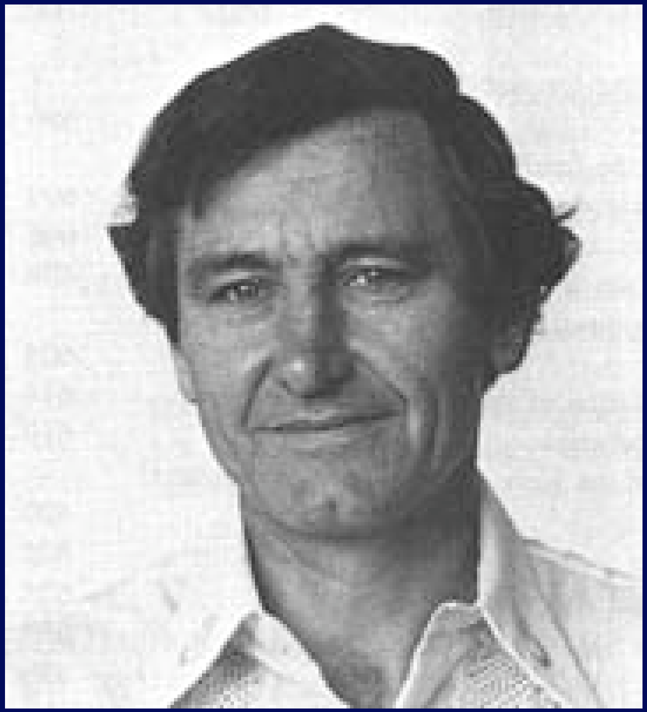
KERR (SPINNING) BLACK HOLES



Roy Kerr

Generalized BH solution that includes **spin**

ANGULAR MOMENTUM OF A BLACK HOLE

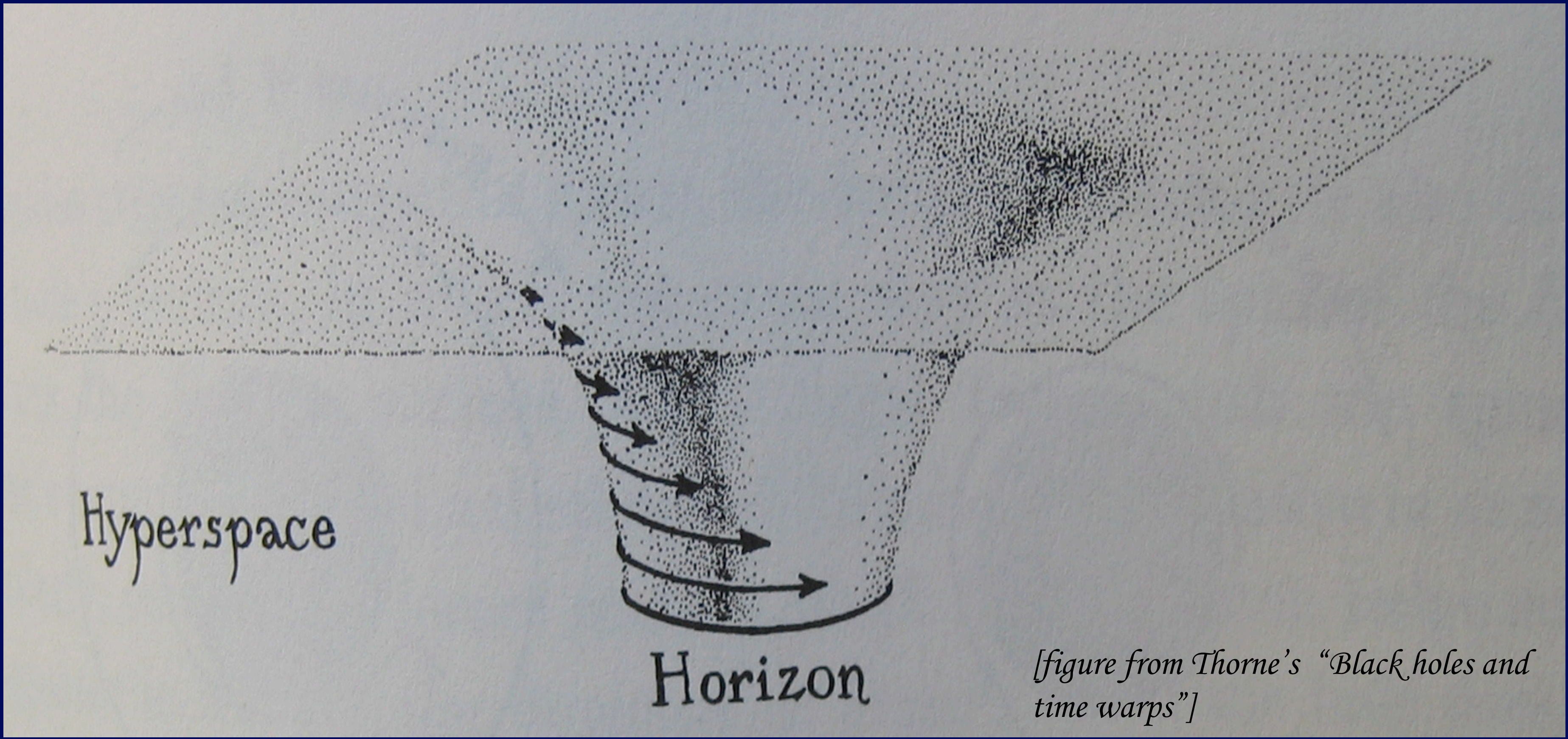
= a x M, where M is the black hole mass and "a" is a parameter.

a = "Kerr parameter" - solution for spinning BH depends on mass and Kerr parameter.

a/M = 0: no spin: Schwarzschild black hole - solution depends on mass only.

a/M = 1: maximally rotating (Kerr) black hole.

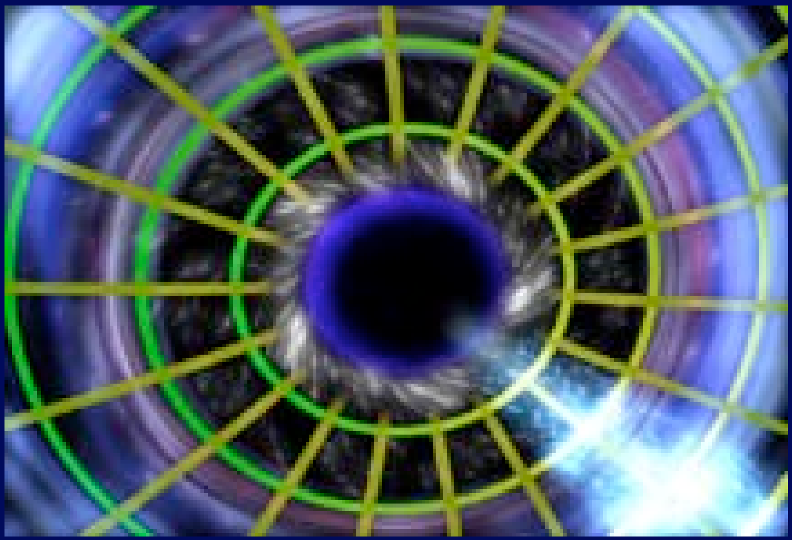
Space around a spinning Black Hole



[figure from Thorne's "Black holes and time warps"]

Because spacetime is "stuck" to the horizon, **space is dragged along with the spin.** This appears as a tornado-like swirl in hyperspace.

Differences between a spinning and a non-spinning Black Hole



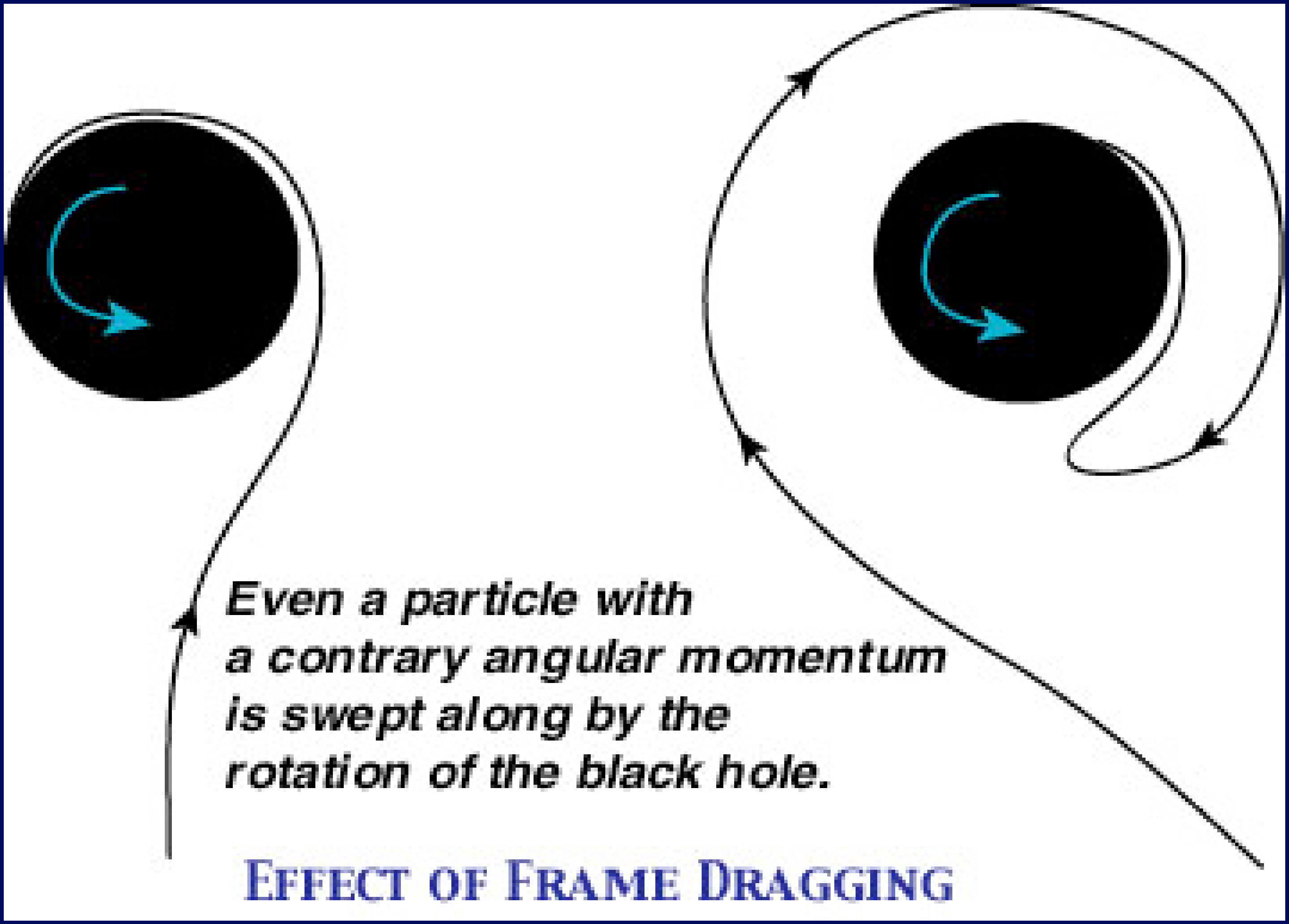
Non-spinning black hole

Spinning black hole

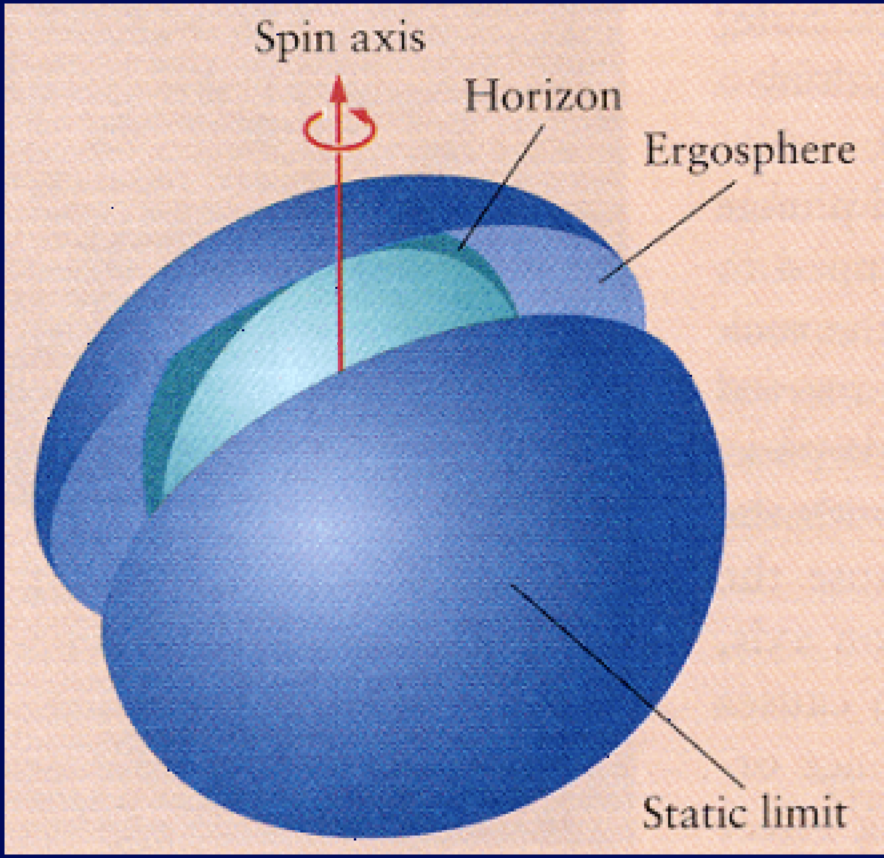
These two images show (by an artist's illustration) the difference between a static and a rotating black hole. The inner black region represents the event horizon, The surroundings blue and white rings represent hot gas that is whirling around The black hole on its way to oblivion.

The green grid depicts space-time coordinates. Note how the spinning black hole distorts the space time grid. A spinning black hole modifies the fabric of spacetime near it, allowing matter to orbit at a closer distance than if the black hole were not spinning. *[Images and example credit of NASA/HONEYWELL MAX-Q Digital group]*

Particle trajectories near spinning black holes



STRUCTURE OF A SPINNING BLACK HOLE



[Image from "Gavity's Fatal Attraction" by Begelman & Rees]

Two "surfaces":
The **Horizon**: region from which no signal can escape.
The **Ergosphere**: region inside which space rotates so fast that is is impossible for a body to hover in such a way to appear stationary to a distant observer.

The horizon is smaller: $R_s/2$ for max. spinning BHs

Why "ERGOSPHERE"?

ERGO = ENERGY (from Greek)

All the spin energy of a Black Hole resides outside the horizon, and it can be extracted (at least in principle…).

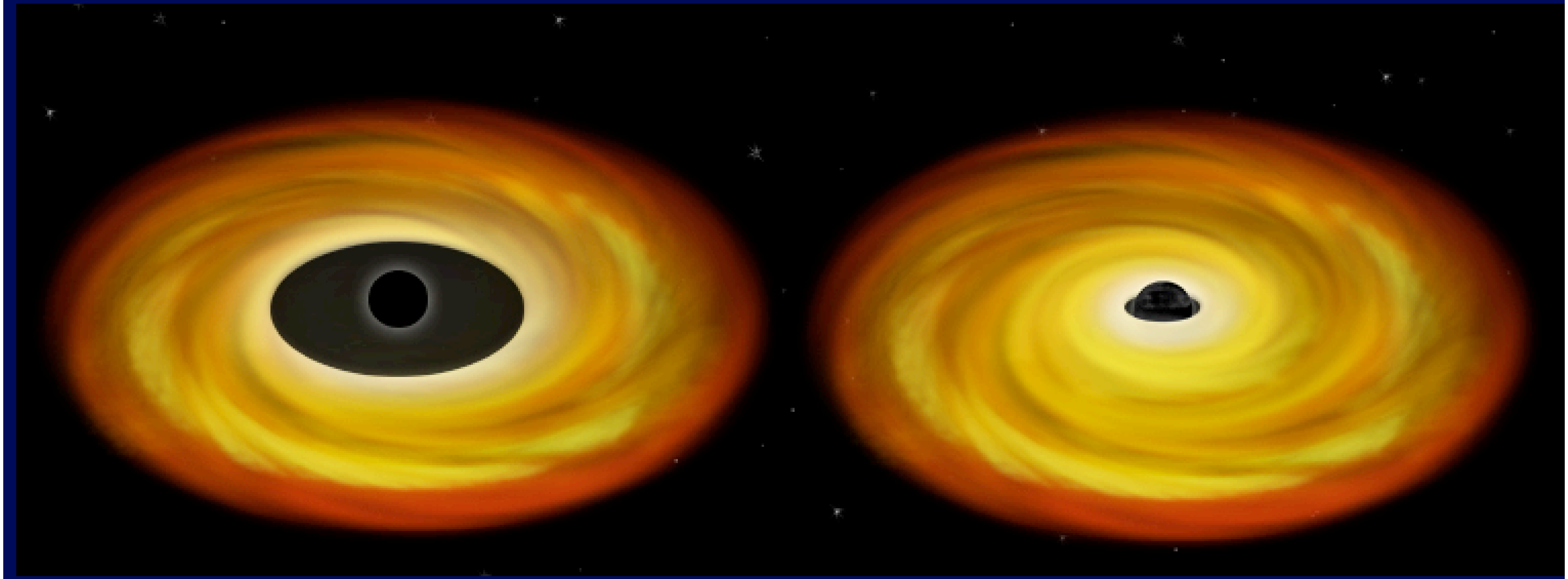
For a maximally rotating black hole of mass M, the maximum energy that can be extracted is

SPIN ENERGY = $0.29\ Mc^2$

[Image credit of NASA]

Since gas as can orbit closer to a spinning black hole than to a non-rotating one

→ **Higher efficiency for energy extraction**



{Image credit: NASA}

IMPORTANCE OF KERR'S SOLUTION

Kerr's solution describes *all black holes without electric charge*. More generally:

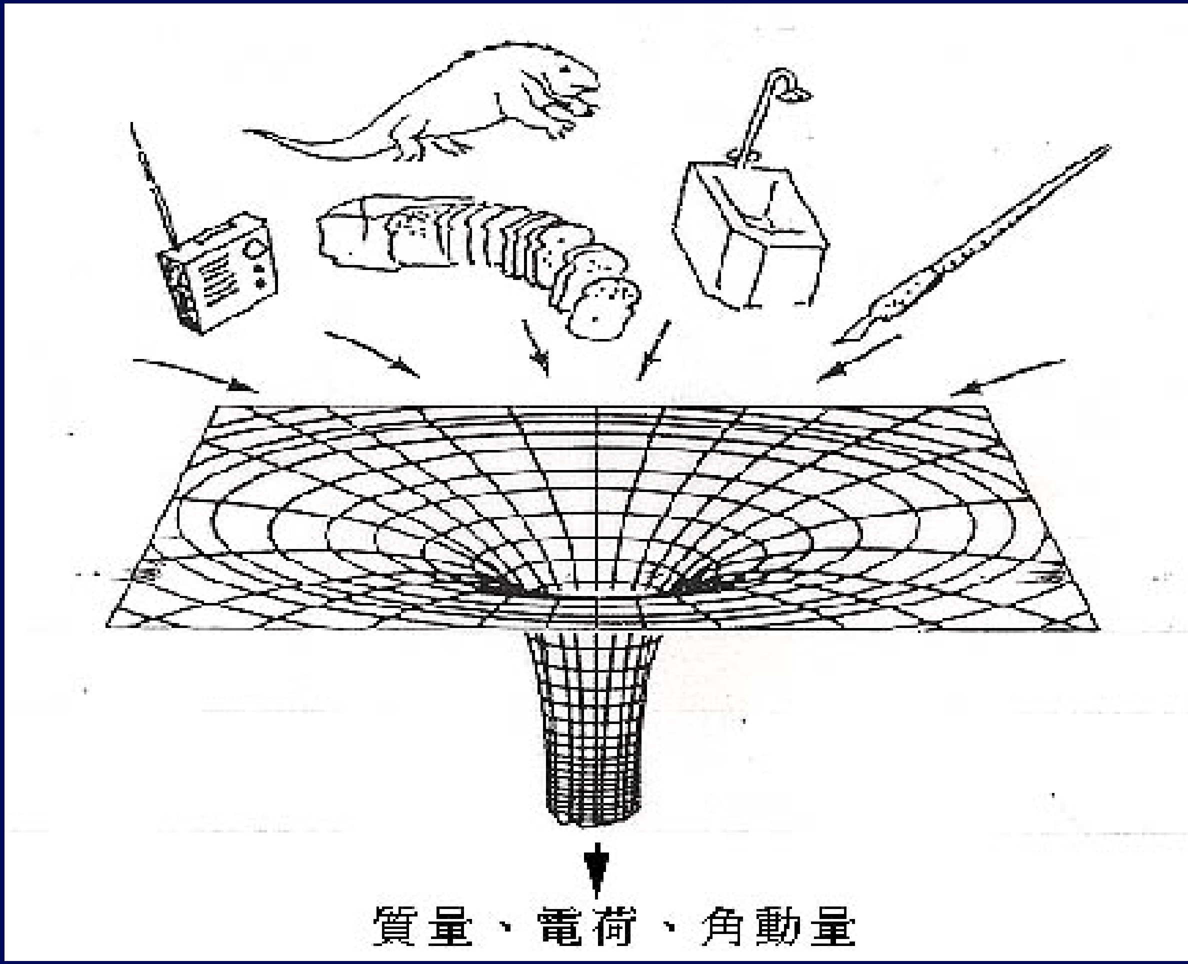
BLACK HOLES HAVE NO "HAIR"

The only properties that describe a black hole are

Mass
Angular Momentum
Charge

Since *astrophysical black holes* are electrically neutral, Kerr's solution can be considered the most general description of astrophysical black holes.

NO "HAIR" THEOREM



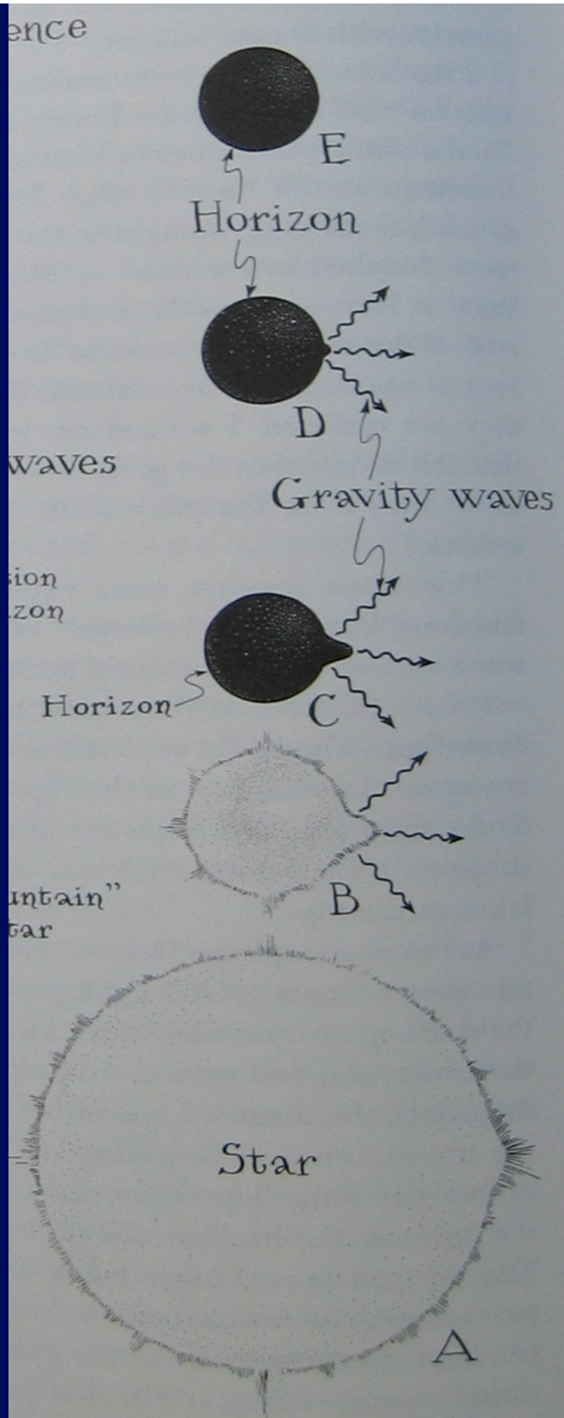
mass spin charge

HOW IS ALL THE "HAIR" LOST?

Price's Theorem:

WHATEVER CAN BE RADIATED, IS RADIATED.

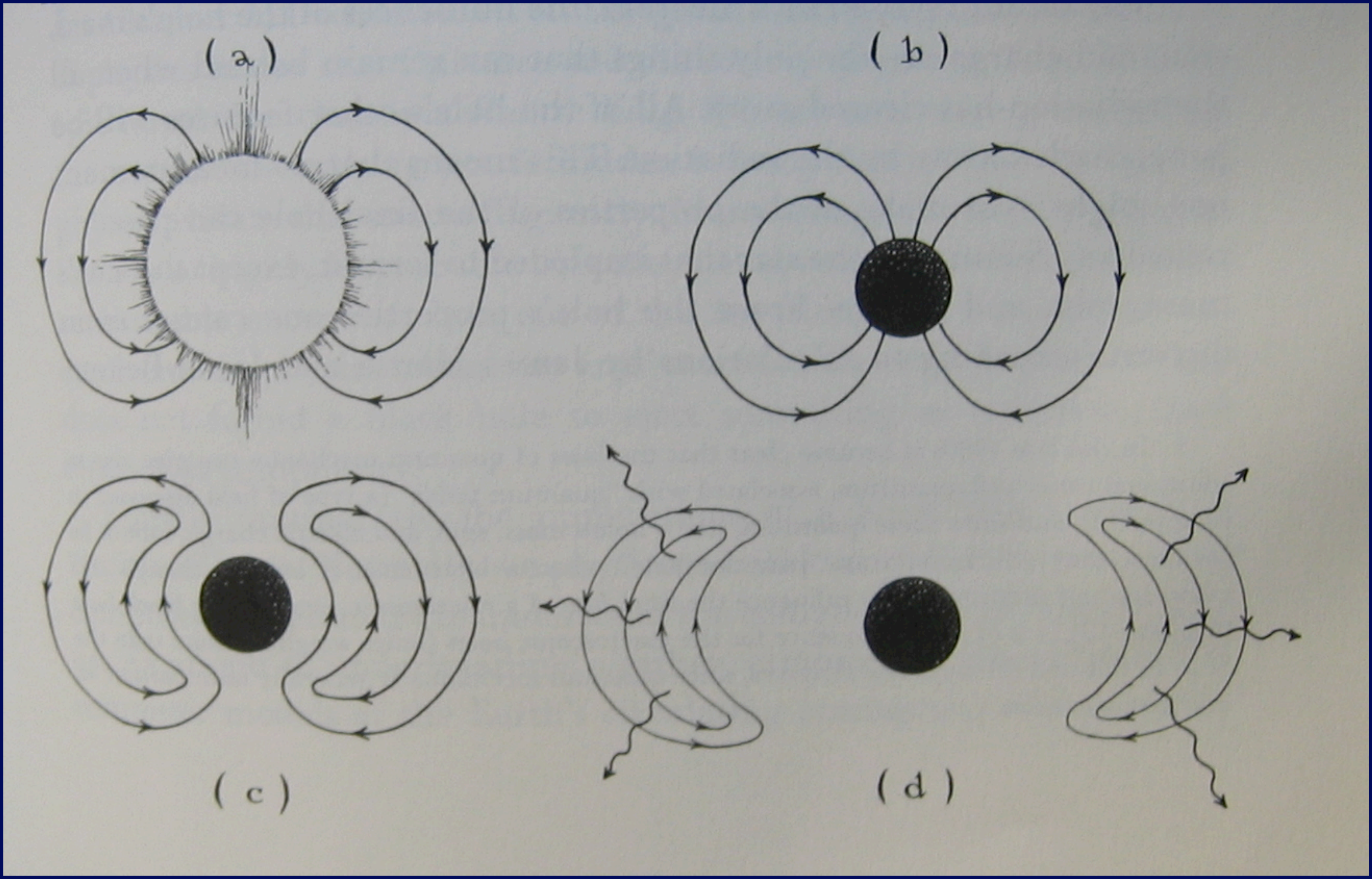
time



A black formed from an imploding star radiates its hair away, where its “hair” here is the mountain on top of the star

[Figure from Thorne’s “Black holes and time warps”]

The BH is losing more "hair"… (i.e. magnetic field)



[Figure from Thorne's "Black holes and time warps"]

Is there anything that CANNOT be radiated away according to Price's theorem?

Among the laws of physics, there is a special set of laws called *Conservation Laws*. According to these laws, there are certain quantities that can never be converted into radiation and ejected from a BH vicinity. These conserved quantities are:

- The gravitational pull due to the hole's mass;
- The swirl of space due to the hole's spin;
- Radially pointing electric field lines due to the hole's electric charge.

Thus, according to Price's theorem, **the hole's mass, spin and charge are the only things that can remain behind when all the radiation has cleared away.**

Press coverage for Price's Theorem

Los Angeles Times; 27 August 1970
Column by Jack Smith, describing his visit to Caltech in the aftermath of Price's Theorem

"After luncheon at the Faculty Club, I walked alone around the campus. I could feel the deep thought in the air. Even in the summer it stirs the olive trees. I looked in a window. A blackboard was covered with equations, thick as leaves on a walk, and three sentences in English: "*Price's Theorem: Whatever can be radiated is radiated. Schutz's Observation: Whatever is radiated can be radiated. Things can be radiated if and only if they are radiated.*"
I walked on, wondering how it will affect Caltech this fall when they let girls in as freshmen for the first time. I don't think they'll do the place a bit of harm…. I have a hunch they'll radiate"