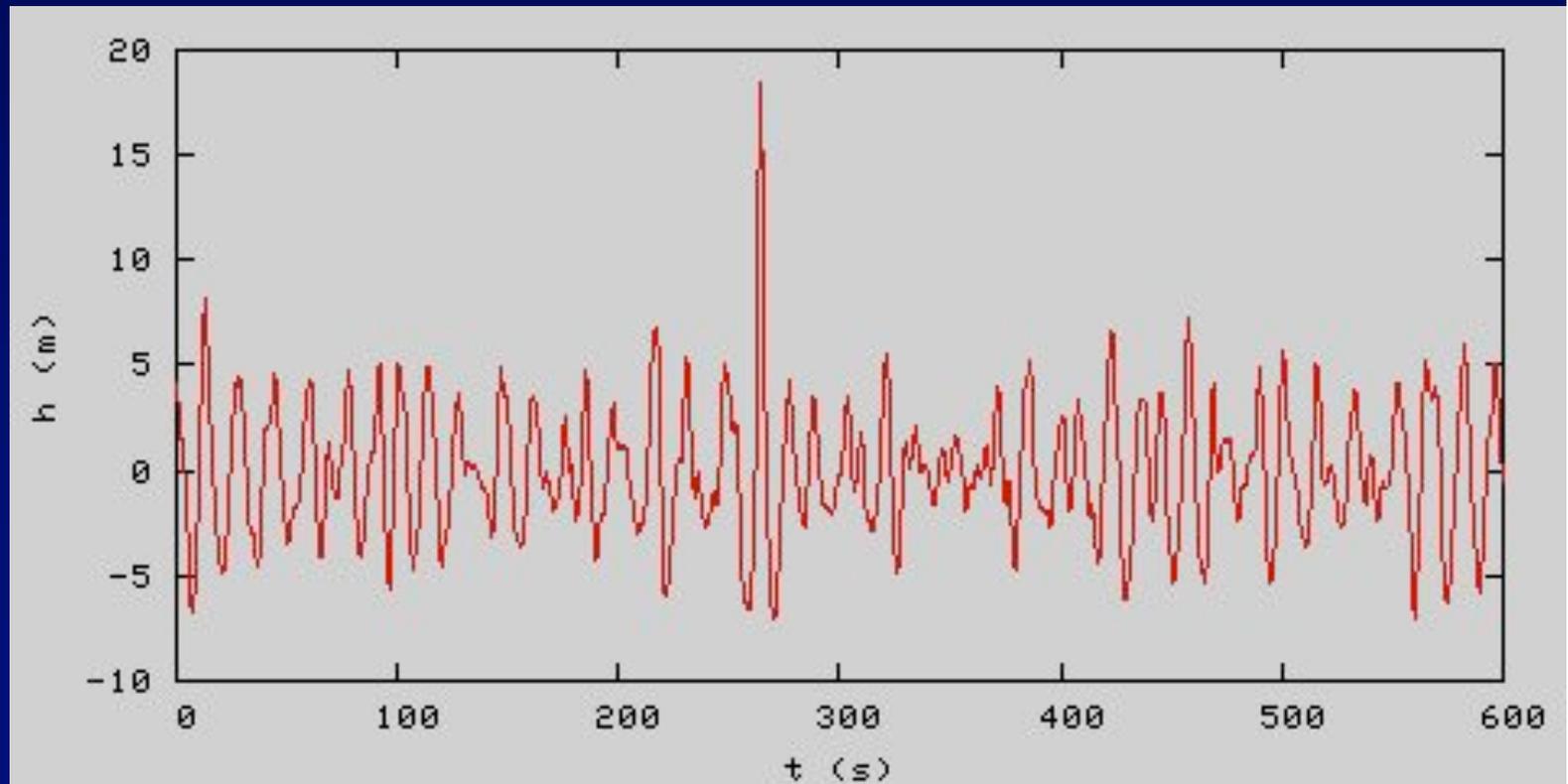


Cophasage:

la vague monstre

- Enregistrée sur une plate-forme pétrolière Mer du Nord (1/1/1995)



Vibrations en phase:

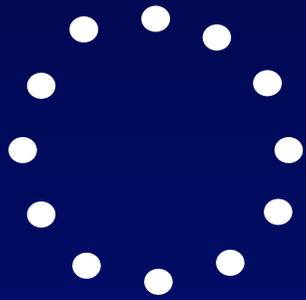
la vague monstre



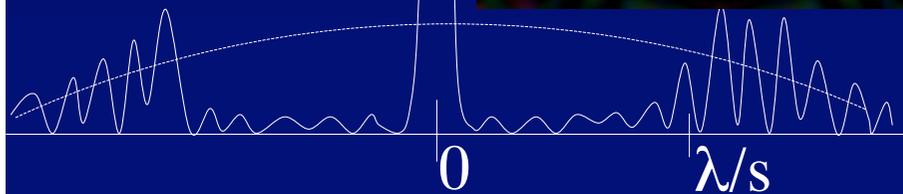
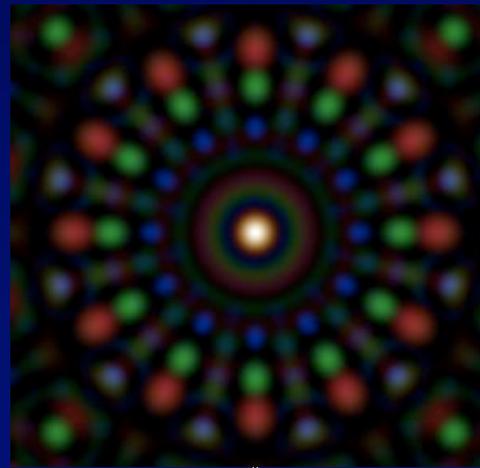
Comparaison: hypertélescope

cohérent

- Gain pic/fond
- Gain bruit de photons

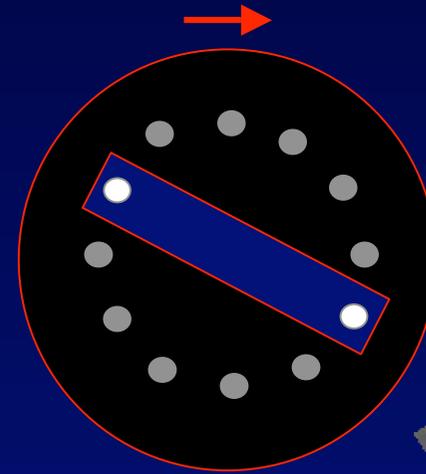


A



synthèse d'ouverture optique

incohérente



B

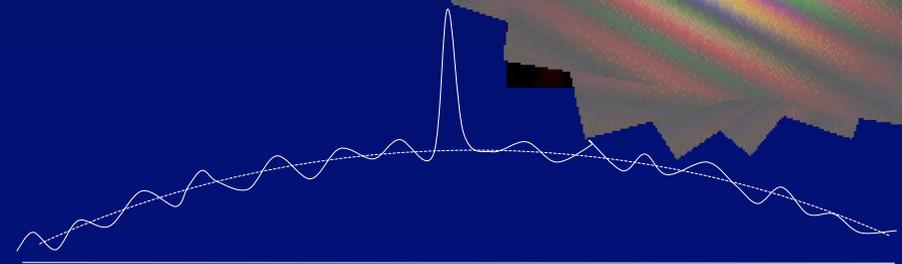
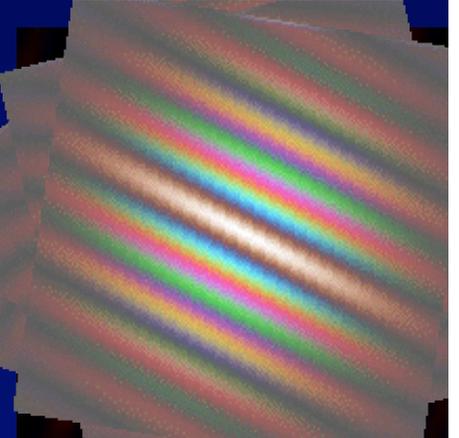
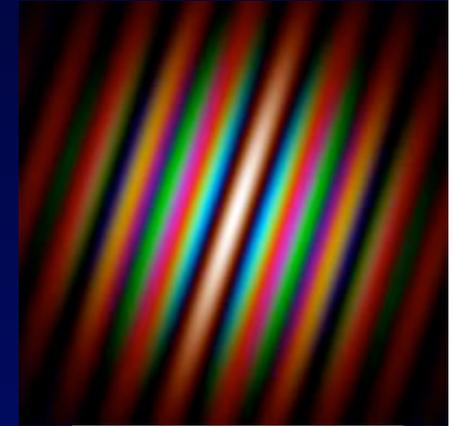
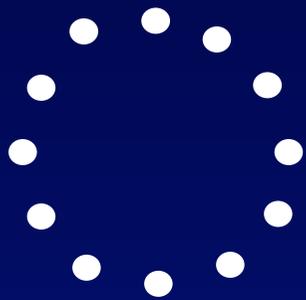


Image intégrée

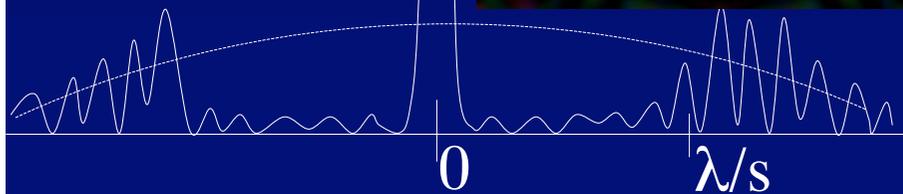
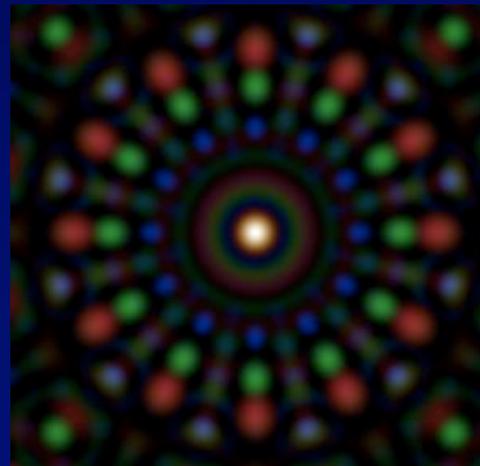
Comparaison: hypertélescope

cohérent

- Gain pic/fond
- Gain bruit de photons

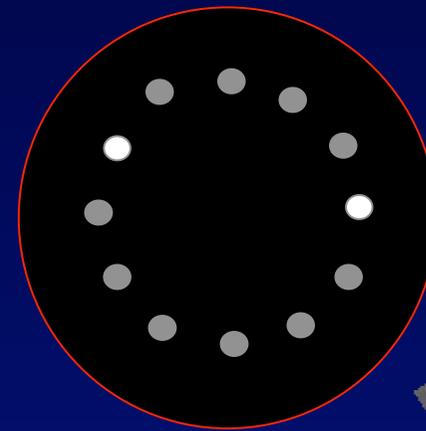


A



synthèse d'ouverture optique

incohérente



B

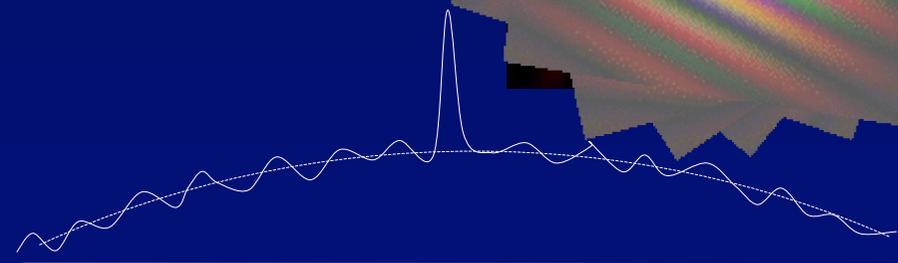
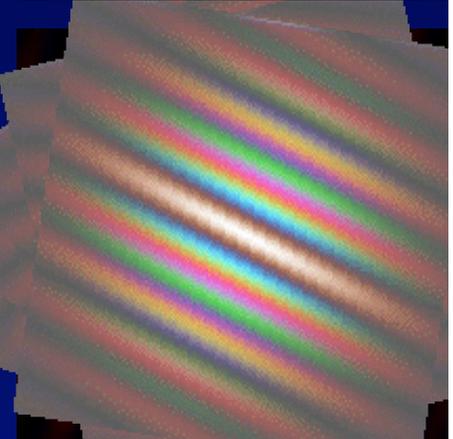
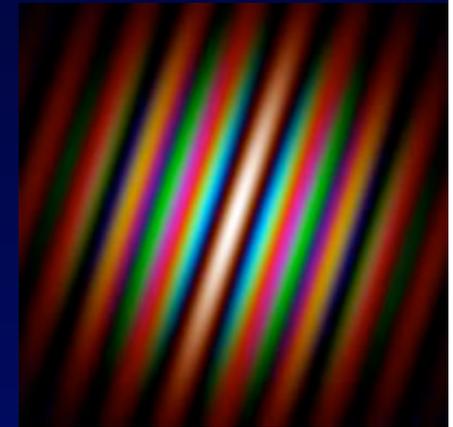


Image intégrée

Comparaison dans l'espace de Fourier



- Comparer l'auto-corrélation de N ouvertures...
- ... à la somme des auto-corrélations de paires ou triplets:
 - pic central $\times N/2$, noyant l'image dans un halo
- et multiplier par la TF de l'objet
- puis revenir dans l'espace image: contraste atténué...
-dégradant le rapport signal/(bruit de photons)

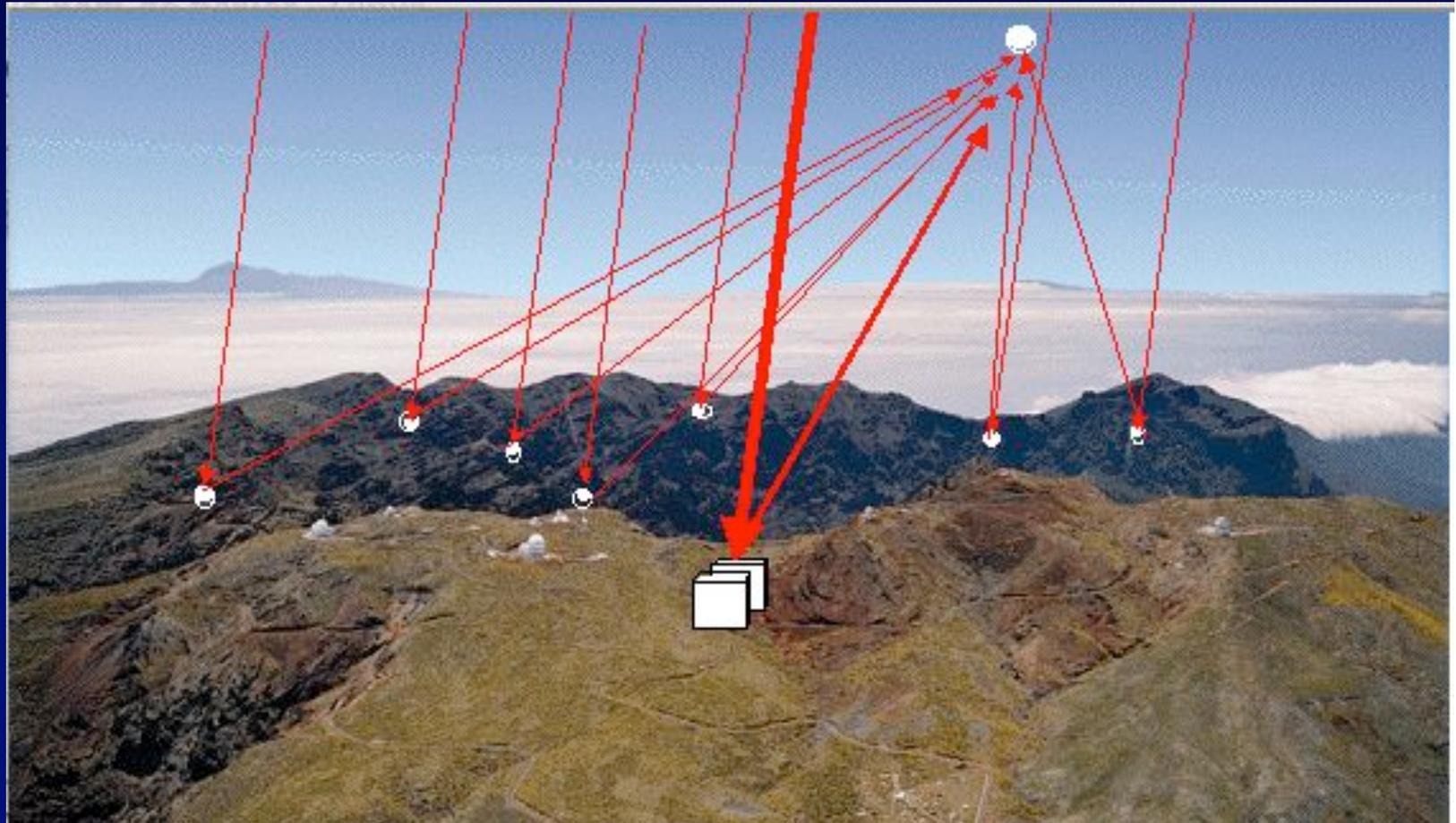
Comparaison hypertélescope et synthèse d'ouverture: Signal et bruit de photons

(Labeyrie 2007, Labeyrie 2008)

- Hypertélescope : $\text{signal/bruit}_h = (\mathbf{N} P_t / k_d)^{1/2}$
- Synthèse d'ouverture: $\text{signal/bruit}_p = 2 (P_t / \mathbf{N})^{1/2}$
- Gain de l'hypertélescope $(1/2) \mathbf{N} (k_d)^{-1/2}$

k_d est l'atténuation du fond dans le champ propre

Couplage ELT et hypertélescope : science, technique et sites



sSismologie stellaire

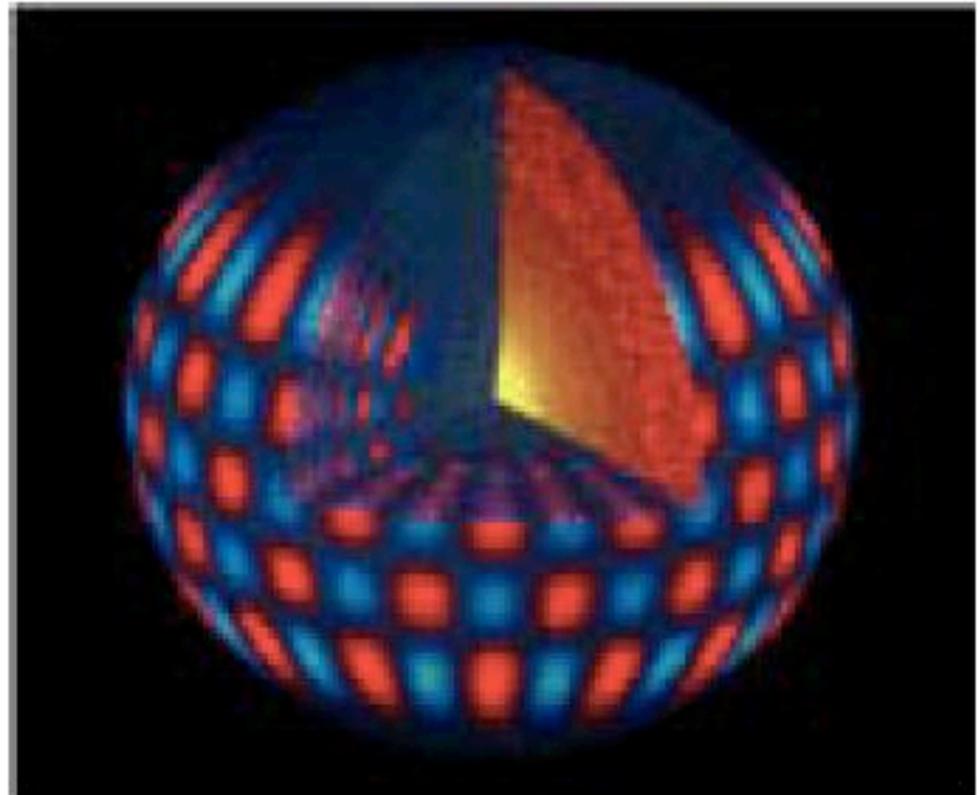
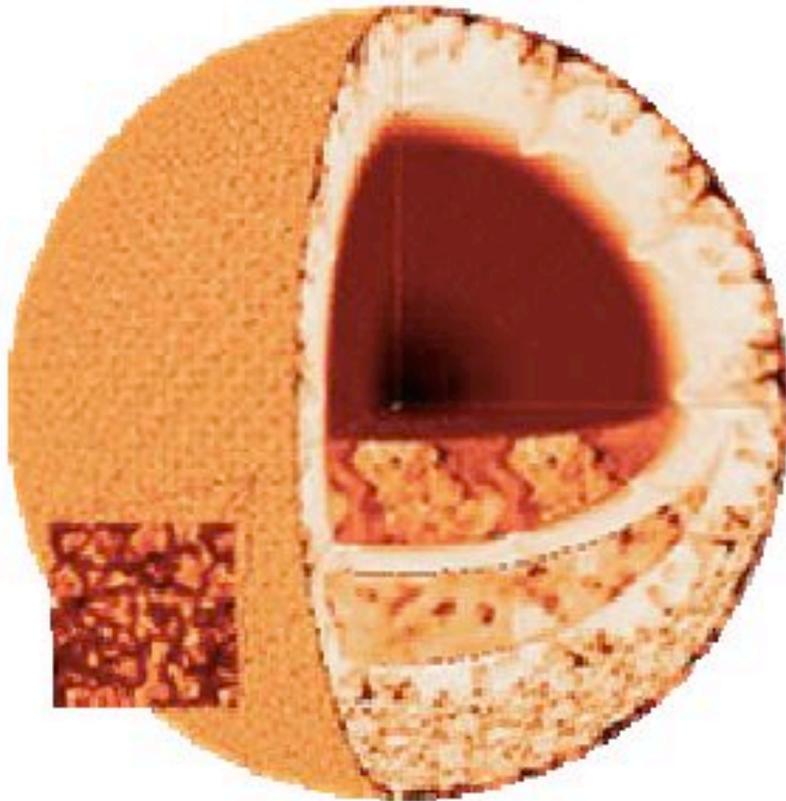


Figure 4.3: Oscillations generated at the inside a star will travel outwards and will become visible as parts of the surface moving up and down. The mode, frequency and intensity of these oscillations give valuable information about the inside of the star. It can be compared to the information that we get about the inside of the earth from the propagation of the seismic waves below the crust.

Jets stellaires

SS433
VLBA

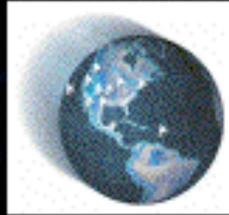
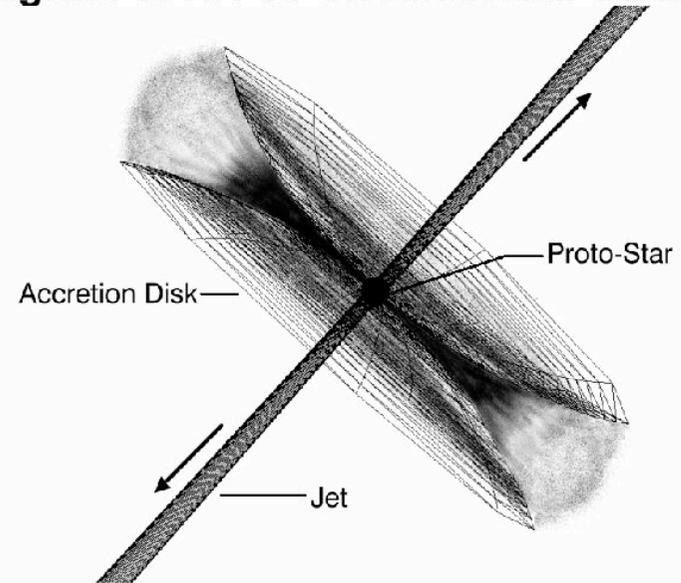


Diagram of HH 30 Circumstellar Disk & Jet

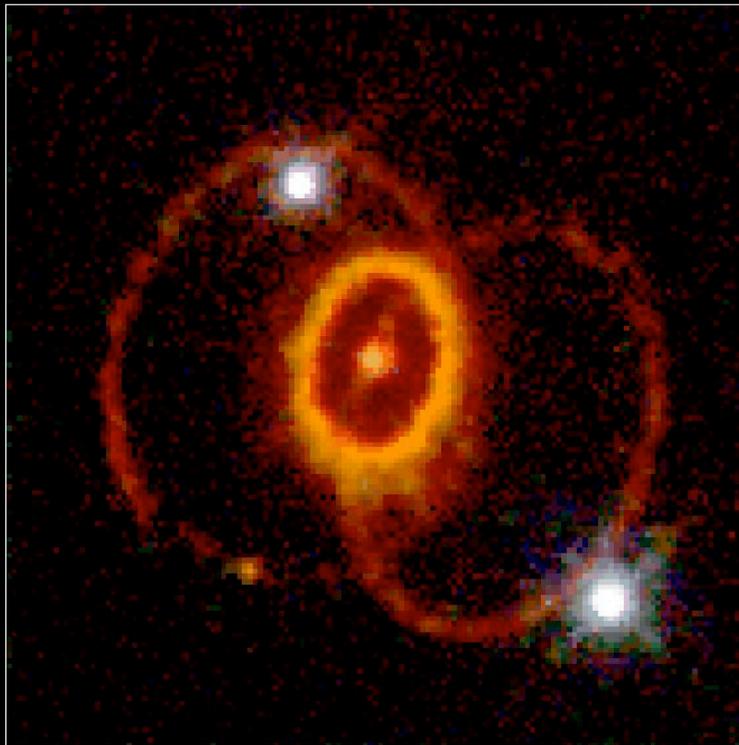


Amy Mioduszewski
Michael Rupen
Craig Walker
Greg Taylor

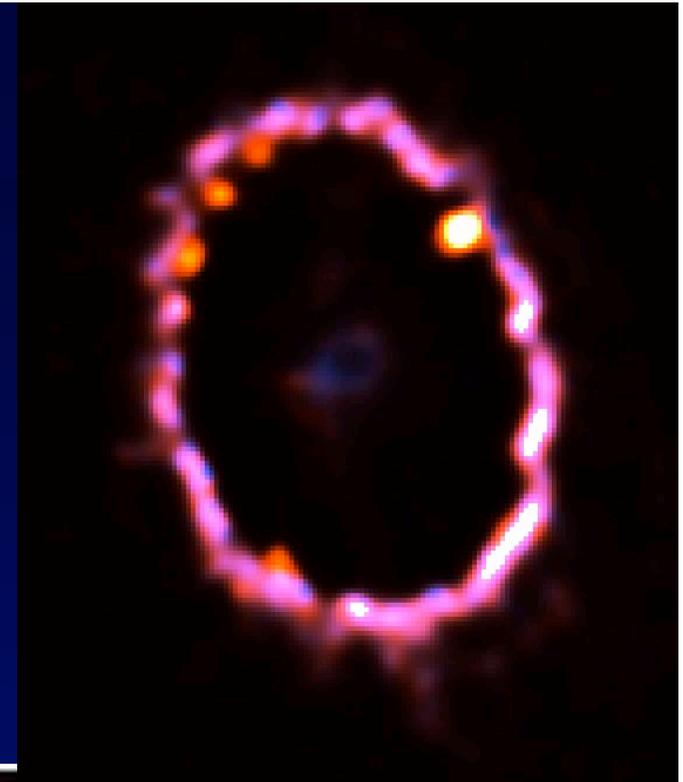


Supernova SN 1987A vue par Hubble

Supernova 1987A Rings



Hubble Space Telescope
Wide Field Planetary Camera 2



Amas
globulaire
47 Tucanae

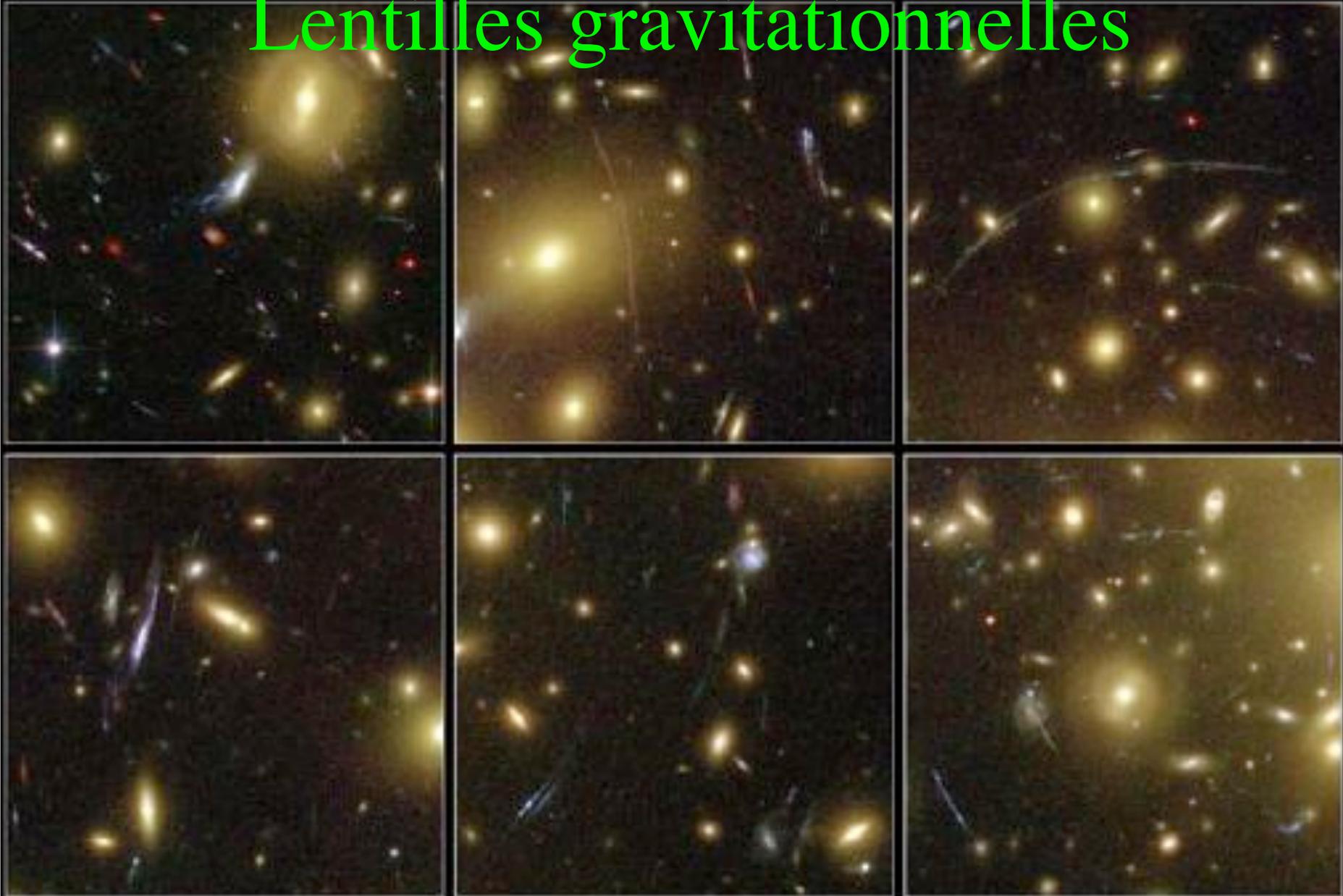


Jet du quasar 3C273

- Rayons X, visible, radio
- Vitesses apparentes dépassant celle de la lumière
- ...explicable par effet de perspective



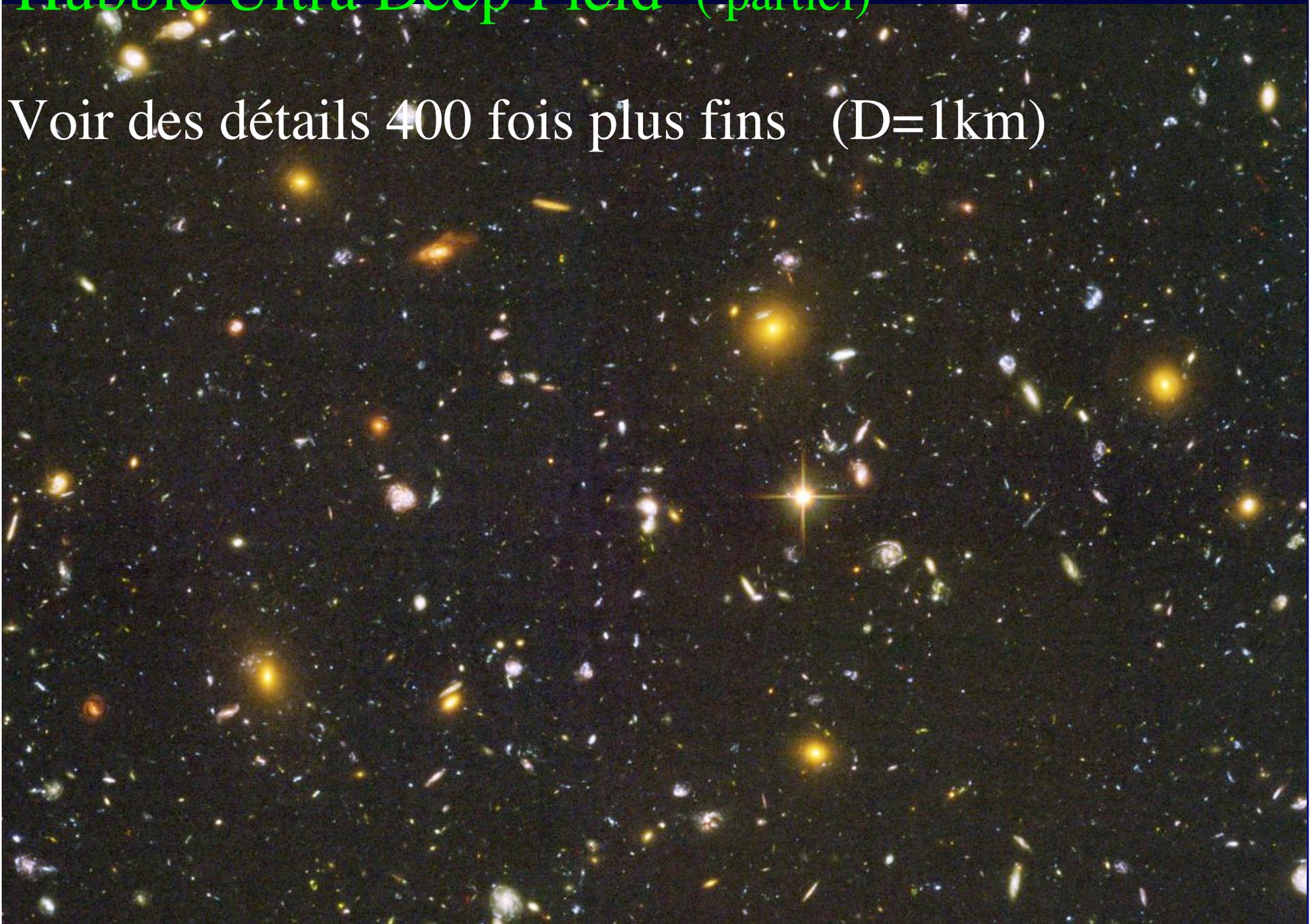
Lentilles gravitationnelles



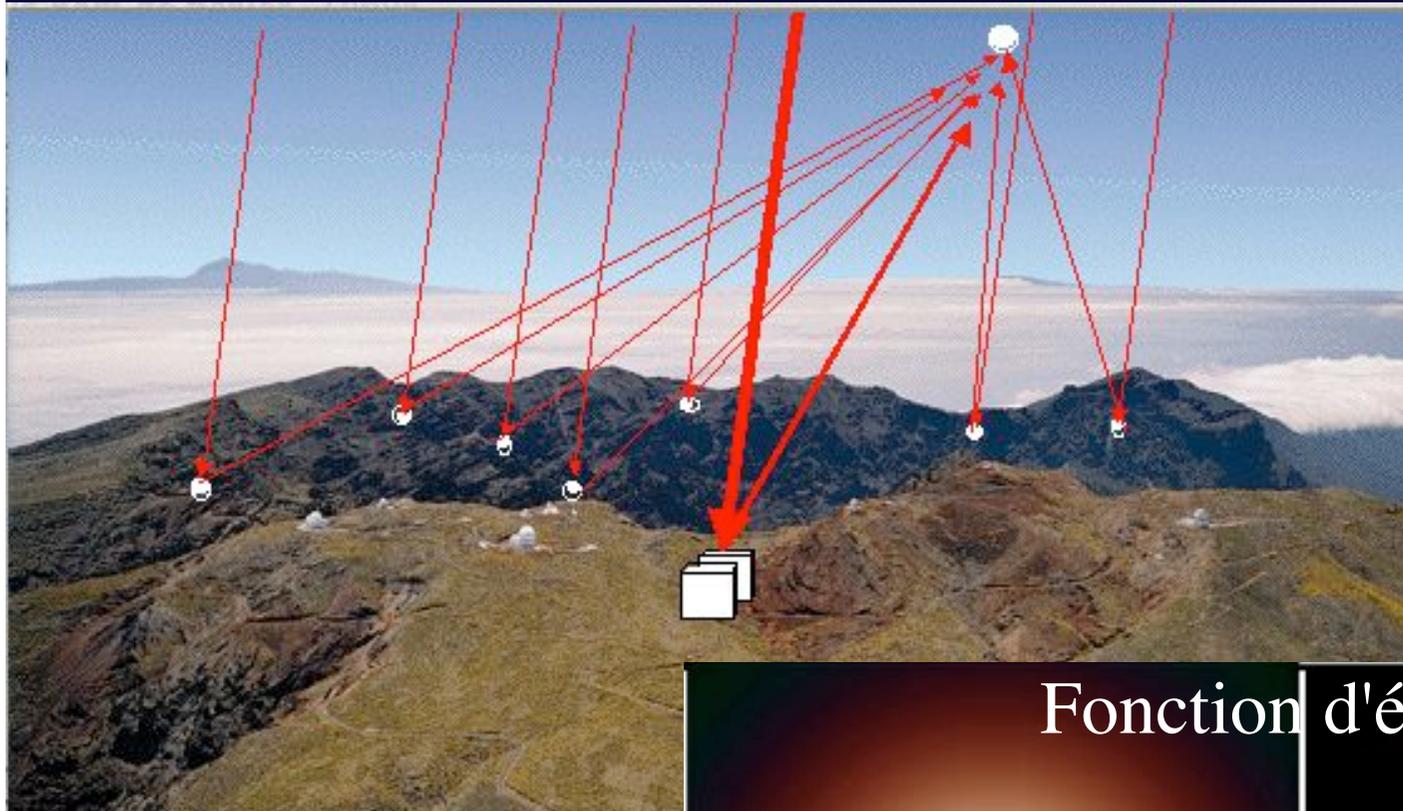
Galaxy Cluster Abell 1689 Details
Hubble Space Telescope • Advanced Camera for Surveys

Hubble Ultra Deep Field (partiel)

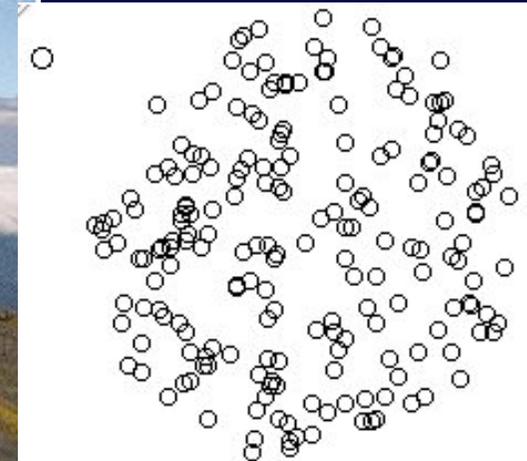
Voir des détails 400 fois plus fins (D=1km)



Une synergie intéressante: ELT et hypertélescope couplés

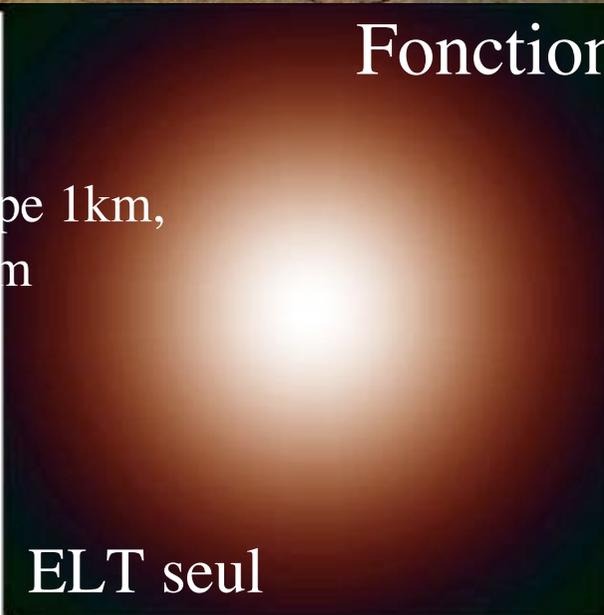


Densification de pupille
inégale: 1 et 40

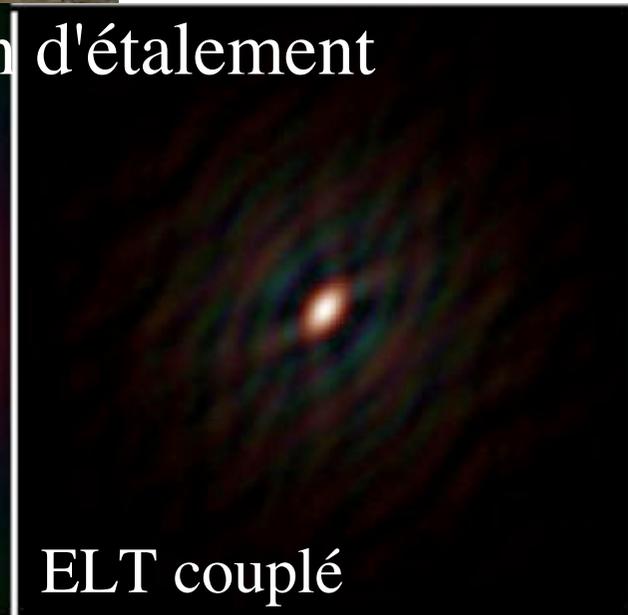


Fonction d'étalement

- ELT de 50m + hypertélescope 1km,
à 200 ouvertures de 1m
- pic rétréci et intensifié x 17



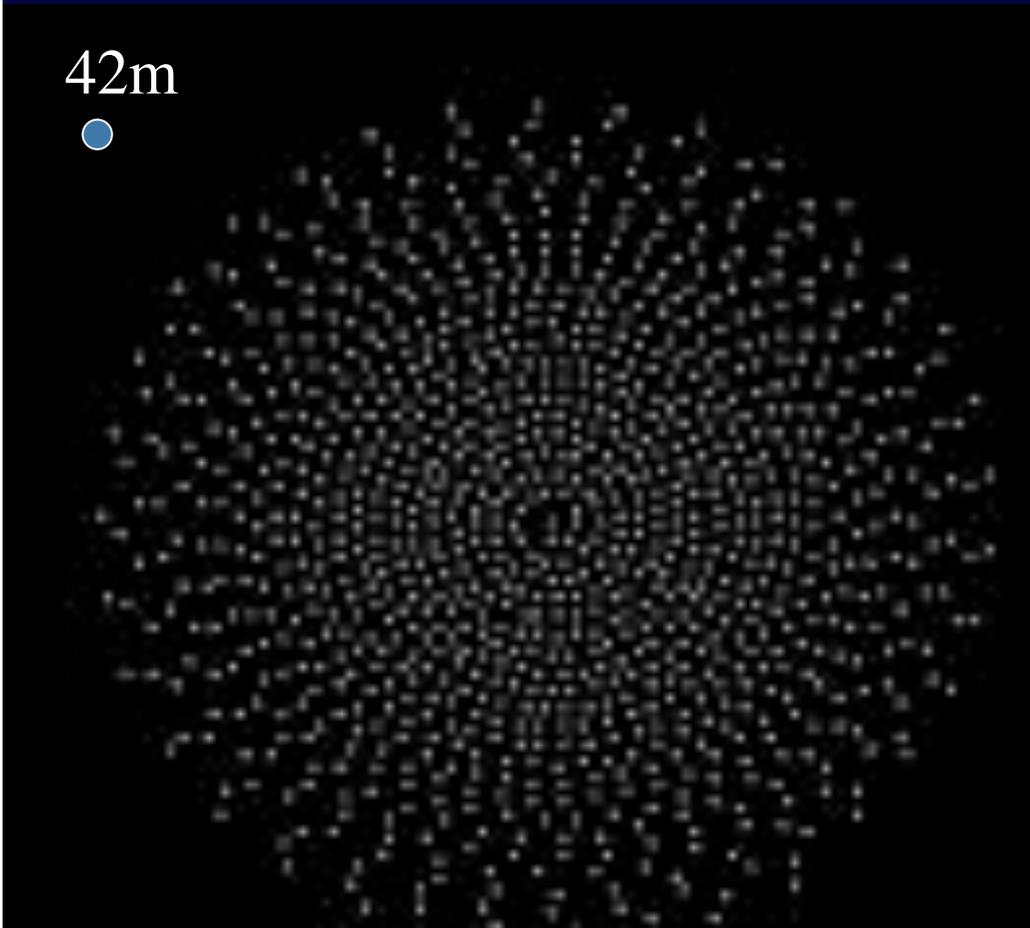
ELT seul



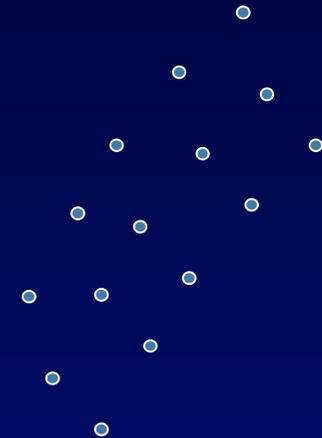
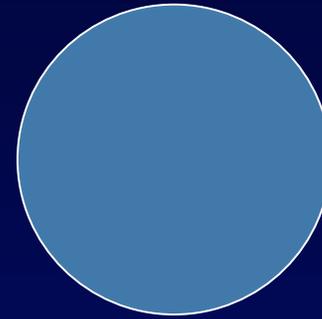
ELT couplé

Couplage ELT-hypertelescope

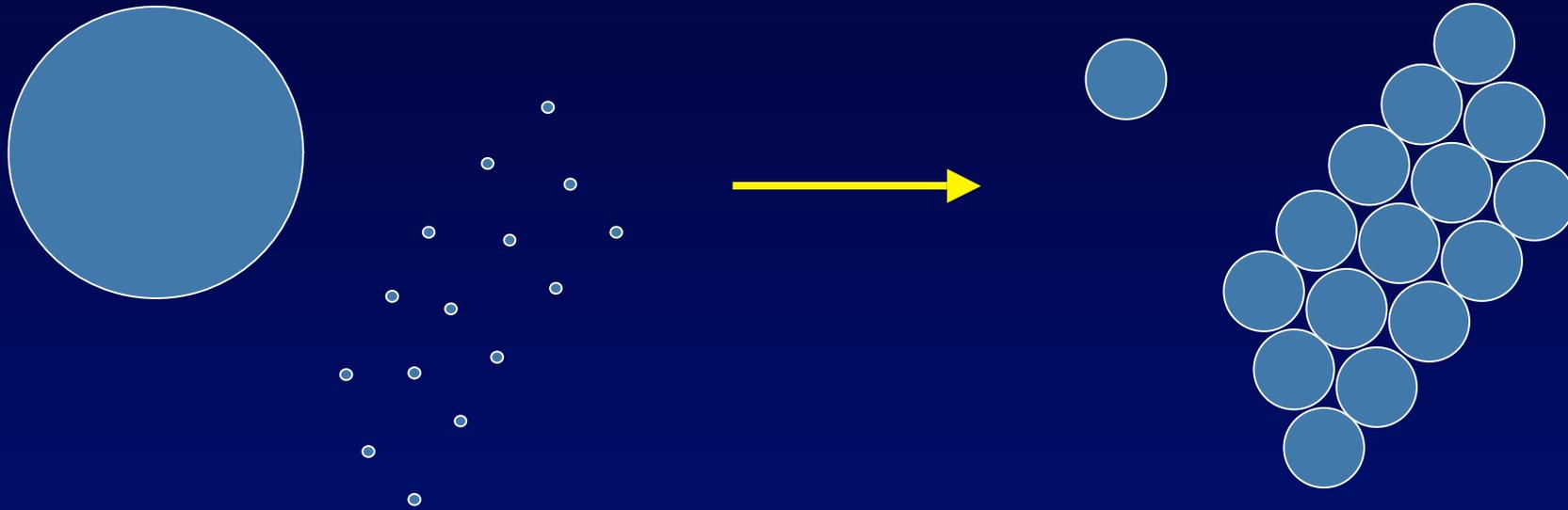
42m



1 km

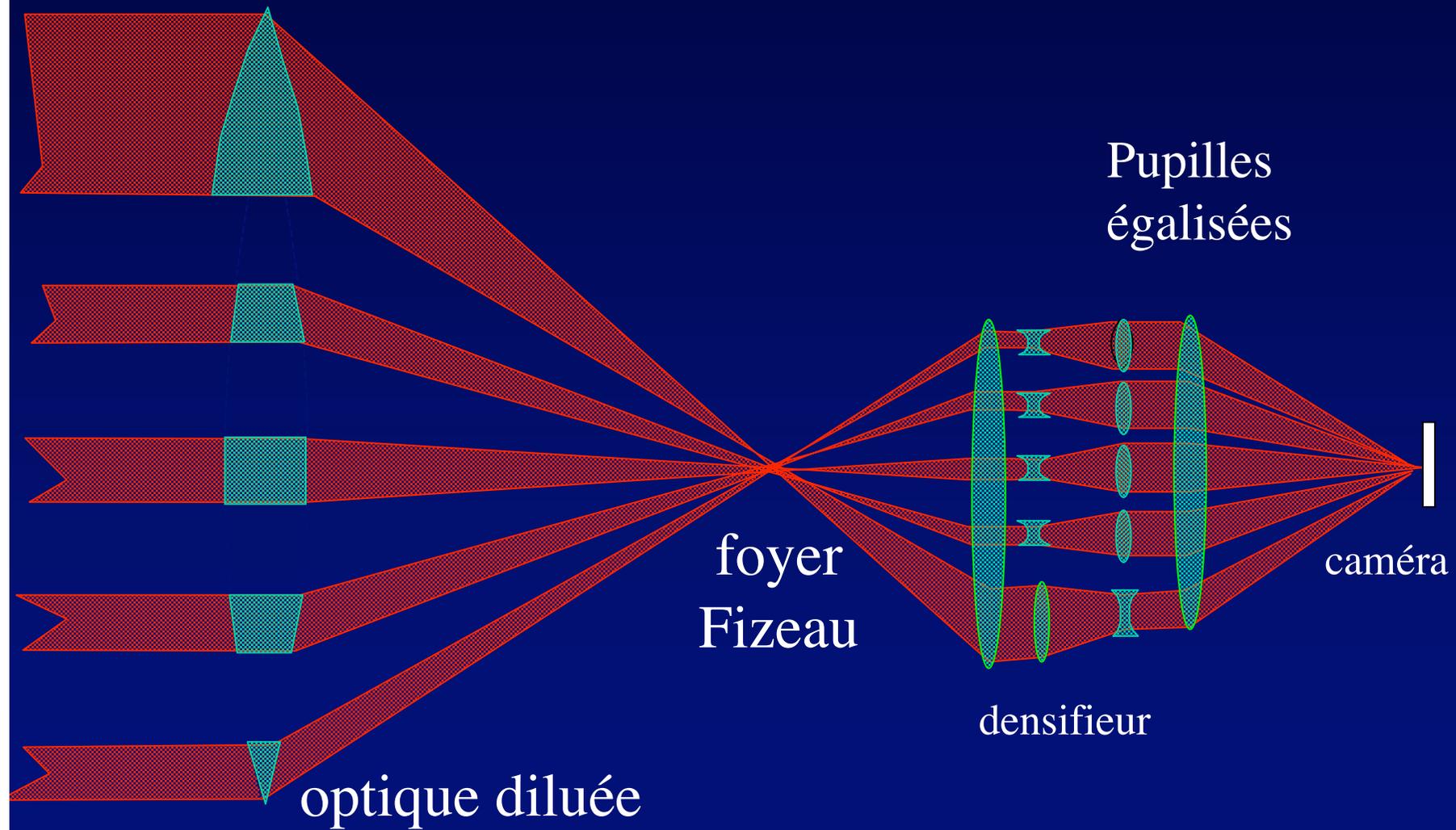


Couplage ELT-hypertelescope: densification inégale



- égalise les diamètres des enveloppes diffractives

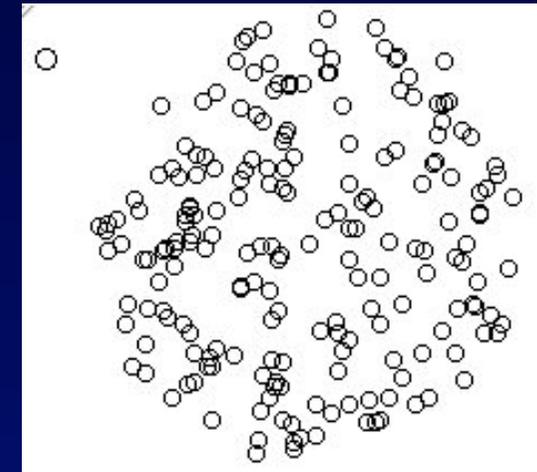
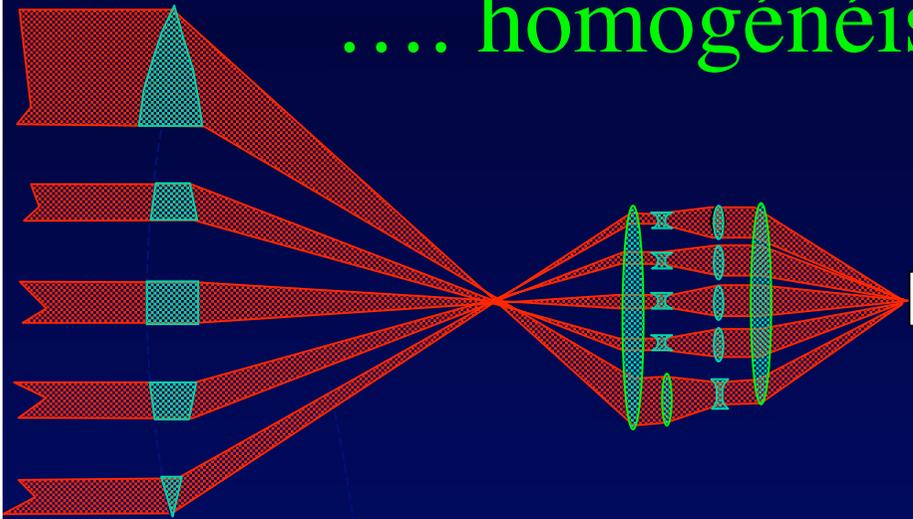
Ouvertures inégales et densification inégale



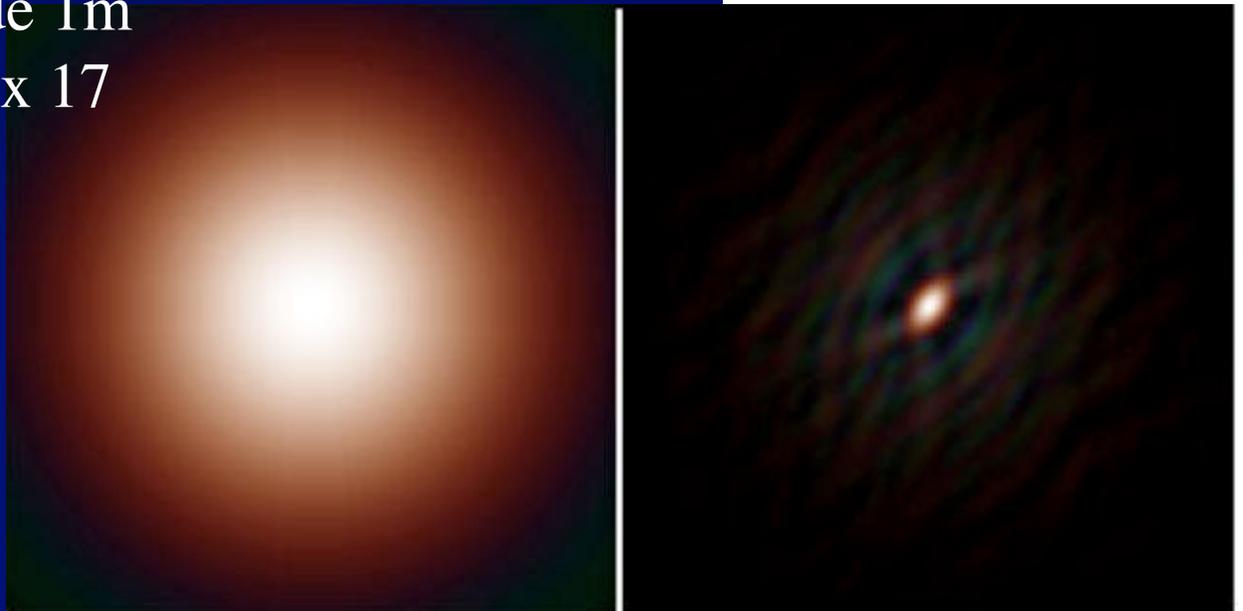
Ouvertures inégales et densification inégale...

.... homogénéisant la pupille de sortie

Densification de pupille
inégale: 1 et 40



- ELT de 50m + hypertélescope 1km,
à 200 ouvertures de 1m
- pic rétréci et intensifié x 17



Simulations d'imagerie hypertélescope

objet

ouverture

fonction
d'étalement

image

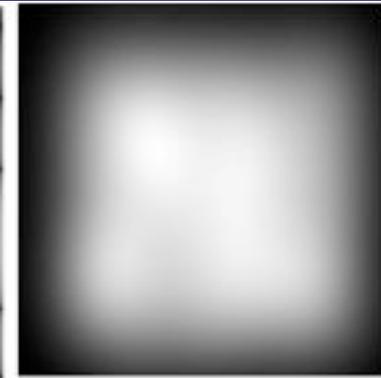
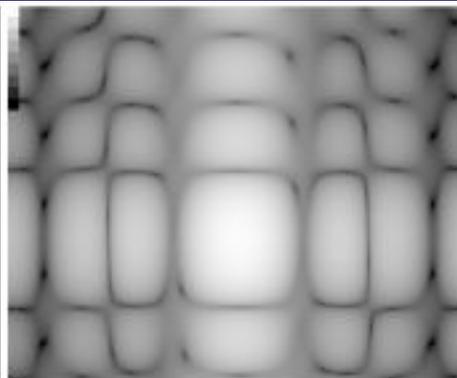
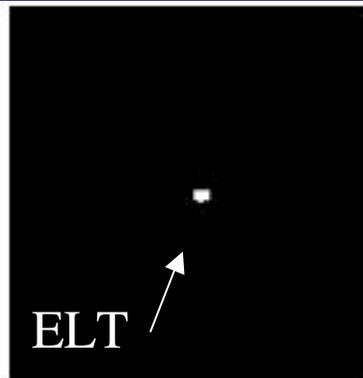
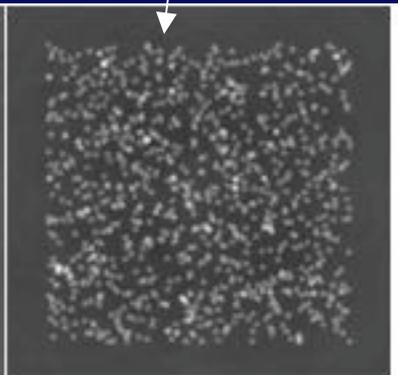
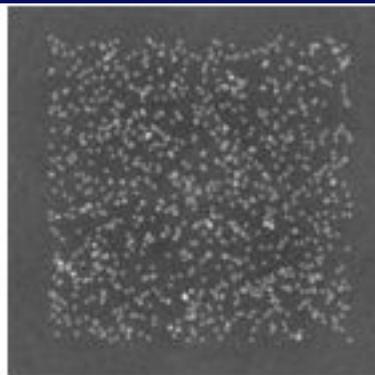
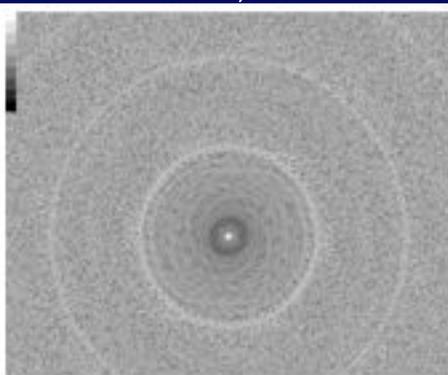
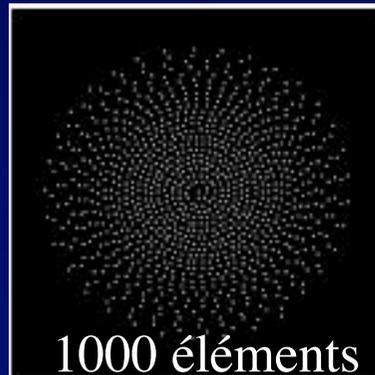
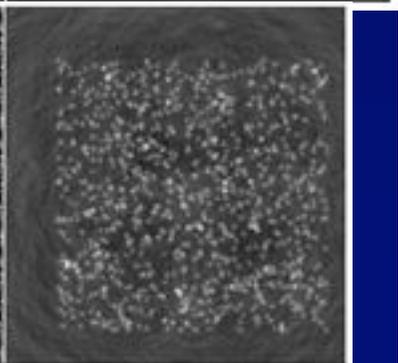
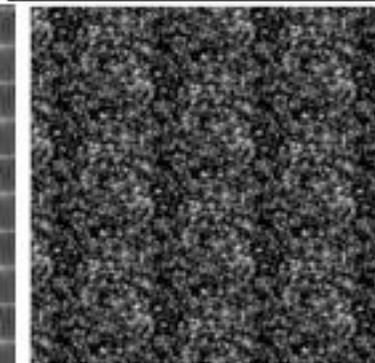
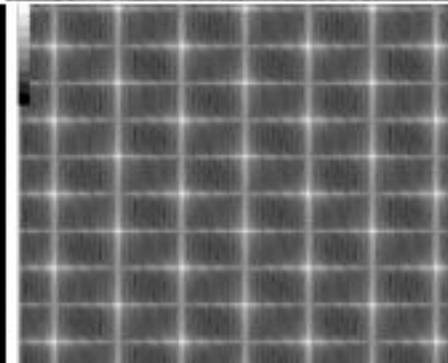
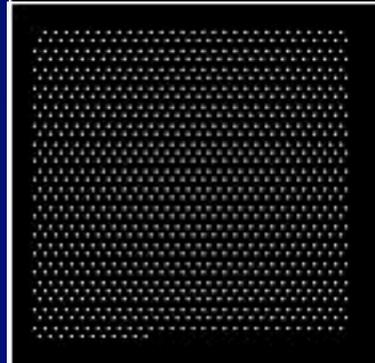


Image avec rotation

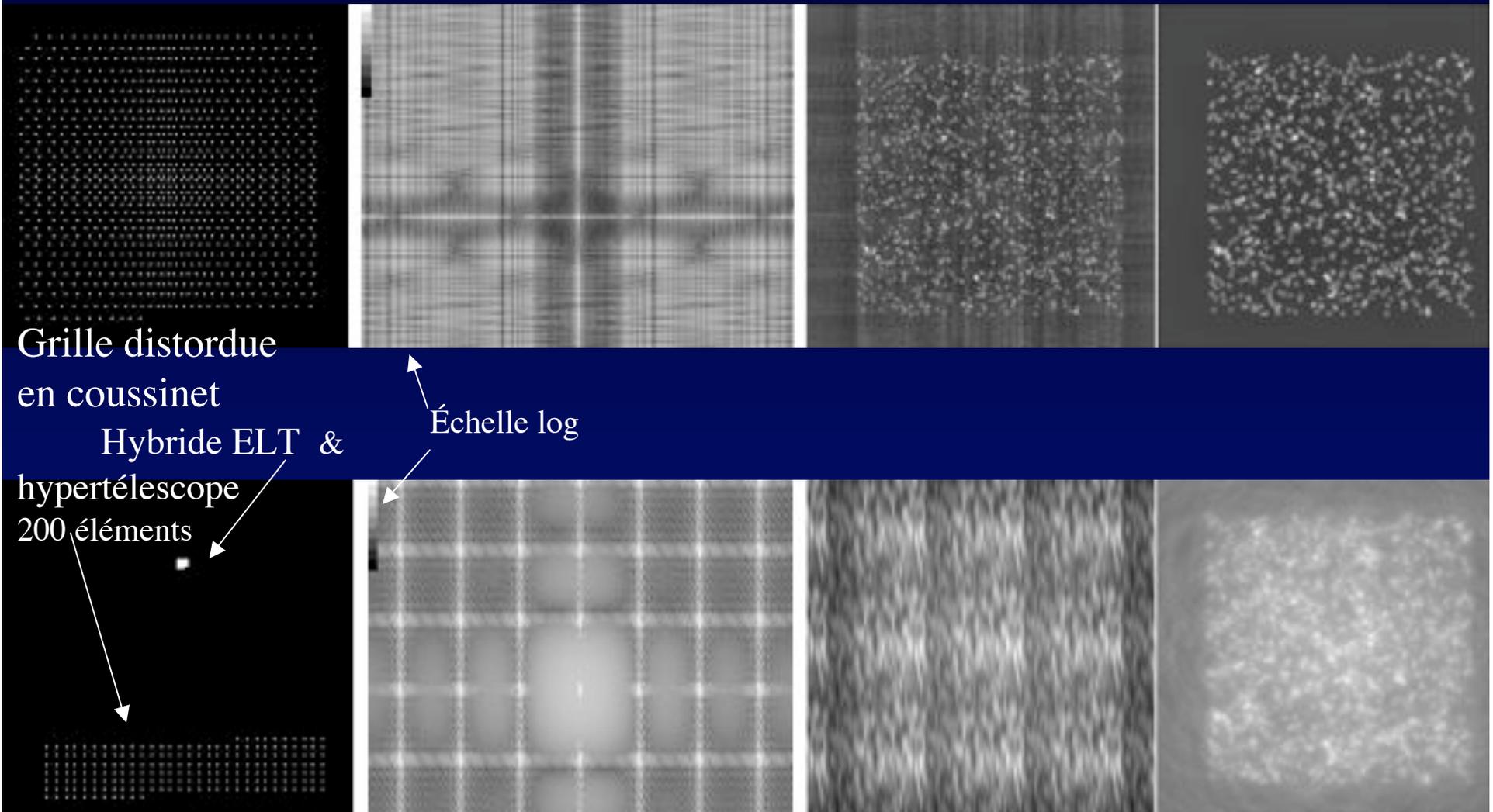
spirale



grille



Simulations d'imagerie hypertélescope (suite)



- la rotation d'ouverture améliore l'image en lissant les pieds
- le couplage ELT & hypertélescope est un peu moins bon

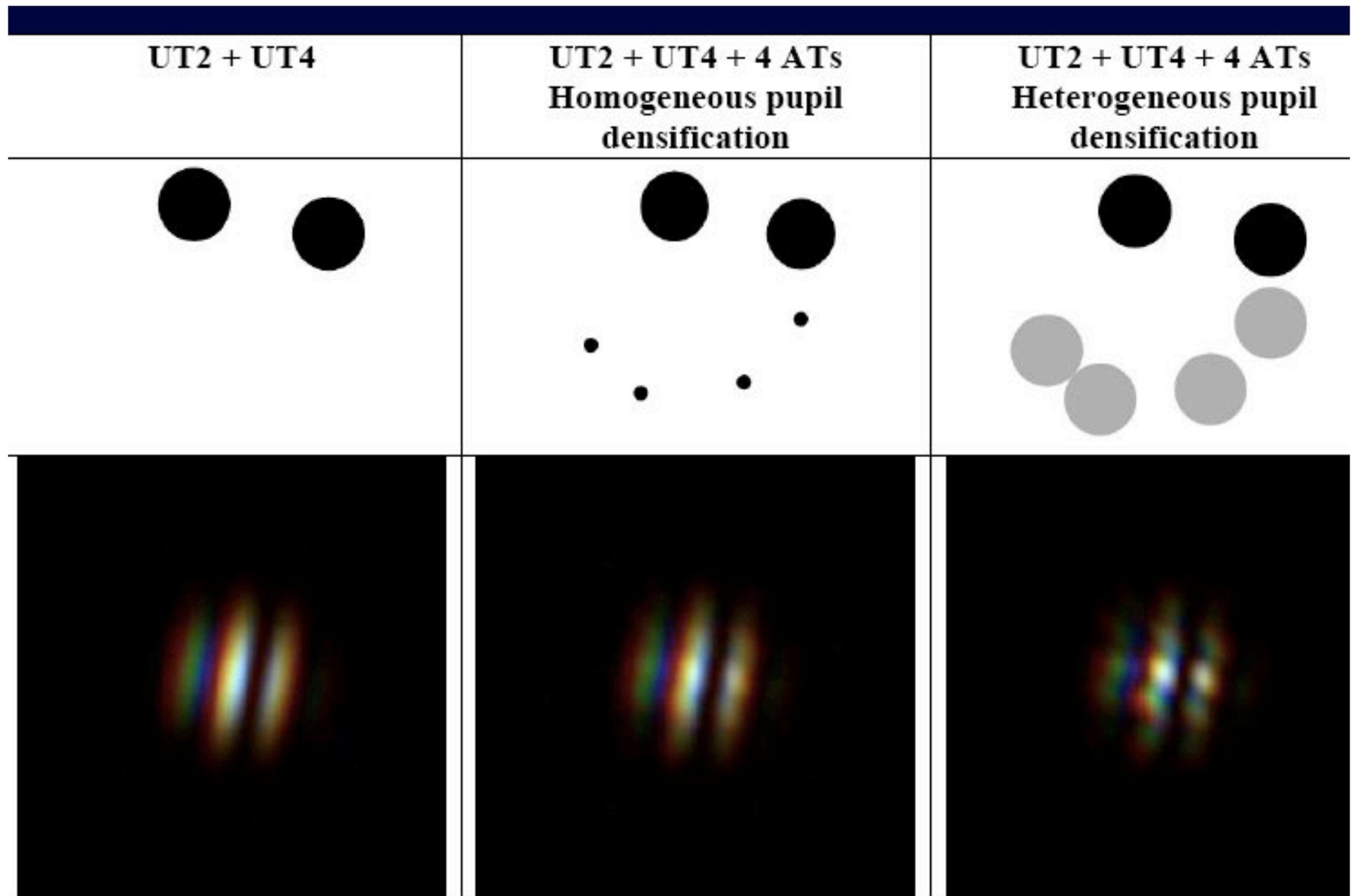
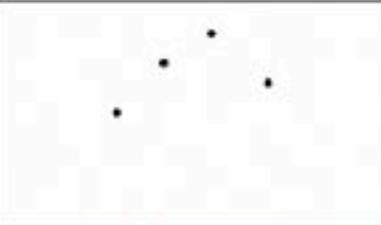
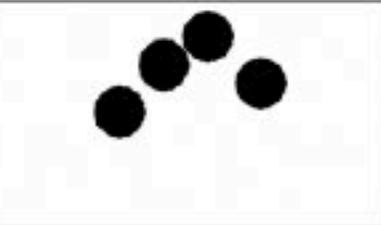
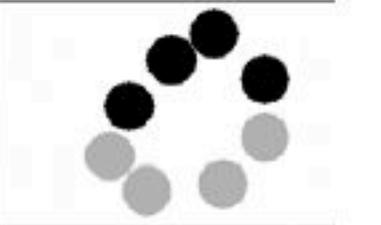
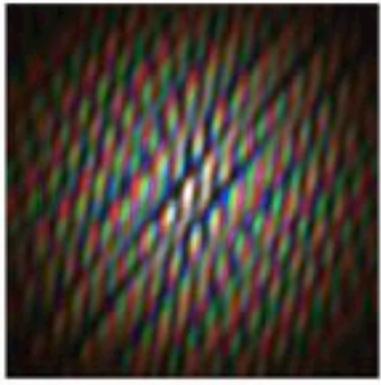
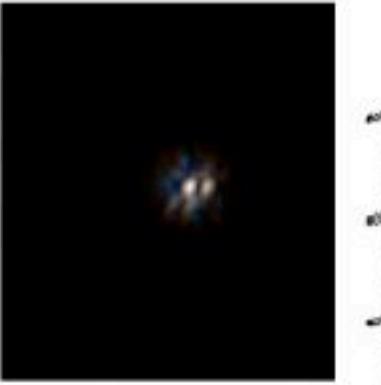


Figure 13: Images at three wavelengths around $1\mu\text{m}$ of a binary star ($\text{sep.}=2\text{mas}$) with 2 UTs (UT2,UT4) after pupil densification (left), with 2 UTs and 4 ATs (A1, D2, I1, M0) after an homogenous densification (center) and after an heterogeneous densification (right).

C

	Fizeau mode 4 UTs	Hypertelescope mode 4 UTs Homogeneous pupil densification	Hypertelescope mod 4 UTs + 4 ATs Heterogeneous pupil densification
Output pupil			
Image of a binary star (sep. = 1 resel, $\Delta m = 0.4$)			
Pupil densification factor	1	5.67	UT: 5.67 , AT: 25.83
Central peak intensity magnification	X 1	X 32.3 (+3.8mag.)	X 44.8 (+4.1mag.)
Direct imaging field extend	Infinite	3.6 resels	3.6 resels

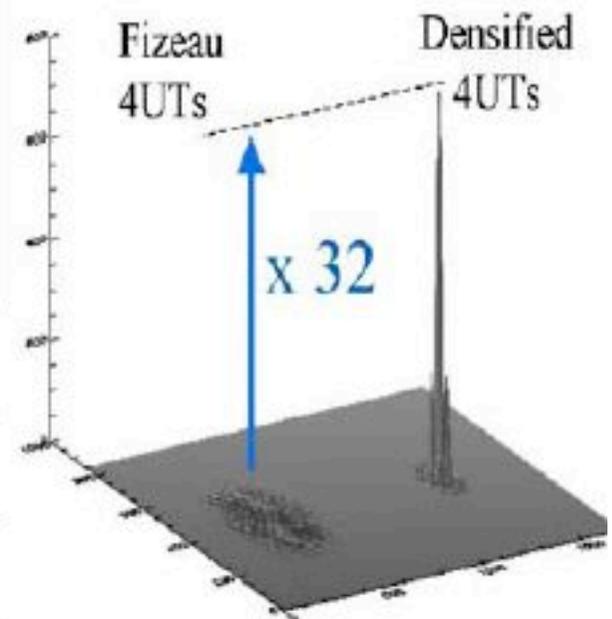
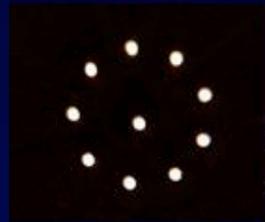


Figure 1: Left: Exit pupil and direct imaging of a binary star with the VLTI (intensity scale in power 0.3). Right: Densified 4UT PSF compared to the Fizeau 4UT PSF.

Senseur de piston à « tavelures dispersées »

(Labeyrie, Borkowski, Martinache, 2005)

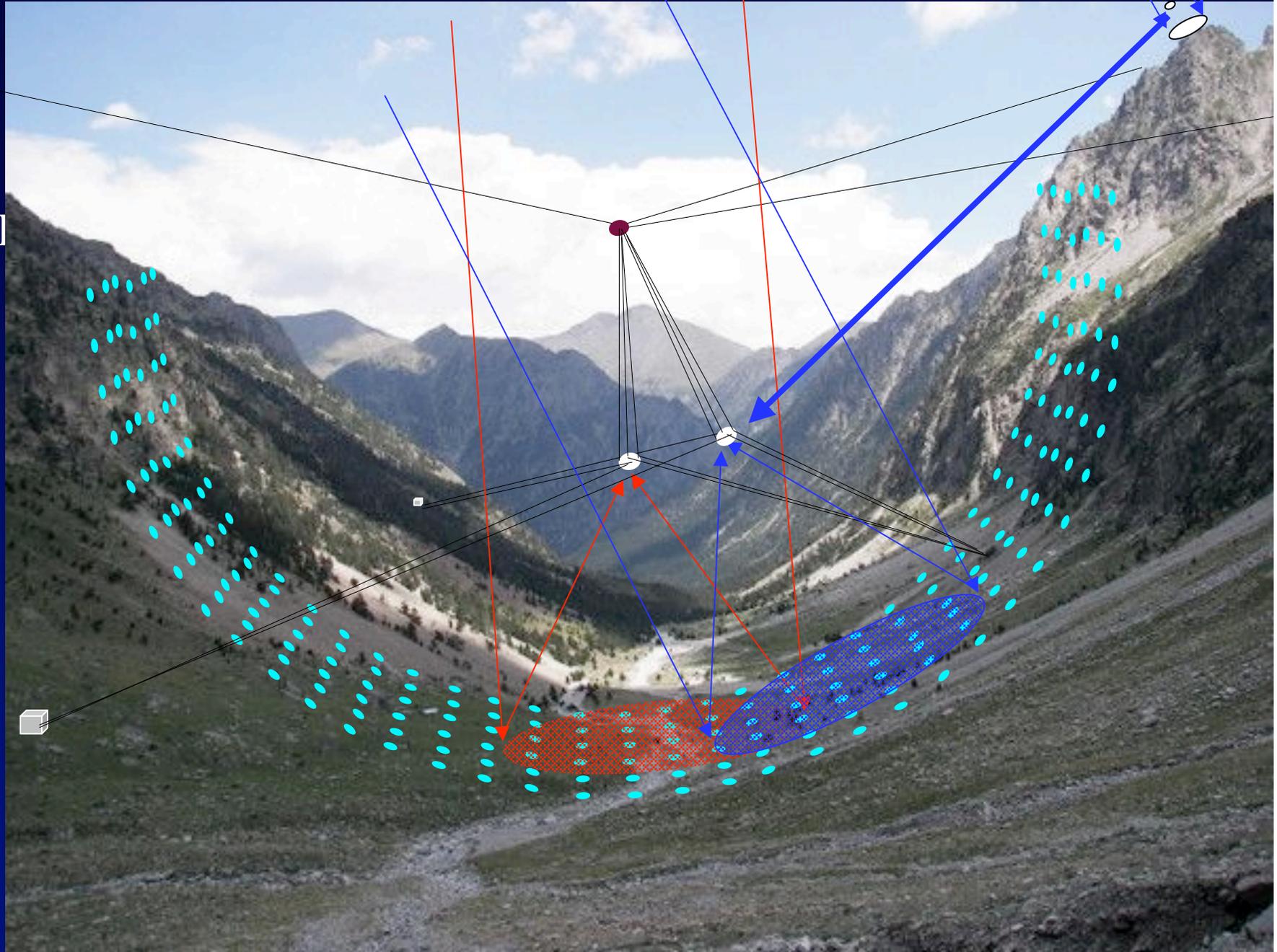


9+1 ouvertures
non redondantes

Tavelures dispersées

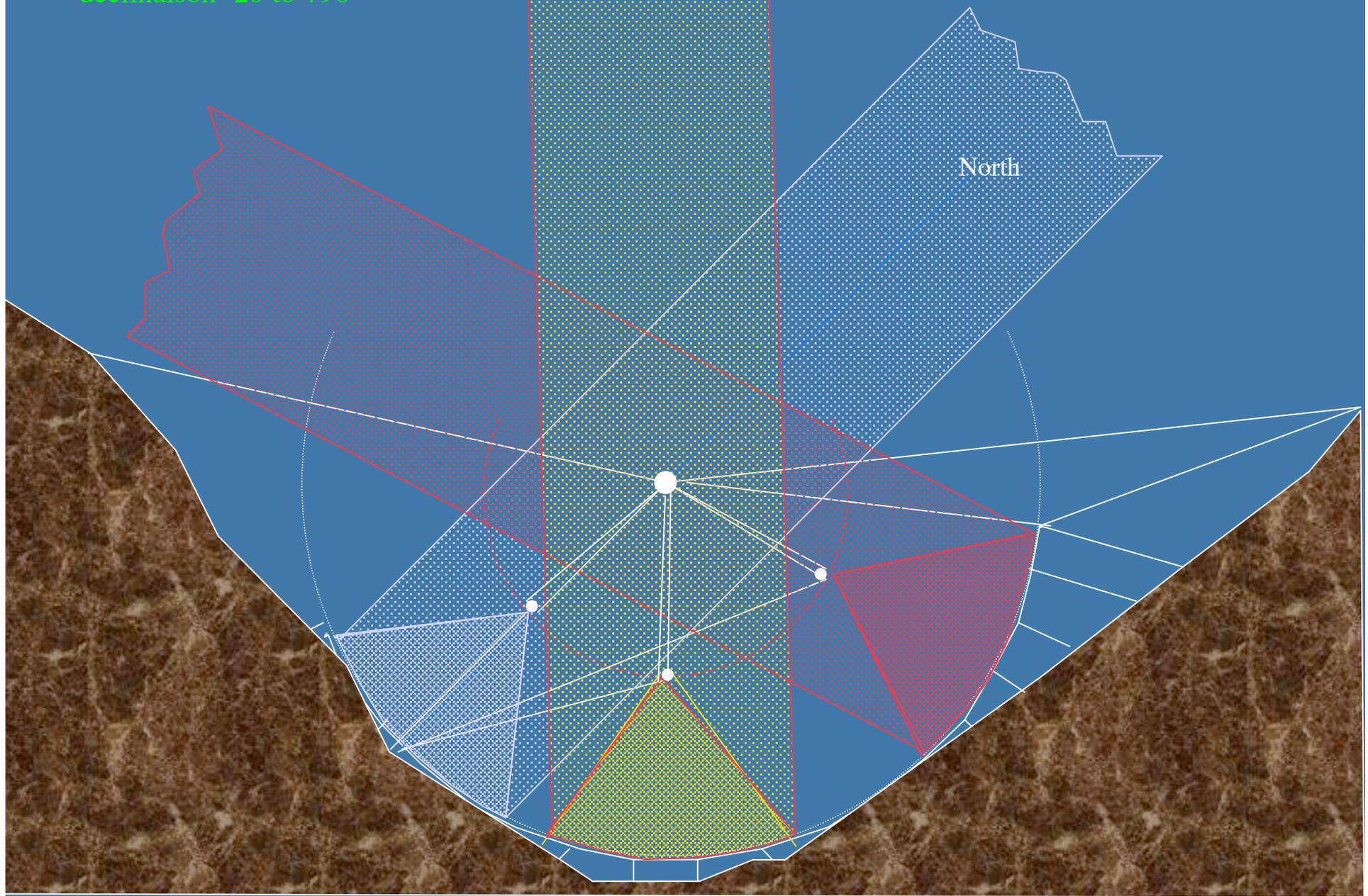
$$\Delta_{\max} = 0,35 \text{ mm}$$

Couplage ELT/hypertélescope à Barrosa



Insertion à Barrosa pour distance focale 200m

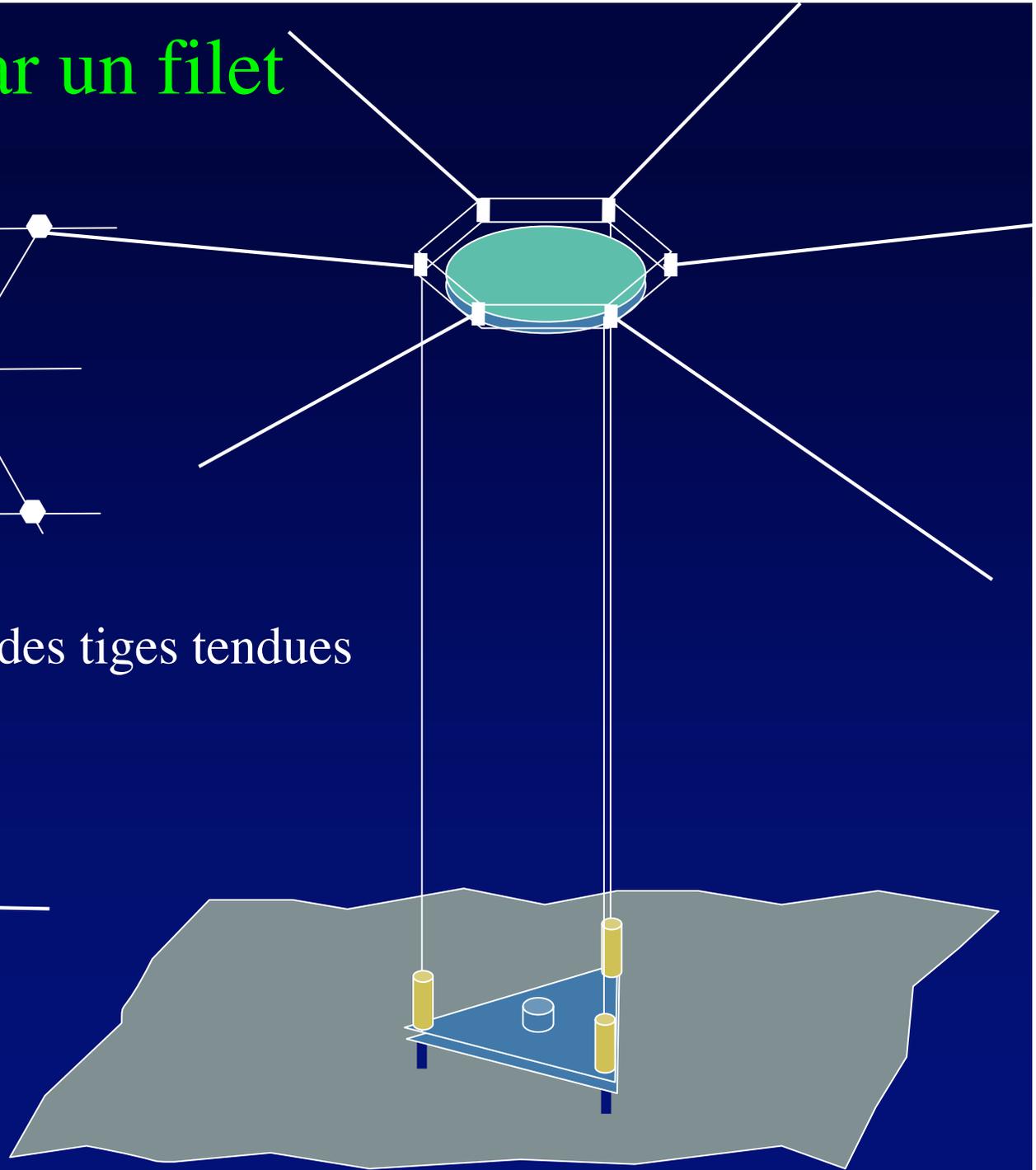
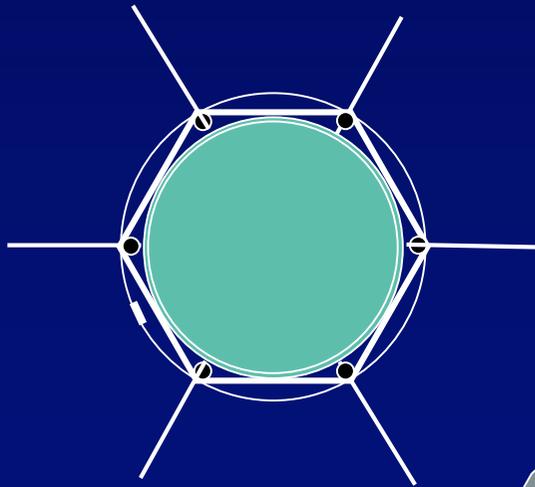
déclinaison -20 to +90°



Miroirs portés par un filet



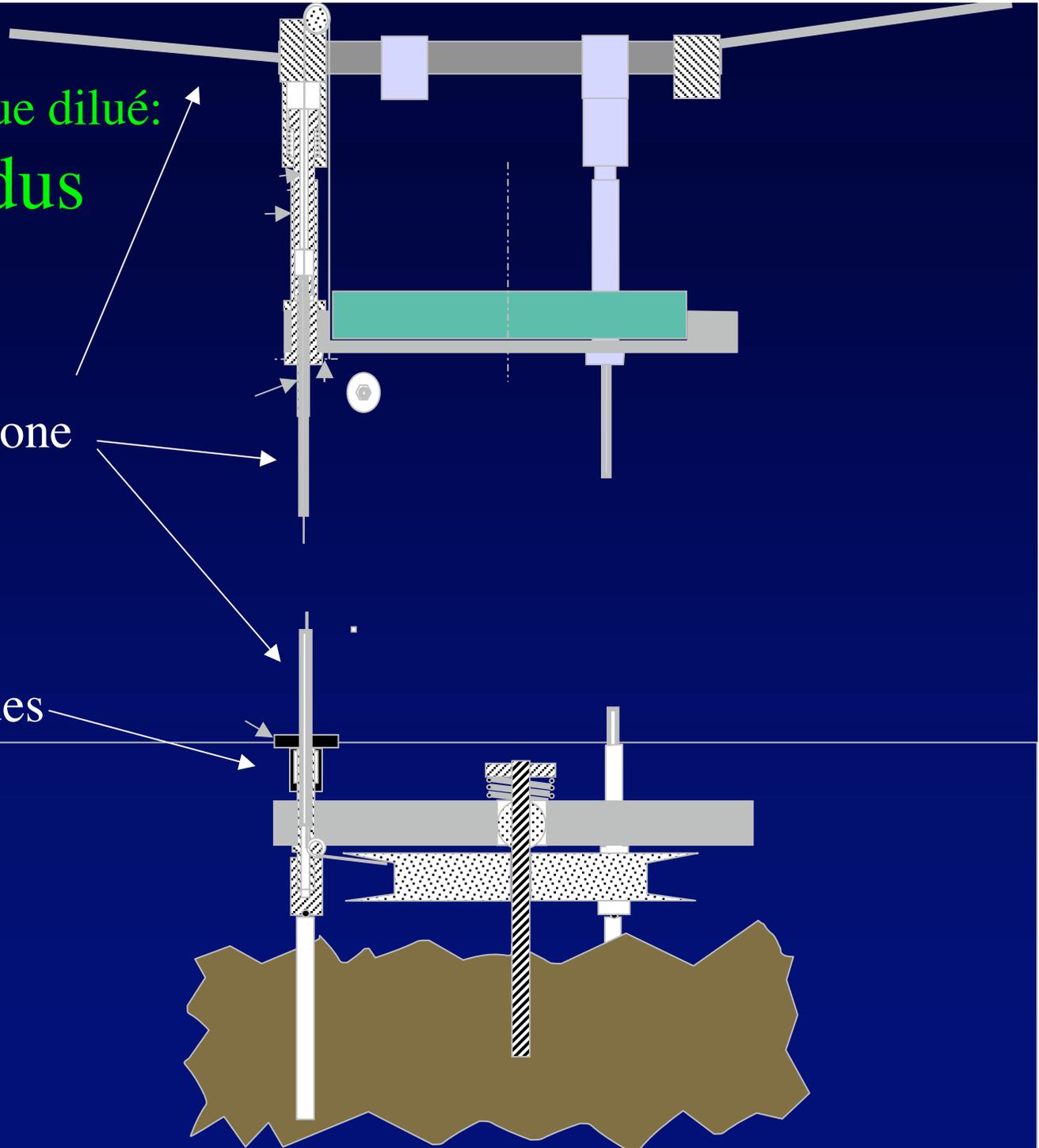
- Hauteur définie par des tiges tendues



Version Arécibo optique dilué:
miroirs suspendus

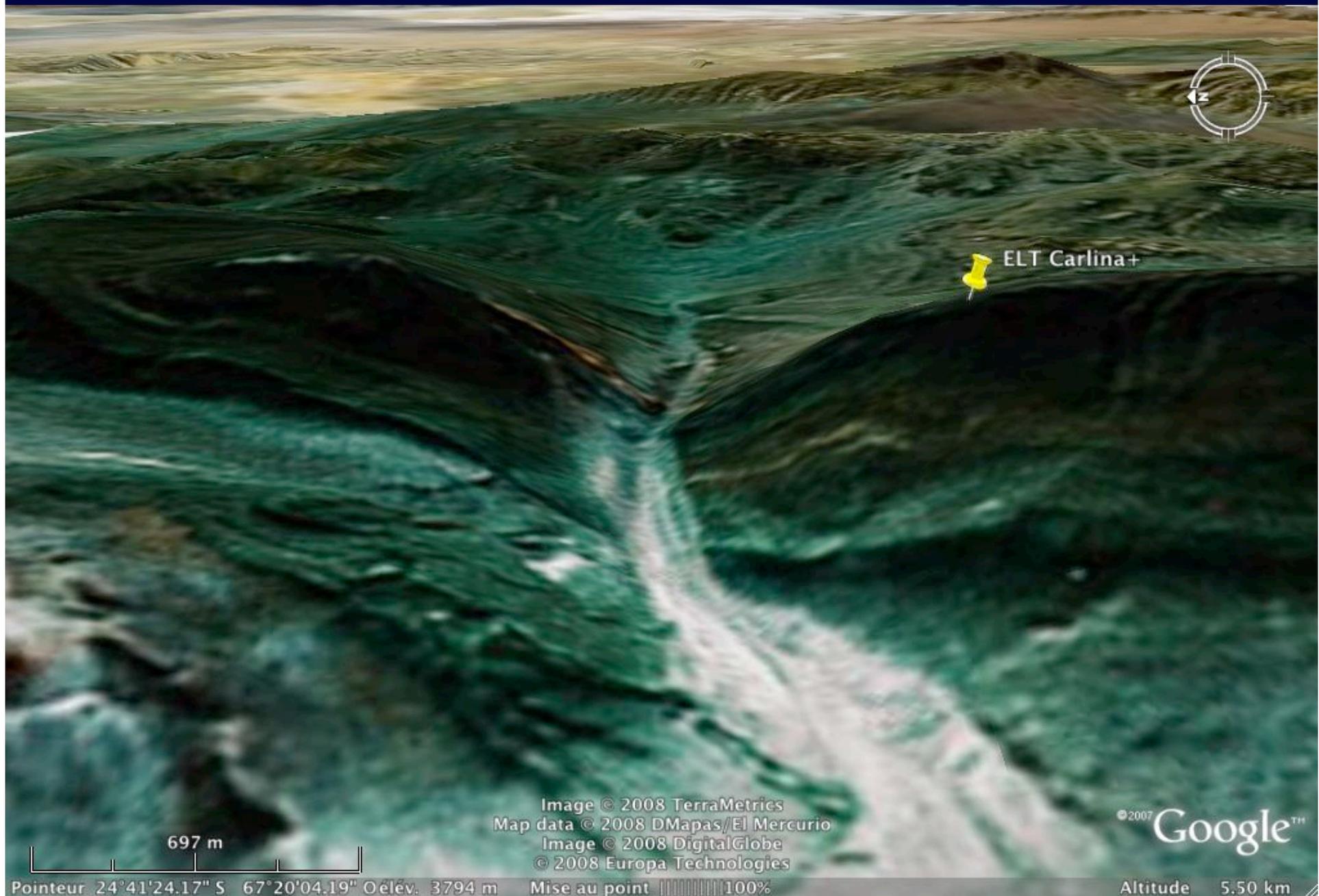
Tiges en carbone

Vis micrométriques





Compatibilité d'un site étudié pour E-ELT en Argentine

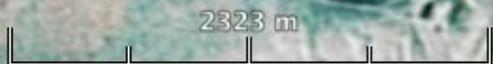




ELT Carlina+

Image © 2008 TerraMetrics

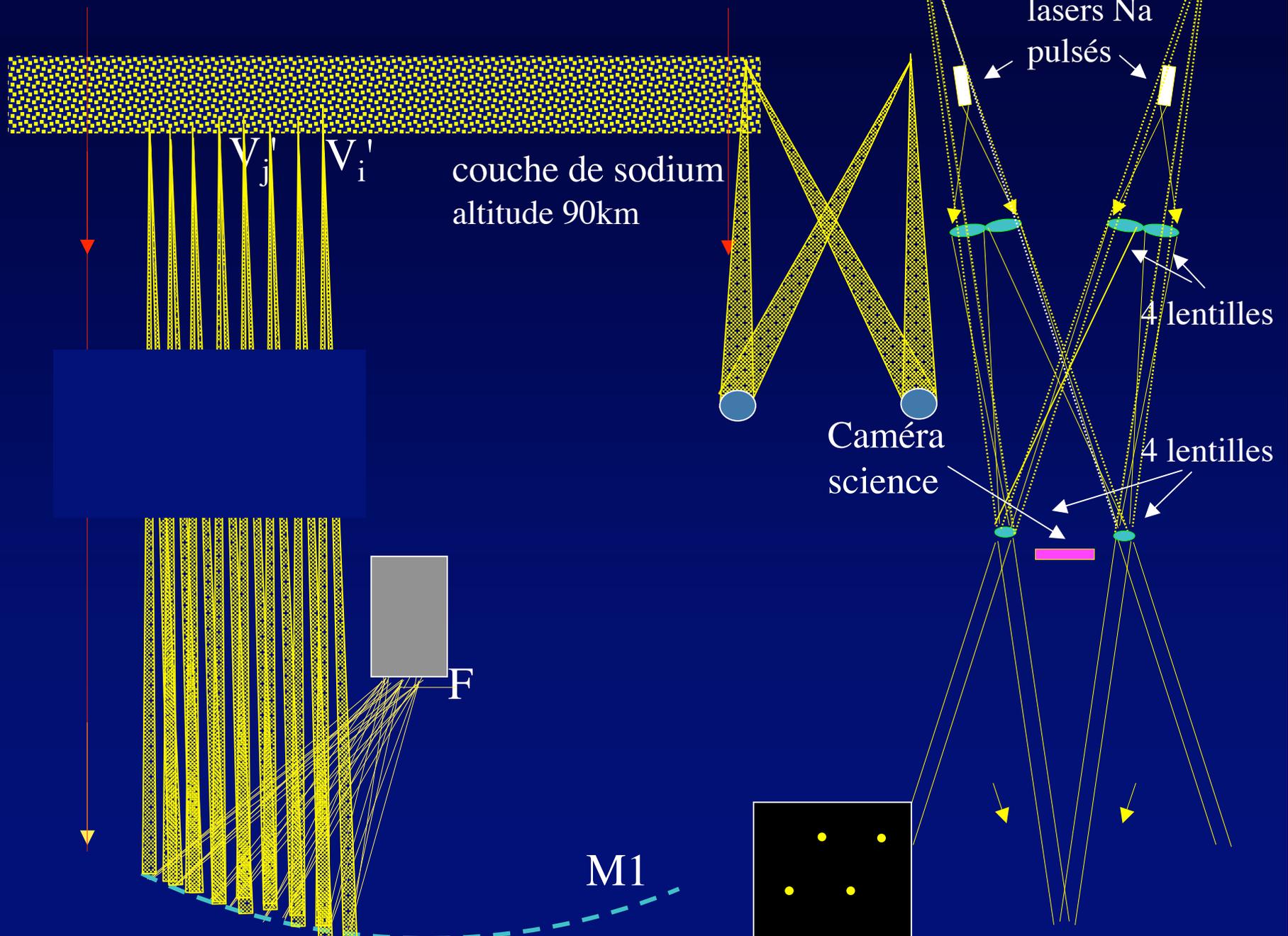
© 2007 Google™



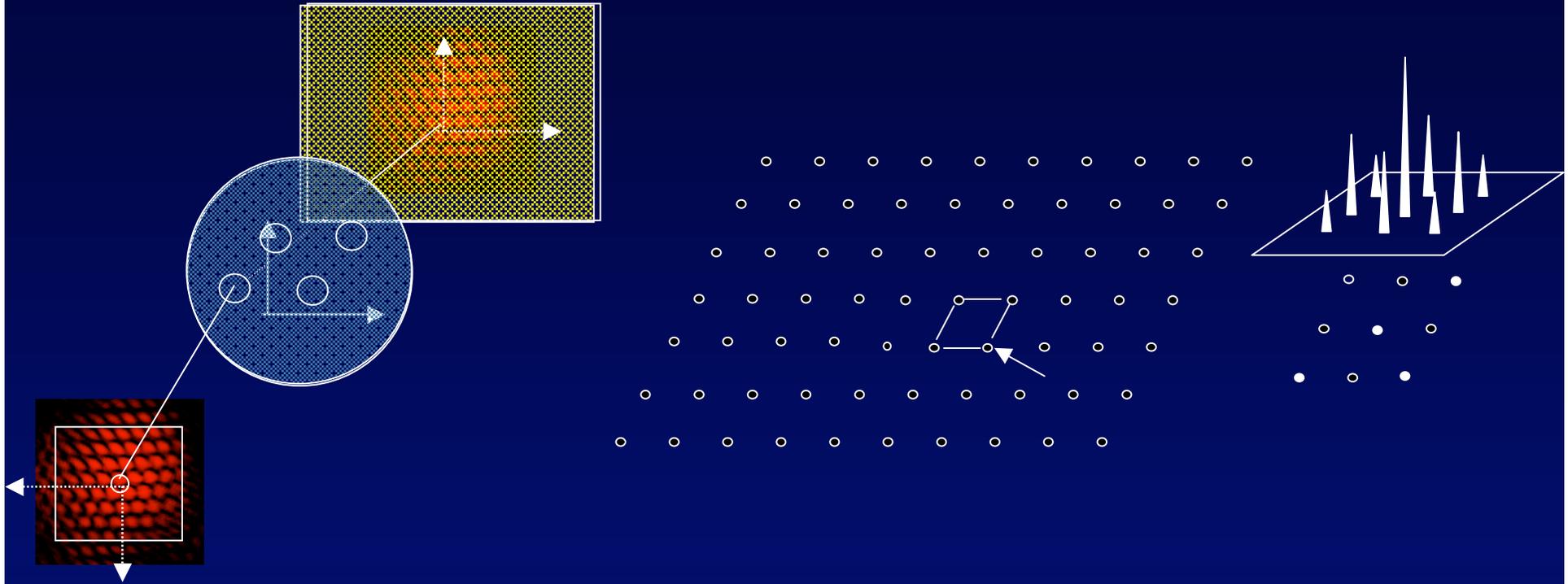
Pointeur 24°41'24.17" S 67°20'04.19" O élév. 3794 m Mise au point 100%

Altitude 11.64 km

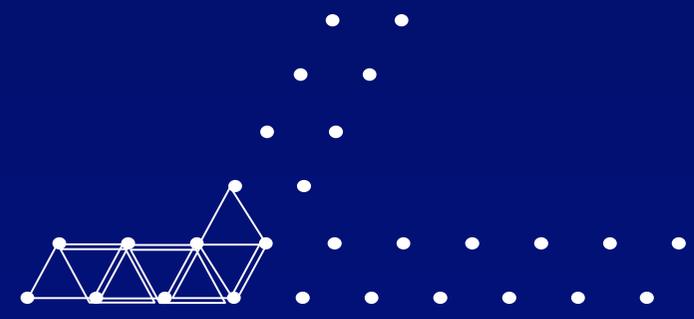
"Hypertelescope Laser Guide Star" V_i (H-LGS)



Etoile guide laser pour hypertélescope

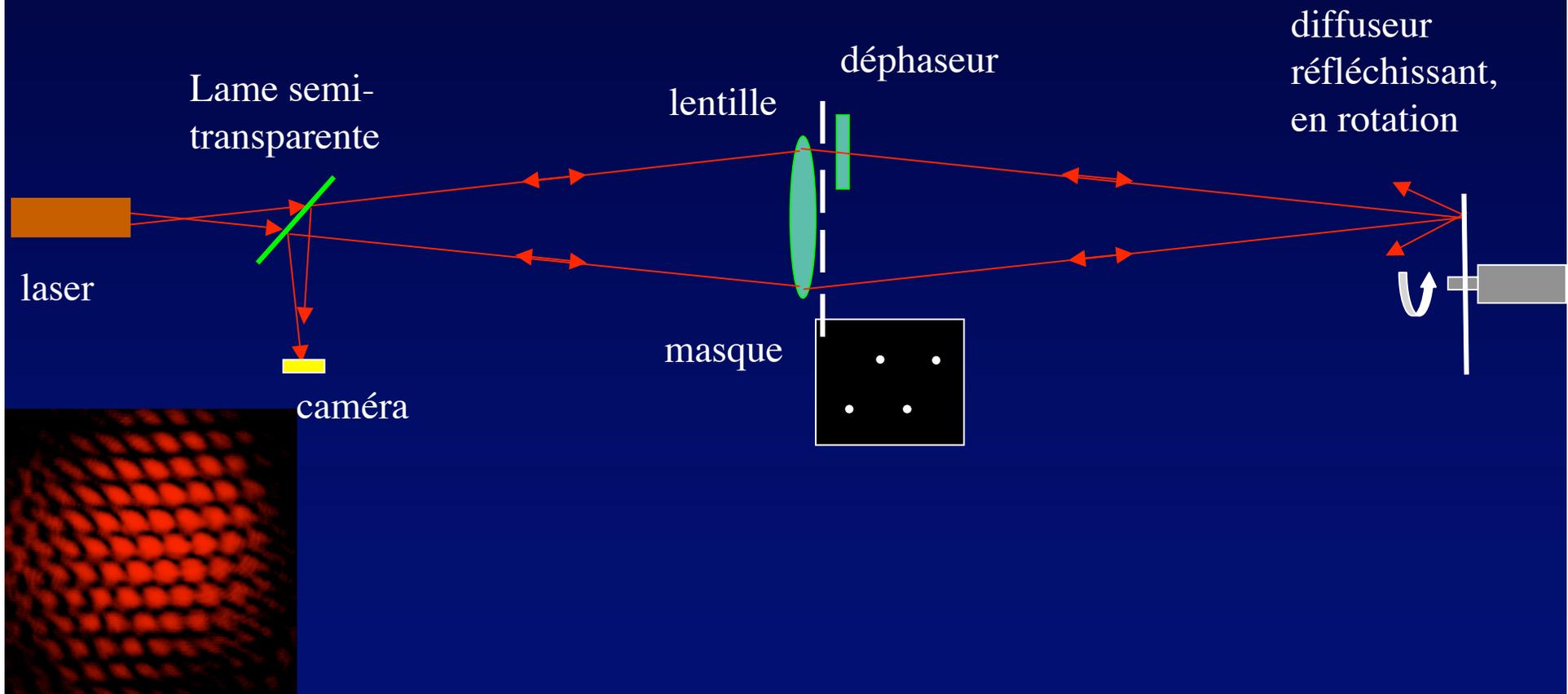


$$I_{hcam}(x, y) = I_h(x, y) \otimes I_h(-x, -y)$$



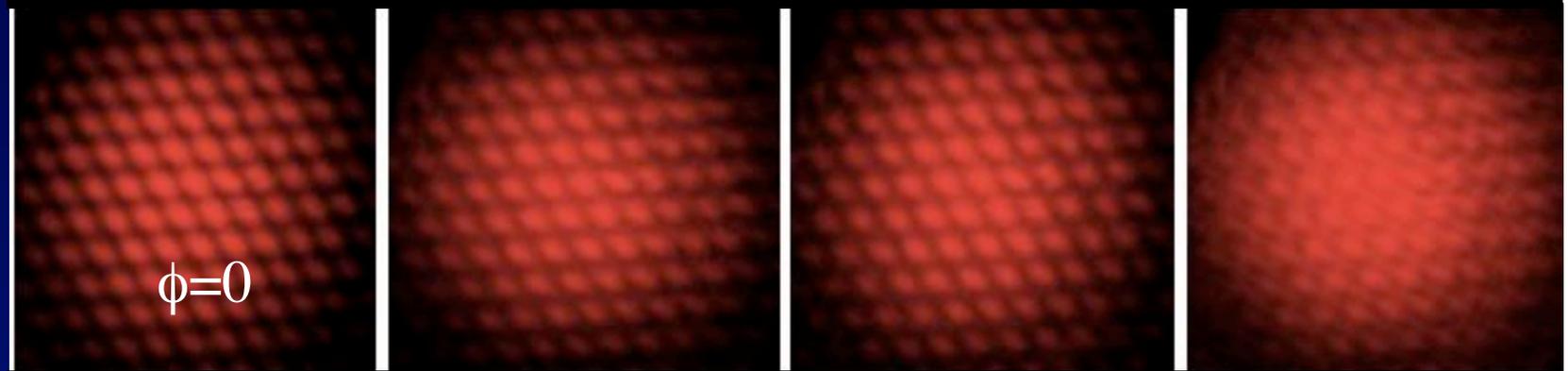
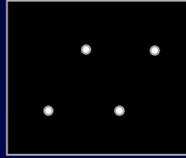
$$i_{hcam}(u, v) = AC[P_h(u, v)] \quad AC[P_h(-u, -v)] = AC[P_h(u, v)] \quad \overline{AC}[P_h(u, v)] = |AC[P_h(u, v)]|^2$$

Etoile guide laser pour hypertélescopes: simulateur en laboratoire

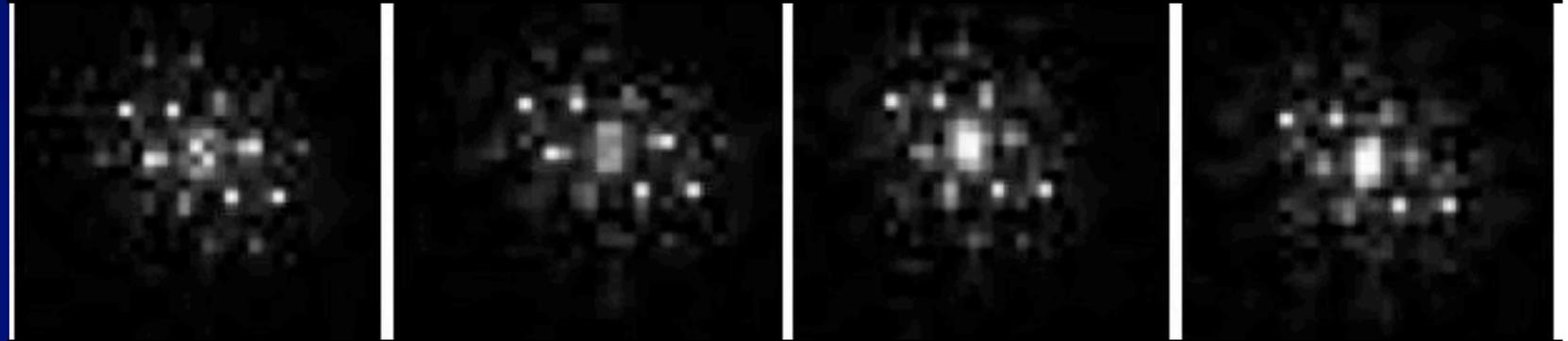


Etoile guide laser pour hypertélescopes: simulation au laboratoire

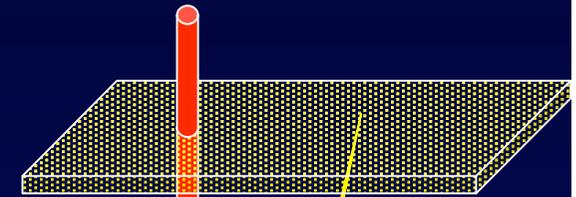
4 ouvertures
poses longues



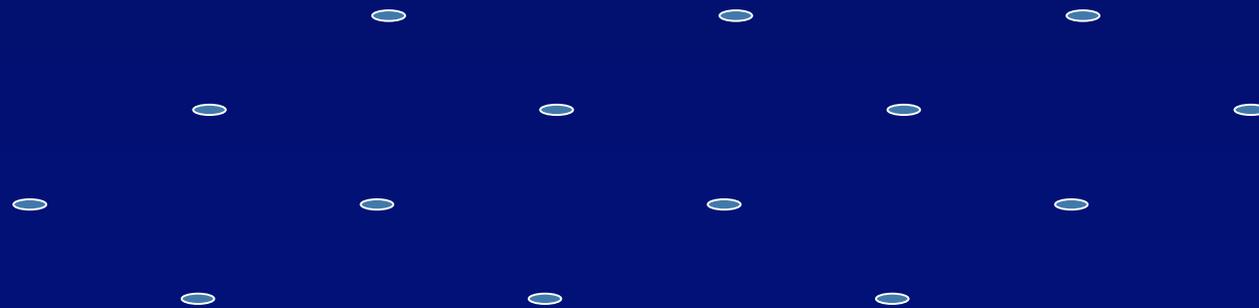
Transformées
de Fourier



Pourquoi séparer les sources laser ?

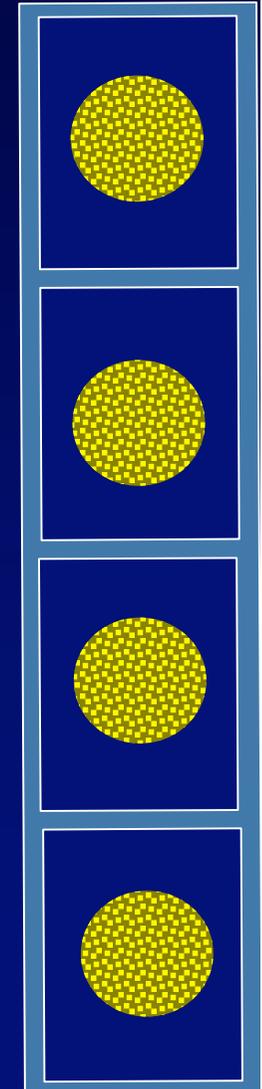
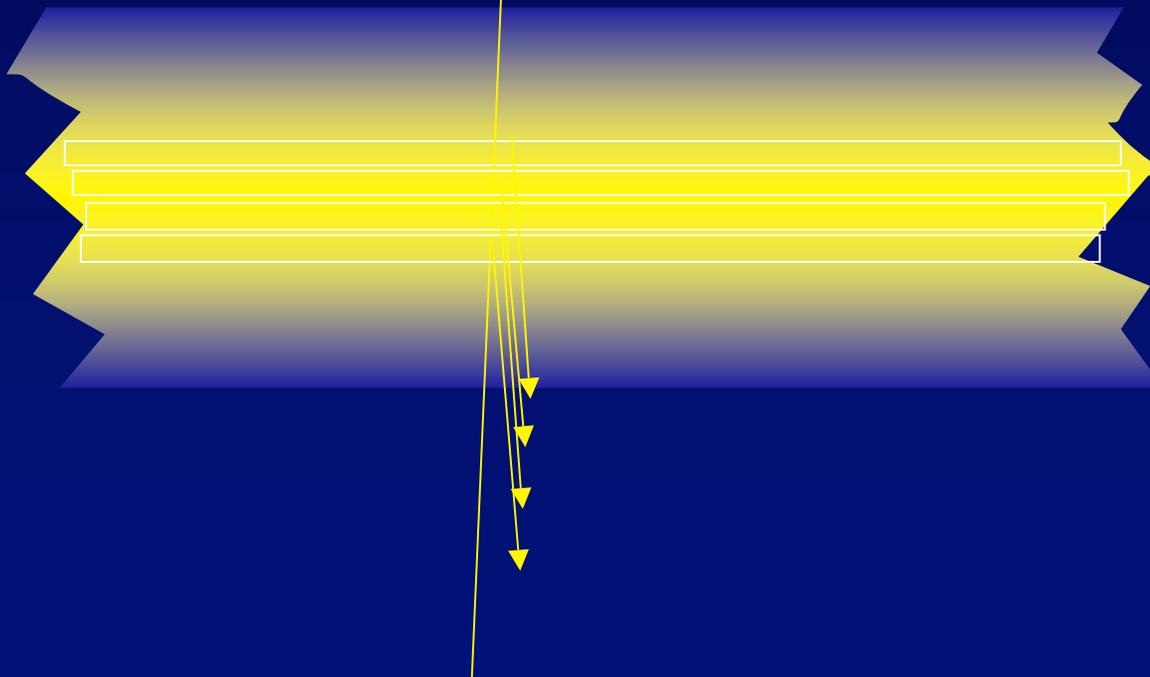


- Pour rapprocher les rayons des lasers de ceux de l'étoile...
- ...afin de sonder la même atmosphère
- Exemple: écart de 10m à 90km,
- Se réduit à 11cm à 1km
- Et 1,1cm à 100m $< r_0$
- .

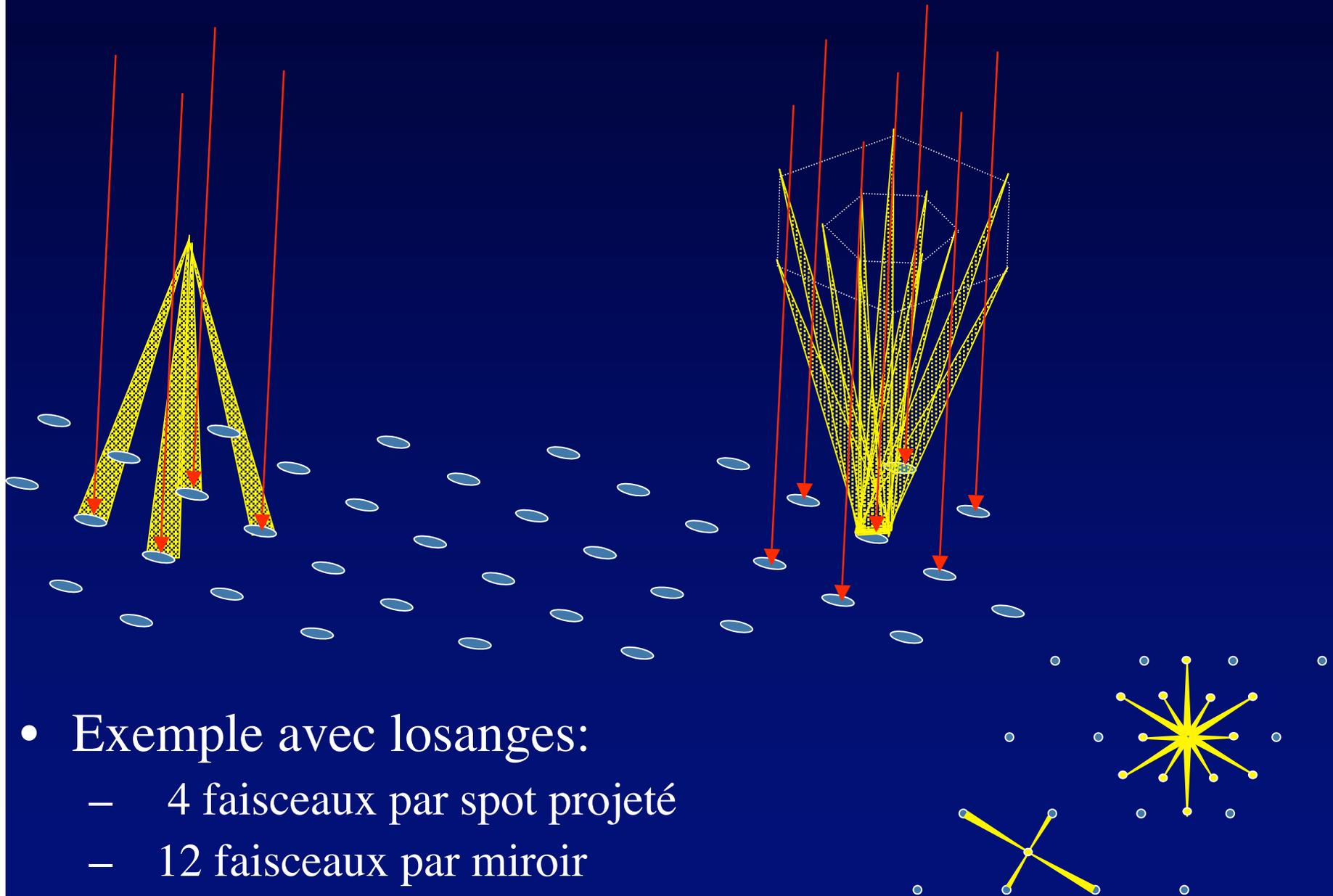


Sous-couches de sodium

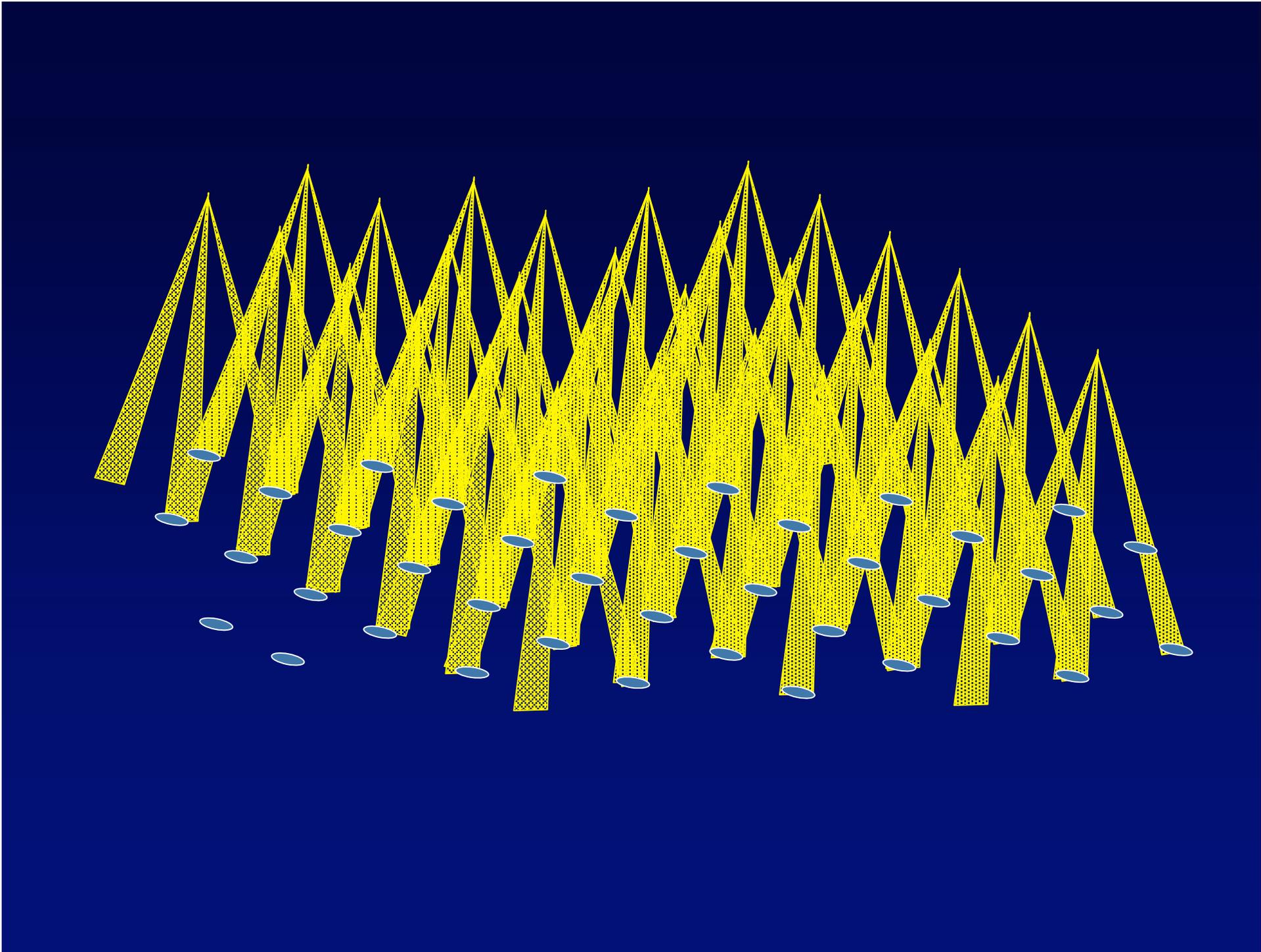
- Sélectionnées par impulsions brèves de laser...
- et caméra ultra-rapide
- Exploitable pour :
 - "diversité de phase" par défocalisation
 - sensibilité accrue



Pourquoi séparer les sources laser ?



- Exemple avec losanges:
 - 4 faisceaux par spot projeté
 - 12 faisceaux par miroir



Conclusion et travail futur

- Préciser le concept Carlina d'hypertélescope terrestre
 - Miroirs sur filet ou au sol
 - Vérifier étoile laser "Hypertelescope Laser Guide Star"
 - Essais sur prototypes Carlina 1 et 2
- Etudier les versions spatiales