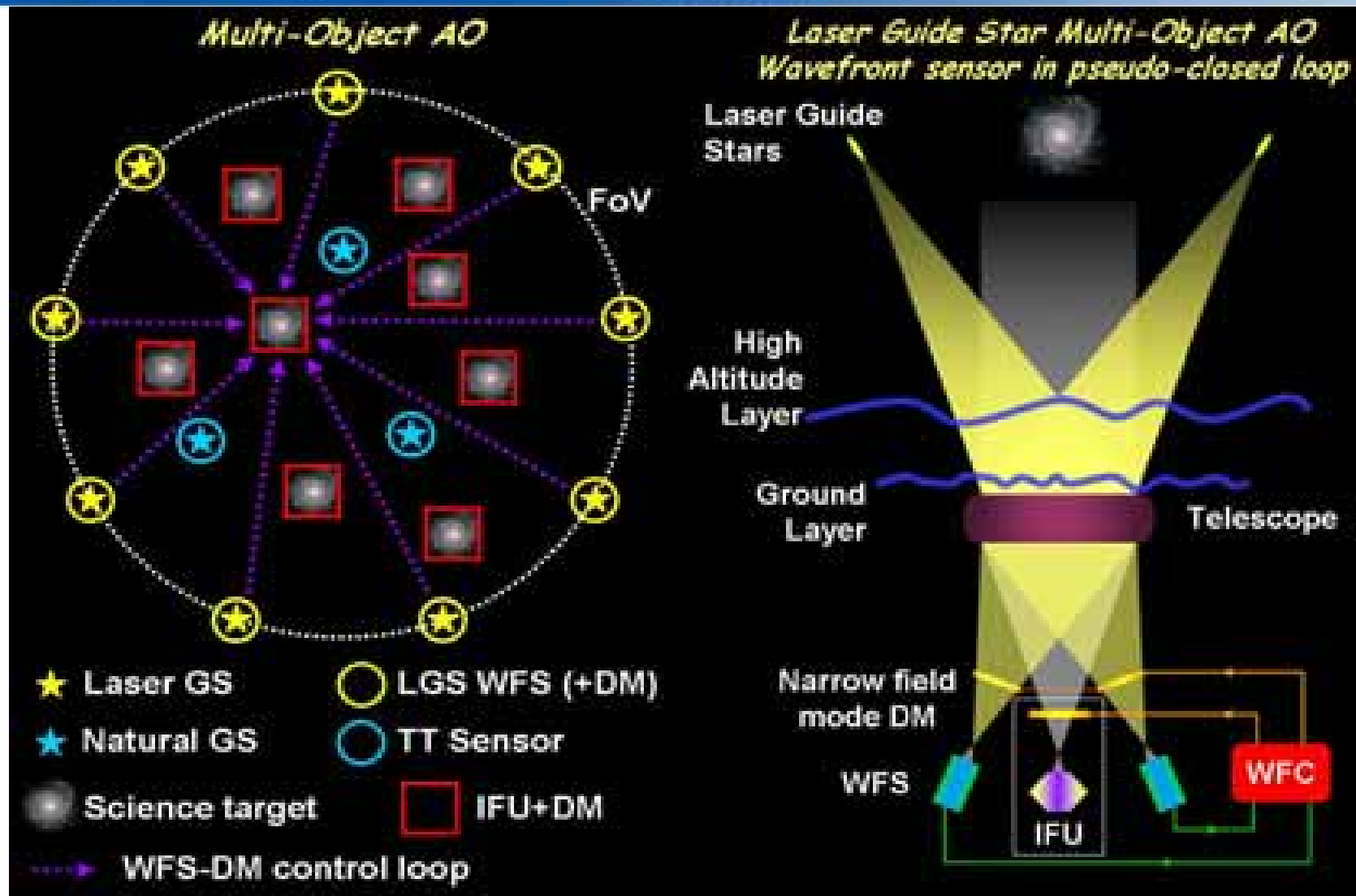
- 3 Miroirs déformable
- Multi LGS (6 à 9)
- Champs typiques 1'x1'

- MOAO (EAGLE)

*LAM, LESIA, GEPI, ONERA, UK-ATC,
Univ Durham*



MOAO + Laser Guide Star

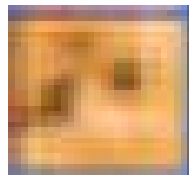
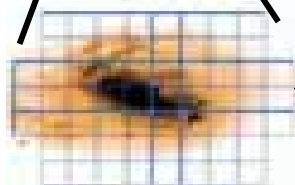
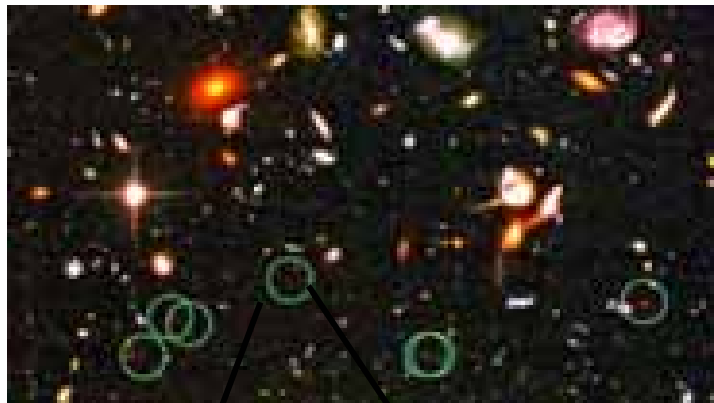


**WFS LGS specific issues : elongation, tip/tilt/defoc indetermination...
Handling of NGS + LGS data (different geometry/rate...)**

Un exemple d'instrumentation : EAGLE (I)

Étude des galaxies primordiales et des populations stellaires

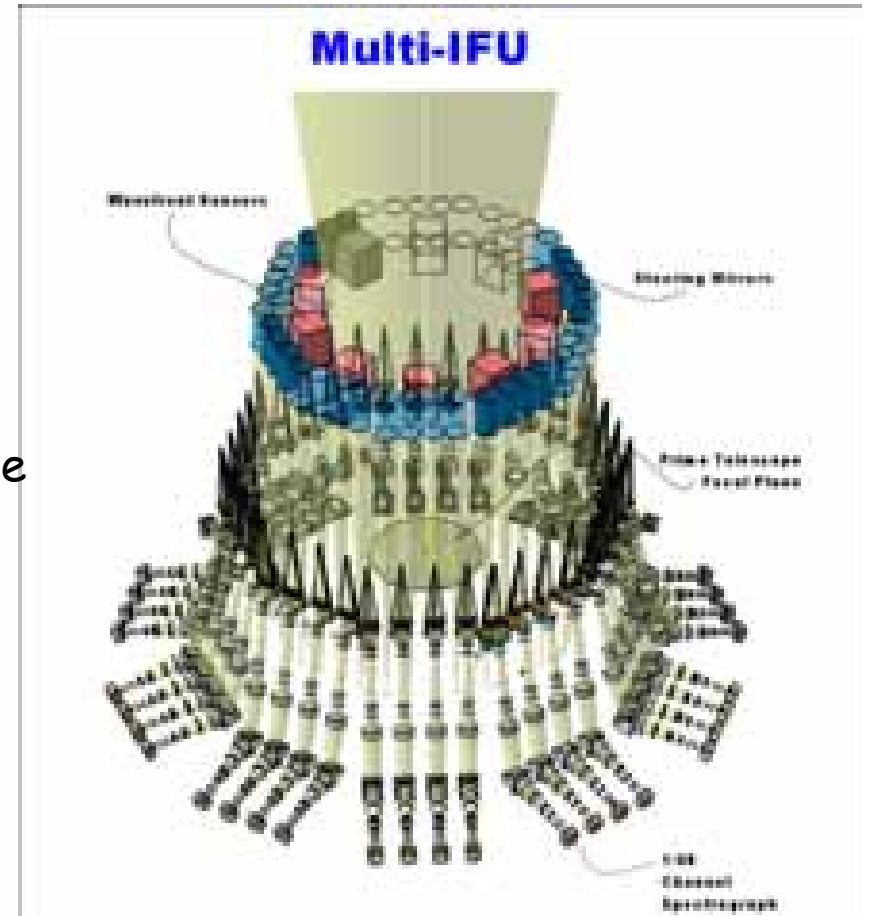
- EAGLE: "Elt Ao for GaLaxy Evolution"
 - ⇒ OA à grand champs
 - ⇒ Utilisation de micro miroirs déformables
 - ⇒ Reconstruction tomographique
 - ⇒ Étoiles lasers multiples
 - ⇒ Mesure de front d'onde en boucle ouverte



to map physical parameters within these galaxies

With an high spatial resolution

And with an high spectral resolution



Conclusion

- **A l'origine de l'OA pour l'astro (COME-ON)**
- **Implication forte de l'ONERA dans les projets astro pour VLT & ELT**
 - Etudes systèmes
 - Validations expérimentales
 - Intégration et tests de systèmes opérationnels
- **Nombreux moyens expérimentaux**
- **Etudes amont**
 - analyse de front d'onde
 - Commande (voir Kulcsar et al.)
 - Traitement des données
- **Collaborations avec les principaux observatoires Français (PHASE)**
- **Interactions fortes avec l'ESO**
- **Synergie activités astro, civil (oeil, telecom) et défense**
 - Posters : C. Robert, N. Schwartz, G. Chenegros
 - talk : Y. El Mrabet et al.
 - talk : J.-M. Conan et al.