Magnetic field in intergalactic space

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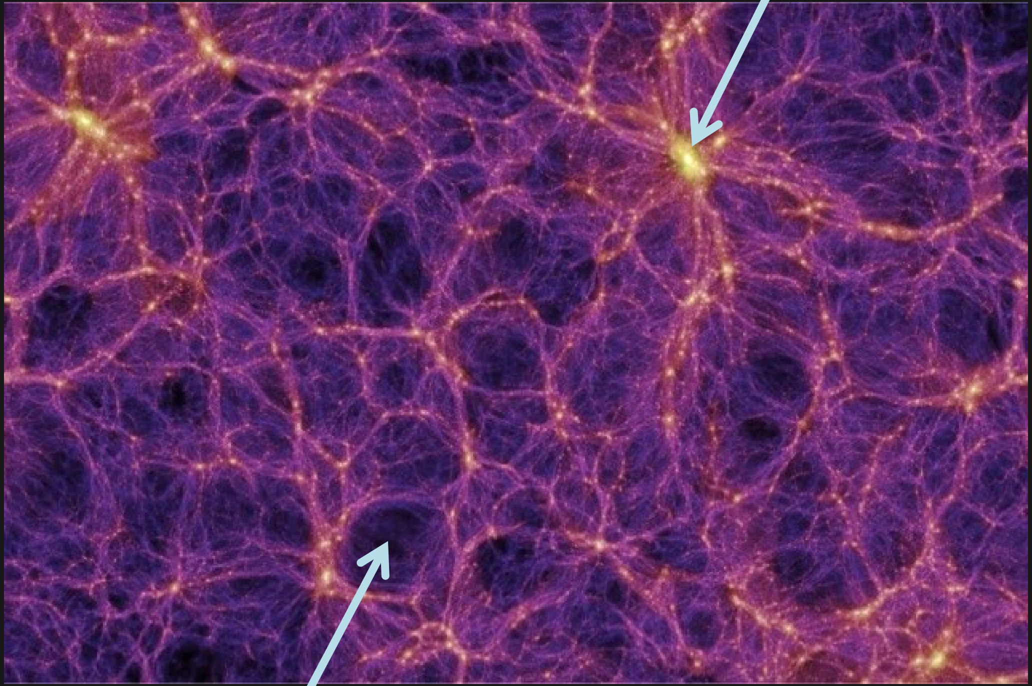
with Sergei Vafin, Iman Rafighi, and Jacek Niemiec

Introduction

- TeV-scale gamma rays produce pair cascades in cosmic voids
- In some cases the cascade emission is not observed
- Possible explanation: Magnetic field at fG level
- Alternative explanation: Plasma instabilities

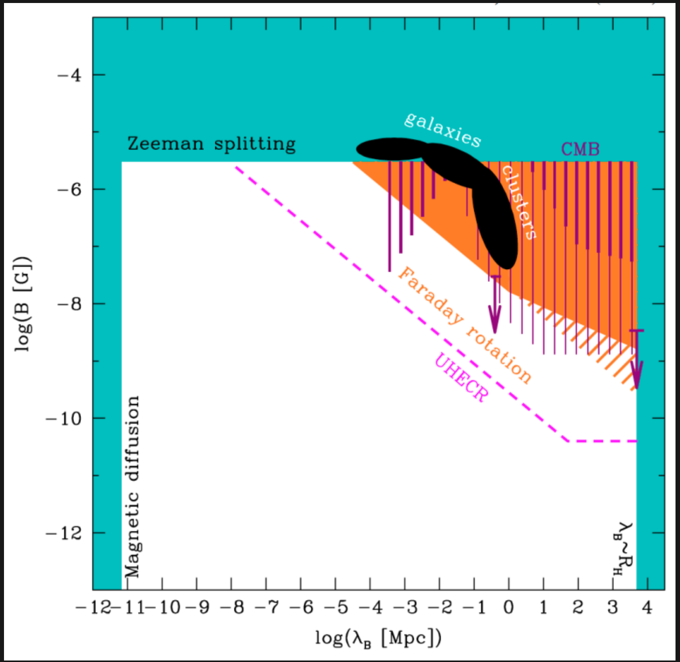
Introduction

B=few μG



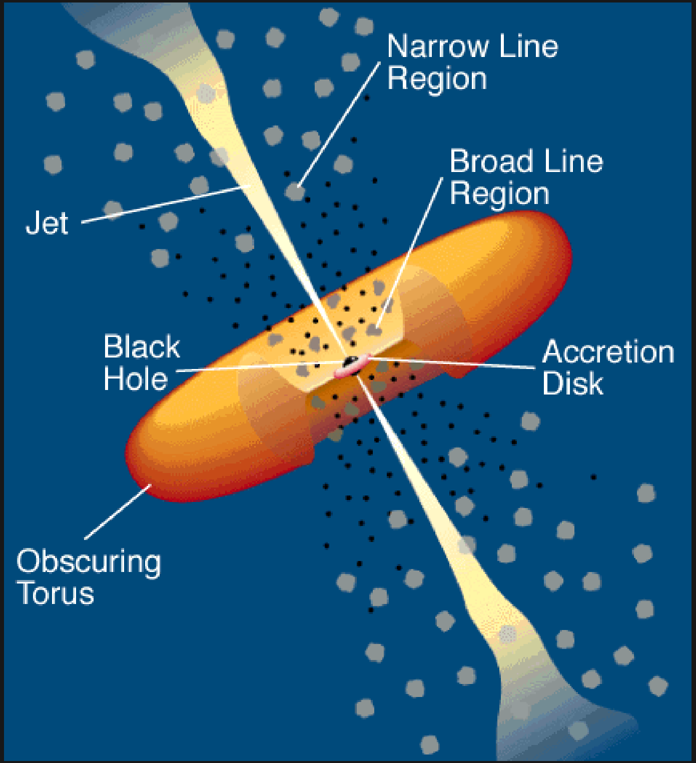
B= ??

Millenium simulation



Neronov 2009

Let‘s shine light on it …



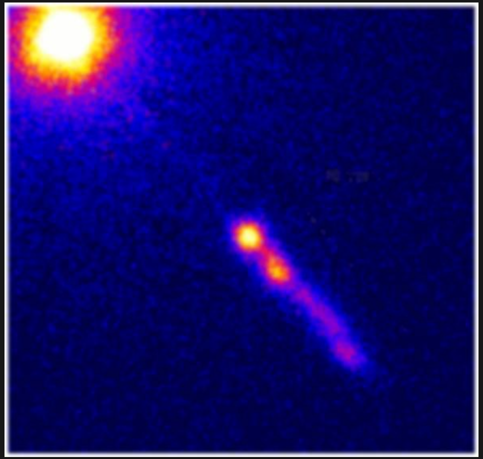
Blazars

TeV gamma-ray sources

Observable out to z~1

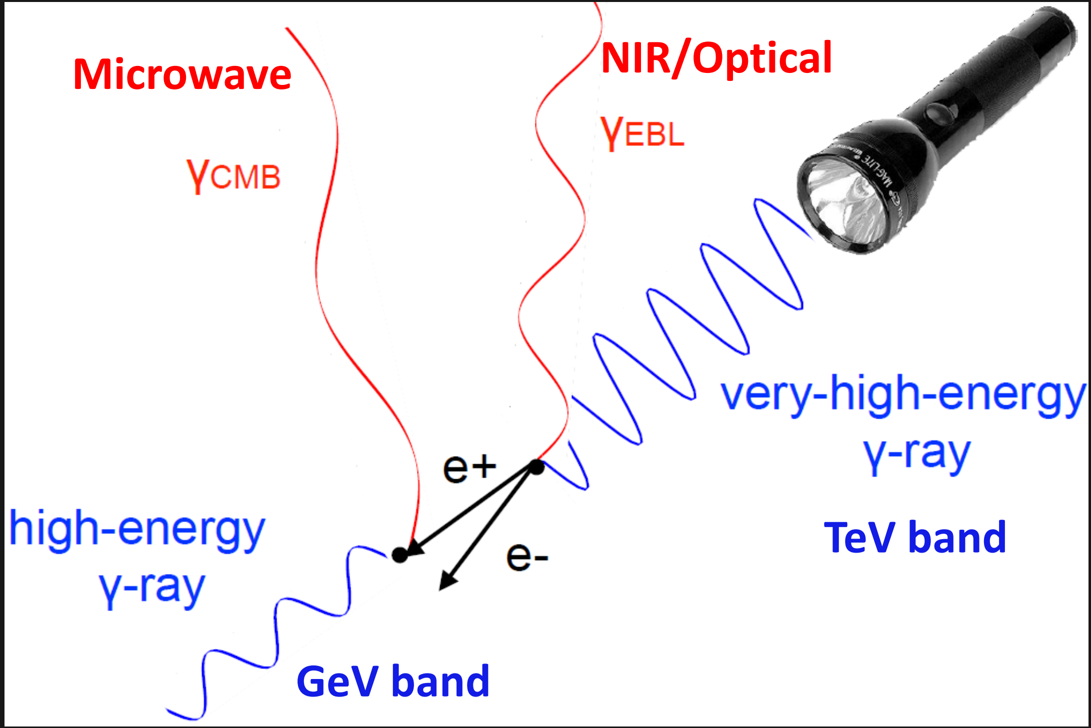
Collimated jets

Beamed gamma-ray emission



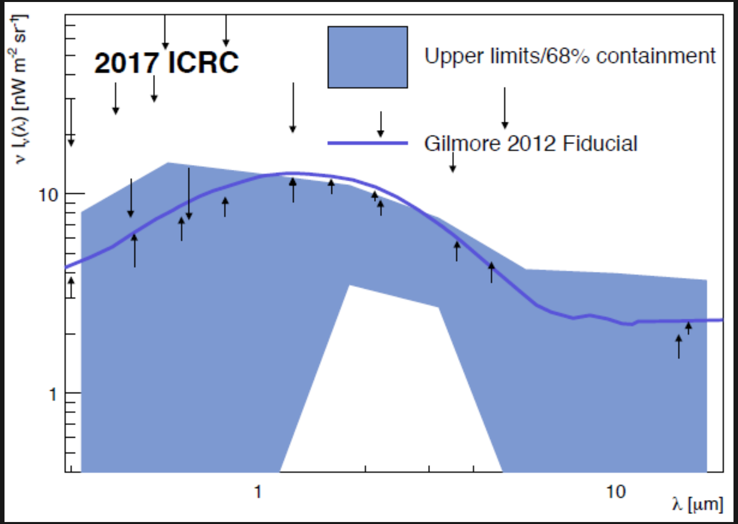
3C273 in X rays
(Credit: NASA)

Electromagnetic cascade



Is it seen? No!

EBL spectrum known reasonably well

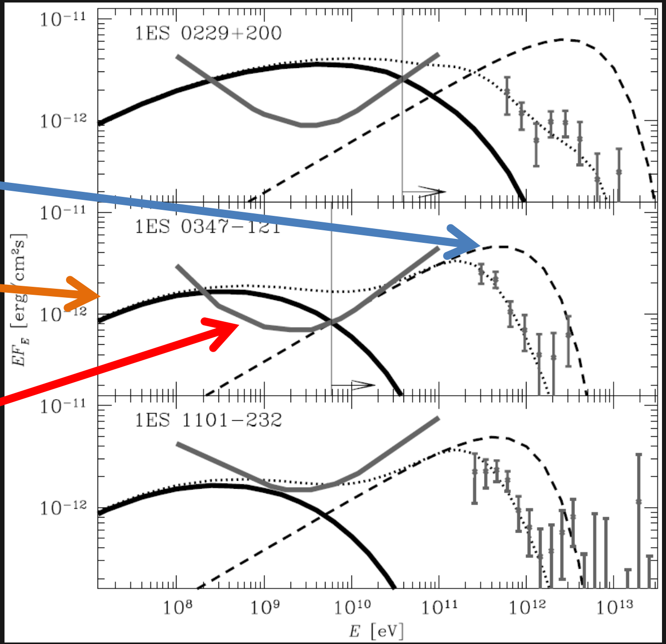


Wavelength

Deabsorbed emission

Cascade emission

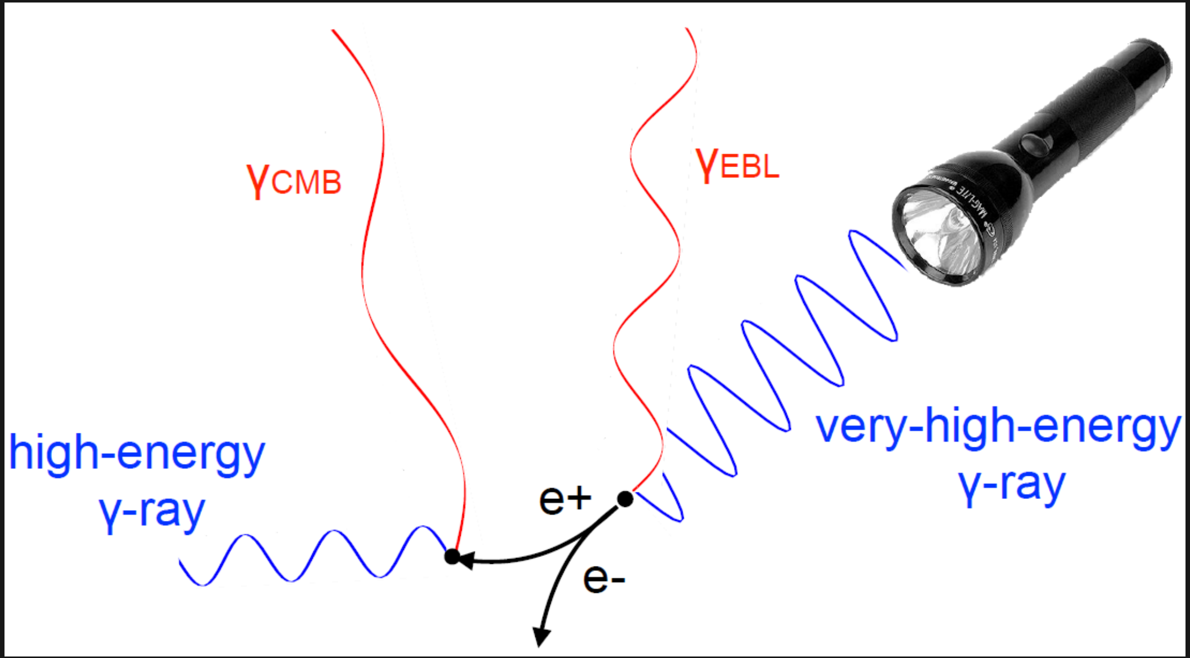
Upper limit



Neronov & Vovk 2010

Now what?

Magnetic deflection → fG fields required

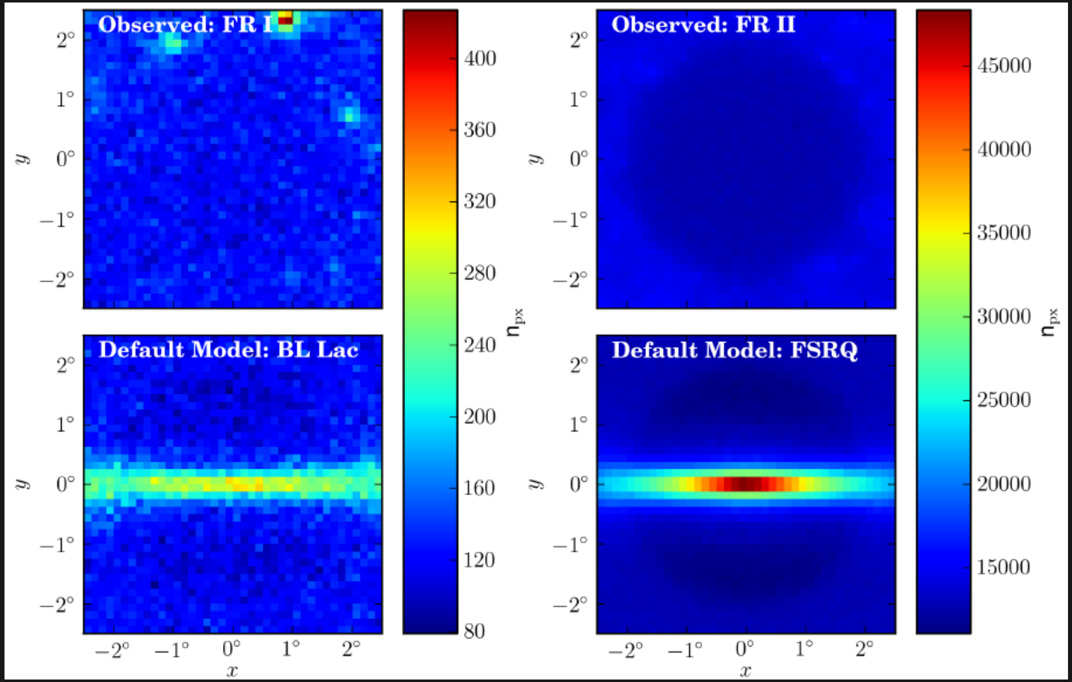


Deflected signal

Broderick et al. 2018:

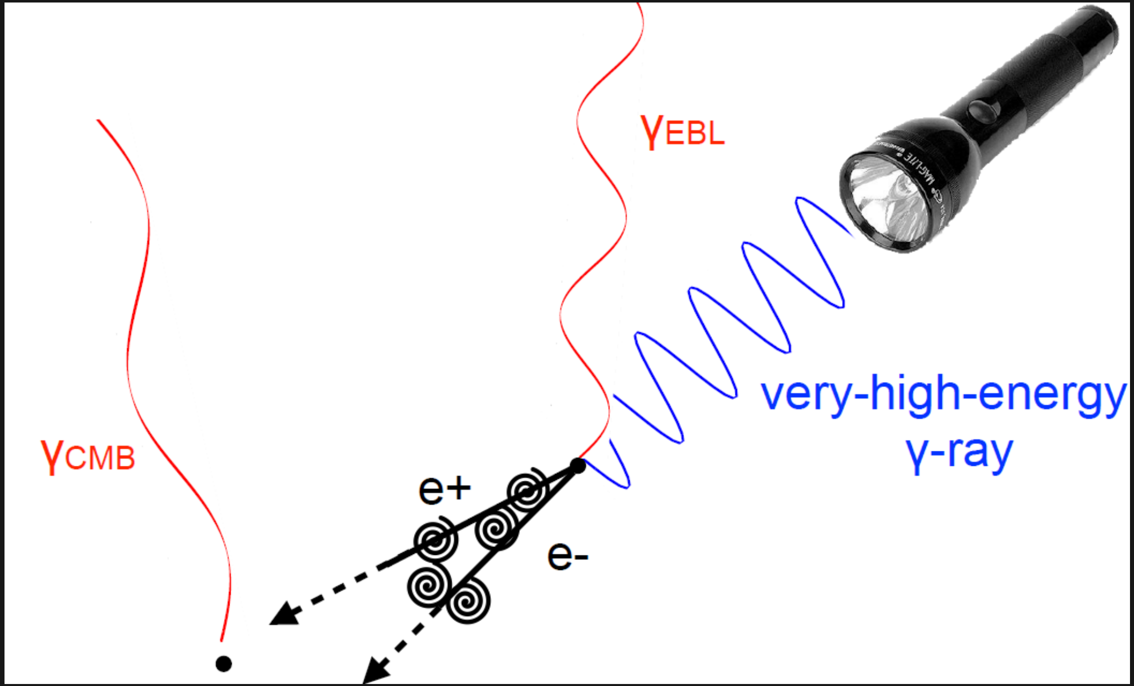
Search for isotropized cascade emission from radio galaxies

Nothing seen
→ argues against magnetic deflection



Now what?

Energy losses through plasma instabilities?



The question

Cascade emission not always seen

Intergalactic magnetic field?

Profound consequences for magnetogenesis

Plasma instabilities

Would have to be faster than Compton scattering

Compton scattering

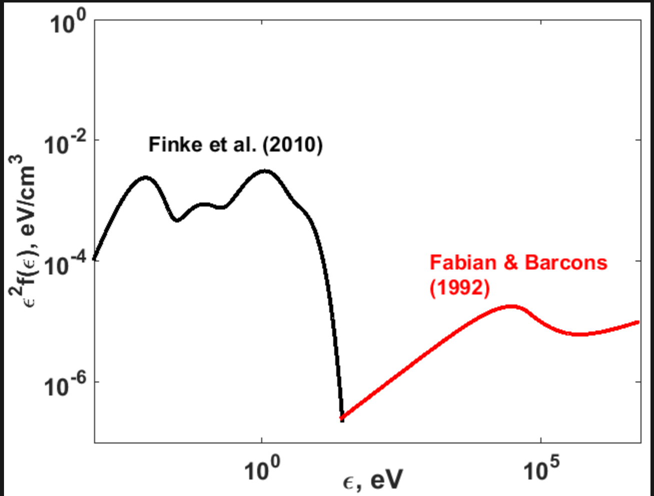
Compton scattering of CMB	ε=5.e-4 eV	
Cascade emission at 4 GeV	γ=3.e6	Electron Lorentz factor
Primary gamma rays	ε=6 TeV	
Photon mean free path is	λ=100 Mpc	We are in voids!!
Compton cooling length	l_c=0.3 Mpc	
Pair density ~ photon density	~ $1/D^2$	Fiducial distance D=50 Mpc

Test dominance of plasma instabilities → use uncooled pair spectrum

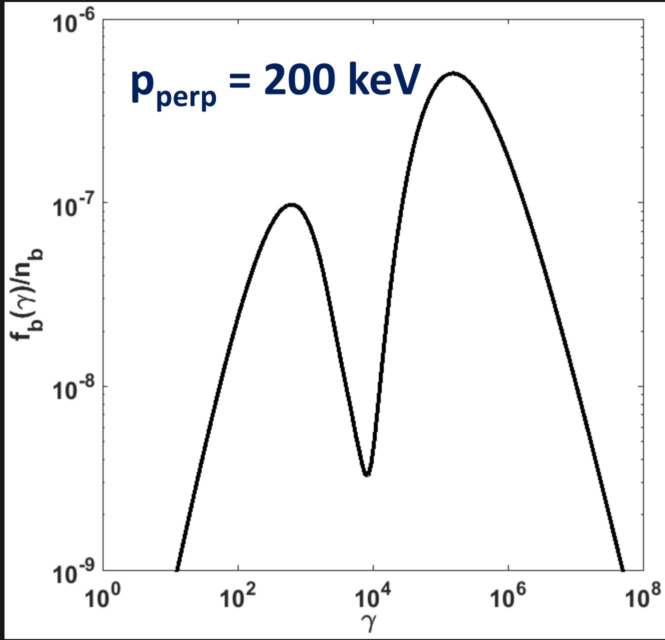
Pair beams

Fiducial blazar, spectral index -1.8

EBL spectrum



Pair beam spectrum



Plasma instability

Longitudinal instability

Velocity resonance k_{par} fixed

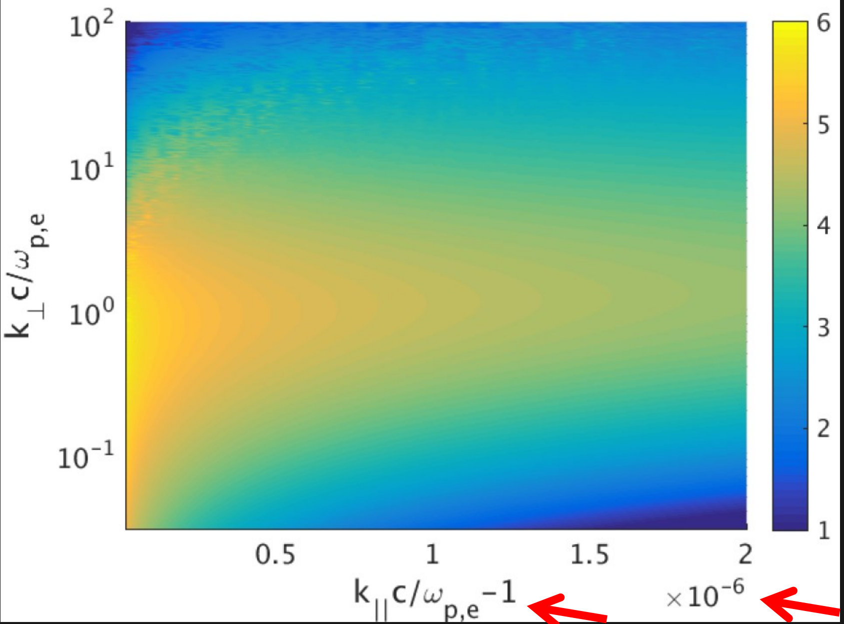
Maximum growth in oblique direction
1D treatment is dangerous

We need saturation level!

Need to be in the right regime!
Simulation must be carefully designed!

Rafighi et al. 2017

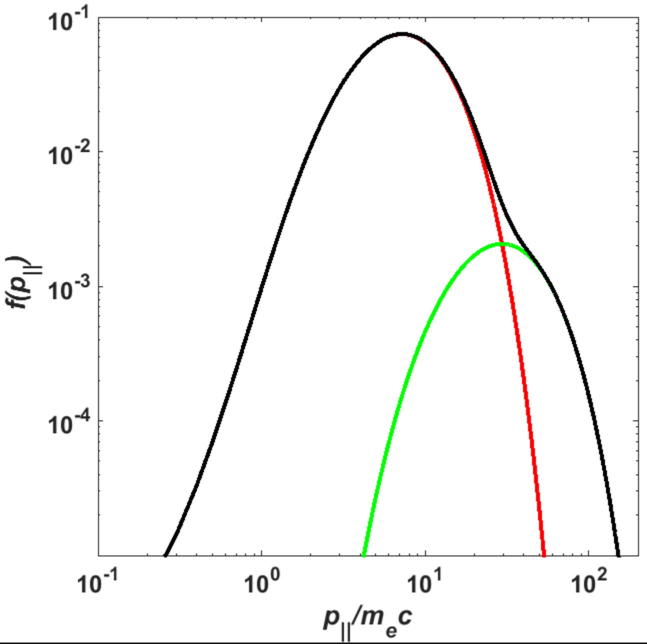
Linear growth rate
Real parameters



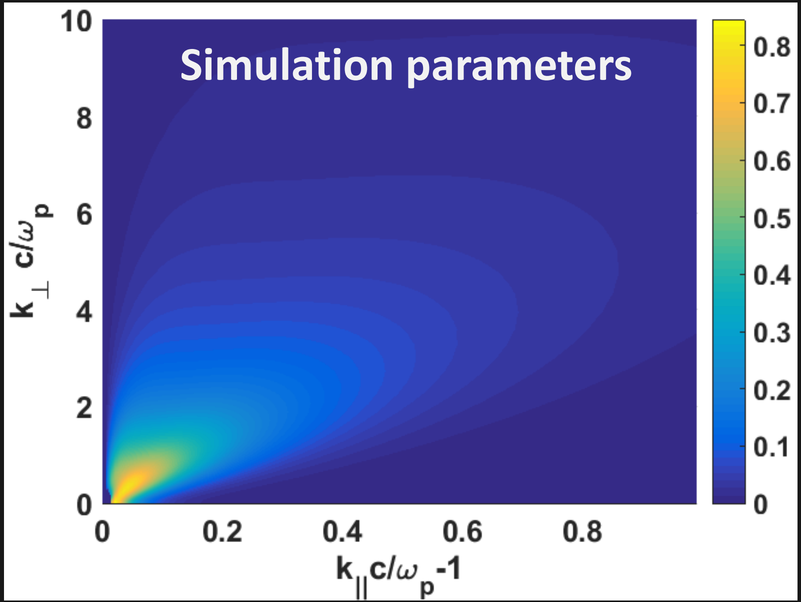
Pair-beam simulation

Particle-in-cell simulations

Simulated pair spectrum

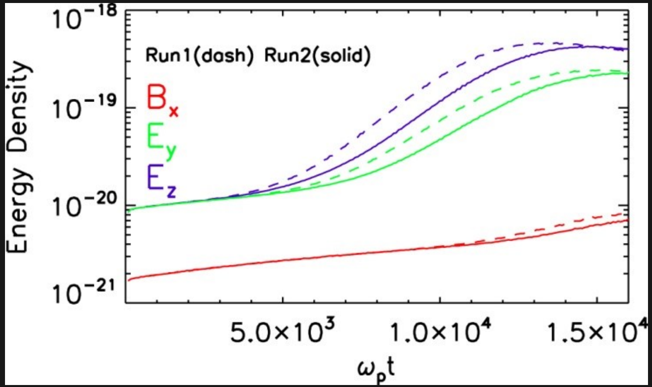


Analytically estimated growth rate

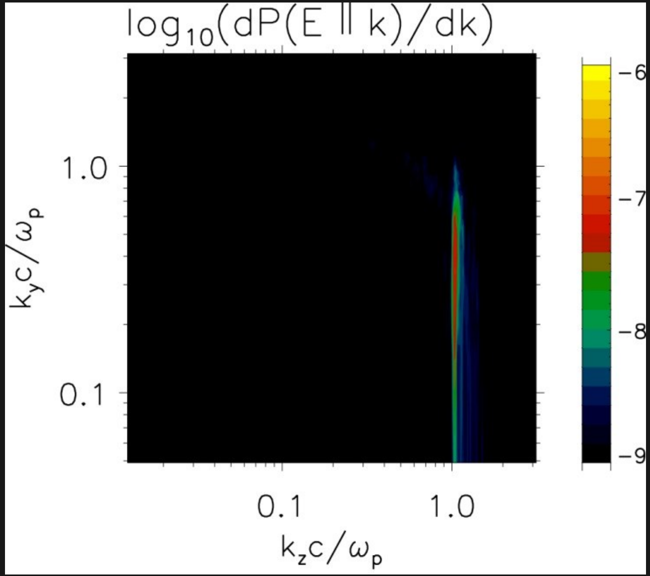


Pair-beam simulation

Growth to saturation level



Wave spectrum



Saturation process is analytically modelled

Nonlinear Landau damping and modulation instability

Extrapolation to reality

Simulation too short to capture energy loss

Understanding of saturation allows scaling to real pair beams

Saturation level W_k reflects equilibrium between driving and damping

Can calculate energy loss rate $\propto \int d^3k \, \omega_I W_k$

Plasma instabilities are ten times faster than Compton scattering

Cascade emission is suppressed!

Vafin et al. 2018

Extrapolation to reality

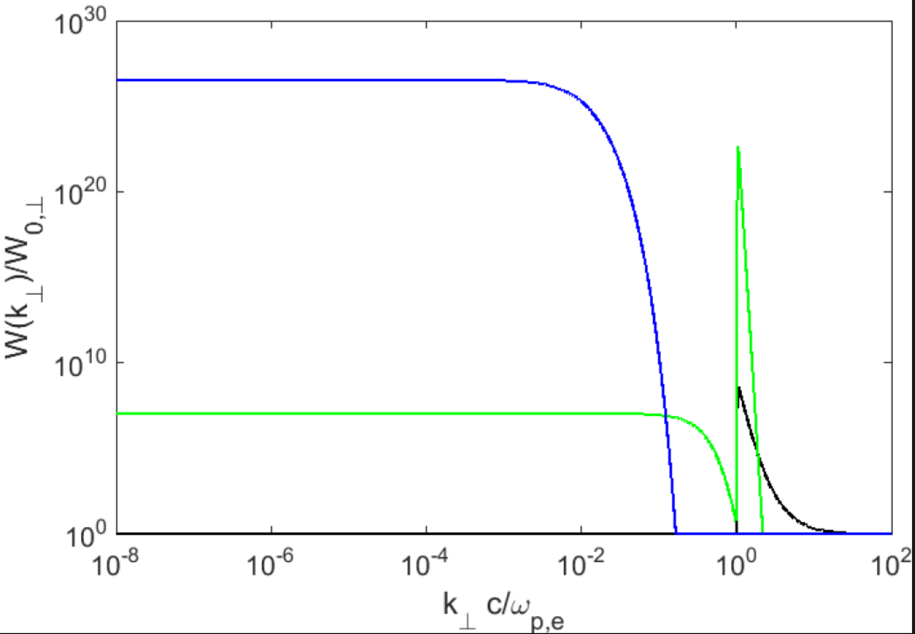
Does the analytical handling of the saturation work?

Nonlinear Landau damping

Numerical treatment

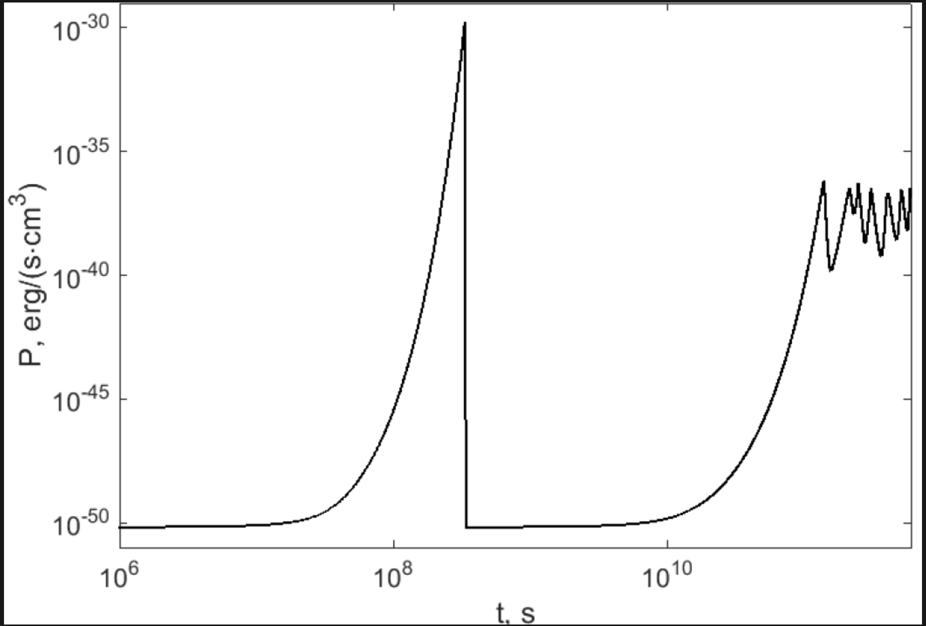
Vafin et al. 2019

→ no constant saturation level



Extrapolation to reality

→ no constant energy loss rate



Subdominant processes matter!

Adding collisions
increases the total energy loss
by a factor 10

What else do we miss??

Summary

Cascade emission following pair production of TeV radiation not seen

Interpretation as magnetic deflection requires strong fields in cosmic voids

We find that plasma instabilities can cool the pairs and suppress cascading, alleviating the need for a strong magnetic field

Substantial uncertainties in the estimate

Can we trust analytical treatment of saturation?

A fully time-dependent calculation for specific objects is needed.