The problematic connection between GRBs and UHECR

Cosmic Explosions, 2019 06 04

Filip Samuelsson, Damien Bégué, Felix Ryde, & Asaf Pe’er

Samuelsson et al. (2019), ApJ, 876, 93

Introduction

- Ultra High Energy Cosmic Ray (UHECR): $E \geq 10^{18}$ eV
- Prompt phase of gamma-ray bursts (GRBs) have been proposed accelerators
- High-luminosity GRBs vs low-luminosity GRBs

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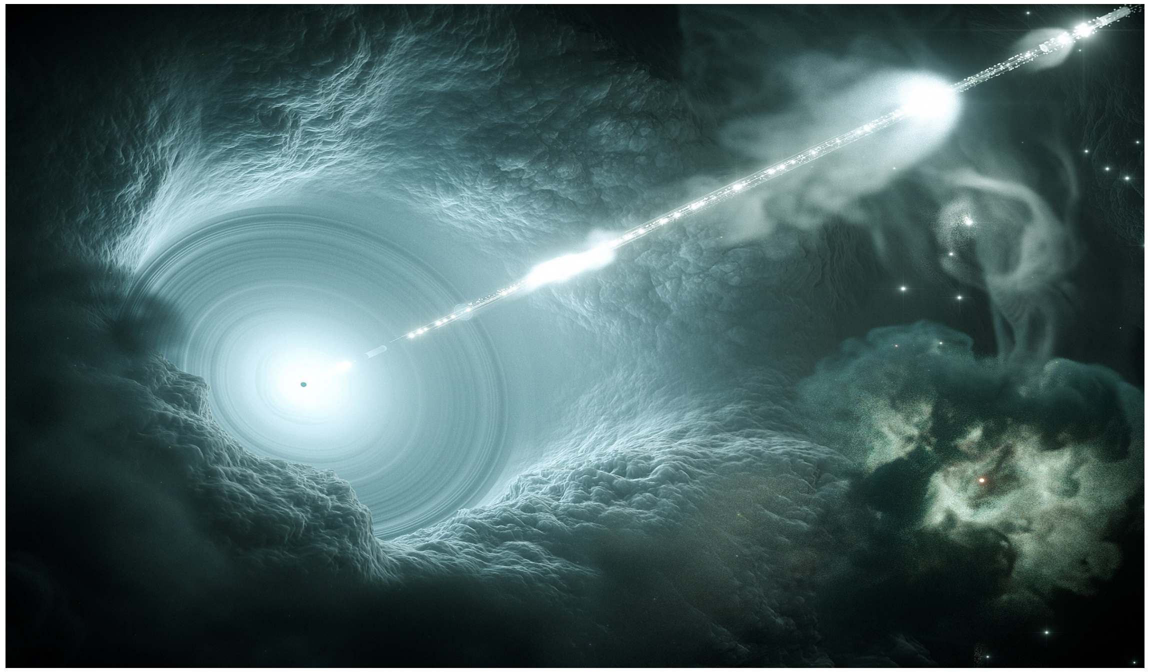

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Introduction

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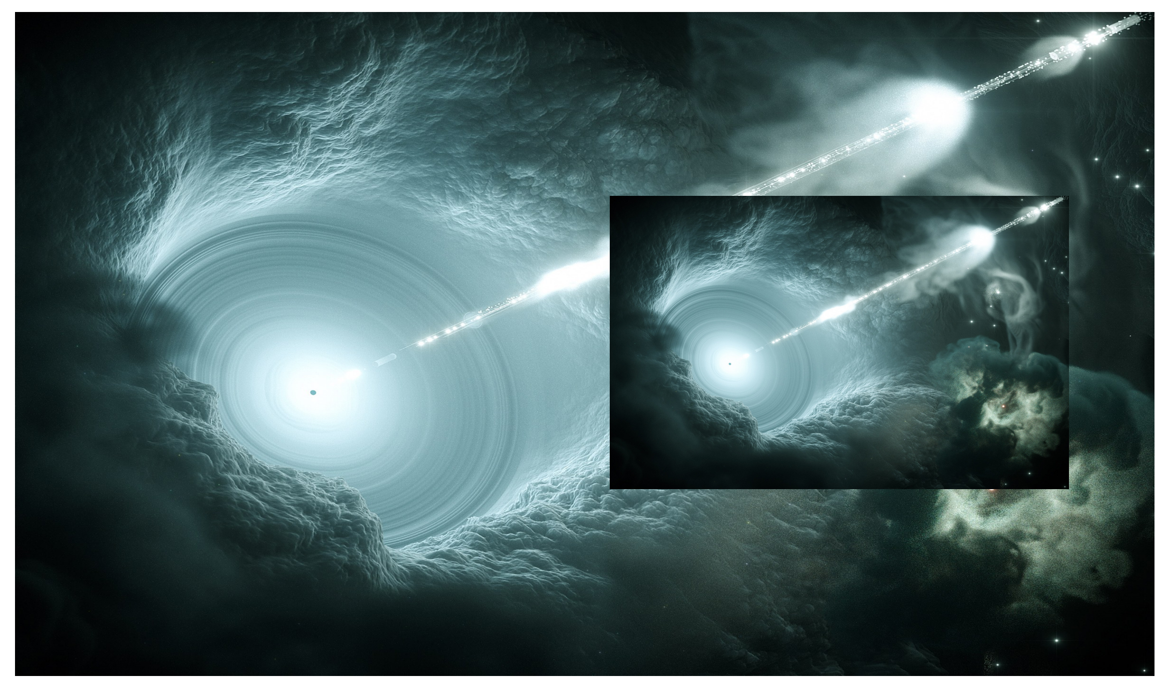

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Idea

- If cosmic-rays (CR) are accelerated, so are electrons
- Electrons in magnetic fields radiate
- Is this radiation compatible with observations?

Method

- Requirement of UHECR
- Conditions on magnetic field
- Determine the synchrotron spectrum for electrons in this magnetic field
- Compare it with observations

- Magnetic field
- Spectrum
- Results and conclusion

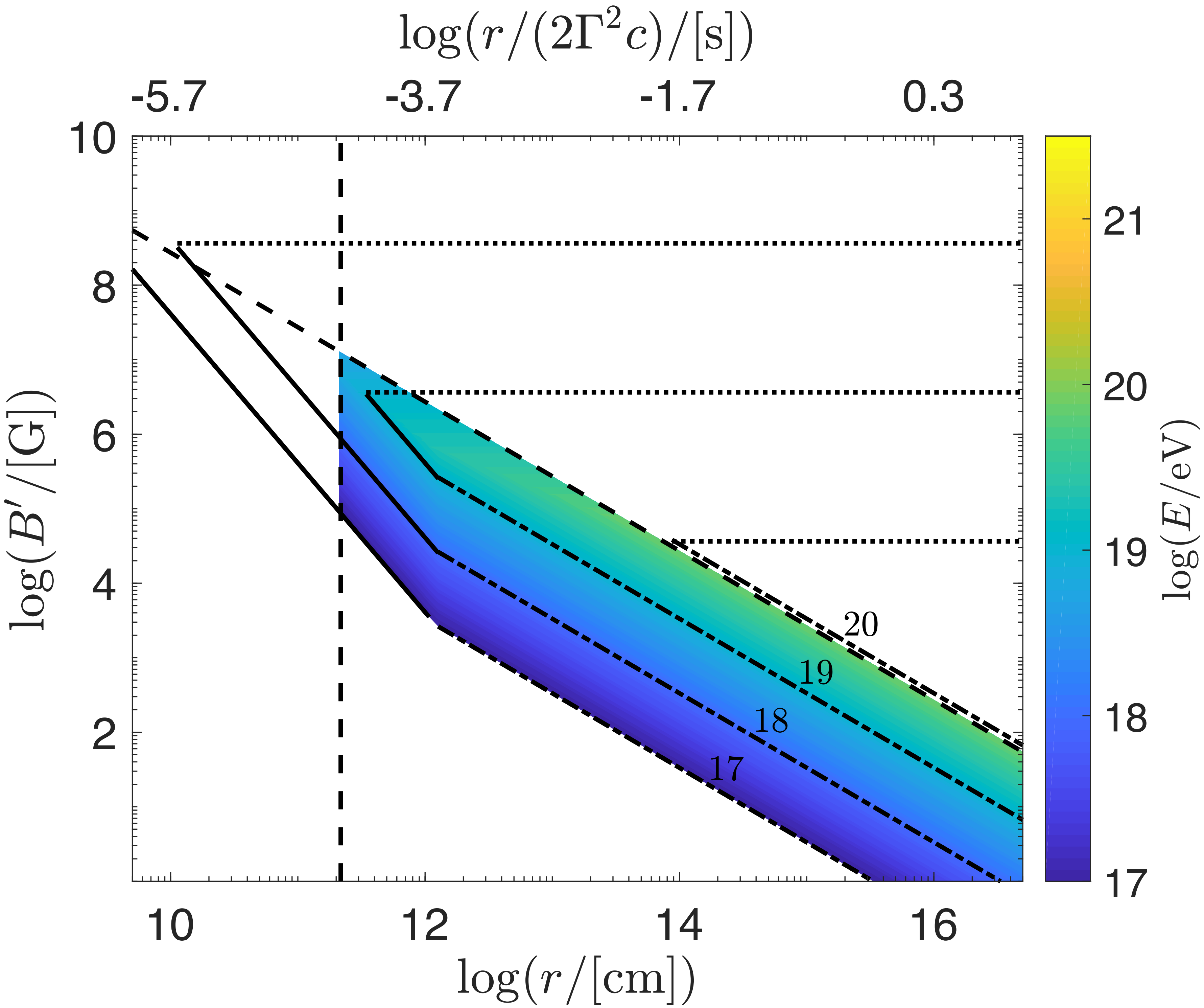
Constraints

- Acceleration time scale shorter than cooling time scales

$$t'_{\mathrm{acc},i}(E) < \min[t'_{\mathrm{sync},i}(E),\, t'_{\mathrm{ad}},\, t'_{p\gamma}]$$

- Magnetic luminosity cannot be larger than total luminosity

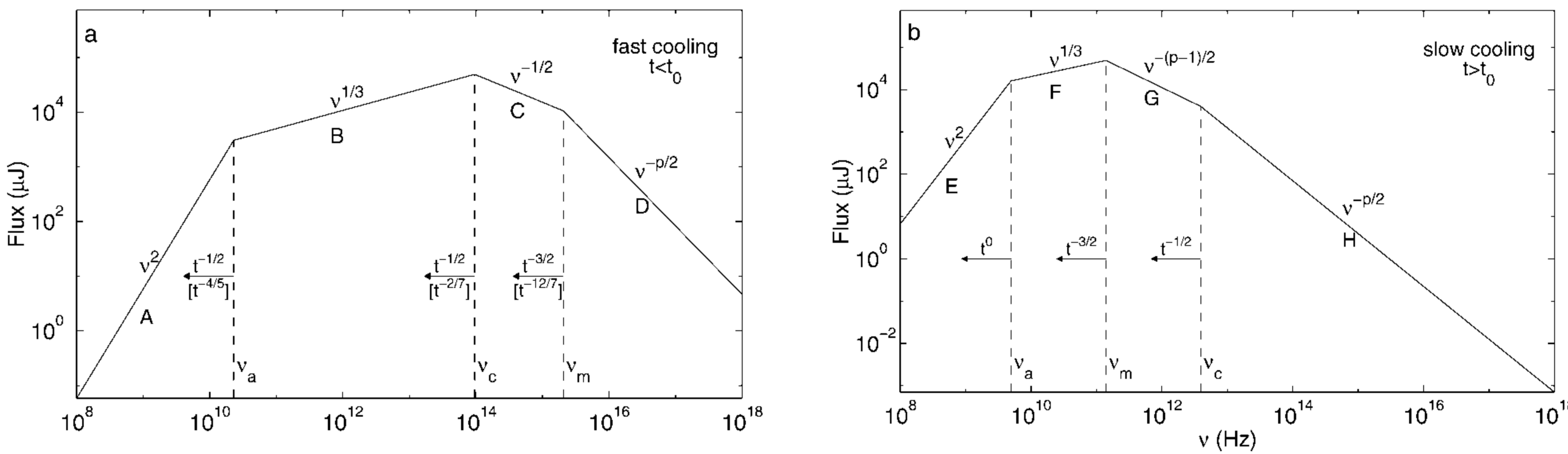
Proton in high-luminosity GRB with $\Gamma = 300$



- Magnetic field
- Spectrum
- Results and conclusion

Synchrotron spectrum

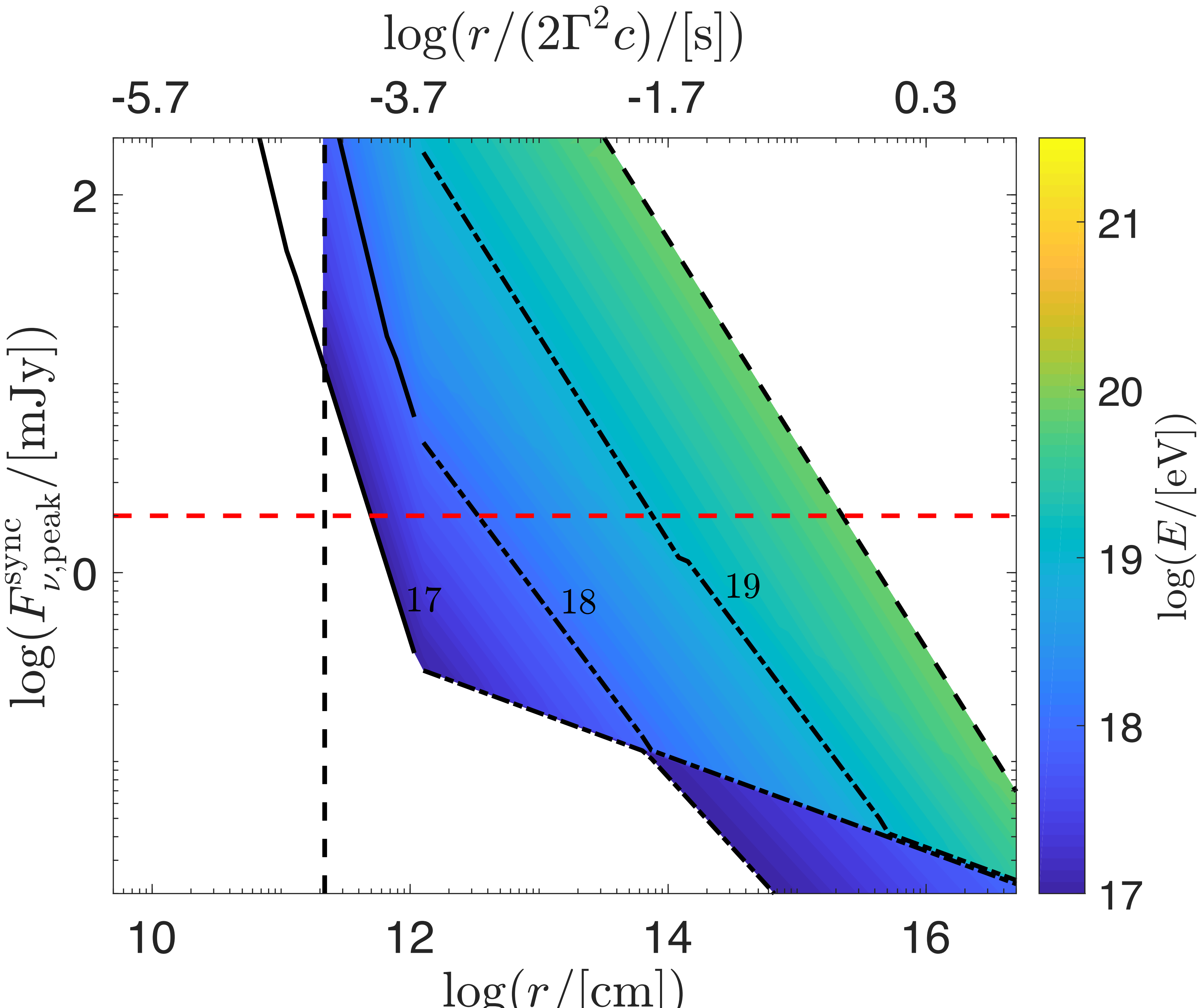
- The spectrum is a function of B' and r
- You can calculate the flux in any band you want



Sari, Piran, Narayan (1998), ApJL, 497, L17

- Magnetic field
- Spectrum
- Results & conclusion

Proton in high-luminosity GRB with $\Gamma = 300$



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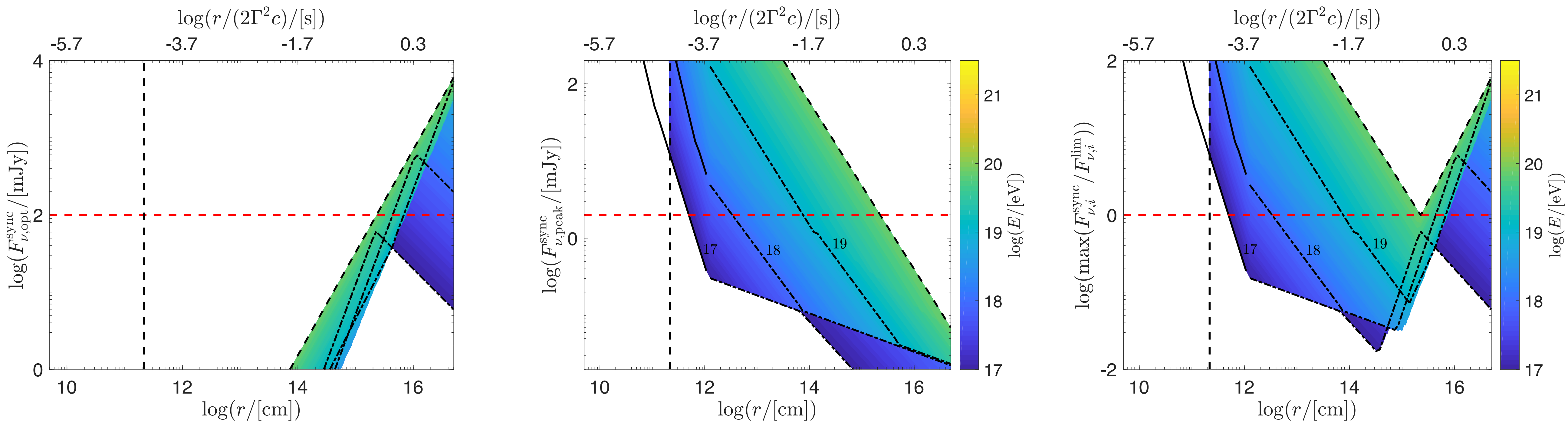
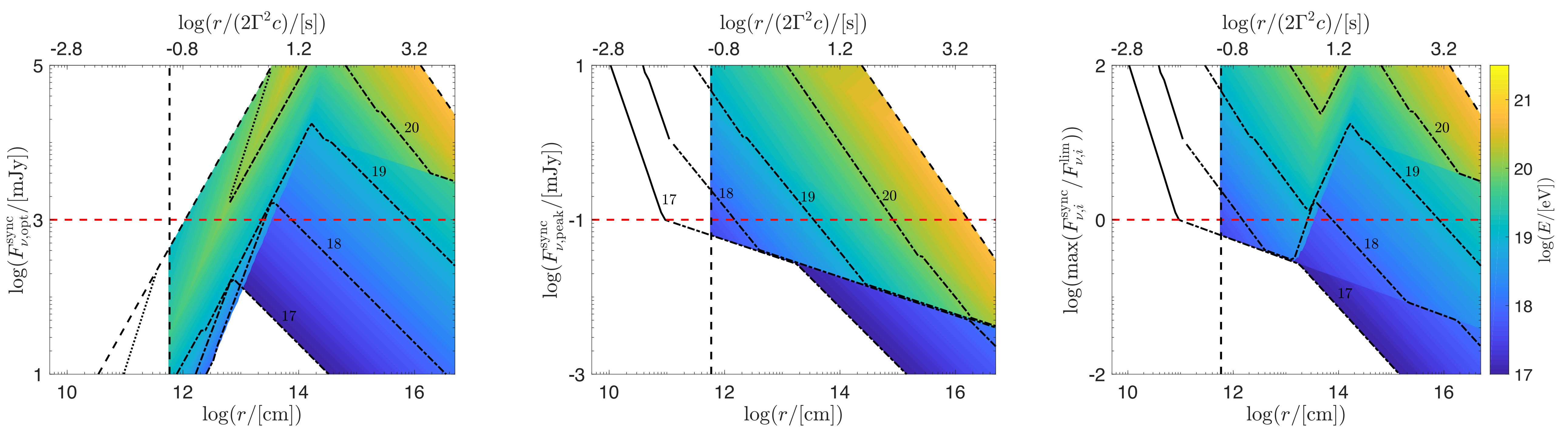


Iron in low-luminosity GRB with $\Gamma = 10$



Conclusion

- UHECR acceleration in GRBs is problematic because it would necessarily result in very high fluxes, especially in optical, which is not observed
- Thank you

Relevant time scales

- Acceleration time scale shorter than cooling time scales

$$t'_{\mathrm{acc},i}(E) < \min[t'_{\mathrm{sync},i}(E),\ t'_{\mathrm{ad}},\ t'_{p\gamma}]$$

- Acceleration time scale $$t'_{\mathrm{acc},i} = \frac{E}{\eta c Z_i e B' \Gamma}$$
- Synchrotron time scale $$t'_{\mathrm{sync},i} = \frac{6\pi}{Z_i^4 \sigma_{\mathrm{T}}} \frac{(m_i c^2)^2}{c} \left(\frac{m_i}{m_e}\right)^2 \frac{1}{(E/\Gamma) B'^2}$$
- Adiabatic time scale $$t'_{\mathrm{ad}} = \frac{r}{c\Gamma}$$
- Photohadronic time scale $$t'_{p\gamma} = \frac{10}{\sigma_{p\gamma} n'_\gamma c}$$
- (Larmor radius) $$R'_{\mathrm{L},i} = \frac{E}{Z_i e \Gamma B'}$$

Conditions

$$t'_{\mathrm{acc},i} < t'_{\mathrm{sync},i} \quad \longrightarrow \quad B'_i < \frac{6\pi}{Z_i^3 \sigma_\mathrm{T}} \frac{(m_i c^2)^2}{\left(m_e/m_i\right)^2} \frac{\eta e}{\left(E/\Gamma\right)^2}$$

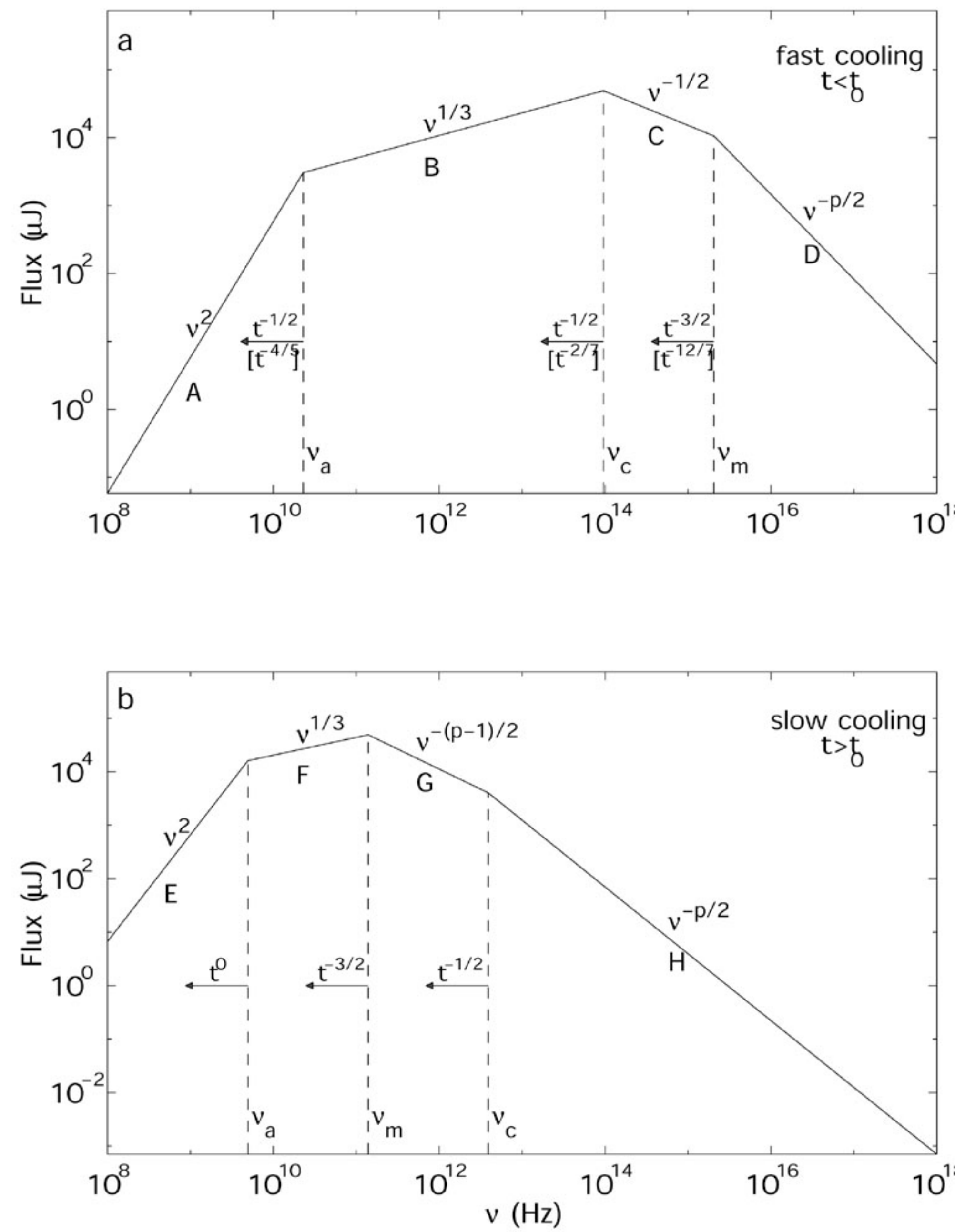
$$t'_{\mathrm{acc},i} < t'_{\mathrm{ad}} \quad \longrightarrow \quad B'_i > \frac{E}{\eta Z_i e r}$$

$$t'_{\mathrm{acc},i} < t'_{p\gamma} \quad \longrightarrow \quad B'_i > \frac{\sigma_{p\gamma}}{20\pi Z_i e c} \frac{E L_\gamma}{\eta \left\langle \varepsilon \right\rangle r^2 \Gamma^2}$$

$$R'_{\mathrm{L},i} < \frac{r}{\Gamma} \quad \longrightarrow \quad B'_i > \frac{E}{Z_i e r}$$

Synchrotron spectrum

- Shape is well determined but depends on the relative position of $\gamma'_{\rm m}$, $\gamma'_{\rm c}$, $\gamma'_{\rm SSA}$
- $\gamma'_{\rm m}$: minimum electron Lorentz factor
- $\gamma'_{\rm c}$: cooling break Lorentz factor
- $\gamma'_{\rm SSA}$: Synchrotron self-absorption Lorentz factor



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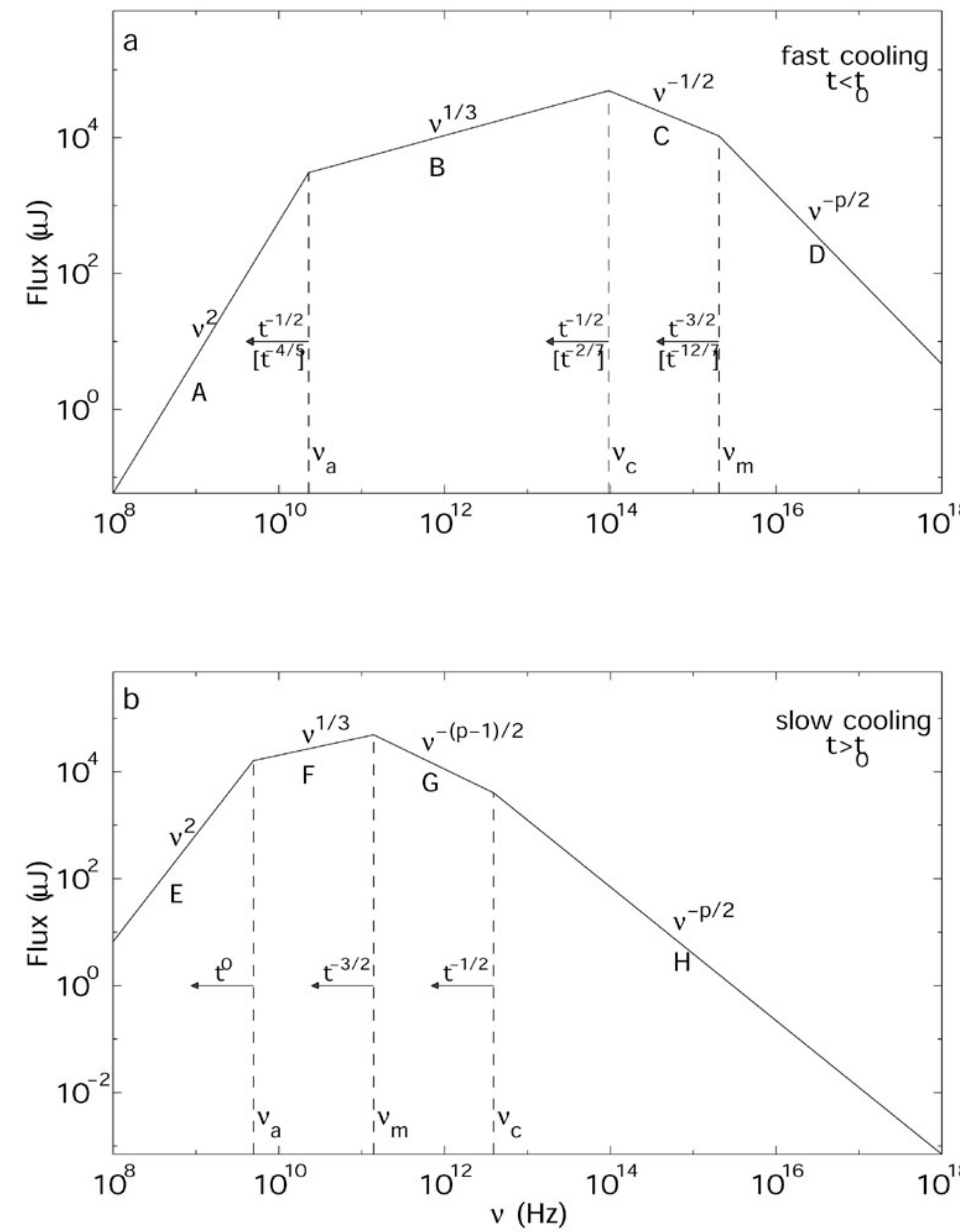
Synchrotron spectrum

- Normalization is set by
  - Number of radiating electrons
  - Power radiated per electron
  - Distance to source
- For each value of B' and r a spectrum can be calculated



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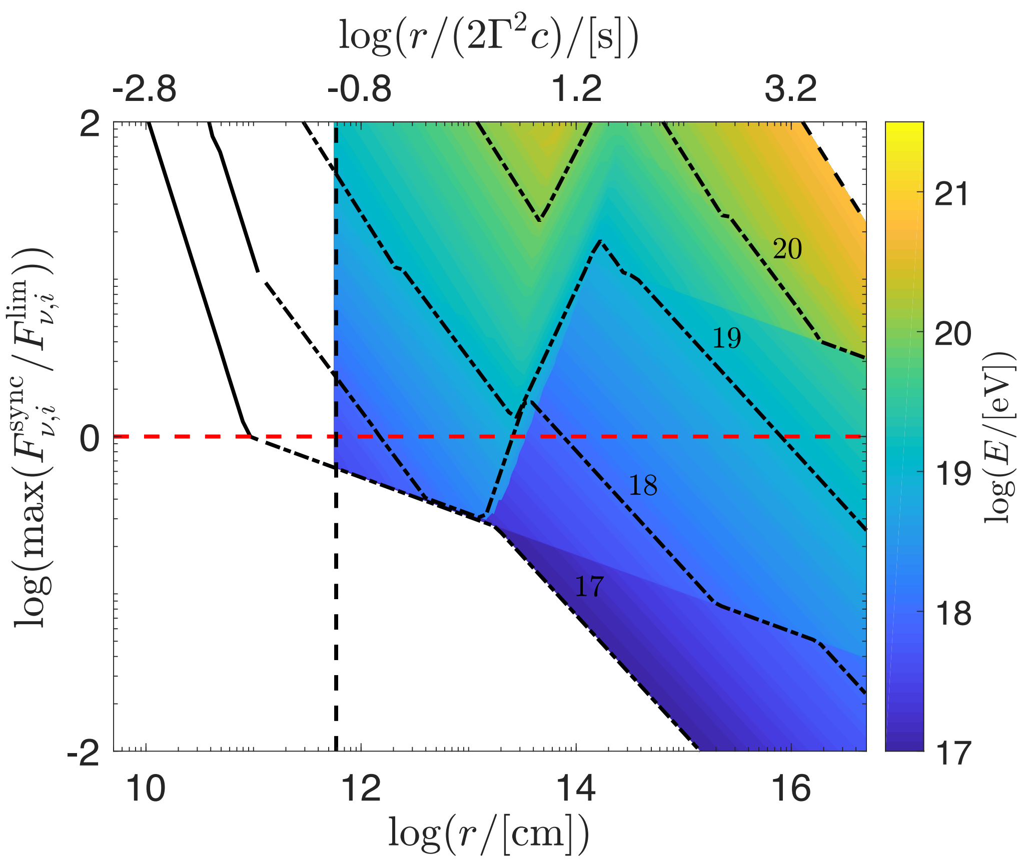
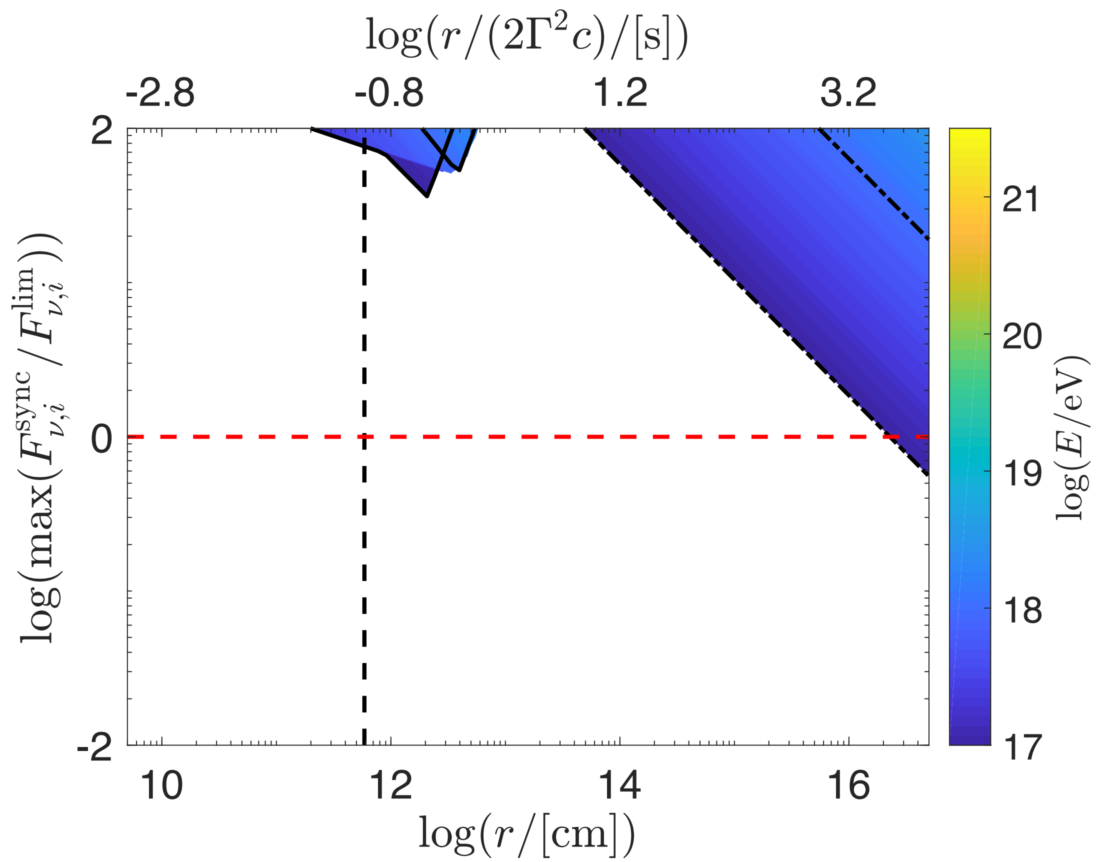
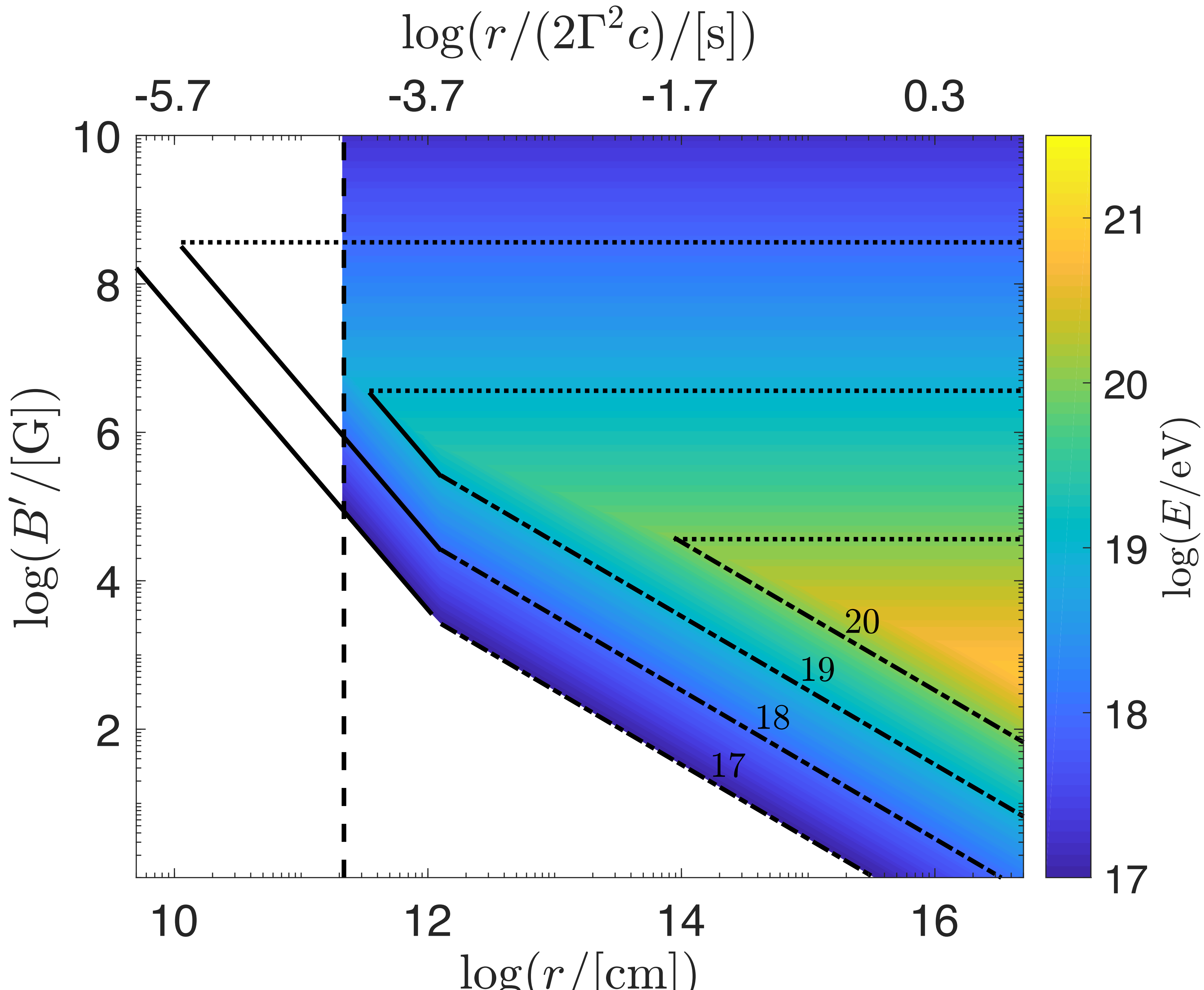
- Magnetic field
- Spectrum
- Results and conclusion
- Bonus (preliminary) results!

Low-luminosity GRB 060218 with $\Gamma = 10$





Proton in high-luminosity GRB with $\Gamma = 300$



Proton in high-luminosity GRB with $\Gamma = 300$

- Relatively large allowed parameter space
- Problems with energy budget; magnetic luminosity too large