Images & turbulence — 22

```
function wfimg2, diam, obs, lambda_psf, filewf, filepsf

;+
; example of use:
;   diam      = 64L            ; [px] telescope pupil dimension
;   obs       = 0. [0-1]       ; (linear) obscuration ratio
;   lambda_psf= 500E-9         ; [m] PSF wavelength
;   filewf    = 'cube.sav'     ; cube of wf filename
;   filepsf   = 'cube_psf.sav'; cube of PSFs filename
;   print, wfimg2(diam,obs,lambda_psf,filewf,filepsf)
;   -> compute the cube of PSFs, save it, and tell how it went
;
; sub-routines needed: make_PSF.pro, wfgeneration.pro, makepup.pro
;
; Marcel Carbillet [marcel.carbillet@unice.fr], Lagrange (UniCA, OCA, CNRS)
; written: Feb. 2018, last modified: March 11th 2024.
;-

; preliminaries
restore, filewf               ; restores variable 'cube' containing nn wf
dim= (size(cube))(1)          ; linear size of wf
nn = (size(cube))(3)          ; nb of wf
cube_psf=fltarr(dim,dim,nn) ; initialize cube of PSFs

; compute and save PSFs
pup = makepup(dim,diam,obs) ; compute entrance pupil
for i=0, nn-1L do cube_psf[*,*,i] = make_PSF(pup,cube[*,*,i],lambda_psf)
                              ; compute the PSF corresponding to each wf
save, cube_psf, FI=filepsf  ; save cube of PSFs to disk

; return back
return, 'Cube of PSFs '+filepsf+' saved on disk...'
end
```

<u>image formation:</u>

1- cube of instantaneous PSFs (500nm & H-band)

```
function make_PSF, pup, wf, lambda

;+
; PSF computation from a wavefront
;
; pup    = input pupil,
; wf     = input wavefront [float],
; lambda = wavelength at which PSF is computed.
; PSF = make_PSF(pup, wf, lambda)
; -> compute the PSF corresponding to wf and pup, at wavelength lambda
;
; Marcel Carbillet [marcel.carbillet@unice.fr],
; UMR 7293 Lagrange (UNS/CNRS/OCA), Feb. 2013.
; Last modification: March 11th 2024
;-

; preliminary
dim = (size(wf))[1]

; compute PSF
psf = (abs(fft(pup*exp(complex(0,1)*2*!PI/lambda*wf*pup))))^2
; NB: (abs(fft(pup*exp(complex(0,1)*2*!PI/lambda*wf))))^2 would suffice
psf = shift(psf, dim/2, dim/2)

; return back
return, psf
end
```

```
IDL> .r wfimg2
% Compiled module: WFIMG2.
IDL> print, wfimg2(64L, 0., 500E-9, 'wf_r0=10cm_L0=10m.sav', 'PSF_r0=10cm_L0=10m_lambda=500nm.sav')
Cube of PSFs PSF_r0=10cm_L0=10m_lambda=500nm.sav saved on disk...
```

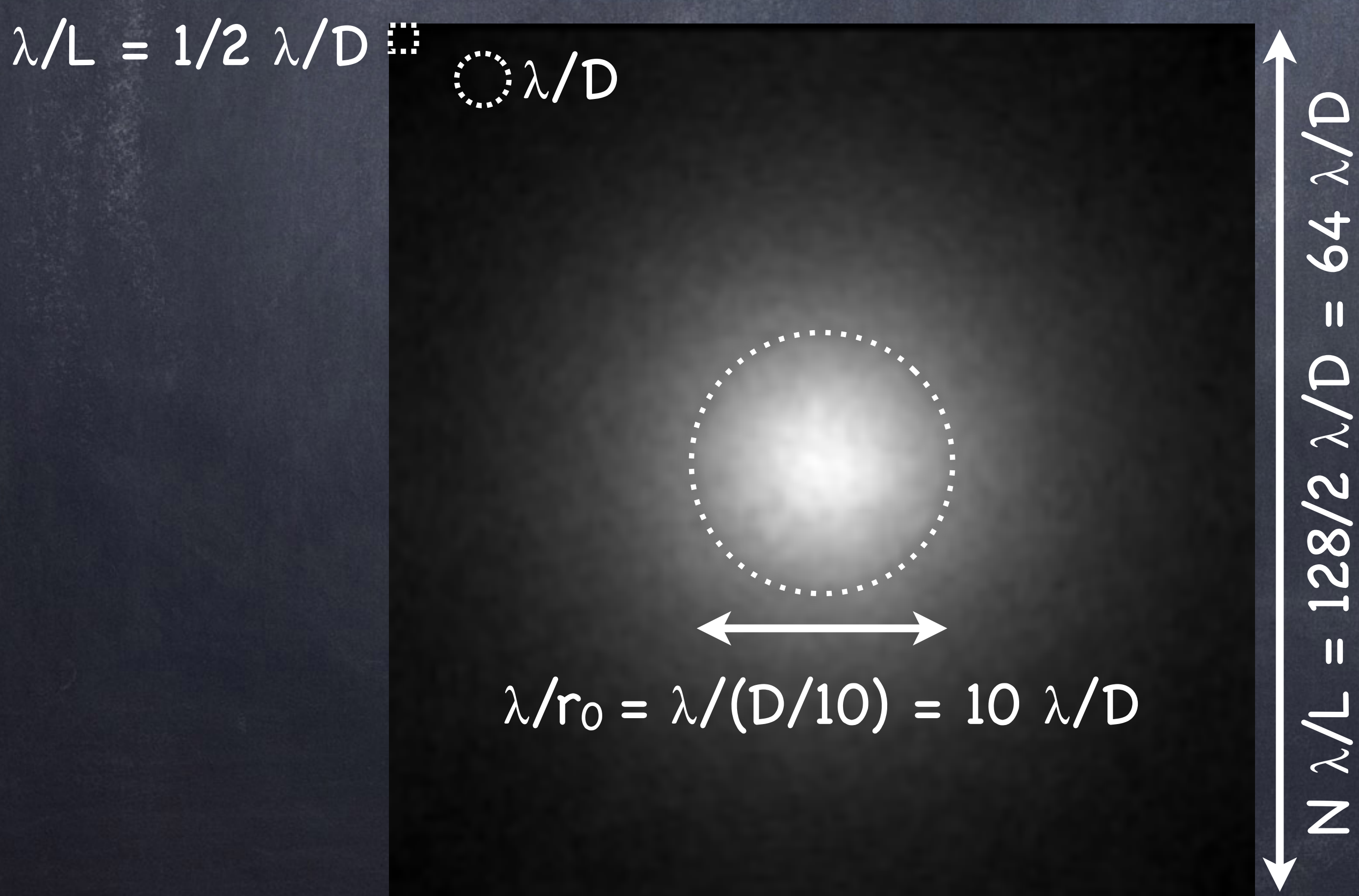
Images & turbulence — 23

```
IDL> restore, 'PSF_r0=10cm_L0=10m_lambda=500nm.sav'
IDL> help
% At $MAIN$
CUBE_PSF        FLOAT     = Array[128, 128, 100]
I               INT       =        100
Compiled Procedures:
    $MAIN$

Compiled Functions:
  COMPUTE_RMS DIST        MAKEPUP      MAKE_PSF     WFCUBE2      WFGENERATION            WFIMG2

IDL> window, XS=512, YS=512, /FREE
IDL> for i=0,99 do tvscl, rebin(cube_PSF[*,*,i], 512, 512, /SAMPLE)
```

```
IDL> longexp=total(cube_PSF,3)
IDL> tvscl, rebin(longexp, 512, 512, /SAMPLE)^.1
```

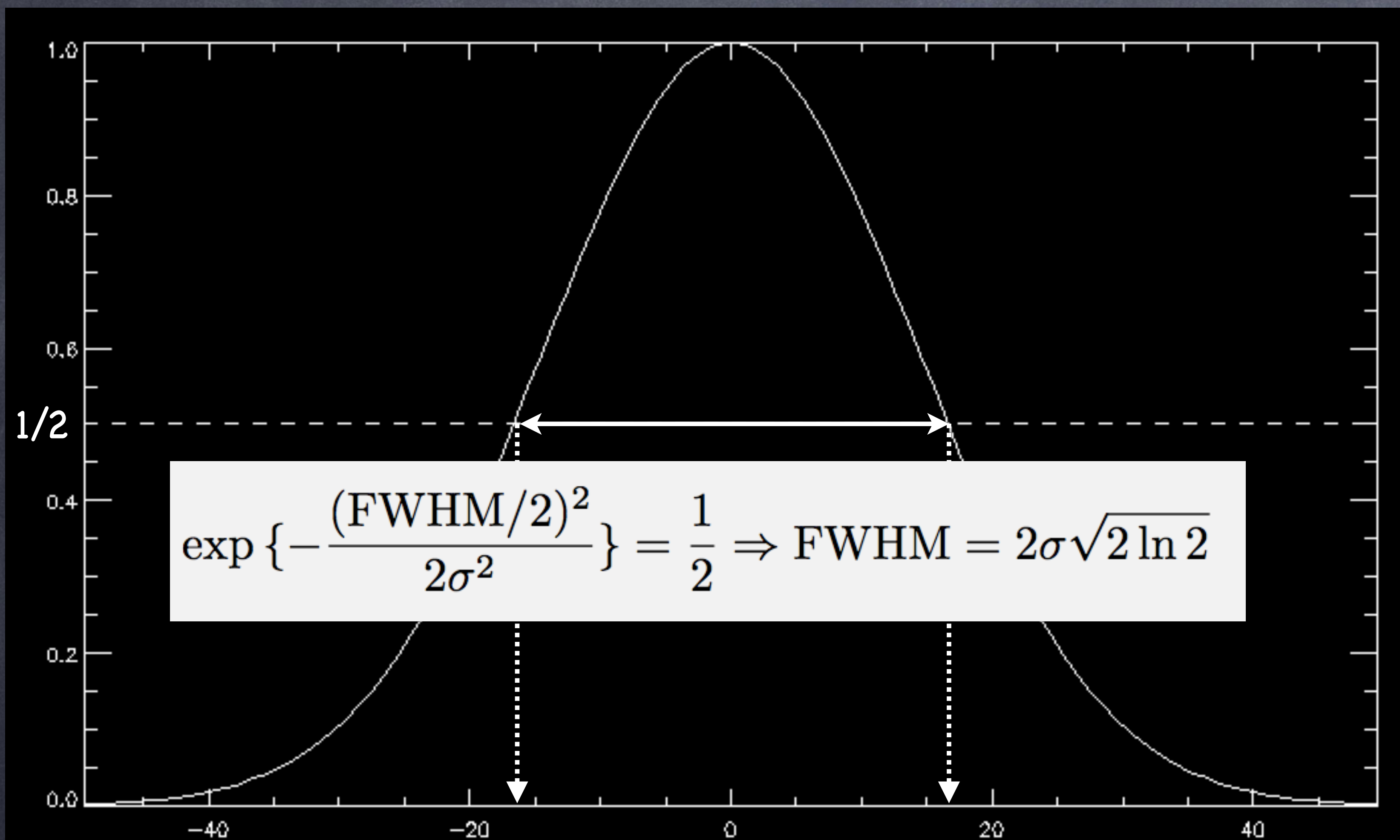


<u>image formation:</u>

1- cube of instantaneous PSFs (500nm & band H)

2- long-exposure PSF

Images & turbulence — 24



<u>image formation:</u>

1- cube of instantaneous PSFs (500nm & H-band)

2- long-exposure PSFs

3- fit with gaussian and compare FWHM vs. λ/r_0 (seeing), also in function of the outerscale L_0.

-> Also read Martinez...

```
IDL> res=gauss2dfit(longexp,a)
% Program caused arithmetic error: Floating underflow
IDL> print, 2*((a[2]+a[3])/2)*sqrt(2*alog(2))
      15.9637
IDL>
```

In this example, the FWHM is ≈16px and, since we have here: 1px=(λ/D)/2, we have hence: FWHM≈8 (λ/D)
[i.e. 8*0.1″≈0″8 here (@500nm)]

Images & turbulence — 25

On the Difference between Seeing and Image Quality: When the Turbulence Outer Scale Enters the Game

Patrice Martinez[1]
Johann Kolb[1]
Marc Sarazin[1]
Andrei Tokovinin[2]

[1] ESO
[2] Cerro-Tololo Inter American Observatory, Chile

We attempt to clarify the frequent confusion between seeing and image quality for large telescopes. The full width at half maximum of a stellar image is commonly considered to be equal to the atmospheric seeing. However the outer scale of the turbulence, which corresponds to a reduction in the low frequency content of the phase perturbation spectrum, plays a significant role in the improvement of image quality at the focus of a telescope. The image quality is therefore different (and in some cases by a large factor) from the atmospheric seeing that can be measured by dedicated seeing monitors, such as a differential image motion monitor.

of telescope diameters and wavelengths. We show that this dependence is efficiently predicated by a simple approximate formula introduced in the literature in 2002. The practical consequences for operation of large telescopes are discussed and an application to on-sky data is presented.

Background and definitions

In practice the resolution of ground-based telescopes is limited by the atmospheric turbulence, called "seeing". It is traditionally characterised by the Fried parameter (r_0) – the diameter of a telescope such that its diffraction-limited resolution equals the seeing resolution. The well-known Kolmogorov turbulence model describes the shape of the atmospheric long-exposure point spread function (PSF), and many other phenomena, by this single parameter r_0. This model predicts the dependence[1] of the PSF FWHM (denoted ε_0) on wavelength (λ) and inversely on the Fried parameter, r_0, where r_0 depends on wavelength (to

A finite L_0 reduces the variance of the low order modes of the turbulence, and in particular decreases the image motion (the tip-tilt). The result is a decrease of the FWHM of the PSF. In the von Kàrmàn model, r_0 describes the high frequency asymptotic behaviour of the spectrum where L_0 has no effect, and thus r_0 loses its sense of an equivalent wavefront coherence diameter. The differential image motion monitors (DIMM; Sarazin & Roddier, 1990) are devices that are commonly used to measure the seeing at astronomical sites. The DIMM delivers an estimate of r_0 based on measuring wavefront distortions at scales of ~ 0.1 m, where L_0 has no effect. By contrast, the absolute image motion and long-exposure PSFs are affected by large-scale distortions and depend on L_0. In this context the Kolmogorov expression for ε_0[1] is therefore no longer valid.

Proving the von Kàrmàn model experimentally would be a difficult and eventually futile goal as large-scale wavefront perturbations are anything but stationary. However, the increasing number of esti-

```
REPORT

- Preliminary measures
+ introduction
+ PSD(r0, L0) plot
+ => ccl on the influence of r0 and L0
+ rms(r0, L0) plot or table
+ => ccl on the influence of r0 and L0
+ image formation and FWHM(r0 or lambda, possibly L0)
+ => ccl on the influence of r0 or lambda (and poss. L0)
+ => comparison with the 'seeing' lambda/r0
+ (more to come...)
```