Multi-conjugate adaptive optics

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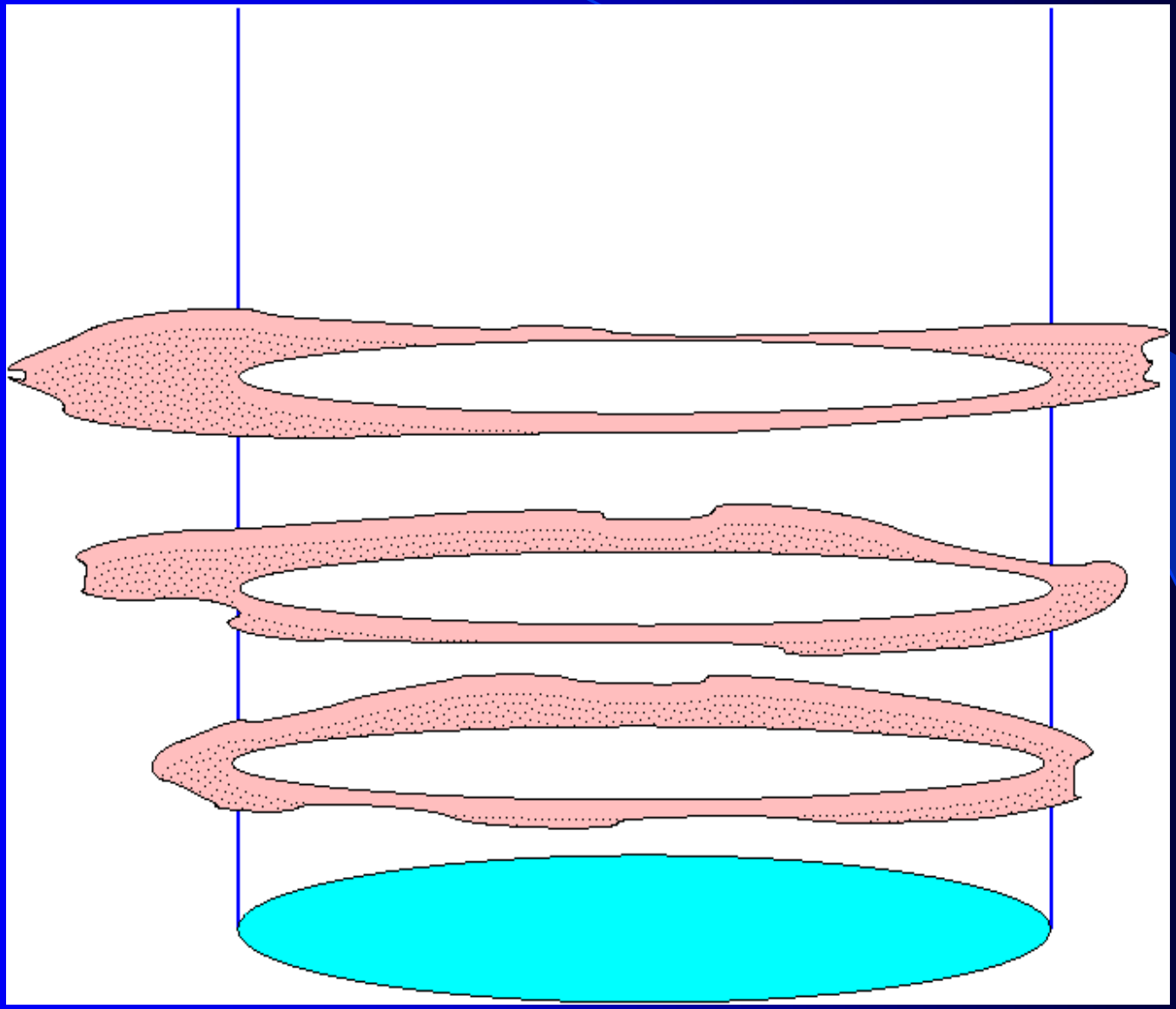
Outline

- In this talk, I will:
  - Present why we need MCAO
  - Show a simple way to control MCAO systems ("star oriented")
  - Show some complications when LGSs are used
  - Variation on MCAO: Layer oriented WFS
  - Some MCAO projects

Why MCAO ?

- Main limitations of single star/DM AO:
  - Cone effect → No LGS in the visible on large tel.
  - Anisoplanatism → reduces corrected FOV
    - ~30" (radius) in IR, ~3" in visible
    - PSF variations in FOV make data analysis difficult
- Solutions:
  - use several guide stars to probe larger turbulence volume ("tomography" WFS)
  - use several DMs conjugated to different altitudes, to correct a larger volume of turbulence

On-axis AO



Seeing of 0.5", J band

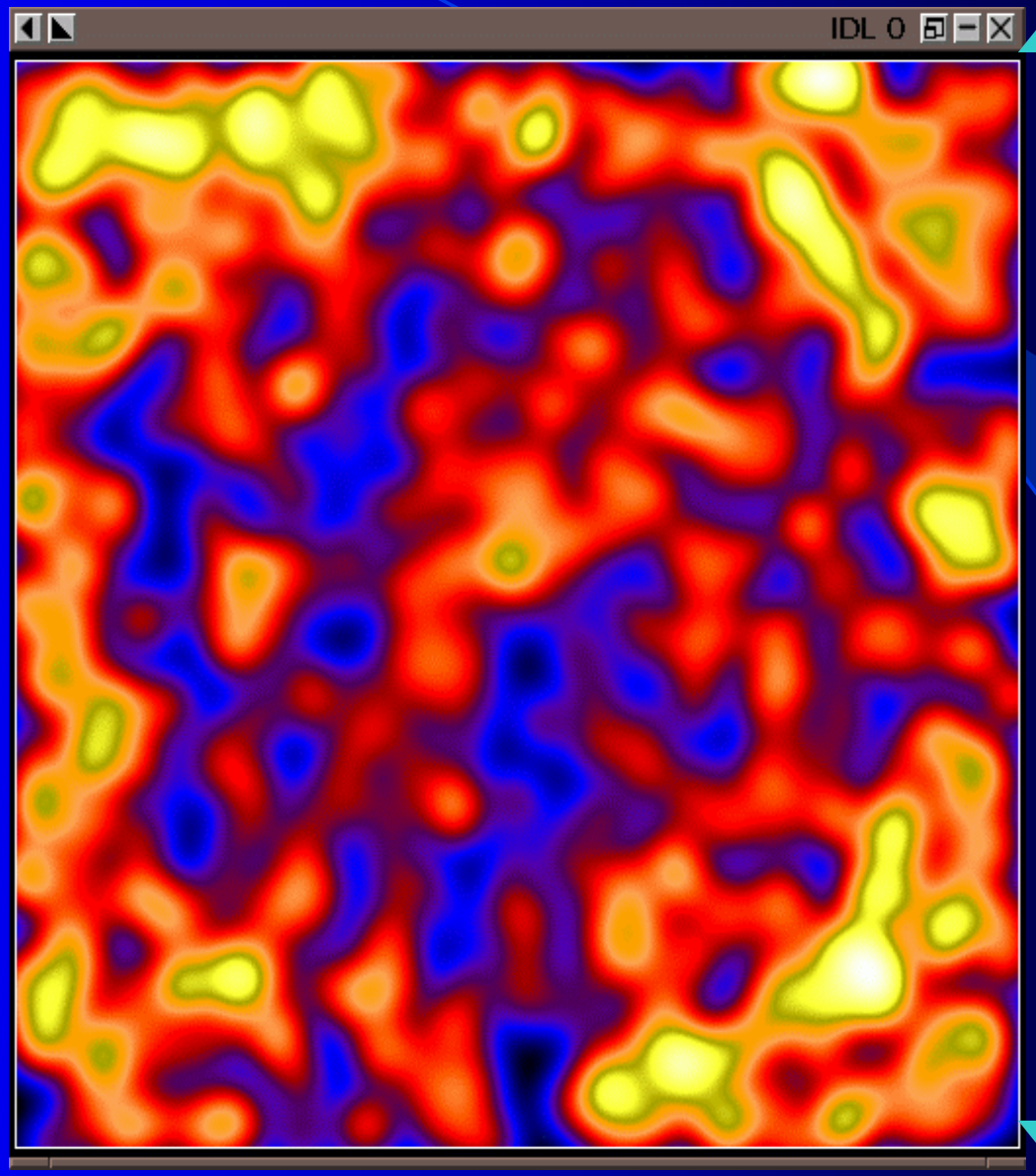
ø 80"

J band

1000 stars

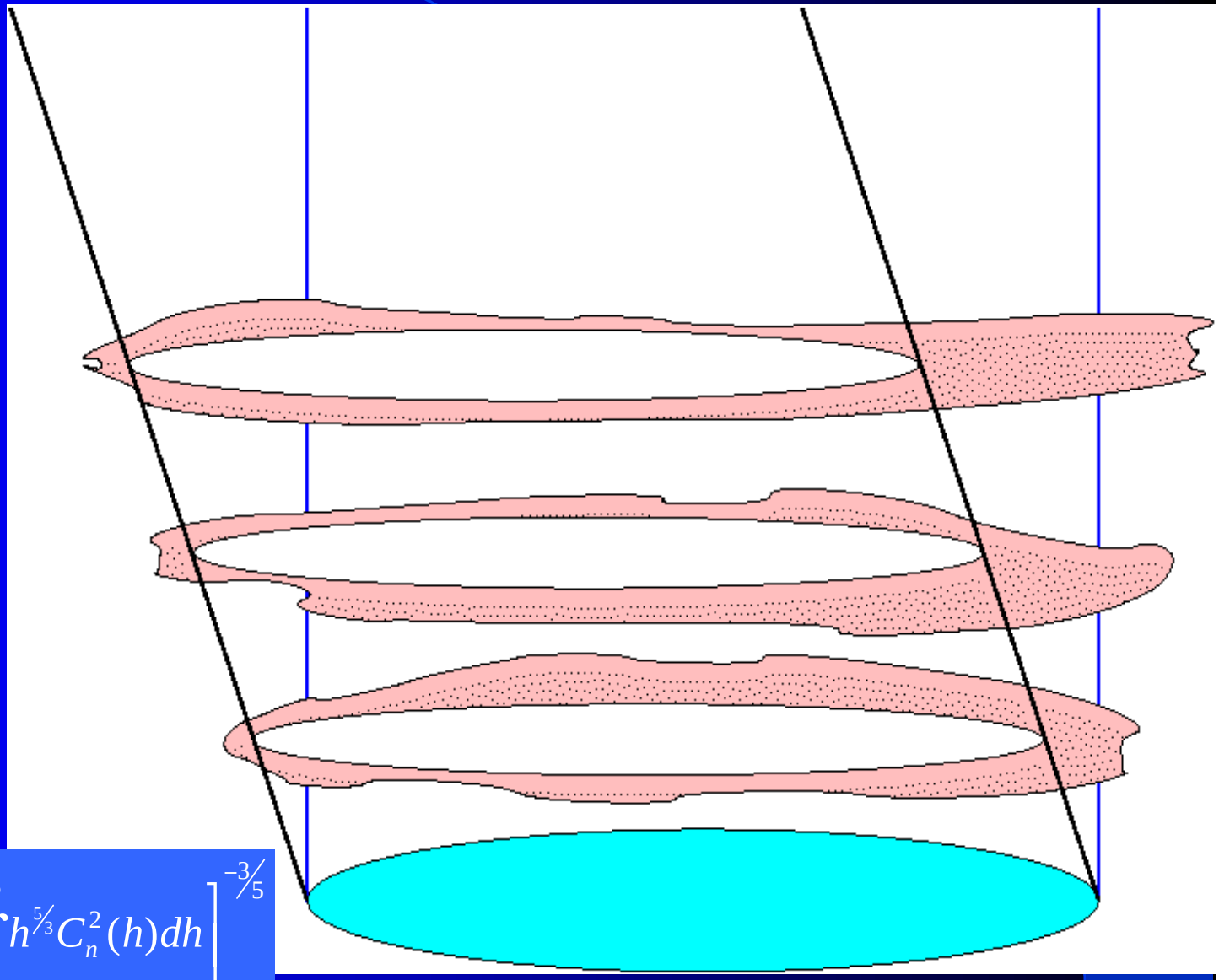
FWHM

~ 0.4"



80"

AO: anisoplanatism



$$\theta_0(\lambda) = \left[2.91 k^2 \sec(z) \int_0^\infty h^{5/3} C_n^2(h) dh \right]^{-3/5}$$

NGS-AO, J band

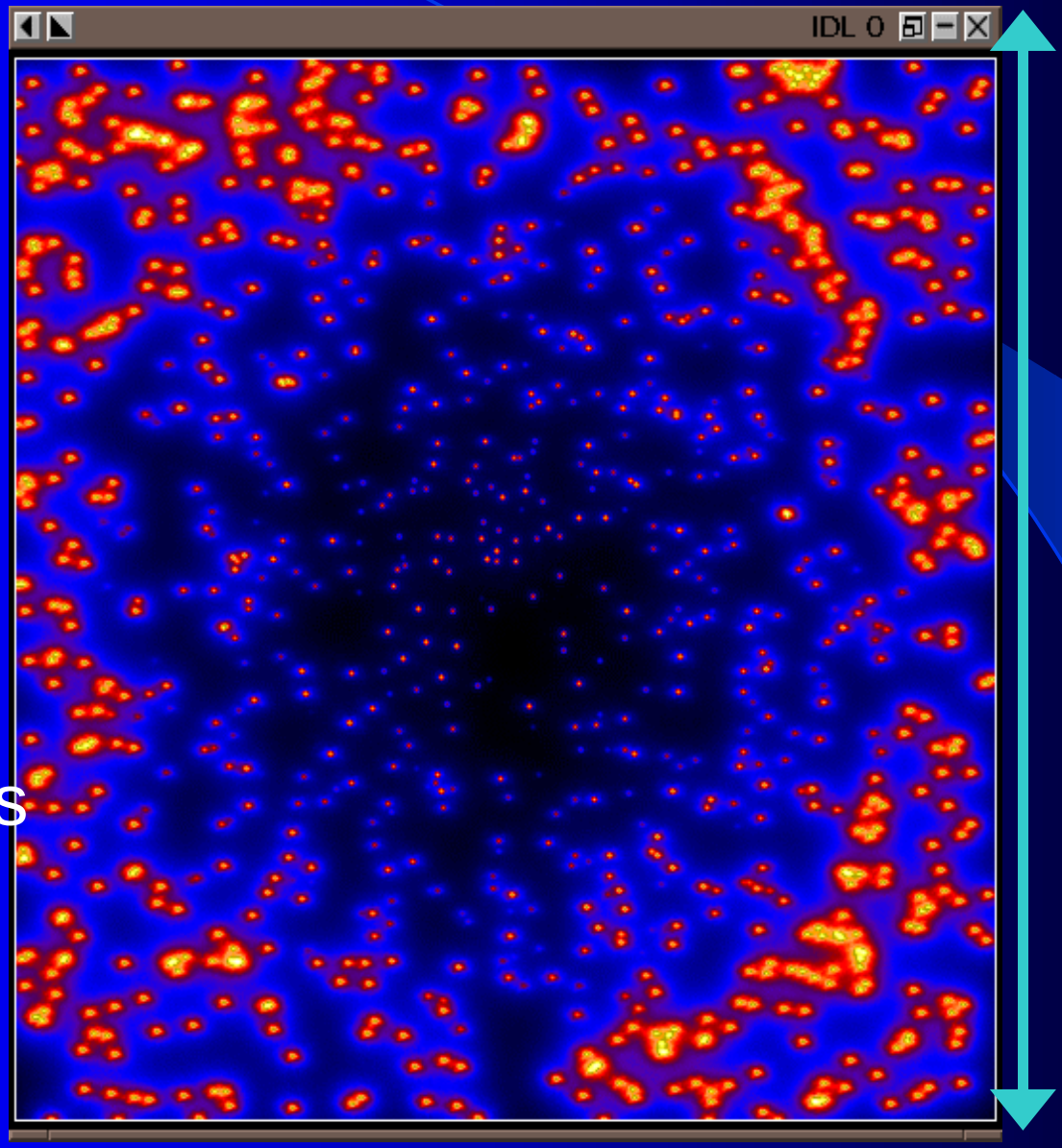
ø 80"

J band

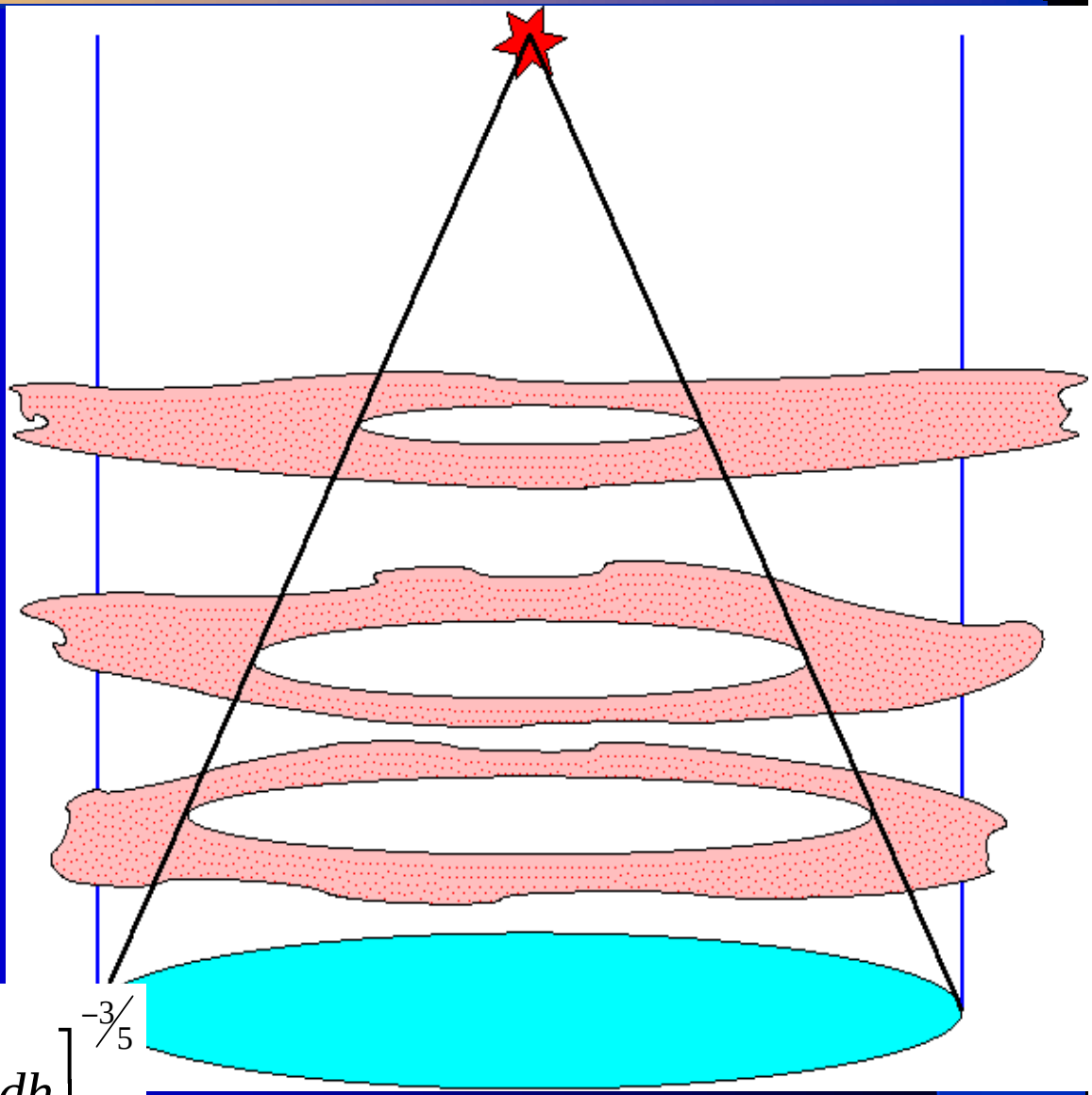
1000 stars

FWHM

34 → 70 mas



AO: cone effect



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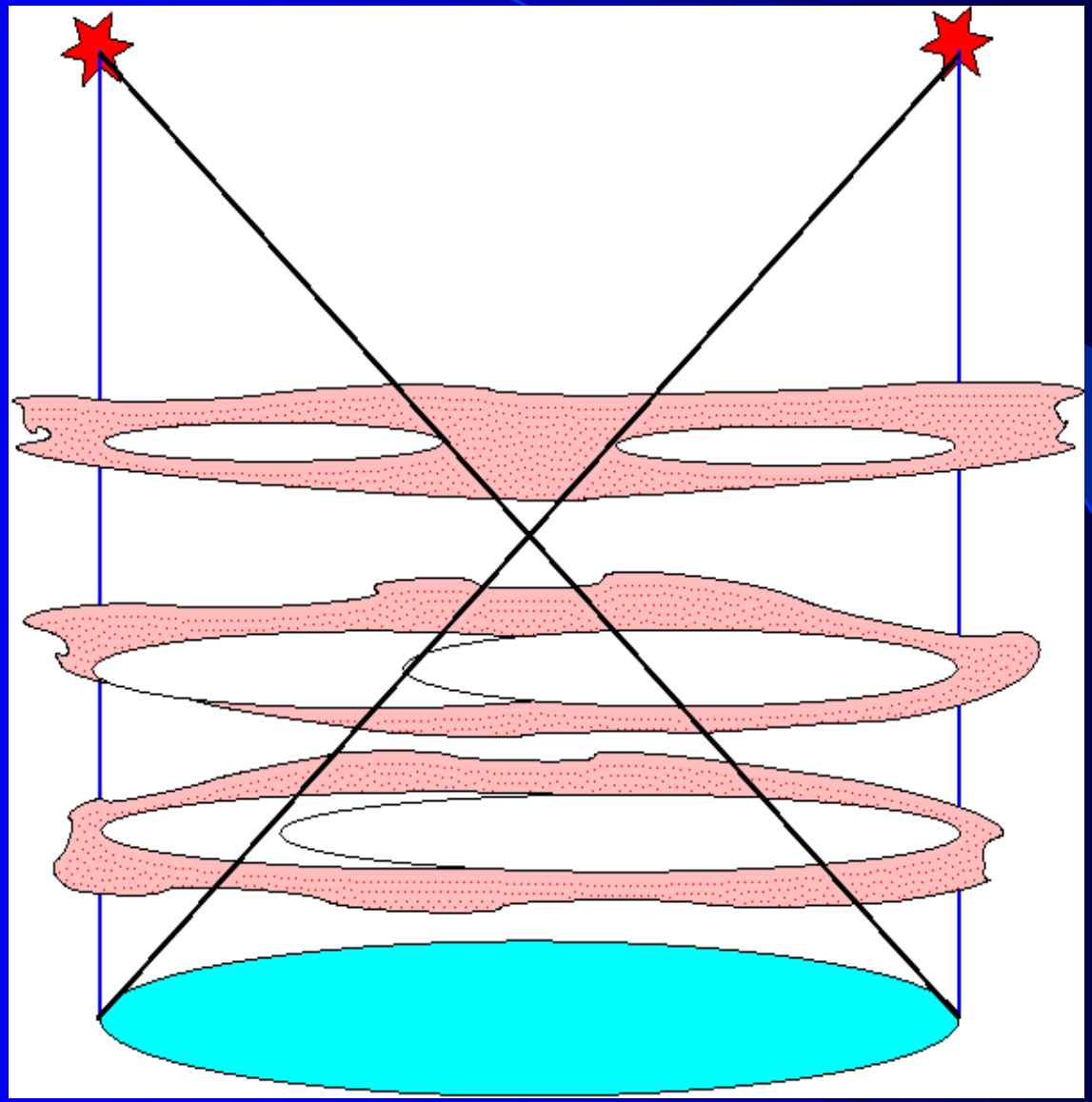
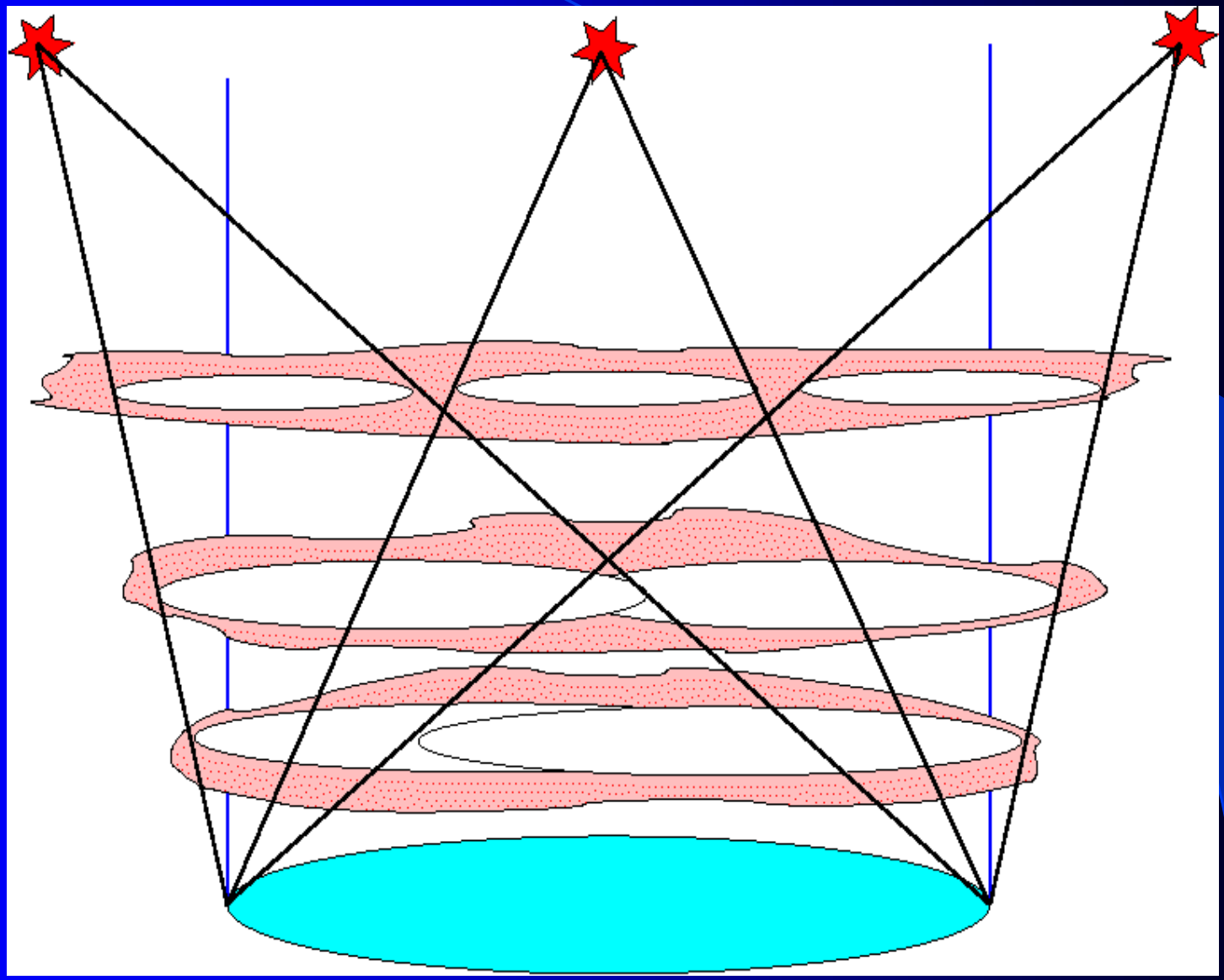
$$d_0(\lambda) = \left[k^2 \sec(\varsigma) \int_0^{\infty} C_n^2(h) F\left(\frac{h}{H}\right) dh \right]^{-3/5}$$

AO: Multiple LGSs



AO: Increasing the FOV



MCAO, J band

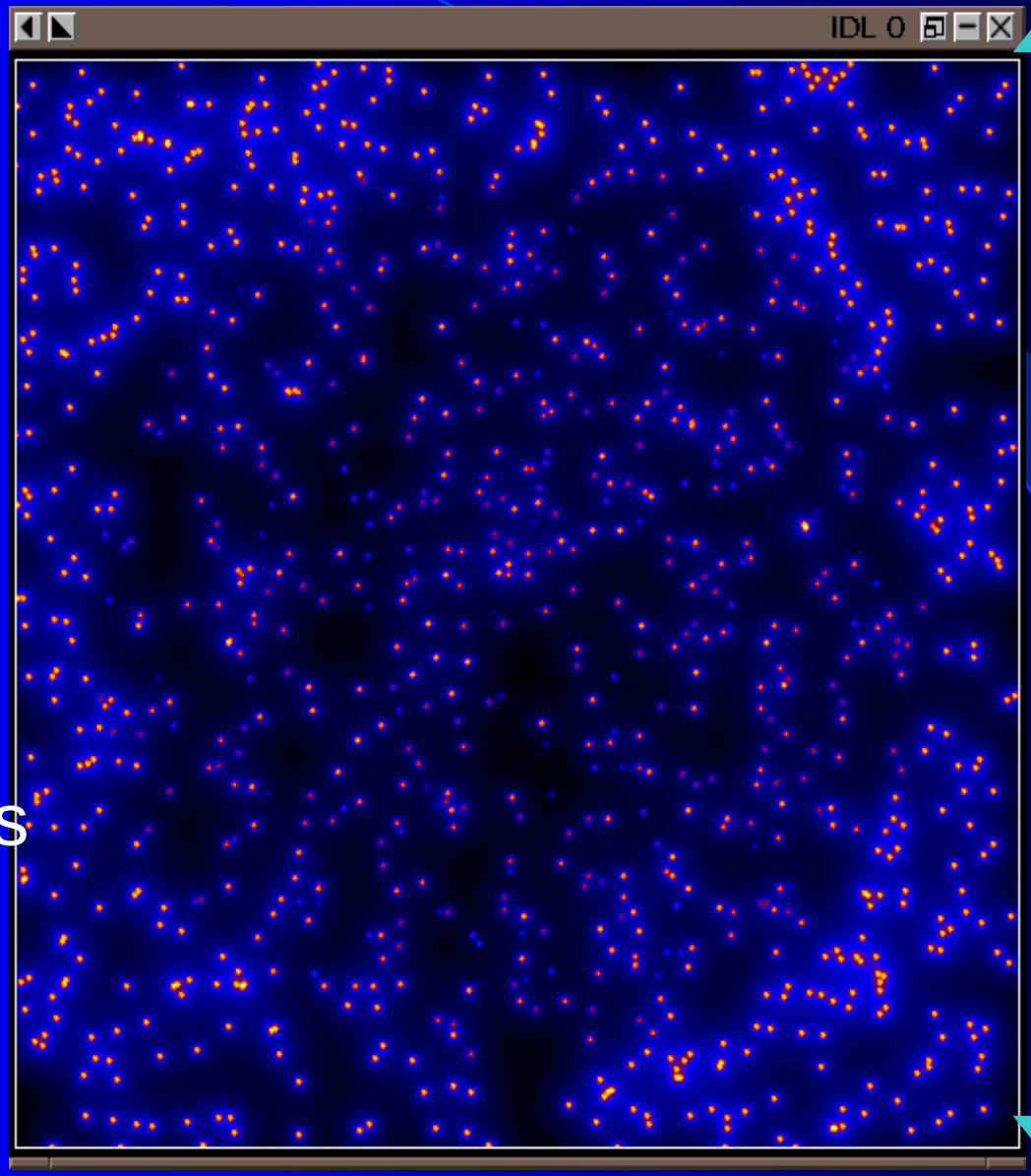
ø 80"

J band

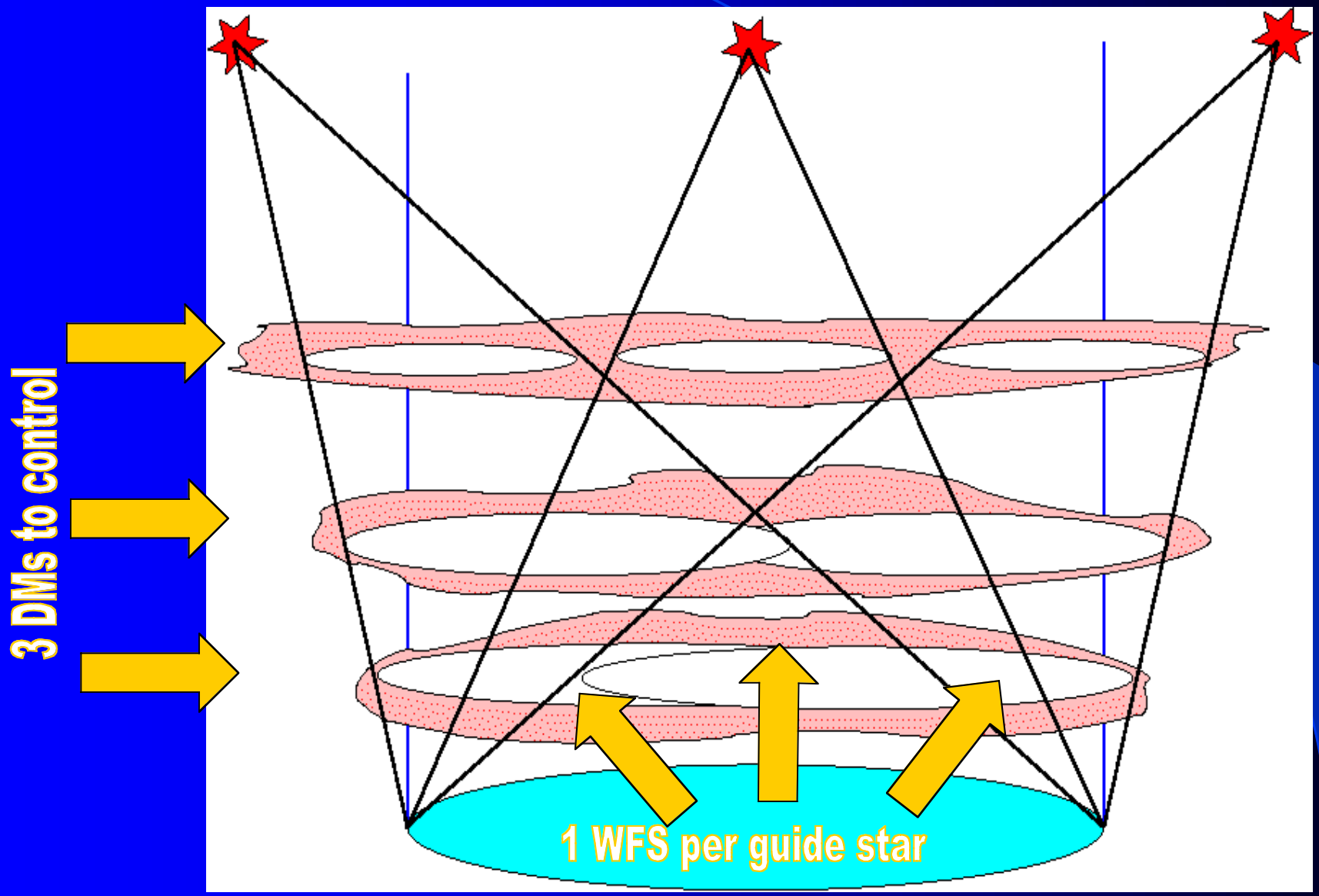
1000 stars

FWHM

37 → 39 mas



AO: Increasing the FOV

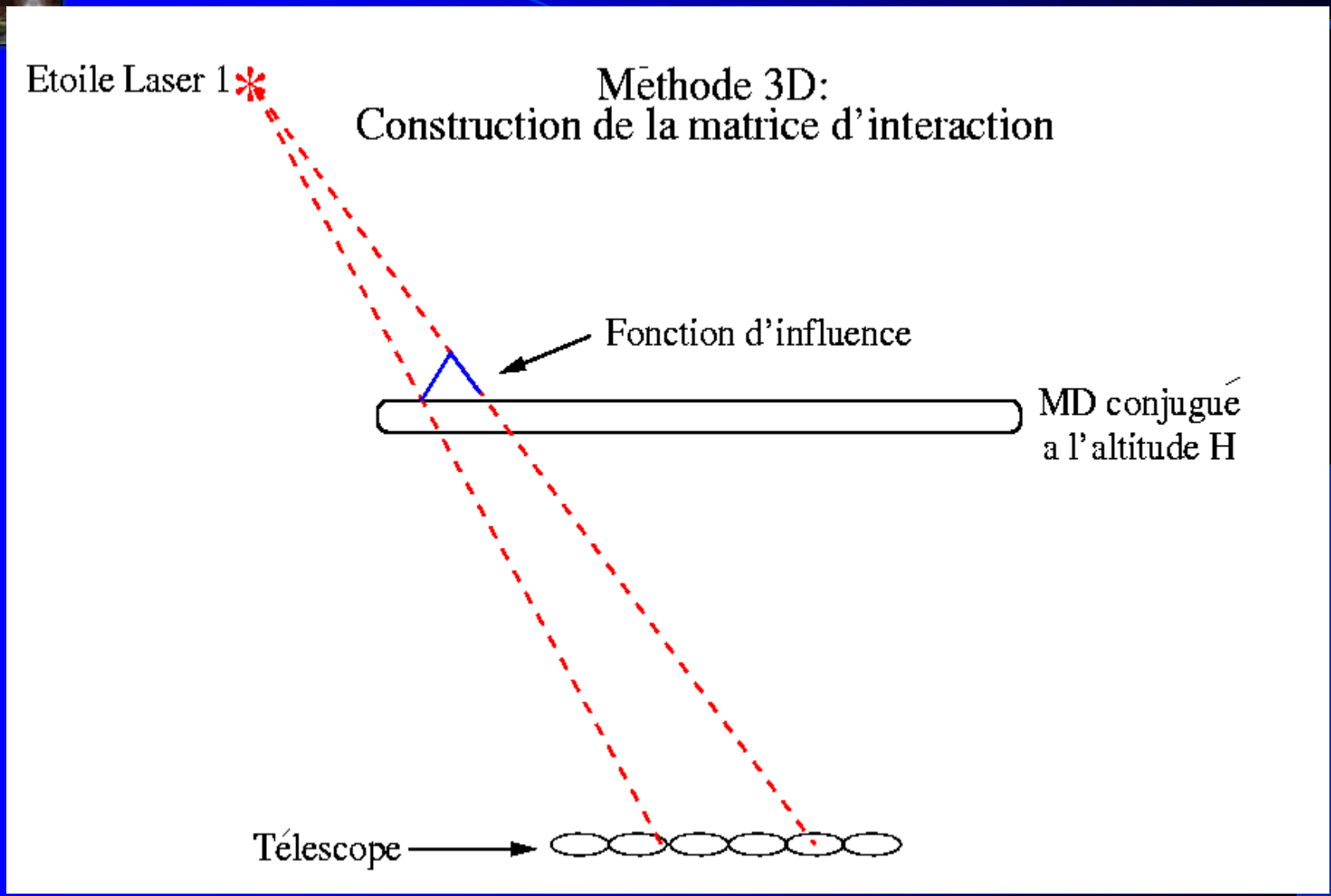


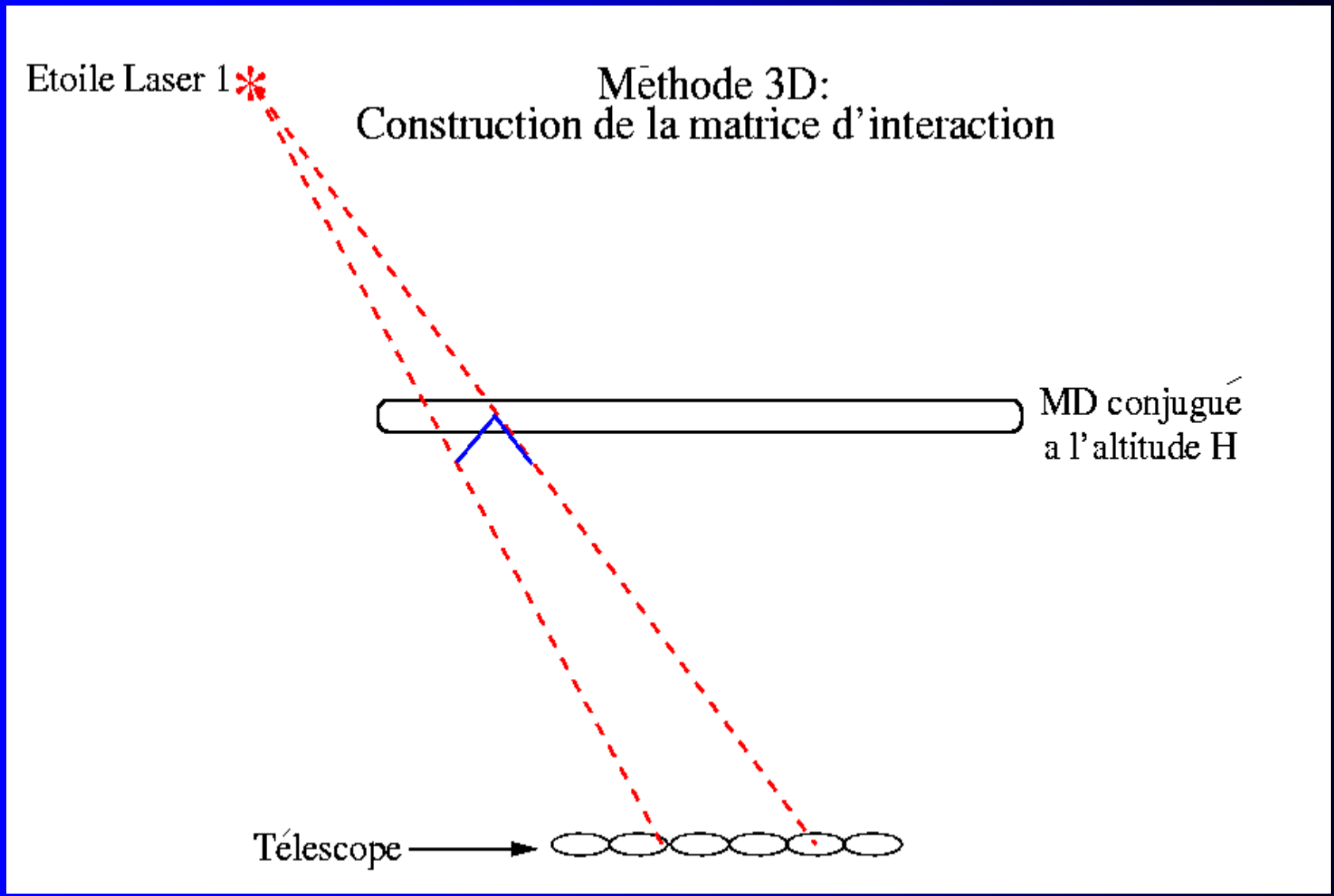
Interaction matrix in (MC)AO

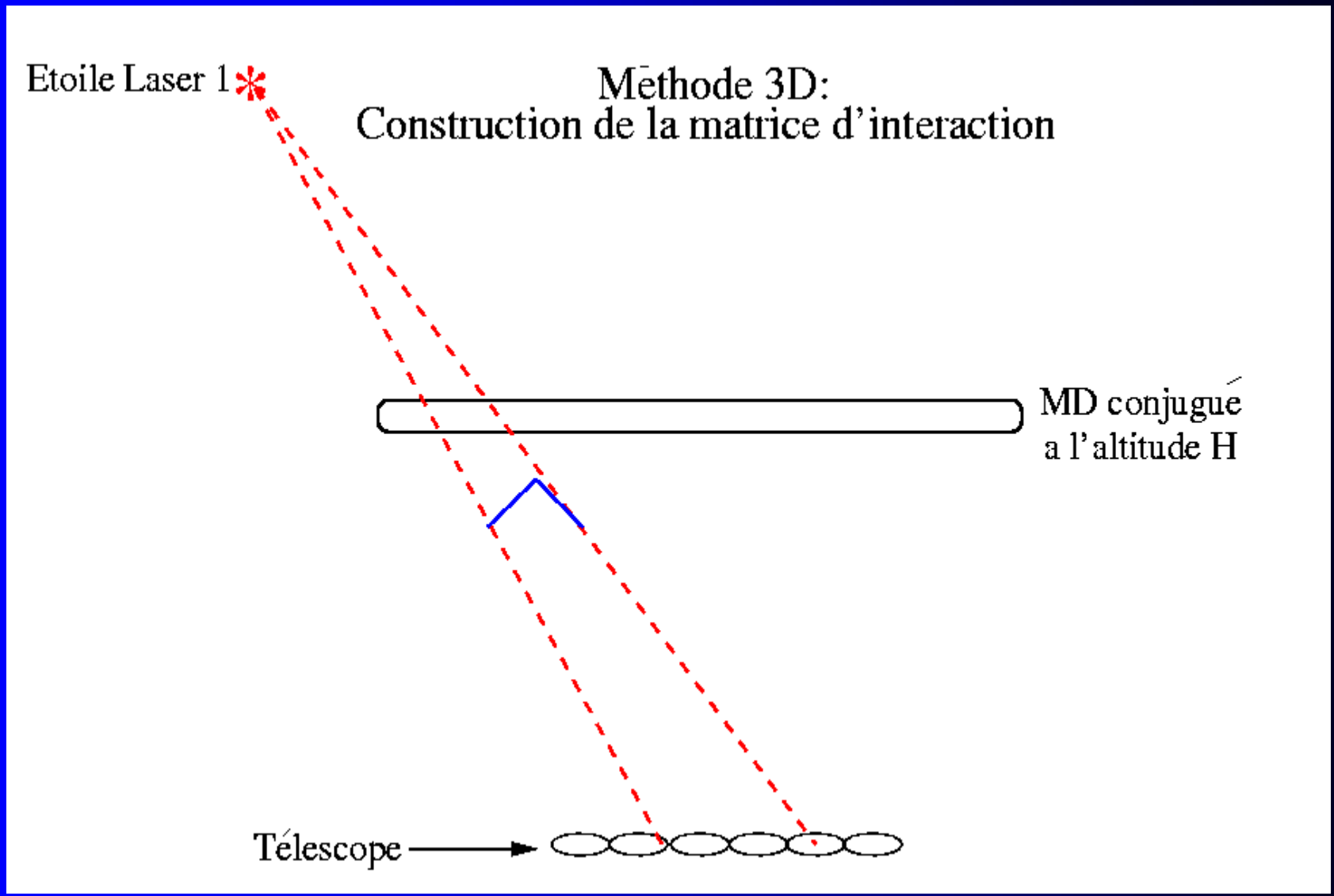
- Move one actuator on the deformable mirror
  - response DM → influence function
- Propagate this DM shape to the conjugation height of the WFS (here ground)
- measure of the response current WFS (b)
- store b in the interaction matrix (M)
  - as many rows as measurements and columns as actuators
- Invert that matrix (+ filter ↔ piston)
  → command matrix: M^+ (LS estimate)

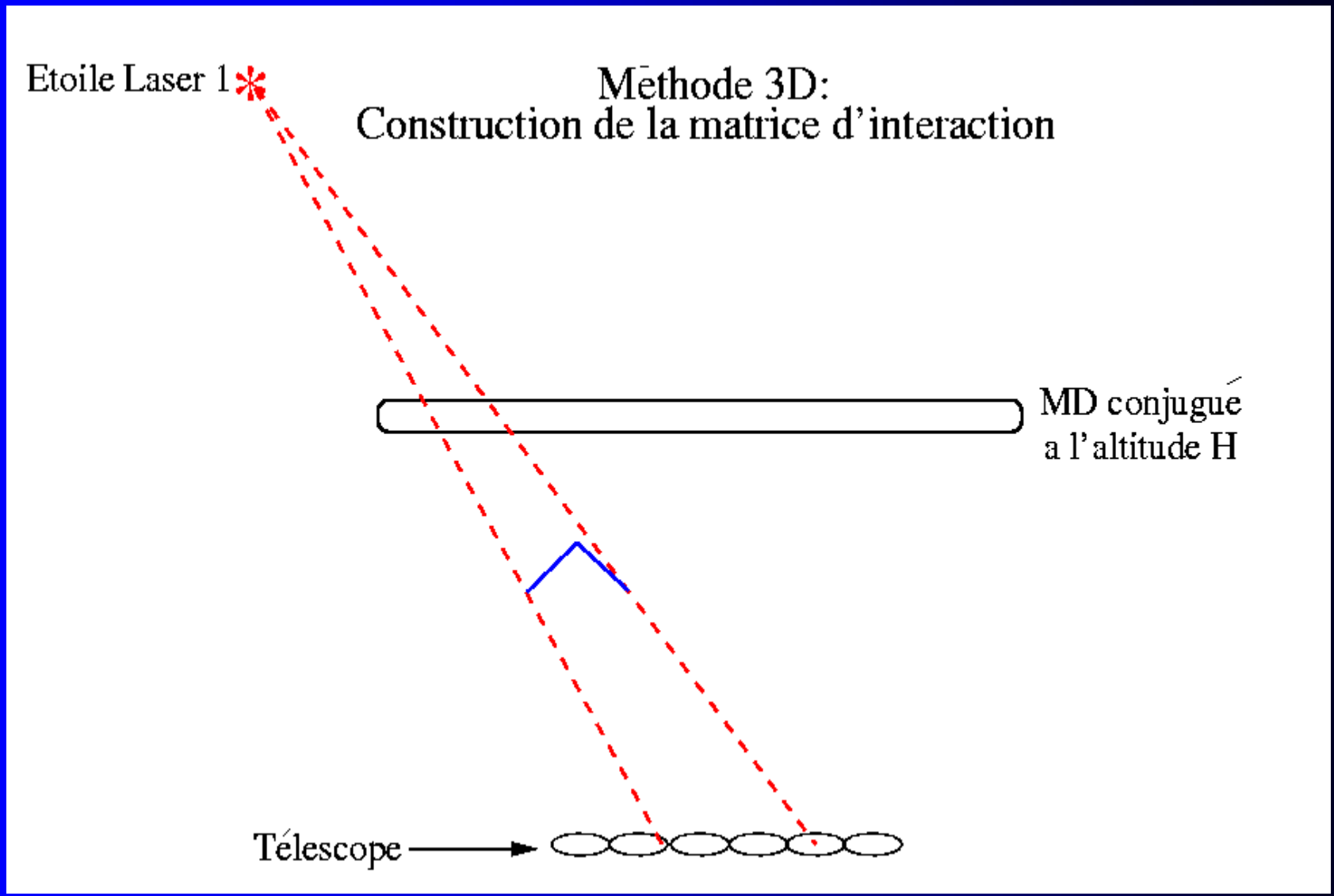
ν → command c of the DM :

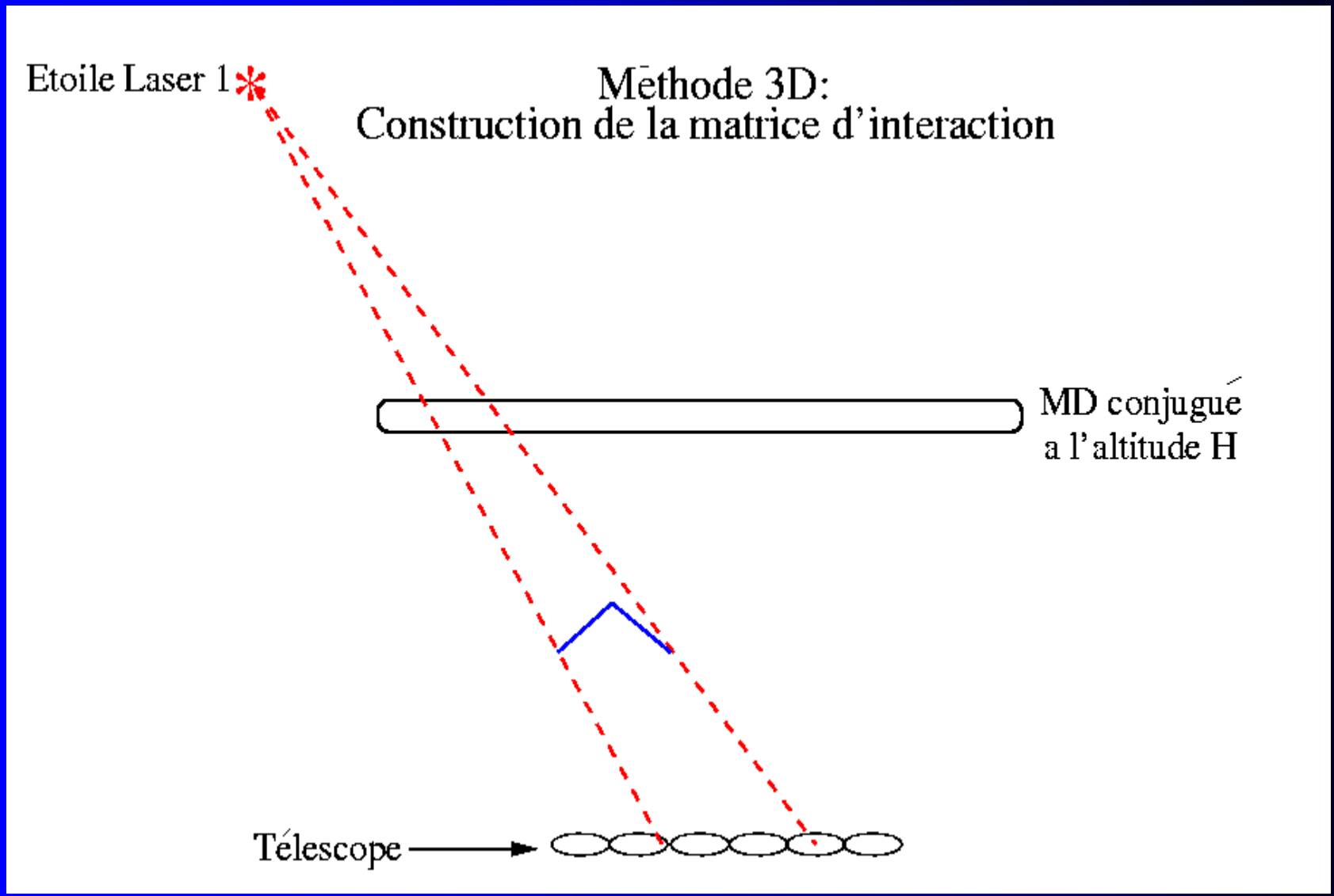
$$\vec{c} = M^+ \cdot \vec{b} = (M^t M)^{-1} M^t \cdot \vec{b}$$

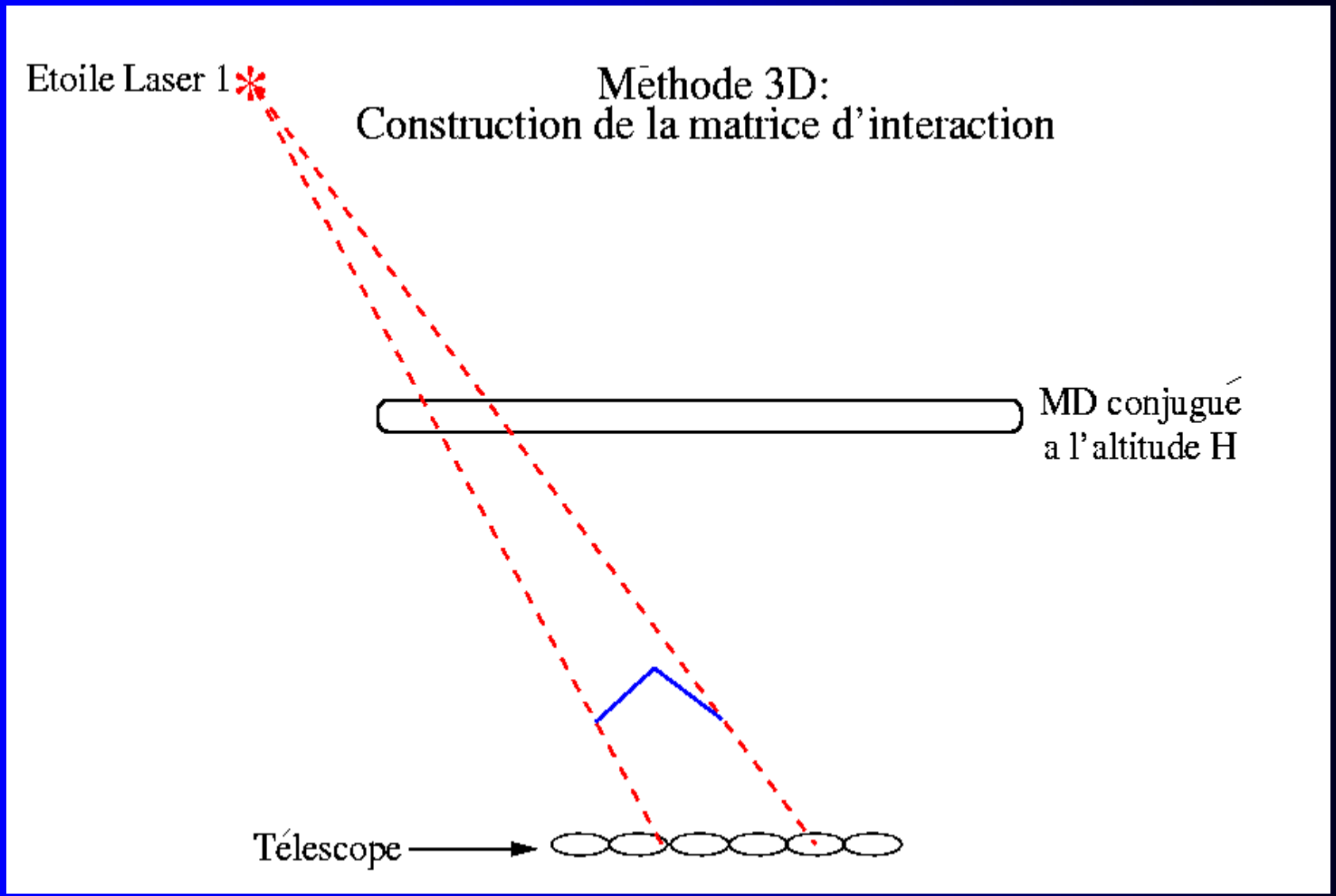

Etoile Laser 1
Méthode 3D:
Construction de la matrice d'interaction
Fonction d'influence
MD conjugué
a l'altitude H
Télescope

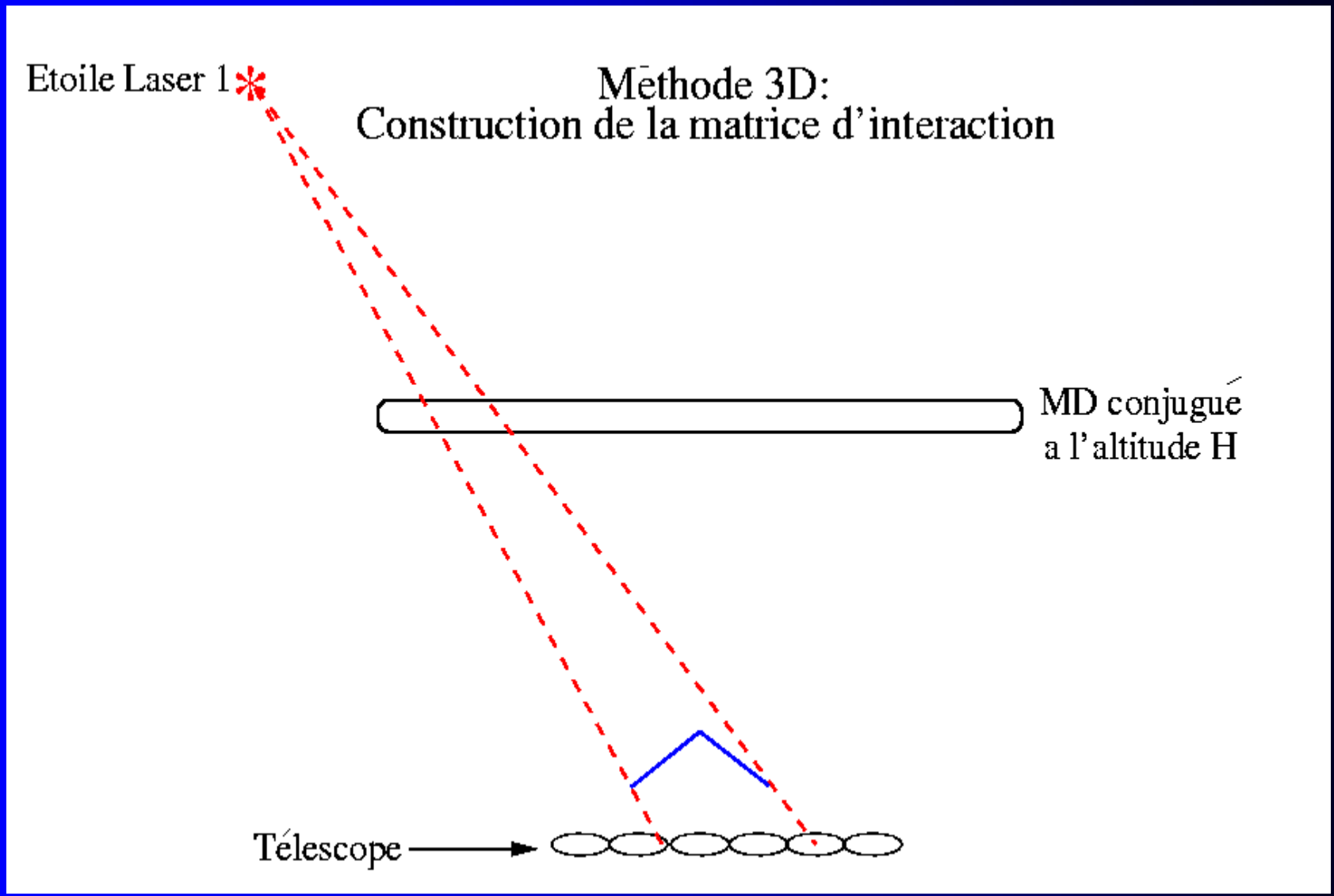

Etoile Laser 1
Méthode 3D:
Construction de la matrice d'interaction
MD conjugué
a l'altitude H
Télescope

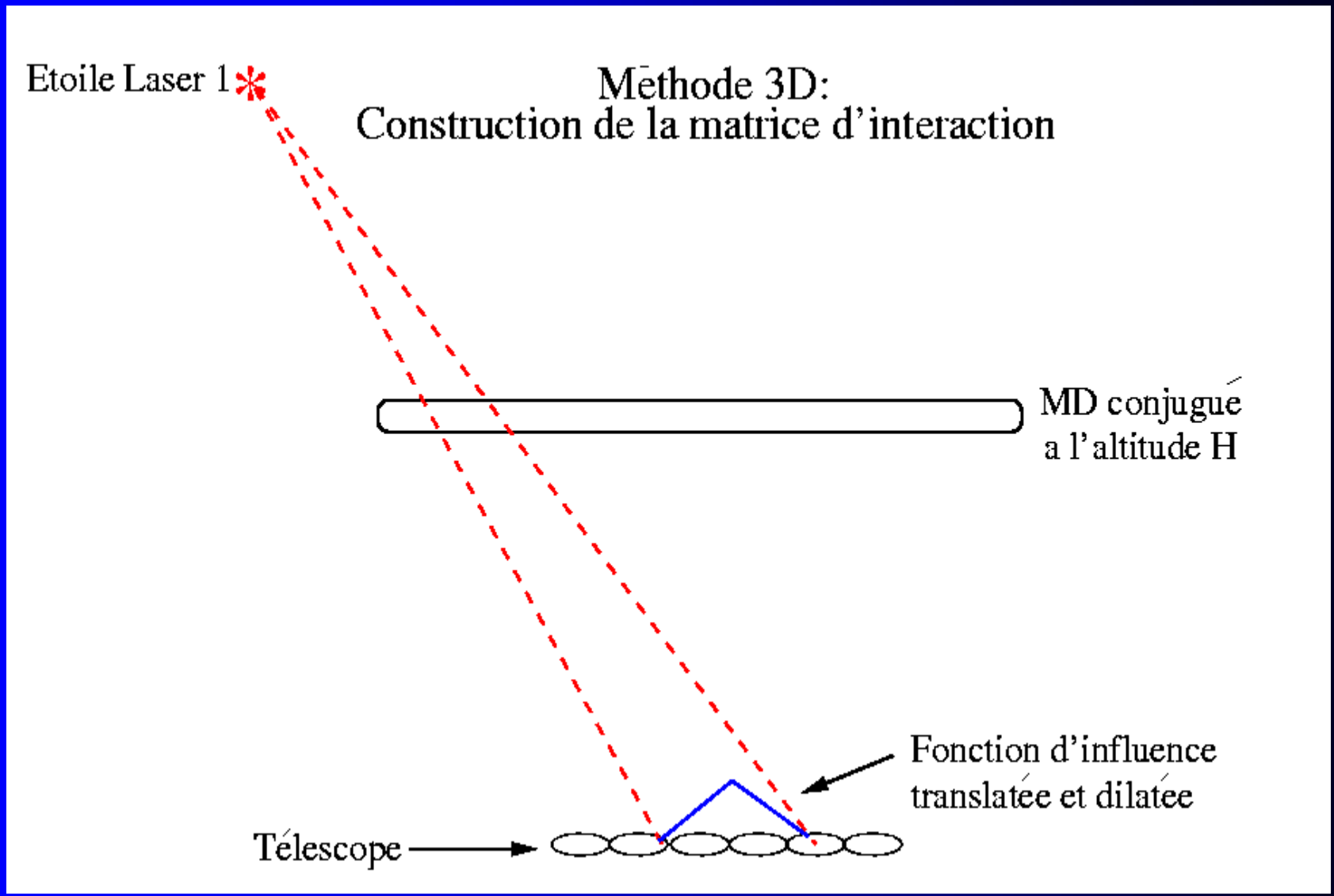

Etoile Laser 1
Méthode 3D:
Construction de la matrice d'interaction
MD conjugué
a l'altitude H
Télescope


Etoile Laser 1
Méthode 3D:
Construction de la matrice d'interaction
MD conjugué
a l'altitude H
Télescope


Etoile Laser 1
Méthode 3D:
Construction de la matrice d'interaction
MD conjugué
a l'altitude H
Télescope


Etoile Laser 1
Méthode 3D:
Construction de la matrice d'interaction
MD conjugué
a l'altitude H
Télescope


Etoile Laser 1
Méthode 3D:
Construction de la matrice d'interaction
MD conjugué
a l'altitude H
Télescope


Etoile Laser 1
Méthode 3D:
Construction de la matrice d'interaction
MD conjugué
a l'altitude H
Fonction d'influence
translatée et dilatée
Télescope

Interaction matrix

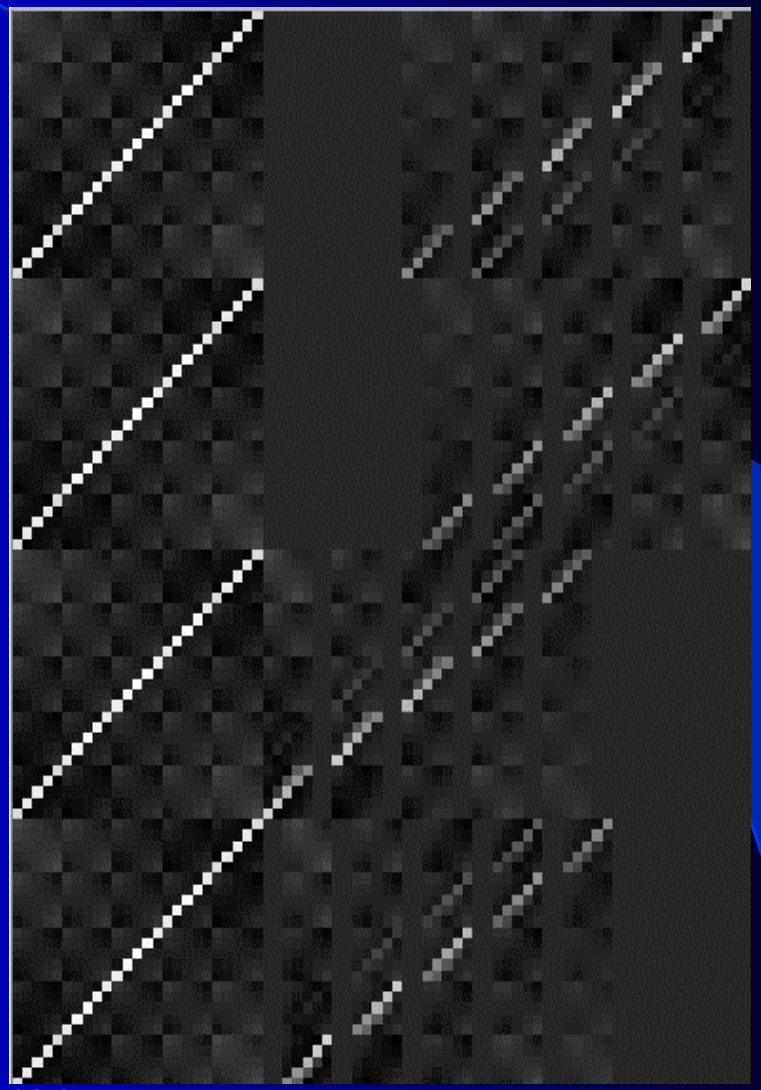
LGS 4

LGS 3

2 DMs (5x5, 7x7)
4 LGS at the edge of the FOV
8m tel

LGS 2

LGS 1



Ground conjugate DM produces same measurements on all WFSs

DM 1 DM 2

Control of MCAO

- This was the easiest way to control MCAO
- More performance w/ Regularization
- Minimum variance / optimal estimators
- Kalman filtering (closed loop control)
- Sparse matrix methods (for ELTs)
- CG minimization methods (for ELTs)
- [...]