Understanding the spectrum of GRB 190114C

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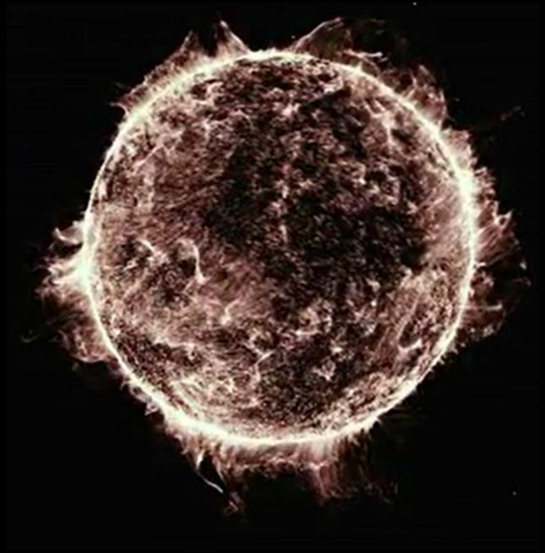
HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

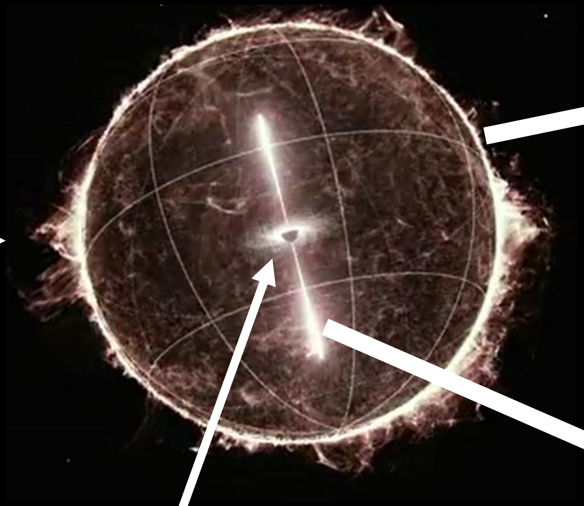
DESY.

GRB ? → Gamma-ray burst



massive star
rotating

$\mathcal{O}(10^{10} cm)$



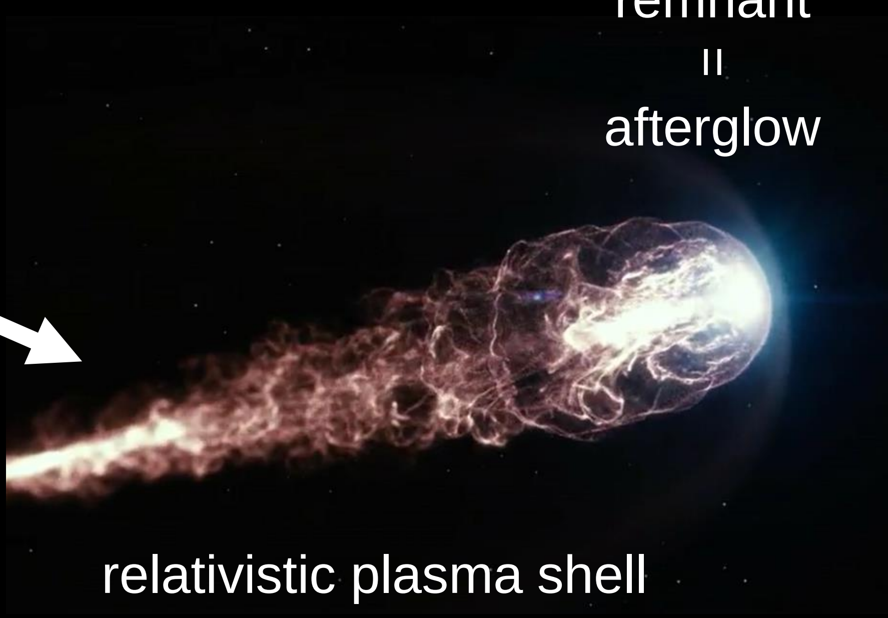
core collapse

compact object
$\mathcal{O}(10 km \sim 10^{6} cm)$

supernova

jet

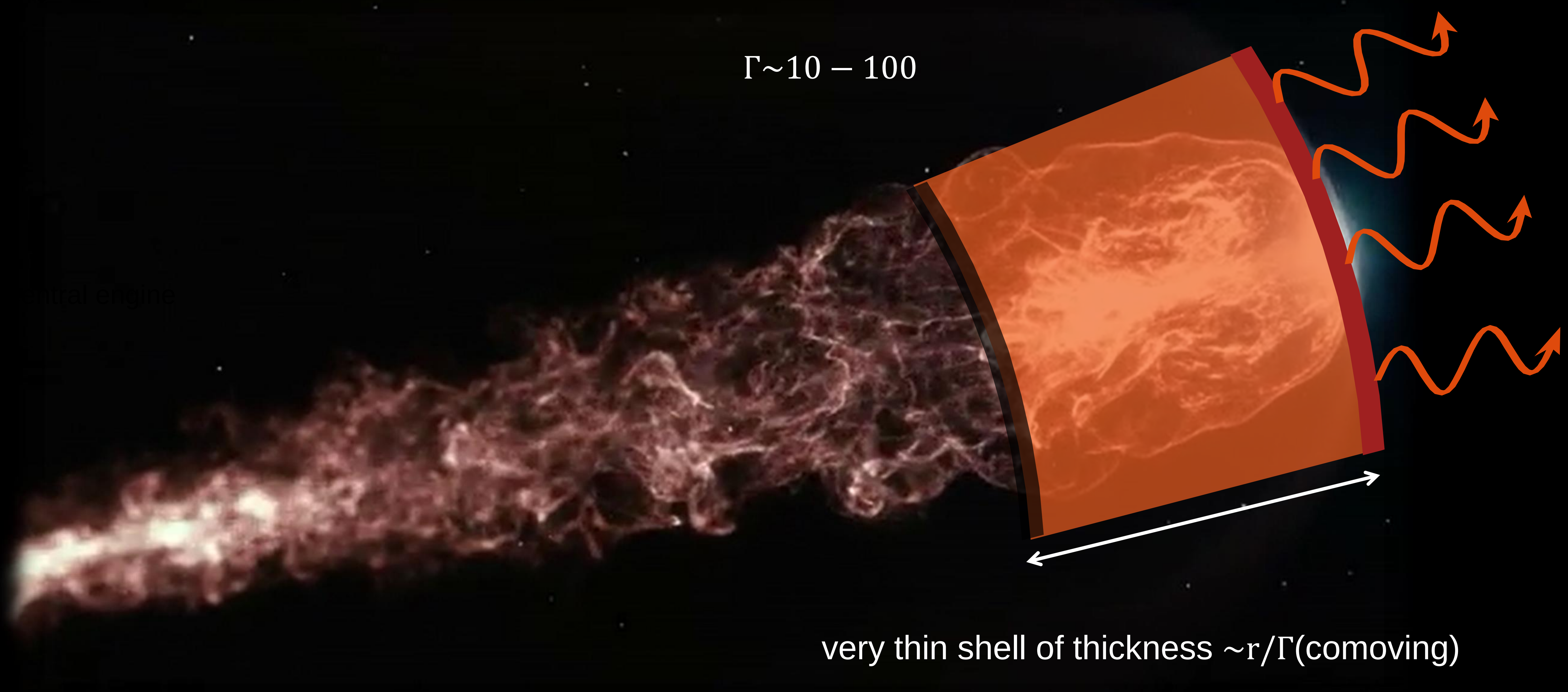
remnant
=
afterglow



relativistic plasma shell

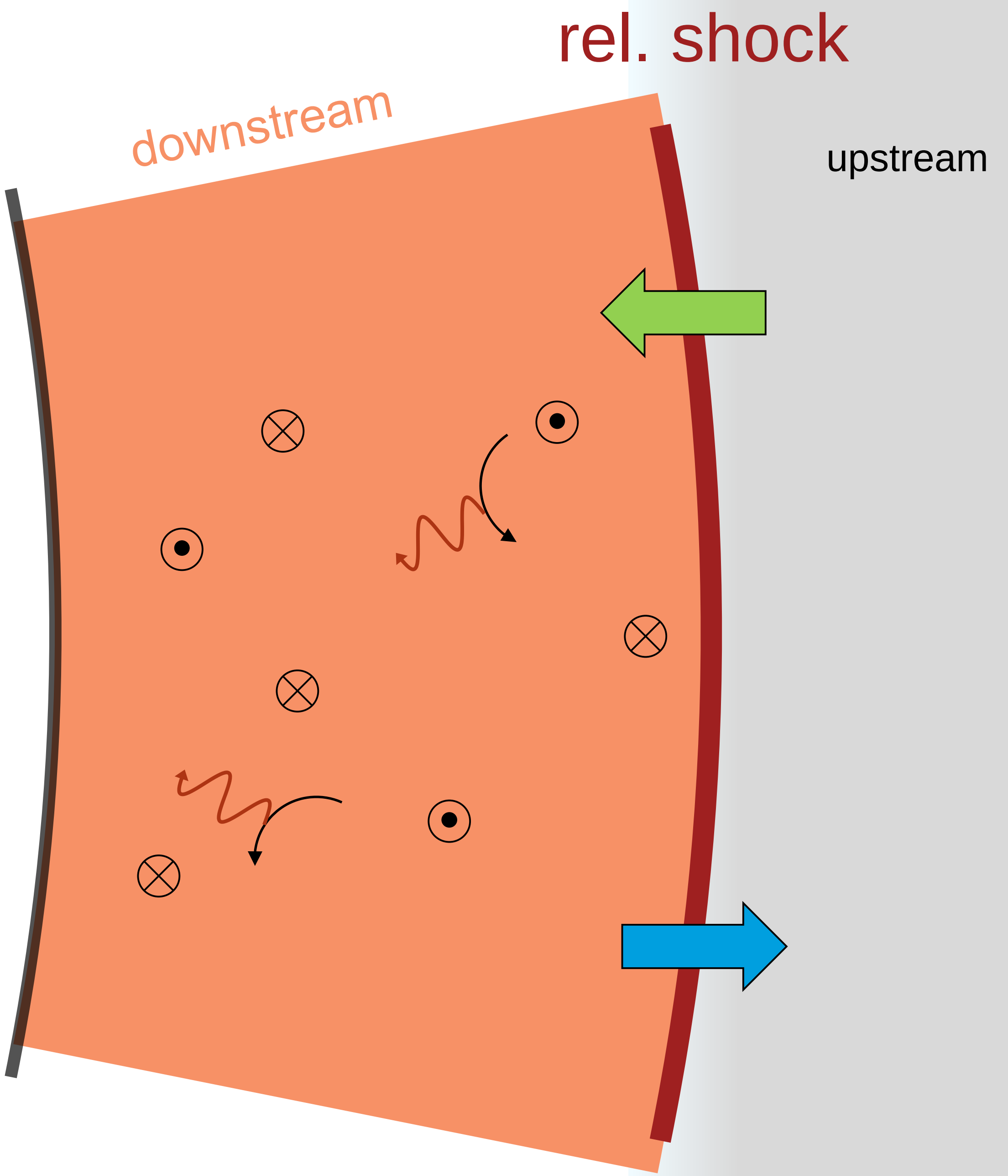
$\mathcal{O}(10^{16} cm \sim 0.01 lyr)$

GRB ? → Relativistic, Radiating Blast Wave



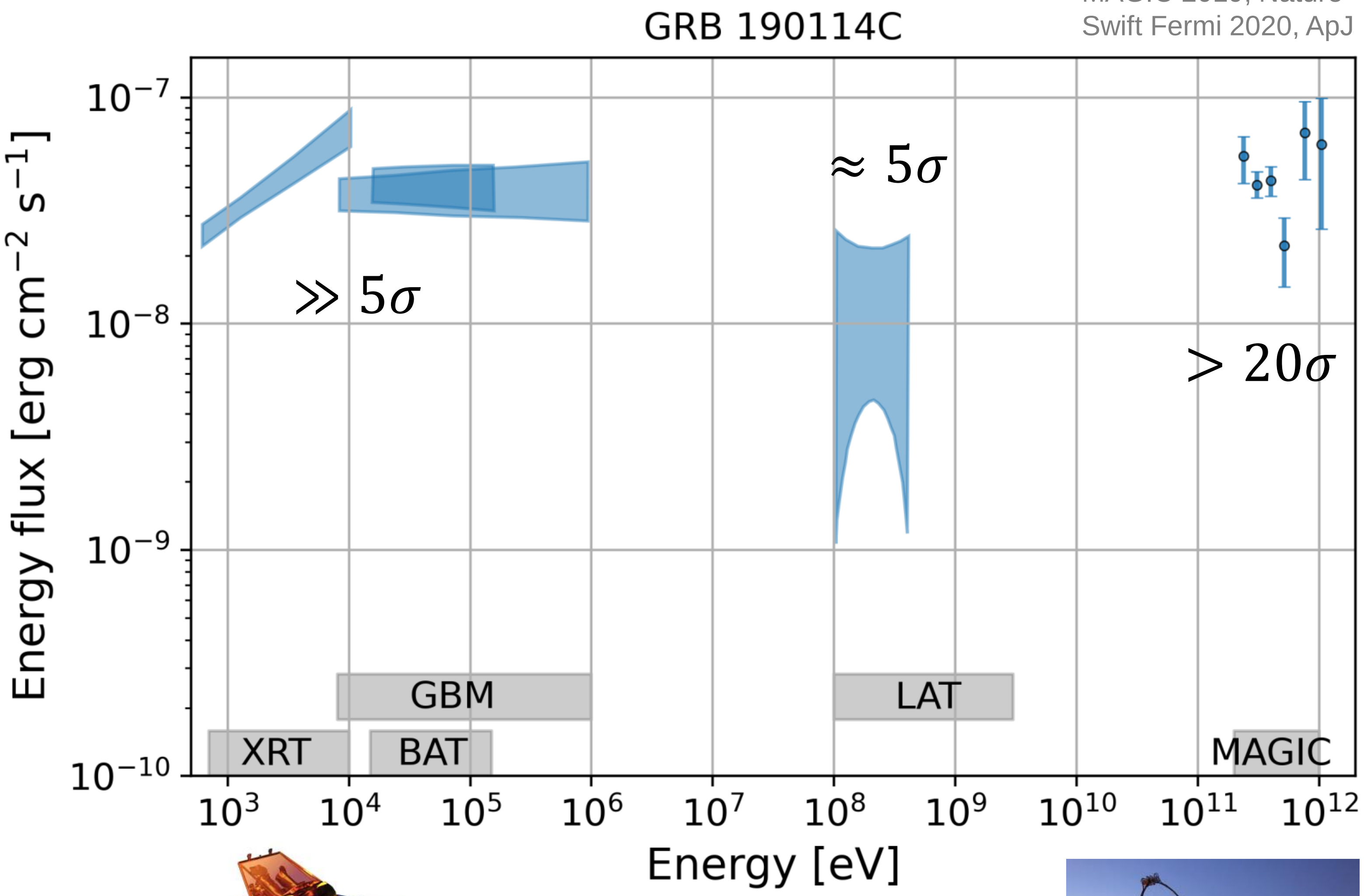
Simple Box Assumption

- Homogeneous shell of electrons/positrons and photons
- relativistic shock
  - → injection of non-thermal particles
  - → turbulent magnetic fields
- particles cool
- photons escape

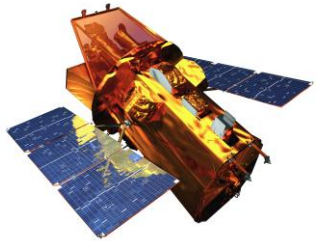


GRB 190114C - Afterglow

MAGIC 2019, Nature
Swift Fermi 2020, ApJ



- triggered:
  - → Swift satellite (BAT, XRT)
  - → Fermi satellite (GBM, LAT)
- rapid follow up by MAGIC



NASA

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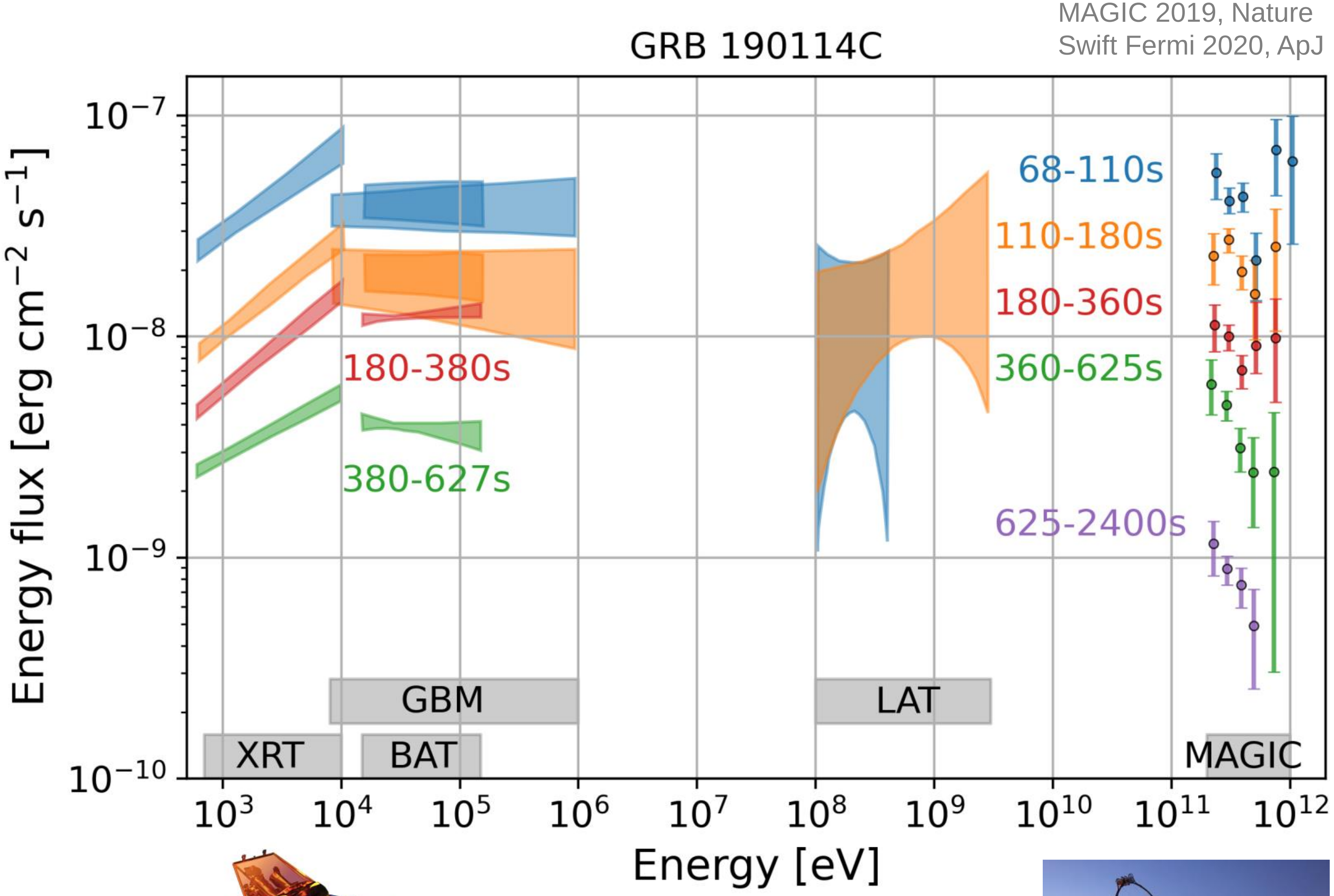
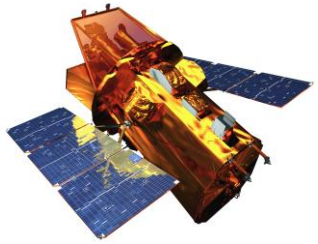
GRB 190114C - Afterglow

MAGIC 2019, Nature
Swift Fermi 2020, ApJ



- triggered:
  - → Swift satellite (BAT, XRT)
  - → Fermi satellite (GBM, LAT)
- rapid follow up by MAGIC
- **afterglow** observed from 1 to 40 minutes
- redshift $z = 0.42$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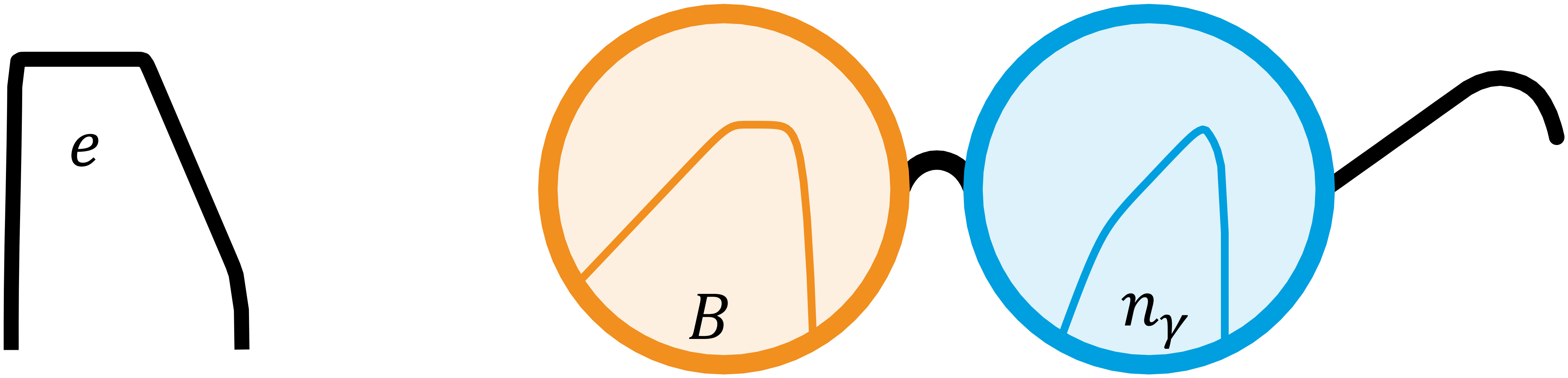
MAGIC Coll.

What can we learn from this?

- photon spectrum basically resembles electron spectrum
  - → **synchrotron spectacle**: electron spectrum + magnetic field + smearing
  - → **inverse Compton spectacle**: electron spectrum + size of region + more smearing
  - → understanding these spectacles we can see the high energy electrons at work

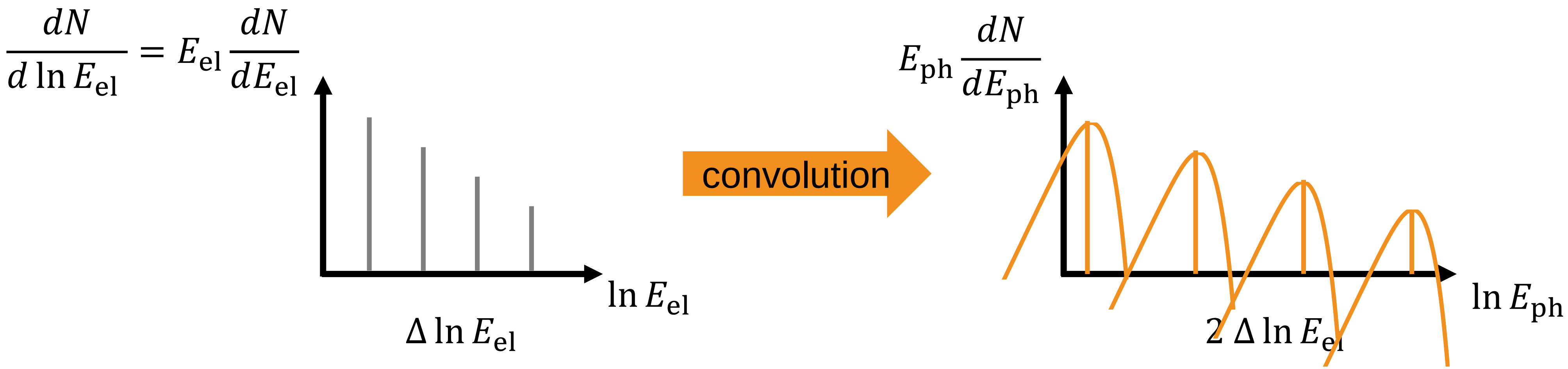


Synchrotron Radiation

- electron (energy E_{el}) spiraling in turbulent magnetic field B emits synchrotron radiation at characteristic energy:

$$E_{\mathrm{ph,syn}} = \frac{B}{B_{\mathrm{crit}}} \frac{E_{\mathrm{el}}^2}{m_{\mathrm{e}} c^2} \propto E_c$$

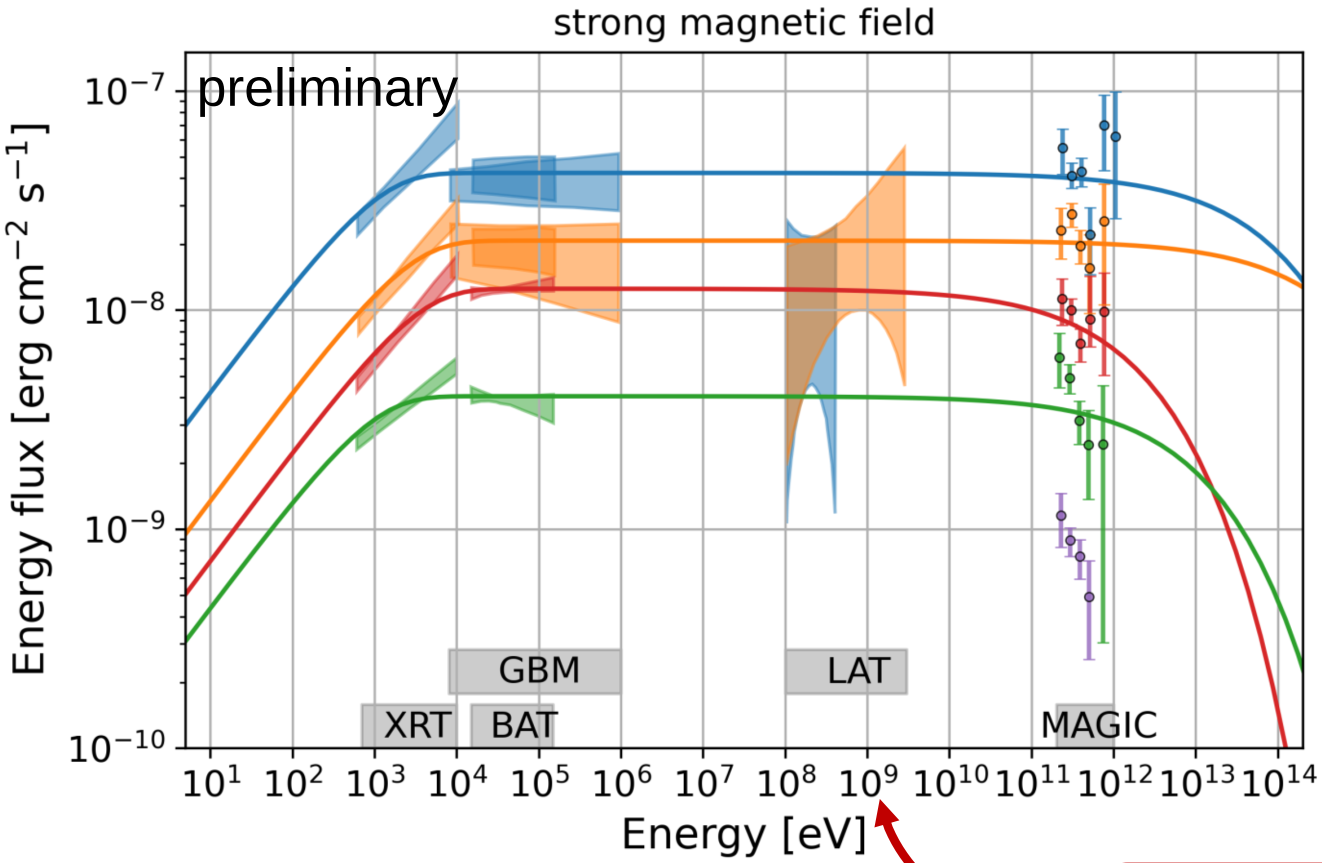
$$E \frac{\mathrm{d}N}{\mathrm{d}E}_{\mathrm{ph,syn}} \propto \left(\frac{E}{E_c}\right)^{\frac{1}{3}} e^{-\frac{E}{E_c}}$$

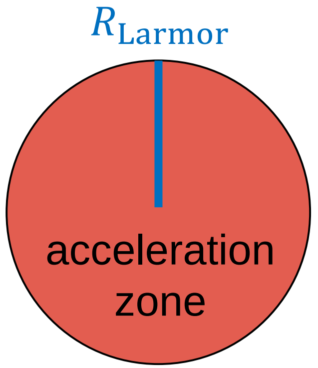


electrons

photons

Strong B-field solution





Problem:

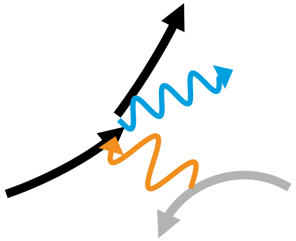
$$\tau_{\text{acc}} = \eta \frac{R_{\text{Larmor}}}{\beta c} \approx \frac{\eta E_{\text{el}}}{eBc}$$

$$\tau_{\text{syn}} = \frac{9}{8\pi} \frac{h}{\alpha} \left(\frac{B_{\text{c}}}{B}\right)^2 \frac{1}{E_{\text{el}}}$$

$$\rightarrow E_{\text{el,max}}^2 = \frac{9}{4} \frac{1}{\alpha} \frac{1}{\eta} \frac{B_{\text{c}}}{B} m_e^2 c^4$$

$$\rightarrow E_{\text{ph,max}} = \frac{B}{B_{\text{c}}} \frac{E_{\text{el,max}}^2}{m_e c^2} = \frac{9}{4} \frac{m_e c^2}{\alpha\eta} \approx \frac{160 MeV}{\eta}$$

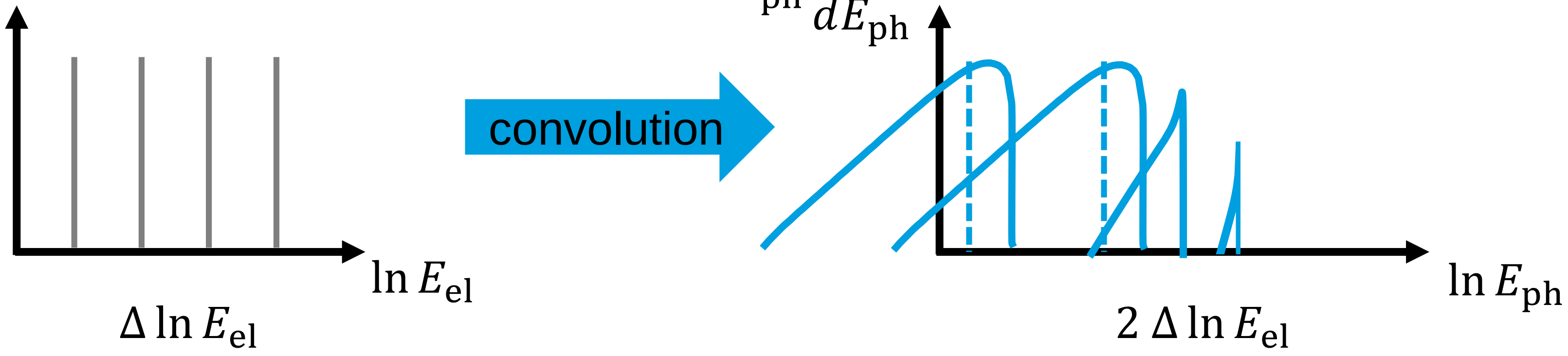
Inverse Compton Scattering



- electron scatters photon to higher energy (similar to synchrotron)
- Klein-Nishina suppression when photon momentum non-negligible

$$\frac{dN}{d\ln E_{\mathrm{el}}} = E_{\mathrm{el}} \frac{dN}{dE_{\mathrm{el}}}$$

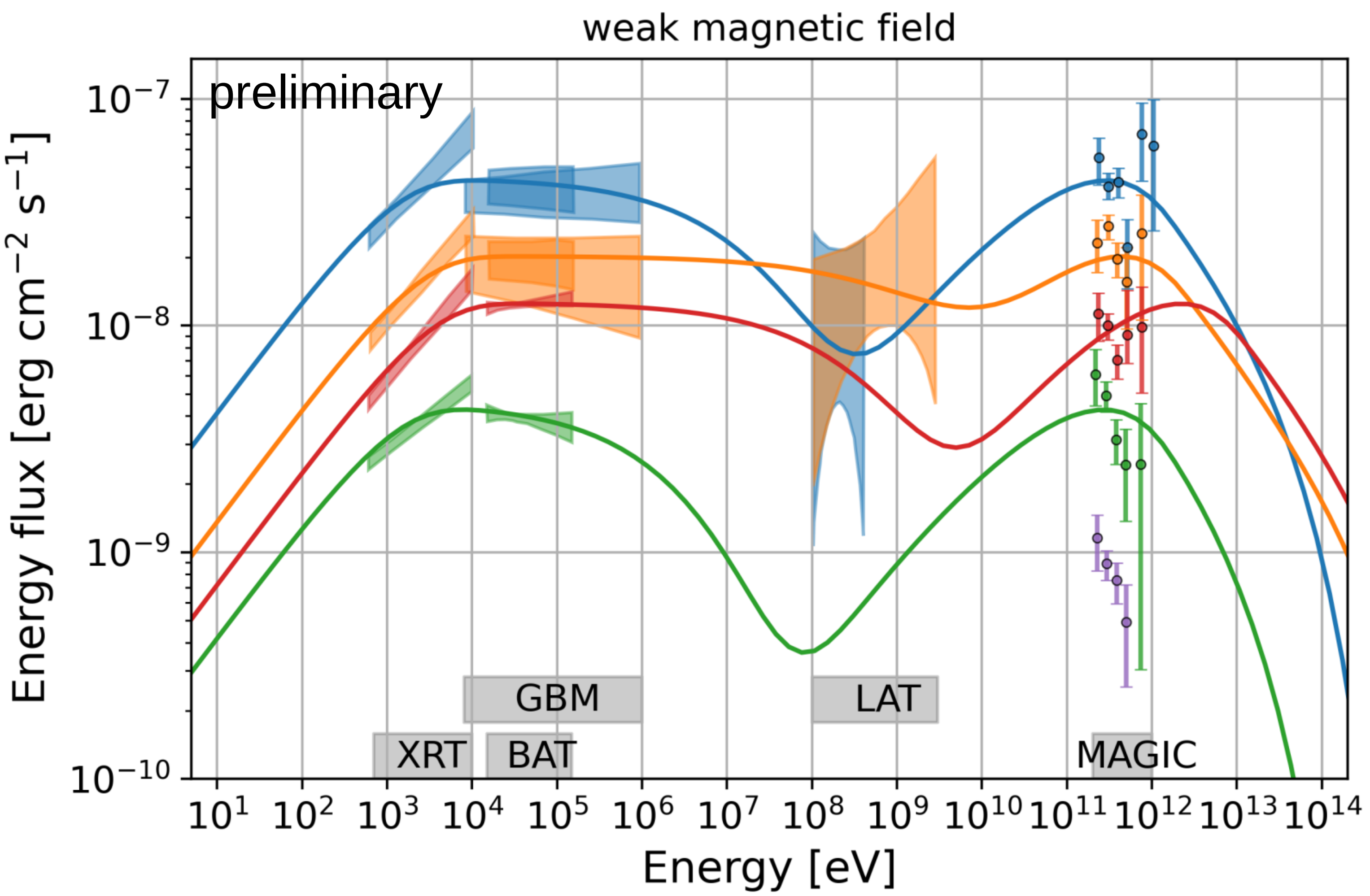
$$E_{\mathrm{ph}} \frac{dN}{dE_{\mathrm{ph}}}$$



electrons

photons

Weak B-field solution

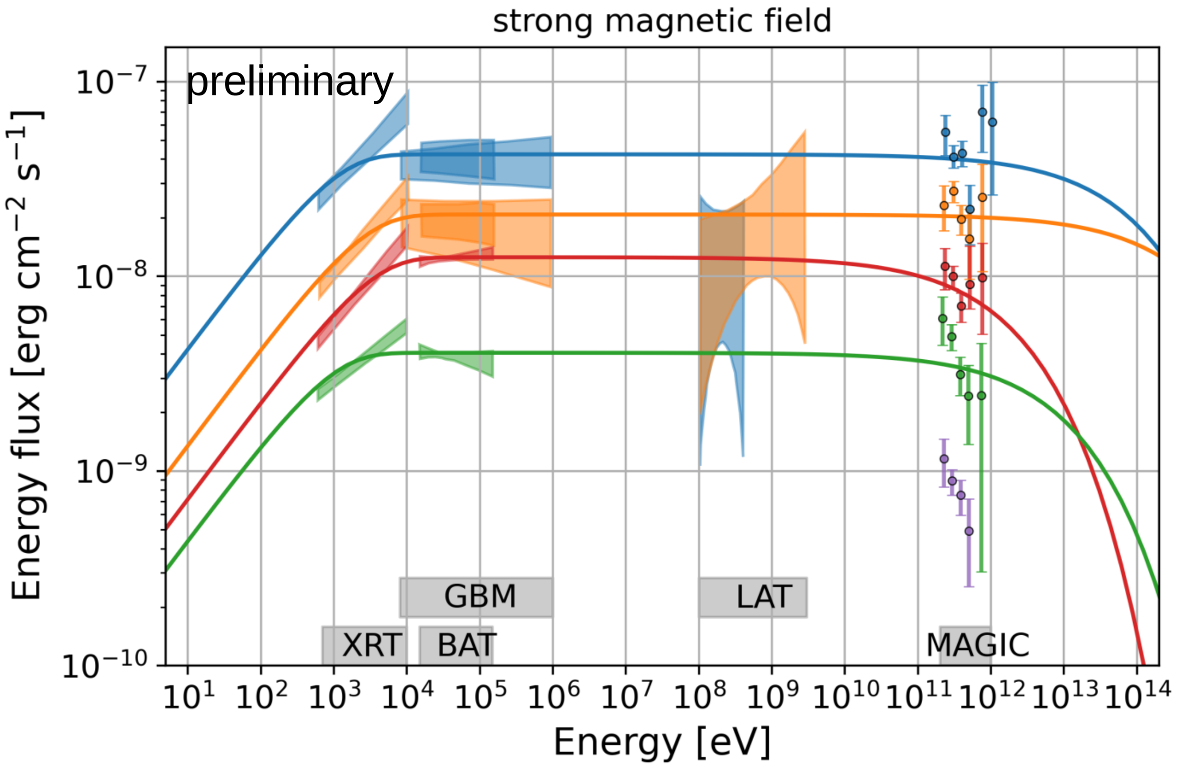


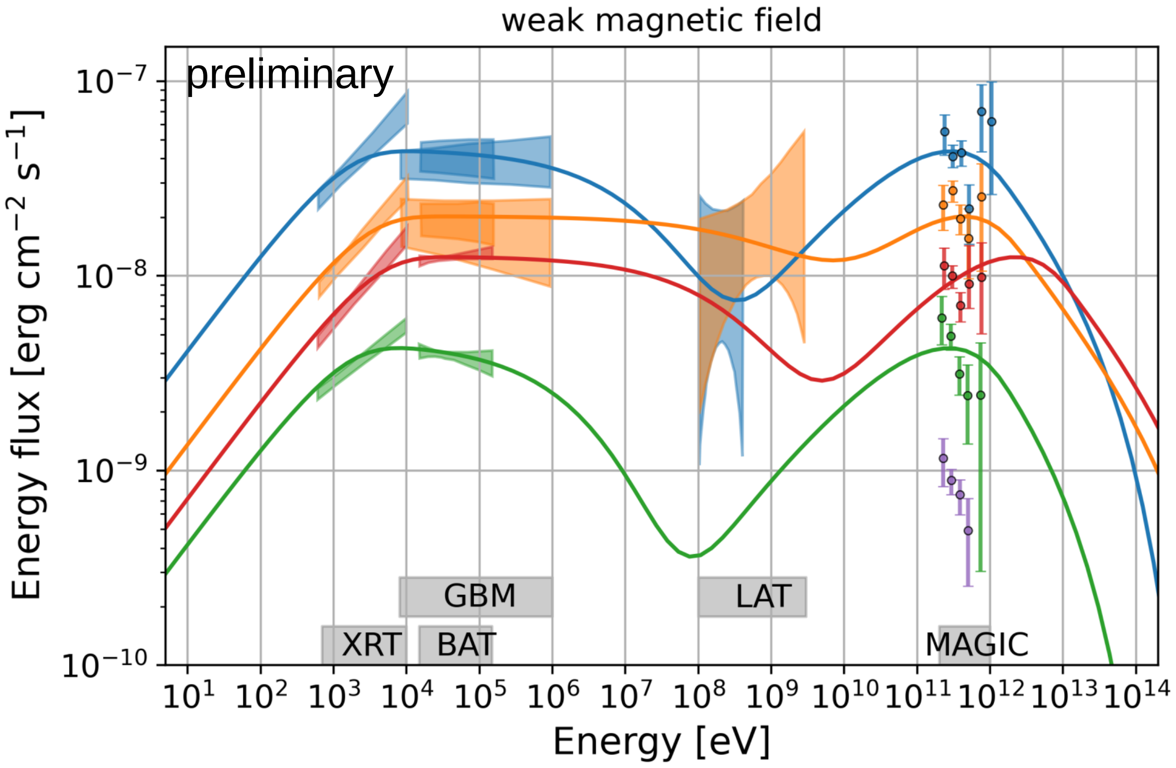
- Problems:

→ statistical preference of strong B-field case over weak B-field case
(like for other GRBs)

→ naturalness: why keV and TeV emission at the same height?

Weak or strong magnetic field?





Let the data decide!