ASTR469 Lecture 1: Introduction (Birney et al., Ch. 5)

NOTE:
These should be a conceptual helper/reminder for you but do not 100% stand in for the assigned reading, for attending class, or for taking notes in class! You should still do all of those things.

Assess yourself/study guide after lecture (without peeking at notes)...

1. What types of objects are in the Universe and what are the types of particles and/or waves can we use to observe them?

2. What are the wavelength and frequency regimes of the EM spectrum?

3. Use the equations from today to fill in the remainder of Table 1.

4. What is the approximate volume of a spherical cow of radius 1 m? [do this in your head to practice order-of-magnitude estimation!]

5. Pick a mountain, telephone pole, or building you can see that you can estimate the distance to. Using your hand as an angle measure, determine the angular size of that object and then apply trigonometry to estimate the linear size of the object (then compare it with a measurement of that object). Note, you will need to estimate or measure the distance to the object. Alternately, you can do the same trick to determine how far you are from an object of known size.

6. If an object is 1" across and is 5 Mpc away, what is its actual (projected) linear size?

7. What is the total solid angle of an object that covers one eighth of an entire sphere (e.g. the Milky Way galaxy)?

8. What is the solid angle of a single $6''$ square pixel?

1 Neutrinos, cosmic rays, gravitational waves, EM radiation.

Astronomy is an "observational science." We learn about the Universe passively by observing, but we cannot experiment by altering the physical conditions like we can in physics or chemistry. Fortunately, we do have several messengers that carry information:

- **Electromagnetic waves** (caused by accelerated charged particles: electrons, protons).
- **Neutrinos** (created during radioactive decay).
- **Gravitational Waves** (happens when mass is accelerated; we will learn more about this later in the semester!).

1.1 Neutrinos (and a note on cosmic rays)

Neutrinos are small, light particles that essentially do not interact with matter. Among other sources, they are produced in large numbers by the Sun, but also by supernovae. We can detect them using large vats of material (e.g., water), and thereby learn about fusion rates in the Sun, and the interactions within a supernova. Because they so weakly interact with matter, they are a great way to see where we might otherwise not be able to using only "standard" electromagnetic observing techniques.

Cosmic rays are high-energy charged particles (protons, neutrons) travelling at relativistic speeds. They are produced in explosive or high-energy phenomena such as SN, neutron stars, etc. They create quite a lot of electromagnetic emission from the cosmos and in our own atmosphere by either interacting with magnetic fields (e.g. synchrotron radiation, which we will discuss later on this semester), or by interacting with other particles to then create subatomic particles and light (can occur in our atmosphere).

1.2 Gravitational waves (GW)

GWs are produced from any non-spherically-symmetric mass acceleration. A good example of this is the rapid acceleration experienced in a supernova explosion, or any two (or more!) massive objects in close orbits, such as black holes or neutron stars. In fact, most mass produces minor gravitational waves when it moves (you included), however for waves to

Name	Wavelength	Frequency (Hz)	Photon Energy (eV)
Gamma ray			100 kev - 300+ GeV
X - ray			120 eV - 120 keV
Ultraviolet	10 nm - 400 nm		3 eV - 124 eV
Visible	390 nm - 750 nm		
Infrared	750 nm - 1 mm		
Microwave	1 mm - 1 meter	300 GHz - 300 MHz	
Radio		300 GHz - 3 Hz	

Figure 1: Common divisions in the EM spectrum. Practice your conversions and fill in the rest of the grid!

be detected they must come from a very massive, and rapidly accelerated, object. Just like electromagnetic waves, gravitational waves carry away energy from the system. Like neutrinos, they only have weak interactions with intervening material so can be used to see within areas inaccessible by electromagnetic observations.

1.3 Electromagnetic (EM) radiation/waves

These will be by far the most familiar to most people who discuss astronomy. Propagating photons are referred to as "electromagnetic waves" and are produced when a charged particle is accelerated. These are produced by most objects in the Universe, except for black holes (however note that some matter, like the diffuse intergalactic medium, is nearly impossible to observe directly due to being too cold and diffuse). EM radiation is strongly affected by interactions with any matter, and is often absorbed, scattered, and polarized by intervening media between us and the target of observation. This can be a setback (e.g. absorption in the atmosphere) but also provides a rich area of study (e.g. allows us to study the in-depth properties of dust in galaxies, allows us to detect absorption, giving information about density, ionization, and temperature of particular atoms and molecules present in other galaxies).

There are a few common sub-divisions of the electromagnetic spectrum, as shown in Table 1.

2 Solid Angles

When we start discussing the quantification of light on Wednesday, we will use solid angles; many students haven't yet heard of these. A solid angle, measured in dimensionless steradians (sr), is simply a two-dimensional angle. Think of it as a cone spreading out from the center of a sphere to its edge. A solid angle is the area of a unit sphere such that there are

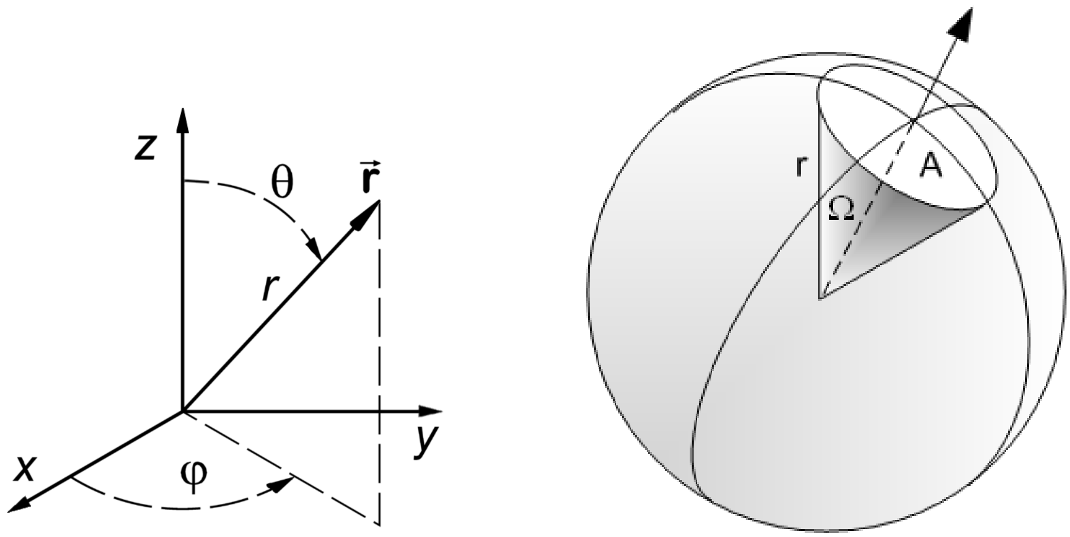

Figure 2: Spherical coordinate setup (left) and defining solid angle (right).

4π sr total on a sphere. The obvious application is the sky. Objects that appear larger on the sky have a larger solid angle.

The mathematical definition is

$$d\Omega = \sin\theta d\theta d\phi \tag{1}$$

or

$$\Omega = \int_A \int \sin\theta d\theta d\phi \,, \tag{2}$$

where θ and ϕ are angles in spherical coordinates and the integration is over surface A. The set-up for this is shown in Figure 2.

For conical solid angles with small θ, we can approximate the solid angle with:

$$\Omega \simeq \pi\theta^2 \,, \tag{3}$$

with θ in radians of course. Notice that this is just the area of a circle of radius θ. The true solid angle will be slightly smaller than this for a given value of θ, although this is almost always appropriate for astronomical measurements. The true formula is

$$\Omega = 2\pi(1 - \cos\theta) \tag{4}$$

Solid angles need not be conical though. We can just as easily have a square projected area or something asymmetric (think of world map figure in Fig. 3, or some kind of blobby astronomical source).

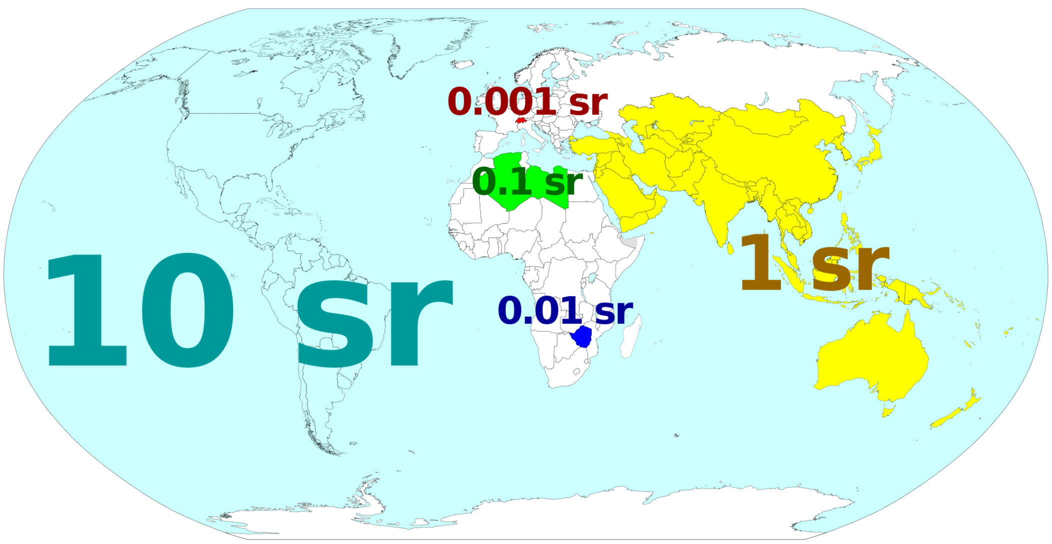

Figure 3: Build your intuition on how much of a sphere steradians cover.