MICRO-COMET
GRADES 3-4
A Teacher’s Program Guide

Comet Halley
2012-2013
Comet Hale-Bopp

Comet Hale Bopp, named for its discoverers, was spotted further from the sun than any previous comet - a good sign that it could become very bright, easily visible to the naked eye. A comet bright enough to see without a telescope occurs only about once a decade. The large coma and long tail of bright comets are so unusual and impressive that they have been considered omens of change by many cultures. A comet does not streak by in few seconds - but it may change its position and structure noticeably from night to night.
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January 28, 1986…”On the morning of the launch, the weather was freezing cold. We looked out at a clean blue sky that served as a magnificent backdrop to what appeared to be, from a distance, a small replica of the greater-sized shuttle. It glistened in the light, all white and sparkling, perhaps because of the bright Florida sun and the ice that hung from the platform, launch pad, and shuttle…”

“That morning, riding out on the chilly bus...I prayed for us all – for our loved ones waiting to be launched, for those of us waiting to watch the launch, for our children, for the children around the world waiting for lessons to be taught from the classroom in space…”

“When we arrived at the launch Control Center, the families departed the buses and were escorted into the offices that were traditionally set aside for the immediate families of the crew...We looked out the window. We watched the TV news announcers, the NASA select channel, and our children…”

“We all waited. The clock ticked away each moment as though it carried a heavy burden. Finally, the long-awaited countdown began. We picked up the babies and cameras and climbed the stairs to the rooftop viewing area…”

“We cheered as the solid rocket boosters ignited, and the shuttle carrying its precious cargo lifted off the pad. Only a few anxious moments were left…”

“We watched in silence as our loved ones climbed the sky sunward. Their craft from the distance seemed to sit atop a great flume of smoke. The floor shook with the sheer raw power of the million pounds of thrust…”

Then…”it happened! The unspeakable happened. Standing there together, watching with all the world, we saw the shuttle rip apart. The SRBs went screaming off on their own separate paths, the orbiter with our loved ones exploded in the cold blue sky, like our hearts it shattered into a million pieces.”

“In stunned silence, we looked to each other...for answers, for information, for hope?…”

Excerpts from Silver Linings, Triumph of the Challenger 7, by June Scobee Rodgers.

That day, hundreds of thousands of school children and citizens were watching with anticipation the launch of this “Teacher in Space” mission that had captured the excitement and awe of the nation only to see a major space tragedy before their eyes. It was truly a sad day in history. But with determination and vision, the Challenger families turned this tragedy into a monumental educational opportunity for children and adults alike.

About Us

Challenger Center is an international, not-for-profit education organization that was founded by the families of the astronauts from Challenger Space Shuttle mission 51-L. Through Challenger Center’s programs and its international network of Challenger Learning Centers, the diversity, spirit, and commitment to education that exemplified the Challenger 51-L mission continues to make an impact on students, teachers, and families today. These positive learning experiences raise students’ expectations of success; foster a long-term interest in mathematics, science, and technology; and motivate them to pursue careers in these fields.

Our Mission

As new advances in science and technology occur at an ever more accelerated pace, the need for excellence in education has never been more essential. Perhaps that’s one reason why so many communities throughout the world are actively engaged in developing a local Challenger Learning Center.

Organizational History

In the aftermath of the Challenger accident, the 51-L crew’s families came together, still grieving from loss, but firmly committed to the belief that they must carry on the spirit of their loved ones by continuing the Challenger crew’s educational mission.

Excerpts from http://www.challenger.org
Dear Friends,

January 28, 1986, is a day in history that stands out as one of excitement, tragedy, and remembrance. On that day, *Challenger, 51-L*, the “Teacher in Space” mission, launched into space carrying teacher Christa McAuliffe, Commander Dick Scobee, Pilot Mike Smith and astronauts Judy Resnik, Ellison Onizuka, Greg Jarvis, and Ron McNair. Thousands of school children and citizens were watching with anticipation the launch of this mission that had captured the excitement and awe of the nation only to see a major space tragedy before their eyes. It was truly a sad day in history, but with determination and vision, we turned this tragedy into a monumental educational opportunity for children and adults alike.

In April of that same year, the families of the *Challenger* astronauts met in the living room of June Scobee, widow of Commander Dick Scobee, to discuss a memorial for our loved ones. Choosing not to have a monument in stone but rather something that would continue the education that was part of the mission of *51-L*, we chose to create an educational organization to inspire young people across the nation. Gathering educators, scientists, astronauts, and leaders in business and industry, we were able to create Challenger Center for Space Science Education, which became a network of Learning Centers that uses space as a motivator to inspire students to succeed in mathematics, science, technology, and engineering.

These Challenger Learning Centers provide simulations in which students climb aboard a space station and work in teams to solve problems as astronauts and mission controllers in scenarios that take them through a comet, to the surface of the Moon, to a rotating platform to observe Earth, and to Mars. New scenarios are being developed to take education into new realms of excitement, creating tomorrow’s prepared work force. Recognized by the United States Department of Education for being a top motivator in mathematics, science, and technology, Challenger Center embraces the National Science Education Standards in each of its missions so that students receive hands-on, minds-on delivery of concepts that must be taught.

As we begin our historic 25th year, our Challenger Learning Centers will honor the crew and commemorate their lives and legacies throughout the year in a number of events. Through the growing network of 51 Challenger Learning Centers in the United States, Canada, and the United Kingdom, the mission of the crew truly lives on. And as new centers open, we will celebrate those communities which, like our families, come together from diverse backgrounds and experiences to create opportunities to enrich and expand the education of students in a unique and fun approach.

Our Challenger Learning Centers touch lives and create opportunities for students, our future leaders, who are the true continuation of the mission of the *Challenger, 51-L*. Please help us continue this mission by contacting us at the Challenger Center for Space Science Education.

Sincerely,

June Scobee Rogers, Ph.D.                Joseph P. Allen, Ph.D.
Founding Chairman                      Chairman
Dear Classroom Educator,

It is the year 2061. You and your students are in pursuit of Comet Halley, which last passed through our solar system in 1986. Once the comet is located, the crew will then intercept the comet and send a probe into its coma. Data collected from the probe will be used as a part of the long-term study of small bodies in the solar system.

For the Comet Mission, it will enhance the student experience if you can review the following basics concepts listed below.

The Mission Prep Activities (MPA) and the Comet Prep Activities (CPA) have specific lessons to address each topic.

1. Longitude and latitude (Declination and Inclination)
2. “X & Y Coordinates” and “Longitude and Latitude” (MPA)
3. The pH scale
4. “Acids and Bases”
5. “Chromatography” (MPA)
6. “Pulse and Blood Pressure” (MPA)
7. Measurement and Estimation
8. “Reading Equipment” (CPA)
9. “Comet Orbits” (CPA)
10. The Solar System
11. “Investigating a Comet” (CPA)
12. Communication skill
13. “Mission Survival” (MPA)
14. “Communication” (MPA)

Please call (# 423-425-4126) if we can help you with any other educational issues regarding your mission or any of our educational activities.

You can also check out our website at: http://www.utc.edu/Outreach/ChallengerCenter

We are looking forward to meeting you and your students.

The UTC Challenger Center
# Micro-Comet Team Descriptions

<table>
<thead>
<tr>
<th>Team</th>
<th>Space Lab</th>
</tr>
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</table>
| **PROBE** | Constructs a probe motherboard with parts and wires  
Skills: reading, following directions |
| **ISO 1** | Uses robotic arm to examine isolated chemicals  
Uses robotic arm to examine holes in meteoroid shields |
| **ISO 2** | Uses robotic arm to examine radioactive panels  
Skills: reading a digital scale, patience, good hand-eye coordination |
| **ISO 3** | |
| **REM 1** | Examines meteorite rocks for geological make-up and determines mass and volume  
Skills: metric measurement, observation |
| **REM 2** | Examines greenhouse plants for insects and conducts chlorophyll tests  
Skills: metric measurement, observation |
| **LS 1** | Checks O2 system, environmental conditions, and monitors power from solar panels  
Skills: collecting data, following written instructions |
| **LS 2** | Conducts pH and TDS testing of water treatment systems  
Skills: measurement, following directions |
| **NAV** | Launches the comet and finds the correct particle density for probe launch  
Skills: following instructions, math, observation and reasoning, grid coordinates |
| **MED** | Conducts medical tests on the Space Lab crew  
Skills: following and giving instructions, basic math functions |
Navigation: The navigators have excellent reading comprehension, verbal, and math skills. They follow oral and written directions well. This specialist is able to work within a set timeline.

Probe: The probe engineers are self-starters, able to follow oral instructions well and are good listeners. This specialist is able to complete work within a set timeline.

Remote: The remote specialist is comfortable in working with oversized gloves in the glovebox. This specialist is observant, knows how to read and use metric equipment, and has excellent research skills. Keyboarding and organizational skills also required.

Life Support: The life support specialist is a multi-tasker and a problem solver. This specialist follows written and oral instructions with ease. Keyboarding and research skills also required.

Medical: The medical specialists are self-starters, comfortable with giving and following both written and oral instructions as they perform a variety of tests on the spacecraft crew. Keyboarding, problem solving and research skills also required.

Isolation: The isolation specialist possesses excellent hand-eye coordination skills and patience to work with sophisticated robotic equipment. This specialist reads well and follows written and oral instructions. Keyboarding and research skills also required.
Mission Date  ________________  Time  ________________
Teacher name  ________________  School  ________________
Grade(s)  ________________  # of students  ________________  # of chaperones  ________________

1. Use the numbers as a guideline for assigning the rest of the crew. Maximum crew size is 18.
2. FAX the Manifest prior to mission day. FAX #: 423.425.2190

<table>
<thead>
<tr>
<th>TEAM NAME</th>
<th>SPACECRAFT CREW</th>
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<tbody>
<tr>
<td><strong>NAVIGATION</strong></td>
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<td><strong>PROBE</strong></td>
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<td><strong>REMOTE 1</strong></td>
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<td><strong>REMOTE 2</strong></td>
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<td>11</td>
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<tr>
<td><strong>LIFE SUPPORT 1</strong></td>
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<td><strong>LIFE SUPPORT 2</strong></td>
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<td><strong>MEDICAL</strong></td>
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<td><strong>ISOLATION 1</strong></td>
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<td>16</td>
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<td><strong>ISOLATION 2</strong></td>
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<td>18</td>
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## MINI-COMET TEAM DESCRIPTIONS

<table>
<thead>
<tr>
<th>Team</th>
<th>Spacecraft</th>
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<tbody>
<tr>
<td>COM / DATA</td>
<td>Sends verbal messages to MC. Manages the message flow in the Spacecraft. Manages and monitors outgoing text messages from all teams. Skills: 5th grade reading level, good oral communication and time management, prioritize information, keyboarding</td>
</tr>
<tr>
<td>NAV</td>
<td>Initialize star fields and determine star magnitudes, location of comet, launch angles and coordinates. Skills: following written instructions, math, reasoning, good time management skills</td>
</tr>
<tr>
<td>PROBE</td>
<td>Constructs and deploys a probe that will be launched into the comet. Skills: reading, following written directions</td>
</tr>
<tr>
<td>REM 1</td>
<td>Collects and analyzes data on mass, volume, and geological make-up of meteorites. Skills: metric measurement, observation, keyboarding, math skills</td>
</tr>
<tr>
<td>REM 2</td>
<td>Collects and analyzes data on pH of water, oxygen tests, and solar panels. Skills: collecting data, math, following written instructions and keyboarding</td>
</tr>
<tr>
<td>LS</td>
<td>Conducts medical tests on the Spacecraft crew. Skills: proper use of testing equipment and keyboarding</td>
</tr>
<tr>
<td>MED</td>
<td>Conducts experiments regarding radioactivity, meteoroids, and hazardous materials. Skills: good hand-eye coordination, patience when working with robotic arms and keyboarding</td>
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</table>
# Rendezvous with Comet Halley

## MINI-CREW MANIFEST

**Mission Date** __________________________  **Time** __________________________

**Teacher name** __________________________  **School** __________________________________________

**Grade(s)** _________  **# of students** _________  **# of chaperones** _________

1. Assign the crew following the numbers listed below.

2. FAX the Manifest prior to mission day. FAX #: 423.425.2190

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<th><strong>TEAM NAME</strong></th>
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<td><strong>REMOTE 1</strong></td>
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<td><strong>LIFE SUPPORT 1</strong></td>
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<td>18. ________________</td>
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<td>Comet Name Tags</td>
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<td>NAV SS</td>
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<td>ISO 3 SS</td>
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While in training, the crew designs a patch that identifies its unique mission. Each member of the crew contributes to the patch design. The team uses color, shape, images, and text to represent different aspects of their mission.

The mission patch for flight 51-L (Challenger Crew) offers symbols for its mission of education and flight. The shuttle is launched from Kennedy Space Center in Florida; it encircles the planet to signify America's presence in space and to illustrate the nation's drive to explore the space frontier.

The shuttle's open cargo doors represent three mission objectives: to launch a communications satellite, collect data from Comet Halley, and conduct various scientific experiments. The apple next to Christa McAuliffe's name signifies her role as the first teacher in space, as well as the education component of the mission. Finally, the scene is encircled by the surnames of each of the seven crew members.

We would like to invite your group to design its own patch to represent your Challenger Center mission.

Your patch should include:

Name of your mission

Date of your mission

School name

Symbols, logos, or characters that represent your group's mission

The SIZE of your patch should be designed to fit on a sheet 5 1/2 inches by 8 1/2 inches.

[1/2 of a standard letter page]

BE CREATIVE AND COLORFUL!!!!!

Bring your designed patch with you on mission day. It will be displayed in Mission Control.
KEYS TO A SUCCESSFUL VISIT

Classroom preparation is vital to a successful visit.

Total time at the Challenger Center:

- 15 minutes prior to start time
- 2 hours per mission
- Up to 1 hour for lunch (Lunches must be at least 30 minutes long.)

A minimum of 2-3 chaperones is recommended for the mission and EVA(s).

Lunch facilities do not exist at the Challenger Center. You may bring lunch and eat across the street in the Administration Building Lunchroom. You may also purchase lunch at the University Center.

The UTC Challenger Center is unable to provide free parking for personal vehicles. Bus parking is still free. Please make arrangements through UTC Parking Services.

Personal vehicles must register through UTC Parking Services prior to event date. Please allow an additional 20 minutes to your trip time for parking.

**The UTC Parking Services office hours:** Monday - Friday from 7:30 AM to 4:30 PM

**Phone:** (423) 425-4051  **Fax:** (423) 425-2674  **E-mail:** parking@utc.edu

**Web Address:** www.utc.edu/Administration/Parking/

Parking Options:

1. UTC Parking Garage located at the end of 5th street by McKenzie Arena (limited during the fall and spring semesters).

   **Cost:**
   - 0 - 1 hr $1.00
   - 1 - 1 1/2 hrs $1.50
   - 1 1/2 hr - 2 hrs $2.00
   - 2 - 3 hrs $3.00
   - Over 3 hrs $4.00

2. Engel Stadium Lot located on 3rd Street. Ride shuttle to front of Challenger Center.

   **Cost:** Requests should be submitted to Parking Services at least 48 hours in advance. The charge for this area will be $4.00 per day (TO PARK). Shuttle ride is free.

3. Any city street curb parking (limited during the fall and spring semesters)

   **Cost:** free

   After 4:30pm parking is free except for 24 hour reserved lots.
Comets are leftover materials that formed the planets and the Sun more than 4.5 billion years ago.

**NASA FACT**

The Stardust spacecraft passes Comet Wild 2 at 13,000 mph (21,000 kph), over six times faster than a speeding bullet.

**NASA FACT**

Stardust is the first NASA mission dedicated to exploring a comet.

**COMET INFORMATION**

(Excerpts from NASA’s 2006 Press Kit)

**NASA FACT**

Most particles from a comet are smaller than the diameter of a human hair.

**NASA FACT**

Less than one-thousandth of an ounce of cometary dust will be collected. More than 1000 particles collected will be large enough for complete scientific analysis, plus millions of smaller particles can be analyzed as groups.
**Spacecraft**

Dimensions: Main structure 1.7 meters (5.6 feet) high, 0.66 meter (2.16 feet) wide, 0.66 meter (2.16 feet) deep; length of solar arrays 4.8 meters (15.9 feet) tip to tip; sample return capsule 0.8 meter (32 inches) diameter and 0.5 meter (21 inches) high

Weight: 385 kg (848 lbs) total at launch, consisting of 254-kilogram (560-pound) spacecraft and 46-kilogram (101-pound) return capsule, and 85 kilograms (187 pounds) fuel

**Power:**

Solar panels providing from 170 to 800 watts, depending on distance from Sun

**Mission Milestones:**

Launch: Feb. 7, 1999 from Cape Canaveral Air Force Station, Fla.

Launch vehicle: Delta II (model 7426) with Star 37 upper stage

Earth-comet distance at time of launch: 820 million kilometers (508 million miles)

Interstellar dust collection: Feb. 22-May 1, 2000; Aug. 5-Dec. 9, 2002

Earth gravity assist flyby: Jan. 15, 2001

Altitude at Earth gravity assist: 6,008 kilometers (3,734 miles)

Asteroid Anne Frank flyby: Nov. 2, 2002

Comet Wild 2 encounter: January 2, 2004

Number of pictures of comet nucleus taken during encounter: 72

Earth-comet distance at time of encounter: 389 million kilometers (242 million miles)

Total distance traveled Earth to comet: 3.41 billion kilometers (2.12 billion miles)

Spacecraft speed relative to comet at closest approach: 22,023 km/h (13,684 mph)

Earth return: Jan. 15, 2006

Landing site: Utah Test & Training Range

Velocity of sample return capsule entering Earth’s atmosphere: 46,440 km/h (28,860mph) -- fastest reentry of spacecraft in history

Total distance traveled comet to Earth: 1.21 billion kilometers (752 million miles)

Total distance traveled entire mission (Earth to comet to Earth): 4.63 billion kilometers (2.88 billion miles)

**Program:**

Cost: $168.4 million total (not including launch vehicle), consisting of $128.4 million spacecraft development and $40 million mission operations

Excerpts from NASA Stardust Press Kit 2006
Comets have been studied by several spacecraft, not all of which were originally designed for that purpose. Several new missions to comets are being developed for launch in coming years.

Other past and present cometary missions include:

- In 1985, NASA modified the orbit of the International Sun-Earth Explorer spacecraft to execute a flyby of Comet 21P/Giacobini-Zinner. At that point, the spacecraft was renamed International Comet Explorer. It successfully flew through the tail of comet Giacobini-Zinner in 1985 and flew in the vicinity of comet 1P/Halley in 1986.

- An international armada of robotic spacecraft flew out to greet Halley’s Comet during its return in 1986. The fleet included the European Space Agency’s Giotto, the Soviet Union’s Vega 1 and Vega 2, and Japan’s Sakigake and Suisei spacecraft.

- Comet Shoemaker-Levy 9’s spectacular collision with Jupiter in 1994 was observed by NASA’s Hubble Space Telescope, the Jupiter-bound Galileo spacecraft and the Sun-orbiting Ulysses spacecraft.

- Deep Space 1 launched from Cape Canaveral on October 24, 1998. During a highly successful primary mission, it tested 12 advanced, high-risk technologies in space. In an extremely successful extended mission, it encountered comet 19P/Borrelly and returned the best images and other scientific data taken from a comet up to that time.

- The Comet Nucleus Tour, or Contour, mission launched from Cape Canaveral on July 3, 2002. Six weeks later, on August 15, contact with the spacecraft was lost after a planned maneuver that was intended to propel it out of Earth orbit and into its comet-chasing solar orbit.

- A European Space Agency mission, Rosetta, was launched March 2, 2004 to orbit comet 67P/Churyumov-Gerasimenko and deliver a scientific package to its surface via a lander in 2014. NASA provided scientific instruments for the cometary orbiter.

- Launched in January 2005, NASA’s Deep Impact spacecraft traveled about 431 million kilometers (268 million miles) to the vicinity of comet Tempel 1. On July 3, 2005, the spacecraft deployed an impactor that was essentially “run over” by the nucleus of comet Tempel 1 on July 4. Before, during and after the demise of this 372-kilogram (820-pound) impactor, a flyby spacecraft watched the 6.5-kilometer (about 4-mile) wide comet nucleus from nearby, collecting pictures and data of the event.
Launched in 1999, the Stardust spacecraft has circled the Sun a total of three times over seven years. On the way to its comet encounter, it collected interstellar dust on two different solar orbits. The Stardust spacecraft will eject a capsule that will descend into the Department of Defense’s Utah Test & Training Range carrying the mission’s cosmic booty of cometary and interstellar dust samples.

Launch

Stardust began its voyage on Feb. 7, 1999 from Space Launch Complex 17A at Cape Canaveral Air Station, Fla., on a variant of the Delta II launch vehicle. Launch events occurred in three phases. First, the Delta lifted off and entered orbit; then it coasted for about a half-hour; and finally an upper-stage engine fired to send Stardust out of Earth’s orbit.

Cruise

Stardust’s first two years of flight carried it on the first of its three orbital loops around the Sun. In January 2000, when Stardust was between the orbits of Mars and Jupiter -- the most distant point from the Sun that it reached during that orbit -- the spacecraft’s thrusters fired to place it on course for a later gravity assist swing-by of Earth. As Stardust traveled back inward toward the Sun, it collected interstellar particles flowing through the solar system. From February through May 2000, the spacecraft deployed its collector to capture these interstellar particles. The spacecraft completed its first solar orbit when it flew by Earth on Jan. 15, 2001. The effect of Earth’s gravity increased the size of Stardust’s orbit so that it circled the Sun once each 2-1/2 years, and placed it on a flight path leading to an intercept of its quarry, comet Wild 2. Beginning in August 2002, as the spacecraft traveled back inward toward the Sun on the later part of its second orbit, Stardust continued to collect interstellar particles flowing through the solar system until December 2002. The total time it spent collecting interstellar particles over the entire mission was 195 days.

Comet Flyby

Nine days out when Stardust deployed its “cometary catcher's mitt,” a tennis-racket-shaped particle catcher featuring more than 1,000 square centimeters (160 square inches) of collection area filled with a material called aerogel. Stardust entered the comet’s coma -- the vast cloud of dust and gas that surrounds a comet’s nucleus -- on December 31, 2003. From that point on it kept its defensive shielding between it and the stream of cometary particles it would fly through. On Jan. 2, 2004, after traveling 3.41 billion kilometers (2.12 billion miles) across the solar system over four years -- the Stardust spacecraft made its closest approach of comet Wild 2 at a distance of 240 kilometers (149 miles). During this close encounter, the faster-moving comet actually hurtled past the slower Stardust at a relative speed of 22,023 kilometers per hour (13,684 miles per hour). In terrestrial terms such velocity is guaranteed to smoke any police officer’s radar gun, but in cosmic terms such relative speed between spacecraft and comet is relatively leisurely, allowing Stardust to “soft-catch” samples of comet dust without changing them greatly.

Following the encounter, images and other science and engineering data recorded onboard during the event were transmitted to Earth. As particles impacted the spacecraft, onboard instruments performed near-instantaneous analysis of some samples. Other particles were stored onboard for return to Earth. The spacecraft also took some remarkable images of comet Wild 2’s nucleus. The otherworldly landscape included such features as steep, near vertical cliffs; house-size boulders; pinnacles; flat-floored craters with near vertical walls; haloed pit craters; overhangs and materials with varying brightness. The images of Wild 2 showed a complex rugged surface that is quite different from those of other comets, asteroids and moons that have been imaged. The deep depressions on the comet suggest that regions of the surface have eroded to depths of 100 meters or more. One of the most spectacular findings was the comet had more than 20 active jets, localized hotspots, spewing gas and dust into space. Six hours after the comet encounter, the spacecraft carried out a half-hour process of retracting and stowing the sample collector with its cometary pickings. From that point on, the sample canister was to remain sealed until it is opened in a cleanroom at NASA’s Johnson Space Center.
Deep Space Navigation
To bring the spacecraft from beyond Earth’s orbit to a predetermined landing zone on Earth, navigators will use techniques that have legacies in the Apollo missions of the 1960s and 1970s – as well as the return of the Genesis spacecraft’s solar wind samples in 2004. The Stardust navigation team must know the spacecraft’s position and speed precisely – and for this, they call upon the giant dishes of NASA’s Deep Space Network. Navigators analyze the spacecraft’s radio signal using techniques called radiometric and Doppler tracking to help pinpoint its distance from Earth as an aid to navigation.

Earth Return
The capsule will arrive at the top of Earth’s atmosphere at an altitude of 125 kilometers (410,000 feet) on Jan. 15 at 2:57 a.m. Mountain Standard Time (MST). Mission navigators are targeting the capsule to land within an ellipse 76 by 44 kilometers (47 by 27 miles) around a target point within the Utah Test & Training Range.

Atmospheric Entry
The capsule will enter Earth’s atmosphere at an altitude of 125 kilometers (410,000 feet). At this point, the capsule will be about 886 kilometers (551 miles) from its landing zone in Utah, moving at a velocity of about 12.8 kilometers per second (28,600 miles per hour). This will be the fastest human-made object to enter Earth’s atmosphere. In second place was the Apollo 10 command module, which entered at a speed of 11.11 kilometers per second (24,861 mph). Within minutes of entering the atmosphere, the radar and other tracking assets at the Utah Test & Training Range are expected to acquire the incoming capsule.

Drogue Chute Deploy
At entry plus 116 seconds, the capsule’s deceleration will ease off to 3 G’s, which will initiate a timer. About 16 seconds later, the capsule will deploy a drogue parachute. The drogue parachute is deployed when the capsule is traveling at a supersonic speed (about mach 1.4). At about entry plus 3 minutes the capsule will begin its vertical descent over the Utah Test & Training Range.

Utah Test & Training Range
The Utah Test & Training Range provides the largest overland contiguous block of restricted airspace in the continental United States authorized for supersonic flight, available for aircrew training and weapons testing. An Air Force building at the Army’s Michael Army Air Field will be home to the cleanroom erected to temporarily house the Stardust capsule after it is captured.

Dugway Proving Ground
The U.S. Army’s Dugway Proving Ground serves as the nation’s chemical and biological defense proving ground. Dugway is supporting Stardust by providing facilities, logistical, weather and range expertise as well as security and support personnel. The majority of the events surrounding the Stardust return will occur at the facility’s Ditto Test Area which approximately 19 kilometers (12 miles) from the installations main gate. Located in Ditto is the Michael Army Air Field, where the Stardust recovery helicopters will be based.

Main Chute Deploy
After descending into the Utah Test & Training Range’s controlled airspace on its drogue parachute, when it reaches an altitude of about 3 kilometers (10,000 feet), the capsule will cut one of the lines holding the drogue chute. This in turn will allow the drogue to pull out a larger parachute. At the same time the capsule will activate its UHF locator beacon, transmitting through a single antenna located in a leg of the main chute’s bridle. The UHF antenna remains with the sample return capsule after ground impact. Batteries powering the UHF have enough capacity to operate the beacon for 20 hours.
**Touchdown**

When Stardust reaches the ground, the capsule will be traveling at about 16 kilometers per hour (10 miles per hour). When the impact of landing is sensed, a cutter will release the main chute from the capsule. This will prevent the main chute from dragging the capsule across the desert. The landing footprint for the sample return capsule is about 44 by 76 kilometers (27 by 47 miles), an ample space to allow for aerodynamic uncertainties and winds that might affect the direction the capsule travels in the atmosphere.

**Sample Return Capsule Ground Recovery**

The primary goal of landing site operations is to preserve the condition of the interior of the science canister, and the cleanliness and physical integrity of the canister itself. Helicopters and vehicles will approach the capsule from a crosswind direction to avoid potential contamination of the capsule. The recovery team’s safety lead visually evaluates the condition of the capsule. Photographs will be taken of the capsule before moving it from its landed condition. After verifying that the capsule’s state is nominal, personnel will prepare the capsule for stowage in the helicopter.

**Cleanroom**

Once the capsule is onboard, the helicopter will fly it to a hangar at Michael Army Air Field. Here the capsule will be transferred from the helicopter to a truck, secured and then transported to an adjacent building, where scientists and engineers will be waiting in a temporary cleanroom. In the temporary cleanroom, the sample canister will be removed from the capsule and connected to a purge system that feeds it with a constant flow of ultra-pure gaseous nitrogen. Time-critical events will conclude when the purge is in place. The capsule, sample canister and associated hardware will then be prepared for travel by aircraft to NASA’s Johnson Space Center in Texas.

**Sample Curation**

Once safely in the lab, the canister will be opened and the aerogel and its comet and interstellar dust harvest will be inspected. A preliminary investigation period has the goal of answering a few key questions about comets and the birth of the solar system. While the mission will return about a million dust particles, the total mass of the sample returned by Stardust will probably be about 1 milligram. Though this sample quantity could seem small, to cometary scientists this celestial acquisition is nearly an embarrassment of riches.

**Planetary Protection**

The United States is a signatory to the United Nations’ 1967 Treaty of Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies. Known as the “Outer Space Treaty,” this document states in part that exploration of the Moon and other celestial bodies shall be conducted “so as to avoid their harmful contamination and also adverse changes in the environment of the Earth resulting from the introduction of extraterrestrial matter.” Stardust has been evaluated by NASA’s planetary protection officer to be appropriate for an “unrestricted” Earth return, meaning its sample is considered safe to Earth’s biosphere and inhabitants, which is consistent with recommendations of the Space Studies Board of the National Research Council. Comet dust is not considered to be a threat because it is a natural component of our environment.
The purpose of the Stardust mission is to expand the knowledge of comets by flying a spacecraft through the coma of Comet Wild 2, collecting samples from the comet, and returning those samples to Earth for laboratory analysis. Additional objectives include collecting and returning interstellar particles, imaging the comet nucleus, and in situ analysis of comet particles.

The mission’s primary goal was to collect samples of a comet’s coma and return them to Earth. In addition, interstellar dust samples were also gathered en route to the comet. Laboratory investigation will allow examination of cometary matter and interstellar grains at the highest possible level of detail. Advances in microanalytical instruments provide unprecedented capabilities for analysis on the micron and sub-micron level, even to the atomic scale for imaging. These instruments will provide direct information on the nature of the actual particles that initiated the formation of the Sun and planets 4.6 billion years ago. They will provide a highly intimate view of both pre-solar dust and solar nebula materials that existed at the very edge of the solar system at the time of its formation. Such materials will be compared with primitive meteorites and interplanetary dust samples to understand how solids that built the solar system were formed. One of the most important aspects of the mission is that it will provide materials from the edge of the solar system to be compared with primitive materials that formed in the inner solar system and are pre-served in meteorites from the asteroid belt. The ability to compare the ancient asteroidal materials that formed just beyond the orbit of Mars with the cometary solids that accreted near Pluto will provide fundamental insight into the materials, processes and environments that existed during the origin and early evolution of the solar system.

The Stardust mission is also expected to return interstellar grains formed around other stars. These will include both grains that assimilated into comets during their formation as well as dust from the galaxy that is currently passing the Sun. Interstellar grains are generally studied by astronomical techniques capable only of revealing general physical properties such as size and shape. The recent discovery and study of rare interstellar grains preserved in meteorites and interplanetary dust has shown that they contain excellent records about the nature of their parent stars, including details of the complex nuclear reactions that occur within the stars.

Since comets are rich in water and other volatiles, it has been postulated that they carried to Earth elements critical to the origin of life. The study of cometary material is essential for understanding the formation of the solar system and the role of organic matter from interstellar sources.

Finally, the discovery of an iridium-rich layer in rocks at Earth’s Cretaceous-Tertiary geologic boundary marking the end of the age of the dinosaurs about 65 million years ago has, along with other evidence, shown that the impact of an asteroid-sized body with Earth was probably responsible for the demise of the giant creatures and the death of many of Earth’s creatures living at the time. Although the chance of finding a unique elemental signature in captured cometary coma material might be slight, such a discovery would be extremely valuable in distinguishing whether it was an asteroid or a comet that made the impact.

**Stardust Science Team** Co-Investigators:

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Dr. Peter Tsou, Jet Propulsion Laboratory, Pasadena, Calif., Deputy Principal Investigator
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Dr. Anthony Tuzzolino, University of Chicago
Dr. Michael E. Zolensky, NASA Johnson Space Center, Houston

Excerpts from NASA Stardust Press Kit 2006
Beyond the orbits of the planets on the outer fringes of the solar system, a vast swarm of perhaps a trillion dormant comets circles the Sun. Frozen bodies of dust and ice, they are the most distant survivors of the disc of gas and dust that formed the Sun and planets about 4.6 billion years ago. From time to time, the gravitational pulls of other bodies will nudge some of them out of their orbits, plunging them into the inner solar system, where they erupt with glowing tails as they loop around the Sun.

Closer to home, a stream, of interstellar dust, flows continuously through the solar system. Each about 1 percent the width of a human hair, these tiny particles formed around ancient stars, are the initial building blocks of planetary systems like our own. This “stardust” is literally the stuff of which we are all made, being the source of nearly all of the elements on Earth heavier than helium.

These two niches bearing clues of the dawn of the solar system are the target for NASA’s Stardust mission. The spacecraft used a collector mechanism that employed a unique substance called aerogel to snag comet particles as well as interstellar dust flowing through the solar system, returning them to Earth for detailed study in laboratories.

Data returned from the Stardust spacecraft and the precious samples it returns to Earth will provide opportunities for significant breakthroughs in areas of key interest to astrophysics, planetary science and astrobiology. The samples will provide scientists with direct information on the solid particles that permeate our galaxy.

Stardust’s cometary dust and interstellar dust samples will help provide answers to fundamental questions about the origin of solar systems, planets and life: How did the elements that led to life enter the solar system? How were these materials transformed within the solar system by forces such as heating and exposure to ultraviolet light? How were they distributed among planetary bodies, and in what molecular and min-eral-based forms? These questions are of major importance for astrobiology and the search for life-generating processes and environments elsewhere in the universe.

Comets

Though frequently beautiful, comets traditionally have stricken terror as often as they have generated excitement as they wheel across the sky during their passage around the Sun. Astrologers interpreted the sudden appearances of the glowing visitors as ill omens presaging famine, flood or the death of kings. Even as recently as the 1910 appearance of Halley’s Comet, entrepreneurs did a brisk business selling gas masks to people who feared Earth’s passage through the comet’s tail.

In the 4th century B.C., the Greek philosopher Aristotle concluded that comets were some kind of emission from Earth that rose into the sky. The heavens, he maintained, were perfect and orderly; a phenomenon as unexpected and erratic as a comet surely could not be part of the celestial vault. In 1577, Danish astronomer Tycho Brahe care-fully examined the positions of a comet and the Moon against the stars during the evening and predawn morning. Due to parallax, a close object will appear to change its position against the stars more than a distant object will, similar to holding up a finger and looking at it while closing one eye and then the other. The Moon appeared to move more against the stars from evening to morning than the comet did, leading Tycho to conclude that the comet was at least four times farther away.

A hundred years later, the English physicist Isaac Newton established that a comet appearing in 1680 followed a nearly parabolic orbit. The English astronomer Edmund Halley used Newton’s method to study the orbits of two dozen documented cometary visits. Three comet passages in 1531, 1607 and 1682 were so similar that he concluded they in fact were appearances of a single comet wheeling around the Sun in a closed ellipse every 75 years. He successfully predicted another visit in 1758-9, and the comet thereafter bore his name.

Since then, astronomers have concluded that some comets return relatively frequently, in intervals ranging from 3 to 200 years; these are the so-called “short-period” comets. Others have enormous orbits that bring them back only once in many centuries.
**Cut n’ Paste Worksheet #2**

**Directions:** Cut out the moon pictures from Worksheet #1. Paste the pictures onto the appropriate moon phases.

<table>
<thead>
<tr>
<th></th>
<th>New Moon</th>
<th>Waxing Crescent</th>
<th>First Quarter</th>
<th>Waxing Gibbous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full Moon</td>
<td>Waning Gibbous</td>
<td>Last Quarter</td>
<td>Waning Crescent</td>
<td></td>
</tr>
</tbody>
</table>


Phases of the Moon

The revolution of the Moon around the Earth makes the Moon appear as if it is changing shape in the sky. This is caused by the different angles from which we see the bright part of the Moon's surface. These are called "phases" of the Moon. Of course, the Moon doesn't generate any light itself; it just reflects the light of the Sun. The Moon passes through four major shapes during a cycle that repeats itself every 29.5 days. The phases always follow one another in the same order. Below are pictures of the four major shapes and a description of each.

**New Moon:** The lighted side of the Moon faces away from the Earth. This means that the Sun, Earth, and Moon are almost in a straight line, with the Moon in between the Sun and the Earth. The Moon that we see looks very dark.

**First Quarter:** The right half of the Moon appears lighted and the left side of the Moon appears dark. During the time between the New Moon and the First Quarter Moon, the part of the Moon that appears lighted gets larger and larger every day, and will continue to grow until the Full Moon.

**Full Moon:** The lighted side of the Moon faces the Earth. This means that the Earth, Sun, and Moon are nearly in a straight line, with the Earth in the middle. The Moon that we see is very bright from the sunlight reflecting off it.

**Last Quarter:** Sometimes called Third Quarter. The left half of the Moon appears lighted, and the right side of the Moon appears dark.

During the time between the Full Moon and the Last Quarter Moon, the part of the Moon that appears lighted gets smaller and smaller every day. It will continue to shrink until the New Moon, when the cycle starts all over again.
Why Stardust?

In the mid-1800s, scientists also began to turn their attention to the question of comets’ composition. Astronomers noted that several major meteor showers took place when Earth passed through the known orbits of comets, leading them to conclude that the objects are clumps of dust or sand. By the early 20th century, astronomers studied comets using the technique of spectroscopy, breaking down the color spectrum of light given off by an object to reveal the chemical makeup of the object. They concluded that comets also emitted gases as well as molecular ions.

In 1950, the American astronomer Fred L. Whipple authored a major paper proposing the “dirty snowball” model of the cometary nucleus. This model, which has since been widely adopted, pictures the nucleus as a mixture of dark organic material, rocky grains and water ice. (“Organic” means that the compound is carbon-based, but not necessarily biological in origin.) Typical active comets are a few kilometers across. The shields that protected the Stardust spacecraft from the impacts of centimeter-sized rocks were named for Whipple because he conceived this technology half a century ago, just before the dawn of the space age.

Comets contain icy material, proving that they formed in the colder regions of the solar nebula. In 1950, the Dutch astronomer Jan Hendrick Oort (1900-1992) used indirect reasoning from observations to establish the existence of a vast cloud of comets orbiting many billions of miles from the Sun -- perhaps 50,000 astronomical units (AU) away (one AU is the distance from Earth to the Sun), or nearly halfway to the nearest star. This region has since become known as the Oort Cloud.

A year later, the Dutch-born American astronomer Gerard Kuiper (1905-1973) made the point that the Oort Cloud is too distant to act as the nursery for short-period comets. He suggested the existence of bodies lying just outside the orbits of the planets at perhaps 30 to 100 AU from the Sun; this has become generally known as the Kuiper Belt. Gravitational tugs from the outer planets occasionally perturb these bodies into orbits that ultimately reach inside the orbit of Jupiter where solar heating begins to release volatile materials. These comets are scattered inwards from planet to planet like a game of cosmic billiards.

The Oort Cloud, by contrast, would be the source of long-period comets. They are periodically nudged from their orbits by any one of several influences -- perhaps the gravitational pull of a passing star or giant molecular cloud, or tidal forces of the Milky Way Galaxy. It is generally believed that the Oort cloud comets actually formed closer to the Sun than the Kuiper belt comets and were ejected outwards by close encounters with giant planets. When the solar system was forming, small, icy, comet-like bodies were the dominant form of solid planetary building block. The Oort Cloud and the Kuiper Belt are two places where a tiny fraction of the original ice-rich bodies have survived over the full history of the solar system. All of the others either collided with planets or the Sun or were ejected into the galaxy.

In addition to the length of time between their visits, another feature that distinguishes short- and long-period comet is that the orbits of short-period comets are all fairly close to the ecliptic plane, the plane in which Earth and most other planets orbit the Sun. Long-period comets, by contrast, dive inwards toward the Sun from virtually any part of the sky; many of them have retrograde orbits, orbiting in the opposite direction to that of the planets. The Kuiper Belt is a relatively flat ring in the outer part of the solar system, whereas the Oort Cloud is a three-dimensional sphere surrounding the solar system.

Residing at the farthest reaches of the solar system, comets were not strongly influenced by most of the processes that modified small bodies that formed closer to the Sun. As the preserved building blocks of the outer solar system, comets offer direct clues to the materials and processes that formed the planets 4.6 billion years ago.

The geologic record of the Moon shows that, about 3.9 billion years ago, a period of heavy comet or asteroid bombardment tapered off. The earliest evidence of life on Earth dates from just after the end of this heavy bombardment. Before this time, Earth was impacted with objects from the outer solar system that were large enough to heat Earth’s surface to sterilizing temperatures. Scientists therefore wonder: How could life form so quickly when the period of heavy bombardment ended? Part of the answer may be that comets, which are abundant in both water and carbon-based molecules, delivered essential ingredients for life to begin.
Comets are also at least partially responsible for the delivery of Earth’s water. While Earth has long been regarded as the “water planet,” it and the other terrestrial planets (Mercury, Venus and Mars) are actually poor in the percentage of water and in carbon-based molecules they contain when compared to objects that reside in the outer solar system at Jupiter’s orbit or beyond. Comets may contain up to 50 percent water by weight and about 10 to 20 percent carbon by weight. It has long been suspected that what little carbon and water there is on Earth was delivered here by objects such as comets and asteroids that came from in colder regions of the solar nebula where it was possible to incorporate water into solid bodies.

While comets are a likely source for life’s building blocks, they have also played a devastating role in altering life on our planet. A comet or asteroid is credited as the likely source of the impact that changed Earth’s climate, wiped out the dinosaurs and gave rise to the age of mammals 65 million years ago. A catastrophic collision between a comet or asteroid and Earth of several kilometers in size is estimated to happen at intervals of several tens of millions of years.

Right Place, Right Time, Right Snowball

Comet 81P/Wild 2 is a periodic comet that currently moves about the Sun in an elliptic orbit every 6.39 years. Its nucleus is thought to be a mix of ice and dust, with dimensions of 3.3 by 4 by 5.5 kilometers (2 by 2.5 by 3.4 miles).

Until September 10, 1974, comet Wild 2’s orbit lay between Jupiter and a point past Uranus. But on that date over 30 years ago, the comet passed within 897,500 kilometers (557,735 miles) of the solar system’s biggest planet, Jupiter. That encounter with Jupiter altered the comet’s orbit, carrying it into the inner solar system. The new flight path brings it as close to the Sun as just beyond the distance of Mars and far from the Sun as about Jupiter. On January 6, 1978, astronomer Paul Wild (pronounced “Vilt”) discovered the comet during its first passage relatively near to the Earth -- passing within 181,014,000 kilometers (112,476,679 miles).

When a comet comes close enough to the Sun, solar heating causes it to lose volatile material through a process called sublimation. This happens when a solid turns to vapor without first melting into a liquid. If a comet lasts long enough, after about 1,000 orbits inside the orbit of Jupiter, it can lose most of its volatile materials and no longer generate a coma or tail. Many comets mysteriously break up into fragments long before they lose all their volatiles and literally run out to steam.

When Stardust reached Wild 2, the comet had made only five trips around the Sun in its new orbit. By contrast, Comet Halley has passed close to the Sun more than 100 times, coming close enough to have been greatly altered from its original condition. The past history of Wild 2 is unknown but it is likely that it had previously been inside the orbit of Jupiter. Scientists believe the comet probably formed near the orbit of Pluto where it orbited for nearly the entire age of the solar system. In the last few million years, it began a “wandering stage” where repeated gravitational tugs from planets started it on a series of encounters that led it to its present orbit inside the orbit of Jupiter. If it survives the effects of solar heating and also does not fragment, Wild 2 will most likely be ejected from the solar system or perhaps collide with a planet within the next few million years.

Interstellar Dust

In 1990, NASA launched the Ulysses spacecraft on a flight path that would take it close to Jupiter, in turn flinging it into an orbit around the Sun far above and below the ecliptic, the plane in which most planets orbit the Sun. While en route from Earth to Jupiter, the spacecraft’s dust detector measured a flow of dust particles -- each about a micron in size, or 1 percent of the diameter of a human hair -- entering the solar system from interstellar space. This observation was corroborated by a similar dust detector on the Galileo spacecraft, which reached Jupiter in 1995.

Interstellar dust is ubiquitous in the space between the stars of the Milky Way Galaxy. The dust curtains huge areas of the sky; the broad, dark line across the length of the Milky Way that can be seen with the naked eye is a blanket of interstellar dust. The numerous but tiny particles carry nearly all of the atoms heavier than helium that are used to make new generations of stars, planets and even life. All of the atoms in our bodies were inside these grains before the Sun and planets formed.
As the Sun orbits the galactic center, it cuts through the dust like a car driving through rain. From our perspective within the solar system, the dust seems to be flowing from approximately the direction that the Sun is moving toward -- a point called the “solar apex” in the constellation Hercules.

Interstellar dust provided the initial building blocks for making Earth and the other solid bodies in the solar system. In the life cycle of stars, elements coalesce under gravity to form the star, which in develops internal temperatures high enough to drive ongoing nuclear reactions. All elements heavier than helium were made inside stars by these nuclear reactions. When stars reach the ends of their lives they eject some of these elements back into space where they condense into tiny grains of interstellar dust. The resulting interstellar particles contain a record of the processes at work in their parent stars as well as the environments they have passed through in the galaxy. This information is retained in particles at a scale smaller than a micron.

Interstellar dust forms by condensation in circumstellar regions around evolved stars of different types, including red giants, carbon stars, novas and supernovas. The process gives rise to silicate grains when there is more oxygen than carbon in the star, and carbon-based grains when the carbon content exceeds that of oxygen. Pristine grains will retain the isotopic signatures of the environments they formed in.

In the past decade, scientists have gained new understanding about the formation and early evolution of the solar system and the role of interstellar dust and comets in that process. Studies of interstellar dust have been conducted with Earth and space-based telescopes; in addition, scientists have positively identified interstellar grains that are contained inside certain meteorites and ultra-primitive interplanetary dust collected with U-2 aircraft in the stratosphere. The samples returned by Stardust will be compared with these and others to better understand how dust evolves from its interstellar state to help create stars, planets and life in the universe.

Infrared observations have also provided new knowledge of star-formation and the role that dust plays in that process. Scientists have found both similarities and differences between interstellar dust and cometary composition. The same gases, ice particles and silicates believed to be in comets also are found in interstellar clouds.

Even though the interstellar dust particles are small, they contain billions of atoms and open a significant new window of information on galactic and nebular processes, materials and environments. Having actual samples in hand provides many unique advantages. Just as the return of lunar samples by the Apollo missions of the 1960s and 1970s revolutionized our understanding of the Moon, scientists expect that the Stardust mission’s sample return will also have a profound impact on our knowledge of comets and stars.

Earth Assist

Assisting the Stardust team in their celestial pursuit of comet Wild 2 are several teams of Earth-based astronomers. These observatories made observations and measurements of Wild 2 from mid to late December 2003. These observations assisted the Star-dust team in validating the size of coma and amount of activity taking place on comet Wild 2, as well as assisting in further reducing uncertainty in the plotting of the comet’s orbit.

Program/Policy Management

Stardust’s principal investigator is Dr. Donald Brownlee of the University of Washington, Seattle. Dr. Peter Tsou of NASA’s Jet Propulsion Laboratory, Pasadena, Calif., is deputy principal investigator. The Stardust mission is managed by the Jet Propulsion Laboratory for NASA’s Science Mission Directorate, Washington. At NASA Headquarters, Mary Cleave is associate administrator for space science. Andy Dantzler is the director of NASA’s Solar System Exploration Division, Kenneth Ledbetter is deputy associate administrator for programs, Dr. Thomas Morgan is Stardust program executive and program scientist. At the Jet Propulsion Laboratory, Tom Duxbury is project manager. Bob Ryan is mission manager. JPL is a division of the California Institute of Technology, Pasadena, Calif.

At Lockheed Martin Space Systems, Denver, Colo., Joseph M. Vellinga is the company’s Stardust program manager, and Dr. Benton C. Clark is the company’s chief scientist for space exploration systems. Lockheed Martin Space Systems designed, built and operates the spacecraft, and will recover the sample return capsule.

Excerpts from NASA Stardust Press Kit 2006
Spacecraft

The Stardust spacecraft incorporates innovative, state-of-the-art technologies pioneered by other recent missions with off-the-shelf spacecraft components and, in some cases, spare parts and instrumentation left over from previous missions. The Stardust spacecraft is derived from a rectangular deep-space bus called Space Probe developed by Lockheed Martin Space Systems, Denver, Colo. Total weight of the spacecraft, including the sample return capsule and propellant carried onboard for trajectory adjustments, is 385 kilograms (848 pounds). The main bus is 1.7 meters (5.6 feet) high, 0.66 meter (2.16 feet) wide and 0.66 meter (2.16 feet) deep, about the size of an average office desk. Panels are made of a core of aluminum honeycomb, with outer layers of graphite fibers and polycyanate face sheets. When its two parallel solar panels are deployed in space, the spacecraft takes on the shape of a letter H. There are three dedicated science packages on Stardust -- the two-sided dust collector, the comet and interstellar dust analyzer, and the dust flux monitor. Science data is also be obtained without dedicated hardware. The navigation camera, for example, provided images of the comet both for targeting accuracy and scientific analysis.

Aerogel Dust Collectors

To collect particles without damaging them, Stardust used an extraordinary substance called aerogel -- a silicon-based solid with a porous, sponge-like structure in which 99 percent of the volume is empty space. Originally invented in 1931 by a researcher at the College of the Pacific in Northern California, aerogel is made from a gelatin-like mix of silica and a liquid. The mixture is set in molds of the desired shape and thickness, and then pressure-cooked at high temperature to remove the liquid.

Over the past several years, aerogel has been made and flight-qualified at the Jet Propulsion Laboratory for space missions. A cube of aerogel looks like solid, pale-blue smoke. It is the lightest-weight, lowest-mass solid known, and has been found to be ideal for capturing tiny particles in space. There is extensive experience, both in laboratory and space flight experiments, in using aerogel to collect hypervelocity particles. Eight space shuttle flights have been equipped with aerogel collectors.

The exotic material has many unusual properties, such as uniquely low thermal and sound conductivity, in addition to its exceptional ability to capture hypervelocity dust. Aerogel was also used as a lightweight thermal insulator on Mars Pathfinder’s Sojourner rover. When Stardust flew through the comet’s coma, the impact velocity of particles as they are captured were up to six times the speed of a bullet fired from a high-powered rifle.

Although the particles captured in aerogel are each smaller than a grain of sand, Stardust spacecraft speed capture in most substances would alter their shape and chemical composition -- or vaporize them entirely. With aerogel, however, particles are softly caught in the material and slowed to a stop. When a particle hits the aerogel, it buries itself, creating a carrot-shaped track in the aerogel up to 200 times its own length as it slows down and comes to a stop. The aerogel made for the Stardust mission has extraordinary, water-like clarity that will allow scientists to locate a particle at the end of each track etched in the substance. Each narrow, hollow cone leading to a particle will easily be seen in the aerogel with a stereo microscope.
The sizes of the particles collected in the aerogel are expected to range mostly from less than a micron (a millionth of a meter, or 1/25,000th of an inch, or about 1/100th of the width of a human hair) to nearly a millimeter. Most of the scientific analysis will be devoted to particles that are 15 microns (about 1/1,700th of an inch, or about one-third the width of a human hair) in size. The Stardust science team expects that the samples returned will be profoundly complex, and some particles will be probed for years in research labs.

One side of the dust collection module, called the “A side”, was used for the comet encounter, while the opposite side (“B side”) has been used for interstellar collection. More than 1,000 square centimeters (160 square inches) of collection area is provided on each side. Each of Stardust’s two collectors has 130 rectangular blocks of aerogel each measuring 2 by 4 centimeters (0.8 by 1.6 inches), plus two slightly smaller rhomboidal blocks.

The thickness of the aerogel on the cometary particle collection side is 3 centimeters (1.2 inches), while the thickness of the aerogel on the interstellar dust particle collection side is 1 centimeter (0.4 inch). The density of the aerogel is graded -- less dense at the point of particle entry, and progressively denser deeper in the material. Each block of aerogel is held in a frame with thin aluminum sheeting.

Overall, the collection unit resembles a metal ice cube tray set in an oversize tennis racket. It is similar to previous systems used to collect particles in Earth orbit on SpaceHab and other space shuttle borne experiments. The sample return capsule is a little less than a meter (or yard) in diameter, and opens like a clamshell to extend the dust collector into the dust stream. After collecting samples, the cell assembly folds down for stowage into the sample return capsule.

**Comet and Interstellar Dust Analyzer**

The comet and interstellar dust analyzer is derived from the design of an instrument that flew on the European Space Agency’s Giotto spacecraft and the Soviet Union’s Vega spacecraft when they encountered Comet Halley in 1986. The instrument obtained unique data on the chemical composition of individual particulates in Halley’s coma. Stardust’s version of the instrument studied the chemical composition of particulates in the coma of comet Wild 2.

The instrument is what scientists call a “time-of-flight” mass spectrometer, which separates the masses of ions by comparing differences in their flight times. When a dust particle hits the instrument’s target, the impact creates ions which are extracted from the particle by an electrostatic grid. Depending on the polarity of the target, positive or negative ions can be extracted. As extracted ions move through the instrument, they are reflected and then detected. Heavier ions take more time to travel through the instrument than lighter ones, so the flight times of the ions are then used to calculate their masses. From this information, the ion’s chemical identification can be made. In all, the instrument consists of a particle inlet, a target, an ion extractor, a mass spectrometer and an ion detector.

Co-investigator in charge of the comet and interstellar dust analyzer is Dr. Jochen Kissel of the Max-Planck-Institute für Extraterrestrische Physik, Garching, Germany. The instrument was developed and fabricated by von Hoerner & Sulger GmbH, Schwetzingen, Germany, under contract to the German Space Agency and the Max-Planck-Institute. Software for the instrument was developed by the Finnish Meteorological Institute, Helsinki, Finland, under subcontract to von Hoerner & Sulger.

**Dust Flux Monitor**

The dust flux monitor measures the size and frequency of dust particles in the comet’s coma. The instrument consists of two film sensors and two vibration sensors. The film material responds to particle impacts by generating a small electrical signal when penetrated by dust particles. The mass of the particle is determined by measuring the size of the electrical signals. The number of particles is determined by counting the number of signals. By using two film sensors with different diameters and thicknesses, the instrument provides data on what particle sizes were encountered and what the size distribution of the particles is.

The two vibration sensors are designed to provide similar data for larger particles, and are installed on the Whipple shield that protect the spacecraft’s main bus. These sensors detected the impact of large comet dust particles that penetrate the outer layers of the shield. This system, essentially a particle impact counter, will give mission engineers information about the potential dust hazard as the spacecraft flies through the coma environment.
**Stardust Parts**

Co-investigator in charge of the dust flux monitor is Dr. Anthony Tuzzolino of the University of Chicago, where the monitor was developed.

**Navigation Camera**

Stardust’s navigation camera is an amalgam of flight-ready hardware left over from other NASA solar system exploration missions. The main camera is a spare wide-angle unit left over from the two Voyager spacecraft missions launched to the outer planets in 1977. The camera uses a single clear filter, thermal housing, and spare optics and mechanisms. For Stardust, designers added a thermal radiator.

Also combined with the camera is a modernized sensor head left over from the Galileo mission to Jupiter launched in 1989. The sensor head uses the existing Galileo design updated with a 1024-by-1024-pixel array charge-coupled device (CCD) from the Cassini mission to Saturn, but has been modified to use new miniature electronics. Other components originated for NASA’s Deep Space 1 program.

During distant imaging of the comet’s coma, the camera took pictures through a periscope in order to protect the camera’s primary optics as the spacecraft enters the coma. In the periscope, light is reflected off mirrors made of highly polished metals designed to minimize image degradation while withstanding particle impacts. During close approach, the nucleus was tracked and 72 images were taken.

**Propulsion System**

The Stardust spacecraft needs only a relatively modest propulsion system because of its carefully designed trajectory, which included three loops around the Sun with flybys of Earth, the comet and an asteroid plus its return to Earth.

The spacecraft is equipped with two sets of thrusters that use hydrazine as a mono-propellant. Eight larger thrusters, each of which puts out 4.4 newtons (1 pound) of thrust, will be used for trajectory correction maneuvers or turning the spacecraft. Eight smaller thrusters producing 0.9 newton (0.2 pound) of thrust each are used to control the spacecraft’s attitude, or orientation. The thrusters are in four clusters located on the opposite side of the spacecraft from the deployed aerogel. At launch the spacecraft carried 85 kilograms (187 pounds) of hydrazine propellant.

**Altitude Control**

The altitude control system manages the spacecraft’s orientation in space. Like most solar system exploration spacecraft, Stardust is three-axis stabilized, meaning that its orientation is held fixed in relation to space, as opposed to spacecraft that stabilize themselves by spinning.

Stardust determines its orientation at any given time using a star camera or one of two inertial measurement units, each of which consists of three ring-laser gyroscopes and three accelerometers. The spacecraft’s orientation is changed by firing thrusters. The inertial measurement units are needed only during trajectory correction maneuvers and during the fly-through of the cometary coma when stars may be difficult to detect. Otherwise, the vehicle can be operated in a mode using only stellar guidance for spacecraft positioning. Two Sun sensors serve as backup units, coming into play if needed to augment or replace the information provided by the rest of the attitude control system’s elements.

**Command and Data Handling**

The spacecraft’s computer is embedded in the spacecraft’s command and data-handling subsystem, and provides computing capability for all spacecraft subsystems. At its heart is a RAD6000 processor, a radiation-hardened version of the PowerPC chip used on some models of Macintosh computers. It can be switched between clock speeds of 5, 10 or 20 MHz. The computer includes 128 megabytes of random-access memory (RAM); unlike many previous spacecraft, Stardust does not have an onboard tape recorder, but instead stores data in its RAM for transmission to Earth. The computer also has 3 megabytes of programmable memory that can store data even when the computer is powered off.

The spacecraft uses about 20 percent of the 128 megabytes of data storage for its own internal housekeeping. The rest of the memory is used to store science data and for computer programs that control science observations. Memory allocated to specific instruments includes about 75 megabytes for images taken by the navigation camera, 13 megabytes for data from the comet and interstellar dust analyzer, and 2 megabytes for data from the dust flux monitor.

Excerpts from NASA Stardust Press Kit 2006
Power

Two solar array panels affixed to the spacecraft were deployed shortly after launch. Together they provide 6.6 square meters (7.9 square yards) of solar collecting area using high-efficiency silicon solar cells. One 16-amp-hour nickel-hydrogen battery provides power when the solar arrays are pointed away from the Sun and during peak power operations.

Thermal Control

Stardust’s thermal control subsystem uses louvers to control the temperature of the inertial measurement units and the telecommunications system’s solid-state power amplifiers. Thermal coatings and multi-layer insulation blankets and heaters are used to control the temperature of other parts of the spacecraft.

Telecommunications

Stardust is equipped with a transponder (radio transmitter/receiver) originally developed for the Cassini mission to Saturn, as well as a 15-watt radio frequency solid-state amplifier. Data rates will range from 40 to 33,000 bits per second.

During cruise, communications are mainly conducted through the spacecraft’s medium-gain antenna. Three low-gain antennas are used for initial communications near Earth and to receive commands when the spacecraft is in nearly any orientation.

A 0.6-meter-diameter (2-foot) high-gain dish antenna is used primarily for communication immediately following closest approach to the comet. Stardust will use it to transmit images of the comet nucleus, as well as data from the comet and interstellar dust analyzer and the dust flux monitor, at a high data rate to minimize the transmission time and the risk of losing data during the extended time that would be required to transmit the data through the medium-gain antenna. Most data from the spacecraft will be received through the Deep Space Network’s 34-meter-diameter (112-foot) ground antennas, but 70-meter (230-foot) antennas will be used during some critical telecommunications phases, such as when Stardust transmits science data during and after the comet encounter.
Aerogel

Aerogel is not like conventional foams, but is a special porous material with extreme microporosity on a micron scale. It is composed of individual features only a few nanometers in size. These are linked in a highly porous dendritic-like structure.

This exotic substance has many unusual properties, such as low thermal conductivity, refractive index and sound speed - in addition to its exceptional ability to capture fast moving dust. Aerogel is made by high temperature and pressure-critical-point drying of a gel composed of colloidal silica structural units filled with solvents. Aerogel was prepared and flight qualified at the Jet Propulsion Laboratory (JPL). JPL also produced aerogel for the Mars Pathfinder and Stardust missions, which possess well-controlled properties and purity. This particular JPL-made silica aerogel approaches the density of air. It is strong and easily survives launch and space environments. JPL aerogel capture experiments have flown previously and been recovered on Shuttle flights, Spacelab II and Eureca.

**Aerogel is made of the same basic material as glass, but it is much lighter because it is 99.8 percent air.**

It is 39 times more insulating than the best fiberglass insulation.

This photo illustrates the excellent insulating properties of aerogel. The crayons on top of the aerogel are protected from the flame underneath, and are not melting.

The matches on top of the aerogel are protected from the flame underneath.

Aerogel is sometimes referred to as "blue smoke" or "solid smoke." It is as delicate as a flower, yet durable enough to withstand extreme environments.

Aerogel can support 1000 times its own weight. A 2.5 kg brick is supported on top of a piece of aerogel weighing only 2 grams. Though with a ghostly appearance like an hologram, aerogel is very solid. It feels like hard styrofoam to the touch.

These speeding particles are trapped gently in aerogel after leaving long, cone-shaped tracks.

Excerpts from NASA and JPL Websites 2006
DID YOU KNOW
The stardust capsule hits the Earth’s atmosphere at 28,000 mph, faster than the Apollo Mission capsules and 70% faster than the reentry velocity of the shuttle.

NASA FACT
Comets contain many of the organic materials thought to be essential for the origin of life.

NASA FACT
Aerogel is a special type of foamed glass, made so lightweight that it is barely visible and almost floats in air.

NASA FACT
Comet particles are captured using a material called aerogel.

NASA FACT
Aerogel can support 1000 times its own weight.

NASA FACT
Comet particles make carrot-shaped tunnels in the aerogel as they are stopped. At the pointed tip of each tunnel a tiny particle will be found.

DID YOU KNOW
The stardust capsule hits the Earth’s atmosphere at 28,000 mph, faster than the Apollo Mission capsules and 70% faster than the reentry velocity of the shuttle.
The spacecraft designers were all in a tizzy
With a really tough job that was making them dizzy.
"A comet is coming! How can we catch it?
And chase down some dust, then home to Earth fetch it?

"The comet, Wild 2, will be rocky and icy
And dodging its jets will be chancy and dicey.
The dust blasting out will be awfully speedy.
Is hoping to catch some just being too greedy?

"Grabbing specks gently is really what matters.
We don't want to bring back a bunch of smashed splatters!"
So they set to work on some stuff they'd had word of,
Some stuff made of sand but with traits all unheard of!

It looked just like smoke but with shapes round and squarish.
Though hard to light touch, touch it hard—it will perish!
Dioxide of silica makes just one little part of it,
But nine ninety-nine parts of air is the heart of it.

"This stuff is so light that it's almost not there.
It seems to be solid but it looks more like air!"
The science guys wondered aloud what would go down
If comet dust slammed it quite hard. Would it slow down
The dust in its tracks? Would it stop the dust cold?
Would comet dust do the stuff damage untold?
So the stuff they called AEROGEL went through its paces,
Was blasted with particles and run 'round its bases.

"Huzzah!" cried the science guy on seeing the tracks
That the dust left behind. "Now we'll have no lack
Of clues where to look where the comet stuff landed.
We'll follow the cone tracks and there we'll be handed
A piece of a comet! A clue! How we got here!"
For comets can help us unravel the knot here
Of how all our planets, the Sun, moon, and space rocks
Became what they are now, with Earth in the Goldilocks Zone of our system, not too hot, nor chilly,
Nor right in the path of too many rocks, really.
So off to the comet the aerogel blasted,
Carried by Stardust. The journey? It lasted
Five years! In a spacecraft all specially built to
Chase down and grab dust from the comet named Wild 2.
It’s now heading home. "We’re excited to see
What the aerogel brings us. Real comet debris!"

From: http://spaceplace.nasa.gov/en/kids/
What is Aerogel?

Aerogel is a lightweight, nearly transparent substance that has many uses in space science. At one-thousand times less dense than glass, a result of being made of 99 percent air, it is the lightest solid in existence. It has superior insulating qualities [an inch of Aerogel insulates as well as six inches of fiberglass!], and has proven particularly useful for collecting small particles traveling at high velocities.

How does Aerogel act as a mechanism for capture?

Aerogel has proven itself as an excellent collector of high-speed particles. Although very tiny, these particles move so swiftly that they are very difficult to collect without damaging the particles, or the collector itself. Tests done in labs on Earth and on the Space Shuttle show, if engineered properly, Aerogel virtually eliminates both of these issues. When a particle hits Aerogel, it buries itself in the material, creating a carrot-shaped track as it comes to a stop. Because Aerogel is almost completely transparent, it is relatively easy to find these tracks and locate the particle at the tip of the "carrot."

The limitations of the Aerogel-O model

Because Aerogel has so many unique properties, it is particularly difficult to find a substance that models it accurately. In this activity, "Aerogel-O" is used as an example, although there are many differences between the two. Among these are its high water content, which would not allow it to travel intact in the extreme environment of space, and its relatively large weight.
How to Make the Teacher Demonstration Model

Materials: (Makes Two)
1 Microwaveable Bowl  2-3 wad cutter pellets .22 caliber
2 cups of cold water  2-3 BBs
Clear Gelatin  2 Clear plastic cups 9oz.
Straws

Recipe:
1. Into Microwaveable bowl add 2 cups cold water
2. Sprinkle 1 packet of unflavored Knox gelatin on top of water
3. Let sit for 2 minutes
4. Microwave 2 minutes
5. Stir
6. Pour mixture into two 9 ounce clear cups
7. Chill until set

Procedures:
1. Once gelatin has set it is now time to add the pellets and BBs (comet debris).
2. Place the pellet or BB into the end of the straw.
3. Standing above the areogel blow into straw and “shoot” the pellets into the Jell-O.
   *Be careful to not touch the Jell-O with the straw. *Caution—Do not inhale with straw in your mouth.
4. Repeat steps 3 through 5 until all pellets and BBs have been added.
5. Using the Aerogel-O Demonstration Model and the Aerogel Fact Sheet have students complete the Student Worksheet. (Additional pictures and information on page 29.)
Student Procedures

1. Observe track marks made by the pellet in the teacher demonstration.
2. If possible, view the image of the track from the STARDUST website at: http://stardust.jpl.nasa.gov/spacecraft/Aerogel.html.
3. Read the Aerogel Fact Sheet and discuss Aerogel.
4. Using the Venn Diagram compare and contrast aerogel-O to Aerogel.
Students work in teams or individually to build the STARDUST spacecraft from edible products. Fill plastic baggies or paper lunch bags with the needed materials. Remind students that they will present their spacecraft to the class, so they are not to eat all of the candy. Icing holds the smaller parts together very well. For stability the solar arrays need to be connected to the body of the spacecraft. Toothpicks may not be appropriate for younger students to use. Try pretzel sticks, lollipop sticks, or popsicle sticks with icing.

**Materials**

**Solar Arrays**
- Graham crackers
- wafer cookies
- rectangular crackers

**Sample Return Capsule**
- Large marshmallows
- Mini peanut butter cups

**Glue to hold spacecraft together**
- Icing in tubes or a tub
- Toothpicks
- Pretzel sticks

**Icing can be separated into mini paper cups and covered with plastic wrap.**
- Small paper cups
- Reynolds wrap
- Popsicle sticks for applying icing

**Paper Towels**

**Aerogel Dust Collector**

**Whipple Shields (Dust Flux Monitors)**
- Plain chocolate bars or mini chocolate bars

**Sample Return Capsule**

**Launch Vehicle Adapter**
- Peppermint patties

**Sample Return Capsule**

**Cometary and Interstellar Dust Analyzer - CIDA**
- Twizzlers

**Sample Return Capsule**

**Sample Return Capsule**
Spacecraft Rubric

4 = Complete, fully developed, very accurate
3= Mostly complete, mostly accurate
2= Partly complete, some accuracy
1= Missing or omitted information, mostly inaccurate

_____ Spacecraft is made with care and creativity.

_____ Spacecraft contains two antenna (high gain and medium gain).

_____ Spacecraft contains two solar arrays.

_____ Spacecraft contains one aerogel dust collector.

_____ Spacecraft contains a Dust Flux Monitor (Whipple Shield).

_____ Spacecraft contains a launch adapter.

_____ Spacecraft contains a Cometary and Interstellar Dust Analyzer. (CIDA)

_____ Spacecraft contains a Sample Return Capsule.

_____ Spacecraft contains a Navigation Camera.

_____ Spacecraft parts are labeled and function defined.

_____ Student can clearly explain the function of each part of the spacecraft.

__________ Total / 44 x 100 = ____________ percentage
Comet Orbital Periods

Comet Halley
76.1 years

D’Arrest
6.51 years

Encke
3.3 years
Comet Orbital Periods

HALE-BOPP
4000 YEARS

HYAKUTAKE
40,000 YEARS

TEMPLE-TUTTLE
32.92 YEARS

WILD 2
6.39 YEARS
Teacher Lesson Plan
Adapted from Montana State University: http://btc.montana.edu/ceres/html/birthday/birthday1.htm#3

Overview
Students become familiar with lunar phases by locating and then graphing the Moon phase of their own birthdays. After listening and discussing lunar myths and legends, they create their own Birthday Moon Stories.

Learner Outcomes
The learner will:
- generate a birthday moon for his/her birth date this year and the previous year using various web sites
- classify his/her birthday moon and produce a "moon card" of his/her own birthday moon
- recognize and describe the patterns of the Moon's phases

Materials and Technology:
- Printer (preferably color)
- Moon phases website: Moon Phase Calculator shows the entire month, plus has previous months archived.
- Scissors, tape, glue, and small Post-it notes
- The following worksheets: Cut n’ Paste Worksheet #1
- Cut n’ Paste Worksheet #2
- Birthday Moon Bar Graph
- Vocabulary: Phases of the Moon
Procedures:

1. Familiarize students with the four phases and then the eight phases of the Moon. Have students cut out the different phases from the *Cut n' Paste Worksheet #1* and paste them on to the *Cut n' Paste Worksheet #2*.

2. Print out the moon phase calendar for the current month. The *Moon Phase Calculator* shows the entire month. Cut out each date, and pass one out to each student. Beginning with the full moon (you may have to tell them the date of the full moon), have students work together to sequence these cards according to the lunar phases.

3. Find out what the Moon looked like or will look like on each student's birthday. The site *Moon Phase Calculator* can also be used to find pictures of the Moon on these dates. The site shows each month from January 1951 to December 2015.

We make the following suggestions for use of this site with this activity:

- During the class, the teacher can go to the above site. Then, as each student gives his/her birthday, that date can be entered in, and the proper Moon picture generated. Each student then can record (by drawing) the Moon picture for his/her birthday.

- A computer lab may be useful for this portion of the activity. The teacher can demonstrate how to use the site, and then the students can work in groups to collect the data.

- If using an Internet hookup in the classroom, students could work in groups to use the site. Once one group has gathered all necessary data, another can start.

- If none of the above is possible, then the teacher can gather the information. Type in each birth date, get the picture, make a printed hardcopy of it, and pass those out the data to the students.

4. Have students print out what the Moon will look like or did look like on their birthdays this year.
5. Have each student draw a picture of his/her own birthday moon for this year on a Post-it note. Make sure the students put their names, birth dates, and identify their lunar phases on their Post-it notes.

6. Once the students have completed their birthday moon pictures, they should classify their picture according to the Phases of the Moon. Since most pictures won't come out to look exactly like the example pictures given on the Moon Graph, the students will have to decide which of the categories looks most like their pictures. Tell the students, "Go to the Moon Graph and place your Moon above the one on the graph that looks the most like yours."

7. Analyze the graphs by asking the students the following questions:

   How many pictures are in each phase?
   Which phase has the most pictures?
   Which phase has the least pictures?
   Which phase contains (student name)'s picture?
   Would you put any pictures in a different category (phase)? If yes, why?

8. Steps 4-7 should be repeated for students' birthdays for the previous year.

9. Have student's compare this year's and last year's pictures. Ask the following question:

   - Do you think that the Moon will look the same on your birthday next year? Why or why not?

   Have students go back to the web site and determine if their predictions were correct.
Extensions:

If time and technology is available, have students look at many birthday moons for different years to make more pattern comparisons and predictions. Start with how the Moon looked on the day they were born. The pictures and graphs created should be compared to show that the Moon would be different on their birthdays every year. Some of the questions above could be asked to allow students to make comparisons.

Connections to Language Arts:

Read about different Moon myths. This extension combines moon lore and the students' birthdays. Go to the Moon Xscape site and read the Moon lore concerning days after the Full Moon. From the same site, the students can enter in their birth dates and see what the Moon looked like on their birthdays (if they haven't done so already). Each student can determine if his/her birth date was close enough to a Full Moon to have some interesting Moon lore written about it. Now the students can write a story about his/her own birthday moon. Here are some more Moon Myths and samples of student Moon Myths.

Students can write a story about their birthday moon.
Cut n’ Paste Worksheet #1

<table>
<thead>
<tr>
<th>Moon Phase 1</th>
<th>Moon Phase 2</th>
<th>Moon Phase 3</th>
<th>Moon Phase 4</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Moon Image 1" /></td>
<td><img src="image2" alt="Moon Image 2" /></td>
<td><img src="image3" alt="Moon Image 3" /></td>
<td><img src="image4" alt="Moon Image 4" /></td>
</tr>
<tr>
<td><img src="image5" alt="Moon Image 5" /></td>
<td><img src="image6" alt="Moon Image 6" /></td>
<td><img src="image7" alt="Moon Image 7" /></td>
<td><img src="image8" alt="Moon Image 8" /></td>
</tr>
</tbody>
</table>
Phases of the Moon

There are also four other phases of the Moon sometimes used. They are as follows:

This is known as a Waxing Crescent Moon. This Moon can be seen after the New Moon, but before the First Quarter Moon. The crescent will grow larger and larger every day, until the Moon looks like the First Quarter Moon.

This Moon is known as a Waxing Gibbous Moon. This Moon can be seen after the First Quarter Moon, but before the Full Moon. The amount of the Moon that we can see will grow larger and larger every day. ("Waxing" means increasing, or growing larger.)

This Moon is called a Waning Gibbous Moon. This Moon can be seen after the Full Moon, but before the Last Quarter Moon. The amount of the Moon that we can see will grow smaller and smaller every day. ("Waning" means decreasing, or growing smaller.)

This Moon is called the Waning Crescent Moon. This Moon can be seen after the Last Quarter Moon and before the New Moon. The crescent will grow smaller and smaller every day, until the Moon looks like the New Moon.
<table>
<thead>
<tr>
<th>New Moon</th>
<th>Waxing Crescent</th>
<th>First Quarter</th>
<th>Waxing Gibbous</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Phase</th>
<th>Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full Moon</td>
<td>![Full Moon Image]</td>
</tr>
<tr>
<td>Waning Gibbous</td>
<td>![Waning Gibbous Image]</td>
</tr>
<tr>
<td>Last Quarter</td>
<td>![Last Quarter Image]</td>
</tr>
<tr>
<td>Waning Crescent</td>
<td>![Waning Crescent Image]</td>
</tr>
</tbody>
</table>
Teacher Lesson Plan

Adapted from NASA.gov:
http://solarsystem.nasa.gov/educ/docs/Make_A_Comet.pdf

Overview
Comets have sometimes been described as dirty snowballs, snowy dirtballs or something in between. What does that really mean? It means that these dirty snowballs are believed to be a cold mixture of frozen water, dry ice, and other sandy/rocky materials left over from the early formation of our solar system. In this activity, students will make a comet model that is edible. Students will trade “comet” and pretend to be a spectrometer. A spectrometer analyzes the structure and composition of comets by using nine different filters. Students will use their four senses individually to decide what is in the “comet”.

Learner Outcomes
The learner will come away with three important ideas:

- Comets are cold.
- Comets have debris from the early solar system.
- We still are not exactly sure what is in them or how they behave.

Background Information

- **A Comet’s Place in the Solar System:** A little history about where comets came from
- **Ten Important Comet Facts:** A quick review of comet facts
- **C-O-M-E-T-S:** A comet acrostic. Good for younger students or comet quick fact reference

Materials

*Note: Survey students ahead of time for any known allergies (milk, peanuts, etc).*

- Student Research Data Sheet
- Can opener
- Something to use to crush cookies and other additives
- Mop, sponges, towels
Supplies needed per group

- One sandwich size re-closable plastic bag per group
- One gallon size re-closable plastic bag per group
- Small cups for eating ice cream one for each person in the group and one extra cup per group for ice cream to feel
- Plastic spoons
- Ice (enough to fill a gallon size bag 1/2 full per group)
- Chunky cookies in black or brown, crushed candies (like toffee or peppermint), gummy bears, coconut flakes, and chocolate chips
- Whole milk (2% will not work)
- Sugar
- Vanilla extract
- Evaporated milk
- Salt

Supplies needed for a class of 20 (10 groups of 2)

- 3 to 4 cans of evaporated milk (12 fl oz each)
- 1 gallon of whole milk
- 20 cookies
- 1/4 lb of sugar
- 1 bag of coconut flakes
- 1 bag of chocolate chips
- 1 bottle of vanilla extract
- 10 sandwich size re-closable bags
- 10 gallon size re-closable bags
- 2 to 3 containers of table salt
- 20 plastic spoons
- 30 small cups
- ice
- other candies
**Classroom Management:**

1. Materials need to be purchased fresh and kept in store-bought containers.

2. Newspaper can be used to cover desks or work areas. A mop and sponge are very helpful for desks or floor areas where measuring is done. You may choose to pre-load cream bags and salt bags at home.

3. The ice needs to be either freshly bought or well frozen in storage. The container for transporting and storing the ice should be pre-cooled if possible or very efficient. If the ice has "warmed", it will be difficult to get the milk/cream to solidify.

4. If the students toss the bags back and forth or bang them against a surface while freezing the ice cream, they may break.

5. Bring dishtowels, cloths, oven mitts, or insulated work gloves to guard hands against discomfort while they are turning their bags over and over.

6. Limit the amount of any materials students put into their ice cream to one plastic spoonful so supplies last.

7. Mark your serving cups with sugar and salt measurements to pre-load bags faster. Mix all ingredients in class if you want your students to work on measurements.

**Procedures**

1. Familiarize the class with comets.

2. Have students wash their hands! You may choose to use food gloves.

3. Form small groups (groups of 2 preferably).

4. One student should hold the sandwich size bag while another pours ingredients into the bag.

5. Have the students pour the following ingredients into the sandwich size bag:
   - One-third cup evaporated milk (or cream)
   - Two-thirds cup whole milk
   - 5 level spoonfuls of sugar
   - Less than 1/4 tsp of vanilla
6. **Comet connection:** Discuss why the following ingredients should be added to the ice cream:
   - black/brown cookies in fine and large chunks to represent dust and rocks
   - peppermint, toffee, chocolate chips, or other candies to represent rocks
   - coconut flakes to represent carbon dioxide

7. Have the students begin to add some or all of the above ingredients. Make sure they are also adding some ingredients to represent what we might find in a comet. Possibilities are gummy bears (early organics for life?). **Remember to choose food that will not dissolve while the ice cream is setting.**

8. Have the students squeeze any extra air out of the sandwich bag and seal it. **Be sure it will not leak.** Have them turn it upside down to check.

9. Have the students place the sandwich bag into the bottom of the gallon bag. They should put in approximately 10 heaping spoonfuls of salt.

10. Have the students fill the gallon bag (containing the sandwich bag) at least 1/2 full of ice.

11. Have the students close the larger bag tightly to remove as much air as possible. They should check for leaks again.

12. Have the students gently shake and roll the bag while keeping it in constant motion for approximately 6 - 10 minutes or until half the bag has turned to water.

   **SUGGESTION:** Insulated gloves, mitts, towels or other thick fabric may be needed to hold the bag because it will get extremely cold. Start with bare hands so students can feel the temperature change.
13. Have the students gently feel the sandwich bag through the icy mixture. When the milk/sugar mixture in the sandwich bag has hardened into soft ice cream, they should carefully open the gallon bag and remove the sandwich bag containing the ice cream.

14. Have the students trade their “comet” with another group so the ingredients are a mystery. Each group should briefly rinse the outside of the sandwich bag they were given with fresh water before opening so that no salt flavor is transferred to the ice cream.

15. Have the students split the ice cream comet by spooning some into the cups provided. **Have the students make one extra cup and put it aside. They will not eat this one!**

16. Have each group complete the Student Research Data Sheet.

17. Have groups share the make up of their comets.
Student Research Data Sheet

A spectrometer collects data through different filters. Pretend you are a spectrometer and use your eyes, hands, nose, and taste buds as scientific instruments taking data from your “comet”. What can you discover about your ice cream “comet” using your sight, touch, smell and taste “filters”.

Look at the “comet”. What do you see?

Take the extra cup you laid aside and touch the contents with your fingers. What do you feel?

Smell the ice cream. What do you smell?

Taste the ice cream. What do you taste?

What is in this “comet”? What are the ingredients?

Go to the team who made the “comet”. Write down exactly what they added to their “comet”. Were you correct?

What does each ingredient represent in a real comet?
A Comet's Place in the Solar System

Our solar system has four rocky inner planets and four giant gas outer planets. In addition, there are other "small bodies" in the solar system. Comets make up a portion of those small bodies and contain a large percentage of ice since they come from a very cold area. Scientists aren't sure whether comets are more like snowy dirtballs or dirty snowballs depending on the amount of rocky debris mixed with the icy material. Comets seem to be found in two places: some far beyond the edge of the solar system called the Oort Cloud, and some beyond Neptune in a region called the Kuiper Belt. The Oort Cloud may contain a trillion icy comets. The Kuiper Belt comets replenish the population of short period comets (comets that orbit the Sun every 20 years or less).

Comets may be an important part of the recipe for making planets and may be material left over from solar system formation. Some comets may have crashed into forming planets adding to their water and rock, while other comets escaped to establish their own orbits around the Sun. Some believe that cometary material may have brought water to Earth through impacts.

The orbits of planets (called ecliptic) line up primarily on one plane like rings on a target. Comet orbits can be different from that of planets. They may arrive in the inner solar system from "above" or "below" the plane of the planets and they travel very far from the Sun. Sometimes, there is a stirring in the Oort Cloud, possibly from the gravity of nearby stars or dark matter bodies that pass through the cloud. That stirring can cause a comet to head from the Oort Cloud into the inner solar system.

The earliest observers who noticed comets in the sky could only learn from looking up just like a person looks at a picture of a comet in a book. Later, observers began to notice that comets moved from night to night in the sky based on their position against the stars. Using what they knew about math, they were able to begin tracking comet orbits. As technologies were developed, scientists could begin observing in a new way to discover the makeup of these icy bodies. Comets may have within them the last pristine clues to the beginning of solar system formation. Scientists want to find evidence of some of those early compounds deep within a comet's interior. Scientists believe the solar system may have formed in this way. As gas and dust swirled around the condensed Sun, molecules came together forming compounds. Water and carbon dioxide are two examples of volatiles/ices while olivine and CH-O-N molecules are dust or refractory compounds. Gravity brings the molecules together in clumps that eventually grow to larger and larger cometesimals. Rather than a solid ice cube, comets may be made of many smaller ice crystals with other organic molecules mixed in.
Ten Important Comet Facts

1. Comets are in orbit around the Sun as are our planets.

2. Comets are composed of ices, dust and rocky debris carried from the early formation of the solar system about 4.5 billion years ago.

3. Comets are remnants from the cold, outer regions of the solar system. They are generally thought to come from two areas - the Oort Cloud and the Kuiper Belt. Both of these are areas where materials left over from the formation of our solar system have condensed into icy objects. Both regions extend beyond the orbits of Neptune and Pluto but are still part of our solar system and much closer to us than the closest star.

4. Comet orbits are elliptical. This brings them close to the Sun and then takes them far away.

5. Short period comets orbit the Sun every 20 years or less. Long period comets orbit the Sun every 200 years or longer. Those comets with orbits in between are called Halley-type comets.

6. Comets have three parts: the nucleus, the coma and the tails. The nucleus is the solid center component made of ice, gas and rocky debris. The coma is the gas and dust atmosphere around the nucleus, which results when heat from the Sun warms the surface of the nucleus so that gas and dust spew forth in all directions and are driven from the comet's surface. The tails are formed when energy from the Sun turns the coma so that it flows around the nucleus and forms a fanned out tail behind it, extending millions of miles through space.

7. We see a comet's coma and tail because sunlight reflects off the dust (in the coma and dust tail) and because the energy from the Sun excites some molecules so that they glow and can form a bluish tail called an ion tail and/or a yellow one made of neutral sodium atoms.

8. Scientists have seen comets range in size from less than 1 km diameter to as much as 300 km, although the 300 km comet (called Chiron) does not travel into the inner solar system.

9. We know a comet could impact Earth and that it is important to understand the nature of comets so we can design better methods to protect ourselves from them should one be on a collision path with Earth.

10. A comet nucleus has a dark, sometimes mottled surface but we don't know if it has an outer crust or if it is layered inside. We don't really know what comets are like beneath their surface.
Comet Acrostic

C
COMETS ARE COLD AND Icy.
COMETS HAVE A COMA; BUT DO THEY HAVE A CRUST?

O
OORT CLOUD OR KUIPER BELT IS WHERE COMETS ARE FORMED.

M
MIDDLE CALLED A NUCLEUS
MILLIONS OF MILES OF TAIL

E
EARLY SOLAR SYSTEM IS WHEN COMETS BEGAN.
ELLiptical ORBITS ARE WHAT COMETS FOLLOW.

T
THREE TAILS (DUST, ION, AND NEUTRAL SODIUM) ARE WHAT MOST COMETS HAVE WHEN THEY TRAVEL CLOSE TO THE SUN.

S
SUN HEAT CAUSES THE COMA BACK TO FORM A TAIL.
SNOWY DIRTBALLS OR DIRTY SNOWBALLS?
Teacher Lesson Plan

Adapted from the following:

http://www.eduref.org/cgi-bin/printlessons.cgi/Virtual/Lessons/Science/Space_Sciences/SPA0016.html
http://www.obliquity.com/cgi-bin/bluemoon.cgi
http://www.obliquity.com/astro/bluemoon.html

Overview

A blue moon the second Full Moon to occur in a single calendar month. A blue moon occurs about once every two or three years. To calculate the next blue moon, go to http://www.obliquity.com/cgi-bin/bluemoon.cgi.

Learner Outcomes

The learner will:

- Understand what a blue moon is
- Understand moon features
- Create an art/writing about the moon’s features

Materials:

- white paper (8 1/2" x 11" (2 sheets per child)
- circle patterns (about 7" in diameter)
- white glue in squeeze bottles
- watercolors green, blue, and purple
- brushes
- pencils
- scissors
- Reference books and pictures about the moon
- book - "The Nightgown of the Sullen Moon"
- white glue stick
Procedures:

- Read the picture book, "The Nightgown of the Sullen Moon", in which the moon is painted in blues, greens, and purples. If this book is not available, choose another favorite book about the moon. Explain to the class that there is a full moon every month.

- Show the class a picture of a full moon from the story you read. Tell the class that occasionally a month will have two full moons and the second full moon is called a blue moon.

- Tell the class that they will be making an art/writing project about the moon.

- Tell the students you are going to demonstrate the art project.

- The teacher will place the circle pattern in the center of the white paper and trace around it with a pencil to make the outline of the moon.

- The teacher will draw five to seven crater outlines inside the moon outline.

- The teacher will trace the top of each crater with a heavy line of glue.

- Now students will be told to trace their own moon, create craters, and outline the craters in white glue.

- When everyone has completed the glue outlining and the glue is partially set, resume the demonstration.

The teacher will paint the inside of the craters first with a dark shade of one of the colors (blue, green, or purple).
ONCE IN A BLUE MOON

- Use watered-down solutions of the other two colors to wash across the face of the moon so it has a hazy appearance.

- Now let students complete their paintings in the same manner. When paintings are completely dry, they can be cut out along the outside line.

- Ask the students what they think the moon looks like.

- Now divide the class into small groups and assign each group to find several facts about the moon from resource books you provide. (Students may also be taken to the library to do research.)

- After research has been completed, ask the students what the moon really looks like.

- As students voice their research, write the descriptions on the board.

- When all ideas are on the board, direct the students to use the moon pattern to trace and cut out another circle of paper of the same size.

- Show them how to begin writing facts about the moon along the edge of the circle, turning the circle every few words and spiraling toward the center until they run out of facts or space.
Facts to include:

- The moon is smaller than the Earth.
- The moon has no light of its own, but reflects light from the sun.
- There is no air or water on the moon.
- The moon's surface is dusty and brown in color.
- There are many craters on the moon.

- Have the students use the glue sticks to glue the back of the watercolor moon to the back of the descriptive moon.

- Display the art and writing by hanging the moons from the ceiling.
Teacher Lesson Plan

Adapted from Mary Urquhart at
http://cosmos.colorado.edu/~urquhart/comet/scale_comet.html

Overview

Comets are similar to asteroids, but contain a high percentage of ices (including water ice). The solid nuclei are generally smaller than asteroids (on average only a few km in diameter). Like asteroids, they are left over bits from the formation of the planets. For a short time in each orbit around the Sun, comets may visit the inner solar system and be visible from the skies of Earth. As they approach the Sun, their character changes dramatically. The Scale Model Comet is a model of an active comet. A comet is active when it is near the Sun, and the ices in the nucleus have heated and sublimated to form a cloud of gas known as the coma. Together the nucleus and coma make the head of a comet. An active comet also has a tail (in fact it has more than one) that always points away from the Sun because of the light emitted by the Sun and the solar wind. The tail that is usually most visible from the Earth is the dust tail, which is white or slightly pink and made of smoke-sized particles. The second tail, the ion tail, is made of ionized gas and is slightly blue. For more information on comets see the Educators’ Comet Workshop. The scale factor for this Scale Model Comet is about 1 to 6 billion, so every meter in the model represents 6 billion meters in the real solar system.

Learner Outcomes

The learner will:

- Understand the components of an active comet
- Understand the scale of an active comet relative to the Earth

Materials

- A small paper plate (6-6 ½ inches)
- Cotton balls
- A pen
- Streamers (25 meters long)
  - One white streamer to represent the dust tail
  - One blue streamer to represent the ion tail
- A peppercorn, or small candy about the size of a peppercorn
Glue

Stapler

Meter stick or Measuring tape

Classroom Management

Although string or yarn can be used instead of streamers to cut costs, the streamers approximate the width of the comet tail as well as the length.

Don’t unwind the streamers outside on a windy day…they tear easily.

To let the student appreciate the true scale involved, have them spread out the tail to the full length in a large area (hallway, gym, or outside on a calm day) and compare with the “Earth” and possible the “Sun”. After the activity display the comets on the wall of your classroom.

The tails can be shorter and still be realistic…after all, comets do have shorter tails when they are farther from the Sun.

Procedures

If possible, let each student make his or her own “model comet.”

Take the paper plate and place a small dot in the center with a pen (as small as is visible). That dot represents the nucleus of the comet. The nucleus is about the size of a mountain or small group of mountains on the Earth (about 1-10 km across), and is actually too small to see at this scale.

Cover the rest of the front of the plate with cotton balls using the glue. The cotton represents the coma. (Suggestion, try pulling the cotton balls apart to make them “fluffy.”) The gas and dust particles that make up the coma all come from the tiny nucleus, and must be spread very, very far apart to fill the roughly spherical volume of the coma.
Scale Model Comet

Measure out the streamer to **25 meters**. For our scale model, 25 m represents 1 AU (150 million km or 93 million miles), which is the distance between the Earth and the Sun. The tail is typically 1-2 AU when a comet is 1 AU from the sun. The 25 meters representing 1 AU gives us our scale factor of 1 to 6 billion.

Attach the streamers to the plate with glue or tape. (Note: You can attach the streamers before gluing on the cotton balls.)

Compare your Scale Model Comet with the peppercorn (or candy) that represents the Earth. Although the nucleus is much smaller than the Earth (about the size of a mountain or group of mountains) the coma and tail are much larger than the Earth.

**Suggestion:** You can use another plate to represent the Sun. The sun on this scale is just over 9 inches in diameter, so a 10-inch dinner plate is approximately the correct size.

**Extension:**

Talk to the three parts of a comet (nucleus, coma, and tail).

Introduce the students to the idea of sublimation (how a comet is formed).

Introduce the students to Comet Halley.

**Adaptations for Younger Students**

Use the measuring as a math activity. Have the students figure out how many times they need to wrap the streamer around the meter or yardstick.

Just make one tail. Two tails might confuse them.
Don’t glue the peppercorn or candy to the comet for scale; it might lead young students to believe that the Earth orbits the Sun on a comet.

Very young students might enjoy using brightly colored streamers.

Display the model comets in your classroom.

**Additional Technology Activity**

Instruct students to go to the following website: http://amazing-space.stsci.edu/resources/explorations/

Scroll down and click on **Comets**.

Once in the “lab”, click on the blue comet mixer.

Students will be able to add several different ingredients to make their comet.

Once they have added their ingredients, they will click on **MIX**.

The students will then be able to see what their comet looks like, depending on the ingredients they added. They can also click the top button on the right to see their comet orbit the Sun in an elliptical path.
National Science Education Standards

Science As Inquiry

CONTENT STANDARD A:
As a result of activities in grades K-4, all students should develop

• Abilities necessary to do scientific inquiry
• Understanding about scientific inquiry

Physical Science

CONTENT STANDARD B:

POSITION AND MOTION OF OBJECTS

• An object's motion can be described by tracing and measuring its position over time.

Earth and Space Science

CONTENT STANDARD D:

OBJECTS IN THE SKY

• The sun, moon, stars, clouds, birds, and airplanes all have properties, locations, and movements that can be observed and described.

CHANGES IN THE EARTH AND SKY

• Objects in the sky have patterns of movement. The moon moves across the sky on a daily basis much like the sun. The observable shape of the moon changes from day to day in a cycle that lasts about a month.

History and Nature of Science

CONTENT STANDARD G:

• Science as a human endeavor
• Nature of science
• History of science
Science and Technology

CONTENT STANDARD E:

UNDERSTANDING ABOUT SCIENCE AND TECHNOLOGY

- People have always had questions about their world. Science is one way of answering questions and explaining the natural world.
- Women and men of all ages, backgrounds, and groups engage in a variety of scientific and technological work.
- Tools help scientists make better observations, measurements, and equipment for investigations. They help scientists see, measure, and do things that they could not otherwise see, measure, and do.

Unifying Concepts & Processes

- Systems, order, and organizations
- Evidence, models and explanation
- Change, constancy and measurement
- Form and function

Thematic Organizing Standards

- Personal Social Connection
- Nature and History of Science
- Unifying Concepts and Processes

Curriculum Content Standards

- Size, Scale and Properties of Solar System Objects
- Energy-Nature and Properties
STANDARD 9

GEOMETRY AND SPATIAL SENSE:
In grades K-4, the mathematics curriculum should include two- and three-dimensional geometry so that students can:

- describe, model, draw, and classify shapes;
- investigate and predict the results of combining, subdividing, and changing shapes;
- recognize and appreciate geometry in their world.

STANDARD 11

STATISTICS AND PROBABILITY:
In grades K-4, the mathematics curriculum should include experiences with data analysis and probability so that students can:

- collect, organize, and describe data;
- construct, read, and interpret displays of data.

STANDARD 13

 PATTERNS AND RELATIONSHIPS:
In grades K-4, the mathematics curriculum should include the study of patterns and relationships so that students can:

- recognize, describe, extend, and create a wide variety of patterns.
“The term "aeronautics" originated in France, and was derived from the Greek words for “air” and “to sail.”

JPL Website

JPL Stardust Homepage
http://stardust.jpl.nasa.gov/home/index.html

Comet Quest for Classroom
http://stardust.jpl.nasa.gov/classroom/cometkids.html

Classroom Activities
http://stardust.jpl.nasa.gov/classroom/kids.html

Teacher Classroom Comet Activities Guide
http://stardust.jpl.nasa.gov/classroom/guides.html
NASA FACT

Stardust traveled 2 billion miles to meet Comet Wild 2, and another 1 billion miles to get back home.

NASA FACT

A satellite is any object that travels around another object, such as the Earth around the sun, or the moon around the Earth. Man-made satellites are machines that are built here on Earth and then launched into space.

NASA FACT

In the early solar system, comets bombarded the planets repeatedly and often.

NASA FACT

In terms of distance from the sun, Stardust will travel all beyond Mars and over half the distance to Jupiter.

NASA FACT

The space object that struck Earth 65 million years ago, causing the dinosaurs to become extinct, may have been a comet.

NASA FACT

Columbia was the first Space Shuttle that traveled to Earth orbit and made the 100th flight in shuttle program history.

Program Information & Pricing

NASA FACT

During the comet flyby, giant 20 story tall antennas on Earth, called the Deep Space Network, will receive transmissions of pictures and other scientific data.
**NASA FACT**

Most of the elements found in the human body originated in stars; we are literally made of stardust.

**NASA FACT**

Did you know that to apply to be an astronaut a pilot must have completed 1000 hours of flying time in a jet aircraft?

**NASA FACT**

Can you hear in space? In theory, if there is nothing to receive the sound, there is no sound. Because there are no "air waves" in space to conduct the sound, it would not carry. So, the object would make a noise, but it would not carry to any receiver, and no one would hear it.

**CONTACT INFORMATION**

PHONE: 423.425.4126

FAX: 423.425.2190

WEB ADDRESS: WWW.UTC.EDU/OUTREACH/CHALLENGERCENTER

MAILING ADDRESS:
UTC CHALLENGER CENTER
DEPT. 6406
615 McCALLIE AVENUE
CHATTANOOGA, TN 37403

**NASA FACT**

Scientists hope to collect more than 100 particles from a newly discovered beam of particles streaming into our solar system from other stars in outer space.

**NASA FACT**

Comets have long amazed people. Since ancient times, myths of their origins and their effect on Earth have made us curious about them.

**NASA FACT**

Some of the powerful scientific instruments on Earth, used to study the cometary material, are more than 100 times larger and heavier than the spacecraft itself.
M I S S I O N S

A **Full Mission** is a 2 hour group simulation that includes Mission Control, being launched into space, and conducting research in the Space Lab.

Maximum **34 participants per mission**; 5th grade reading level required.

Mission preparation materials (standards-based lesson plans, hands-on activities, and other educational resources) are provided for each mission.

**Full Mission Price: $500.00**

A **Mini Mission** is a 1 hour simulation where crew members are launched into space and conduct research in the Space Lab. **10-18 participants.**

**Mini-Mission Price: $250.00**

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**Rendezvous With comet Halley**

It is the year 2061. An earth-orbiting space station moves towards Halley's Comet which last passed through our solar system in 1986 and will not return for another 76 years. During this mission, team members work as scientists and engineers who are headed to Rendezvous with a Comet as part of a continuing study of our Solar System. Their mission is critical in helping scientists verify and better understand data collected by earlier missions at the start of the new millennium, such as STARDUST’s capture of cometary material from comet Wild-2. The onboard astronauts, working with their counterparts in Mission Control, have two hours to rendezvous with the comet and launching a probe to intercept and collect new data.

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**Return to the Moon**

Answering the call of the 2020 Space Initiative for human exploration, the Return to the Moon mission begins with a spacecraft in Earth’s orbit and the Mission Control team monitoring the crew’s status. The crew aboard the spacecraft will leave Earth’s orbit and travel to the Moon. In this mission, our crew establishes a permanent lunar base that will serve as a staging area for further Solar System exploration. As the crew moves toward our closest neighbor, they will capture a stranded probe, repair and rebuild the probe and launch it to the Moon. Together, the crew will place their spaceship into lunar orbit and make the important decision of the location of the first permanent lunar base. A complete team effort is required for the ultimate challenge: a safe and successful lunar landing!

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**Voyage to Mars**

In Earth years, it is 2076, and a now routine Voyage to Mars has brought the latest human crew into Martian orbit. Control of the incoming flight has been transferred from Houston’s Mission Control to Mars Control at Chryse Station. The crew arriving from Earth on the Mars Transport Vehicle has been specially trained to replace the existing crew of astronauts, which has manned Mars Control for the past two years, and to continue their scientific explorations. The Mars Control team is charged with the selection of entry and departure trajectories before the landing and subsequent lift-off of the Mars Transport Vehicle can occur. The relief crew on the Mars Transport Vehicle is tasked with the launching of a probe to one of the Martian moons before they return to Earth. Both the relief crew and the planet-based crew will be under tight deadlines to gather important data and communicate information to the teams, the spacecraft, and the Mars base.
**E X T R A  V E N U E  A C T I V I T Y  P R O G R A M S**

**EVA** (Extra Venue Activity) 2 hours - Hands-on, investigative activities designed as companions to Full Missions which incorporate math and science related themes. EVA's are recommended to accommodate larger groups that require back to back missions.

**EVA Price:** $300.00

**Pop Rockets**
(Grade Level 3 - 7)
Students investigate Newton's Laws of Motion through the construction and launch of pop rockets. They see how the laws affect what happens to the rockets. **This EVA is designed to complement the Rendezvous with Comet Halley Mission.**

**Mars Rover**
(Grade Level 4 - 8)
Students use their creative skills to design and build their own Mars Rover. The engineering design teams follow a basic specification checklist to assign functions, determine mass and the overall cost of their Rover. **This EVA is designed to complement the Voyage to Mars Mission.**

**Moon Maneuvers**
(Grade Level 5 - 9)
Students explore the Lunar Landing sites of the Apollo astronauts. Students use a shaded relief map to investigate the different lunar landing sites, and learn about a variety of lunar surface features. Knowledge of the terrain will assist the team in planning a lunar excursion for their Lunar Rover Vehicle. Students will use map reading, graphing skills and problem solving to calculate the shortest trip time. **This EVA is designed to complement the Return to the Moon Mission.**
EMU (Extra Mobility Unit) Construction
(Grade Level 5-8)
Participants work on a team of five to construct the EMU using the large Quadros pieces. Each member of the team is assigned a unique role with specific guidelines for construction. The emphasis is on clear unambiguous verbal communication between team members. Students will give and follow verbal instructions to replicate the EMU. After construction is complete, students will determine the dimensions of the EMU by measuring length, width, diameter and radius using a meter stick. In addition, students will find the surface area and volume of the EMU by substituting values into mathematical formulas and performing the indicated operations.

Short Circuits
(Grade Level 4-8)
Students use graphing calculators and voltage probes to investigate circuits. The electrician specialist will collect and analyze voltage readings of batteries in series and parallel circuits.

Motion Pictures
(Grade Level 6-9)
Students use graphing calculators and motion sensors to investigate motion. The student Motion Specialist will graph their own motion, calculate motion velocity, and match distance vs. time graphs. The students will work with the latest in data collecting equipment while learning how to calculate slope and velocity. Maximum of 24 students.
*Special booking required
MICRONAUT DISCOVERY - Traveling 230 miles above the Earth’s surface aboard the International Space Station, the Discovery crew continues the mission of the largest scientific cooperative program in history. This elite team of scientists, engineers, and mathematicians will engage in unique research using a variety of hands-on experiments.

Our Micronaut Discovery program is designed for grades K through 2 (for non to beginning reading levels). This program divides students up into small groups and rotates the groups through our Discovery mission in the space simulator and the hands-on EVA activity(s) of your choice. All components of our program are hands-on, standards-based activities that are designed and led by our team of certified teachers.

1 Hour Micronaut Program – includes Mini Discovery Mission and one Micronaut EVA. Maximum is 36 participants—Divided into 2 groups up to 18 students each.

2 Hour Micronaut Program - includes Mini Discovery Mission and two Micronaut EVAs. Maximum is 54 participants—Divided into 3 groups up to 18 students each.

*For groups that are larger than 54, please inquire about available options. Call (423) 425-2191.*

Price:

1 hour Program: $300.00 Maximum is 36 Participants
2 hour Program: $400.00 Maximum is 54 Participants

Micronauts In Orbit

- Students learn about the different parts of a space shuttle launch—from liftoff to landing
- Students work in pairs to put shuttle launch sequence cards in order based upon what they learned
- Students will create a paper model of a space shuttle and learn about an astronaut’s daily routine in space

Micronaut Tech

- Students will learn about the uses of NanoSatellite technology in space
- Students will learn about orbiting objects and will discuss the day & night sky
- Students will work in pairs to build a NanoSatellite (NanoSat) with Geofix pieces

Micronauts to the Moon

- Students will learn how rockets take astronauts to the Moon and back— from liftoff to landing
- Students will work in pairs using sequence cards to show the correct order of a rocket’s liftoff & landing
- Students will count and identify different shapes and use those tangram shapes to construct a paper rocket

Space Fishing

- Students will use the numbered “fish” to create and solve number sentences
- Students will use manipulatives to observe, solve, and create number patterns and formulas

Planet Walk

- Students will learn important facts and characteristics of the planets in our solar system
- Students will discover the order of the planets and will practice putting them in order from the Sun
- Students will learn the relative size and distance of the planets
MICROCOMET - It is the year 2061. Traveling between Earth and Mars, the MicroComet crew is on a mission to locate Comet Halley. After locating the comet, this scientific team of explorers will launch a probe into the comet to discover the secrets of this ancient cosmic material.

Our MicroComet program is designed for grades 2 through 4 (for beginning to advanced reading levels). This program is a standards-based guided exploration the academic disciplines and standards into a fun learning experience. Students are divided into small groups which rotate through our Discovery mission in the space simulator and the hands-on EVA activity(s) of your choice.

1 Hour Micronaut Program – includes Mini Discovery Mission and one Micronaut EVA. Maximum is 36 participants—Divided into 2 groups up to 18 students each.

2 Hour Micronaut Program - includes Mini Discovery Mission and two Micronaut EVAs. Maximum is 54 participants—Divided into 3 groups up to 18 students each.

*For groups that are larger than 54, please inquire about available options. Call (423) 425-2191.*

**Price:**

1 hour Program: $300.00    Maximum 36 Participants
2 hour Program: $400.00    Maximum 54 Participants

**Micronaut EVAs**

**Micronaut Tech**

- Students will learn about the uses of NanoSatellite technology in space
- Students will learn about orbiting and will discuss the day & night sky
- Students will build an origami NanoSatellite (NanoSat) by folding colored paper

**Telescope Tech**

- Students will explore the concepts of reflection and refraction and discuss their differences.
- Students will learn about the different parts of a telescope.
- Students will use a refracting telescope to observe distant objects. (For an additional cost, students can construct telescopes to take home.)

**Moon Phases**

- Students will investigate the sun, earth, and the moon and their interactions with each other.
- Students will learn the eight moon phases and will model and discuss each phase.

**MicroRockets**

- Students will build and launch a MicroRocket.
- Students will organize the rockets’ launch results using a bar graph.
- Students will read and interpret the results of the bar graph.

**Troubled Ladder**

- Students will use fraction building blocks to build a staircase for a stranded lander
- Students will identify, compare, and place fractions in order using manipulatives
- Students will determine patterns between fractions and will complete fraction problems
An Astronomy-based physical science curriculum developed at the Harvard-Smithsonian Center for Astrophysics focusing on how nature behaves and the development of models to explore that behavior. This discovery-based hands on science curriculum addresses the developmental levels of grades 3 through 8, is correlated to State and National Science Standards and provides the basis for a complete physical science program. The pedagogical explorations lead students in the construction and reconstruction of basic science concepts. Curriculum connections are in each module. Upon completion of the workshop participants receive: The Teacher’s Manual, 30 Student Journals and a complete Apparatus Bin. The separate modules of study are listed below.

Exploring Time

Exploring Earth in Motion

Exploring Moon and Stars

Exploring Light and Color

Exploring Motion and Forces

Exploring Energy

Exploring Waves

Exploring Navigation

Place: Challenger Center at UTC

Time: 8:30 AM to 3:00 PM

For special arrangements or a workshop at your location call 423-425-2284. Please note prices may vary.
Join us this summer for an experience that’s out of this world!

The Cosmic Space Quests at the Challenger Center provide for students in grades Pre-K through 8. We offer 4 different camps: 1/2 Day Mini-Quest, 1 Day Quest, 2 Day Quest, and 4 Day Quest. Each camp addresses a particular grade level, so we can best meet the needs of the “Camp Specialists.” Our camps engage the Specialists intellectually by stimulating their interest in space through science and mathematics. As Camp Specialists learn to problem solve and work in teams, they will achieve camp success!

1-Day Future Astronaut Training
Astronauts in 1st-3rd grade
9:00 am—4:00 pm
June 2, June 15, July 8,
July 13, or July 27

2-Day Exploring Satellites
Astronauts in 3rd-5th grade
9:00 am—4:00 pm
June 3 & 4, June 16 & 17, June 28 & 29, July 6 & 7, or July 14 & 15

Quest Price: $100

4-Day Aviation: Above & Beyond
Astronauts in 5th-8th grade
9:00 am—4:00 pm
June 7-10, June 21-24,
or July 20-23

Quest Price: $250 (Lunch included)

½-Day Mini Quest
4 & 5 year old astronauts
9:00 am—12:00 pm
June 14, June 18, July 9,
July 12, or July 28

Quest Price: $35
(Snack included)

Registration begins
February 1, 2012
For more information, visit our website
www.utc.edu/ChallengerCenter

The above Quests are intended for rising grades.
Discovering Space with Micronauts uses the allure of the International Space Station to transport students through an interdisciplinary content curriculum. This one-day workshop is designed for elementary teachers grades K through 3. It will demonstrate through hands-on activities, different strategies to incorporate math, science, social studies, language arts, technology, and performing arts standards using a space theme.

**Important Content:**

**Science**
- Science as inquiry
- Objects in the sky
- Making and using models
- Technology design
- Science as a human endeavor
- Properties of objects and material
- Characteristics of organisms

**Language Arts**
- Reading to learn in a variety of content areas
- Creative skills for writing

**Performing Arts**
- Improvise a melody

**Mathematics**
- Understanding patterns, relations and functions
- Apply transformations and use symmetry to analyze mathematical situations
- Spatial reasoning and geometric modeling

**Social Studies**
- Geography—understand and appreciate relationships between people, places, and environments.

**Participants receive:**

- The Micronaut Teacher’s Guide and CD (11 different lessons correlated to National and TN standards)
- Jumbo Bug Card Templates for Bug-go
- ISS Color Lithograph
- 1 Large Color ISS Poster
- Inflatable Earth Globe

**Place:** Challenger Center at UTC

**Time:** 8:30 AM to 3:00 PM

For special arrangements or a workshop at your location call 423-425-2284. Please note prices may vary.
Plan for next year!

Complete the appropriate Inquiry Form and mail or fax back to us!
Challenger Center
The University of Tennessee at Chattanooga
Phone: 423.425.4126 • Fax: 423.425.2190

MISSION INQUIRY

School/Group Name ________________________________________________________________

Address ________________________________________________________________

Contact Person(s) _____________________________________________________________

Telephone: ____________________________ Best Time to Call: ____________________________

Email address: ________________________________________________________________

Is your school interested in a Teacher Professional Development Mission Workshop?
Yes ☐ No ☐

Full Missions: ☐ Rendezvous with a Comet ☐ Voyage to Mars ☐ Return to Moon

Mini Missions: ☐ Mini Comet ☐ Mini Mars ☐ Mini Moon

EVA’s: ☐ Pop Rockets ☐ Mars Rover ☐ Moon Maneuvers
☐ EMU ☐ Short Circuit ☐ Motion Pictures ☐ None

Mission Date(s): _______________________________________________________________

#Missions __________ #EVAs __________ Total # of Students __________

#Students per mission (34 max) __________ Grade(s) __________ Ages __________

Mission Start Time _______________ Departure Time _______________

Lunch: ☐ Brown Bag-30 minutes ☐ University Center-1hr ☐ Delivery-1hr ☐ None

Are students reading on grade level? Yes ☐ No ☐

Special Information________________________________________________________________

Students with Disability(s) _______________________________________________________

I have reviewed the reservation and coordinating materials, and I confirm at this time this information is accurate to the best of my knowledge. I will notify the Challenger Center of any changes to our reservations.

__________________________________                   __________________________________
Principal’s Signature                           Lead Teacher’s Signature             Date
Micronaut Program Inquiry

School/Group Name: ________________________________

Address: ______________________________________

Contact Person: __________________________ Telephone: __________________________

Email address: __________________________________

Is your school interested in a Teacher Professional Development Workshop? Yes No

Micronaut Program Selection:

- **2 hr Block** Mini Discovery Mission + 2 Micronaut EVAs of your choice,
  Maximum 54 students - 3 groups of up to 18 students

- **1 hr Block** - Mini Discovery Mission + 1 Micronaut EVA of your choice
  Maximum 36 students- 2 groups of up to 18 students

Micronaut Program Date(s)___________________________________________________________

#Total Students _______ Total # of Chaperones _______ Grade(s)_______ Ages _______

Start Time ________________ Departure Time ________________

Lunch:  □ Brown Bag-30 minutes  □ University Center-1hr  □ Delivery-1hr  □ None

Are students reading? Yes No

Special Information______________________________________________________________

Students with Disability(s)______________________________________________________

I have reviewed the reservation and coordinating materials, and I confirm at this time this information is accurate to the best of my knowledge. I will notify the Challenger Center of any changes to our reservations.

____________________________________    ______________________________________
Principal’s Signature                  Lead Teacher’s Signature         Date
MicroComet Program Inquiry

School/Group Name: ____________________________________________

Address: ______________________________________________________

Street
City
State
ZIP

Contact Person: __________________________________________ Telephone: ________________________

Email address: ________________________________________________

Is your school interested in a Teacher Professional Development Workshop? Yes No

Micronaut Program Selection:

☐ 2 hr Block  MicroComet Mission + 2 MicroComet EVAs of your choice

Maximum 54 students - 3 groups of up to 18 students

* 1 Mini Discovery manifest is required for each group of students

☐ 1 hr Block -  MicroComet Mission + 1 MicroComet EVA of your choice

Maximum 36 students - 2 groups of up to 18 students

* 1 Mini Discovery manifest is required for each group of students

Micronaut Program Date(s): ____________________________________

#Total Students ________ Total # of Chaperones _______ Grade(s)______ Ages ______

Start Time ____________________  Departure Time ____________________

Lunch:  ☐ Brown Bag-30 minutes ☐ University Center-1hr ☐ Delivery-1hr ☐ None

Are students reading on grade level? Yes No

Special Information______________________________________________________________

Students with Disability(s)_______________________________________________________

I have reviewed the reservation and coordinating materials, and I confirm at this time this information is accurate to the best of my knowledge. I will notify the Challenger Center of any changes to our reservations.

________________________________________  _________________________________

Signature of Principal  Lead Teacher’s Signature
Directions

To the Challenger Learning Center at
The University of Tennessee at Chattanooga
855 East Fifth Street • Chattanooga, TN 37403 • 423-425-4126
www.utc.edu/Outreach/Challenger Center

From Atlanta to The Challenger Center:
~ Take I-75 North to Chattanooga. Exit I-24 West (Chattanooga).
~ Exit Highway 27 North (to Downtown Chattanooga). Take exit 1C (4th Street Exit).
~ Go to 4th Street Directions at the bottom of the page

From Knoxville to The Challenger Center:
~ Take I-75 South exit I-24 West (Birmingham/Chattanooga).
~ Exit Highway 27 North to Downtown Chattanooga. Take exit 1C (4th Street exit).
~ Go to 4th Street directions at the bottom of the page

From Nashville to The Challenger Center:
~ Take I-24 East to Chattanooga. Exit Highway 27 North to Downtown Chattanooga.
~ Take exit 1C (4th Street exit).
~ Go to 4th Street directions at the bottom of the page.

From Birmingham to The Challenger Center:
~ Take I-59 North to exit I-24 East to Chattanooga.
~ Exit Highway 27 North to Downtown Chattanooga. Take exit 1C (4th Street Exit)
~ Go to 4th Street exit at the bottom of the page.

4th Street Directions:
After entering 4th Street, stay in the middle lane. You will pass UTC McKenzie Arena at the bottom of the hill on the right. Get into the right-hand lane. 4th Street merges with 3rd Street (keep right). You will pass a cemetery on the right and The Chattanooga School for Arts and Sciences on the left. Make a right onto Palmetto Street. The Challenger Center is the first building on the right. If you have problems, please call (423) 425-4126.
FOR MORE INFORMATION
CONTACT US AT: 423.425.4126
FAX US AT: 423.425.2190
EMAIL: ELLIE-WALLIS@UTC.EDU

COMET HYAKUTAKE

CHECK OUT OUR WEBSITE AT:
WWW.UTC.EDU/OUTREACH/CHALLENGERCENTER