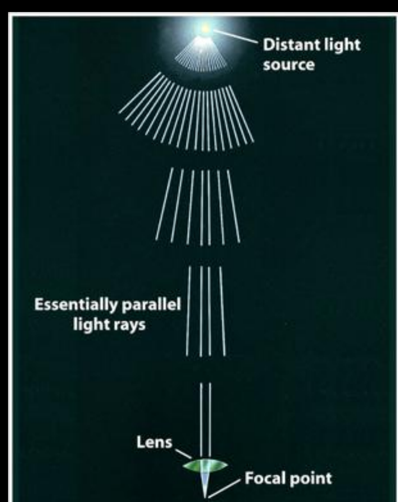
Telescopes

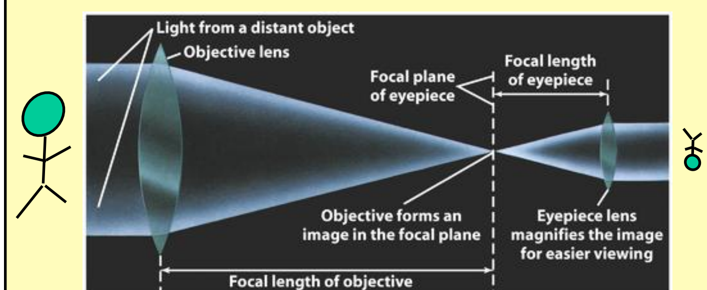
Telescopes

- ***collect & focus* light**
- ***"light buckets"***
- exist for ***all*** parts of ***EM spectrum***

- 2 *main* kinds of ***telescopes***:
- ***refracting***: use *lenses* ***(eg)*** *Galileo*
- ***reflecting***: use *mirrors* ***(eg)*** *Newton*



Telescope Terminology



- ***inverted image***: *telescopes often* ***invert*** *the image*

Q: *Why* ***don't*** *astronomers usually correct for this?*

• ***aperture***: ***diameter*** of primary (mirror or lens)

• ***focal length***: ***distance*** from the primary to the ***focal plane*** (where light rays *come together*)

• ***magnification***: $\text{focal length}_{obj}$ / $\text{focal length}_{eyepiece}$

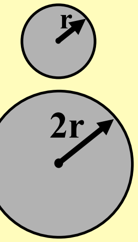
(eg) *a 2000 mm focal length scope is used with a 31 mm eyepiece, yielding M = 2000/31 = 65* x

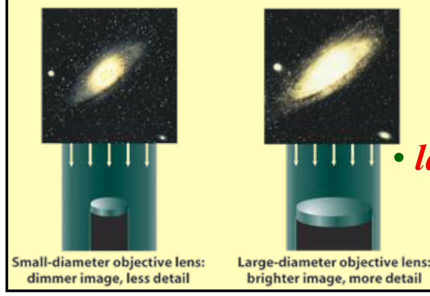
• ***field-of-view***: how *much* sky a telescope can view

• ***focal (f) ratio***: focal length / diameter of primary

• ***light gathering ability*** depends on ***area*** of mirror or lens (***$A = \pi r^2$***); related to ***aperture***

CLICKER: *a 6m scope collects how much more light than a 2m scope?*
(a) 2X (b) 3X (c) 6X (d) 9X (e) 12X

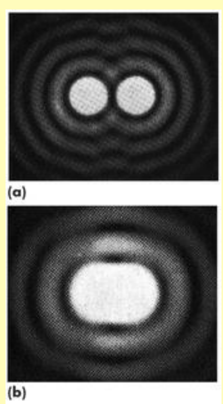




• ***larger scopes*** collect ***more light*** & see ***dimmer objects***

• ***angular resolution***: ***smallest*** angular separation for which a telescope can distinguish point sources ***(eg)*** *smallest detail the telescope can "see"*

• ***diffraction*** of light sets *limit* on best possible *angular resolution* ("***Rayleigh Criterion***")



$$\theta = (2.5 \times 10^5)\ \lambda / D$$

• θ has units of *arcseconds*
• λ (*wavelength*): units of *meters*, *m*
• D (*aperture*): units of *meters, m*

• ***bigger*** *lens/mirror, better* (***smaller***) ***angular res***

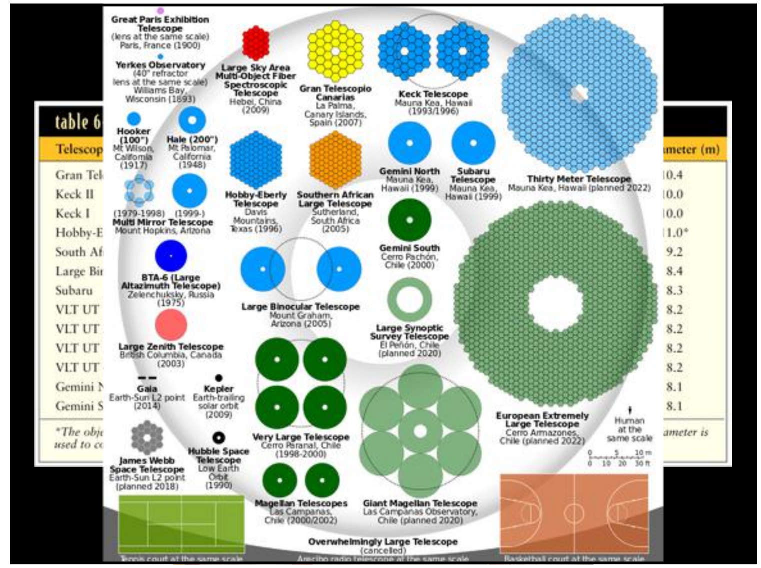
(eg) for ***visible light***: human eye ***$\theta \sim 1'$*** ;
8" scope (0.2 m) ***$\theta \sim 1''$*** ; 10 m scope ***$\theta \sim 0.02''$***

• ***atmospheric turbulence*** (***twinkling***) typically imposes a larger θ than theoretical ***diffraction limit***
(eg) "seeing" at many observatories ~0.5-1.0"

Visible Light Telescopes

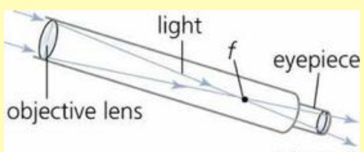
- *largest **refracting** telescope*
- Yerkes Observatory (Chicago)
- lens ***40 inches*** across (102 cm)

- *largest **reflecting** telescope*
- Palomar Obs, San Diego (5 m)
- today, ***segmented*** mirrors



Refracting Telescopes

- ***simple, sealed*** design (a "tube" with two lenses)
- ***more difficult*** to knock out of alignment

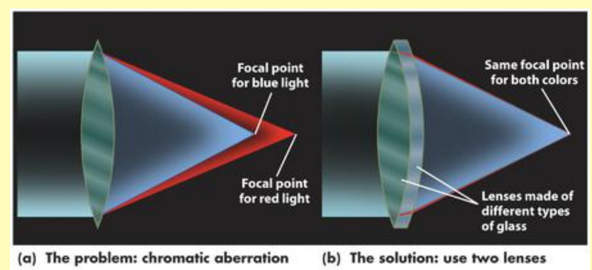


Q: *What are **disadvantages** of refracting scopes?*

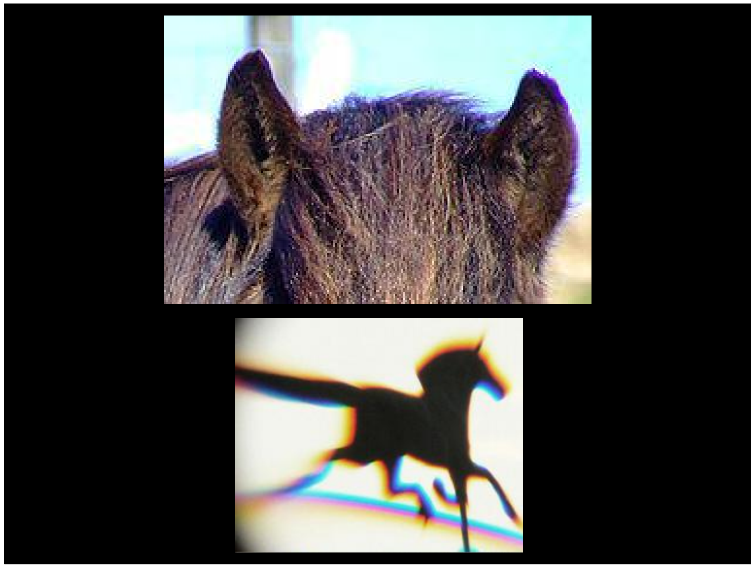
- ***chromatic aberration**, **spherical aberration***
- ***imperfections*** in lens material
- *difficult to balance* a large lens "at top" of tube
- large *lenses* can "sag" under gravity

Problems

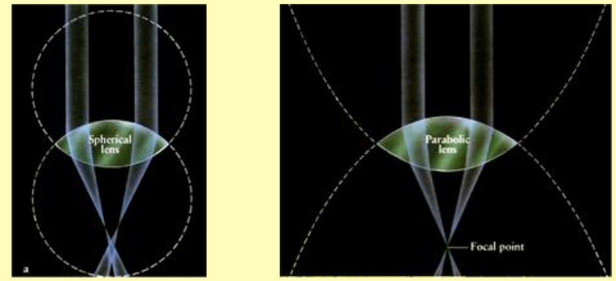
- ***chromatic aberration***: different wavelengths (colors) are ***refracted*** by different amounts; ***focal points** are **not** the same*



- *minimize problem* with long *focal lengths… or?*



• ***spherical aberration***: *spherical lenses* do **not** focus light at a single point



• ***parabolic lenses*** avoid this problem…

• some scopes use *corrective lenses*
(eg) Schmidt-Cassegrains (SCT's)

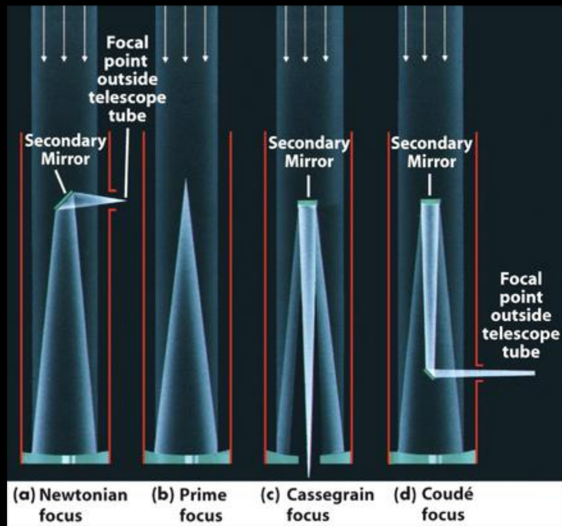
Reflecting Telescopes

• same terminology as *refracting telescopes*
(eg) aperture, ***focal length***, etc.

• developed by ***Newton***
• replaced lens with a *mirror* ("*reflector*")

*Q: What are the **advantages** of a mirror?*

• **no *chromatic aberration***
• only need ***shape*** *one side* of a mirror
• *internal **material defects*** are… *immaterial*
• ***support*** *mirror from behind* – can be bigger!

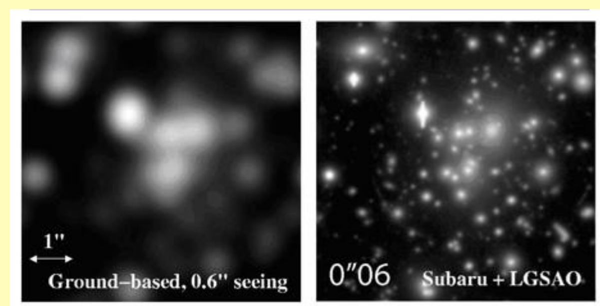


Keck (10 m) primary

CLICKER: *Which one does NOT affect reflectors?*
(a) spherical aberration
(b) chromatic aberration
(c) lens sag
(d) high cost per inch of aperture

Scintillation (twinkling)

• ***atmospheric turbulence*** causes *density changes*, refracting light from a star *differently* from one second to the next, *smearing* its image

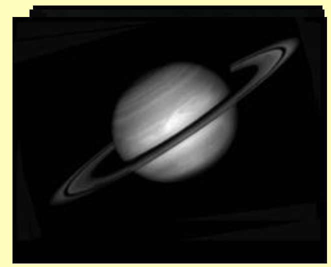


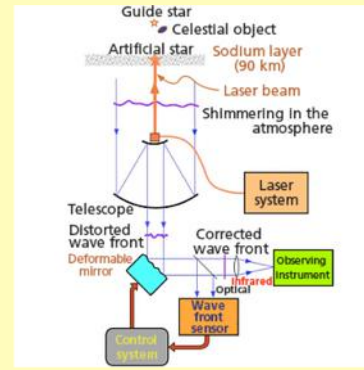
• HST has a *2.5 m primary* with *resolution* of 0.05"

• JWST (March, 2021) *6.5 m primary, 2.5*x *Hubble*

Adaptive Optics

• *computers* determine amount of ***twinkling*** & *rapidly reshape (secondary) mirror* to correct for it

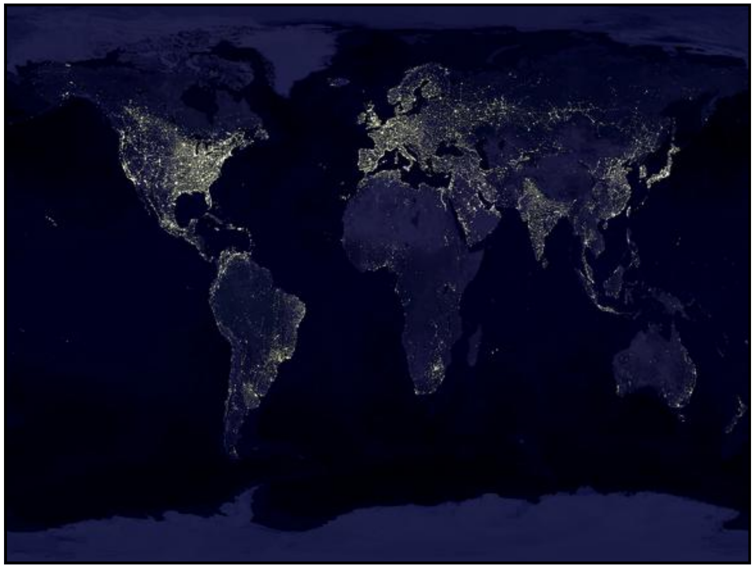


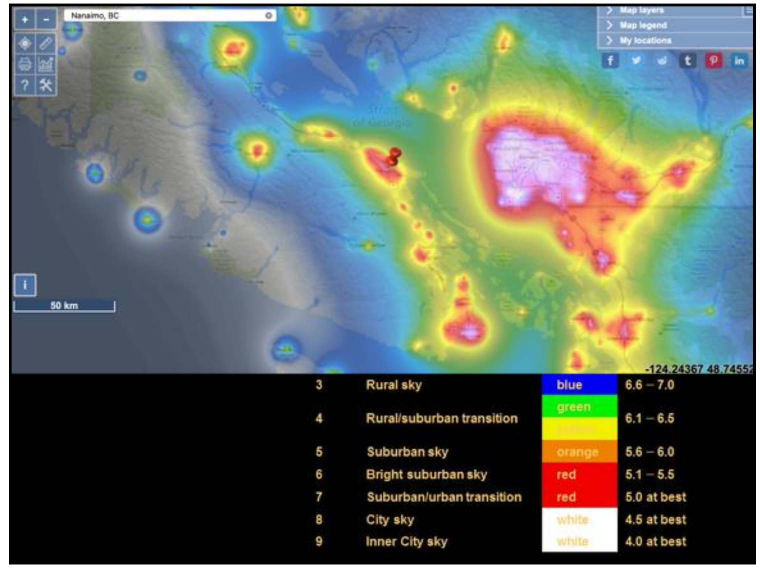


Keck, Subaru

• light pollution at *Kitt Peak National Observatory*

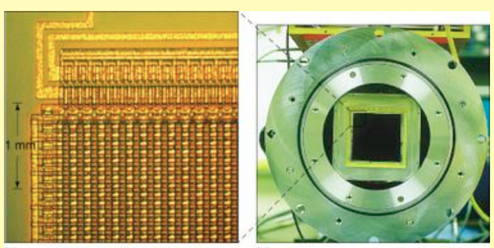
Q: *Anyone been "stargazing" in Vancouver?*



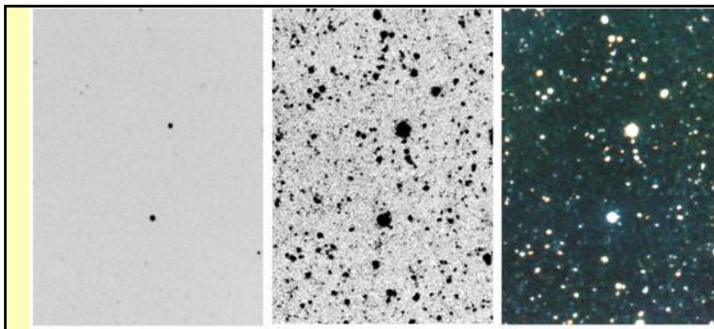


Imaging Visible Light

- ***photographic plate***: records a *photograph* of source
- ***spectrograph***: records the *spectrum* of a light source
- ***CCD***: records a *digital image* of the source



- ***CCD imaging*** has ***revolutionized*** astronomy



(a) Using photographic film (b) Using a CCD (c) Combined CCD image

- ***CCD***'s ~ **50x** more sensitive than film

CLICKER: *Astronomers take advantage by….*

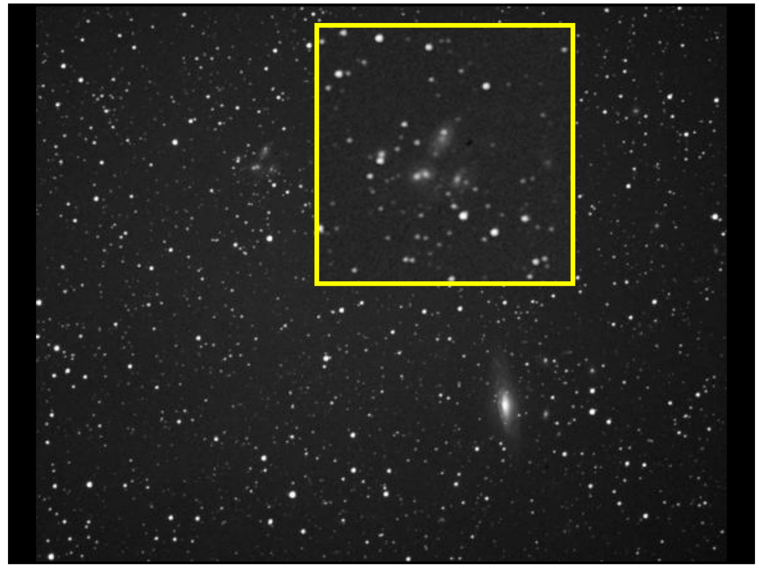
(a) taking shorter exposures to get same detail

(b) taking exposures of same length but more faint detail

(c) imaging the entire sky in reasonable time periods

• amateur photos rival professionals' of years ago!

• *Faworski & Parker* (2003); 10" vs HST
• digital imaging & stacking



Nonvisible Imaging

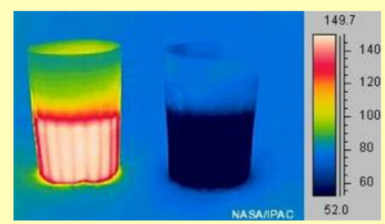
• *infrared, UV, X-Ray and gamma ray* telescopes are generally *located in space*

(eg) Saturn in *visible* and *radio* wavelengths

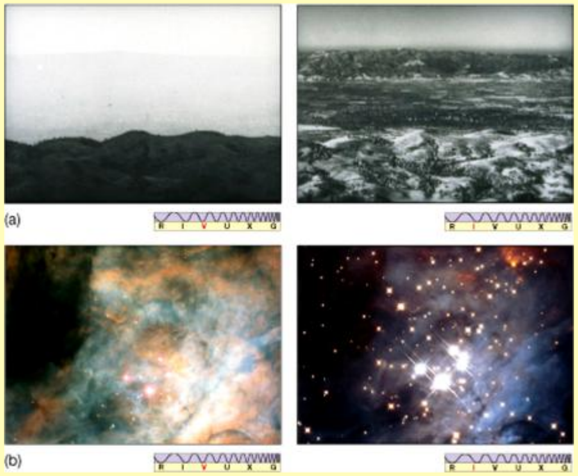
a

b

Q: *Why image in* ***non-visible*** *wavelengths?*



(eg) California & ***M42*** in visible & infrared



Arecibo, Puerto Rico (~300m)

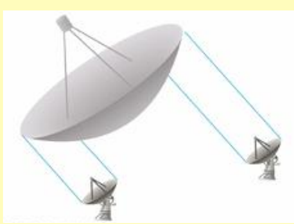
Q: Why are radio telescopes so big?

- $\theta = (2.5 \times 10^5)\ \lambda / D$ & *low strength* of signals
- $\lambda \sim 1$ m for radio; big D needed for *decent* θ

(eg) for Arecibo at $\lambda \sim 1$ m, $\theta \sim 800'' \sim 0.2^{\circ}$ (!!!)

Interferometry

- use *many smaller telescopes* to act as a large one



(eg) ***VLA*** near Socorro, NM; 27 scopes, D ~ 27 km

- used in ***radio astronomy*** but *also visible light* (***eg.*** *Keck*)