Illuminating the Dark Ages: cosmic backgrounds from accretion onto primordial black hole dark matter

Günther Hasinger, ESA Director of Science

Paco Ynduráin Colloquium, Madrid (virtual)
October 7, 2020

https://iopscience.iop.org/article/10.1088/1475-7516/2020/07/022

DER SPIEGEL

Stockholm

Deutscher erhält Physik-Nobelpreis

Der deutsche Astrophysiker Reinhard Genzel ist für seine Arbeit an schwarzen Löchern mit dem Nobelpreis ausgezeichnet worden. Außerdem wurden die US-Amerikanerin Andrea Ghez und der Brite Roger Penrose geehrt.

Kosmologie

S+ Existiert in unserem Sonnensystem ein schwarzes Loch?

Sie sind die rätselhaftesten Objekte im Universum. Nun zeigt sich, dass es viel mehr schwarze Löcher geben könnte als gedacht – viele von ihnen entstanden wohl schon in den ersten Sekunden nach dem Urknall. Von Olaf Stampf

Timely!

Yesterday’s digital front page of the German magazine “Der Spiegel”

… referring to my work, too

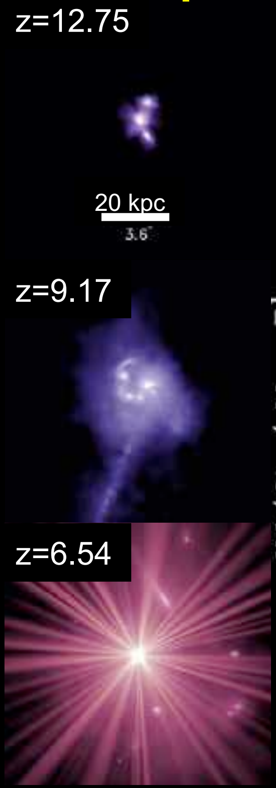
Black Holes of various sizes

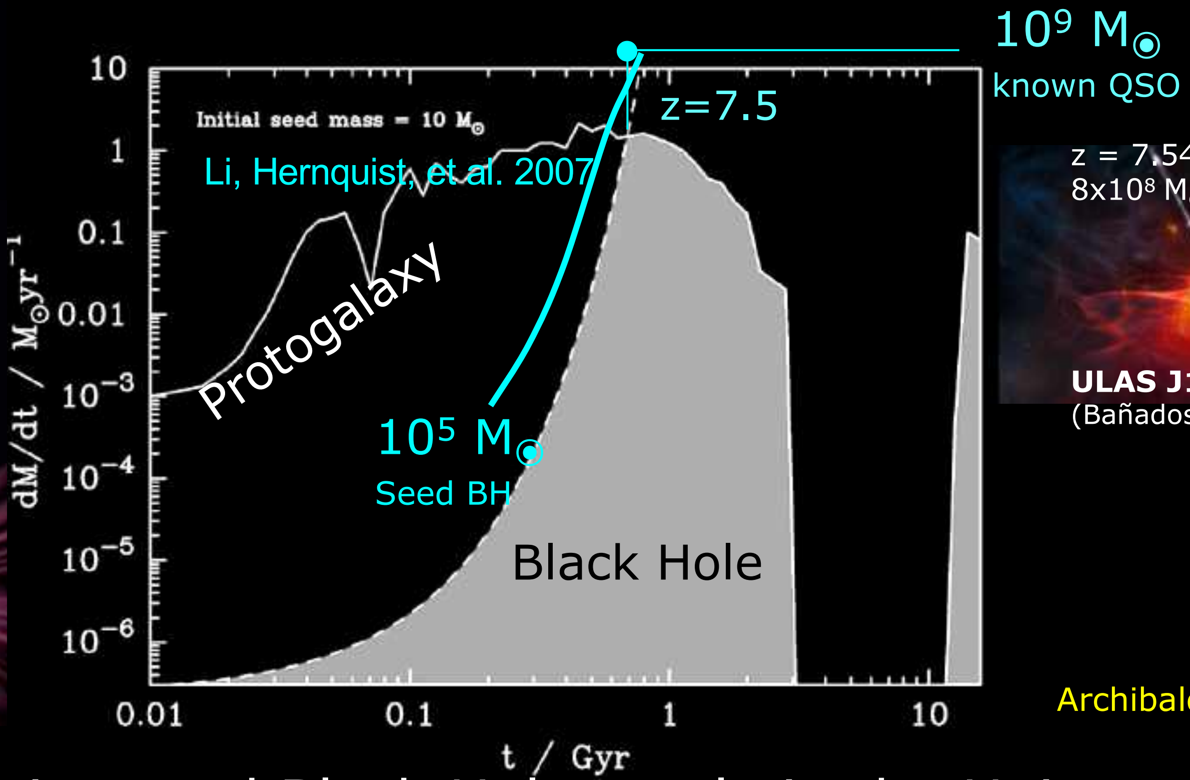
May I introduce to you:

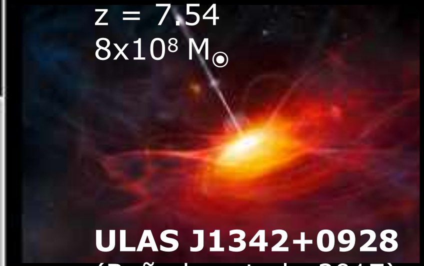
$3 \times 10^9 \, M_\odot$

"*the adorned fathomless dark creation*"
from the Hawaiian generation chant *Kumulipo.*
Courtesy of the Event Horizon Telescope Collaboration.

How to produce the first proto-quasars







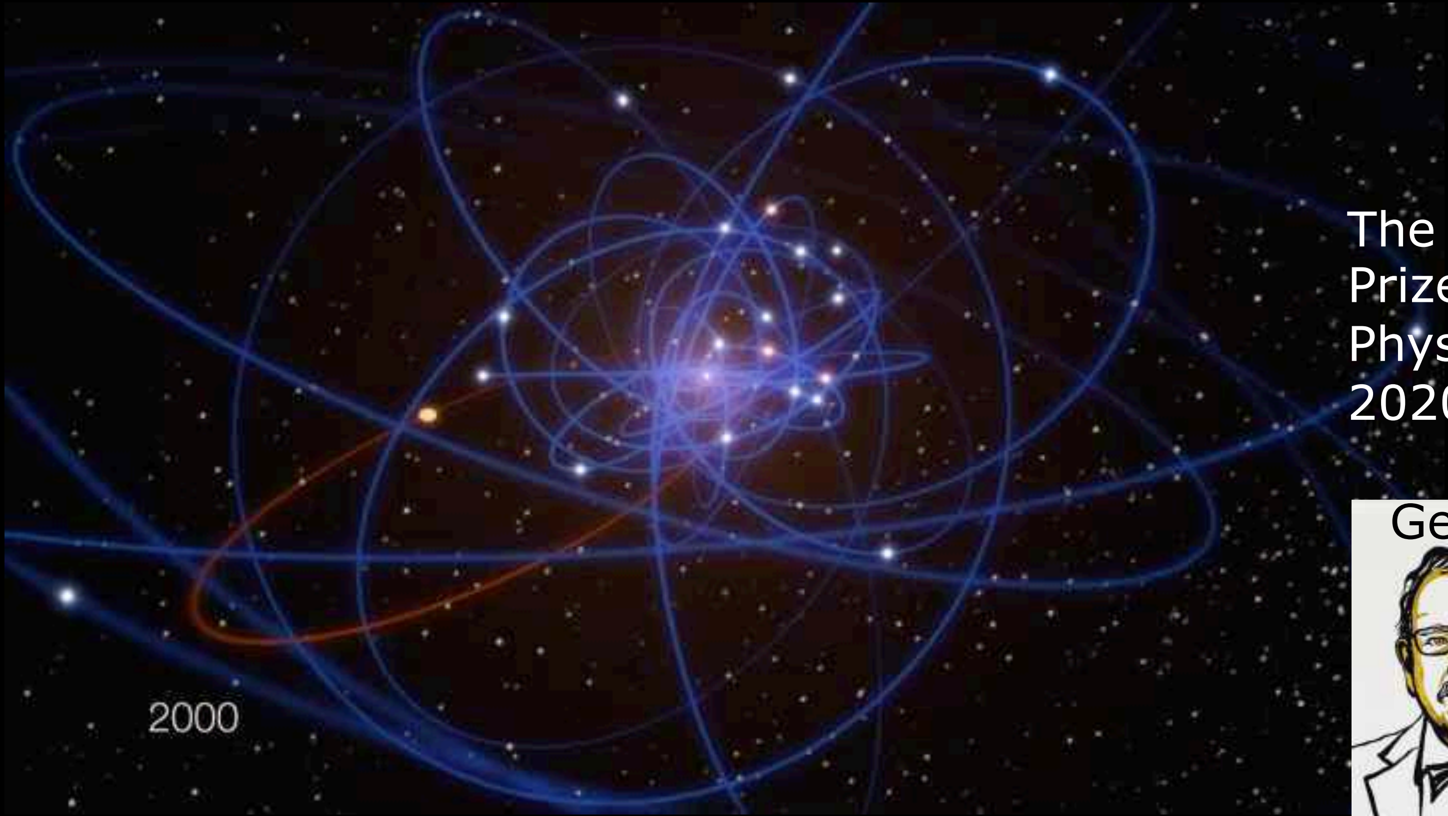
(Bañados et al., 2017)

Archibald et al., 2001

Need massive seed Black Holes early in the Universe !

The Galactic Center Black Hole (Genzel version)

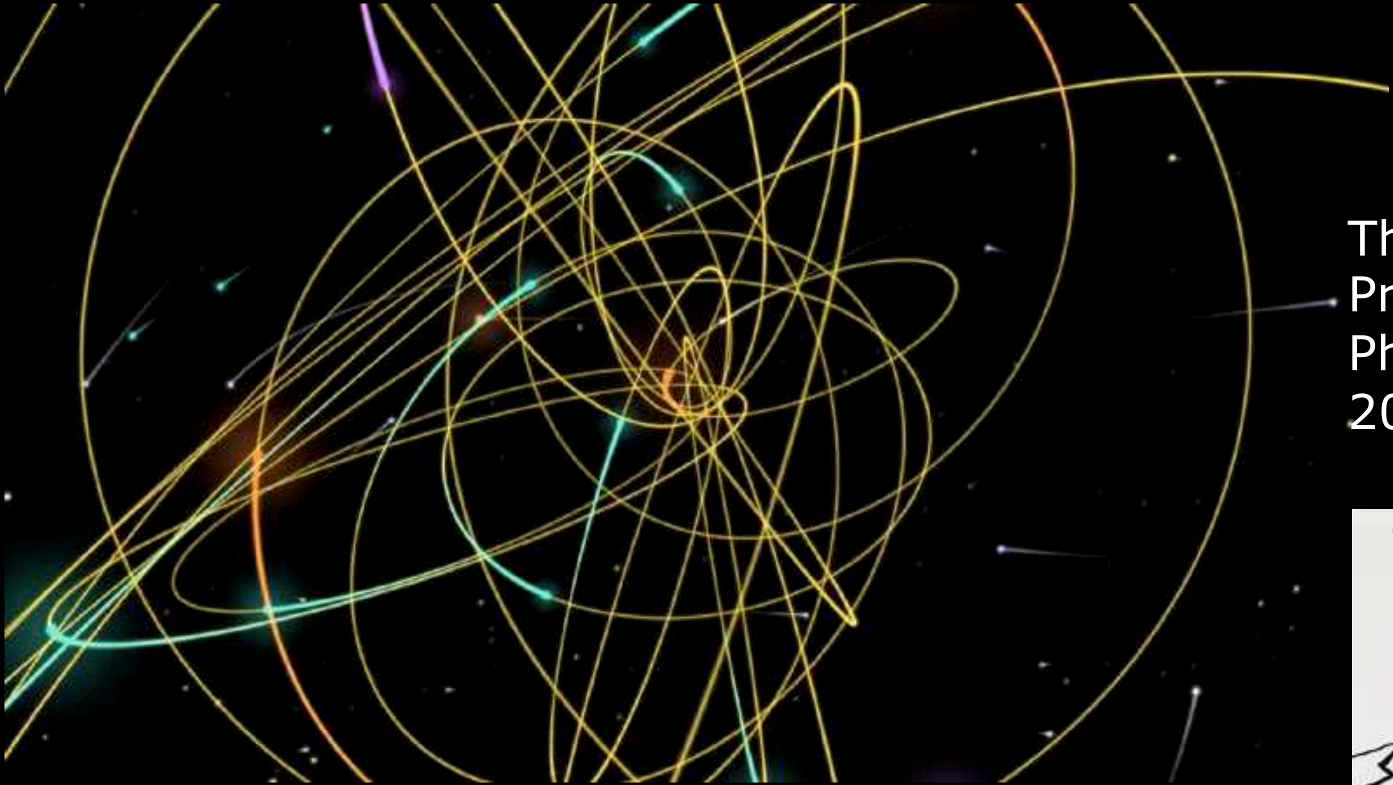
$4 \times 10^6\ M_\odot$



The Nobel Prize in Physics 2020

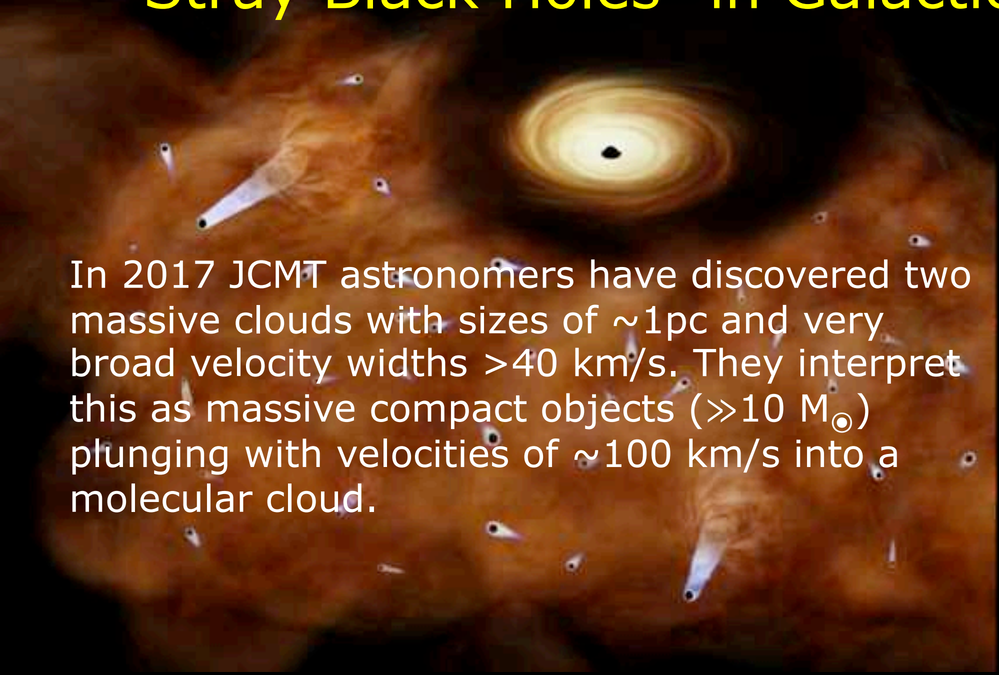
The Galactic Center Black Hole (Ghez version)

$4 \times 10^{6}\ M_{\odot}$



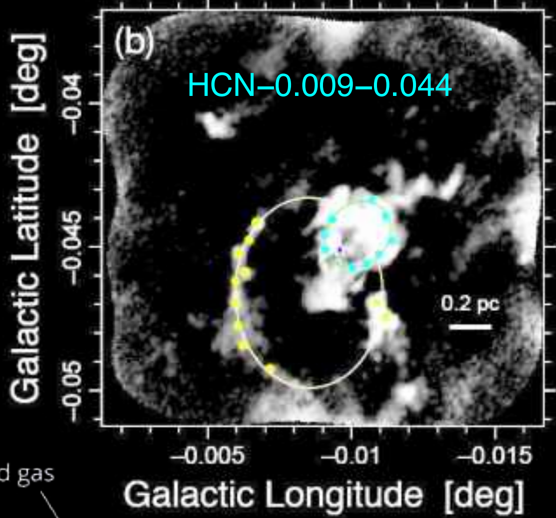
The Nobel Prize in Physics 2020

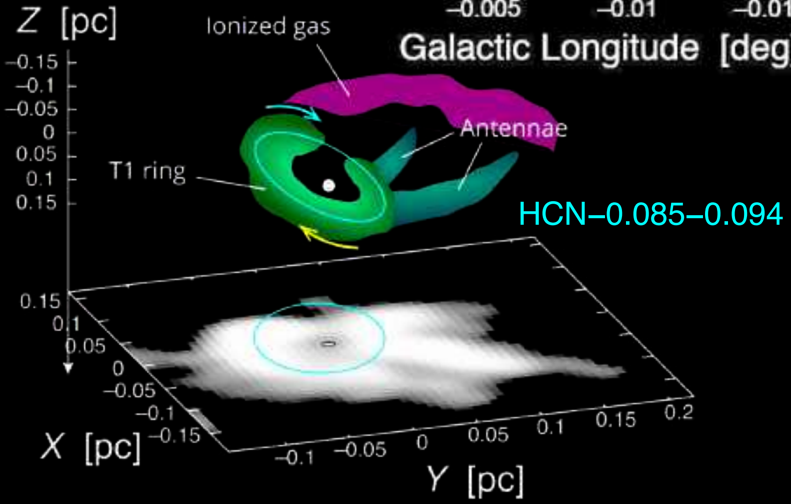
“Stray Black Holes” in Galactic Center



In 2017 JCMT astronomers have discovered two massive clouds with sizes of ~1pc and very broad velocity widths >40 km/s. They interpret this as massive compact objects (≫10 $M_{\odot}$) plunging with velocities of ~100 km/s into a molecular cloud.

$10^{4\text{-}5}$ $M_{\odot}$





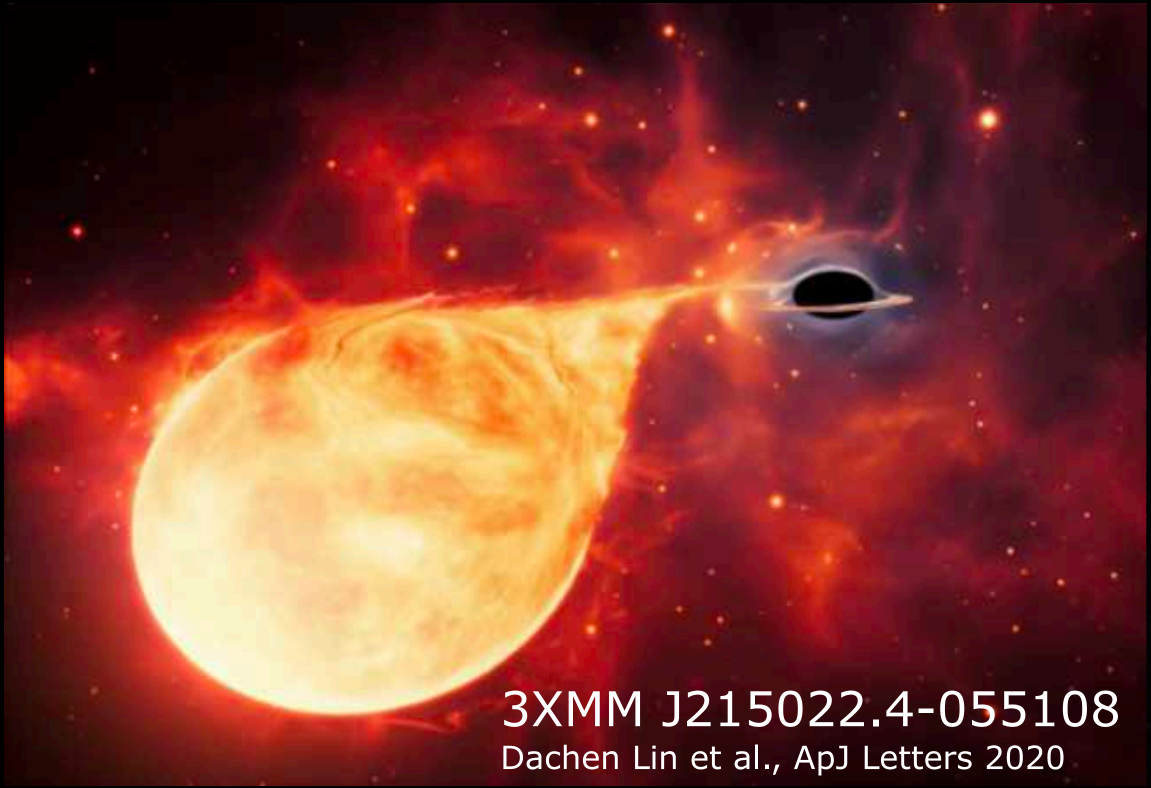
A total of 5 Intermediate-Mass Black Holes ($10^{4\text{-}5}$ $M_{\odot}$) have now been identified in the Central Molecular Zone from high angular resolution ALMA and radio data.

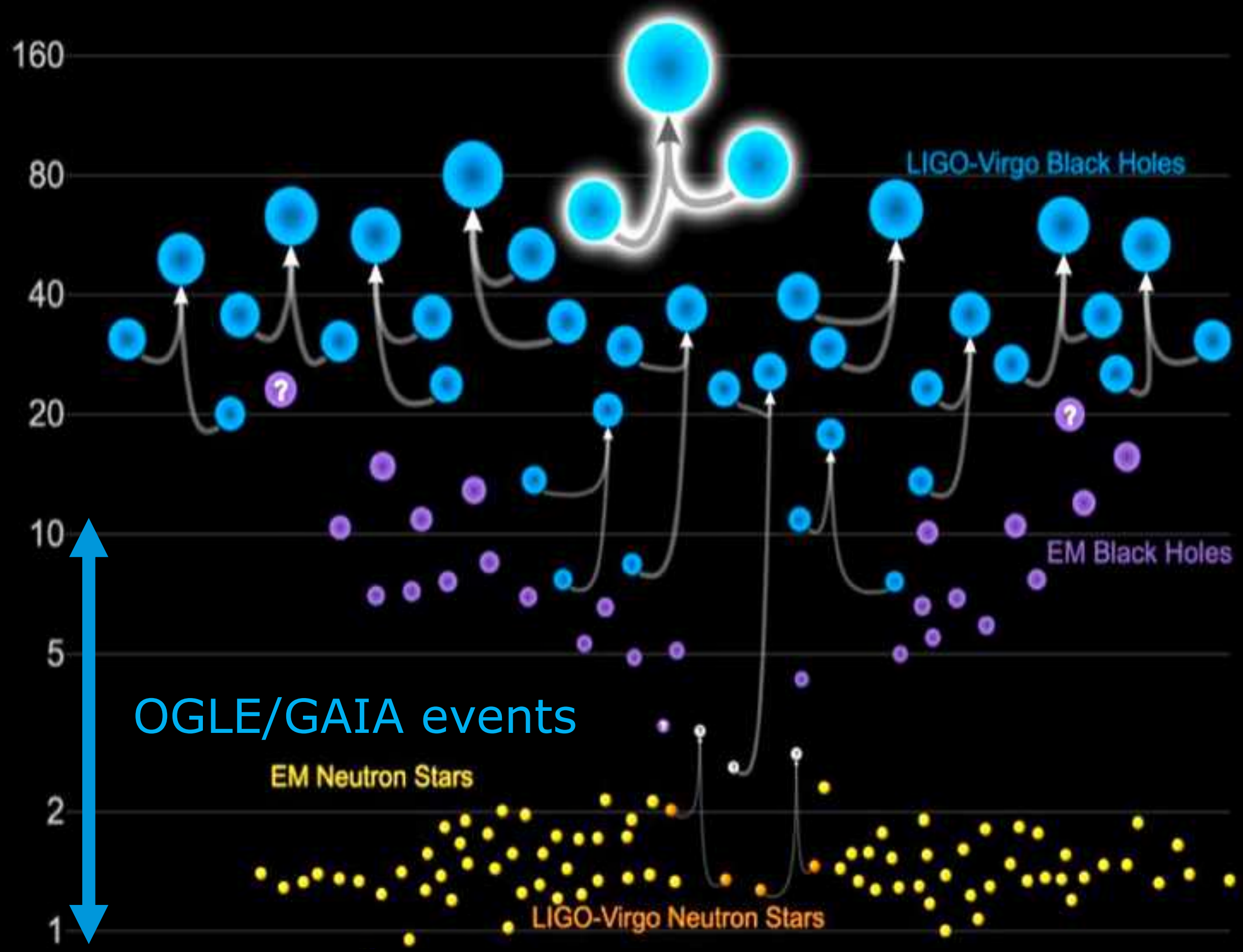
Takekawa et al., 2017, 2019, 2020

Hubble finds best evidence for extragalactic IMBH

$5 \times 10^4\ M_\odot$

Following up the discovery of a tidal capture event by XMM-Newton and Chandra, new data from the NASA/ESA Hubble Space Telescope have provided the strongest evidence yet for mid-sized black holes in the Universe. Hubble confirms that this "intermediate-mass" black hole dwells inside a dense star cluster of a nearby galaxy.





3-150 $M_{\odot}$

LIGO/Virgo BH mergers

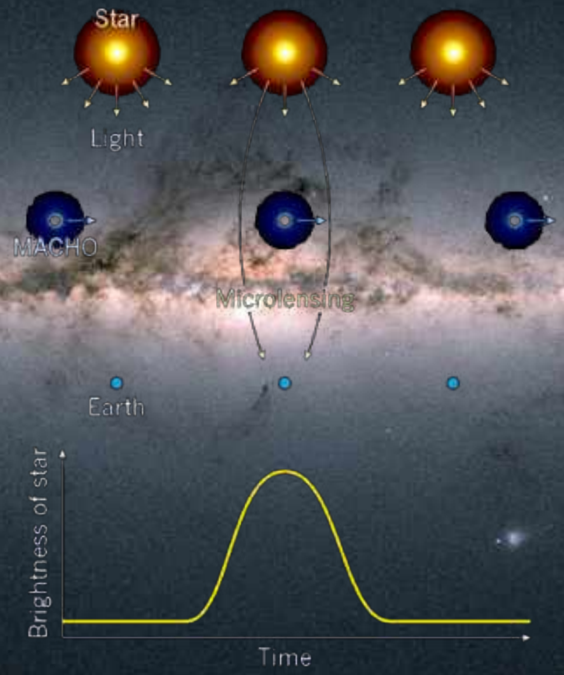
GW190521: Record BH Merger

GW190412: Mass-gap object

… the plot thickens!

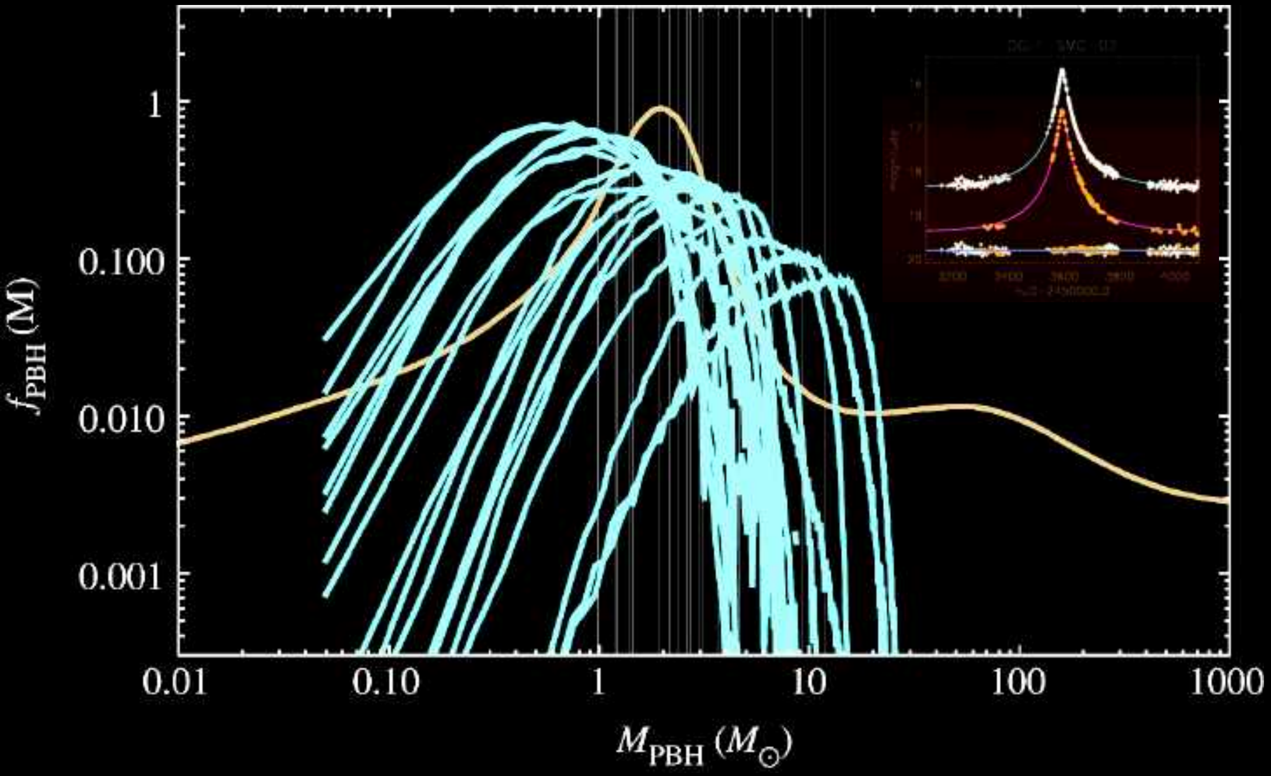
Microlensing and the ESA GAIA Mission

MACHOS
EROS
OGLE
M31 HSC
WFIRST ...



OGLE/GAIA Microlensing events

1-10 $M_\odot$

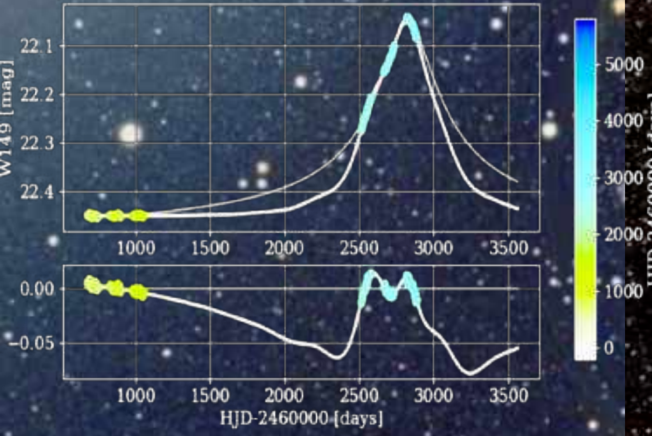


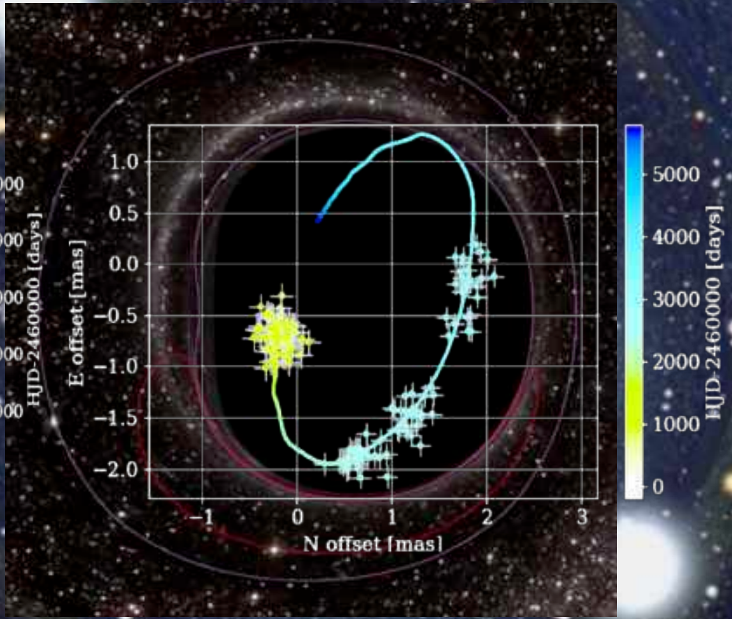
Wyrzykowski L, Mandel I., 2019; García-Bellido 2019

OGLE has detected ~60 long-duration microlensing events. ~20 of these have GAIA parallax distances of a few kpc, which break the mass–distance degeneracy of microlensing and allow the determination of masses in the few solar mass range, which imply that they are probably black holes, since stars at those distances would be visible by OGLE.

Their masses overlap the stellar BH mass gap, and are consistent with the predicted peak around 2 $M_\odot$ in the PBH mass distribution.

Microlensing by 10 M_{sun} Black Holes

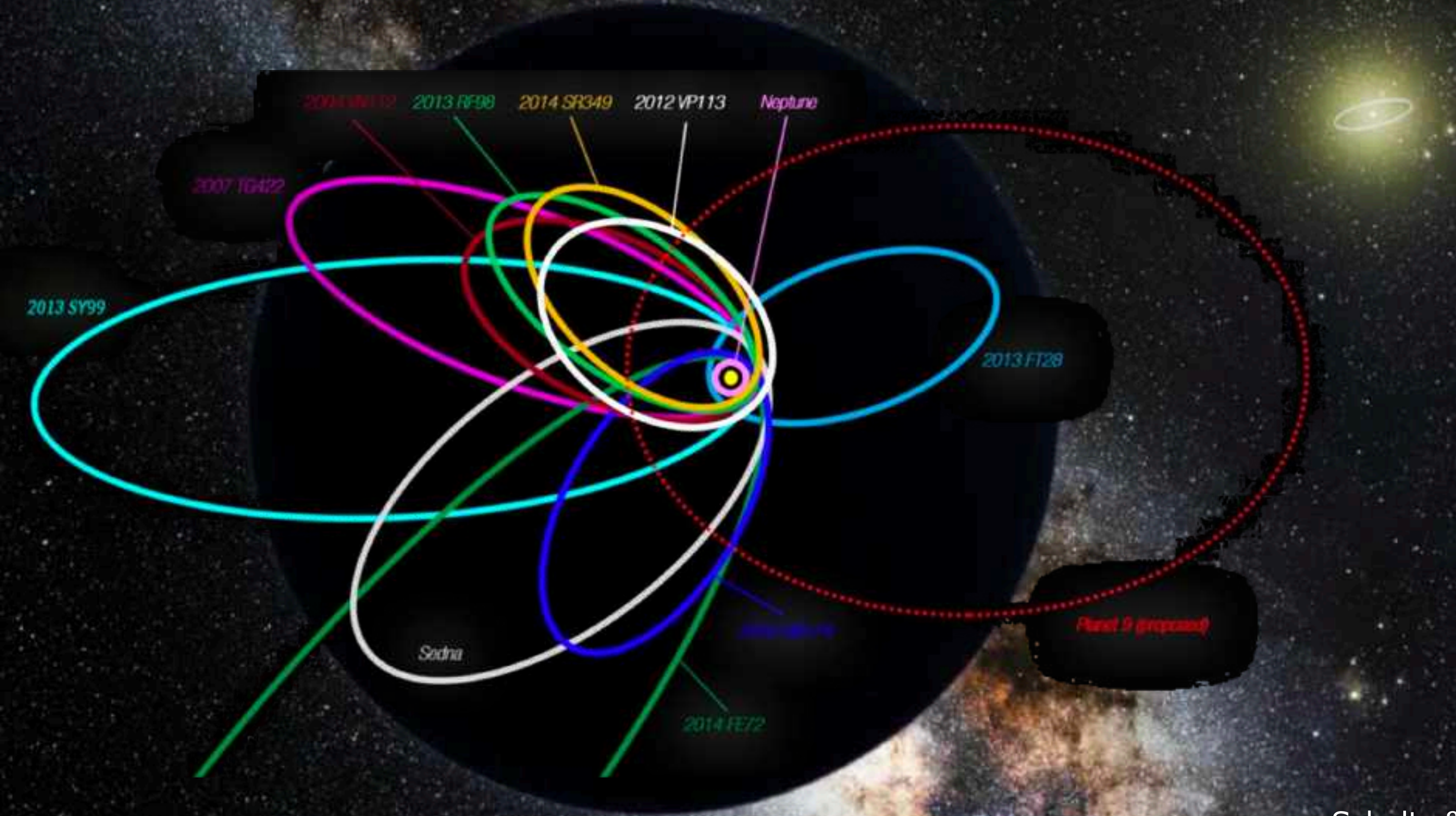




Renamed the „Nancy Grace Roman“ Space Telescope

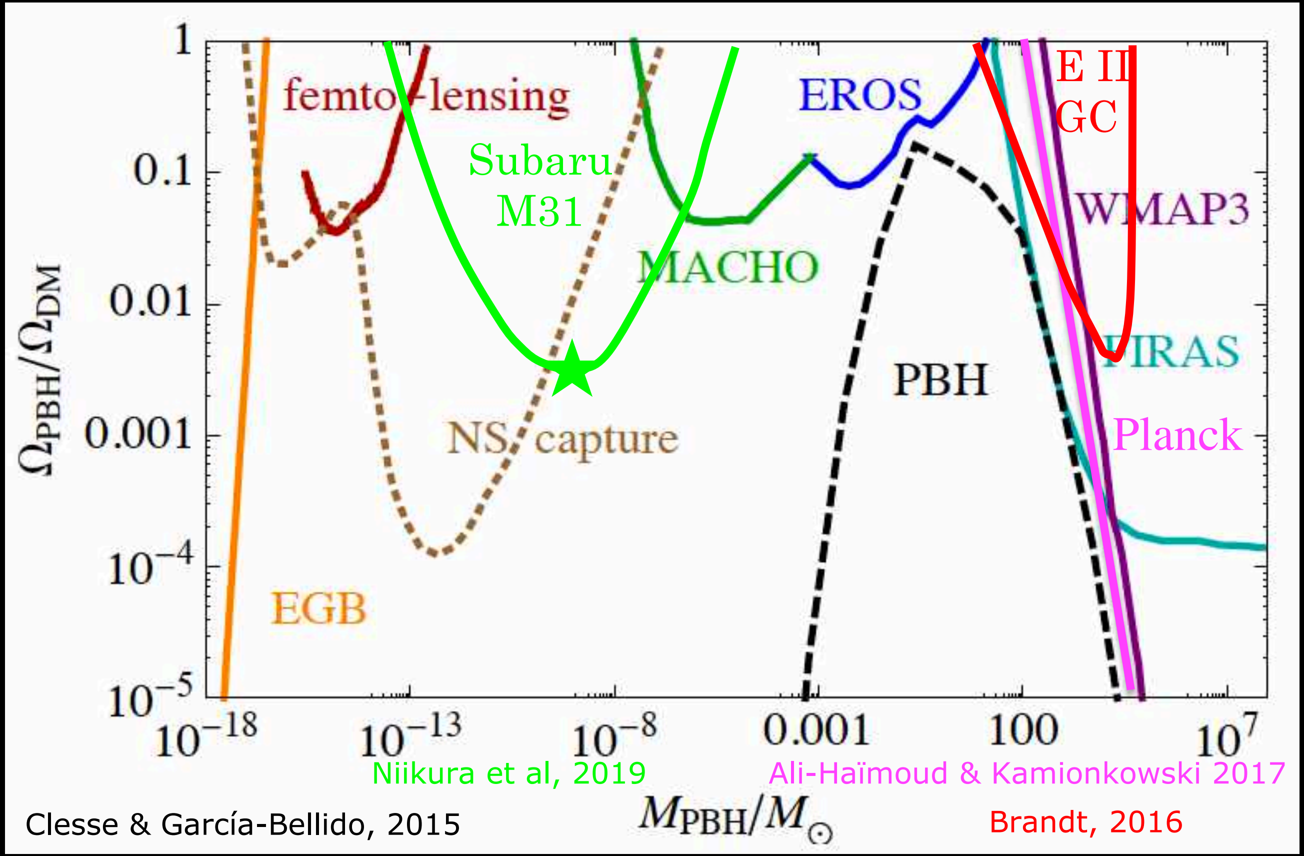
Is Planet 9 (Planet X) a Black Hole?

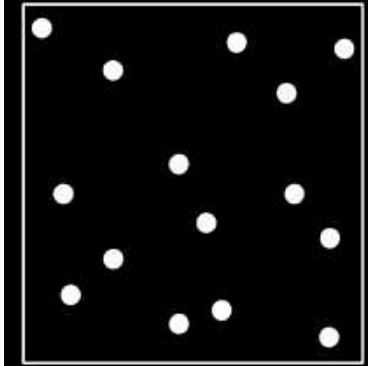
$10^{-5}\ M_{\odot}$



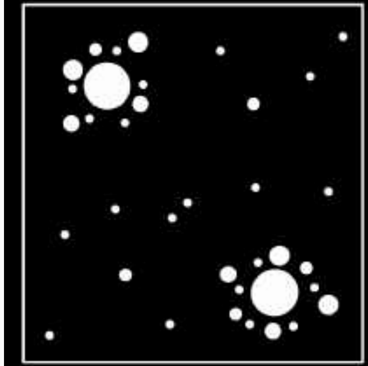
Scholtz & Unwin, 2019

Constraints on Primordial Black Holes (PBH)





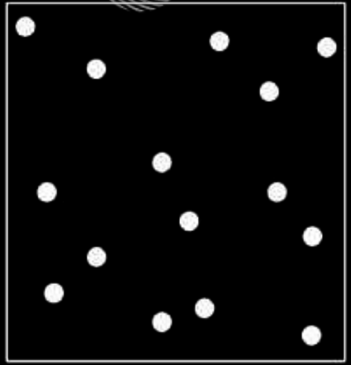
Uniform single mass PBH already ruled out



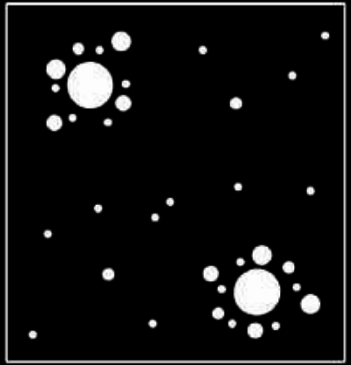
Clustered wide mass distribution still feasible

Hubble finds Clumping of Dark Matter

Meneghetti et al, 2020, Science



Uniform single mass Dark Matter



Clustered wide mass distribution Dark Matter

A paper that threw me off my chair …

esa

Primordial black holes and the origin of the matter–antimatter asymmetry

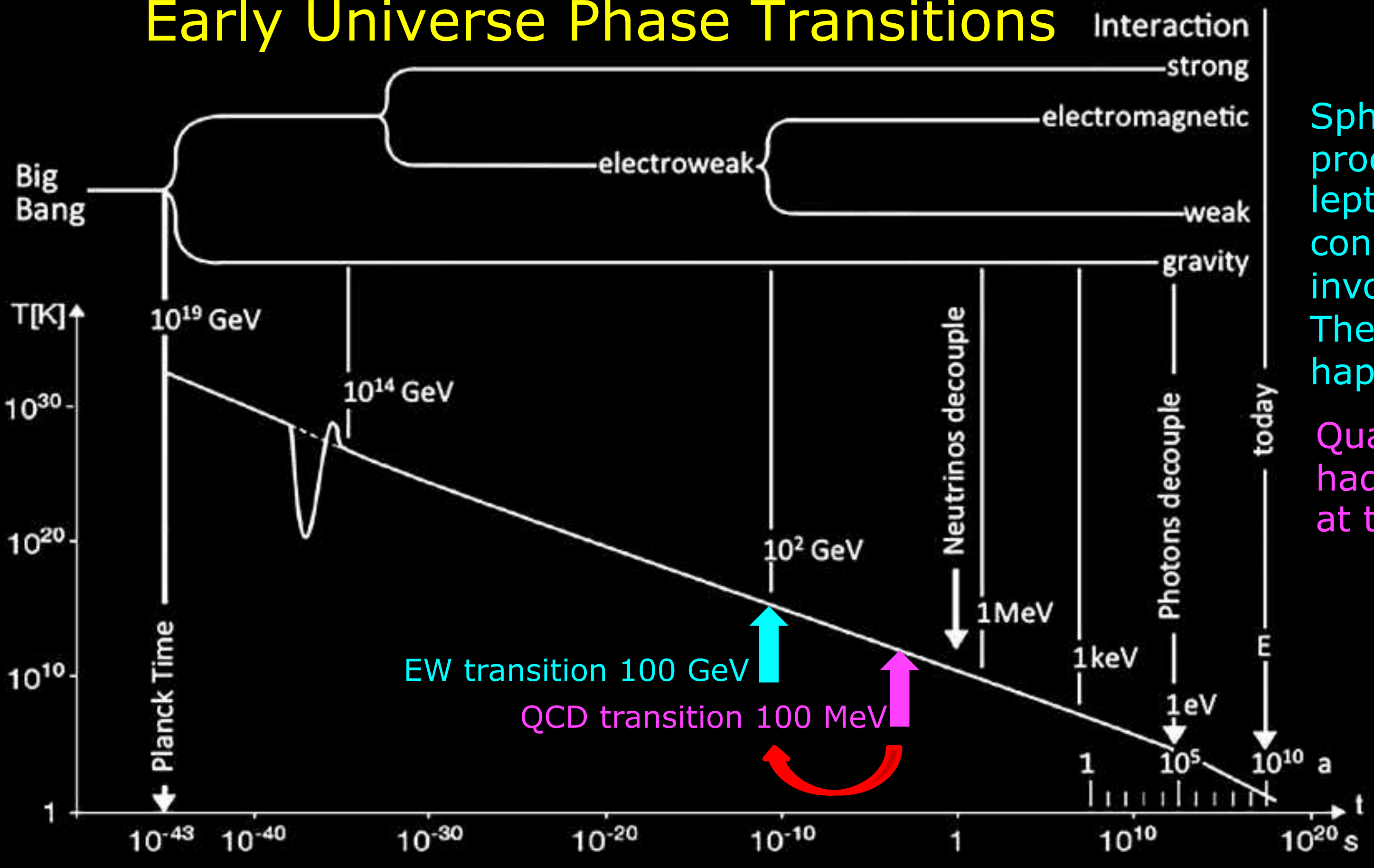
Juan García-Bellido

Phil. Trans. Roy. Soc. Volume: 377, Issue: 2161

Published: 11 November 2019 https://doi.org/10.1098/rsta.2019.0091

Primordial Black Holes are created by large inflationary curvature fluctuations at the QCD phase transition, when pions, neutrons and protons are formed, as well as at the e^+e^- annihilation. The abrupt reduction of the sound velocity at each of these events exponentially enhances gravitational collapse, ejecting hadron jets and engaging "funny" physics (generating over-the-barrier electroweak sphaleron transitions responsible for Higgs windings around the EW vacuum or, through the chiral anomaly, baryon number generation) creating the matter-antimatter asymmetry. The preferred mass scale corresponds to the size of the horizon at the corresponding transition. Baryons correspond to the Chandrasekhar mass. The baryon/photon ratio of 10^{-9} is naturally explained.

Early Universe Phase Transitions

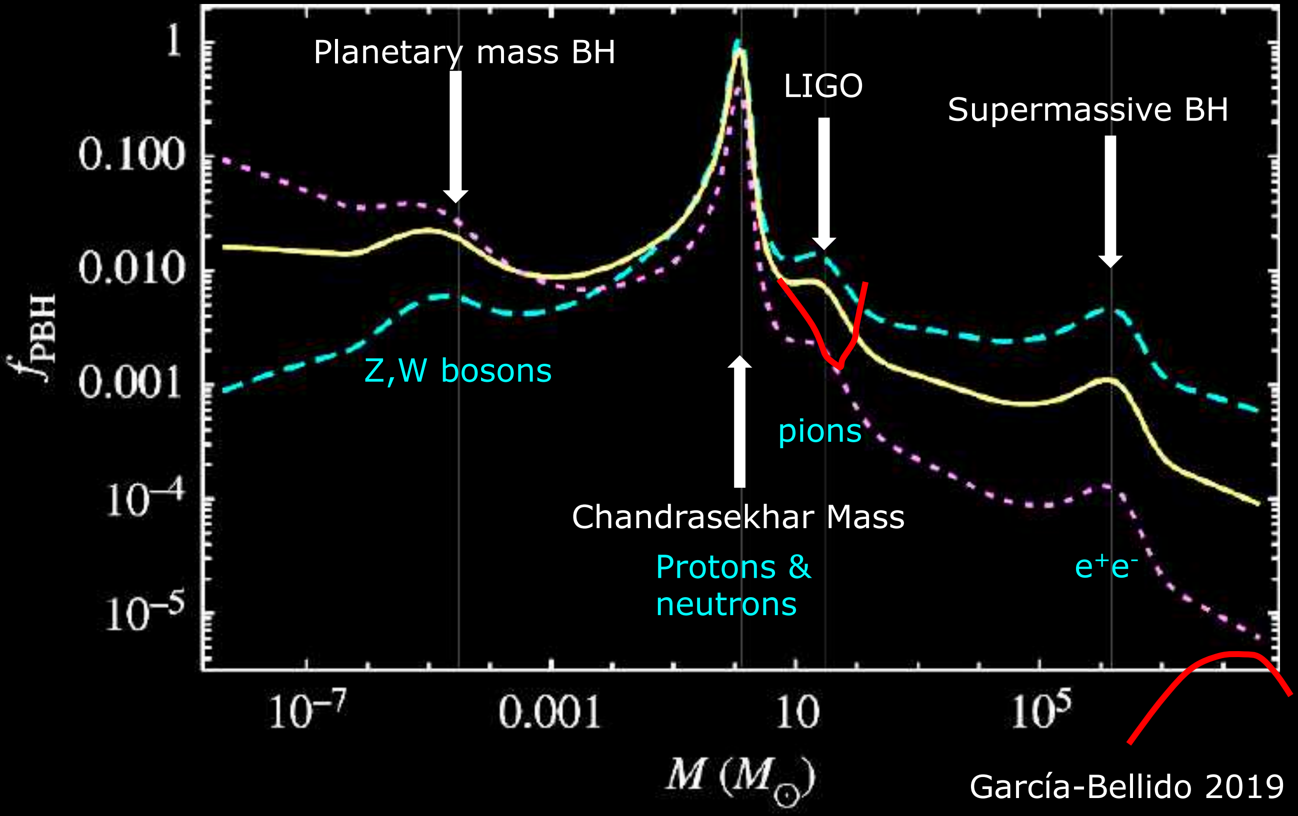


Sphaleron transitions are processes violating the lepton and baryon number conservation and are invoked for baryogenesis. They are expected to happen at the EW scale.

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

PBH collapse locally re-heats hot spots to the EW scale

PBH Mass Spectrum

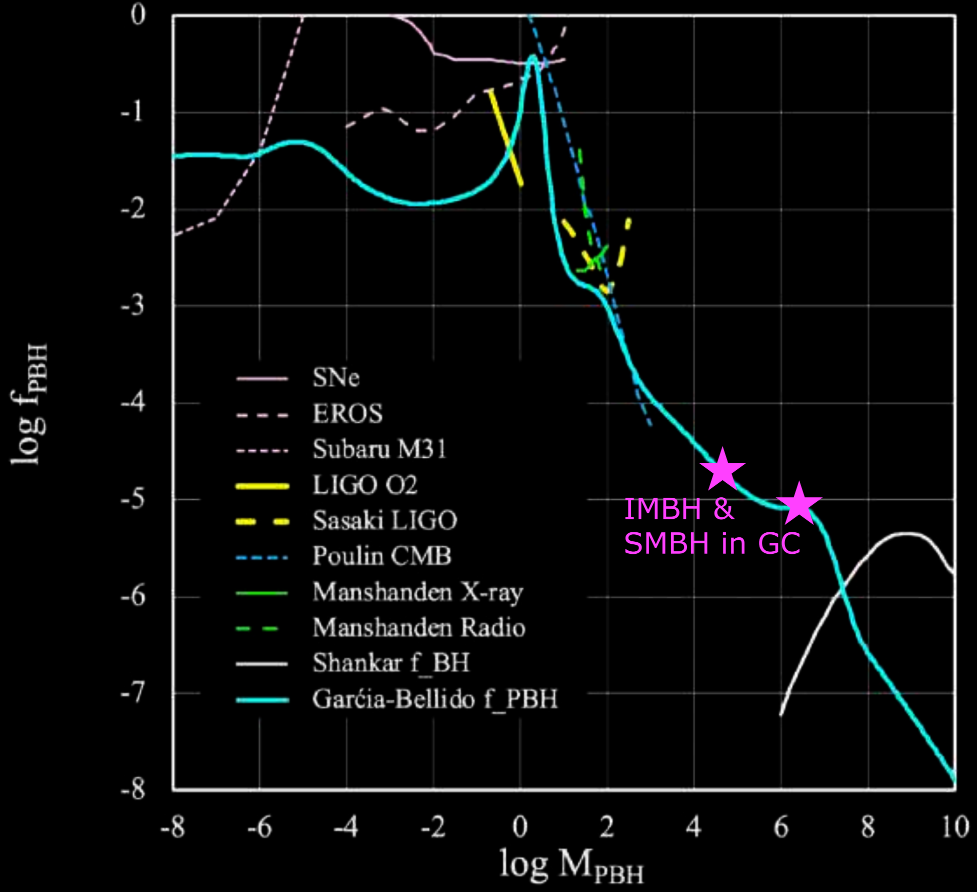


García-Bellido 2019

Different peaks correspond to different baryons created at the QCD phase transition and e^+e^- annihilation and the corresponding reduction in the sound velocity.

However, the original PBH mass spectra were somewhat in conflict with important observational constraints.

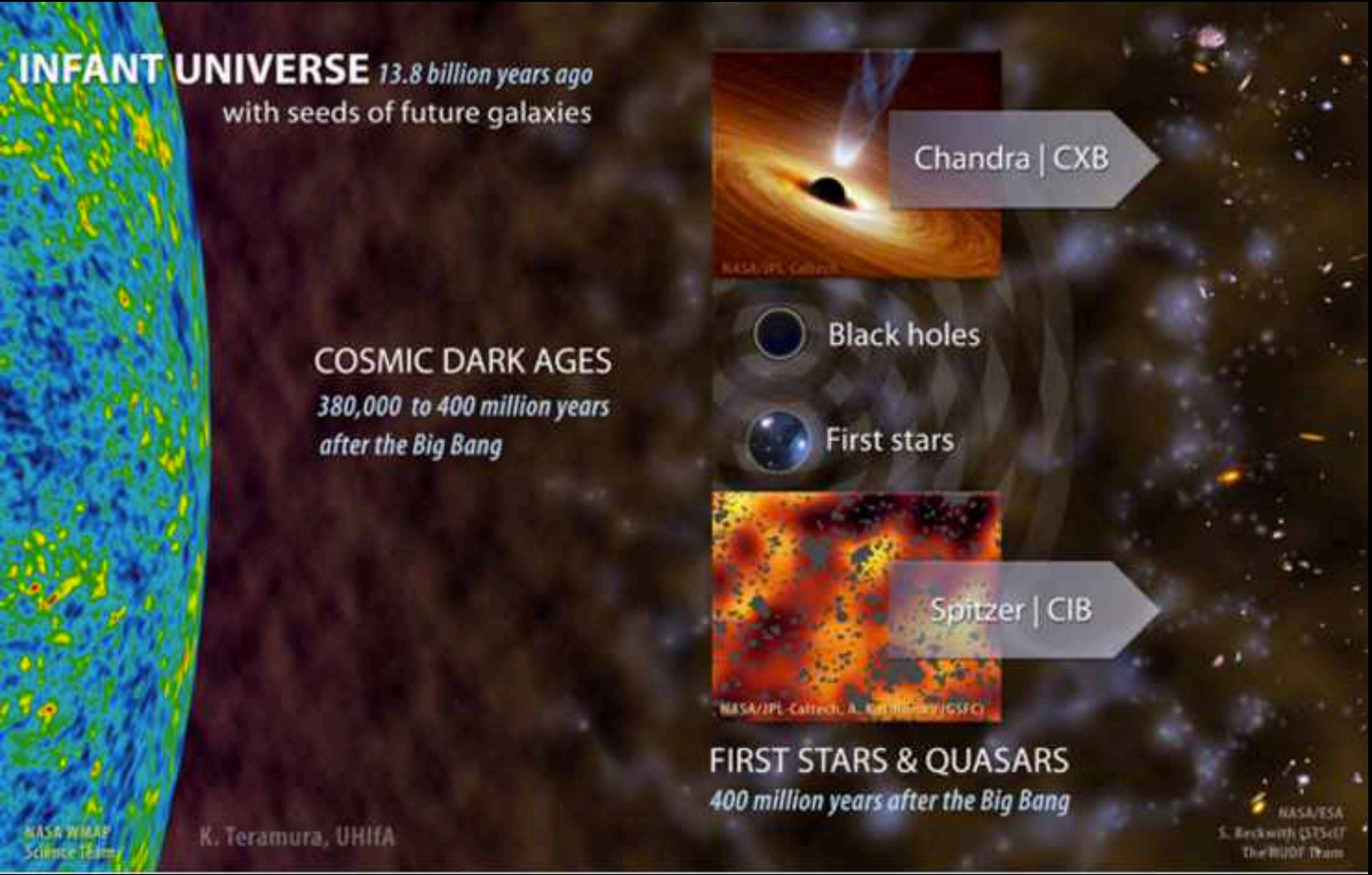
PBH mass spectrum assumed for this work



García-Bellido et al. (2020) are working on a new version of their PBH mass spectrum, which has a steeper decline at large PBH masses and is now practically fully consistent with all observational constraints.

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

CIB x CXB fluctuations indicate high-z BH population



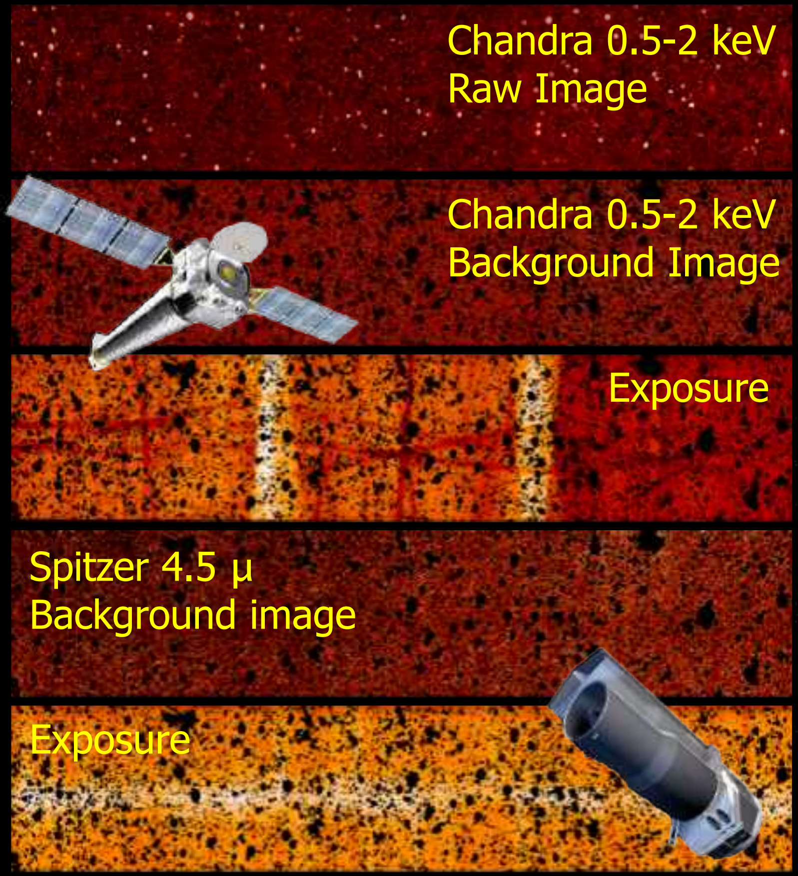
Significant cosmic background fluctuations have been found both in the NIR and in X-rays.

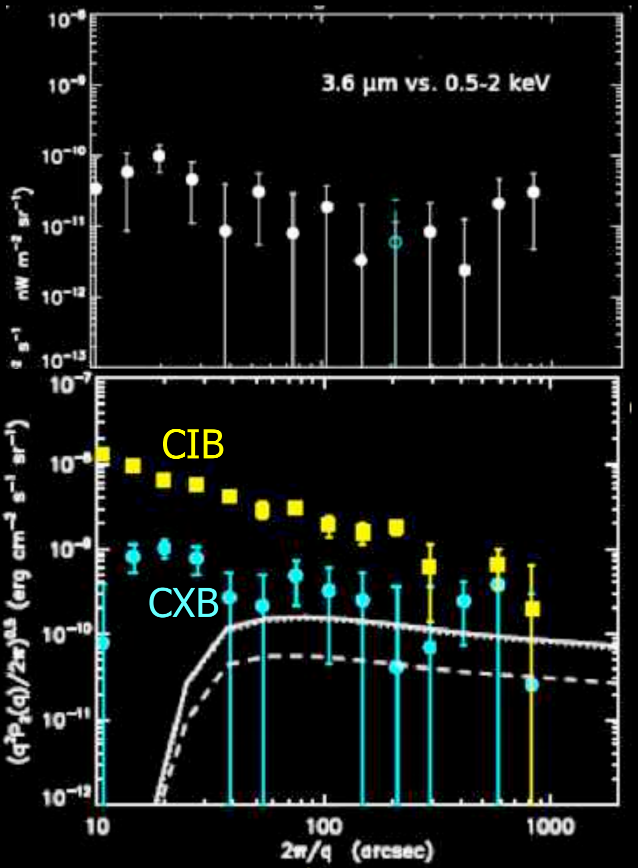
The strong CIB/CXB cross-correlation signal indicates a substantial contribution of Black Holes to the signal.

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.

CIB x CXB Cross-Power



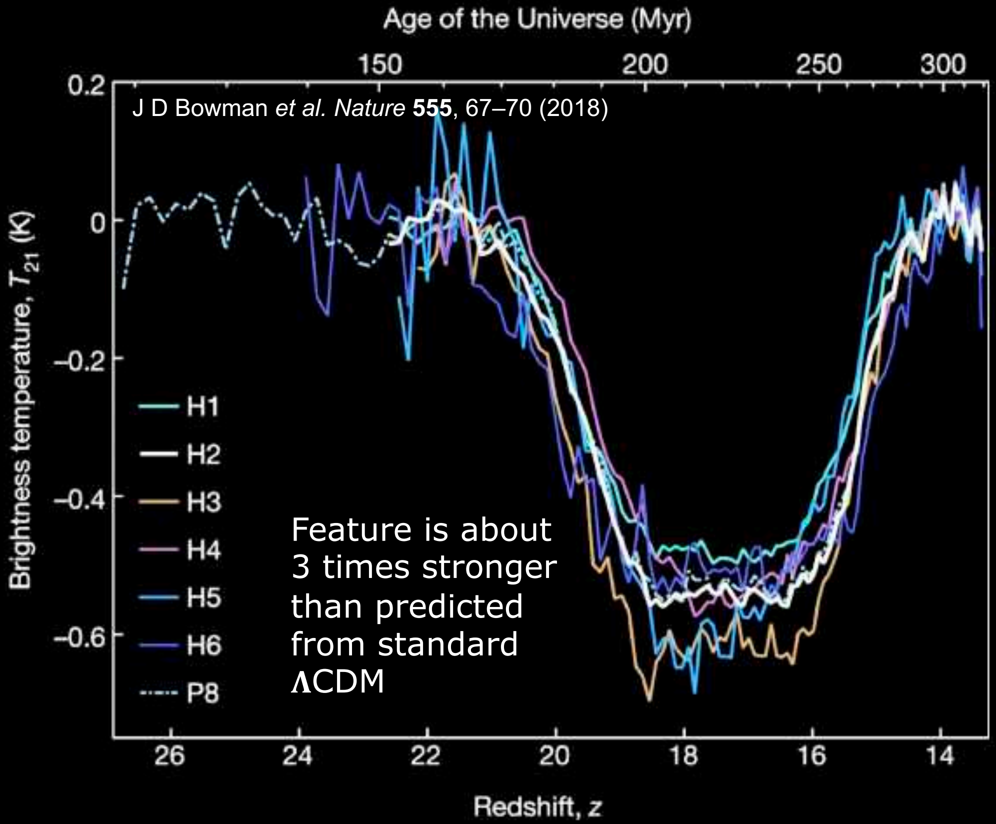


Fingerprint of th
first Black Holes

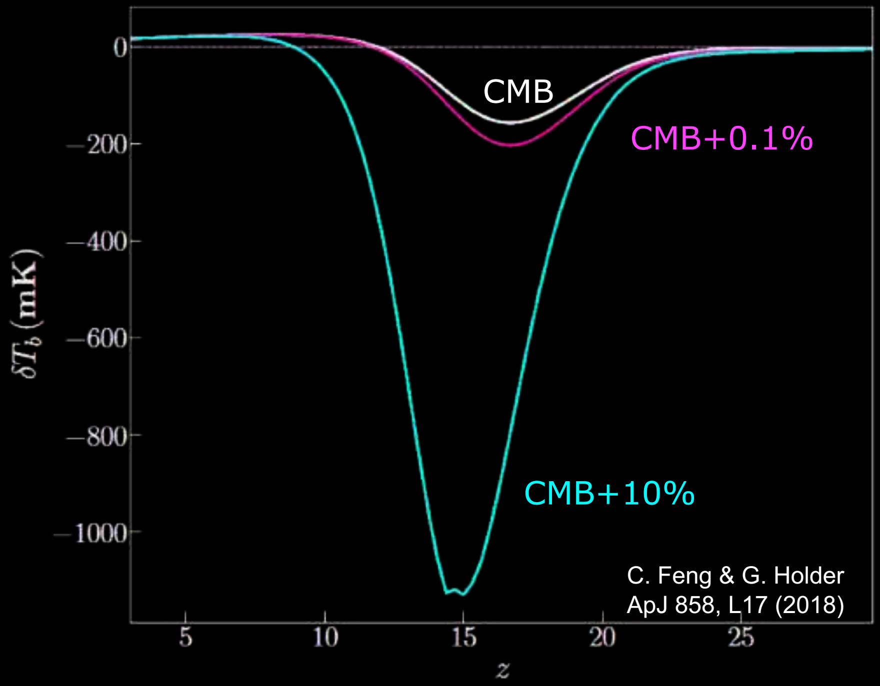
Cappelluti+13, Mitchell-Wynne+16, Yue+13, Pacucci+15, Helgason+14

A redshifted 21cm absorption feature in the sky-averaged spectrum

Experiment to Detect the Global Epoch of Reionization Signature (EDGES)

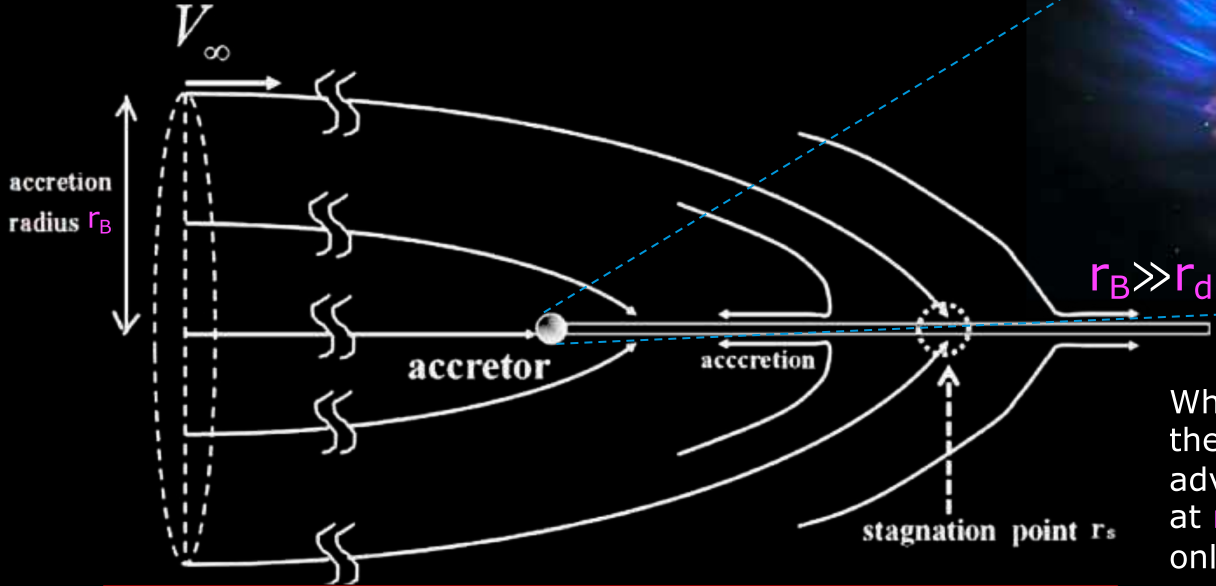


Independent prediction of a 21cm signal enhanced by additional radio background emission. ➔ 5% additional radio background can explain the EDGES data.



Bondi capture & advection dominated disk flow

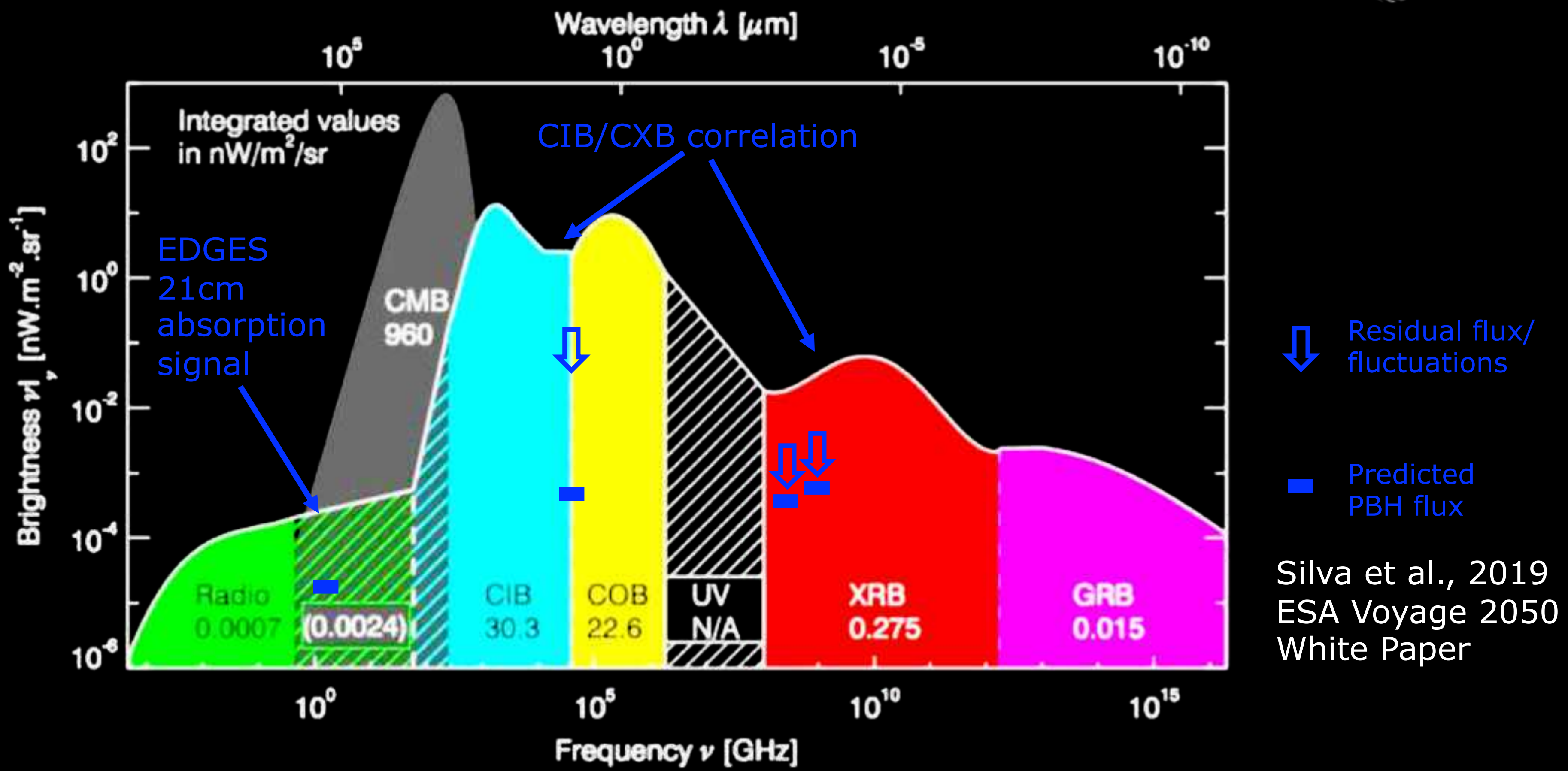
Bondy-Hoyle-Lyttleton capture: magnetic field plays an important role for the fluid to get rid of the angular momentum at the stagnation point. The magnetic field and is amplified towards the accretor.



$$r_B = \frac{G\,M}{v_{eff}^2} \approx 1.34 \cdot 10^{16} \left(\frac{M}{M_\odot}\right) \left(\frac{v_{eff}}{1 \text{ km s}^{-1}}\right)^{-2} cm$$

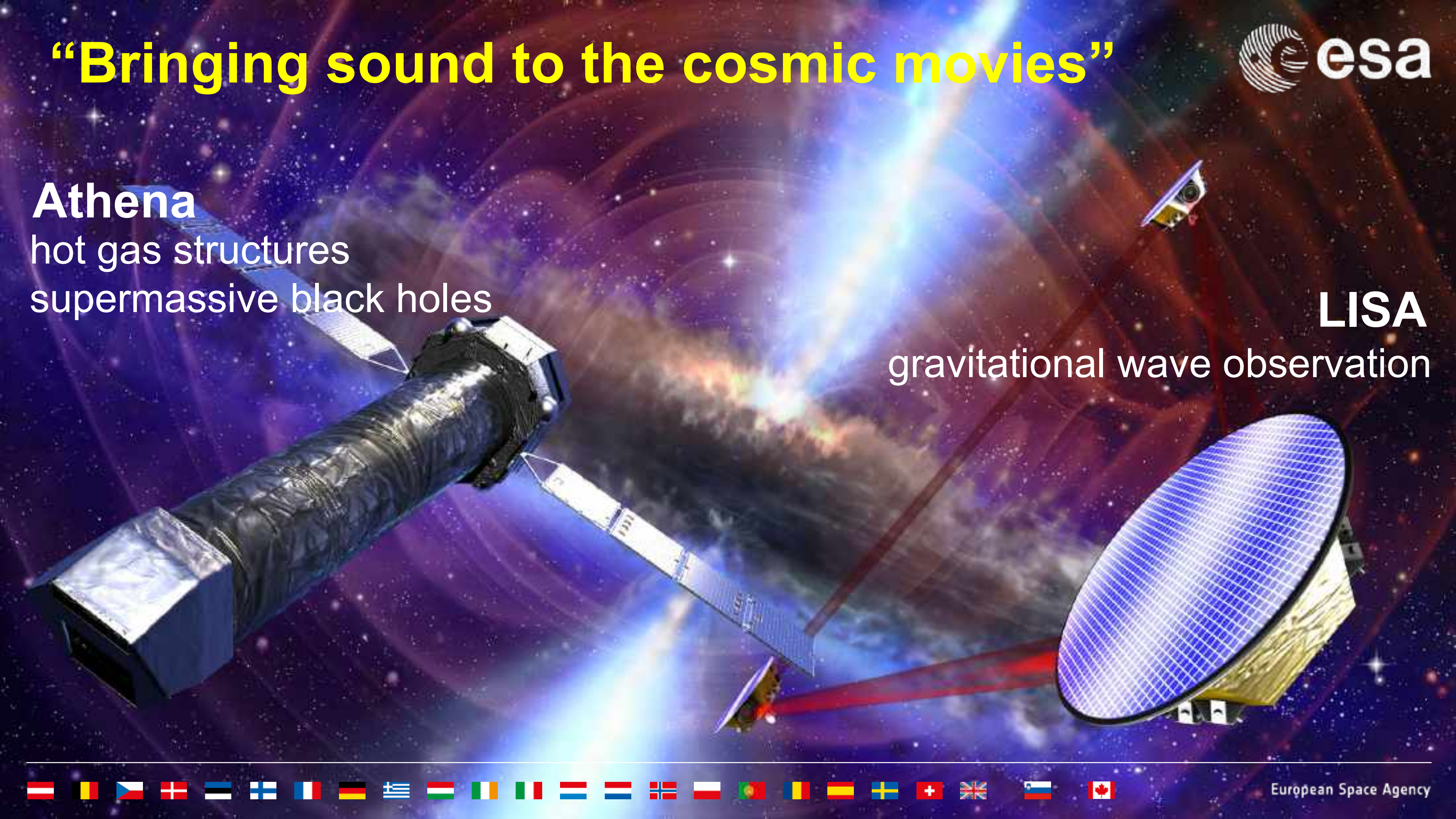
When the turbulence and inhomogeneity at the Bondi radius r_b is large enough an advection dominated accretion disk forms at r_d. Until about 10 Schwarzschild radii r_g only a small fraction (~5%) of the captured matter is actually accreted. Then standard Shakura-Sunyaev accretion down to last stable orbit $3r_g$.

The Extragalactic Background Light



Silva et al., 2019
ESA Voyage 2050 White Paper

Multi-Messenger Quest for first Black Holes



"Bringing sound to the cosmic movies"
esa
Athena
hot gas structures
supermassive black holes
LISA
gravitational wave observation
European Space Agency


Voyage 2050: Preparing the Future of Space Science
esa
GAUSS
Teams are working over Covid restrictions. Recommendations expected by end 2020!
➔ Inputs for Space22+
Voyage 2050 Workshop Madrid
→ THE EUROPEAN SPACE AGENCY

Thank you very much!