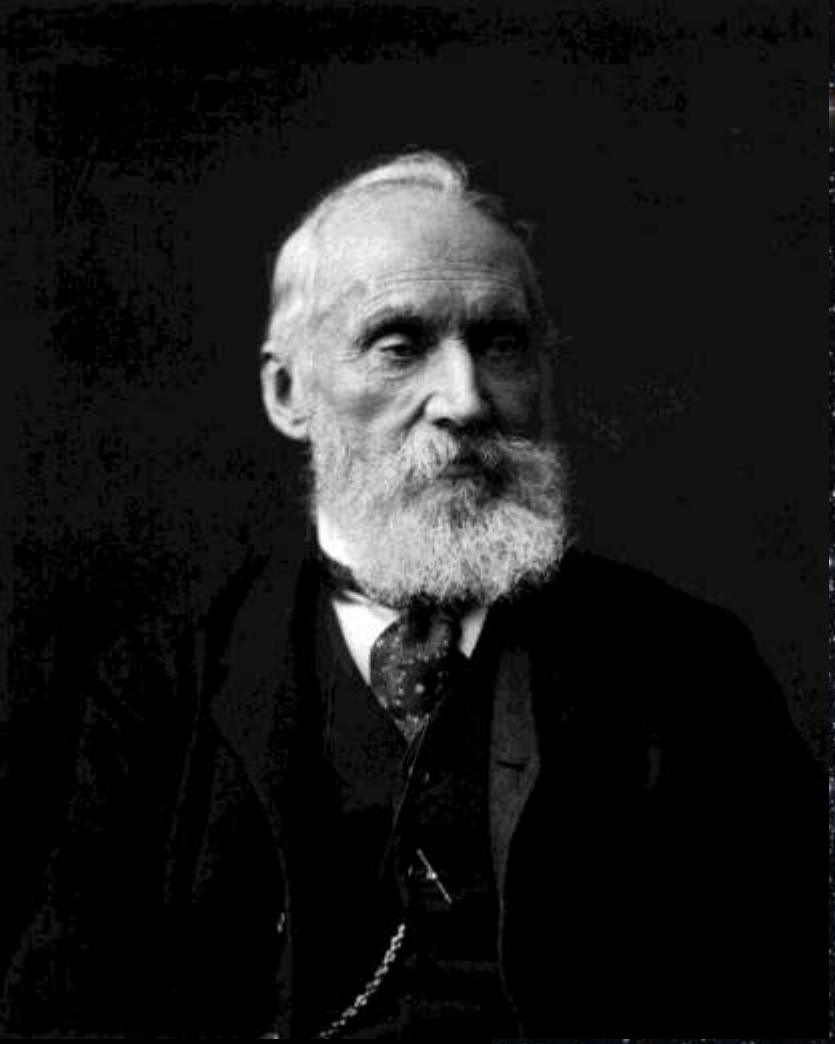
The next big questions…

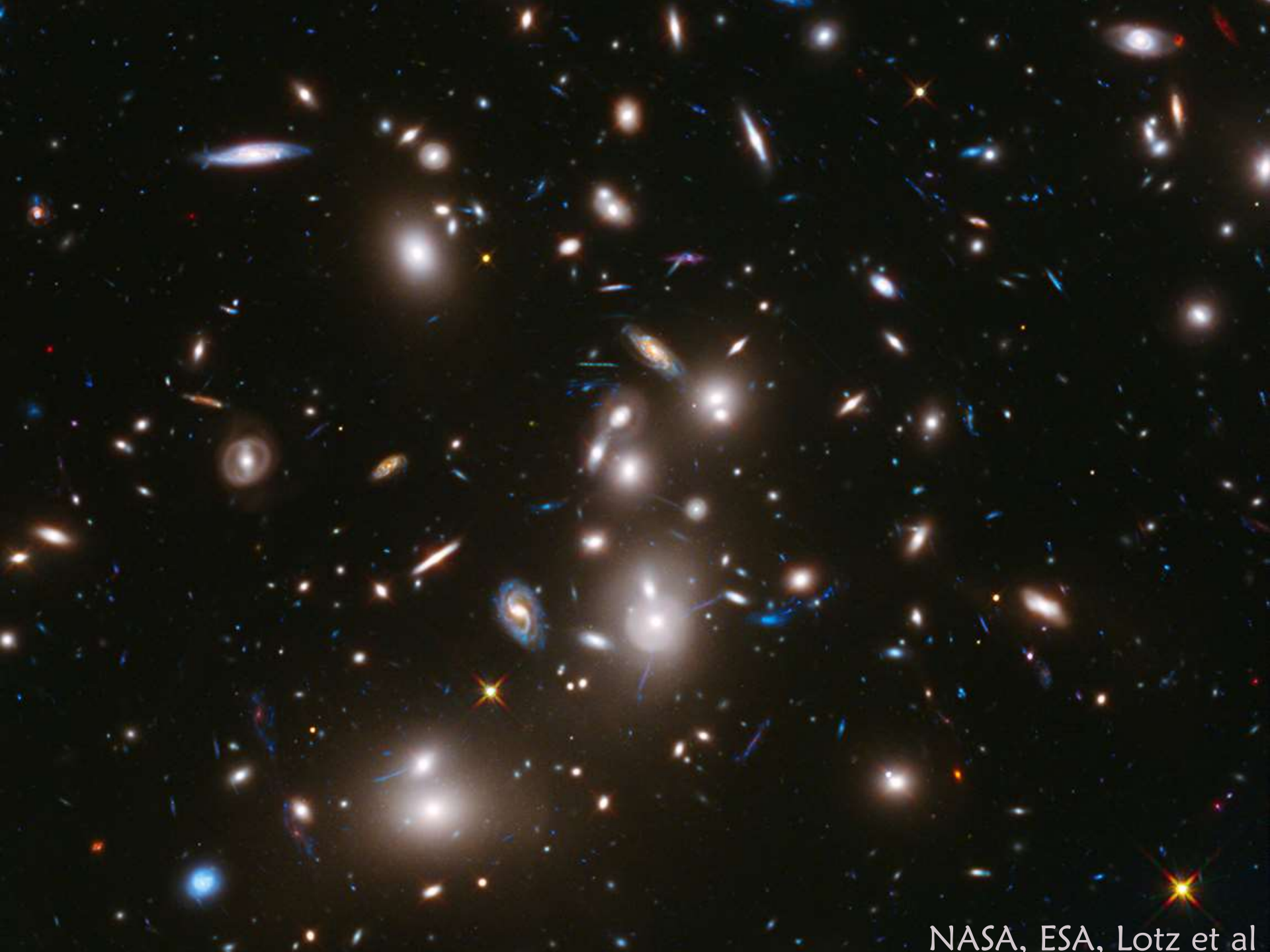
Carolin Crawford

Professor of Astronomy, Gresham College

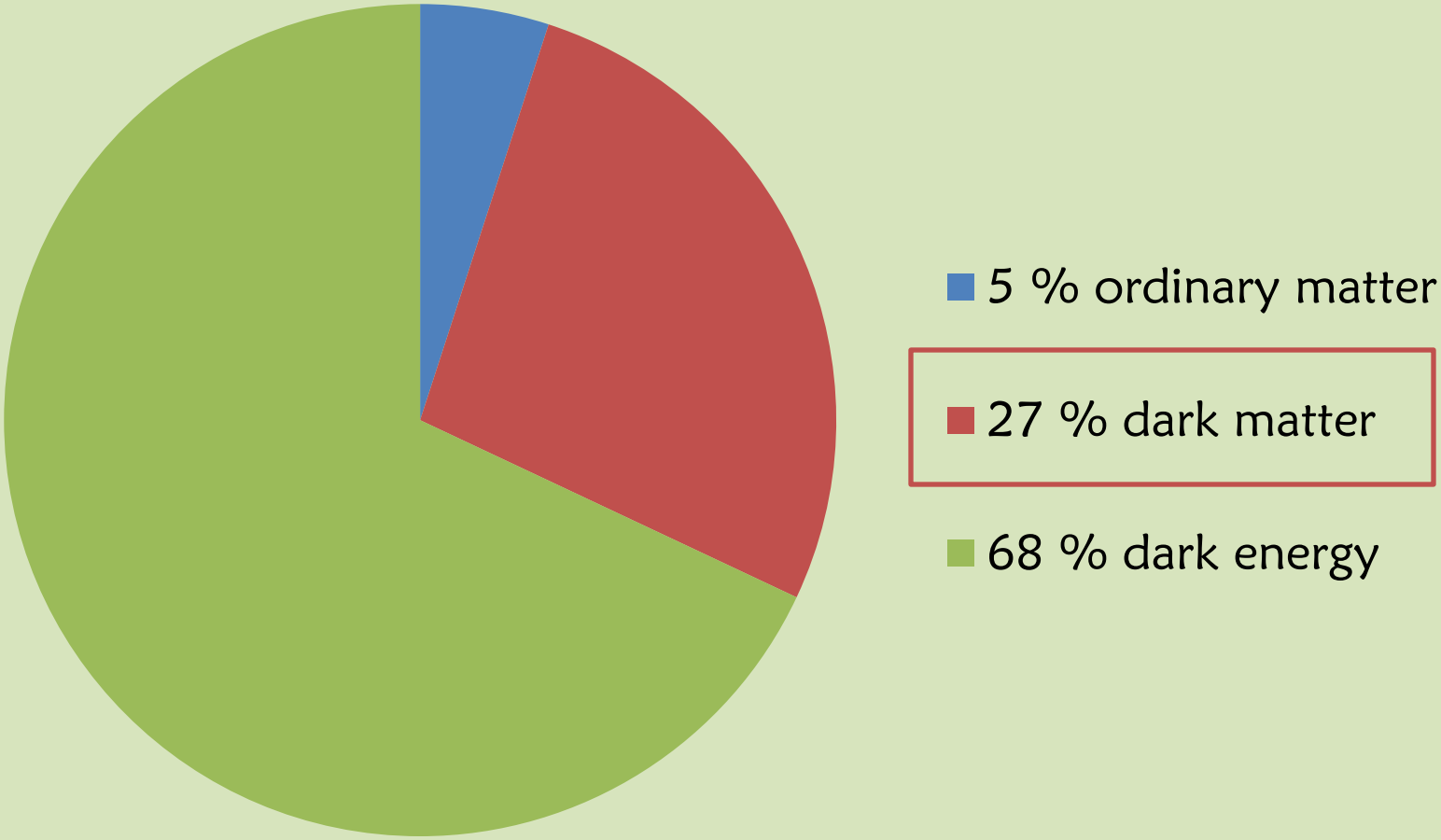
NASA, ESA, Dalcanton et al



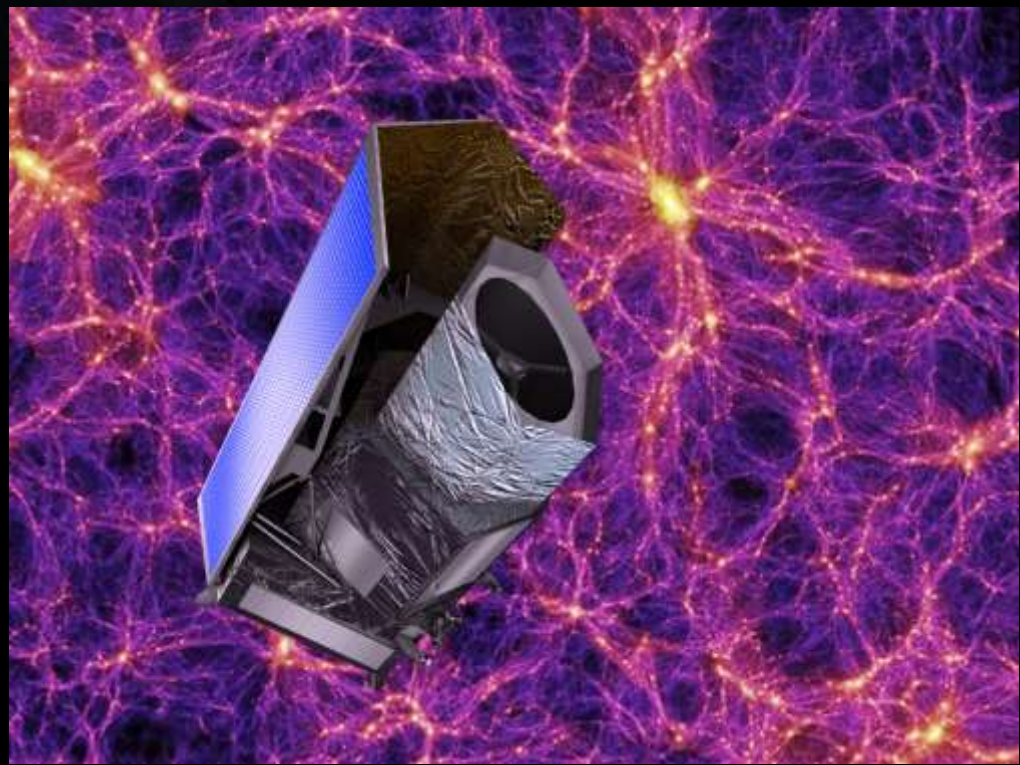
NASA, ESA, Hubble, HPOW


NASA, ESA, Lotz et al

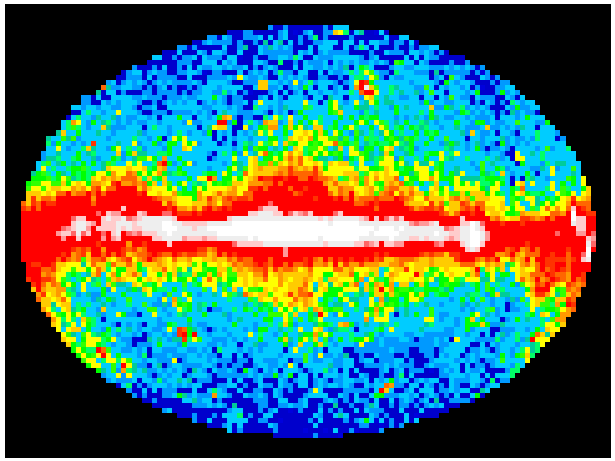
Contents of the Universe

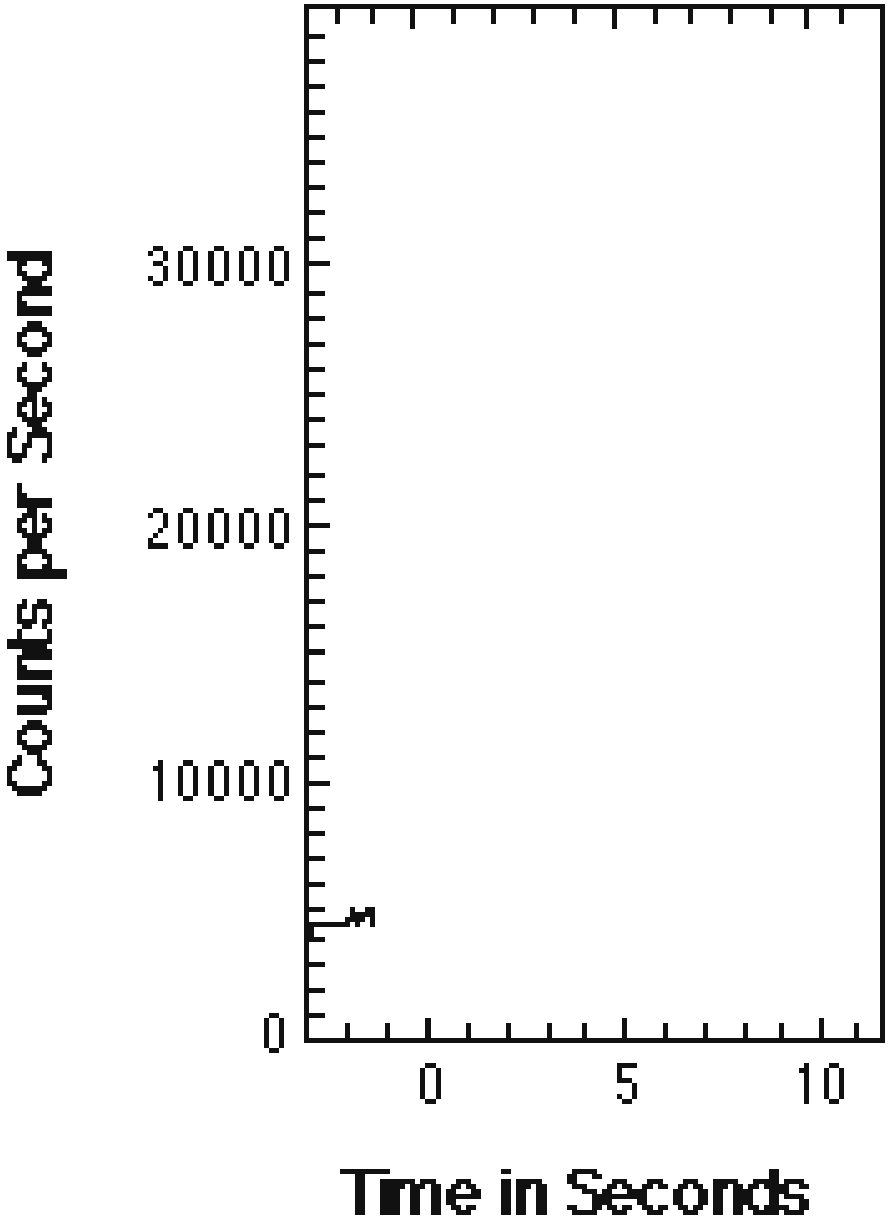


NASA / *WFirst*

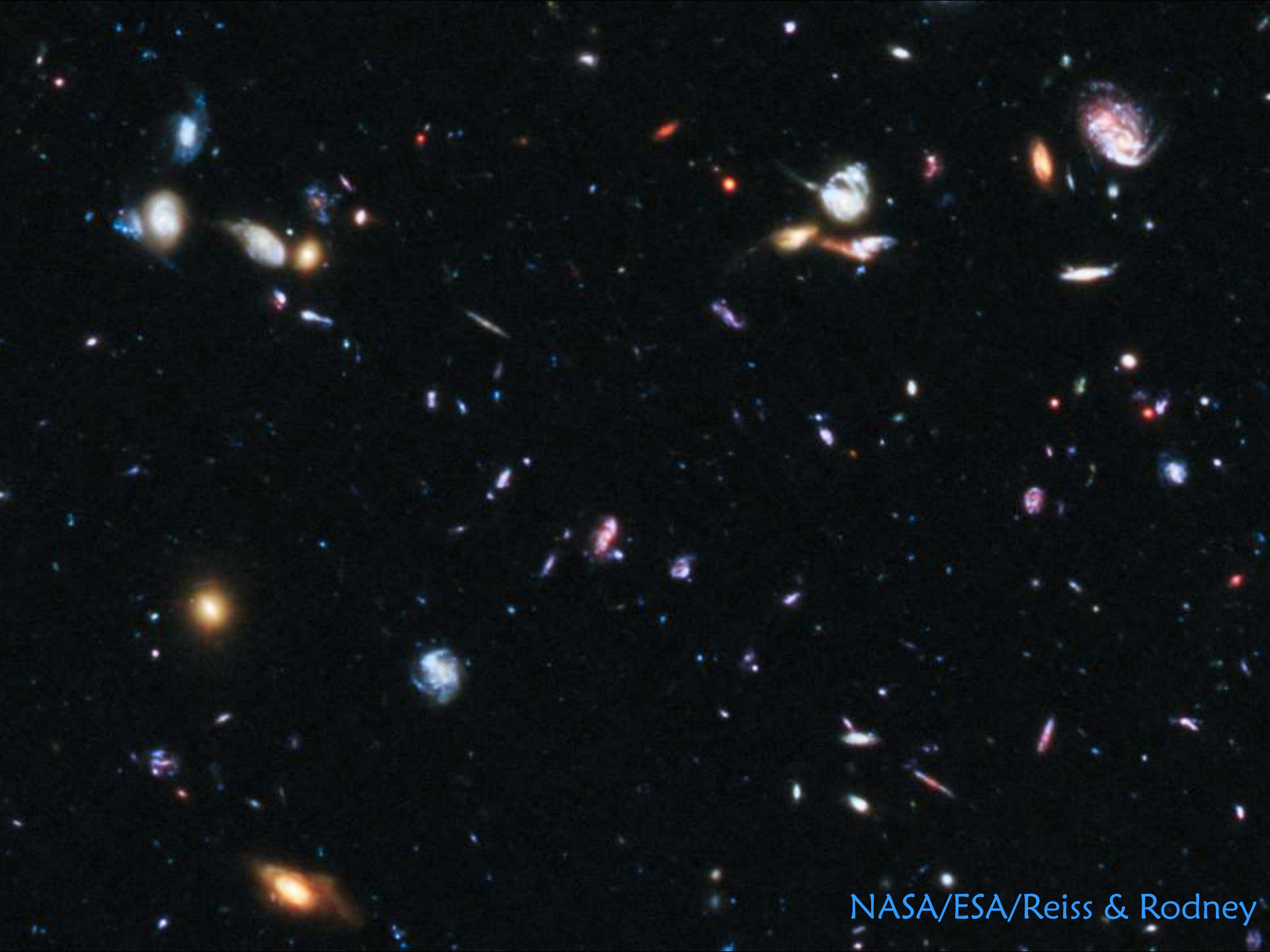


ESA / *Euclid*



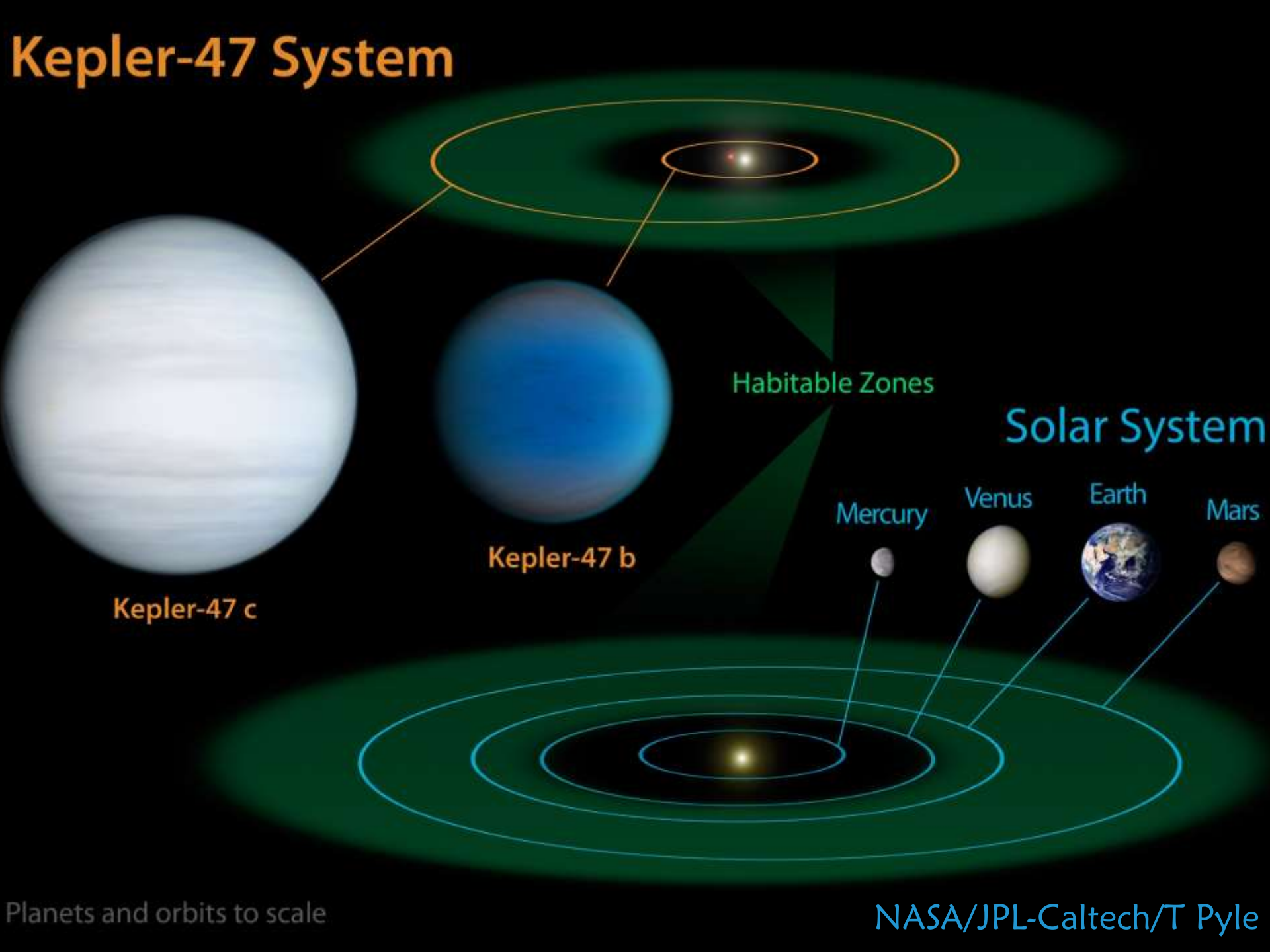

Counts per Second
30000
20000
10000
0
0
5
10
Time in Seconds

NASA

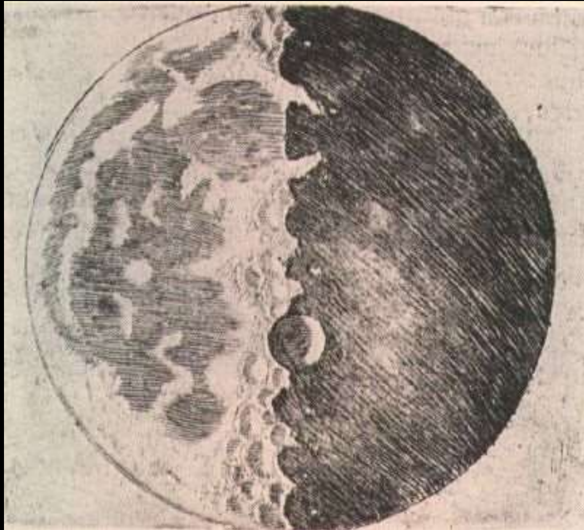

NASA/ESA/Reiss & Rodney

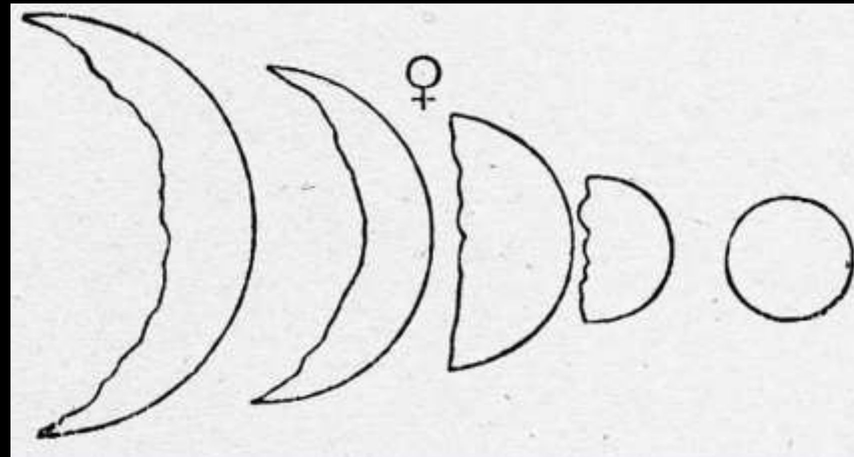

NASA

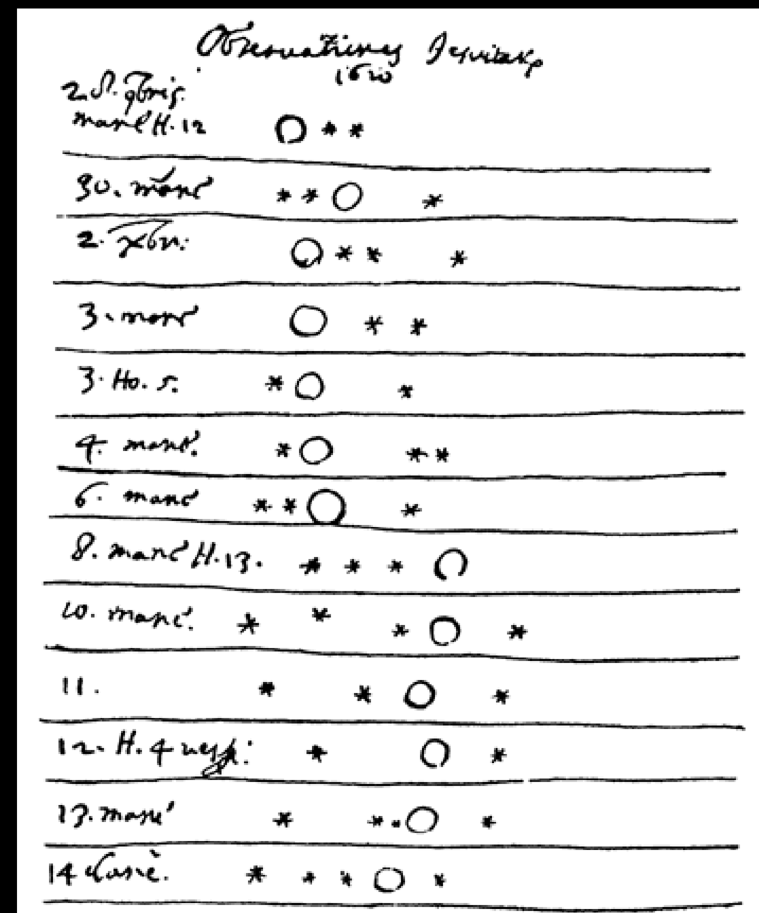

NASA / R Hurt (JPL-Caltech)

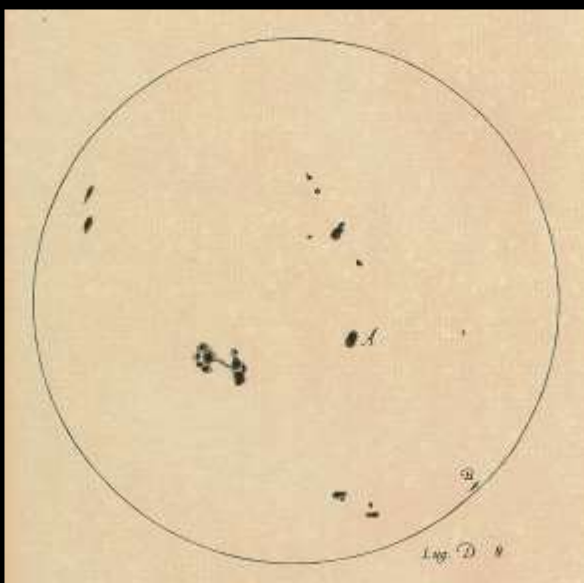

Kepler-47 System
Habitable Zones
Solar System
Mercury
Venus
Earth
Mars
Kepler-47 b
Kepler-47 c
Planets and orbits to scale
NASA/JPL-Caltech/T Pyle

NASA/ESA/Hubble

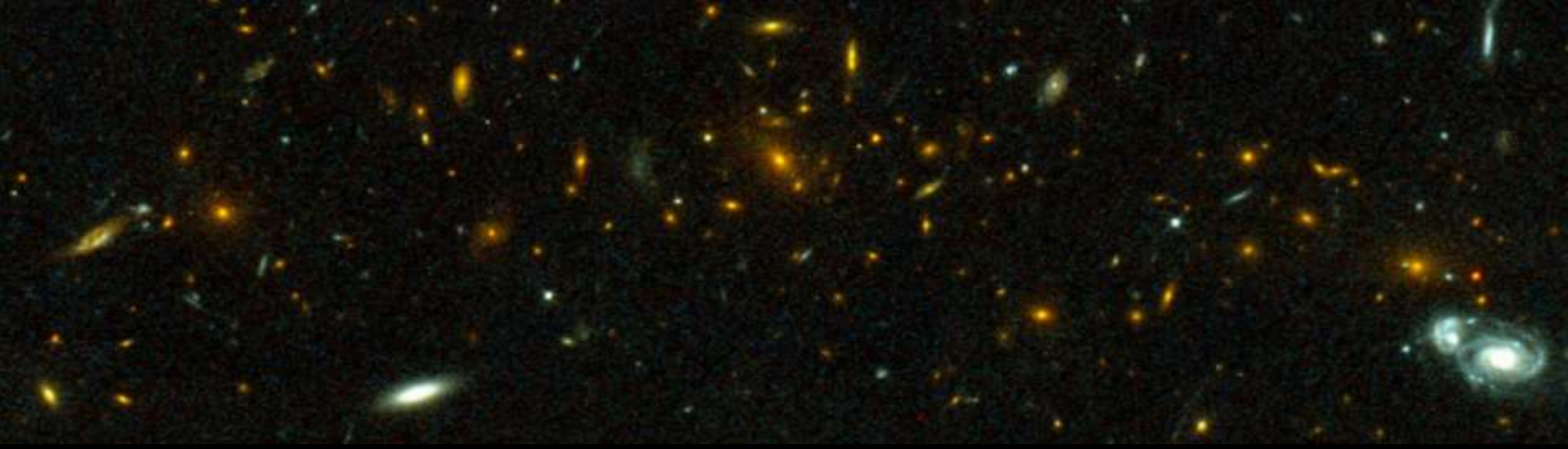



♀


1610
30. mane
3. mane
3. Ho. s.
6. mane
8. mane H. 13.
10. mane
11.
12. H. 4 vesp:
13. mane
14


A
B

Gemini Observatory



radio	micro-wave	infra-red		UV	X-rays	γ-rays

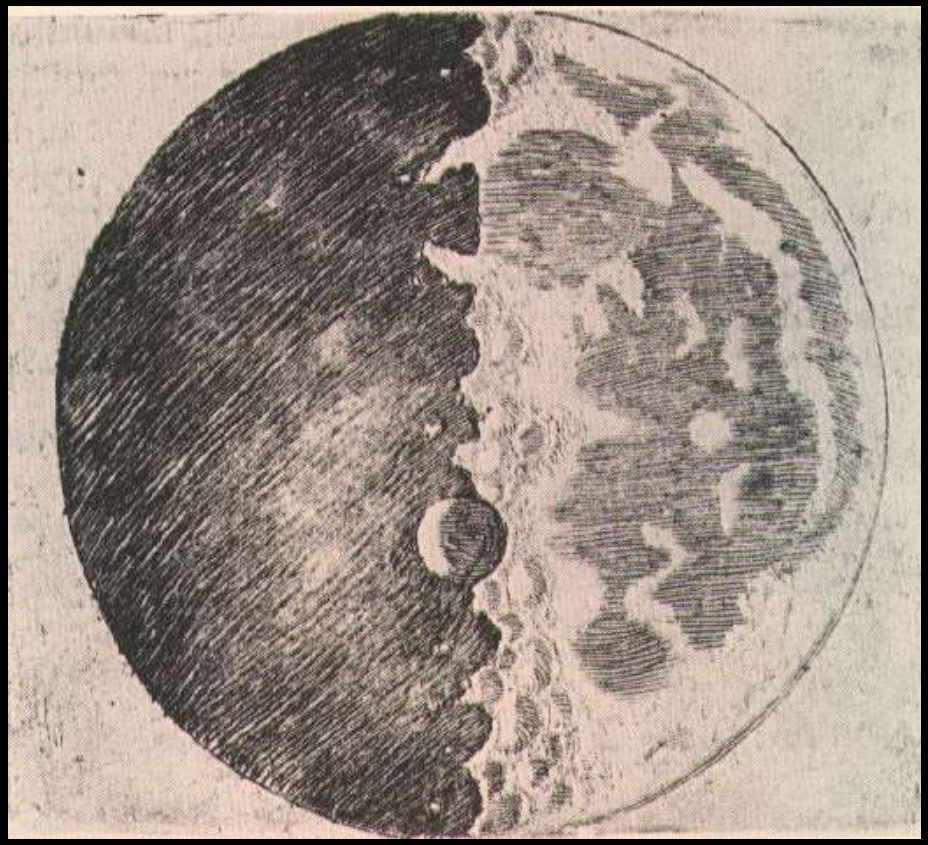




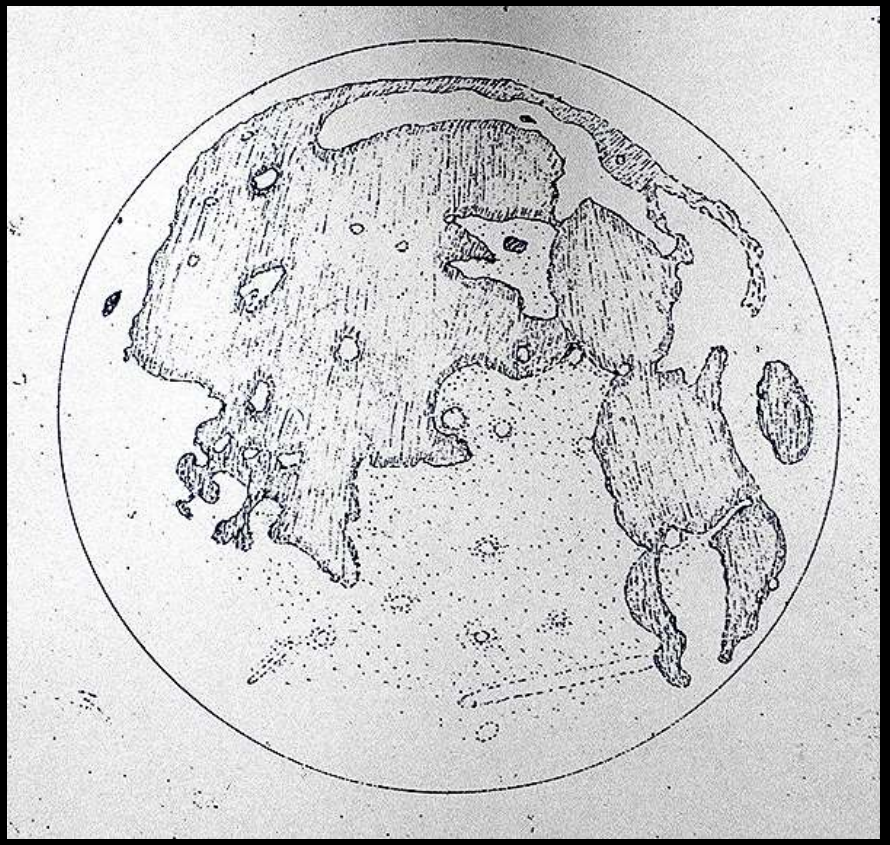
ELECTROMAGNETIC SPECTRUM


ESA/ESO/S Brunier


LSST / NSF



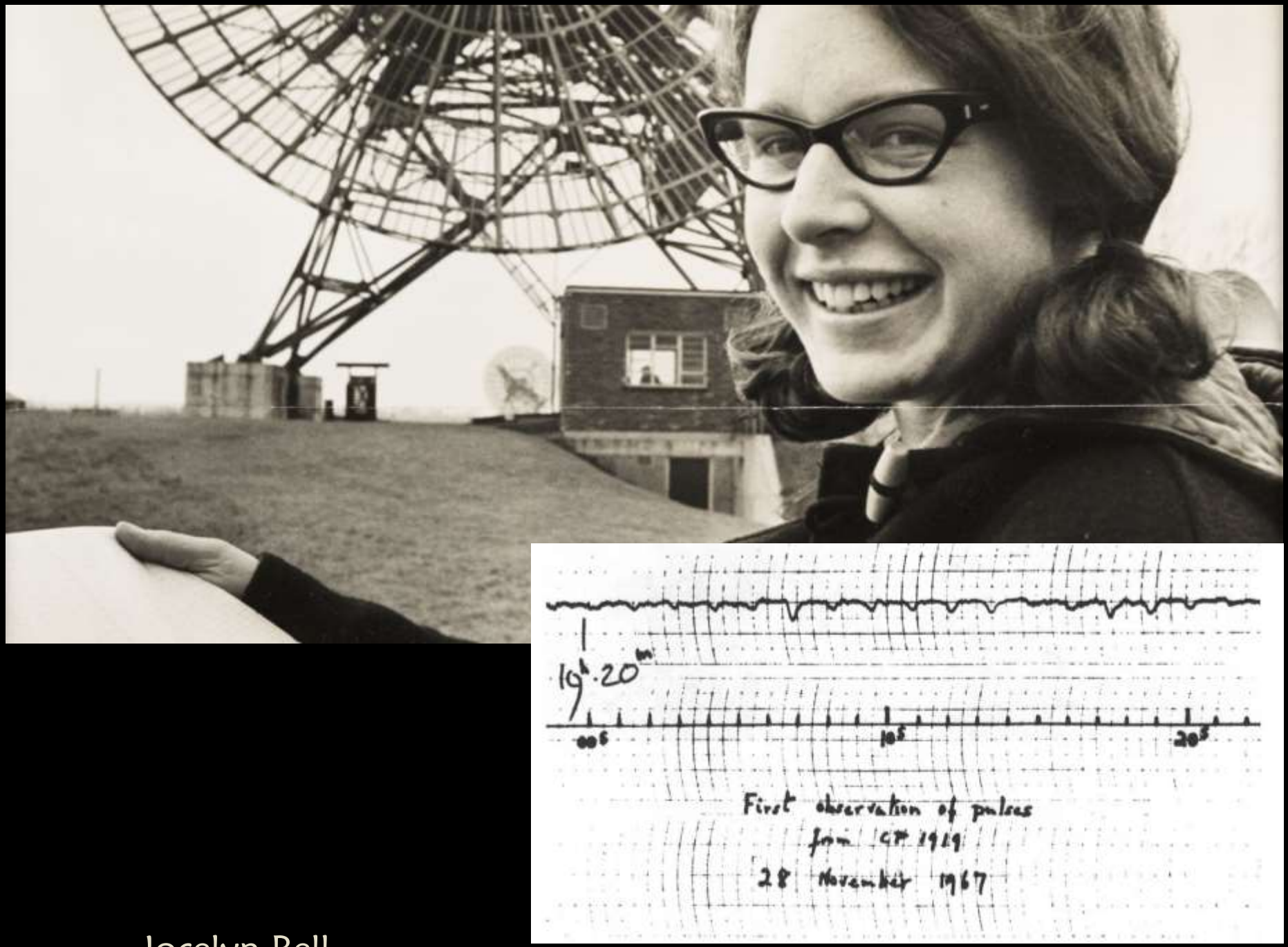
Galileo



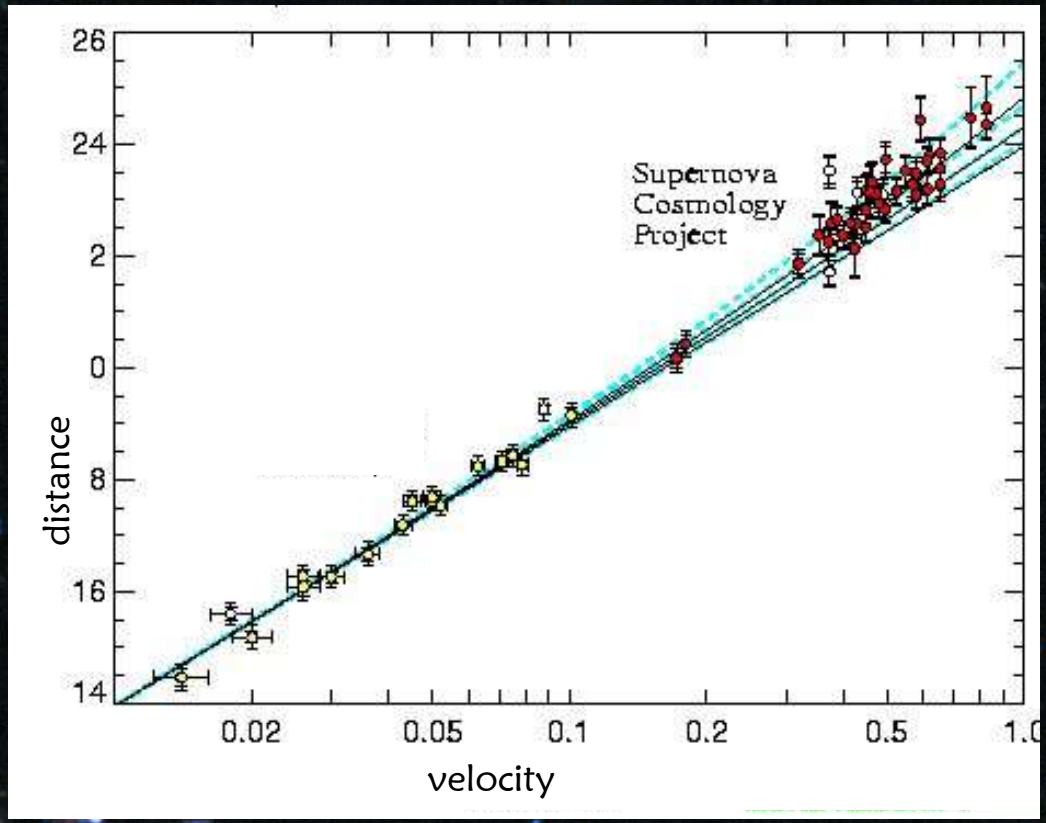
Thomas Harriott

William Herschel

Wilhelm Röntgen



Jocelyn Bell

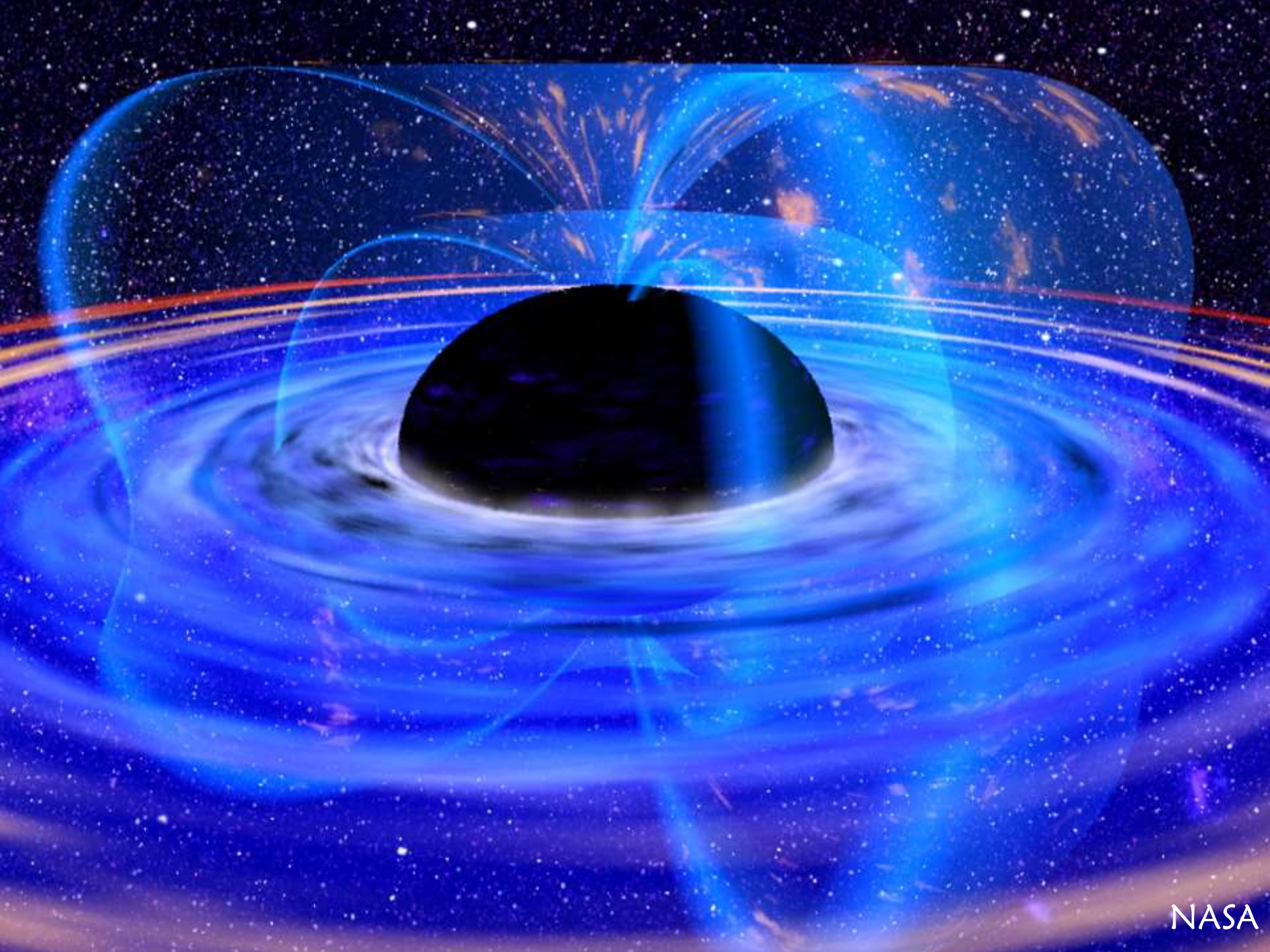


Perlmutter

Schmidt

Riess

NASA/ESA/Riess et al

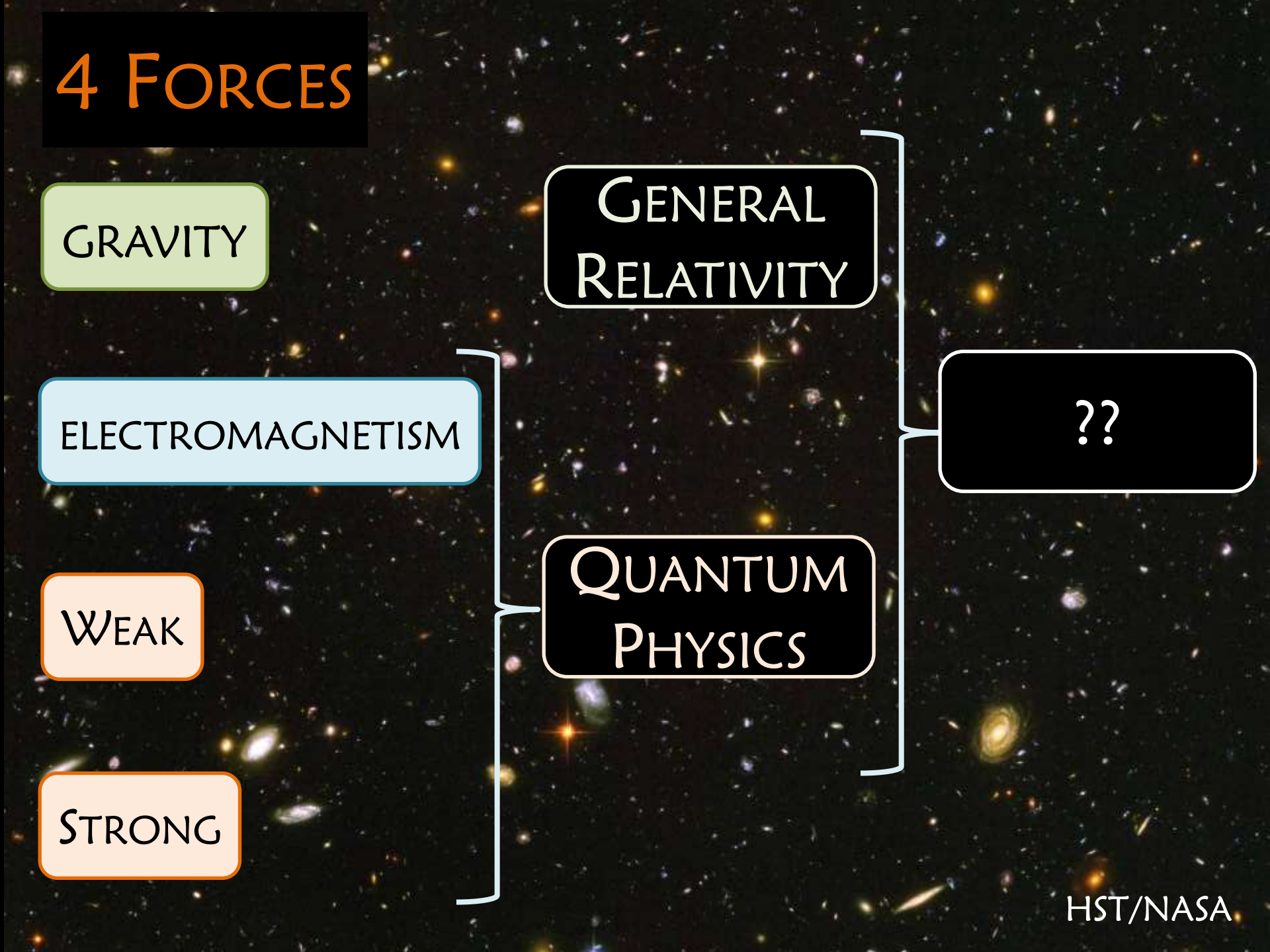

NASA

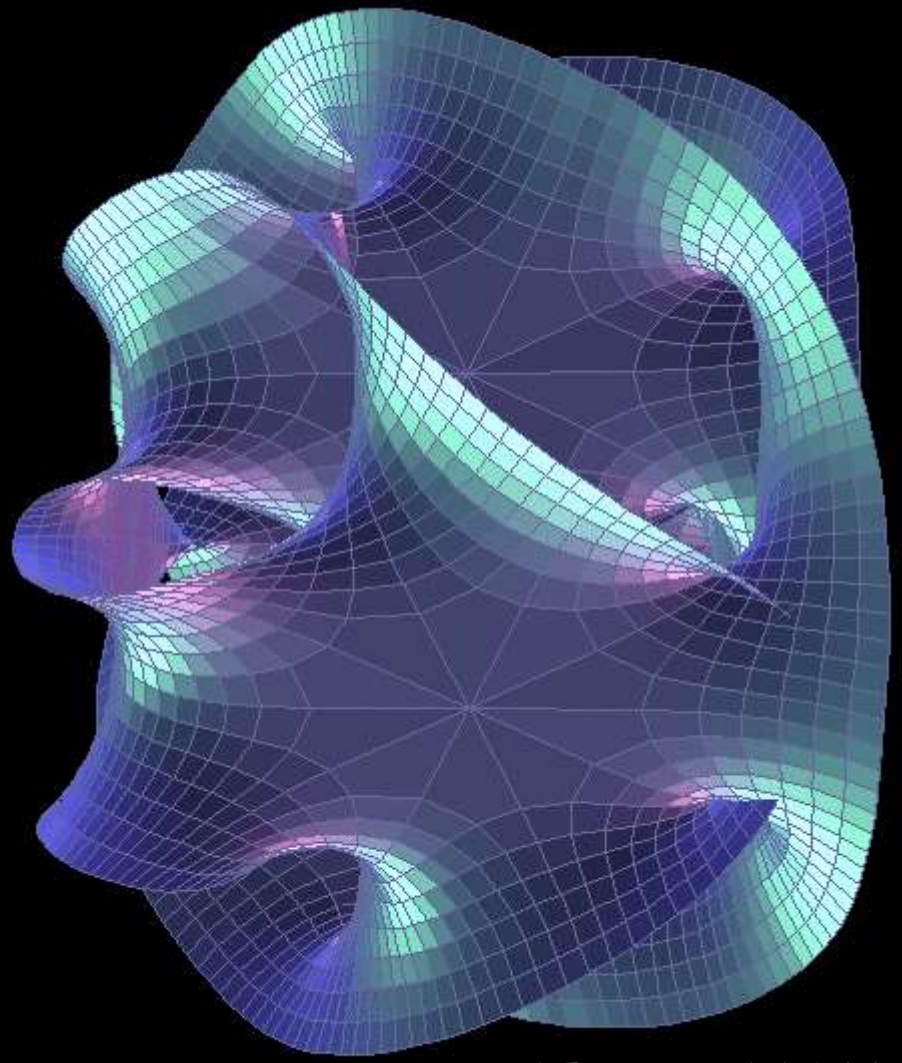
4 Forces

- Gravity
- Electromagnetism
- Weak
- Strong

- General Relativity
- Quantum Physics

- ??

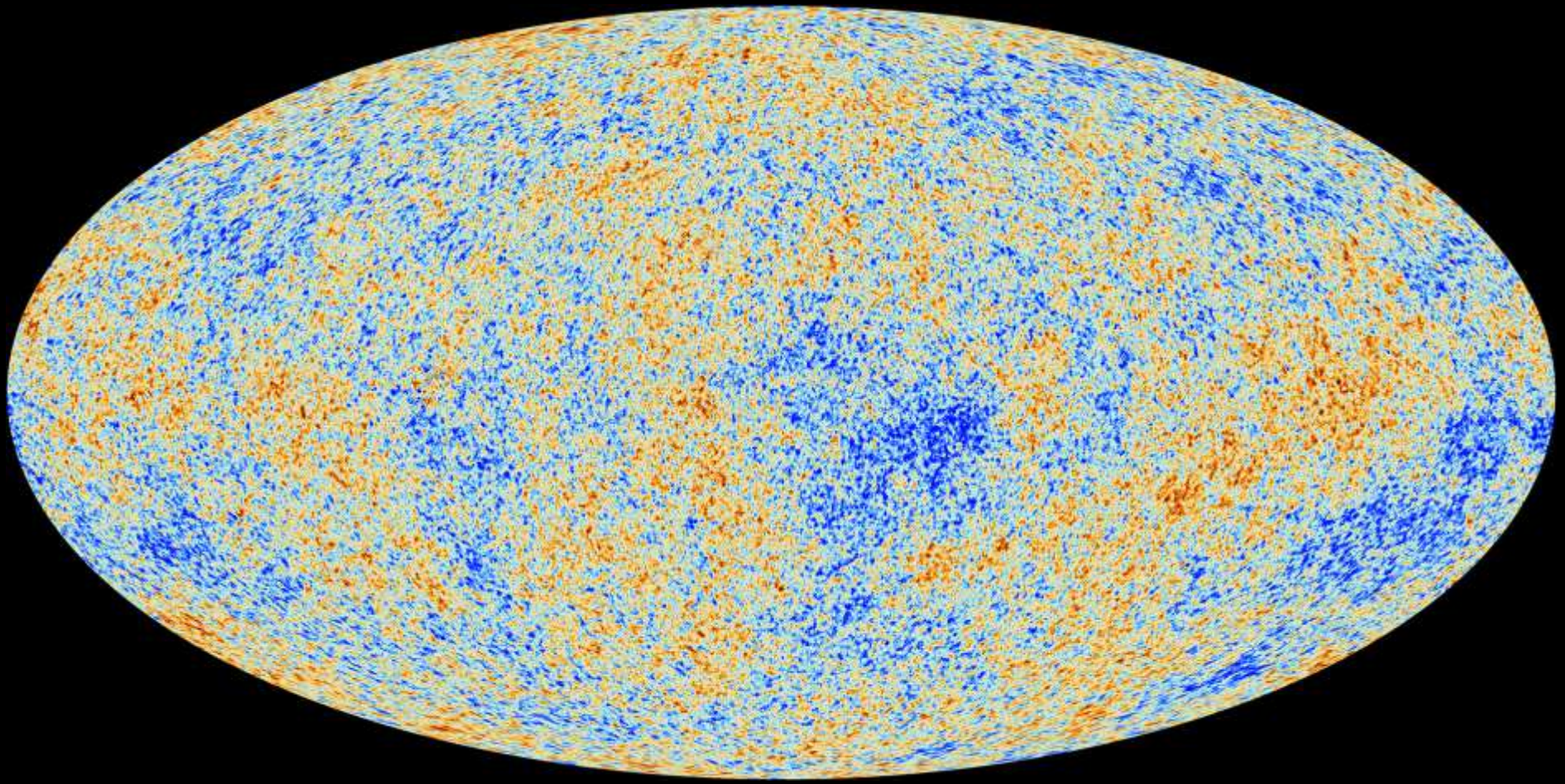




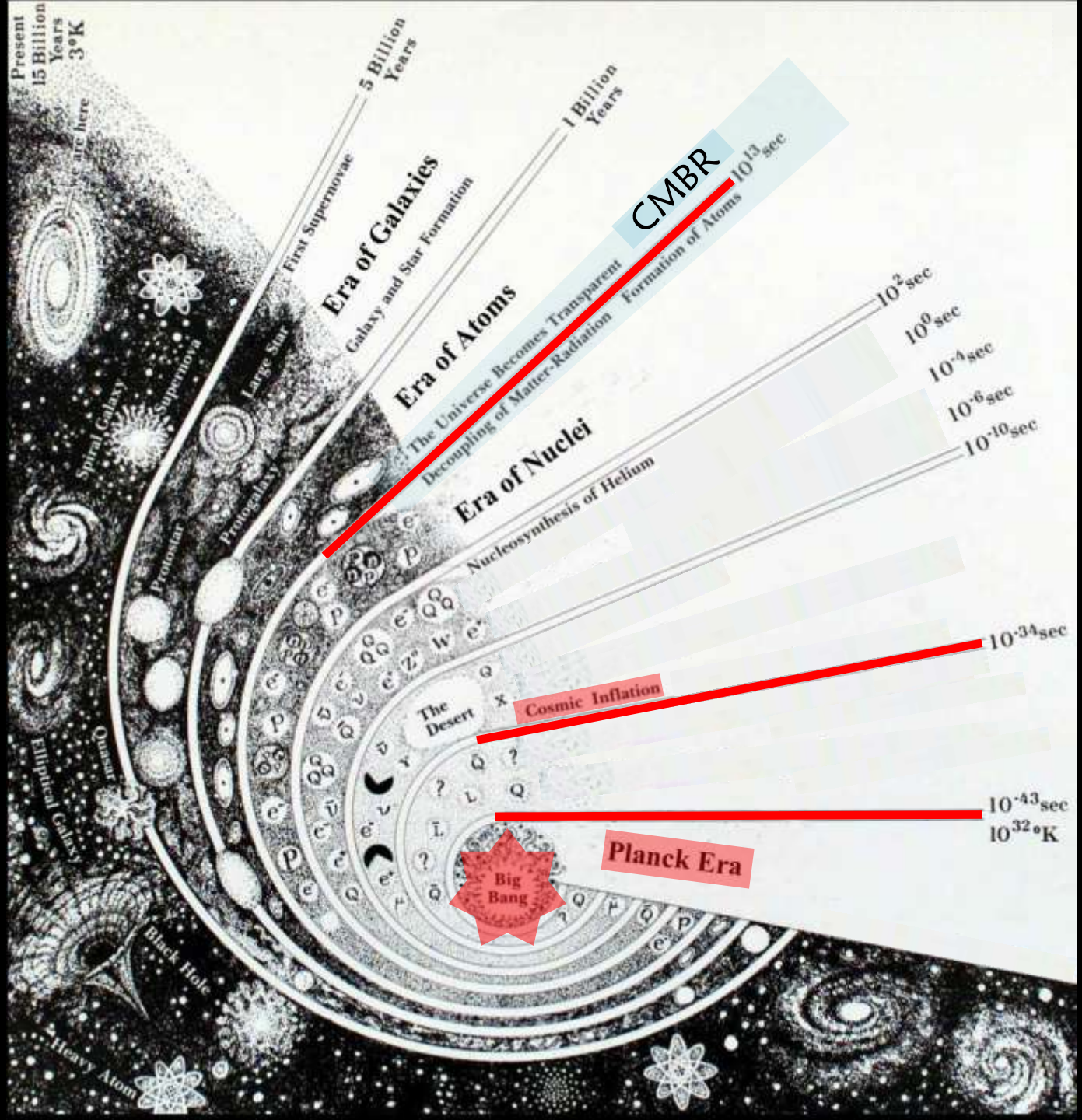
J Bryant / AJ Hanson

“How the Universe works”

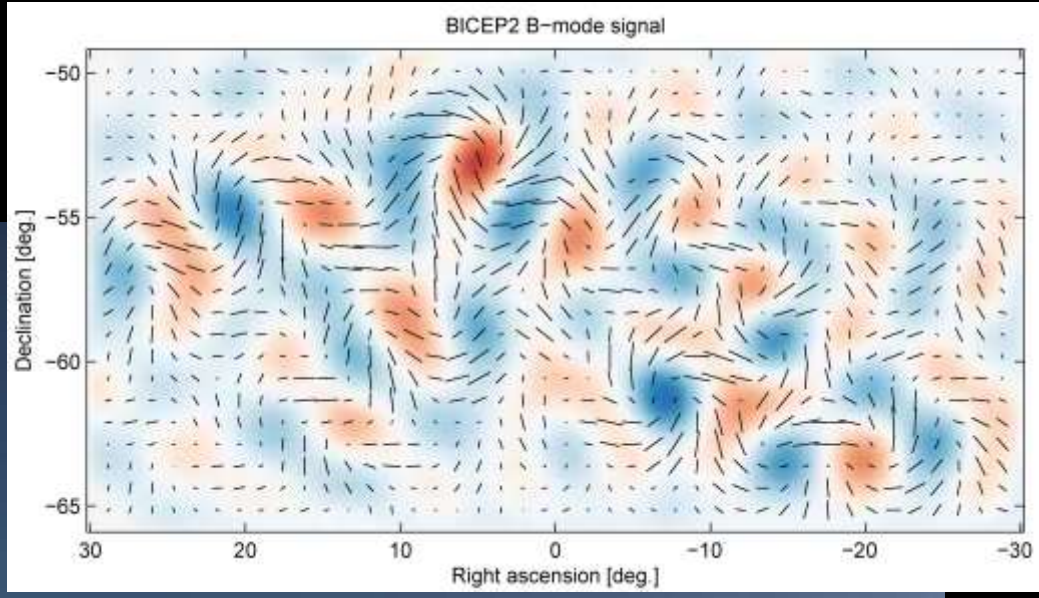
Planck



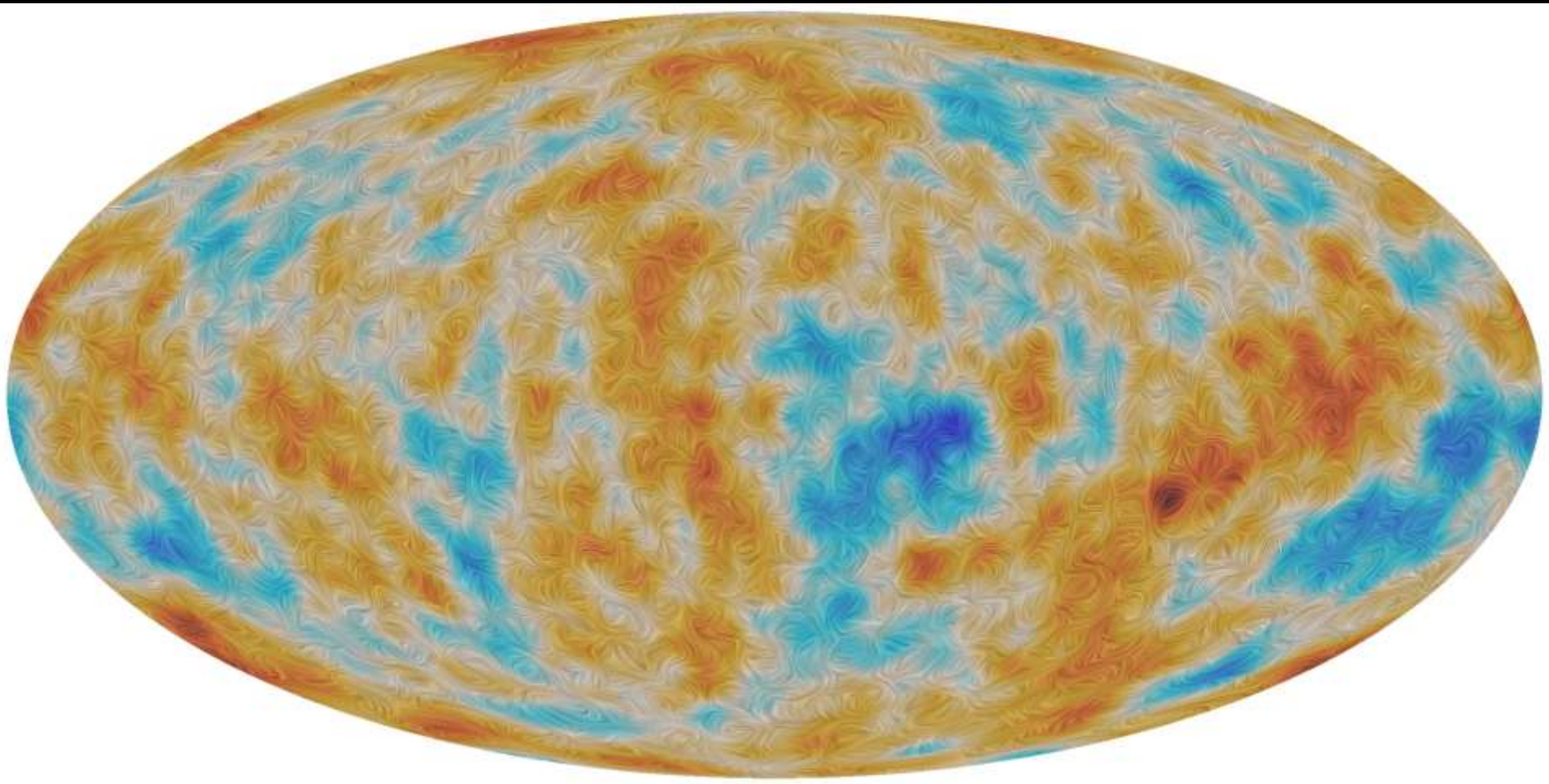
ESA / *Planck* collaboration


Present
15 Billion Years
3°K
We are here
5 Billion Years
First Supernovae
Era of Galaxies
Galaxy and Star Formation
1 Billion Years
Era of Atoms
The Universe Becomes Transparent
Decoupling of Matter-Radiation
Formation of Atoms
CMBR
10^{13}sec
Era of Nuclei
Nucleosynthesis of Helium
10^{2}sec
10^{0}sec
10^{-4}sec
10^{-6}sec
10^{-10}sec
10^{-34}sec
Cosmic Inflation
The Desert
10^{-43}sec
10^{32}°K
Planck Era
Big Bang
Spiral Galaxy
Supernova
Large Star
Protogalaxy
Protostar
Quasar
Elliptical Galaxy
Black Hole
Heavy Atom

Fermilab


BICEP2 B−mode signal
−50
−55
−60
−65
Declination [deg.]
30
20
10
0
−10
−20
−30
Right ascension [deg.]

BICEP 2

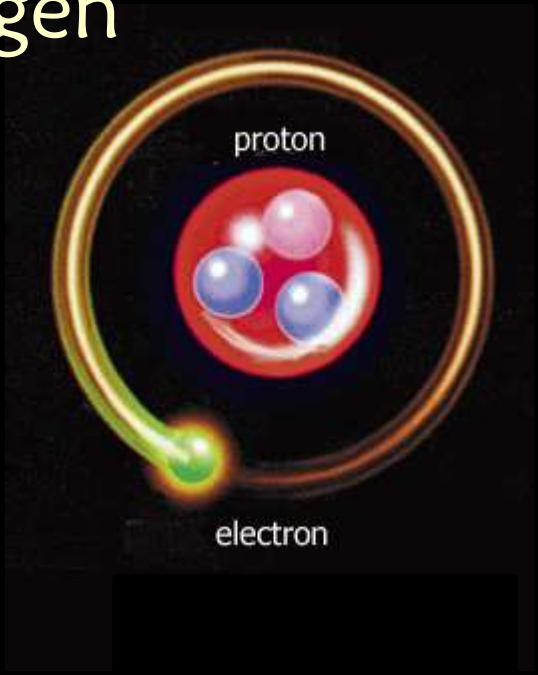


ESA / Planck

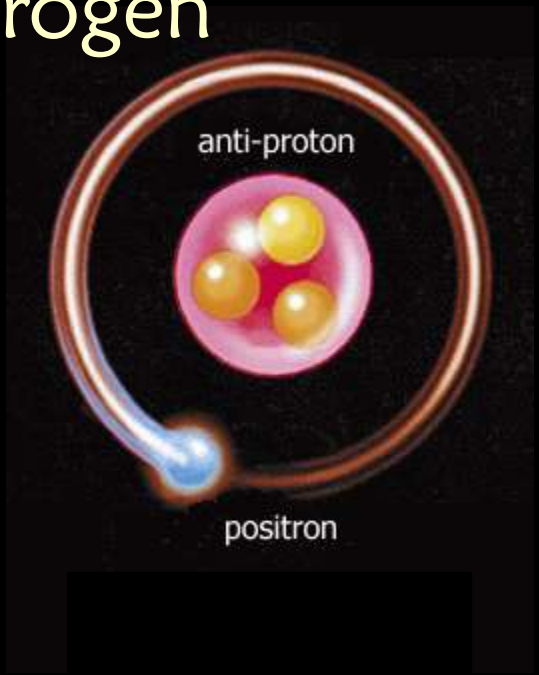
“How the Universe works”

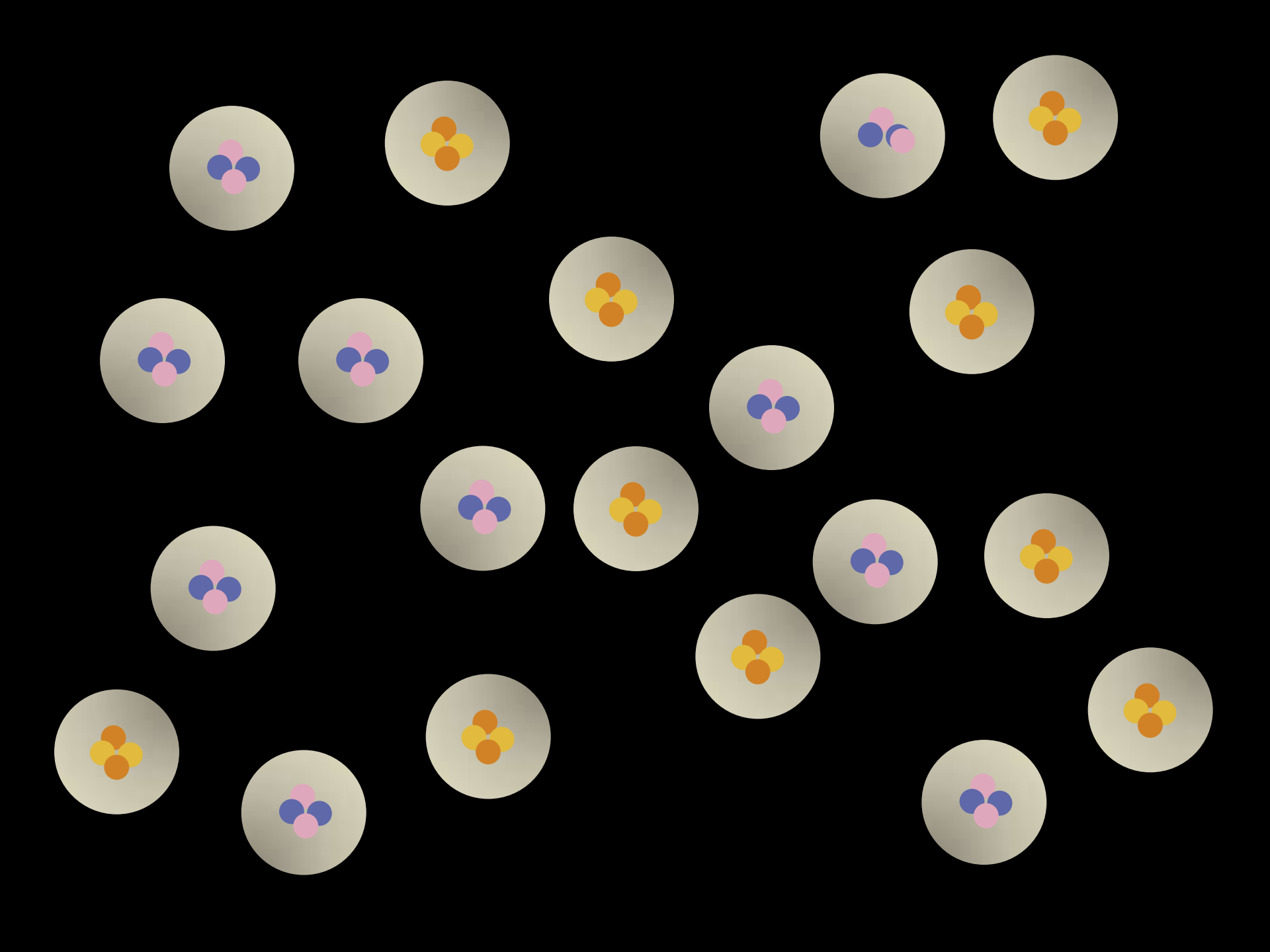
Particle		Anti-particle	
electron	-	positron	+
proton	+	antiproton	-
neutrino		antineutrino	

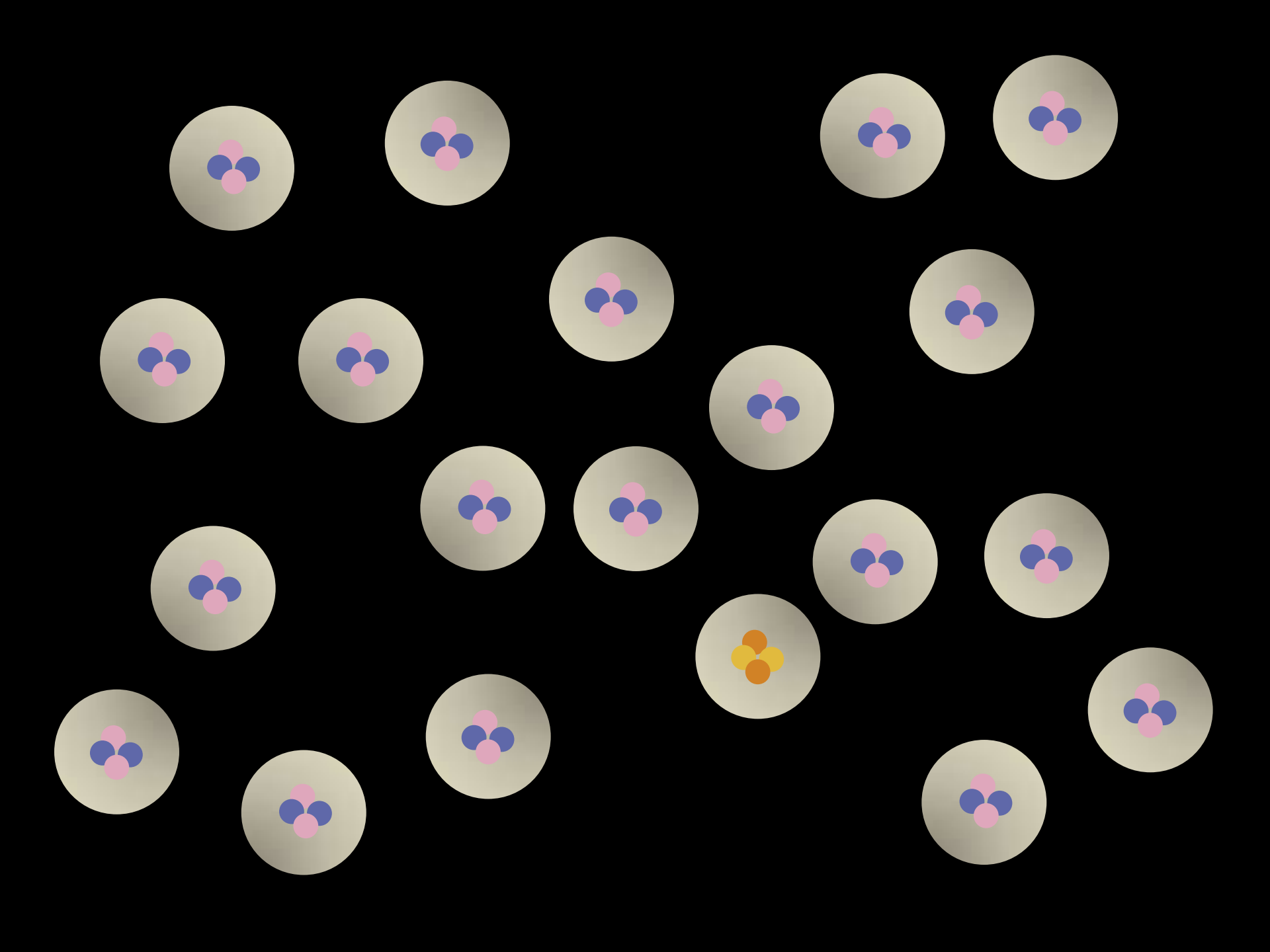
hydrogen



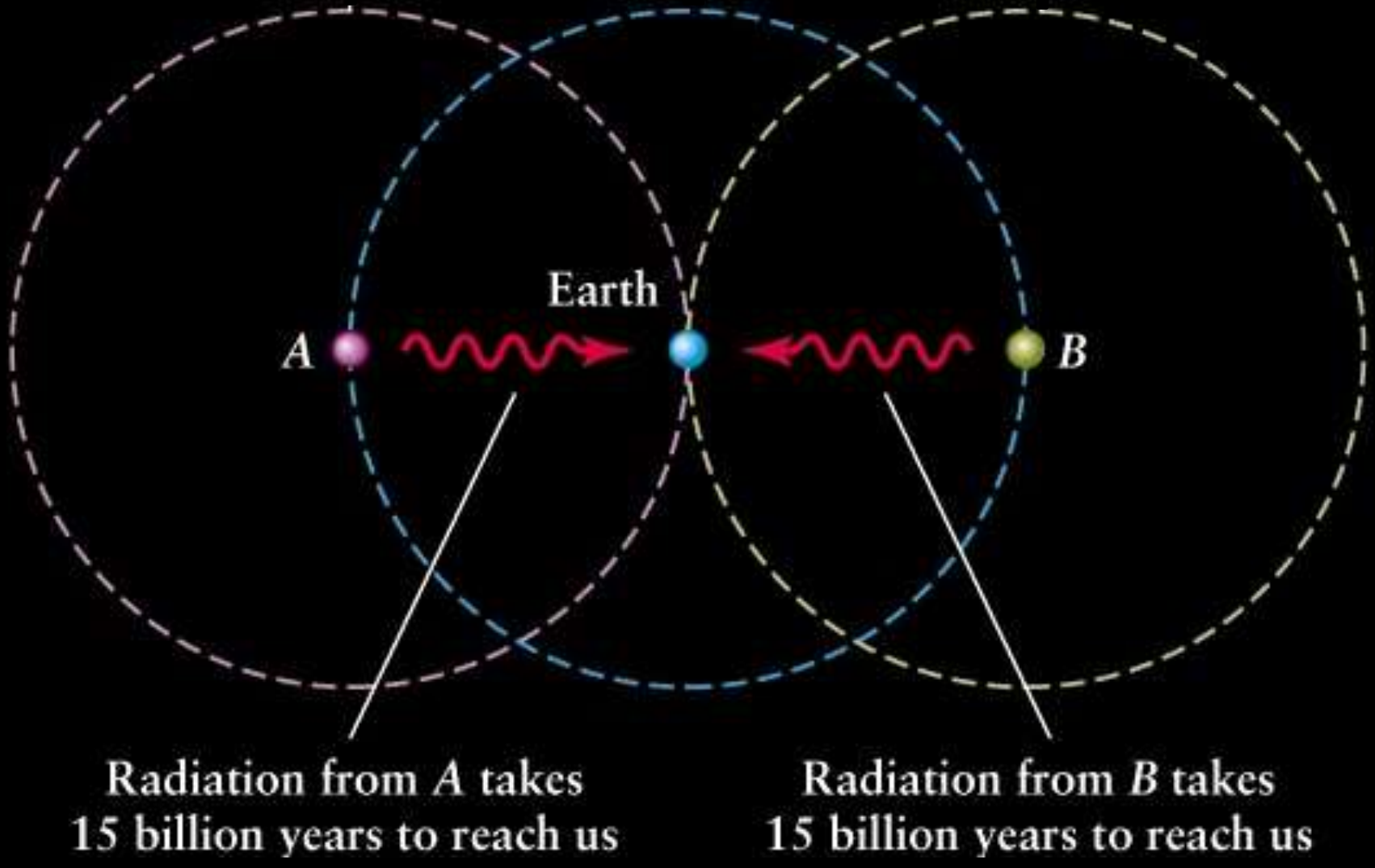
anti-hydrogen

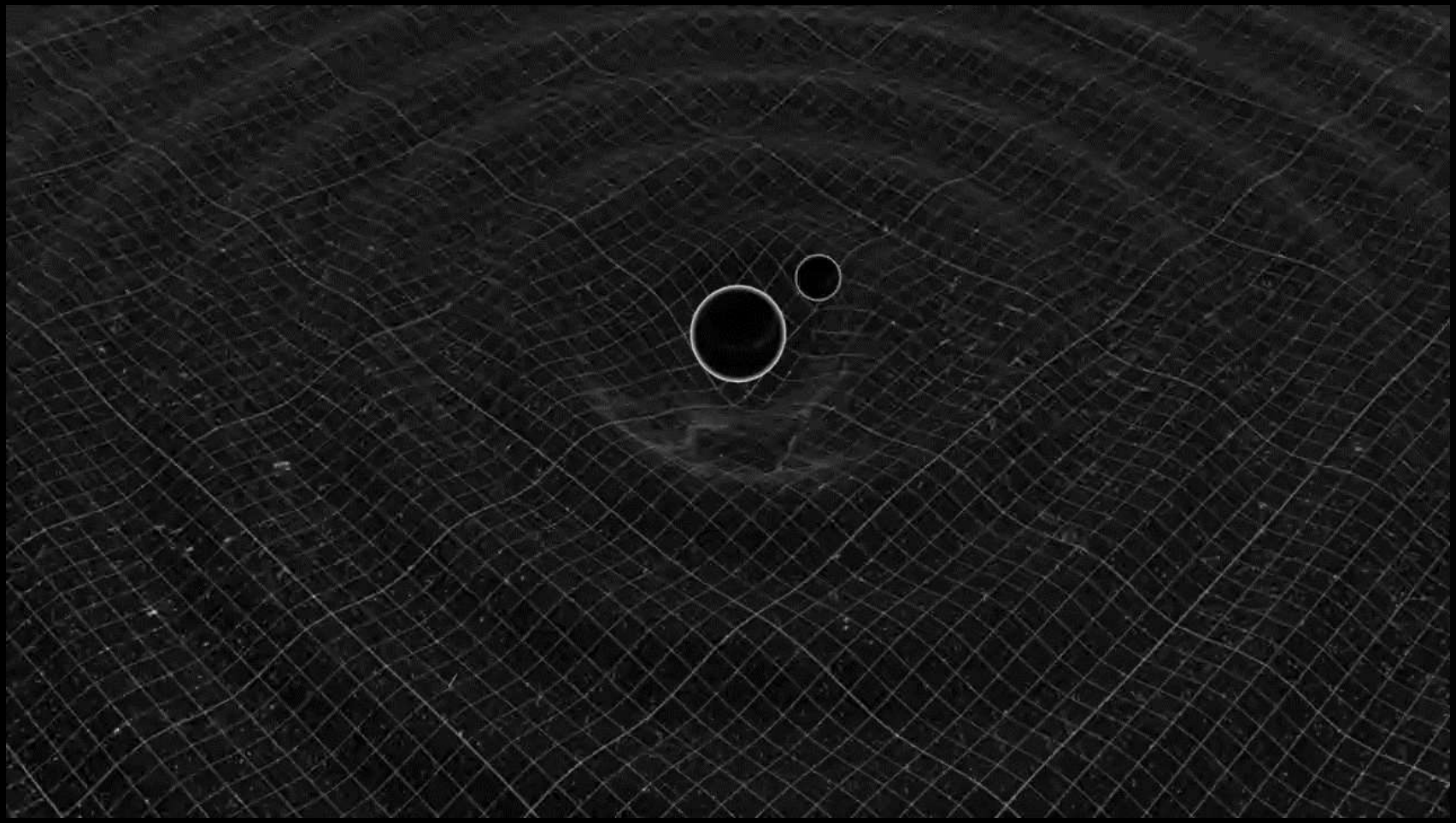






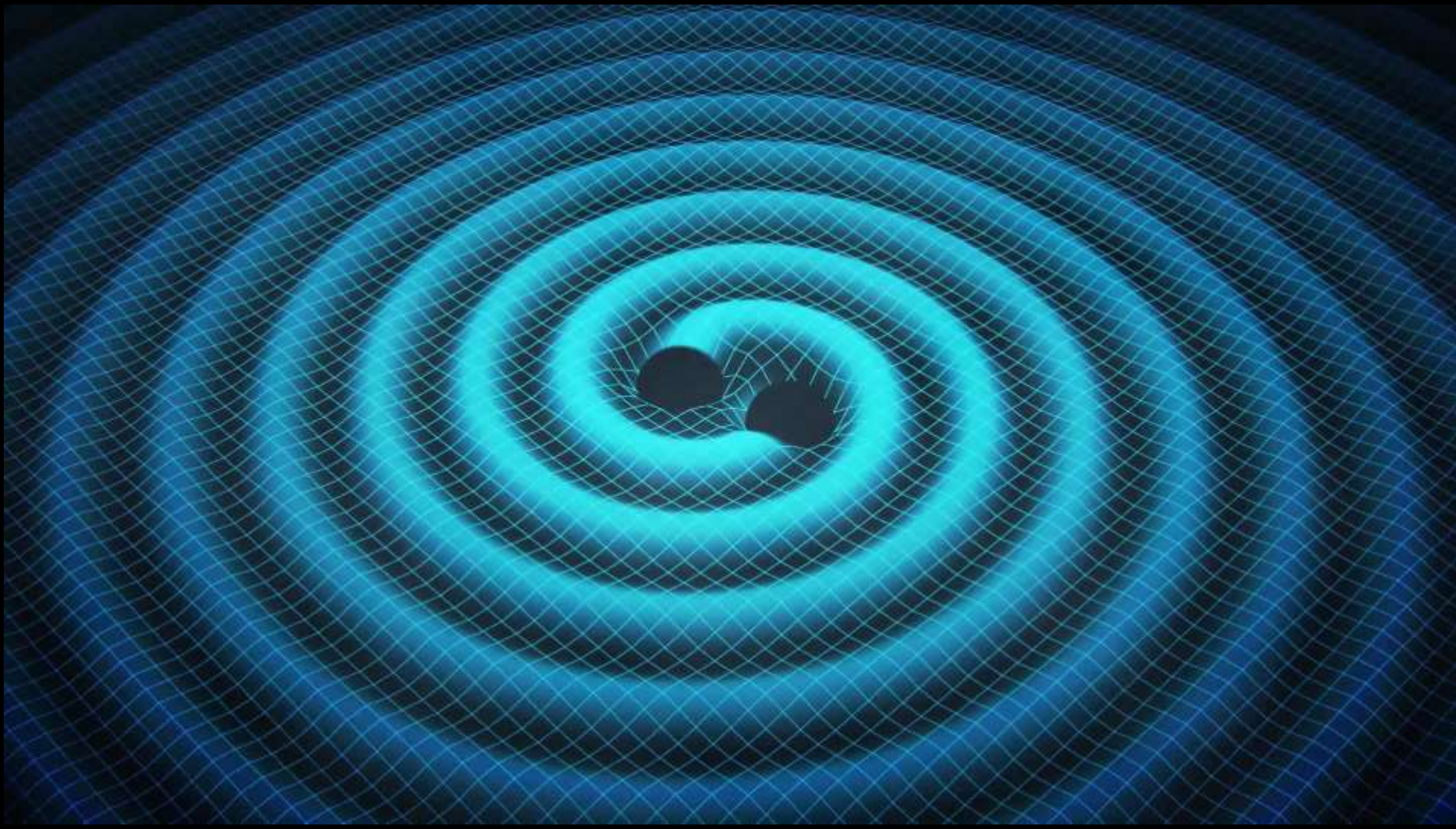

BellaCielo


Earth
A
B
Radiation from A takes
15 billion years to reach us
Radiation from B takes
15 billion years to reach us

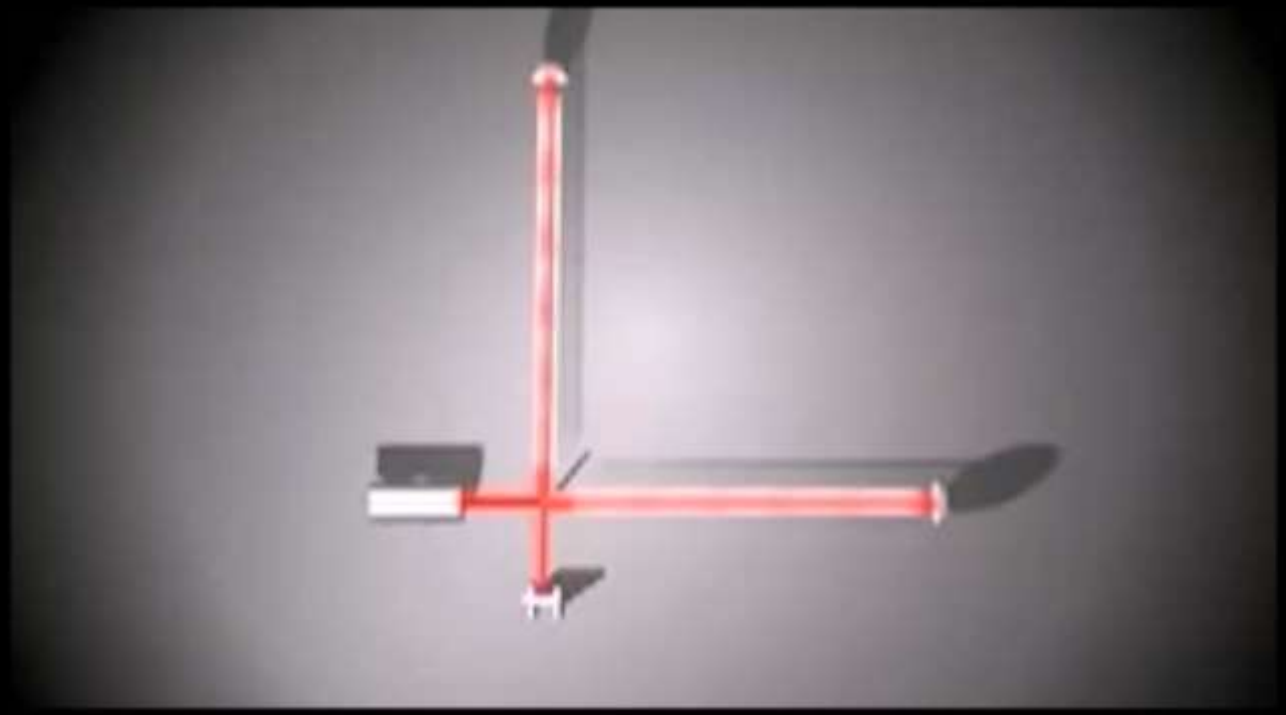


Northwestern Visualization

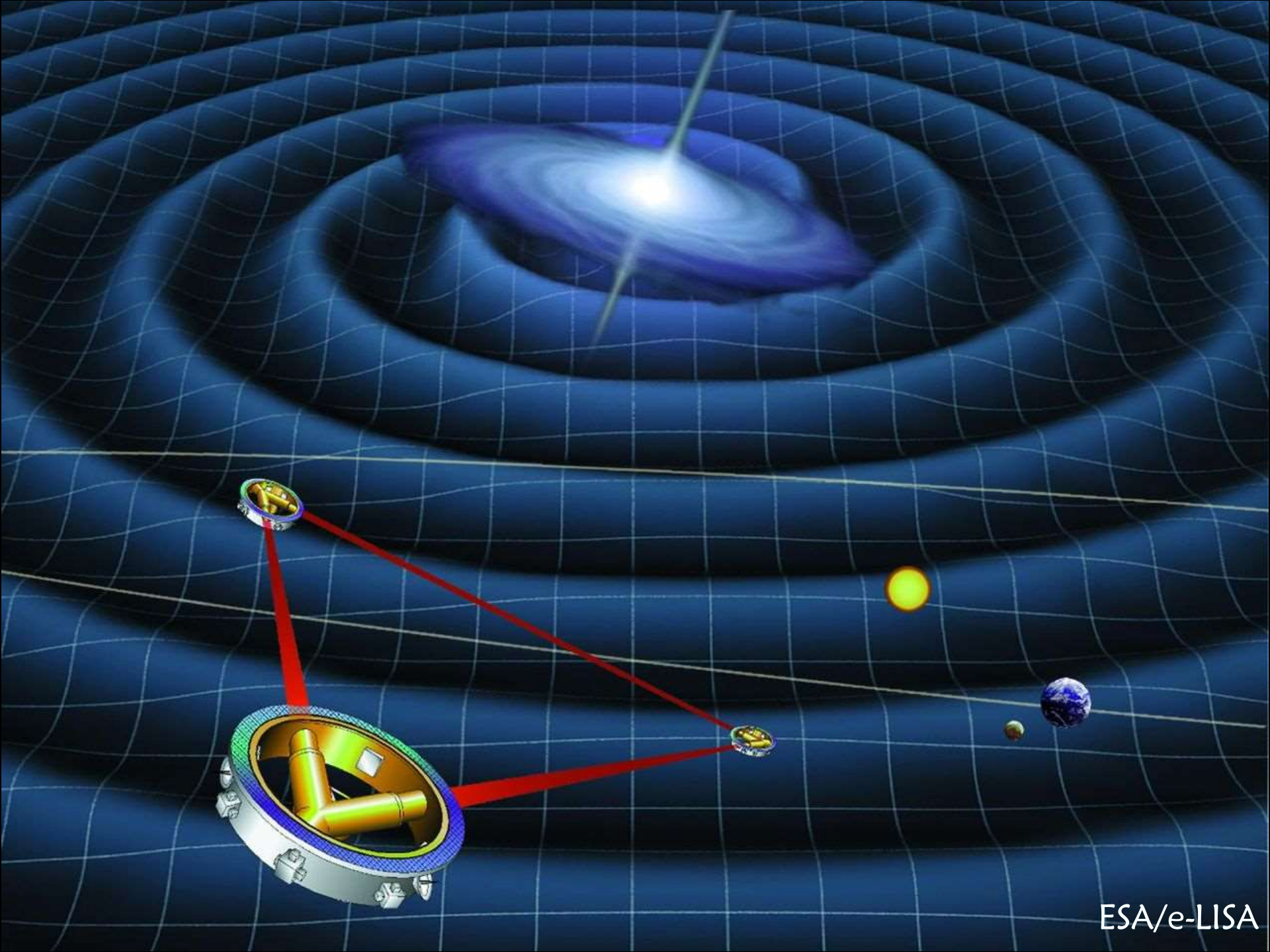
GSFC / D Berry

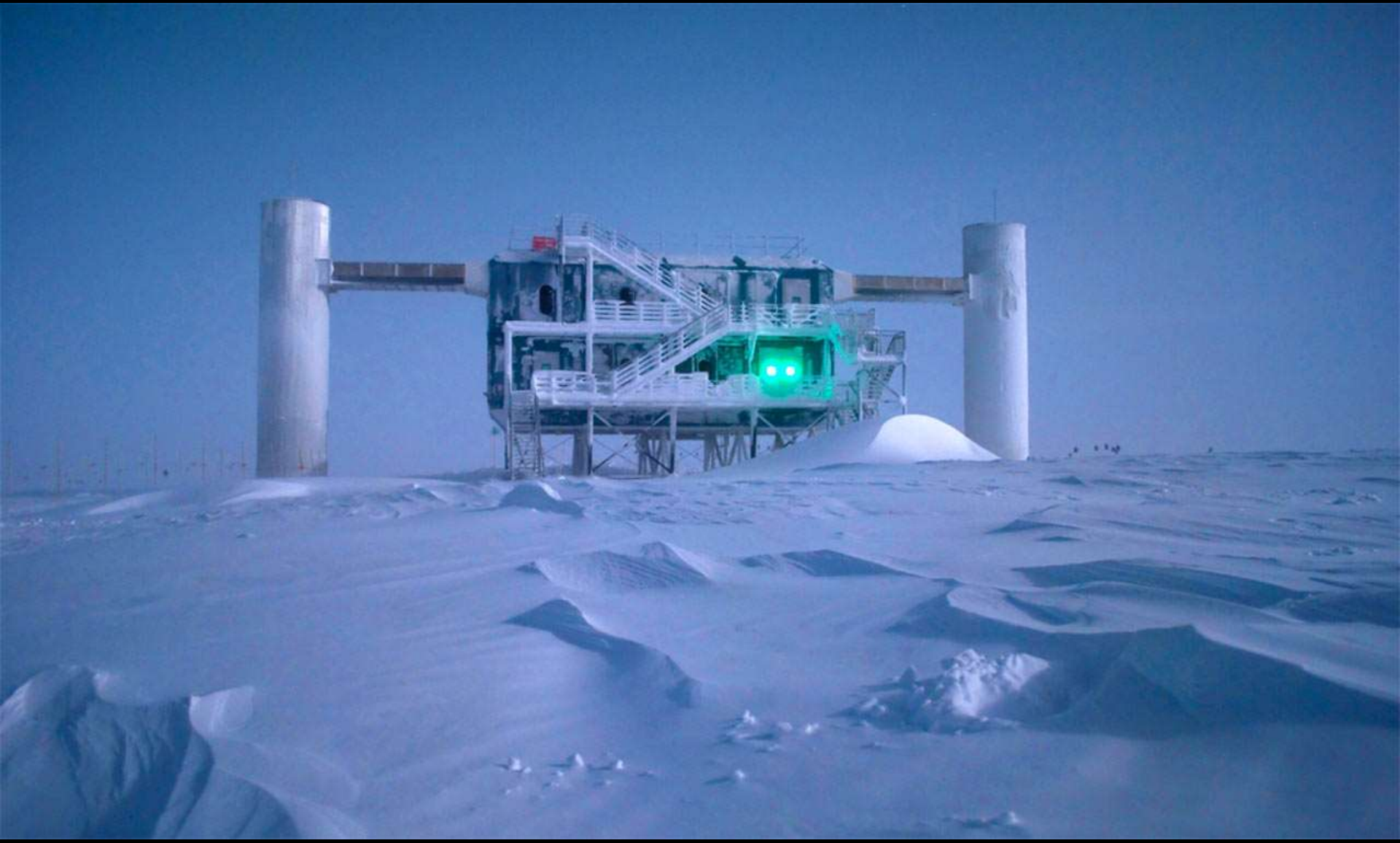


Swinburne Astronomy Productions

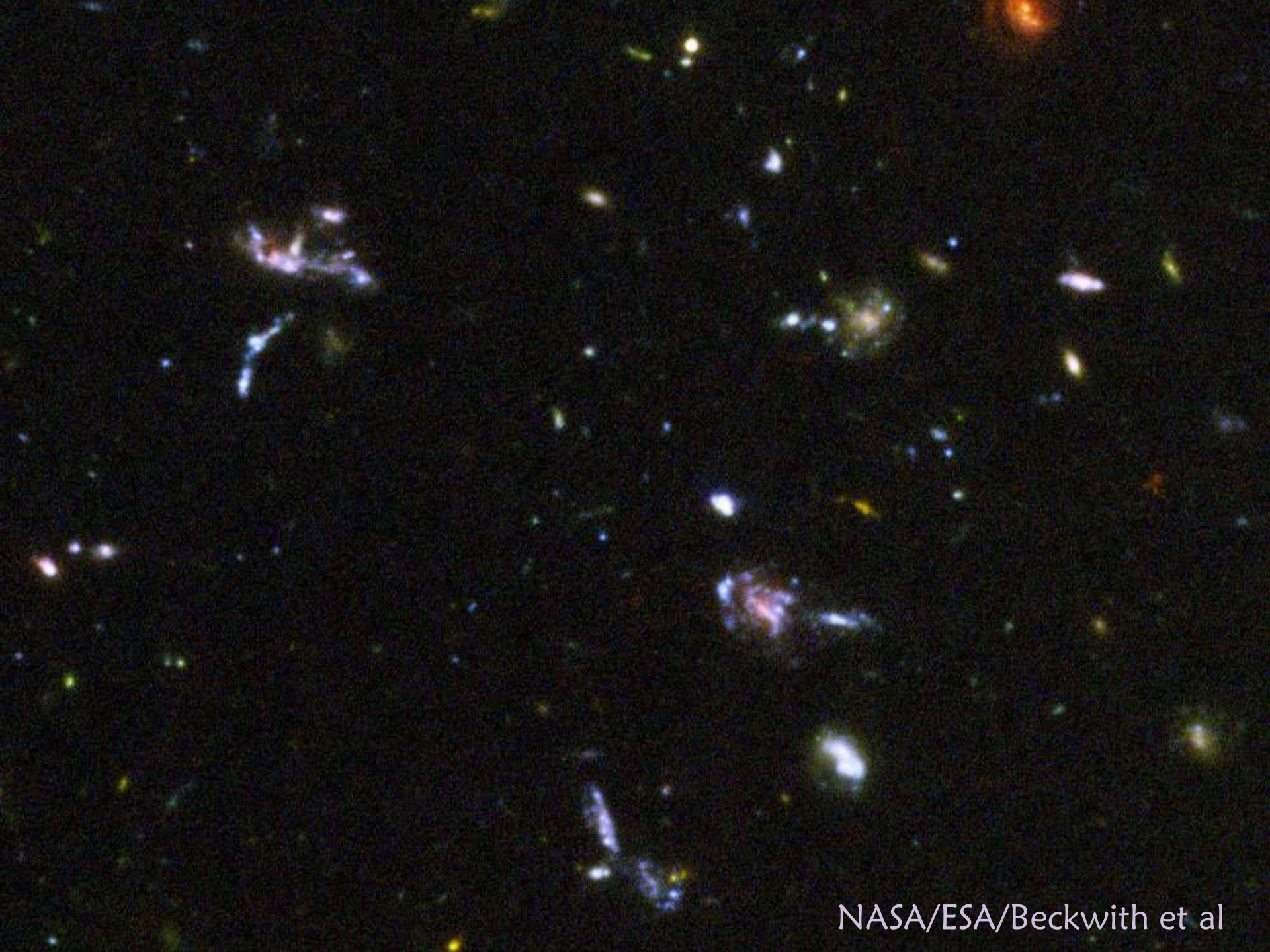


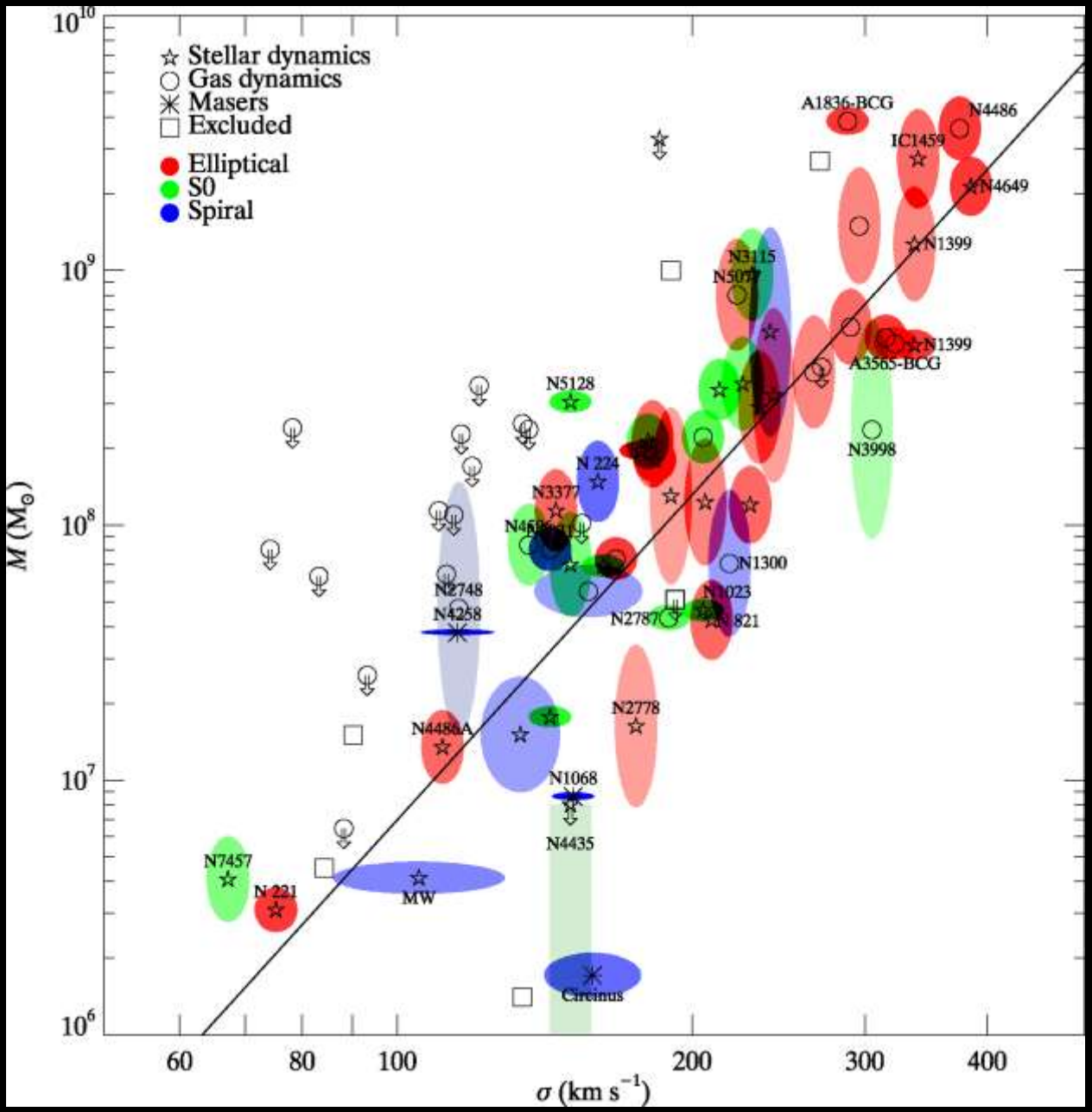
LIGO


ESA/e-LISA



ICECUBE/Jacobi/NSF

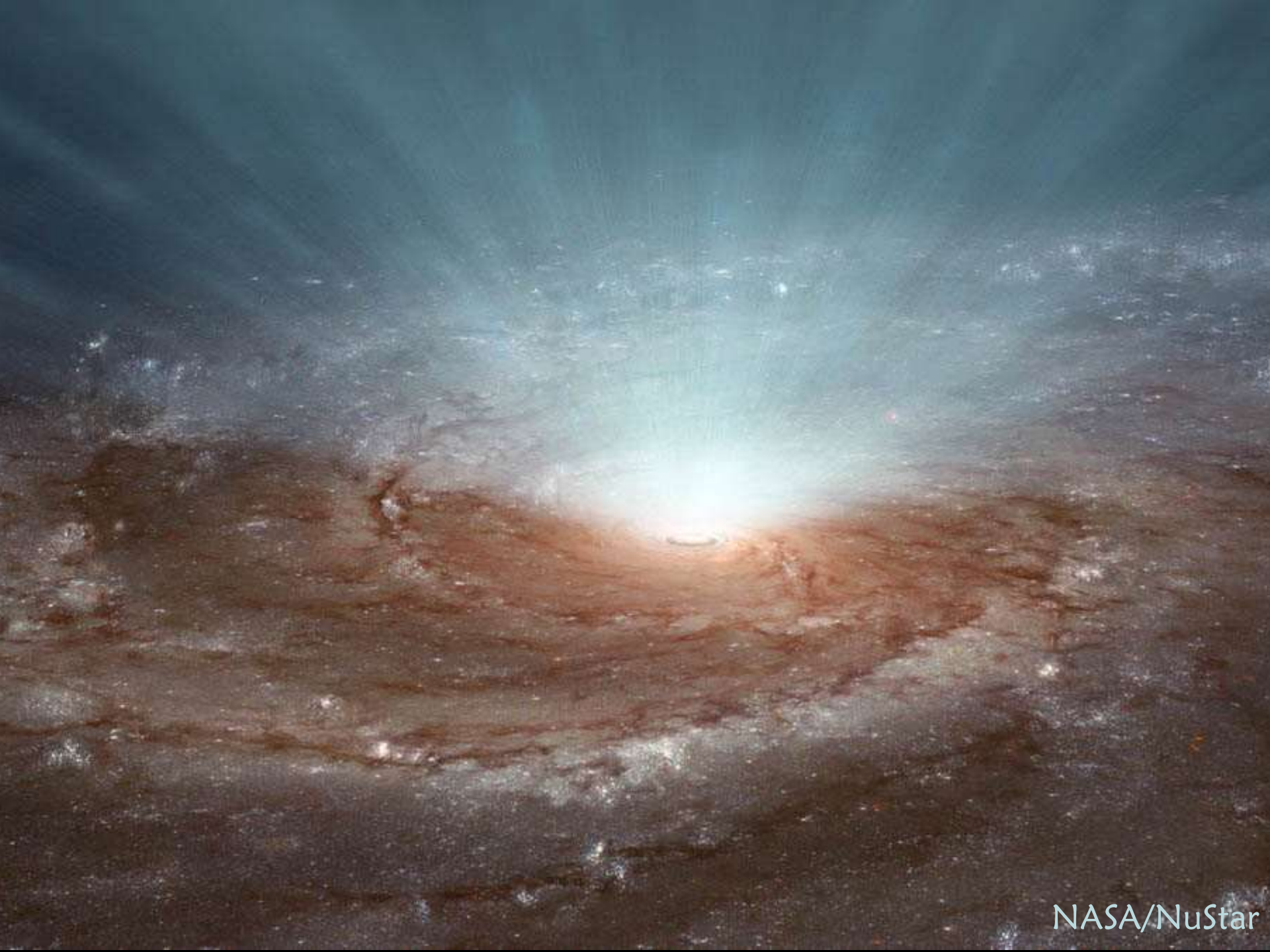

NASA/ESA/Beckwith et al



Mass of black hole

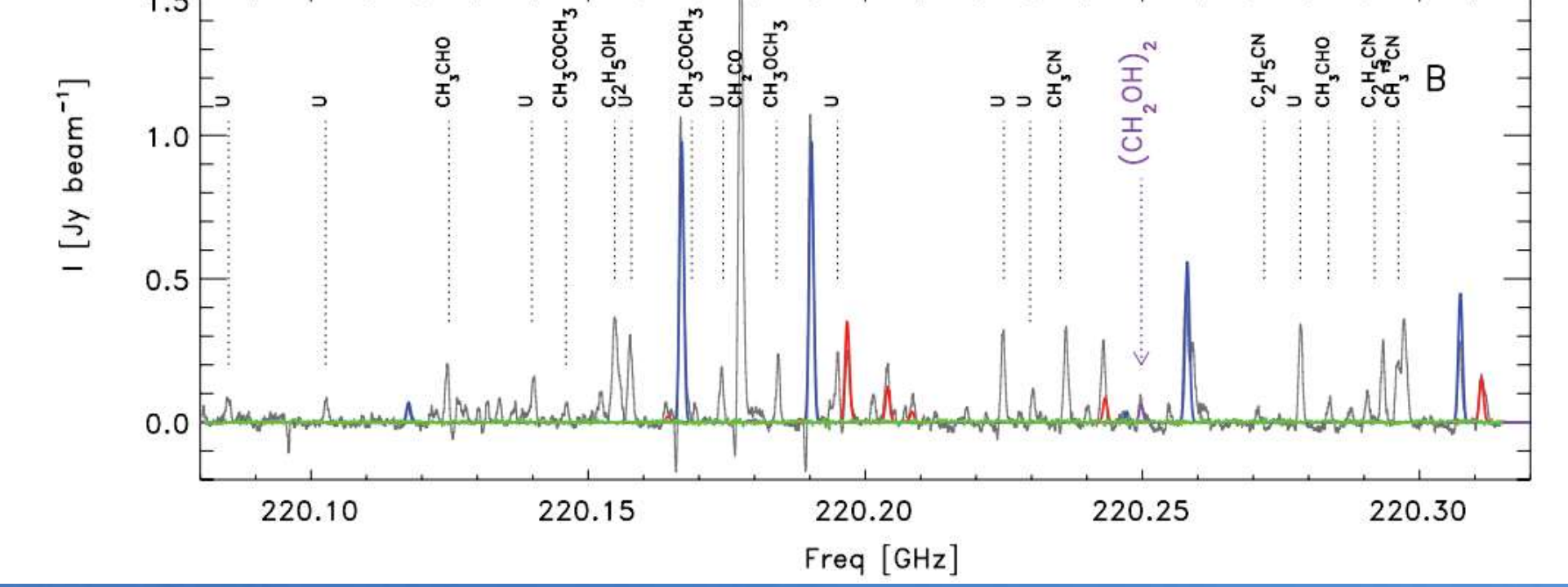
Mass of host galaxy

Gultekin et al

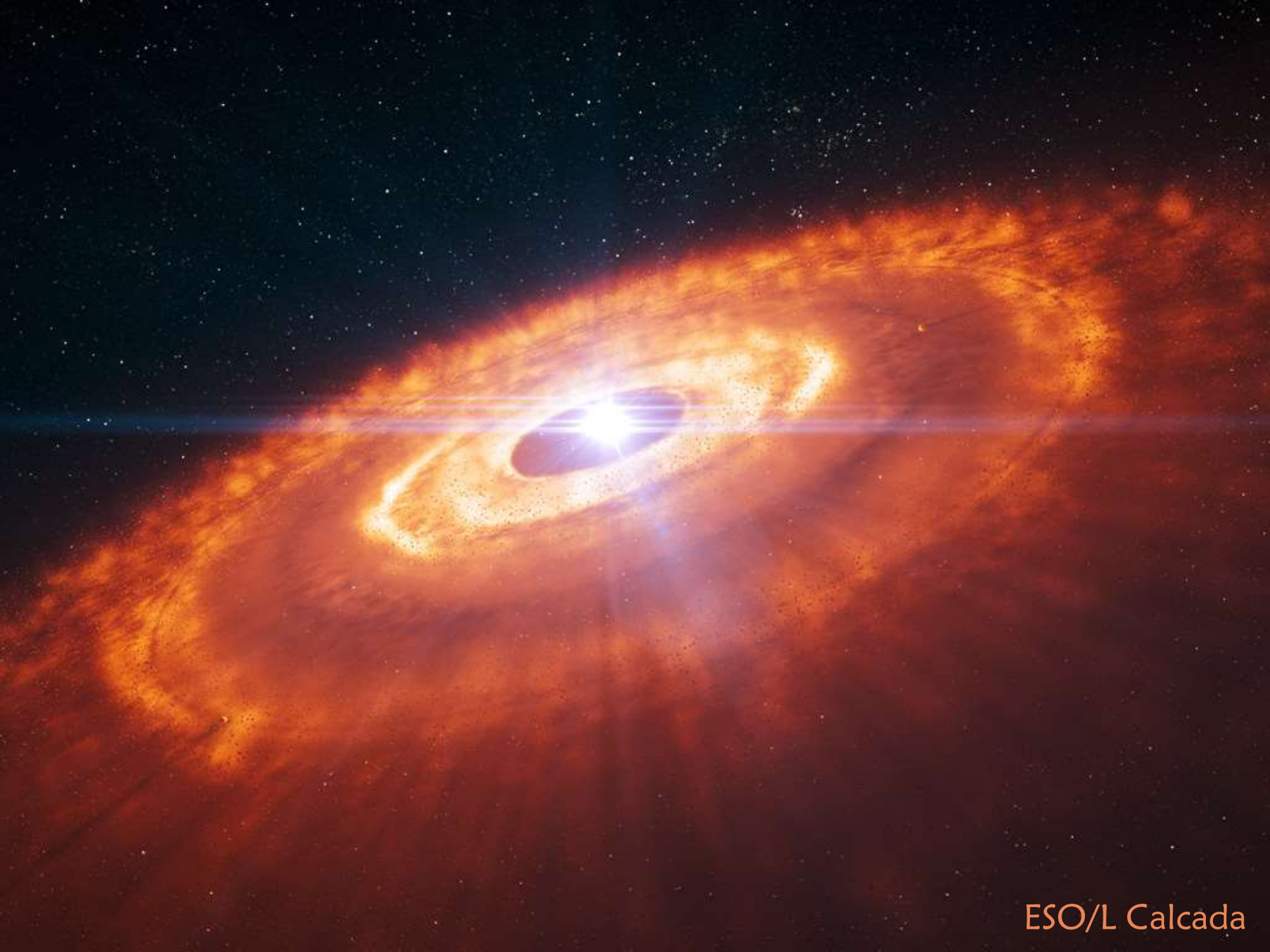

NASA/NuStar


N Carboni & G Parker

NASA/ESA/Hubble Heritage

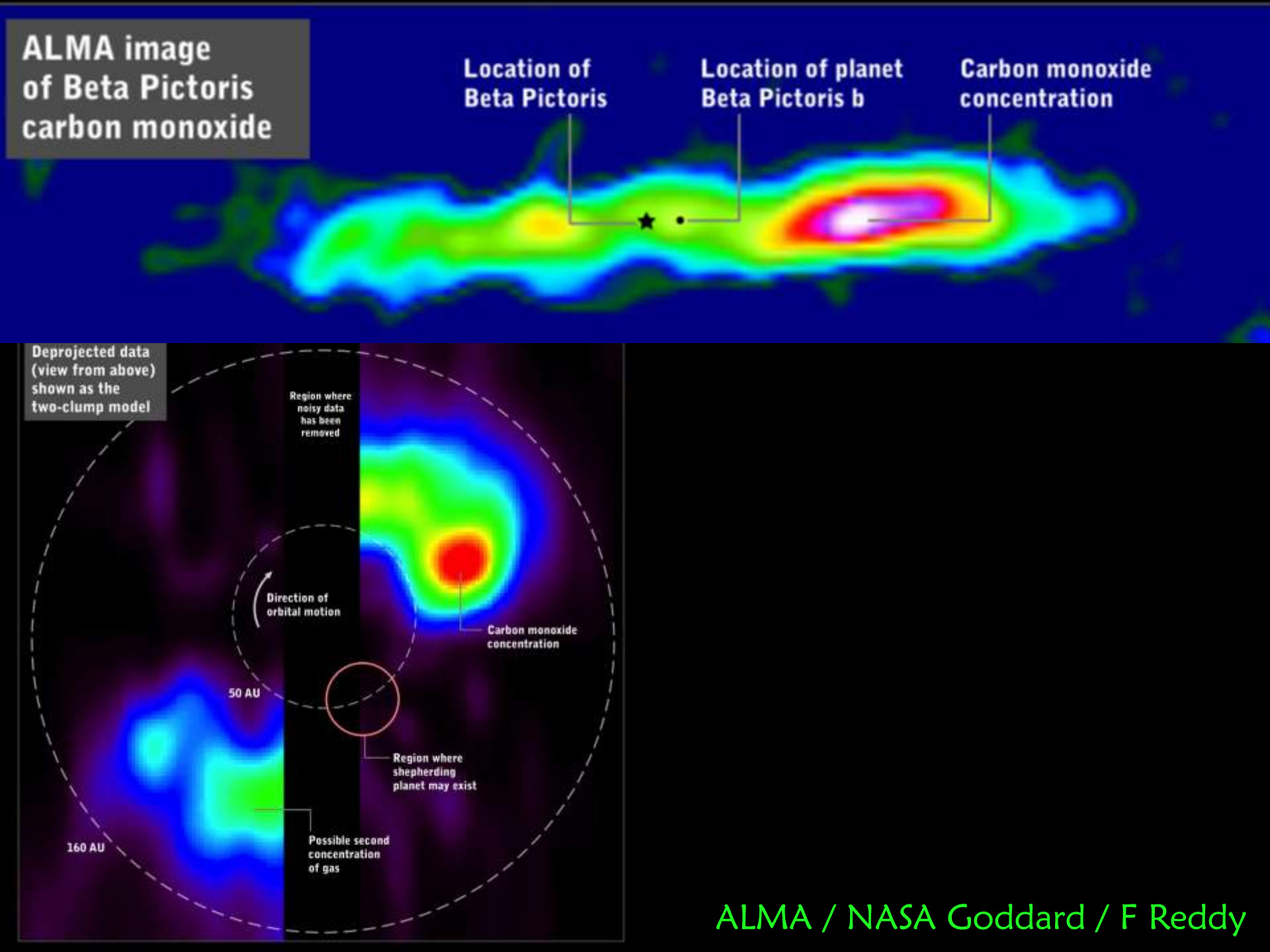

I [Jy beam^{-1}]
1.5
1.0
0.5
0.0
U
U
CH_3CHO
U
CH_3COCH_3
C_2H_5OH
U
CH_3COCH_3
U
CH_2CO
CH_3OCH_3
U
U
U
CH_3CN
$(CH_2OH)_2$
C_2H_5CN
U
CH_3CHO
C_2H_5CN
$CH_3{}^{13}CN$
B
220.10
220.15
220.20
220.25
220.30
Freq [GHz]


ALMA/ESO/NAOJ/NRAO

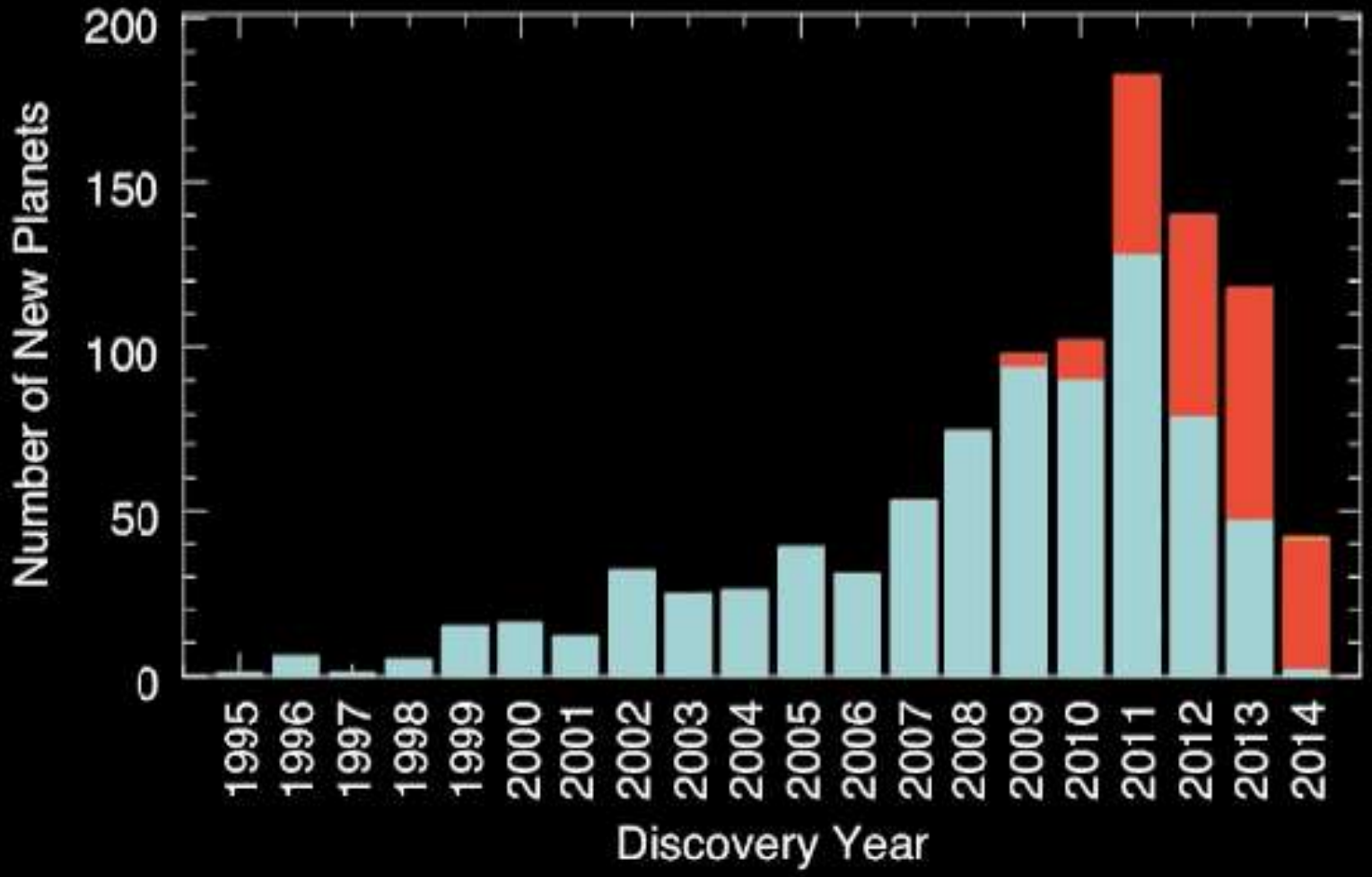

ESO/L Calcada


NASA/ESA/HST

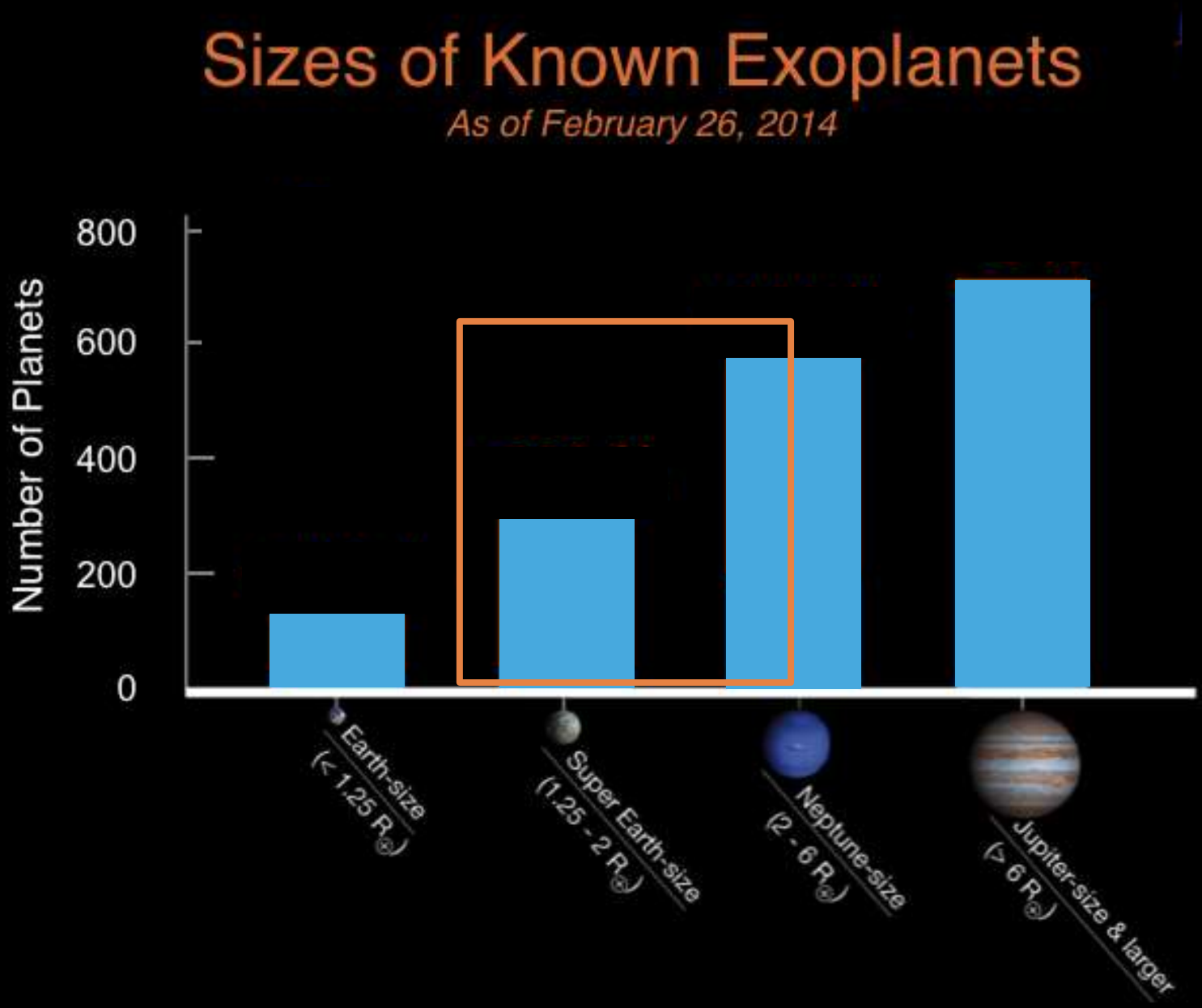

ALMA/ESO/NAQ/NRAO



ALMA / NASA Goddard / F Reddy


Number of New Planets
200
150
100
50
0
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
Discovery Year

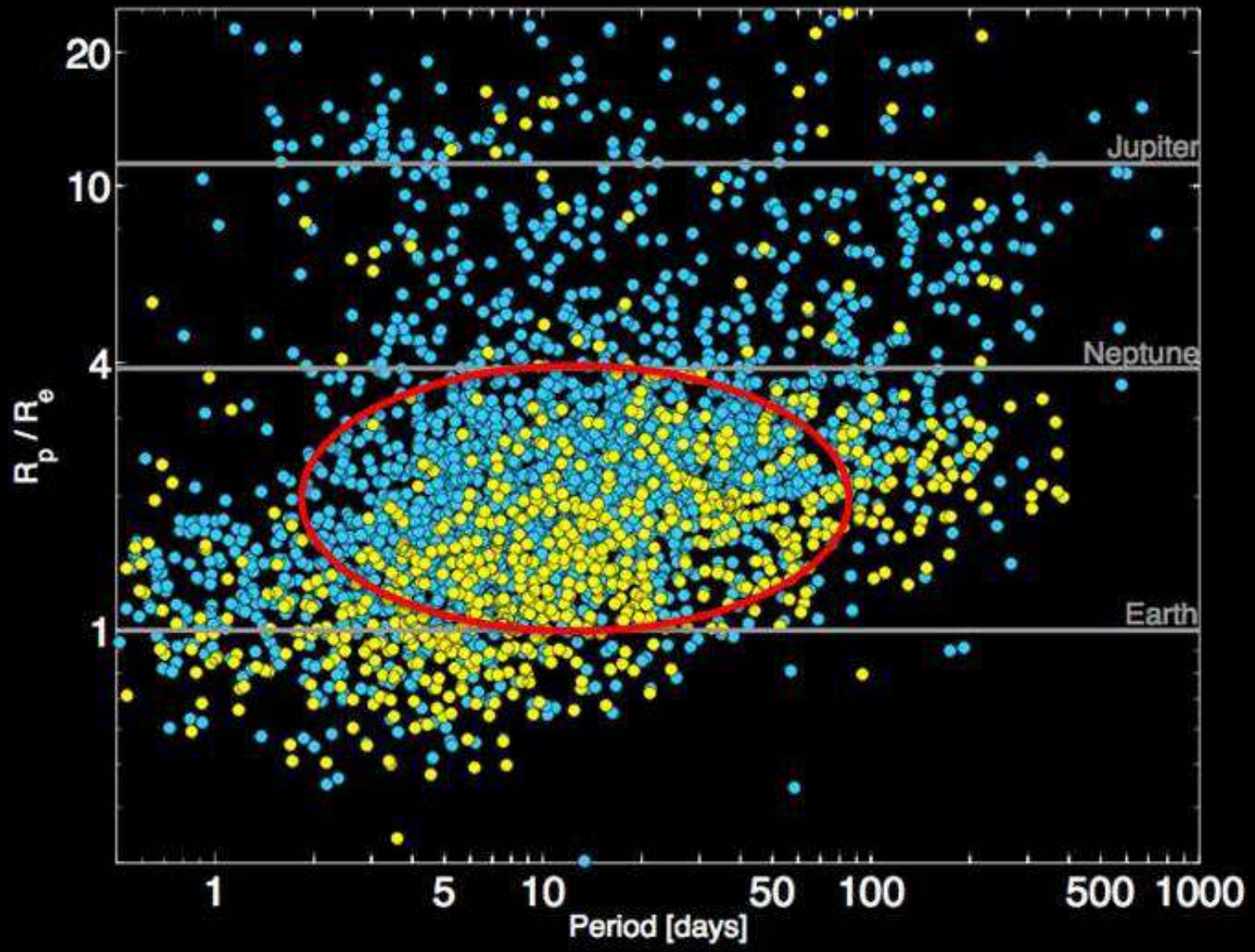
NASA/Kepler


Sizes of Known Exoplanets
As of February 26, 2014
Number of Planets
800
600
400
200
0
Earth-size
(< 1.25 R⊕)
Super Earth-size
(1.25 - 2 R⊕)
Neptune-size
(2 - 6 R⊕)
Jupiter-size & larger
(> 6 R⊕)

NASA/Kepler

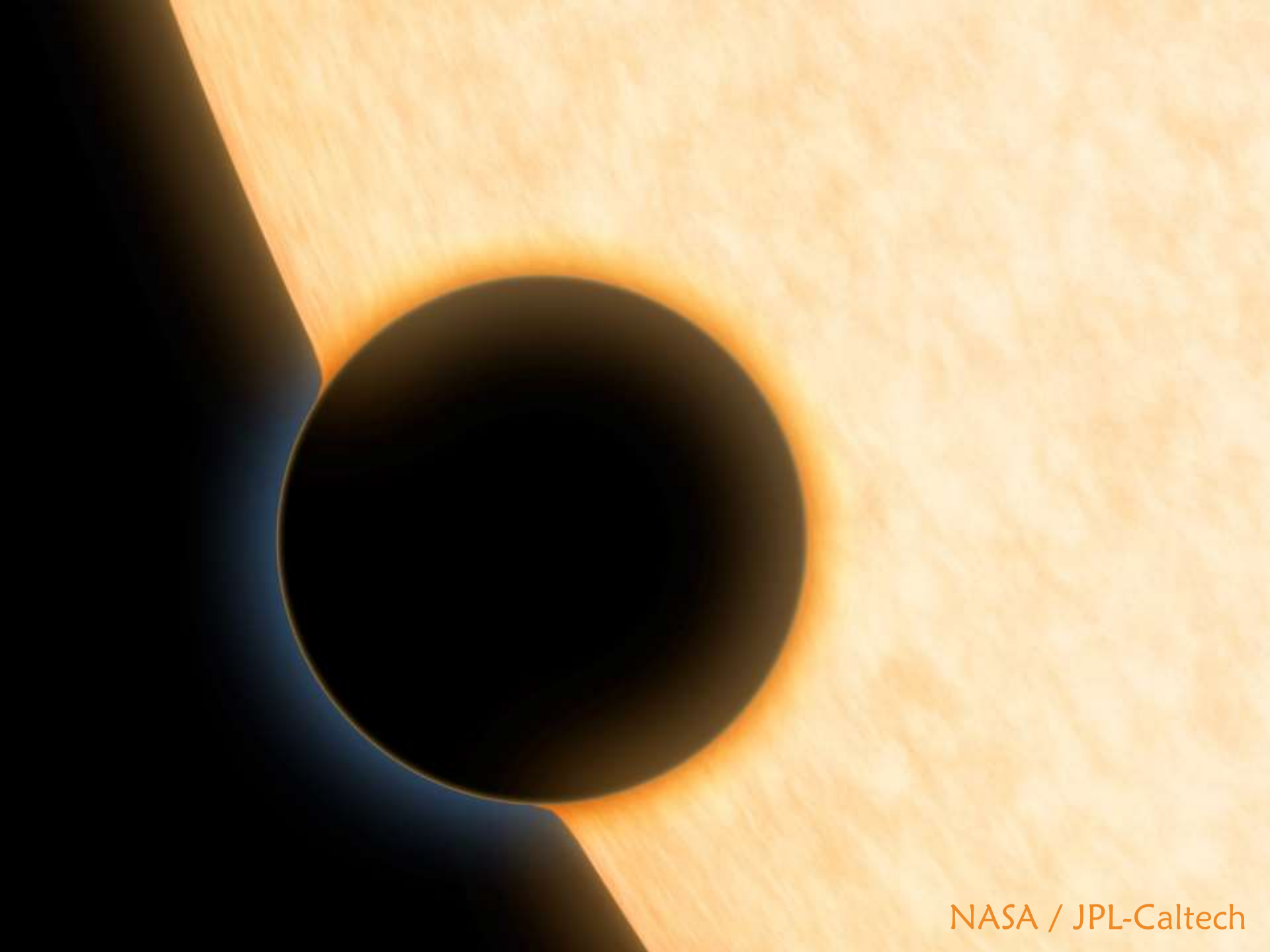
Kepler Planet Candidates

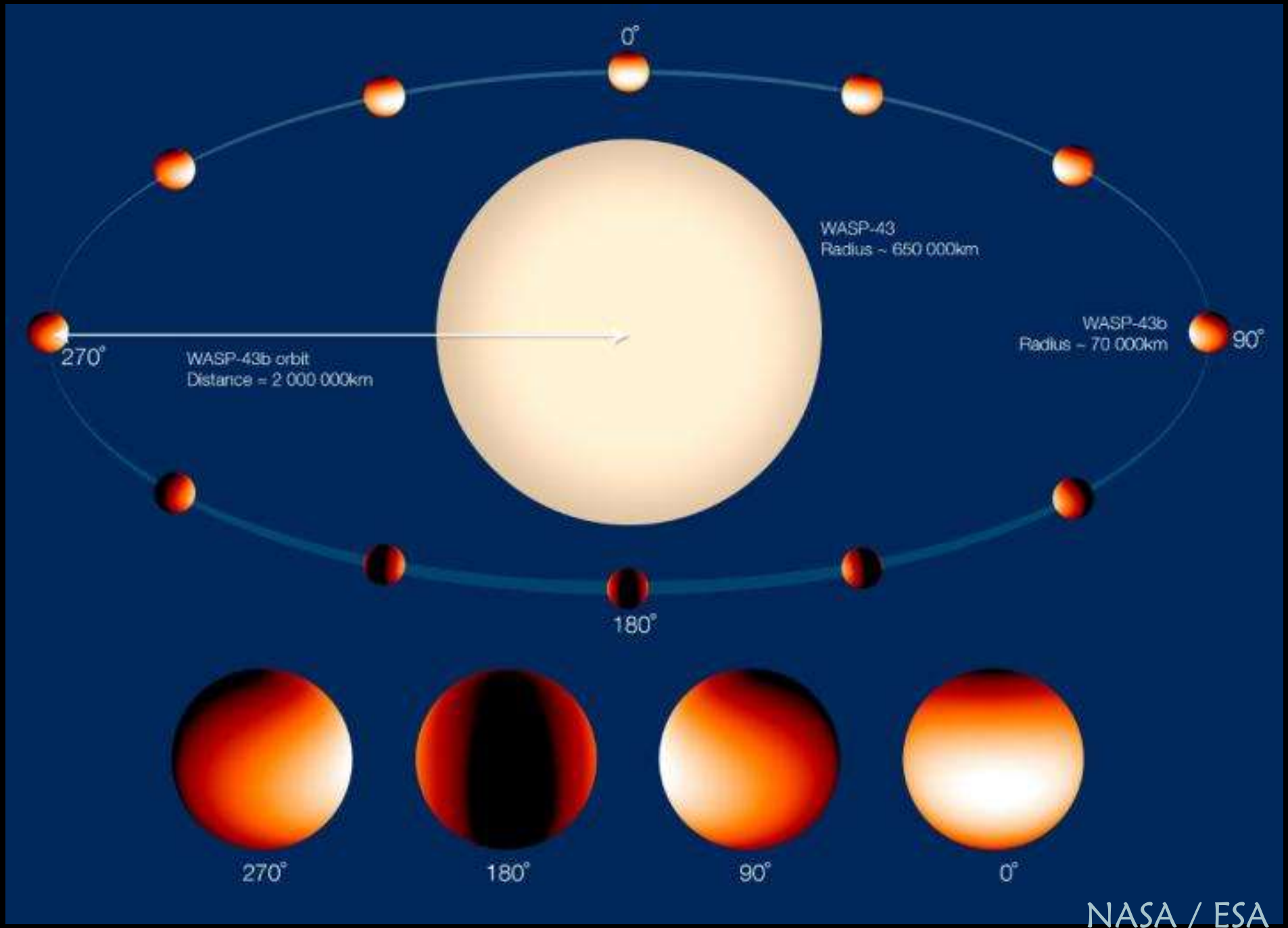
January 2014

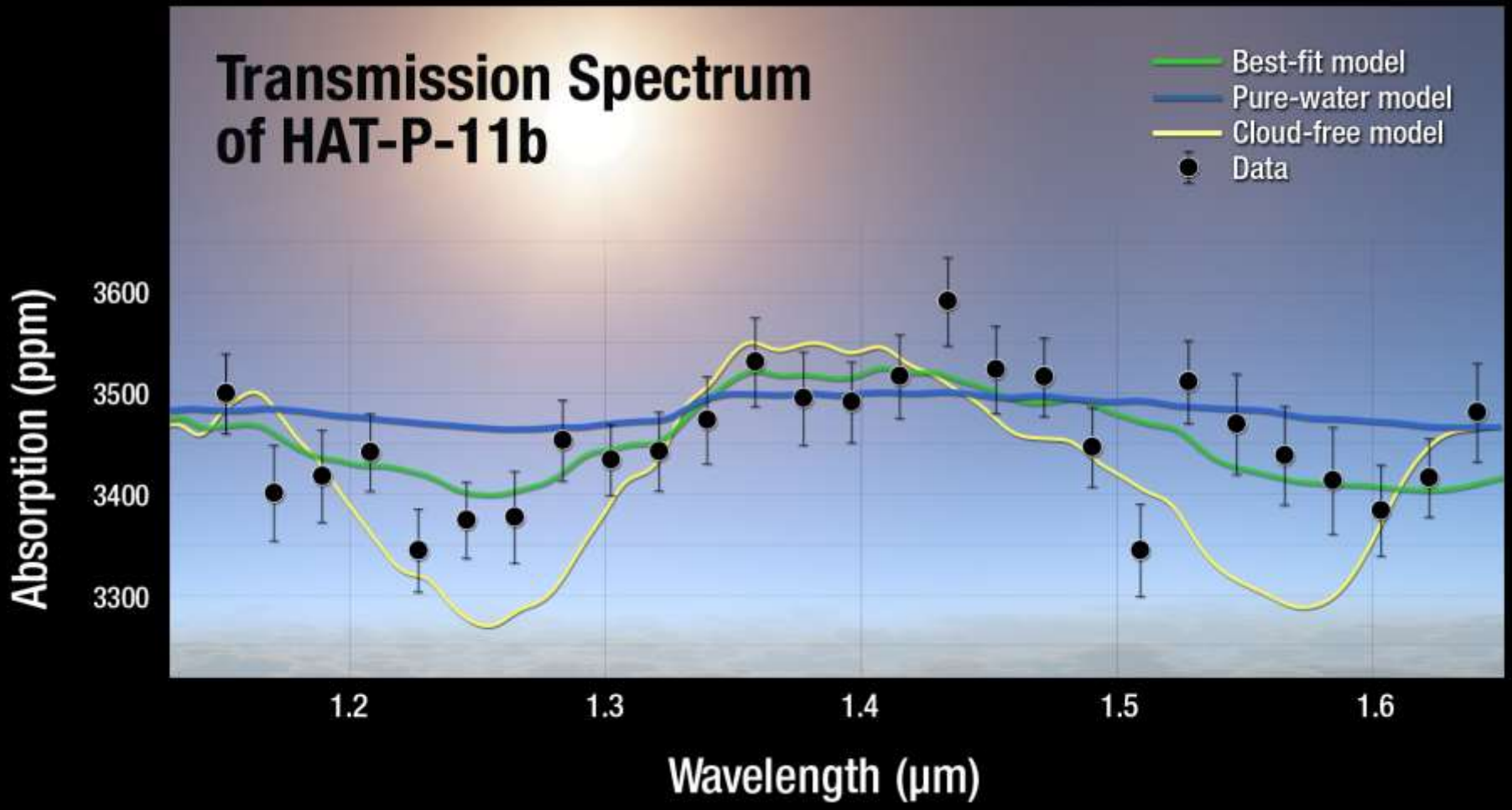


NASA/Kepler

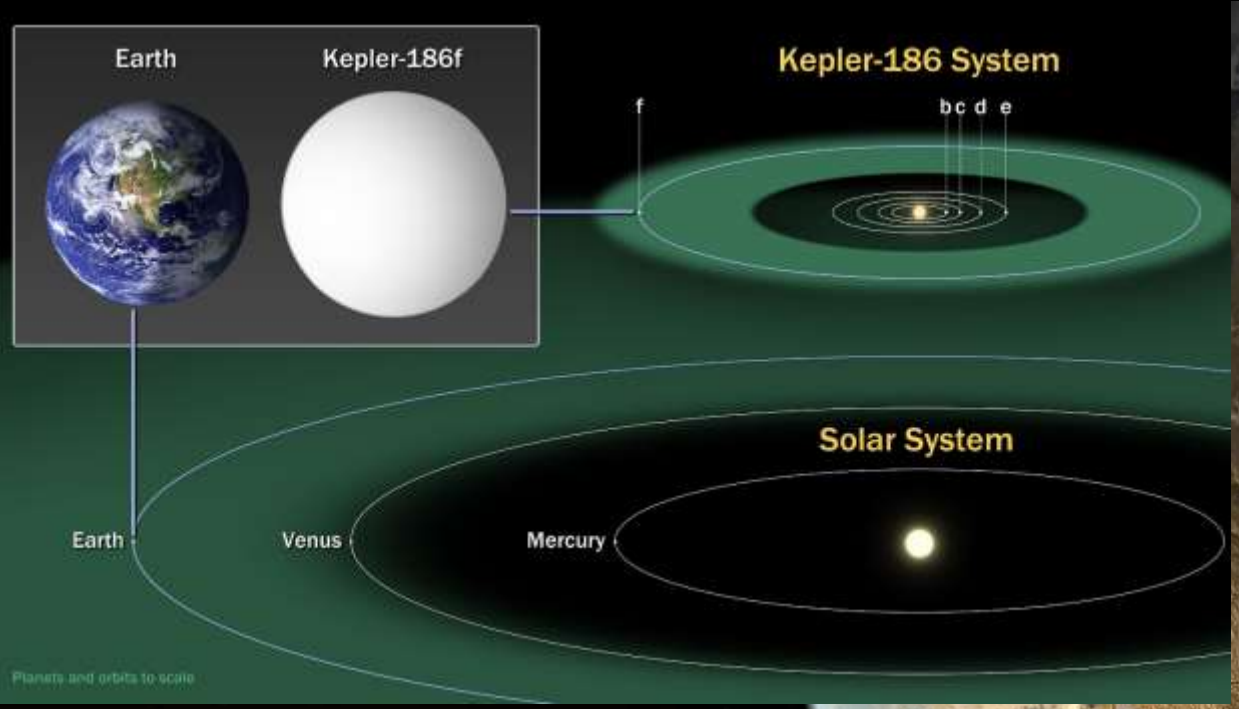
NASA Ames / JPL-Caltech


NASA / JPL-Caltech


0°
WASP-43
Radius ~ 650 000km
WASP-43b
Radius ~ 70 000km
90°
270°
WASP-43b orbit
Distance = 2 000 000km
180°
270°
180°
90°
0°
NASA / ESA

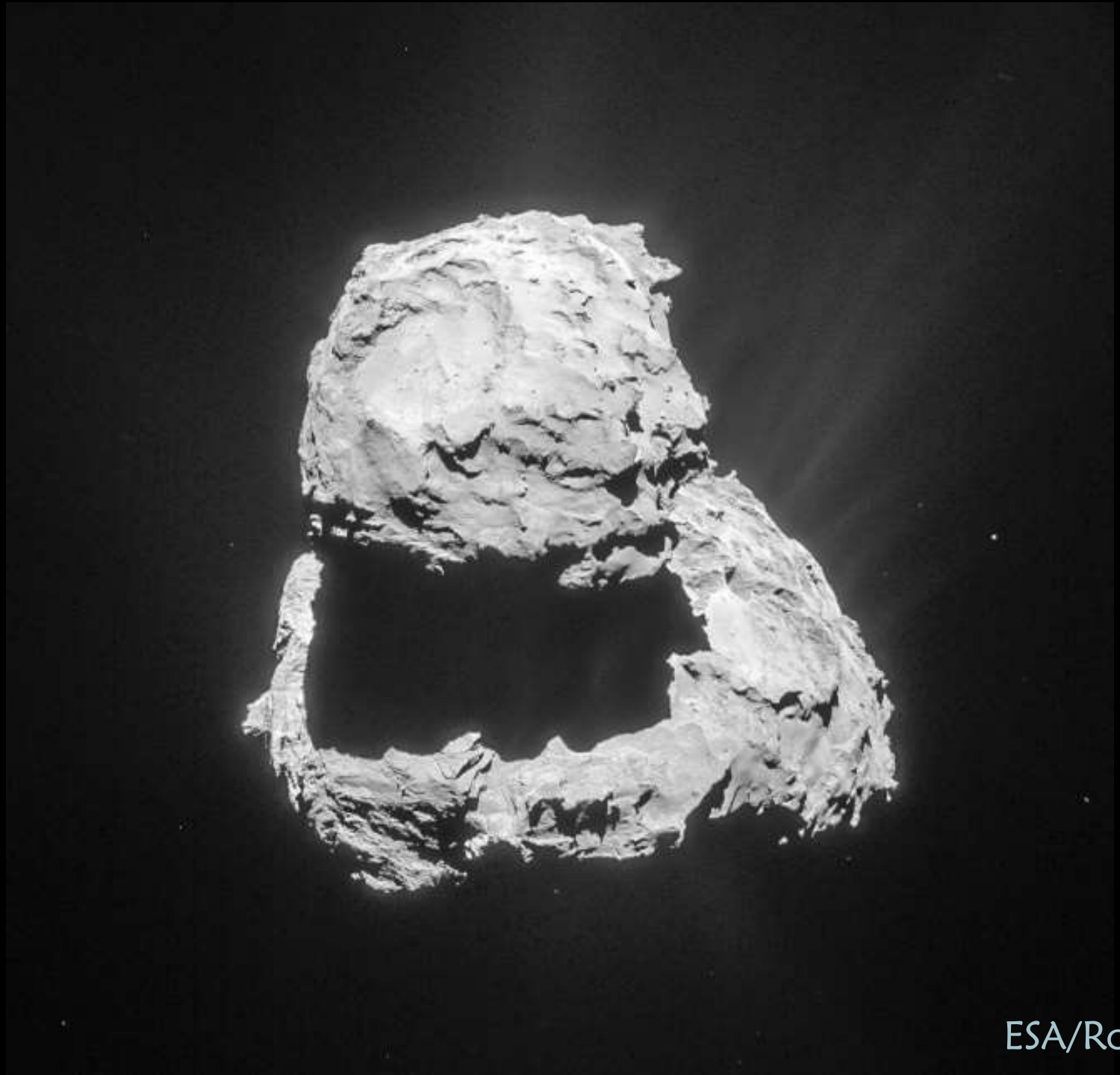


NASA /ESA/STSci



NASA Ames / SETI / JPL-Caltech

NASA / JPL-Caltech / R Hurt

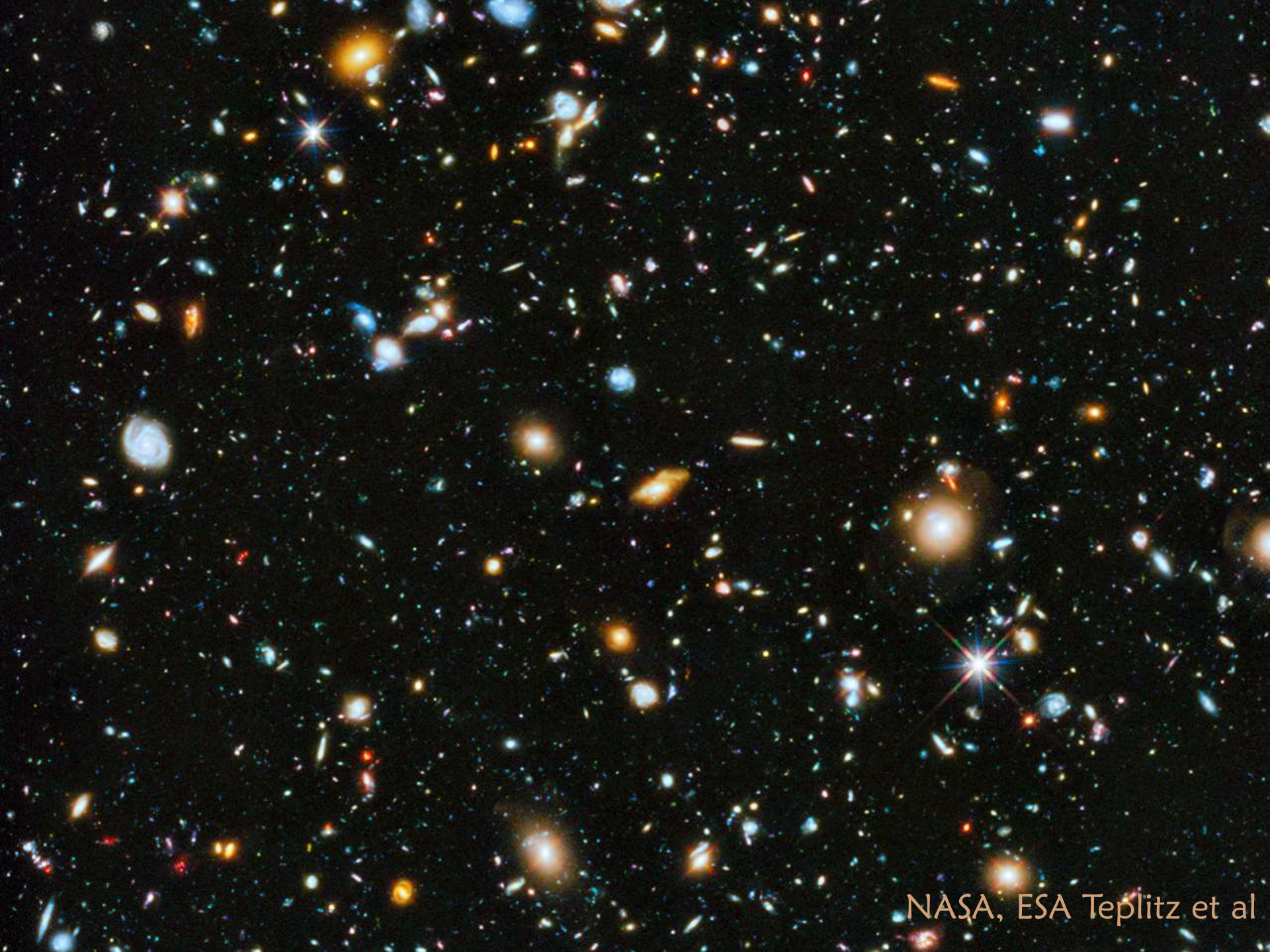


ESA/Rosetta/NavCam

ESA/Altwegg et al

NASA / Dawn mission

NASA/NOAA/GSFC/Suomi NPP/VIIRS/Norman Kuring


NASA, ESA Teplitz et al

Realm of the Nebulae – Hubble (1936)

Thus the explorations of space end on a note of uncertainty. And necessarily so. We are, by definition, in the very center of the observable region. We know our immediate neighbourhood rather intimately. With increasing distance, our knowledge fades rapidly. Eventually, we reach the dim boundary – the utmost limits of our telescopes. There, we measure shadows, and we search among ghostly errors of measurement of landmarks that are scarcely more substantial.

The search will continue. Not until the empirical resources are exhausted, need we pass on to the dreamy realms of speculation.

NASA, ESA Teplitz et al