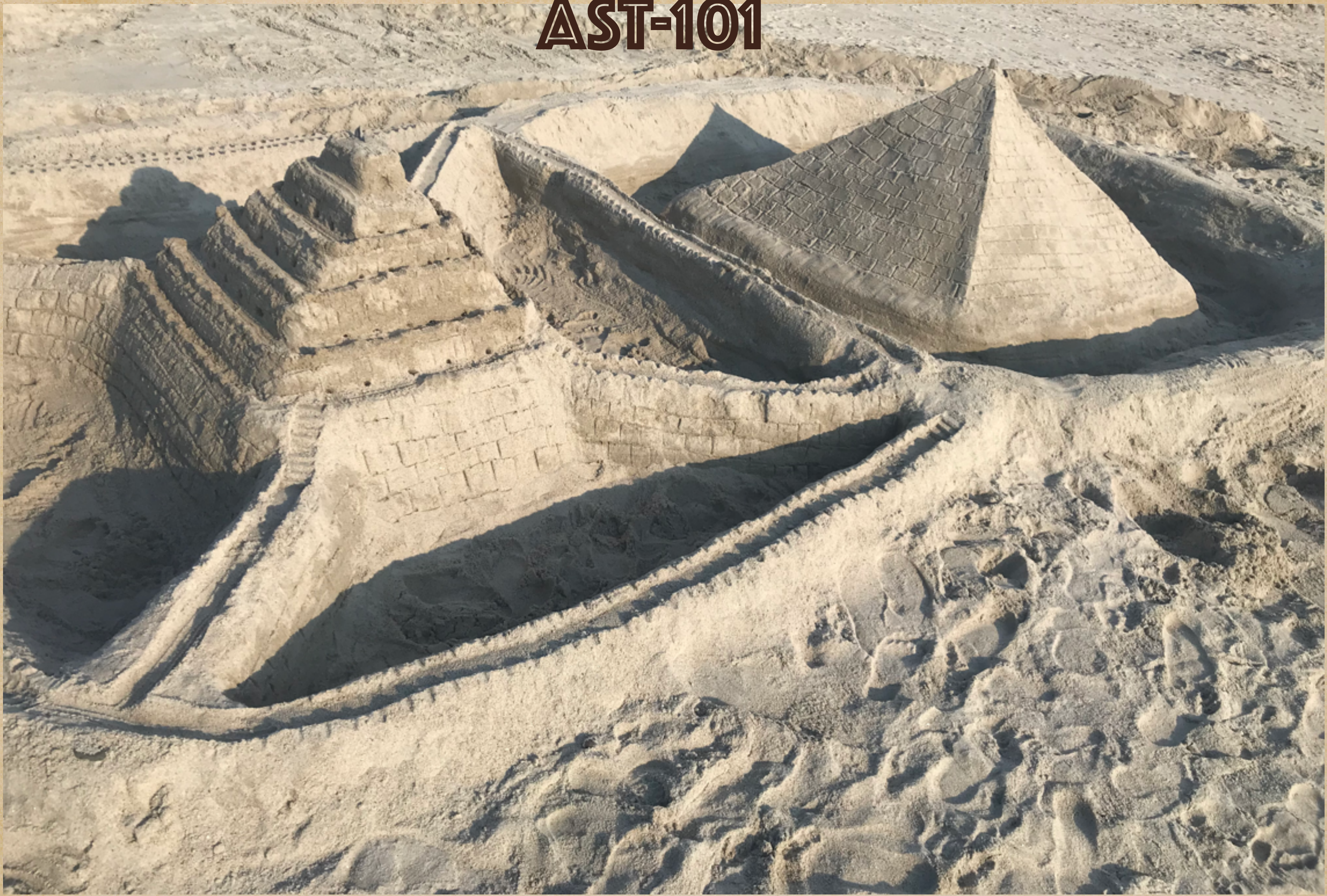
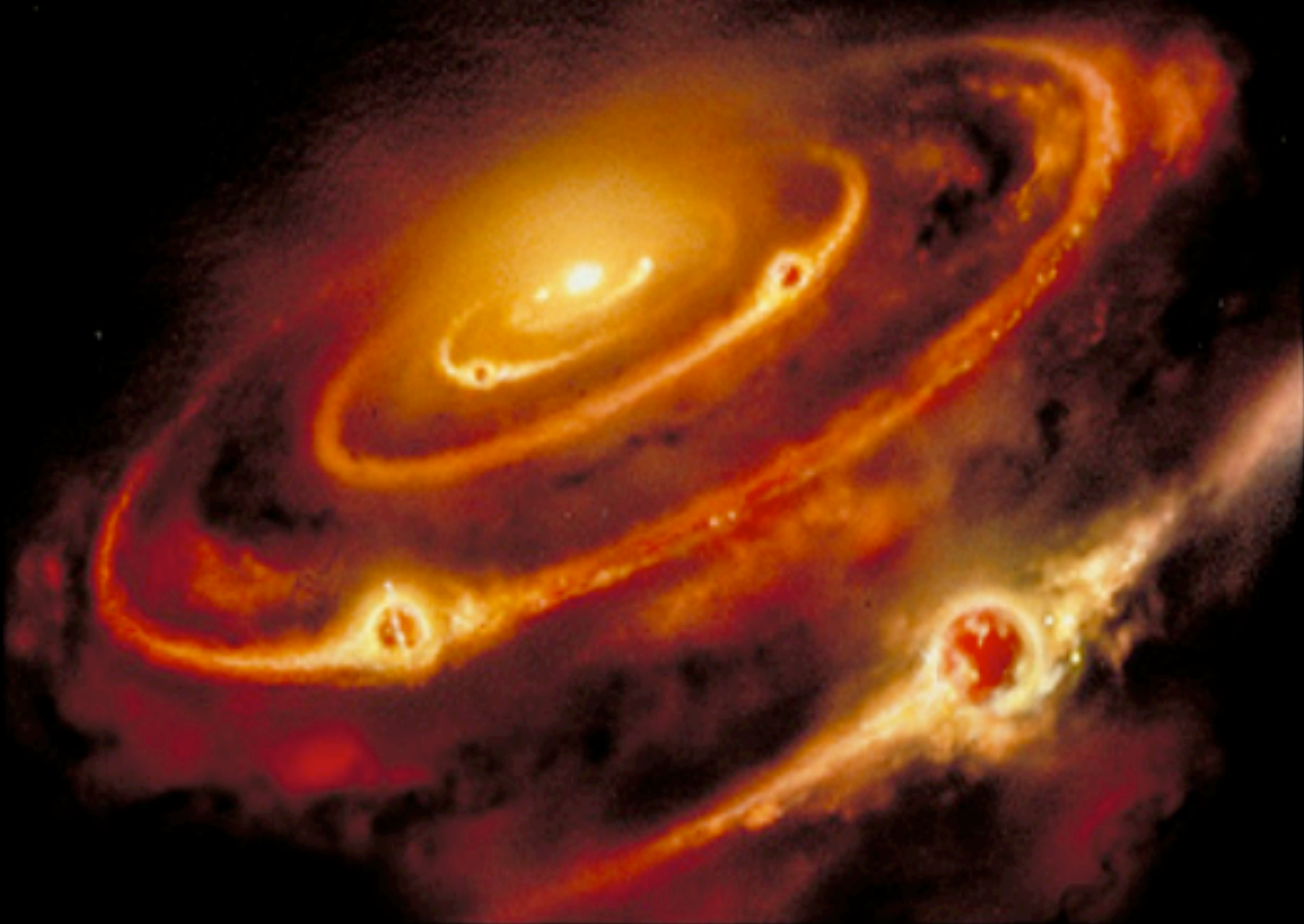
AST-101



Solar System: origin and exploration

Luis Anchordoqui

Origin of the Solar System



What any theory must address?

- Why do the orbits of the planets lie in the same plane ?
- Why do the eight planets and asteroids all orbit the Sun with prograde revolution?
- Why does the Sun rotate in this prograde sense?
- Why are the orbits of the planets nearly circular?
- Why do six of the eight planets have prograde rotation? (With the exception of Venus and Uranus)
- Why does Bode's Rule describe the nearly regular spacing of planetary orbits? (Each planet has approximately twice the distance to the Sun as its nearest inner neighbor)

What any theory must address?

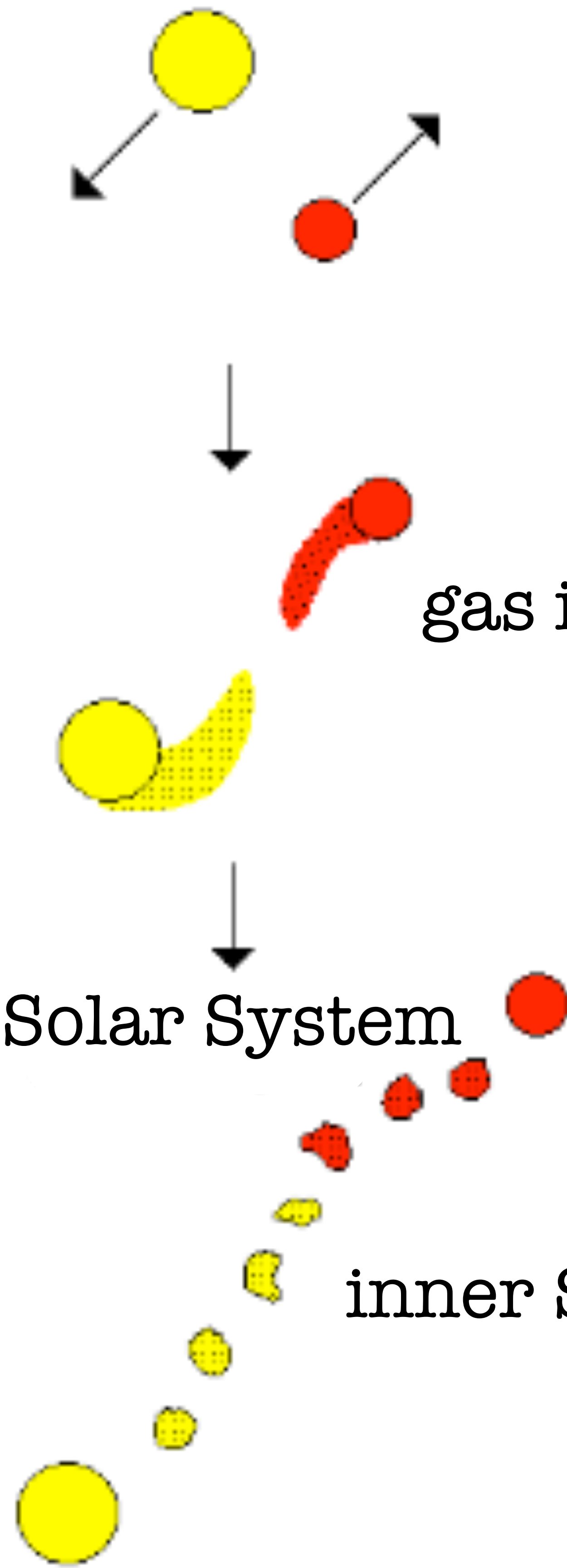
Questions of Planetary Composition

- Why do the planets vary systematically in composition and density, with the innermost planets tending toward high density and heavy elements, and the outermost planets tending toward low density and substances of low melting point?

Gross Properties of the Planets

Planet	Distance AU	Diameter 10^3 km	Mass (Earth = 1)	Density (gm/cm^3)	Orbital Inclination
Mercury	0.39	4.9	0.055	5.4	7.0°
Venus	0.72	12.1	0.82	5.25	3.6°
Earth	1.00	12.7	1.00	5.52	--
Mars	1.52	6.8	0.11	3.93	1.9°
Jupiter	5.20	143	318	1.33	1.3°
Saturn	9.54	120	95	0.71	2.5°
Uranus	19.2	51	15	1.27	0.8°
Neptune	30.1	50	17	1.70	1.8°
Pluto	39.4	2.4	0.03	1.99	17.2°

Encounter Hypothesis



rogue star passes close to the Sun

gas is tidally removed from both rogue star and Sun

outer Solar System

rogue star material is less dense
and becomes outer Solar System planets

inner Solar System

inner Solar System material is more
dense and becomes terrestrial planets

Encounter Hypothesis

(Buffon 1745)

1. A "near miss" encounter occurs between the Sun and a passing star
2. Material is pulled from the stellar surfaces by tidal forces
3. Material cools and condenses to form planetary bodies

Principal Shortcoming: This Requires a highly unlikely event

Calculation ☛ Collision rate is proportional to

- Relative speed
- Collision Cross-Section (How close is "close"?)
- Density of stars

This gives a typical collisional interval of 10^{20} years!

Predictive Successes ☛

Direct, coplanar, low eccentricity orbits

Common planetary ages (but an older Sun)

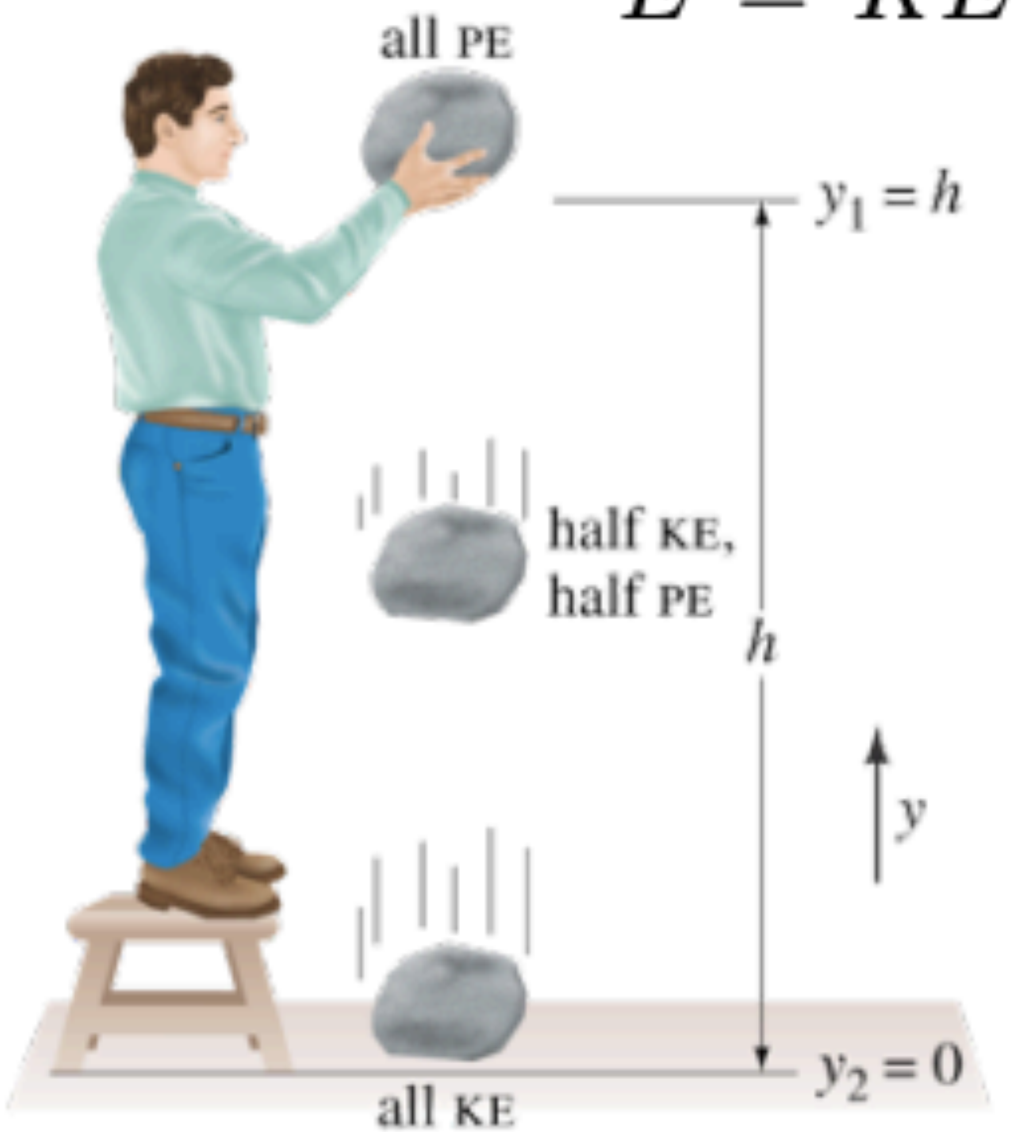
But it Doesn't Work ☛

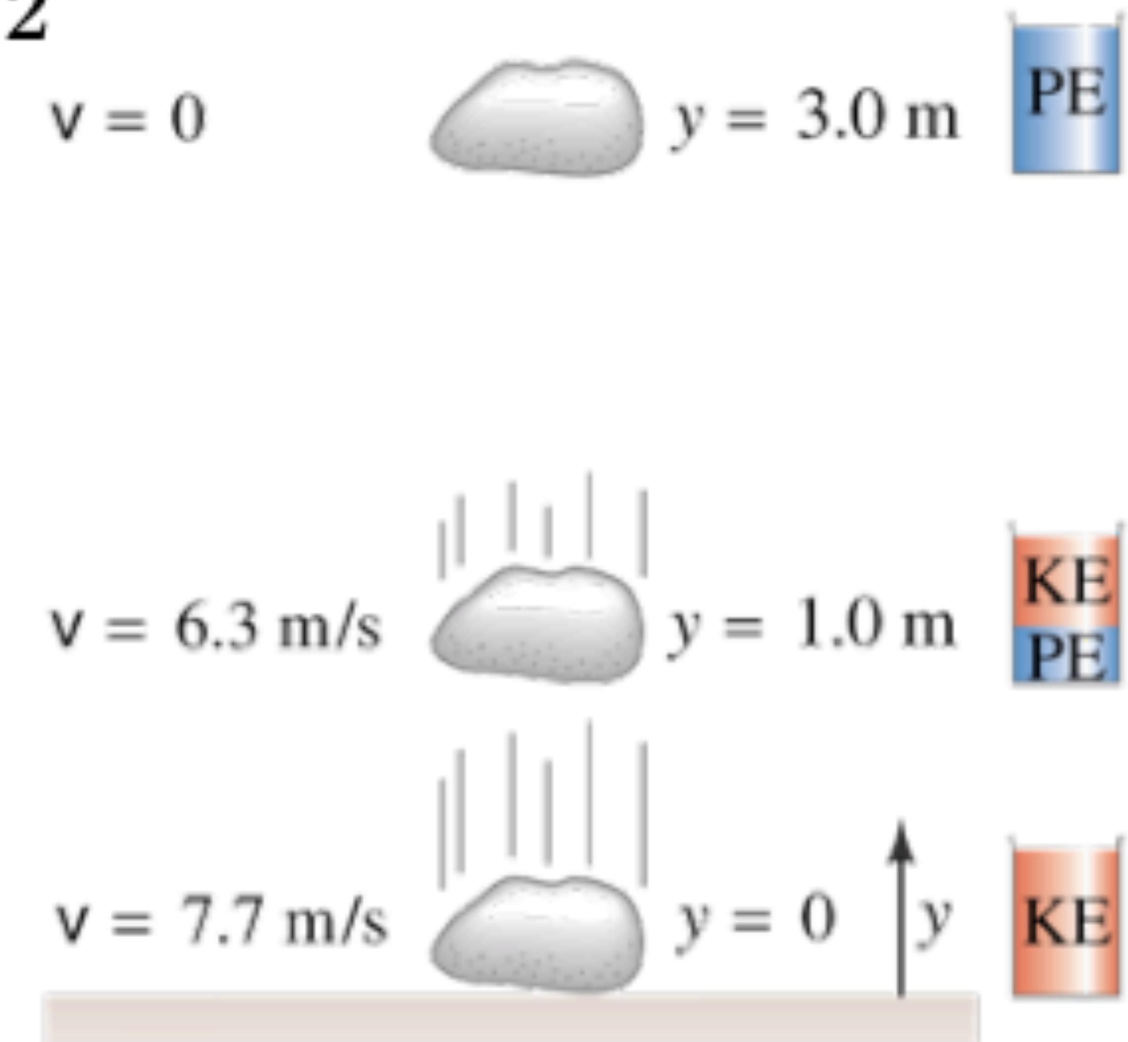
Ejected gas escapes before cooling

Conservation of Energy

Energy = Kinetic Energy + Potential Energy

$$E = KE + PE = \frac{1}{2}mv^2 + mgy$$





Energy buckets (right) show how energy moves from all potential to all kinetic

Ejected Gas Escapes before Cooling

$$\text{Potential Energy} = \frac{GMm}{r}$$

$$\text{Kinetic Energy} = \frac{1}{2}\,mv^2$$

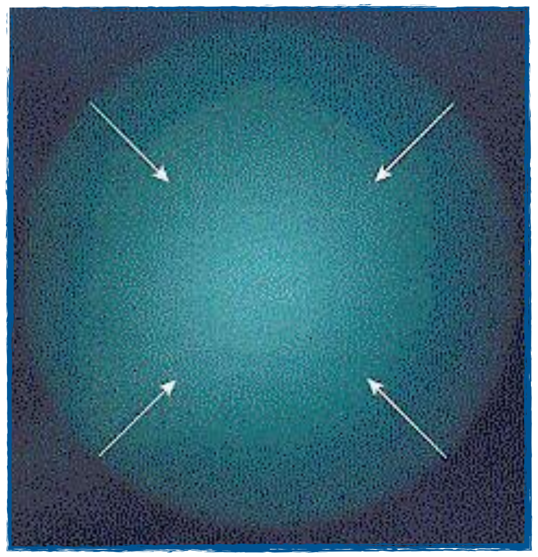
$$\text{Initial Kinetic Energy} = \text{Potential Energy}$$

$$\frac{1}{2}mv^2 = \frac{GMm}{r} \quad ☛ \quad v_{\text{escape}}^2 = \frac{2GM}{r}$$

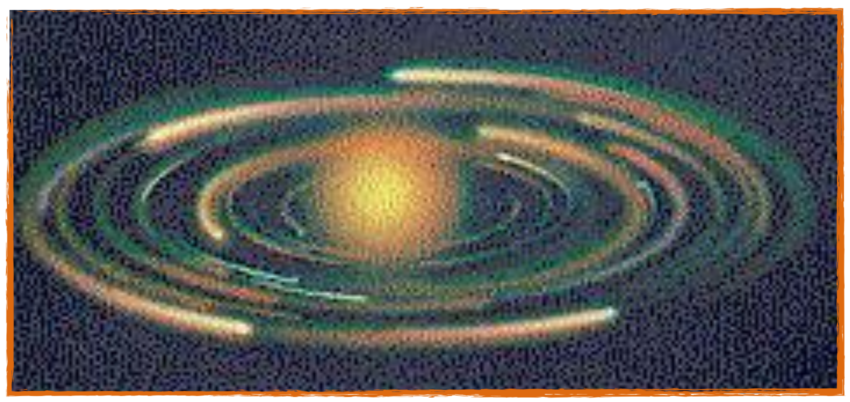
$$v_{\text{thermal}}^2 = 3kT/m$$ k ☛ Boltzmann constant

For high temperature T ☛ $v_{\text{escape}}^2 \ll v_{\text{thermal}}^2$

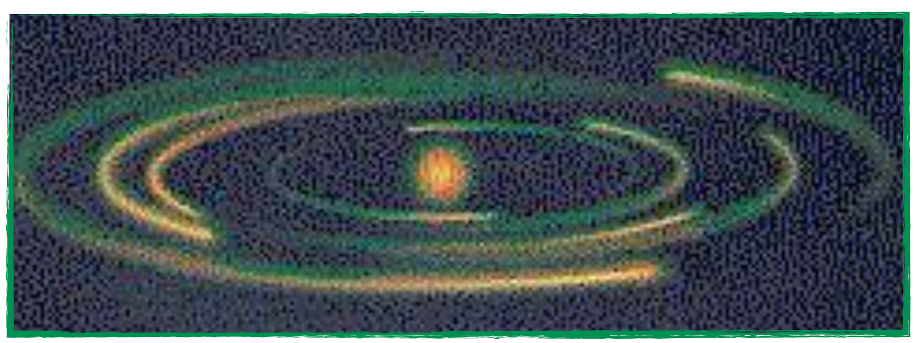
Nebular Hypothesis



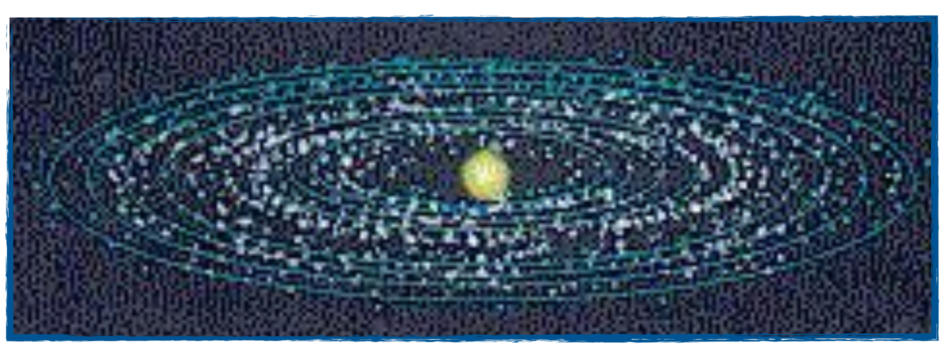
The solar nebula contracts



As the nebula shrinks,
its motion causes it to flatten



The nebula is a disk of matter
with a concentration near the center



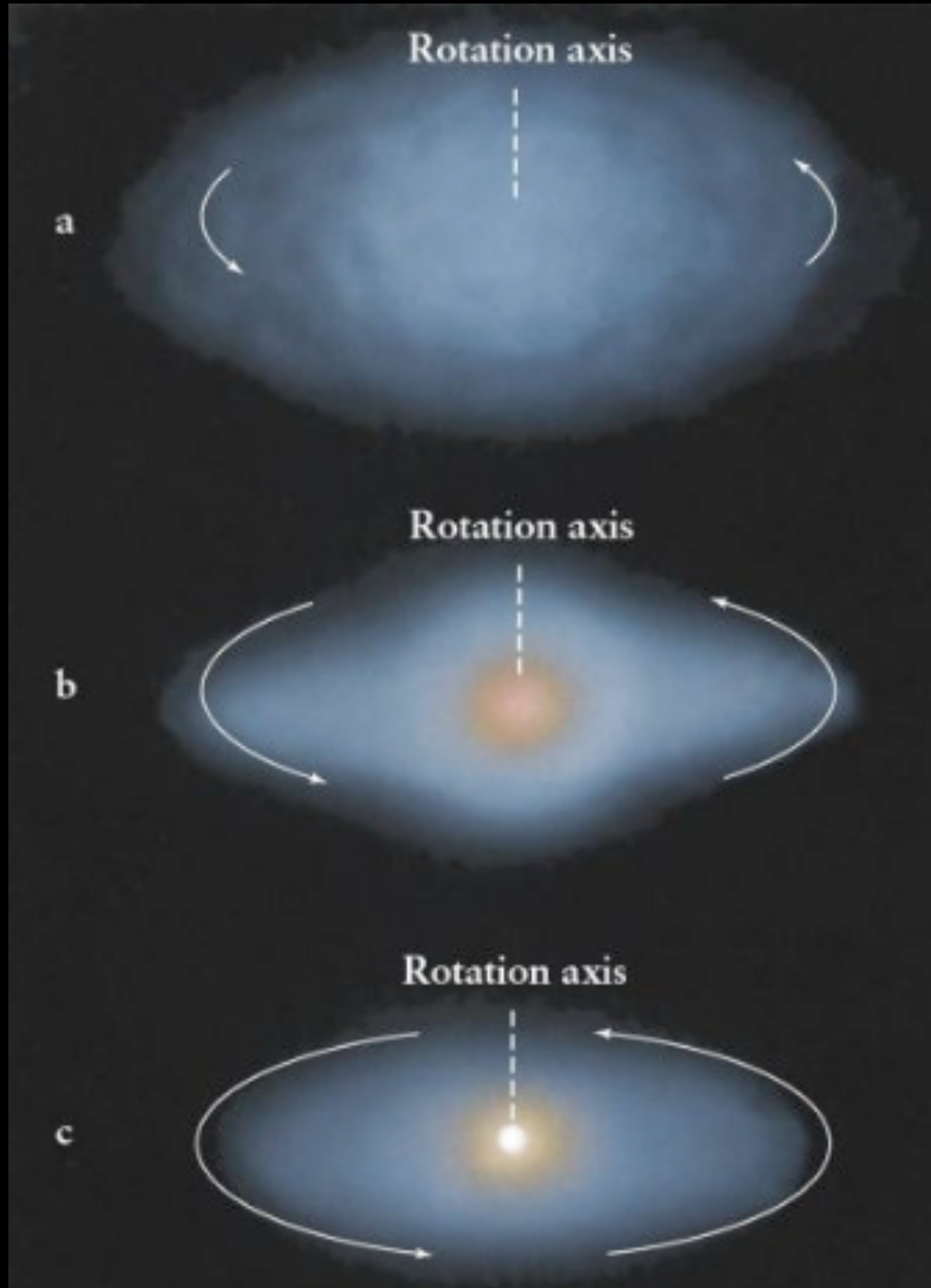
Formation of the protosun

Solid particles condense as the nebula cools,
giving rise to the planetesimals,
which are the building blocks of the planets

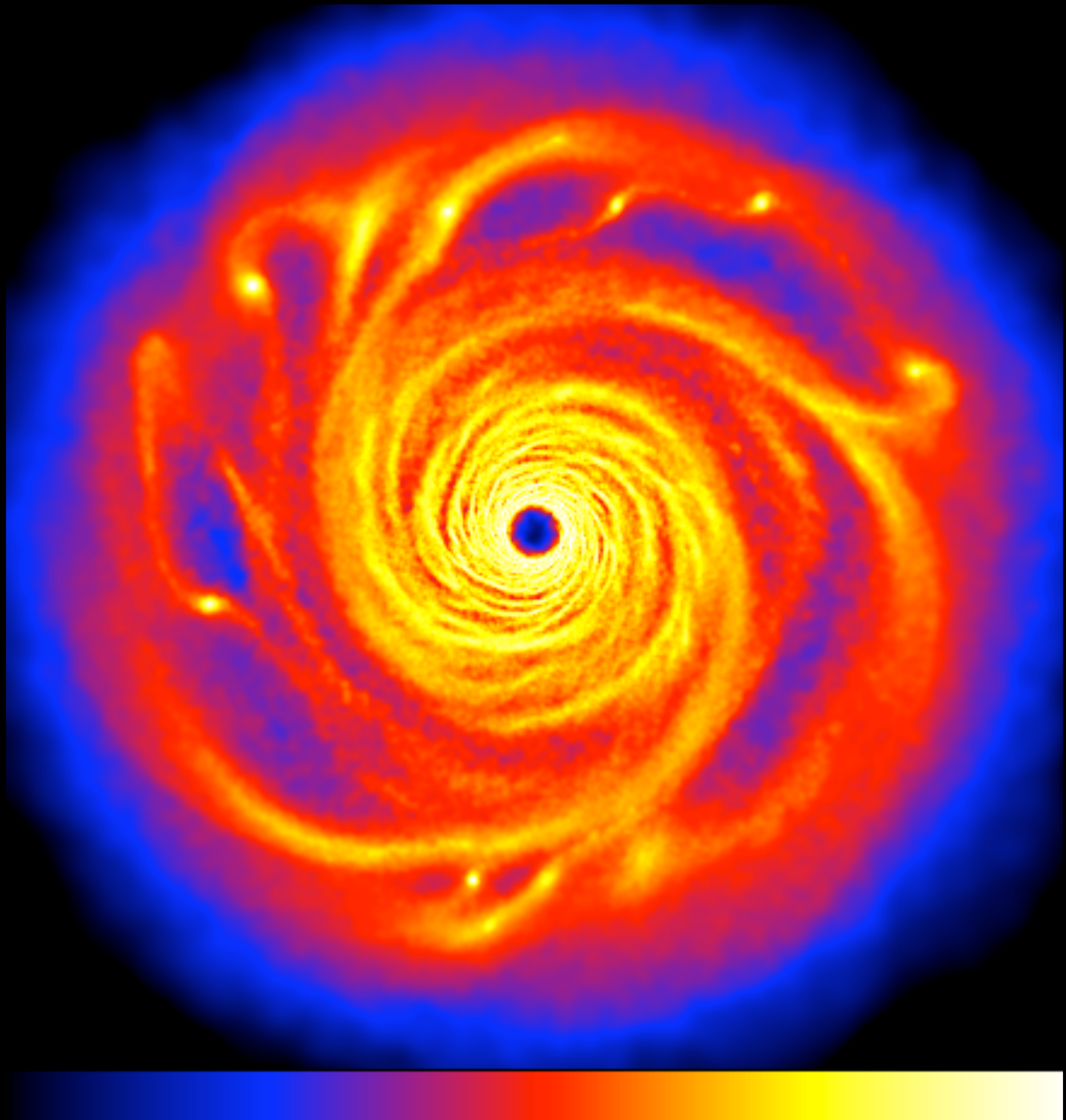
Nebular Hypothesis & Protoplanets

- The Sun forms from a collapsing cloud of **cold** interstellar gas and dust
- The material forms a proto-Sun surrounded by a **cool** gas and dust disk
- Small particles form and grow in the disc by **collisional accretion**
- Larger bodies (**planetesimals**) accrete rapidly with the aid of gravity
- Planetesimals grow by accretion of gas, dust, and other planetesimals
  - — gradually clearing the disk of remaining material.
  - — maintained in gaseous states by collisional heating
- Final states of planetesimals growth form protoplanets
  - — surfaces cooling and solidifying as accretion slows
  - — atmospheres dissipate at a decreasing rate
- The protoplanets evolve with time to become the present-day planets
  - — differentiation between inner and outer planets

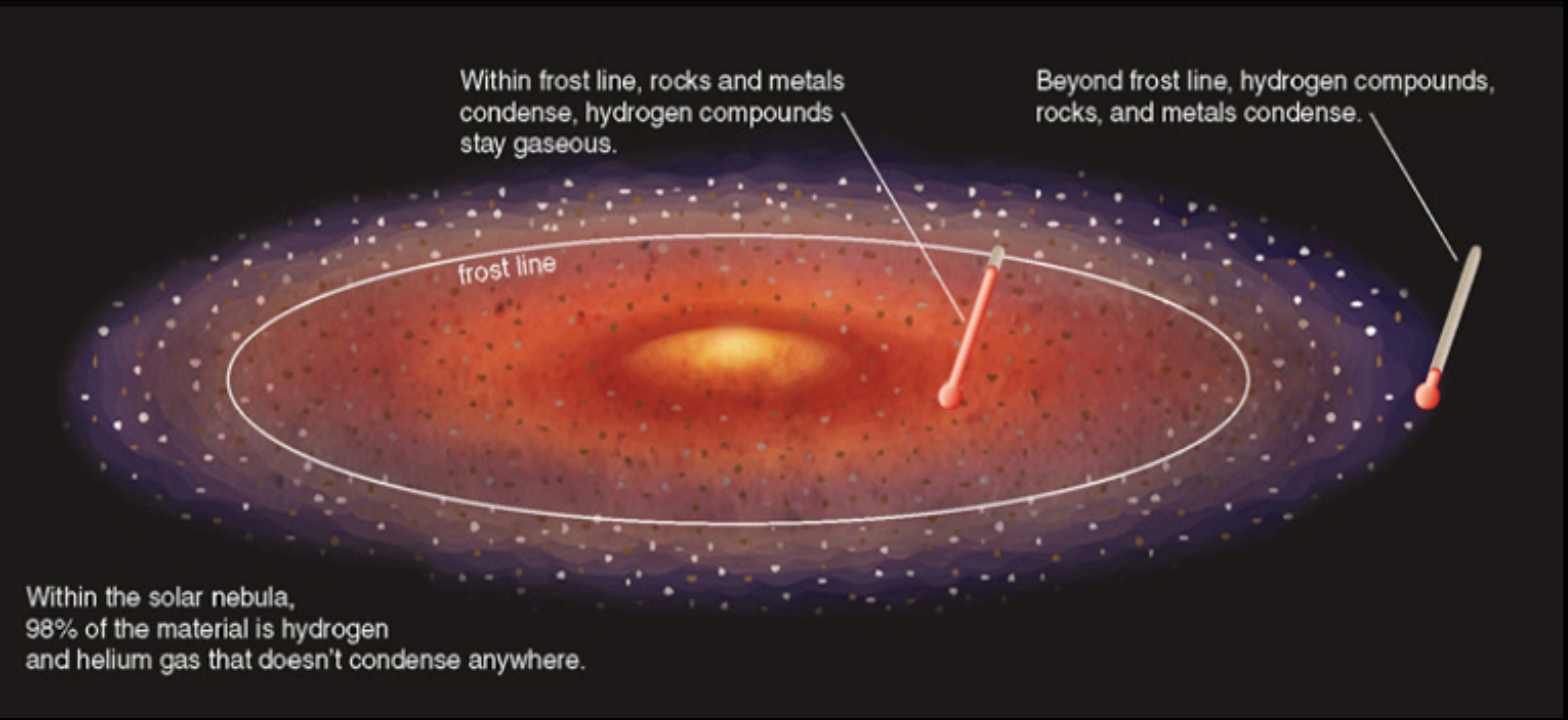
Note: Satellites are formed by accretion in disks about protoplanets or acquired by later capture or result from collisions



Rotation axis
a
Rotation axis
b
Rotation axis
c



Inner planets have all of their volatile elements "boiled off" by the heat of the Sun (hydrogen, lithium, helium)



Jovian planets do not receive enough solar radiation for this to happen so the lighter elements remain and accumulate over time

Nebular Hypothesis

Some History

- ☑ Descartes 1644 ☛ Eddies and whirlpools in a turbulent disk
- ☑ Kant 1755 ☛ Planet formation in a rotating Keplerian disk
- ☑ Laplace 1796 ☛ A disk with "tidal rings"

Some Virtues

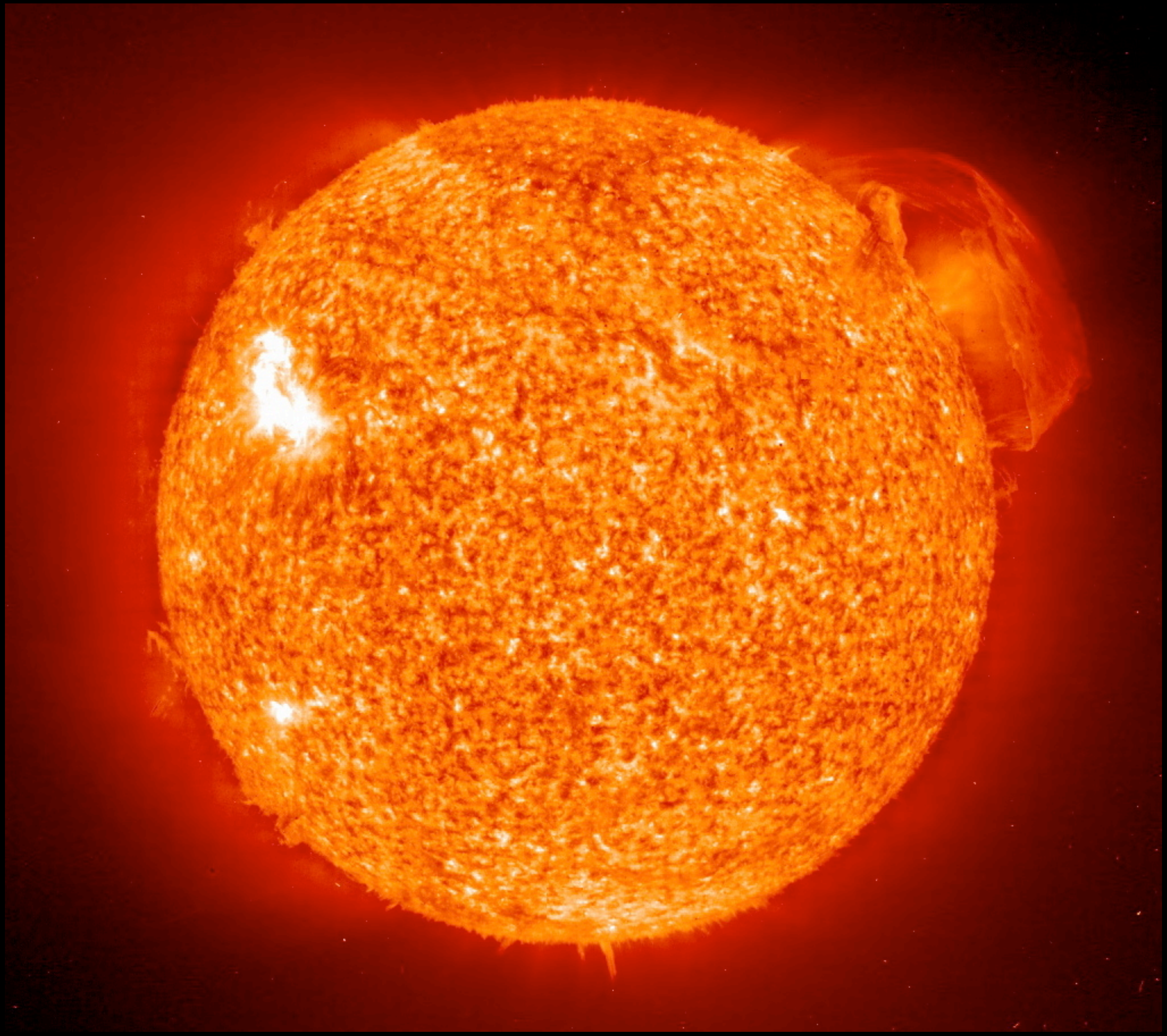
- ☑ Cool early environment allows formation of larger solid bodies
- ☑ Planet and star (Sun) formation are part of a single process ☛ accounts for gross orbital properties
- ☑ Accounts for composition similarities and differences (Jovian/Terrestrial)

Current Status

- ☑ Very great explanatory and predictive power ➢ Eminently testable
- ☑ No fundamental issues or problems outstanding
- ☑ Is a successful model for star formation as well as stellar systems

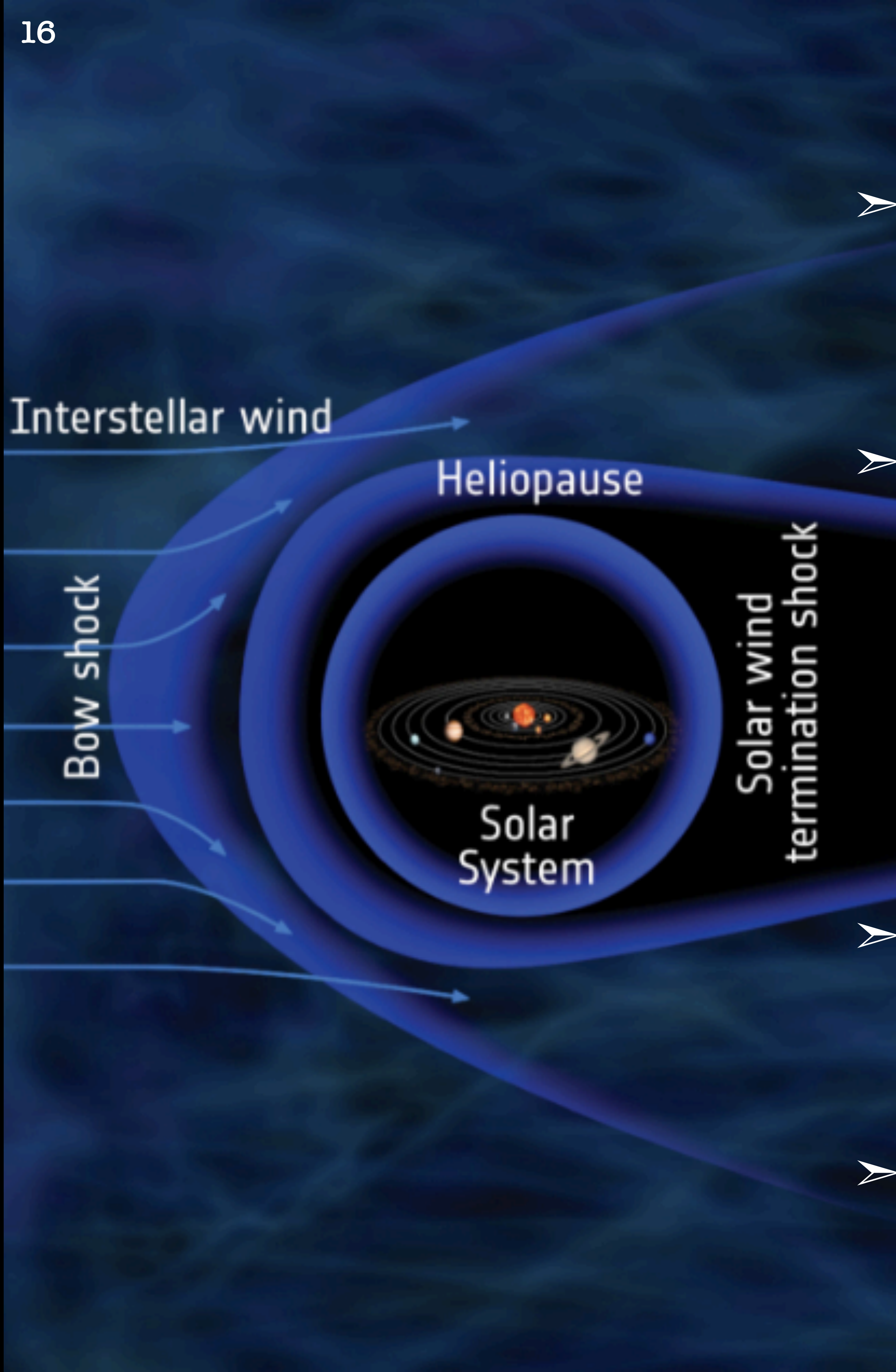
  (Stars are now known and observed to form from cool interstellar clouds)
- ☑ No viable competing model has been forthcoming

The sun still contains most of the material of the original solar nebula



Its internal nuclear reactions have modified the material at the sun's core

However, the surface layers, which have not mixed with the core in its present state, have quite accurately preserved the original nebular composition

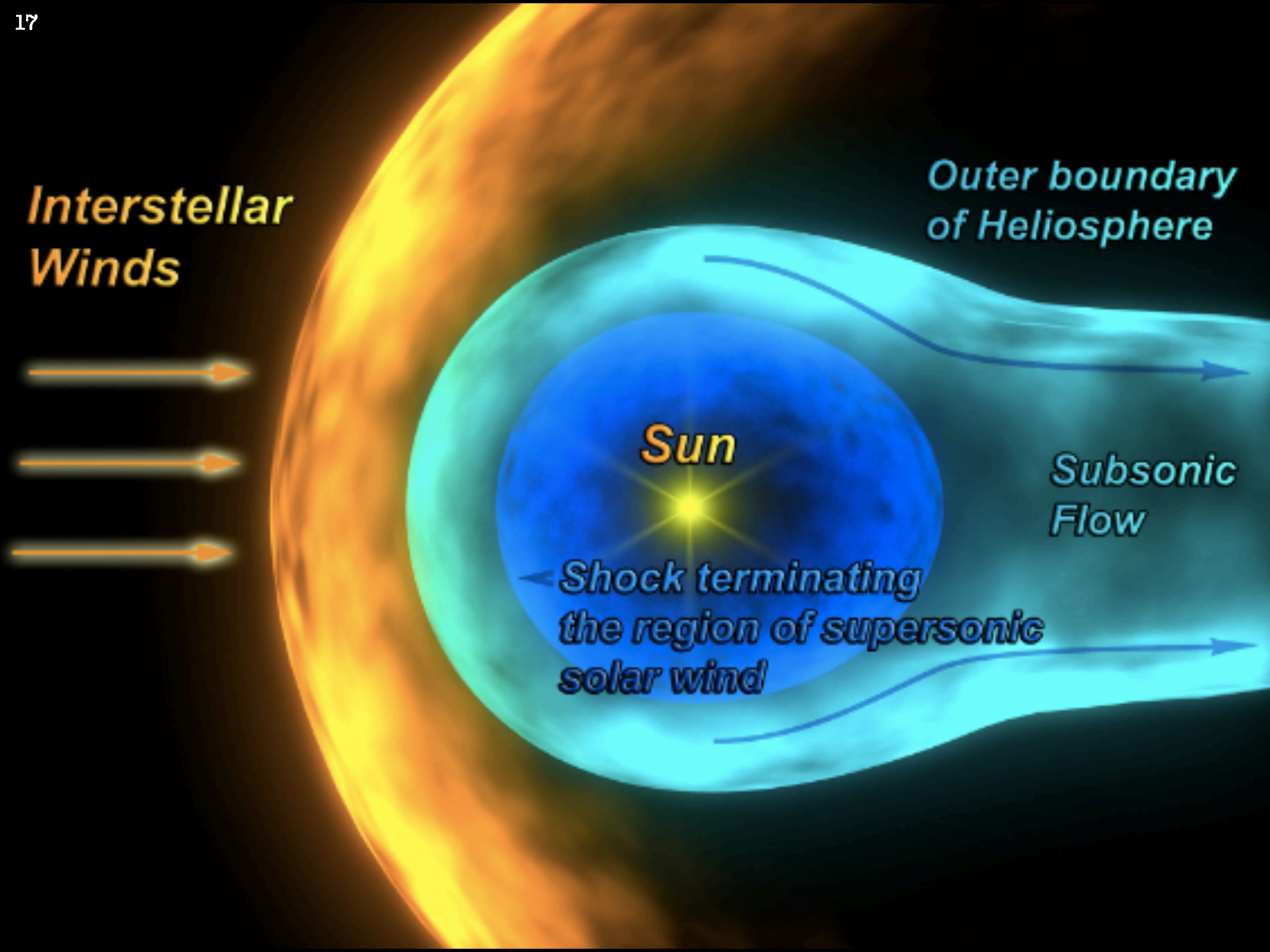


- The solar wind is a flow of particles that comes off the sun at about one million miles per hour and travels throughout the solar system

- At the outer limits of the solar system, the solar wind finally begins to lose out and its speed drops below the speed of sound (relative to the interstellar medium), resulting in a roughly spherical shell known as the termination shock front

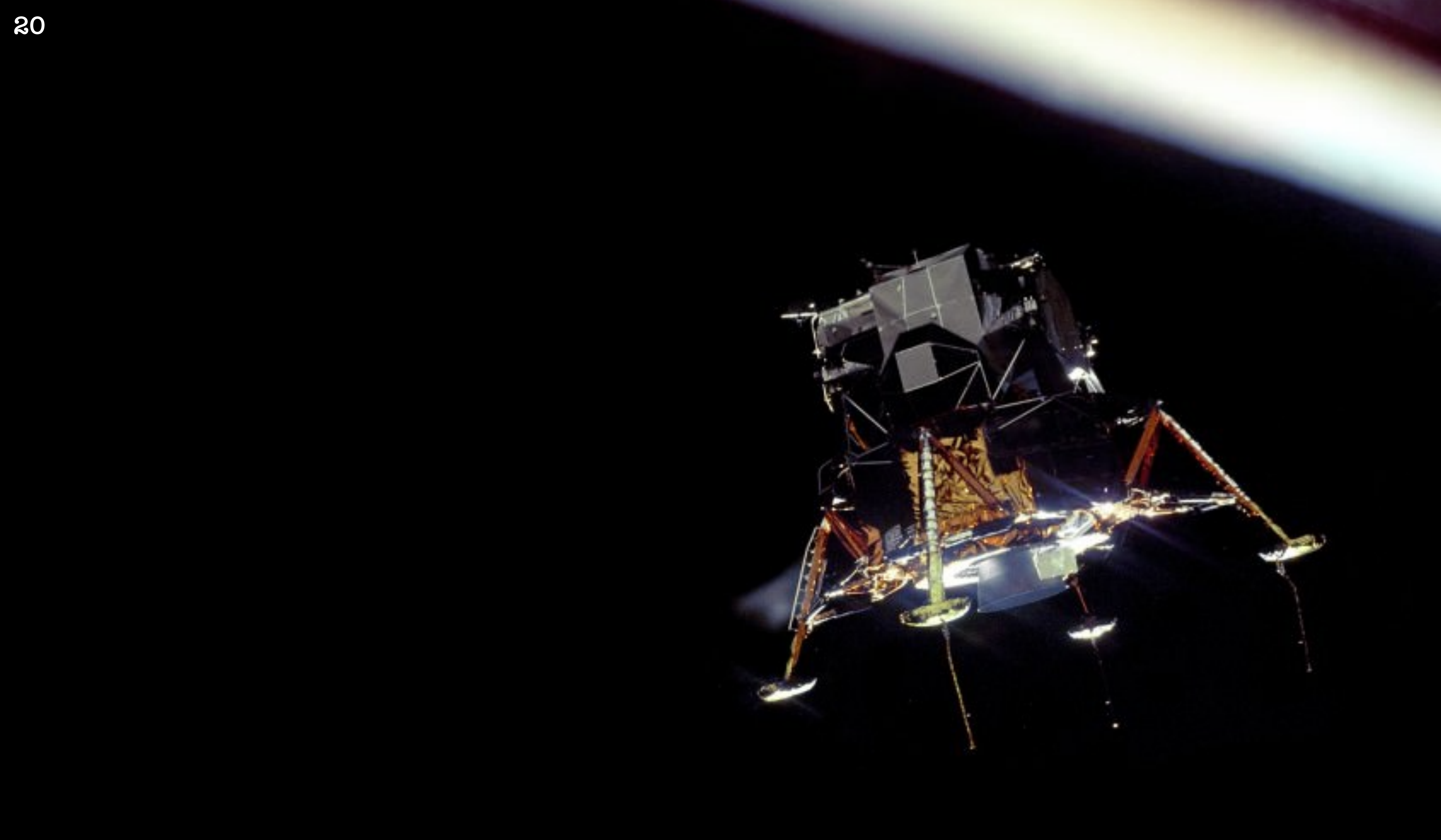
- Heliopause is the boundary where the interstellar medium and solar wind pressures balance

- The bow shock is tipically the boundary between the stellar wind and the interstellar medium


Interstellar
Winds
Outer boundary
of Heliosphere
Sun
Subsonic
Flow
Shock terminating
the region of supersonic
solar wind

Exploration of the Solar System

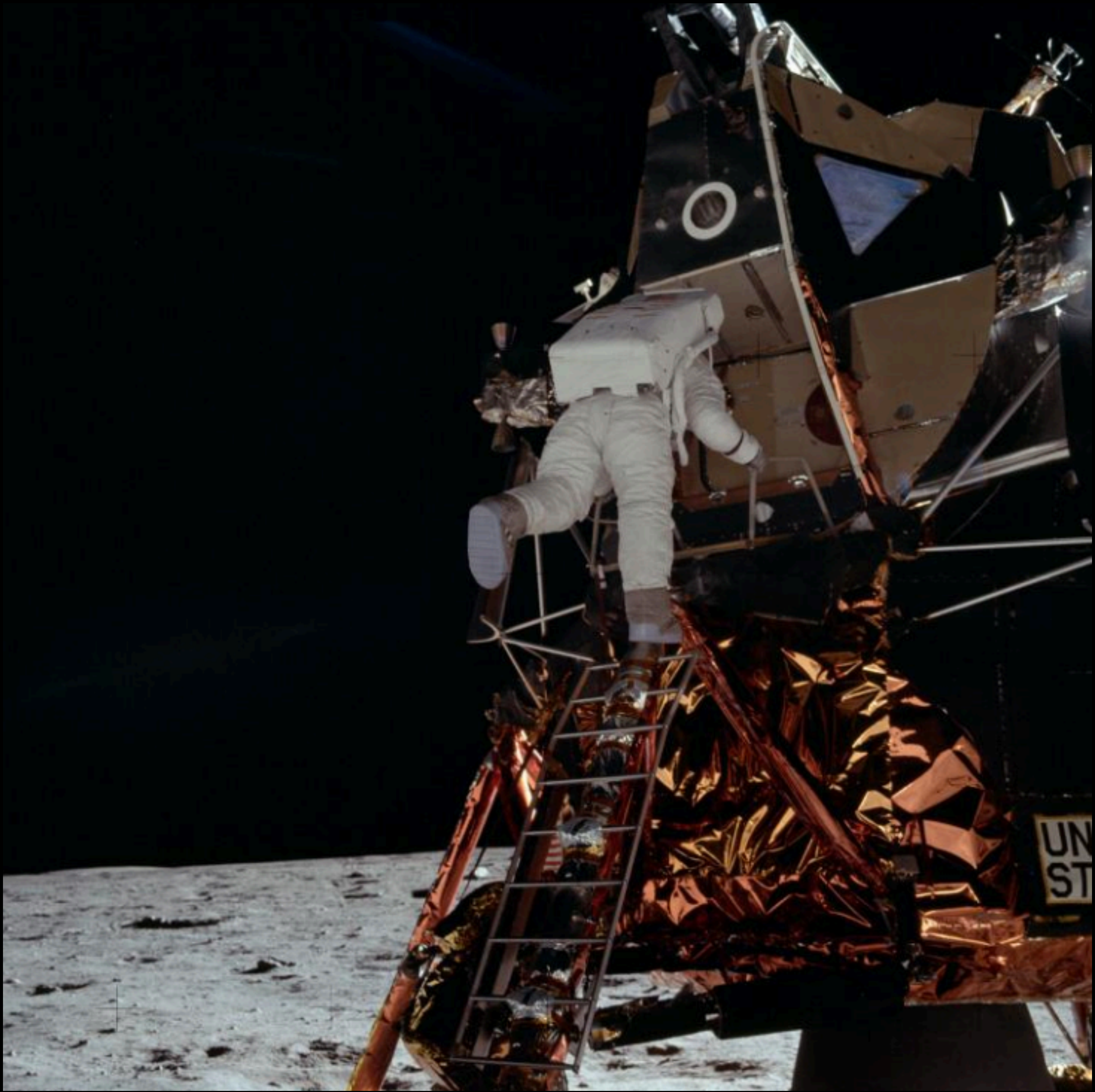
Apolo 11 ➢ July 16, 1969 @13:32 UTC

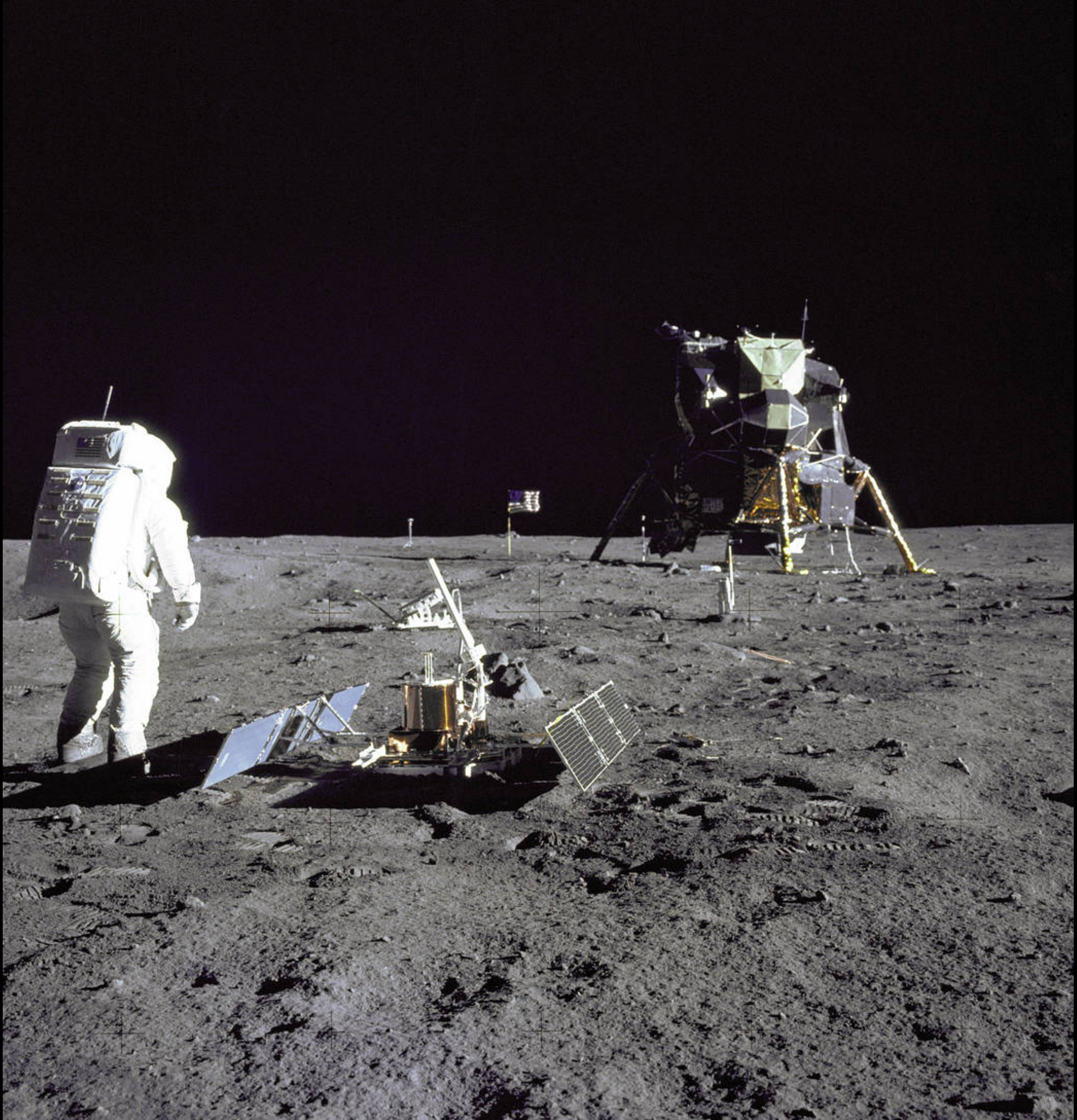


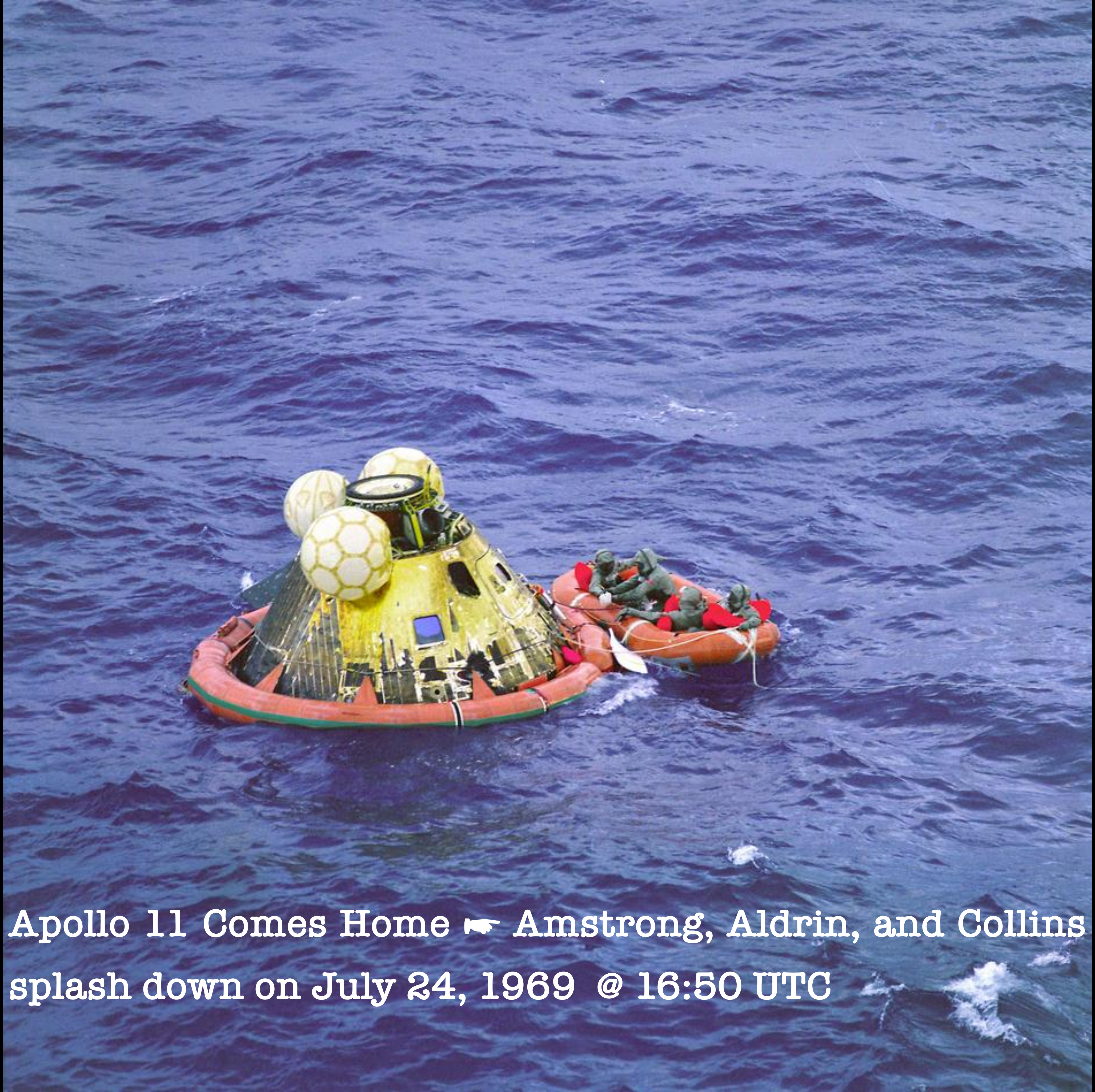
Apollo 11 Lunar Module Eagle, in a landing configuration was photographed

in lunar orbit from the Command and Service Module Columbia

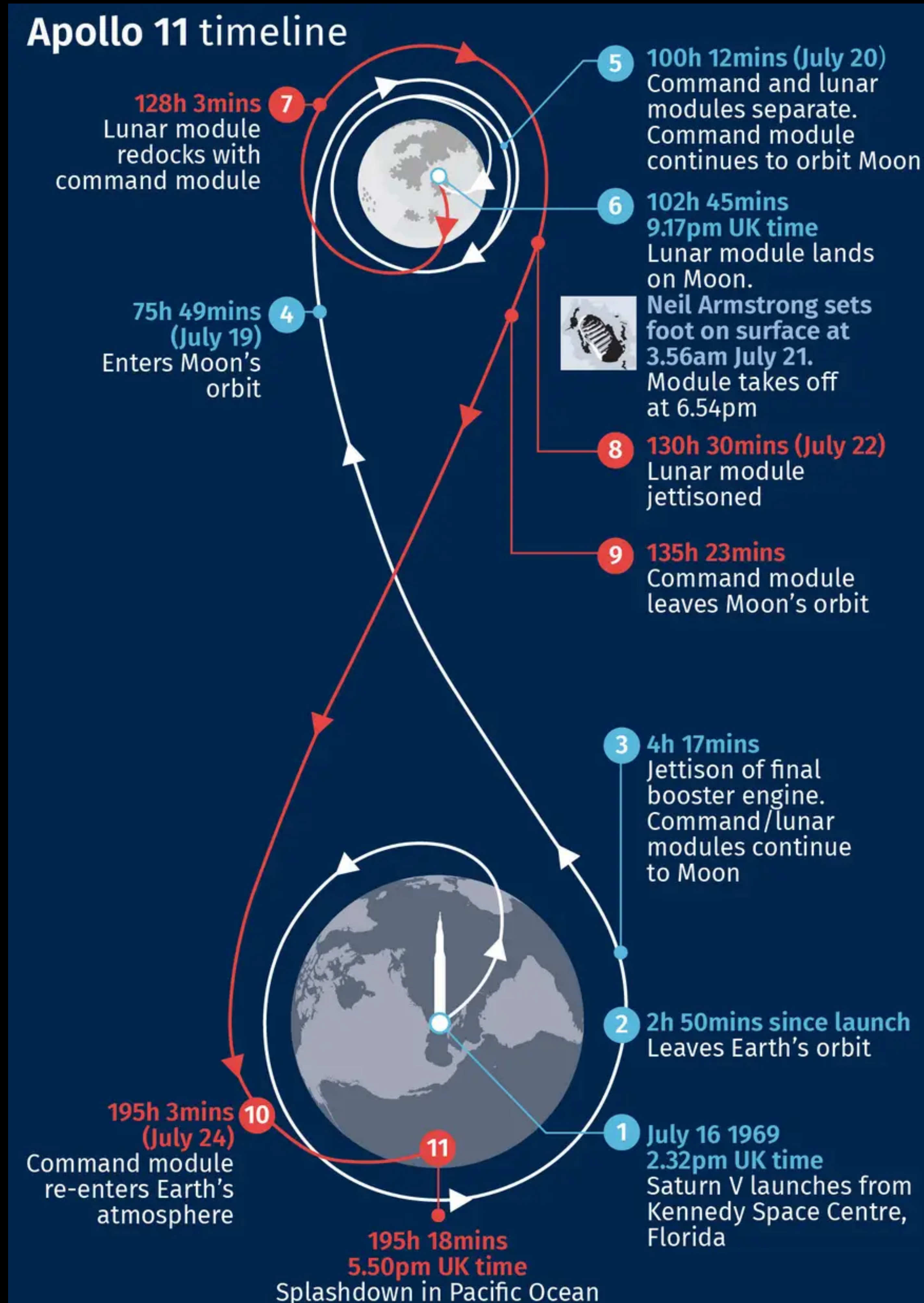
Neil Armstrong ☛ first step on the Moon
July 20, 1969 @20:17 UTC

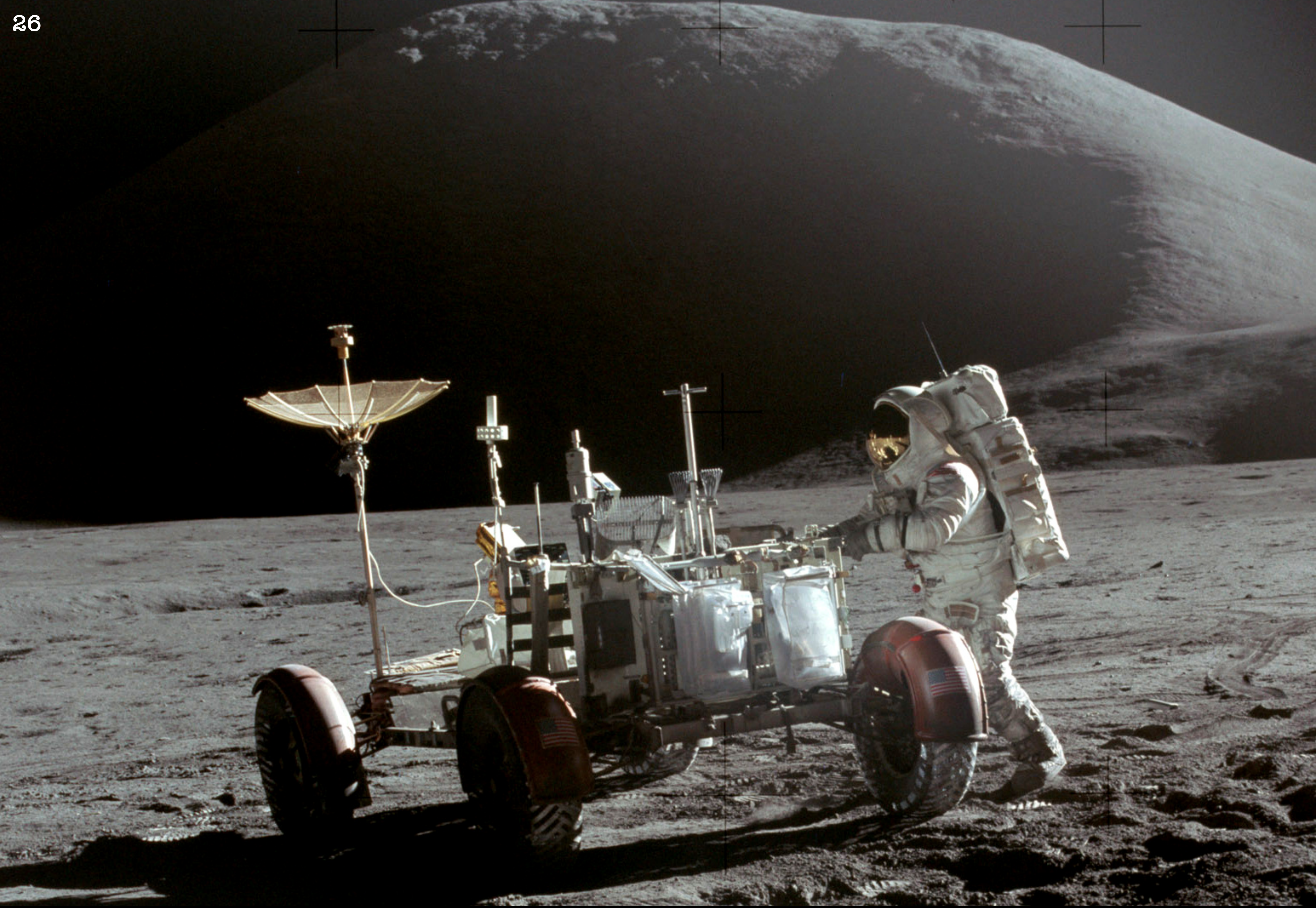

UN
ST



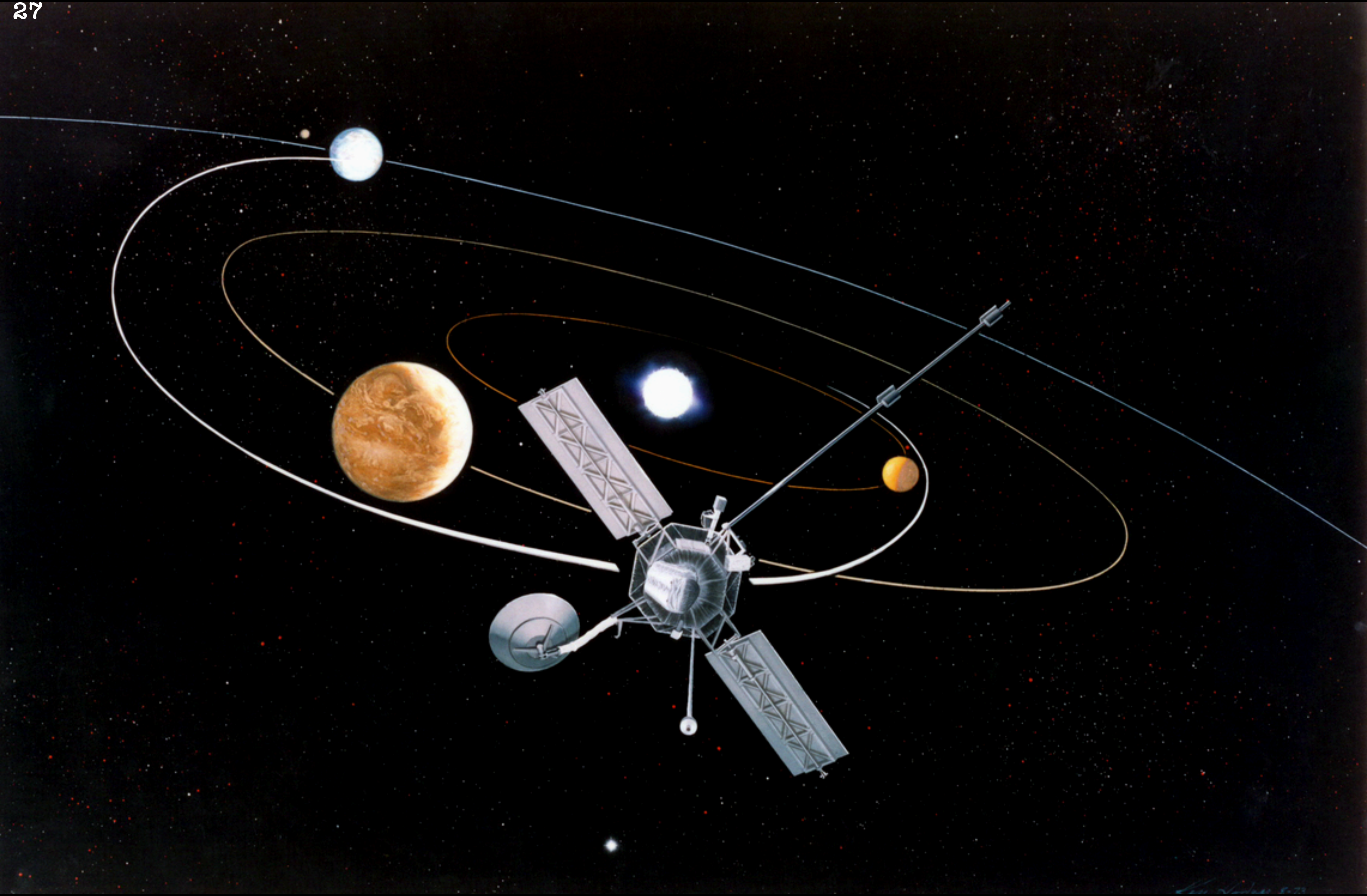


Apollo 11 Comes Home ☛ Amstrong, Aldrin, and Collins splash down on July 24, 1969 @ 16:50 UTC

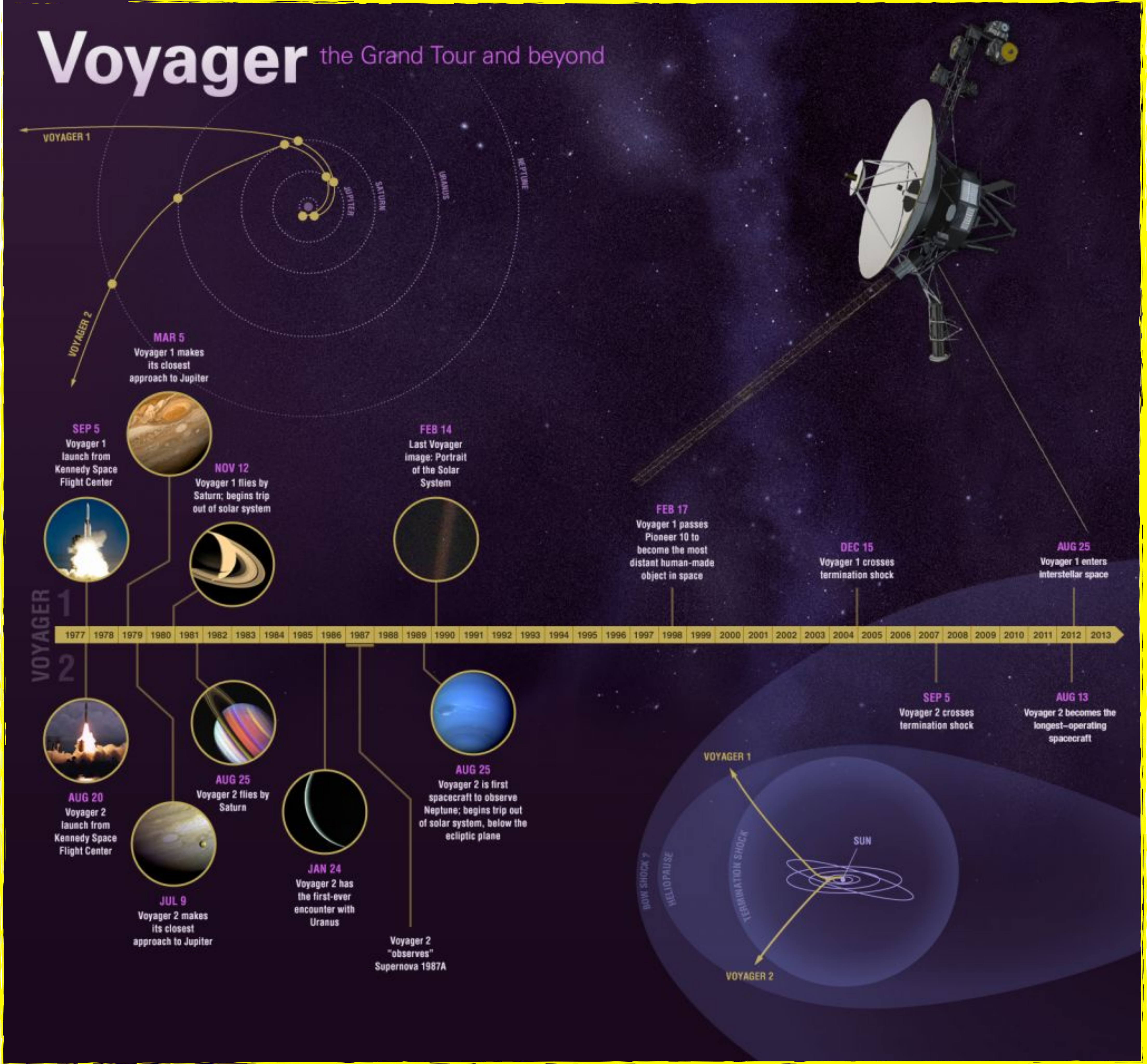

Apollo 11 timeline
1 July 16 1969
2.32pm UK time
Saturn V launches from Kennedy Space Centre, Florida
2 2h 50mins since launch
Leaves Earth's orbit
3 4h 17mins
Jettison of final booster engine. Command/lunar modules continue to Moon
4 75h 49mins (July 19)
Enters Moon's orbit
5 100h 12mins (July 20)
Command and lunar modules separate. Command module continues to orbit Moon
6 102h 45mins
9.17pm UK time
Lunar module lands on Moon.
Neil Armstrong sets foot on surface at 3.56am July 21.
Module takes off at 6.54pm
7 128h 3mins
Lunar module redocks with command module
8 130h 30mins (July 22)
Lunar module jettisoned
9 135h 23mins
Command module leaves Moon's orbit
10 195h 3mins (July 24)
Command module re-enters Earth's atmosphere
11 195h 18mins
5.50pm UK time
Splashdown in Pacific Ocean

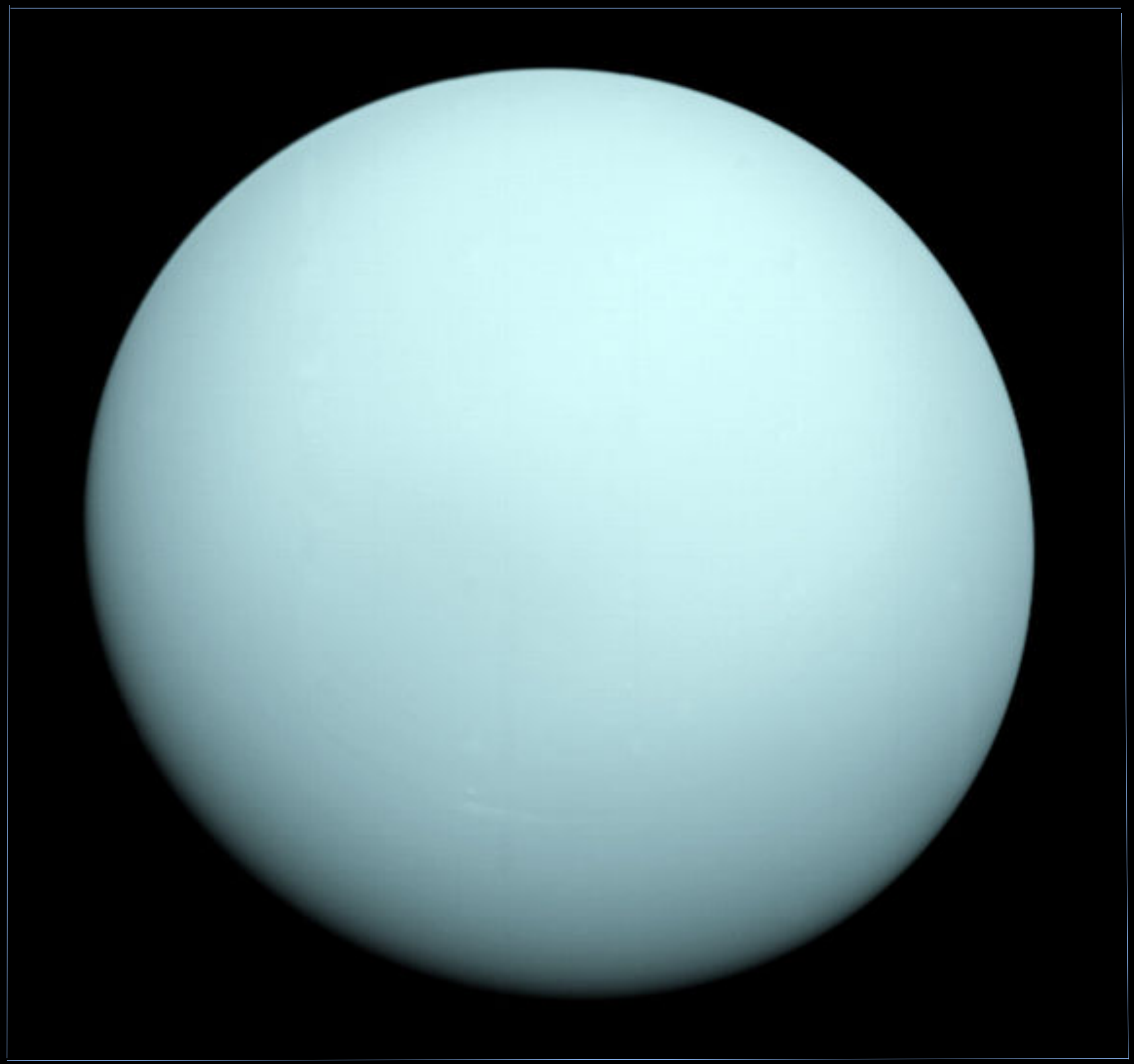


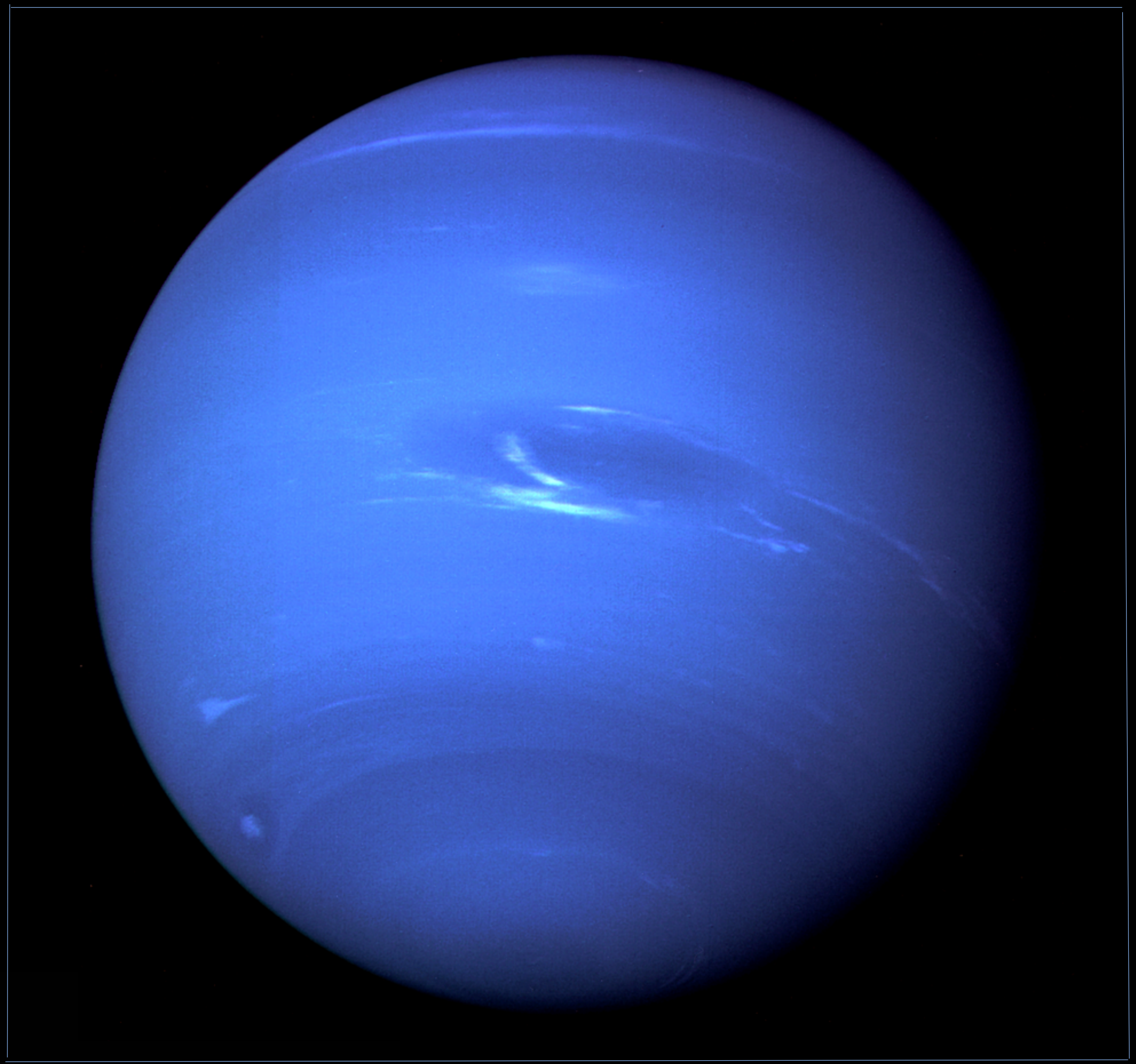
Jim Irwin sets up the first Lunar Rover Vehicle during Apollo 15 in 1971

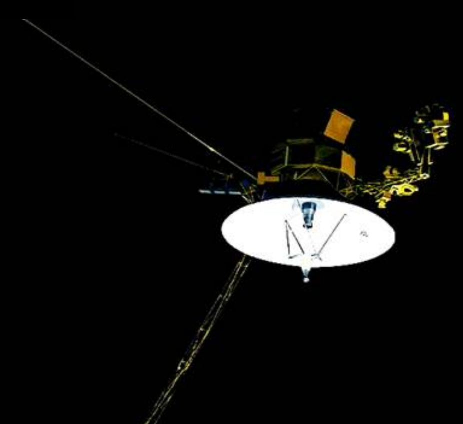


Mariner 10 was an American robotic space probe launched by NASA on November 3, 1973 to fly by the planets Mercury and Venus

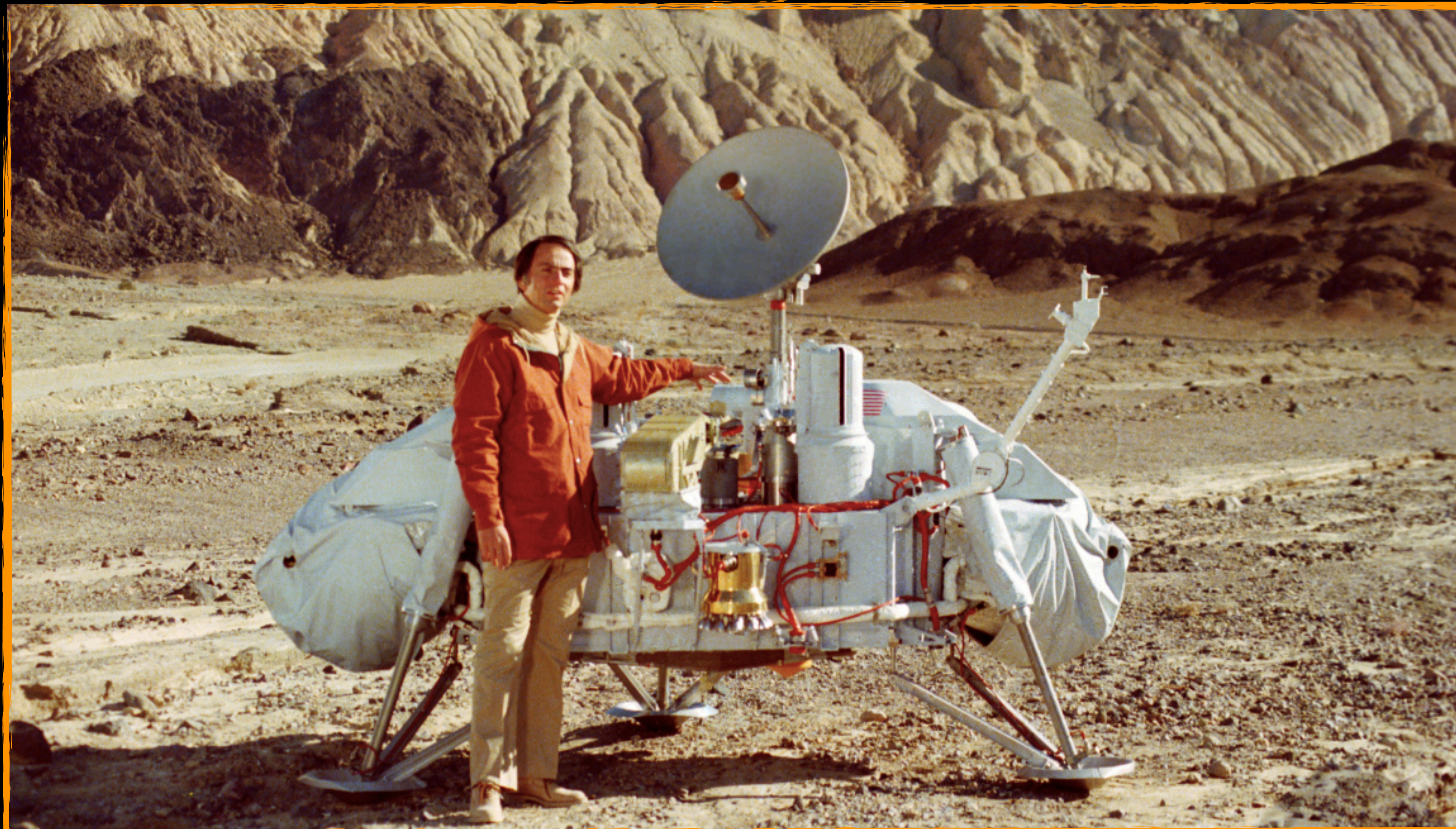

Voyager the Grand Tour and beyond
VOYAGER 1
VOYAGER 2
JUPITER
SATURN
URANUS
NEPTUNE
VOYAGER 1
VOYAGER 2
SEP 5
Voyager 1 launch from Kennedy Space Flight Center
MAR 5
Voyager 1 makes its closest approach to Jupiter
NOV 12
Voyager 1 flies by Saturn; begins trip out of solar system
FEB 14
Last Voyager image: Portrait of the Solar System
FEB 17
Voyager 1 passes Pioneer 10 to become the most distant human-made object in space
DEC 15
Voyager 1 crosses termination shock
AUG 25
Voyager 1 enters interstellar space
1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013
AUG 20
Voyager 2 launch from Kennedy Space Flight Center
JUL 9
Voyager 2 makes its closest approach to Jupiter
AUG 25
Voyager 2 flies by Saturn
JAN 24
Voyager 2 has the first-ever encounter with Uranus
Voyager 2 "observes" Supernova 1987A
AUG 25
Voyager 2 is first spacecraft to observe Neptune; begins trip out of solar system, below the ecliptic plane
SEP 5
Voyager 2 crosses termination shock
AUG 13
Voyager 2 becomes the longest-operating spacecraft
VOYAGER 1
SUN
BOW SHOCK ?
HELIOPAUSE
TERMINATION SHOCK
VOYAGER 2







Uranus and Neptune with Voyager 2, Picture from Neptuno was taken at a range of 4.4 million miles from the planet, 4 days and 20 hours before closest approach

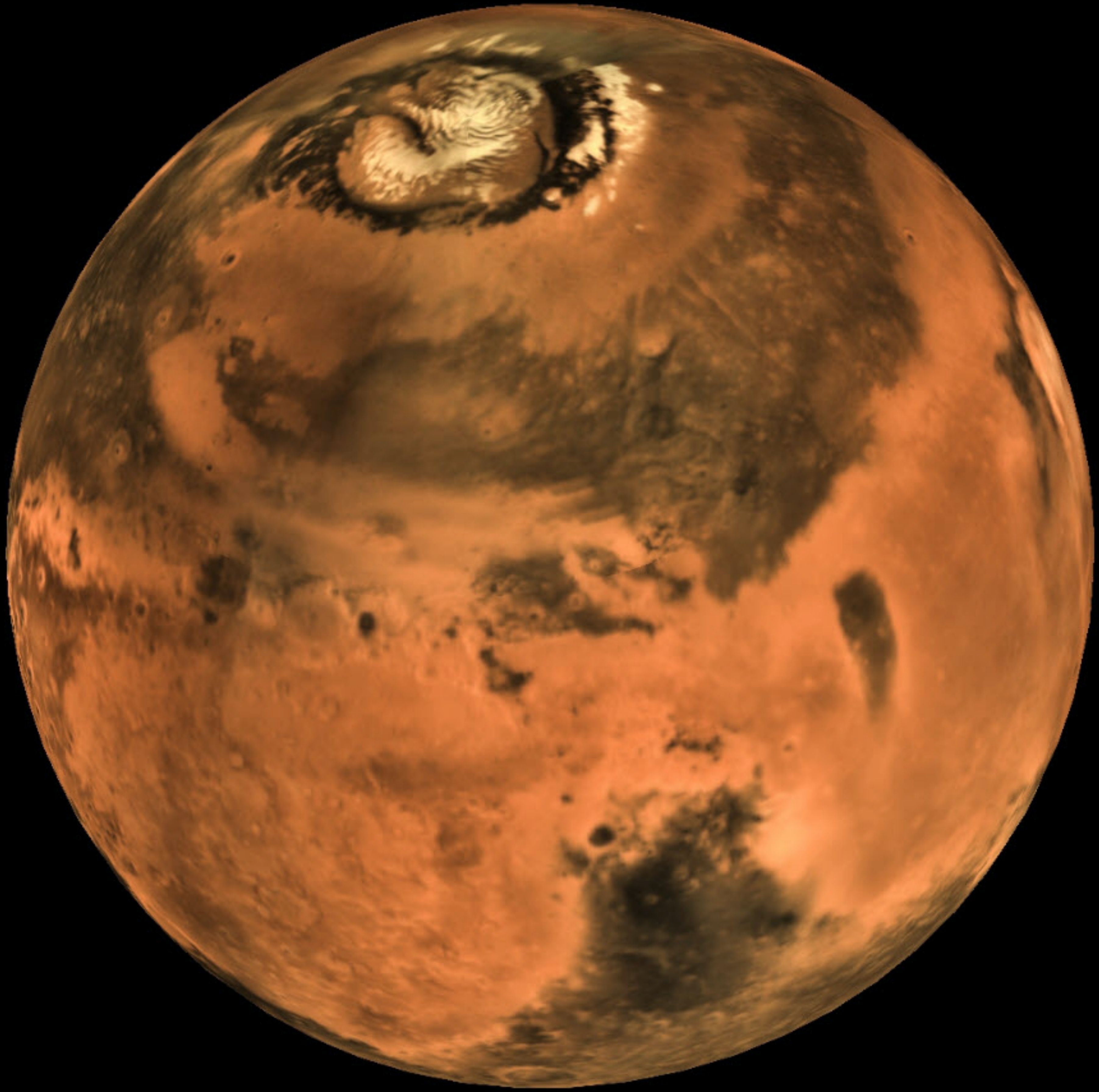


The Soviet Mars 3 achieved the first soft landing on Mars in 1971, but its instruments stopped working after only 20 seconds on the surface

The Twin Vikings landed on Mars in 1976

Viking 2 returned data until 1980, and contact with Viking 1 was lost in late 1982

Carl Sagan next to Viking lander mockup in Death Valley, California



The Mars Orbiter Camera was in orbit around Mars between 1997 and 2006
(MOC)

The largest volcano in the solar system

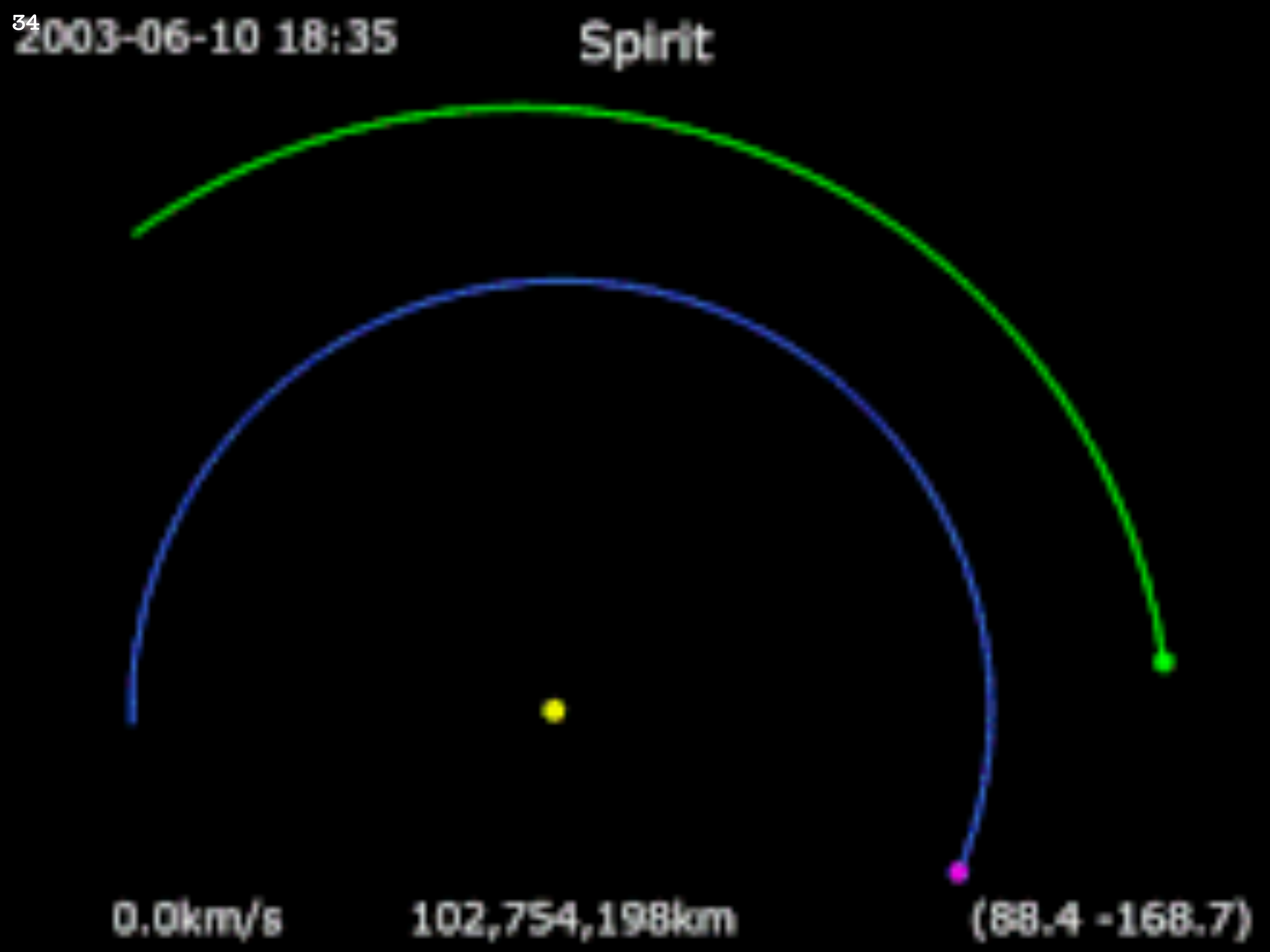
MOC obtained this spectacular wide-angle view of Olympus Mons on Mars Global Surveyor's 263rd orbit (April 25 1998)

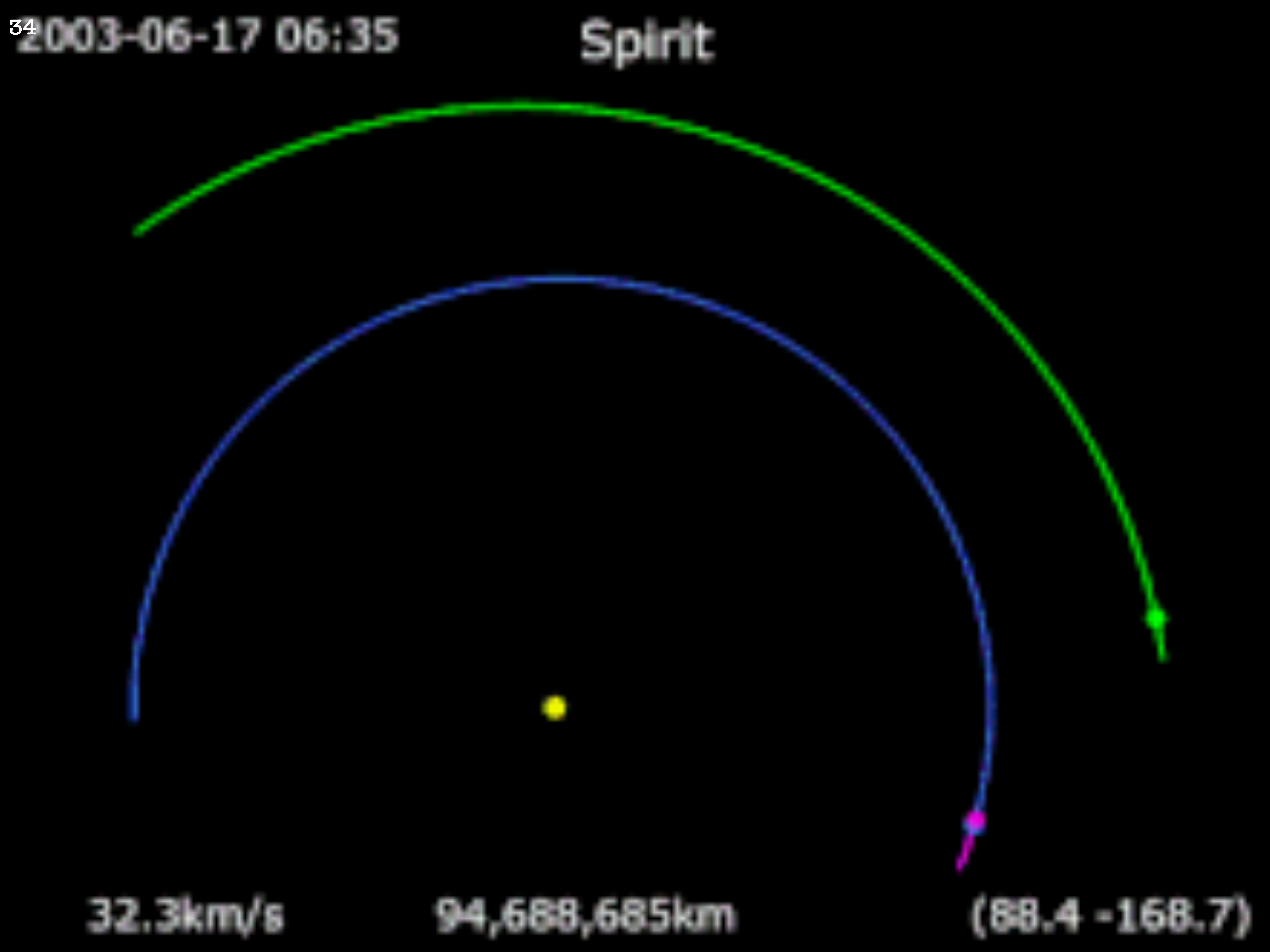
Giant volcano on Mars ☛ three times as high as Everest and as wide as France

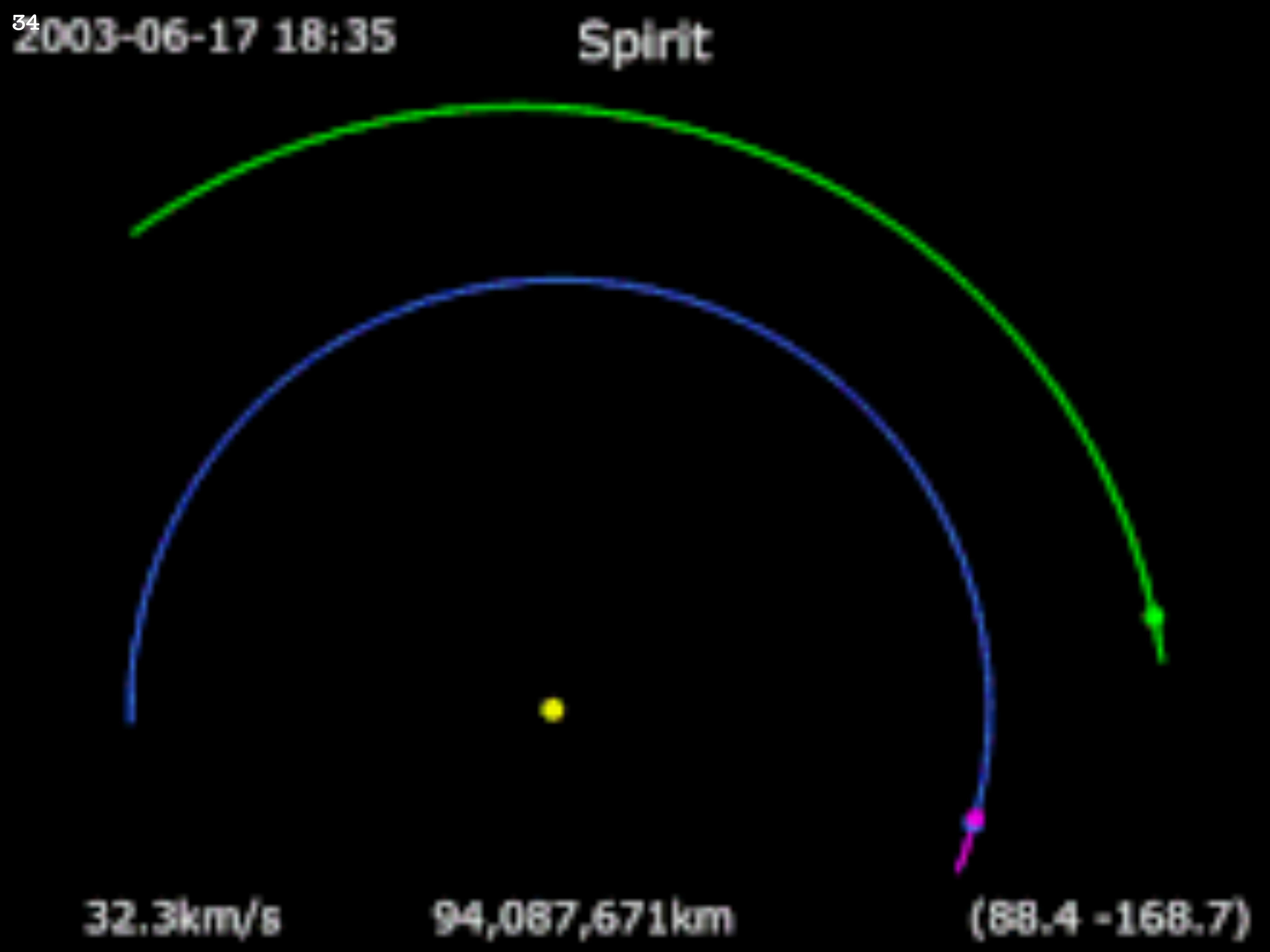
8.8km

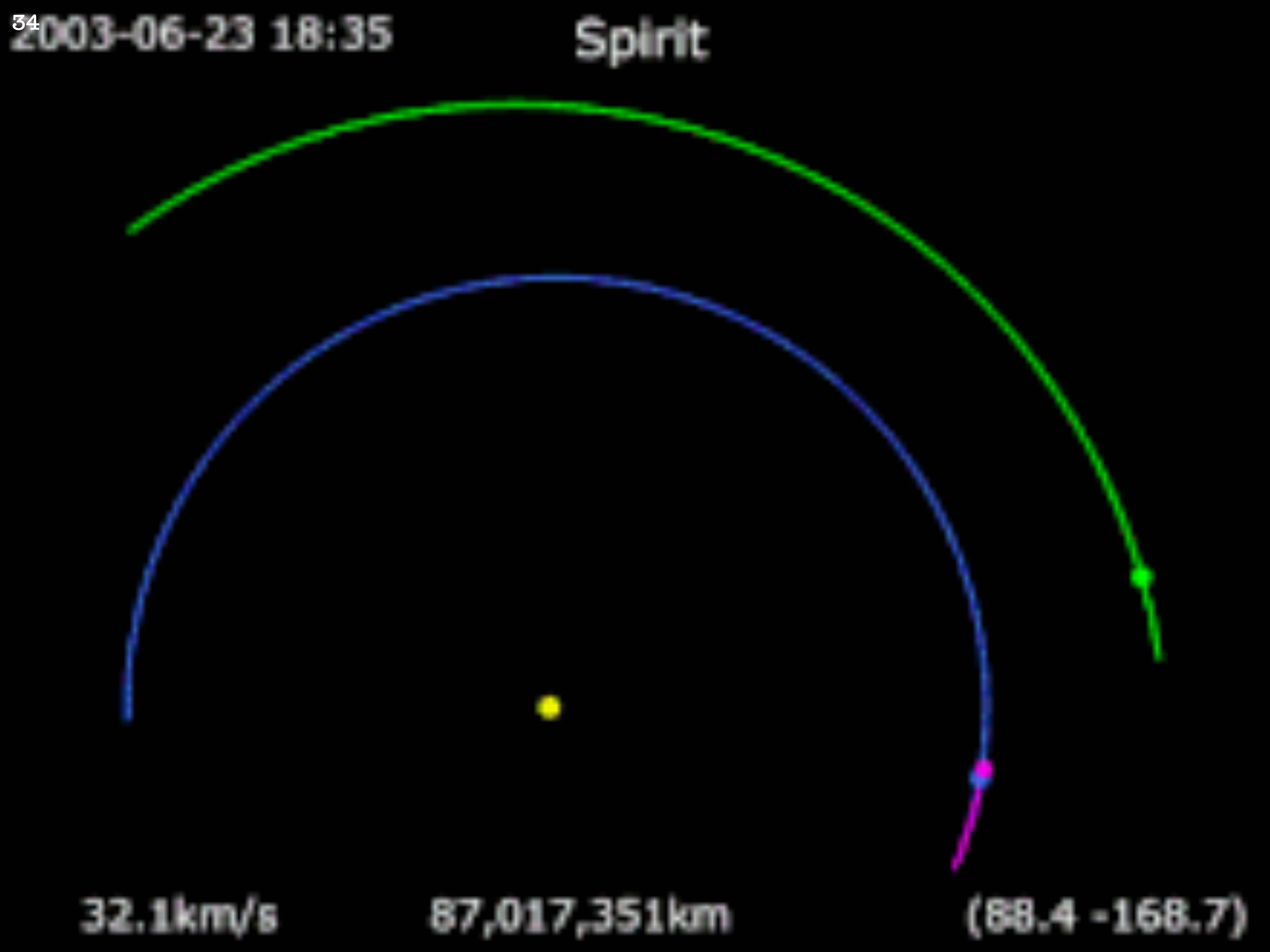
NASA's Spirit and Opportunity Mars rovers landed on the Red Planet on Jan. 3 and 24, 2004, respectively

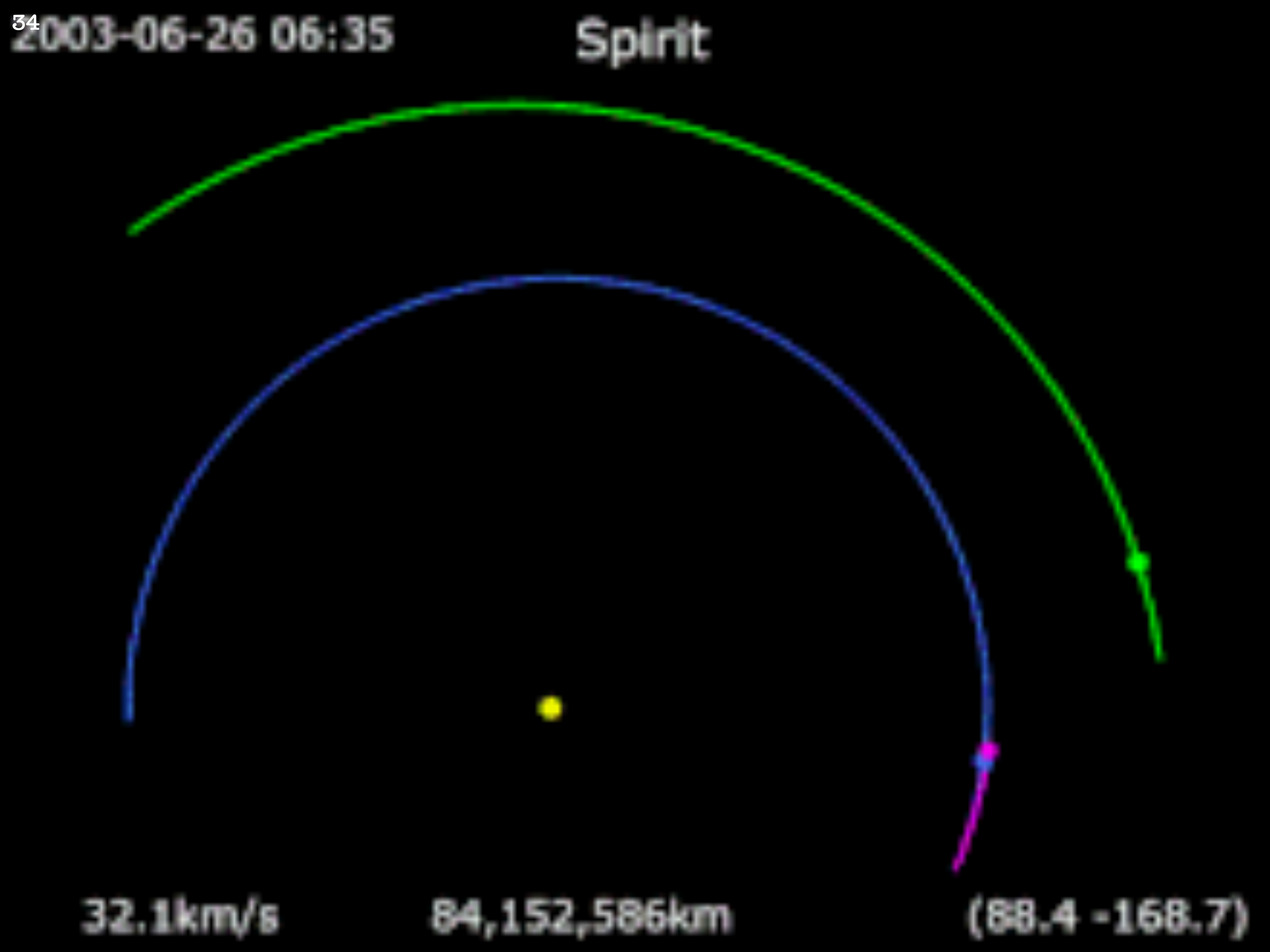
This image shows a view Opportunity captured of its own shadow on July 26 of that year, the 180th Martian day of its mission

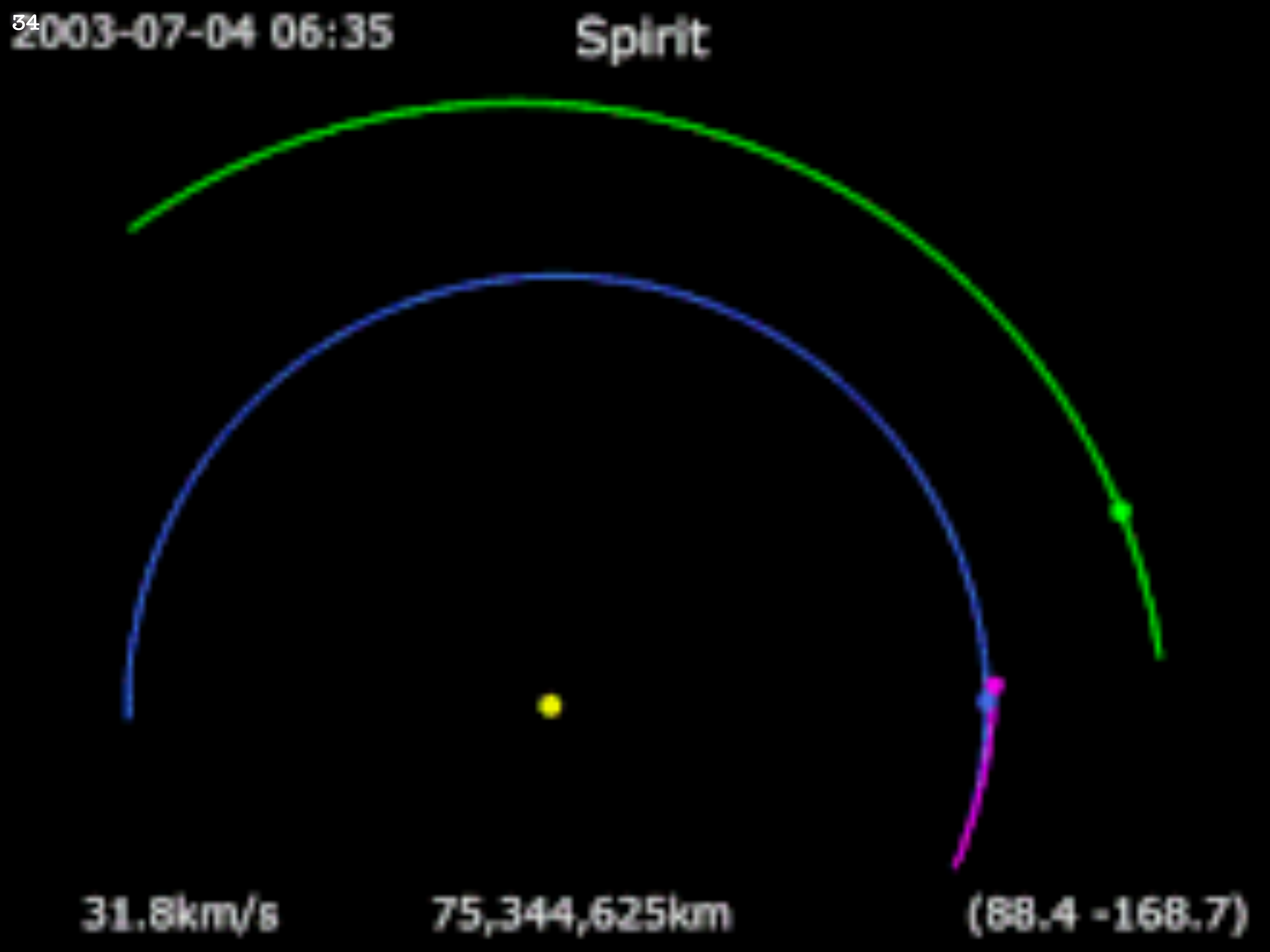

2003-06-10 18:35
Spirit
0.0km/s
102,754,198km
(88.4 -168.7)

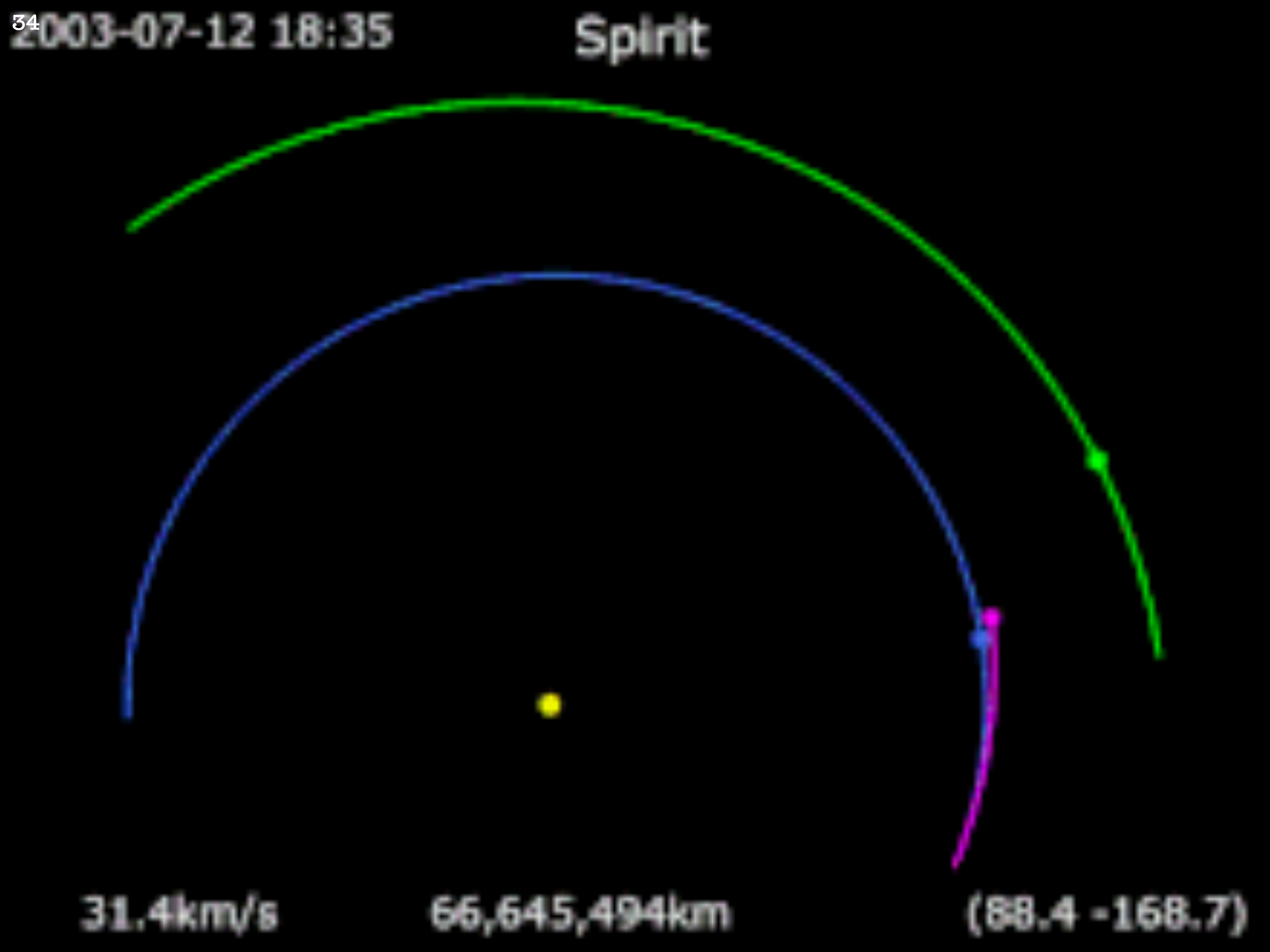

34
2003-06-17 06:35
Spirit
32.3km/s
94,688,685km
(88.4 -168.7)

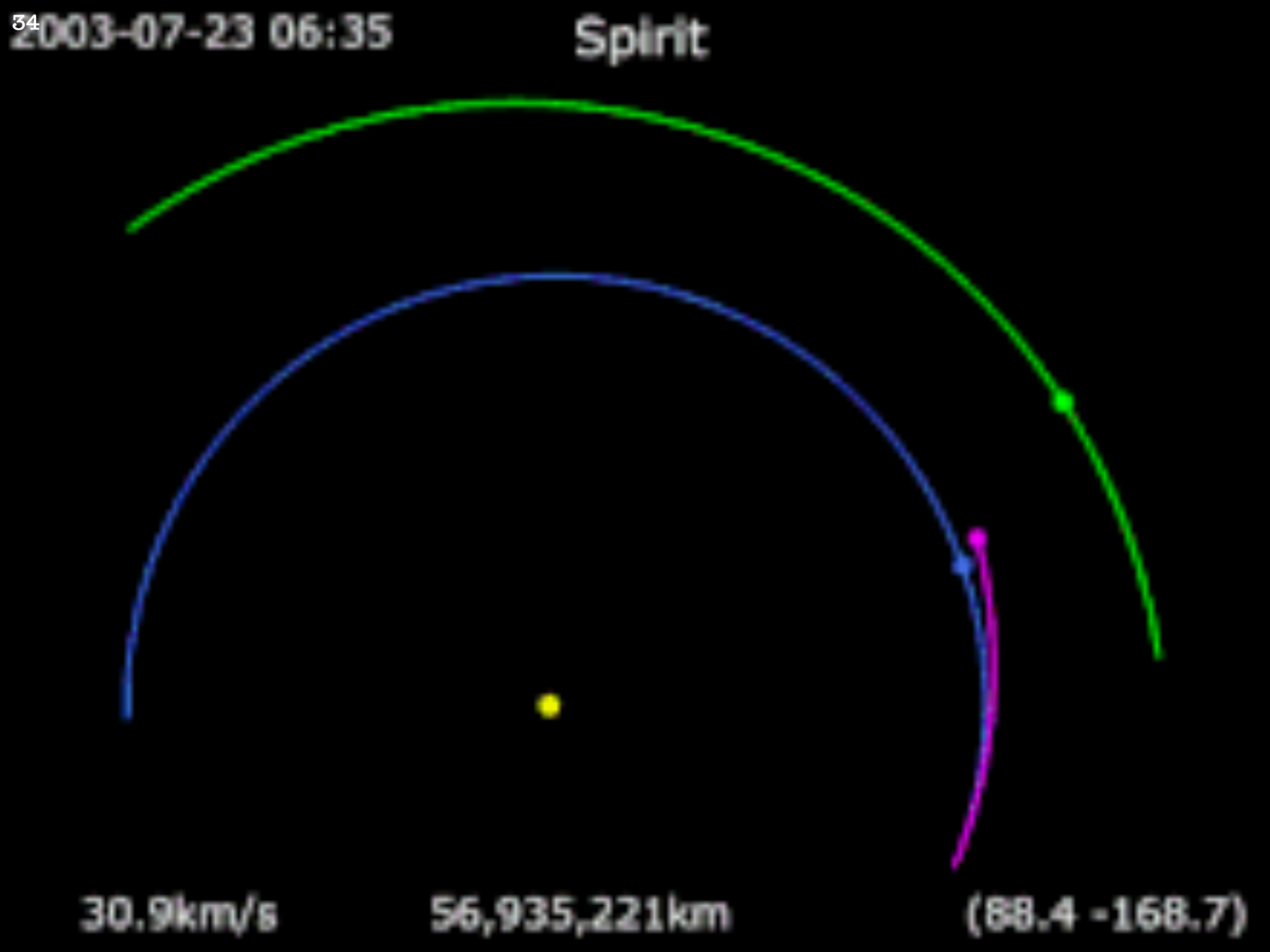

2003-06-17 18:35
Spirit
32.3km/s
94,087,671km
(88.4 -168.7)

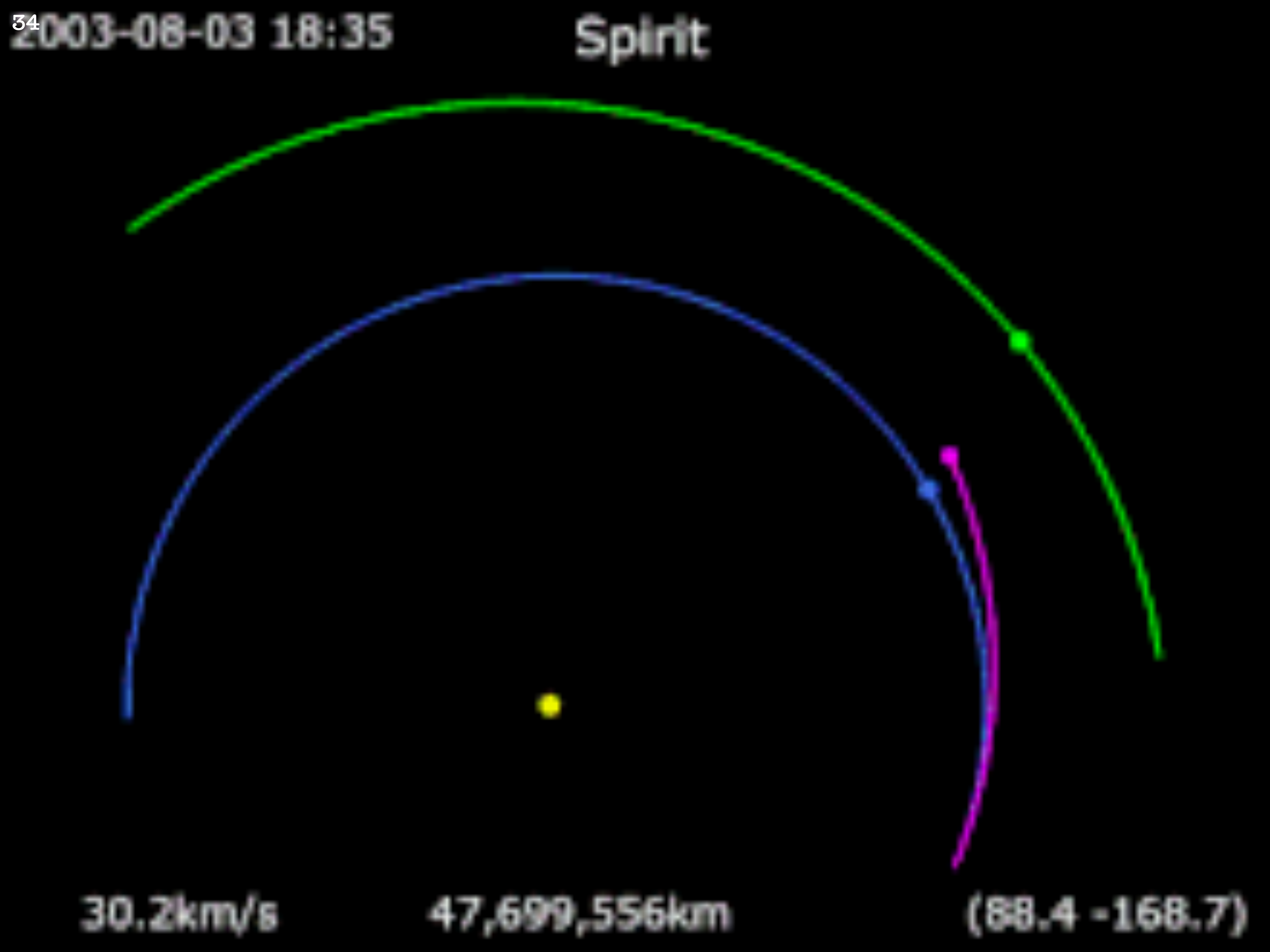

2003-06-23 18:35
Spirit
32.1km/s
87,017,351km
(88.4 -168.7)

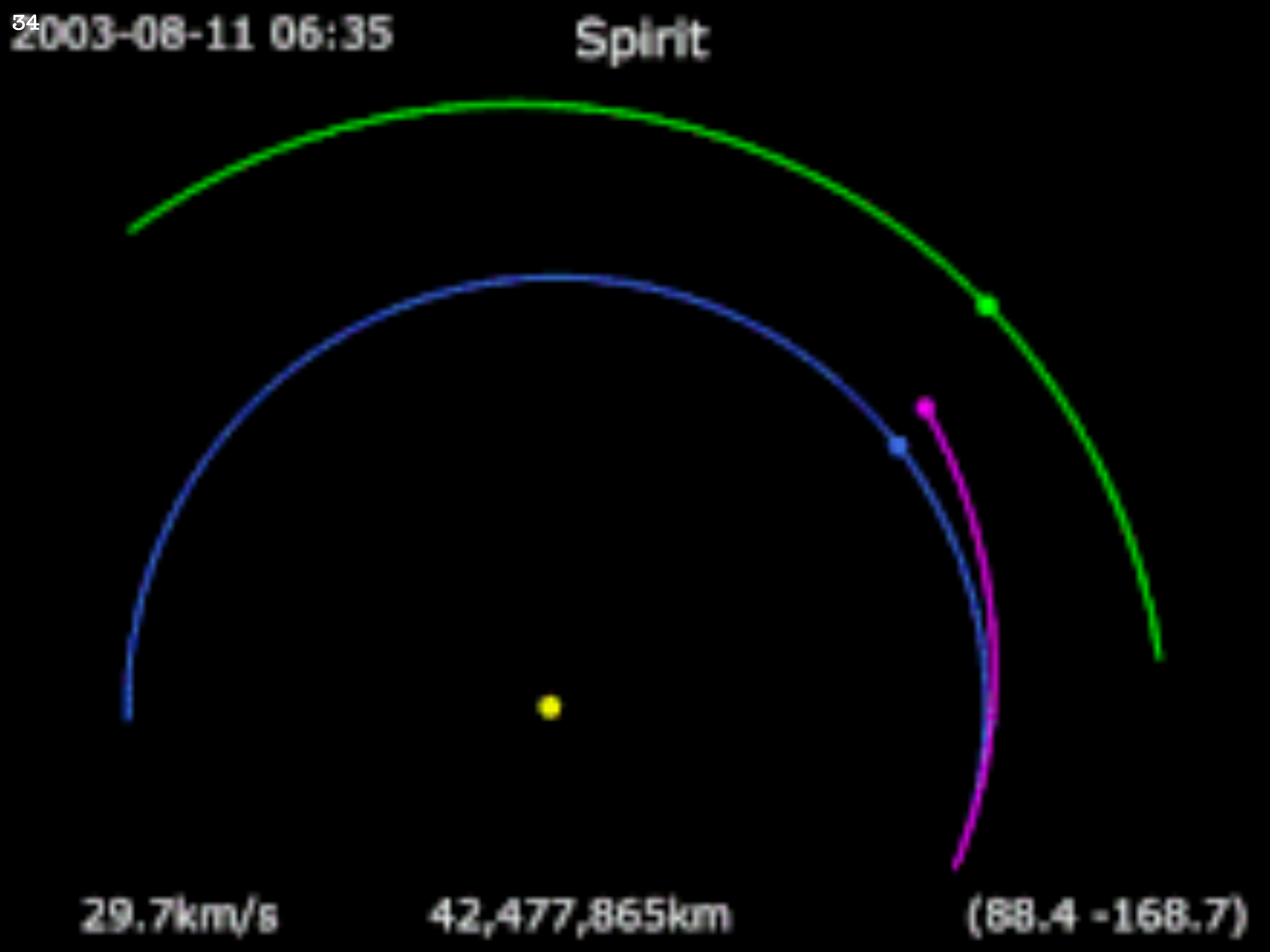

34
2003-06-26 06:35
Spirit
32.1km/s
84,152,586km
(88.4 -168.7)

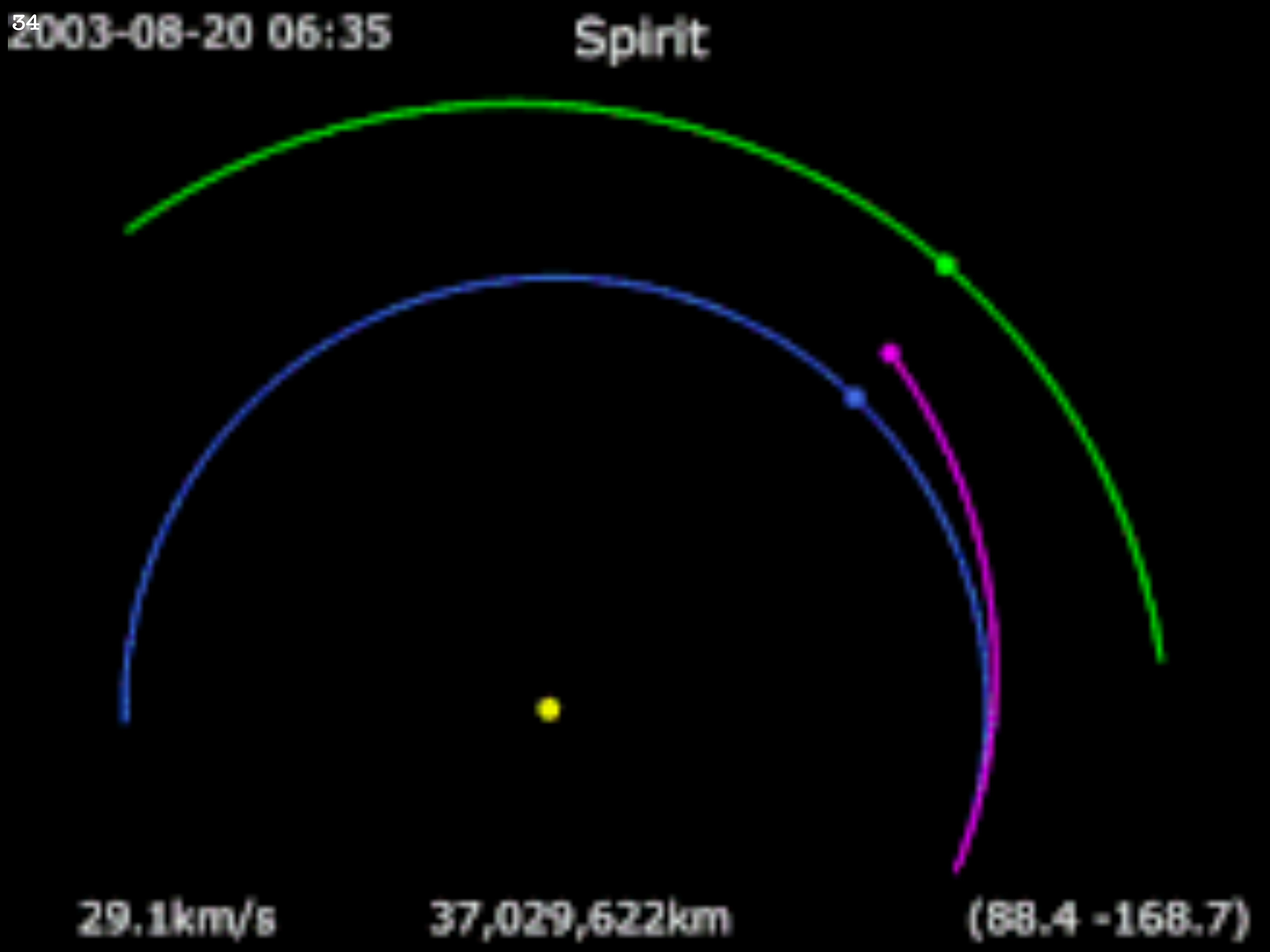

34
2003-07-04 06:35
Spirit
31.8km/s
75,344,625km
(88.4 -168.7)

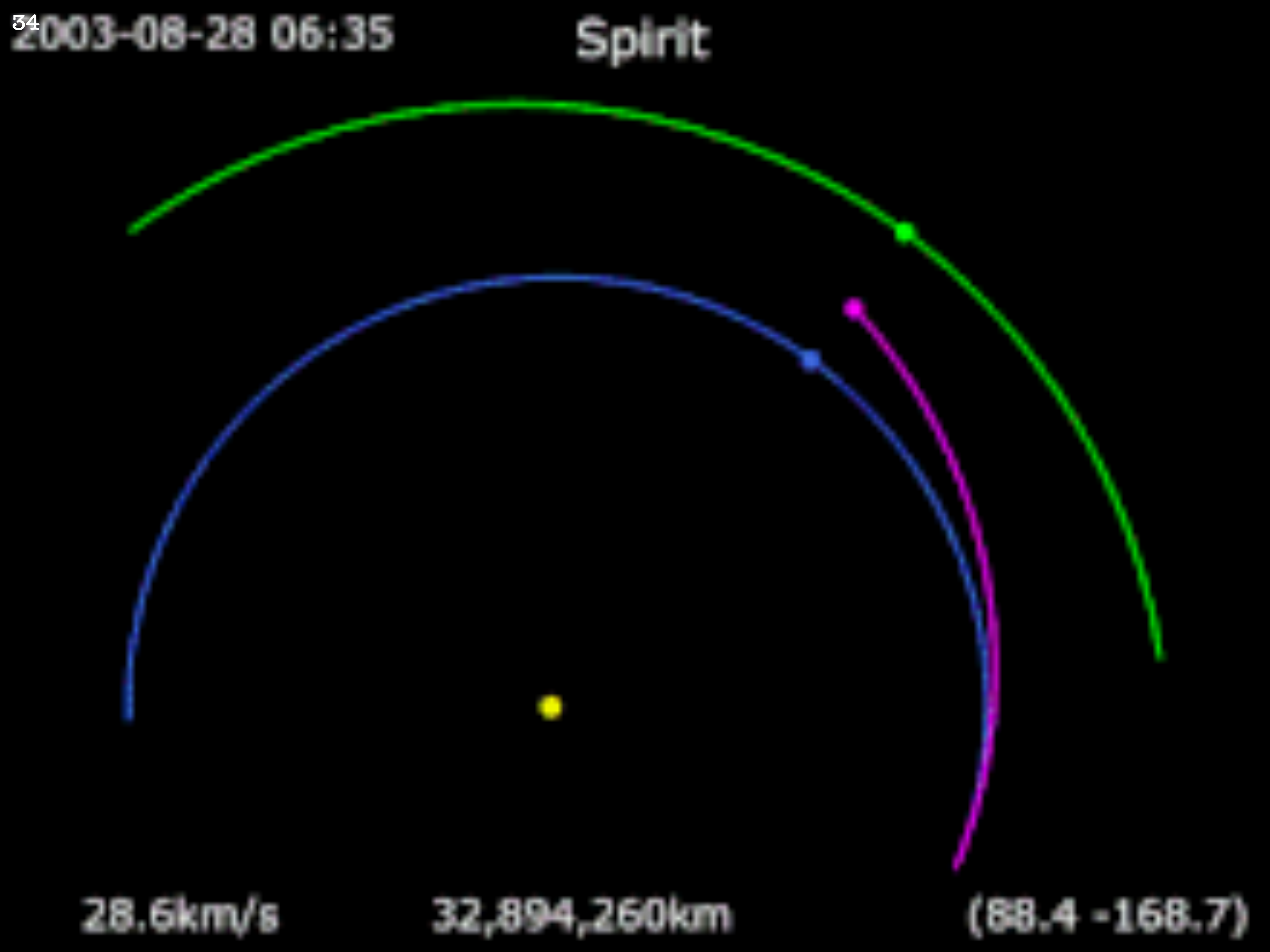

2003-07-12 18:35
Spirit
31.4km/s
66,645,494km
(88.4 -168.7)

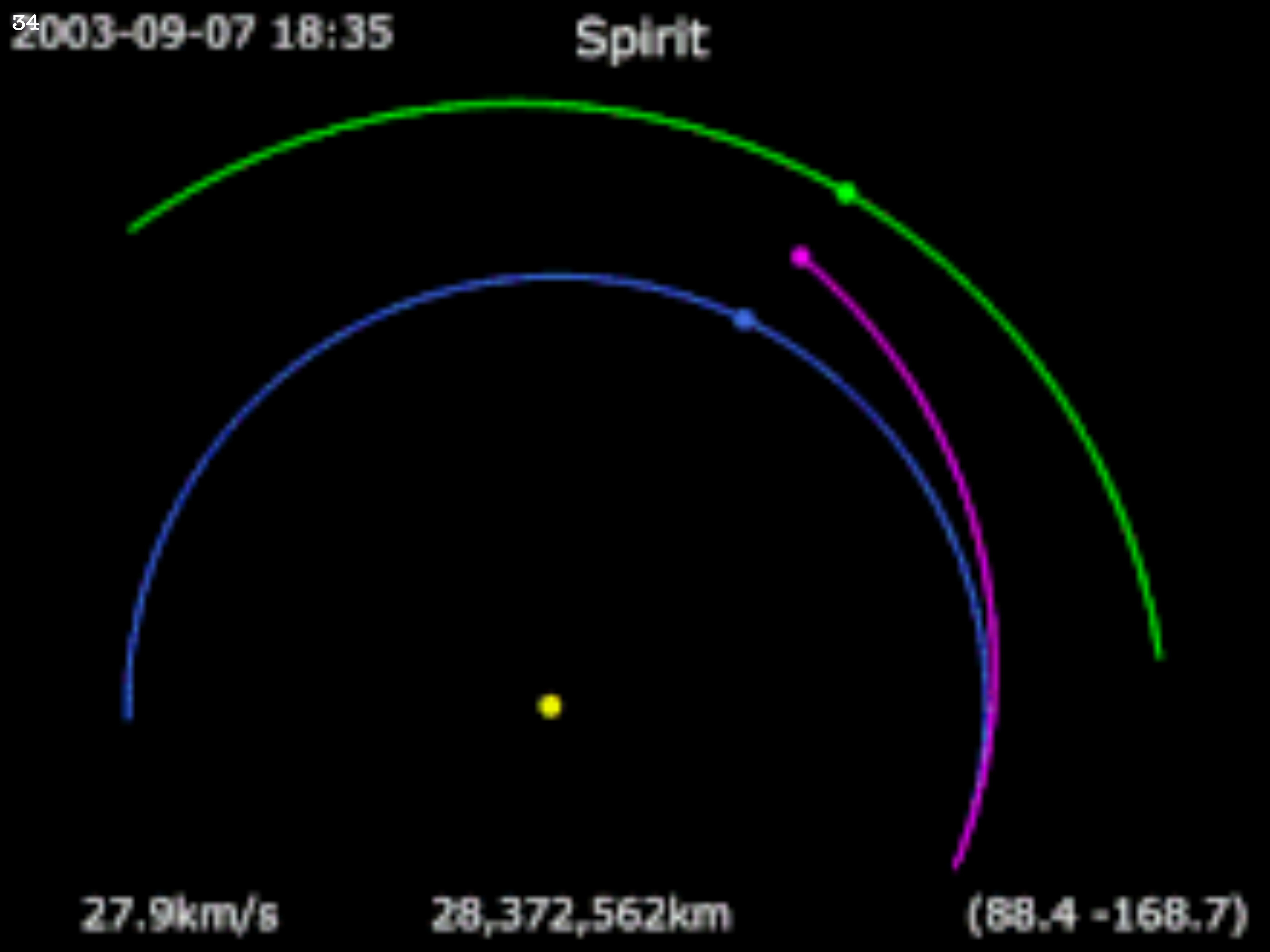

34
2003-07-23 06:35
Spirit
30.9km/s
56,935,221km
(88.4 -168.7)

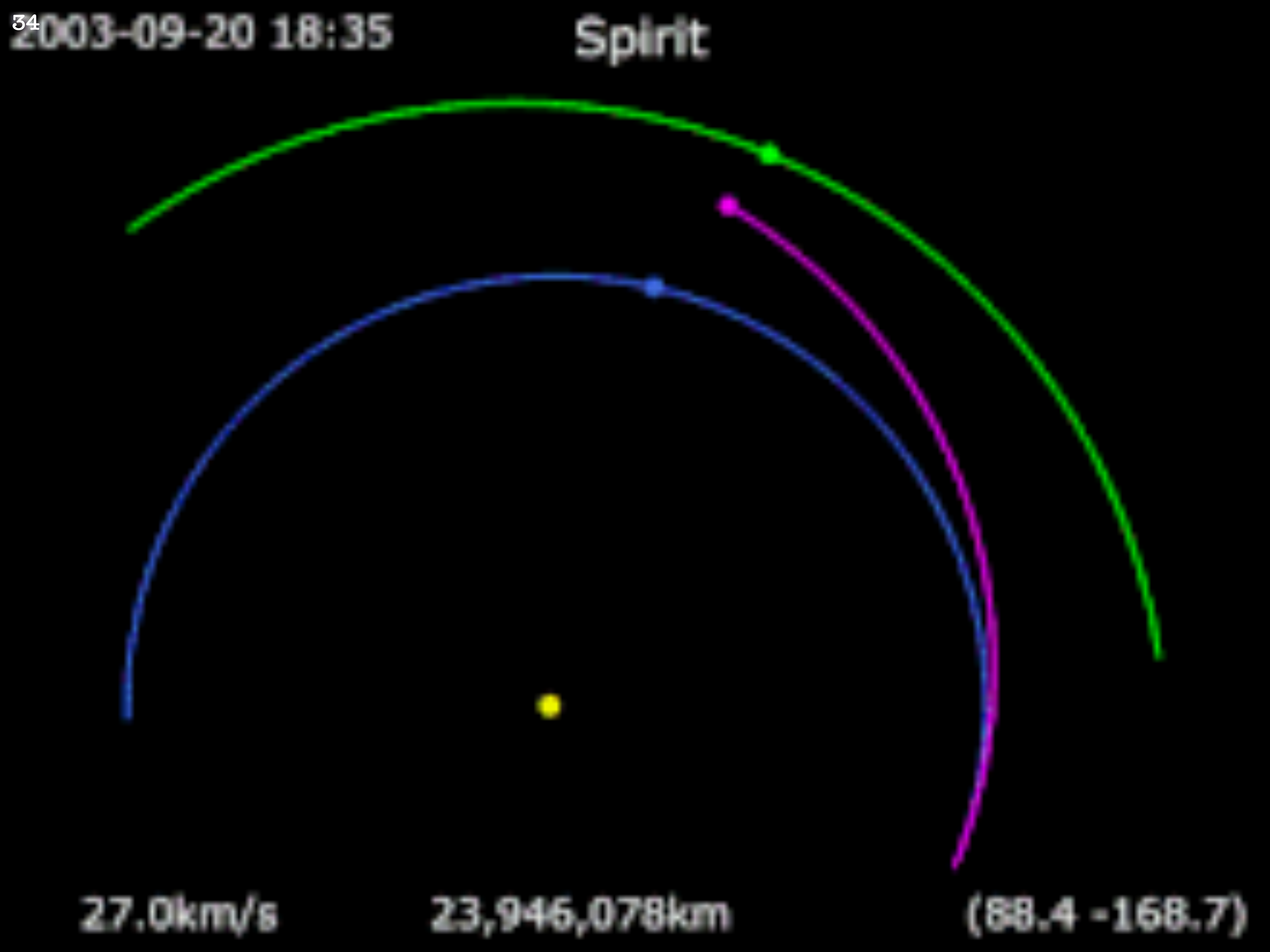

2003-08-03 18:35
Spirit
30.2km/s
47,699,556km
(88.4 -168.7)

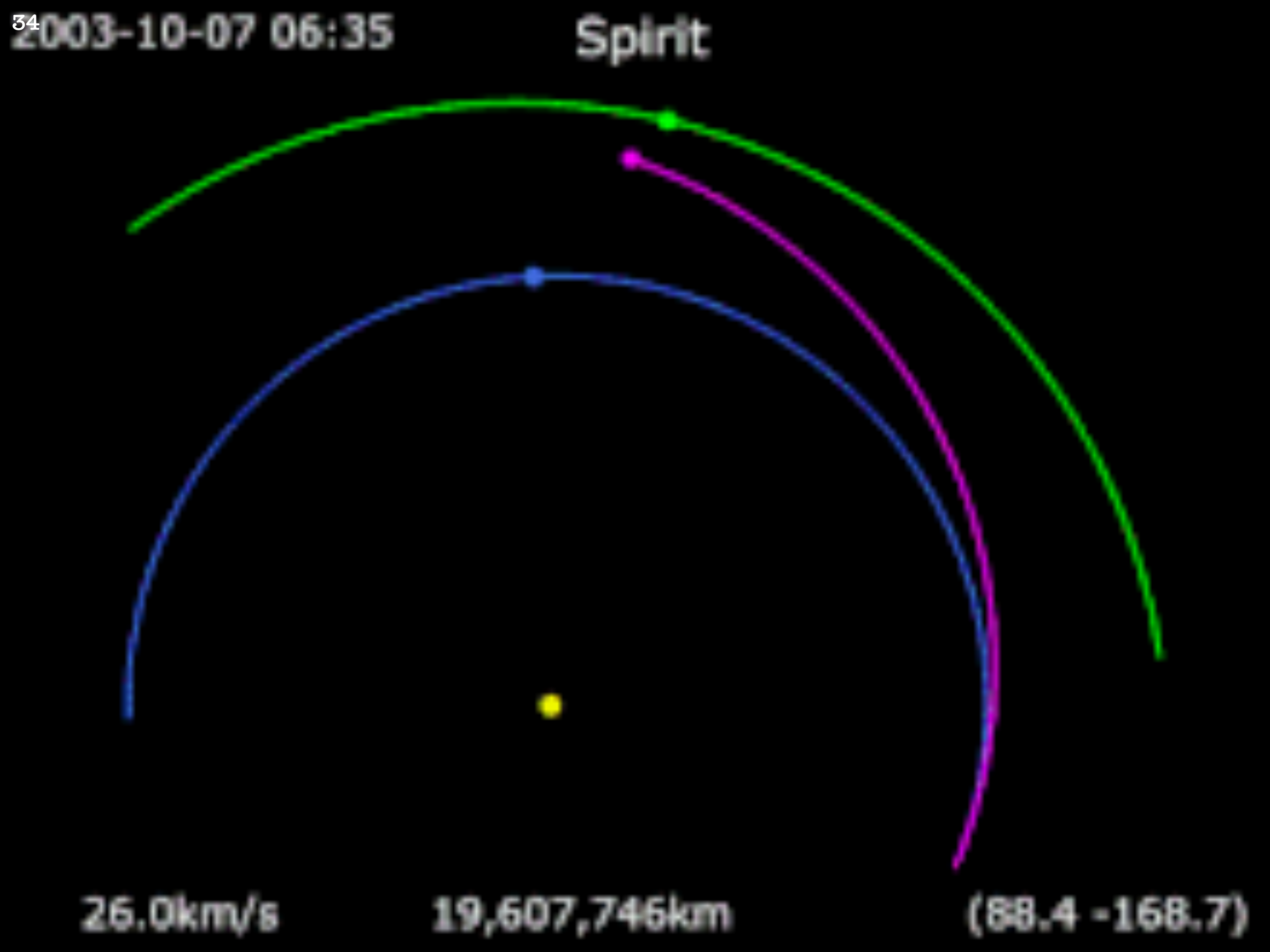

2003-08-11 06:35
Spirit
29.7km/s
42,477,865km
(88.4 -168.7)

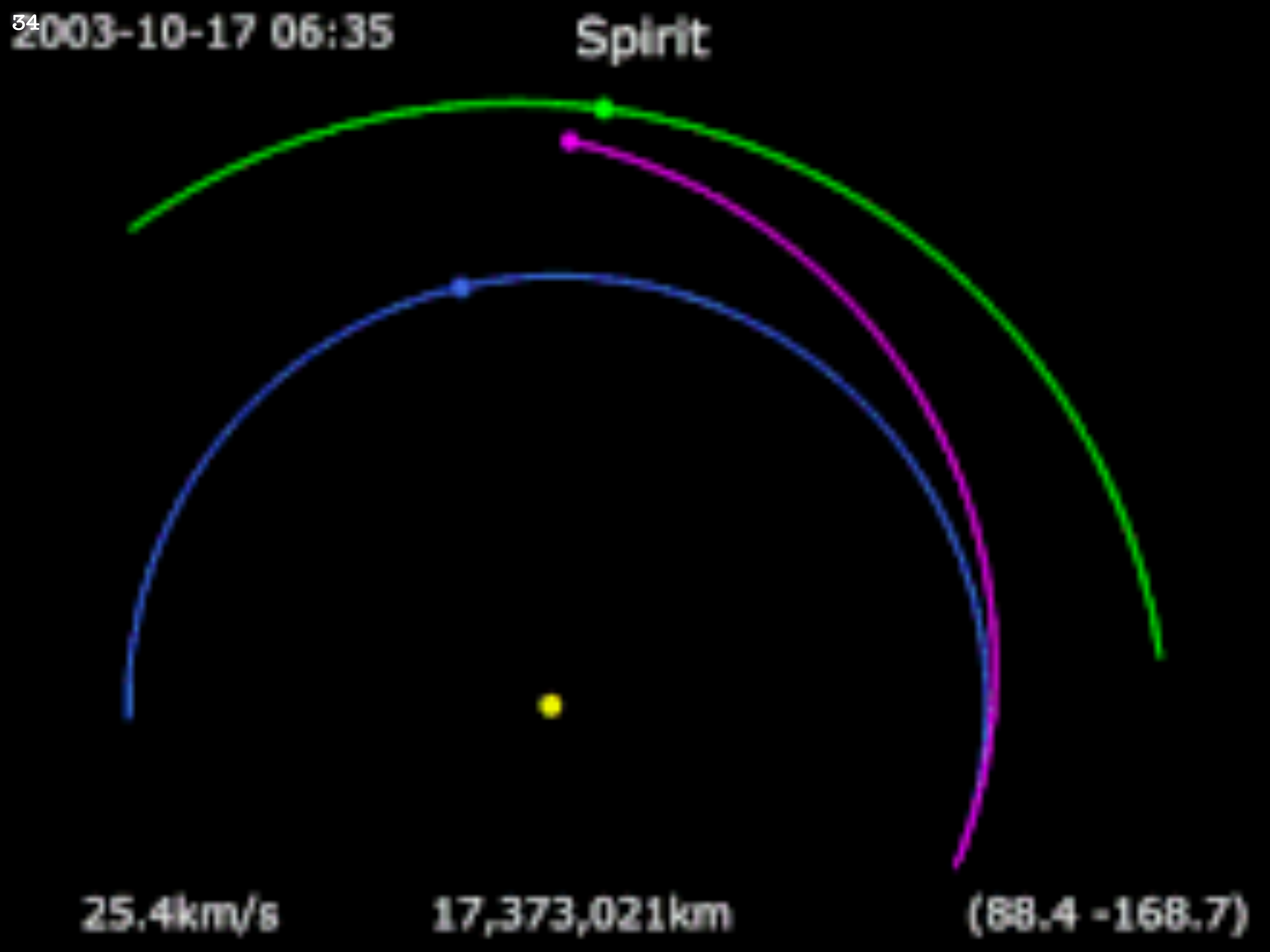

34
2003-08-20 06:35
Spirit
29.1km/s
37,029,622km
(88.4 -168.7)

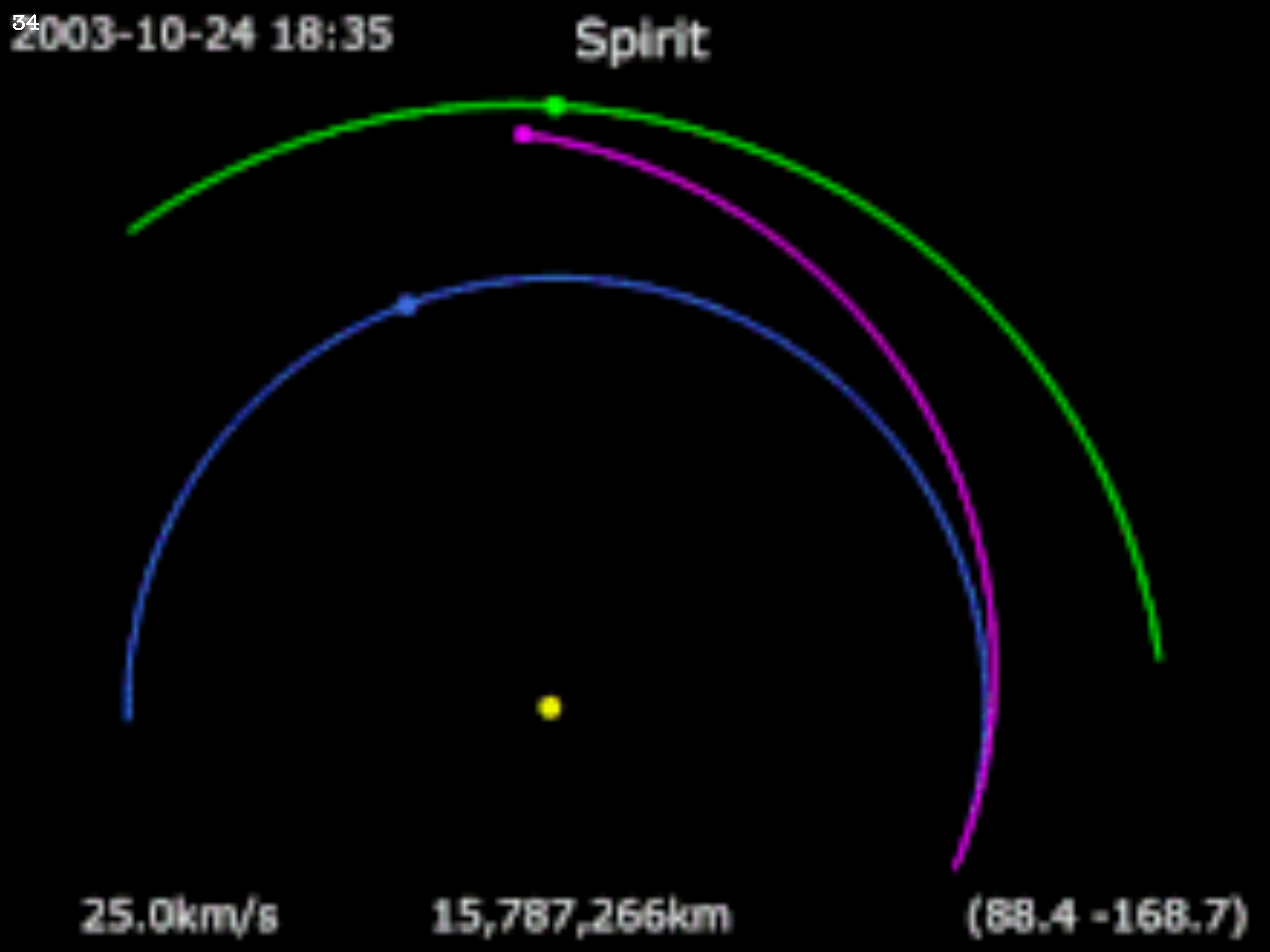

2003-08-28 06:35
Spirit
28.6km/s
32,894,260km
(88.4 -168.7)


2003-09-07 18:35
Spirit
27.9km/s
28,372,562km
(88.4 -168.7)

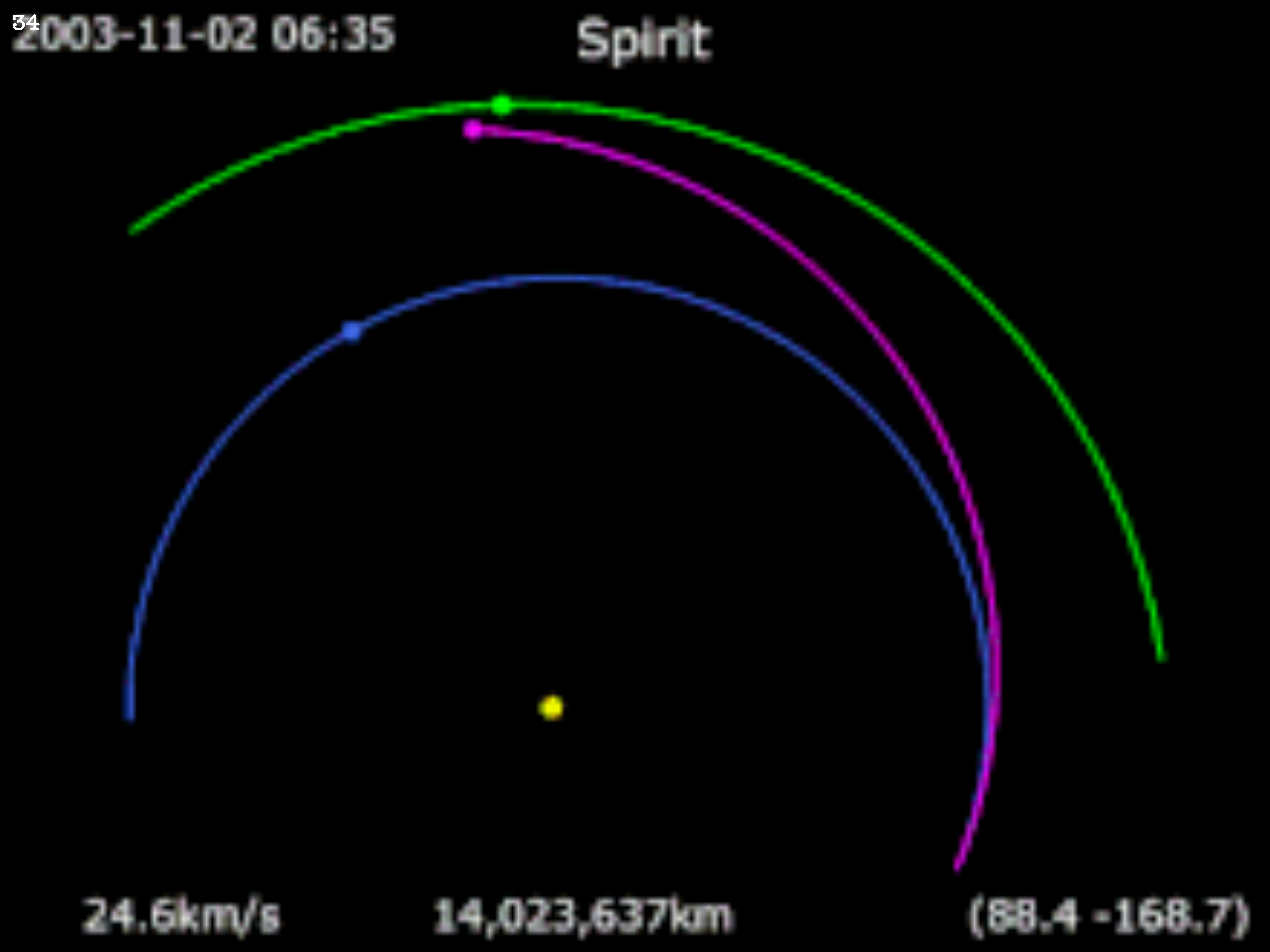

2003-09-20 18:35
Spirit
27.0km/s
23,946,078km
(88.4 -168.7)

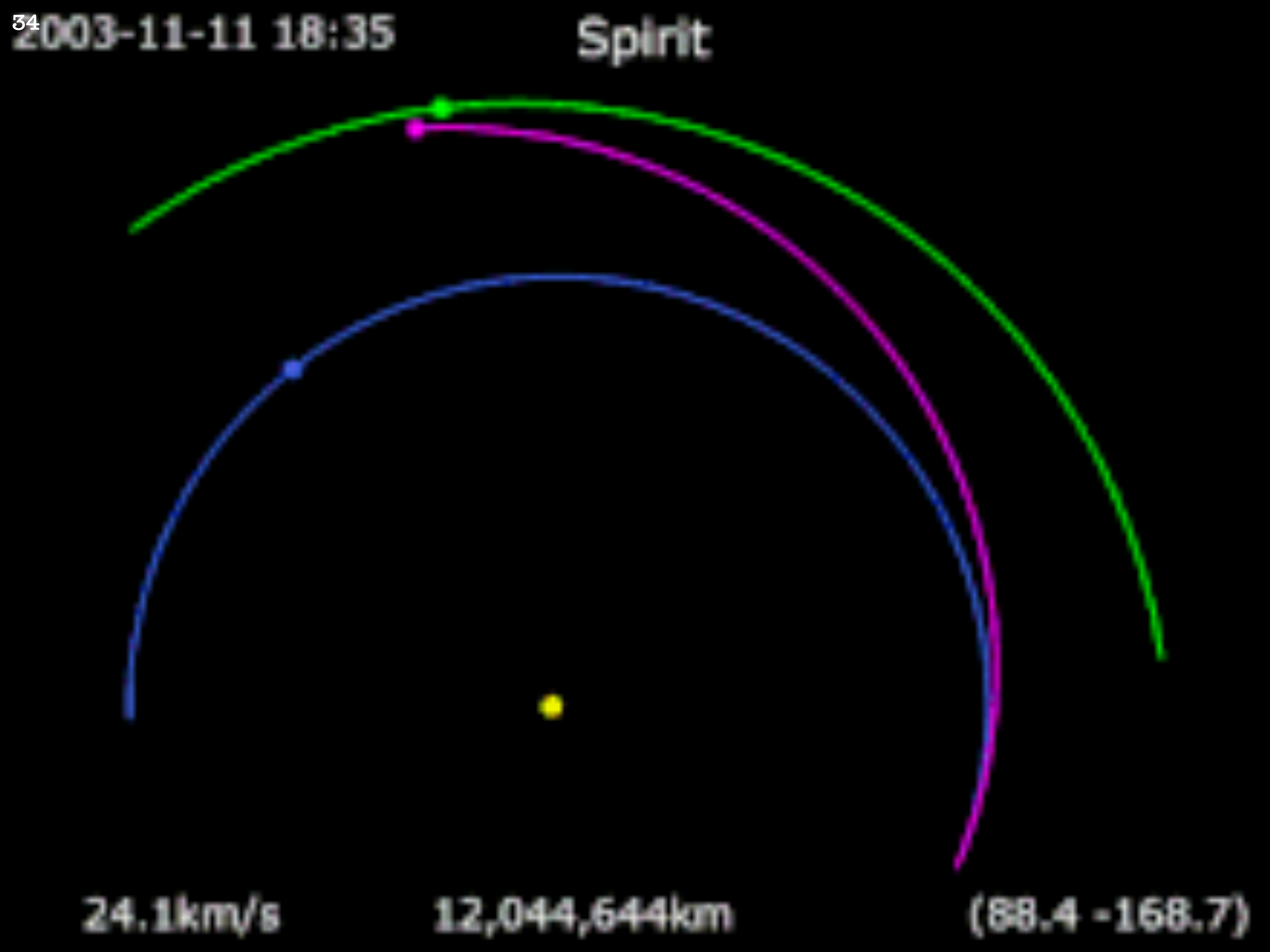

34
2003-10-07 06:35
Spirit
26.0km/s
19,607,746km
(88.4 -168.7)

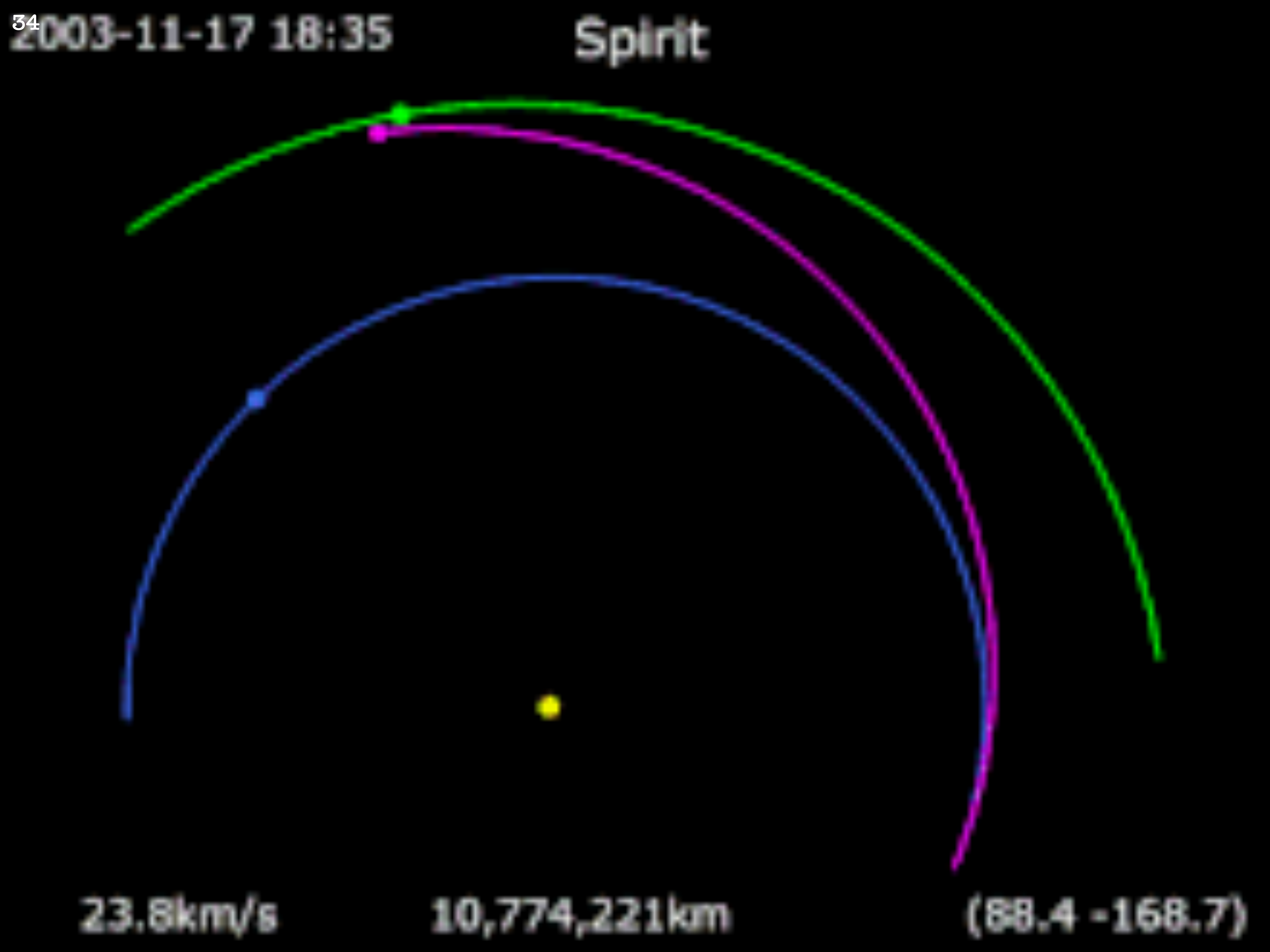

2003-10-17 06:35
Spirit
25.4km/s
17,373,021km
(88.4 -168.7)

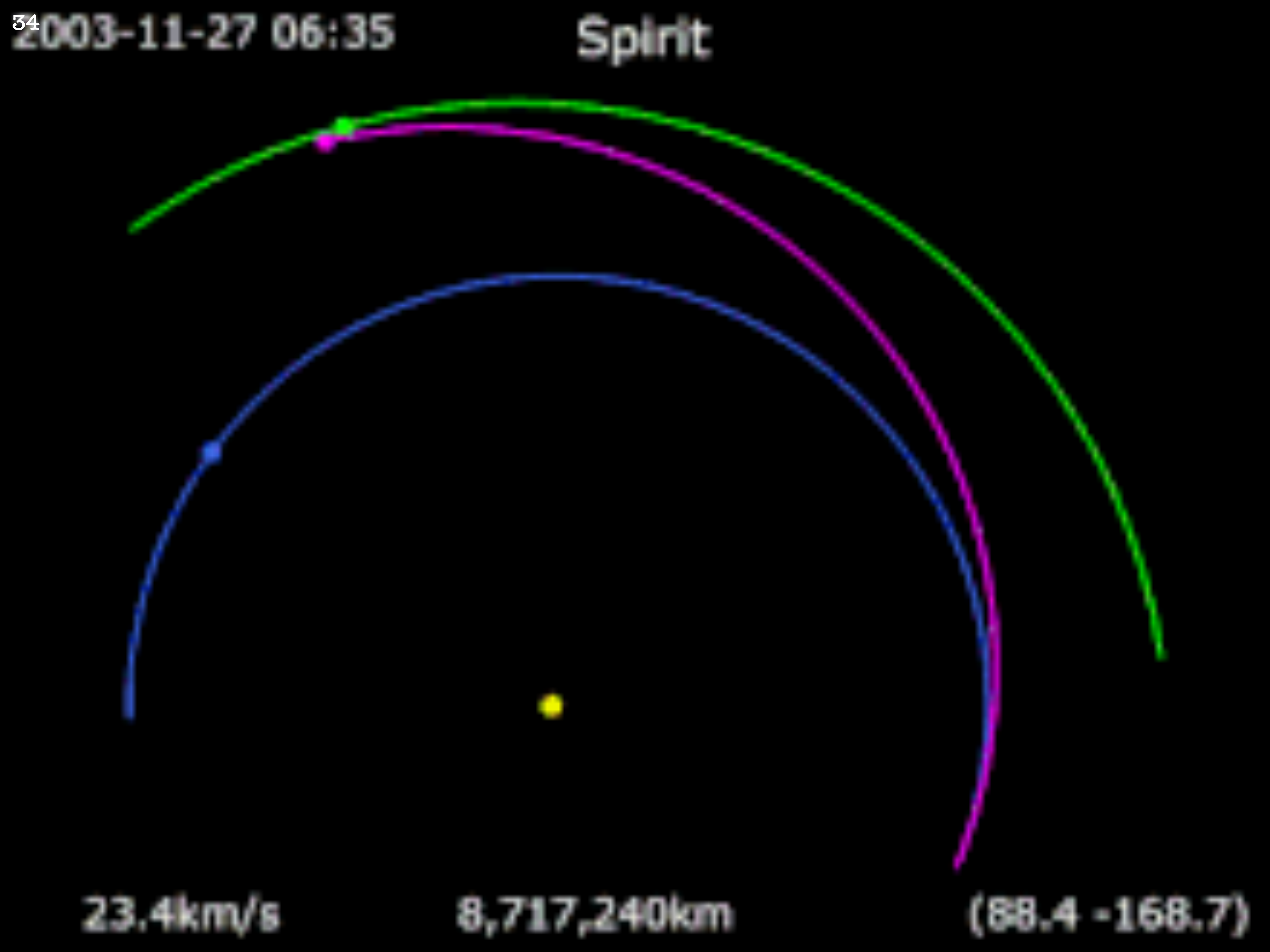


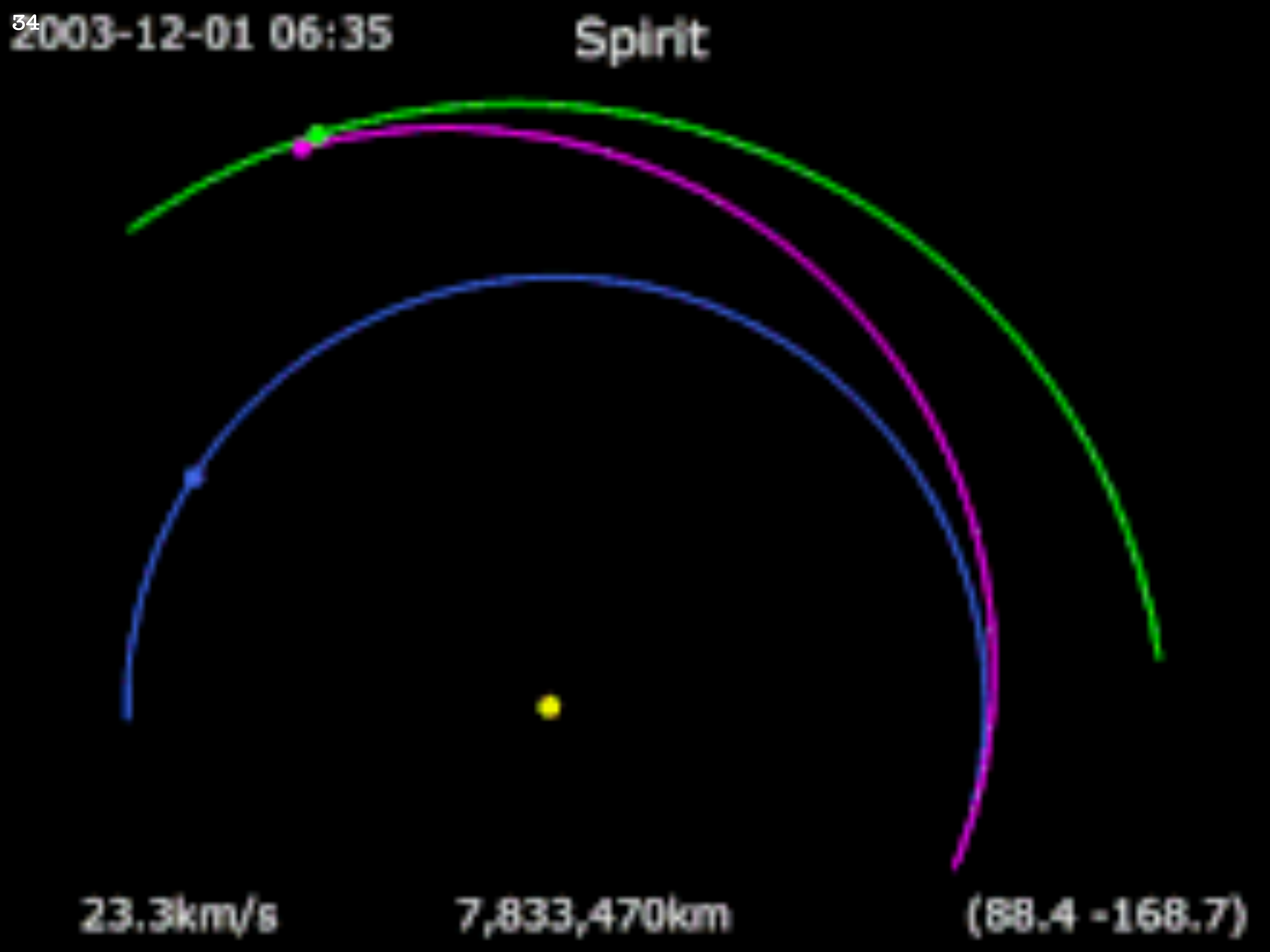
2003-10-24 18:35
Spirit
25.0km/s
15,787,266km
(88.4 -168.7)

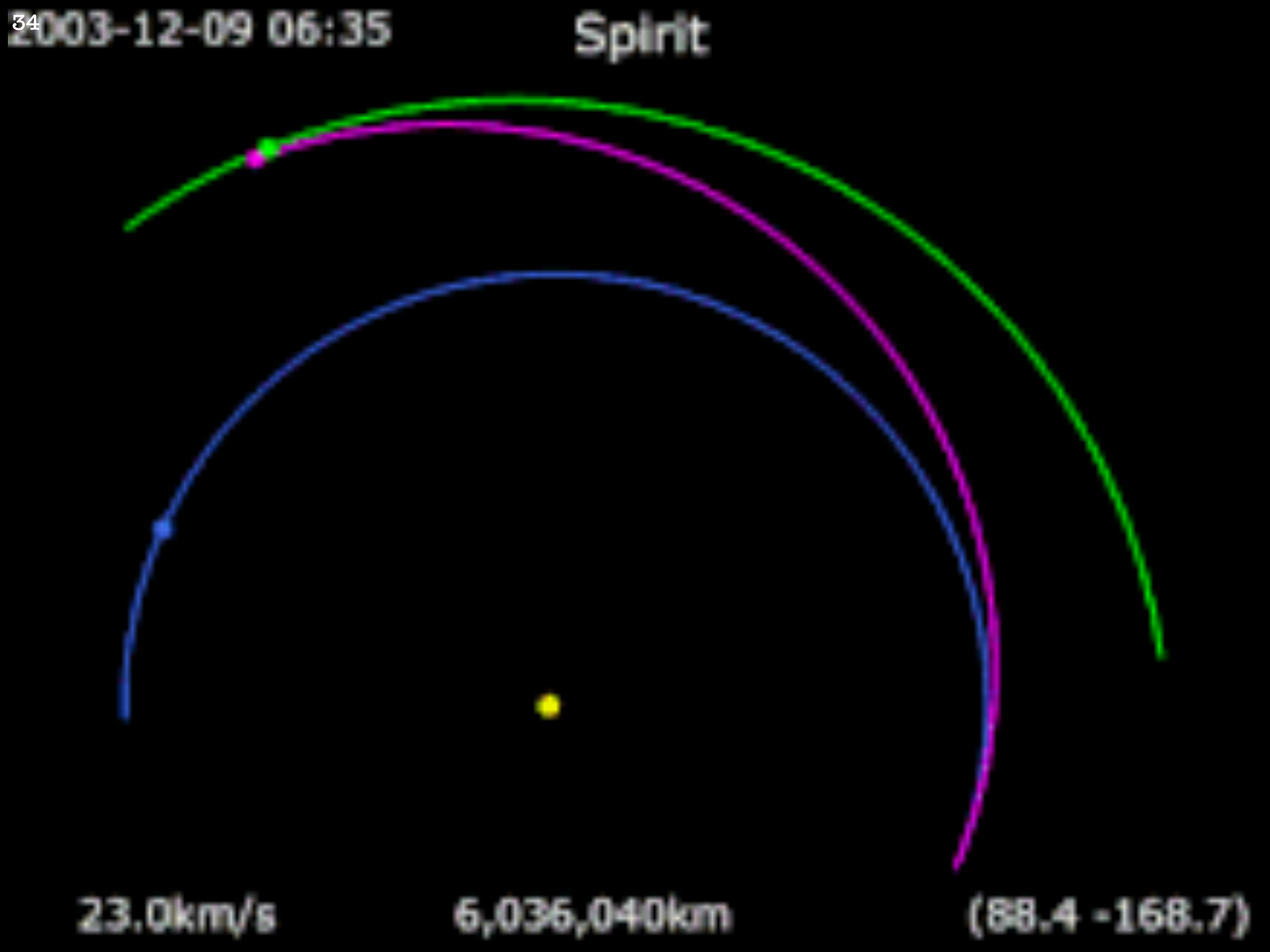

2003-11-02 06:35
Spirit
24.6km/s
14,023,637km
(88.4 -168.7)

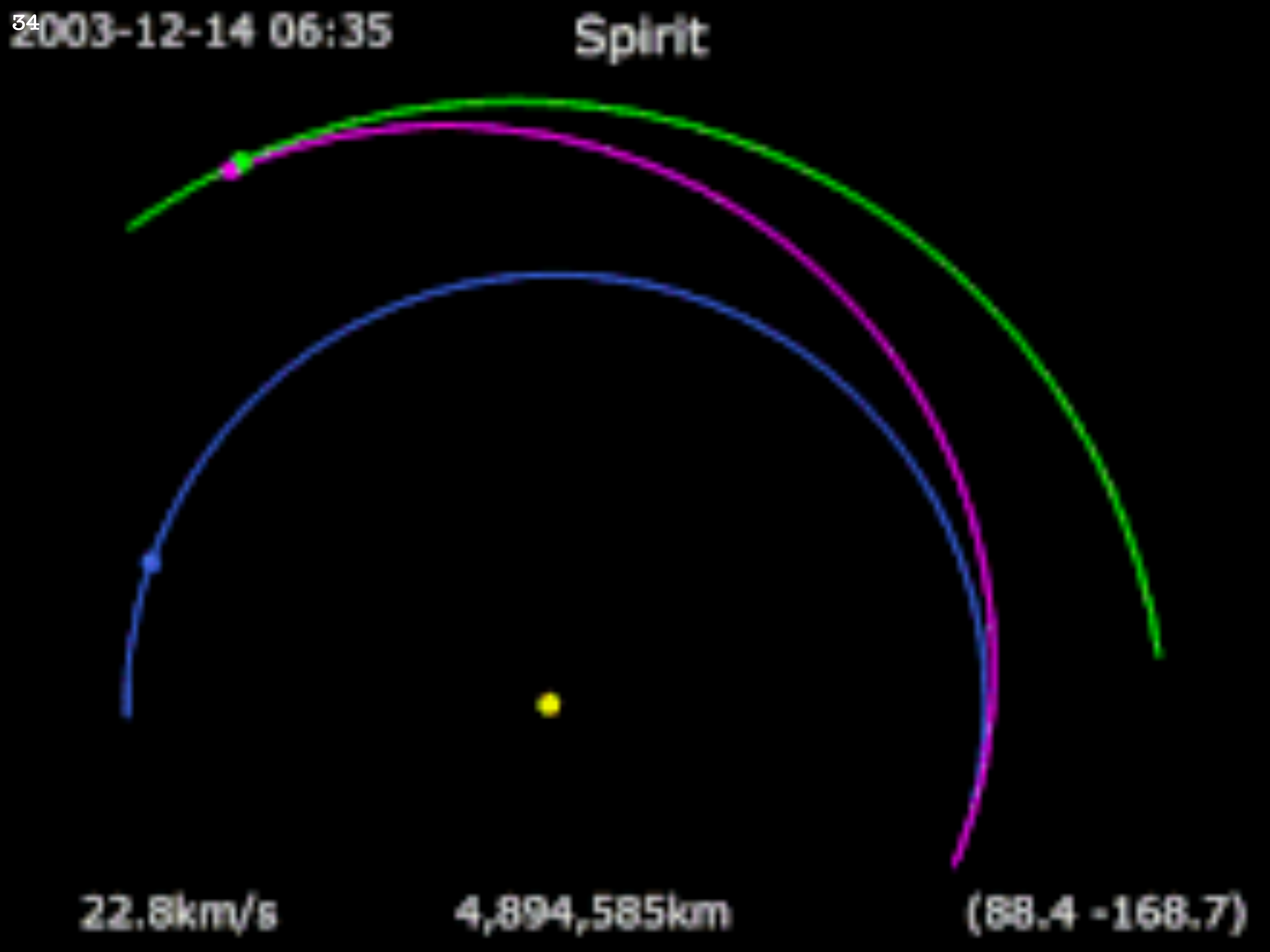

2003-11-11 18:35
Spirit
24.1km/s
12,044,644km
(88.4 -168.7)

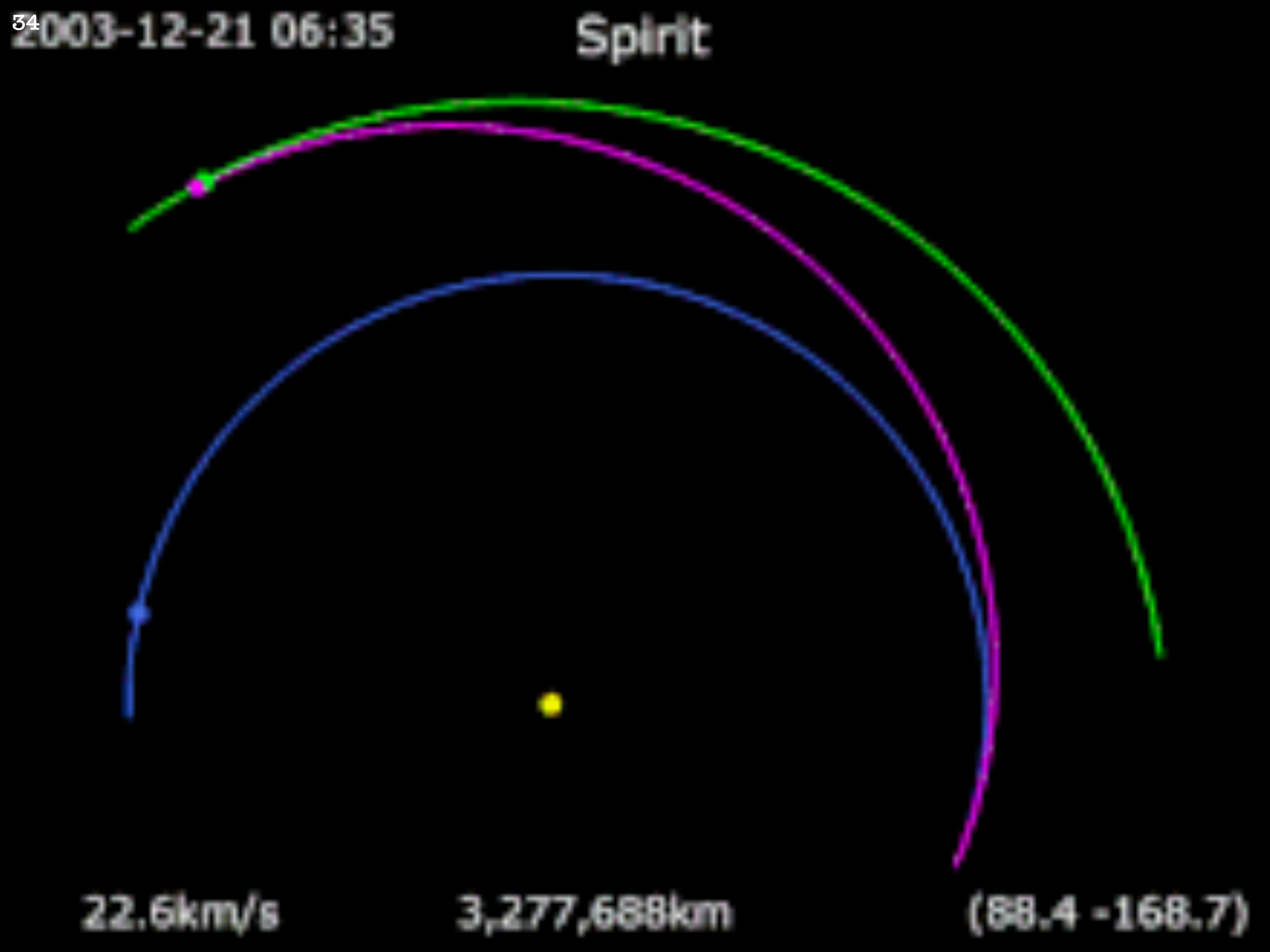

34
2003-11-17 18:35
Spirit
23.8km/s
10,774,221km
(88.4 -168.7)

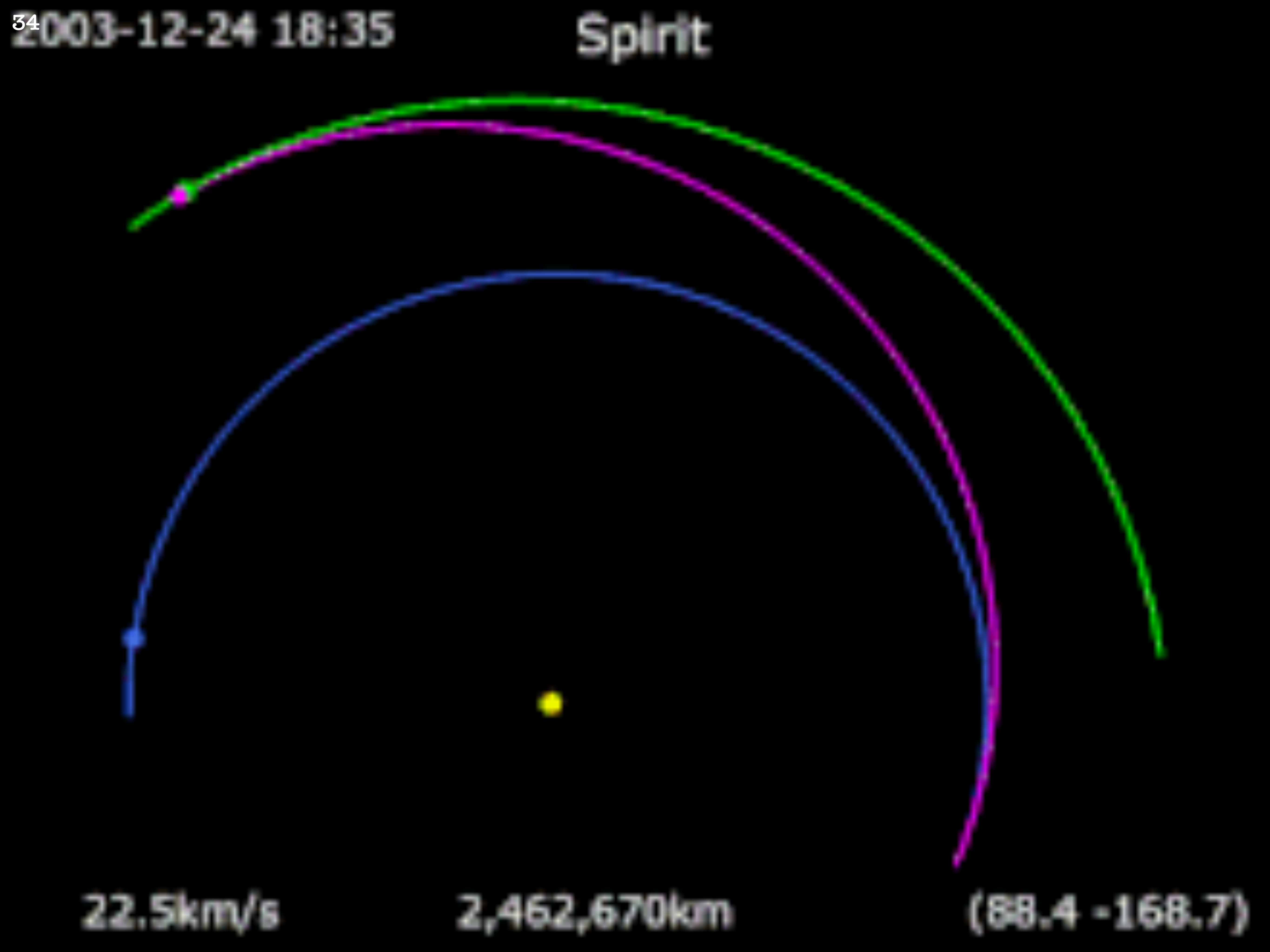

2003-11-27 06:35
Spirit
23.4km/s
8,717,240km
(88.4 -168.7)

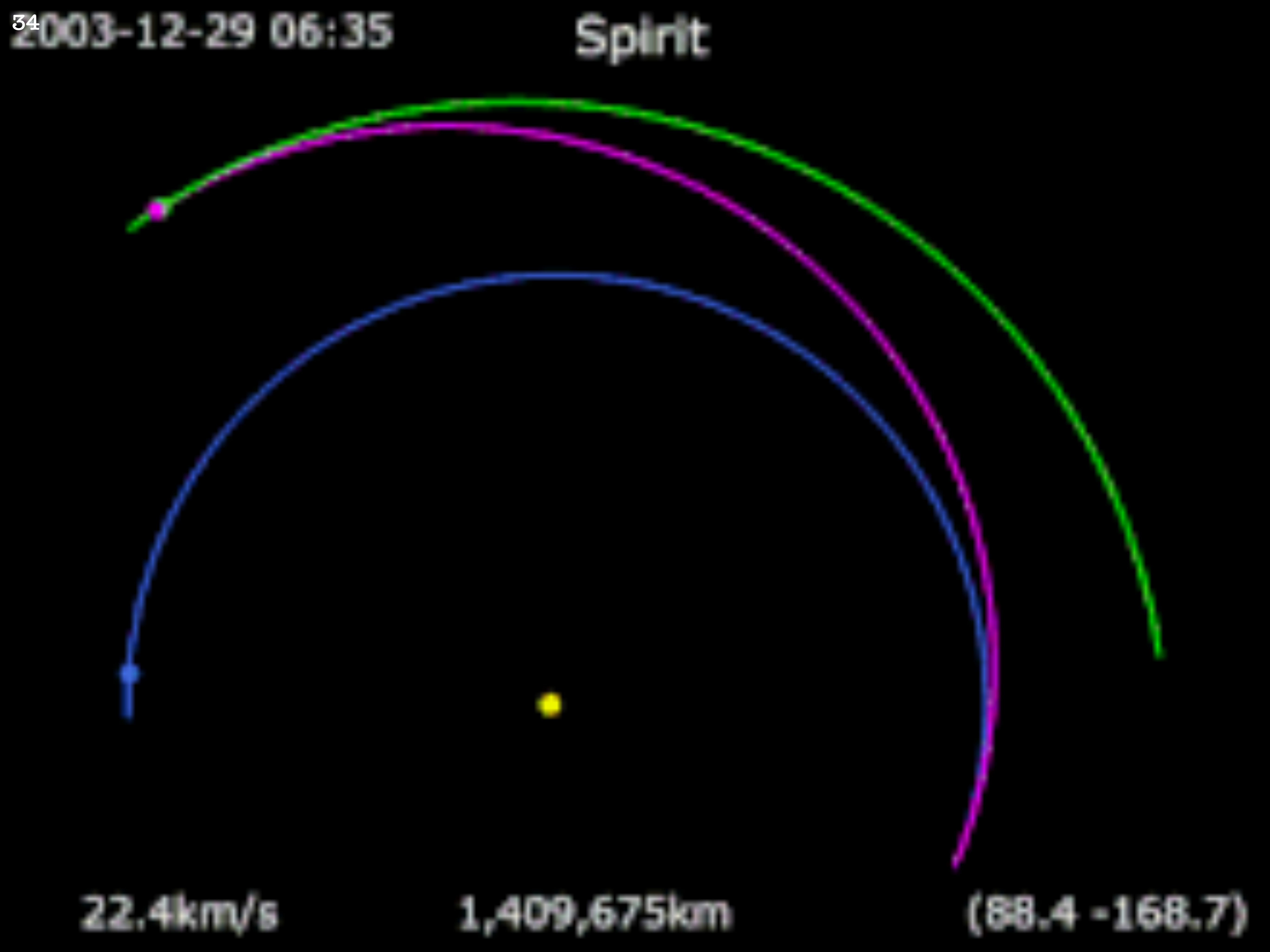

34
2003-12-01 06:35
Spirit
23.3km/s
7,833,470km
(88.4 -168.7)

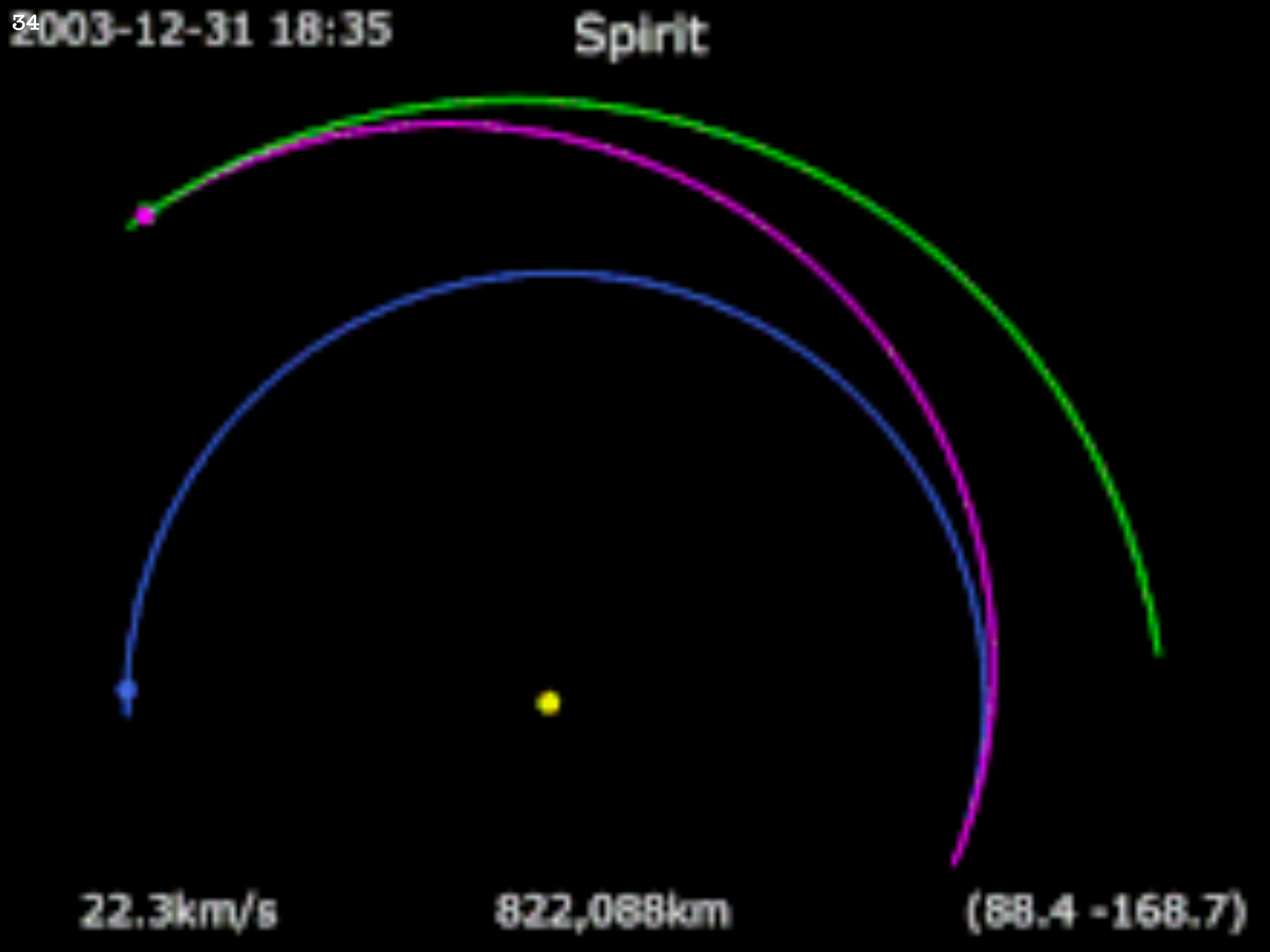

34
2003-12-09 06:35
Spirit
23.0km/s
6,036,040km
(88.4 -168.7)

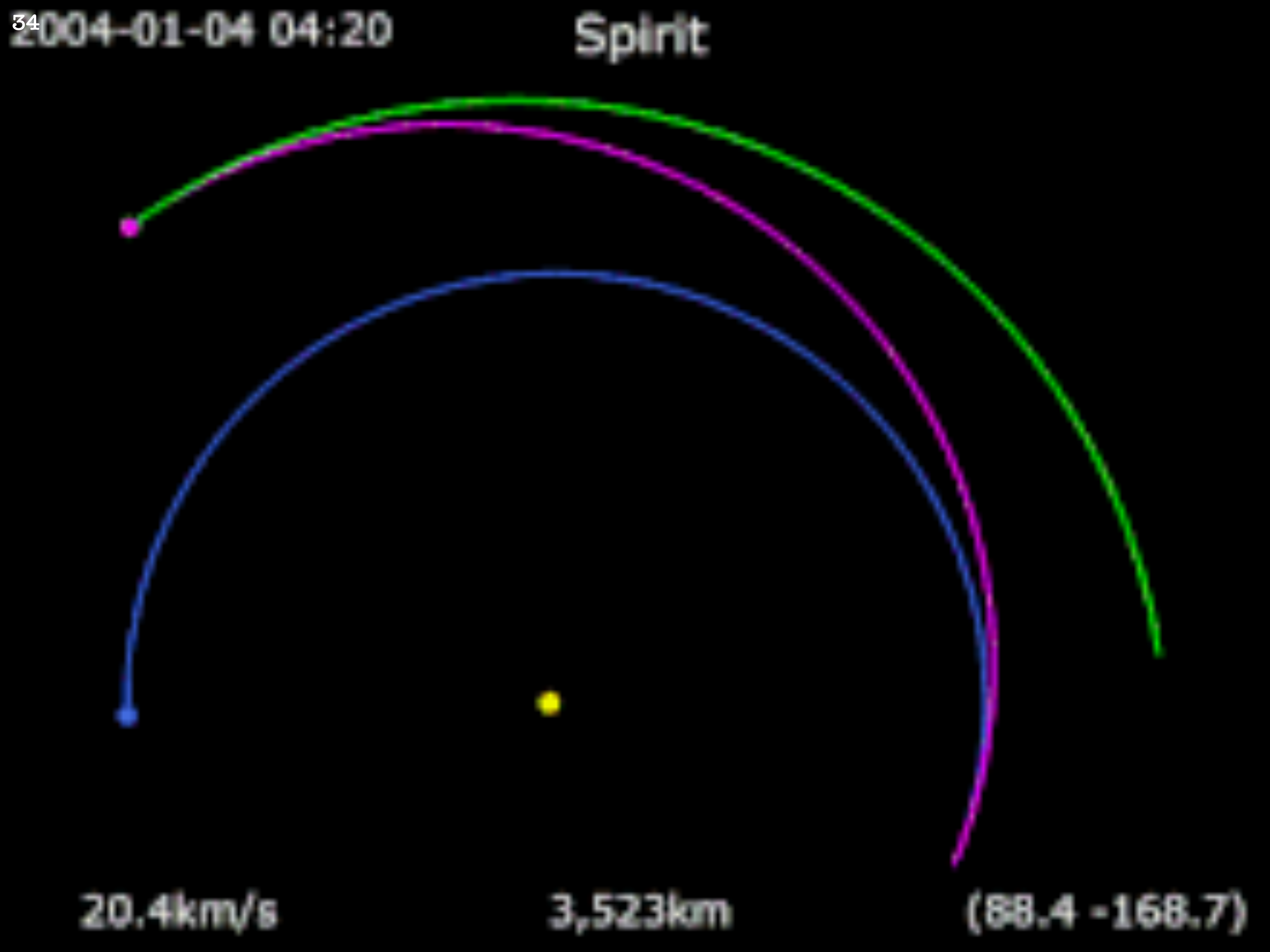

34
2003-12-14 06:35
Spirit
22.8km/s
4,894,585km
(88.4 -168.7)


2003-12-21 06:35
Spirit
22.6km/s
3,277,688km
(88.4 -168.7)

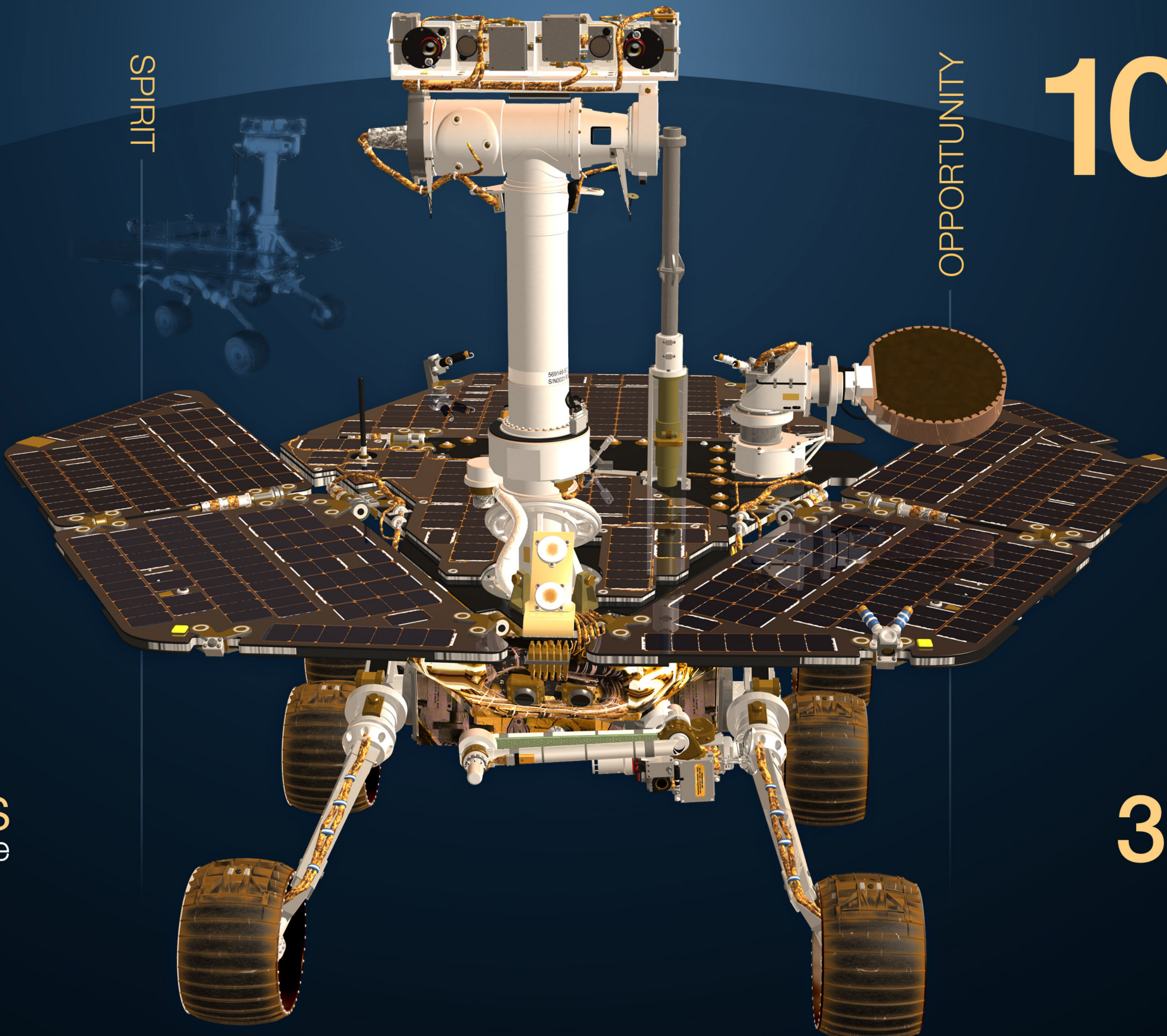

2003-12-24 18:35
Spirit
22.5km/s
2,462,670km
(88.4 -168.7)


34
2003-12-29 06:35
Spirit
22.4km/s
1,409,675km
(88.4 -168.7)


2003-12-31 18:35
Spirit
22.3km/s
822,088km
(88.4 -168.7)


2004-01-04 04:20
Spirit
20.4km/s
3,523km
(88.4 -168.7)

Spirit and Opportunity BY THE NUMBERS



Spirit

6 YEARS lifespan

128,000 raw images

4.8 MILES traveled

30 DEGREES steepest slope

Opportunity

10 YEARS lifespan

187,000 raw images

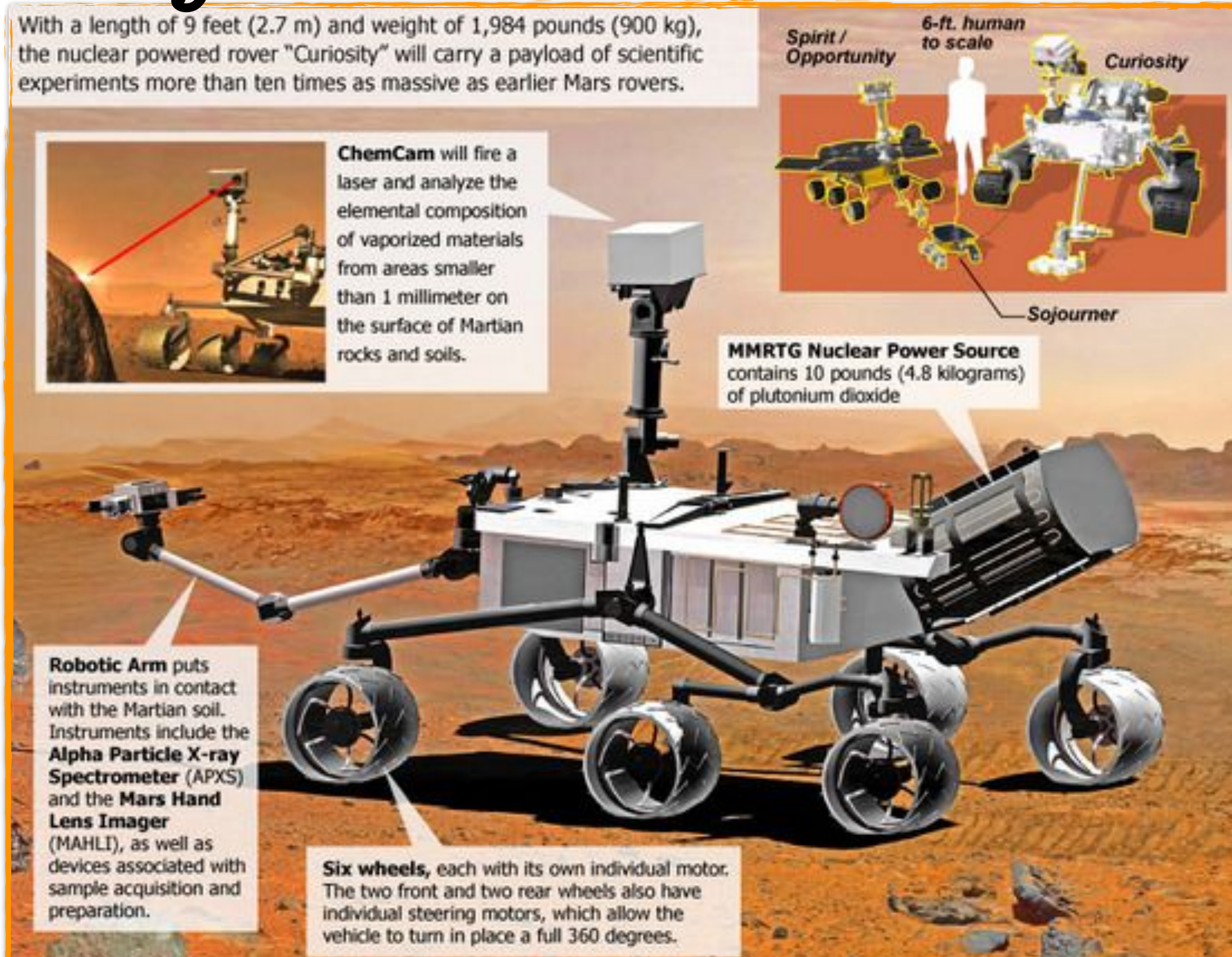
24 MILES traveled

31 DEGREES steepest slope

marsrovers.jpl.nasa.gov

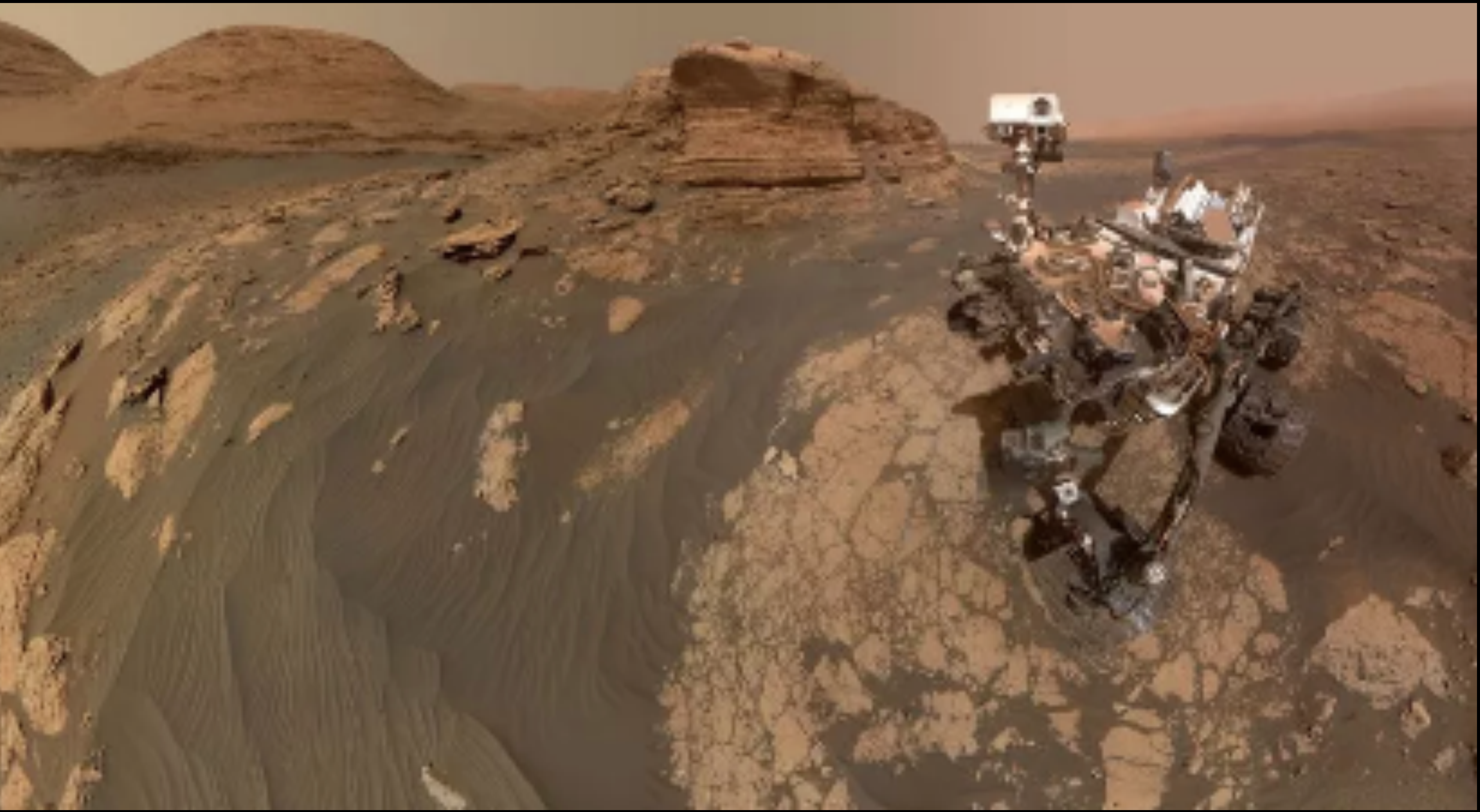
Image captured by the Spirit Rover on May 19, 2005

Curiosity Mars Science Laboratory

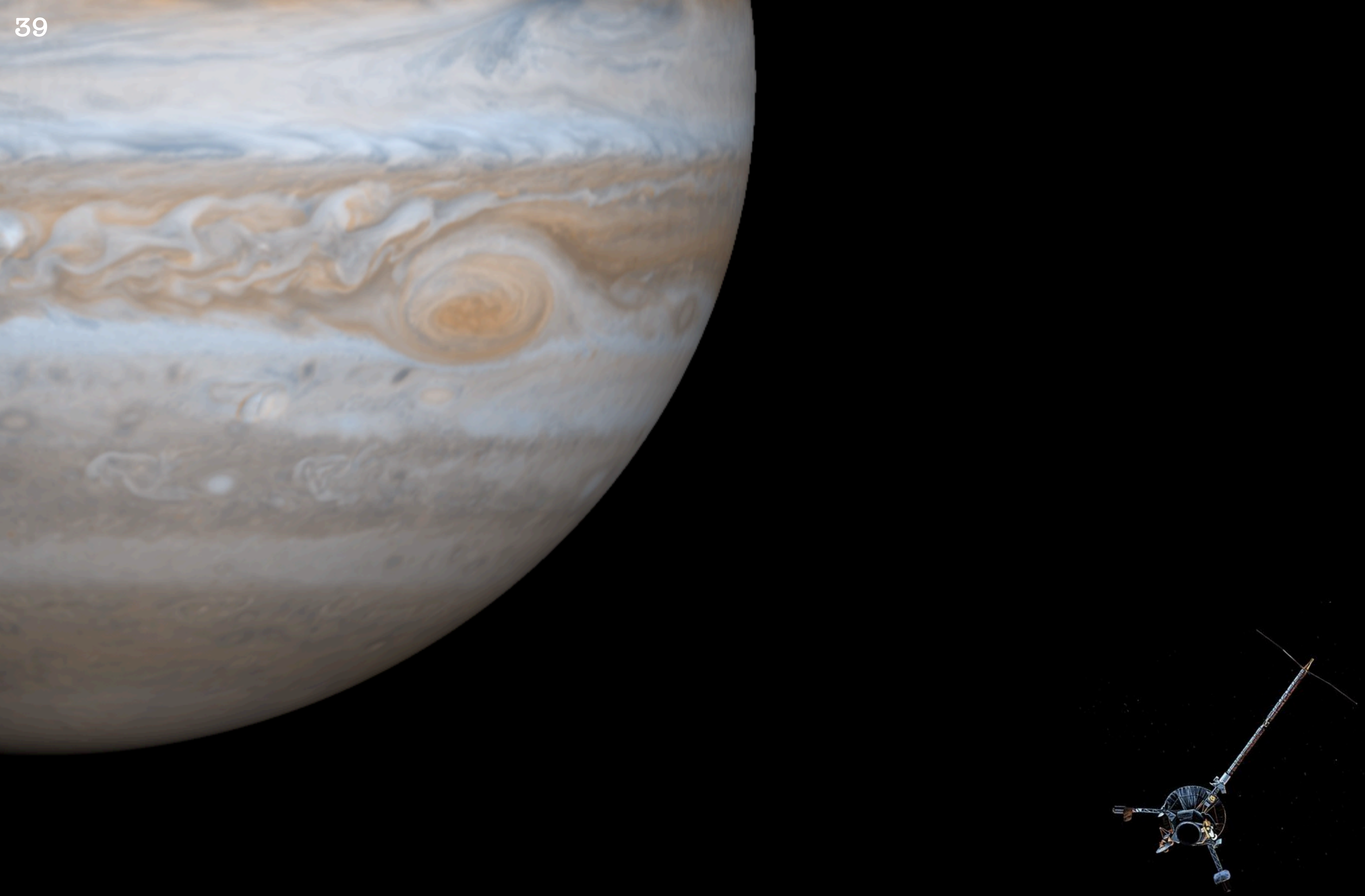


Curiosity was launched from Cape Canaveral on November 26, 2011 @ 15:02 UTC

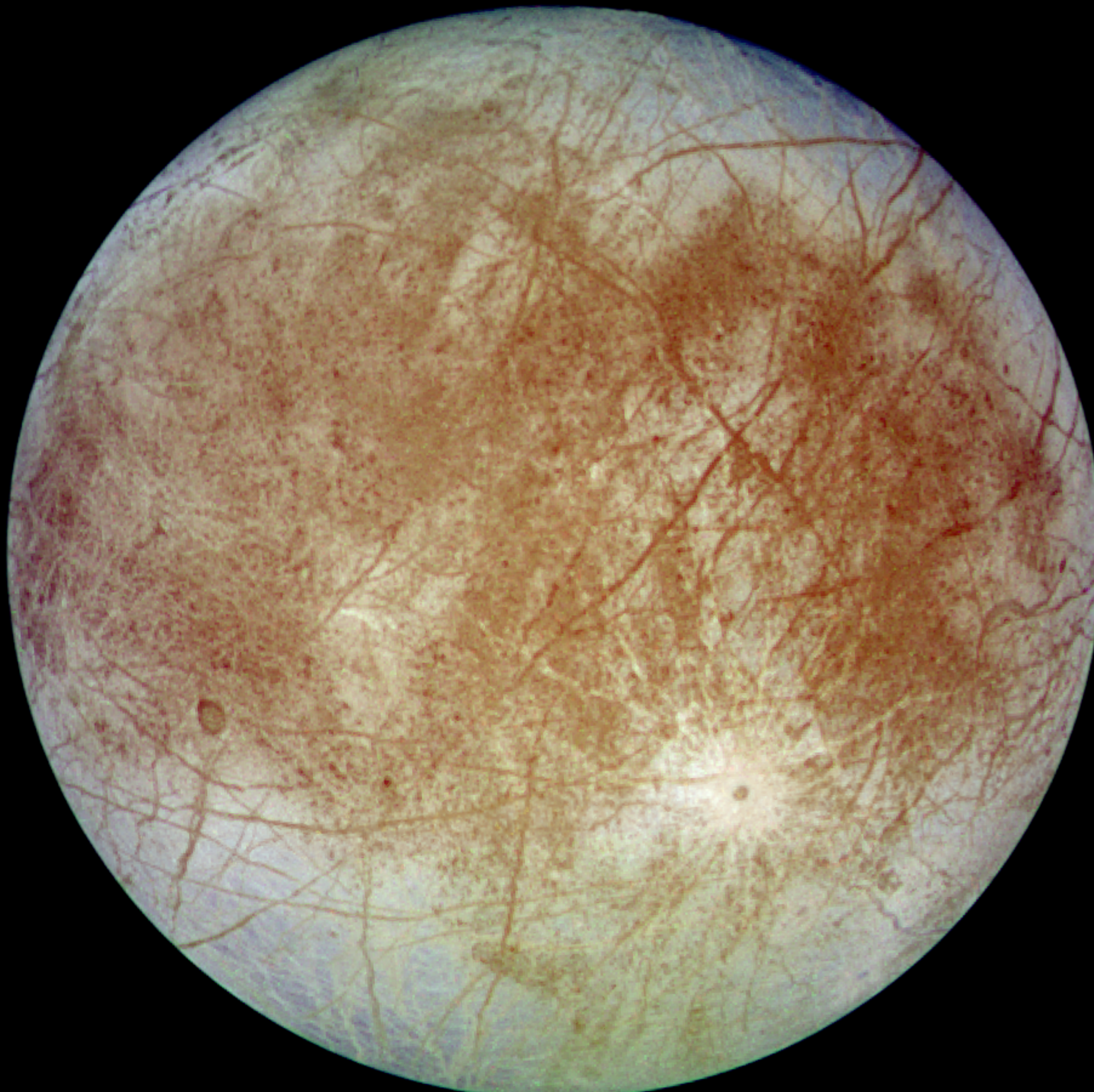
and landed on Aeolis Palus inside Gale crater on Mars on August 6, 2012 @ 05:17 UTC



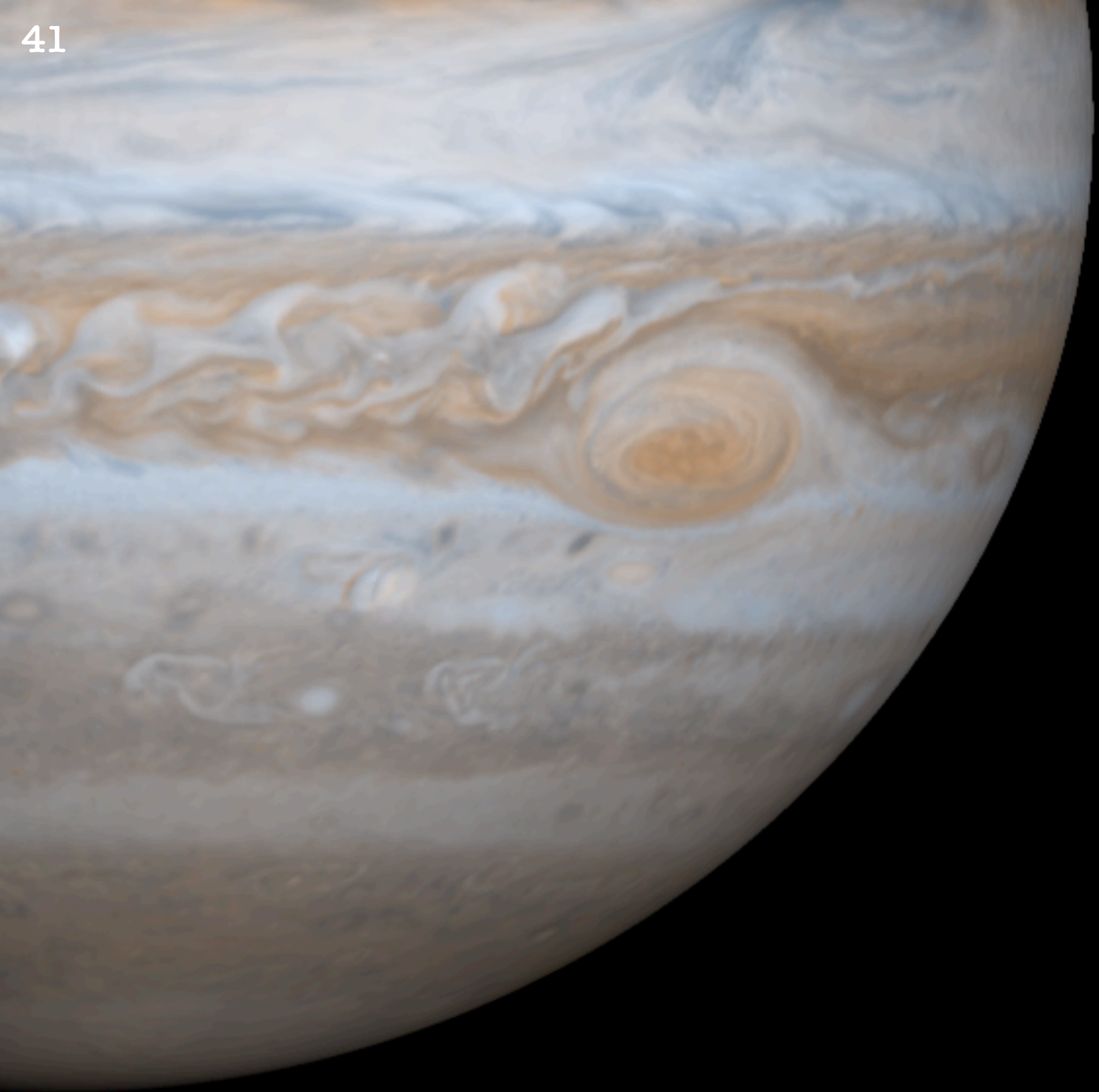
Curiosity sent back a striking selfie captured using the camera on its robotic arm



Galileo orbited Jupiter from 1995 to 2003, and conducted flybys of several of its moons…

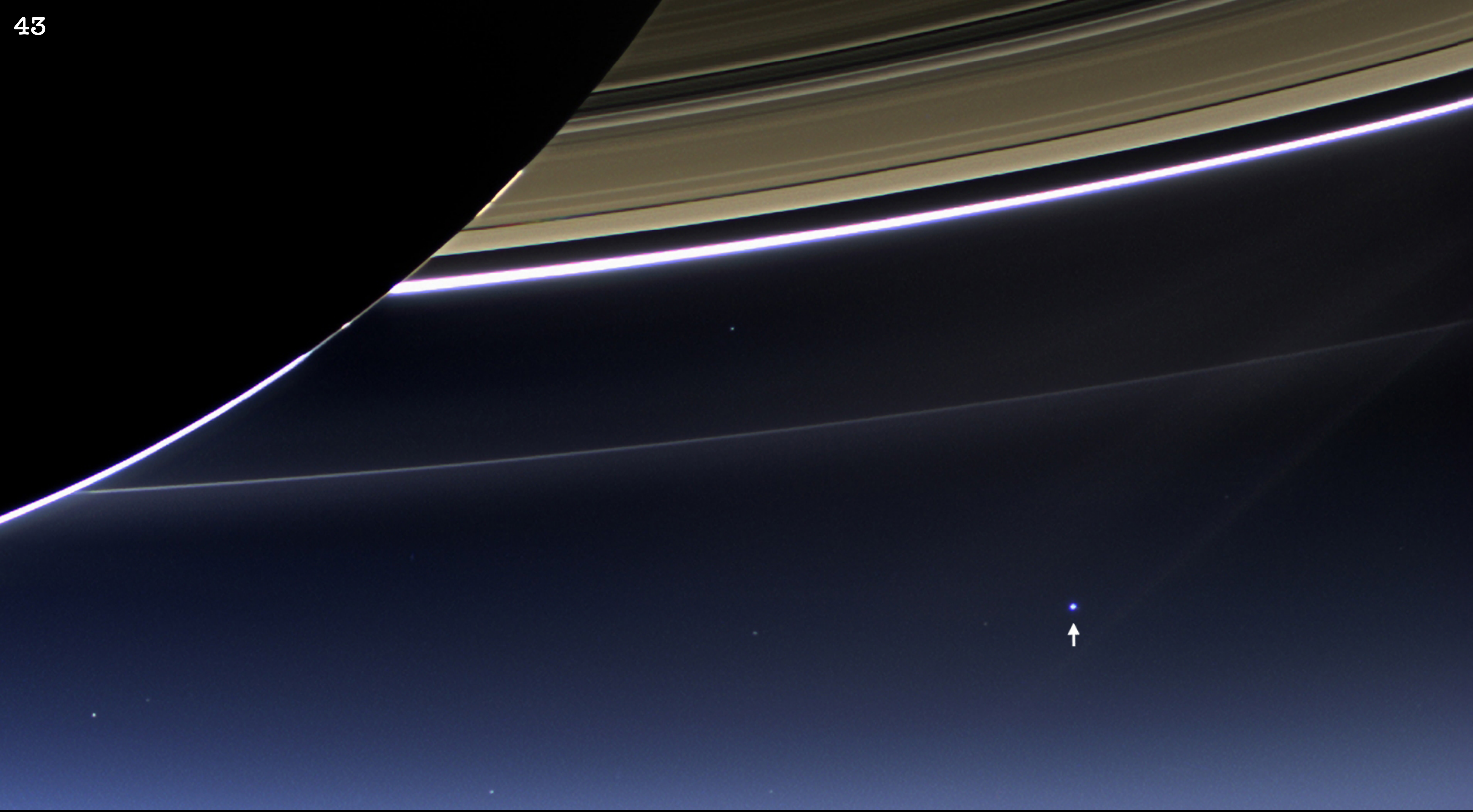


...including this one: Europa



This image of Jupiter was actually taken by the Cassini spacecraft en route to Saturn

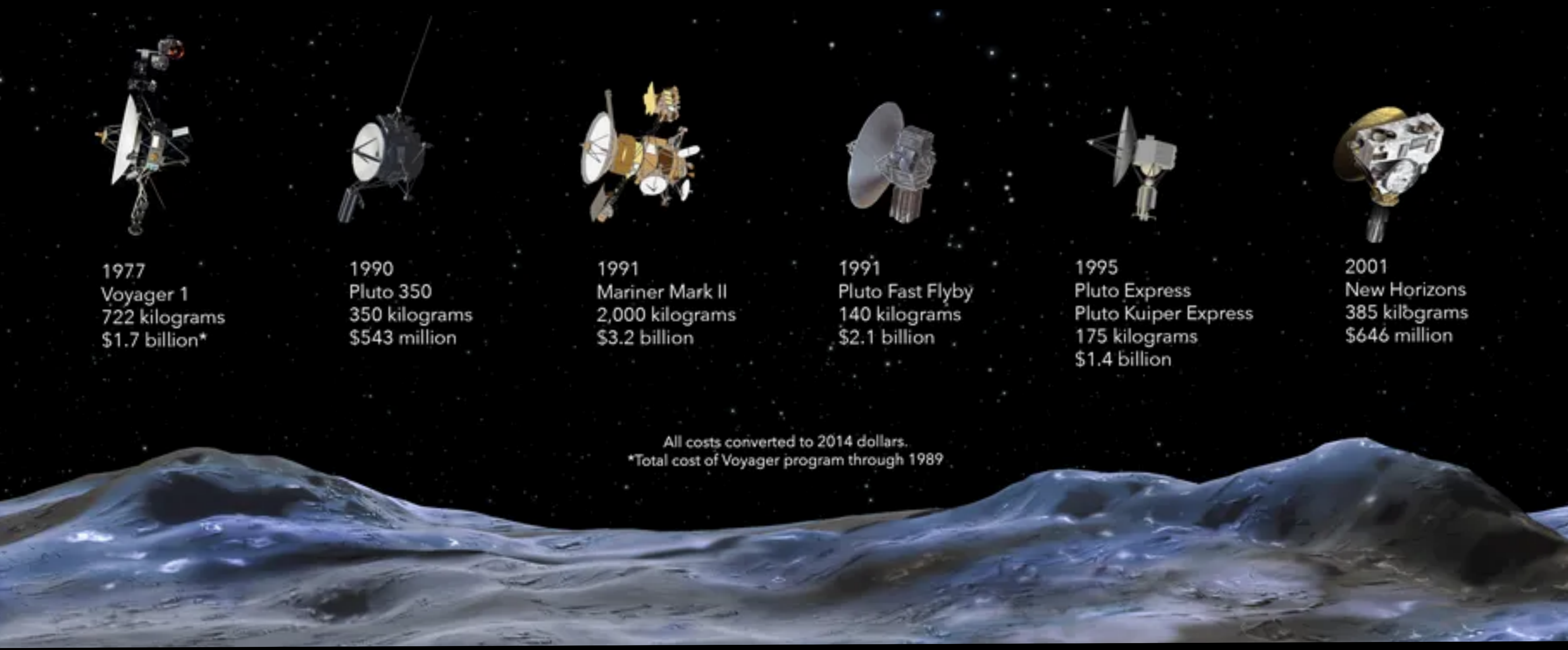
Image of Saturn was taken by the Cassini spacecraft from a distance of 177 million miles (285 km) as it approached the planet. The little dot to Saturn’s upper left is Titan, whose brightness has been enhanced relative to Saturn



Launched in 1997, NASA's Cassini space probe arrived in Saturn orbit in 2004

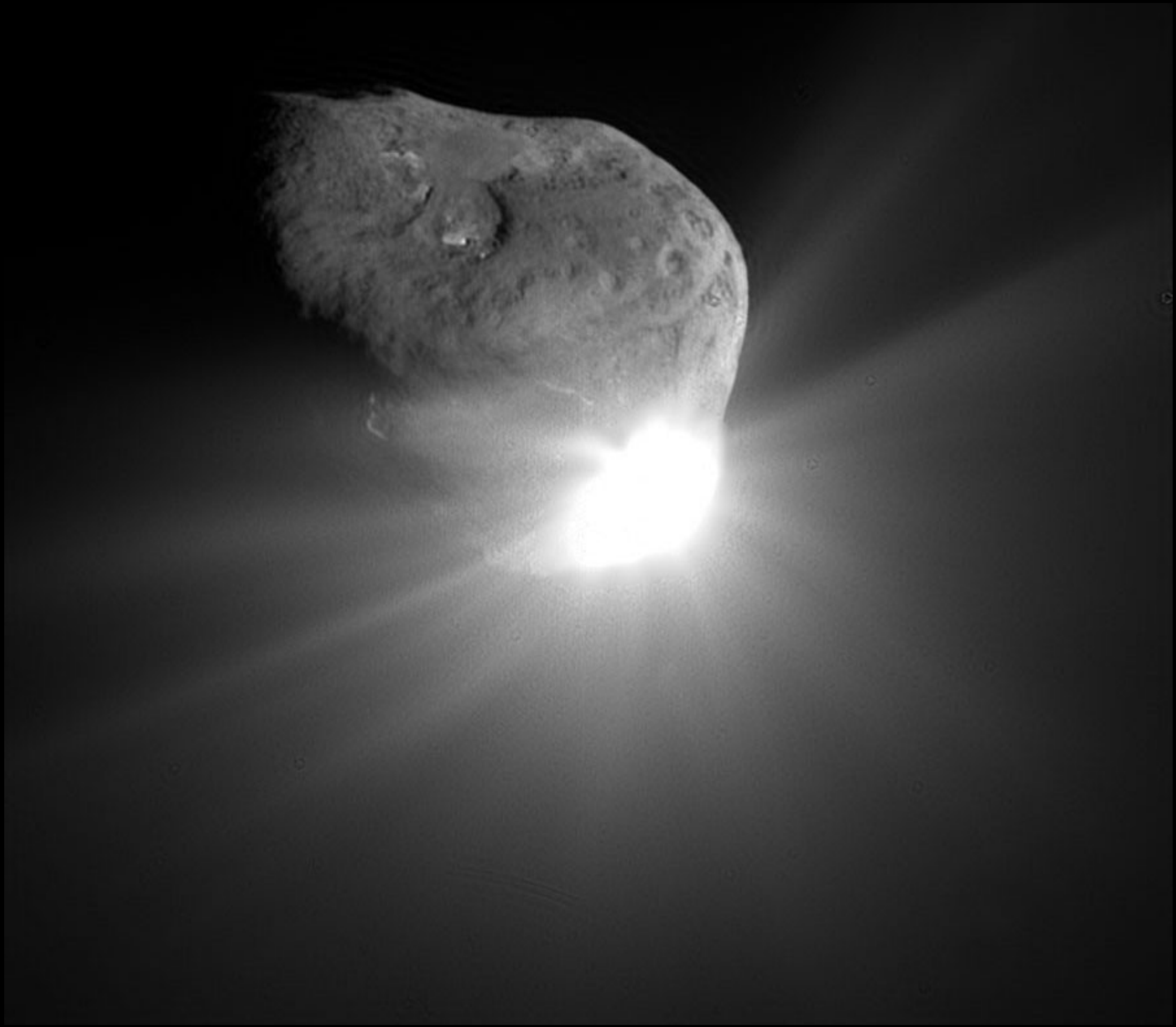
On July 19 of this year the spacecraft took an extraordinary image of our home planet and moon as seen from nearly 900 miles away

The long road to a Pluto mission



Pluto as seen by New Horizons

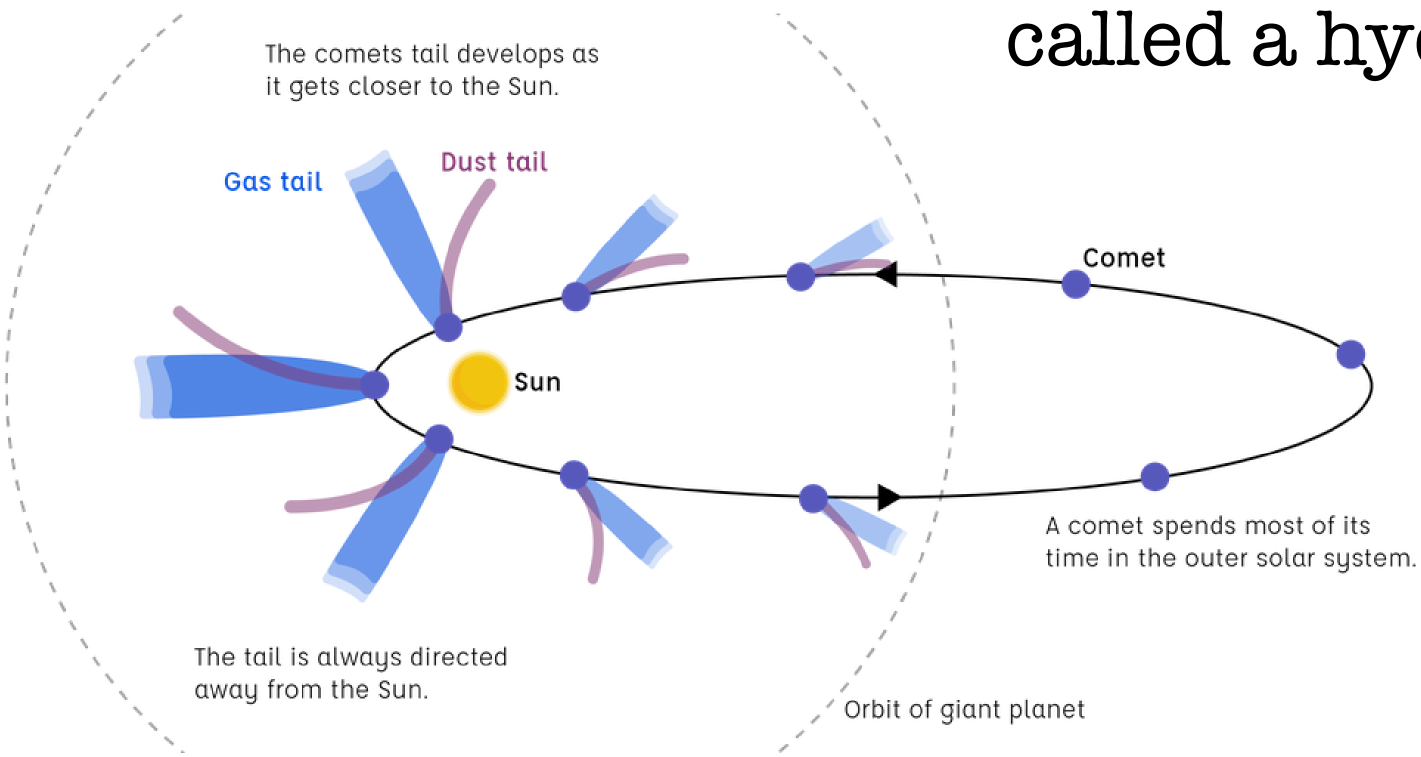
Charon as seen by New Horizons



Comet Tempel 1☛ image was taken 67 seconds after it obliterated Deep Impact's impactor spacecraft

As comets travel close to the Sun, the Sun's heat begins to vaporize the ices and causes them to form a fuzzy, luminous area of vaporized gas around the nucleus of the comet known as a coma

Outside the coma is a layer of hydrogen gas called a hydrogen halo which extends up to 10^{10} meters in diameter



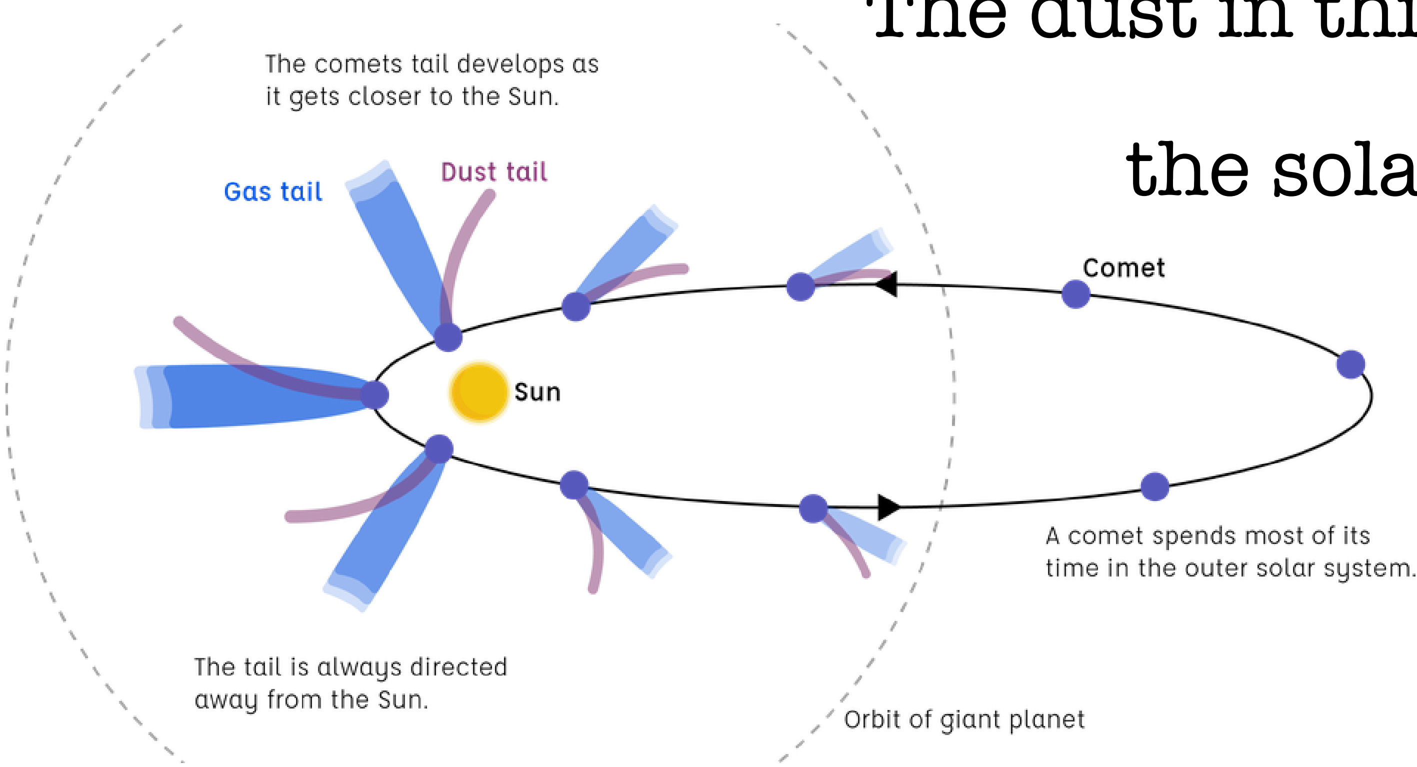
The solar wind then blows these gases and dust particles away from the direction of the Sun causing two tails to form

These tails always point away from the Sun as the comet travels around it

One tail is called the ion tail and is made up of gases which have been broken apart into charged molecules and ions by the radiation from the Sun

Since the most common ion, CO^+ scatters the blue light better than red light, to observers, this ion tail often appears blue

The other tail is called a dust tail and normally appears white



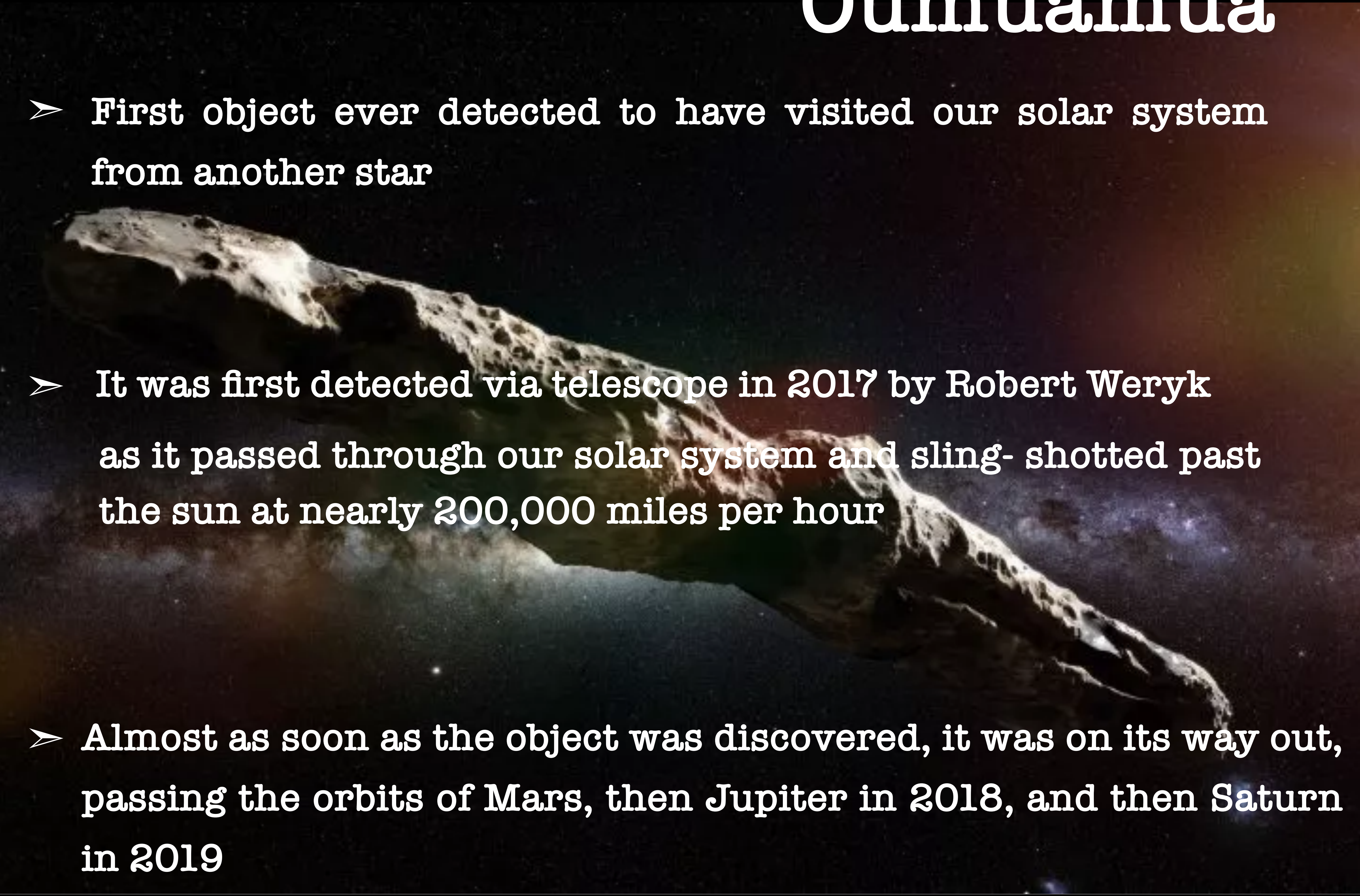
The dust in this tail is less strongly affected by the solar wind since the particles of dust are much larger than the ions in the ion tail

That is why the dust tail is usually curved rather than straight, and does not point directly away from the Sun, because it is also influenced by the motion of the comet

The tails of the comet can be extremely large and may extend a distance of up to 1 AU (the distance between the Earth and the Sun)!

Both tails can be seen in the image of Comet Hale-Bopp

'Oumuamua

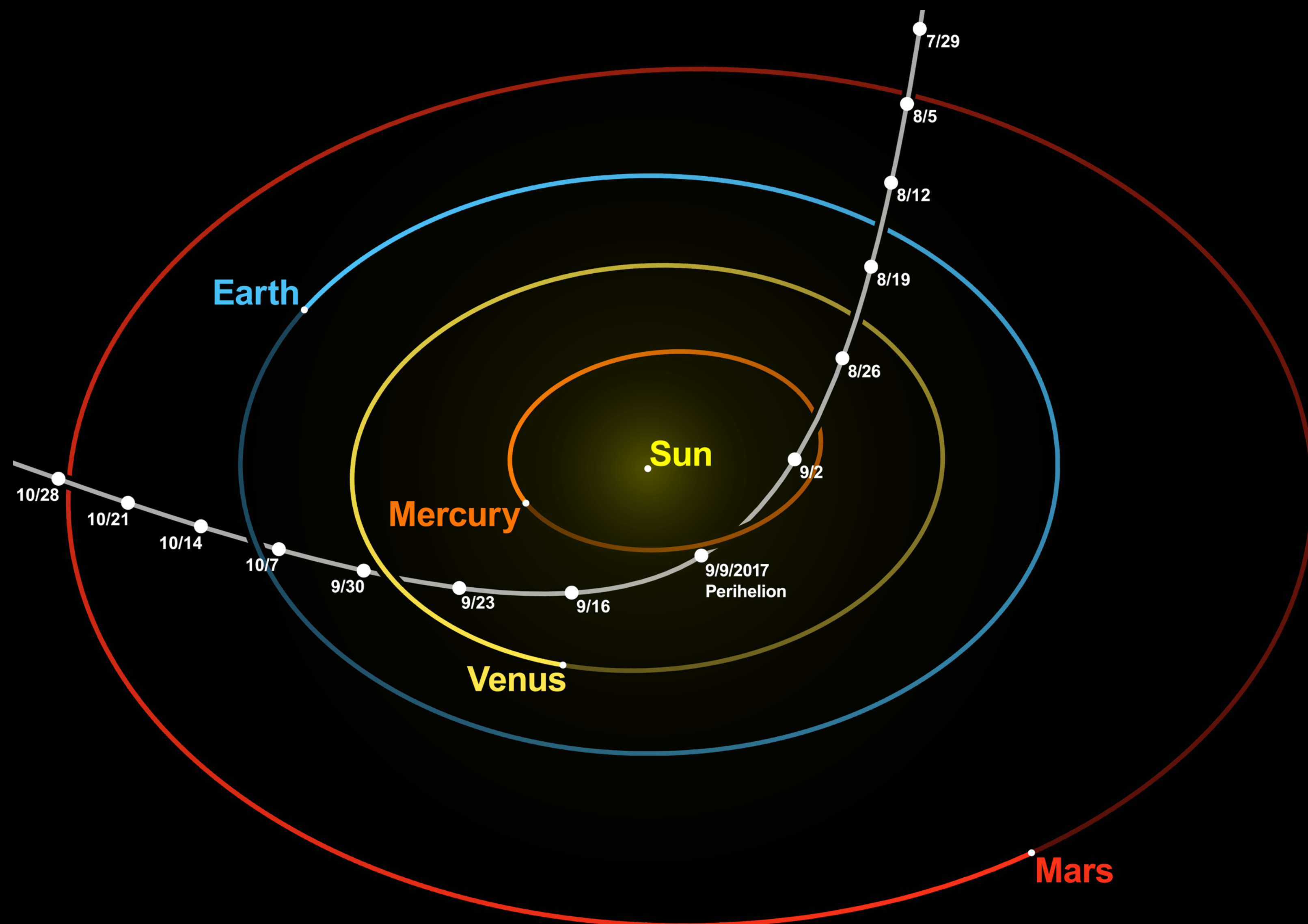


- First object ever detected to have visited our solar system from another star

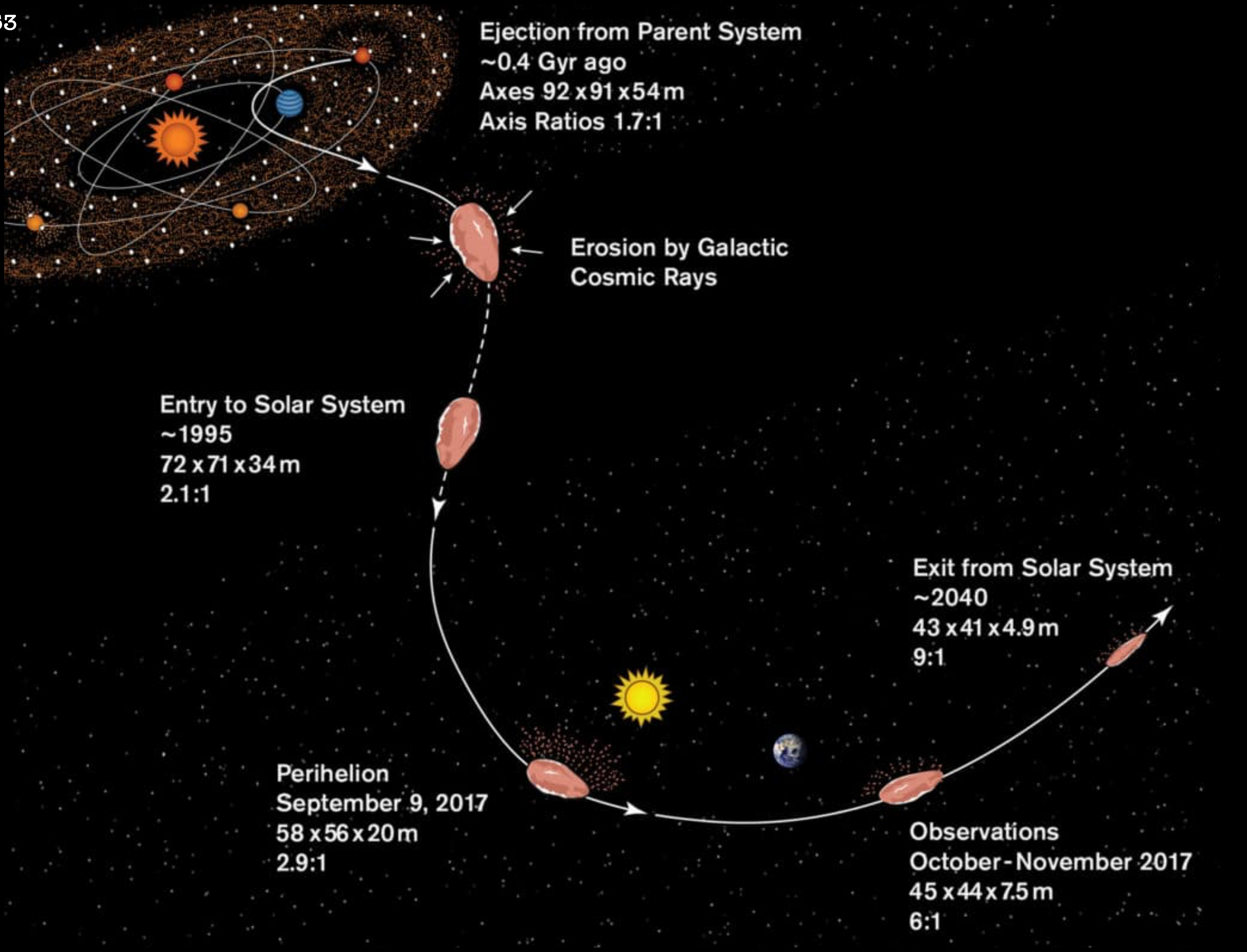
- It was first detected via telescope in 2017 by Robert Weryk as it passed through our solar system and sling- shotted past the sun at nearly 200,000 miles per hour

- Almost as soon as the object was discovered, it was on its way out, passing the orbits of Mars, then Jupiter in 2018, and then Saturn in 2019

A Mission to 'Oumuamua?



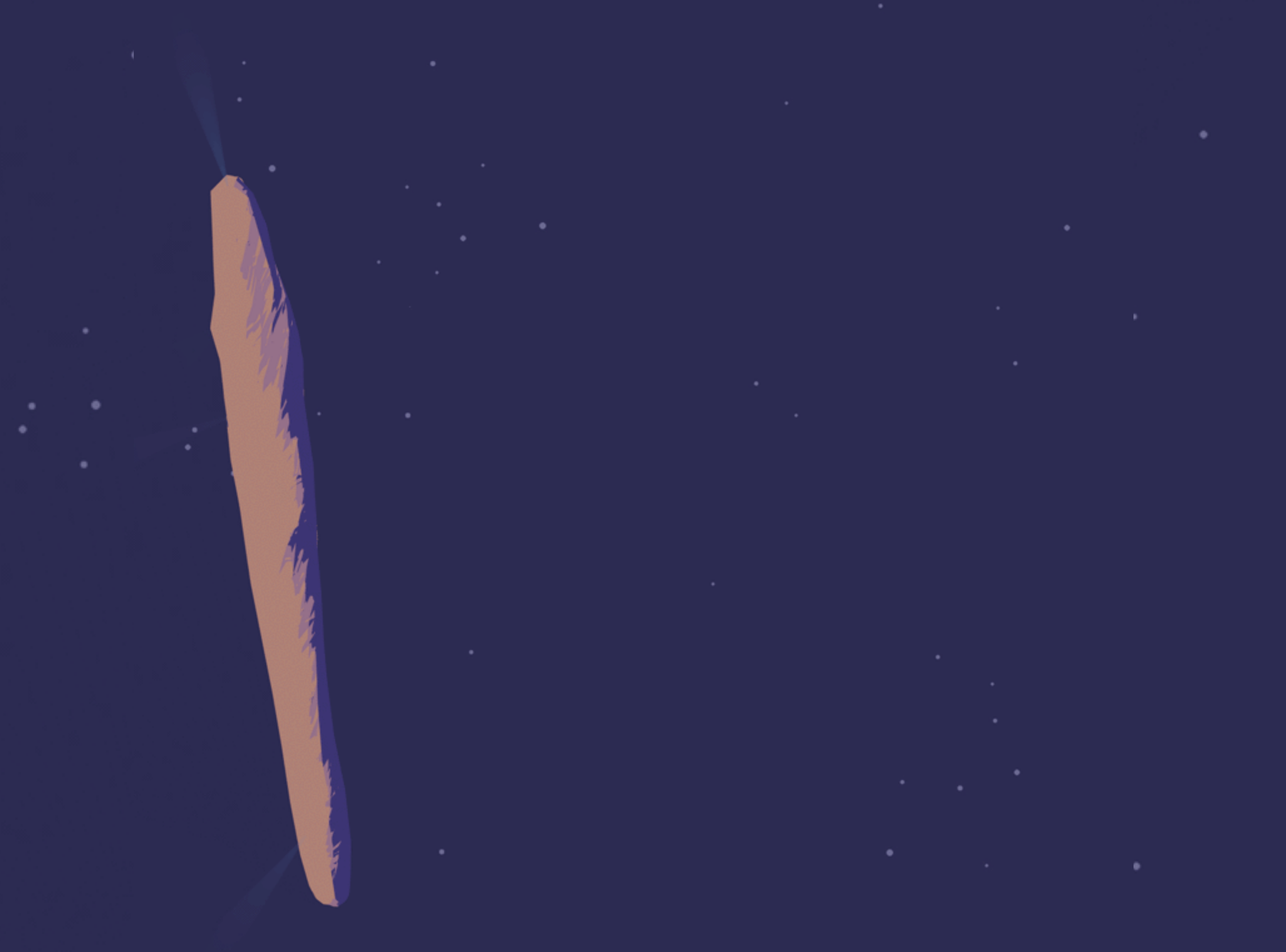
- Large uncertainty in its current position
- At its current distance from the Sun, 'Oumuamua is more than a million times fainter than it was near Earth and any targeting spacecraft will need to be equipped with a large telescope to find 'Oumuamua

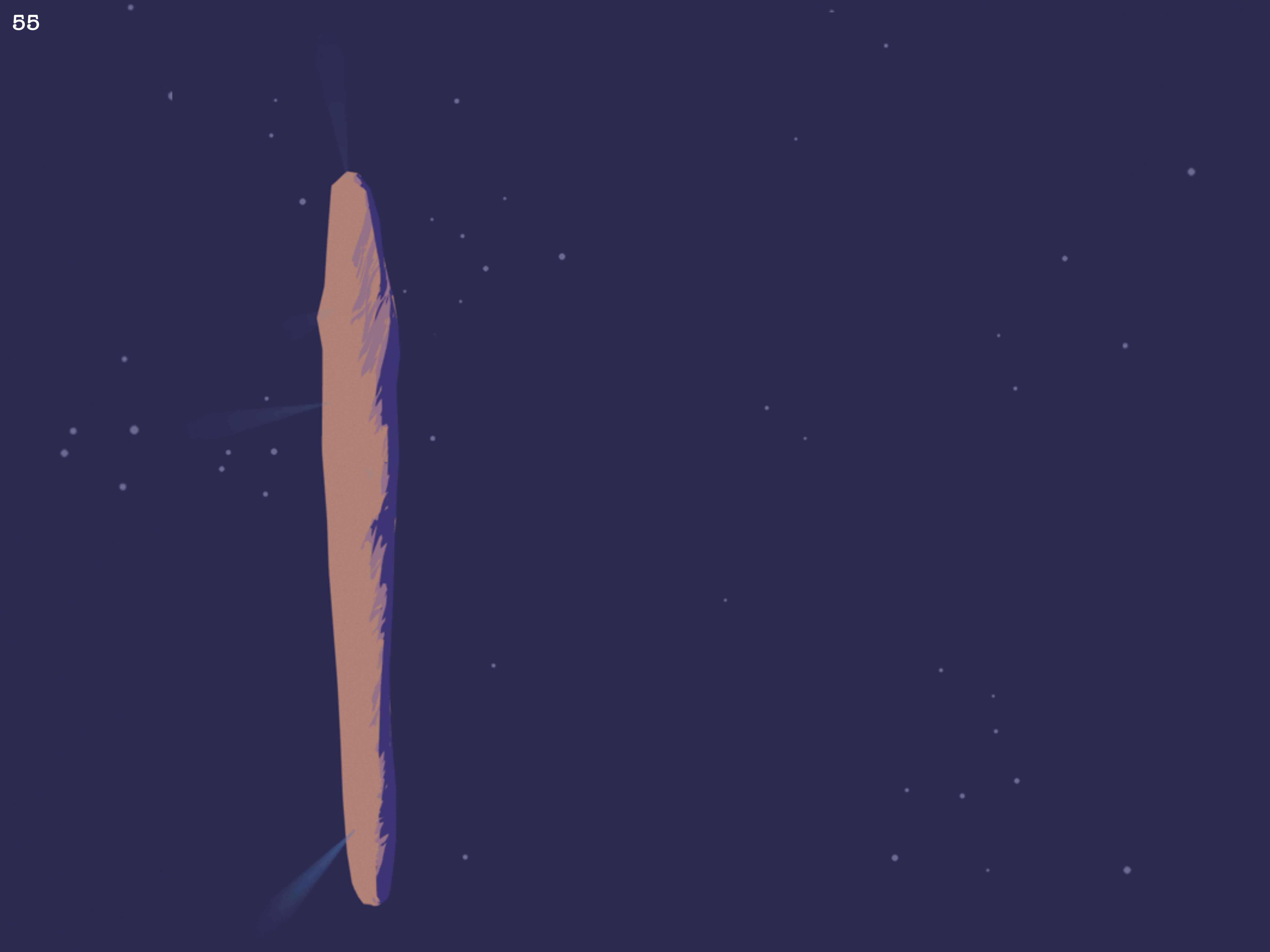

Ejection from Parent System
~0.4 Gyr ago
Axes 92 x 91 x 54 m
Axis Ratios 1.7:1
Erosion by Galactic
Cosmic Rays
Entry to Solar System
~1995
72 x 71 x 34 m
2.1:1
Exit from Solar System
~2040
43 x 41 x 4.9 m
9:1
Perihelion
September 9, 2017
58 x 56 x 20 m
2.9:1
Observations
October-November 2017
45 x 44 x 7.5 m
6:1

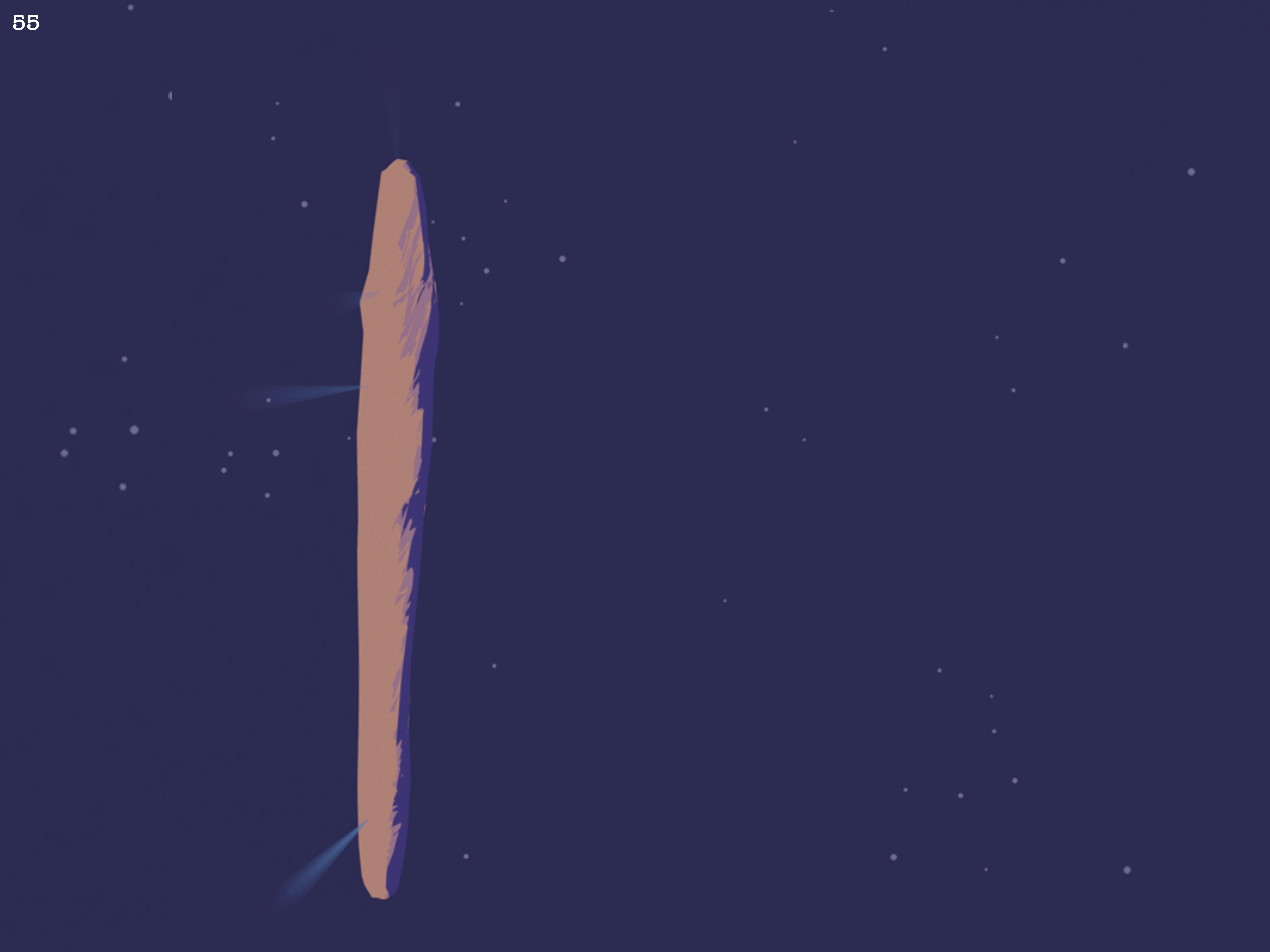
‘Oumuamua (pronounced oh-MOO-ah-MOO-ah) means “a messenger from afar arriving first” in Hawaiian

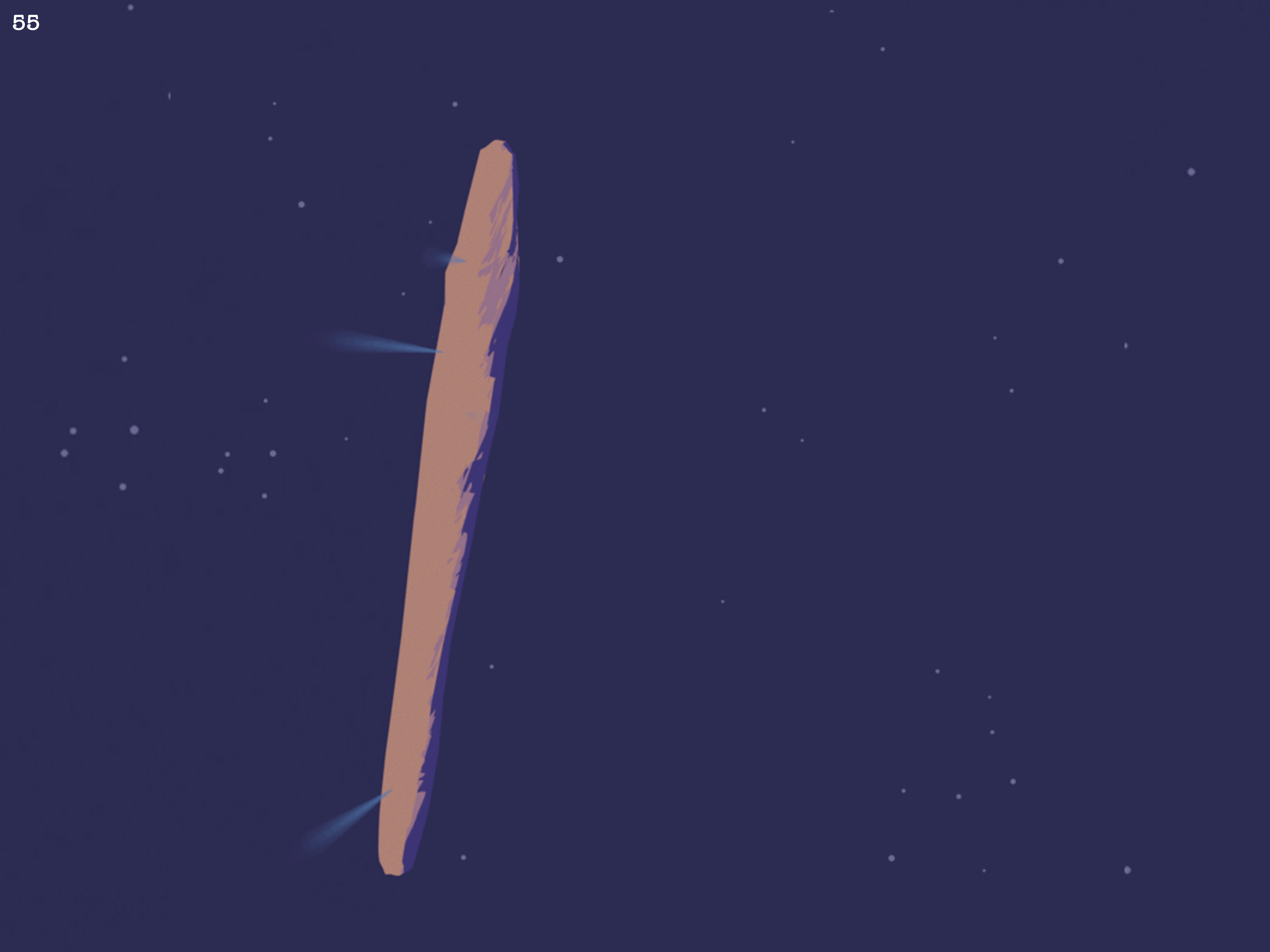
The object appears to have come from roughly the direction of Vega in the constellation Lyra and is now far beyond the orbit of Neptune heading toward the constellation Pegasus

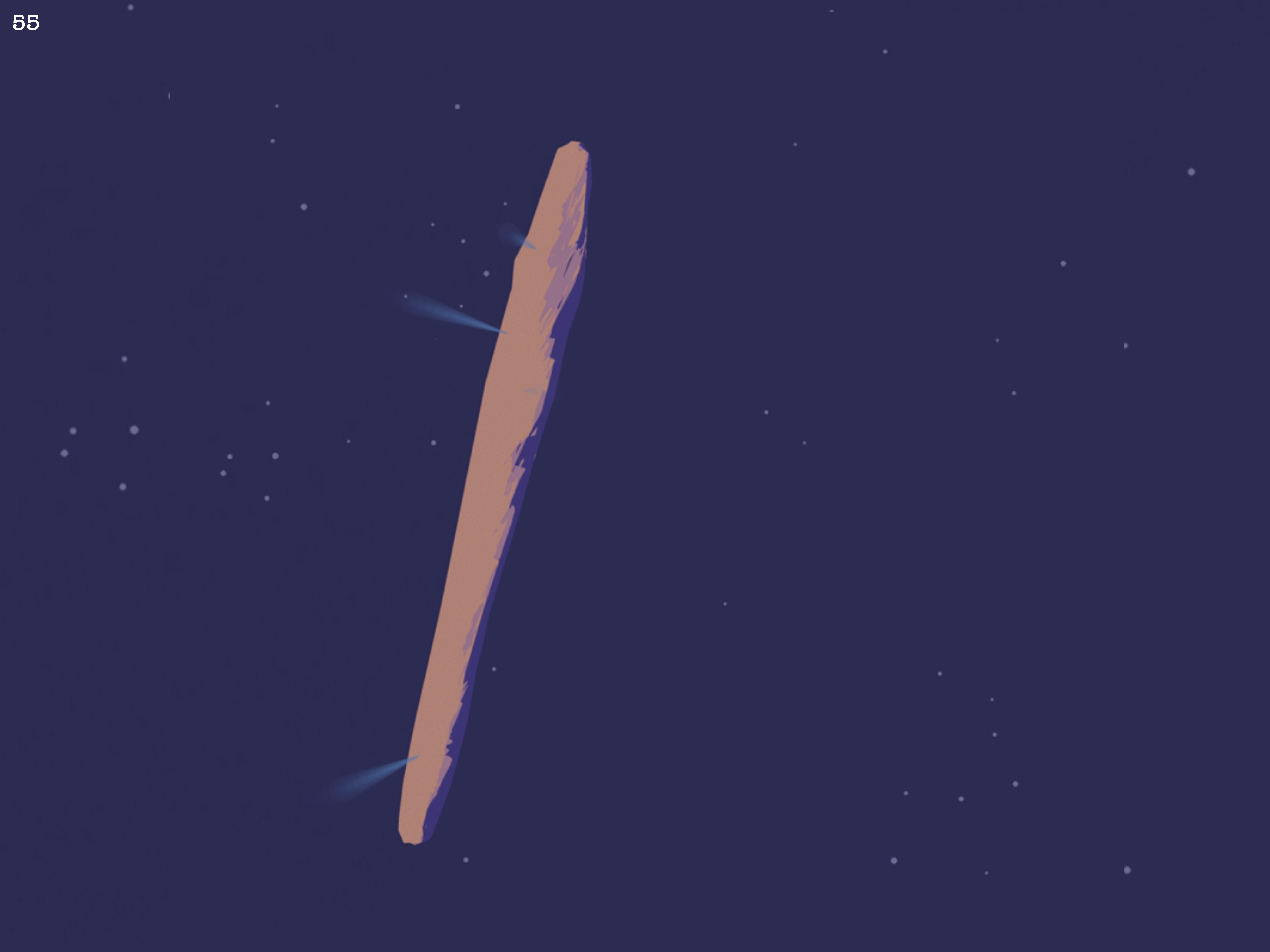
Vega is a star relatively close at only 25 light-years from the Sun

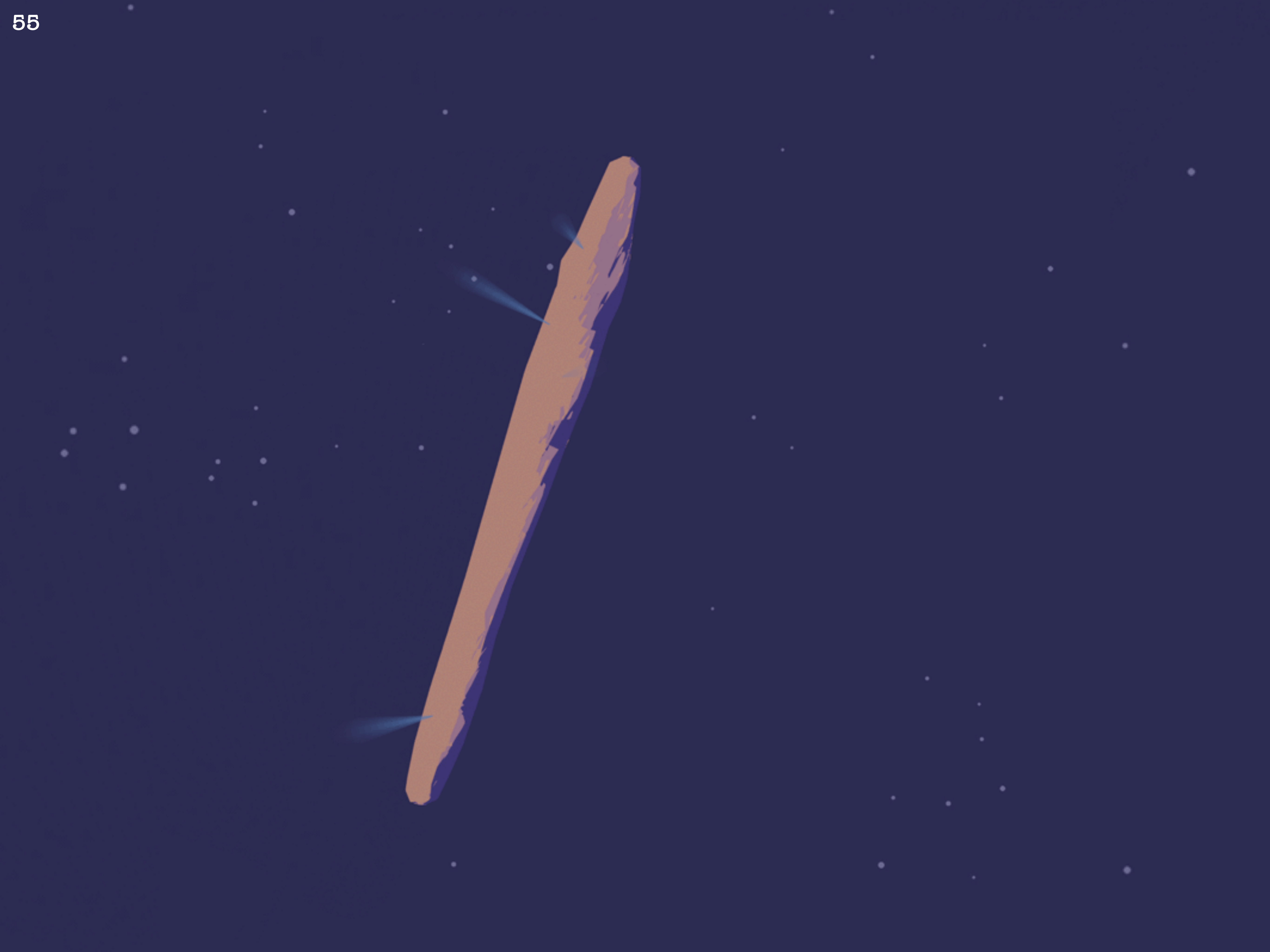


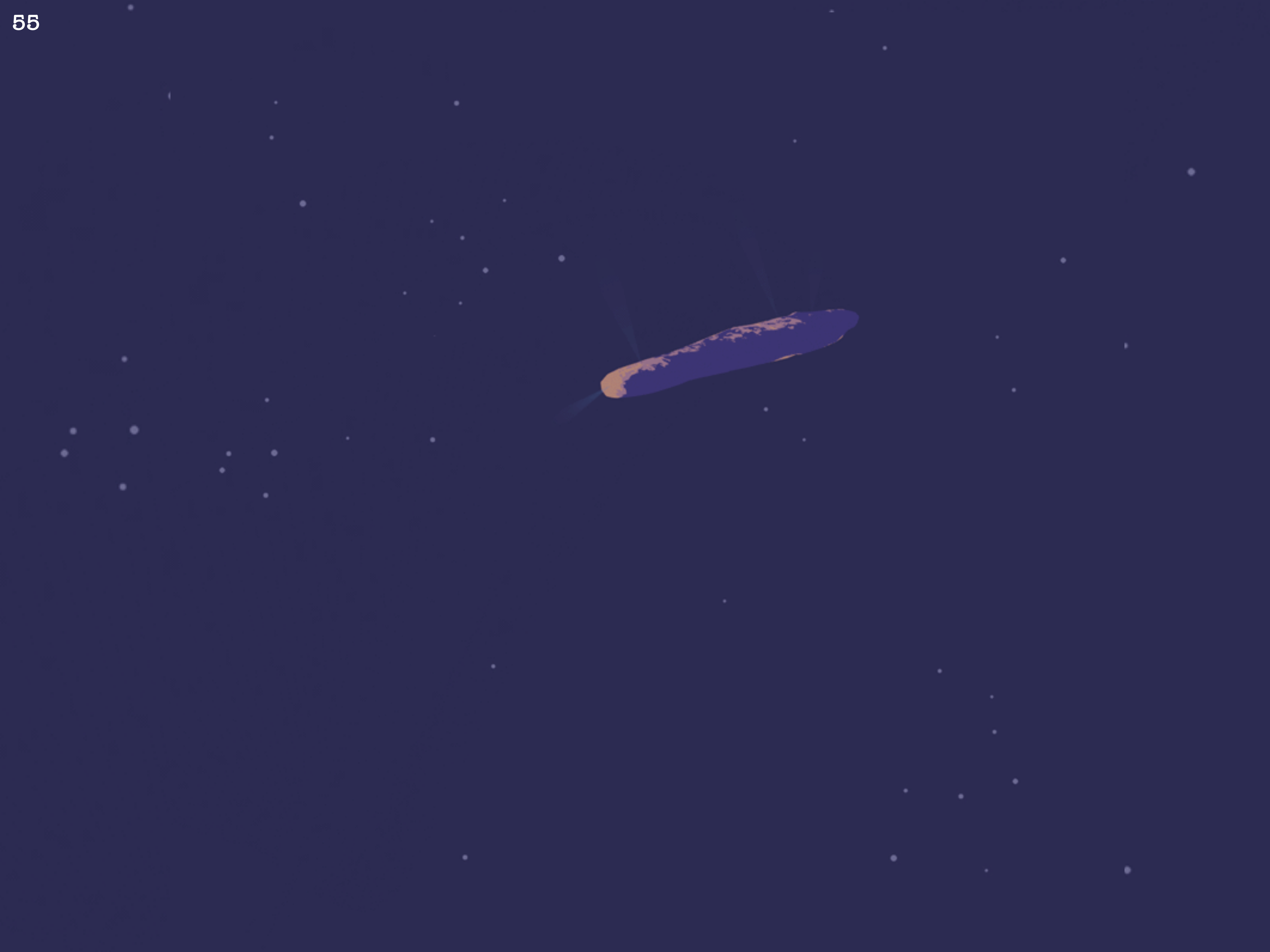


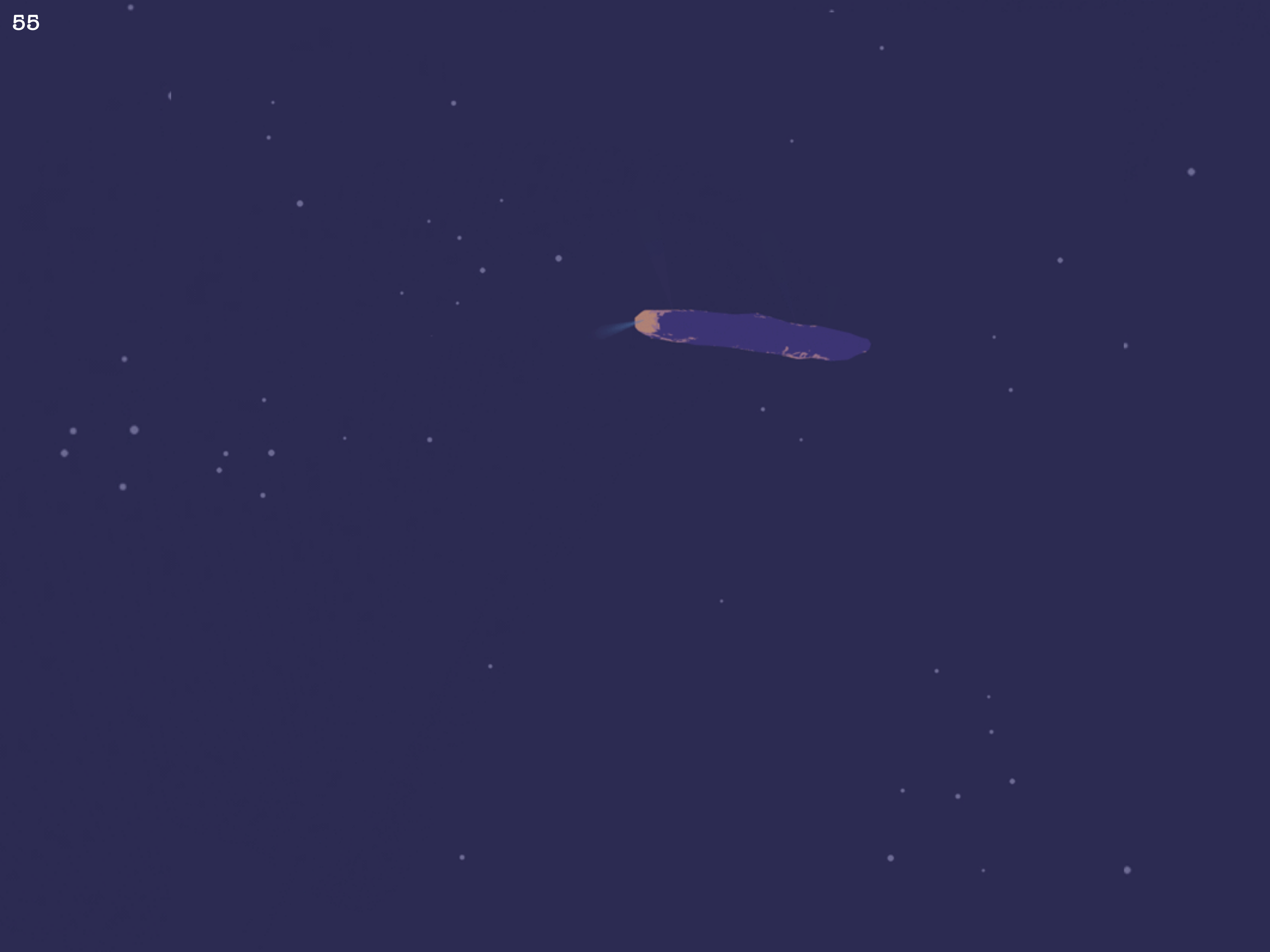


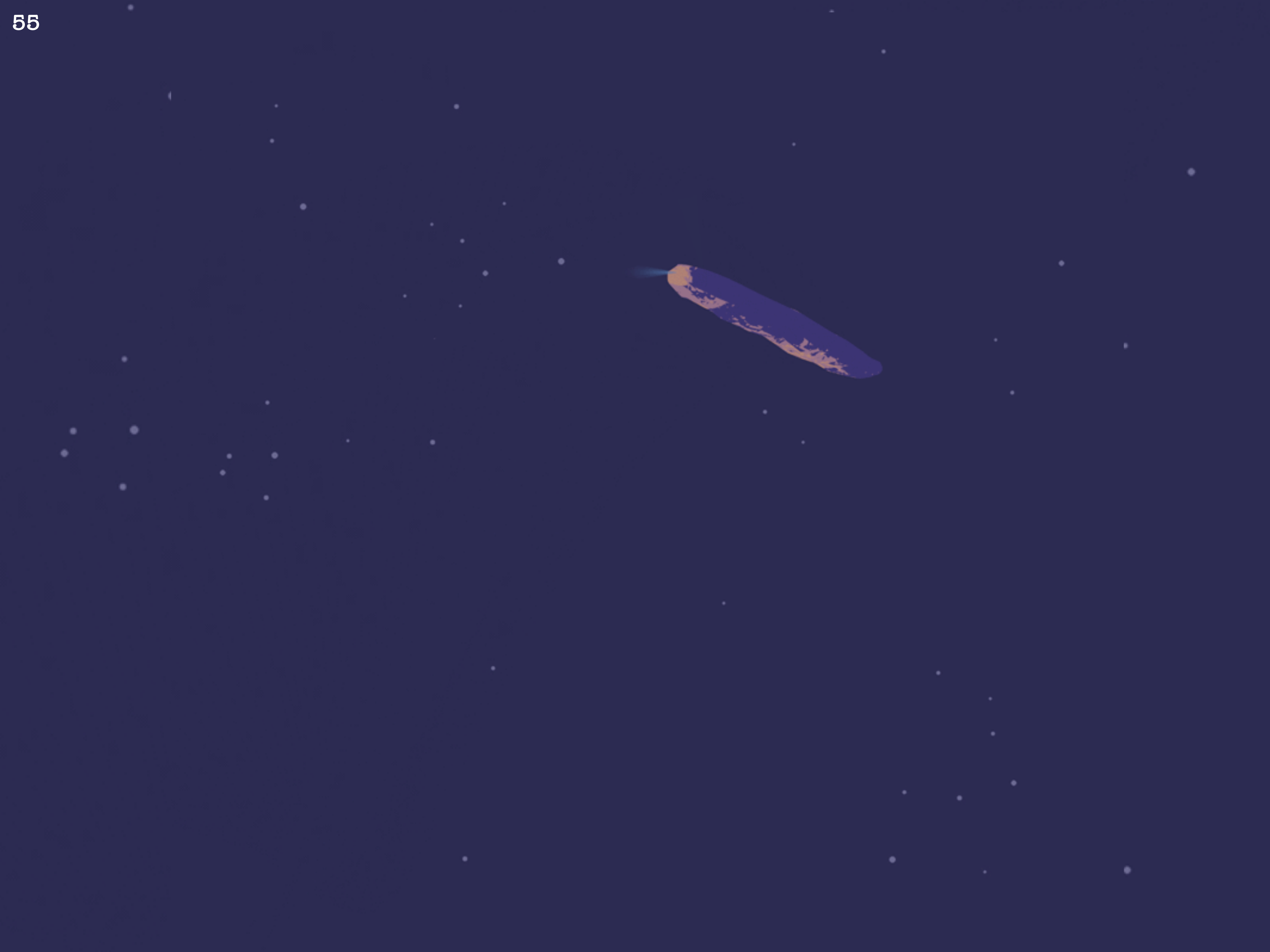


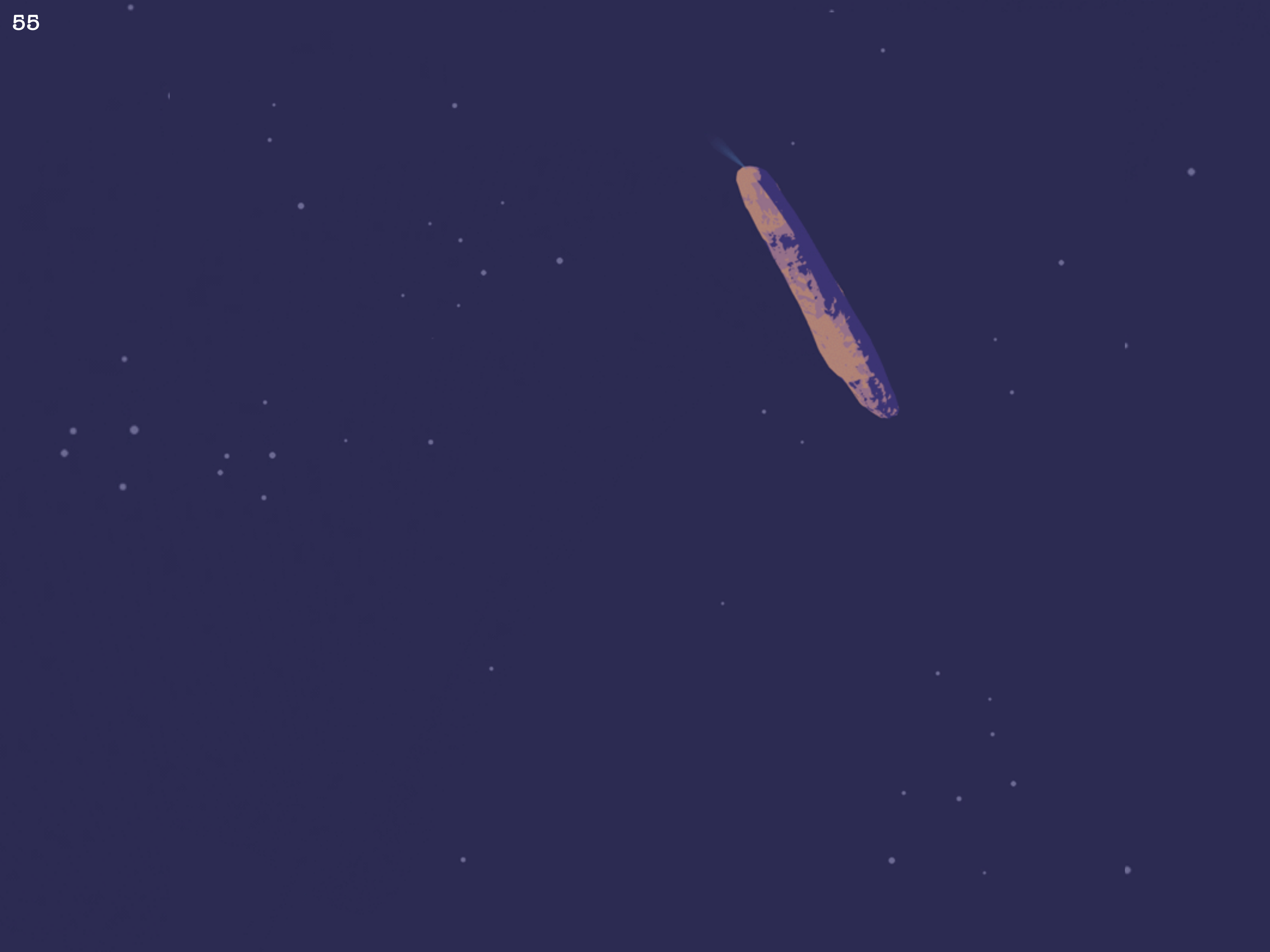


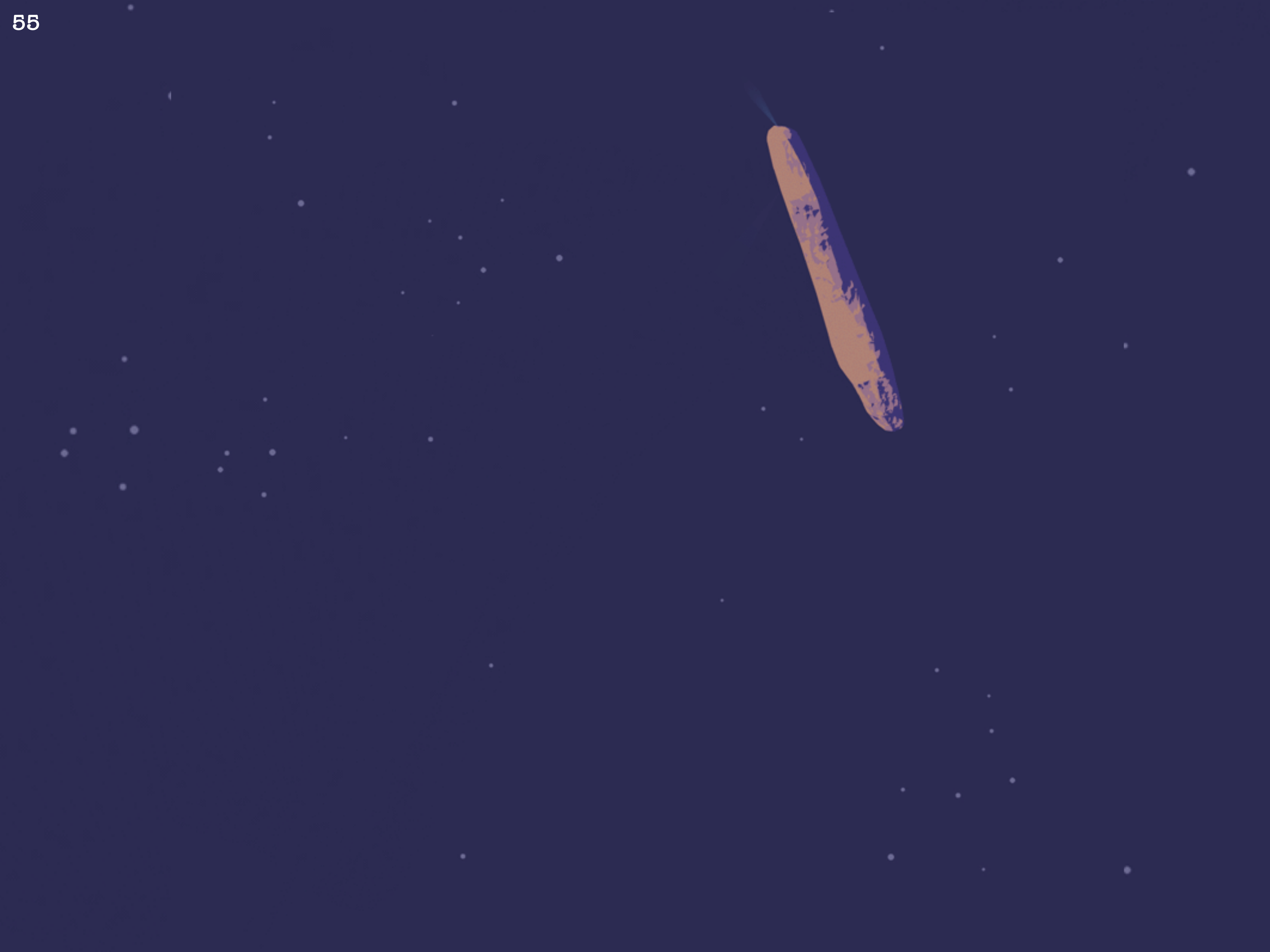


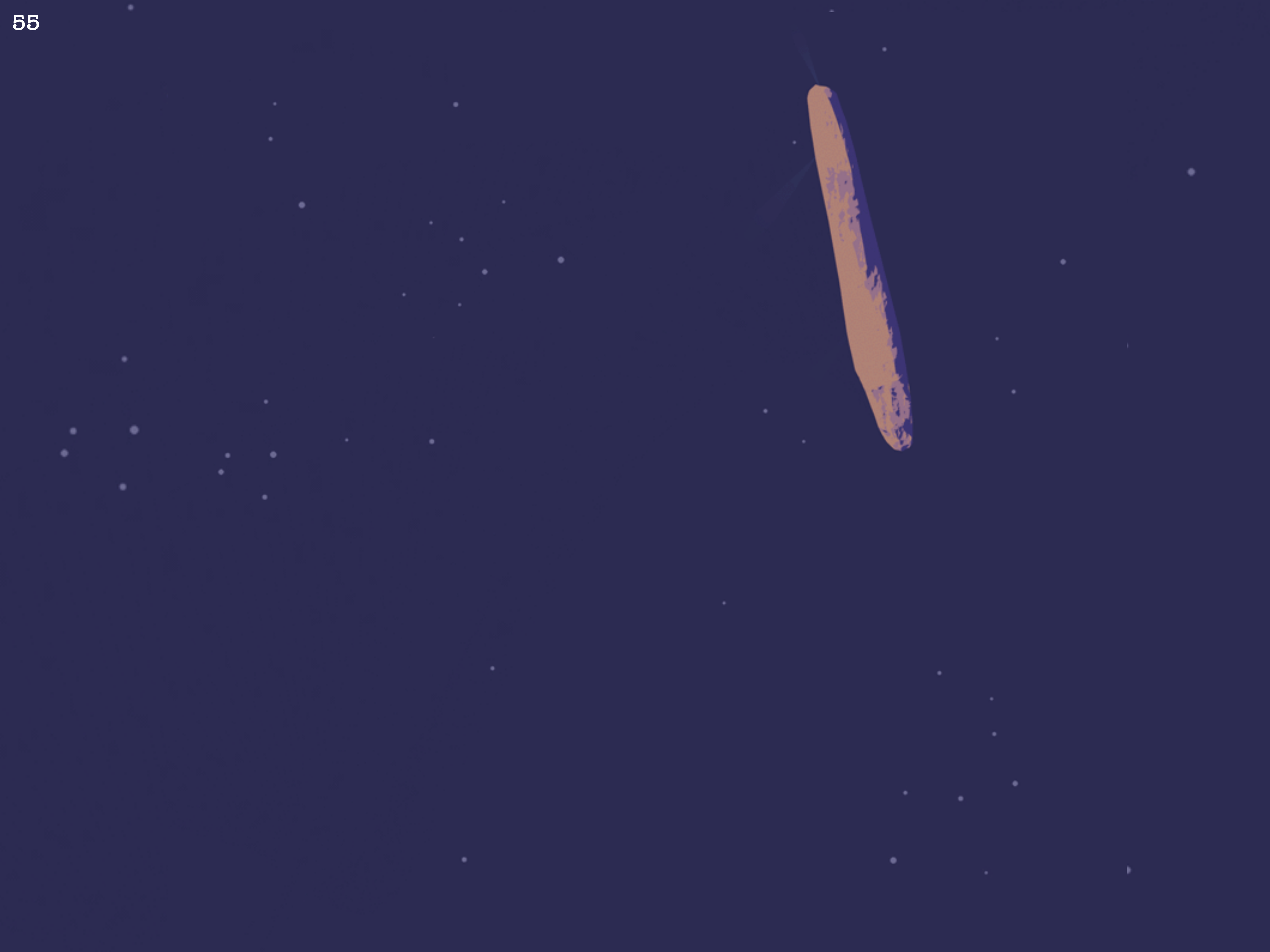


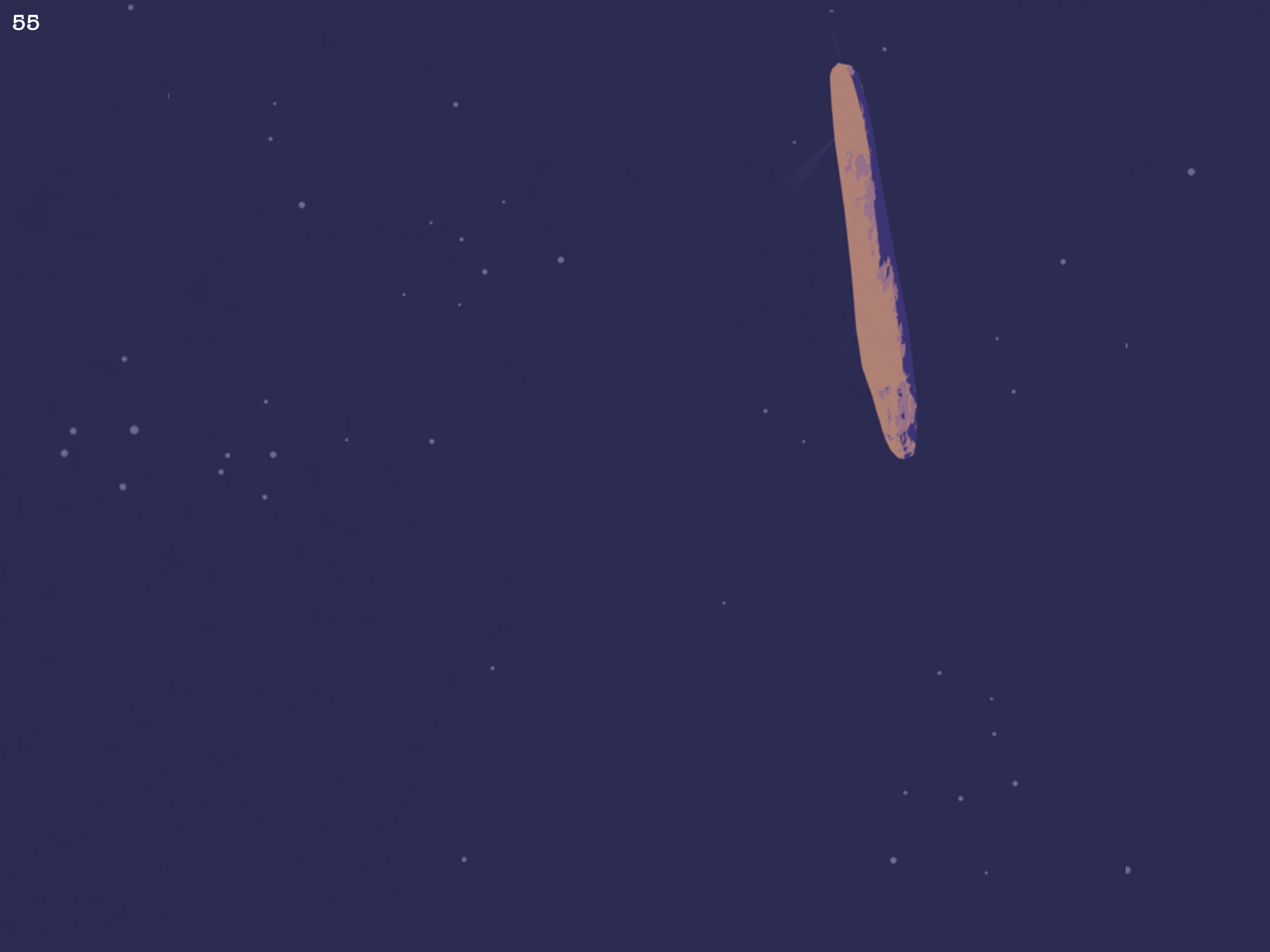


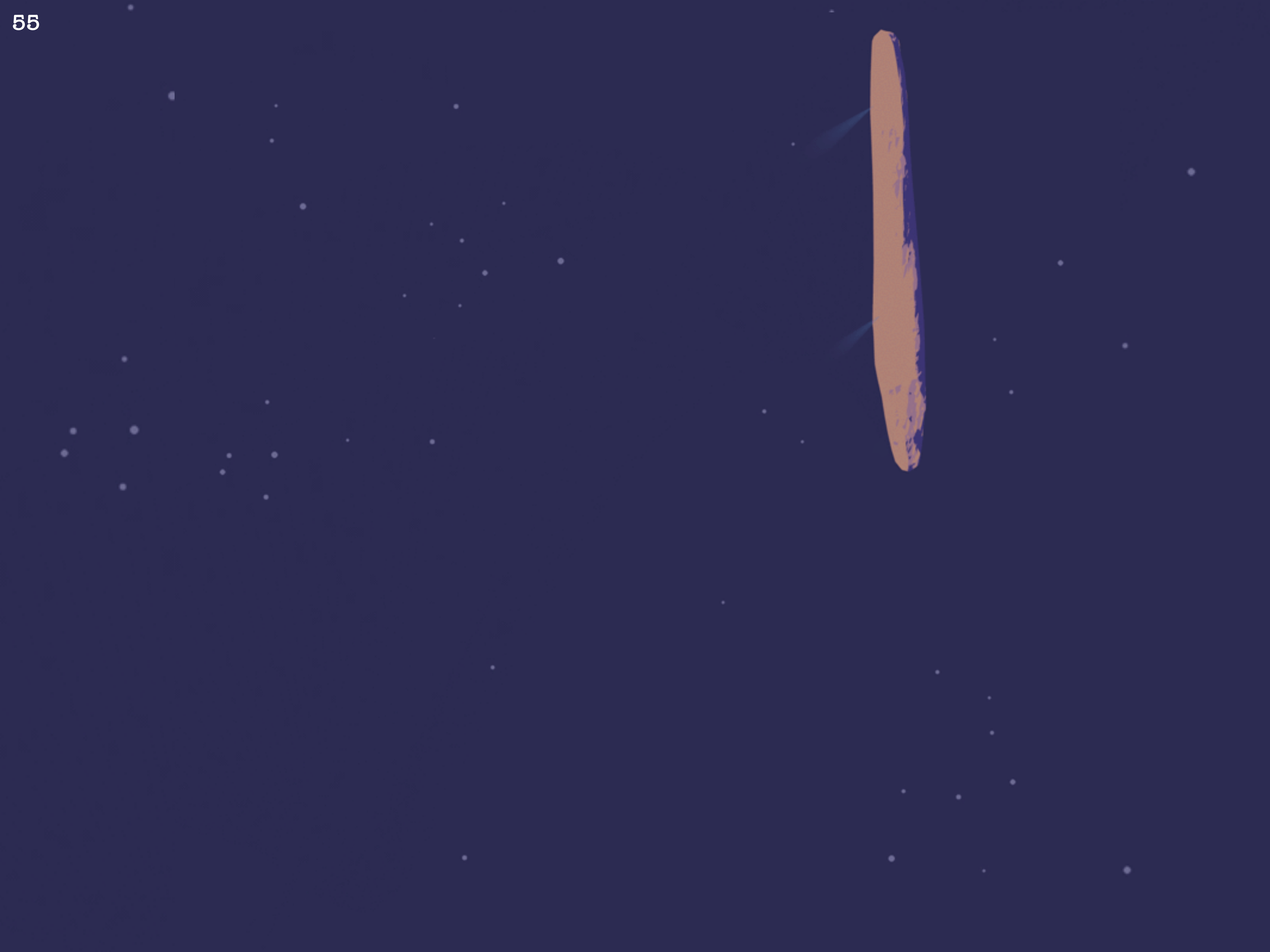


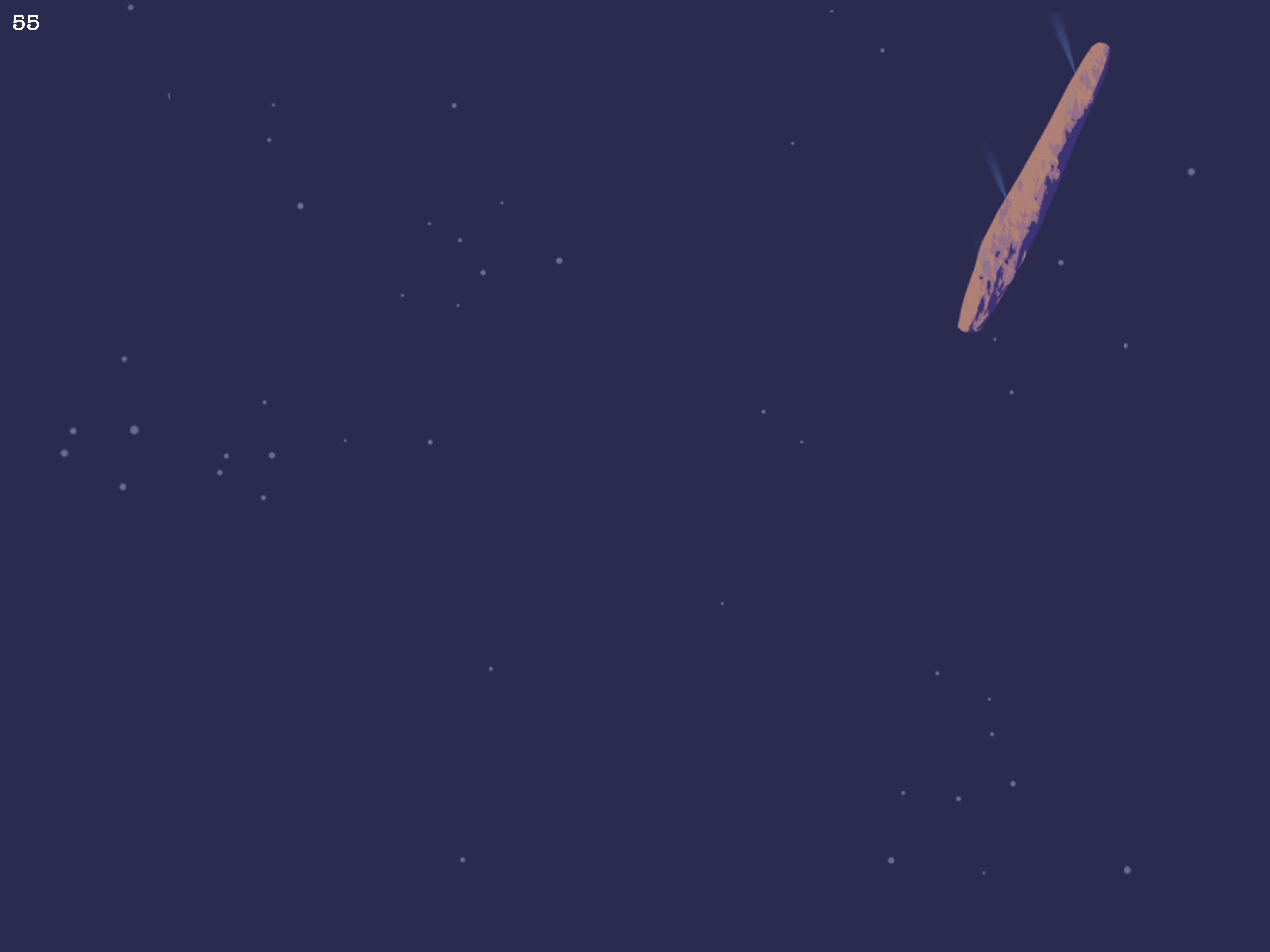












What planet has the highest mountain in the Solar System?

A. Venus

B. Earth

C. Mars

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A. The Hubble Telescope

B. Voyager 1

C. Voyager 2

D. Halley Armada

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How long would a one-way mission from Earth to Mars take?

A. 7 days

B. 7 weeks

C. 7 months

D. 7 years

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Comets have two tails. One is a dust tail comprises of particles from its surface

What is the other tail called..?

A. Ion

B. Stream

C. Double tail

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The nucleus of a comet is surrounded by..?

A. A tail

B. A coma

C. A full stop

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How old is the Solar System

A. 4.6 billion years

B. 1 million years

C. 100,000 years

D. 10,000 years

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What is the most widely accepted theory for the formation of the solar system?

A. Nebular hypothesis

B. Ptolemaic Model

C. Encounter hypothesis

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B. Neil Armstrong

C. Michael Collins

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What was the name of the mission?

A. Apollo 11

B. Starbuck 11

C. Halo 11

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What year did a man first walk on the Moon?

A. 1966

B. 1967

C. 1968

D. 1969

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What was the name of the rocket they launched in?

A. Mars V

B. Jupiter V

C. Saturn V

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B. Jupiter V

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How long did the mission take?

A. 6 days

B. 8 days

C. 10 days

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‘Oumuamua was discovered by Robert Weryk using the Pan-STARRS telescope at

A. Haleakalā Observatory, Hawaii

B. Arecibo Observatory, Puerto Rico

C. Argentine Institute of Radio Astronomy, Berazategui, Argentina

D. Arcetri Observatory, Florence, Italy

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QUERY 9

Determine the escape velocity of Earth, Mars, and the Moon

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$$v_{\text{escape,Earth}} = \sqrt{2GM/R} = \sqrt{2 \cdot 6.67 \times 10^{-11}\text{N m}^2/\text{kg}^2 \cdot 5.9 \times 10^{24} \text{ kg}/(6.4 \times 10^6 \text{ m})} = 1.1 \times 10^4 \text{ m/s} = 11 \text{ km/s}$$

$$v_{\text{escape,Mars}} = \sqrt{2GM/R} = \sqrt{2 \cdot 6.67 \times 10^{-11}\text{N m}^2/\text{kg}^2 \cdot 6.5 \times 10^{23} \text{ kg}/(3.4 \times 10^6 \text{ m})} = 5.0 \times 10^3 \text{ m/s} = 5 \text{ km/s}$$

$$v_{\text{escape,Moon}} = \sqrt{2GM/R} = \sqrt{2 \cdot 6.67 \times 10^{-11}\text{N m}^2/\text{kg}^2 \cdot 7.2 \times 10^{22} \text{ kg}/(1.7 \times 10^6 \text{ m})} = 2.4 \times 10^3 \text{ m/s} = 2.4 \text{ km/s}$$

QUERY 10

The escape speed from Earth is 11 km/s, so a gas molecule travelling away from Earth near the outer boundary of the Earth atmosphere would, at this speed, be able to escape from the Earth gravitational field. Actually, if the thermal speed of a gas is greater than about 15 to 20% of the escape speed of a planet, virtually all of the molecules of that gas will escape the atmosphere of the planet.

At what temperature is the thermal speed of (i) oxygen molecules and (ii) helium molecules equal to 1.65 km/s

(iii) Explain why our atmosphere contains oxygen but not helium

[Hint: The masses of one molecule of O_2 $(\text{molecular mass} = 32\ \text{u})$ and He $(\text{molecular mass} = 4\ \text{u})$ are $m(O_2) = 5.3 \times 10^{-26}$ kg

$m(\text{He}) = 6.6 \times 10^{-27}$ kg where $1\ \text{u} = 1.66 \times 10^{-27}$ kg

QUERY 10

(i)

$$T_{O_2} = \frac{(0.15\ v_{\text{escape}})^2\ m}{3k} = \frac{32 \cdot 1.66 \times 10^{-27}\ \text{kg} \cdot (0.15 \cdot 1.1 \times 10^4\ \text{m/s})^2}{3 \cdot 1.38 \times 10^{-23}\ \text{J/K}} = 3,708\ \text{K}$$

(ii)

$$T_{\text{He}} = \frac{(0.15\ v_{\text{escape}})^2 m}{3k} = \frac{4 \cdot 1.66 \times 10^{-27}\ \text{kg} \cdot (0.15 \cdot 1.1 \times 10^4\ \text{m/s})^2}{3 \cdot 1.38 \times 10^{-23}\ \text{J/K}} = 46\ \text{K}$$

(iii) Because the **escape temperature** is so high for oxygen, very few oxygen molecules ever escape the atmosphere

But helium, with one-eighth the mass, can escape at much lower temperature

The average surface temperature on Earth is approximately 15˚C

QUERY 11

Compute the temperature for which the thermal speed of O_2 is equal to 15% of the escape speed at the surface of the Moon. How does this account for the absence of an atmosphere on the Moon?

QUERY 11

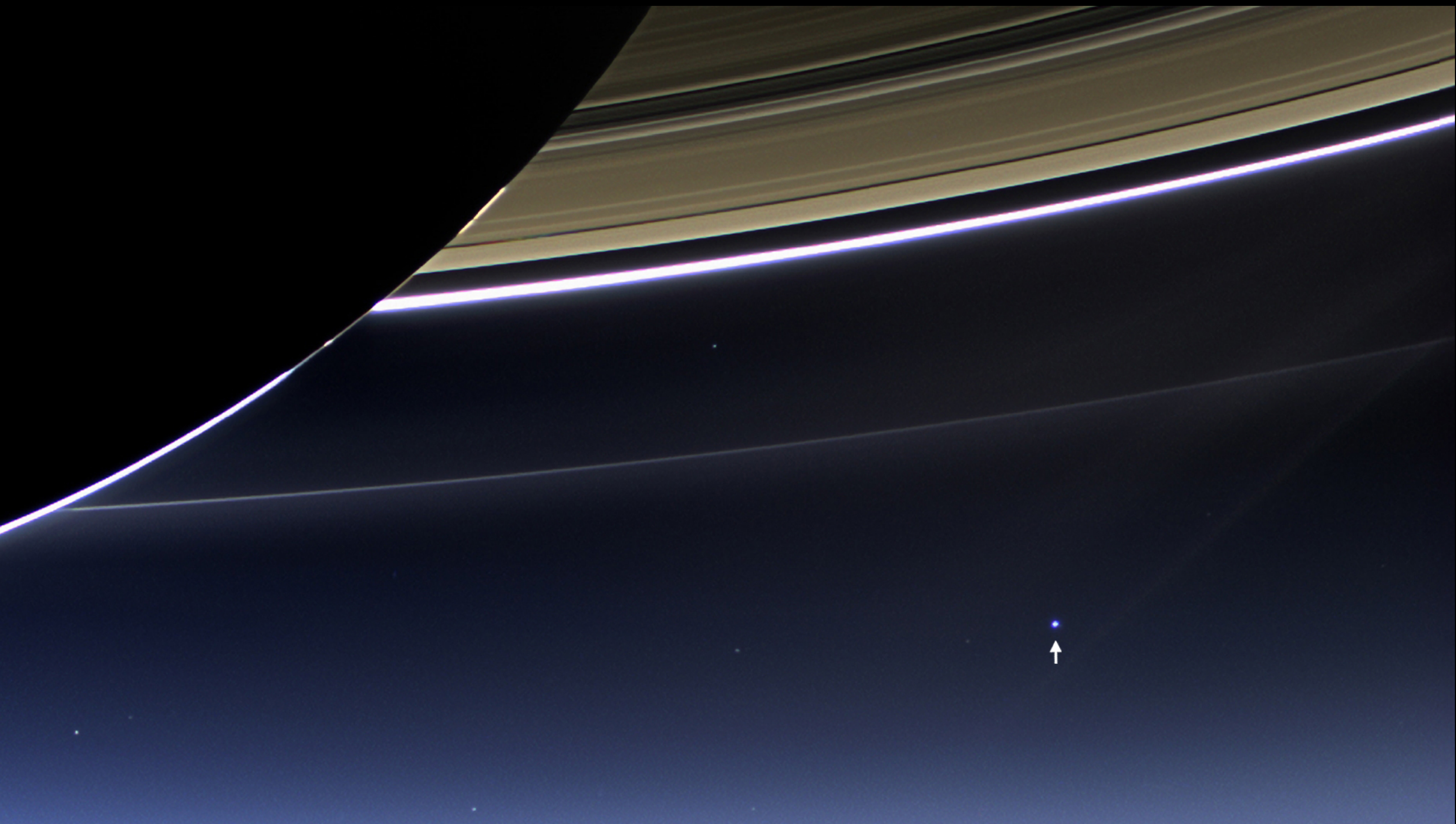
Compute the temperature for which the thermal speed of O_2 is equal to 20% of the escape speed at the surface of the Moon. How does this account for the absence of an atmosphere on the Moon?

$$T_{O_2} = \frac{(0.15\ v_{\text{escape}})^2\ m}{3k} = \frac{32 \cdot 1.66 \times 10^{-27}\ \text{kg} \cdot (0.15 \cdot 2.3 \times 10^3\ \text{m/s})^2}{3 \cdot 1.38 \times 10^{-23}\ \text{J/K}} = 162\ \text{K}$$

The mean surface temperature of the Moon is 106°C during the day and -183°C during night. The temperature during the day is hot enough that oxygen (and other gases) would have escaped during the time since the formation of the moon to the present

Moreover, the temperature during the moon formation could have been approximately $1000\ \text{K}$

Pale Blue Dot



Consider again that blue dot. That's here. That's home. That's us.

On it everyone you love, everyone you know, everyone you ever heard of, every human being who ever was, lived out their lives.

The aggregate of our joy and suffering, thousands of confident religions, ideologies, and economic doctrines, every hunter and forager, every hero and coward, every creator and destroyer of civilization, every king and peasant, every young couple in love, every mother and father, hopeful child, inventor and explorer, every teacher of morals, every corrupt politician, every "superstar," every "supreme leader," every saint and sinner in the history of our species lived there – on a mote of dust suspended in a sunbeam

The Earth is a very small stage in a vast cosmic arena. Think of the rivers of blood spilled by all those generals and emperors so that, in glory and triumph, they could become the momentary masters of a fraction of a dot. Think of the endless cruelties visited by the inhabitants of one corner of this pixel on the scarcely distinguishable inhabitants of some other corner, how frequent their misunderstandings, how eager they are to kill one another, how fervent their hatreds.

Our posturings, our imagined self-importance, the delusion that we have some privileged position in the Universe, are challenged by this point of pale light. Our planet is a lonely speck in the great enveloping cosmic dark. In our obscurity, in all this vastness, there is no hint that help will come from elsewhere to save us from ourselves.

The Earth is the only world known so far to harbor life. There is nowhere else, at least in the near future, to which our species could migrate. Visit, yes. Settle, not yet. Like it or not, for the moment the Earth is where we make our stand.

It has been said that astronomy is a humbling and character-building experience. There is perhaps no better demonstration of the folly of human conceits than this distant image of our tiny world. To me, it underscores our responsibility to deal more kindly with one another, and to preserve and cherish the pale blue dot, the only home we've ever known.

Carl Sagan