Astronomy 113
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Introduction

Astronomy & Astrophysics

ASTRON = Star
NOMOS = Law
PHYSIC = Nature

Outline:

1. Astronomy: observable properties of objects in the sky (brightness, motion, spectra)
2. Astrophysics: intrinsic properties of objects (mass, density, temperature, size)

Goals

- Explain Scientific Method
- Discuss Importance of using physical laws & lab measurements in Astronomy to investigate remote objects
- Understand scientific notation
- Define major units used by Astronomers to express distance

Notes:

1. The Scientific Method: hypothesis, design observations to falsify hypothesis, improve observations. No "proof" theory is correct, just accumulation of supporting evidence
2. No definitive answers
3. Sky/universe is ever-changing - a wonderful and violent place
4. Celestial objects evolve: stars are born and die, universe expands
5. Astronomy is a time machine
6. An indirect science
Scientific:

- Must assume laws of physics are valid everywhere (space & time)
- Astronomy is a branch of Physics
- Modern Astronomers try to determine physical nature of celestial objects & relationship among the various objects

Astronomy is observational rather than experimental:
All direct information about physical conditions of celestial objects must come from an understanding of the nature of atoms & their constituents (i.e., the smallest entities in the universe - how ironic!)

Scientific Method

Our ideas must agree with what we observe
So... Devise a theory (a collection of ideas which appear to explain an observation):
- Theory must be consistent with observation
- Theory must make predictions which can be tested
- Experimental verification
- Observe, theorize, test
  - Theory is scientific only if it can be potentially disproved

We will see later the example of Geo/Heliocentric views.

Scientific Notation

1 million billion = 1,000,000,000,000,000,000,000,000,000,000,000,000
Cumbersome!!

So...
Scientific Notation: 10 followed by an exponent or superscript = # of zeroes/digits after “1” “Powers of Ten”

- Positive exponents
  - $10^0 = 1$
  - $10^1 = 10 (10 \times 1)$
  - $10^2 = 100 (10 \times 10)$
  - $10^3 = 1,000 (10 \times 10 \times 10)$
  - $10^4 = 10,000 (10 \times 10 \times 10 \times 10)$ “ten to the fourth”

Distance between Sun and Earth = 150,000,000 km
1.5 x 10^8 km
Negative exponents

\[ 10^0 = 1 \]
\[ 10^{-1} = 0.1 \text{ (1/10)} \]
\[ 10^{-2} = 0.01 \text{ (1/100)} \]
\[ 10^{-3} = 0.001 \text{ (1/1000)} \]

5.678 \times 10^6 = 5,678,000
2.3 \times 10^{-9} = 0.0000000023

Thousand, million, billion, trillion

Math:

To multiply:
add exponents \( (5 \times 10^5)(2 \times 10^3) = 10 \times 10^8 \text{ or } 1 \times 10^{10} \)

To divide:
subtract exponents \( 6 \times 10^2 / 2 \times 10^7 = 3 \times 10^6 \)

Distances

Numbers are vast
- Quickly make human scales (inches, meters, etc) unruly - or numbers unimaginably large

In the Solar System we use the Astronomical Unit (AU)
- Average distance Earth - Sun = 1.5 \times 10^8 \text{ km or 93 million miles}
- Sun to Jupiter is 5.2 AU

But even AUs are awkward...

Light Years

..."light year" = distance light travels in 1 year (going 186,000 miles/s or 300,000 km/s)

1 Light year (ly) = \( 9.46 \times 10^{12} \text{ km} = 6 \times 10^{12} \text{ miles or about 63,000 AU} \)

Parsec (pc) = the distance at which 1 AU makes an angle of 1/3600° = 1 arcsecond [PARallax SECond]

1 pc = 3.09 \times 10^{13} \text{ km} = 3.26 ly
1 kpc = 10^3 pc = kilo pc
1 Mpc = 10^6 pc = Mega pc

Proxima Centauri is at 1.3 pc
Sun to center of Milkyway = 8.6 kpc
Distance to Virgo Cluster = 20 Mpc
Earth - $10^3$ km
Solar System - $10^{8-10}$ km
Stars (nearby) - $10^{13-15}$ km
Galaxy - $10^{18}$ km
Local Group - $10^{19}$ km
Nearby Clusters - $10^{20}$ km
Perceivable Universe - $10^{23}$ km

Time
- Remember, light (information) travels at a fast but finite speed (186,000 miles/sec).
- It takes time for light to travel between objects (light year = distance light travels in one year = 6 trillion miles).
- So, all astronomical objects are observed in the past.
  - Current values for age of universe are 13.748 yrs

Astronomical Time Machine
- Moon: 1.5 seconds ago
- Sun: 8.5 minutes ago
- Pluto: 4-5 hours ago
- Nearest Star: 4 years ago
- Center of Galaxy: 25,000 years ago
- Andromeda Galaxy: 2.6 million years ago
- Most distant Galaxies: 8-10 billion years ago
- Quasars: 11-12 billion years ago

Time & Large Numbers
- What is a billion (other than a big number)?
  - In a "typical" human lifetime of 80 yrs, there are: 3 Billion seconds
  - (If you start counting 1 number every second as soon as you are born, you will only get to 3 billion after 80 years)
- The universe has been around 400 million billion seconds!!!

Size/Distance Example

<table>
<thead>
<tr>
<th>Object</th>
<th>Diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sun</td>
<td>$7 \times 10^{13}$ cm</td>
</tr>
<tr>
<td>Earth</td>
<td>$6 \times 10^9$ cm</td>
</tr>
<tr>
<td>Moon</td>
<td>$2 \times 10^8$ cm</td>
</tr>
</tbody>
</table>

If Sun were 1 meter diameter:
- Earth’s diameter = 1 cm
- Moon’s diameter = 0.3 cm
  - Jupiter’s = 20 cm (~8 inches)

At this scale, 1 AU ($1.5 \times 10^{13}$ cm)
- Becomes 214 meters (2 football fields)
- Proxima Centauri, 4.2 ly ($4 \times 10^{12}$ cm)
  - Becomes 35,200 miles!

Nature of Light
6-1 Goals

- List major regions of the spectrum in wavelength order & give examples.
- List major regions of the spectrum in wavelength order & give examples.
- Name two classes of telescopes & describe how they work.

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6-2 Nature of Light

- White Light is actually a mixture of all colors (Newton - Prism)
  - This is not a property of the prism, since the process can be reversed
  - Image of prism
- Speed of light is finite, but fast
  - In vacuum, \( c = 300,000 \text{ km/s} = 186,000 \text{ miles/s} \) (ultimate speed limit)
  - Light in water, air, glass, etc. travels slower than in vacuum, and other objects can travel faster than light - Cherenkov radiation

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6-3 History

- Isaac Newton - 1660s - “light is composed of particles too small to detect.”
- Christiaan Huygens - 1678 - light is like a wave
- Thomas Young - 1801 - experiments showing wavelike properties

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6-4 Waves

- What is waving?
  - Electric and Magnetic fields
  - James Clerk Maxwell - 1860 - describes all basic properties of E&M in four easy equations, finding:
  - E & M Forces are two aspects of the same phenomena
  - E & M fields travel through space at the speed of light
  - EM Radiation is thus combined, oscillating E & M fields

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6-5 Wavelength

- Different “colors” because wavelength of light is different
  - \( \lambda = \text{angstrom (Å, } 10^{-10} \text{ m, or nanometers, } 10^{-9} \text{ m) } \)
  - Visible light is 4000-7000Å (400-700nm)

- FIG - e/m wave

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6-6 Particle-Wave Duality

- Light is sometimes like a wave and sometimes like a particle
  - Particle nature is seen in the “photo-electric” effect (Einstein, Nobel prize, 1905)
  - Some colors of light remove electrons from a metal, but not others. Electrons received different amounts of energy from light “packets”, or PHOTONS

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The Spectrum

- The shorter a photon's wavelength, the higher its energy: \( E = (h \times c)/\lambda \)
- Visible light is only a small component of EM radiation:

<table>
<thead>
<tr>
<th>Radio</th>
<th>Infrared</th>
<th>Visible</th>
<th>Ultraviolet</th>
<th>X-rays</th>
<th>( \gamma )-rays</th>
</tr>
</thead>
</table>

Visible spectrum:
- Red
- Orange
- Yellow
- Green
- Blue
- Indigo
- Violet

Not all transmitted by atmosphere

Electromagnetic Radiation & Spectra

Goals

- Know Stefan-Boltzmann law and Wien's law
- State Kirchhoff's 3 laws of spectral analysis
- Describe Bohr model of the atom; spectral lines
- Know how spectral analysis provides info about chemical composition of celestial objects
- Indicate how protons, neutrons, and electrons are used to define elements

Heat an Iron Bar

1. As it heats, it becomes brighter because it emits more EM radiation
2. The color (\( \lambda \) of emitted radiation) changes with temperature

Cool: IR, red
Hot: UV, blue

First noted by Thomas Wedgwood in 1792

Blackbody: a body which absorbs all EM radiation which strikes it and is heated. Energy is re-emitted. Amount at each wavelength depends on temperature.

Temperature

Energy

Blackbody curves: temperature profiles of intensity of blackbody at different wavelengths

\[ E = \sigma T^4 \]
Wien’s Law

Relationship between color peak & temperature found by Wien in 1893

Wien’s Law: \[ \lambda_{\text{max}} = \frac{2.99 \text{(cm)}}{T(\text{K})} \]

The hotter an object, the shorter \( \lambda_{\text{max}} \).

Very useful for determining temperatures of star’s surface - since brightness & size don’t need to be known.

Peak of Sun about 5800A (5000K), so why not blue-green? (scattering)

7-4

Fraunhofer: solar spectrum has dark lines
(spectral lines)

Kirchhoff-Bunsen: spectra of each element has characteristic pattern of spectral lines

Element: a fundamental substance which can’t be broken into more basic chemicals

Spectral analysis led to discovery of new elements (e.g., cesium & rubidium)

1868, solar eclipse, saw helium on Sun 27 years before detected on Earth

7-5

Each element has characteristic spectrum so by observing a spectrum of an astronomical object, we can determine types of elements present.

We use instruments - spectrometers and spectrographs - to observe spectra (like a prism)

Kirchhoff noted dark lines (absorption) and bright lines (emission) in spectra from different conditions of source.

7-6

Kirchhoff’s Laws

1. A hot object, or hot dense gas produces a continuous spectrum (no “lines”), a blackbody spectrum
2. A hot rarified (low density) gas produces emission lines (bright features)
3. A cool gas in front of a continuous source of light produces absorption (dark) lines [absorption if background is hotter than foreground gas. Emission if background is cooler]

7-7

Kirchoff’s Laws

\[ \lambda_{\text{max}} = \frac{2.99 \text{(cm)}}{T(\text{K})} \]

7-8

Why Do Spectra Occur?

Rutherford (1910): Atoms consist of positively charged, massive nucleus, orbited by tiny, negatively charged electrons

Nucleus: protons (\( + \)) and neutrons (\( 0 \))

Attract electrons (-)

\# of protons determines element:

\( H = 1p \)

\( He = 2p \)

\( Li = 3p \)

\# of neutrons can vary: O has 8p but can have 8, 9, or 10 neutrons leading to slightly different types of O (isotopes)

Atoms usually have same \( \# \) of \( p \) and \( e^- \)

\( \text{Ion} \) if different \( \# \) of \( p \) and \( e^- \)

\( \text{Ionization} \) process which removes \( e^- \), creating \( \text{ion} \) (knock away \( e^- \) with high energy photon = photoionization)

Molecules: atoms bound together which share \( e^- \)
The Bohr Model

H has 1 e\(^{-}\) and 1 p\(^{+}\): spectrum has pattern of lines from 656nm to 383nm, called the Balmer series (after the person who discovered formula for calculating 1865).

Niels Bohr understood mathematically/physically e\(^{-}\) can have specific orbits (n=1,2,3,4...). To move from 1 level to another, e\(^{-}\) must lose or gain a specific amount of energy.

Outer - inner (4-1): e\(^{-}\) must lose energy
Inner - outer (1-3): e\(^{-}\) must gain energy

Doppler Shift

Spectral lines shifted due to motion

Doppler shift for sound and light (because light is a wave)

Motion towards source (or source towards you) compresses wavelength \(\Rightarrow\) shorter wavelength = bluer light (blueshift)
Motion away from source (or source away from you) stretches wavelength \(\Rightarrow\) longer wavelength = redder light (redshift)

\[
\frac{\lambda_{\text{obs}} - \lambda_{\text{rest}}}{\lambda_{\text{rest}}} = \frac{\Delta \lambda}{\lambda_{\text{rest}}} = \frac{v_{i}}{c}
\]