PHYS 7810: Solar Physics with DKIST

Lecture 4: Diffraction (Hands-on)

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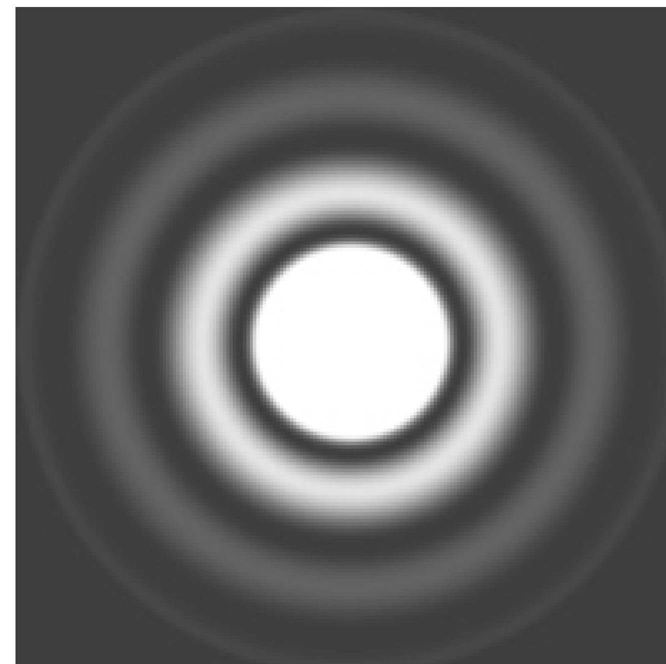
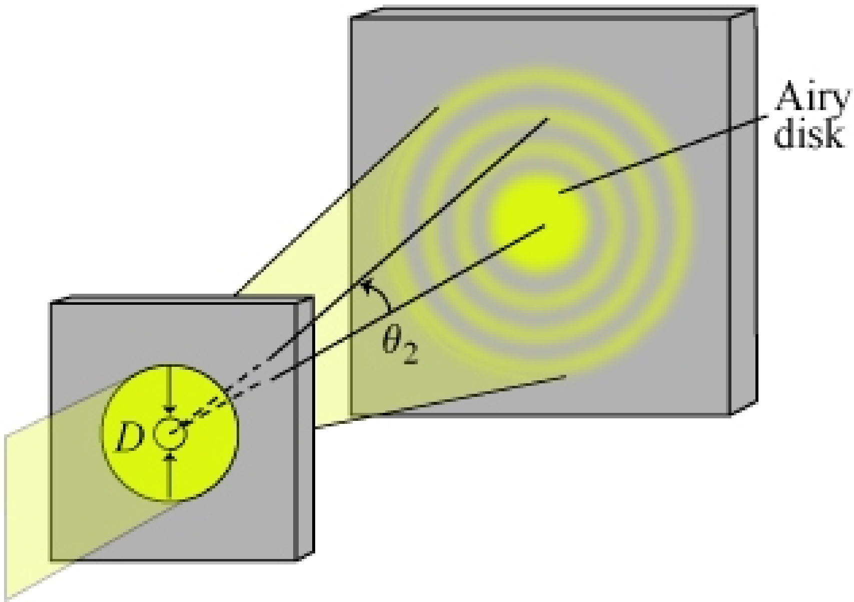


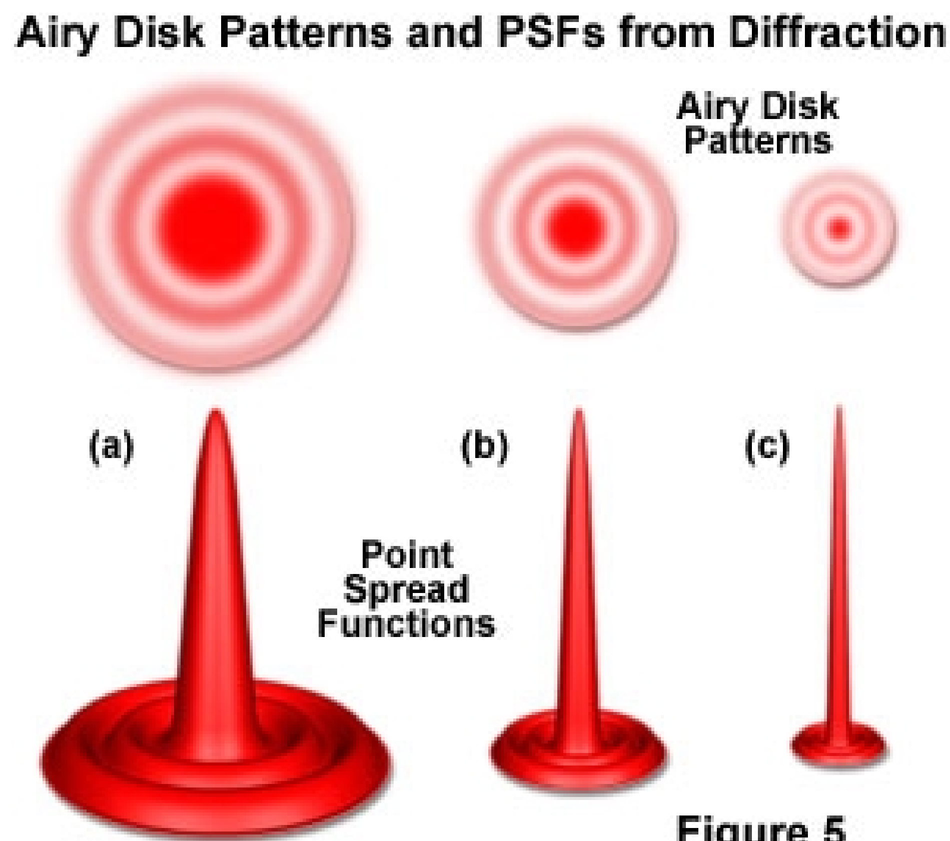
Previous classes

- We agreed that what we want to measure is the specific monochromatic intensity and its spatial, temporal and wavelength variations (we can’t measure angular variations with only one telescope)
- When we choose a wavelength, and look at the Sun, we record an **image**
- This image is a result of many wavefronts entering our primary
- A plane harmonic wave will diffract on the finite aperture and create the diffraction pattern – **PSF**
- We saw the PSF will smear our image – we will not see all the details we want.
- Today we will talk a bit about what our atmosphere does and we will try to simulate these effects. (thanks to Dr. Jose Marino (NSO), for the slides).

Diffraction on a circular aperture

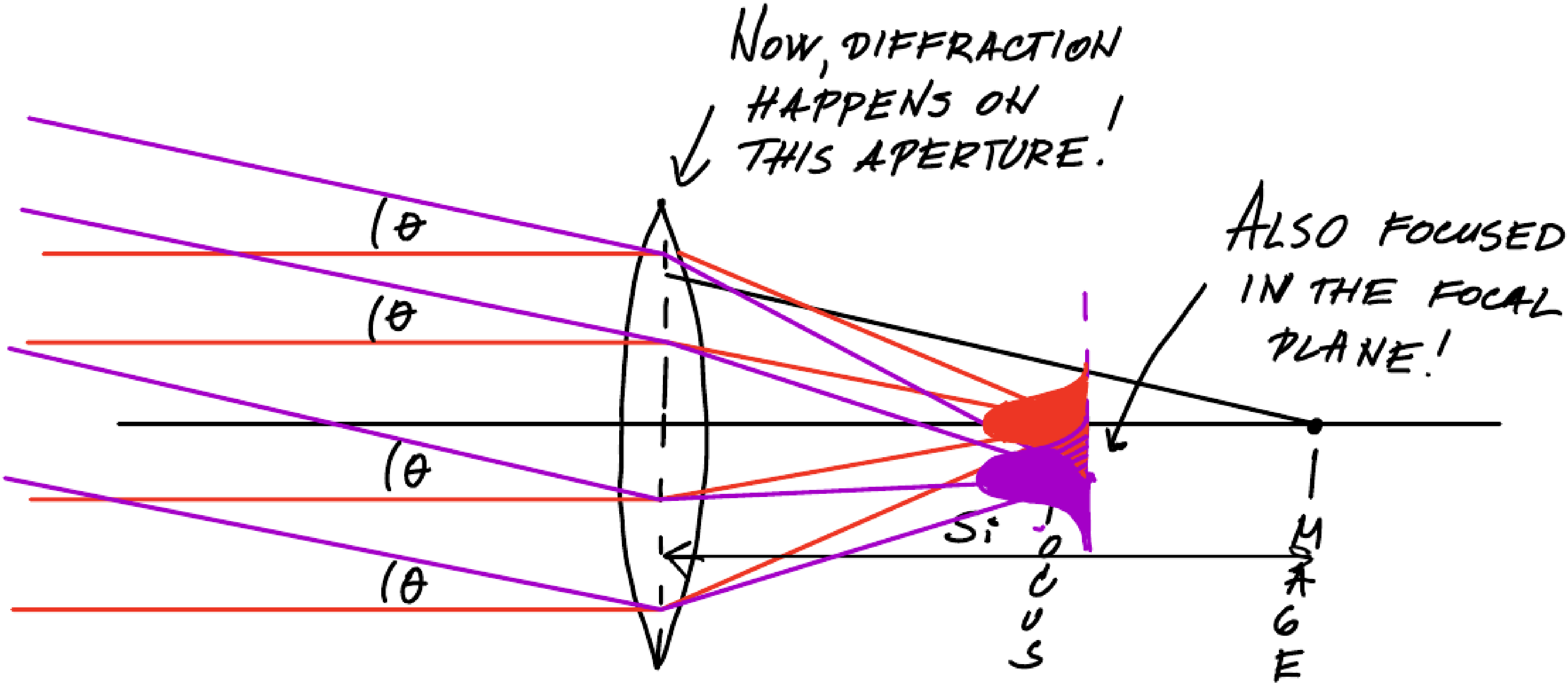


Why is this relevant for us? - Because our primary (lens, mirror) is a circular aperture!



$$I \propto \left[\frac{J_1(\rho)}{\rho} \right]^2 ; \quad \rho = k\theta a/2$$

What happens when we have two sources (directions)



Ground Based Solar Telescopes

- DKIST: highest resolution solar telescope
  19 km @ 500 nm
  (0.025”)
- Current solar telescopes (~1 m)
  75 km @ 500 nm
  (0.1”)

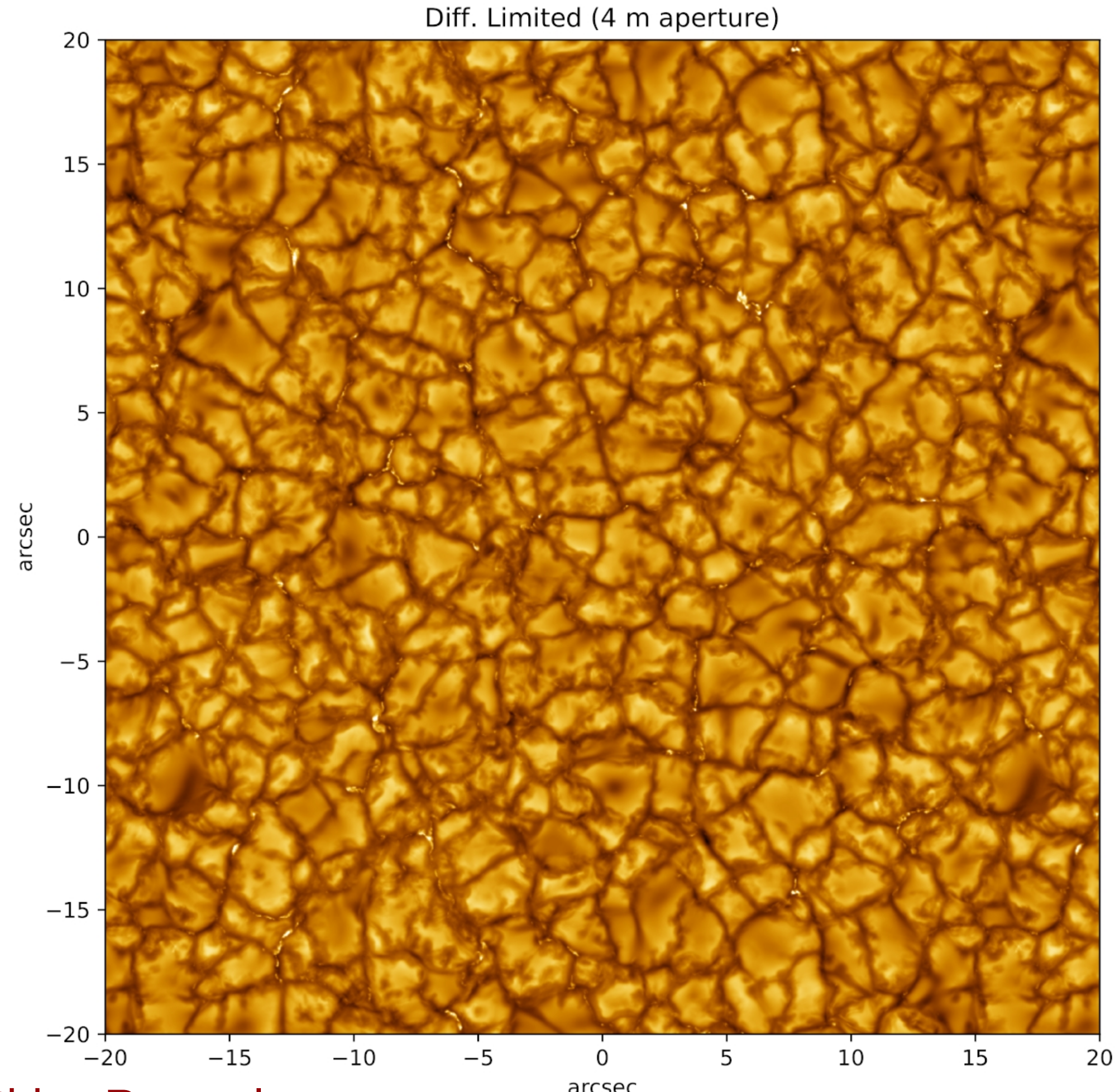
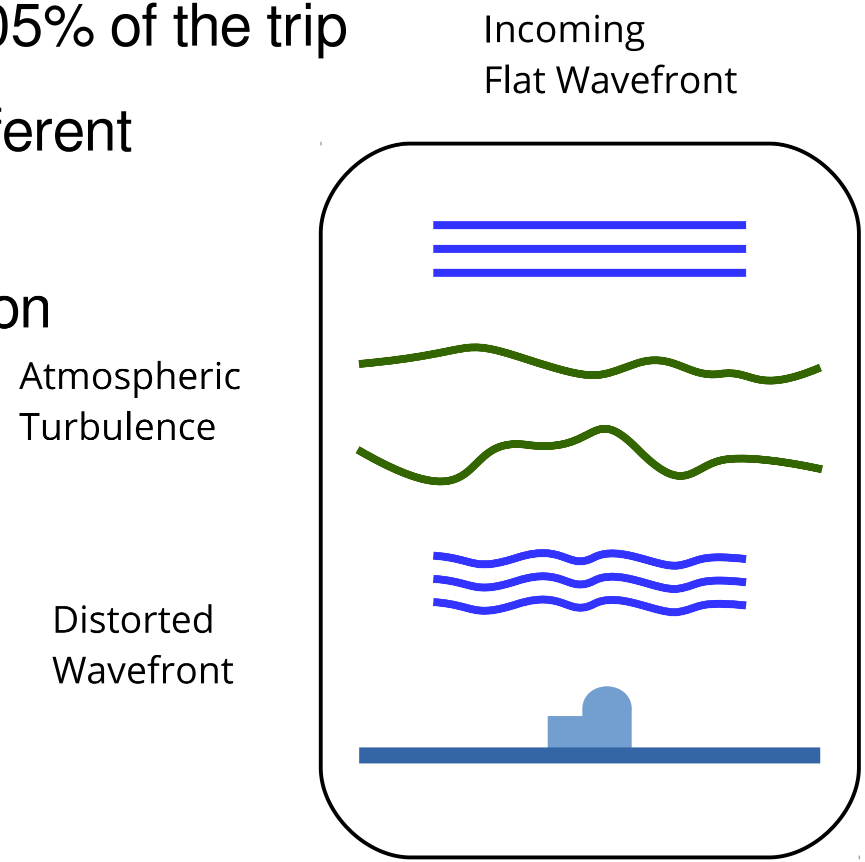


Image credits : Matthias Rempel

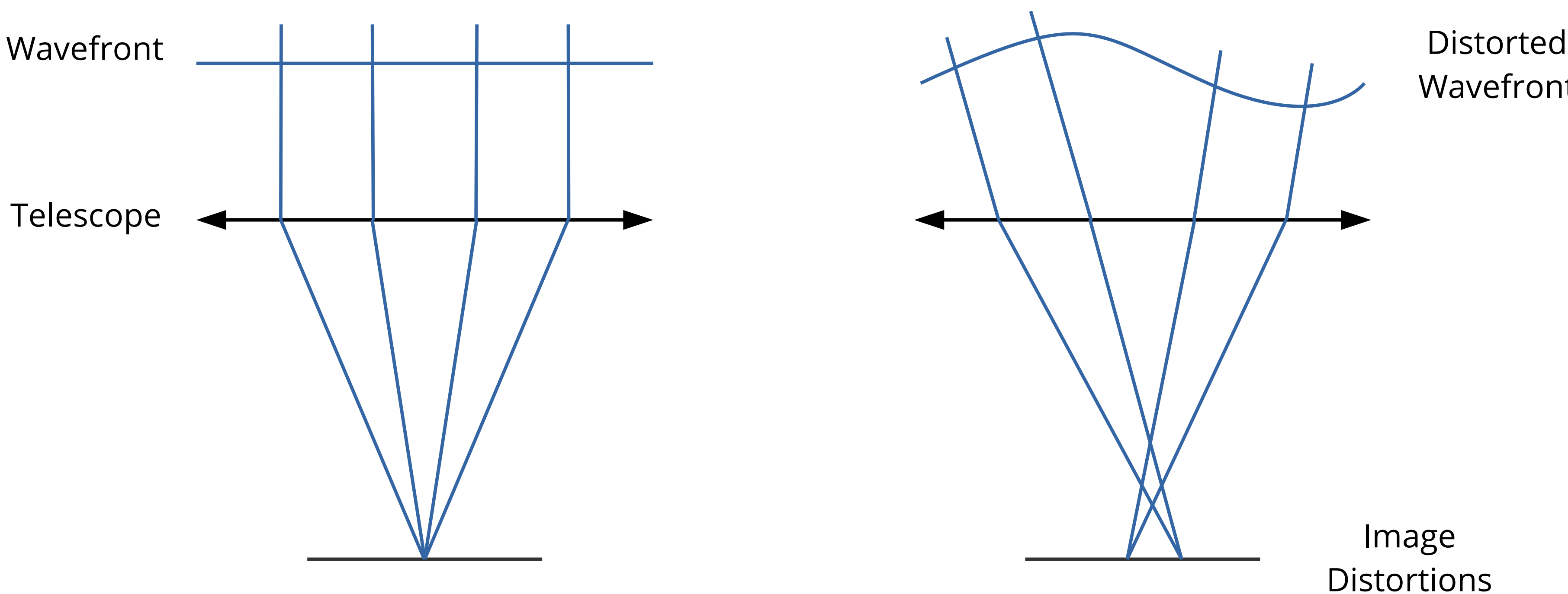
Atmospheric turbulence

- Ground based solar telescopes look through the Earth's atmosphere
- Light from the Sun travels undisturbed through space for millions of km
- Earth's atmosphere is only the last 0.00005% of the trip
- Atmospheric turbulence mixes air with different temperatures (densities):
- This creates variations in index of refraction



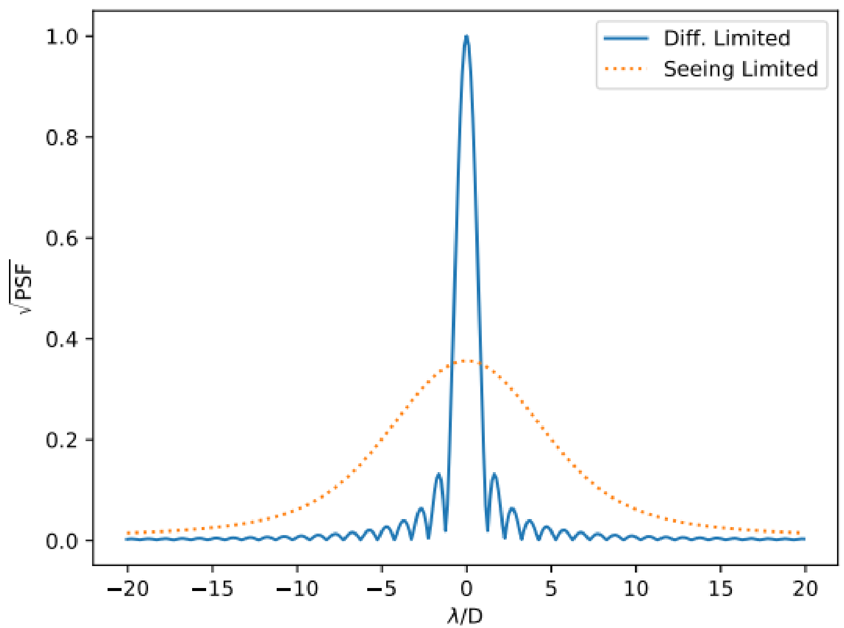
Atmospheric turbulence

- Atmospheric turbulence $\rightarrow$ wavefront distortions
- Wavefront distortions $\rightarrow$ image distortions **(phase difference on the wavefront)**

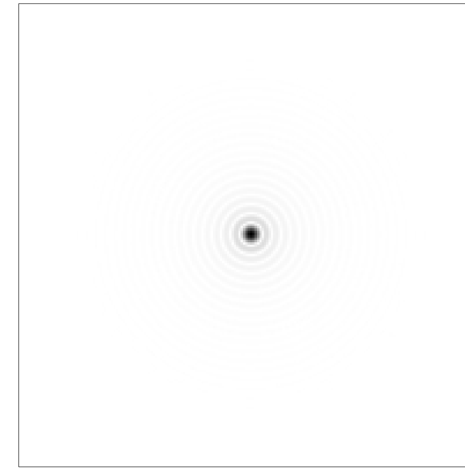


Atmospheric Turbulence

- Width of diffraction limited PSF: λ/D
- Width of seeing limited PSF: λ/r_0
- Fried parameter (r_0 [m]): Diameter of area with 1 rad wavefront rms error

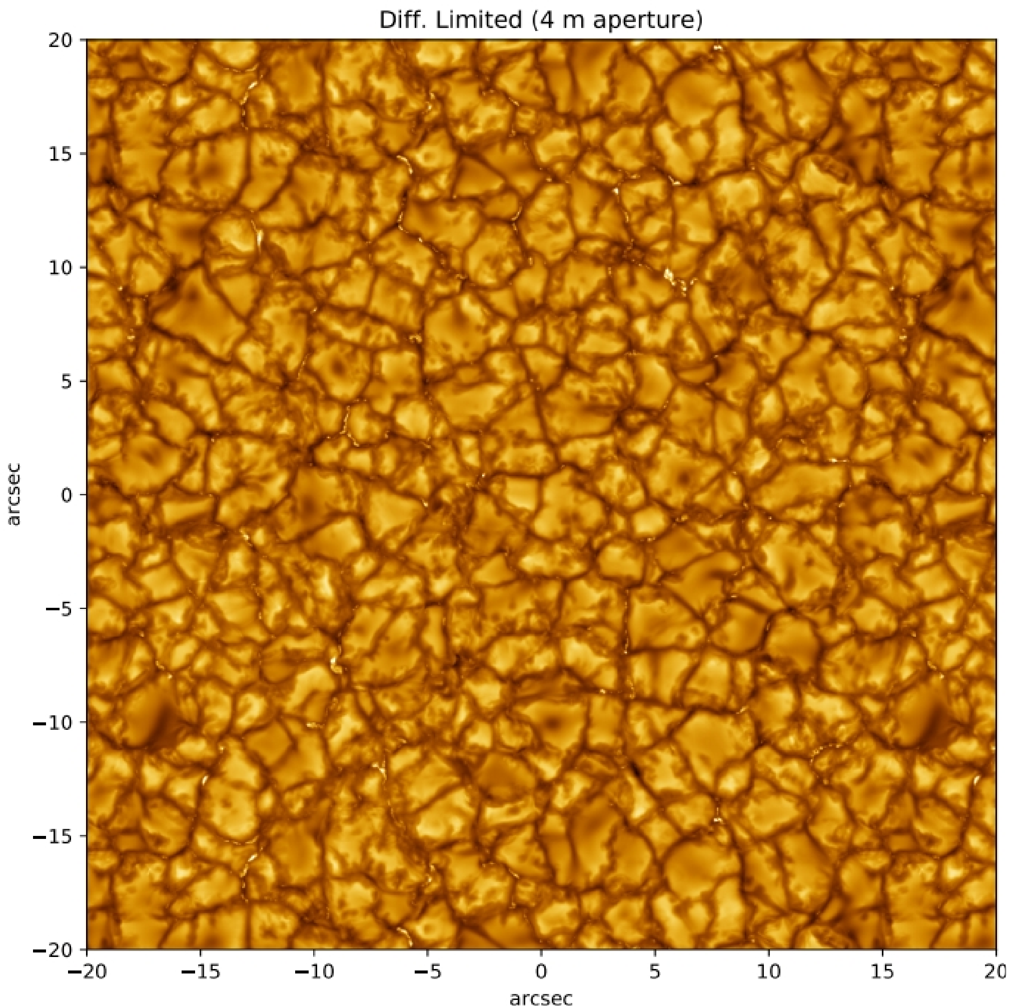


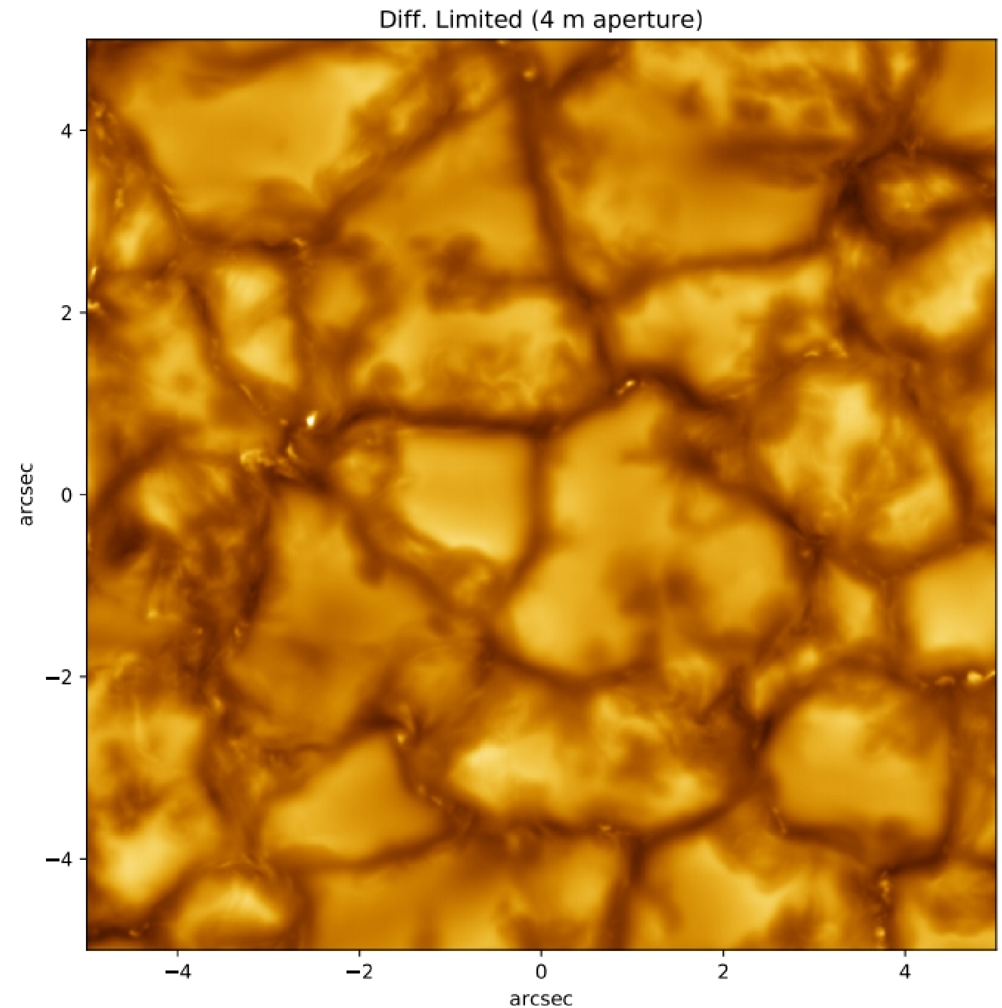
Diffraction Limited PSF



Seeing Limited PSF

Atmospheric turbulence



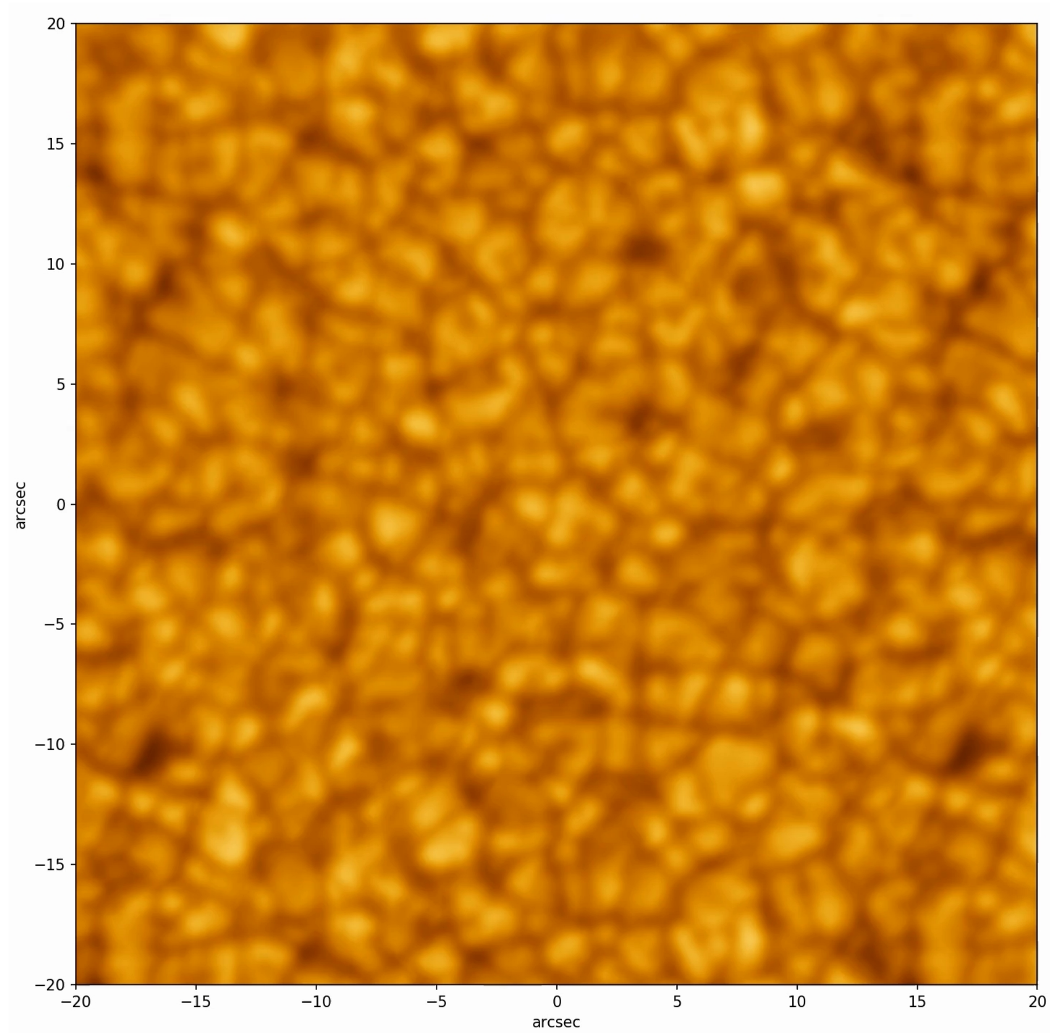


λ/D (@500 nm)=0.0258″

Image credits : Matthias Rempel

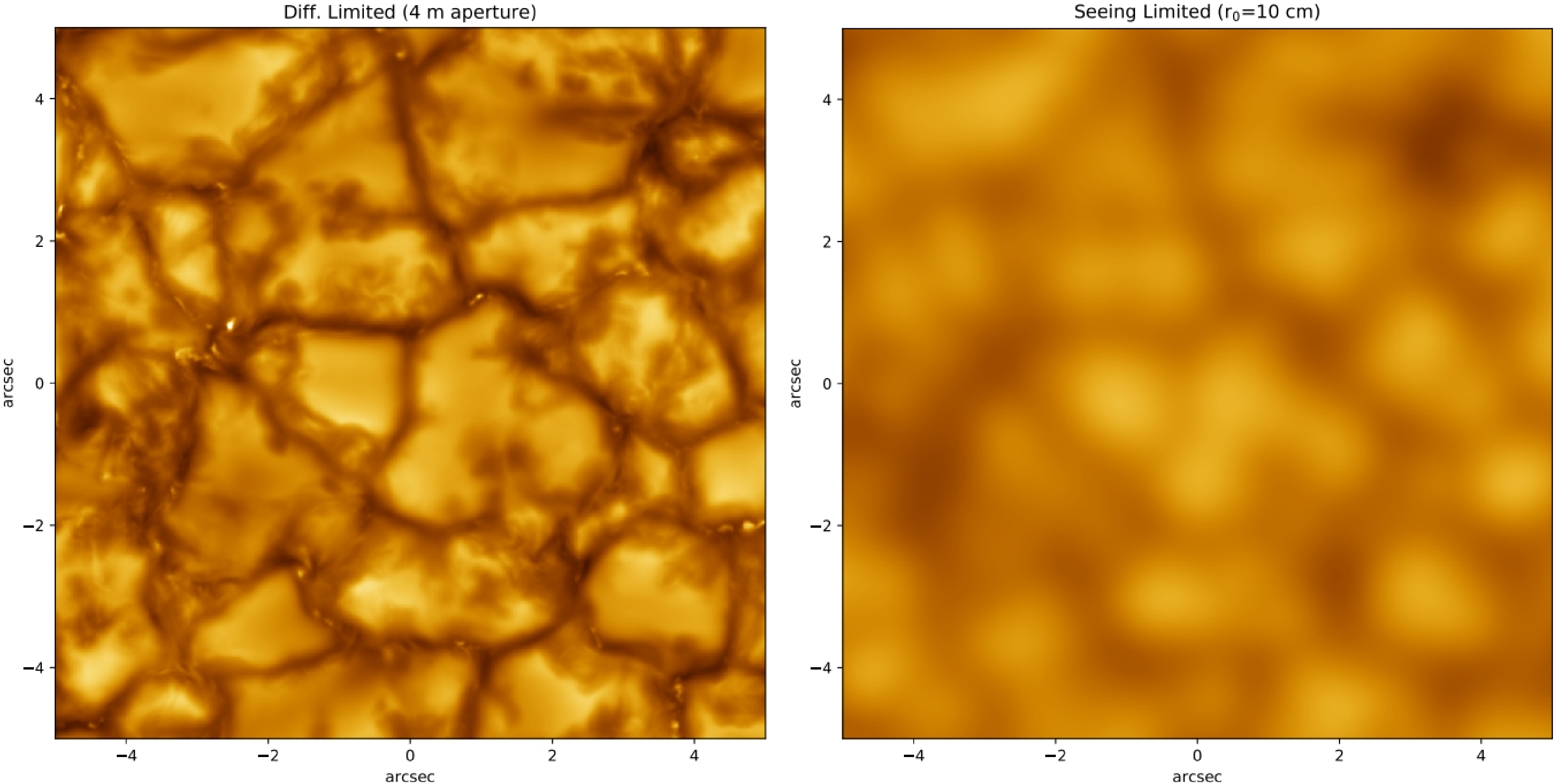
Atmospheric turbulence

- Seeing limited performance
- DKIST D=4 m
- 40” FOV
- r_0=10 cm
- 6 s @ 30 fps



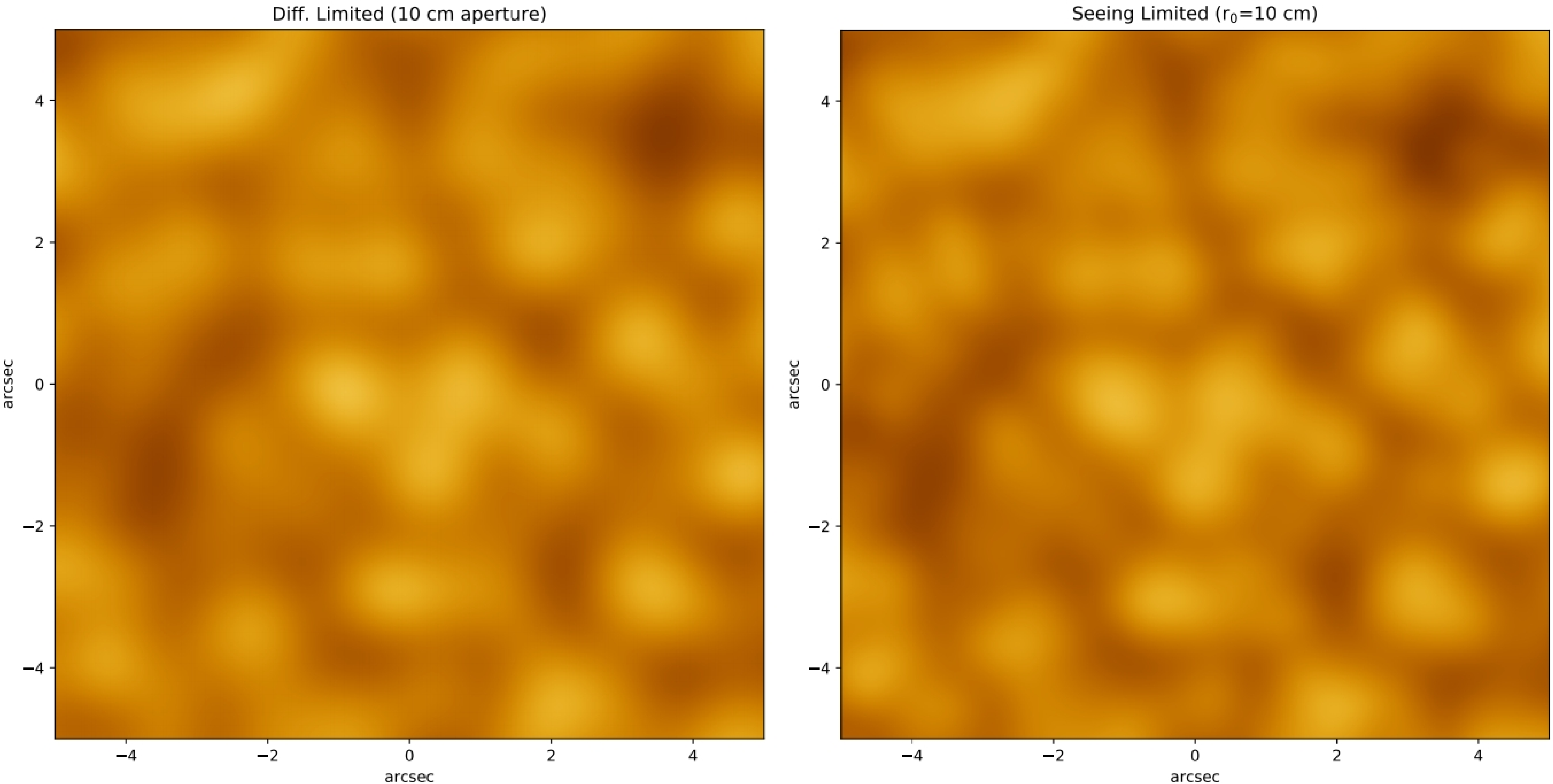
Atmospheric turbulence

- DKIST: D=4 m, 40” FOV, r_0=10 cm, exp: 1 s



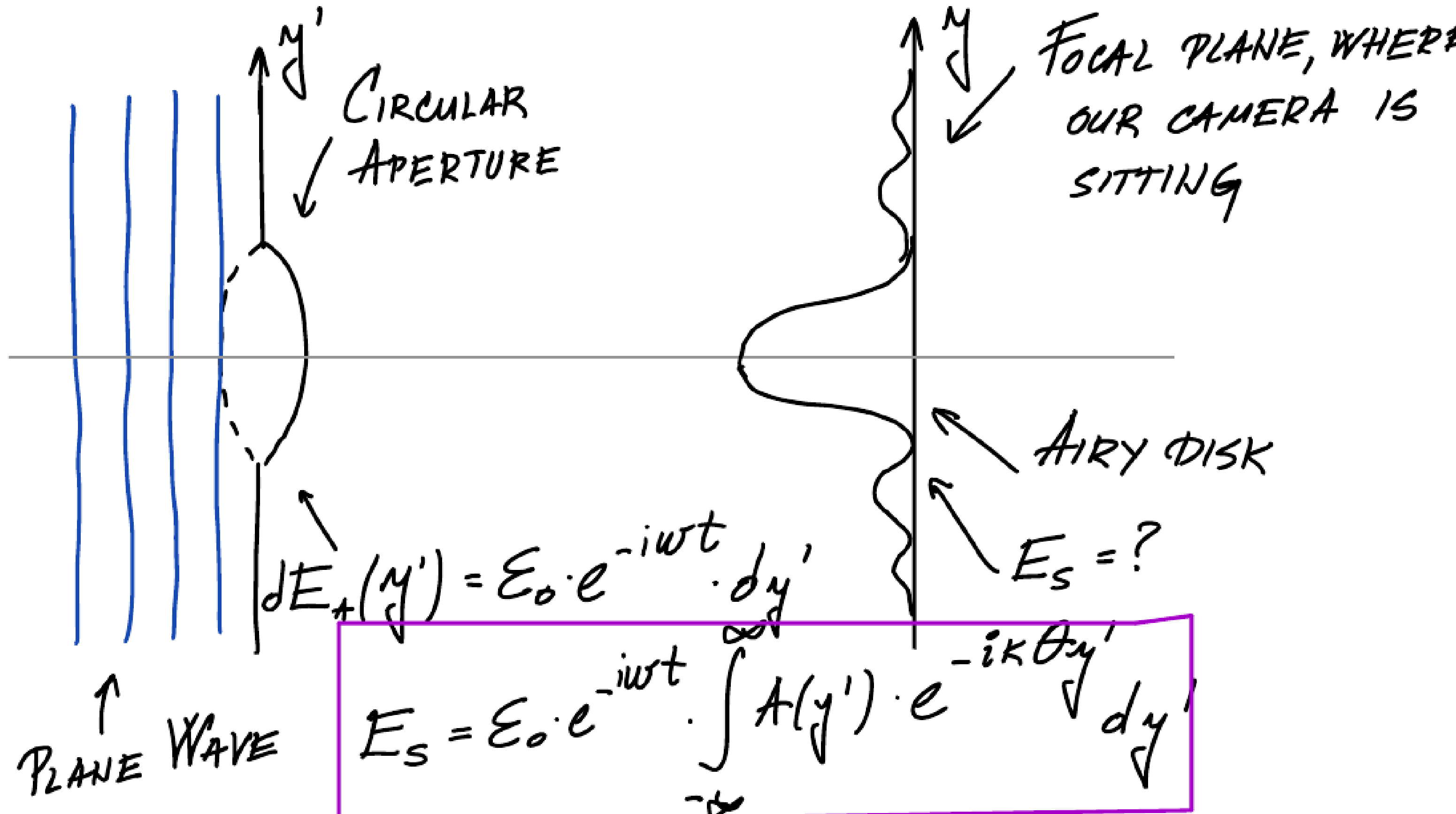
Atmospheric turbulence

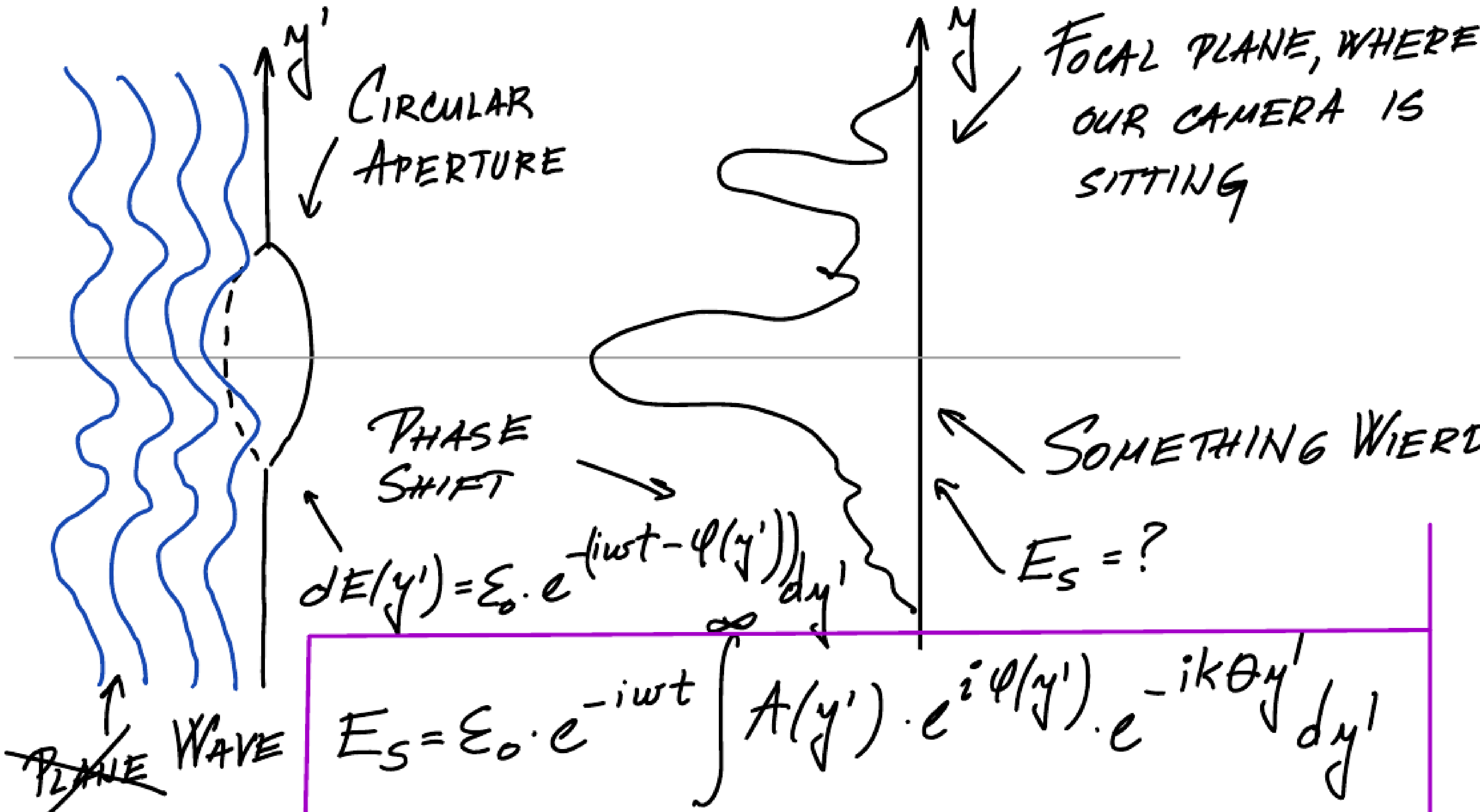
- D=10 cm telescope vs. DKIST in r_0=10 cm seeing



Our goal today is to model these processes

- We will take an "ideal" image of solar atmosphere and degrade it with the PSF of the primary, then later add atmospheric turbulence.





$$dE(y') = \mathcal{E}_0 \cdot e^{-(i\omega t - \varphi(y'))} dy'$$

$$E_S = \mathcal{E}_0 \cdot e^{-i\omega t} \int_{-\infty}^{\infty} A(y') \cdot e^{i\varphi(y')} \cdot e^{-ik\theta y'} dy'$$

So, process is like this:

- Make your aperture A(x’,y’) . If there is turbulence, add phase information to it:

$$E_s = \oint A(x', y') e^{i\phi(x'y')} e^{-ik(xx'+yy')/R} dx' dy'$$

- PSF is the square of the electric field at the screen, keep in mind it is complex:

$$PSF(x,y) = (E_s(x,y))^2$$

- Finally the image we see is the original image convolved with the PSF:

$$I(x,y) = I_0(x,y) \star PSF(x,y)$$

- You will need **phase.fits** and **synth_sun.fits** from the Dropbox folder I shared.