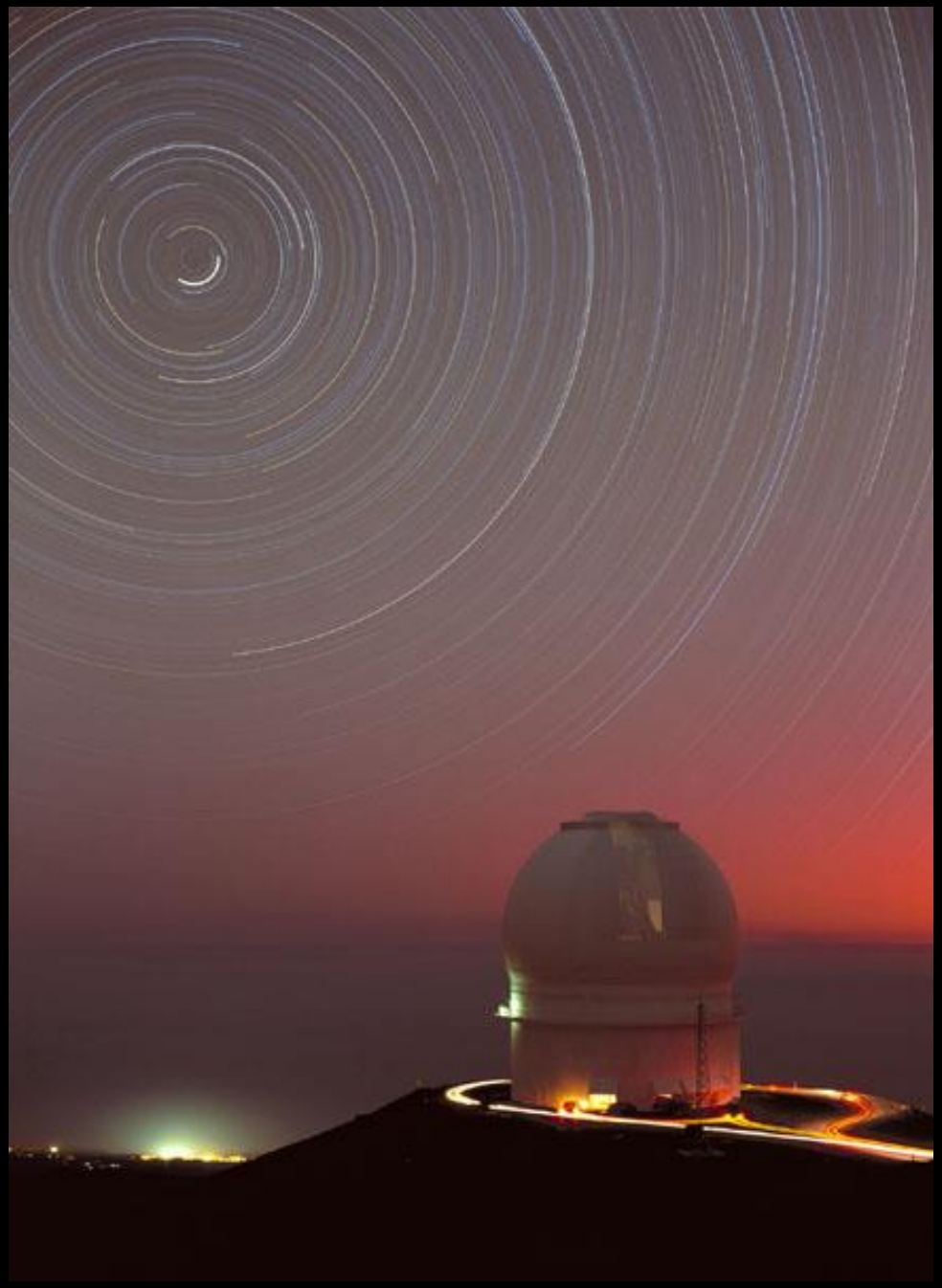
光與望遠鏡



http://www.wainscoat.com/astronomy/

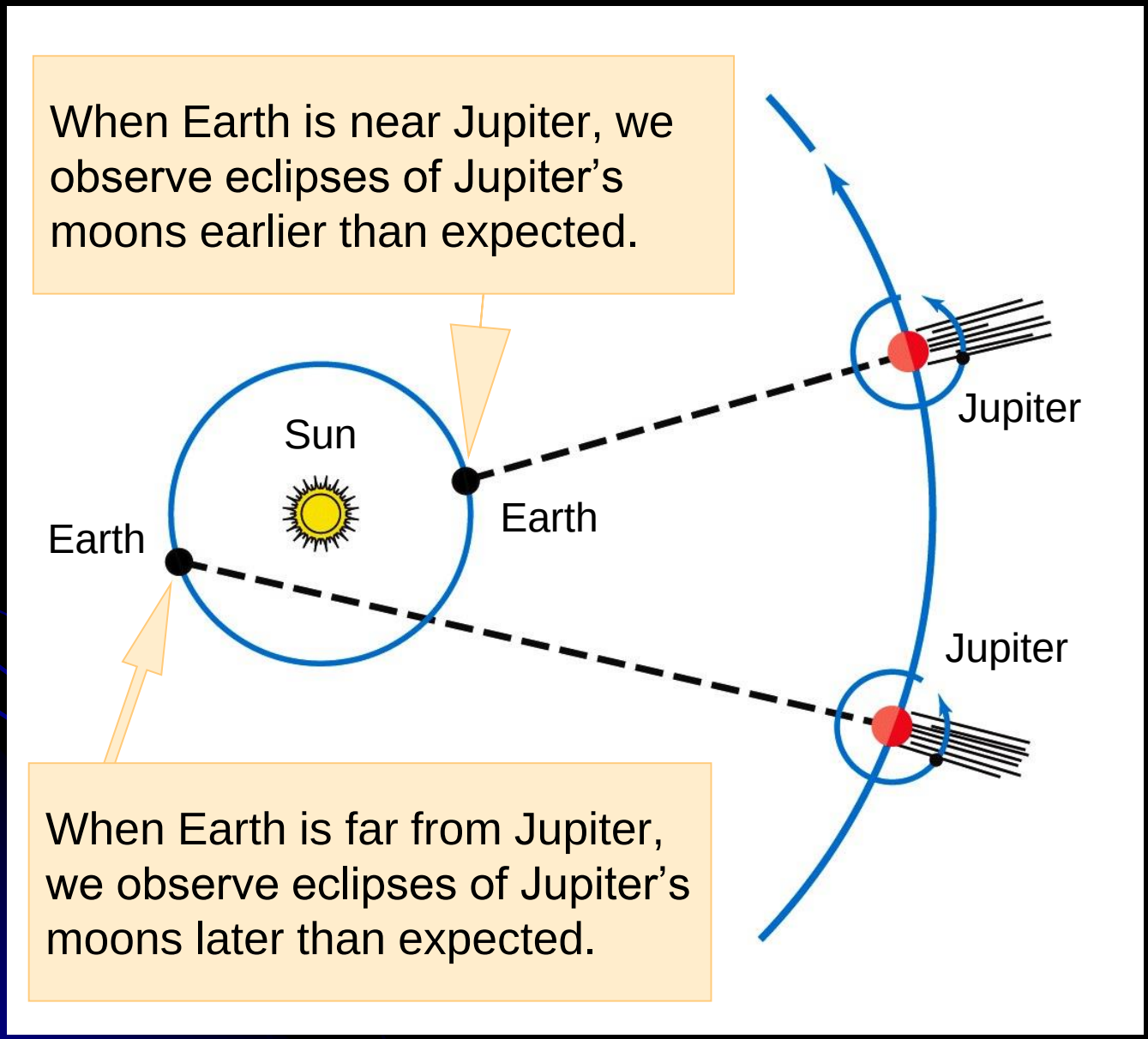
What Do You Think? 你覺得呢？

- 光是什麼東西？

  光是一種電磁波...

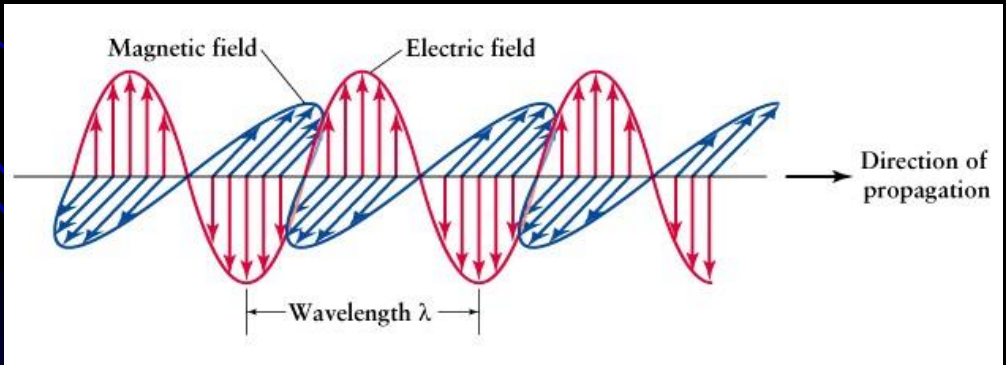
  那，電磁波是什麼？波是什麼？
- 哪種電磁輻射對生物危害最大？
- 天文望遠鏡最主要的功能為何？
- 星星為何看起來會閃動？
- 星星有多熱？怎麼知道的呢？
- 太陽是什麼顏色？

Olaus Rømer in 1676 presented the first argument that light does not travel instantaneously.



光是什麼東西？

- 波動 → 傳遞能量 e.g.，水波、聲波、電磁波
- 電與磁 電場改變 → 磁場　磁場改變 → 電場
  電磁互變 → 電磁波前進
- 光有波動性質，也有粒子性質
- 真空中光速固定 $c=3 \times 10^5$ km/s



平常看到的透明（白）光
乃由不同顏色的光線組成

迦瑪射線

X射線

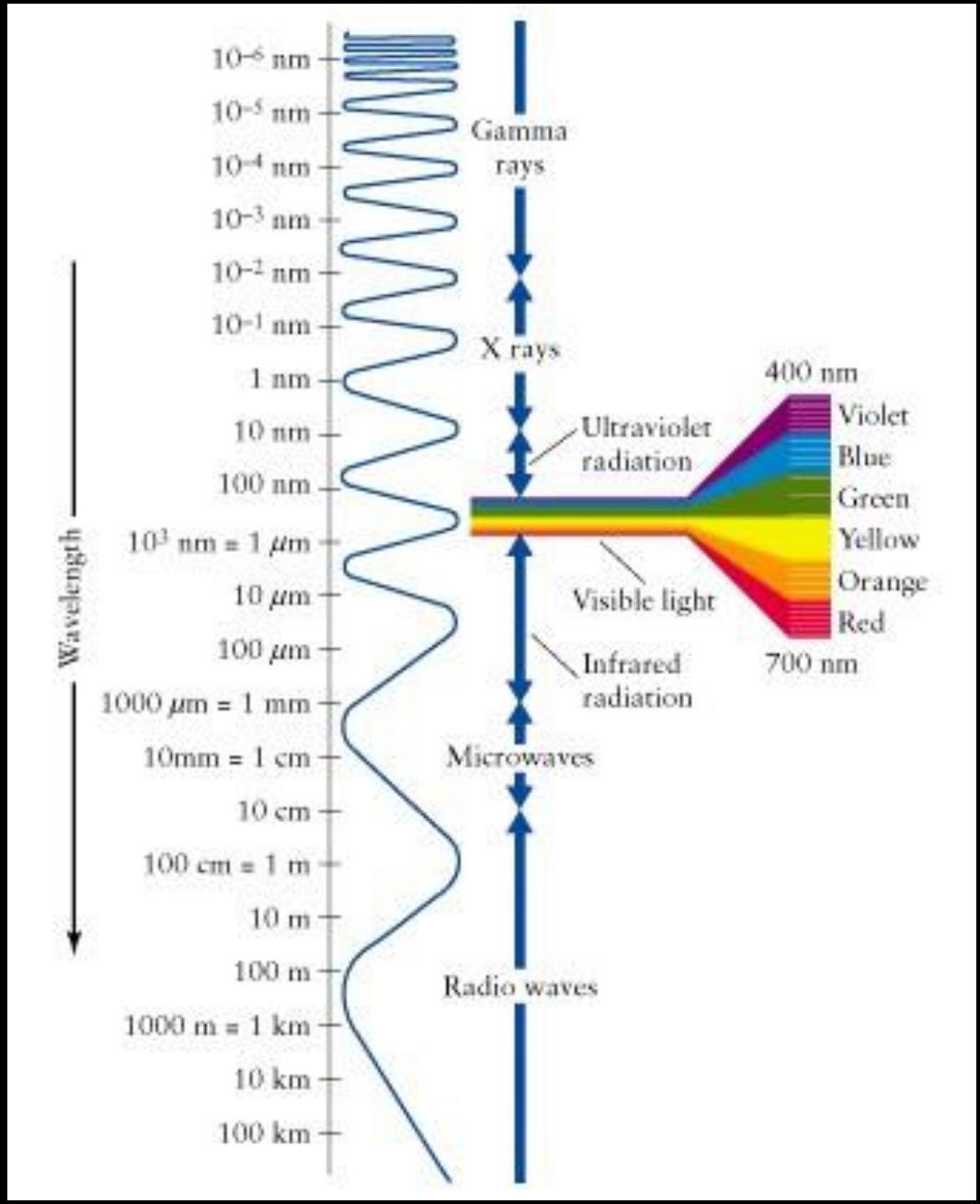
紫外線

可見光

紅外線

微波

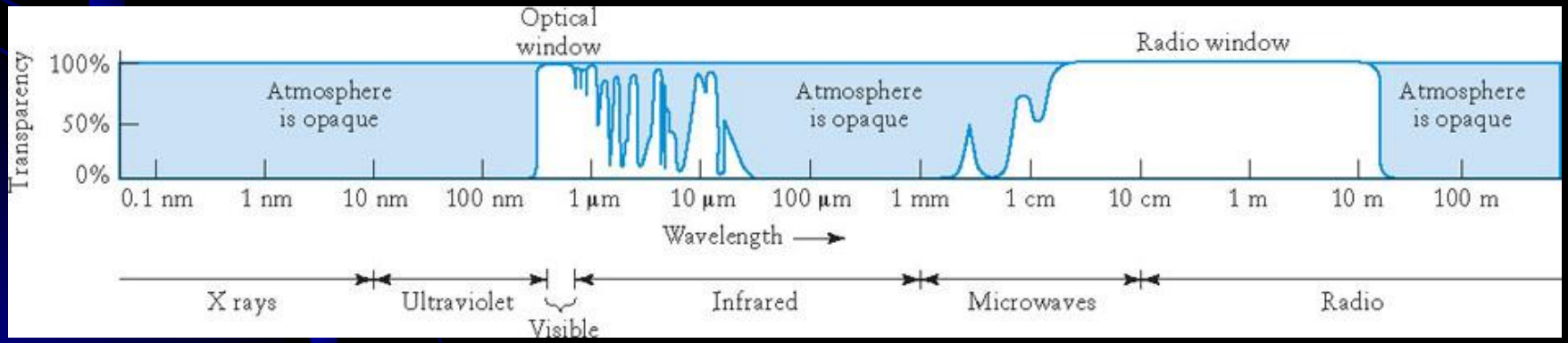
（無線）電波



由於空氣分子吸收，只有部分波段的電磁波能夠穿過地球大氣層，**稱為「大氣窗口」(atmospheric windows)**

可見光與大部分（無線）電波能夠穿透

部分紅外線（介於分子吸收之間）能穿透



透明度

波長

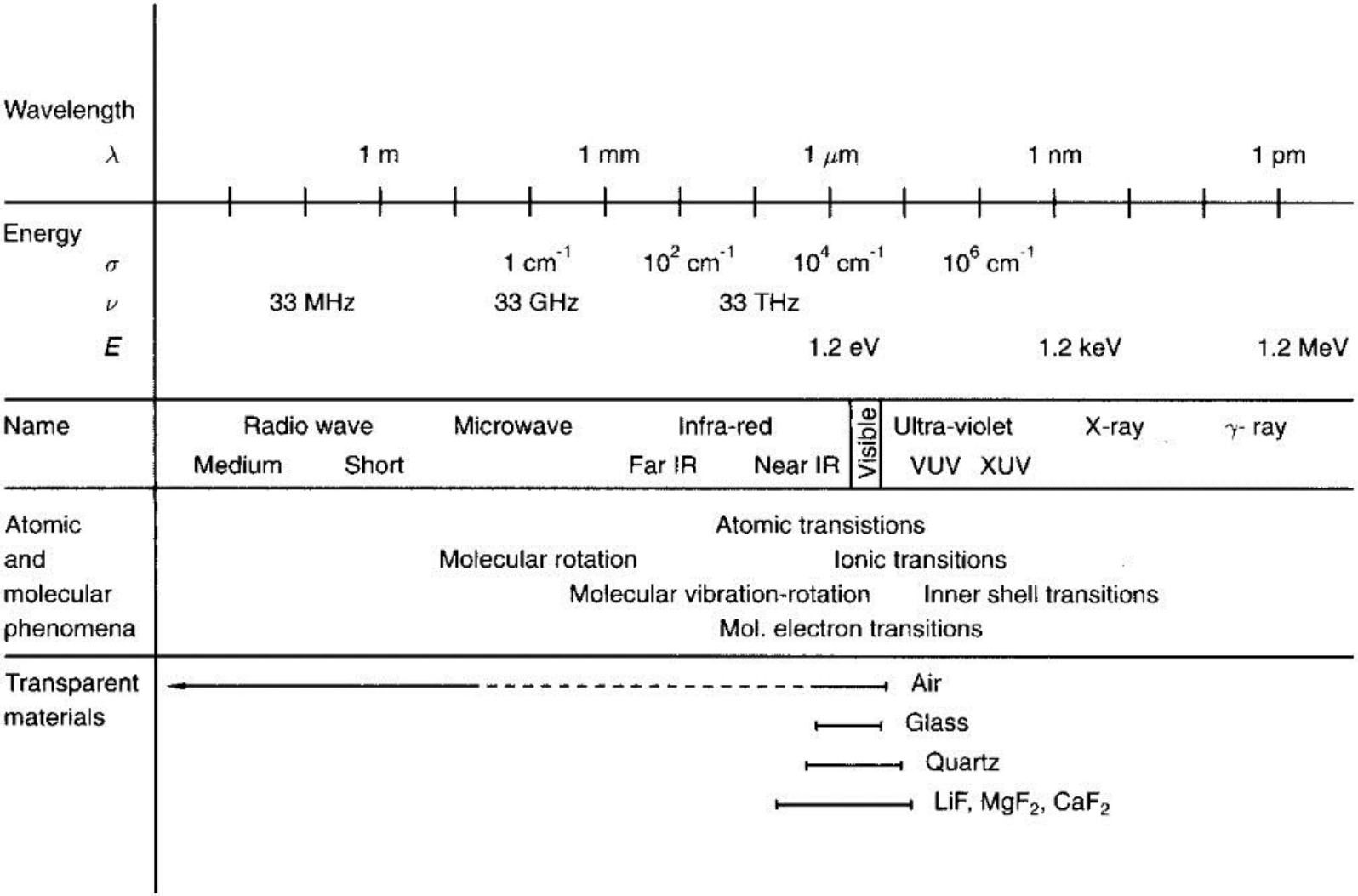


Fig. 1.1. The electromagnetic spectrum.

"Spectrophysics" by Thorne et al.

Sidereal Time（恆星時）

＝ 在子午線上的赤經座標；隨時間增加

春分點 ＝ 赤經起點 ＝ 0h

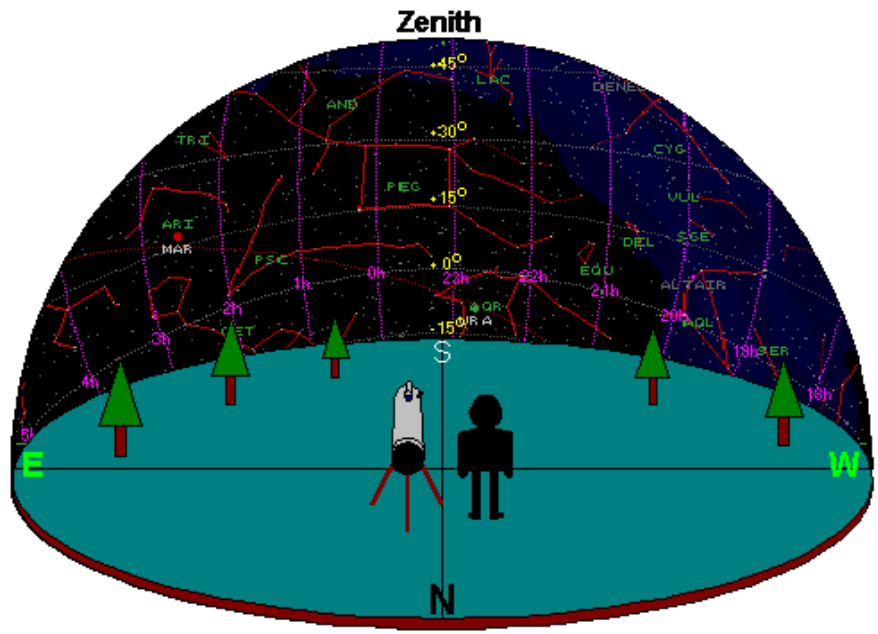
所以恆星時「半夜」＝ 春分點過子午線

∴ 春分點從地平升起

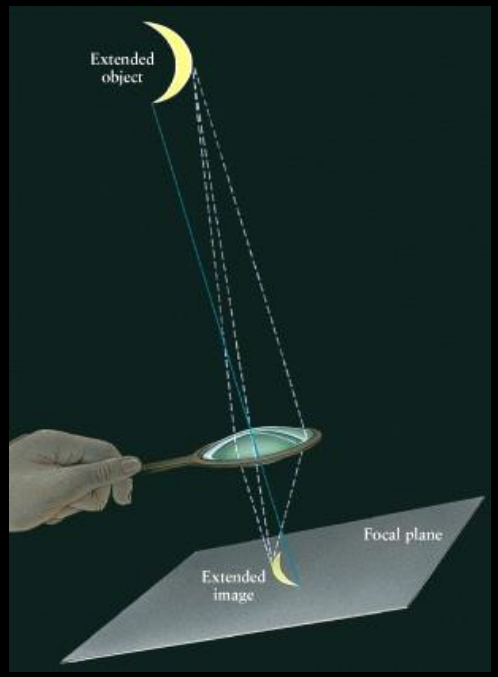
➔ 當時恆星時 = 18 h

∴ 恆星時 ≒ 太陽時

➔ 秋分時期

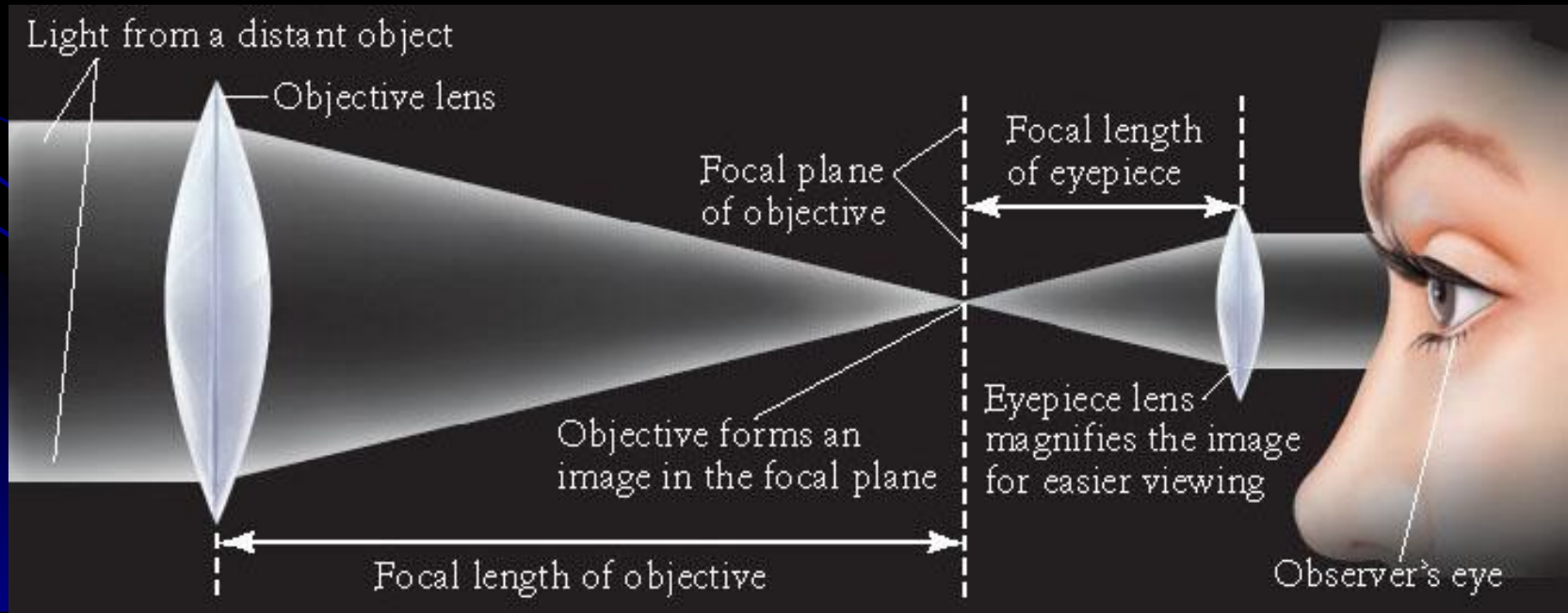


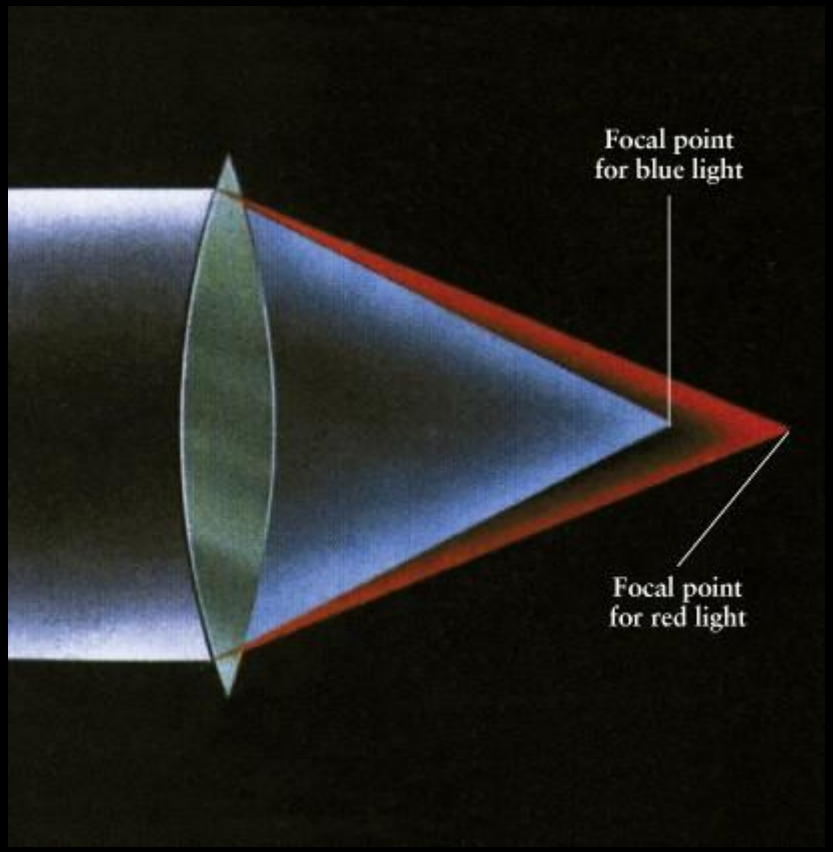
Lines of Right Ascension



利用玻璃等透光物質將光線彎曲（折射 refraction）聚集

望遠鏡：收集光線、成像





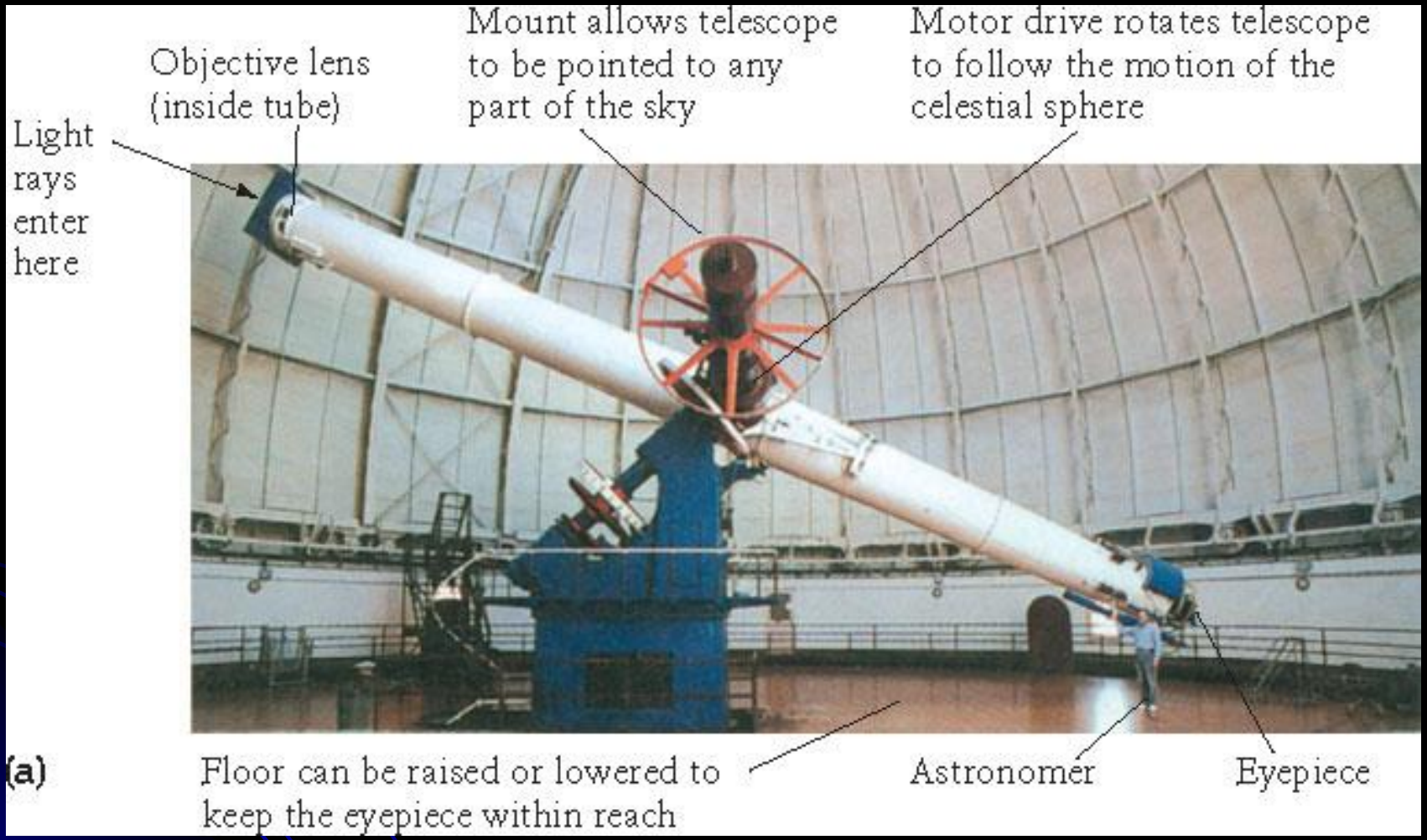
折射式望遠鏡

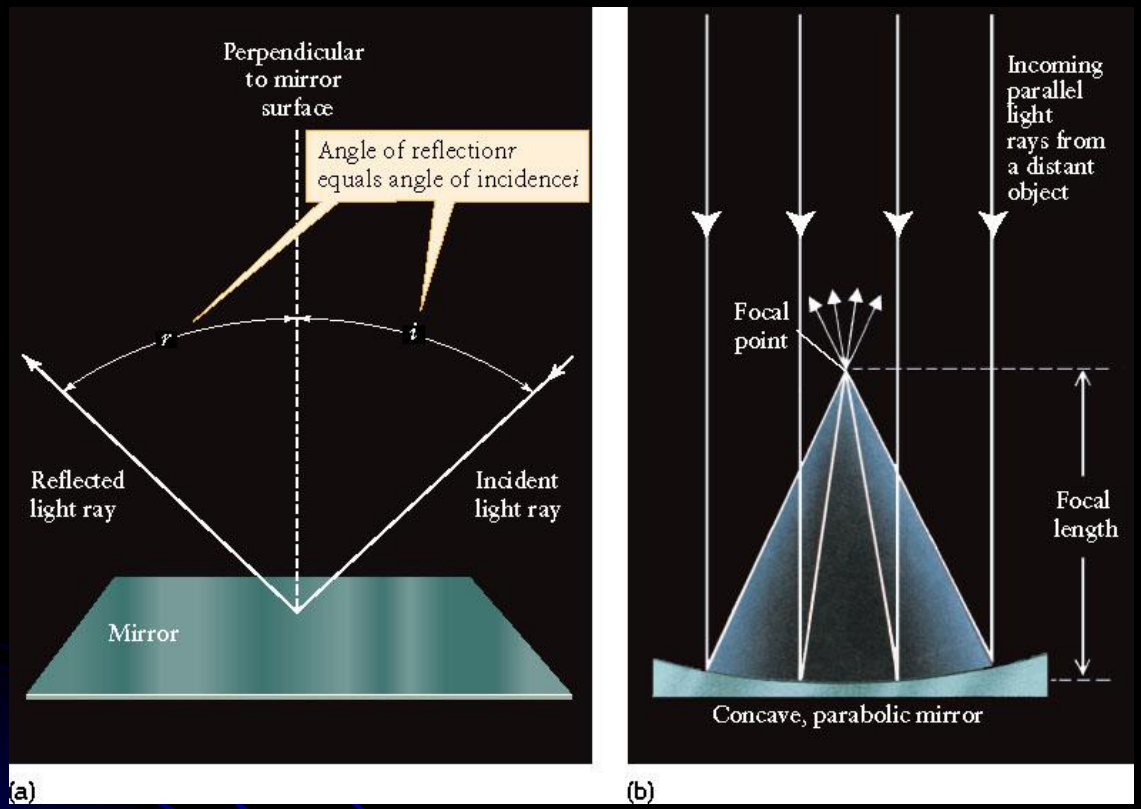
A refracting telescope; a refractor

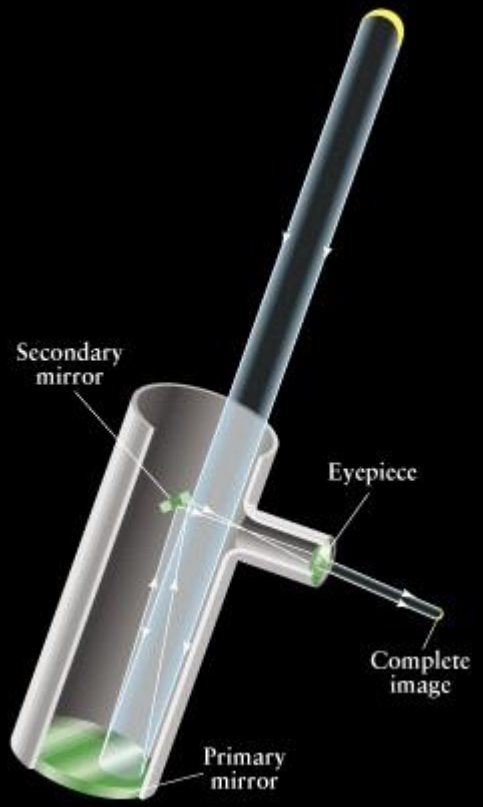
不同顏色的光折射程度不同，無法成像在同一點

➔ **色差現象**

(chromatic aberration)


Mount allows telescope to be pointed to any part of the sky
Motor drive rotates telescope to follow the motion of the celestial sphere
Objective lens (inside tube)
Light rays enter here
(a)
Floor can be raised or lowered to keep the eyepiece within reach
Astronomer
Eyepiece



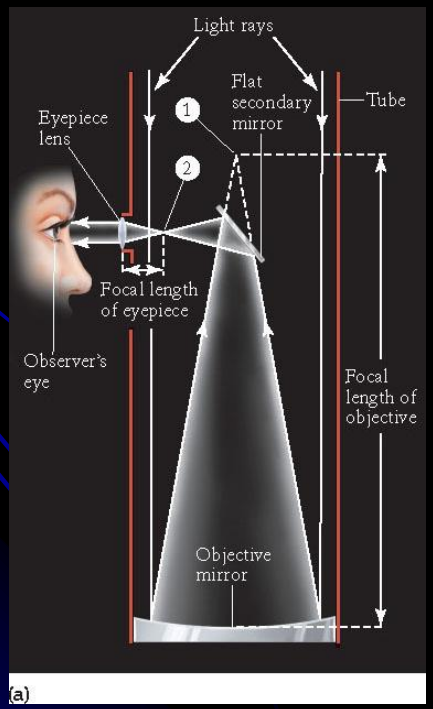


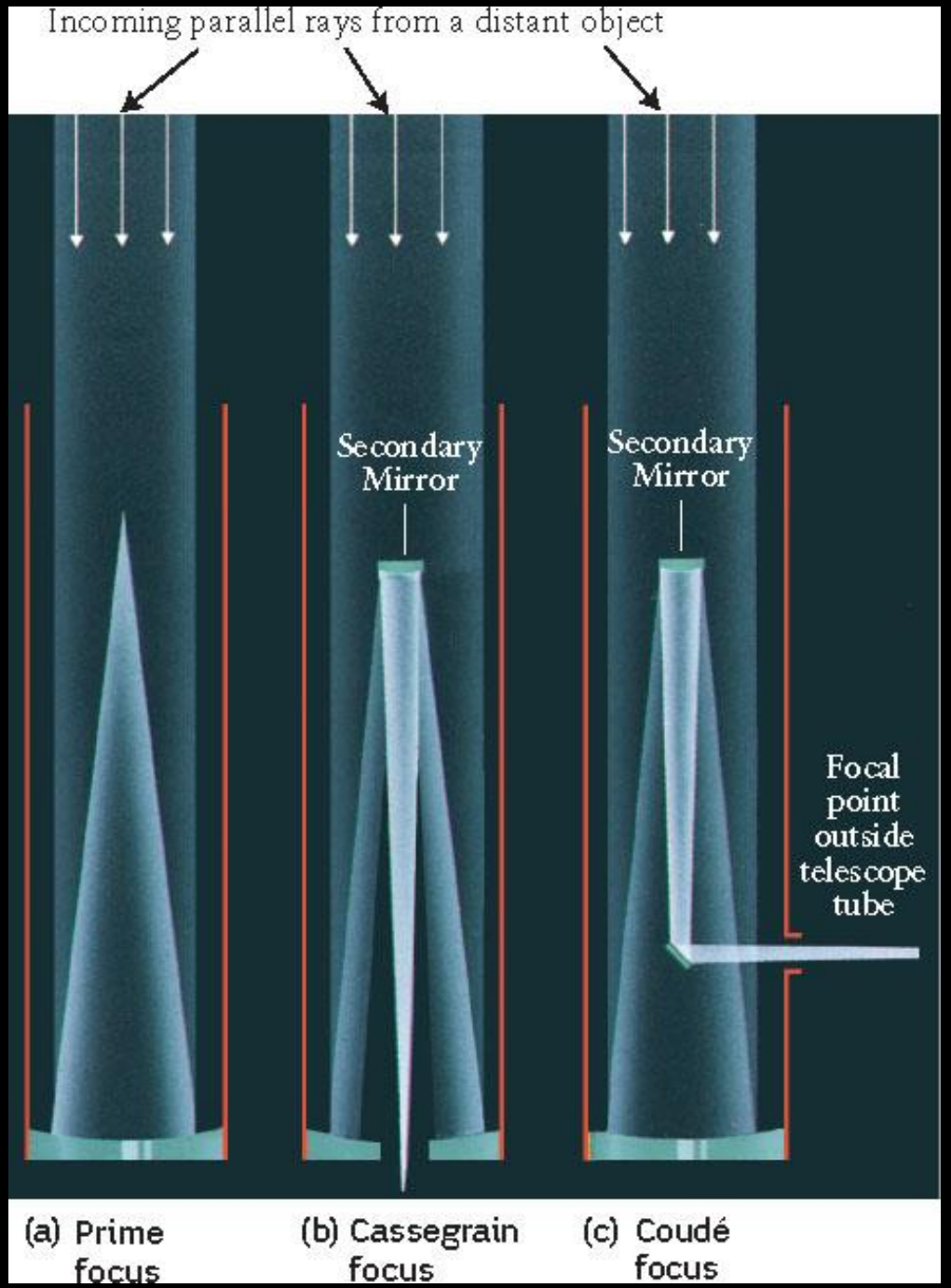
反射式望遠鏡利用反射 (reflection) 的方式將光線聚集

A reflecting telescope; a reflector

反射式望遠鏡聚焦方式

- ✓主焦式
- ✓卡賽格林式
- ✓庫德式
- ✓牛頓式

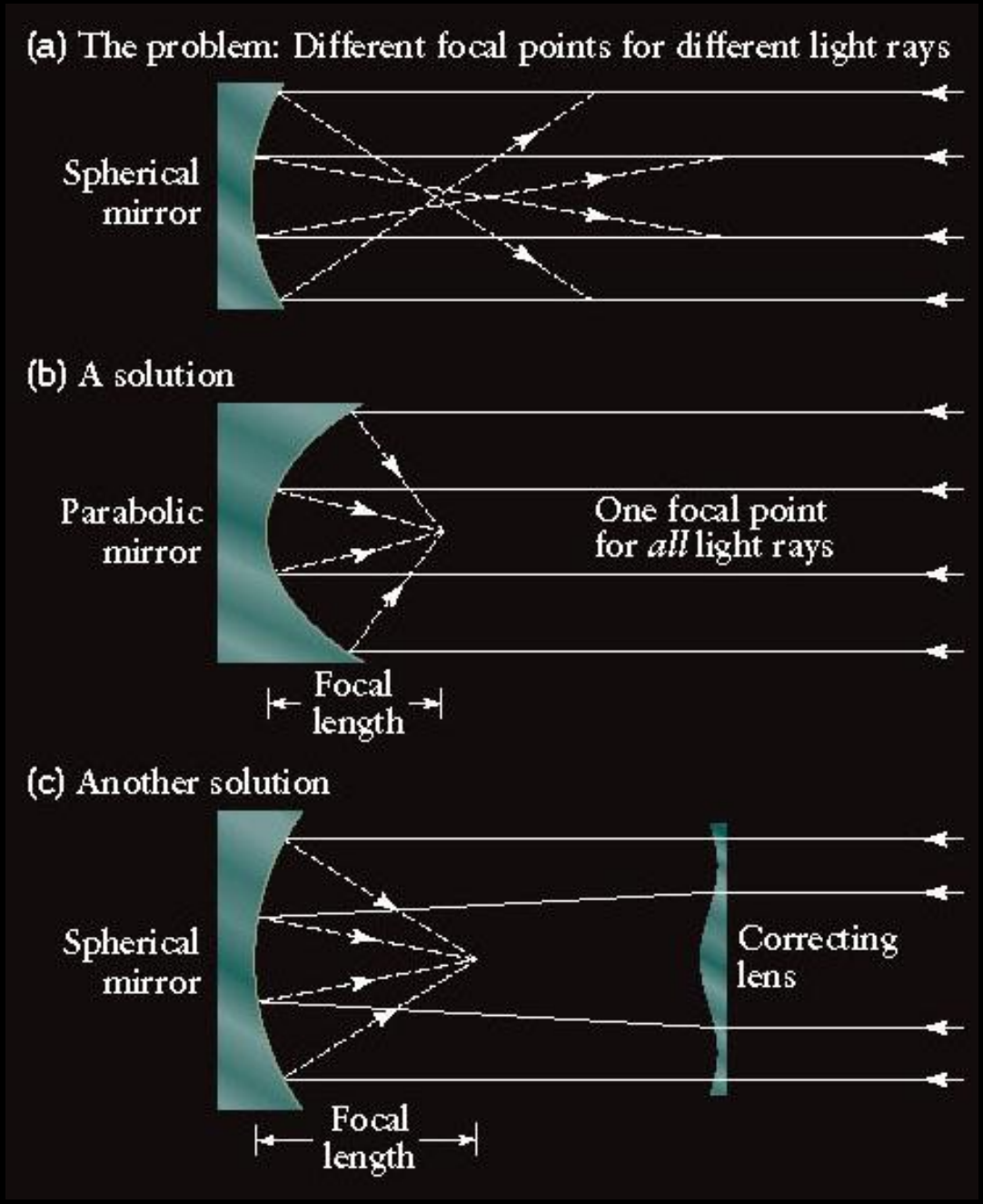




球狀鏡面或鏡片無法聚焦成一點

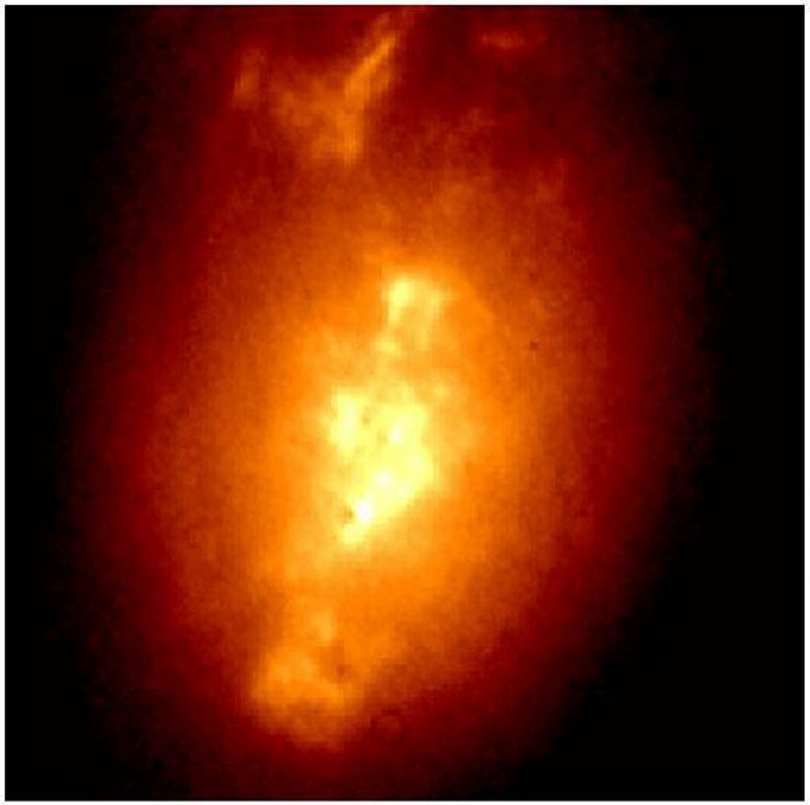
➔ **球面像差**

(spherical aberration)

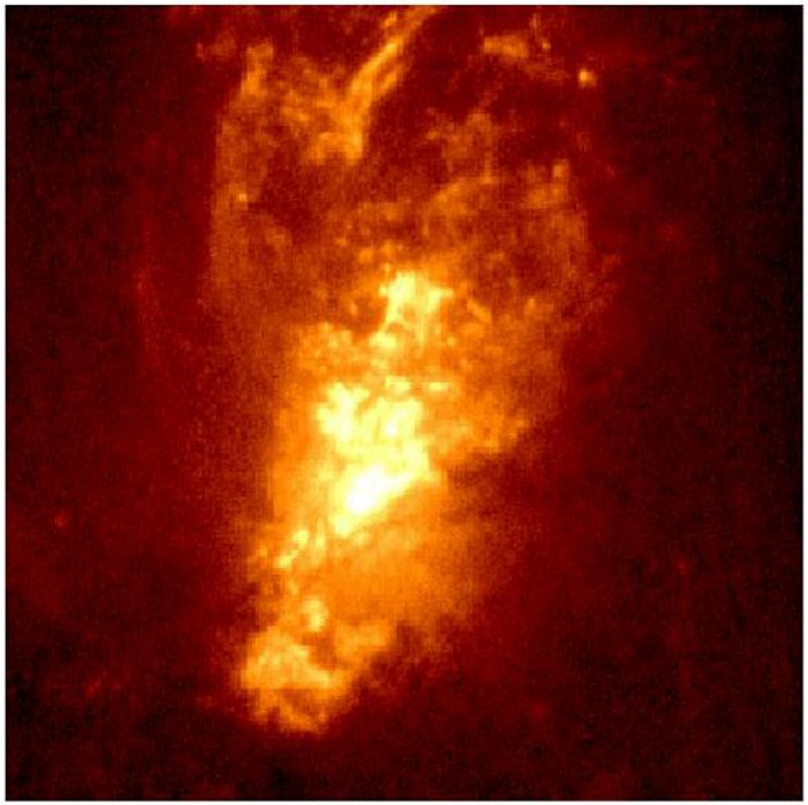


The Central Region of the Active Galaxy NGC 1068

Hubble Space Telescope
Faint Object Camera



Pre-COSTAR



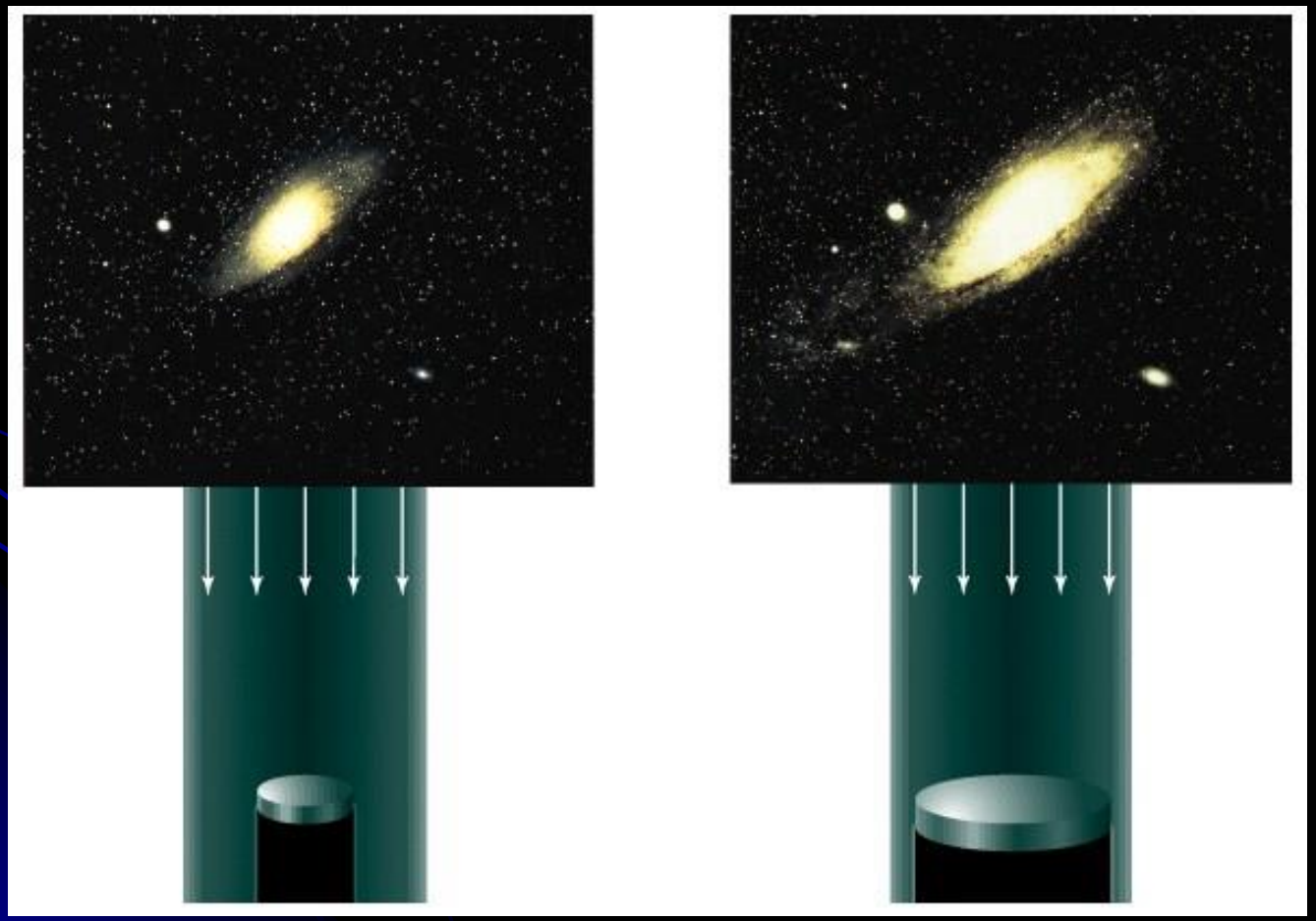
With COSTAR

1994 NASA press release


MEADE LX10 EMC
Meade

望遠鏡口徑越大，收集光線的能力越強，能看到越暗的天體

集光力 ∝ 集光面積 ∝ [口徑]^2



Using a lens or a mirror to **collect light**
or to **form an image**

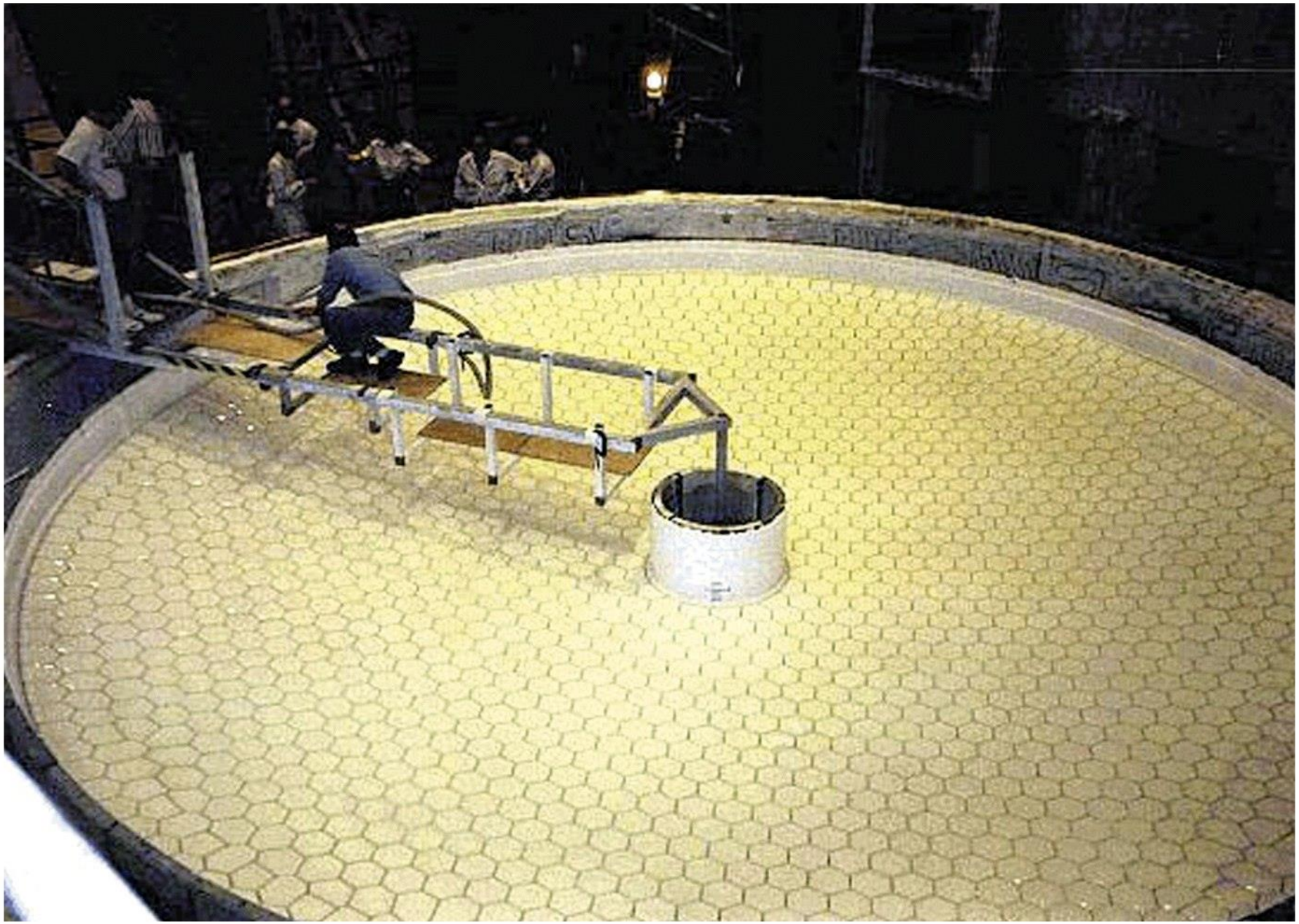
- **To collect light** (actually EM waves)

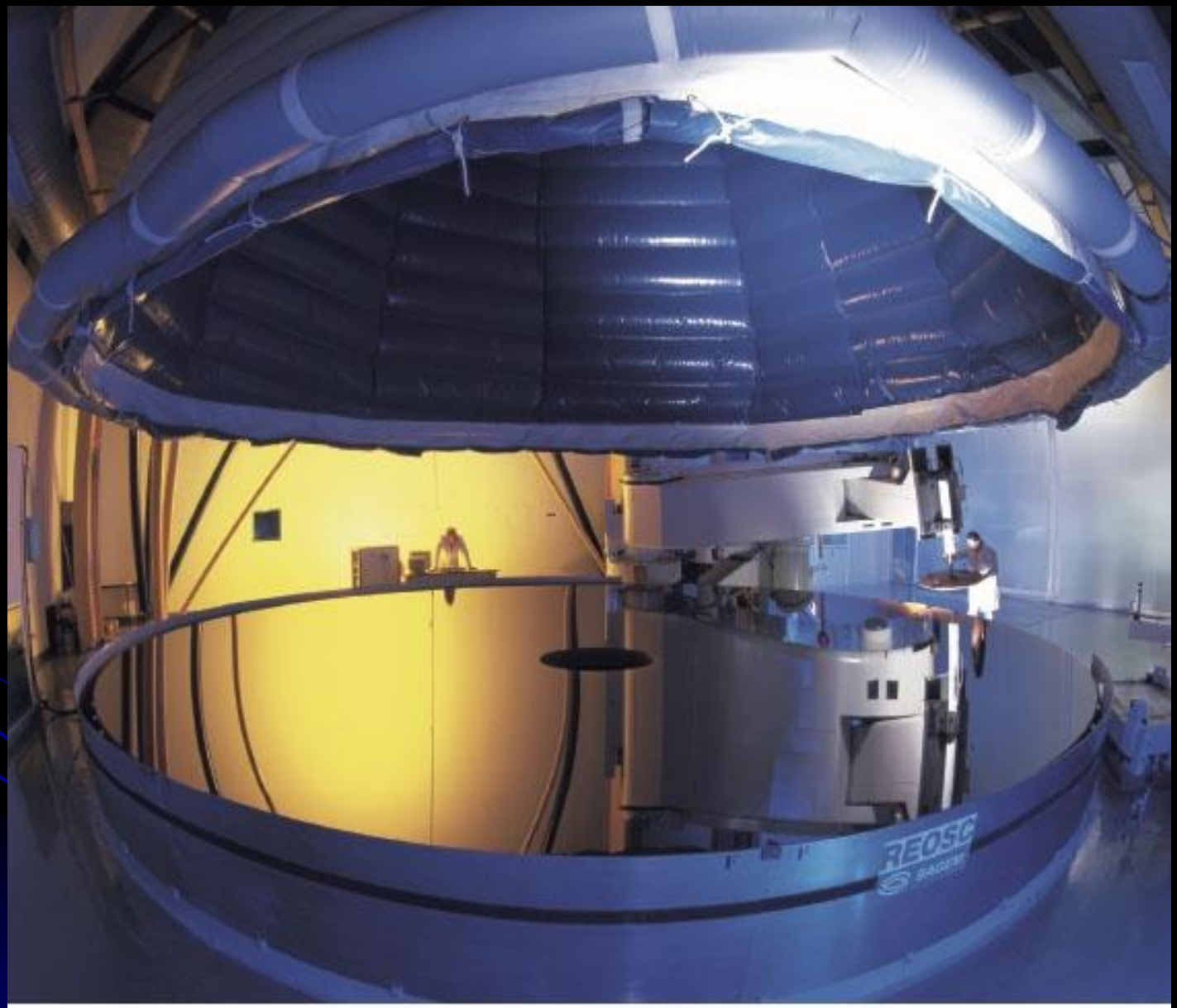
  口徑 (D) 越大，單位時間收集的光量越多

  集光能力與主鏡面積 $\propto D^2$

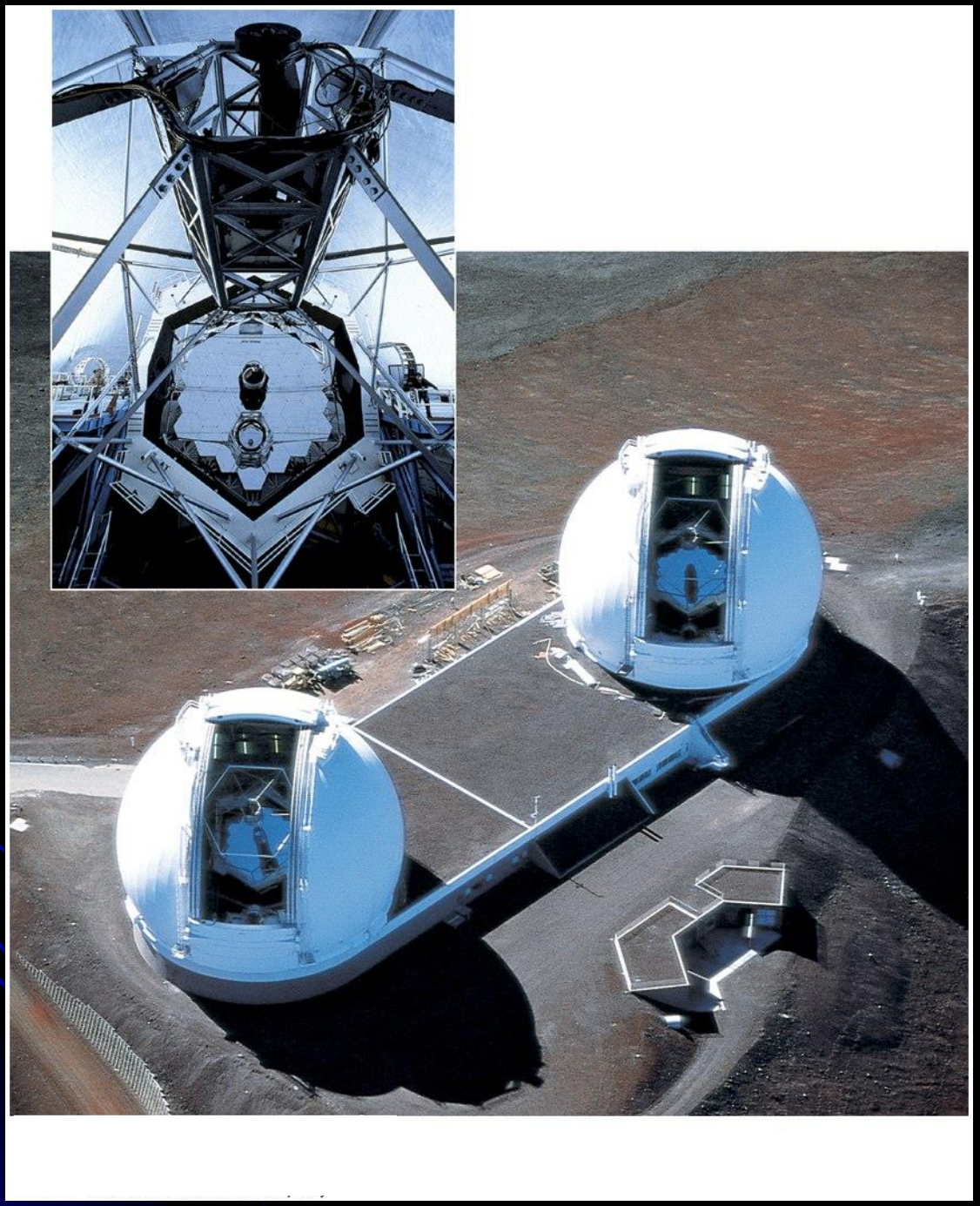
  e.g., Aperture D=2 m 的集光能力
  為 D=1 m telescope 的四倍

mirror diameter or
telescope aperture

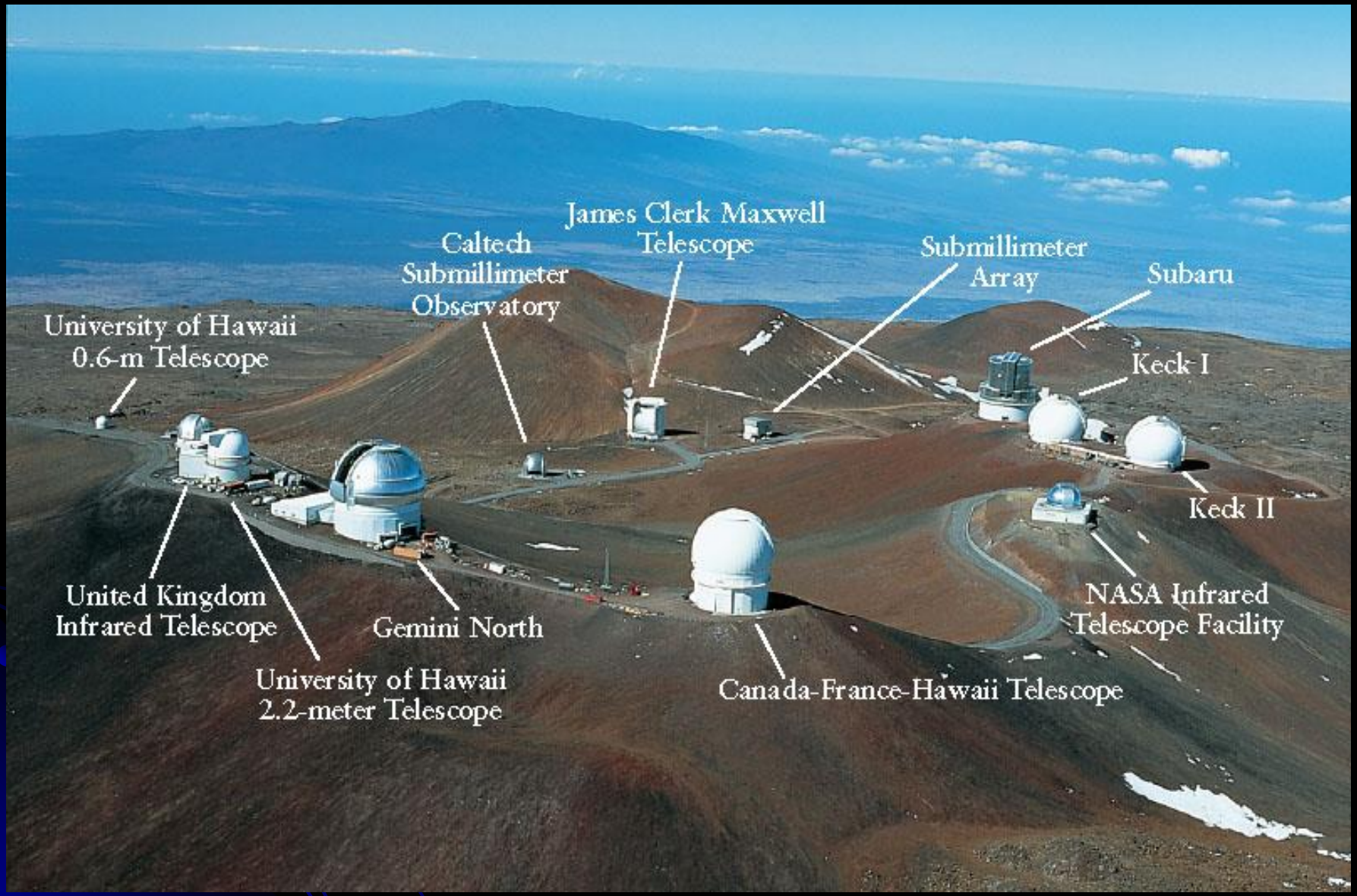




(a) A large objective mirror



Keck
Telescopes


James Clerk Maxwell
Telescope
Caltech
Submillimeter
Observatory
Submillimeter
Array
Subaru
University of Hawaii
0.6-m Telescope
Keck I
Keck II
United Kingdom
Infrared Telescope
Gemini North
NASA Infrared
Telescope Facility
University of Hawaii
2.2-meter Telescope
Canada-France-Hawaii Telescope

- **To form an image** (interference from different parts on the aperture)

口徑越大，看得越清楚（成像越清晰）

最小的角度（細節）$\theta = 1.22\,\lambda/D$ radian

乃望遠鏡的「繞射極限」(diffraction limit)

又稱 **Dawnes' limit**

解像力 (resolving power) $\propto$ D

(*What does resolving power mean anyway?*)

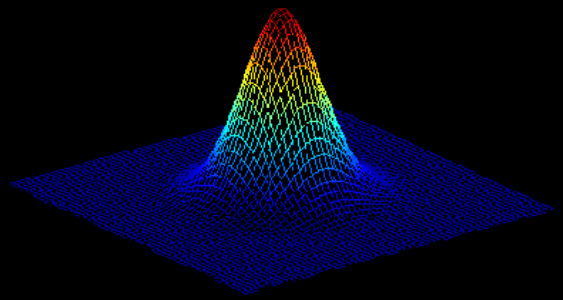
$\theta'' = \lambda/D = \lambda(\mu m) / 4D(m)$

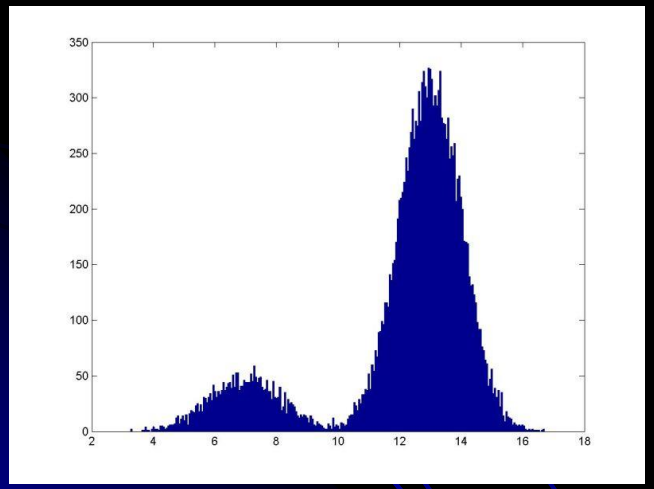
e.g., λ = 500nm = 0.5 μm, θ = 1/ 8D (m)

$\therefore$ D = 1 m, θ = 0.125"

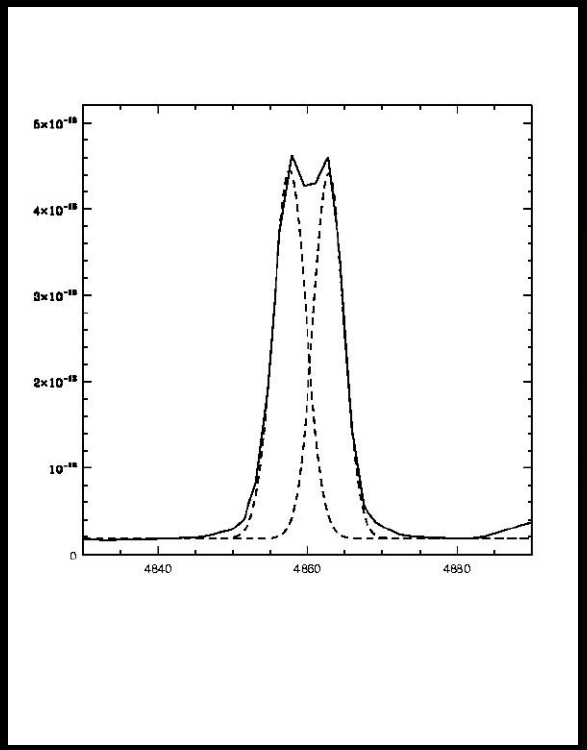
A single Gaussian

Without noise, one can have an infinite resolving power!





Two well separated, noisy Gaussians



Two nearby Gaussians

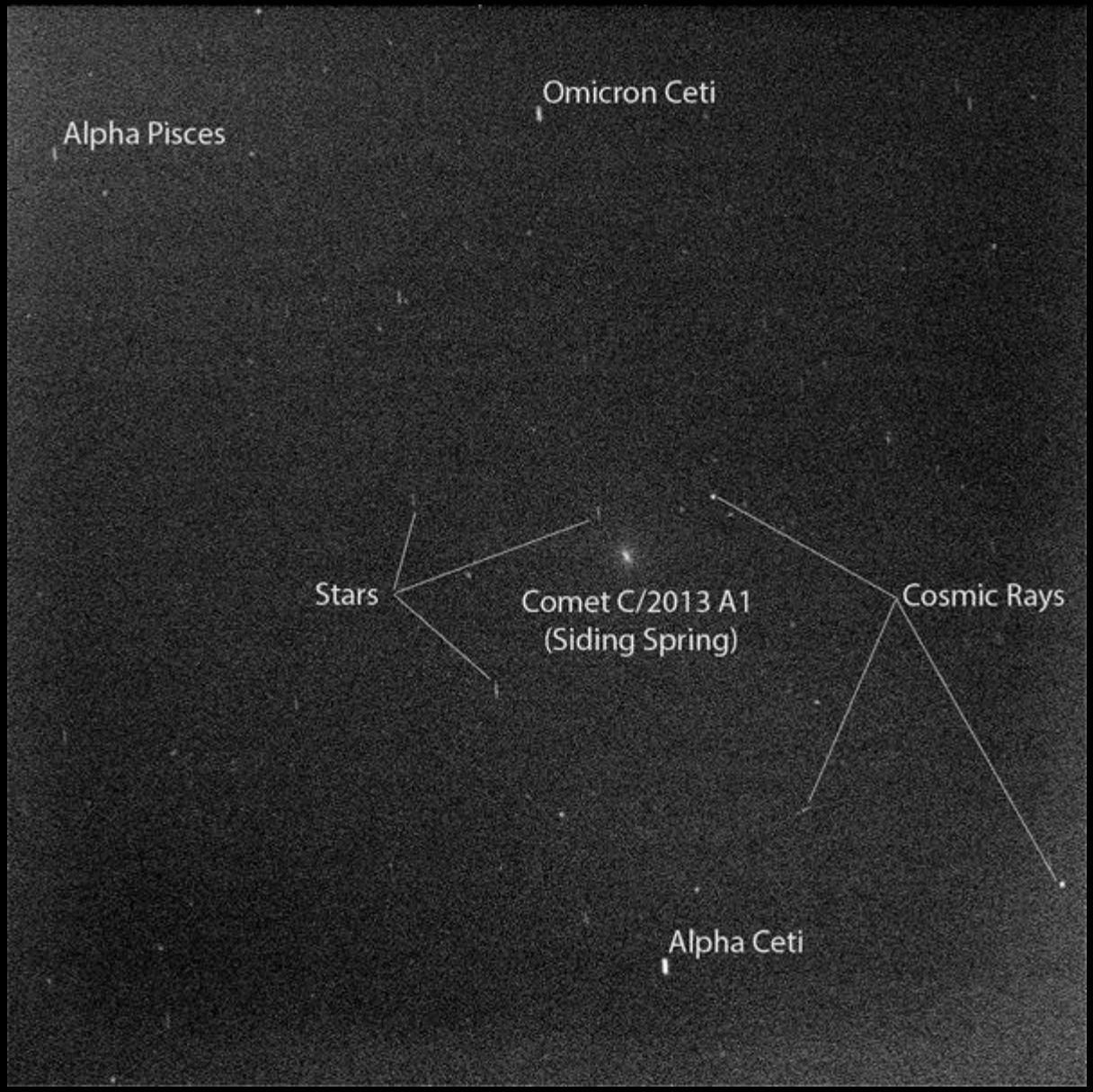
A double-star image

Grayscaling is an art!

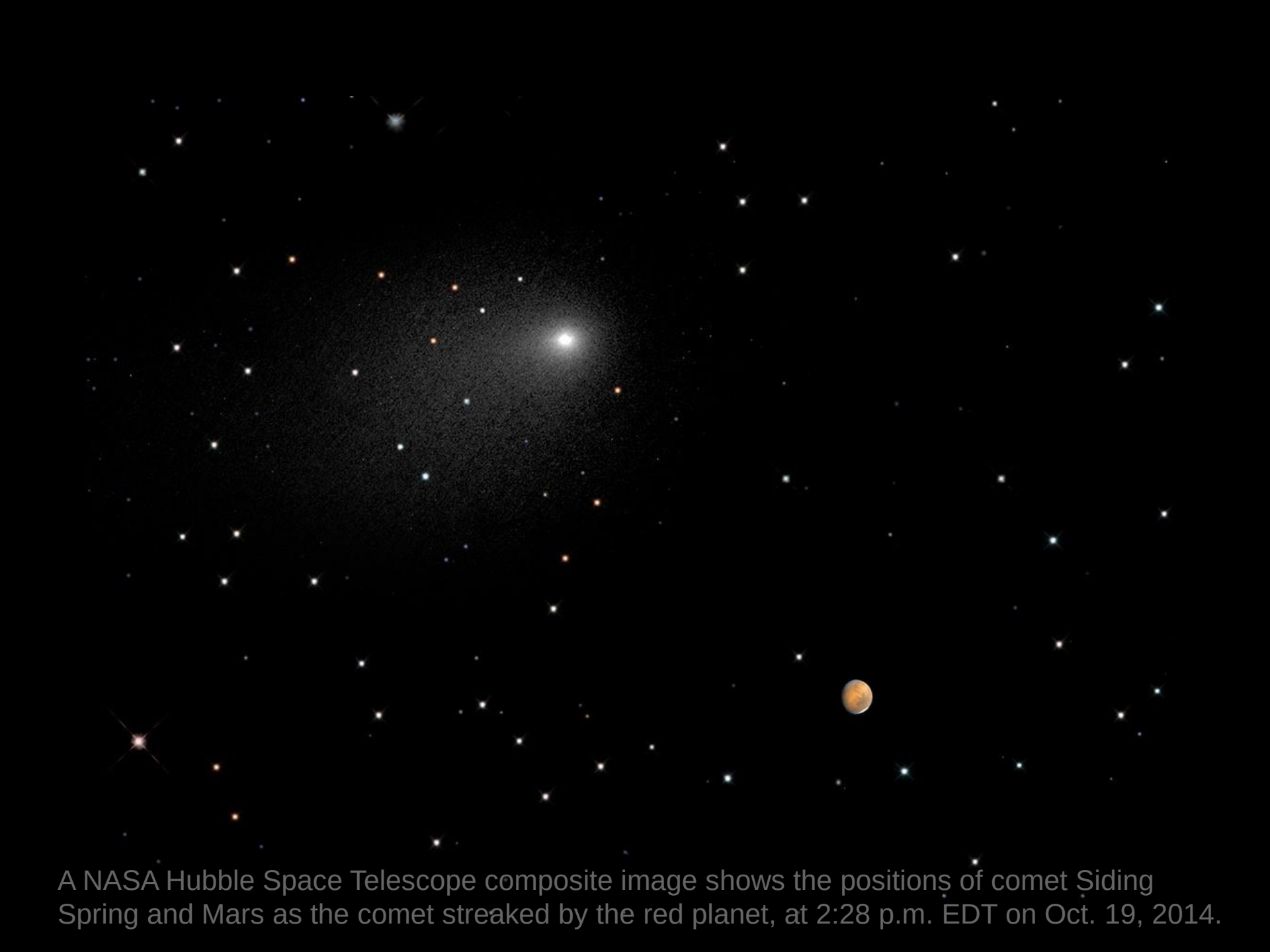
Diffraction Limit $\theta \propto \lambda/D$

D [m]	Θ["] ~1/ 8D
10	0.01
4	0.03
2	0.06
1	0.12
0.2	0.62
0.1	1.2

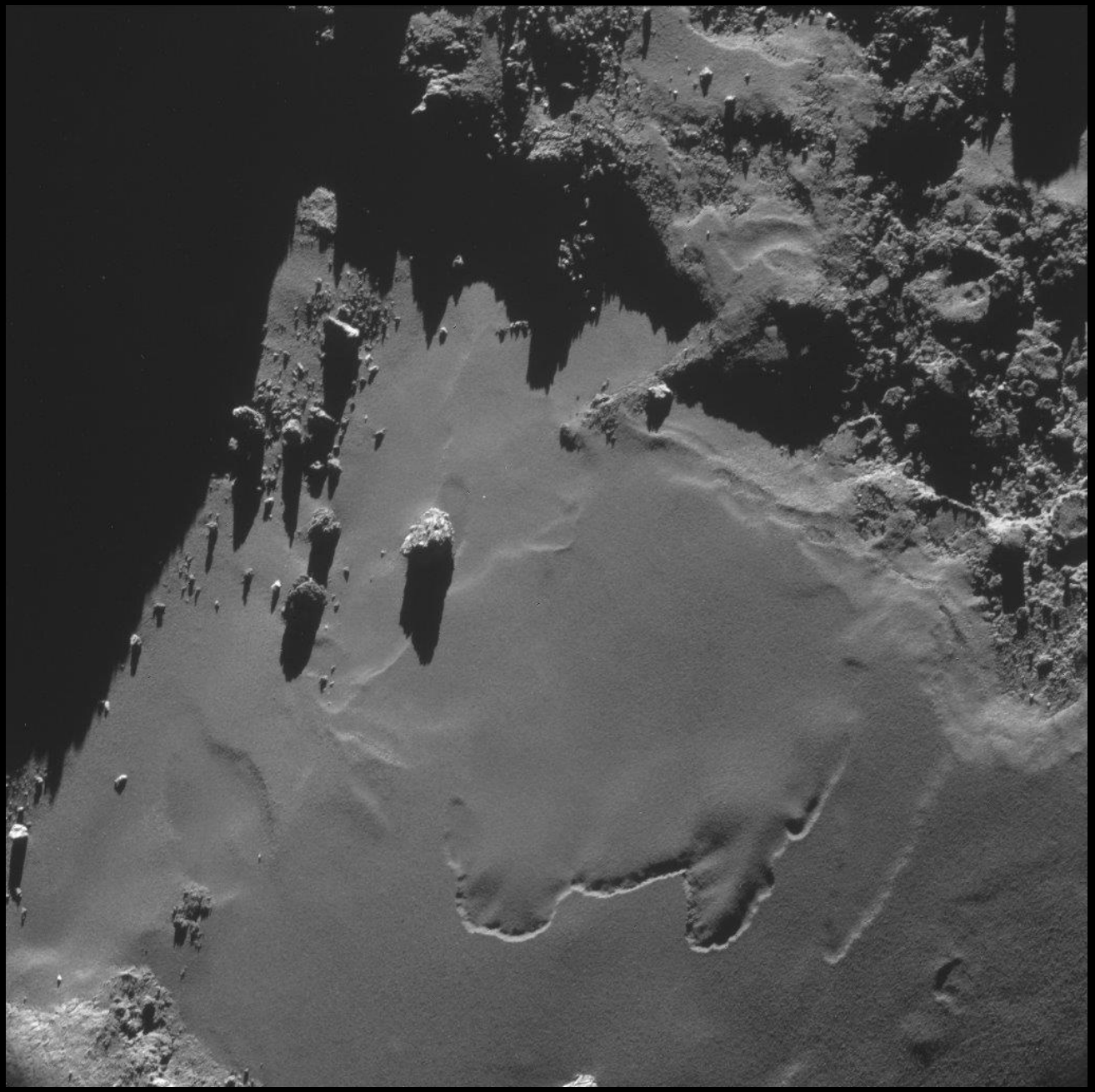
Comet C/2013 A1 (Siding Spring) passed Mars, 19 October 2014

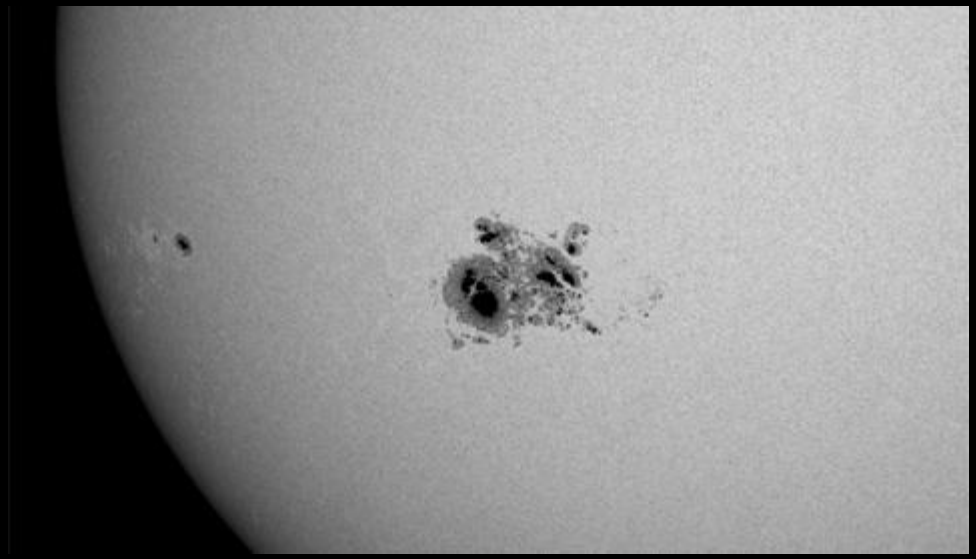


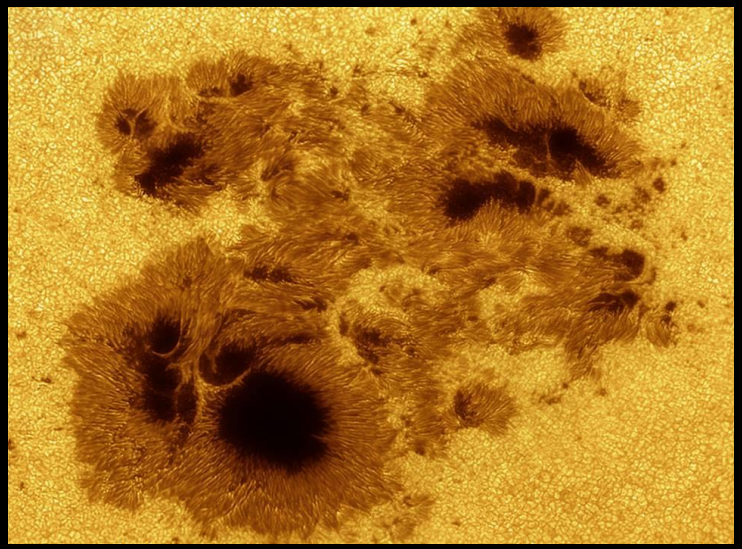
Seeing a comet from the surface of Mars

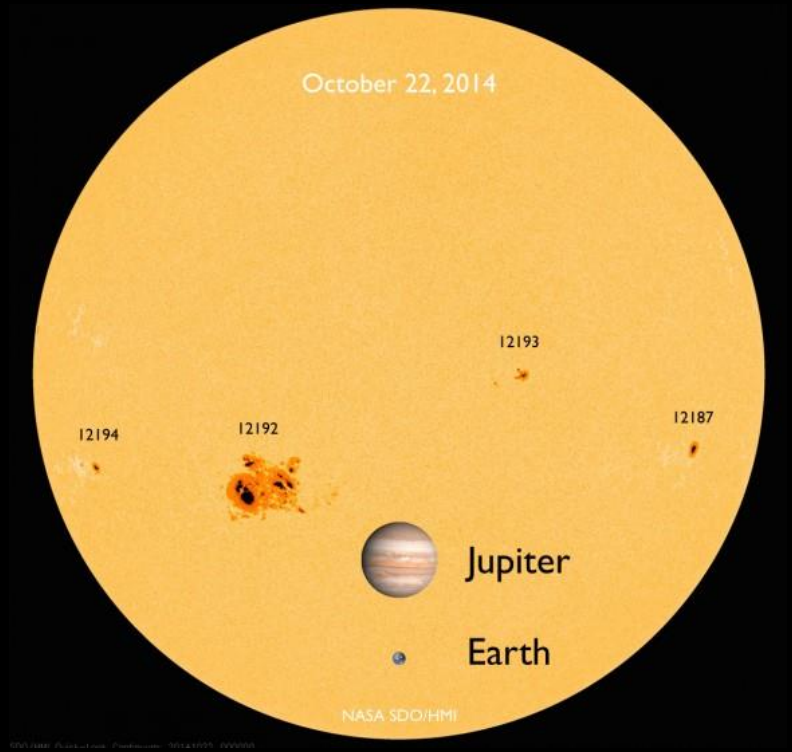


A NASA Hubble Space Telescope composite image shows the positions of comet Siding Spring and Mars as the comet streaked by the red planet, at 2:28 p.m. EDT on Oct. 19, 2014.

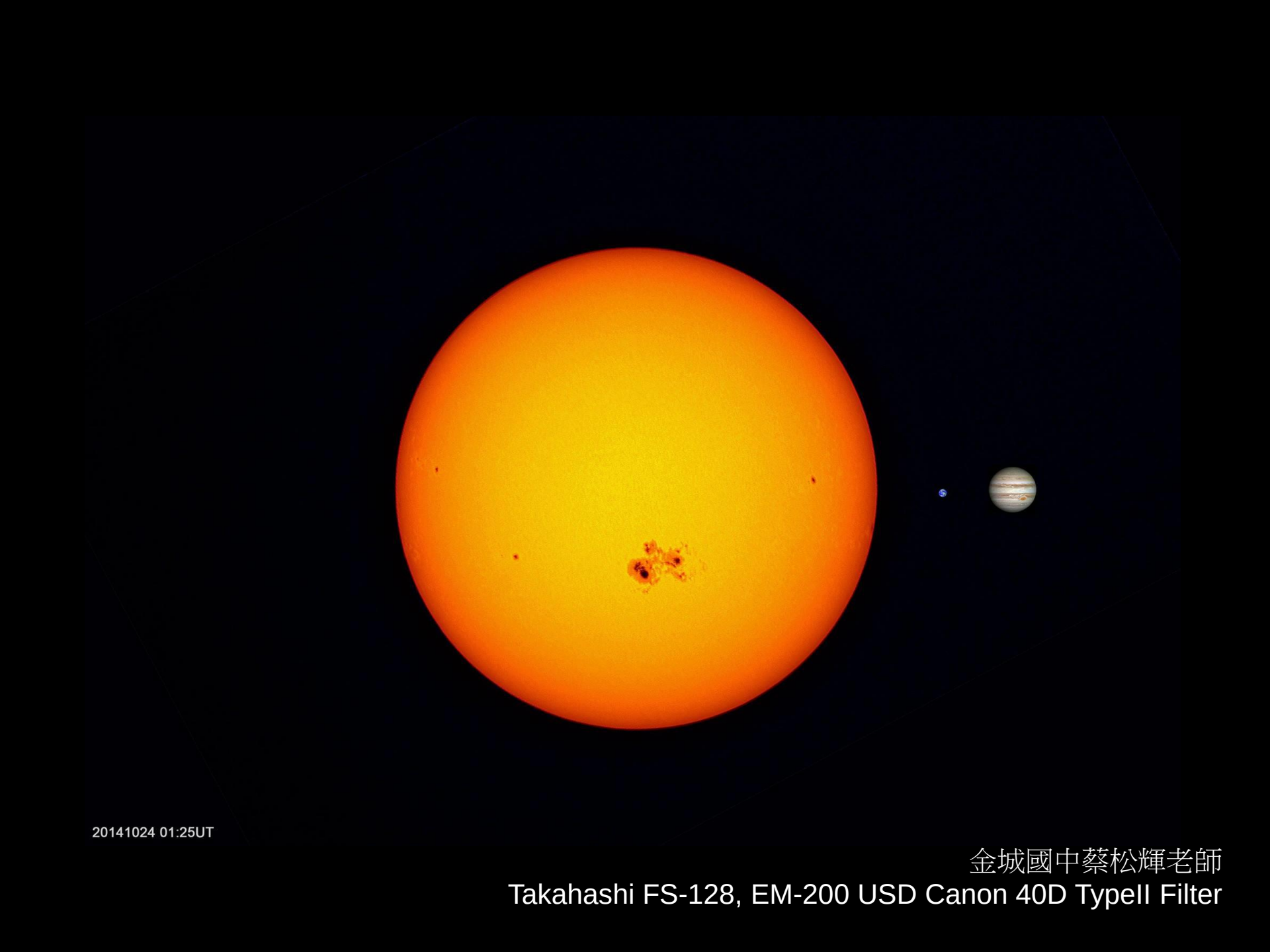






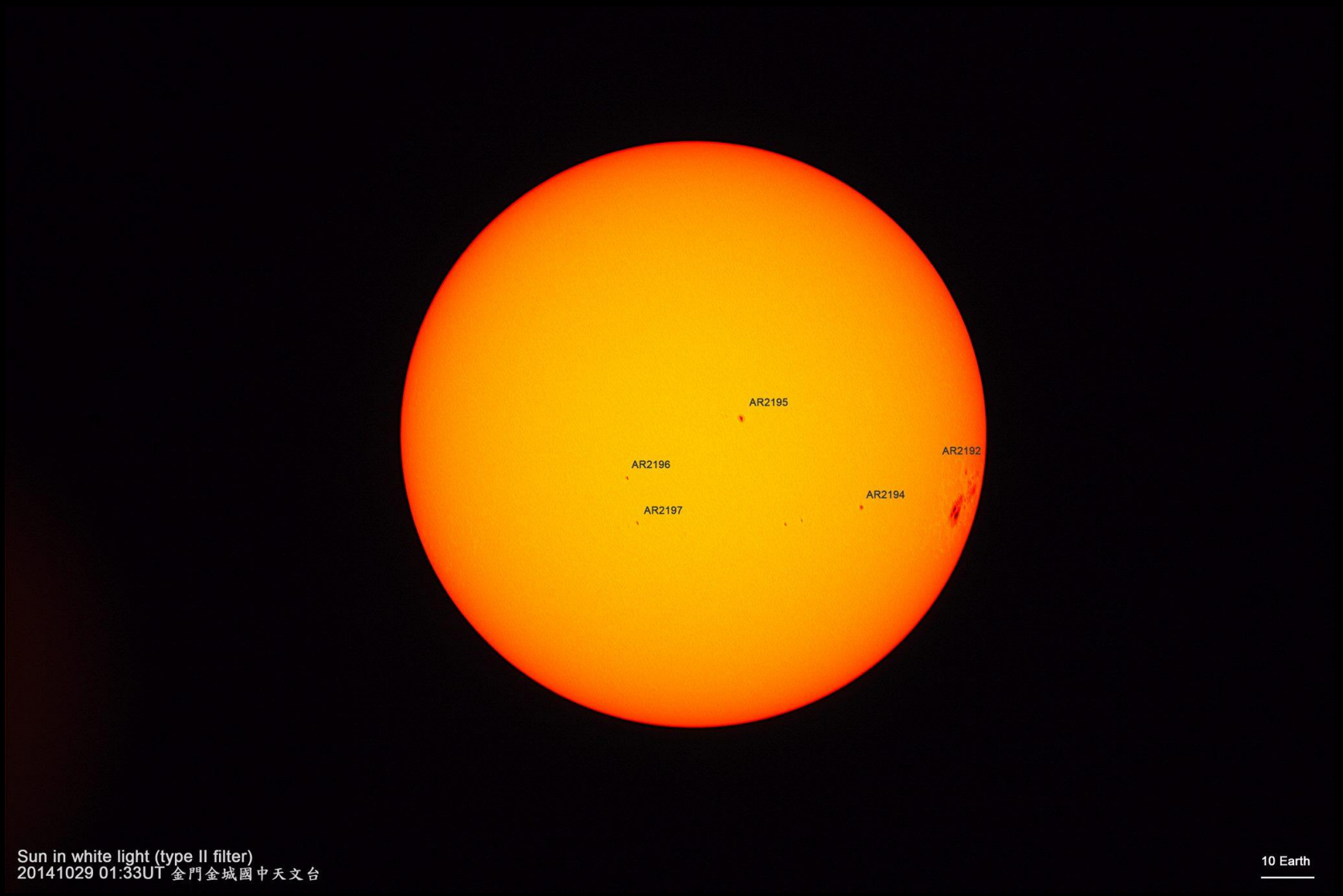


APOD: AR 2192: Giant on the Sun (2014 Oct 24)
Image Credit & Copyright: Randall Shivak
and Alan Friedman (Averted Imagination)



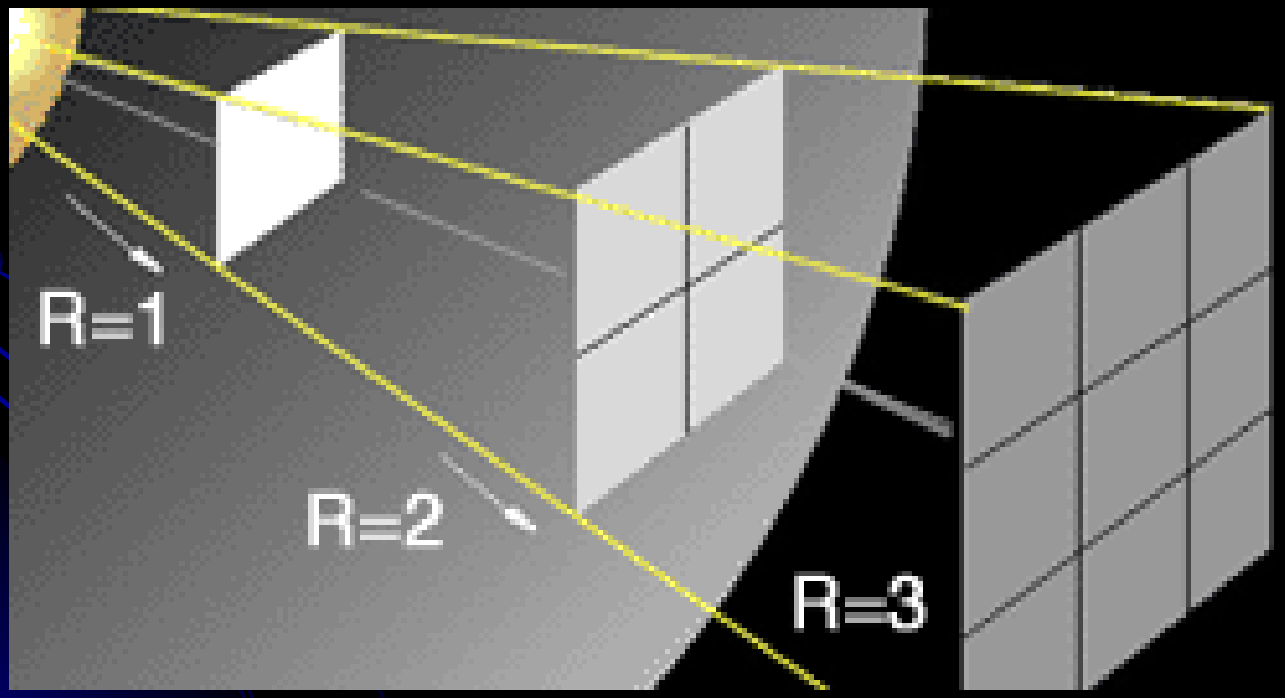
金城國中蔡松輝老師

Takahashi FS-128, EM-200 USD Canon 40D TypeII Filter

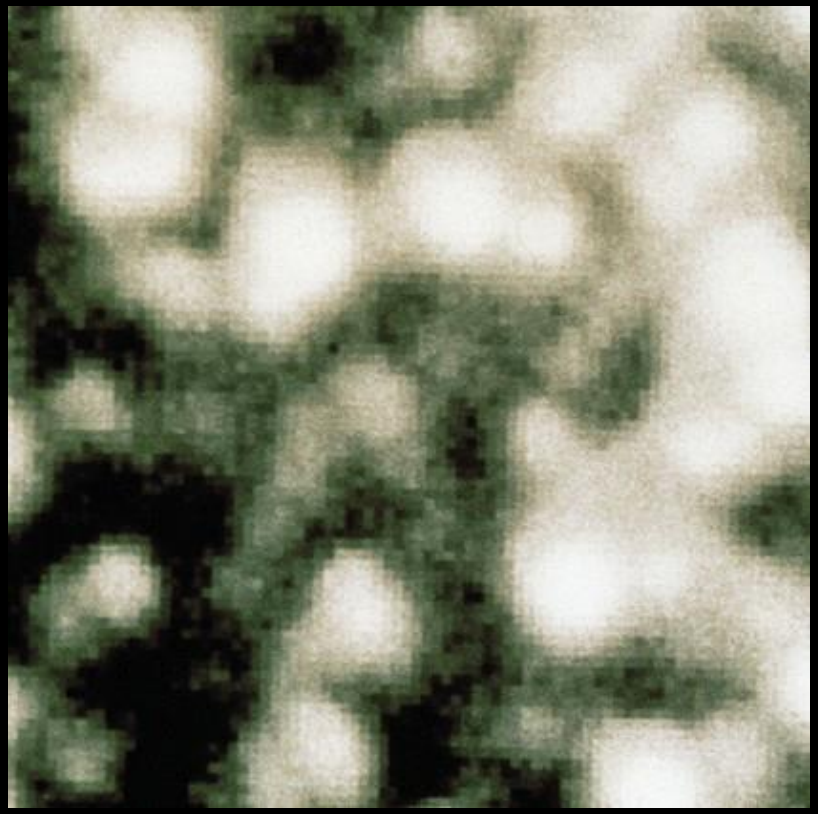

AR2195
AR2196
AR2192
AR2194
AR2197
Sun in white light (type II filter)
20141029 01:33UT 金門金城國中天文台
10 Earth

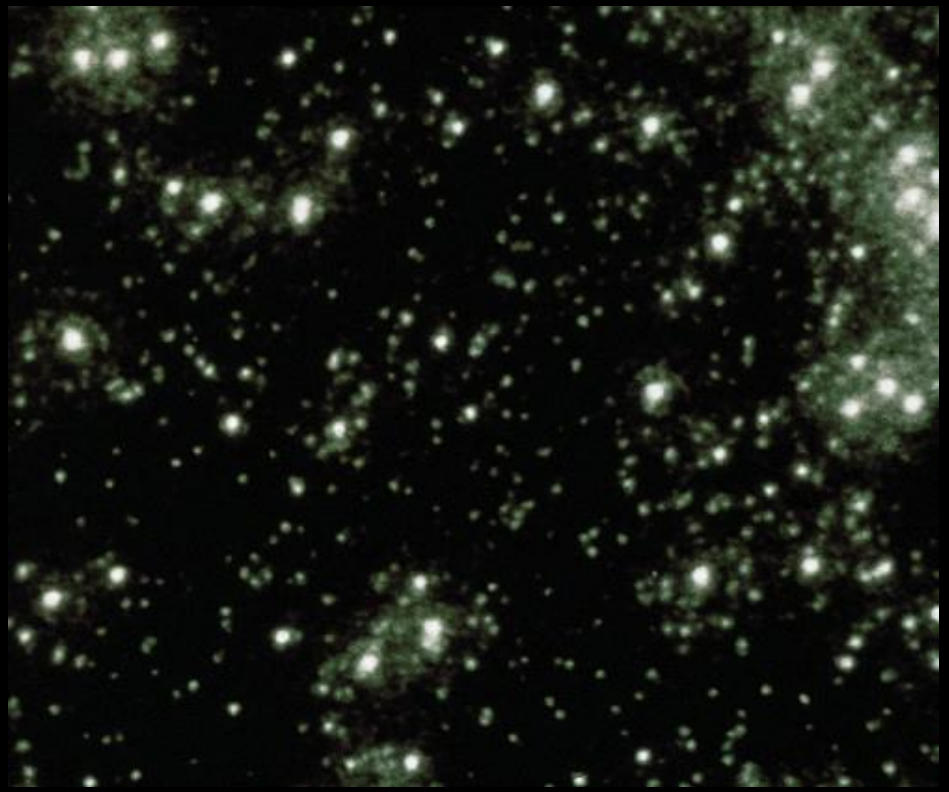

APOD

天體發出的輻射向四面八方傳播，分佈在球面上，隨時間（距離）而擴展。某地收到的強度，與距離平方成反比



空氣不斷流動，使得星星影像閃爍晃動，
在太空觀測則沒有大氣干擾的問題



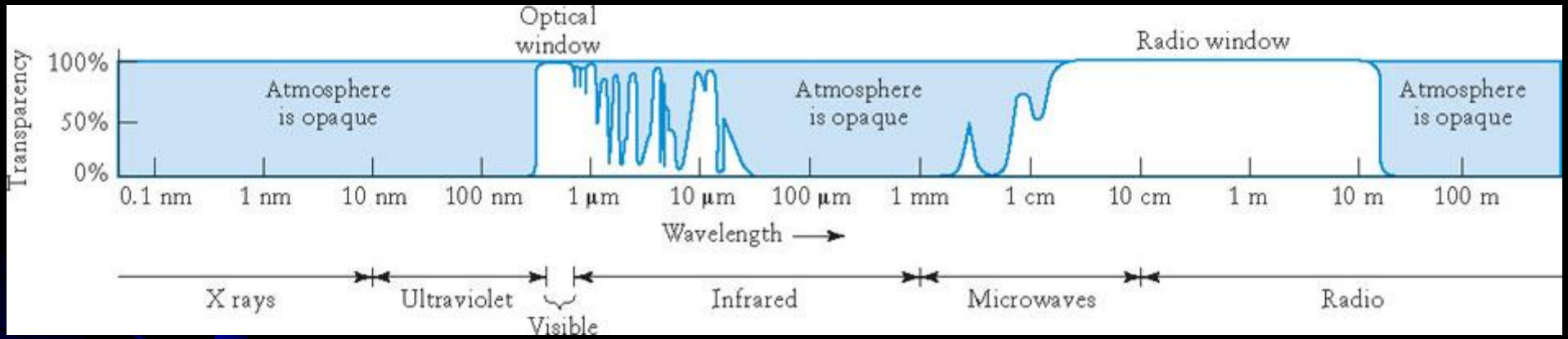


In a good site, seeing ~0.5”

Observing in Space

- 沒有大氣擾動 → 影像比較清晰
- 沒有大氣吸收 → 能夠接收到所有電磁波段
- 但是費用昂貴，且技術困難，限制了太空望遠鏡的口徑
  Hubble Space Telescope (HST) D=2.4 m;
  Subaru Telescope D=8 m;
  Keck I and I, D=10 m

Q: 月球表面呢？把望遠鏡放在月球表面有什麼優點，有什麼缺點？


Optical window
Radio window
Transparency
100%
50%
0%
Atmosphere is opaque
Atmosphere is opaque
Atmosphere is opaque
0.1 nm
1 nm
10 nm
100 nm
1 μm
10 μm
100 μm
1 mm
1 cm
10 cm
1 m
10 m
100 m
Wavelength
X rays
Ultraviolet
Visible
Infrared
Microwaves
Radio

Hubble Space Telescope

Spitzer Space Telescope

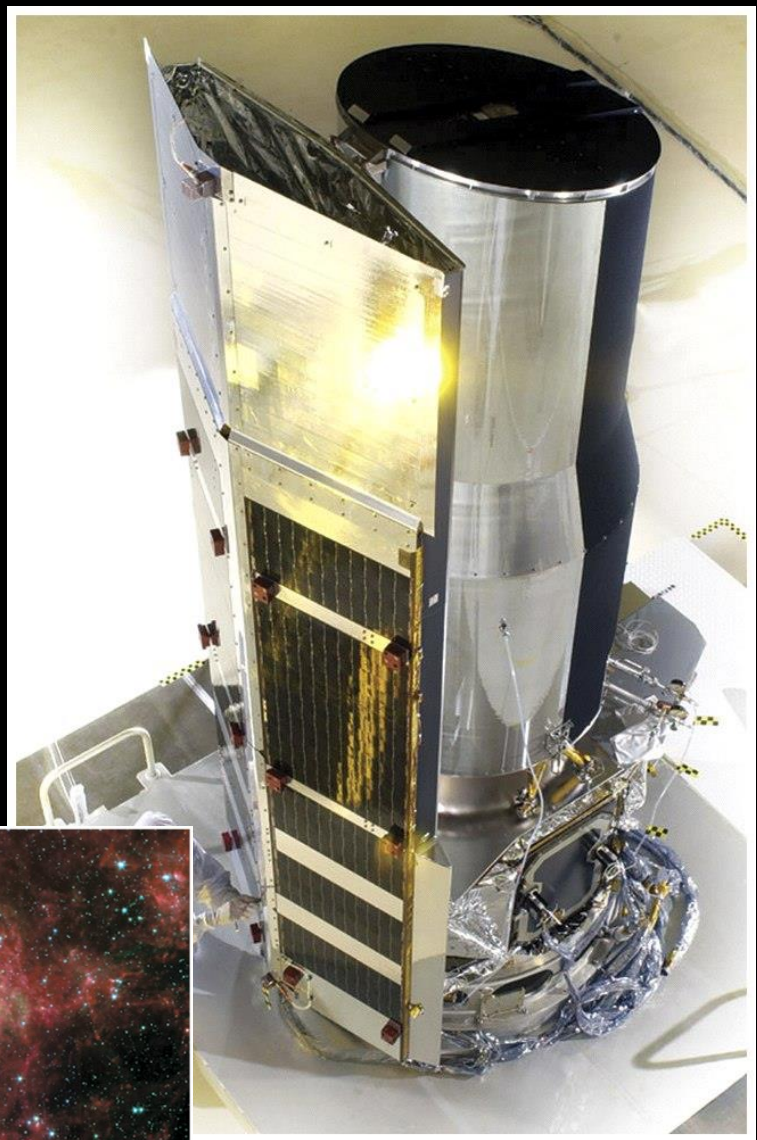
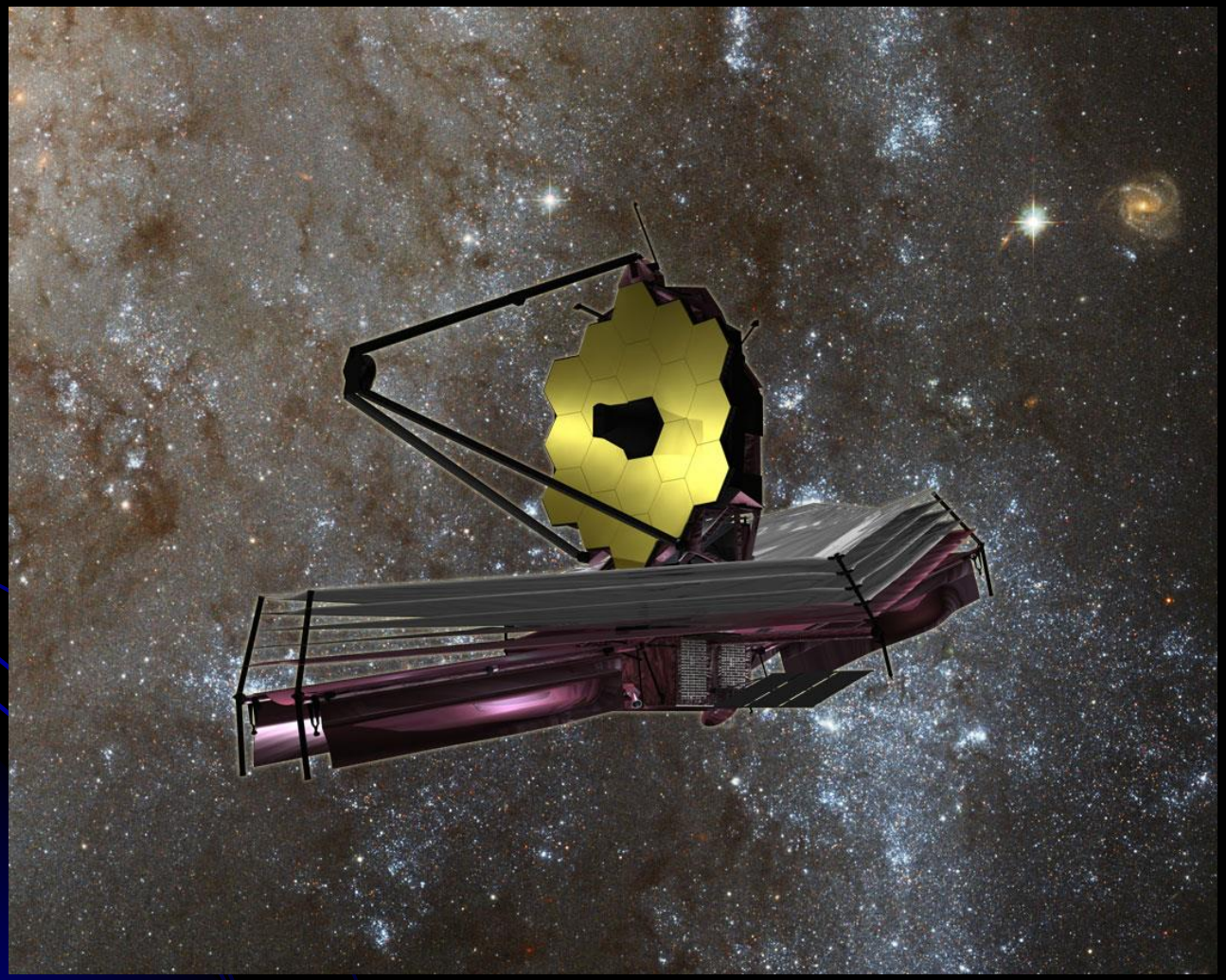


Figure 3-32b inset
Discovering the Universe, Seventh Edition
© 2006 W. H. Freeman and Company

James Webb Space Telescope (JWST)
新一代太空望遠鏡



口徑
6.5 m

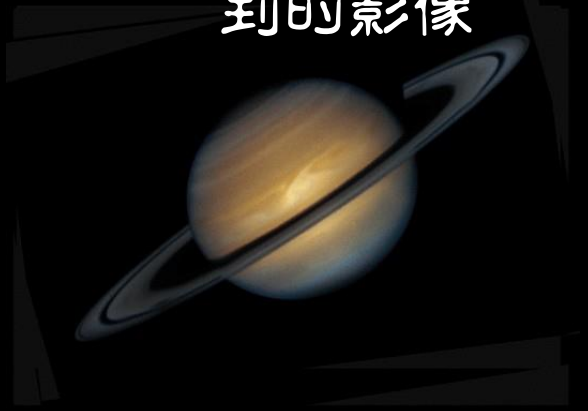
都市照明的光害使得夜空明亮，影響天文觀測

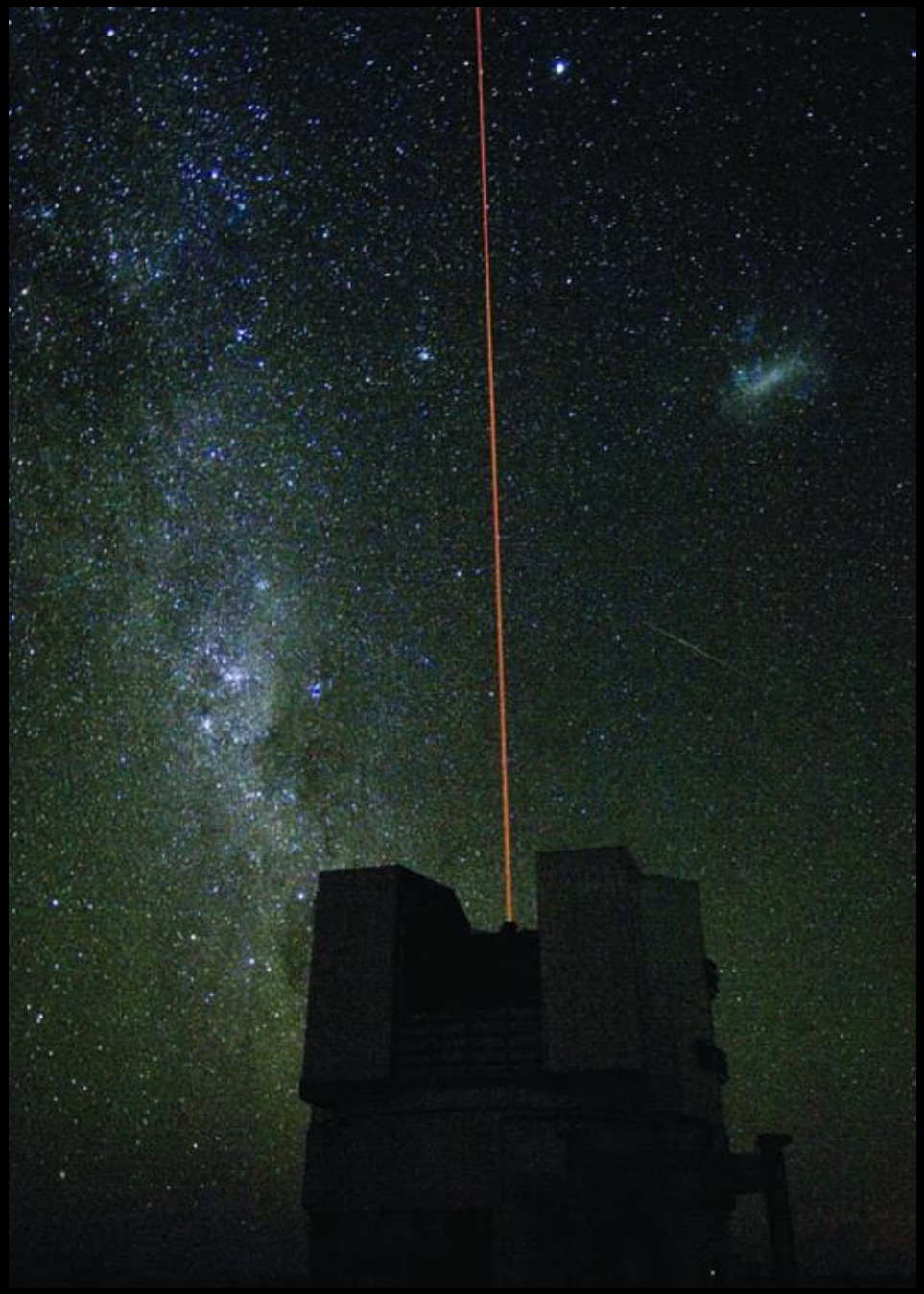
Adaptive optics 自適應光學

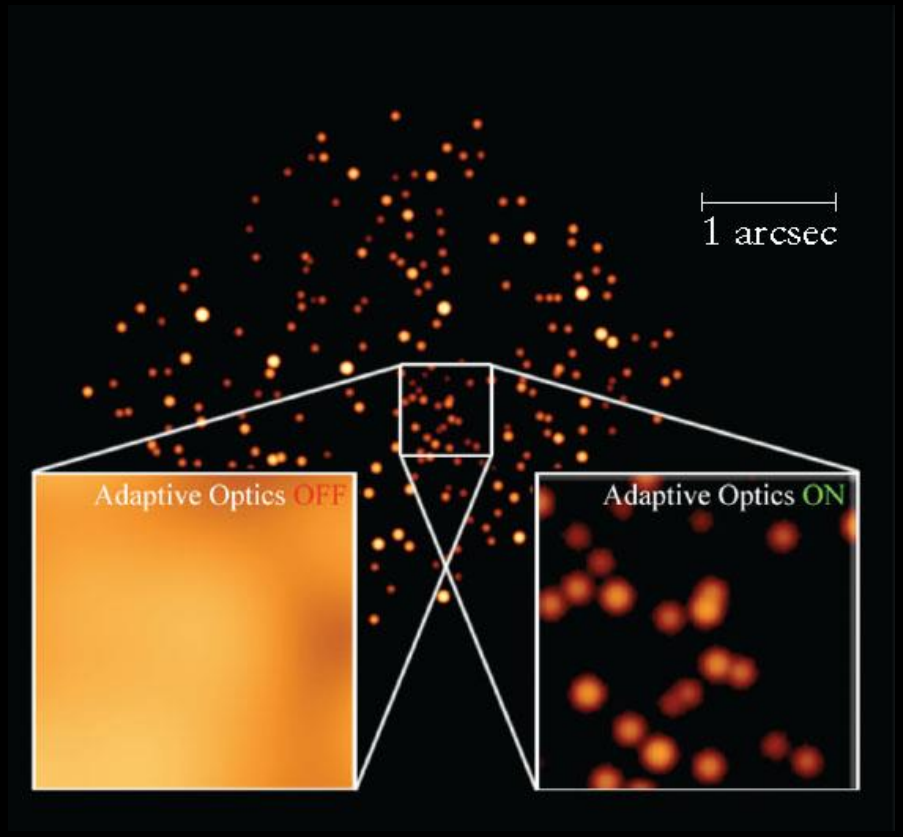
一般地面影像

利用特殊技術減少大氣干擾的地面影像

太空中拍攝到的影像

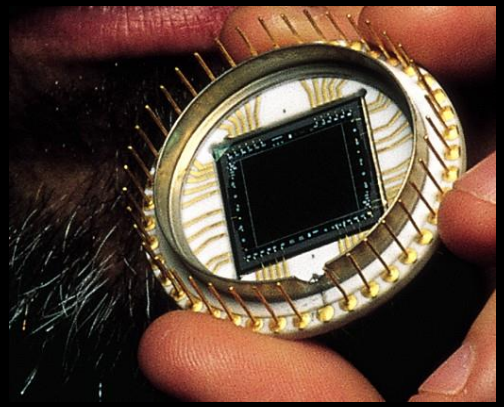


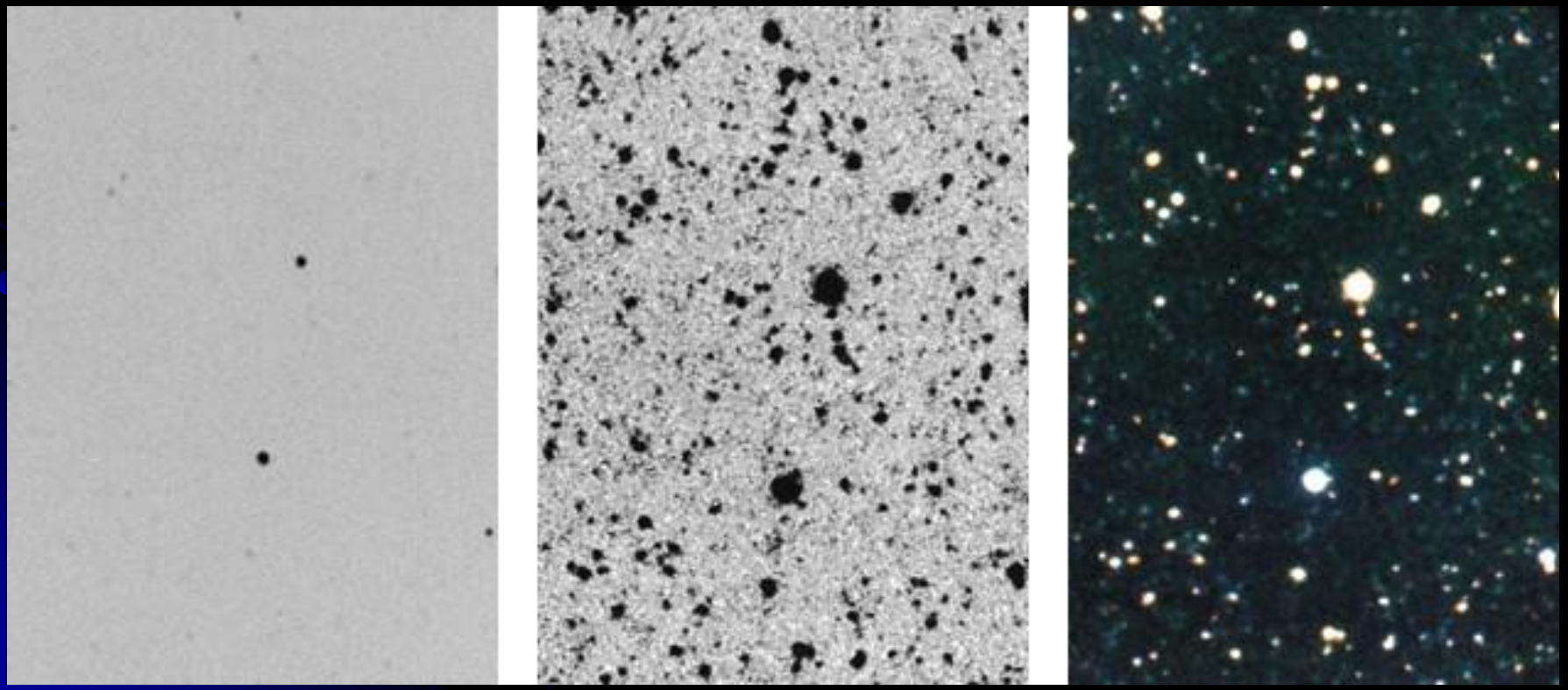


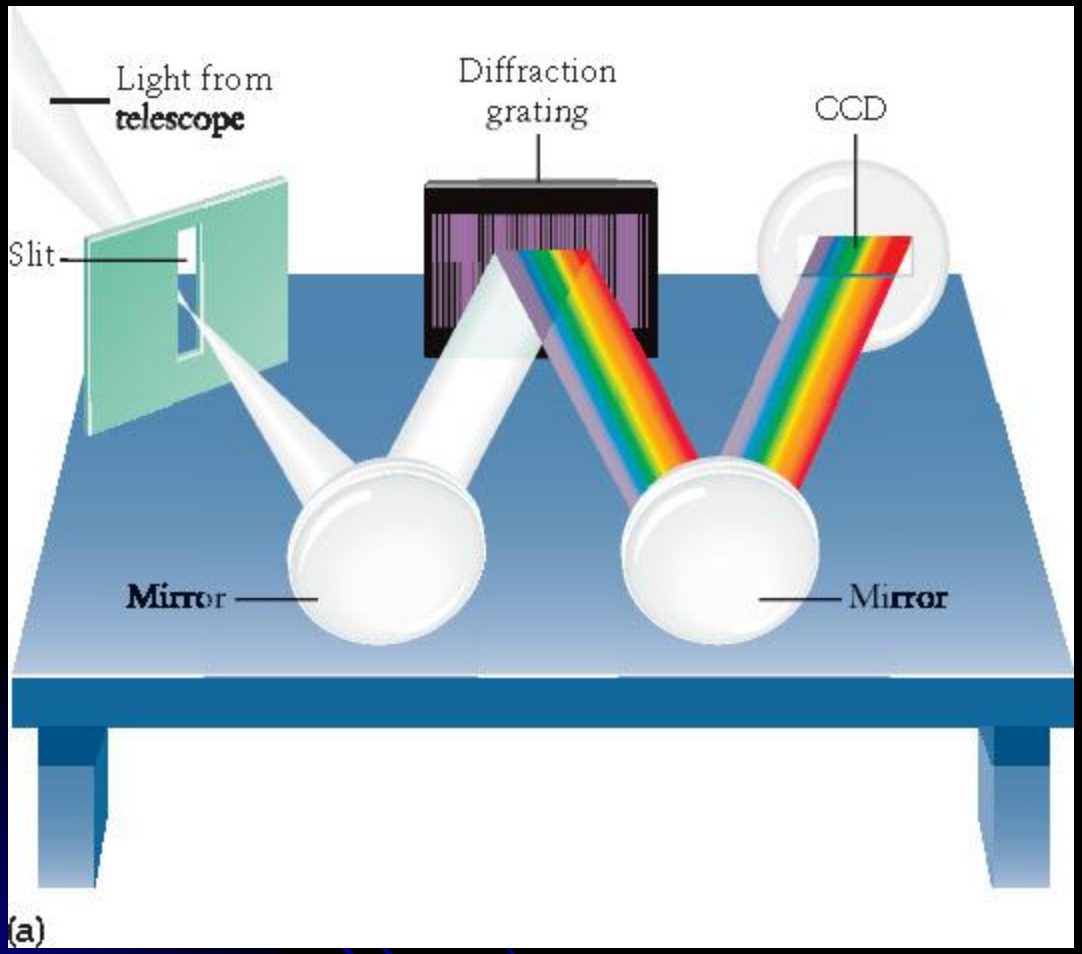

1 arcsec
Adaptive Optics OFF
Adaptive Optics ON

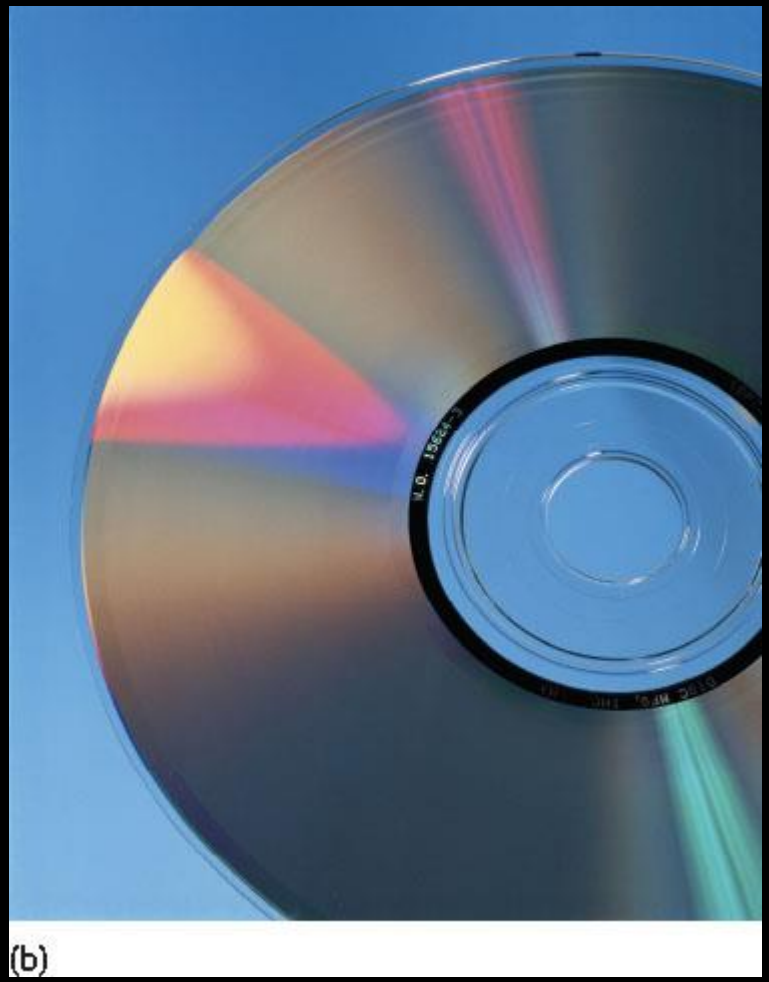
偵測器 —— 將光線轉變成可記錄的訊號

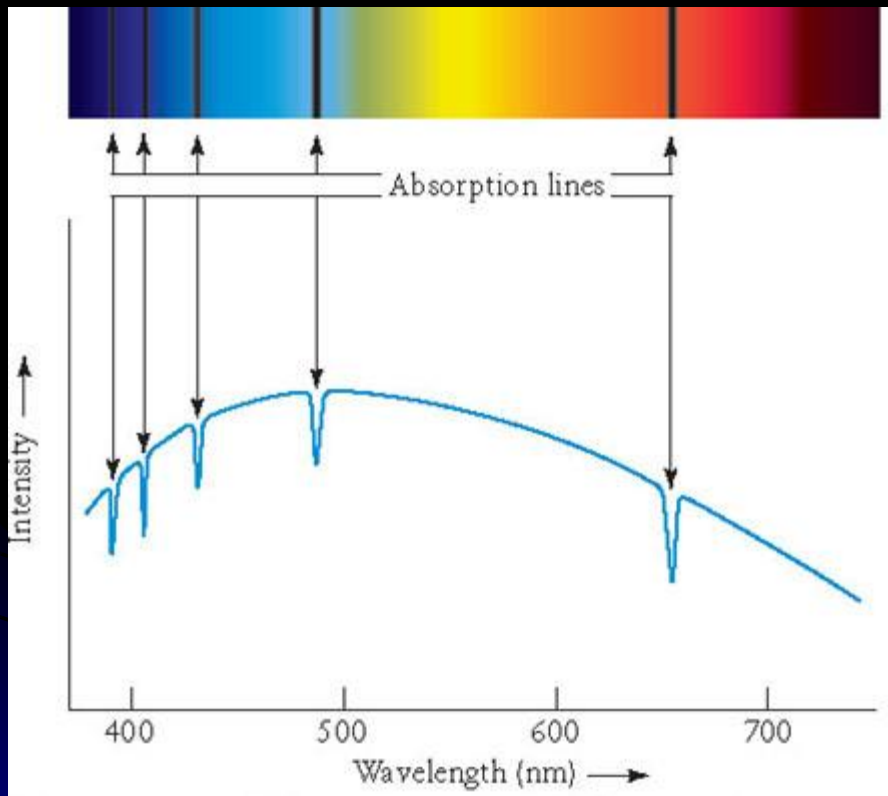
Charge-coupled device (CCD)



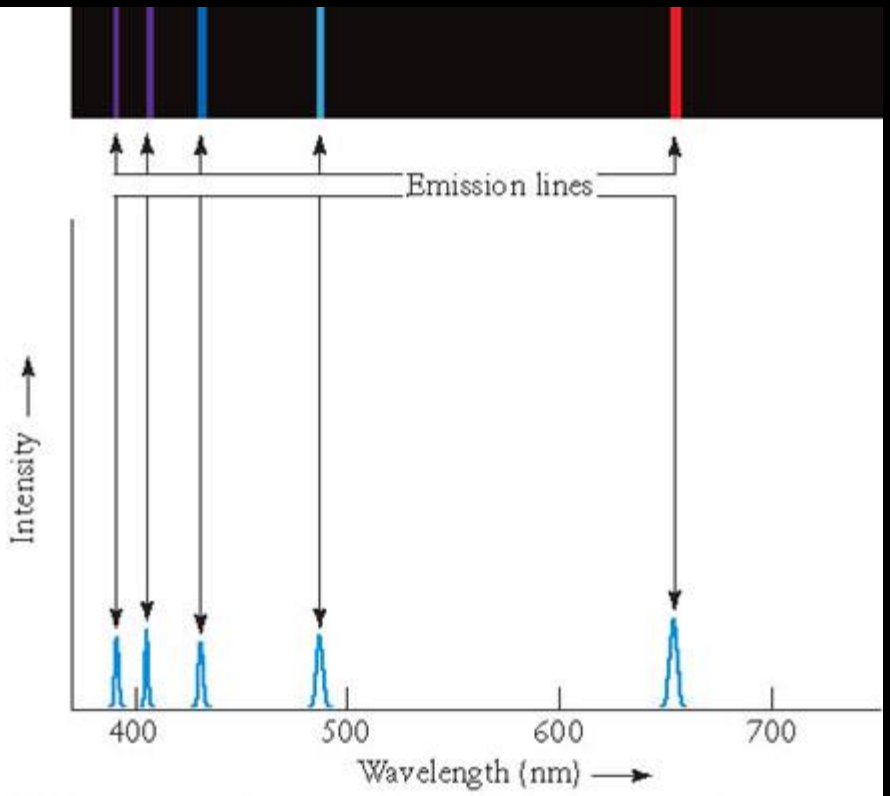



Light from
telescope
Diffraction
grating
CCD
Slit
Mirror
Mirror
(a)

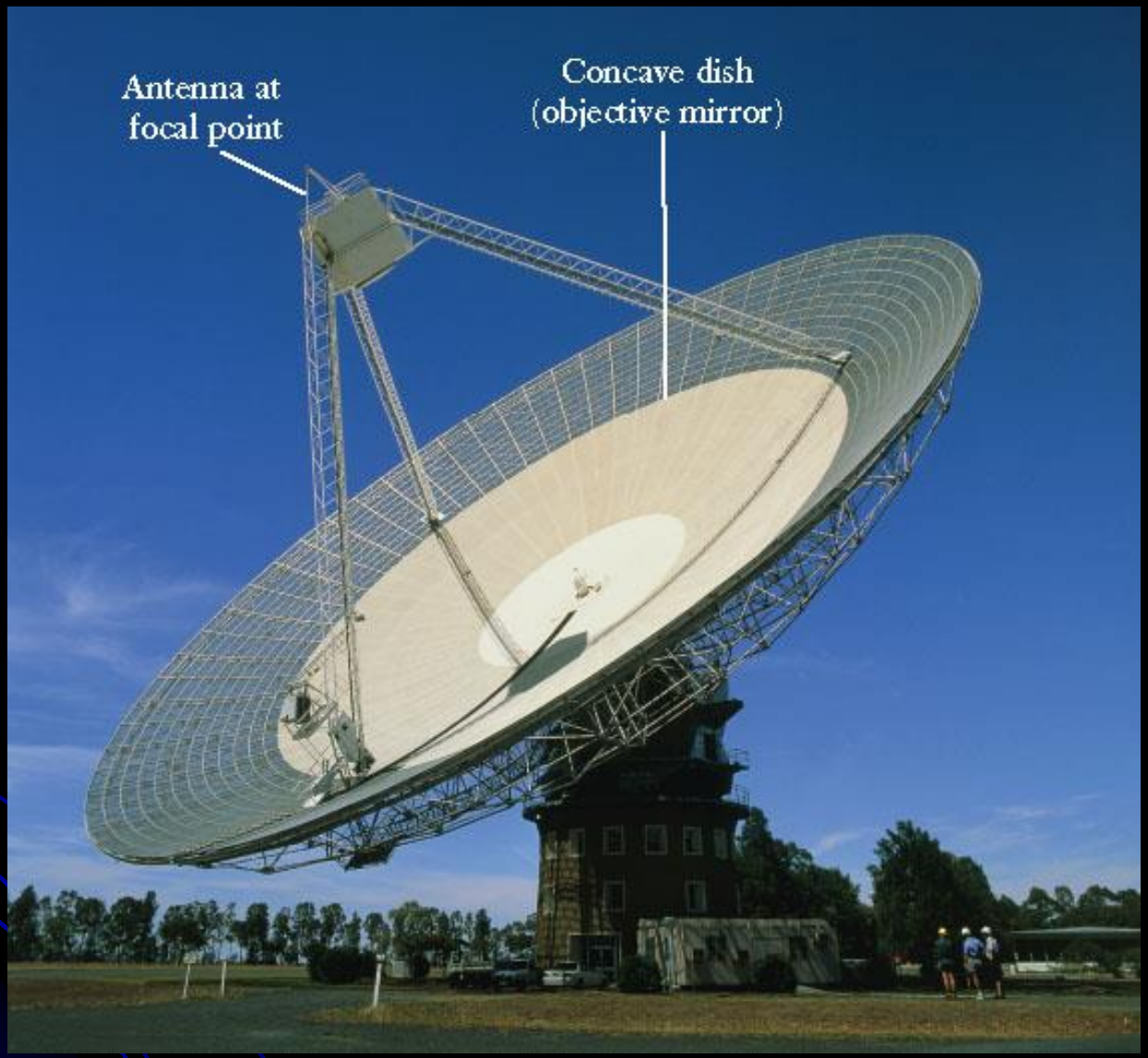

(b)



(a) Two representations of an absorption line spectrum

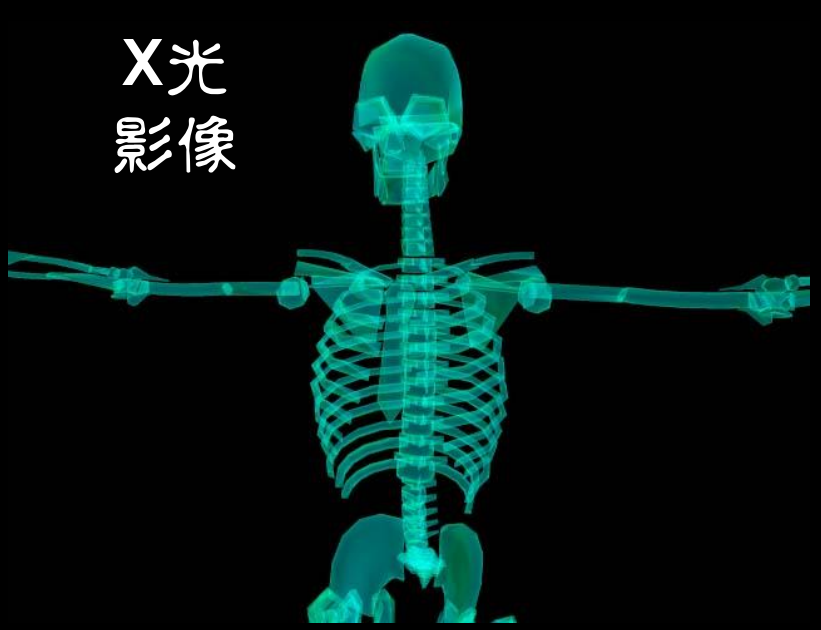


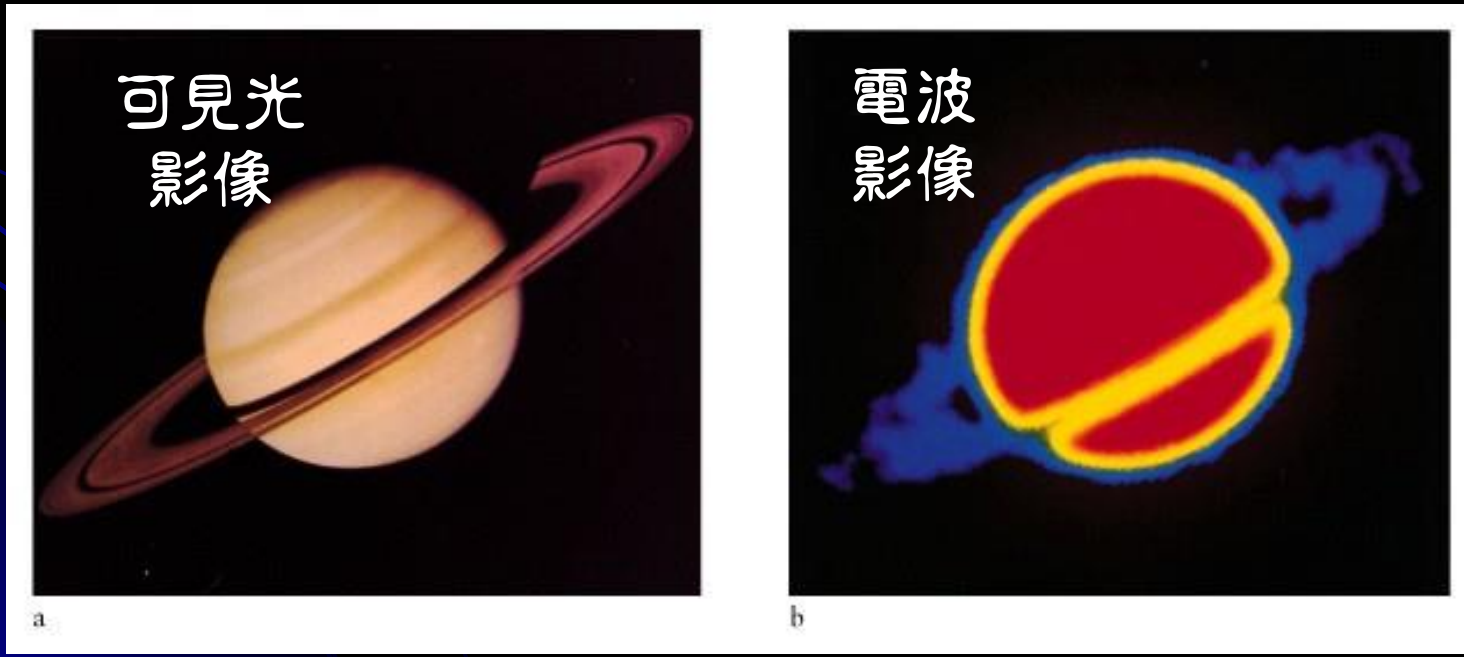
(b) Two representations of an emission line spectrum

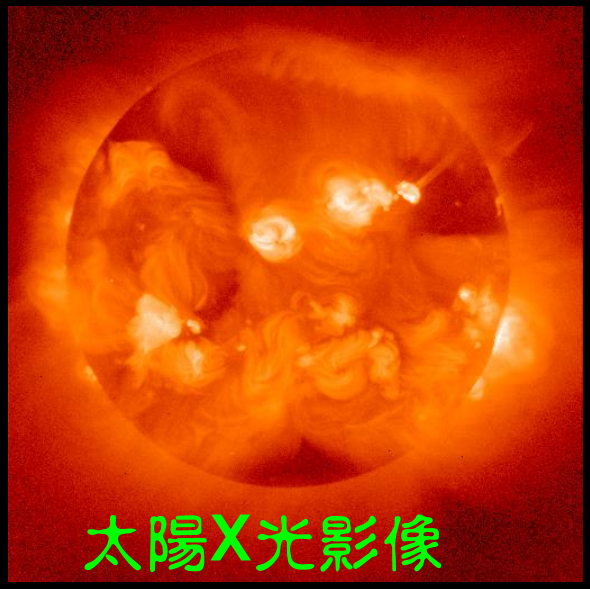


（無線）電波望遠鏡（碟型天線）

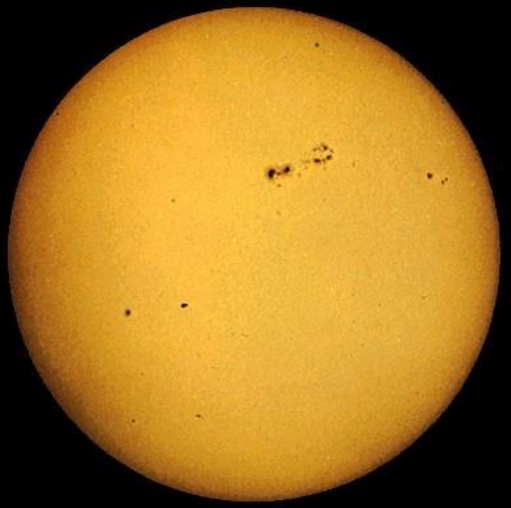

可見光
影像


X光
影像

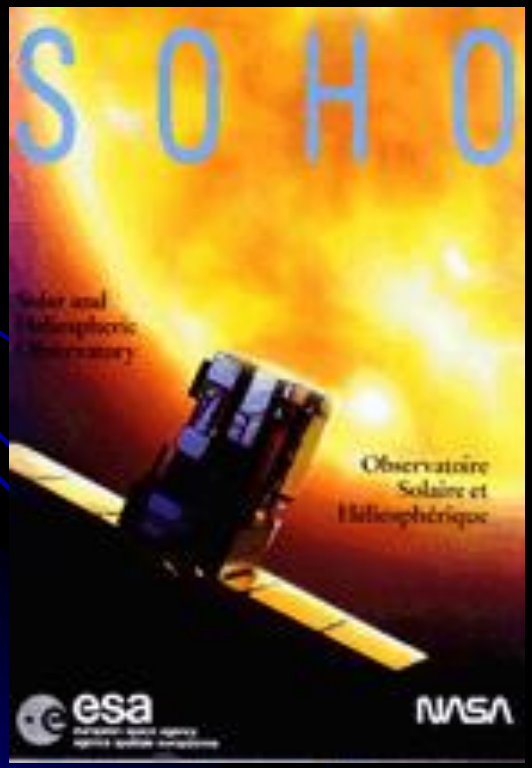

可見光
影像
電波
影像
a
b



太陽X光影像



太陽可見光影像

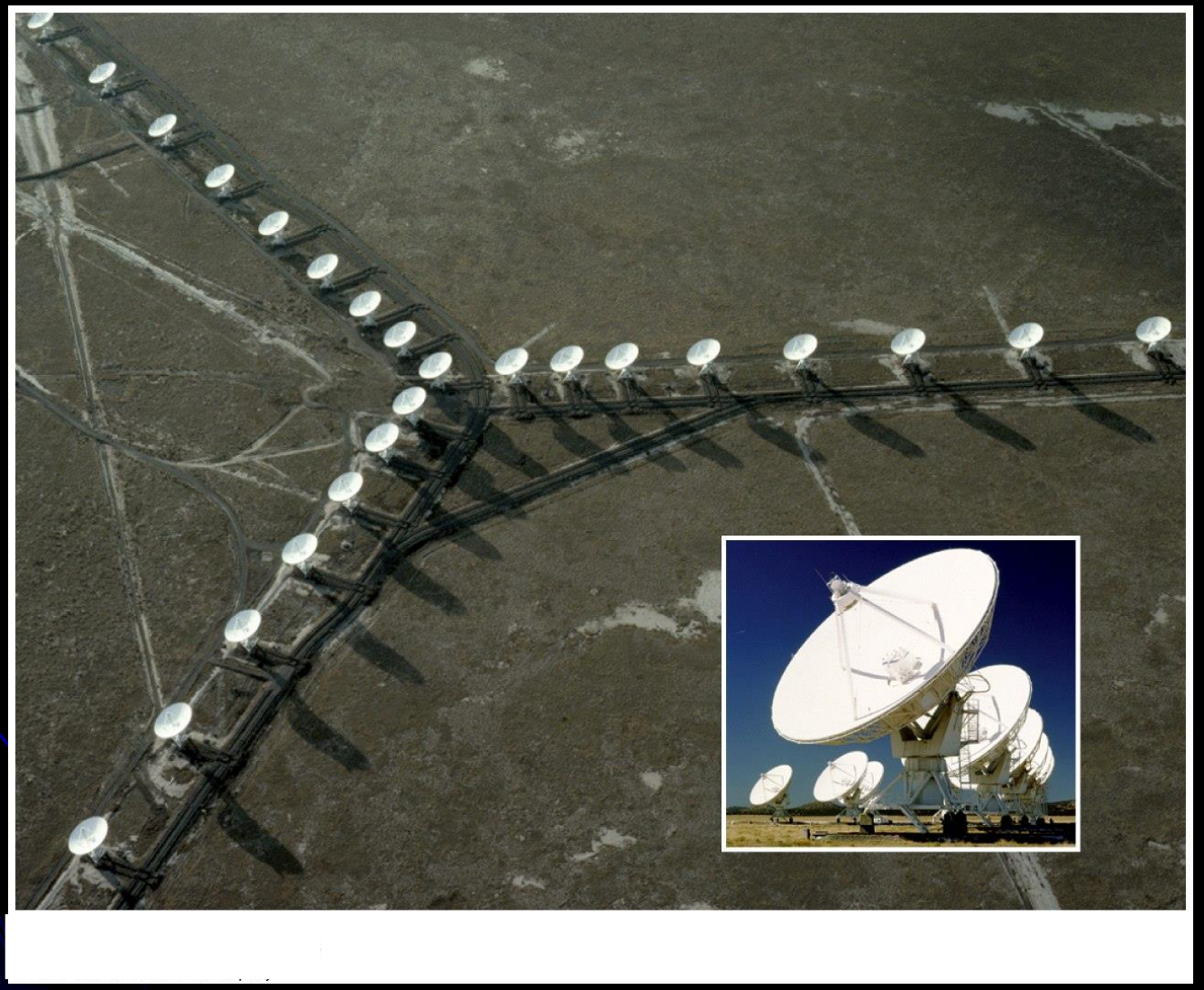


利用干涉術 (interferometry) 提高解析力
例如電波望遠鏡陣列 Very Large Array (VLA)

27 x 25 m antennas in New Mexico, USA

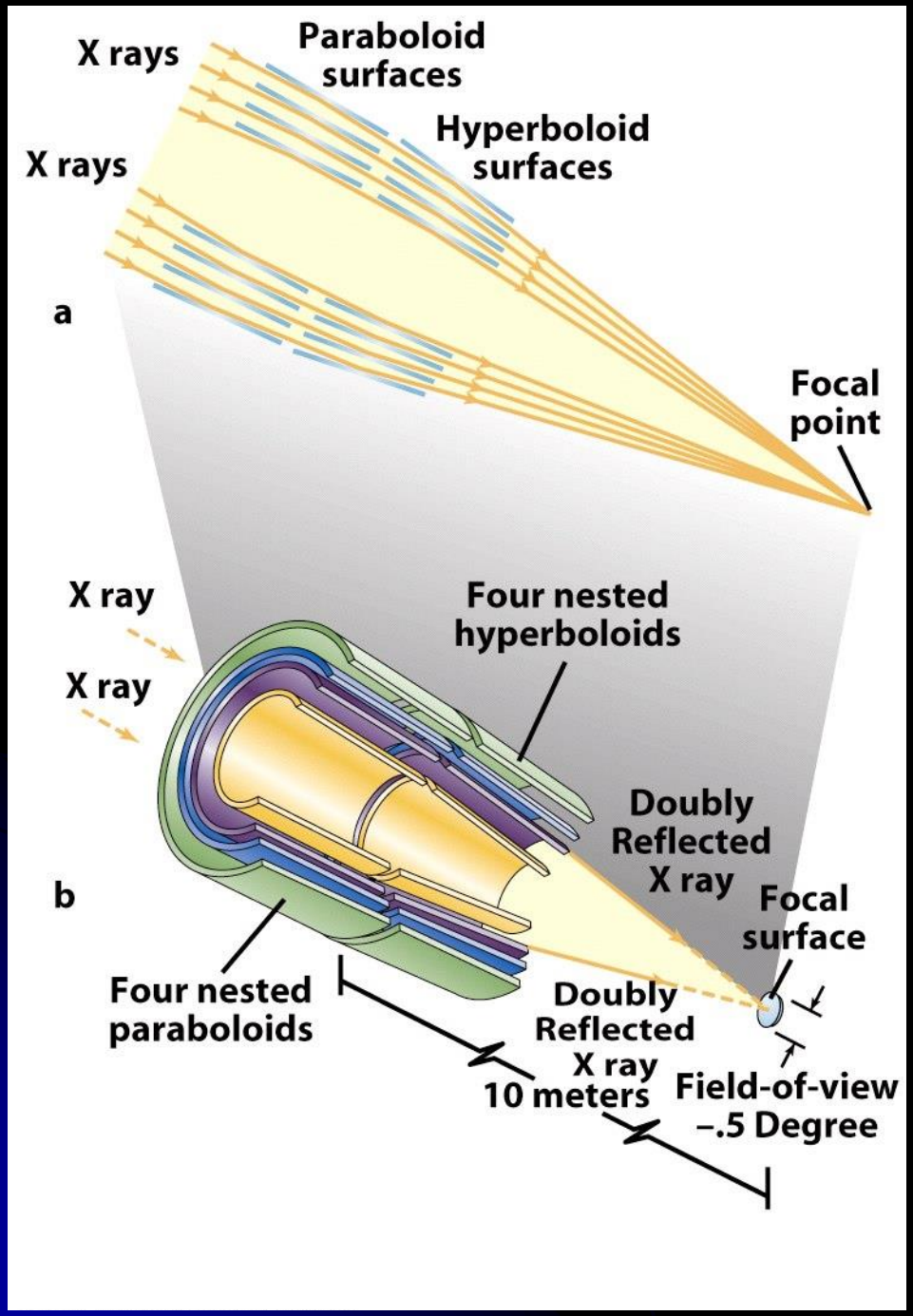
Sensitivity as a 130 m dish

Resolution as 36 km across



Atacama Large Millimeter/submillimeter Array (ALMA) 為毫米波與次毫米波望遠鏡陣列，位於智利5千公尺高原 (50 x 12 m + 12 x 7 m)

光學與紅外線干涉儀
Very Large Telescope (VLT)



Chandra X-ray Telescope

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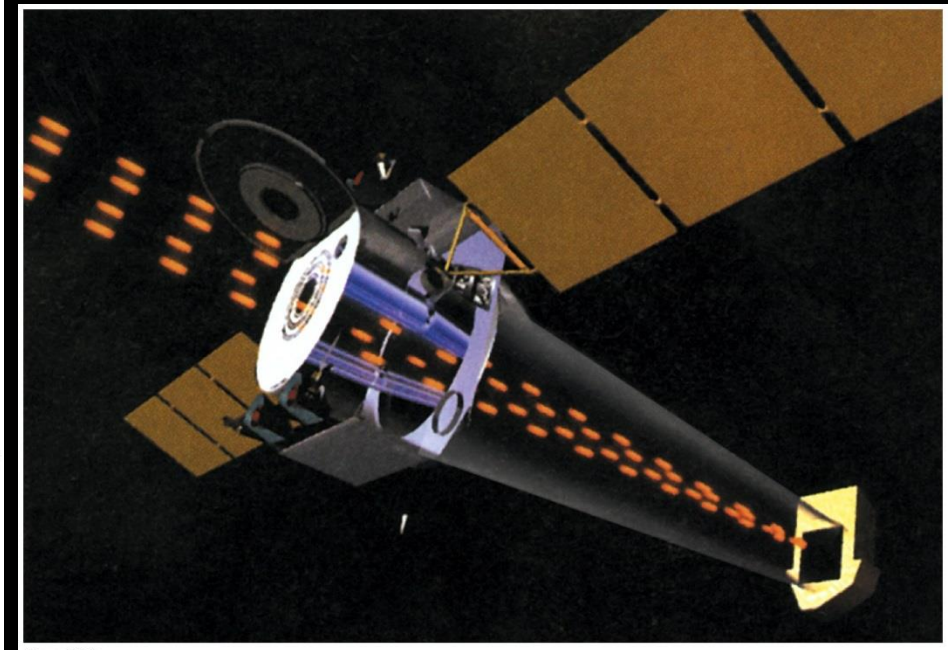
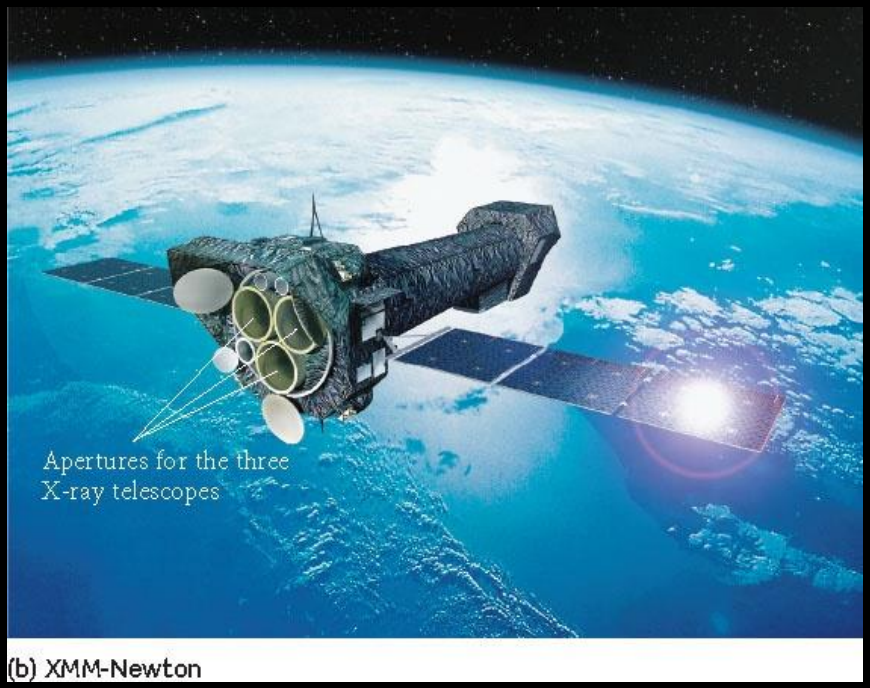
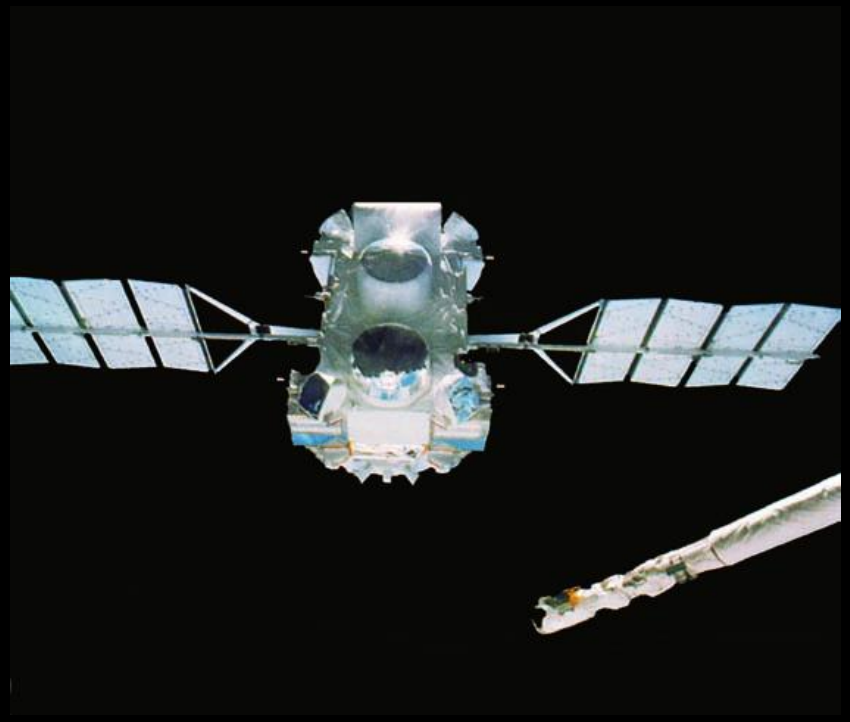




(b) XMM-Newton

XMM-Newton X-ray Telescope



Compton Gamma-ray Telescope