Un mecanismo electro-gravitomagnético para extraer energía a un agujero negro y sus implicaciones en GRBs y AGN

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Why do we (want to) extract mass-energy from a black hole?

We want to explain the extreme energetics of some astrophysical systems of extragalactic nature, e.g.:

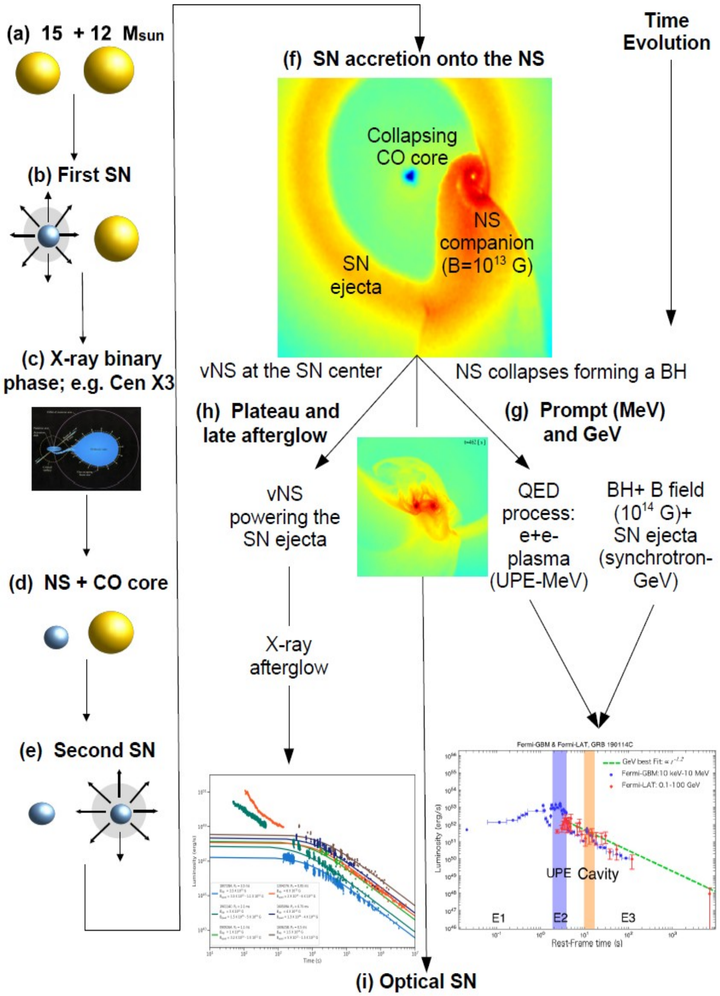
- Gamma-ray bursts (GRBs): up to a few 10^54 erg released in gamma-rays (from MeV up to TeV; but also X-rays, optical) in just a few seconds!! Short-lived (transient) source.
- Active Galactic Nuclei (AGN): e.g. a few 10^43 erg/s over long times (long-lived source) of the order of billion years implying 10^60 erg of energy released in their lifetime!!

Of course, to explain the whole energetics, at which pace it is emitted, and at which wavelengths, we need a theoretical model. The two essential ingredients are:

Great Energetics and Great Efficiency

Because of the above properties, the models of GRBs and AGN have always invoked the presence of black holes (BHs): in GRBs of stellar-mass (a few solar masses), in AGN supermassive (up to a few billion solar masses)

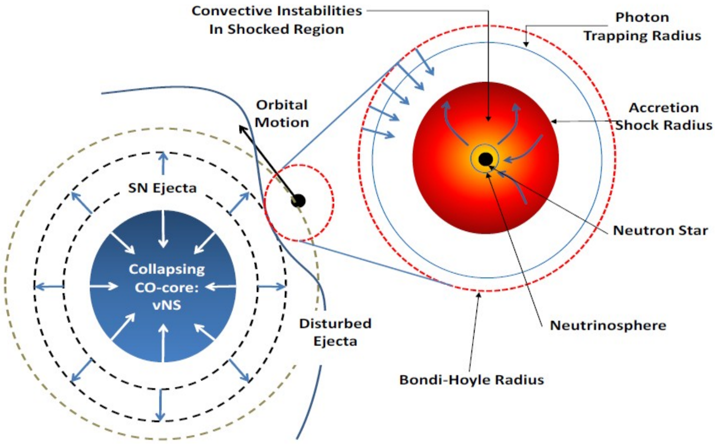
Long GRBs: binary-driven hypernova (BdHN)



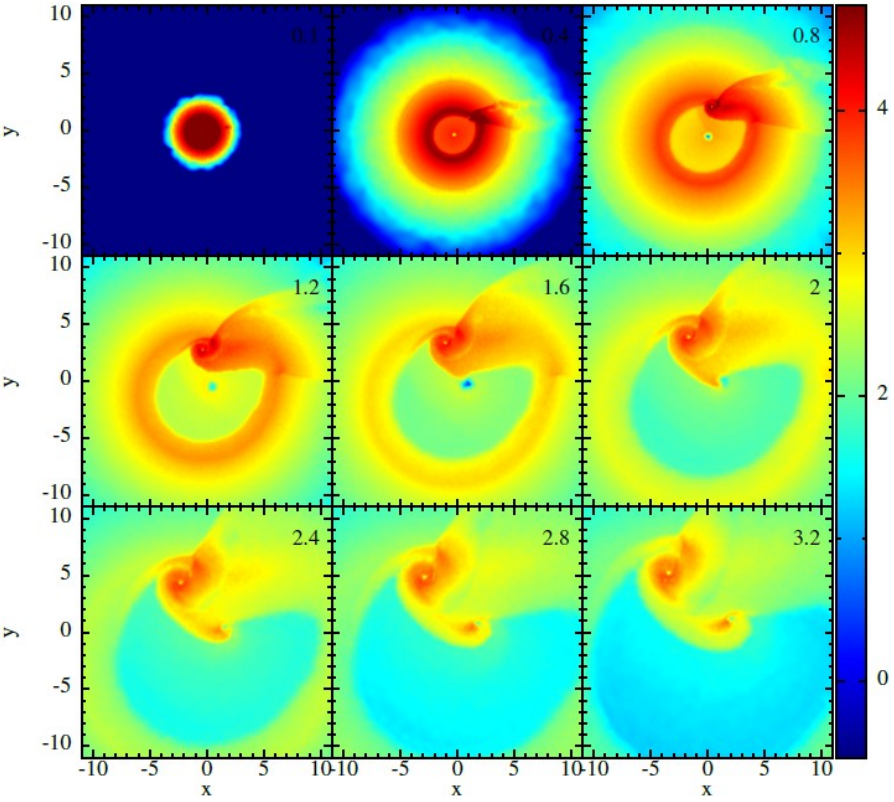
BdHN component/phenomena	GRB observable				
	X-ray precursor	Prompt (MeV)	GeV-TeV emission	X-ray flares early afterglow	X-ray plateau and late afterglow
SN breakout[a]	⊗				
Hypercritical accretion onto the NS[b]	⊗				
e^+e^- from BH formation: transparency in low baryon load region[c]		⊗			
Inner engine: newborn BH + B-field+SN ejecta[d]			⊗		
e^+e^- from BH formation: transparency in high baryon load region (SN ejecta)[e]				⊗	
Synchrotron emission by νNS injected particles on SN ejecta[f]					⊗
νNS pulsar-like emission[f]					⊗

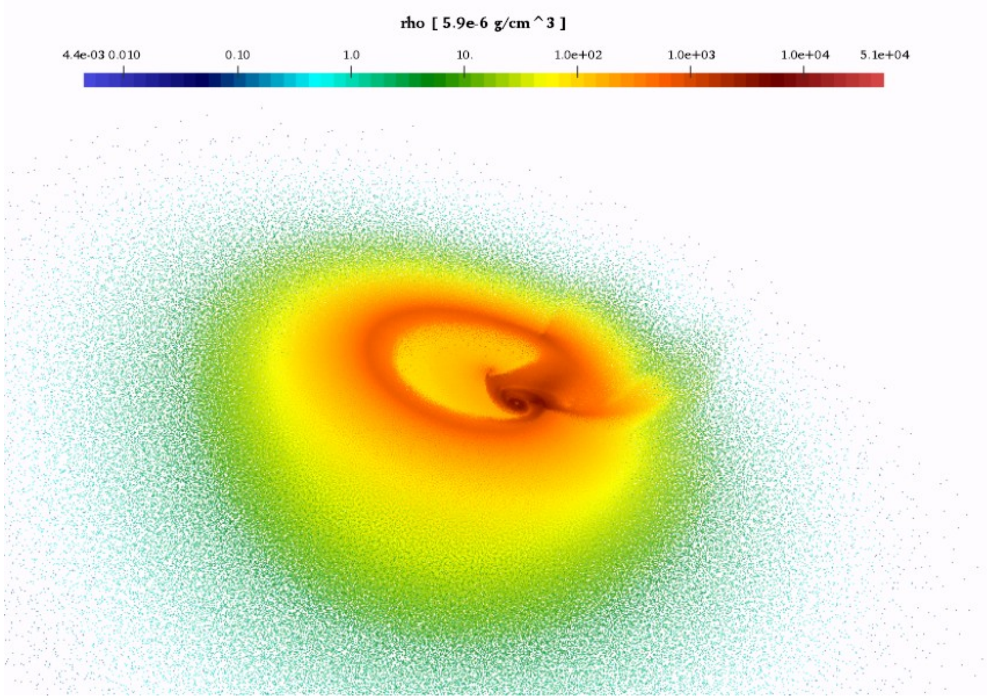
Theoretical treatment:

Rueda & Ruffini, ApJL (2012)
Fryer, Rueda, Ruffini, ApJL (2014)
Becerra, et al. ApJ (2015)
Fryer, et al. PRL (2015)
Becerra, et al. ApJ (2016)
Cipolletta, et al., PRD (2017)
Becerra, et al.ApJ (2018)
Becerra, et al. ApJ (2019)
Wang, et al., ApJ (2019)
Ruffini, et al., ApJ (2020)
Rueda, et al., ApJ (2020)
Rueda & Ruffini, EPJC (2020)



3D SPH simulations of BdHNe





Becerra, Ellinger, Fryer, Rueda, Ruffini; ApJ 871, 14 (2019); arXiv:1803.04356

Why do we (want to) extract mass-energy from a black hole?

- Black holes are the greatest storehouses of energy in the Universe; Christodoulou (1970) and Christodoulou & Ruffini (1971) derived BH mass-energy formula

BH mass-energy = "irreducible mass" + rotational energy (+ electric energy for KN BH)

$$M^2 = \frac{c^2}{G^2}\frac{J^2}{4M_{\rm irr}^2} + M_{\rm irr}^2$$

- From it, we have that: up to 29% of the mass-energy of a rotating (Kerr) black hole can be extracted
(Eextr ≈ 0.29*Mc² for J=G*M^2/c)

- Penrose's ideal process (1971): particle 1 splits into particles 2 and 3 (1-->2+3), particle 2 falls into the BH and particle 3 scapes to infinity with energy larger than particle 1! (obs. At infinity measures energy of 1 as negative). It sounds great but … poorly plausible (extreme fine-tuned parameters) and energetically expensive (split must occur in the "ergosphere" which is very close to the BH horizon)

“Papetrou-Wald” solution of EM eqs: Kerr BH embedded in (test) B-field

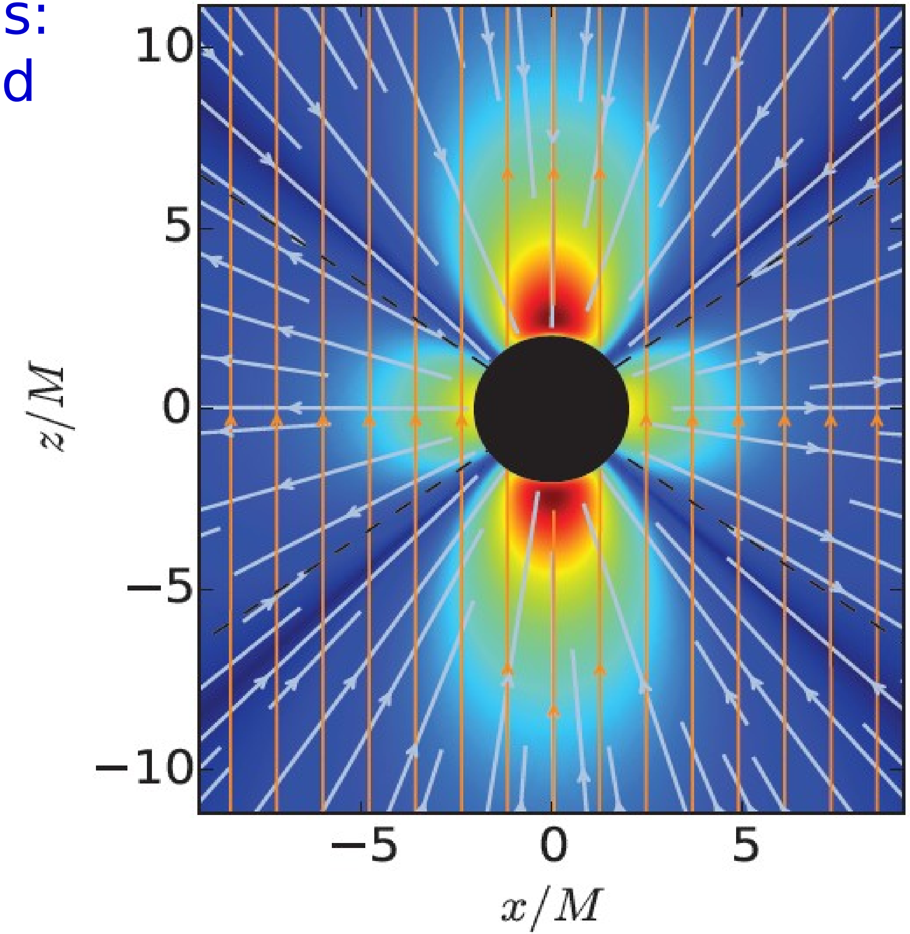
$$ds^2 = -\left(1 - \frac{2Mr}{\Sigma}\right)dt^2 + \frac{\Sigma}{\Delta}dr^2 + \Sigma d\theta^2 + \frac{A}{\Sigma}\sin^2\theta d\phi^2 - \frac{4aMr\sin^2\theta}{\Sigma}dtd\phi,$$

$$E_{\hat{r}} = \frac{B_0 aM}{\Sigma^2 A^{1/2}}\left[2r^2\sin^2\theta\Sigma - (r^2+a^2)(r^2 - a^2\cos^2\theta)(1+\cos^2\theta)\right],$$

$$E_{\hat{\theta}} = B_0 aM\frac{\Delta^{1/2}}{\Sigma^2 A^{1/2}}2ra^2\sin\theta\cos\theta(1+\cos^2\theta),$$

$$B_{\hat{r}} = \frac{B_0\cos\theta}{\Sigma^2 A^{1/2}}\left\{(r^2+a^2)\Sigma^2 - 2Mra^2[2r^2\cos^2\theta + a^2(1+\cos^4\theta)]\right\},$$

$$B_{\hat{\theta}} = -\frac{\Delta^{1/2}}{\Sigma^2 A^{1/2}}B_0\sin\theta[Ma^2(r^2 - a^2\cos^2\theta)(1+\cos^2\theta) + r\Sigma^2].$$



Ruffini, et al., ApJ (2019)
Rueda, Kerr, Ruffini, to be submitted (2021)

For moderate dimensionless spin values, $\alpha \lesssim 0.7$, where $\alpha \equiv \hat{a}/\hat{M} = cJ/(GM^2)$, the electric and magnetic fields are accurately represented by the first order expansion ($\alpha \ll 1$ or $\hat{a} \ll \hat{M}$):

$$E_{\hat{r}} \approx -\frac{B_0 \hat{a} \hat{M}}{r^2}(3\cos^2\theta - 1), \quad E_{\hat{\theta}} \approx 0, \qquad B_{\hat{r}} \approx B_0 \cos\theta, \quad B_{\hat{\theta}} \approx -B_0 \sqrt{1 - \frac{2\hat{M}}{r}} \sin\theta.$$

Far-away from the BH the magnetic field behaves as:
(x-y-z are Kerr-Schild Cartesian coordinates)

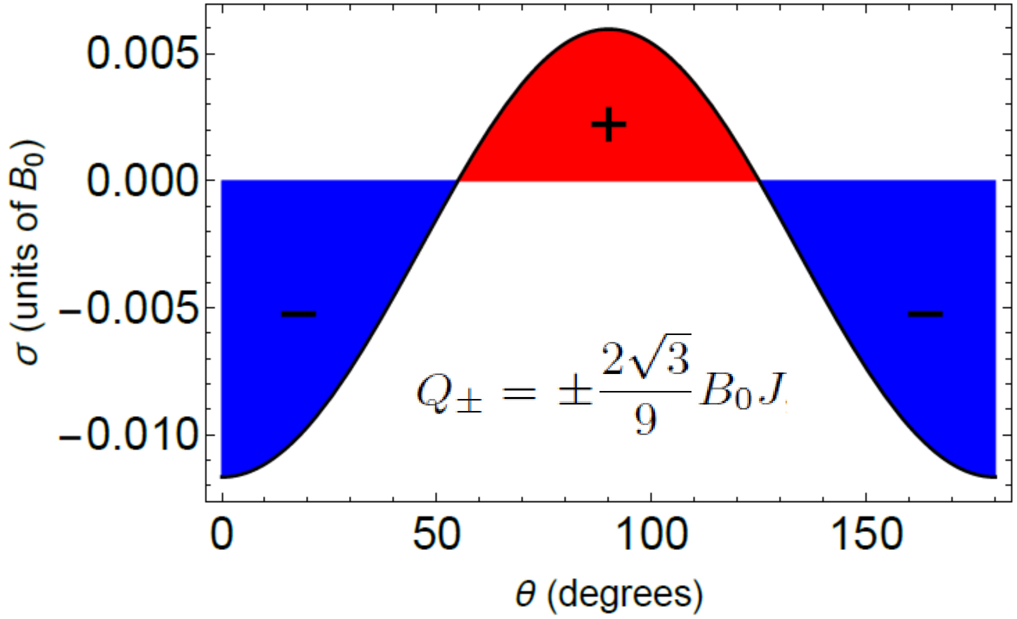
$$B_{\hat{x}} = B_{\hat{r}} \sin\theta + B_{\hat{\theta}} \cos\theta = B_0 \sin\theta \cos\theta \left(1 - \sqrt{1 - \frac{2M}{r}}\right),$$

$$B_{\hat{y}} = B_{\hat{\theta}} \frac{a}{r} \cos\theta = -B_0 \sin\theta \cos\theta \, \frac{a}{r} \sqrt{1 - \frac{2M}{r}},$$

$$B_{\hat{z}} = B_{\hat{r}} \cos\theta - B_{\hat{\theta}} \sin\theta = B_0 \left(\cos^2\theta + \sin^2\theta \sqrt{1 - \frac{2M}{r}}\right).$$

Ruffini, et al., ApJ (2019)
Rueda, Kerr, Ruffini, to be submitted (2021)

"Surface charge" of the black hole



$$\sigma = \frac{1}{4\pi} B_0 a r_+ (r_+ - M) \frac{r_+ \sin^4\theta - M\cos^2\theta(1+\cos^2\theta)}{(r_+^2 + a^2\cos^2\theta)}$$

$$\sigma \approx \frac{B_0}{16\pi}\frac{a}{M}(1 - 3\cos^2\theta)$$

$$Q_{\rm patch} = \iint \sigma \sqrt{|h_{ij}|}\, dx^i dx^j = \iint \sigma \sqrt{|h_{\theta\theta} h_{\phi\phi}|}\, d\theta\, d\phi$$

$$Q_{\rm patch} = 4\pi M r_+ \int_{\Delta\theta} \sigma(\theta) \sin\theta d\theta \approx \frac{1}{2} M^2 B_0 \frac{a}{M} \cos\theta(\cos^2\theta - 1)\Big|_{\Delta\theta}$$

Rueda, Kerr, Ruffini, to be submitted (2021)

Particle acceleration along the BH rotation axis

Energy gained by a proton from the BH horizon to infinity:

$$\epsilon_p = eA_\mu\eta^\mu|_\infty - eA_\mu\eta^\mu|_{\mathrm{r}_+}$$

$$\epsilon_p = e\,a\,B_0$$

Electric field at the horizon:

$$E_+ = \frac{1}{2}\frac{a}{M}B_0 \approx \Omega_+ r_+ B_0$$

BH angular velocity:

$$\Omega_+ = \frac{a}{r_+^2 + a^2} = \frac{1}{2}\frac{a/M}{r_+}$$

Electrostatic potential drop:

$$\Delta\phi = \frac{\epsilon_p}{e}$$

Acceleration timescale:

$$\tau_{\mathrm{el}} = \frac{\epsilon_p}{eE_+} \approx r_+$$

So the BH angular velocity can be written as:

$$\Omega_+ \approx \frac{1}{2}\frac{a/M}{\tau_{\mathrm{el}}}$$

Rueda & Ruffini; EPJC 80, 300 (2020); arXiv:1907.08066

The "blackholic quantum" of energy

$$\mathscr{E} = \hbar\, \Omega_{\rm eff}\,, \quad \Omega_{\rm eff} \equiv 4\left(\frac{m_{\rm Pl}}{m_n}\right)^8 \left(\frac{\hat{a}}{\hat{M}}\right)\left(\frac{B_0^2}{\rho_{\rm Pl}}\right)\Omega_+$$

$$\varepsilon_e = \hbar\, \omega_p, \quad \omega_p \equiv \frac{4\,G}{c^4}\left(\frac{m_{\rm Pl}}{m_n}\right)^4 e\, B_0\, \Omega_+$$

Rueda & Ruffini; EPJC 80, 300 (2020); arXiv:1907.08066

There are no losses along the BH rotation axis

↓

Ultrahigh-energy Cosmic Rays (UHECRs)

UHECRs: acceleration along the BH rotation axis

$$(\Delta\Phi)_{\rm em} \approx 5.8521 \times 10^{18} \left(\frac{a/M}{0.3}\right)\left(\frac{B_0}{10^{11}\,{\rm G}}\right)\left(\frac{M}{4.4\,M_\odot}\right)\ {\rm eV}$$

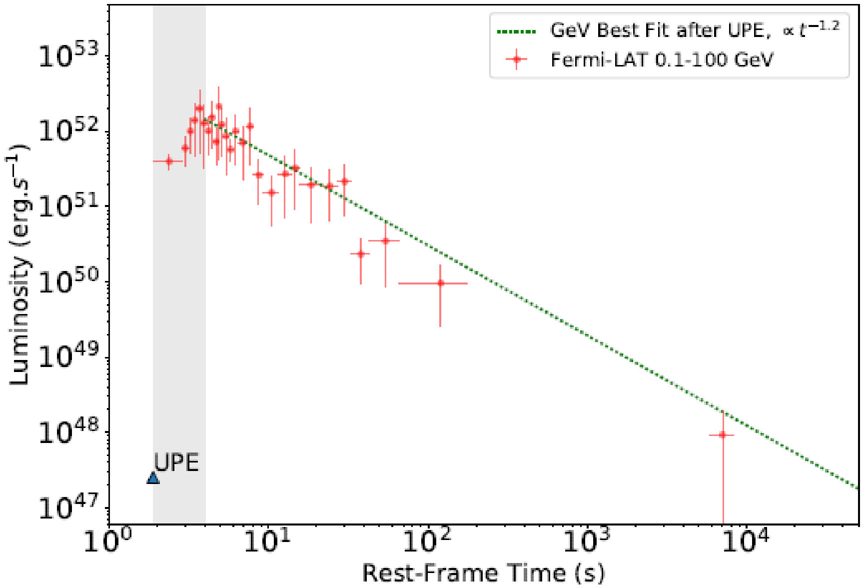
$$\tau_{\rm em} \approx \frac{r_+^2}{2M} \approx r_+ \approx 4.2248 \times 10^{-5}\left(\frac{M}{4.4\,M_\odot}\right)\ {\rm s}$$

$$\dot{\epsilon}_{\rm pole} \approx \frac{|(\Delta\Phi)_{\rm em}|}{\tau_{\rm em}} \approx \frac{eaB_0}{r_+} \approx \frac{eaB_0}{2M}$$

$$\approx 1.3533 \times 10^{23}\left(\frac{a/M}{0.3}\right)\left(\frac{B_0}{10^{11}\,{\rm G}}\right)\ {\rm eV\,s^{-1}}$$

$$\boxed{\begin{aligned}\dot{\mathcal{E}}_{\rm pole} &\approx N_\pm \dot{\epsilon}_{\rm pole} = \frac{2\sqrt{3}}{9}\frac{(aB_0)^2 M}{r_+} \approx \frac{\sqrt{3}}{9}(aB_0)^2\\ &\approx 1.3722 \times 10^{54}\left(\frac{a/M}{0.3}\right)^2\left(\frac{B_0}{10^{11}\,{\rm G}}\right)^2\left(\frac{M}{4.4\,M_\odot}\right)^2\ {\rm eV\,s^{-1}}\end{aligned}}$$

GeV (and beyond) emission: off-axis radiation



Inner engine parameters (M, J, B) can be obtained from:

(i) GeV energy budget from BH
(ii) Mechanism: synchrotron radiation by accelerated electrons
(iii) Transparency of high-energy photons (>0.1 GeV) to magnetic pair production

Moradi, Rueda, Ruffini, Wang; submitted (2020); arXiv:1911.07552

An approximate solution of the electron synchrotron emission in the PW EM field:

Ruffini, Rueda, Moradi, et al., ApJ 886, 82 (2019); arXiv:1812.00354

$$m_e c^2 \frac{d\gamma}{dt} = e\frac{1}{2}\alpha B_0\, c - \frac{2}{3}e^4 \frac{B_0^2 \sin^2\langle\chi\rangle}{m_e^2 c^3}\gamma^2,$$

$$\gamma_{\rm max} = \frac{1}{2}\left[\frac{3}{e^2/(\hbar c)}\frac{\alpha}{\beta \sin^2\langle\chi\rangle}\right]^{1/2}$$

$$t_c = \frac{\hbar}{m_e c^2}\frac{3}{\sin\langle\chi\rangle}\left(\frac{e^2}{\hbar c}\alpha\,\beta^3\right)^{-1/2}$$

$$\epsilon_\gamma = \frac{3e\hbar}{2m_e\, c}B_0 \sin\langle\chi\rangle\,\gamma_{\rm max}^2 = \frac{9}{8}\frac{m_e c^2}{e^2/\hbar c}\frac{\alpha}{\sin\langle\chi\rangle}$$

$$\approx \frac{78.76}{\sin\langle\chi\rangle}\alpha \text{ MeV}.$$

Estimating the "*inner engine*" parameters

The 3 conditions to obtain the 3 *inner engine* parameters: M, a, and B

(i) GeV energy budget from BH:

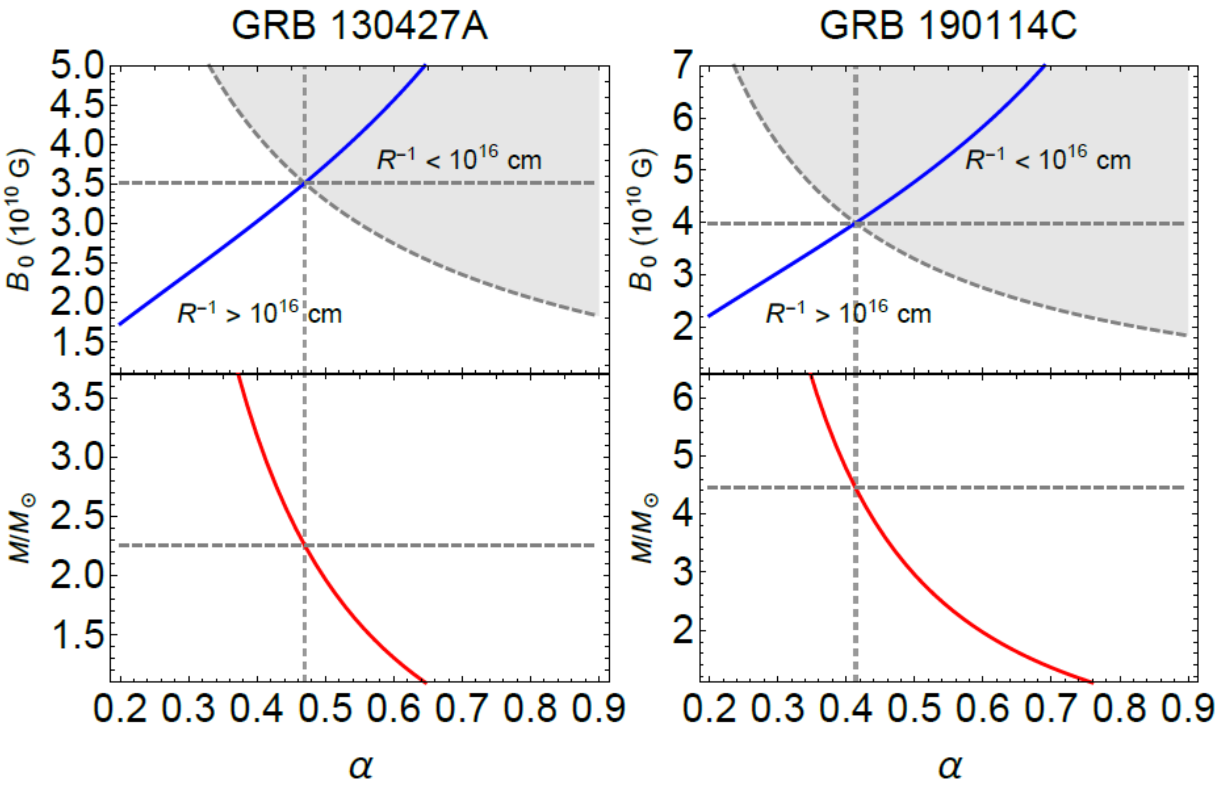
$$M \geq \left(1 - \sqrt{\frac{1+\sqrt{1-\alpha^2}}{2}}\right)^{-1} \frac{E_{\rm GeV}}{c^2}$$

(ii) Mechanism: synchrotron radiation by accelerated electrons:

$$\tau_{\rm ob,1} = \frac{\mathcal{E}_1}{L_{\rm GeV,1}}$$

(ii) Transparency of high-energy photons (>0.1 GeV) to magnetic pair production

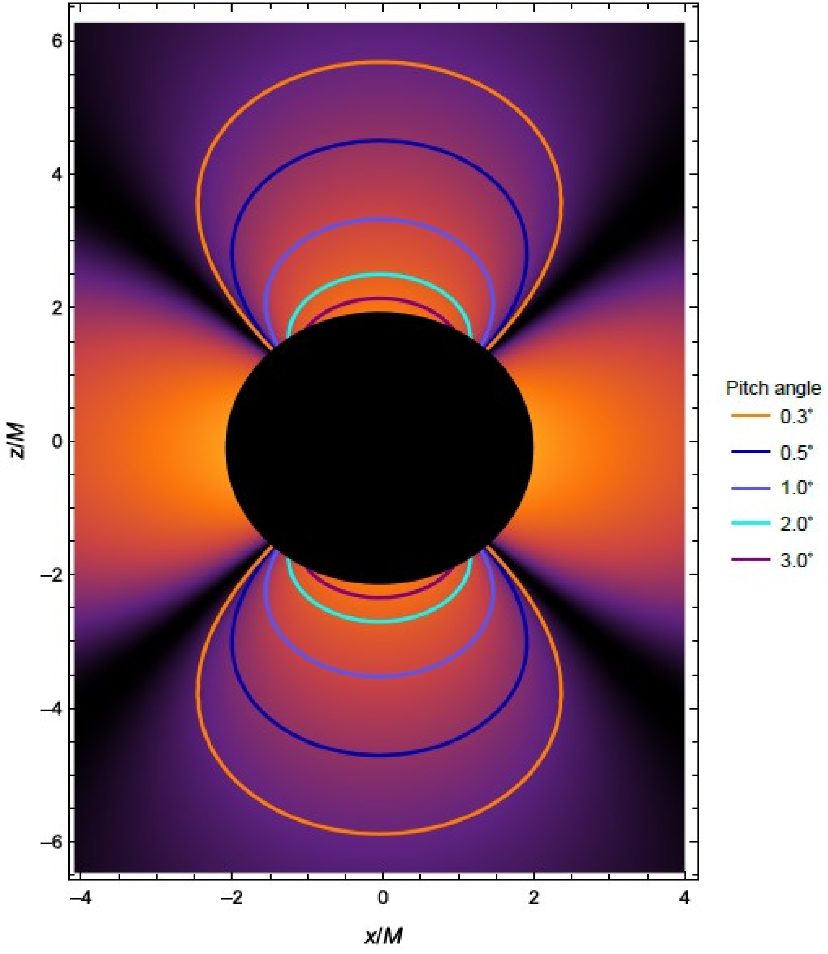
$$B_0 \ll \frac{5.728 \times 10^{11}}{\alpha}\ {\rm G}$$



Moradi, Rueda, Ruffini, Wang; submitted (2020); arXiv:1911.07552

Estimating the *inner engine* parameters

	GRB 190114C	AGN (M87*-like)
M ($M_\odot$)	4.4	6.0×10^9
α	0.4	0.1
B_0 (G)	4.0×10^{10}	10
$\tau_{\rm pole}$	4.33×10^{-5} s	0.68 d
$\Delta\Phi$ (eV)	3.12×10^{18}	2.66×10^{17}
$\mathcal{E}$ (erg)	7.02×10^{37}	6.96×10^{44}
$\dot{\mathcal{E}}_{\rm pole}$ (erg s^{-1})	1.62×10^{42}	1.18×10^{40}
χ (°)	0.1805–18.05	0.0451–4.51
t_c (s)	1.45×10^{-16}–1.45×10^{-14}	0.2939–29.39
$L_{\rm GeV}$ (erg s^{-1})	4.83×10^{51}–4.83×10^{53}	2.37×10^{43}–2.37×10^{45}



Picture and Table from: Moradi, Rueda, Ruffini, Wang; submitted (2020)

$$\frac{Du^{\hat{a}}}{d\tau} = \dot{u}^{\hat{a}} + \omega_{\hat{c}}{}^{\hat{a}}{}_{\hat{b}} u^{\hat{b}} u^{\hat{c}} = \frac{q}{m} F^{\hat{a}}{}_{\hat{b}} u^{\hat{b}} - \mathcal{F}^{\hat{a}}$$

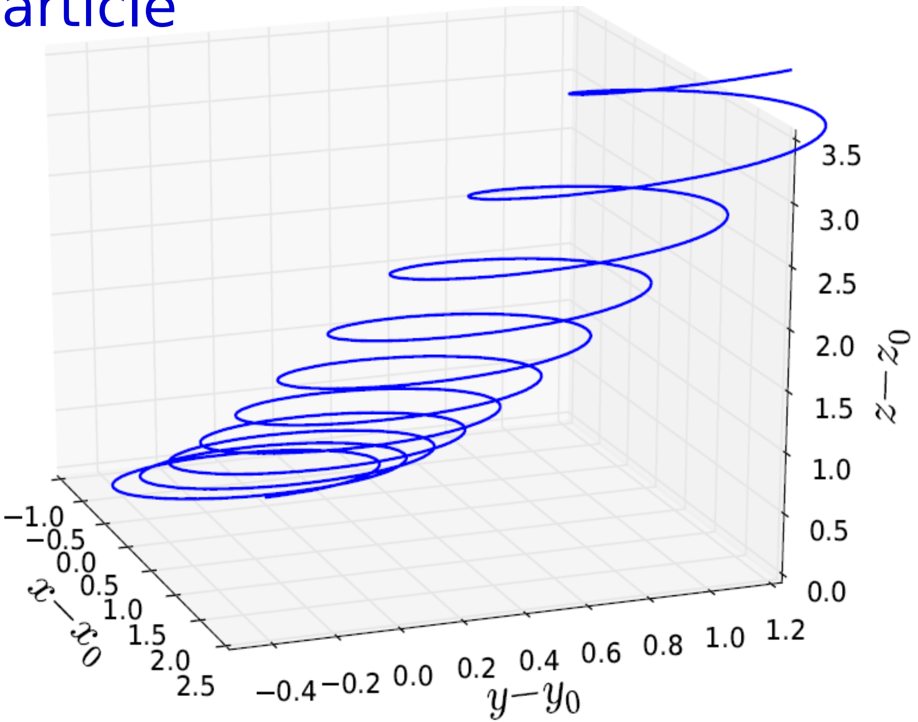
$$\mathcal{P} \equiv \frac{2}{3}\left(\frac{q}{m}\right)^2 q^2 \hat{\gamma}^3 \left[(\boldsymbol{E} + \boldsymbol{v} \times \boldsymbol{B})^2 - (\boldsymbol{v} \cdot \boldsymbol{E})^2\right].$$

$$\mathcal{F}^{\hat{a}} = \frac{2}{3}\left(\frac{q}{m}\right)^2 \frac{q^2}{m}\left(F_{\hat{c}\hat{d}} F^{\hat{d}}{}_{\hat{e}} u^{\hat{c}} u^{\hat{e}}\right) u^{\hat{a}} + \frac{2}{3}\left(\frac{q}{m}\right)^2 \frac{q^2}{m} F^{\hat{a}}{}_{\hat{b}} F^{\hat{b}}{}_{\hat{c}} u^{\hat{c}}$$
$$+ \frac{2}{3}\left(\frac{q}{m}\right)^2 q \frac{DF^{\hat{a}}{}_{\hat{b}}}{dx^{\hat{c}}} u^{\hat{b}} u^{\hat{c}} \approx \frac{2}{3}\left(\frac{q}{m}\right)^2 \frac{q^2}{m}\left(F_{\hat{c}\hat{d}} F^{\hat{d}}{}_{\hat{e}} u^{\hat{c}} u^{\hat{e}}\right) u^{\hat{a}} = -\frac{\mathcal{P}}{m} v^{\hat{a}}$$

Motion of a charged, accelerated particle in the PW solution

$$\dot{\hat{\gamma}} = -\frac{e}{m} E^{\hat{r}} v^{\hat{r}} \hat{\gamma} - \frac{\mathcal{P}}{m} + \left[\frac{M}{r^2\sqrt{1-2M/r}} - \frac{6Ma\sin\theta}{r^3} v^{\hat{\theta}}\right] \hat{\gamma} v^{\hat{r}},$$

$$\begin{aligned}
\dot{v}^{\hat{i}} = &-\frac{e}{m}\left[(E^{\hat{r}} - v^{\hat{\phi}} B^{\hat{\theta}})\delta^{\hat{i}}{}_{\hat{r}} + v^{\hat{\phi}} B^{\hat{r}} \delta^{\hat{i}}{}_{\hat{\theta}} + (v^{\hat{r}} B^{\hat{\theta}} - v^{\hat{\theta}} B^{\hat{r}})\delta^{\hat{i}}{}_{\hat{\phi}} - E^{\hat{r}} v^{\hat{r}} v^{\hat{i}}\right] \\
&- \frac{\mathcal{P}}{m\hat{\gamma}} v^{\hat{i}} - \left(\frac{M}{r^2\sqrt{1-2M/r}} - \frac{6Ma\sin\theta}{r^3} v^{\hat{\theta}}\right) \hat{\gamma} v^{\hat{r}} v^{\hat{i}} \\
&- \left[\frac{6Ma\sin\theta}{r^3} v^{\hat{\phi}} + \frac{M(v^{\hat{\theta}})^2}{r^2(1-2M/r)^{5/2}} + \frac{\sqrt{1-2M/r}}{r}(v^{\hat{\phi}})^2\right] \hat{\gamma}\, \delta^{\hat{i}}{}_{\hat{r}} \\
&+ \left[\frac{M}{r^2(1-2M/r)^{5/2}} v^{\hat{r}} v^{\hat{\theta}} - \frac{\cos\theta}{r\sin\theta}(v^{\hat{\phi}})^2\right] \hat{\gamma}\, \delta^{\hat{i}}{}_{\hat{\theta}} \\
&- \left[\frac{6Ma\sin\theta}{r^3} v^{\hat{r}} - \frac{\sqrt{1-2M/r}}{r} v^{\hat{r}} v^{\hat{\phi}} - \frac{\cos\theta}{r\sin\theta} v^{\hat{\theta}} v^{\hat{\phi}}\right] \hat{\gamma}\, \delta^{\hat{i}}{}_{\hat{\phi}}.
\end{aligned}$$



Rueda, Kerr, Ruffini, to be submitted (2021)

Photon four-momentum measured by the observer at rest at infinity

$$k^\mu = e^\mu{}_{\hat{b}}\,\Lambda^{\hat{b}}{}_{(a)}\,k^{(a)}, \qquad \boldsymbol{e}_{\hat{b}} = e^\mu{}_{\hat{b}}\,\boldsymbol{e}_\mu,$$

$$\Lambda^{\hat{0}}{}_{(0)} = \hat{\gamma}, \quad \Lambda^{\hat{0}}{}_{(i)} = \hat{\gamma} v_{\hat{i}}, \quad \Lambda^{\hat{i}}{}_{(j)} = \delta^i_j + \frac{\hat{\gamma}^2}{\hat{\gamma}+1} v^{\hat{i}} v_{\hat{j}}$$

$$\boldsymbol{e}_{\hat{t}} = e^{-\nu}\boldsymbol{e}_t + \omega e^{-\nu}\boldsymbol{e}_\phi = \sqrt{\frac{A}{\Sigma\Delta}}\,\boldsymbol{e}_t + \frac{2Mar}{\sqrt{\Sigma\Delta A}}\,\boldsymbol{e}_\phi,$$

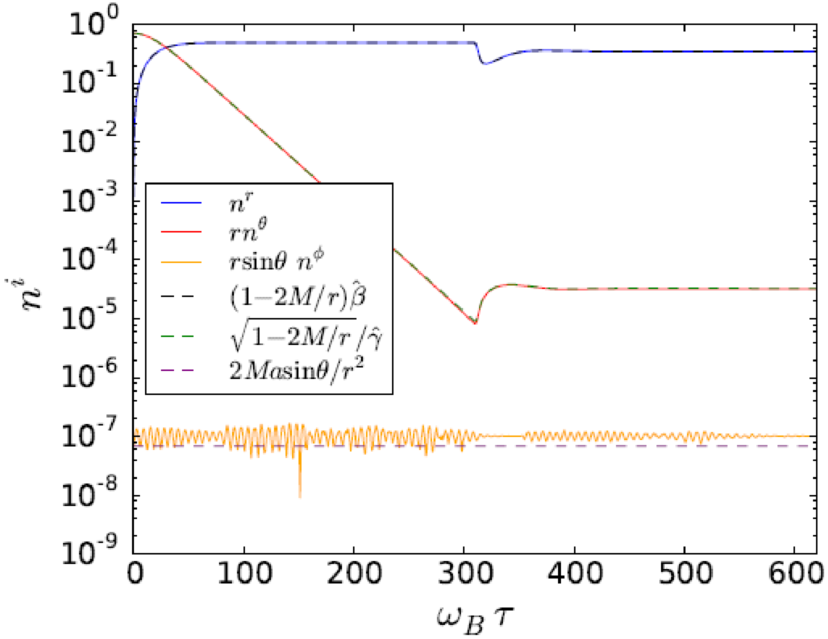
$$\boldsymbol{e}_{\hat{r}} = e^{-\mu_1}\boldsymbol{e}_r = \sqrt{\frac{\Delta}{\Sigma}}\,\boldsymbol{e}_r,\ \boldsymbol{e}_{\hat{\theta}} = e^{-\mu_2}\boldsymbol{e}_\theta = \frac{1}{\sqrt{\Sigma}}\,\boldsymbol{e}_\theta,\ \ \boldsymbol{e}_{\hat{\phi}} = e^{-\Psi}\boldsymbol{e}_\phi = \sqrt{\frac{\Sigma}{A}}\frac{1}{\sin\theta}\,\boldsymbol{e}_\phi$$

$$\boxed{\begin{gathered} k^0 = k^{(0)}\hat{\gamma}e^{-\nu}[1 + v_{\hat{i}}\,n^{(i)}], \quad n^r = \frac{k^{(0)}}{k^0}e^{-\mu_1}\left[\hat{\gamma}v^{\hat{r}} + n^{(1)} + \frac{\hat{\gamma}^2}{\hat{\gamma}+1}v^{\hat{r}}v_{\hat{j}}n^{(j)}\right], \quad n^\theta = \frac{k^{(0)}}{k^0}e^{-\mu_2}\left[\hat{\gamma}v^{\hat{\theta}} + n^{(2)} + \frac{\hat{\gamma}^2}{\hat{\gamma}+1}v^{\hat{\theta}}v_{\hat{j}}n^{(j)}\right], \\ n^\phi = \frac{k^{(0)}}{k^0}e^{-\Psi}\left\{e^{\Psi-\nu}\omega\hat{\gamma}[1 + v_{\hat{j}}\,n^{(j)}] + \hat{\gamma}v^{\hat{\phi}} + n^{(3)} + \frac{\hat{\gamma}^2}{\hat{\gamma}+1}v^{\hat{\phi}}v_{\hat{j}}n^{(j)}\right\} \end{gathered}}$$

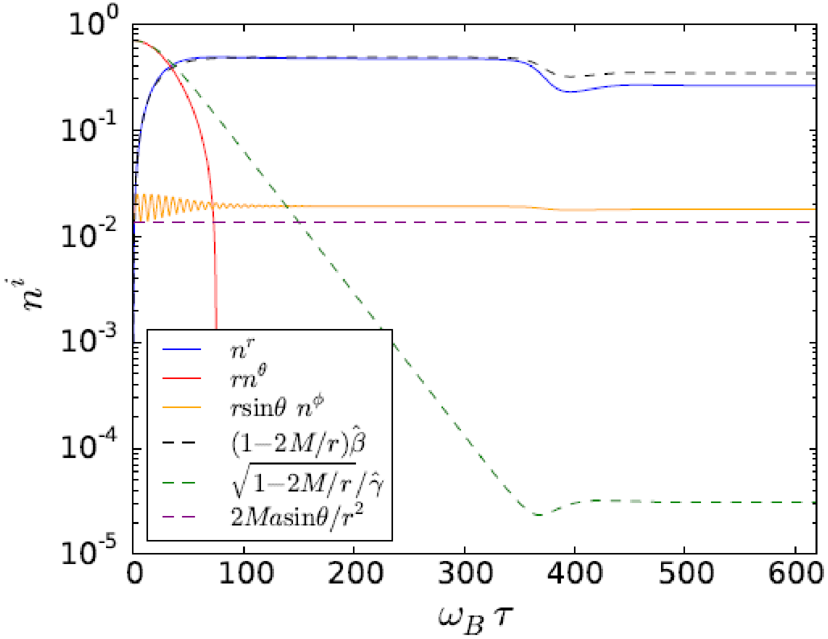
	$\Phi = 0$: plane $\boldsymbol{e}_{(z)}$-$\boldsymbol{e}_{(x)}$			$\Phi = \pi/2$: plane $\boldsymbol{e}_{(z)}$-$\boldsymbol{e}_{(y)}$		
	$\Theta = 0$	$\Theta = \pi/2$	$\Theta = \pi$	$\Theta = 0$	$\Theta = \pi/2$	$\Theta = \pi$
k^0	$\frac{k^{(0)}}{\sqrt{1-2M/r}}\sqrt{\frac{1+\hat{\beta}}{1-\hat{\beta}}}$	$k^{(0)}\gamma$	$\frac{k^{(0)}}{\sqrt{1-2M/r}}\sqrt{\frac{1-\hat{\beta}}{1+\hat{\beta}}}$	$\frac{k^{(0)}}{\sqrt{1-2M/r}}\sqrt{\frac{1+\hat{\beta}}{1-\hat{\beta}}}$	$k^{(0)}\gamma$	$\frac{k^{(0)}}{\sqrt{1-2M/r}}\sqrt{\frac{1-\hat{\beta}}{1+\hat{\beta}}}$
n^r	$1 - 2M/r$	$(1 - 2M/r)\hat{\beta}$	$-(1 - 2M/r)$	$1 - 2M/r$	$(1 - 2M/r)\hat{\beta}$	$-(1 - 2M/r)$
n^θ	0	$(1/\gamma)(1/r)$	0	0	0	0
n^ϕ	$2Ma/r^3$	$2Ma/r^3$	$2Ma/r^3$	$2Ma/r^3$	$2Ma/r^3 + (1/\gamma)(1/r\sin\theta)$	$2Ma/r^3$

Rueda, Kerr, Ruffini, to be submitted (2021)

Photon four-momentum measured at infinity

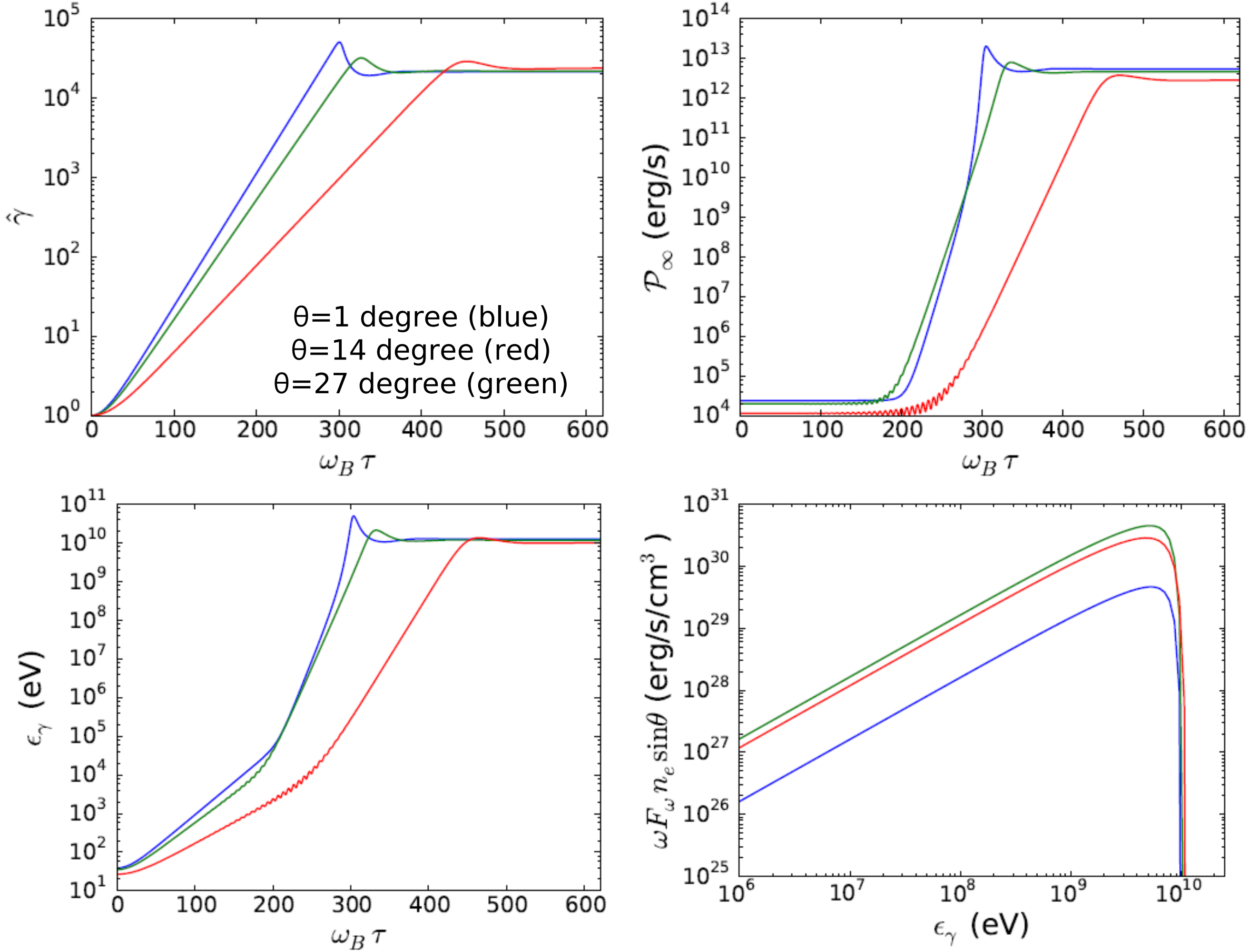


θ=10^{-4} degrees



θ=20 degrees

Rueda, Kerr, Ruffini, to be submitted (2021)



Electron accelerated from different positions near the BH:

M=4 Msun, a/M = 0.3, B = 10^{11} G

r~4M and different polar angles θ

Rueda, Kerr, Ruffini, to be submitted (2021)

Conclusions UHECRs: acceleration along the BH axis

(1) The gravitomagnetic interaction of a Kerr BH with a B-field induces an electric field

(2) The induced electric field accelerates particles in the BH surroundings

(3) Along the BH rotation axis, there are no energy losses, so particles reach ultrahigh-energies of the order of the electric potential energy between the horizon and infinity. For stellar-mass BH and trillion gauss B-field (GRB case) or in billion solar masses supermassive BH and a few gauss B-field (AGN case):

-) Electrons reach up to 10^18 eV

-) Protons reach up to 10^21 eV

(4) The number of accelerated particles per unit energy per unit time is a Universal constant: are we in presence of a new cosmological candle?

Conclusions HE emission: off-axis acceleration/radiation

(i) There is ***no need of bulk expansion motion*** (i.e. no massive jet but jetted emission).

(ii) Electrons radiate in the ~***GeV regime*** during their acceleration.

(iii) The GeV energetics is paid by the ***BH extractable energy, i.e. the BH rotational energy.***

(v) For appropriate value of B, the system is ***transparent to GeV*** photons.

(vi) The GeV emission is radiated from e- ***within 60 degrees from the BH rotation axis***: this is crucial for testing the morphology of long GRBs from observations