Lecture 4: The Electromagnetic Spectrum
Understanding Stellar and Galaxy Properties, and Cosmology

Four blocks: introduction to astrophysical tools, stars, galaxies, cosmology.

The goals of this class are:

• Understanding the formation and evolution of stars using simple physical principles

• Understanding the formation and evolution of galaxies

• Understanding the cosmological evolution of the Universe
Physics that we need to know

Before we start with astrophysics, you need to be familiar with these terms:

- **scientific notation**

- **definition and units**: distance, time, velocity, acceleration, angular size, mass, momentum, angular momentum, force, energy, power, temperature

- **states of matter**: solid, liquid, gas, ions

- **the four forces of nature**: gravity, electromagnetic force, weak and strong nuclear force

- **light**: dual wave/particle nature, interaction with matter
- energy transfer mechanisms: conduction, convection, radiation

- thermal radiation: Planck function
Thermal radiation distribution:

• If it's hotter, it's **BLUER**.
• If it's hotter, there's **MORE** of it →

(Log-log plot)
Thermal radiation distribution:
• This spectral shape is closely related to the distribution of particle velocities.

P.S. Note that the plots on the right have energy decreasing to the right, whereas the left hand plot is opposite.
Planck Function

Describes how much electromagnetic power is emitted at a given wavelength (or frequency) by a black body of a given temperature:

\[ I_\nu(\nu, T) = 4\pi \left( \frac{\hbar \nu^3}{c^2} \right) \left( \frac{1}{\exp\left( \frac{\hbar \nu}{kT} \right) - 1} \right) \quad (1) \]

This form gives power per per unit area of emitting surface, and per unit frequency (the unit is W m\(^{-2}\) Hz\(^{-1}\)).

Here, \( \hbar = 6.63 \times 10^{-34} \) Js is the Planck constant, and \( c = 2.998 \times 10^8 \) m/s is the speed of light (roughly 200,000 miles/second!).

Also, the power per unit wavelength (see the plots on previous slides) is

\[ I_\lambda(\lambda, T) = \frac{\nu}{\lambda} I_\nu(\nu, T) \quad (2) \]

with \( \nu \lambda = c \) (true for any wave).
From Planck function, we can derive:

- the Stefan-Boltzmann law: \( F = \sigma T^4 \), and

- the Wien’s law: \( T\lambda_{\text{max}} = C \), with \( C \approx 3000 \text{ K } \mu\text{m} \).

More details: http://en.wikipedia.org/wiki/Planck’s_law
Electromagnetic Radiation

Astronomers care for every photon: from radio to gamma rays!
Why do astronomers care for every photon? That is, why are the wavelengths other than visual important? After all, the Planck function radiation is described by 2 numbers (temperature and flux)!

- Radiation from astronomical sources is **NOT** Planckian
Multiple components
Bright in infrared,
...and invisible in optical
Circumstellar disk (the star is masked)
Comet
Saturn
• Radiation from astronomical sources is **NOT** Planckian
  
  – Radiative transfer effects (e.g. circumstellar dust)
  
  – Non-thermal processes (e.g. synchrotron emission)
Optical Continuum Emission

NGC 300 B band
NGC 300 Halpha+[NII]

Optical Line Emission
NGC 300 X-ray Broadband (0.1-2.4 keV)

Soft X rays
NGC 300 Infrared 60 microns

Infrared (60 μm) Emission
Radio Continuum (6 cm) Emission

NGC 300 Radio 1.49GHz continuum
Radio Line (21 cm) Emission
Why do astronomers care for every photon?

- Radiation from astronomical sources is *NOT* Planckian
  - Radiative transfer effects
  - Non-thermal processes (e.g. synchrotron emission)

- Dust Obscuration (end emission!)
- Dust obscures optical radiation, and re-emits it at infrared wavelengths.

Optical – Near-IR (1 \(\mu m\))– Far-IR (100 \(\mu m\))
Again, an infrared view can be VERY different from optical view.
Why do astronomers care for every photon?

• Radiation from astronomical sources is **NOT** Planckian
  – Radiative transfer effects
  – Non-thermal processes (e.g. synchrotron emission)

• Dust Obscuration (end emission!)

• Cosmological Reddening
The most distant known quasars:
A quasar at $z \approx 6.28$

Hint: Look between the star and the galaxy, and down a little
Atmospheric water absorbs infrared radiation, except in a few 1-2 and 100 $\mu m$ windows.
Can we get at least some photons at the ground level?
Yes, if you go high and dry.
Next time: sections 1.1 and 1.2!