Astronomy 280

Evolution Of The Universe

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Basic Concepts

• For the most part, astronomers learn about the universe by detecting and analyzing radiation.

[To a limited degree, they also detect particles like cosmic rays and neutrinos and meteorites, and can now directly accumulate samples in the solar system.]

• Electromagnetic radiation. Transfer of energy at the speed of light, 300,000 km/s. Equivalence between energy in waves and in discrete “bullets” called photons. The amount of energy carried by a photon determines its wavelength or frequency.
Light Waves

- Frequency = number of waves passing by per second
- Long wavelengths $\rightarrow$ low frequency
- Short wavelengths $\rightarrow$ high frequency

- **High** frequency (short wavelength) $\rightarrow$ **high** energy
- **Low** frequency (long wavelength) $\rightarrow$ **low** energy

- The electromagnetic spectrum:
  - Low energy .........................$\rightarrow$........................................ high energy
  - Radio – submillimeter - infrared – optical - ultraviolet – X ray - $\gamma$ ray
  - Mauna kea outstanding for submillimeter, infrared, optical
    [Minimal water vapor and non- turbulent atmosphere]
galaxy images in different passbands

Messier 33

Hα superimposed on visible image

ultraviolet  red  Hydrogen α spectral line
Neutral Hydrogen images of galaxies
Telescope Resolving Power

\[ \Theta \sim \frac{\lambda}{D} \]

Resolution \(\sim\) wavelength/diameter

To maintain good resolution, long wavelengths require large telescopes

Arecibo 300 meter

Very Large Array – 36 kilometers

Very Long Baseline Array – 8,600 kilometers
Discrete Radiation Processes

Line Emission or Absorption:

These energy transitions are between discrete energy levels → “quantized” energy transitions at specific wavelength (or frequency) → elements or molecules will have characteristic “spectral features” depending on the energy states available for electrons in their atoms.
A Continuum Radiation Process

“Recombination” and “ionization” where an electron becomes attached to or escapes from a nucleus by filling or emptying an orbit location. Radiation is released or absorbed in this process.

- **Ionization**: energy absorbed to kick electron out of atom
- **Recombination**: energy emitted, allowing electron to settle into lower energy state

Ionization and recombination radiation are drawn from a “continuum” of possible wavelengths (frequencies) at higher energies (shorter wavelengths) than a threshold.
Other Examples of “Continuum” Energy Exchange / Transitions:

- Free-free transitions: electron scattering outside atoms
- Synchrotron radiation: electrons accelerated in a magnetic field
- Thermal or black body spectrum:
  Increase temperature $\rightarrow$ spectrum shift to higher energies (higher frequencies / shorter $\lambda$)
Doppler Shift of Radiation

- Consider as an example a spectral line associated with a transition between two specific energy states in an atom:
  - Suppose the source of the radiation is approaching
    - waves are compressed; arrive more frequently - blueshift
  - Or if the source is receding, waves stretched out - redshift