Imaging through turbulence

(image formation, atmospheric turbulence, intro to adaptive optics)

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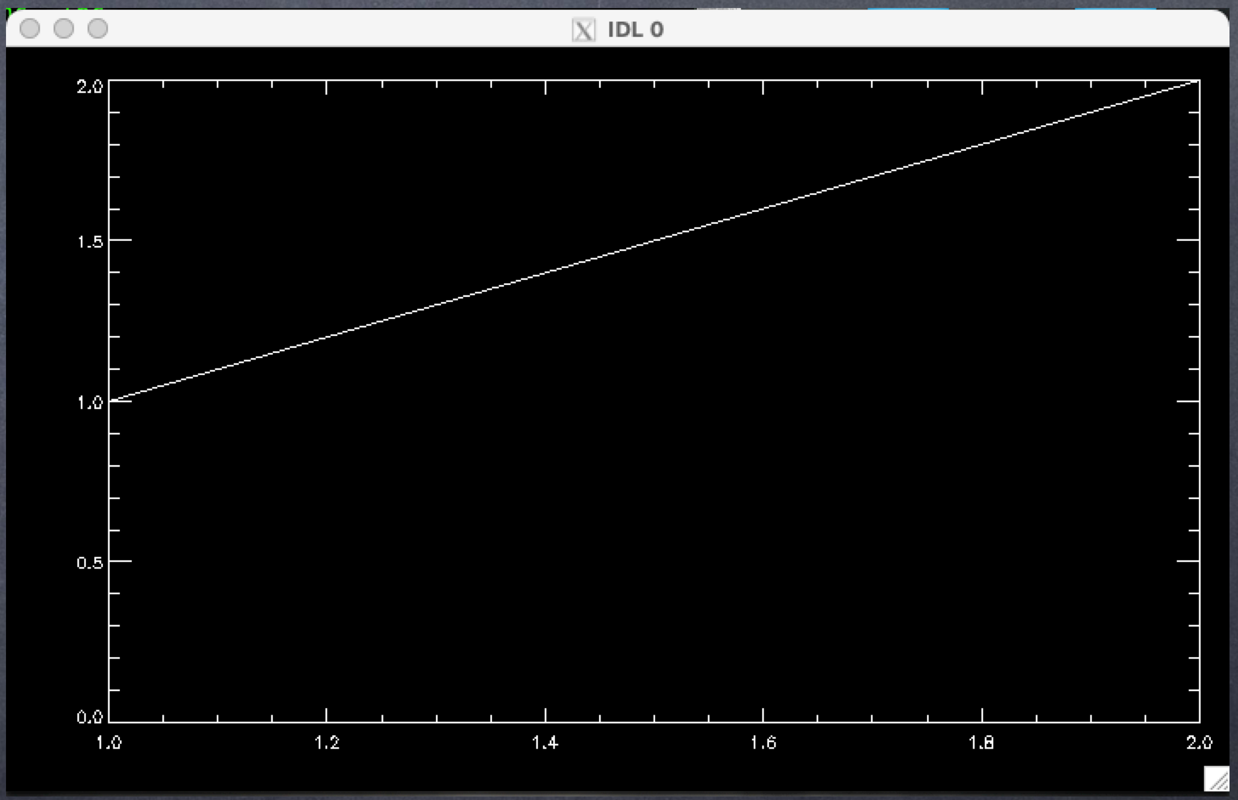
Menu

- High-angular resolution imaging in astronomy
- Atmospheric turbulence (reminder)
- Numerical modelling of perturbed wavefronts
- Formation of resulting images (+detection noises)
- *(Introduction to speckle interferometry)*
- Introduction to adaptive optics (AO)
- AO error budget
- Post-AO point-spread function morphology
- Anisoplanatic error study (ideal AO system)

(IDL preliminaries…)

- launch IDL (or IDLDE=IDL+interface), with an OCA VPN running if doing it through the wifi.

- test it:
  IDL> 'hello'
  IDL> plot, [1,2], [1,2]



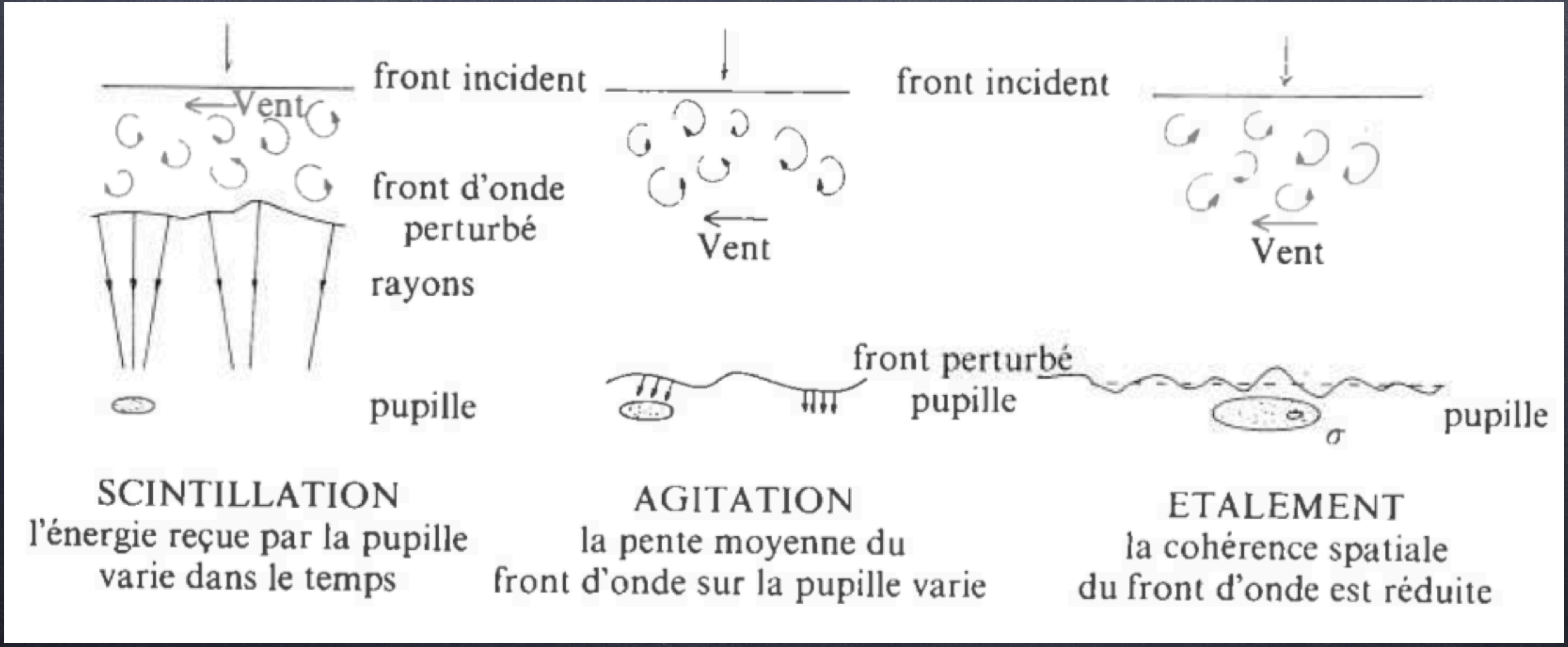
=> problems with the VPN

=> problems with the IDL graphical windows (plot)

Images & turbulence - 1

The image formed through turbulent atmosphere (optically speaking) is degraded:

- Scintillation (due to intensity fluctuation in the pupil).
- Agitation (due to angle-of-arrival variation).
- Spreading (due to a loss of spatial coherence).



(Illustration from Pierre Léna, Astrophysique — Méthodes physiques de l'observation, CNRS Éd. (2me éd.), p.177)

Images & turbulence - 2

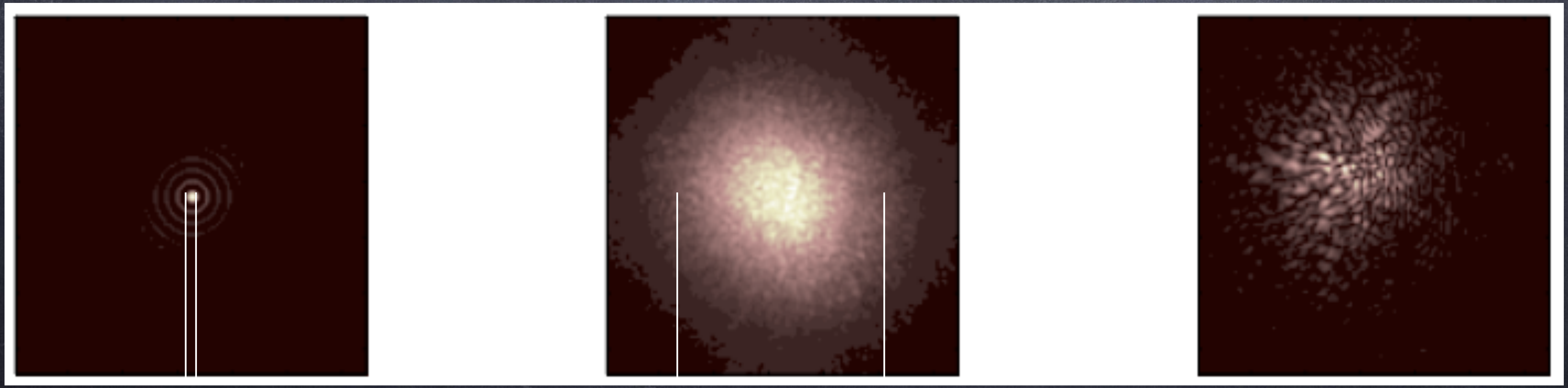
The object-image relation between the intensity *I(α)* in the image plane (i.e. the focal plane of the telescope) and the brightness *O(α)* of the object (in the sky) is a relation of convolution implying the point-spread function (PSF) *S(α)* of the whole ensemble telescope+atmosphere, with *α* the angular coordinates in the focal plane:

$$I(\vec{\alpha}) = O(\vec{\alpha}) * S(\vec{\alpha})$$

Images & turbulence - 3

$$I(\vec{\alpha}) = O(\vec{\alpha}) * S(\vec{\alpha})$$

This relation is valid when the system is invariant by translation (i.e. everything happens within the isoplanatic domain)…



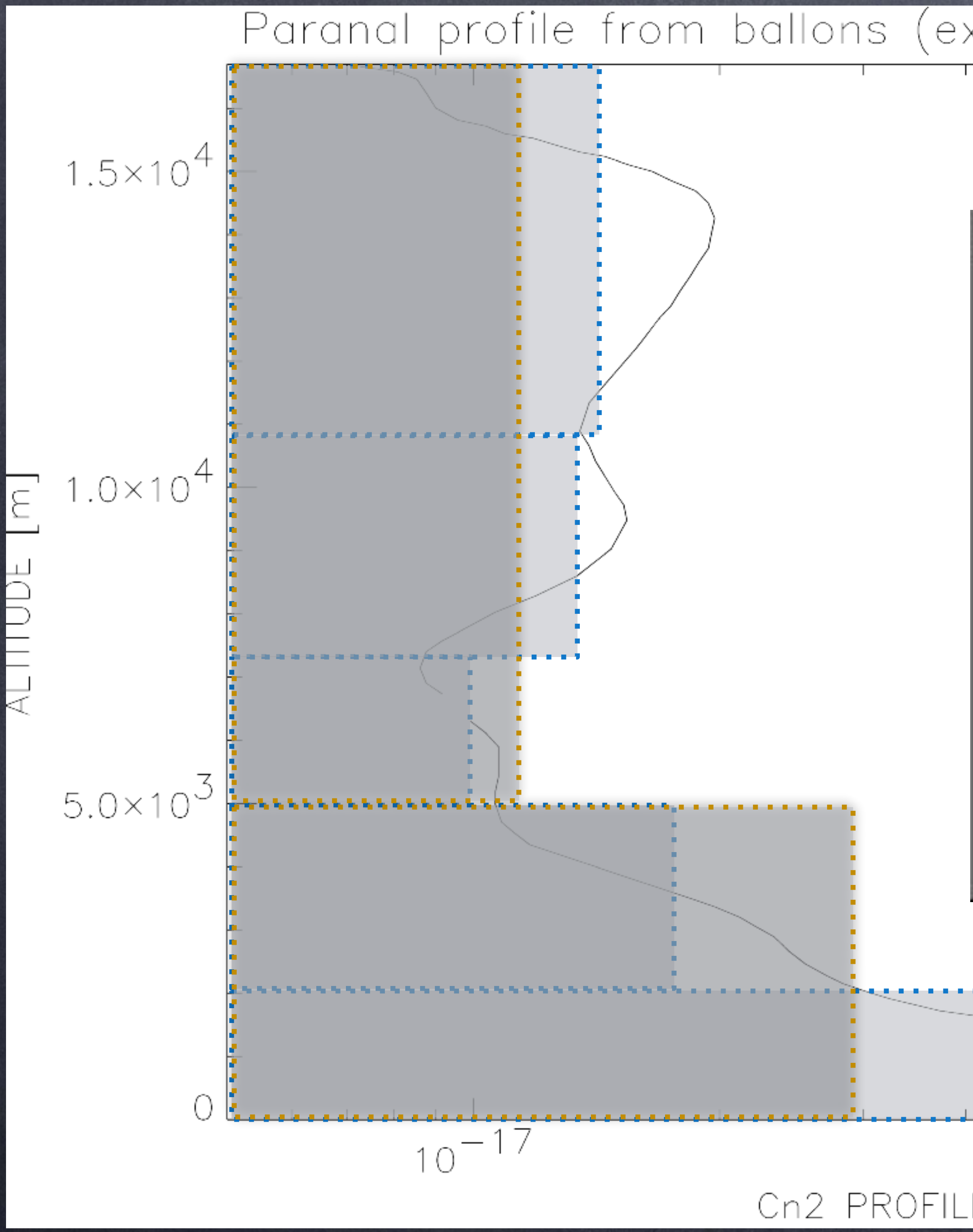
λ/D λ/r_0

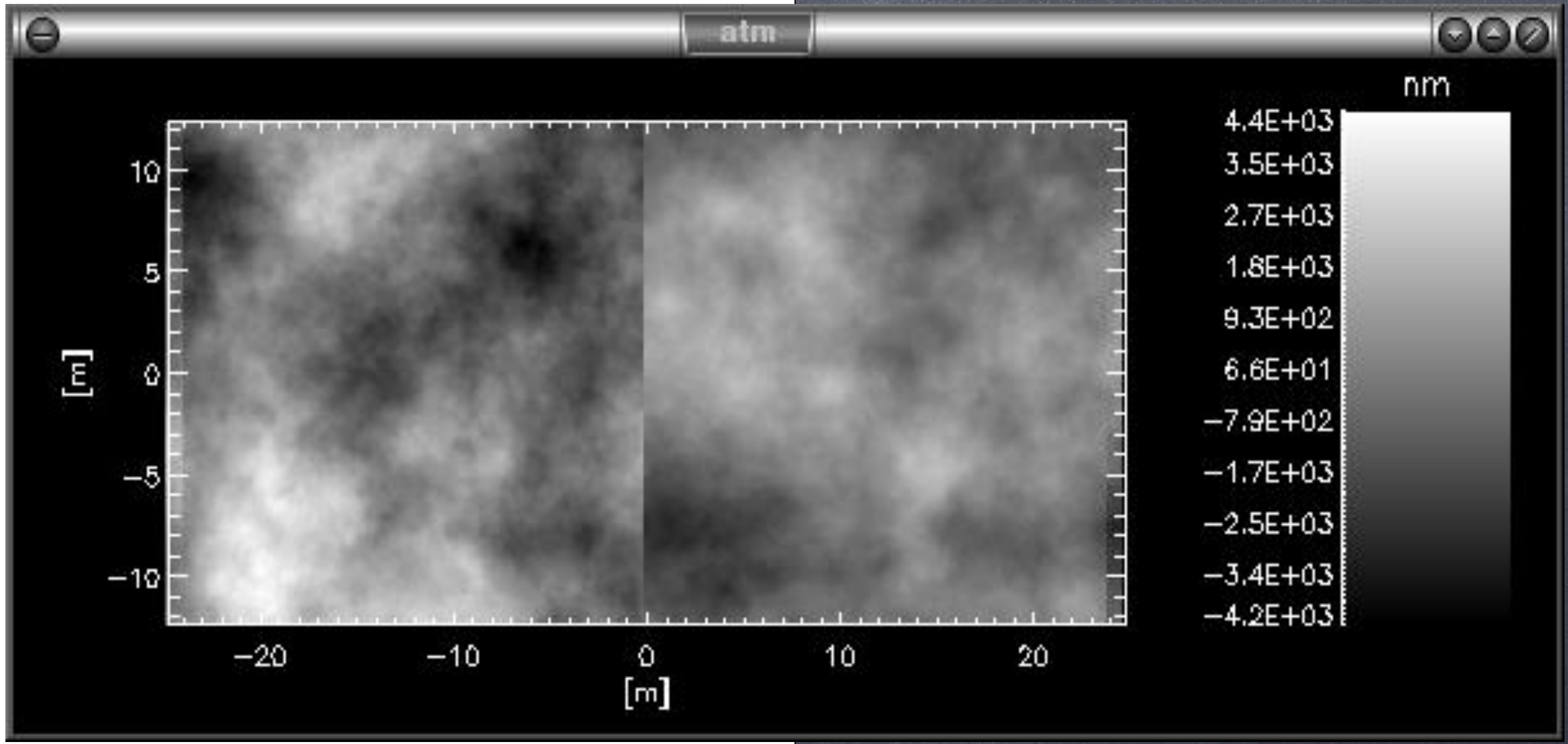
Images & turbulence - 4

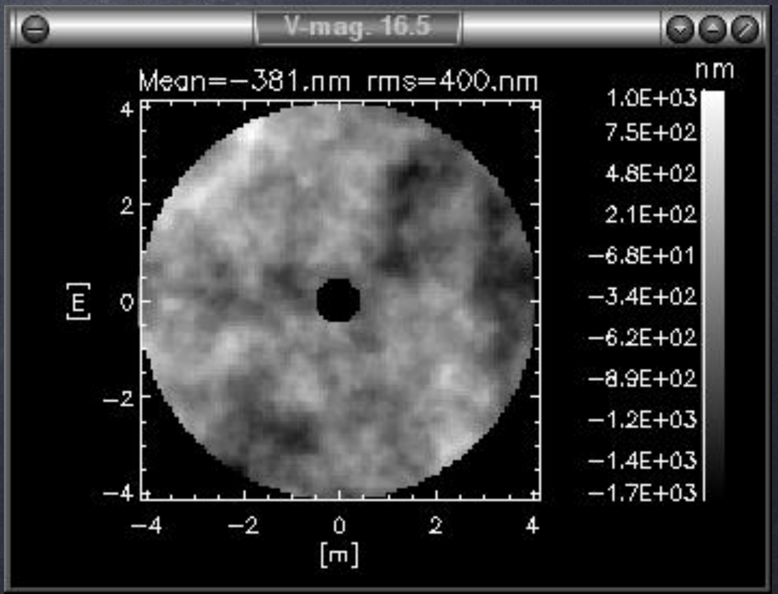
Some orders of magnitude concerning the turbulent atmosphere:

	λ = 500 nm	λ = 2.2 μm
Fried parameter (r_0)	→ 10 cm	60 cm
velocity of the turbulent layers (v)	→ 10 m/s	id.
=> image FWHM ($\epsilon \approx \lambda / r_0$)	→ 1"	~1"
=> evolution time ($\tau_0 \propto r_0 / v$)	→ 3 ms	18 ms

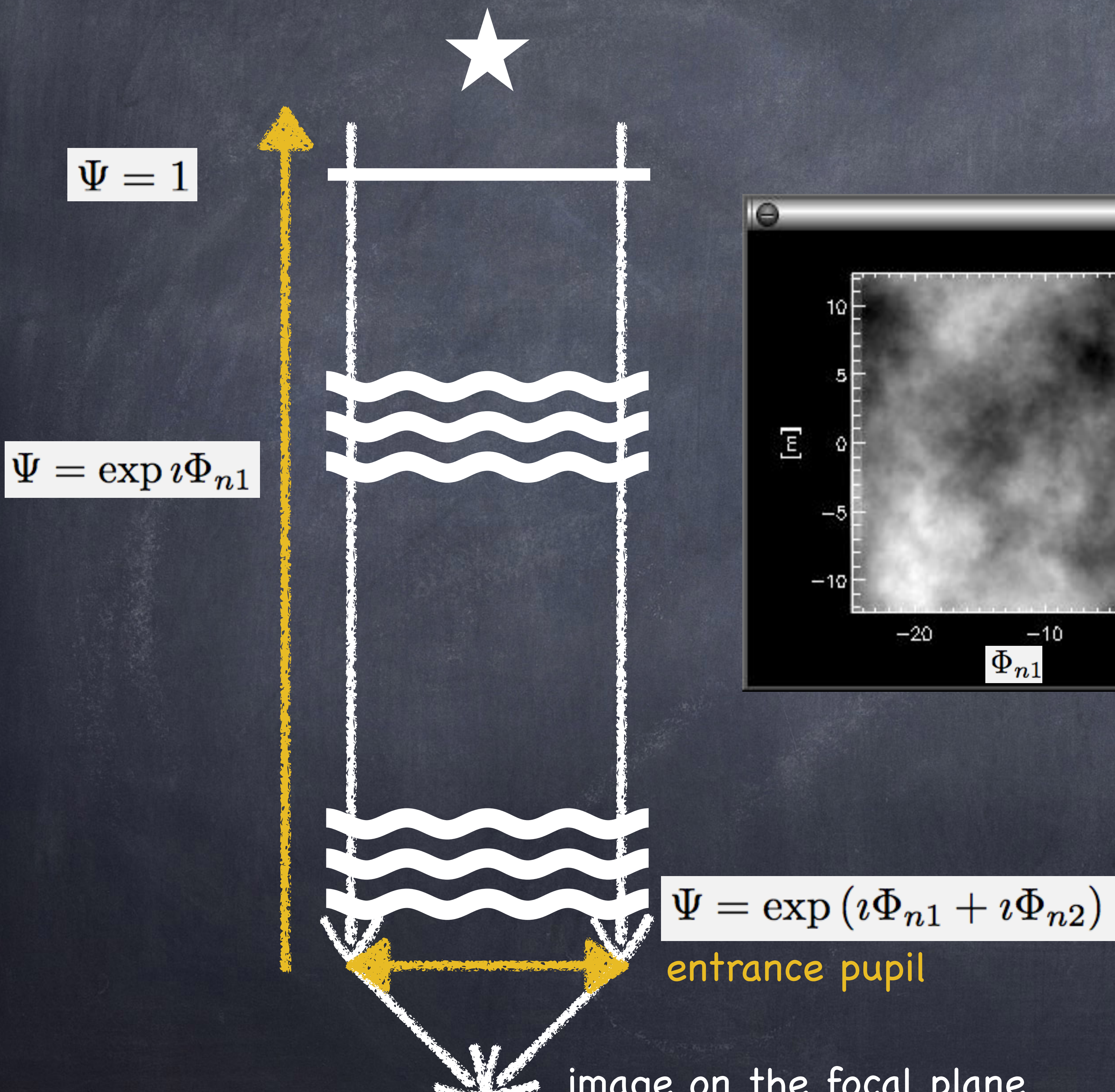
Images & turbulence - 5

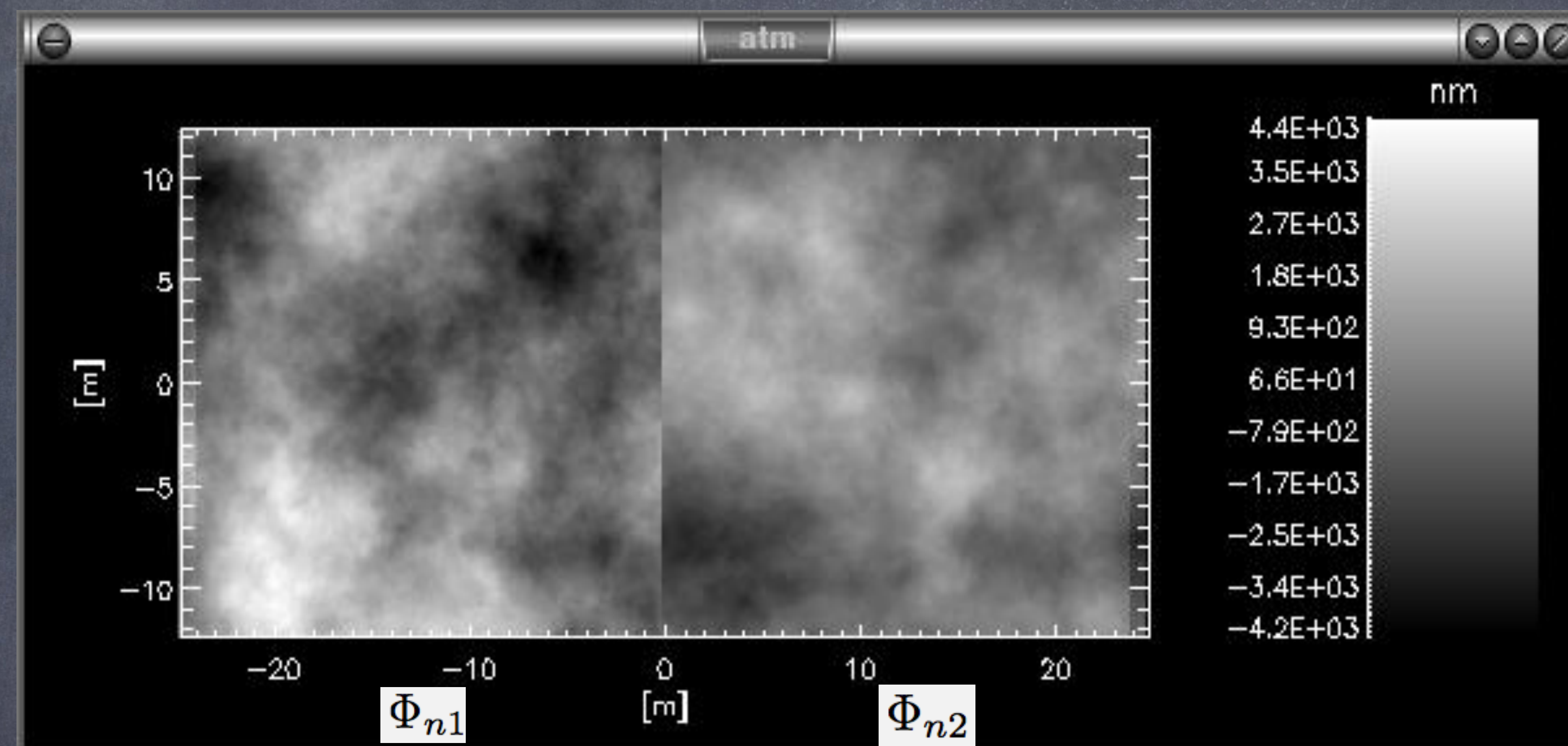


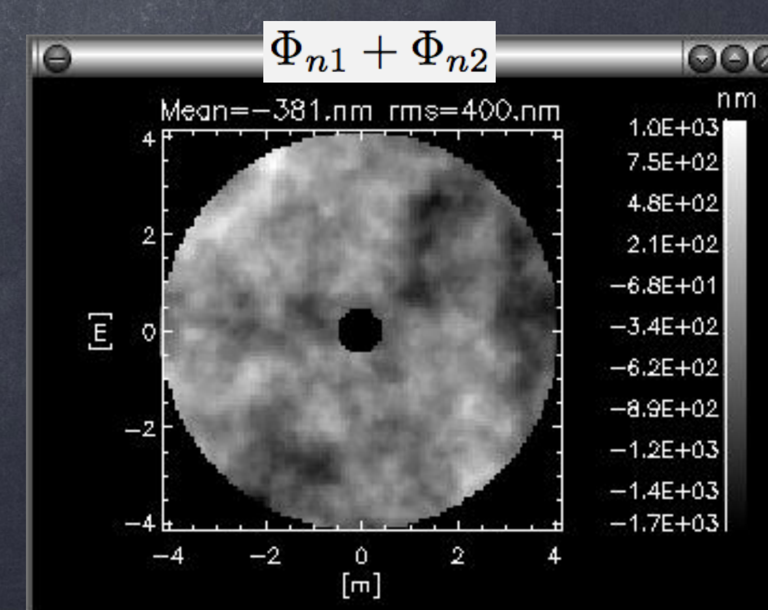




Images & turbulence - 6

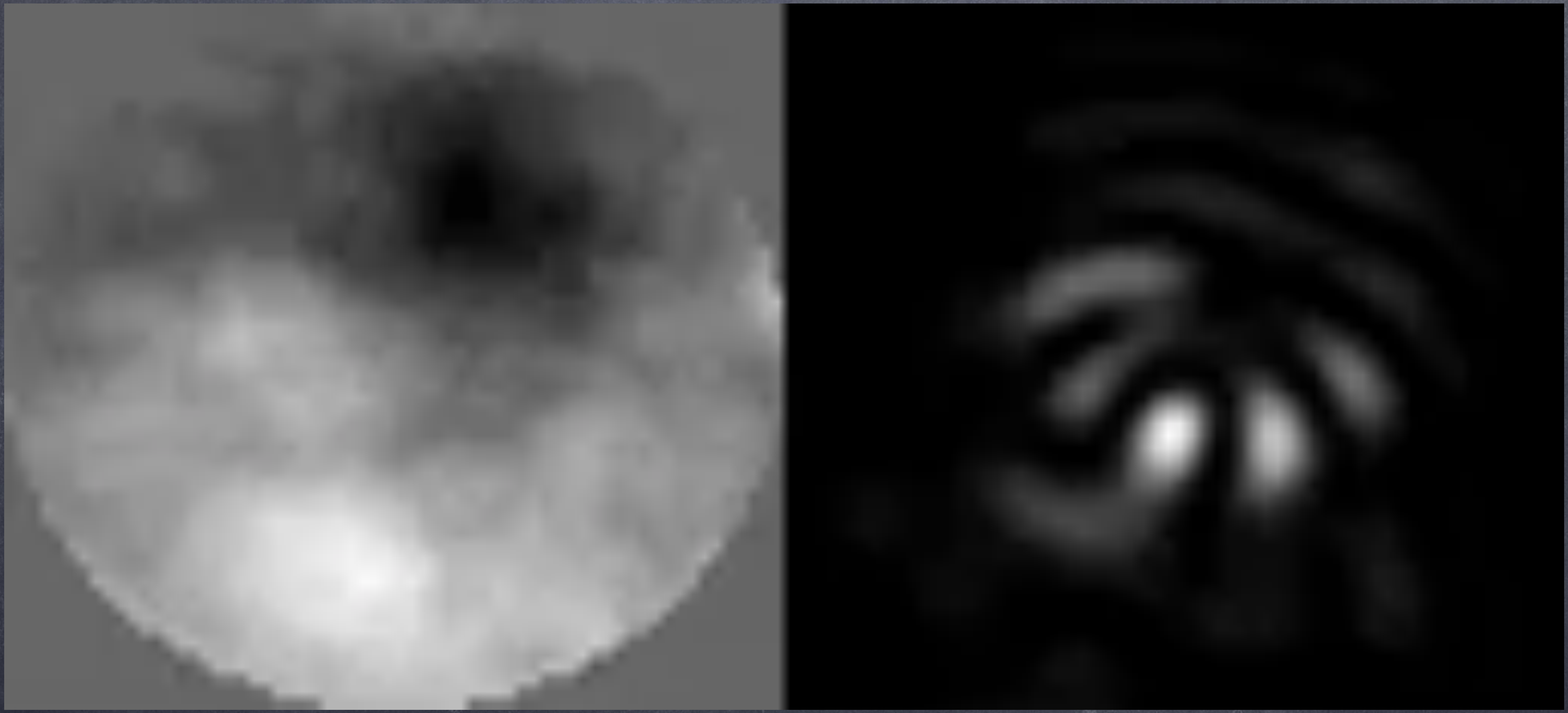






Images & turbulence - 7

entrance pupil　　　　image on the focal plane



remembering eq. 2.17 from the course of Éric Aristidi:

$$I(x,y) = \frac{1}{\lambda^2 F^2} \left| \hat{f}_0 \left(\frac{x}{\lambda F}, \frac{y}{\lambda F} \right) \right|^2$$

directly coming from (eq. 2.16):

$$f_F(x,y) = \frac{e^{ikF}}{i\lambda F} \, e^{\frac{i\pi\rho^2}{\lambda F}} \, \hat{f}_0 \left(\frac{x}{\lambda F}, \frac{y}{\lambda F} \right)$$

Images & turbulence - 8

The wavefront is, modulo $\lambda/2\pi$, proportional to the phase $\Phi(r)$ of the wave $\Psi(r)$ which has went through the turbulent atmosphere before reaching the telescope:

$$\Psi(\vec{r}) = A(\vec{r}) \exp\{\imath \Phi(\vec{r})\}$$

Note that this phase can be decomposed following a base of polynomials, for example Zernike ones:

$$\Phi(\vec{r}) = \sum_i a_i \, Z_i(\vec{r})$$

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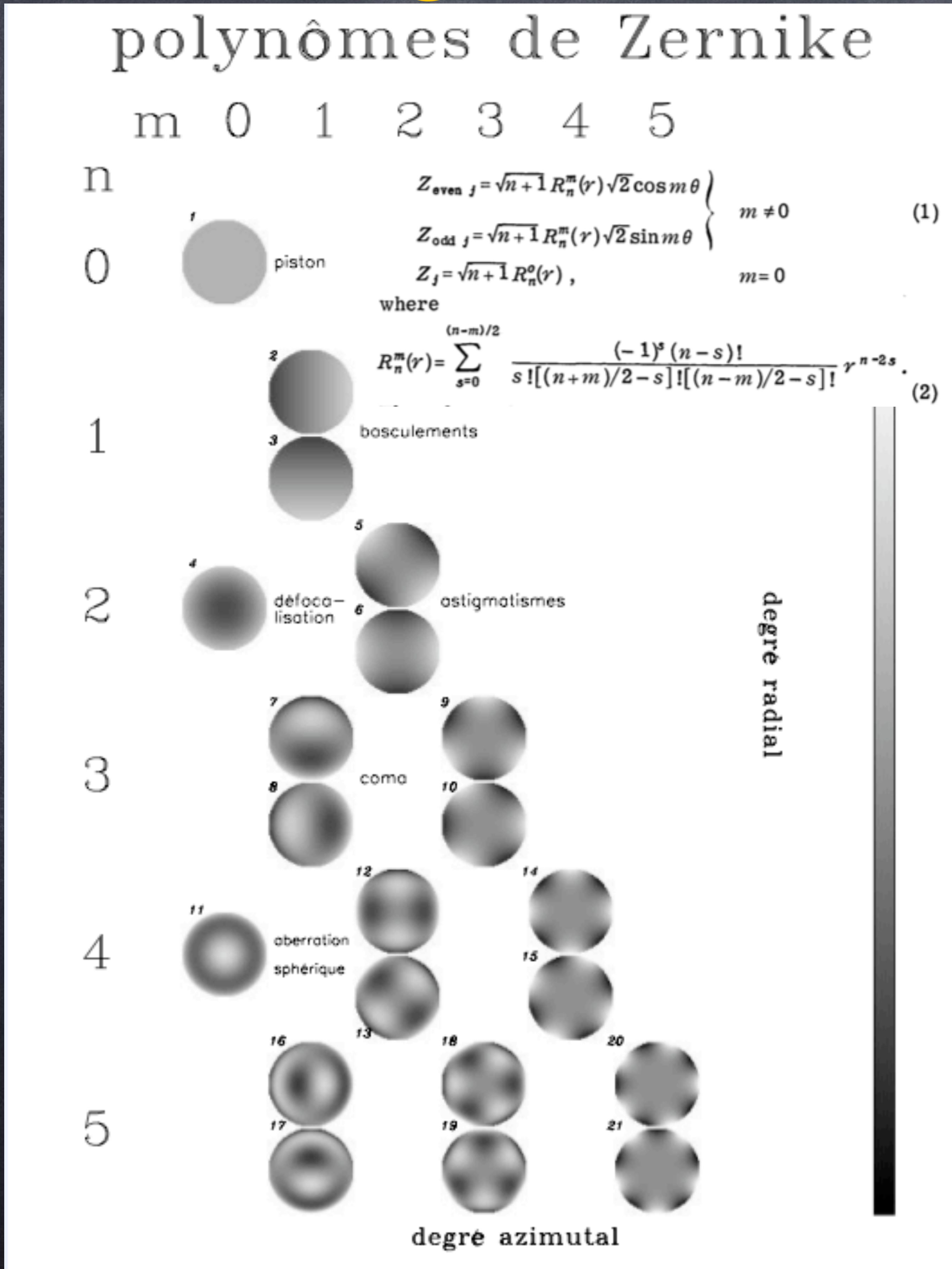
entrance pupil



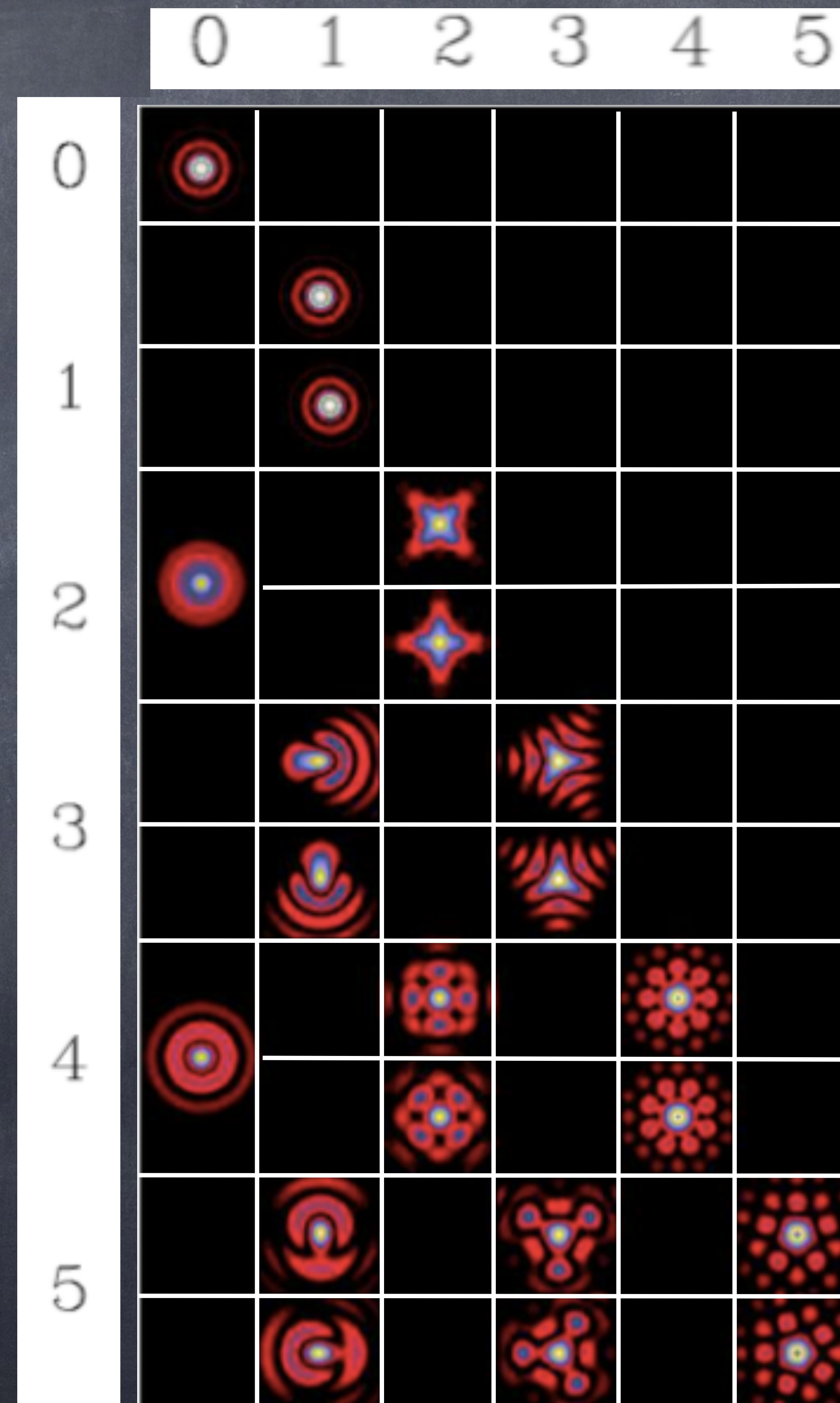


image on the focal plane

Images & turbulence - 10

turbulence intensity [m$^{1/3}$]

$$r_0 = 0.185\ \lambda^{\frac{6}{5}}\ \cos(\gamma)^{\frac{3}{5}}\ \left[\int_0^\infty C_n^2(z)\ dz\right]^{-\frac{3}{5}}$$

dimension of r_0 ? value in band H knowing r_0 at 500nm (10cm) ?...

$$\tau = 0.36\ \frac{r_0}{v}$$

$$\epsilon = 0.98\ \frac{\lambda}{r_0}$$

$$\theta_0 = 0.314\ \frac{r_0}{\bar{h}}$$

$$\bar{v} = \left(\frac{\int C_n^2(h) v(h)^{\frac{5}{3}} dh}{\int C_n^2(h) dh}\right)^{\frac{3}{5}}$$

$$\bar{h} = \left(\frac{\int C_n^2(h) h^{\frac{5}{3}} dh}{\int C_n^2(h) dh}\right)^{\frac{3}{5}}$$

$$f_G = 3.185 \frac{\bar{v}}{r_0}$$

$$N_s \simeq 0.34 \left(\frac{D}{r_0}\right)^2$$

Number of speckles for r_0=10cm and D=1m ?
(also in H band)