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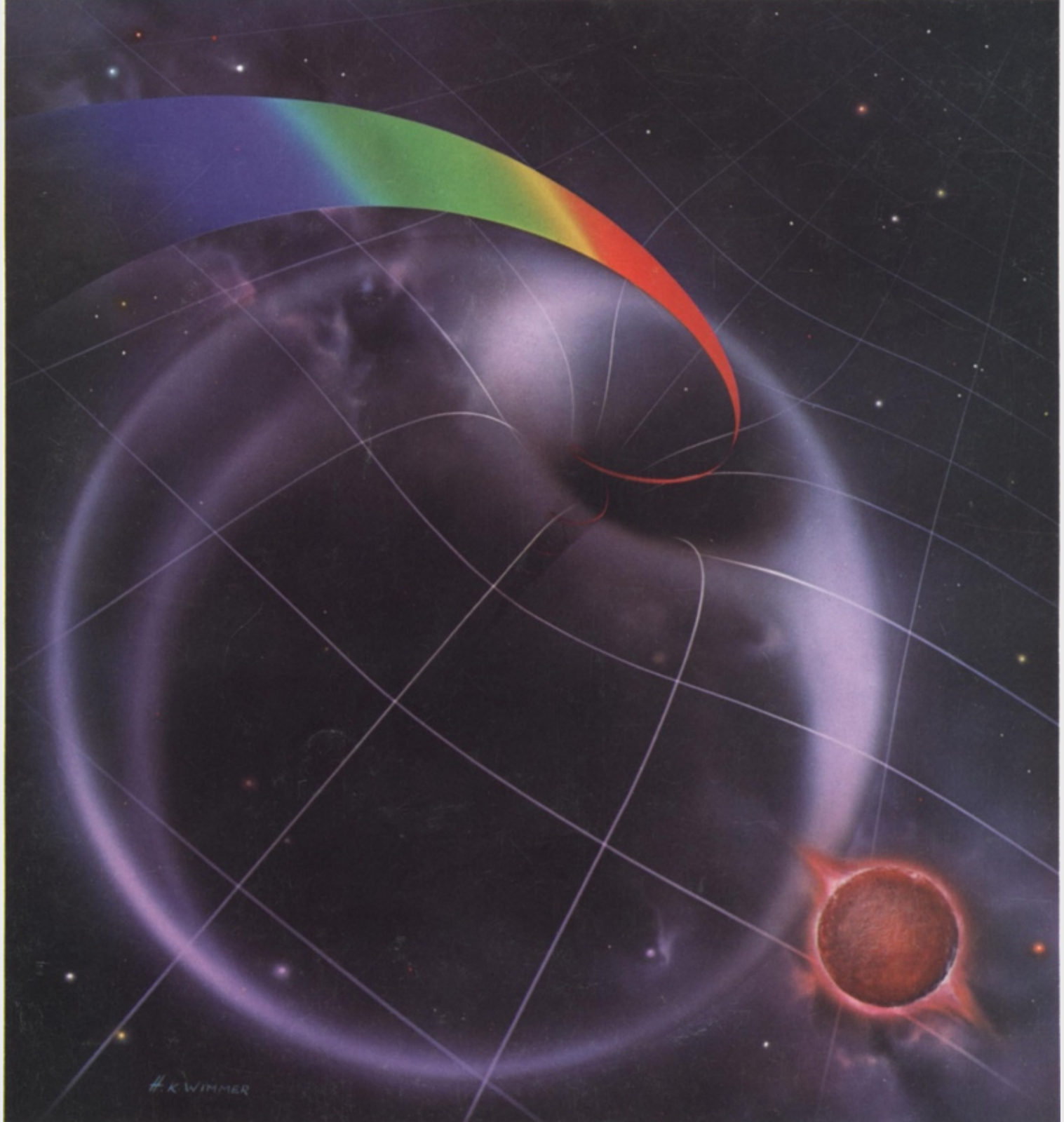
School of Mathematical and Computing Sciences
Te Kura Pangarau, Rorohiko

Black Holes

Matt Visser

Carter Observatory
National Observatory of New Zealand
Teacher in-service day
28 April 2006


H.K WIMMER

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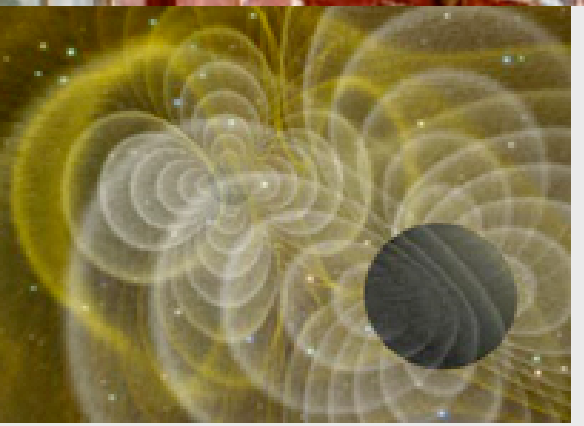
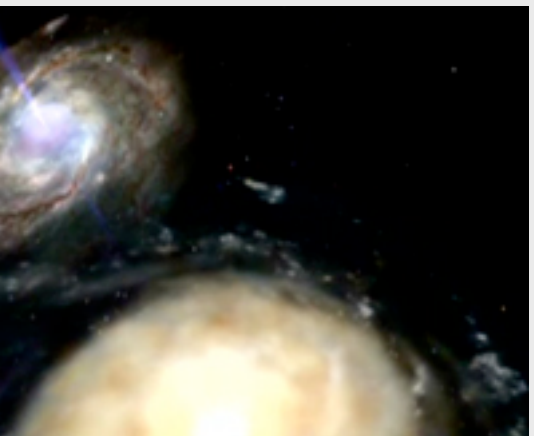


Black holes are good science.

Black holes can be tied into physics, astronomy, and mathematics...

Black holes involve everything from direct observation to hard core abstract theory...



Black holes can be used to excite and motivate students, in a completely honest way, regarding the universe around us...

Some light reading:

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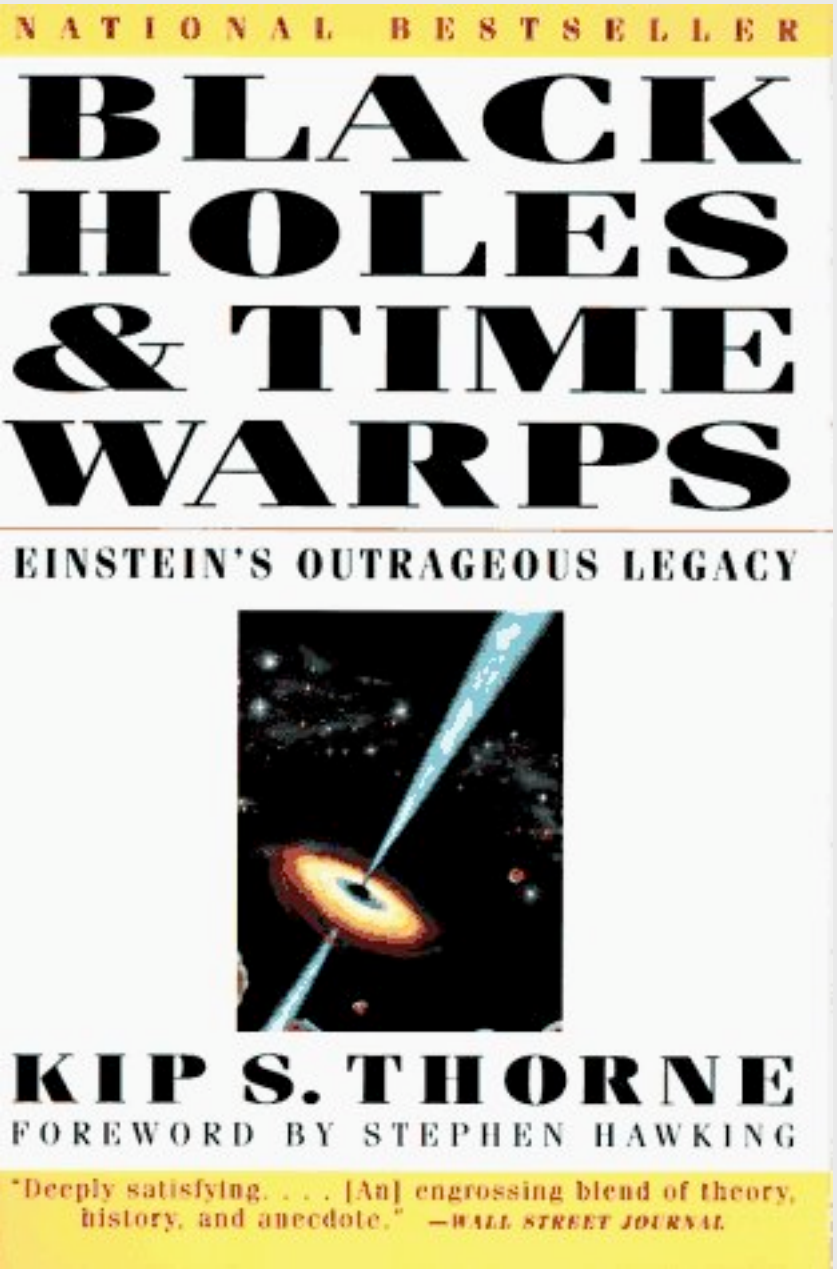

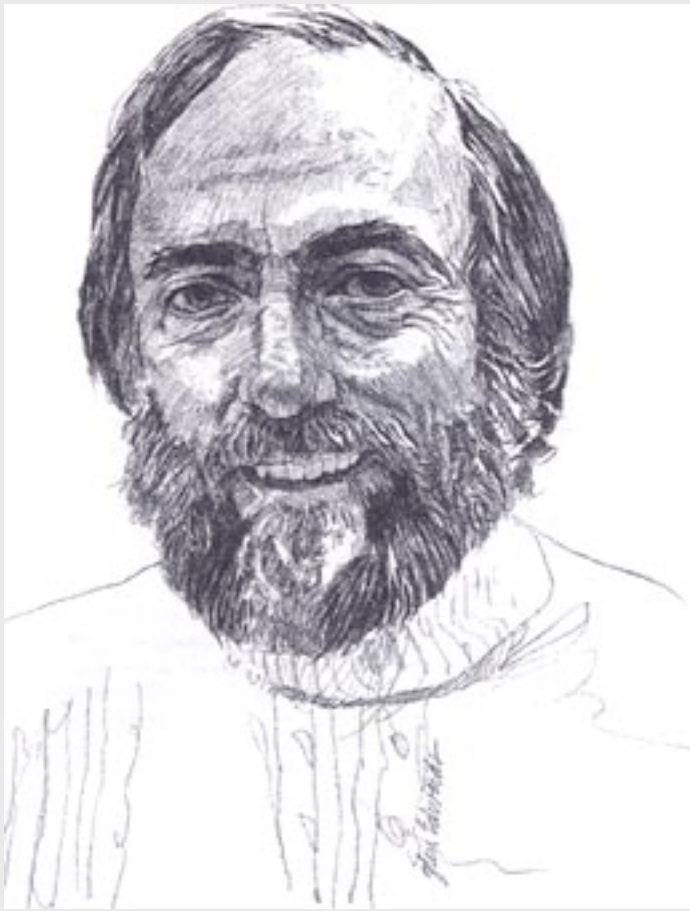

Kip S. Thorne

Theoretical Astrophysics,
California Institute of Technology, Pasadena, California, USA

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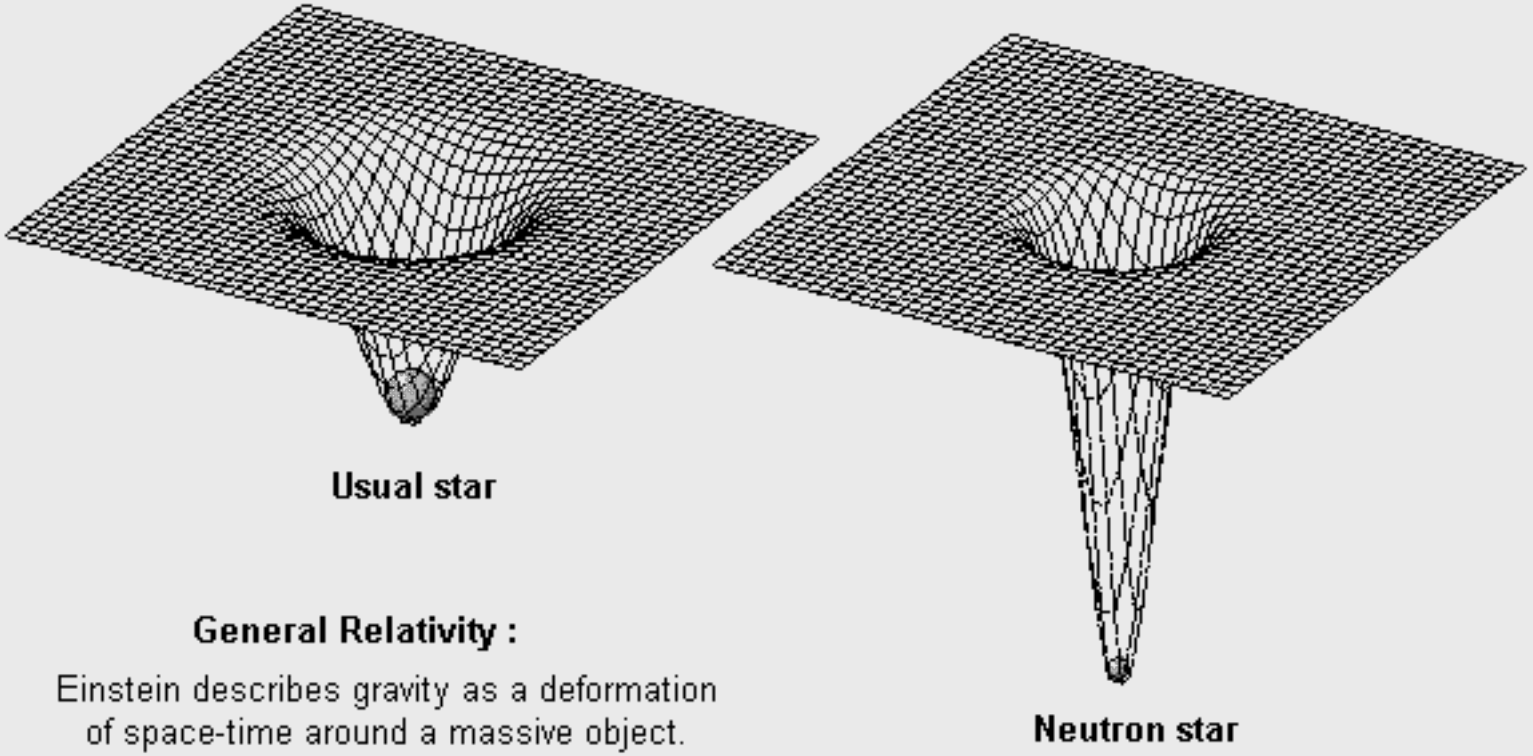
What is a black hole? (Theorist's perspective.)



Usual star

Neutron star

General Relativity :

Einstein describes gravity as a deformation of space-time around a massive object.

Euclid's geometry is not the final answer...

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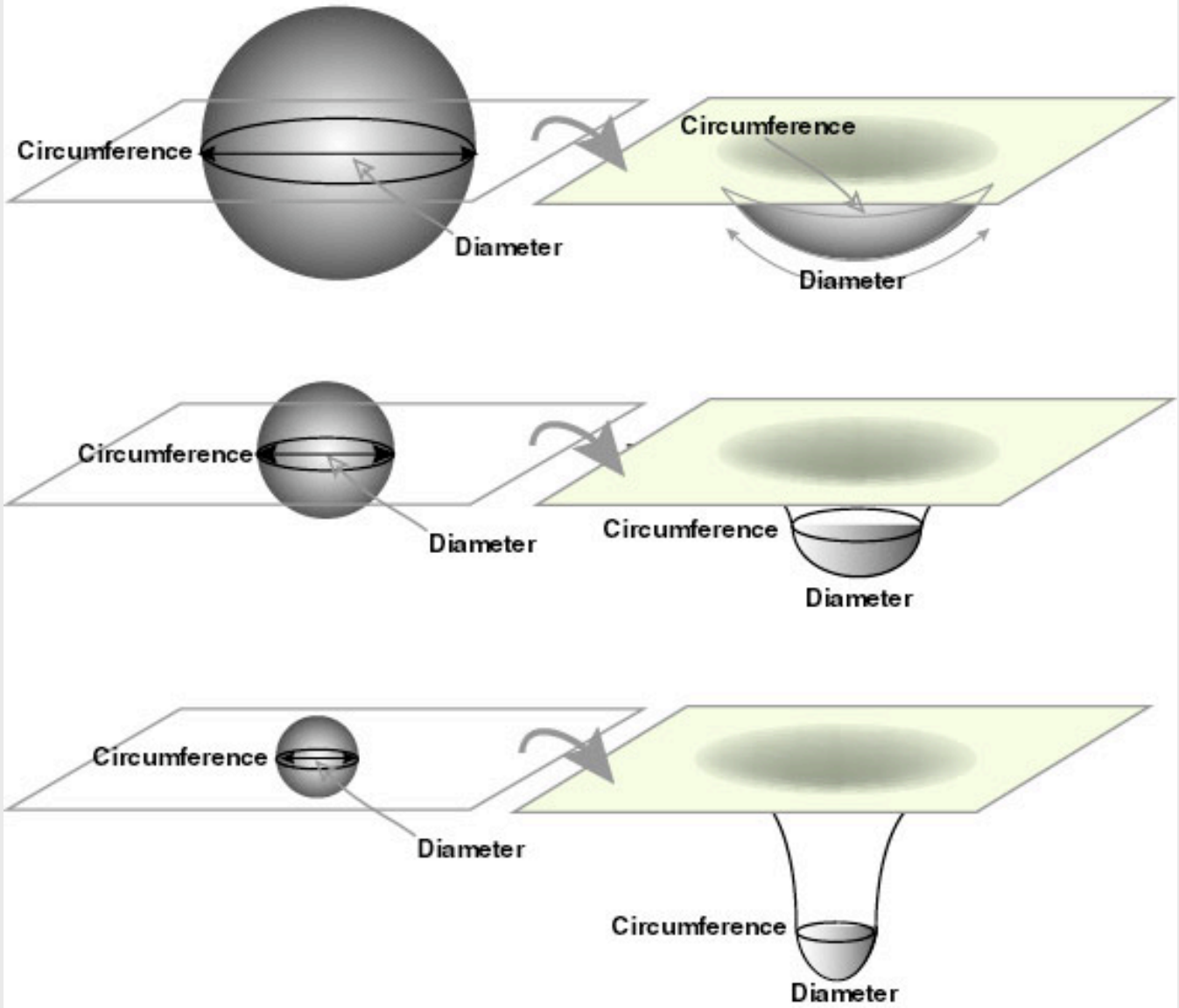
STARS WITH THE SAME MASS, BUT DIFFERENT SIZES: HOW CURVED?



Riemann's geometry is needed to describe the "real world"...

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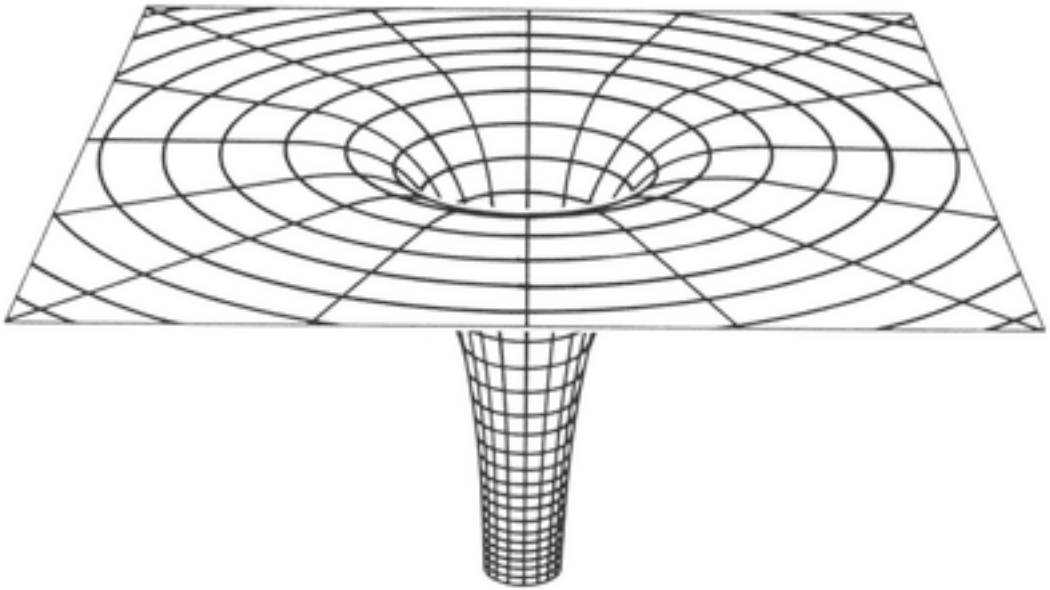
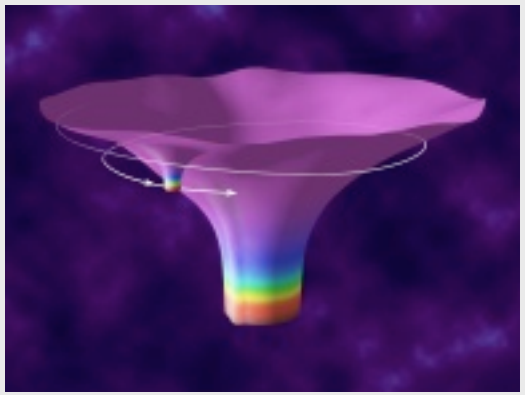


Eventually a black hole forms...

$$R = \frac{2GM}{c^2}$$



Schwarzschild's black hole...

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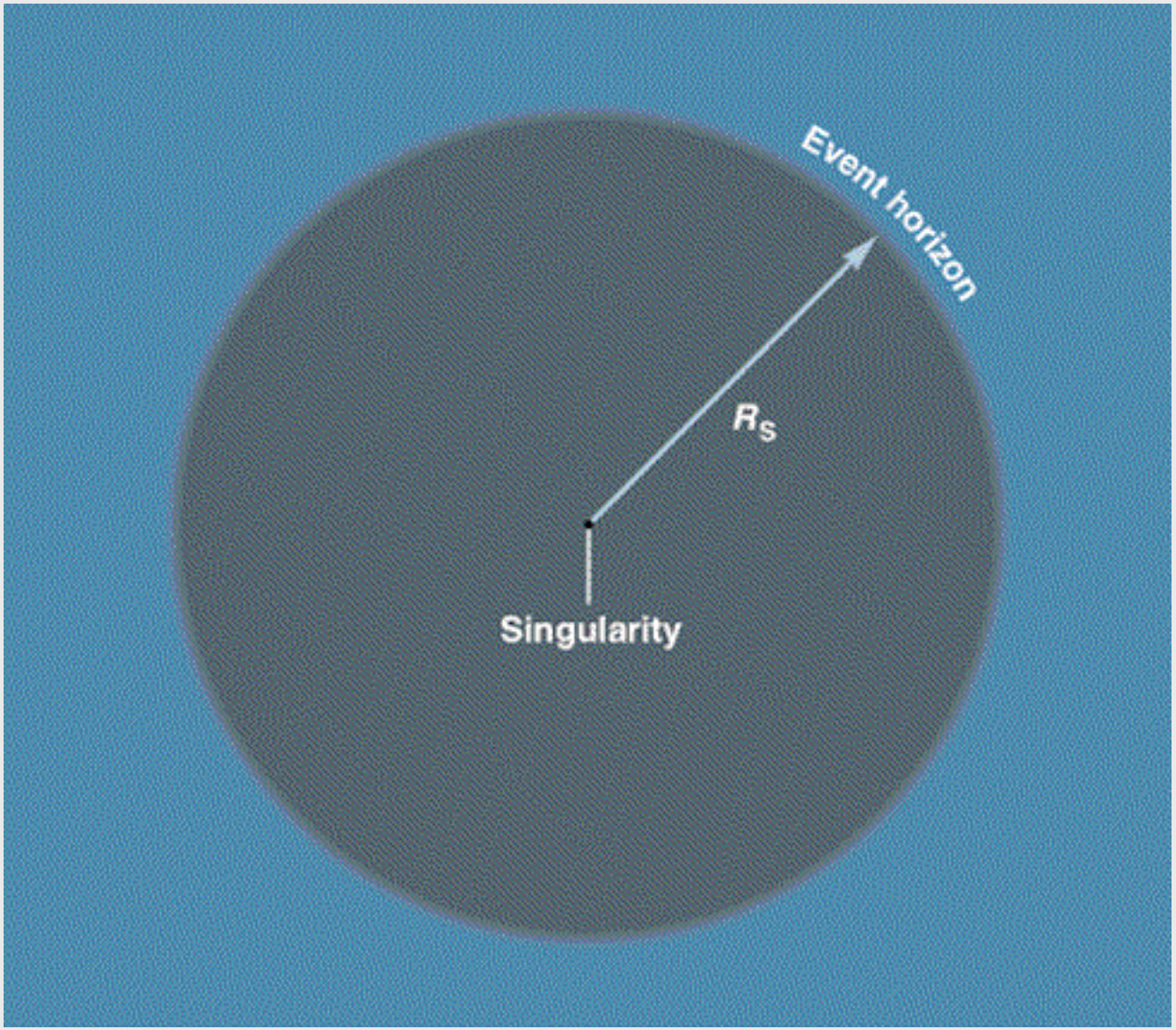
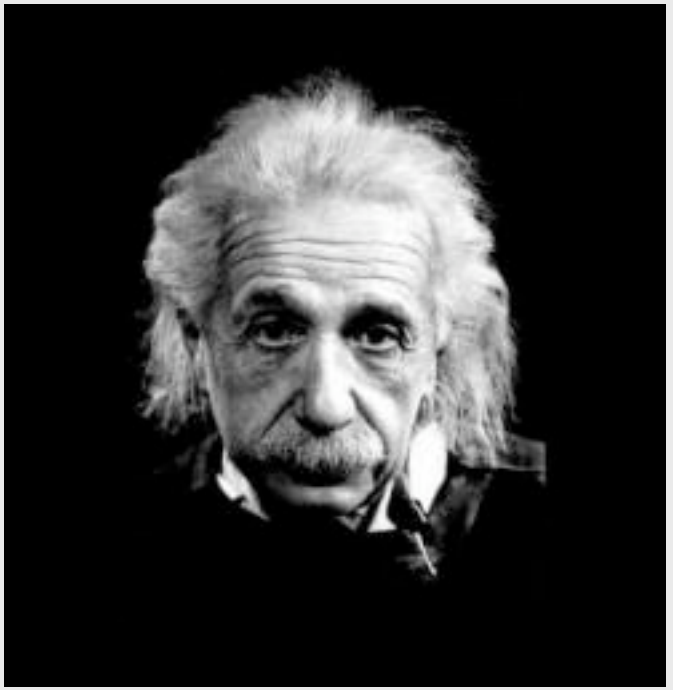


$$R = \frac{2GM}{c^2}$$



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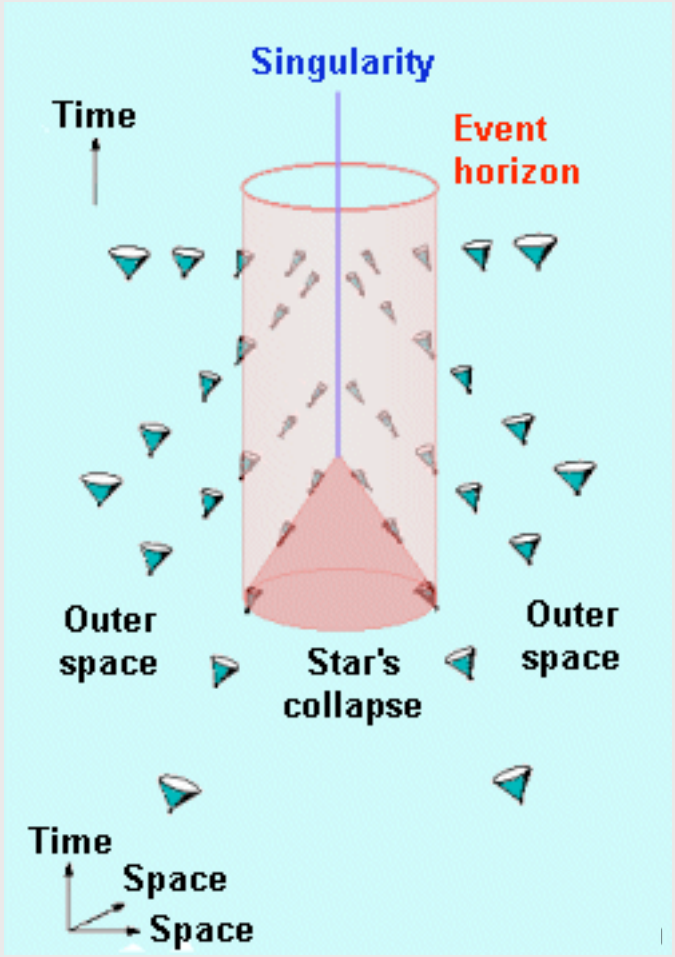

Light can no longer escape...

The “light cones” are all tipped inwards...

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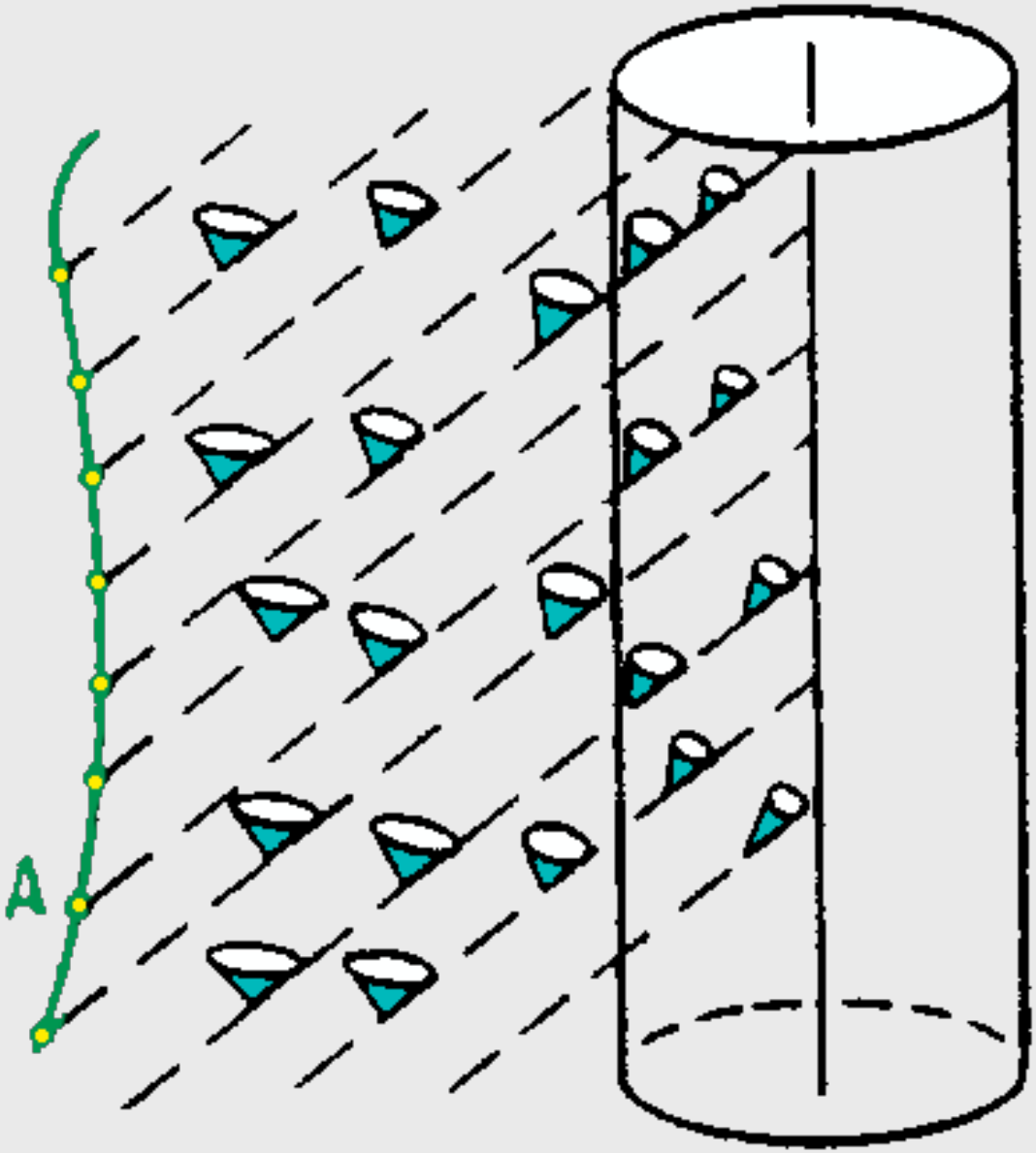

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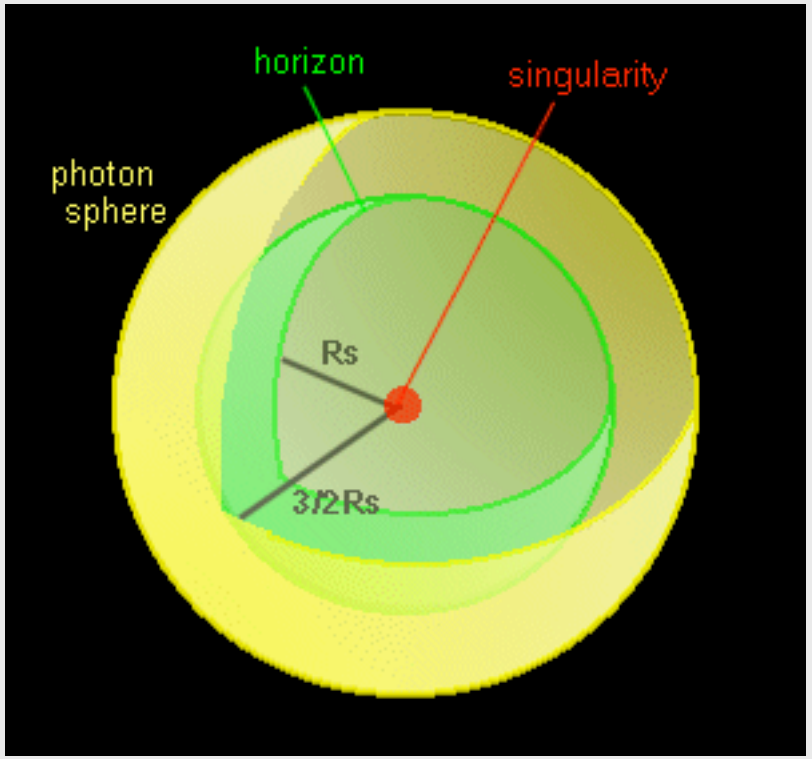

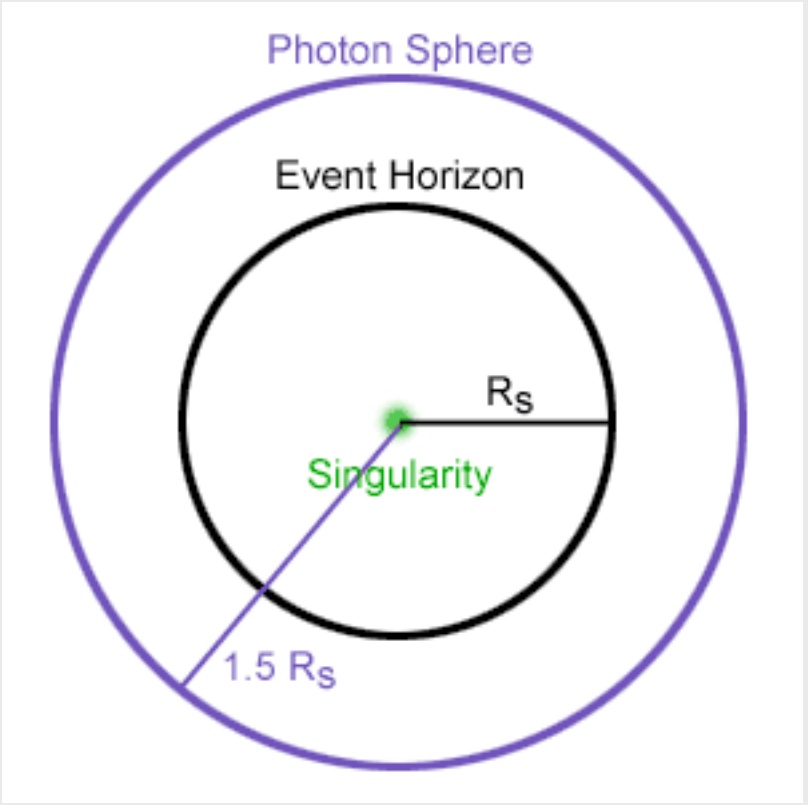

Light can "orbit" the black hole at: R=3GM/c^2.

Horizon is at: R=2GM/c^2.

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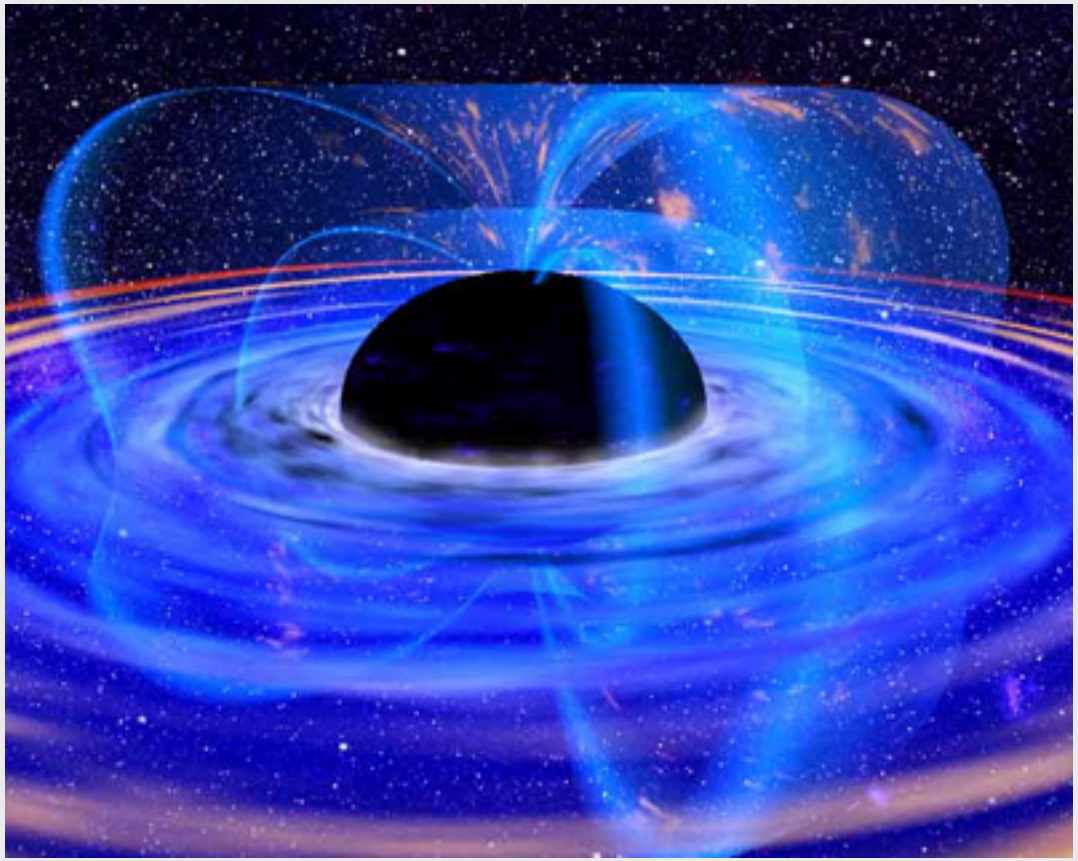
What is a black hole? (Observational perspective.)



Look for something dark and compact...

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So how would you actually see a black hole?

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"It's black, and it looks like a hole.
I'd say it's a black hole."

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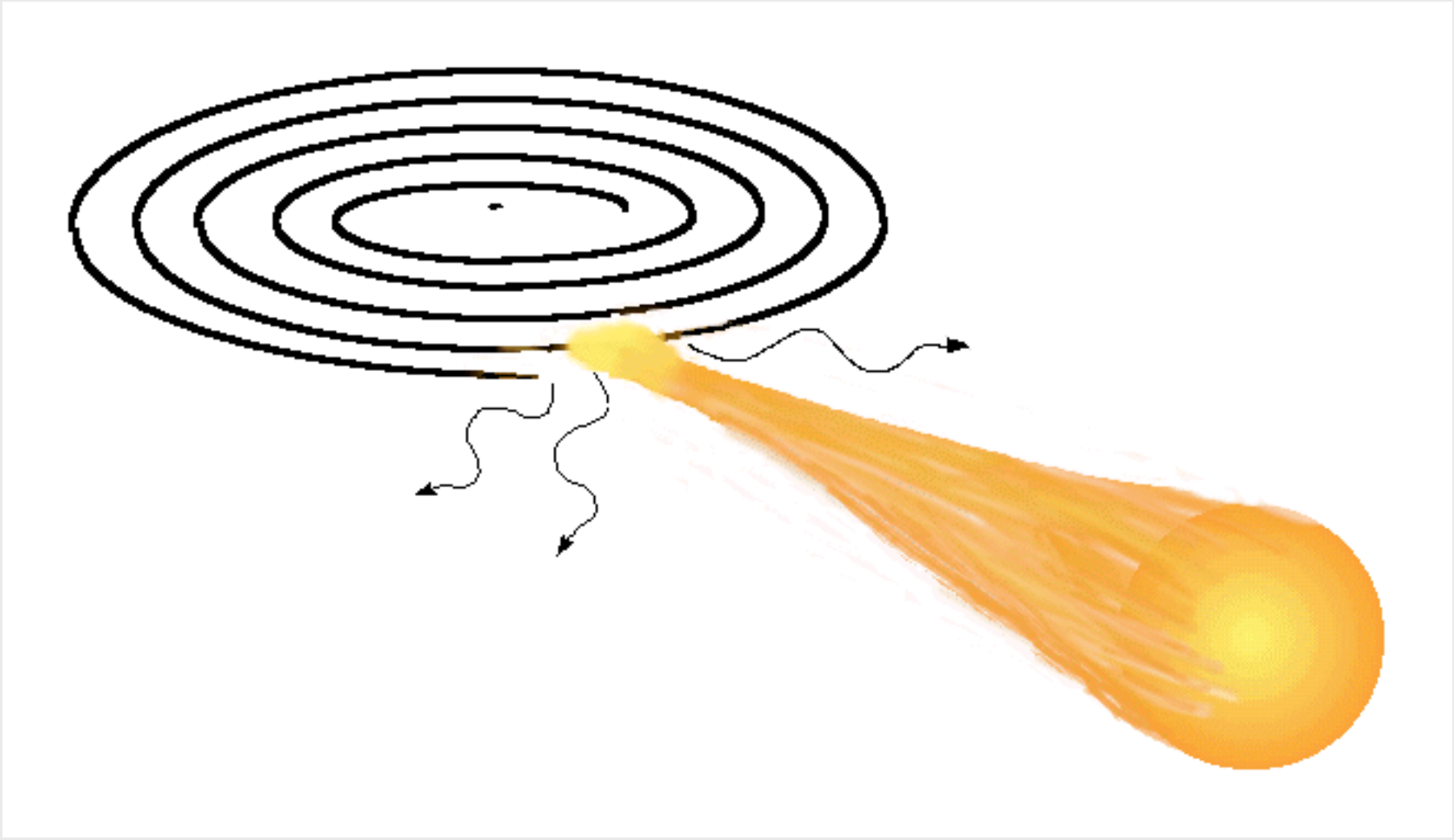
Look for the stuff that is being sucked in...



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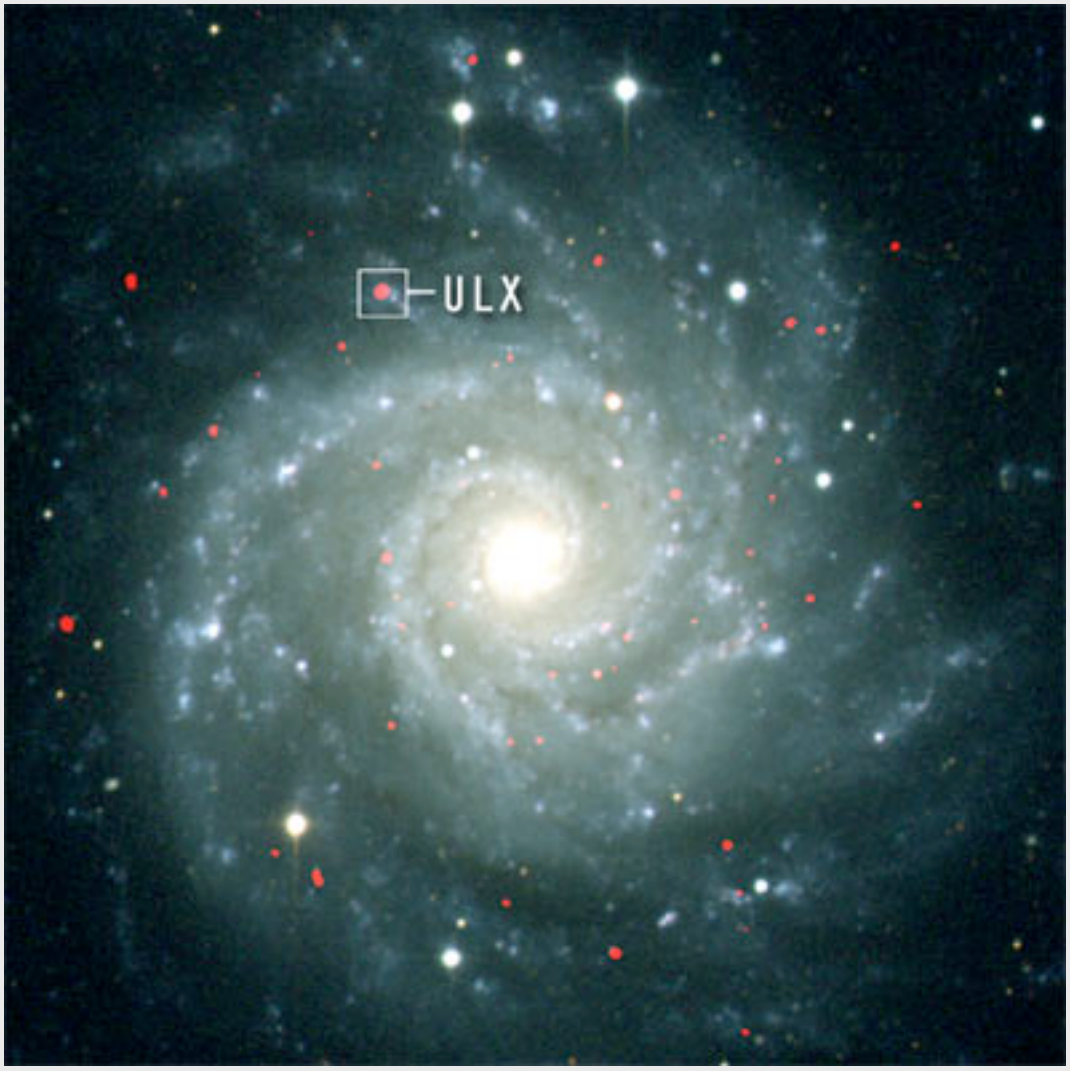
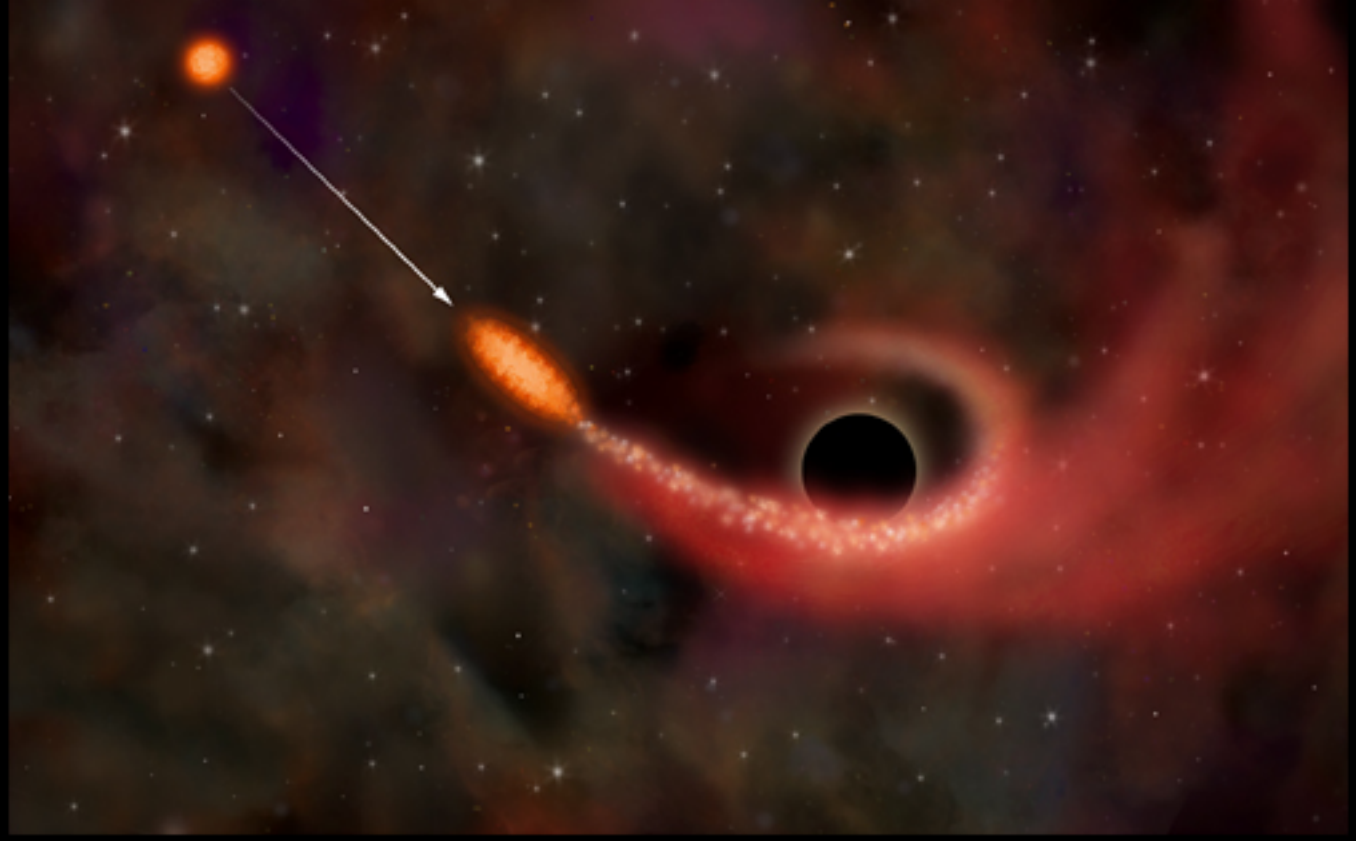
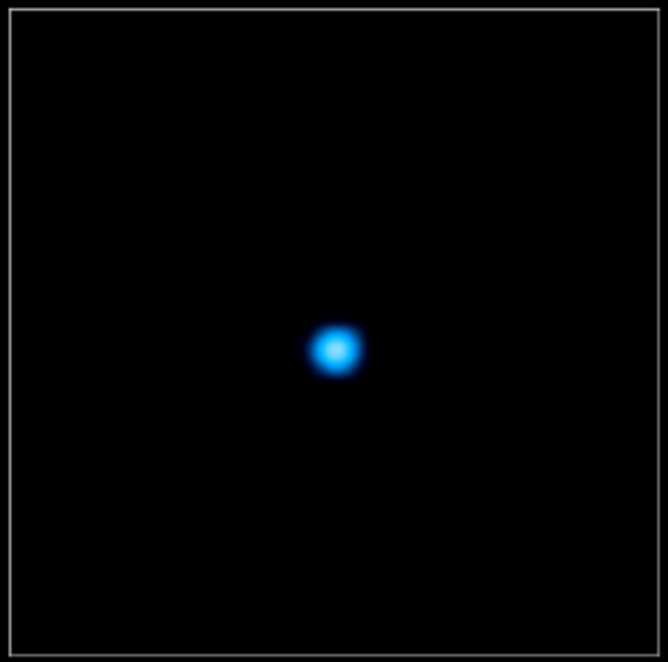
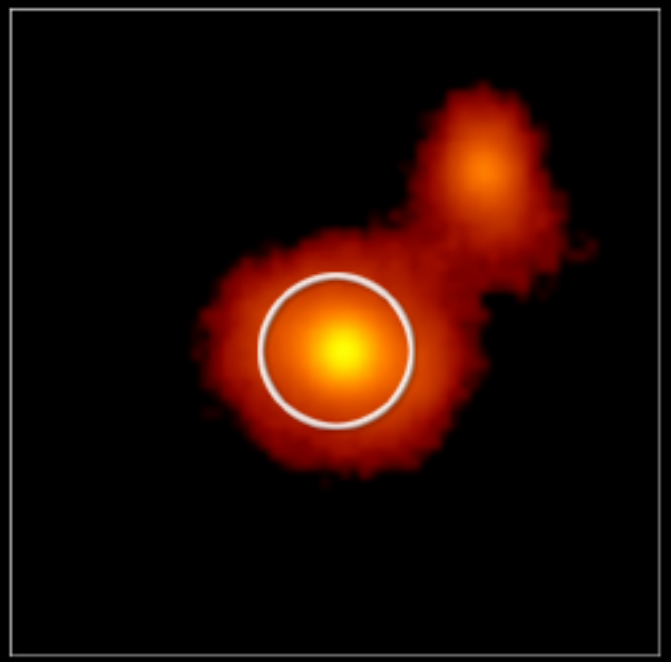


Look for X-ray sources
in the sky...







CHANDRA X-RAY

ESO OPTICAL

Compact:

heavy,
small.

Strong gravity:

rips stars apart

Look for radiation from the stuff falling in

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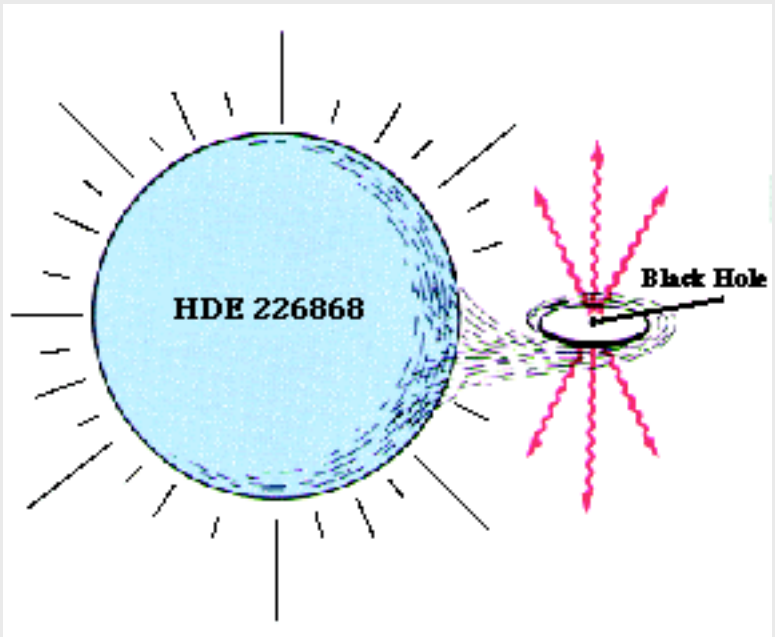
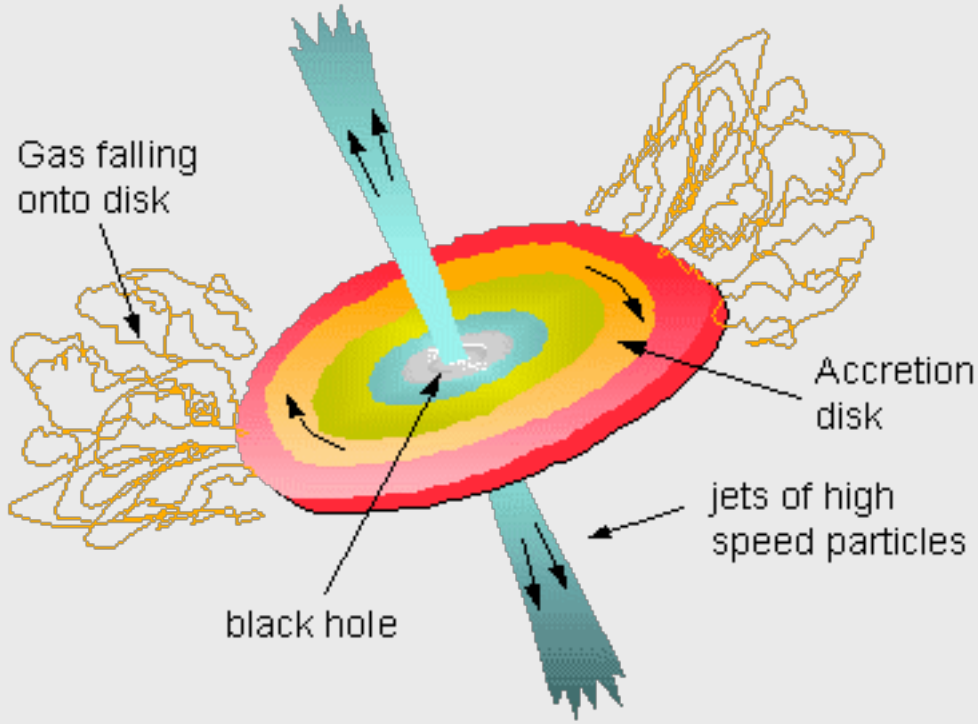
What we think is going on:





Accretion disks are very important for astrophysics...

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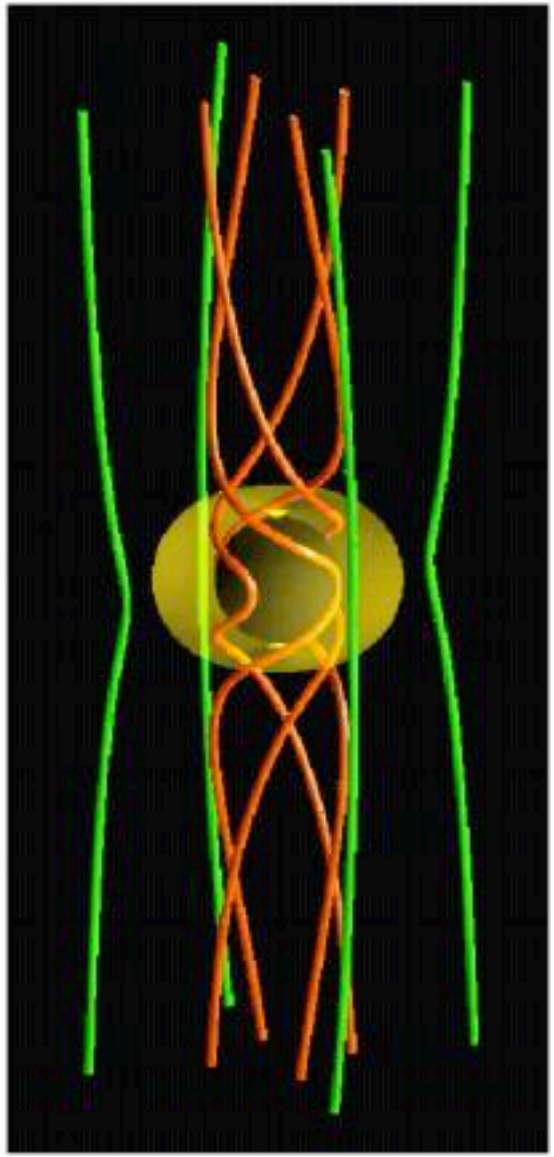
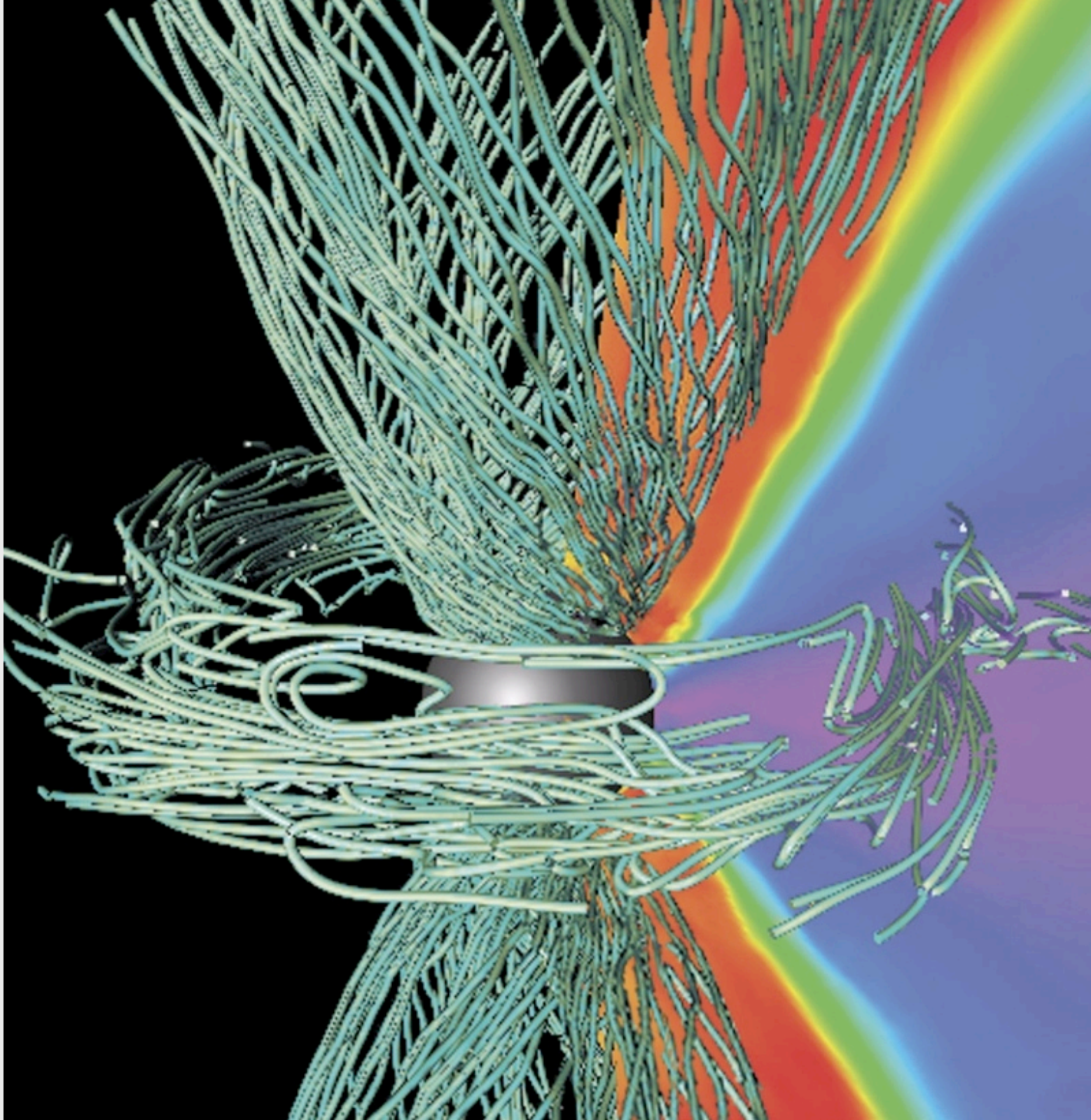
Magnetic field lines get "trapped" in the black hole ...

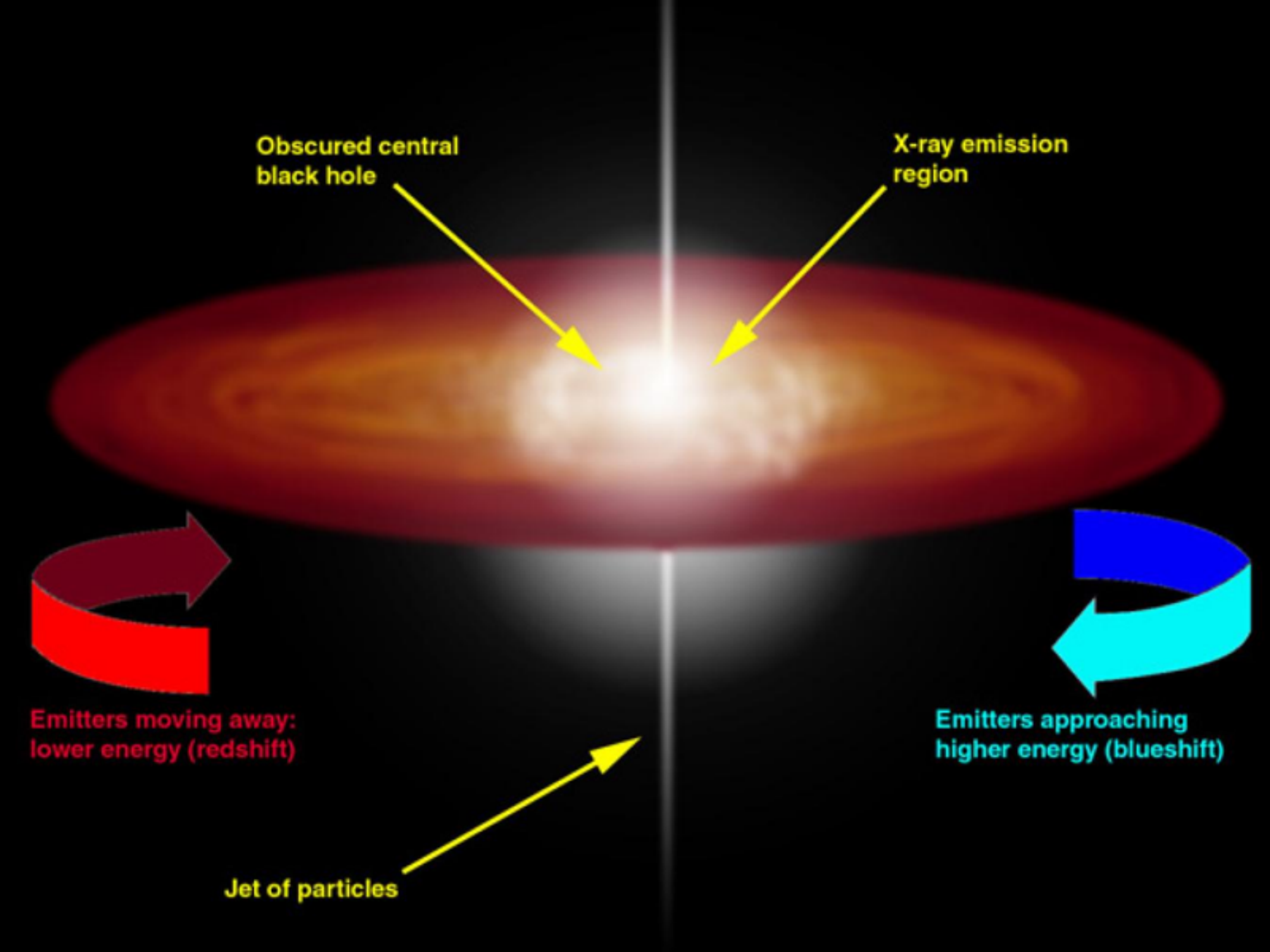
... and are twisted and churned by the rotation of the black hole ...

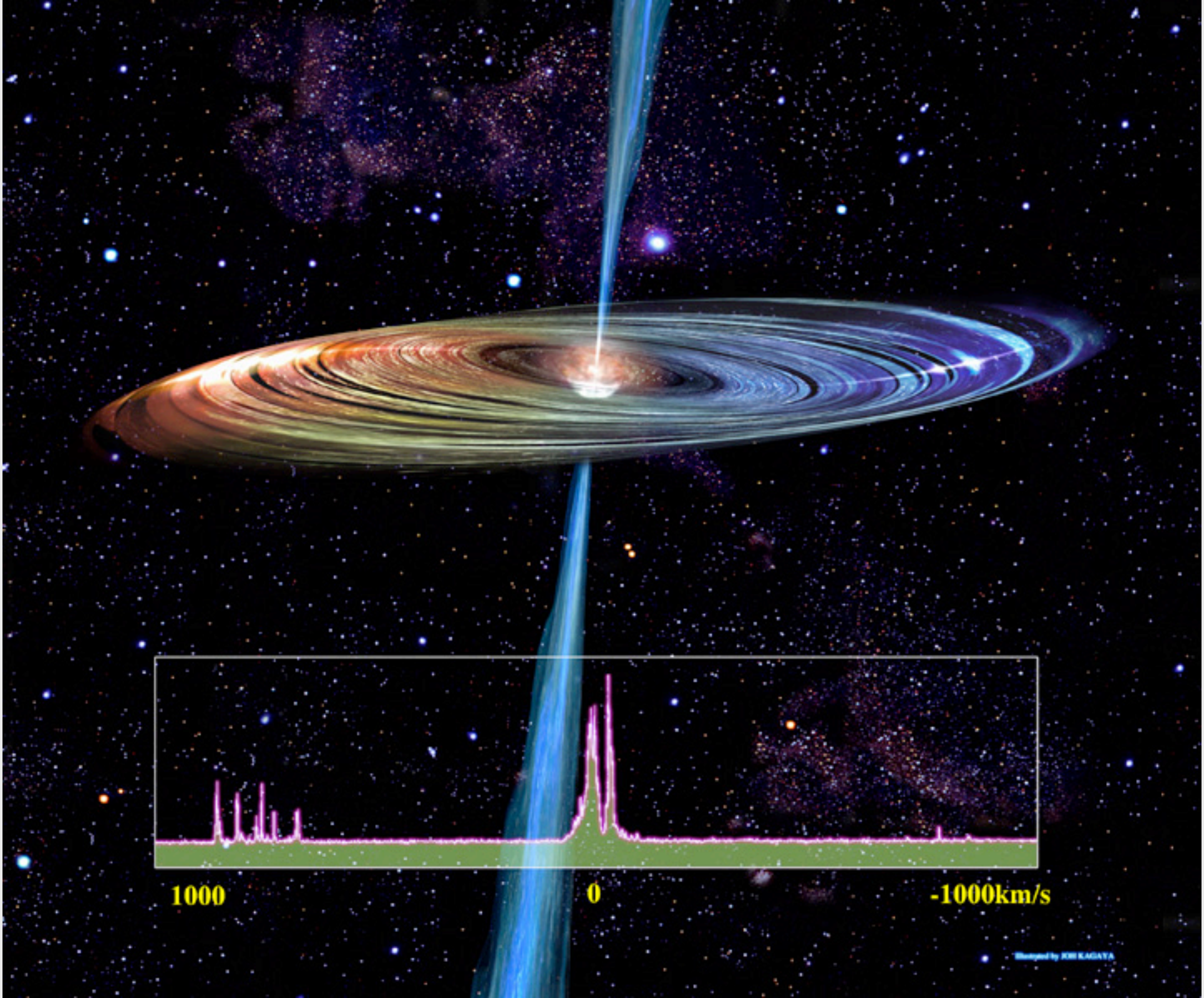


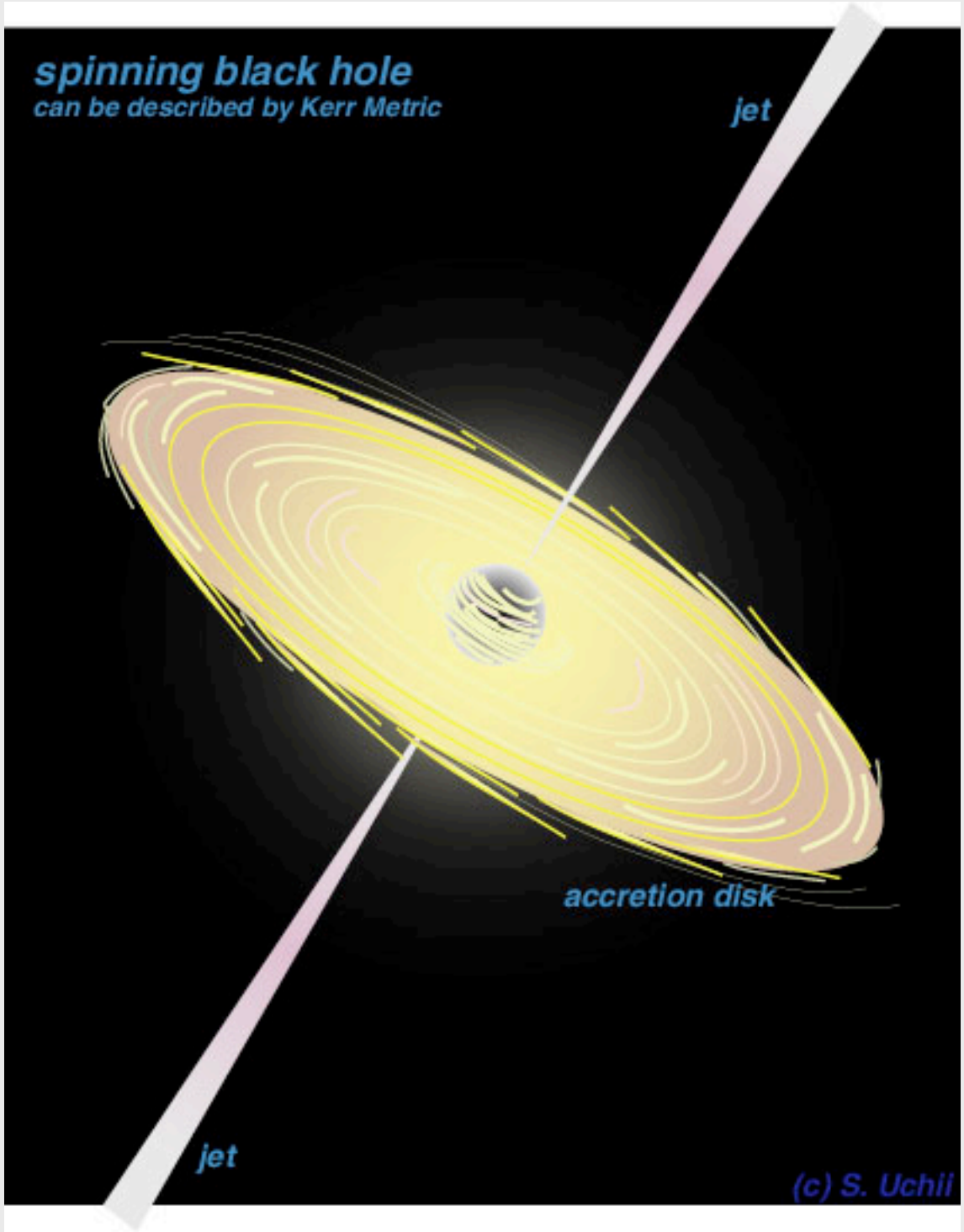
Spaghetti junction...

There's lots of energy in the magnetic field --- to do interesting things to the infalling matter...




Obscured central black hole
X-ray emission region
Emitters moving away: lower energy (redshift)
Emitters approaching higher energy (blueshift)
Jet of particles


1000
0
-1000km/s

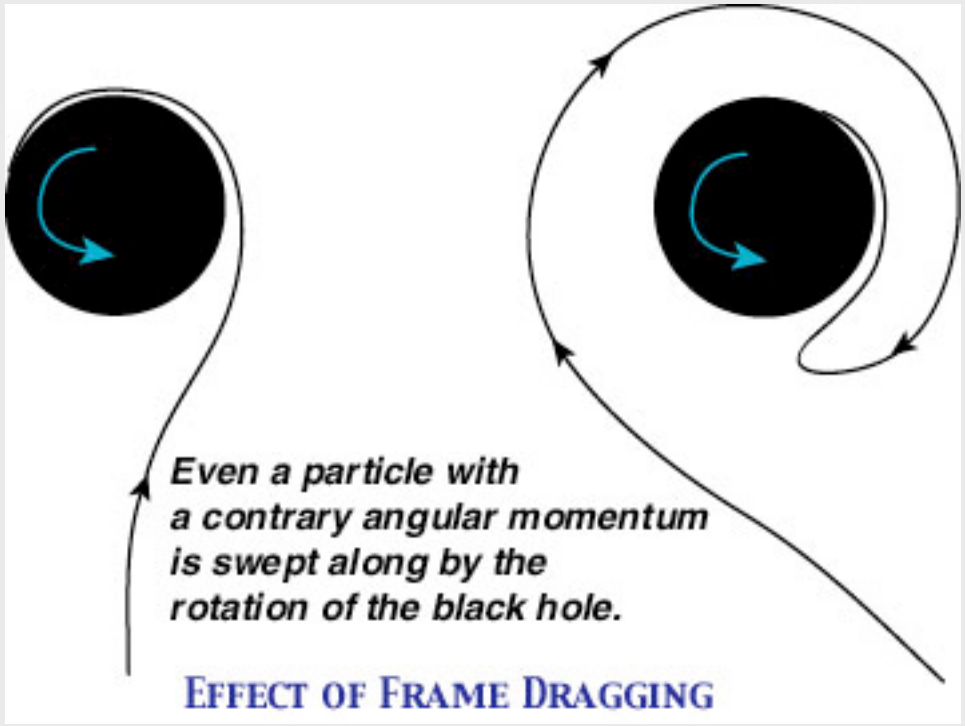


Back to some theory:

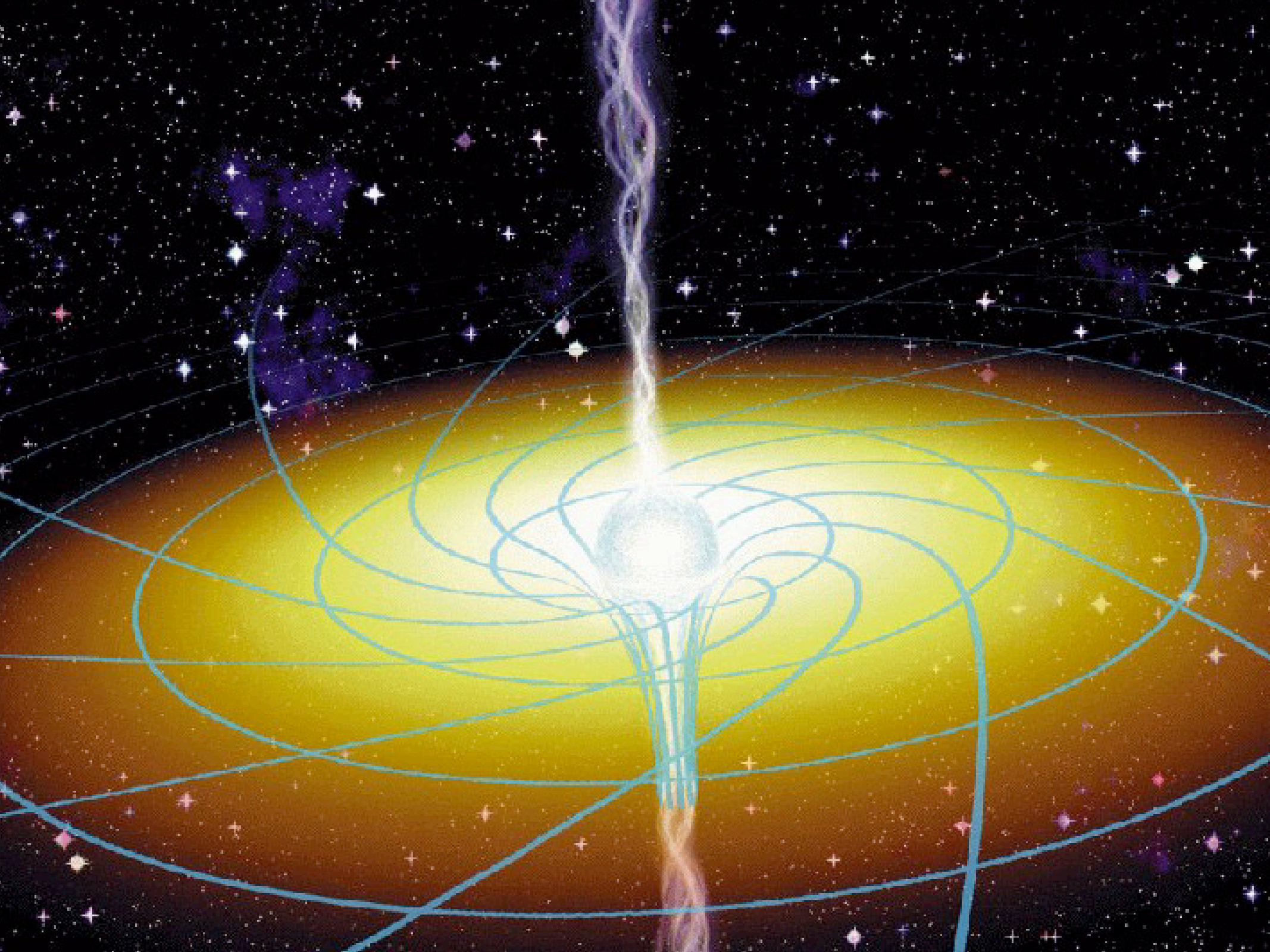
Most astrophysical black holes are expected to rotate...

Schwarzschild's black hole is not good enough as a model...

Need to use Roy Kerr's rotating black hole...



Gravity now has a “twist” to it as well as pointing more or less “down”...



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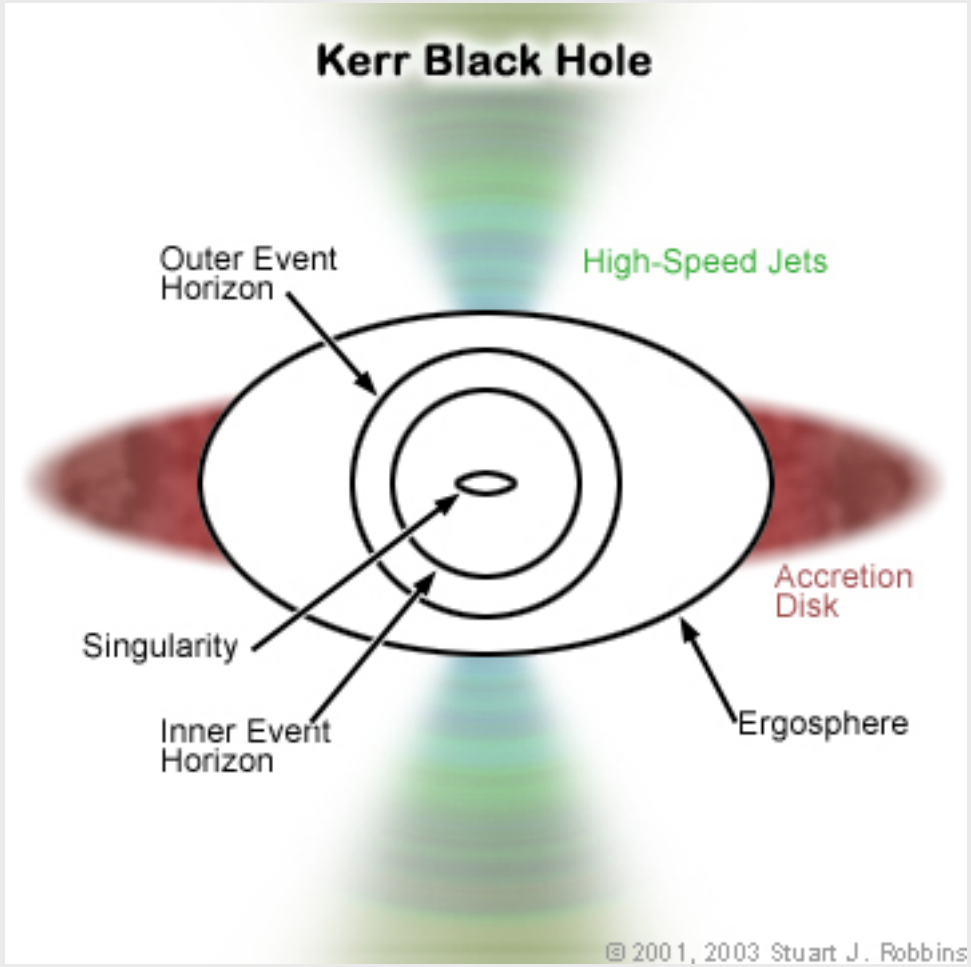

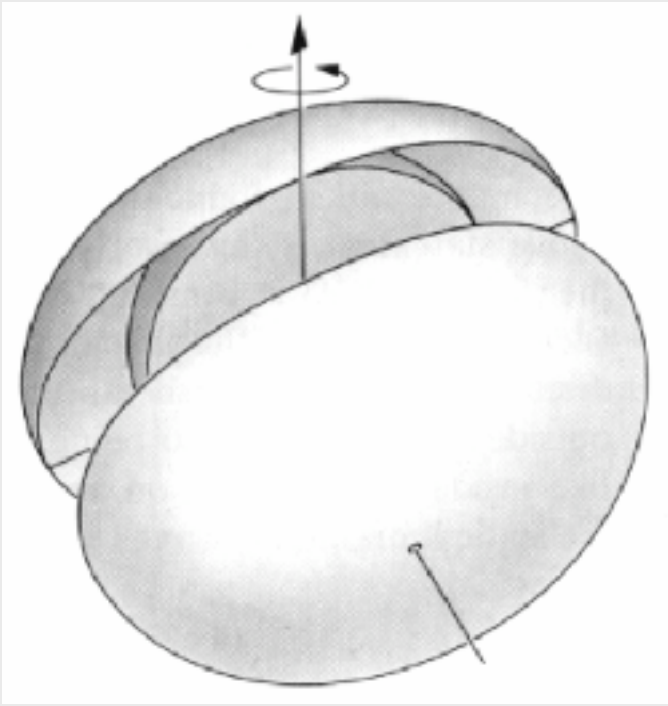

More than just a horizon and photon sphere...

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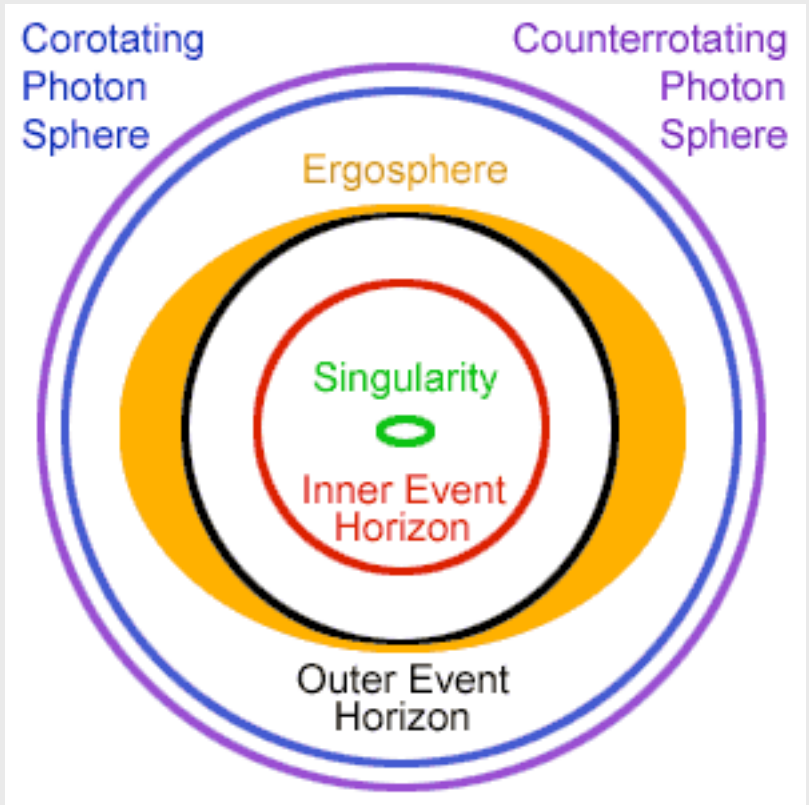
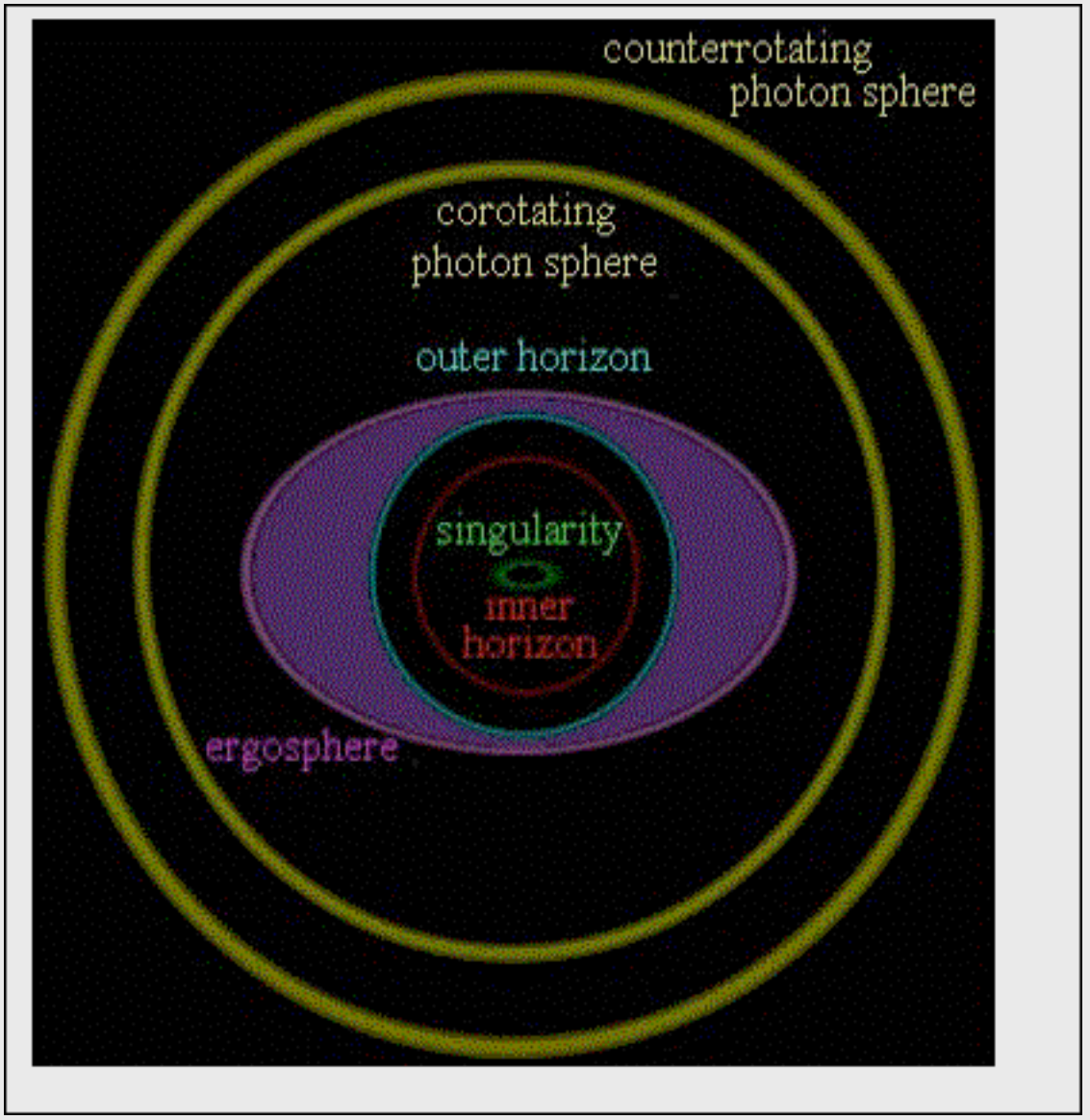
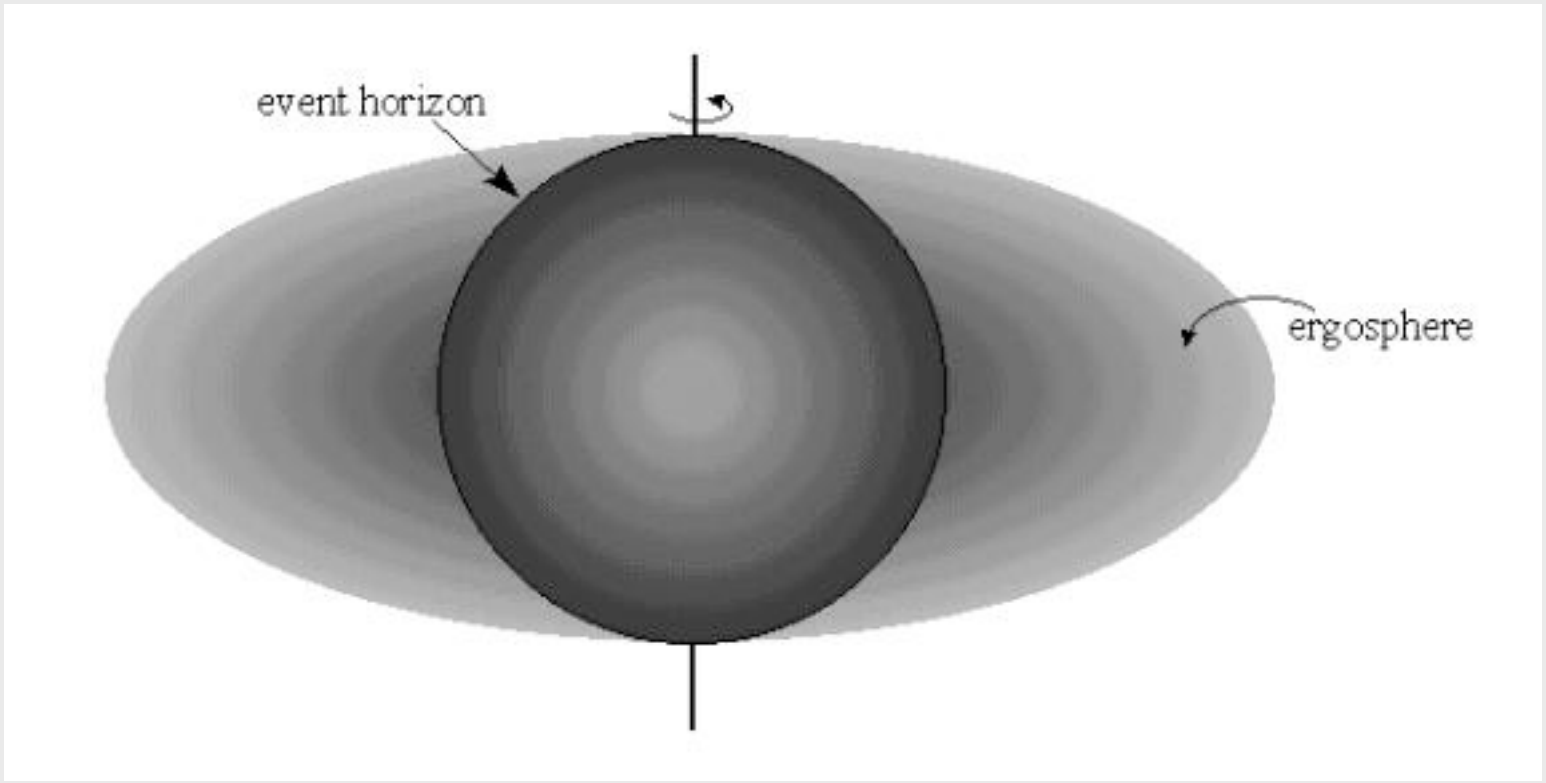




Now have two photon spheres....



From the outside, ergoregion and horizon is all you will ever see --- internal "structure" will be invisible...

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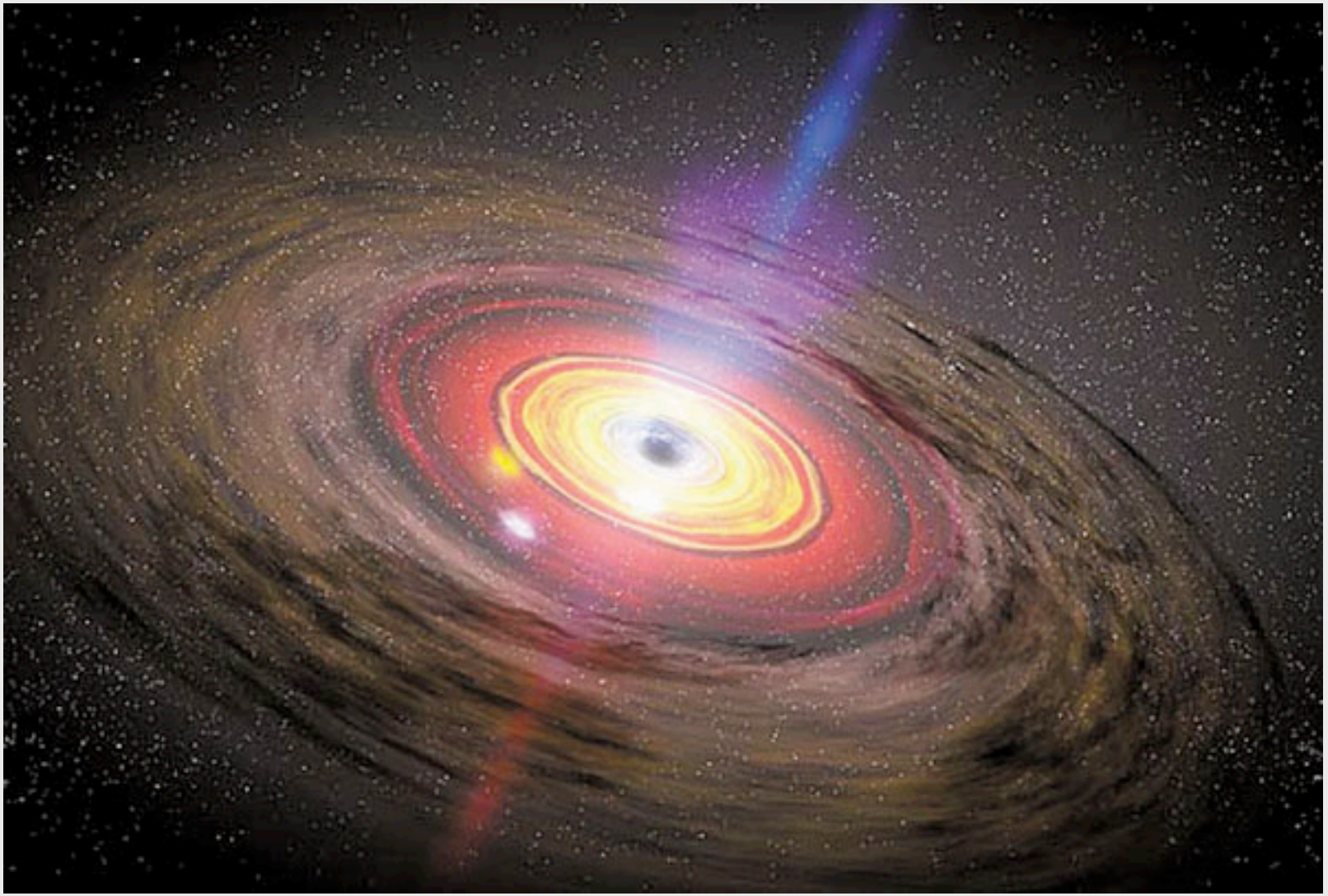
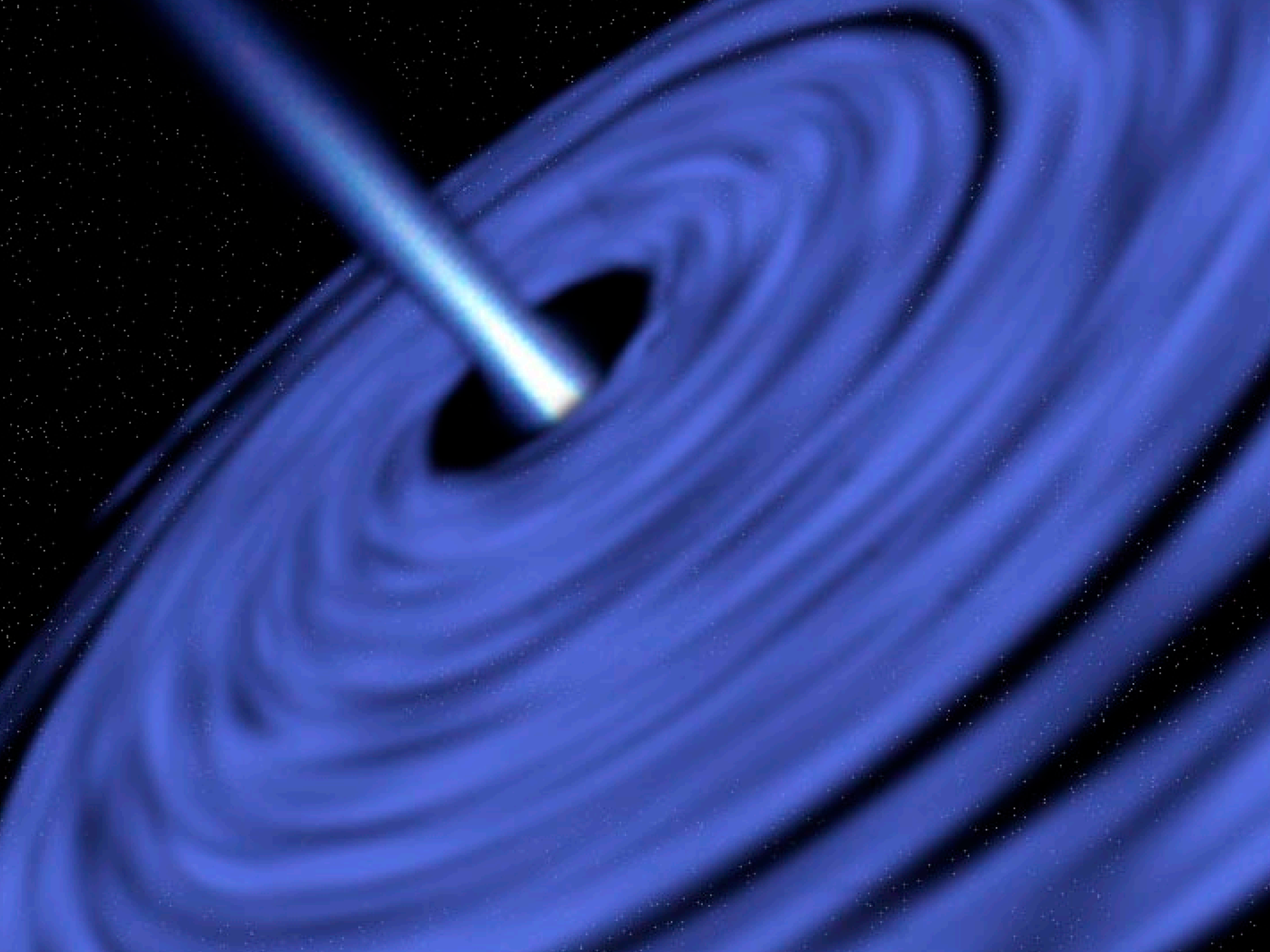
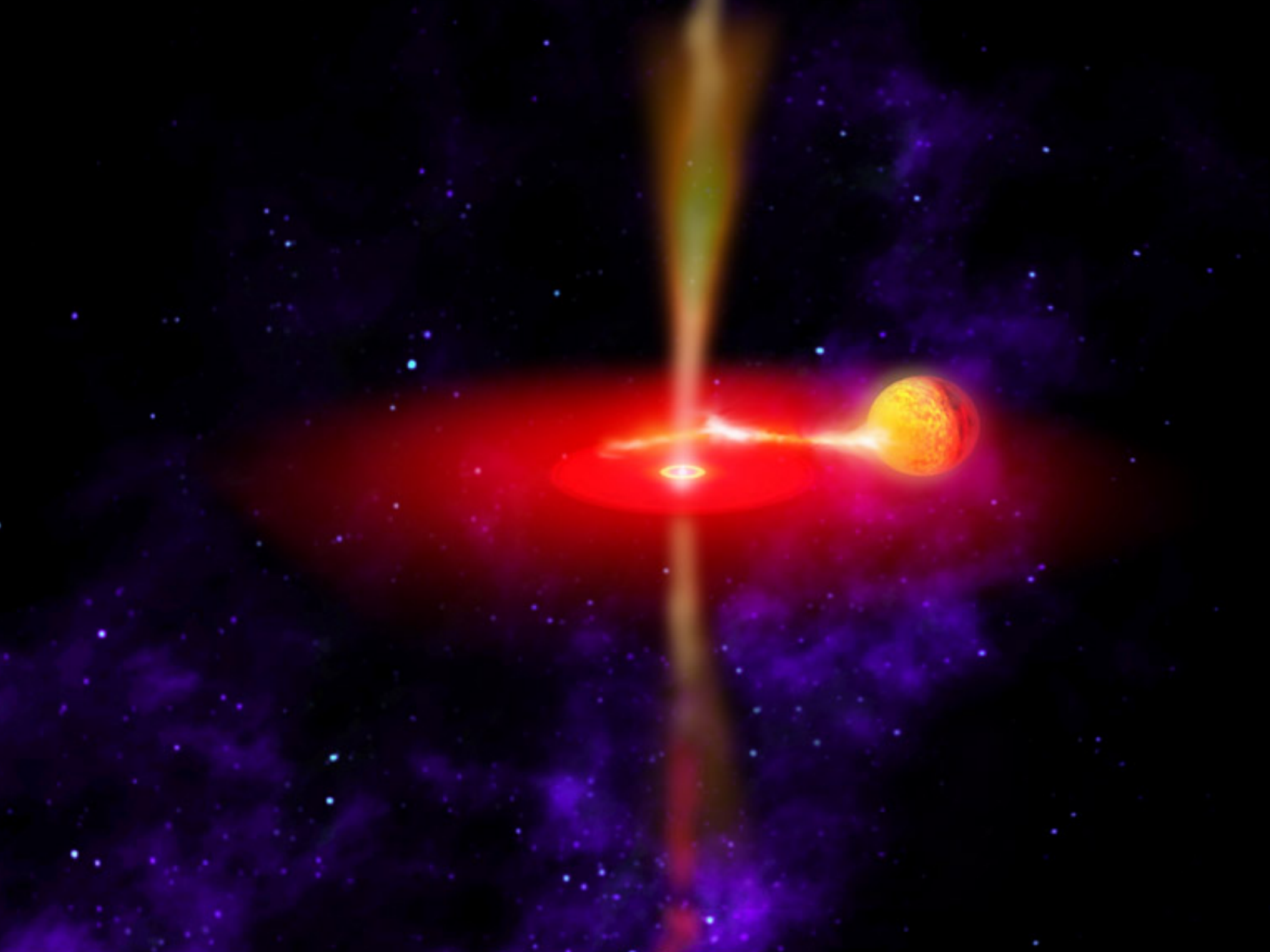
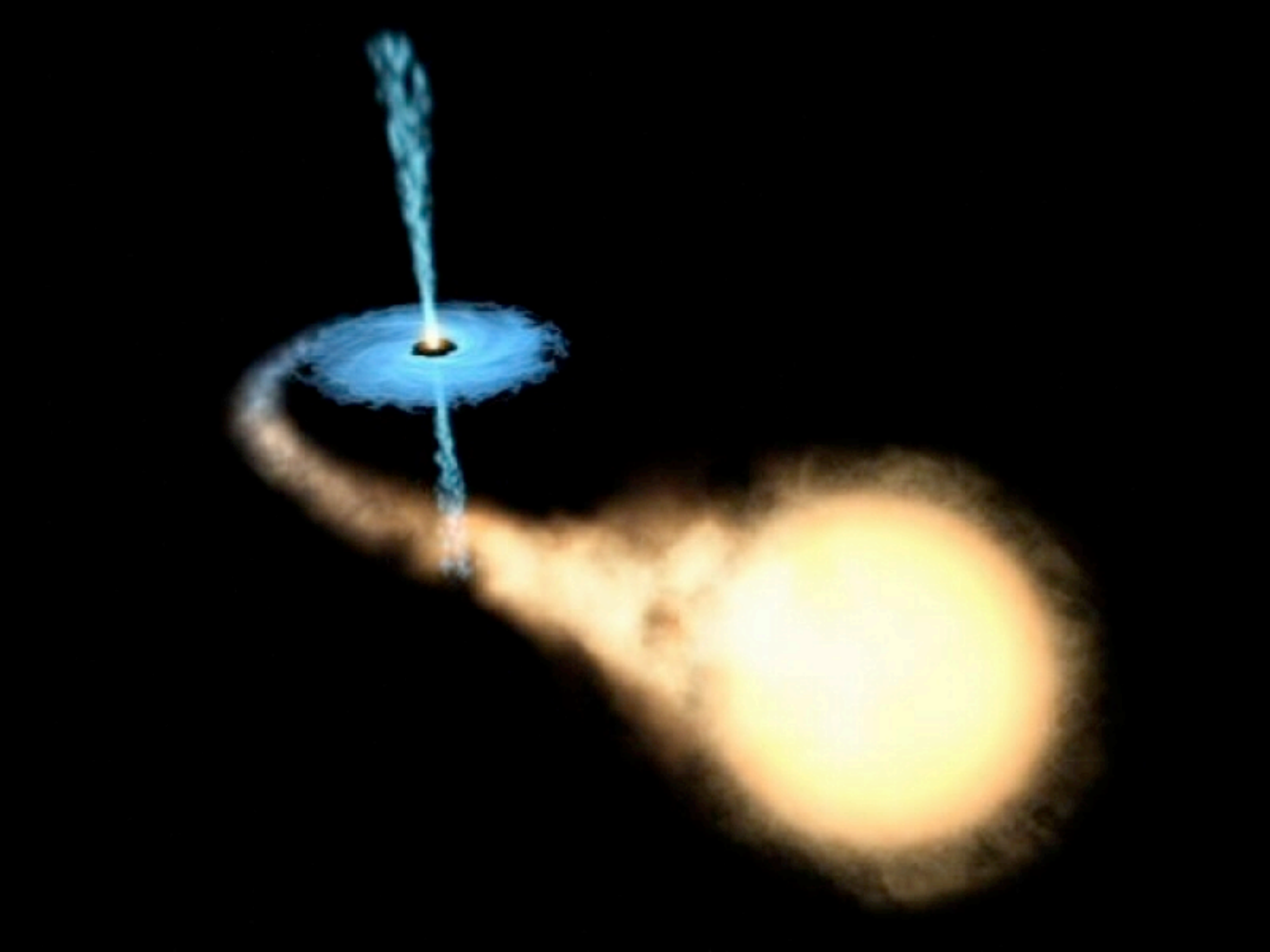


With a little dramatic license...







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Some real data...

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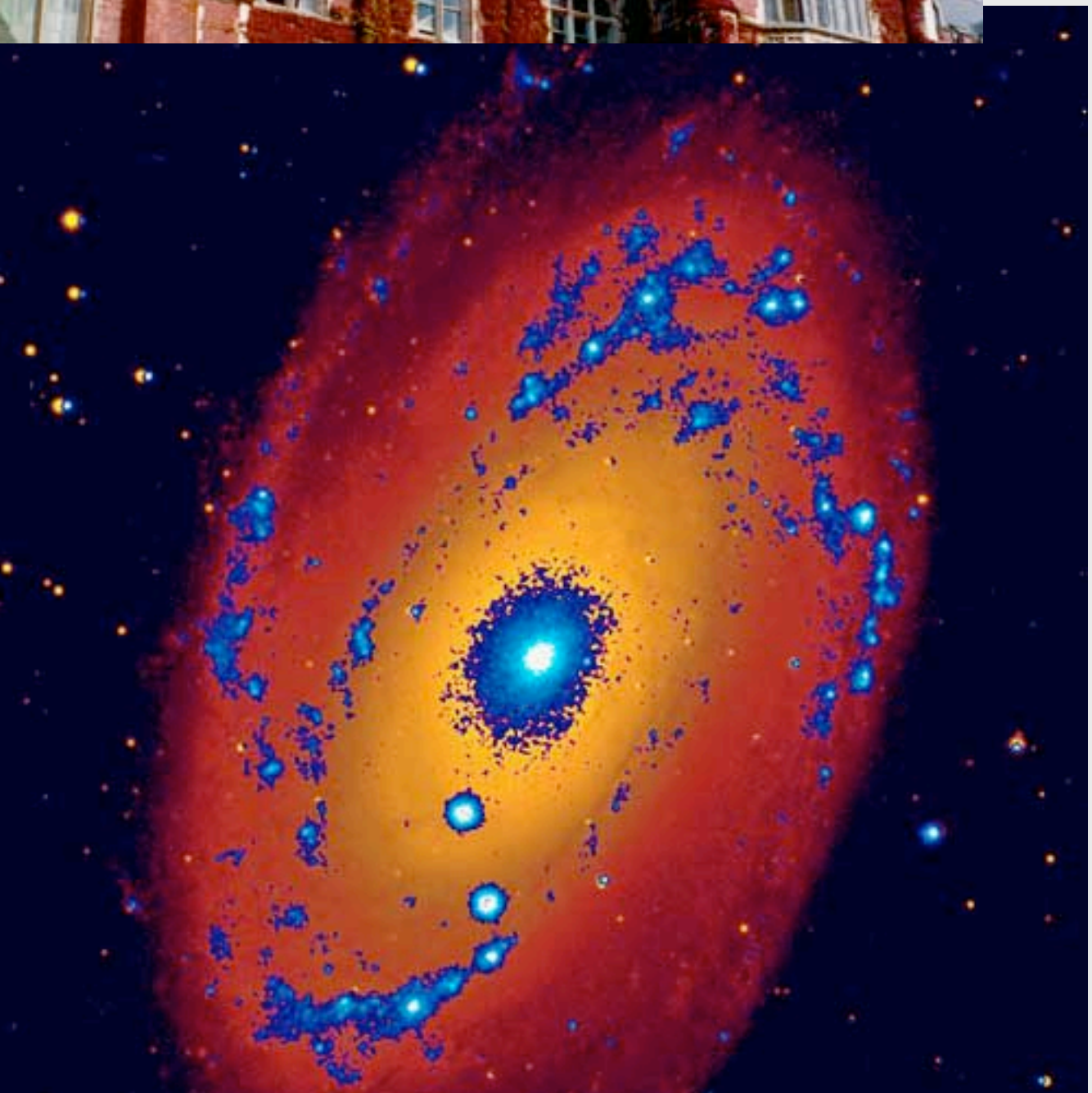
Galaxy M81 --- with a big black hole in the center...



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M81 again...

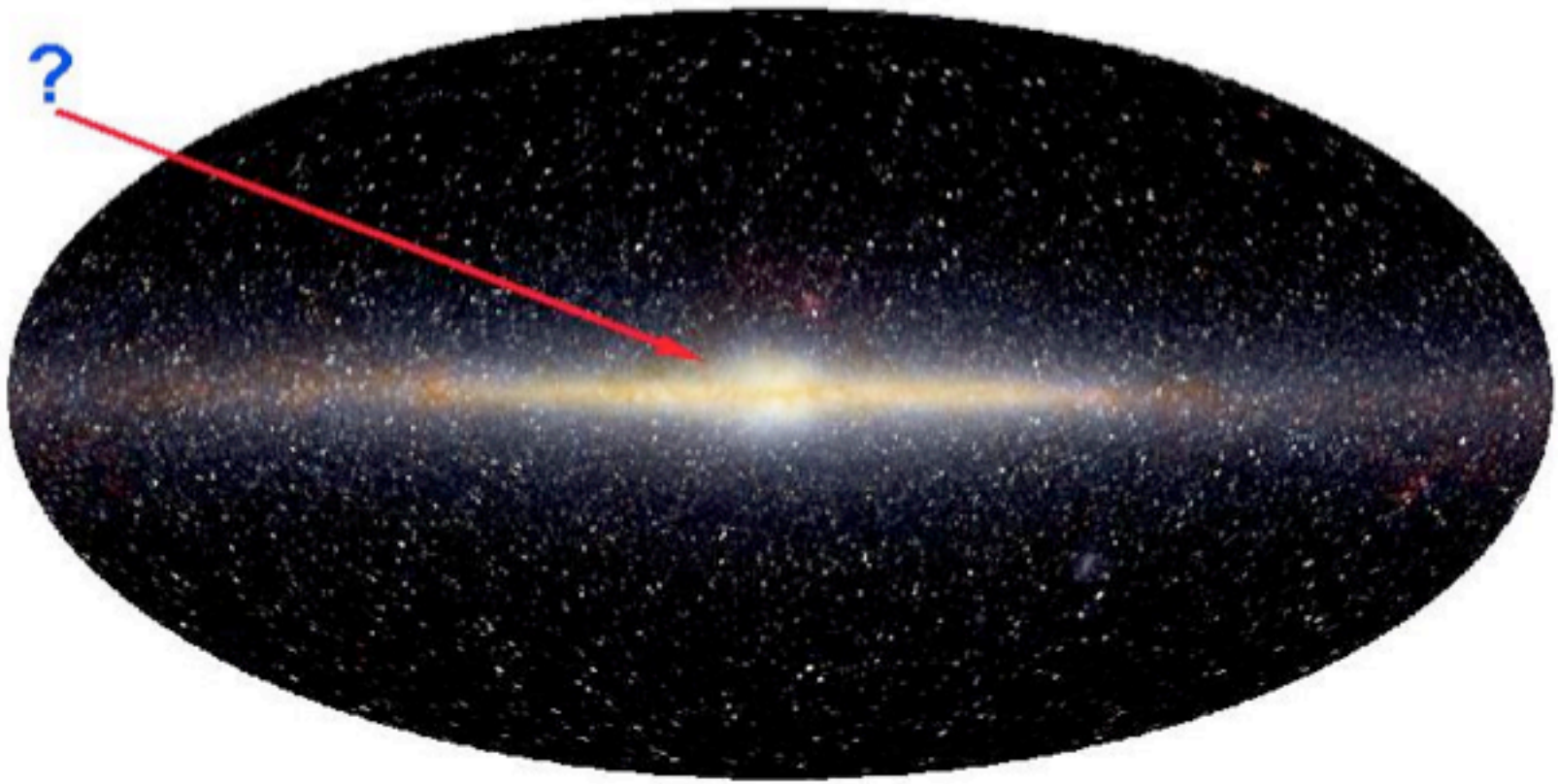
This view of M81, obtained by a telescope aboard a space shuttle mission, shows the galaxy in both visible (red and yellow) and ultraviolet (blue) wavelengths.

The blue regions are much hotter than the others, and outline the galaxy's spiral arms and its nucleus.

The nucleus may contain a supermassive black hole.

Is there a black hole in the center of the Milky Way?

- **The Milky Way is our galaxy**
  - Many galaxies are thought to have black holes in their centers
  - Remnants of dead quasars which formed after the Big Bang



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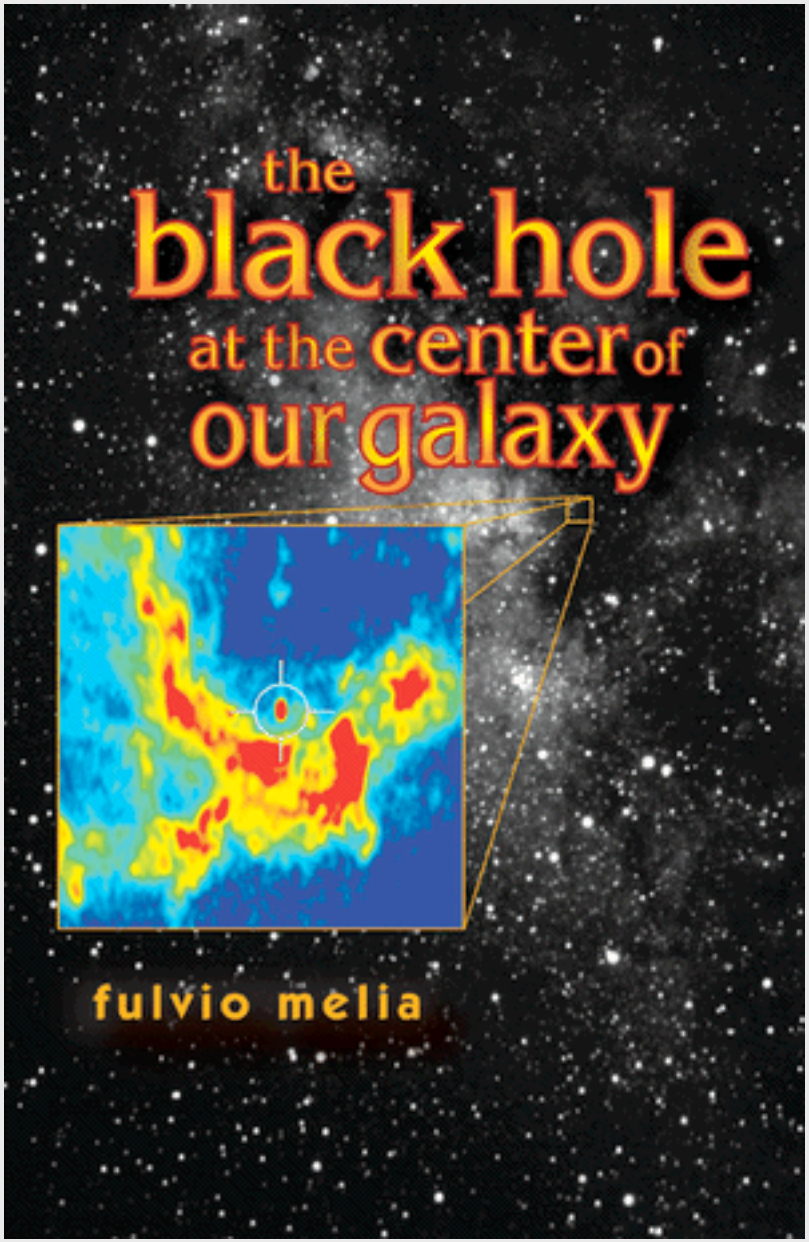

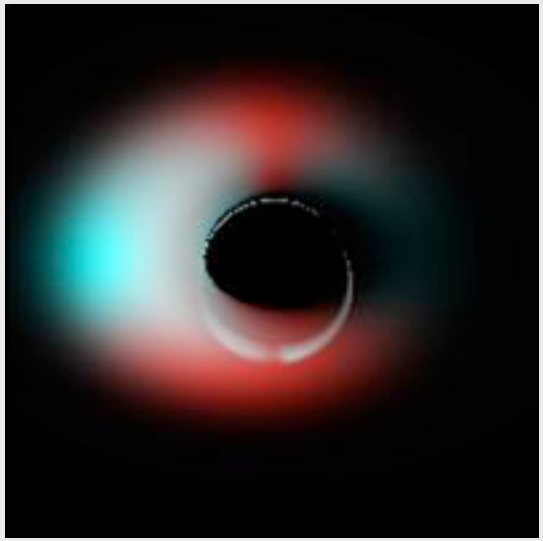

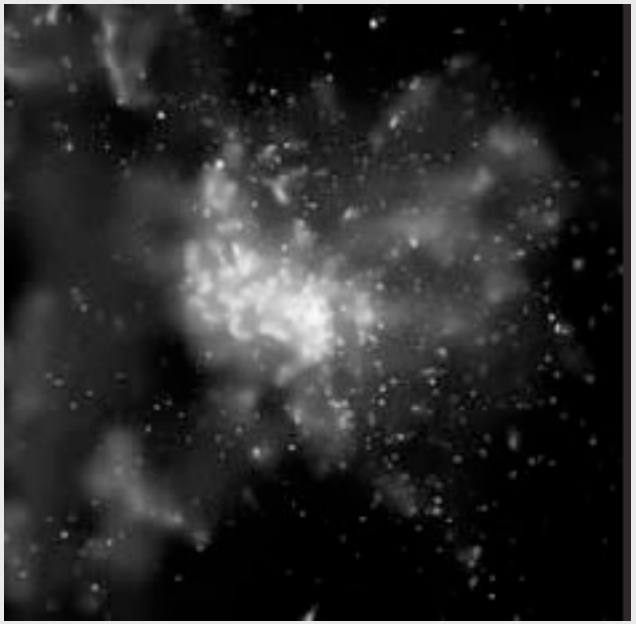

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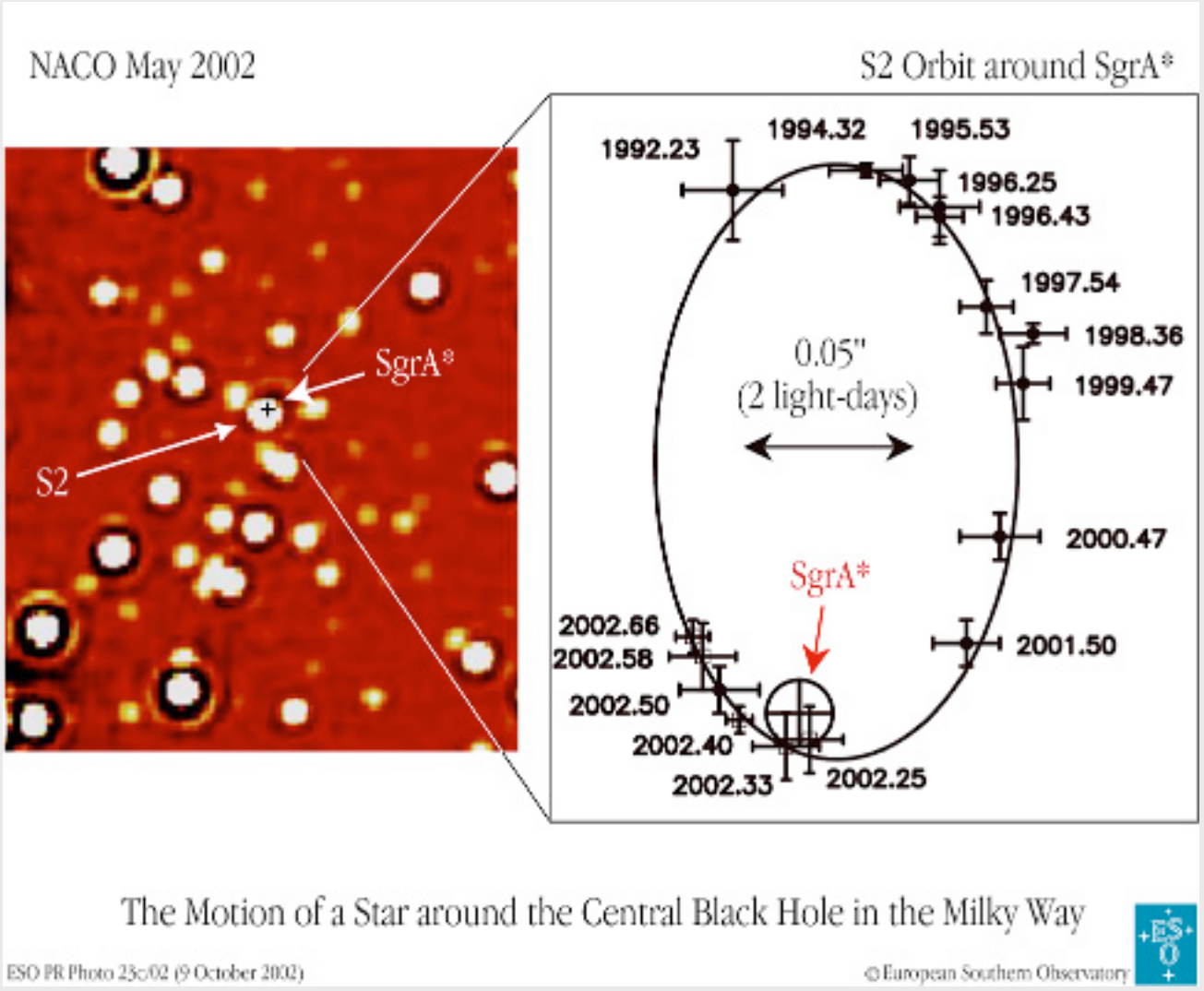

Stars orbiting around the central black hole of our own galaxy...

Gravity waves

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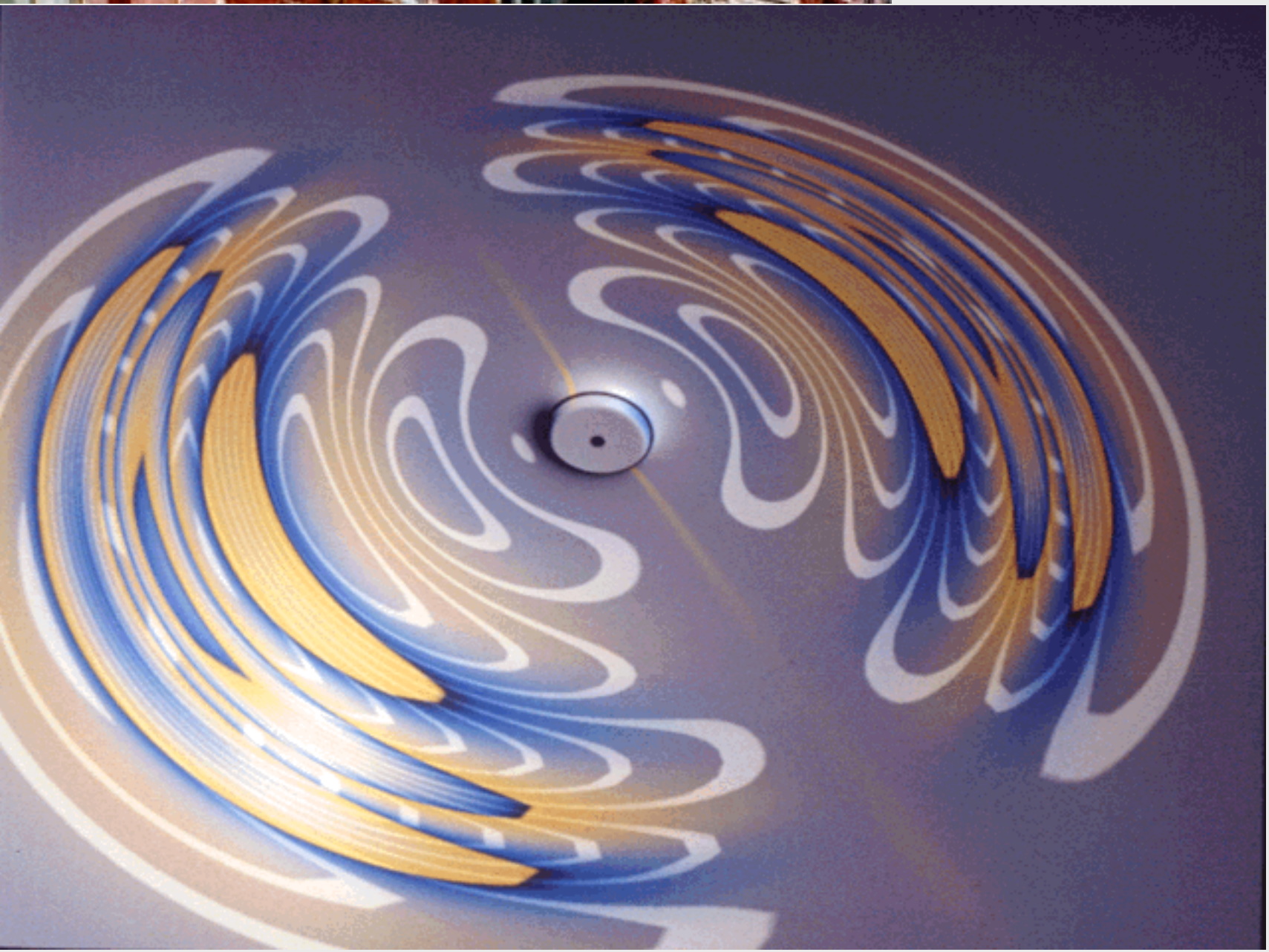

Ripples
in
space-time

Still
collecting
data...

LIGO

LIGO: (Hanford)

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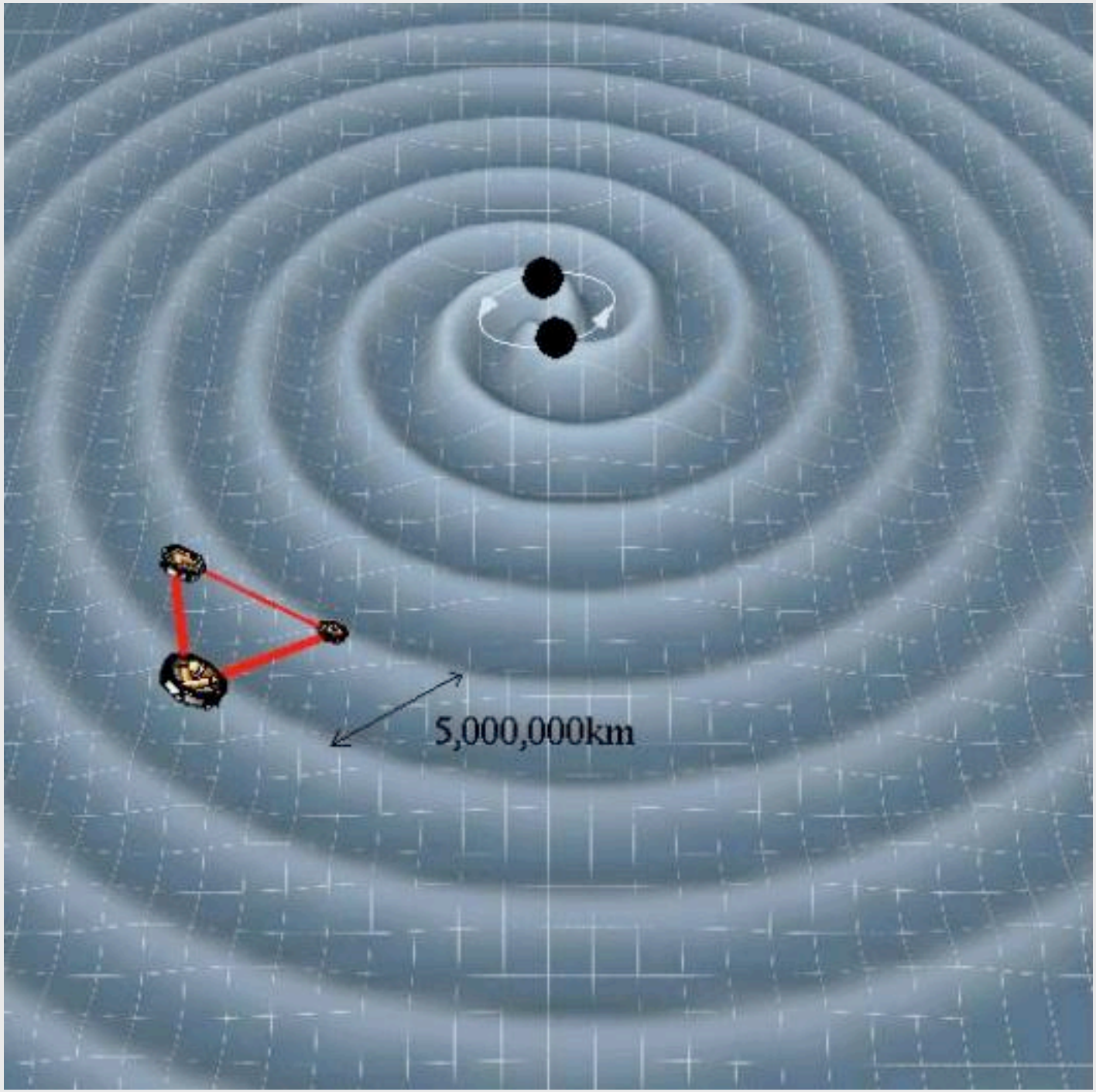
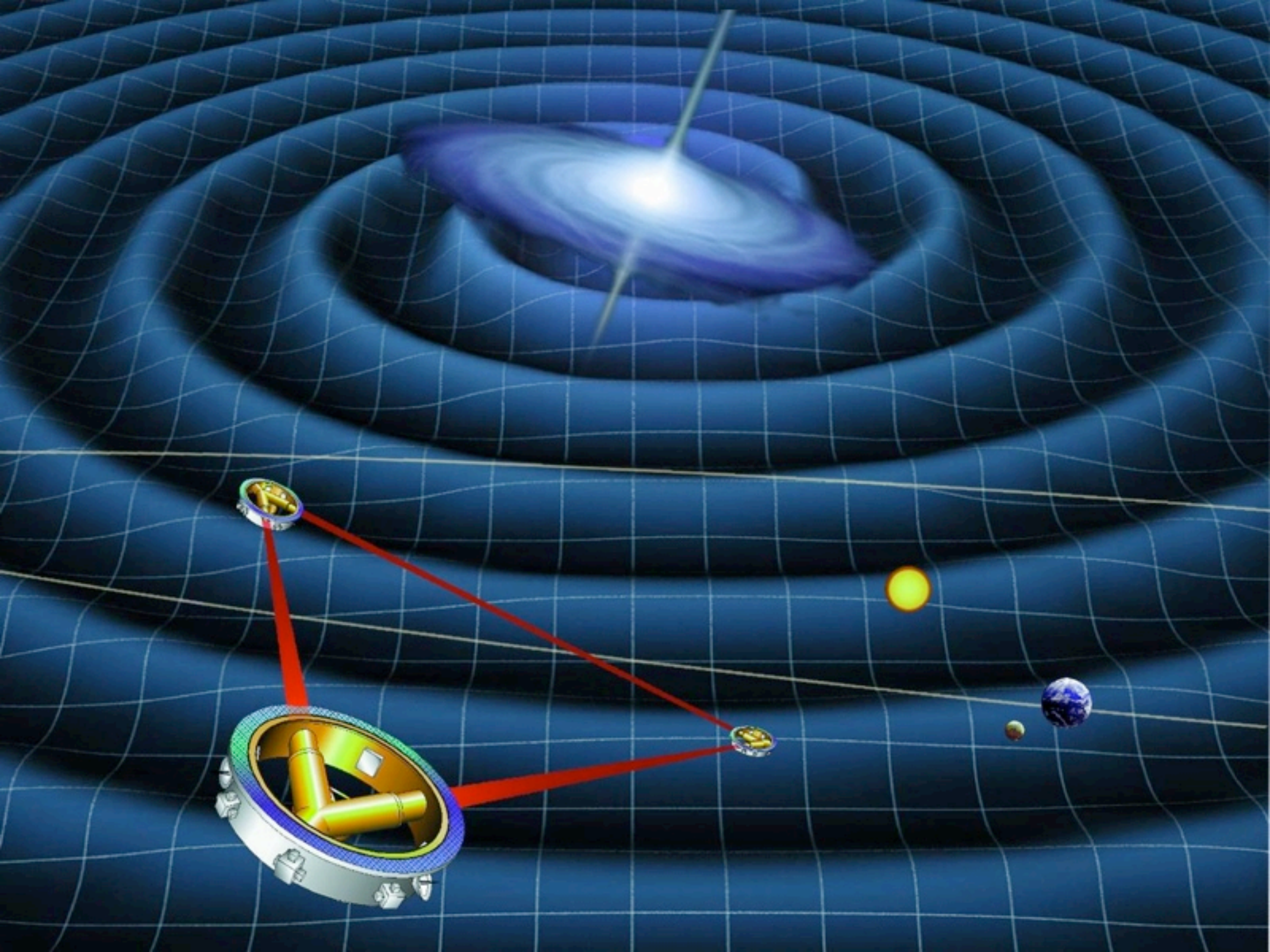
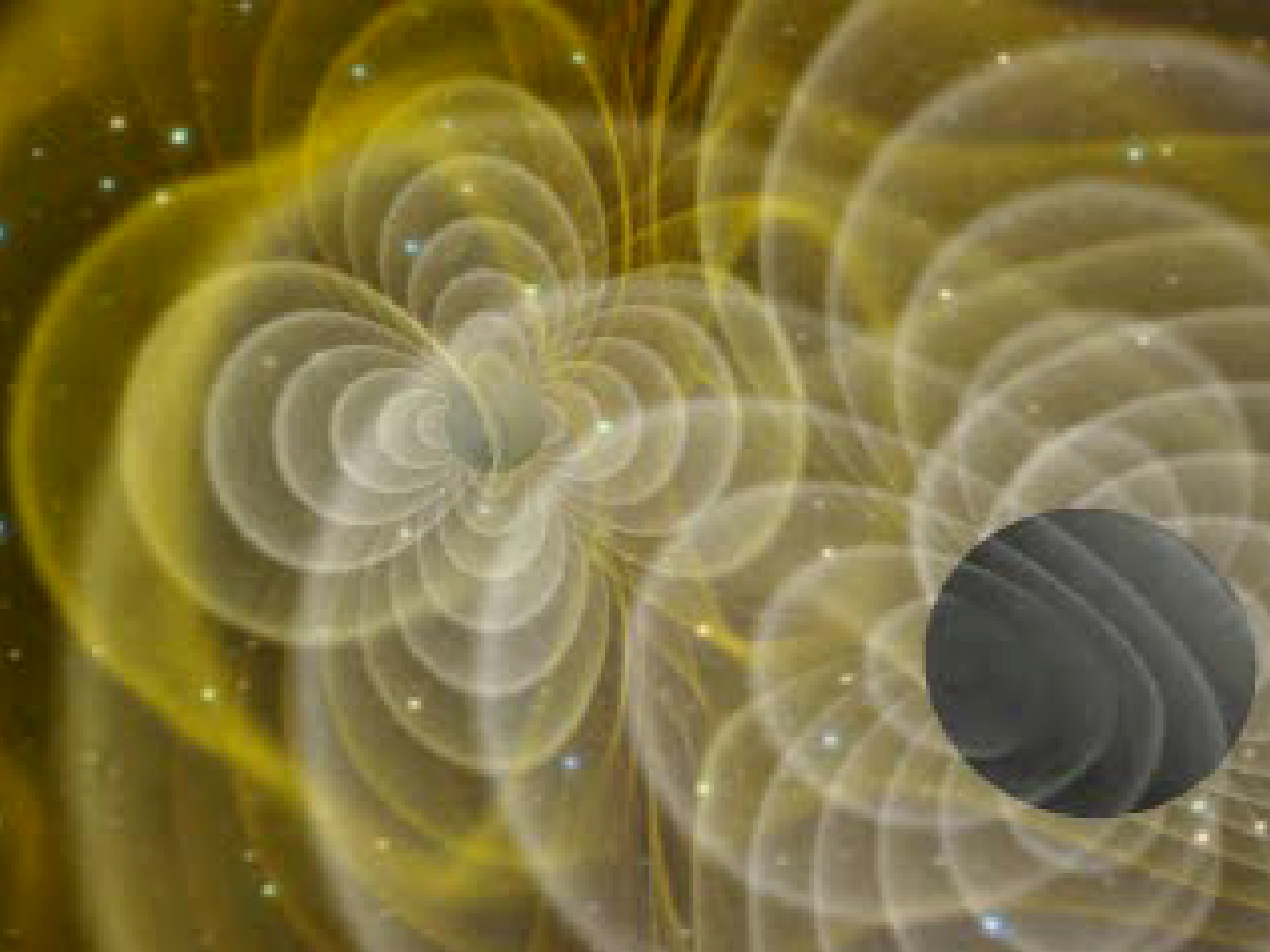
Gravity waves? We're looking...



LISA...





Commun. math. Phys. 31, 161–170 (1973)

The Four Laws of Black Hole Mechanics

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Department of Physics, Yale University, New Haven, Connecticut, USA

B. Carter and S. W. Hawking
Institute of Astronomy, University of Cambridge, England

Received January 24, 1973

Abstract. Expressions are derived for the mass of a stationary axisymmetric solution of the Einstein equations containing a black hole surrounded by matter and for the difference in mass between two neighboring such solutions. Two of the quantities which appear in these expressions, namely the area A of the event horizon and the "surface gravity" κ of the black hole, have a close analogy with entropy and temperature respectively. This analogy suggests the formulation of four laws of black hole mechanics which correspond to and in some ways transcend the four laws of thermodynamics.

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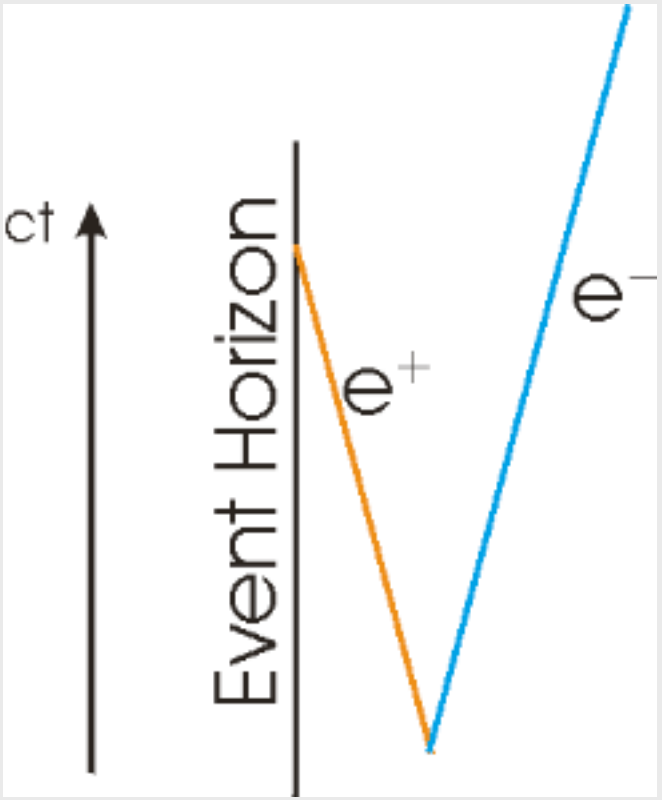

Stephen Hawking:

Black holes will eventually evaporate due to subtle quantum effects...

We're still calculating...

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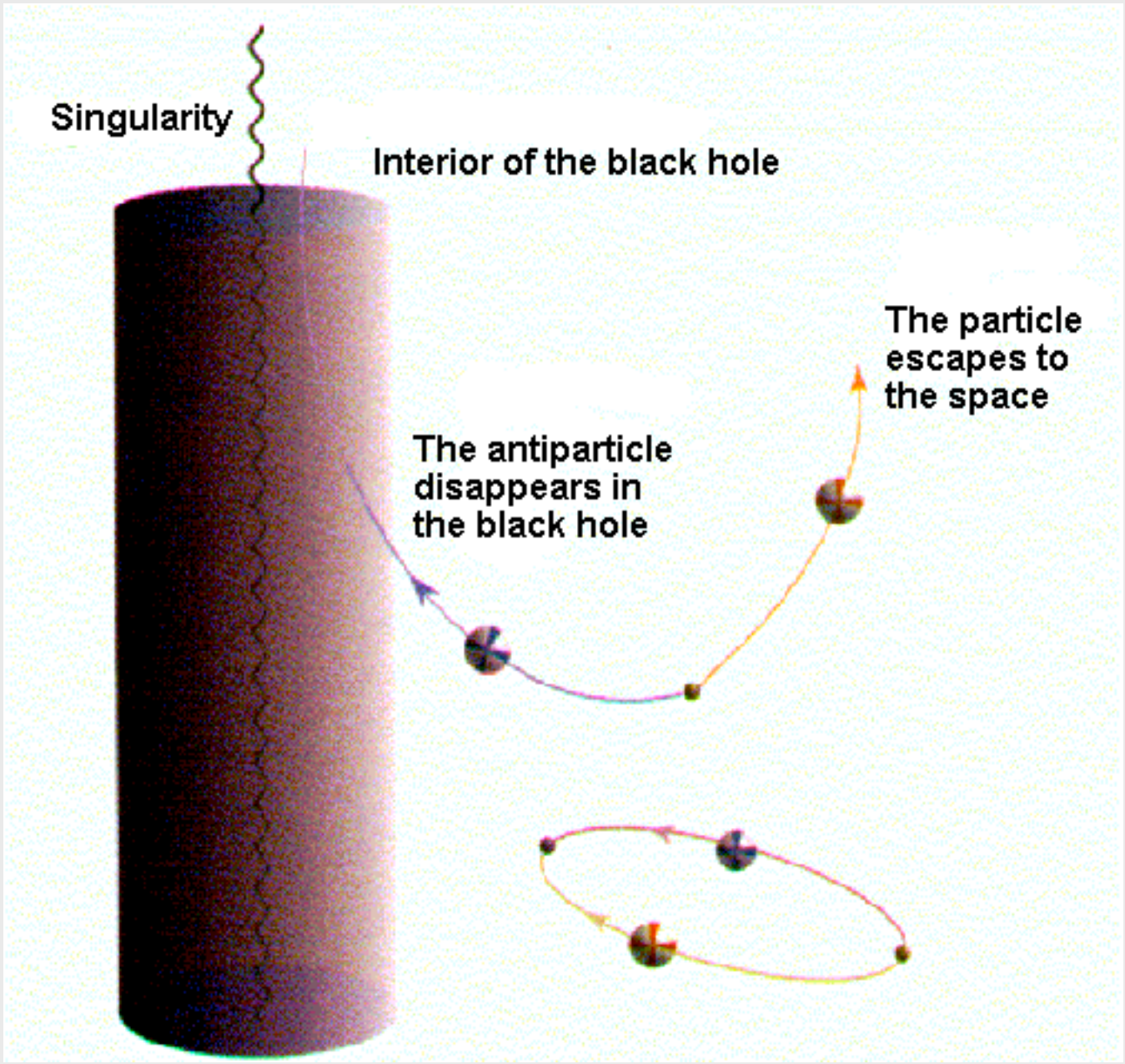

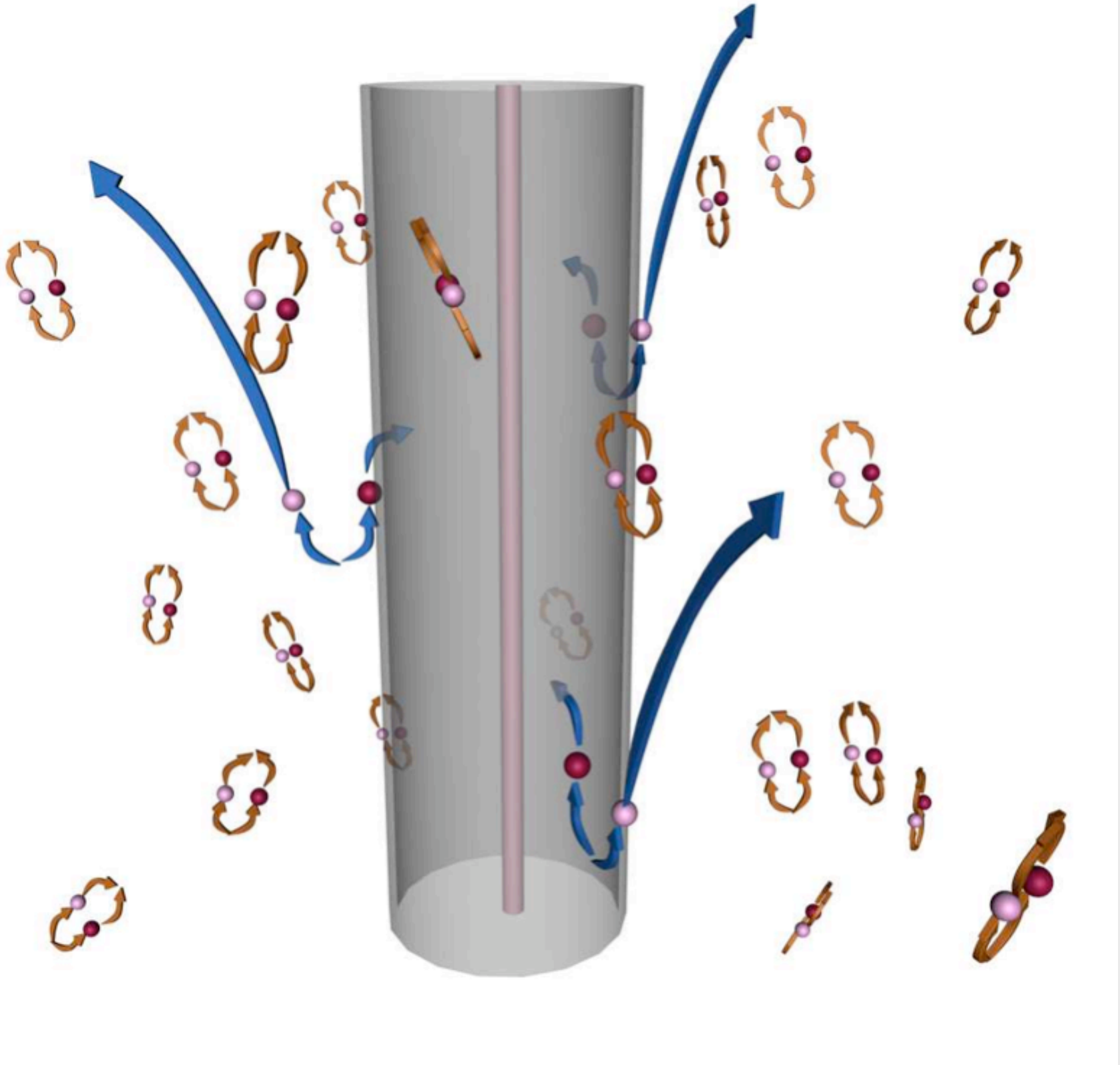

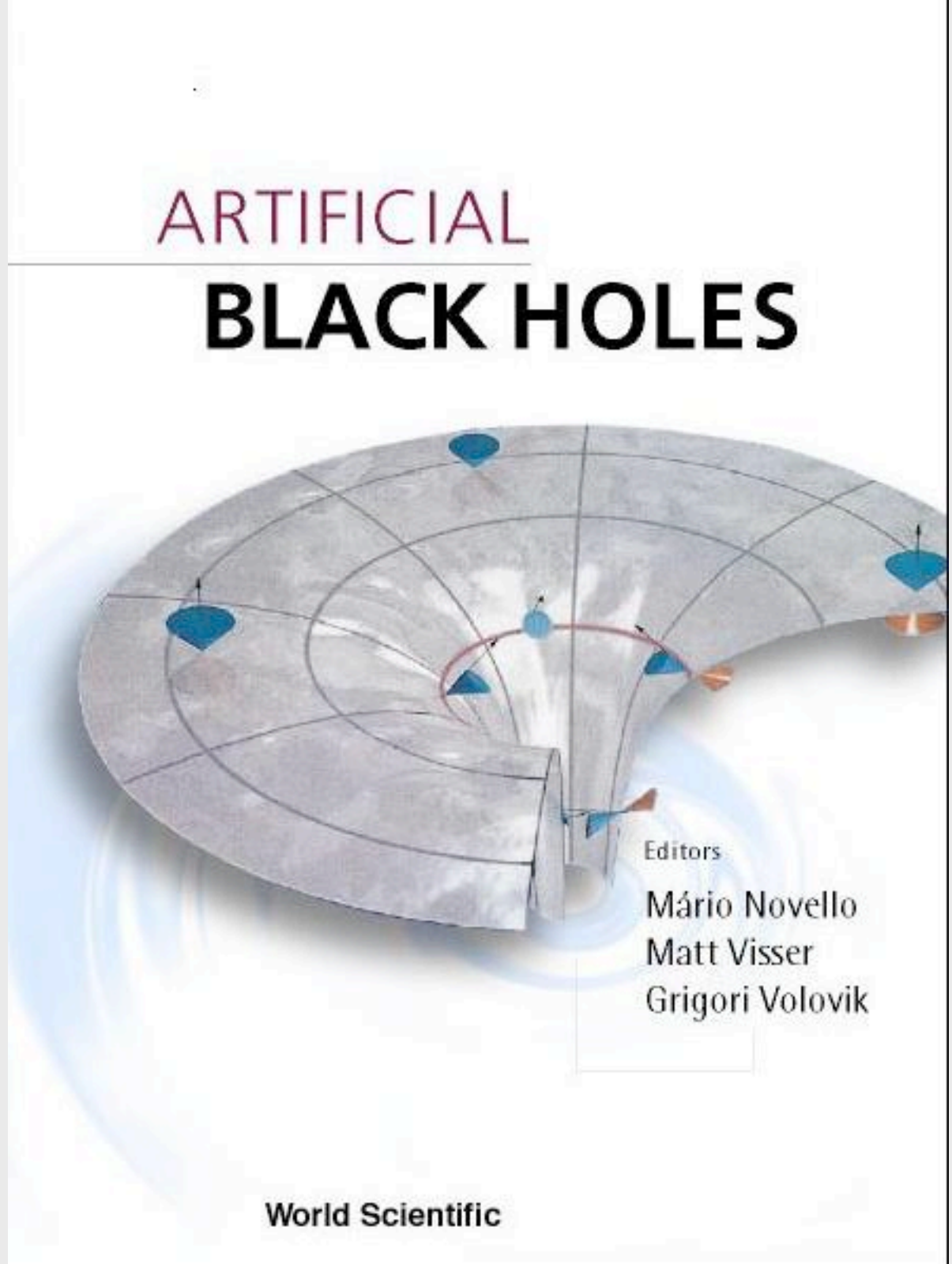

Scientists are trying to test Hawking radiation by simulating it in simpler systems...

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If you cannot build
a gravitational
black hole in
your laboratory,
at least try
something similar...

See how much of
"black hole physics"
can be carried over
into these "simpler"
systems...

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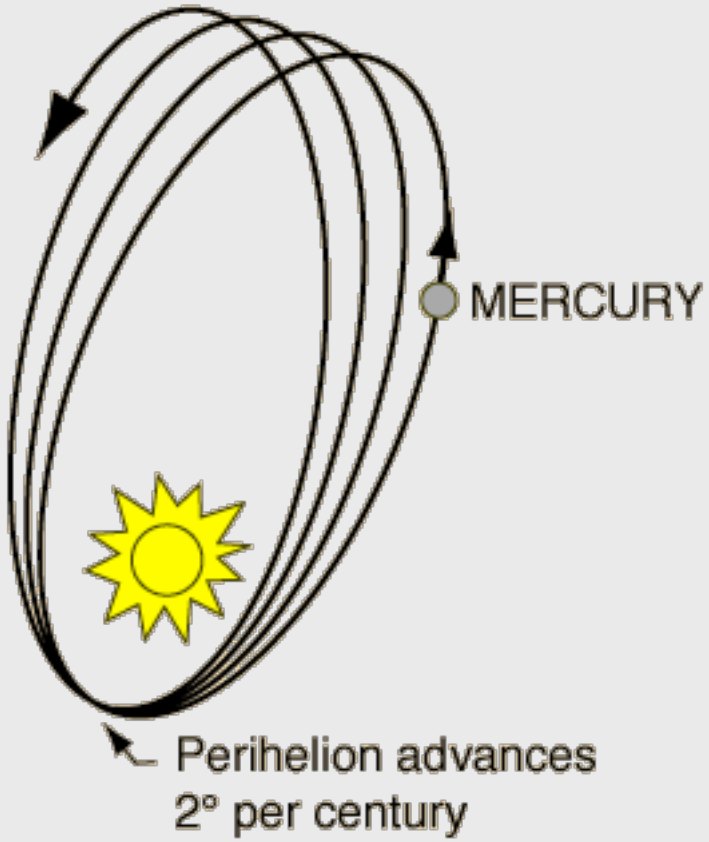
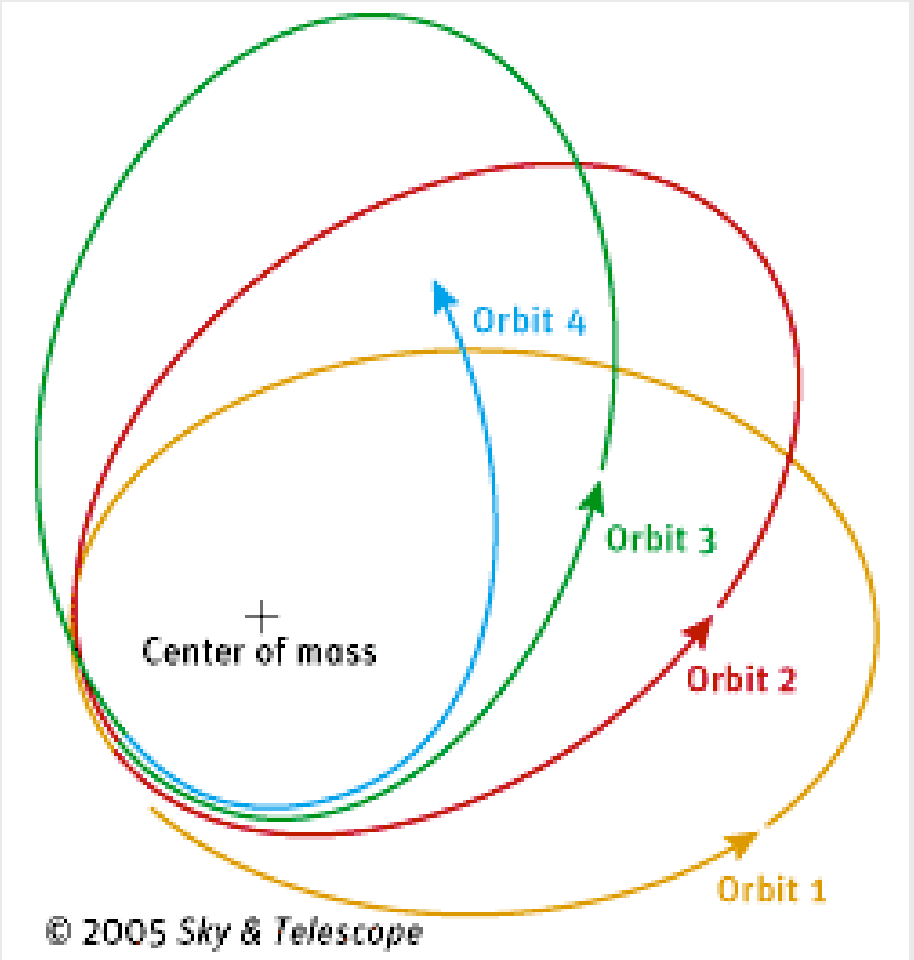
Orbits in general relativity are not exactly ellipses...





Bending of starlight

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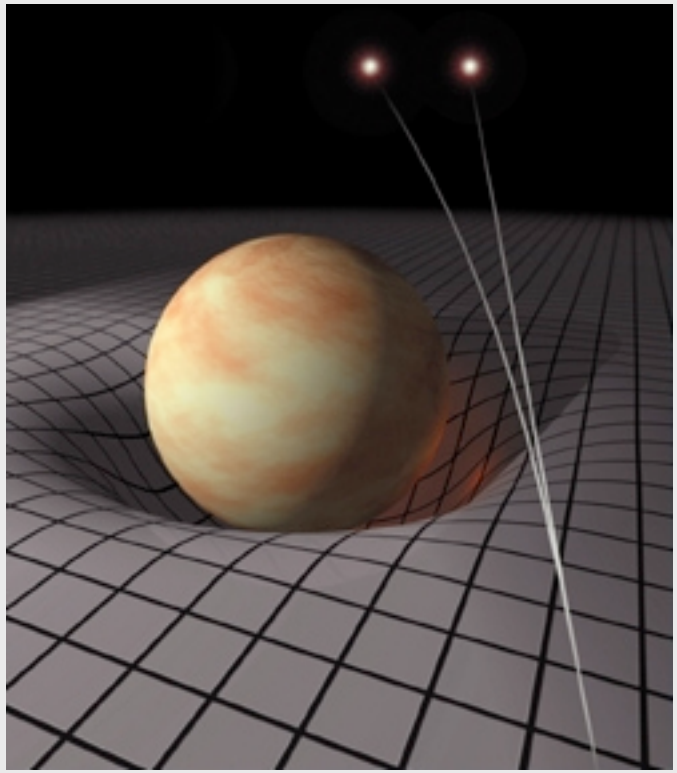

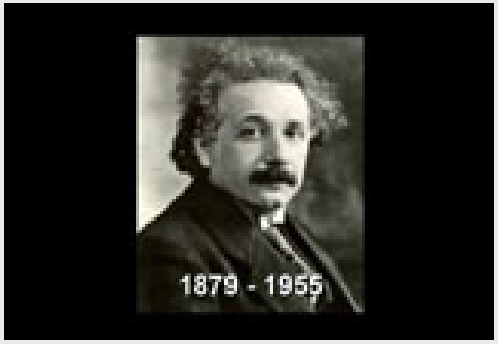

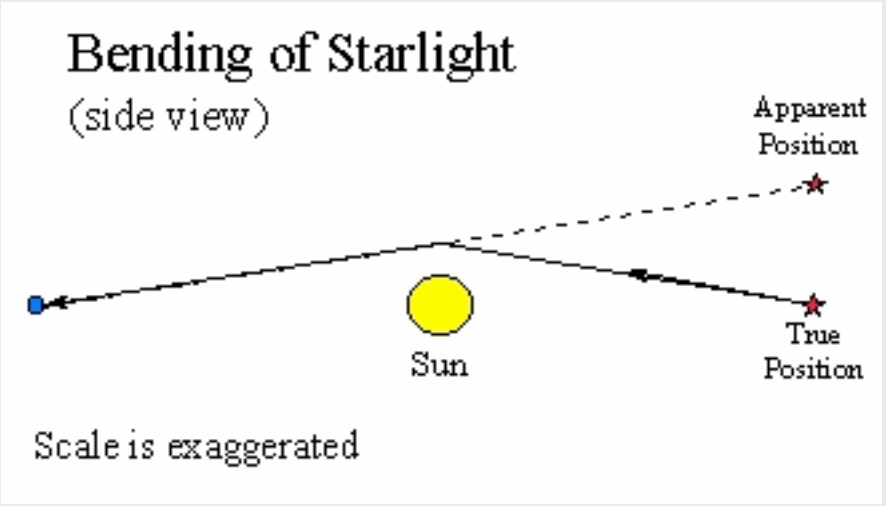

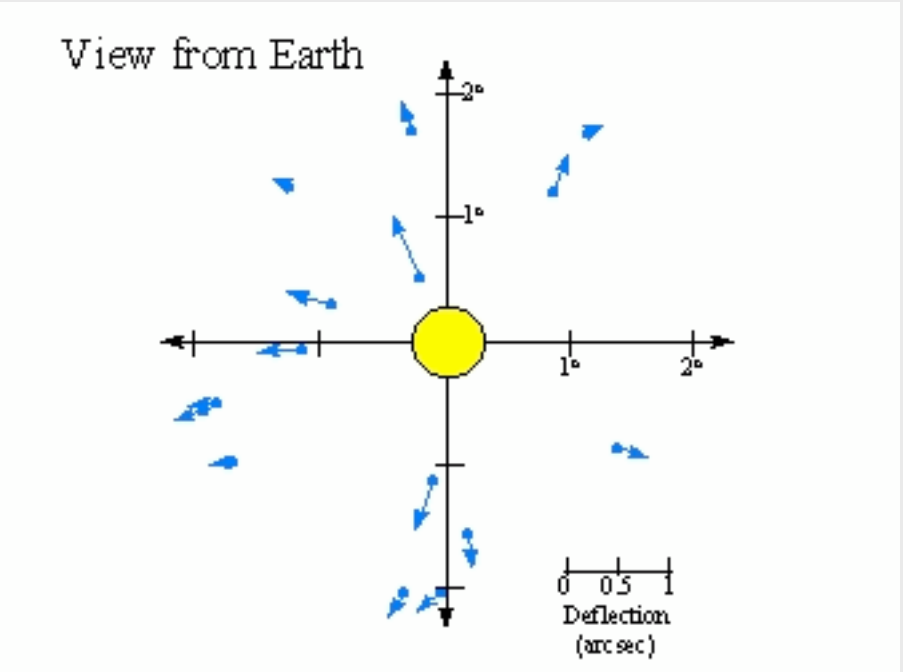

Bending of starlight

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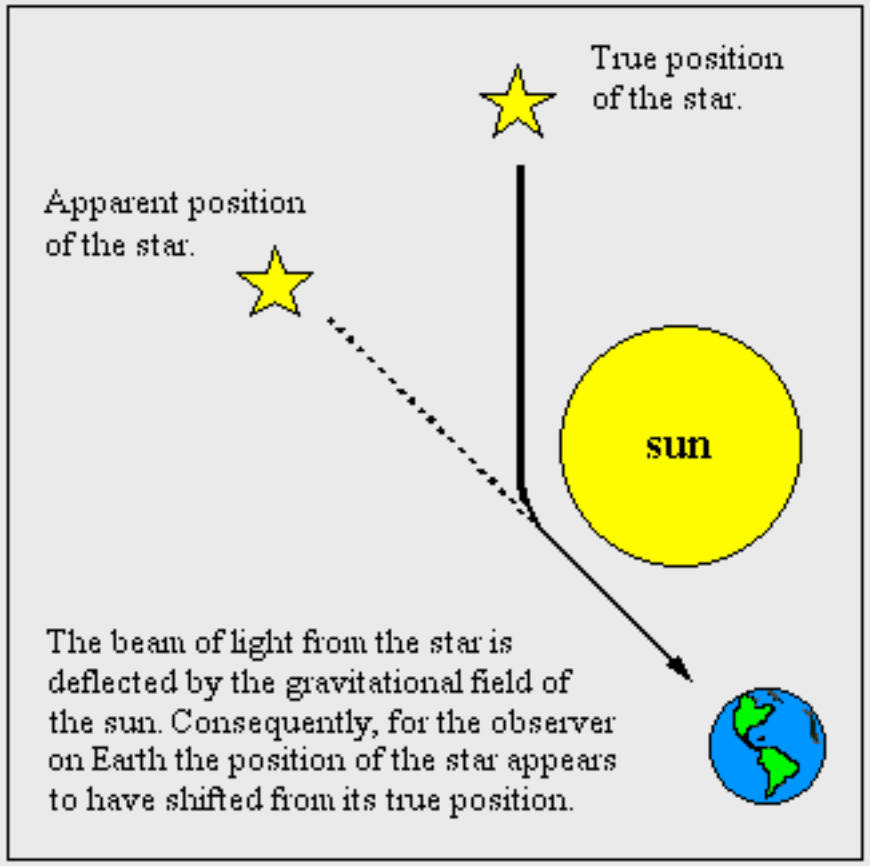

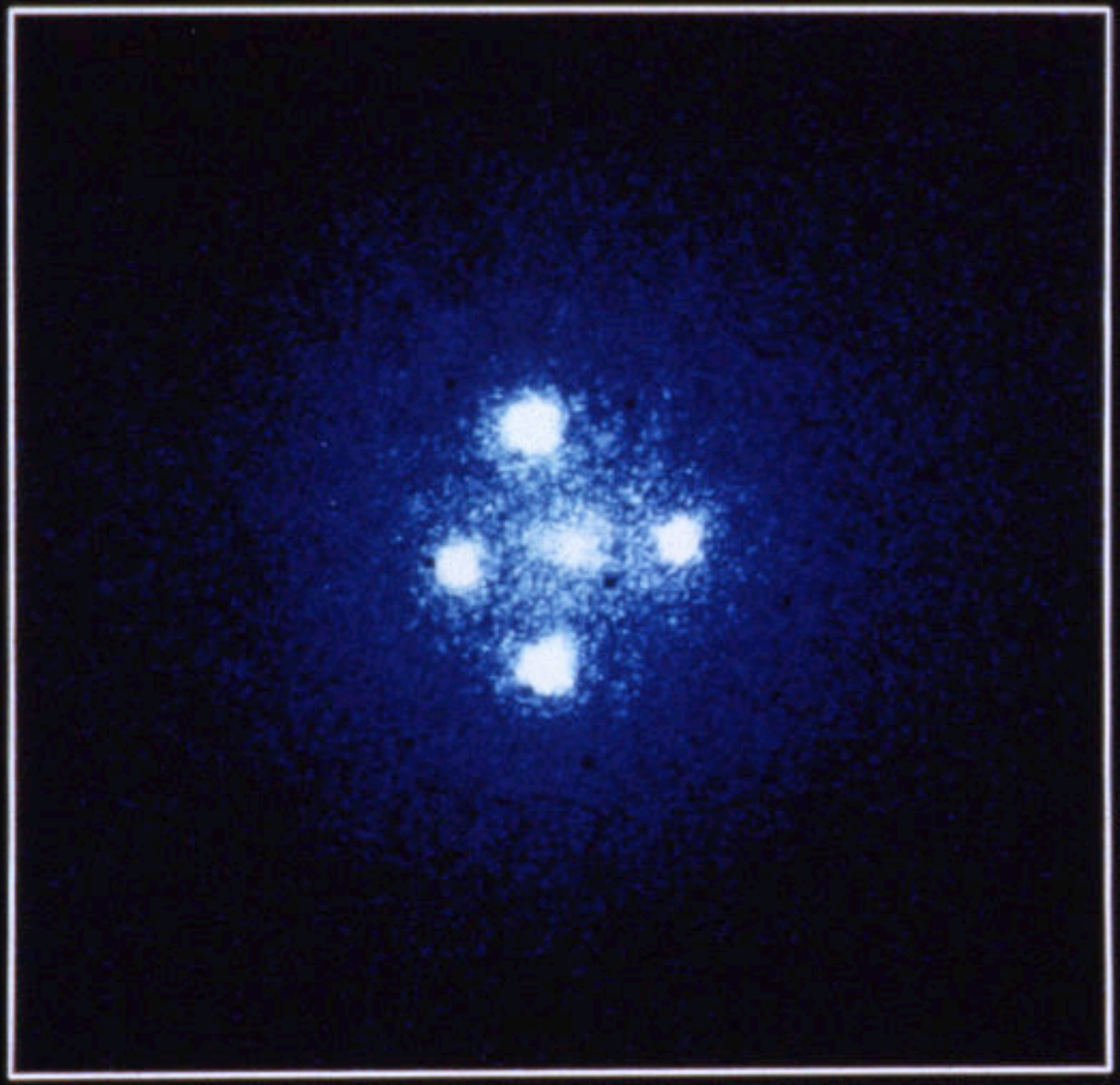

Gravitational Lens G2237+0305

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Gravitational Lens in Abell 2218

HST · WFPC2

PF95-14 · ST ScI OPO · April 5, 1995 · W. Couch (UNSW), NASA

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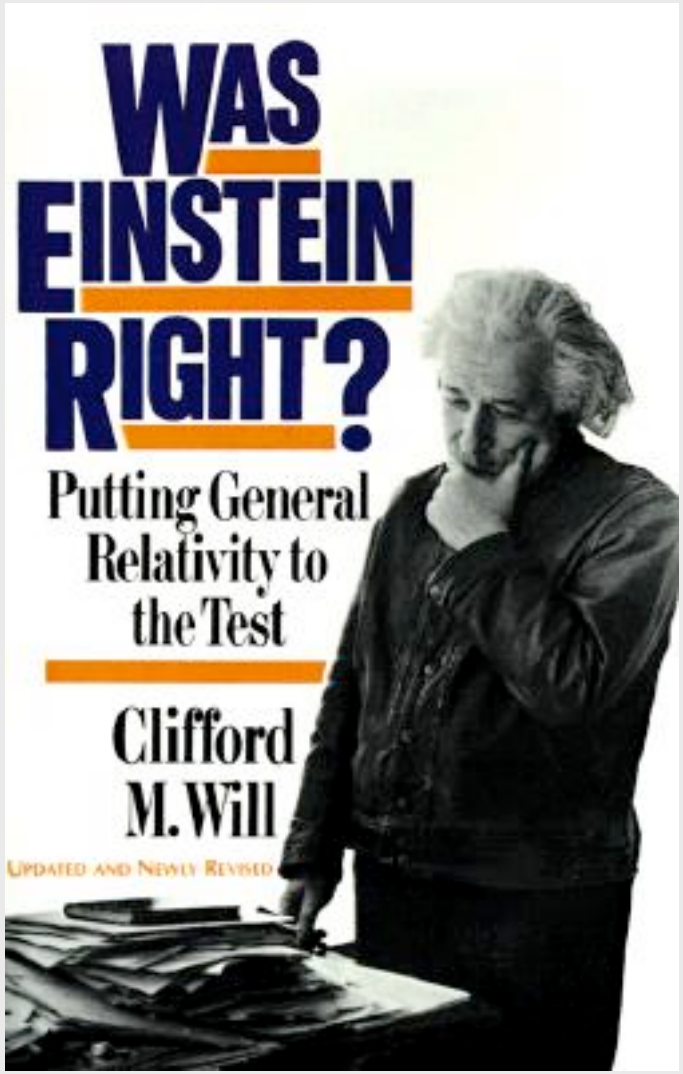

Yes...

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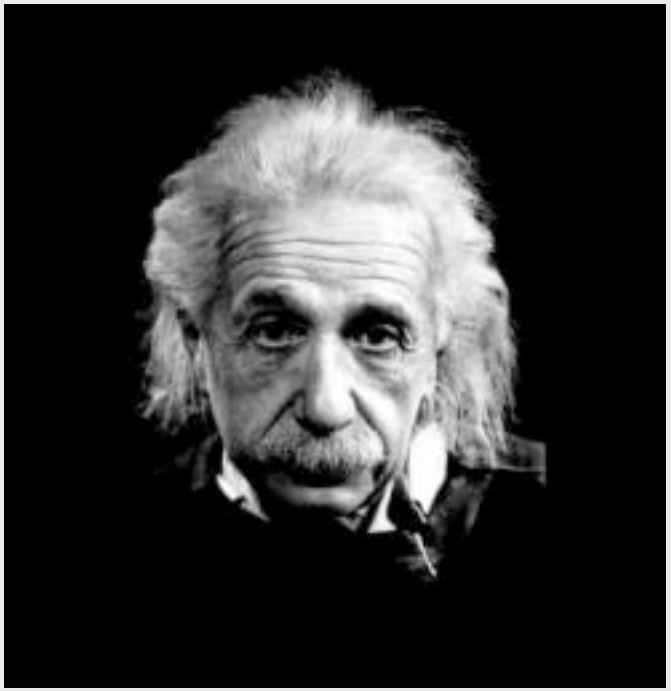

Long answer: Standard special and general relativity are completely compatible with present day experiment...

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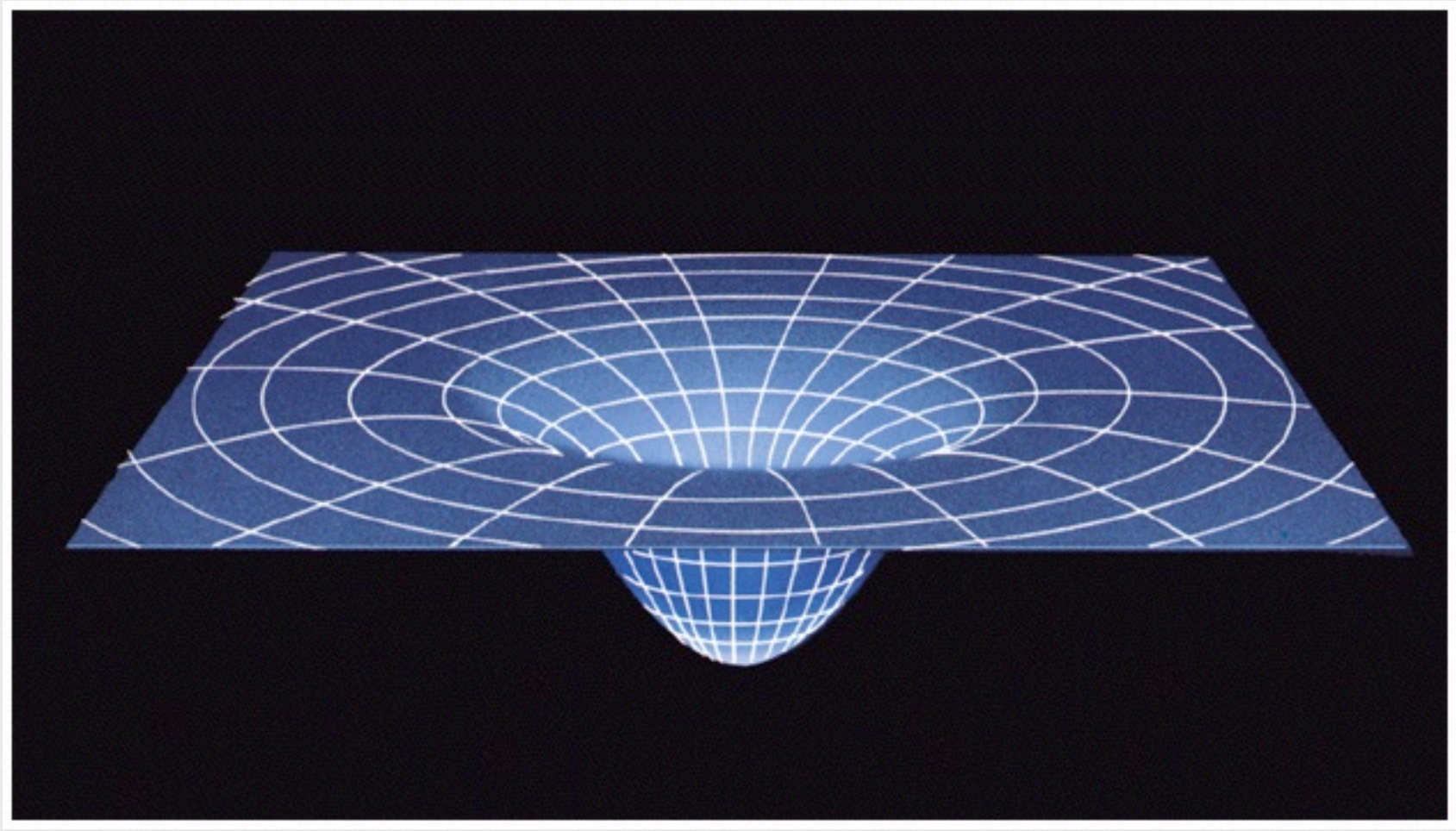

Spacetime curves --- in the manner Einstein predicted.

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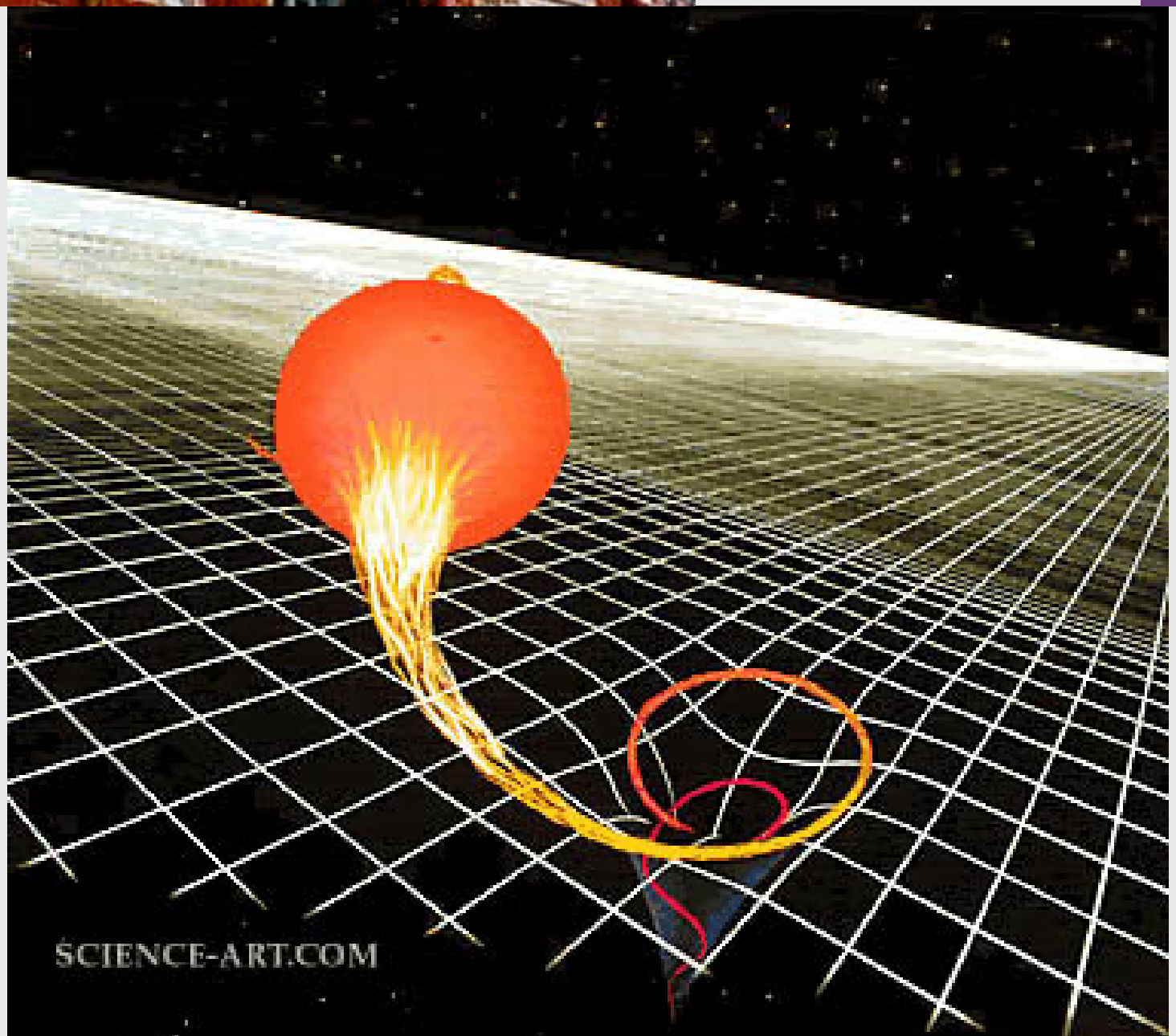

physics today

JANUARY 1971

Introducing the black hole