Introduction

Astronomy & Astrophysics

ASTRON = Star
NOMOS = Law
PHYSIC = Nature

Astronomy 113
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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

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

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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
- 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

Cumbersome!!

So...

Scientific Notation: 10 followed by an **exponent** or **superscript** = # of zeroes/digits after "1"

"Powers of Ten"

- $$10^0 = 1$$
- $$10^1 = 10 \times 1$$
- $$10^2 = 100 \times 10$$
- $$10^3 = 1,000 \times 10 \times 10$$
- $$10^4 = 10,000 \times 10 \times 10 \times 10$$

Distance between Sun and Earth = 150,000,000 km
- $$1.5 \times 10^8$$ km
Negative exponents

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

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

Thousand, million, billion, trillion

To multiply:

add exponents → \((5 \times 10^5) \times (2 \times 10^{20}) = 10 \times 10^{25}\) or \(1 \times 10^{26}\)

To divide:

subtract exponents → \(6 \times 10^{23} / 2 \times 10^7 = 3 \times 10^{16}\)

Math:

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 = 1.5x10^8 km or 93 million miles
- Sun to Jupiter is 5.2 AU

But even AUs are awkward...

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

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

"light year" = 1/3600° = 1 arcsecond (PARallax SECond)

1 parsec (pc) = 3.09 x 10^{13} km = 3.26 ly

Proxima Centauri is at 1.3 pc
1 kpc = 10^3 pc = kilo pc
Sun to center of Milkyway = 8.6kpc
1 Mpc = 10^6 pc = Mega pc
Distance to Virgo Cluster = 20 Mpc
Earth - $10^3$ km
Solar System - $10^8-10^9$ 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**

<table>
<thead>
<tr>
<th>Object</th>
<th>Time ago</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moon</td>
<td>1.5 seconds ago</td>
</tr>
<tr>
<td>Sun</td>
<td>8.5 minutes ago</td>
</tr>
<tr>
<td>Pluto</td>
<td>4-5 hours ago</td>
</tr>
<tr>
<td>Nearest Star</td>
<td>4 years ago</td>
</tr>
<tr>
<td>Center of Galaxy</td>
<td>25,000 years ago</td>
</tr>
<tr>
<td>Andromeda Galaxy</td>
<td>2.6 million years ago</td>
</tr>
<tr>
<td>Most distant Galaxies</td>
<td>8-10 billion years ago</td>
</tr>
<tr>
<td>Quasars</td>
<td>11-12 billion years ago</td>
</tr>
</tbody>
</table>

**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>$7 \times 10^{10}$ cm</td>
</tr>
<tr>
<td>Earth</td>
<td>$6 \times 10^8$ cm</td>
</tr>
<tr>
<td>Moon</td>
<td>2 x $10^8$ 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 ($4 \times 10^{18}$ 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.

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

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

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

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)

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
The Spectrum

- The shorter a photon’s wavelength, the higher its energy:
  \[ E = \frac{hc}{\lambda} \]
  - \( E \) = energy, \( h \) = constant, \( c \) = speed of light, \( \lambda \) = wavelength
- 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>
<tbody>
<tr>
<td>Long ( \lambda )</td>
<td>Low E</td>
<td>Short ( \lambda )</td>
<td>High E</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Red</td>
<td>Orange</td>
<td>Yellow</td>
<td>Green</td>
<td>Blue</td>
<td>Indigo</td>
</tr>
</tbody>
</table>

Not all transmitted by atmosphere

Electromagnetic Radiation & Spectra

6-8

The Spectrum

- Add figure of spectrum Zeilick p. 185

Goals

- Know Stefan-Boltzman law and Wien’s law
- State Kirchoff’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

7-1

Blackbody - I

1. As it heats becomes brighter because it emits more EM radiation
2. The color \( (\lambda \text{ of emitted radiation}) \) changes with temperature
   - Cool \( \rightarrow \) IR, red
   - Hot \( \rightarrow \) UV, blue

First noted by Thomas Wedgwood in 1792

7-2

Blackbody - II

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

\[ E = \sigma T^4 \]

Stefan-Boltzman Law (Intensity-temperature relationship for blackbodies):
An object emit energy at a rate proportional to the 4th power of its temperature (in Kelvin, absolute scale)
Wien's Law

Relationship between color peak & temperature found by Wien in 1893

Wien's Law: \( \lambda_{\text{max}} = \frac{2.898 \text{ cm}}{T} \) (in 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 5800Å (5000K), so why not blue-green? (scattering)

Spectra - I

Fraunhofer: solar spectrum has dark lines (spectral lines)

Kirchoff-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

Spectra - II

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)

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

Kirchoff'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]

Why Do Spectra Occur?

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

Nucleus: protons (+) and neutrons (x)

Attract electrons (-)

\( n \) of protons determines element:

\( n = 1p \quad \text{He} = 2p \quad \text{U} = 92p \)

\( n \) 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 \( n \) of p and e'

Ion if different \( n \) of p & e'

Ions: process which removes e', creating 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 656 nm to 364 nm, called the Balmer series (after the person who discovered formula for calculating it in 1885).

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)

\[
\frac{\lambda_{\text{observed}} - \lambda_{\text{emitted}}}{\lambda_{\text{emitted}}} = \frac{\Delta \lambda}{\lambda_{\text{emitted}}} = \frac{v}{c}
\]