Astronomical imaging

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

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Menu

- High-angular resolution imaging in astronomy
- Atmospheric turbulence
- 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 – 1)

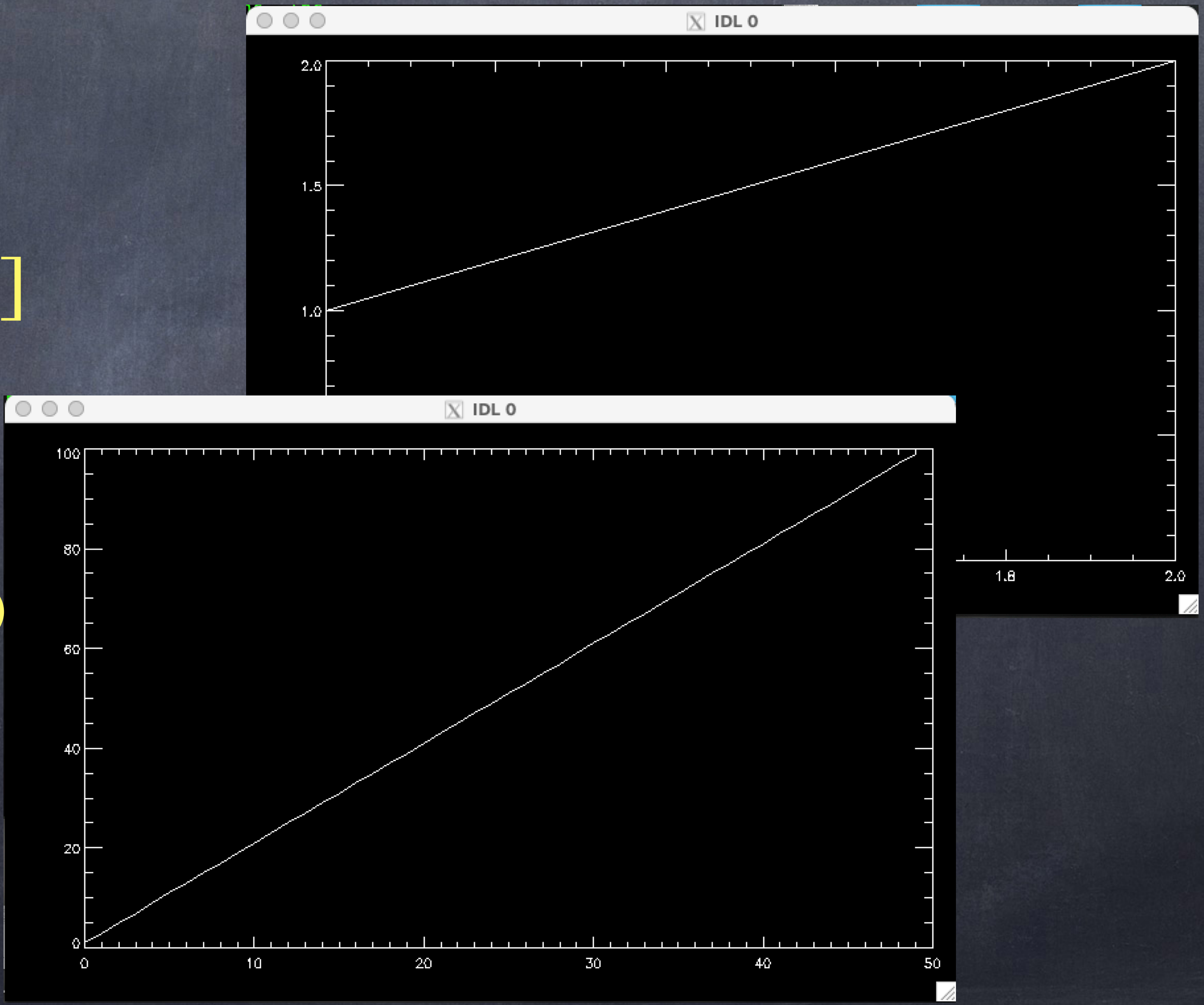
- launch IDL (or IDLDE=IDL+interface), on zztop (+VPN launched before).

- test it:

```
IDL> print, ‘hello’
IDL> plot, [1,2], [1,2]
```

- test it more:

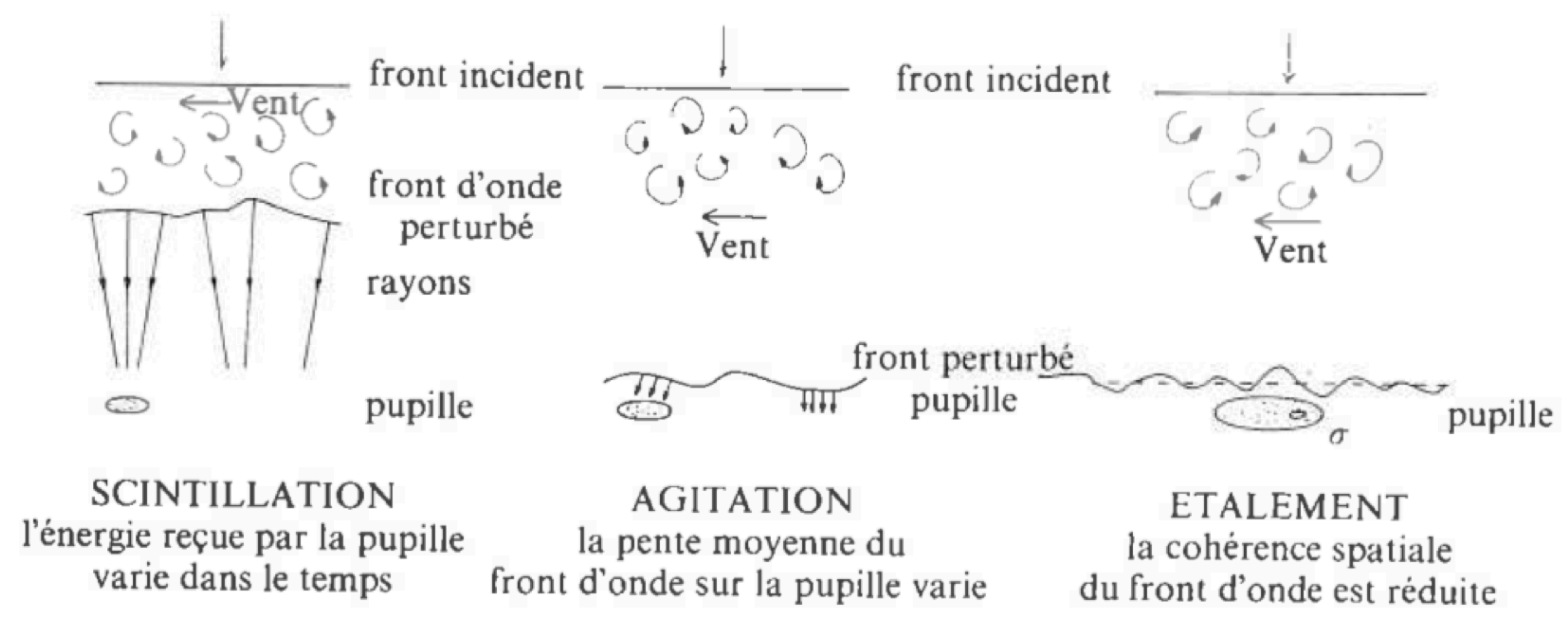
```
IDL> xx=findgen(50)
IDL> yy=2*xx+1
IDL> plot, xx, yy
```



Images & turbulence — 01

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 — 02

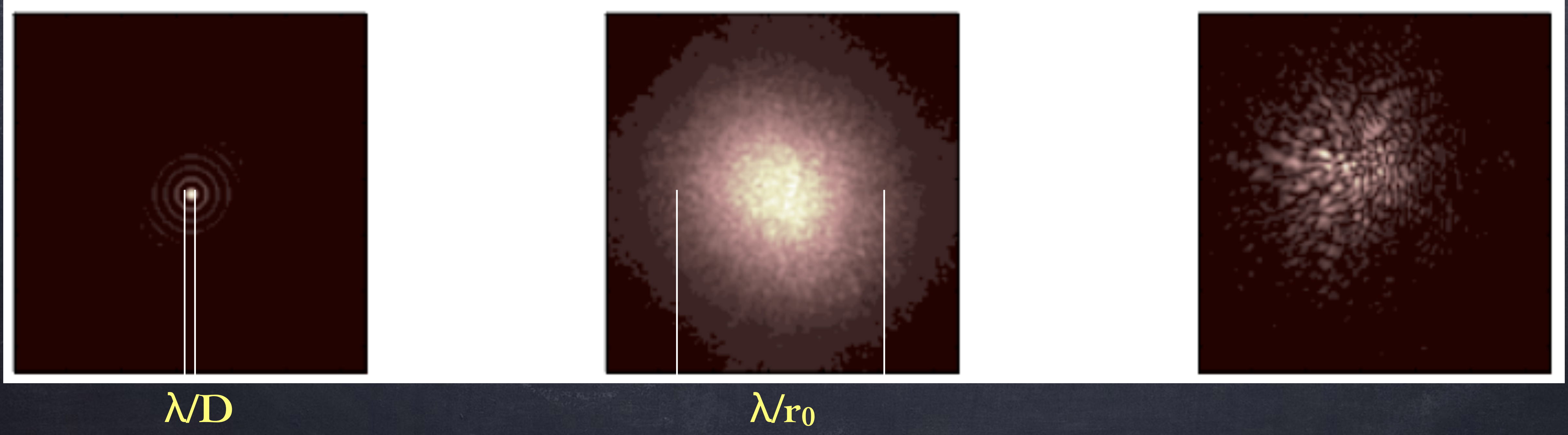
The object-image relation between the intensity $I(\alpha)$ in the image plane (i.e. the focal plane of the telescope) and the brightness $O(\alpha)$ of the object (in the sky) is a relation of convolution implying the point-spread function (PSF) $S(\alpha)$ of the whole ensemble telescope+atmosphere,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

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

Images & turbulence — 03

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

This relation is valid notably at the condition that the system is invariant by translation (everything happens within the isoplanatic domain)...

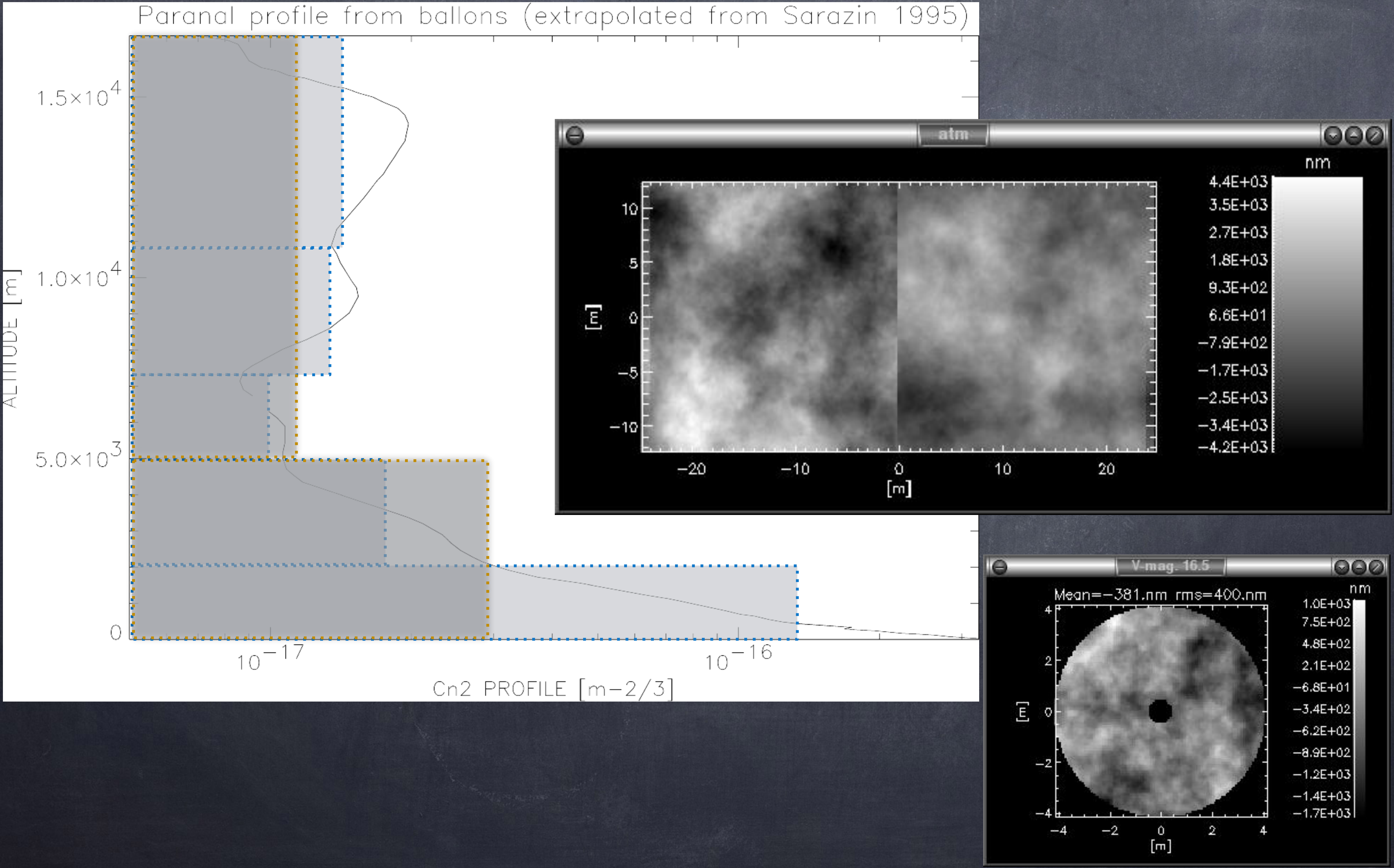


Images & turbulence — 04

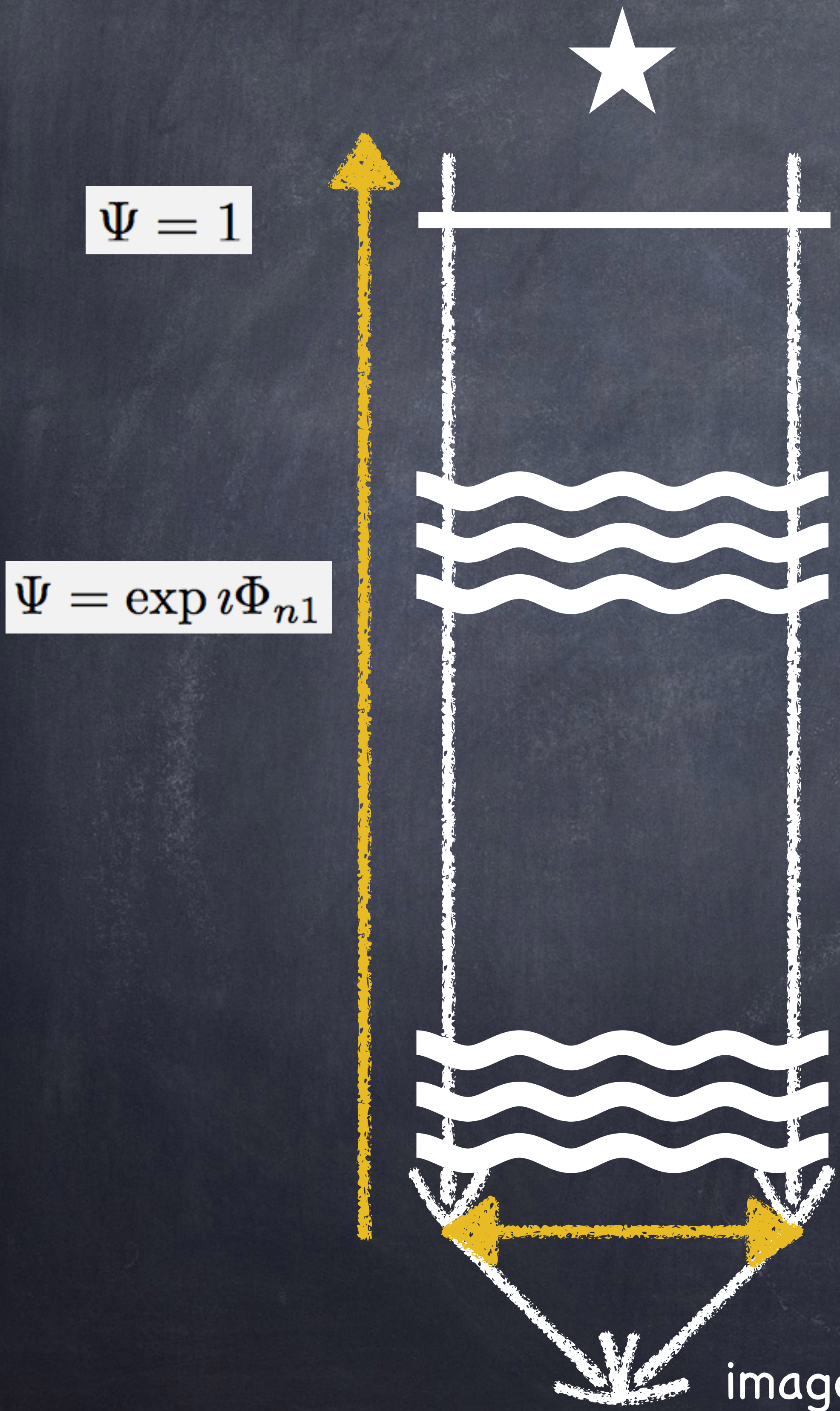
Some orders of magnitude concerning the turbulent atmosphere:

	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 — 05



Images & turbulence — 06



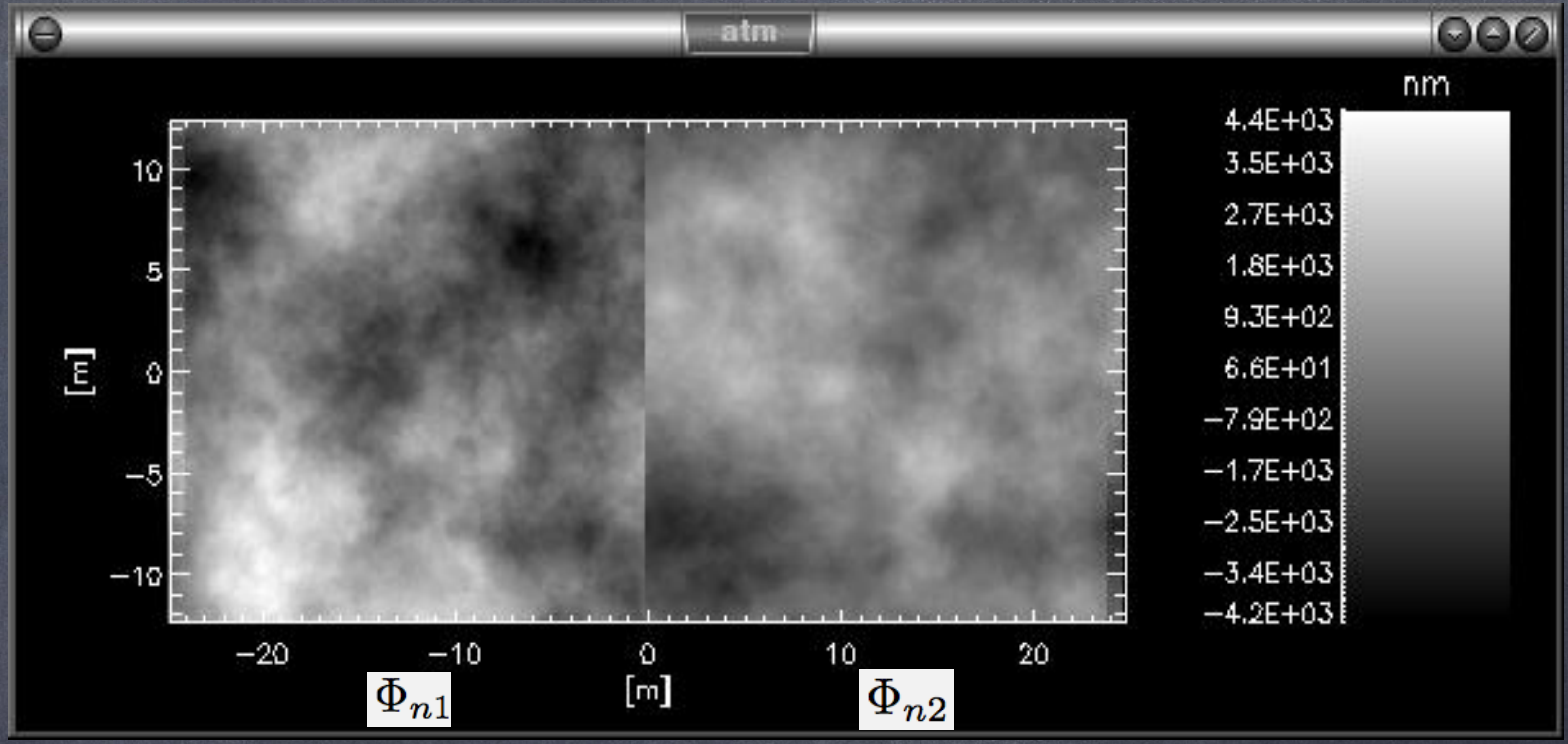
$\Psi = 1$

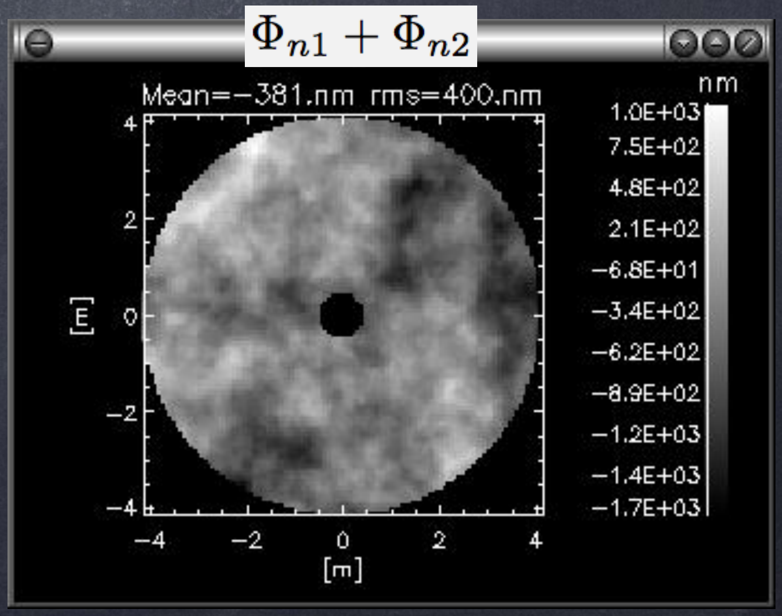
$\Psi = \exp \imath\Phi_{n1}$

$\Psi = \exp\left(\imath\Phi_{n1} + \imath\Phi_{n2}\right)$

entrance pupil

image on the focal plane





$\Phi_{n1} + \Phi_{n2}$

Mean=−381.nm rms=400.nm

Images & turbulence — 07

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):

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

Images & turbulence — 08

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:

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