Grand Tour of the Universe

A Brief Introduction to Cosmology
Discovery of Dark Energy

Nao Suzuki
Lawrence Berkeley National Lab

Menu

- Part 1: Space Time Travel
  Travel in Time
  Travel in Space
  Current Understanding of the Universe

- Part 2 : Observing the Universe
- Discovery of Dark Energy
- Future Research

Universe (宇宙）

- 宇　：　Space
- 宙　：　Present, Past, Future (Time)
- 往古来今宙謂、四方上下宇謂（「淮南子」、斉俗訓）
- Space Time : 時空

The Top 10 Biggest Events in the Universe

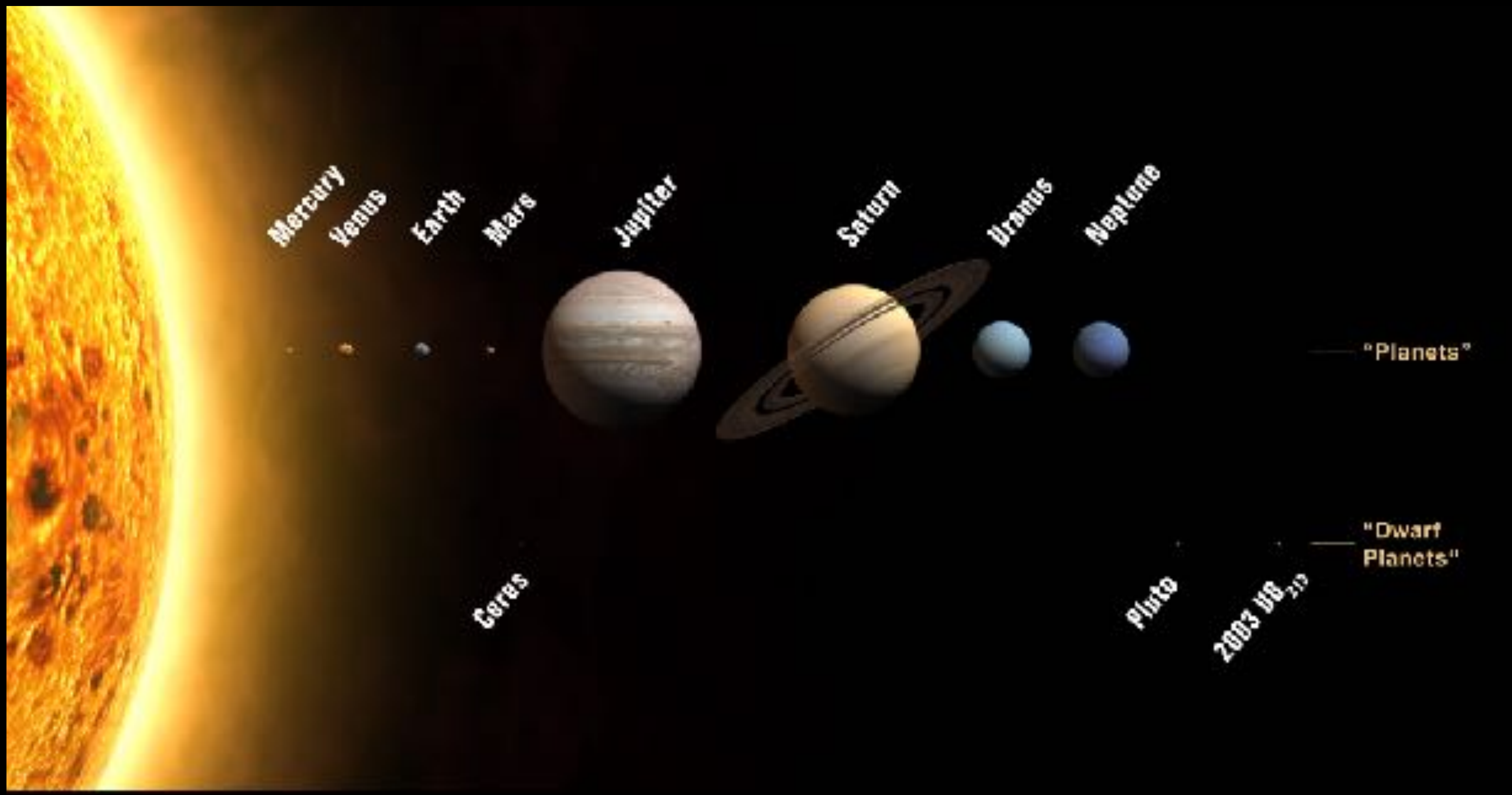
- 1.Big Bang
- 2. Big Bang Nucleosynthesis (Birth of Elements)
- 3. The Birth of the First Star
- 4. Galaxies Formation
- 5. Solar System forms
- 6. The oldest life-form appears on the Earth
- 7. The first animals appeared
- 8. Animals begin colonization of land
- 9. Extinction of Dinosaurs
- 10. Modern Human-being appears

Cosmic Calendar
Universe (13.8Gyr) in One Year

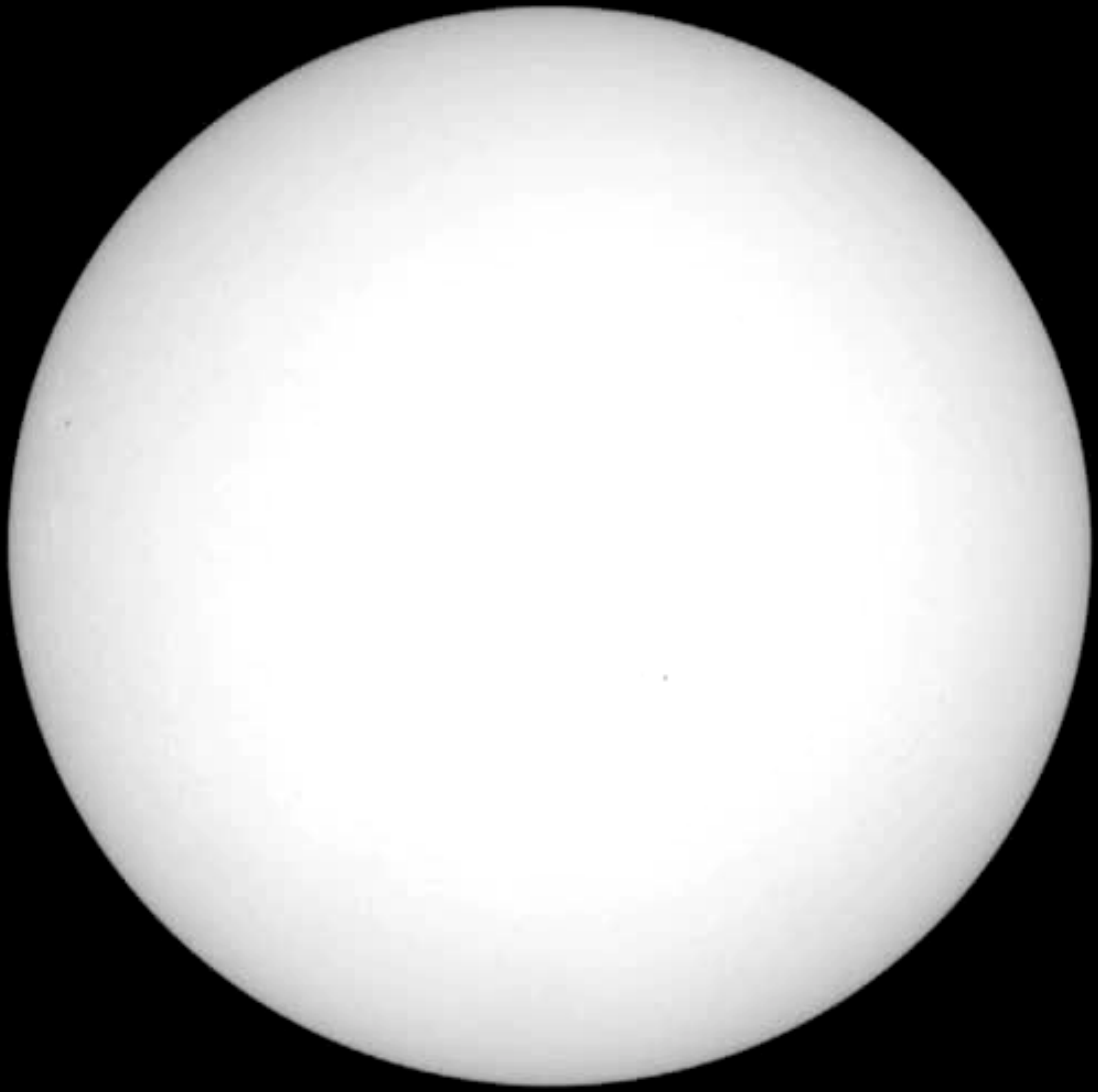
•1. Big Bang	Jan 1st 0:00:00
•2. Big Bang Nucleosynthesis	Jan 1st 0:00:00.00000001
•3. First Star	Jan 1st 10:00:00
•4. Galaxy Formation	May 1st
•5. Birth of the Solar System	Aug 30th : 4.6 billion years ago
•6. First Life Form	Sep 28th
•7. First Animal	Dec 16th
•8. Land Colonization	Dec 20th
•9. Extinction of Dinosaurs	Dec 29th
•10. Modern Human	Dec 31st 23:59:36.9

Travel in Space

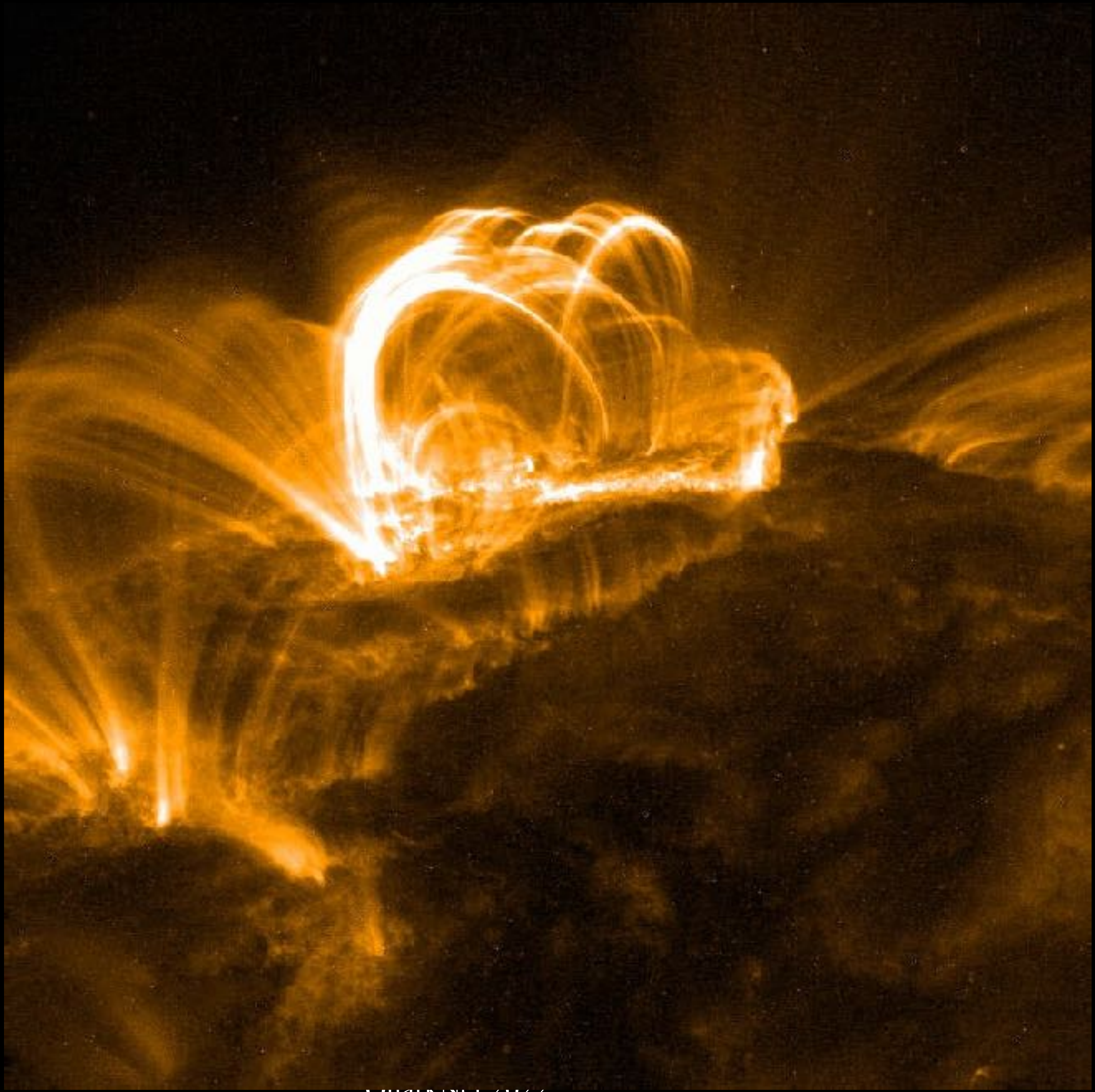
- Q. Suppose the Size of the Sun is a Quarter Coin, what are the distances to the planets?



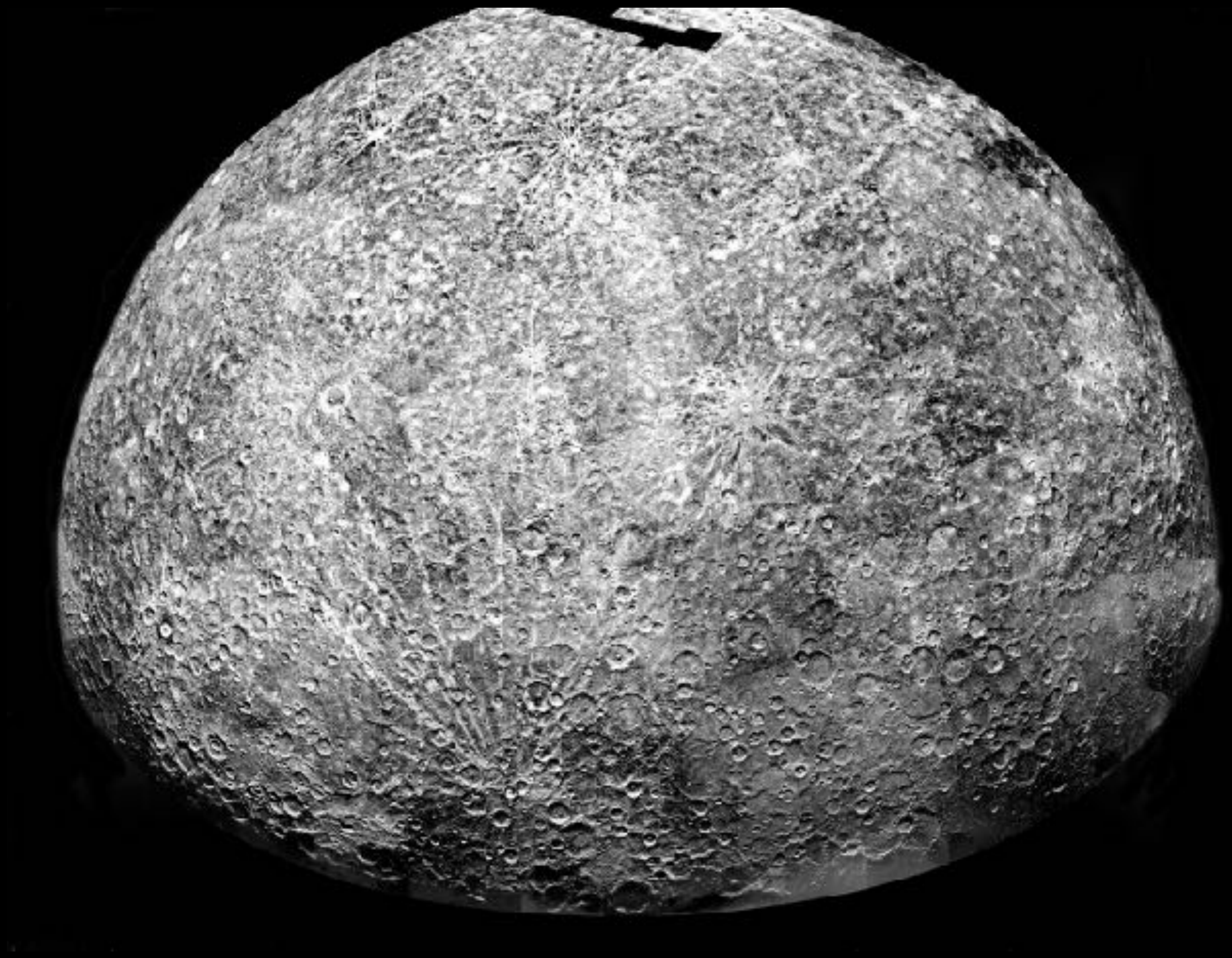
Sun



QuarkNet 2022



Mercury R=1.0 m (0.387AU)

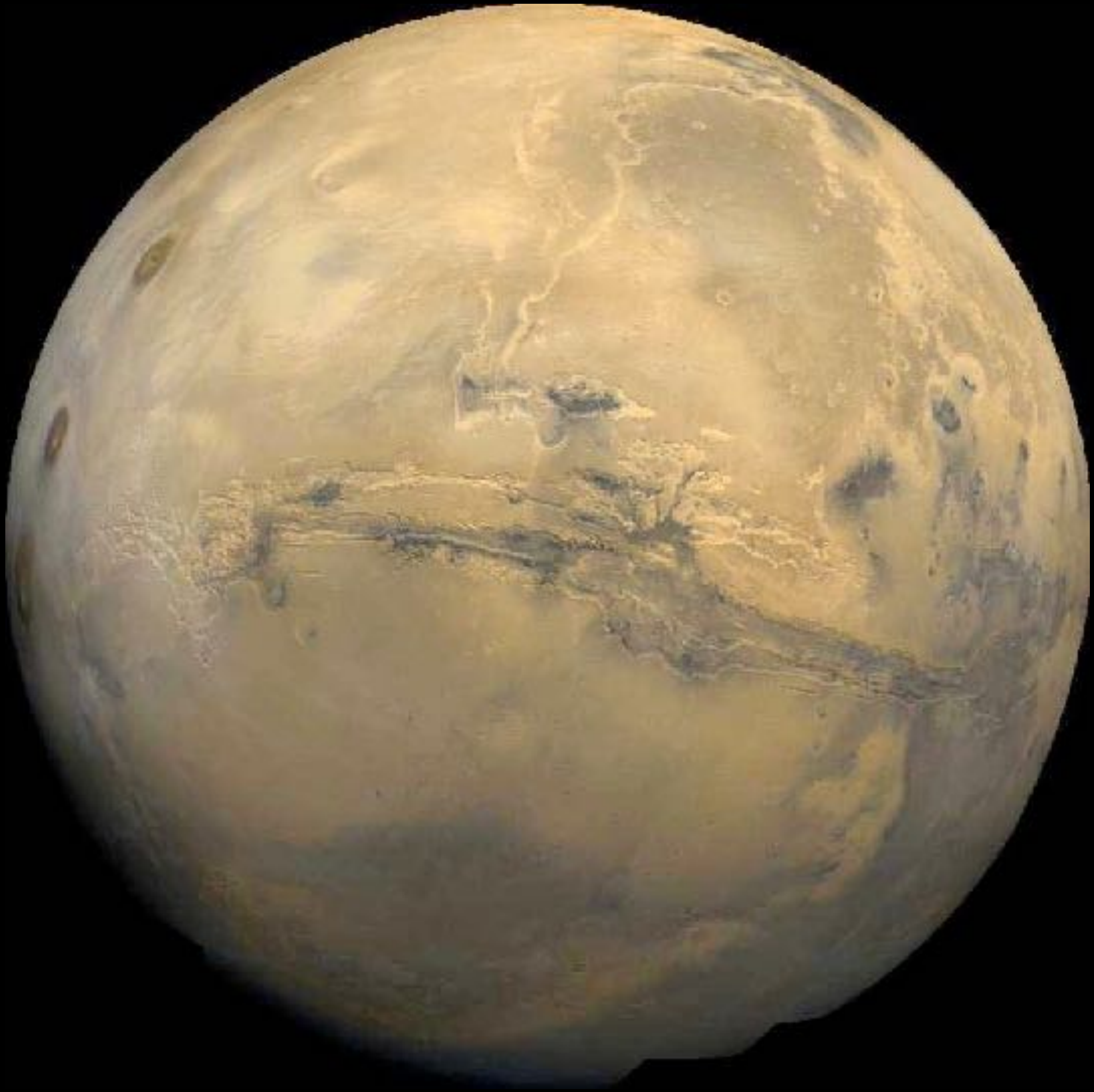


Venus

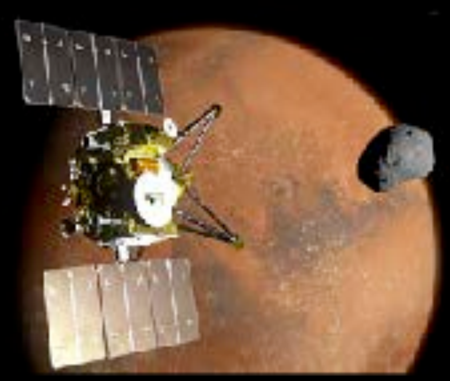
R=1.86 m (0.723AU)

Earth R=2.58 m (1.00AU)

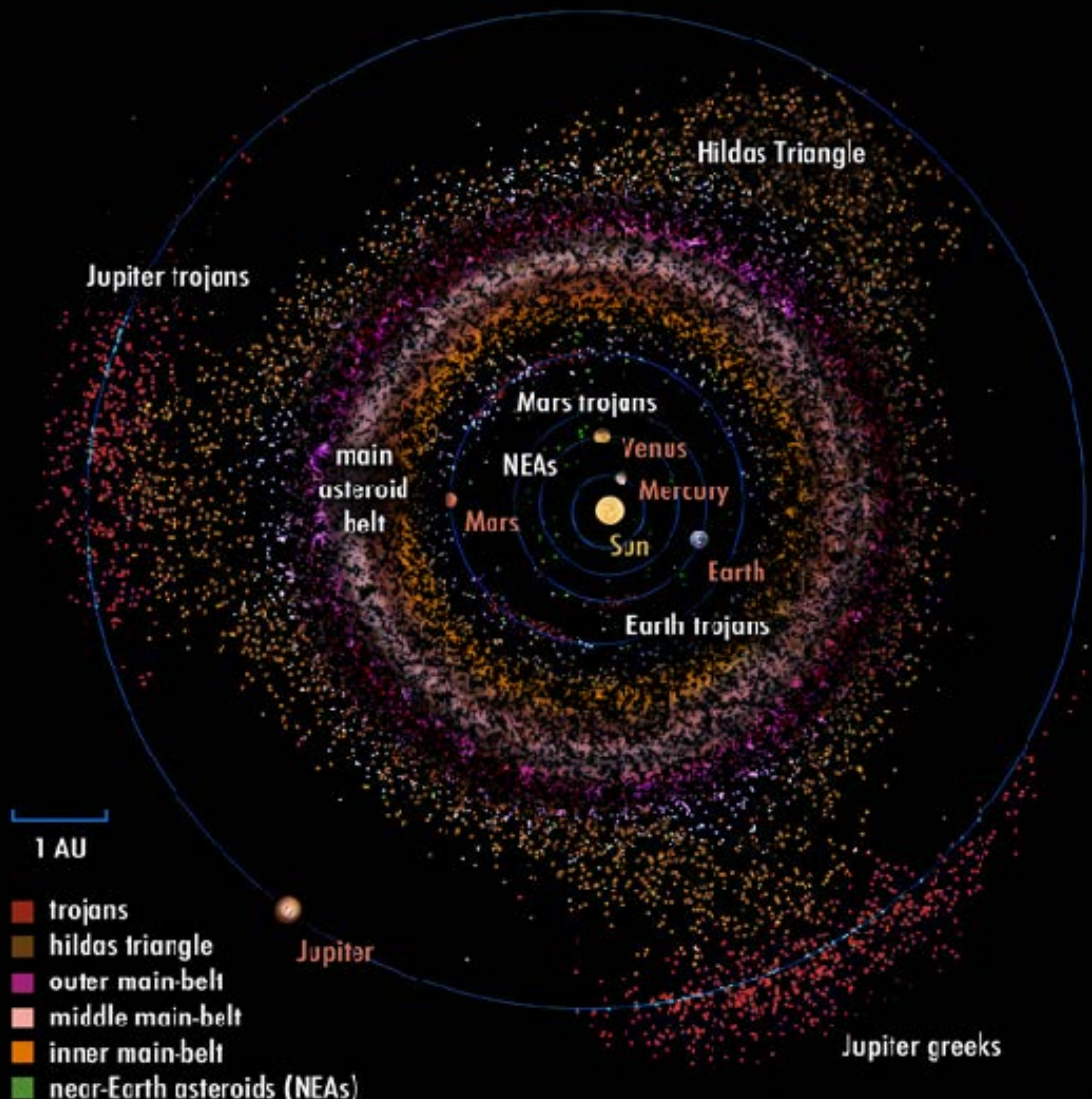
Mars R=3.97 m (1.524AU)



Mars Satellite Phobos



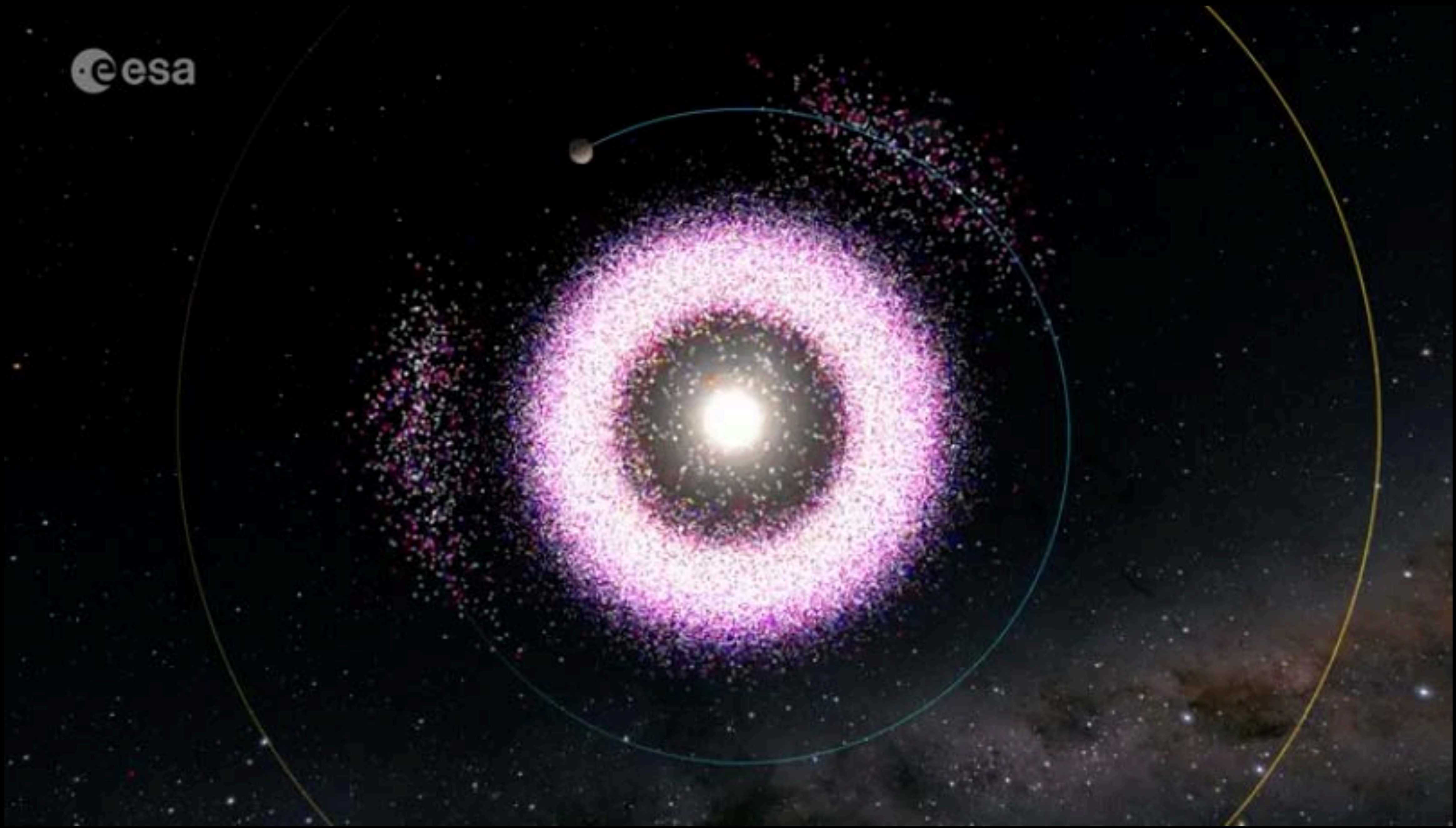
Asteroids

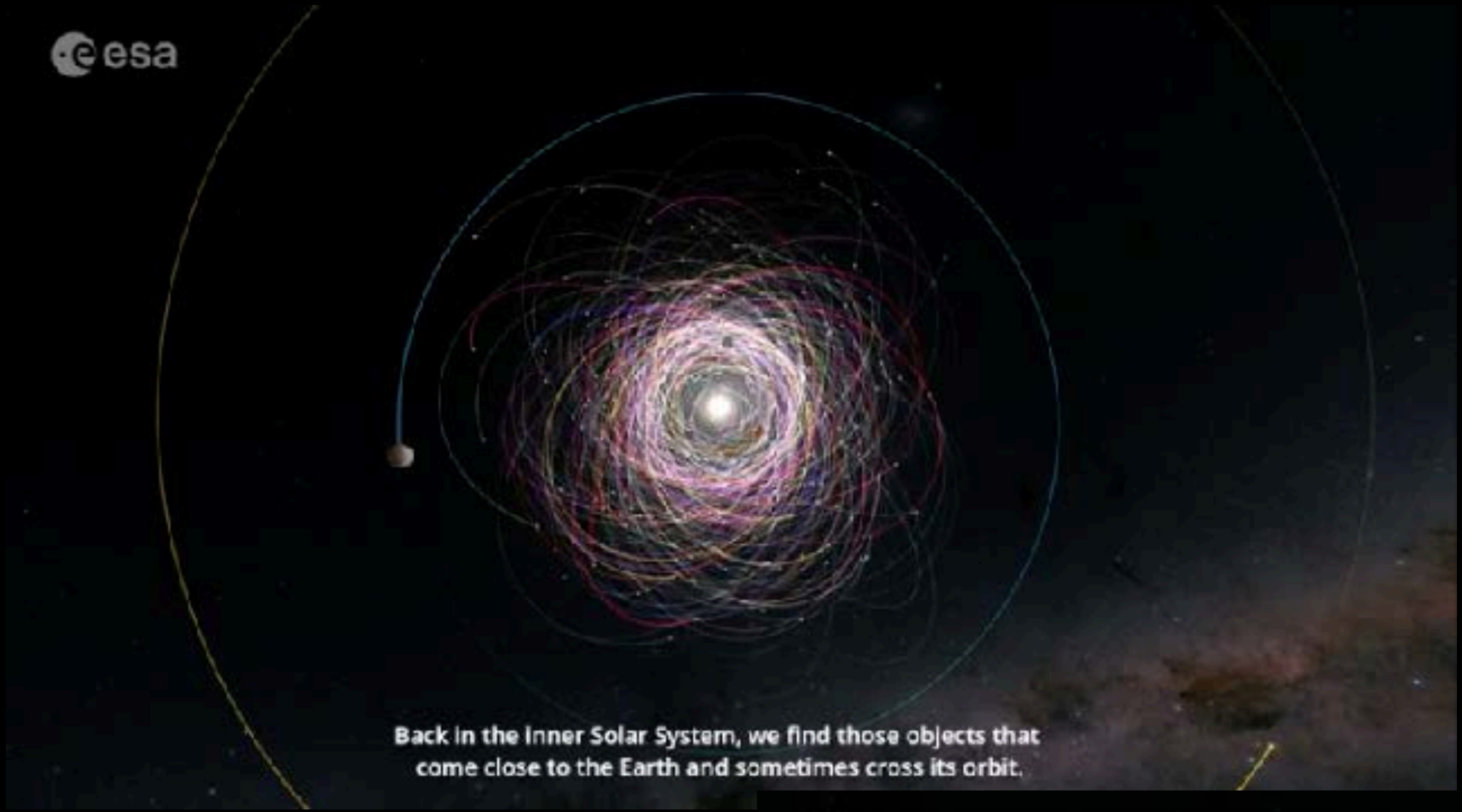


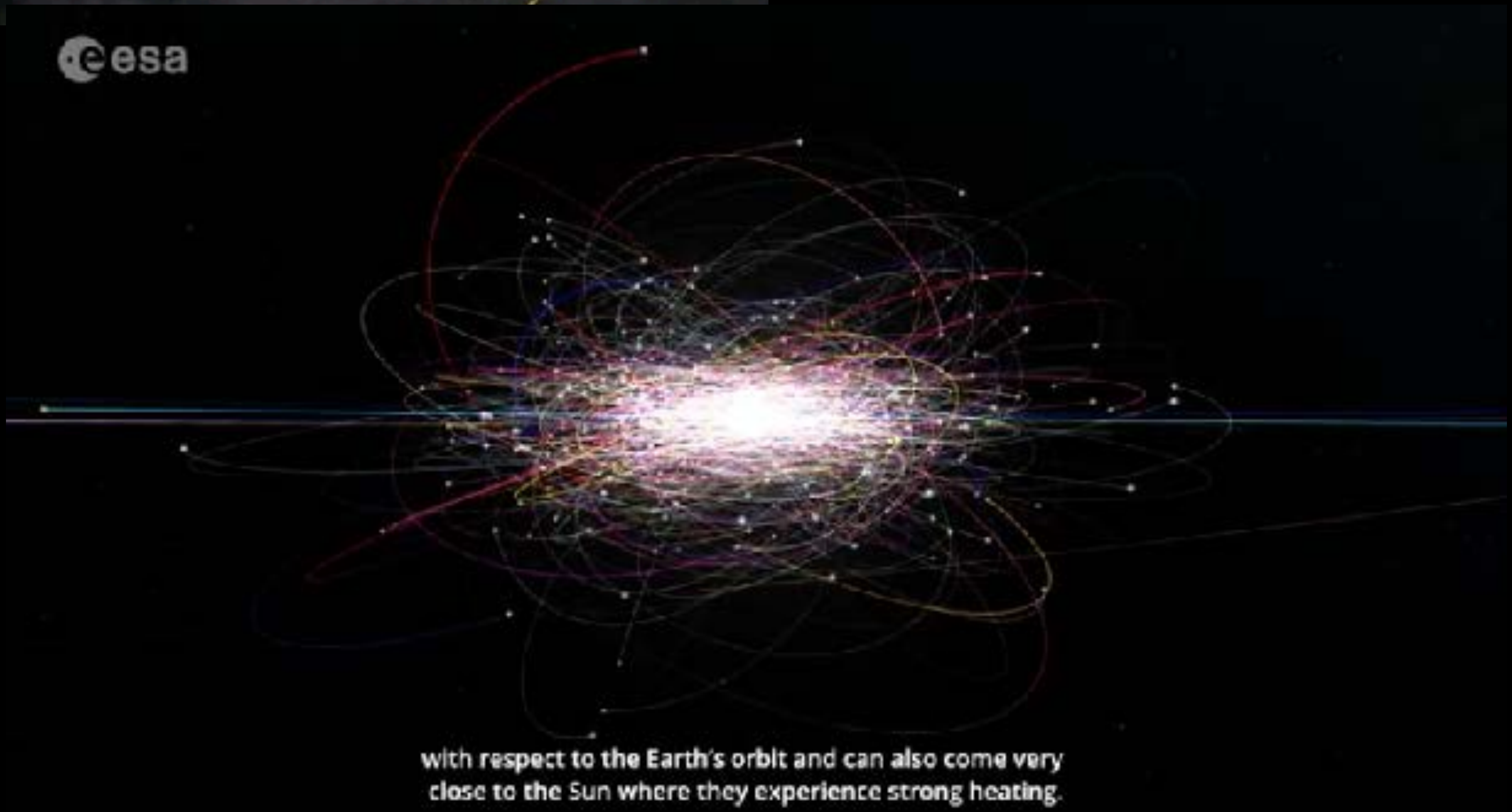
1921: 1,000
1981: 10,000
2000: 100,000

2022-06-12 GAIA DR3
154,721 Asteroids

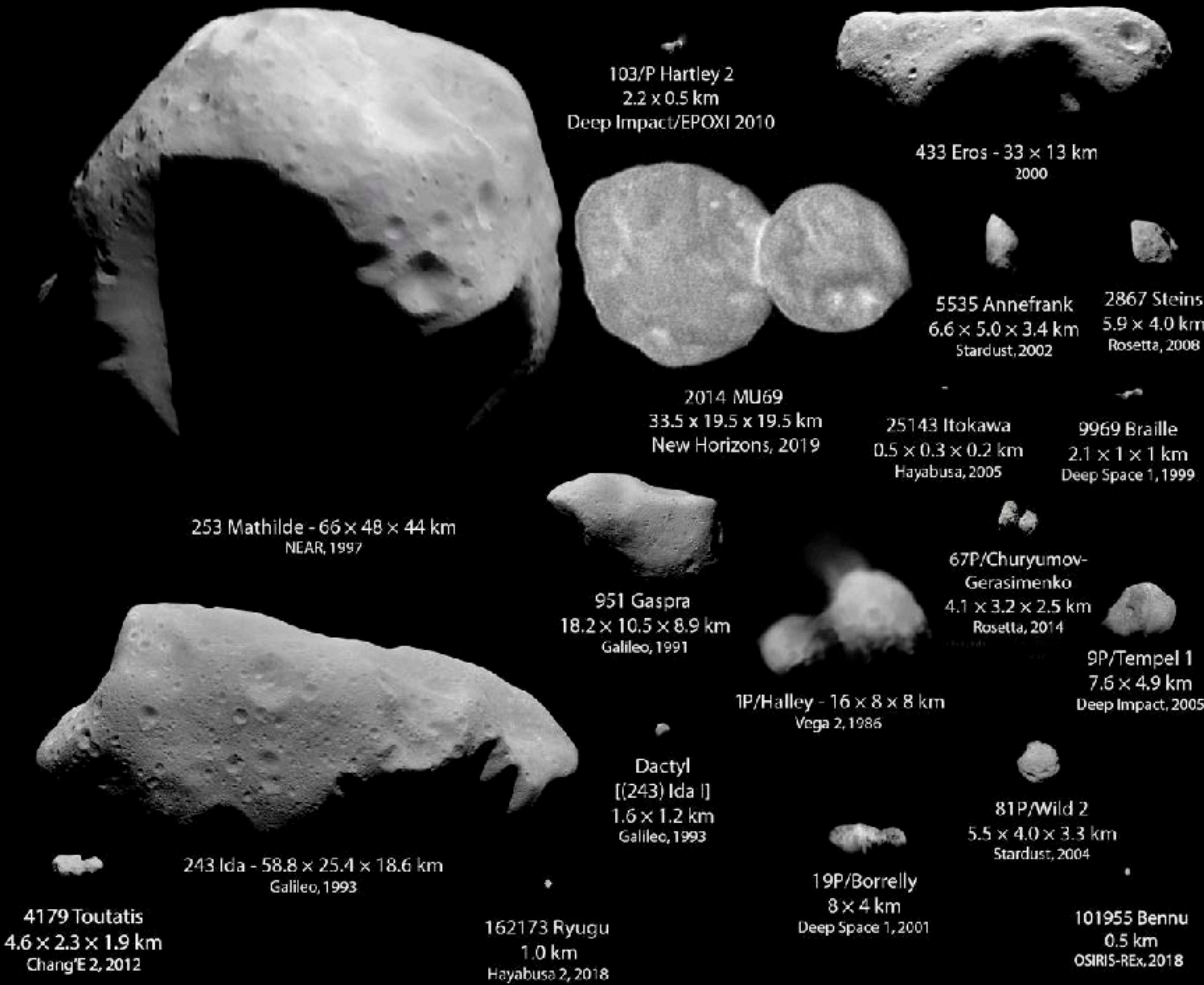
154,721 Asteroids



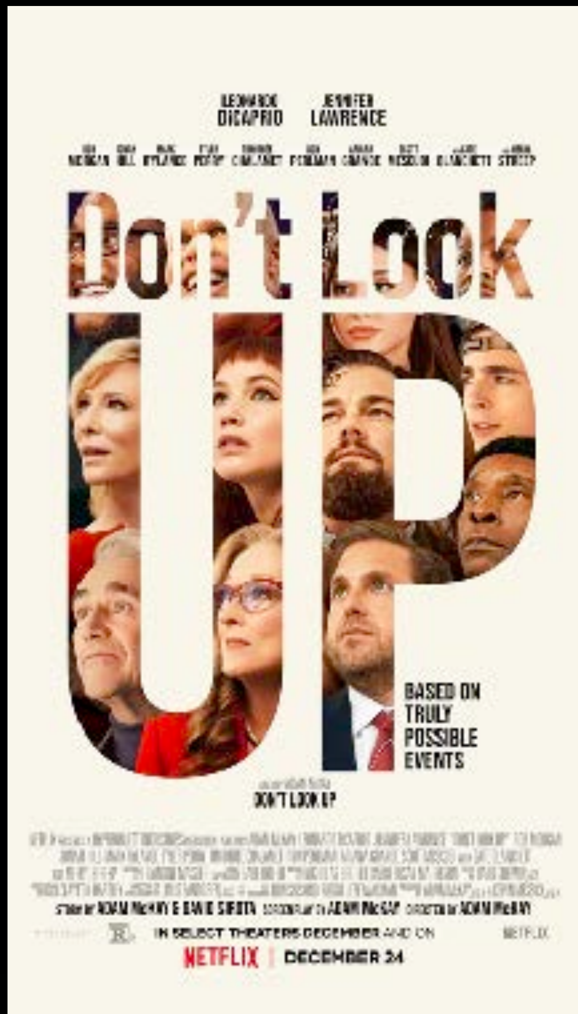

esa
Back in the Inner Solar System, we find those objects that
come close to the Earth and sometimes cross its orbit.


esa
with respect to the Earth's orbit and can also come very
close to the Sun where they experience strong heating.

446 Near Earth Asteroids


103/P Hartley 2
2.2 x 0.5 km
Deep Impact/EPOXI 2010
433 Eros - 33 × 13 km
2000
2014 MU69
33.5 x 19.5 x 19.5 km
New Horizons, 2019
5535 Annefrank
6.6 × 5.0 × 3.4 km
Stardust, 2002
2867 Steins
5.9 × 4.0 km
Rosetta, 2008
25143 Itokawa
0.5 × 0.3 × 0.2 km
Hayabusa, 2005
9969 Braille
2.1 × 1 × 1 km
Deep Space 1, 1999
253 Mathilde - 66 × 48 × 44 km
NEAR, 1997
951 Gaspra
18.2 × 10.5 × 8.9 km
Galileo, 1991
67P/Churyumov-
Gerasimenko
4.1 × 3.2 × 2.5 km
Rosetta, 2014
9P/Tempel 1
7.6 × 4.9 km
Deep Impact, 2005
1P/Halley - 16 × 8 × 8 km
Vega 2, 1986
Dactyl
[(243) Ida I]
1.6 × 1.2 km
Galileo, 1993
81P/Wild 2
5.5 × 4.0 × 3.3 km
Stardust, 2004
243 Ida - 58.8 × 25.4 × 18.6 km
Galileo, 1993
19P/Borrelly
8 × 4 km
Deep Space 1, 2001
4179 Toutatis
4.6 × 2.3 × 1.9 km
Chang'E 2, 2012
162173 Ryugu
1.0 km
Hayabusa 2, 2018
101955 Bennu
0.5 km
OSIRIS-REx, 2018

Hunting for Supernova using Subaru Hyper-Suprime Cam



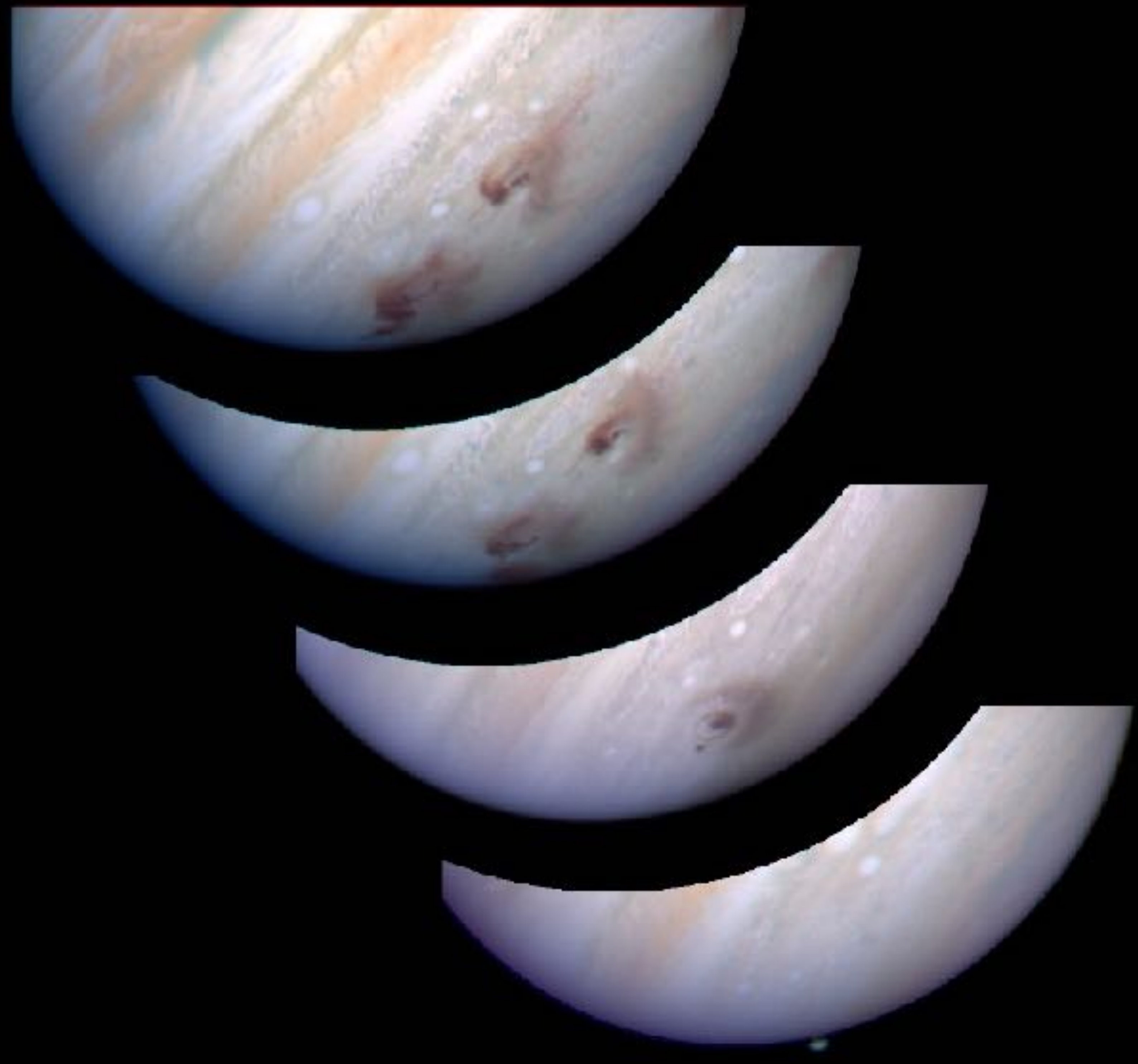
But they happen to find a killer asteroid

Credit: Don't Look Up (2021); Netflix

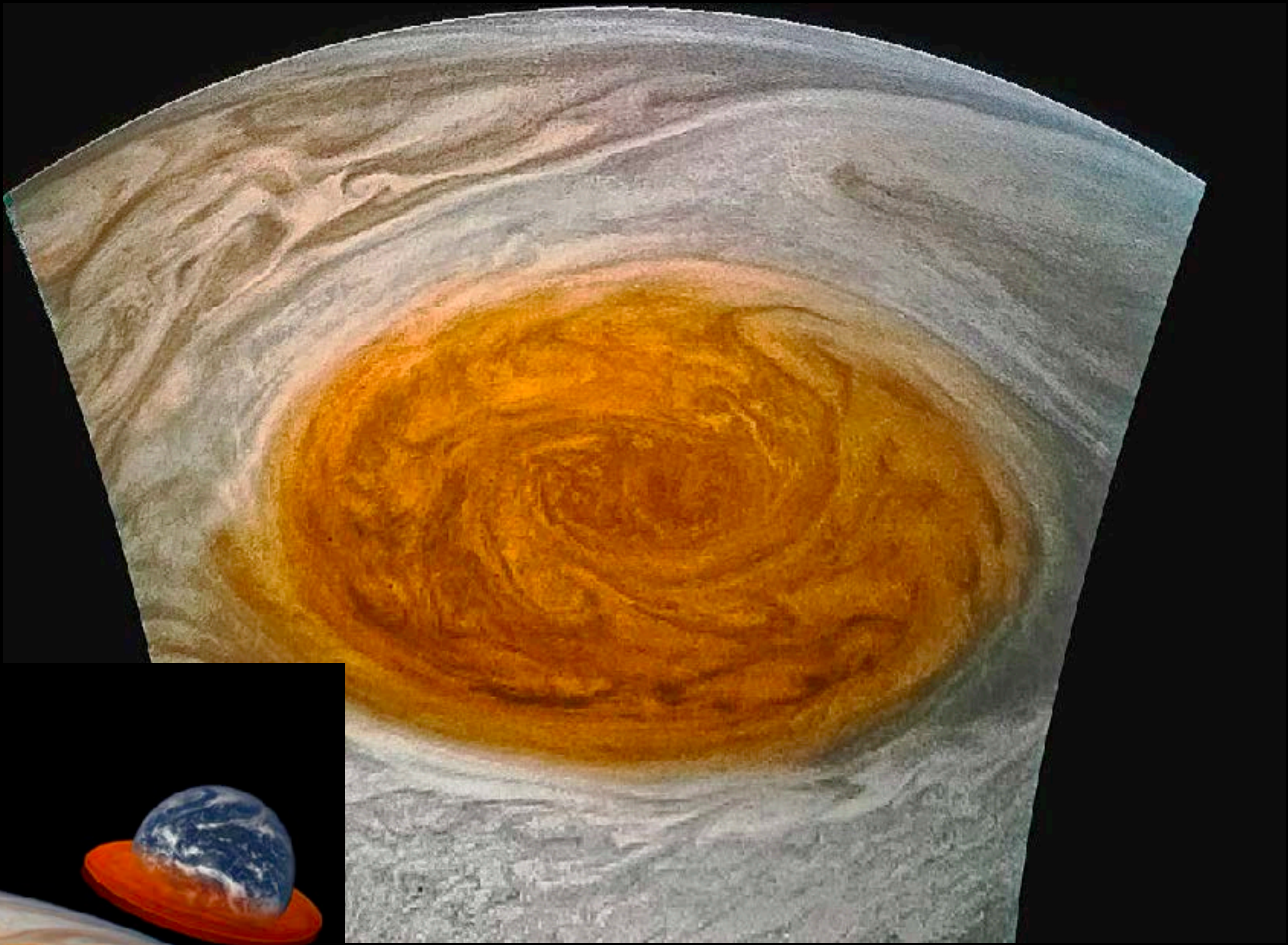
Credit: Don't Look Up (2021); Netflix

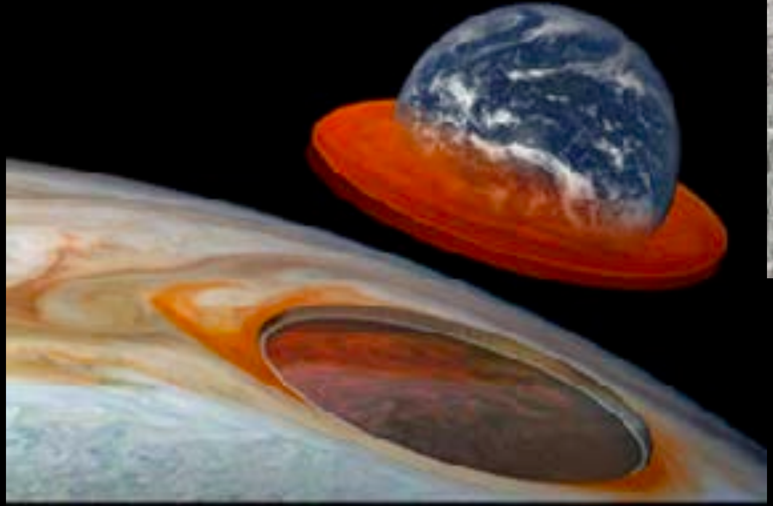
Jupiter R=13.4 m (5.203AU)

Deep Impact in 1992

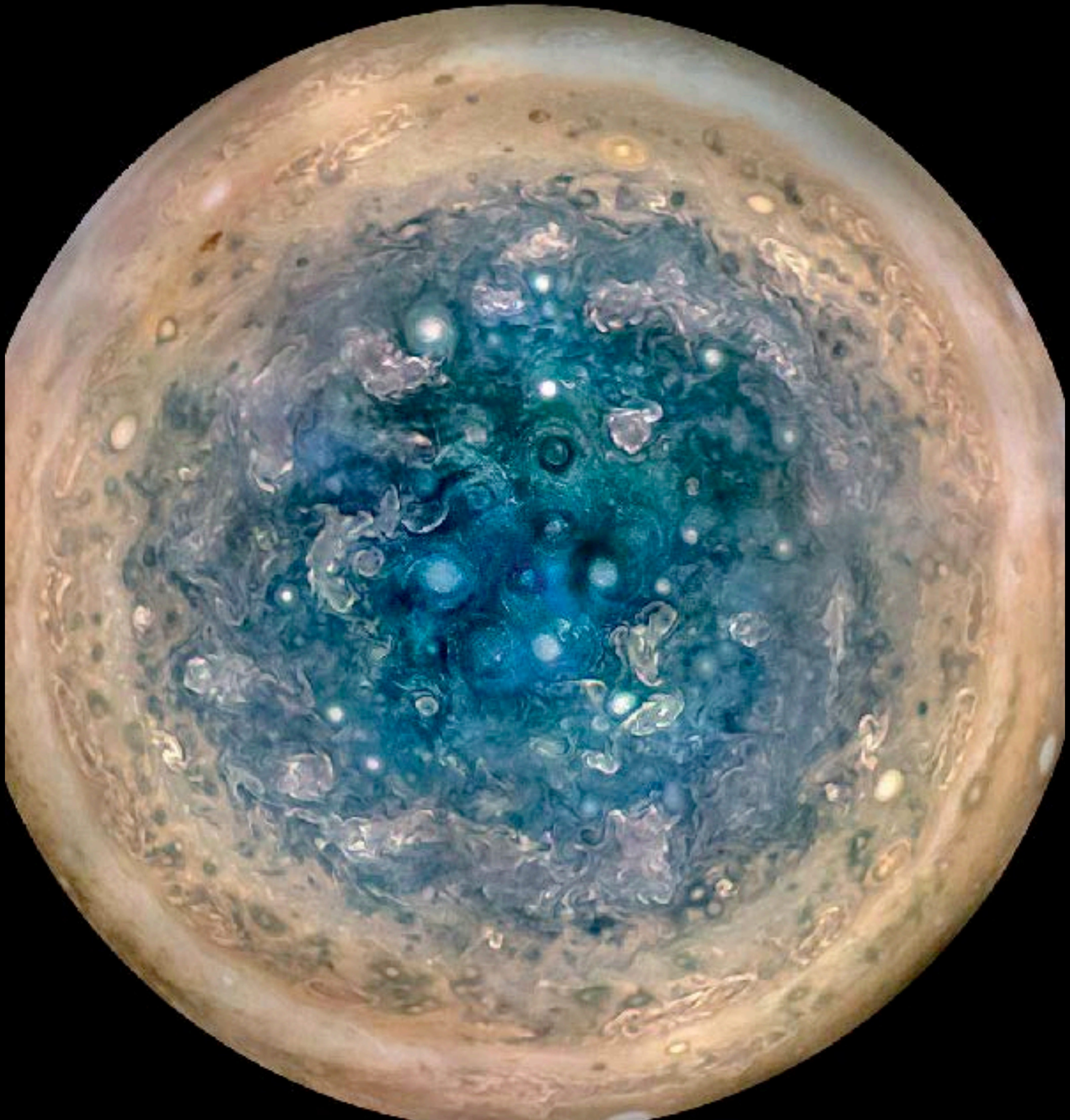



Juno Mission

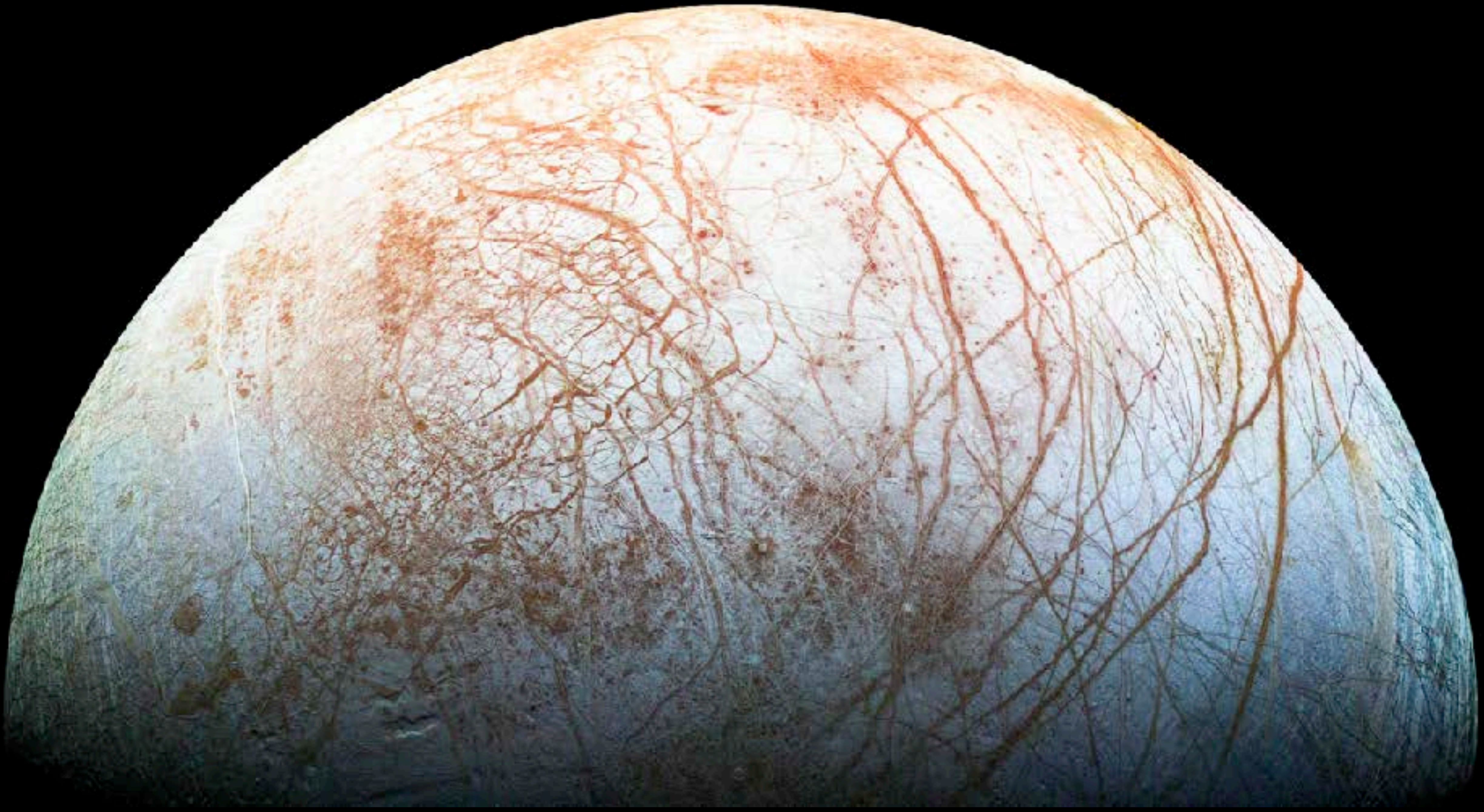




QuarkNet 2022



Jupiter’s Satellite Europa



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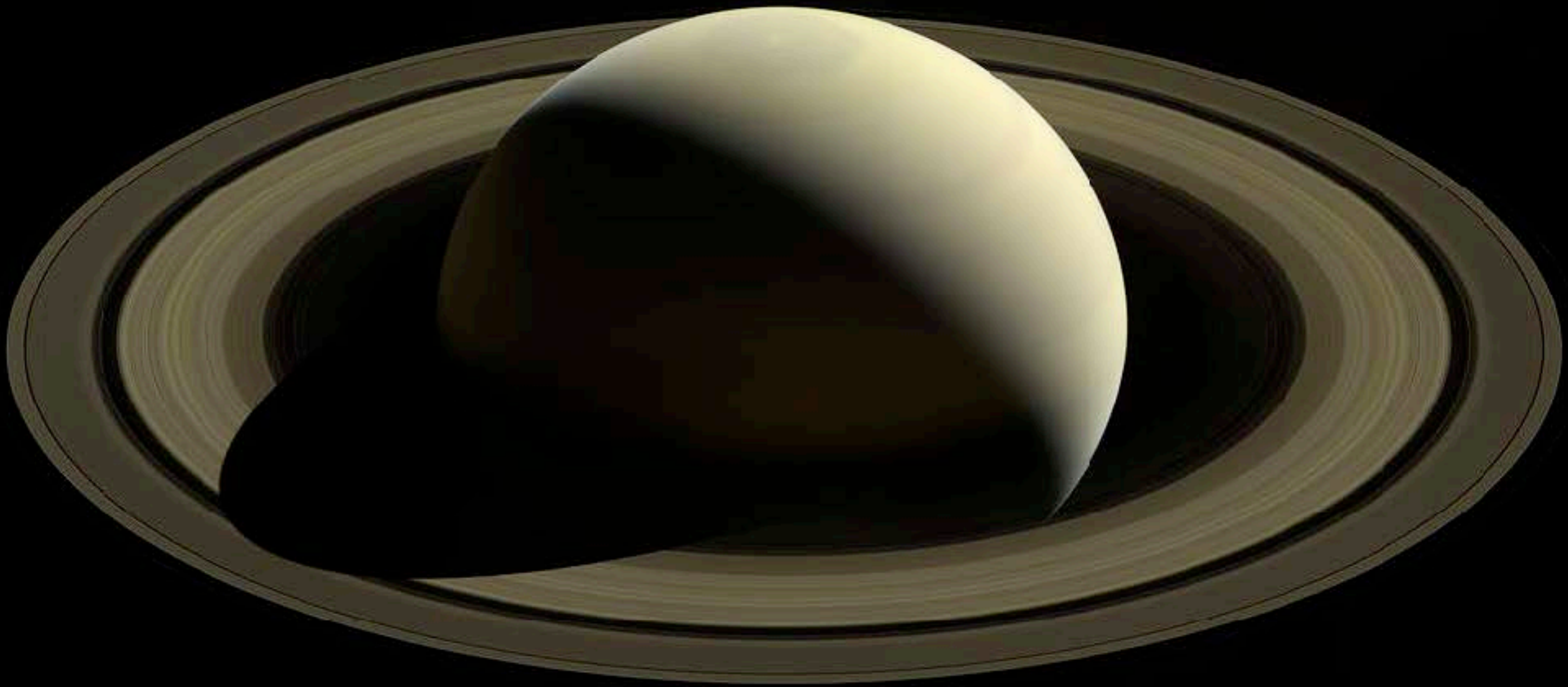
Saturn R=24.6 m (9.54AU)



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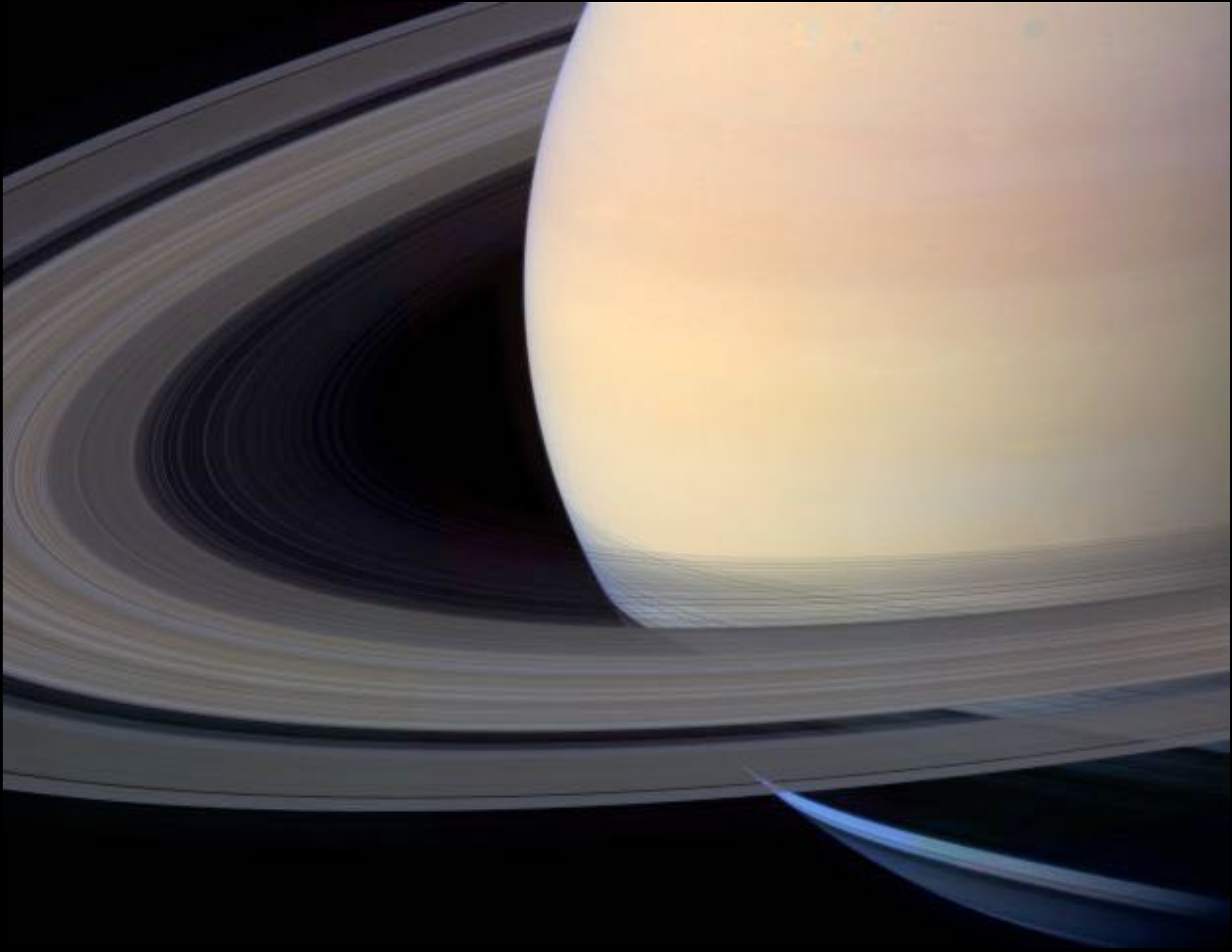

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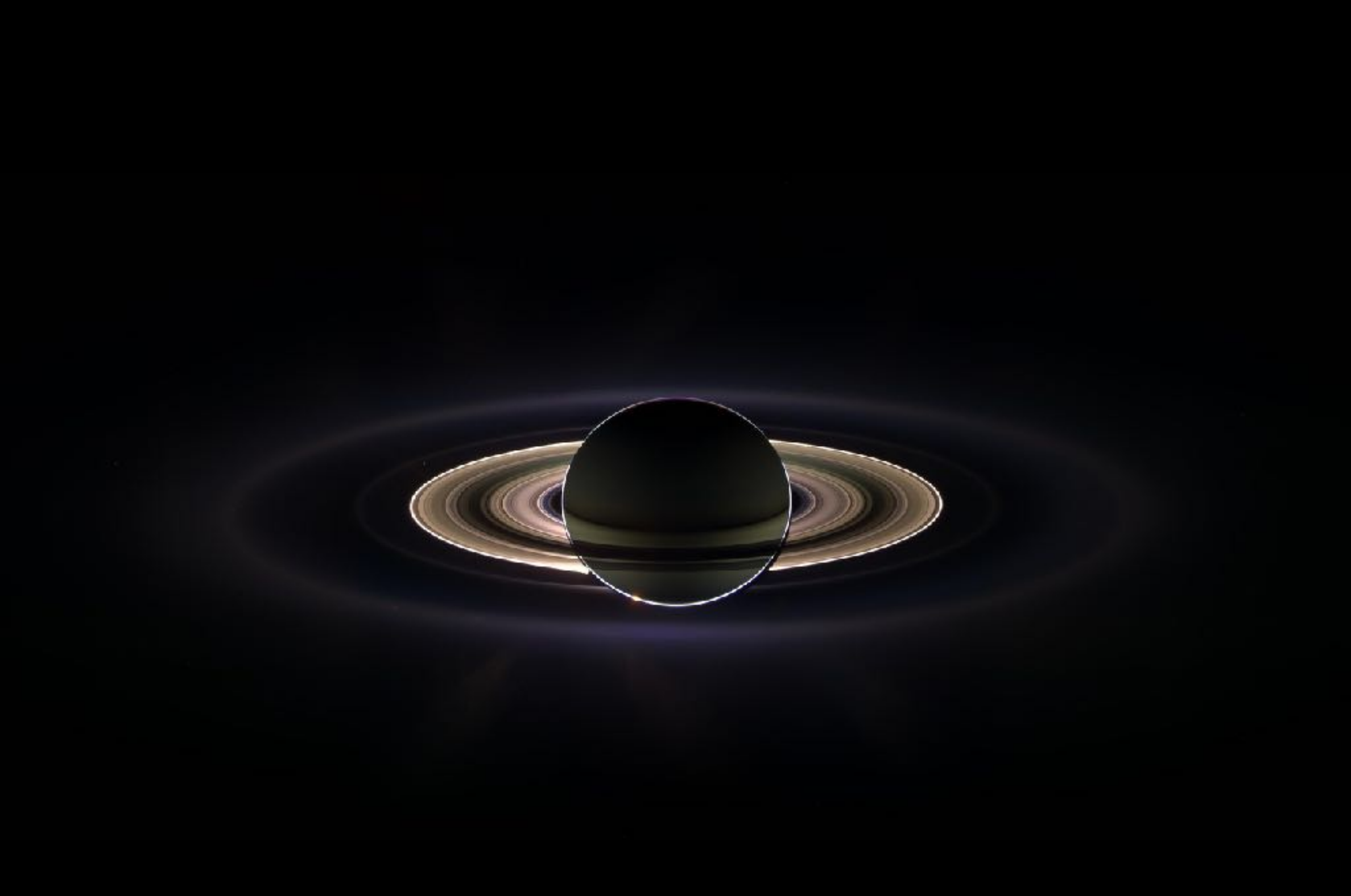
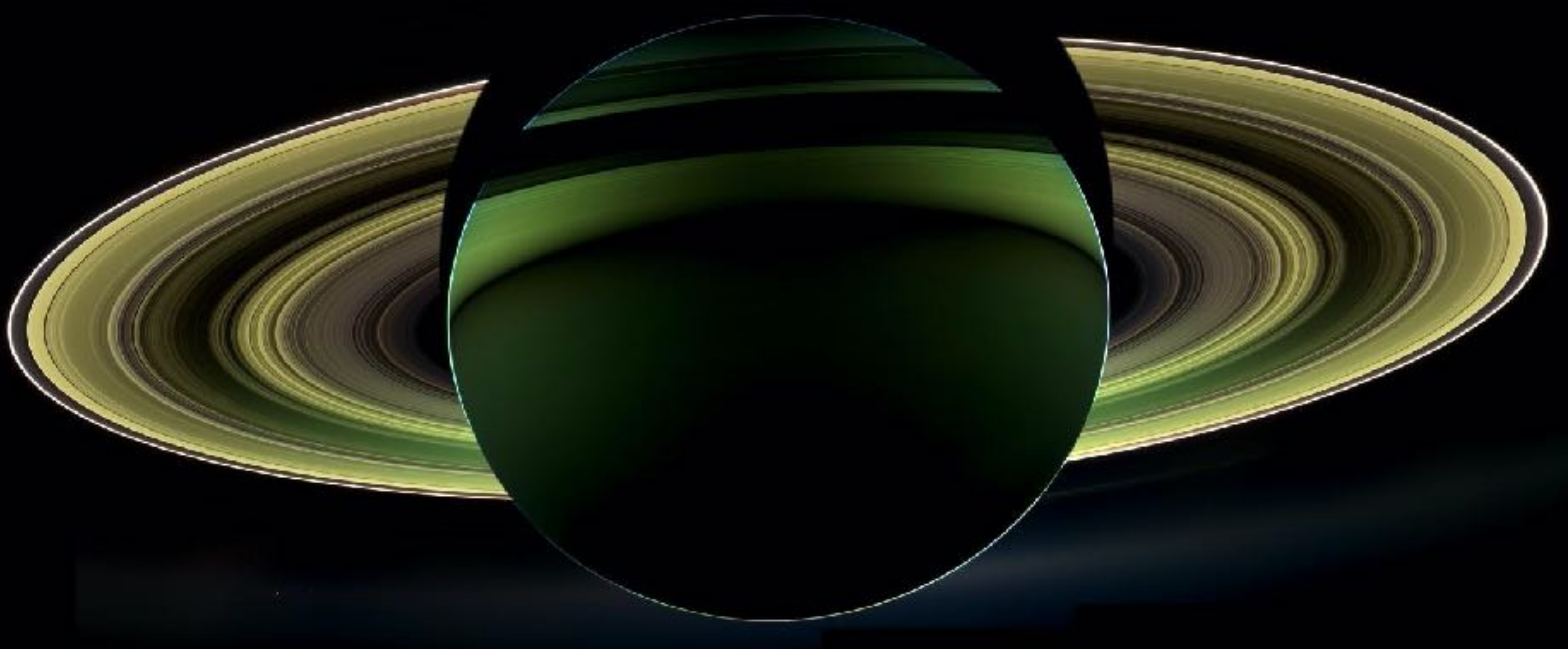
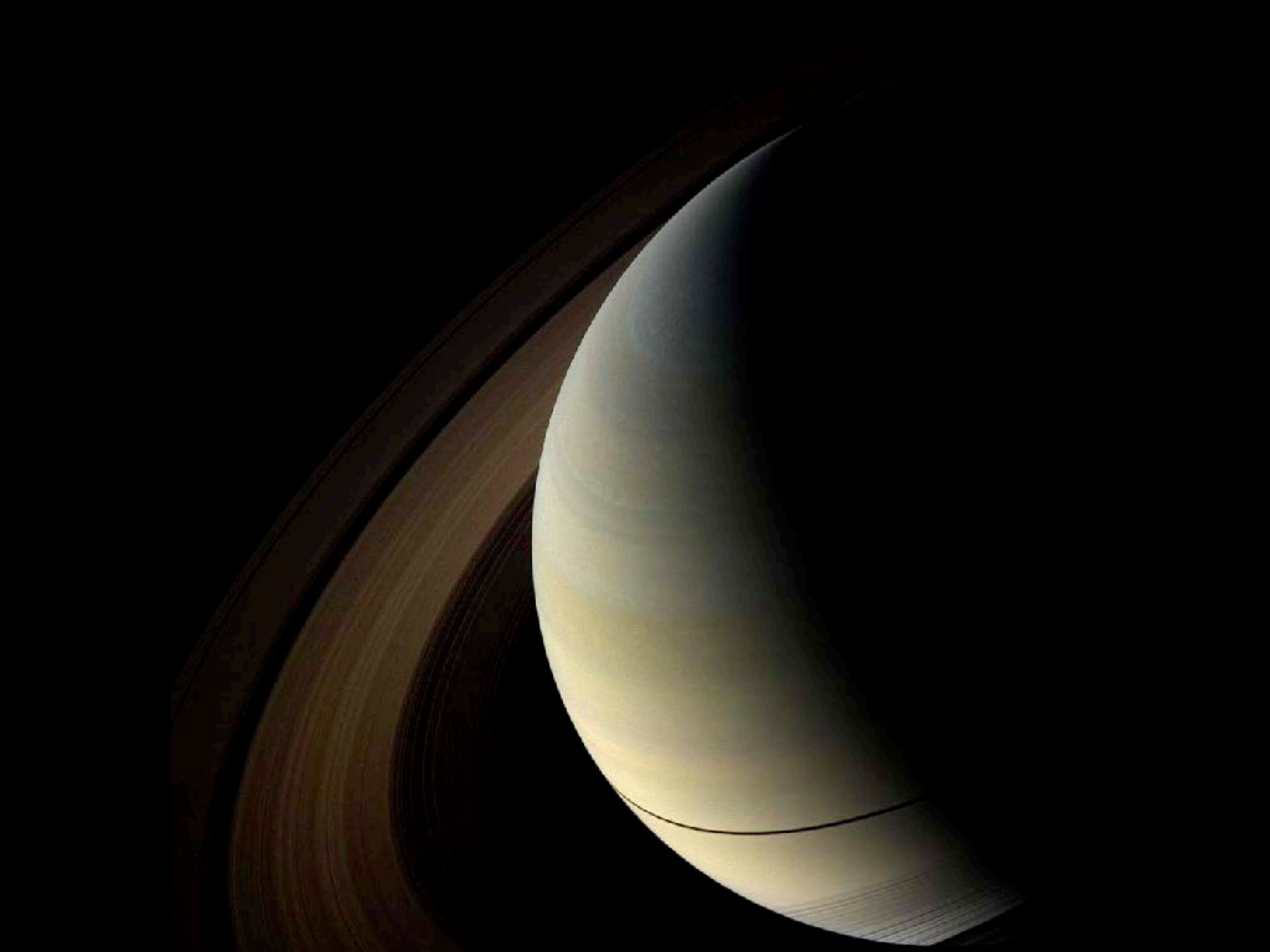
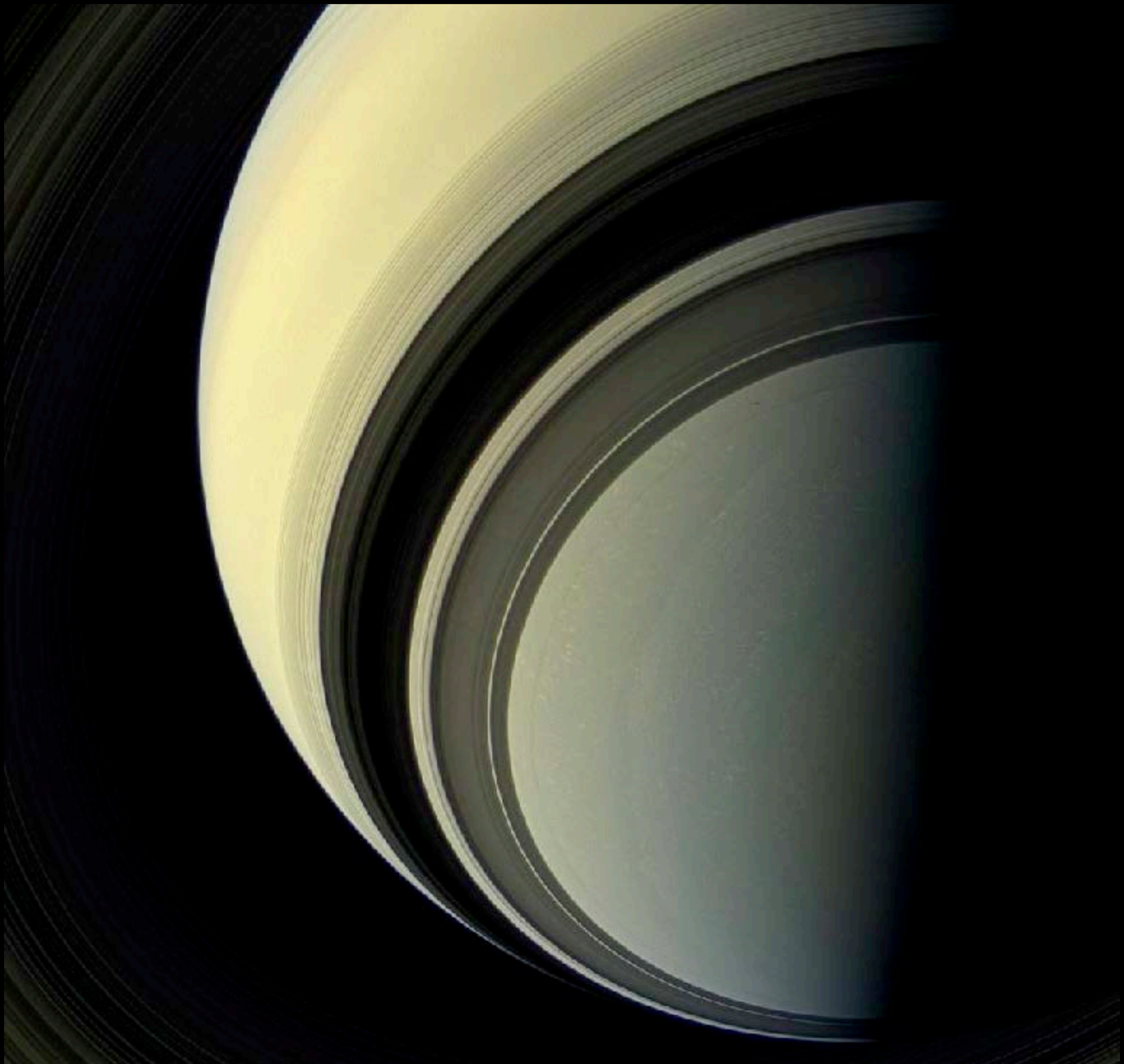
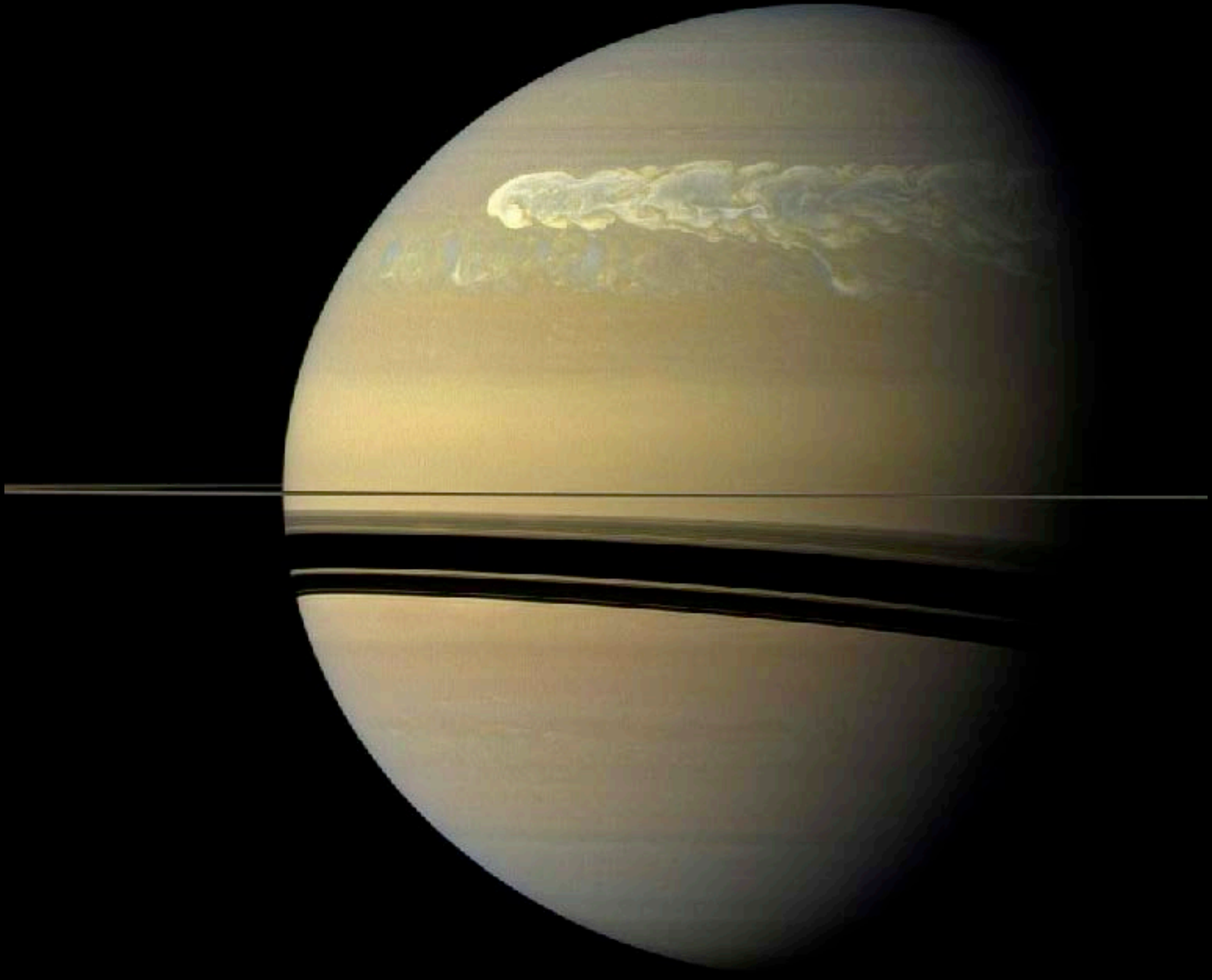
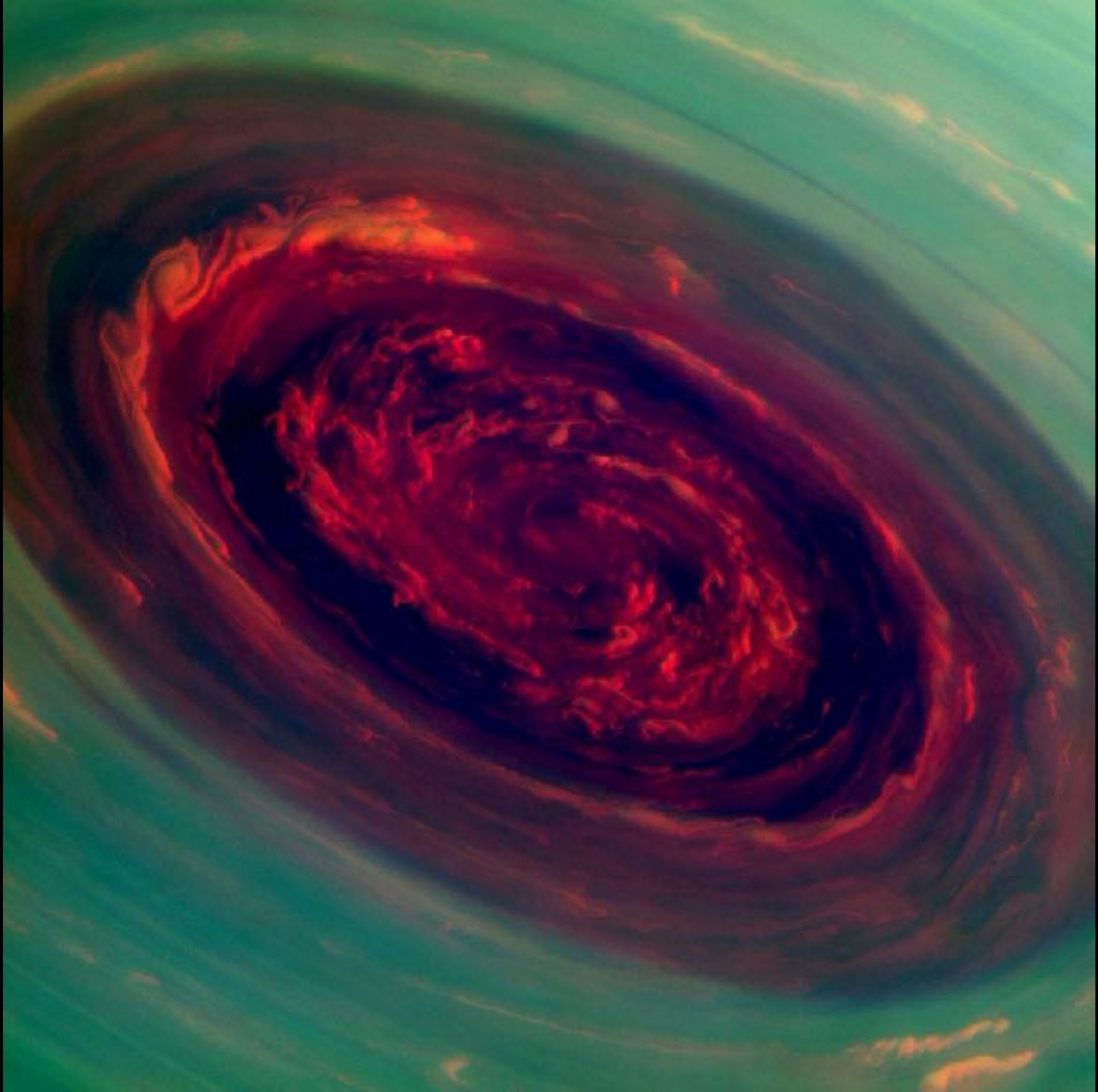


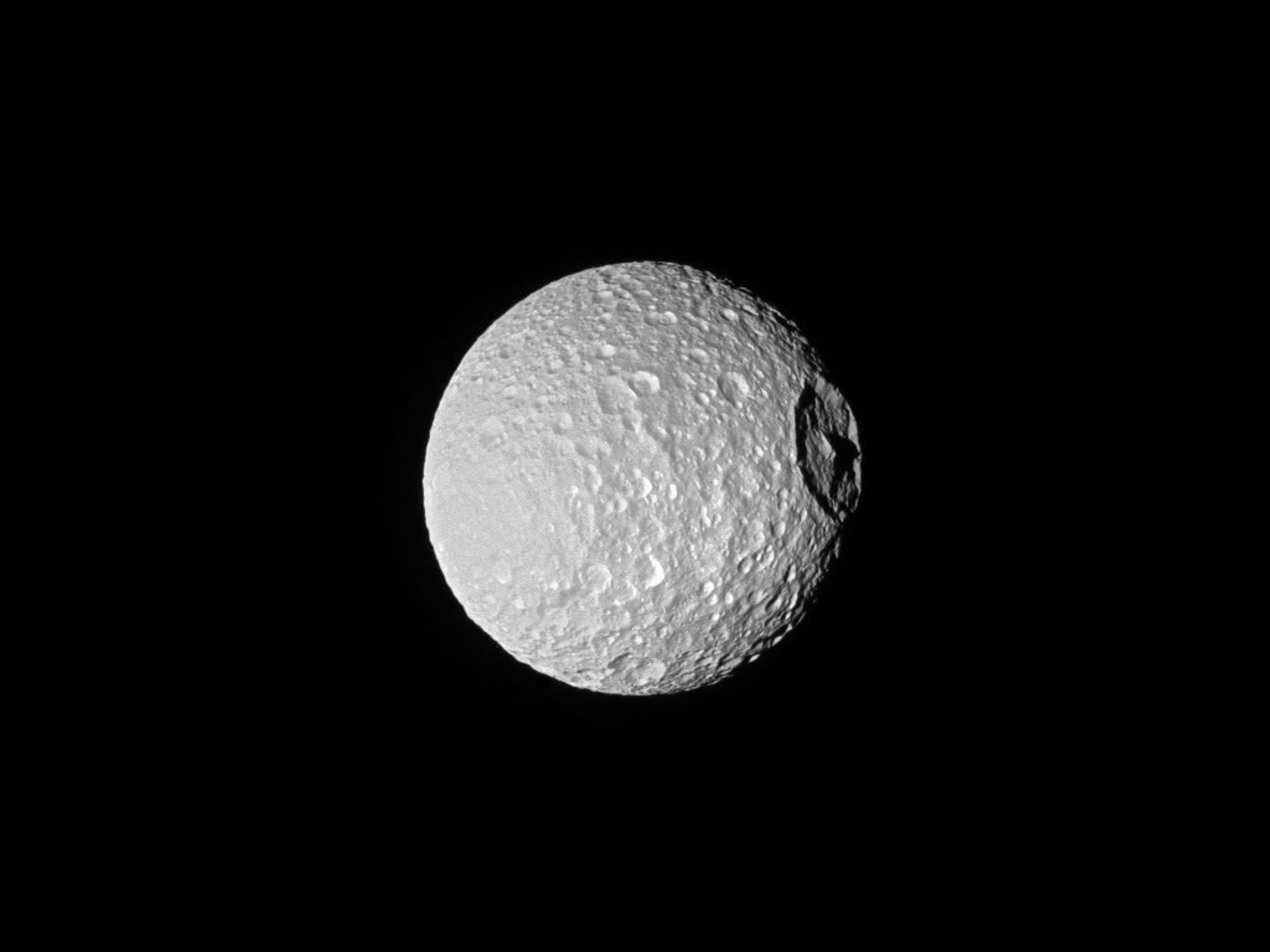




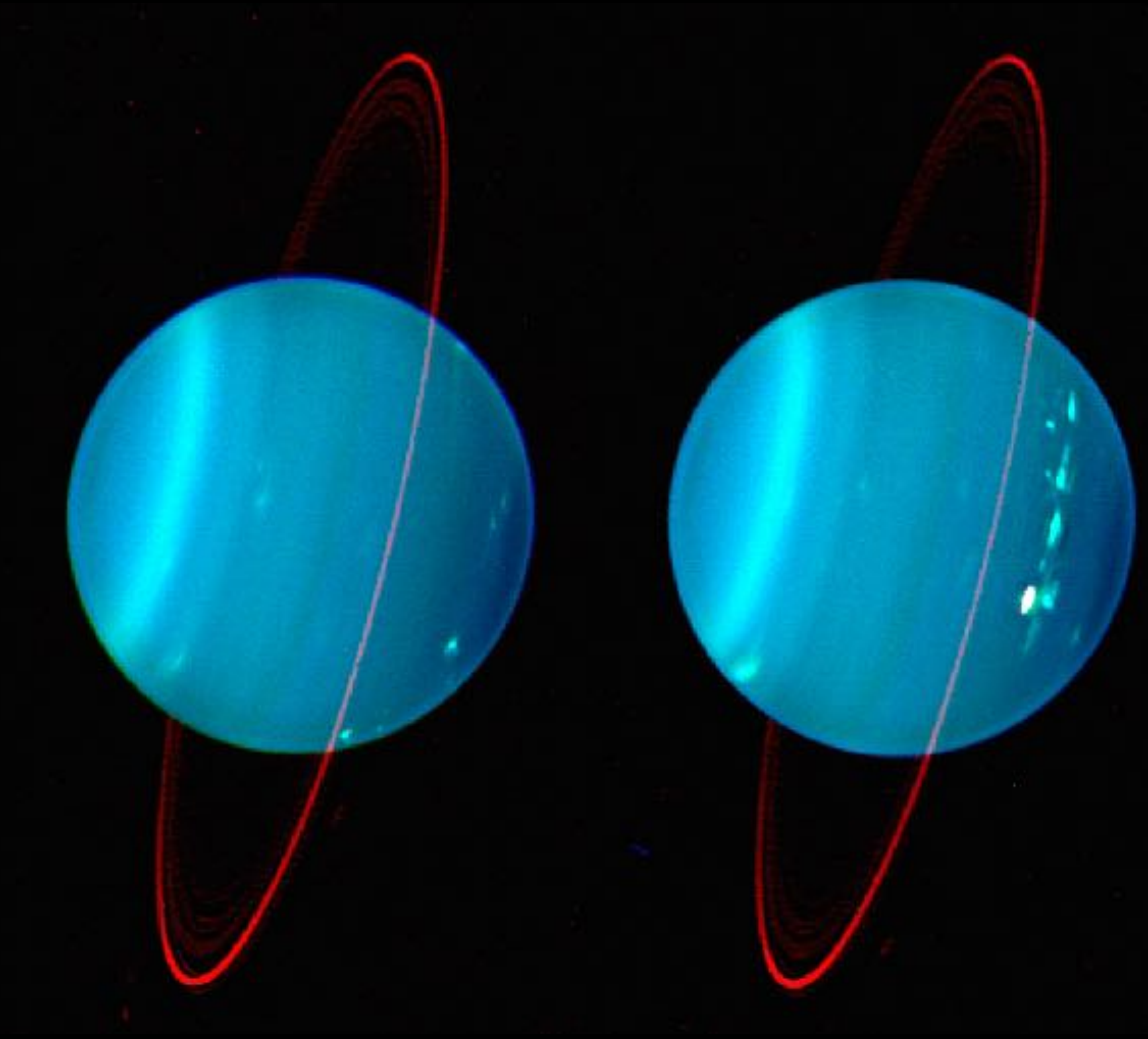








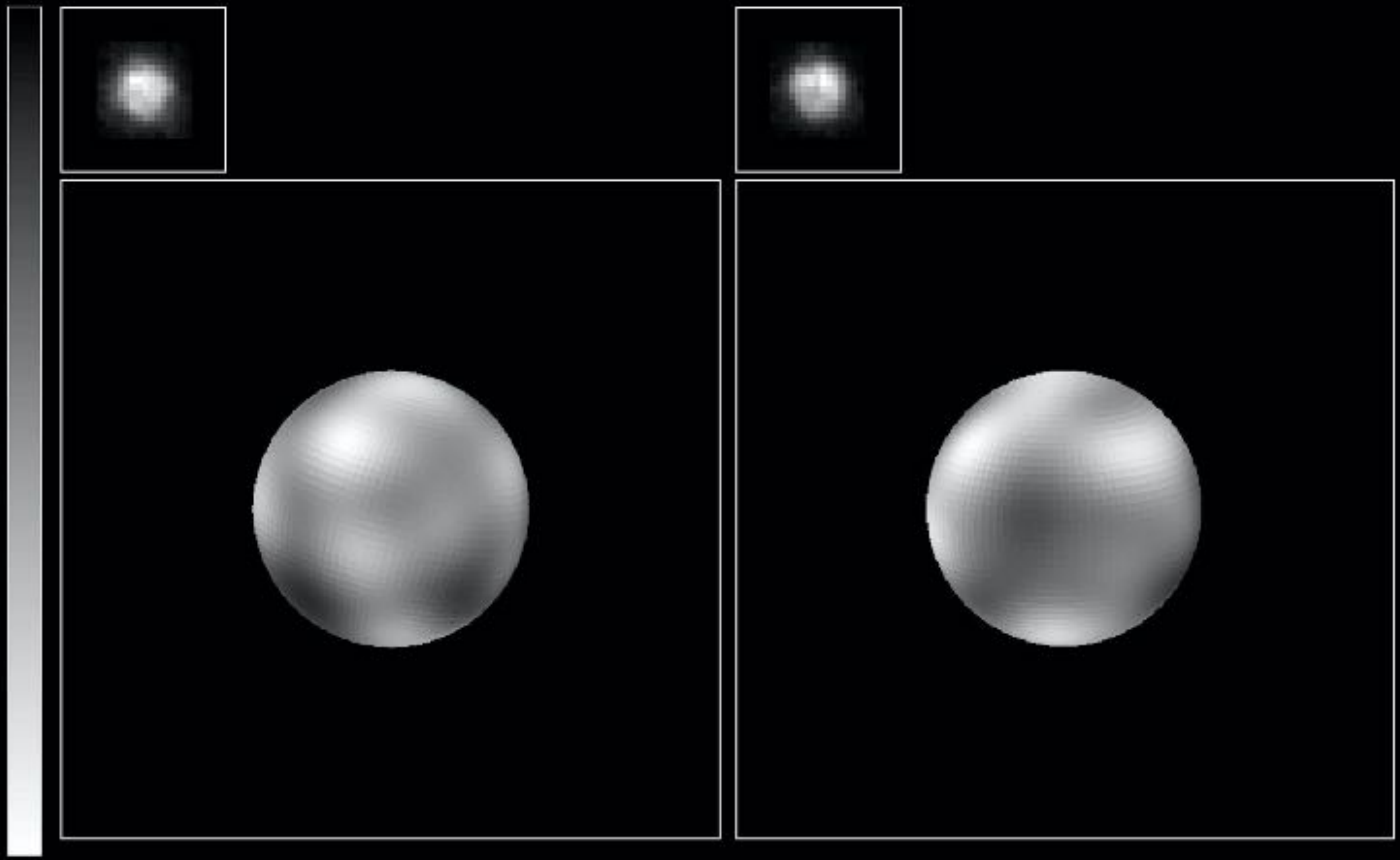
Uranus R=49.48 m (19.18AU)



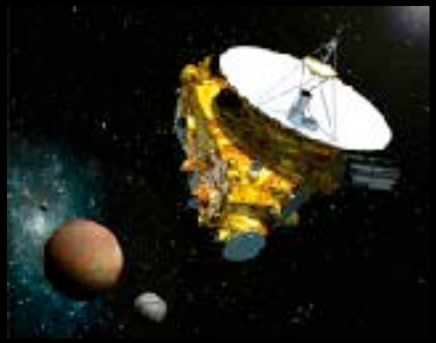
Nepture R=77.55 m (30.06AU)

Pluto R=101.7 m (39.44AU)

Hubble Space Telescope Image

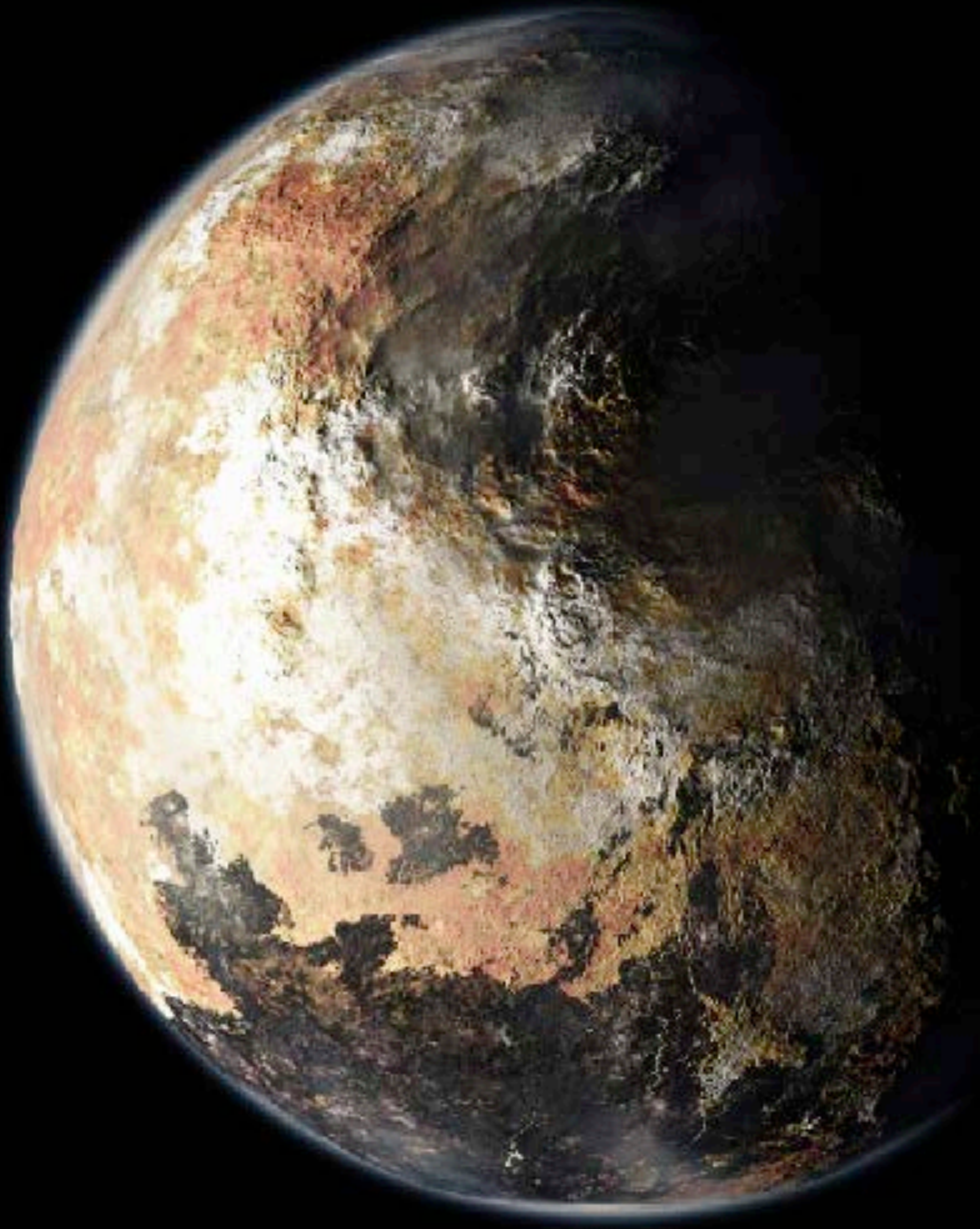


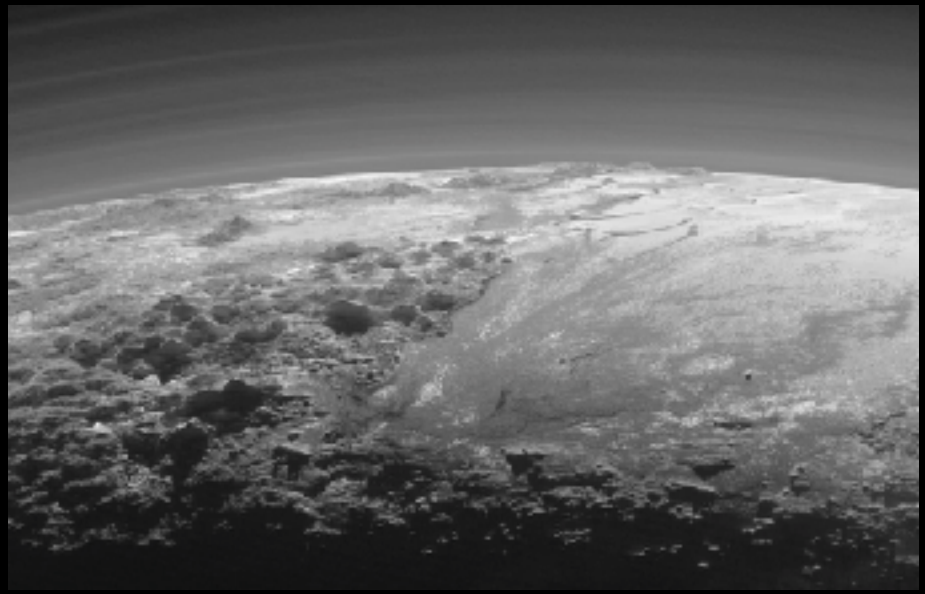
Pluto R=101.7 m (39.44AU)

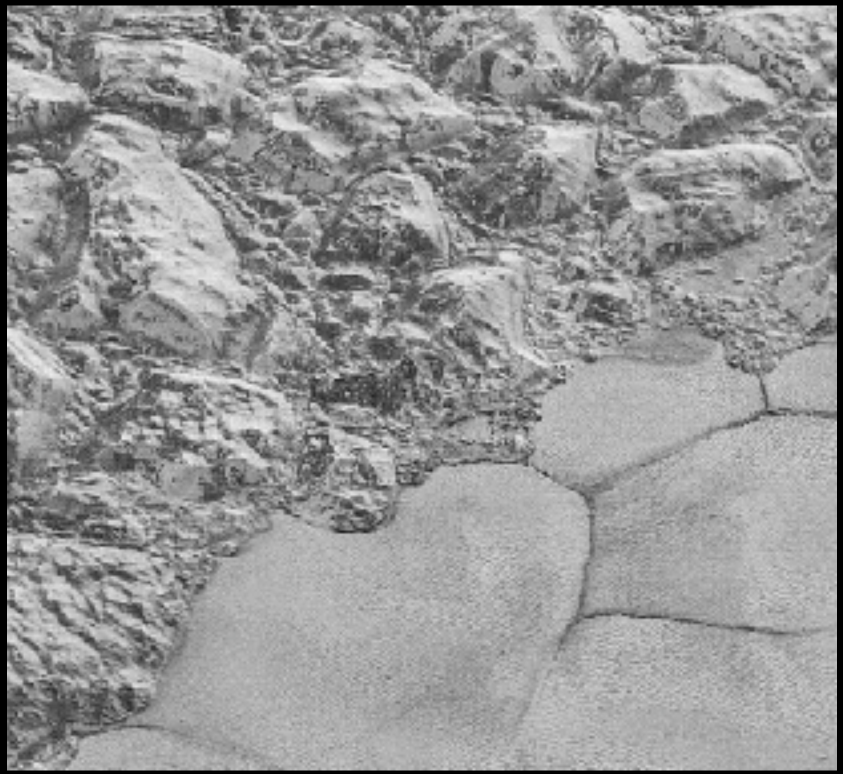


New Horizons

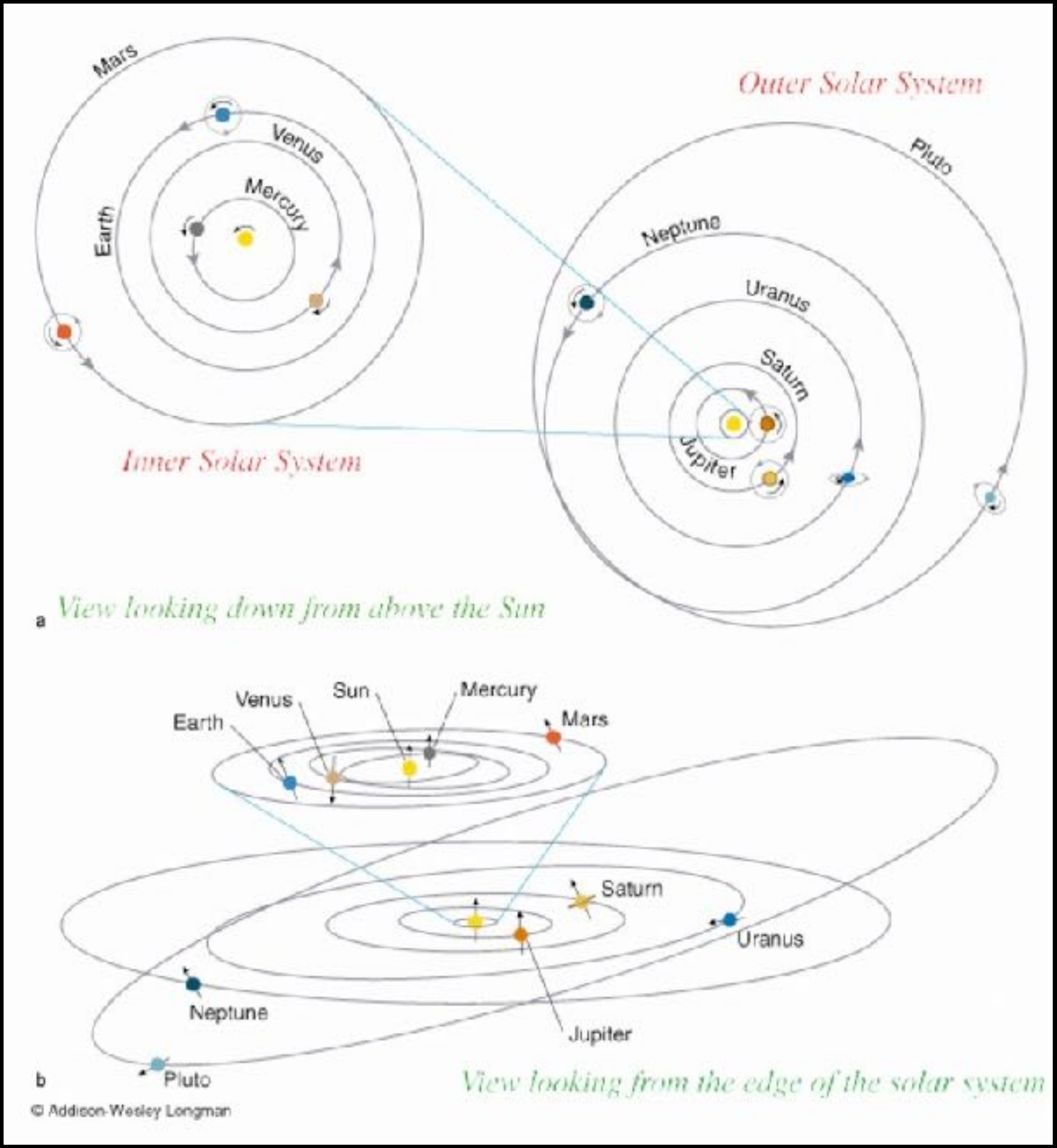
Pluto R=101.7 m (39.44AU)

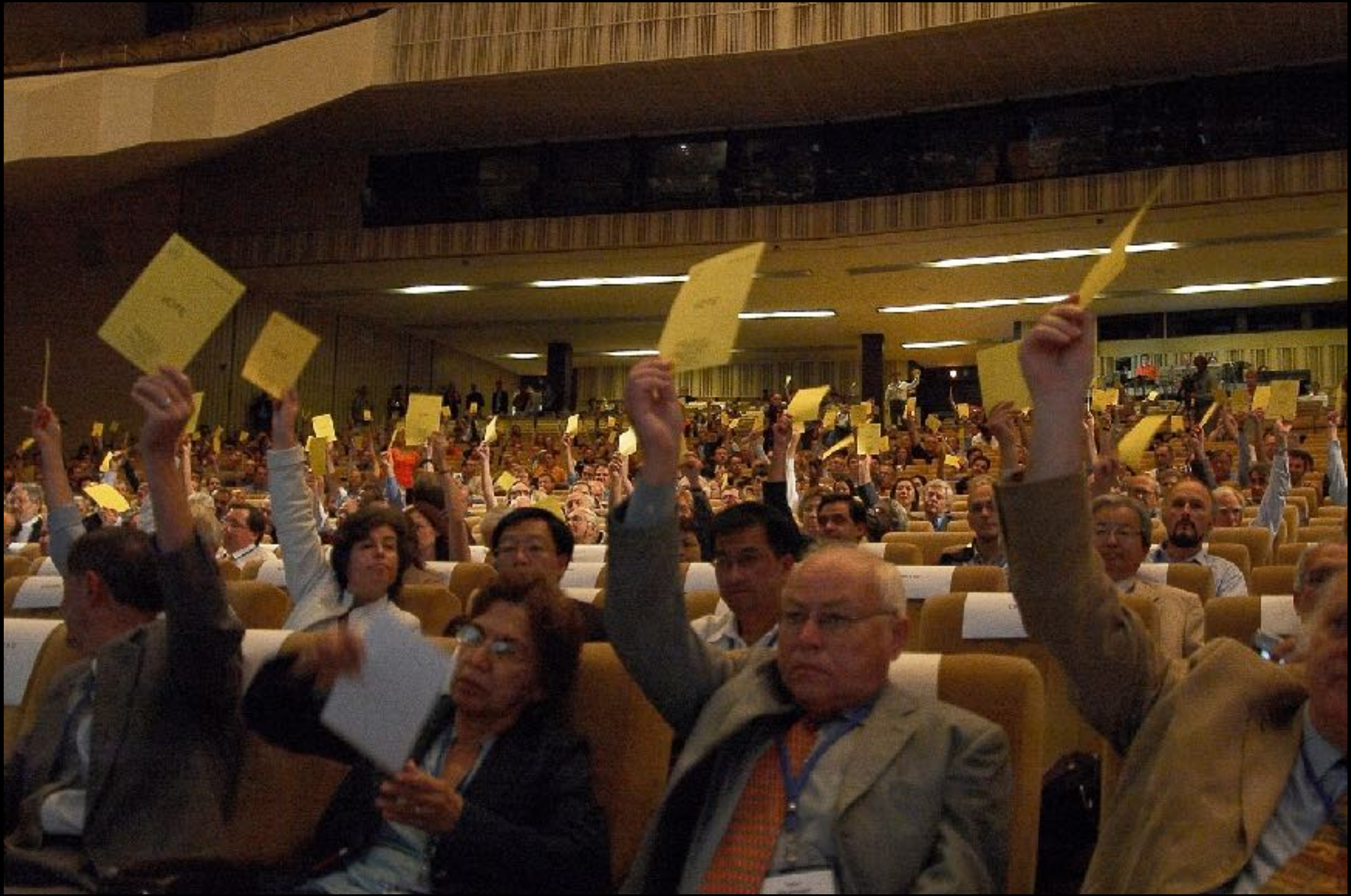






Dwarf Planets


Outer Solar System
Pluto
Neptune
Uranus
Saturn
Jupiter
Mars
Venus
Mercury
Earth
Inner Solar System
a View looking down from above the Sun
Venus
Sun
Mercury
Earth
Mars
Saturn
Uranus
Neptune
Jupiter
b Pluto
View looking from the edge of the solar system
© Addison-Wesley Longman



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Beyond Solar System

Nearest Star : Cen α

- Q. If the size of the Sun is a quarter coin sitting at LBNL, where is Cen α?
- 1. : Cafeteria (1/4 mile)
- 2. : UC Berkeley Campus (1/2 mile)
- 3. : San Francisco Pier 39 (16 miles)
- 4. : San Jose Airport (50 miles)
- 5. : Los Angeles (380 miles)

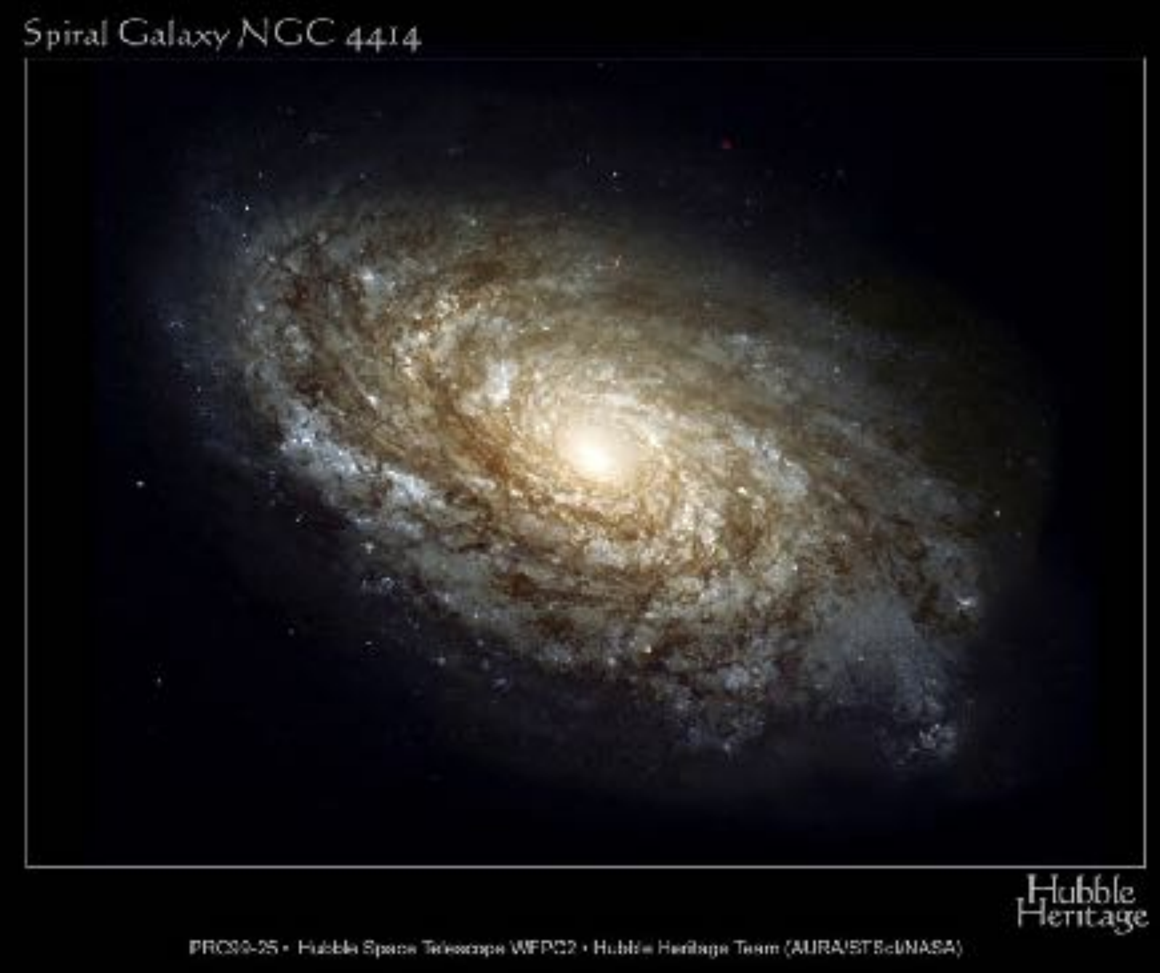
Cen α : 4.3 Light Years

- How long does it take to travel to Cen α with the fastest airplane on the Earth?

  (X-15 Mach 6.3)
- 1. 5.5 yrs
- 2. 55 yrs
- 3. 550 yrs
- 4. 5,500 yrs
- 5. 550,000 yrs

Milky Way Galaxy I

- How many stars do we have in our Galaxy?
- 1. : 2,000
- 2. : 20,000
- 3. : 200,000
- 4. : 200,000,000
- 5. : 200,000,000,000



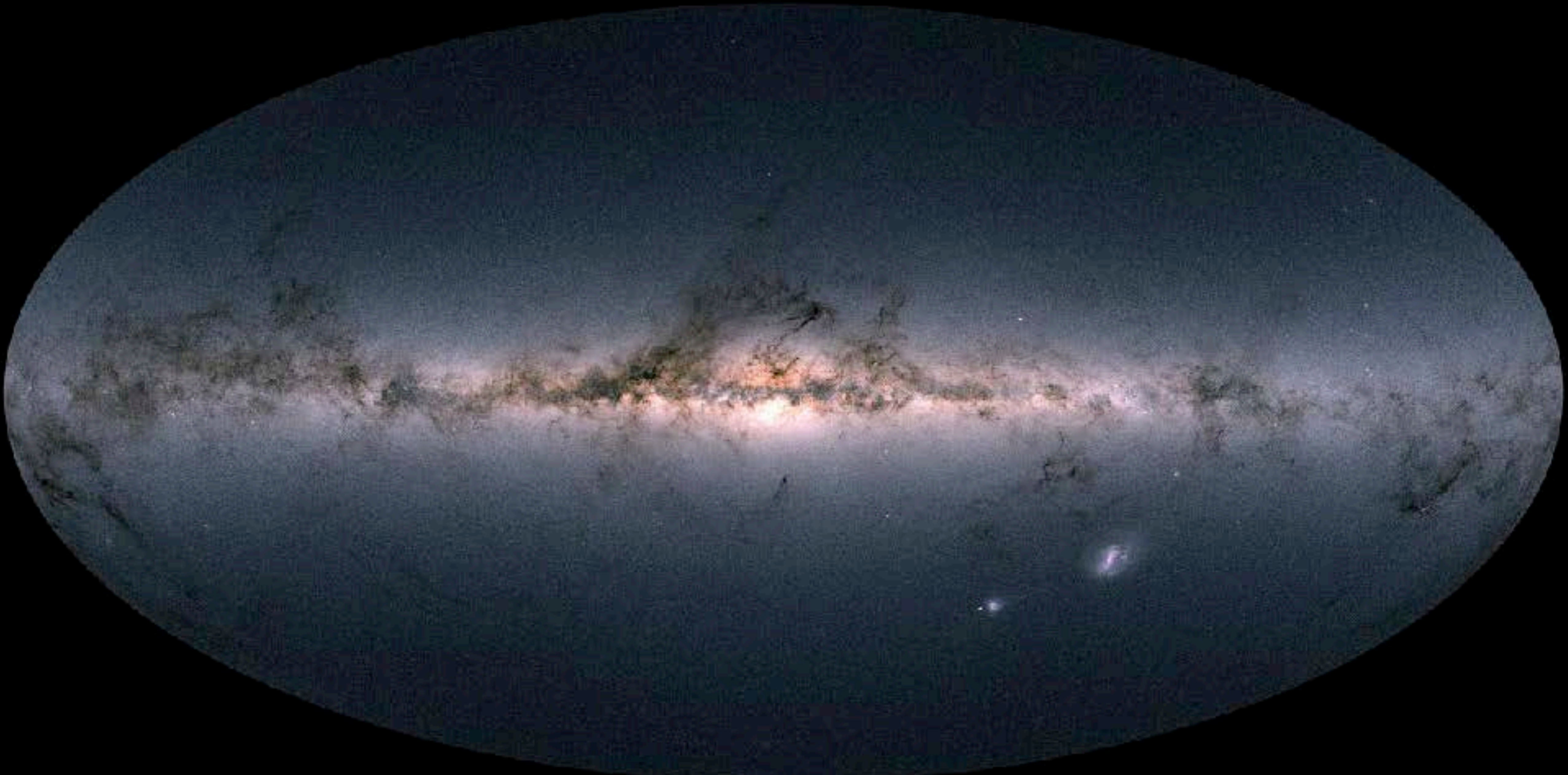
Our Galaxy II

- Suppose the size of a star is a grain of salt.
  200 billion grains of salt would fill up :
- 1. a cup
- 2. a bucket
- 3. a car
- 4. a truck
- 5. an olympic size pool

1.8 billion Stars are observed

1,811,709,711 Stars
June 13th 2022 Release

But it's only 1% of Milky Way Stars (200 Billion)



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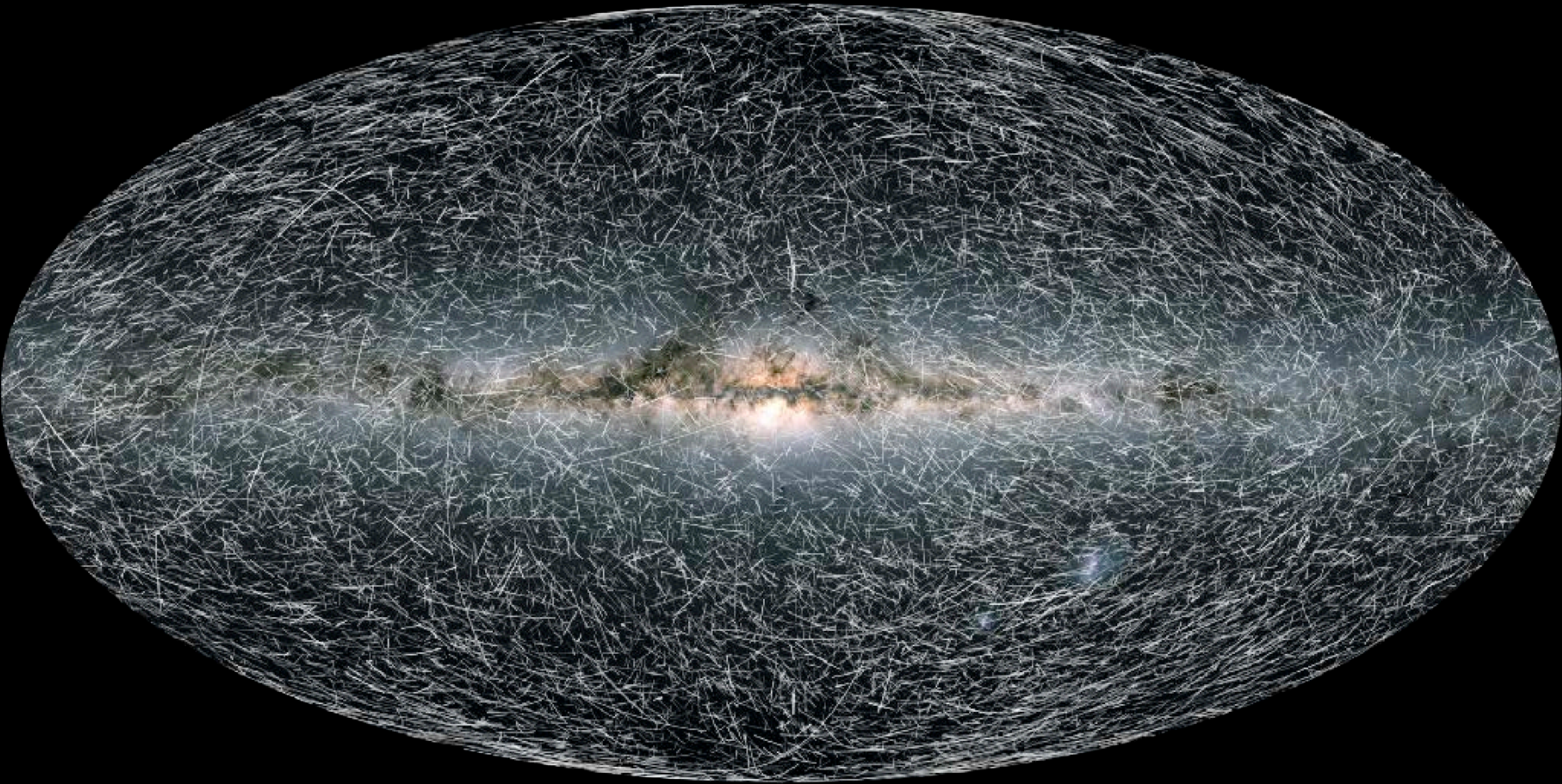
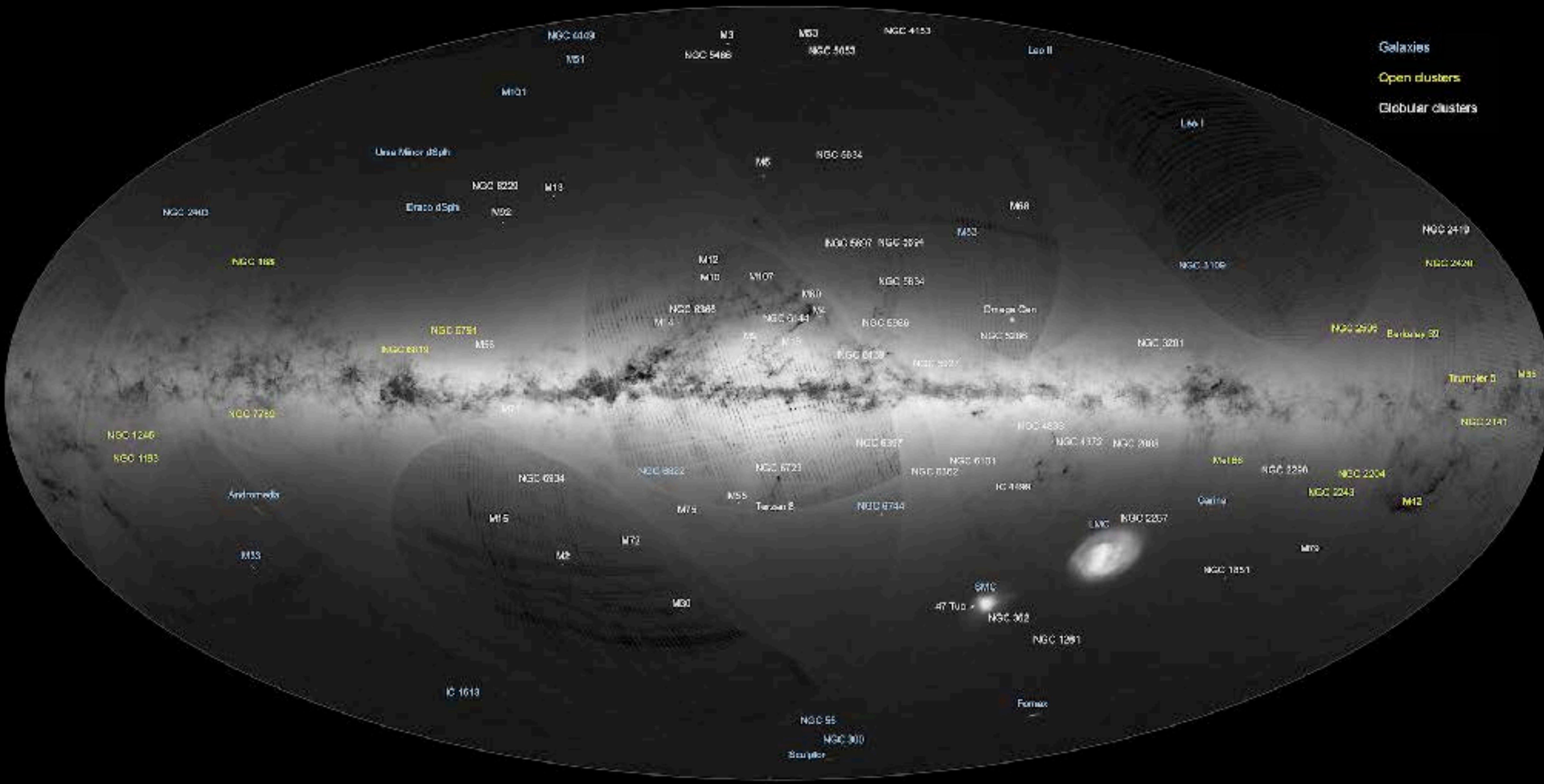


QuarkNet 2022

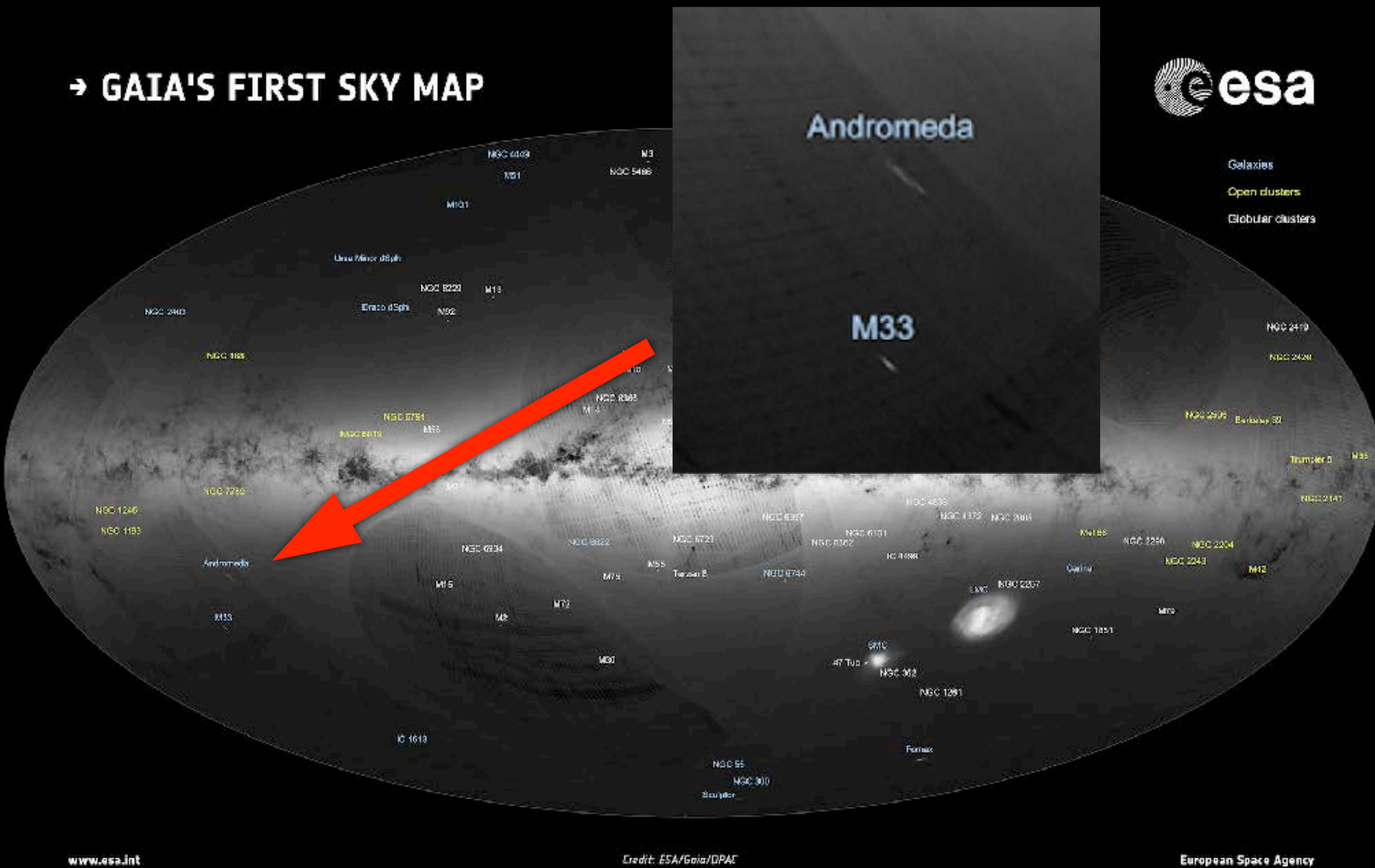
→ GAIA'S FIRST SKY MAP

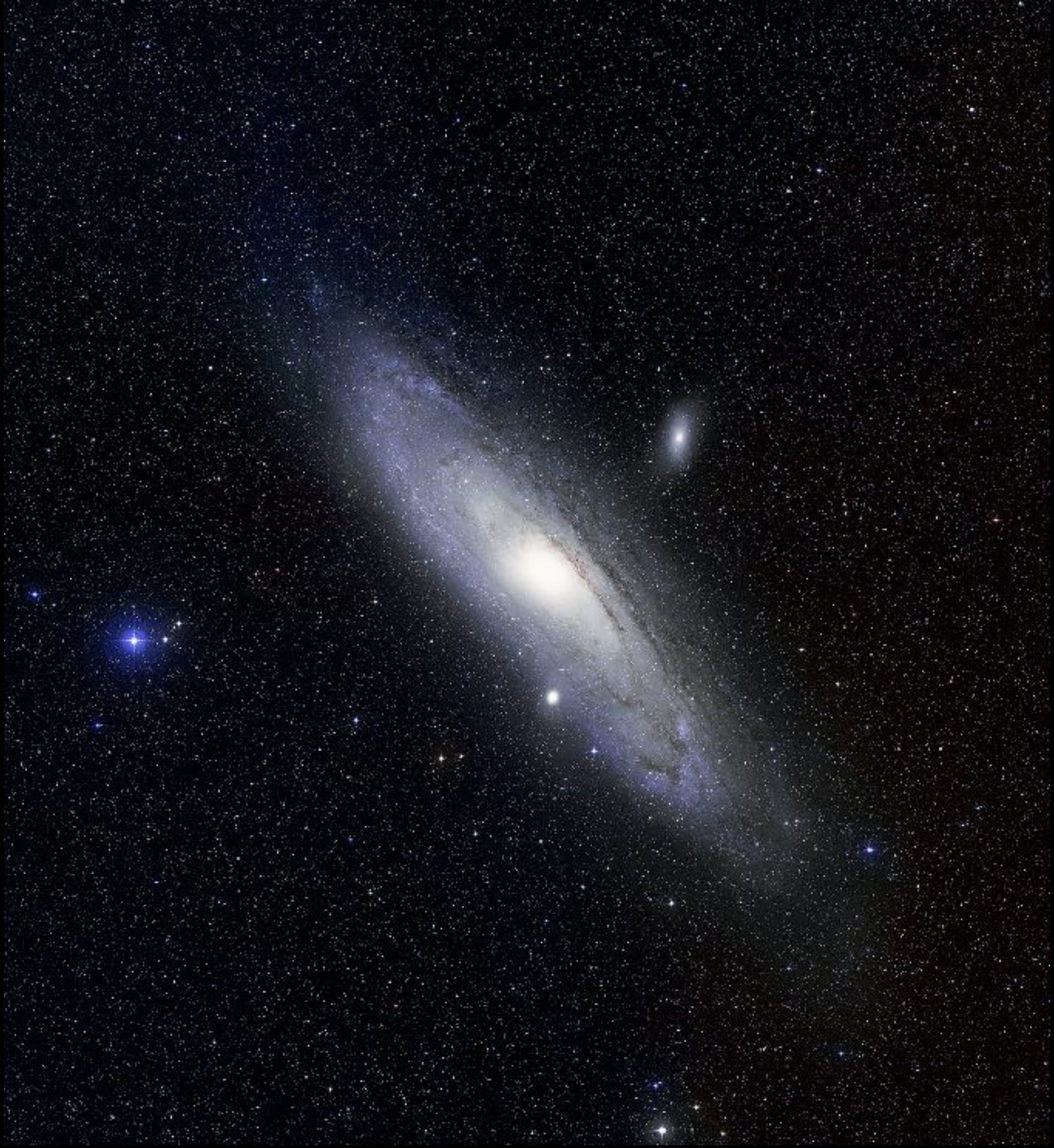


www.esa.int

Credit: ESA/Gaia/DPAC

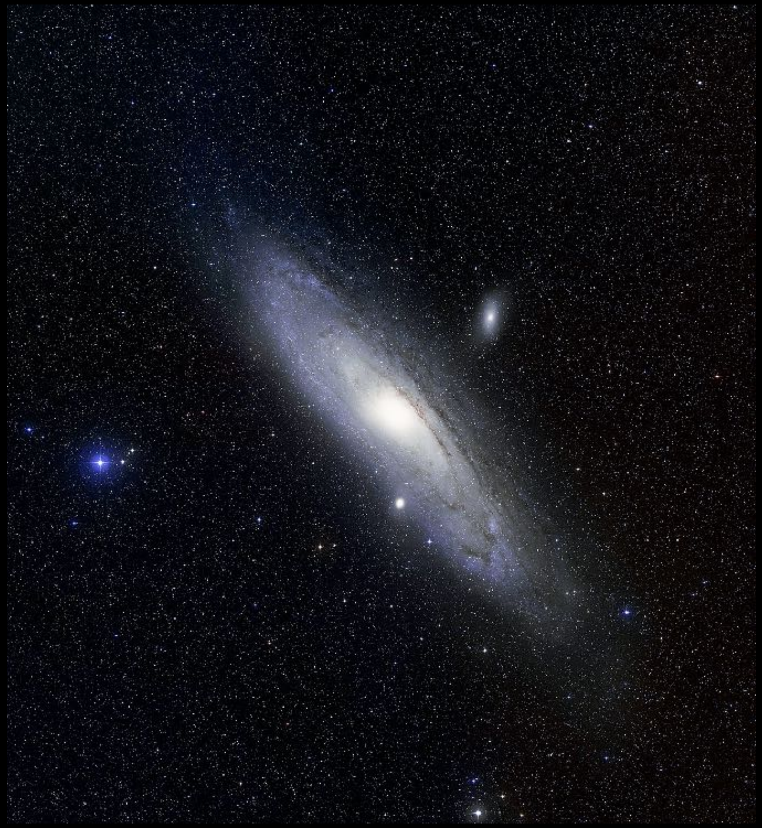
European Space Agency


→ GAIA'S FIRST SKY MAP
esa
Andromeda
M33
Galaxies
Open clusters
Globular clusters
www.esa.int
Credit: ESA/Gaia/DPAC
European Space Agency



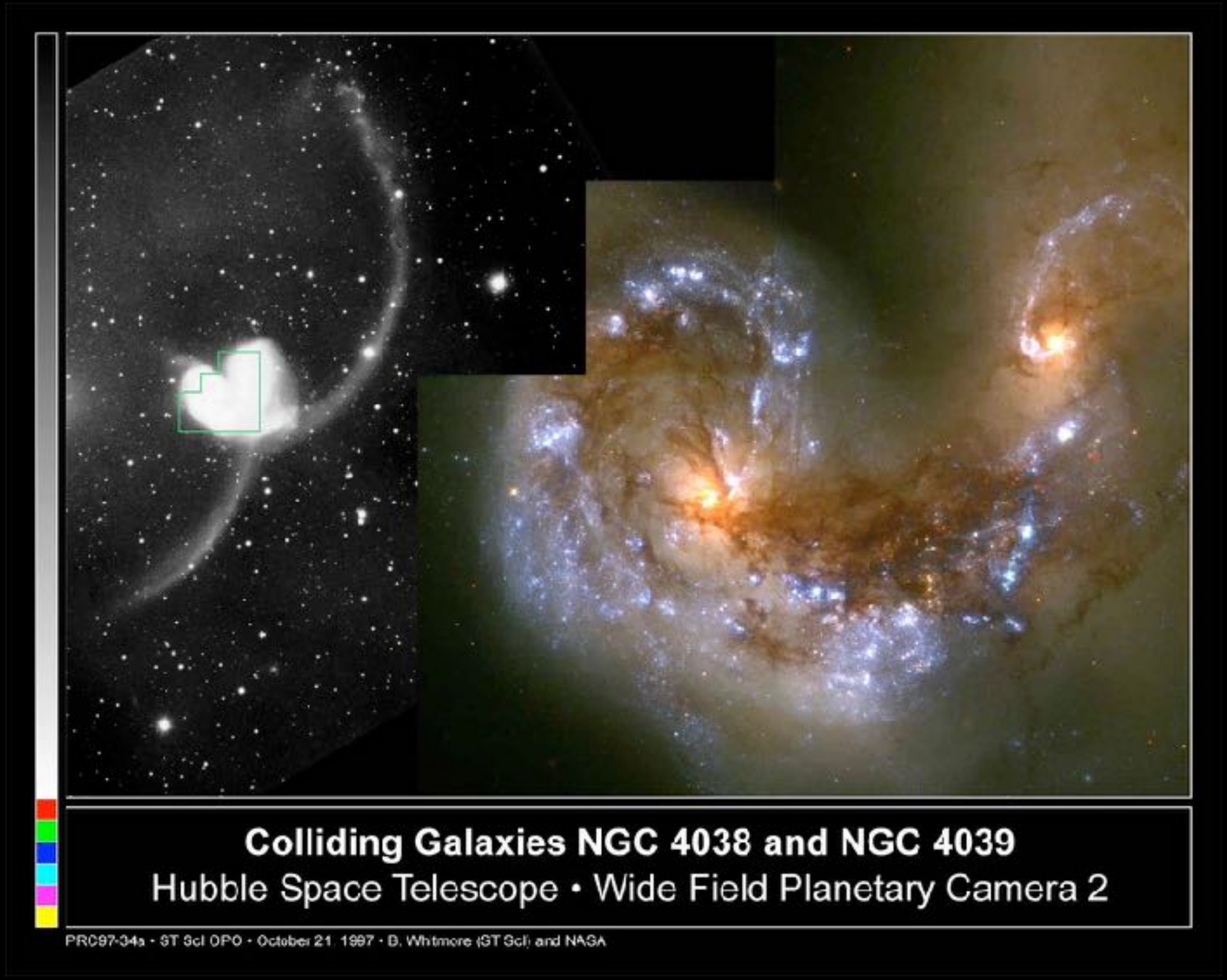
Nearest Galaxy : Andromeda

- Q. Suppose the size of our Milky Way Galaxy is a quarter coin. What is the distance to the Andromeda Galaxy?
- 1. 40 cm
- 2. 4 m
- 3. San Francisco
- 4. New York
- 5. Tokyo



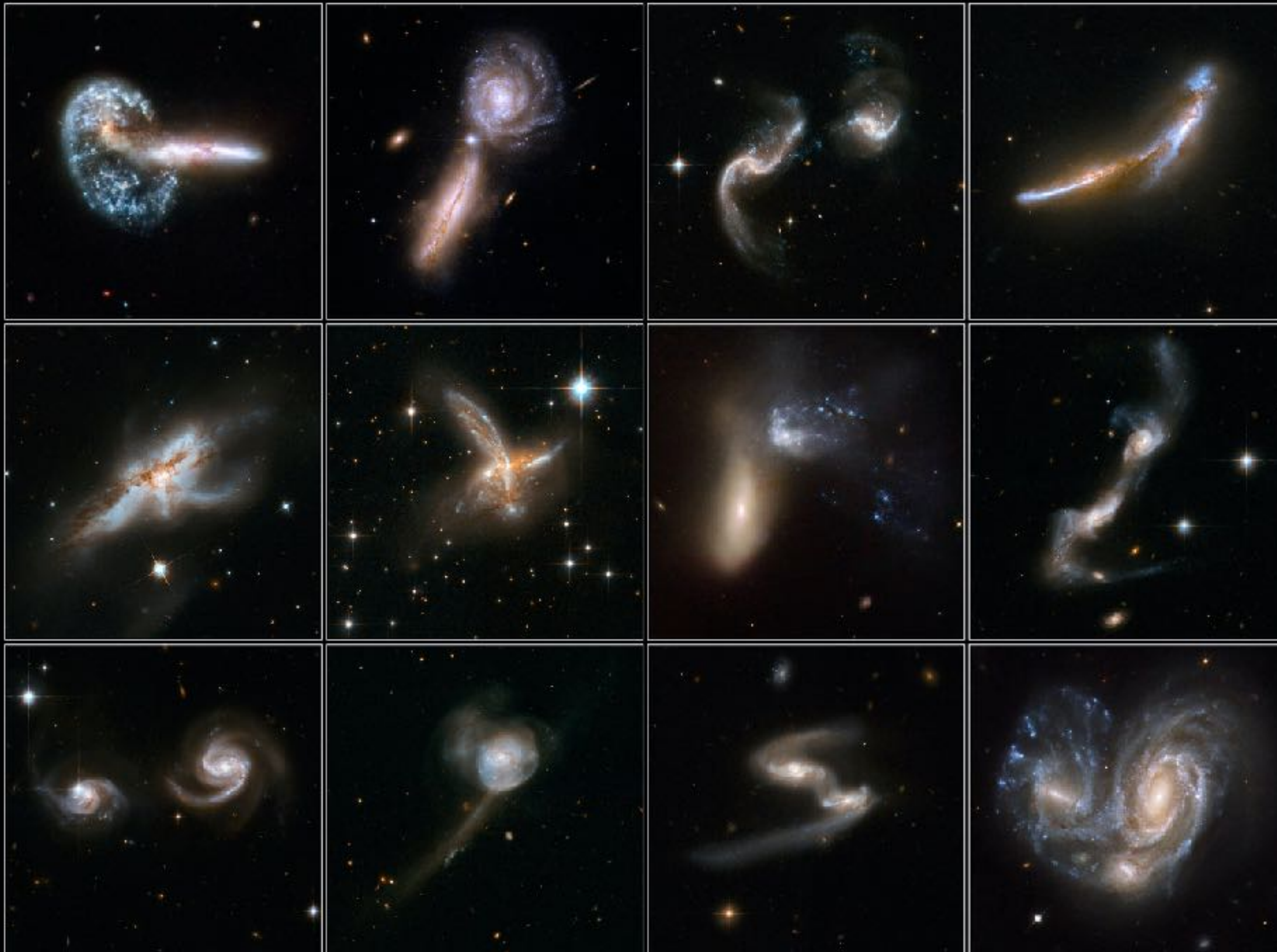
Colliding Galaxies

Colliding Galaxies: Observation



Interacting Galaxies

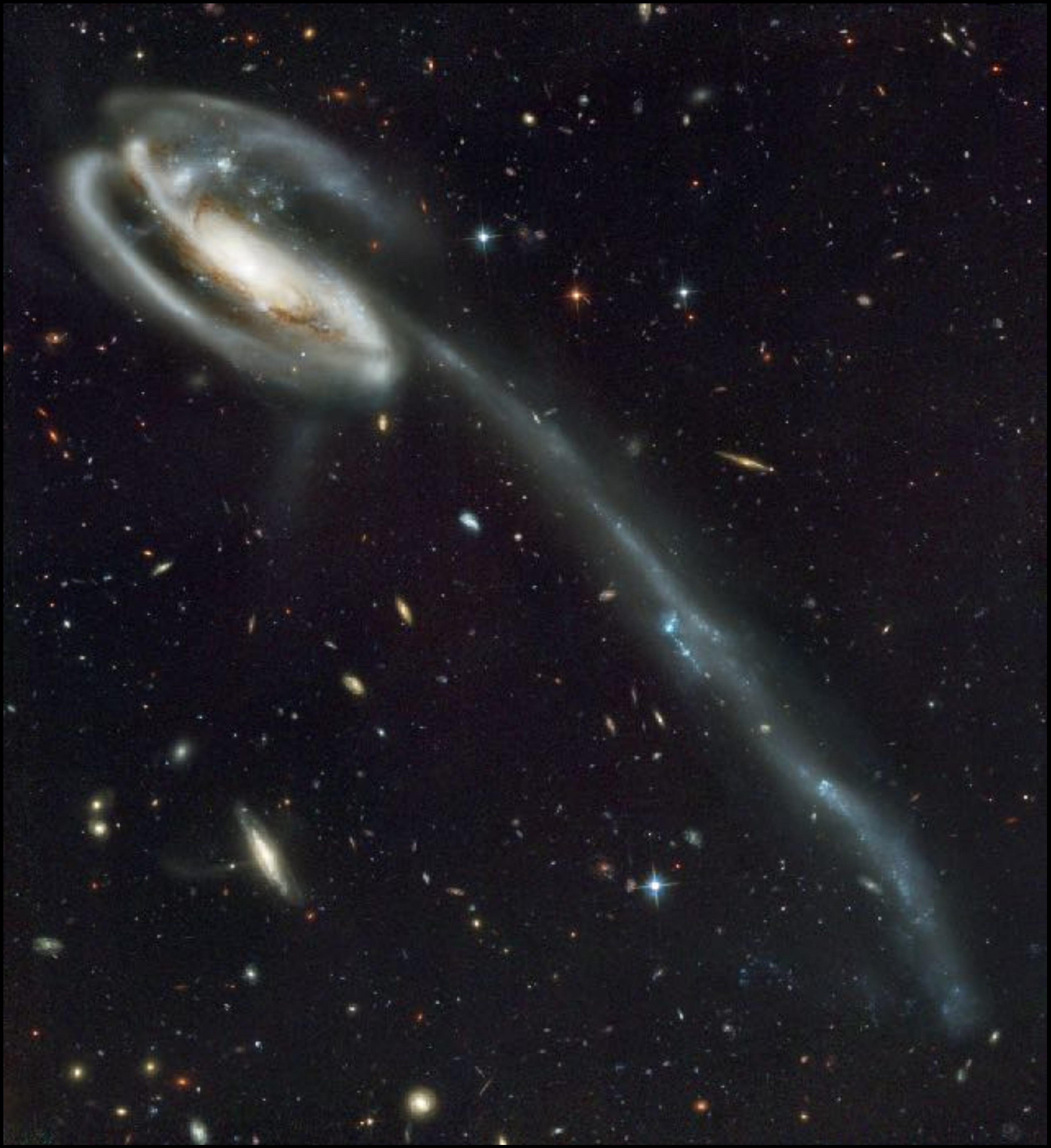
Hubble Space Telescope • ACS/WFC • WFPC2

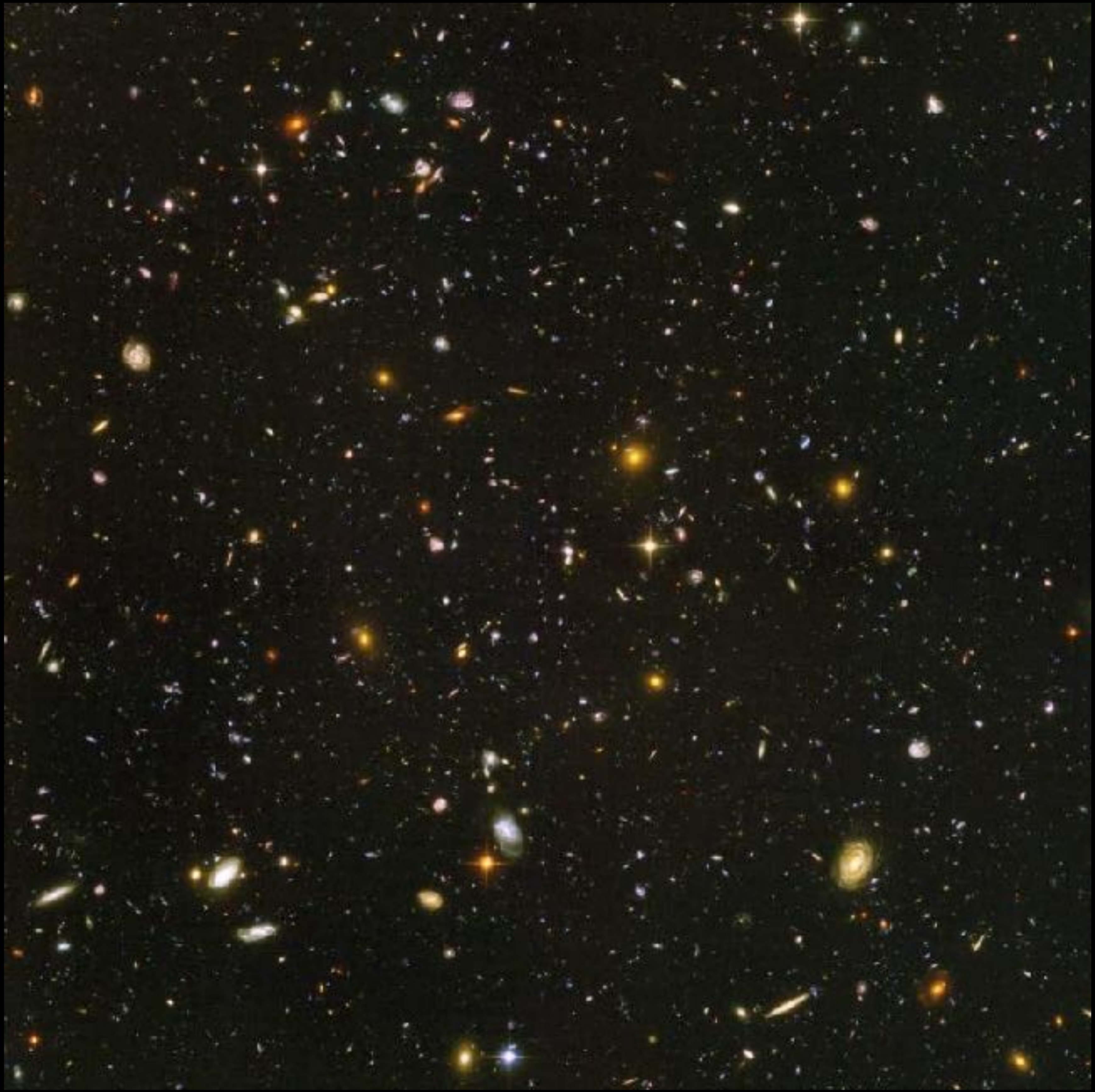


NASA, ESA, the Hubble Heritage (AURA/STScI)-ESA/Hubble Collaboration, and
A. Evans (University of Virginia, Charlottesville/NRAO/Stony Brook University)

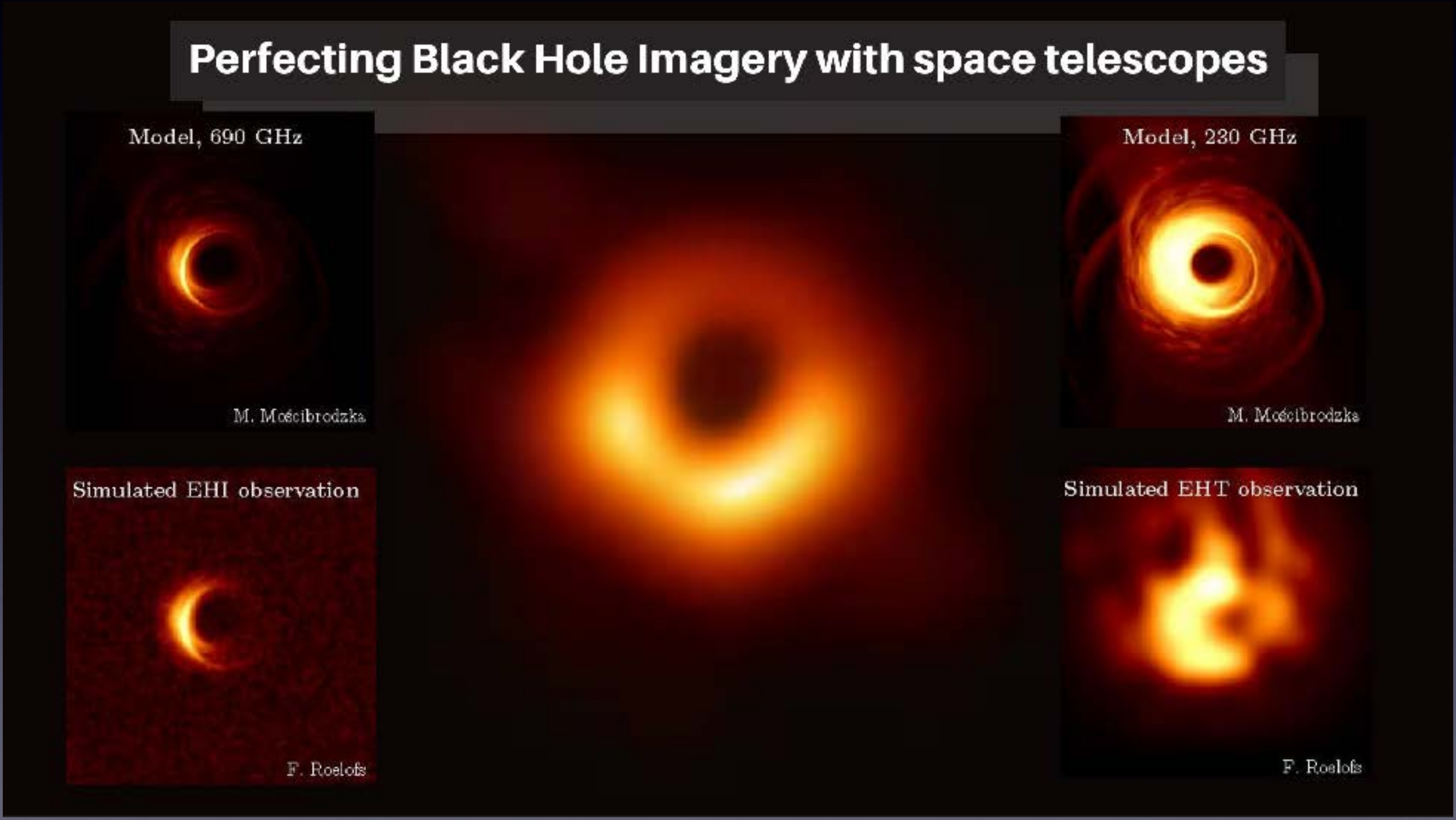
STScI-PRC08-16a


In 3.75 billion years



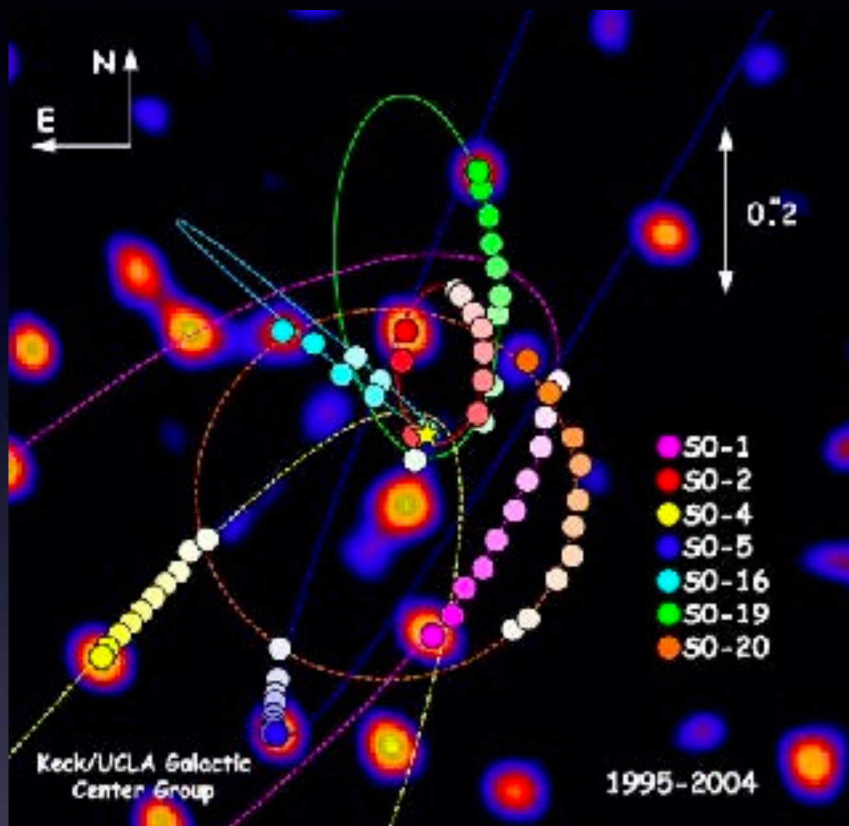


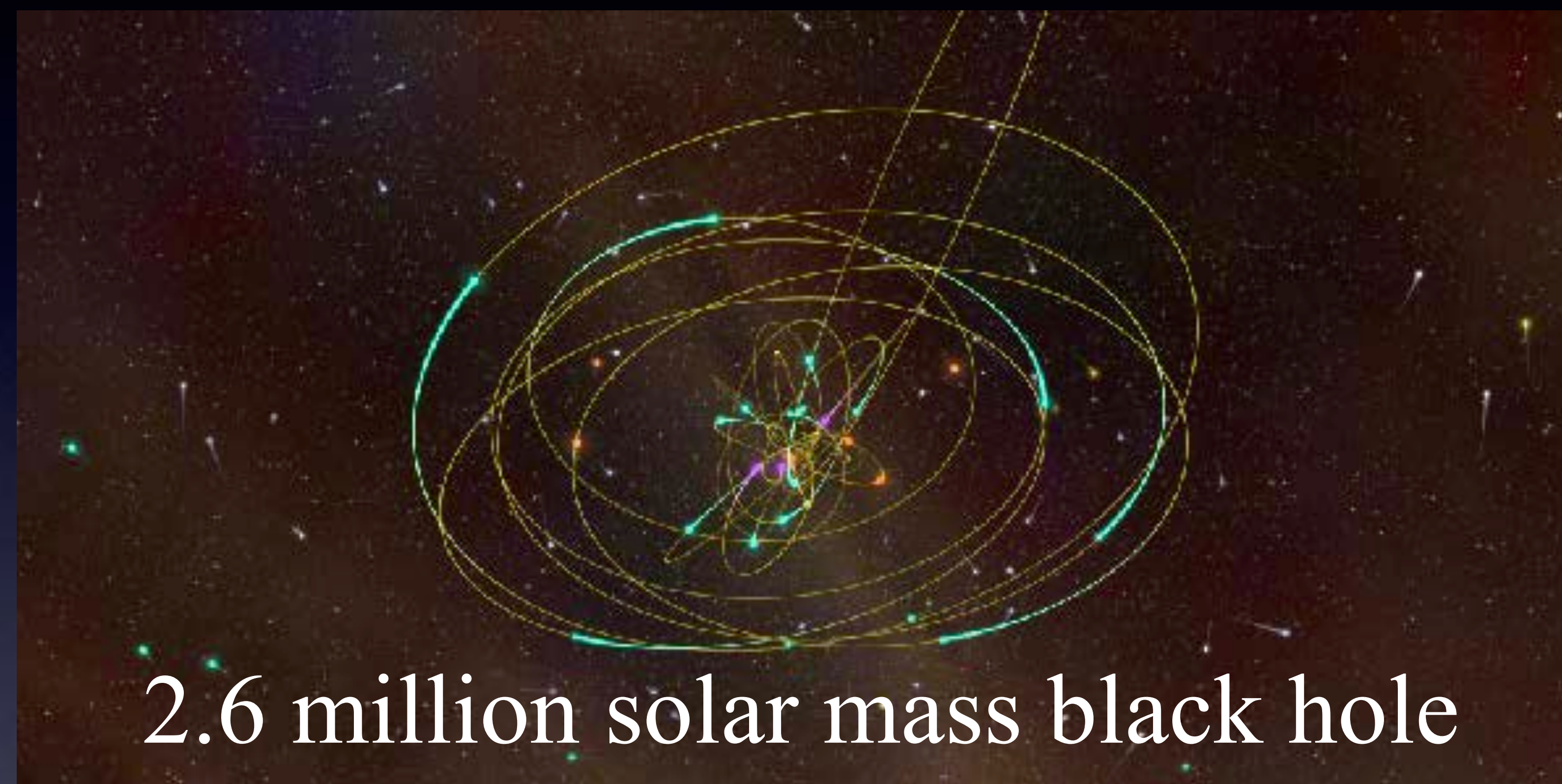
Blackhole Image in M87 by Event Horizon Telescope



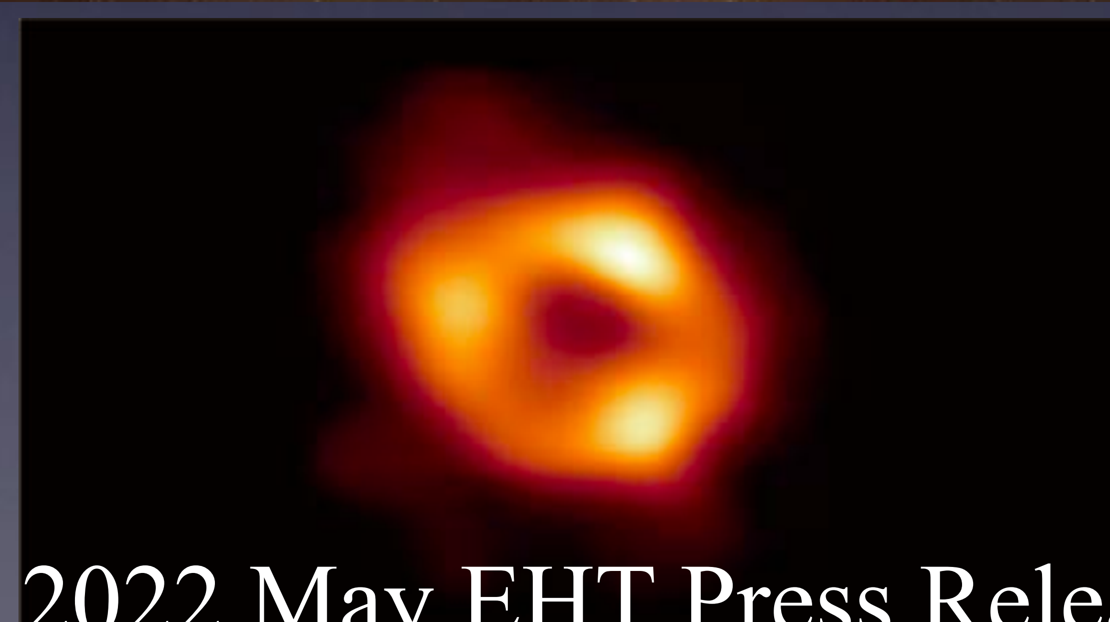
Supermassive Black Hole At the Center of Milky Way

2020 Nobel Prize





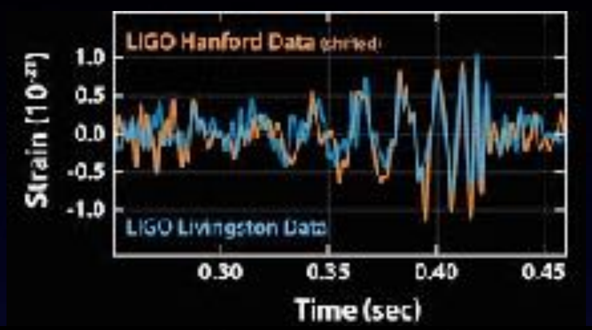
2.6 million solar mass black hole

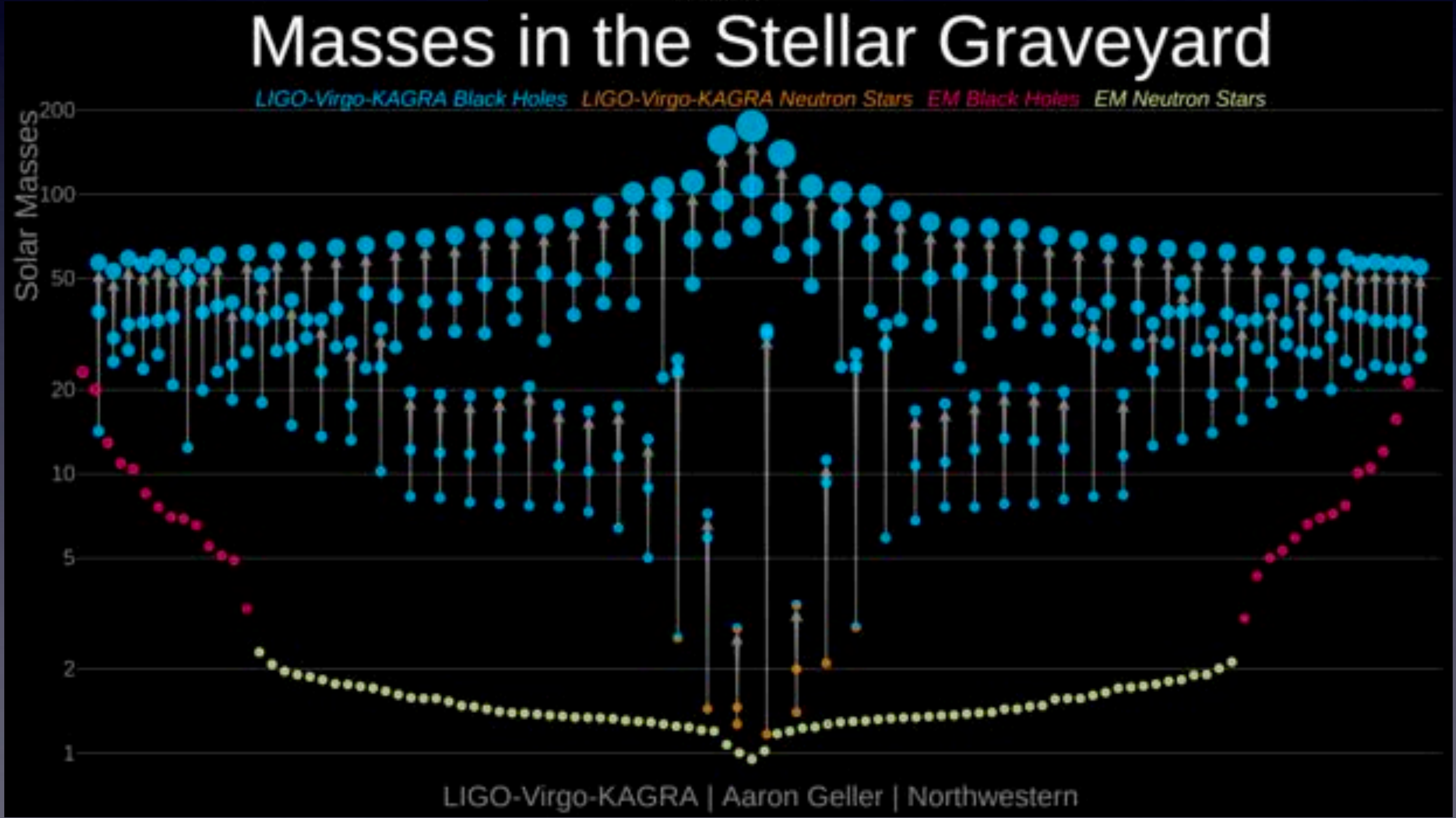


2022 May EHT Press Release

Blackhole-Black Hole Merger by Gravitational Wave

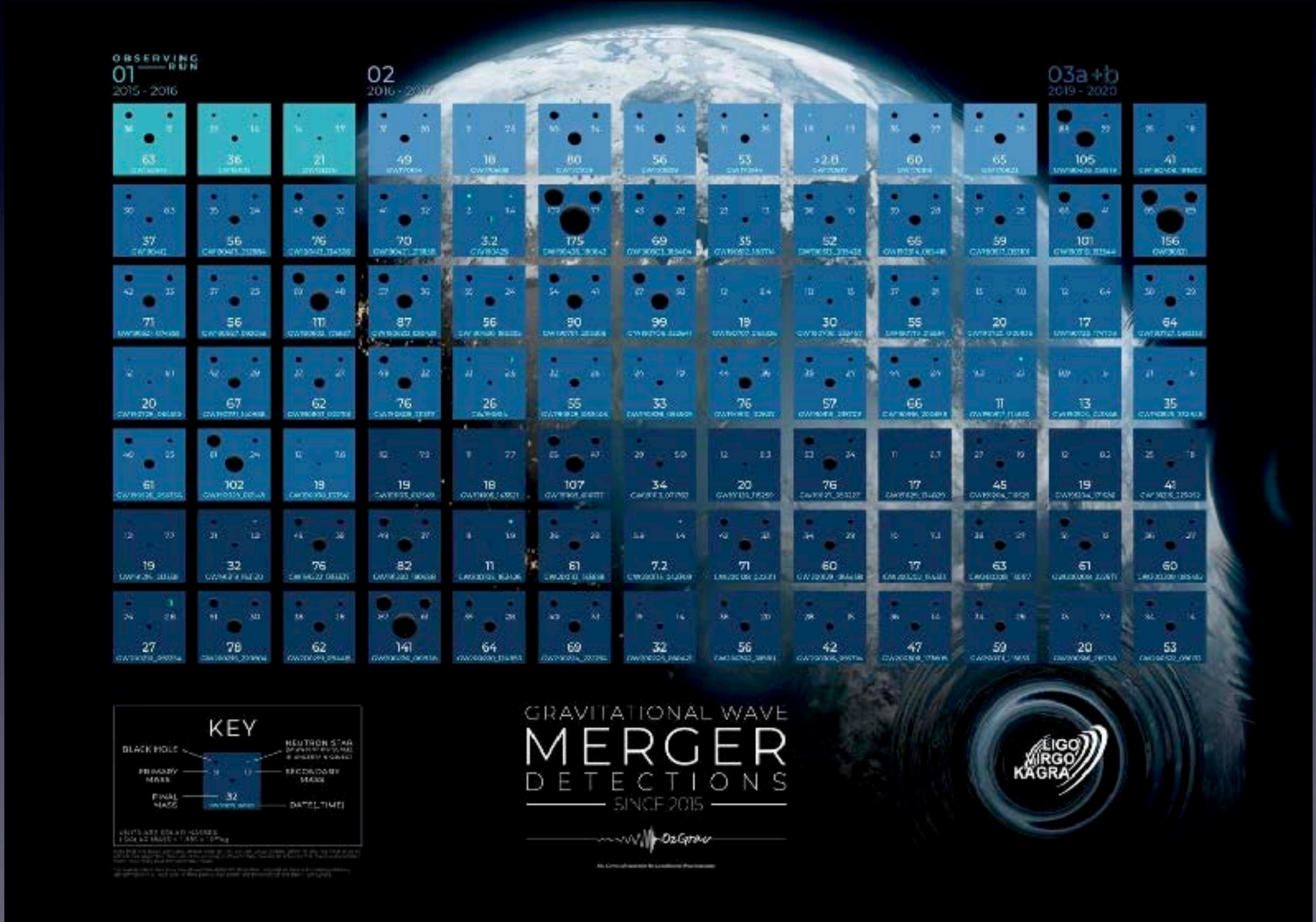
2017 Nobel Prize



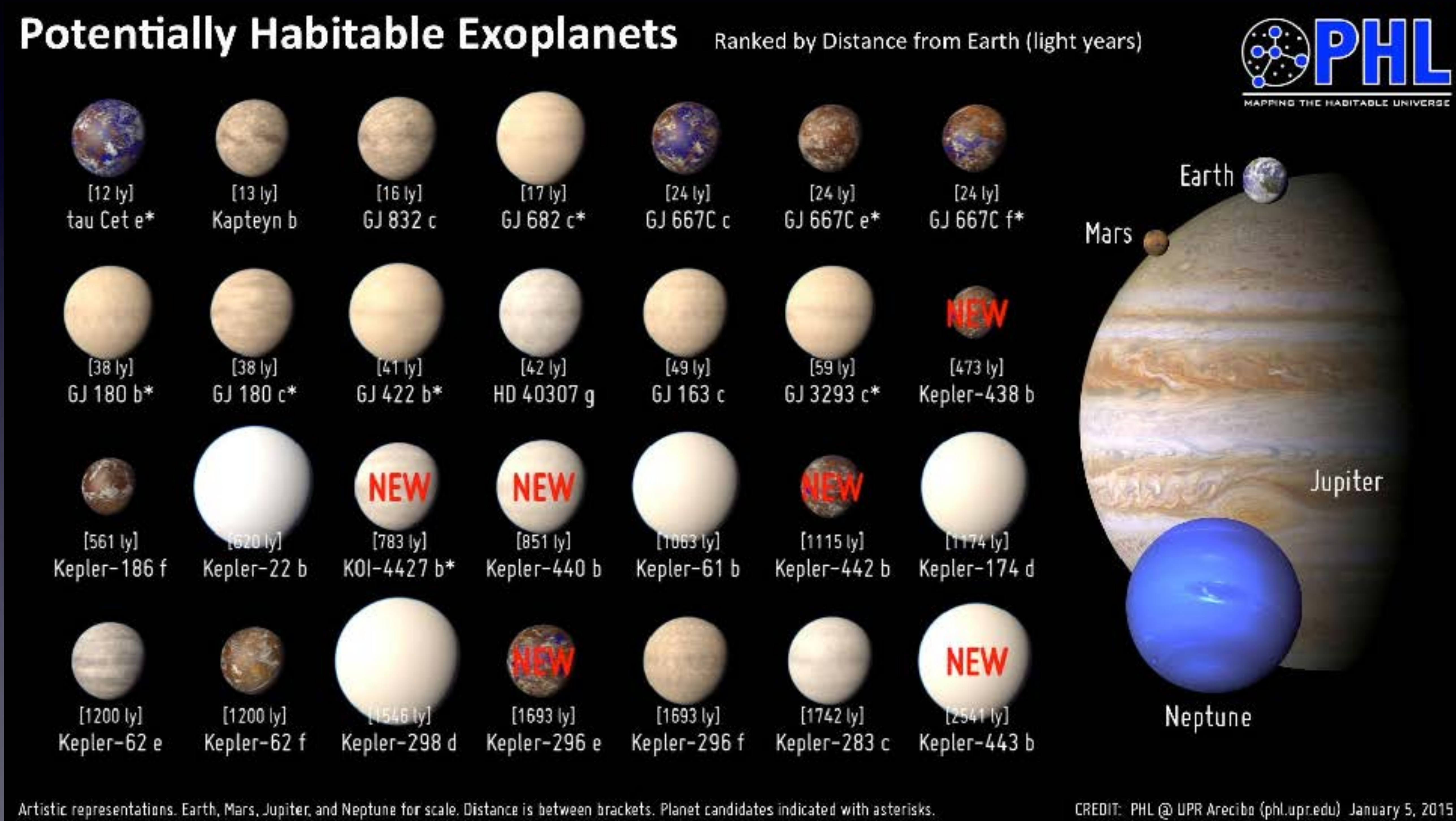


Blackhole-Black Hole Merger by Gravitational Wave

90 Events are reported as of Today



Exoplanet Discoveries
4884 planets today

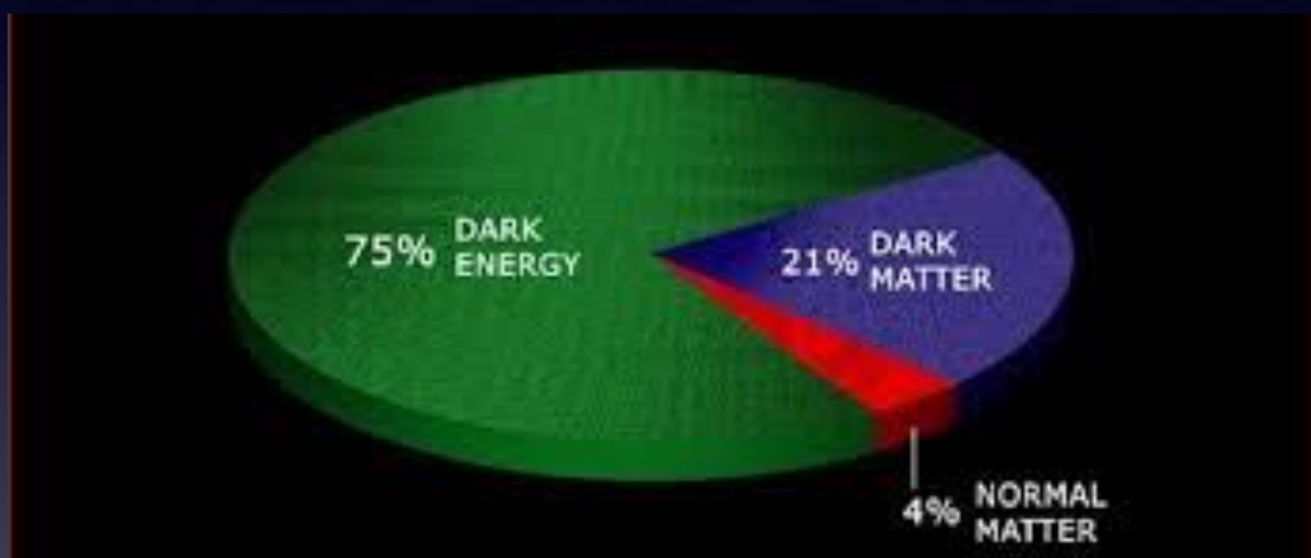


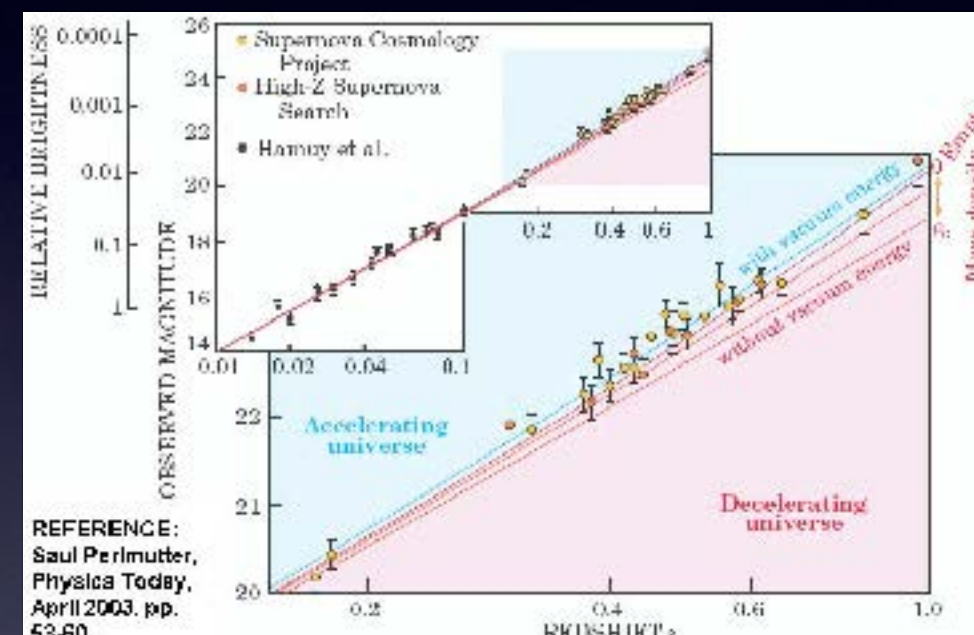
Biggest Discovery in Astrophysics in the last 30 years => Dark Energy

#	Bibcode Authors	Cites Title	Date	List of Links Access Control Help
1	1998AJ....116.1009R Riess, Adam G.; Filippenko, Alexei V.; Challis, Peter; Clocchiatti, Alejandro; Diercks, Alan; Garnavich, Peter M.; Gilliland, Ron L.; Hogan, Craig J.; Jha, Saurabh; Kirshner, Robert P.; and 10 coauthors	11836.000 Observational Evidence from Supernovae for an Accelerating Universe and a Cosmological Constant	09/1998	A E F X D R C S N U H
2	1999ApJ...517..565P Perlmutter, S.; Aldering, G.; Goldhaber, G.; Knop, R. A.; Nugent, P.; Castro, P. G.; Deustua, S.; Fabbro, S.; Goobar, A.; Groom, D. E.; and 23 coauthors	11745.000 Measurements of Ω and Λ from 42 High-Redshift Supernovae	06/1999	A E F X D R C S N U H
3	1998ApJ...500..525S Schlegel, David J.; Finkbeiner, Douglas P.; Davis, Marc	11266.000 Maps of Dust Infrared Emission for Use in Estimation of Reddening and Cosmic Microwave Background Radiation Foregrounds	06/1998	A E F X R C S U H
4	1981PhRvB..23.5048P Perdew, J. P.; Zunger, Alex	11147.000 Self-interaction correction to density-functional approximations for many-electron systems	05/1981	E R C U
5	1973A&A....24..337S Shakura, N. I.; Sunyaev, R. A.	9271.000 Black holes in binary systems. Observational appearance.	00/1973	F G R C S O U H
6	2003ApJS..148..175S Spergel, D. N.; Verde, L.; Peiris, H. V.; Komatsu, E.; Nolta, M. R.; Bennett, C. L.; Halpern, M.; Hinshaw, G.; Jarosik, N.; Kogut, A.; and 7 coauthors	9000.000 First-Year Wilkinson Microwave Anisotropy Probe (WMAP) Observations: Determination of Cosmological Parameters	09/2003	A E F X R C S N U H
7	2005Natur.438..197N Novoselov, K. S.; Geim, A. K.; Morozov, S. V.; Jiang, D.; Katsnelson, M. I.; Grigorieva, I. V.; Dubonos, S. V.; Firsov, A. A.	8735.000 Two-dimensional gas of massless Dirac fermions in graphene	11/2005	A E X R C U

Dark Energy 

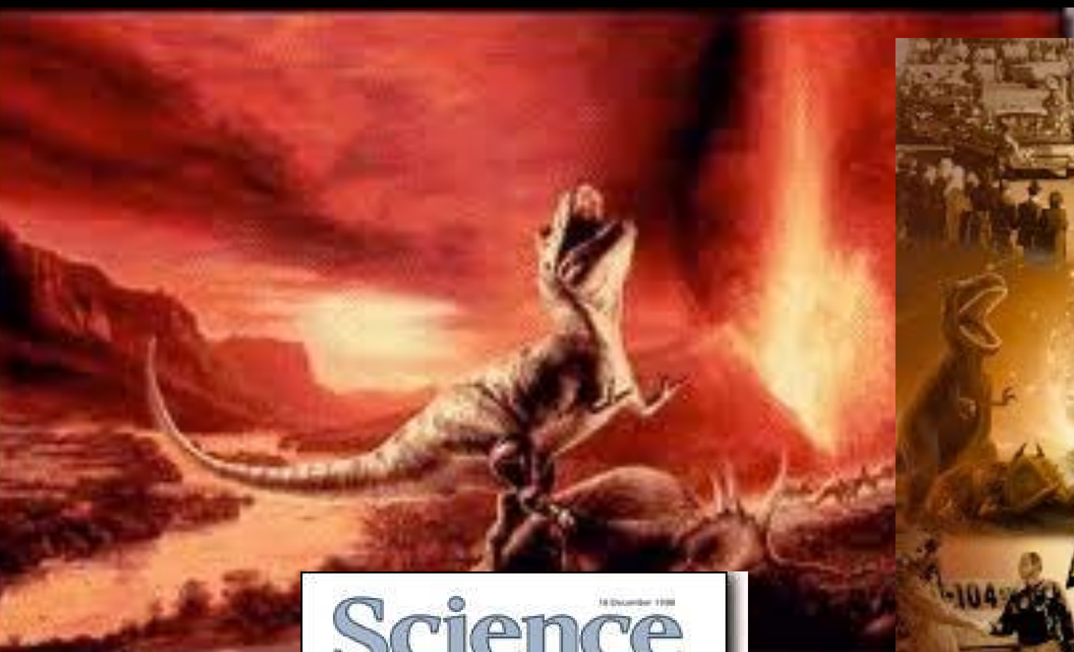
Discovery of Accelerating Universe
Nobel Prize in Physics 2011

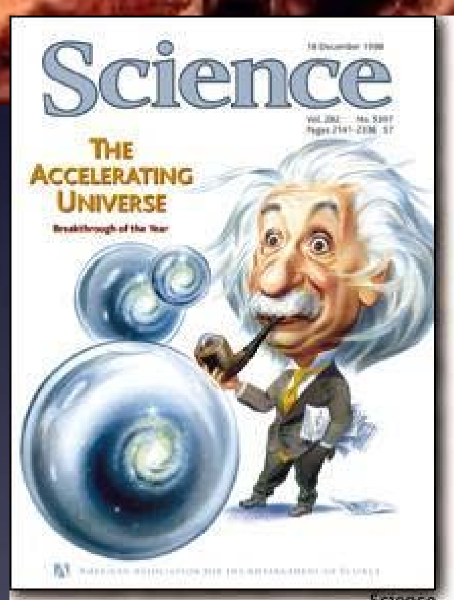


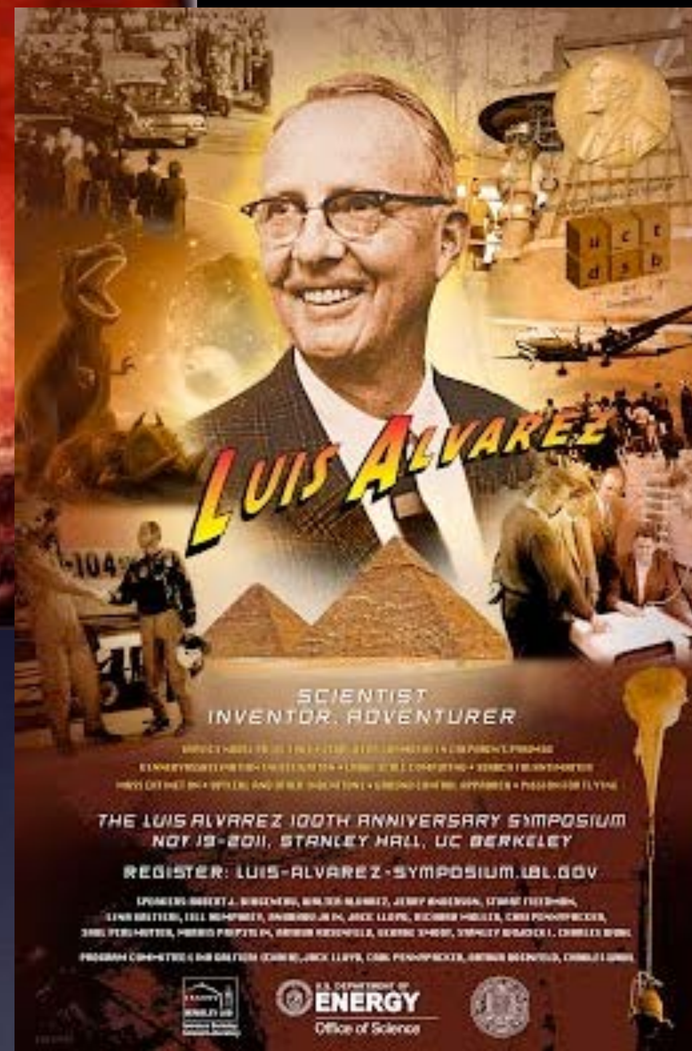


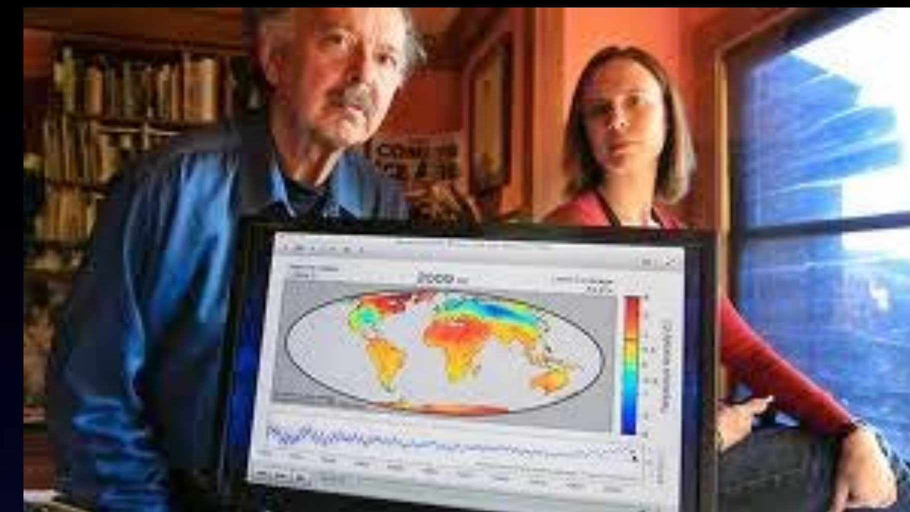
- 70% of Energy in the Universe today, is in the form of mysterious Dark Energy which is causing the acceleration of the expansion of the universe. We don’t know what it is

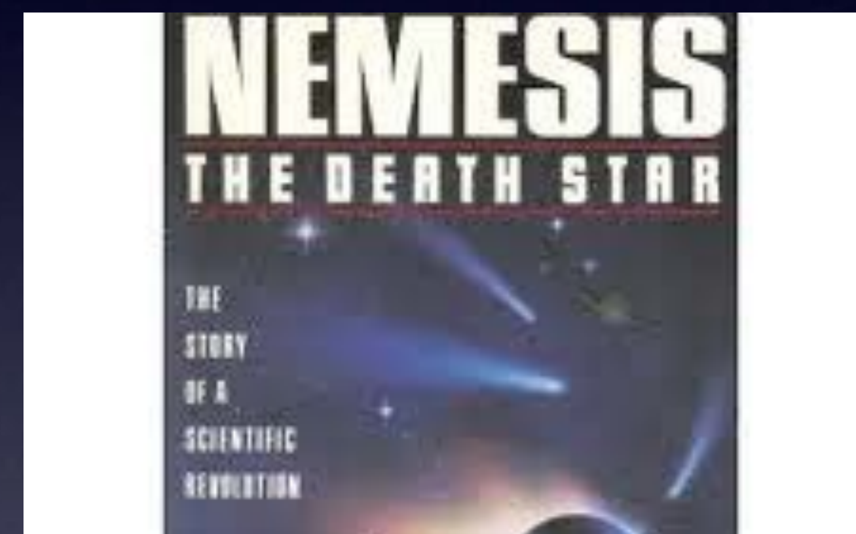
Adventure of Luis Alvarez (1911-88)











The Astrophysical Journal, 237:181-185, 1980 May 1

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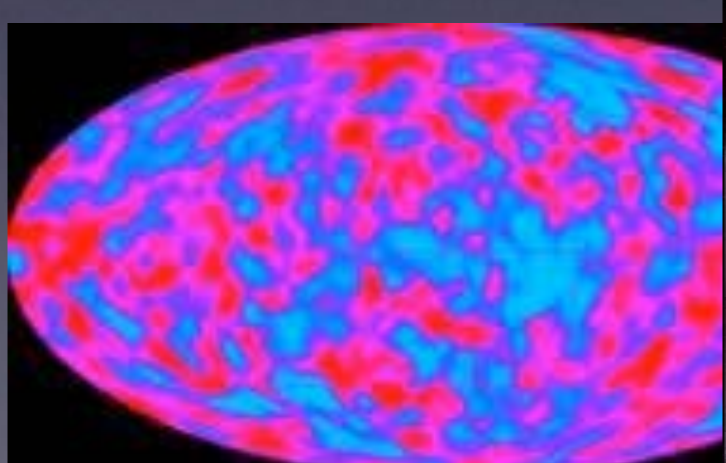
THE LUMINOSITY OF TYPE I SUPERNOVAE

Stirling A. Colgate
University of California, Los Alamos Scientific Laboratory, Los Alamos, New Mexico; and New Mexico Institute of Mining and Technology, Socorro, New Mexico
Albert G. Petschek
New Mexico Institute of Mining and Technology, Socorro, New Mexico
and
John T. Kriese
University of California, Los Alamos Scientific Laboratory, Los Alamos, New Mexico
Received 1979 [illegible]; accepted 1980 [illegible]

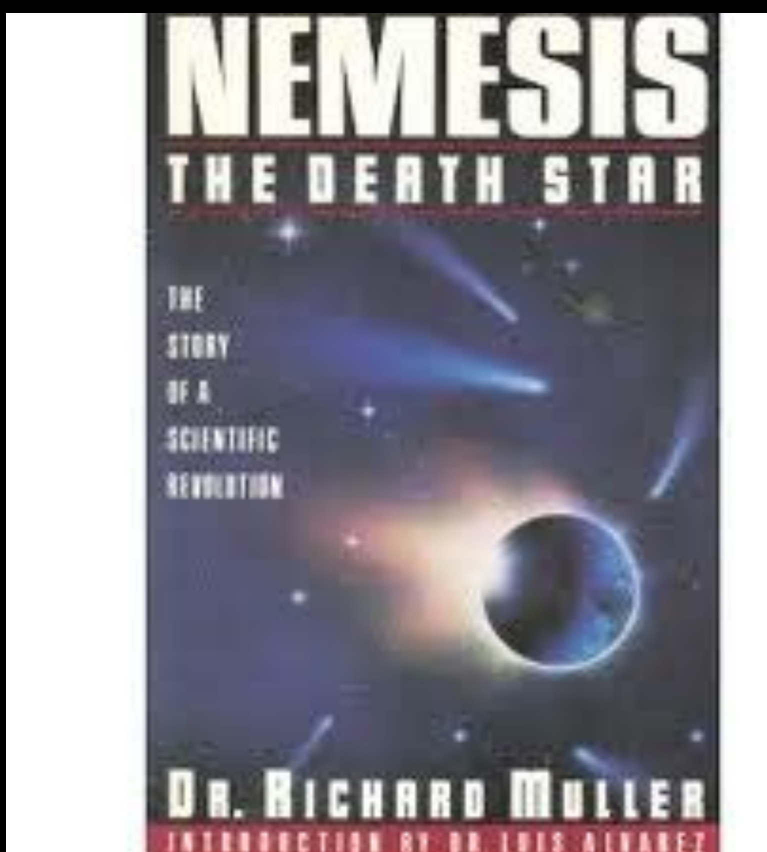
ABSTRACT

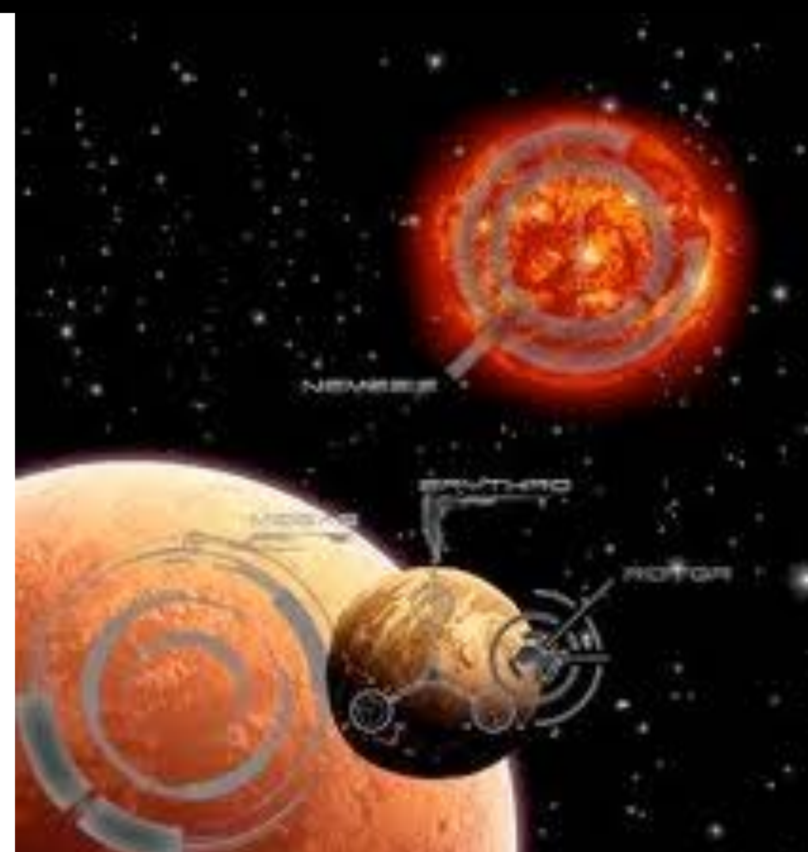
We have recalculated the luminosity of type I supernovae by using (1) the diffusive release of Ni^{56} decay energy (Colgate and McKee), (2) the progressive gamma-ray transparency as calculated by a Monte Carlo gamma-ray simulation code, and (3) the fractional deposition of positrons (Arnett). If we take 100% optical fluorescence efficiency (Meyerott) and choose a nebula that is expanding uniformly and at constant velocity such that it is one γ-ray mean free path (31.5 g cm^{-2}) thick at 28 days, we obtain excellent agreement with observations. Three independent physical phenomena are involved. The first is the diffusive release of thermal radiation that with the 6.1 day Ni^{56} decay determines the height and width of the optical peak. The second is the initial fast decay of the optical peak by a factor of roughly 100 as determined by the progressive transparency to γ-rays. The third is the apparent 56 day half-life that results from the progressive escape of the positron fraction of the 77 day Co^{56} decay. To obtain agreement with observations, each of these three independent phenomena requires that the expanding nebula be described by a single relation $M_{ej}v_9^{-1} = 0.22 \pm 0.05$, where M_{ej} is the ejected mass in solar masses and v_9 is the expansion velocity in units of 10^9 cm s^{-1}. Total energy requirements exclude the possibility of the ejection of an envelope $\geq 0.75\ M_\odot$ yet the optical luminosity requires that $\sim 0.25\ M_\odot$ of the ejected matter be Ni^{56}.
Subject headings: nuclear reactions — stars: supernovae



Dinosaur Extinction
Key Signature : Iridium
with Walter Alvarez (Geology)

Thesis Advisor : Richard Muler
Grad Student : Saul Perlmutter
PhD Thesis
“An Astrometric Search for a Stellar Companion to the Sun” PhD 1986

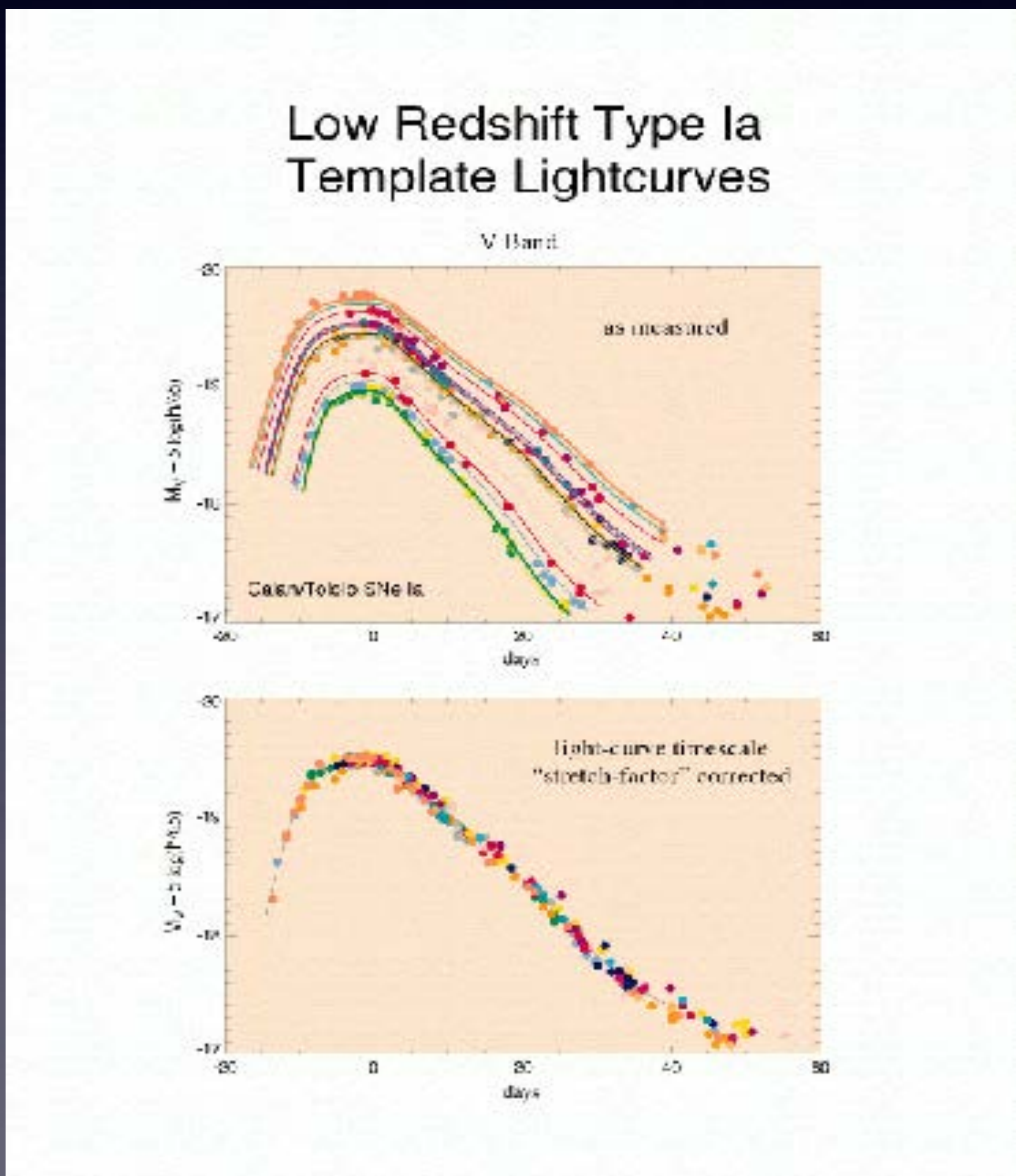




Hunting for Killer Astroids but happened to find supenovae

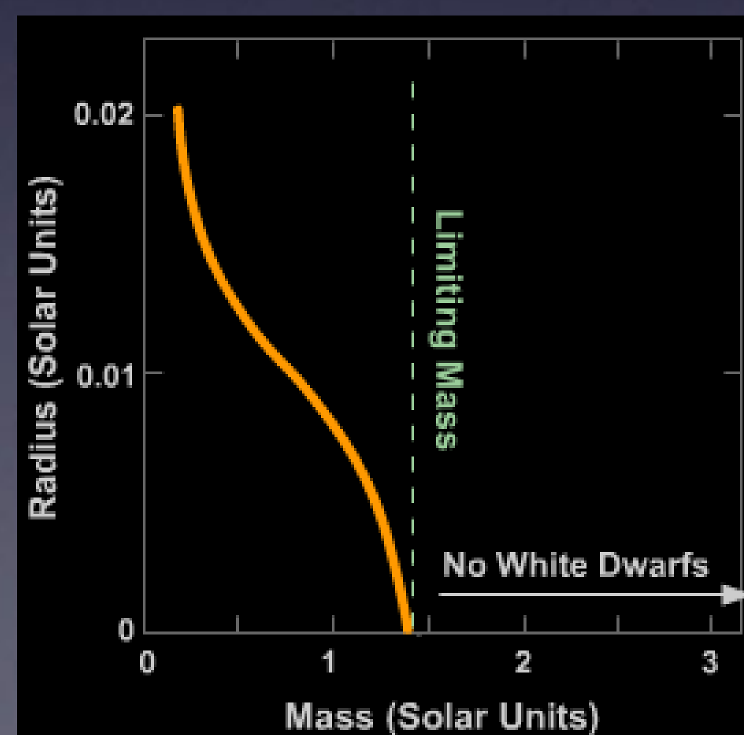
Q: How fast the Universe is Expanding?
Type Ia Supernova Cosmology

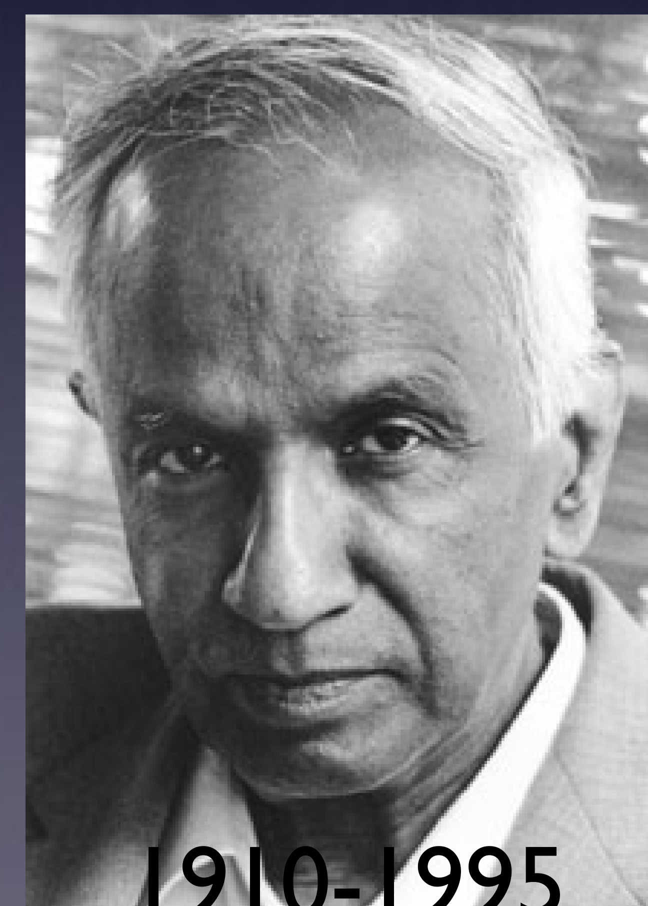
Phillips Relation (1993)
Brightness is Constant



Chandrasekah Mass Limit

Type Ia Supernova always explodes at 1.4 Solar Mass



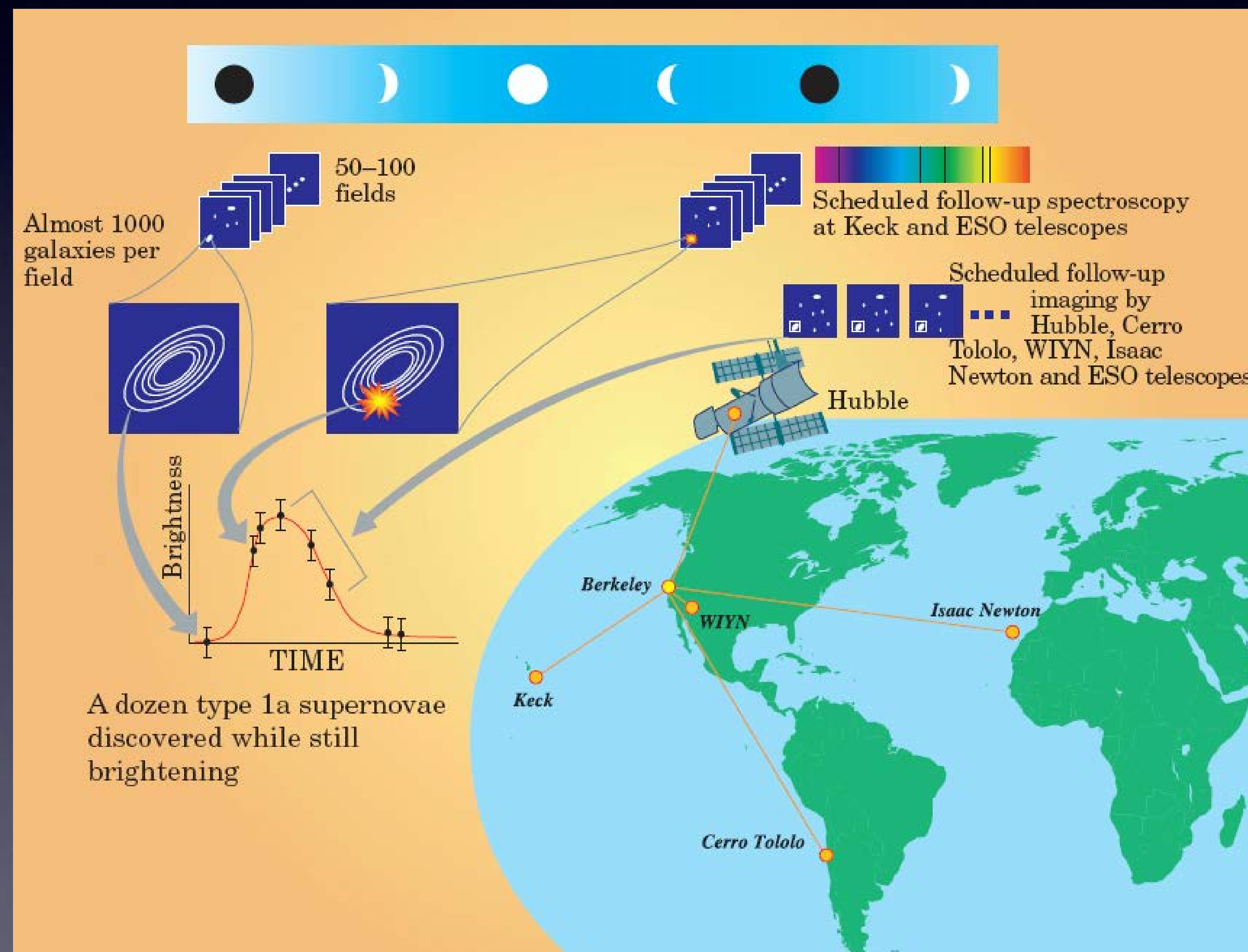


1910-1995

Supernvoa Cosmology Project (SCP)

Phillips ('93), Hubble Space Telescope('90), 10m Keck Telescope ('92) , VLT & Subaru ('98)

Saul Perlmutter

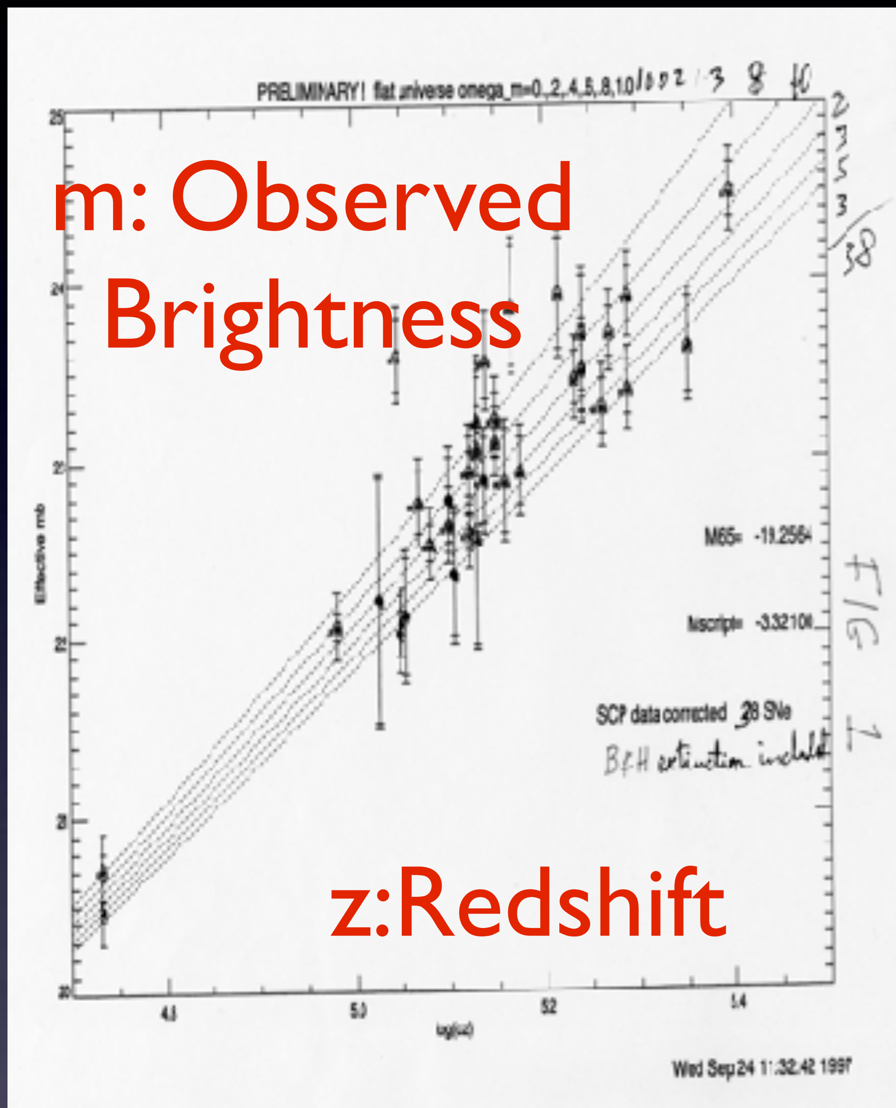


Supernova Cosmology Project
1986-1992

1991. Early days of the Supernova Search project, later to become the SCP.
L. to r., Carl Pennypacker, Saul Perlmutter, Heidi Marvin, Gerson, Rich Muller, at LBL.

FIGURE 1. The SCP group at Berkeley in 1990-91. Carl Pennypacker, Saul Perlmutter, Heidi Marvin Gerson Goldhaber, and Rich Muller l. to r.

Discovery of Dark Energy (SCP 1997)



Gerson Goldhaber

Λ is needed !

1997 Sep 24th

Einsteins Equation

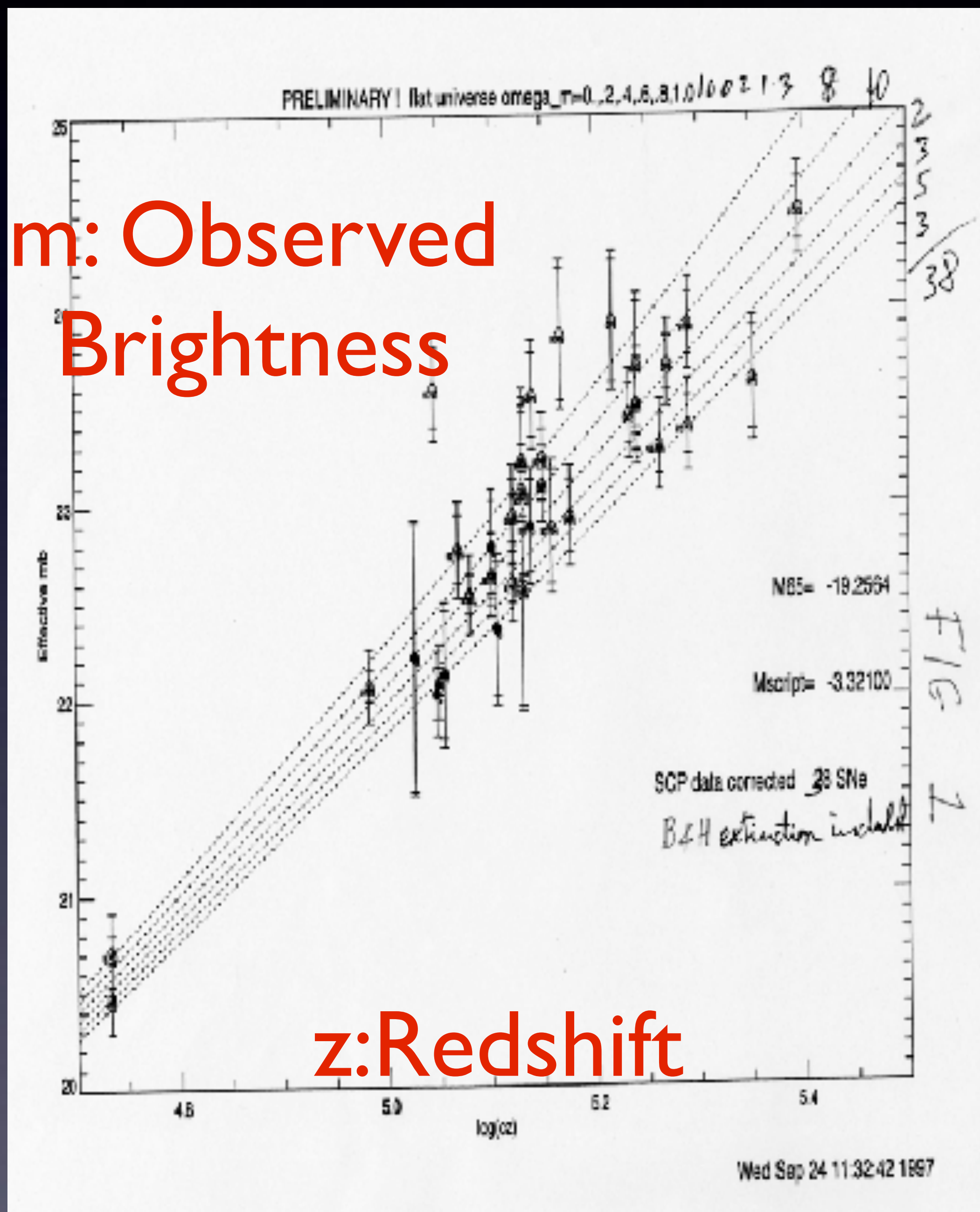
$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R - \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3}\rho - \frac{Kc^2}{a^2} + \frac{\Lambda c^2}{3}$$

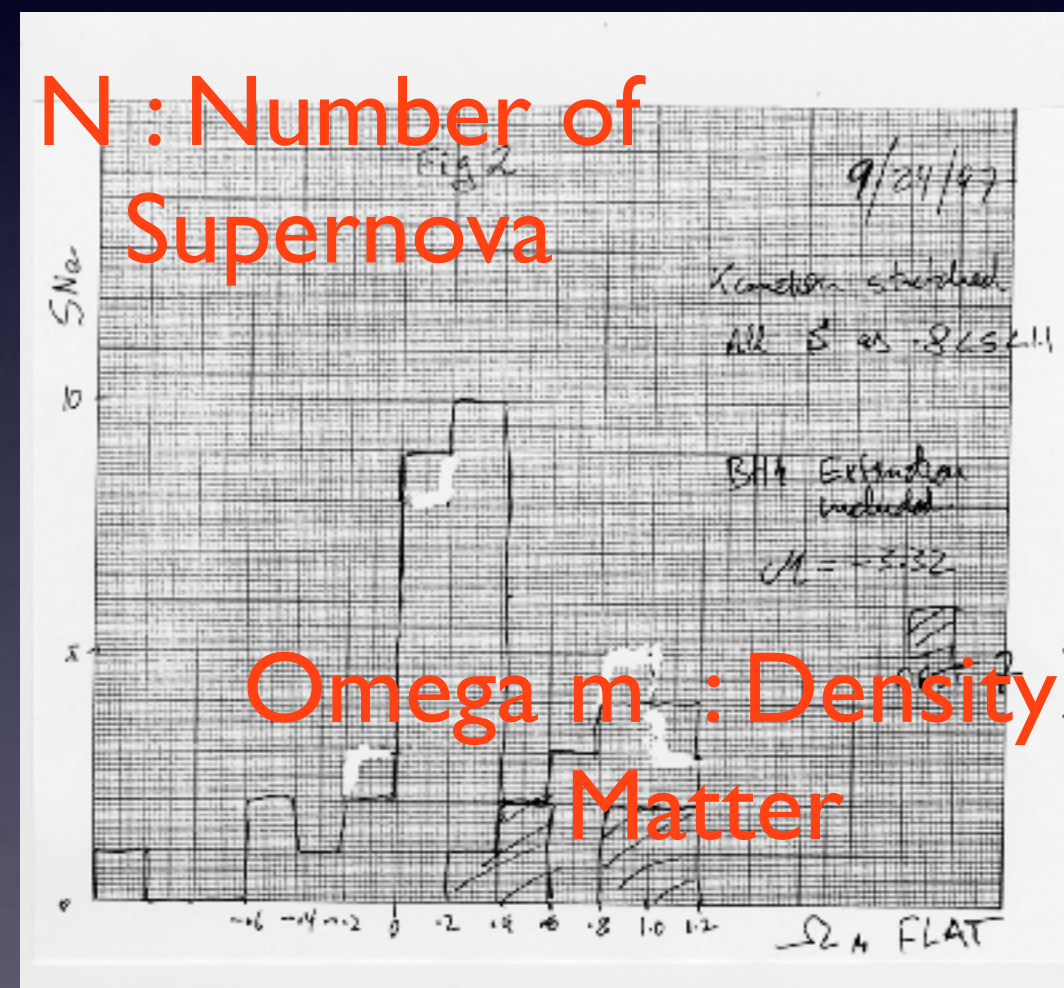
Observed magnitude (Brightness) is a function of cosmological model

$$M_V^0 - 5\log H_0 = m_V^0 - 25 - 5\log\left(c(1+z)\int_0^z \left[\Omega_M(1+z')^3 + \Omega_\Lambda\right]^{-1/2} dz'\right),$$

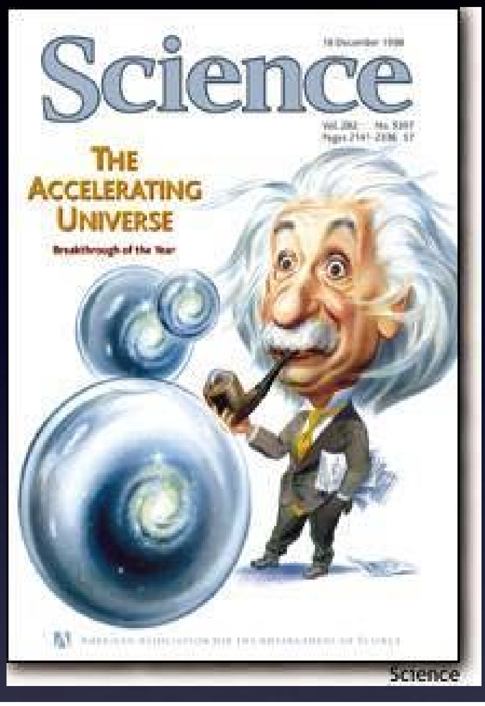
Discovery of Dark Energy (SCP 1997)



Gerson Goldhaber reported non-zero Λ on 24th in Sep '97

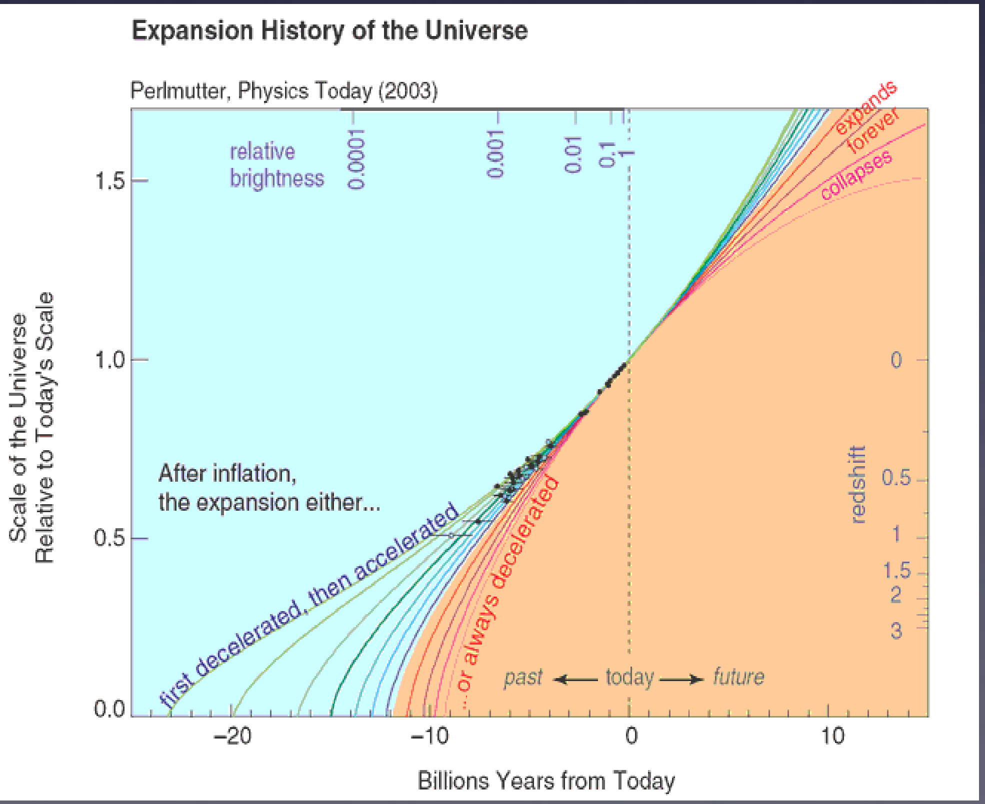


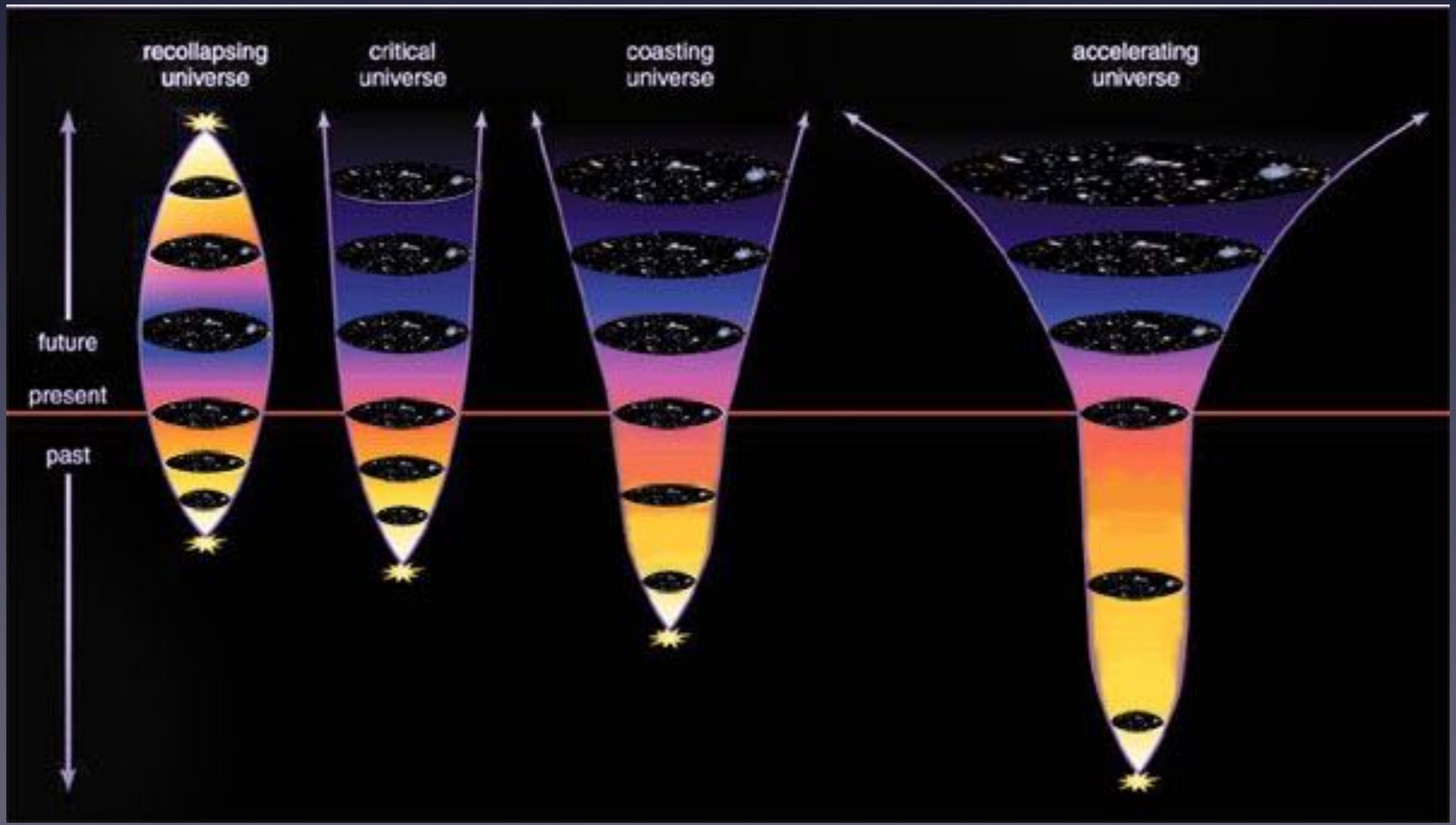
Discovery of Accelerating Universe Breakthrough of the Year in 1998!



Our Universe expands forever!
In fact, the expansion is accelerating now!

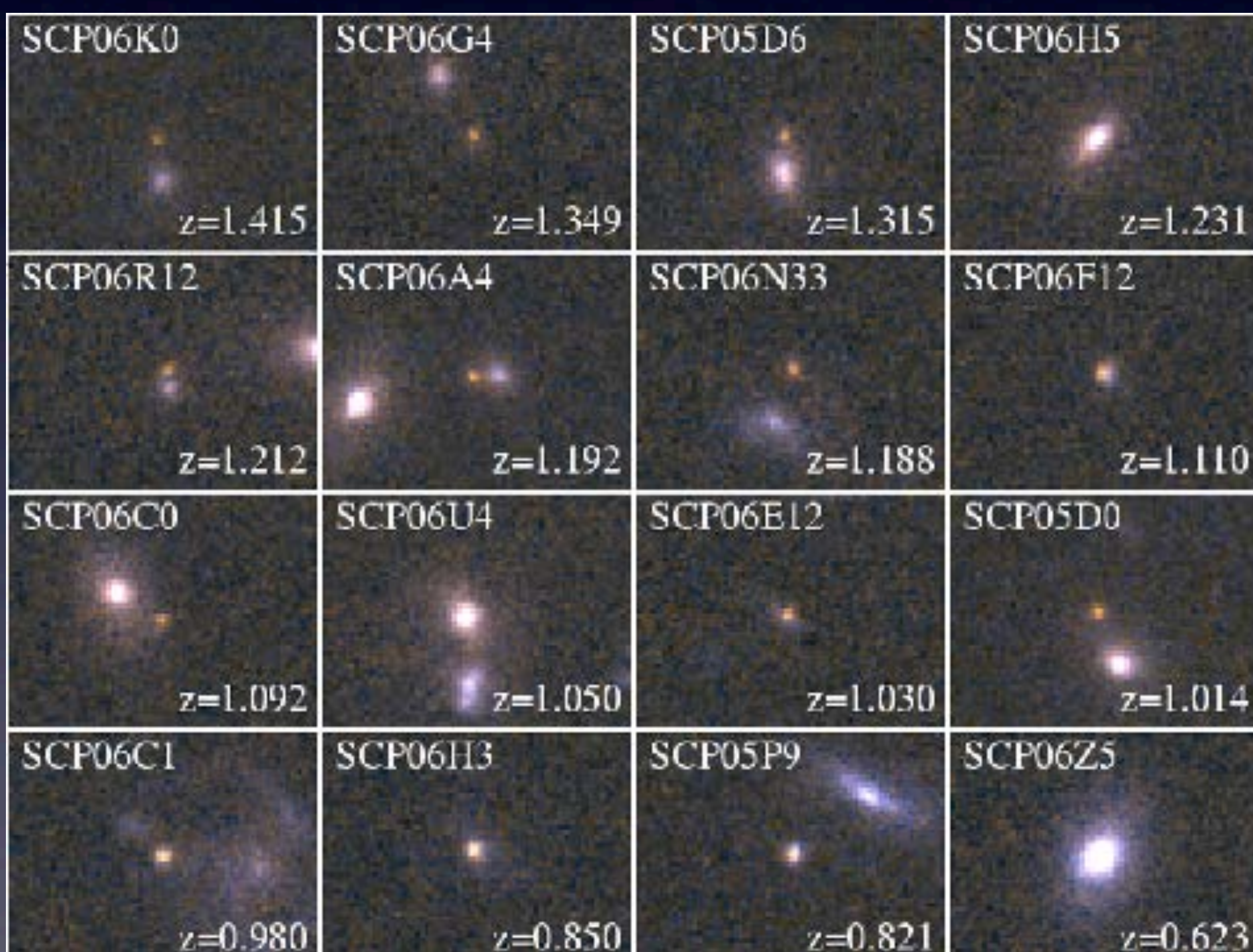
Science 1998

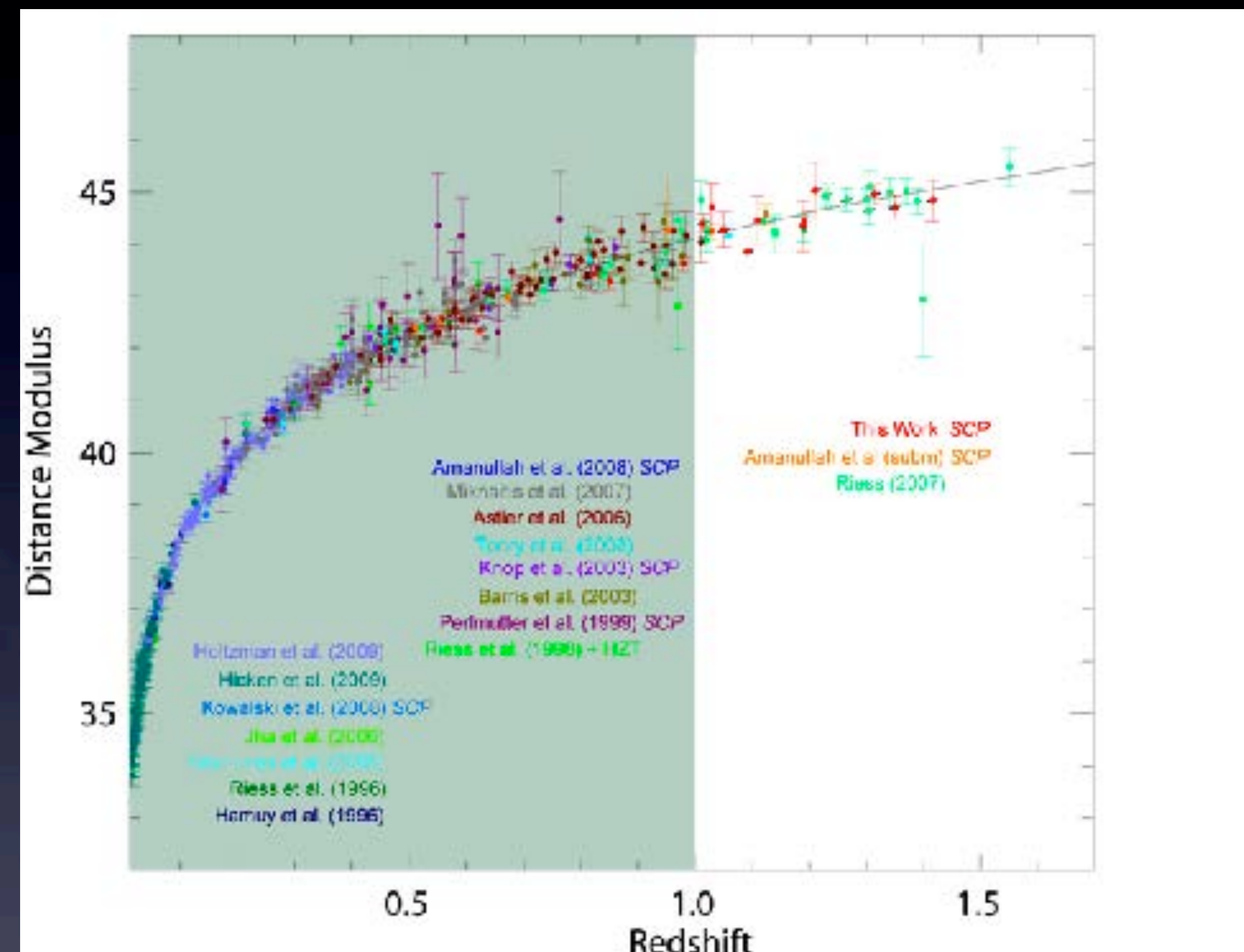




HST Cluster SN Survey

Nao Suzuki & SCP
PI: Saul Perlmutter

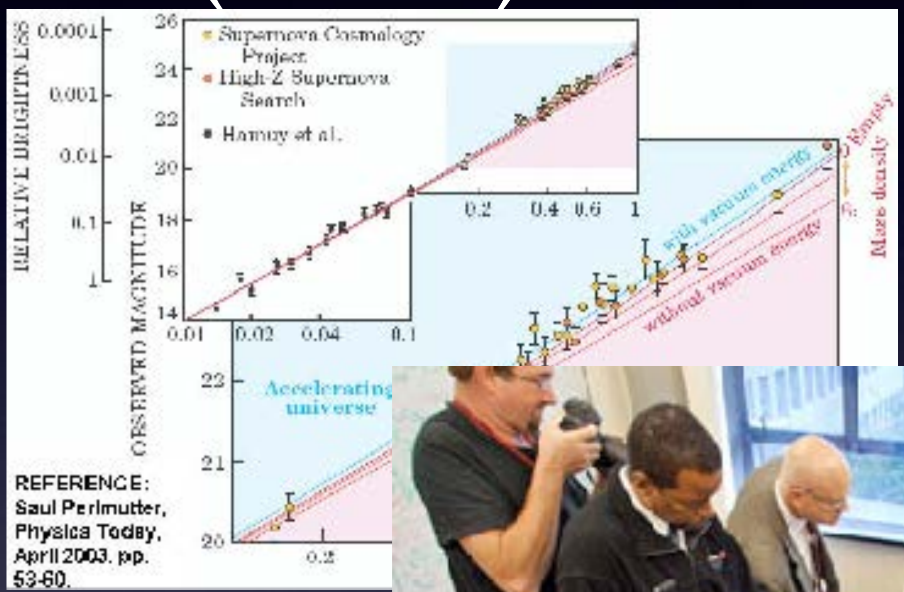


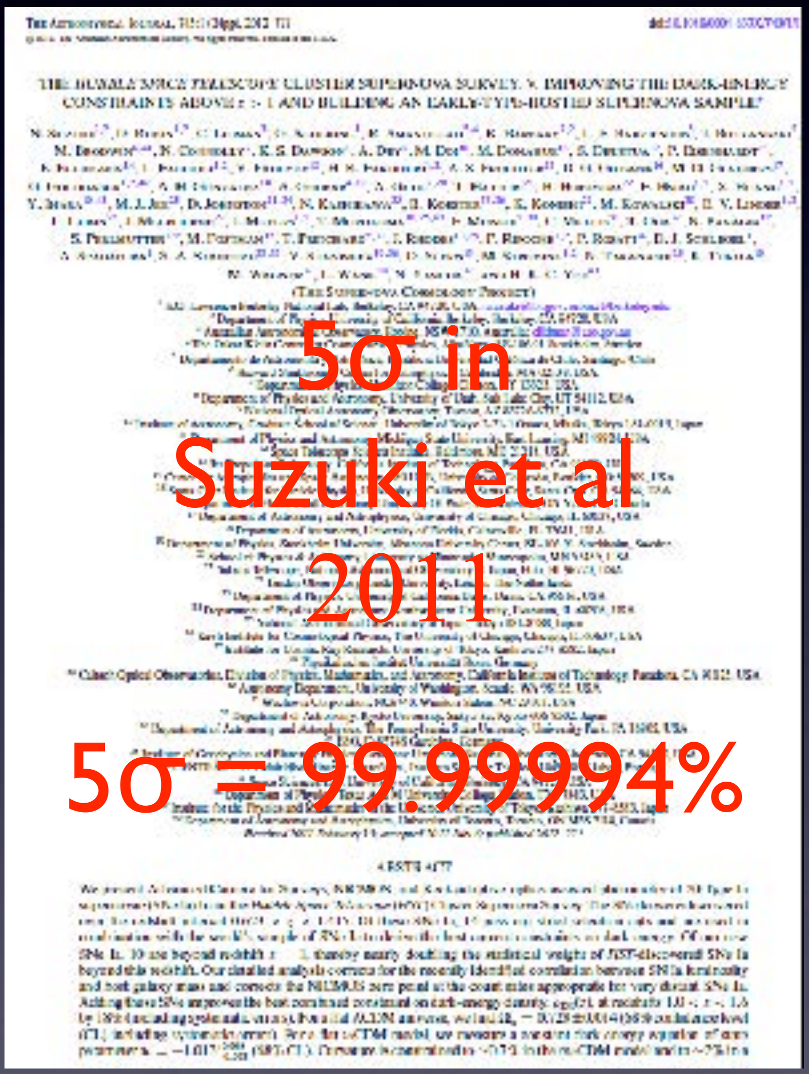


Dark Energy

Discovery of Accelerating Universe
Nobel Prize in Physics 2011

2σ (95.4 %) in 1997

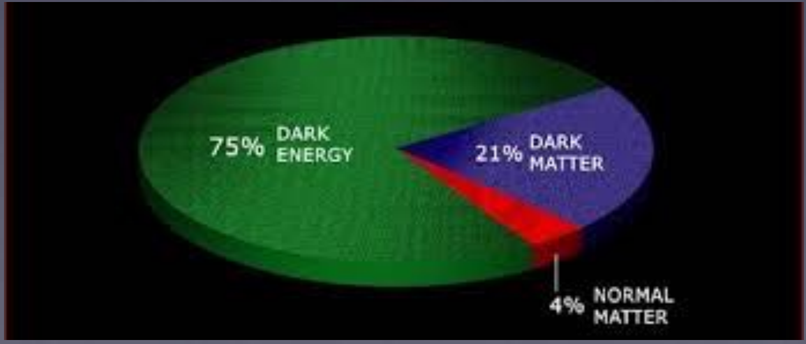



THE HUBBLE SPACE TELESCOPE CLUSTER SUPERNOVA SURVEY. V. IMPROVING THE DARK-ENERGY CONSTRAINTS ABOVE z > 1 AND BUILDING AN EARLY-TYPE-HOSTED SUPERNOVA SAMPLE

5σ in Suzuki et al 2011

5σ = 99.99994%

- 70% of Energy in the Universe is in the form of mysterious Dark Energy

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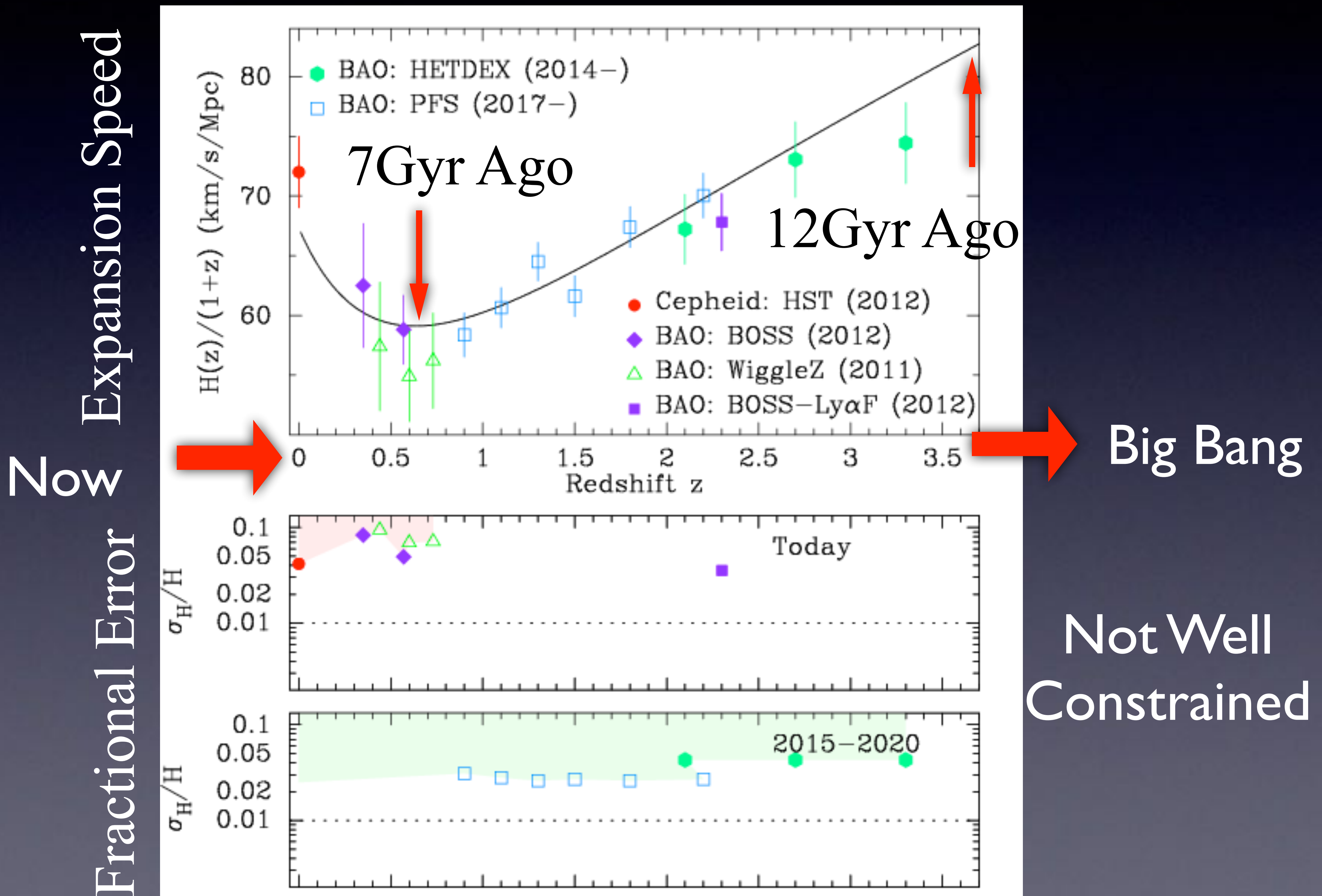
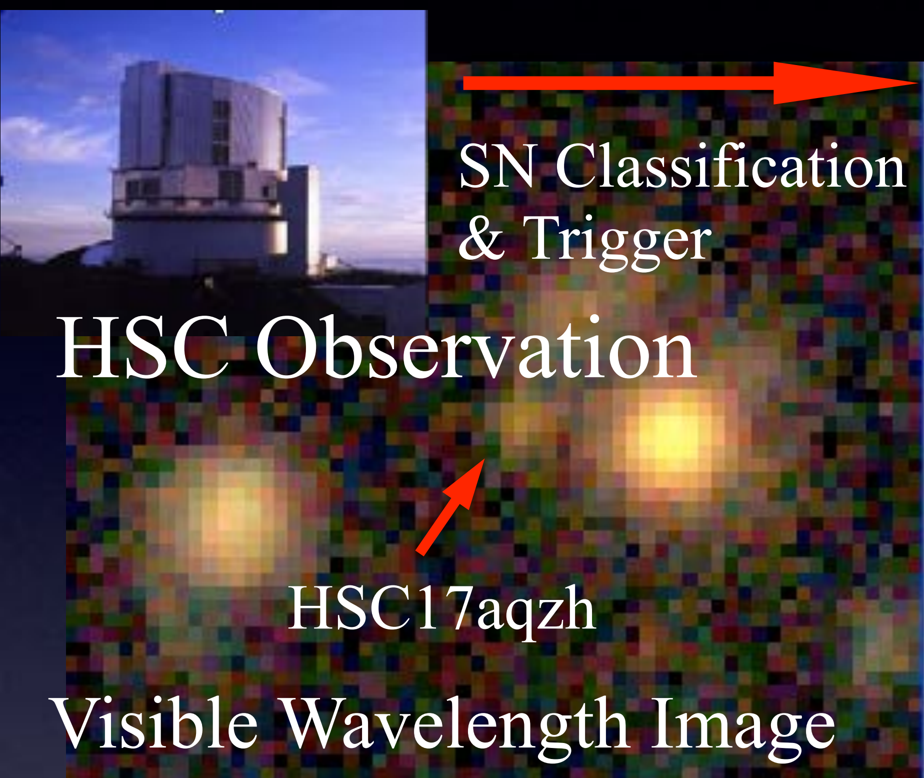
Mysterious Expansion of the Universe
Deceleration to Acceleration
Dark Energy is not well understood…

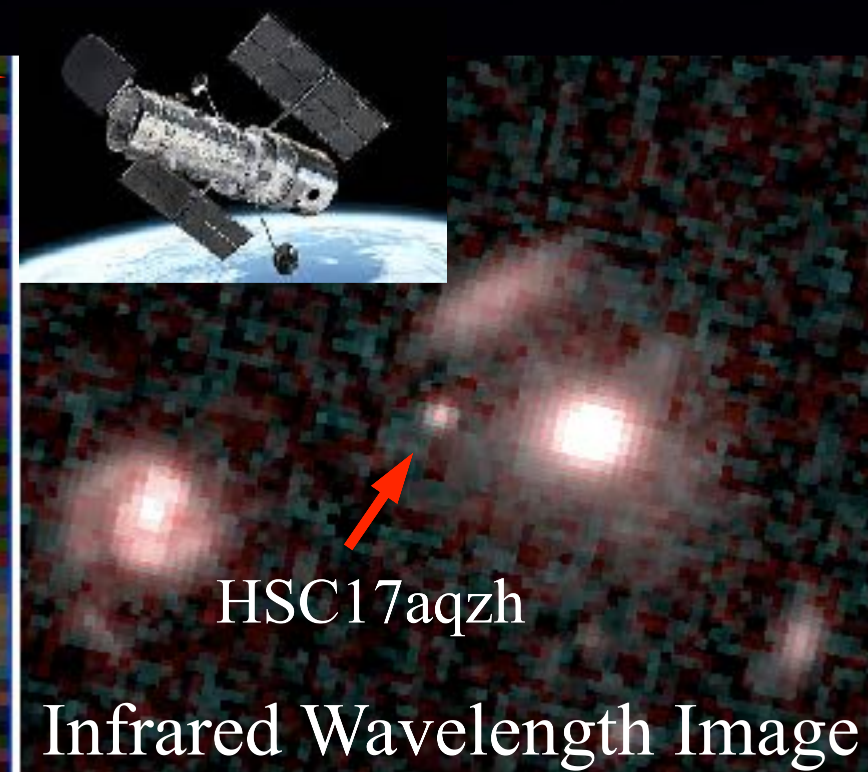


HSC SNIa Cosmology for Dark Energy

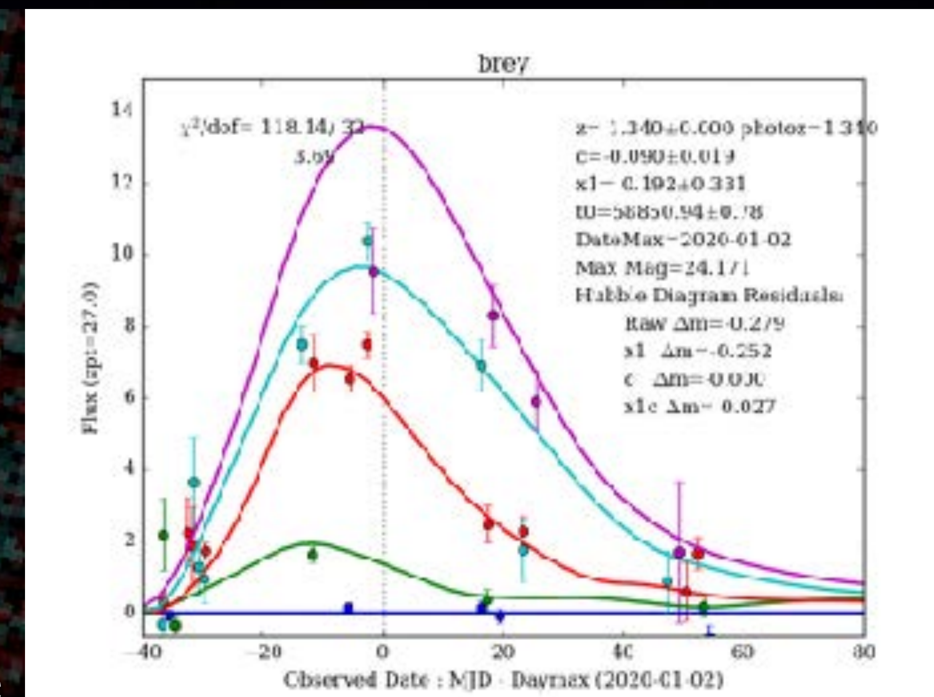
Subaru HSC Discovery



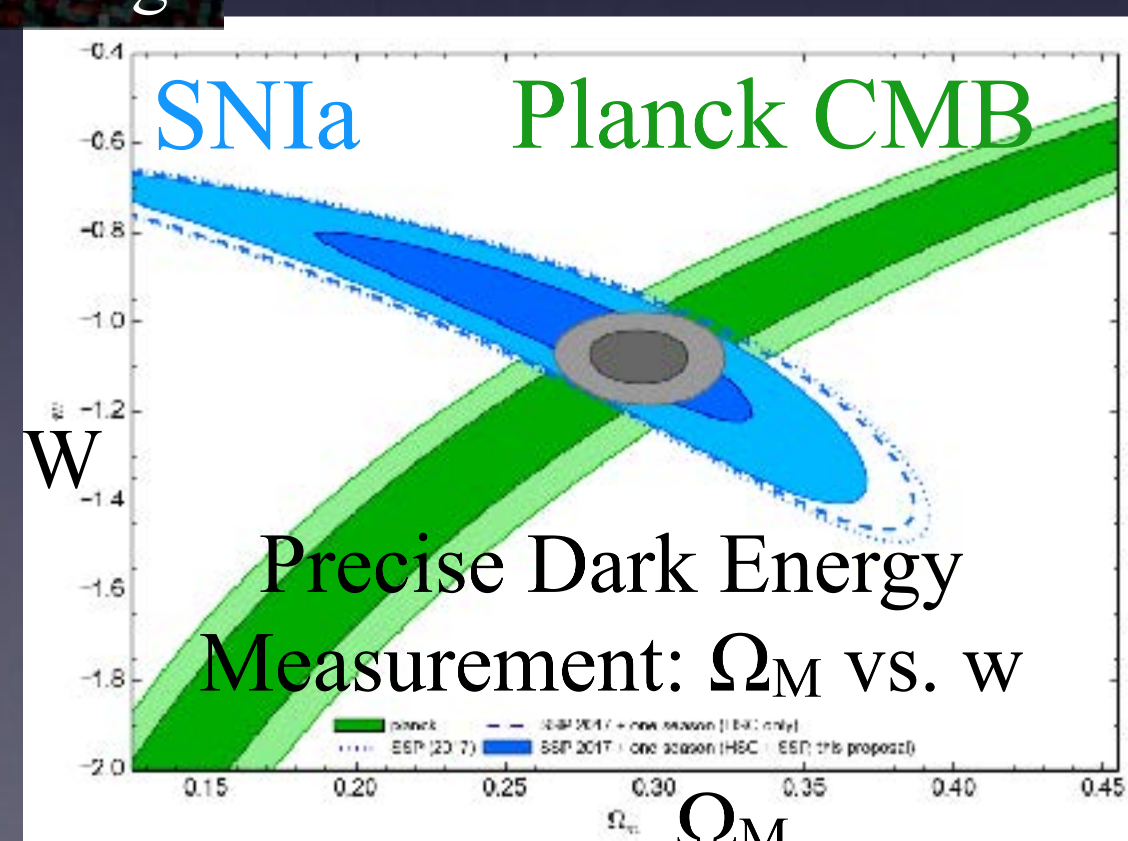
Hubble Space Telescope



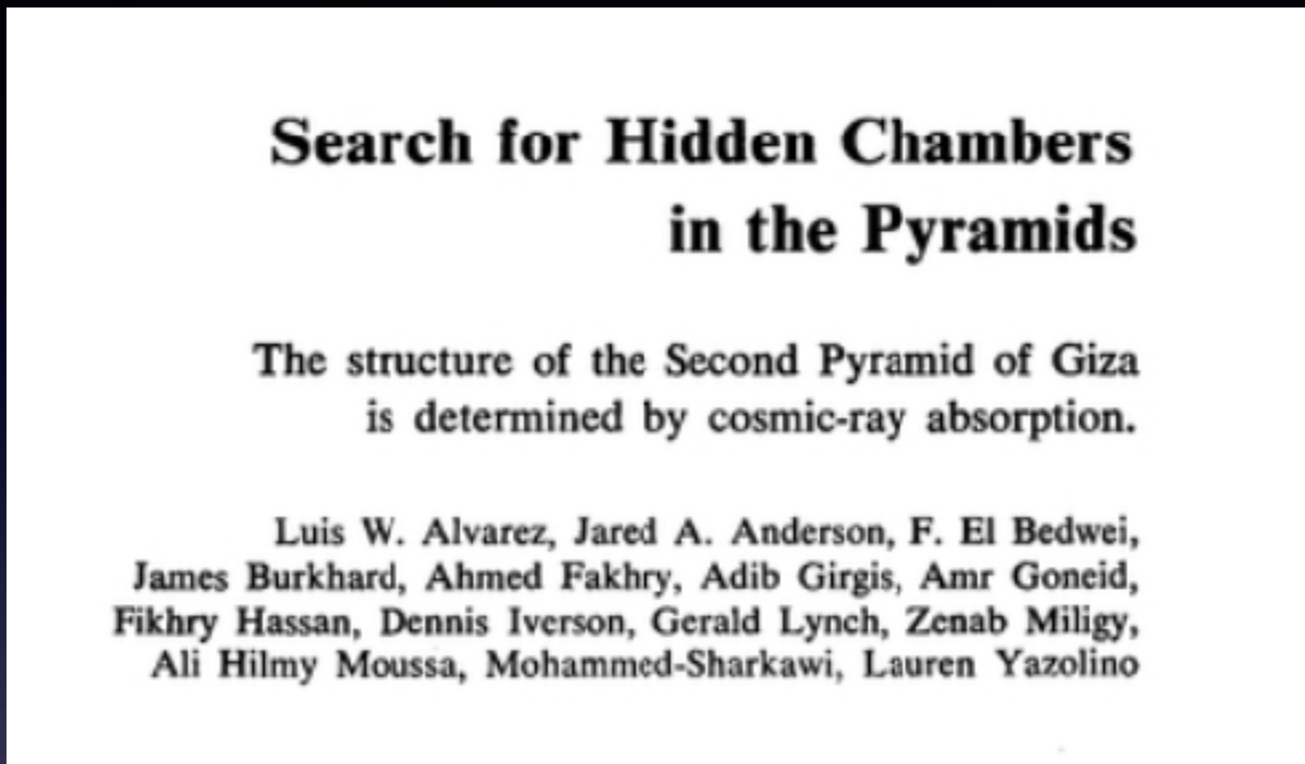
HSC SNIa Light Curve: z=1.34



Spectroscopic Follow-up by International Collaborators
Berkeley Lab (US), LPNHE (Paris), Barcelona (Spain), Lancaster (UK) , Australian National University



Alvarez's Dream on Pyramids comes true in 2017

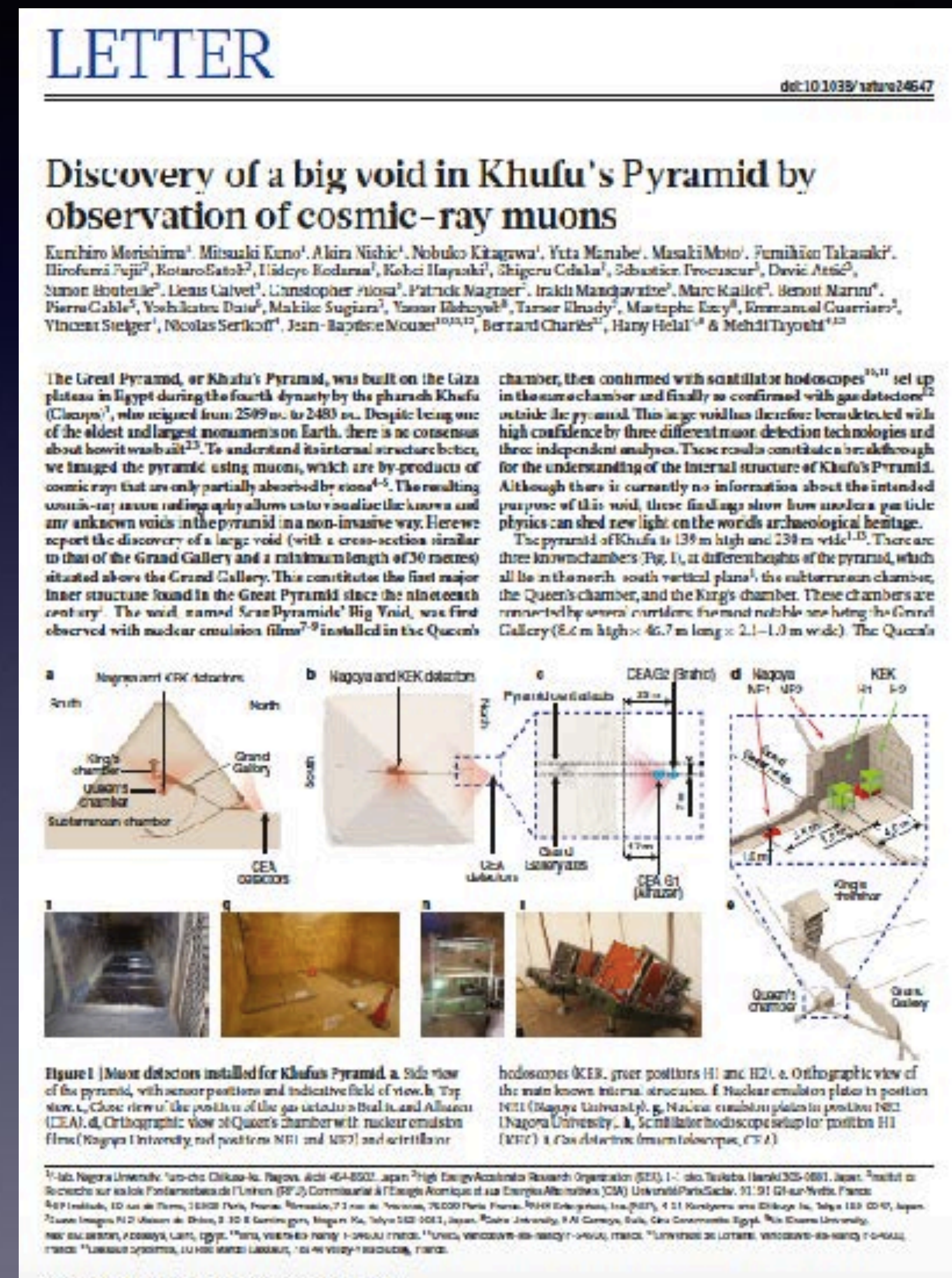


Search for Hidden Chambers in the Pyramids

The structure of the Second Pyramid of Giza is determined by cosmic-ray absorption.

Luis W. Alvarez, Jared A. Anderson, F. El Bedwei, James Burkhard, Ahmed Fakhry, Adib Girgis, Amr Goneid, Fikhry Hassan, Dennis Iverson, Gerald Lynch, Zenab Miligy, Ali Hilmy Moussa, Mohammed-Sharkawi, Lauren Yazolino

Science, 167, 832 (Feb 1970)



LETTER

doi:10.1038/nature24647

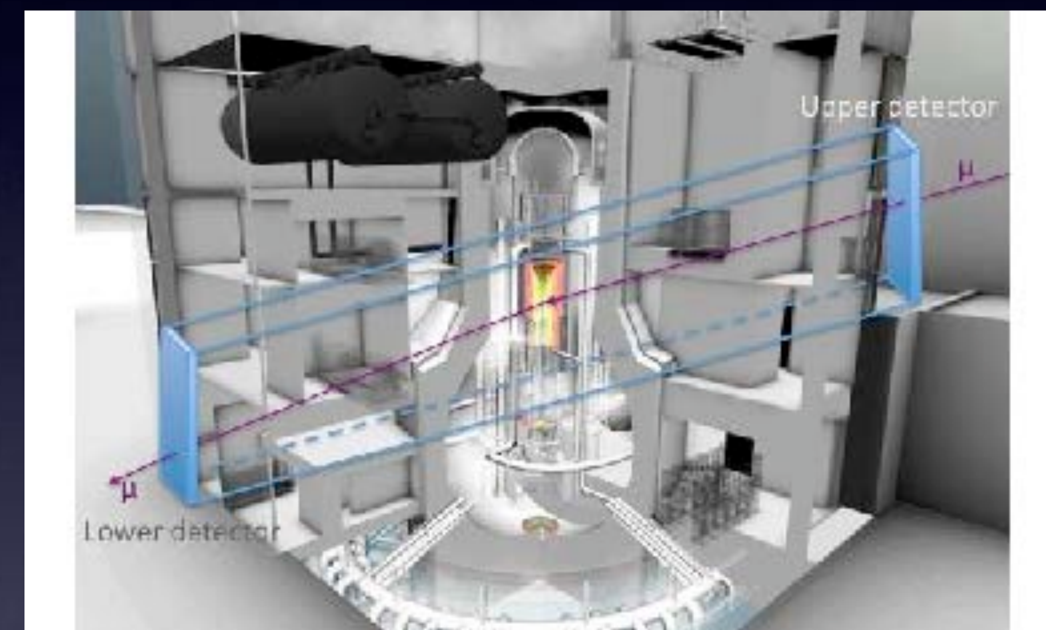
Discovery of a big void in Khufu's Pyramid by observation of cosmic-ray muons

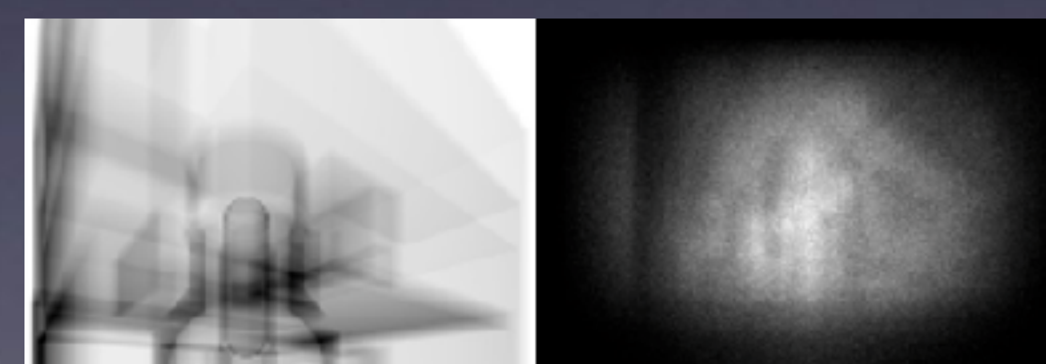
Detected!!! Nature Nov 2017

Alvarez’s idea is applied to Fukushima Nuclear Power Plant Disaster (2011)

Probe the status of Nuclear Fuels inside the system

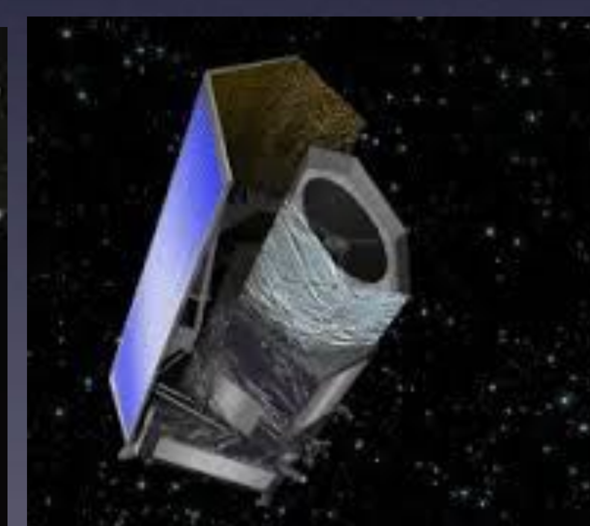
LBNL Team Members





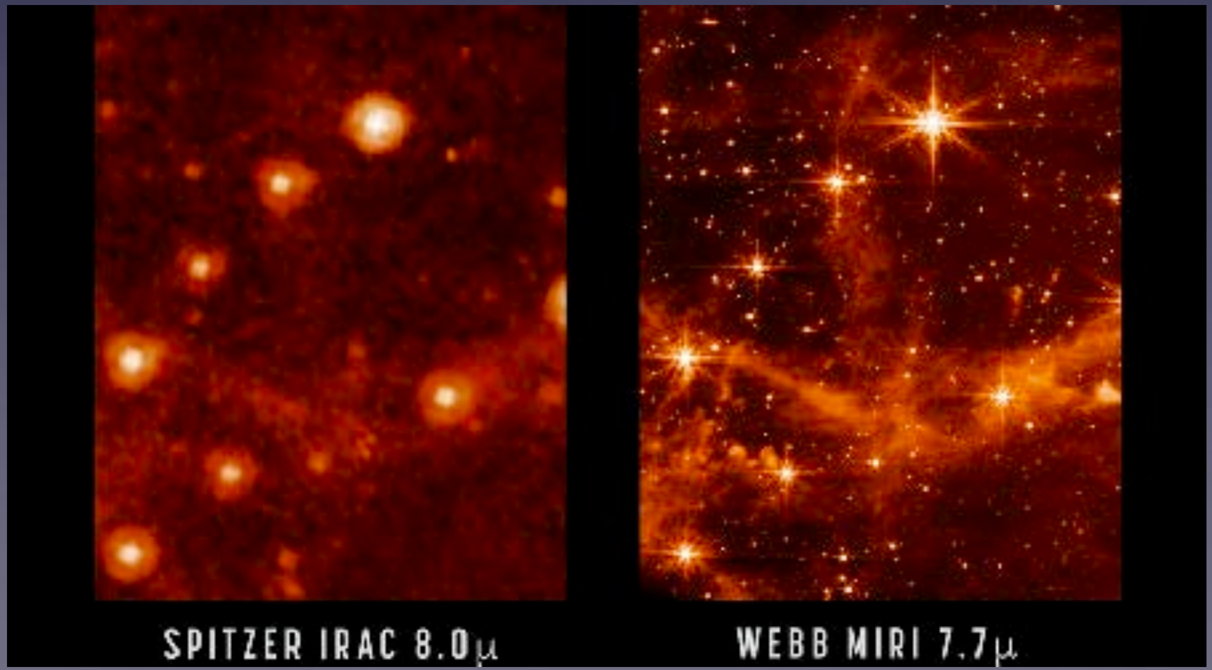
Toshiba Press Release

Future Prospects
Big Data grows Bigger Quickly

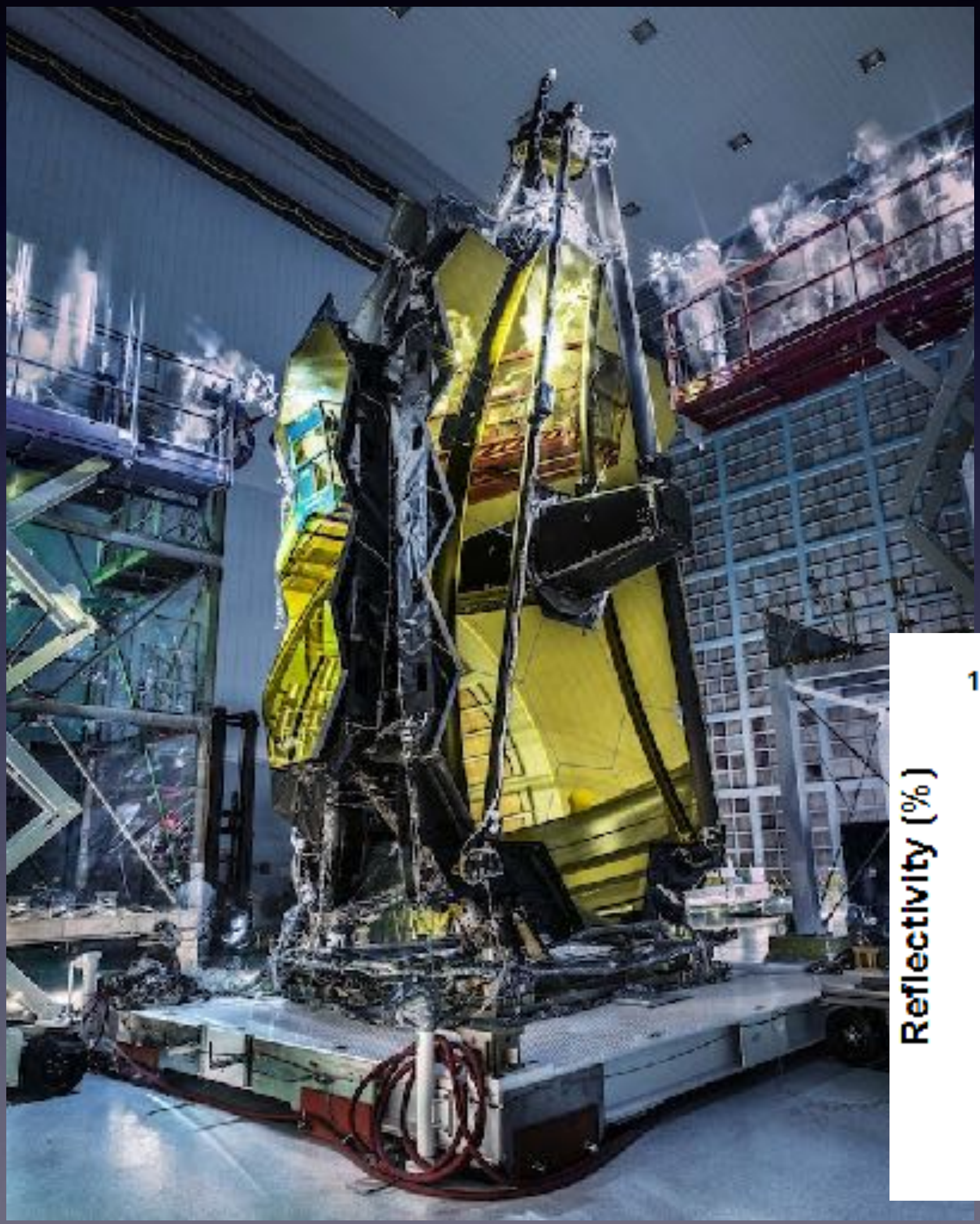


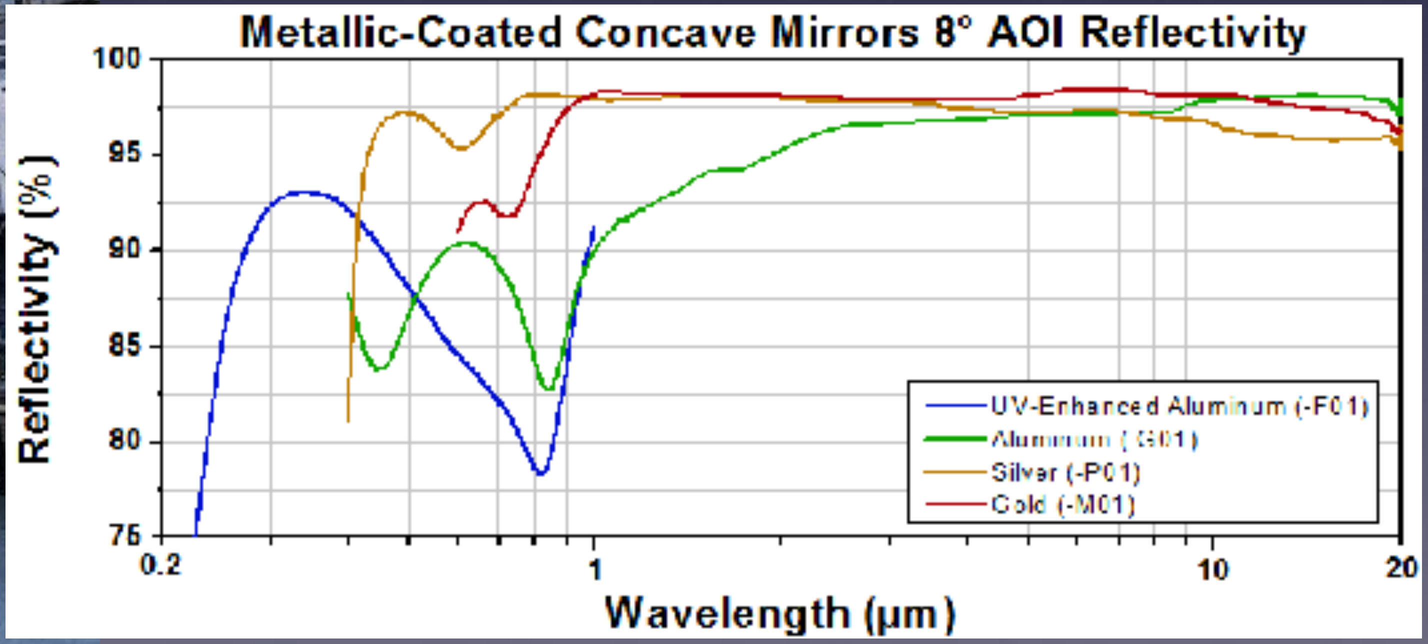
Euclid 2023

JWST Press Release July 12th!



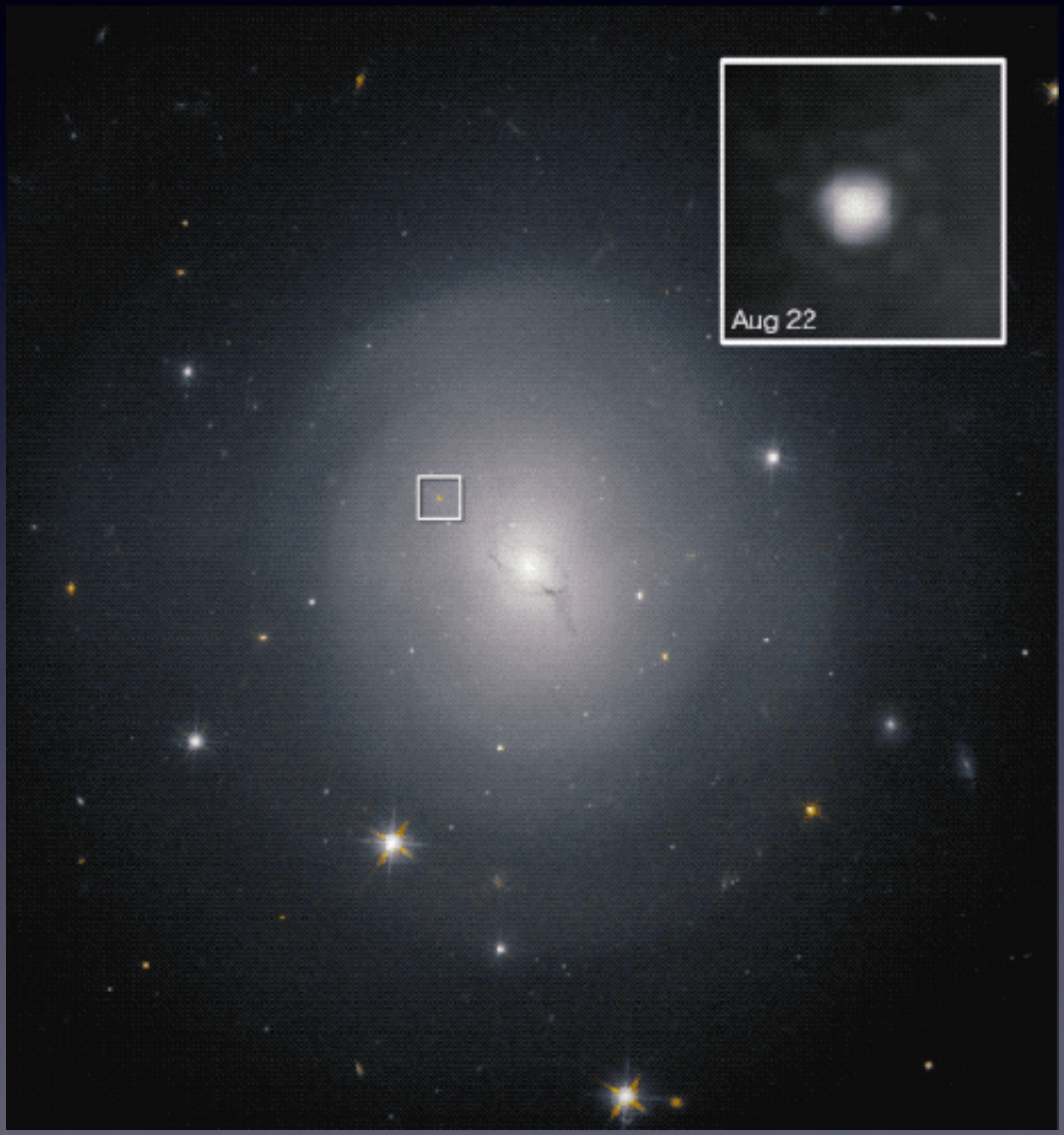
Gold Primary Mirror

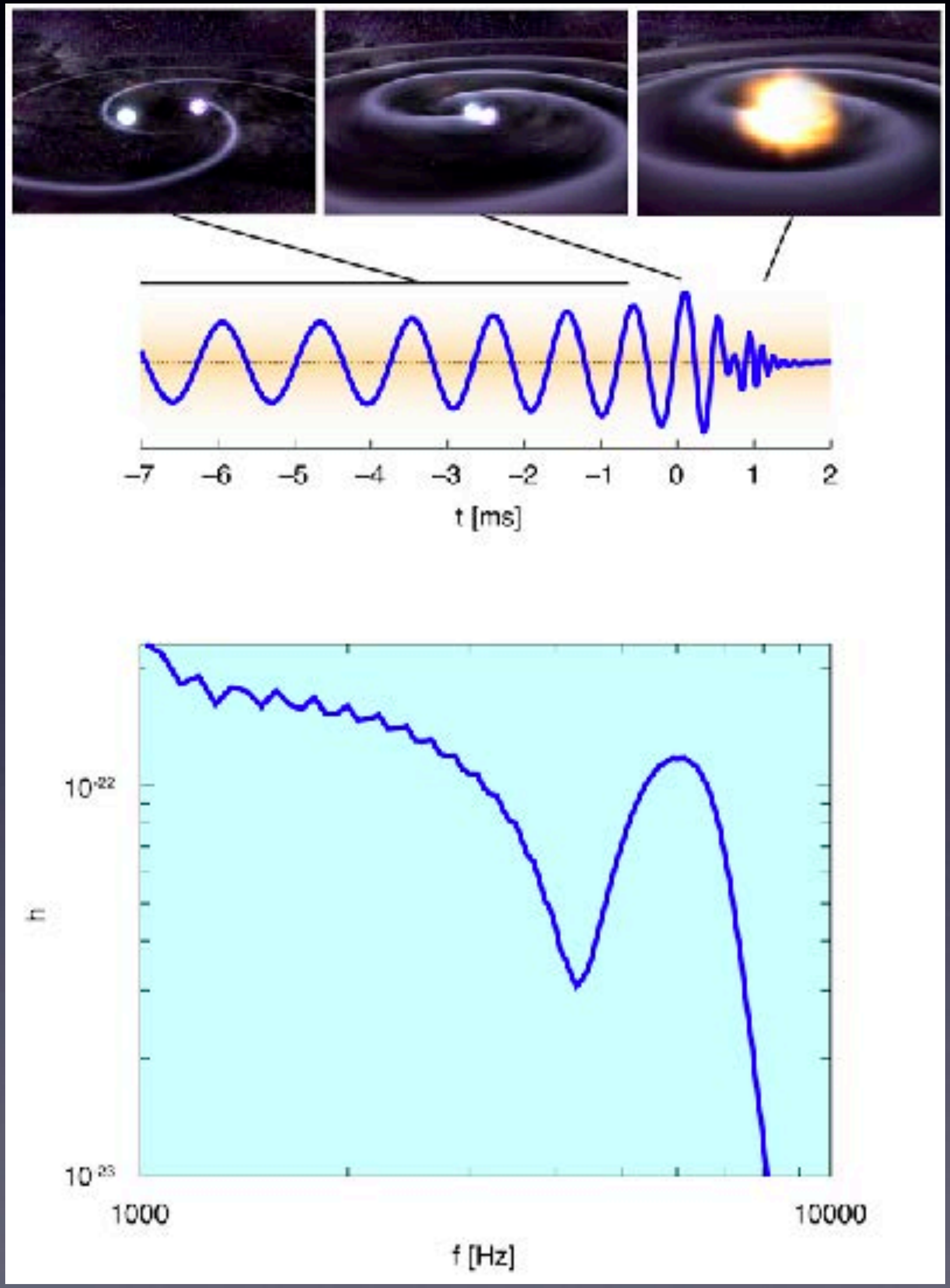


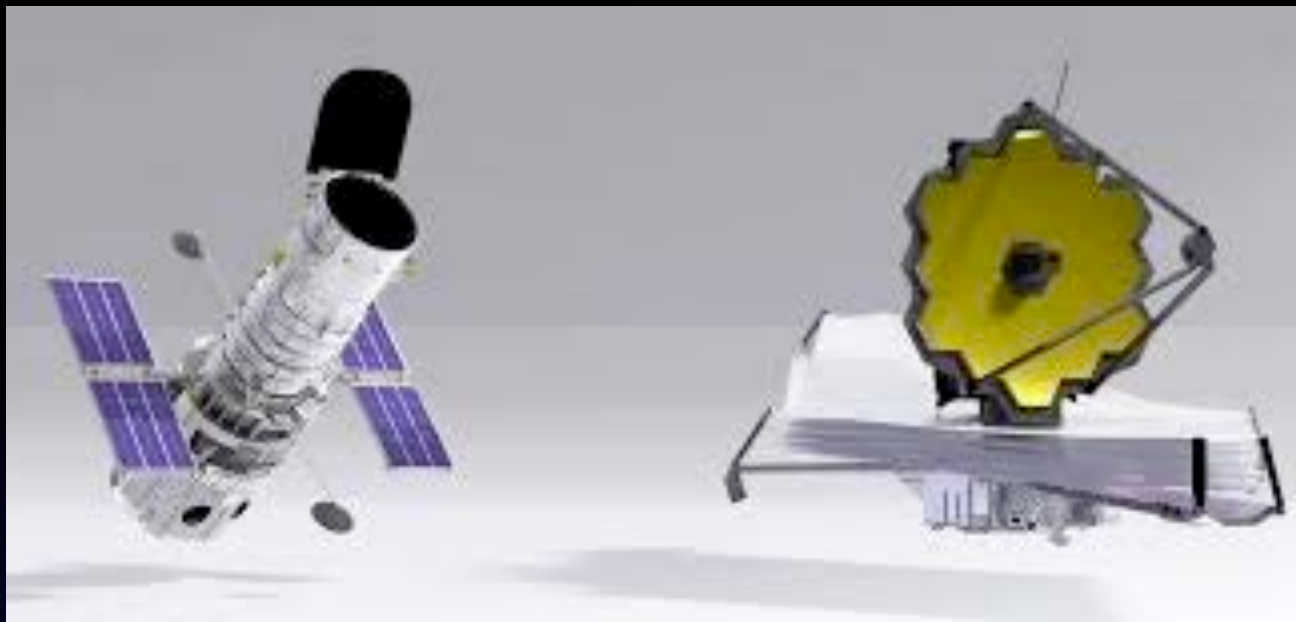


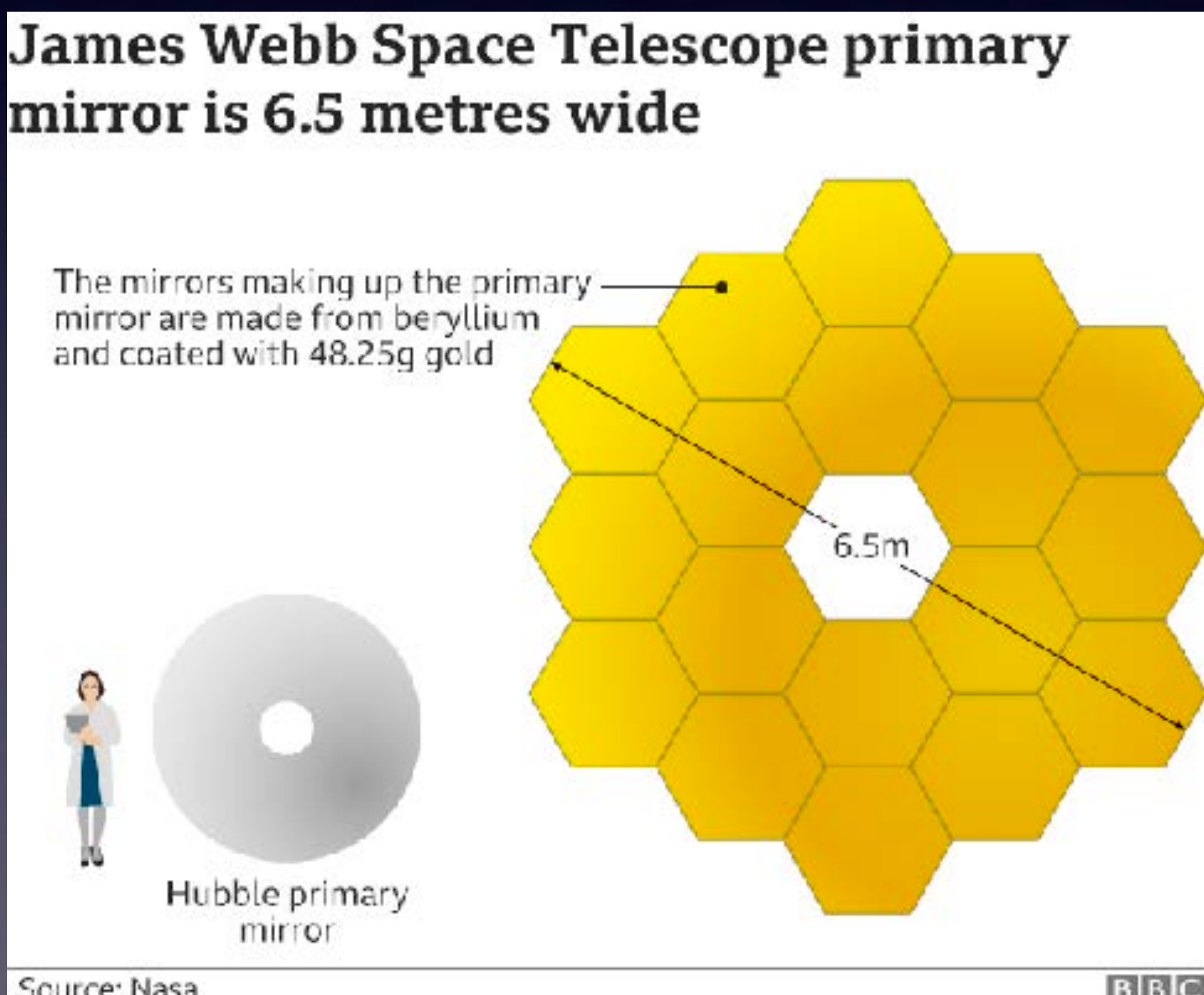
Gold : 48.25g, 1000 Angstrom thick

Gold is made in “Neutron Star Merger” (GW170817) Gravitational Wave Detection

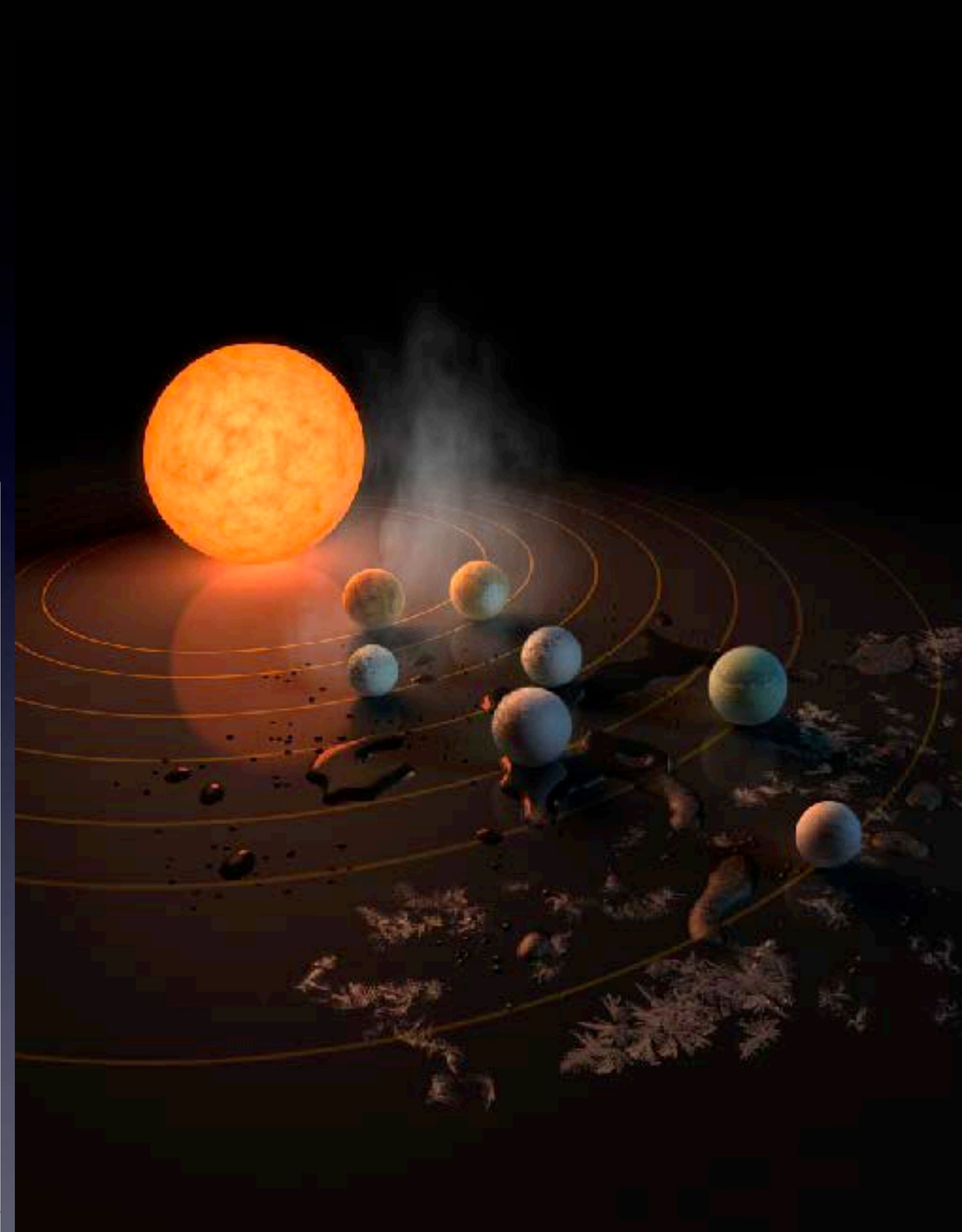








James Webb Space Telescope primary mirror is 6.5 metres wide
The mirrors making up the primary mirror are made from beryllium and coated with 48.25g gold
6.5m
Hubble primary mirror
Source: Nasa
BBC



Great Discoveries are waiting for you!

Primordial Blackhole

Habitable Planets

Galactic Supernova

In other words: We mortal, limited humans joining together in teams from around the world, and in time across civilizations, become *capable* – in our case, capable of just glimpsing one additional bit of how the universe works. It is exhilarating,

But it is in the doing, in the process of working together to explore the universe that we learn to truly appreciate each other, and to enjoy each other's company and ... spark, as all humans should be appreciated. – And that, too, is exhilarating.