Terascale New Physics from evaporating Black Holes and Black Morsels

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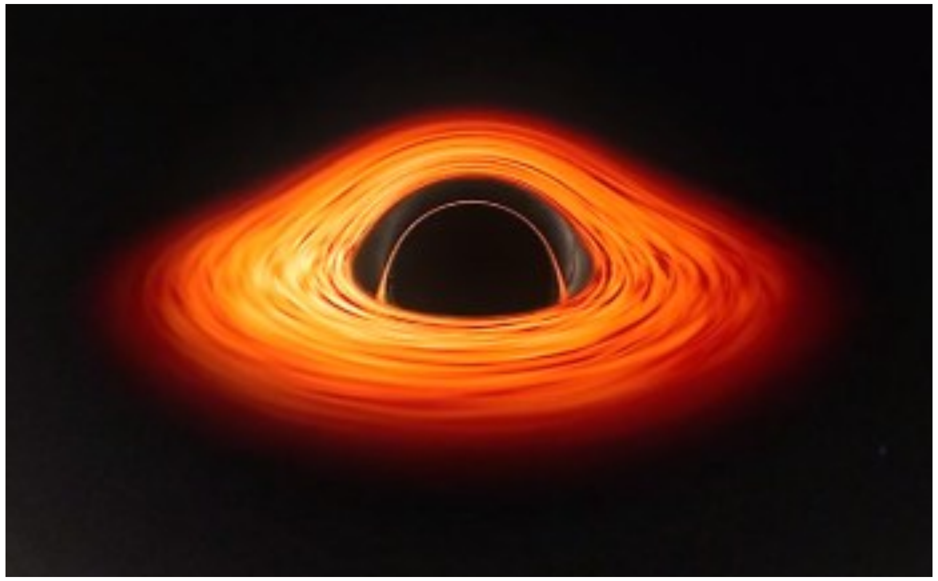
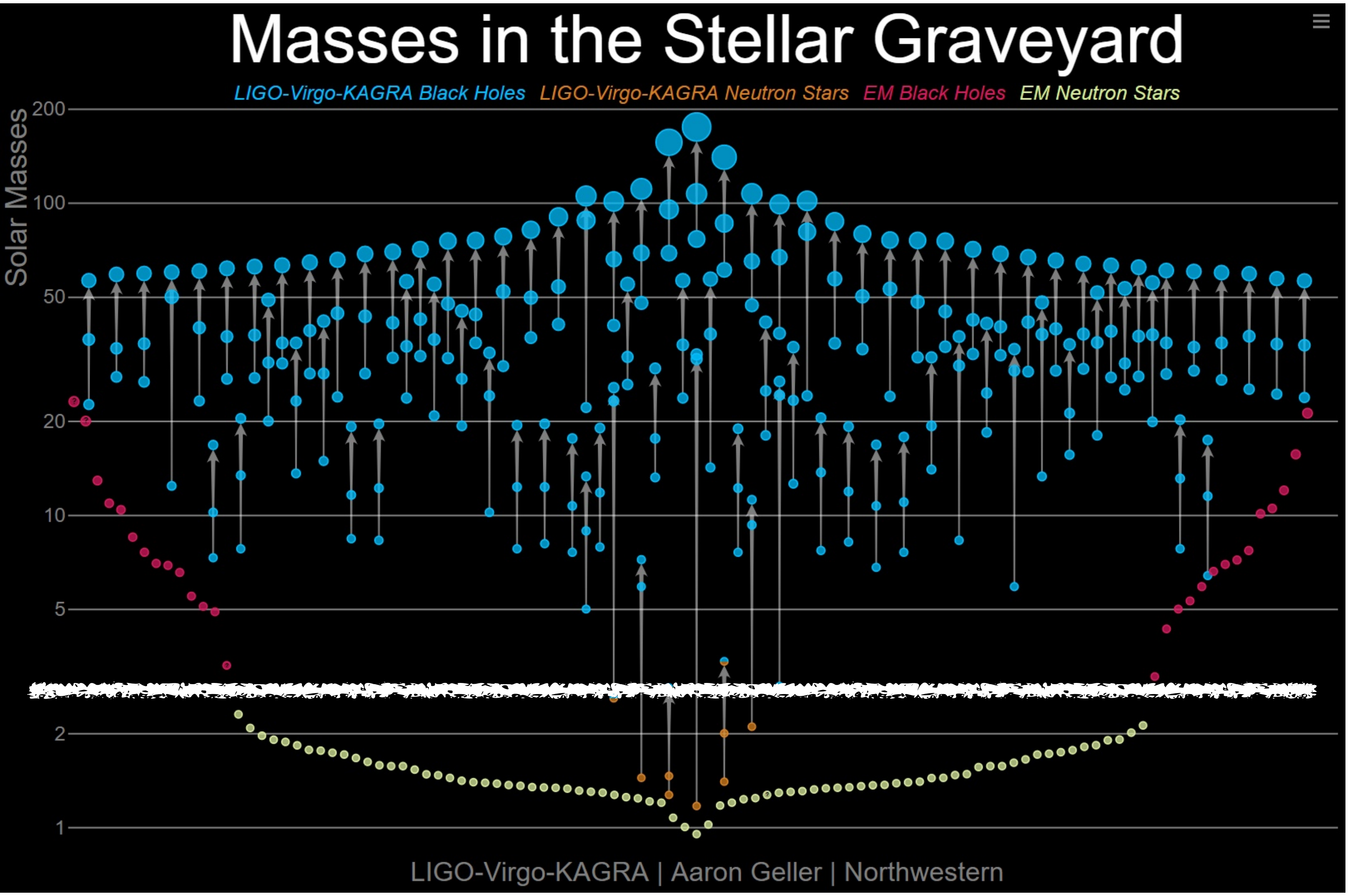
Astrophysical Black Holes

Stellar mass BHs produced at the end of heavy star life

SMBH ~ 10^5 — billions $M_\odot$ and found at the centre of galaxies





Stellar BH masses seen by GWs from the NS threshold to 200 solar masses.

Heavier masses may exist thanks to successive mergers.

Astrophysical Black Holes

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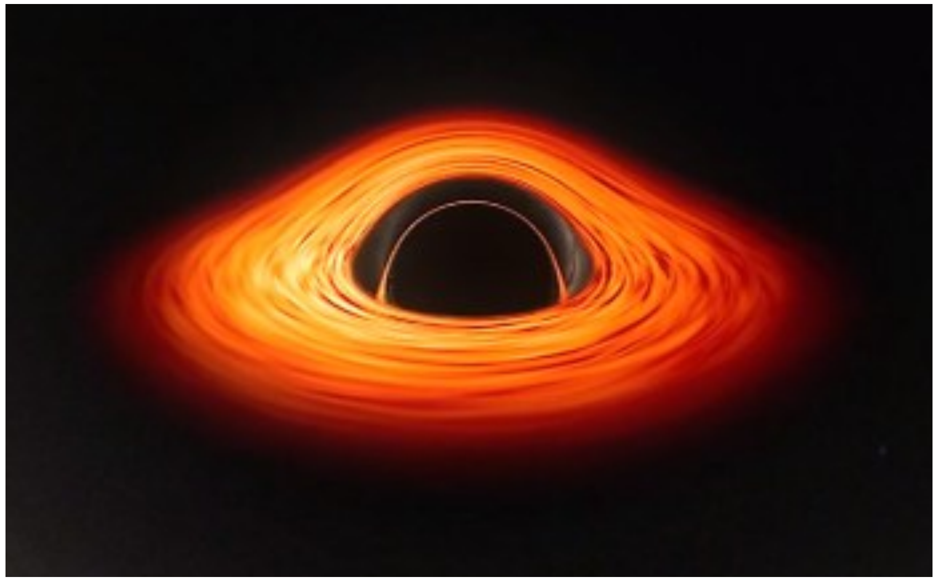

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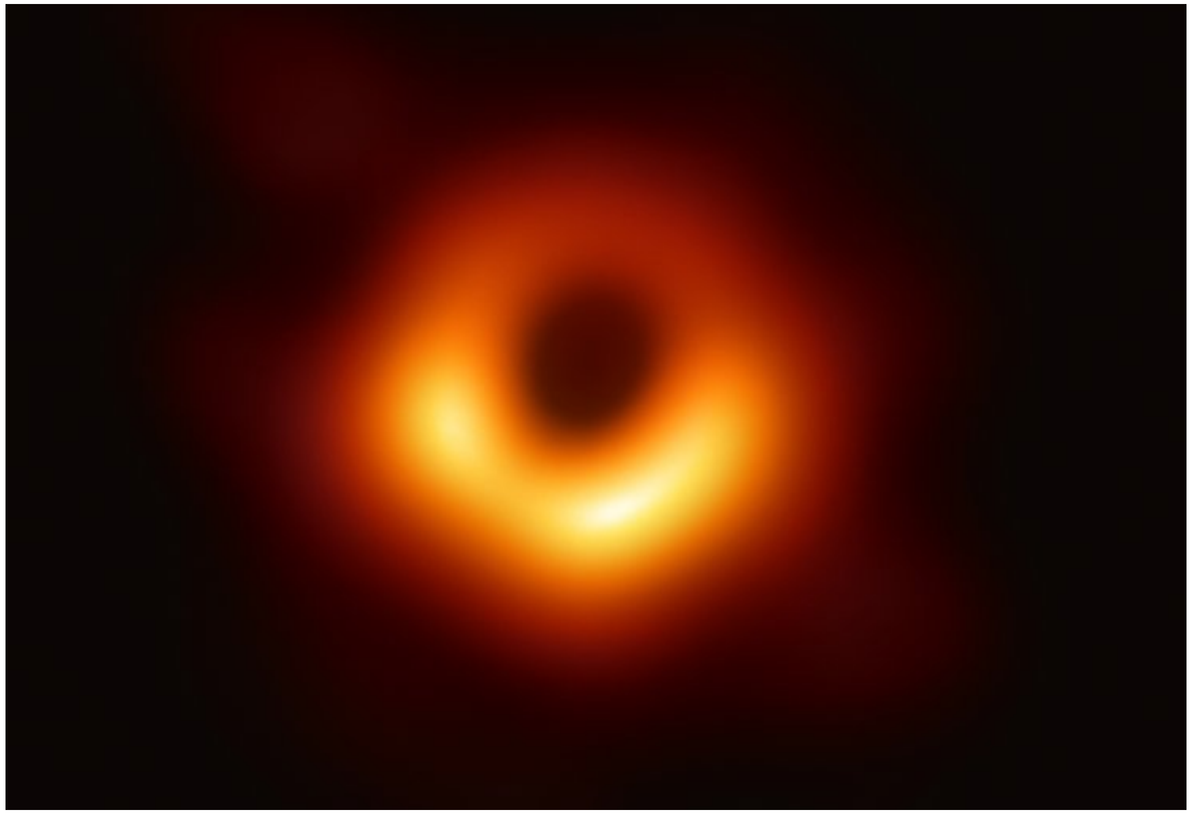


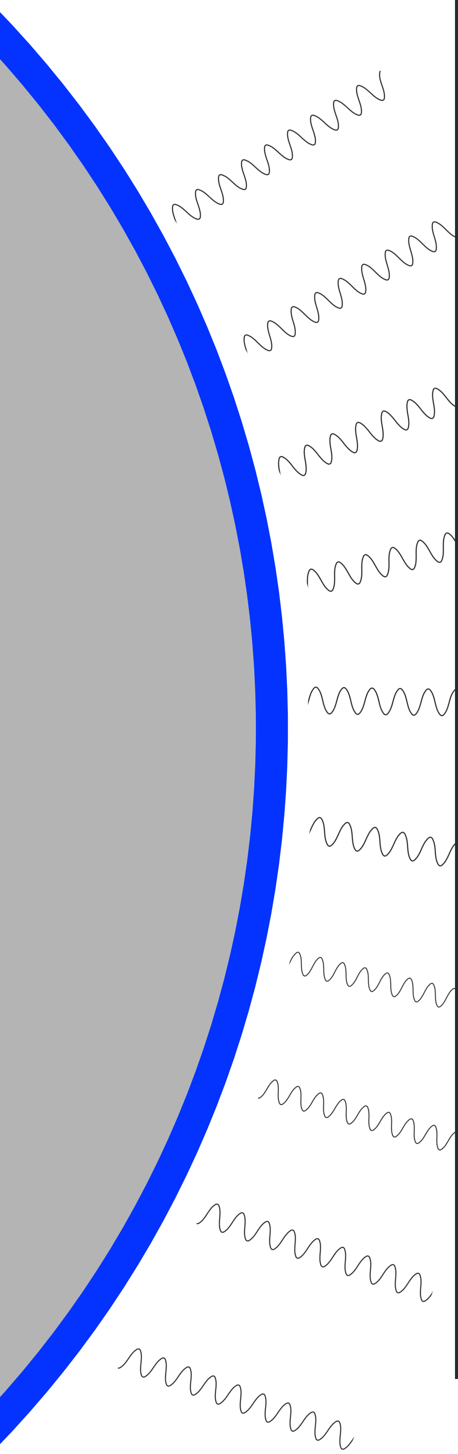
SMBHs exist at the centres of galaxies. They are responsible for AGNs and for the motion of central stars.

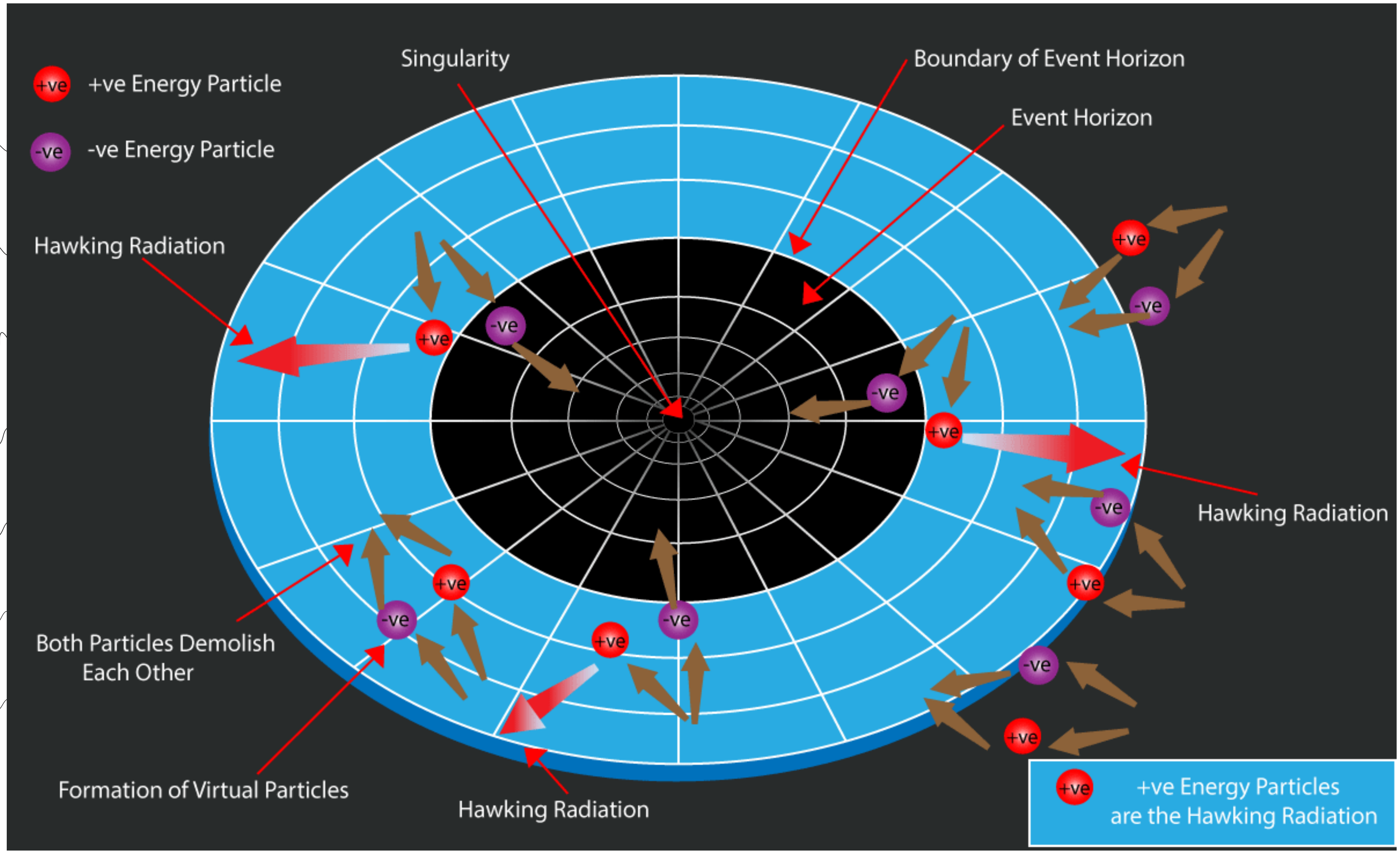
Recently photographed by EHT.

Note that all observations are indirect!

Hawking's Radiation

1974

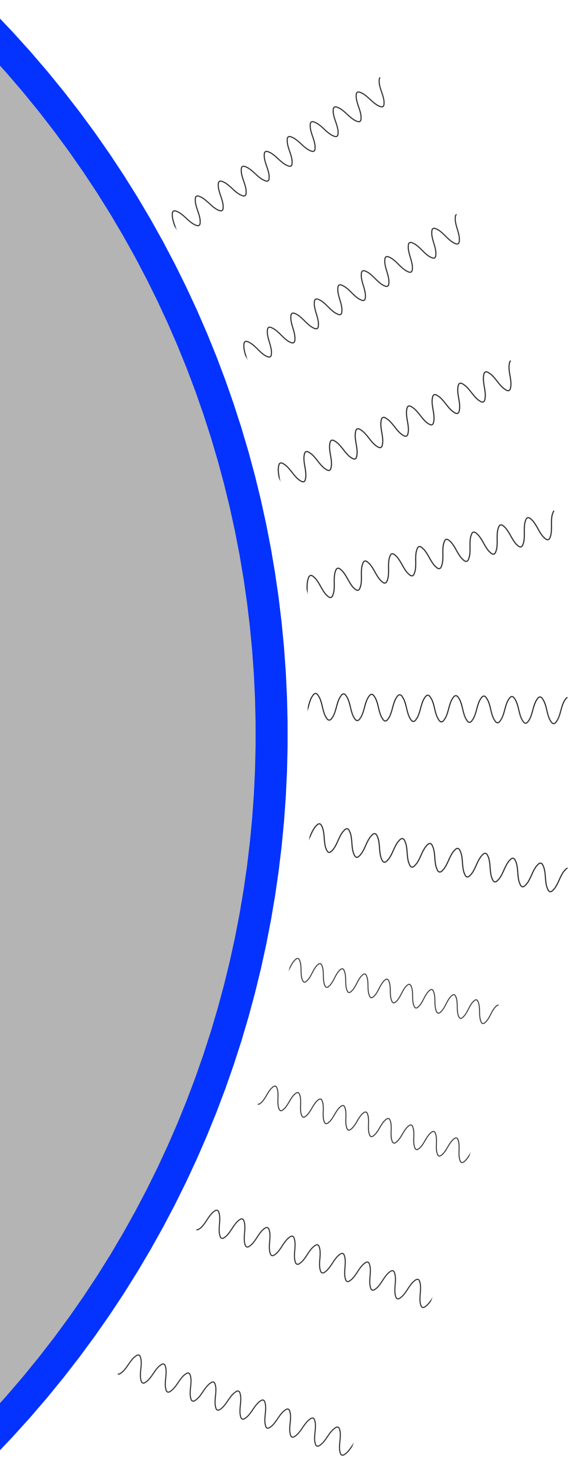


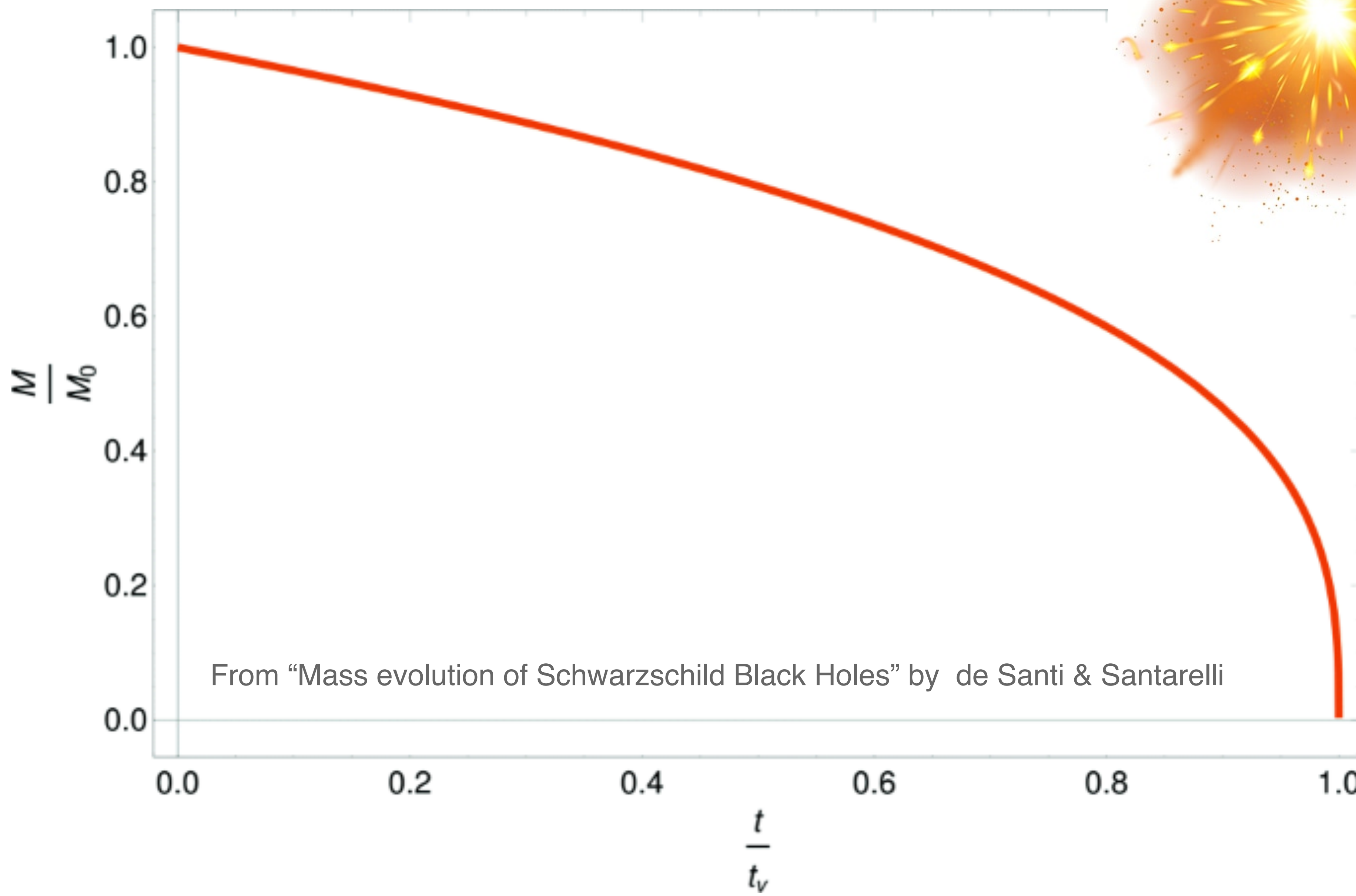


Credit: Physics Feed

Hawking's Radiation

1974



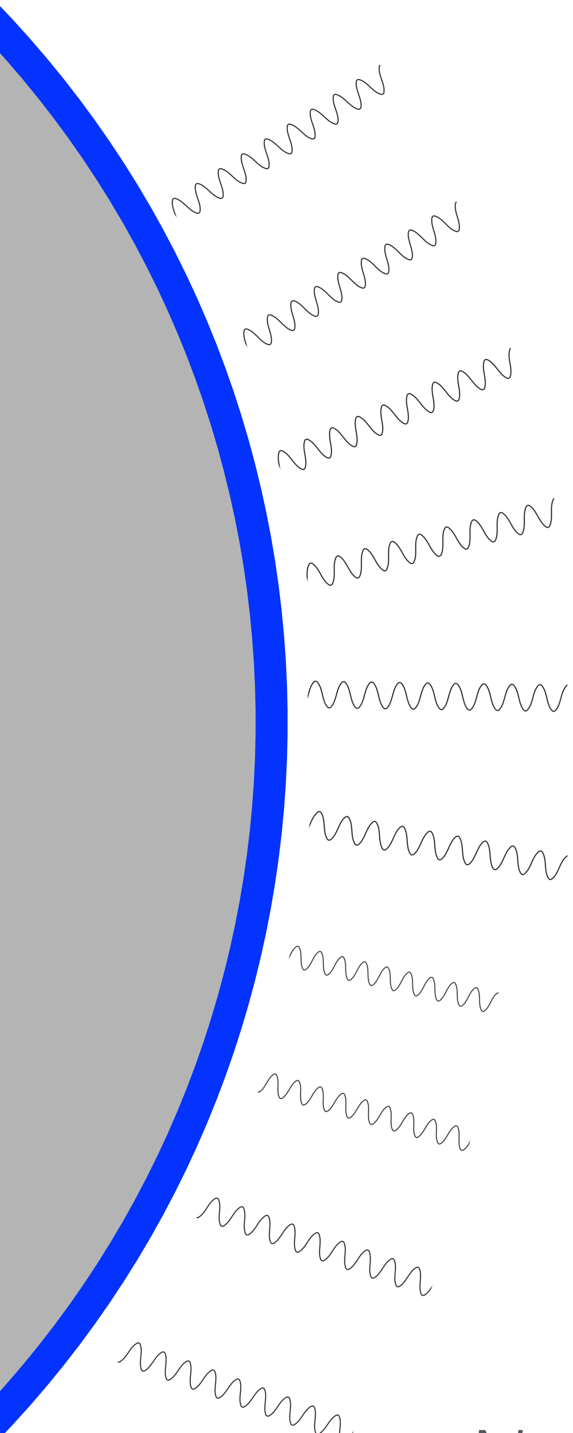


BHs end with a bang!

It would be observable as a Gamma Ray Burst (GRB)

Hawking's Radiation

1974



$$T_H = \frac{\hbar\, c^3}{8\,\pi\, G\, k_B\, M}$$

Black holes evaporate

$$t_{evaporate} \approx 2.140 \times 10^{67}\ \text{years} \left(\frac{M}{M_\odot}\right)^3$$

$$t_{Universe-age} \approx 1.40 \times 10^{10}\ \text{years}$$

The smaller the BH the higher the temperature

BHs heavier than 1/2 the moon are colder than the CMB!

No chance to observe HR for any ordinary astrophysical BH

HR from smaller BHs

Smaller BHs can emit HR that could be potentially observed

Asteroid size BHs could be produced in the early universe (PBHs)

Potential candidates for dark matter, if sufficiently long lived

HR from PBHs constrained by diffuse gamma ray background

Kimura, Takahashi, Koma, 1607,.01964

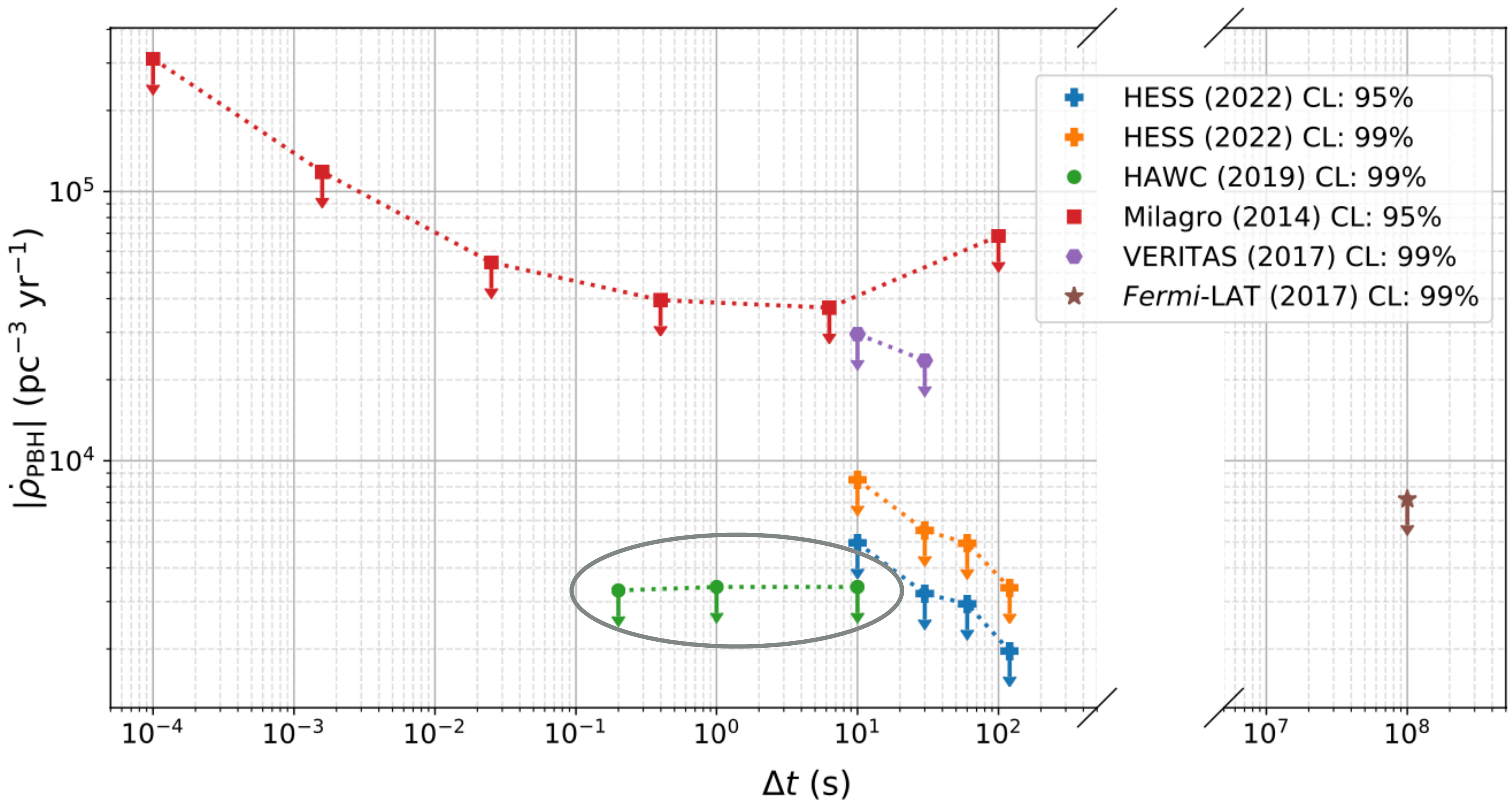
Albert et al.(HAWC), JCAP 04 (2020), 026

PBH connection

PBHs evaporate via TeV photons

Ideal for HAWC, HESS, LHAASO (Atmospheric Cherenkov Telescopes)

Search for point-like unaccounted GRBs



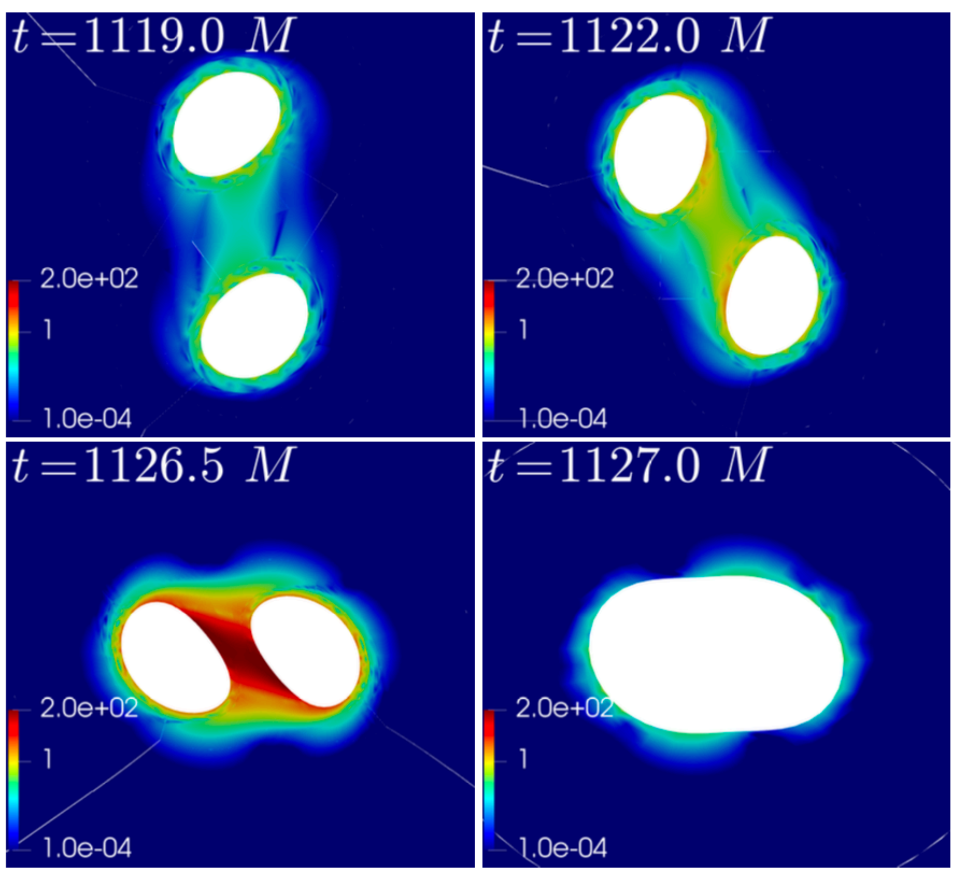
Strongest bound from HAWC

Albert et al.(HAWC), JCAP 04 (2020), 026

What if?

BH mergers could leave a trail of small BHs (BH morsels)

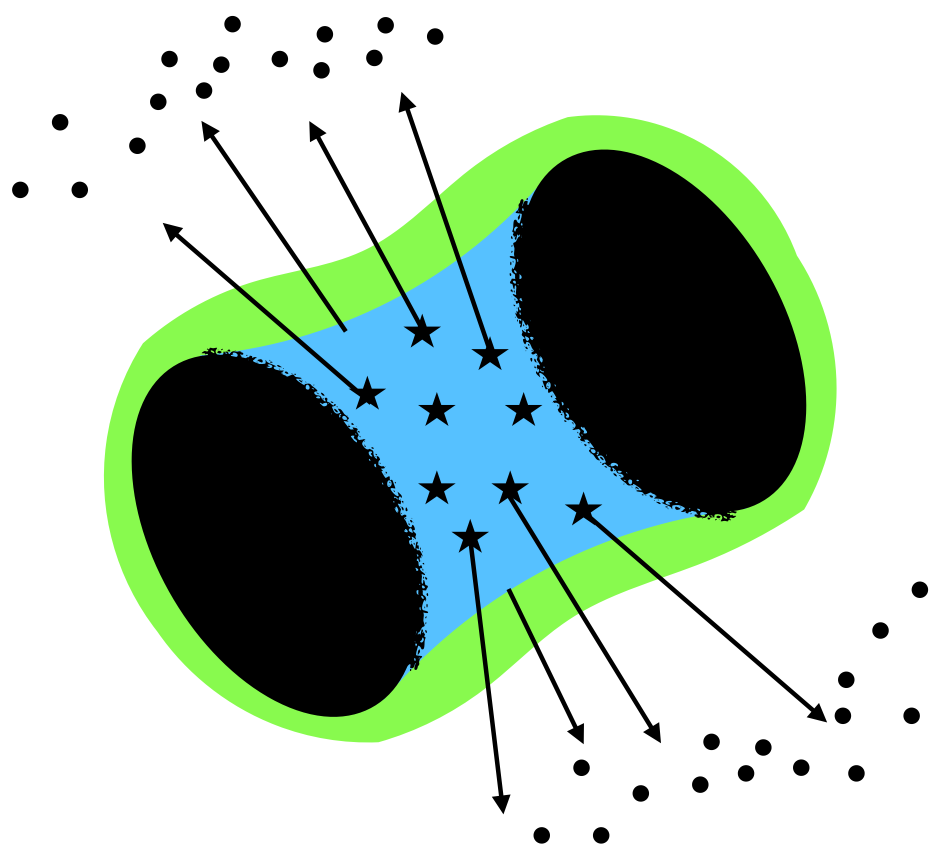
While not expected in general relativity, they may be related to the presence of strong non-linearities, or new physics effects...



Okunkova, Phys. Rev. D.96, 104054 (2017)

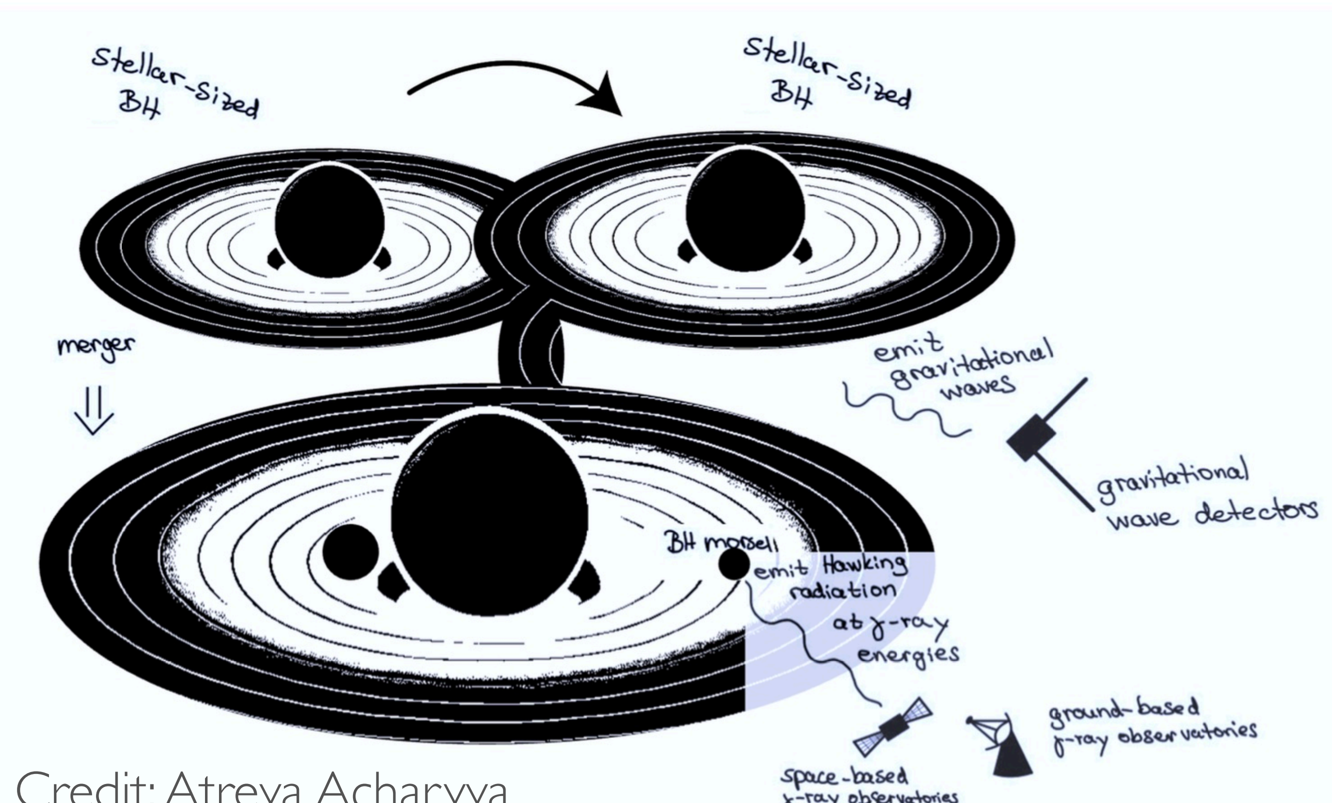
Colour shades measure non-linearity

BH morsels?



BH morsels

Is the Hawking radiation from BH morsels observable?



Cacciapaglia, Hohenegger, Sannino, 2405.12880

- The HR emission is isotropic, hence signal will not depend on the geometry of the emission.
- The particle flux only depends on the morsel masses (i.e. Hawking temperature).

- The energy of the emitted particles increases with time, hence giving a characteristic smoking-gun signature!
- Coincidence with gravitational wave observation (depending on the morsel masses…)

Morsels & Mergers Energy Budget

LIGO/VIRGO/KAGRA pre-merger masses between a few and several $M_\odot$

Abbott et al. (LIGO), PRX 9, 031040 (2019), PRX 11, 021053 (2021),...

Distance 240 Mpc to 3 Gpc

Initial and final masses indirectly measured via GW spectrum

Example: GW170814 (first BH merger observed by all 3 detectors)

$$30.5^{5.7}_{-3.0} + 25.3^{2.8}_{-4.2} = 53.2^{3.2}_{-2.7}$$

GW energy emitted $2.7^{0.4}_{-0.3}$

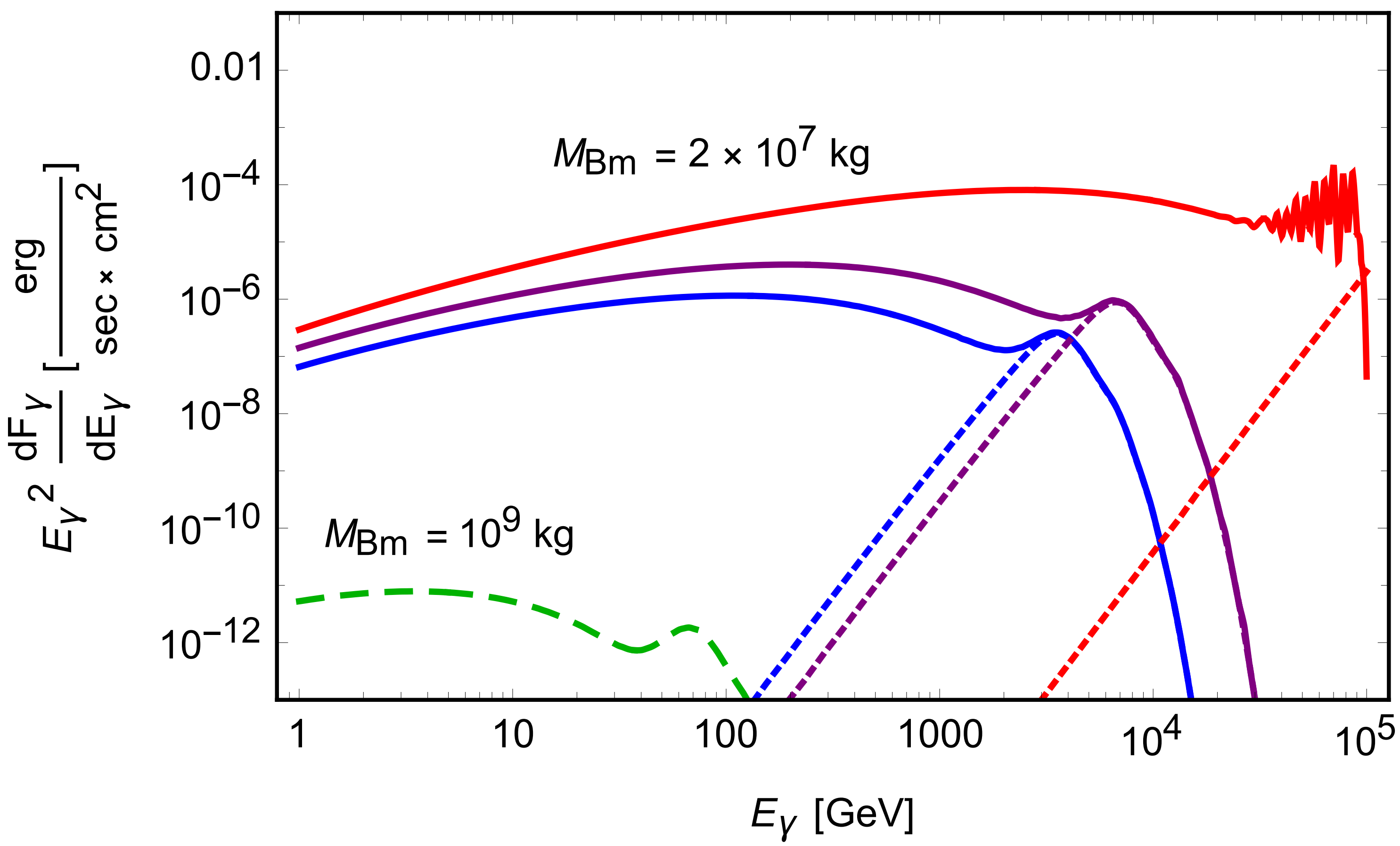
Several $M_\odot$ can go into BH morsels, but conservatively we assume one.

Photon flux

Same mass Bm distribution normalised to $M_\odot$

Solid lines $2 \times 10^7\,\mathrm{kg}$ & 3400 sec evaporation time

Colours: different times from production 500 sec (blue) 3000 sec (purple) 3400 sec (red)



Emission constant up to 500 sec

Explosive at end of BH lifetime

Red curve exceeds 100 TeV!

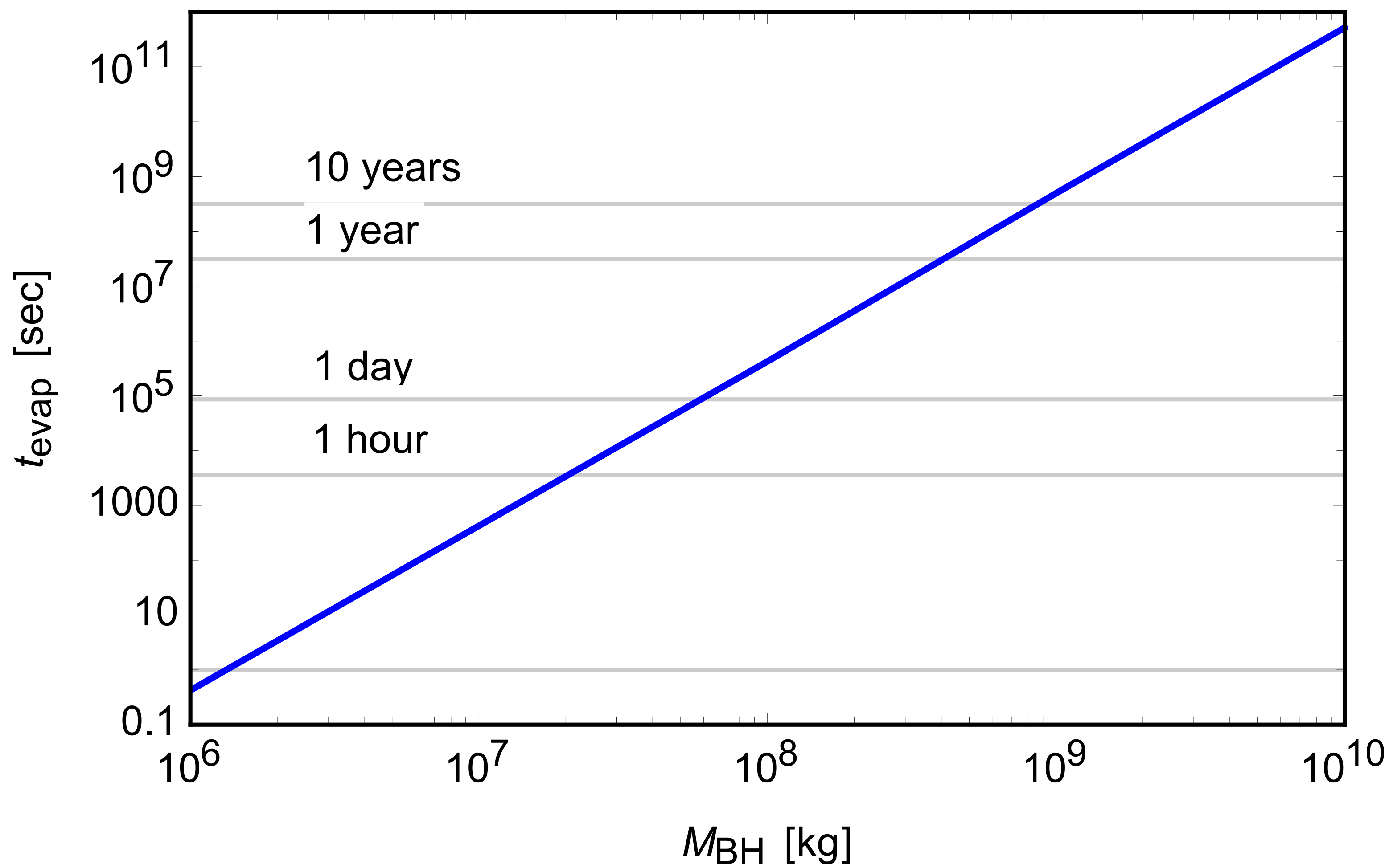
100TeV cutoff, photon optical transparency intergalactic medium

Green curve $2 \times 10^9\,\mathrm{kg}$

16 years evaporation time

Evaporation time $\propto M_{Bm}^3$

Evaporation time

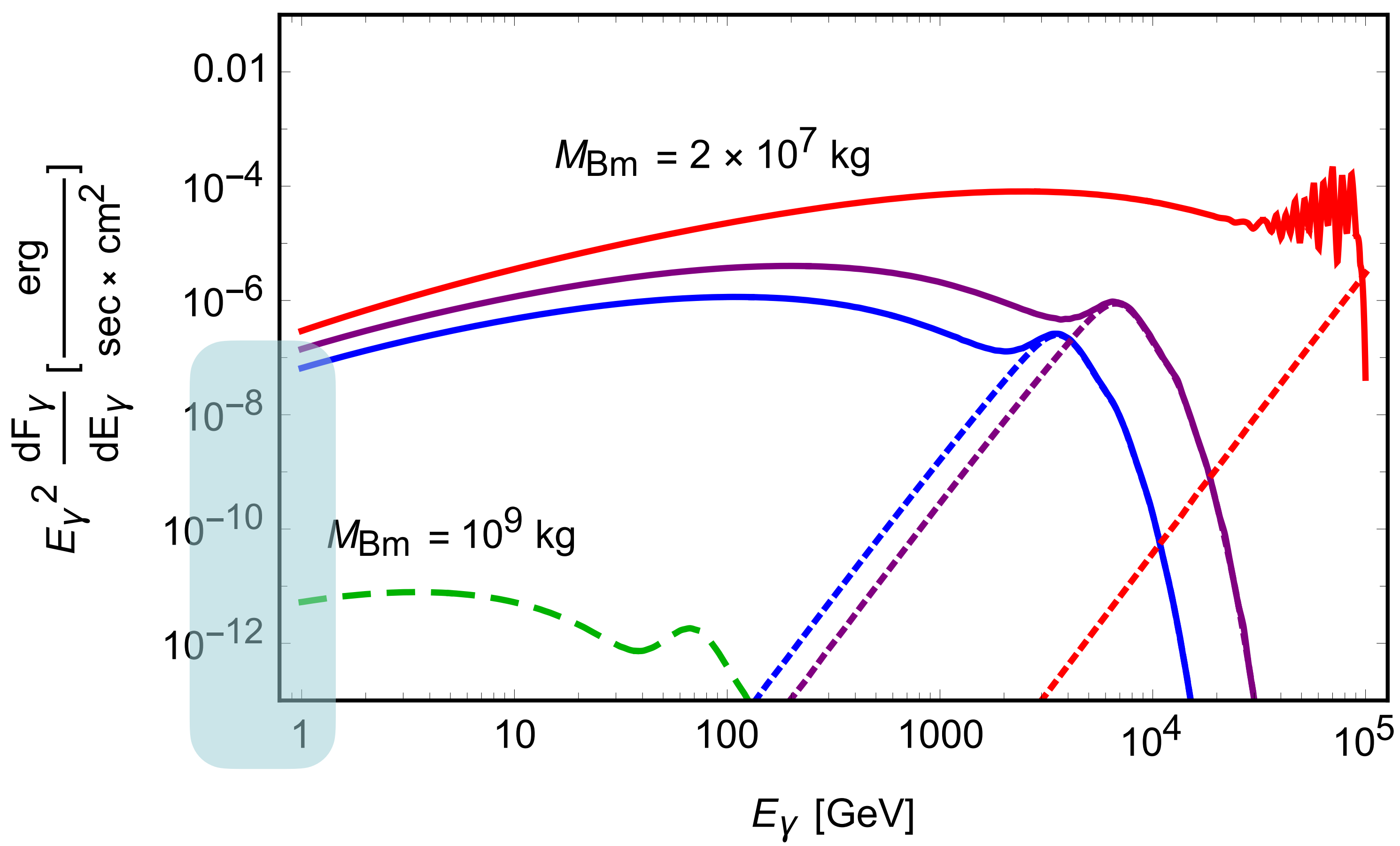


Multi-messenger approach

Fermi-GBM & Swift-BAT monitor photons within 30 sec from event alerts

Coverage between keVs and MeVs (Neutron star merger range)

In this range the signal is below exp sensitivity $10^{-7}\,\mathrm{erg\ sec^{-1}\ cm^{-2}}$



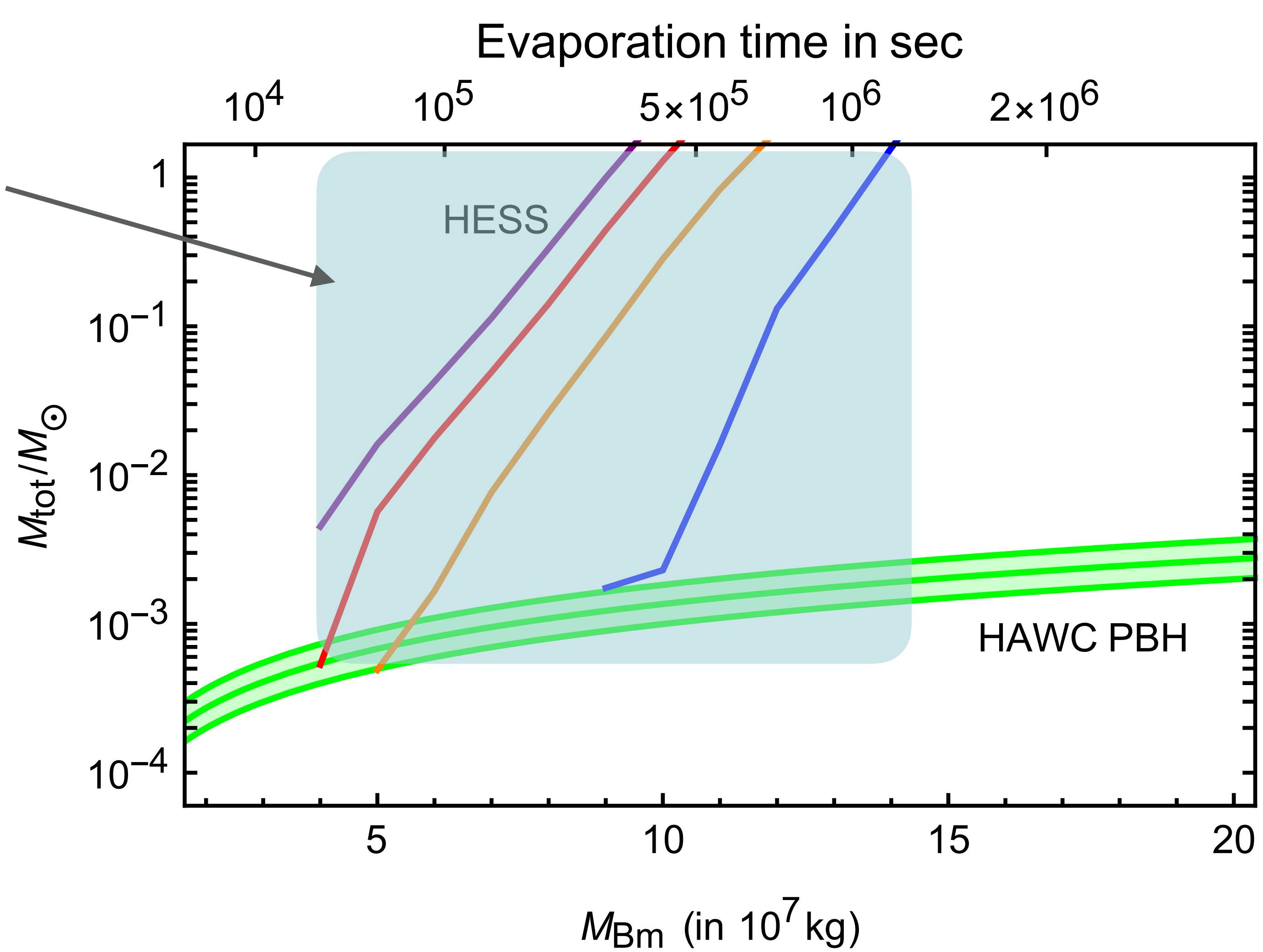
Preliminary bounds (HESS)

HESS followed four LIGO/VIRGO BH mergers (O2 and O3 runs)

1 - 10 TeVs, time: 10^4 - 10^5 sec after the BH merger

Energy flux from mergers below $10^{-12}\,\mathrm{erg\ sec^{-1}\ cm^{-2}}$

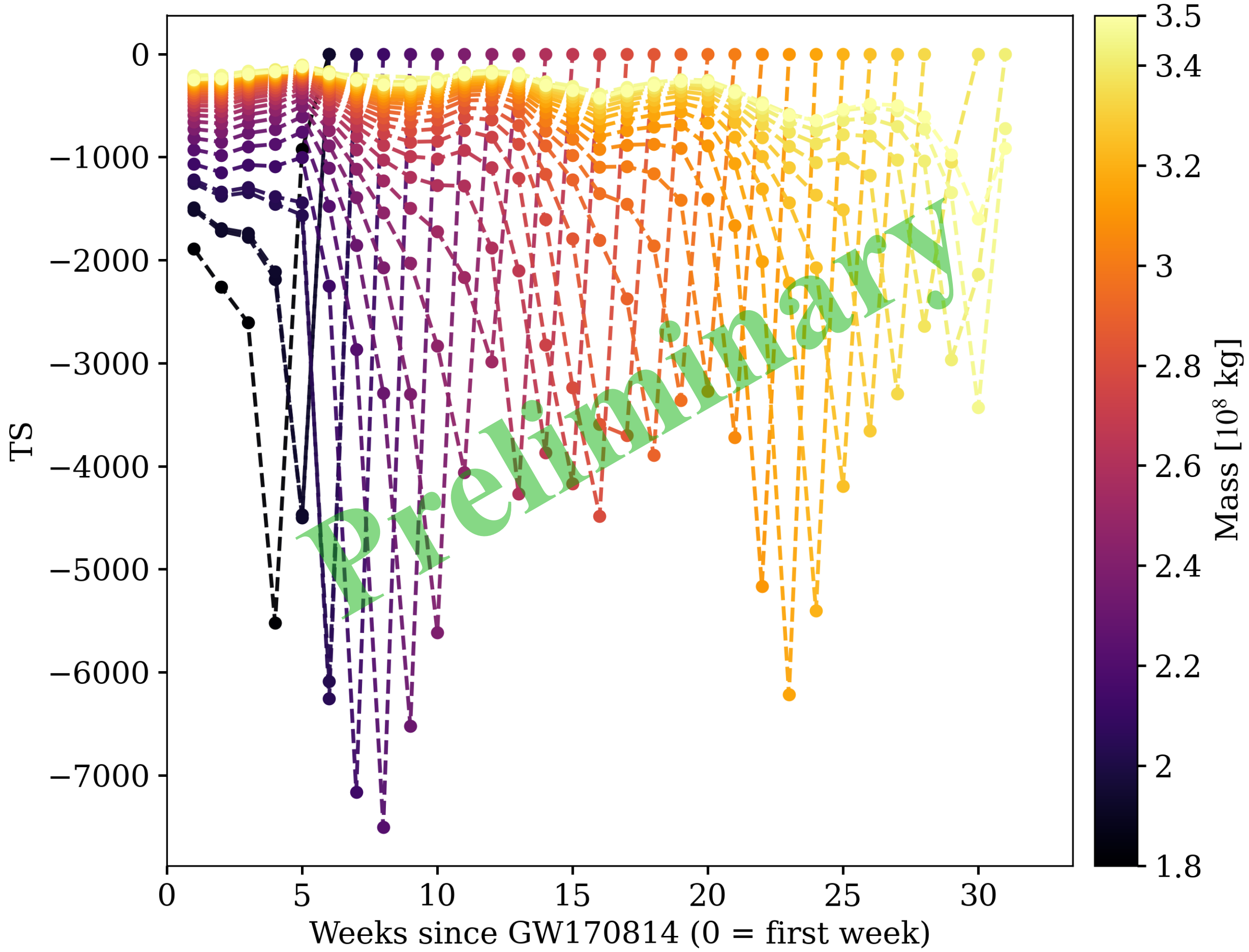
Relevant region



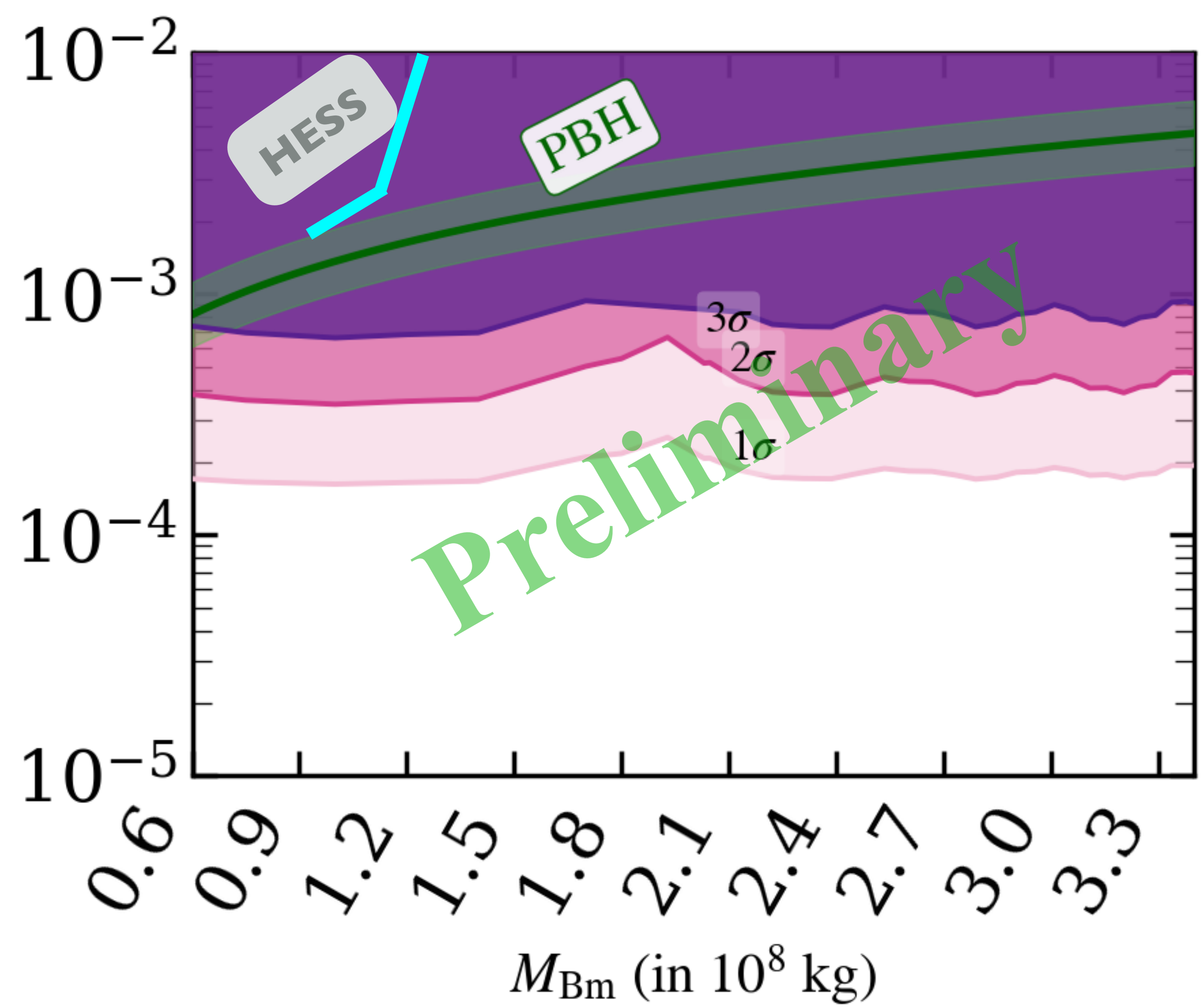
Fermi-LAT

Acharyya, Cacciapaglia, Meyer, Sannino, 2509.17599
+ in preparation (w. Chen Si-Yu)

- Consider test masses for prolonged observation in the vicinity of GW170814



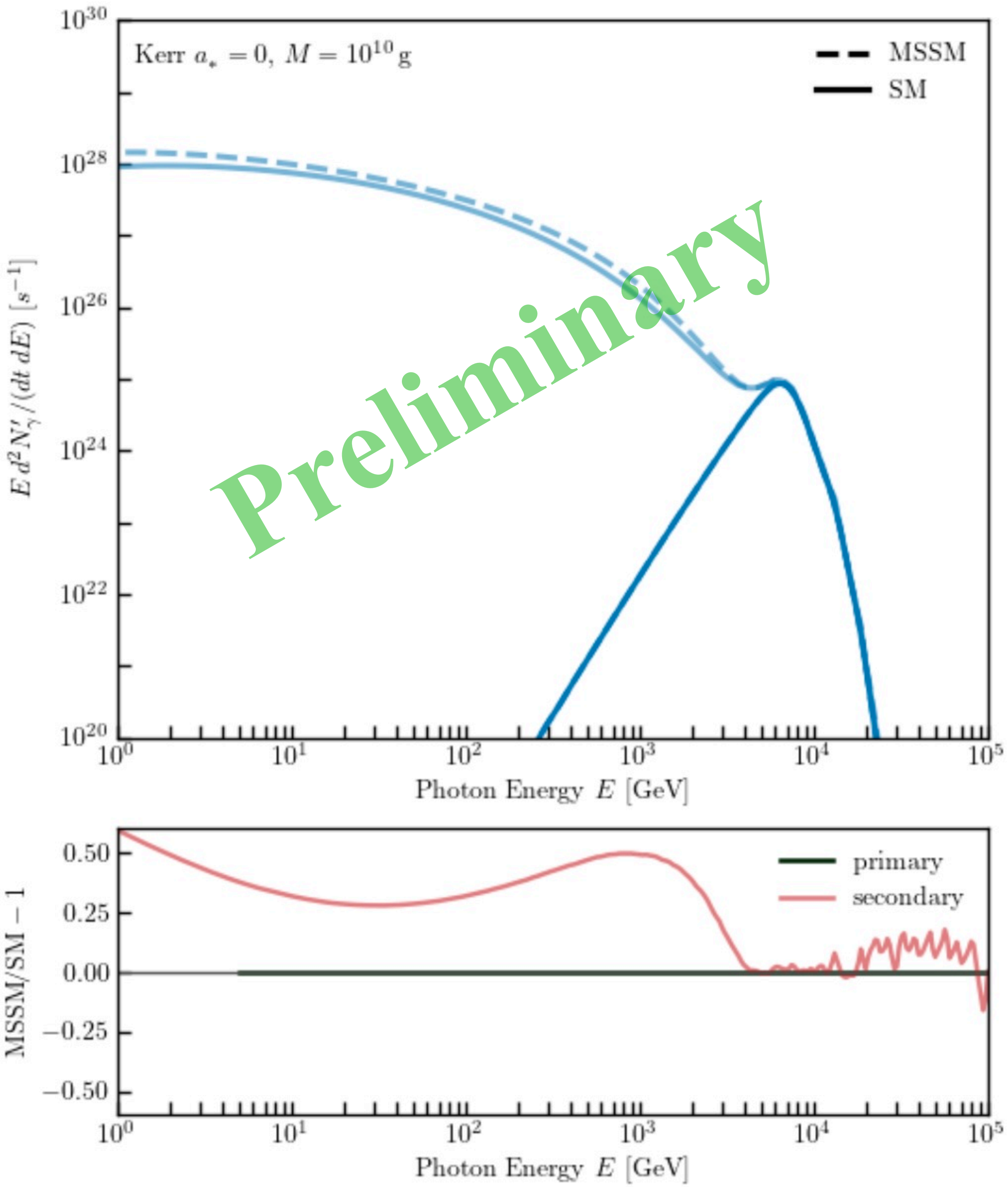
Test-Statistics (TS) per week for various mass hypotheses.

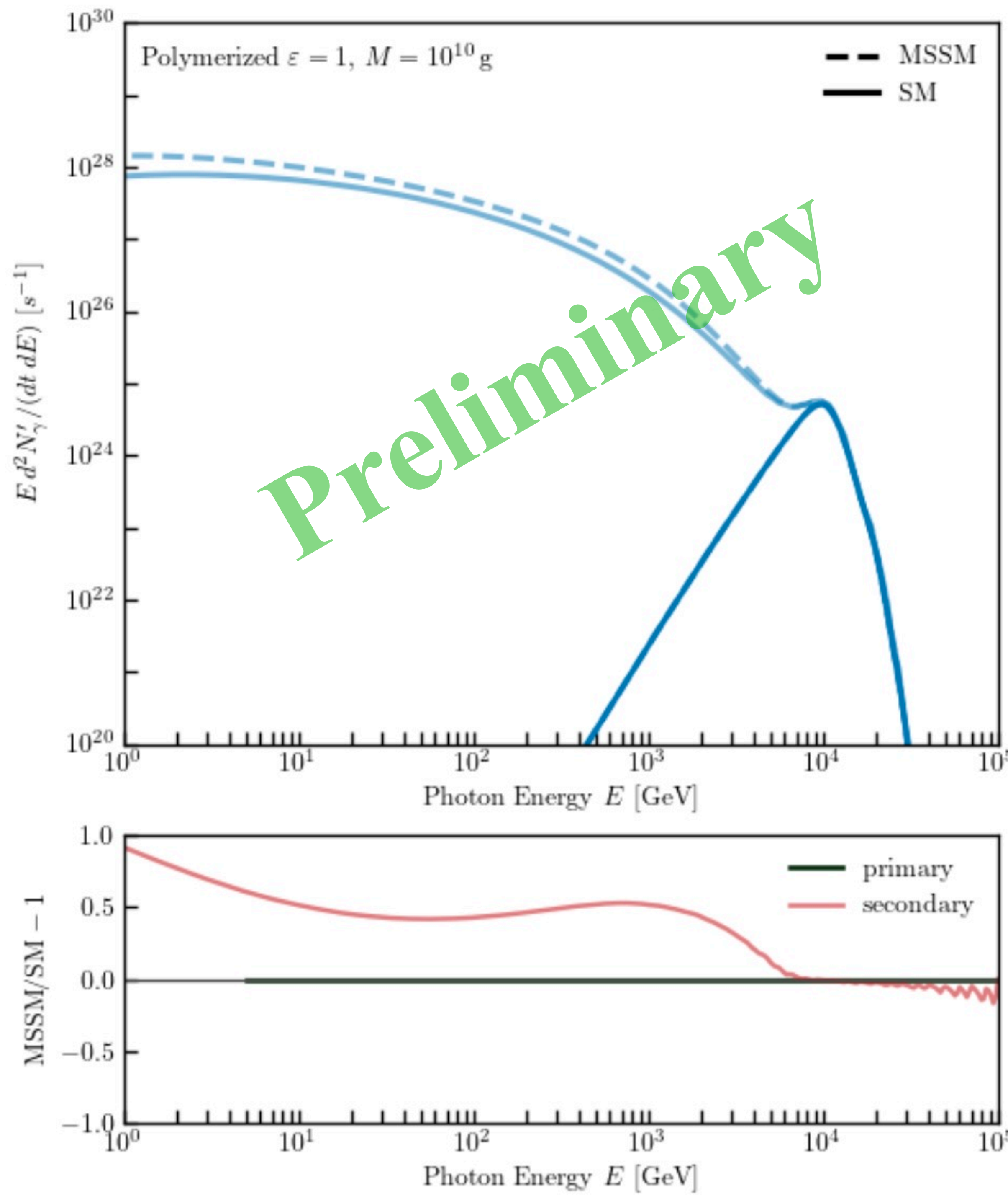


Impact of Terascale physics

Work in progress with Paola Simone and F.Sannino

- Consider a MSSM benchmark on a Schwarzschild BH





Next steps

- Golden opportunity for gamma ray telescopes (work in progress with Fermi-LAT colleagues).
- New physics effects may appear in the spectrum at the end of the evaporation time (modelling of NPh effects in progress).
- Modelling of the BH morsel production necessary: we are exploring various ideas at the moment.

Extras

Preliminary bounds (HAWC)

A morsel distribution at D is equivalent to a single PBH at D_{PHB}

$$D_{\mathrm{PBH}} = \frac{D}{\sqrt{n_{\mathrm{Bm}}}}$$

Naive:

Rescaling LIGO/VIRGO BH mergers rate

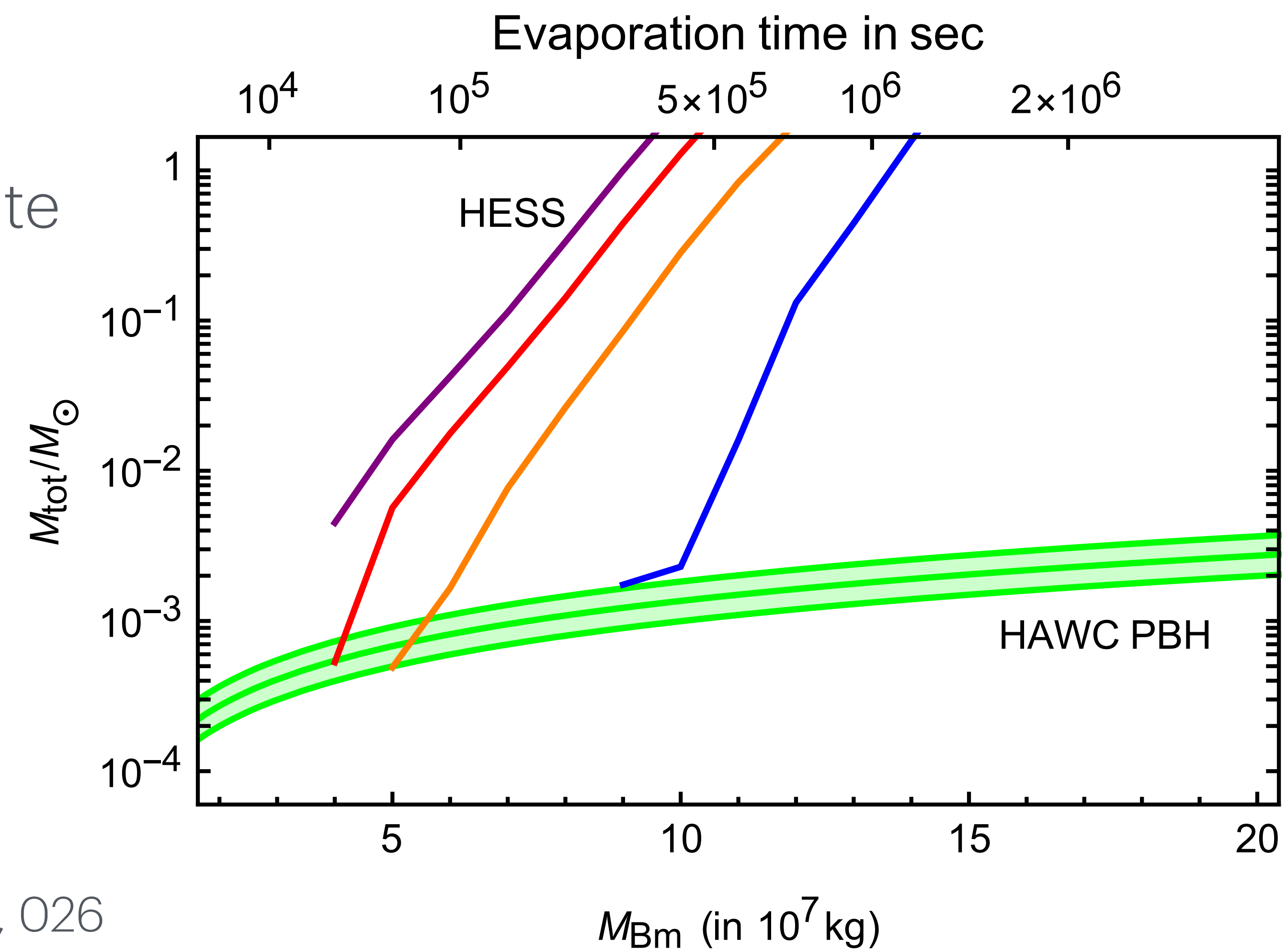
$$\rho_{\mathrm{LV}} = 24^{+14}_{-9}\ \mathrm{Gpc}^{-3}\ \mathrm{yr}^{-1}$$

PBH rescaled densities for HAWC

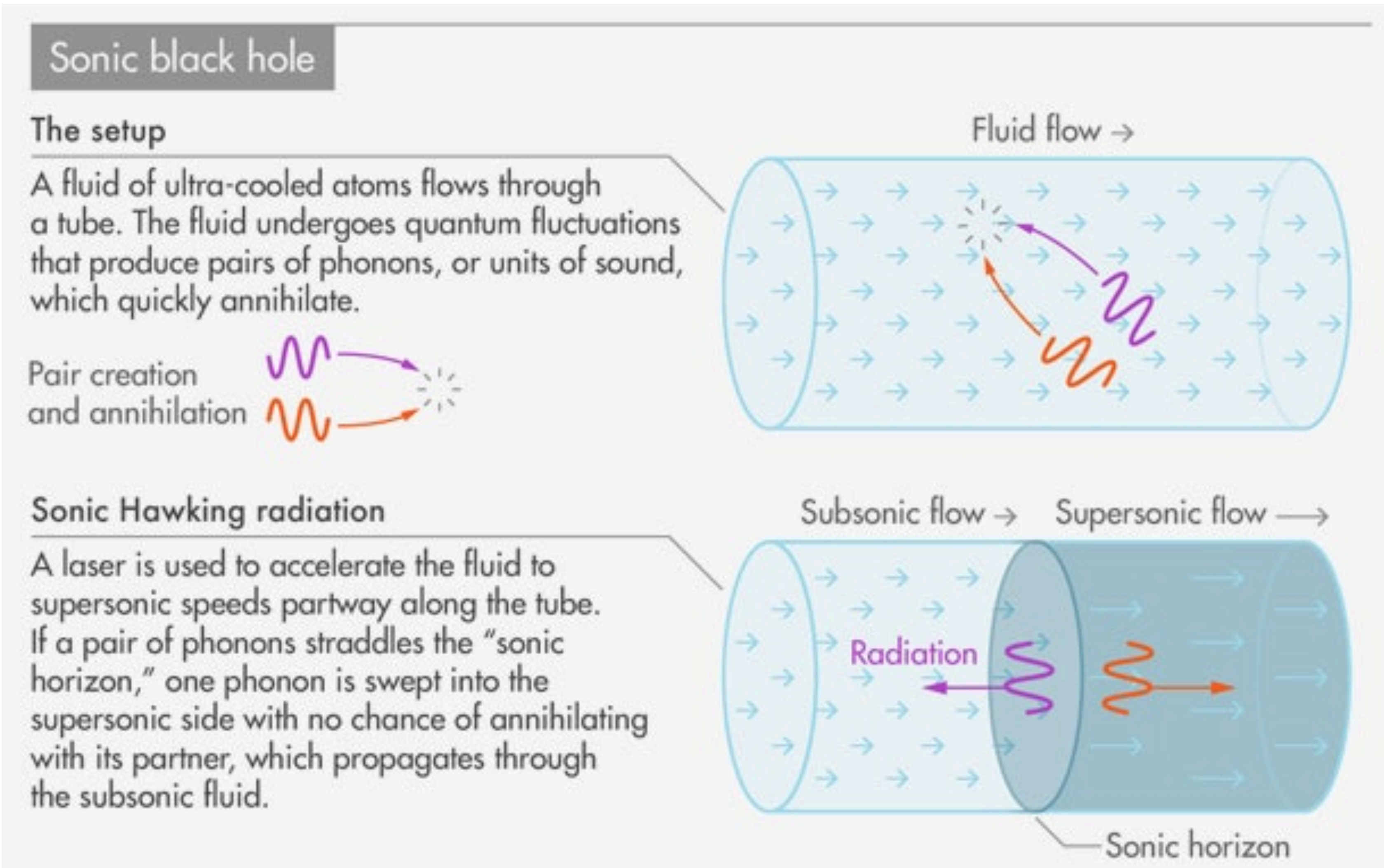
$$\rho_{\mathrm{PBH}} = 3400\ \mathrm{pc}^{-3}\ \mathrm{yr}^{-1}$$

Upper limit on the total morsel mass

Albert et al.(HAWC), JCAP 04 (2020), 026

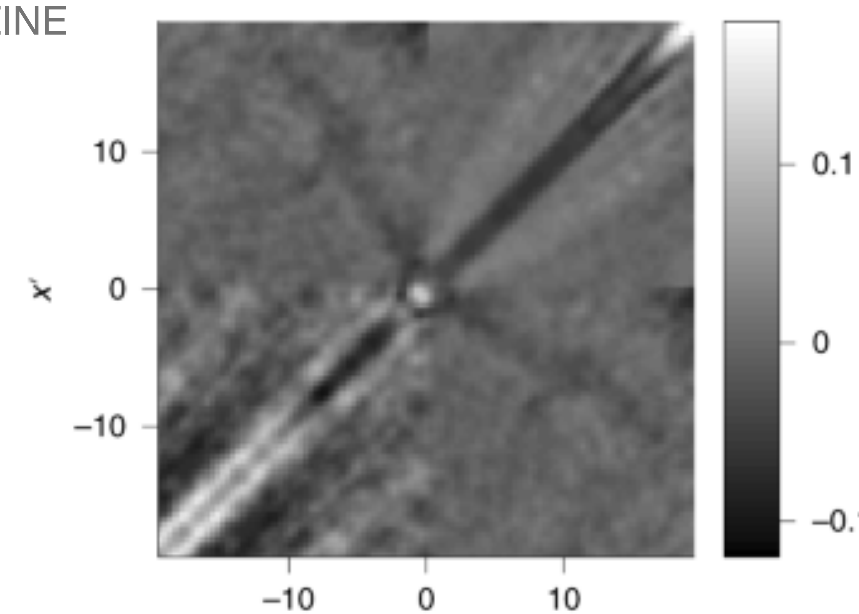


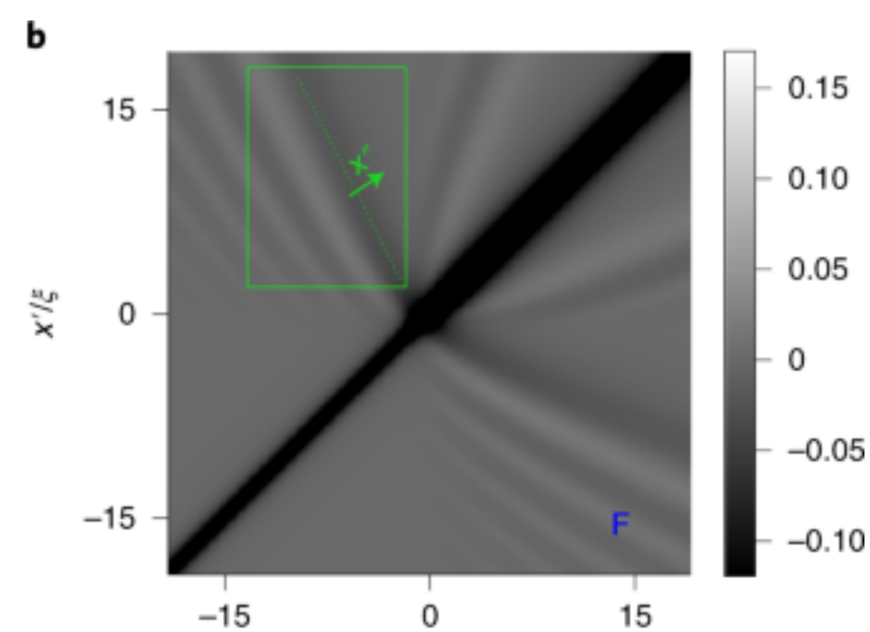
A Black Hole Analogy



LUCY READING-IKKANDA FOR QUANTA MAGAZINE

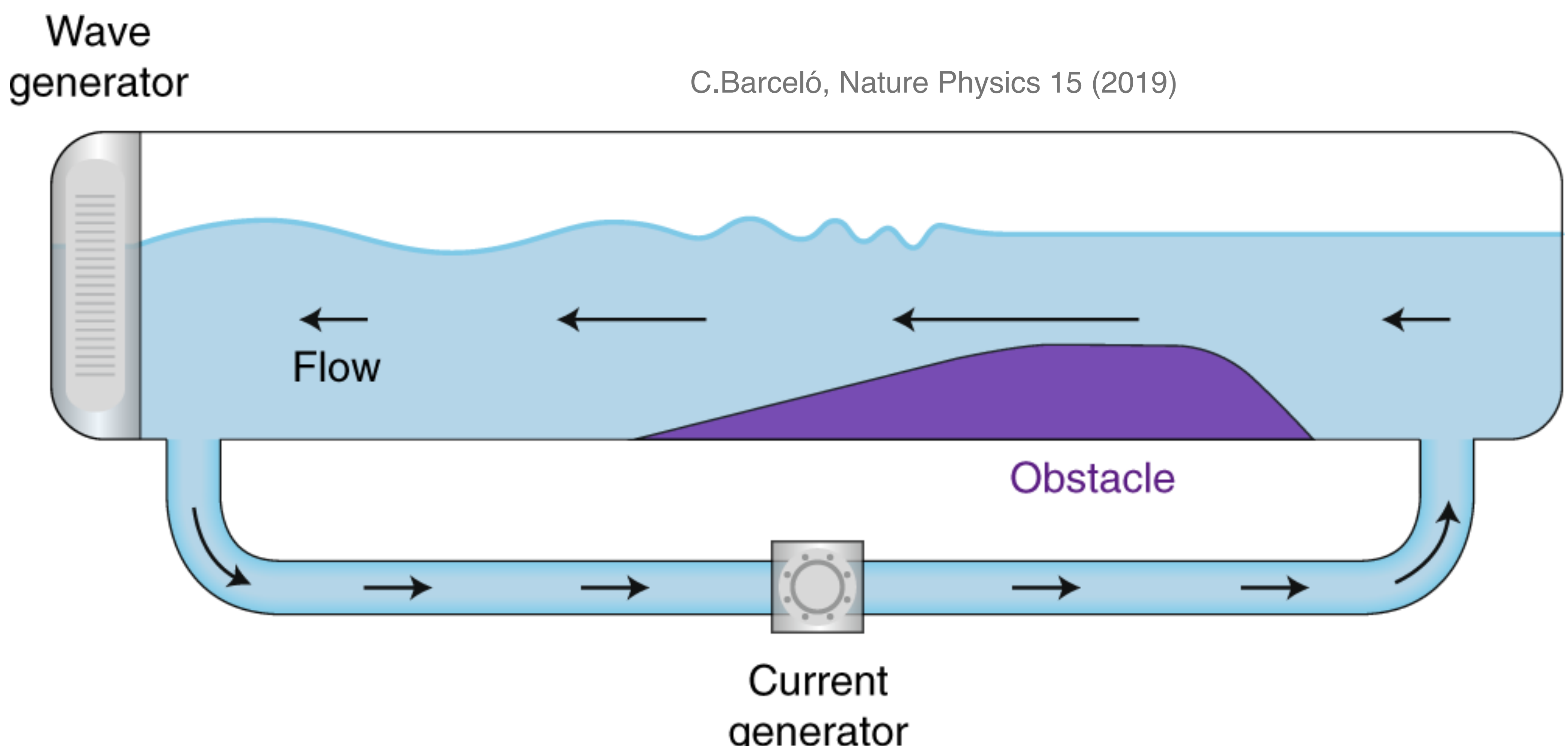
J.Steinhauer et al, Nature Physics 17 (2021)





A Black Hole Analogy

C.Barceló, Nature Physics 15 (2019)



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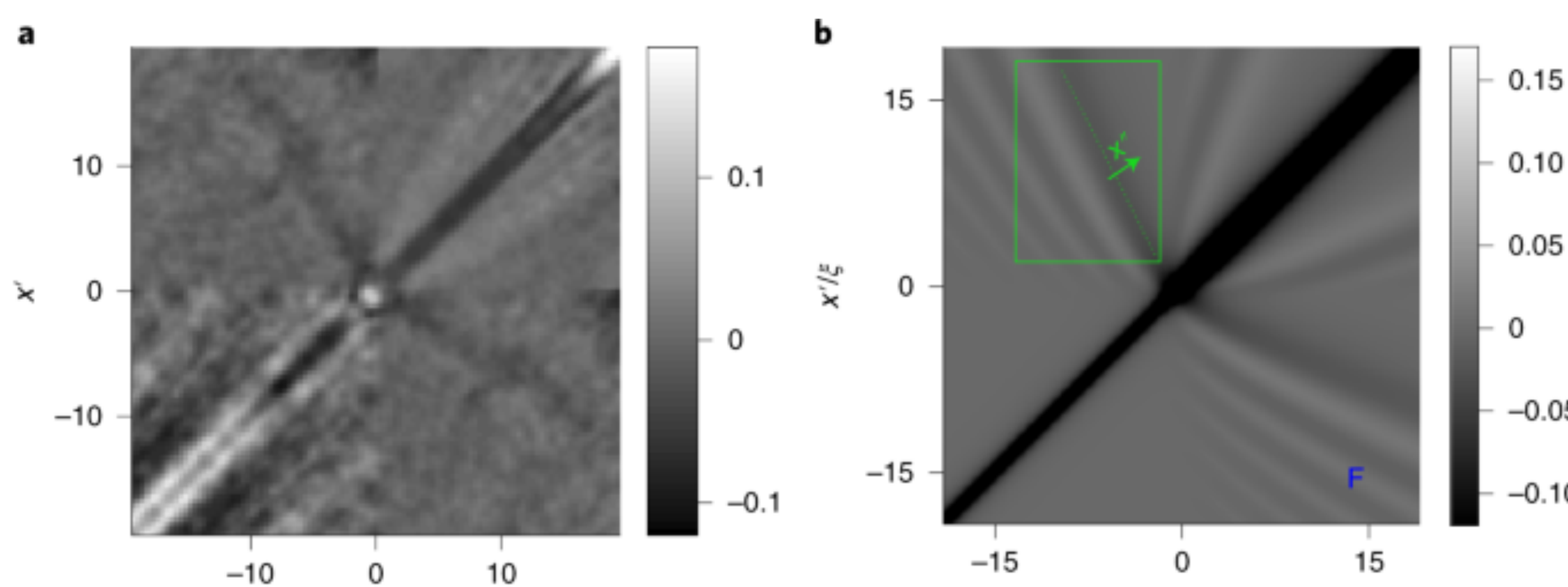

Neutrinos

Neutrino observatories ANTARES and IceCube monitor BH mergers

ANTARES and IceCube ~ 500 sec window

No excess found

However, flux limits are orders of magnitude above photon ones

Require a luminosity of 10^{51} erg sec^{-1}

BH morsels predict neutrino fluxes similar to photons.

Experiments not competitive

Super Massive BH Mergers