LOOKING INTO THE DARK: THE FINGERPRINT OF NEUTRALINOS AND AXIONS IN GAMMA-RAYS

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Gamma-ray Dark Matter searches

A. **Direct detection:** scattering of DM particles on target nuclei (nuclei recoil expected).

B. **Indirect detection:** DM annihilation products (neutrinos, positrons, gammas…)

C. **Direct production** of DM particles at the lab (e.g. LHC @ CERN).

In gamma-rays, most of the effort based on the detection of neutralino annihilations.

IACTs and satellites: MAGIC, HESS, VERITAS, CANGAROO, Fermi, AGILE…

E. range: 10 MeV - 300 GeV

E. resolution: <10% @ 10 GeV

FoV: ≈2.4 sr

Angular resolution: 0.1º@10 GeV

Fermi/LAT

E. range: 100 GeV - 30 TeV

E. resolution: >20%

FOV: ≈ 4 deg.

Angular resolution: ≈ 0.1º

Typical IACT

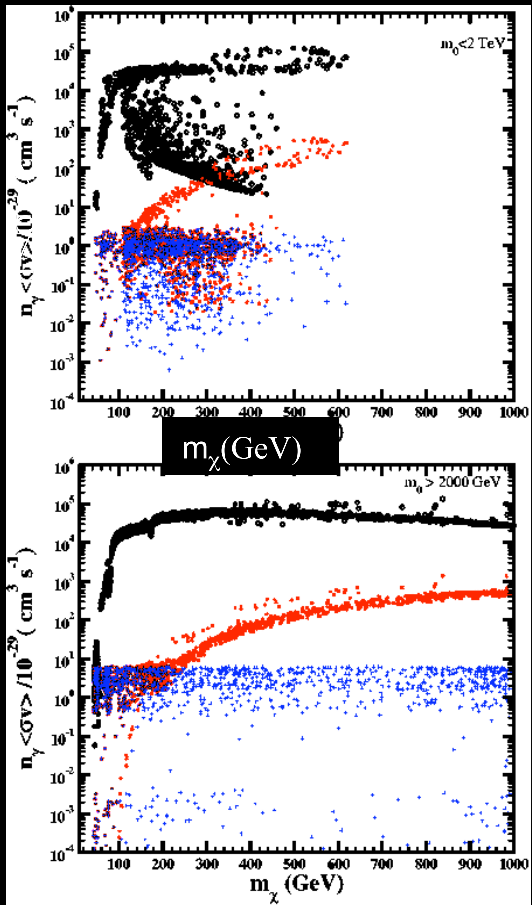
The gamma-ray DM annihilation flux

$$F_\gamma(E > E_{th}) = \frac{1}{4\pi} f_{susy} \cdot U(\Psi_o)$$ photons cm^{-2} s^{-1}

Particle physics

Astrophysics

(Sánchez-Conde et al. 2007)



SUSY Model:

$$f_{susy} = \frac{n_\gamma \langle \sigma \cdot v \rangle}{2 m_\chi^2}$$

- n_γ: Number of photons
- $<\sigma$ v>: cross section
- m_χ: neutralino mass

Large uncertainties!

$$U(\Psi_o) = \int J(\Psi) B(\Omega) d\Omega$$

Integral along the l.o.s.:

$$J(\Psi) = \int_{l.o.s} \rho_{dm}^2(r) dl$$

Telescope PSF:

$$B(\Omega) d\Omega = \exp\left(\frac{-\theta^2}{2\sigma_t^2}\right) \sin\theta d\theta d\phi$$

Where to search?

- Galactic Center
- Dwarf spheroidal galaxies (e.g. Draco, Willman-1…)
- Andromeda
- Galaxy clusters (e.g. Virgo, Coma)
- Etc, etc.

No success up to now…

- IACTs (above 100 GeV):
  - Several dwarfs: Draco, Willman 1, Segue 1, CMa, Bootes 1, UMi, Sagittarius…
  - Some clusters: Perseus, Coma, Abell 496, Abell 85, Abell 3667, Abell 4608…
  - Upper limits seem to be 3-4 orders of magnitude above predictions

- Fermi (below few dozens GeV):
  - Analysis done for 8 out of the best dwarfs using 11 months of data.
  - Clusters: no gamma-signal found for 33 targets. 6 of them analyzed in a DM context.
  - DM spectral line signatures all over the sky: no hint of lines up to 300 GeV.

- Situation somewhat discouraging but still a lot of work to do! Clarification of best targets and new strategies still welcome.

Cluster of galaxies VS dwarfs

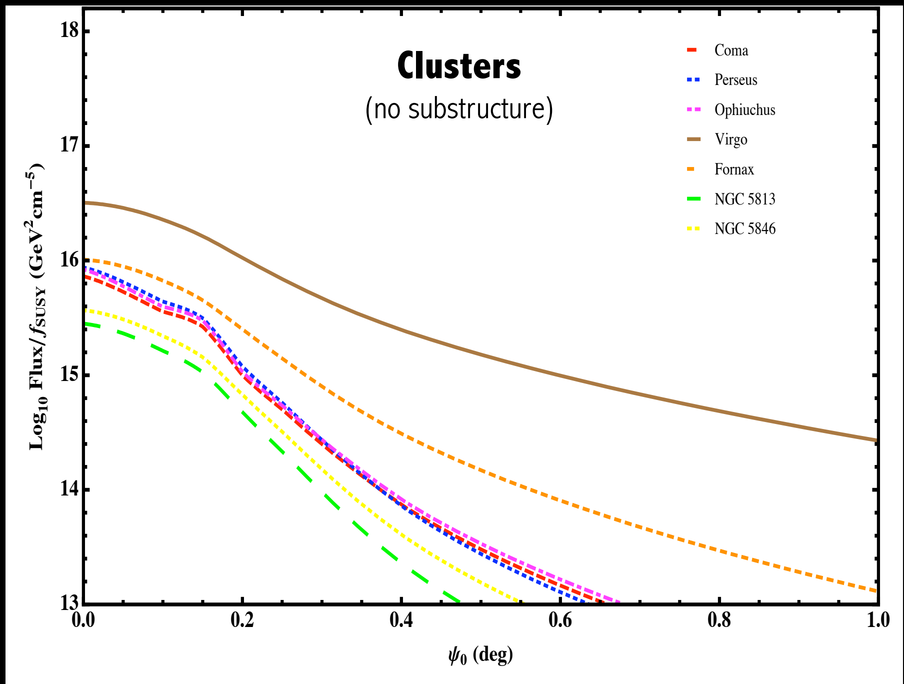
CLUSTERS

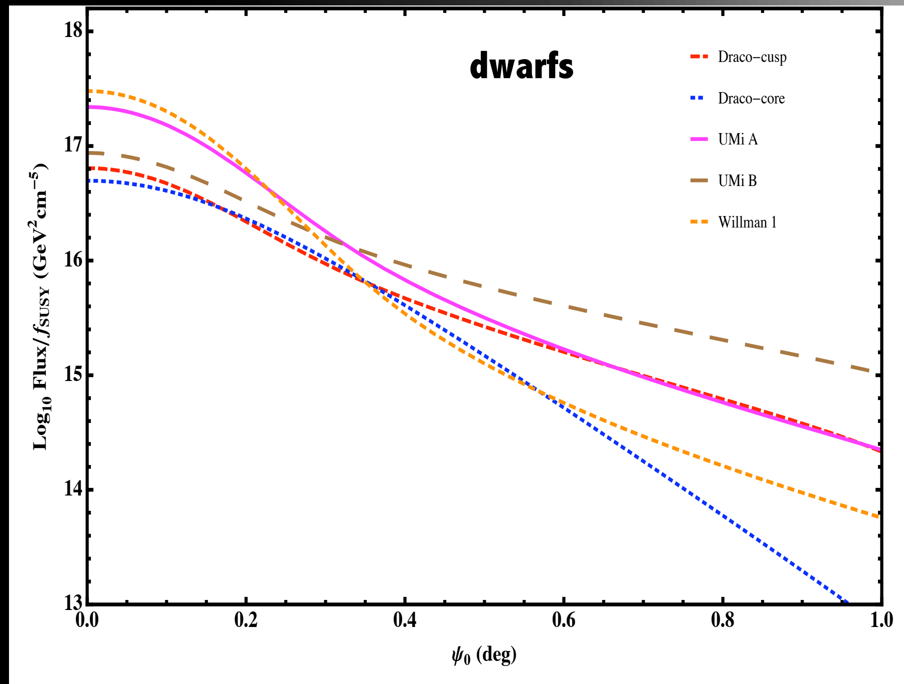
- ✓ Much more distant, but they content impressive amounts of DM.
- ✓ Substructure boosts may be really important.
- ✓ Contamination by other gamma sources expected

DWARFS

- ✓ Very near.
- ✓ No gamma-ray astrophysical sources expected in most cases.
- ✓ Most DM-dominated systems in the Universe

A quantitative comparison of the DM detection prospects for the most promising clusters and nearby dwarf galaxies is ongoing.





(MASC et al., in prep.)

Learning from CLUES

CLUES
Constrained Local UniversE Simulations

- Main characteristics of CLUES:
  - Constrained N-body cosmological simulations of the Local Universe.
  - Runs with WMAP3 and WMAP5 parameters.
  - 1 box 160 h^{-1} width and 5 boxes 64 h^{-1} Mpc each.
  - More details on http:// clues-project.org.

- Different works already ongoing using CLUES data:
  - I. Extragalactic component of the DM annihilation flux.
  - II. Comparison between galaxy clusters and MW subhalos.
  - III. Angular spectrum of anisotropies in the EGB.

COMA
LSC
GA
PP
Virgo
Local Group

MULTIDARK
Multimessenger Approach for Dark Matter Detection

CLUES from Fermi

CLUES
Constrained Local UniversE Simulations

"Extragalactic gamma-rays from dark matter decay and annihilation"

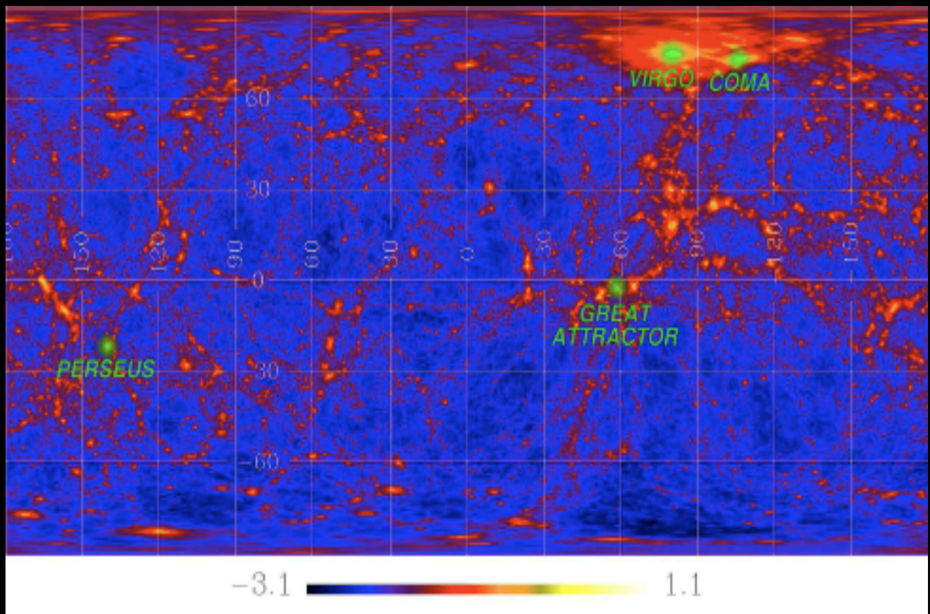
Cuesta, Jeltema, Zandanel, Profumo, Prada, Yepes, Klypin, Hoffman, Gottlöber, Primack, MASC & Pfrommer

(submitted to ApJ letters, astro-ph/)

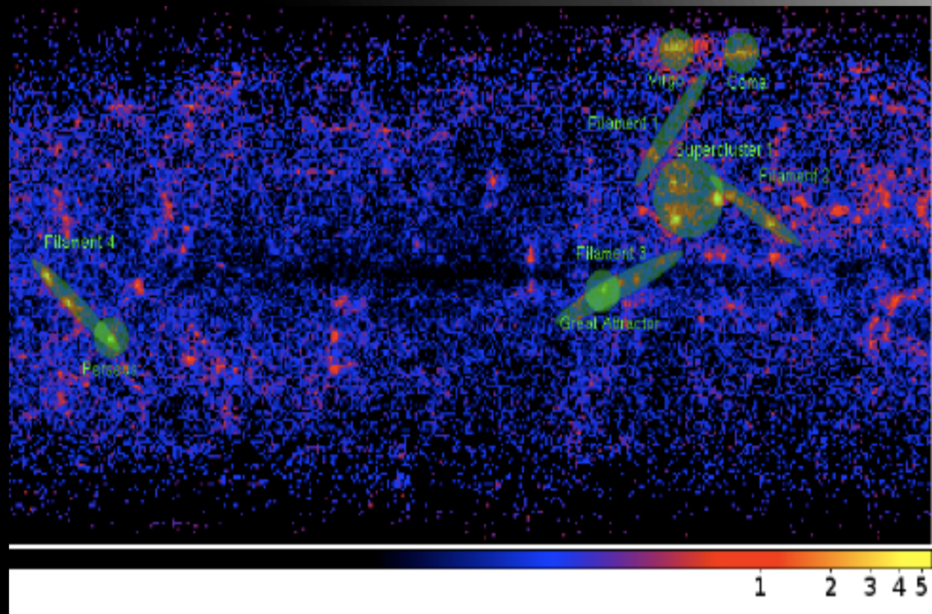
- We use CLUES to obtain γ-ray all-sky maps of the Local Universe from DM decay and annihilation.
- By running *Fermi* observation simulation (5-year survey) we properly take into account the real backgrounds and instrument response:

  → *Fermi* may detect DM-induced γ-rays from extragalactic objects (clusters, groups, filaments)

  → DM decay more promising than DM annihilations



DM density distribution in the Local Universe

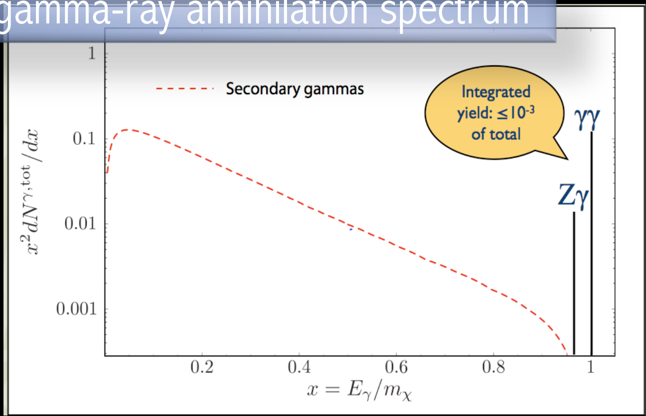


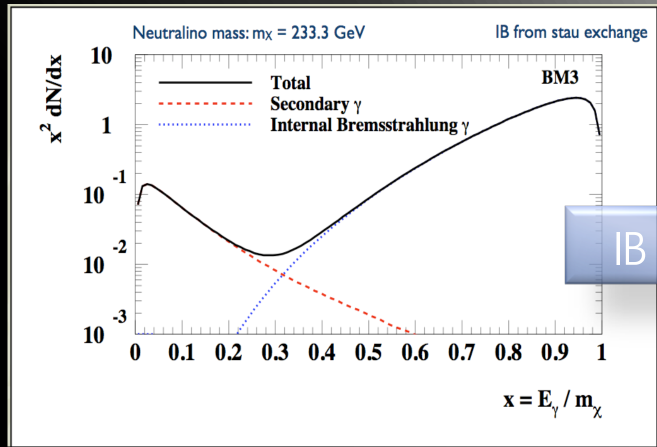
S/N all-sky map from Fermi simulations for DM decay

Impact of Internal Bremsstrahlung on annihilation signal

- Some effects (subestructure, Sommerfeld effect, IB) may enhance the expected gamma signal
- Commonly neglected first-order radiative corrections (IB) may be very important, specially for IACTs.

Typical gamma-ray annihilation spectrum

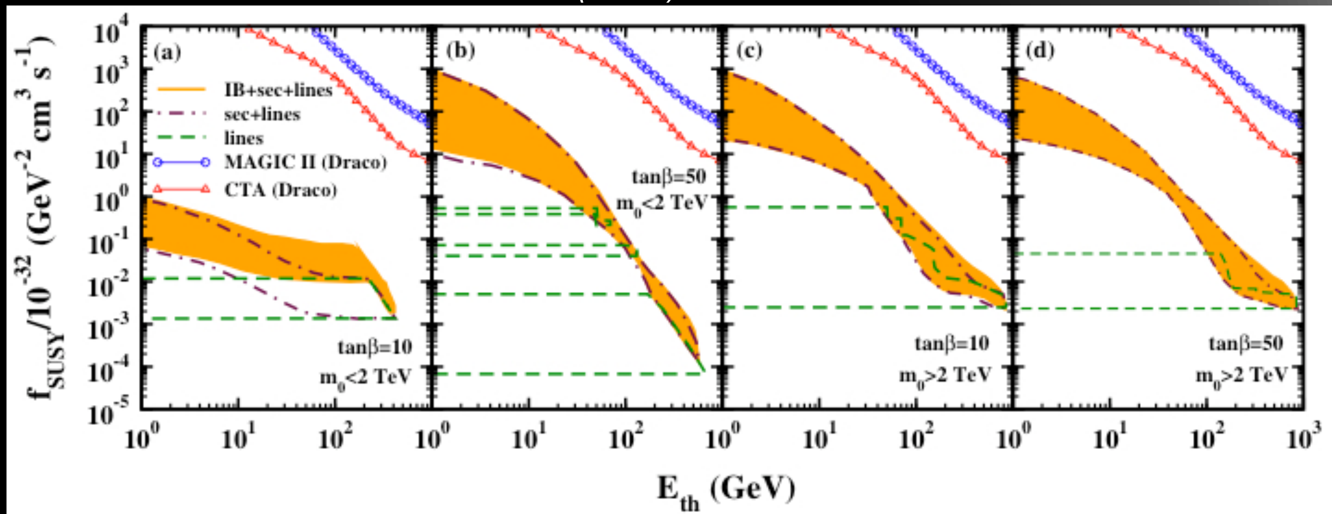




IB at work!

Bringmann et al. (2008)

Cannoni, Gómez, MASC, Prada, Panella (2010)



The most affected models are those with the lowest cross sections

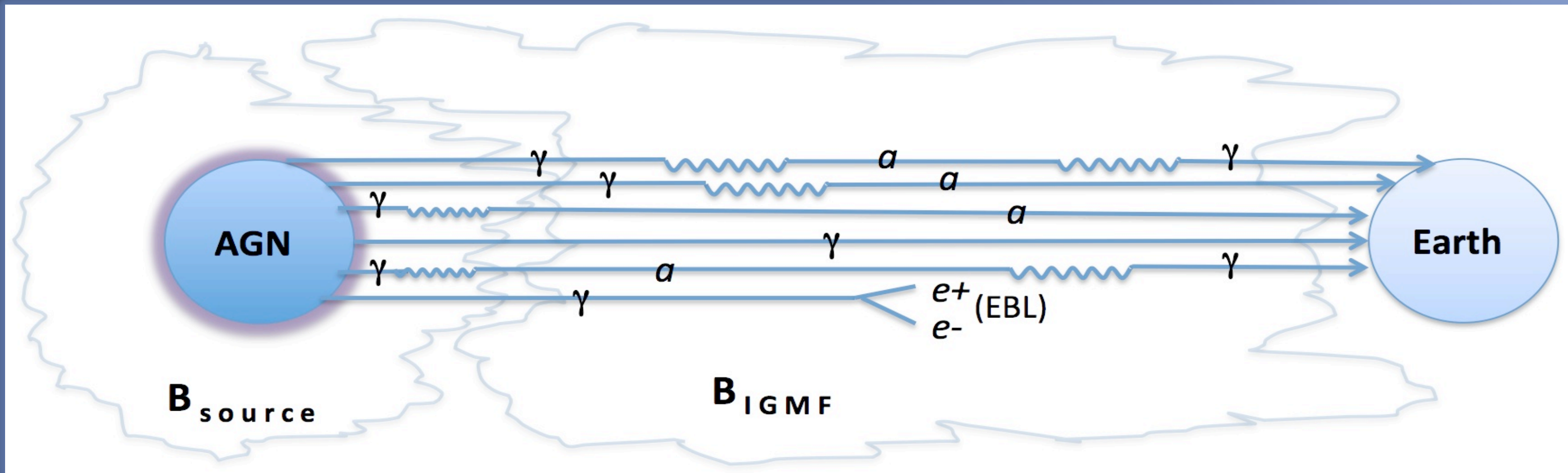
Conclusion: prospects don't change so much!

AXIONS

Exploring an alternative scenario

Photon/axion conversions in gamma-rays

- Axions (pseudoscalar boson) were postulated to solve the strong-CP problem in the 70s.
- Good Dark Matter candidates
- They are expected to convert into photons (and viceversa) in the presence of magnetic fields:



(Sánchez-Conde+, PRD 09)

AGNs located at cosmological distances will be affected by both mixing in the source (e.g. Hooper & Serpico 07) and in the IGMF (De Angelis+07):

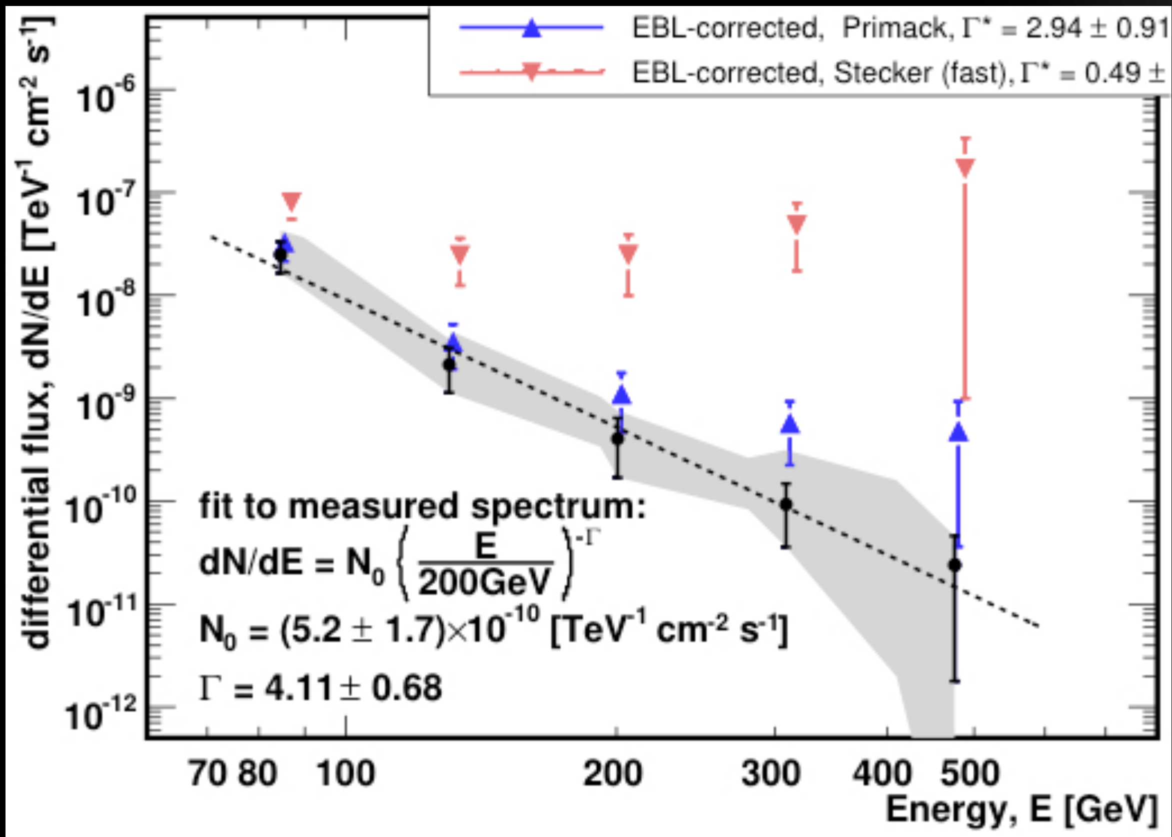
A. Source mixing: flux attenuation
B. IGM mixing: flux attenuation and/or enhancement

$$E_{crit}(GeV) \equiv \frac{m^2_{\mu eV}\ M_{11}}{0.4\ B_G}$$

In order to observe both effects in the gamma-ray band, we need ultralight axions.

Hints for new physics?

- Recent gamma observations might already pose substantial challenges to the conventional models to explain the observed source spectra and/or EBL density.
  - More high energy photons than expected.
  - Very hard intrinsic spectrum, difficult to explain with conventional EBL models and physics.

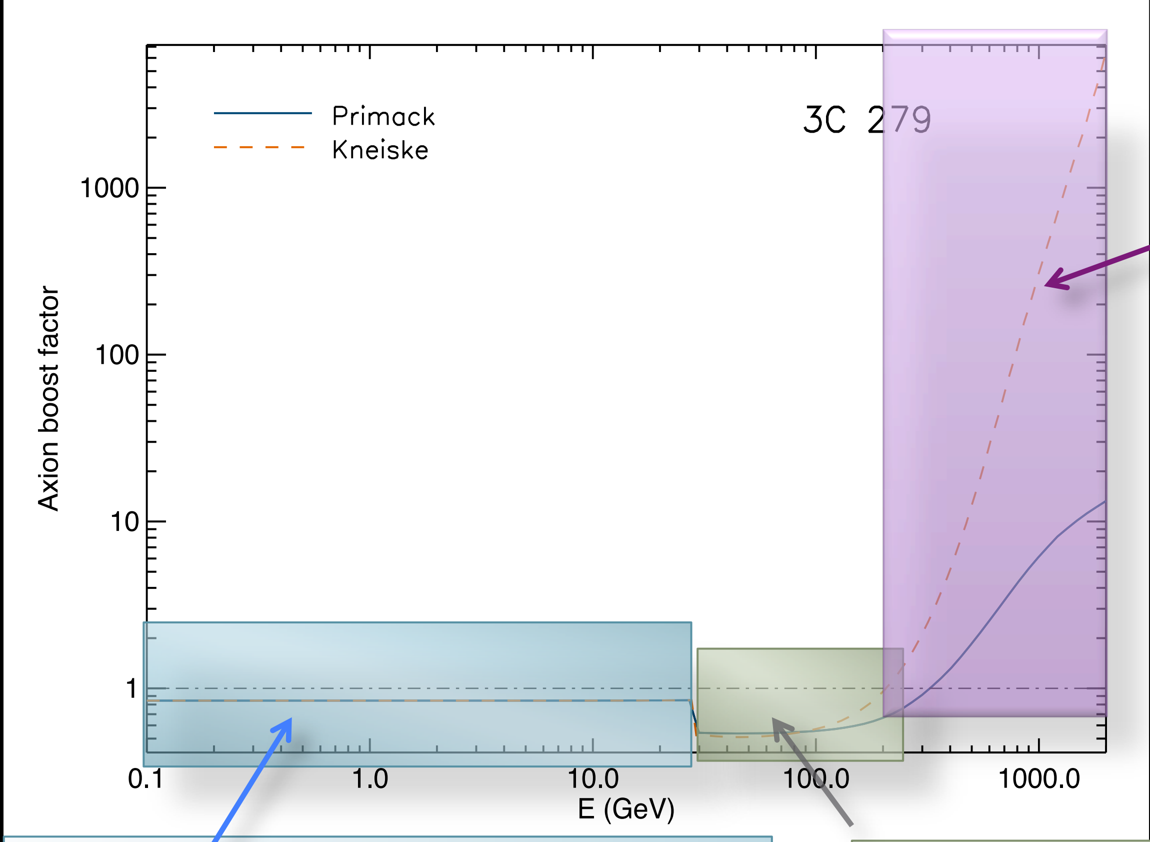


[MAGIC Collaboration, Albert et al. 2008]

3C 279

- ✓ Flat spectrum radio quasar
- ✓ z=0.54
- ✓ The most distant AGN in gamma-rays (>100 GeV)
- ✓ Push EBL models already to the limit!
- ✓ Modeling of AGN emission mechanisms typically assume **spectral index >1.5**

Observational strategy with Fermi and IACTs



IACTs observations

Look for systematic intensity **enhancements** at energies where the EBL is important.

Distant ($z > 0.2$) sources at the highest possible energies (>1 TeV), to push EBL models to the extreme.

Source and EBL model dependent, but very important enhancement expected in some cases.

Fermi/LAT and/or IACTs

Look for intensity **drops** in the residuals ("best-model"-data).

Source model dependent.

Powerful, relatively **near** AGNs.

Fermi/LAT and/or IACTs

Look for intensity **drops** in the residuals.

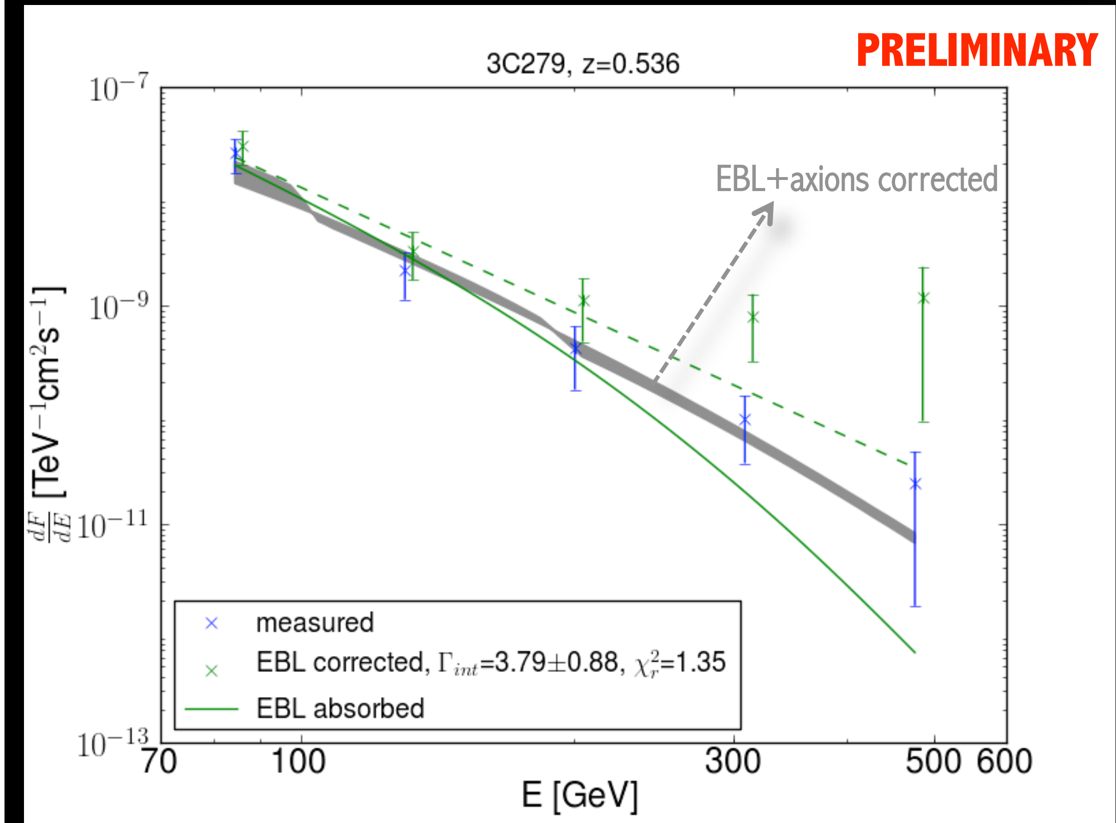
Only depends on the IGMF and axion properties (mass and coupling constant).

Independent of the sources -> CLEAR signature!

Testing the photon/axion scenario

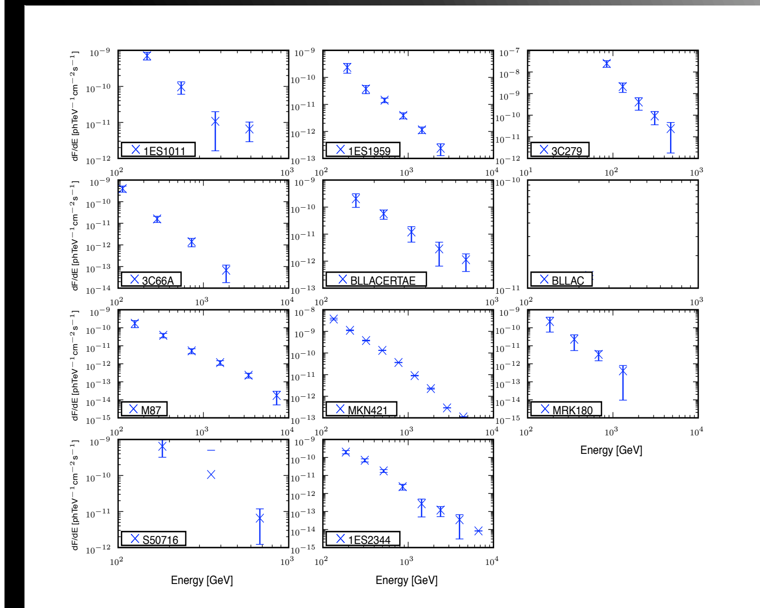
Applying the photon/axion mixing scenario to some controversial spectra of distant AGNs:

- Scanning the region of the B-mass parameter space which is accessible to IACTs and Fermi.
- The best results are achieved by assuming critical energies around 100-200 GeV for the most distant AGNs (3C279, 3C66A).



[3C279 data points from the MAGIC Collaboration, Albert et al. 2008]

11 suitable (public) AGN spectra have been collected from MAGIC observations. Similar work will be done with Fermi data



New AGN observed by MAGIC at z=0.435 !!

(ATel #2684)

SPAIN won the World Cup !!!

Future of neutralino and ALP searches in γ-rays

MULTIDARK
Multimessenger Approach for Dark Matter Detection

NEUTRALINOS

- **Dwarfs** probably the best candidates at present. However, **galaxy clusters** could be at the same flux level.
- **DM decay** might be very promising, with predicted fluxes comparable to those expected from DM annihilations
- **Fermi** especially important in neutralino searches:
  - All-sky survey -> e.g. great to seach for new DM candidates!
  - **IACT follow-up** of possible DM candidates discovered by Fermi and deeper observations at high energies
- Instruments that join an improved sensitivity with a Large FoV: MAGIC II, **CTA**…
- Explore **other possible DM scenarios**: IMBHs, microhalos, other particle physics models…

AXIONS

- If axions exist, they could **distort the spectra** of astrophysical sources importantly.
- If there is mixing in the IGMFs, then also mixing in the source. **If $m_{axion} \approx 10^{-10}$ eV -> γ-rays**.
- The effect is expected to be present over several decades in energy -> **joint effort of Fermi and current IACTs** needed.
- **Detailed observations of AGNs** at different redshifts and different flaring states could be used to identify the signature of an effective photon/axion mixing.