Abstract

The initial data from the Event Horizon Telescope (EHT) on M87*, the supermassive black hole at the center of the M87 galaxy, provide direct observational information on its mass, spin, and accretion disk properties. A combination of the EHT data and other constraints provide evidence that M87* has a mass $\sim 6.5 \times 10^9 M_\odot$ and dimensionless spin parameter $|a^*| \geq 0.5$. These determinations disfavor ultra light bosons of mass $\mu_b \sim 10^{-21}$ eV via the phenomenon of superradiance, within the range considered for fuzzy dark matter, invoked to explain dark matter distribution on $\sim$ kpc scales. Future observations of M87* could be expected to strengthen our conclusions.
Ultralight Boson Dark Matter Constraints from Superradiance Leveraging the Event Horizon Telescope Collaboration’s Observations of M87

Peter B. Denton

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1904.09242

with Hooman Davoudiasl

Feliz Cinco de Mayo!
The first picture of a black hole opens a new era of astrophysics

The supermassive beast lies in a galaxy called M87 more than 50 million light-years away
Breaking!

The first picture of a black hole opens a new era of astrophysics
The supermassive beast lies in a galaxy called M87 more than 50 million light-years away

TACC Supercomputers Play Pivotal Role in Event Horizon Telescope’s First-Ever Black Hole Image
April 15, 2019
The Two Scientific Ways We Can Improve Our Images Of Event Horizons
Face to Face with a Cosmic Wonder

Physicists have been theorizing about black holes for generations. Now science has made it possible to see one.

By Frank Wilczek

April 17, 2019 11:28 am ET
First ever black hole image released

By Pallab Ghosh
Science correspondent, BBC News

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Breaking!
What's in a name is clearly not the case with newly photographed black hole
Pertama dalam Sejarah, Foto Sesungguhnya dari Lubang Hitam Dirilis ke Publik
Breaking!
Breaking!

AS EU DICTATES BRITAIN'S FUTURE

WHAT BREXIT LOOKS LIKE FROM SPACE

DEAL APPEARS AS FAR, FAR AWAY AS THIS BLACK HOLE
HELPLESS MAY SUCKED INTO THE BRUSSELS VORTEX

IT'S a going sight that makes in
orange with no drawbridge here.
This first-ever image of a black hole was undoubtedly
tremely beautiful in Brussels - where
nera organizations ever once thought
ow less as difficult to
eaders were deciding whether
t to agree to put off
in five minutes.

by AIDAN RADWEDGE

June 30 gave her counterparts
the other 27 EU countries an
her long-harried on progress.
Not that they had to lose
the room while they decided
France's ever-demanding.
How they did it

M87*

3C 279 (callibration)

Hard drives by the pound
What is this good for?

Black holes seem to follow $r \propto M$ over a huge range of masses.
Superradiance

Rotating BHs will create particles on-shell out of the vacuum:
Extracts angular momentum

Y. Zeldovich JETP Lett. 14, 180 (1971)
Conceptually similar to Hawking and Unruh radiation

Phenomenologically: BHs can constrain the existence of bosons,
independent of coupling

A. Arvanitaki, et al. 0905.4720
A cloud of particles forms around the BH ⇒ no fermions
Superradiance

Boson cloud growth rate:

$$\Gamma_0 = \frac{1}{24} a^* r_g^8 \mu_B^9, \quad \Gamma_1 = 4 a^* r_g^8 \mu_B^7$$

$$a^* \equiv J/\mathcal{G}M^2 \in [-1, 1]$$

$$r_g \equiv GM$$

Leading to an occupation number after spinning down $\Delta a^*$:

$$N = GM \Delta a^*$$

Superradiance depletes the spin of a BH if:

$$e^{\Gamma_B \tau_{BH}} > N$$

$$\tau_{BH} \sim \text{time to spin the BH back up}$$

Wavelength has to enter into the ergosphere:

$$\mu_B > \Omega_H$$ \hspace{1cm} (2)

Angular velocity:

$$\Omega_H \equiv \frac{1}{2r_g} \frac{a^*}{1 + \sqrt{1 - a^*2}}$$

Only include dominant $m = 1$ spherical harmonic mode

M. Baryakhtar, R. Lasenby, M. Teo 1704.05081
Spin

- EHT can infer the spin
- Some degeneracies with disk properties
- EHT (conservative): $|a^*| \gtrsim 0.5$
- Twisted light: $|a^*| = 0.9 \pm 0.1$
  
  F. Tamburini, B. Thidé, M. Valle 1904.07923
  Updated to $|a^*| = 0.9 \pm 0.05$ at 95% CL ruling out $a^* = 0$ at 6 $\sigma$

- Circularity: No real power yet

C. Bambi, et al. 1904.12983

If a BH with large $|a^*|$ is measured, it could not have spun down much

Peter B. Denton (BNL) 1904.09242
Time scale

Astrophysics can spin the BH back up, possibly faster than superradiance

- From the Eddington limit, $\tau_{\text{Salpeter}} \sim 4.5 \times 10^7$ yrs
- EHT: $\dot{M}_{\text{M87}}^*/\dot{M}_{\text{Edd}} \sim 2 \times 10^{-5}$
- Mergers: one $\sim 10^9$ yrs ago with a much smaller galaxy

- $\mu_B$ constraint has very weak dependence: $\tau_{\text{BH}}^{-1/7}$ or $\tau_{\text{BH}}^{-1/9}$

We take $\tau_{\text{BH}} = 10^9$ yrs
Past Ultra Light Boson Constraints

Vector constraints

M. Baryakhtar, R. Lasenby, M. Teo 1704.05081
New Constraints from M87*

Bosons with masses in the regions in color are ruled out.
Spin Dependence

\[ \mu_b \quad [\text{eV}] \]

FDM

\[ \tau_{\text{BH}} = 10^9 \text{ yr} \]

Vector Scalar

\[ |a_{M87}^*| \]

Peter B. Denton (BNL)
Core-cusp is an interesting topic

- Galaxy simulations suggest a cuspy central DM distribution
- Data suggests many galaxies are cored
- Baryonic feedback could play a role
- Fuzzy DM with $\lambda_{\text{DM}} \sim 1$ kpc ($\sim [10^{-22}, 10^{-21}]$ eV) could also explain this
- M87* rules out upper part of the region for spin-1 particles

Our constraints don’t care if it’s present in the center of Galaxies, nor do they care if the particle has any couplings: SM, self, dark sector, …
How to Detect Ultra Light Bosons with Superradiance

Vector with \( \mu_B = 10^{-12} \) eV

\[ \sigma_{a^*} \sim 0.3, \sigma_M/M \sim 10\% \]

M. Baryakhtar, R. Lasenby, M. Teo 1704.05081
Key Points

▶ Superradiance causes BHs to spin down
▶ Happens efficiently when a boson of $\mu_B \sim 1/M_{\text{BH}}$ exists  Interactions don’t matter!
▶ EHT observed M87*: constrains bosons in fuzzy DM region
▶ M87* has the most angular momentum of any measured single object!

Future:
▶ TON 618 is one order of magnitude more massive ($\sim 200x$ farther away)

Thanks!
Backups
Superradiance Spin-down

Different spherical harmonic modes lead to different maximum spins.

Vector (scalar) in bold (dotted) for $\mu_B = 10^{-12}$ eV

M. Baryakhtar, R. Lasenby, M. Teo 1704.05081