# Supernovae, Neutron Stars and Black Holes in the GRBs Era some historical considerations


**Remo Ruffini**

*ICRANet – Pescara-Rome*

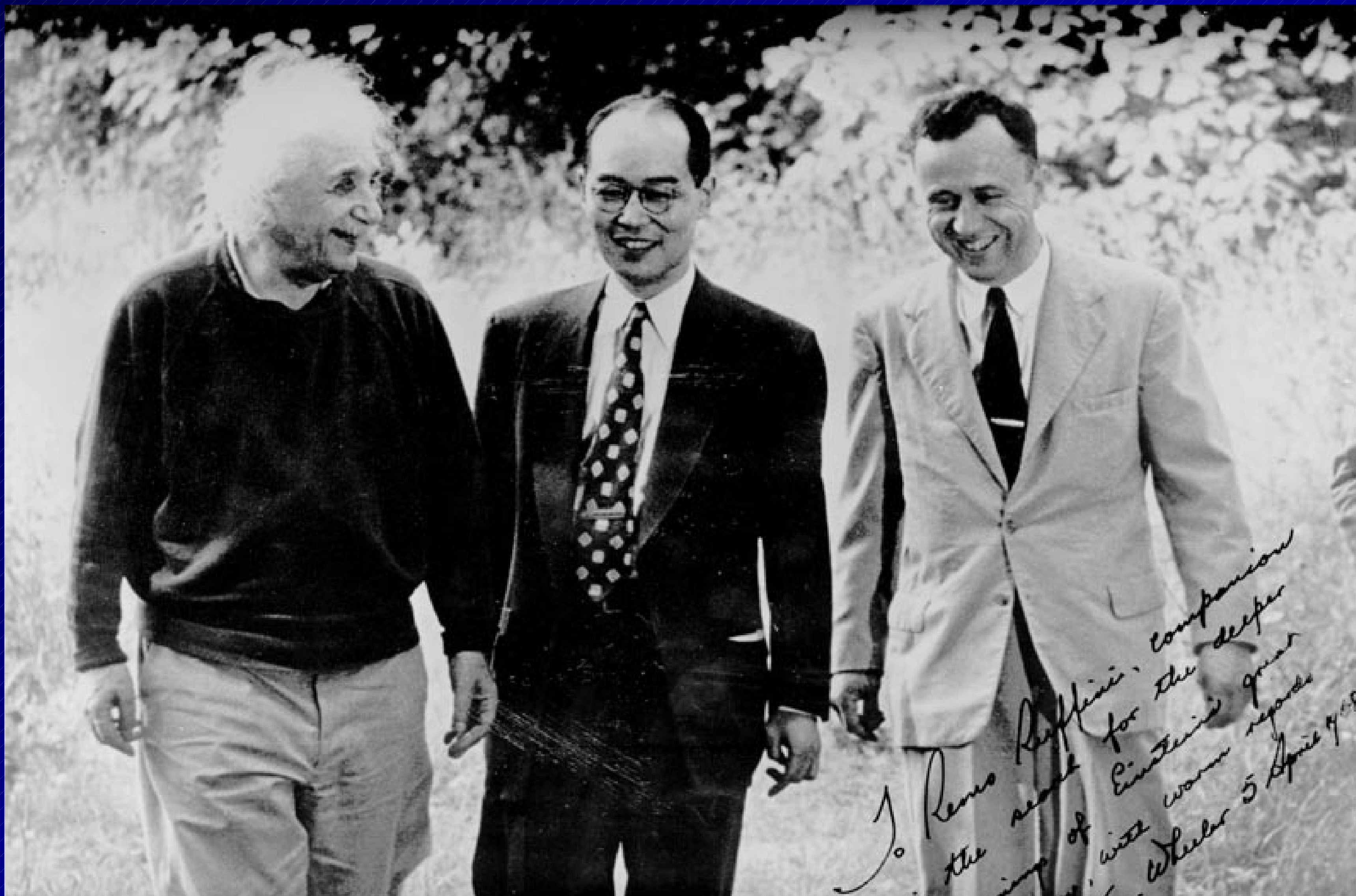
*Università "La Sapienza" - Rome*



**27th Texas Symposium on Relativistic Astrophysics**

**Dallas, TX – December 8-13, 2013**

# Einstein, Yukawa and Wheeler: the birth of Relativistic Astrophysics



# Einstein 70th birthday

# Princeton, 1971

Joseph Henry Laboratories, Princeton University

# 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

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.

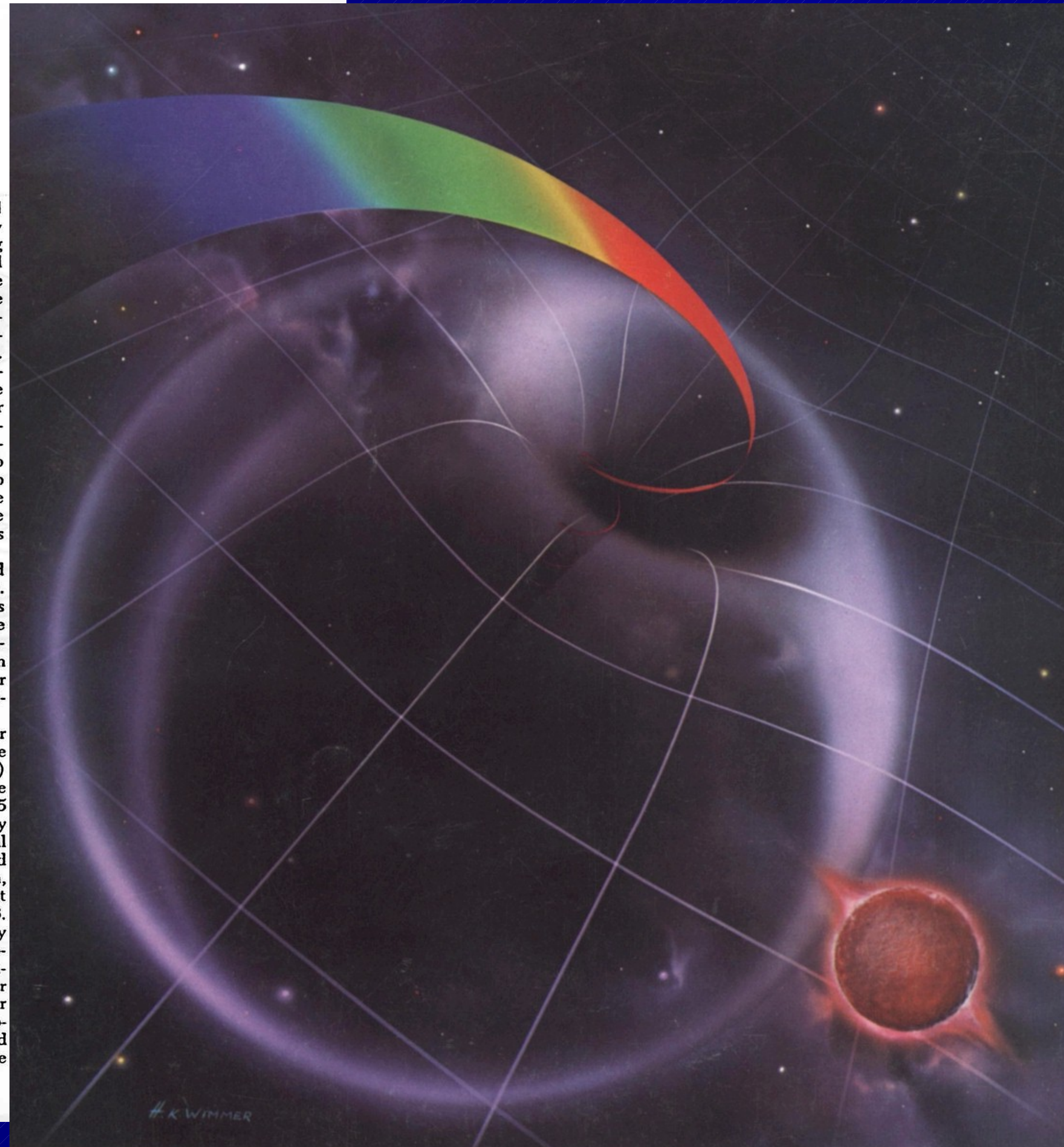
A black hole is what is left behind after an object has undergone complete gravitational collapse. Spacetime is so strongly curved that no light can come out, no matter can be ejected and no measuring rod can ever survive being put in. Any kind of object that falls into the black hole loses its separate 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

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.



# Demetrios Christodoulou's Ph.D. Thesis defence Committee

# Demetrios Christodoulou's Ph.D. Thesis defence Committee

# Wigner questioning

# Wigner attacks

# Princeton, Physics graduate students, 1968

1. Jerol M. Lind
2. Danny L. Hawley
3. Alan M. Nathan
4. William C. Mead
5. Glennys R. Farrar
6. Richard Chang
7. Niall O Murchadha
8. Robert T. Baumel
9. Edward J. Groth
10. George C-N Hsieh
11. James R. Milch
12. Jesse I. Treu
13. David M. Fram
14. Robert M. Wald
15. Charles S. Borso
16. Mark R. Nelson
17. Charles P. Benedict
18. Vincent P. Ruddy
19. William E. Caswell
20. William R. Shanahan
21. Robert C. Webb
22. Peter C. Colter
23. Paul T. Debevec
24. Demetrios Christodoulou
25. Frank A. Chambers
26. Edward A. Williams
27. Thomas C. Rich
28. Richard T. Williams
29. James R. Campbell
30. J. David Cohen
31. Matthew D. Miller

Not present: Terrence J. Sejnowski

DEPARTMENT OF PHYSICS - GRADUATE STUDENTS, ENTERING CLASS 1968

# The Black Hole Mass-Energy formula

$$m^2 = \left(m_{ir} + \frac{e^2}{4m_{ir}}\right)^2 + \frac{L^2}{4m_{ir}^2}\,,$$

$$S = 16\pi m_{ir}^2\,,$$

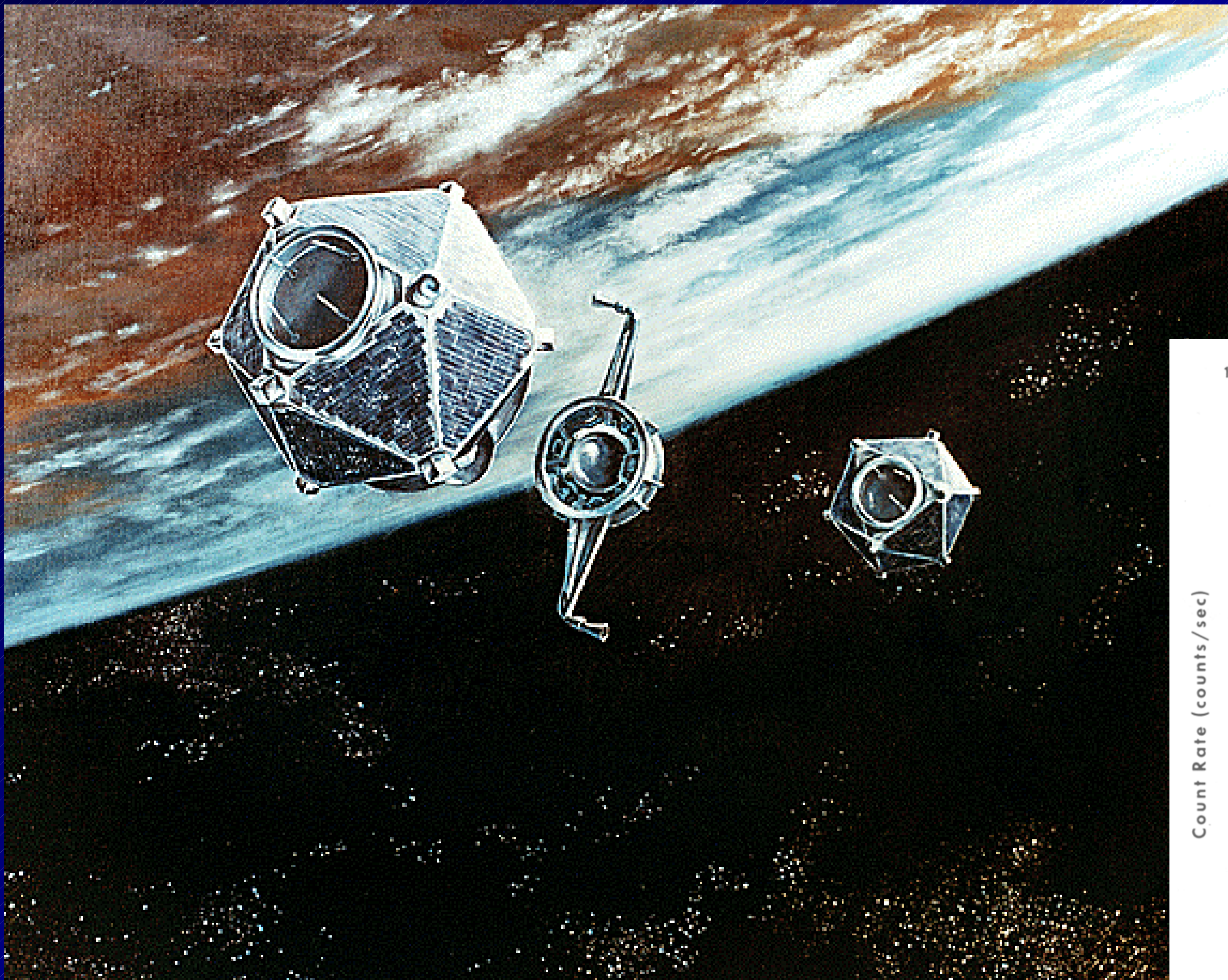
$$\frac{L^2}{4m_{ir}^4} + \frac{e^4}{16m_{ir}^4} \leq 1\,,$$

$$\delta S = 32\pi m_{ir}\delta m_{ir} \geq 0$$

**5th Texas Symposium, 1970**

**Christodoulou, Ruffini, 1971**

# Vela satellites and GRBs



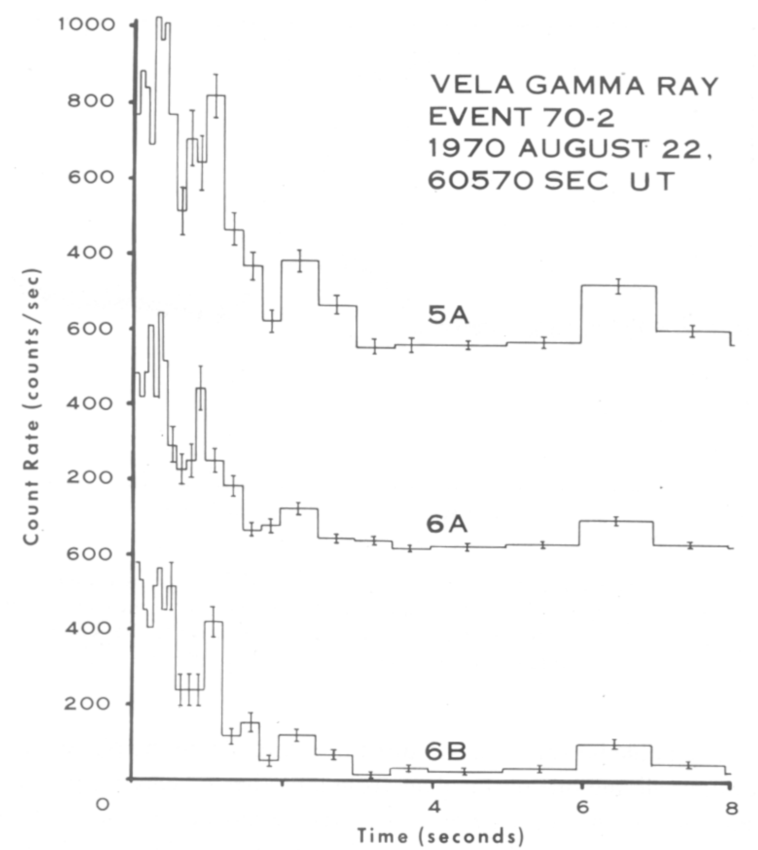


Fig. 5. Event 70-2, on 1970 August 22, beginning 60571 s UT.

H. Gursky & R. Ruffini, AAAS,
S. Francisco, 1974

# Quantum Electrodynamical Effects in Kerr-Newmann Geometries

Thibaut Damour*
*Joseph Henry Physical Laboratories, Princeton University, Princeton, New Jersey 08540*

and

Remo Ruffini †
*Institute for Advanced Study, Princeton, New Jersey 08540*
(Received 13 January 1975)

Following the classical approach of Sauter, of Heisenberg and Euler and of Schwinger the process of vacuum polarization in the field of a "bare" Kerr-Newman geometry is studied. The value of the critical strength of the electromagnetic fields is given together with an analysis of the feedback of the discharge on the geometry. The relevance of this analysis for current astrophysical observations is mentioned.

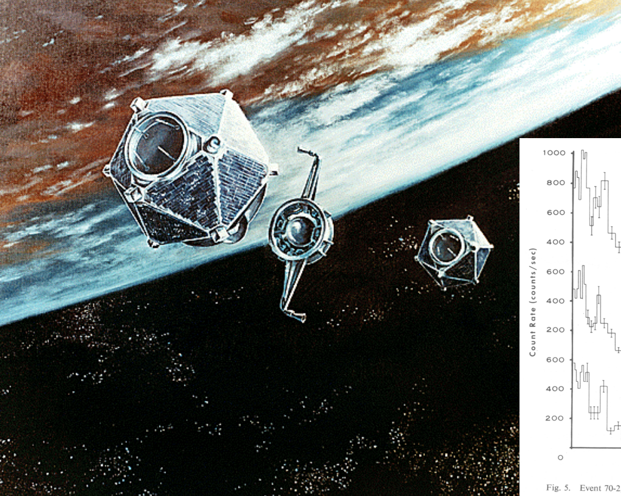
and possibly of galactic nuclei. In particular this work naturally leads to a most simple model for the explanation of the recently discovered $\gamma$-rays bursts.[19] It is desirable that possible coin-

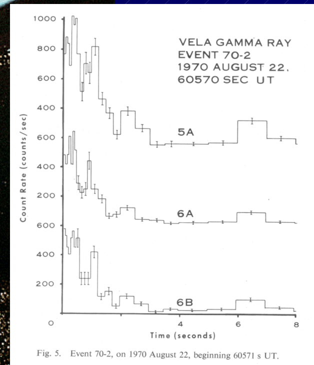
**Expected energy: ~ $10^{54}$ ($M_{BH}/M_{Sun}$) erg**

# Vallée des Merveilles, 1975

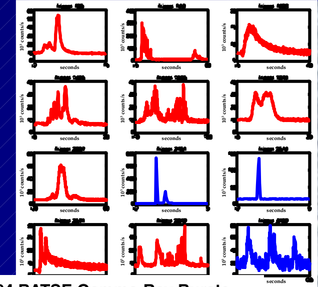
# Wilson – Everitt – Ruffini – Damour

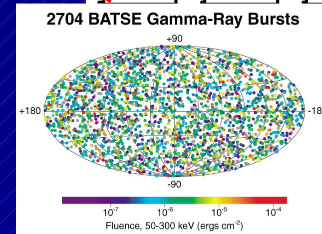
# E=$10^{54}$ erg



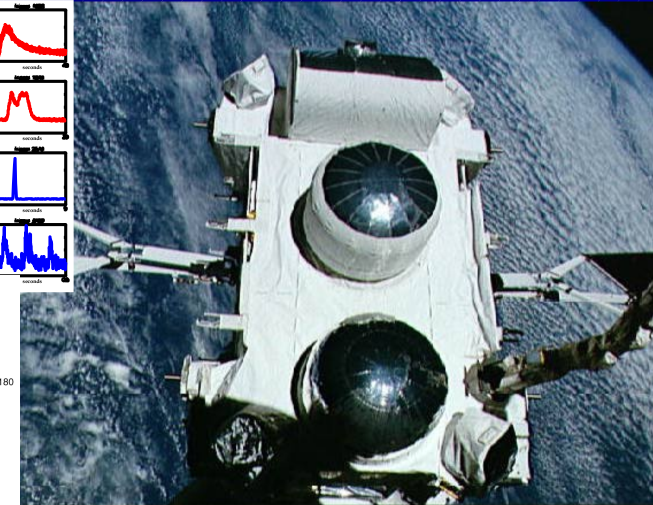


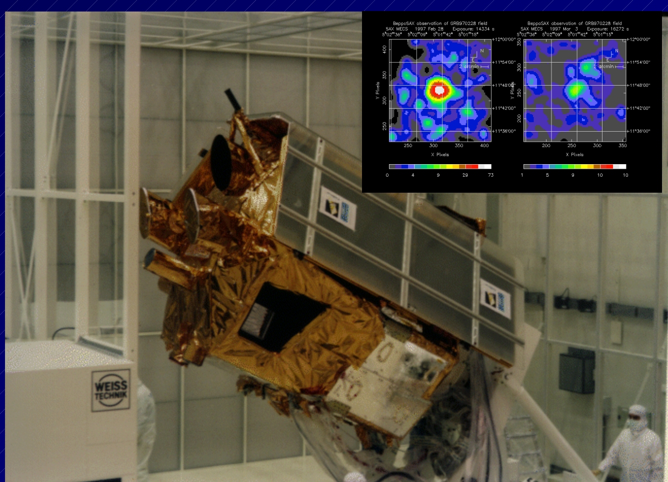
VELA GAMMA RAY EVENT 70-2 1970 AUGUST 22. 60570 SEC UT
5A
6A
6B
Count Rate (counts/sec)
Time (seconds)
Fig. 5. Event 70-2, on 1970 August 22, beginning 60571 s UT.

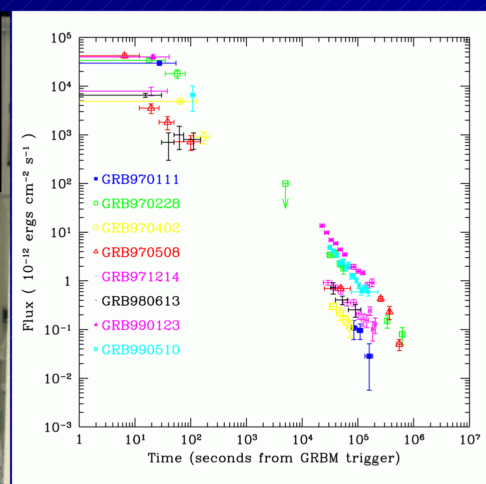





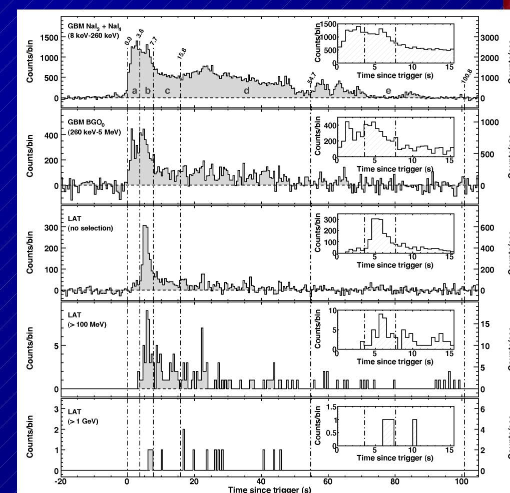
2704 BATSE Gamma-Ray Bursts
+90
+180
-180
-90
Fluence, 50-300 keV (ergs cm$^{-2}$)

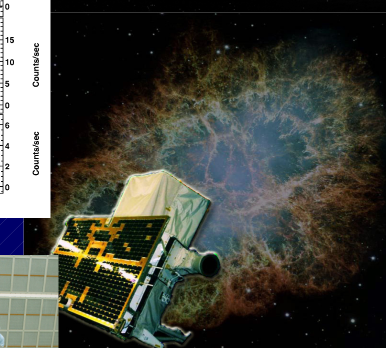


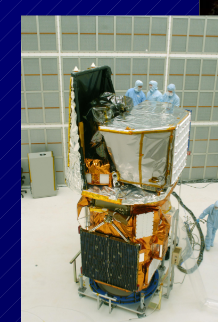


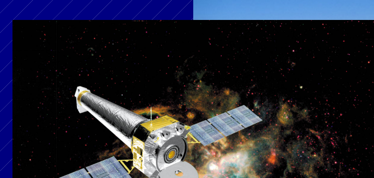
GRB970111
GRB970228
GRB970402
GRB970508
GRB971214
GRB980613
GRB990123
GRB990510
Flux ( $10^{-12}$ ergs cm$^{-2}$ s$^{-1}$ )
Time (seconds from GRBM trigger)

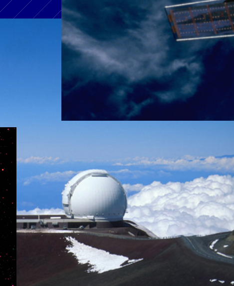



GBM NaI + NaI (8 keV-260 keV)
GBM BGO (260 keV-5 MeV)
LAT (no selection)
LAT (> 100 MeV)
LAT (> 1 GeV)
Counts/bin
Counts/sec
Time since trigger (s)

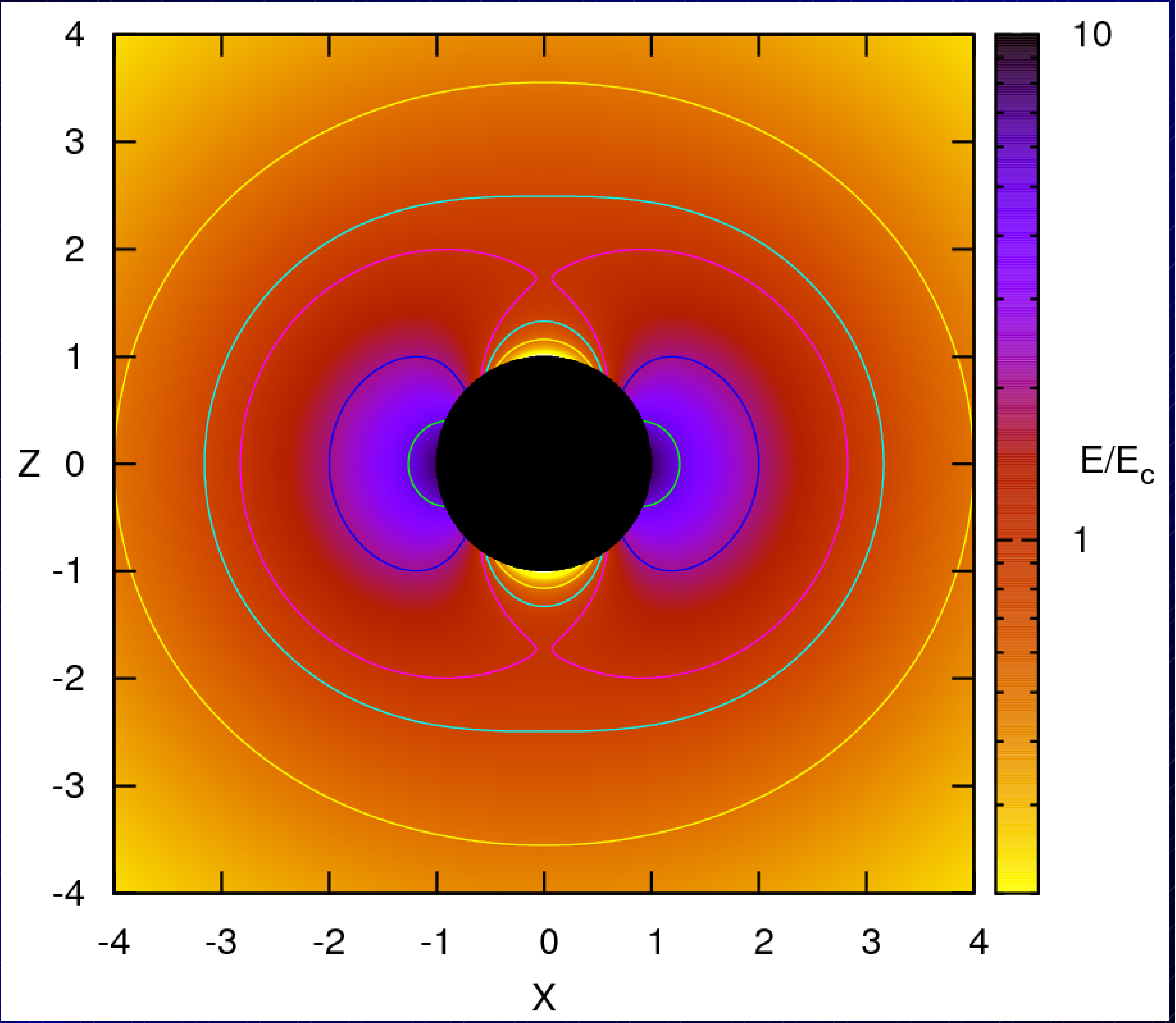







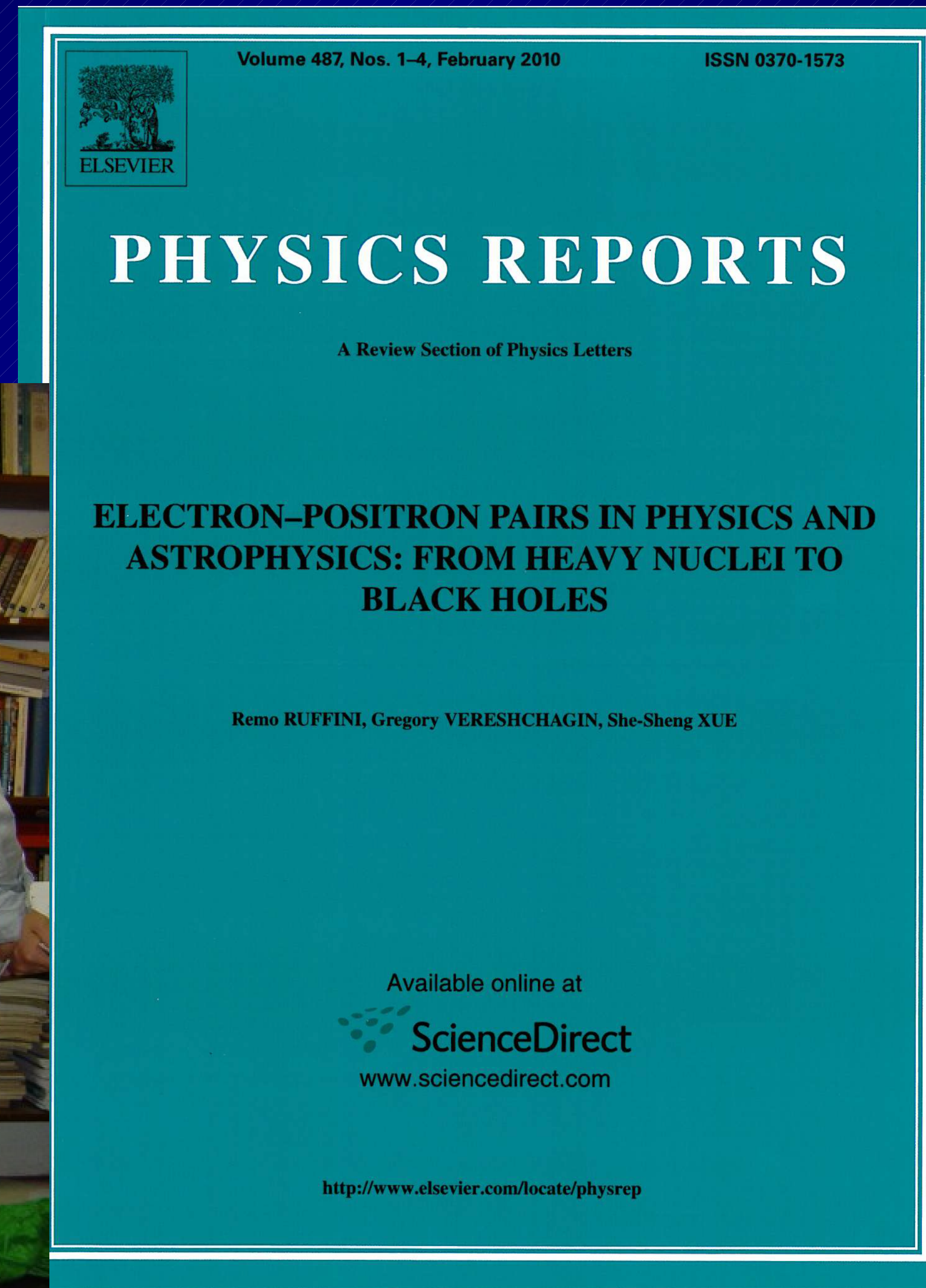


# The Dyado-torus




Cherubini, Geralico, Rueda, Ruffini, *PRD* 79, 124002 (2009). Ruffini, Vereshchagin, Xue, *Phys.Rep.* 487, 1 (2010).

# “Von Kernen zu den Sternen”


Volume 487, Nos. 1–4, February 2010 ISSN 0370-1573

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PHYSICS REPORTS

A Review Section of Physics Letters

ELECTRON–POSITRON PAIRS IN PHYSICS AND ASTROPHYSICS: FROM HEAVY NUCLEI TO BLACK HOLES

Remo RUFFINI, Gregory VERESHCHAGIN, She-Sheng XUE

Available online at

ScienceDirect

www.sciencedirect.com

http://www.elsevier.com/locate/physrep

$$ds^2 = e^{\nu(r)} dt^2 - e^{\lambda(r)} dr^2 - r^2 d\theta^2 - r^2 \sin^2\theta d\varphi^2$$

## TOV Equations

$$e^{-\lambda(r)} = 1 - \frac{2GM(r)}{r} \quad \Rightarrow \quad e^{-\lambda(r)} = 1 - \frac{2GM(r)}{r} + Gr^2 E^2(r)$$

$$e^{-\lambda(r)} \left( \frac{1}{r^2} - \frac{1}{r}\frac{d\lambda}{dr} \right) - \frac{1}{r^2} = -8\pi G T_0^0$$

$$e^{-\lambda(r)} \left( \frac{1}{r^2} + \frac{1}{r}\frac{d\nu}{dr} \right) - \frac{1}{r^2} = -8\pi G T_1^1$$

$\Rightarrow$

$$e^{-\lambda(r)} \left( \frac{1}{r^2} - \frac{1}{r}\frac{d\lambda}{dr} \right) - \frac{1}{r^2} = -8\pi G T_0^0$$

$$e^{-\lambda(r)} \left( \frac{1}{r^2} + \frac{1}{r}\frac{d\nu}{dr} \right) - \frac{1}{r^2} = -8\pi G T_1^1$$

$$\frac{dP}{dr} = -\frac{(\mathcal{E}+P)}{2}\frac{d\nu}{dr}$$

$\Rightarrow$

$$V'' + \frac{2}{r}V'\left[1 - \frac{r(\nu' + \lambda')}{4}\right] = -4\pi e\, e^{\nu/2} e^{\lambda}(n_p - n_e)$$

$$\frac{d^2\sigma}{dr^2} + \frac{d\sigma}{dr}\left[\frac{2}{r} - \frac{1}{2}\left(\frac{d\nu}{dr} + \frac{d\lambda}{dr}\right)\right] = e^{\lambda}\left[\partial_\sigma U(\sigma) + g_s n_s\right]$$

$$\frac{d^2\omega}{dr^2} + \frac{d\omega}{dr}\left[\frac{2}{r} - \frac{1}{2}\left(\frac{d\nu}{dr} + \frac{d\lambda}{dr}\right)\right] = -e^{\lambda}\left[g_\omega J_\omega^0 - m_\omega^2 \omega\right]$$

$$\frac{d^2\rho}{dr^2} + \frac{d\rho}{dr}\left[\frac{2}{r} - \frac{1}{2}\left(\frac{d\nu}{dr} + \frac{d\lambda}{dr}\right)\right] = -e^{\lambda}\left[g_\rho J_\rho^0 - m_\rho^2 \rho\right]$$

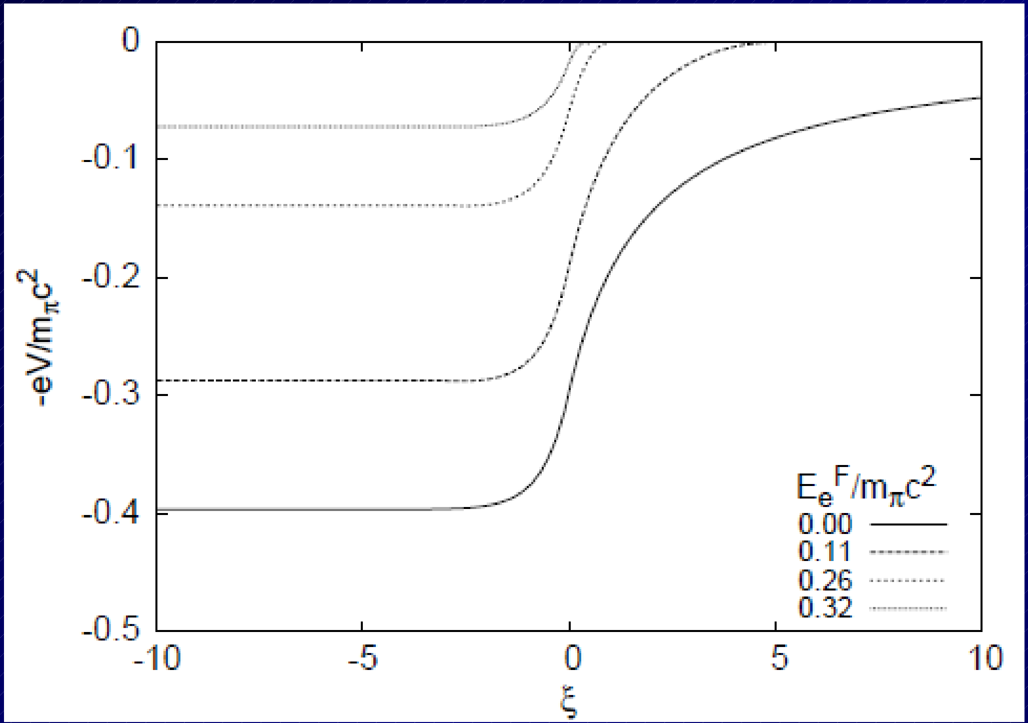
## Constancy of Klein potentials

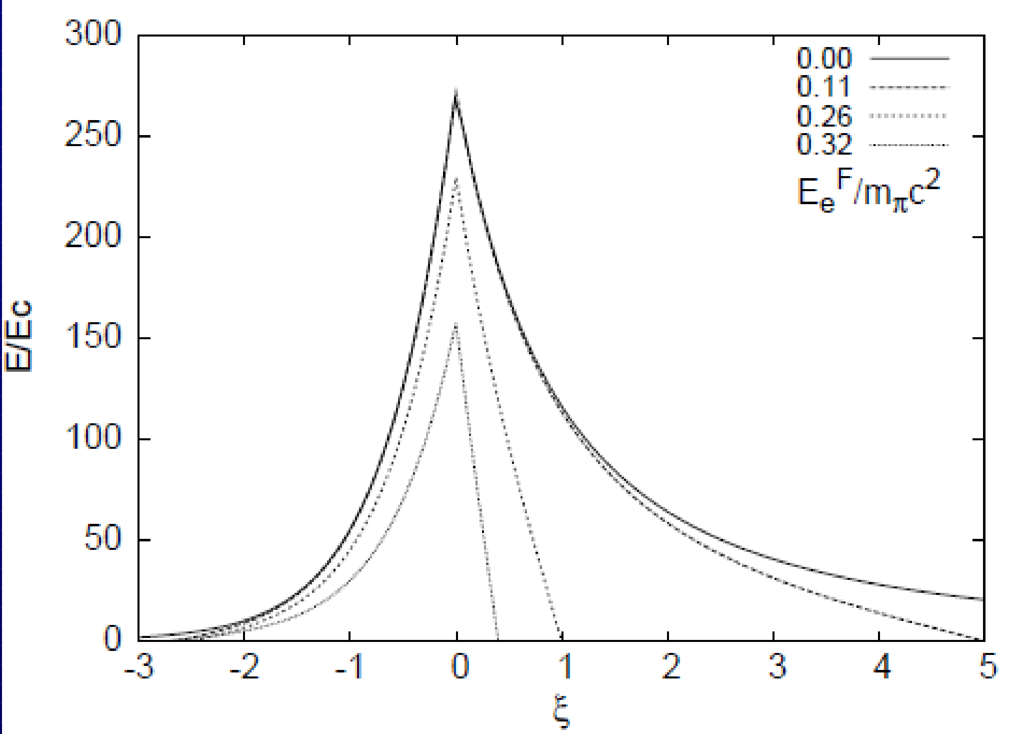
$$E_e = e^{\nu/2}\mu_e - eV = \text{constant}$$

$$E_p = e^{\nu/2}\mu_p + \mathcal{V}_p = \text{constant}$$

$$E_n = e^{\nu/2}\mu_n + \mathcal{V}_n = \text{constant}$$

# On the electrodynamical structure of a self-consistent approach to neutron star cores

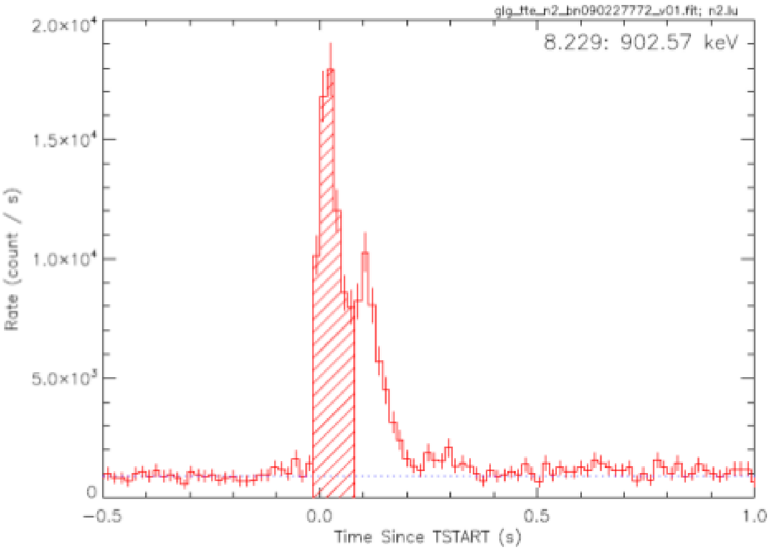


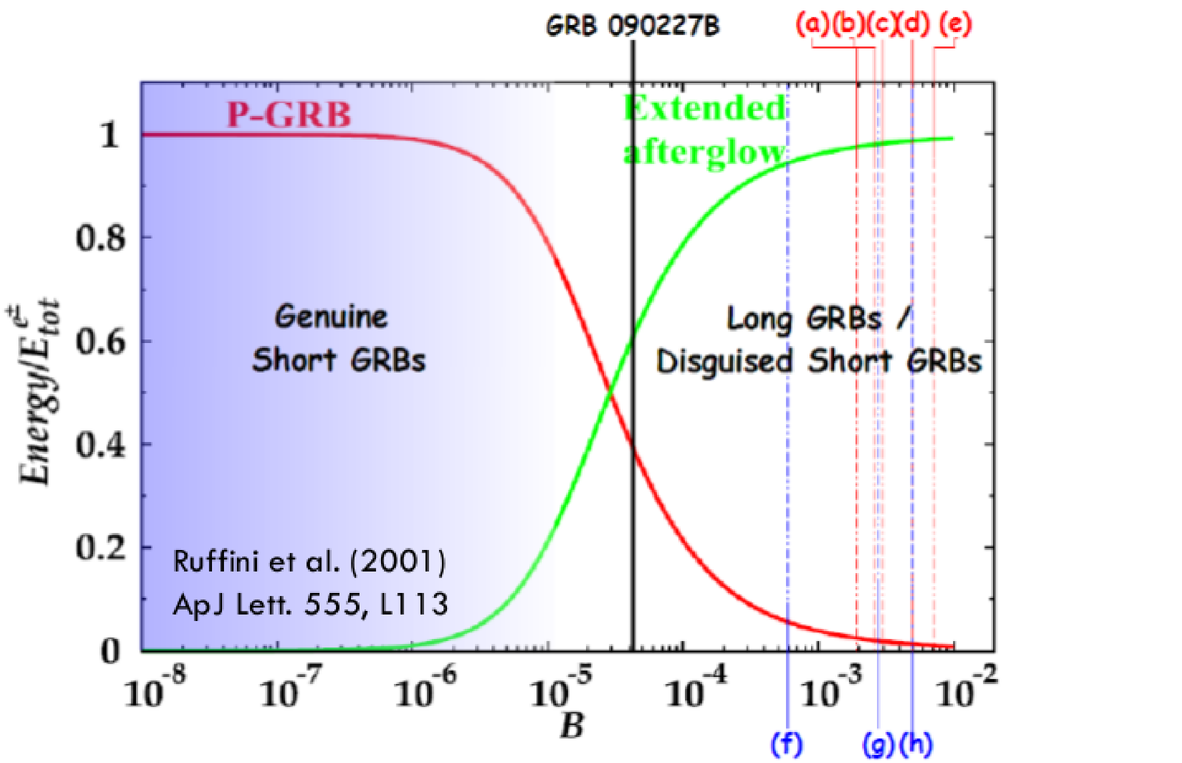

M. Rotondo, J. Rueda, R. Ruffini, S.-S. Xue, *PRC*, in press.

# The first genuine short GRB 090227B

Muccino et al. ApJ 763, 125 (2013)




| Fireshell Parameter | Value |
|---|---|
| $E^{tot}_{e^+e^-}$ [erg] | $(2.83 \pm 0.15) \times 10^{53}$ |
| $B$ | $(4.13 \pm 0.05) \times 10^{-5}$ |
| $\Gamma_{tr}$ | $(1.44 \pm 0.01) \times 10^{4}$ |
| $r_{tr}$ [cm] | $(1.76 \pm 0.05) \times 10^{13}$ |
| $kT_{blue}$ [keV] | $(1.34 \pm 0.01) \times 10^{3}$ |
| $z$ | $1.61 \pm 0.14$ |
| $\langle n \rangle$ [particles/cm$^3$] | $(1.90 \pm 0.20) \times 10^{-5}$ |
| $\langle \delta n/n \rangle$ | $0.82 \pm 0.11$ |




**Binary Neutron Star Progenitor:**

**M1=M2=1.34 Msun R1=R2=12.24 km**

PHYSICAL REVIEW D VOLUME 5, NUMBER 12 15 JUNE 1972

# Pulses of Gravitational Radiation of a Particle Falling Radially into a Schwarzschild Black Hole*

Marc Davis, Remo Ruffini, and Jayme Tiomno†
*Joseph Henry Laboratories, Princeton University, Princeton, New Jersey 08540*
(Received 20 December 1971)

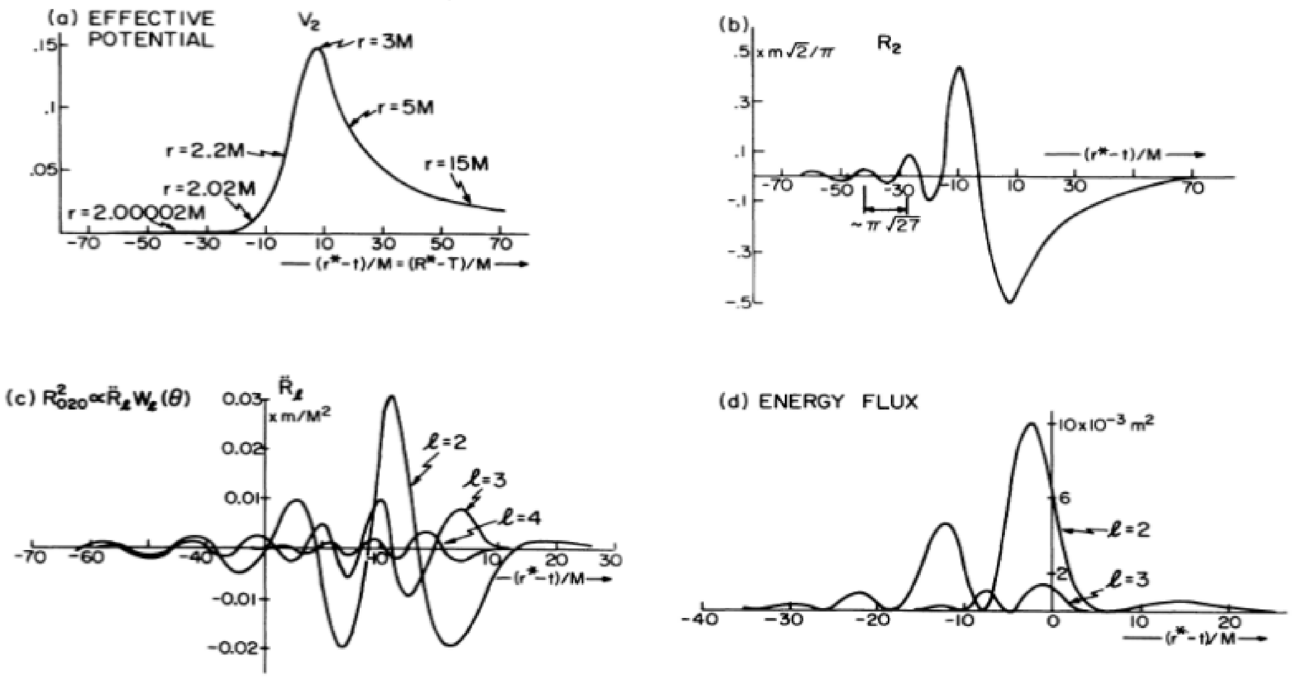
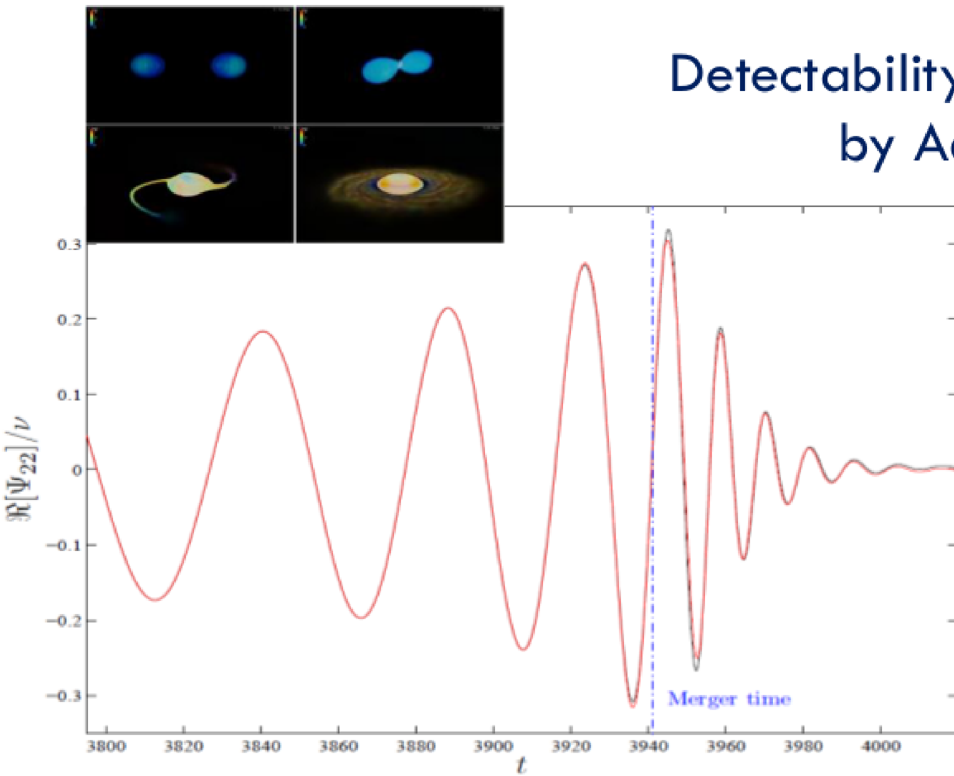
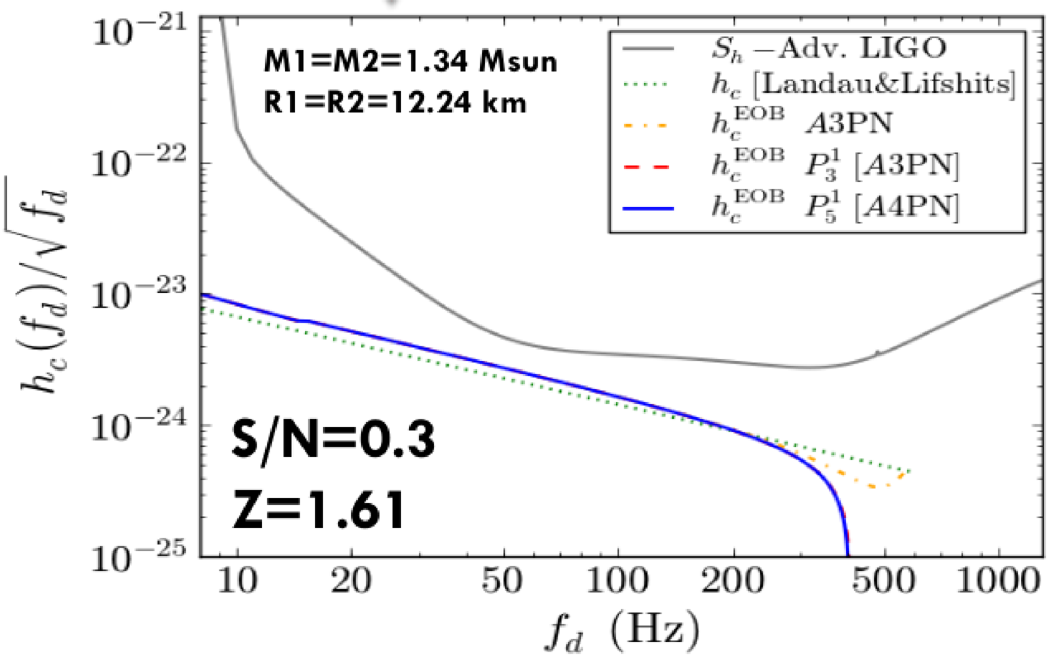



FIG. 1. Asymptotic behavior of the outgoing burst of gravitational radiation compared with the effective potential, as a function of the retarded time $(t-r^*)/M$. (a) Effective potential for $l=2$ in units of $M^2$ as a function of the retarded time $(t-r^*)/M=(T-R^*)/M$. For selected points the value of the Schwarzschild coordinate $r$ is also given. (b) Radial dependence of the outgoing field $R_l(r,t)$ as a function of the retarded time for $l=2$. (c) $\ddot{R}_l(r^*,t)$ factors of the Riemann tensor components (see text) given as a function of the retarded time for $l=2,3,4$. (d) Energy flux integrated over angles for $l=2,3$; the contributions of higher $l$ are negligible.

# Gravitational Waves vs. X and Gamma Ray Emission in a Short GRB




Detectability GRB 090227B
by Adv. LIGO


Plot taken from Review Effective One-Body Formalism: T. Damour; arXiv.1212.3169

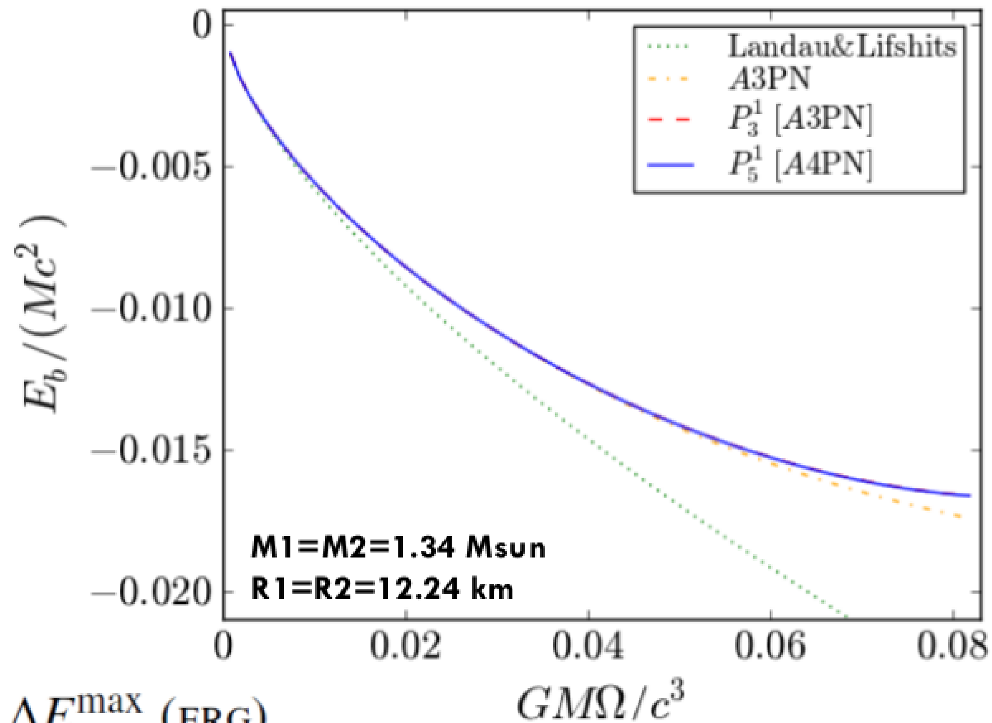
Oliveira, Rueda, Ruffini, submitted to ApJ. arXiv:1205.6915

# Gravitational Waves vs. X and Gamma Ray Emission in a Short GRB

Oliveira, Rueda, Ruffini, submitted to ApJ
arXiv:1205.6915

## GRB 090227B

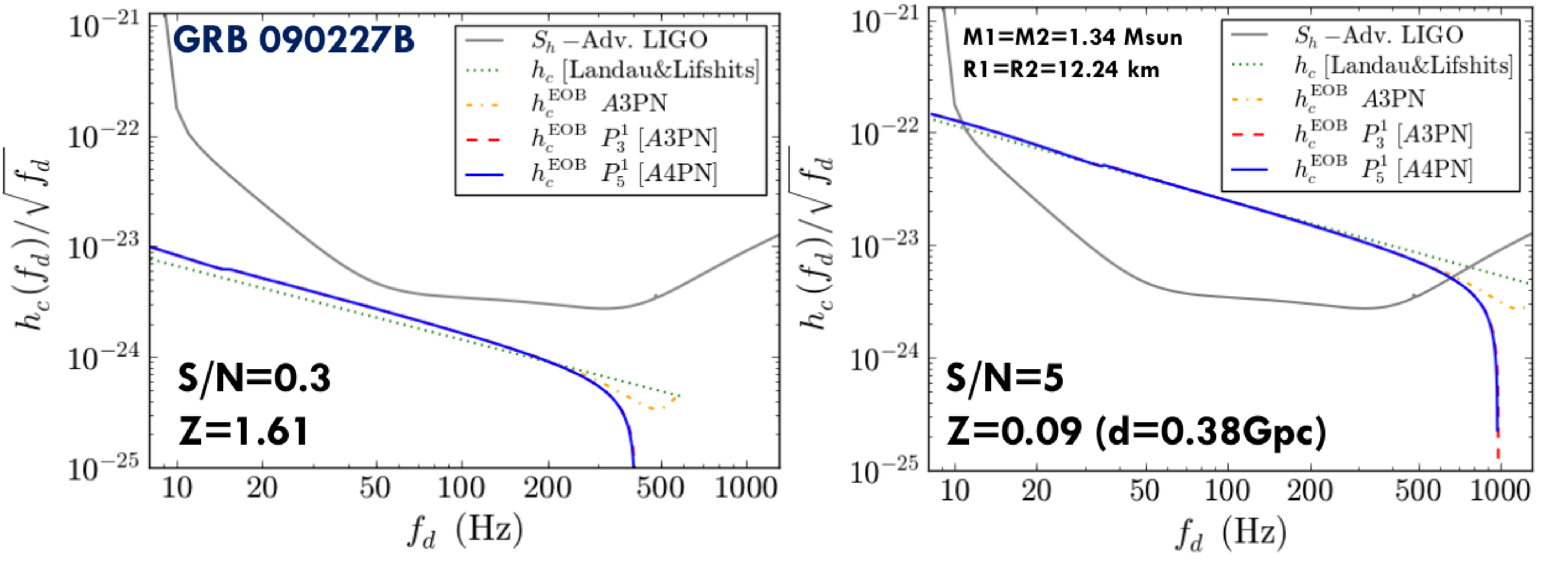
| $E_{\rm tot}^{\rm GRB}$ (erg) |
| --- |
| $2.83 \times 10^{53}$ |



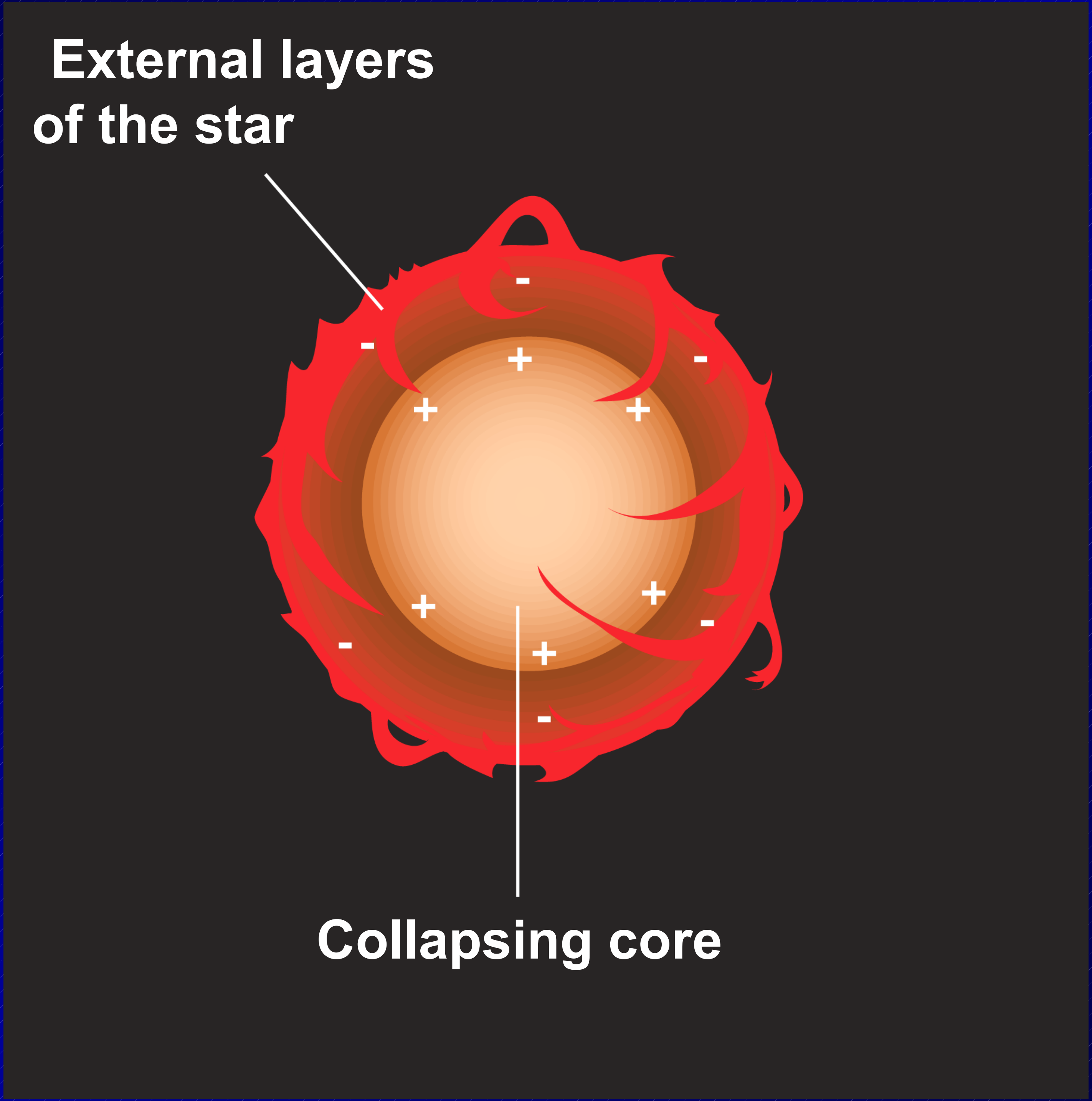

UPPER LIMIT FOR THE TOTAL GW EMISSION, $\Delta E_{\rm GW}^{\rm max}$ (ERG).

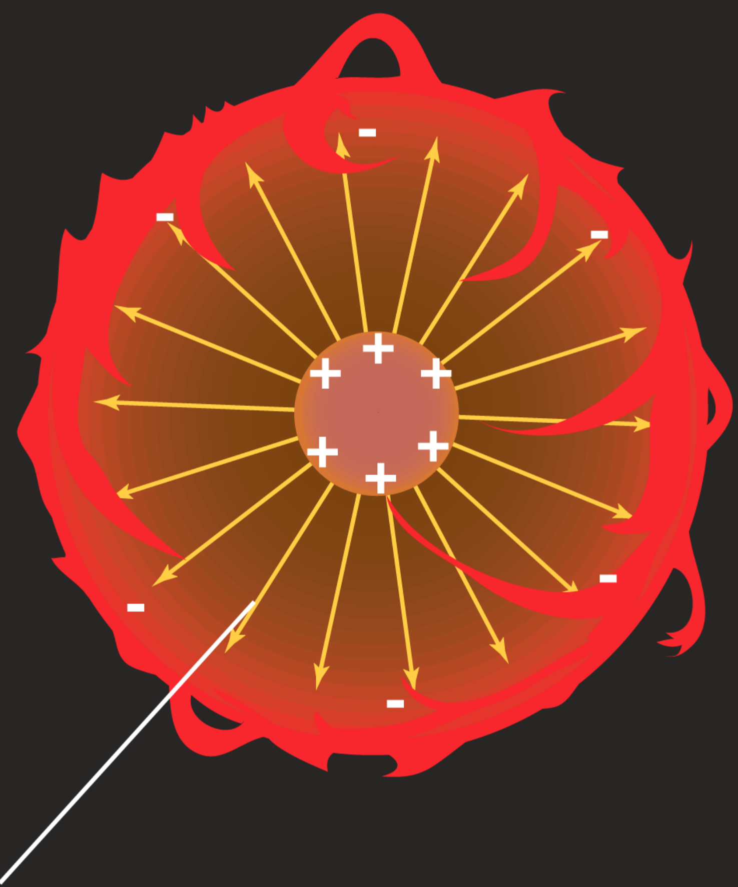
| Landau & Lifshits | EOB $A3PN$ | EOB $P_3^1[A3PN]$ | EOB $P_5^1[A4PN]$ |
| --- | --- | --- | --- |
| $9.6 \times 10^{52}$ | $9.68 \times 10^{52}$ | $7.41 \times 10^{52}$ | $7.42 \times 10^{52}$ |

# Gravitational Waves vs. X and Gamma Ray Emission in a Short GRB

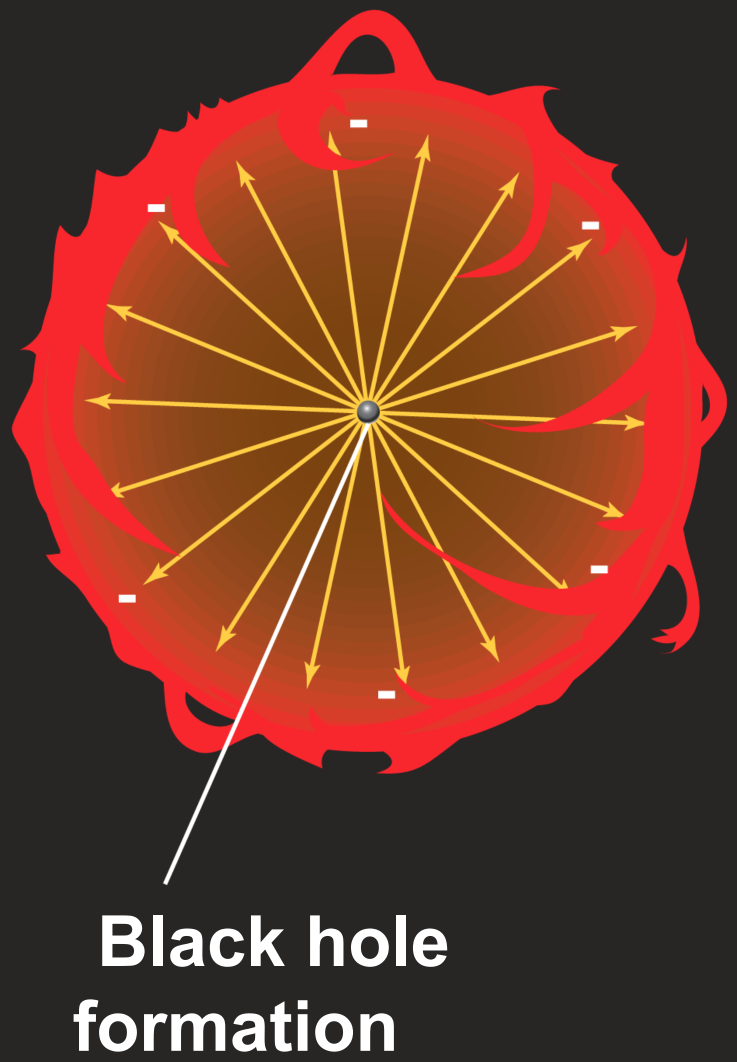


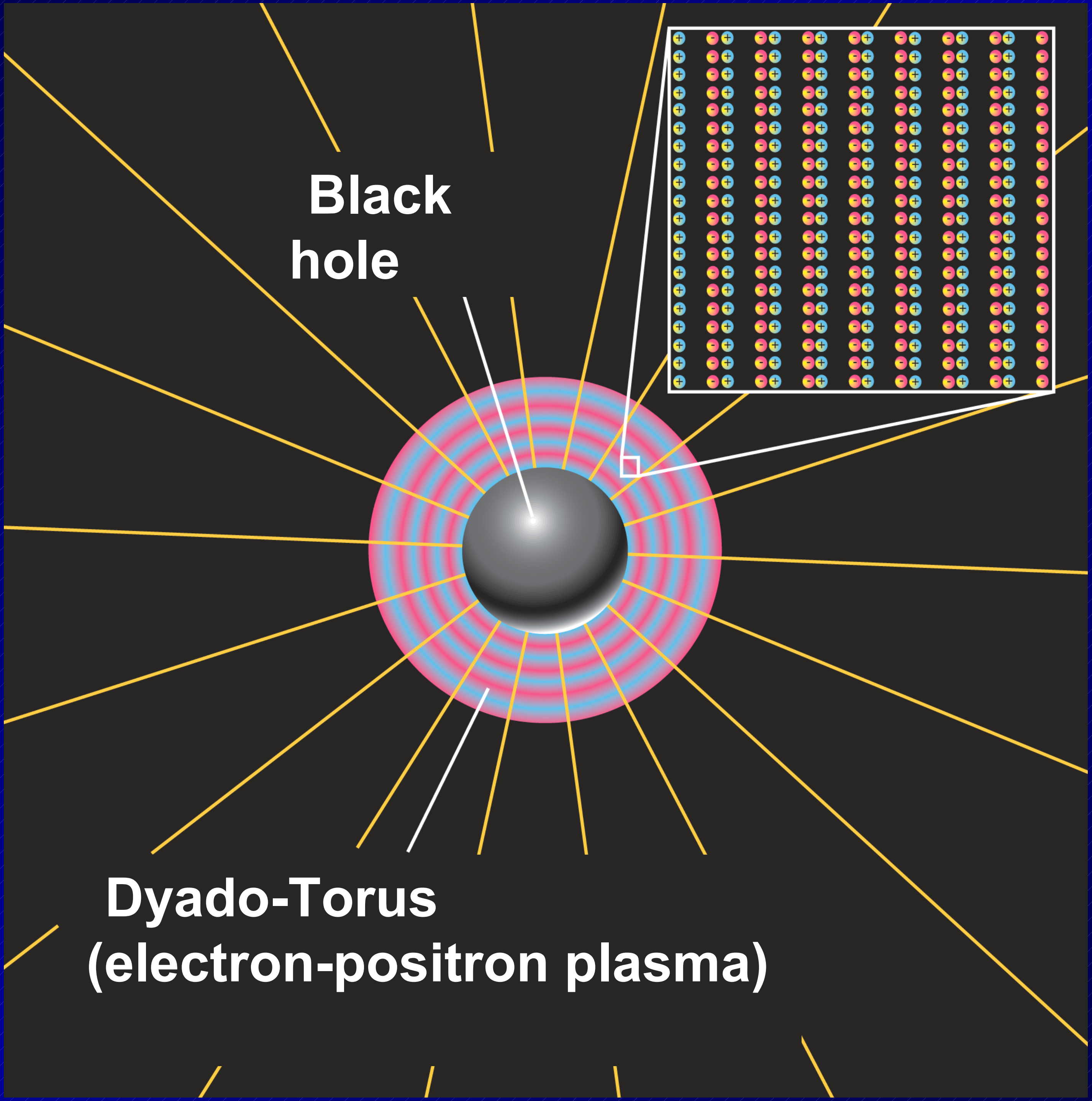

Oliveira, Rueda, Ruffini, submitted to ApJ. arXiv:1205.6915

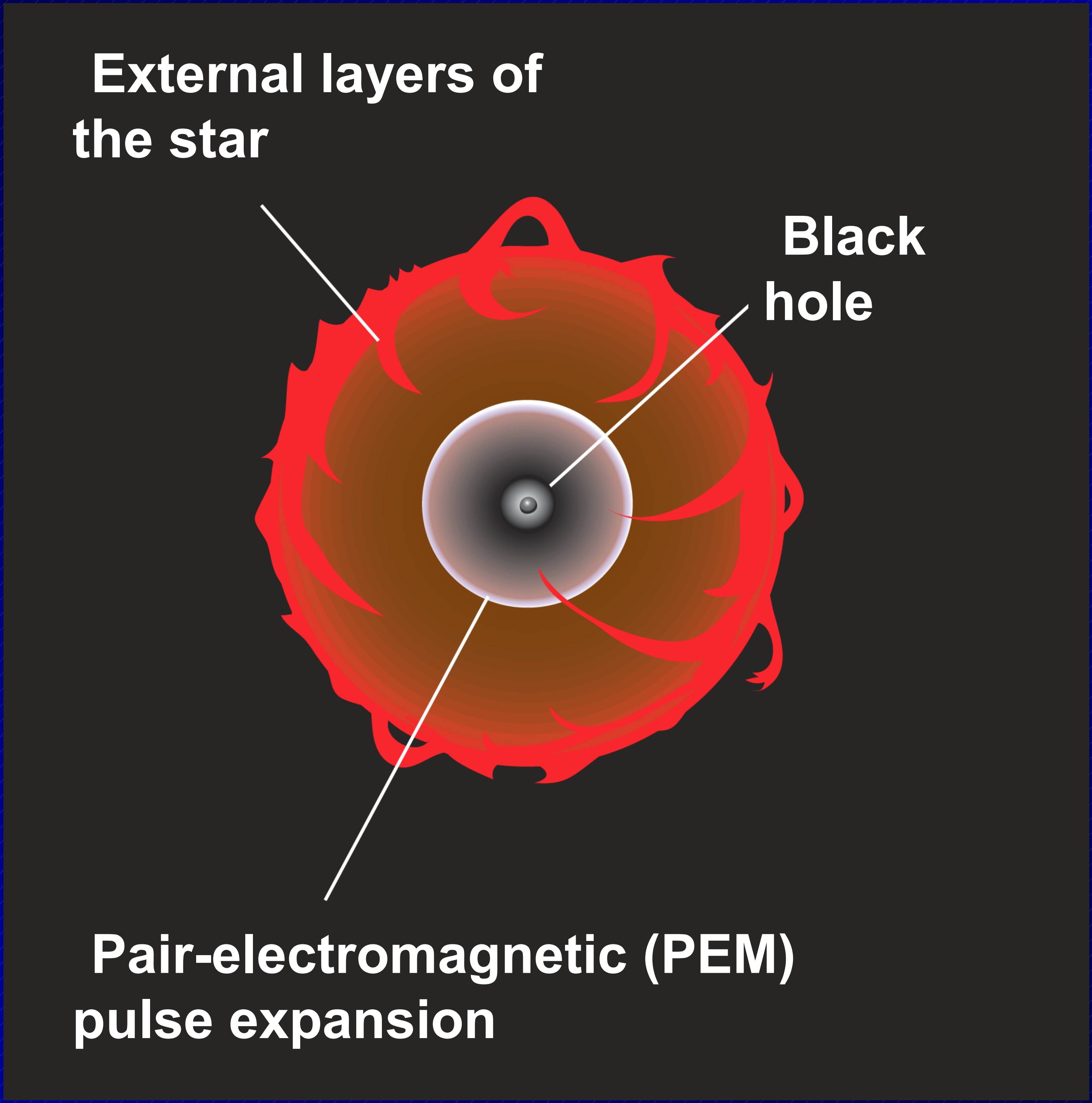

External layers
of the star
Collapsing core

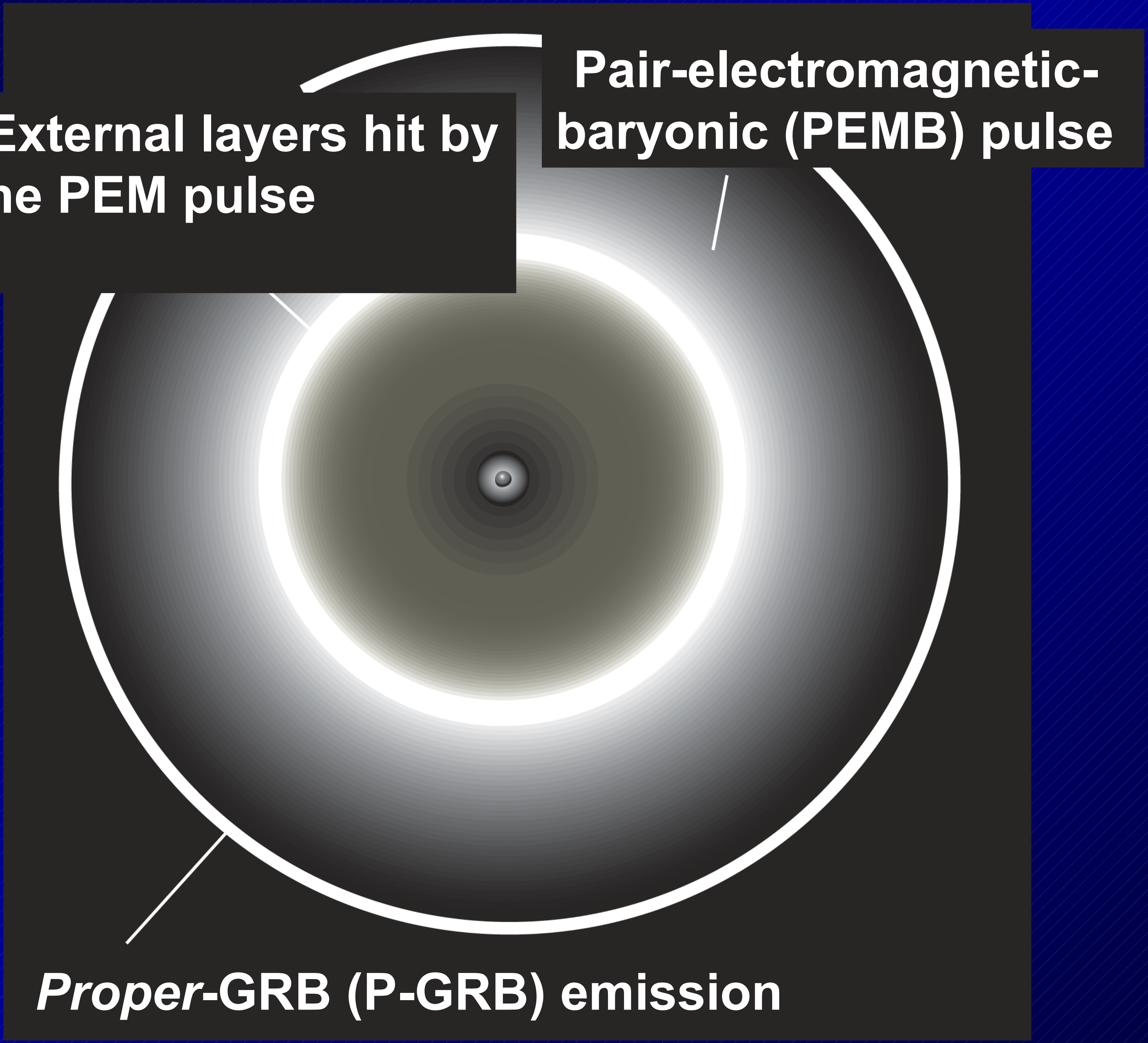


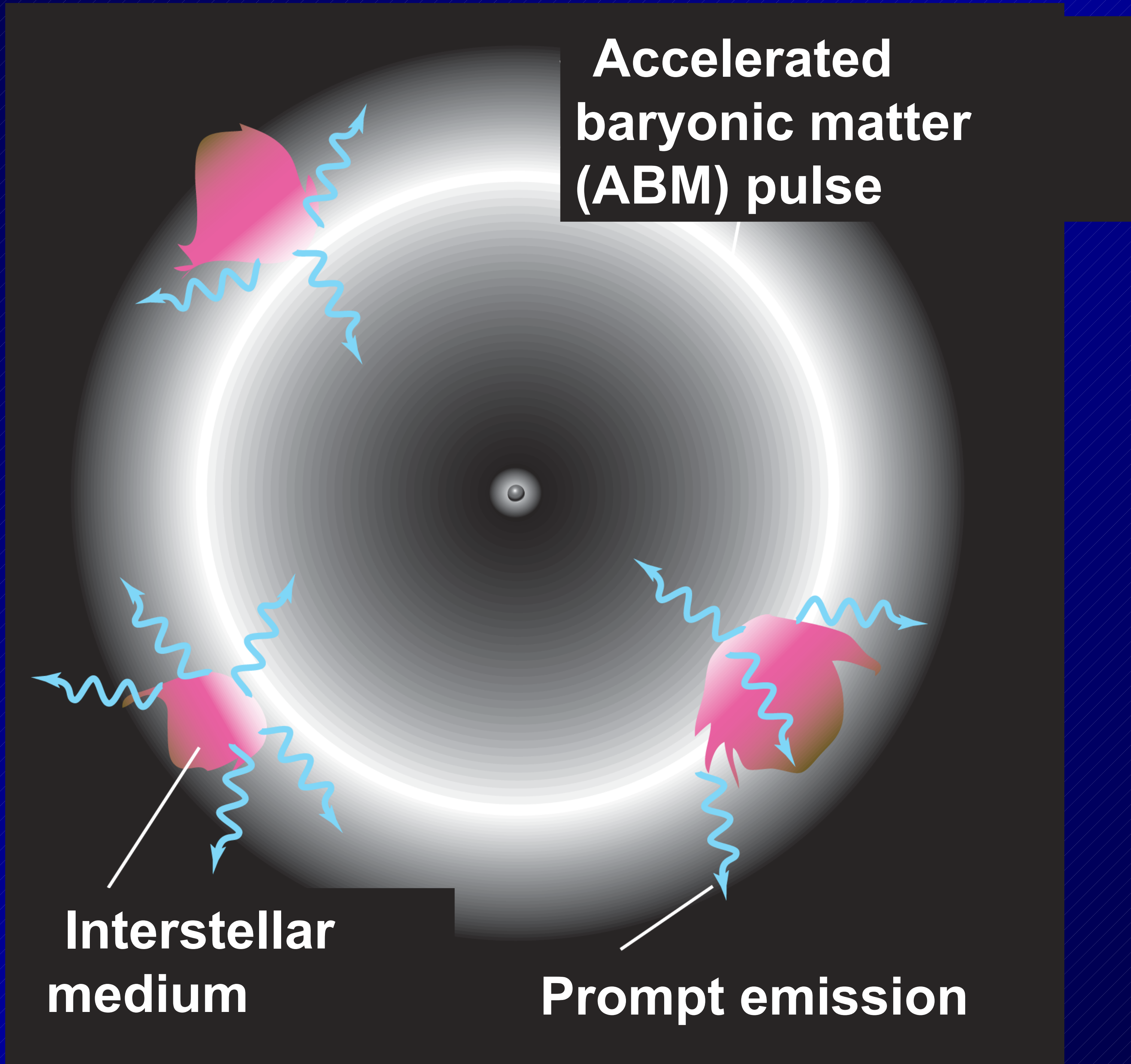

Electromagnetic field created by the charge segregation at the moment of the collapse.


Black hole
formation


Black
hole
Dyado-Torus
(electron-positron plasma)


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


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


Accelerated
baryonic matter
(ABM) pulse
Interstellar
medium
Prompt emission


ULTIMATE
HEAVYWEIGHT
BOXING
IRON
FIST

Stockholm University
Tartu
Max-Planck-I
für Gravitation
(Albert-Einstein-I
Berlin
Observatoire
de la COTE d'AZUR
Université
Nice
SOPHIA
UNIFE
SAPIEN
UNIVERSITÀ DI
Shanghai Astronomical Observatory, CAS
FROM DARK-
NESS TO LIGHT
2009
60
ANOS
RIO
SHANGHAI
KOLKOTA
NORWAY
SWEDEN
FINLAND
North Atlantic Ocean
UNITED KINGDOM
IRELAND
GERMANY
FRANCE
BELARUS
UKRAINE
ROMANIA
HUNGARY
BULGARIA
TURKEY
GREECE
ITALY
SPAIN
PORTUGAL
ALGERIA
TUNISIA
Mediterranean Sea
Scale 1: 19,500,000
Lambert Conformal Conic Projection,
standard parallels 40°N and 56°N