TECHNISCHE UNIVERSITÄT DRESDEN

DZA

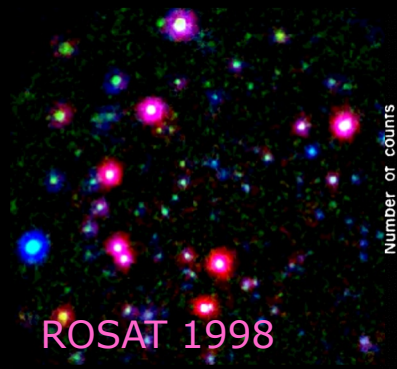
Is Dark Matter made of Primordial Black Holes?

Günther Hasinger

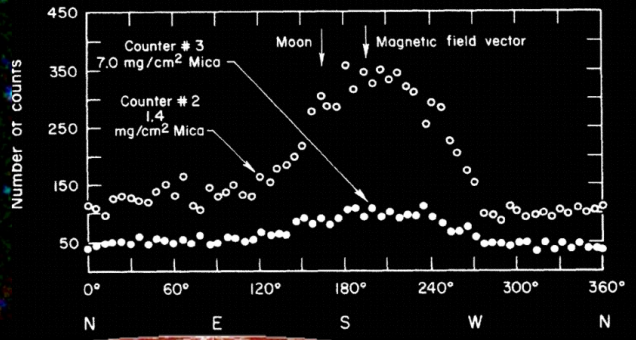
Polish-German-WE-Heraeus Seminar
MAX BORN SYMPOSIUM
Synagoge Görlitz, 5. December 2023

Wissenschaftsjahr 2023
unser UNIVERSUM

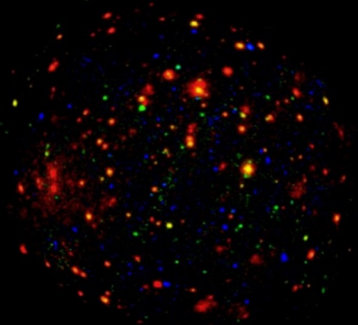
The X-ray background

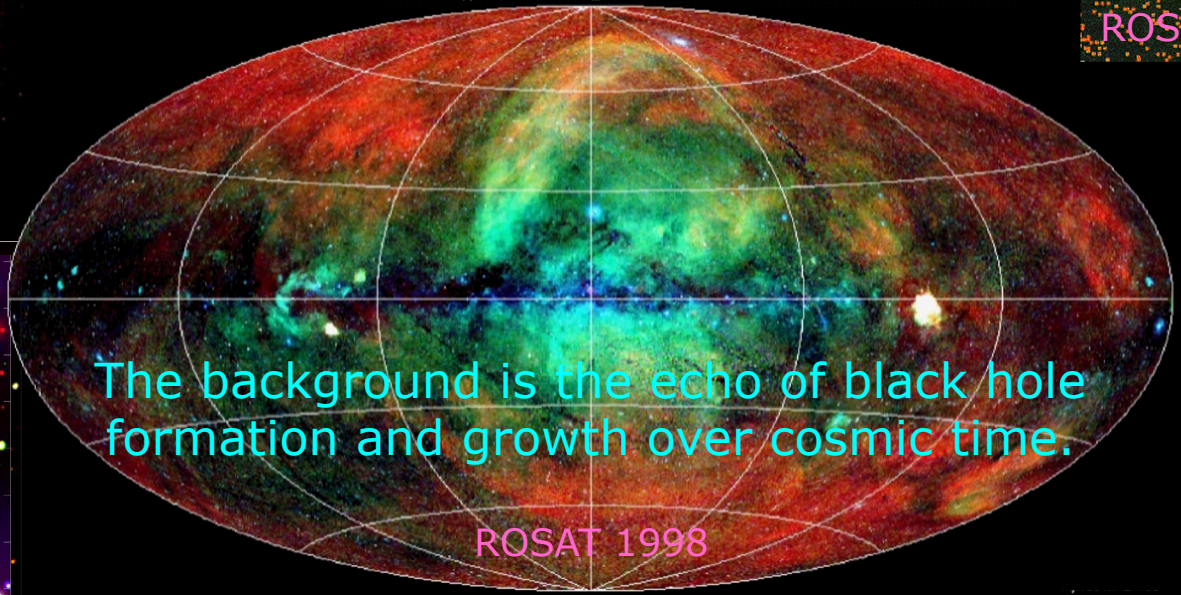

ROSAT 1998

Giacconi 1962




ROSAT 1991


XMM-Newton 2012




Chandra 2011

Resolving the 0.5-2 keV X-ray background

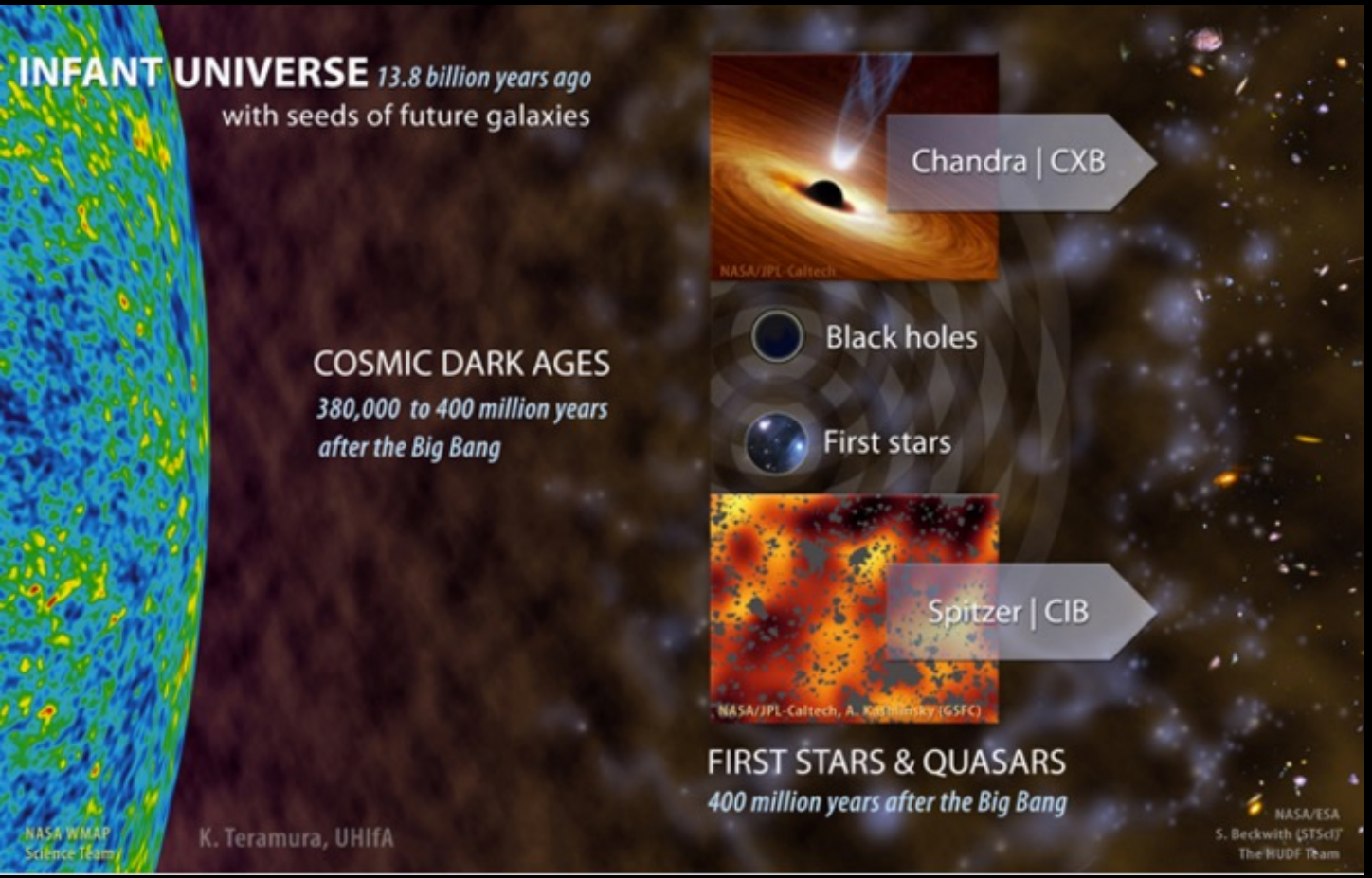
75-80% ROSAT sources

90-95% Chandra/XMM sources

Few % Stacking Galaxies

1% Correlation with CIB

CIB x CXB fluctuations indicate high-z BH population



Significant cosmic background fluctuations have been found both in the NIR and in X-rays.

The strong CIB/CXB cross-correlation signal indicates a substantial contribution of Black Holes to the signal.

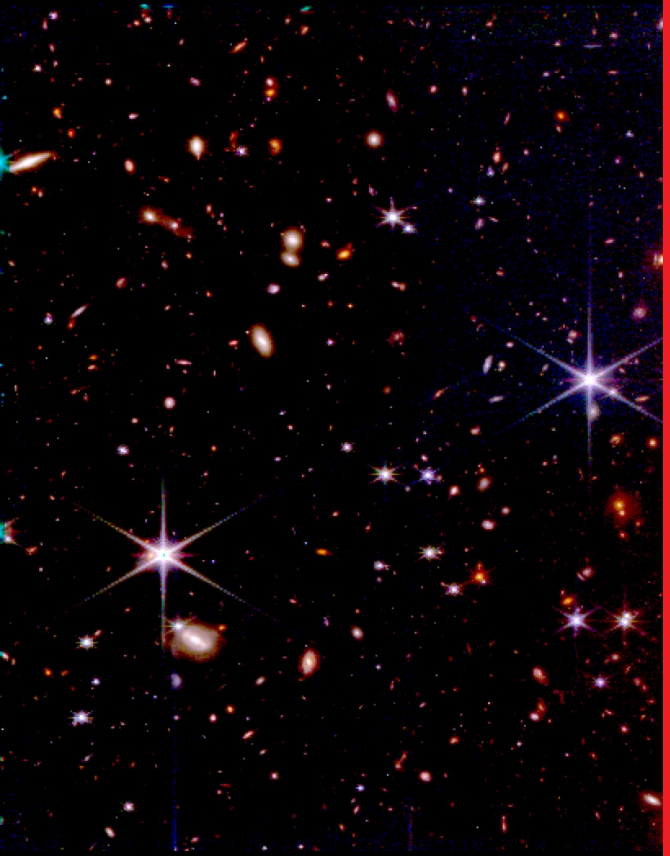
There is no correlation with fluctuations in the deepest HST images, therefore the signal likely comes from redshifts z>13.

Large angular scale also points to high-z origin.

Could these be primordial?

Cappelluti et al., 2013

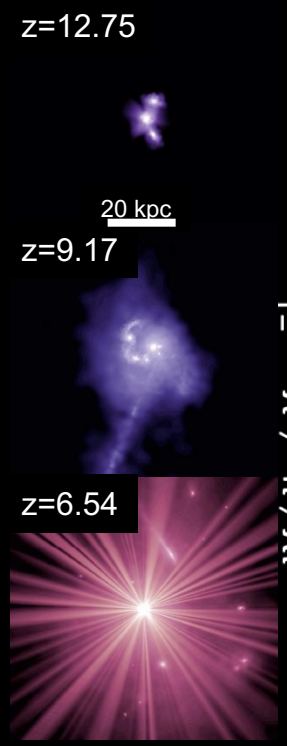
The first JWST Deep Image revealed by President Biden!



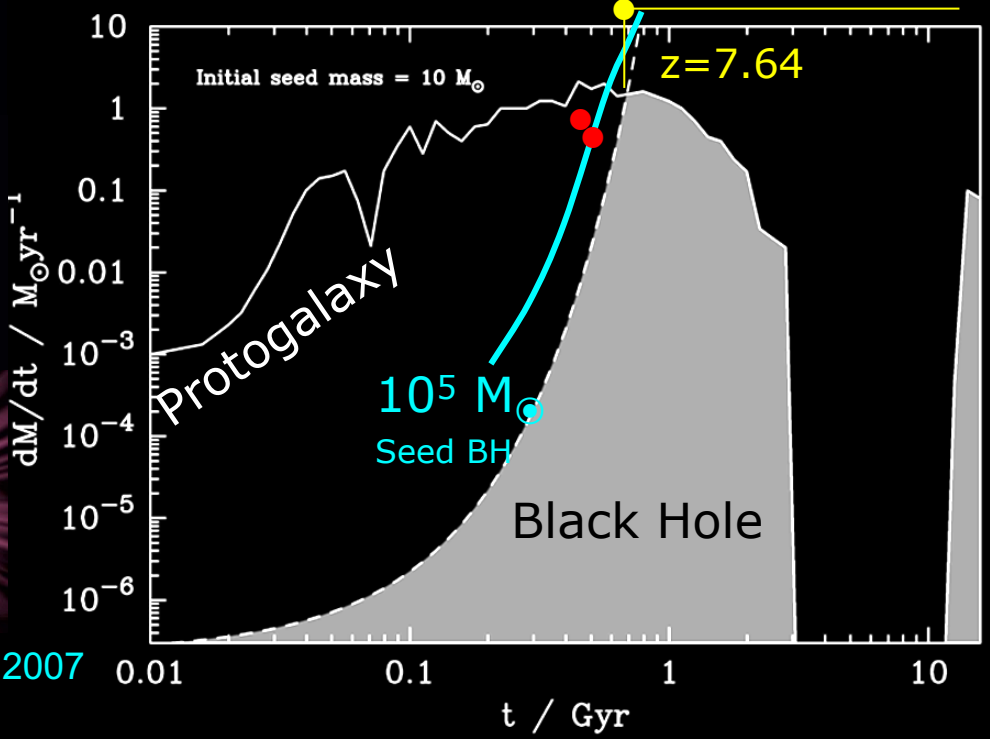
esa

→ THE EUROPEAN SPACE AGENCY

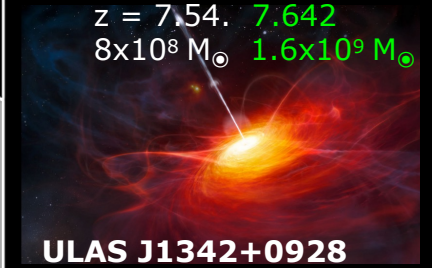
How to produce the first proto-quasars



Li, Hernquist, et al. 2007



10^9 $M_\odot$
known QSO



ULAS J1342+0928
(Bañados et al. 2018)

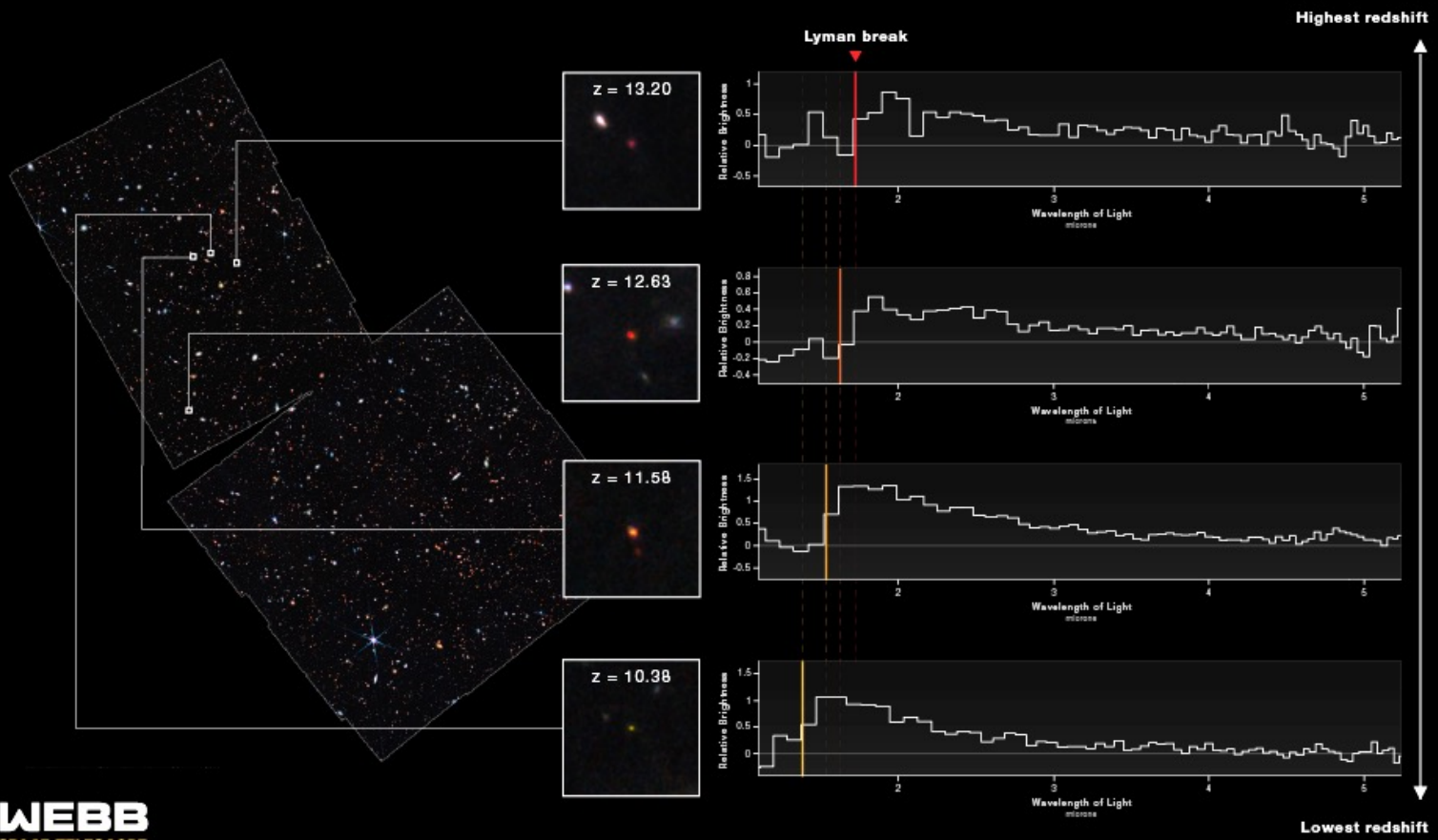
J0313-1806
(Wang et al. 2021)

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

Need massive ($10^{5\text{-}7}$ $M_\odot$) seed Black Holes early in the Universe !

JWST: new distance records!



325 Myr

346 Myr

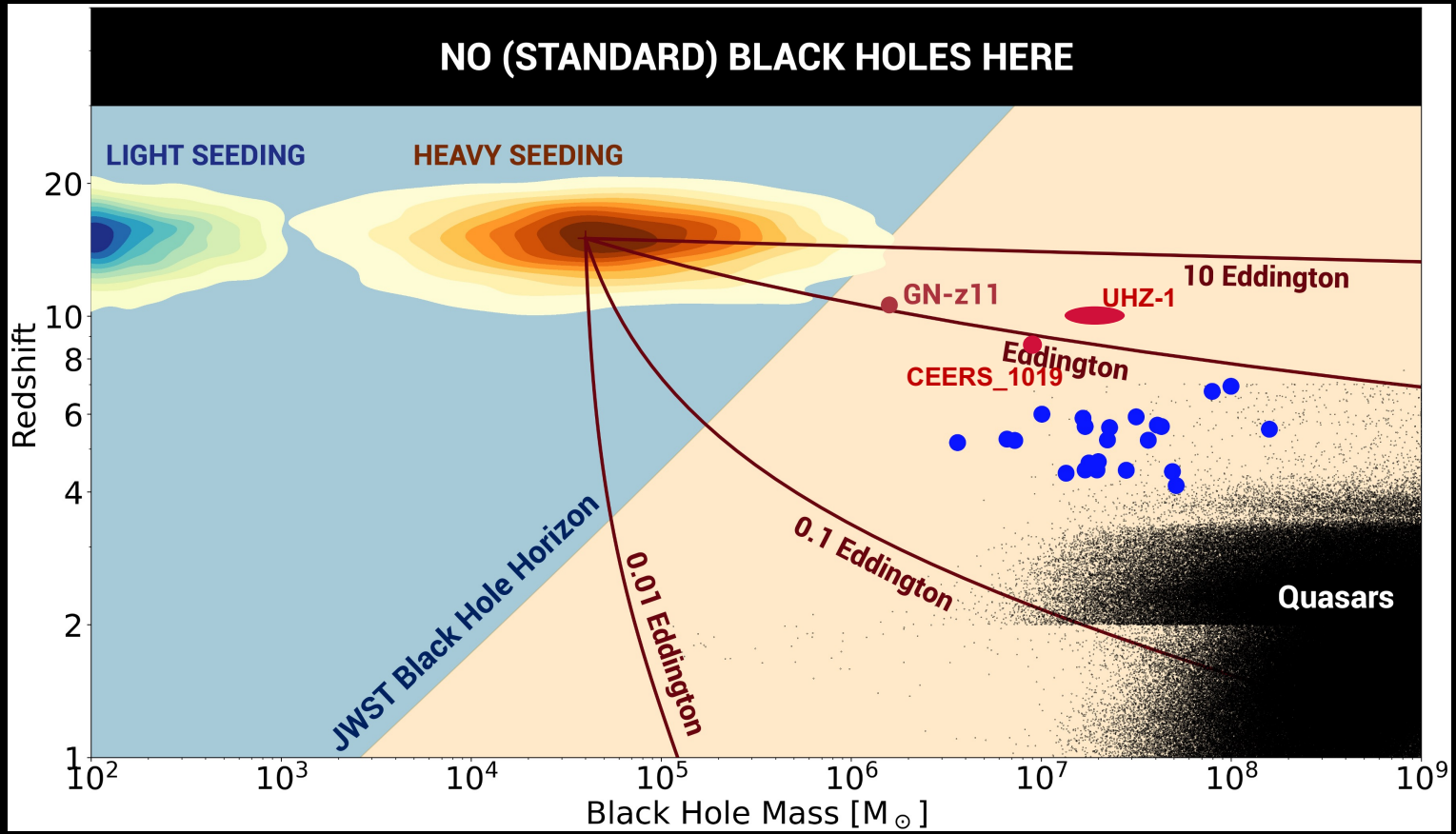
390 Myr

454 Myr

after Big Bang

WEBB SPACE TELESCOPE

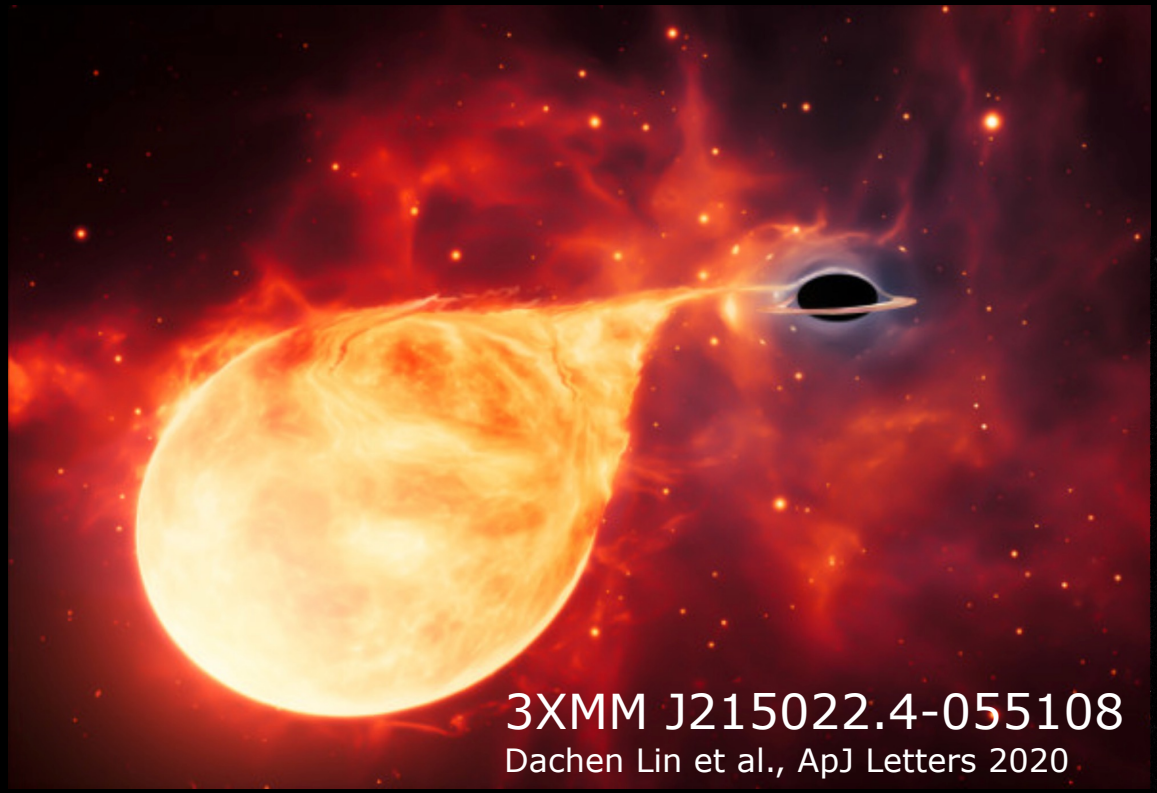
Evidence for Heavy Seeds gets stronger!



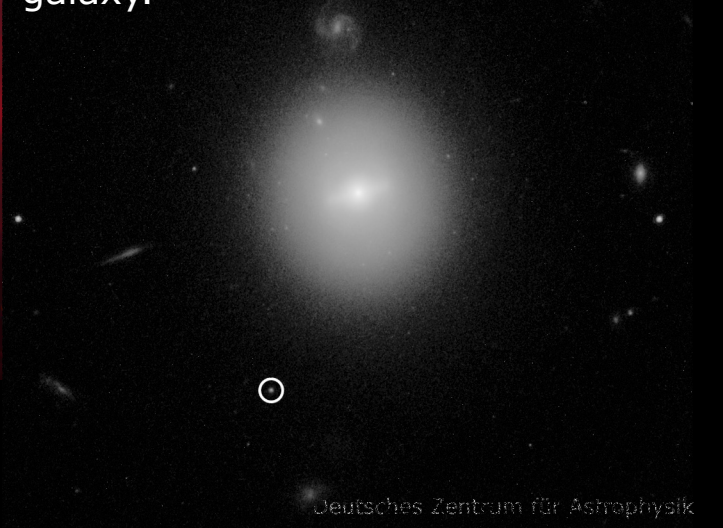
Pacucci et al., *arXiv:2308.12331v1*

UHZ-1: Goulding et al., 2023
CEERS_1019: Larson et al., 2023

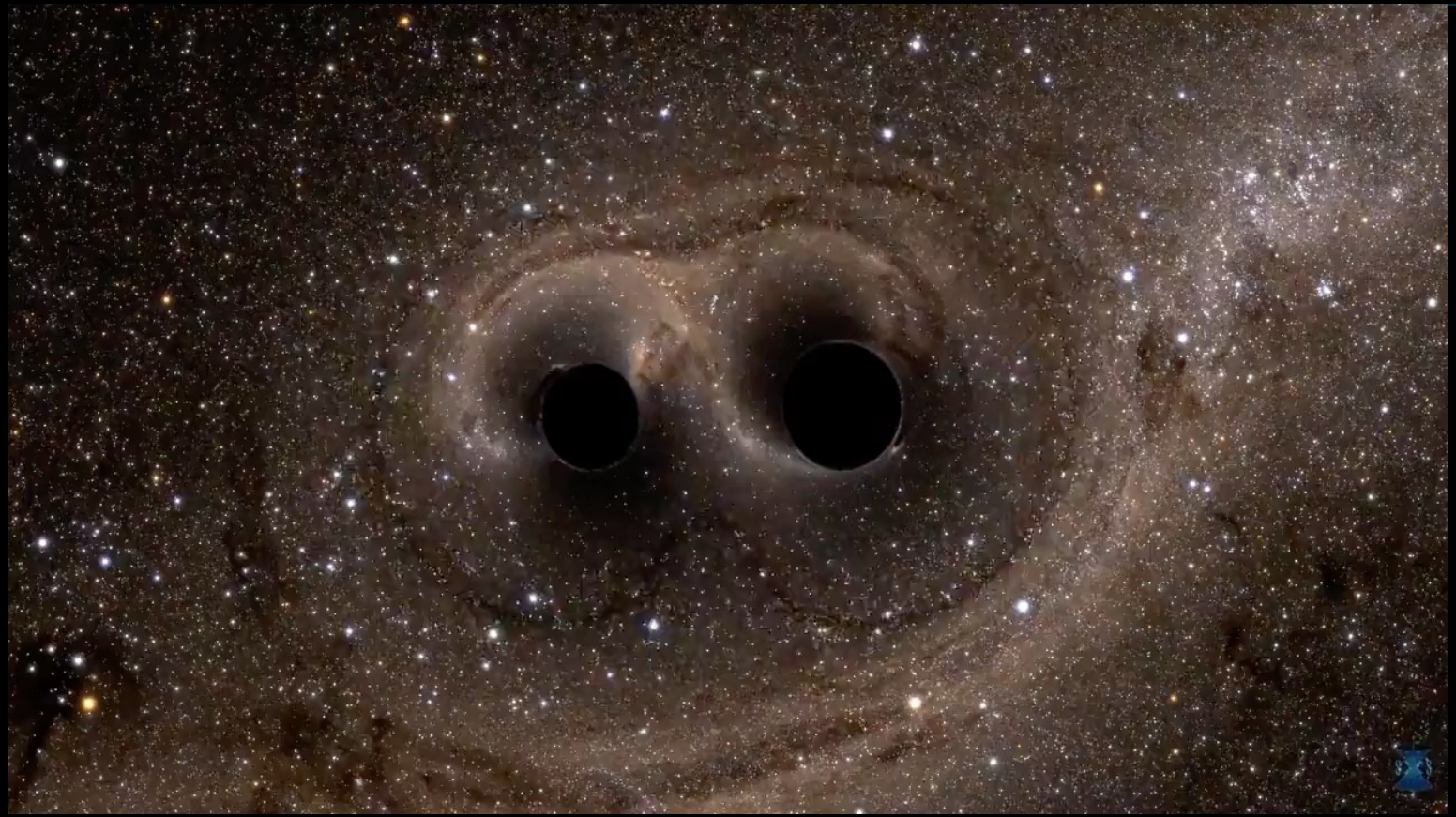
Hubble reveals an “Intermediary” Black Hole



The X-ray telescopes XMM-Newton and Chandra have detected a Black Hole, which is just in the process of disrupting and swallowing a star. The Hubble Space Telescope showed that this is an “Intermediary” Black Hole of about 50.000 solar masses in a globular cluster of another galaxy.

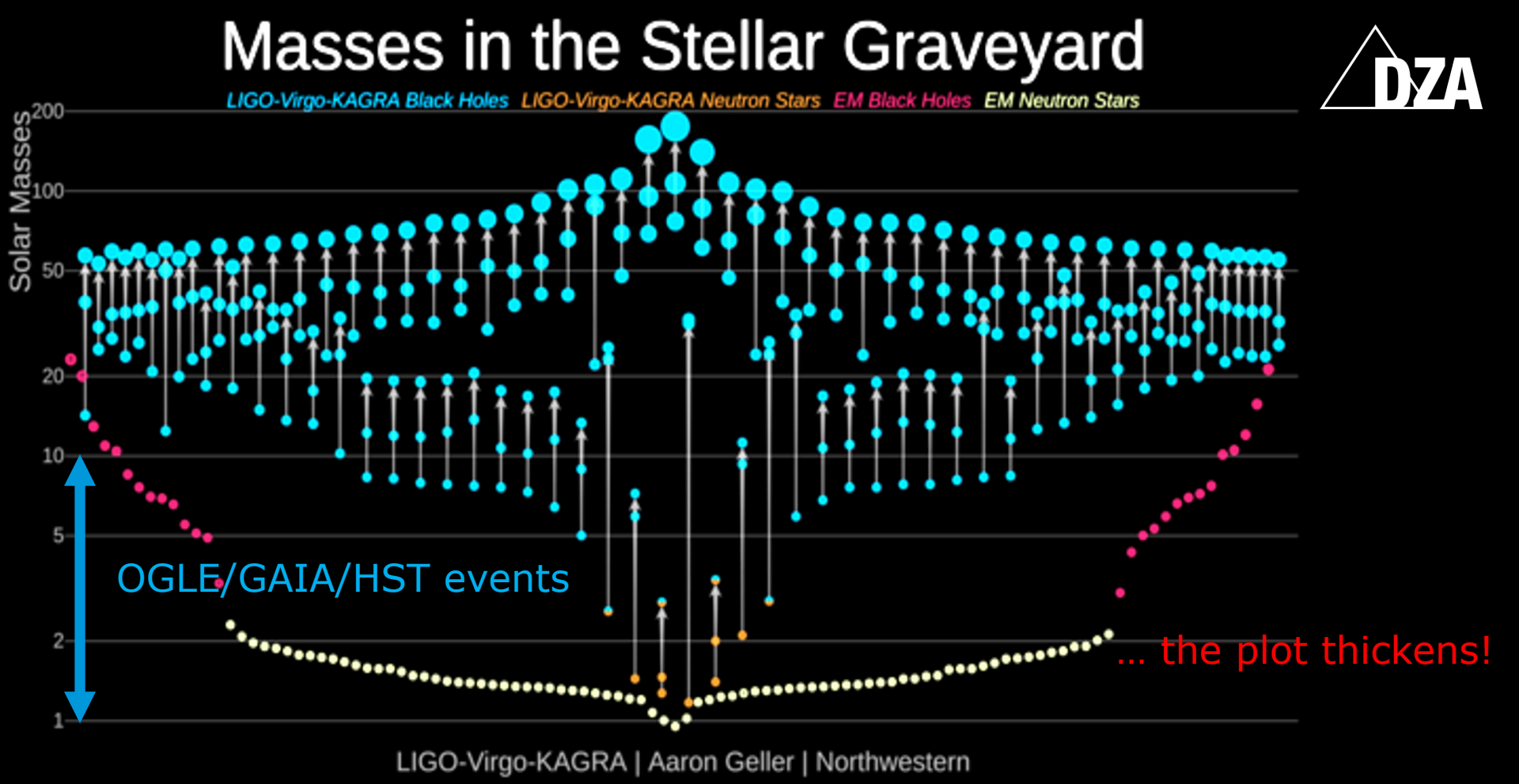


Simulation of the merger between two Black Holes

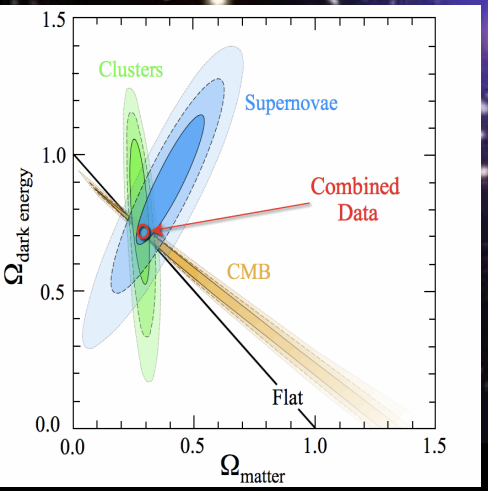


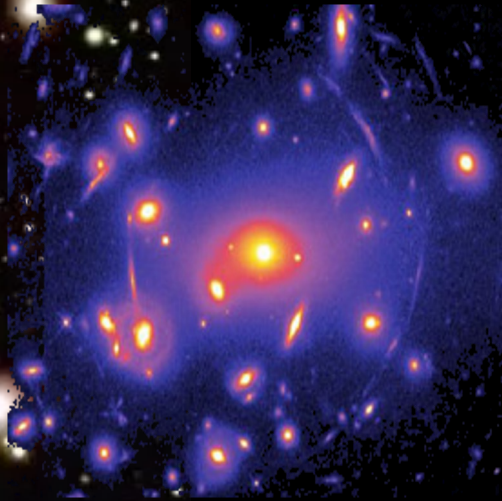
LIGO/Virgo/
Kagra/GEO O4
observations
start in May
2023!

Masses in the Stellar Graveyard



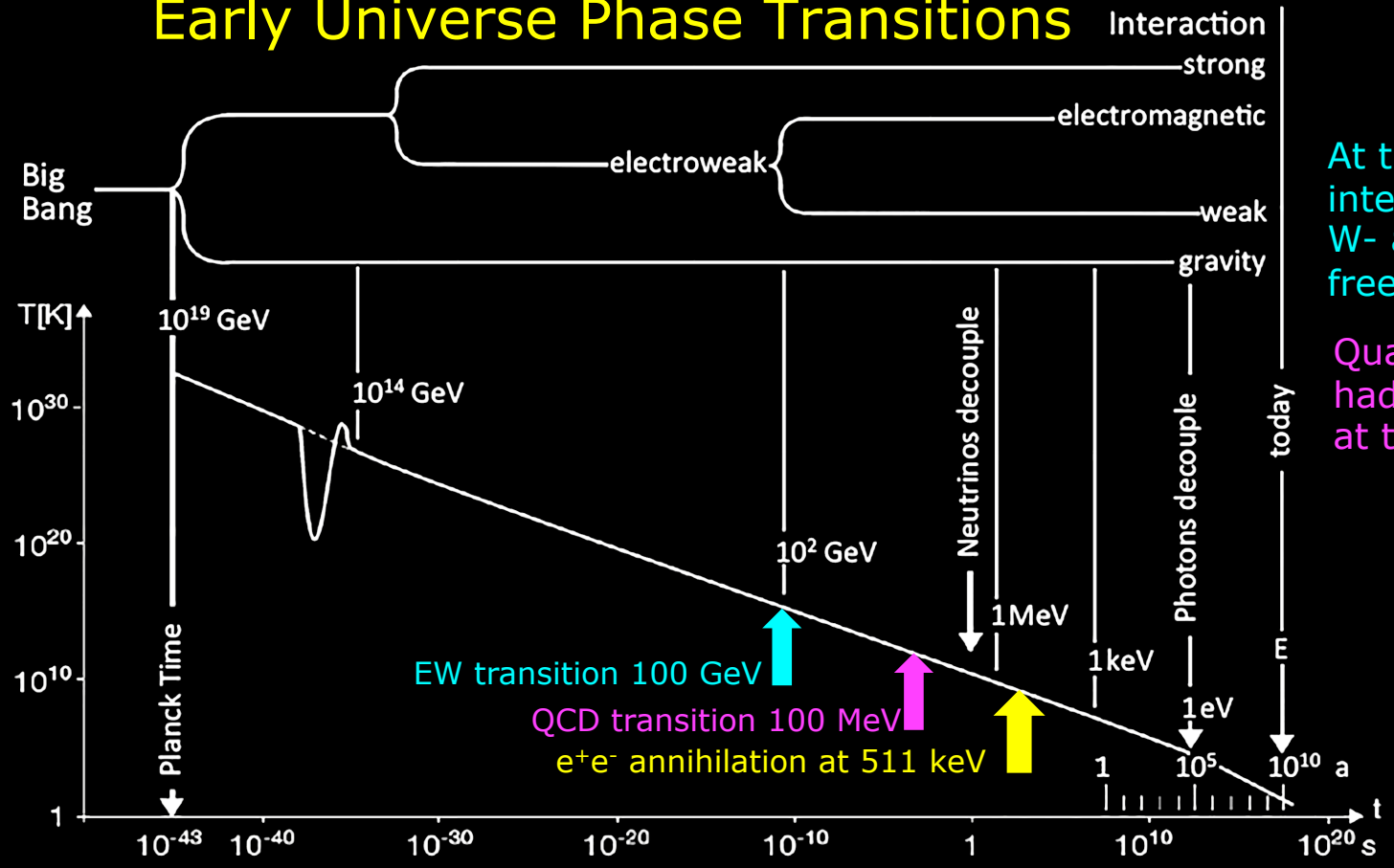
What is Dark Matter?





Generations of physicists are desperately searching the Dark Matter particle. Primordial Black Holes may be an alternative.

Early Universe Phase Transitions

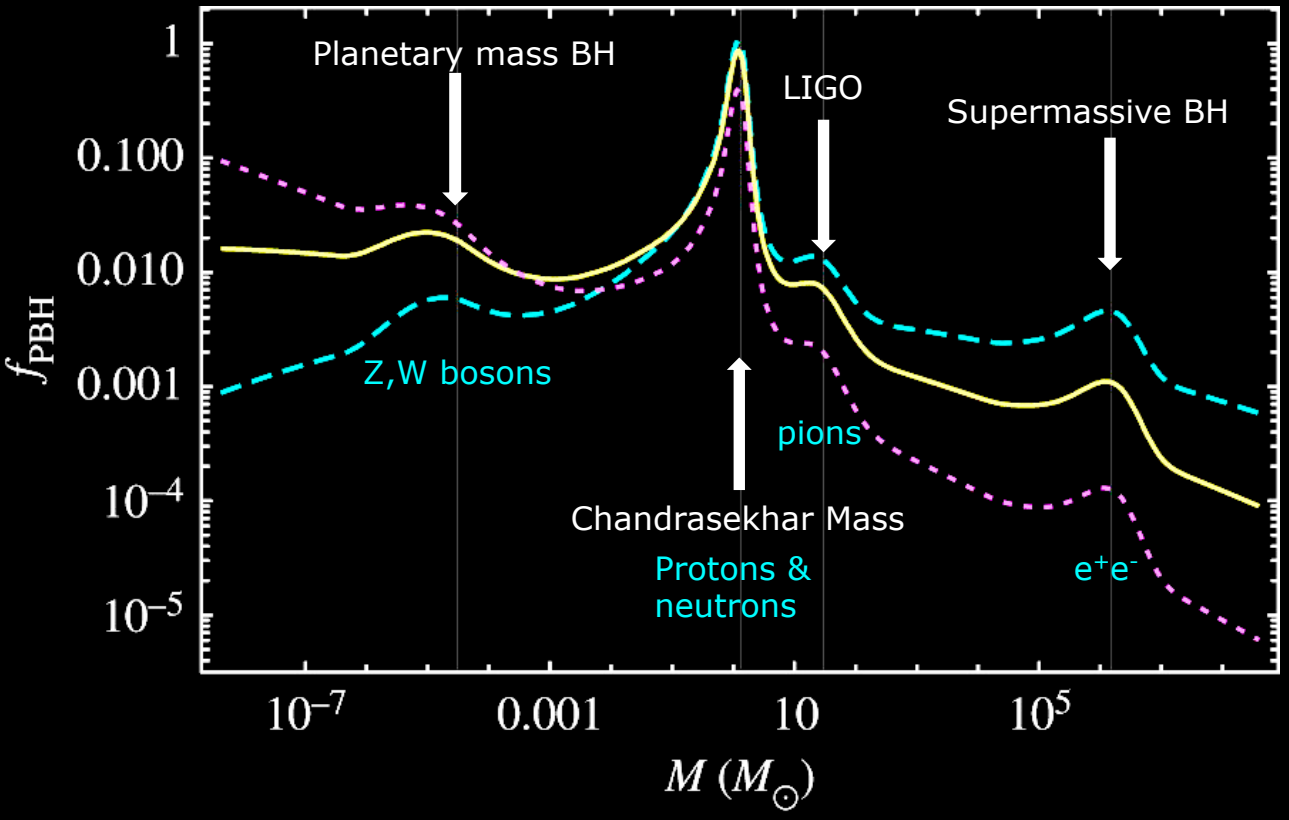


At the electroweak interaction scale the first W- and Z-bosons are freezing out.

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 enables black hole collapse.

PBH Mass Spectrum



Different peaks correspond to different particles created at the early universe phase transitions and the corresponding reduction in the sound velocity.

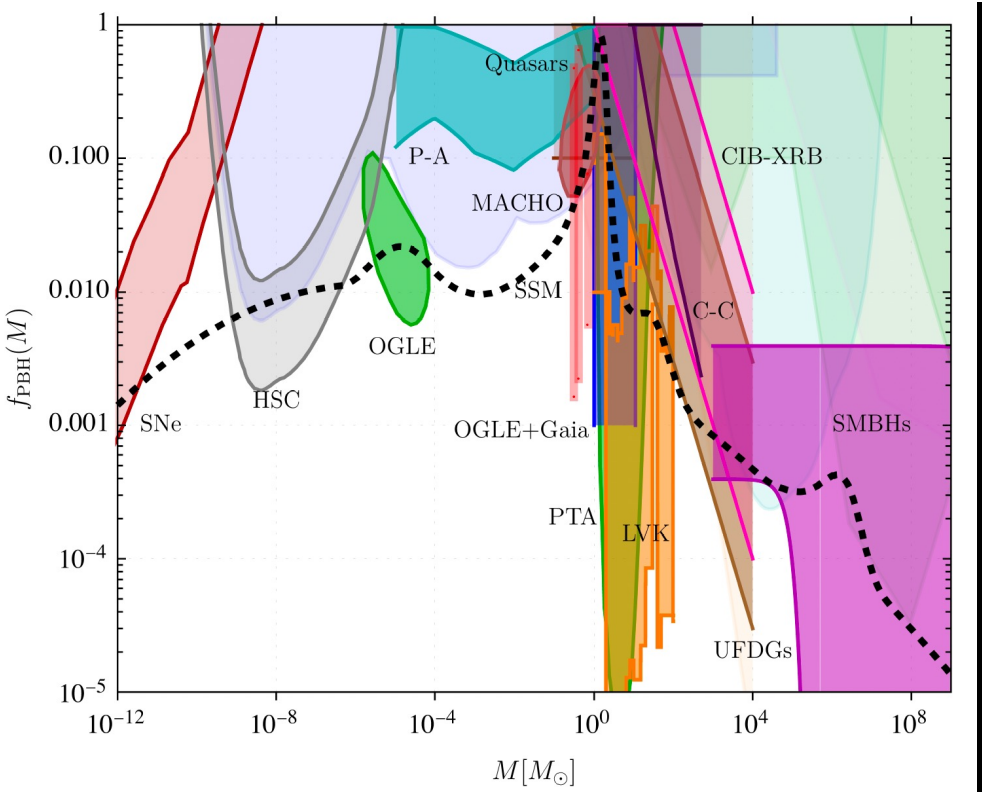
BH mass corresponds to the horizon size at each time.

Only requirement is enough fluctuation power in a volume fraction of 10^{-9} of the early Universe.

Carr, Clesse, García-Bellido 2019

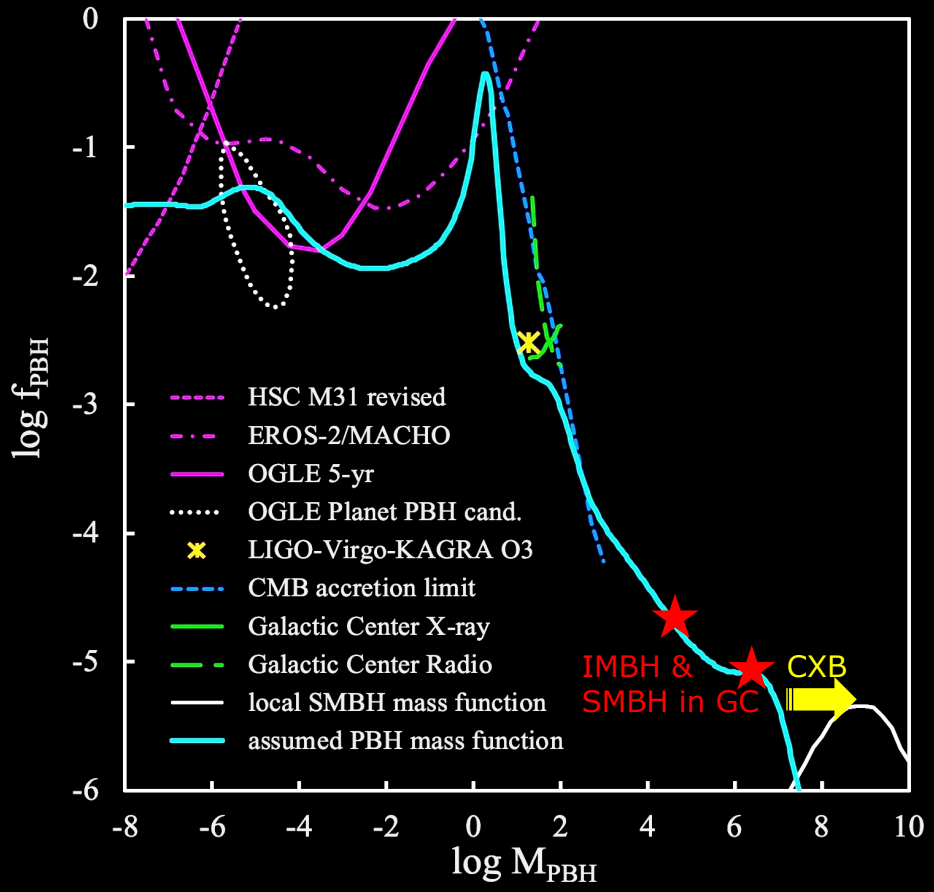
Observational Evidence for Primordial Black Holes: A Positivist Perspective

B. J. Carr,[1,*] S. Clesse,[2,†] J. García-Bellido,[3,‡] M. R. S. Hawkins,[4,§] and F. Kühnel[5,¶]



arXiv:2306.03903v1 [astro-ph.CO] 6 Jun 2023

PBH mass spectrum assumed for our work



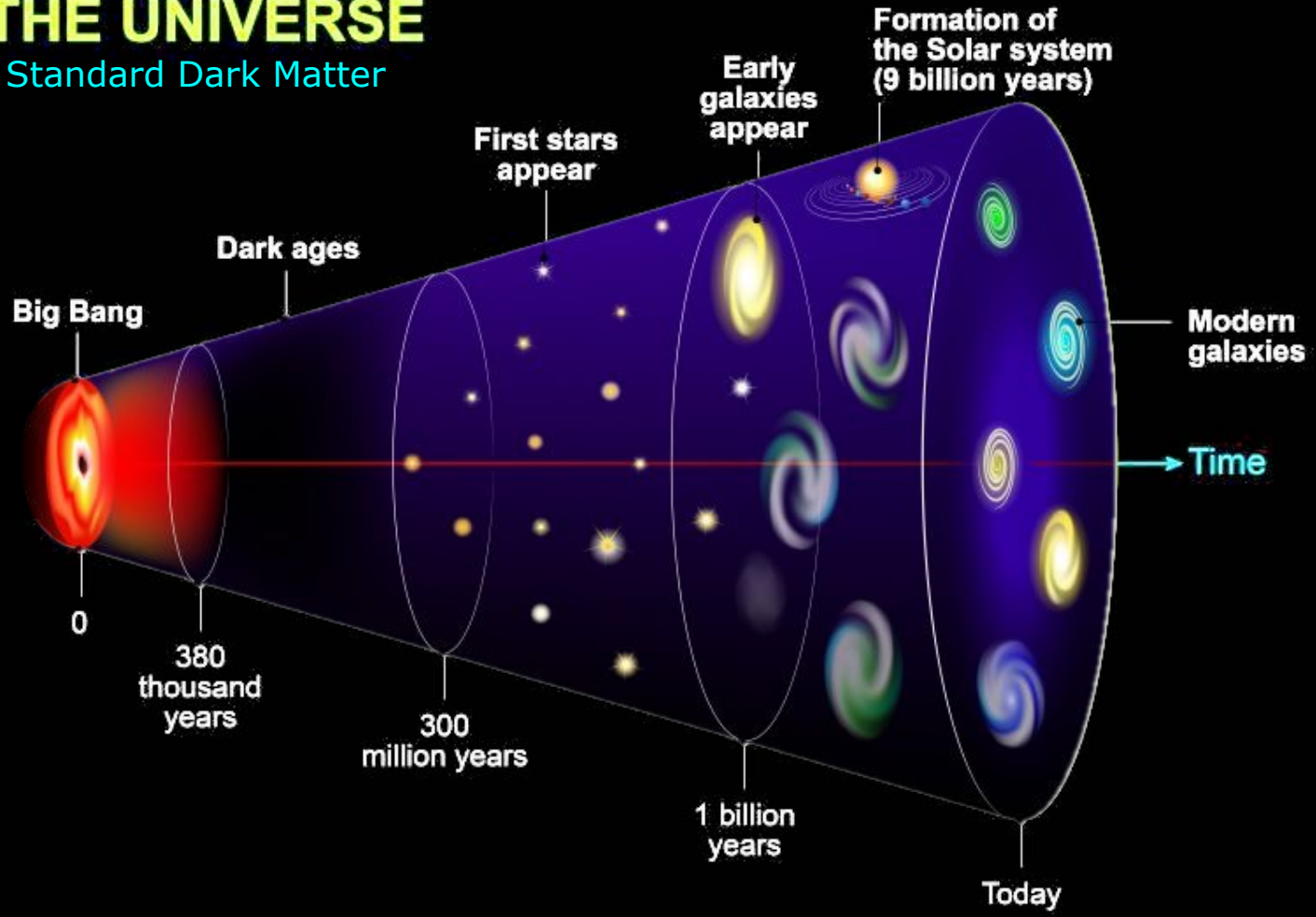
Bernard Carr, Juan García-Bellido et al. are working on a new version of their PBH mass spectrum, which assumes a rolling index of the primordial power spectrum and thus has a steeper decline at large PBH masses. This is now fully consistent with all observational constraints.

This is, what we use to estimate the PBH contribution to the extragalactic backgrounds.

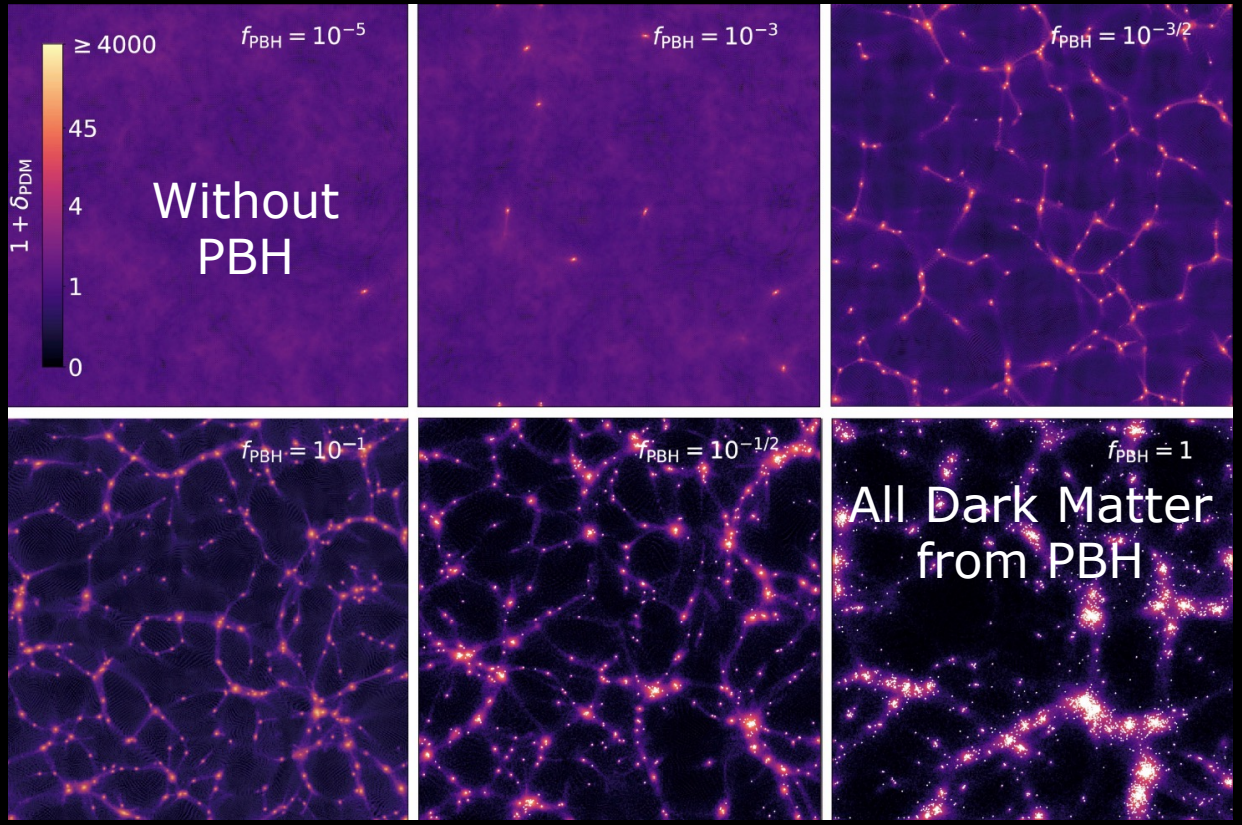
Hasinger 2020

EVOLUTION OF THE UNIVERSE

Standard Dark Matter



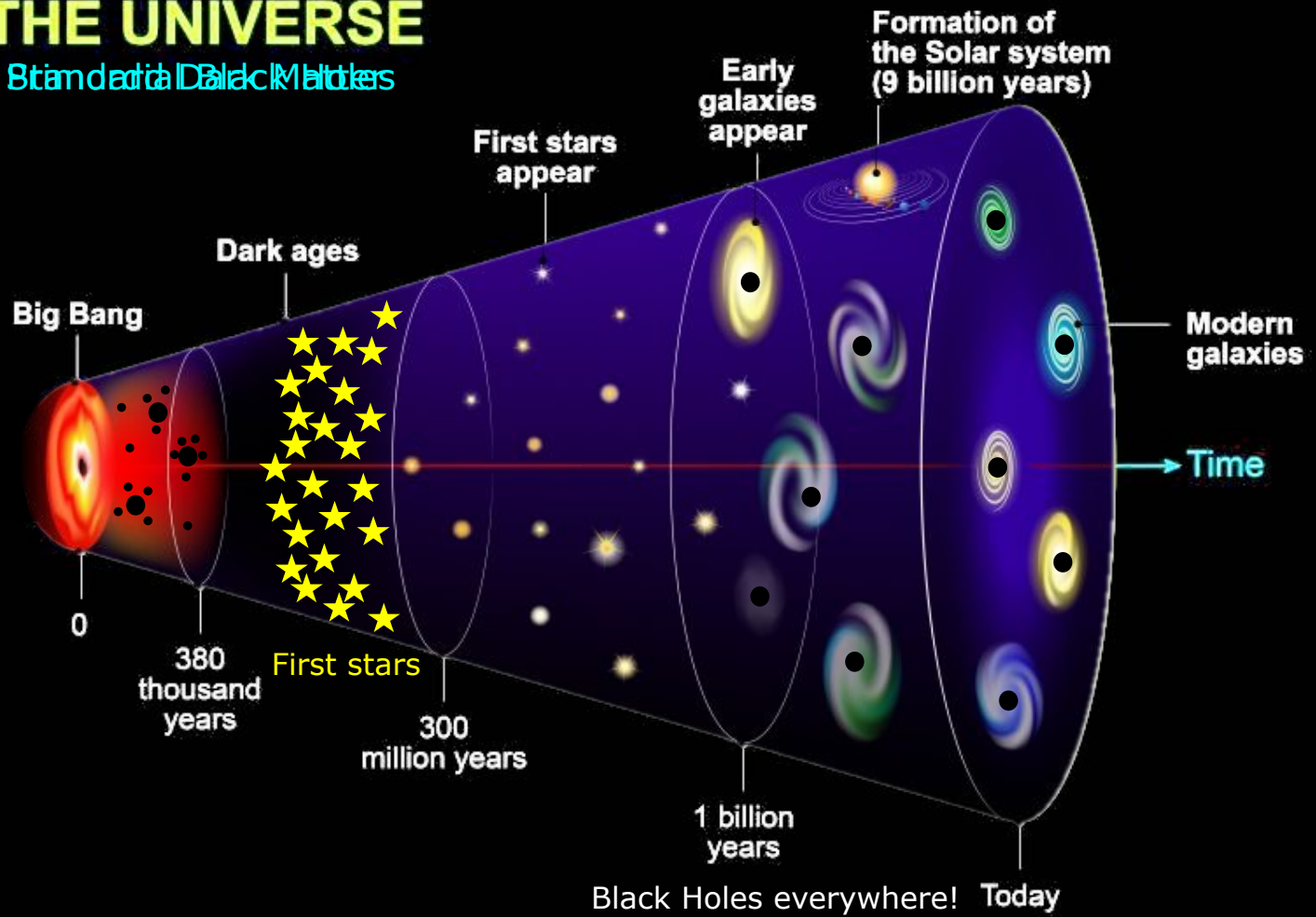
Growth of Large-Scale Structure at z=10



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

EVOLUTION OF THE UNIVERSE

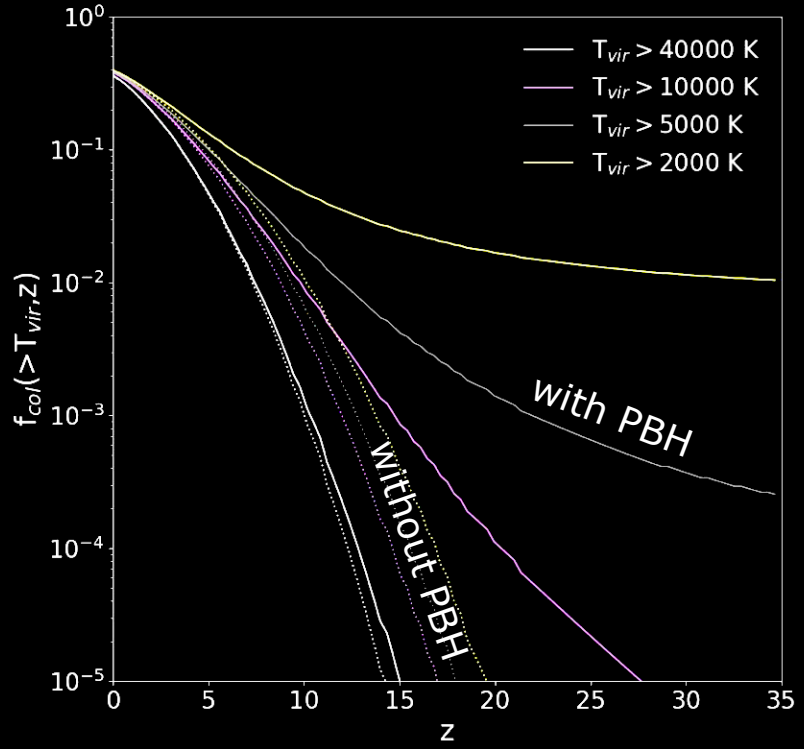
Standard Dark Matter Black Holes



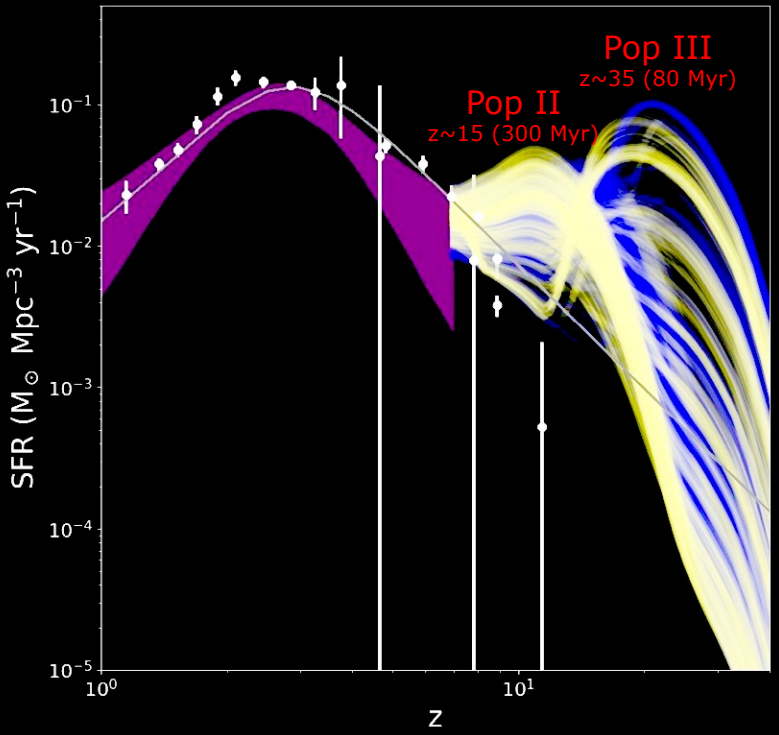
Black Holes everywhere!

PBH add small DM haloes and early star formation

Dark Matter Halo Growth



Star Formation History

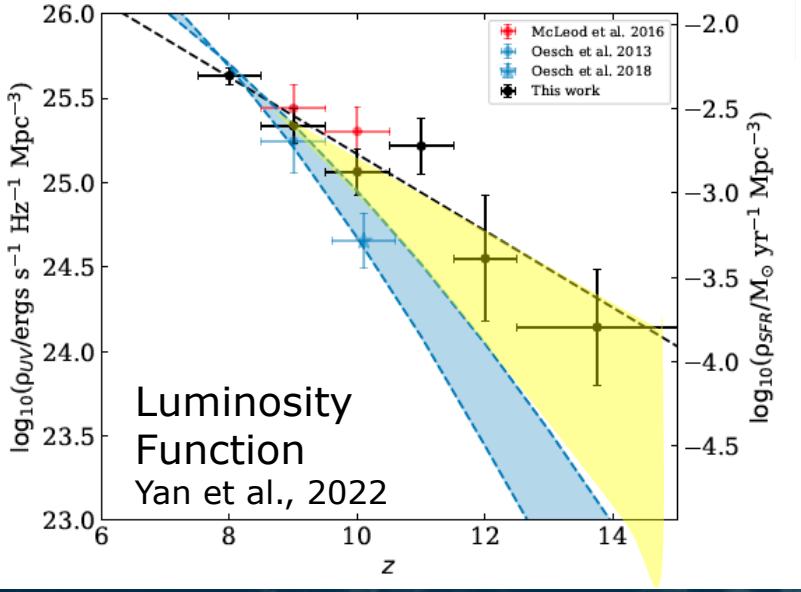


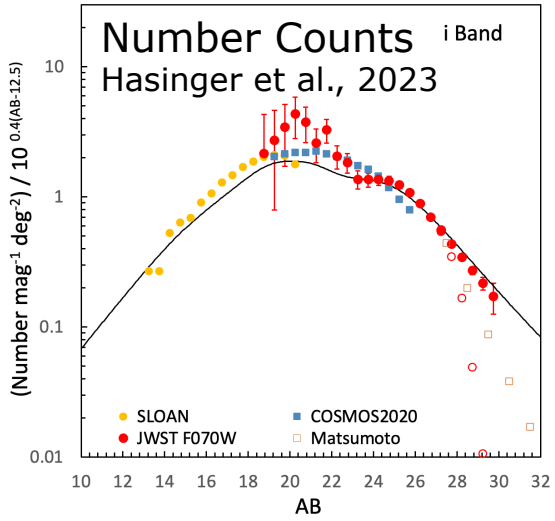
Cappelluti, Hasinger, Natarajan, 2022, ApJ

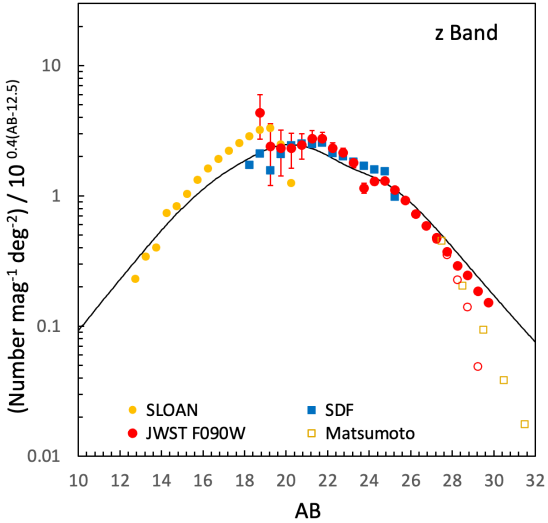
Number of Galaxies
in JWST Medium-Deep Fields

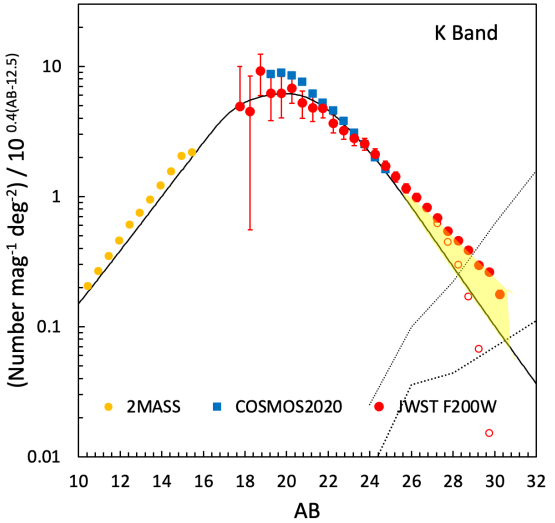
First hints for a new population of early galaxies.

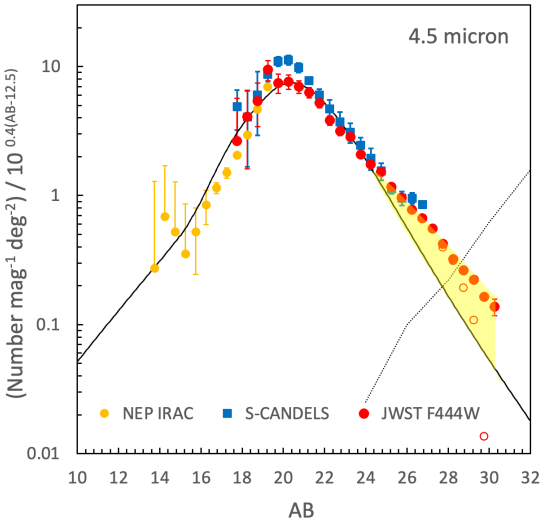
This has been predicted by the primordial black hole dark matter model!

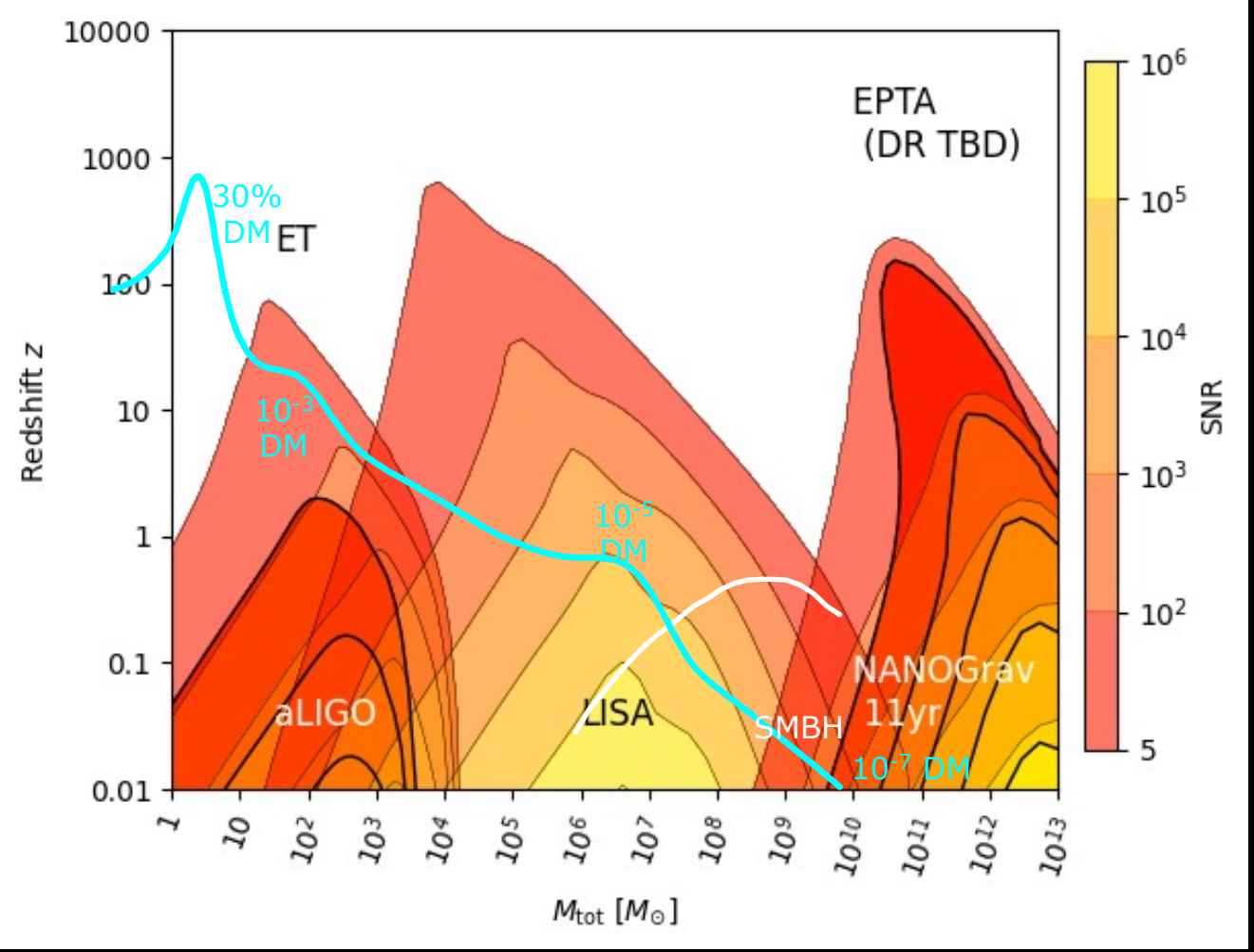












Sensitivity to BH-BH Mergers

So far, all of these "fingerprints" are tantalizing, but only circumstantial evidence.

However, future Gravitational Wave observations can uniquely discriminate between astrophysical and primordial black holes!

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

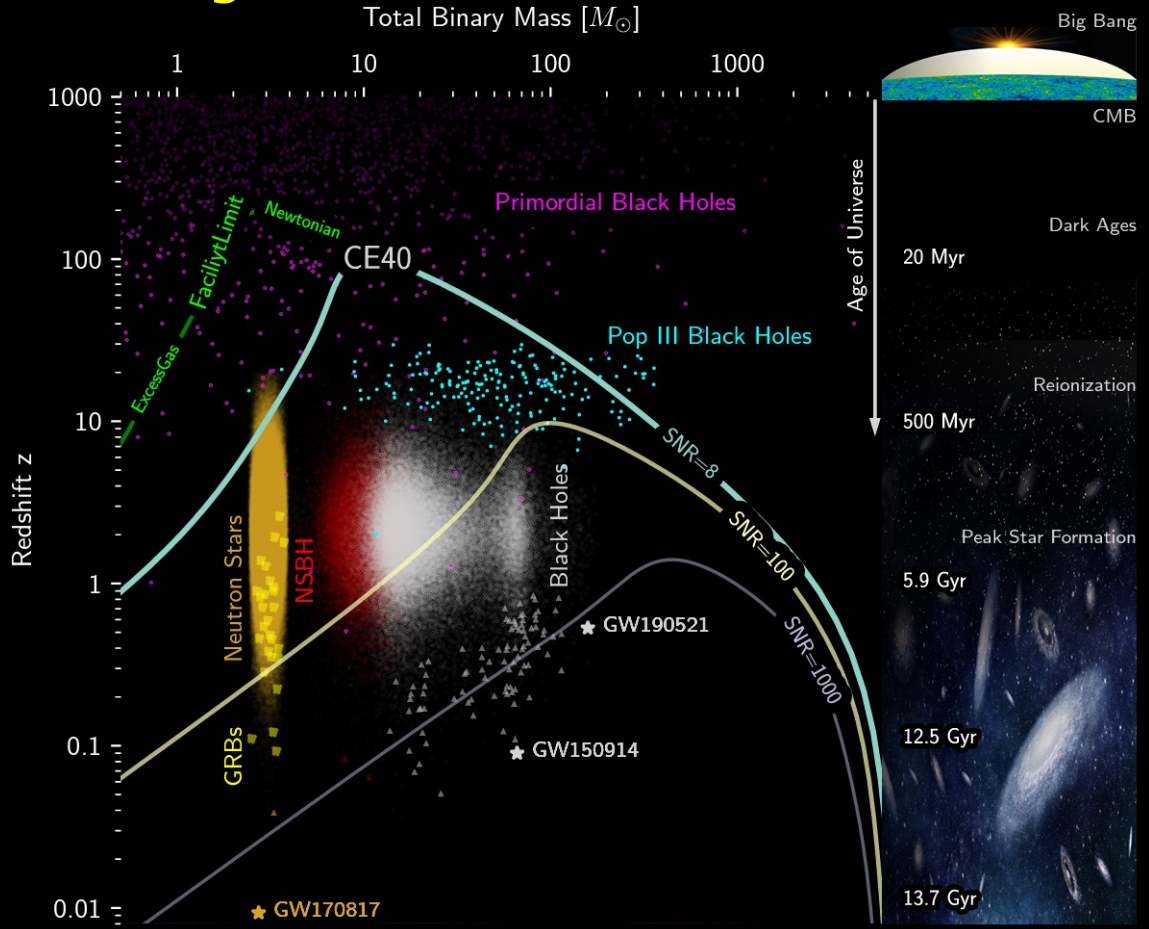
Merging neutron stars in other galaxies

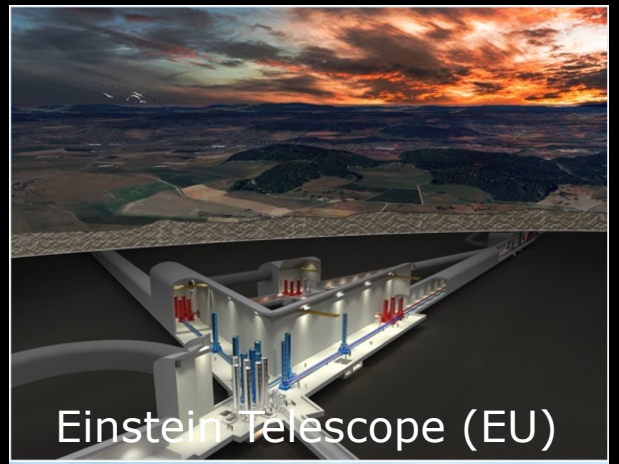
Merging stellar-mass black holes in other galaxies

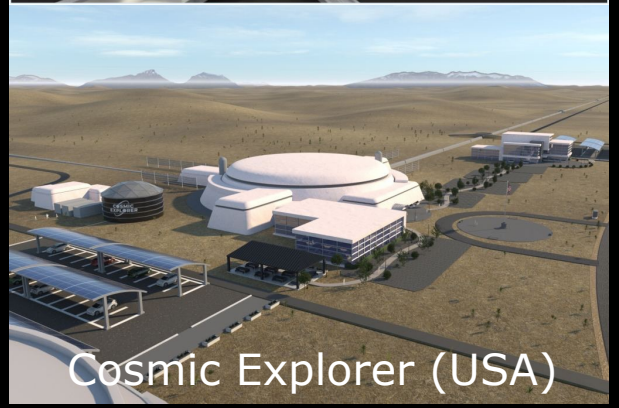
Merging white dwarfs in our Galaxy

#lisa

Sensitivity of the next generation groundbased gravitational wave interferometers







Forschung.
Technologie.
Digitalisierung.

The new national center for astrophysics in Lusatia (DZA)

DZA

Deutsches Zentrum für Astrophysik


DZA
Thank you very much!
Deutsches Zentrum für Astrophysik