

A short history of black holes images

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Relativité et Objets Compacts

LUTH, Meudon, France

12 June 2019

James M. Bardeen (1972) : the black hole shadow

Dept. of Physics, Yale University

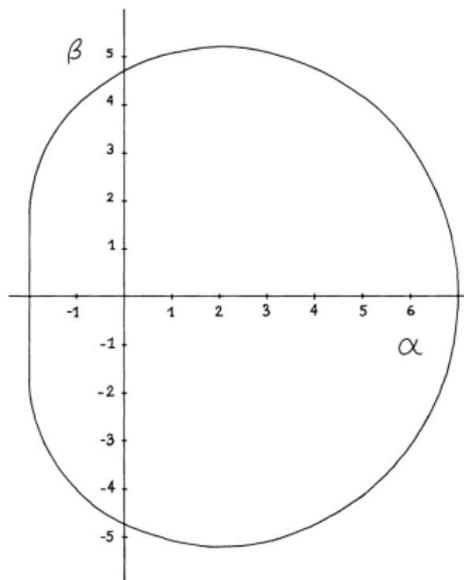


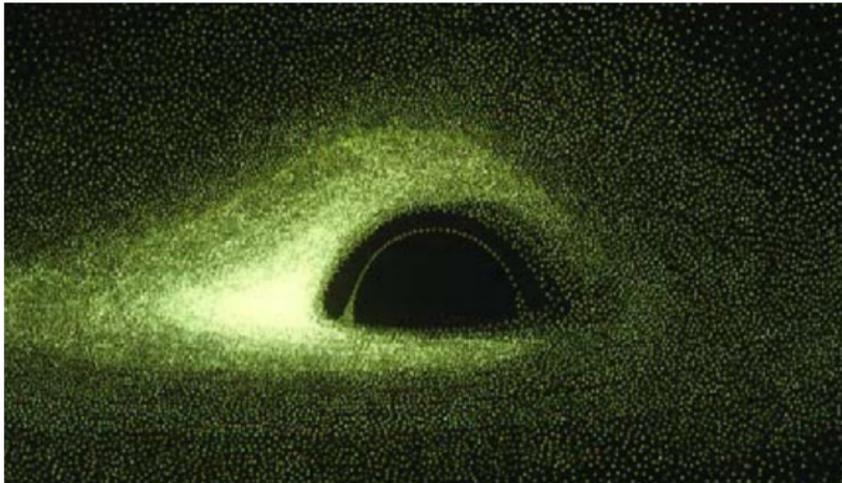
Figure 6. The apparent shape of an extreme ($a = m$) Kerr black hole as seen by a distant observer in the equatorial plane, if the black hole is in front of a source of illumination with an angular size larger than that of the black hole.

Shadow of an extreme Kerr black hole

Bardeen, in *Black Holes – Les astres occlus*, proc. of *Les Houches Summer School 1972*, ed. C. DeWitt and B. DeWitt, (1973), p. 215.

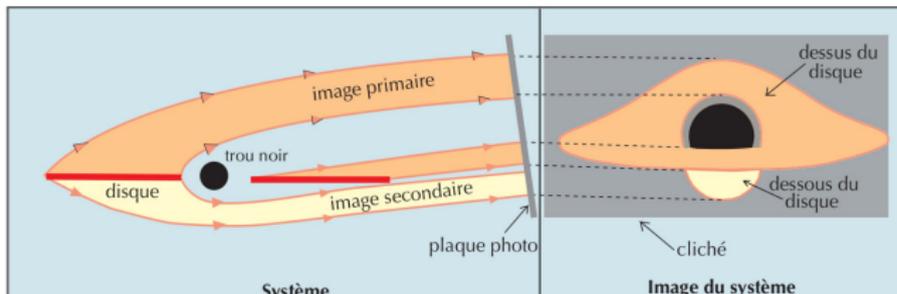
Jean-Pierre Luminet (1979) : the first (computed) image

Groupe d'Astrophysique Relativiste, Observatoire de Paris, Meudon



First image of an accretion disk around a Schwarzschild black hole

Luminet, *A&A* 75, 228 (1979)

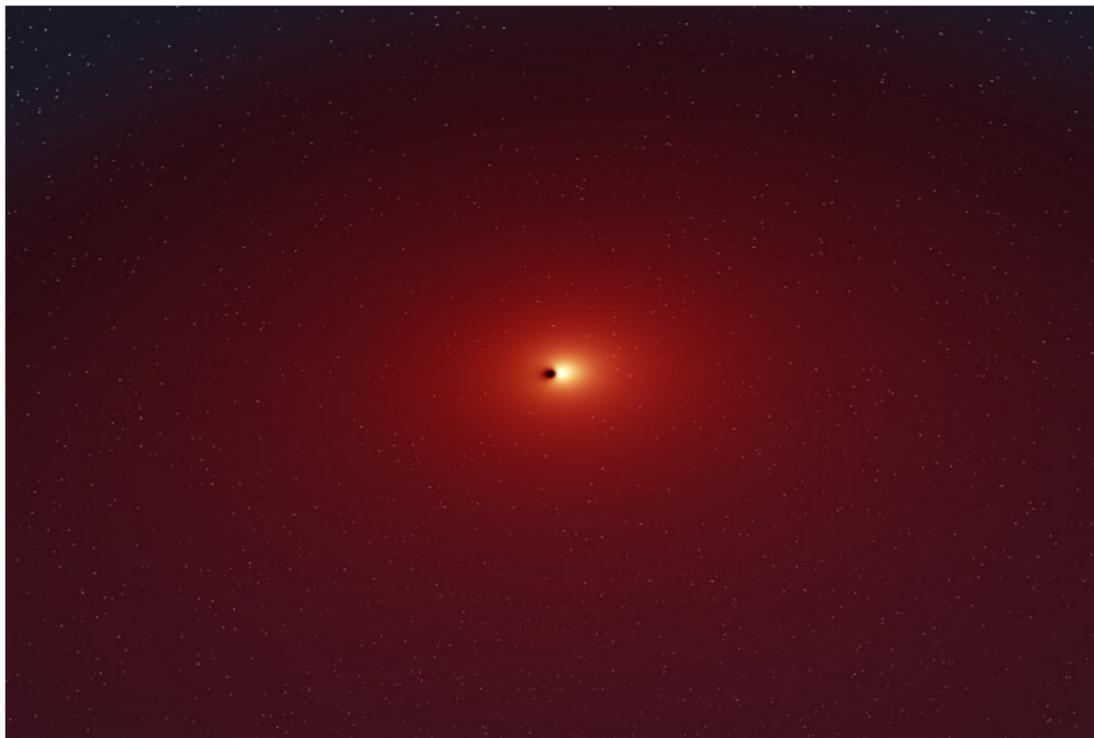


Light ray trajectories

<https://luth.obspm.fr/~luminet/>

Jean-Alain Marck (1991, 1996) : the first movie

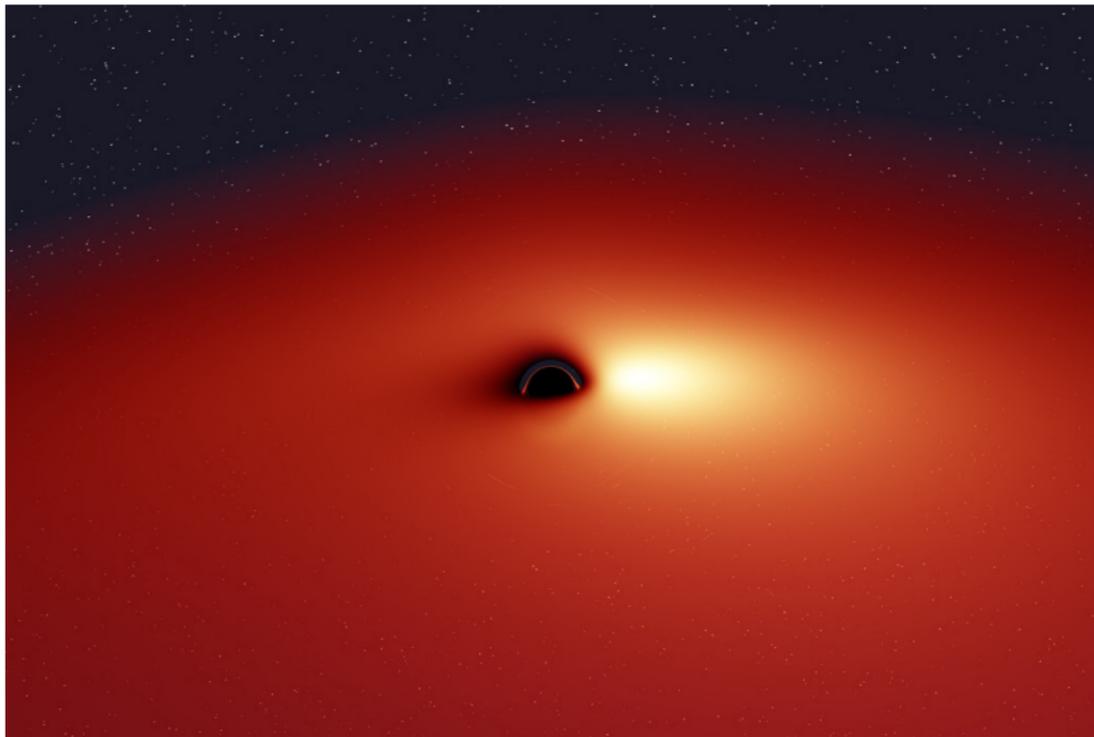
Département d'Astrophysique Relativiste et de Cosmologie, Observatoire de Paris, Meudon



Flight to a black hole, Marck, CQG 13, 393 (1996)

Jean-Alain Marck (1991, 1996) : the first movie

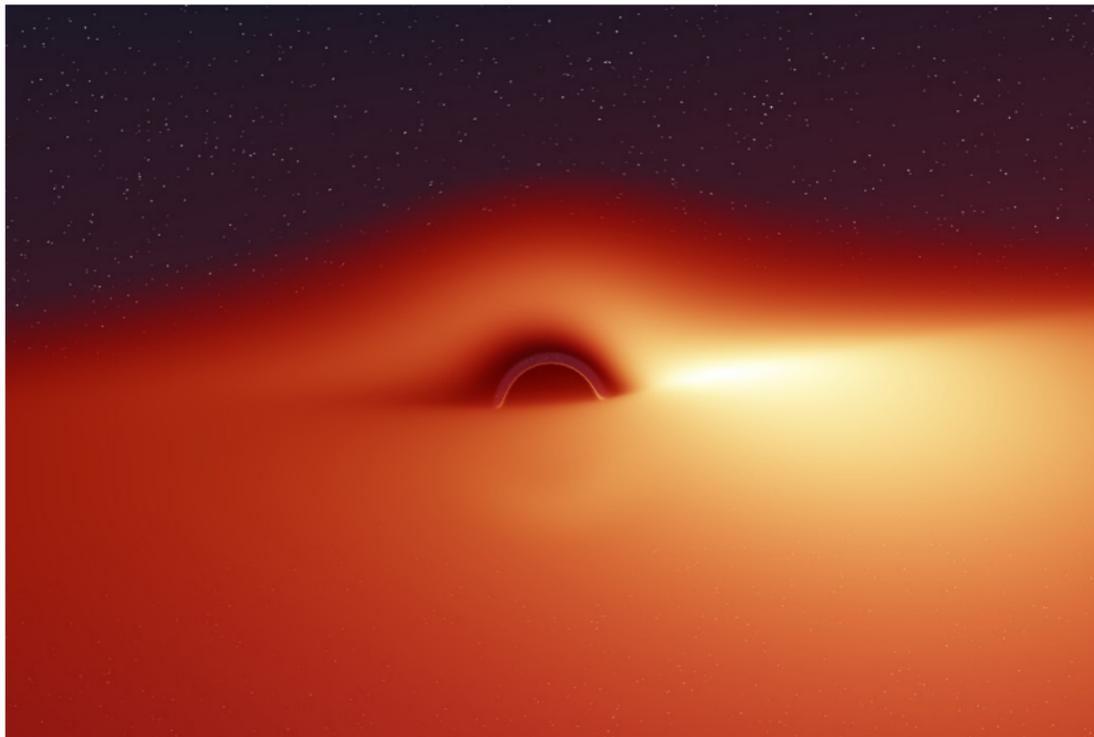
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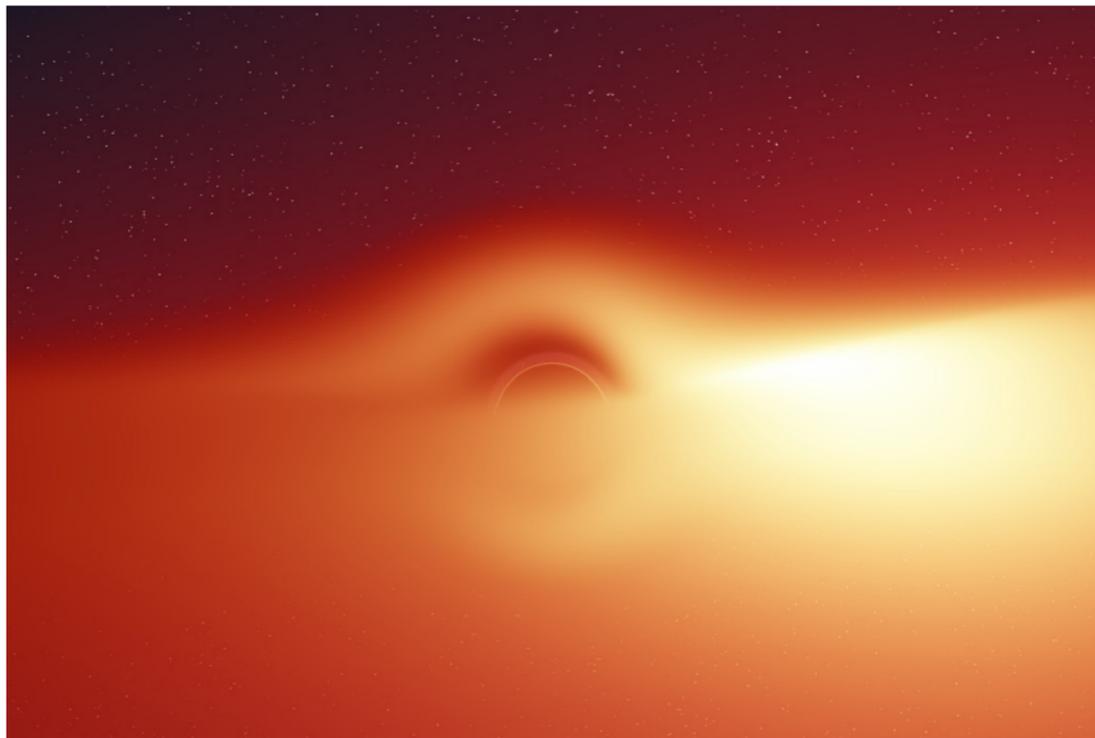
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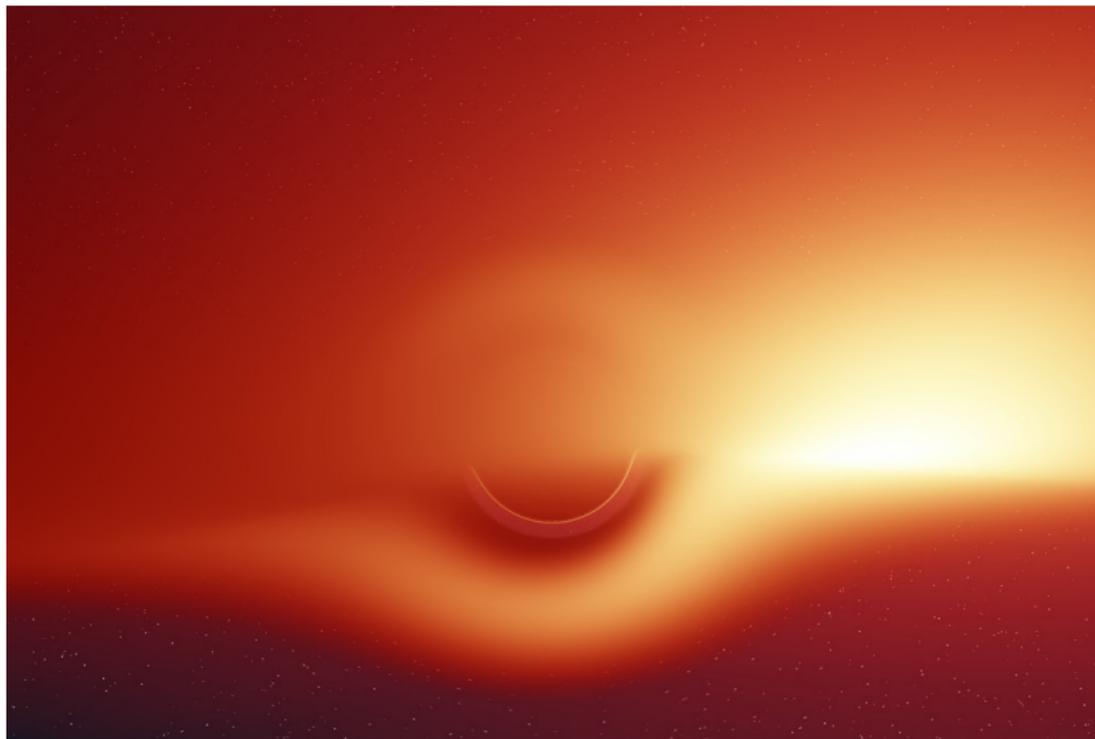
Département d'Astrophysique Relativiste et de Cosmologie, Observatoire de Paris, Meudon



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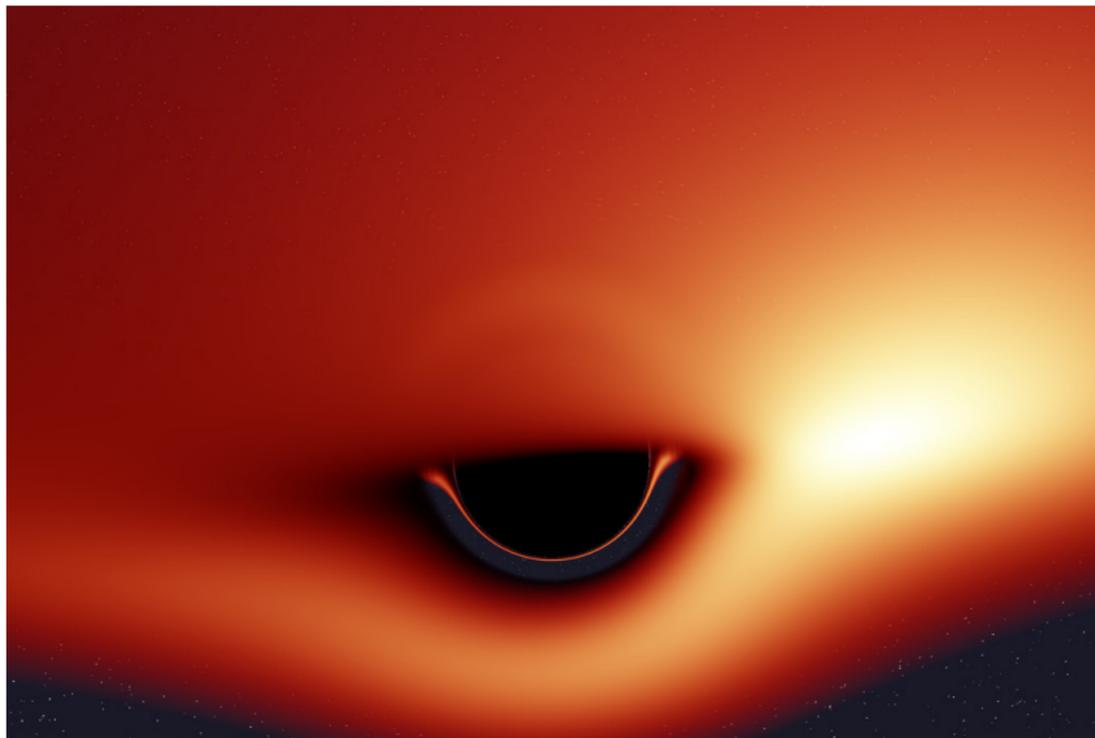
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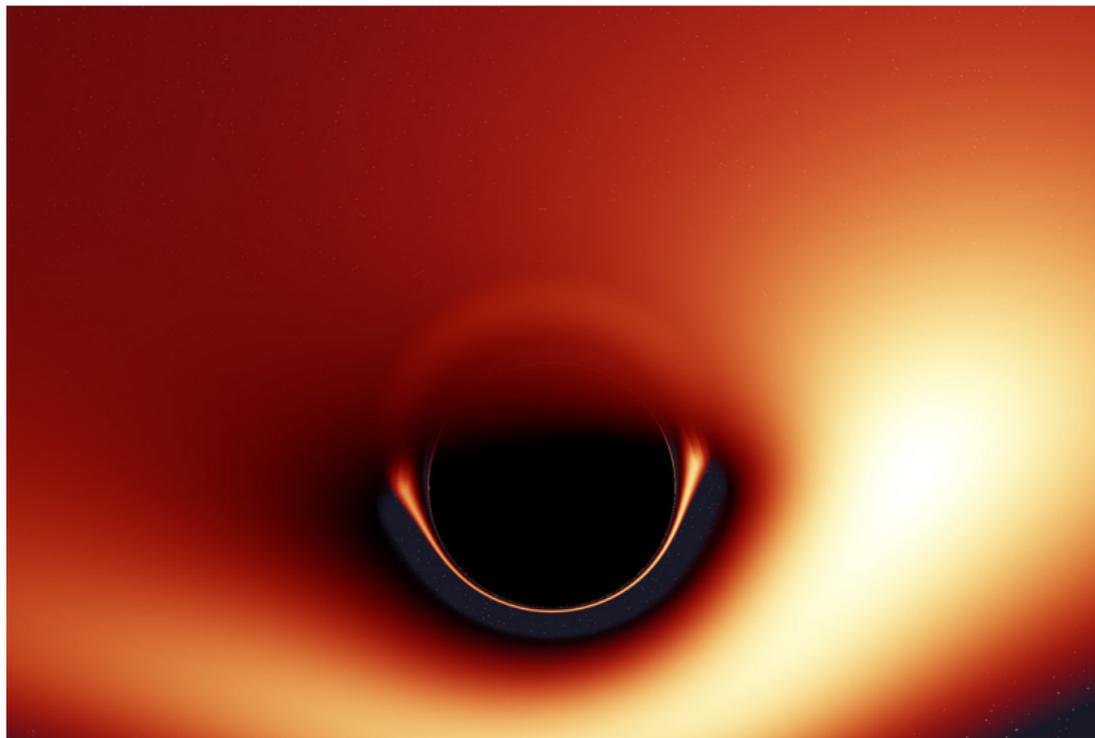
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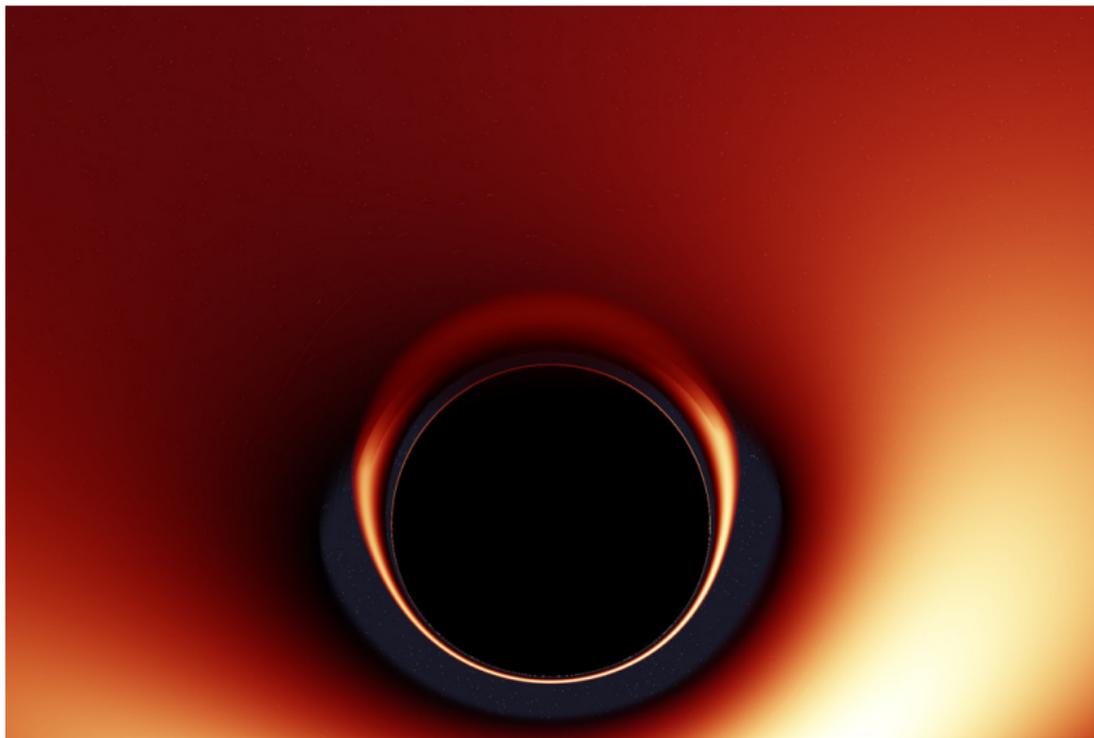
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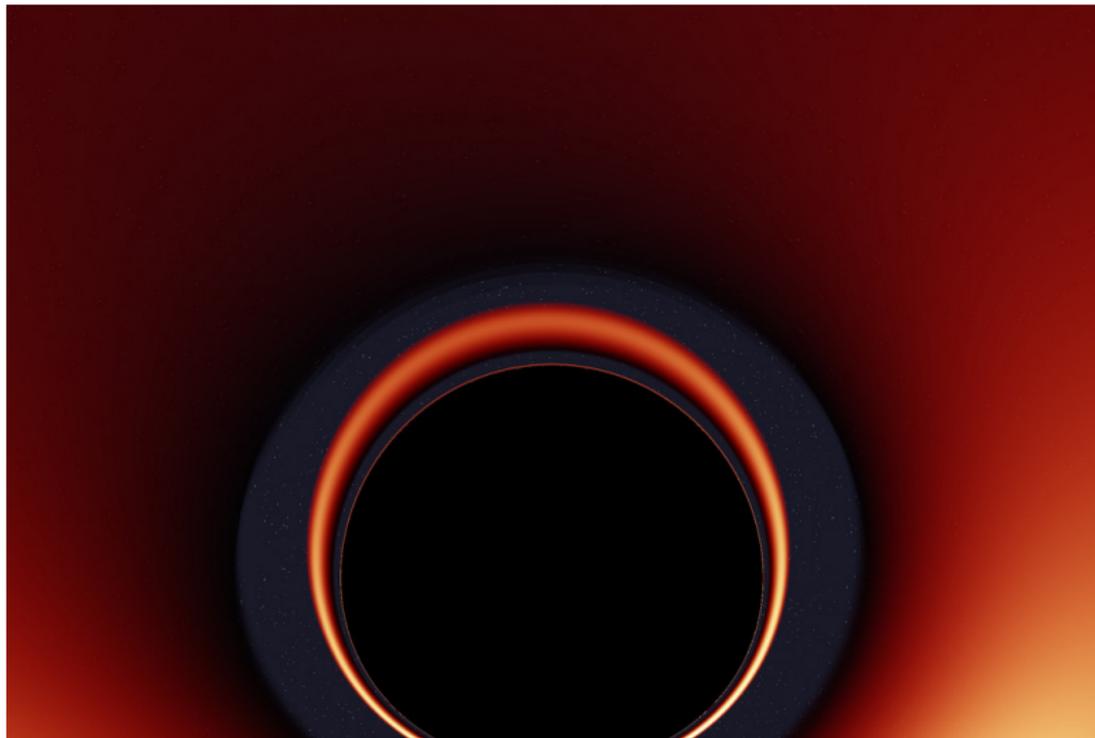
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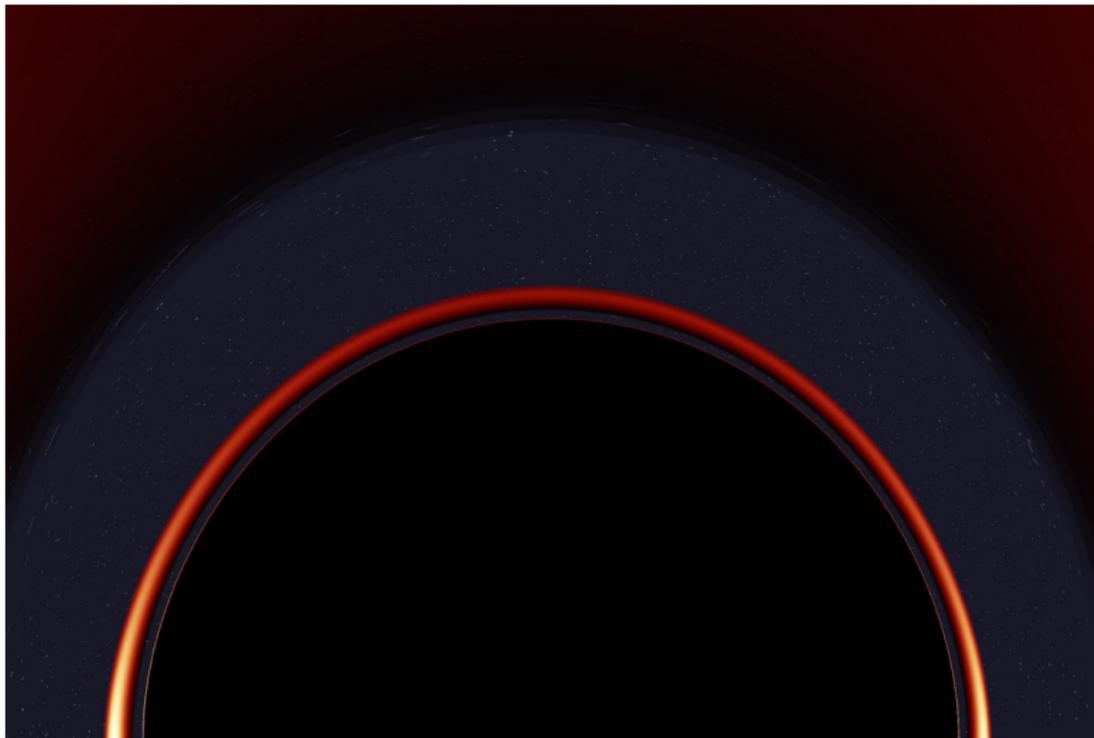
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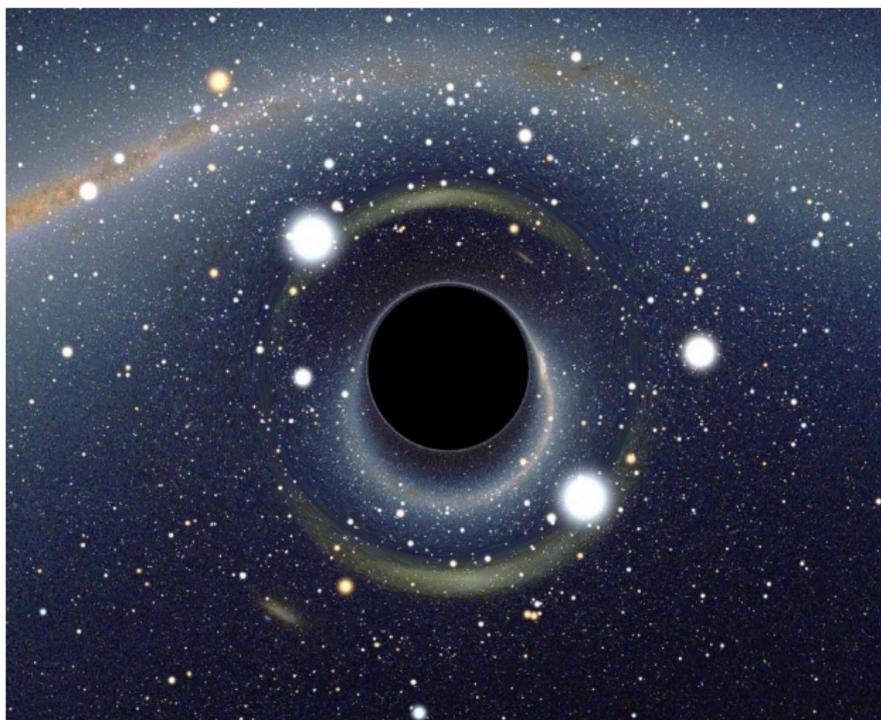
Département d'Astrophysique Relativiste et de Cosmologie, Observatoire de Paris, Meudon



Flight to a black hole, Marck, *CQG* **13**, 393 (1996)

Alain Riazuelo (2007) : the black hole in the sky

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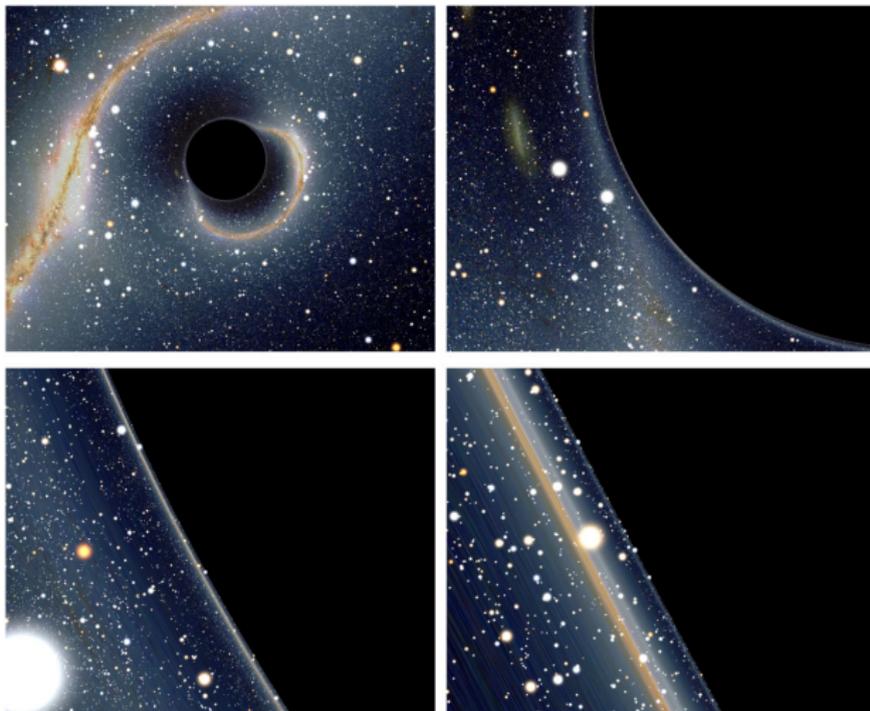


Schwarzschild black hole

Riazuelo (2007) ; Riazuelo, IJMPD 28, 1950042 (2019)

Alain Riazuelo (2007) : very high precision computations

Institut d'Astrophysique de Paris

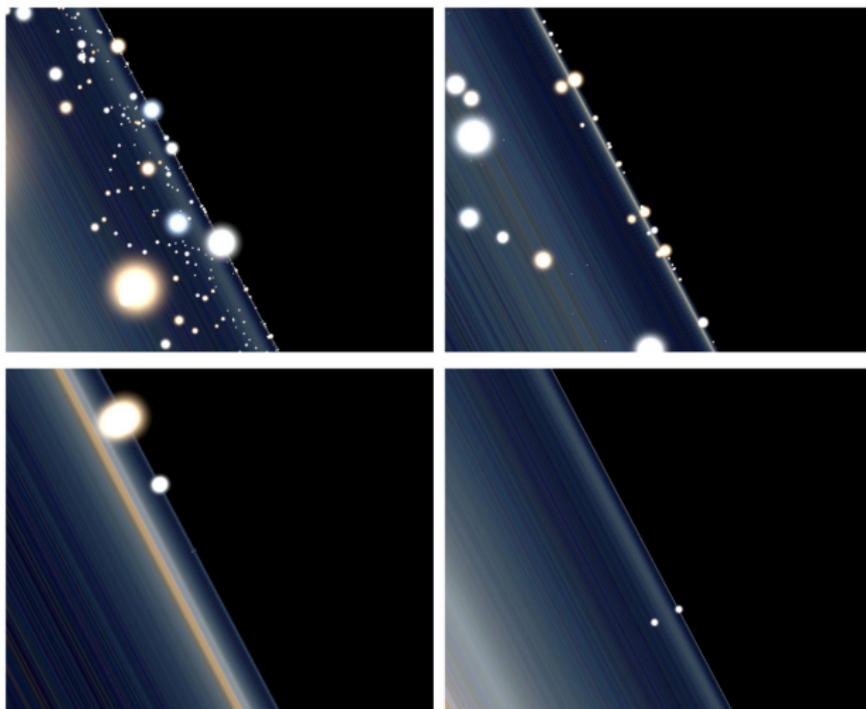


Zoom 1

Riazuelo (2007) ; Riazuelo, JMPD 28, 1950042, (2019)

Alain Riazuelo (2007) : very high precision computations

Institut d'Astrophysique de Paris

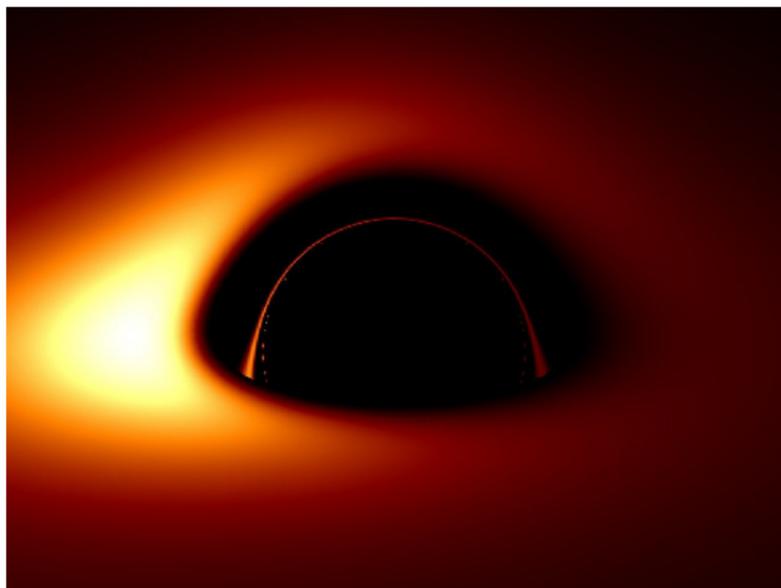


Zoom 2

Riazuelo (2007) ; Riazuelo, IJMPD 28, 1950042 (2019)



<https://gyoto.obspm.fr/>



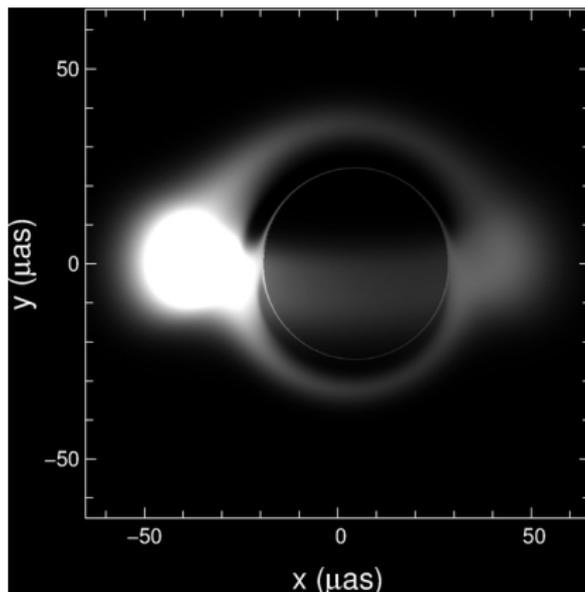
Thin accretion disk around a Schwarzschild black hole

Vincent, Paumard, Gourgoulhon & Perrin, *CQG* **28**, 225011 (2011)

GYOTO (2012) : an open-source and flexible code

LESIA & LUTH, Observatoire de Paris, Meudon

<https://gyoto.obspm.fr/>

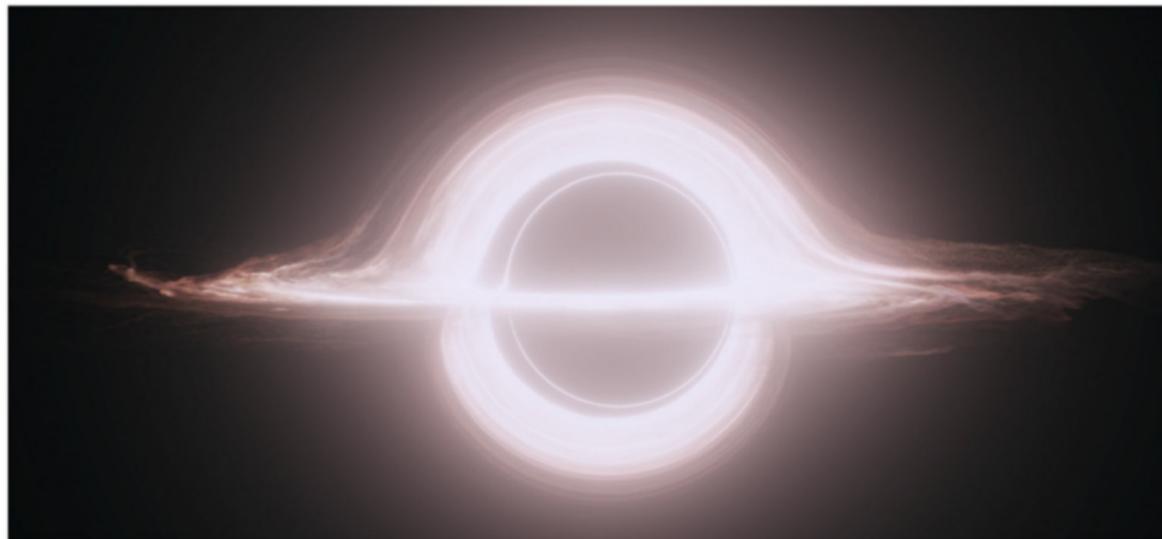


Ionised torus around a Schwarzschild black hole

Straub, Vincent, Abramowicz, Gourgoulhon & Paumard, *A&A* 543, A83 (2012)

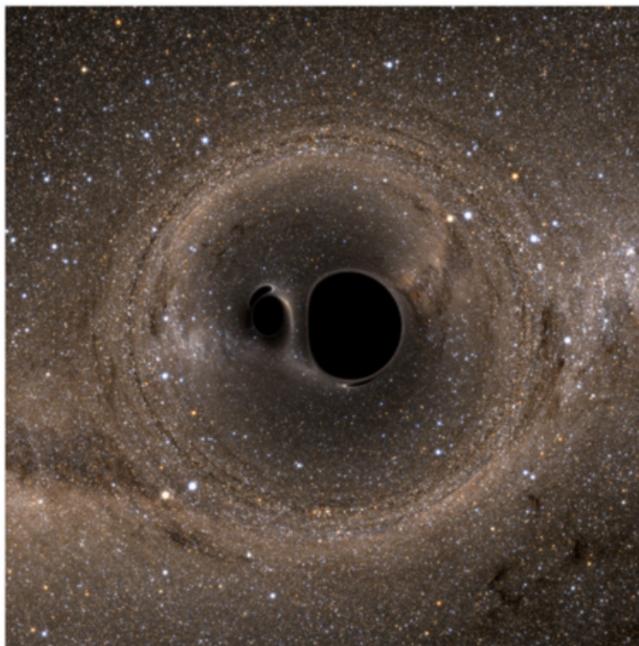
Oliver James, Eugénie von Tunzelmann, Paul Franklin & Kip S Thorne (2015) : the *Interstellar* black hole

Double Negative Visual Effects, London



Thin accretion disk around a Kerr black hole with $a/M = 0.6$
for the movie *Interstellar* (Christopher Nolan, 2014)

James, von Tunzelmann, Franklin & Thorne, *CQG* 32, 065001 (2015)

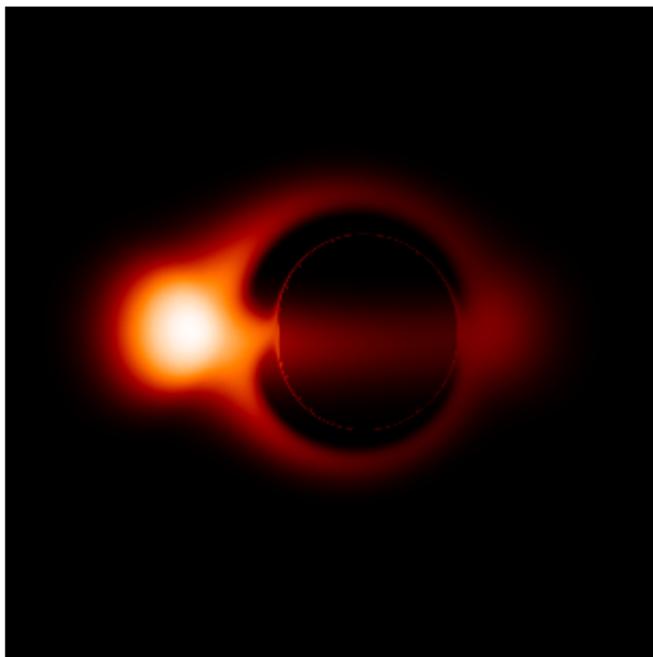


Binary black hole with mass ratio $m_1/m_2 = 3$
seen along an axis perpendicular to the orbital plane

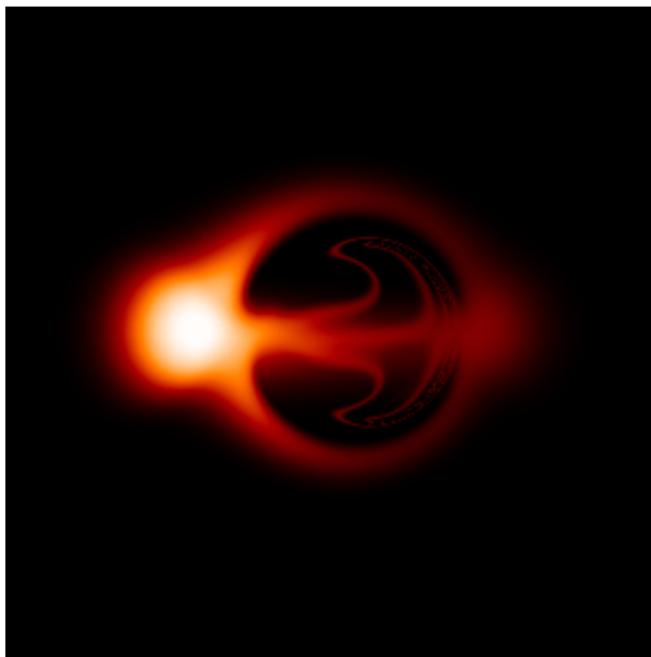
Bohn et al., CQG 32 065002 (2015)

GYOTO (2016) : alternatives to the Kerr black hole

Kerr black hole $a/M = 0.9$

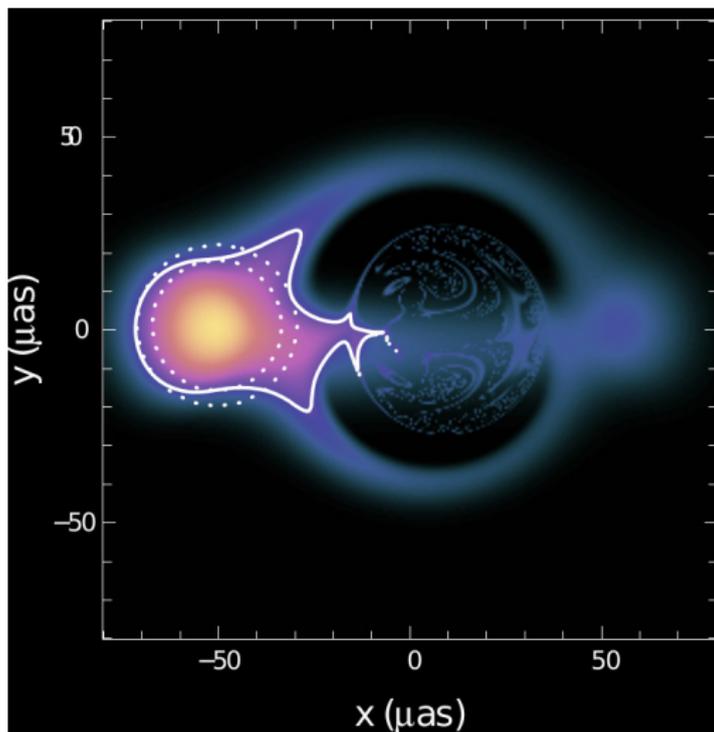


Boson star $k = 1, \omega = 0.70 m/\hbar$



Vincent, Meliani, Grandclément, Gourgoulhon & Straub, CQG 33, 105015 (2016)

GYOTO (2016) : alternatives to the Kerr black hole

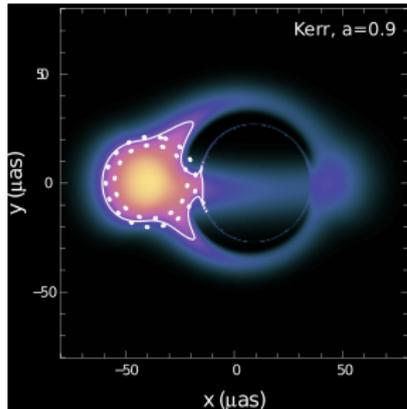


Accretion torus around a scalar-field-hairy rotating black hole

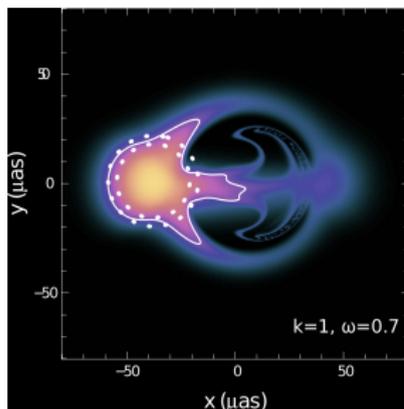
Vincent, Gourgoulhon, Herdeiro & Radu, *Phys. Rev. D* **94**, 084045 (2016)

GYOTO (2016) : alternatives to the Kerr black hole

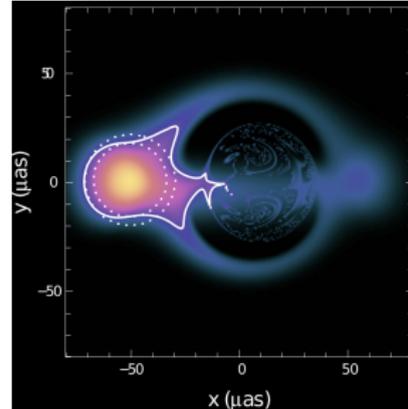
Kerr black hole
 $a/M = 0.9$



boson star [1]
 $k=1, \omega=0.7 m/\hbar$



hairy black hole [2]
 $a/M = 0.9$



Kadath → metric

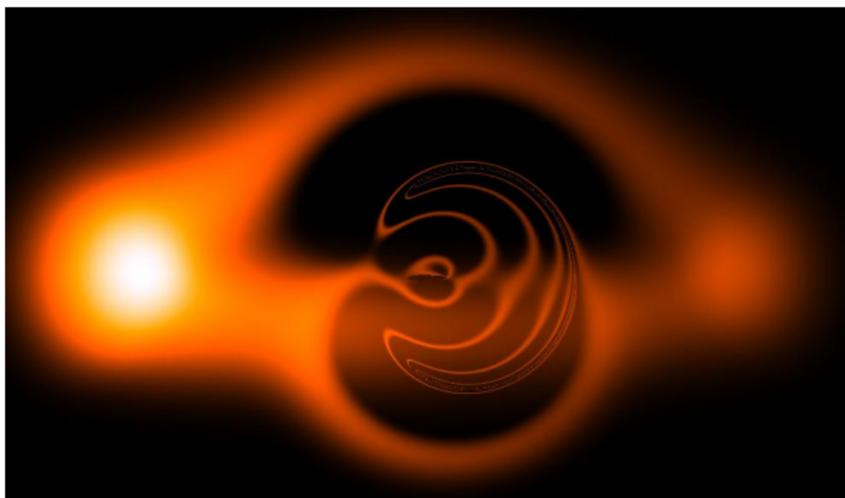
HR code → metric
(via Lorene)

Gyoto → ray-tracing

Gyoto → ray-tracing

[1] Vincent, Meliani, Grandclément, Gourgoulhon & Straub, *Class. Quantum Grav.* **33**, 105015 (2016)

[2] Vincent, Gourgoulhon, Herdeiro & Radu, *Phys. Rev. D* **94**, 084045 (2016)

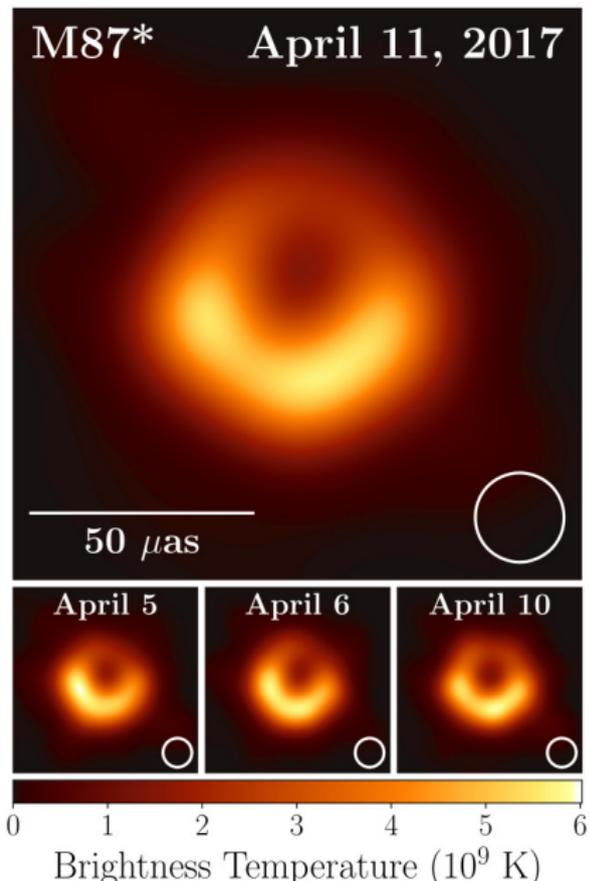


zoom on the central region

Rotating naked wormhole

Lamy, Gourgoulhon, Paumard & Vincent, *CQG* **35**, 115009 (2018)

Observations at last (2019)



EHT observations of M87 central black hole
EHT Collaboration, ApJ 875, L1 (2019)