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

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https://iopscience.iop.org/article/10.1088/1475-7516/2020/07/022
Deutscher erhält Physik-Nobelpreis


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: Pōwehi

"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

Need massive seed Black Holes early in the Universe!
The Galactic Center Black Hole (Genzel version)

The Nobel Prize in Physics 2020

Genzel

Ghez
The Galactic Center Black Hole (Ghez version)

The Nobel Prize in Physics 2020

Genzel Ghez
“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☉) plunging with velocities of ~100 km/s into a molecular cloud.

A total of 5 Intermediate-Mass Black Holes (10^4-5 M☉) 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

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.

3XMM J215022.4-055108
LIGO/Virgo
BH mergers

GW190521: Record BH Merger

GW190412: Mass-gap object

... the plot thickens!

OGLE/GAIA events

3-150 M☉
Microlensing and the ESA GAIA Mission

MACHOS
EROS
OGLE
M31 HSC
WFIRST...
OGLE/GAIA Microlensing events

OGLE has detected \( \sim 60 \) long-duration microlensing events. \( \sim 20 \) 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.

Wyrzykowski L, Mandel I., 2019; García-Bellido 2019
Microlensing by 10 $M_{\text{sun}}$ Black Holes

Renamed the „Nancy Grace Roman“ Space Telescope
Is Planet 9 (Planet X) a Black Hole?

Scholtz & Unwin, 2019

$10^{-5} M_\odot$
Constraints on Primordial Black Holes (PBH)

- Constraints from femtolensing
- Subaru M31
- Niikura et al., 2019
- Constraints from EGB
- MACHO
- EROS
- WMAP3
- Planck
- PBH
- Niikura et al., 2019
- Ali-Haïmoud & Kamionkowski, 2017
- Brandt, 2016

Uniform single mass PBH already ruled out

Clustered wide mass distribution still feasible
Hubble finds Clumping of Dark Matter

Meneghetti et al, 2020, Science
A paper that threw me off my chair ...

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

Juan García-Bellido

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.
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.
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.
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.
Fingerprint of the first Black Holes

CIB x CXB Cross-Power

3.6 μm vs. 0.5-2 keV

CIB

CXB

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)

Feature is about 3 times stronger than predicted from standard ΛCDM

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

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 ($\sim 5\%$) of the captured matter is actually accreted. Then standard Shakura-Sunyaev accretion down to last stable orbit $3r_g$. 

\[ r_B = \frac{G M}{v_{eff}^2} \approx 1.34 \cdot 10^{16} \left( \frac{M}{M_\odot} \right) \left( \frac{v_{eff}}{1 \text{ km s}^{-1}} \right)^{-2} \text{ cm} \]
The Extragalactic Background Light

CIB/CXB correlation

EDGES 21cm absorption signal

Integrated values in nW/m²/sr

Wavelength $\lambda$ [µm]

Brightness $I_\nu$ [nW.m⁻².sr⁻¹]

Frequency $\nu$ [GHz]

Silva et al., 2019
ESA Voyage 2050 White Paper
Multi-Messenger Quest for first Black Holes

INFANT UNIVERSE 13.8 billion years ago
with seeds of future galaxies

COSMIC DARK AGES
380,000 to 400 million years after the Big Bang

GRB
EP
theseus

FIRST STARS & QUASARS
400 million years after the Big Bang

Athena & eROSITA

JWST

Euclid
Roman

GW: LIGO\/ LISA

JCMT/ALMA IMBH

IN BRIEF

NASA/ESA

THE EUROPEAN SPACE AGENCY
“Bringing sound to the cosmic movies”

Athena
hot gas structures
supermassive black holes

LISA
gravitational wave observation
Teams are working over Covid restrictions. Recommendations expected by end 2020!

→ Inputs for Space22+
Thank you very much!