"Looking Back" in Time: Galaxy Evolution

- The Photon Conveyor Belt -

(credit: NIRCam E/PO team, J. Donley, D. McCarthy)

Overview:

This activity builds on our introductory exercises with "lookback time." Here we apply this concept to objects at large distances to understand how astronomers are able to explore the birth and growth of galaxies throughout the history of our Universe. This topic of "galaxy evolution" is central to the scientific goals of the JWST and NIRCam.

Review:

Imagine that you are standing outside when you see a distant flash of lightning. Several seconds later, you hear a loud clap of thunder. What is the reason for the delay? It turns out that the speed of light is much faster than the speed of sound so the flash of light arrives much more quickly. At a speed of 186,000 miles/hour, light travels one million times faster than sound. Thus, the sound of thunder from a distant storm takes a long time to reach us (more than four seconds per mile). Only when a storm is directly overhead will the lightning and thunder be simultaneous. However, even light does not travel instantly through space, and astronomers benefit from that fact.

Looking back to distant galaxies:

Because the distances to the sun, other stars, and distant galaxies are so large, it takes a long time for their light to reach us. The images that we see are therefore always 'old,' because they can show us only what the Sun and distant stars and galaxies looked like when their light left on its long journey to Earth. **When we look out into space, we are always looking back in time to moments when objects were younger!**

For example, our Sun is located a distance of 8 light-minutes from Earth so we see it as it was 8 minutes ago. The nearest spiral galaxy (Andromeda) is 2.5 million light-years away, so when we see it in our nighttime sky, we see it as it was 2.5 million years ago. With modern technologies, astronomers can study galaxies 12 billion light-years away, more than one-thousand times farther away than the Andromeda galaxy.

Using this concept, can you find the error in the following headline from CNN.com?

Exploding star is oldest object seen in universe

April 29, 2009 -- Updated 1720 GMT (0120 HKT)

STORY HIGHLIGHTS

- Scientists detect oldest seen object in universe by gamma ray burst
- Enormous star exploded 13 billion years ago - close to formation of universe
- Star which exploded was 30 to 100 times larger than our own sun

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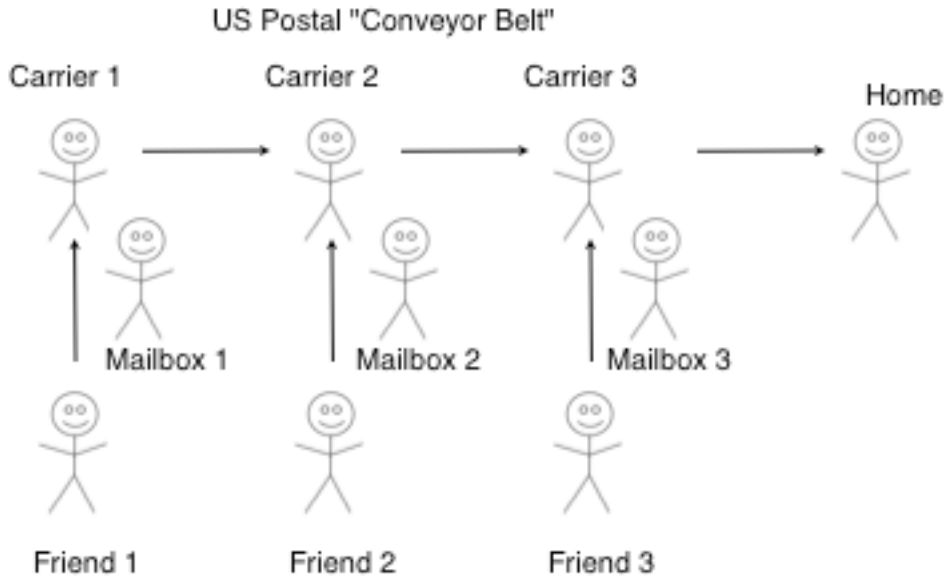
Activity #1: Lookback time and the US Postal Service

Materials:
Nine postcards
Three pens

"Lookback time" is analogous to delivering mail using the US Postal Service. Once a friend mails you a letter, it takes time to arrive – more time the farther away your friend is. This activity requires student actors to be the three "Friends" and the three mail "Carriers" in the "Postal Conveyor Belt." Additional students could also serve as the mailboxes. Give each of the three "friends" a set of postcards that will be mailed to their common friend at "Home." The three friends are located at different distances from "Home" with Friend 1 the farthest. Each friend will send one postcard each day.



Day #1 (morning): Each of the three friends mails a postcard.
Each "friend" writes a brief note on a postcard, dates it "Day #1,"and places it in his/her mailbox.

Day #1 (afternoon): The mail carriers pick up the postcards.
The carriers hold the postcards but do not yet pass them down the line. (The mailboxes are now empty.)

Has "Home" received any mail? (No. "Home" is not aware of where the three friends are or what they are doing.)

Day #2 (morning): Each of the three friends mails a second postcard.

Each "friend" writes a brief note on a postcard, dates it "Day #2,"and places it in his/her mailbox.

Day #2 (afternoon): The mail carriers pick up the postcards.
Each carrier passes his/her postcard down to the next carrier. Carrier 3 hands her postcard to "Home." All three postcards move closer to home, but only one of the postcards written on Day #1 has arrived on Day #2. All three postcards are now one day older.

Has "Home" received mail? (Yes. However, the postcard was only from Friend #3 and is one day older. "Home" only knows about Friend 3's activities yesterday and knows nothing about Friends 1,2.)

The carriers pick up the new postcards from the mailbox. They hold the postcards but do not yet pass them down the line. (The mailboxes are again empty.)

Day #3 (morning): Each of the three friends mails a third postcard.
Each "friend" writes a brief note on a postcard, dates it "Day #3,"and places it in his/her mailbox.

Day #3 (afternoon): The mail carriers pick up the postcards.
Each carrier passes his/her postcards down to the next carrier. Carrier 3 hands her two postcards to "Home." All postcards move closer to home, but now two of the postcards arrive at "Home" (Day #1 from Friend 2; Day #2 from Friend 3). All postcards are now one day older.

Has "Home" received mail? (Yes. "Home" now reads about Friend 2 on Day #1 and Friend 3 on Day #2 but still does not know about Friend 1.)

The carriers pick up the new postcards from the mailbox. They hold the postcards but do not yet pass them down the line. (The mailboxes are again empty.)

Day #4: Repeat the process
"Home" learns about Friend 1 (Day #1), Friend 2 (Day #2), Friend 3 (Day #3)

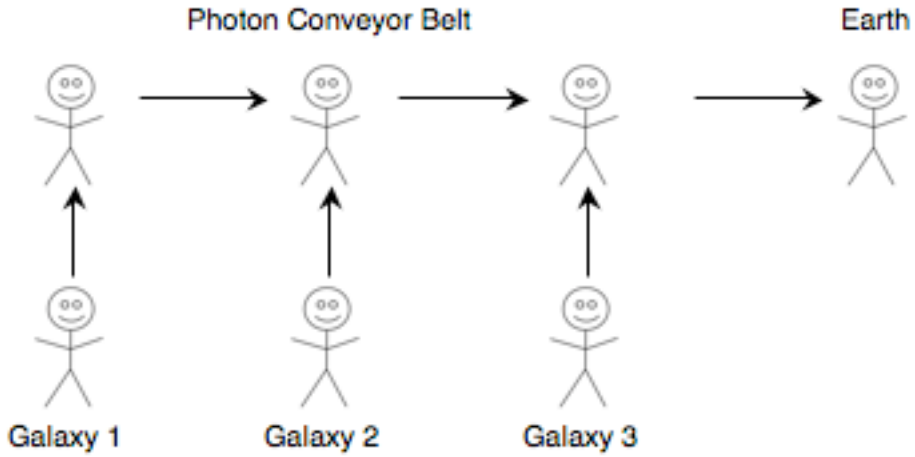
Day #5: Repeat the process
"Home" learns about Friend 1 (Day #2), Friend 2 (Day #3), Friend 3 (Day #4)

Questions to ask after each step:
1. What does the person at home observe?
2. Does s/he know what all three friends are doing at the same time?
3. How long has each letter been traveling" What is the "lookback time" in each case?
4. Does the person at home read about the friends as they are today?

Activity #2: Lookback time and the Universe: Galaxy Evolution

Materials:
Three sets of the galaxy evolution cards (below). [Better versions on our Web site.]

To experience how "lookback time" helps astronomers study the formation of galaxies, position students in two parallel lines extending from left-to-right as shown below. Give each of the students labeled "Galaxy 1,2,3" a set of images showing galaxies at different distances from Earth.



Step #1: Each of the three galaxies is born.
The galaxy volunteers hold up the first card in their sets, showing the galaxy at the earliest time. They then pass their cards to the members of the photon conveyor belt, who hold them, but do not yet pass them down the line.

Step #2: One billion years pass.
Question #1: What happens to the pictures? (They each move one billion light-years closer to Earth.) To simulate this, the cards should each be passed one person closer to Earth.

Question #2: What happens to the galaxies? (They each get one billion years older.) To simulate this, each galaxy person holds up his/her next card before handing it to the photon conveyor belt.

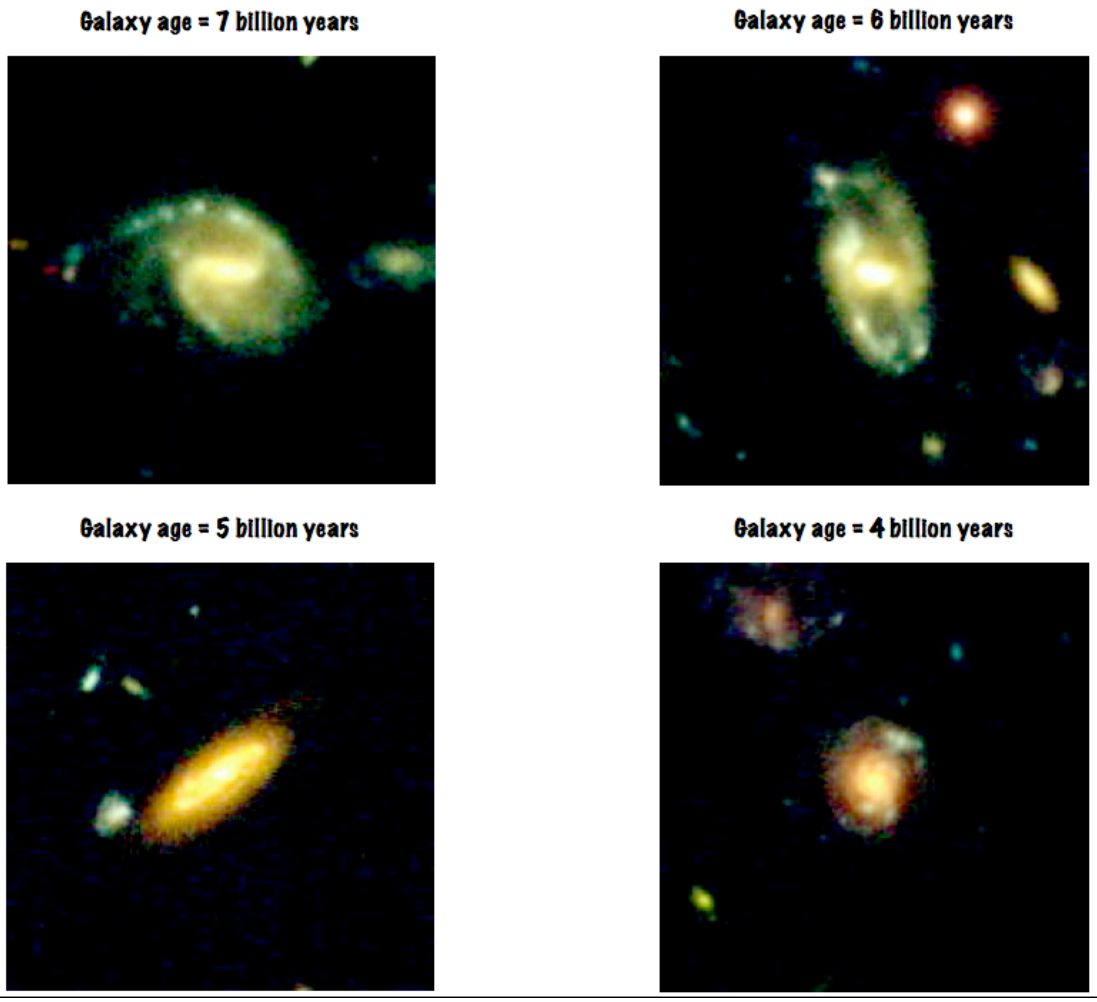
Steps #3, 4, 5, etc.:
Another billion years pass. Once again, the pictures are each passed one person closer to Earth, and the galaxies age by another billion years.

Questions to ask after each step:
1. What does the observer on Earth see?
2. Does he/she know about all three of the galaxies?
3. How long has each picture been traveling to Earth, i.e. what is the lookback time?

4. Does the observer on Earth see the galaxies as they are today?
5. Do the galaxies look the same to the observer? Are they currently the same?

Additional Discussion:

1. How do galaxies change over time? If the speed of light were infinite, would we be able to answer this question?
2. In what ways is this model accurate and inaccurate?
3. What would an observer elsewhere in the universe observe?



Galaxy age = 3 billion years

Galaxy age = 2 billion years

Galaxy age = 1 billion years

The galaxies are born