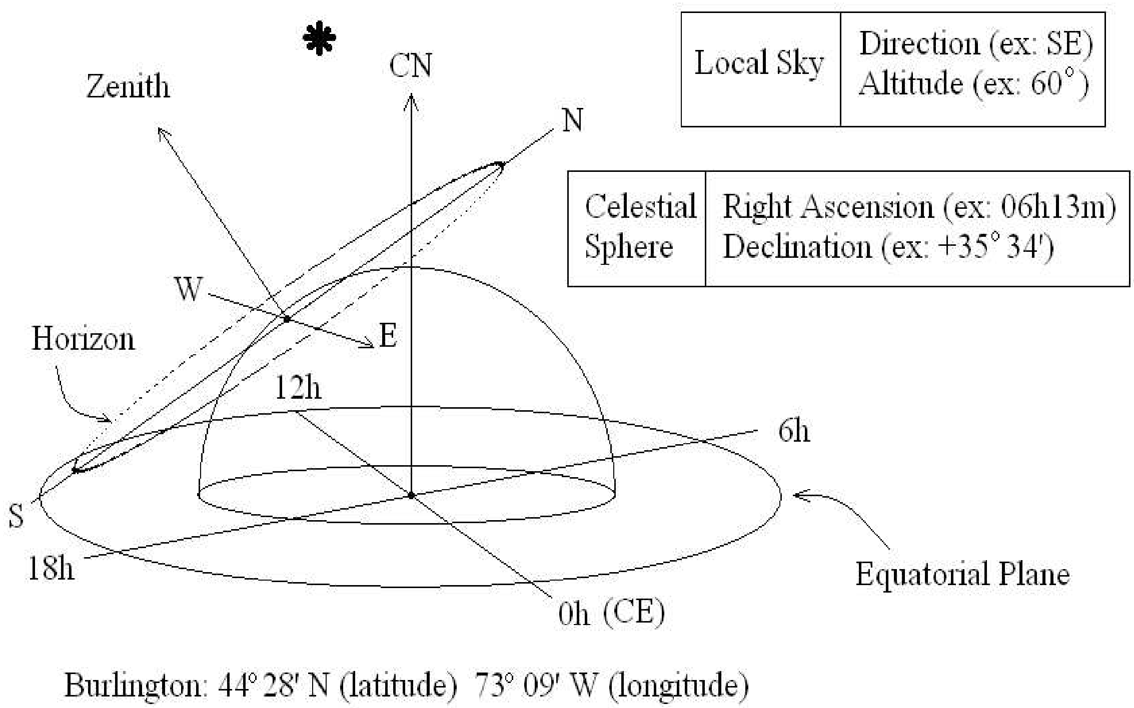
ASTRONOMY LECTURE NOTES
MIDTERM REVIEW

ASTRONOMY LECTURE NOTES
Chapter 1 – Charting the Heavens

How Do We Locate Objects in the Sky?
Local-Sky Coordinates versus Celestial-Sphere Coordinates

When the sky is viewed from our perspective (the *local sky*), the location of any object in the sky is given in terms of its direction (for example, south-west direction) and its altitude above the horizon (for example, 60^o). Although these local-sky coordinates are useful for anyone making observations next to you, they are not useful to someone making observations far away from you (since they have a different horizon and a different zenith).



Celestial-sphere coordinates pinpoint the position of any object with respect to a *fixed celestial sphere*. Thus, the position of an object is given in terms of its Right Ascension (RA) – measured in hours (hh), minutes (mm), and seconds (ss) from Celestial East (CE) – and its Declination (Dec) – measured in degrees (^{o}), arcminutes ($1' = 1^o/60$), and arcseconds ($1'' = 1'/60 = 1^o/3600$) from the Equatorial Plane. An object located in the northern celestial hemisphere is given a positive declination, while an object located in the southern celestial hemisphere is given a negative declination. For example, the Celestial North Pole (CN) is located at a declination of $+90^o\ 00'\ 00''$.

Angular Sizes and Distances

The *angular* size Δ of an object of *linear* size D located at a distance L is measured in degrees (^{o}) and is calculated as

$$\Delta \;=\; \frac{D}{L} \times \frac{360^o}{2\pi}$$

A human eye with *perfect* vision can resolve two dots separated by 1 cm at a distance of 30 m and, hence, human vision has an angular resolution of $0.019^o = 1.14'$. The optical telescope at Mount Palomar has an angular resolution of $0.0275''$, i.e., it can resolve two dots separated by 1 cm from a distance of 75 km!.

ASTRONOMY LECTURE NOTES
Chapter 2 – The Copernican Revolution

• History of Astronomy

- ◦ $\sim$ 4000 BC — Earliest astronomical observations recorded
- ◦ $\sim$ 2000 BC — Constellations first drawn up by astronomers
  First solar-lunar calendars
- ◦ 330 BC — Aristotle: Geocentric model of the Solar system
- ◦ 140 AD — Ptolemy: Geocentric model based on epicycles to explain retrograde motion of planets
- ◦ 1543 — Copernicus publishes Heliocentric model (30 years after its inception)
- ◦ 1576 — Tycho Brahe (Denmark) observes motion of planets and supernova (Cassiopea)
- ◦ 1608 — First telescope (Holland)
- ◦ 1609 — Kepler proposes his first two laws of planetary motion
  ⋆ First Law: Planets moved around the Sun in elliptical orbits
  ⋆ Second Law: Equal areas are swept in equal times
  Galileo uses telescope for astronomical purposes (Moon & Jovian Moons, ...)
- ◦ 1619 — Kepler proposes his third law of planetary motion
  ⋆ Third Law: $[\mathrm{Period(year)}]^2 = [\mathrm{Radius(A.U.)}]^3$
- ◦ 1632 — Galileo supports Copernicus' Heliocentric theory of the Solar system
- ◦ 1687 — Newton publishes his Universal Theory of Gravitation
  → explains Kepler's Three Laws of Planetary Motion

ASTRONOMY LECTURE NOTES
Chapter 2 – Copernican Revolution

The Copernican Revolution

- Nicolai Copernicus (1473-1543)

Copernicus introduced (on his death bed) a heliocentric model of the solar system, which challenged the geocentric model of Ptolemy (100-170 AD). The Copernican model easily explains the retrograde motion of planets around the Sun as viewed from Earth.

- Tycho Brahe (1546-1601)

Tycho made precise measurements of the positions of the planets but failed to discover the laws of planetary motion.

- Johannes Kepler (1571-1630)

Kepler, Tycho's apprentice, tried to match Tycho's planetary data to circular motions. A discrepancy of $8'$ for Mars (rembember that perfect human vision has an angular resolution of $1'$) forced Kepler to abandon the idea of circular motions. From 1610 to 1618, Kepler published his three laws of planetary motion.

Kepler's First Law: Each planet moves along an elliptical orbit around the Sun (located at one focus).

Kepler's Second Law: As a planet moves around its orbit, it sweeps an equal area in an equal amount of time.

Kepler's Third Law: More distant planets orbit the Sun at slower average speeds, obeying the precise relation $p(\mathrm{y})^2 = a(\mathrm{AU})^3$.

- Galileo Galilei (1564-1642)

Galileo perfected the telescope (invented in 1608) and applied it (in 1609) to astronomical observations of the Sun, planets, and moons (e.g., the Moon and the moons of Jupiter). His numerous observations provided an experimental basis for the Copernican model of the solar system.

ASTRONOMY LECTURE NOTES
Chapter 2 – Copernican Revolution

Glossary of Terms

• **Speed** [m/s]	tells how far an object travels in a given amount of time.
• **Velocity** [m/s]	is given as speed in a given direction.
• **Acceleration** [m/s^2]	tells the rate of change of velocity (either speed or direction).
• **Mass** [kg]	is defined as the measure of inertia.
• **Momentum** [$kg \cdot m/s$]	is defined as the product of mass and velocity.
• **Force** [$N = kg \cdot m/s^2$]	is defined as the rate of change of momentum.
• **Weight** [N]	describes the force due to gravity.
• **Energy** [$J = N \cdot m$]	comes in four types: kinetic (motion), potential (position), radiative (light), and thermal (total kinetic energy).

Newton's Laws of Motion

- Newton's 1st Law: An object moves with constant velocity (including being at rest) unless a net force acts on it.

  If an object does not move in a straight line at constant speed, a net force must be acting on it.

- Newton's 2nd Law: Force = mass × acceleration.

- Newton's 3rd Law: When object A exerts a force on object B, object B **reacts** back on object A with a force of equal magnitude but opposite direction.

  The gravitational attraction of Earth to the Sun is as strong as the graviational attraction of the Sun to Earth.

Conservation Laws in Astronomy

- Conservation Law of Angular Momentum

As a planet (mass m) orbits the Sun, its motion conserves a quantity known as angular momentum, defined as the product of mass m × velocity v × orbital radius r. This conservation law is the basis of Kepler's Second Law, which states that equal areas are swept in equal times as a planet moves about the Sun.

- Conservation Law of Energy

Energy can be transferred from one object to another or transformed from one type to another, but the total amount of energy is always conserved.

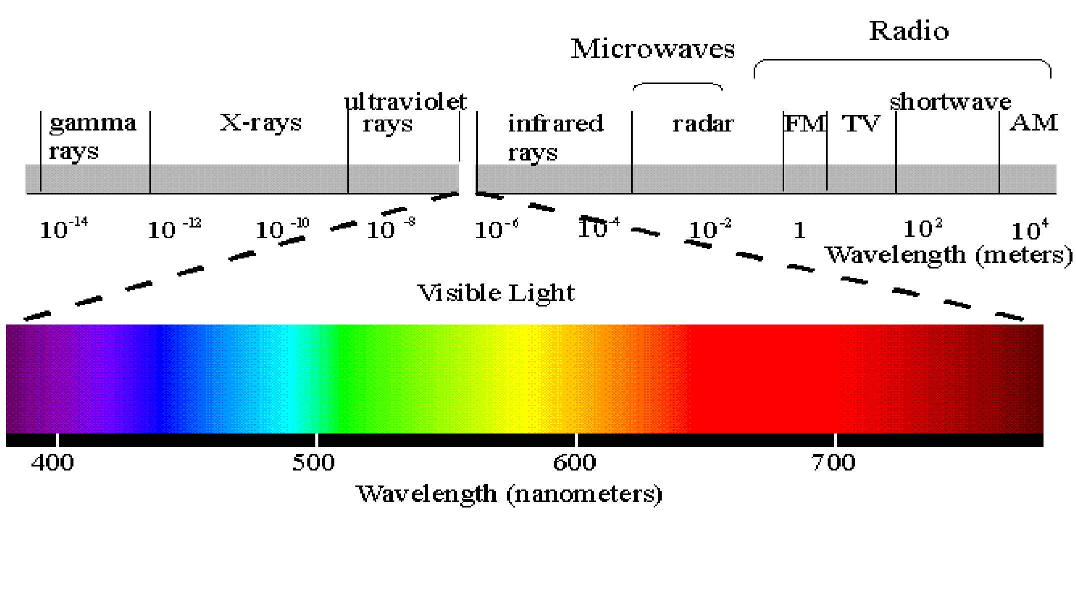
The thermal energy of a gas is defined as the total kinetic energy of the gas particles. The temperature of the gas is defined in terms of the average kinetic energy of the gas particles. The unit of temperature is the Celsius (C) or Kelvin (K): $T_K = T_C + 273\,\mathrm{K}$.

ASTRONOMY LECTURE NOTES
Chapter 3 – Radiation: Information from the Cosmos

Properties of a Light Wave

- **Amplitude** describes the strength of a wave.
- **Frequency** $f(\mathrm{Hz})$ = number of times a wave cycle repeats itself per second.
- **Wavelength** $\lambda(\mathrm{m})$ = spatial period of the wave.
- **Wavespeed** $v(\mathrm{m/s}) = \lambda \cdot f$ = speed at which wave travels.
- **Photon** light *particle* whose energy E is proportional to frequency f.

Electromagnetic (Light) Spectrum



Properties of Matter

- **Atom** — Matter is composed of atoms; it is composed of a nucleus (protons + neutrons) and is surrounded by electrons.
- **Element** — Each atom corresponds to a single chemical element.
- **Atomic Number** — Number of protons in the nucleus of an atom (Z).
- **Atomic Mass Number** — Number of protons and neutrons in the nucleus (A).
- **Isotopes** — Versions of a chemical element (same Z) with different numbers of neutrons (different A).

Light Interacts with Matter

- **Emission**: Matter can emit light waves.
- **Absorption**: Matter can absorb light.
- **Transmission**: Light can go through matter under certain conditions.
- **Reflection/Scattering**: Light waves can be reflected/scattered by matter.

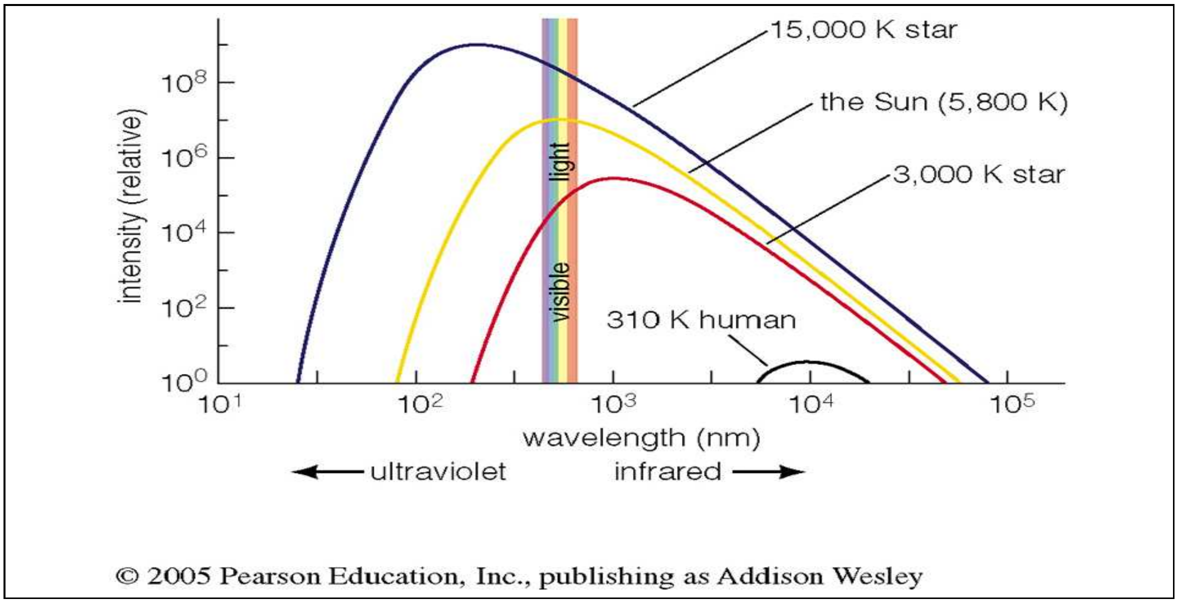
ASTRONOMY LECTURE NOTES
Section 3.4 – Thermal Radiation

Thermal Radiation and Temperature

The continous spectrum emitted by a radiating object is characterized by its surface temperature; hence, the continuous radiation is called thermal radiation (a.k.a. blackbody radiation). The Figure below shows that thermal radiation has two important properties:

- Hotter objects show greater intensity at all wavelengths.
- Hotter objects emits photons of higher average energy represented by Wien's Law, which states that the peak intensities of thermal radiation coming from hot objects occur at shorter wavelengths.

$$\lambda_{\max} = \frac{\text{constant}}{T}.$$



Hence, the location of the peak intensity in the continuous spectrum of a star can tell us something about its surface temperature.

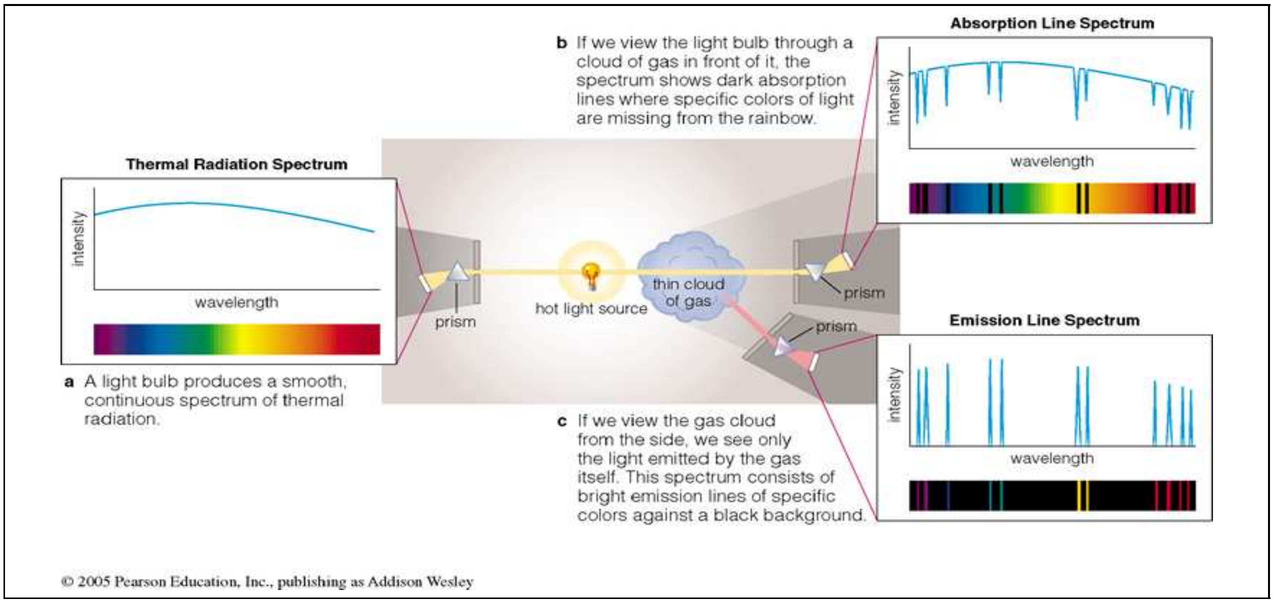
Kirchhoff's Three Laws of Radiation

◦ **First Law (Continuous Spectrum)**: a radiating object produces a continuous thermal radiation spectrum that depends on its it surface temperature.

◦ **Second Law (Emission Spectrum)**: All chemical elements, ions, and molecules emit a line spectrum composed of discrete wavelengths that form a specific pattern characteristic of its chemical origin. The emission spectrum is associated with light emitted during the de-excitation of electrons from higher atomic energy levels to a lower energy level.

◦ **Third Law (Absorption Spectrum)**: When light coming from a hot continuous-spectrum source passes through a cooler gas, certain specific wavelengths characterisitic of the cooler gas are removed from the continuous spectrum. The absorption spectrum is associated with light absorbed during the excitation of electrons from a lower energy level to higher energy levels.

The Figure below shows applications of the Kirchhoff's Laws for the case of hydrogen.



Note that the emission (and absorption) spectrum of each chemical element provides a unique fingerprint and, thus, the absorption spectra of stars can tell us something about their chemical composition.

Doppler Shift for Moving Light Sources

The location of the peak intensity in the continuous spectrum and the location of absorption lines associated with a star is affected by the relative motion of the star as viewed from Earth. This effect is know as the Doppler effect, which applies to all types of waves (e.g., sound and light).

When a star is in *radial* relative motion (i.e., its distance to Earth changes), its emission spectrum is shifted according the Doppler-shift equation

$$\frac{\Delta\lambda}{\lambda_0} = \frac{\lambda - \lambda_0}{\lambda_0} = \pm \frac{v_r}{c},$$

where λ_0 denotes the *rest* wavelength of an emission line, λ denotes the *observed* wavelength of that emission line, and $\pm v_r/c$ denotes the ratio of the radial velocity to the speed of light ($+v_r$ if the star is moving away, or receding, from us and $-v_r$ if the star is moving toward us).

A spectrum becomes redshifted when its source is moving away from us. On the other hand, a spectrum is blueshifted when its source is moving toward us.

ASTRONOMY LECTURE NOTES
Chapter 4 – Telescopes

TELESCOPE

A device used to COLLECT star light over a large area and FOCUS it onto a small viewing area (i.e., eye or camera).

Telescope Powers

- Light Gathering Power $\propto$ (Diameter)^2
- Magnification Power = f_o/f_e
- Resolving Power

$$\text{angular resolution (arc sec)} = 0.25 \times \frac{\lambda(\mu\text{m})}{\text{Diameter(m)}}$$