Energy of Black Holes, Dark Matter, Dark Energy

Remo Ruffini
ICRANet, ICRA and Università di Roma "La Sapienza"

Thursday 20 October 2005

"Geometry and the Universe" - A symposium on General Relativity
Stony Brook University, New York, USA

Einstein and Levi Civita

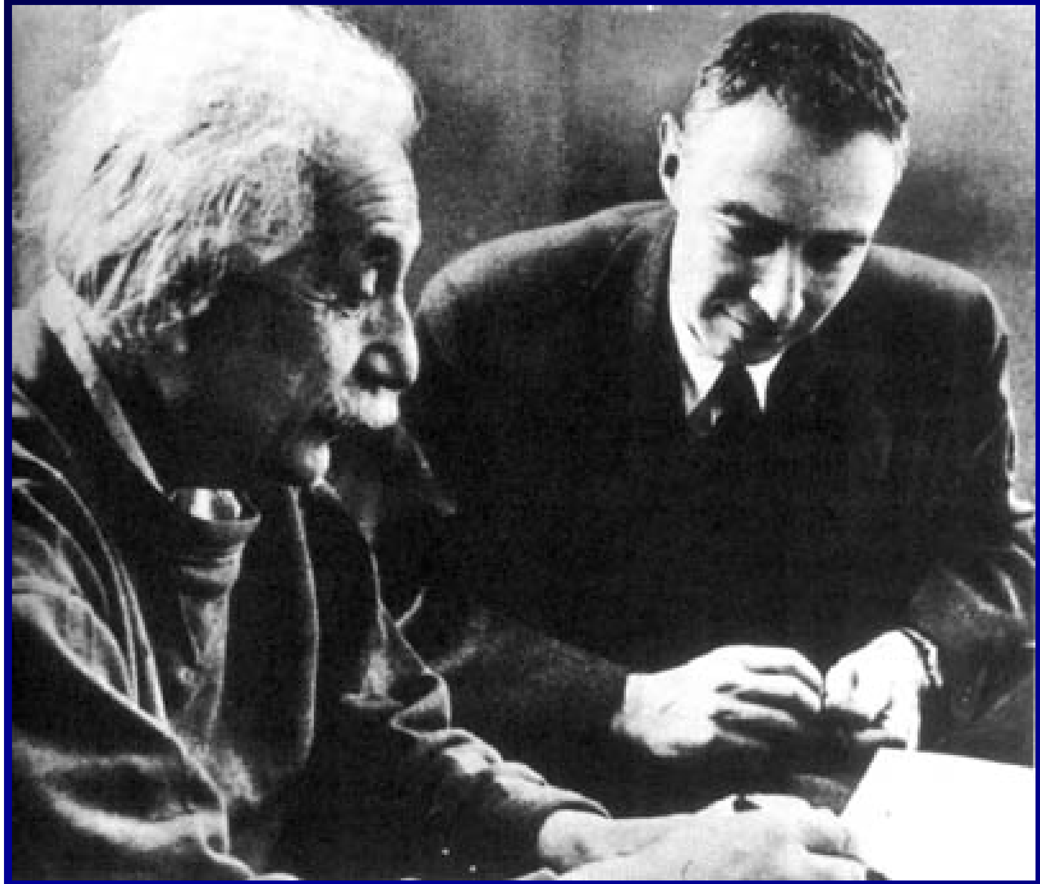
Einstein (1916)

$$R_{\mu\nu} - \tfrac{1}{2} g_{\mu\nu} R = kT_{\mu\nu}$$

$$ds^2 = g_{\mu\nu}(x) dx^{\mu} dx^{\nu}$$

… an incredible conceptual revolution with very few experimental evidences in 1916!

On the continued gravitational contraction



Einstein Clusters,
***Ann. Mat.* 40, (1939) 922:**

"On a stationary system with spherical symmetry consisting of many gravitating masses"

Oppenheimer & Volkoff,
***Phys. Rev.* 55 (1939) 374:**

- ***Free degenerate neutrons***
- ***Einstein equations for equilibrium***
- $M_{crit} = 0.7M_{\odot}$

Oppenheimer & Snyder,
***Phys. Rev.* 56 (1939) 455:**

On the "gravitational collapse" of a sufficiently heavy star at the end point of the thermonuclear source of energy described within Einstein theory of general relativity

Einstein Relativistic Clusters

ANNALS OF MATHEMATICS
Vol. 40, No. 4, October, 1939

ON A STATIONARY SYSTEM WITH SPHERICAL SYMMETRY CONSISTING OF MANY GRAVITATING MASSES

BY ALBERT EINSTEIN

(Received May 10, 1939)

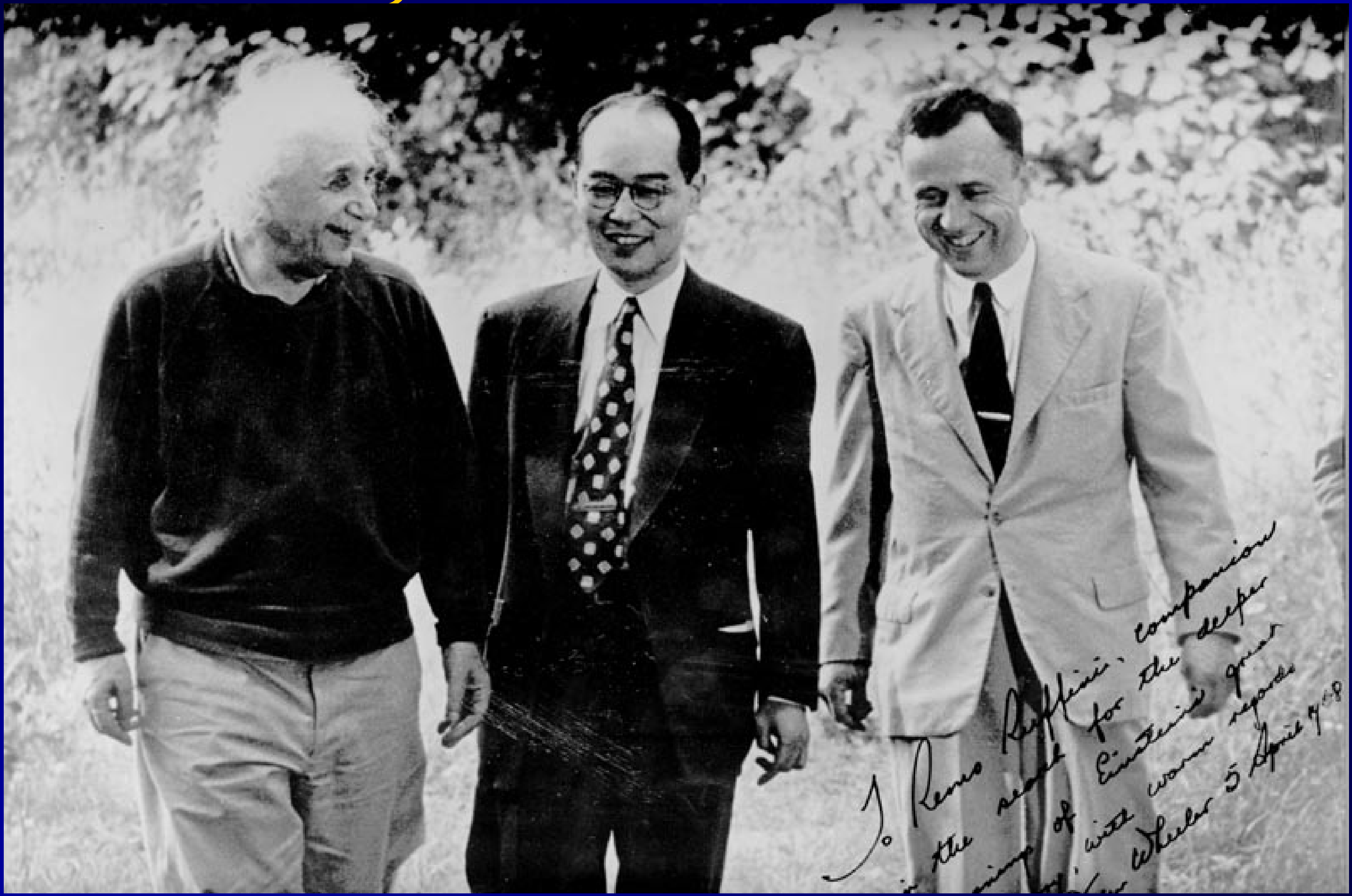
“If one considers Schwarzschild's solution, [....] there arises the question whether such regions with vanishing g_{44} do not exist in cases which have physical reality.

In fact this can be done by choosing, as the field producing mass, a great number of small gravitating particles which move freely under the influence of the field produced by all of them together. [...]

We can further simplify our considerations by the special assumption that *all particles move along circular paths* around the center of symmetry of the cluster. [...].

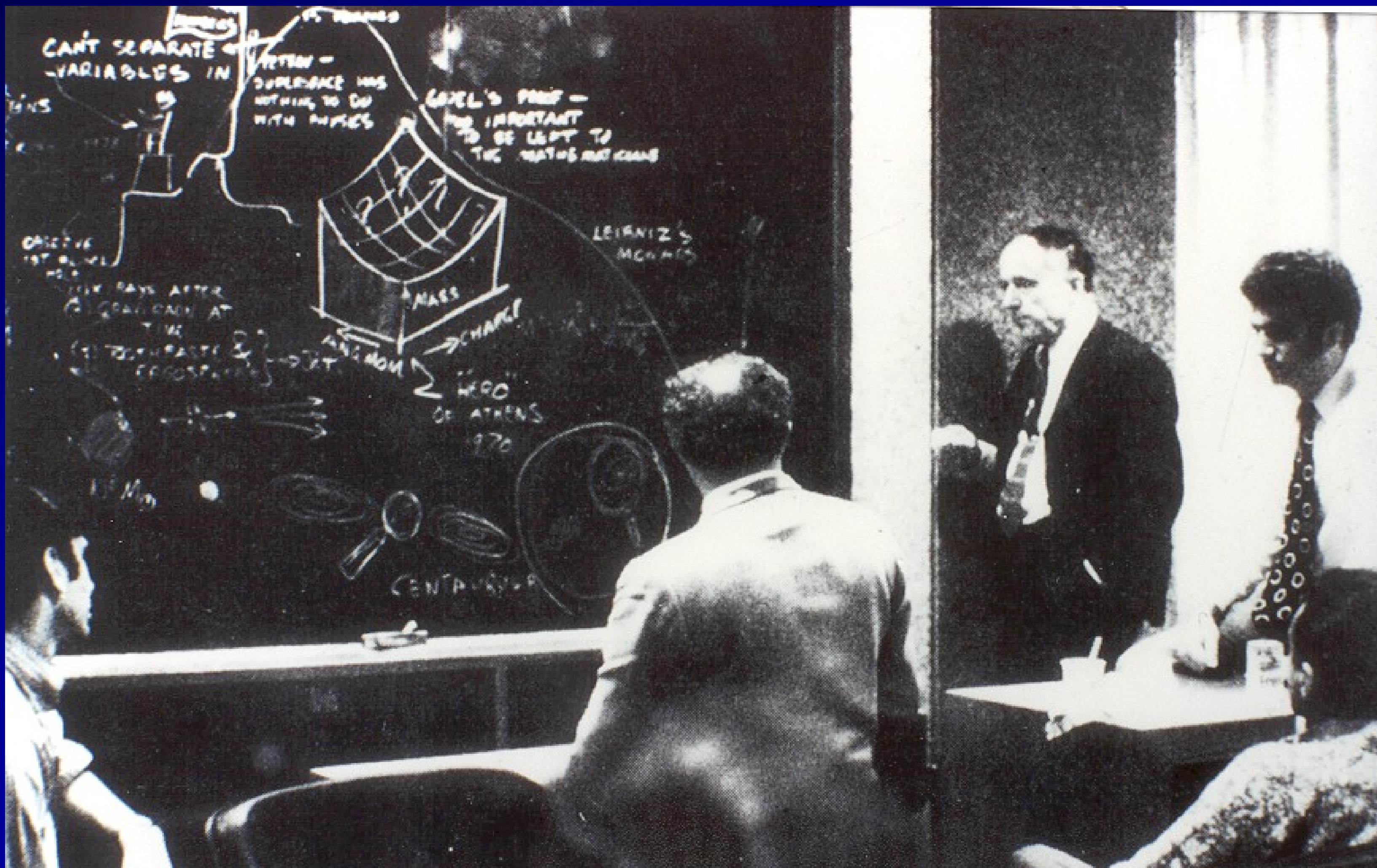
The result of the following consideration will be that it is impossible to make g_{44} *zero anywhere, and that the total gravitating mass which may be produced by distributing particles within a given radius, always remain below a certain bound*”.

Einstein, Yukawa and Wheeler

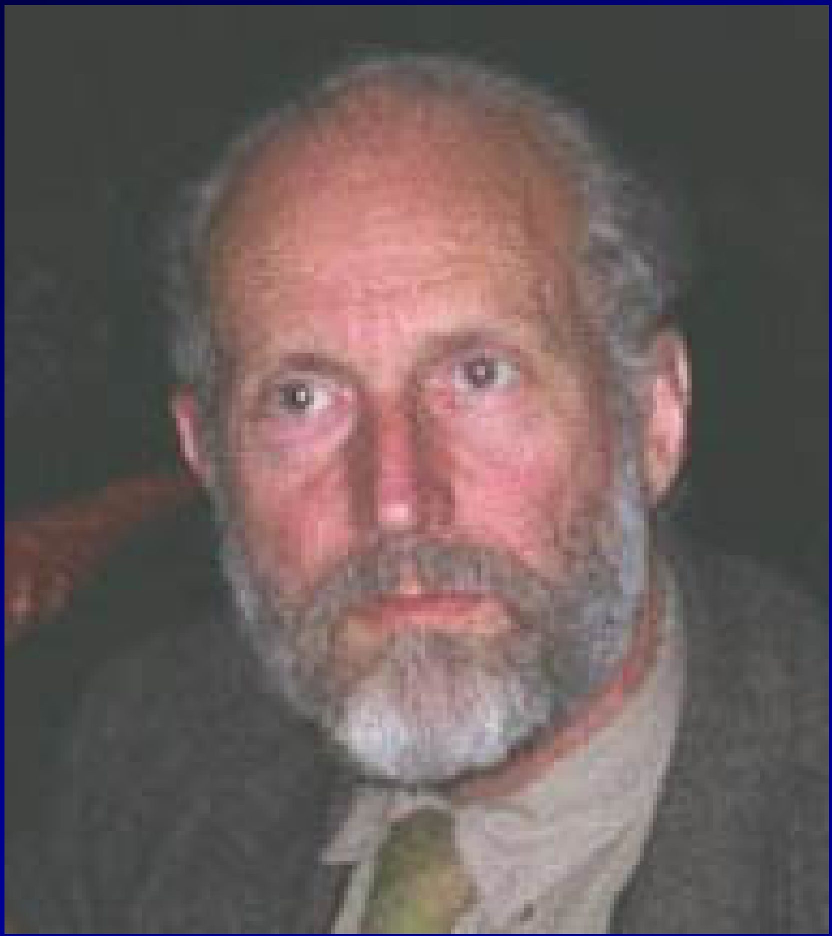


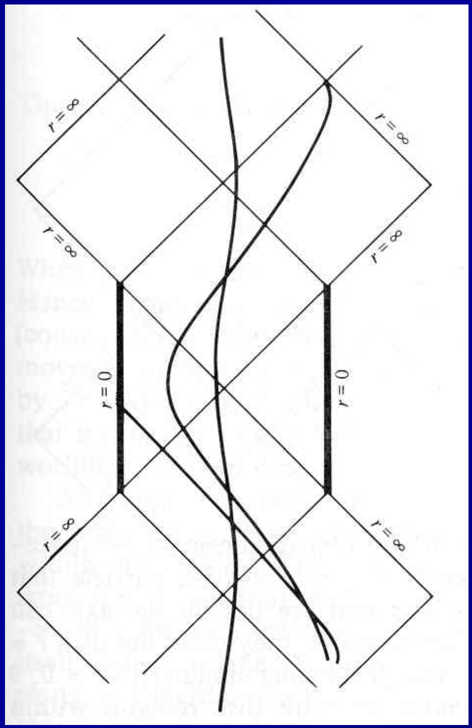
Dedicated: to Remo Ruffini, companion in the search for the deeper meaning of Einstein great theory, with warm regards, John Wheeler, 5 April 1968

Princeton 1970



Equations of motion in Kerr-Newman geometry





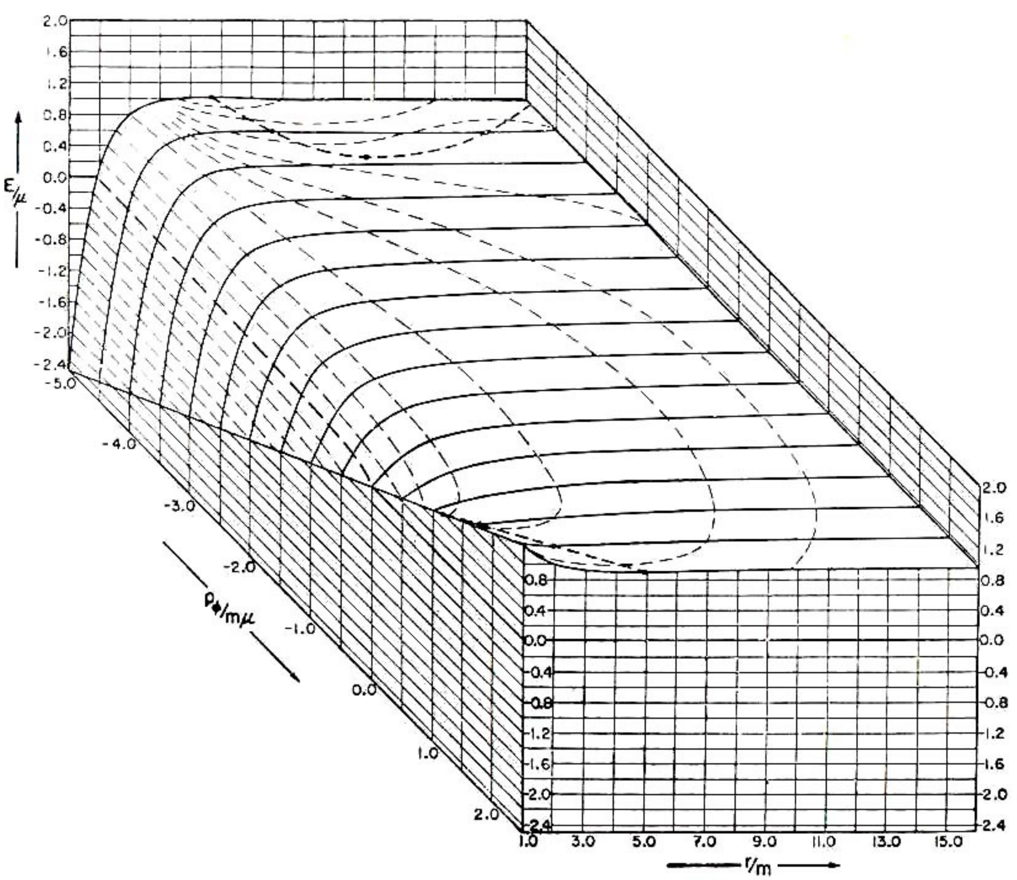
… Although the symmetries provide only three constants of the motion, a fourth one turn out to be obtainable from the unexpected separability of the Hamilton-Jacobi equations… The equations of charged particle orbits can be integrated completely in terms of explicit quadrature.

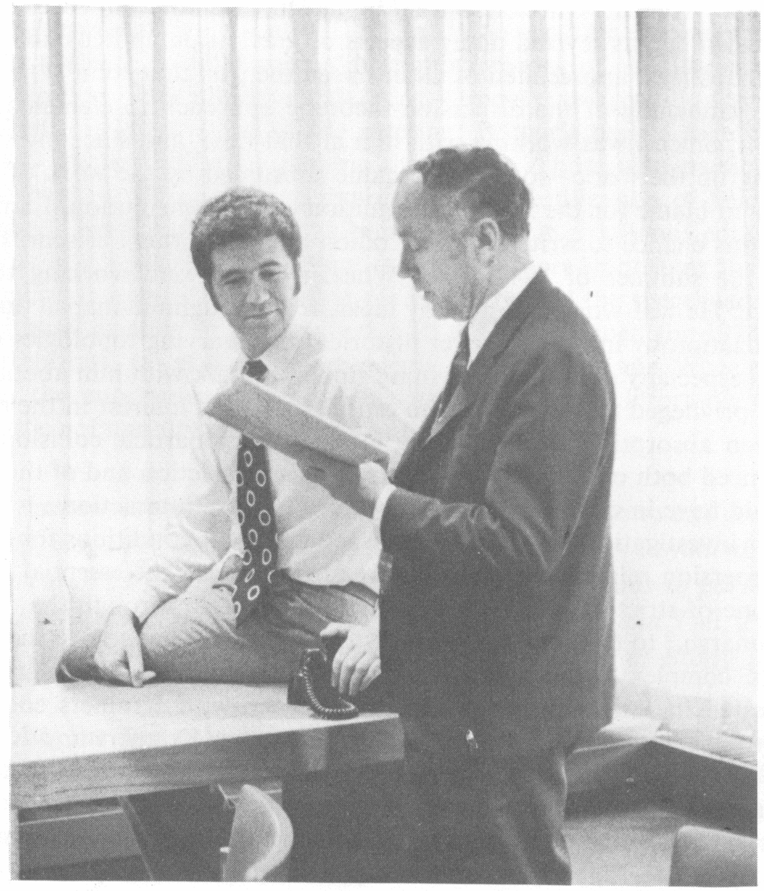
Brandon Carter, *Phys.Rev.*, 174, 1559 (1968)

Magnetized Plasma around collapsed stars

Victor F. Shvartsman,
Astron. Zhurnal, **48**, 479 (1971)

The effective potential of a Kerr-Newmann geometry





Joseph Henry Laboratories, Princeton University

Introducing the Black Hole

Introducing the black hole

According to present cosmology, certain stars end their careers in a total gravitational collapse that transcends the ordinary laws of physics.

Remo Ruffini and John A. Wheeler

PHYSICS TODAY / JANUARY 1971

The quasistellar object, the pulsar, the neutron star have all come onto the scene of physics within the space of a few years. Is the next entrant destined to be the black hole? If so, it is difficult to think of any development that could be of greater significance. A black hole, whether of "ordinary size" (approximately one solar mass, $1\ M_{\odot}$), or much larger (around $10^6\ M_{\odot}$ to $10^{10}\ M_{\odot}$, as proposed in the nuclei of some galaxies) provides our "laboratory model" for the gravitational collapse, predicted by Einstein's theory, of the universe itself.

A black hole is what is left behind after an object has undergone complete gravitational collapse. Spacetime is so strongly curved that no light can come out, no matter can be ejected and no measuring rod can ever survive being put in. Any kind of object that falls into the black hole loses its separate identity, preserving only its mass, charge, angular momentum and linear momentum (see figure 1). No one has yet found a way to distinguish between two black holes constructed out of the most different kinds of matter if they have the same mass, charge and angular momentum. Measurement of these three determinants is permitted by their effect on the Kepler orbits of test objects, charged and uncharged, in revolution about the black hole.

How the physics of a black hole looks depends more upon an act of choice by the observer himself than an anything else. Suppose he decides to follow the collapsing matter through its collapse down into the black hole. Then he will see it crushed to indefinitely high density, and he himself will be torn apart eventually by indefinitely increasing tidal forces. No restraining force whatsoever has the power to hold him away from this catastrophe, once he crossed a certain critical surface known as the "horizon." The final collapse occurs a finite time after the passage of this surface, but it is inevitable. Time and space are interchanged inside a black hole in an unusual way; the direction of increasing proper time for the observer is the direction of decreasing values of the coordinate r. The observer has no more power to return to a larger r value than he has power to turn back the hands on the clock of life itself. He can not even stay where he is, and for a simple reason: no one has the power to stop the advance of time.

Suppose the observer decides instead to observe the collapse from far away. Then, as price for his own safety, he is deprived of any chance to see more than the first steps on the way to collapse. All signals and all information from the later phases of collapse never escape; they are caught up in the collapse of the geometry itself.

That a sufficient mass of cold matter will necessarily collapse to a black hole (J. R. Oppenheimer and H. Snyder,[1]) is one of the most spectacular of all the predictions of Einstein's standard 1915 general relativity. The geometry around a collapsed object of spherical symmetry (nonrotating!) was worked out by Karl Schwarzschild of Göttingen, father of the American astrophysicist Martin Schwarzschild, as early as 1916. In 1963 Roy Kerr[2] found the geometry associated with a rotating collapsed object. James Bardeen has recently emphasized that all stars have angular momentum and that most stars—or star cores—will have so much angular momentum that the black hole formed upon collapse will be rotating at the maximum rate, or near the maximum rate, allowed for a black hole ("surface velocity" equal to speed of light). Roger Penrose[3] has shown that a particle coming from a distance into the immediate neighborhood of a black hole (the "ergosphere") can extract energy from the black hole. Demetrios Christodoulou[4] has shown that the total mass–energy of a black hole can be split into three parts,

$$E^2 = m_{ir}^2 + L^2/4m_{ir}^2 + p^2$$

The first part is "irreducible" (left constant in "reversible transformations"; always increased in "irreversible transformations") and the second and third parts (arising from a rotational angular momentum L and a linear momentum p) can be added and subtracted at will.

The three most promising ways now envisaged to detect black holes are:

- pulses and trains of gravitational radiation given out at the time of formation (see PHYSICS TODAY, August 1969, page 61, and August 1970, page 41, for accounts of Joseph Weber's pioneering attempts to detect gravitational radiation),
- broadband electromagnetic radiation extending into the hard x-ray and gamma-ray regions emitted by matter falling into a black hole after it has been formed (this is the concept of Ya. B. Zel'dovich and I. D. Novikov. The radiation is not emitted by the individual particles as they fall in, but by the gas as a whole as it is compressed and heated to 10^{10} or 10^{11} K by the "funnel effect" on its way towards the black hole),
- jets and other activity produced in the ergosphere of rotating black holes.

Equilibrium configurations

The mass of a superdense star (reached in collapse that does not go to

Remo Ruffini and John Wheeler are both at Princeton University; Wheeler, currently on leave from Princeton, is spending a year at Cal Tech and Moscow State University.

Les Houches, Mont Blanc, 1972

Les Houches, Août 1972
Cours de l'Ecole d'été de Physique théorique
Organe d'intérêt commun de l'U.S.M.G.
et I.N.P.G. subventionné par l'OTAN et
le Commissariat à l'Energie Atomique

BLACK HOLES
LES ASTRES OCCLUS

edited by C. DeWitt
Faculté des Sciences, Grenoble
Dept. of Astronomy, University of Texas, Austin, et
B. S. DeWitt
Dept. of Physics, University of Texas, Austin

CONTENTS

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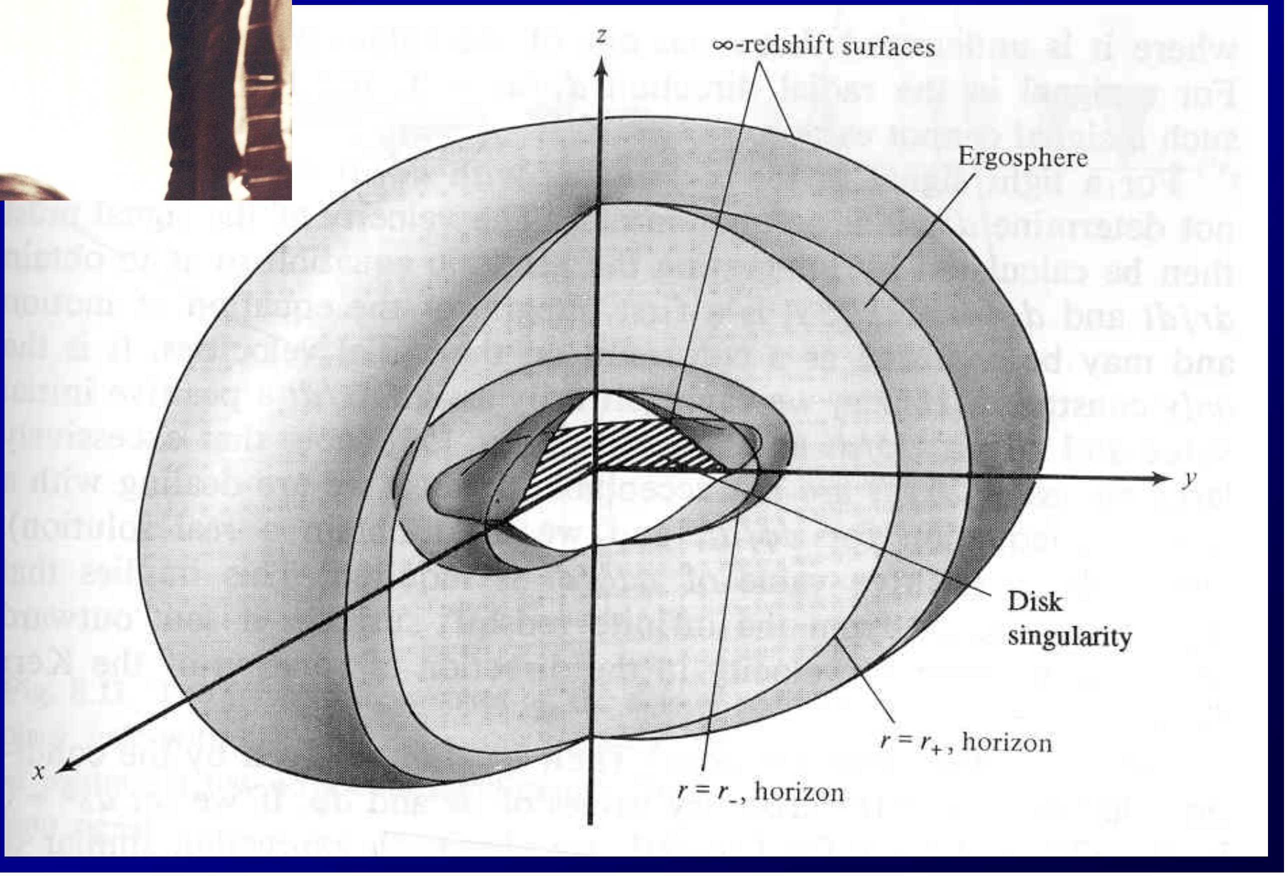
The Black Hole structure

The only three parameters: Mass *M*, Charge *Q* and Angular momentum *L*



Particles around a Kerr Black Hole

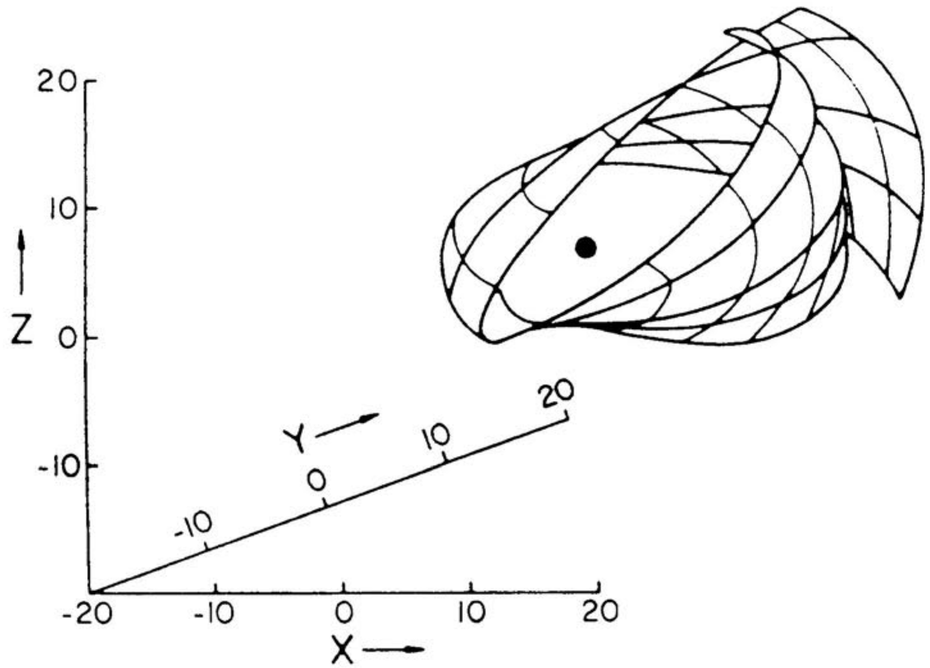
$$\dot{r} = \rho^{-2}\{[E(r^2+a^2) - a\Phi]^2 - \Delta(\mu^2 r^2 + K)\}^{1/2}$$

$$\dot{\theta} = \rho^{-2}\{K - (\Phi - aE)^2 - \cos^2\theta[a^2(\mu^2 - E^2) + \Phi^2 \sin^{-2}\theta]\}^{1/2}$$

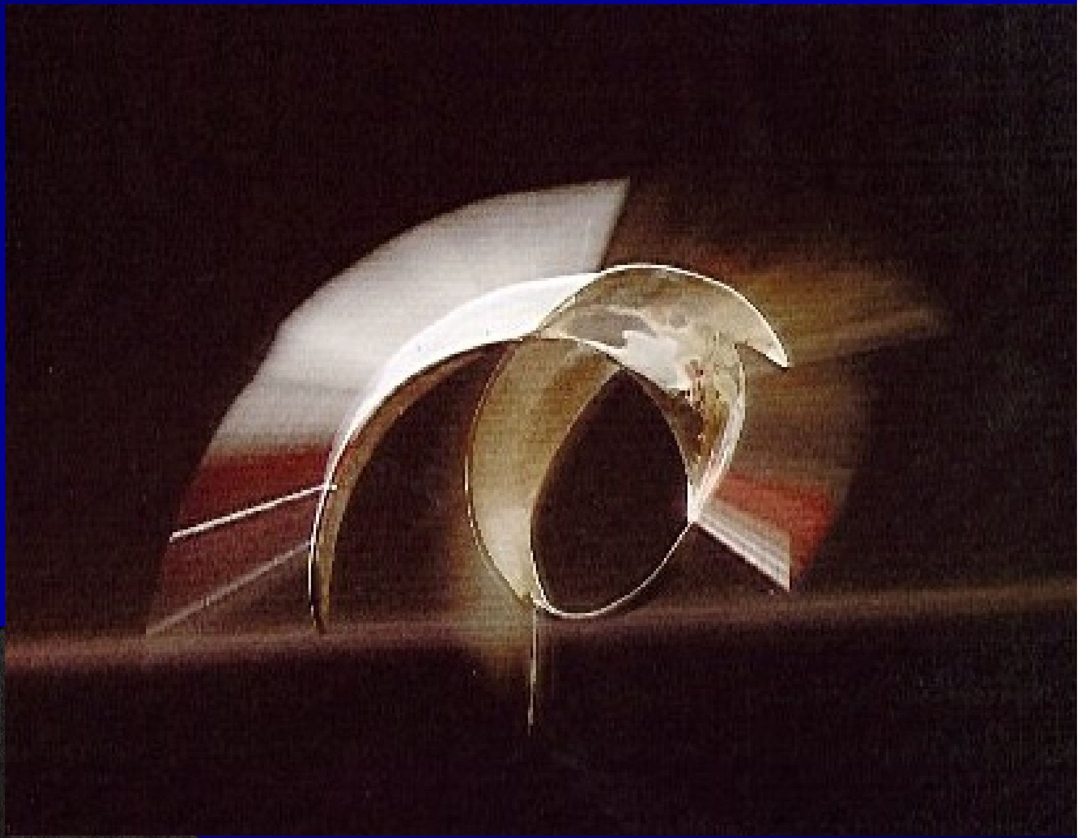
$$\dot{t} = -a\rho^{-2}(aE\sin^2\theta - \Phi) + \rho^{-2}(r^2+a^2)\Delta^{-1}P$$

$$\dot{\phi} = -\rho^{-2}(aE - \Phi\sin^{-2}\theta) + a\rho^{-2}\Delta^{-1}P$$

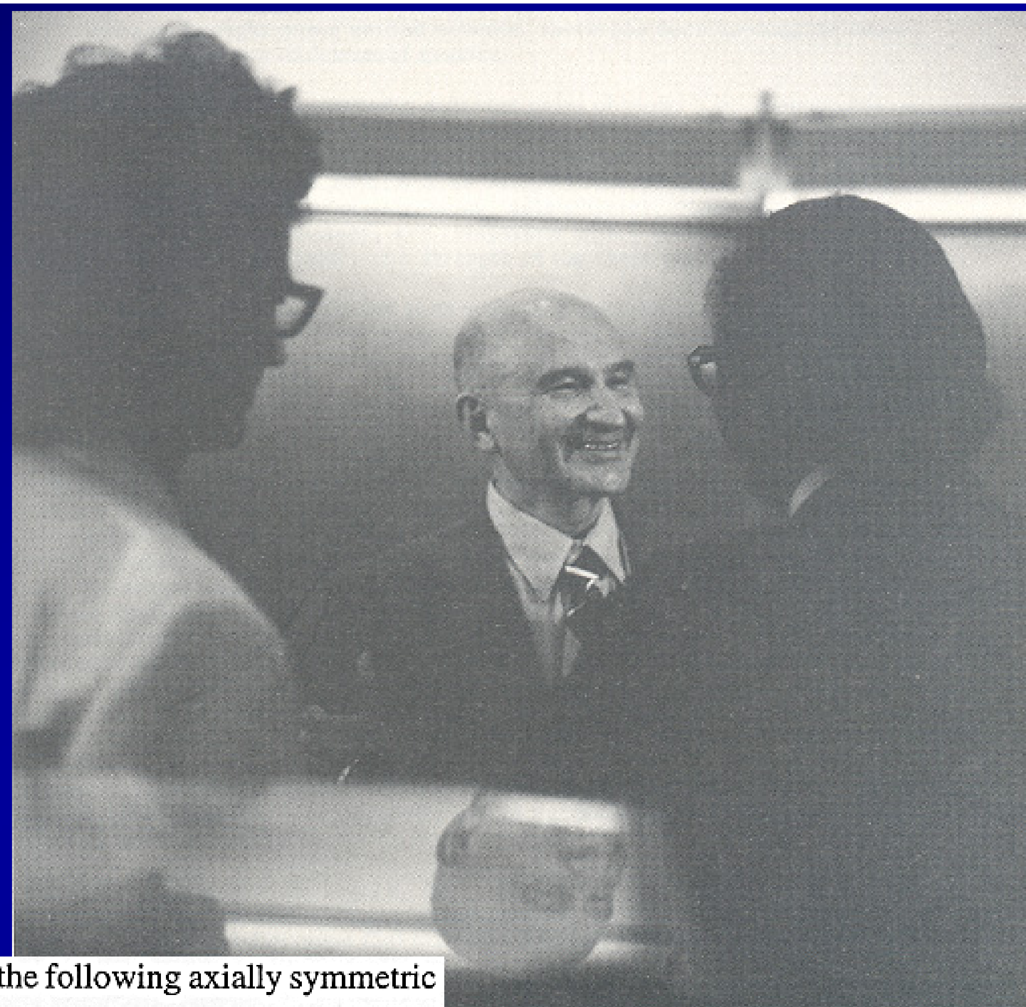
$$E = .968\ ,\ \Phi = 2\ ,\ Q = 10\ ,\ a = e = 1/\sqrt{2}$$



Pierelli TEST & Takahashi photos



Landau - Lifschitz: The classical theory of fields



$E/\mu = 1/\sqrt{3}$

$p_\phi/m\mu = 2/\sqrt{3}$

The gravitational field of the rotating black hole is given by the following axially symmetric stationary *Kerr metric:*¶

$$ds^2 = \left(1 - \frac{r_g r}{\rho^2}\right) dt^2 - \frac{\rho^2}{\Delta} dr^2 - \rho^2 \, d\theta^2 -$$

$$- \left(r^2 + a^2 + \frac{r_g r a^2}{\rho^2} \sin^2\theta\right) \sin^2\theta \, d\phi^2 + \frac{2 r_g r a}{\rho^2} \sin^2\theta \, d\phi \, dt, \qquad (104.2)$$

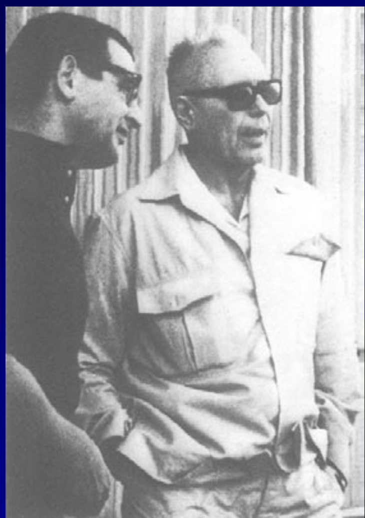
1. Carry out the separation of variables in the Hamilton–Jacobi equation for a particle moving in the Kerr field (B. Carter, 1968).

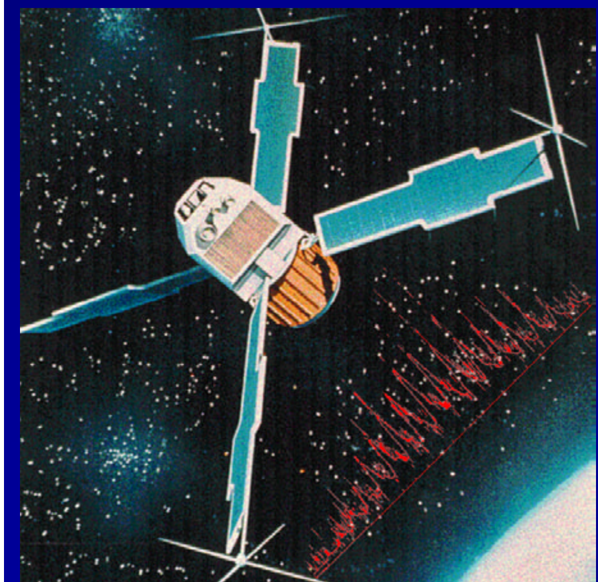
2. Determine the radius of the circle, closest to the centre, that is a stable orbit for a particle moving in the equatorial plane of the limiting ($a \to r_g/2$) Kerr field (R. Ruffini and J. A. Wheeler, 1969).

$E/\mu = 5/(3\sqrt{3})$

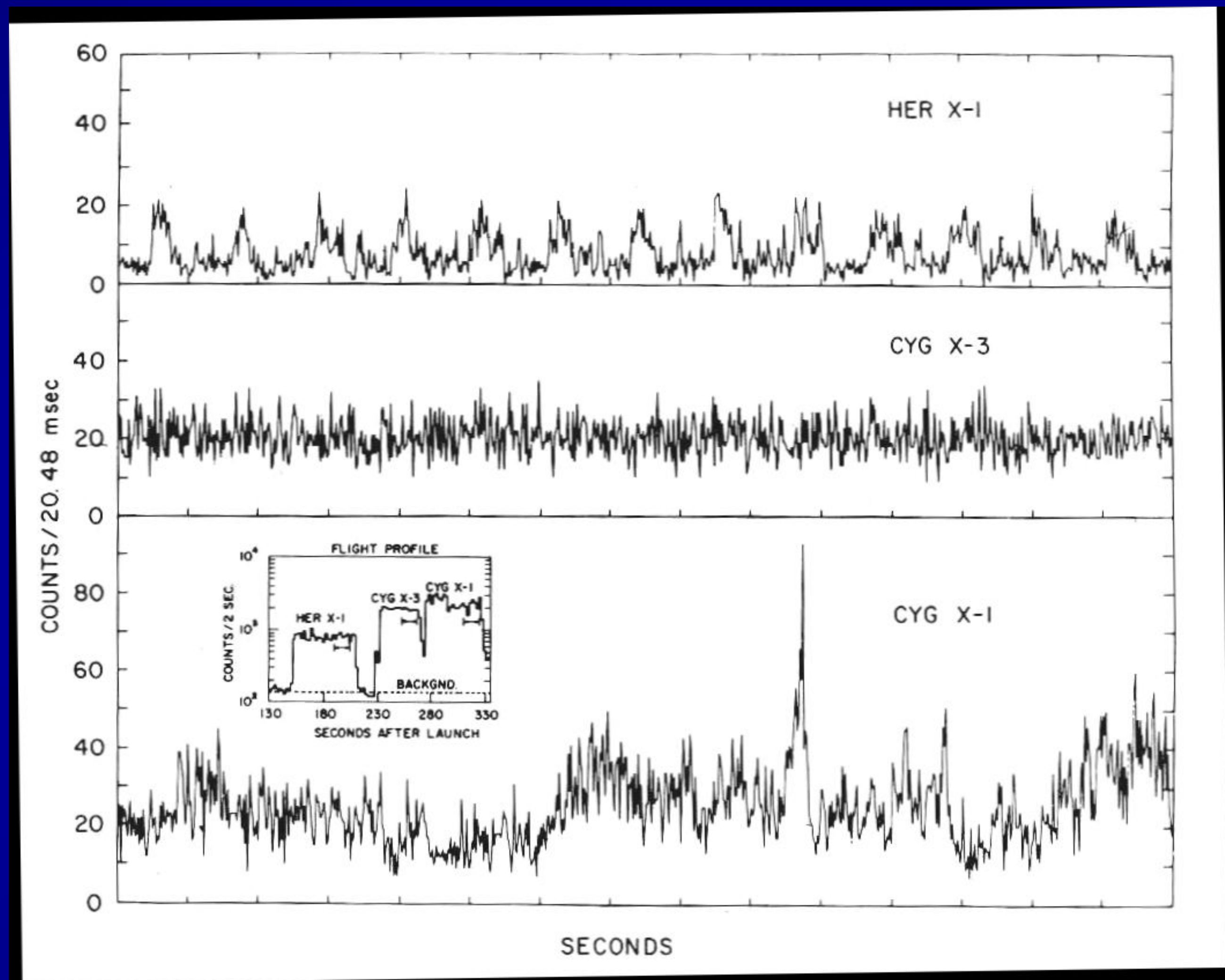
$p_\phi/m\mu = -22/(3\sqrt{3})$

The Uhuru satellite





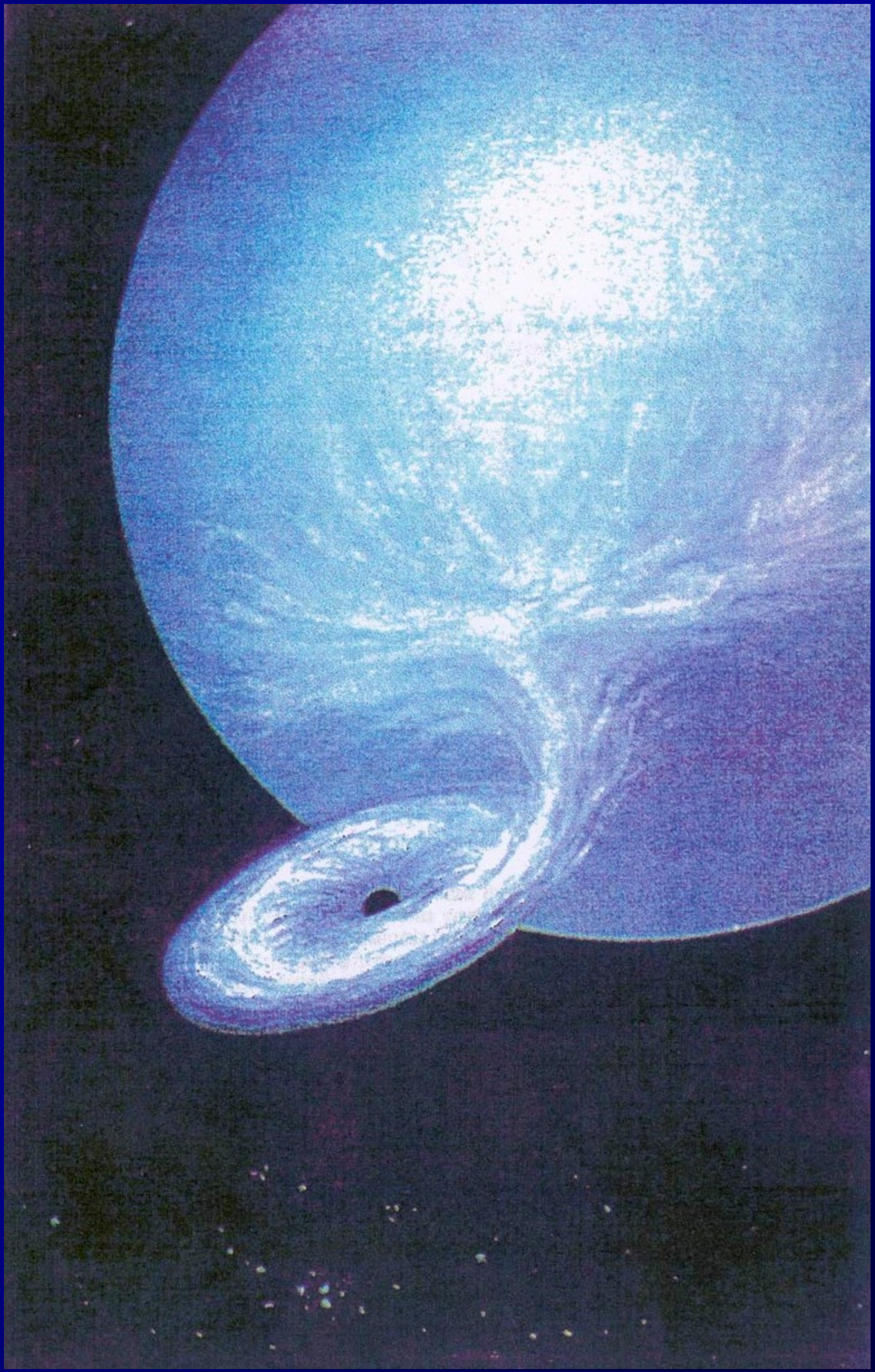
The discovery of the binary X-ray sources



The identification of the first black hole in our galaxy: Cygnus X-1

- $\Phi = 10^{37}$ erg/s = $10^4\ L_\odot$
  $= 0.01(dm/dt)_{acc}c^2$
- Absence of pulsation due to uniqueness of Kerr-Newmann black holes
- $M > 3.2\ M_\odot$

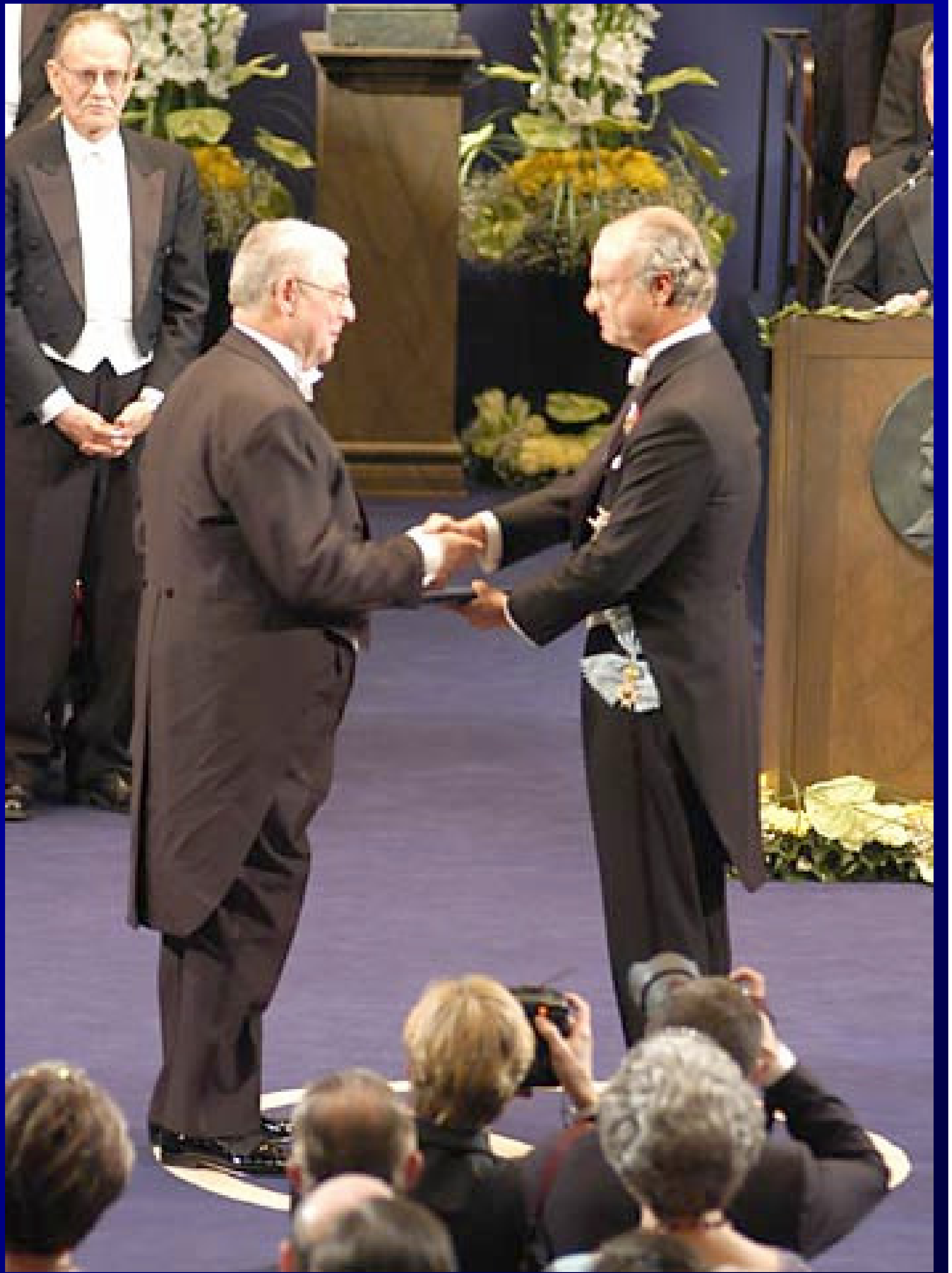
Leach & Ruffini, *ApJ* 180 (1973) L15

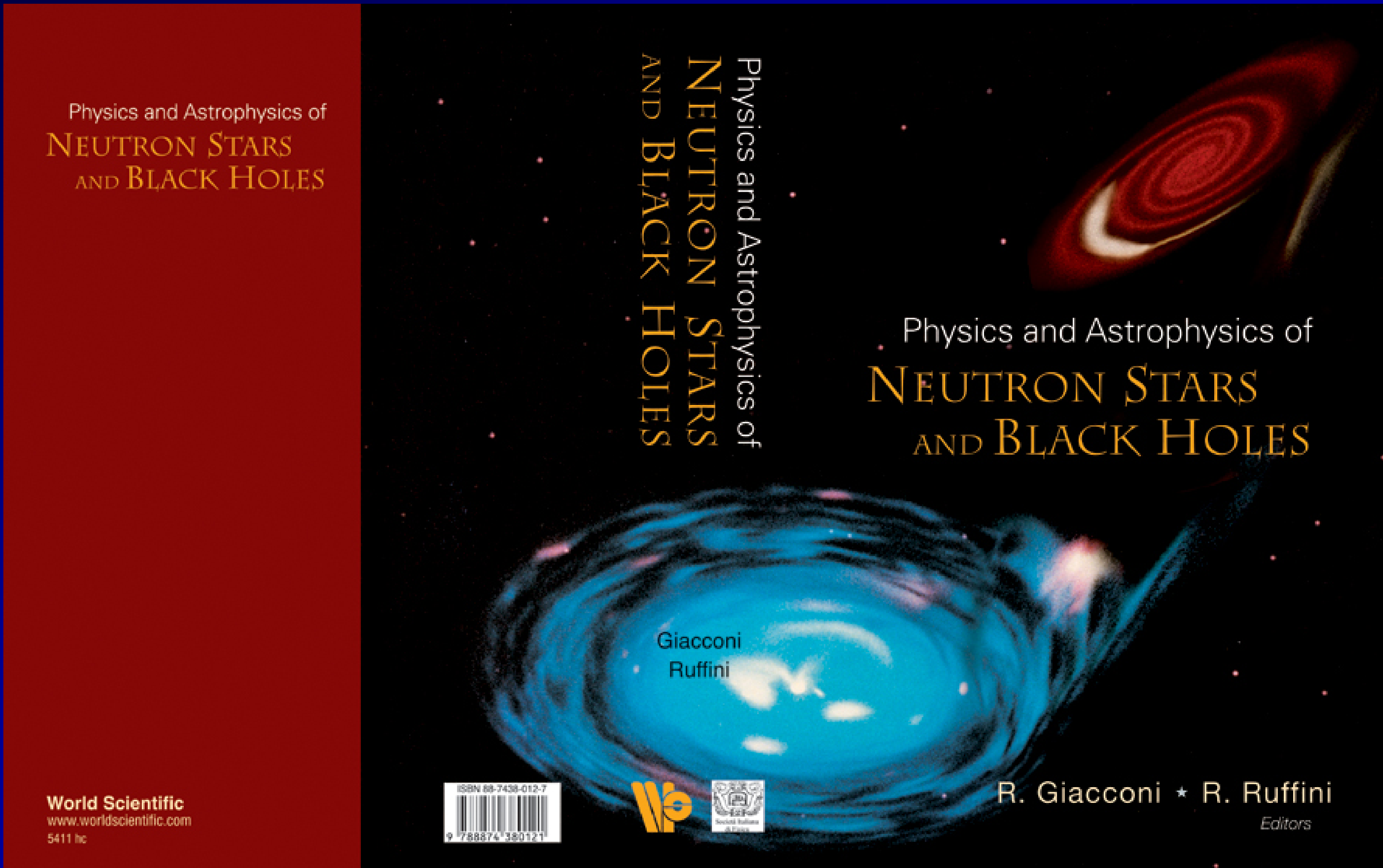


Varenna, 1975

Cressy - Morrison Award (NY, 1973)

Giacconi, Sweden (2002)

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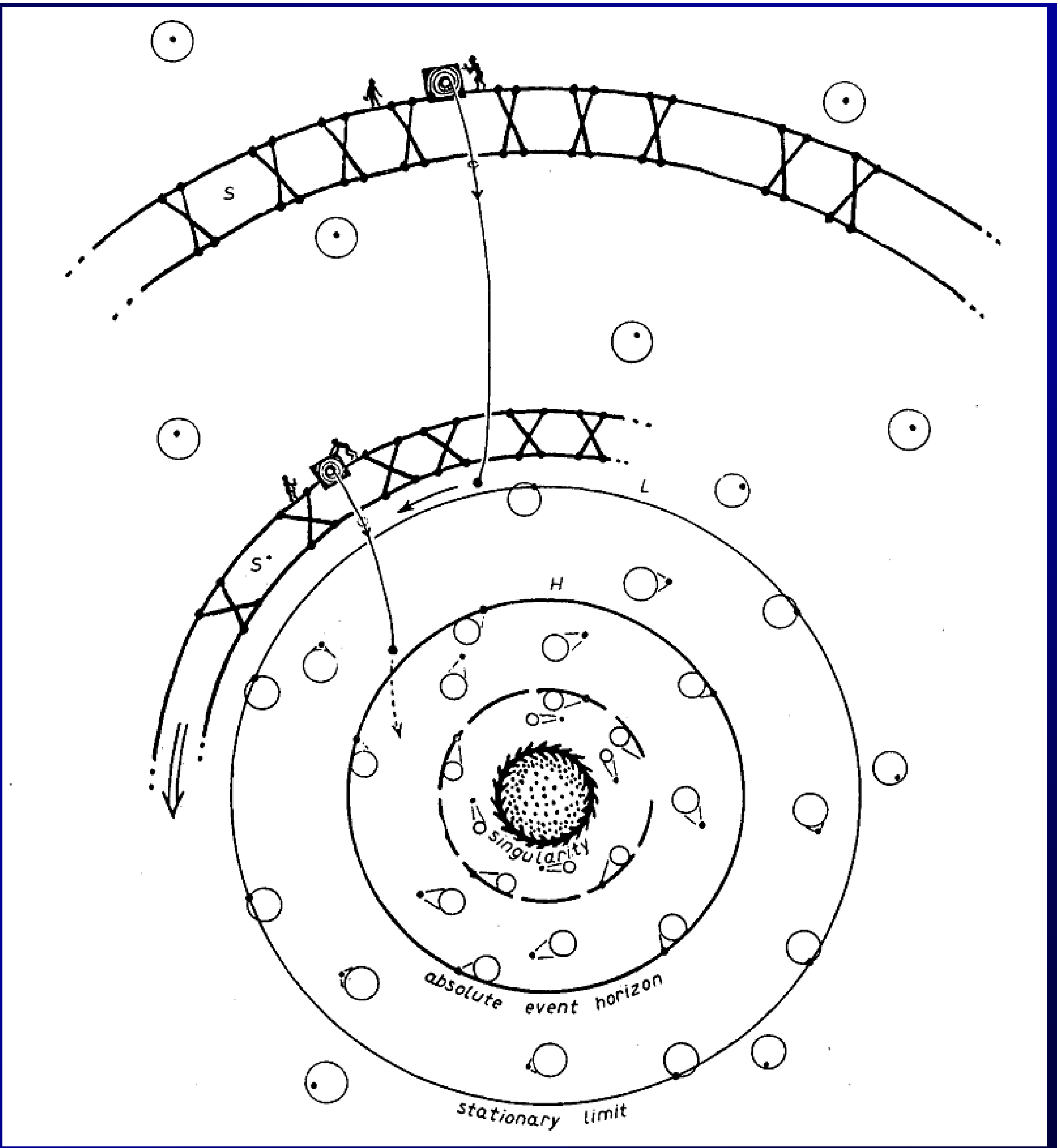
Editors

Extraterrestrial Civilizations working on Kerr metric



Roger Penrose,
Riv.N.Cim., 1, 252 (1969)

Ergosphere of an extreme Kerr Hole

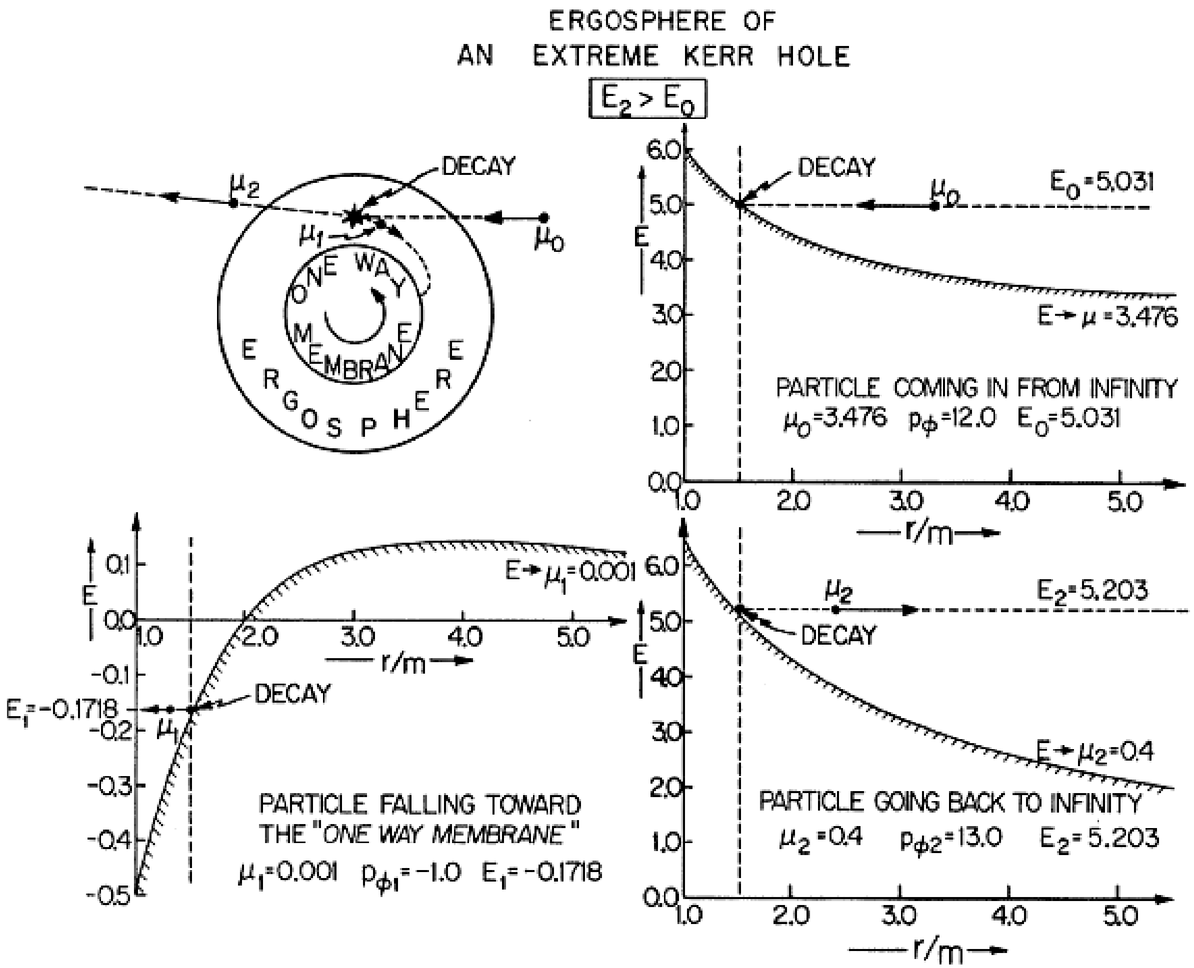


FIG. 2. (Reproduced from Ruffini and Wheeler, Ref. 4, with their kind permission.) Decay of a particle of rest-plus-kinetic energy E_0 into a particle which is captured into the black hole with positive energy as judged locally, but negative energy E_1 as judged from infinity, together with a particle of rest-plus-kinetic energy $E_2 > E_0$ which escapes to infinity. The cross-hatched curves give the effective potential (gravitational plus centrifugal) defined by the solution E of Eq. (2) for constant values of p_φ and μ.

Demetrios Christodoulou, *Phys.Rev.Lett.*, 25, 1596 (1970)

Floyd - Penrose manuscript

Copy made by Penrose for Wheeler 19 Dec 1970
Sent to Nature ~ 10 Dec 1970
Penrose said he will revise to refer to

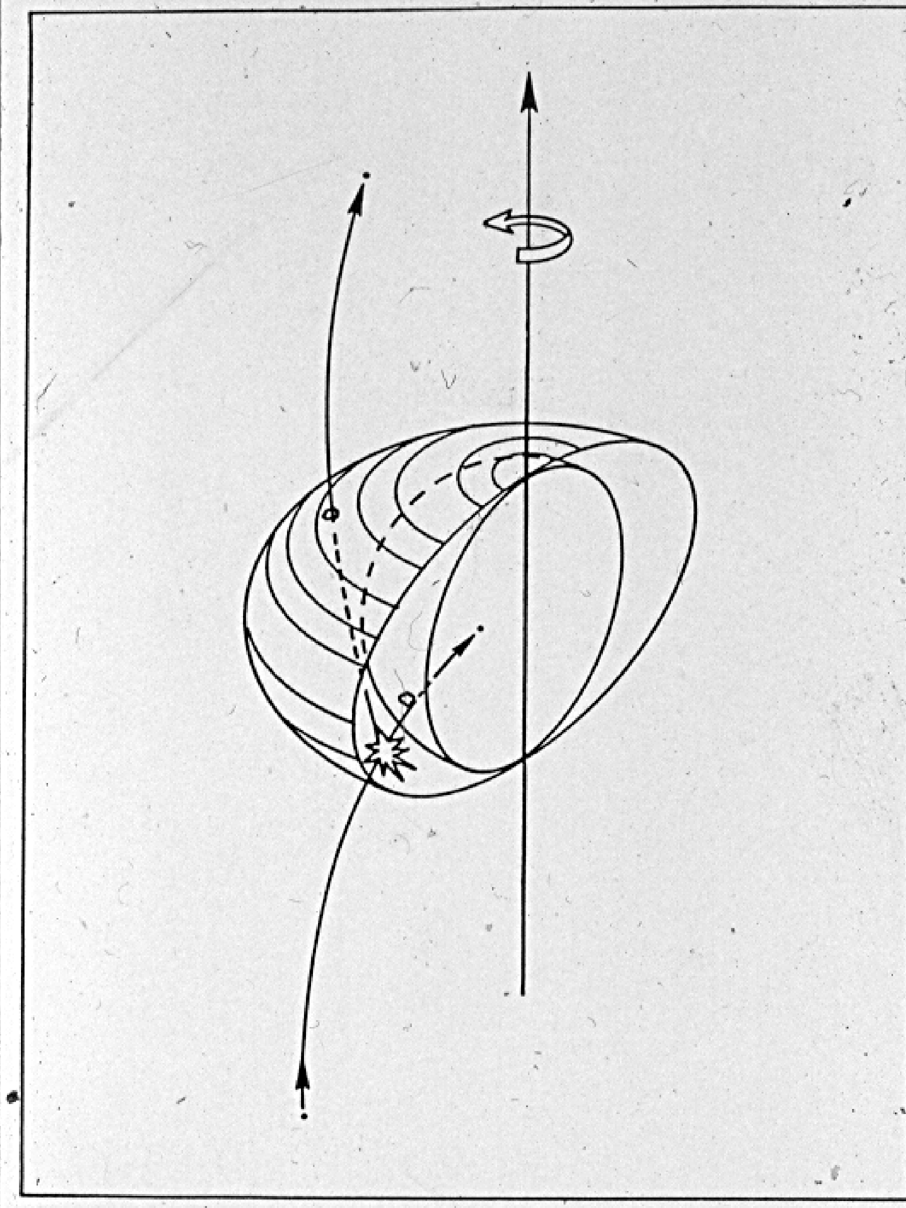
Extraction of Rotational Energy from a "Black Hole"

Christodoulou 30 nov 1970 Phys Rev Letter on "Reversible and Irreversible Transformations in Black Hole Physics"

In recent years there has been considerable interest in the question of the gravitational collapse of a massive body and of possible astrophysical consequences of the existence of the "black hole" which general relativity predicts should sometimes be the result of such a collapse. In particular, the question has arisen whether the mass-energy content of a black hole could, in principle, be a source of available energy under suitable circumstances. In this note we consider the question of the extraction of rotational energy from a black hole. This has some interest particularly because it is to be expected that the rotational energy (defined appropriately) of a black hole should, in general, be comparable with its total mass-energy.

Later Penrose could not revise for strike of [illegible] & work
RP.

The Ergosphere



Ergosphere of a rotating black hole. The region between the surface of infinite redshift (outer) and the event horizon (inner), here shown in a cutaway view, is called the "ergosphere." When a particle disintegrates in this region and one of the fragments falls into the black hole, the other fragment can escape to infinity with more rest plus kinetic energy than the original particle. Figure 5

Ruffini, Wheeler, *Phys.Today*, January 1971

The “Blackholic” energy:

$$E^2 = (M_{ir}c^2 + Q^2/2\rho)^2 + (Lc/\rho)^2 + p^2$$

$$E^2 = M^2c^4 = \left(M_{ir}c^2 + \frac{Q^2}{2\rho}\right)^2 + \frac{L^2c^2}{\rho^2}$$

$$S = 4\pi\rho^2 = 4\pi\left(r_{horizon}^2 + \frac{L^2}{c^2M^2}\right) = 16\pi\left(\frac{G^2}{c^4}\right)M_{ir}^2$$

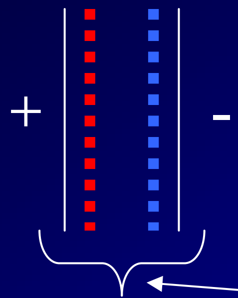
$$\frac{1}{\rho^4}\left(\frac{G^2}{c^8}\right)\left(Q^4 + 4L^2c^2\right) \le 1$$

$$\rightarrow \Delta E_{extractable} = 29\% E_{initial}$$

$$\rightarrow \Delta E_{extractable} = 50\% E_{initial}$$

Christodoulou, Ruffini, 1971

The blackholic energy and the Quantum



$$\frac{\hbar}{m_e c}$$

$$E_c = \frac{m^2 c^3}{\hbar e}; \quad Z_c \sim \frac{\hbar c}{e^2} \sim 137; \quad \Delta t \sim \frac{\hbar}{m_e c^2} \sim 10^{-18} s$$

Heisenberg, Euler, 1935, Schwinger, 1951

$$E^2 = M^2 c^4 = \left(M_{ir} c^2 + \frac{Q^2}{2\rho} \right)^2 + \frac{L^2 c^2}{\rho^2}$$

Christodoulou, Ruffini, 1971

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$$\Delta E_{extractable} = 29\% E_{initial}$$

$$\Delta E_{extractable} = 50\% E_{initial}$$

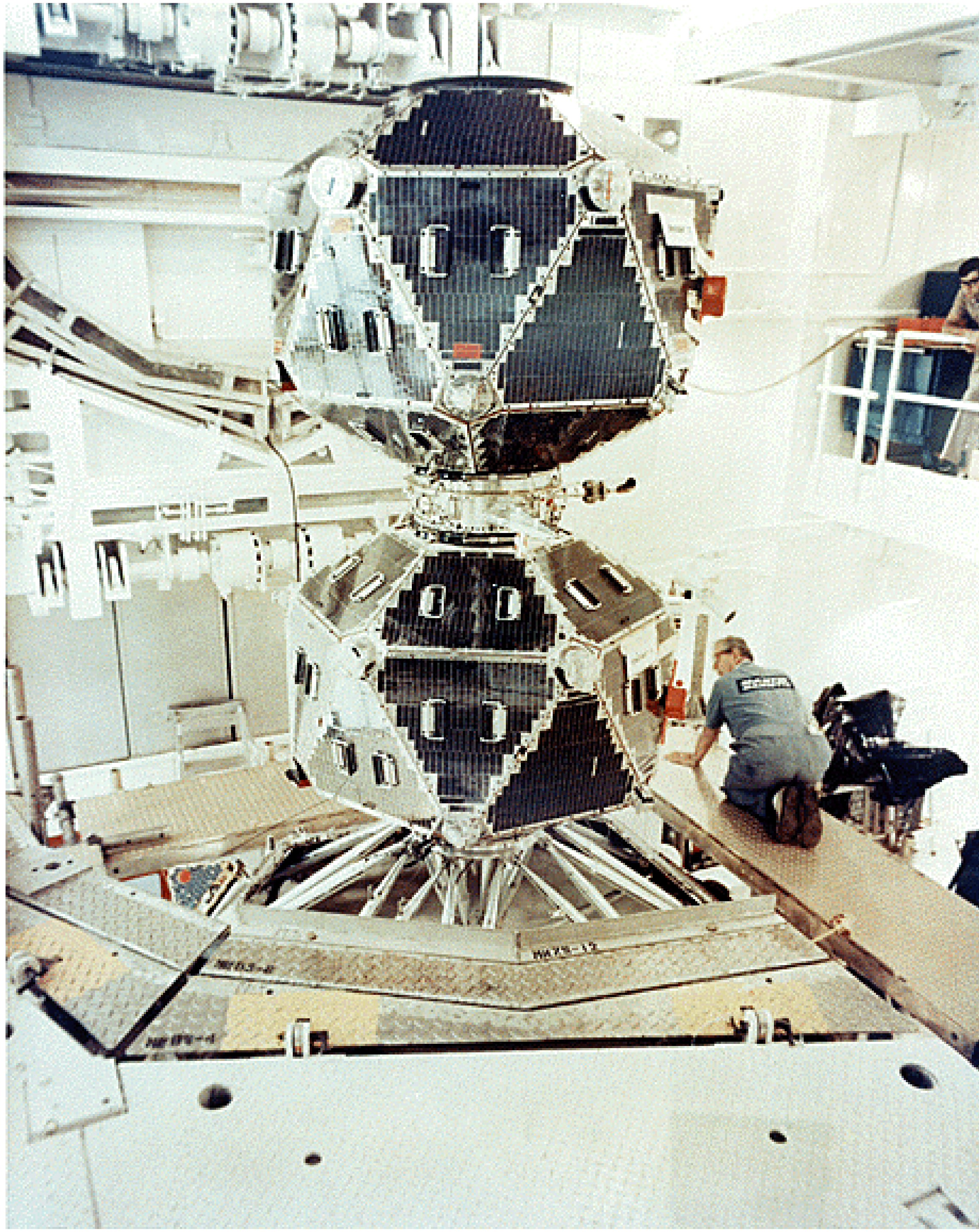
Damour & Ruffini 1974

- **In a Kerr-Newmann black hole vacuum polarization process occurs if $3.2 M_{Sun} \leq M_{BH} \leq 7.2 \cdot 10^6 M_{Sun}$**
- **Maximum energy extractable $1.8 \cdot 10^{54}$ (M_{BH}/M_{Sun}) ergs**
- **"…naturally leads to a most simple model for the explanation of the recently discovered γ-rays bursts"**

Yacob Borisovich Zel'dovich (before)

Yacob Borisovich Zel’dovich (after)

The *Vela* Satellites



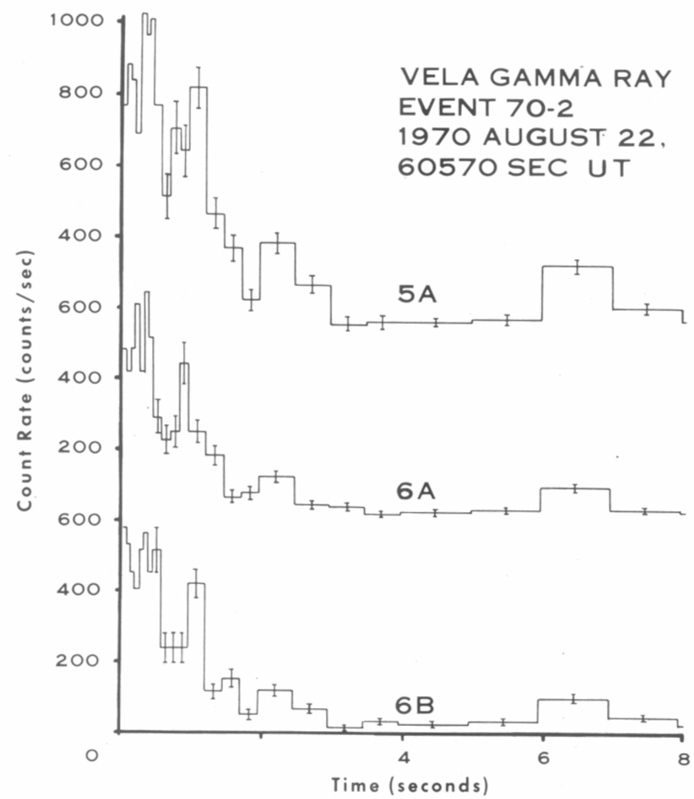
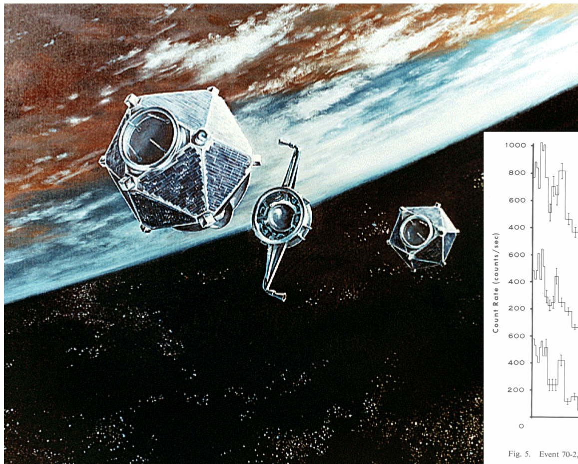
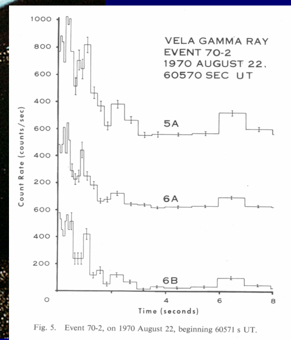
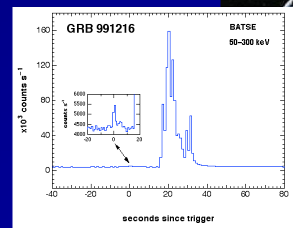


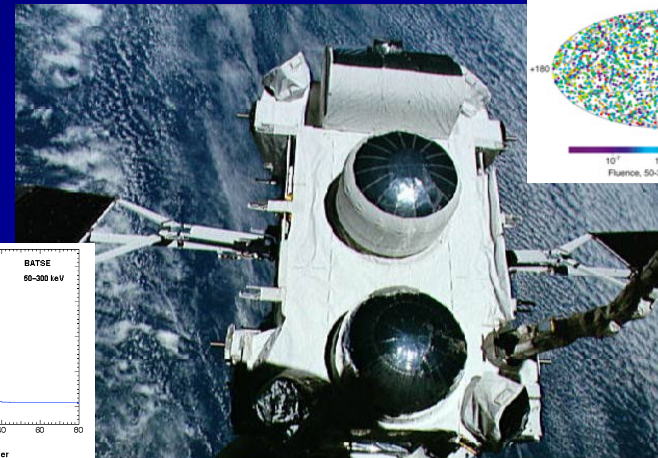
Fig. 5. Event 70-2, on 1970 August 22, beginning 60571 s UT.

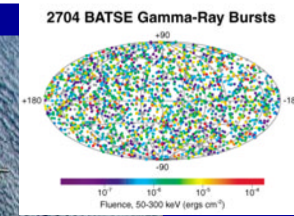
$E=10^{54}$ ergs

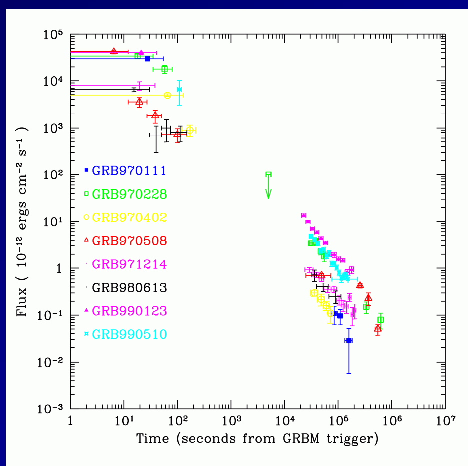


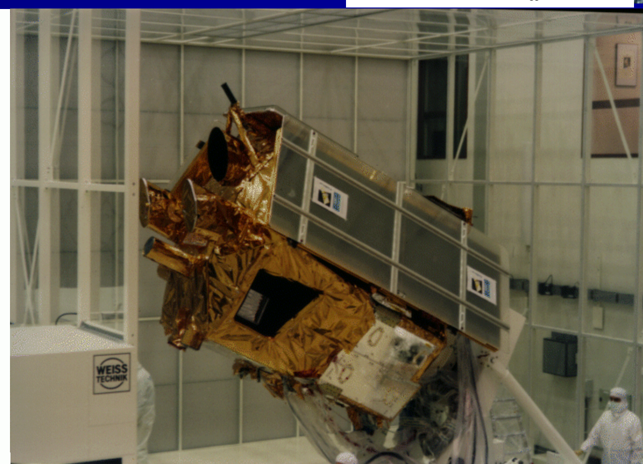

VELA GAMMA RAY
EVENT 70-2
1970 AUGUST 22.
60570 SEC UT
5A
6A
6B
Time (seconds)
Count Rate (counts/sec)
Fig. 5. Event 70-2, on 1970 August 22, beginning 60571 s UT.

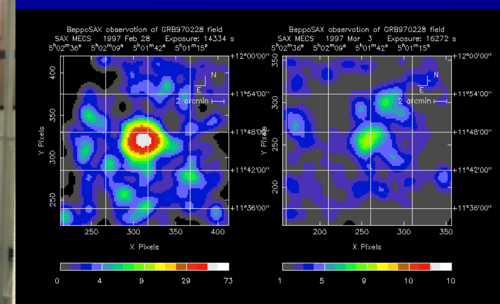

GRB 991216
BATSE
50–300 keV
x10³ counts s⁻¹
seconds since trigger

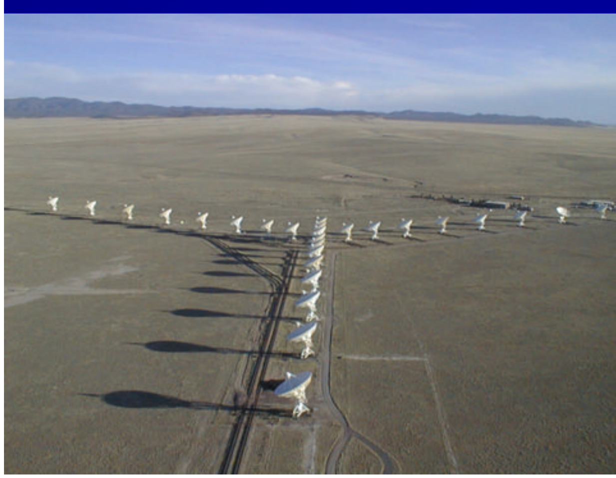


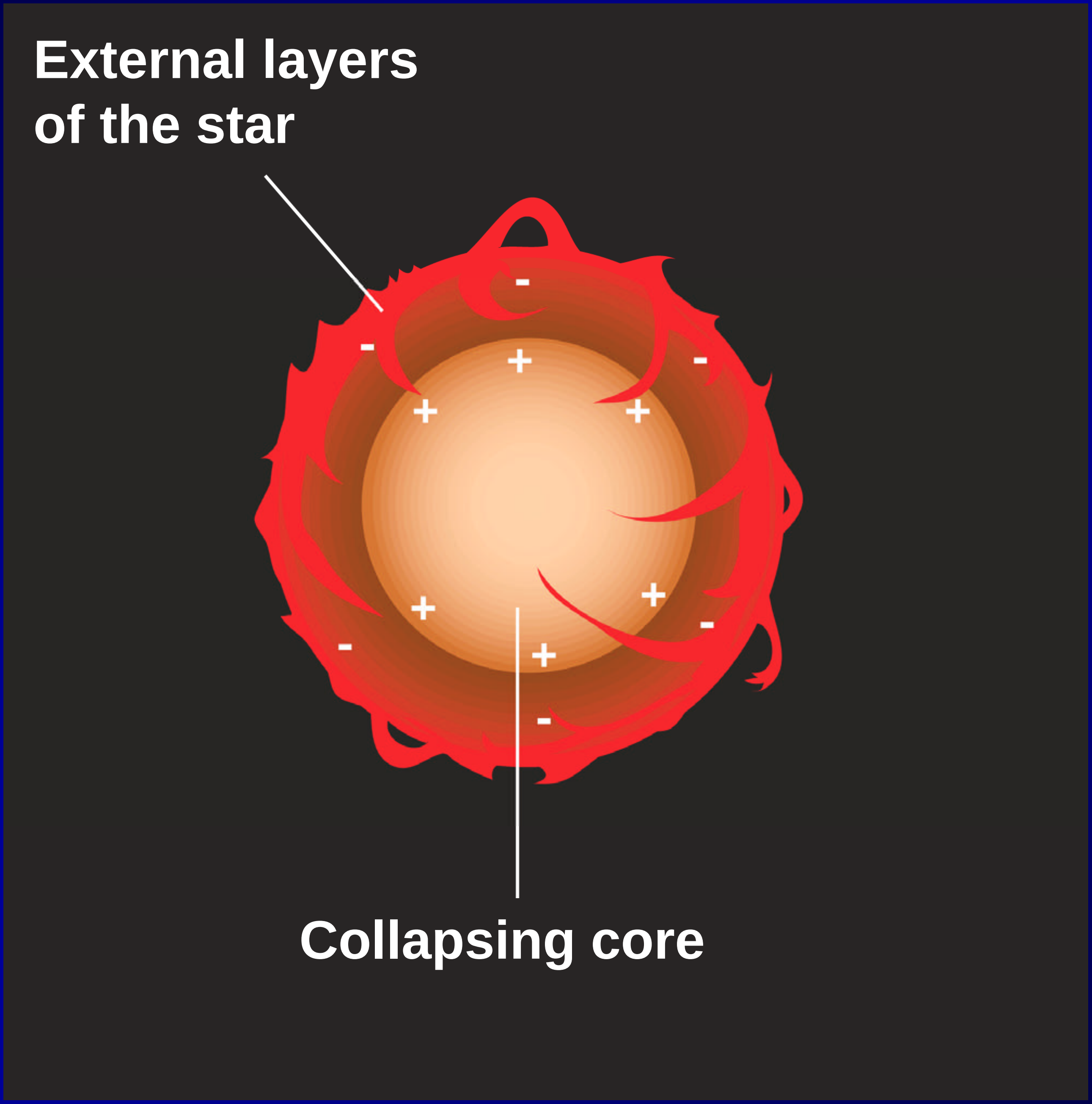

2704 BATSE Gamma-Ray Bursts
Fluence, 50-300 keV (ergs cm⁻²)

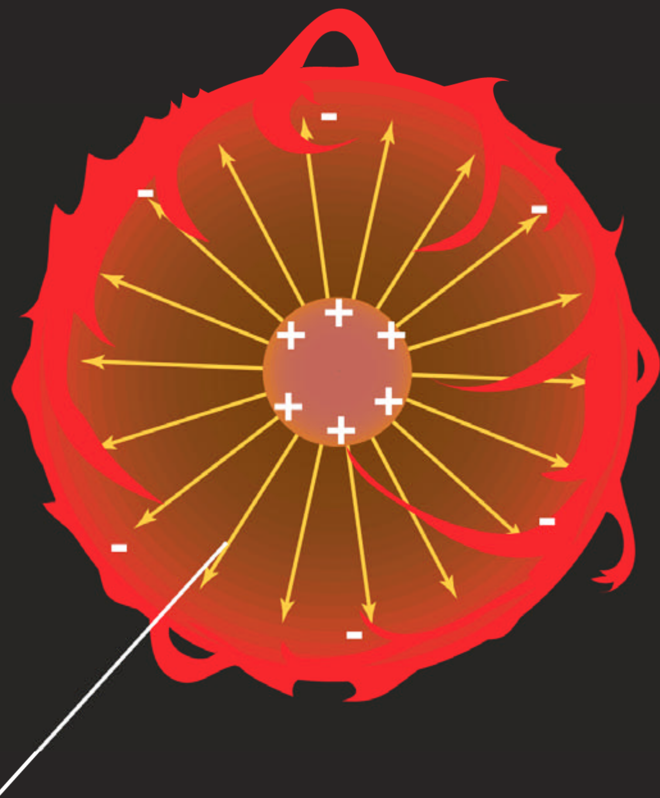

Flux (10⁻¹² ergs cm⁻² s⁻¹)
Time (seconds from GRBM trigger)
GRB970111
GRB970228
GRB970402
GRB970508
GRB971214
GRB980613
GRB990123
GRB990510



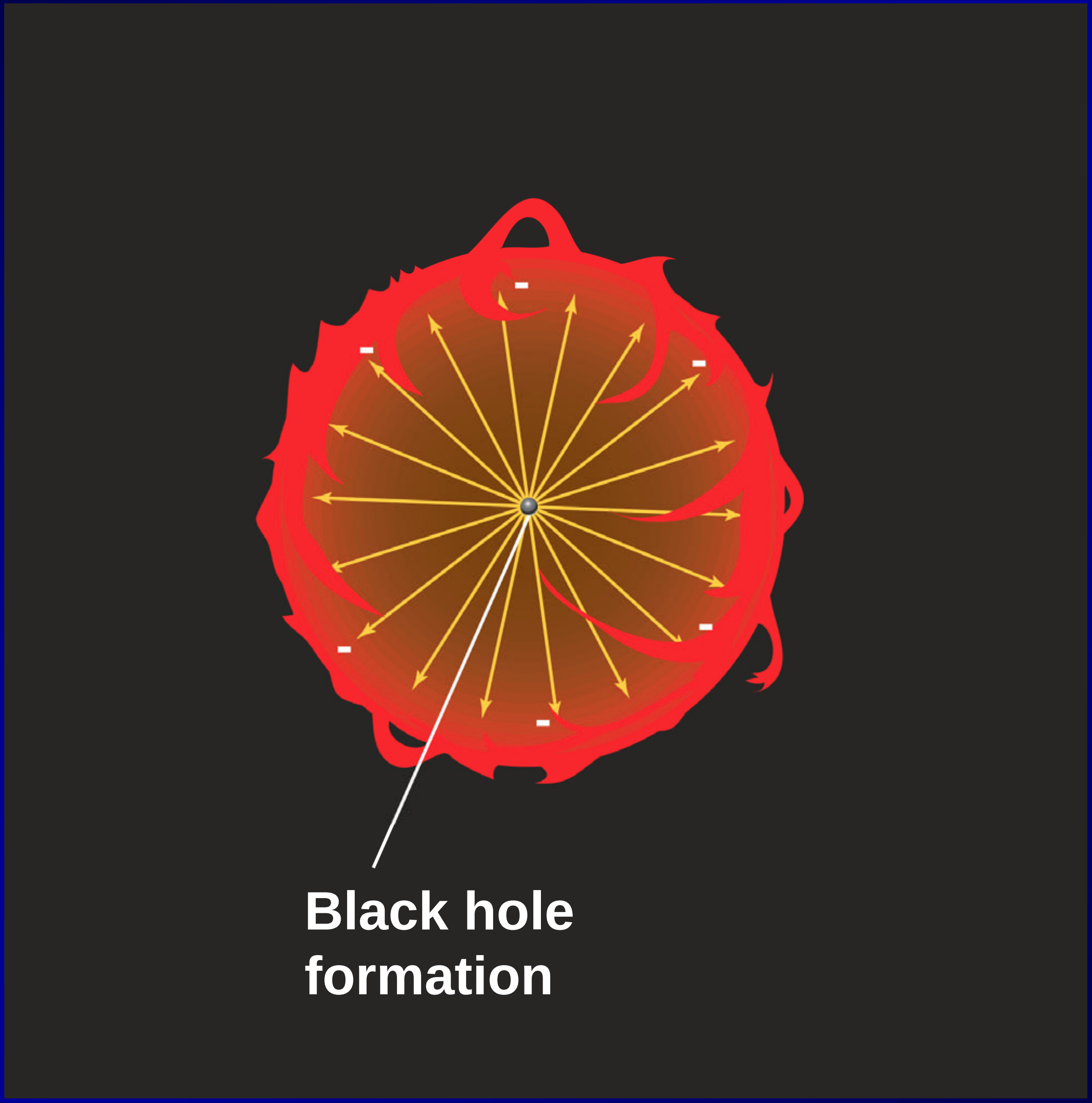

BeppoSAX observation of GRB970228 field
X Pixels
Y Pixels

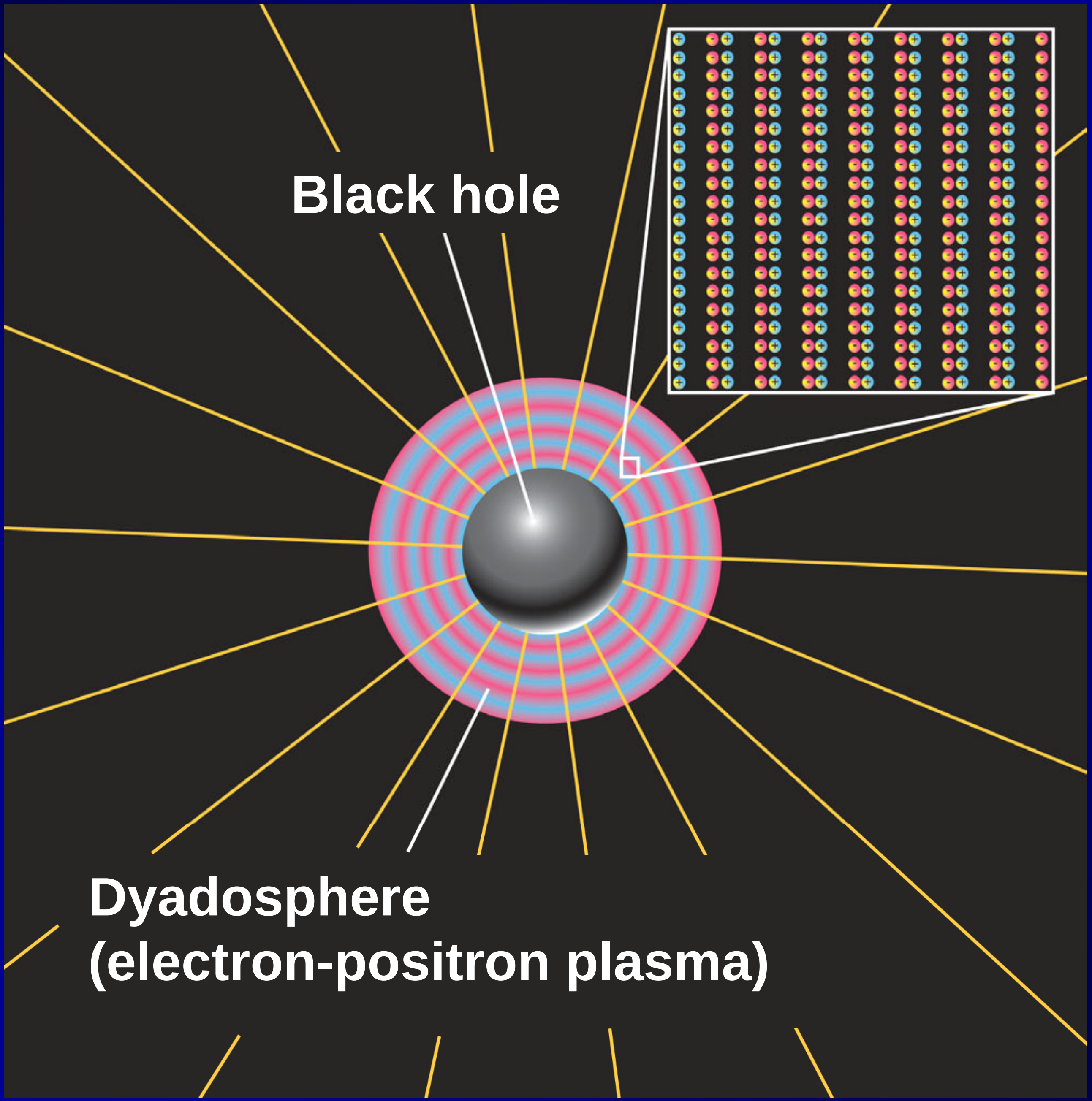


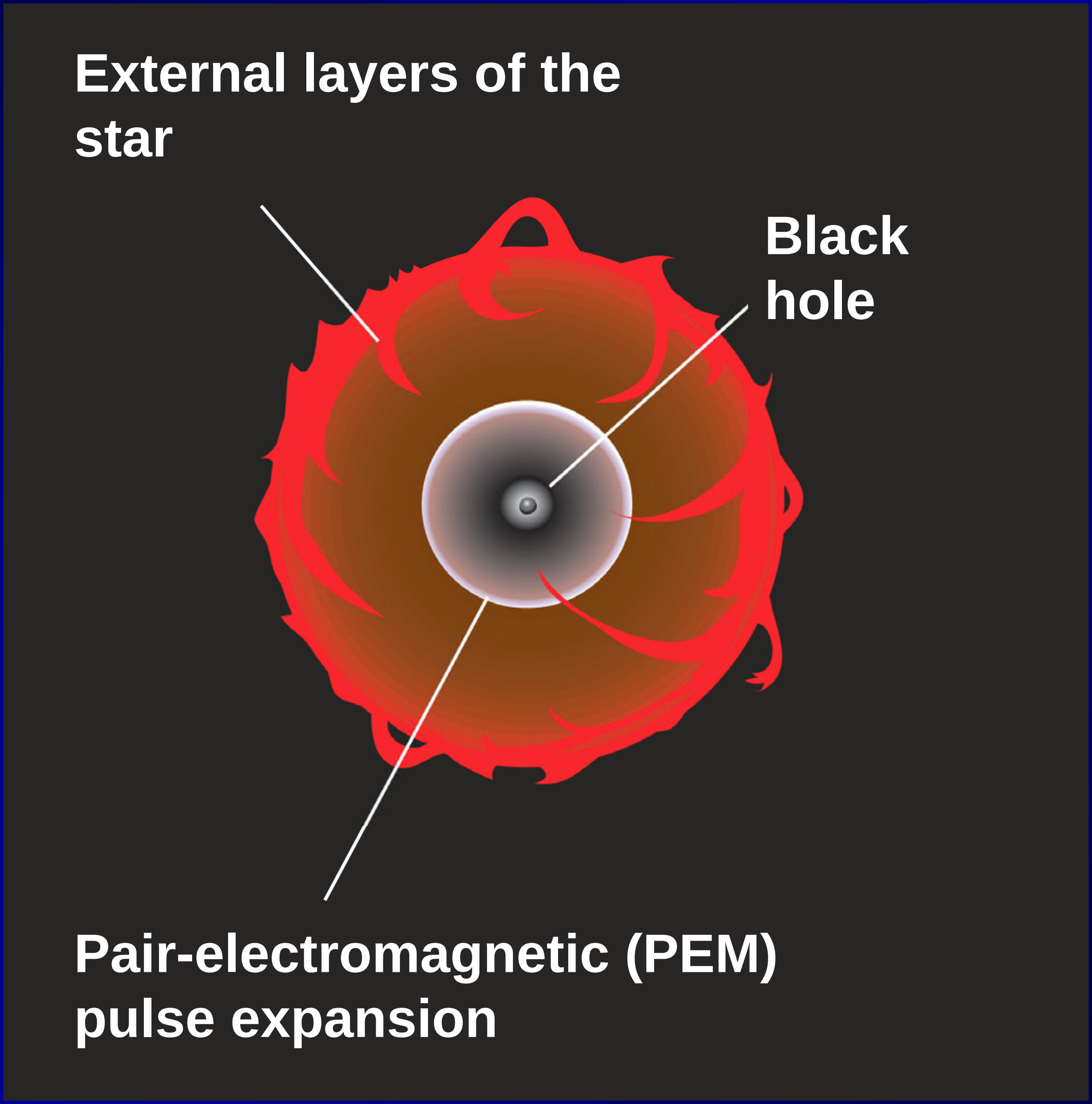

External layers
of the star
Collapsing core

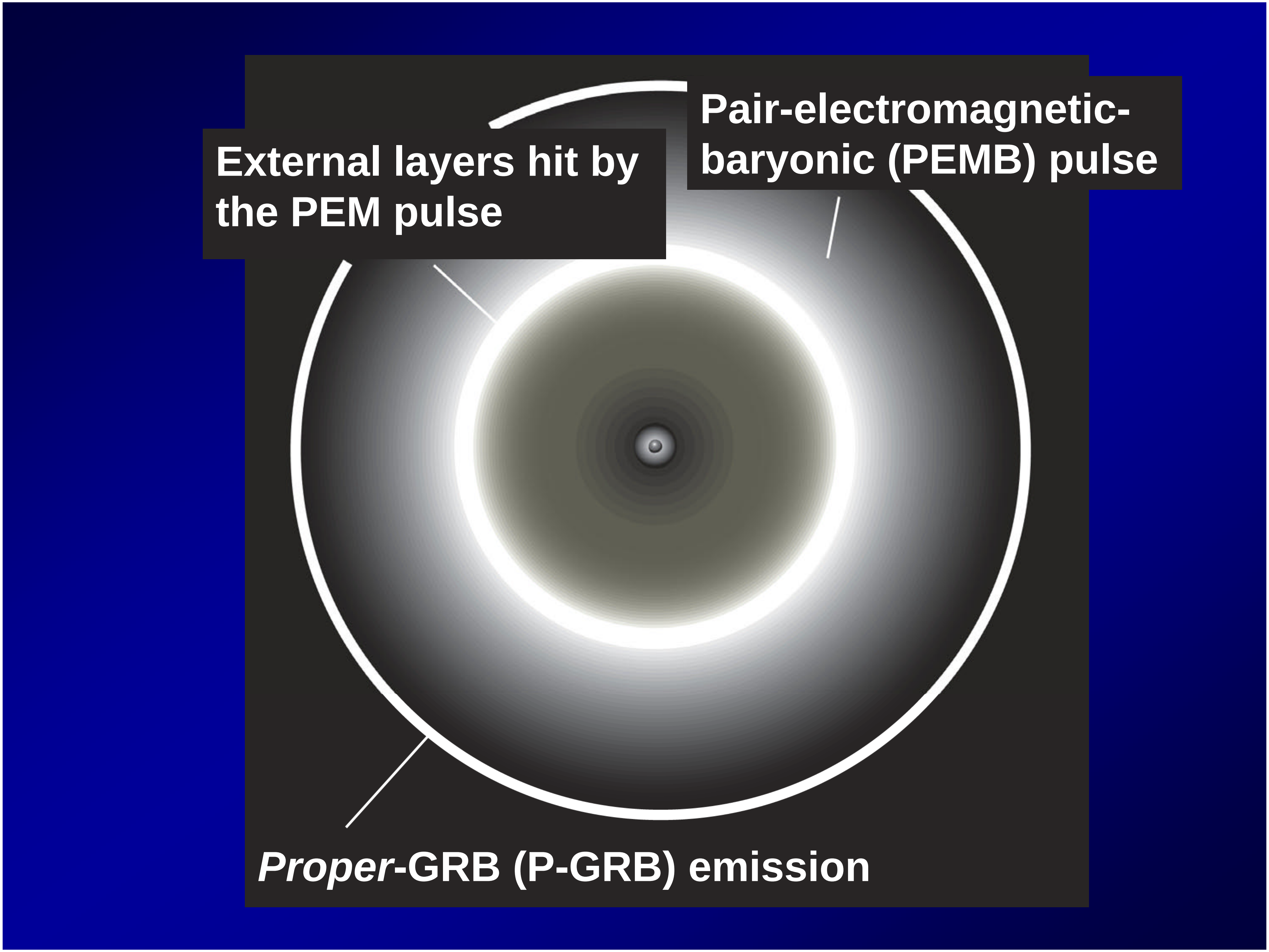


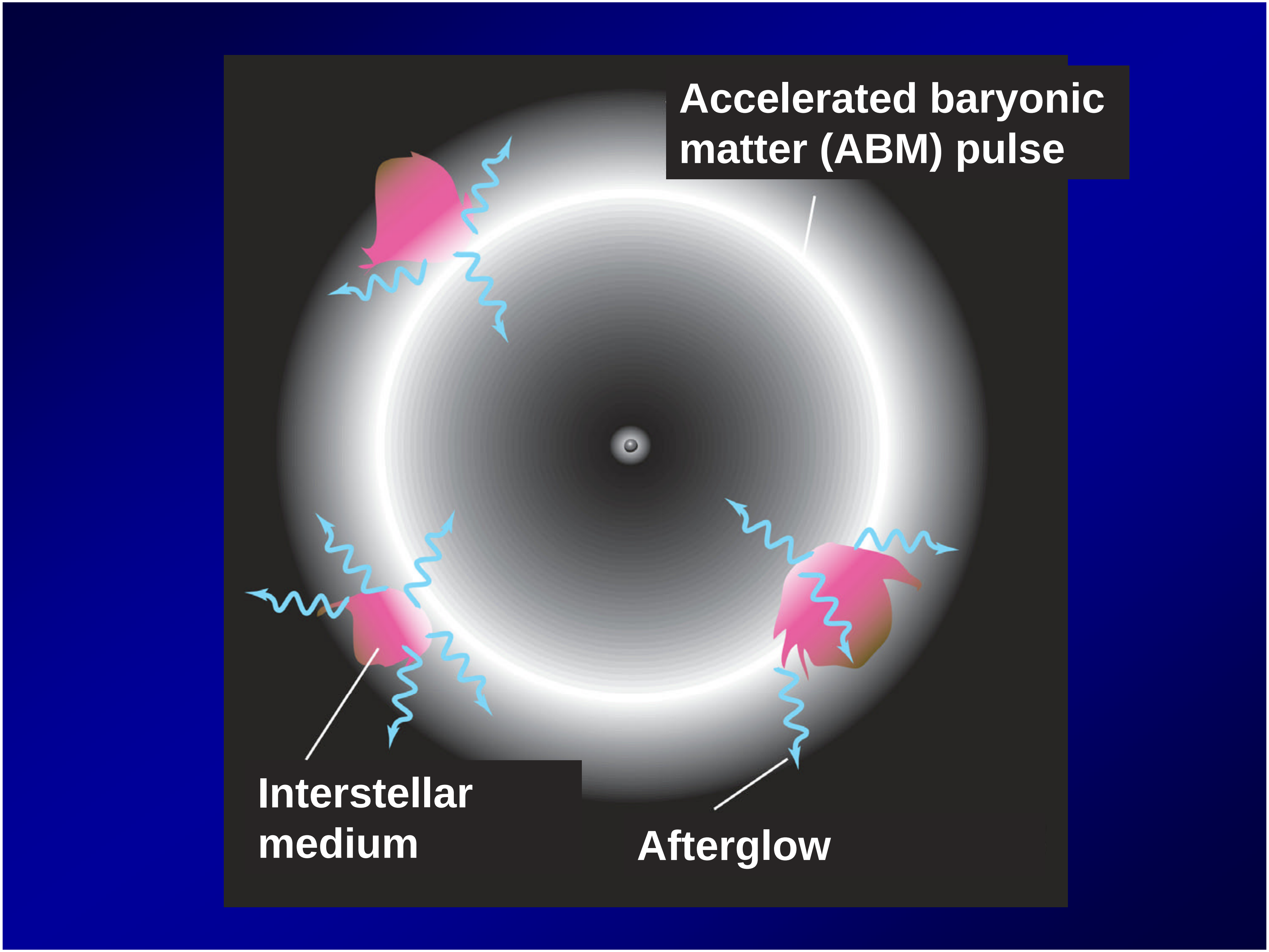
Electromagnetic field created by the charge segregation at the moment of the collapse.


Black hole
formation


Black hole
Dyadosphere
(electron-positron plasma)

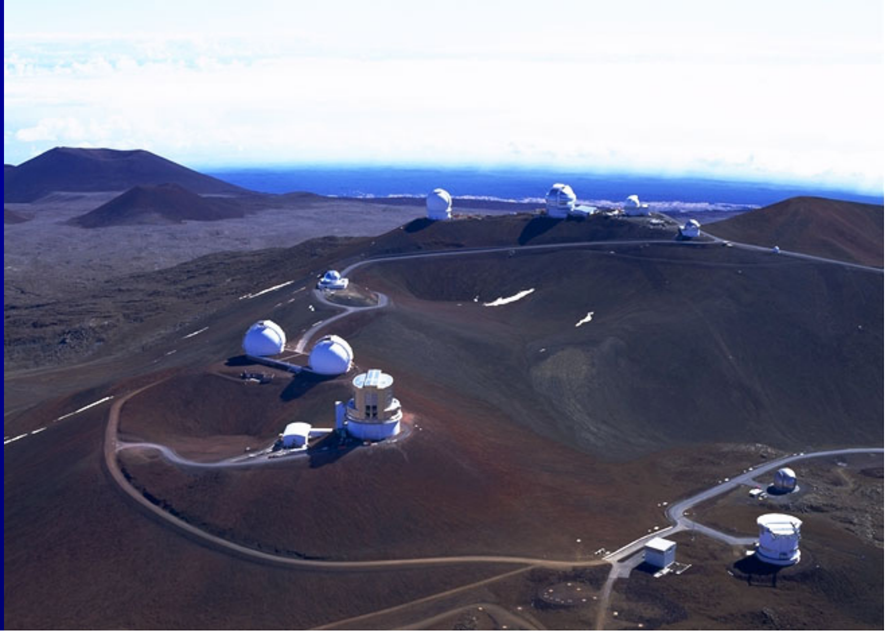

External layers of the star
Black hole
Pair-electromagnetic (PEM) pulse expansion


External layers hit by the PEM pulse
Pair-electromagnetic-baryonic (PEMB) pulse
Proper-GRB (P-GRB) emission

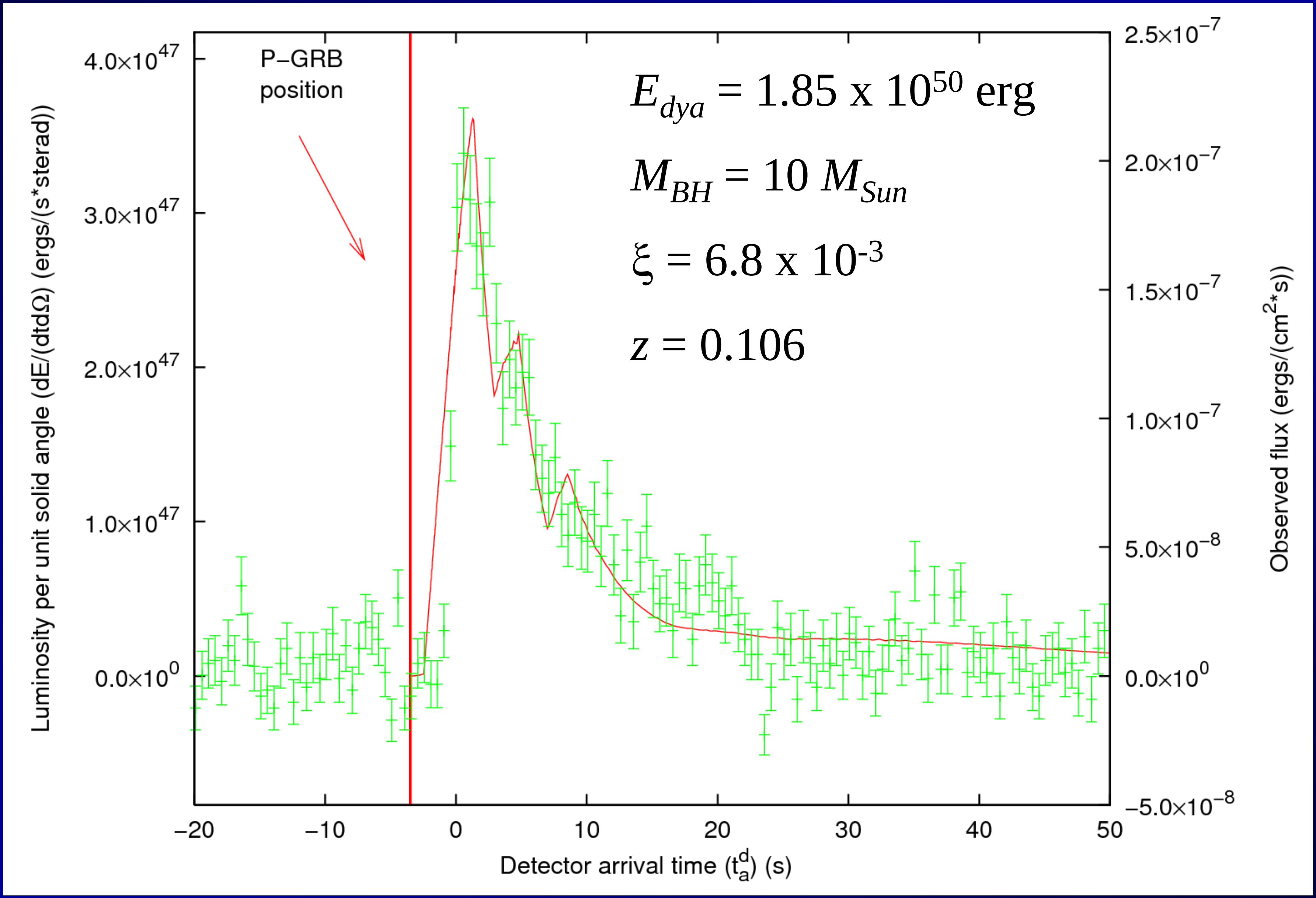


Accelerated baryonic matter (ABM) pulse
Interstellar medium
Afterglow

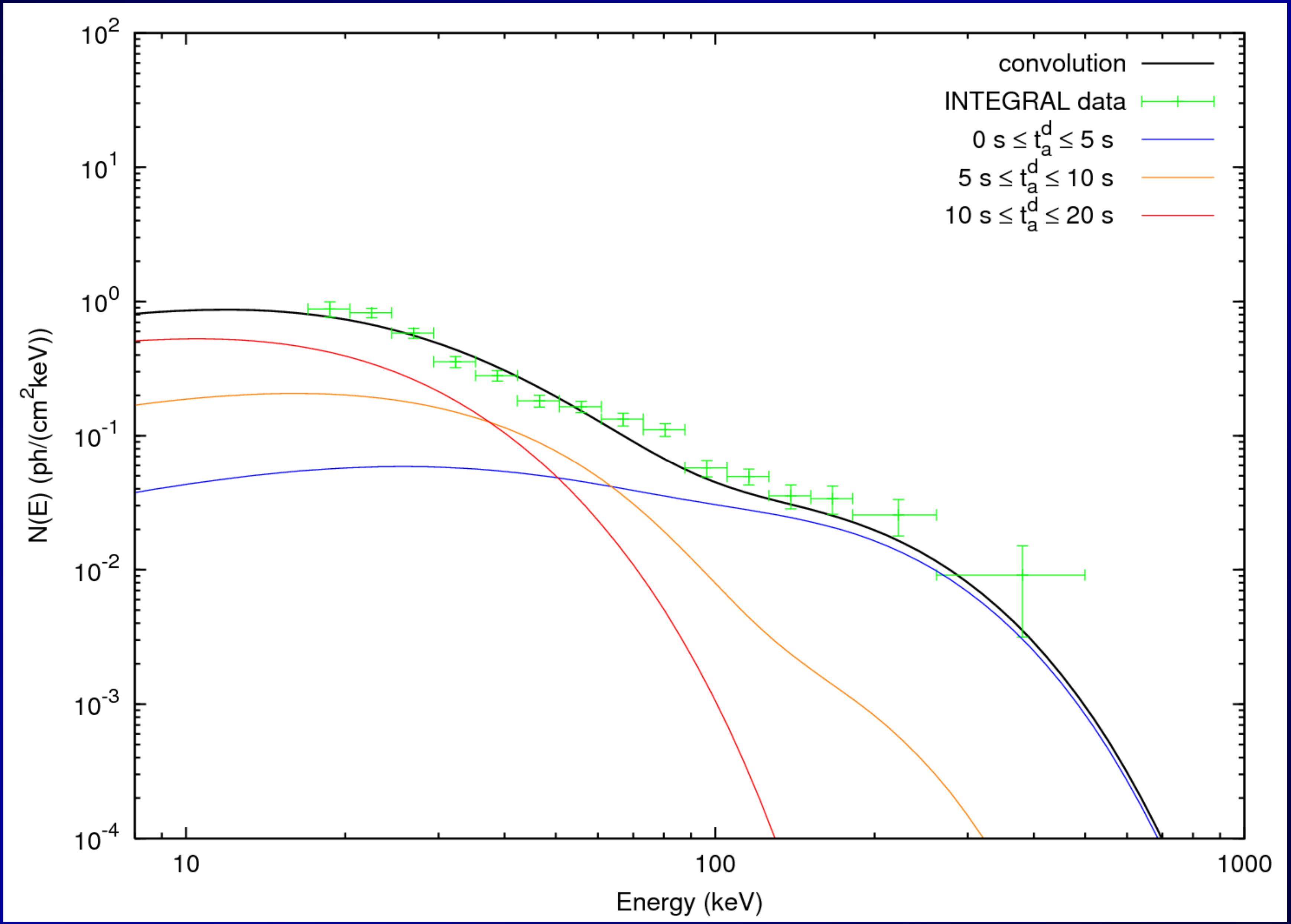
GRB 031203



A model by us accepted by ApJ Lett. (in press)



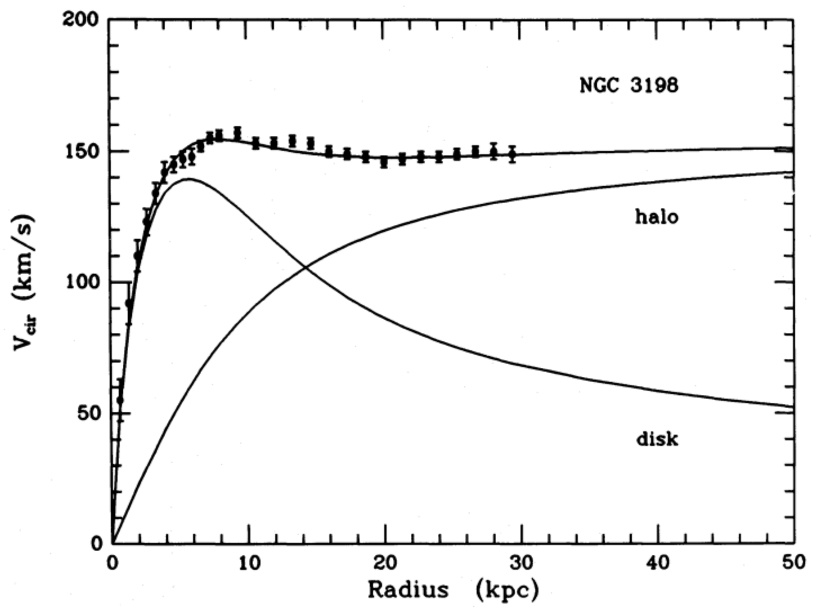
A model by us accepted by ApJ Lett. (in press)



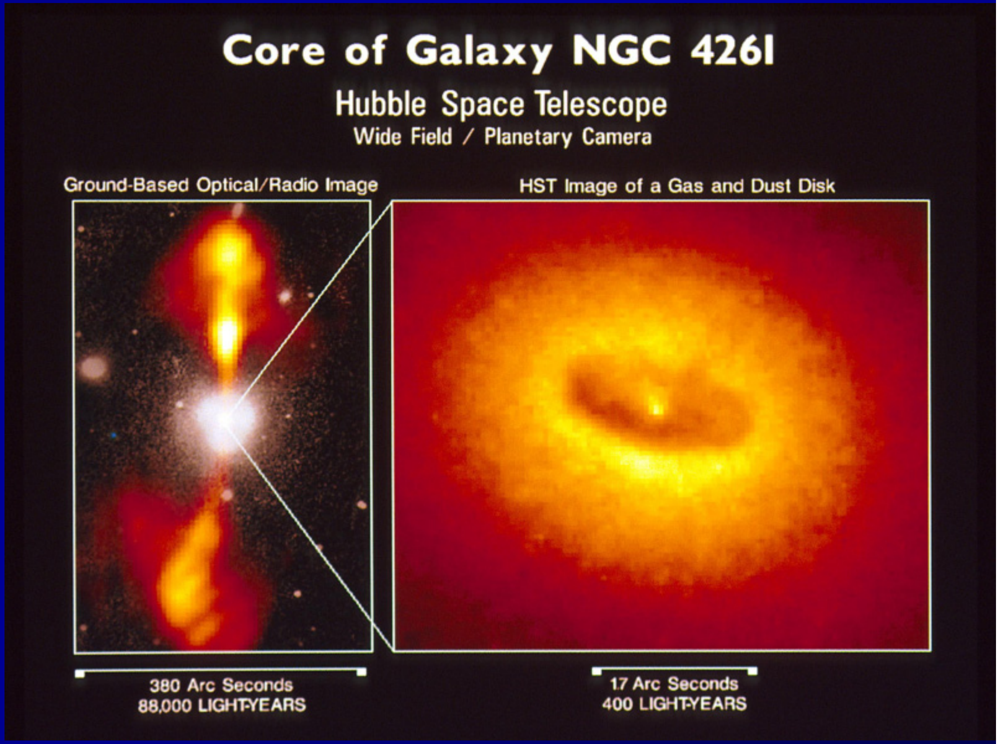
Dark matter and Neutrinos in the Universe

Victor F. Shvartsman,
ZhETF Pis. Red., 9, 315 (1969)

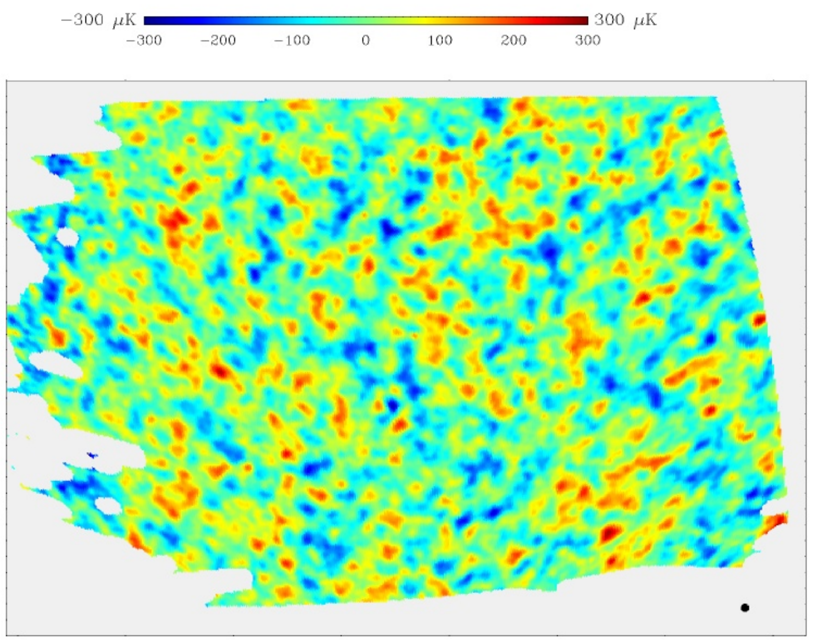
Evidence for Dark Matter



Flat Galaxy rotation curves

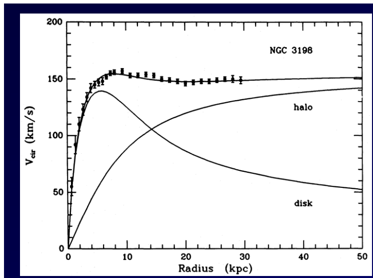


Active Galactic Nuclei



Cosmic Microwave Background Radiation

Neutrinos and Rotation Curves



van Albada, Bahcall, Begeman, Sancisi,
ApJ 295 (1985) 305

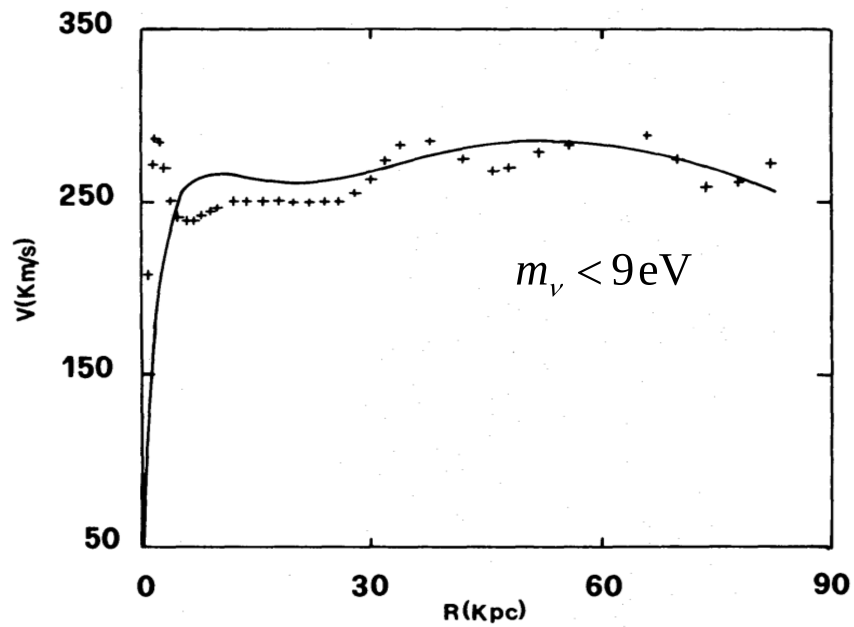
VOLUME 42, NUMBER 6 PHYSICAL REVIEW LETTERS 5 FEBRUARY 1979

Dynamical Role of Light Neutral Leptons in Cosmology

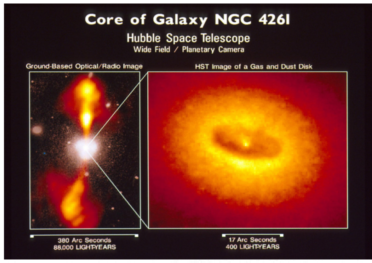
Scott Tremaine and James E. Gunn

Using the Vlasov equation, we show that massive galactic halos cannot be composed of stable neutral leptons of mass $\lesssim 1$ MeV. Since most of the mass in clusters of galaxies probably consists of stripped halos, we conclude that the "missing mass" in clusters does not consist of leptons of mass $\lesssim 1$ MeV (e.g., muon or electron neutrinos). Lee and Weinberg's hypothetical heavy leptons (mass ≈ 1 GeV) are not ruled out by this argument.

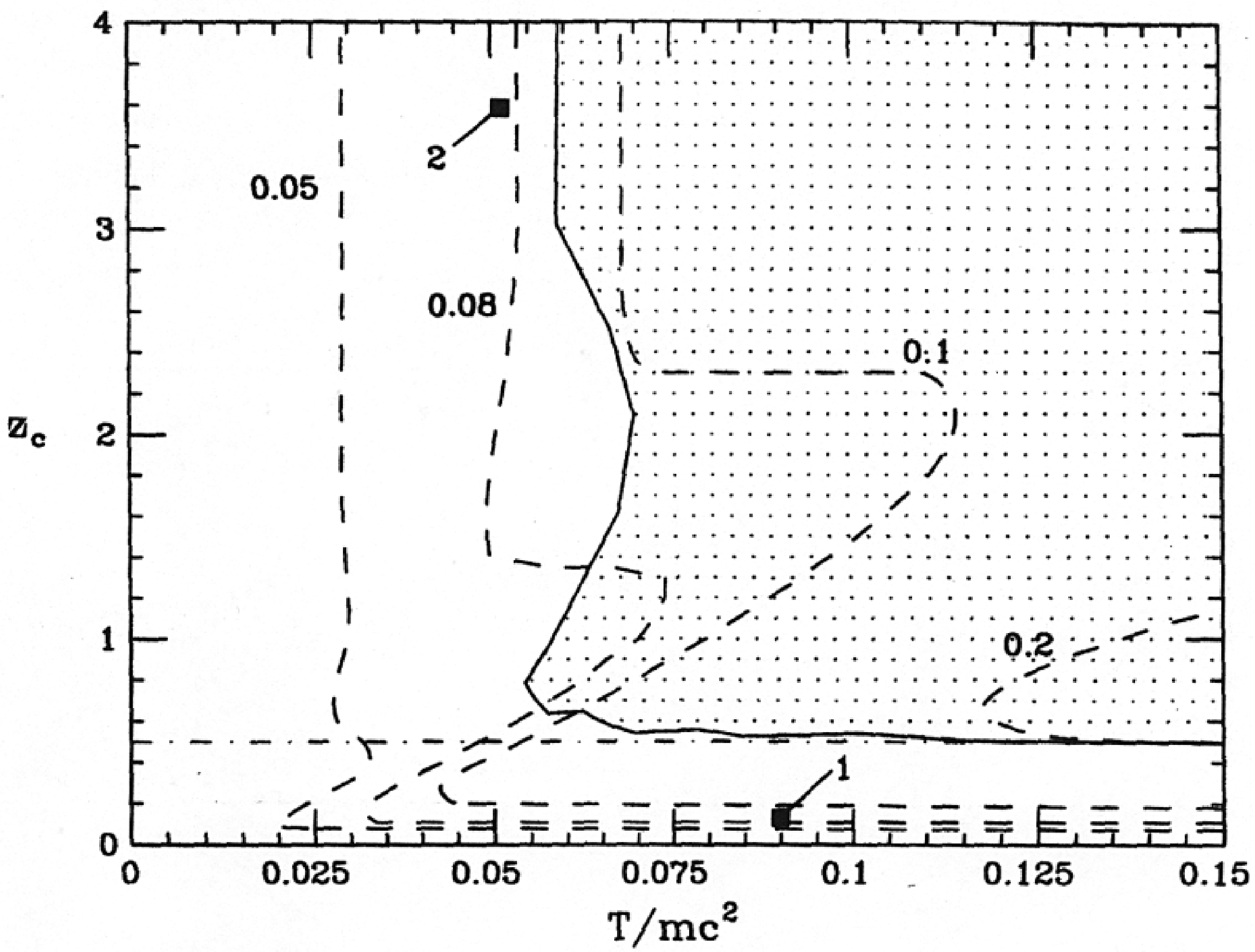
 407



M. V. Arbolino, R. Ruffini,
Astron. Astrophys., 192 (1988) 107



From Einstein Clusters to Relativistic Clusters via Zel’dovich Podurets



Ya.B. Zel’dovich, M.A. Podurets, *Sov. Astron AJ* 9 (1966) 742

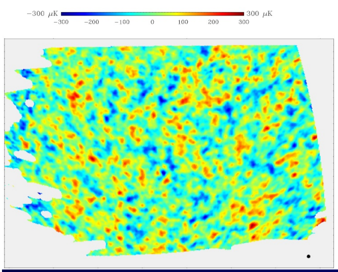
M. Merafina, R. Ruffini, *ApJ*, 454 (1995) L89

V. Cocco, R. Ruffini, *N. Cim. B* 112 (1997) 271

$$\begin{cases} f = Be^{-E/T} & \text{for } E \le E_{\rm cut} \equiv mc^2 - \dfrac{\alpha T}{2}\,, \\ f = 0 & \text{for } E > E_{\rm cut}\,, \end{cases}$$

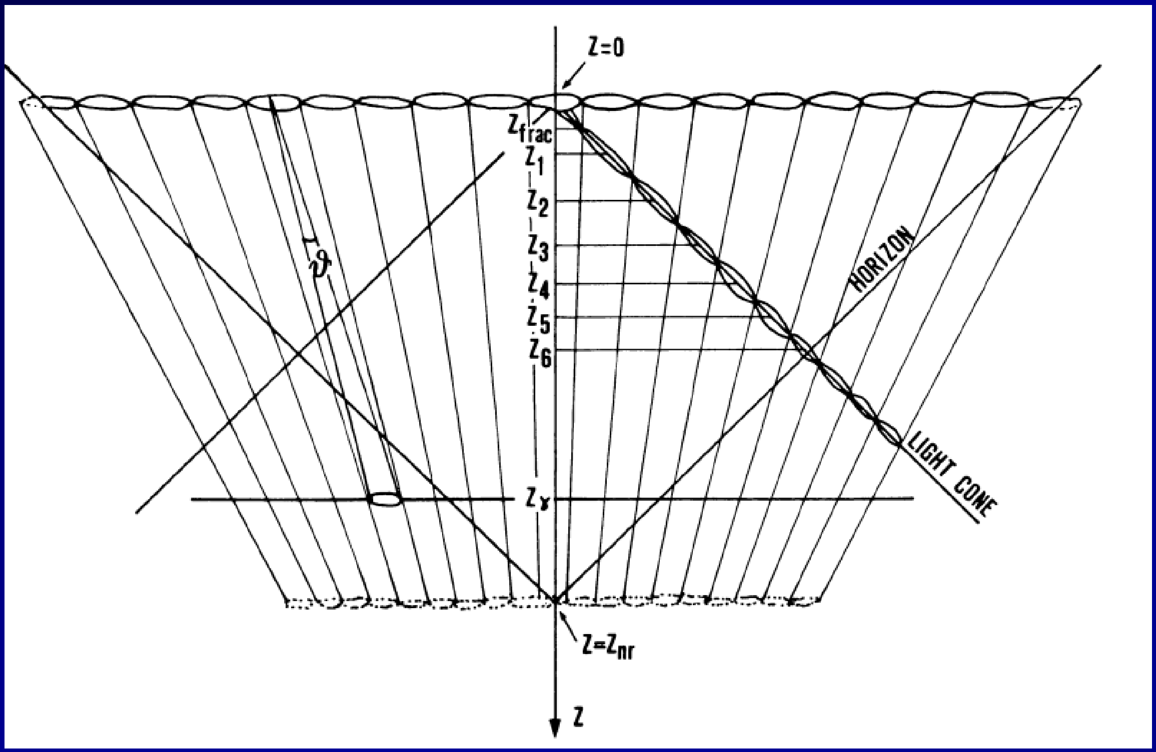
$$\begin{cases} e^{-\lambda}\left(\dfrac{1}{r}\dfrac{d\nu}{dr} + \dfrac{1}{r^2}\right) - \dfrac{1}{r^2} = \dfrac{8\pi G}{c^4}P\,, \\ e^{-\lambda}\left(\dfrac{1}{r}\dfrac{d\lambda}{dr} - \dfrac{1}{r^2}\right) + \dfrac{1}{r^2} = \dfrac{8\pi G}{c^4}\varepsilon\,, \end{cases}$$

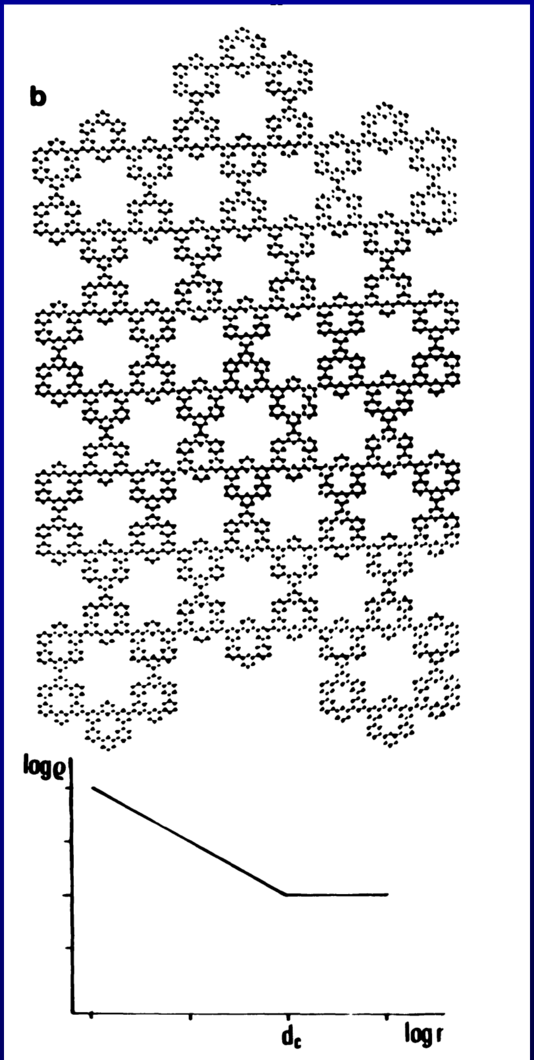
$$\varepsilon = \frac{4\pi}{c^3}Be^{-3\nu/2}\int_{mc^2e^{\nu/2}}^{mc^2-\alpha T/2} e^{-E/T}\sqrt{e^{-\nu}E^2-1}\;E^2dE\,, \quad P = \frac{4\pi}{3c^3}Be^{-\nu/2}\int_{mc^2e^{\nu/2}}^{mc^2-\alpha T/2} e^{-E/T}(e^{-\nu}E^2-1)^{3/2}dE\,.$$



Fractal Structure of the Universe

de Bernardis, et al. *Nature*, 404 (2000) 955



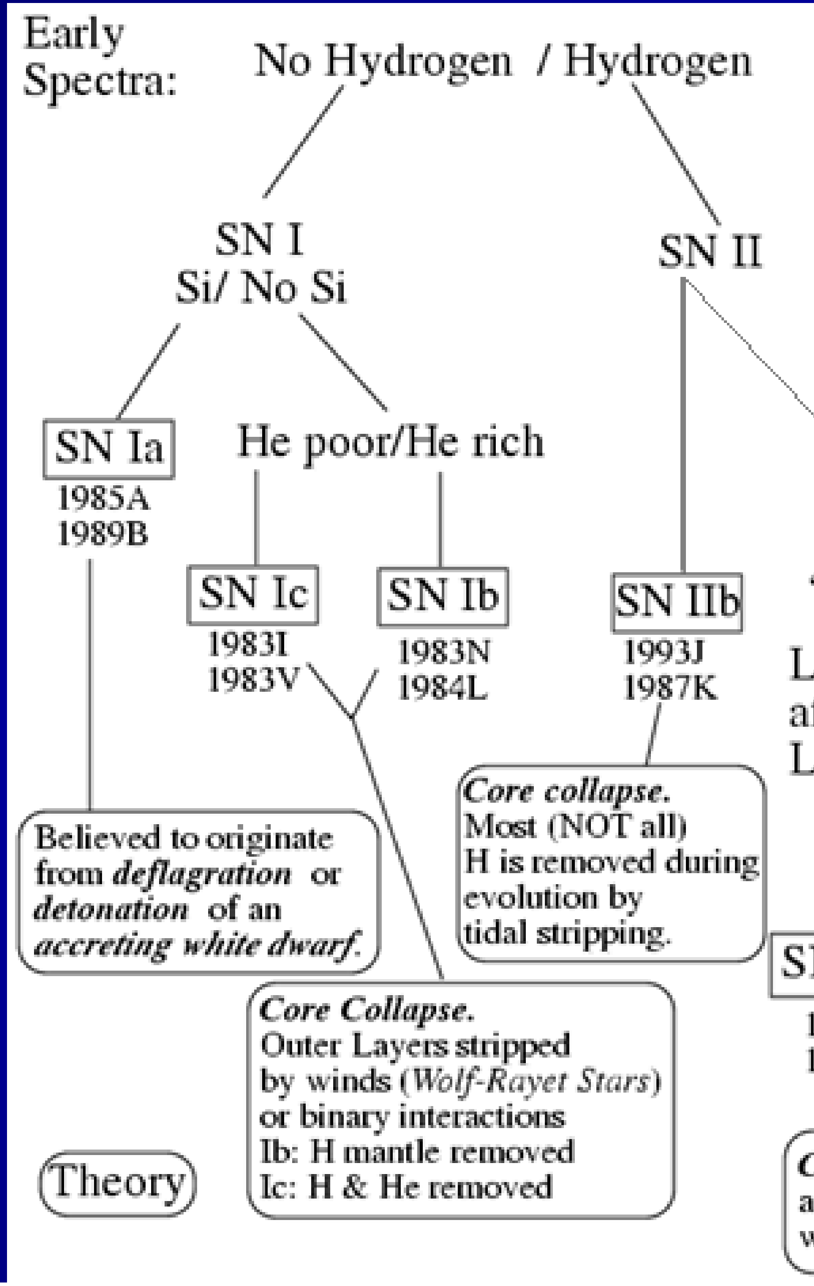


R. Ruffini, D. J. Song, S. Taraglio
Astron. Astrophys., 190 (1988) 1

$$N = \left(\frac{m_{Pl}}{m_{\nu}} \right)^3$$

On Dark Energy

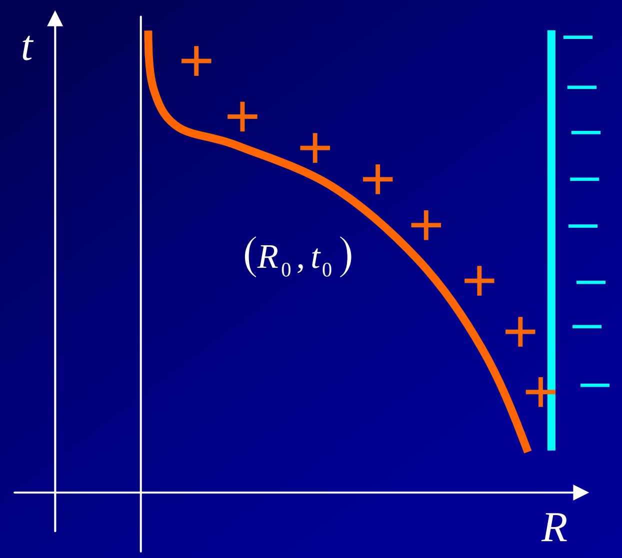
There is a novelty in the Universe or an additional problem with the understanding of Supernovae?



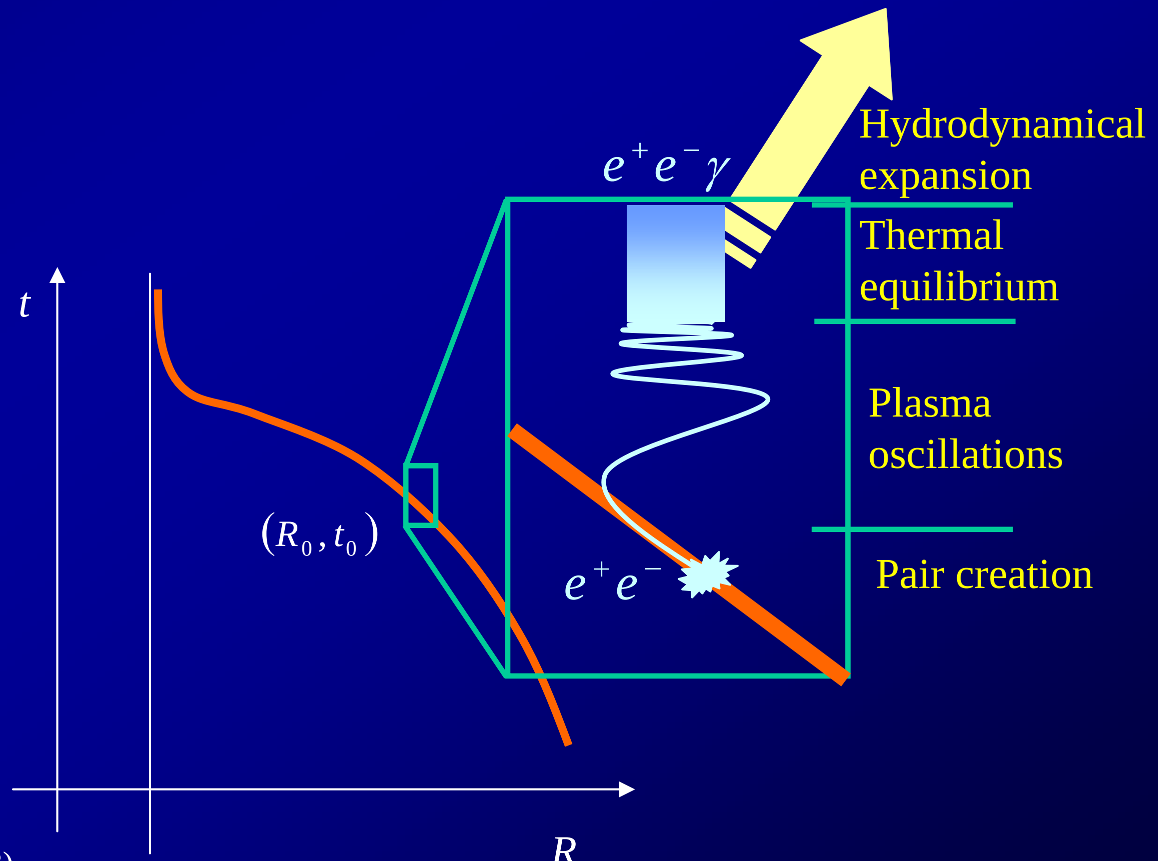
Reproduced from M. Della Valle, with his kind permission

Perlmutter, et al.
***ApJ* 517 (1999) 565**

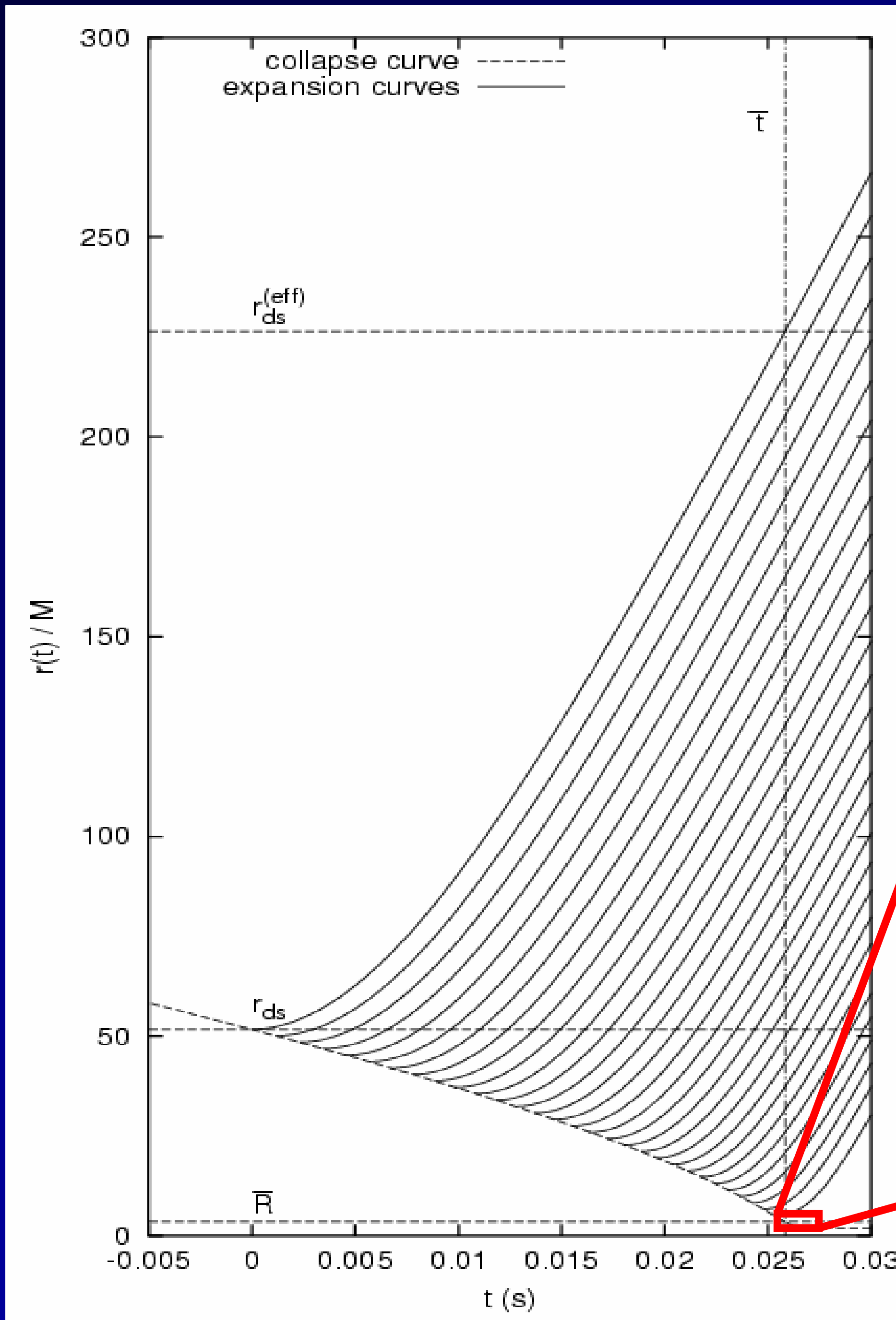
On an alternative cosmological candle. Gravitational collapse of the charged core of an initially neutral star (< 1 sec.)



If $E > E_c$, then…

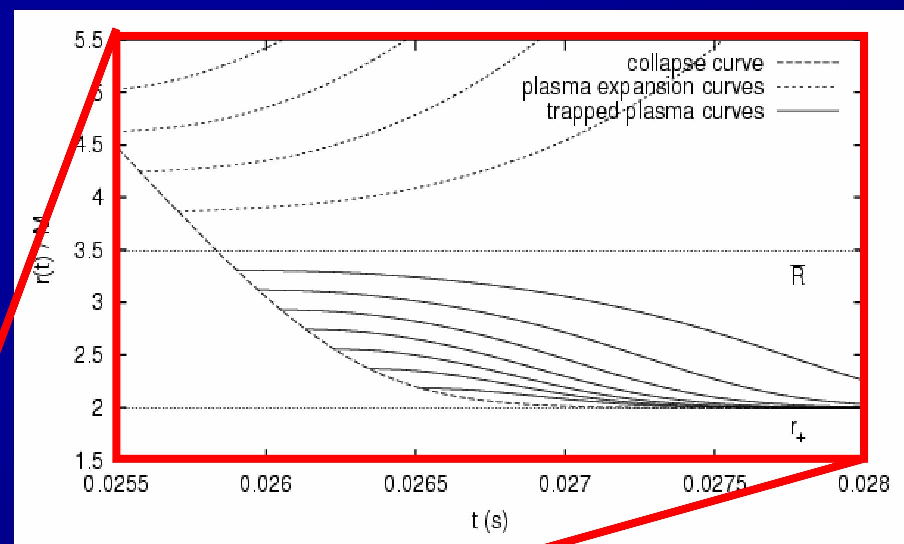


Ruffini, Vitagliano, *Phys. Lett. B*, **545**, 233, (2002).
Ruffini, Vitagliano, Xue, *Phys. Lett. B*, **559**, 12 (2003).



The existence of a separatrix is a general relativistic effect: the radius of the gravitational trap is

$$R^* = \frac{2GM}{c^2}\left[1+\sqrt{1-\frac{3}{4}\left(\frac{Q}{\sqrt{G}M}\right)^2}\,\right]$$



The fraction of energy available in the expanding plasma is about 1/2.

Ruffini, Vitagliano, Xue, *Phys. Lett. B*, **573**, 33, (2003).

The *Proper*-GRB (P-GRB)

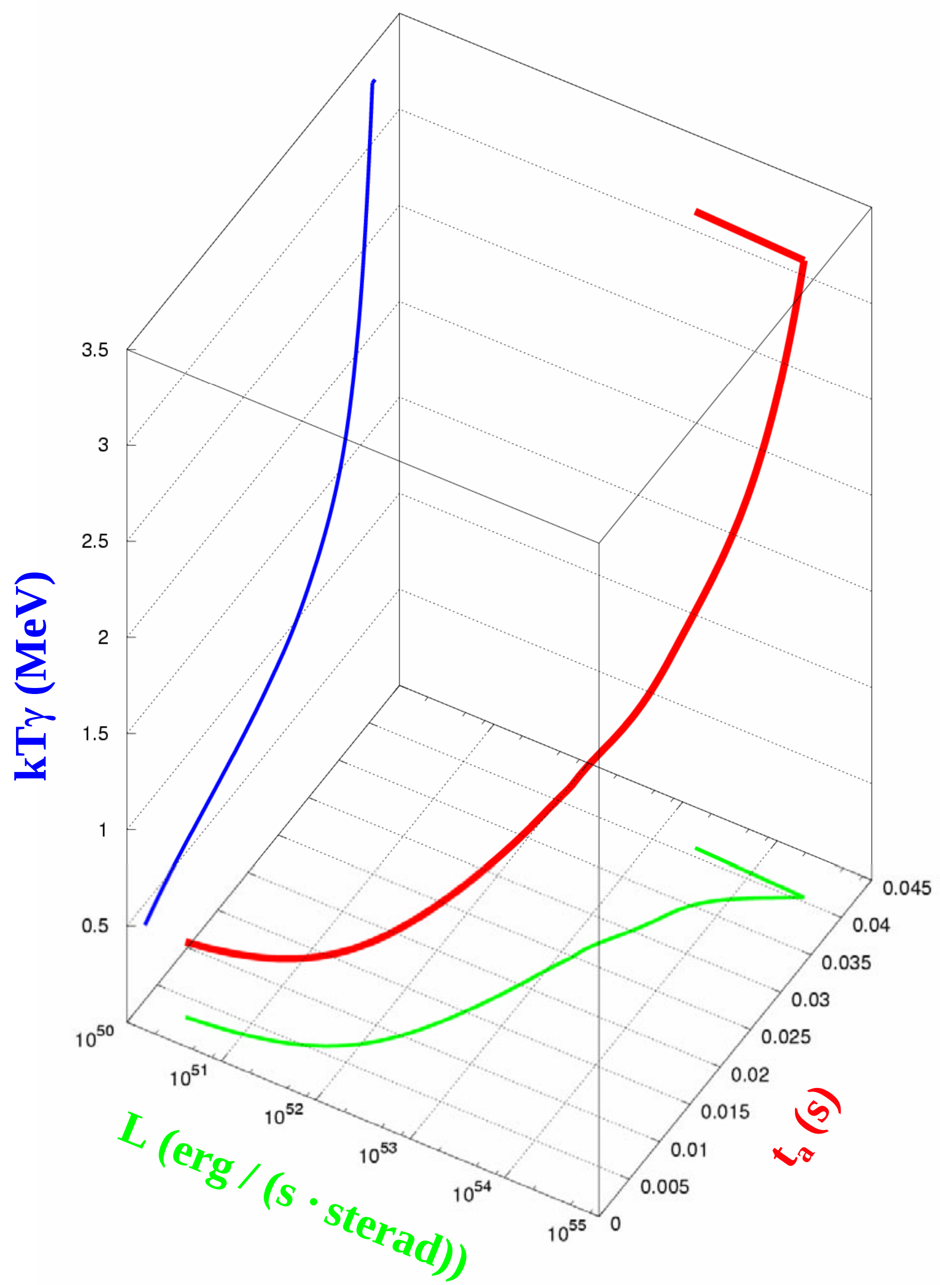
Temporal, spectral structure, luminosity of a **short-GRB** emitted by plasma created in the Dyadosphere of an EMBH with

$$M = 20\ M_{Sun}$$

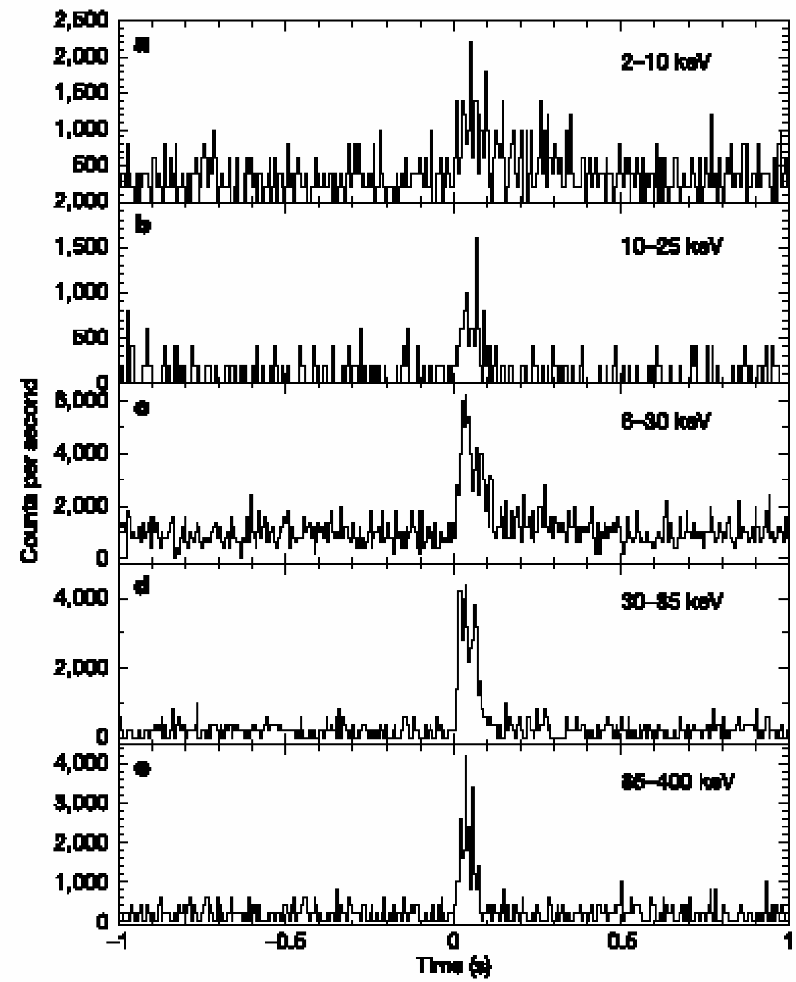
$$Q = 0.1\ M$$

A most powerful tool for cosmology!

Ruffini, Fraschetti, Vitagliano, Xue, *Int.J.Mod.Phys.D* 14 (2005) 131



The
Italy - UK - USA
Swift mission



Villasenor et al. (2005)