General constraints on sources of UHECRs Updated Hillas diagrams

International Conference on Particle Physics and Cosmology dedicated to memory of Valery Rubakov

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Constraints

- Geometrical criterion (The Hillas criterion) [1]

  A particle must not leave the accelerator region until it has gained the required energy

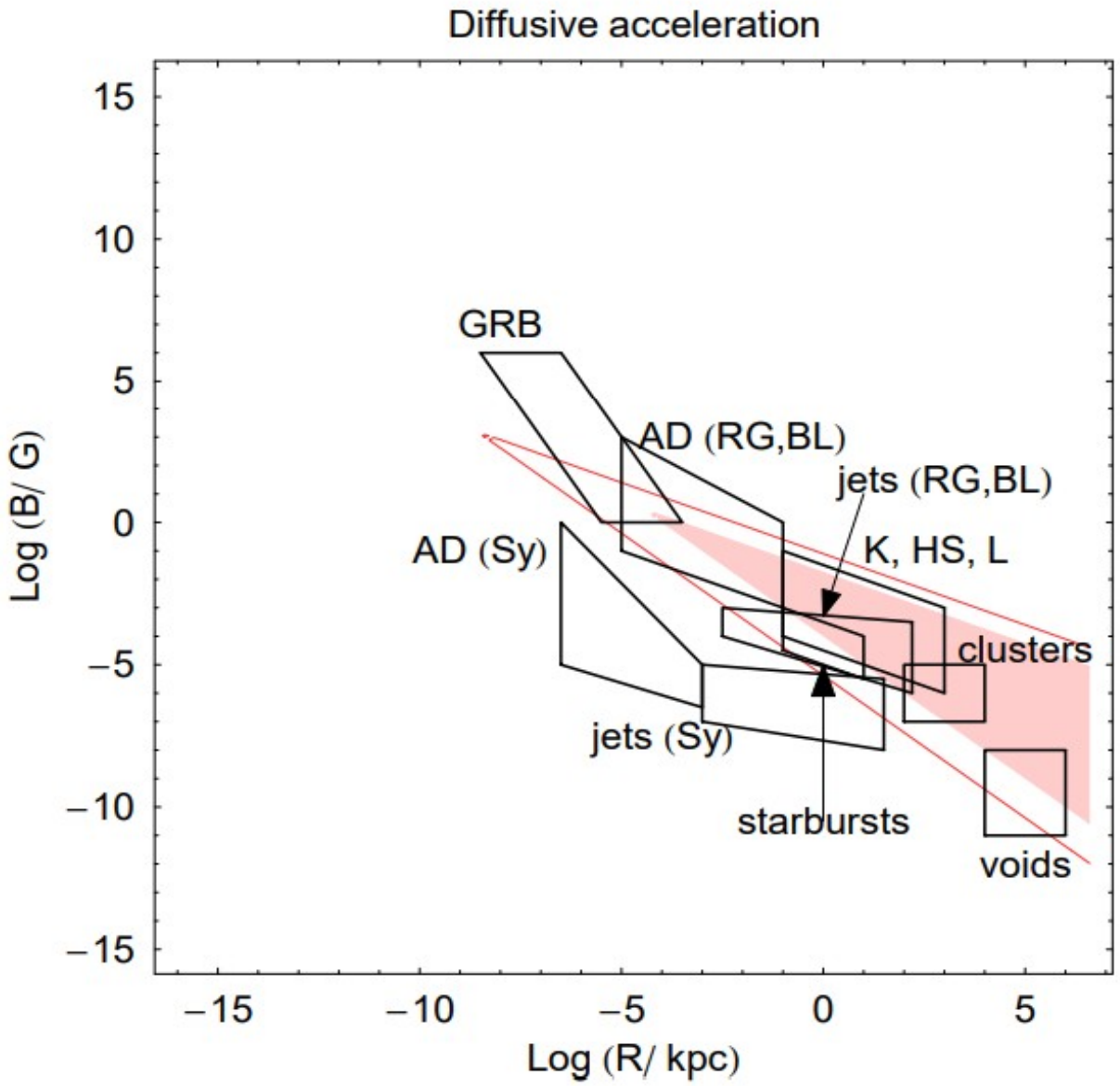
- Radiation losses [2]

  A particle radiates energy during movement in a source magnetic field

[1] A. M. Hillas, Ann. Rev. Astron. Astrophys. 22, 425 (1984).

[2] M. V. Medvedev, Phys. Rev. E 67, 045401 (2003)

An example the Hillas diagram [3]



[3]: K. V. Ptitsyna and S. V. Troitsky, Phys. Usp. 53, 691 (2010)

Constraints

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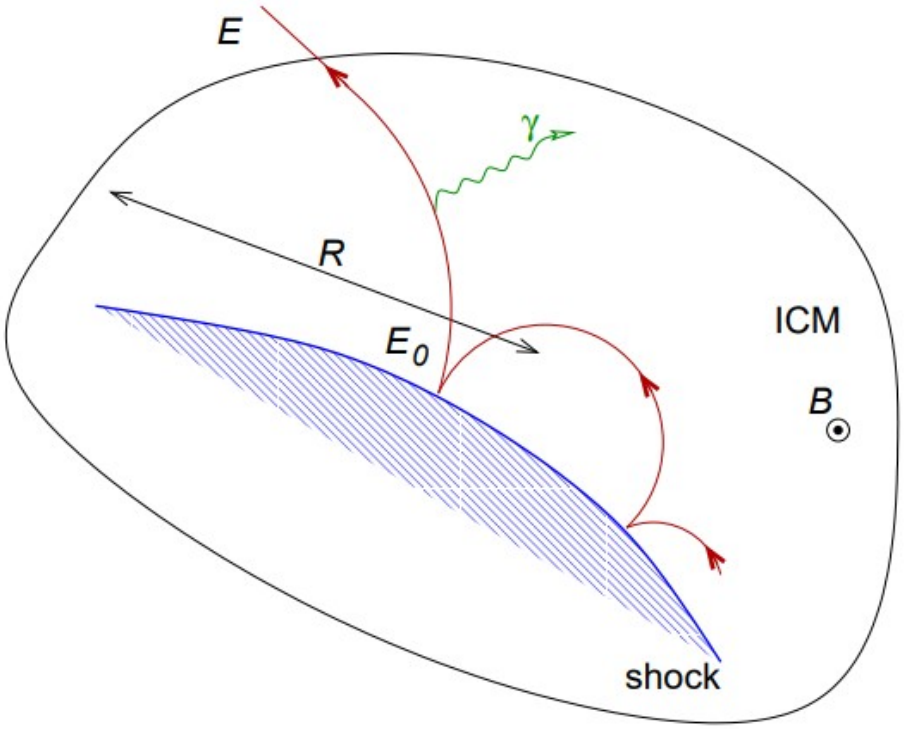
- Interaction losses (This work)

  Losses associated with interactions in a source medium

[1] A. M. Hillas, Ann. Rev. Astron. Astrophys. 22, 425 (1984).
[2] M. V. Medvedev, Phys. Rev. E 67, 045401 (2003)

Acceleration model



A particle moves inside the accelerator and from time to time receives a portion of energy as a result of interaction with a shock.

For more details see [2]

Radiation losses

Expression for synchrotron losses for a proton moving in an astrophysical source with a magnetic field **B**

$$-\frac{dE_{rad}}{dt} = \frac{2}{3}\frac{q^4}{m_p^4}E^2B^2 = D\left(\frac{E}{\mathrm{eV}}\right)^2\left(\frac{B}{\mathrm{G}}\right)^2 \mathrm{eV/s}$$

Interaction losses

In this work only photohadronic and photopair processes are considered:

$$p + \gamma \rightarrow \Delta^{+} \rightarrow \begin{cases} n + \pi^{+} \\ p + \pi^{0} \end{cases}$$

$$p + \gamma \rightarrow p + e^{-} + e^{+}$$

Power-law case

Photohadronic losses

$$-K_1 \left(\frac{E}{\mathrm{eV}}\right)^2 \left(\frac{R}{\mathrm{kpc}}\right)^{-2} \left(\frac{L_{\geq\omega}}{\mathrm{eV/s}}\right) \mathrm{eV/s}, \quad \alpha > 2$$

$$K_1 = (\alpha-2)/(\alpha^2-1) \cdot 10^{-89}$$

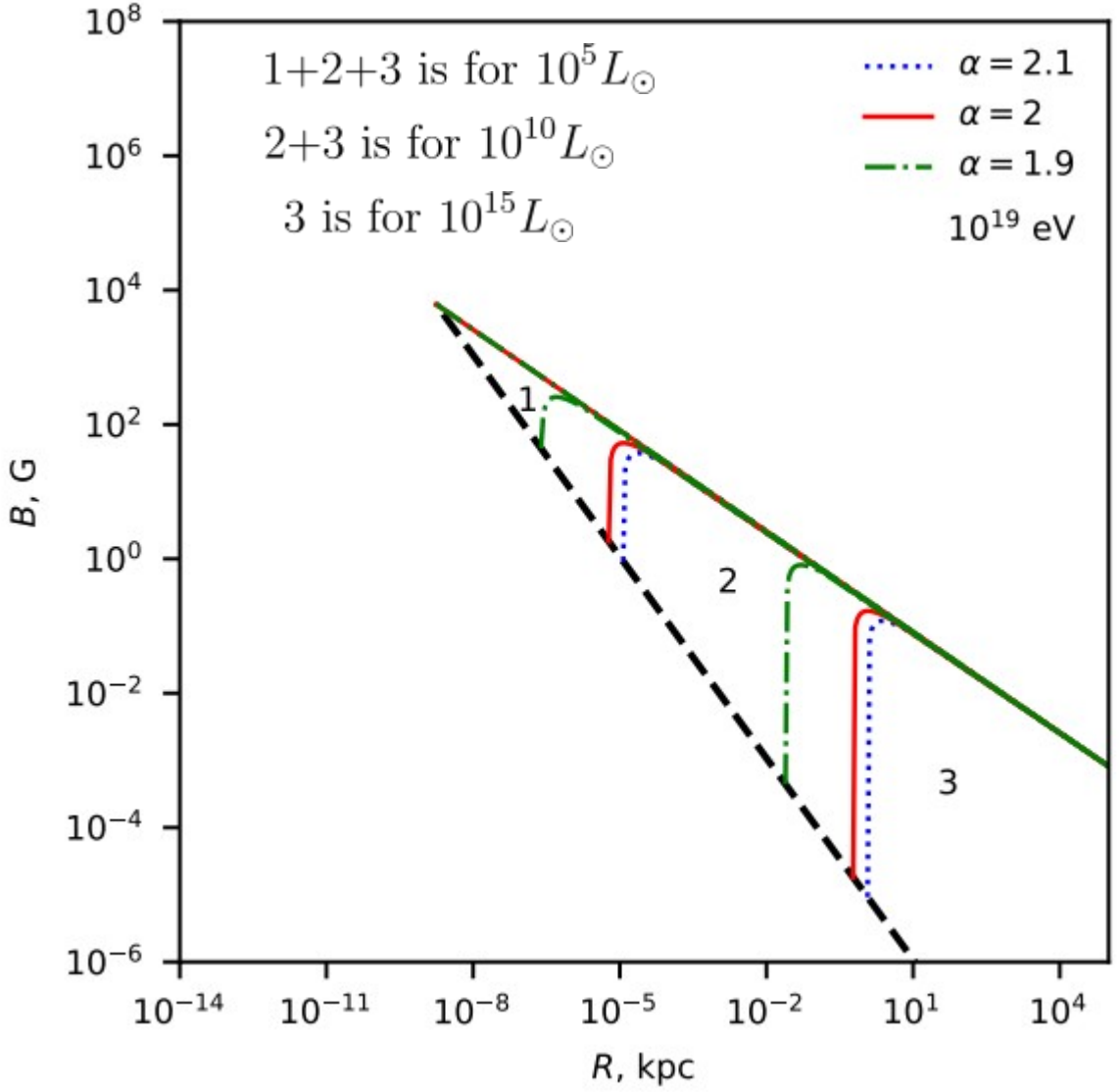
Photopair losses

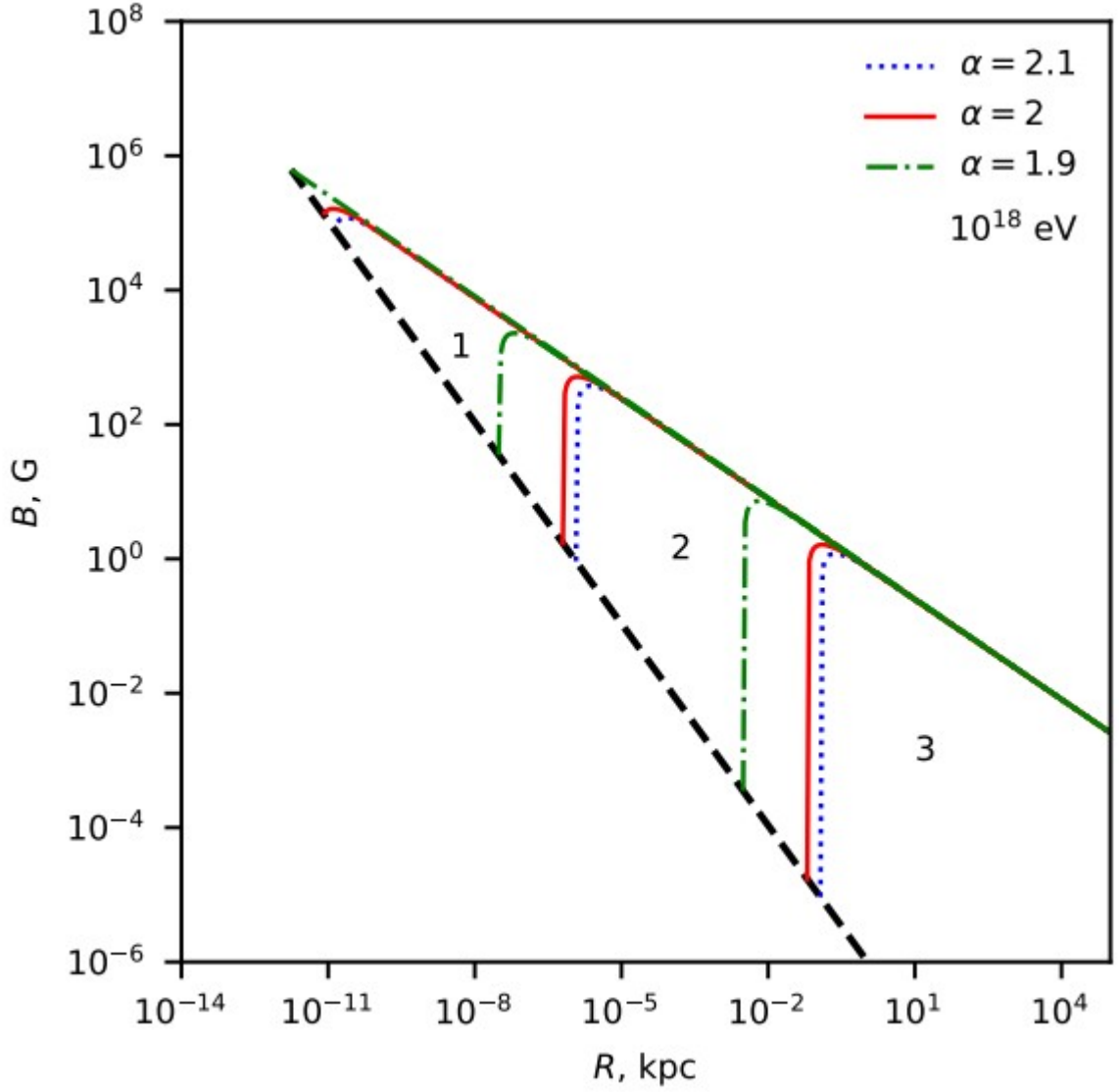
$$-C_1 \left(\frac{E}{\mathrm{eV}}\right)^2 \left(\frac{R}{\mathrm{kpc}}\right)^{-2} \left(\frac{L_{\geq\omega}}{\mathrm{eV/s}}\right) \mathrm{eV/s}, \quad \alpha > 2,$$

$$C_1 = 10^{-89}(\alpha-2)\epsilon_{\mathrm{thr}}^{\alpha-2} I(2)$$

$$I(\alpha) = \int_2^\infty \frac{\epsilon^{-\alpha}\varphi(\epsilon)}{\epsilon^2} d\epsilon$$

Power-law case



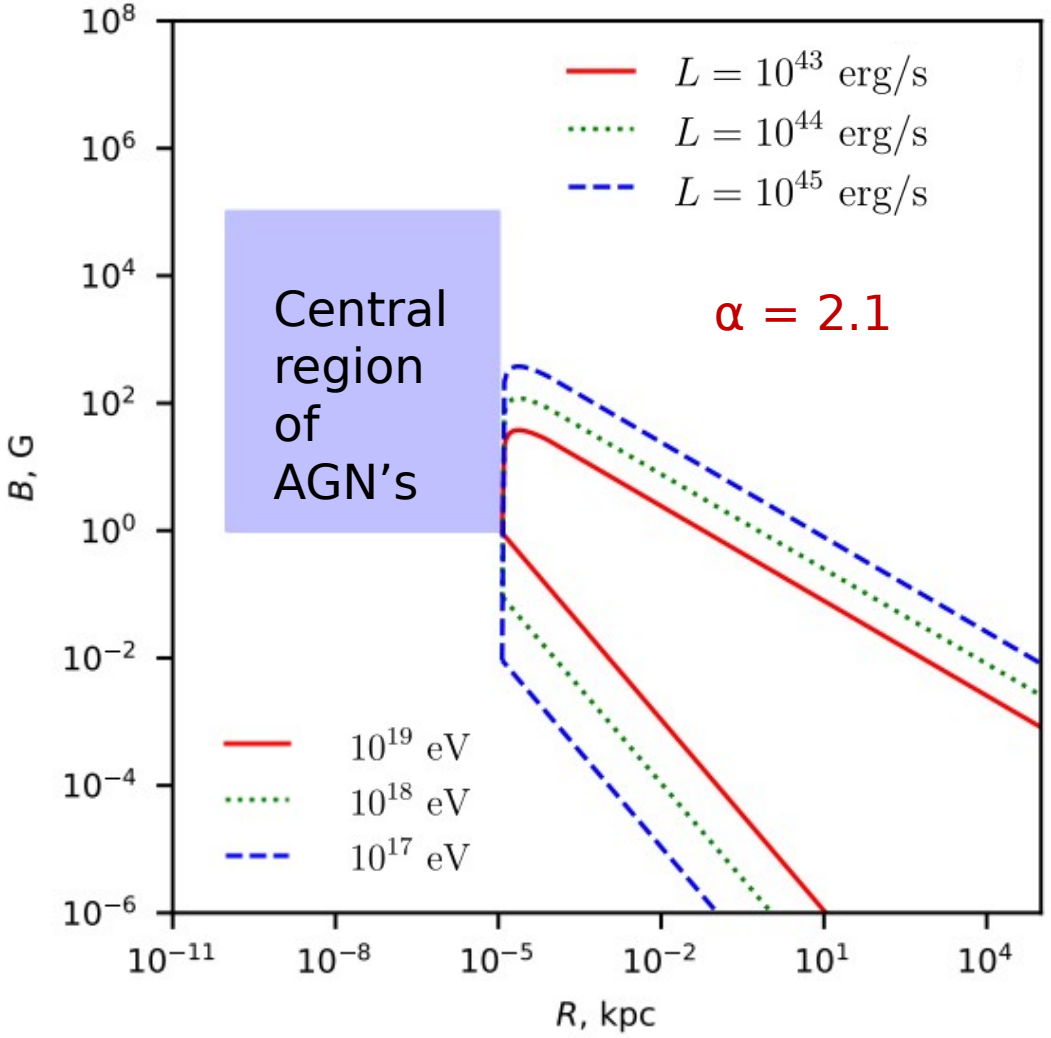


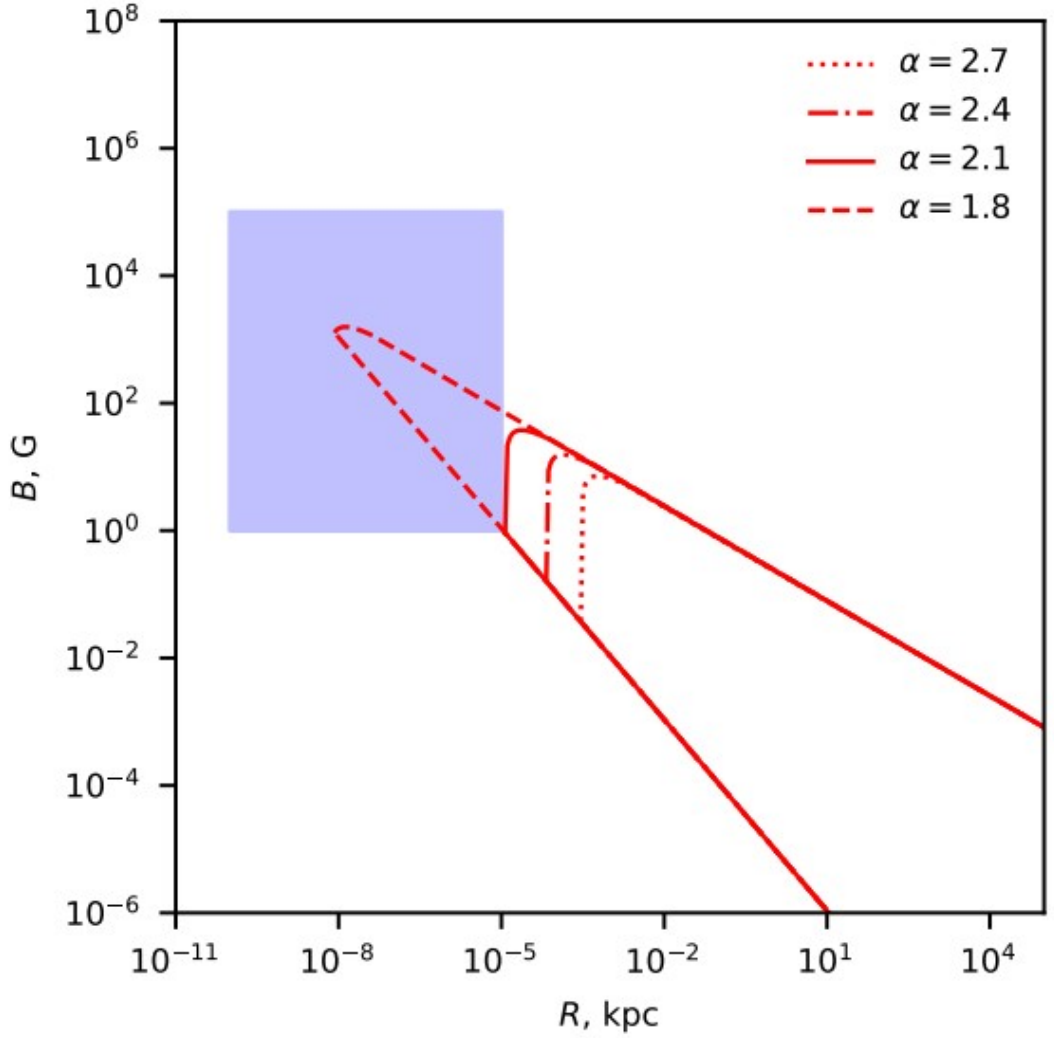
Location of central regions of AGN's

$$R \sim 5R_s \approx 5 \times 10^{-8} \, \frac{M_{\rm BH}}{10^8 M_\odot} \, {\rm kpc}$$

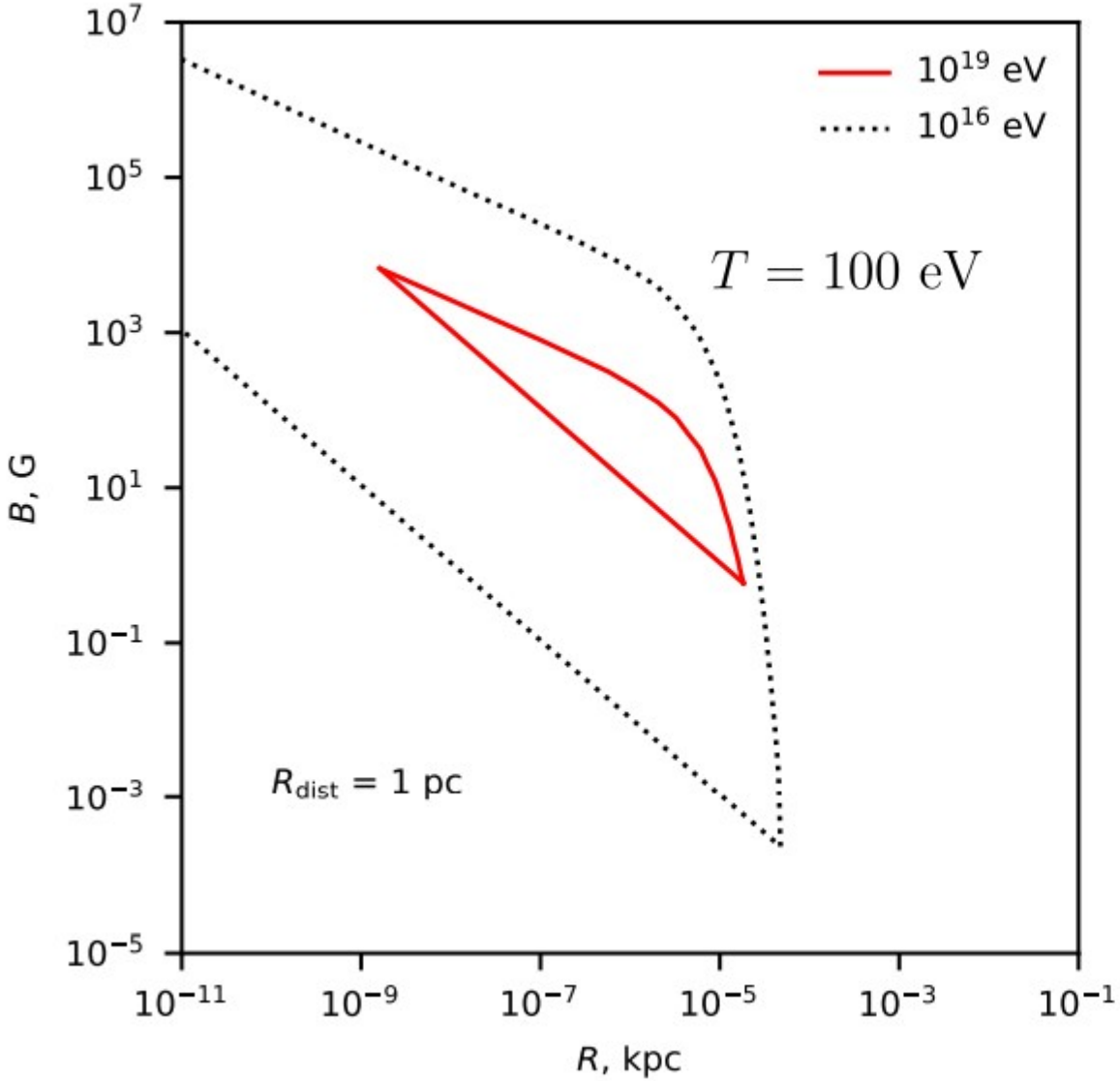
$$B_{\rm BH} \sim 10^8 \left(\frac{M_{\rm BH}}{M_\odot} \right)^{-0.5} \, {\rm G}$$

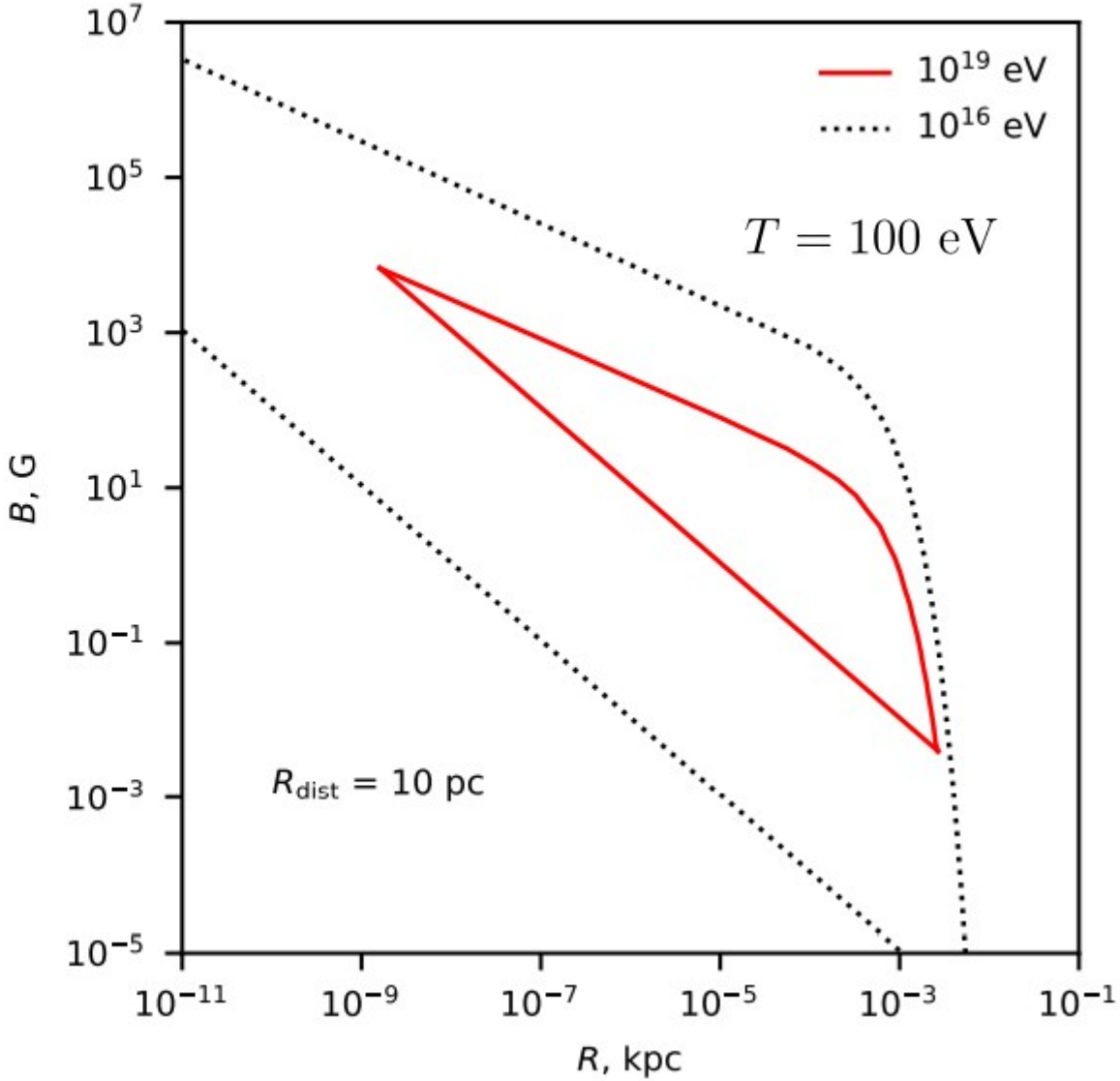
Power-law case



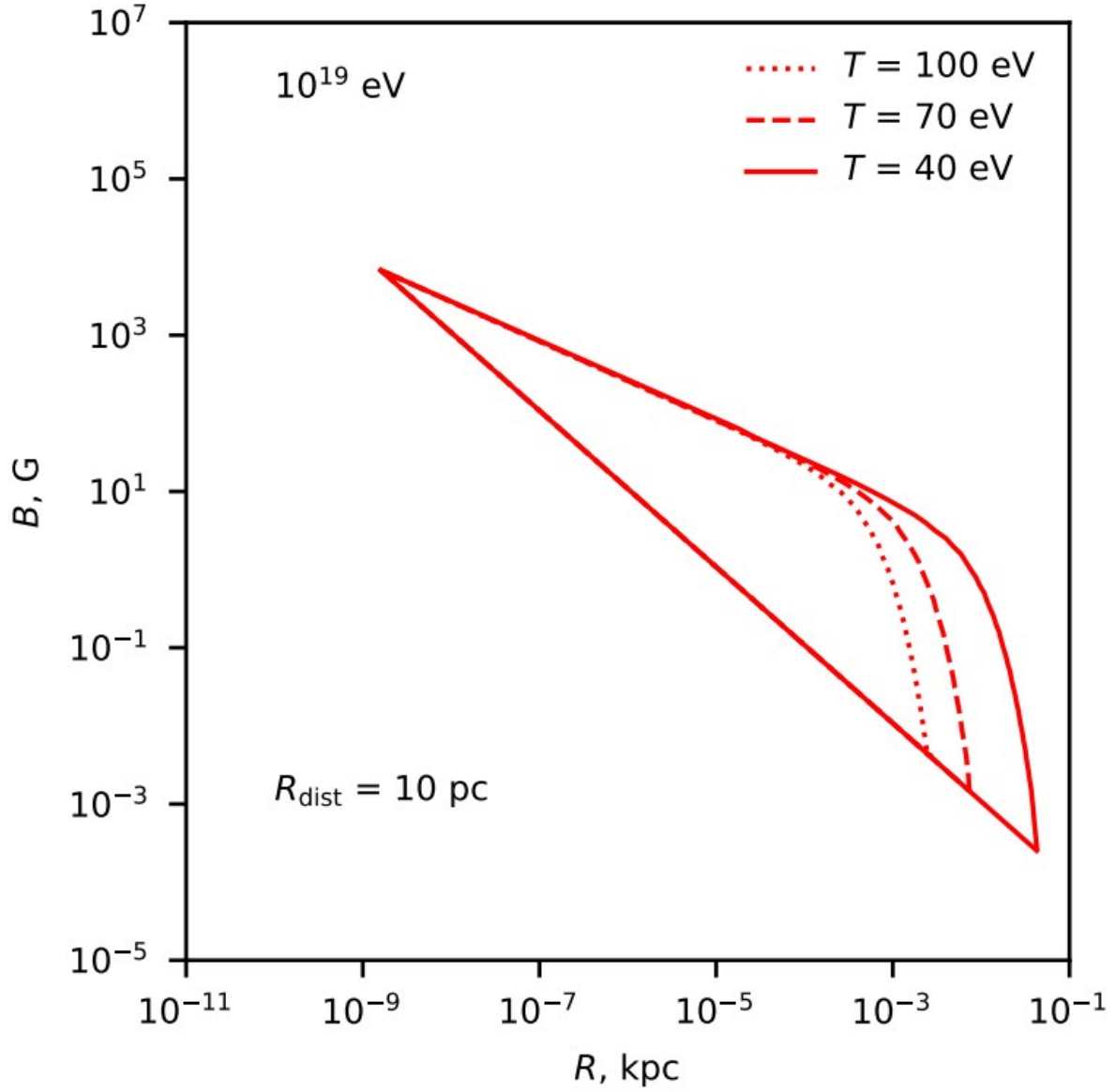


Thermal radiation case





Thermal radiation case



Conclusions

- A constraint was added to the Hillas diagram associated with the interaction of protons with source photons

- A class of central regions of AGNs which can not accelerate protons was singled out assuming power-law (and thermal) radiation field and diffuse acceleration mechanism.

- In our model of diffuse acceleration In the case of thermal radiation field, it was also possible to narrow down the search area for high-energy proton accelerators (jets) .

For more details see Phys.Rev.D 107 (2023) 12, 123018 e-Print: 2212.03483