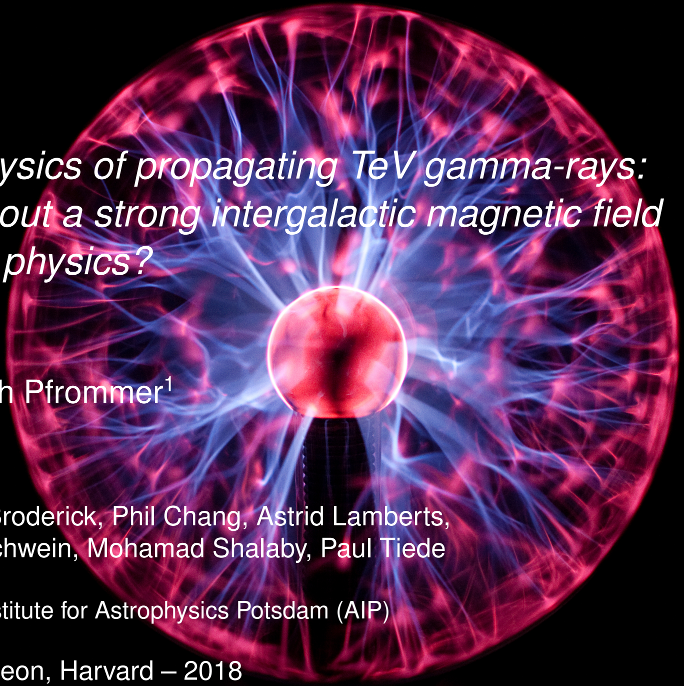


The physics of propagating TeV gamma-rays: Ruling out a strong intergalactic magnetic field or new physics?

Christoph Pfrommer[1]

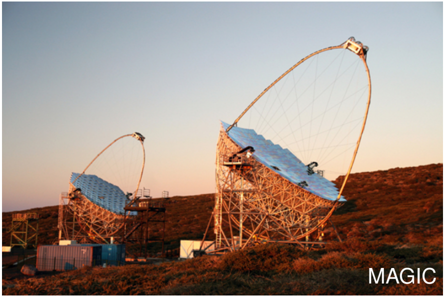
with

Avery E. Broderick, Phil Chang, Astrid Lamberts,
Ewald Puchwein, Mohamad Shalaby, Paul Tiede

[1]Leibniz Institute for Astrophysics Potsdam (AIP)

ITC Luncheon, Harvard – 2018

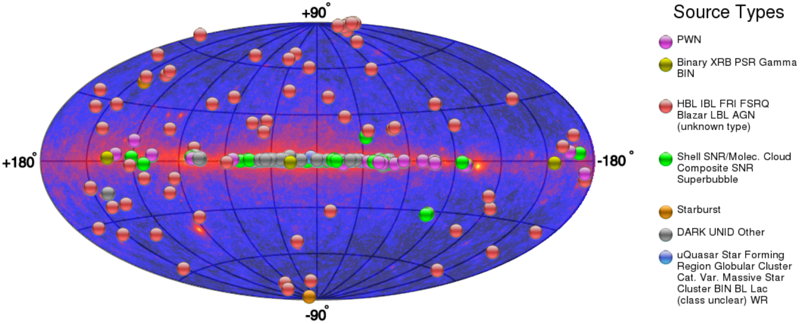
TeV gamma-ray observations



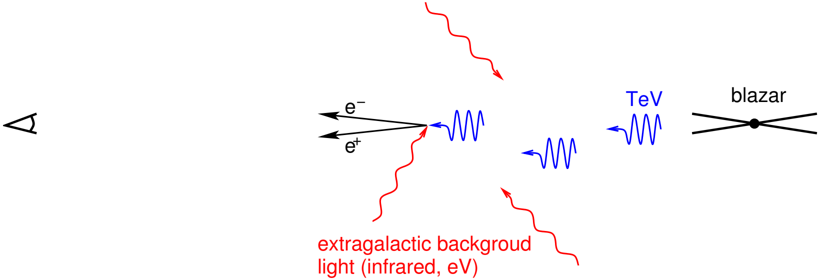
The TeV gamma-ray sky

There are several classes of TeV sources:

- Galactic - pulsars, BH binaries, supernova remnants
- Extragalactic - **mostly** blazars, two starburst galaxies

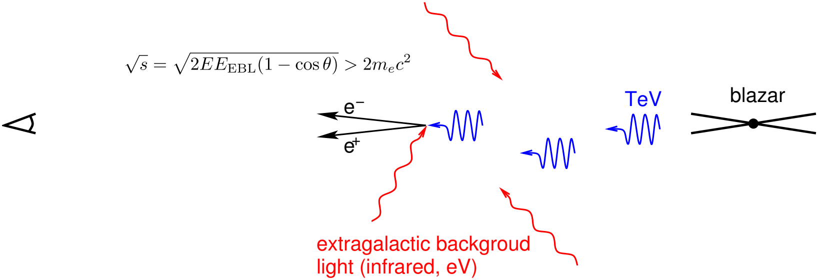


Annihilation and pair production



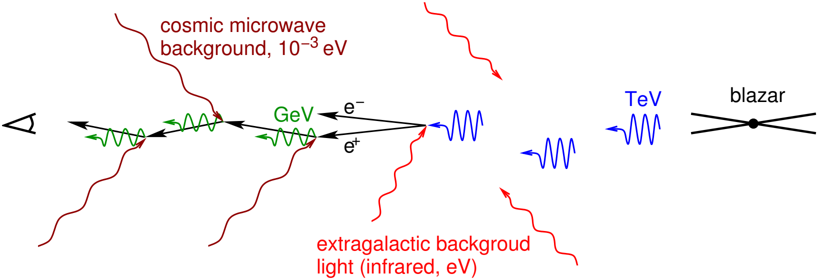
Annihilation and pair production

$$\sqrt{s} = \sqrt{2EE_{\mathrm{EBL}}(1-\cos\theta)} > 2m_e c^2$$



$$\lambda_{\gamma\gamma} \sim (35\ldots700)\ \mathrm{Mpc\ for}\ z = 1\ldots0$$

Inverse Compton cascades



$\lambda_{\rm IC} \sim \lambda_{\gamma\gamma}/1000$ $\lambda_{\gamma\gamma} \sim (35 \ldots 700)$ Mpc for $z = 1 \ldots 0$

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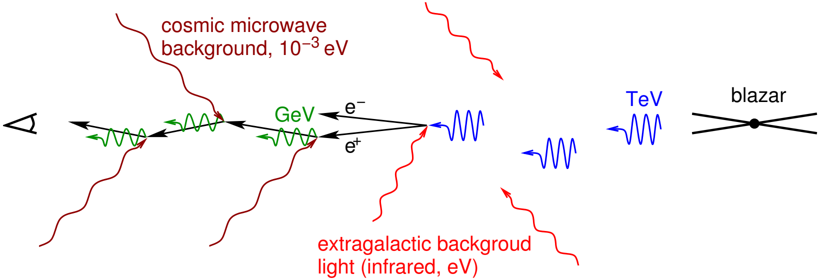
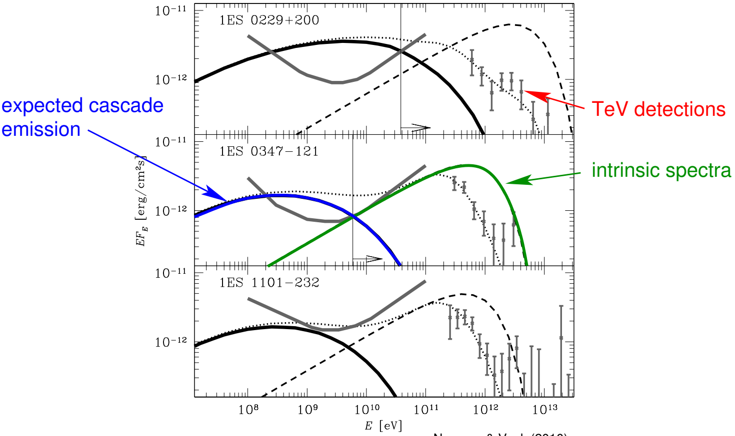


$\lambda_{\rm IC} \sim \lambda_{\gamma\gamma}/1000$ $\lambda_{\gamma\gamma} \sim (35 \ldots 700)$ Mpc for $z = 1 \ldots 0$

$\longrightarrow$ each TeV point source should also be a GeV point source!

What about the cascade emission?

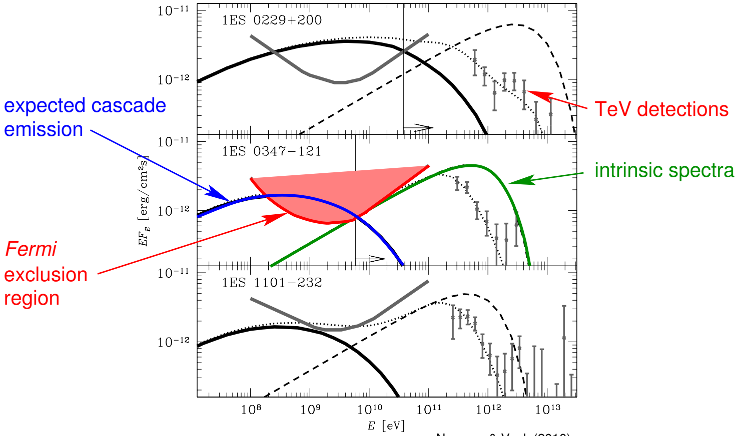
Every TeV source should be associated with a 1-100 GeV gamma-ray halo



Neronov & Vovk (2010)

What about the cascade emission?

Every TeV source should be associated with a 1-100 GeV gamma-ray halo – **not seen!**



Neronov & Vovk (2010)

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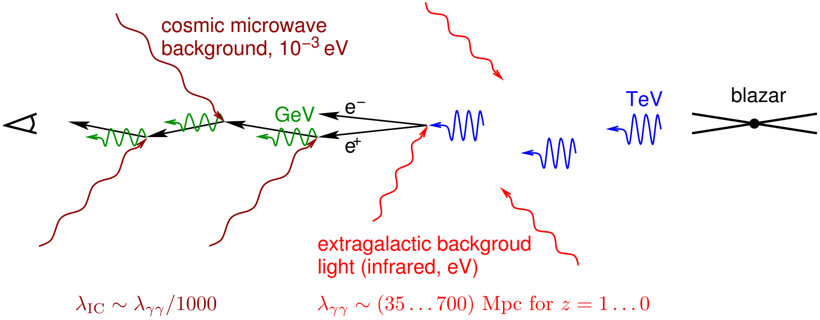
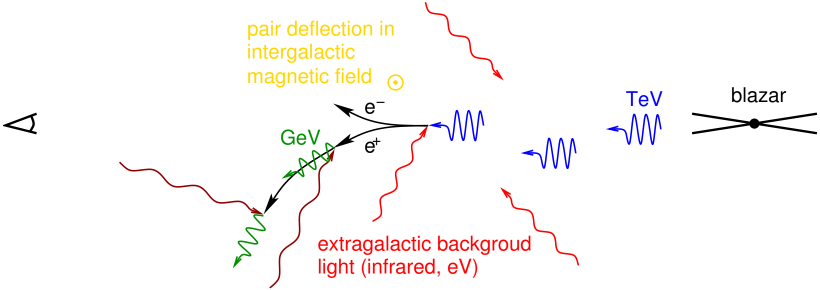


Extragalactic magnetic fields?



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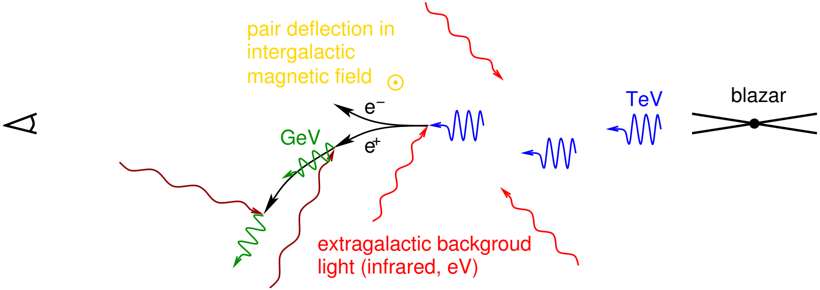
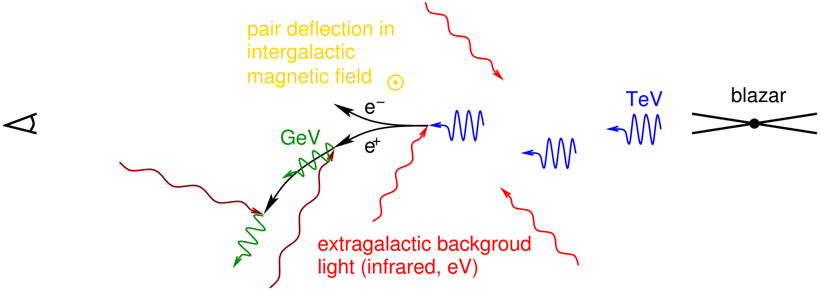


- GeV point source diluted $\longrightarrow$ weak "pair halo"
- stronger B–field implies more deflection and dilution,
  gamma–ray non–detection $\longrightarrow$ $B \gtrsim 10^{-16}\,\mathrm{G}$ – primordial fields?

Extragalactic magnetic fields?



- problem for unified AGN model: no increase in comoving blazar density with redshift allowed (as seen in other AGNs) since other–wise, extragalactic GeV background would be overproduced!

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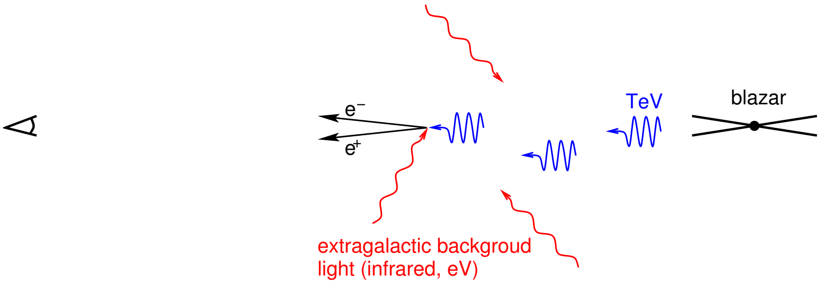
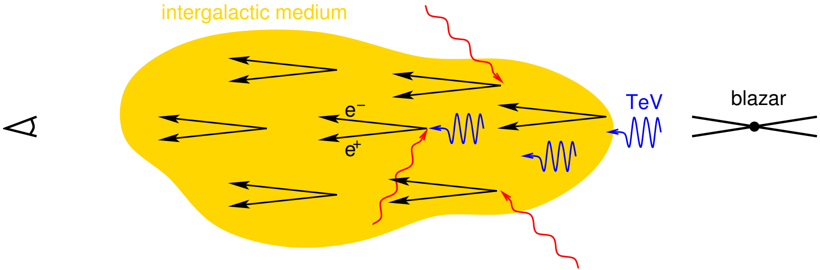
What else could happen?

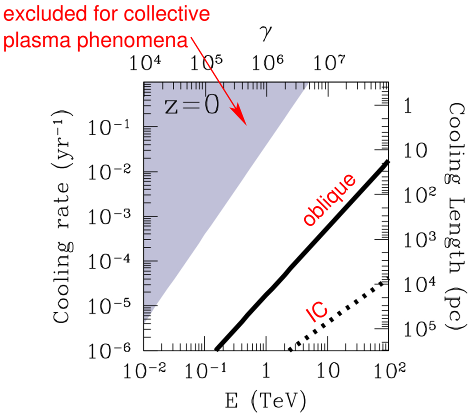


Plasma instabilities



→ pair plasma beam propagating through the intergalactic medium

Beam physics – growth rates



Broderick, Chang, C.P. (2012), also Schlickeiser+ (2012)

- consider a light beam penetrating into relatively dense plasma
- maximum growth rate

$$\Gamma \simeq 0.4\,\gamma\,\frac{n_{\rm beam}}{n_{\rm IGM}}\,\omega_p$$

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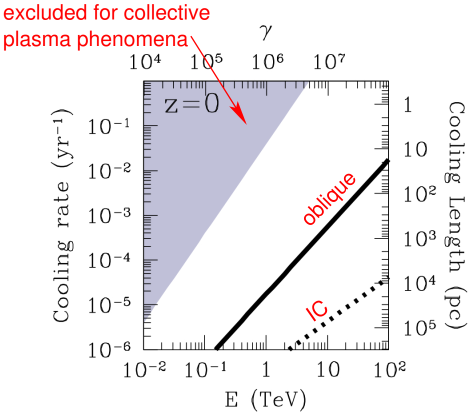

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- oblique instability beats inverse Compton cooling by factor 10-100
- **assume** that instability grows at *linear* rate up to saturation

TeV emission from blazars – a new paradigm

$$\gamma_{\mathrm{TeV}} + \gamma_{\mathrm{eV}} \rightarrow e^{+} + e^{-} \rightarrow \begin{cases} \text{inv. Compton cascades} & \rightarrow \gamma_{\mathrm{GeV}} \\ \text{plasma instabilities} & \end{cases}$$

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TeV emission from blazars – a new paradigm

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absence of γ_{GeV}'s has significant implications for ...

- intergalactic magnetic field estimates
- unified picture of TeV blazars and quasars
  explains *Fermi's* γ-ray background and blazar number counts

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- thermal history of the IGM: Lyman-α forest
- late-time formation of dwarf galaxies

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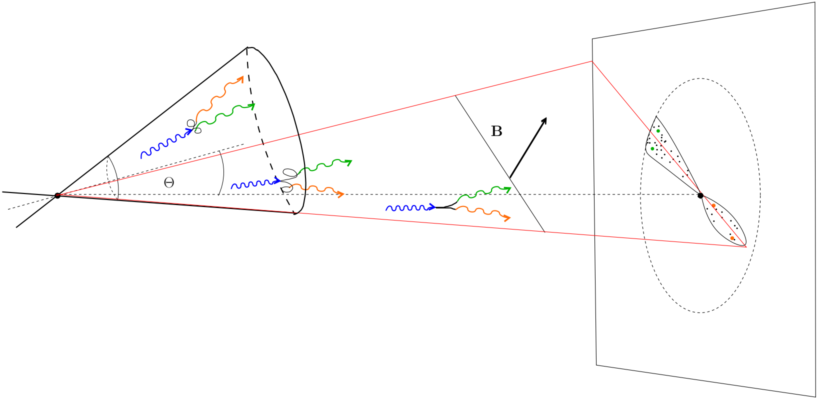
Cartoon of IC halo: blazar with homogeneous field



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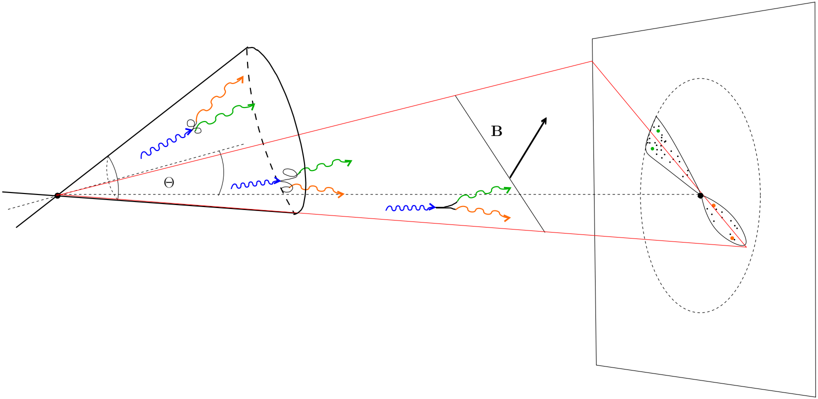

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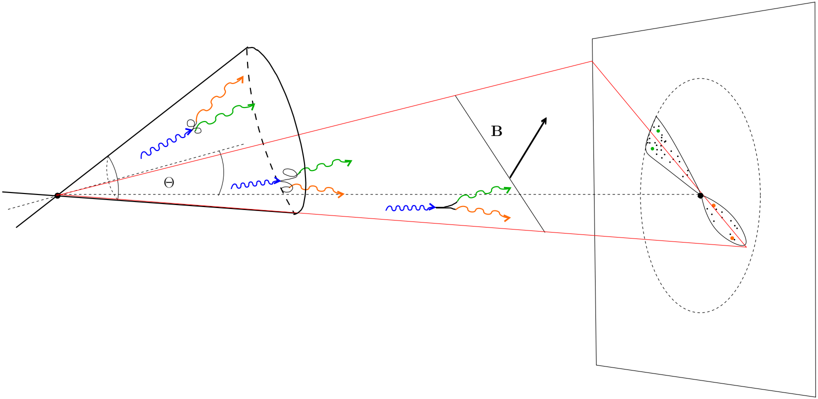

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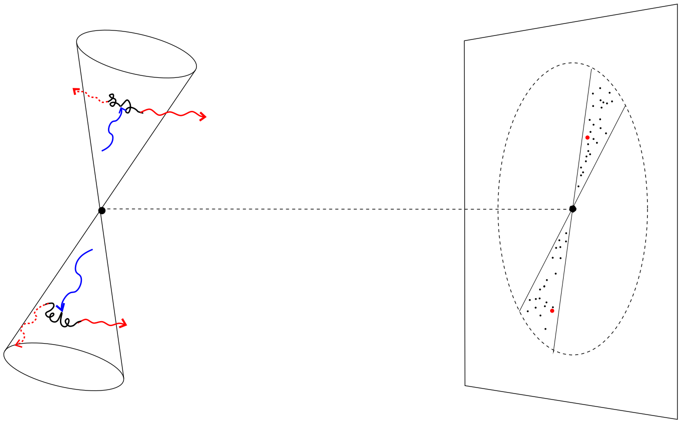
  $\Rightarrow$ no signal $\Rightarrow$ rule out large-scale intergalactic magnetic field with $3 \times 10^{-18}\mathrm{G} < B < 10^{-14}\mathrm{G}$

Cartoon of IC halo: radio galaxy with small-scale field



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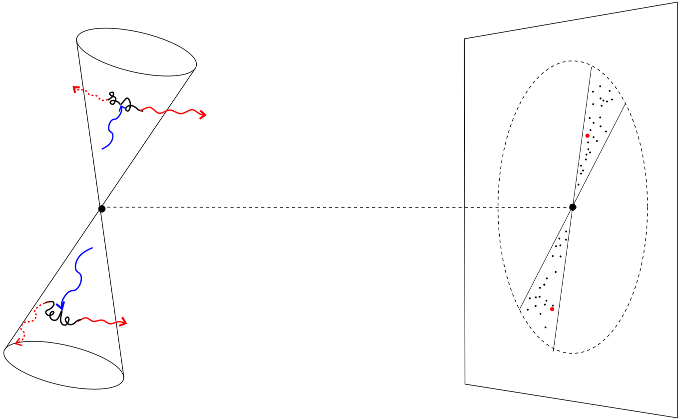

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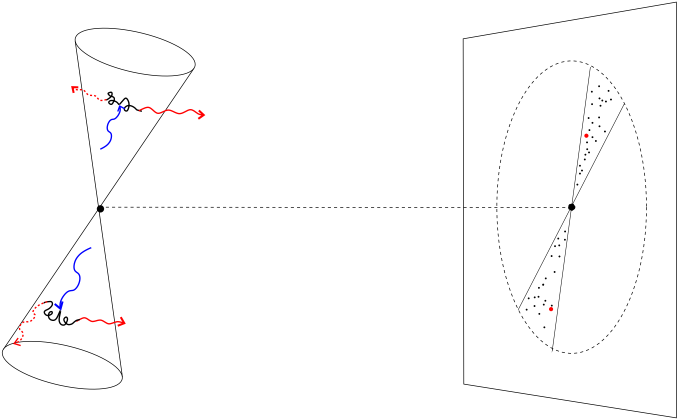
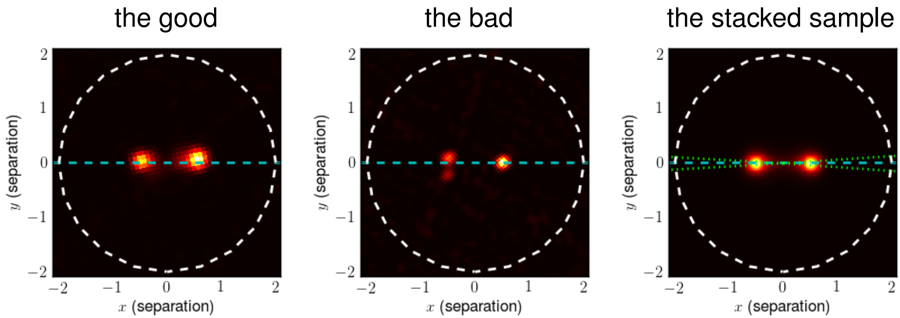


Broderick, Tiede, Shalaby, C.P., Puchwein, Chang, Lamberts (2016), Broderick+ (subm.)

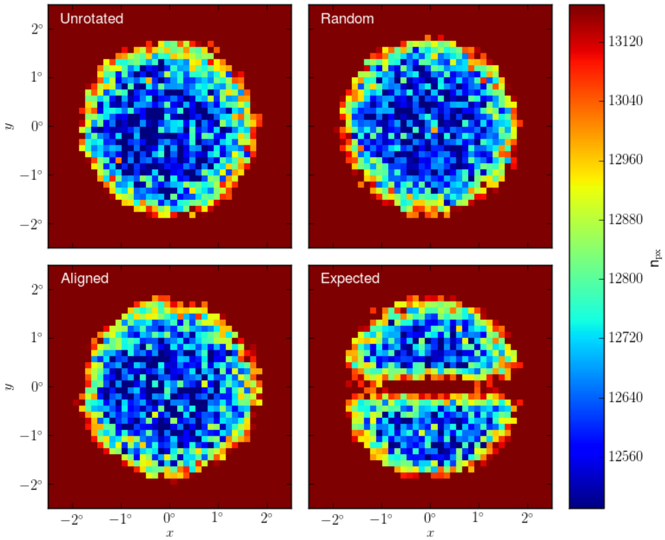
- select 9,000 isolated radio jets of the VLA FIRST sources
- align and stack GeV γ-ray images of oblique radio jets

Aligned VLA FIRST radio jets



Broderick, Tiede, Chang, Lamberts, C.P., Puchwein, Shalaby (subm.)

Stacked 1-100 GeV *Fermi* gamma-ray data



Broderick, Tiede, Chang, Lamberts, C.P., Puchwein, Shalaby (subm.)

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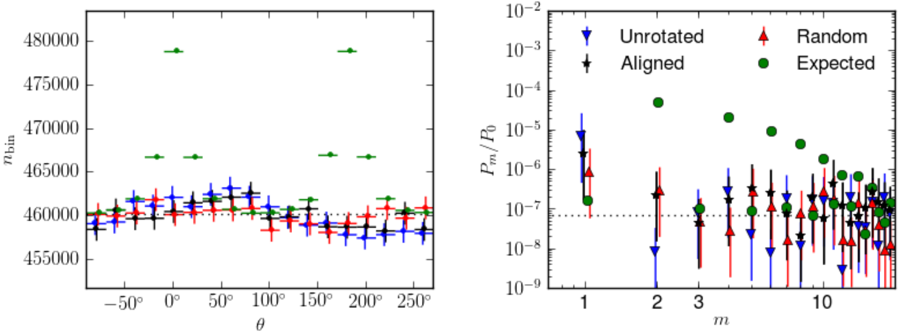
Angular histogram and power spectra of photons



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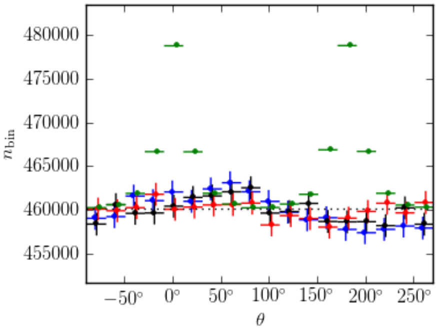

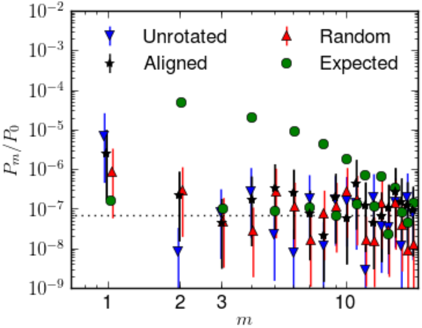

Broderick, Tiede, Chang, Lamberts, C.P., Puchwein, Shalaby (subm.)

- non-detection of IC halos in stacked GeV γ-ray data:

  $B < 10^{-15}$G independent on correlation length

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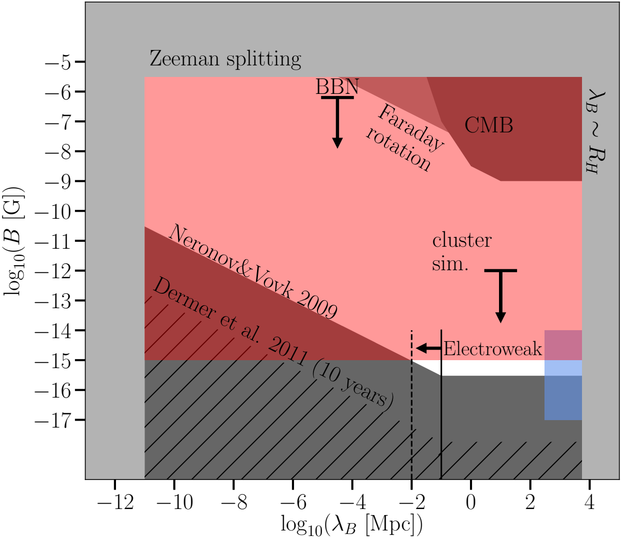
Constraints on intergalactic magnetic fields



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TeV emission from blazars – a new paradigm

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Literature for the talk

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