# PRIMORDIAL BLACK HOLES AND GALACTIC POSITRONS

**A.D. Dolgov**

*ITEP, 117218, Moscow, Russia*
*INFN, Ferrara 40100, Italy*
*University of Ferrara, Ferrara 40100, Italy*

**New Topics in Modern Cosmology**

**Spontaneous Workshop III**
**Cargese, April 27 - May, 1, 2009**

## Based on:

**1. C. Bambi, A.D., A. Petrov, 0801.2786 [astro-ph].**

**2. C. Bambi, A.D., A. Petrov, 0806.3440 [astro-ph].**

## 0.511 MeV LINE FROM GALACTIC CENTER:

$$\Phi_{511\ \mathrm{keV}} \approx 1.0 \cdot 10^{-3}\ \mathrm{photons\ cm^{-2}\,s^{-1}}$$

**Implies about $3 \cdot 10^{43}$ annihilation per second inside the central kiloparsec.**

**Hints for the line from the halo!**

**Suggested mechanisms of explanation of 0.511 MeV line:**

1. **Ia supernovae.**
2. **Low mass X-ray binary systems.**
3. **Energetic $e^{\pm}$ and $\gamma$ created by accretion on the super–massive black hole at the Galactic Center.**
4. **Positron production in accretion to super–massive central black hole and to surrounding primordial black holes with mass about $10^{17}$ g.**

**5. Annihilating light DM particles.**

**6. Decaying unstable relics e.g. sterile neutrinos.**

**7. MeV right-handed neutrino interacting with baryonic matter.**

**8. Strangelets.**

**9. (Anti)quark nuggets.**

**10. Positrons originating from primordial antimatter.**

**11. Decays of milli–charged particles.**

**12. Evaporation of $10^{16}-10^{17}$ g PBH.**

**Evaporating BH with mass centered near $10^{17}$ g**

**Smaller masses lead to an excessive e.m. radiation at high energy, while larger masses result in an excess of lower energy photons.**

**The mass distribution of PBH is essential. Rather well described with log-normal mass distribution:**

$$\frac{dN}{dM} = C \exp\left(-\gamma \ln^2 \frac{M}{M_0}\right),$$

Affleck-Dine field $\chi$ with CW potential coupled to inflaton $\Phi$:

$$U(\chi, \Phi) = g|\chi|^2(\Phi - \Phi_1)^2 + \lambda|\chi|^4 \ln\left(\frac{|\chi|^2}{\sigma^2}\right)$$
$$+\lambda_1\left(\chi^4 + h.c.\right) + (m^2\chi^2 + h.c.).$$

$m$ may be complex but CP would be still conserved - "phase rotate" $\chi$.

Last two terms break B-conservation.

$J_\mu^{(B)} = i\chi^\dagger\partial_\mu\chi + h.c.,$

$B = J_t^{(B)}$ is the angular momentum.

**BH temperature:**

$$T = \frac{1}{8\pi G_N M} = 1.06 \left(\frac{10^{16}\ \mathrm{g}}{M}\right) MeV$$

**and life-time:**

$$\tau_{evap} = 15 \left(\frac{M_i}{5 \cdot 10^{14}\ \mathrm{g}}\right)^3 Gyr\,,$$

**Luminosity:**

$$\frac{dM}{dt} = -4.8 \cdot 10^{20} \left( \frac{10^{16}\ \mathrm{g}}{M} \right)^2 \ MeV\ s^{-1},$$

**The positron production rate per BH is**

$$\frac{dN_{e^+}}{dt} \approx \frac{\alpha'_{e^+}}{G_N M} = 2 \cdot 10^{19}\ e^+\ \mathrm{s}^{-1}$$

**About $10^{24}$ PBHs, with total mass $\sim 10^7\ M_\odot$ inside the spherical region with $r = 500 - 700$ pc are necessary.**

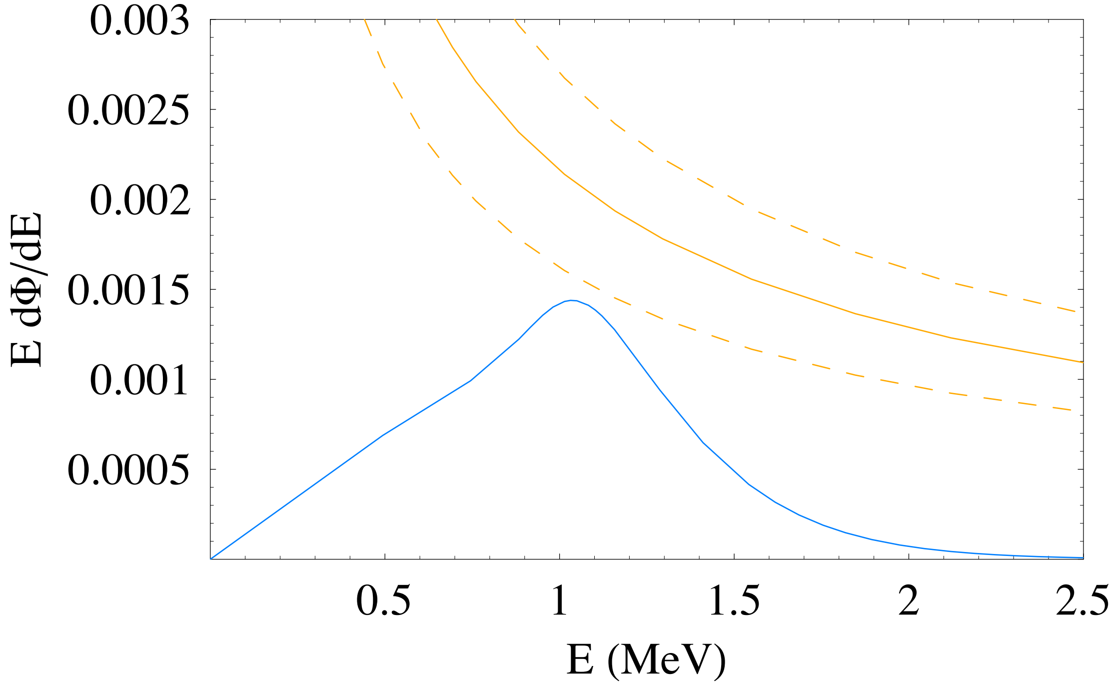



Figure 1: **Gamma ray spectra from primordial BHs with mass $\mathbf{M = 6 \cdot 10^{16}}$ g (blue solid curve) and of the diffuse background (red dashed curve) in $\boldsymbol{\gamma}$ cm$^{-2}$ s$^{-1}$ as a function of energy $\boldsymbol{E}$ in MeV. The number of BHs is normalized by the condition that they produce the observed positron flux.**

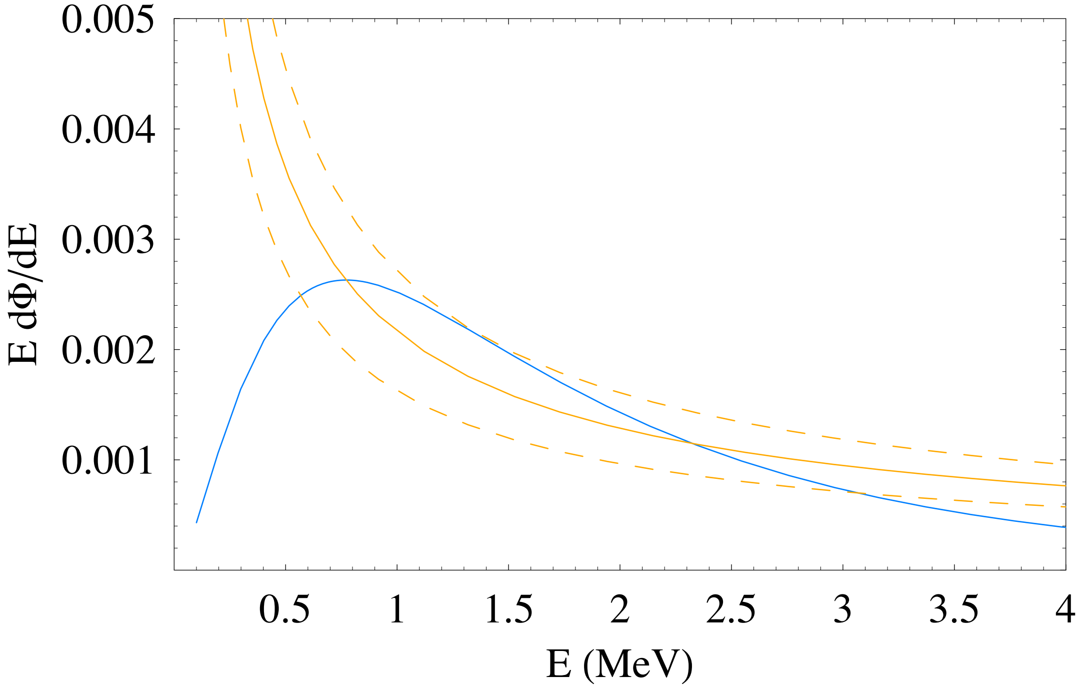



Figure 2: **Gamma ray spectra from primordial BHs (dark–blue solid curve) and of the measured background (light–red solid curve) from the Galactic Bulge in $\gamma$ cm$^{-2}$ s$^{-1}$ as a function of energy $E$ in MeV. The BHs are assumed to have log–normal mass distribution, with the parameters: $\gamma = 1$ and $M_0 = 6 \cdot 10^{16}$ g. The number of BHs is now normalized by the condition that their total mass in the innermost 0.6 kpc is $5 \cdot 10^9\ M_\odot$. The gamma flux from primordial BHs does not exceed the $\pm 25\%$ uncertainty of the measured gamma ray flux (red dashed lines) and can produce enough positrons to explain the 511 keV line.**

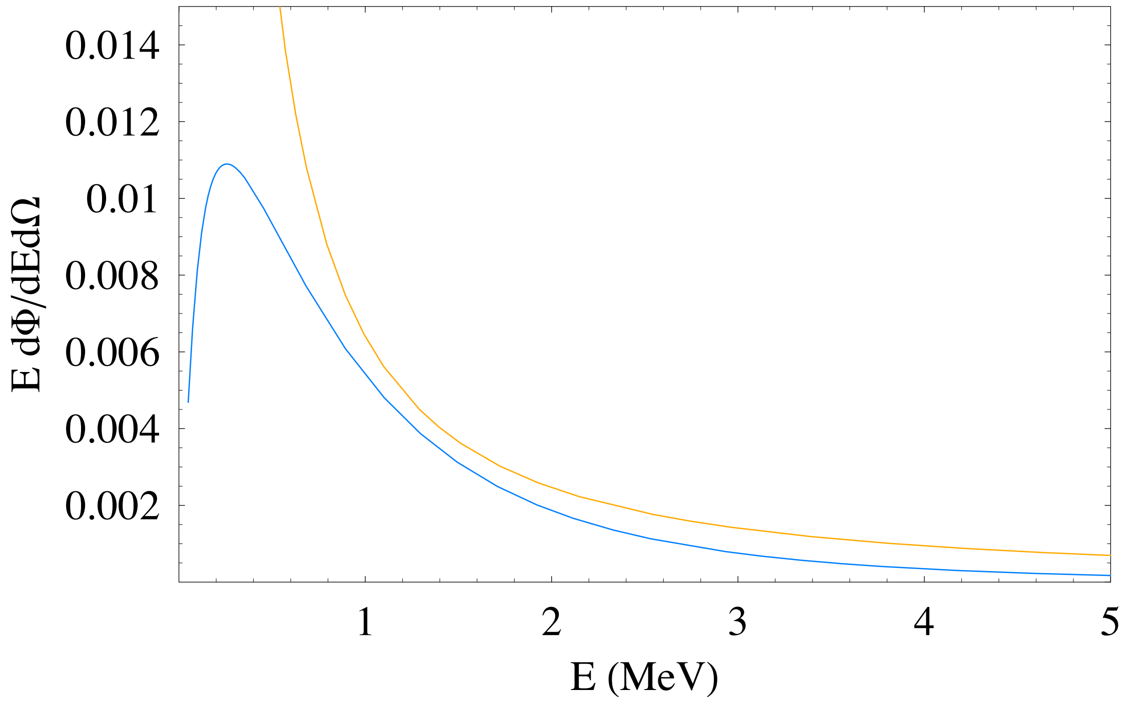



Figure 3: **Cosmic isotropic gamma ray spectra from primordial BHs (dark–blue curve) and of the measured background (light–red curve) in $\gamma$ cm$^{-2}$ s$^{-1}$ sr$^{-1}$ as a function of energy $E$ in MeV. Here we assume that the BHs make the whole cosmological dark matter and have log–normal mass distribution, with the parameters: $\gamma = 1$ and $M_0 = 6 \cdot 10^{16}$ g.**

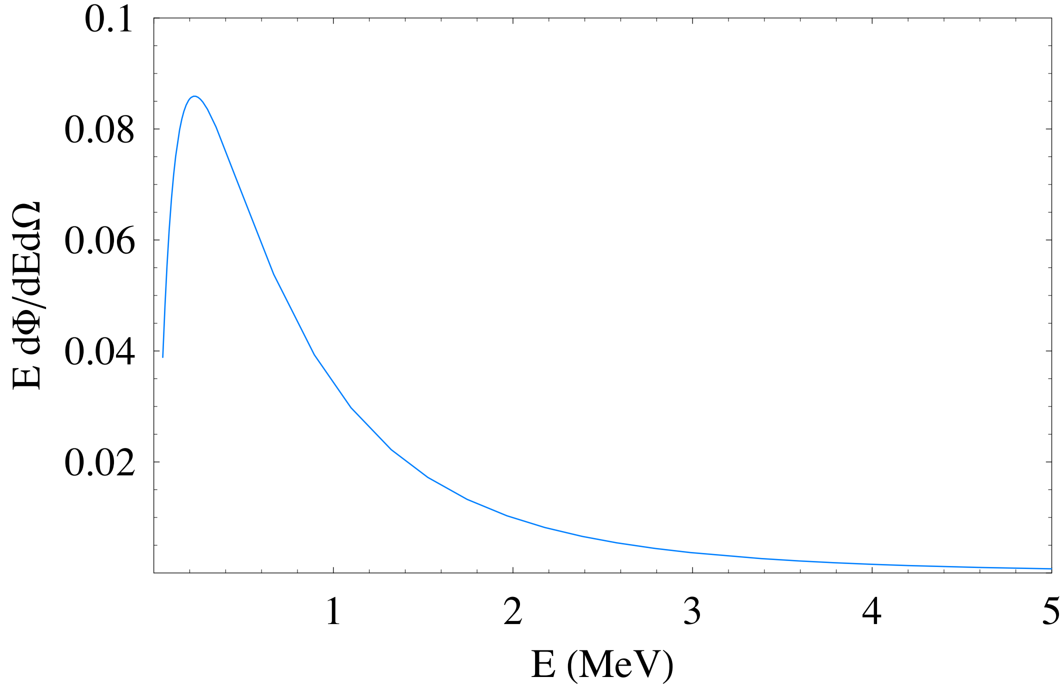
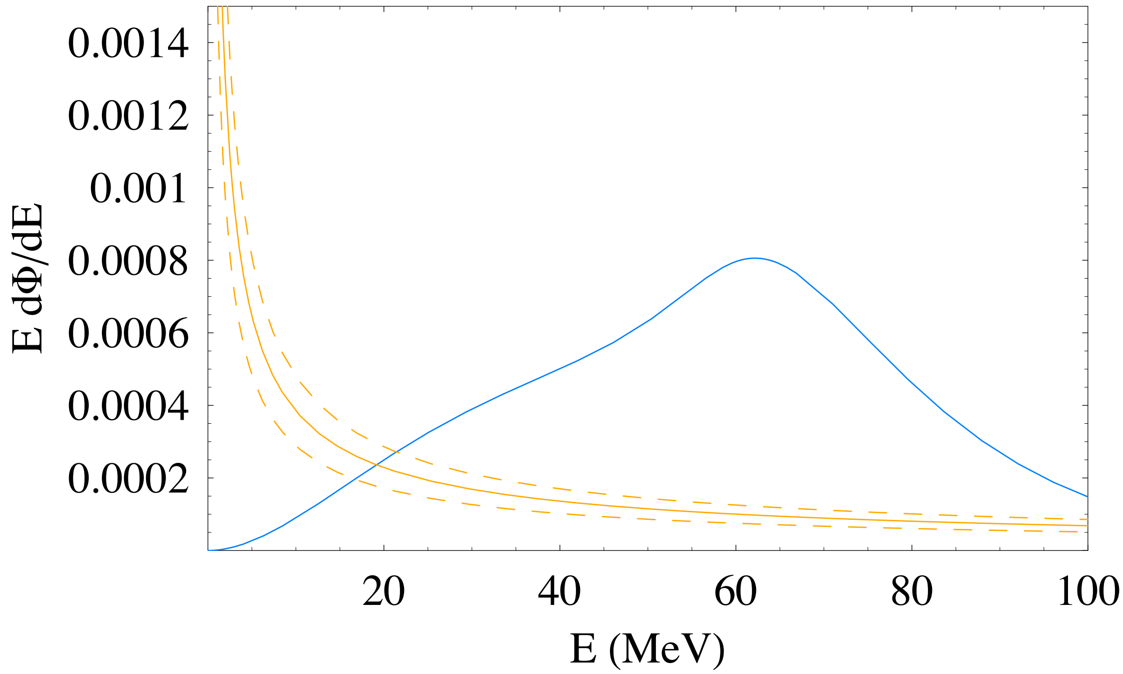
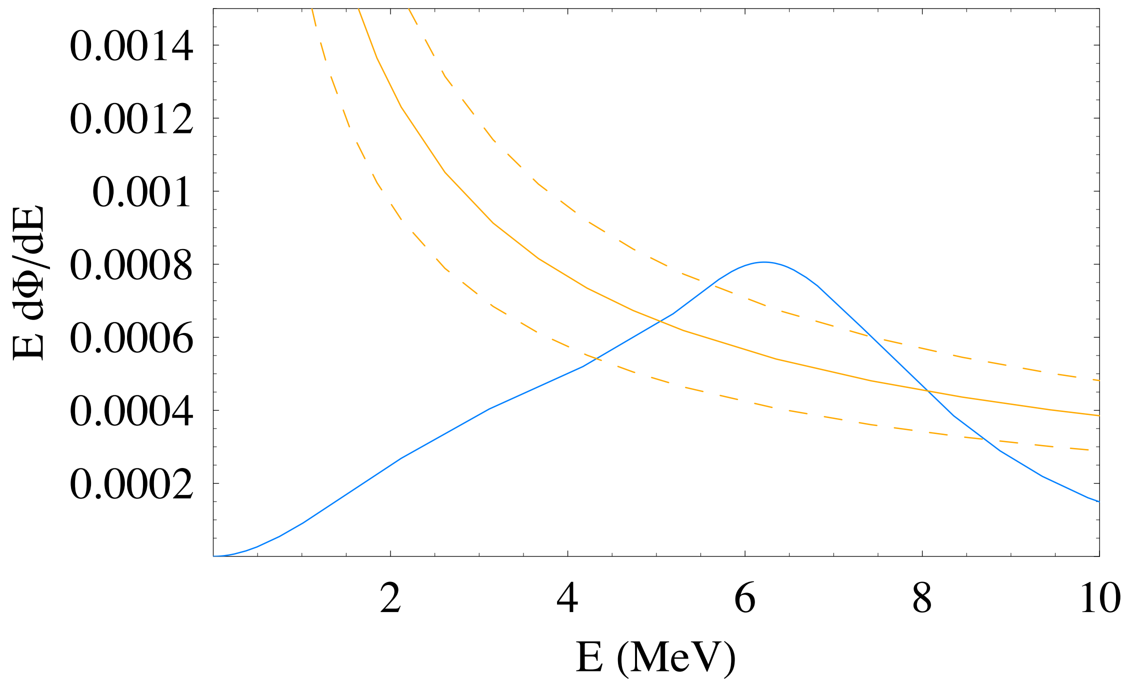


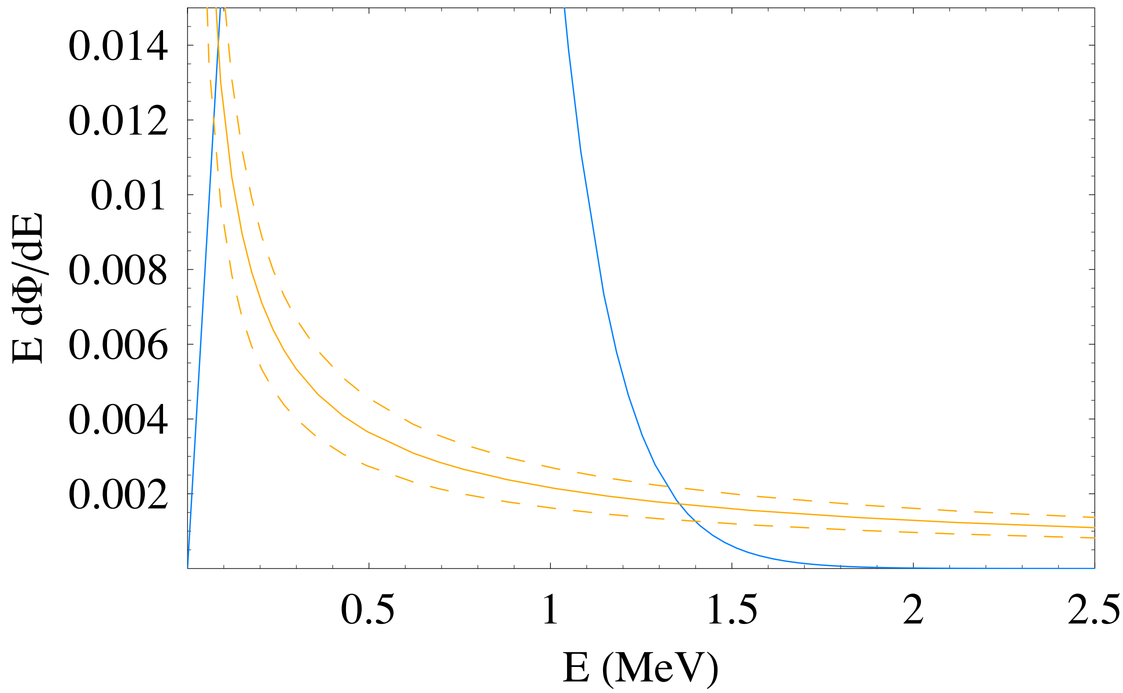

Figure 4: **Diffuse cosmic neutrino spectrum from primordial BHs in $\nu$ cm$^{-2}$ s$^{-1}$ sr$^{-1}$ as a function of energy $E$ in MeV. The assumptions are the same as of Fig. 3.**

**Gamma ray spectra from primordial BHs (dark–blue solid curve) and of the measured background (light–red solid curve) from the Galactic Bulge in $\gamma$ cm$^{-2}$ s$^{-1}$ as a function of energy $E$ in MeV. The BHs are assumed to have all the same mass: $M = 10^{15}$ g, $M = 10^{16}$ g, and $M = 10^{17}$ g. The number of BHs is normalized by the condition that they produce the right amount of positrons to explain the observed 511 keV line. Red dashed lines are the $\pm 25\%$ uncertainty of the measured diffuse gamma flux.**



0.0014
0.0012
0.001
0.0008
0.0006
0.0004
0.0002
E dΦ/dE
20
40
60
80
100
E (MeV)


0.0014
0.0012
0.001
0.0008
0.0006
0.0004
0.0002
E dΦ/dE
2
4
6
8
10
E (MeV)



0.014
0.012
0.01
0.008
0.006
0.004
0.002
E dΦ/dE
0.5
1
1.5
2
2.5
E (MeV)

# PROTON–POSITRON TRANSFORMATION BY SCHWINGER PROCESS AT SCHWARZSCHILD HORIZON.

**Charging of PBH by proton influx up to the critical field and proton-to-positron transformation.** **Flux of p dominates over that of e due to larger mobility of protons and BH (and other celestial) acquire a positive charge.**

**A simple estimate of maximum charge:**

$$\frac{F_{el}}{F_g} = \frac{\alpha Q_{max}\, m_{Pl}^2}{M_{BH} m_p} \sim 1$$

**Electric field on the surface,**
$r = r_g = 2M/m_{pl}^2$:

$$E_{max} = \frac{\alpha Q_{max}}{r_g^2} \approx \frac{10^{20}\, g}{M_{BH}}\, MeV^2$$

**The pair production probability per unit time and volume is**

$$W = \frac{m_e^4}{\pi^2}\left(\frac{E}{E_c}\right)^2 \sum_{n=1}^{\infty} \frac{1}{n^2}\, exp\left(-\frac{n\sqrt{\pi}E_c}{2E}\right),$$

**where** $E_c = m_e^2/e$.

$$
\begin{aligned}
\dot{v}_p \;=\; & -\frac{G_N M}{r^2} + \frac{\alpha Q}{r^2 m_p} + \frac{L\,\sigma_{\gamma p}}{4\pi r^2 m_p} \\
& - \frac{\sigma_{\gamma p} n_\gamma \omega_\gamma}{m_p} v_p - \frac{n_p \sigma_{pe} P}{m_p}(v_p - v_e)\,, \\
\dot{v}_e \;=\; & -\frac{G_N M}{r^2} - \frac{\alpha Q}{r^2 m_e} + \frac{L\,\sigma_{\gamma e}}{4\pi r^2 m_e} \\
& - \frac{\sigma_{\gamma e} n_\gamma \omega_\gamma}{m_e} v_e + \frac{n_e \sigma_{pe} P}{m_e}(v_p - v_e).
\end{aligned}
$$

**$P$ is momentum transfer from $e$ to $p$.**

The accumulated electric charge at equilibrium is

$$\alpha Q \approx \frac{r_g m_p}{4K^{1/4}} \left(T_e/T_p\right)^{3/4} \sqrt{\frac{\ln(\lambda_p/r_g)}{\ln(\lambda_e/r_g)}}$$

Where $K = m_p/m_e \gg 1$.

For $T_p = T_e$: $\alpha Q \approx 0.1\, m_p r_g$,
while $\alpha Q_{max} \approx m_p r_g/2$

The equilibrium electric field at horizon is

$$E = \frac{\alpha Q}{r_g^2} \approx 0.15 \frac{m_p}{r_g}$$

and the ratio $E_c/E$ is

$$\frac{E_c}{E} = 0.6 \left( \frac{M}{10^{20}\ g} \right) .$$

**The accretion rate of protons per second per BH:**

$$\dot{N}_p \approx 10^{16} \frac{n_p}{10^{10}/\mathrm{cm}^3} \left(\frac{r_g}{10^{-8}\mathrm{cm}}\right)^2 \left(\frac{1\ \mathrm{keV}}{T_p}\right)^{3/2} \left[\frac{\ln(\lambda_p/r_g)}{70}\right] \mathrm{s}^{-1}$$

**The energy of positrons is about** $\alpha Q/r_g \approx 0.15\, m_p \approx 140\ \mathrm{MeV}$.

**For accreting heavy nuclei, the positron energy may reach 100 GeV.**

**Subsequent acceleration by Fermi mechanism?**

**The mechanism can operate in the neighborhood of the super–massive BH in the Galactic Center. There is an ionized medium with the temperature of roughly 1 keV and the particle number density of the order of $10^8$ cm$^{-3}$ in the sphere with the radius $\sim 10^{16}$ cm around the central BH.**

**A more favorable environment is the hot and dense atmosphere around accreting compact stars: here the temperature of the plasma can reach 10 keV and the particle number density can be as high as $10^{20}$ cm$^{-3}$, as occurs in the accretion disk of the X-ray source known as Cygnus X-1.**