

# Astronomy 210

Section 1 – MWF 1500-1550  
134 Astronomy Building

This Class (Lecture 13):

Thermal Radiation

**Exam #1 on Friday!**

**Thursday Review Session**

Next Class:

Hour Exam #1

Music: *The Space Race is Over* – Billy Bragg

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## Midterm #1

- 1 hour exam in this classroom.
- It will cover material up to, but not including, Blackbody emission
- Will consist of a few short-answers, 1-2 short essay, and a few problems + extra credit.
- You can bring a normal-sized sheet of paper with notes on both sides.

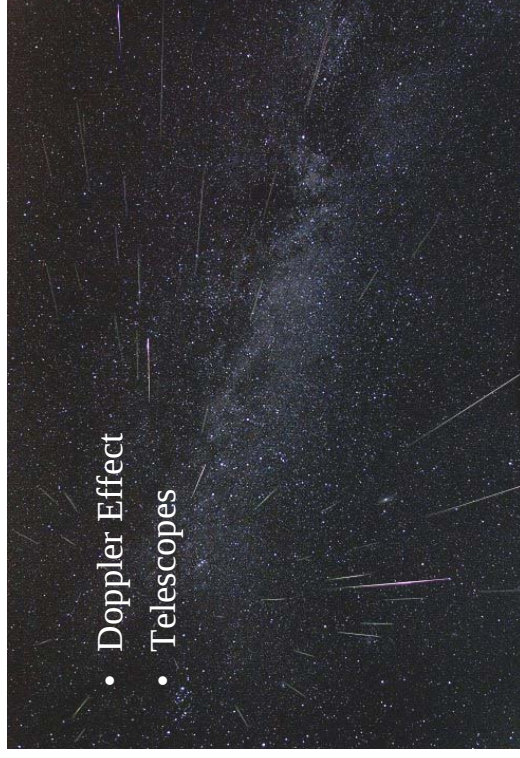
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## Outline

- Doppler Effect
- Telescopes



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## Doppler Effect

Those of you use to racing events like the Indy 500, or the sound of a police siren, are use to the Doppler effect.



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## Doppler Shift



- The amount of shift in wavelength depends on the *relative* velocity of the source and the observer

$$\lambda_{obs} - \lambda_{source} = \lambda_{source} \times \left( \frac{v_{source}}{c} \right)$$

- By measuring the Doppler shift of the light we observe, we can study the motions of the planets and stars
- The Doppler effect is also used by modern storm-tracking radar

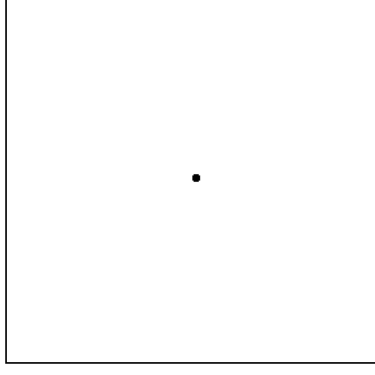
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## The Doppler Effect



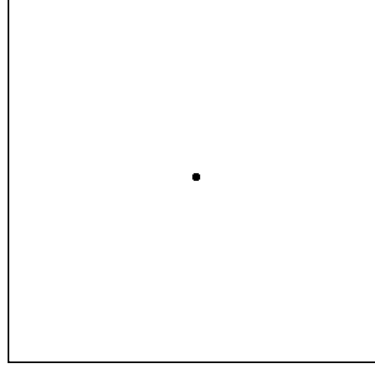
The effect arises from the relative motion of the observer and the source of light, sound, etc. The waves get squashed in the direction of motion and stretched in the opposite direction.



Source standing still

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Source moving to right

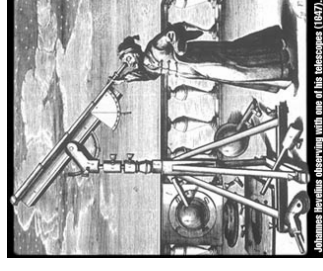
## We need telescopes to observe Starlight



## Telescopes & Astronomy



- The single most important tool to astronomers is the telescope
  - They collect more light than the eye
  - Allow us to see heavenly objects more clearly and to greater distances
- Astronomers have been using telescopes for about 400 years to explore the Universe



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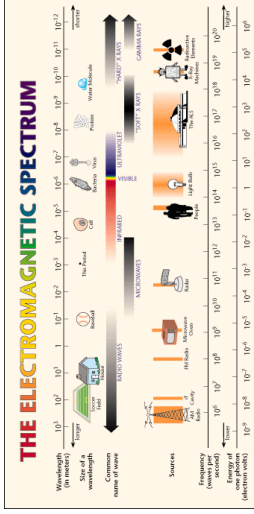
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# The Electromagnetic Spectrum



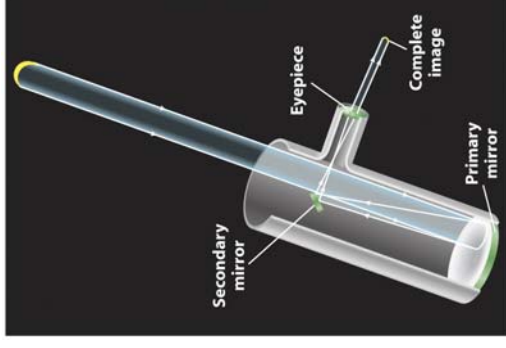
- Electromagnetic waves can have wavelengths outside of visible range
- Astronomical objects usually emit light at many wavelengths
- *Need telescopes which work at all wavelengths*



# Functions of a Telescope



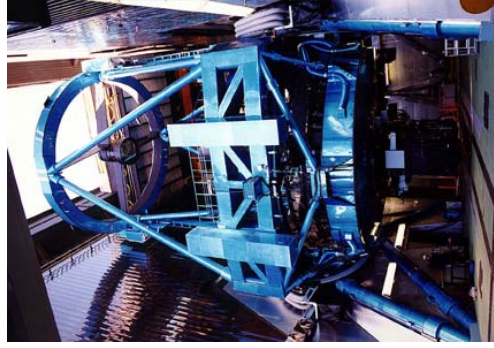
- Telescope functions
  - Collect light over a large area
  - Resolve image onto an eyepiece or a scientific instrument
- Extract maximum possible information
  - Form image or take spectrum
- Can do this with either lenses (refracting) or mirrors (reflecting)
- Three priorities (in order)
  - Gathering light
  - Angular resolution
  - Magnification



# Light Gathering



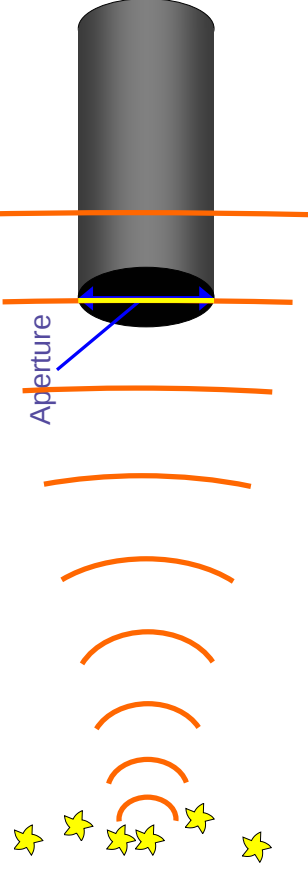
- Top priority since most celestial objects are dim
- Telescope = “light bucket”
- Key: **collecting area**
- Human eye – ~5 mm,
- Subaru telescope mirror – 8.3 m
  - 3 million times the area of your eye!



# Telescopes



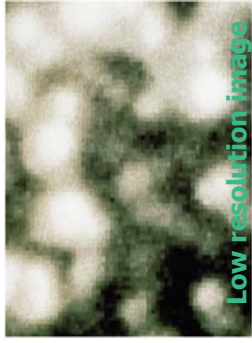
- A **telescope** collects light
- The larger the **aperture**, the more light can be collected in a given amount of time



## Angular Resolution



- Reveal details of objects
- Angular resolution:
  - Measures finest detail that is not smeared out
  - Smallest angle for which two stars aren't smeared together to one
  - e.g., human eye resolution =  $1/60^{\text{th}}$  of a degree
  - Hubble Space Telescope resolution  $< 1/36,000^{\text{th}}$  of a degree



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## Resolve This



- What is the limitation on how well a telescope can resolve objects?
  - The size of the telescope, silly
  - The diffraction of a telescope is  $\theta_{\text{diff}} = 1.22\lambda/D$ 
    - We want the angle to be small as possible
    - So, again we want a large telescope!
    - The Keck 10 meter has a  $\theta_{\text{diff}} = 0.05$  arcsec
  - But, there is another limitation!
    - The atmosphere

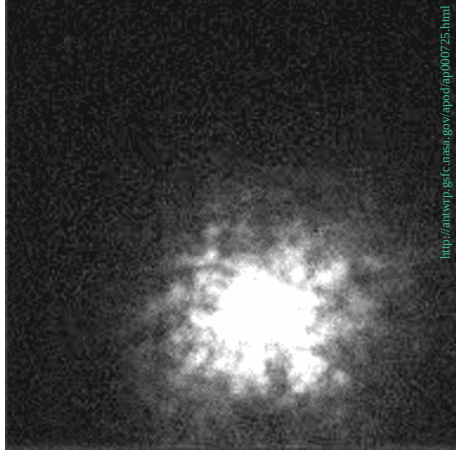
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## Twinkle, Twinkle Little Star



- Turbulence in the atmosphere “jiggles” image
- We see it as stars “twinkling”
- Astronomers use the term *seeing* to describe the steadiness of the sky
- A good atmosphere will allow  $\theta \sim 1$  arcsec.
- So for modern telescopes, we are limited by the atmosphere.



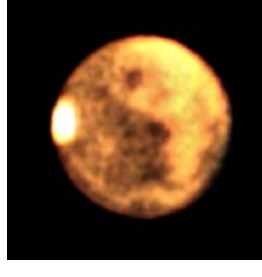
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## Magnification



- Makes the object appear larger
- Useful for studying detail
- Least important issue
  - If you don't have the other two, this is not at all relevant
    - No good to magnify a blurry image
- Magnification is  $f_{\text{obs}}/f_{\text{eye}} \propto D$



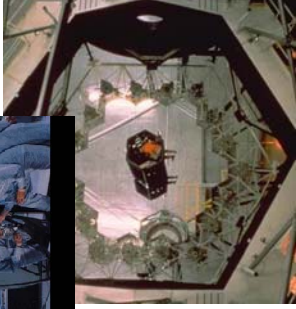
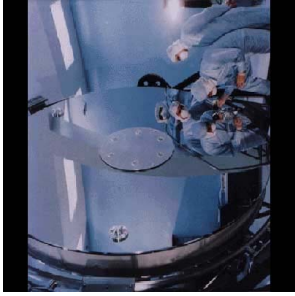
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## *In The End Size Does Matter*



- Both light collecting and resolution improve as the diameter of the scope – its lens or mirror – increases



- **Bigger is better!**

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## *Focusing*



For distant objects: light rays arrive in parallel

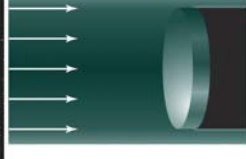
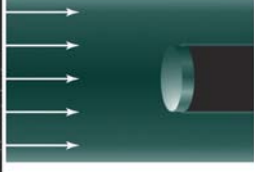
Telescope job:

- ✓ collect rays over large area
- ✓ focus to a point
- ✓ then re-straighten over smaller area: brighter

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## *Bigger Is Better!*



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## *Telescope Types*



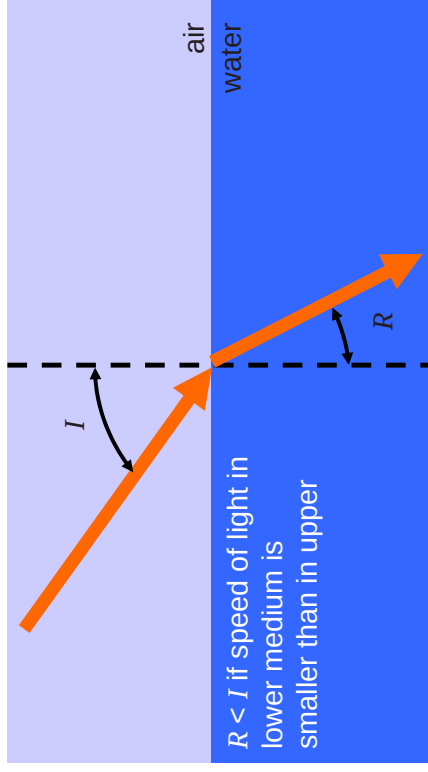
- Optical (visible light)
  - Refracting
  - Reflecting
- Radio, infrared, ultraviolet
  - Reflecting
- X-ray
  - Reflecting (grazing incidence)

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## Refraction

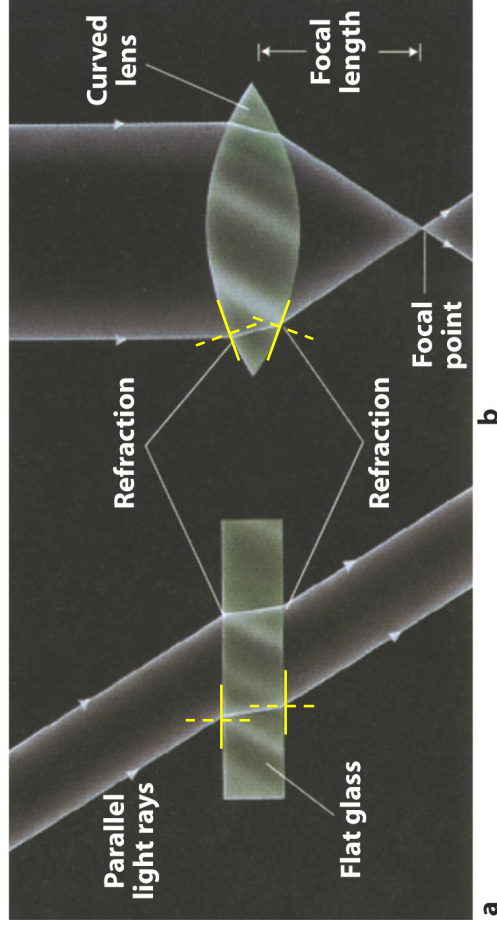
- Light travels more slowly in transparent materials than it does in vacuum
- When passing from one medium to another (e.g. air to water), light is bent (**refracted**)



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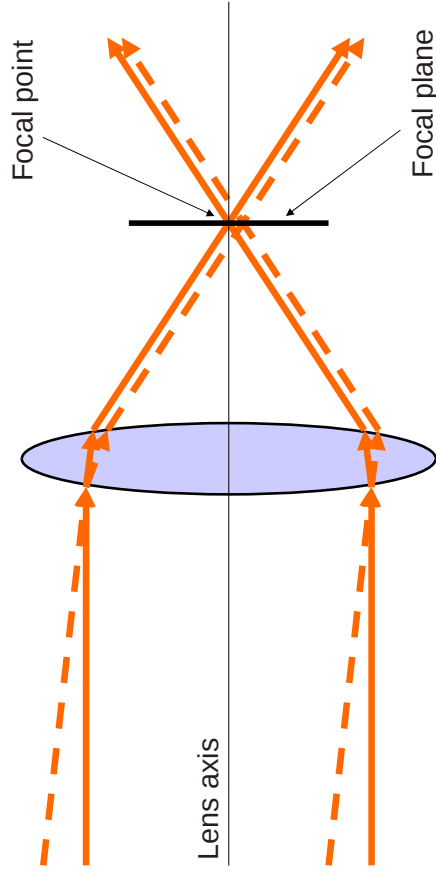
## Refraction by plates vs. by lenses



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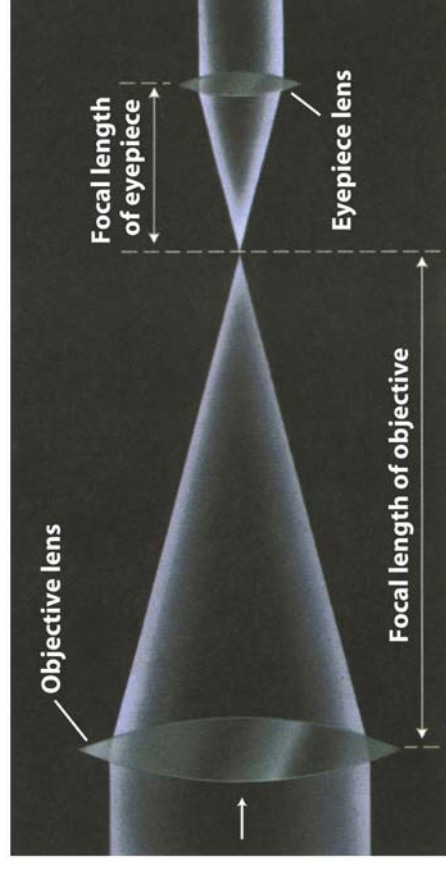
## Focusing by lenses



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## A refracting telescope uses at least two lenses



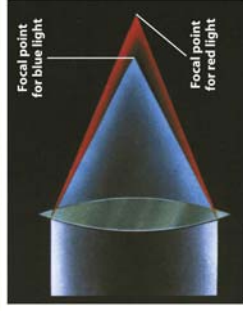
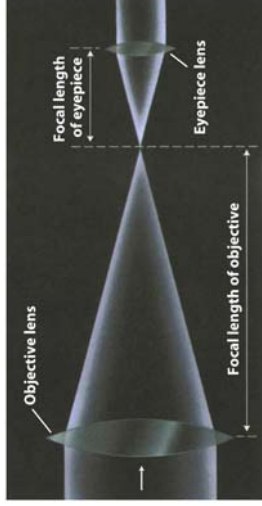
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# Refracting Telescopes: Lenses



- Use Lenses
  - Curved glass
  - Light bent to focus
- Problems:
  - Lenses focus colors differently
  - Sag
    - Large lens distorted as it hangs
    - Limits lens size
  - Limited wavelengths



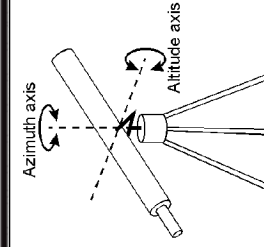
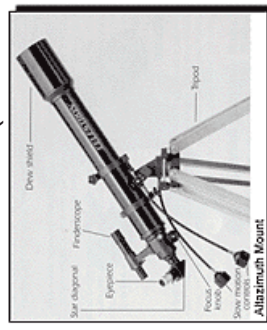
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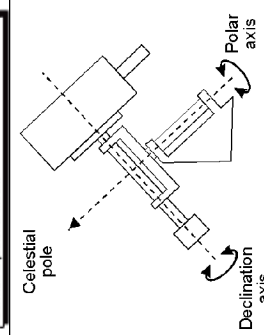
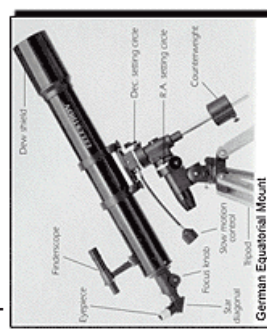
## Telescope mounts



Altitude-azimuth (alt-azimuth)



Equatorial

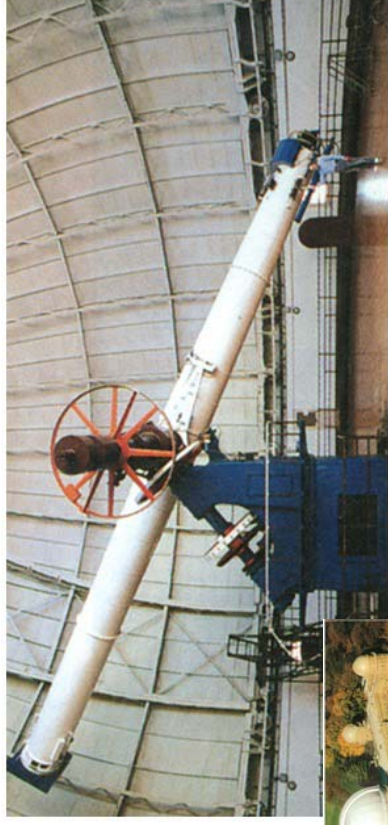


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# The Largest Refractor

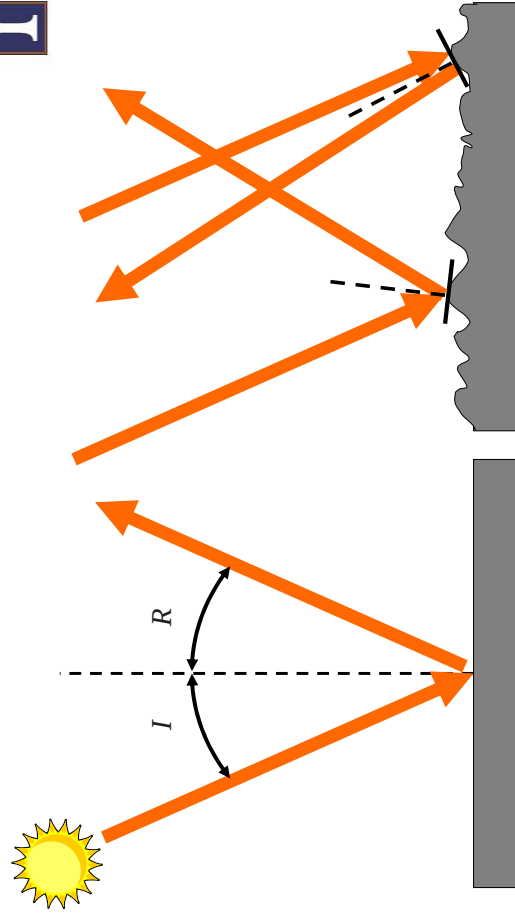


- At Yerkes Observatory near Chicago
- 40 inch diameter lens, 63½ feet long!



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## Reflection



Smooth surface

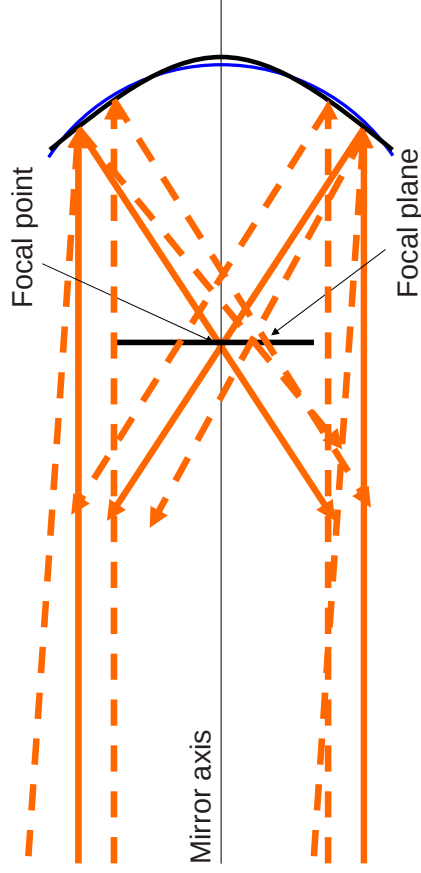
Angle of incidence  $I$  = Angle of reflection  $R$

Rough surface

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## Focusing by mirrors



### Spherical aberration

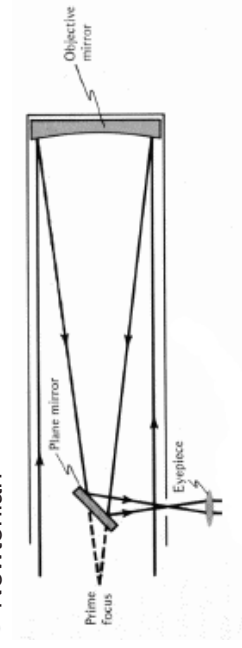
Occurs when section of a sphere is used instead of a paraboloid  
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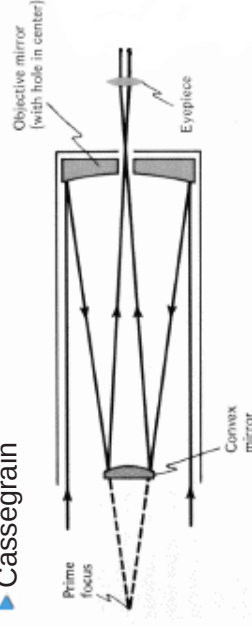
## Reflecting telescope designs



### ▶ Newtonian



### ▶ Cassegrain

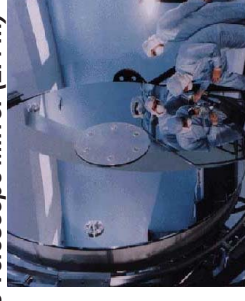


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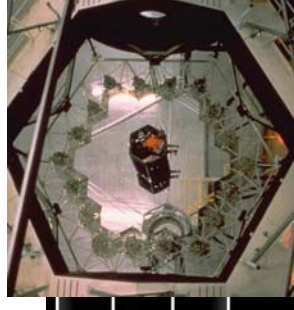
## Reflecting Telescopes



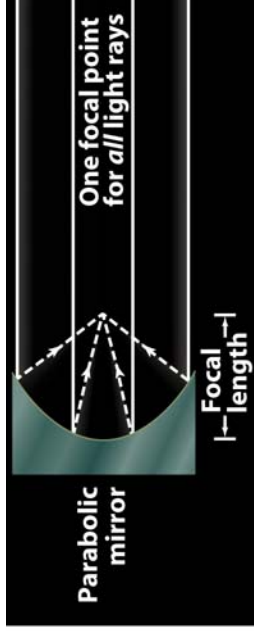
Hubble Telescope Mirror (2.4 m)



Keck Telescope Mirror (10m)



- Use Mirrors
  - Sag not a problem – support the mirror from below
  - Parabolic mirror gives good focus
- Today, all large professional telescopes are reflectors



## The Largest Reflector

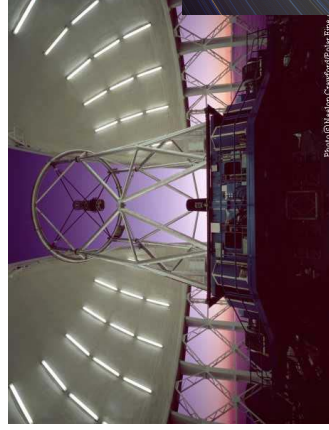


- Keck Observatory on Mauna Kea in Hawai'i
- Twin 10-meter reflecting telescopes
- Completed 1993 & 1996

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## Gemini Telescopes



- Twin telescopes
- One in Hawaii, one in Chile
- 8-meter mirrors

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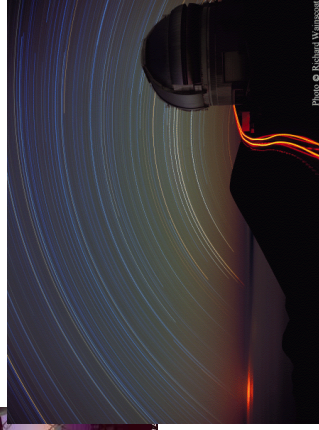


Photo © Richard Wainwright

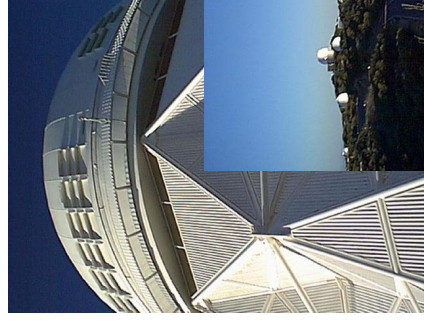
## Cerro-Telolo Interamerican Observatory



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## Kitt Peak, Arizona



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## Astronomy as a Hobby



- Did you know you can see a galaxy  $2\frac{1}{2}$  million light-years away with your unaided eyes?
- Or that you can see craters on the Moon with binoculars?



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## Your First Steps...

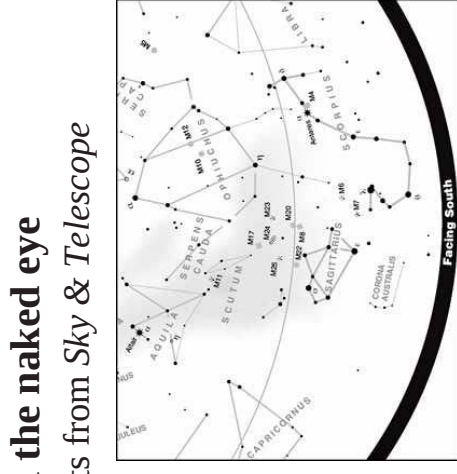


- **Read**
  - The night sky is beautiful to behold, but astronomy is a *learning* hobby
  - You can find good guides to the night sky at your local library or bookstore
  - Get a copy of *Sky & Telescope* from the library
    - Offers a big evening-sky map for beginners
    - Practical observing tips

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## Learn The Sky



- **Learn the sky with the naked eye**
  - Download star charts from *Sky & Telescope*
  - Buy a planisphere from a bookstore
  - Generate sky charts with the *Starry Night* software that came with your textbook

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## Start With Binoculars



- Binoculars are an ideal first telescope
  - Wide field of view, making it easy to find your way around
  - Relatively inexpensive
  - Widely available
  - Easy to carry and store
  - Allow you to easily see lunar craters, Jupiter's moons, and the brighter star clusters, galaxies, and nebulae
  - The larger the front lenses are the better

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## Seek Out Others



- There are two amateur astronomy clubs here
  - University of Illinois Astronomical Society
  - Champaign-Urbana Astronomical Society
- Attend star parties where you can meet members and discuss astronomy
  - Try out different types of telescopes
  - Get advice

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## Your Own Telescope



- When you're ready, it's time for your own telescope
- Don't skimp on quality, you'll regret it later
- What do you want?
  - Solid, steady, smoothly working mount
  - High quality optics
  - Large aperture – but not too large, you have to carry it!
  - The best telescope for you is *the one you'll use most!*



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## Relax and Have Fun!



- This is the most important step!
- Take pleasure in whatever your eyes, binoculars, or telescope can show you
- The more you look, the more you will see, and the more you will become at home in the night sky
- Set your own pace, and revel in the beauty and mystery of our amazing universe!



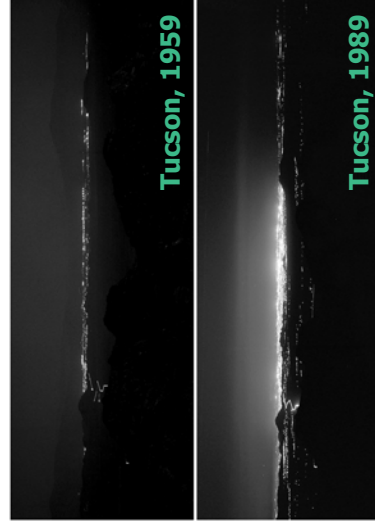
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## Light Pollution



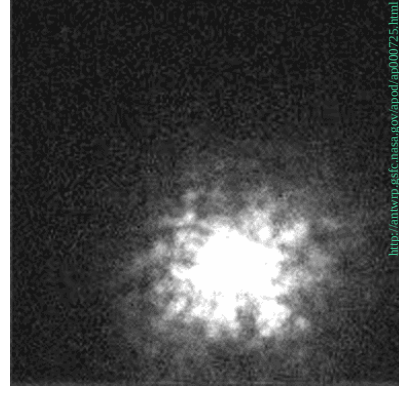
- Another problem for astronomers is light pollution
- City lights raise the “background light” level
- Makes it more difficult to collect light from stars



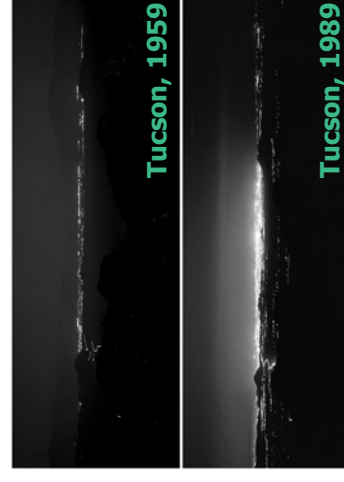
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## Twinkling & Light Pollution



<http://antwp.gsfc.nasa.gov/apod/ap000725.html>



How do we combat these problems?

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