Activity 7: The Sky Through the Year

Materials:

Post-It Notes (or paper and tape)	Colored markers
Light bulb	Globe
Polystyrene ball	LEGO Minifigure

Recently we've been using models to investigate the rotation of the Earth and its effect on our sky (i.e., changes in the sky over the course of a *day*). Today we are going to investigate how the Earth's *orbit* affects our sky (i.e., changes in the sky over the course of a *year*). We will also add another element to our model: the tilt of the Earth's axis.

Part 1: The Night Sky and Time of Year [1]

In a past Activity we used a light bulb as a model of the Sun and your head as a model of the Earth while imagining a person standing on your nose. We are going to repeat that today, but this time we will add the Earth's orbit to our model.

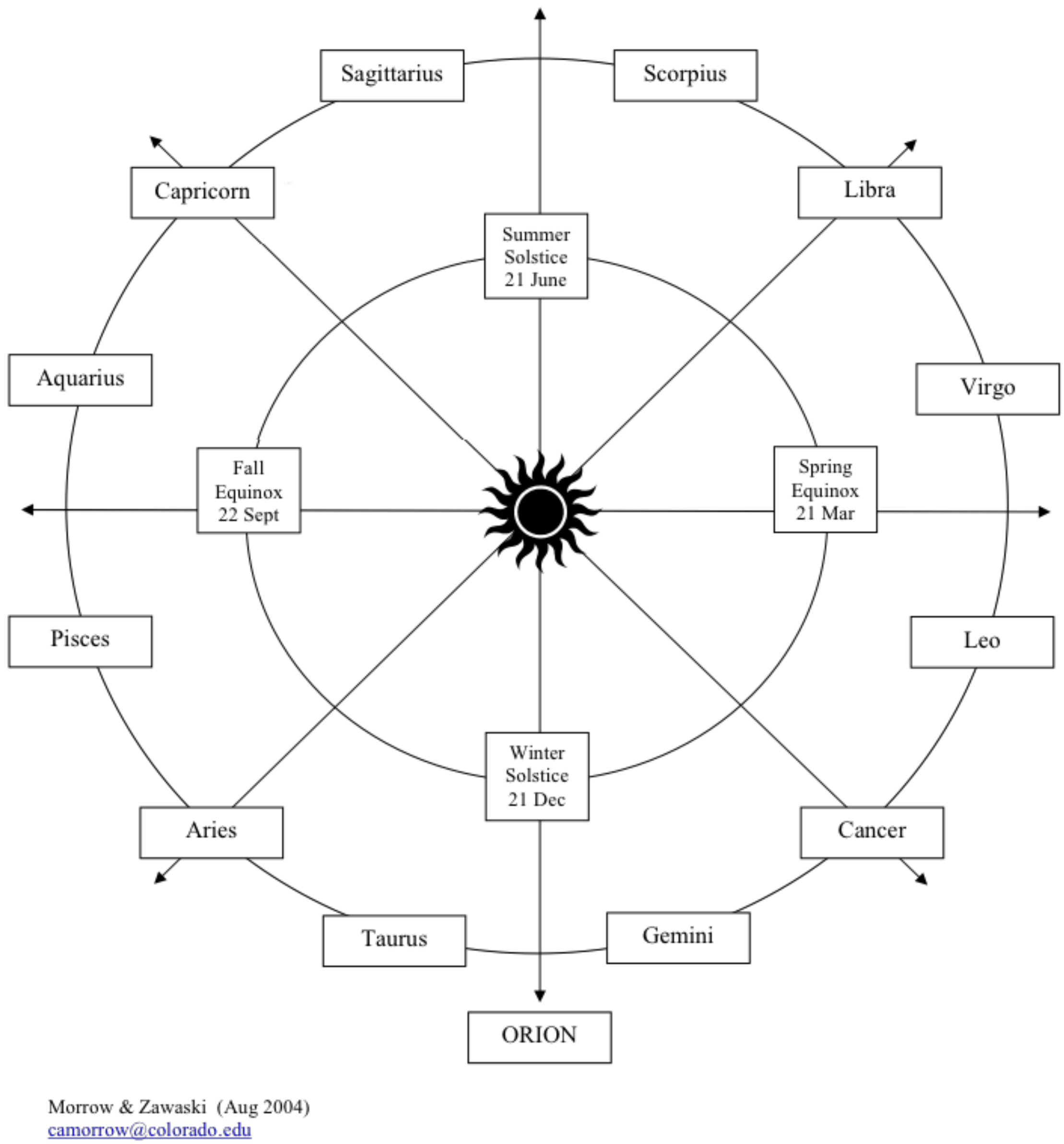
Let's begin by constructing a model of Earth's orbit around the Sun along with some constellations that lie in the plane of Earth's orbit. Consult the diagram below (next page) as you set up the model.

STEP 1: Place an object on the floor in the middle of the room to represent the Sun.

STEP 2: Place Post-It notes on the *floor* (or use pieces of paper taped down to the floor) in a diamond shape around the Sun. Label these June, March, December, and September, as shown in the diagram.

STEP 3: Place Post-It notes around the *walls* of the room to represent constellations, ideally at about eye level. Place them in roughly the same arrangement as is shown in the diagram, taking care to place them in proper position relative to the dates which you've already posted on the floor. This part doesn't need to be exact. You also don't need to do all 13 constellations shown in the diagram. Pick a few that are evenly spaced around the circle, and also include Orion. Label the Post-It notes on the wall with the proper constellation names.

[1] This Part adapted from *Kinesthetic Astronomy* by Morrow & Zawaski, Space Science Institute, University of Colorado at Boulder



STEP 4: Now that it's been set up, let's familiarize ourselves with the model of the Earth's orbit. Find the approximate location of your birthday and stand in the orbit at that spot. You are now at the Earth's position during the time of year of your birthday.

STEP 5: Is this model to scale? (You should know by now to always expect this question!) Why or why not?

STEP 6: Face the Sun so that it is noon for the person on your nose. Which of your ears is to the person's East and which of your ears is to the person's West? One way to figure this out is to imagine North America drawn on your face with the imaginary person standing somewhere in North America.

Is the east coast closer to your left ear or right ear?

Is the west coast closer to your left ear or right ear?

STEP 7: Turn so that it's now sunset for the person on your nose. Which of your ears should point to the Sun?

Observing the Motions of Constellations

STEP 8: Turn another quarter turn so that it's now midnight for the person on your nose. Take note of the constellations posted on the walls. Which constellations are visible (i.e., above the horizon) at night for the person standing on your nose? Write down two or three of them and also write down the current approximate month of the year.

Time of Year: __________________ Night Sky Constellations:

Which constellation is closest to directly overhead for the person on your nose? Write it down and remember it.

STEP 9: Let's see what happens to that constellation (the one you just wrote down above) over the course of 24 hours. First, rotate back to noon. Where is the constellation in the sky for the person on your nose, if they can see the constellation at all?

STEP 10: Rotate to sunset. Where is the constellation in the sky for the person on your nose: *in what direction* and *how high*?

STEP 11: Rotate to midnight. Where is the constellation in the sky for the person on your nose: *in what direction* and *how high*?

STEP 12: Rotate to sunrise. Where is the constellation in the sky for the person on your nose: *in what direction* and *how high*?

Did the constellation rise and set over the course of the day and night?

Including Earth's Orbit in the Model

STEP 13: Now let's start to orbit the Sun. Looking at the dates marked on the floor, which way should you walk? What direction is this (CW or CCW) if you are looking down on the Earth/Sun model from the classroom ceiling?

Orbit the Sun about a quarter of a year.

Technically, you should be spinning while orbiting since that's what the Earth does. Roughly how many times would you have to spin around in a quarter of a year? In other words, how many days are in a quarter of year?

This should give you a sense of just how fast our Earth is spinning like a top as it orbits the Sun. And now you see why I suggest you skip including Earth's spin while you orbit!

STEP 14: After a quarter of a year has passed, stop where you are. Rotate until it is nighttime for the person on your nose. What constellations are visible now? Write down two or three and the time of year.

Time of Year: __________________ Night Sky Constellations:

Is your list of constellations the same as it was before? How or how not?

STEP 15: Orbit the Sun another quarter of a year. What are the nighttime constellations now?

Time of Year: __________________ Night Sky Constellations:

STEP 16: Orbit the Sun until you are back to your birthday month again.

As we went around the Sun, we only paid attention to the constellations at night. Why not during the day?

If you *could* see the stars during the day, what constellations would you see beyond the Sun on your birthday? Do you see one that is especially recognizable to you?

Zodiacal sun sign

This is the origin of your **Zodiacal sun sign**: it is the constellation that lies behind the Sun on your birthday.

As far as astronomy is concerned, your Zodiac sign is merely the constellation that is aligned with the Sun during the time of year you were born, and nothing more.

<u>Your Actual Zodiacal Sun Sign</u>

Whether one wishes to ascribe additional meaning to their Zodiacal sign is up to them, and that is the realm of *astrology*. Astrology is not a scientific endeavor because it does not make scientific claims.

Furthermore, astrology uses a 3000 year old picture of our sky and therefore ascribes the wrong constellation to many birth dates.

To see what your *actual* Zodiacal sun sign is, find your birthdate on this chart:

Zodiac Sign	Old Dates	New Dates
Capricorn	Dec 23 to Jan 21	Jan 20 to Feb 16
Aquarius	Jan 22 to Feb 20	Feb 16 to Mar 11
Pisces	Feb 21 to Mar 19	Mar 11 to Apr 18
Aries	Mar 20 to Apr 20	Apr 18 to May 13
Taurus	Apr 21 to May 21	May 13 to Jun 21
Gemini	May 22 to Jun 22	Jun 21 to Jul 20
Cancer	Jun 23 to Jul 22	Jul 20 to Aug 10
Leo	Jul 23 to Aug 22	Aug 10 to Sep 16
Virgo	Aug 23 to Sep 22	Sep 16 to Oct 30
Libra	Sep 23 to Oct 22	Oct 30 to Nov 23
Scorpio	Oct 23 to Nov 22	Nov 23 to Nov 29
Ophiuchus	not included in original Zodiac	Nov 29 to Dec 17
Sagittarius	Nov 23 to Dec	Dec 17 to Jan 20

What was your Zodiac sign before? What is it now? Did it change once we updated the constellations to the present day, rather than as they were 3000 years ago?

I admit that the Zodiac we used in today's activity is in fact the old one (notice Ophiuchus is not included in today's model). And this was intentional: If we'd used the new one, you probably wouldn't have recognized your Zodiacal sun sign.

<u>More Stars</u>

In our model, there are no stars on the ceiling. Should there be? Why or why not?

What is one star that should be on the ceiling?

Ecliptic Plane

We focused on the constellations along the walls for an important reason: they are the constellations that are aligned with the plane of Earth's orbit around the Sun. This plane is called the **ecliptic**. We will come back to it later.

SQ1:

a) Find the constellation Orion. During what time of year would you see the Orion constellation directly overhead at midnight? Return to our model of the Earth's orbit around the Sun if needed.

b) Referencing the classroom model of Earth's orbit, what constellations should be visible in the night sky if we went outside tonight?

<u>Note:</u> Recall that, for various reasons, this classroom model is an incorrect approximation of the locations of constellations in the sky. Don't count on this classroom model to accurately predict the real locations of constellations! We will look at more accurate computer-based models very soon. This classroom model is meant to be instructive only.

SQ2:

a) In the broadest sense, what causes sky objects to rise and set? *Hint:* what did we do in our model in Part 1 that made the constellations rise and set?

b) We've seen the Sun rises and sets. The constellations that are along the ecliptic plane also rise and set. Do *all* stars rise and set? Recall what we learned last time about someone living at mid-latitude. Do you expect that there would be any constellations that *don't* rise and set over the course of a day/night cycle? If so, where would you find the stars of such constellations in today's model?

c) With regards to rising and setting, the stars (and other objects) along the ecliptic are special. How so?

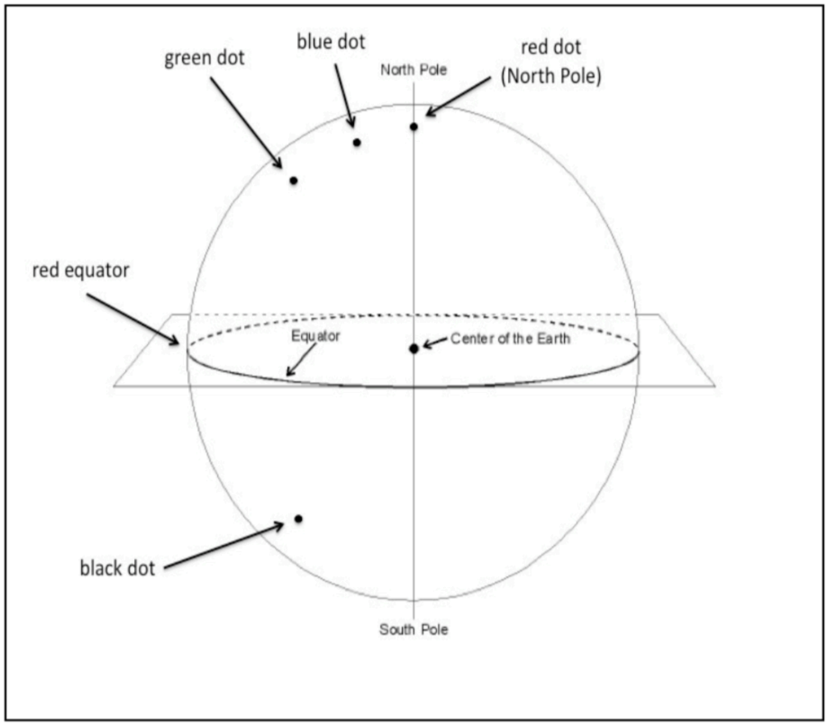
d) The *Moon's orbit around Earth* very nearly lies within the ecliptic plane (they are actually off by an angle of 5°, which we'll discuss in our next Activity). Therefore, do you expect the Moon would rise and set in our sky? Why or why not?

For the Moon we call this **moonrise** and **moonset**.

e) The orbits of the other planets also lie in the ecliptic plane because they all orbit around the Sun in the same plane as the Earth does. Therefore, do you expect the planet Saturn would rise or set in our sky? Why or why not?

Part 2: Tilt of the Earth and Length of Day and Night [2]

So far, we have seen how the rotation and orbit of the Earth affect what we see in the sky. However, we have simplified the situation because we never talked about the length of day and night. We just treated day and night as if they were each exactly half of one Earth rotation. As you have probably noticed in your daily life, sometimes days are long and sometimes they are short (and likewise – but reversed – for nights). Why? What does this do to what we see in the sky? Those are the questions we will answer in this and the next Part.



STEP 1: In this model, use a nearby light bulb (ideally right on your desk) to represent the Sun. The polystyrene ball represents the Earth. Using colored markers, make the following marks on the polystyrene ball.

a) Draw a red line to represent the equator. The easiest way to do this is to find the seam on your polystyrene ball that separates it into two hemispheres, and color along this lone.
b) Make a large red dot at the North Pole
c) Make a green dot roughly halfway between the North Pole and the Equator. This will represent a mid-latitude city like San Francisco.
d) Make a blue dot at roughly 70° of latitude (i.e., closer to the pole than to the equator). This will represent a city in a far northern region, like Norway or Alaska. To make this easier, align the blue dot so that it is due north of the green dot (i.e., the dots are at the same *longitude*).
e) Make a black dot roughly halfway between the South Pole and the Equator. This will represent a mid-latitude city in the Southern Hemisphere like Melbourne, Australia. Again, try to align the black dot with the other two dots so that they are all on the same longitude.

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[2] This Part adapted from *The Real Reasons for the Seasons*, Lawrence Hall of Science, University of California at Berkeley

STEP 2: Stick a pen or a pencil into the South Pole of the polystyrene ball so that you can easily hold the ball and spin it around its axis. *Important:* the pencil should lie on the same line as the spin axis. Make sure the ball is firmly mounted on the pencil.

Turn on your light bulb Sun.

STEP 3: Orient your "Earth" with *the North Pole pointed straight up* and hold it near to the "Sun". *Be careful to hold the Earth at the same height as the Sun*. For instance, you could hold the Earth somewhere beyond the edge of the desk, and/or prop the Sun up on some books so that they are at the same level.

Roughly what percentage of the ball is illuminated (i.e., not in shadow)?

Is this a scale model of the Sun and Earth? Why or why not?

STEP 4: Using the pencil as a handle, spin the Earth about its axis in the correct direction that it really turns. Keep the Earth at the same height as the Sun.

As the Earth turns, watch the green, blue, and black dots that represent cities. How much time does each city spend in the light (daytime)? How much time in the dark (nighttime)? Write your answer below as an estimate of hours, based on the fact that there are 24 hours in a complete rotation of the Earth.

<u>Green dot</u>

Daylight hours: Nighttime hours:

<u>Blue dot</u>

Daylight hours: Nighttime hours:

<u>Black dot</u>

Daylight hours: Nighttime hours:

STEP 5: Now tilt the Earth so that its axis is no longer straight up and down. Roughly what percentage of the ball is illuminated?

SQ3: Repeat Step 5 for several different orientations and positions of the ball. What do you conclude about the percentage of the Earth that is illuminated by the Sun?

Would you expect each colored dot to spend the same amount of time in day and night as each other dot when the Earth's axis is tilted? Why or why not? Write down your hypothesis and keep going.

STEP 6: The actual tilt of the Earth's axis is about 23.5° from the vertical. Tilt the Earth so that its axis has roughly this tilt (i.e., about a quarter of the way between the axis being straight up-and-down and the axis pointing directly at the Sun). To start with, let's tilt the Earth so that the *North Pole* is tilted 23.5° *toward* the Sun (e.g., the North Pole should be tilted towards the Sun about a quarter of the way).

STEP 7: Spin your Earth again and carefully watch the colored dots so that we can test your written hypothesis above.

Does the green dot have the same amount of day and night as the black dot? If not, explain how they are different (i.e., write down which one has more daytime hours and which one has more nighttime hours).

As the Earth spins, watch the blue dot. Record what is happening to its day and night (which is longer and which shorter, or are they the same?)

Watch the South Pole as the Earth spins. Record what is happening to its day and night?

Knowing that in the summer we experience long days and in the winter we experience short days, what season is it for each of the dots? If you're unsure, watch the dots again as the Earth spins and see how much time each dot spends in the dark vs in the light. Also record in which hemisphere is each dot (North or South).

<u>Green</u>

Season: Hemisphere:

<u>Blue</u>

Season: Hemisphere:

<u>Black</u>

Season: Hemisphere:

STEP 8: So far we've kept the Earth spinning in one place. Now let's see what happens when it also orbits around the Sun.

Choose an object on your ceiling to represent the North Star. Tilt the Earth so that its North Pole points towards the North Star. If possible, select your North Star object such that it is positioned far away from your Sun and so that the Earth has a tilt of about 23.5° (roughly a quarter of the way between straight up-and-down and on-its-side) when the North Pole points to the North Star.

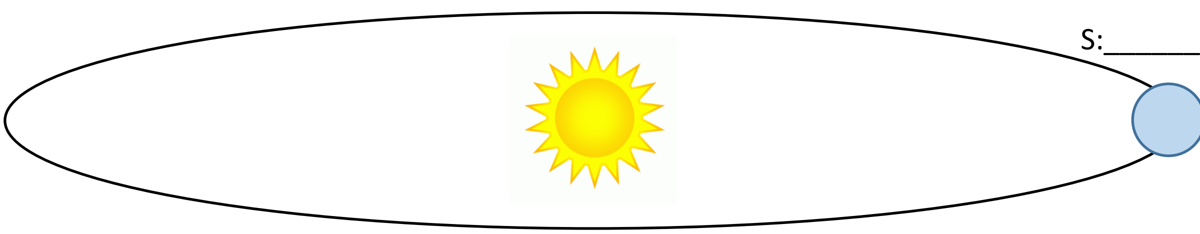
Where does the Earth need to be so that it is summer for the Northern Hemisphere? Place the polystyrene ball relative to the light bulb so that it is summer in the Northern Hemisphere. Make sure the North Pole still lines up with the North Star.

Consider the perspective space diagram below. Note that the Earth's actual orbit is shaped very nearly circular. It is stretched and squished here to create the illusion of a 3D perspective.

Draw the Earth's equator and rotation axis.

N:___________________

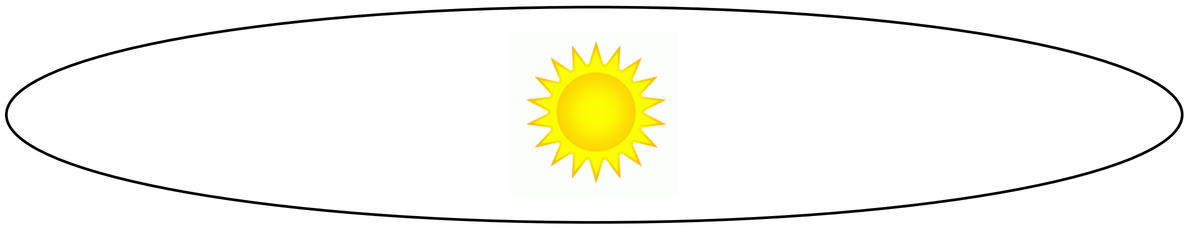
S:___________________



What season is it in the Northern hemisphere? In the Southern hemisphere? If you're not sure, rotate the ball and watch how much time each dot spends in the light and in the dark. Label your diagram above with the seasons for each hemisphere.

STEP 9: Using your ball-and-light-bulb model, move the Earth so that it is now 6 months later, recalling that it takes about 12 months for the Earth to make one complete orbit of the Sun.

In its new location, make sure the Earth's axis still points towards the North Star. Draw the Earth in the appropriate position below (next page). Also draw the Earth's equator and rotation axis.



What season is it in the Northern hemisphere? In the Southern hemisphere? If you're not sure, rotate the ball and watch how much time each dot spends in the light and in the dark. Label your diagram above with the seasons for each hemisphere (denote the hemispheres with *N* and *S* as in the previous diagram).

STEP 10: Using your ball-and-light-bulb model, move the Earth so that it is now 3 months later. Remember, the Earth orbits *counter clockwise* around the Sun when viewed by looking straight down at the plane of the Earth's orbit.

Spin your Earth and carefully watch the colored dots. Roughly how much time does each dot spend in the light? In the dark?

Green dot

Daylight hours: Nighttime hours:

Blue dot

Daylight hours: Nighttime hours:

Black dot

Daylight hours: Nighttime hours:

STEP 11:

When the length of day and night are the same as each other, we call this the **equinox** (from the Latin for "equal night"). We have one equinox in the fall and one in the spring. Therefore, there is a **fall equinox** and a **spring equinox**.

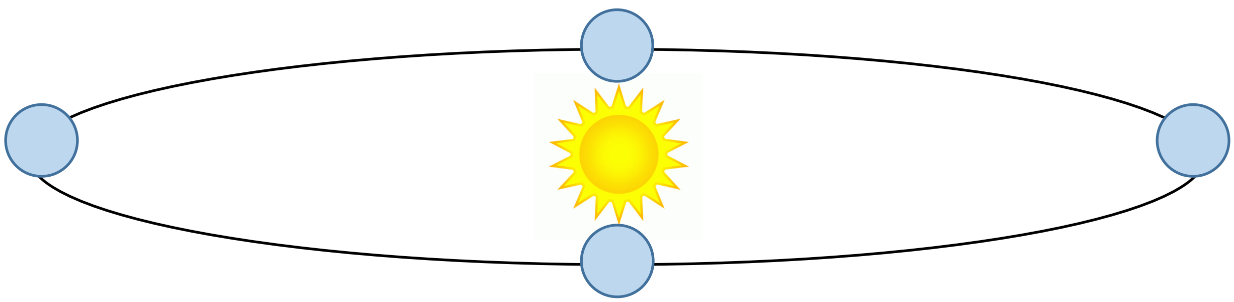
When the length of day is at its maximum or its minimum, we call this the **solstice**. We have one solstice in the summer (on which we have the longest day of the year) and we have one solstice in the winter (on which we have the shortest day of the year). Therefore, there is a **summer solstice** and a **winter solstice**.

In the Northern Hemisphere, the *summer solstice* occurs on or around *June 21* and the *winter solstice* occurs on or around *December 21*.

SQ4:

a) In the diagram below, we have drawn the Earth at the two equinoxes and two solstices. Draw the Earth's axis and its equator in each location. Label each location either *solstice* or *equinox*.

b) In the diagram, write down what season it is for each hemisphere (denote the hemispheres with *N* and *S* as in the previous diagrams). Remember, the Earth orbits *counter clockwise* around the Sun when viewed by looking straight down at the plane of the Earth's orbit.

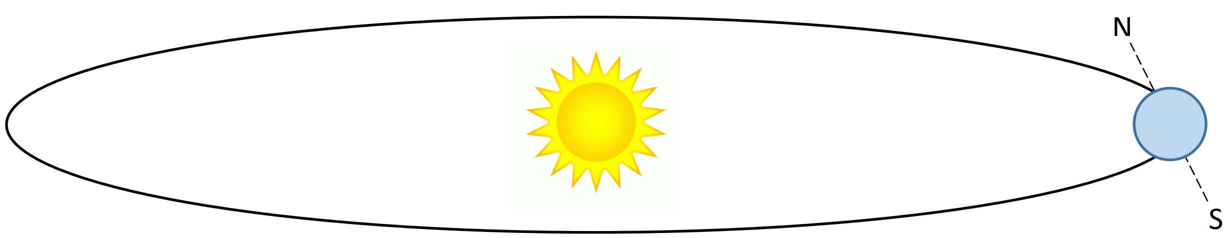


Part 3: Height of the Sun at Different Times of Year [3]

We saw in Activity 5 that the height of the Sun at noon differs depending on the latitude of your position on Earth. In this Part, we will investigate what changes (if anything) about the height of the Sun at noon for *different times of year* when we stay put in the *same location* (in our case, Austin, TX) throughout the year.

STEP 1: Below is another perspective space diagram of the Earth and Sun with the Earth's tilt represented.

In the diagram, what season is it for the Northern Hemisphere?



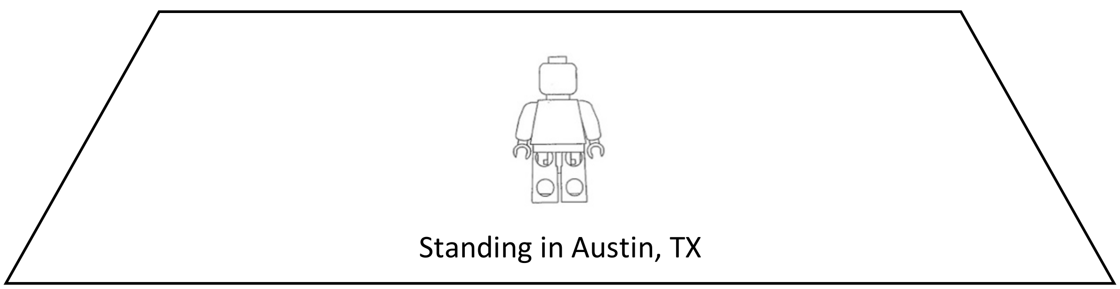
[3] This part adapted from the Hands-on-Science lab manual from UTeach, College of Natural Sciences, The University of Texas at Austin.

STEP 2: On the diagram above (previous page), draw the equator on the Earth. Assuming it's noon (midday) for Austin, TX, draw an observer in Austin using an X. Draw a line to represent the observer's horizon.

Which direction (North or South) would the observer need to face to see the Sun?

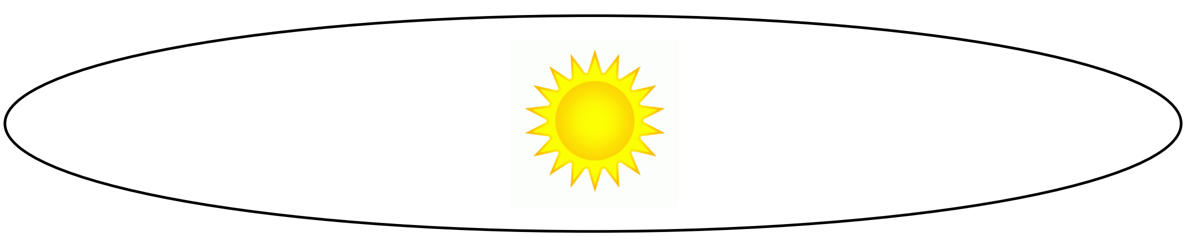
STEP 3: Now let's translate this 3D picture of space (above) into what the observer sees in his/her sky (below). First, using your previous answer, label the horizon with directions N, E, S, and W in the sky diagram below. Also note on the diagram what season it is for the observer in Austin.

X



STEP 4: Now draw the location of the Sun in the minifig's sky above. Make sure to include both the correct *direction* and the correct *height* of the Sun in your drawing.

STEP 5: Now let's jump ahead 6 months. Below is another space-based diagram. Draw the Earth in its orbit 6 months later.



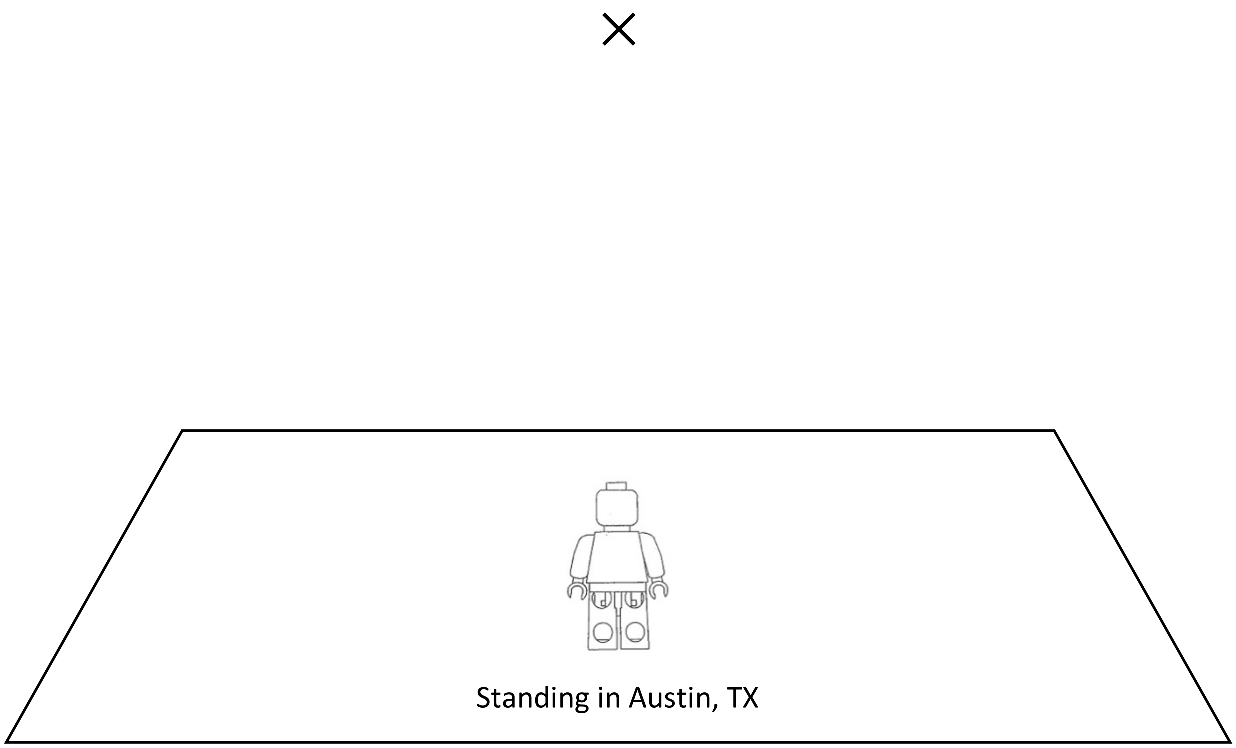
Draw the Earth's equator. Draw two dashed lines to represent the Earth's axis. Make sure you draw it tilted in the proper direction (if you aren't sure, look back at SQ4 at the end of Part 2).

What season is it in the Northern Hemisphere?

STEP 6: Assuming it's noon (midday) for Austin, TX, draw an observer that's still standing in Austin.

Draw a line to represent the observer's horizon. Which direction (North or South) would the observer need to face to see the Sun?

STEP 7: Again, let's translate the 3D picture of space (above) into what the observer sees in his/her sky (below). First, using your previous answer, label the horizon with directions N, E, S, and W in the sky diagram below. Also note on the diagram what season it is for the observer in Austin.



STEP 8: Now draw the location of the Sun in the minifig's sky above. Make sure to include both the correct *direction* and the correct *height* of the Sun in your drawing.

SQ5: How does the height of the Sun at noon compare for the observer in Austin at the two different times of year?

https://apod.nasa.gov/apod/ap120121.html

STEP 9: Consider the time lapse photograph above. This image was taken with a pinhole (i.e., extremely small aperture) camera that took a continuous exposure photograph for *6 months*.

SQ6: Answer the following questions:

a) What bright object do you think caused the streaks in the sky? Remember, this was taken over a period of *6 months*.

b) Which streak corresponds to the summer solstice? How can you tell?

c) Which streak corresponds to the winter solstice? How can you tell?

d) Do your observations of this photograph make sense with regards to what you learned in Part 2 about the length of day at different times of year? Why?

What do you think caused some gaps to appear between the streaks?

Why do you think some streaks are broken (dashed) lines and not continuous (solid) lines?

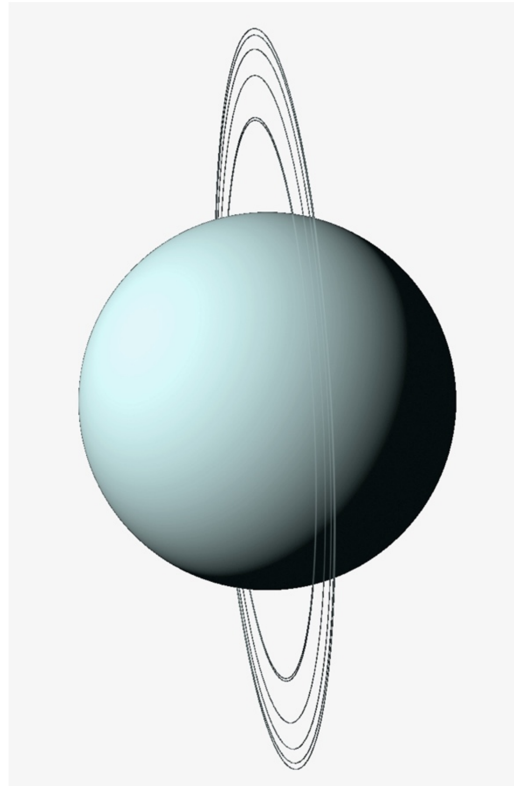
SQ7: The above photo was taken in the Northern Hemisphere (The Netherlands) from December 21 to June 21.

a) Which streak occurred first?

b) Which streak occurred last?

c) If another photograph were to be exposed for an additional 6 months, starting when this first one left off on June 21, what would happen? How would the photograph be different and/or the same as compared to the photograph of the first 6 months?

Part 4: Seasons on Uranus (Optional)



Let's take a look at the seasons on another planet. Uranus is particularly interesting because it lies "on its side". The axial tilt of Uranus is about 98°!

To simplify our analysis a little bit, let's approximate the tilt of Uranus's spin axis to be 90° (instead of 98°).

STEP 1: Using your light bulb as the Sun and the polystyrene ball (formerly Earth) as Uranus, place Uranus in orbit around the Sun with an axial tilt of 90°.

In which direction does the spin axis point? To answer this, find an object in the periphery of the room (walls, floor, ceiling) that roughly lines up with the spin axis of Uranus. Write down what that object is.

STEP 2: Suppose you live on the North Pole of Uranus. Place Uranus in its orbit so that the Sun is directly overhead. Be sure that the spin axis of Uranus still lines up with the object that you wrote down in Step 1.

What "time of day" is it for someone on the North Pole?

Start to spin Uranus on its axis. What happens to the Sun as a result of Uranus's spin? Does it rise and set? If not, what does it do?

Does the "time of day" changing for someone on the North Pole as Uranus spins?

STEP 3: Start moving Uranus around the Sun in an orbit.

Important: Make sure the spin axis always stays lined up with the same object (the one you wrote down in Step 1) as Uranus orbits the Sun.

Note: Uranus, like the Earth and the rest of the planets in our solar system, orbits around the Sun in the counter-clockwise direction.

After a quarter of an orbit, now where is the Sun in the sky of the observer on the North Pole?

Does spinning Uranus on its spin axis change your previous answer? If so, how so?

Now what “time of day” is it for someone on the North Pole?

STEP 4: After another quarter of an orbit (so half of an orbit so far), now where is the Sun in the sky of the observer on the North Pole?

Does spinning Uranus on its spin axis change your previous answer?

Now what “time of day” is it?

STEP 5: After another quarter of an orbit (so ¾ of an orbit so far), now where is the Sun in the sky of the observer on the North Pole?

Now what “time of day” is it?

STEP 6: If you live on the North Pole of Uranus, what causes the Sun to rise and set?

STEP 7: The orbital period of Uranus is about 84 Earth-years. This means that in the same time it takes Uranus to orbit the Sun once, the Earth orbits the Sun 84 times.

If you live on the North Pole of Uranus, approximately how long is a day, starting from sunrise and ending at sunset?

STEP 8: For someone living on the North Pole of Uranus, describe the relationship between "time of day" and "time of year".

For someone on the North Pole of Uranus, how do noon and midnight relate to the summer and winter solstice?

STEP 9: The spin period of Uranus is about 17 hours, meaning it takes 17 hours for it to spin around once on its axis.

Place Uranus in its orbit so that it is sunset for someone living on the North Pole. Spin Uranus on its spin axis. What is the day/night cycle like for someone living on Uranus's equator?

SQ8:

a) In this Part, what was the shortest day you saw for an observer on Uranus?

b) And, what was the longest day you saw for an observer on Uranus?

c) Can the length of day on Uranus vary depending on the time of year and where you are on the planet's surface? A lot or a little?

d) Uranus holds the record for coldest temperature ever recorded in the solar system, at -224° C (-371° F). Why do you think Uranus's winters can get so cold, even colder than on Neptune which is farther from the Sun?