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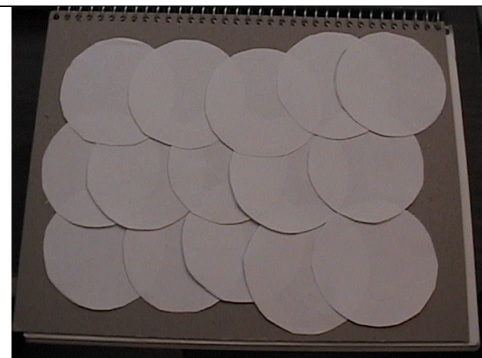
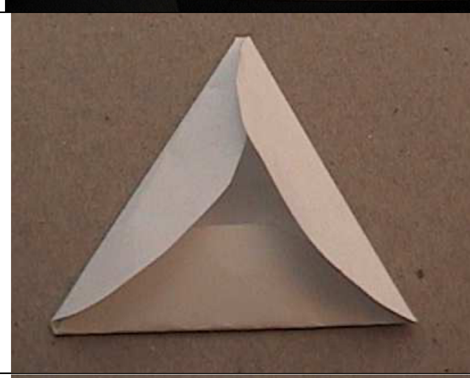
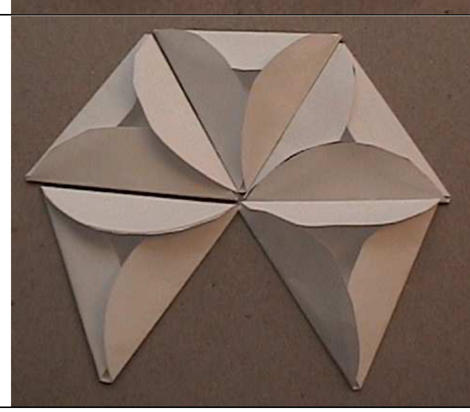
CA1 4.4: A Small 1-F Dome Activity

Hands-On Activity

Purpose: Build a simple desktop dome or sphere using circles formed into triangles.

Materials: compass, scissors, glue, thick paper, ruler, pencil or marker, glue

In technical terms, this is a one-frequency geodesic dome, or a dodecahedron (if fully assembled). One-frequency (1-f) refers to the fact only one type of triangle is needed.

1. Draw 15 identical circles. You can make the circles out of paper, construction paper, or cardboard. You can draw the circles by using a compass, or tracing a can, or whatever method suits you. Cut each out carefully. If you want to make a dodecahedron make 20 circles.	
2. Fold each circle into the shape of an equilateral triangle as shown in Figure 2. Fold by trial and error to make an equilateral triangle that appears to be the same length on all three sides. It doesn't have to be perfect.	
3. Arrange five triangles into a pattern as shown below.	

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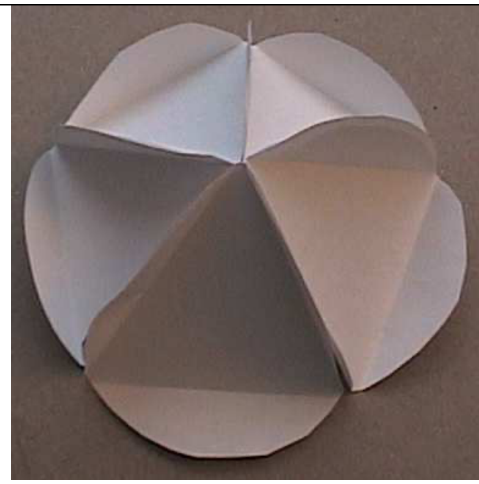
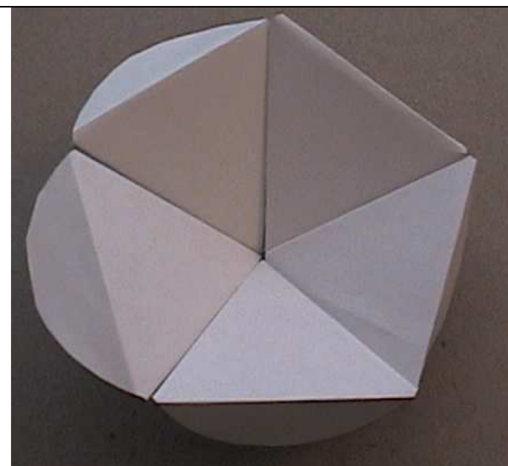
4. Unfold the adjacent flaps and glue them together. When the glue is dry enough to take the stress, glue the final two flaps together by lifting the center of the construction together to form a little cap. Then the two remaining flaps can be brought together to be permanently attached. This is what the finished cap should look like.	
5. If you want a dodecahedron (complete "sphere") make another cap with five more triangles.	
6. Arrange the remaining 10 triangles into an alternating pattern like this, gluing adjacent flaps.	

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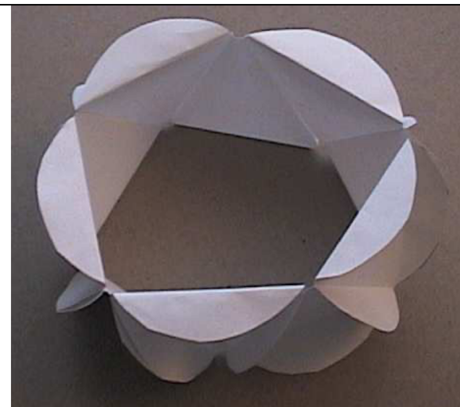
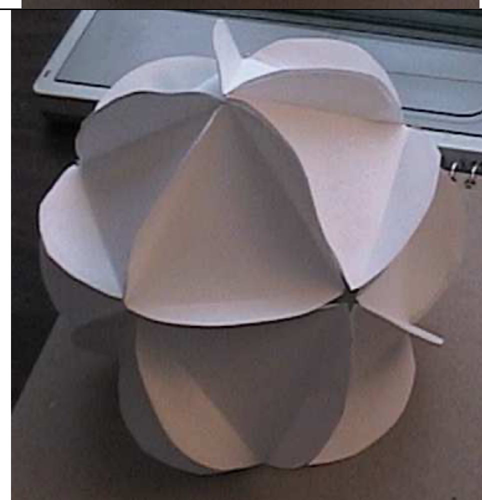
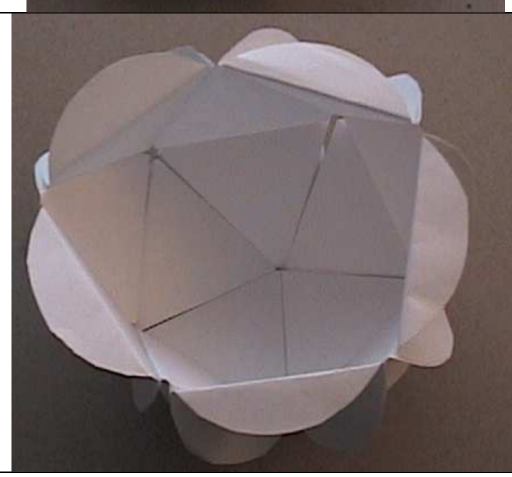
7. Form this strip of 10 triangles into a ring, with flaps out to match the caps you made earlier.	
8. You will notice that on the top of the ring has 5 flaps, and so does the bottom of the cap. Match them up and glue them together and you have a little 1-f planetarium dome model made of one type of triangle!	
9. Turn over the dome to see the inside surface.	
If you want a dodecahedron, attach the second cap to the bottom to close the interior. (Don't do this if you are doing CA1 4.5 Lines in the Sky.) Design adapted from a diagram at www.desertdomes.com. Used with permission.	

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CA1 4.5: Lines in the Sky Activity

Concept Development

Purpose: The purpose of this activity is to build a simple hemisphere and use it to understand how coordinate systems are arranged in the sky.

This activity is adapted from the "Build your own planetarium" project posted at http://www.cccoe.net/stars/.

Equipment needed: Marker, clear plastic dome OR 1-f dome materials from the previous activity.

Procedure:

This activity is based on the idea that the sky looks like a giant inverted bowl. Defining the position of an object in the sky, then, becomes a matter of drawing it on the underside of a bowl. The problem is: there is more than one bowl, and one of them is moving!

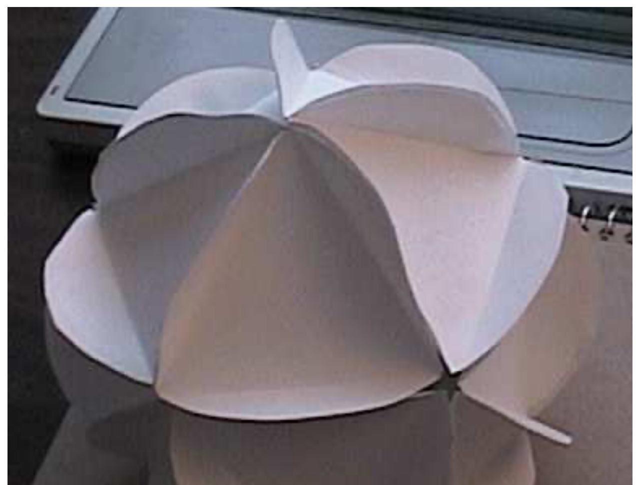

Figure 1. A 1-frequency dome. Make two of these, using 3 inch circles for one and 4 inch circles for the other.

1. Start by following the directions at the end of this activity for making a "Small 1-frequency Dome." Use 3-inch circles for making this dome, with flaps out (you'll understand when you read the directions.) Then make *another* dome using 4-inch circles.

2. (Optional) Fold the flaps of the smaller dome against its outer surface and tape them flat. This may make the dome easier to visualize as a smooth dome in the sky.

The Alt-Az coordinate system

Altitude and Azimuth have been used previously in this course (during the sun and moon units) but this will show you another way to look at them and serve as a review.

3. The small bowl represents the local sky around you. Hold it over your head and imagine you are looking straight up. Where would straight up appear in the dome?

In the center of the original cap of 5 triangles.

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CA1 4.5: Lines in the Sky Activity

4. Draw a large dot in this location and label it *zenith*. (The *nadir* is in the opposite direction of zenith, but your dome has no bottom so we can't draw it.)

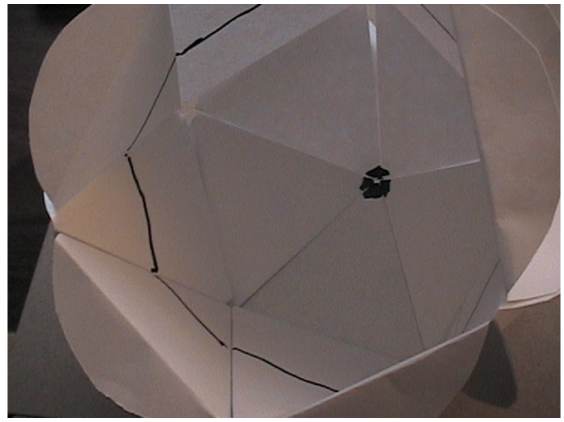

Figure 2. In your model, the horizon runs through the middle of the ring of 10 triangles.

5. Located 90 degrees from the zenith is the *horizon*. It is equivalent to where the earth meets the sky on the surface of a flat ocean. In your model, the horizon runs halfway up the first row of triangles, all the way around. Draw the horizon on your dome and label it.

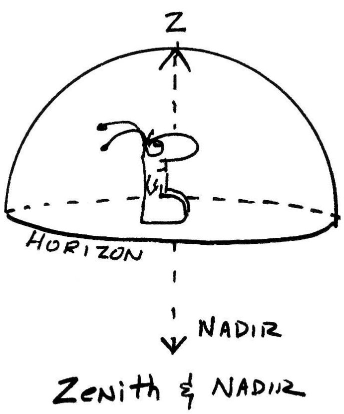

Figure 3. A line connecting zenith and nadir is perpendicular to the plane of the horizon.

Here is another illustration of the zenith, nadir, and horizon to help you understand the arrangement. In the illustration, the "dome of the sky" is drawn as a smooth circle instead of with triangles for clarity.

6. Altitude angles are measured from the horizon (at zero degrees) to the zenith (at 90 degrees.) What is the vertex of the angle we are discussing?

You are. (The observer)

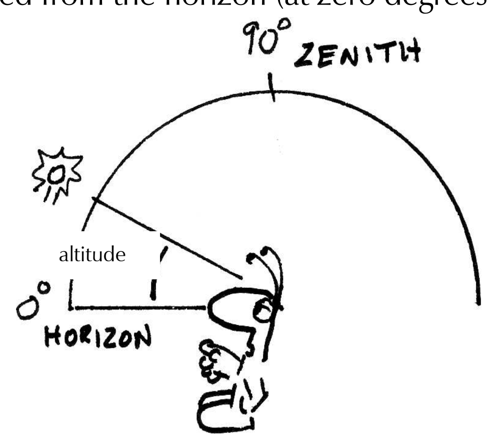

Figure 4. Altitude is measured from the horizon up towards the zenith.

7. Azimuth angles start due north on the horizon and proceed towards east on the horizon. Mark North, South, East, and West on your horizon line inside your dome. Since there are 360 degrees in a circle, what degree measure is the azimuth of West?

Two hundred seventy (270) degrees.

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8. Here are two diagrams to help you understand Azimuth. Sketch the azimuth angle shown in the first illustration onto the second one.
Note the second picture is the view seen from above. The azimuth angle starts at North and increases in a clockwise direction towards east.

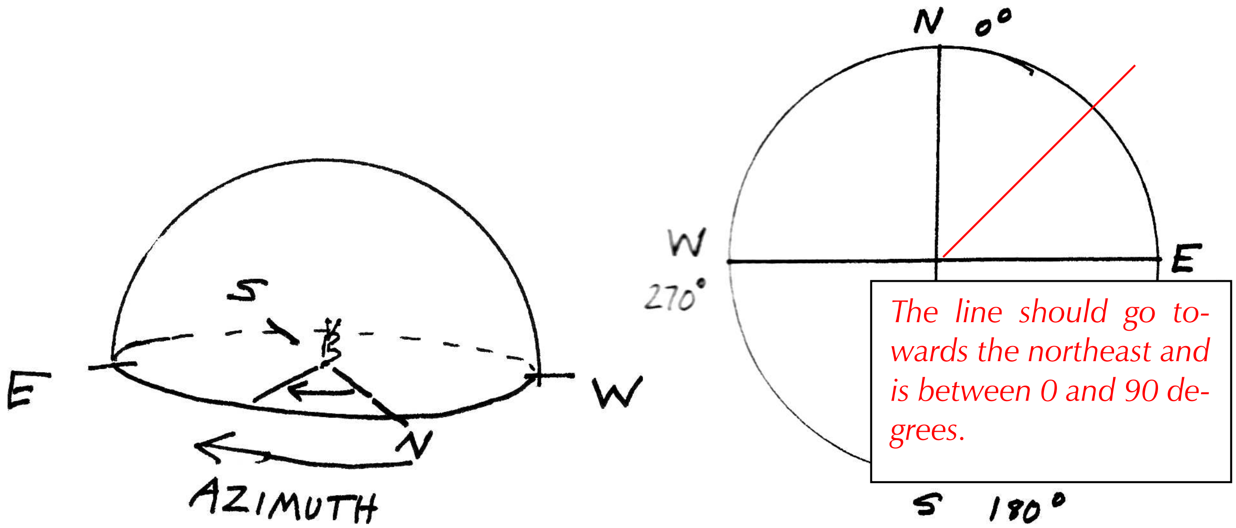

Figure 5. Azimuth angles are measured horizontally, with North as zero.

Pilots need azimuth skills to know which direction they are flying a plane. Also, when you hear a pilot refer to "Runway 22," that means the runway is lined up with an azimuth of 22 degrees. Spacecraft pilots need to know about azimuth as well (trust me on this one.)

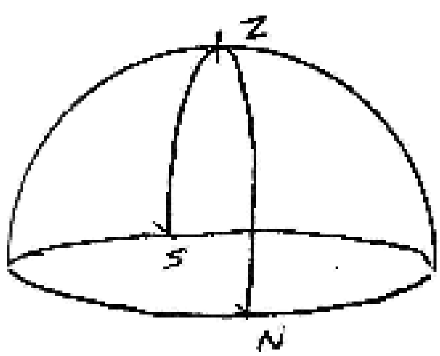

Figure 6. The meridian is a line going from North to South, through the zenith.

One last (important) component of the Alt-Az coordinate system is called the *meridian*. The meridian is an imaginary line which starts from due North on the horizon, goes through the zenith, and ends due South on the horizon. The meridian is important because objects reach their highest point of the day when they cross the meridian. This event is called *culmination* for most objects. It is called *local solar noon* for the sun. Draw the meridian in your dome and label one intersection with the equator N (for north) and the other S (for south).

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Alt-Az coordinates are fine, as far as they go, but the problem is the sky *moves*. As the earth turns, the sun, moon and stars appear to spin around you. If you gave the coordinates of a particular star, two hours later it would have moved to a new place. Three weeks later at the same time it would be in a different position. So we need another set of coordinates—ones that move with the stars so that the coordinates don't change. In other words, another coordinate system.

Keep your dome for the next portion of the activity.

Rubric for dome construction:
0 - No dome
1 - Dome incomplete or built incorrectly; parts don't fit
2 – Dome built, no labels or only one label correct
labels include zenith and horizon and meridian
3 – Dome built, 2 of 3 labels are correct (Zenith, Horizon, Meridian) or dome has a construction flaw such as triangles of unequal size
4.—Dome built, all labels correct.

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CA1 4.5: Lines in the Sky Activity

Right Ascension and Declination

These steps use your *second dome*, made from the 4 inch circles. Right Ascension and Declination are equivalent to longitude and latitude on earth, respectively. There are some differences, however. We'll get to that presently.

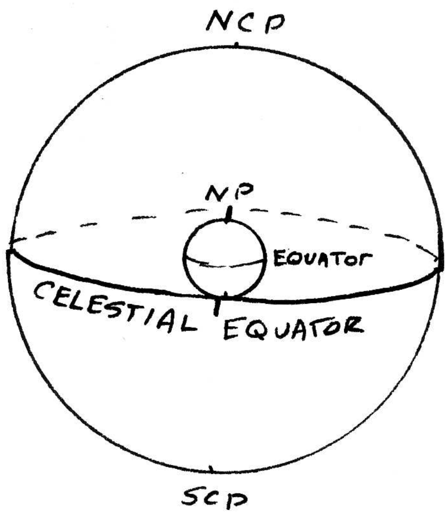

Figure 7. The North Celestial Pole (NCP) is directly above the North Pole of the Earth. The Celestial Equator is directly above the Earth's equator.

1. First, like zenith in the Alt-Az system, the RA-Dec system is based on the location of a single point called the *North Celestial Pole*, located directly above the earth's rotation axis. The star Polaris is very close to this direction from the earth. Put a dot in the center of the top of your larger dome's cap and label it NCP (for North Celestial Pole).

2. Just like latitude on the earth, *declination* refers to a North-South coordinate. You can't get any farther north than the NCP, so the declination of the NCP is 90 degrees. Zero degrees declination is called the *celestial equator* and is located (again) in the center of the base row of triangles that make up your dome.

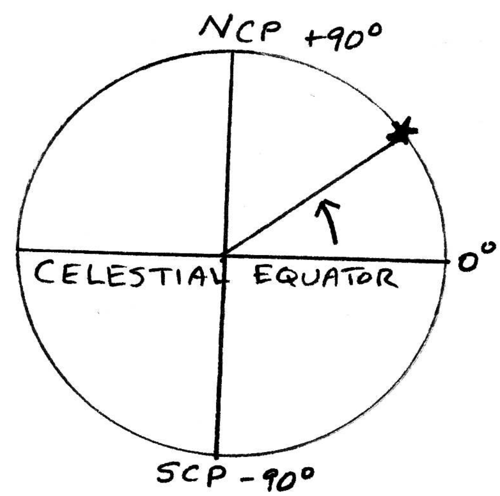

Figure 8. The arrow shows the declination of the star.

Negative declinations are below the equator.

3. What is located at the vertex of the declination angle we are discussing here?

The earth is, or you can say the observer, because the observer is on the earth. The technical definition is the center of the earth. For an object at a great distance, it doesn't make any difference.

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4. What do declination values which are negative supposed to represent? What is the declination of the South Celestial Pole?

Negative declination values are angles which start at the celestial equator and go south, toward the south celestial pole. The SCP has a declination = -90 degrees.

5. If there is "sky latitude" there must be "sky longitude." This is known as *Right Ascension*, and it is somewhat more complex than any of the coordinates discussed so far.

This next part may take a couple of readings before you get it, but make sure you don't skip it!

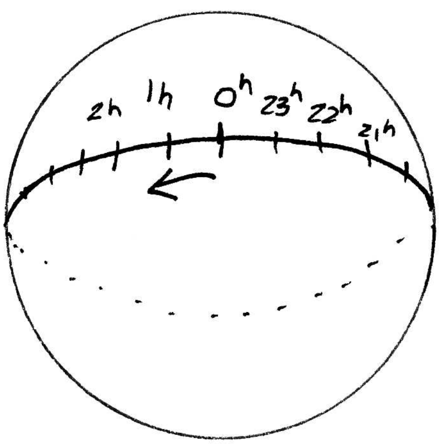

Figure 9. RA increases to the left in the sky. In this view, the observer in the center of the sphere facing south.

The first problem is that if you want the "sky longitude" coordinate to stay with the stars—so they always have the same map coordinate for plotting—then the coordinate system must move with the stars because the stars *move*.

The stars move because the earth turns; the earth turns once in 24 hours; therefore isn't it *logical* that the "sky longitude coordinate" is based on a system of 24 *hours* instead of degrees?

6. If *that* makes sense, then it should make sense that when you look up into the sky, the Right Ascension coordinates increase to the *left* while you face south. Why is that?

The shortest correct answer in this context is that the numbers increase to the left because the sky appears to move to the right, and we want objects that cross the meridian later to have bigger numerical values.

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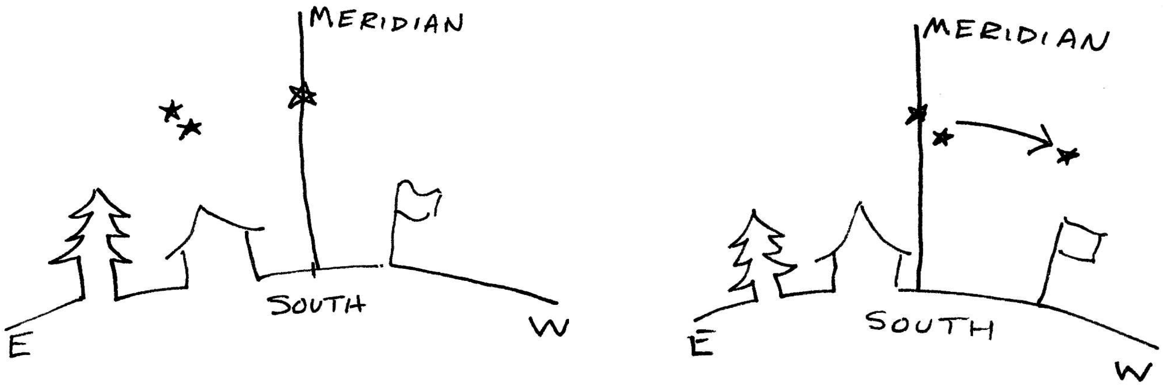


Figure 9. A star on the meridian moves towards the west as an hour passes; new stars are now on the meridian. If the star on the meridian at the top is at 0 hour RA, the star on the meridian in the right illustration is at 1 h RA.

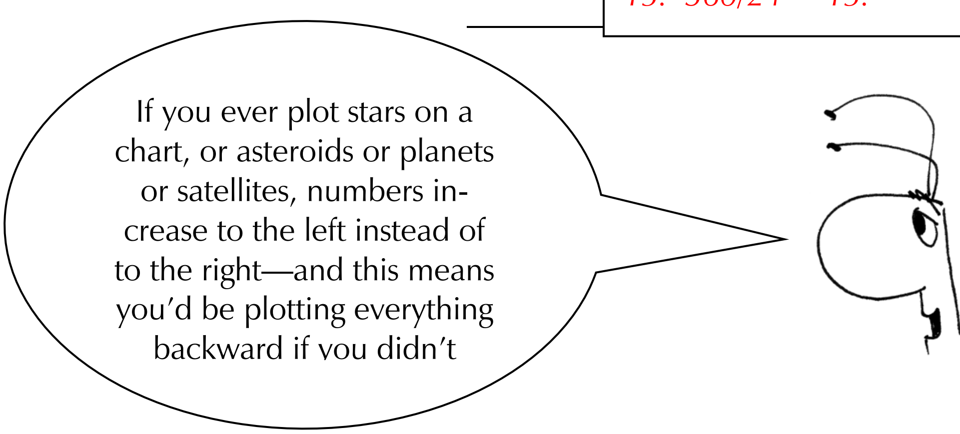
The reason is because as the earth turns from west to east, it makes things *appear* to rise from east to west. Consider an object on the meridian with Right Ascension zero hours.

One hour later, this object has moved 1/24th of a circle to the West (everything in the southern sky moves towards west when you live in the northern hemisphere). Now *new* objects are on the meridian. They are exactly *one hour (or 1/24th of a circle)* to the left of the object designated *zero*, therefore they are located at *one* hour of Right Ascension.

This is why RA increases to the *left* as you face south.

When you write Right Ascension (R.A.) coordinates, then, they aren't the same as degrees, minutes or seconds.

7. Given that 24 hours of RA is the same as 360 degrees on a standard protractor, how many degrees are in one hour of RA? Explain. 15. 360/24 = 15.



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8. Inside your large dome, label the following RA coordinates: 0 hours, 6 hours, 12 hours, and 18 hours. It doesn't matter where you put zero, but the hour marks should be 90 degrees or 2 1/2 triangles apart.

Zero Hours RA

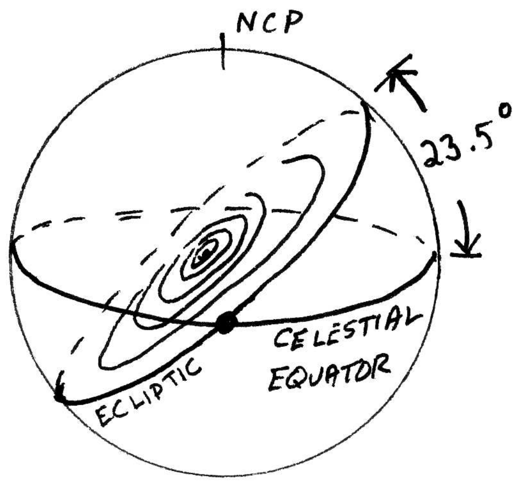


Figure 8. Zero hours RA (The first point of Aries) is defined as where the ecliptic crosses the celestial equator with the sun heading north.

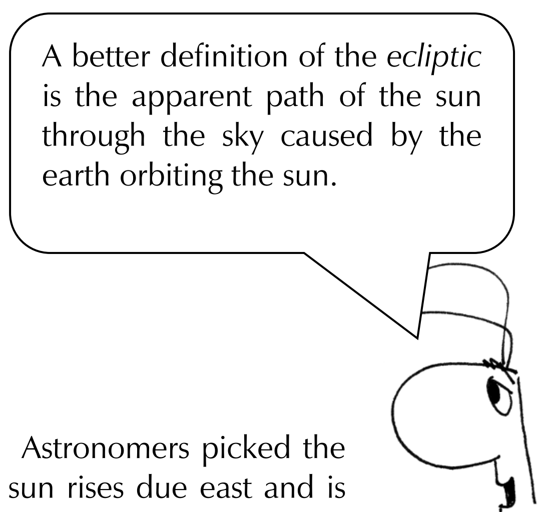
That brings up a final point about Right Ascension: where does zero start? Zero could have been defined to be a particular star, or a certain galaxy or some other object. Astronomers instead chose an imaginary point not corresponding to a real object. This point is called the *First Point of Aries*. The first point of Aries has this symbol: ♈ (for Aries the Ram).

What is this imaginary point? Recall the ecliptic is the plane of the earth's orbit in space. The earth's axis (and the RA/dec system with it) is tilted 23.5 degrees with respect to its orbit.

Cut out another circle roughly the size of the bottom of your large dome. Draw concentric circles on it to represent the solar system. The circle represents the plane of the solar system and it is aligned with the ecliptic (some of the planets are tilted a bit, but we'll let that slide for now.)

If you put your solar system inside your dome and tilt it 23.5 degrees, this would represent how the ecliptic and the RA/dec system are related. Notice the edge of the solar system disk intersects the RA circle in just two places. One of those is marked with a large dot in the illustration.

To emphasize this point flip the solar system circle over and draw just one circle representing the earth's orbit. If this were inside the dome, tilted at 23.5 degrees, you can see that as the earth goes around the sun, the sun appears to move around the ecliptic.



We could pick either intersection as a zero place. Astronomers picked the one that defines the first day of Spring: when the sun rises due east and is crossing the celestial equator, heading towards the summer solstice.

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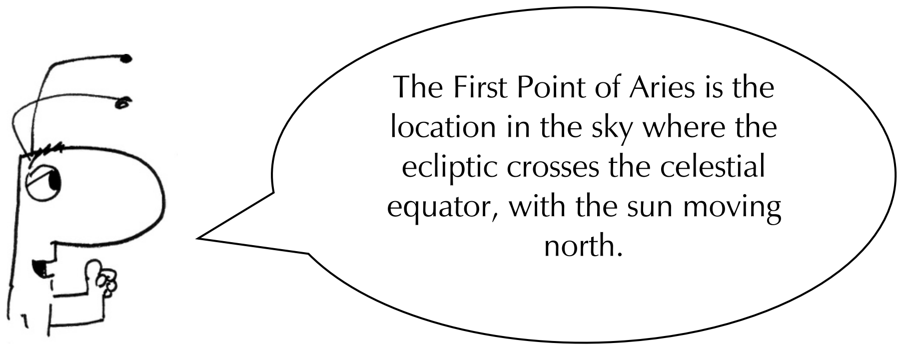
The First Point of Aries ♈ therefore represents *all* of the following:

Zero Hours Right Ascension
Location of the Sun on the first day of Spring
One of the days when the sun rises due East*



9. Mark 0h Right Ascension with this symbol ♈ in your dome.

One last point: Unfortunately, it turns out that the First Point of Aries *moves*. (Kind of negates the whole point, doesn't it?). It moves because the earth's axis wobbles a bit as it spins—an effect called precession. This means that when astronomers make star charts, they have to specify the *year* the coordinates were measured, because as the wobble continues, a star's Right Ascension and Declination *change!*

Figure 9. A dreidel is a kind of top. It is used to play a game which requires the top to precess when it spins.

Precession

If you spin a top, the top will wobble as it spins. The rotation axis will *precess*, or describe a circle. The Earth's axis precesses. This has the effect that the Earth's rotation axis is not always pointing at the North Star; sometimes it points at other stars, sometimes it doesn't point to anything in particular. (This is the case today with the South Celestial Pole. There is no South Star *per se*.)

The precession has about a 27,000 year period. That means it has not even completed one cycle during recorded history. However, it has precessed enough that records show that thousands of years ago, the star Thuban in the constellation Draco the Dragon was once considered to be the North Star!

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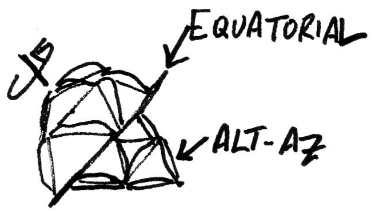
On star maps you'll see a label like this: 1950 Epoch, 2000 Epoch, etc. This refers to the coordinates as set up for that year. Most astronomers use 2000 Epoch coordinates as of this writing, but as this book goes on into the immortal future and is used by future generations that may not be true. (Forgive my wishful thinking.)

Why did we build two domes?

Well, there had to be a reason, right? If the smaller dome has its flaps flattened, the bigger one fits on top of it. Set the large dome on top of the small one. If that is the way the sky were arranged, the earth's axis wouldn't be tilted. Since the earth's axis is tilted, you would have to hold the domes like this to make it simulate the earth.



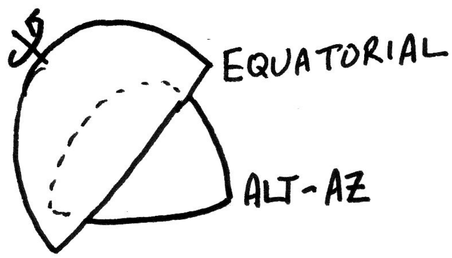


Figure 10. The equatorial dome is tilted with respect to the alt-az dome. The amount of the tilt is 23.5 degrees.

Keep in mind that not only are the domes tilted with respect to each other, the larger one is also *spinning*. No wonder celestial coordinates are complicated!

*Note: I have to add this for the astronomers who may be reading this: The sun does not rise due east exactly on the Spring Equinox. One reason is that the Spring Equinox is a moment in time, whereas the sun could rise up to nearly 24 hours later during the day that the equinox occurs. Another reason is that the analemma is not perfectly vertical; it has width due to the elliptical nature of the earth's orbit. This offset will put the sun slightly off of due east during sunrise on the day of the Spring Equinox. But it's *close*, so we're going to let this little technicality slide for the sake of the concept. But interestingly, this helps explain the significance of the fact that the analemma is not a perfect figure 8 but has a top smaller than the bottom.

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Questions:

1. If the earth's axis were not tilted, how is the definition of the First Point of Aries affected?

Since the celestial equator and the ecliptic would be coplanar, every point would be the first point of Aries, or another interpretation is that it would be impossible to define a single point as the first point of Aries.

2. Does 2 hours of RA always represent the same angular size as seen by the observer? Hint: consider 2 hours of RA near the pole as opposed to near the equator. Think orange slices.

No. Like longitude's relationship with miles, the scale depends on the vertical angle (declination or latitude). One hour of RA is 15 degrees of declination wide only at the celestial equator. Above the equator, it is less.

3. Explain in as simple terms as you can manage why Right Ascension numbers increase to the left as you look south in the sky.

RA increases to the left as you face south because any object you see in the south moves from west to east. Objects which will cross the meridian later are to the left...they should have larger coordinates because they happen later.

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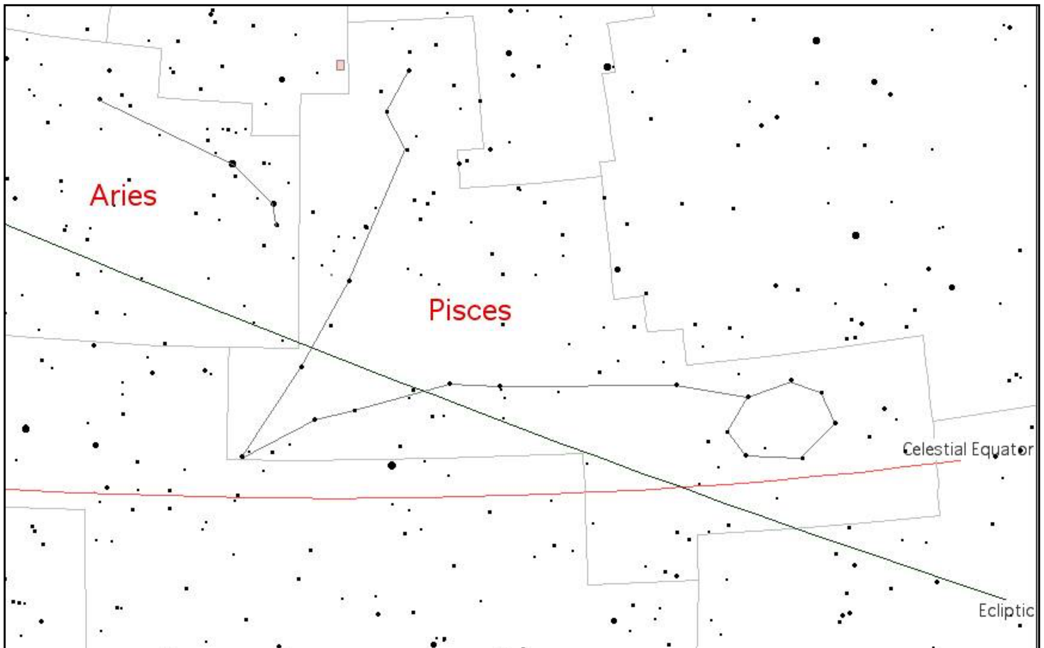

Figure 11. Star Map generated by Starry Night software showing the area near the First Point of Aries.

4. Look on a star map above and mark where 0h RA is located. Is the First Point of Aries actually in the constellation Aries? Given that the definition of the First Point of Aries is very ancient, what is the significance of this answer?

It is not in the constellation Aries. The significance is that the sky has moved, due to precession, since the definition was invented.

5. What implications does this have for the pseudoscience of astrology?

Astrologers do not generally acknowledge that the constellations have shifted. A person who is supposed to be an Aries might actually be a Pisces, etc.