

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

Pheno 2020

May 5, 2020

[1904.09242](#)

with Hooman Davoudiasl

Feliz Cinco de Mayo!



Breaking!

The image shows a screenshot of a ScienceNews article. At the top left is a menu icon (three horizontal lines). To its right is the "ScienceNews" logo in blue. Below the logo is a navigation bar with two tabs: "NEWS" (which is highlighted in a blue box) and "ASTRONOMY". The main title of the article is "The first picture of a black hole opens a new era of astrophysics". Below the title is a subtitle: "The supermassive beast lies in a galaxy called M87 more than 50 million light-years away".

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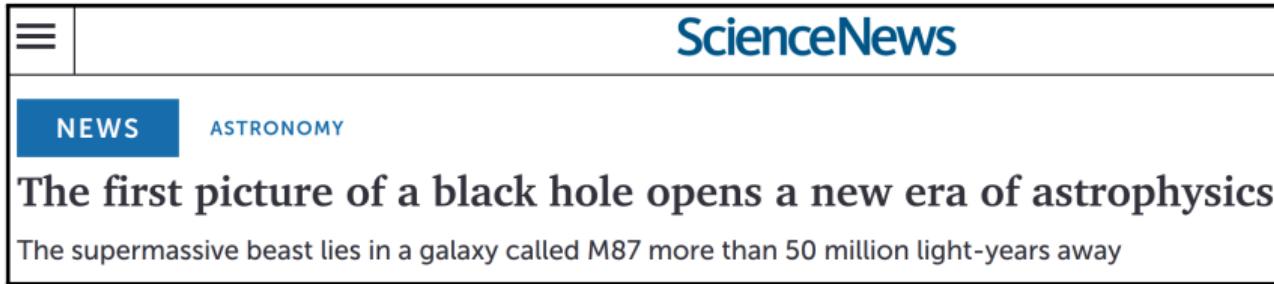
ScienceNews

NEWS ASTRONOMY

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 ScienceNews website header features a top navigation bar with a menu icon (three horizontal lines) and the "ScienceNews" logo in blue. Below this, a secondary navigation bar includes "NEWS" and "ASTRONOMY" categories. The main headline is "The first picture of a black hole opens a new era of astrophysics". A subtitle below the headline reads, "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

Breaking!

Forbes



The
The su

11,446 views | Apr 15, 2019, 02:00am EDT

The Two Scientific Ways We Can Improve Our Images Of Event Horizons

HPC

ysics

ole in Event
Hole Image

Breaking!

Forbes

THE WALL STREET JOURNAL.

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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

in Event
e Image

HP

Breaking!

Forbes

The screenshot shows a news article from BBC News. At the top, there's a navigation bar with the BBC logo, a microphone icon, and links for News, Sport, Reel, More, and Settings. Below the navigation is a red banner with the word "NEWS". Underneath the banner, there's a menu with "LIFE" (partially visible), Home, Video, World, US & Canada, UK, Business, Tech, Science, and a "More" dropdown. The "Science" link is underlined. The main headline is "First ever black hole image released" by Pallab Ghosh, a science correspondent for BBC News. The date is April 17, 2019, 11:28 am ET. To the left of the main content area, there's a large blue "HP" logo. To the right, there's a sidebar with the text "in Event Image". The background of the page is white.

THE WALL STREET JOURNAL

BBC News Sport Reel More Settings

NEWS

LIFE Home | Video | World | US & Canada | UK | Business | Tech | Science More

Science & Environment

First ever black hole image released

By Pallab Ghosh
Science correspondent, BBC News

April 17, 2019 11:28 am ET

in Event Image

Breaking!

Forbes

THE WALL STREET JOURNAL



News Sport Reel More



NEWS

홈 > 전체기사 > 뉴스

블랙홀 연구진 속 韓 과학자도? ‘영화가 현실로’

HP

Event
Image

SC

First ever black hole image released

By

Pallab Ghosh

Science correspondent, BBC News

April 17, 2019 11:28 am ET

Breaking!

Forbes

The image is a collage of news snippets from various sources. At the top left is a BBC logo with a speech bubble icon. Next to it are links for News, Sport, Reel, and More. Below this is a red banner with the word 'NEWS' in white. To the right is a snippet from The Wall Street Journal with a 'Skip' button. In the center is a large snippet from India Today. It features the 'INDIA TODAY' logo in red, with 'NEWS' and 'LIVE TV' below it, and 'APP' and 'MAGAZINE' options. A red navigation bar at the bottom includes links for HOME, CORONA, E-CONCLAVE, VIDEOS, NEWSMO, DIU, FACT CHECK, and INDIA, along with icons for a television, a person, a search, and a share. Below this is a sub-headline: 'News / SCIENCE / What's in a name is clearly not the case with newly photographed black hole'. The main headline is 'What's in a name is clearly not the case with newly photographed black hole'. On the far left, there is a large blue 'HP' logo. On the far right, there are partial Korean characters '로' and '이' followed by 'Event' and 'Image'. The entire collage is set against a white background.

THE WALL STREET JOURNAL

BBC NEWS Sport Reel More

NEWS

INDIA TODAY

NEWS LIVE TV APP MAGAZINE

HOME CORONA E-CONCLAVE VIDEOS NEWSMO DIU FACT CHECK INDIA

News / SCIENCE / What's in a name is clearly not the case with newly photographed black hole

What's in a name is clearly not the case with newly photographed black hole

Breaking!

Forbes

The image is a collage of news snippets from various sources. At the top left is a snippet from BBC News featuring the BBC logo and a red banner with the word "NEWS". Below it is a snippet from The Wall Street Journal with the title "INDIA TODAY" in large red letters. To the right is a snippet from India Today with the same title. The India Today snippet includes links for "APP" and "MAGAZINE". Below these are several other snippets, some partially visible, including one from India Today with the headline "Pertama dalam Sejarah, Foto Sesungguhnya dari Lubang Hitam Dirilis ke Publik" and another snippet from India Today with the headline "News / SCIENCE / What's in a name is clearly not the case with newly photographed black hole". The overall theme is the first photograph of a black hole.

Breaking!

Forbes

BBC NEWS

THE WALL STREET JOURNAL

HOME > 정치/국제 > 뉴스

SH/FTER

TECNOLOGIA

Como se “fotografa” um buraco negro? Com algoritmos e muito trabalho

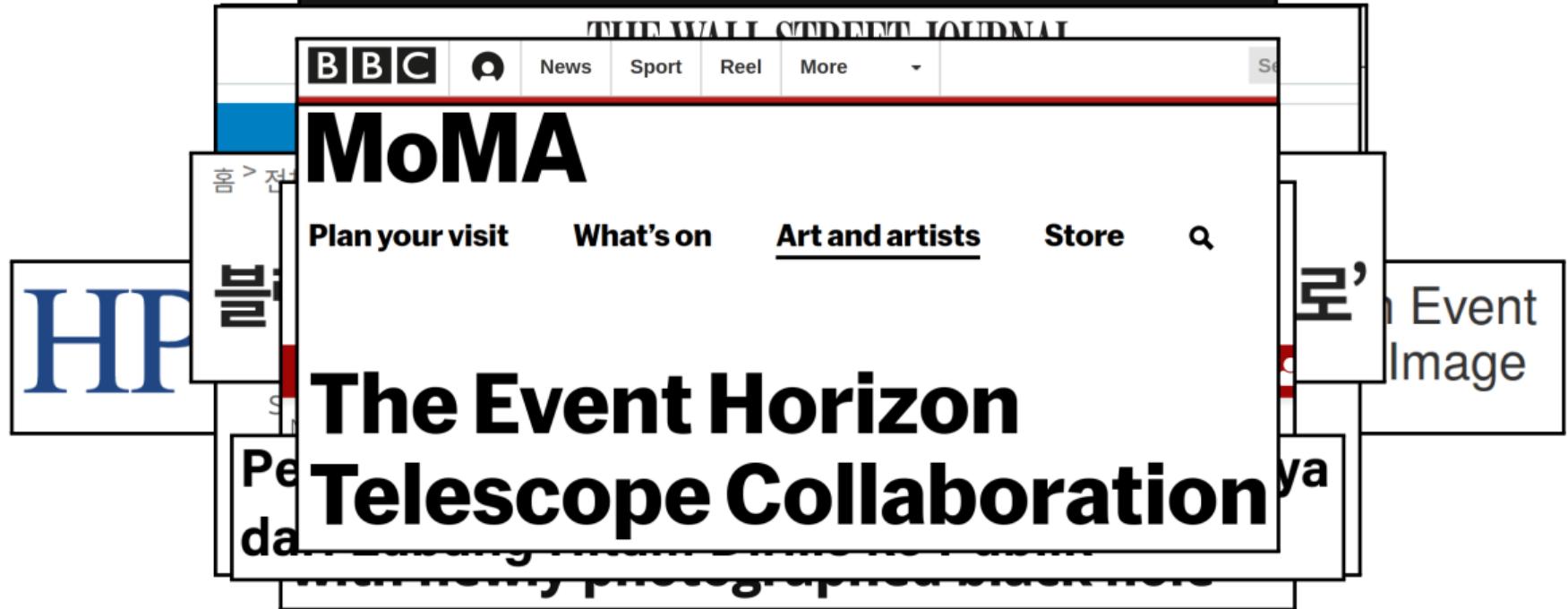
Pertama dari Lubang Hitam Dirilis ke Publik

Event Image

guhnya

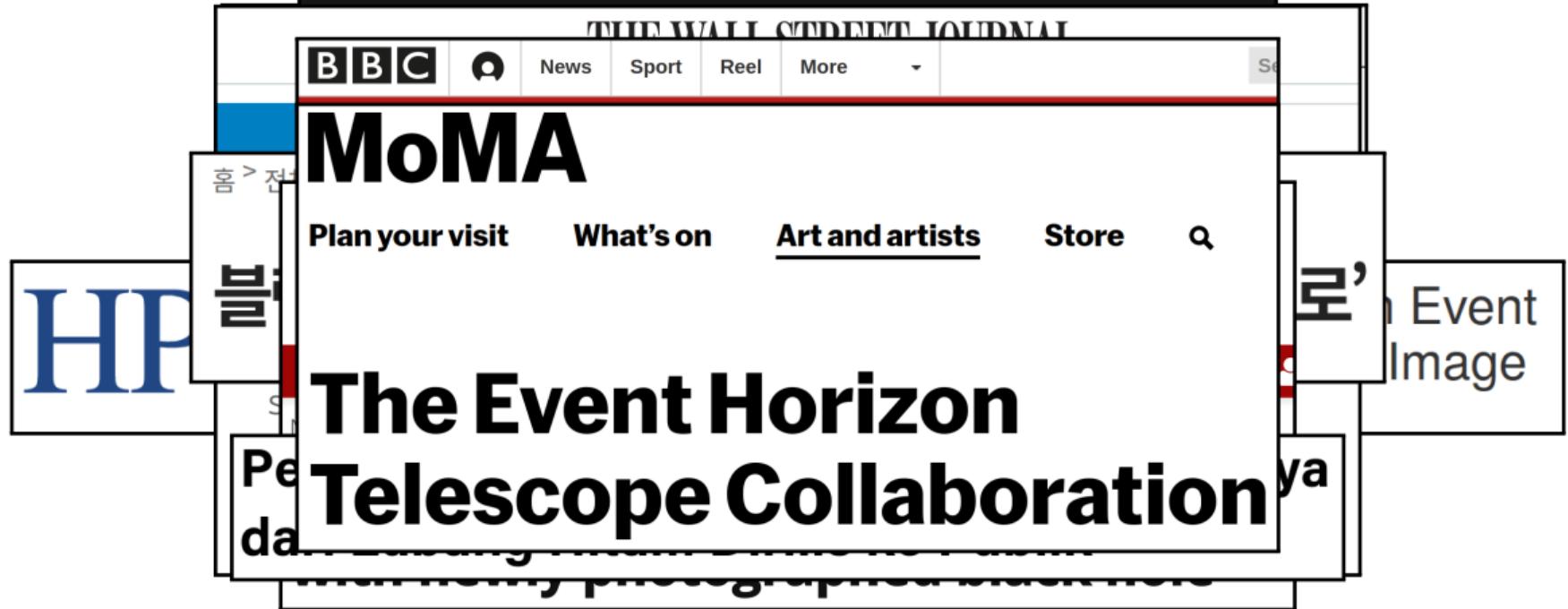
Breaking!

Forbes



Breaking!

Forbes



Breaking!

Forbes

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THURSDAY, APRIL 11, 2019

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 gaping void that sucks in everything in its path. 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.

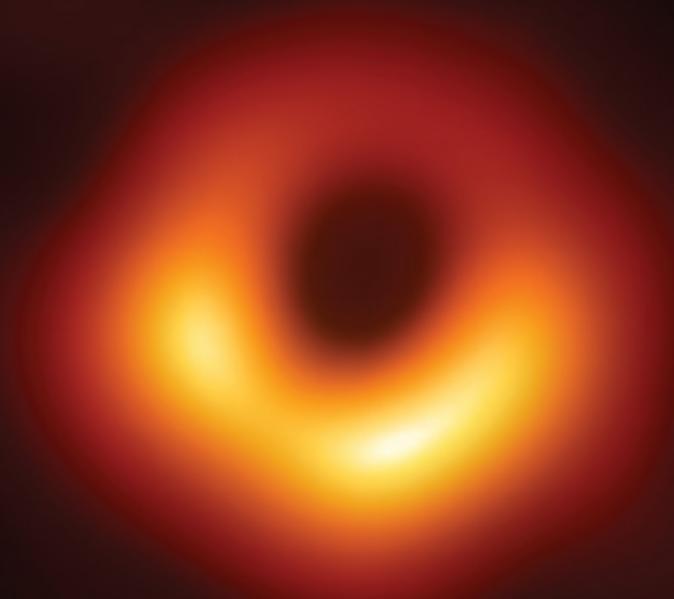
EU leaders were deciding whether to give the UK a grace period to leave beyond tomorrow.

EU leaders were deciding whether to give the UK a grace period to leave beyond tomorrow.

by AIDAN RADNEDGE

June 30, gave her counterparts from the other 27 EU members an hour-long briefing on progress. But she then had to leave the room while they decided Britain's fate over dinner. She 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

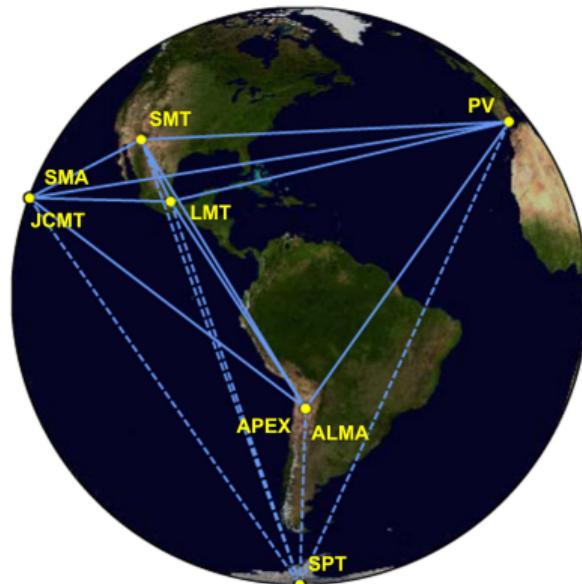
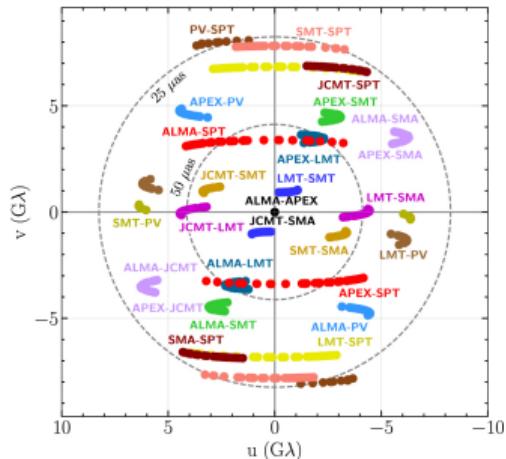
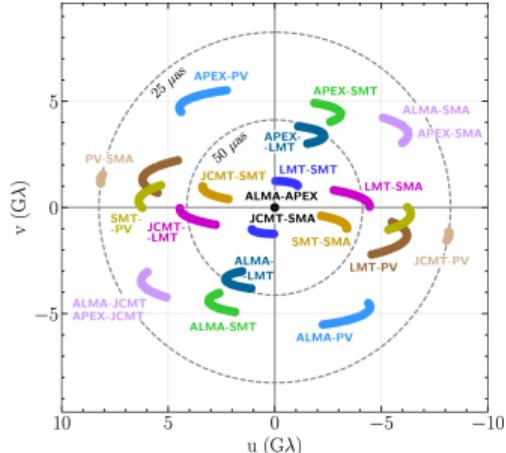
Continued on Page 6 ►



Event Horizon Telescope: [ApJL 875 L1 \(2019\)](#)

How they did it

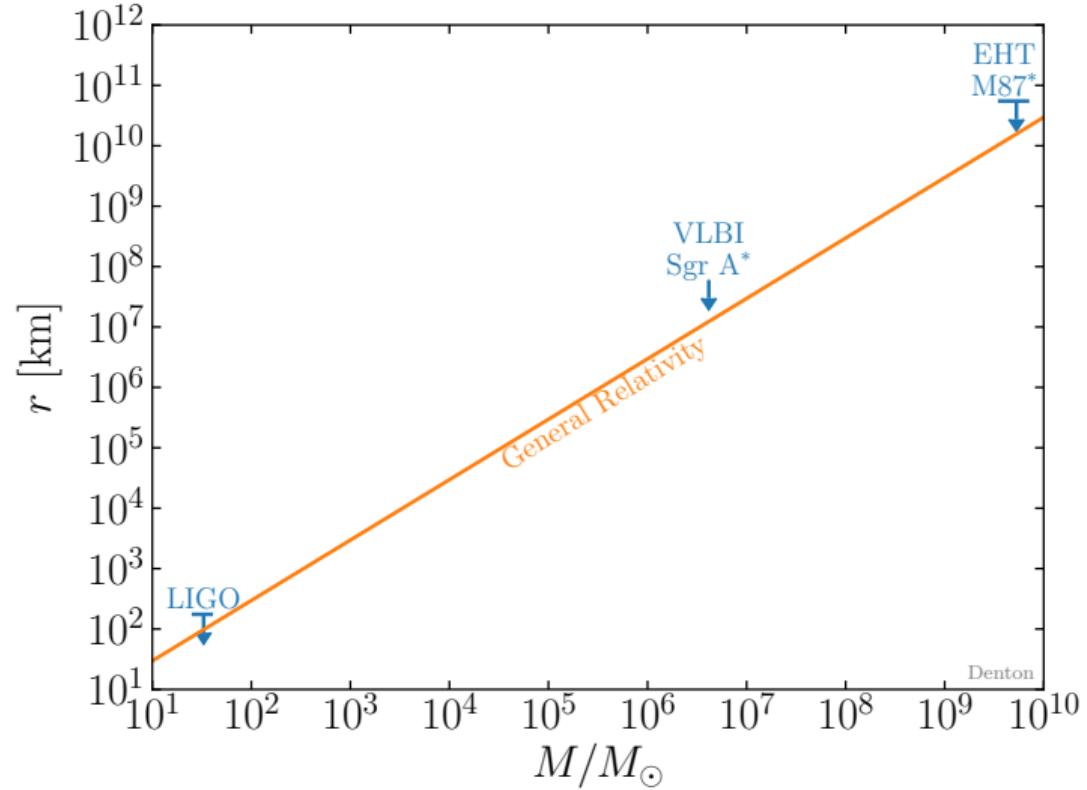
M87*
3C 279
(calibration)



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:

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

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

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

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

Superradiance depletes the spin of a BH if:

$$e^{\Gamma_B \tau_{\text{BH}}} > N \quad (1)$$

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

Wavelength has to enter into the ergosphere:

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

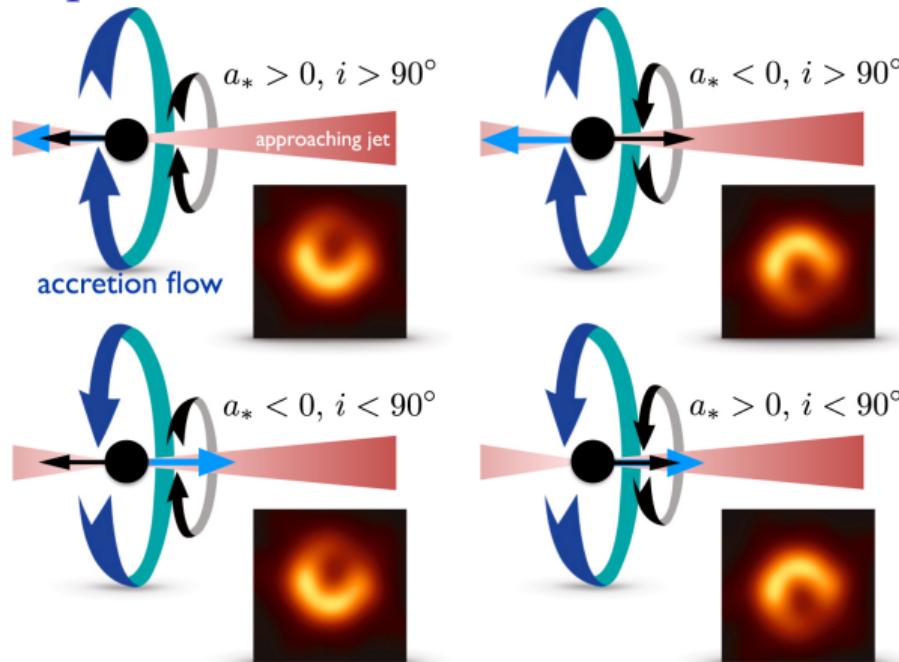
Angular velocity:

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

Only include dominant $m = 1$ spherical harmonic mode

M. Baryakhtar, R. Lasenby, M. Teo [1704.05081](#)

Spin



EHT: [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 6σ

- ▶ 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

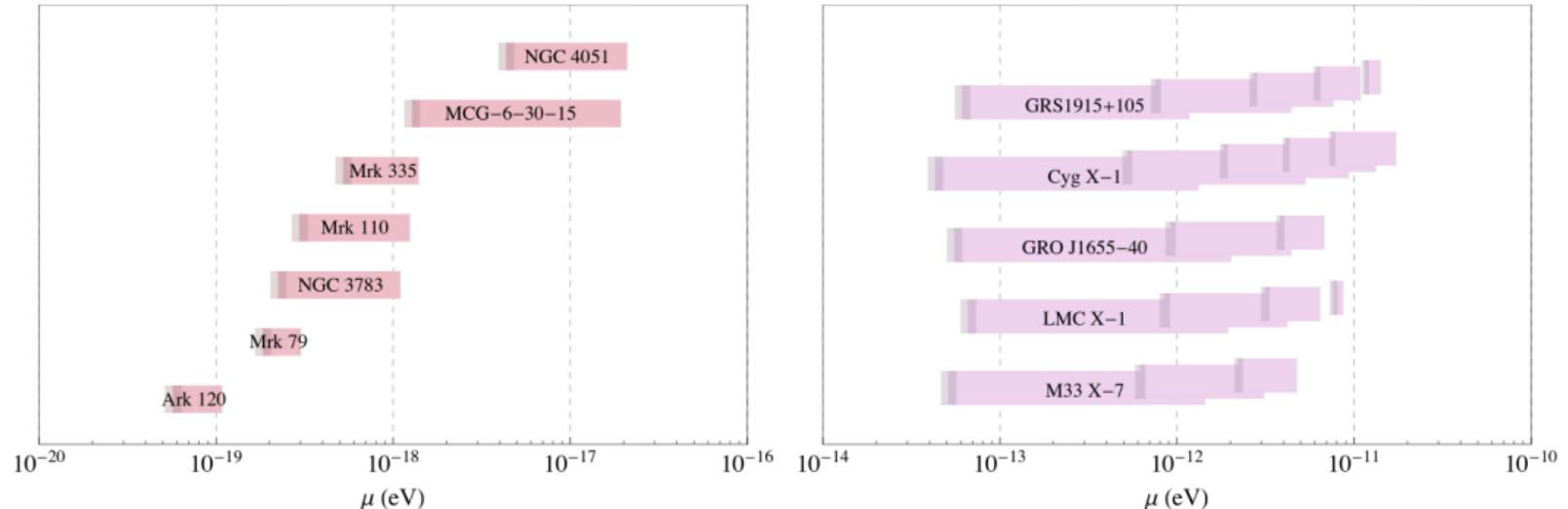
- ▶ From the Eddington limit, $\tau_{\text{Salpeter}} \sim 4.5 \times 10^7$ yrs
- ▶ EHT: $\dot{M}_{\text{M87}^*}/\dot{M}_{\text{Edd}} \sim 2 \times 10^{-5}$
- ▶ Mergers: one $\sim 10^9$ yrs ago with a much smaller galaxy

A. Longobardi, et al. [1504.04369](#)

- ▶ μ_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

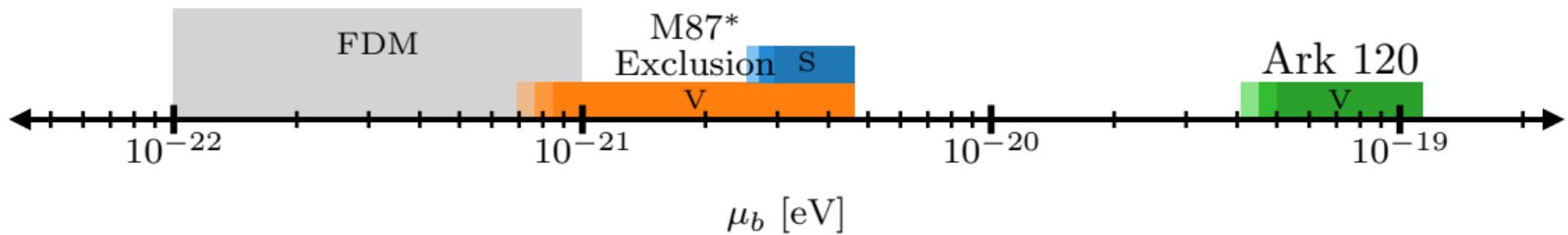
Past Ultra Light Boson Constraints



Vector constraints

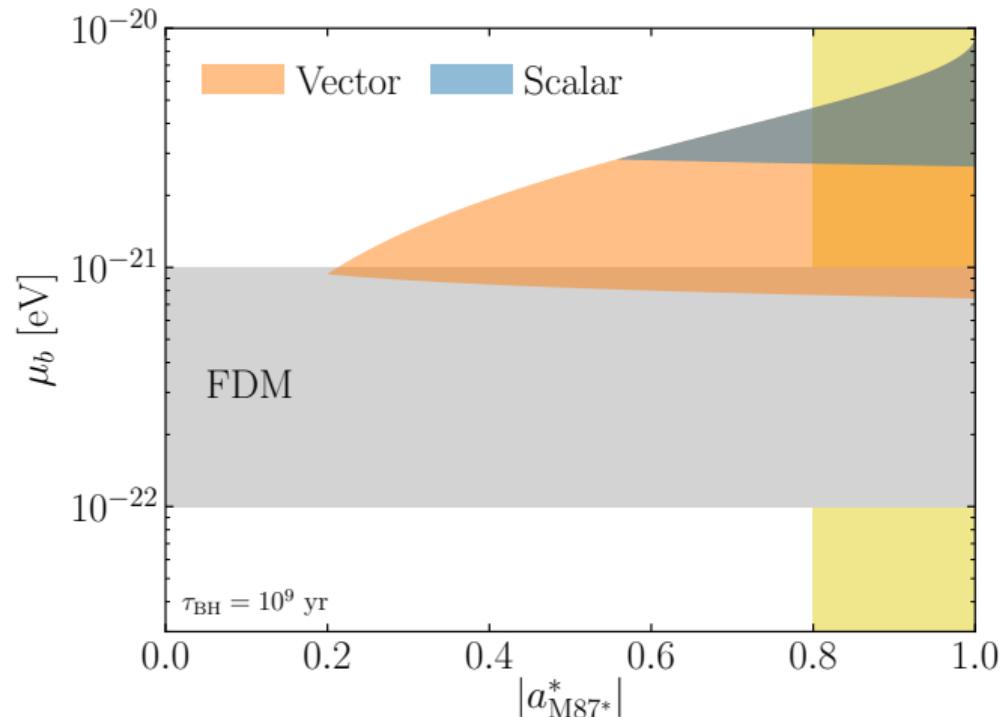
M. Baryakhtar, R. Lasenby, M. Teo [1704.05081](https://arxiv.org/abs/1704.05081)

New Constraints from M87*



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

Spin Dependence



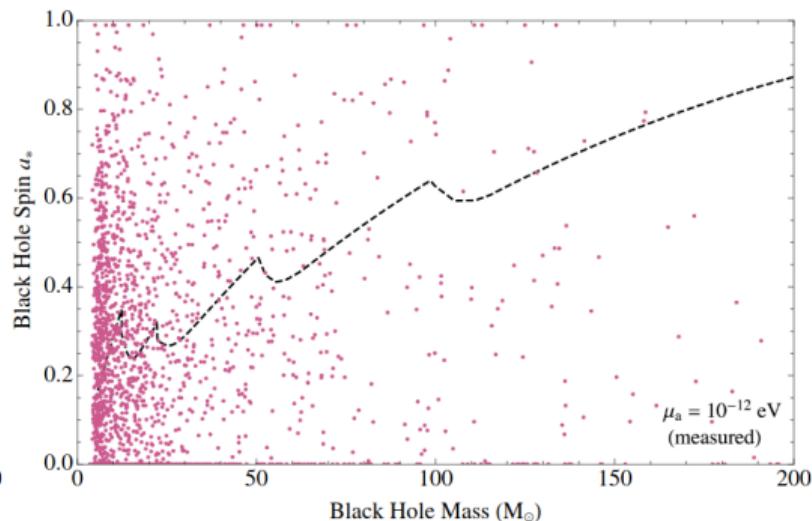
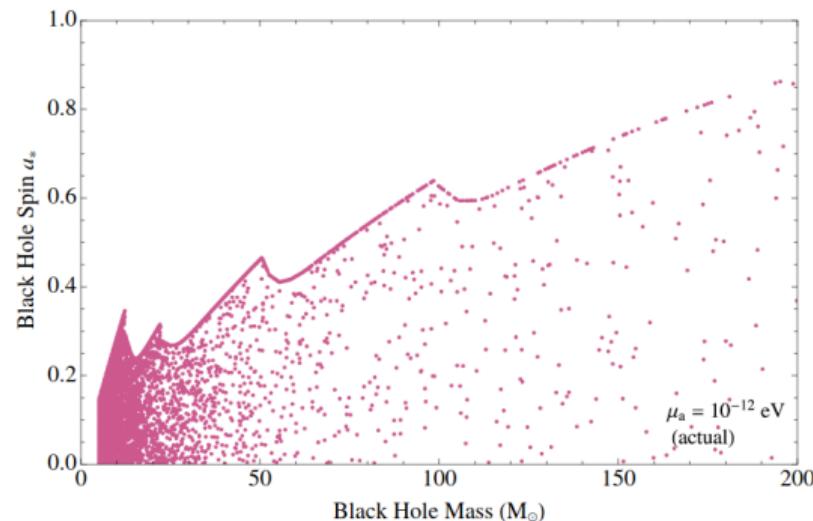
Dark Matter

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 $\lambda_{\text{DM}} \sim 1 \text{ kpc}$ ($\sim [10^{-22}, 10^{-21}] \text{ eV}$) 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 $\mu_B = 10^{-12} \text{ eV}$
 $\sigma_{a^*} \sim 0.3, \sigma_M/M \sim 10\%$

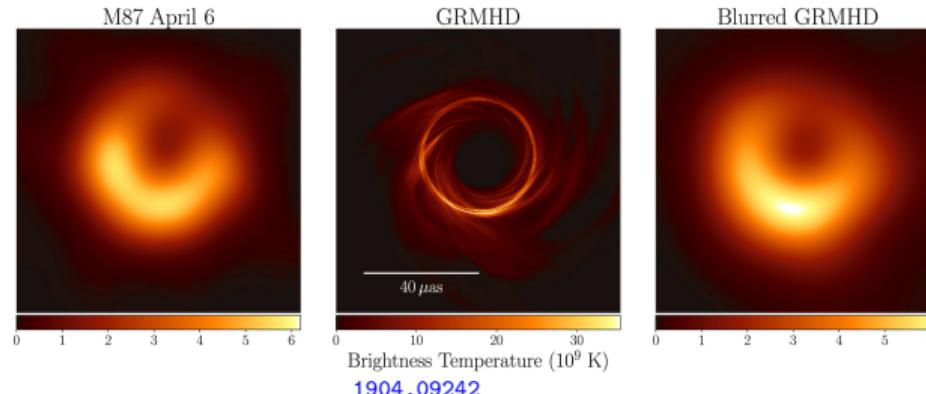
M. Baryakhtar, R. Lasenby, M. Teo [1704.05081](#)

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)



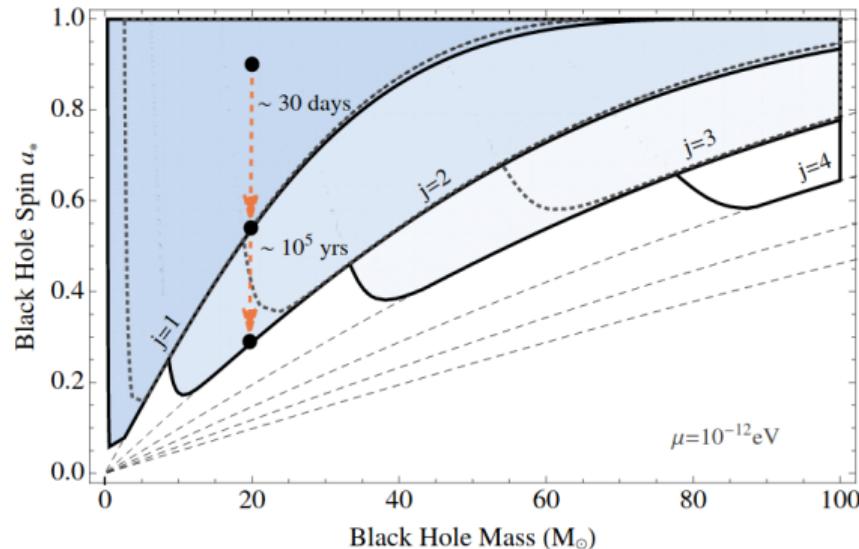
EHT: [ApJL 875 L5 \(2019\)](#)

Thanks!

Backups

Superradiance Spin-down

Different spherical harmonic modes leads to different maximum spins



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

M. Baryakhtar, R. Lasenby, M. Teo [1704.05081](#)