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

NOTE:
These notes should be a helpful reminder of what we cover in class but do not stand in for reading the textbook, attending class, or taking notes! You should still do all of those things.

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:

- **Neutrinos** (created in energetic phenomina such as supernovae and also by fusion).
- **Cosmic rays** (created in energetic phenomena such as supernovae).
- **Gravitational Waves** (created when mass is accelerated).
- **Electromagnetic waves** (caused by accelerated charged particles; spontaneously emitted by excited atoms and molecules).

Of these, electromagnetic (EM) radiation is of course the most often used. We'll deal with this last today, and discuss it over the next couple lectures.

1.1 Neutrinos

Neutrinos are small, low-mass particles that essentially do not interact with matter - they are streaming through you right now! Among other sources, they are produced in large numbers by the Sun (and other stars of course) as a byproduct of fusion, 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. In SN1987A, for instance, we detected the neutrinos before we saw the EM radiation.

1.2 Cosmic rays

Cosmic rays are high-energy charged particles (protons, atomic nuclei, and electrons) travelling at relativistic speeds. They are produced in explosive or high-energy phenomena such as SN, neutron stars, etc, and also via fusion. They create EM radiation when they interact with matter; either in our atmosphere or in the cosmos. When cosmic ray electrons interact with magnetic fields, they produce synchrotron radiation, which we will discuss later on this semester. When cosmic ray nuclei interact with other particles they cause "showers" of other subatomic particles and light (can occur in our atmosphere).

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!

1.3 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 individual GW events to be detected by current technology they must come from a very massive, and rapidly accelerated, object. Just like EM 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 of the Universe that are inaccessible by EM observations.

1.4 Electromagnetic (EM) radiation/waves

EM waves are by far the most familiar and useful to most students. Propagating photons are referred to as "electromagnetic waves." EM waves are produced when a charged particle is accelerated, and also by spontaneous emission from excited atoms and molecules.

EM radiation is strongly affected by interactions with matter, and is often absorbed, scattered, and polarized by intervening media between us and the target of observation. This can be a setback since the signal is weakened, but also provides a rich area of study (for example is allows us to study the properties of the "dust" doing the absorption).

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

2 Solid Angles

Instead of distances, which we rarely know, we usually use angles on the sky. For example, the Sun and moon are about $30'$ in diameter, and Mizar and Alcor in the Big Dipper are $11.8'$ from each other. The "arc" in "arcminute" is due to the fact that the sky is curved - it is a non-Euclidean surface.

If a source has an angular extent (i.e., it's not a star, which are point sources), we will use

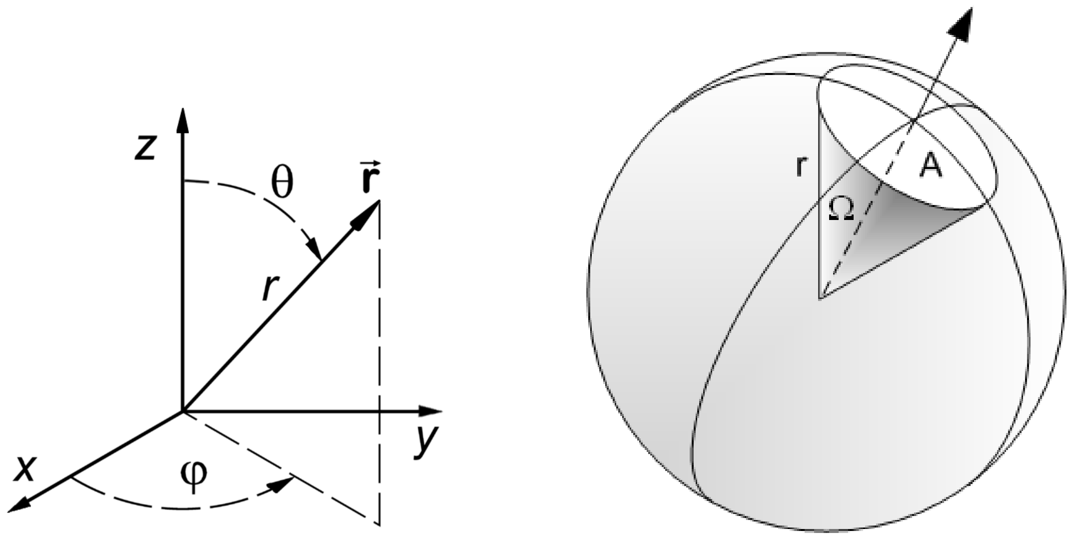

Figure 2: Spherical coordinate setup (left) and definition of solid angle (right).

"solid angles" to denote its (angular) area. Many students haven't yet heard of these! A solid angle, measured in dimensionless steradians (sr), is simply a two-dimensional angle. Imagine it as the area created by rotating a conventional angle about one of its "legs." By definition, a solid angle is the area of a unit sphere such that there are 4π sr total on a sphere. Objects that appear larger on the sky have a larger solid angle, up to a maximum of 4π.

The mathematical definition for the solid angle 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 (see Figure 2). Note that θ in these equations refers to the radius of the source. We are often dealing with the situation of $\phi = \theta$, which we'll call "conical."

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 (e.g., a pixel!) or something asymmetric (think of world map figure in Fig. 3, or some kind of blobby astronomical source).

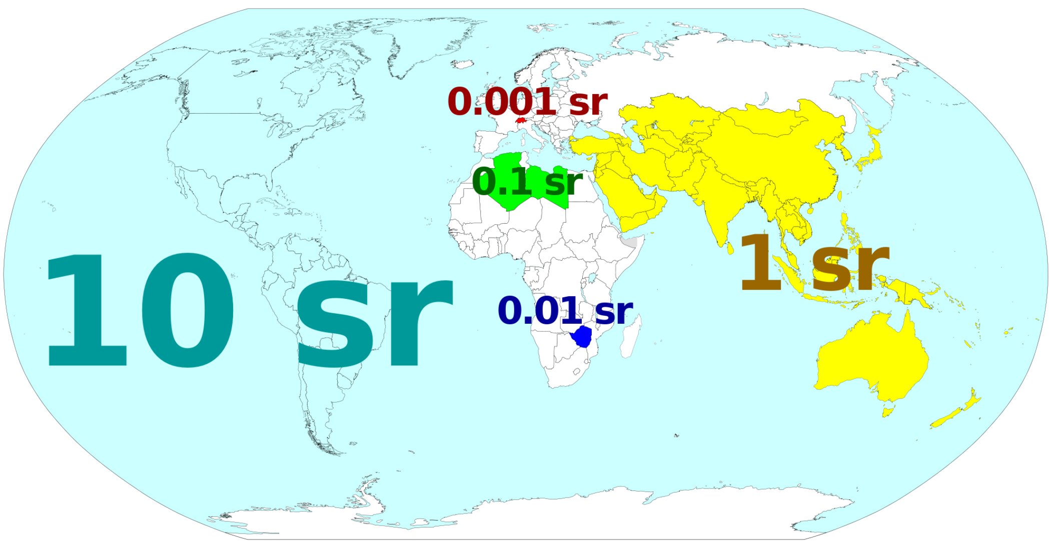

Figure 3: Build your intuition on how much of a sphere steradians cover.

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. Fill in the remainder of Table 1.

4. 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.

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

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