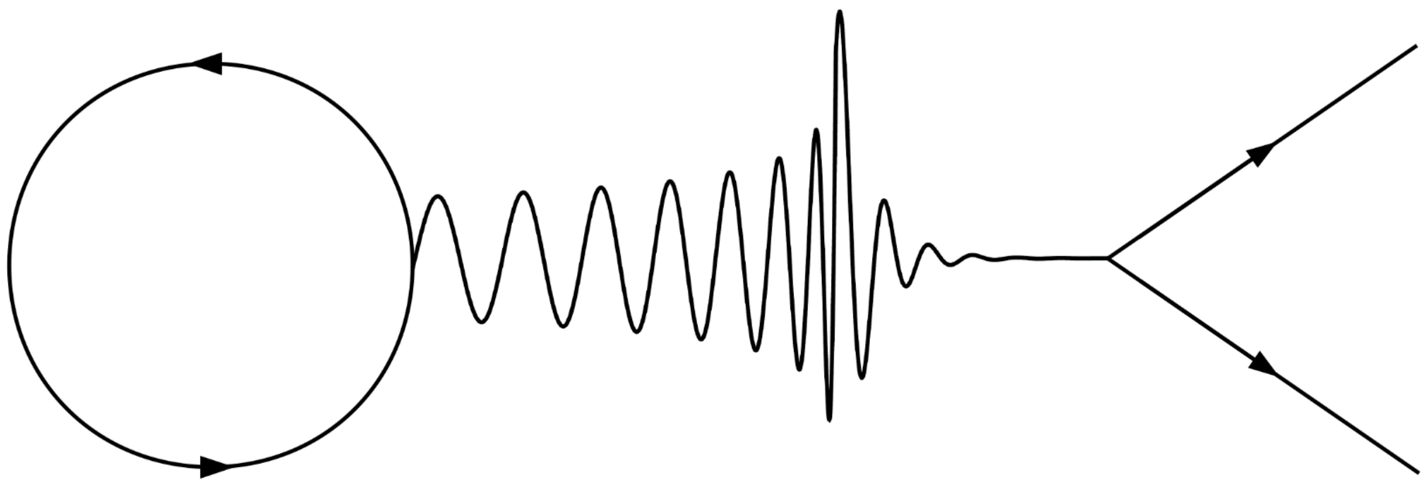
GW4FP



Vítor Cardoso

Image: Cardoso & Pani
CERN Courier (2016)

1919. May 29 eclipse confirms that gravity "bends" light

REVOLUTION IN SCIENCE.

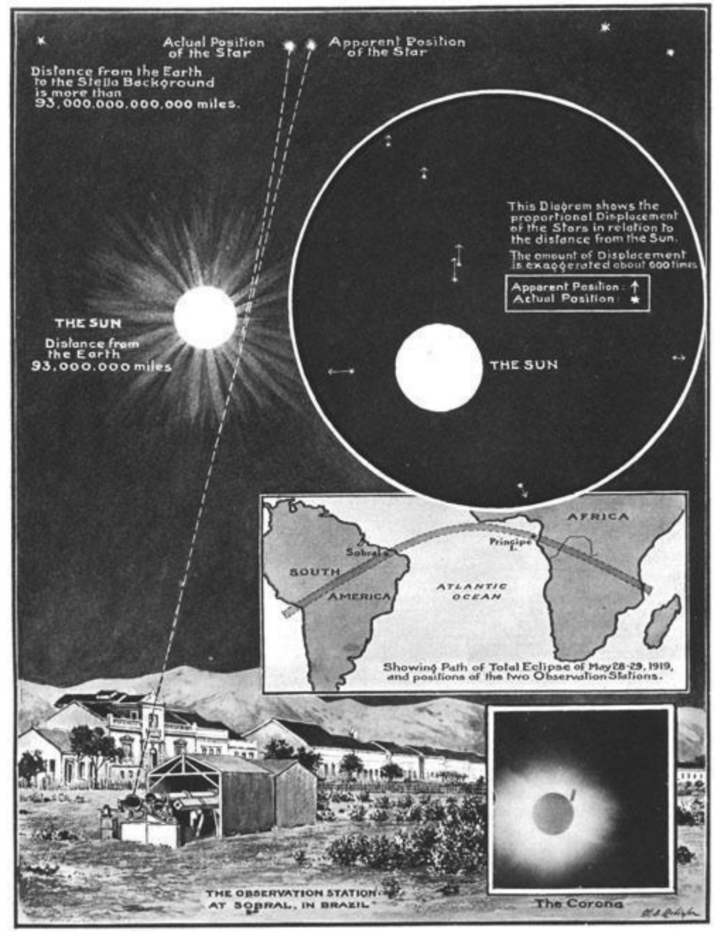
NEW THEORY OF THE UNIVERSE.

NEWTONIAN IDEAS OVERTHROWN.

Yesterday afternoon in the rooms of the Royal Society, at a joint session of the Royal and Astronomical Societies, the results obtained by British observers of the total solar eclipse of May 29 were discussed.

The greatest possible interest had been aroused in scientific circles by the hope that rival theories of a fundamental physical problem would be put to the test, and there was a very large attendance of astronomers and physicists. It was generally accepted that the observations were decisive in the verifying of the prediction of the famous physicist, Einstein, stated by the President of the Royal Society as being the most remarkable scientific event since the discovery of the predicted existence of the planet Neptune. But there was differ-

'Times of London', Nov 7 1919



'Illustrated London News', Nov 22 1919

GWs and fundamental physics

Astrophysics: the Universe as we know it

Source-modelling: the Universe if only GR existed

Fundamental physics: the real Universe is for losers

Marta Volonteri, in the opening of GWverse COST Action in Malta, 2018

GWs and fundamental physics

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We’ve learned a lot about the Universe

…only 4% of normal matter!

Problem with particle physics,

Problem with theory of gravity,

Or both!

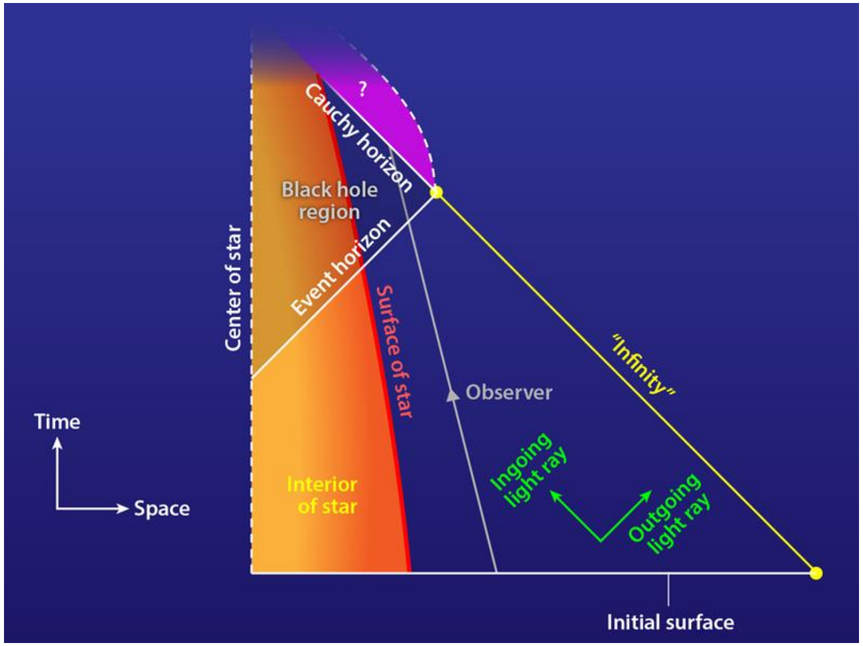
Particle physics

a. But DM is not in it (new particles?)

b. Strong CP problem (axions?)

c. Large hierarchy between electroweak - 100 GeV- and Planck - 10^(19) GeV- scales (supersymmetry, extra dimensions...?)

Gravity and censorship



Cauchy horizons can (conceptually) survive

Event horizons always form? And then?

Unruh & Wald Rept. Progr. Phys. 80 (2017) 092002

Cardoso+ PRL 120 (2018) 031103; Cardoso & Pani Living Reviews in Relativity 22 (2019)

Plenty of room around and time at the bottom

Test classical BH geometry (ISCOs, ergoregions, light rings)

Search for new fields, model DM lumps and BH alternatives

When were BHs born, how do they grow?

Work out EM counterparts to strong gravity phenomena

Hubble constant, on large and small scales?

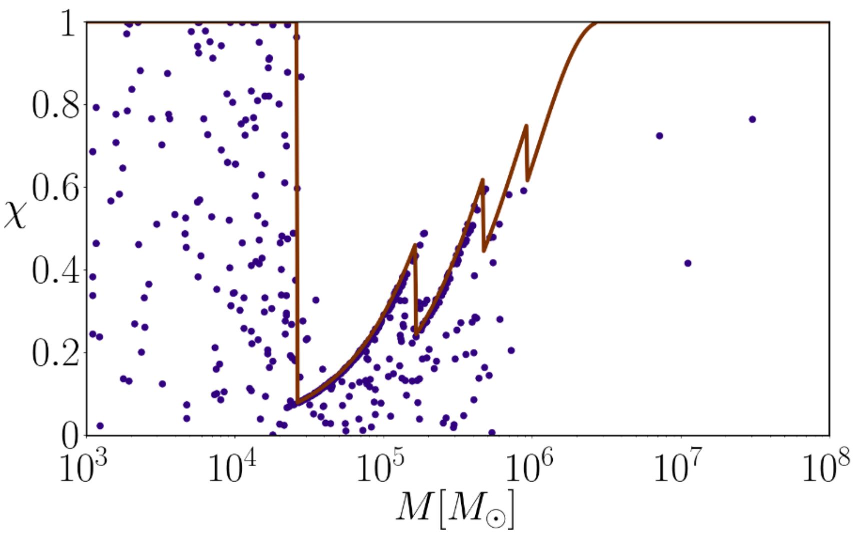
Stochastic backgrounds from inflation, cosmic strings…

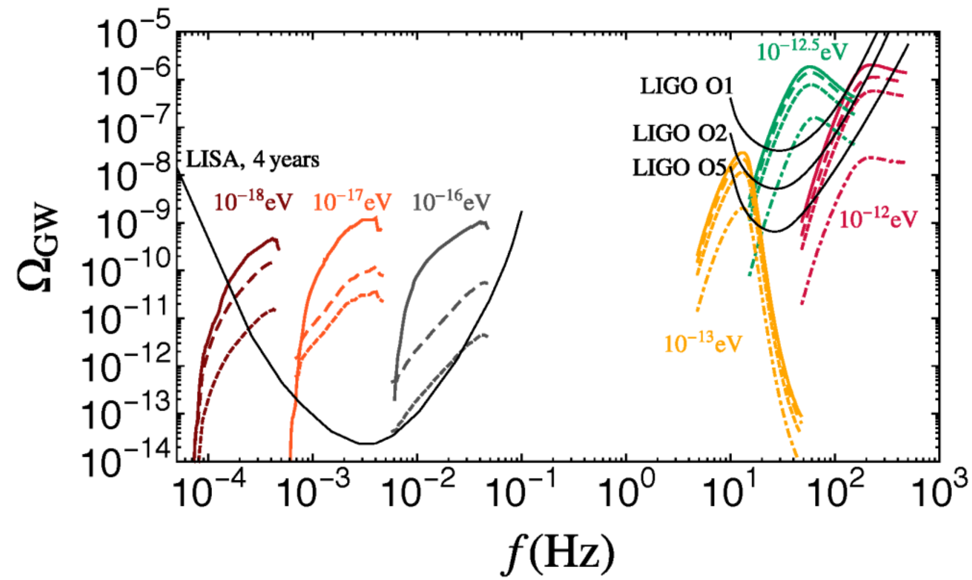
Question physics based on small amount of matter that we actually know

Need to interact to even understand some new questions

Surprises?

Arvanitaki+2011; Brito+2015, 2017





Zero abundance required

Small fluctuations trigger superradiant instability

Cloud forms, emitting GWs on long timescales (or stationary in some cases)

Universal imprints, holes in mass-angular momentum

Need to understand couplings to SM or self-interactions

Surprises?

Bekenstein and Mukhanov 1995; Kleban+2019

i. Postulate some area quantization

$$A = \alpha l_P^2 N = \alpha \frac{\hbar G}{c^2} N$$

$$\Delta A = \alpha \frac{\hbar G}{c^3} \Delta N = 32\pi \frac{G^2}{c^4} M \Delta M$$

ii. Compute absorbed energy of graviton

$$\Delta M = \alpha \frac{c\hbar}{32\pi G} \frac{\Delta N}{M}$$

$$\omega_n = \frac{\Delta M c^2}{\hbar} = \frac{n\alpha}{32\pi} \frac{c^3}{MG}$$

Classical!

Conclusions: exciting times!

Gravitational wave astronomy *will* become a precision discipline, mapping compact objects throughout the entire visible universe, probing the content of the universe and its cosmological history.

BHs play the role of perfect particle physics laboratories, and are ideal testing grounds for strong-gravity predictions

"The excitement of the next generation of astronomical facilities is not in the old questions which will be answered, but in the new questions that they will raise."

K. I. Kellermann + "The exploration of the unknown"

Thank you

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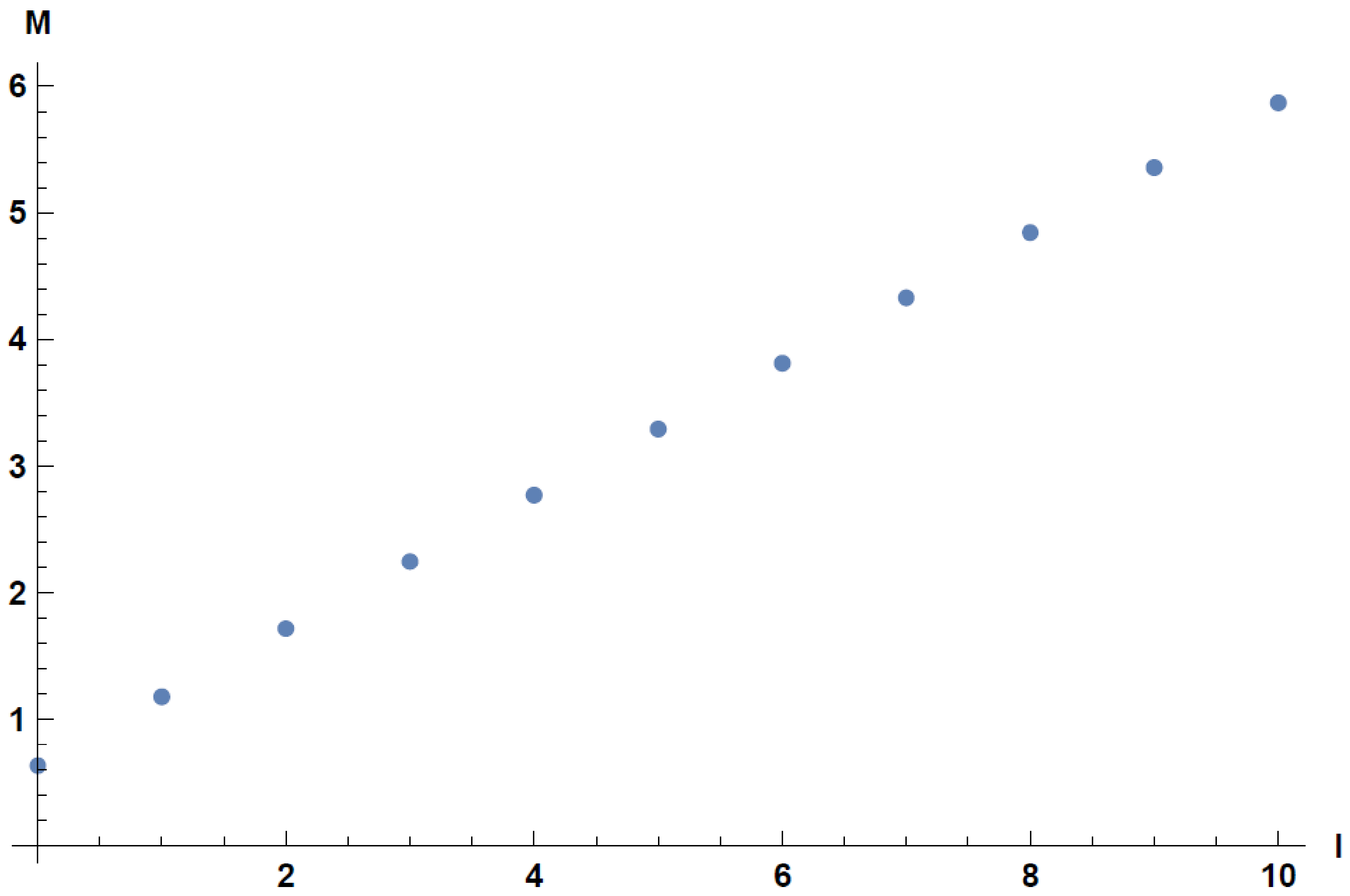
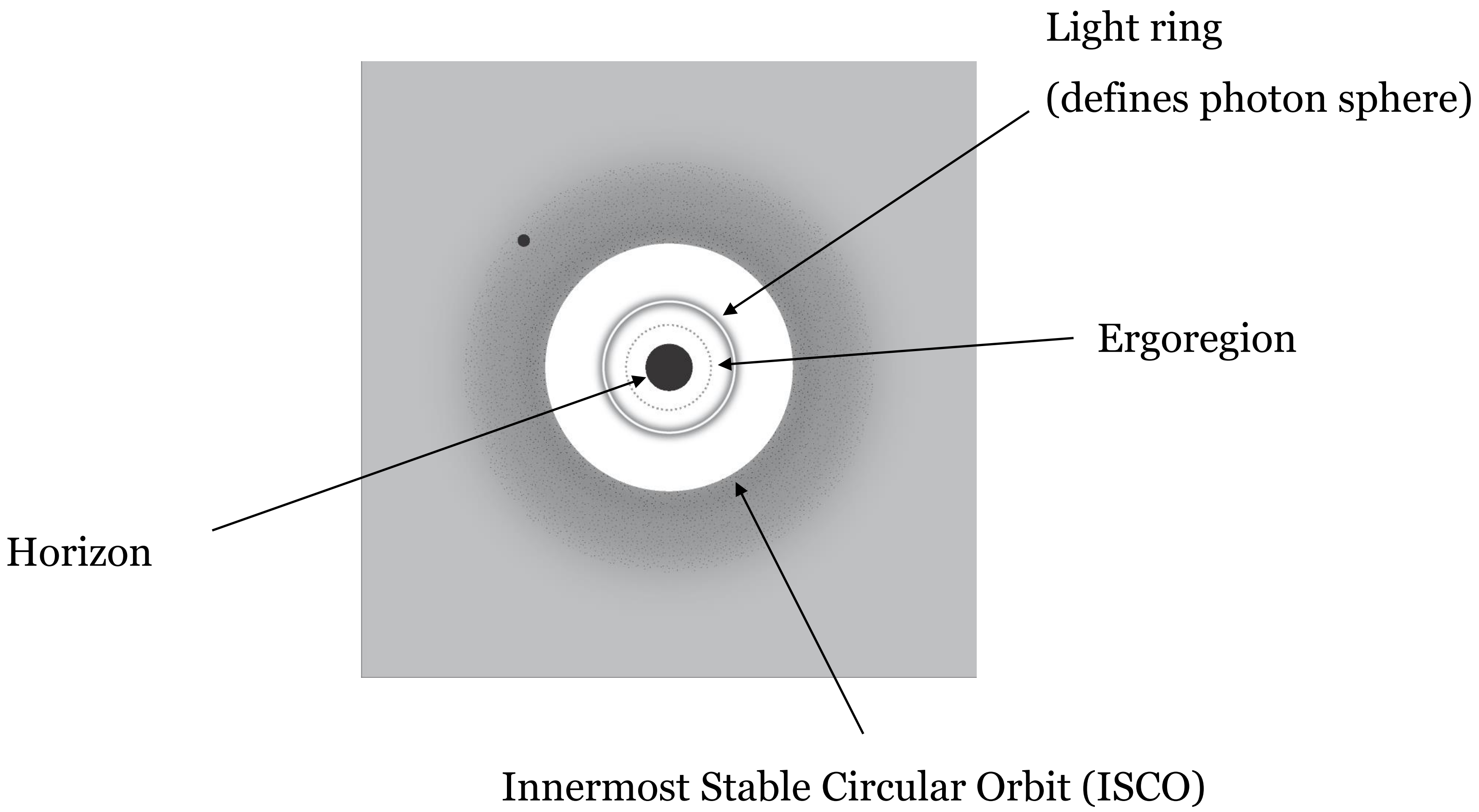


From Xianming Liu (unpublished); see Alcubierre + CQG35: 19 LT01 (2018)

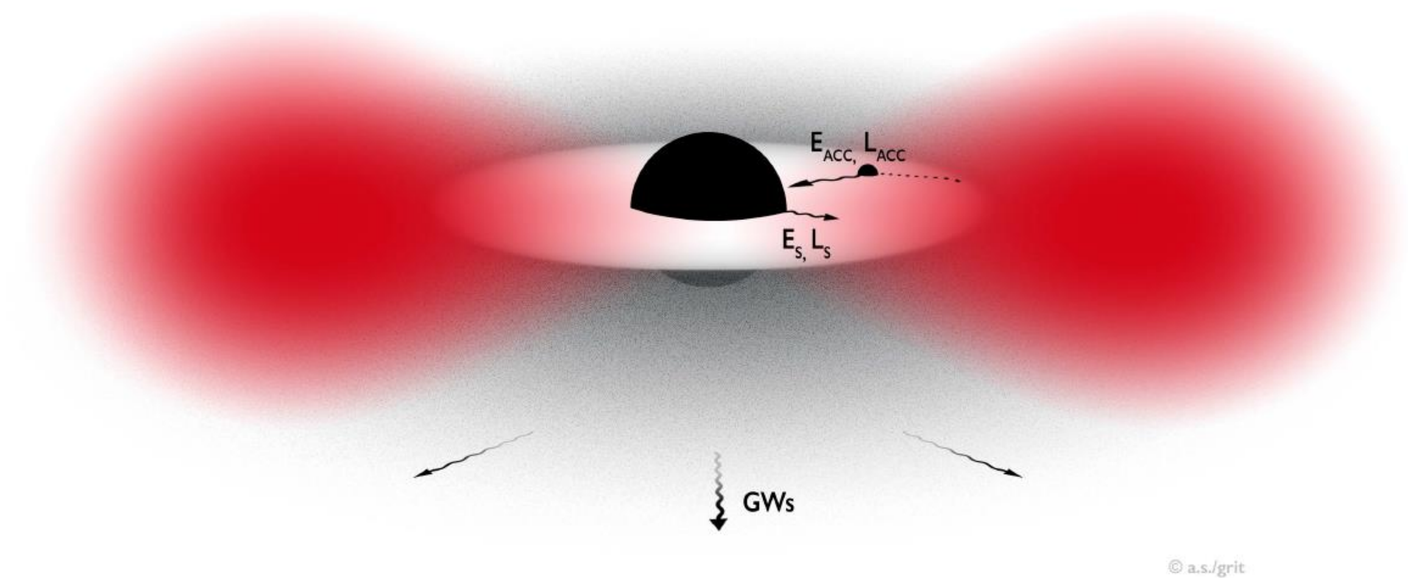
Black holes are black



Cardoso & Pani, Living Reviews in Relativity 22: 1 (2019)

Image: Ana Carvalho

Fundamental fields: bounding the boson mass



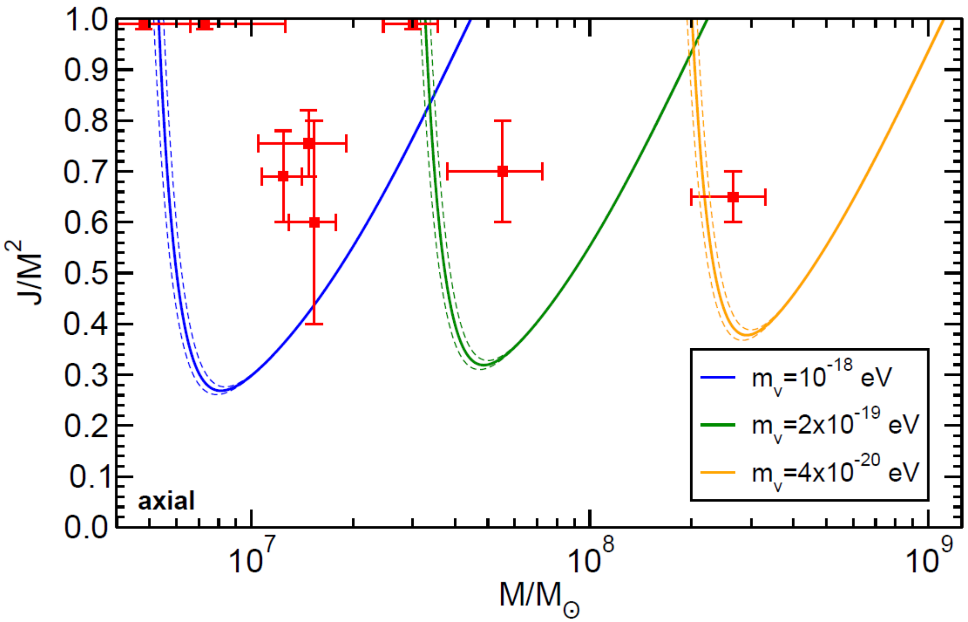
$$\tau \sim 100 \left(\frac{10^6 M_\odot}{M}\right)^8 \left(\frac{10^{-16}\mathrm{eV}}{\mu}\right)^9 \text{ seconds}$$

Wonderful sources of GWs

Brito, Cardoso, Pani, Lecture Notes Physics 906: 1-237 (2015)

Bounding the boson mass with EM observations

Pani + PRL109, 131102 (2012)

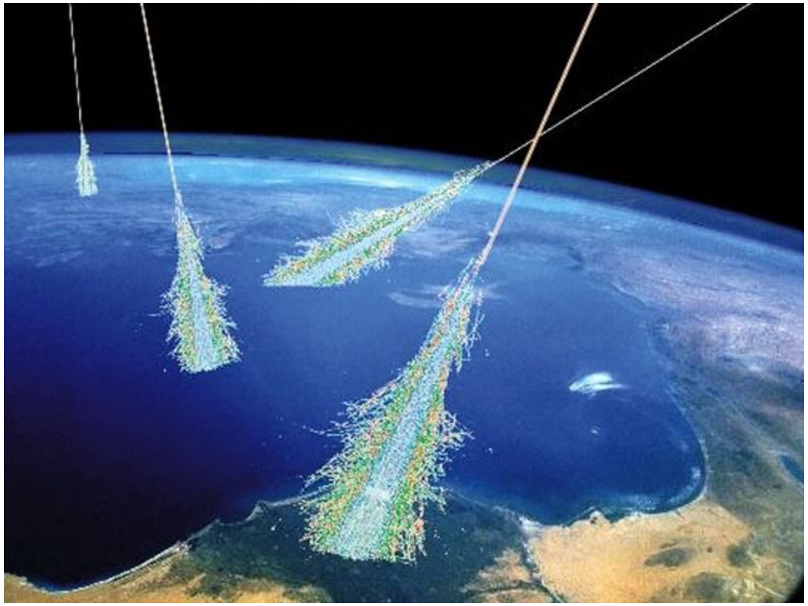


Bound on photon mass is model-dependent: details of accretion disks or intergalactic matter are important… but gravitons interact very weakly!

$$m_g < 5 \times 10^{-23}\,\mathrm{eV}$$

Brito + PRD88:023514 (2013); Review of Particle Physics 2014

Speed of GWs



$$1 - c_{\mathrm{gw}} \lesssim 10^{-17}$$

From Cherenkov-Vavilov radiation

Moore and Nelson JHEP 09 (2001) 023

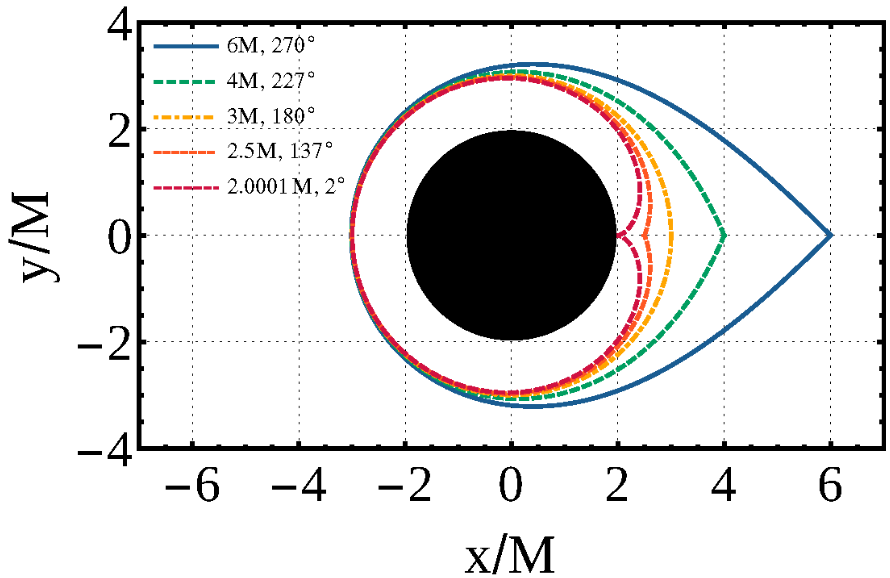
III. EM constraints

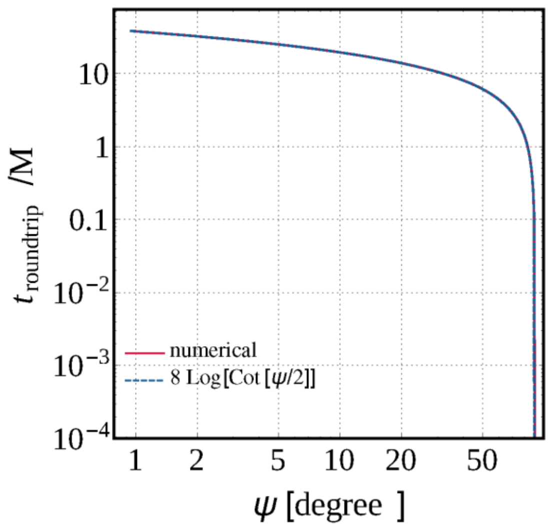
$r = 2M\,(1+\epsilon)$

$\epsilon \lesssim 10^{-5}$ Absence of transients from tidal disruptions

$\epsilon \lesssim 10^{-35}$ Dark central spot on SgrA

Carballo-Rúbio, Kumar, PRD97:123012 (2018)
Broderick, Narayan CQG24:659 (2007)





Lensing has to be properly included, as well as emission into other channels

Abramowicz, Kluzniak, Lasota 2002; Cardoso, Pani Nature Astronomy 1 (2017)