HARCOURT C. “ACE” VERNON MEMORIAL LECTURE

Tuesday, October 3, 2017 | 7:30 PM
Clayton Hall Conference Center

Preparing to Explore the Universe with the James Webb Space Telescope

Like a giant golden eye, NASA's James Webb Space Telescope will peer back to the beginning of time and watch galaxies collide. It will capture gorgeous images of stars and planets being born. It will search for new planets and pursue the age-old question: Is life out there?

Astrophysicist Jane Rigby, who grew up in Sussex County, Delaware, is the deputy project scientist for this amazing new space tool. She will show us how it will revolutionize our view of the universe and fill us in on preparations for the telescope's launch in October 2018.

Jane Rigby
Deputy Project Scientist for Operations - JWST, NASA

Illustration courtesy of Northrop Grumman

Free and open to the public. Please register online at mountcuba.org

Sponsored by the Delaware Astroseismic Research Center at the University of Delaware, Mount Cuba Astronomical Observatory & Mount Cuba Astronomical Foundation
Assignments

• For Fri.
  – Do Online Exercise 09 including “The Sun” tutorial

• 1st Midterm is Friday, Oct. 13 (not on purpose!).
Chapter 5
Light: The Cosmic Messenger
Wavelength, Frequency, and Energy

$$\lambda \times f = c$$

$$\lambda = \text{wavelength, } f = \text{frequency}$$
$$c = \text{speed of light} = 300,000 \text{ km/s}$$

$$E = h \times f = \text{photon energy}$$
What is matter?
Atomic Terminology

- **Atomic Number** = # of protons in nucleus
- **Atomic Mass Number** = # of protons + # of neutrons

**atomic number** = number of protons
**atomic mass number** = number of protons + neutrons
(A neutral atom has the same number of electrons as protons.)

<table>
<thead>
<tr>
<th>Element</th>
<th>Atomic Number</th>
<th>Atomic Mass Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen ((^1\text{H}))</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1 electron)</td>
</tr>
<tr>
<td>Helium ((^4\text{He}))</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2 electrons)</td>
</tr>
<tr>
<td>Carbon ((^12\text{C}))</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(6 electrons)</td>
</tr>
</tbody>
</table>
Atomic Terminology

• **Isotope**: same # of protons but different # of neutrons ($^4\text{He}$, $^3\text{He}$)

• **Molecules**: consist of two or more atoms ($\text{H}_2\text{O}$, $\text{CO}_2$)
Four Ways that Light Interacts with Matter

1. **emission** – matter releases energy as light

2. **absorption** – matter takes energy from light

3. **transmission** – matter allows light to pass through it

4. **reflection** – matter repels light in another direction
Light as Information Bearer

We can separate light into its different wavelengths (spectrum).

By studying the spectrum of an object, we can learn its:

1. Composition
2. Temperature
3. Velocity
Interaction of Light with Matter

- Electron can only have certain energies in an atom.
- Electrons can
  - absorb light & gain energy
  - emit light & lose energy.

- Only photons with energies (colors) matching the “jump” in electron energy levels can be emitted or absorbed.
Kirchoff’s laws

1. hot solid/dense-gas: continuous spectrum
2. hot gas: emission line spectrum
3. cold gas + continuous source: absorption line spectrum
Spectral lines & Doppler shift

- Atoms of a gas absorb & emit light at discrete frequencies
- Motion of atoms shifts frequency by Doppler effect
The Doppler Effect

1. Light emitted from an object moving towards you will have its wavelength shortened. **BLUESHIFT**

2. Light emitted from an object moving away from you will have its wavelength lengthened. **REDSHIFT**

3. Light emitted from an object moving perpendicular to your line-of-sight will not change its wavelength.
The Doppler Effect

\[ \Delta \lambda = \frac{\lambda_{\text{obs}} - \lambda}{\lambda} = \frac{v}{c} \]
A star’s spectral lines are shifted to longer wavelengths than measured in the lab. This implies that the star must be

A. Hotter than the sun
B. Colder than the sun
C. Moving away from us
D. Moving toward us
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How does light tell us the temperatures of planets and stars?
Thermal Radiation

- Nearly all large or dense objects emit thermal radiation, including stars, planets, and you.

- An object’s thermal radiation spectrum depends on only one property: its temperature.
Thermal Radiation

1. Hotter objects emit photons with a higher average energy.
2. Hotter objects emit more light at all frequencies per unit area.
Thought Question

Which is hottest?
A. A blue star
B. A red star
C. A planet that emits only infrared light
Thought Question

Which is hotter?
A. A blue star
B. A red star
C. A planet that emits only infrared light
Temperature dependence of wavelength at peak intensity

Wien’s law

\[ \lambda_{\text{max}} = \lambda_{\text{max, sun}} \frac{T_{\text{sun}}}{T} = 500 \text{nm} \frac{6000 \text{K}}{T} \]

Observed color depends on temperature.
Temperature dependence of total energy flux

Stefan-Boltzmann law

\[ F = \sigma T^4 \]
\[ \sigma = \text{Stefan-Boltzman constant} \]
Temperature dependence of total energy flux

Stefan-Boltzman law

\[ F \sim T^4 \]
Luminosity

\[ L = F \cdot A = \sigma T^4 \cdot 4\pi R^2 \]

Using the sun as reference gives:

\[ \frac{L}{L_{\text{sun}}} = \left( \frac{T}{T_{\text{sun}}} \right)^4 \left( \frac{R}{R_{\text{sun}}} \right)^2 \]
Emission by Opaque Objects

1. Hotter objects emit more total Energy per unit surface area, or Energy Flux
   ➢ Stephan-Boltzmann Law
     ➢ \( F = \sigma T^4 \)

2. Hotter objects emit *bluer* photons (with a higher average energy.)
   ➢ Wien’s Law

\[ \lambda_{\text{max}} = 2.9 \times 10^6 / T(\text{K}) \text{ [nm]} \]
Measuring Rotational Velocity

Narrow spectral lines indicate that star A rotates slowly.

Wide spectral lines indicate that star B rotates rapidly.

Slow rotation:
- This light is slightly blueshifted.
- This light is slightly redshifted.

Fast rotation:
- This light is greatly blueshifted.
- This light is greatly redshifted.

Approaching side:
- Intensity vs. wavelength

Receding side:
- Intensity vs. wavelength
Rotational Broadening of Absorption Lines from a Star’s Surface Layers