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 ∼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*

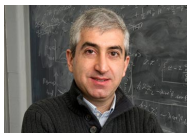
Peter B. Denton

Pheno 2020

May 5, 2020

1904.09242

with Hooman Davoudiasl



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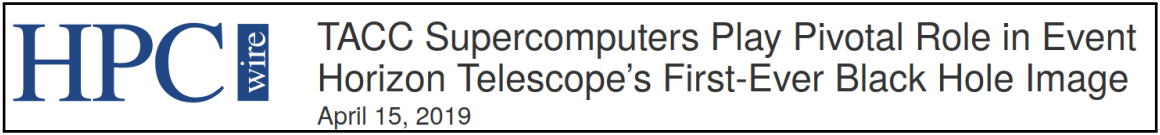
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Face to Face with a Cosmic Wonder

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

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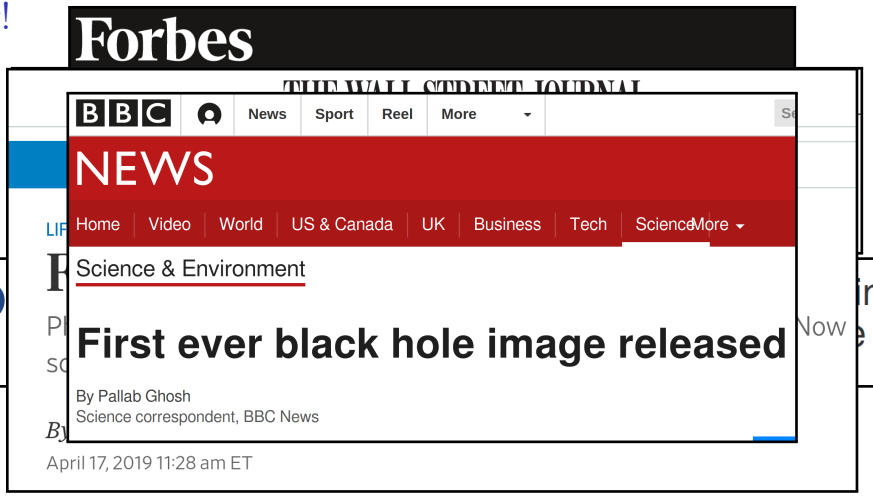
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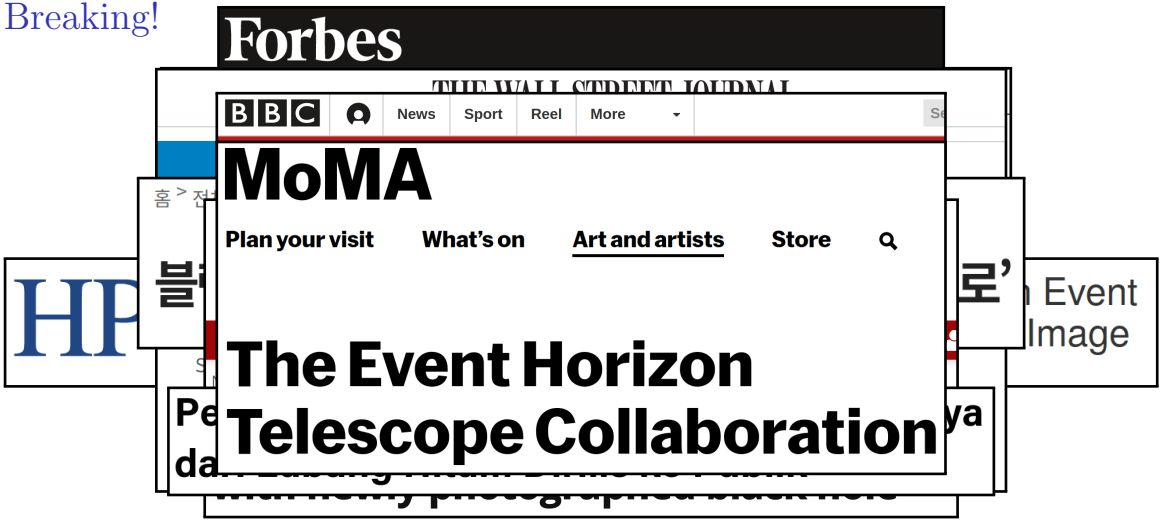
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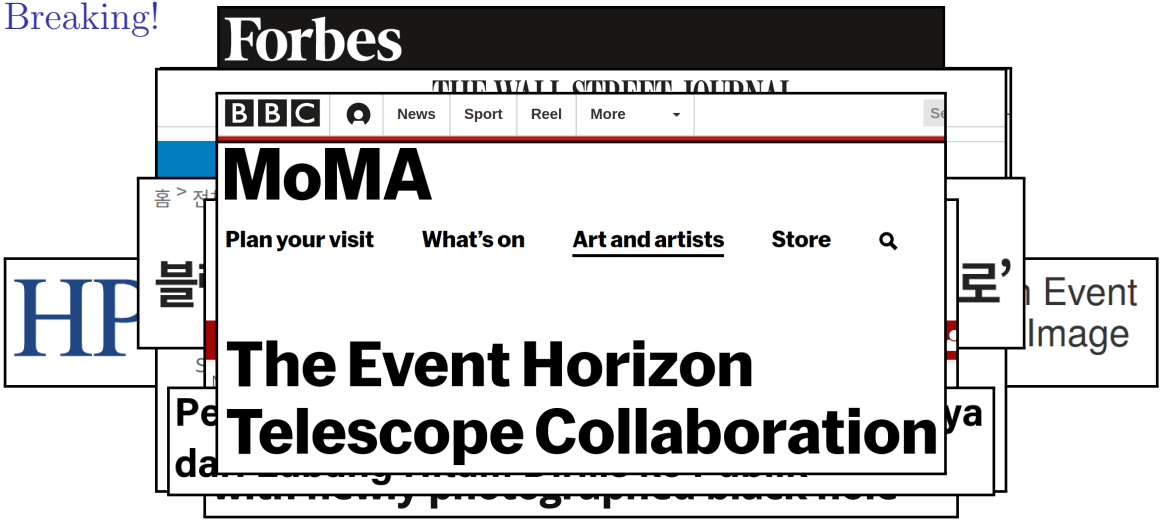
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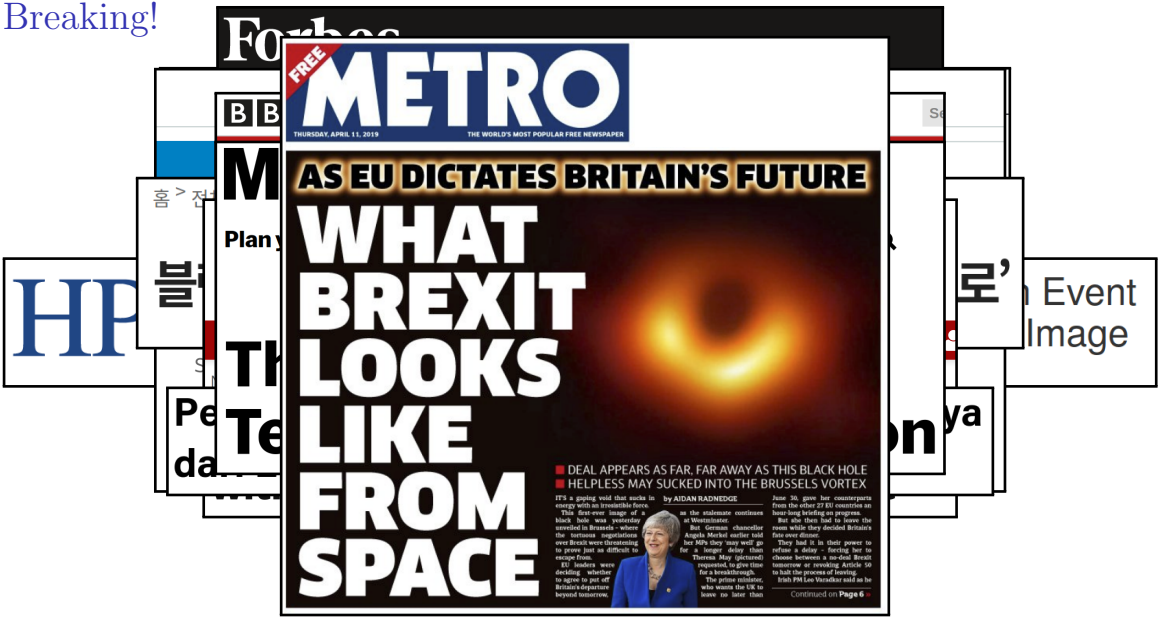
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WHAT BREXIT LOOKS LIKE FROM SPACE
DEAL APPEARS AS FAR, FAR AWAY AS THIS BLACK HOLE
HELPLESS MAY SUCKED INTO THE BRUSSELS VORTEX
by AIDAN RADNEDGE
IT'S a gaping void that sucks in energy with an irresistible force.
This first-ever image of a black hole was yesterday unveiled in Brussels – where the tortuous negotiations over Brexit were threatening to prove just as difficult to escape from.
EU leaders were deciding whether to agree to put off Britain's departure beyond tomorrow.
as the stalemate continues at Westminster.
But German chancellor Angela Merkel earlier told her MPs they 'may well' go for a longer delay than Theresa May (pictured) requested, to give time for a breakthrough.
The prime minister, who wants the UK to leave no later than June 30, gave her counterparts from the other 27 EU countries an hour-long briefing on progress.
But she then had to leave the room while they decided Britain's fate over dinner.
They had it in their power to refuse a delay – forcing her to choose between a no-deal Brexit tomorrow or revoking Article 50 to halt the process of leaving.
Irish PM Leo Varadkar said as he
Continued on Page 6
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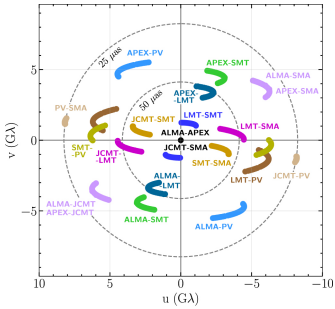
Event Horizon Telescope: ApJL 875 L1 (2019)

How they did it

M87*



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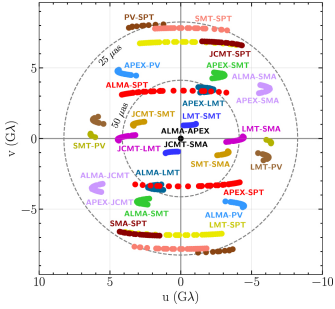
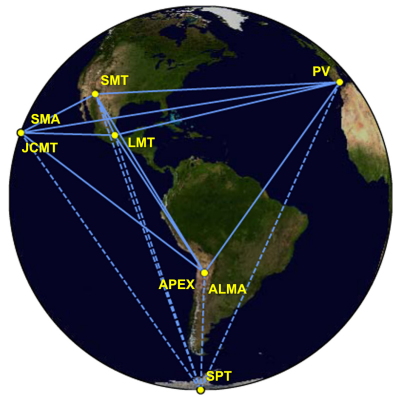
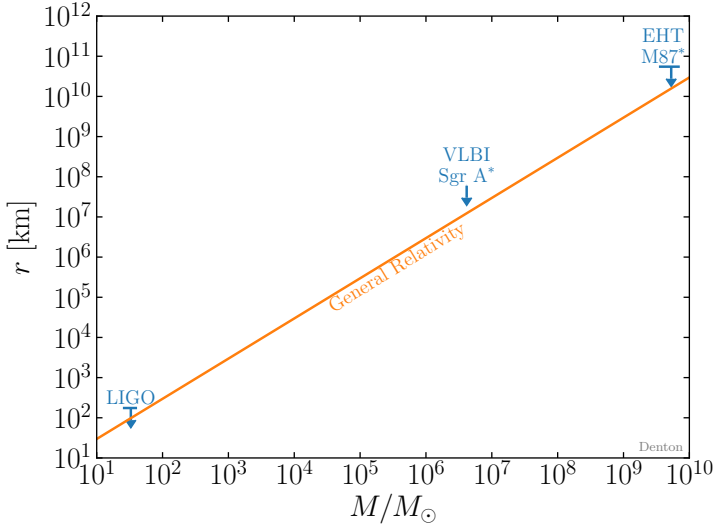




Hard drives by the pound

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 $\Rightarrow$ no fermions

Superradiance

Boson cloud growth rate:

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

$a^* \equiv J/GM^2 \in [-1, 1]$
$r_g \equiv GM$

Leading to an occupation number after spinning down Δa^*:

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

Superradiance depletes the spin of a BH if:

$$e^{\Gamma_B \tau_{\rm BH}} > N \qquad (1)$$

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

Wavelength has to enter into the ergosphere:

$$\mu_B > \Omega_H \qquad (2)$$

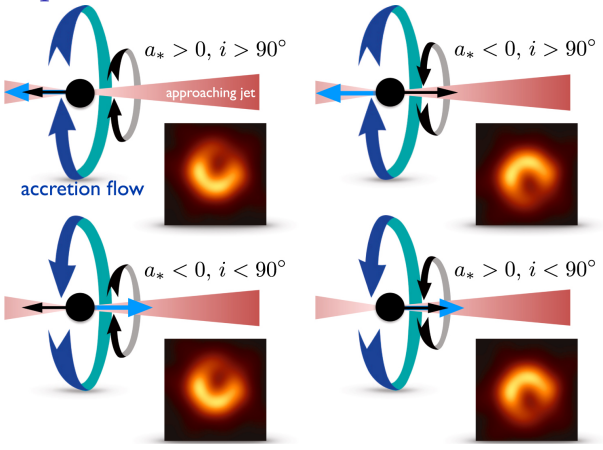
Angular velocity:

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

Only include dominant $m = 1$ spherical harmonic mode

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

Spin



EHT: ApJL 875 L5 (2019)

- 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 σ
- 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

Time scale

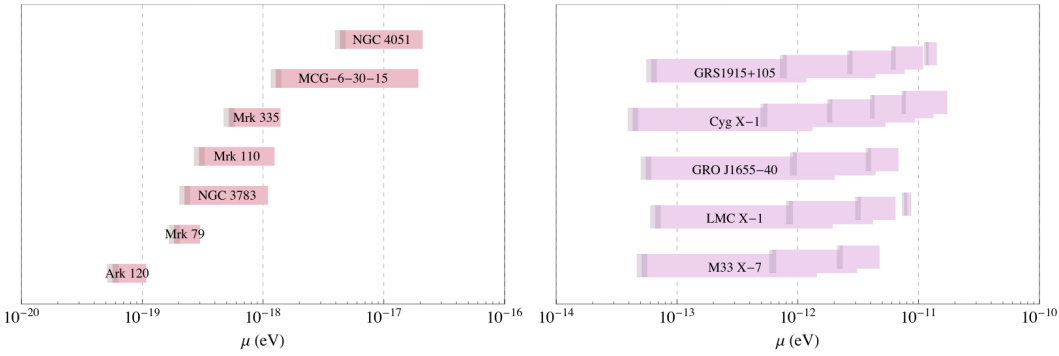
Astrophysics can spin the BH back up, possibly faster than superradiance

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

  A. Longobardi, et al. 1504.04369
- μ_B constraint has very weak dependence: $\tau_{\rm BH}^{-1/7}$ or $\tau_{\rm BH}^{-1/9}$

We take $\tau_{\rm BH} = 10^9$ yrs

Past Ultra Light Boson Constraints



Vector constraints

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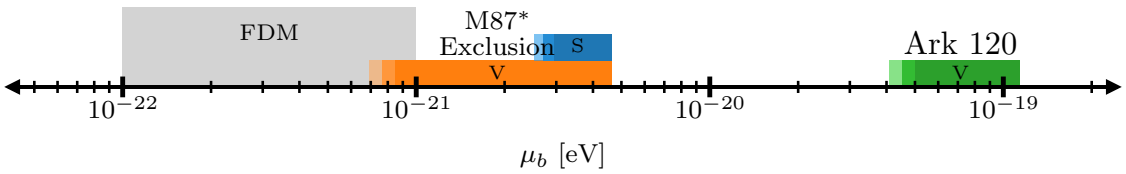
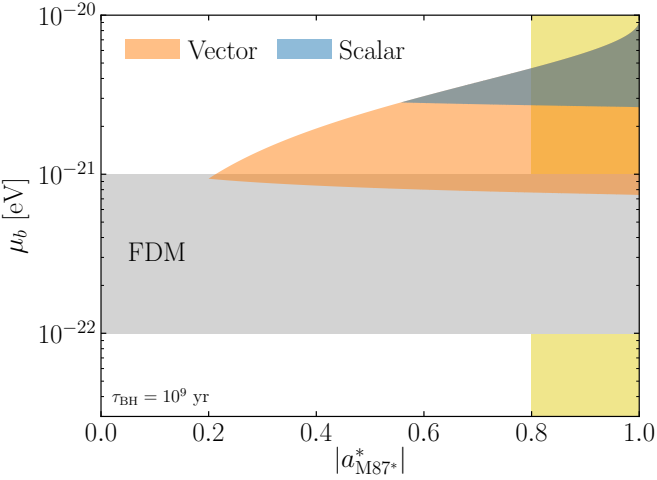
New Constraints from M87*



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

Spin Dependence



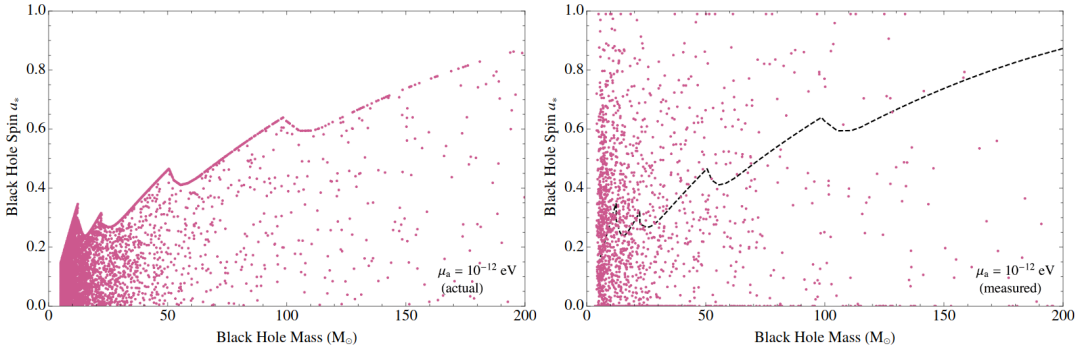
Dark Matter

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 $\lambda_{\rm DM} \sim 1$ 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

$\sigma_{a*} \sim 0.3$, $\sigma_M/M \sim 10\%$

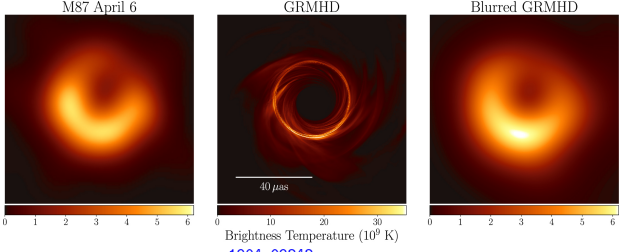
M. Baryakhtar, R. Lasenby, M. Teo 1704.05081

Key Points

- Superradiance causes BHs to spin down
- Happens efficiently when a boson of $\mu_B \sim 1/M_{\rm BH}$ 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)



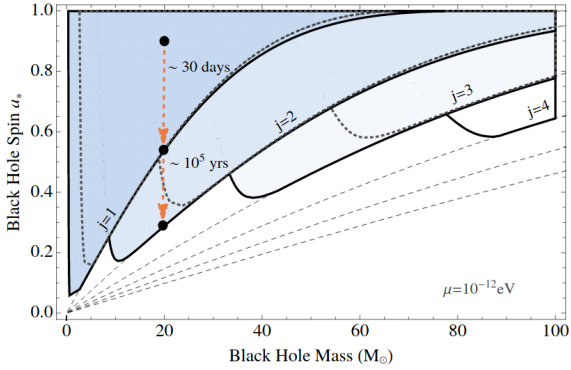
EHT: ApJL 875 L5 (2019)

Thanks!

Backups

Superradiance Spin-down

Different spherical harmonic modes leads to different maximum spins



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

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