“Choisir, c’est se priver du reste …”

André Gide

http://www.aeos.ulg.ac.be/teaching.php

Astrophysics and Space Techniques (2) ASTR0004-2 Surdej Jean

Slides of the 4th lecture “Astrophysics and Space Techniques” (2015-16) And 1st lecture “Observing the sky”. Un ancien vidéo de ce cours en français est accessible via le lien http://orbi.ulg.ac.be/handle/2268/74101 fichier pdf taille (octets) : 1698109

Introduction to optical/IR interferometry

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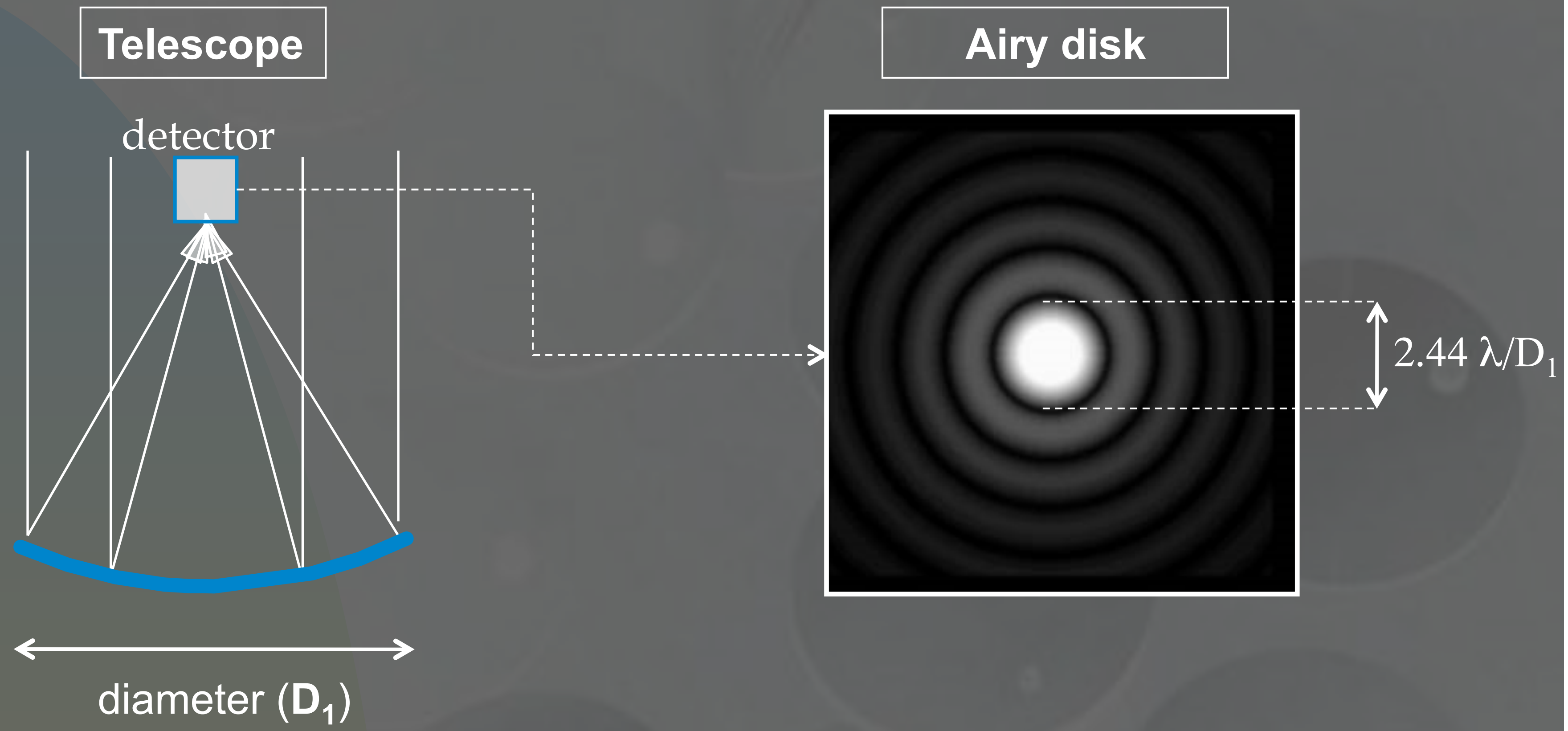
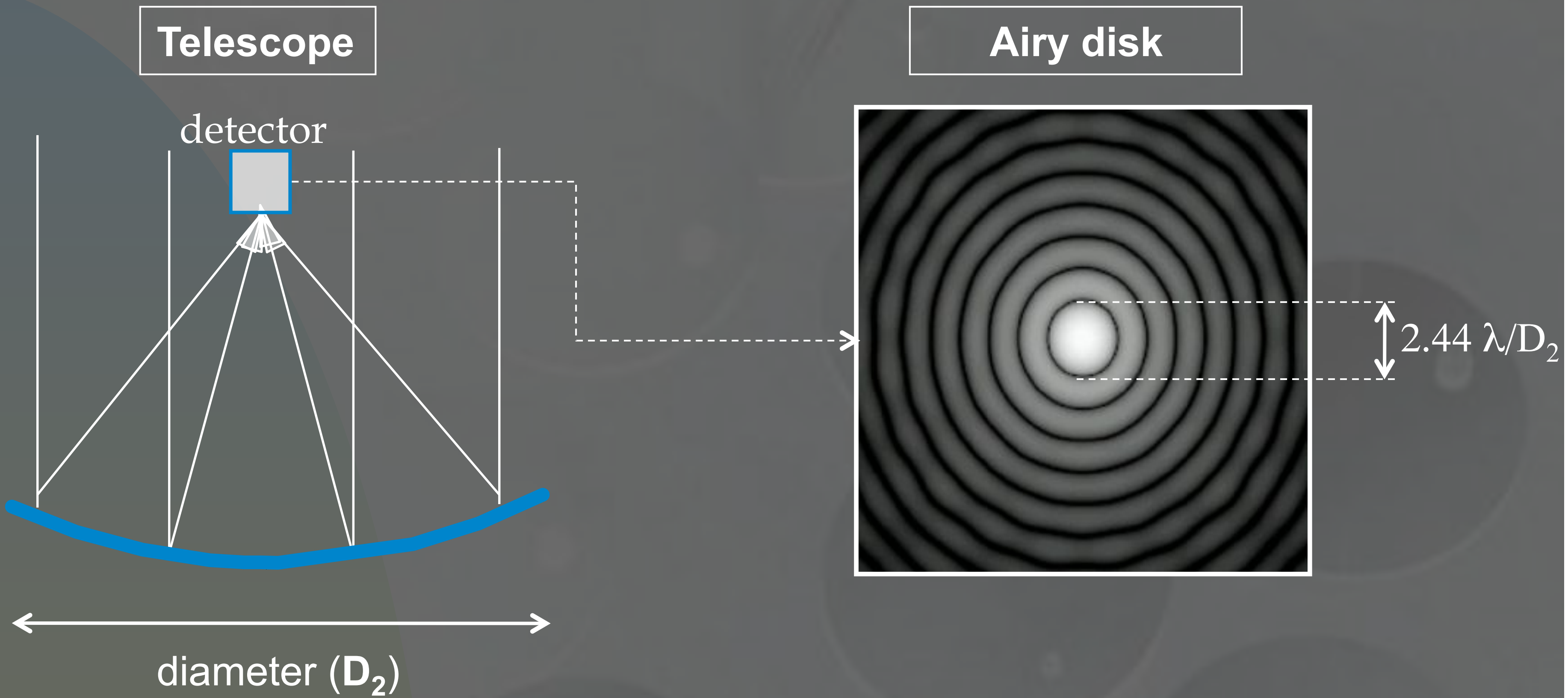
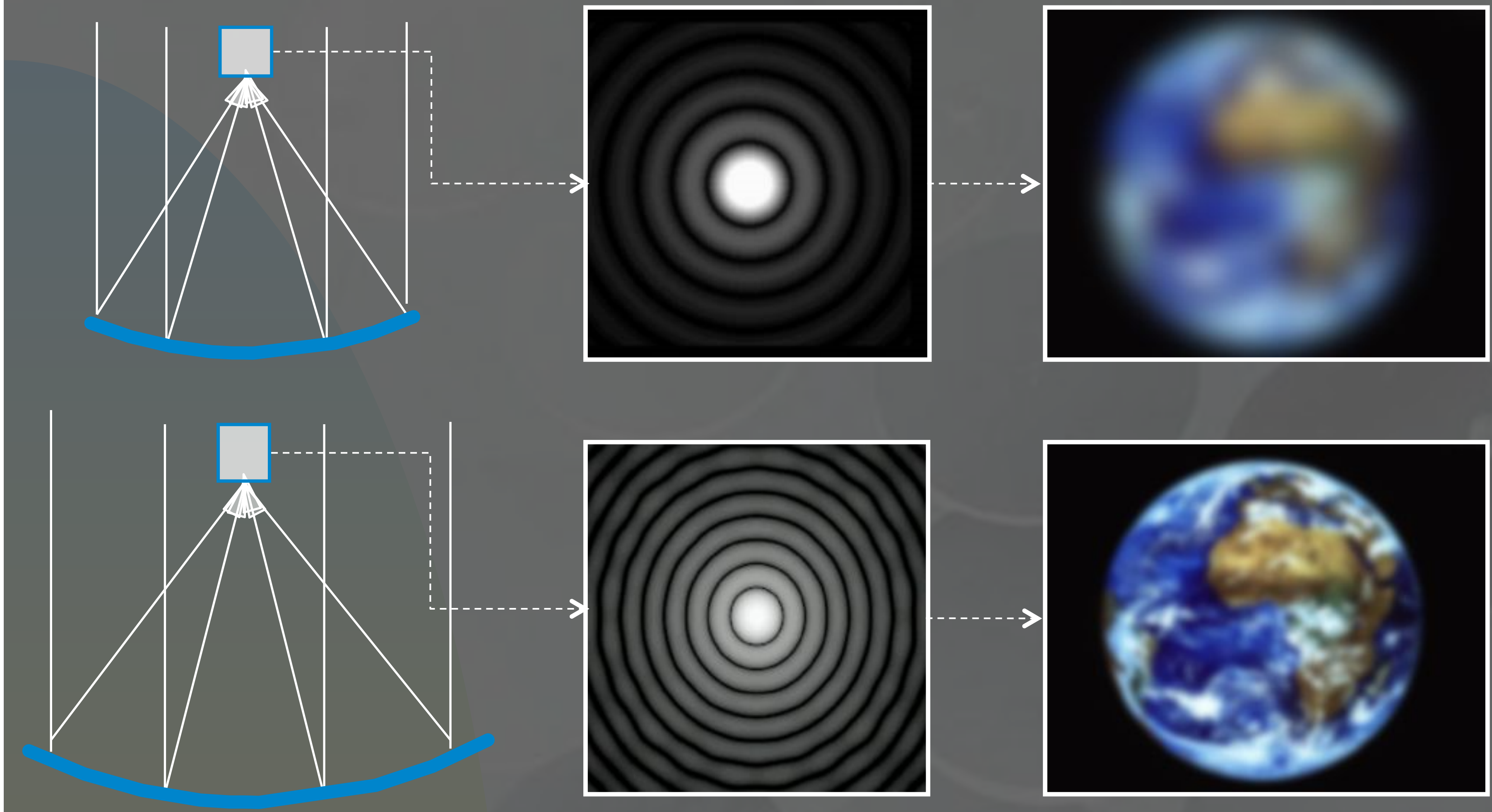
http://hdl.handle.net/2268/155589



- The image of a star is like a dot!



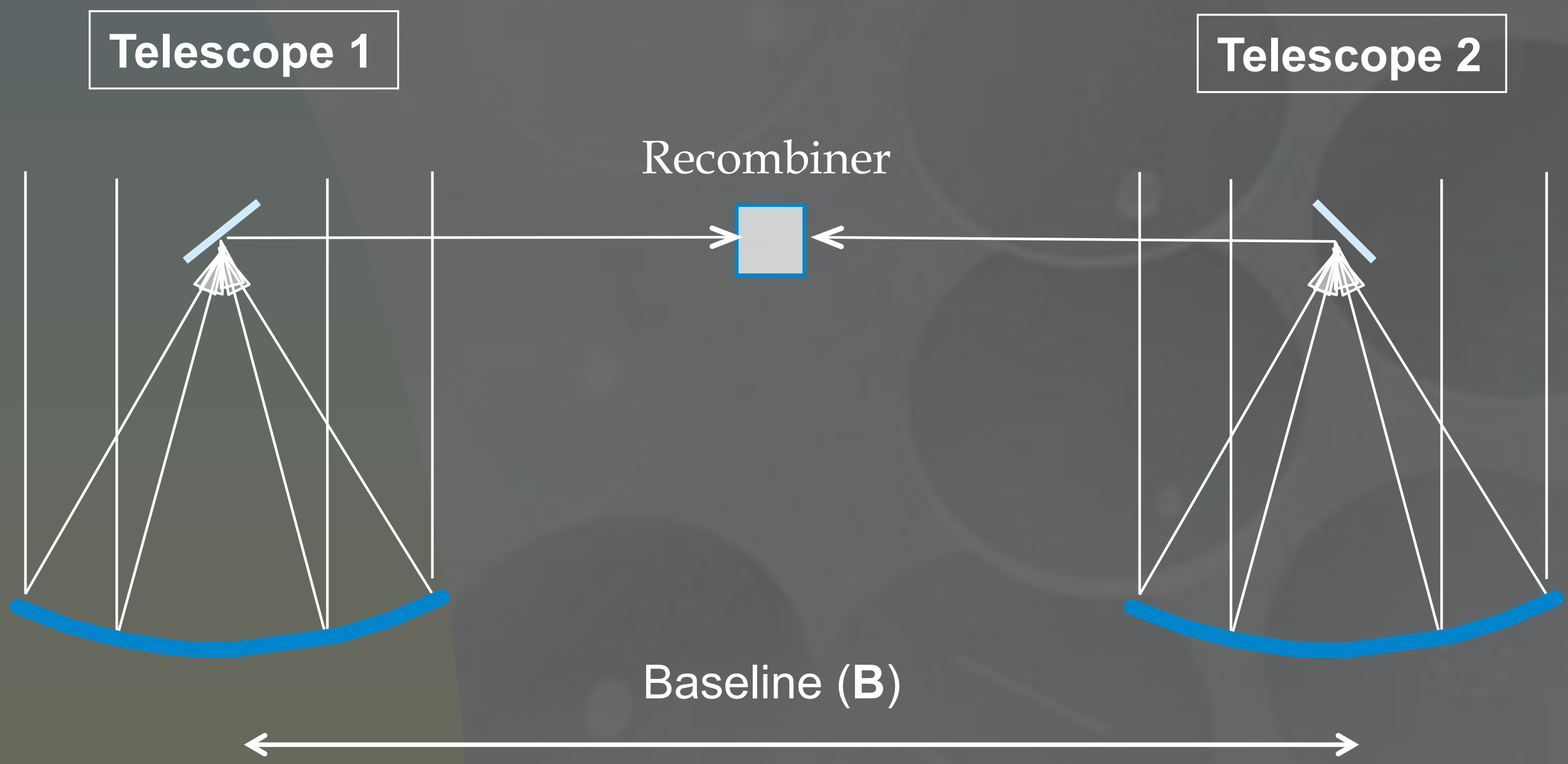
- The image of a star is still like a dot!

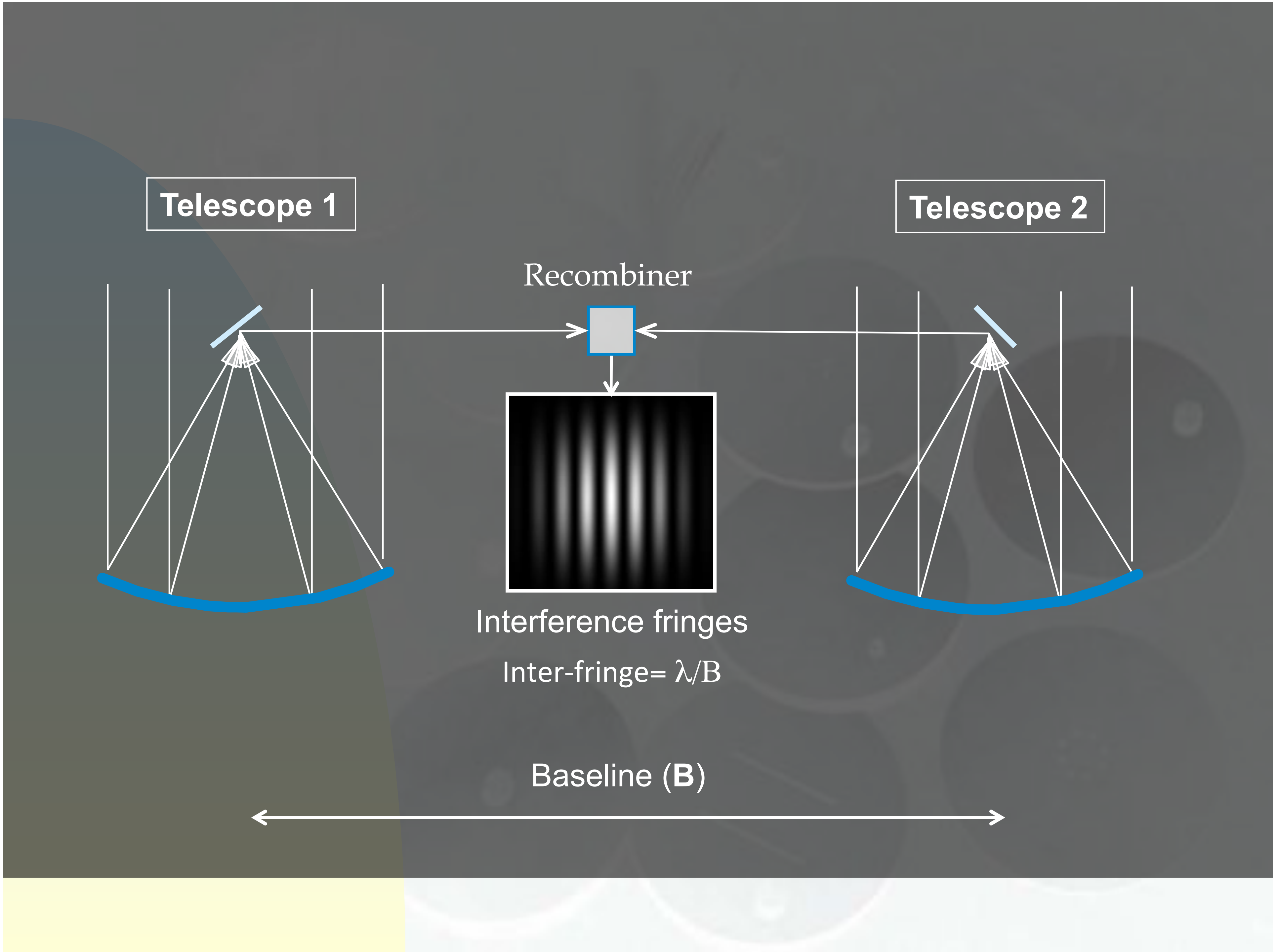


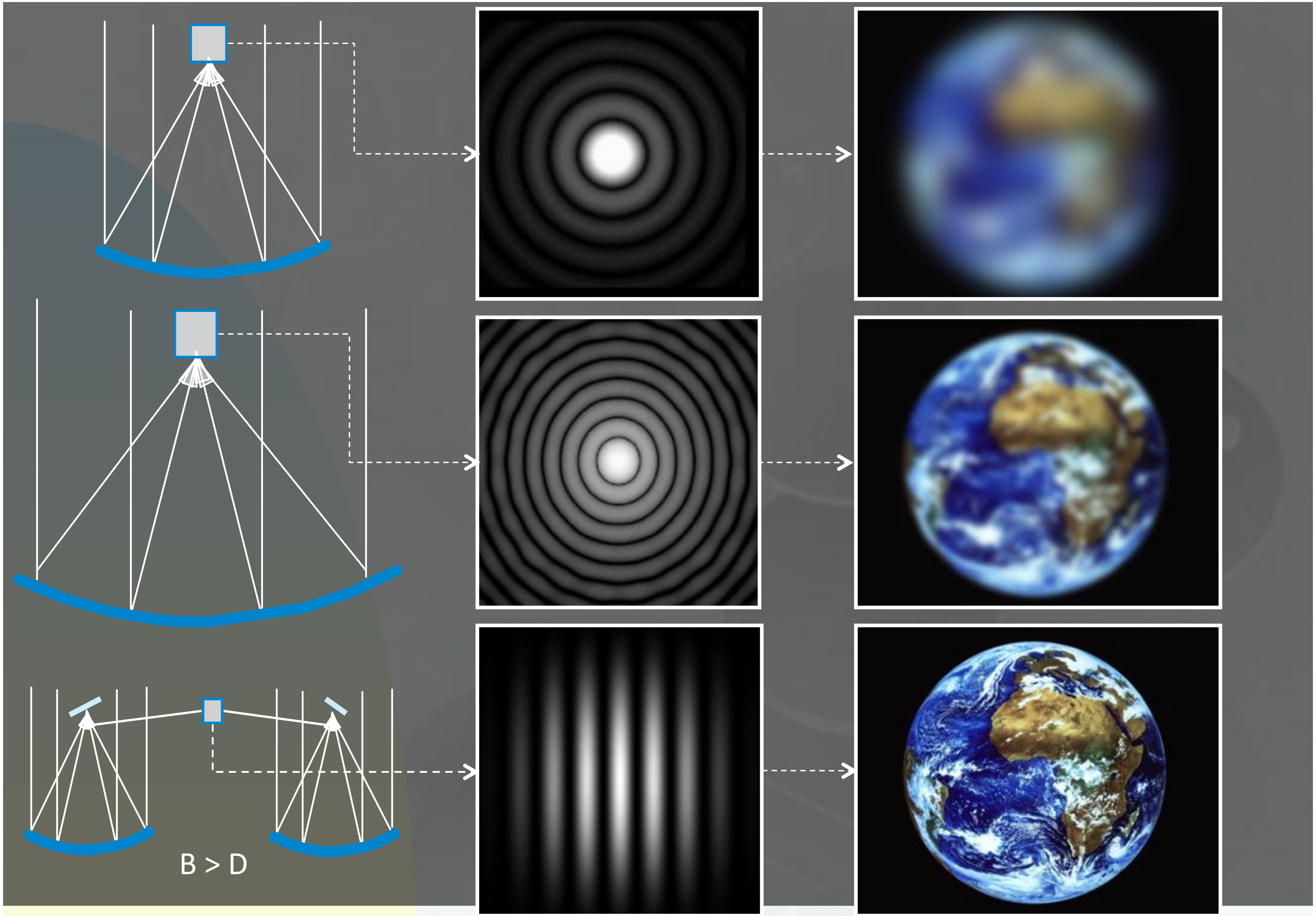
- Need for very large telescopes !!!

- H. Fizeau and E. Stephan (1868-1870):

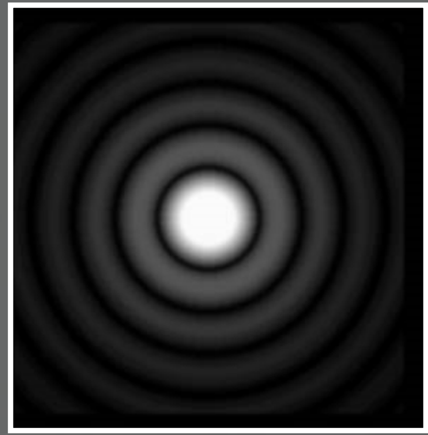
  "In terms of angular resolution, two small apertures distant of B are equivalent to a single large aperture of diameter B"




Telescope 1
Telescope 2
Recombiner
Interference fringes
Inter-fringe= λ/B
Baseline (B)


B > D

=



$\otimes$

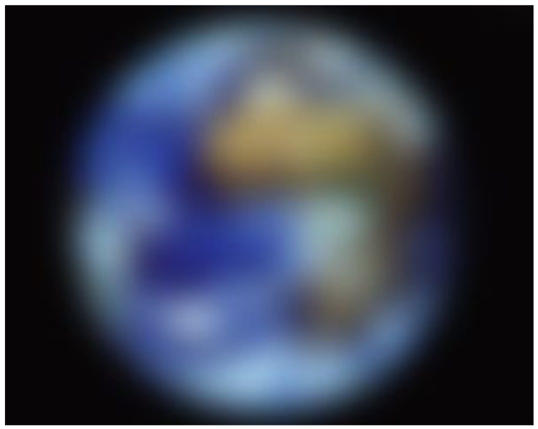
Convolution theorem

$$I(\zeta,\eta) = \iint PSF(\zeta-\zeta',\eta-\eta')\,O(\zeta',\eta')\,d\zeta' d\eta' = PSF(\zeta,\eta) \otimes O(\zeta,\eta)$$

$$TF(I(\zeta,\eta))(u,v) = TF(PSF(\zeta,\eta))(u,v) \cdot TF(O(\zeta,\eta))(u,v)$$

$u = B_u / \lambda$, $v = B_v / \lambda$

$$O(\zeta,\eta) = TF(-1)TF(O(\zeta,\eta)) = TF(-1)(TF(I(\zeta,\eta)) / TF(PSF(\zeta,\eta)))$$



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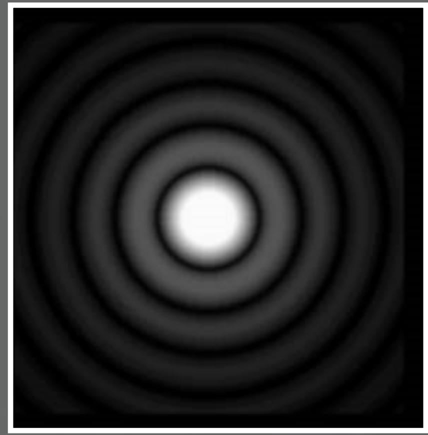


⊗

Wierner Kitchen theorem

$$TF(PSF(\zeta,\eta))(u,v) = \iint A^{*}(x,y)\; A\;(x+u, y+v)\, dx\, dy$$

An introduction to optical/IR interferometry

- 1 Introduction
- 2 Reminders
- 3 Brief history of stellar diameter measurements
- 4 Interferometry with two independent telescopes
- 5 Light coherence (Zernicke-van Cittert theorem)
- 6 Examples of optical interferometers
- 7 Results
- 8 Three important theorems (Fundamental theorem, Convolution theorem and Wiener-Khintchin theorem)!

An introduction to optical/IR interferometry

- 1 Introduction

An introduction to optical/IR interferometry

- 1 Introduction

$$\rho = R / z \qquad (1.1)$$

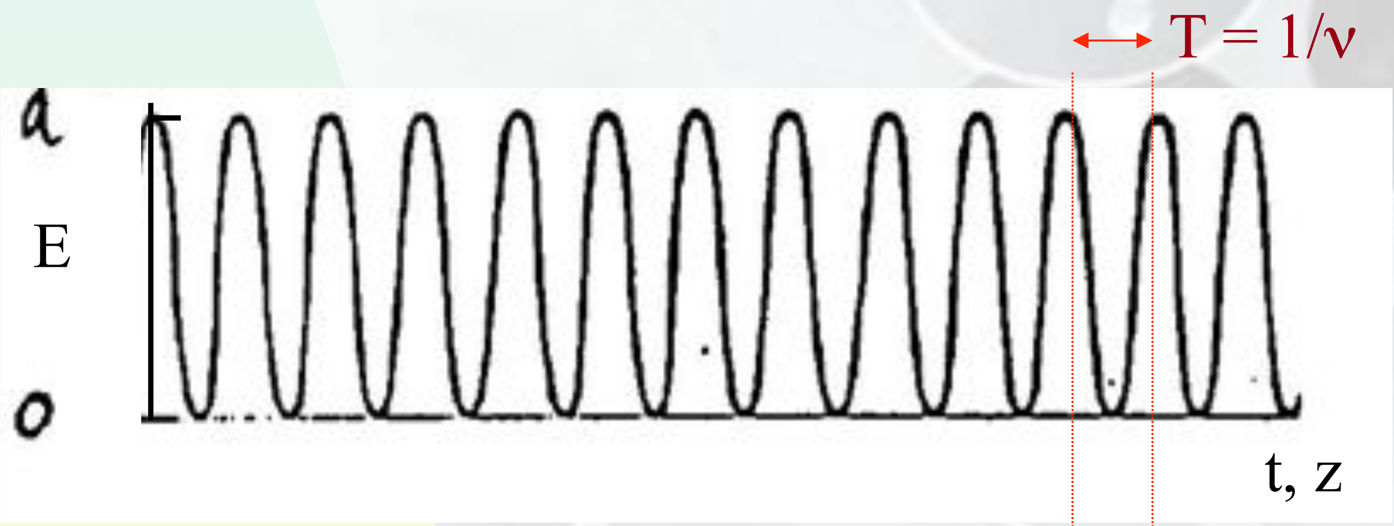
$$F = f / \rho^2 \qquad (1.2)$$

$$T_{eff} = (F/\sigma)^{1/4} = (f / \sigma\, \rho^2)^{1/4} \qquad (1.3)$$

An introduction to optical/IR interferometry

- 2 Reminders

- 2.1. Representation of an electromagnetic wave



$$E = a \cos[2\pi (\nu t - z / \lambda)] \quad (2.1.1)$$

where $\lambda = c\,T = c / \nu$. (2.1.2)

An introduction to optical/IR interferometry

- 2.1. Representation of an electromagnetic wave

$$E = \mathrm{Re}\{ a \exp[i2\pi(\nu t - z / \lambda)]\} \quad (2.1.3)$$

$$E = \mathrm{Re}\{ a \exp[-i \phi] \exp[i2\pi\nu t]\} \quad (2.1.4)$$

where $\phi = 2\pi z / \lambda.$ (2.1.5)

$$E = a \exp[-i \phi] \exp[i2\pi\nu t] \quad (2.1.6)$$

An introduction to optical/IR interferometry

- 2.1. Representation of an electromagnetic wave

$$E = A \exp[i2\pi\nu t] \qquad (2.1.7)$$

with $$A = a \exp[-i\ \phi] \qquad (2.1.8)$$

$\nu \sim 6\ 10^{14}$ Hz for $\lambda = 5000$ Å

An introduction to optical/IR interferometry

- 2.1. Representation of an electromagnetic wave

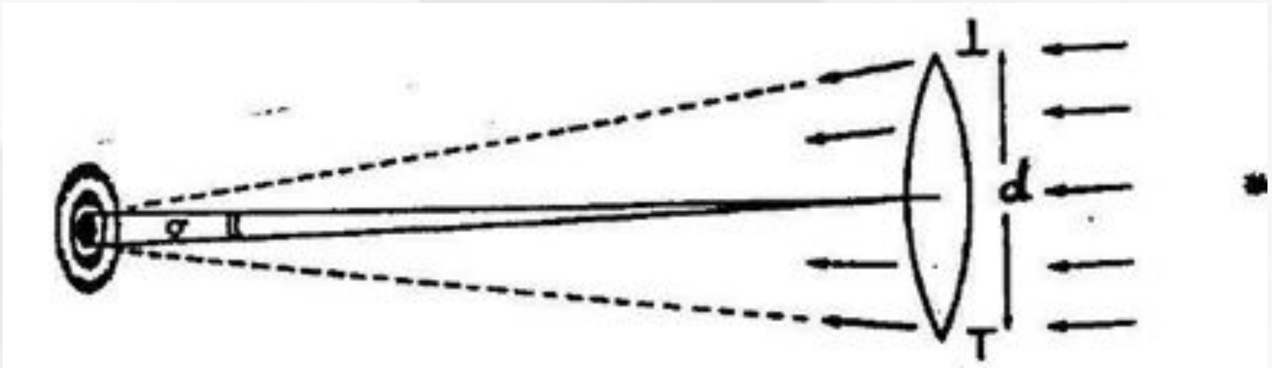
$$\langle E^2 \rangle = \lim_{T \to \infty} \frac{1}{2T} \int_{-T}^{+T} E^2 dt \qquad (2.1.9)$$

$$\langle E^2 \rangle = a^2 / 2 \qquad (2.1.10)$$

$$I = A A^* = |A|^2 = a^2 . \qquad (2.1.11)$$

An introduction to optical/IR interferometry

- 2.2. The Huygens-Fresnel principle

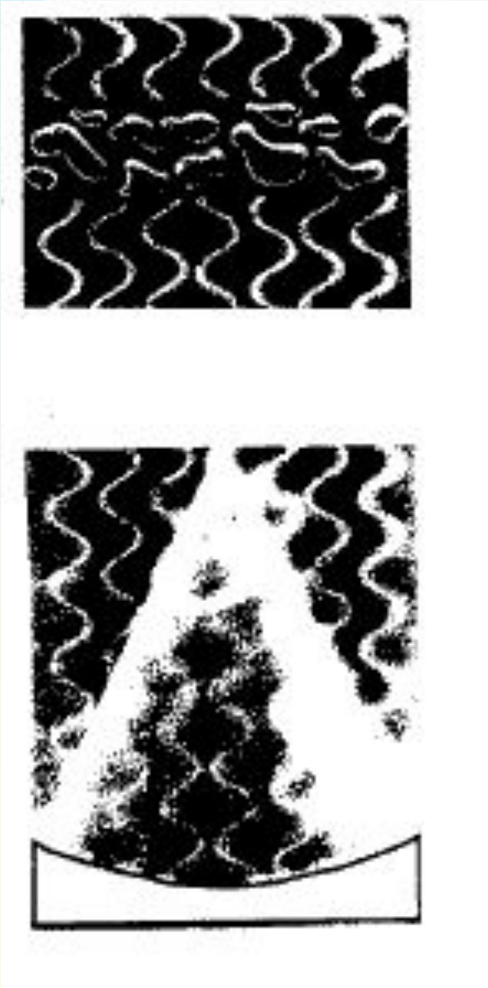


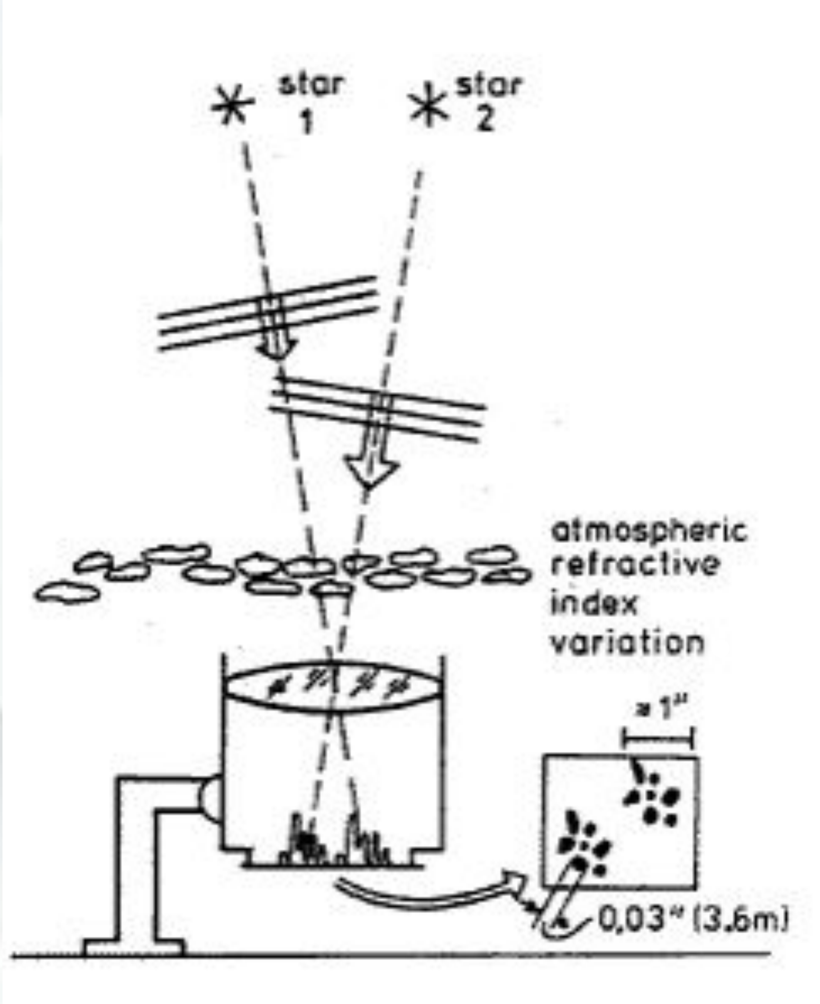
$$\sigma = 2.44\ \lambda / d$$

(2.2.1)

An introduction to optical/IR interferometry

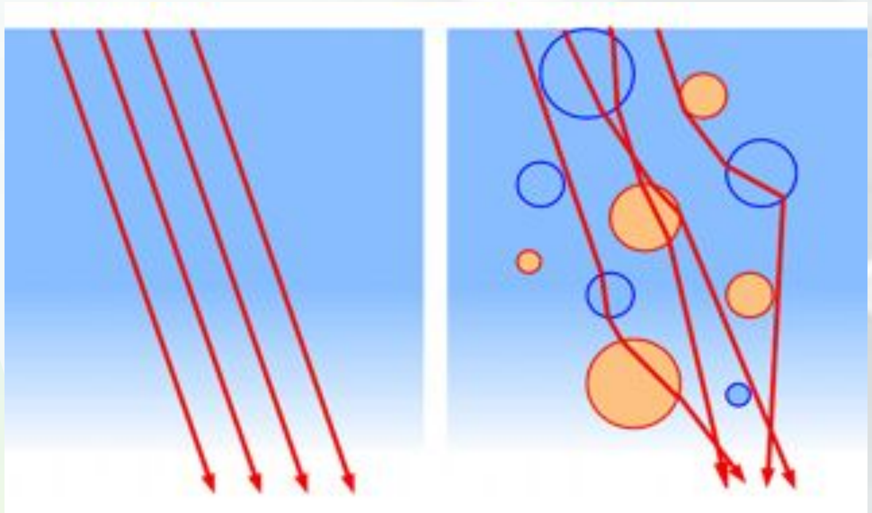
- 2.3. Atmospheric turbulences





An introduction to optical/IR interferometry

- 2.3. Atmospheric turbulences



Fried parameter: r_0

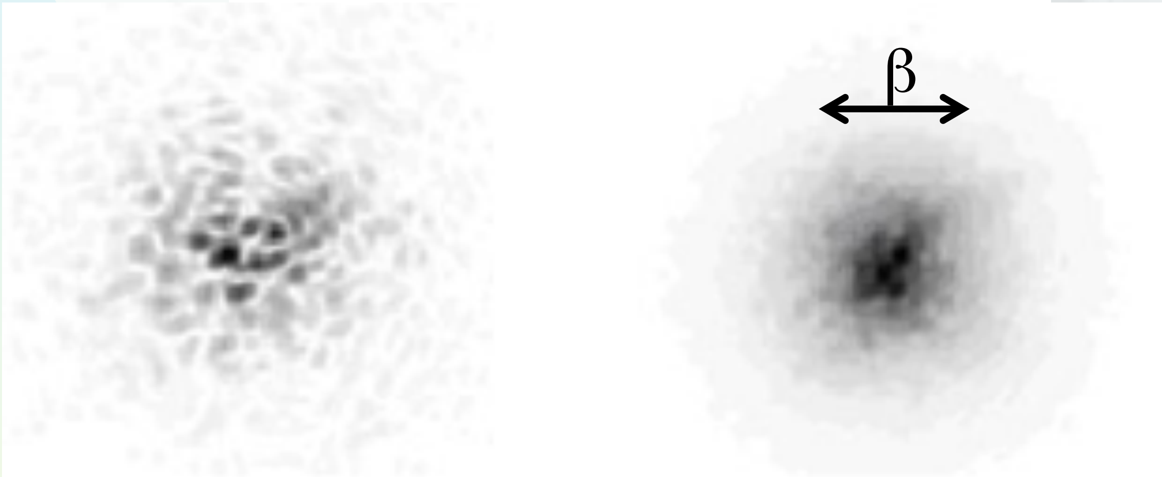
Coherence time (Greenwood time) : $\tau_0 = 0{,}314\ r_0/v$

Seeing : $\beta = 0{,}98\ \lambda / r_0$

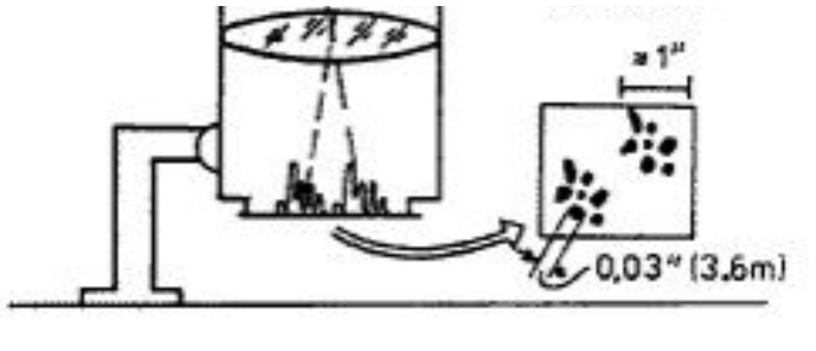
An introduction to optical/IR interferometry

- 2.3. Atmospheric turbulences

Speckles

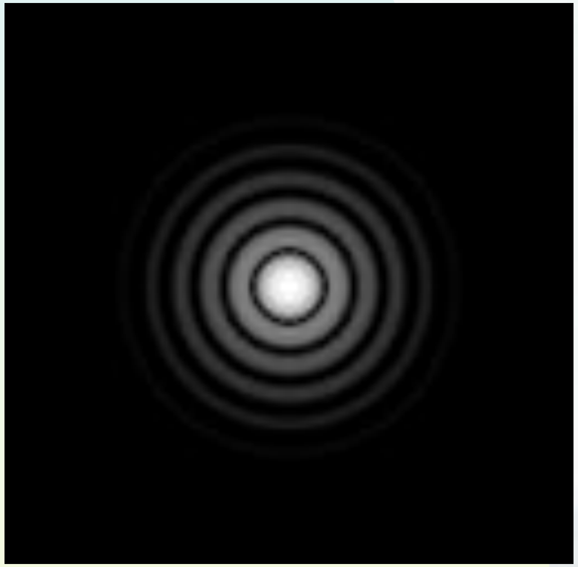


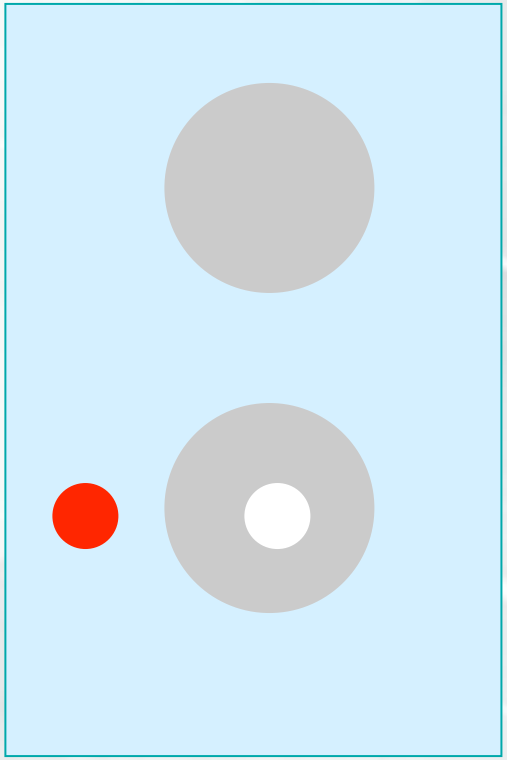
Short exposure vs Long exposure



An introduction to optical/IR interferometry

- 2.2. The Huygens-Fresnel principle



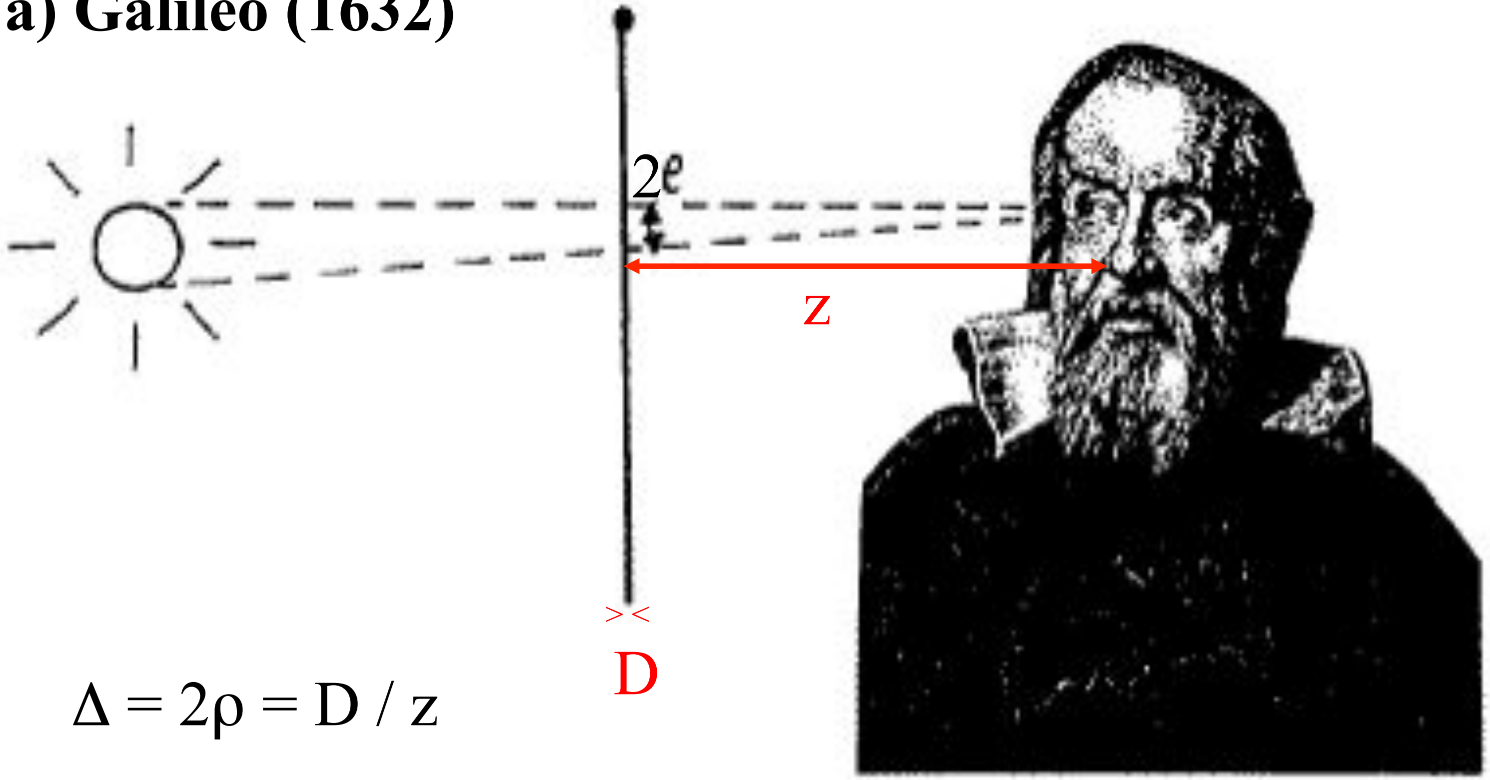


1st experiment!

An introduction to optical/IR interferometry

- 3 Brief history of stellar diameter measurements

a) Galileo (1632)



$$\Delta = 2\rho = D / z$$

An introduction to optical/IR interferometry

- 3 Brief history of stellar diameter measurements

b) Newton:

$$V_{\odot} - V = -5 \log (z / z_{\odot}) , \qquad (3.1)$$

$$\Delta = 2 R_{\odot} / z \quad , \qquad (3.2)$$

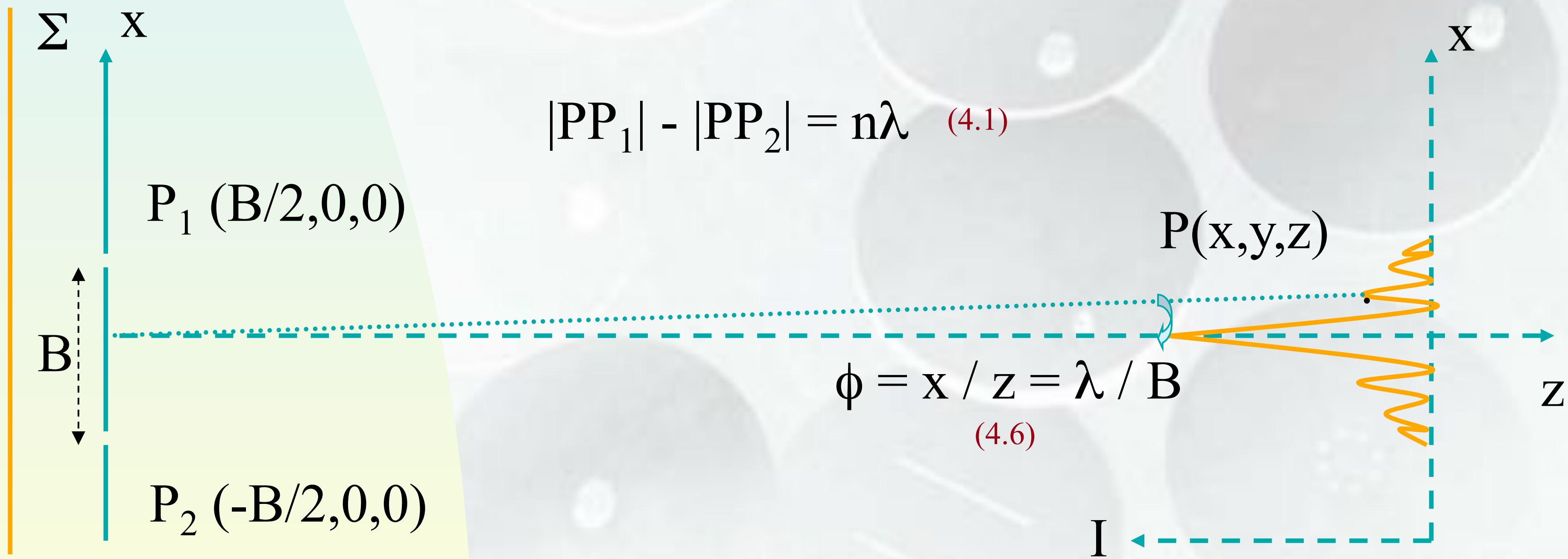
$$\Delta \sim 2\ 10^{-3}{}'' \ (8\ 10^{-3}{}'') \ . \qquad (3.3)$$

c) Fizeau-type interferometry

An introduction to optical/IR interferometry

- 4 Interferometry with two independent telescopes

a) Young's double hole experiment (24-11-1803)



An introduction to optical/IR interferometry

- 4 Interferometry with two independent telescopes

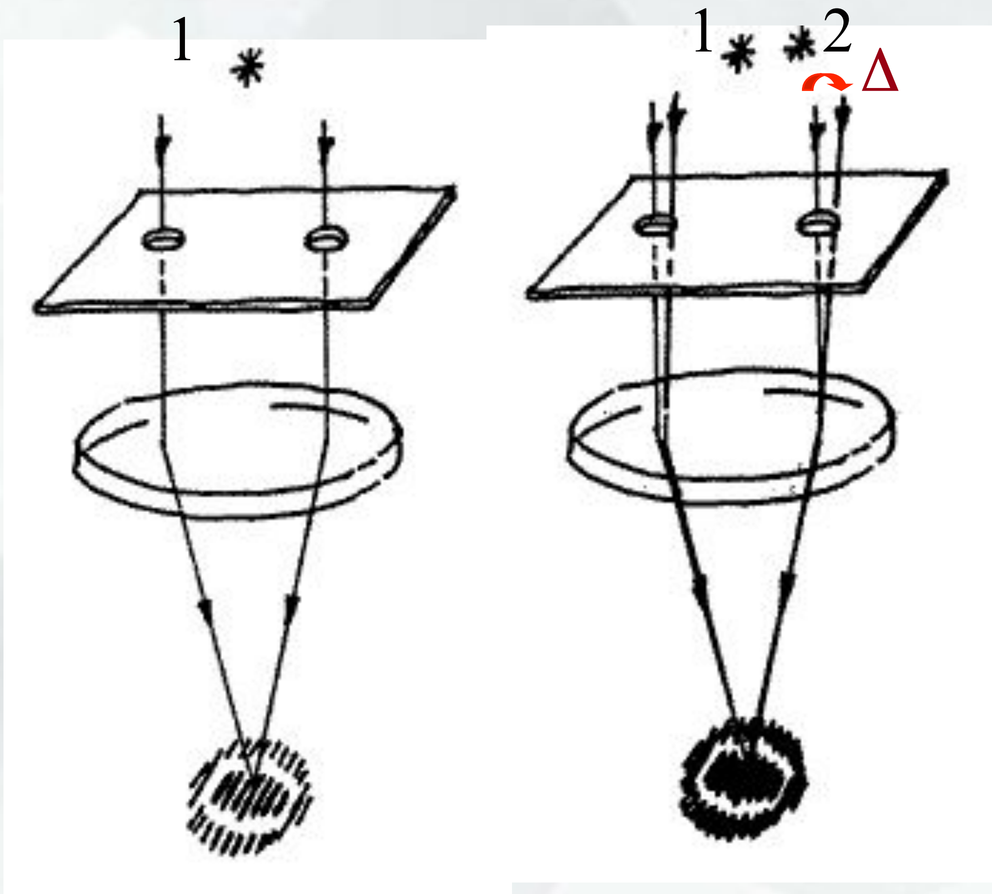
b) Fizeau … the father of stellar interferometry (1868)

If $\Delta \geq \phi/2 = \lambda / (2B)$, (4.7)

fringe disappearance!

Fringe visibility:

$$\upsilon = \left(\frac{I_{max} - I_{min}}{I_{max} + I_{min}} \right)$$

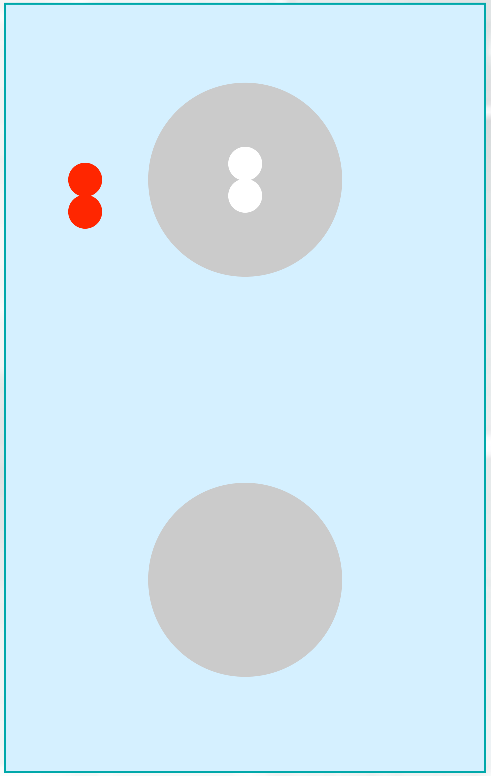


An introduction to optical/IR interferometry

- 4 Interferometry with two independent telescopes

b) Fizeau … the father of stellar interferometry (1868)

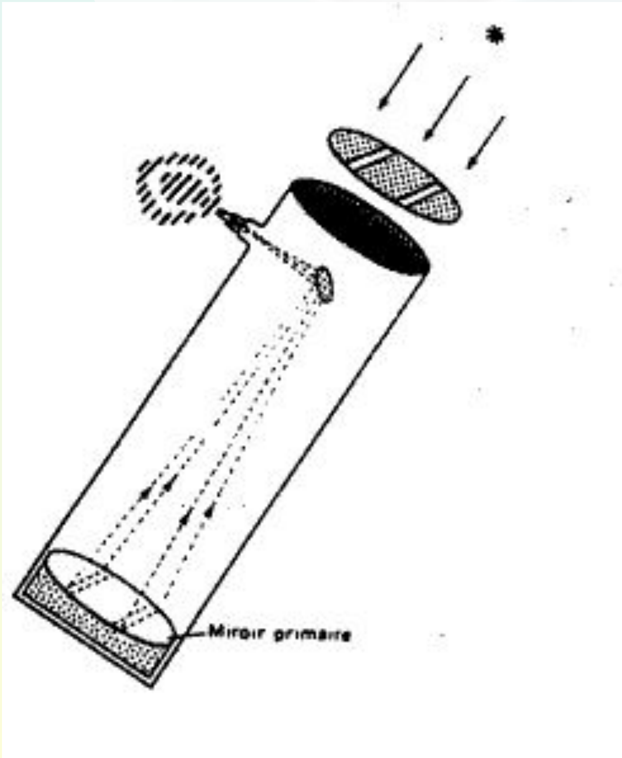
2nd experiment!



An introduction to optical/IR interferometry

- 4 Interferometry with two independent telescopes

b) Fizeau … the father of stellar interferometry (1868)



Stéphan, 1873
$\Delta << 0{,}16''$

An introduction to optical/IR interferometry

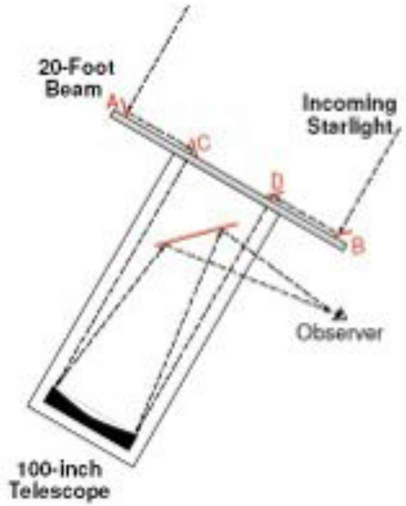
- Marseille 80 cm telescope

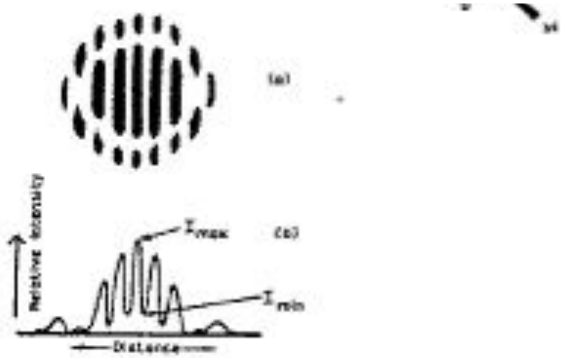
An introduction to optical/IR interferometry

4 Interferometry with two independent telescopes

b) Fizeau … the father of stellar interferometry (1868)

- Michelson, 1890 (satellites of Jupiter)
- Michelson and Pease (1920)



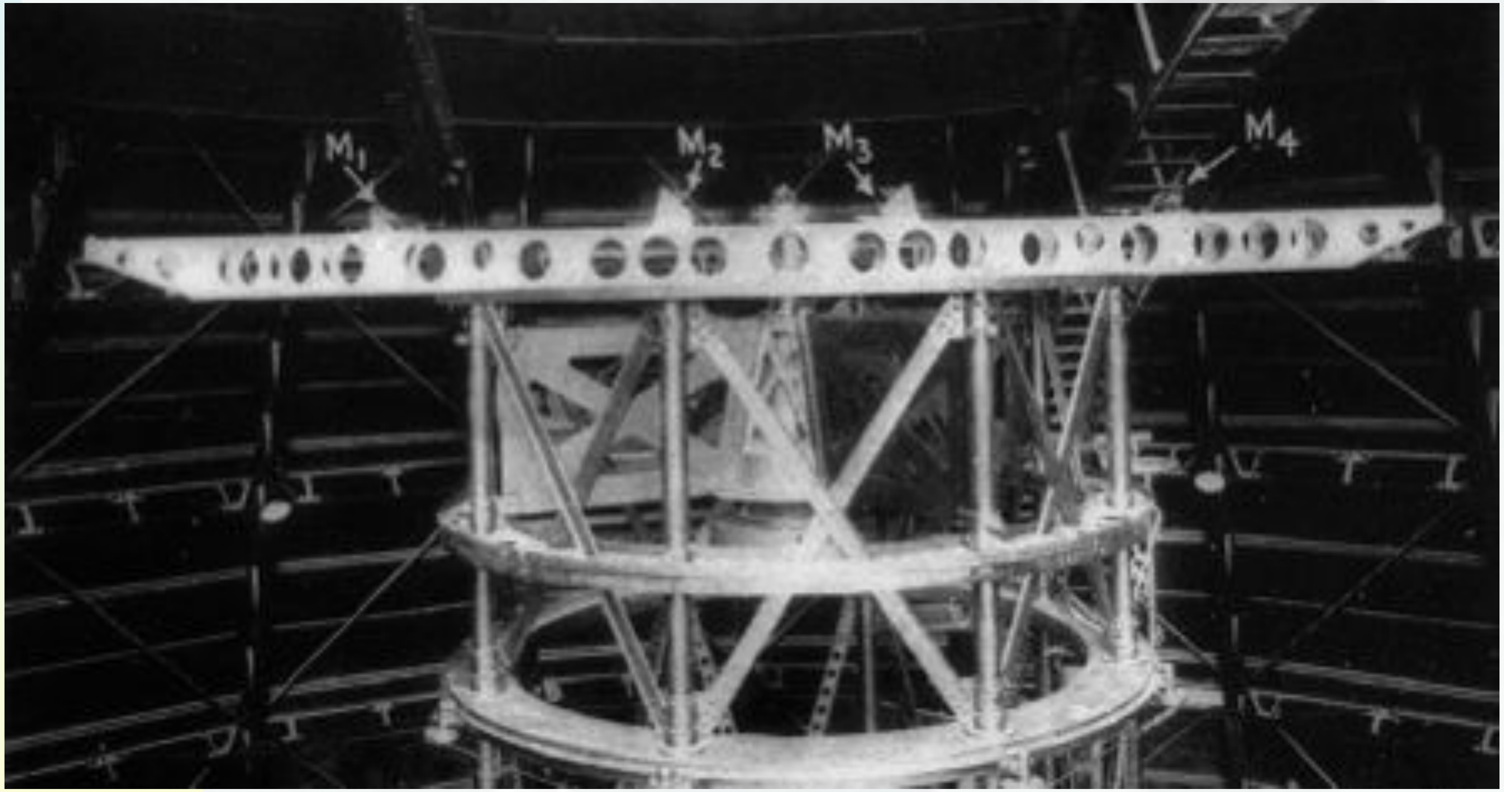


An introduction to optical/IR interferometry

- 4 Interferometry with two independent telescopes

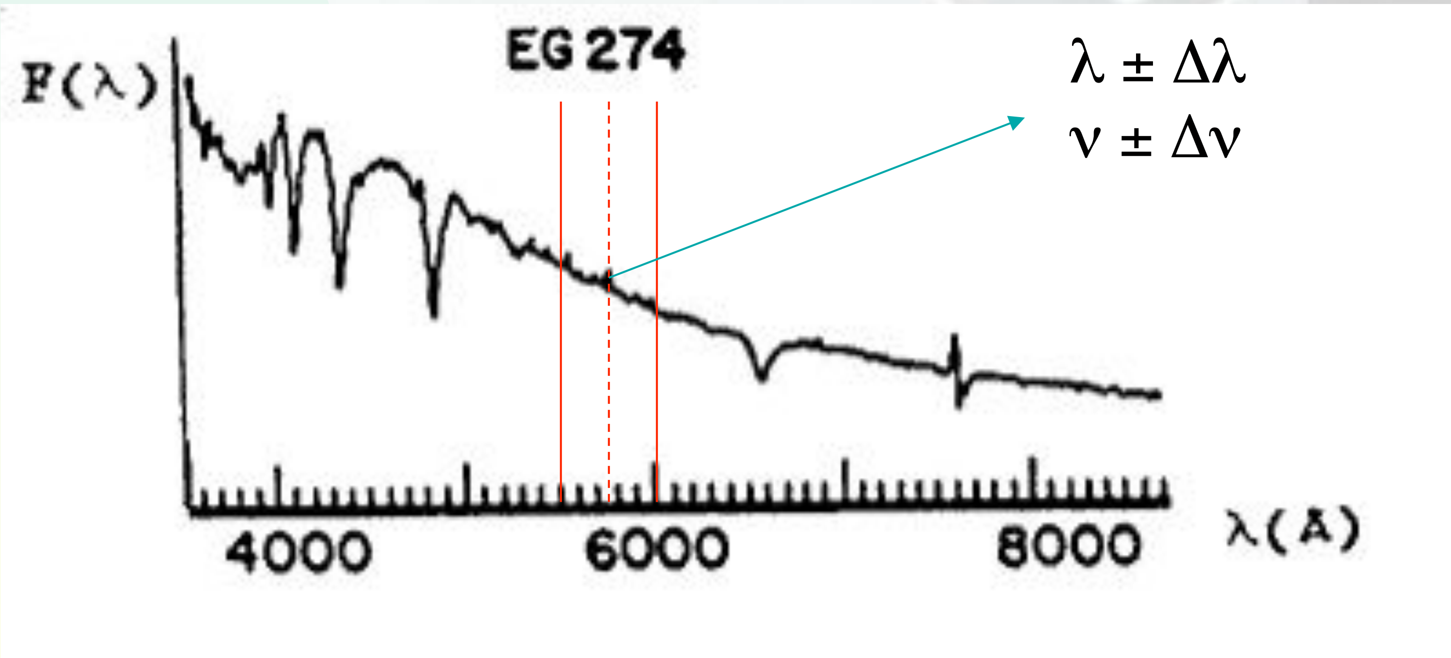
b) Fizeau … the father of stellar interferometry (1868)

- Anderson
- Brown and Twiss (1956)
- Radio Inter-ferometry (1950)



An introduction to optical/IR interferometry

- 5 Light coherence
- **5.1 Quasi monochromatic light (waves and wave groups)**



An introduction to optical/IR interferometry

- 5 Light coherence
- **5.1 Quasi monochromatic light (waves and wave groups)**

$$I = \langle V(t) V^{*}(t) \rangle \qquad (5.1.1)$$

$$V(z,t) = \int_{\nu-\Delta\nu}^{\nu+\Delta\nu} a(\nu') \exp(i2\Pi(\nu' t - z/\lambda'))d\nu' \qquad (5.1.2)$$

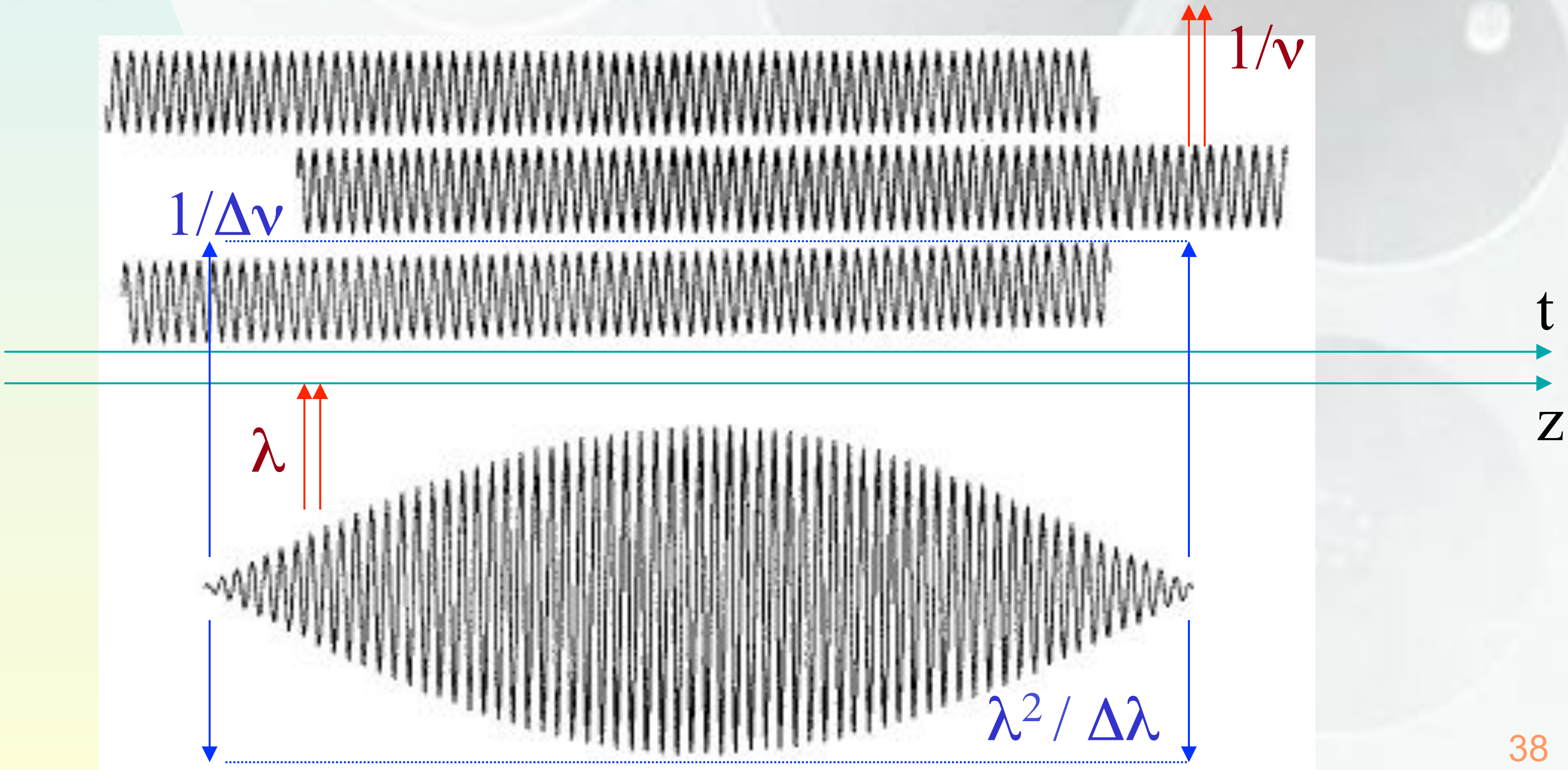
$\exp(-i2\Pi(\nu t\text{-}z/\lambda))$ $\exp(i2\Pi(\nu t\text{-}z/\lambda))$

$$V(z,t) = A(z,t)\exp(i2\Pi(\nu t - z/\lambda)) \qquad (5.1.3)$$

$$A(z,t) = \int_{\nu-\Delta\nu}^{\nu+\Delta\nu} a(\nu') \exp(i2\Pi((\nu' - \nu)t - z(1/\lambda' - 1/\lambda)))d\nu' \qquad (5.1.4)$$

An introduction to optical/IR interferometry

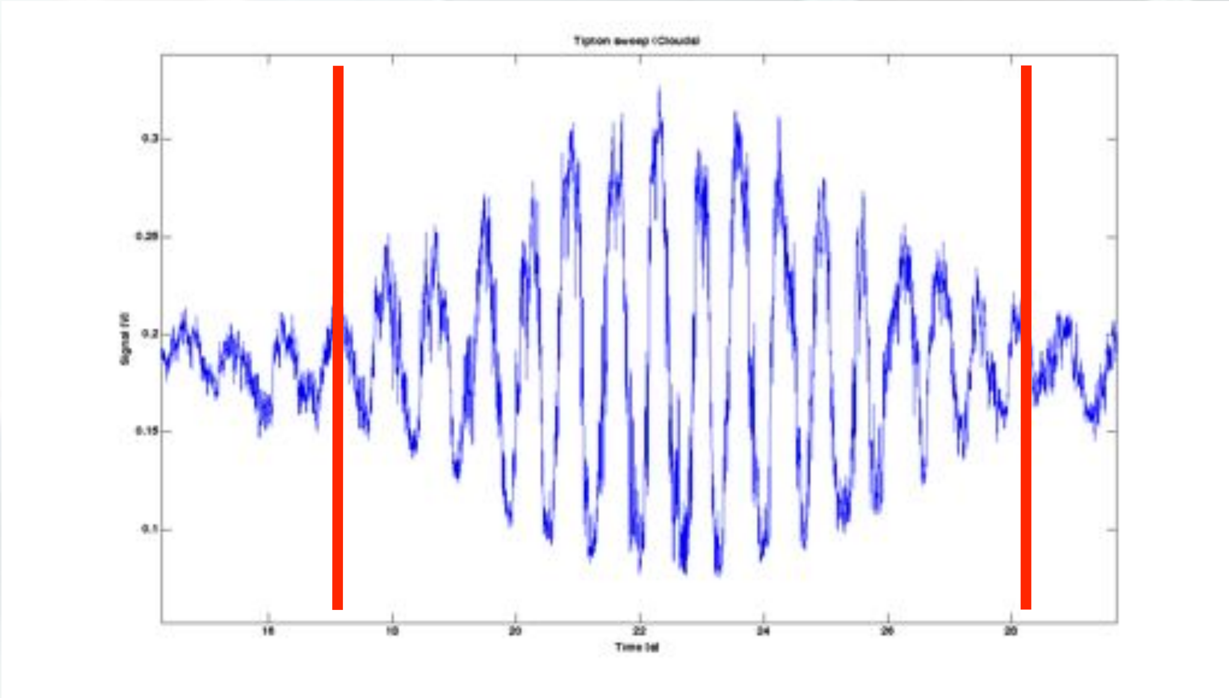
- 5 Light coherence
- **5.1 Quasi monochromatic light (waves and wave groups)**



An introduction to optical/IR interferometry

- 5 Light coherence
- **5.1 Quasi monochromatic light (waves and wave groups)**

$\lambda_0 = 2.2\mu m$
$\lambda \in [2.07\ ;\ 2.33]\mu m$
$\Delta\lambda = 0.13\mu m$

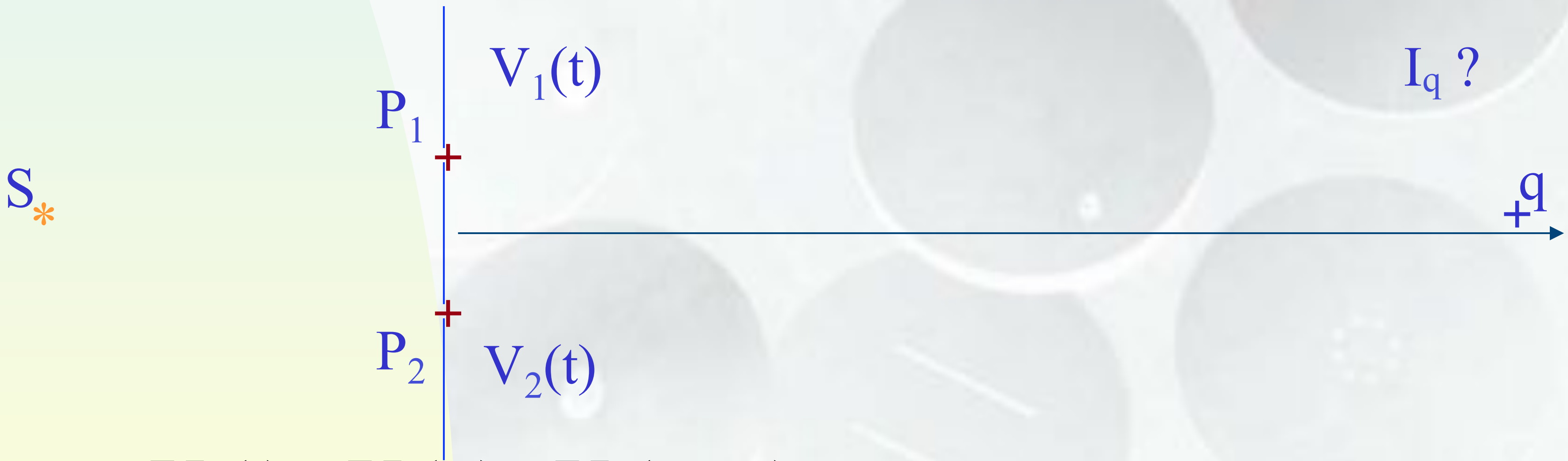


An introduction to optical/IR interferometry

- 5 Light coherence
- **5.2 Fringe visibility**

$$I_q = \langle V_q^*(t) V_q(t) \rangle \quad (5.2.1)$$

$$V_q(t) = V_1(t - t_{1q}) + V_2(t - t_{2q}) \quad (5.2.2)$$



$$V_q(t) = V_1(t) + V_2(t - \tau) \quad (5.2.3)$$

$$\tau = t_{2q} - t_{1q} \quad (5.2.4)$$

An introduction to optical/IR interferometry

- 5 Light coherence
- **5.2 Fringe visibility**

$$I_q = I + I + 2I \,\mathrm{Re}\{\gamma_{12}(\tau)\} \quad (5.2.5)$$

$$\gamma_{12}(\tau) = \langle V_1^*(t) V_2(t-\tau) \rangle / I \quad (5.2.6)$$

$$\gamma_{12}(\tau) = \langle A_1^*(z,t)\, A_2(z,t-\tau) \rangle \exp(-i2\Pi\nu\tau) / I \quad (5.2.7)$$

If $\tau \langle\langle 1/\Delta\nu$

$$\gamma_{12}(\tau) = |\gamma_{12}(\tau=0)| \exp(i\beta_{12} - i2\Pi\nu\tau) \quad (5.2.8)$$

- 5 Light coherence
- **5.2 Fringe visibility**

$$I_q = I + I + 2I\,|\gamma_{12}(0)|\cos\left(\beta_{12} - 2\Pi\nu\tau\right) \qquad (5.2.9)$$

$$\upsilon = \left(\frac{I_{\max} - I_{\min}}{I_{\max} + I_{\min}}\right) = \left|\gamma_{12}(0)\right| \qquad (5.2.10)$$