Light and Telescopes
ASTR 2110
Sarazin

LBT Telescope (U.Va. is partner)
Light = Electromagnetic Waves

“electromagnetic radiation”
Electromagnetic Spectrum
Atmospheric Transmission

Only short wavelength radio, visible, parts of infrared, and a bit of ultraviolet penetrate from space to Earth

All gamma-ray, X-ray, almost all UV, most IR, and long wavelength radio must be observed from space
Wave Effects in Light

• Refraction
  – Light bends in different materials
    • Lens
Wave Effects in Light

• Refraction
• Reflection
  – mirrors

Equal Angles of Reflection

Figure 2
Wave Effects in Light

• Diffraction or Wave Interference

Constructive Interference

Destructive Interference
Interference Patterns

Each slit acts as a source of waves; the waves from the two slits interfere constructively or destructively at the screen.

Pattern of light and dark fringes observed on the screen.
Diffraction Limit for Telescopes

Light waves from different parts of lens or mirror interfere
Diffraction Pattern
Diffraction Limit for Telescopes
Resolving Power

D = diameter of aperture of telescope

Smallest detail in angle is:

\[ \theta = \frac{1.22 \lambda}{D} \text{ radians} \]

\[ \theta = 2.5 \times 10^5 \left(\frac{\lambda}{D}\right) \text{ arcseconds} \]

Both \( \lambda \) and \( D \) in same units (\( D \) in meters \( \rightarrow \lambda \) in meters).
A. Objective size = 0.1524 m (6 in)
   $\theta = 0.826$ arc sec at $\lambda=500$ nm
   integration time = 30 minutes

B. Objective size = 0.508 m (20 in)
   $\theta = 0.248$ arc sec at $\lambda=500$ nm
   integration time = 2.7 minutes

C. Objective size = 2.3876 m (94 in)
   $\theta = 0.0527$ arc sec at $\lambda=500$ nm
   integration time = 7.3 seconds

D. Objective size = 5.08 m (200 in)
   $\theta = 0.0248$ arc sec at $\lambda=500$ nm
   integration time = 1.6 seconds
Resolving Power

- For a given wavelength, better images if telescope is larger
- To give the same resolution (image quality), longer wavelengths require larger telescopes
Resolving Power

Hubble Space Telescope

- $\lambda = 500 \text{ nm} = 500 \times 10^{-9} \text{ m}$ (green light)
- $D = 2.4 \text{ m}$
- $\theta = \frac{1.22 \lambda}{D} = 2.5 \times 10^{-7} \text{ radians} = 0.05 \text{ arcseconds}$
Seeing

Motions in air blur images = “seeing”

Good sites on Earth, blurs images by ~1 arc second
Video of enlarged image of bright star in a large telescope. Image size/motion caused by motions of atmosphere
Adaptive Optics

The Galactic Center at 2.2 microns

Adaptive Optics OFF
Laser Guide Stars
McCormick Observatory (UVa, 1883)
Fan Mountain Observatory
Fan Mountain 40 inch
COLLECTING AREA OF THE LARGE TELESCOPES

Northern Hemisphere

WHT UKIRT CFHT WYIN ARC TNG MPA KPNO

SUBARU SAO Palomar MMT Gemini N

Keck 1 Keck 2 HET

LBT 1 LBT 2 ORM

Southern Hemisphere

NTT CTIO AAT ESO

VLT 1 VLT 2 VLT 3 VLT 4

Magellan 1 Magellan 2 Gemini S

© ESO EPR
8.4-m Mirror Blank for Large Binocular Telescope
Thirty-Meter Telescope (TMT)
“Overwhelmingly Large Telescope” (OWL)
Arecibo 300 meter radio telescope
NRAO Green Bank Telescope West Virginia 100x110 m
Green Bank Telescope (100-m, steerable)
GBT Compared
Radio Interferometers

• Multiple telescopes $\rightarrow$ resolution of telescope of diameter $D$

• (But, light collecting power = sum of individual telescopes)
Jansky Very Large Array (New Mexico)
Very Large Array, Socorro, NM
Very Long Baseline Array
Atacama Large Millimeter Array (ALMA)
Hubble Space Telescope
SOFIA
Spitzer Infrared Space Telescope
Chandra X-Ray Observatory
X-ray Mirrors

Mirror elements are 0.8 m long and from 0.6 m to 1.2 m diameter
Centaurus A
XMM-Newton
Fermi Gamma-ray Observatory

LAT "First Light" All-Sky Map
Wave Effects in Light
Doppler Effect

True of waves, too

lower frequency

higher frequency
Doppler Effect - Sound

lower frequency

higher frequency
Doppler Demonstrations
Doppler Effect

Same effect in wavelength
- Source moving toward us: waves bunch up – shorter wavelength = *blueshift*
- Source moving away from us: waves stretch out – longer wavelength = *redshift*
Doppler Effect

Same effect in wavelength

- Source moving toward us: waves bunch up
  - shorter wavelength = *blueshift*
- Source moving away from us: waves stretch out – longer wavelength = *redshift*
Doppler Effect

\[ v_r \equiv \frac{dr}{dt} \equiv \text{radial velocity} \]

> 0 moving apart

< 0 moving toward
Doppler Effect

\[ \lambda_{obs} = \lambda_{em} + s = \lambda_{em} + v_r P_{em} \]

\[ P_{em} = \frac{1}{v_{em}} = \frac{1}{(c / \lambda_{em})} = \lambda_{em} / c \]

Recall \( v = c / \lambda \)

\[ \lambda_{obs} \approx \lambda_{em} (1 + v_r / c) \]

\[ v_{obs} \approx v_{em} / (1 + v_r / c) \approx v_{em} (1 - v_r / c) \]

approximate, assuming \( v << c \)
Doppler Effect (Cont.)

Time Dilation

\[ \Delta t_{\text{obs}} = \Delta t_{\text{em}} \sqrt{1 - \frac{v^2}{c^2}} \]

for radial motion \( v = v_r \)

# of waves emitted = \( v \Delta t \)

\[ \nu_{\text{obs}} \Delta t_{\text{obs}} = \nu_{\text{em}} \Delta t_{\text{em}} \]

\[ \nu_{\text{obs}} = \nu_{\text{em}} \sqrt{1 - \frac{v_r^2}{c^2}} / \left(1 + \frac{v_r}{c}\right) \]

\[ \lambda_{\text{obs}} = \lambda_{\text{em}} \sqrt{\frac{1 + \frac{v_r}{c}}{1 - \frac{v_r}{c}}} \]
Redshift

\[ z \equiv \frac{\lambda_{obs} - \lambda_{em}}{\lambda_{em}} \quad \text{redshift} \]

\[ z \approx \frac{v_r}{c} \quad \text{for} \quad v \ll c \]

> 0 moving apart (redshift)

< 0 moving toward (blueshift)
Doppler Effect - Summary

$v_r \equiv \frac{dr}{dt} \equiv \text{radial velocity}$

for radial motion

$v_{obs} = v_{em} \sqrt{\frac{1 - v_r / c}{1 + v_r / c}}$

$\lambda_{obs} = \lambda_{em} \sqrt{\frac{1 + v_r / c}{1 - v_r / c}}$

for $v \ll c$, only depends on $v_r$

$v_{obs} \approx v_{em} \left(1 - \frac{v_r}{c}\right)$

$\lambda_{obs} = \lambda_{em} \left(1 + \frac{v_r}{c}\right)$
Doppler Effect - Summary

Frequency and wavelength of light changes if source or observer move.