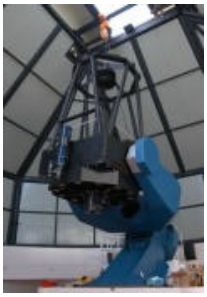
Telescope



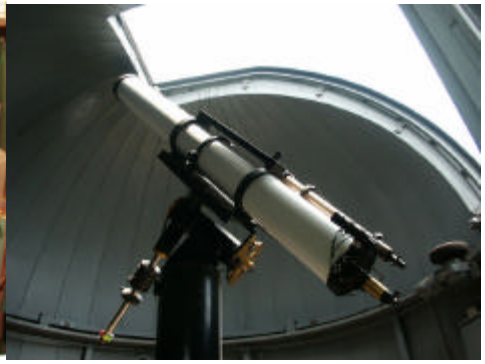
用透鏡 (lens) 或面鏡 (mirror)
「收集光線」並「成像」

- **收集光線**（廣義的說，收集電磁波）

  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



- **成像** （口徑不同部份產生互相干涉的像）

口徑越大，看得越清楚（成像越清晰）
最小的角度（細節） θ =1.22 λ/D radian
乃望遠鏡的「繞射極限」 (diffraction limit)
又稱 Dawnes' limit
解像力 (resolving power) ∝ D
(*What does resolving power mean anyway?*)

q '' = λ/D = l (㎜) / 4D(m)

e.g., λ =500nm= 0.5 μm, θ=1/ 8D(m)

∴ D=1 m, θ=0.125"

Diffraction Limit θ μ λ/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

Q: At what distance, a $10 coin would subtend an angle of 1”?

Q: What is the diffraction limit of the Hubble Space Telescope, observing in visible wavelengths?

Q: What is the angle between two stretched arms of a person on the surface of the Moon, seen from the Earth?

但實際在地面上無法看得如此清楚

∵ 大氣擾動造成星點影像晃動

$\theta \sim$ several arcseconds

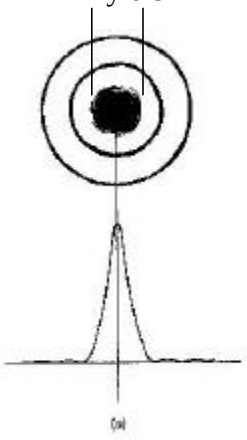
（有如游泳池水晃動，造成池底光影搖曳）

良好的天文觀測地點（氣流穩定的高山上）

視相（大氣寧靜度；seeing) $<$ 1“，**遠大於望遠鏡的繞射極限**

∴ 將望遠鏡置入太空，或起碼放在高海拔的地方，頂上空氣 column water vapor **越少越好，起碼應在逆溫層** (inversion layer) **之上**

中央亮點
Airy disk



Diffraction pattern of a point source

Spikes → diffraction pattern of the supports of the secondary mirror

Central blurred spot → seeing disk and halo from scattering of photons in photographic emulsion

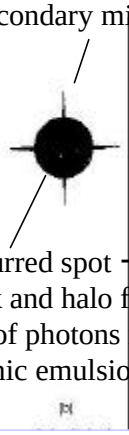
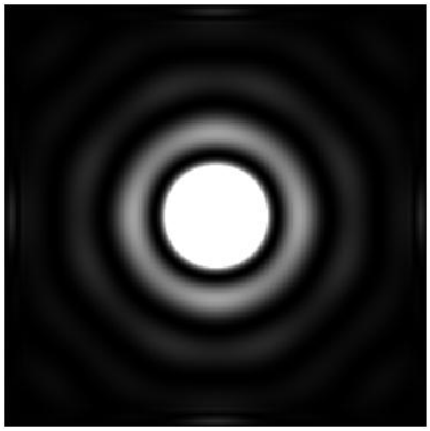
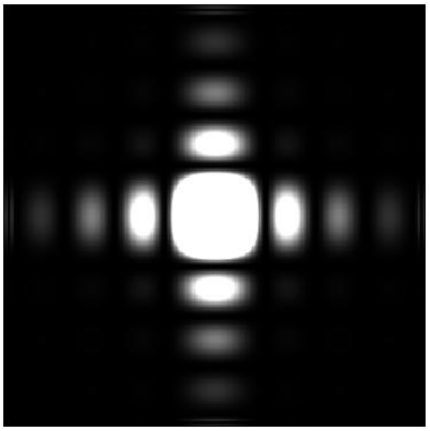


Image of a bright star on a photograph

Diffraction by a circular aperture



Diffraction by a square aperture, e.g., GAIA mission



Telescope System

- **Telescope** → To collect light (or in general EM radiation); a reflector or refractor
- **Analyser** → image analyser or flux analyser or spectrograph or polarimeter, or …
- **Detector** → eye or photographic plate or photoelectric device, or …

Basic modes of operation

✓ **Imaging** --- picture; need good optics

✓ **Photometry** --- flux; good optics not critical

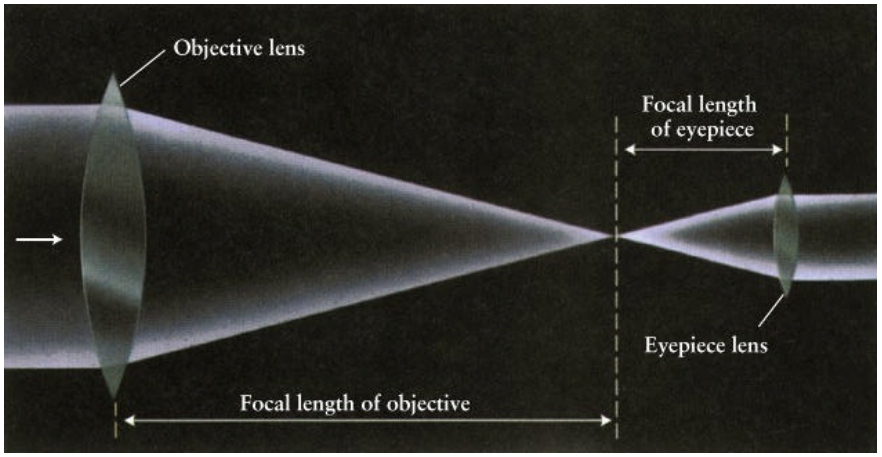
Test on Constellations

English ←→ Mandarin

雙魚座、白羊座、金牛座、雙子座、巨蟹座、獅子座、
室女座、天秤座、天蠍座、射手座、摩羯座、寶瓶座

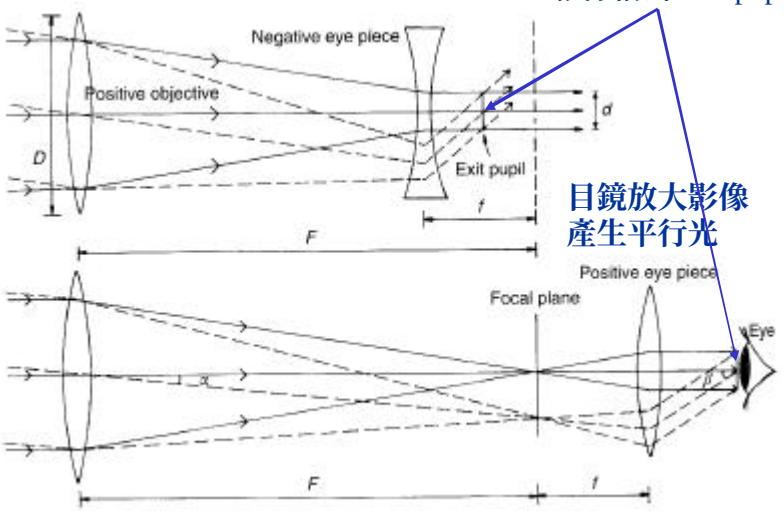
Andromeda	人馬座
Pegasus	杜鵑座
Ursa Major	北冕座
Lupus	天鵝座
Monoceros	波江座

Refracting Telescope (refractor)
折射式望遠鏡



Galilean telescope

目鏡所產生物鏡的
影像稱為 exit pupil



目鏡放大影像
產生平行光

物鏡聚焦於焦平面

Keplerian telescope

- For professional observing, a photographic plate or electronic recording device is placed in the focal plane

➔望遠鏡＋偵測器 ＝ 鏡頭＋照相機（底片）

- The speed of telescope system is determined by the **focal ratio（焦比）, F/D**
  F: focal length of the objective lens;
  D: aperture size
- F/D ↑ ➔ the optical system is said to be "slow" because the light is "spread"
  ➔ a lower efficiency

- **Refractors** typically F/D~15, i.e., of slow optical systems, so not suitable to search for faint objects. But large **plate scales** ➔ good for **astrometry**
- If re-imaging of the objective (e.g., by an eyepiece) → amount of light actually into the eye is determined by the size of the **exit pupil**
- Most effective design, i.e., no waste of light

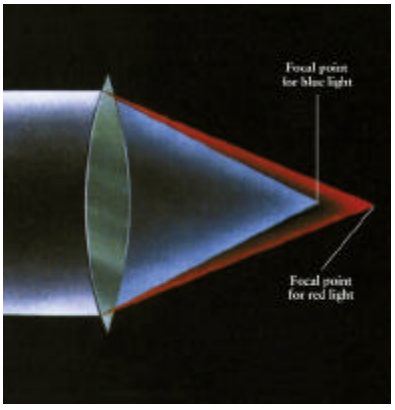
  exit pupil ˜ pupil of eye ˜ 8 mm
- Same consideration for other instruments; i.e., instrument **entrance pupil** should match telescope exit pupil

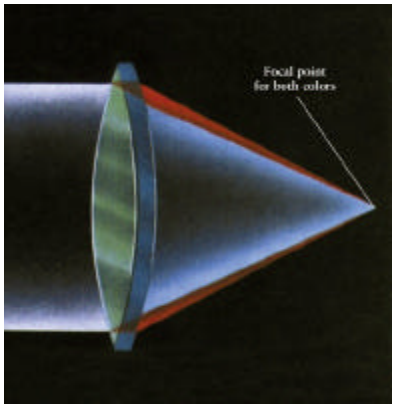
Refractors

- are thermally stable --- optical properties not sensitive to temperature changes
- need little maintenance --- optics remains aligned for years

➔ star positions recorded on photographic plates taken years apart and under different temperature conditions can be precisely measured
→ **proper motions（自行運動）**

折射式望遠鏡的一項大缺點為
chromatic aberration（色差）
light of different wavelengths → different focus





利用修正鏡改正色差現象

- The objective can be supported only round its edge, not at the center where it is the thickest

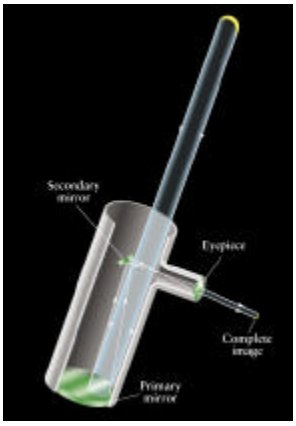
➔折射式望遠鏡無法做得太大

- The largest refractor in use is the 1 m (40 inch) telescope at Yerkes Observatory in Wisconsin, USA

www.geocities.com/rbell.geo/Yerkes/40inch.html

- **折射式望遠鏡還有個缺點，就是因為長焦，而鏡身又必須比焦距長**
  ➔ a very large, expensive dome is required.
- **由於有以上這些折射式望遠鏡的缺點，現代專業研究用的大型天文望遠鏡皆採「反射式」**

Reflecting Telescope (reflector)
反射式望遠鏡



A parabolic mirror brings all the light from a point source to a focus at a single point

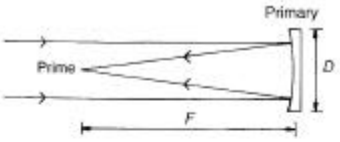
Different secondary mirrors can be used → a variety of foci

Typical primary F/D~3

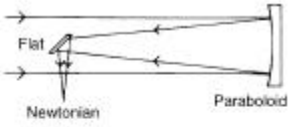
Reflectors do not have chromatic aberration

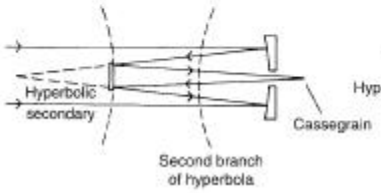
Main foci used in reflecting telescopes

主 (prime) 焦點

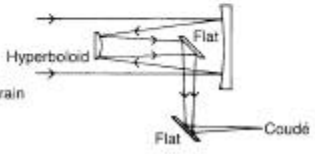


牛頓式 (Newtonian)焦點
＝折軸主焦





卡塞格林式 (Cassegrain) 焦點

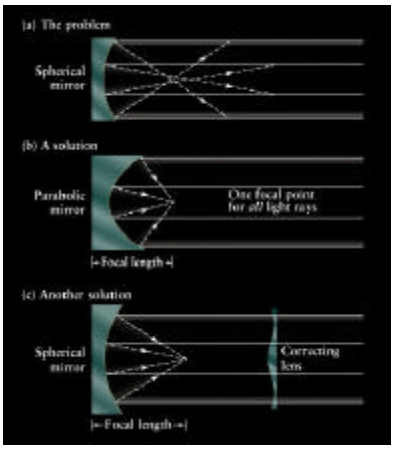


庫德式 (Codé)焦點

透鏡的表面常是球面的一部份

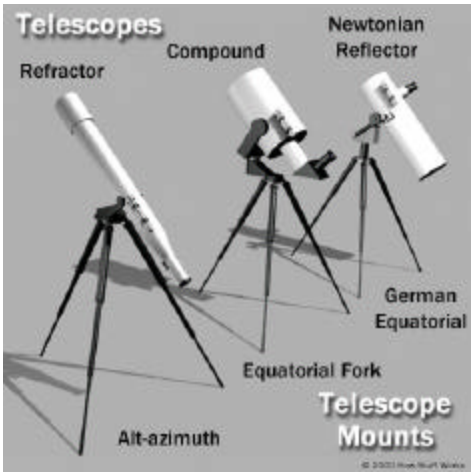
→ rays from the edge of the lens come to a focus nearer the lens than do rays through the center of the lens →**影像模糊**

➔ **spherical aberration（球面像差）**



- **無論是折射式或反射式望遠鏡，都可能會有球面像差**
- **如果做成拋物面理論上就可以解決球面像差的問題**
- **但實務上，拋物面不容易研磨，通常總有些球面像差的問題**
- Hubble Space Telescope **（哈伯太空望遠鏡; HST）就是個著名的例子**

Telescope Mounts（架台）



- ✓保持望遠鏡穩定
- ✓使得望遠鏡指向目標（星體或鳥）
- ✓追蹤抵銷地球自轉
- ✓空出雙手（調焦、做筆記、換目鏡）

http://science.howstuffworks.com/telescope5.htm

Telescope Mounts（架台）I

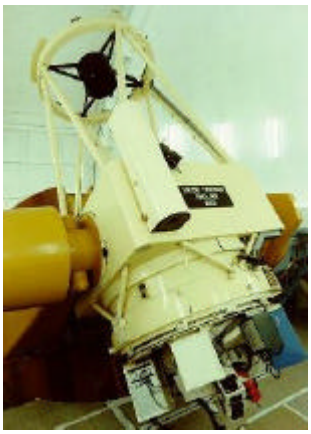
- **Equatorial mount（赤道儀）**

極軸（平行地球自轉軸），以及垂直於極軸的**赤緯軸**，可以只驅動極軸，抵銷地球自轉，保持望遠鏡指向天球同一位置

實際上，在長曝光時，仍須微調兩軸以維持目標在視野內的位置 ➔ 人工或自動導星

「重心不穩」力矩→望遠鏡變形與齒輪負荷

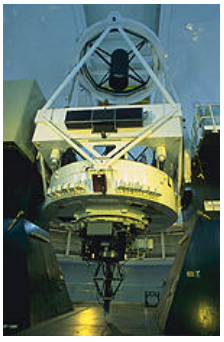
➔ 改良，例如撐住赤緯軸 folk mounting, disk or horseshoe



Isaac Newton Telescope at La Palma, Spain. D=2.5 m, with a polar-disk/folk type of equatorial mount

Telescope Mounts（架台）II

- **Alt-azimuth mount （經緯儀）**
  有如照相機角架，仰角軸（垂直）與方位角軸（水平）
  重心穩定，機械簡單
  追蹤時必須同時驅動兩個軸（電腦控制）
  http://science.howstuffworks.com/telescope5.htm
  像場會旋轉 → 如果要成像，必須讓相機反著轉；無法觀測「天頂」 (zenith)
  大型電波望遠鏡皆使用此種架台
  大部分新建造的光學望遠鏡亦使用此種架台



William Herschel Telescope, D=4.2 m

ESO Very Large Telescope --- an array of 4 telescopes, each of D=8.2 m

Subaru telescope in Hawaii, D=8.2 m