Comet Ion Tails

By Samuel Harrold

TEKS for Science
§112.33. Astronomy. …
(c) Knowledge and skills.
(9) Science concepts. The student knows that planets of different size, composition, and surface features orbit around the Sun. The student is expected to:
(D) explore the origins and significance of small solar system bodies, including asteroids, comets, and Kuiper belt objects.
(10) Science concepts. The student knows the role of the Sun as the star in our solar system. The student is expected to:
(D) analyze solar magnetic storm activity, including coronal mass ejections, prominences, flares, and sunspots.

Purpose

The purpose of this activity is to model the interaction between a comet ion tail and the solar wind using a fan and paper streamers. In doing so, students will qualitatively describe the behavior of comet ion tails

Introduction

All comets have two tails, a dust tail and an ion tail (see images included with activity). As a comet approaches the Sun, ices (water, carbon monoxide, carbon dioxide, methane, ammonia) within the comet sublimate causing the comet nucleus to outgas. The dust (silicates) released from the sublimating ice is gently pushed away from the comet by the Sun's starlight via radiation pressure and forms the most recognizable part of a comet, the arcing dust tail.

In contrast, the process by which the ion tail is formed is very different. The sublimated gas about the nucleus is ionized by the Sun's starlight and is carried away by charged particles emanating from the Sun. These moving charged particles constitute the solar wind. Because the solar wind moves much faster than the speed at which the comet travels – several hundred km/s compared to tens of km/s – the ion tail will always appear straight. For both the dust and ion comet tails, their lengths increase as the comet moves closer to the Sun. This is because the comet receives more light from the Sun at close distances, which makes it hotter and causes it to release more gas and dust.

Appearances of comets have been recorded throughout human history since antiquity, but the relationship of a comet's ion tail and the solar wind was postulated only as recently as the 1950s[1]. For a brief overview of comets, see http://www.nasa.gov/worldbook/comet_worldbook.html.

Materials

Advanced Preparation:
Acquire images of comets (included with this exercise)
Acquire desktop fan
Acquire safety pins
Cut out paper streamers (printer paper cut into long, thin strips ~ 3 mm width)
Note: Streamers from printer paper work better than plastic streamers that come in a roll because of the curl induced by the roll.

[1] Biermann, L. 1951, Zeitschrift für Astrophysik, 29, 274

Optional: Acquire foam balls (~ 2 inches in diameter), coffee stirrers, and straight pins in place of safety pins

For whole class demonstration:

Images of comets (displayed via paper, transparency, or digital projector)

For each student group of 2 students:

1 safety pin, 1 paper streamer
Optional: 1 foam ball, 1 coffee stirrer, 5 safety pins, 5 paper streamers

ENGAGE

*This part of the lesson is designed for **whole group instruction**.*

1. Ask students what they know about comet tails.
2. Ask students what they know about the solar wind.
3. Tell students they will see a couple images of comets and that they should consider where the location of the Sun relative to the comet and in which direction the comet appears to be moving.

Facilitation Questions – **Engage Phase**

1. How many tails do comets have?
   Two – a dust tail and an ion tail
2. Why do we sometimes see one tail and not the other?
   Comets sometimes have more ice or dust. There are always two tails, but one may be extremely faint.
3. Of what are the two comet tails made?
   Dust and ionized gas
4. Describe what the dust and ion tails look like.
   The ion tail is straight and blue. The dust tail is curved and white.
5. What is the solar wind?
   Energetic charged protons and electrons streaming away from the surface of the Sun.
6. Why can some comet tails point in very different directions despite being far from the Sun (i.e. farther than the Earth)?
   Comet tails look different from different perspectives along Earth's orbit. When looking at an object in the sky, like a comet tail, the object is usually so far away that we cannot discern depth. The object appears as a 2D projection onto the sky.

PREPARATION

This part of the lesson is designed for ***whole group instruction and for groups of 2 students.***

Making the model comet

1. Instructor: Set up the fan at one end of the room for students to interact with the wind.
2. Students thread the end of the streamer with a safety pin. (see Figure 1)
2. Optional:
   a. Using the 5 straight pins, pin the 5 paper streamers to various positions around the foam ball.
   b. Stick the foam ball onto the coffee stirrer to use as a handle. (see Figure 2)

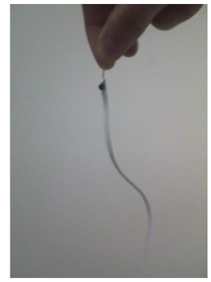


Figure 1. Paper streamer on pin

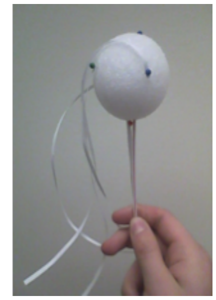


Figure 2. Paper streamers pinned onto foam ball

EXPLORE

This part of the lesson is designed for ***whole group instruction and for groups of 2 students.***

Model the comet ion tail-solar wind interaction

1. For each group, one student will record the data while the other manipulates the model.
2. Tell the students to imagine that they are astronomers in the 1950s trying to understand the behavior of the comet ion tails that they observe in their telescopes, like the German astronomer Ludwig Biermann. Their only data is what they see.
3. Have students hold their models at various positions from the fan. At each position, have the recorders *sketch* what the streamers look like and *describe* their behavior. Also, have the recorders describe the change in the behavior of the streamers as the model is moved toward and away from the fan. (See Facilitation Questions.)
4. Have the students compare and contrast the recorded behavior of the streamers from different positions. (See Facilitation Questions.)

Facilitation Questions – **Explore Phase**
Model the comet ion tail-solar wind interaction

1. What do the wind from the fan and model with streamers represent?
   The solar wind coming from the Sun and the comet's ion tail.
2. Which way are the streamers directed relative to the fan in this position?
   The streamers are always pointed away from the fan. (To instructor: …just as the ion tails of comets are always pointed away from the Sun)
3. What is the shape of the streamers, that is, how much are the streamers bent down?
   When closer to the fan, the streamers are straighter. (To instructor: More of the streamer is supported when there is a stronger wind from the fan. In a similar way, there is a longer ion tail (and dust tail) closer to the Sun.)

TEACHER'S NOTES:

1. Lightweight string tied around toothpicks can be used in place of paper streamers and pins.

2. Several fans arranged in a circle will better simulate the spherical symmetry of the solar wind so that students can move their models azimuthally as well as radially.
3. The basic relationship between the temperature of a comet and its distance from the Sun is an inverse square root dependence. Equating the incident and emitted power from the comet, idealized as a blackbody, gives $T \propto 1/\sqrt{2}$. Thus, decreasing the distance between the comet and the Sun will increase the temperature by a factor of $\sqrt{2}$.

EXPLAIN

The Explain portion of the lesson is directed by the teacher to allow the students to formalize their understanding of the TEKS addressed in the lesson.

1. Have the students generalize the direction and behavior of the streamers for arbitrary positions of the model relative to a spherical arrangement of fans. (See Facilitation Questions.)
2. Tell the students: Ludwig Biermann postulated that a comet's ion tail points away from the Sun because of a steady stream of particles emanating from the Sun's surface like a *wind.*
3. Have the students apply the analogy of the model to explain why comet ion tails always point away from the Sun as the comets move about their orbits. (See Facilitation Questions.)
4. Have the students relate the analogy of the model to the fact that comet ion tails increase in length as they approach the Sun. (See Facilitation Questions.)

Facilitation Questions – **Explain Phase**

1. Was the *direction* of the streamers dependent on the distance of the model? Consider a spherical arrangement of fans all pointed outward. If you were to slowly move the model around a "spherical fan", how would the direction of the streamers change relative to the spherical fan?
   No, the direction of the streamers is independent of the radial distance of the model. The streamers will always point away from the spherical fan regardless of the model's radial distance or azimuthal position.
2. Was the *shape* of the streamers dependent upon the distance of the model? If you were to slowly move the model around a spherical fan, how would the shape of the streamers change relative to the spherical fan?
   Yes, the streamers are straighter when closer to the fan. The straightness of the streamers is dependent on the radial distance of the model to the fan but independent of the azimuthal position.
3. How does the *direction* of the streamers from the model describe the interaction between a comet ion tail and the solar wind?
   Regardless of the distance of the model from the fan, the streamers always point away from the fan due to the movement of the wind. This is like comet ion tails because comet ion tails always point away from the Sun regardless of the comet's distance from the Sun. The direction of the comet ion tails suggests that the ion tails behave like they are in a wind coming from the Sun.
4. How does the *shape* of the streamers from the model describe the interaction between the comet ion tail and the Sun?
   The streamers are the straightest when the model is closest to the fan due to the support from the strong wind. However, the reason why comet ion tails are longest when they are closest to the Sun is not due to the strength of the solar wind. Rather, comets closer to the Sun are hotter from absorbing large amounts of sunlight and have hence released more gas which makes a longer ion tail. The model describes the interaction between the comet ion tail and the Sun only in the sense that the model's streamers are straightest and the comet's ion tail is longest when both are closest to the source of the wind.

ELABORATE

*The Elaborate portion of the lesson provides an opportunity for the student to apply the concepts of the TEKS within a new situation. This part of the lesson is designed for **groups of 2 students**.*

1. Have the students research the following: size and typical period of comet orbit, diameter of a comet, typical speed of a comet, composition of a comet, typical comet tail length, diameter of the Sun, typical speed of solar wind (See information in the Facilitation Questions.)
2. With the above information, have the students describe the strengths and weaknesses of this model. (See Facilitation Questions.)

Facilitation Questions – **Elaborate Phase**

5. A basic Google search will provide resources for all of the information as well as interactive activities. This is a good opportunity to hone internet skills. Here are some good answers:
Halley's comet orbit size:
    short-period comets at aphelion (farthest from Sun) to outer planets (Neptune) ≤ 40 AU
    long-period comets through Kuiper Belt (55 AU) and Oort Clout (50,000 AU)
    comets can come arbitrarily close to the Sun ("Sun grazers")
Comet orbital periods:
    short-period 20-200 yrs
    long-period 200-millions yrs
    single-apparition only once
Typical comet diameter: ~ 10 km
Typical speed of a comet: a couple km/s at aphelion to ~ 100 km/s at perihelion (closest to Sun)
Composition of a comet: silicate dust, hydrocarbons, ices: water, carbon monoxide, carbon dioxide, ammonia, methane
Typical comet tail length: 100 million km
Diameter of the Sun: 1.4 million km
Typical speed of the solar wind: 400-700 km/s
6. Some strengths and weaknesses of the model:
Strengths:
    The model likens the comet ion tail to a streamer in a wind, which is an easily understood analogy. The model's greatest success is that the direction of the ion tail corresponds to what would be expected from a wind-blown streamer.
Weaknesses:
    The model's largest weakness is in addressing the length of the comet ion tail. The straightness of the streamer is influenced by the strength of the supporting wind coming from the fan, but the length of an ion tail is not affected by the strength of the solar wind. Rather, only the temperature of the comet, and in turn the proximity of the comet to the Sun, influences the length of the ion tail. The model's implication that the length of the comet ion tail is related to the strength of the solar wind can be misleading.
    The wind generated from the fan slows as distance from the fan increases. In contrast, the solar wind does not slow at increasing distances from the Sun. The solar wind simply becomes less dense.
    The model's distance scale and relative wind-to-comet speed is of course too small.

EVALUATE

The Evaluate portion of the lesson provides the student with an opportunity to demonstrate his or her understanding of the TEKS addressed in the lesson.

TAKS Format Questions

1. Where are comets in their orbit when they have tails?

A. Close enough to the Sun so that their ices sublimate
B. Close enough to the Sun so that the solar wind is strong enough
C. Close enough to the Sun so that they are moving fast enough
D. Comets always have tails

A – comets have tails because sublimating ice has released dust and gas. B is incorrect since the speed and density of the solar wind is not what causes the tails (otherwise asteroids would also have tails). C is incorrect because the speed of the comet is irrelevant to whether or not it will produce a tail. D is incorrect because the ices are frozen when the comet is far from the Sun.

2. Which of the following best describes the direction of a comet's tail(s)?

A. Comets have only one tail that points directly away from the Sun.
B. Comets have two tails that point directly away from the Sun.
C. Comets have two tails that point almost in the same direction away from the Sun.
D. Comets have two tails that point in opposite directions at each other.

C – comets have a dust and ion tail that both point in general away from the Sun but usually not in the same direction (because they are influenced by different processes: the dust tail by radiation pressure, the ion tail by the solar wind). A is incorrect because comets always have two tails, although they likely differ in brightness. B is incorrect for reasons said in "C". D is incorrect (although the geometry of Earth's vantage point can make an optical illusion, c.f. comet antitail).

Free-Response Questions

Explain why both a comet's ion tail and dust tail become longer as a comet approaches the Sun.

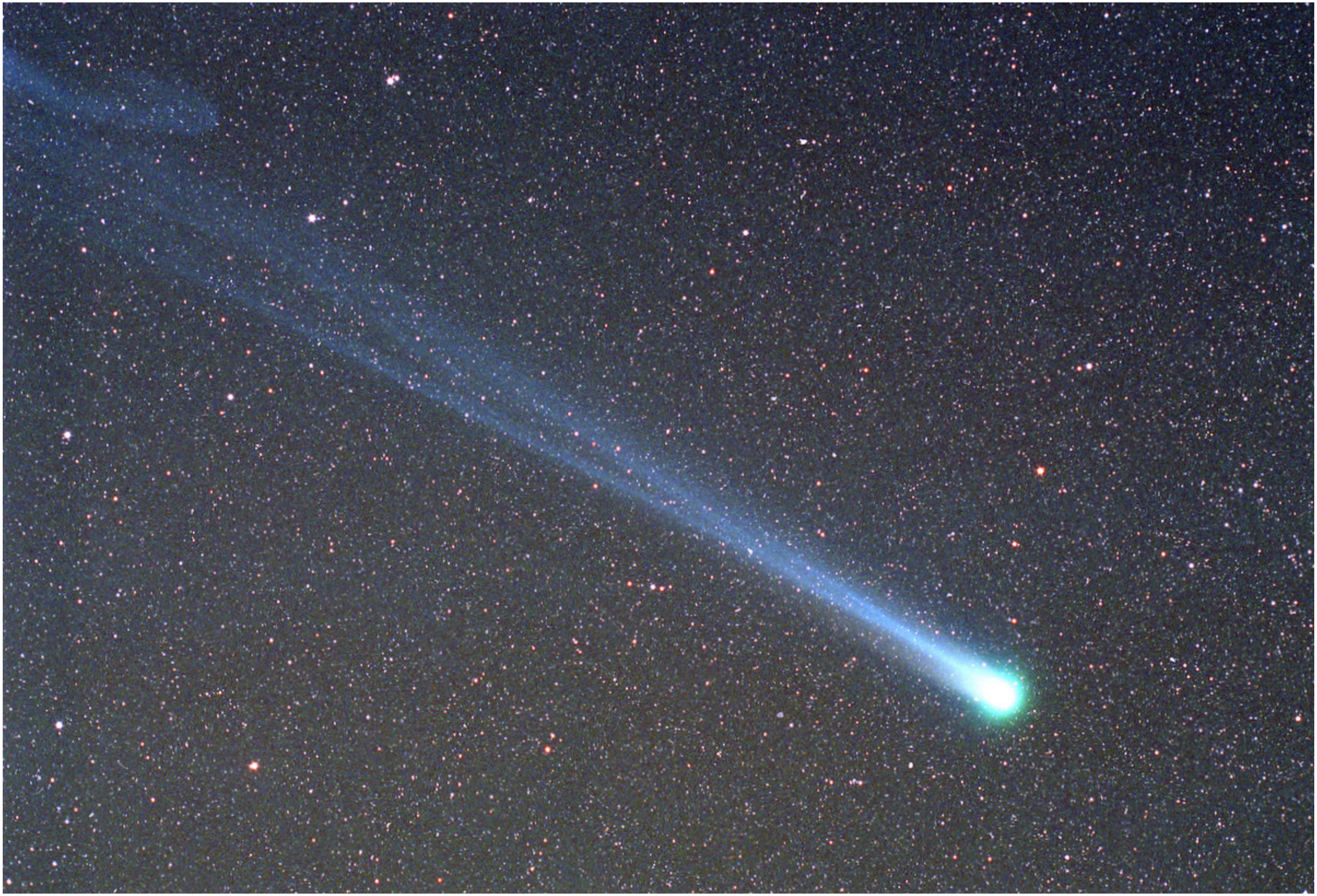
As a comet approaches the Sun the ices comprising the comet sublimate, which releases the surrounding dust. The closer the comet is to the Sun, the more incident radiation it absorbs, which increases the comet's temperature. At this higher temperature, more of the ice is sublimated and thereby releases more gas and dust to make longer comet tails.

RESOURCES

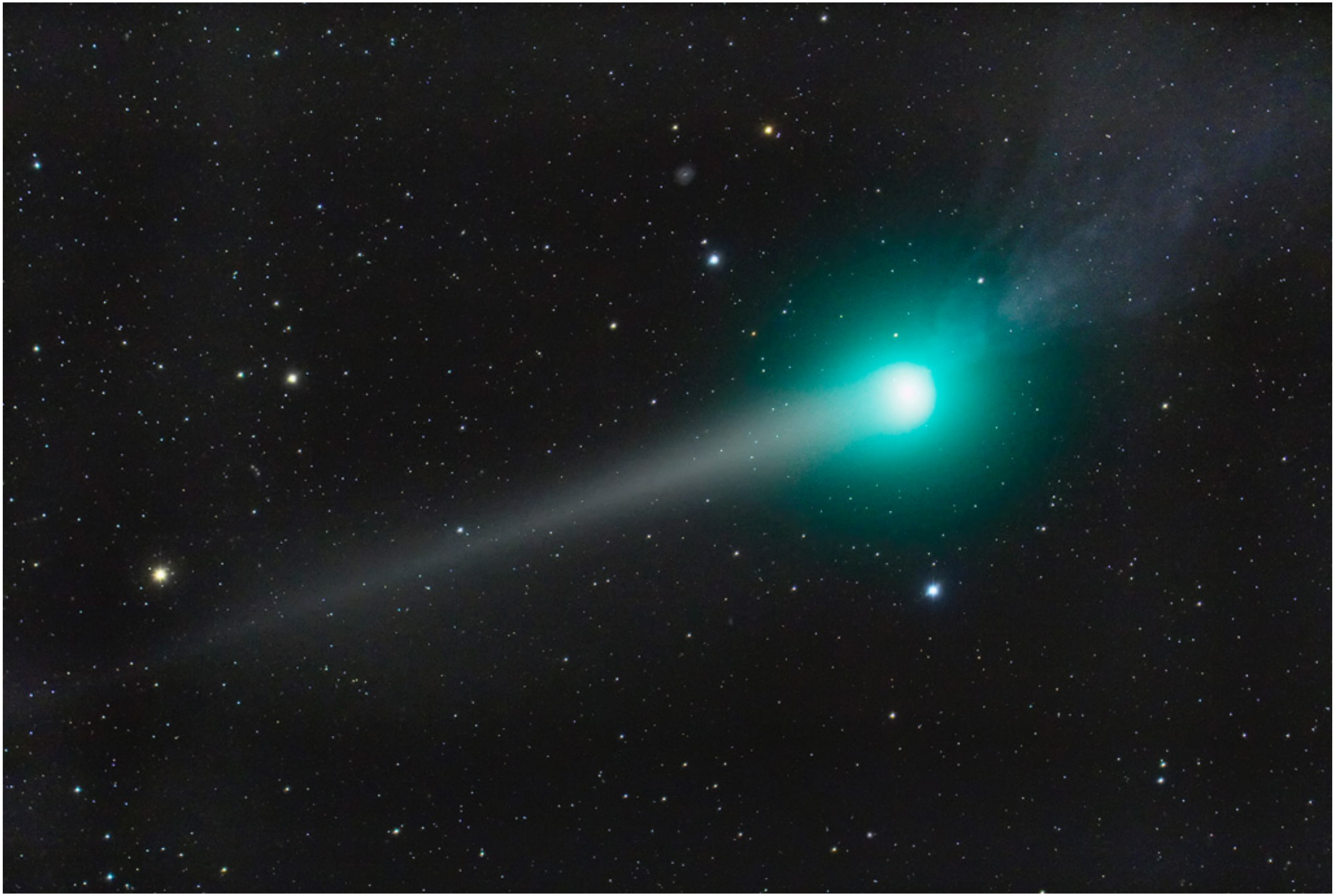
General information on comets:
http://www.nasa.gov/worldbook/comet_worldbook.html
http://en.wikipedia.org/wiki/Comet

http://en.wikipedia.org/wiki/Solar_wind

Images of comets:
http://antwrp.gsfc.nasa.gov/cgi-bin/apod/apod_search (search "comet")



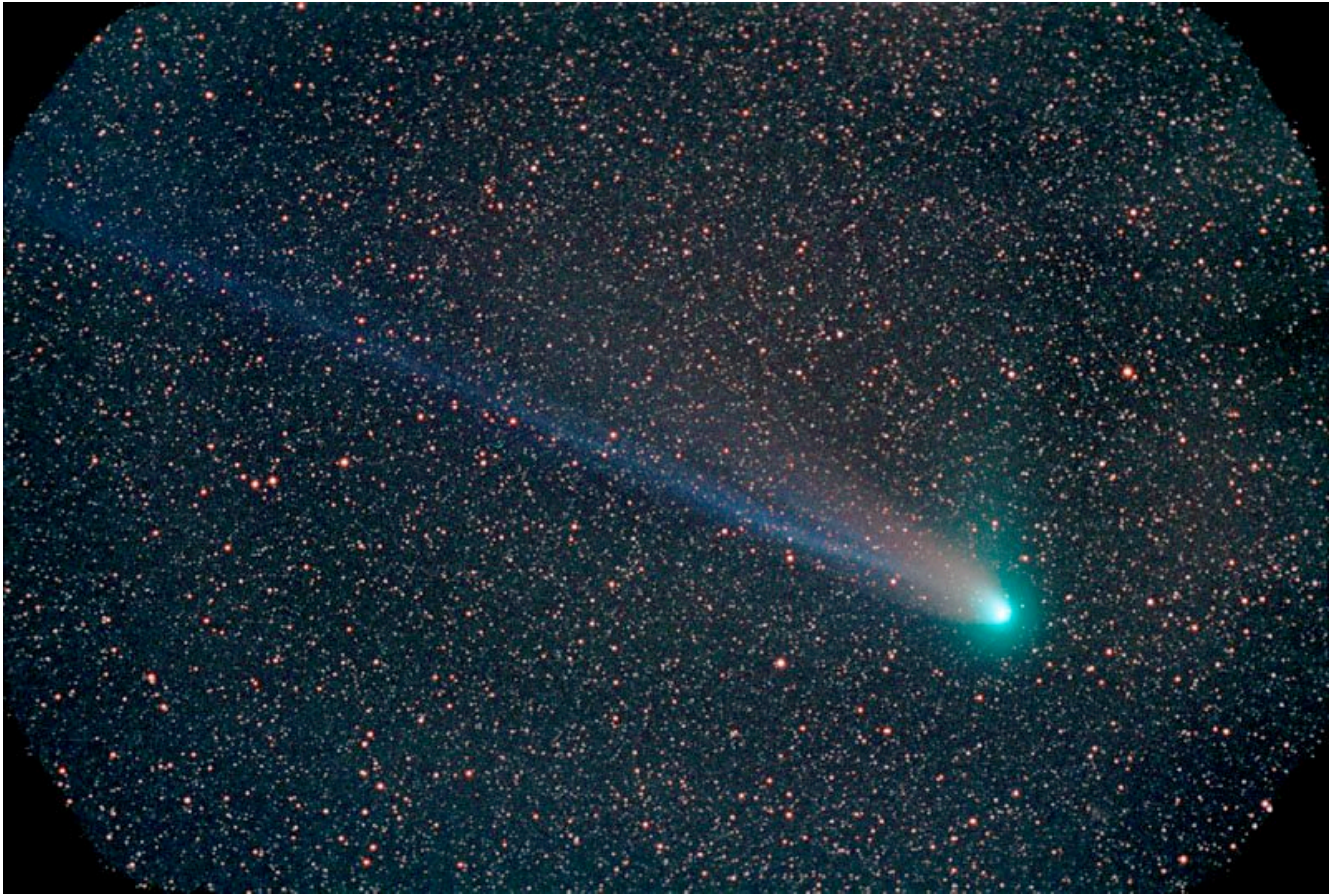
Comet Hyakutake Passes the Earth
Credit & Copyright: Doug Zubenel (TWAN)



Two Tails of Comet Lulin
Credit & Copyright: Richard Richins (NMSU)

A Tale of Comet Holmes
Credit & Copyright: Ivan Eder and (inset) Paolo Berardi

The Dust and Ion Tails of Comet Hale-Bopp
Credit & Copyright: John Gleason (Celestial Images)


The Tails of Comet NEAT (Q4)
Credit & Copyright: Chris Schur

Tails Of Comet LINEAR
Credit & Copyright: Jure Skvarc, Bojan Dintinjana, Herman Mikuz (Crni Vrh Observatory, Slovenia)

Two Tails of Comet West
Credit: Observatoire de Haute, Provence, France

TEACHER'S NOTES:

APOD: 2009 December 16 - Comet Hyakutake Passes the Earth

Explanation: In 1996, an unexpectedly bright comet passed by planet Earth. Discovered less than two months before, Comet C/1996 B2 Hyakutake came within only 1/10th of the Earth-Sun distance from the Earth in late March. At that time, Comet Hyakutake, dubbed the Great Comet of 1996, became the brightest comet to grace the skies of Earth in 20 years. During its previous visit, Comet Hyakutake may well have been seen by the stone age Magdalenian culture, who 17,000 years ago were possibly among the first humans to live in tents as well as caves. Pictured above near closest approach as it appeared on 1996 March 26, the long ion and dust tails of Comet Hyakutake are visible flowing off to the left in front of a distant star field that includes both the Big and Little Dippers. On the far left, the blue ion tail appears to have recently undergone a magnetic disconnection event. On the far right, the comet's green-tinted coma obscures a dense nucleus of melting dirty ice estimated to be about 5 kilometers across. A few months later, Comet Hyakutake began its long trek back to the outer Solar System. Because of being gravitationally deflected by massive planets, Comet Hyakutake is not expected back for about 100,000 years.

APOD: 2009 February 25 - Two Tails of Comet Lulin

Explanation: Go outside tonight and see Comet Lulin. From a dark location, you should need only a good star map and admirable perseverance -- although wide-field binoculars might help. Yesterday, Comet Lulin passed its closest to Earth, so that the comet will remain near its brightest over the next few days. The comet is currently almost 180 degrees around from the Sun and so visible nearly all night long, but will appear to move on the sky about 10 full moons a night. In this image, Comet Lulin was captured in spectacular form two nights ago from New Mexico, USA. The central coma of the comet is appearing quite green, a color likely indicating glowing molecular carbon gasses. Bright stars and a distant spiral galaxy are clearly visible in the image background. The yellow dust tail, reflecting sunlight, is visible sprawling to the coma's left trailing behind the comet, while the textured bluish-glowing ion tail is visible to the coma's right, pointing away from the Sun. Over the past few weeks, from the current vantage point of Earth, these two tails appeared to point in opposite directions. Comet Lulin is expected to slowly fade over the next few weeks.

APOD: 2007 November 10 - A Tale of Comet Holmes

Explanation: A beautiful blue ion tail has become visible in deep telescopic images of Comet Holmes. Pointing generally away from the Sun and also planet Earth, the comet's ion tail is seriously foreshortened by our extreme viewing angle. Still, enthusiastic comet watchers have remarked that on the whole, the compact but tentacled appearance suggests a jellyfish or even a cosmic calamari. This stunning view of the comet's greenish coma and blue tail was recorded on November 4 in clear skies near Budapest, Hungary. The colors are caused by molecules in the tenuous gas, like C_2 (green) and CO^+ (blue), fluorescing in sunlight. In a more recent development, the dramatic inset is a deep image from L'Aquila in central Italy on November 8, showing the ion tail disconnecting from the comet.

APOD: 2005 May 22 - The Dust and Ion Tails of Comet Hale-Bopp

Explanation: In 1997, Comet Hale-Bopp's *intrinsic* brightness exceeded any comet since 1811. Since it peaked on the other side of the Earth's orbit, however, the comet *appeared* only brighter than any comet in two decades. Visible above are the two tails shed by Comet Hale-Bopp. The blue ion tail is composed of ionized gas molecules, of which carbon monoxide particularly glows blue when reacquiring electrons. This tail is created by the particles from the fast solar wind interacting with gas from the comet's head. The blue ion tail points directly away from the Sun. The light colored dust tail is created by bits of grit that have come off the comet's nucleus and are being pushed away by the pressure of light from the Sun. This tail points *nearly* away from the Sun. The above photograph was taken in March 1997.

APOD: 2004 May 12 - The Tails of Comet NEAT Q4
Explanation: Comet NEAT (Q4) is showing its tails. As the large snowball officially dubbed Comet C/2001 Q4 (NEAT) falls toward the inner Solar System, it has already passed the Earth and will reach its closest approach to the Sun this coming Saturday. Reports place the comet at third magnitude, making it easily visible to the unaided eye to northern sky gazers observing from a dark location just after sunset. The above image was captured last Saturday from Happy Jack, Arizona, USA. Visible is a long blue ion tail, a blue coma surrounding the comet's nucleus, and a shorter but brighter sunlight reflecting dust tail. Q4 will likely drop from easy visibility during the next month as it recedes from both the Earth and the Sun. Another separate naked-eye comet, Comet Linear (T7), is also as bright as third magnitude and should remain bright into June.

APOD: 2000 July 27 - Tails Of Comet LINEAR
Explanation: Comet C/1999 S4 LINEAR is only one of many comets discovered with the Lincoln Near Earth Asteroid Research (LINEAR) telescope operating near Soccoro, New Mexico, USA. Traveling steadily southward through Earth's night sky, C/1999 S4 passed perihelion (closest approach to the Sun) yesterday on what is likely its first trip through the inner solar system. Now fading, comet LINEAR became no brighter than about 6th magnitude, but is still easily visible with binoculars in northern hemisphere skies. While the memorable comets Hale-Bopp and Hyakutake were much brighter, comet LINEAR is displaying delightful tails evident in this false-color composite image from the Crni Vrh Observatory in Slovenia. The combined series of exposures made on July 22nd are registered on the comet. In the resulting picture, stars appear as rows of dots, but the faint structures in the comet's tail are beautifully recorded. Presently seen moving from Ursa Major to Leo this comet LINEAR will begin to shine in southern hemisphere skies in August.

APOD: August 26, 1995 - Two Tails of Comet West
Explanation: Here Comet West is seen showing two enormous tails that wrap around the sky. The ion tale of a comet usually appears more blue and always points away from the Sun. The dust tail trailing the comet's nucleus is the most prominent. Comet West was a visually spectacular comet, reaching its most picturesque in March of 1976. A comet this bright occurs only about once a decade. Comets are really just large dirty snowballs that shed material when they reach the inner solar-system. Many astronomers are hopeful that Comet Hale-Bopp will look as spectacular as this in the spring of 1997.