The problematic connection between low-luminosity gamma-ray bursts and ultra-high-energy cosmic rays

ICRC 2021, July 13th
Filip Samuelsson, Damien Bégué, Felix Ryde, Asaf Pe'er, & Kohta Murase

Samuelsson et al. (2019) ApJ, 876:93
Samuelsson et al. (2020) ApJ, 902:148

Introduction

- Ultra-High-Energy Cosmic Ray (UHECR): $E \geq 10^{18}$ eV
- Gamma-ray bursts (GRBs) have long been proposed accelerators (Milgrom & Usov 1995, Waxman 1995)
- At the highest energies, the UHECR spectrum shifts to heavy nuclei, unlikely to survive a GRB jet (Horiuchi+ 2012, Pierre Auger Collaboration 2016, The Telescope Array 2018). Also, the GRB-spectrum has to be extremely fast cooling, in tension with observations (Samuelsson+ 2019)

Introduction

- Low-luminosity GRBs (LLGRBs) suggested more recently (Murase+ 2006)

- We consider UHECR acceleration in GRB 060218, using this canonical LLGRB as a proxy for the population

- GRB 060218 is similar in prompt optical and afterglow radio luminosity to other LLGRBs

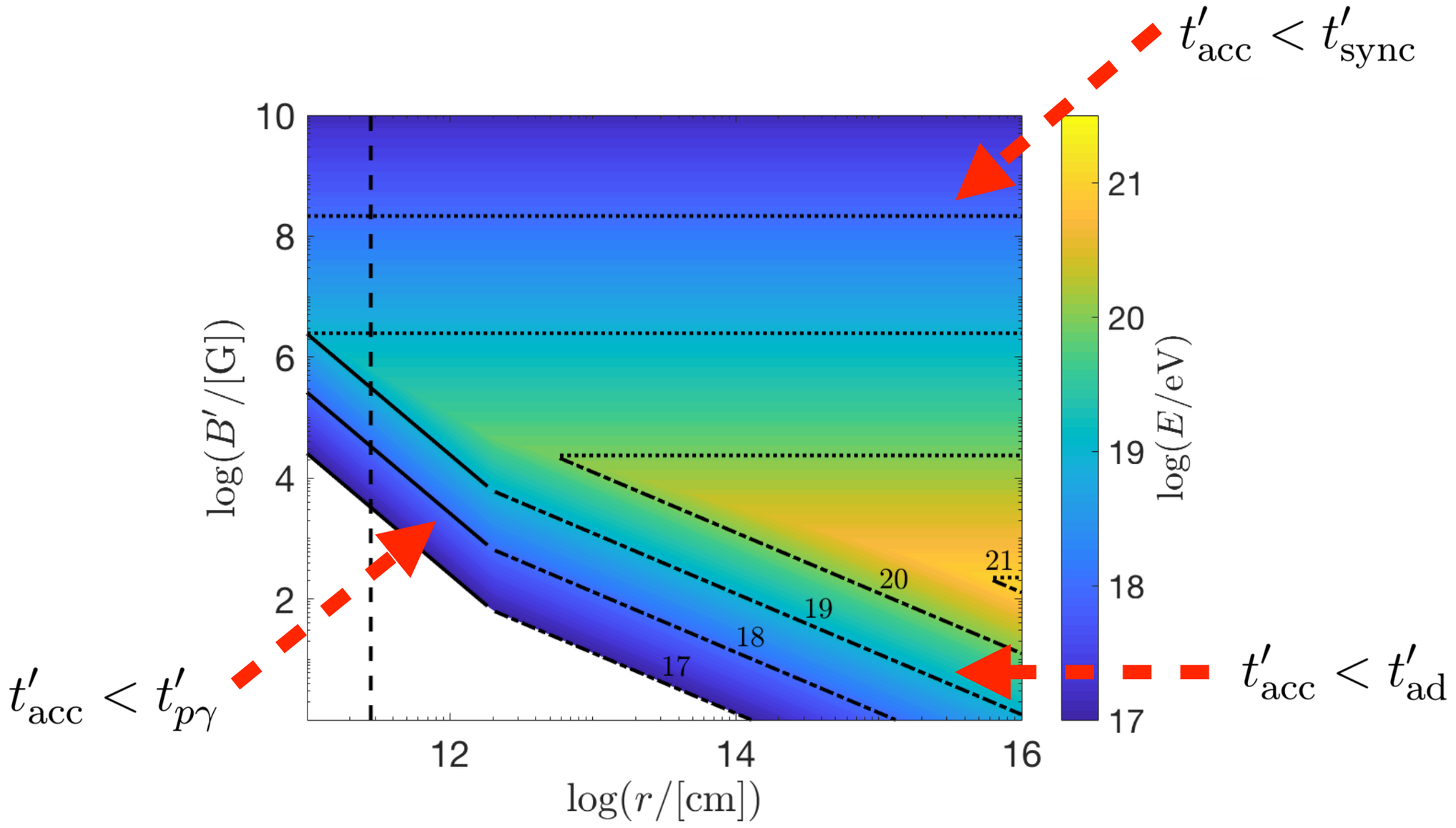
Idea

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

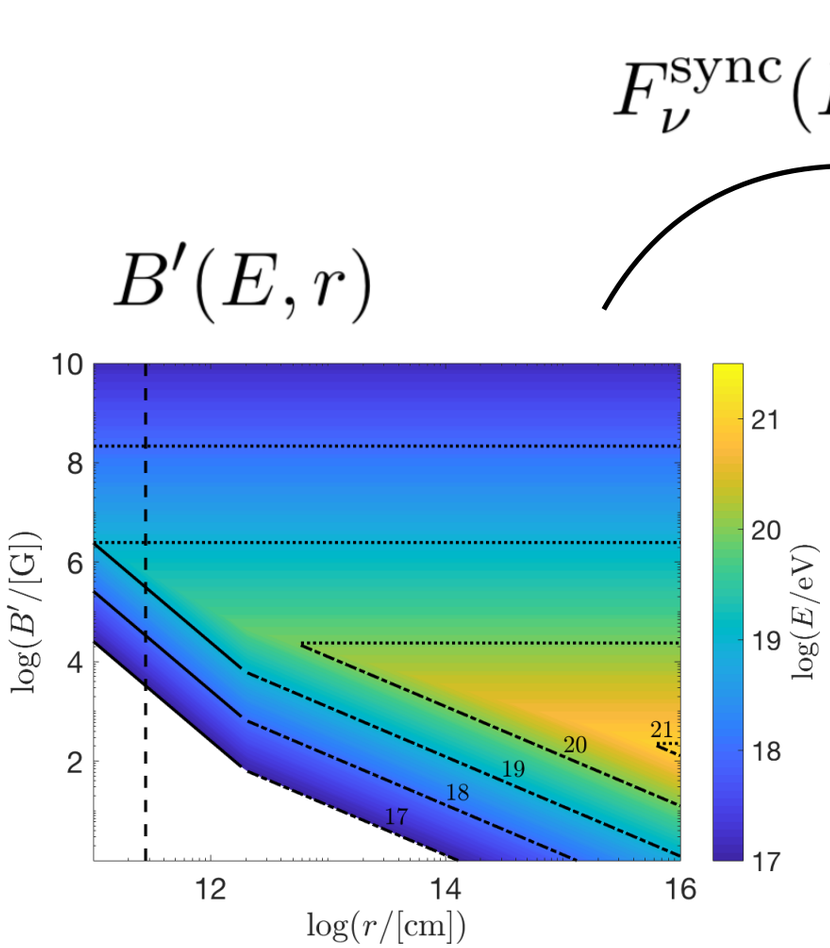
Magnetic field (prompt, iron, $\Gamma = 10$)

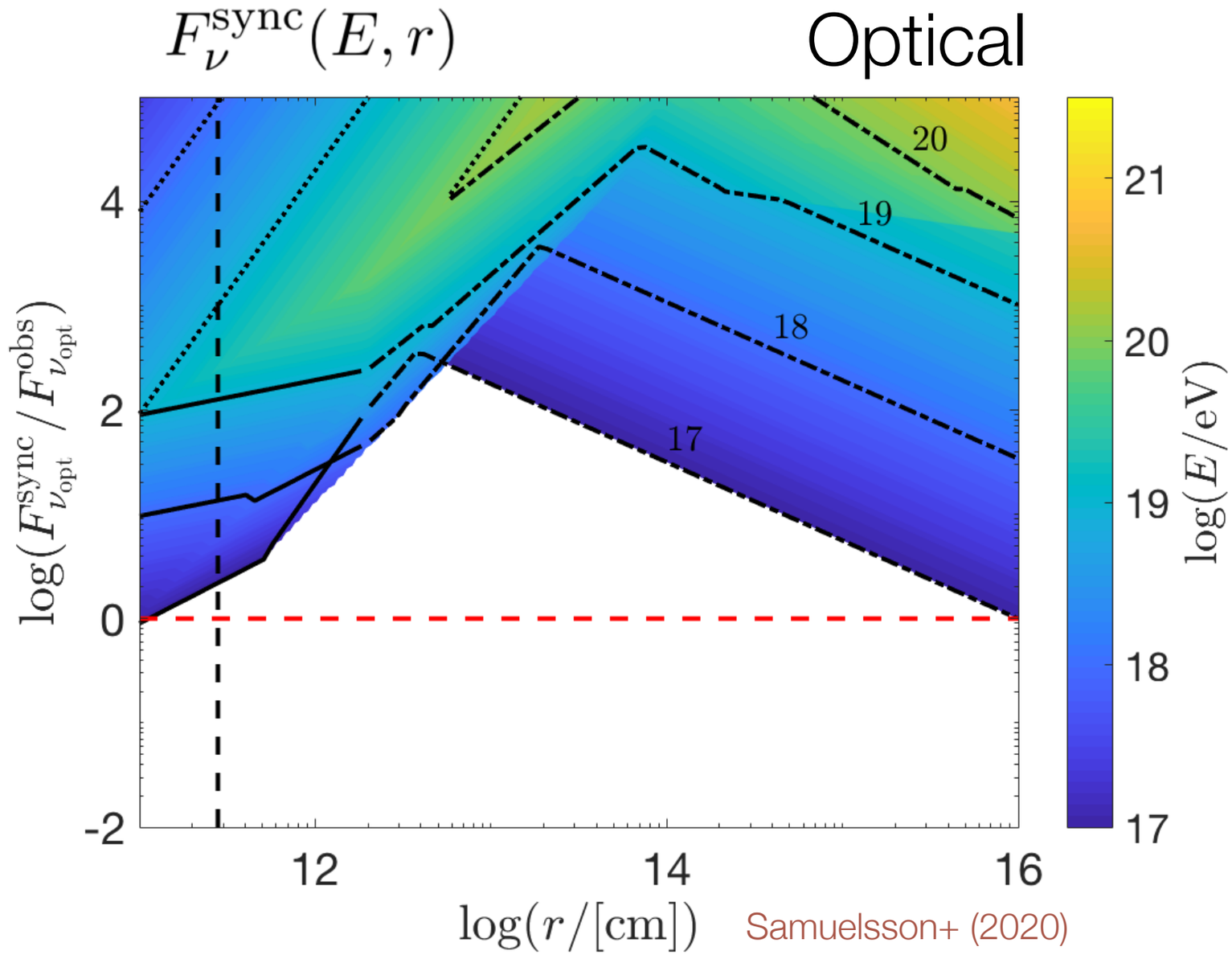
- Acceleration time scale shorter than cooling time scales

$$t'_{\rm acc} < \min[t'_{\rm sync}, t'_{\rm ad}, t'_{p\gamma}]$$



Synchrotron flux (prompt, iron, $\Gamma = 10$)





Samuelsson+ (2020)

No solution

Energy requirement (afterglow)

- Acceleration on the reverse and forward shocks of the afterglow

- Observed UHECR flux at Earth requires $E_{\rm BW} > 10^{51}$ erg much larger than suggested by previous modeling (Soderberg+ 2006, Fan+ 2006, Toma+ 2007)

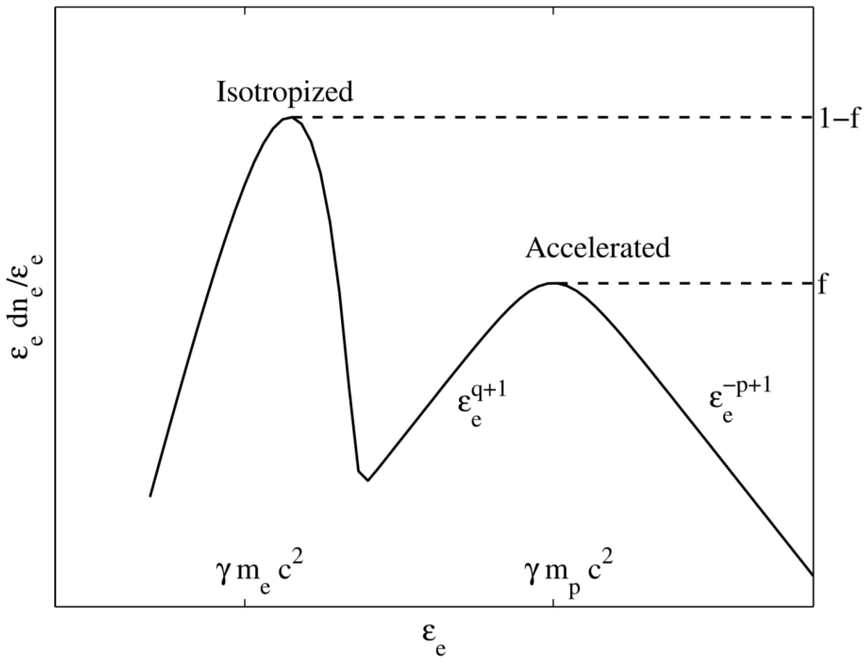
- Observables degenerate with number fraction of accelerated electrons ξ_a (Eichler & Waxman 2005)

- Assumes separation between thermal and non-thermal electrons

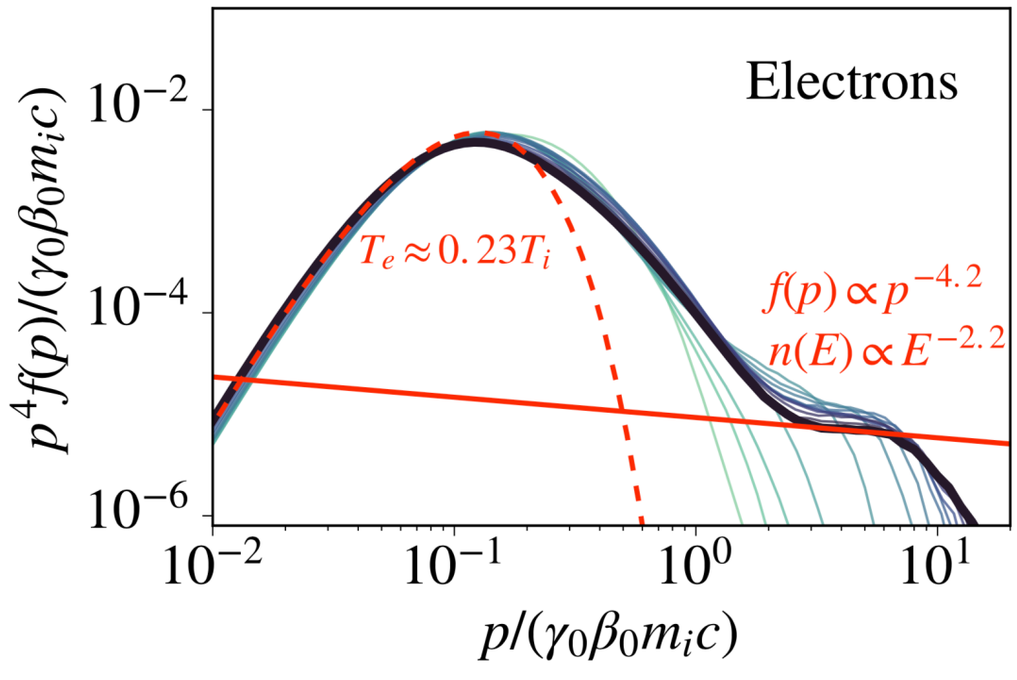
Thermal electron emission (afterglow)

- Recent PIC-simulations show that the power-law extends from the thermal (Sironi & Spitkovsky 2011, Park+ 2011, Crumley+ 2019)

- Emission from thermal electrons non-negligible



Eichler & Waxman (2005)

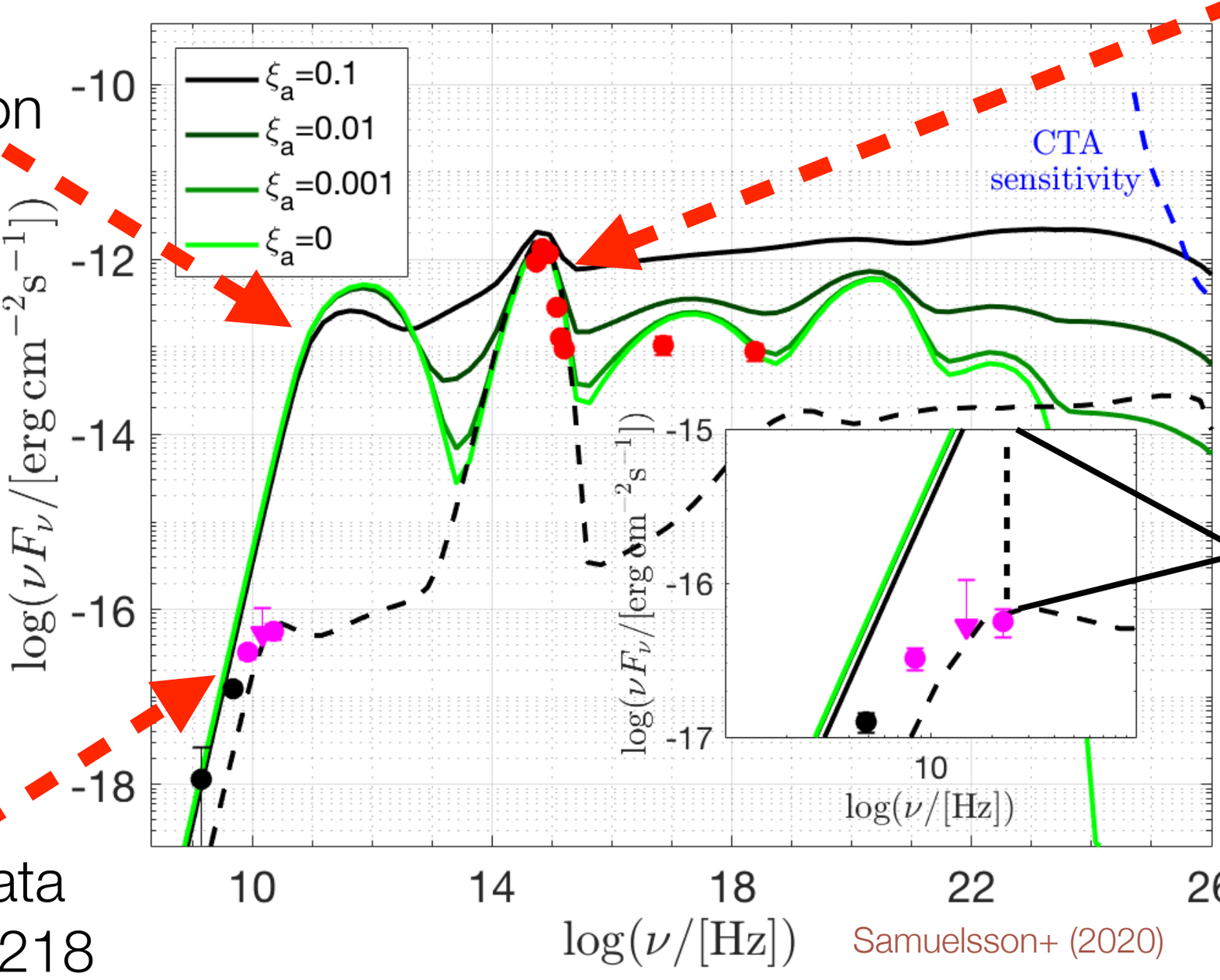


Crumley+ (2019)

Spectrum at ~3 days (afterglow)

Thermal synchrotron

Supernova



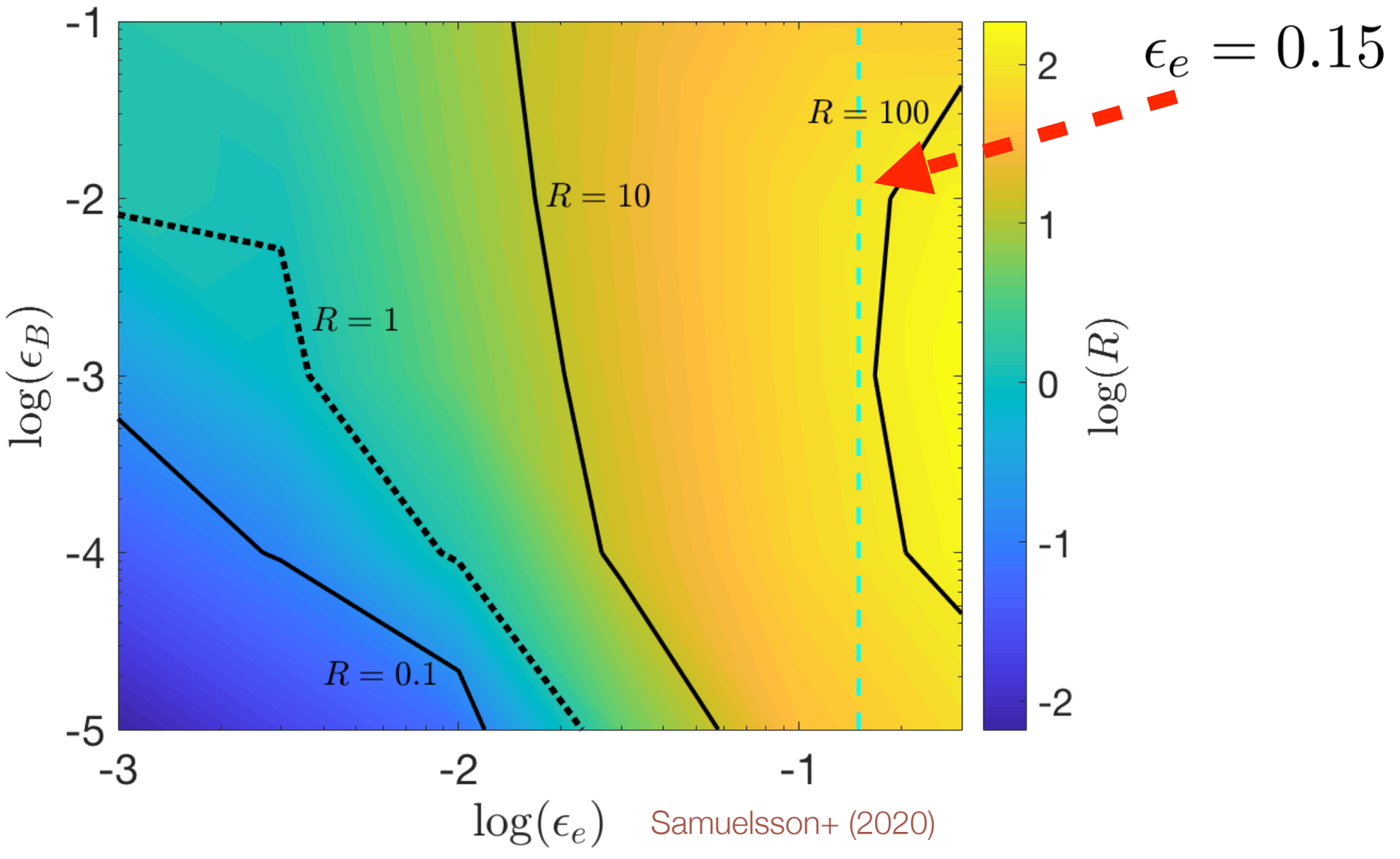
$$R \equiv \frac{F_{22.5}^{\mathrm{code}}}{F_{22.5}^{\mathrm{measured}} + F_{22.5}^{\mathrm{error}}}$$

Radio data
GRB 060218

Samuelsson+ (2020)

Data from Campana+ (2006), Soderberg+ (2006), & Kaneko+ (2007)

Microphysical parameters (afterglow)



Samuelsson+ (2020)

No solution

Conclusion

- UHECR acceleration in GRB 060218 is problematic:
  - Acceleration during the prompt phase is inconsistent with the prompt optical flux
  - Acceleration during the afterglow phase is inconsistent with the radio flux at 3 days
- If GRB 060218 is representative of the sample of LLGRBs, then this results disfavors LLGRBs as the main sources of UHECR

Samuelsson et al. (2019) ApJ, 876:93
Samuelsson et al. (2020) ApJ, 902:148