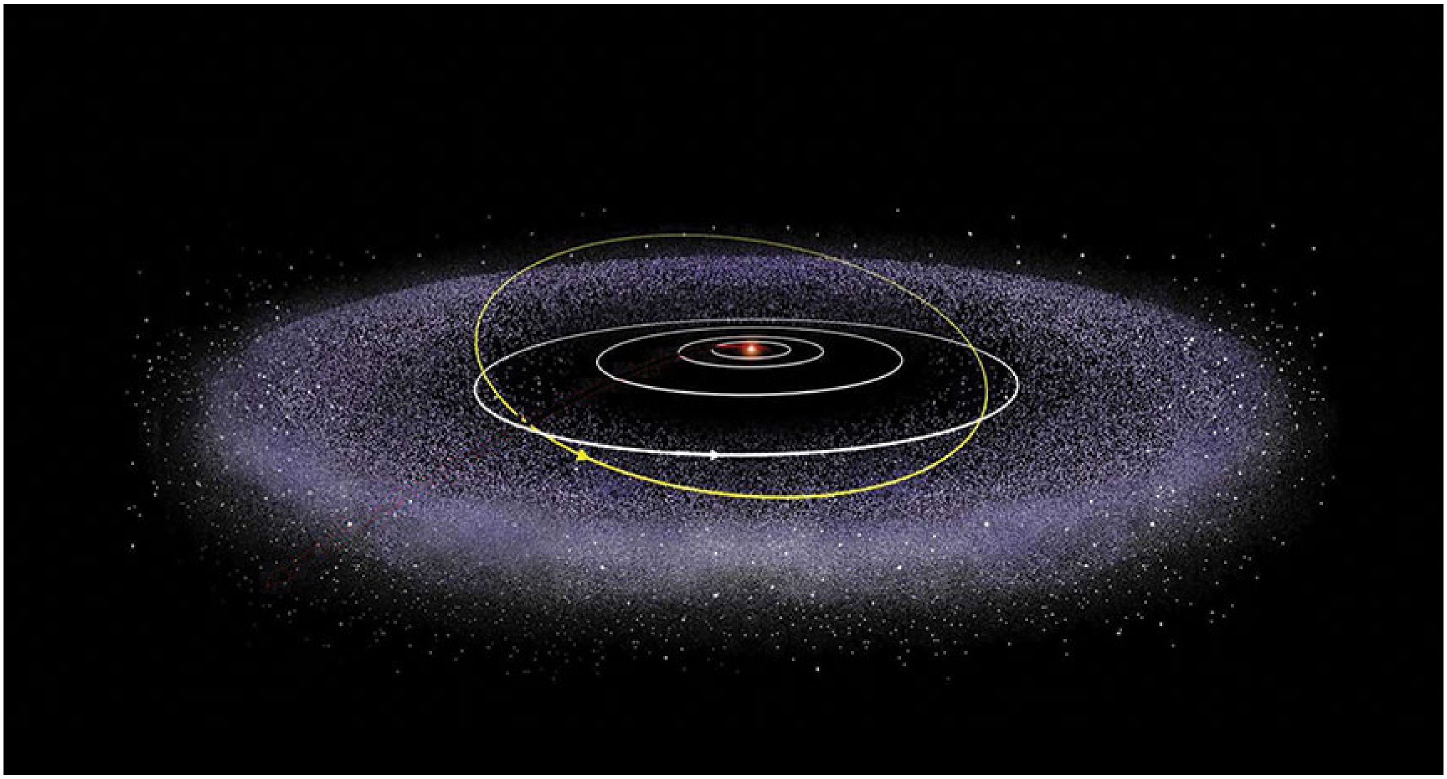
Science News
EDUCATOR GUIDE



NASA

April 27, 2019

Kuiper Belt Dust May Be Sprinkled in Our Atmosphere

SOCIETY FOR SCIENCE & THE PUBLIC

SN EDUCATOR GUIDE

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Kuiper Belt Dust

About this Guide

An estimated 40,000 tons of space dust settle in Earth's stratosphere every year. Scientists have long thought these particles come from comets and asteroids closer to the sun than to Jupiter. But new research, reported in "Kuiper belt dust may be sprinkled in our atmosphere," suggests that some of the particles might have a much more distant source. This Guide asks students to read and report on the article, to put astronomical scales in context and to think about how scientists study phenomena that are distant in space or time. The activity encourages students to analyze data, make graphs and do original calculations based on those graphs.

This Guide includes:

Article-based observation, Q&A — Students will answer questions based on the *Science News* article "Kuiper belt dust may be sprinkled in our atmosphere," Readability: 10.1. Questions ask students to extract information from text and images, evaluate evidence, consider scale and report on scientific tools and their usefulness. Another version of the article, "Some dust in Earth's atmosphere may hail from beyond Neptune," Readability: 7.4, appears on *Science News for Students.*

> **Article-based observations, questions only** — These questions are formatted so it's easy to print them out as a worksheet.

Cross-curricular connections, teacher guide — The discussion prompts provided ask students to put the grand scale of the solar system and universe into context by making comparisons and coming up with analogies. Then, students are encouraged to think about how astronomers and other scientists study phenomena that are distant in space and time, and the challenges associated with each.

Activity: Dusty Data Dive

> **Purpose:** Students will practice analyzing and graphing data using two data tables from a primary research study about space dust. The activity will help students understand why scientists are rethinking where some of the space dust in the atmosphere comes from.
>
> **Approximate class time:** 1 class period to complete the activity questions, calculations and graphing.

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Standards

Next Generation Science	Common Core ELA
Earth's Place in the Universe: HS-ESS1-4	Reading Informational Text (RI): 1, 2, 4, 5, 7
Engineering Design: HS-ETS1-1, HS-ETS1-2, HS-ETS1-3	Writing (W): 1, 2, 3, 4, 6, 7, 8, 9
	Speaking and Listening (SL): 1, 2, 4, 5, 6
	Reading for Literacy in Science and Technical Subjects (RST): 1, 2, 3, 4, 5, 7, 8, 9
	Writing Literacy in History/Social Studies and Science and Technical Subjects (WHST): 1, 2, 4, 7, 8, 9

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Article-Based Observation, Q&A

Directions: After students read the article "Kuiper belt dust may be sprinkled in our atmosphere," have them answer the questions below.

1. Based on the text of the article, where is the Kuiper Belt? Can you infer any additional information about the Kuiper Belt's location from the image that accompanies the article?

The Kuiper Belt is located beyond Neptune's orbit. The image suggests that the Kuiper Belt rings our solar system and passes through Pluto's orbit.

2. What evidence from the Kuiper Belt do scientists think they have found here at Earth?

Scientists think that some grains of dust collected from Earth's stratosphere might have originated from the Kuiper Belt.

3. How do scientists try to determine the original home of a dust grain from space?

Grains of space dust have microscopic tracks where heavy charged particles from solar flares have punched through. More tracks suggest that a grain has wandered through space for longer and thus probably originated farther from Earth.

4. What other object from space did scientists use in the study? What data were known that made the object useful and why?

A moon rock collected during one of the Apollo missions provided a sample with a known age and known track density, allowing scientists to have a reference measurement of how many tracks a typical grain picks up per year.

5. Name at least two scientific tools mentioned in the article and explain what they were used for.

Scientists have used balloons and aircraft to collect dust samples from the stratosphere.
Scientists used an electron microscope to look for microscopic tracks in dust grains from space.

6. Why do the scientists' measurements of the rate at which dust grains pick up tracks differ from previous measurements? How do the old and new rate compare?

The last track rate measurements were made in 1975 with instruments that are less precise than today's instruments. The new rate is about one-twentieth of the old rate.

7. Name one large and one small measurement given in the article. Explain what these are measurements of, and why they are so different in scale.

One possible student response: 10 million years is the approximate amount of time it would take for space dust from the Kuiper Belt to reach Earth. The amount of time is so large because the Kuiper Belt is so far from Earth.

A few tens of micrometers is the approximate width of some dust grains from space. These dust particles are microscopic.

8. Why do you think this article has the label "RETHINK"?

Scientists had thought that some dust particles in Earth's stratosphere came from comets and asteroids between Jupiter's orbit and the sun, but it now appears that a portion of that dust may have come from the more-distant Kuiper Belt. Scientists are rethinking their understanding of the source of this dust.

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Article-Based Observation, Q

Directions: Read the article "Kuiper belt dust may be sprinkled in our atmosphere" and answer the questions below.

1. Based on the text of the article, where is the Kuiper Belt? Can you infer any additional information about the Kuiper Belt's location from the image that accompanies the article?

2. What evidence from the Kuiper Belt do scientists think they have found here at Earth?

3. How do scientists try to determine the original home of a dust grain from space?

4. What other object from space did scientists use in the study? What data were known that made the object useful and why?

5. Name at least two scientific tools mentioned in the article and explain what they were used for.

6. Why do the scientists' measurements of the rate at which dust grains pick up tracks differ from previous measurements? How do the old and new rate compare?

7. Name one large and one small measurement given in the article. Explain what these are measurements of, and why they are so different in scale.

8. Why do you think this article has the label "RETHINK"?

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Cross-Curricular Connections, teacher guide

Directions for teachers: After students have had a chance to read "Kuiper belt dust may be sprinkled in our atmosphere," use these discussion prompts to help your class think about the scale of the solar system and universe — and how scientists study phenomena that are hard to reach in space or very distant in time. If you include the bonus prompts listed under No. 1 and No. 2 below, be sure to give students time to do rough calculations, using pencil and paper or a calculator as necessary.

1. Kuiper Belt Distance in Context

The Kuiper Belt extends from roughly 30 astronomical units (4.5 billion kilometers) to 55 astronomical units (8 billion kilometers) from the sun. It's challenging to fathom such immense distances, but we can try. Ask your students to call out known distances that might be more familiar. What about distances that might be comparable? How do these distances compare with the distance to the Kuiper Belt? How do these distances compare with the width of the Kuiper Belt? (Note that the Kuiper Belt's width is an impressive two-thirds the distance from the sun.) Which of your comparisons are most helpful in imagining great distances and why?

Here are a handful of distances that students might consider:
Length of an American football field, ~0.1 kilometers
Height at which planes fly, ~10 kilometers
Earth's circumference, ~40,000 kilometers
Distance from Earth to the moon, ~380,000 kilometers
Average distance from Earth to Mars, ~225 million kilometers

Bonus prompt: Another way to imagine distance is to think about hypothetical travel time (ignoring for these purposes, the logistics of fuel and the potential hazards of space travel). Give students time to calculate how long it would take to get to the Kuiper Belt and other astronomical destinations they might mention assuming travel by car (100 kilometers per hour), space shuttle (28,000 kilometers per hour) or at the speed of the Voyager probes (56,000 kilometers per hour).

2. Our Galaxy and Universe

Of course, the Kuiper Belt is still within our solar system; the sun's influence extends roughly 120 astronomical units (18 billion kilometers). Without using additional resources, ask students to predict how close the nearest star other than the sun is? What about the nearest spiral galaxy? How do those distances compare to the distance to the Kuiper Belt? What about the width of the observable universe?

The nearest star other than the sun, the binary pair known as Alpha Centauri, is ~40 trillion kilometers (4.0×10^{13}) from Earth. The nearest galaxy (that is not a smaller, companion galaxy) is the Andromeda Galaxy at ~24 billion billion kilometers from Earth (2.4×10^{19}). The diameter of the observable universe is thought to be 880 billion trillion kilometers (8.8×10^{23}).

Bonus prompt: Ask students to make an analogy that expresses two of these astronomical distances in terms of two more familiar distances. For example: If the distance from Earth to the Kuiper Belt were the length of a football field, the distance from Earth to the nearest galaxy would be…? Students can use pencil and paper or calculators depending on how rigorous you'd like the answer to be.

3. Approaches to Studying Astronomy

The article "Kuiper belt dust may be sprinkled in our atmosphere" describes one way that scientists are studying astronomically distant realms — by studying debris that might travel from there to here. Apart from space rocks and dust that arrive at Earth, how else can astronomers explore places that are too distant to visit in person? Encourage students to draw on examples they might have heard of and to use their own logic. What kind of information can astronomers glean through each of these approaches? What are the benefits and what are the limitations?

The most obvious answer is that astronomers use visible light and other forms of electromagnetic radiation to study these distant places. Students might also know that researchers are monitoring gravitational waves, or ripples in spacetime (see Making Waves Educator Guide). And we have sent some probes to distant reaches of the solar system, including the Voyager probes, which have traveled to the edge.

4. Beyond Astronomy

In what other fields of science do researchers study distant, hard-to-reach phenomena? What makes it hard for researchers to study these phenomena directly? What approaches and technology do researchers use and what challenges do they face? How is the work similar to or different from that of astronomers studying the distant reaches of the solar system, galaxy or universe?

Students might point to deep-sea explorers who use tidal motion to make inferences about ocean depth, sounding weights to collect samples, sound waves, seismographs and crewed and autonomous submersibles. Or, students might think of geologists who use seismic waves and cores to study the structure of the Earth's interior. Doctors use probes and scopes to see inside the human body, and researchers are exploring how to deliver drugs using nanotechnology. Computer simulations are also helpful in trying to understand distant and unreachable phenomena. To study Earth's upper atmosphere, scientists use balloons carrying specialized instruments, as well as planes. And scientists use lidar to try to understand inaccessible forested environments from above.

5. Drawing Parallels to Distant Times

Ask students what parallels they can draw between the efforts, techniques and experiences of scientists studying distant reaches in space to those who study the ancient past. Encourage students to use specific examples in their brainstorming. Is studying faraway places easier or harder than studying the distant past and why? Are students more interested in one or the other and why?

Archaeologists, paleontologists and paleoclimatologists all use records found in or on Earth to try to reconstruct the past. Archaeologists examine artifacts to try to understand how people lived, while paleontologists use fossils to study the evolution of other life-forms. Paleoclimatologists want to understand *current and future climate by studying fossils, tree rings, ice cores, how sediments have built up overtime, and so on. Students should consider that any scientific field interested in how things are in the present can benefit from a deeper understanding of how things were in the distant past.*

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Activity Guide for Teachers: Dusty Data Dive

Purpose: Students will practice analyzing and graphing data using two data tables from a primary research study about space dust. The activity will help students understand why scientists are rethinking where some of the space dust in the atmosphere comes from.

Procedural overview: After reading the *Science News* article "Kuiper Belt dust may be sprinkled in our atmosphere" and completing the accompanying Article-Based Observation questions, students will use the data provided to generate graphs and estimate track densities for dust grains traveling various distances.

Approximate class time: 1 class period to complete the activity questions, calculations and graphing.

Supplies:
Dusty Data Dive student activity guide
Calculators
Graph paper or computers with graphing software
Online access to research information about the solar system
A projector for introducing the activity (optional)

Directions for teachers:

To understand the general concepts behind the data being analyzed, students should read the *Science News* article "Kuiper Belt dust may be sprinkled in our atmosphere" and answer the accompanying Article-Based Observation questions prior to engaging in this activity. Reviewing the answers to the Article-Based Observation questions with students would help them understand the data they are analyzing. If you have time, or some students finish early and need an extra challenge, there is a set of bonus questions about the rate at which dust grains accumulate tracks.

If a projector is available, open "Kuiper Belt dust may be sprinkled in our atmosphere" so students can view the article on the screen, show students where the citations are listed at the end of the article, click on the primary research study "A Kuiper Belt source for solar flare track-rich interplanetary dust particles" and scroll to the data tables on the second page. Students can see that the data they will be working with is directly from the primary research study without having to read the research paper. If a projector is not available, explain and show students the data source.

Discuss the following questions and answers with your students before allowing them to engage with the data on their own.

Based on the *Science News* article "Kuiper Belt dust may be sprinkled in our atmosphere," how could the new dust grain findings affect what scientists currently think about the Kuiper Belt?

The track numbers observed on some dust grains collected from Earth's atmosphere are much higher than expected from grains that originated between Mars and Jupiter. That suggests that these grains must have traveled farther in space, possibly from as far away as the Kuiper Belt, or been exposed to more heavy charged particles in some other way. If the grains are in fact from the Kuiper Belt, that could call into question what scientists thought about the existence of liquid water in the Kuiper Belt.

How does the distance a dust grain travels affect the number of tracks on the grain? What else might affect track grain numbers?

Grains that originated farther away take more time to reach Earth's atmosphere, so the grains would spend more time exposed to heavy charged particles and thus accumulate more tracks. There are more heavy charged particles from solar flares closer to the sun, so grains that originate closer to the sun would accumulate more tracks faster than grains that originated farther away from the sun.

What data does Table 1 present?

The first column of the table lists 14 samples of dust grains, also called interplanetary dust particles (IDPs), collected from Earth's atmosphere. The 10 samples without stars are anhydrous. That means they do not contain water. The four samples with stars are hydrated — they do contain water. Information on water content is provided in case it affects the density of tracks an IDP collects over time. The table's second column gives the measured track density, or the number of tracks per unit area (tracks/centimeter^2) for each grain. The table's third column indicates what type of mineral each grain is made of: "pyx" is pyroxene (often a black mineral like augite), "Ol" is olivine (generally a green mineral like peridot gemstones) and "An" is anorthite (generally a white mineral in the feldspar family).

What data does Table 2 present?

Data presented in Table 2 are based on computer models. Table 2 gives the expected track density, or number of tracks/cm^2, for dust grains that have traveled from different initial distances to reach Earth at 1 astronomical unit, or AU. The table gives this information for two models that differ in their assumptions about how the rate at which grains accumulate tracks changes with distance from the sun and their assumptions about how long it takes dust grains from various parts of the solar system to reach Earth.

Directions for students:

After reviewing the general information about the data below with your teacher, look at Tables 1 and 2 and use them to answer the following questions. When needed, use an additional resource to find background information.

Table 1:

IDP #	Track Density Measured (Tracks/cm^2)	Type of Mineral
1*	6×10^{10}	pyx
2	8×10^{10}	Ol
3	6×10^{10}	An
4	10×10^{10}	pyx

5	7 x 10^{10}	An
6	3 x 10^{10}	pyx
7	8 x 10^{10}	pyx
8	3 x 10^{10}	pyx
9	5 x 10^{10}	pyx
10*	7 x 10^{10}	pyx
11*	50 x 10^{10}	pyx, Ol
12	6 x 10^{10}	pyx
13	2 x 10^{10}	pyx
14*	6 x 10^{10}	pyx

Table 2:

Initial Distance of IDP from the sun (AU)	Estimated Track Density Computer Model 1 (Tracks/cm²)	Estimated Track Density Computer Model 2 (Tracks/cm²)
50	6.2 x 10^9	12.6 x 10^9
40	5.4 x 10^9	10.6 x 10^9
30	4.6 x 10^9	8.4 x 10^9
20	3.6 x 10^9	6.0 x 10^9
10	2.2 x 10^9	3.2 x 10^9
5	1.2 x 10^9	1.6 x 10^9
3	0.8 x 10^9	0.8 x 10^9

Background questions

1. Study the first column of Table 2. What does AU stand for and what does it measure? Convert 1 AU to two different units of measurement.

AU stands for astronomical unit. It is a unit of measurement for distance, and is defined as the average distance from sun to Earth. 1 AU is approximately 1.50 x 10^6 kilometers or 9.30 x 10^7 miles.

2. What are the approximate distances of the following objects from the sun in AU?

Mercury	*0.39 AU*
Earth	*1.0 AU*
Asteroid belt	*2.1–3.3 AU*
Uranus	*19 AU*
Kuiper Belt	*30–50 AU*

3. According to the primary research study, dust from the asteroid belt would reach Earth in about 6 x 10^4 years, and dust from the Kuiper Belt would reach Earth in about 1 x 10^7 years. Use this information, Table 2 and your answer to the previous question to answer the following questions.

Approximately how many times further does dust from the asteroid belt need to travel to reach Earth compared with dust from the Kuiper Belt?

Assuming 3 AU as the distance, dust from the asteroid belt travels 2 AU (from 3 AU to 1 AU) to reach Earth. Assuming 30 AU as the distance, dust from the Kuiper Belt travels 29 AU (from 30 AU to 1 AU) to reach Earth, or about 14.5 times as far as dust from the asteroid belt.

Approximately how many times longer does it take for dust from the asteroid belt to travel to Earth compared with dust from the Kuiper Belt?

Dust from the asteroid belt arrives after about 6×10^4 years, or 60,000 years. Dust from the Kuiper Belt arrives after about 1×10^7 years, or 10 million years. Kuiper Belt dust takes roughly 170 times as long to reach Earth as dust from the asteroid belt.

How does the travel time appear to relate to the distance traveled?

Travel time appears to increase roughly like the square of the distance traveled.

4. How does your final answer to question 3 relate to the simple equation for diffusion? In simple diffusion problems, the distance a grain travels (L) depends on a diffusion constant (D) and the time (t) the grain has been traveling: $L^2 = Dt$, or $t = L^2/D$.

In this case, dust traveling or diffusing through the solar system seems to obey the equation for simple diffusion — the travel time increases approximately as the square of the distance.

5. What is a benefit and a drawback of applying the simple equation for diffusion to try to understand how space dust travels?

The diffusion equation is much easier to use than other equations that include complicated trajectories and gravitational interactions. But the simple equation might not yield precise results because they ignore those variables.

Data analysis and graphing

6. In Table 1, do you see any obvious outliers in the data? What can you infer about the history of any outliers? Should they be used to draw more general conclusions about the data?

IDP 11 has way more tracks/cm^2 than any of the other samples. Presumably its history was very different from the histories of the other grains, and it cannot be used to draw more general conclusions.

7. What is the average track density for the 10 anhydrous samples?

5.8×10^{10} tracks/cm^2

8. What is the average track density for the four hydrated samples?

17.25×10^{10} tracks/cm^2

9. What is the average track density for the hydrated samples without the outlier?

6.33×10^{10} tracks/cm^2

10. Does removing the outlier appear to have greatly affected the results? Explain.

Student answers will vary.

11. Use graph paper, a computer or a calculator to graph the data from both computer models shown in Table 2. If both models are represented on the same graph, make sure your graph indicates that Computer Model 1 data is a separate series than Computer Model 2 data. What type of graph might you use?

See example graph. A scatterplot is used as an example.

12. Where would a data point for 1 AU fall on the Table 2 graph?

See example graph. A grain that starts at 1 AU likely originated at or near Earth, so it would arrive at Earth's atmosphere after zero time. As such, the grain would be unlikely to have a lot of tracks from heavy charged particles.

13. What is a simple, approximate equation that fits most of the data points for the Computer Model 2 data? If you graphed the data on the computer or calculator, use the graphing system to find an equation.

The points are nearly linear with tracks/cm^2 = (initial distance / 3.5 AU) 0.9×10^9 tracks/cm^2

14. If you graphed the data on the computer or calculator, use the graphing system to find an approximate equation for Computer Model 1 data. Why is this equation difficult to predict without graphing software?

tracks/cm^2 = (initial distance / 3.5 AU)$^{0.75}$ 0.9×10^9 tracks/cm^2

The equation is difficult to predict without graphing software because the track data from Computer Model 1 is not linear in nature.

15. Using Computer Model 1 data, estimate the track density for dust grains that originated from the following distances. If you have an equation for Computer Model 2, use it to estimate the track densities.

Distance	Computer Model 1	Computer Model 2
100 AU	*~11×10^9 tracks/cm^2*	*~26×10^9 tracks/cm^2*
90 AU	*~10×10^9 tracks/cm^2*	*~23×10^9 tracks/cm^2*

80 AU	*~9.4 x 10^9 tracks/cm^2*	*~21 x 10^9 tracks/cm^2*
70 AU	*~8.5 x 10^9 tracks/cm^2*	*~18 x 10^9 tracks/cm^2*
60 AU	*~7.6 x 10^9 tracks/cm^2*	*~15 x 10^9 tracks/cm^2*

16. Besides travel time and initial distance from the sun, can you think of some other variables that might affect track density?

Other variables that might affect track density include a grain's mineral type, how much water the grain contains, the time it spent on its parent body or another large body in space, or the sources of track-making heavy charged particles. While particles from solar flares are one source of tracks, another source is cosmic rays.

Bonus questions

17. In order to infer travel time from track density, scientists need to determine a track production rate, referred to as "track-rate estimate" in the *Science News* article. What is the track production rate and how is it expressed?

The track production rate is the number of heavy charged particle tracks accumulated by dust grains per cross-sectional area per year in space. It is expressed in number of tracks/cm^2/year.

18. Scientists had previously estimated the track production rate at 6.5 x 10^5/cm^2/year. The new estimated rate is 4.4 x 10^4/cm^2/year. By what multiplicative factor are they different?

The old track production rate is about 15 times the new rate.

19. What would be the effect on the estimated travel time of the dust particles if one used the old track production rate instead of the new track production rate?

The old track production rate is about 15 times the new rate. Assuming the new rate is accurate, using the old rate could overestimate the time it took for a grain to accumulate tracks and thus the time it has been traveling in space by a factor of 15.

20. Based on the answers to question 3, we know that a dust grain's travel time appears to increase roughly like the square of the distance traveled. Use your answer from question 19 to approximate how much closer a grain's initial distance may have been to Earth, relative to what previous estimates would suggest.

If the travel time drops by a factor of 15 compared with old estimates, the distance traveled would be shorter by a factor of about $(15)^{0.5}$ or about 3.9. Thus a dust grain would appear to be coming from a location that is roughly one-fourth the distance from Earth.

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Student Activity Guide: Dusty Data Dive

Directions: After reviewing the general information about the data below with your teacher, look at Tables 1 and 2 and use them to answer the following questions. When needed, use an additional resource to find background information.

Table 1:

IDP #	Track Density Measured (Tracks/cm^2)	Type of Mineral
1*	6×10^{10}	pyx
2	8×10^{10}	Ol
3	6×10^{10}	An
4	10×10^{10}	pyx
5	7×10^{10}	An
6	3×10^{10}	pyx
7	8×10^{10}	pyx
8	3×10^{10}	pyx
9	5×10^{10}	pyx
10*	7×10^{10}	pyx
11*	50×10^{10}	pyx, Ol
12	6×10^{10}	pyx
13	2×10^{10}	pyx
14*	6×10^{10}	pyx

Table 2:

Initial Distance of IDP from the sun (AU)	Estimated Track Density Computer Model 1 (Tracks/cm^2)	Estimated Track Density Computer Model 2 (Tracks/cm^2)
50	6.2×10^9	12.6×10^9
40	5.4×10^9	10.6×10^9
30	4.6×10^9	8.4×10^9
20	3.6×10^9	6.0×10^9
10	2.2×10^9	3.2×10^9
5	1.2×10^9	1.6×10^9
3	0.8×10^9	0.8×10^9

Background questions

1. Study the first column of Table 2. What does AU stand for and what does it measure? Convert 1 AU to two different units of measurement.

2. What are the approximate distances of the following objects from the sun in AU?

Mercury
Earth
Asteroid belt
Uranus
Kuiper Belt

3. According to the primary research study, dust from the asteroid belt would reach Earth in about 6 x 10^4 years, and dust from the Kuiper Belt would reach Earth in about 1 x 10^7 years. Use this information, Table 2 and your answer to the previous question to answer the following questions.

Approximately how many times further does dust from the asteroid belt need to travel to reach Earth compared with dust from the Kuiper Belt?

Approximately how many times longer does it take for dust from the asteroid belt to travel to Earth compared with dust from the Kuiper Belt?

How does the travel time appear to relate to the distance traveled?

4. How does your final answer to question 3 relate to the simple equation for diffusion? In simple diffusion problems, the distance a grain travels (L) depends on a diffusion constant (D) and the time (t) the grain has been traveling: $L^2 = Dt$, or $t = L^2/D$.

5. What is a benefit and a drawback of applying the simple equation for diffusion to try to understand how space dust travels?

Data analysis and graphing

6. In Table 1, do you see any obvious outliers in the data? What can you infer about the history of any outliers? Should they be used to draw more general conclusions about the data?

7. What is the average track density for the 10 anhydrous samples?

8. What is the average track density for the four hydrated samples?

9. What is the average track density for the hydrated samples without the outlier?

10. Does removing the outlier appear to have greatly affected the results? Explain.

11. Use graph paper, a computer or a calculator to graph the data from both computer models shown in Table 2. If both models are represented on the same graph, make sure your graph indicates that Computer Model 1 data is a separate series than Computer Model 2 data. What type of graph might you use?

12. Where would a data point for 1 AU fall on the Table 2 graph?

13. What is a simple, approximate equation that fits most of the data points for the Computer Model 2 data? If you graphed the data on the computer or calculator, use the graphing system to find an equation.

14. If you graphed the data on the computer or calculator, use the graphing system to find an approximate equation for Computer Model 1 data. Why is this equation difficult to predict without graphing software?

15. Using Computer Model 1 data, estimate the track density for dust grains that originated from the following distances. If you have an equation for Computer Model 2, use it to estimate the track densities.

Distance	Computer Model 1	Computer Model 2
100 AU		

90 AU

80 AU

70 AU

60 AU

16. Besides travel time and initial distance from the sun, can you think of some other variables that might affect track density?

Bonus questions

17. In order to infer travel time from track density, scientists need to determine a track production rate, referred to as “track-rate estimate” in the *Science News* article. What is the track production rate and how is it expressed?

18. Scientists had previously estimated the track production rate at $6.5 \times 10^5/cm^2/year$. The new estimated rate is $4.4 \times 10^4/cm^2/year$. By what multiplicative factor are they different?

19. What would be the effect on the estimated travel time of the dust particles if one used the old track production rate instead of the new track production rate?

20. Based on the answers to question 3, we know that a dust grain’s travel time appears to increase roughly like the square of the distance traveled. Use your answer from question 19 to approximate how much closer a grain’s initial distance may have been to Earth, relative to what previous estimates would suggest.

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Related Articles

Science News:

"Surprising astronomers, Bennu spits plumes of dust into space," Readability: 10.0
"Ultima Thule may be a frankenworld," Readability: 10.6
"Voyager 2 spacecraft enters interstellar space," Readability: 11.4

Science News for Students:

"Distant galaxy seems filled with dark matter," Readability: 8.4
"Cool Job: Making stellar connections," Readability: 7.6
"There's a snowman in space," Readability: 6.3

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