From the pinhole camera … to the telescope and … from the telescope … to the optical interferometer

http://galileoscope.org

Case of 6 Kits

$150.00

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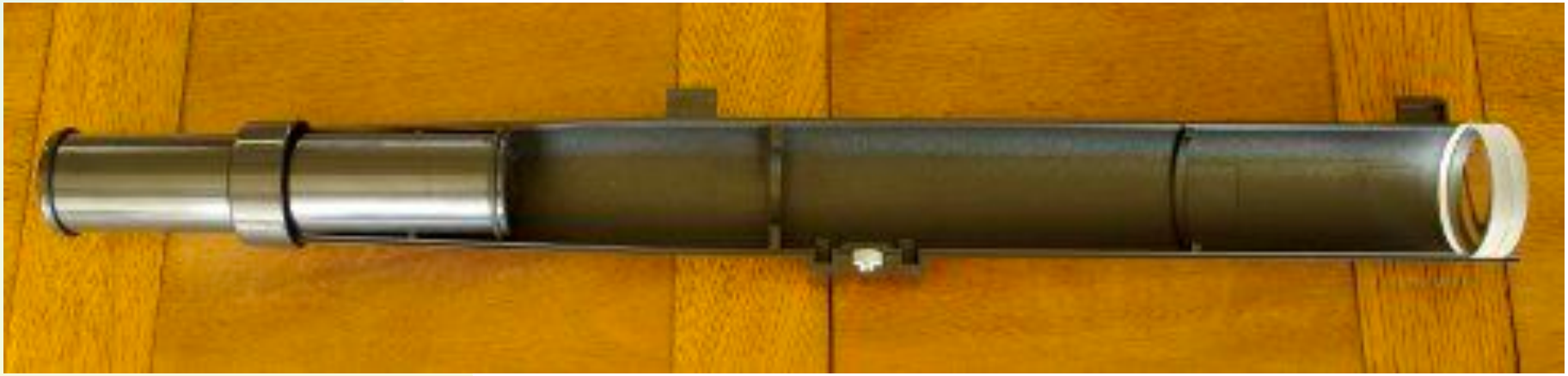
Maximum number of cases per order: 11

SKU: GSCOPE

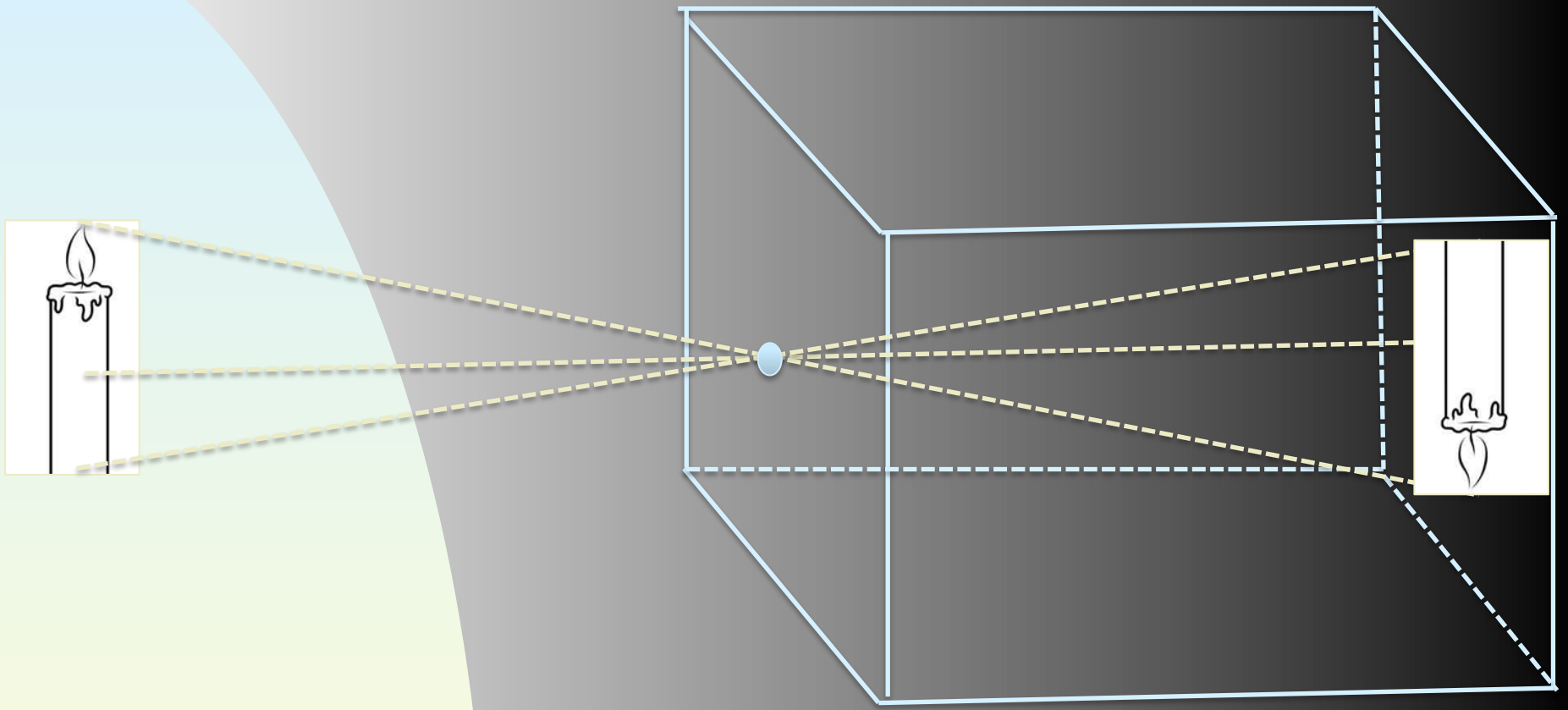
Galileoscope

D = 5cm, F/D = 10, G = 17, 25, 50; cost: 18 €



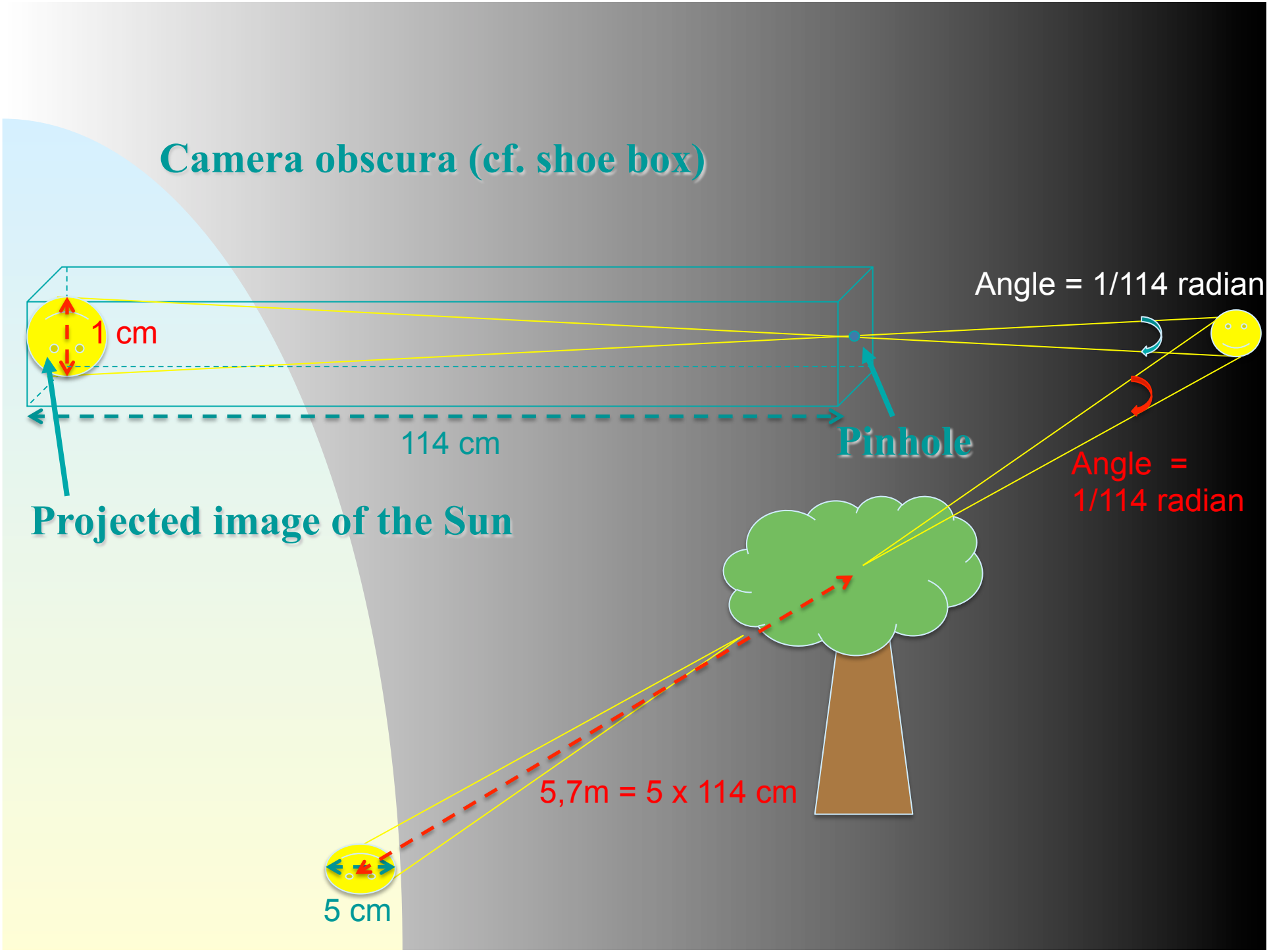
Deconvolution Theorem

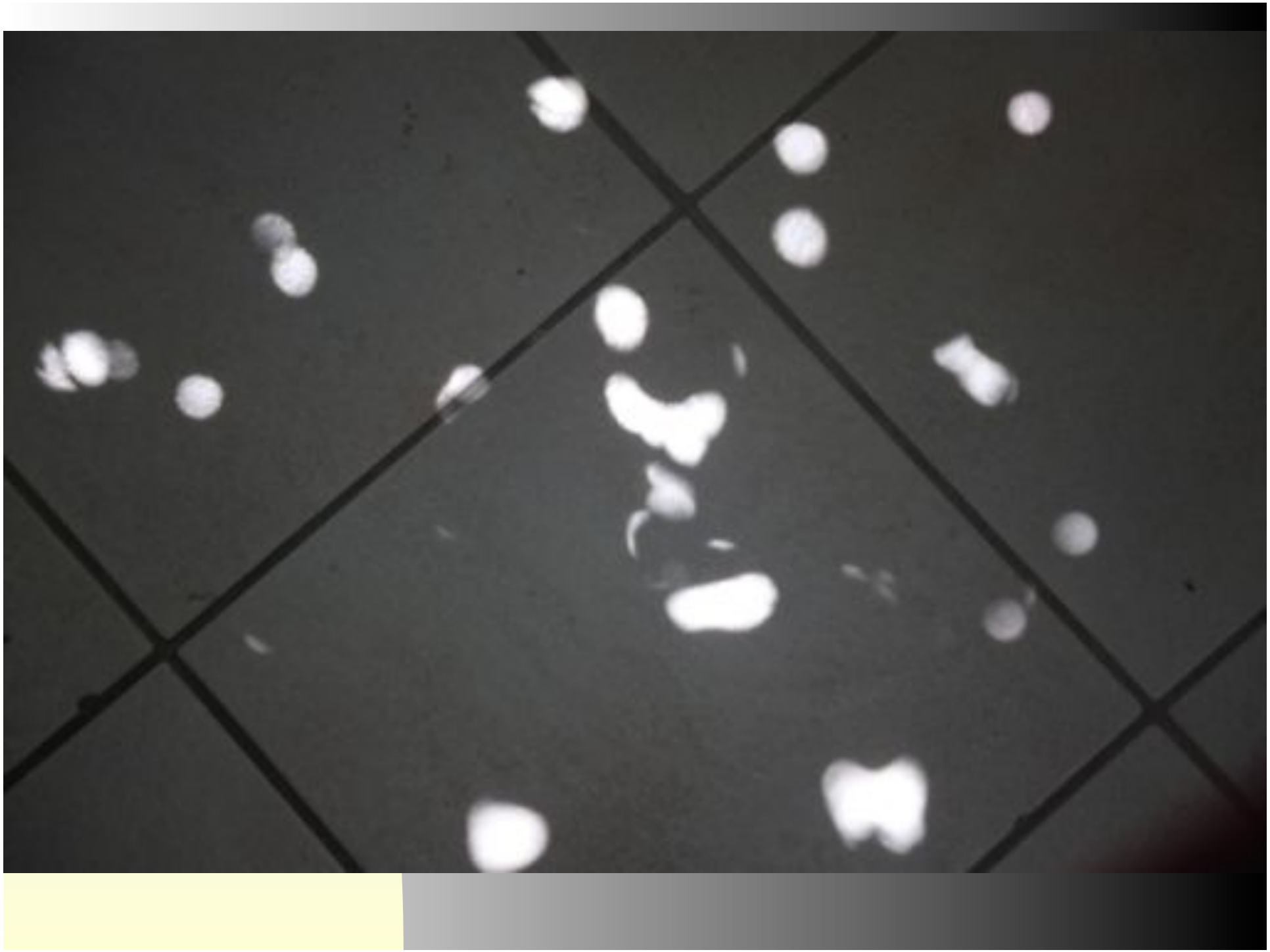
Camera obscura



Pinhole camera

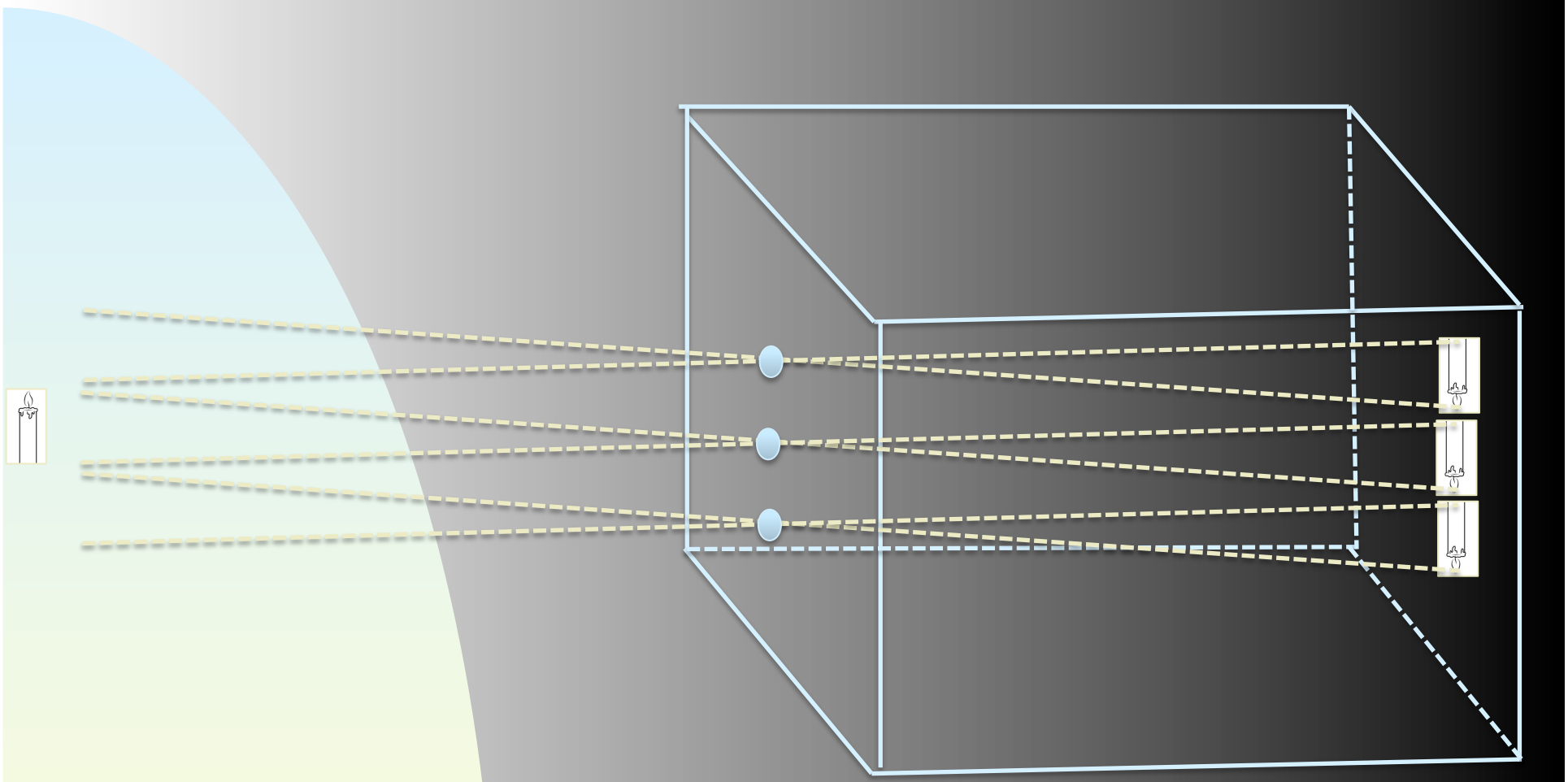
Camera obscura (cf. shoe box)





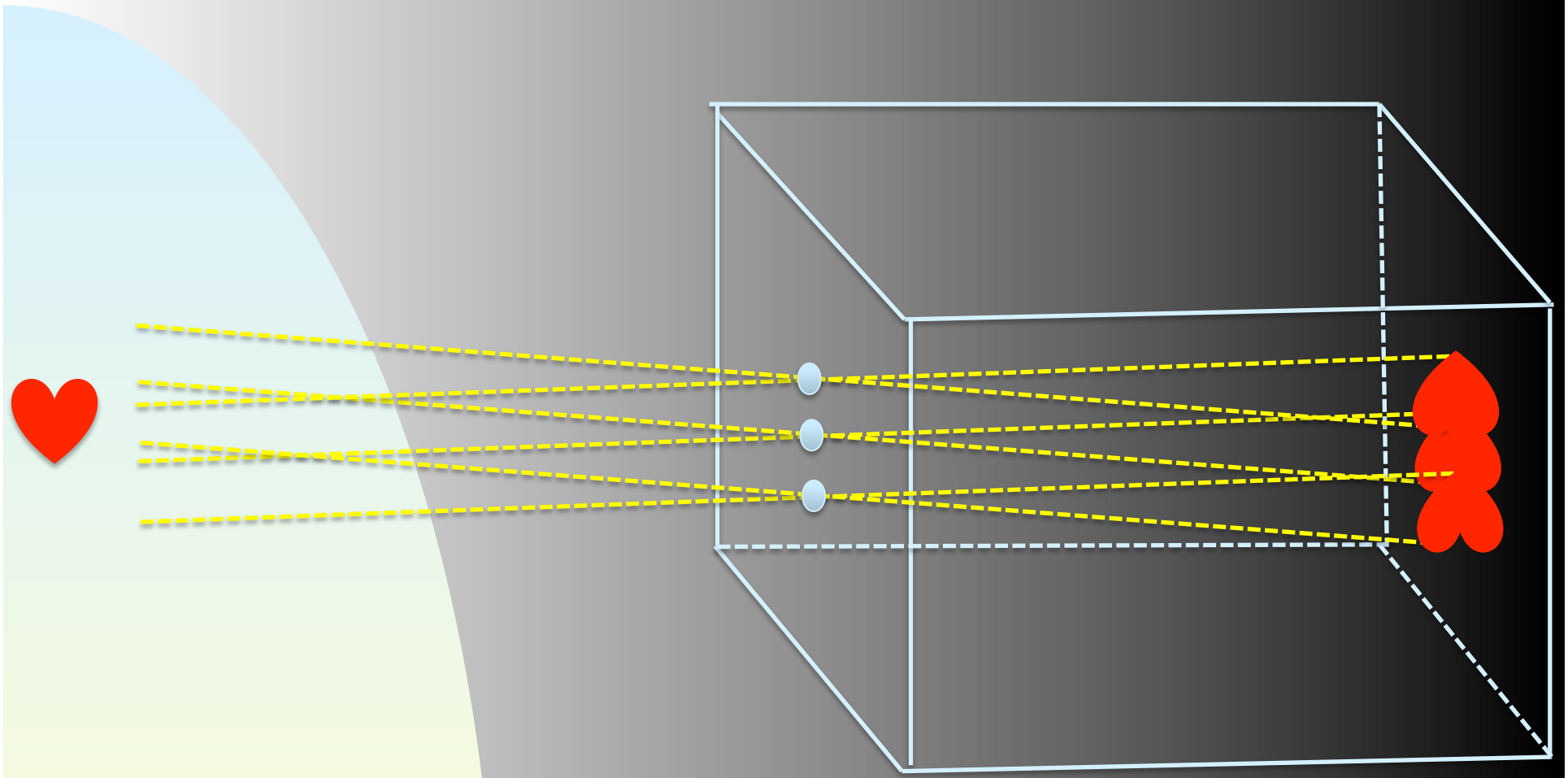

Du feuillage
des arbres
aux grands
télescopes

Camera obscura



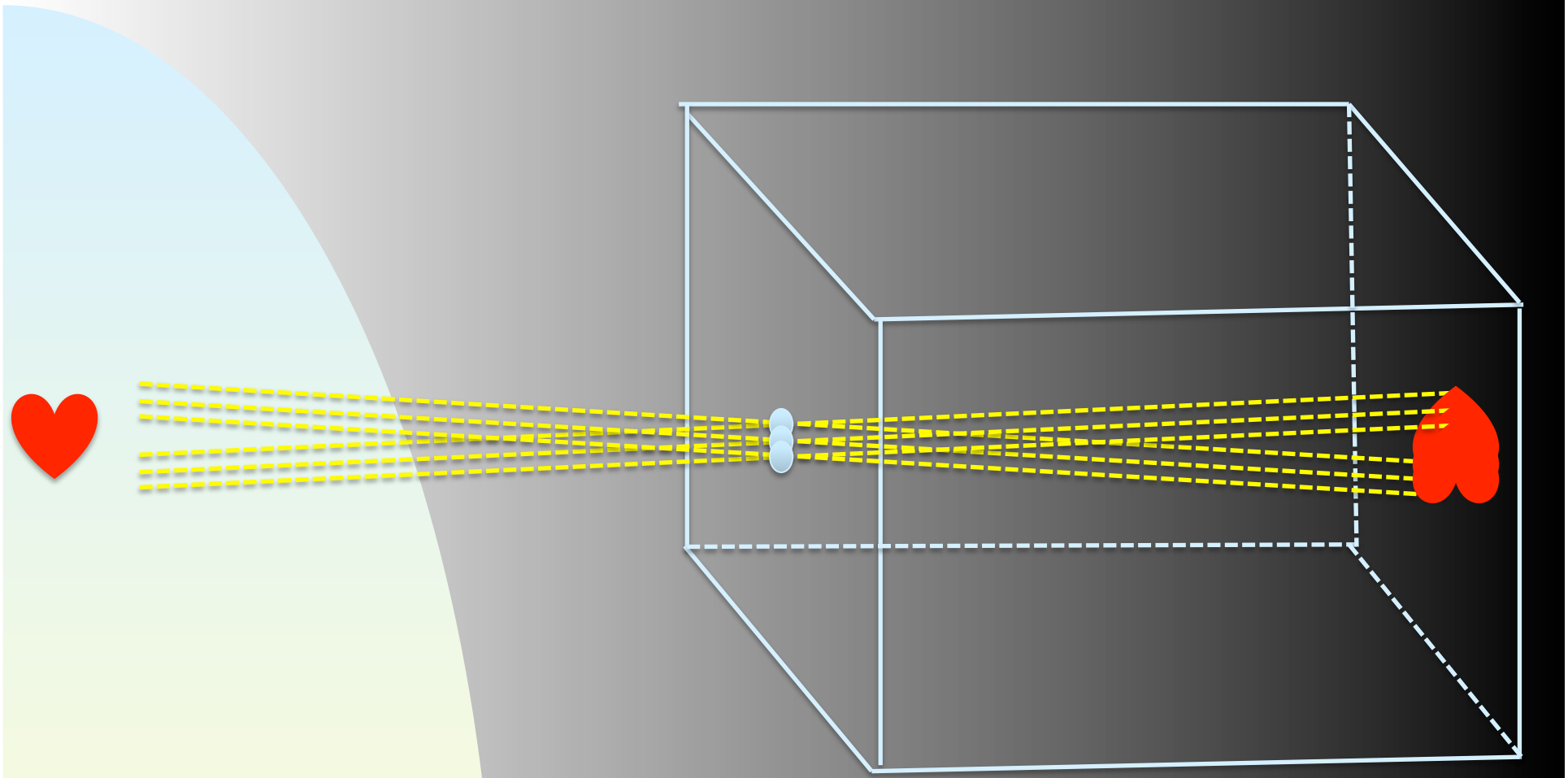
Pinhole camera

Camera obscura

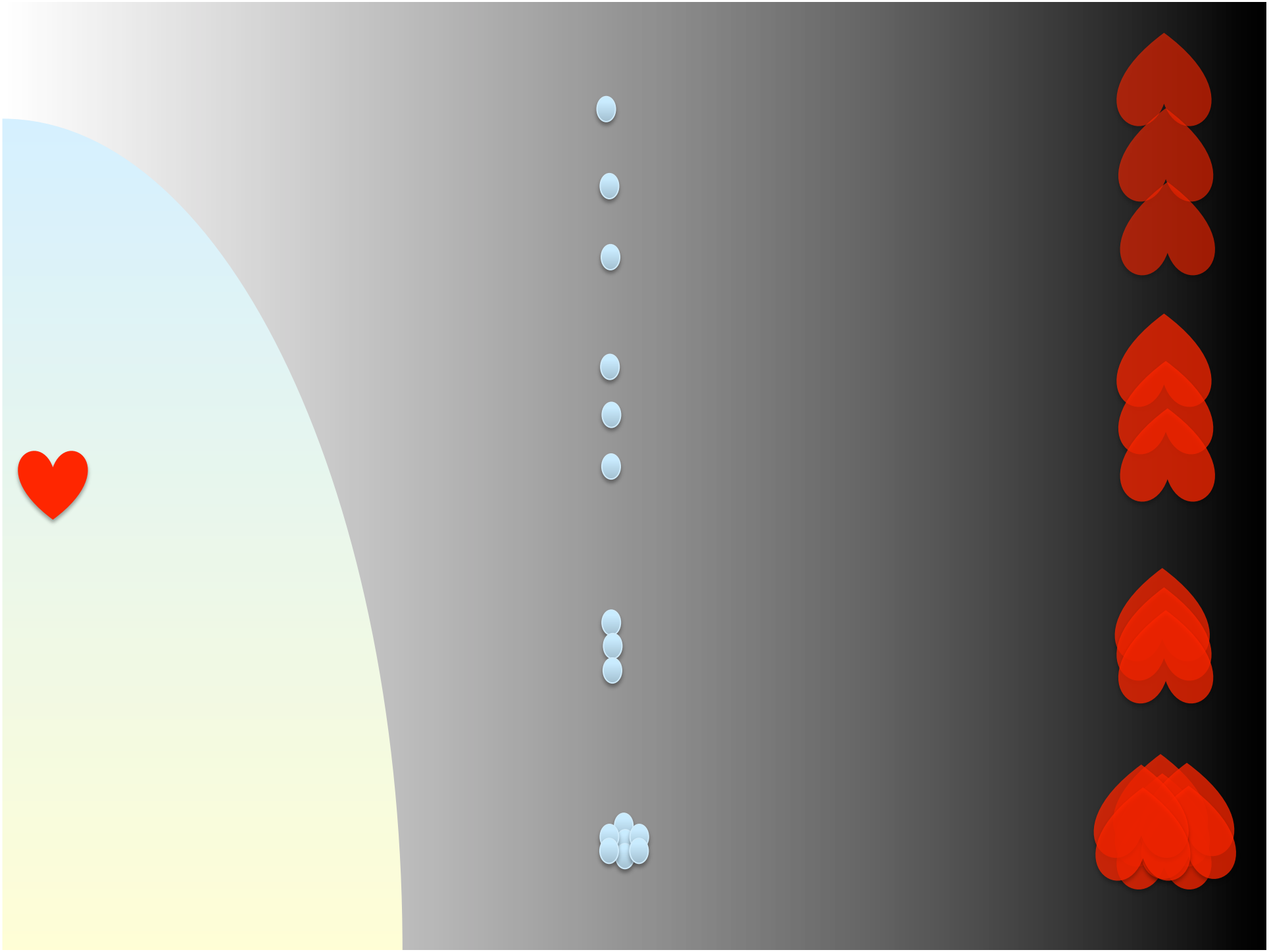


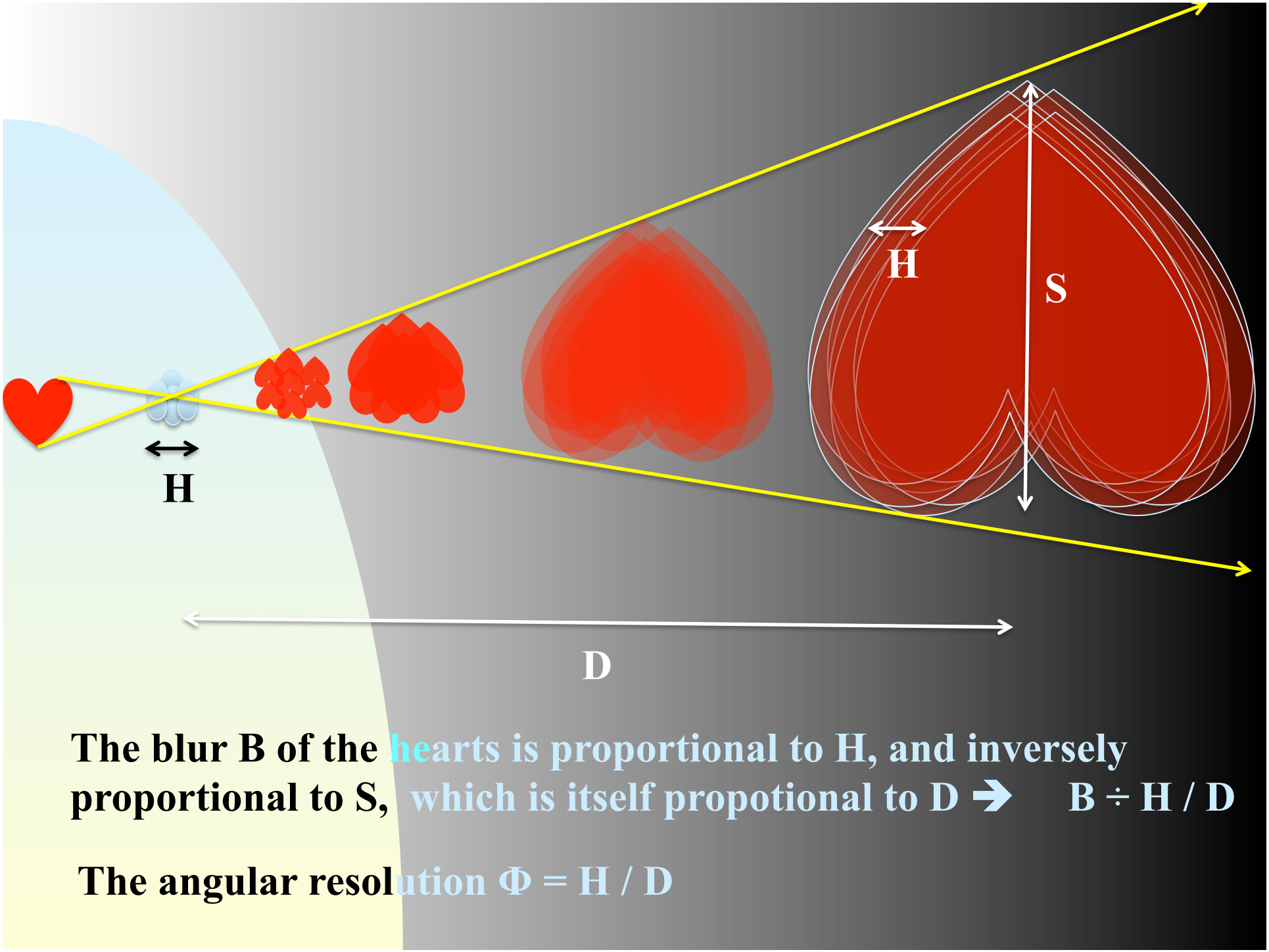
Pinhole camera

Camera obscura



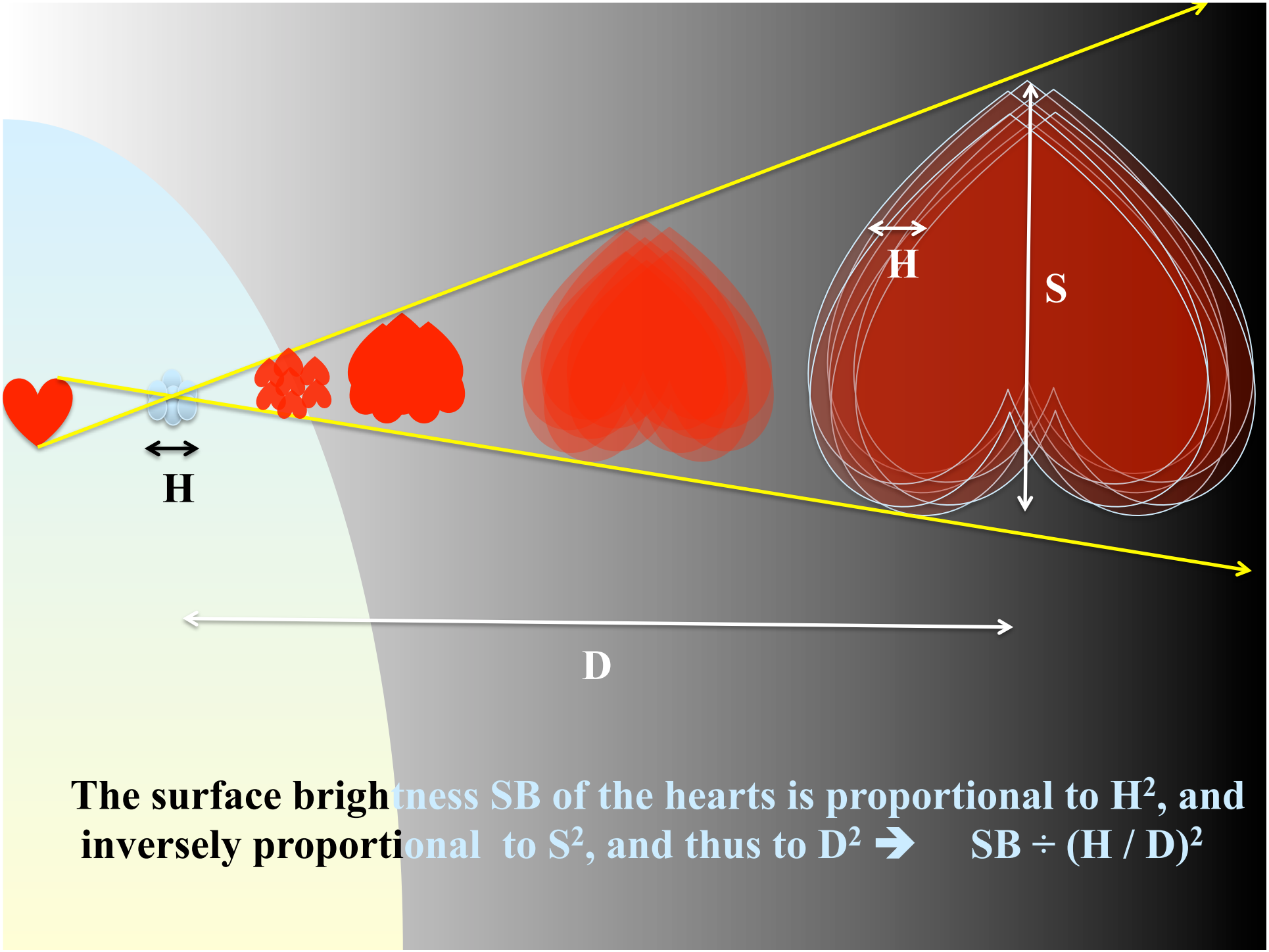
Pinhole camera



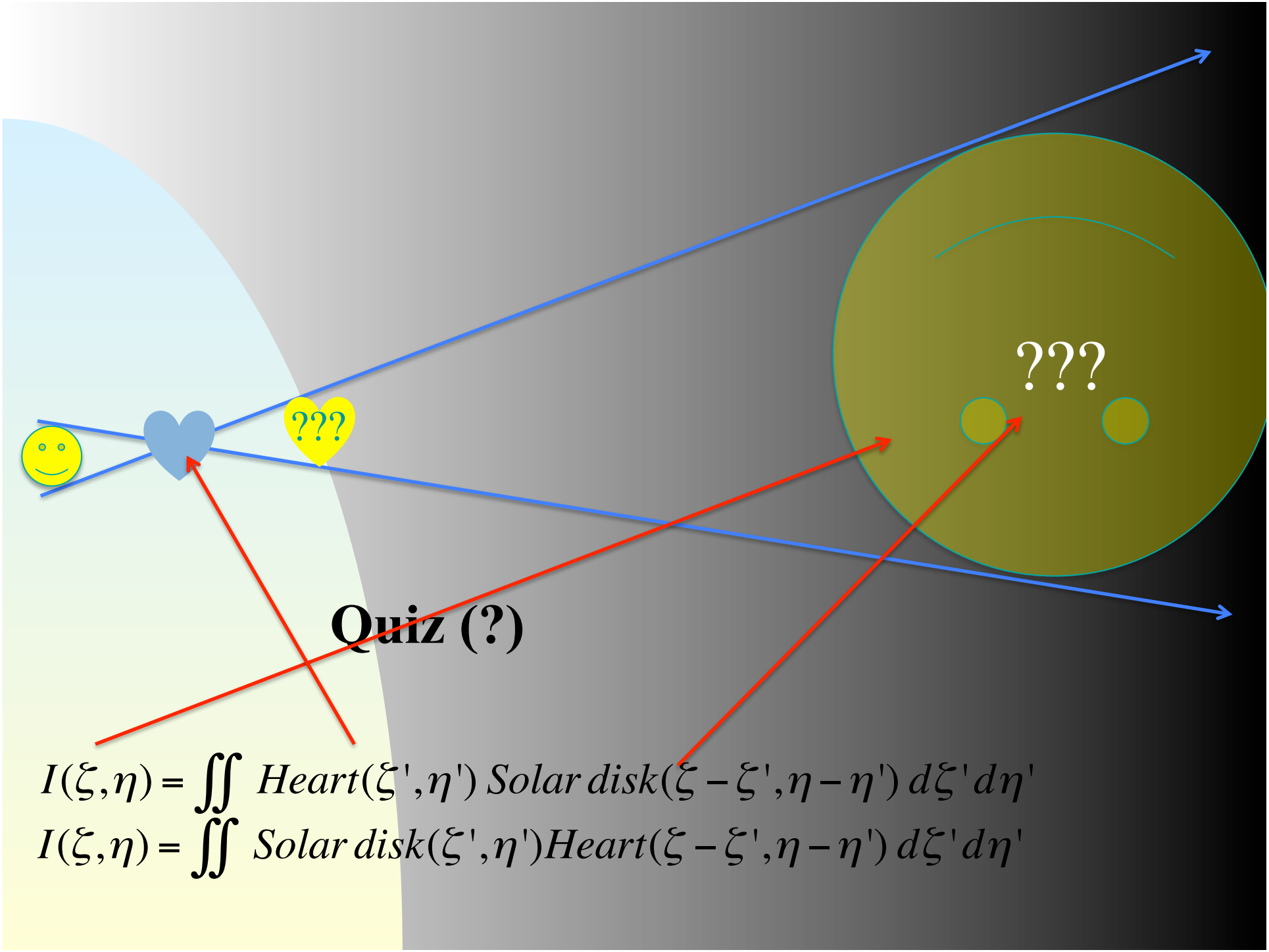


The blur B of the hearts is proportional to H, and inversely proportional to S, which is itself propotional to D ➔ B ÷ H / D

The angular resolution Φ = H / D



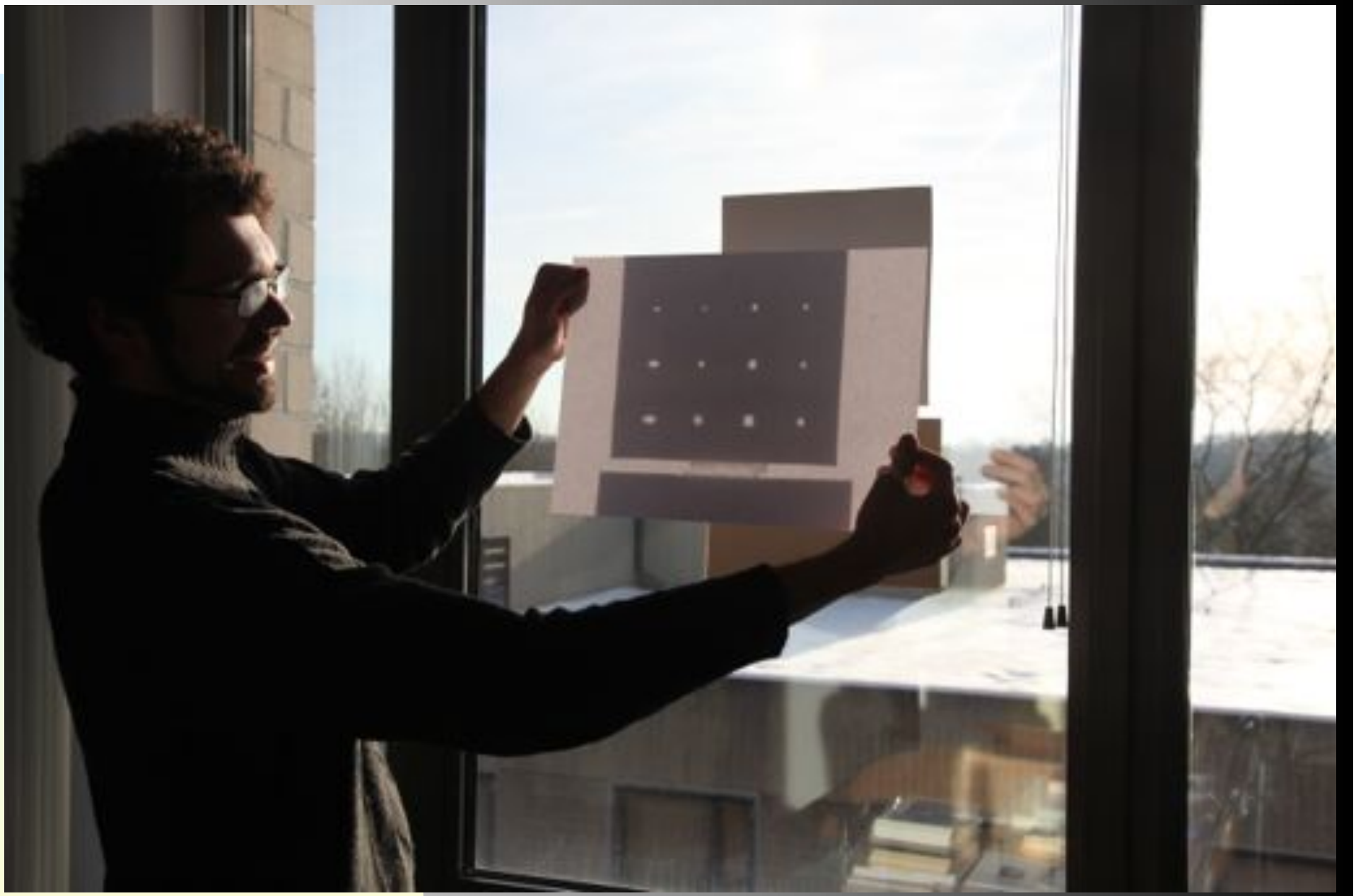
The surface brightness SB of the hearts is proportional to H^2, and inversely proportional to S^2, and thus to D^2 ➔ $SB \div (H / D)^2$

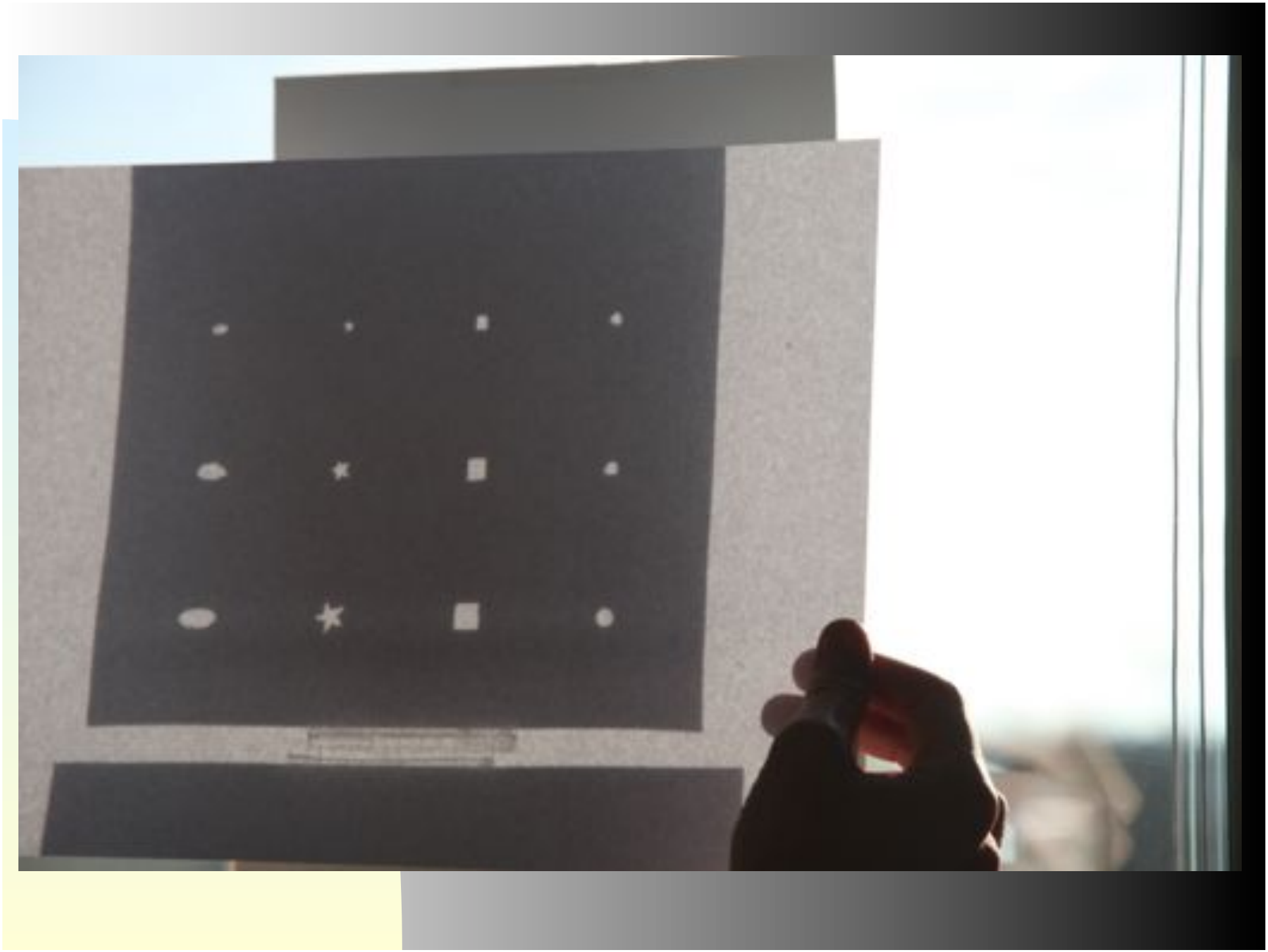


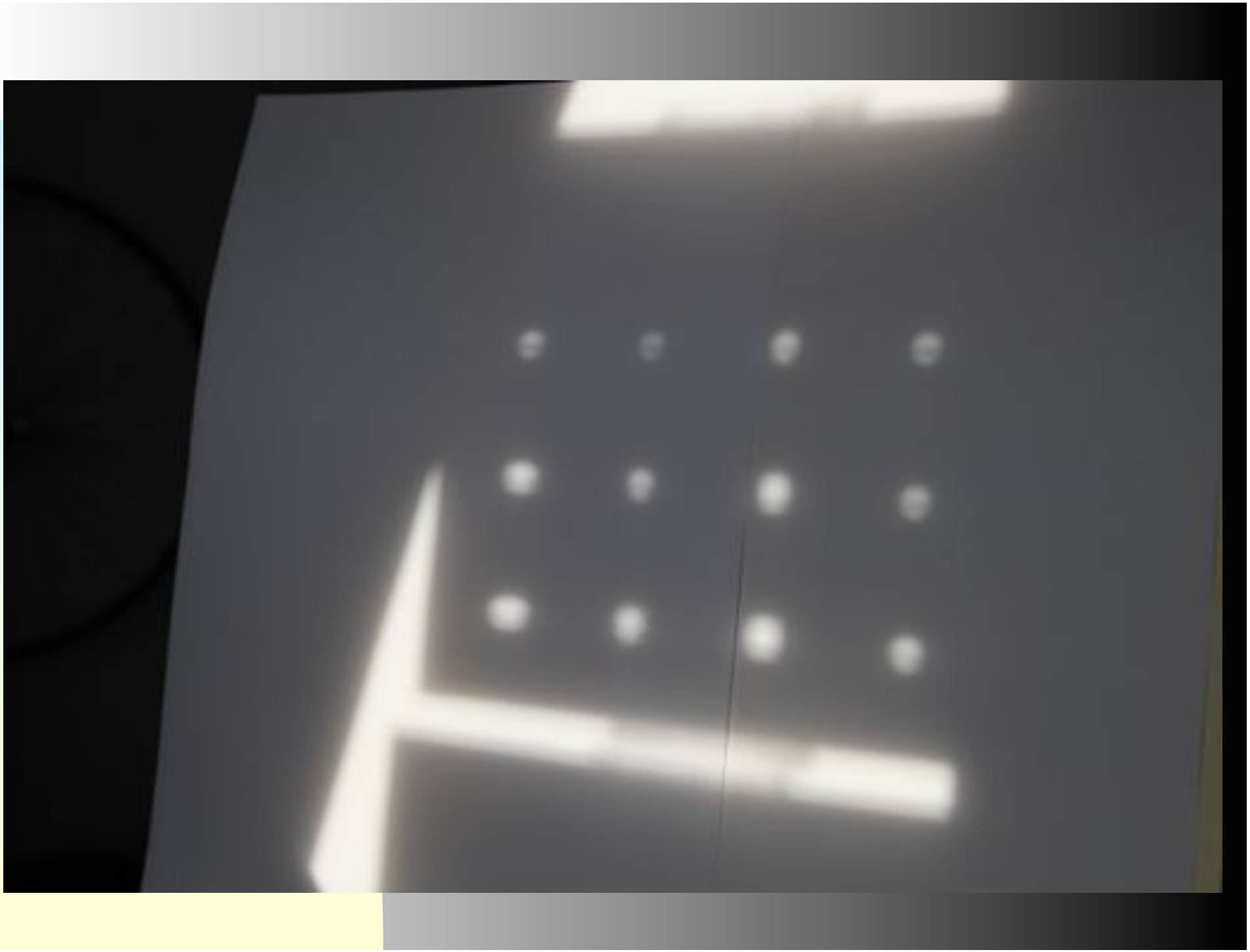
Quiz (?)

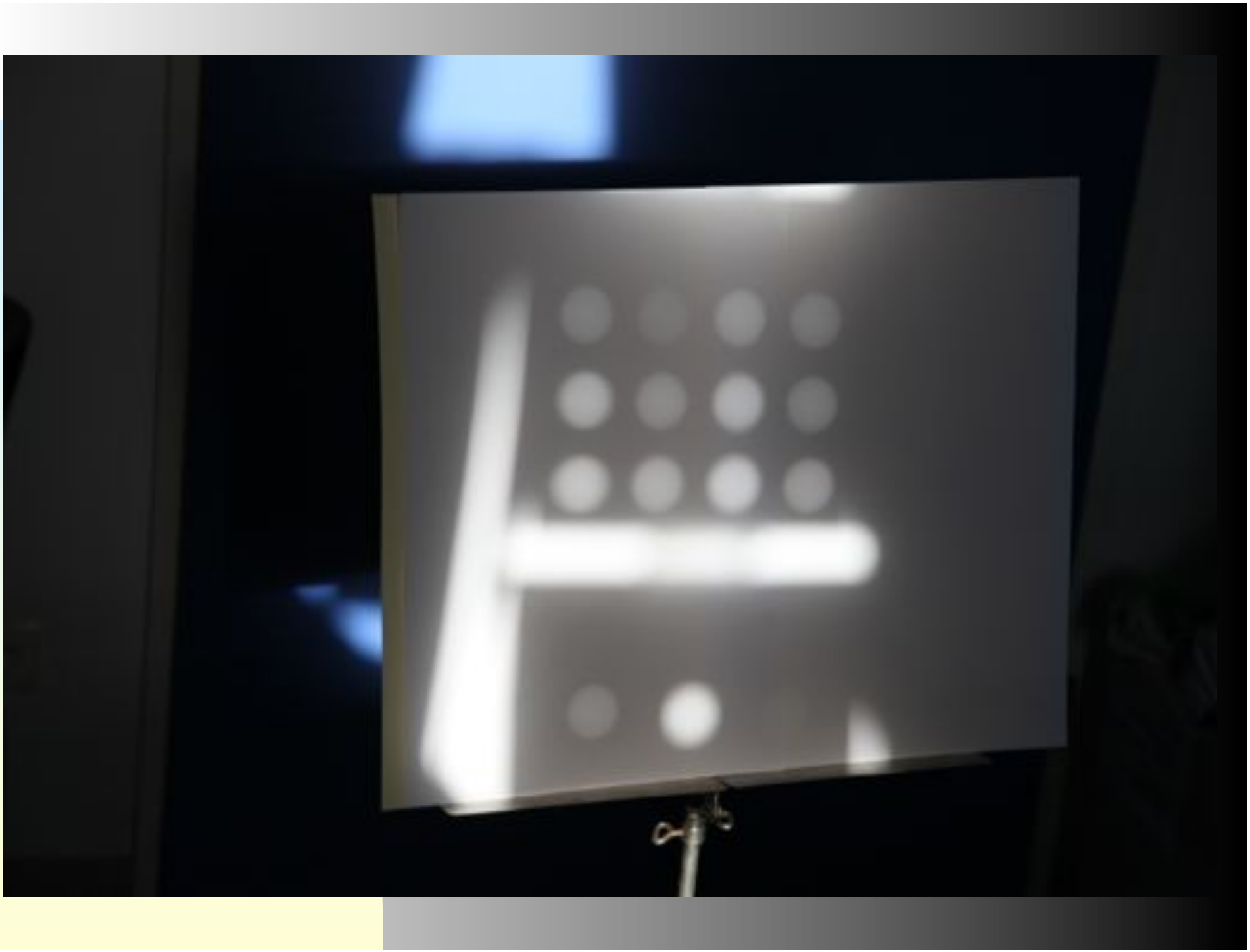
$$I(\xi,\eta) = \iint Heart(\xi',\eta')\, Solar\, disk(\xi-\xi',\eta-\eta')\, d\xi' d\eta'$$

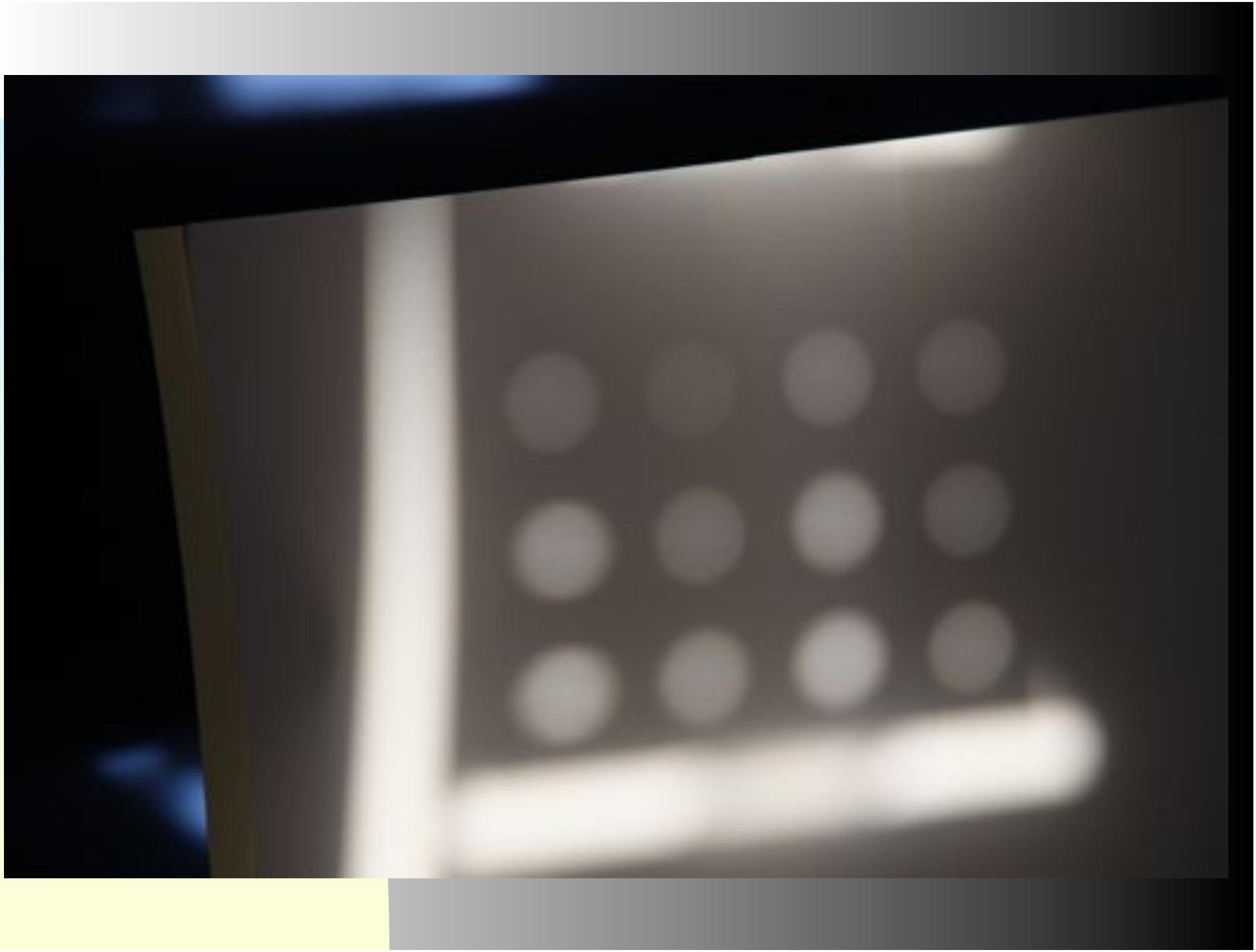
$$I(\xi,\eta) = \iint Solar\, disk(\xi',\eta')\, Heart(\xi-\xi',\eta-\eta')\, d\xi' d\eta'$$



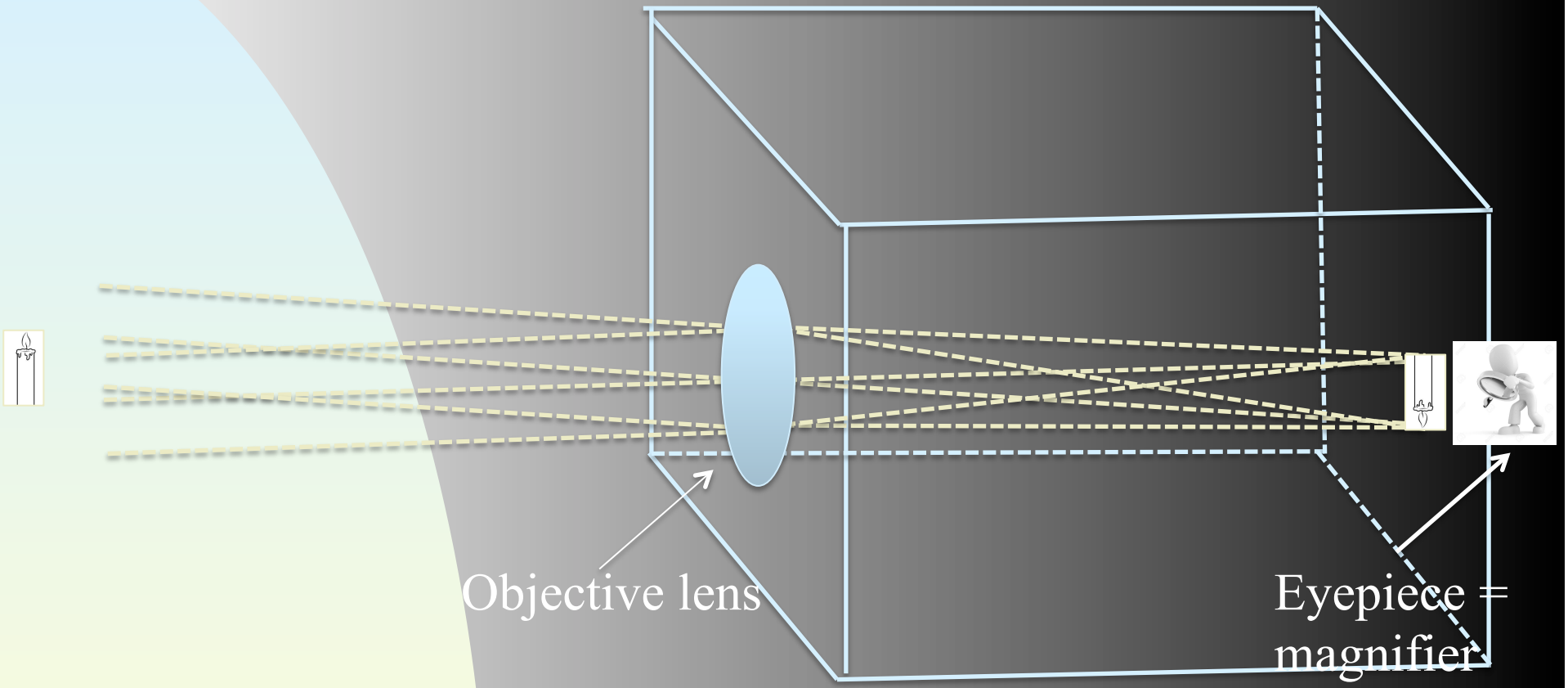








Camera obscura



Pinhole camera

9 Fourier Optical Elements

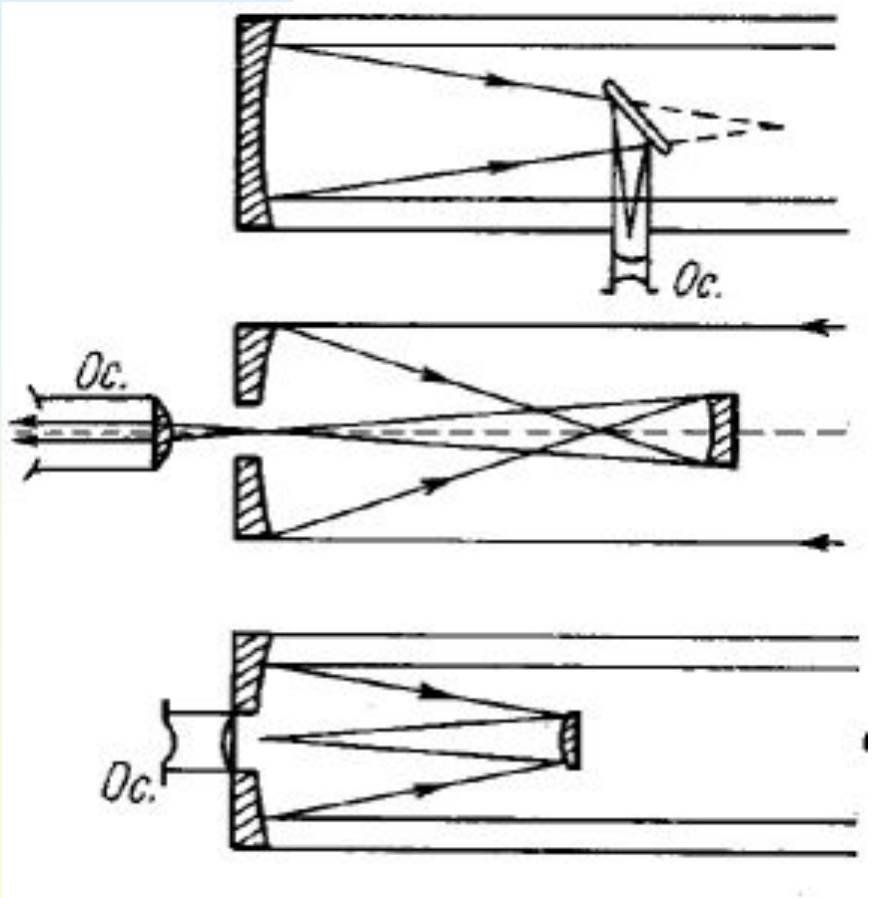
9.3 Telescope applications

- **9.3.1 Optical telescopes**
- **9.3.2 Coupled telescopes**
- **9.3.3 X-ray telescopes**
- **9.3.4 Radio-telescopes and radio-interferometers**

9 Fourier Optical Elements

9.3 Telescope applications

9.3.1 Optical telescopes



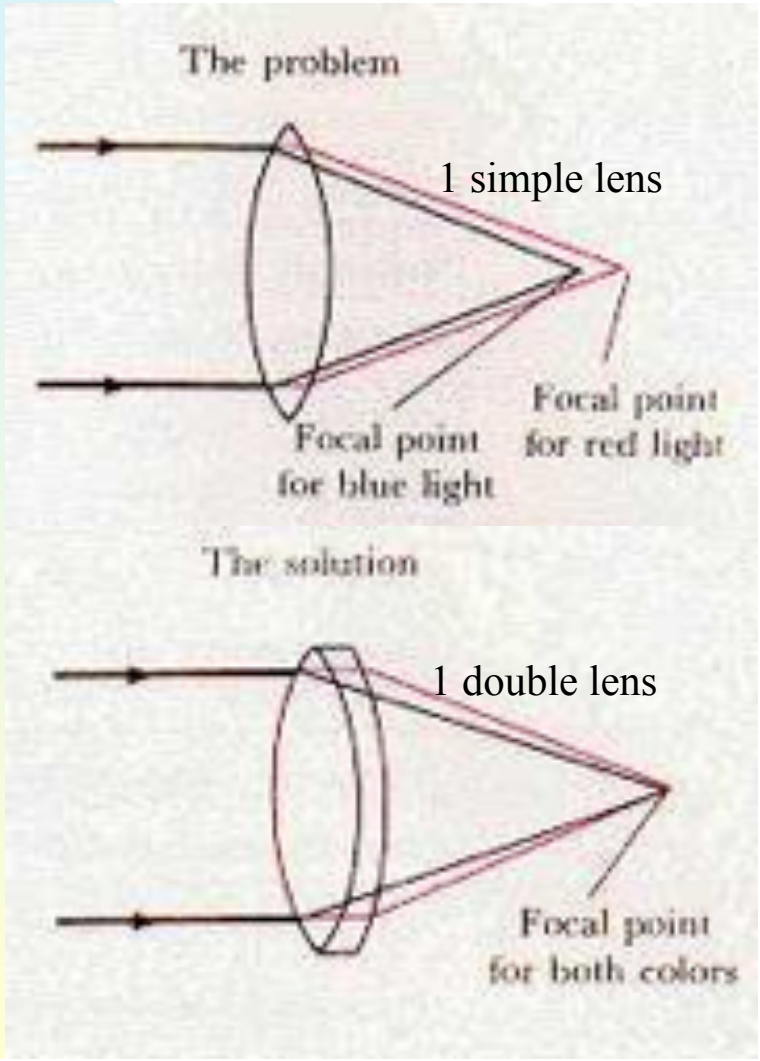
(a)

(b)

9 Fourier Optical Elements

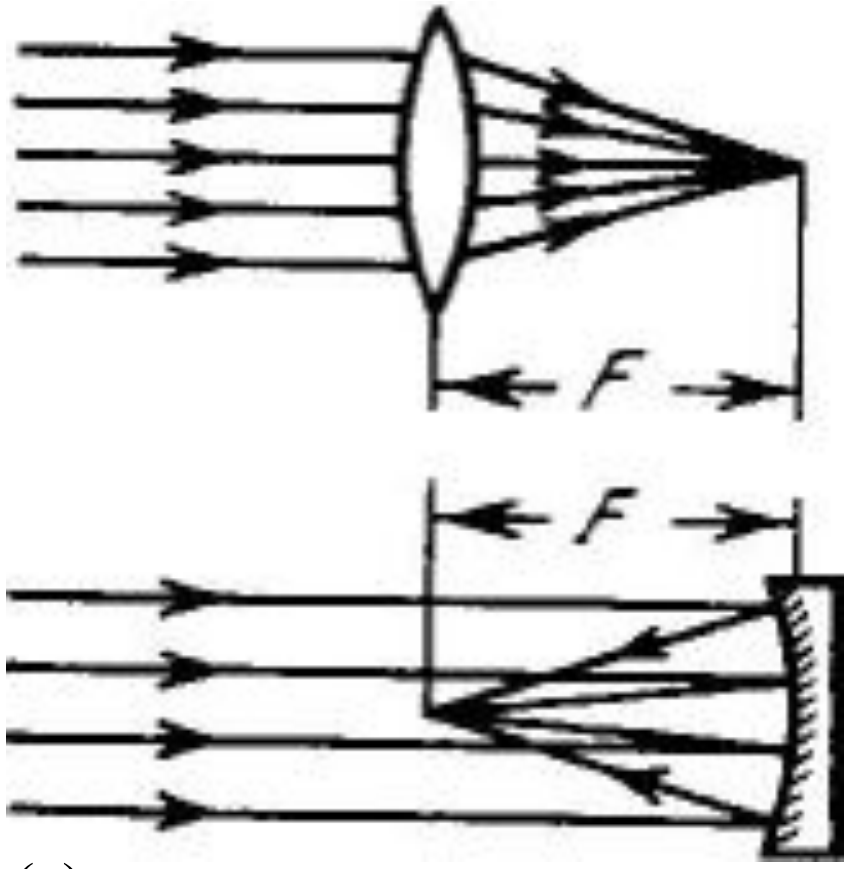
9.3 Telescope applications

9.3.1 Optical telescopes



(a)

(b)

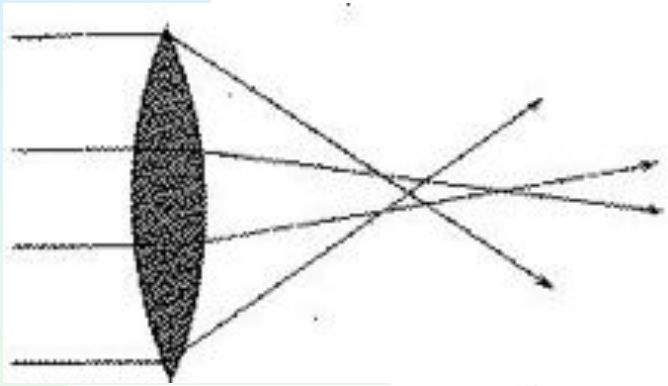


(c)

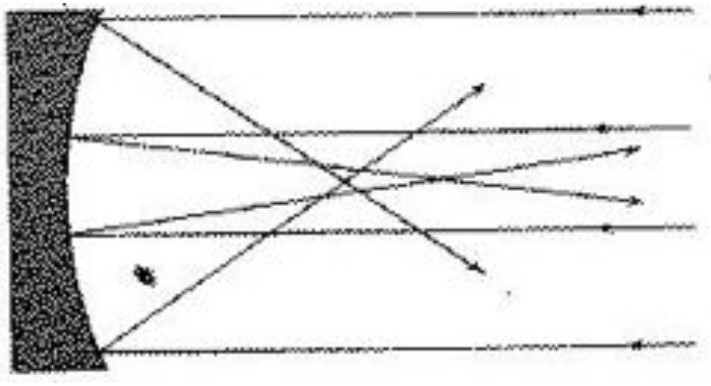
9 Fourier Optical Elements

9.3 Telescope applications

9.3.1 Optical telescopes



(a)



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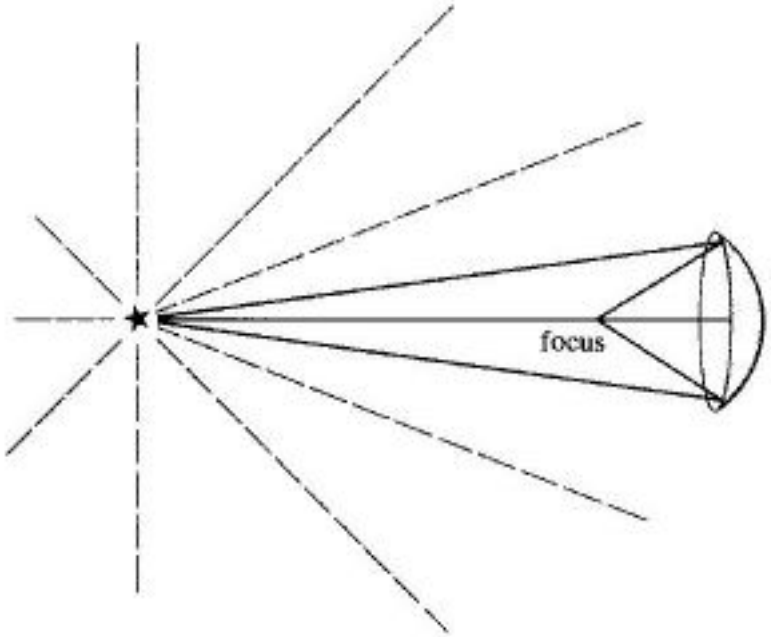

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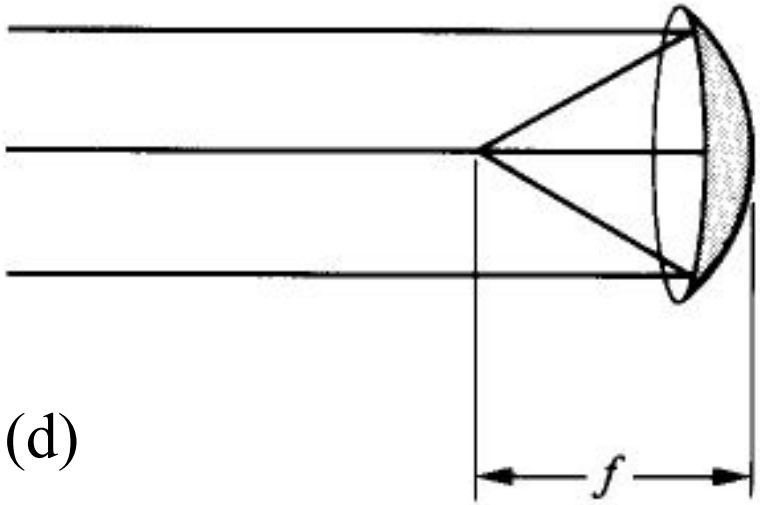


(d)

9 Fourier Optical Elements

9.3 Telescope applications

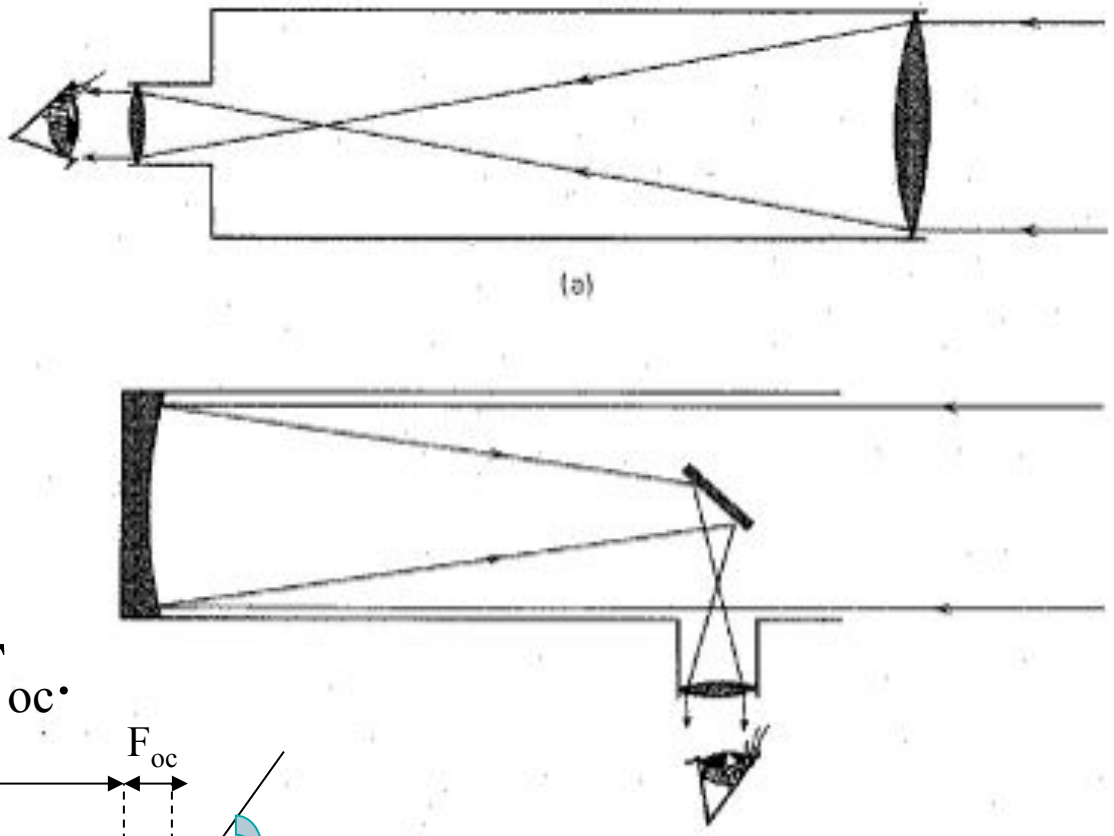
9.3.1 Optical telescopes

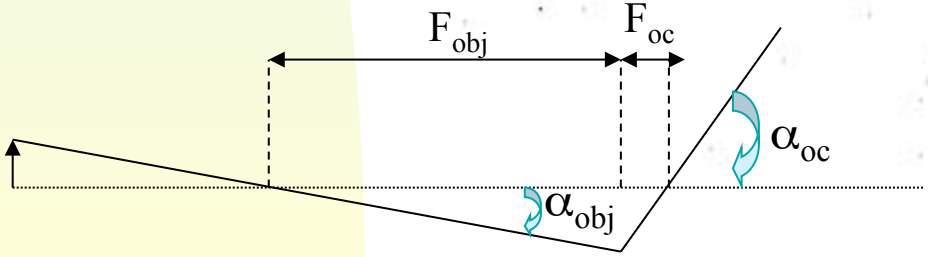
$$\phi = E\,S = \pi\,D^2\,E\,/\,4,$$

$$f = F\,/\,D,$$

$$E' \sim f^{-2}.$$

$$G = \alpha_{oc}\,/\,\alpha_{obj} = F_{obj}\,/\,F_{oc}.$$





9 Fourier Optical Elements

9.3 Telescope applications

9.3.1 Optical telescopes

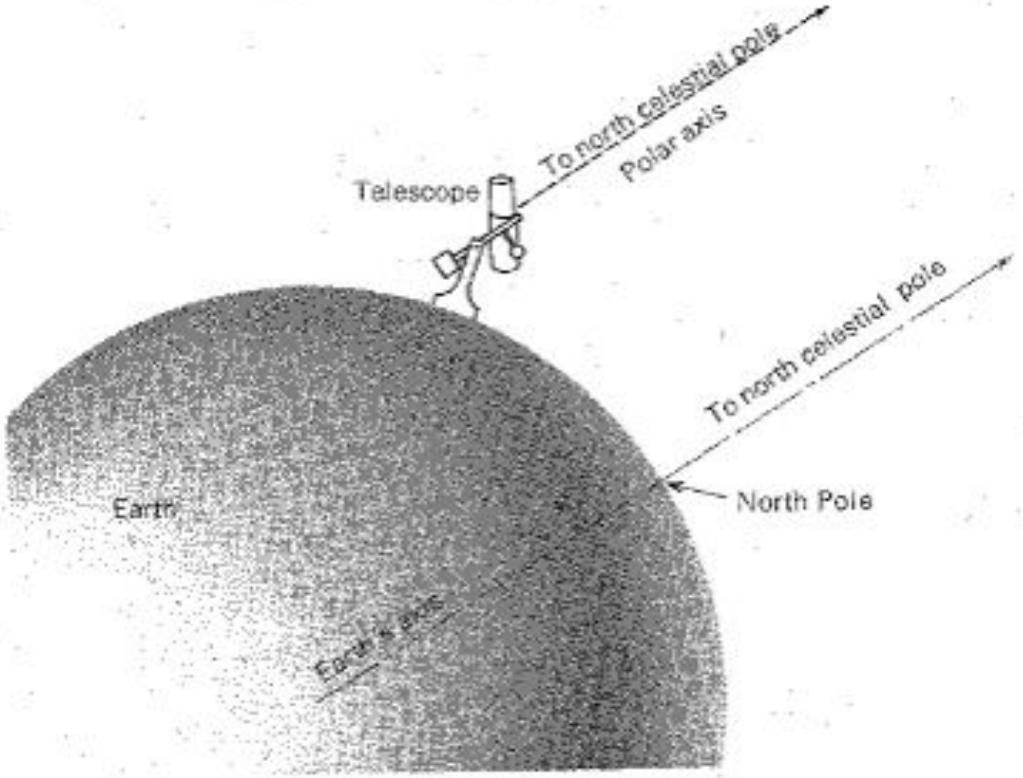
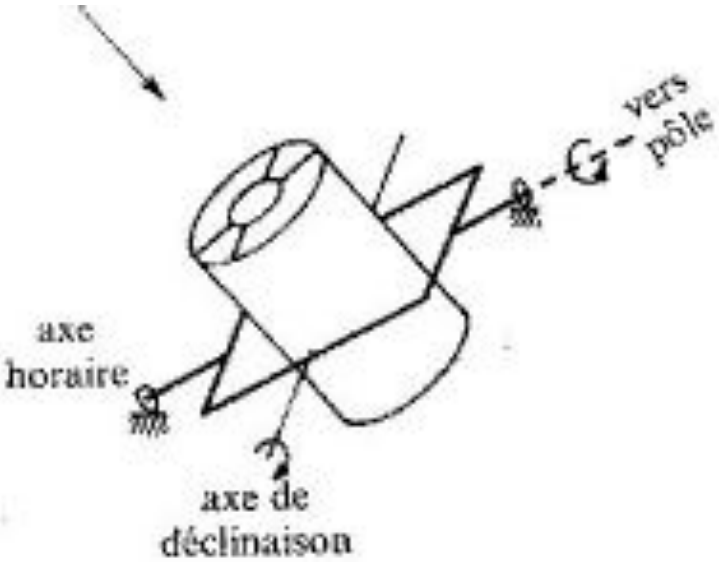
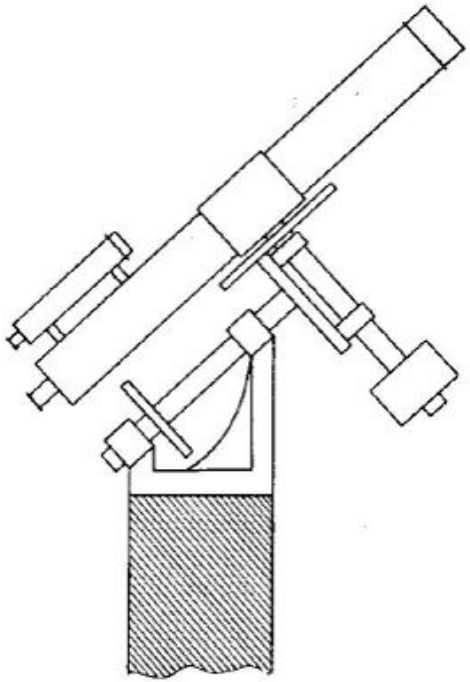


FIGURE 12.14 Equatorial mount.

(a)



(b)

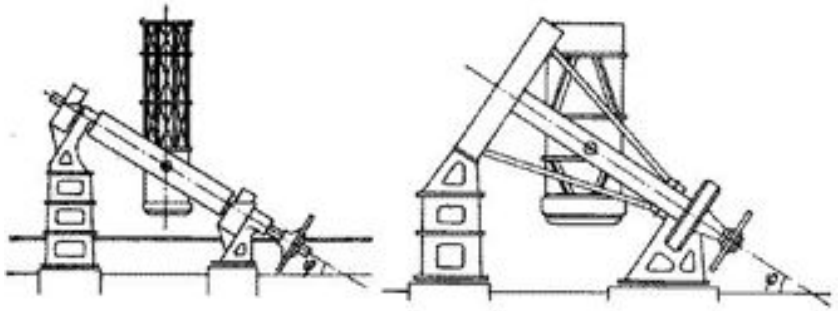


(c)

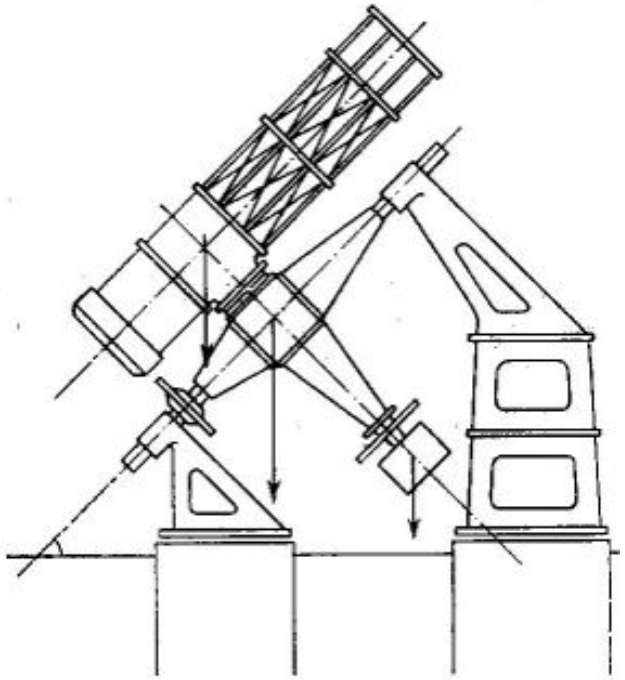
9 Fourier Optical Elements

9.3 Telescope applications

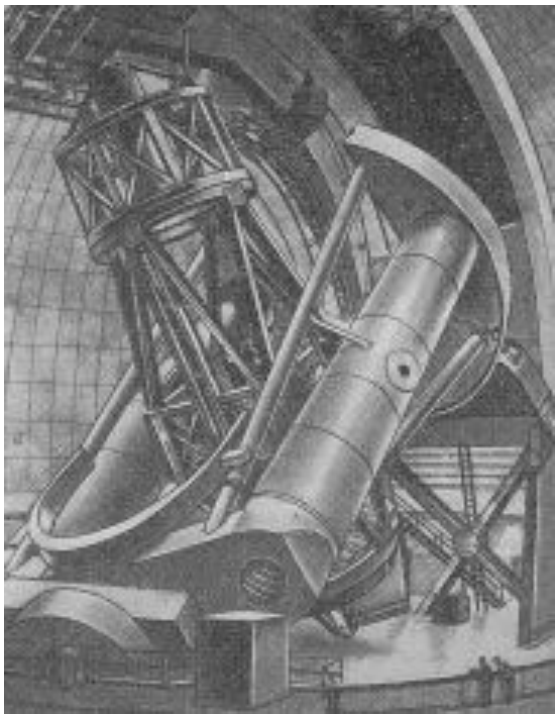
9.3.1 Optical telescopes



(b) (c)



(a)



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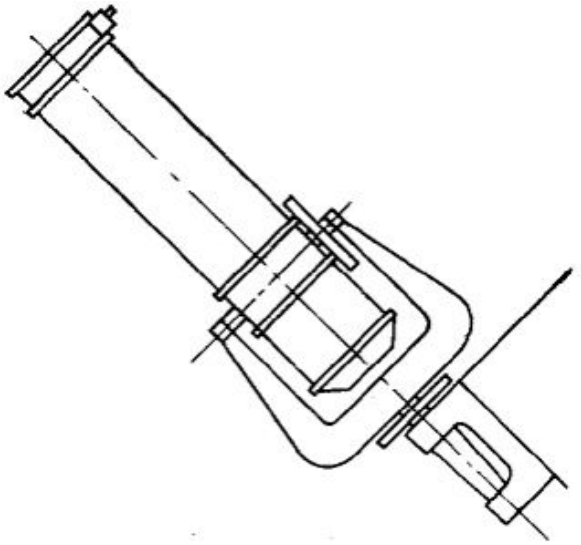
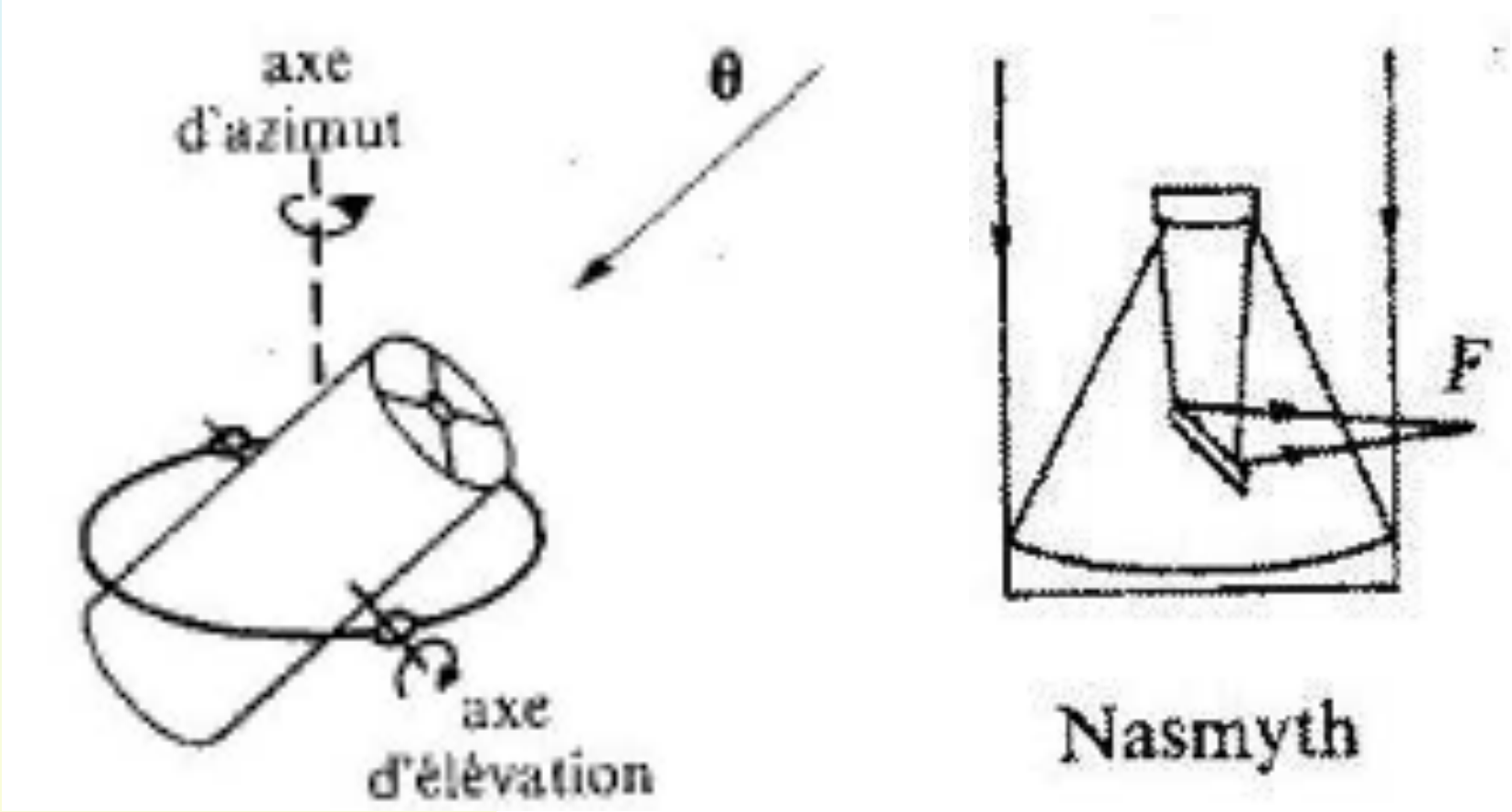


(e)

9 Fourier Optical Elements

9.3 Telescope applications

9.3.1 Optical telescopes

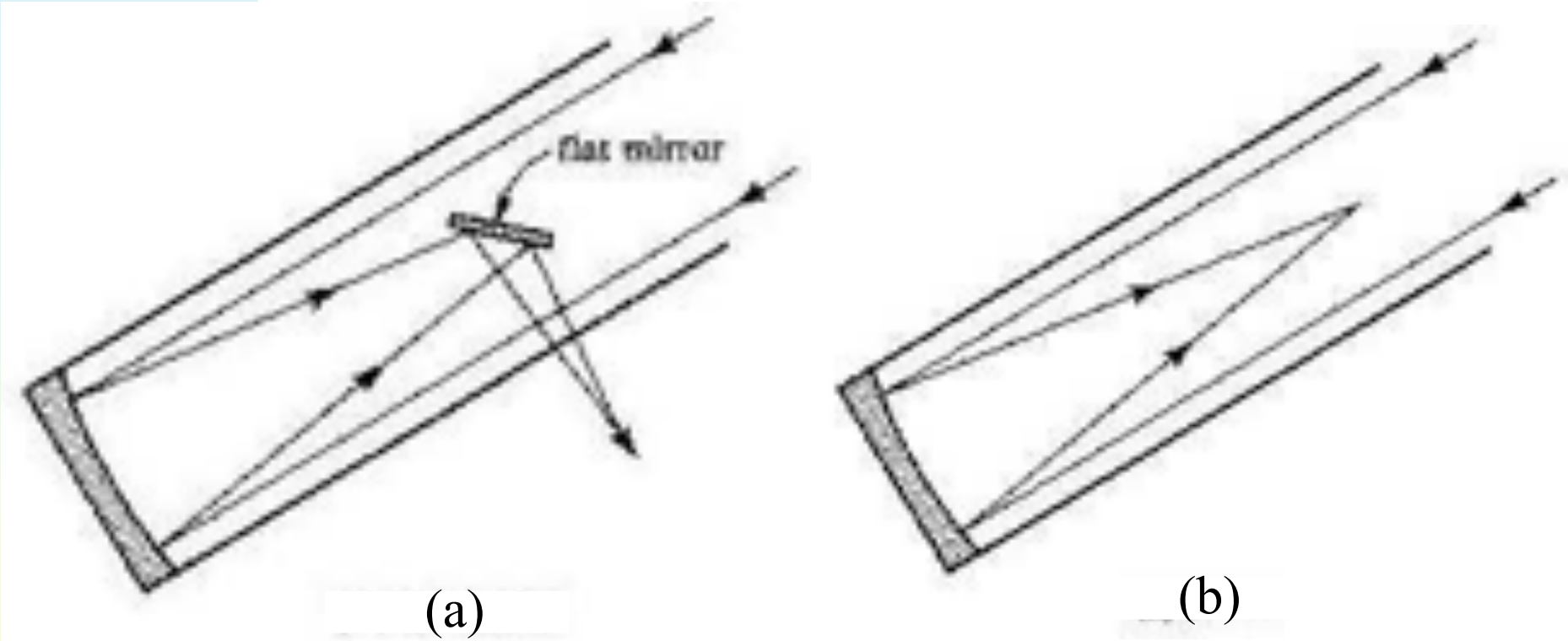


(a) (b)

9 Fourier Optical Elements

9.3 Telescope applications

9.3.1 Optical telescopes

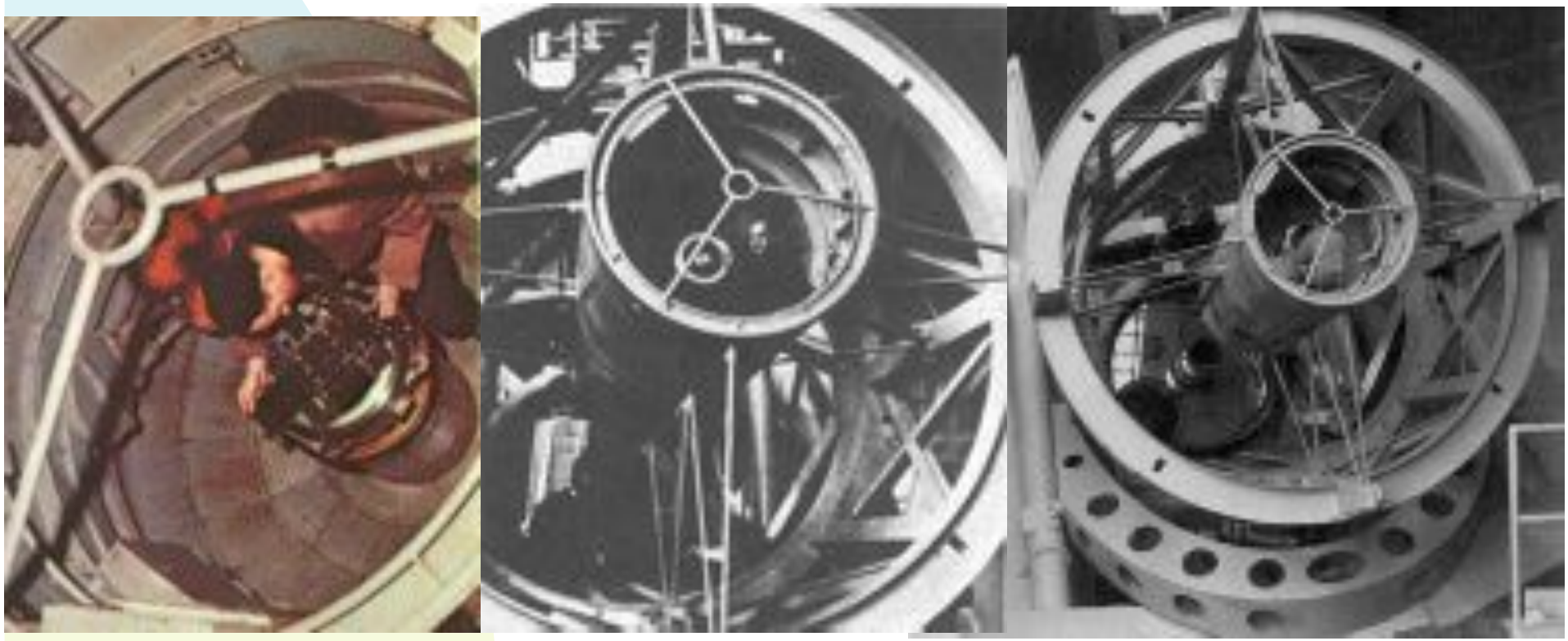


Newton focus (a) and Primary focus (b) of optical telescopes

9 Fourier Optical Elements

9.3 Telescope applications

9.3.1 Optical telescopes



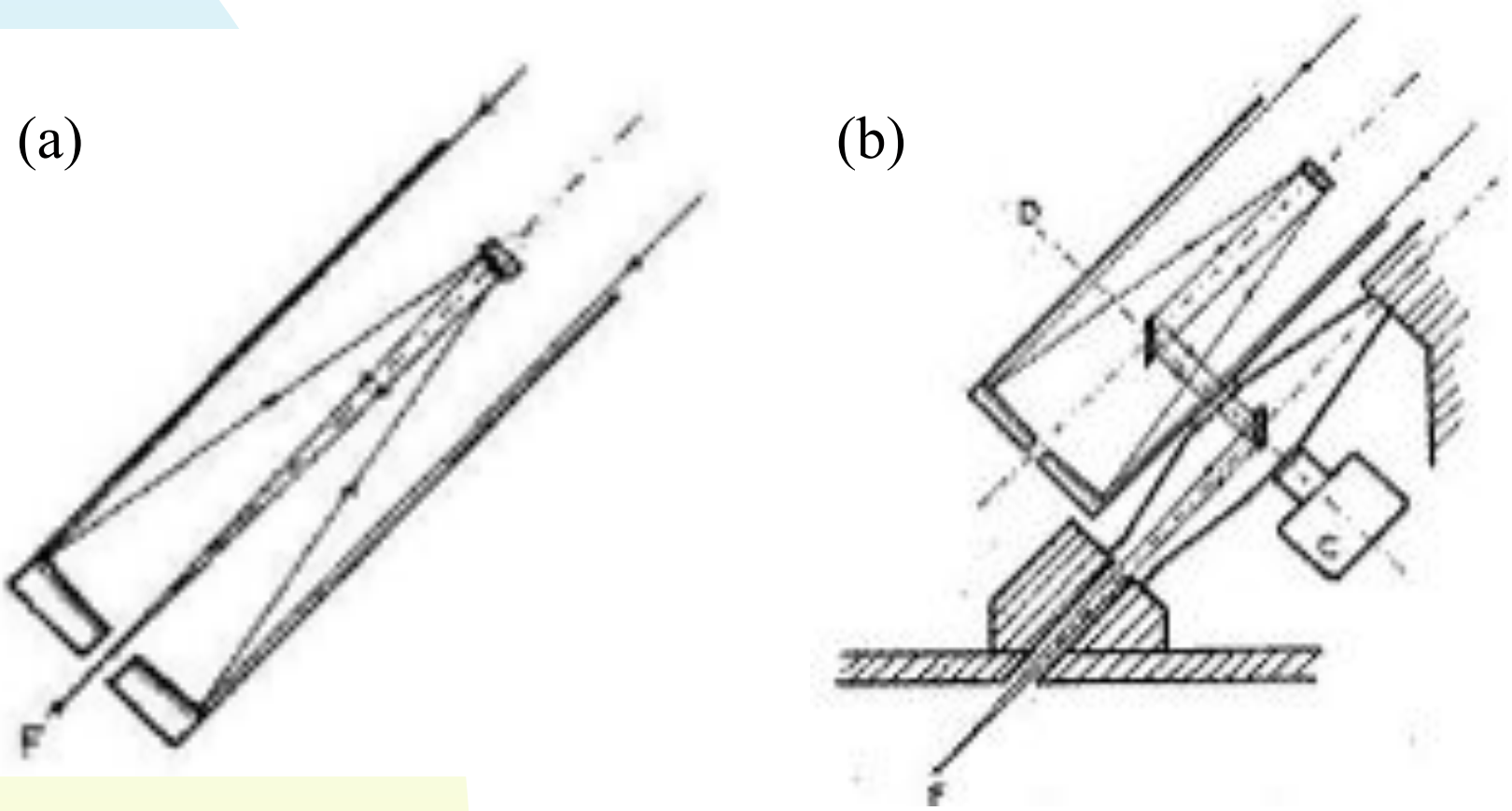
(a) (b) (c)

Observers in the Prime focus cage

9 Fourier Optical Elements

9.3 Telescope applications

9.3.1 Optical telescopes



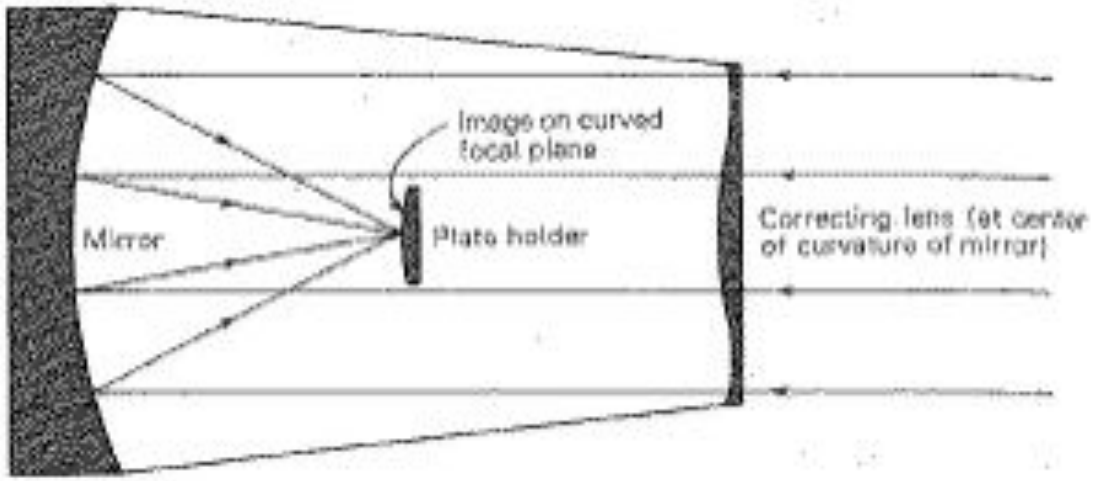
(a) Cassegrain, Ritchey-Chrétien or Strand foci of an optical telescope and
(b) Coudé focus

9 Fourier Optical Elements

9.3 Telescope applications

9.3.1 Optical telescopes

(a)



(b)

(a) Optical components of a Schmidt telescope and
(b) big Schmidt telescope of Mont Palomar

9 Fourier Optical Elements

9.3 Telescope applications

9.3.1 Optical telescopes

ESO VLT (Paranal, Chile)

See the URL:
http://www.eso.org

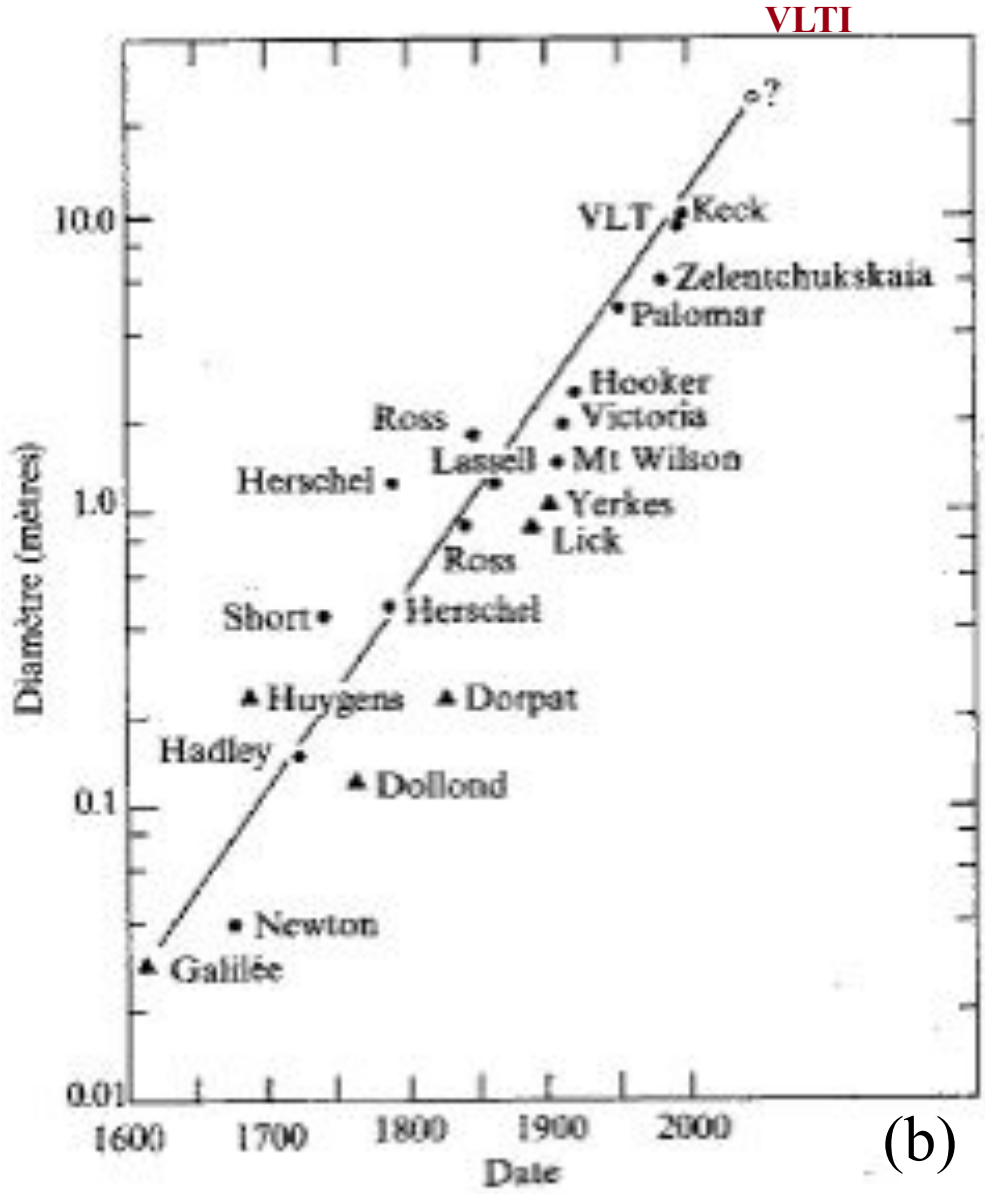
9 Fourier Optical Elements

9.3 Telescope applications

9.3.1 Optical telescopes

http://www.stsci.edu/

(a)



(b)

9 Fourier Optical Elements

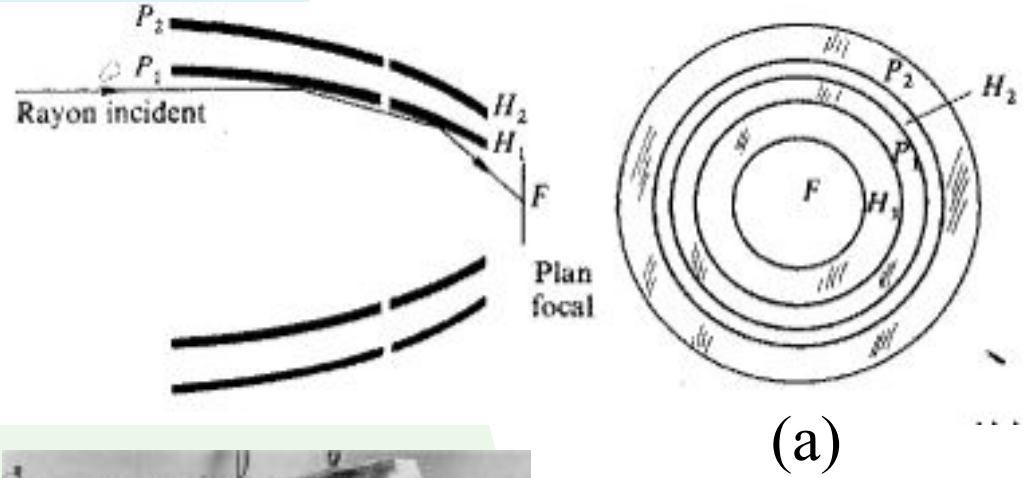
9.3 Telescope applications

- **9.3.1 Optical telescopes**
- **9.3.2 Coupled telescopes**
- **9.3.3 X-ray telescopes**
- **9.3.4 Radio-telescopes and radio-interferometers**

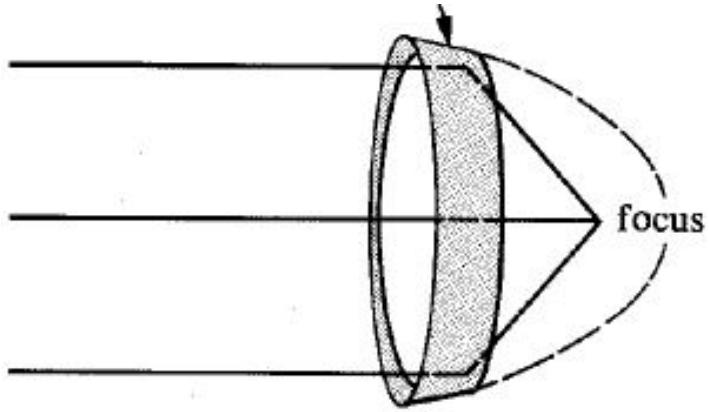
9 Fourier Optical Elements

9.3 Telescope applications

9.3.3 X-ray telescopes

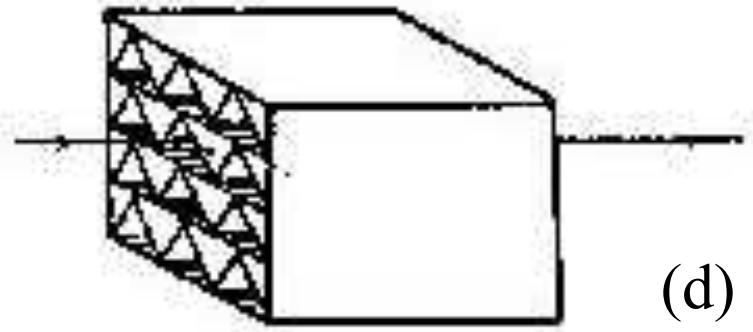


(a)



(b)

(c)



(d)

(a) X-ray telescope with double grazing reflection (P: paraboloid; H: hyperboloid); (b) simple paraboloid; (c) X-ray mirror of the Einstein satellite and (d) Cellular collimator.

9 Fourier Optical Elements

9.3 Telescope applications

9.3.3 X-ray telescopes

(a)

(b)

(c)

9 Fourier Optical Elements

9.3 Telescope applications

9.3.3 X-ray telescopes

(a)

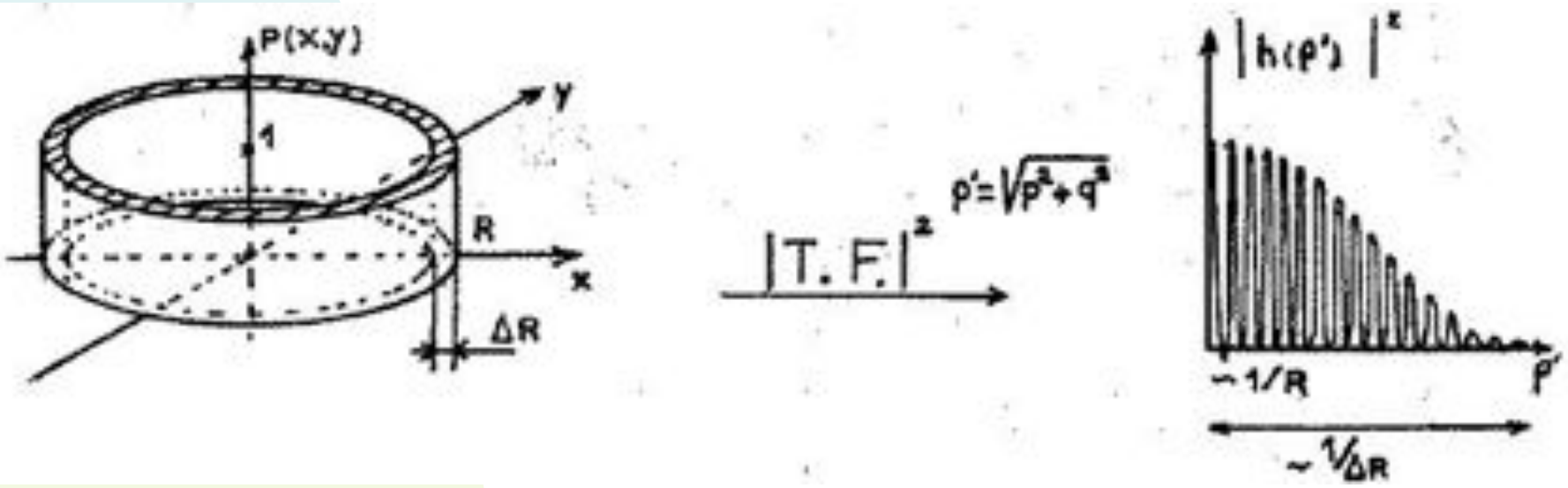
(b)

See the URLs: http://sci.esa.int/xmm/ and http://xmm.vilspa.esa.es/

9 Fourier Optical Elements

9.3 Telescope applications

9.3.3 X-ray telescopes

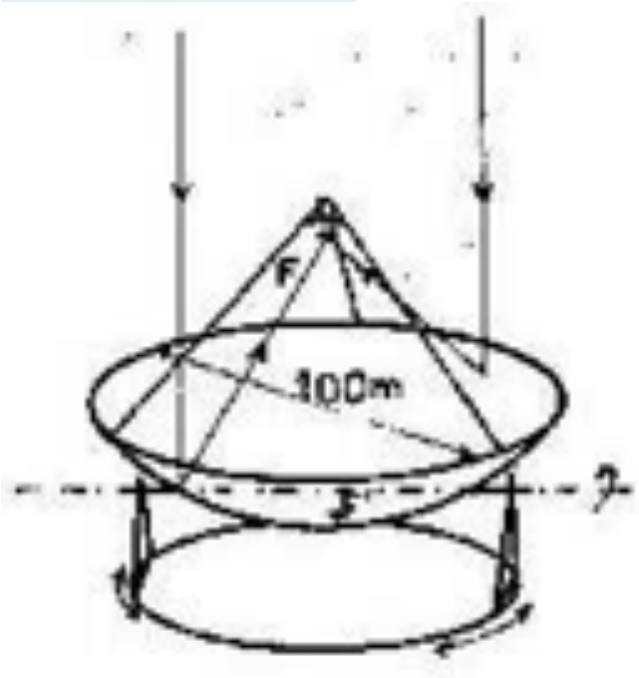


Entrance pupil P(x,y) and response function $|h(\rho')|^2$ for an X-ray telescope (grazing light ray incidence).

9 Fourier Optical Elements

9.3 Telescope applications

9.3.4 Radio-telescopes and radio-interferometers



(a)

(b)

(c)

(a) Effelsberg radio-telescope (F: primary focus; F': Gregory focus).
(b) and (c) Photographs

9 Fourier Optical Elements

9.3 Telescope applications

9.3.4 Radio-telescopes and radio-interferometers

The Green Bank 300ft (West Virginia) … before and after 15/11/1988!

9 Fourier Optical Elements

9.3 Telescope applications

9.3.4 Radio-telescopes and radio-interferometers

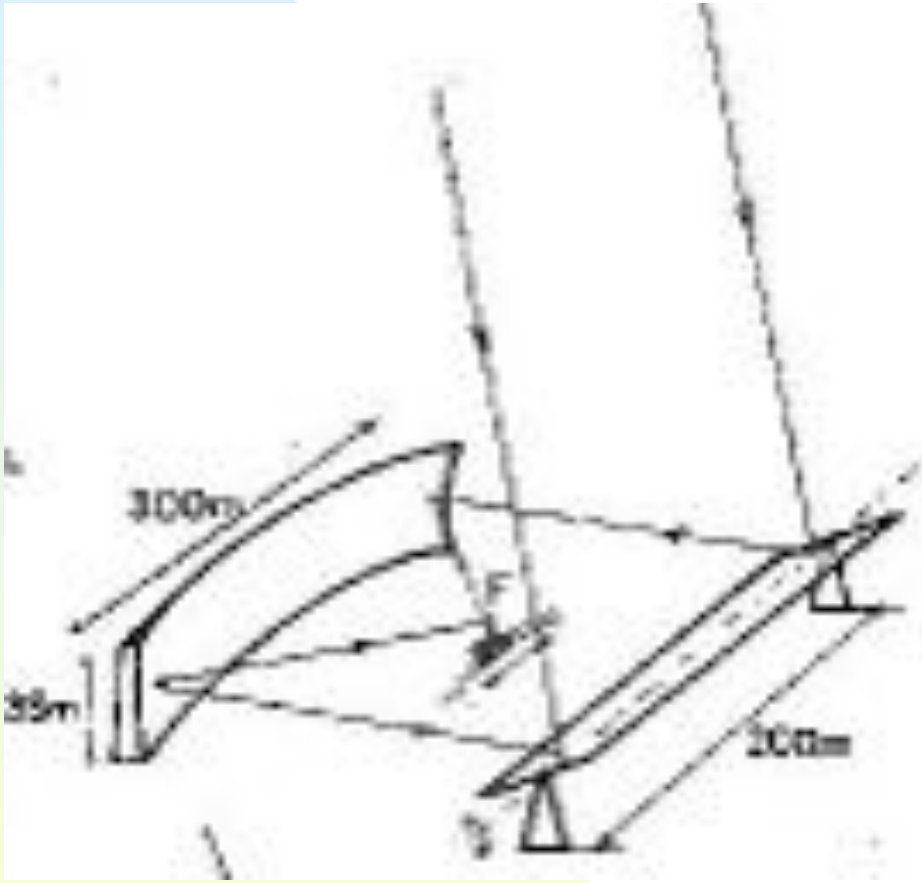
(a) (b) (c)

(a), (b) and (c) : Photographs of the new Green Bank radio-telescope

9 Fourier Optical Elements

9.3 Telescope applications

9.3.4 Radio-telescopes and radio-interferometers



(a)

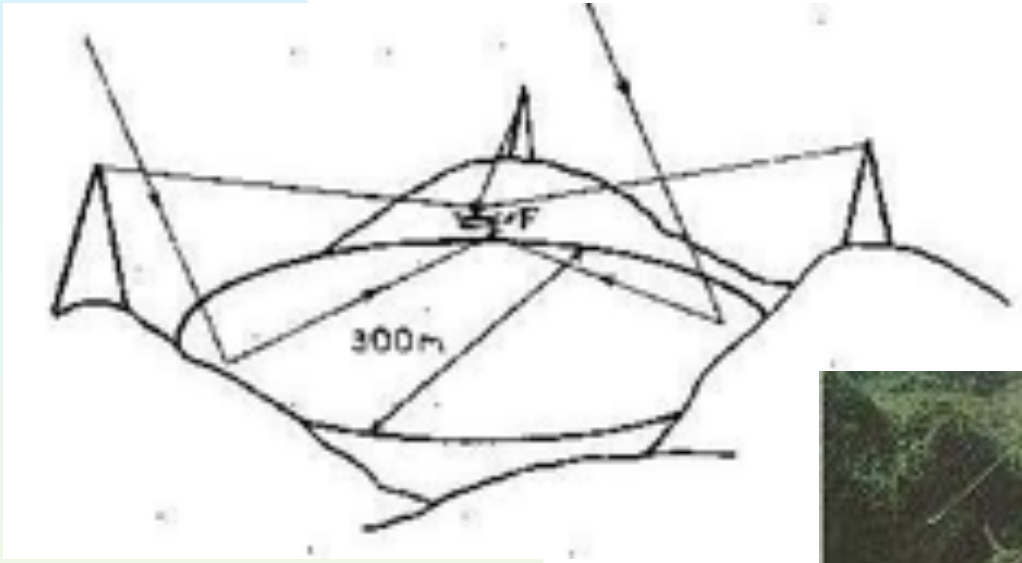
(b)

(a) Nançay radio-telescope

9 Fourier Optical Elements

9.3 Telescope applications

9.3.4 Radio-telescopes and radio-interferometers



Arecibo radio-telescope

9 Fourier Optical Elements

9.3 Telescope applications

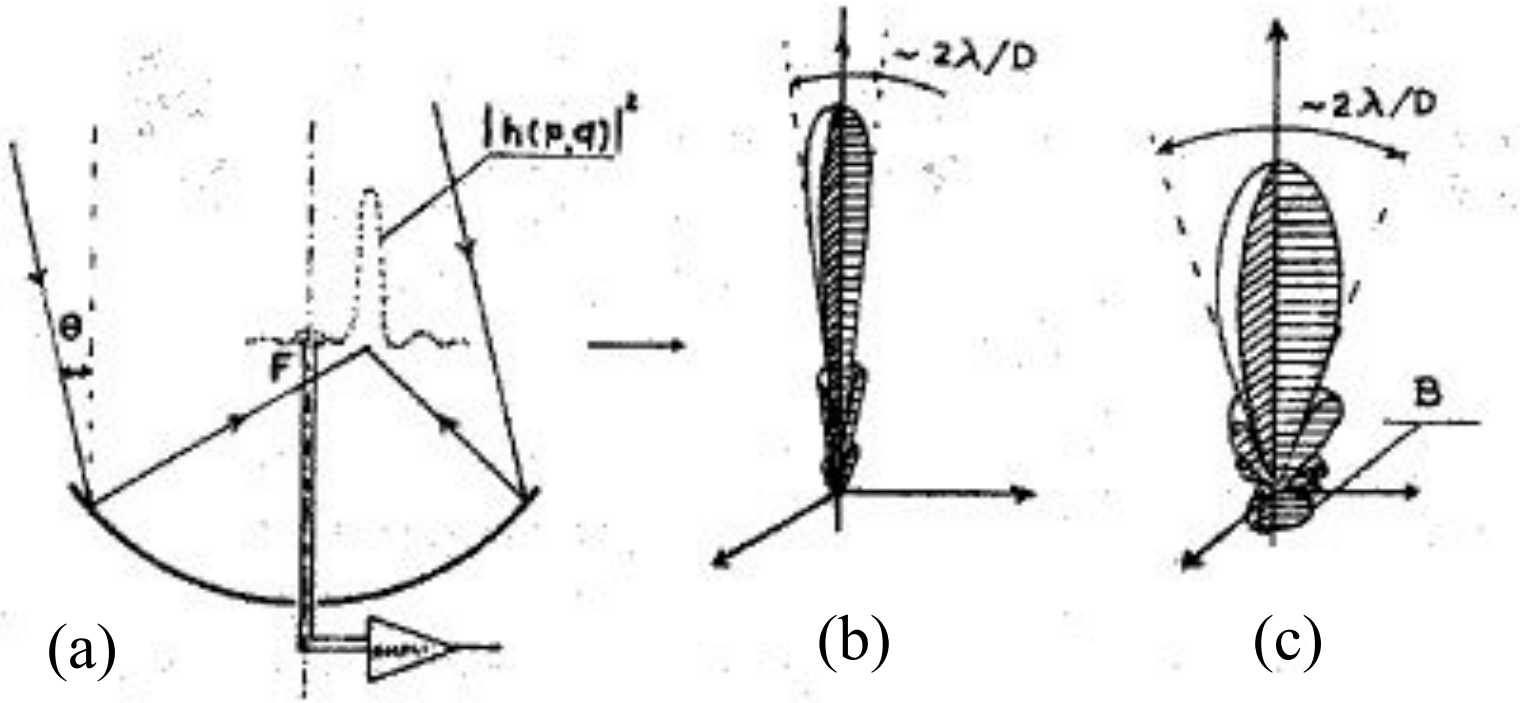
9.3.4 Radio-telescopes and radio-interferometers

The 500-metre aperture spherical telescope (FAST) in China's Pingtang county.

9 Fourier Optical Elements

9.3 Telescope applications

9.3.4 Radio-telescopes and radio-interferometers

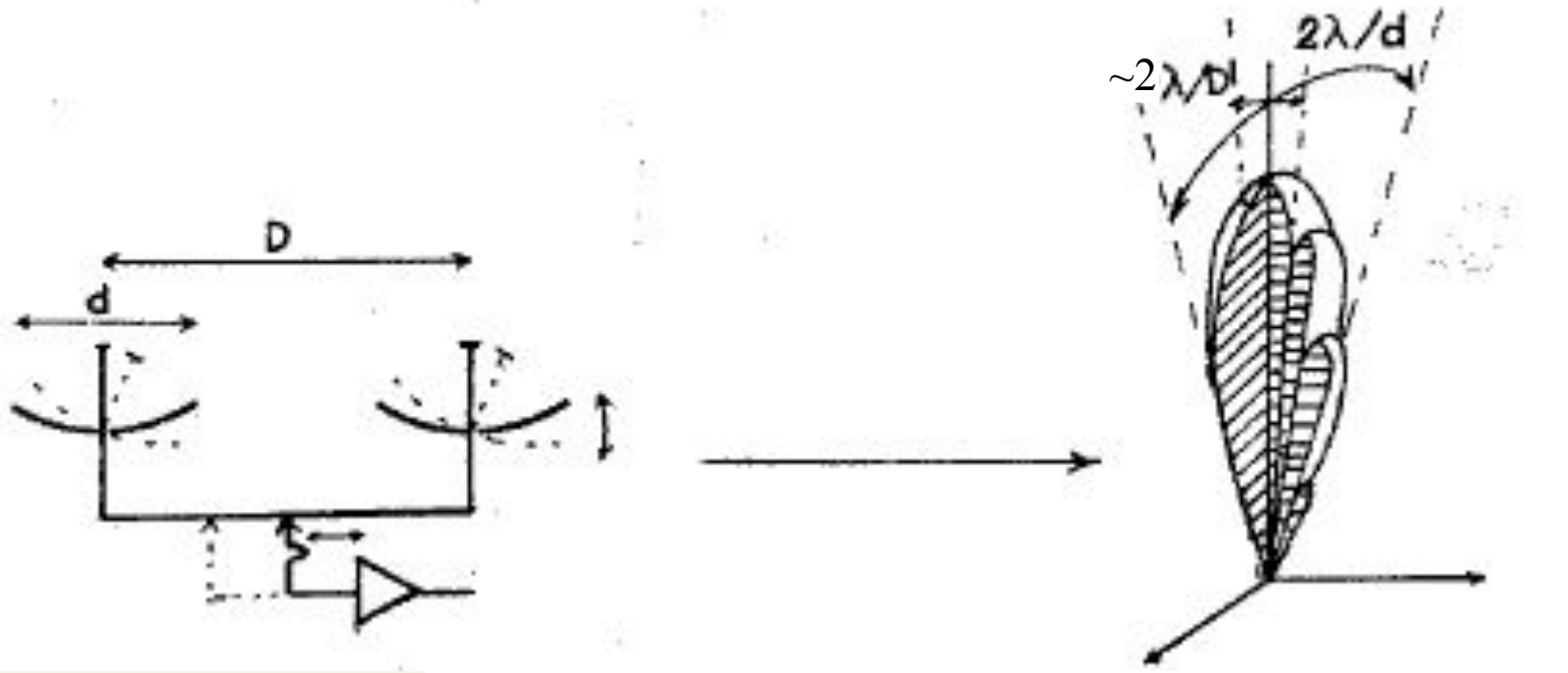


Antenna diagram of a radio-telescope. (a) Excitation of the antenna for a point-like object inclined by an angle θ with respect to the central axis; (b) sensitivity of the mirror + antenna in polar coordinates (or graph of the response function in polar coordinates assuming that the antenna is point-like; (c) real diagram corresponding to $\lambda / D \sim 1 / 10$ and showing the back-side lobe B.

9 Fourier Optical Elements

9.3 Telescope applications

9.3.4 Radio-telescopes and radio-interferometers



(a) (b)

Radio-interferometer: (a) Connection diagram; (b) Antenna diagram (graph in polar coordinates of the response function).

9 Fourier Optical Elements

9.3 Telescope applications

9.3.4 Radio-telescopes and radio-interferometers

$$e(p) = 2d^2 \left(\frac{\sin(\pi pd)}{\pi pd} \right)^2 \left[O(p) * \cos^2(\pi pD) \right], \tag{9.3.10}$$

$$e(p) = 2d^2 \left(\frac{\sin(\pi pd)}{\pi pd} \right)^2 \left[\frac{1}{2} \int_R O(p)dp + \frac{1}{2} O(p) * \cos(2\pi pD) \right], \tag{9.3.11}$$

$$e(p) = A \left[B + \frac{1}{2} \mathrm{Re}\left(O(p) * \exp(2i\pi pD) \right) \right], \tag{9.3.12}$$

$$A = 2d^2 \left(\frac{\sin(\pi pd)}{\pi pd} \right)^2 \quad \textit{and} \quad B = \frac{1}{2} \int_R O(p)\,dp, \tag{9.3.13}$$

9 Fourier Optical Elements

9.3 Telescope applications

9.3.4 Radio-telescopes and radio-interferometers

$$e(p) = A\left[B + \frac{1}{2}\mathrm{Re}\left(\int_R O(r)\exp\left(2i\pi(p-r)D\right)dr\right)\right], \tag{9.3.14}$$

$$e(p) = A\left[B + \frac{1}{2}\cos(2\pi pD)TF\_(O(r))(D)\right], \tag{9.3.15}$$

$$\gamma(D) = (e_{max} - e_{min}) / (e_{max} + e_{min}), \tag{9.3.16}$$

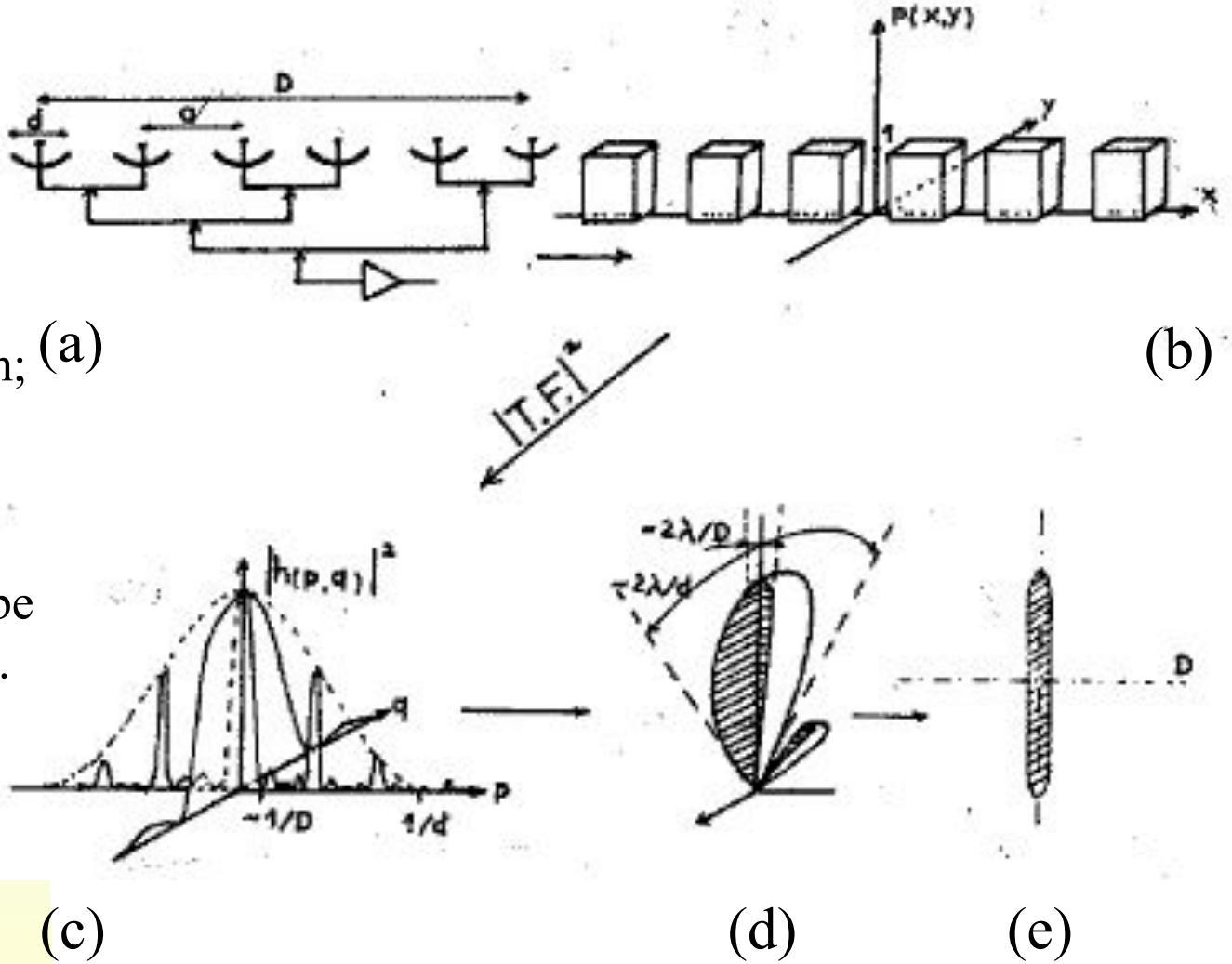
$$\gamma(D) = TF\_(O(r))(D) / (2B) = TF\_(O(r))(D) / \int O(p)\, dp. \tag{9.3.17}$$

9 Fourier Optical Elements

9.3 Telescope applications

9.3.4 Radio-telescopes and radio-interferometers

Radio-telescope interferometer
(a) Connection diagram;
(b) Entrance pupil;
(c) Response function;
(d) Antenna diagram;
(e) Trace of the main lobe over the celestial sphere.



9 Fourier Optical Elements

9.3 Telescope applications

9.3.4 Radio-telescopes and radio-interferometers

$$P_{r,0}(x,y) = \Pi\left[\frac{y}{d}\right] \sum_{n=0}^{N-1} \Pi\left[\frac{x + (N-1)\frac{a}{2} - na}{d}\right], \tag{9.3.18}$$

$$h_{r,0}(p,q) = \int_{-d/2}^{d/2} \exp(-i2\pi qy)dy \sum_{n=0}^{N-1} \int_{\frac{-d}{2}-(N-1)\frac{a}{2}+na}^{\frac{d}{2}-(N-1)\frac{a}{2}+na} \exp(-i2\pi px)dx, \tag{9.3.19}$$

$$h_{r,0}(p,q) = d\frac{\sin(\pi qd)}{\pi qd} \sum_{n=0}^{N-1} \int_{\frac{-d}{2}-(N-1)\frac{a}{2}+na}^{\frac{d}{2}-(N-1)\frac{a}{2}+na} \exp(-i2\pi px)dx, \tag{9.3.20}$$

$$h_{r,0}(p,q) = d\frac{\sin(\pi qd)}{\pi qd} \sum_{n=0}^{N-1} \frac{\exp\left(i\pi p\left(-d + (N-1)a - 2na\right)\right) - \exp\left(i\pi p\left(d + (N-1)a - 2na\right)\right)}{-2i\pi p}, \tag{9.3.21}$$

9 Fourier Optical Elements

9.3 Telescope applications

9.3.4 Radio-telescopes and radio-interferometers

$$h_{r,0}(p,q) = d^2 \left(\frac{\sin(\pi qd)}{\pi qd}\right)\left(\frac{\sin(\pi pd)}{\pi pd}\right)\exp\left(i\pi pa(N-1)\right) \sum_{n=0}^{N-1}\exp\left(-2i\pi pan\right) \quad (9.3.22)$$

$$x = i\pi ap \text{ and } r = \exp(-2x)\ , \quad (9.3.23)$$

$$h_{r,0}(p,q) = d^2 \left(\frac{\sin(\pi qd)}{\pi qd}\right)\left(\frac{\sin(\pi pd)}{\pi pd}\right)\exp\left(x(N-1)\right) \frac{1-\exp(-2xN)}{1-\exp(-2x)}\ , \quad (9.3.24)$$

$$h_{r,0}(p,q) = d^2 \left(\frac{\sin(\pi qd)}{\pi qd}\right)\left(\frac{\sin(\pi pd)}{\pi pd}\right)\frac{\exp(xN)-\exp(-xN)}{\exp(x)-\exp(-x)}\ , \quad (9.3.25)$$

$$h_{r,0}(p,q) = d^2 \left(\frac{\sin(\pi qd)}{\pi qd}\right)\left(\frac{\sin(\pi pd)}{\pi pd}\right)\left(\frac{\sin(N\pi pa)}{\sin(\pi pa)}\right) \quad (9.3.26)$$

9 Fourier Optical Elements

9.3 Telescope applications

9.3.4 Radio-telescopes and radio-interferometers

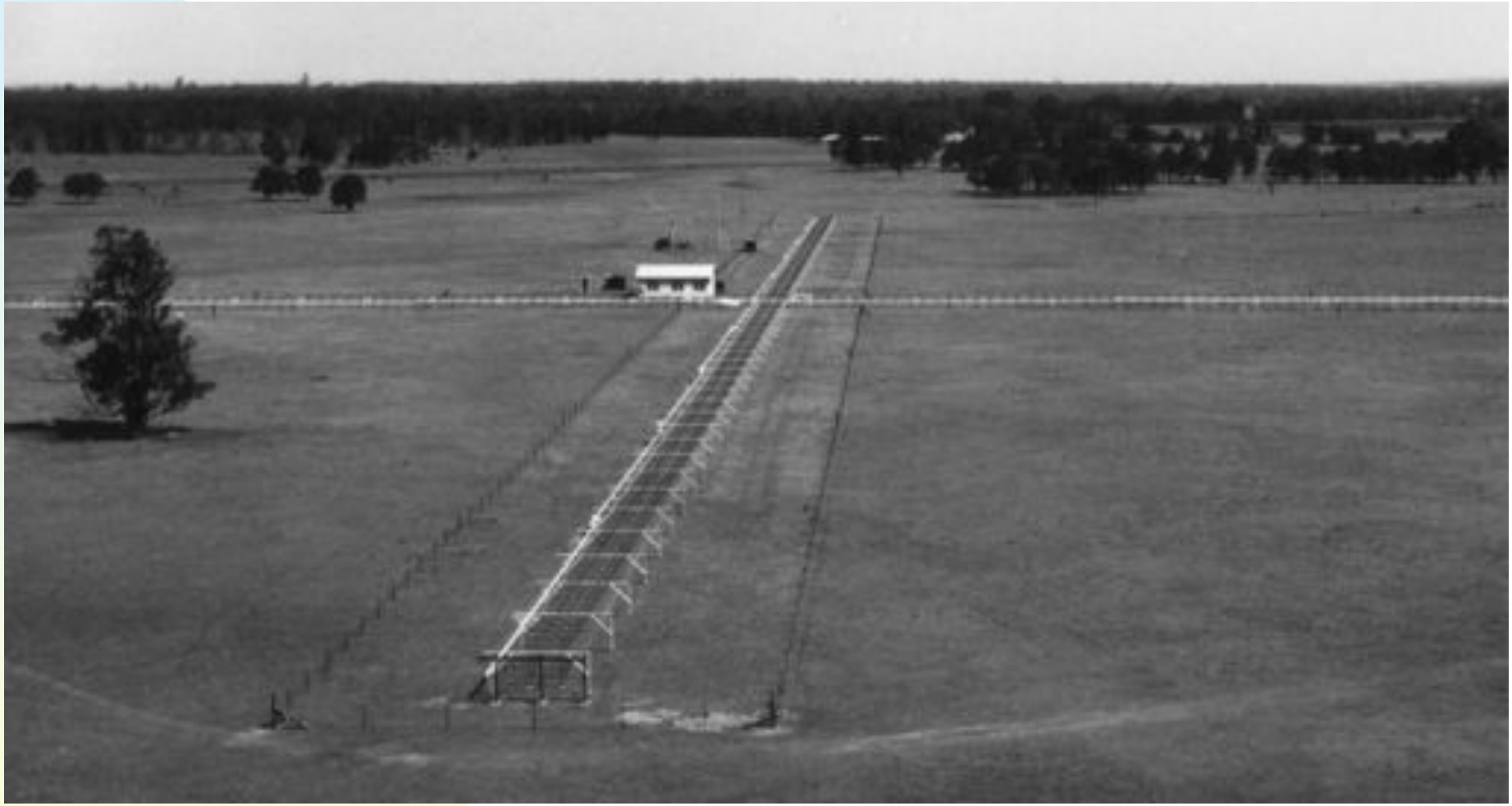
(9.3.27)

$$\left|h_{r,0}(p,q)\right|^2 = (N d^2)^2 \underbrace{\left(\frac{\sin(\pi q d)}{\pi q d}\right)^2 \left(\frac{\sin(\pi p d)}{\pi p d}\right)^2}_{\text{Response function of a single aperture}} \underbrace{\left(\frac{\sin(N\pi p a)}{N\pi p a}\right)^2}_{\text{Central peak}} \underbrace{\left(\frac{\pi p a}{\sin(\pi p a)}\right)^2}_{\text{+ intermediate peaks}}.$$

N apertures!

9 Fourier Optical Elements

9.3 Telescope applications

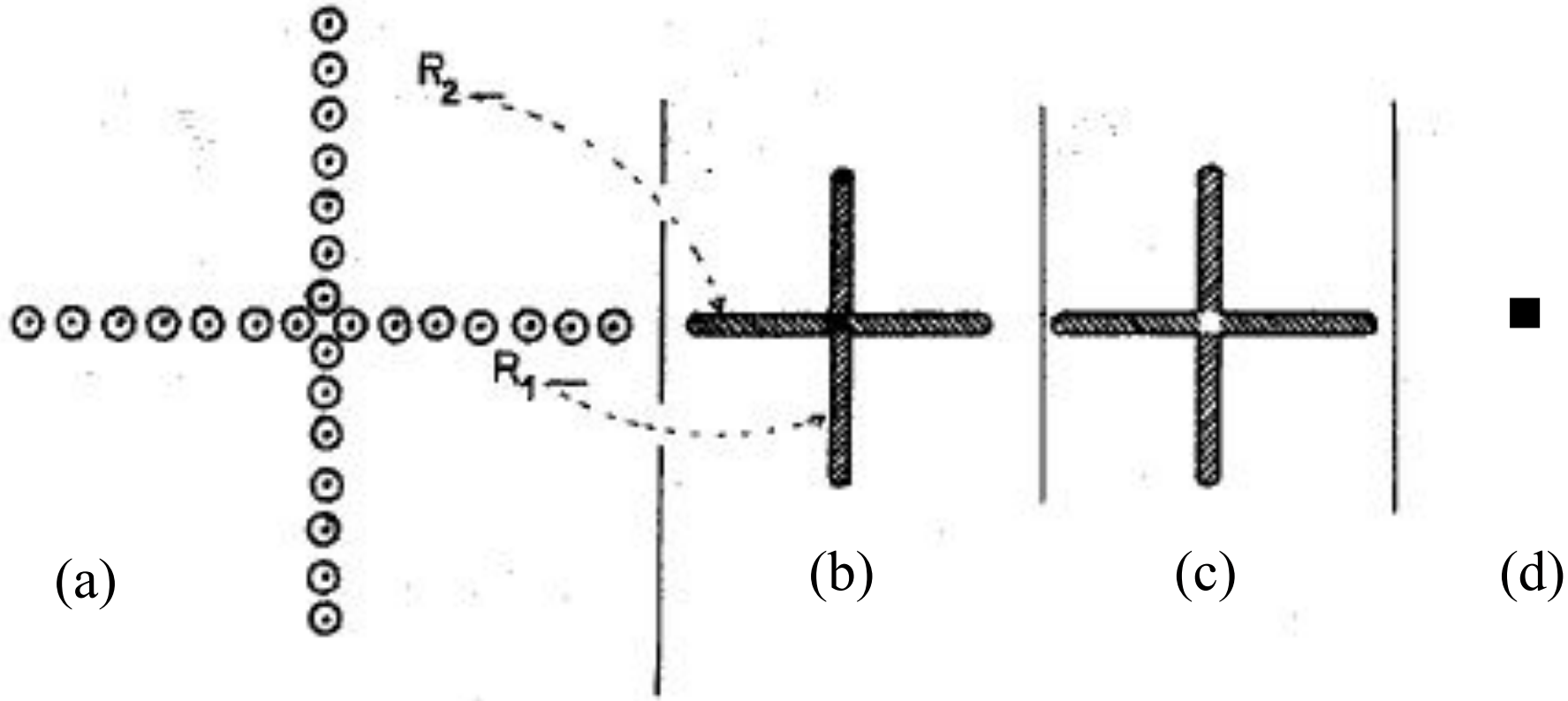


Photograph of the Mills Cross in Australia

9 Fourier Optical Elements

9.3 Telescope applications

9.3.4 Radio-telescopes and radio-interferometers



Mills cross. (a) Disposition of the elements; (b) and (c) Traces over the celestial sphere of the antenna diagram when the two branches R_1 and R_2 are connected in phase (b) and in phase opposition (c); (d) trace over the celestial sphere of the difference diagram

9 Fourier Optical Elements

9.3 Telescope applications

9.3.4 Radio-telescopes and radio-interferometers

$$P_{M,0}(x,y) = P_{r,0}(x,y) + P_{r,0}(y,x), \qquad (9.3.28)$$

$$P'_{M,0}(x,y) = P_{r,0}(x,y) - P_{r,0}(y,x). \qquad (9.3.29)$$

$$h_{M,0}(p,q) = h_{r,0}(p,q) + h_{r,0}(q,p), \qquad (9.3.30)$$

$$h'_{M,0}(p,q) = h_{r,0}(p,q) - h_{r,0}(q,p). \qquad (9.3.31)$$

9 Fourier Optical Elements

9.3 Telescope applications

9.3.4 Radio-telescopes and radio-interferometers

$$|h_c(p,q)|^2 = |h_{M,0}(p,q)|^2 - |h'_{M,0}(p,q)|^2. \quad (9.3.32)$$

$$|h_c(p,q)|^2 = 2[h_{r,0}(p,q)\, h^*_{r,0}(q,p) + h^*_{r,0}(p,q)\, h_{r,0}(q,p)], \quad (9.3.33)$$

$$|h_c(p,q)|^2 = 4\ \mathrm{Re}\ [h_{r,0}(p,q)\, h^*_{r,0}(q,p)]. \quad (9.3.34)$$

$$|h_c(p,q)|^2 = 4d^4 \left(\frac{\sin(\pi pd)}{\pi pd}\right)^2 \left(\frac{\sin(\pi qd)}{\pi qd}\right)^2 \underbrace{\frac{\sin(N\pi pa)}{\sin(\pi pa)} \frac{\sin(N\pi qa)}{\sin(\pi qa)}}_{\text{Interference terms}}. \quad (9.3.35)$$

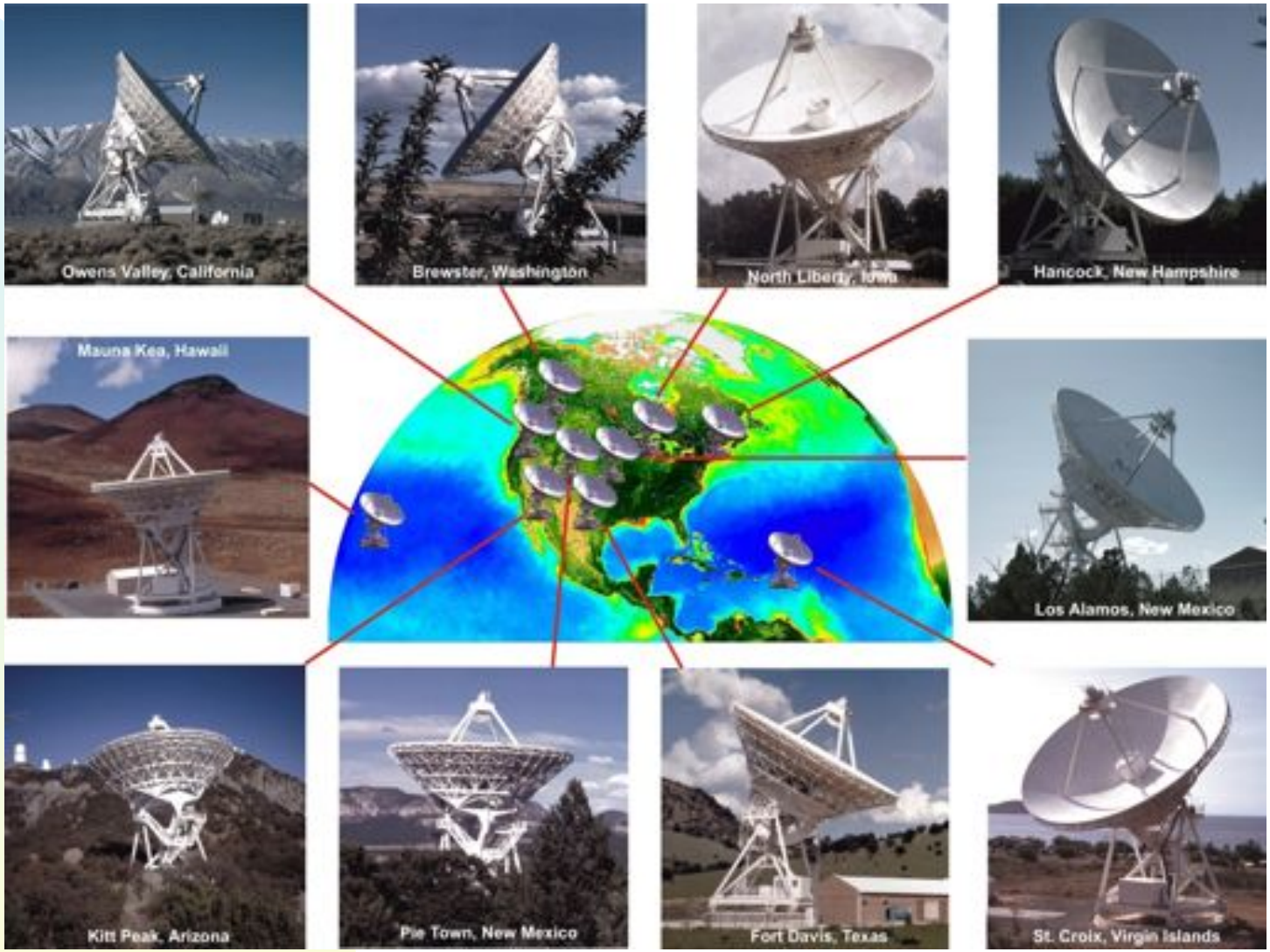
9 Fourier Optical Elements

The Very Large Array near Socorro in New Mexico (USA)

9 Fourier Optical Elements

The Very Large Array near Socorro in New Mexico (USA)

9 Fourier Optical Elements

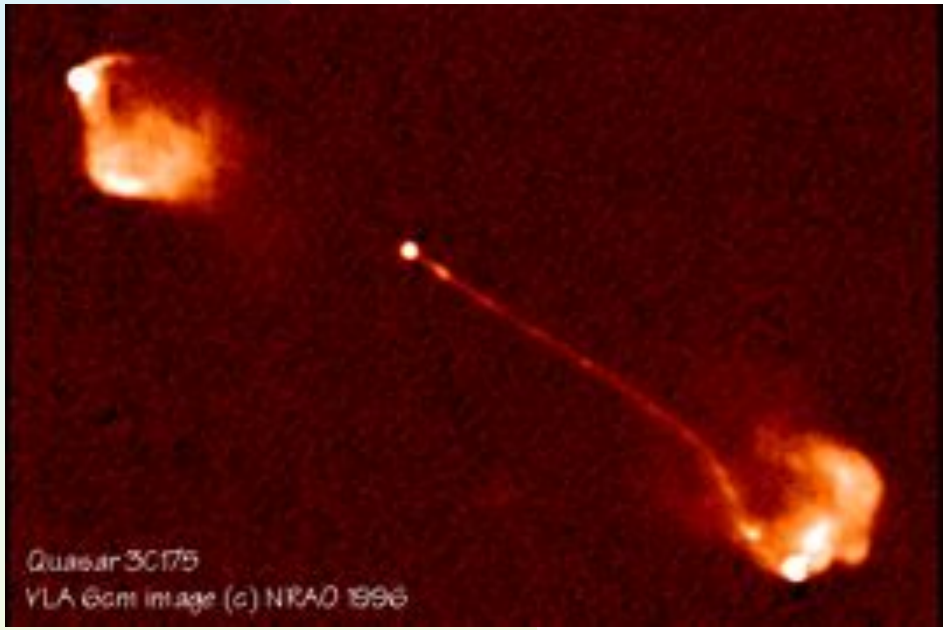


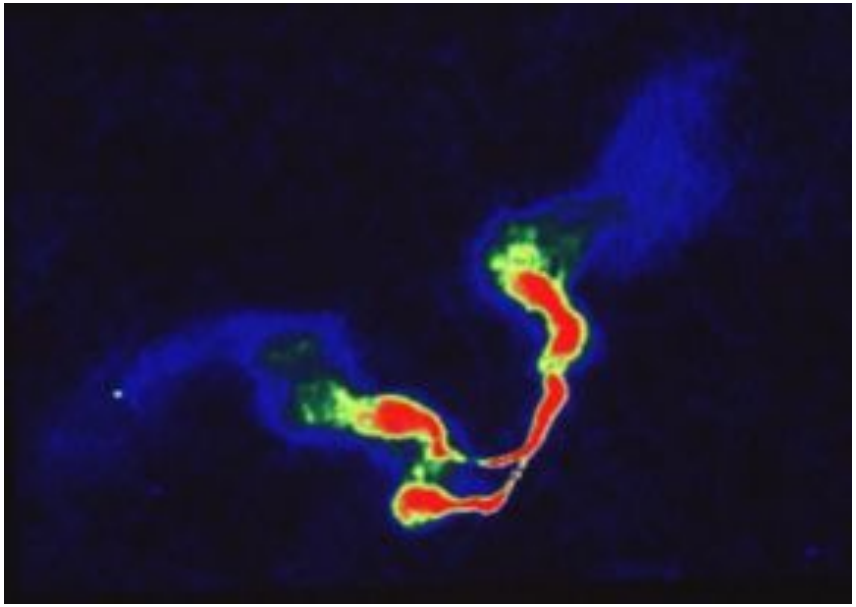
The Very Long Baseline Array (USA)

9 Fourier Optical Elements

The Very Long Baseline Array (USA)

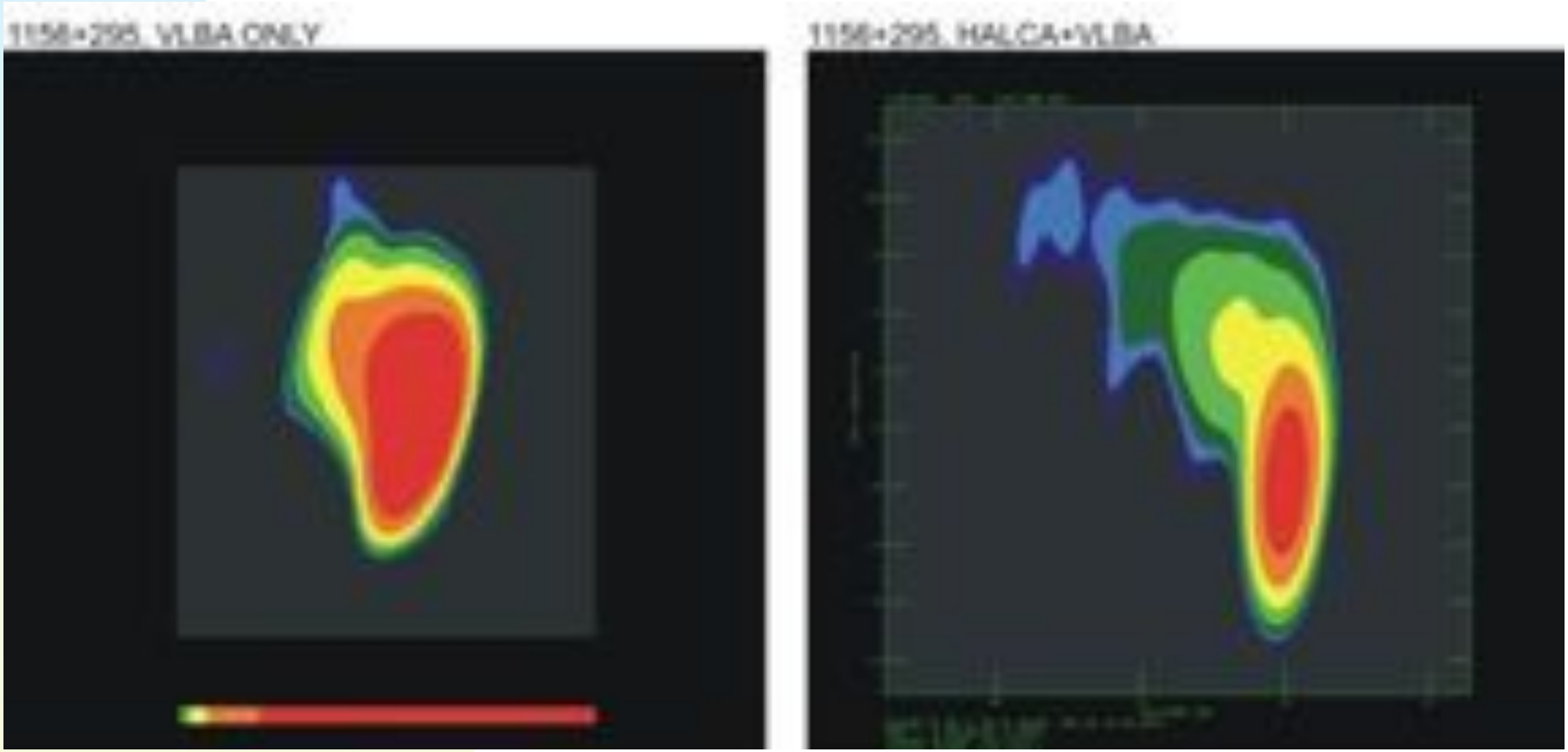
9 Fourier Optical Elements





Quasar and AGN (Very Large Array, USA)

9 Fourier Optical Elements



Quasar and AGN (Very Long Baseline Array, USA)

9 Fourier Optical Elements

The LOFAR 'superterp'. View of the heart of the radio-interferometer located near Exloo, Holland (1,3 - 30m, 20 000 antenna, B ≈ 1000 km, 300 000 m^2) .

9 Fourier Optical Elements

The 'SKA' (Square Kilometer Array) project: phased radio interferometer (Australia / South Africa, Base ≈ 3 000 km, 1 000 000 m^2, 2024).

9 Fourier Optical Elements

The Nançay radio-helio-graphs (France)

See the URL: http://www.obs-nancay.fr/html_an/a_rh.htm

9 Fourier Optical Elements

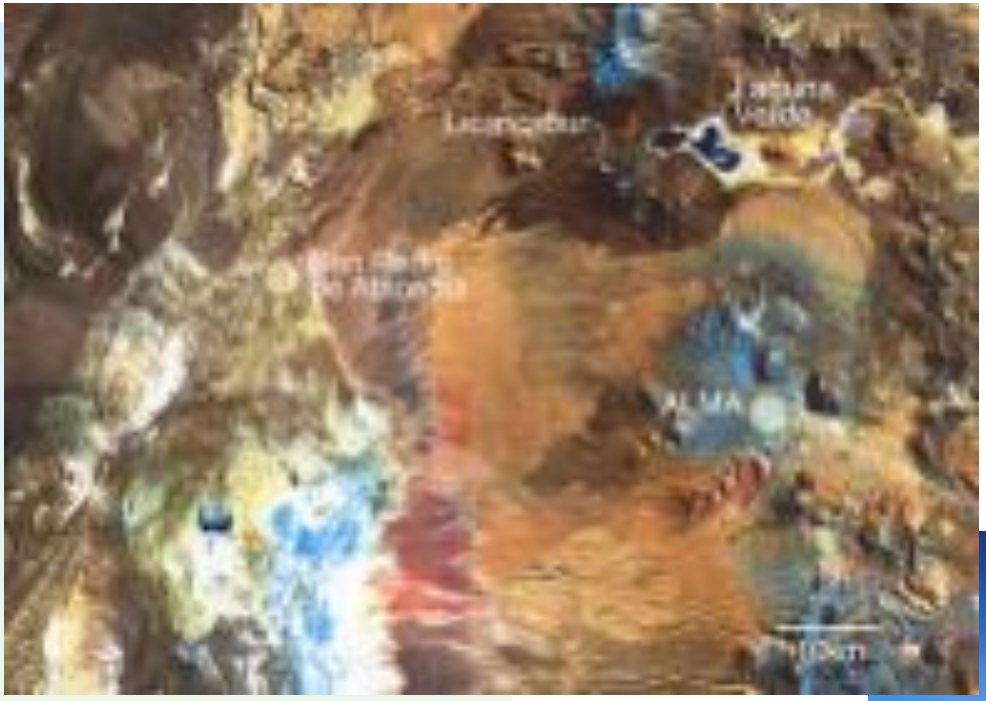
View of North of Chile (space shuttle)

Geographic sites of the VLT and ALMA

Atacama Large Millimeter Array (Chile)

See the URL: http://www.eso.org/projects/alma/

9 Fourier Optical Elements



Aerial view of the ALMA site

Atacama Large Millimeter Array (Chile)

Panoramic view of the ALMA site in Chajnantor

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9 Fourier Optical Elements

Atacama Large Millimeter Array (Chile)

Futuristic model of ALMA

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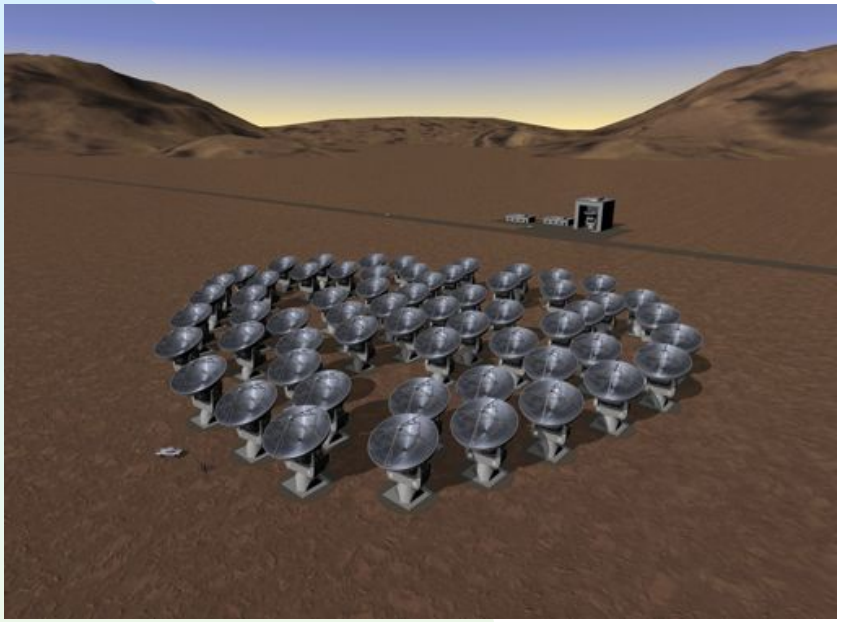
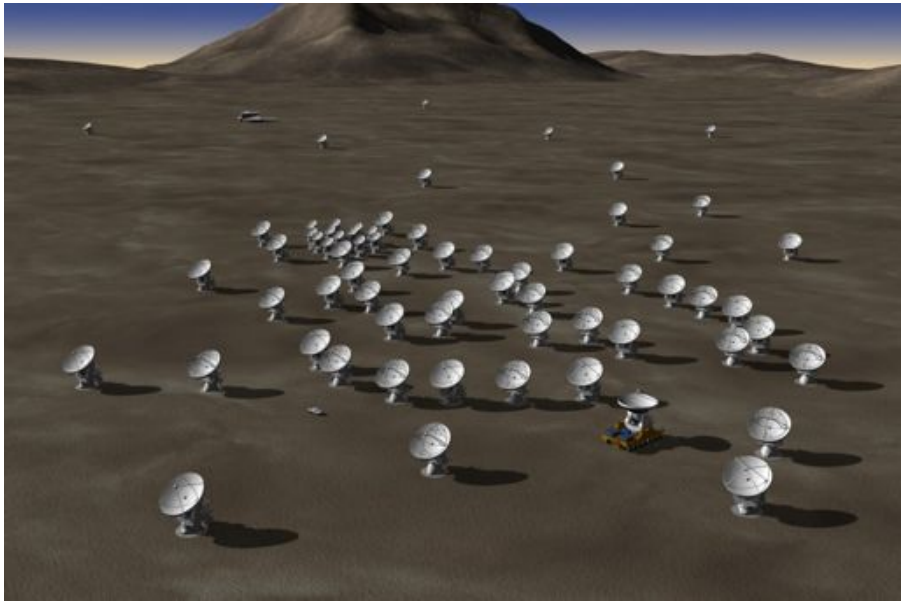
9 Fourier Optical Elements



Atacama Large Millimeter Array (Chile)



Futuristic models of ALMA

See the URL: http://www.eso.org/projects/alma/

9 Fourier Optical Elements

Atacama Large Millimeter Array (Chile)

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9 Fourier Optical Elements

Atacama Large Millimeter Array (Chile)

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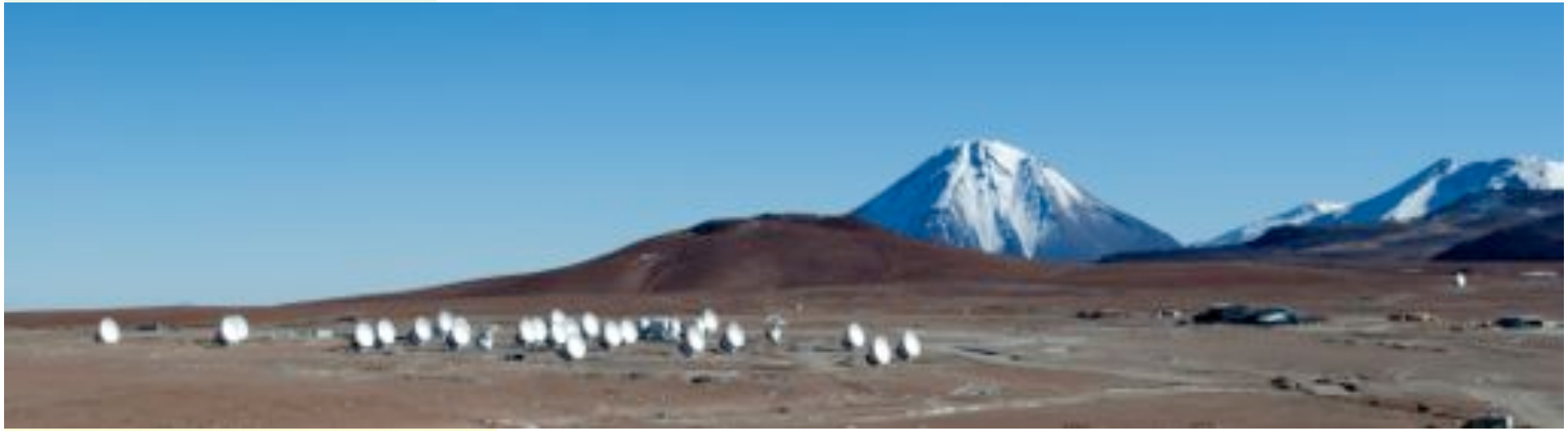
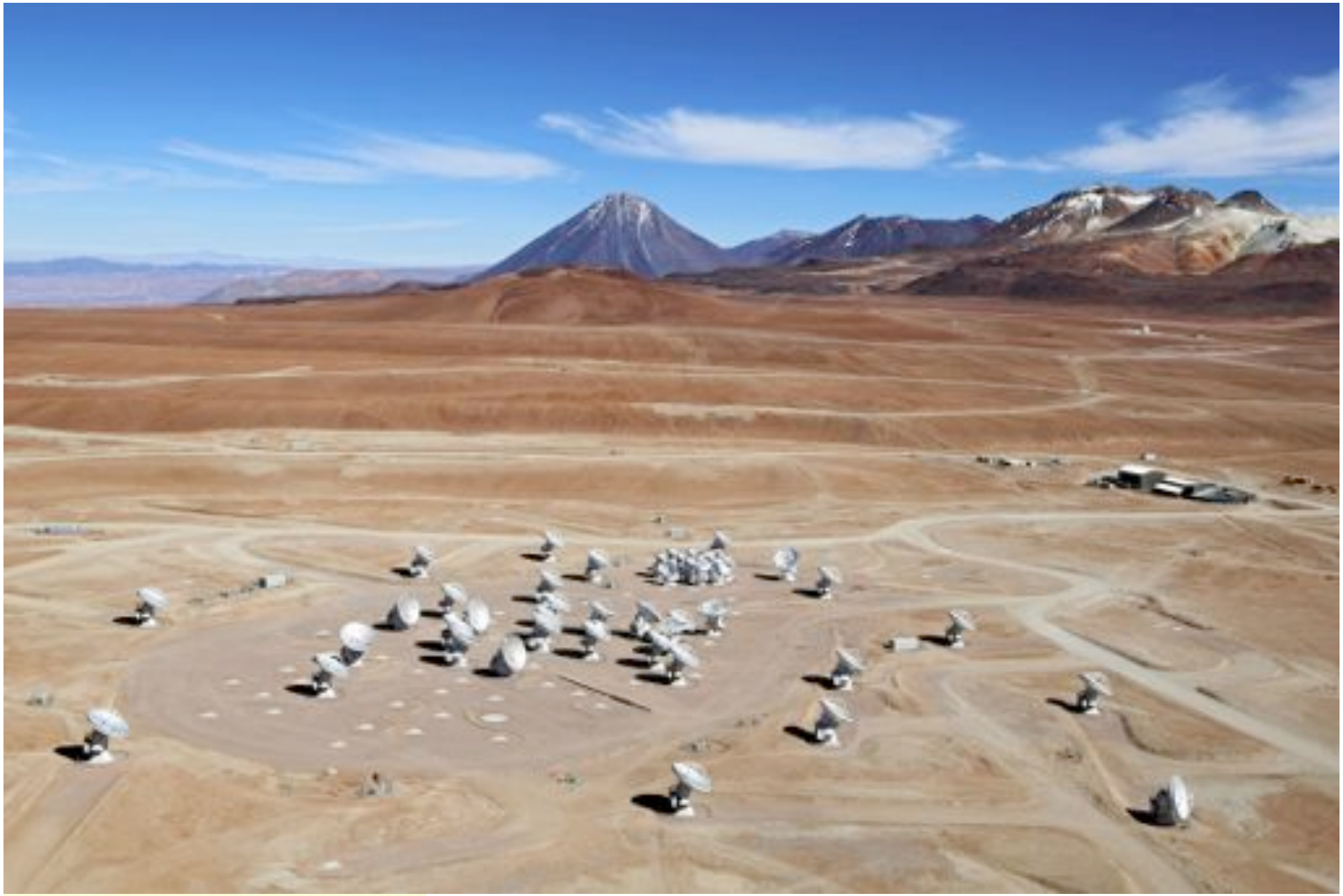
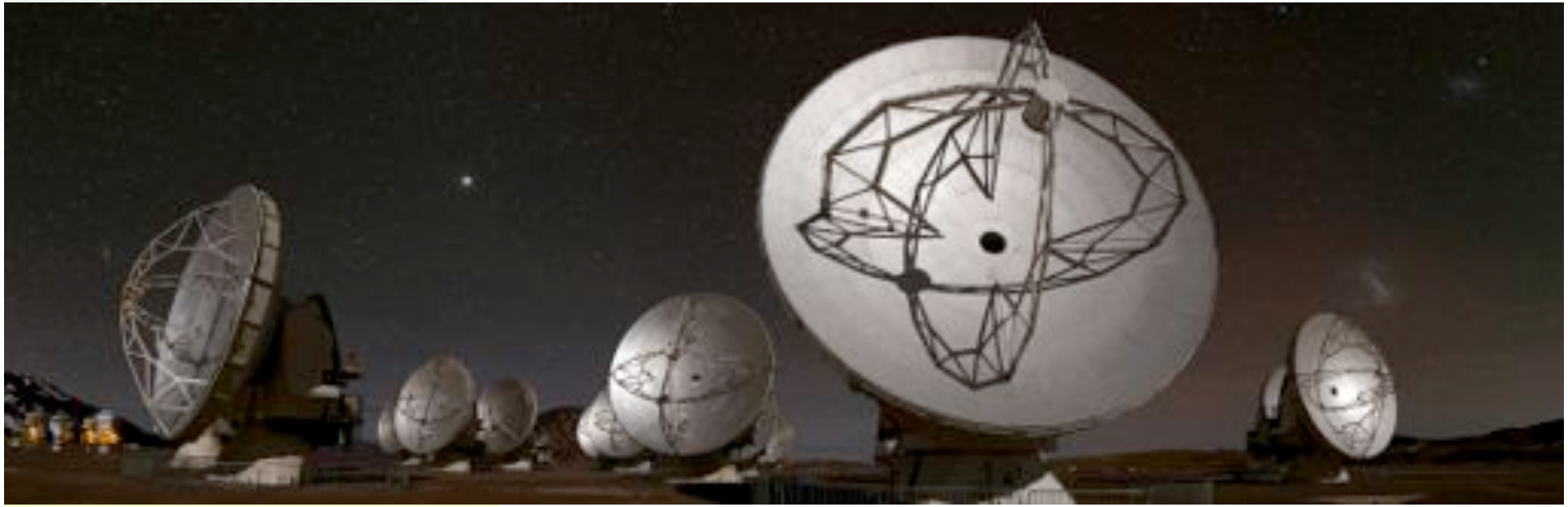
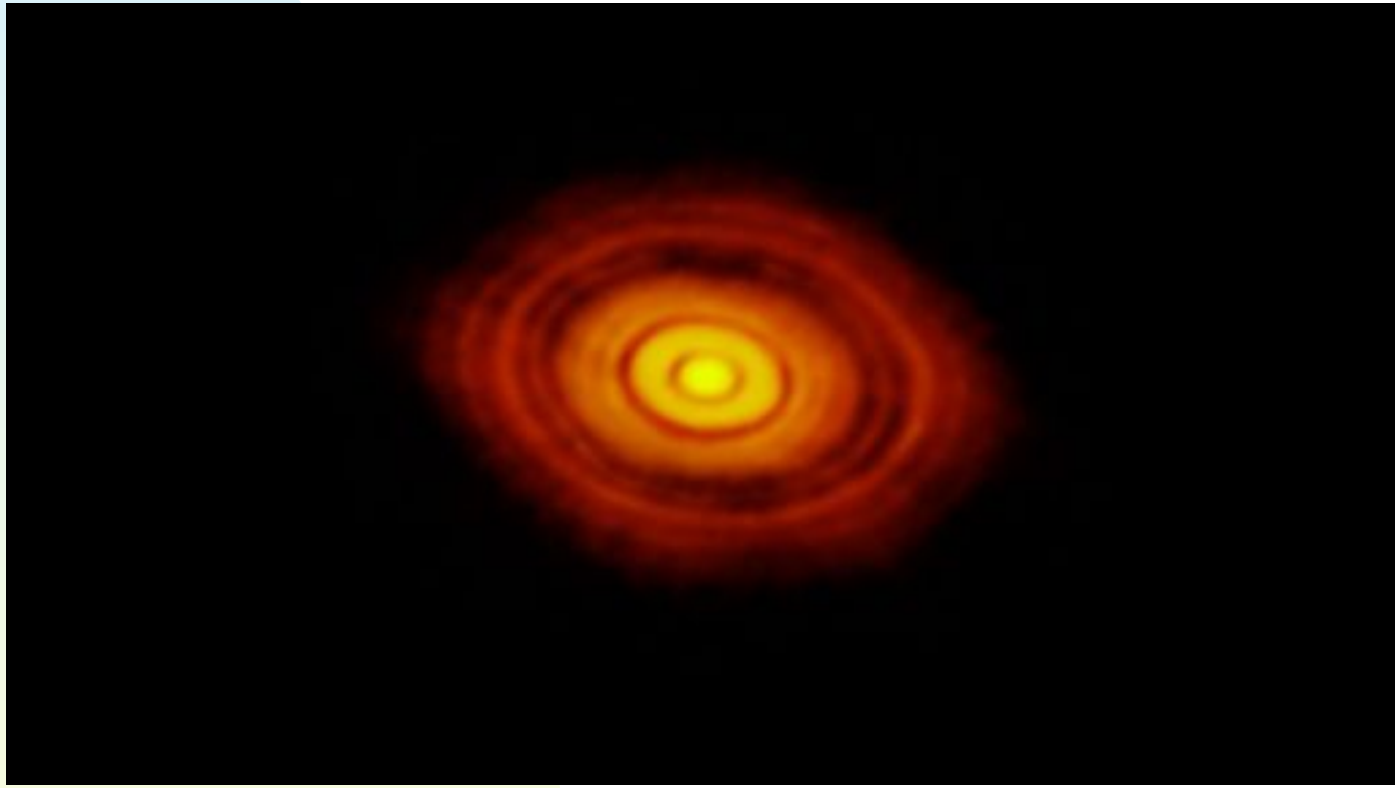






9 Fourier Optical Elements



Atacama Large Millimeter Array (Chile)

HL Tauri, 450 light years from Earth, planetary disk made of gas and dust, spatial resolution is approximately 5 AU

See the URL: http://www.eso.org/projects/alma/