

Asteroids, Meteorites, and the History of the Solar System

Nicholas Moskovitz

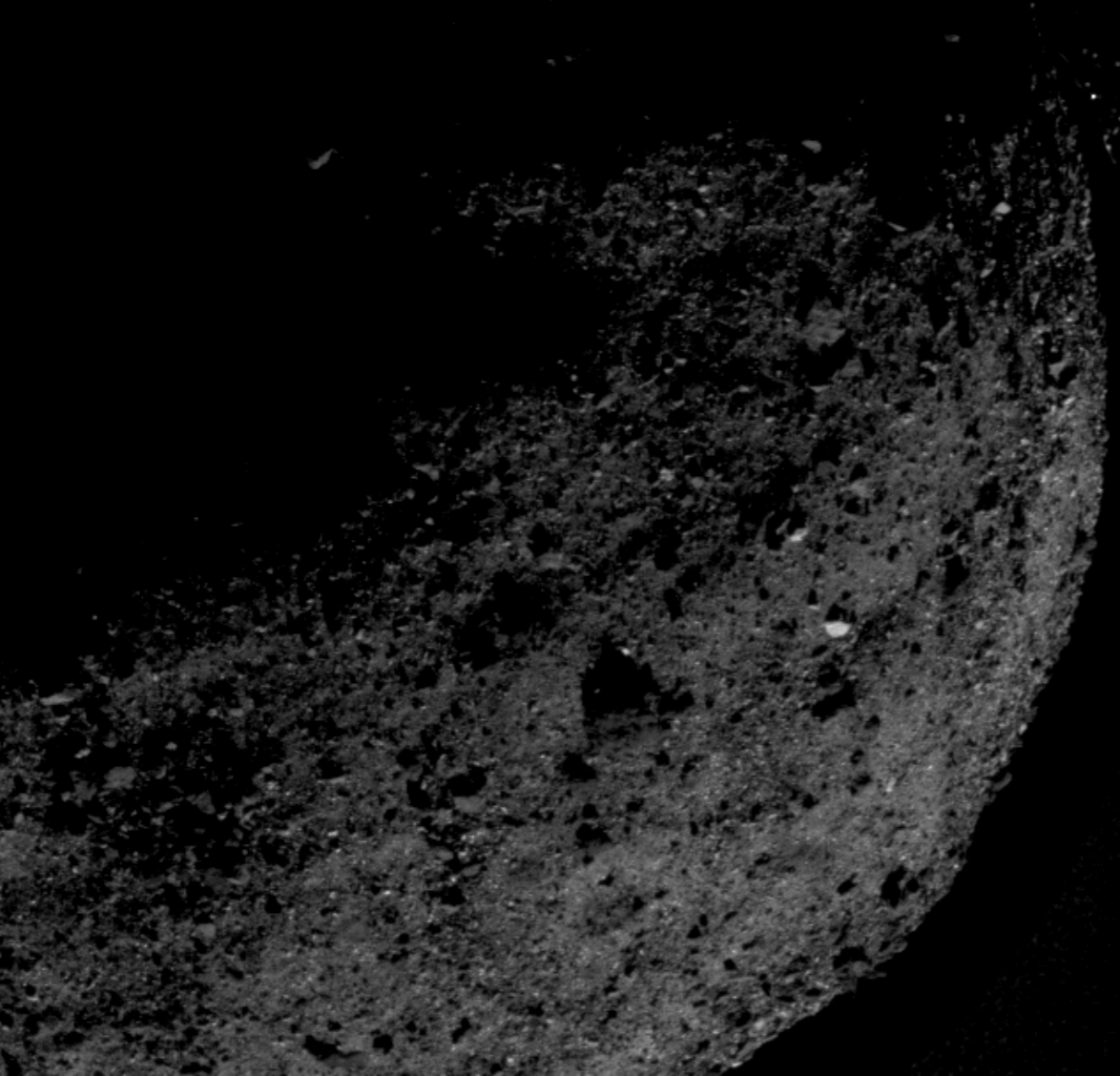



Image: NASA/Goddard/University of Arizona/Lockheed Martin




 **Lowell Observatory**
Storyed facility with
tours & stargazing



24" Clark Telescope



 Lowell Observatory
Storyed facility with
tours & stargazing

13" Pluto
Telescope



24" Clark
Telescope



Lowell Observatory
Storied facility with
tours & stargazing

13" Pluto
Telescope



My
Office



Lowell Observatory
Storyed facility with
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24" Clark
Telescope



13" Pluto
Telescope



My
Office



Lowell Observatory
Stored facility with
tours & stargazing

24" Clark
Telescope



Phoenix, AZ

Thursday
Sunny



106 °F | °C

Flagstaff, AZ

Thursday
Sunny



80 °F | °C

No. 171

Name δ Geminorum

Remarks good plate

Exposure = 9:13 - 10:13; net thr.

H.A. = 0:56 E. at 10:13

13 inch Lawrence Lowell Telescope

Cramer's Hi Speed Plate

Writing at North end of plate

Rodinal developer

 δ Geminorum

Jan. 29, 1930

R.A. = $7^h 15^m 53^s$ DECL. = $+22^\circ 7'$

Series B-3

All of plate was examined.

6 day interval

Fairly good pair to blink

Plates:

165 } Examined together on comparator carefully
 171 } by C.W.

Examination began about Feb. 15, 1930; but I could devote only part time to blinking. The thickness of stars slowed up the work considerably. At the end of the day of Feb. 18, 1930, about 4th of the pair was examined.

On Feb. 18, 1930 at 4:00 PM (Mt. Standard Civil Time) planet X (Pluto) was discovered - using the comparator. The following $\frac{3}{4}$ hour was spent investigating the amount of shift or apparent motion of Pluto, also its direction, and genuineness of images. The last mentioned was settled by the identification of the images in their respective positions on the 5 inch Cogswell Camera plates, which were made simultaneously with the 13 inch telescope discovery plates (no. 165 of Jan. 23, and no. 171 of Jan. 29). A 3rd plate of Jan. 21, also showed the planet in correct position with respect to the other dates.

At 4:45 PM. the discovery was made known to Dr. C. D. Lampland first, and then to Mr. V. M. Slipher and then to Mr. E. C. Slipher. I shall never forget the intense interest that the object caused among the rest of the staff.

No further examination was done for a considerable period - as Mr. Lampland used the comparator for measurement of positions on the 13 inch plates, and also for identification of Pluto images on plates that he made with the 42 inch reflector on following nights for several months.

Examination of this pair of plates was resumed about May 26, 1930, but could devote only a small part of each day, and examination of the entire area of the plate was not completed until June 9, 1930.

The Ottawa object was watched for on the remaining $\frac{3}{4}$ ths of the plate, but nothing else of a transneptunian nature was found.

- C. W. Tombaugh
 June 9, 1930.

Notes of Examination: -

- 8 asteroids "A".
- 7 variable stars "V" (+ 3 or 4 others not marked on this plate - see plate 165 for their position).
- 12 temporary objects (on one plate only) which may be variable stars, novae, or defects.
- two different suspicious objects (transneptunian) of 17th mag. were found to be a variable star in both cases, from checks on other plates - on one plate a variable and a defect on the other).
- No comets.
- Planet "X" (Pluto) at last found !!! P

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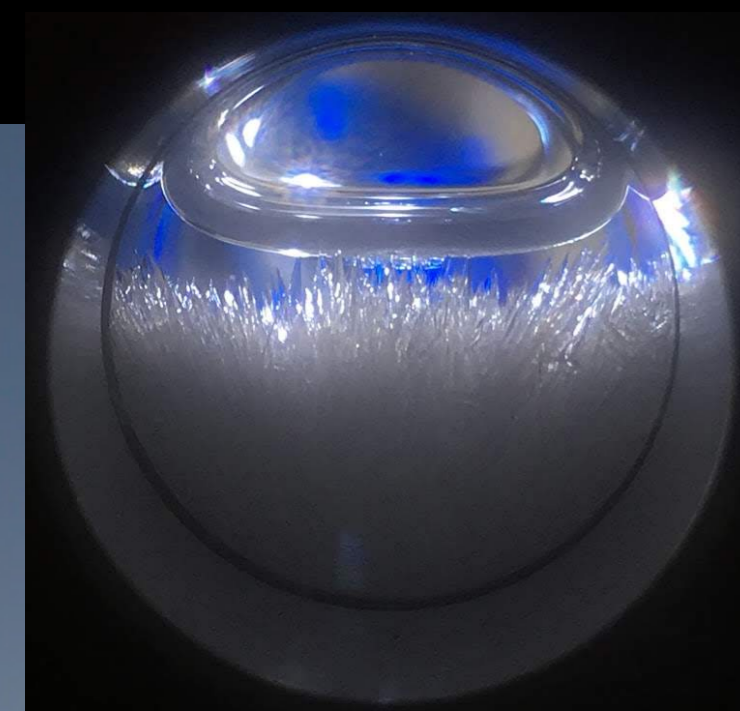
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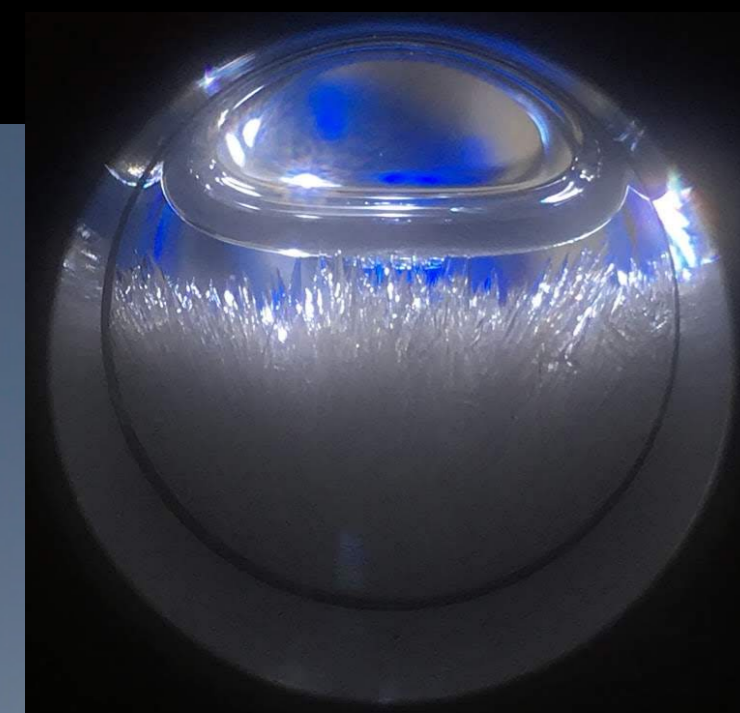
**Lowell's 4.3m
Discovery Channel
Telescope**



**Lowell's 4.3m
Discovery Channel
Telescope**



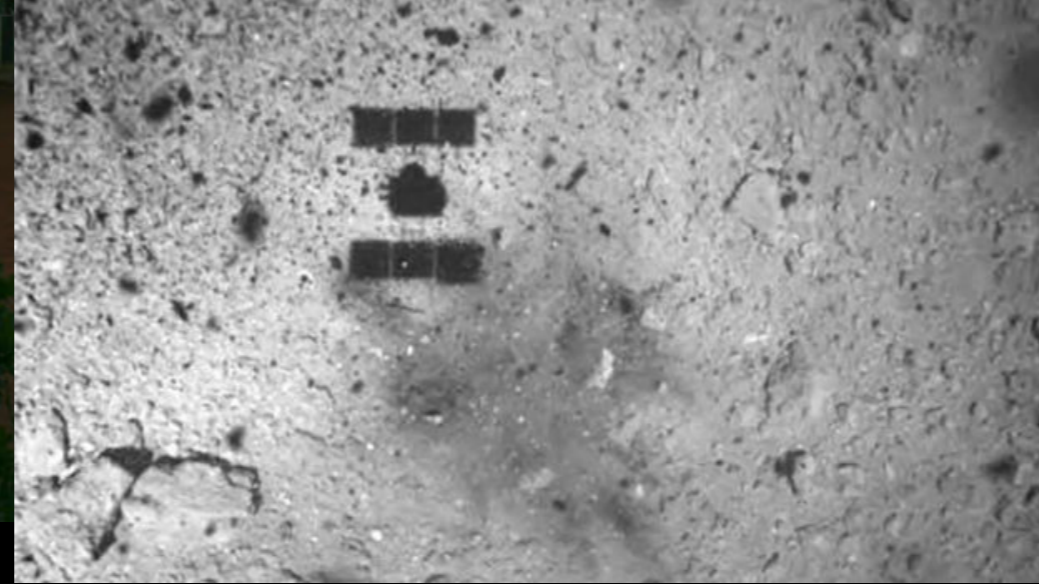
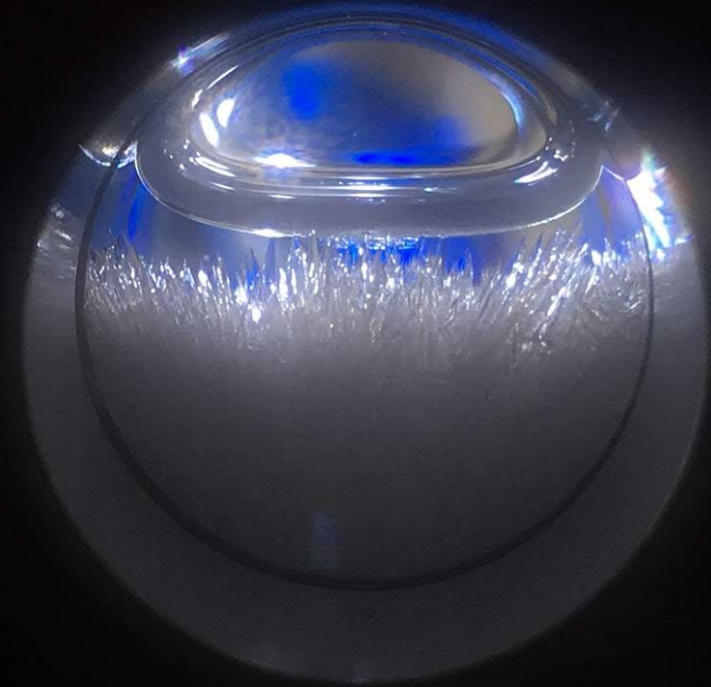
Lowell's 4.3m
Discovery Channel
Telescope



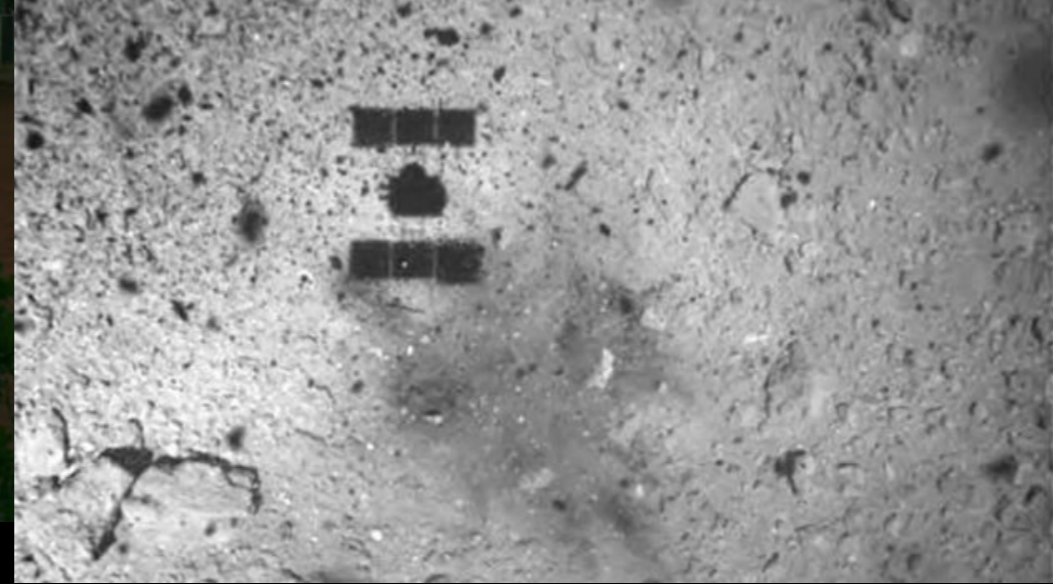
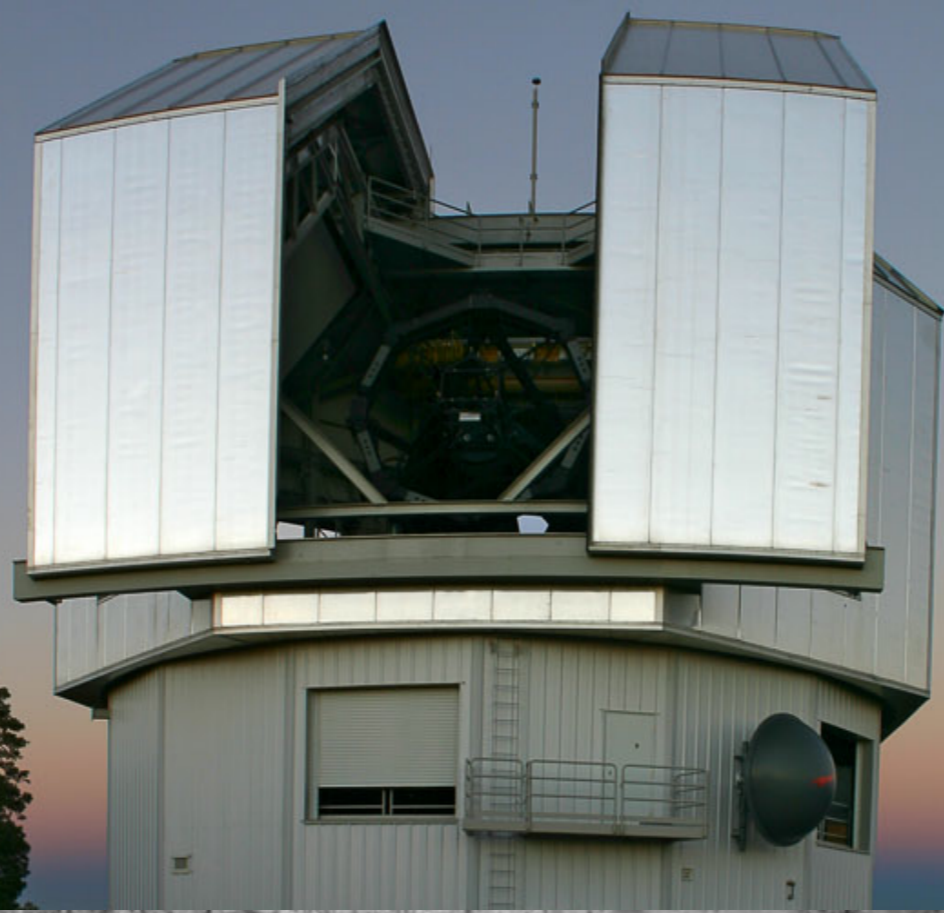
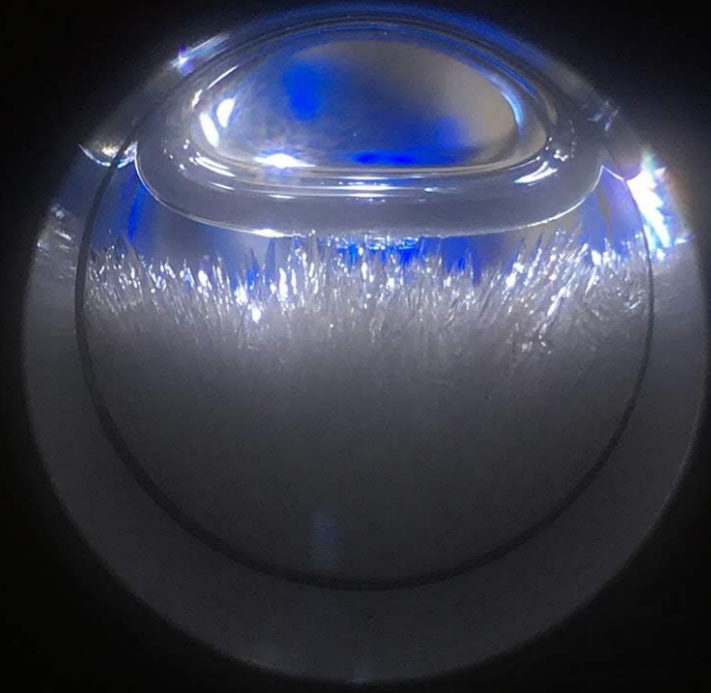
Lowell's 4.3m Discovery Channel Telescope



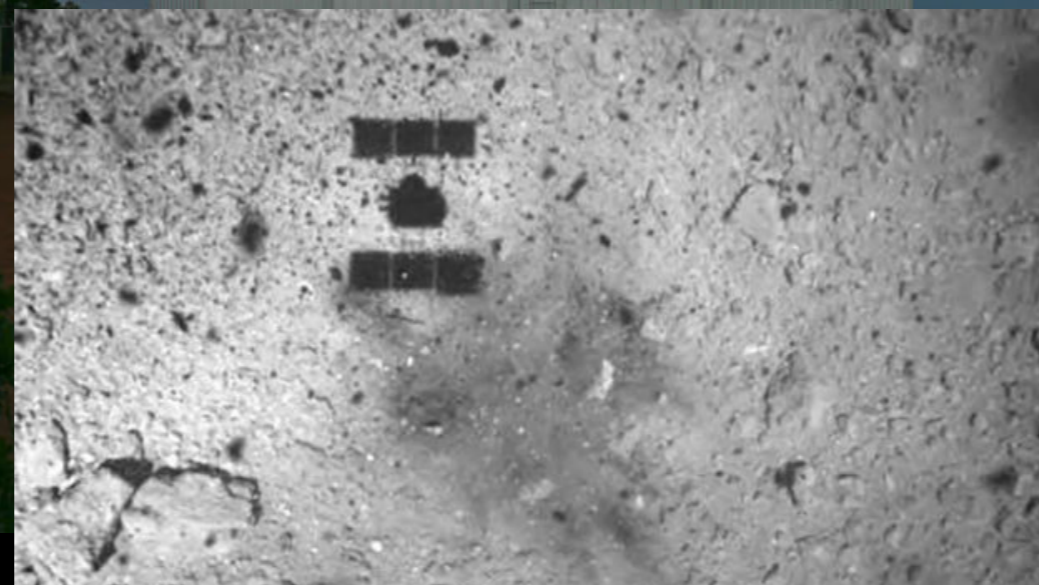
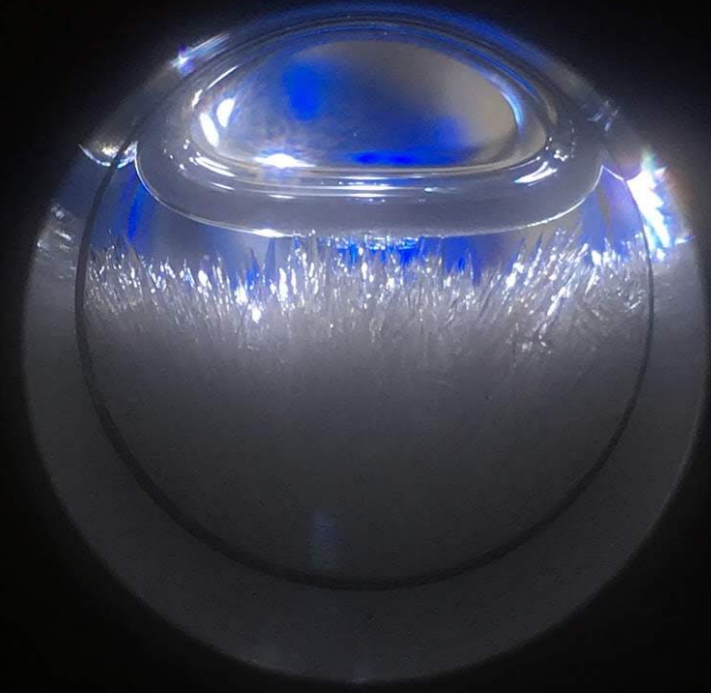
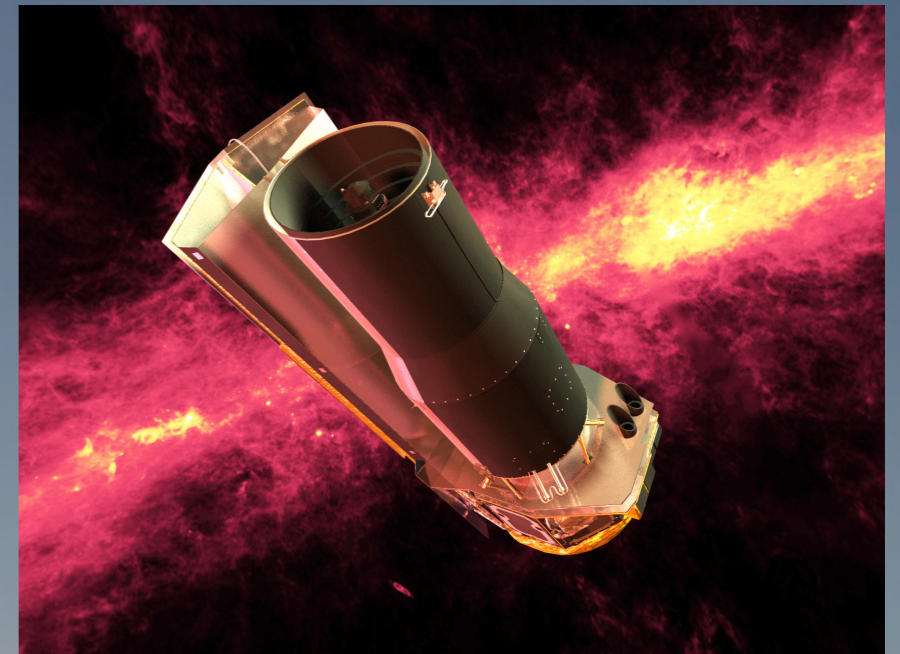
Lowell's 4.3m Discovery Channel Telescope



Lowell's 4.3m Discovery Channel Telescope



Lowell's 4.3m Discovery Channel Telescope



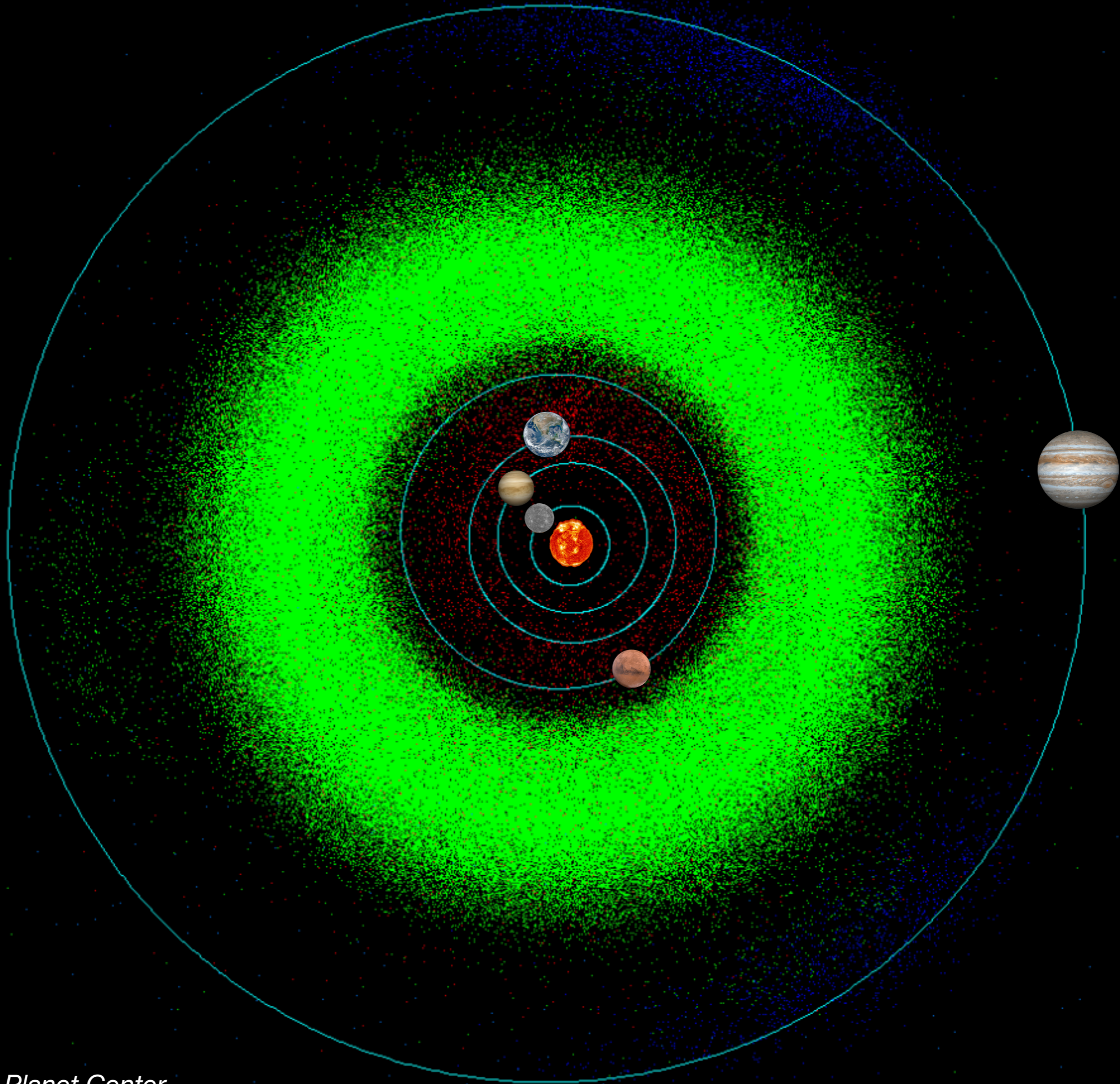
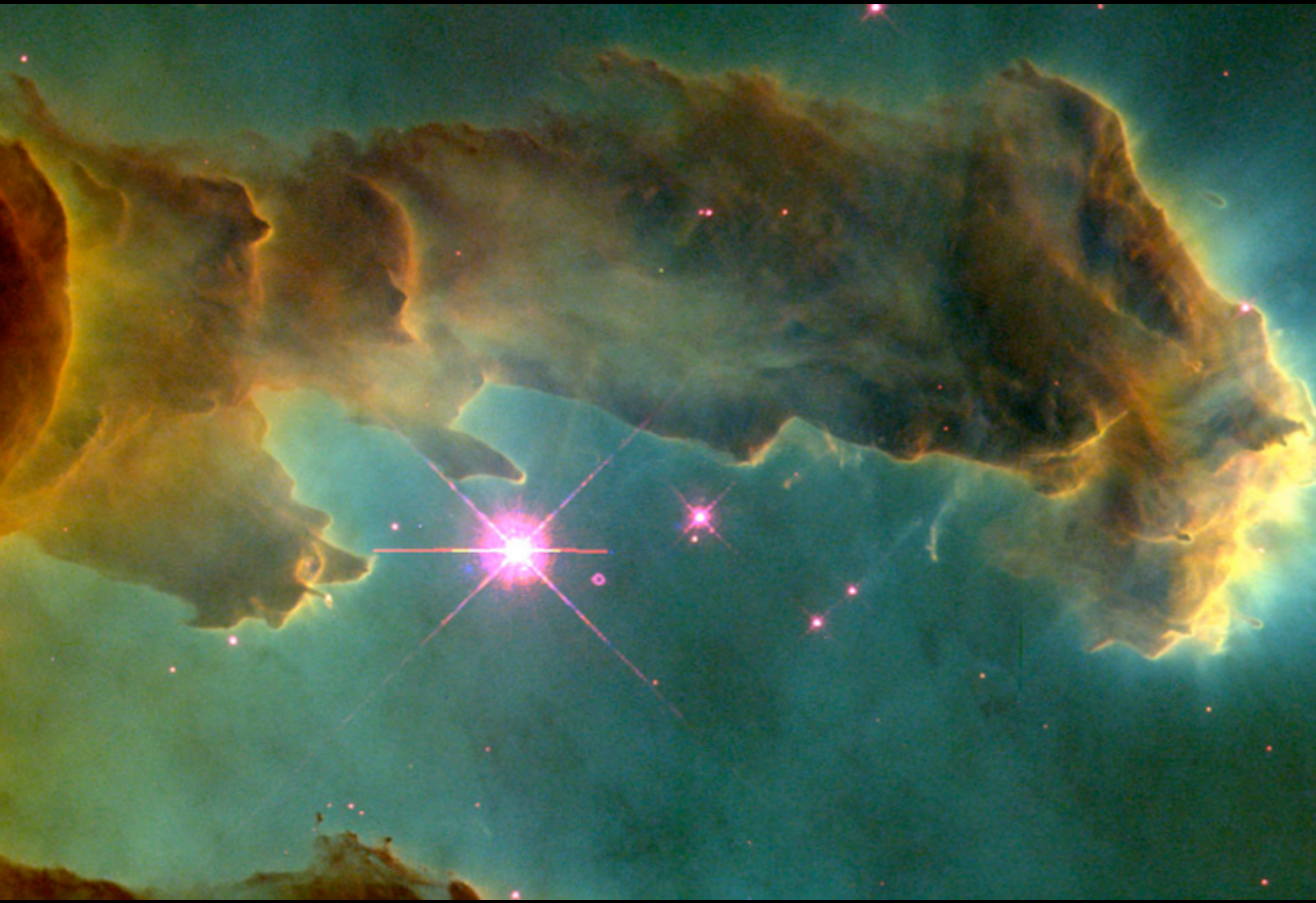
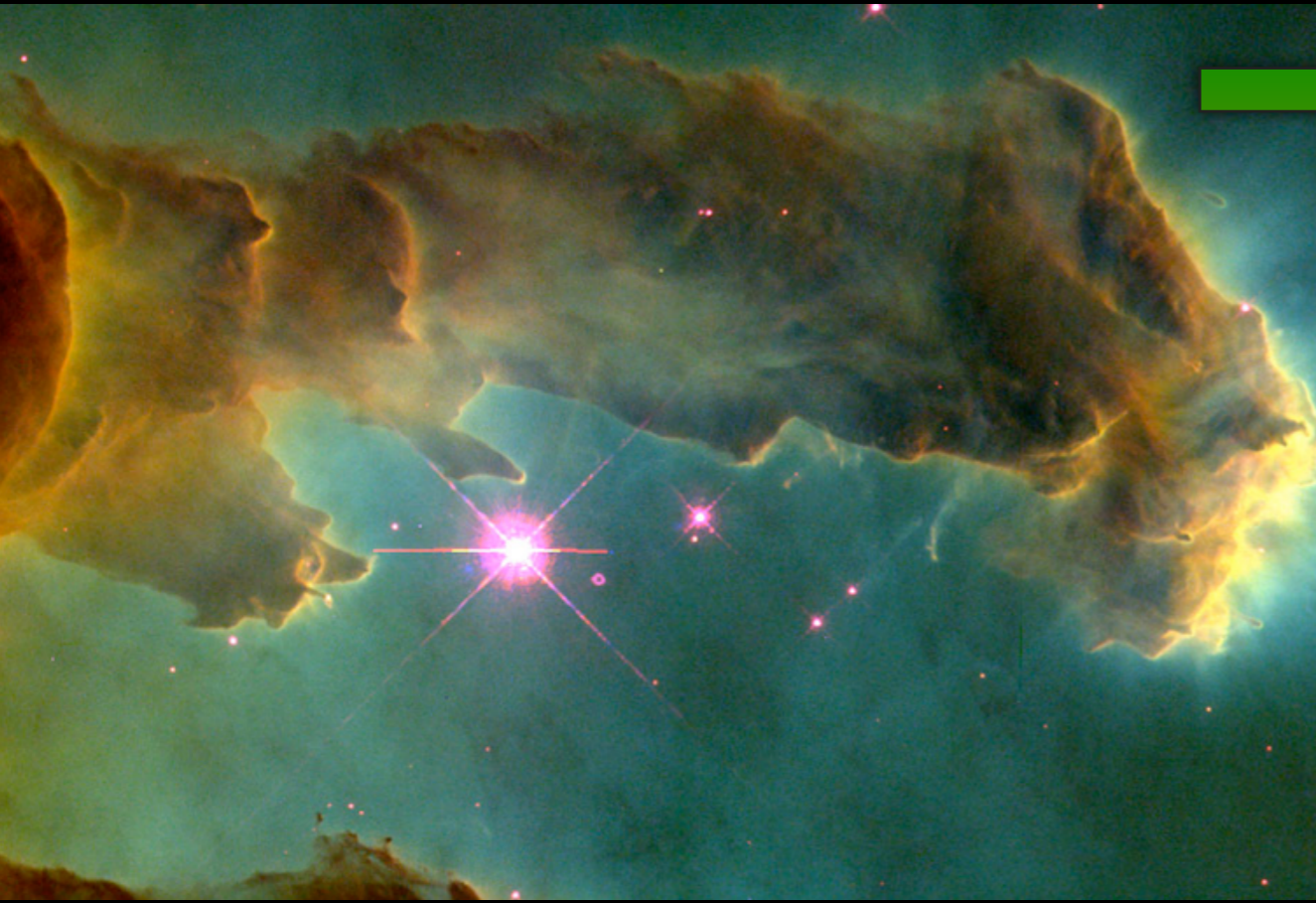


Image: Minor Planet Center

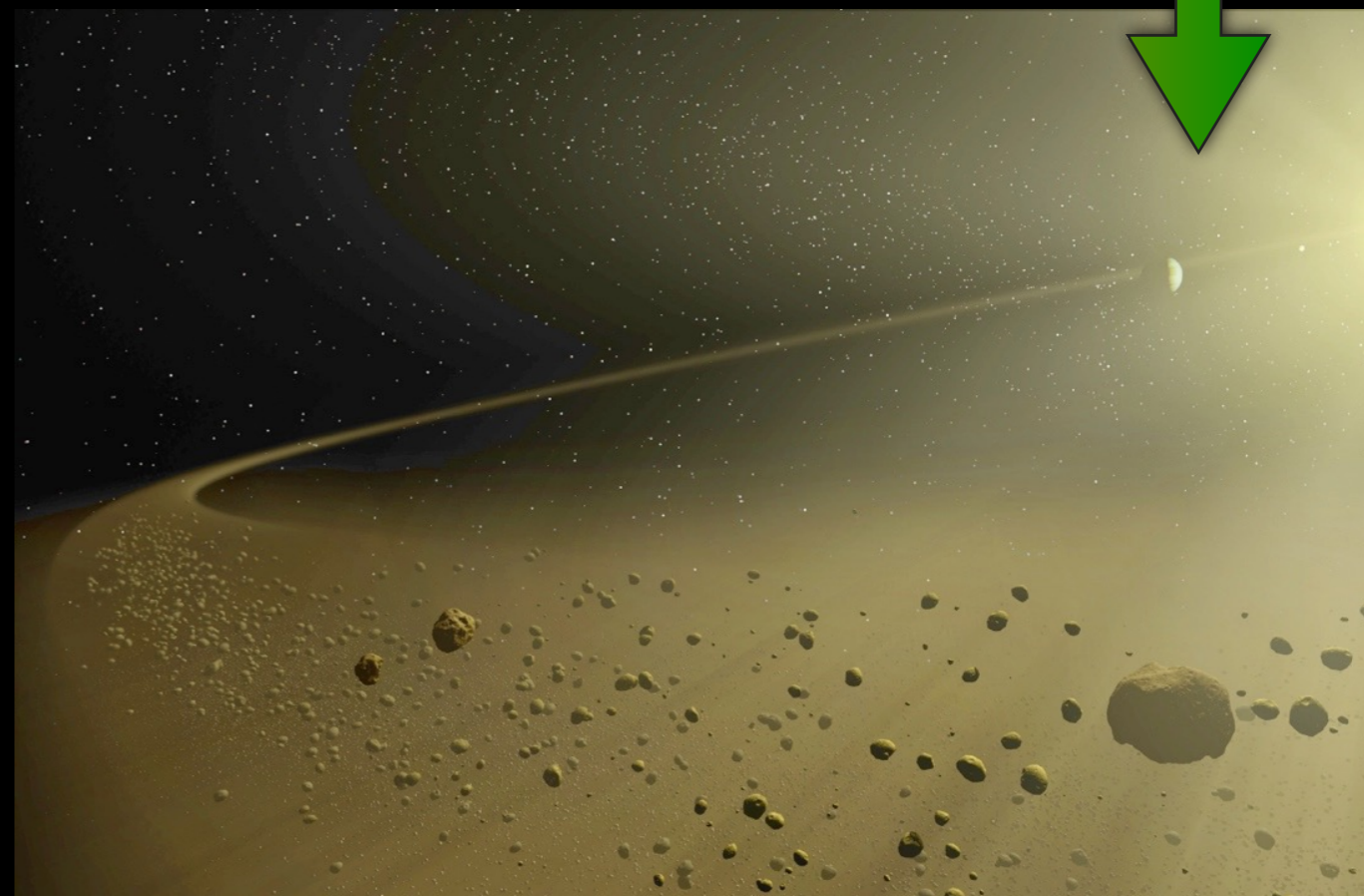
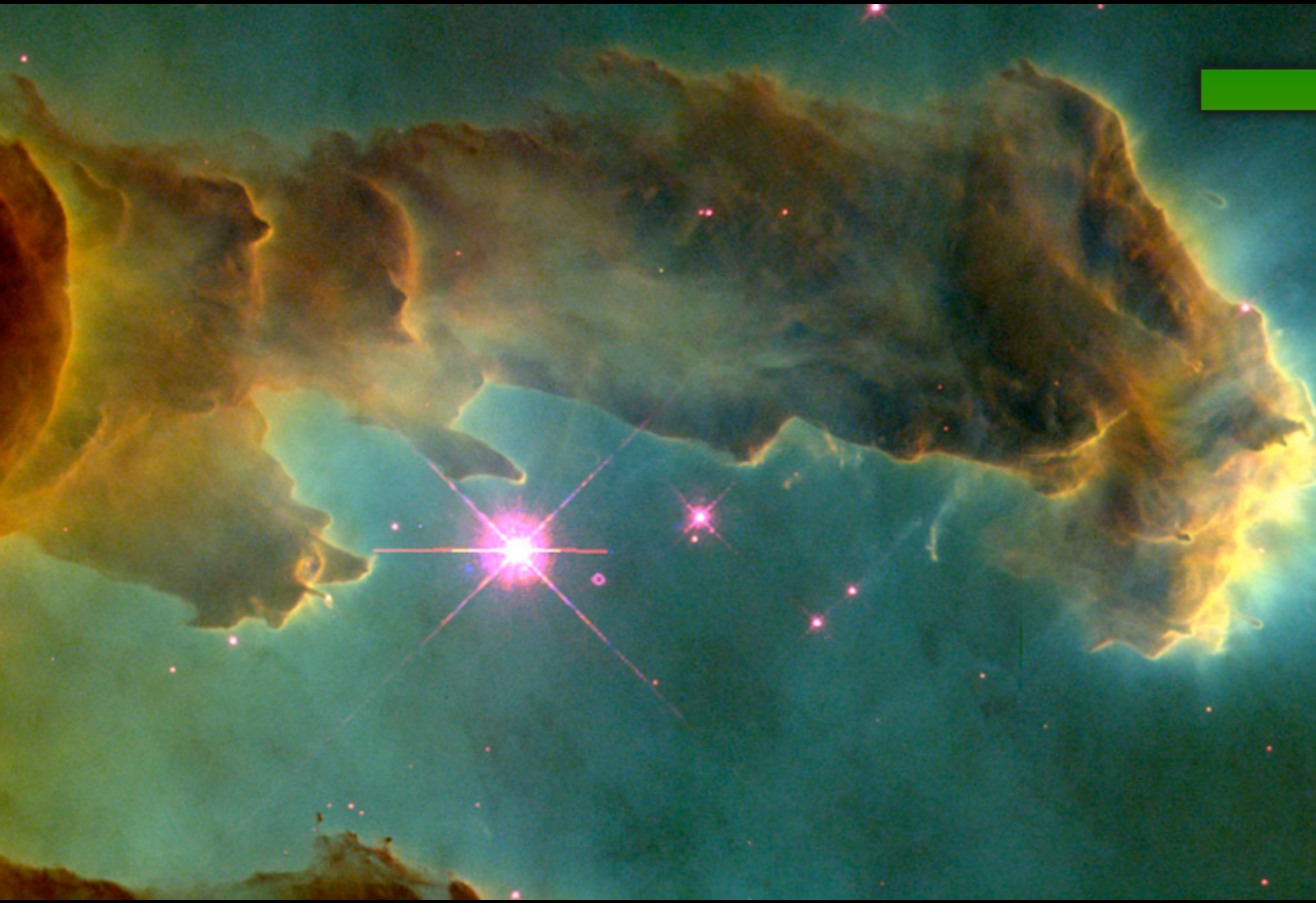
a very brief history of the solar system...



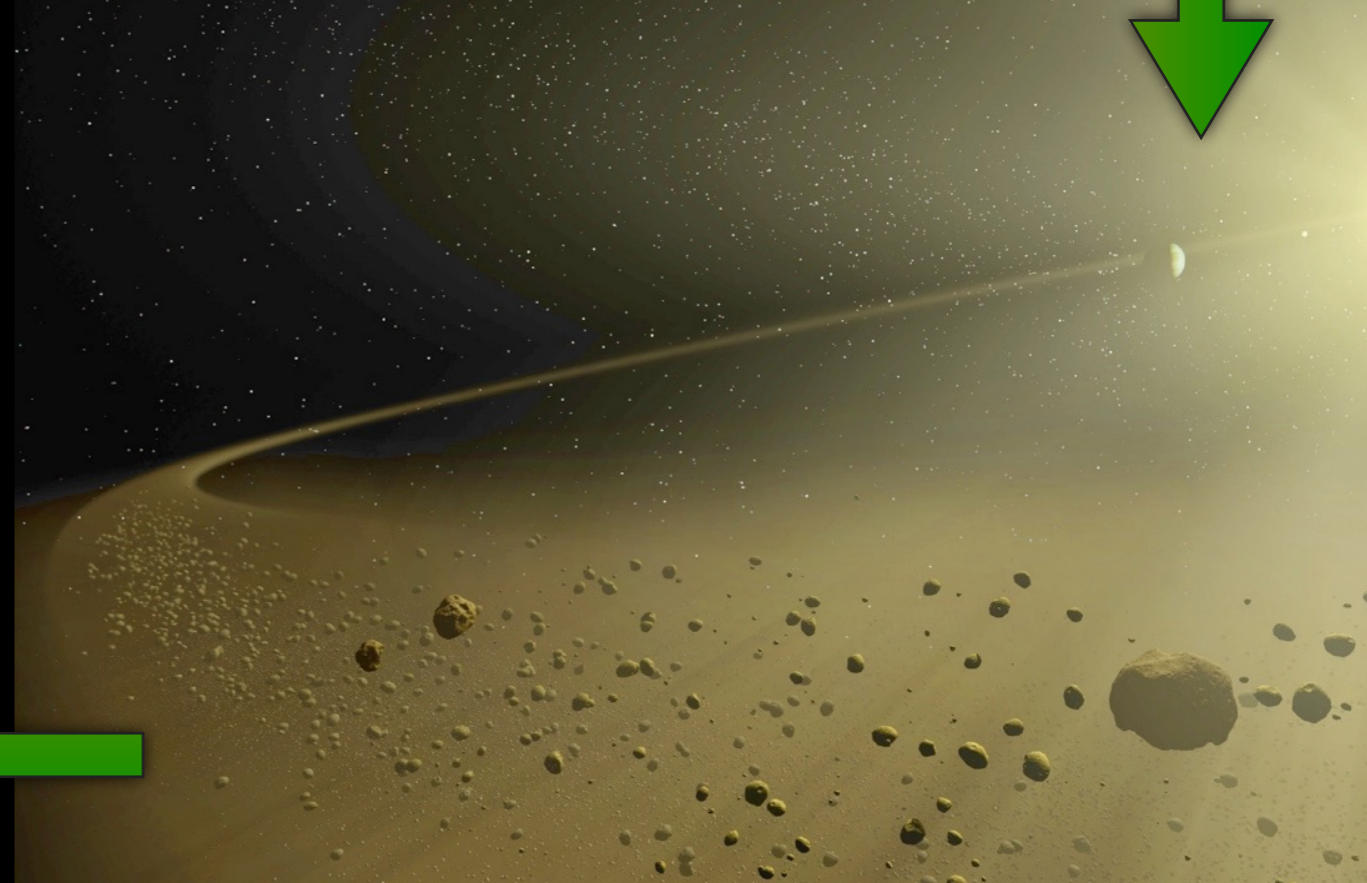
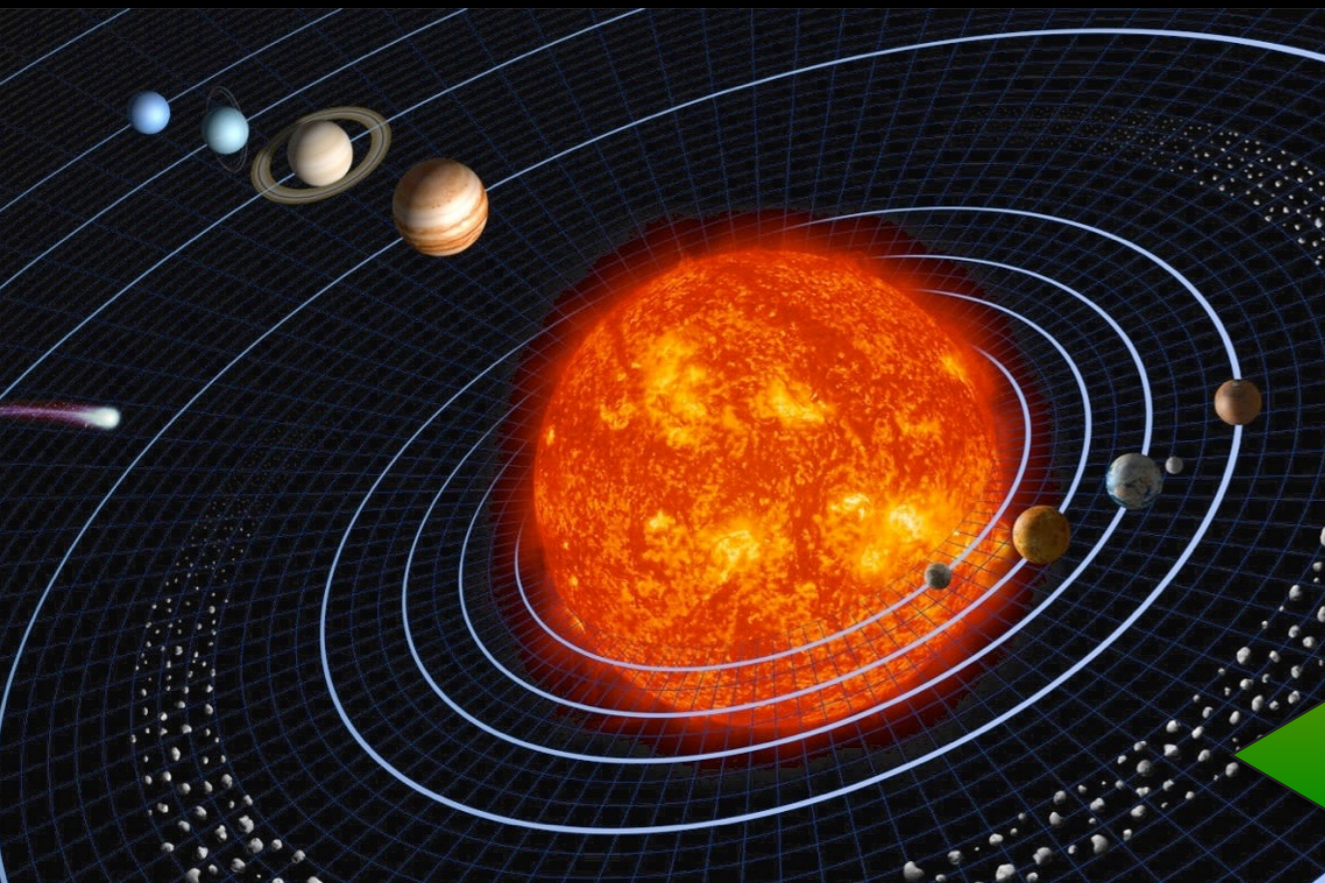
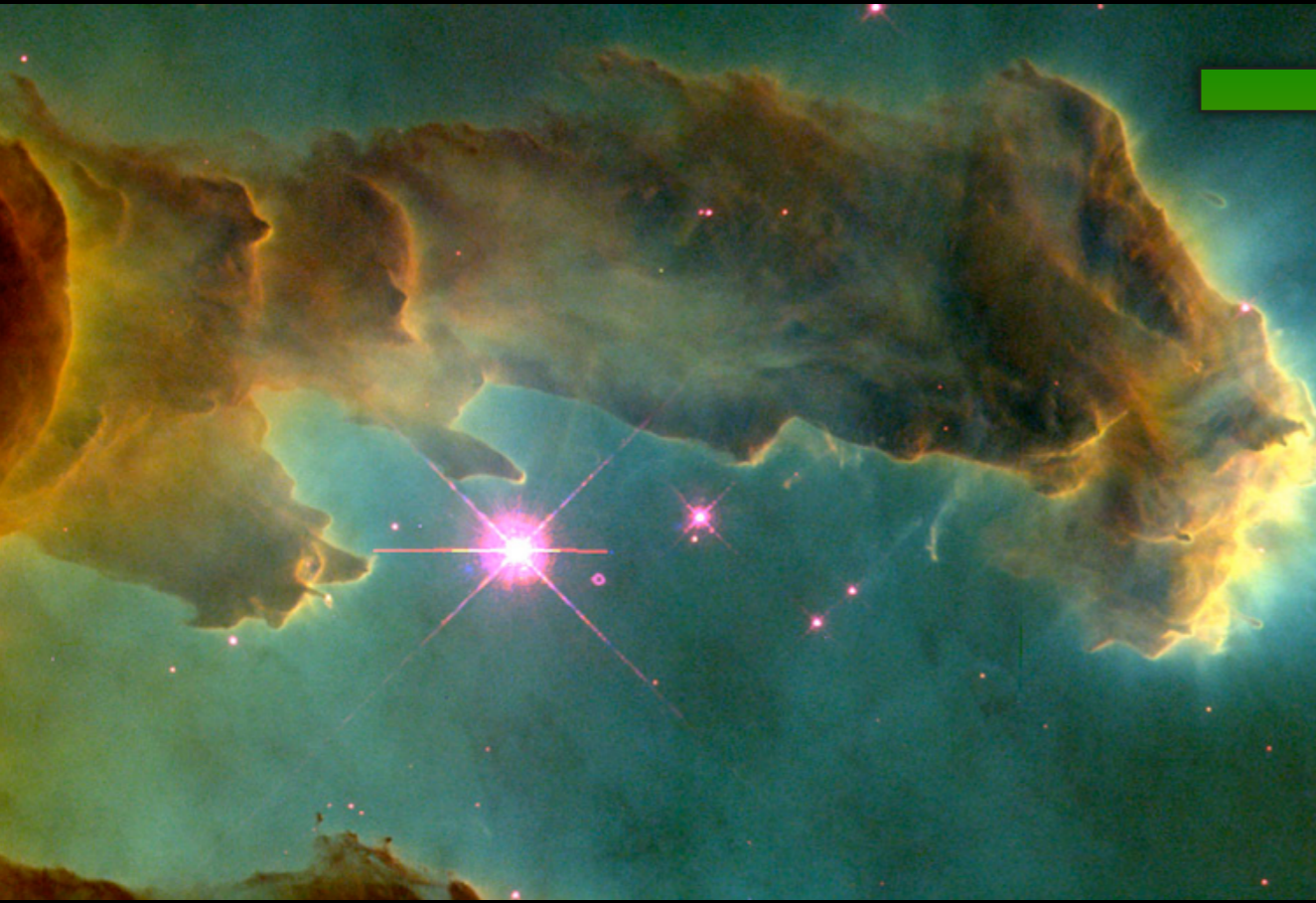
a very brief history of the solar system...

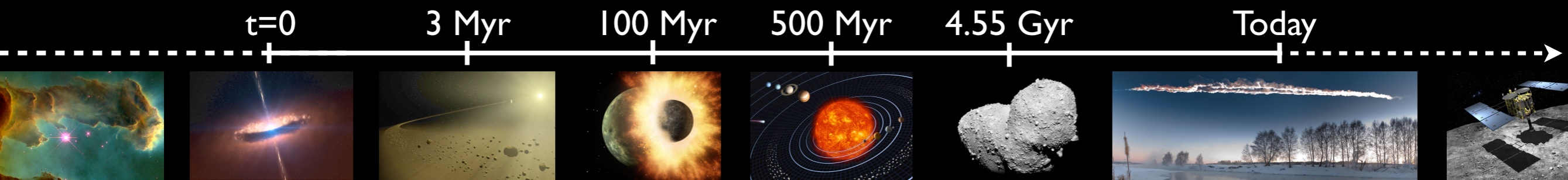


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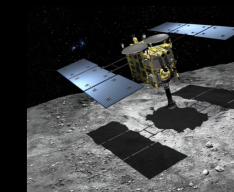
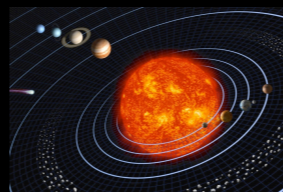
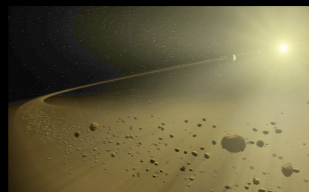
3 Myr

100 Myr

500 Myr

4.55 Gyr

Today



t=0

3 Myr

100 Myr

500 Myr

4.55 Gyr

Today

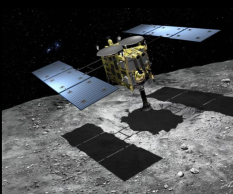
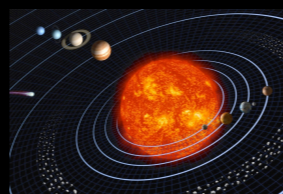
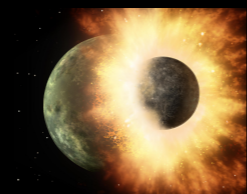
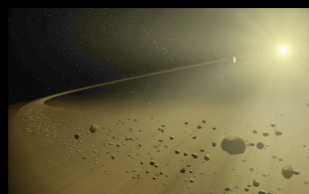
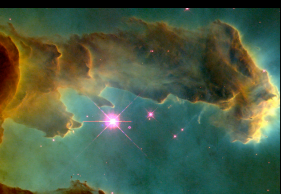
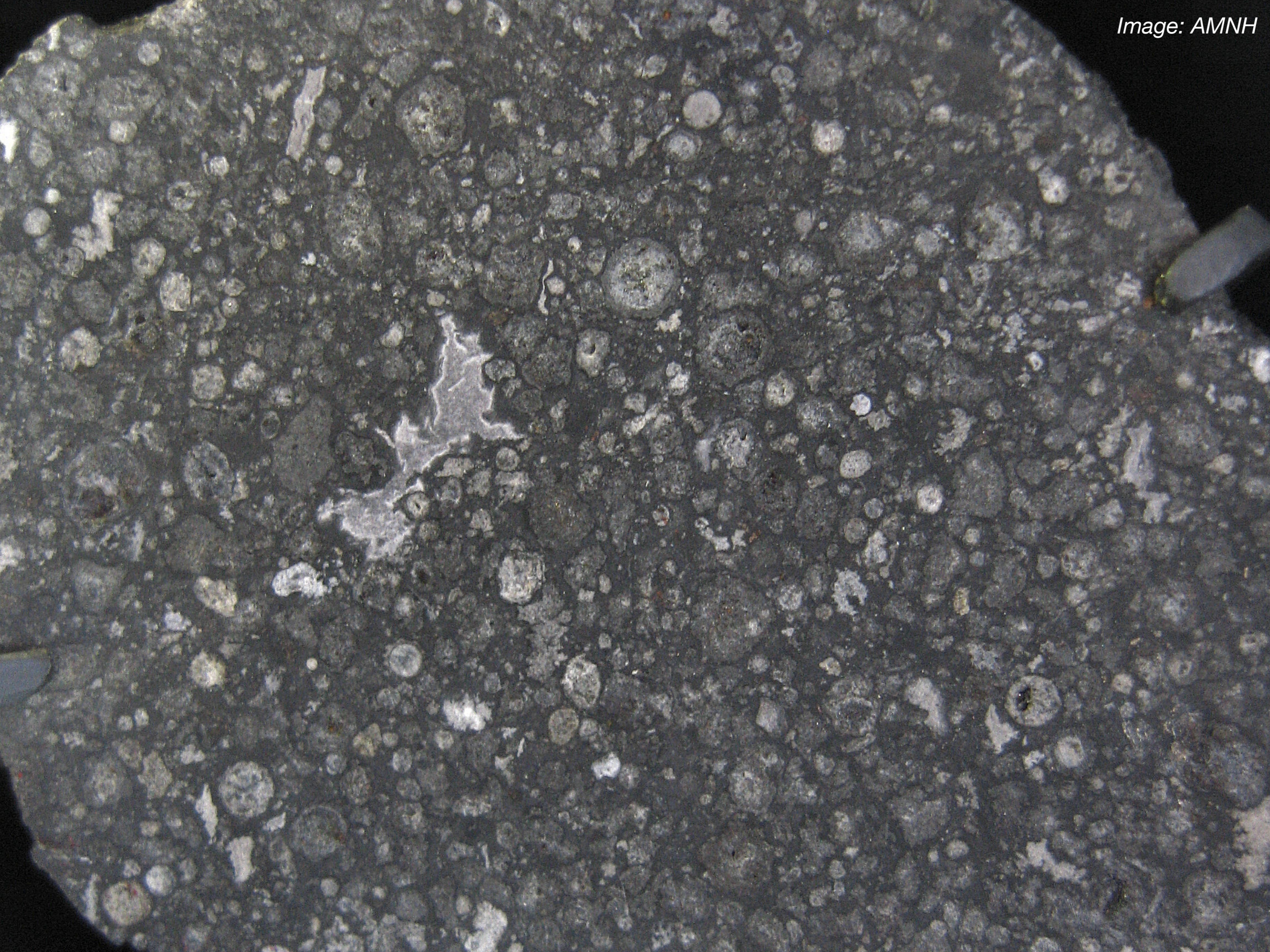




Image: NASA/JPL-Caltech





CAIs = Calcium-Aluminum-rich Inclusions

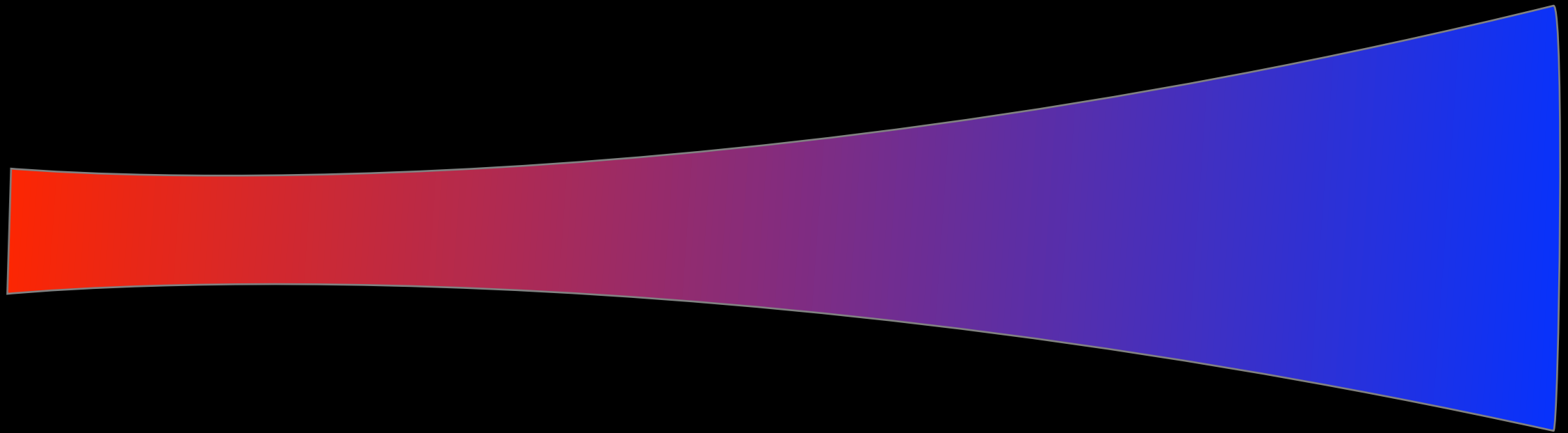
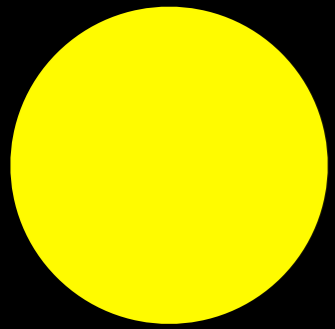
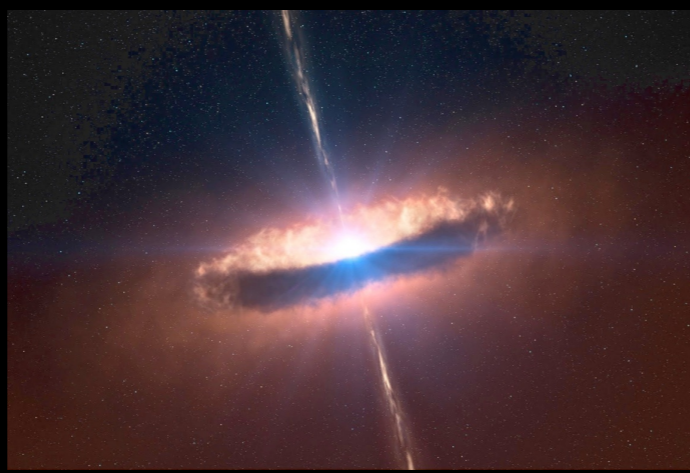


CAIs = Calcium-Aluminum-rich Inclusions

Age = 4568.22 ± 0.17 Myr

MacPherson (2004)

solar nebula





$t=0$

3 Myr

100 Myr

500 Myr

4.55 Gyr

Today

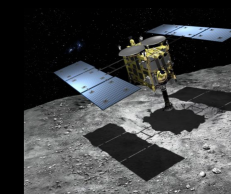
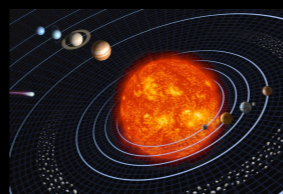
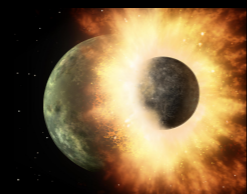
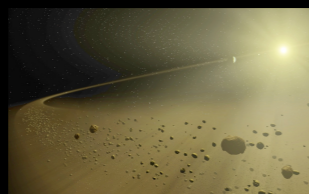
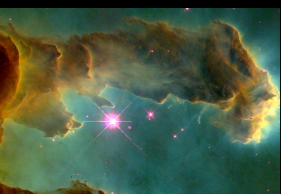
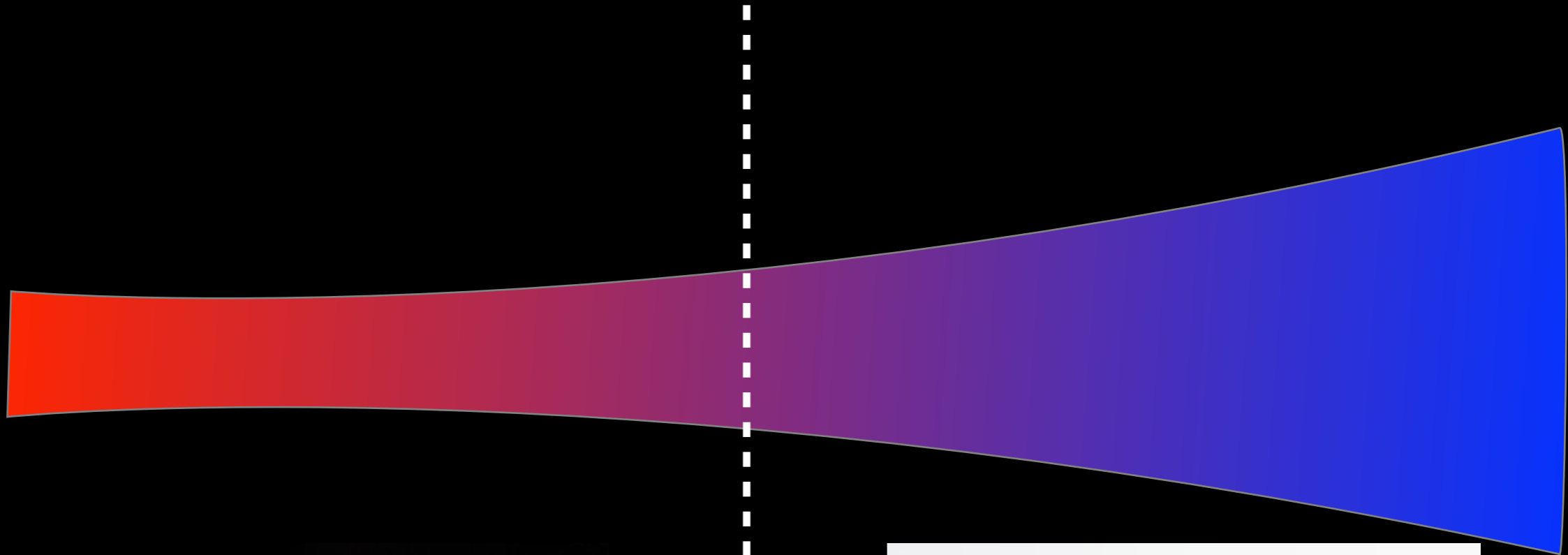
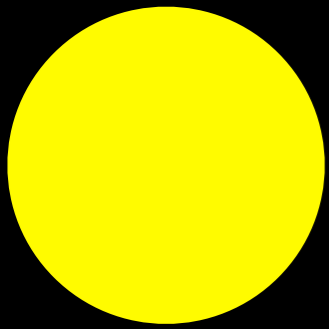
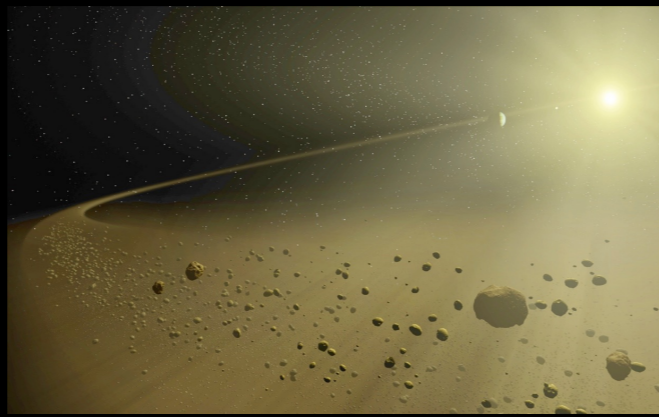




Image: NASA

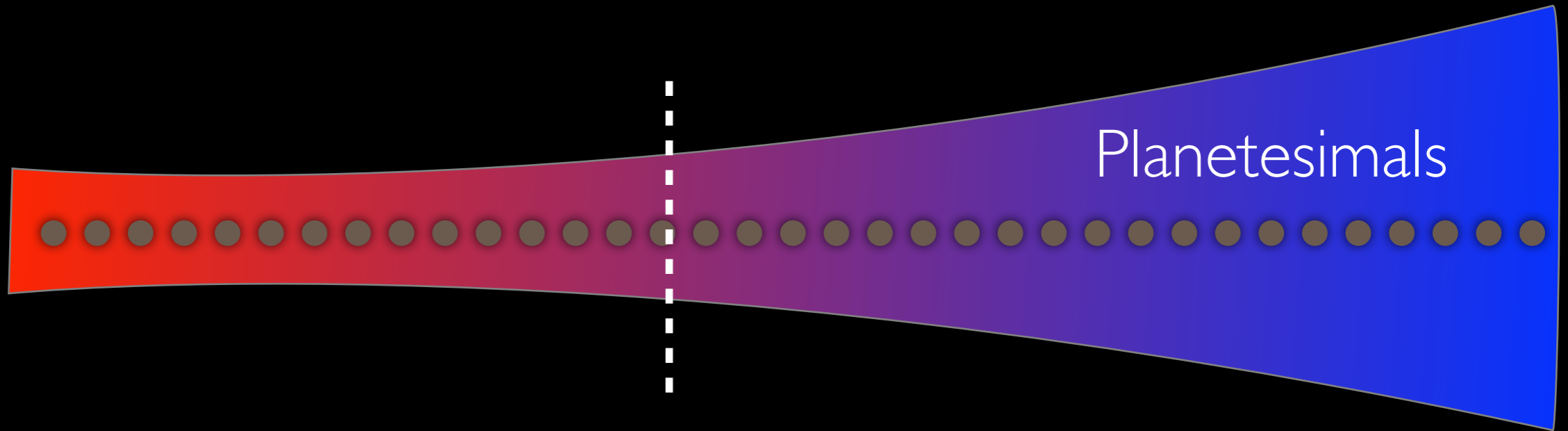
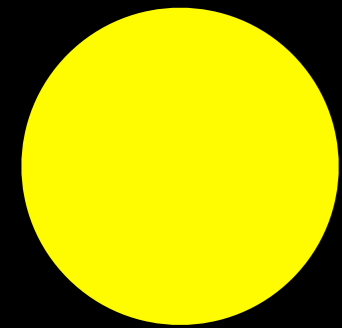
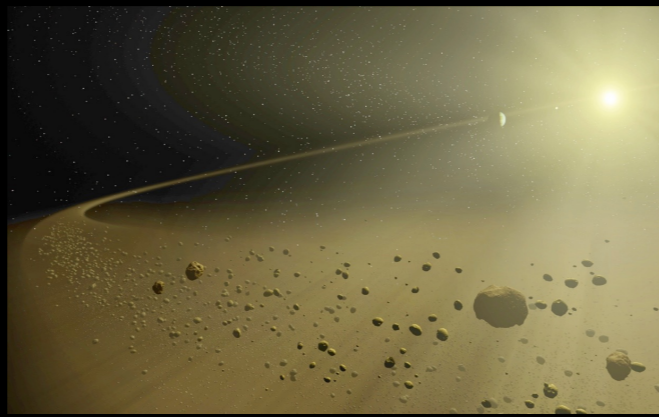
debris disk



snow
line



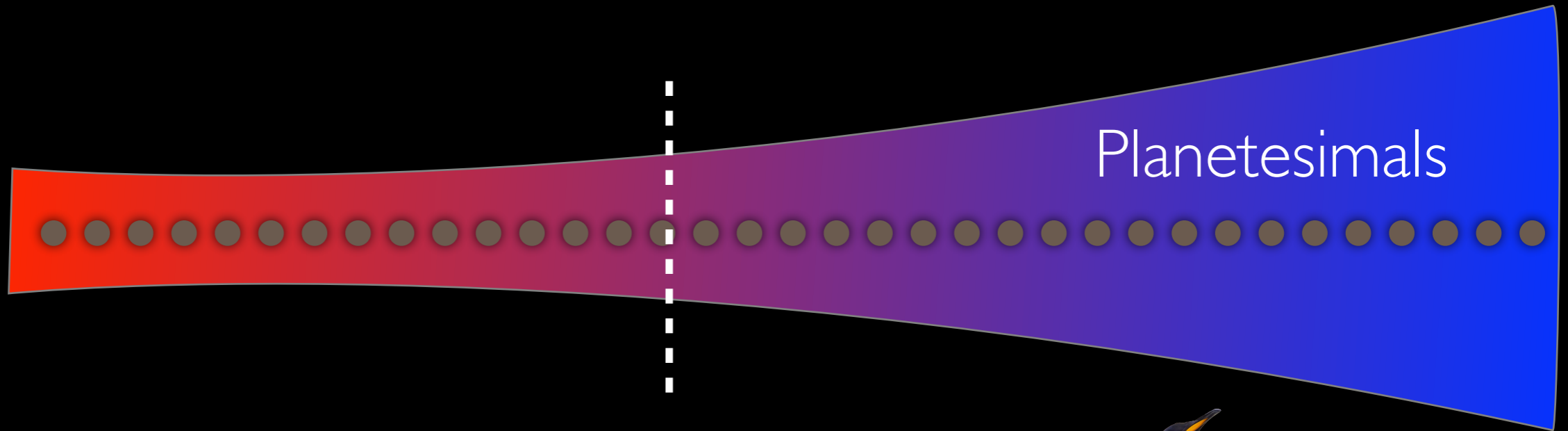
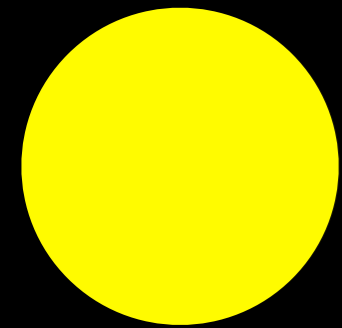
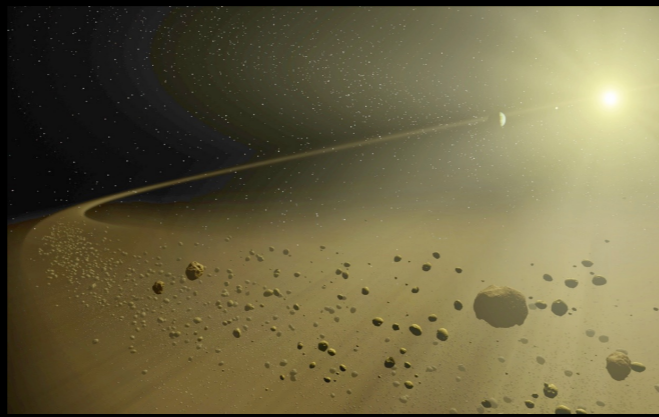
debris disk



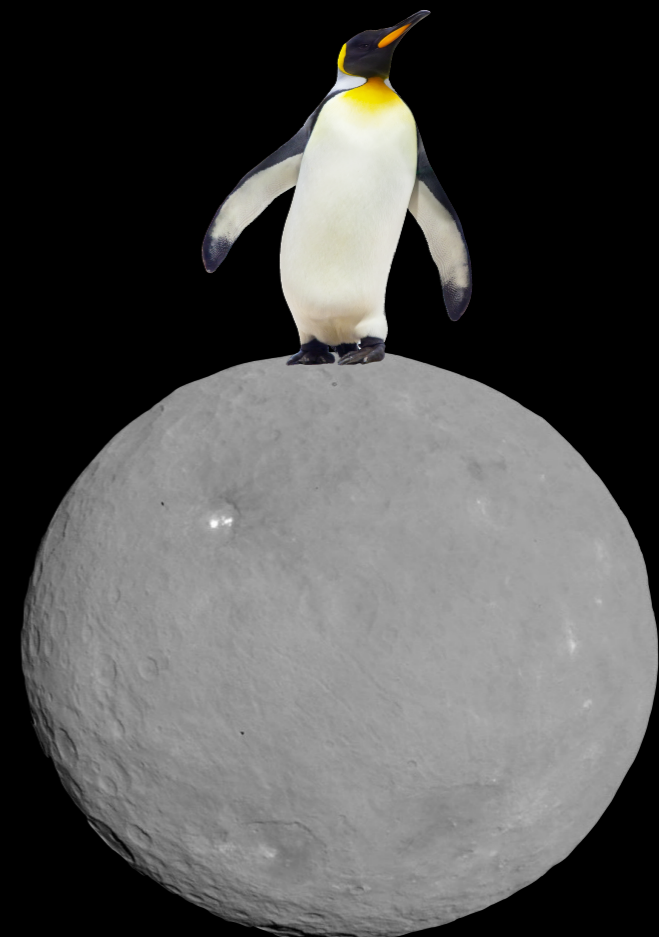
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line

Planetesimals

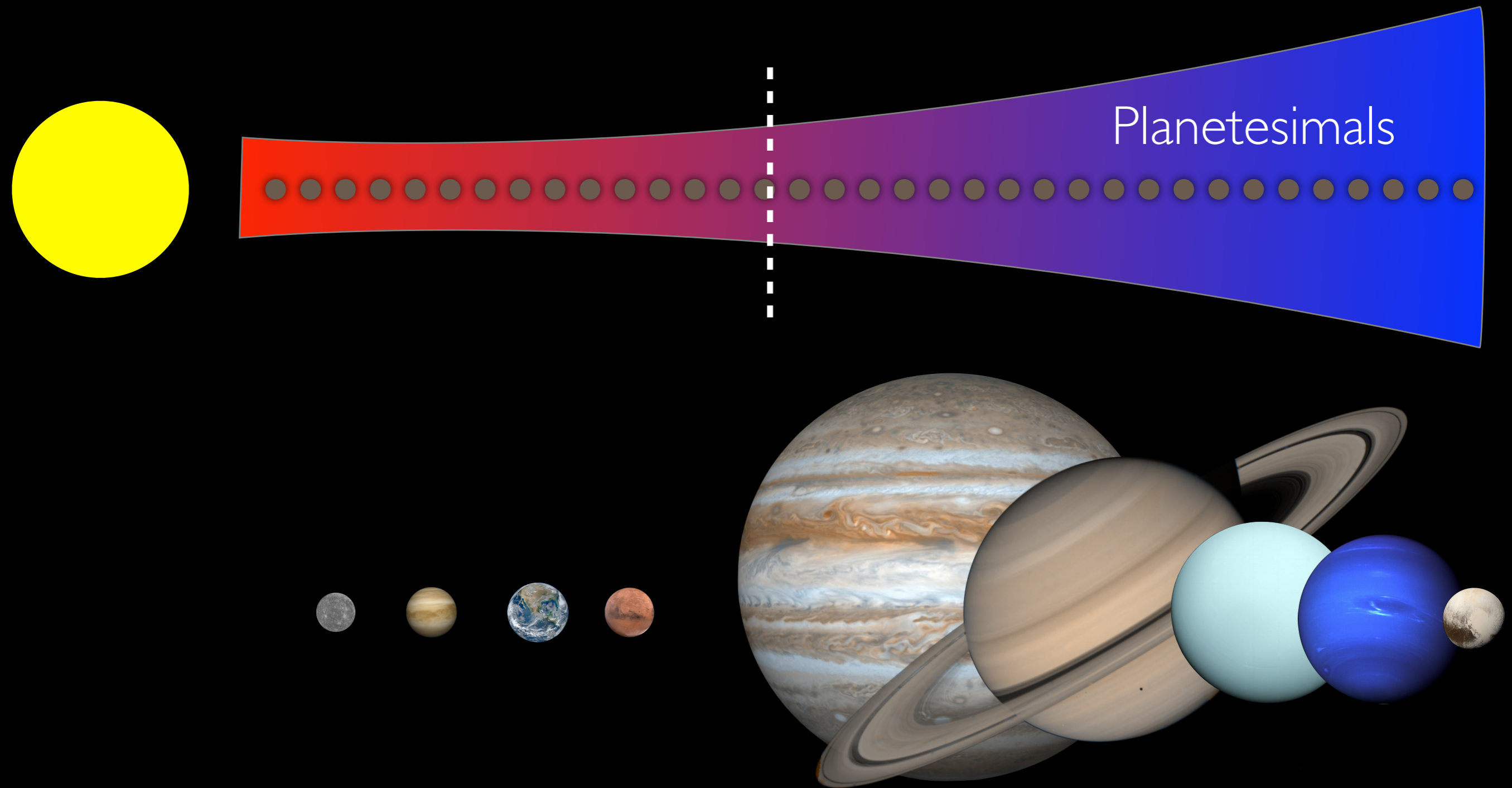
debris disk



snow
line



planetary implications

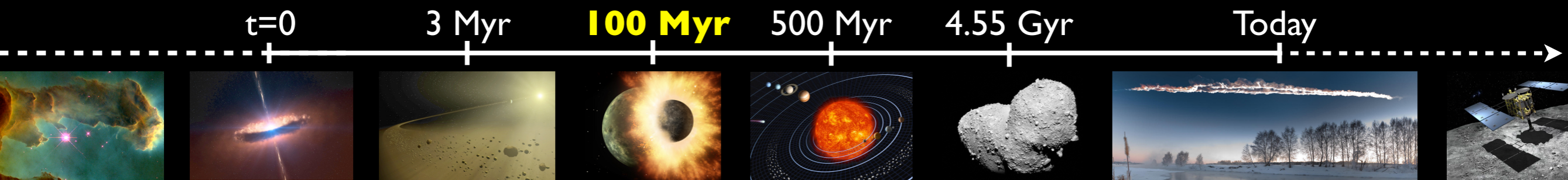




Muonionalusta = 4565.3 ± 0.1 Myr

Blichert-Toft+ (2010)

CAIs = 4568.22 ± 0.17 Myr



$t=0$

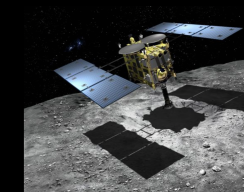
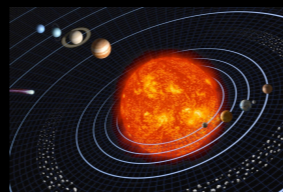
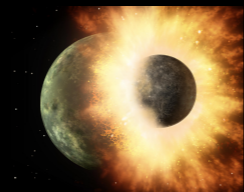
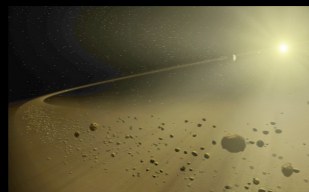
3 Myr

100 Myr

500 Myr

4.55 Gyr

Today



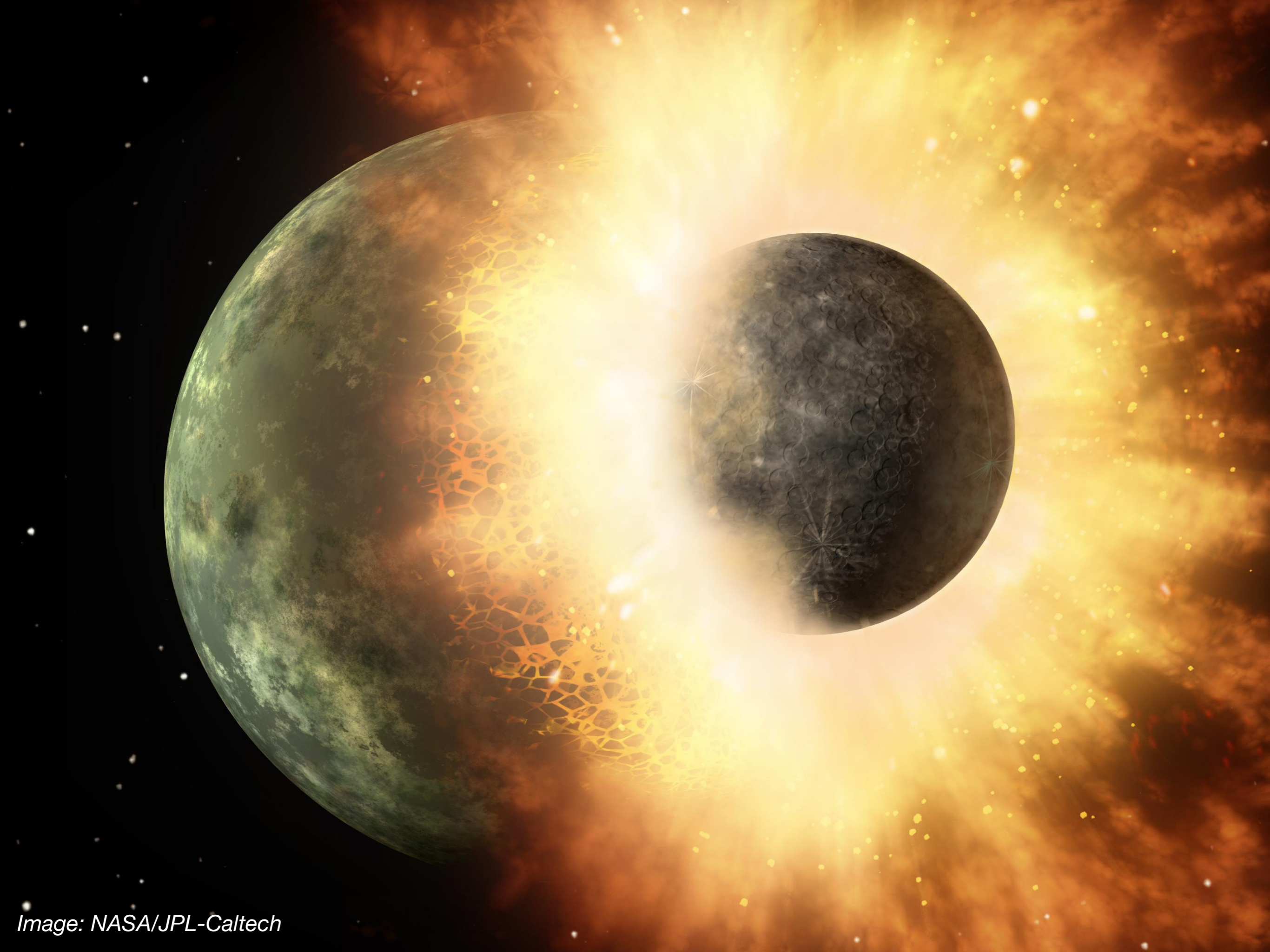


Image: NASA/JPL-Caltech



Image: G.H. Revera

No moon?



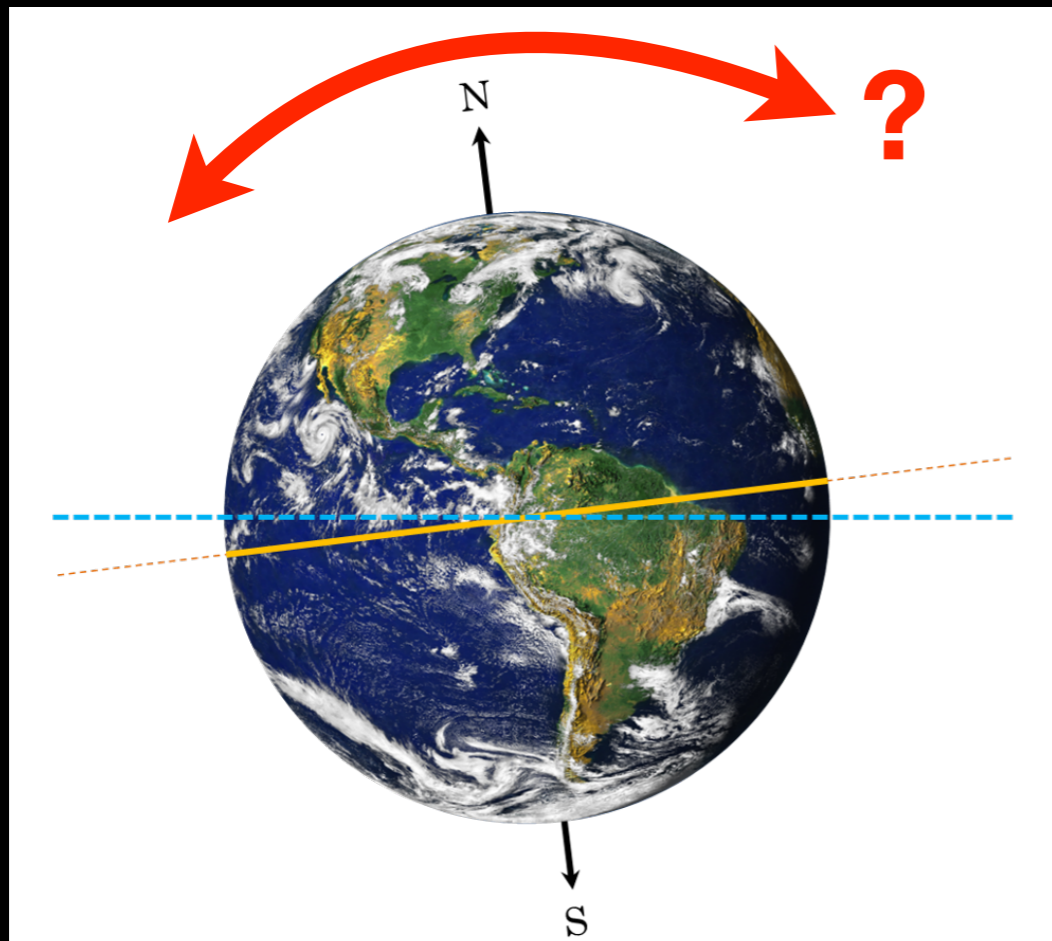
No moon?

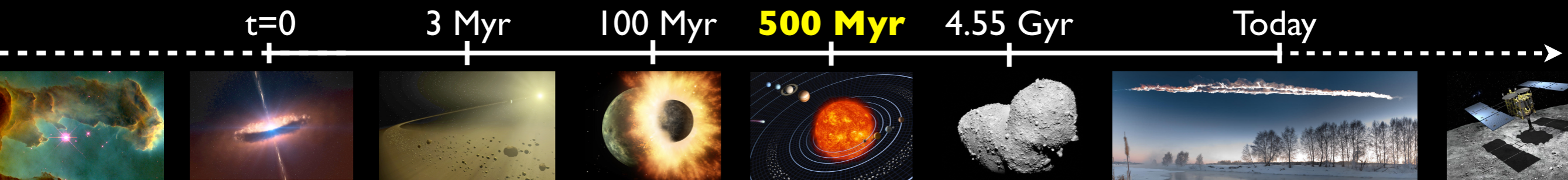


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No moon?





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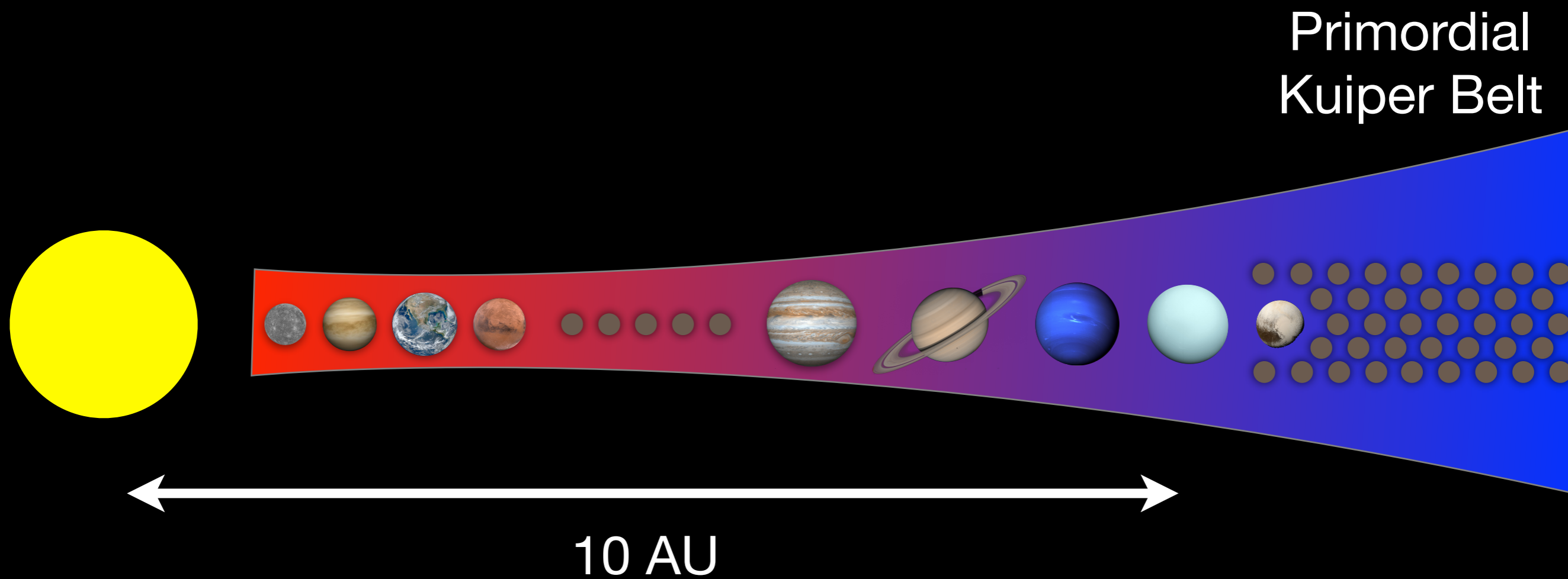
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500 Myr

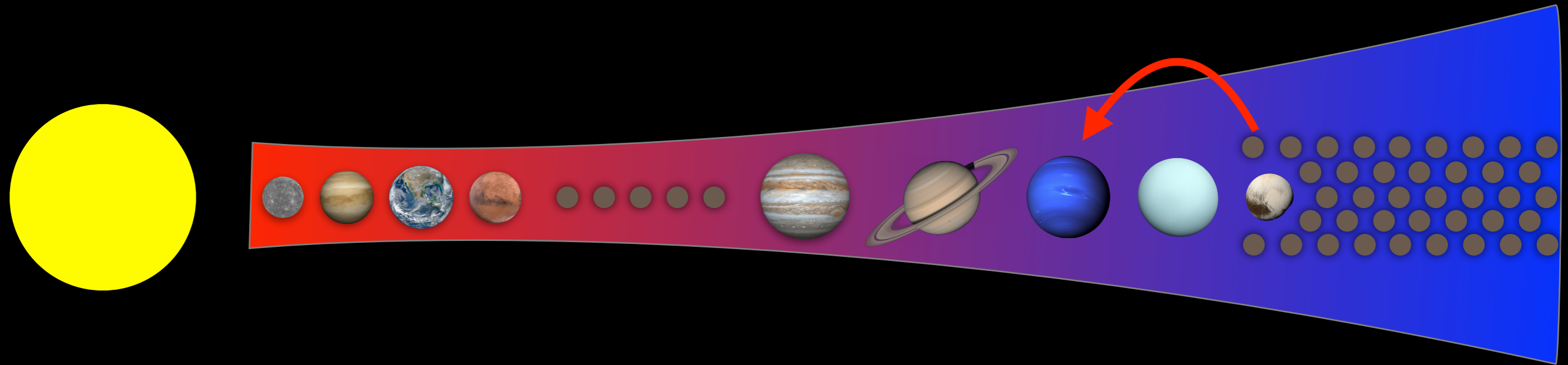
4.55 Gyr

Today

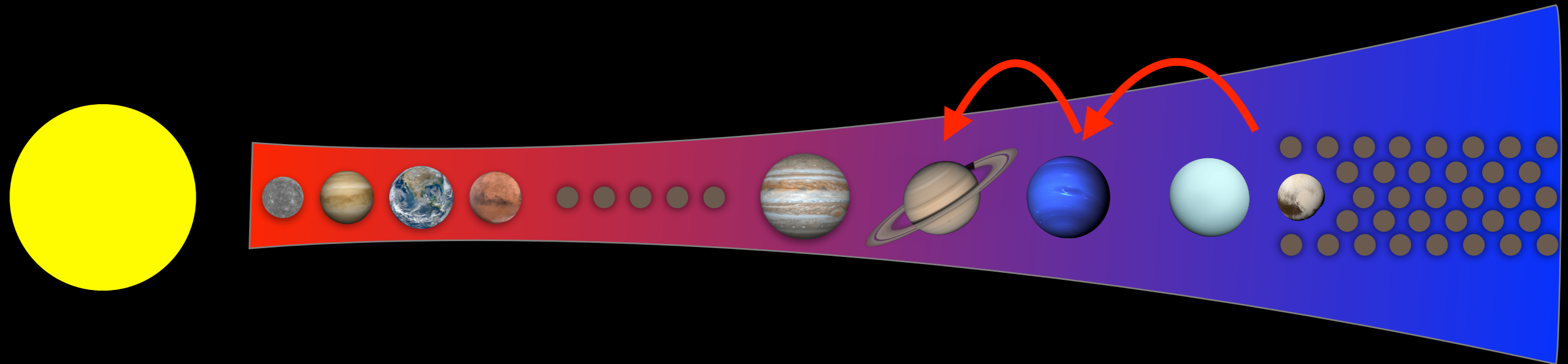
$t \sim 500 \text{ Myr}$



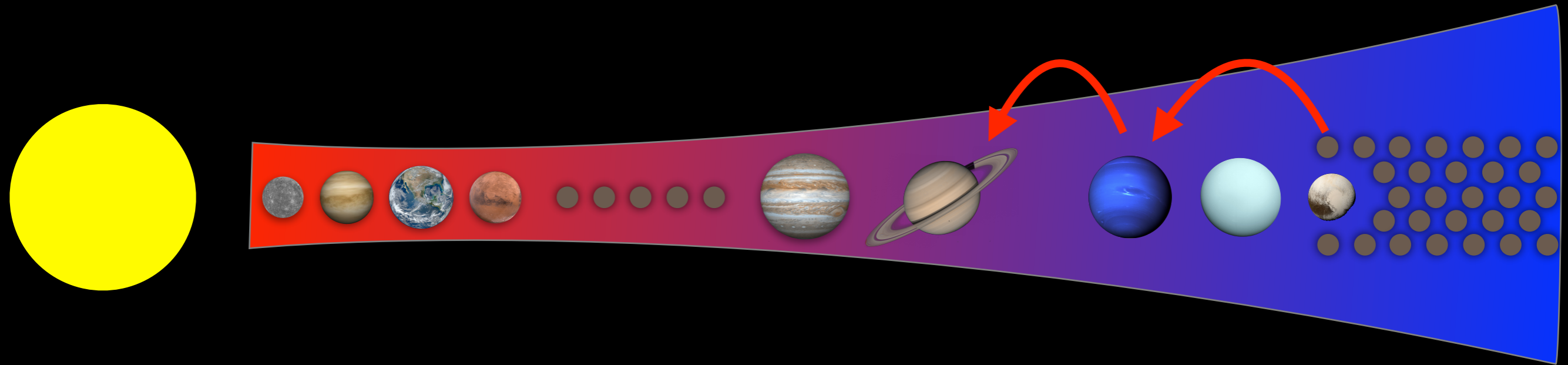
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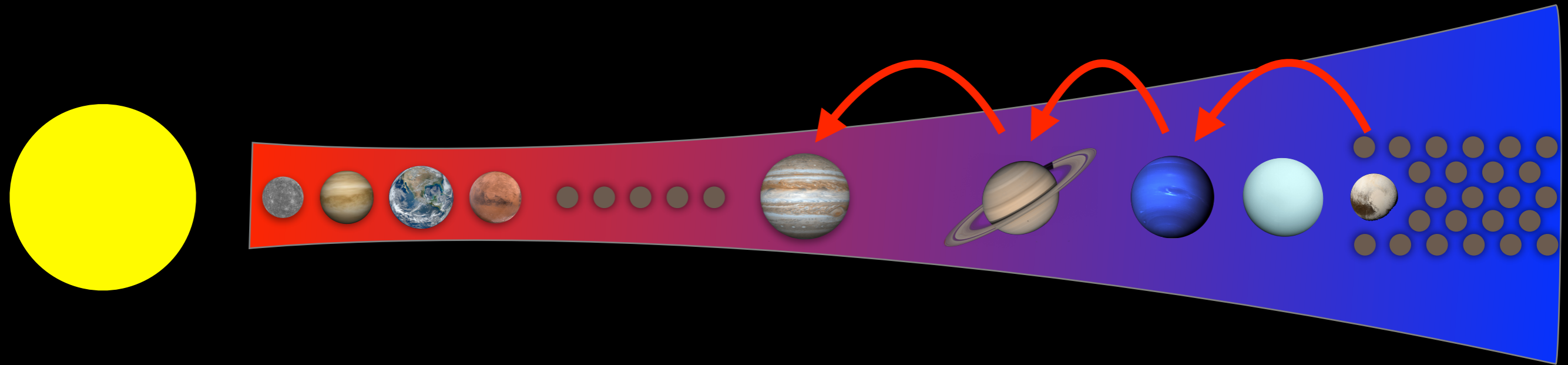
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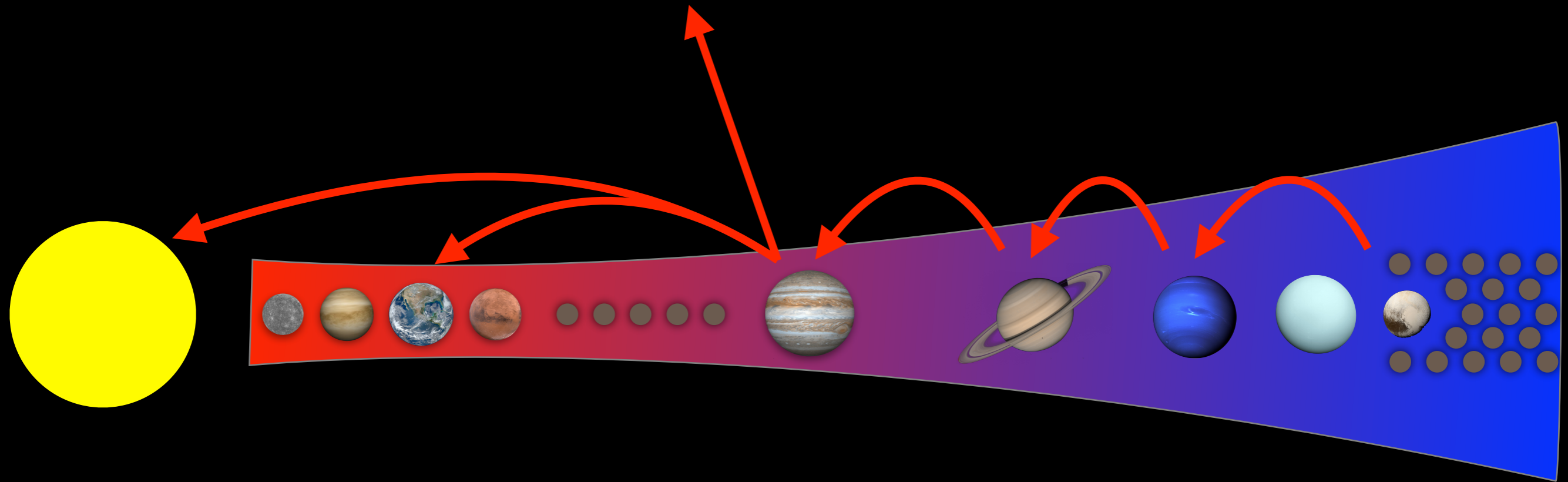
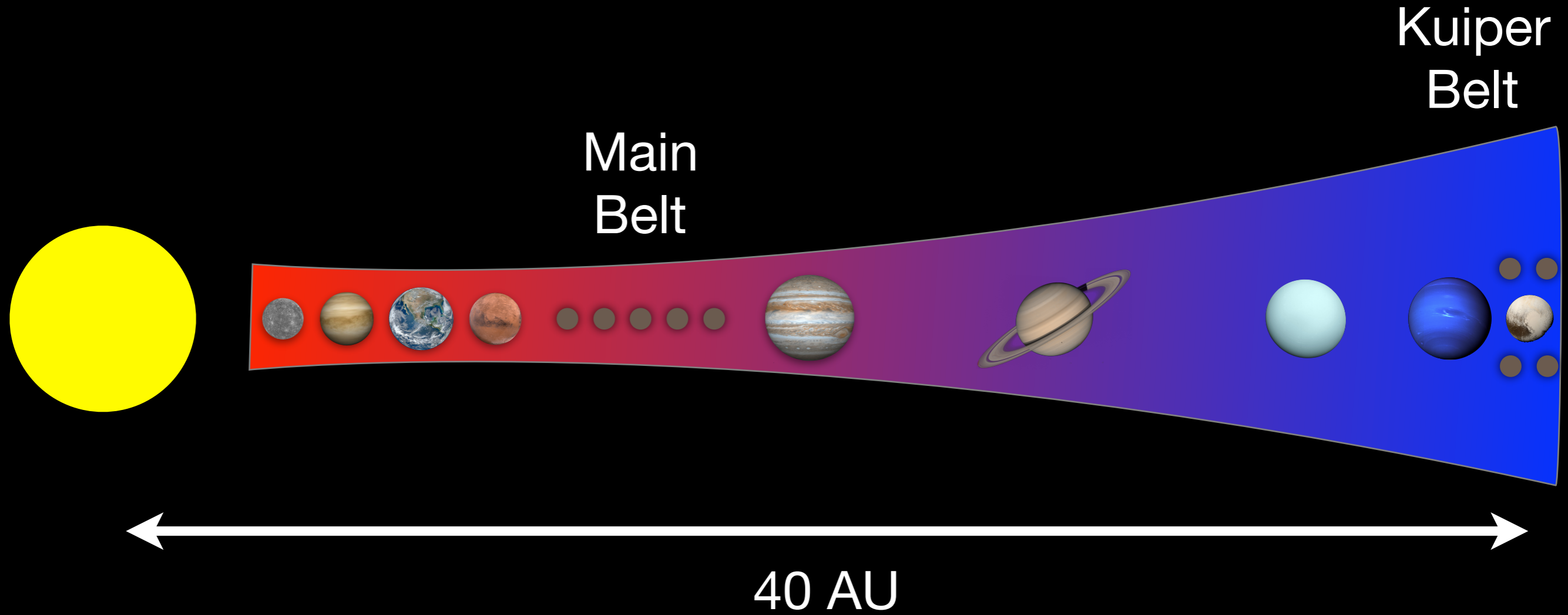
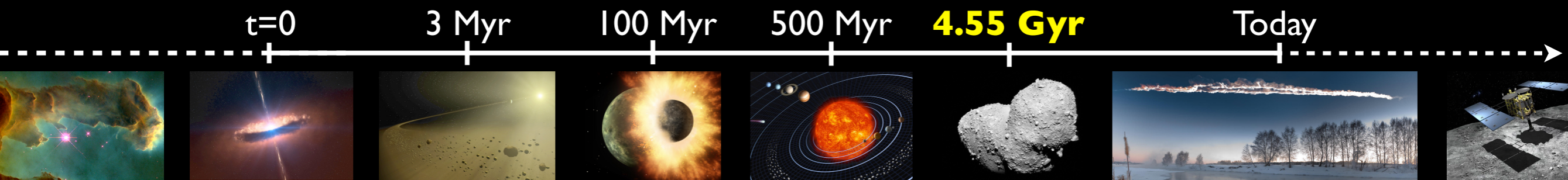




Image: R. Miller

$t \sim 500 \text{ Myr}$





$t=0$

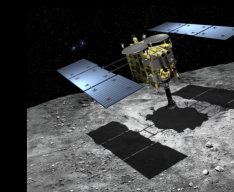
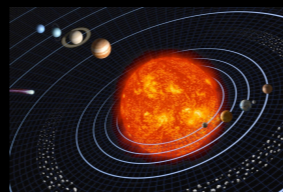
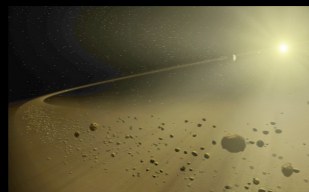
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4.55 Gyr

Today



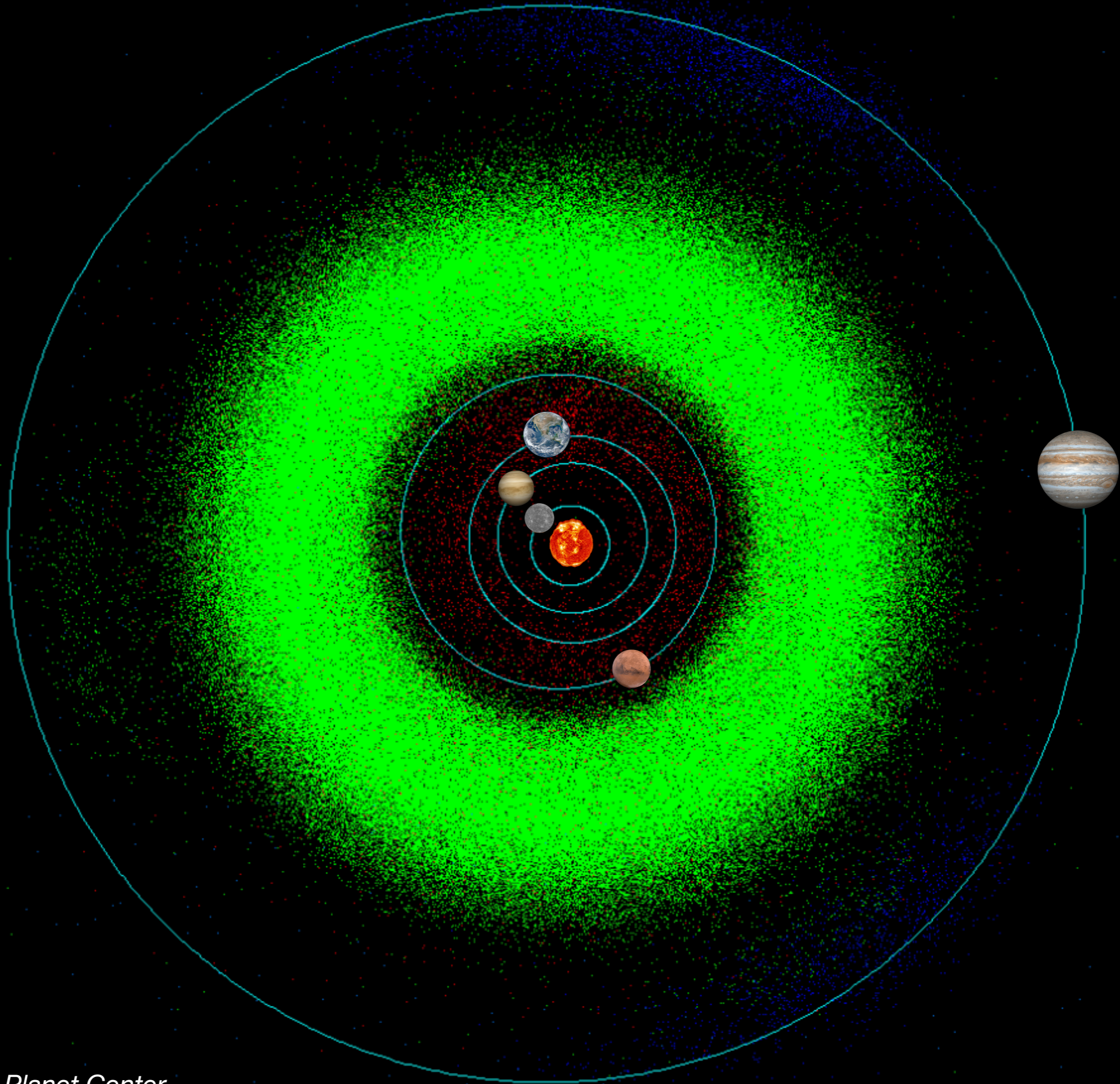


Image: Minor Planet Center

—
2m

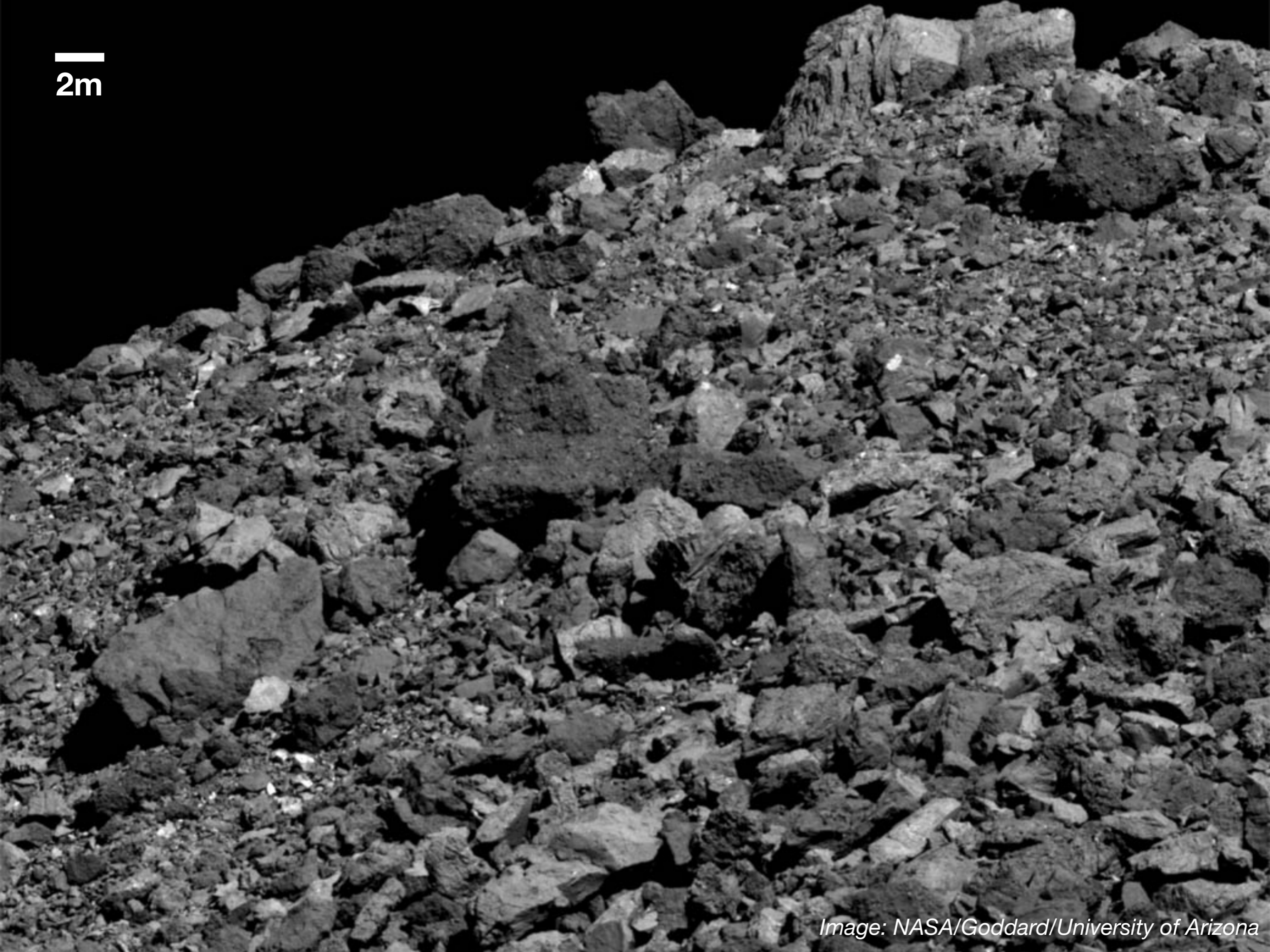


Image: NASA/Goddard/University of Arizona



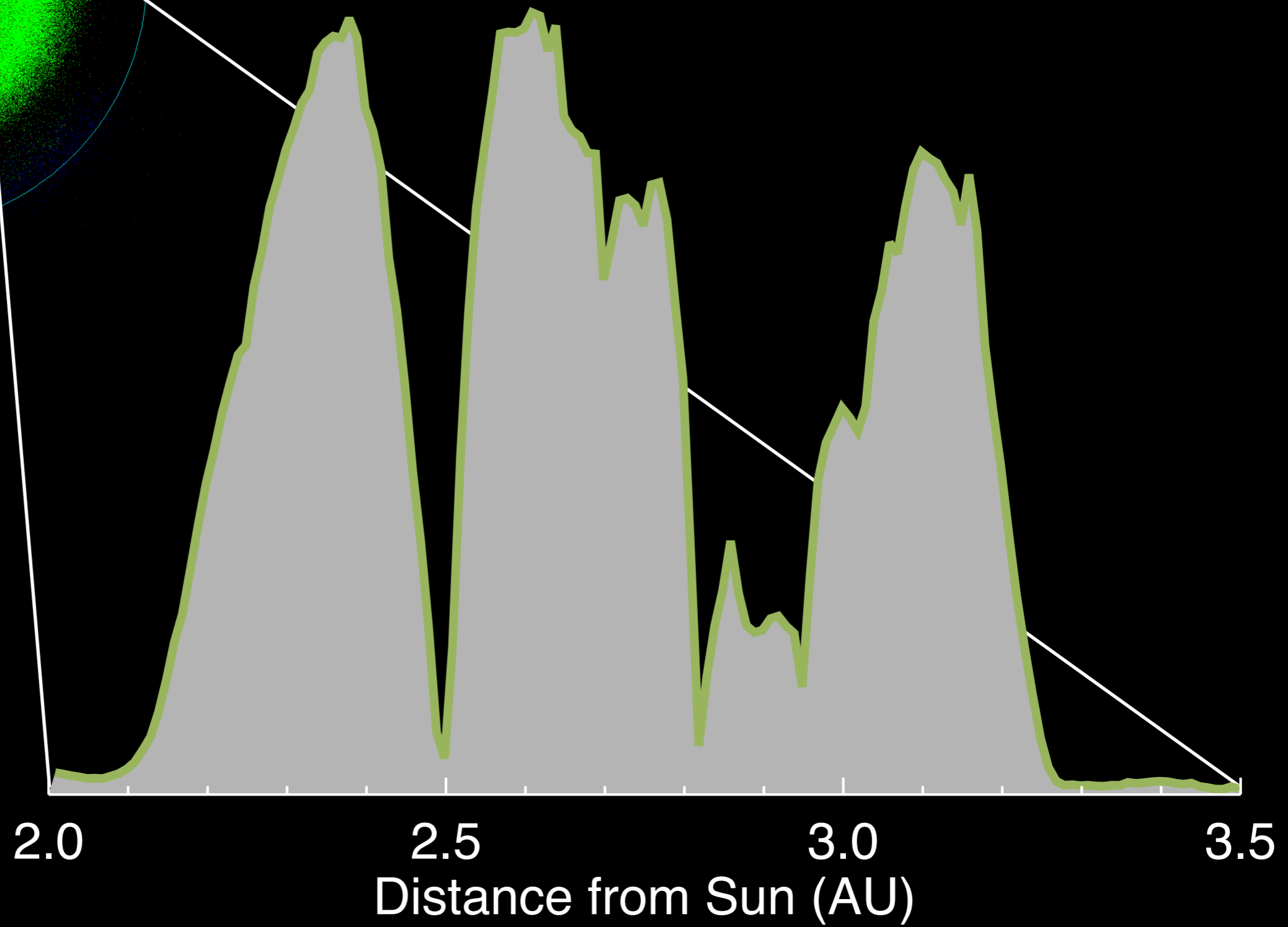
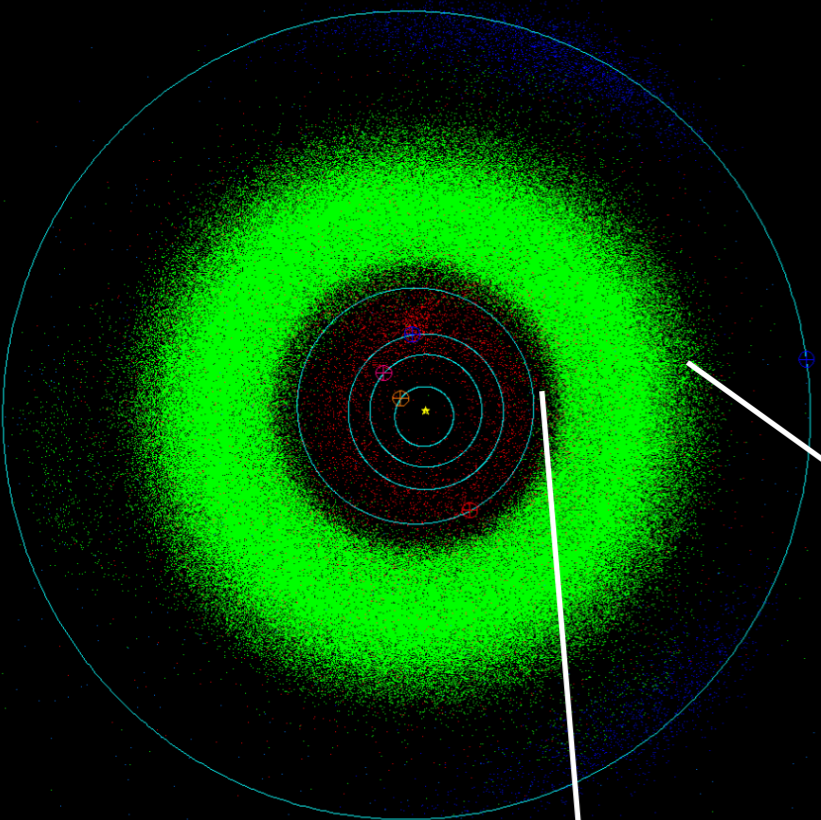
Barringer Crater

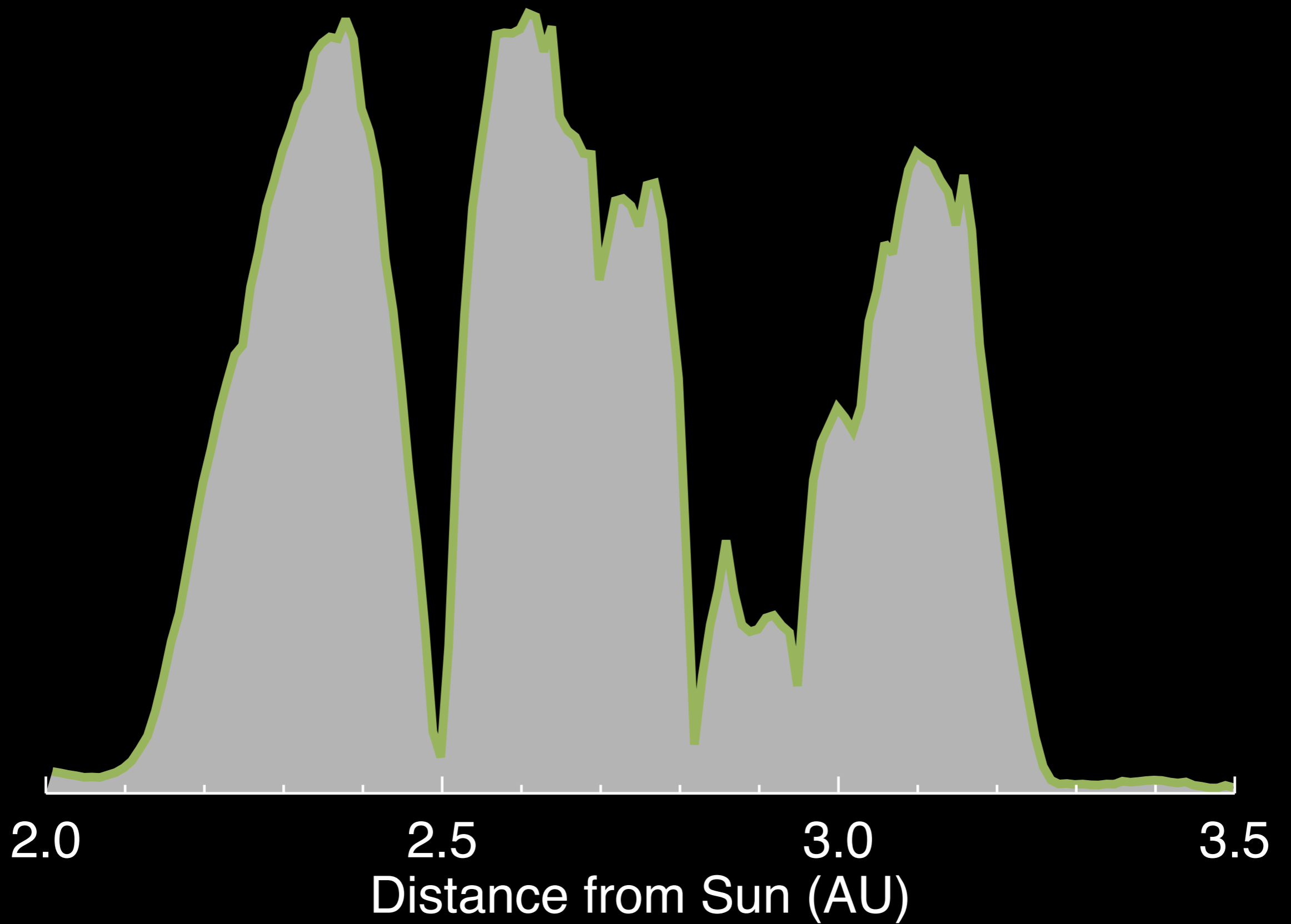


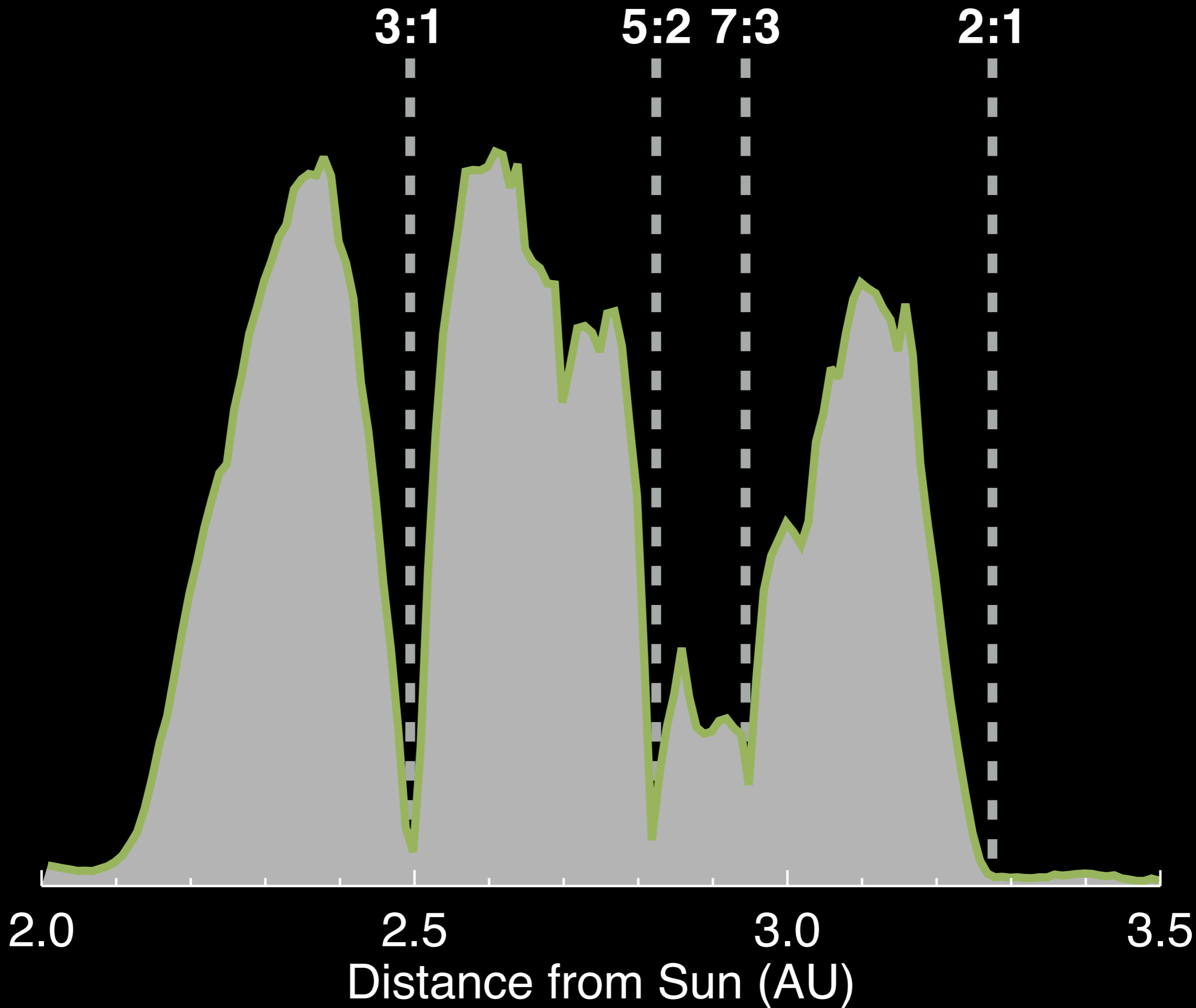


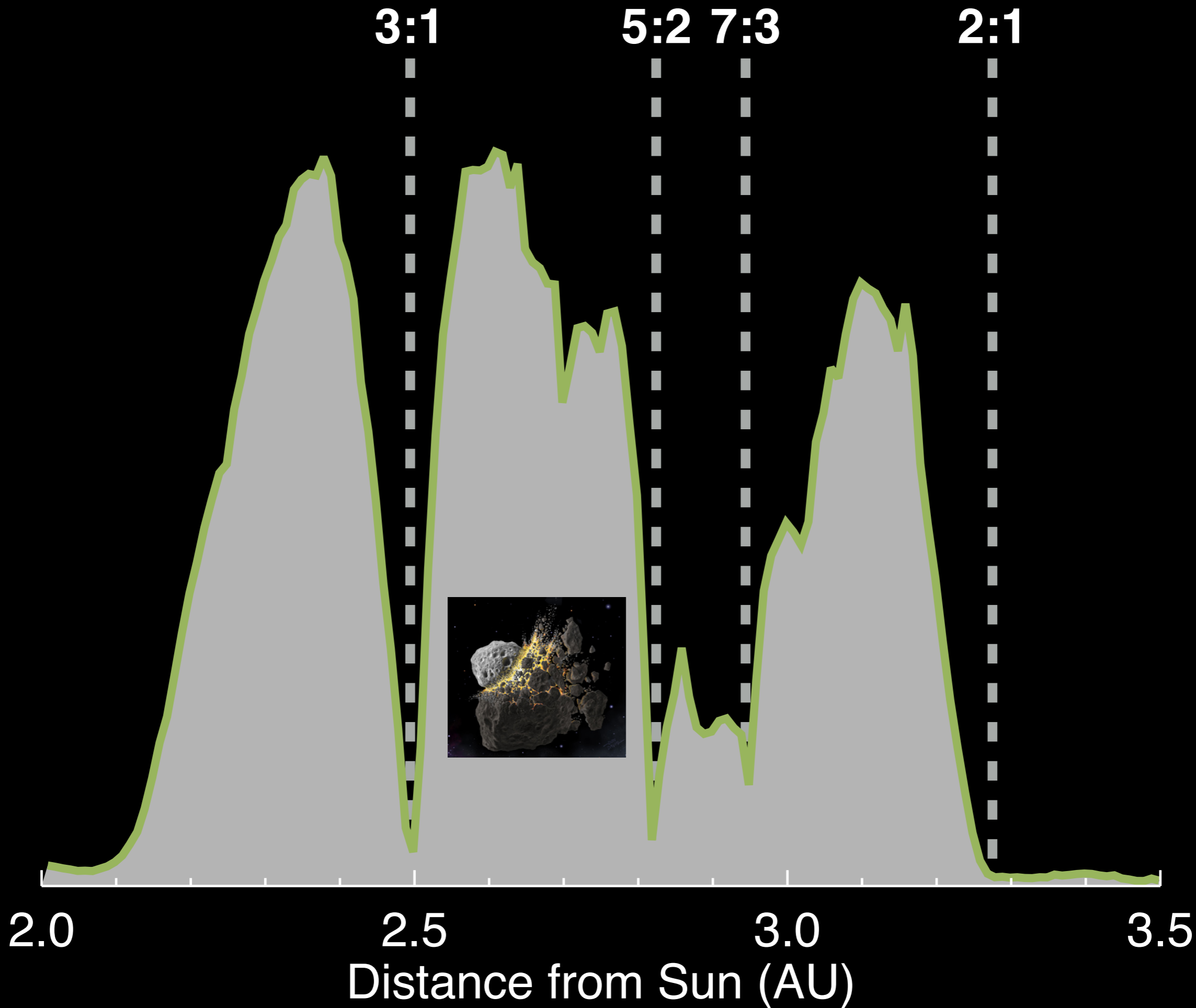
—DON
DAVIS—

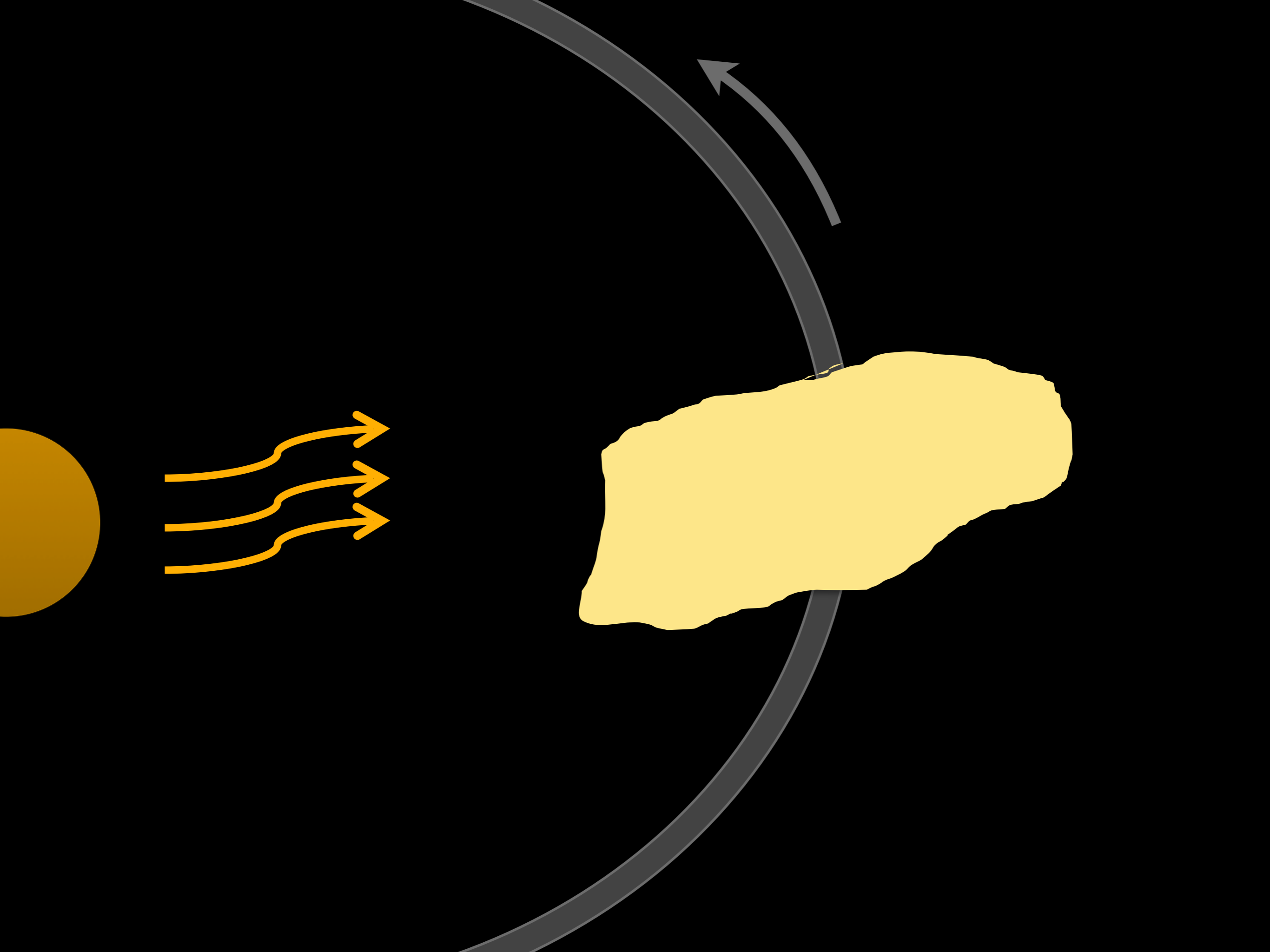
Image: D. Davis

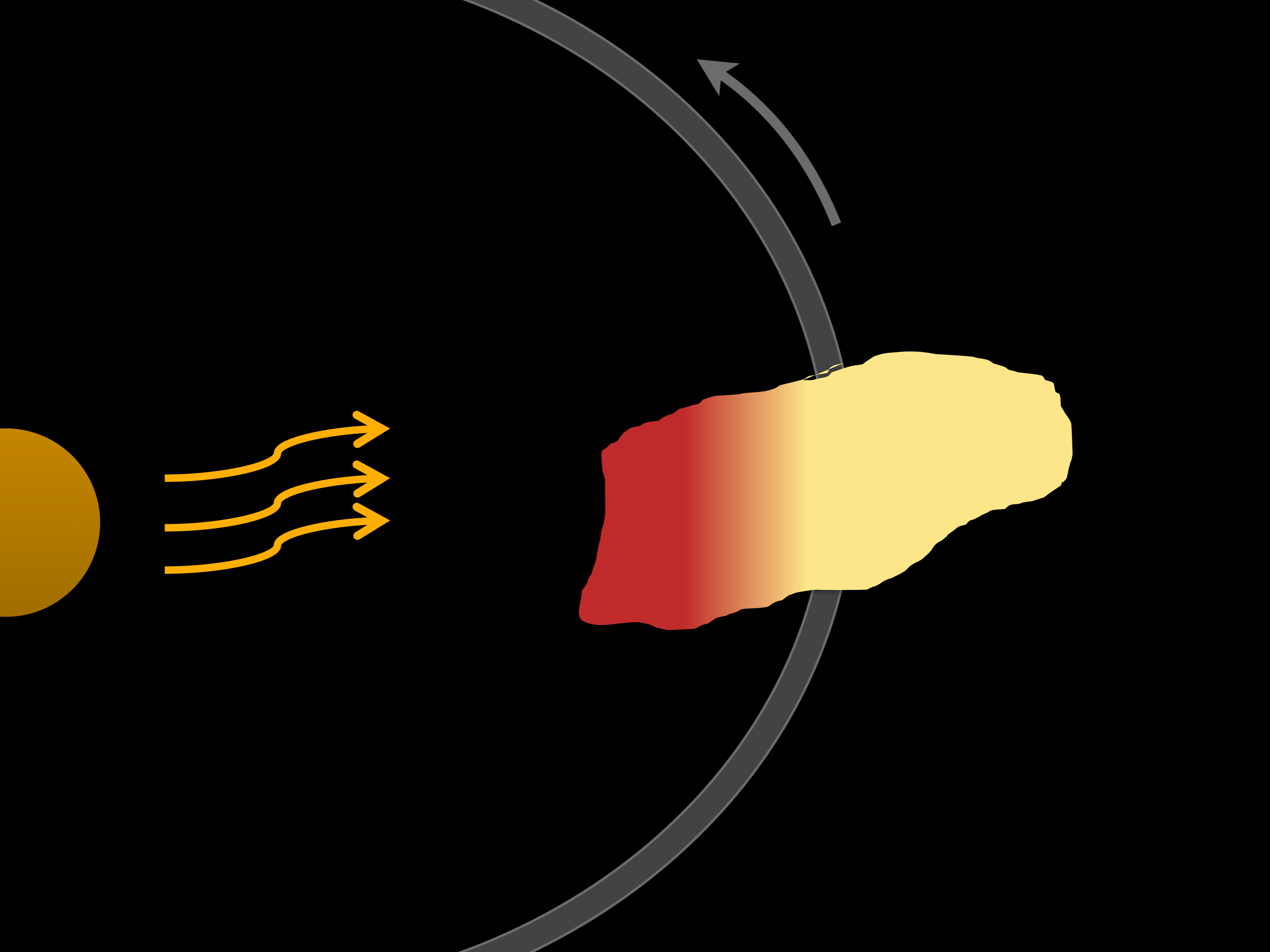


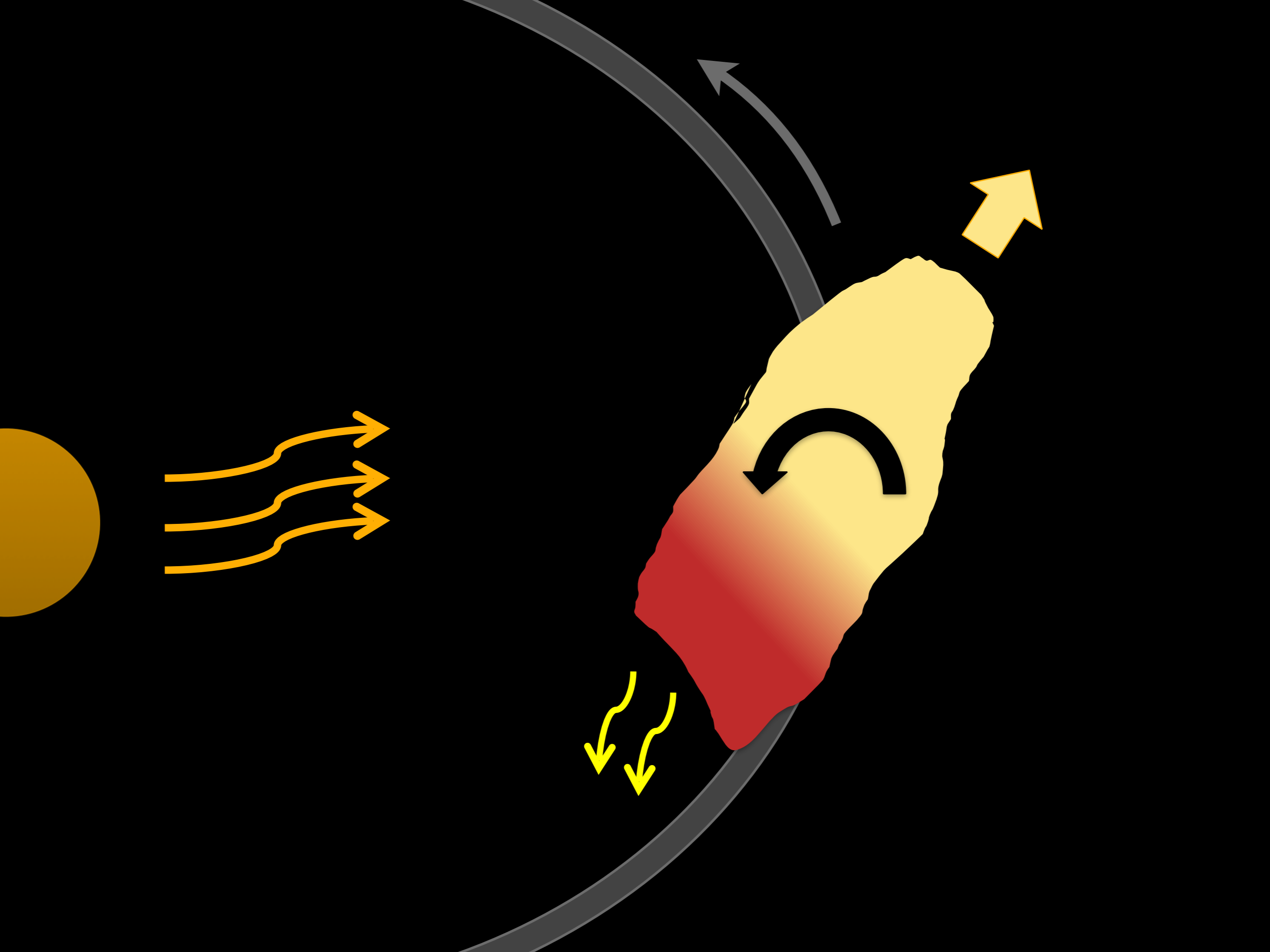


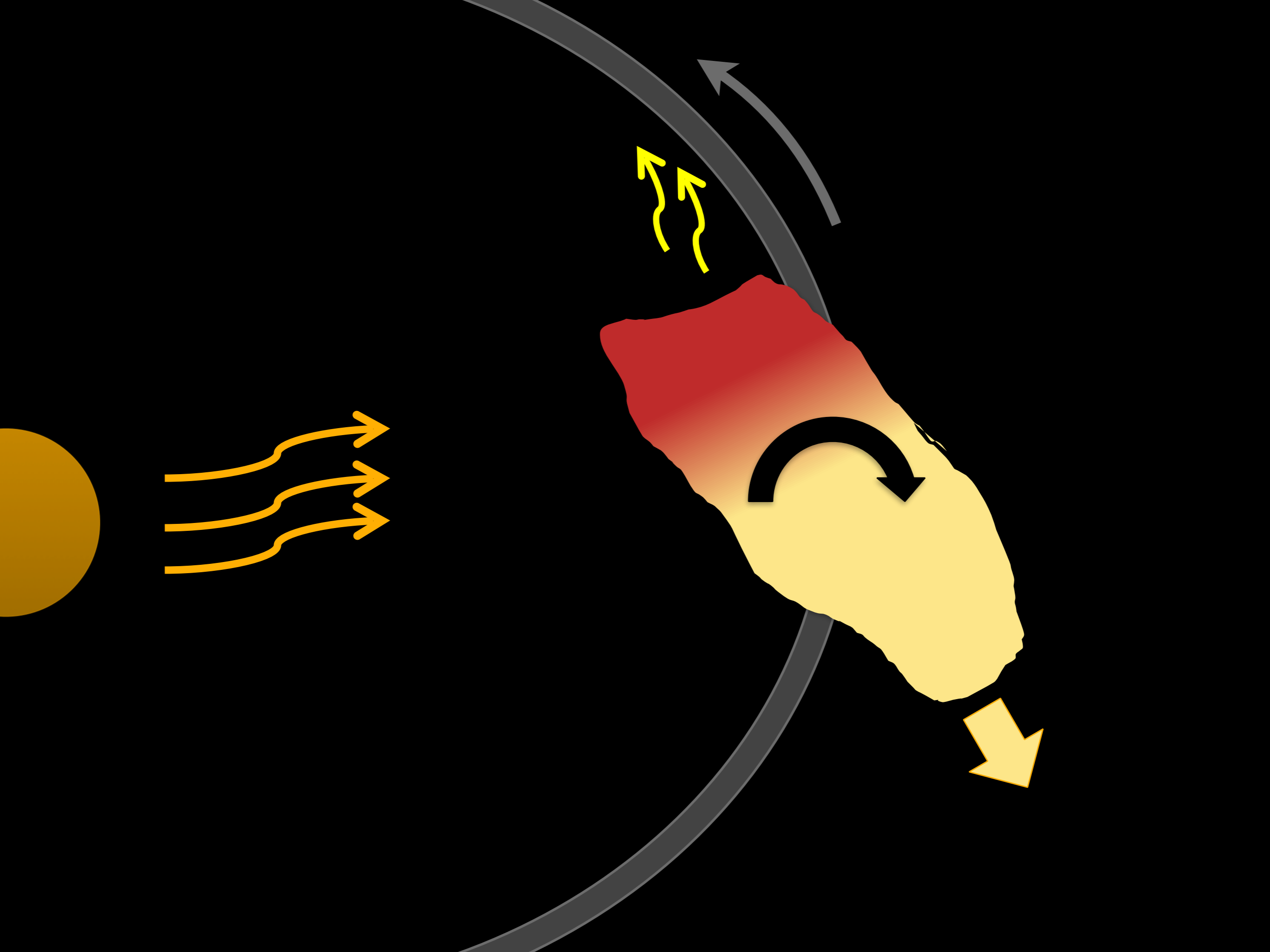


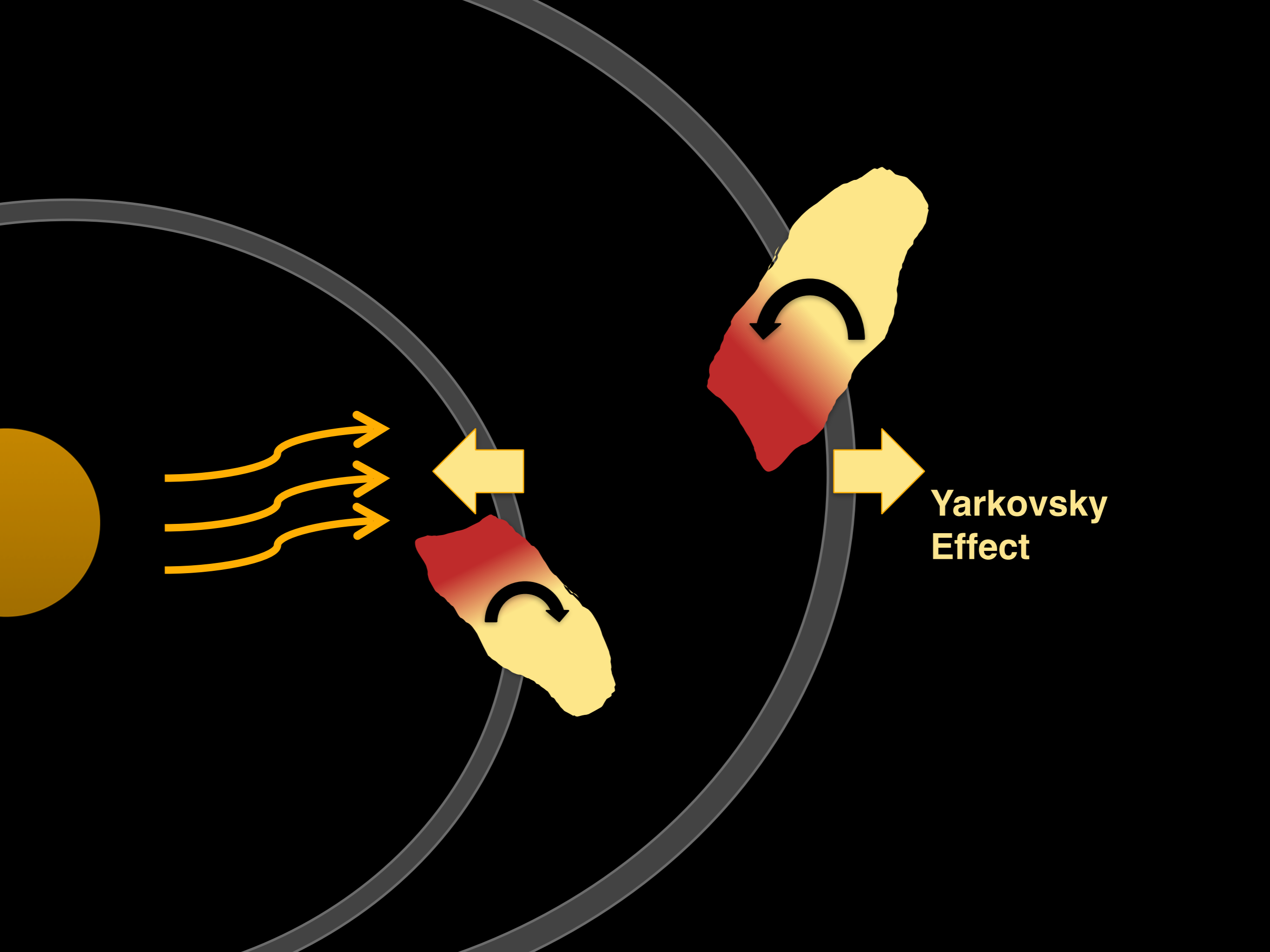




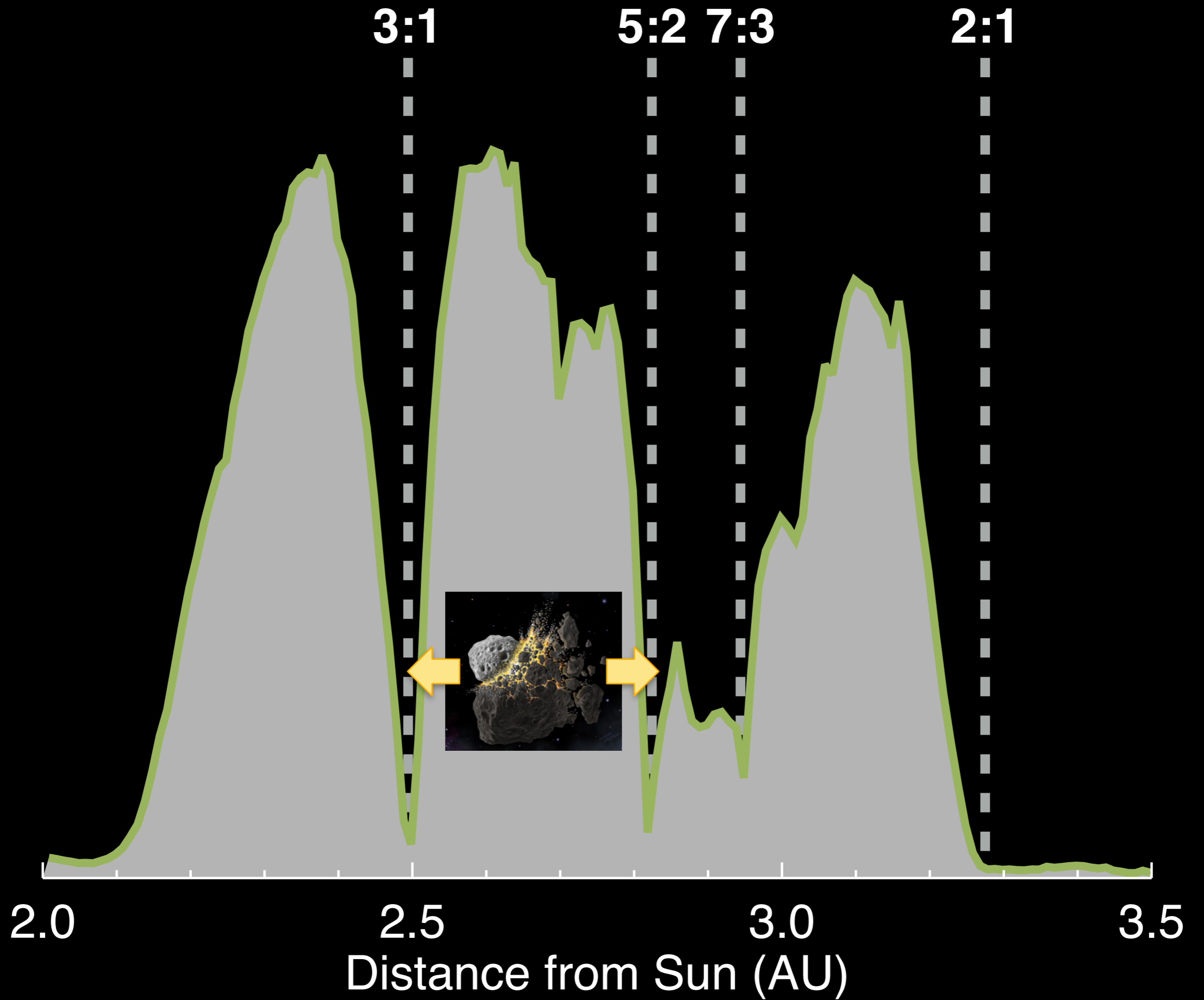






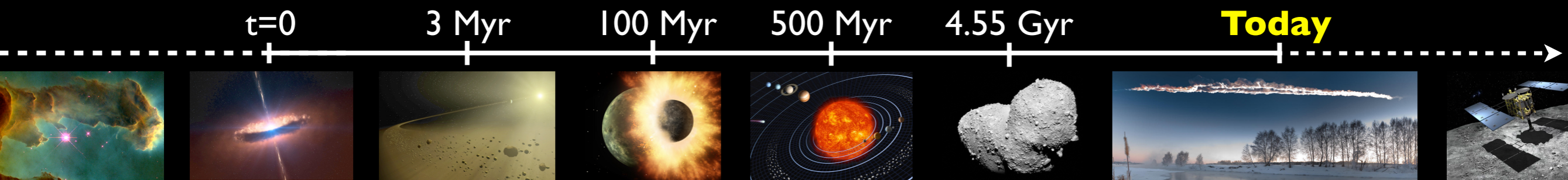


**Yarkovsky
Effect**



Chelyabinsk, Russia
February 2013





$t=0$

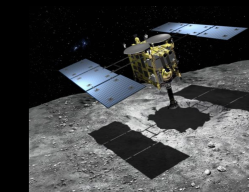
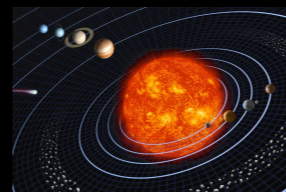
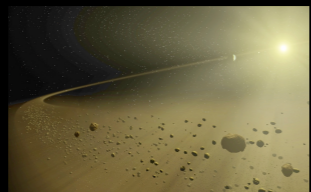
3 Myr

100 Myr

500 Myr

4.55 Gyr

Today



ASTEROIDS

...are nature's way of asking:



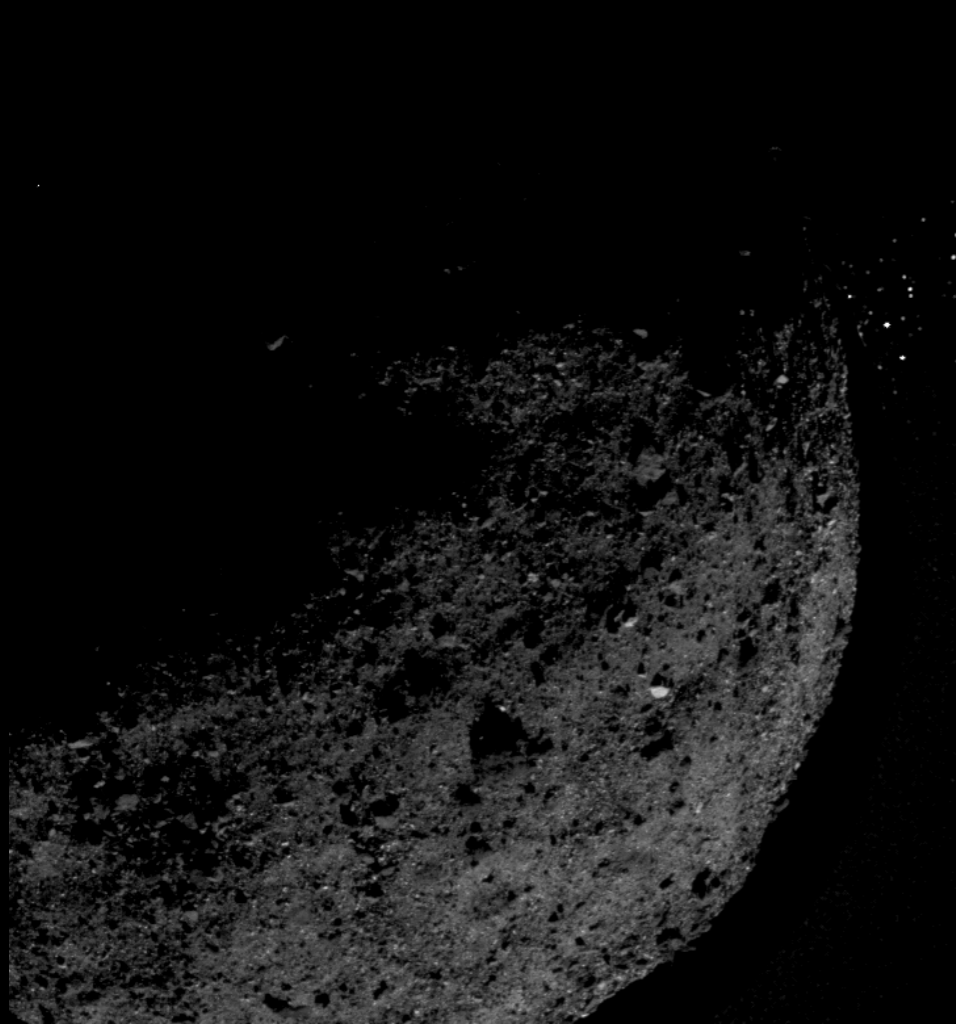
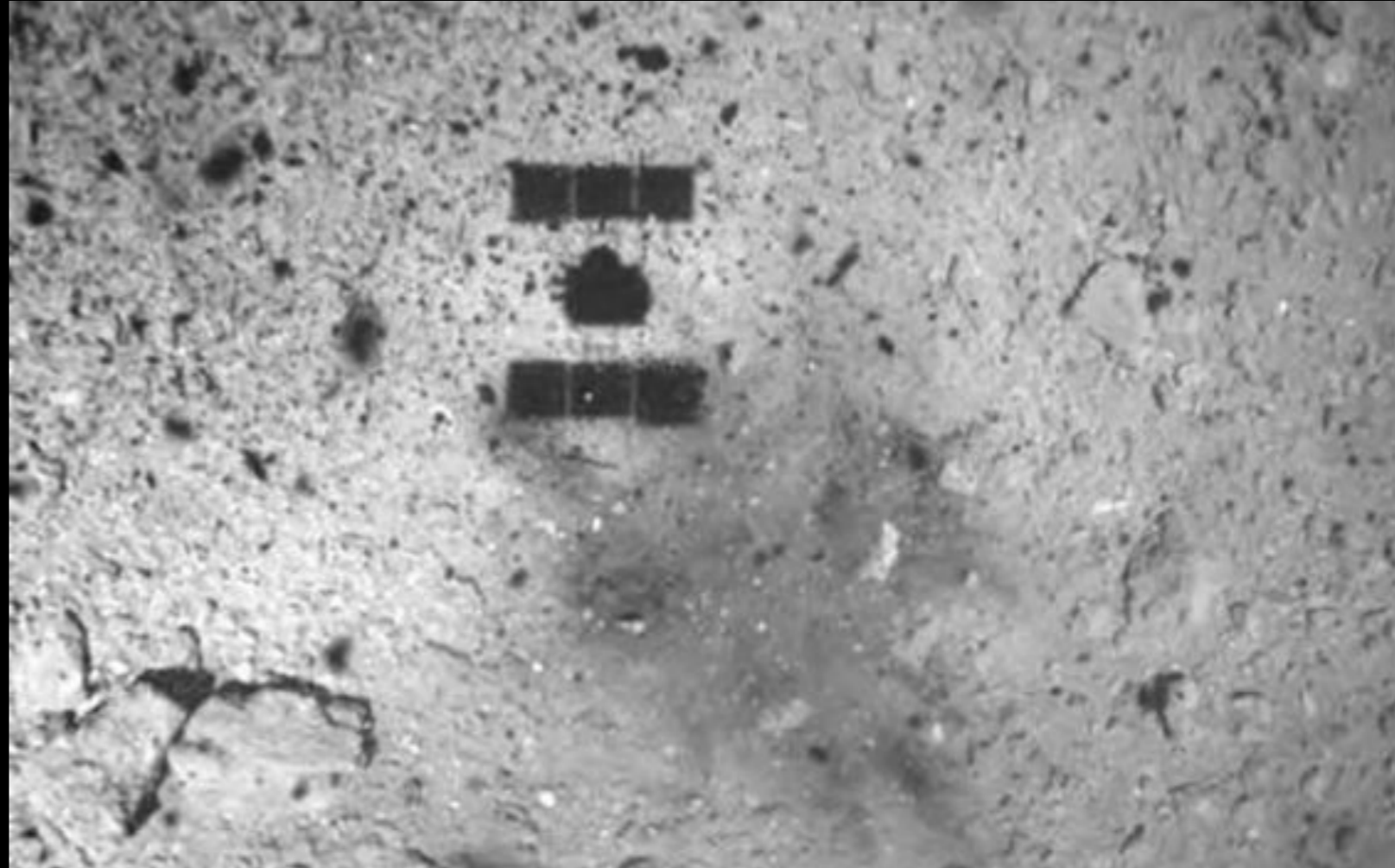
“How’s that space program coming along?”

Exploration



Hayabusa2

Asteroid: Ryugu



OSIRIS-REx

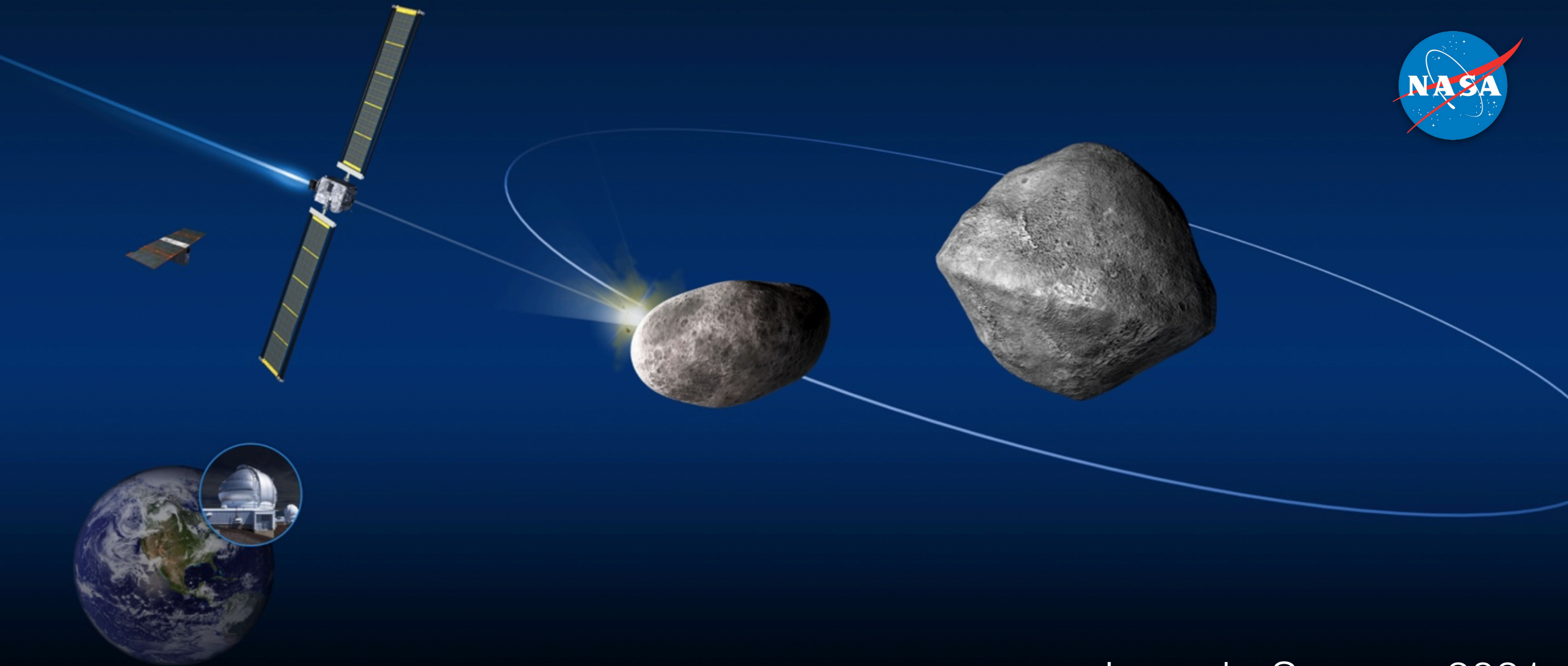
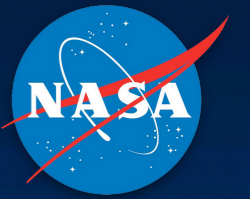
Asteroid: Bennu

Impact Mitigation

Asteroid Impact & Deflection Assessment \ AIDA

DART

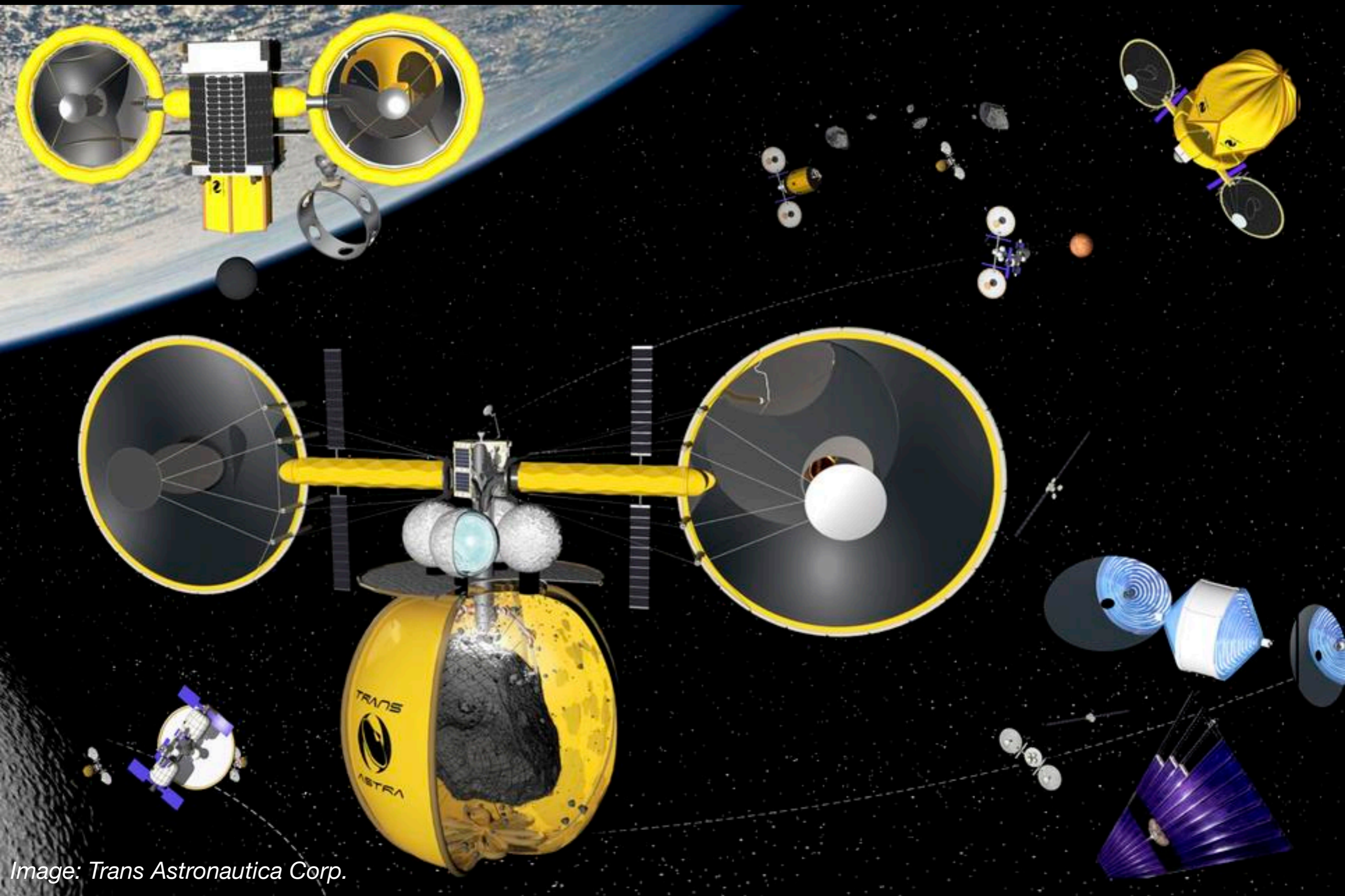
Double Asteroid Redirection Test



Launch: Summer 2021

Impact: Late 2022

Resource Utilization





Thank You!

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nmosko@lowell.edu