望遠鏡

用透鏡 (lens) 或面鏡 (mirror)

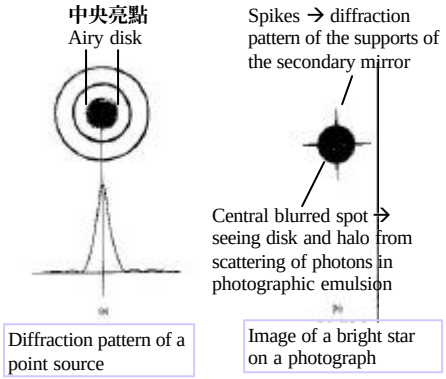
- **收集光線**（廣義的說，收集電磁波）
  - 口徑 (D) 越大，單位時間收集的光量越多
    集光能力與主鏡面積 $\propto D^2$
  - e.g., Aperture D=2 m 的集光能力
    為 D=1 m telescope 的四倍

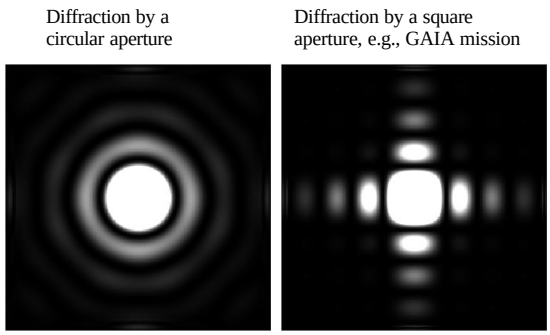
- **成像**（口徑不同部份產生互相干涉的像）
  - 口徑越大，看得越清楚（成像越清晰）
  - 最小的角度（細節） $\theta = 1.22\ \lambda/D$ radian
  - 乃望遠鏡的「繞射極限」(diffraction limit)
  - 又稱 Dawnes' limit
  - 解像力 (resolving power) $\propto D$
  - (*What does resolving power mean anyway?*)
  - $q'' = \lambda/D = 1(\text{mm})/4D(\text{m})$
  - e.g., λ =500nm= 0.5 μm, θ=1/ 8D(m)
  - ∴ D=1 m, θ=0.125"

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

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

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
θ ~ 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





Telescope System

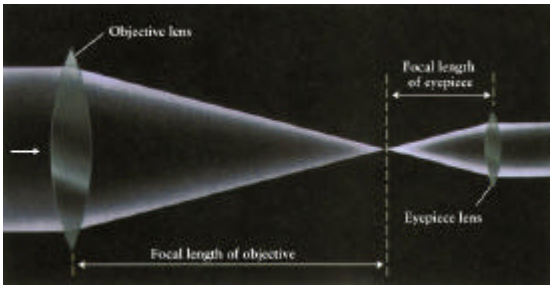
- **Telescope** → To collect light (or in general EM radiation); a reflector or refractor
- **Analyser** → image analyser or flux analyser or spectrograph or polarimeter, or …
- **Detector** → eye or photographic plate or photoelectric device, or …

Basic modes of operation

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

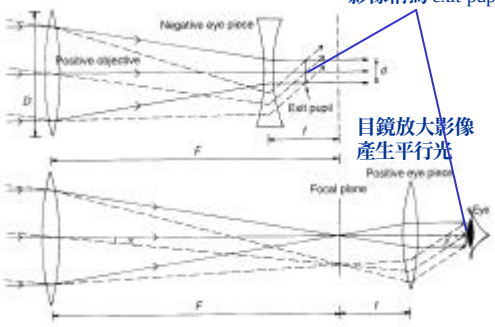
✓ **Photometry** --- flux; good optics not critical

折射式望遠鏡 (refractor)



Galilean telescope

目鏡所產生物鏡的影像稱為 exit pupil



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 ↑➔ 光學系統速度慢，因為光通量小（光「散開」了）

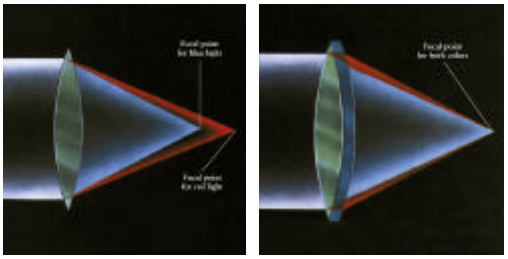
- **折射式望遠鏡通常** F/D~15，**屬於「慢速」光學系統，不適合用來搜尋昏暗天體，但因為 plate scale 大，適合用來測量星體位置 (astrometry)**
- If re-imaging of the objective (e.g., by an eyepiece) → amount of light actually into the eye is determined by the size of the exit pupil
- Most effective design, i.e., no waste of light
  exit pupil ˜ pupil 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

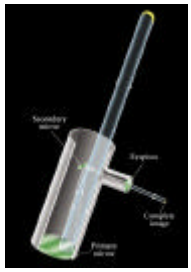
➔折射式望遠鏡無法做得太大

- 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」**

反射式望遠鏡 (reflector)



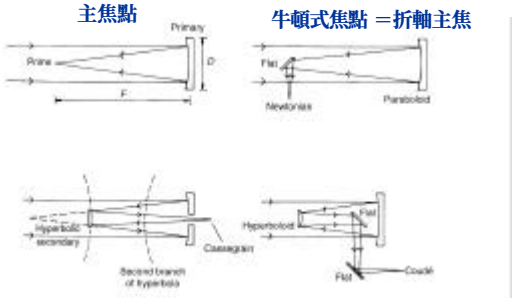
A parabolic mirror, which brings all the light from a point source to a focus at a single point

Different secondary mirrors can be used → a variety of foci

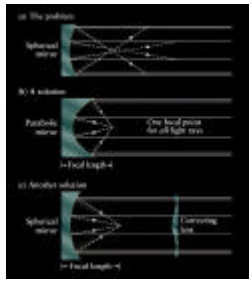
Typical primaryF/D~3

Reflectors do not have chromatic aberration

Main foci used in reflecting telescopes

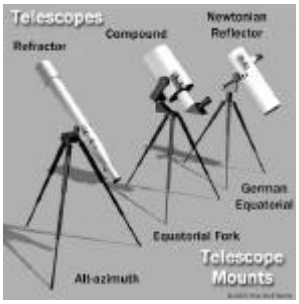


透鏡的表面常是球面的一部份
→ rays from the edge of the lens come to a focus nearer the lens than do rays through the center of the lens →**影像模糊**
➔ **spherical aberration（球面像差）**



- 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