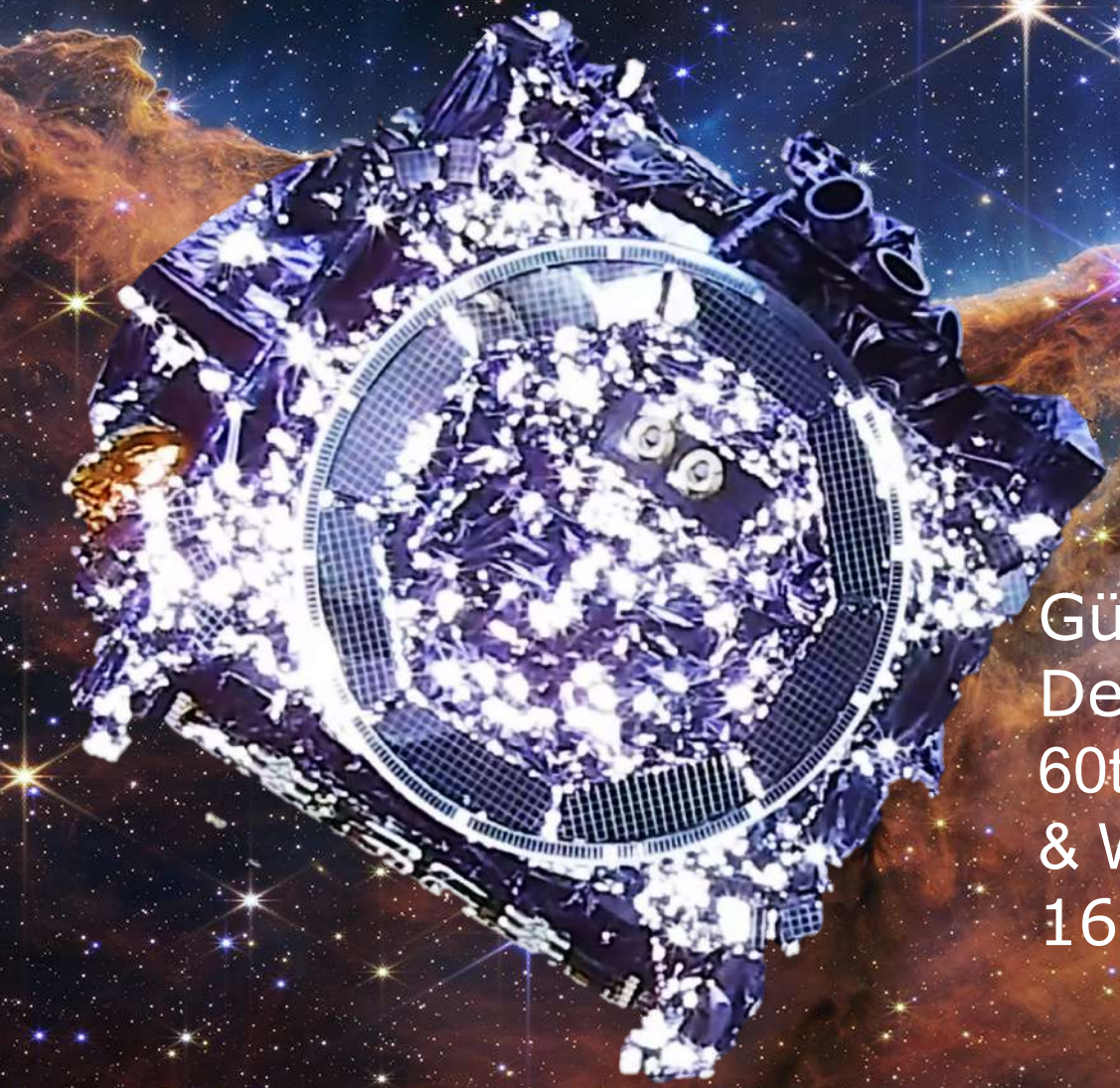
The Fate of the Universe
New results from JWST and Outlook



Günther Hasinger
Deutsches Zentrum für Astrophysik
60th Karpacz Winter School on Theoretical Physics
& WE-Heraeus Physics School, Wrocław
16. May 2024

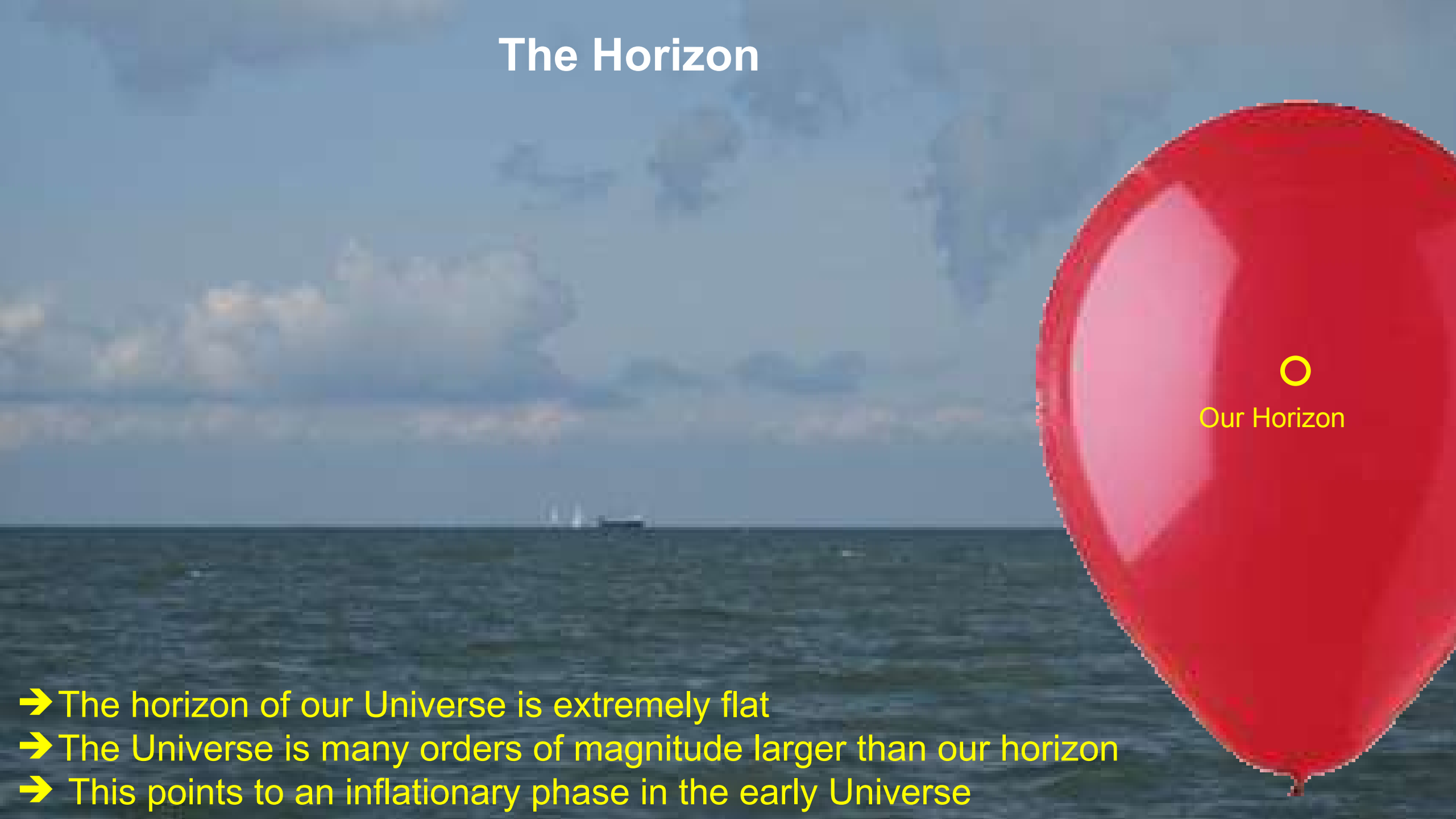
→ THE EUROPEAN SPACE AGENCY

The Horizon

Based on the flatness of the horizon we can estimate the size of the Earth
(as well as the size of the Universe)

Video available at https://www.youtube.com/watch?v=8Are9dDbW24

The Horizon



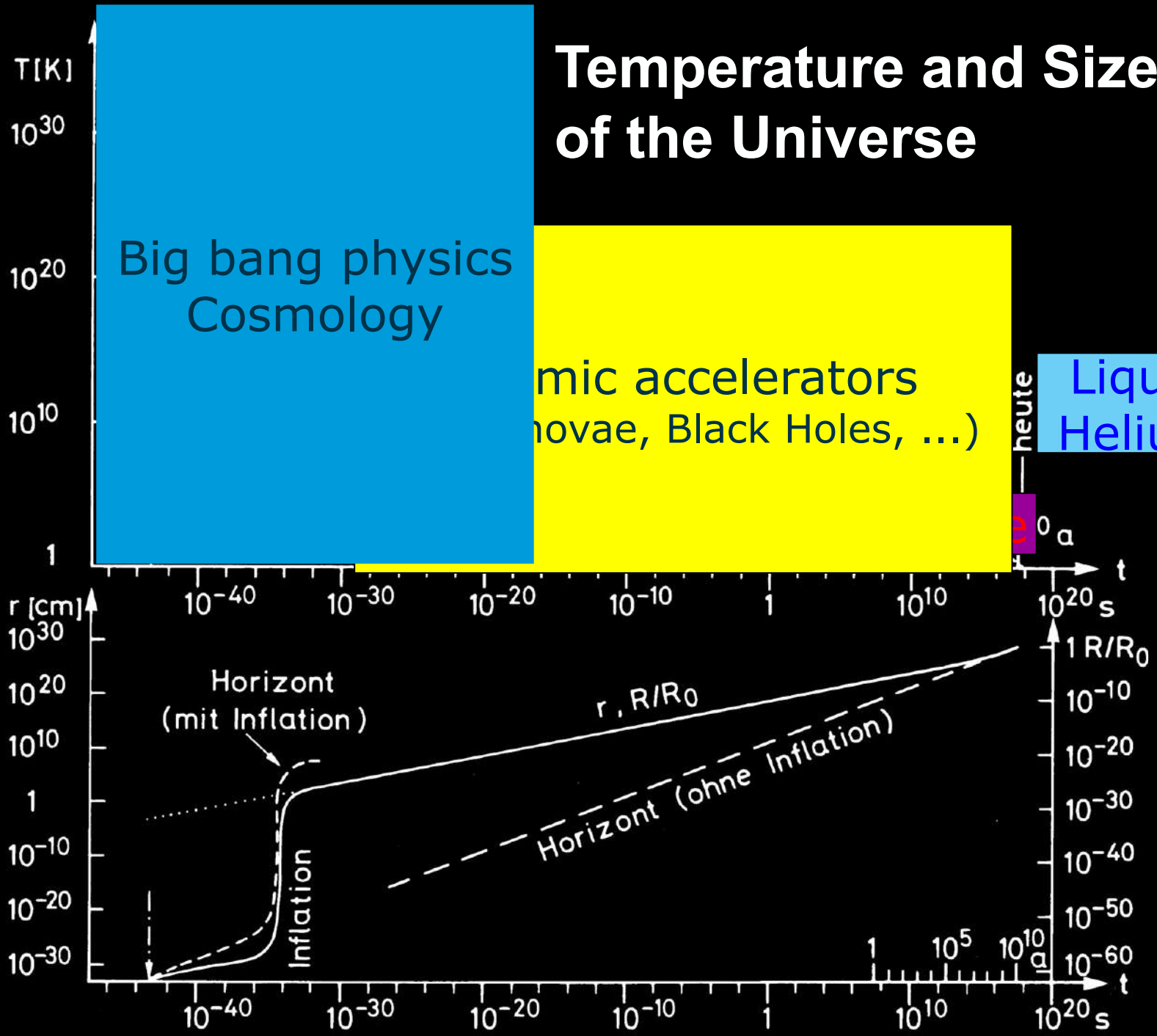
➔ The horizon of our Universe is extremely flat
➔ The Universe is many orders of magnitude larger than our horizon
➔ This points to an inflationary phase in the early Universe

Temperature and Size of the Universe

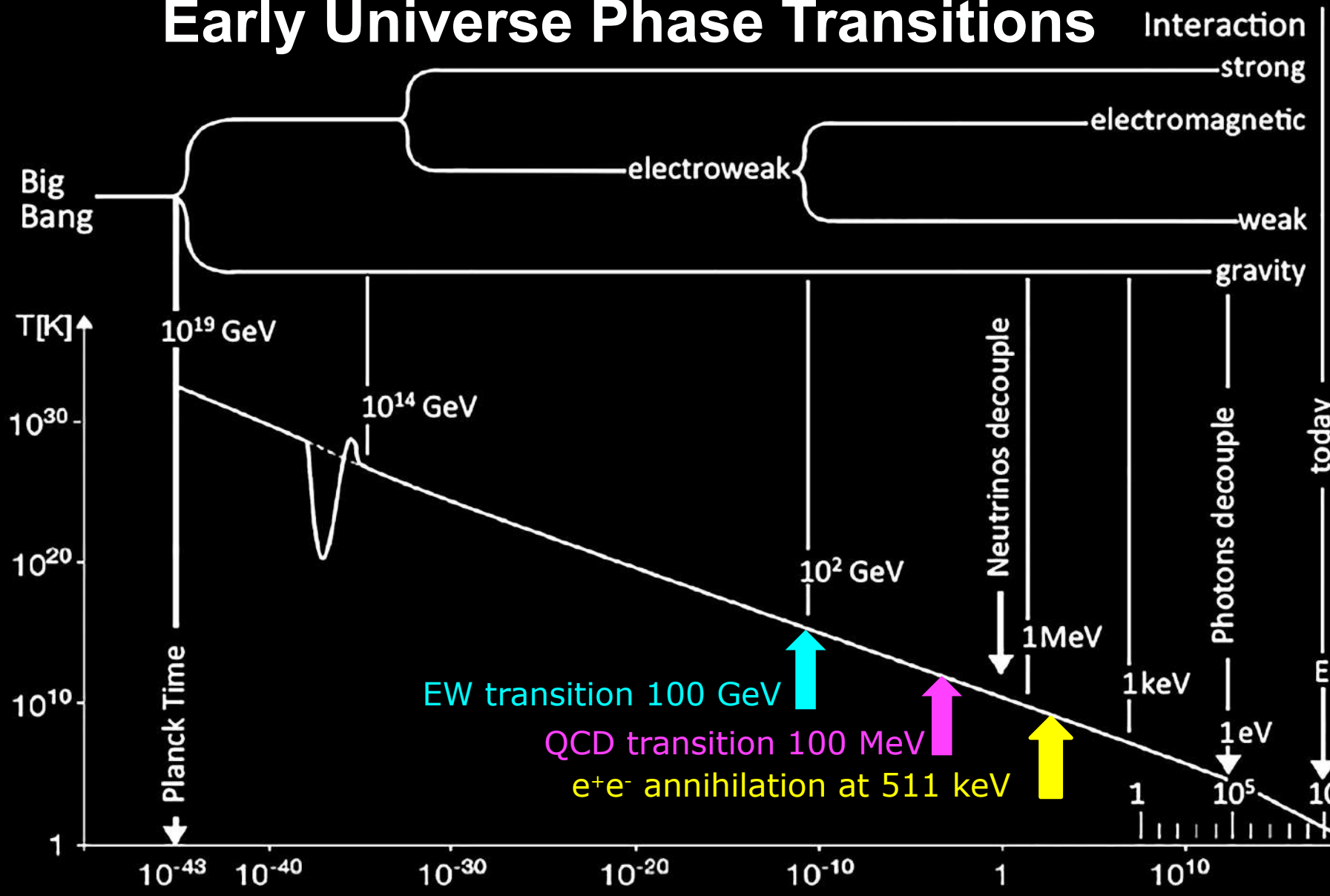
Big bang physics
Cosmology

mic accelerators
novae, Black Holes, ...)

Liquid Helium



Early Universe Phase Transitions



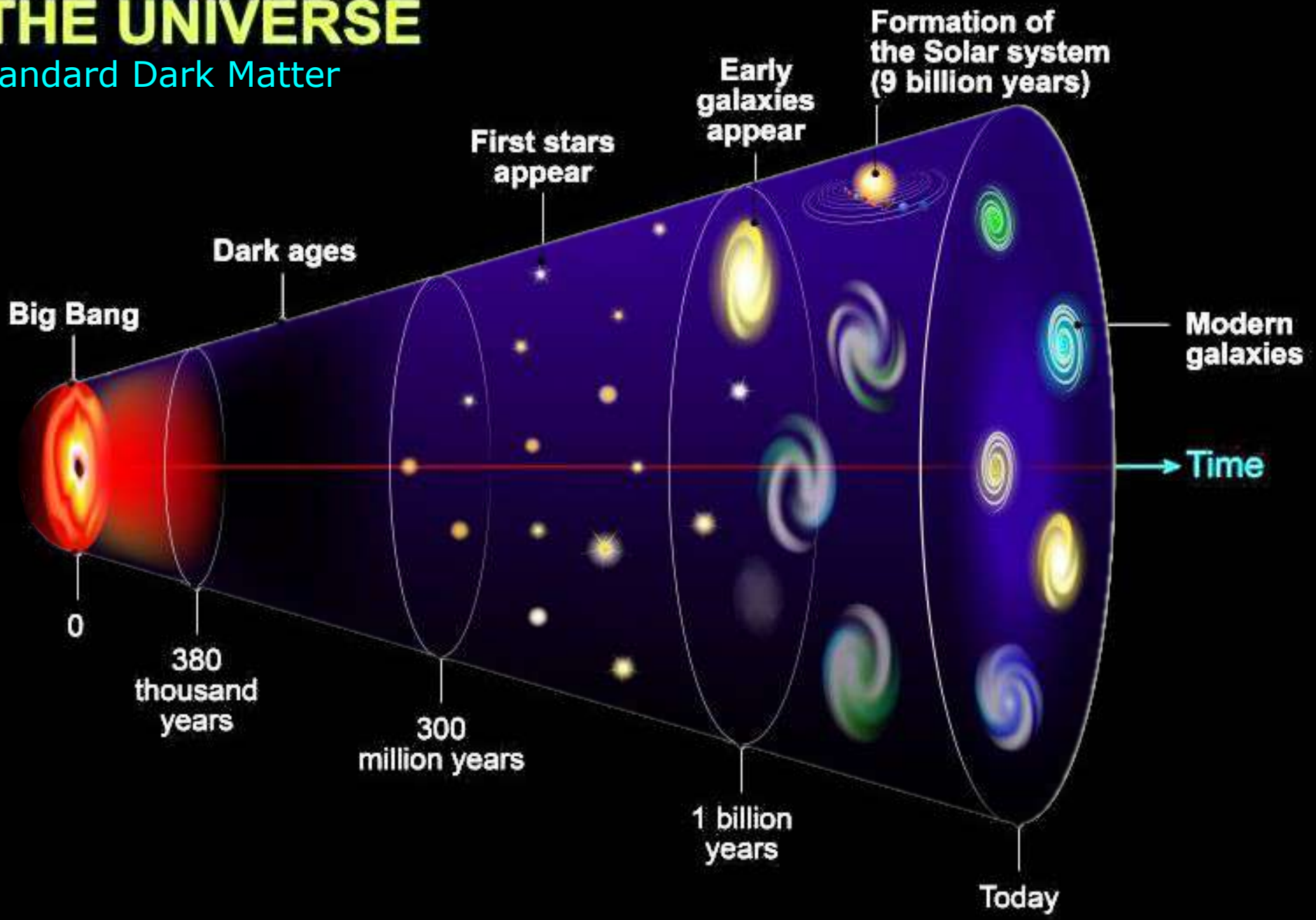
At the electroweak interaction scale the first W- and Z-bosons are freezing out. Higgs Boson gives them mass.

Quarks freeze out to form hadrons (baryons, pions) at the QCD transition.

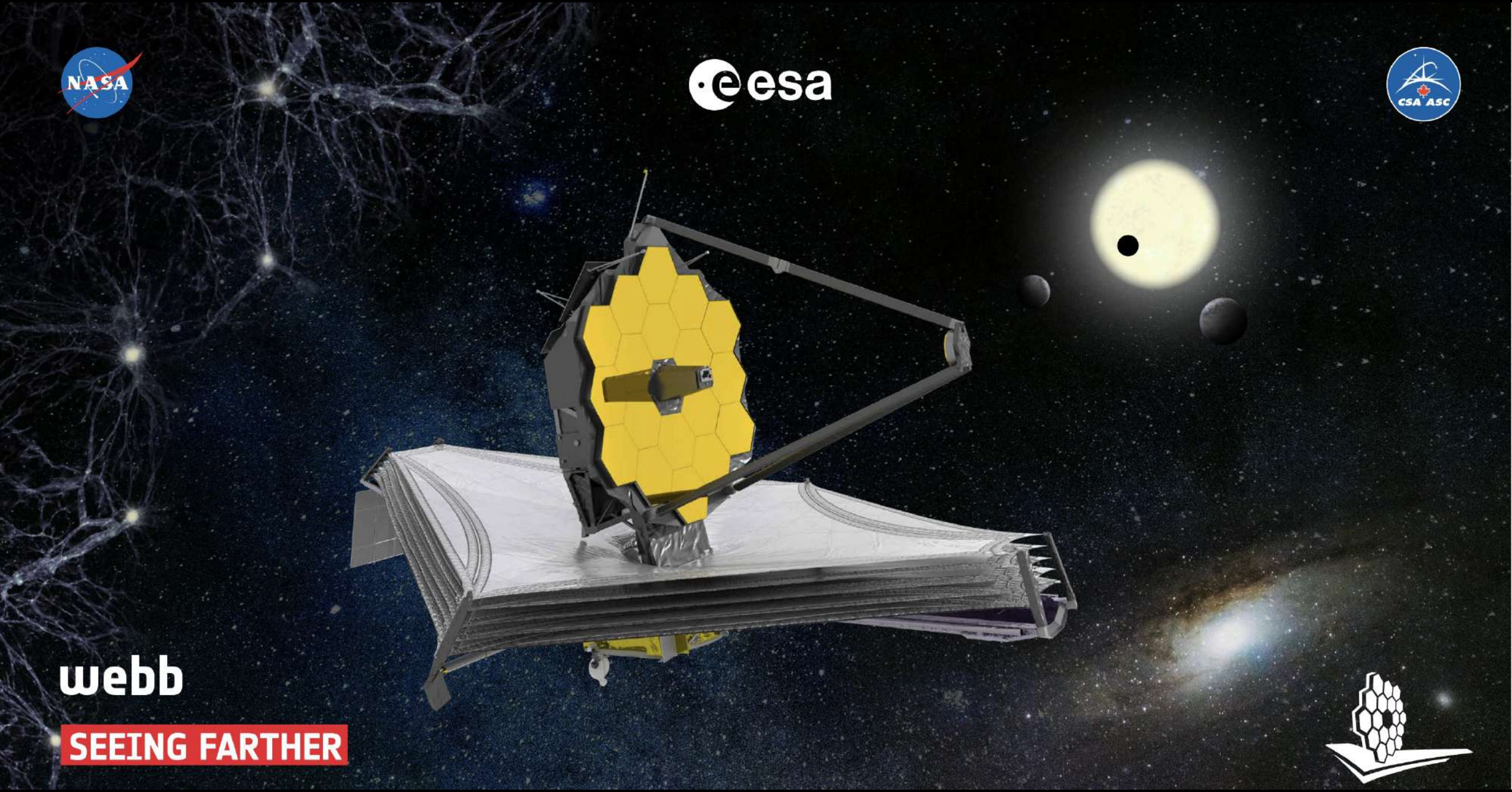
Each of these transitions leaves an imprint on the thermal history of the universe and possibly enables black hole collapse (see tomorrow).

EVOLUTION OF THE UNIVERSE

Standard Dark Matter



Cosmological Simulation of the evolution of the Universe


NASA
esa
CSA ASC
webb
SEEING FARTHER

The assembling of the James Webb Space Telescope

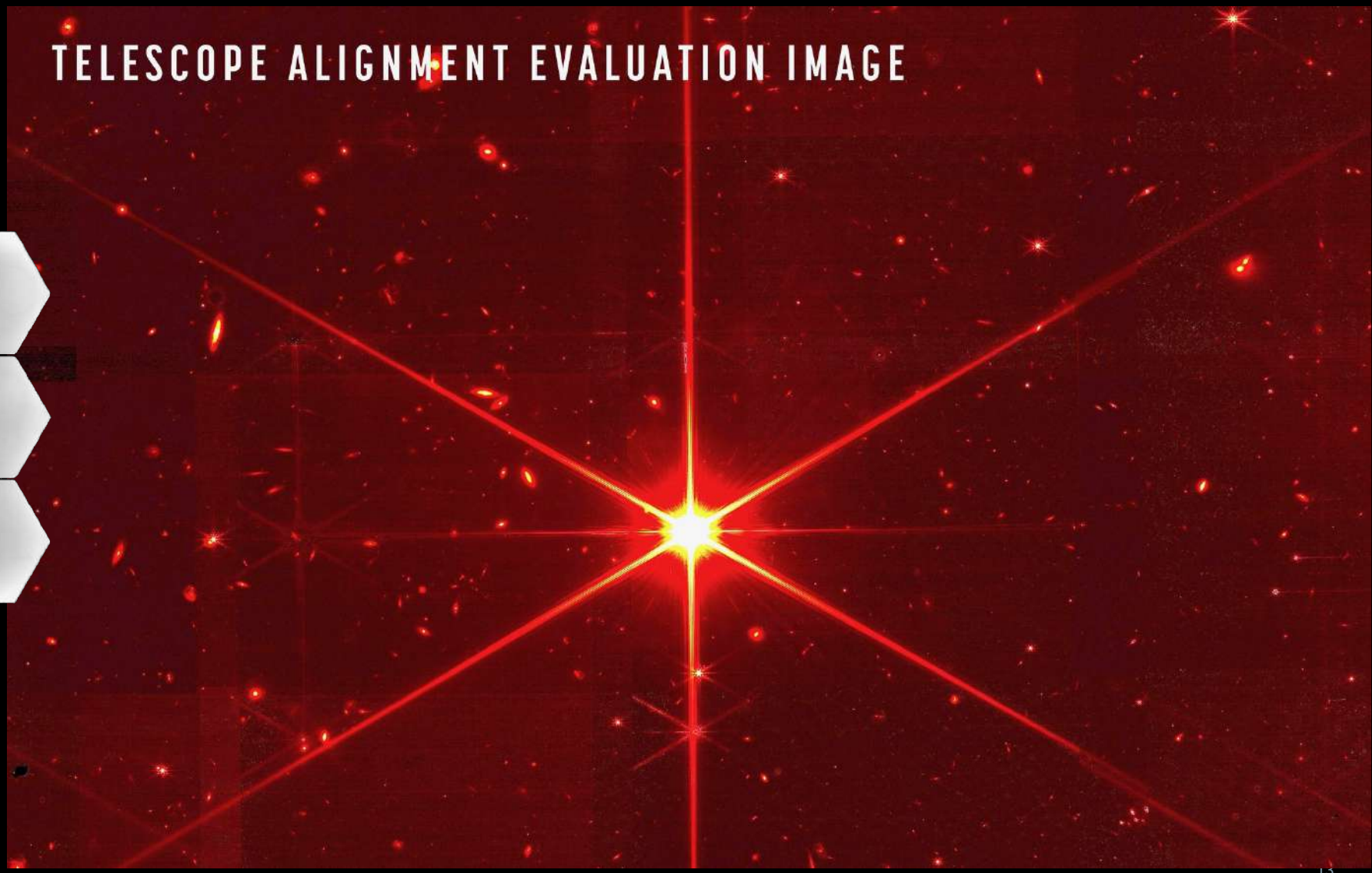
Video availabla at

The launch of the James Webb Space Telescope

Excitement in the control room about the JWST launch

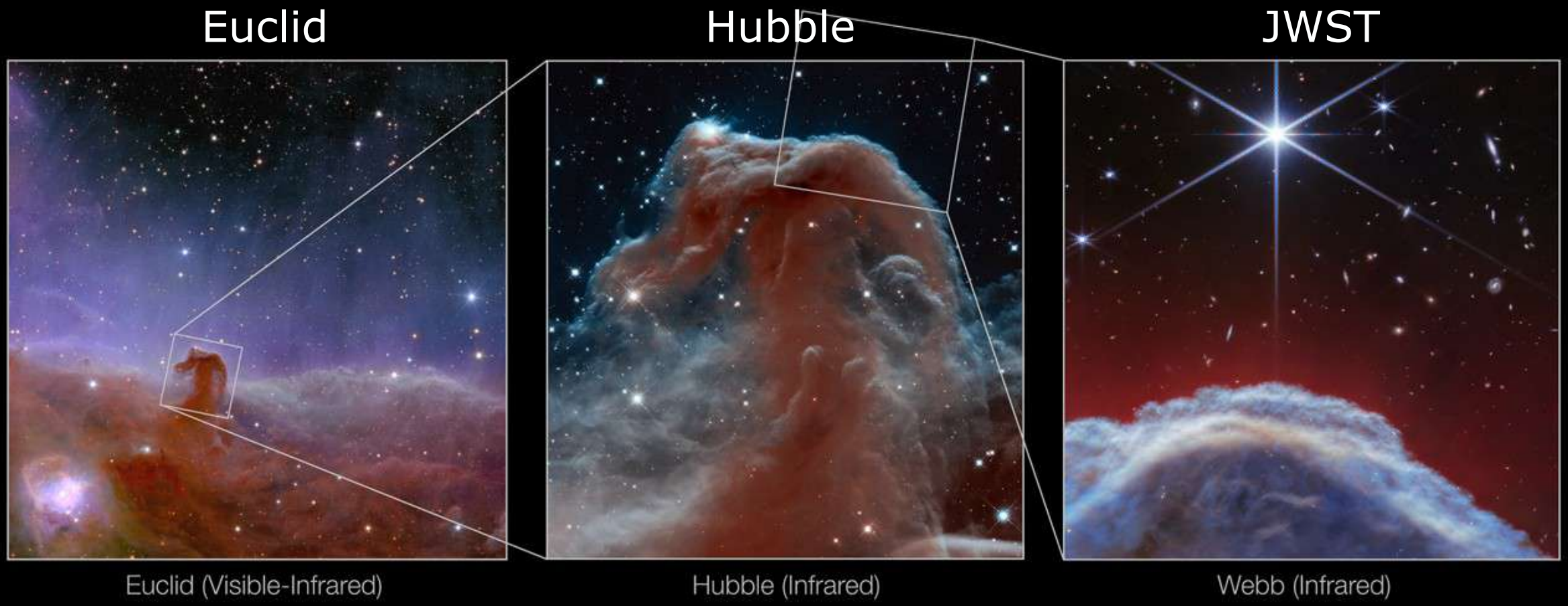
Video available at

JWST Alignment Image



Video available at

Three images of the Horsehead Nebula



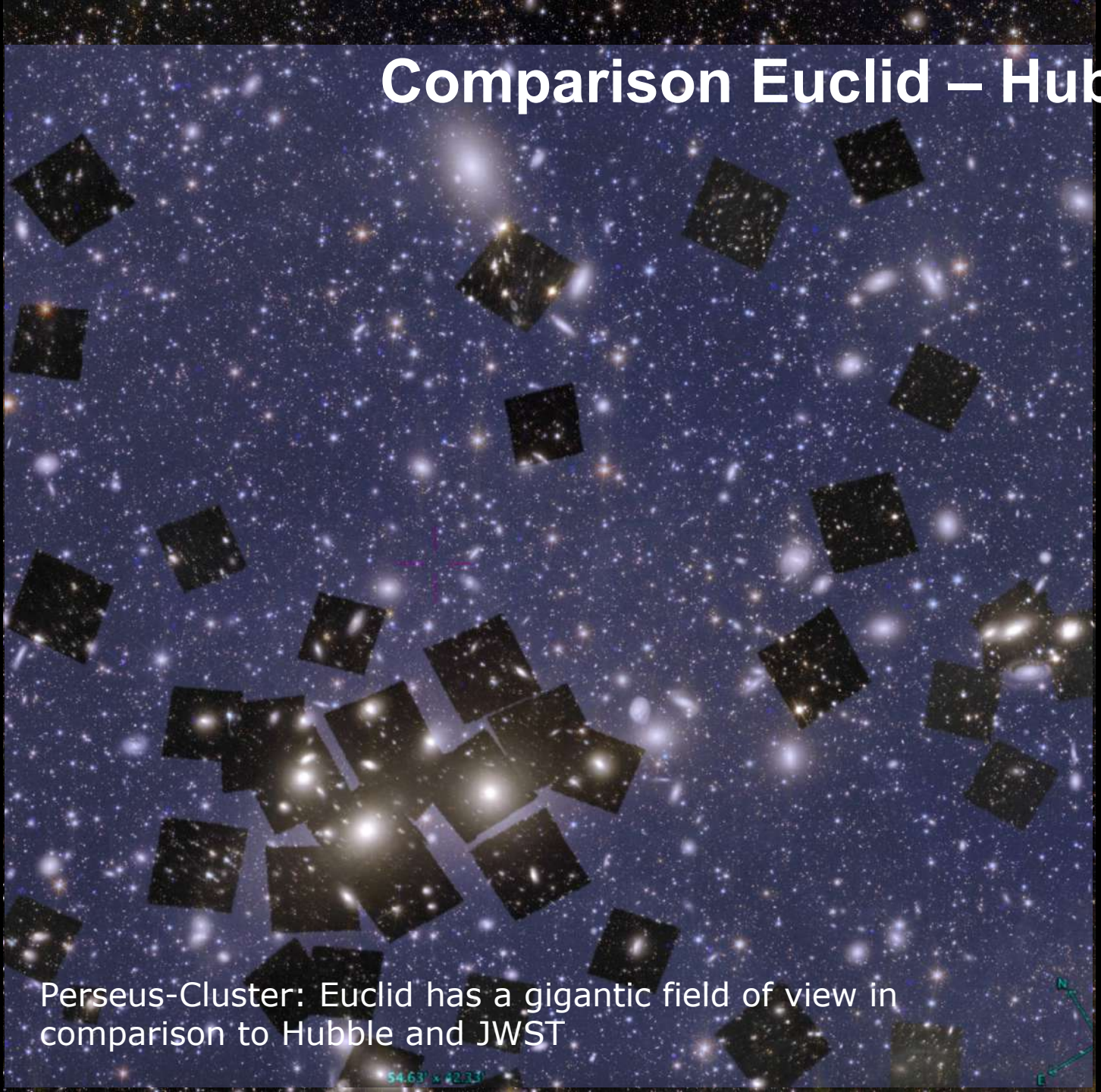
NASA, ESA, CSA, Karl Misselt (University of Arizona), Alain Abergel (IAS, CNRS), Mahdi Zamani The Euclid Consortium, Hubble Heritage Project (STScI, AURA)

Eagle Nebula M16: The Pillars of Creation

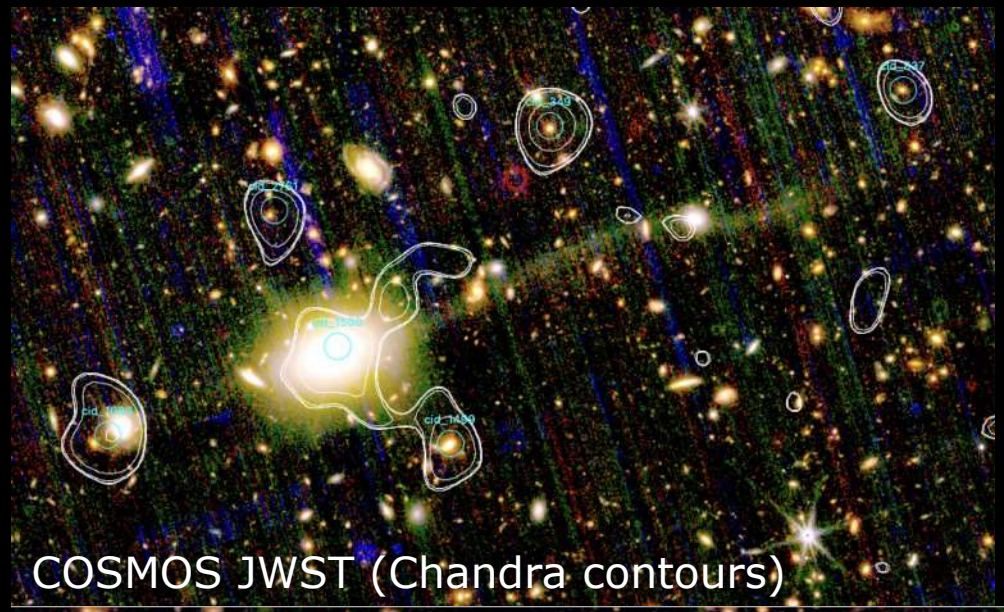
HST JWST NIRCAM JWST MIRI

Video available at

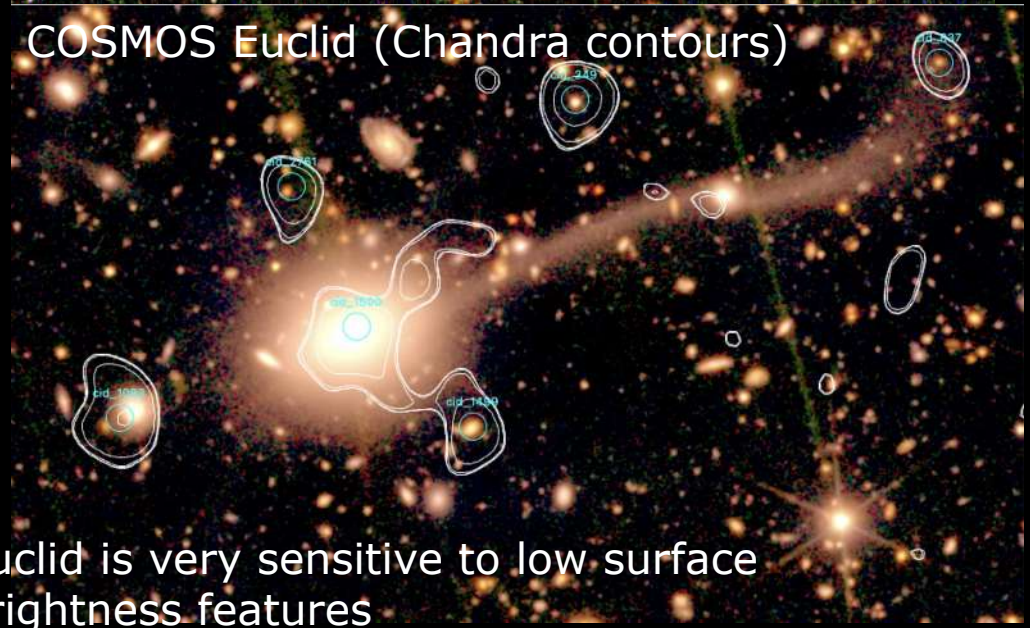
Comparison Euclid – Hubble – JWST



Perseus-Cluster: Euclid has a gigantic field of view in comparison to Hubble and JWST



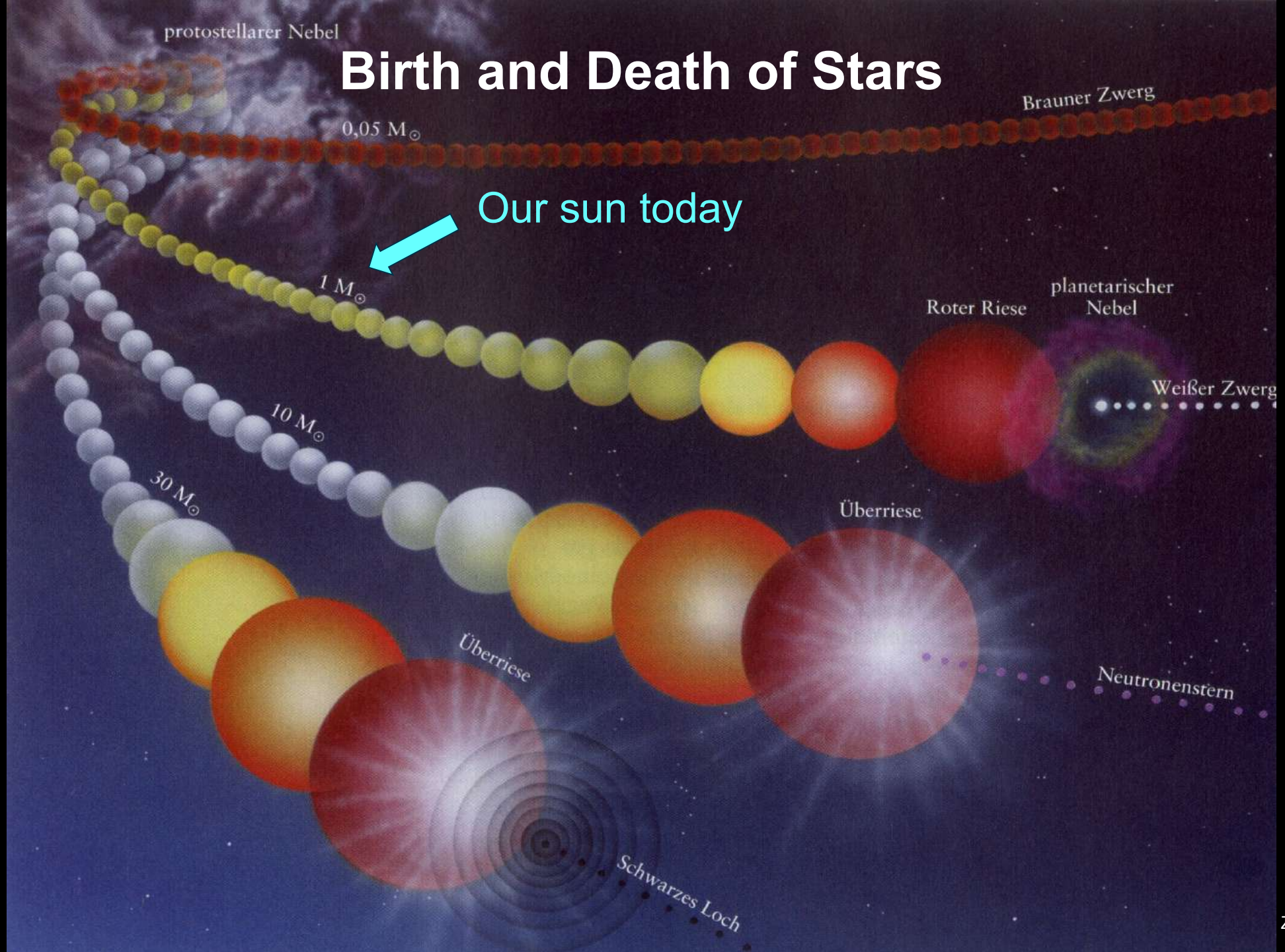
COSMOS JWST (Chandra contours)



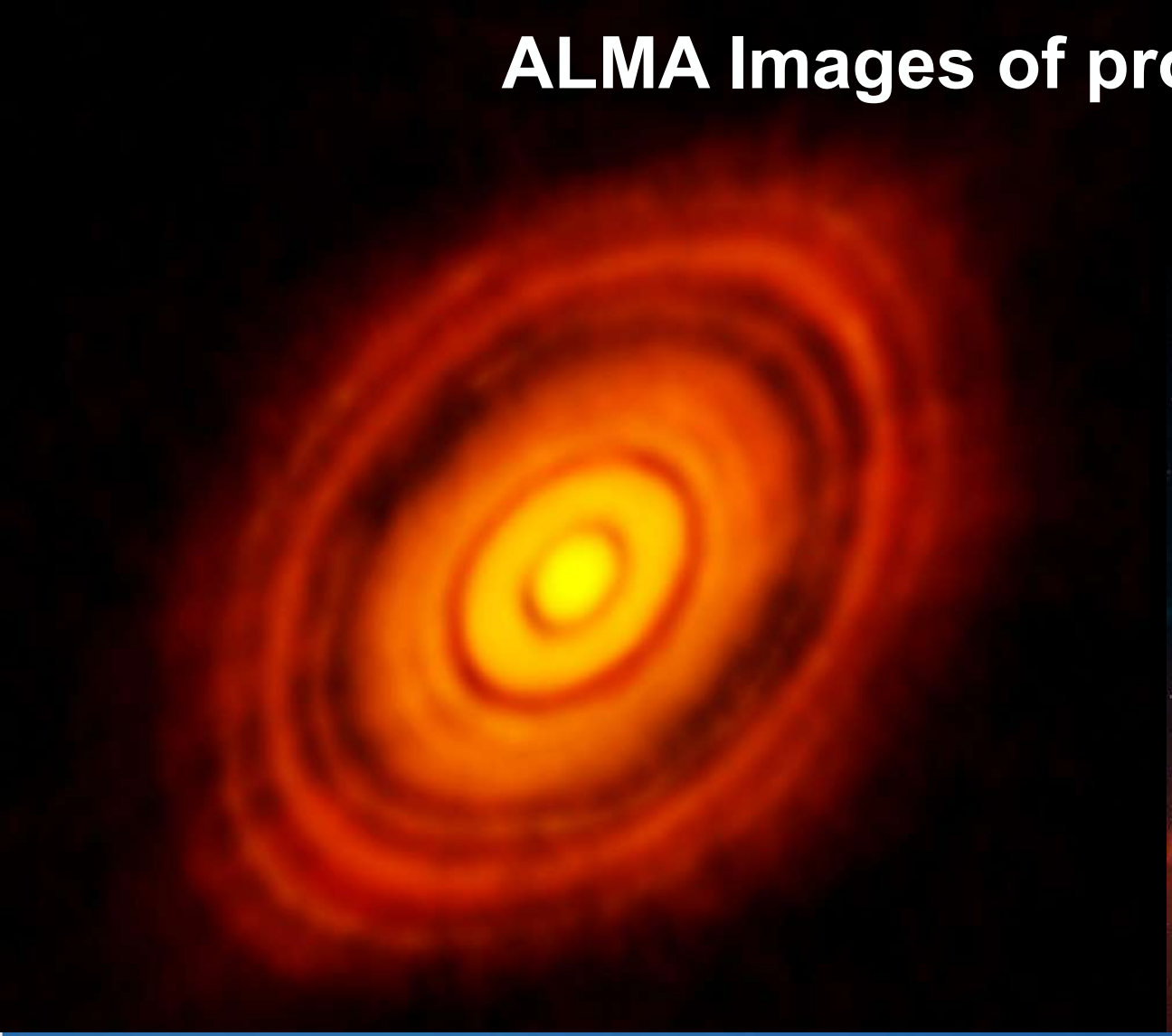
COSMOS Euclid (Chandra contours)

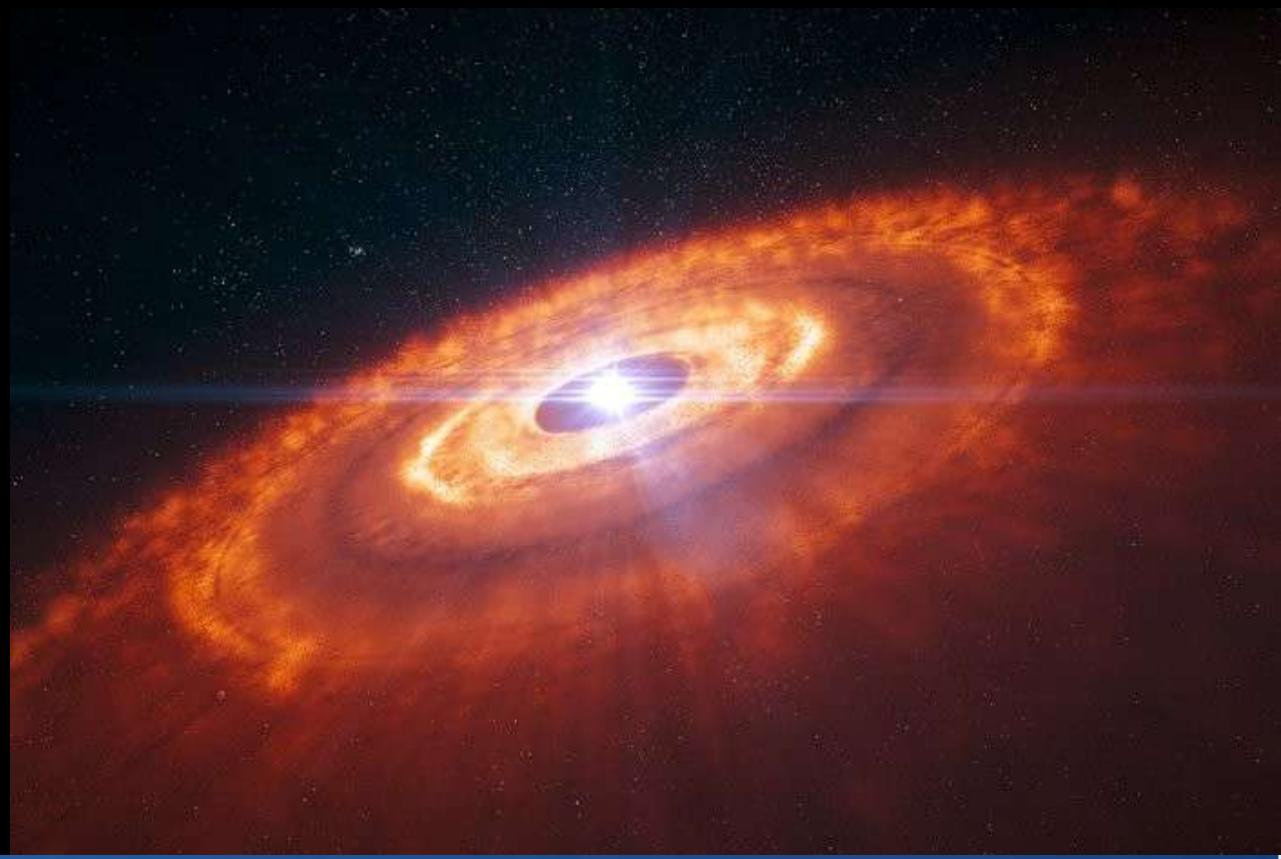
Euclid is very sensitive to low surface brightness features

Birth and Death of Stars

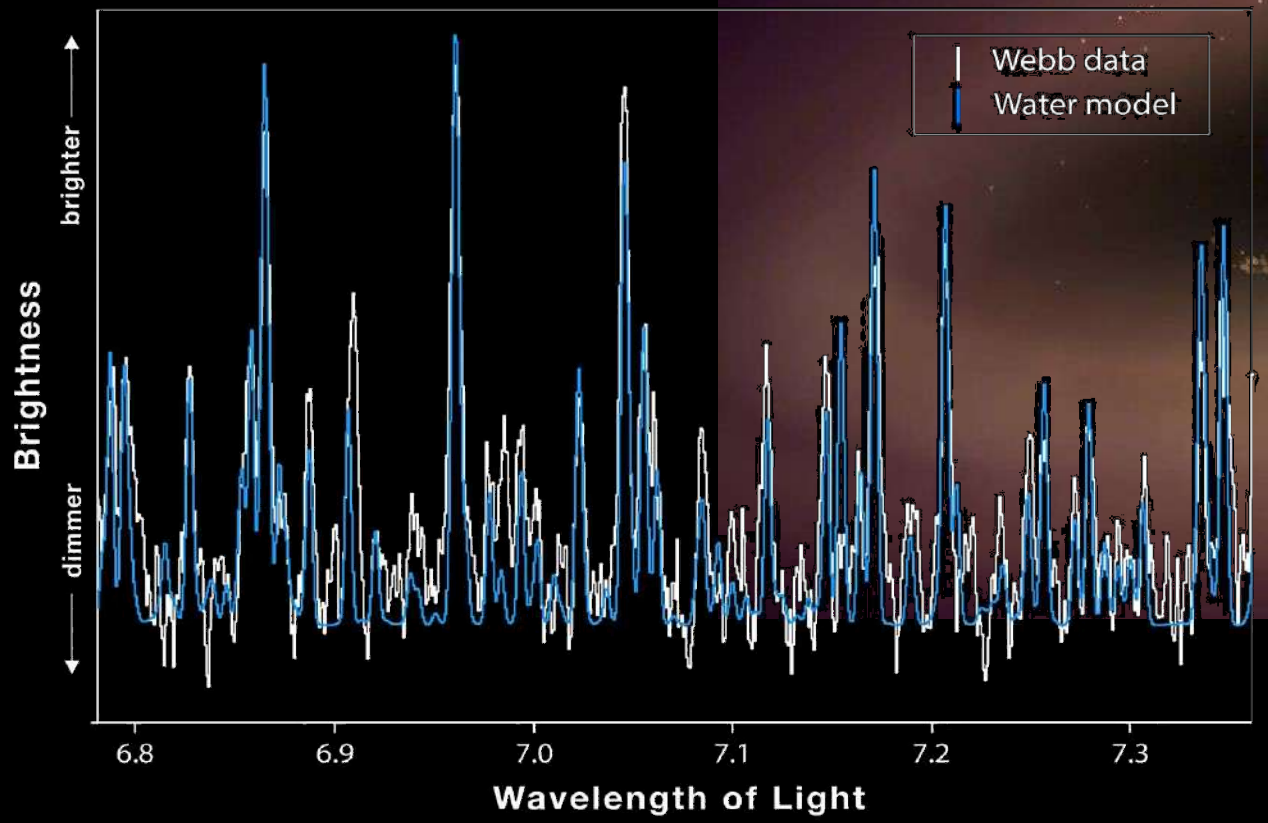


ALMA Images of protoplanetary disks





JWST discovers water in a protoplanetary disk



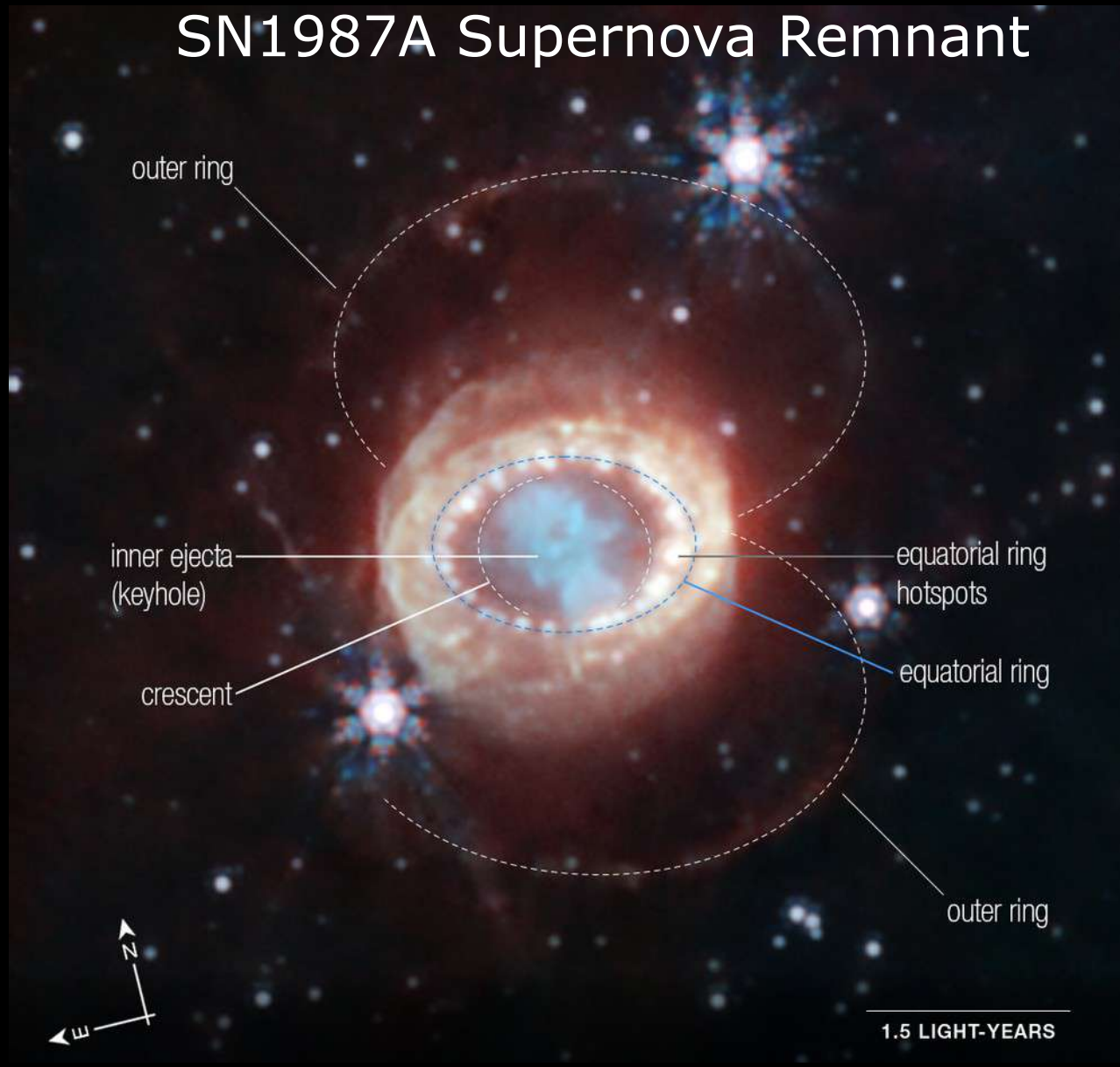
In about 4 billion years

… our sun will develop into a red giant star and reach to the Earth surface. Later it will blow away its envelope into a beautiful planetary nebula!

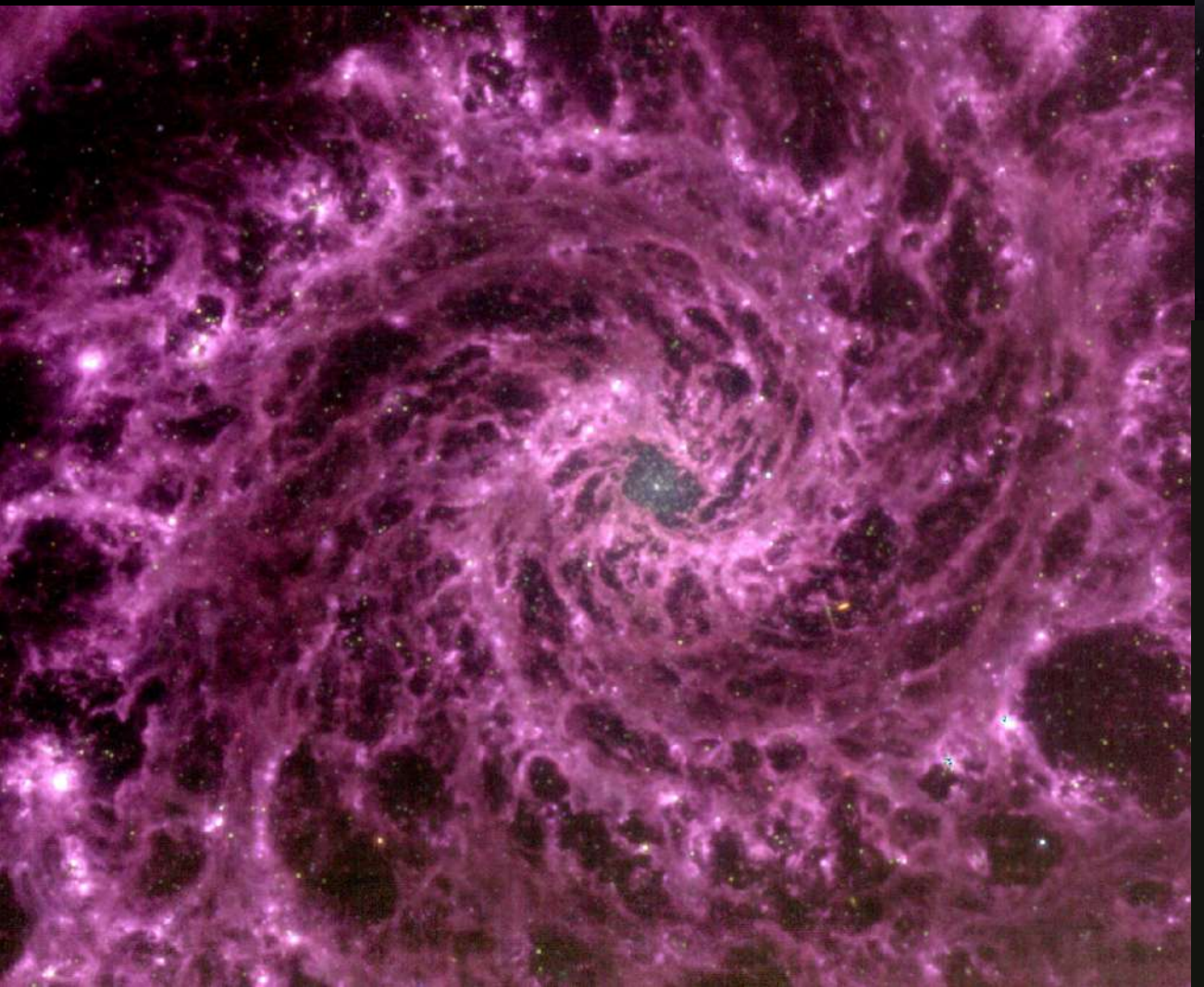
Final stages of stellar evolution

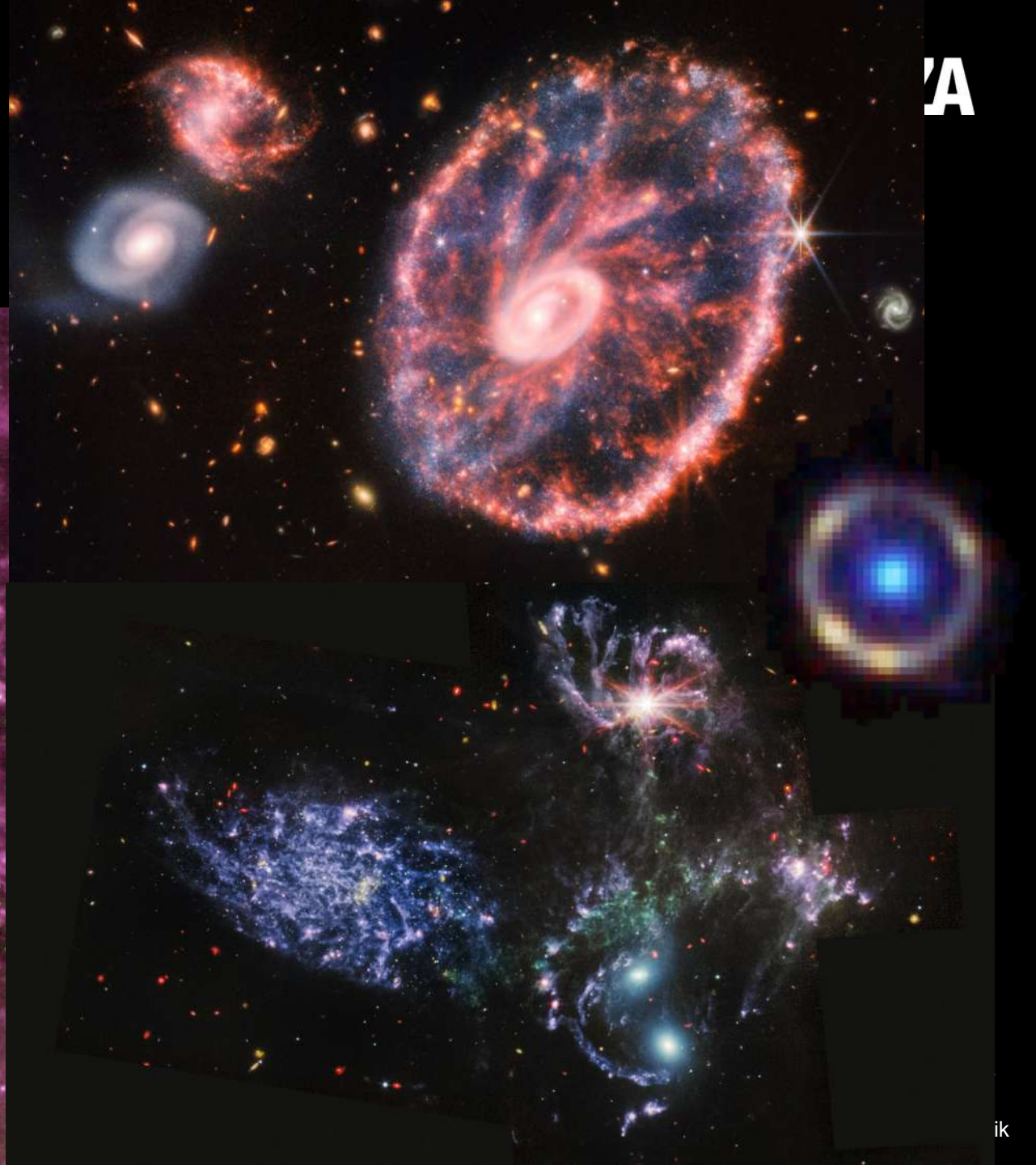
Ring Nebula (planetary nebula)

SN1987A Supernova Remnant



JWST Observations of Galaxies





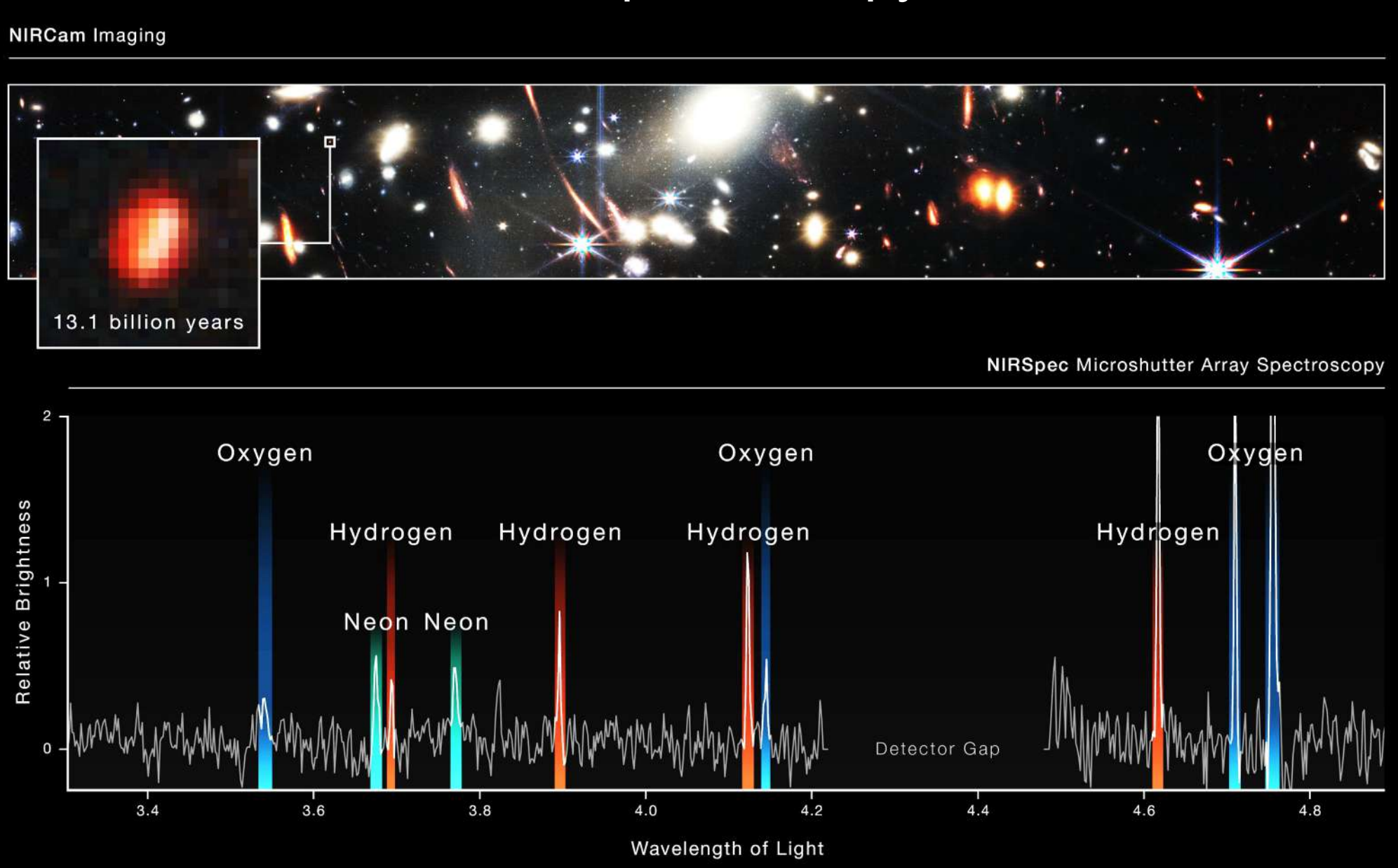
Spiral galaxy IC 5332: Hubble/JWST

Video available at

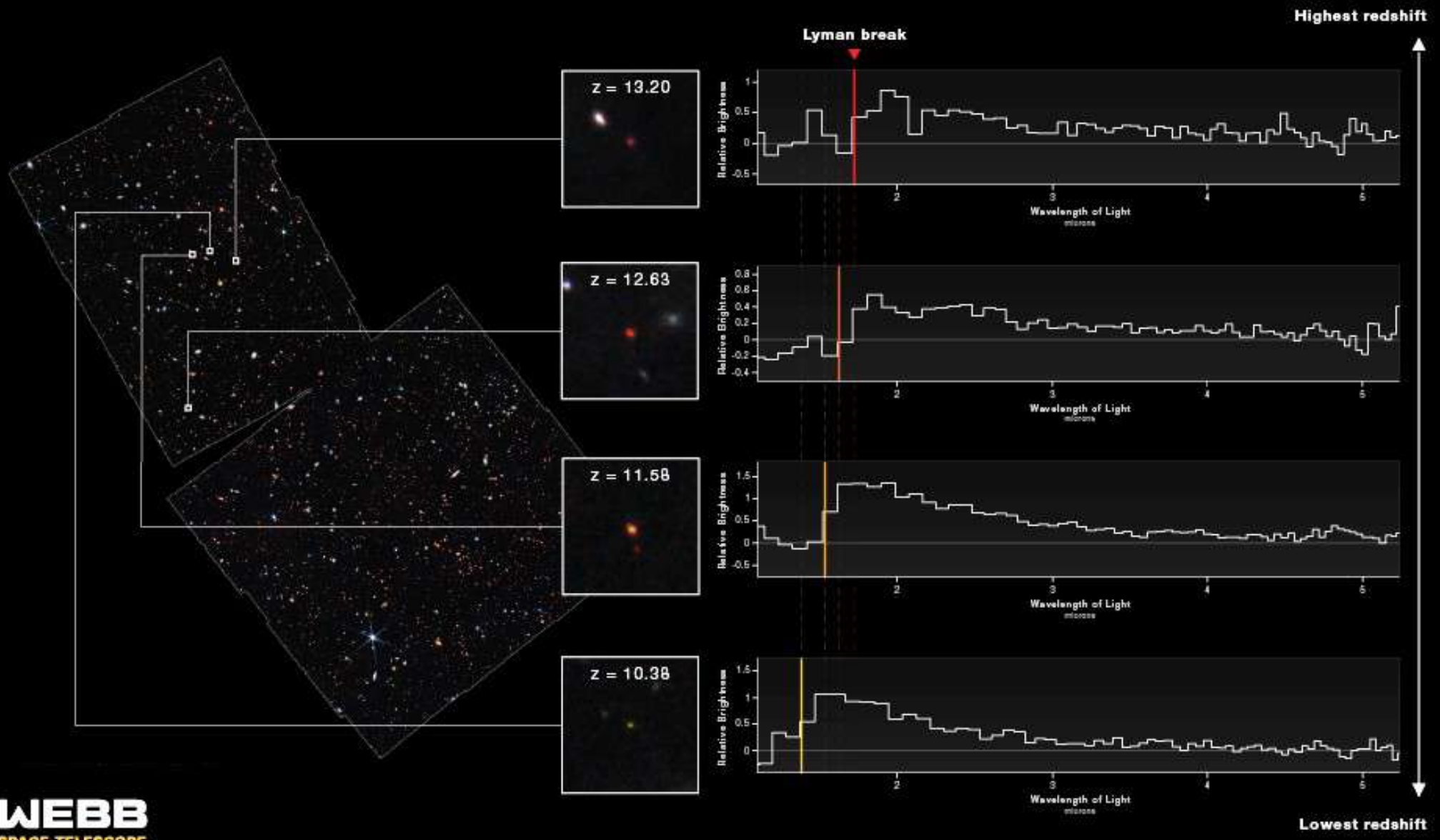
The first deep JWST image revealed by president Biden!

→ THE EUROPEAN SPACE AGENCY

We need JWST Spectroscopy for confirmation



JWST: new distance records!



325 Myr

346 Myr

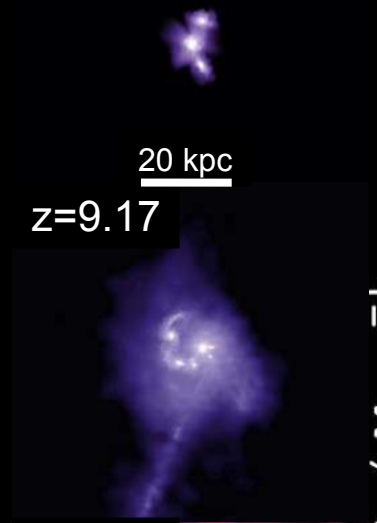
390 Myr

454 Myr

after Big Bang

Formation of first proto-Quasars

z=12.75

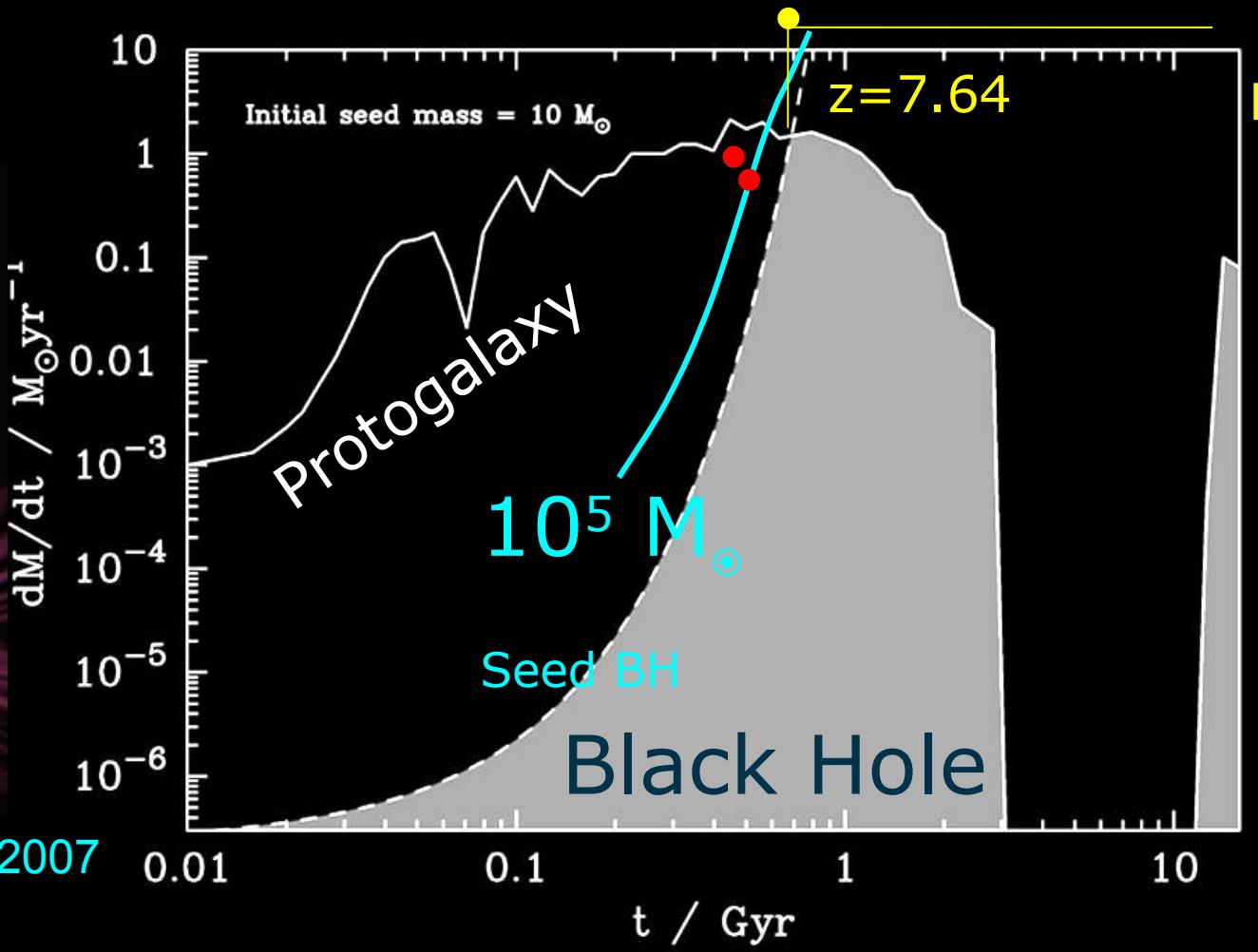


20 kpc

z=9.17

z=6.54

Li, Hernquist, et al. 2007

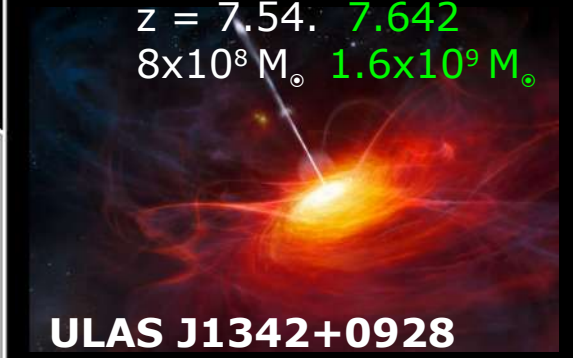


10^9 $M_\odot$

Known QSOs

z = 7.54. 7.642

8×10^8 $M_\odot$ 1.6×10^9 $M_\odot$



ULAS J1342+0928

(Bañados et al. 2018)

J0313-1806

(Wang et al. 2021)

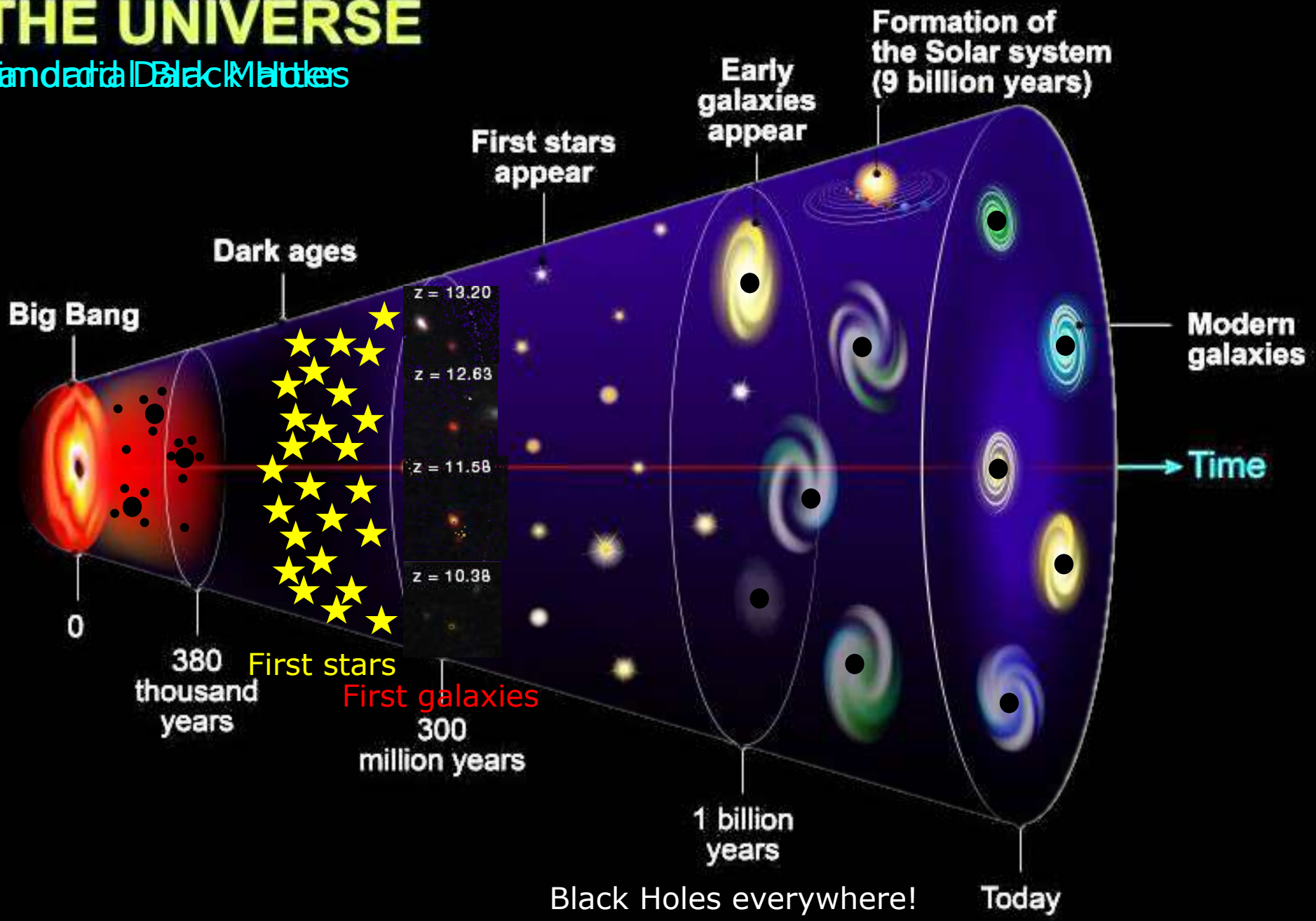
Larsen et al. 2023 & Goulding et al. 2023: JWST discoveries of most distant BHs at z=9&10.1 at $10^{7\text{-}8}$ $M_\odot$

Archibald et al., 2001

We need massive ($10^{5\text{-}7}$ $M_\odot$) seed black holes in the early Universe! They could be primordial (see tomorrow).

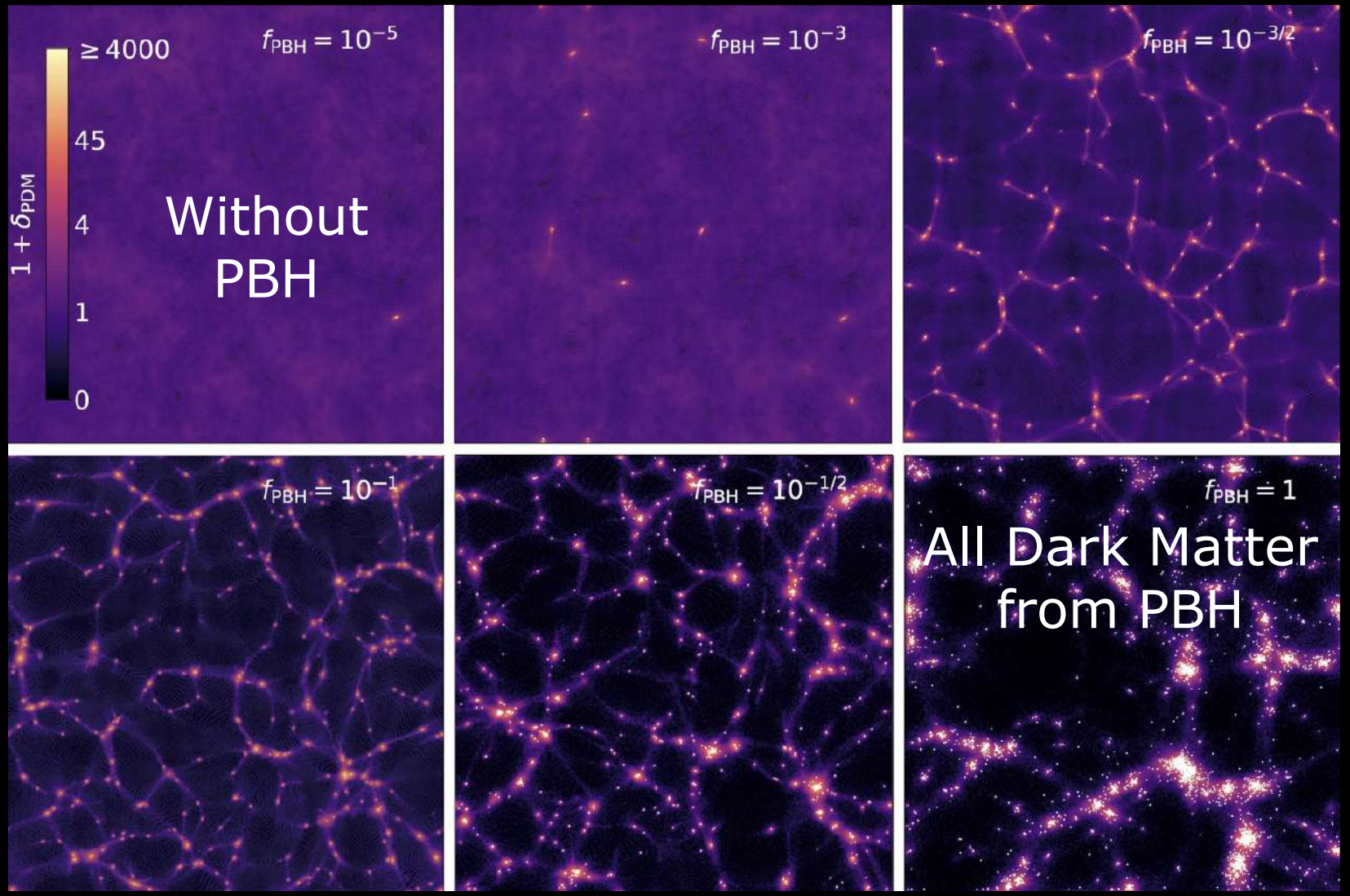
EVOLUTION OF THE UNIVERSE

Standard Model of Cosmology: Dark Matter & Dark Energy



Black Holes everywhere!

Growth of the large-scale structure at z=10



D. Inman and Y. Ali-Haımoud, Early structure formation in primordial black hole cosmologies, Phys. Rev. D 100, 083528 (2019), arXiv:1907.08129

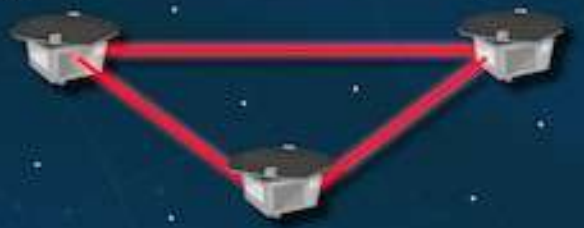
THE SPECTRUM OF GRAVITATIONAL WAVES

esa

Observatories & experiments

Ground-based experiment

Space-based observatory



Pulsar timing array

Cosmic microwave background polarisation

Timescales

milliseconds — seconds — hours — years — billions of years

Frequency (Hz)

100 — 1 — 10^{-2} — 10^{-4} — 10^{-6} — 10^{-8} — 10^{-16}

Cosmic fluctuations in the early Universe

Cosmic sources

Supernova

Pulsar

Compact object falling onto a supermassive black hole

Merging supermassive black holes

Merging neutron stars in other galaxies

Merging stellar-mass black holes in other galaxies

Merging white dwarfs in our Galaxy

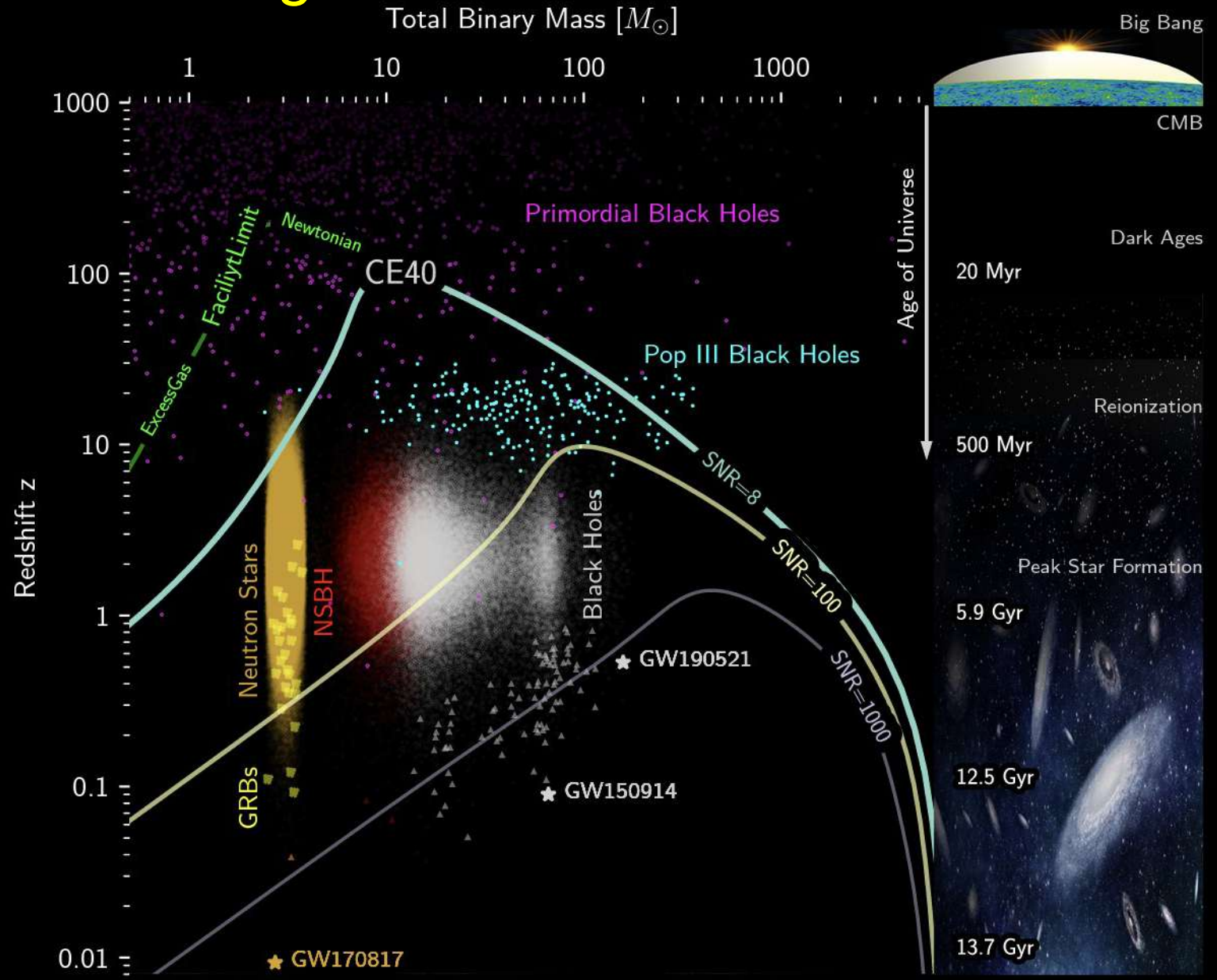
#lisa

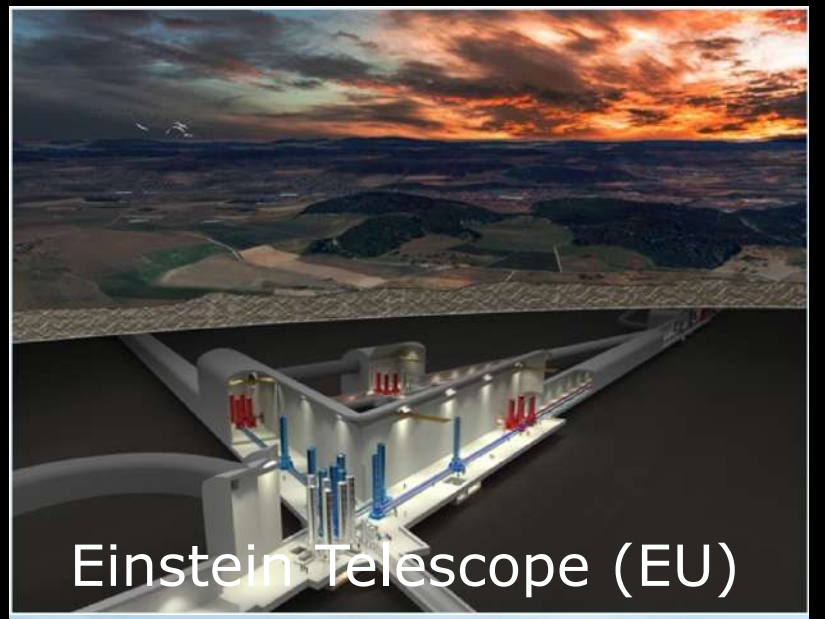
„Auf gutem Grund“

Das Deutsche Zentrum für Astrophysik
Forschung. Technologie. Digitalisierung.

DZA

Sensitivity of the next generation groundbased gravitational wave interferometers





Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr

Calendar of the Universe

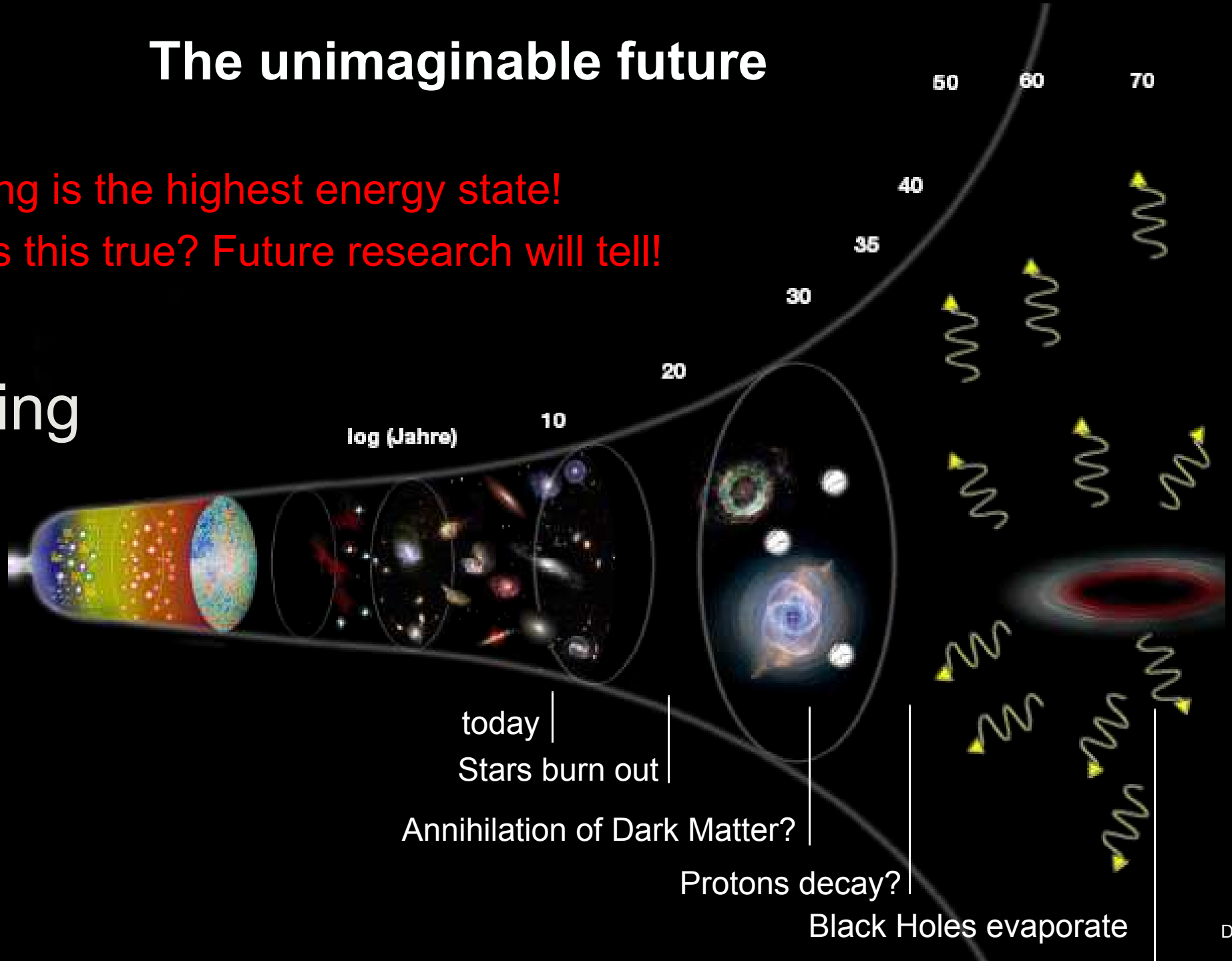
1. Jan 0h00	Big Bang, primordial element synthesis H, He, ..., primordial Black Holes?
1. Jan 0h14	Separation of Radiation and Matter: transparent Universe
1.-5. Jan	First stars form, creat elements C, N, O ...
8. Jan	Oldest known galaxy / Quasar
27. Mar	„The Big Feast“, Maximum of Star Formation and Quasars
9. Sep	Formation of the Solar System
28. Sep	Life creation on Earth, Cyanobacteria (Blue Algae) start „Terraforming“
16.-19. Dec	Vertebrates and plants
20.-24. Dec	Forest, Fish, Reptiles
25. Dec	Mammals
28. Dec	Extinction of the Dinosaurs
31. Dec 20h	First hominids (Hominini)
-39 min	Maunakea (Hawaii Island) was formed
-6 min	Modern humans: Homo Sapiens Sapiens
-70 sec	Extinction of the Neanderthal Man
-4.6 sec	Jesus Christ (all world religions!)
-0.23 sec	Our own life (100 Years)
9. Feb	Earth gets too hot to live on
16. Apr	Milky Way merges with Andromeda
10. Jul	Sun turns into a red giant

The unimaginable future

… Nothing is the highest energy state!

… But is this true? Future research will tell!

Nothing



Nothing

today

Stars burn out

Annihilation of Dark Matter?

Protons decay?

Black Holes evaporate


Many thanks for
your attention!