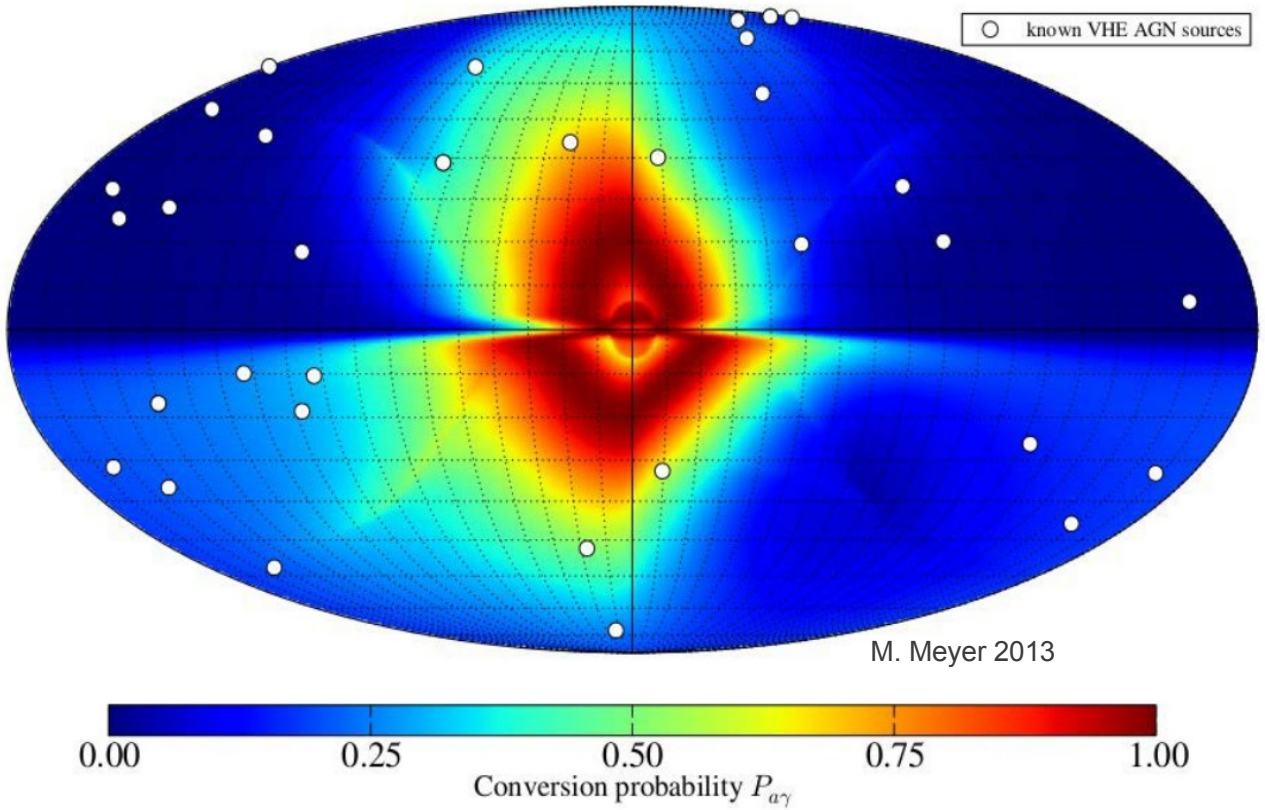
# HE/VHE gamma-ray propagation → sensitivity for ALPs with NeGHE

Dieter Horns, University of Hamburg



# ALPs – motivation → Previous talk

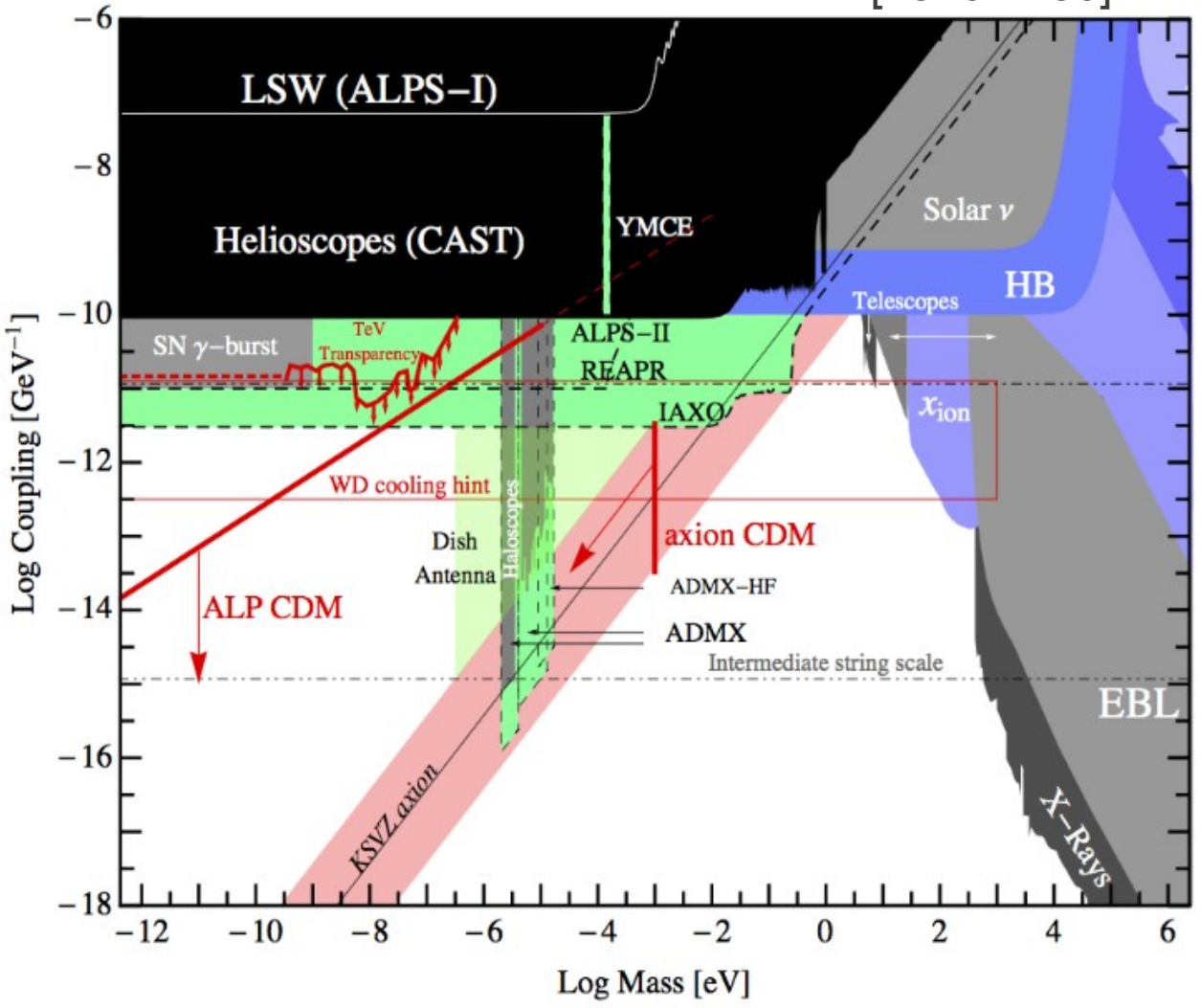
- Strong CP-problem: Solution with addtl. U(1) symmetry → Nambu-Goldstone boson [Weinberg 78, Wilczek 78]: Axion with coupling to Photon

$$\mathcal{L} \supset -\frac{g_{A\gamma}}{4} A F_{\mu\nu} \tilde{F}^{\mu\nu}$$

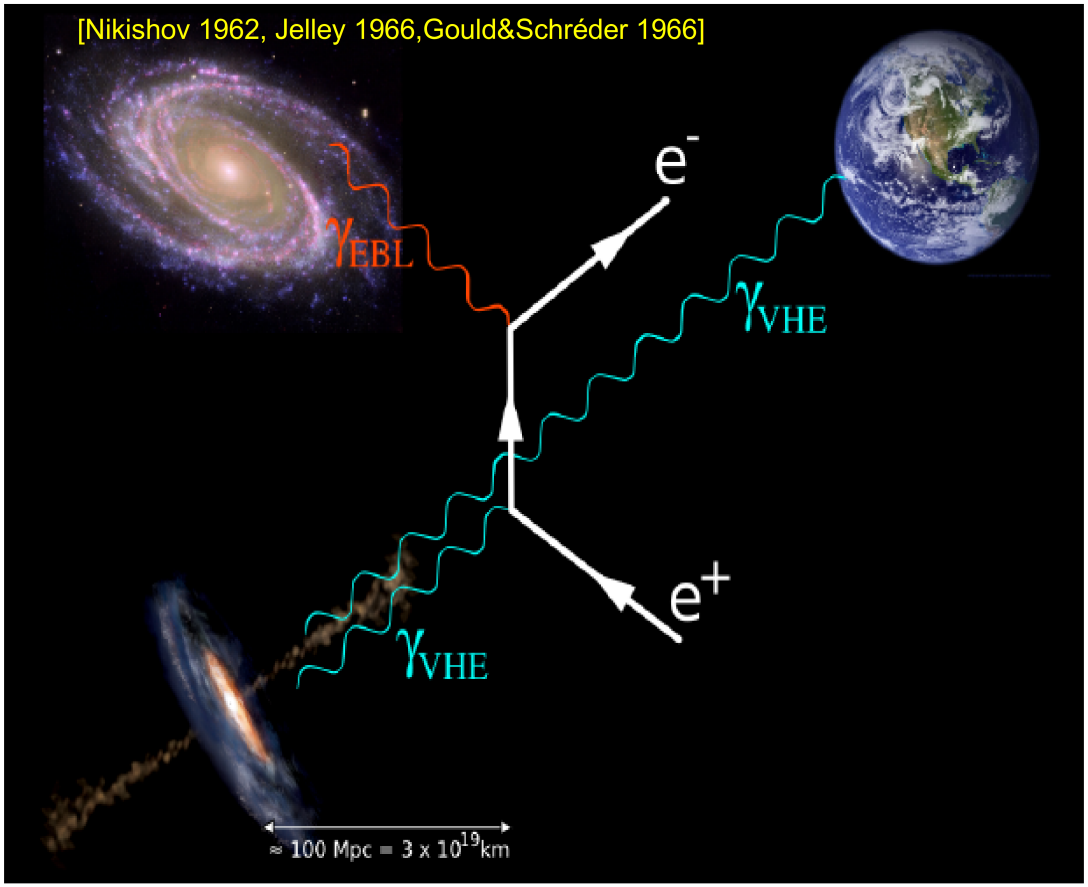
- Axionic dark matter through vacuum re-alignment: ultra-cold dark matter [Preskill et al. 83, Abbott, Sikivie 83, Dine, Fischler 83]
- Bottom-top motivation for generic ALPs: $U(1)_{PQ}$ extension of the SM [Langacker et al. 86, arXiv:1310.1256] motivates intermediate energy ($10^9$-$10^{11}$ GeV), solves DM, Baryon asymmetry, neutrino mass...
- Top-bottom motivation: „Axiverse“ from string theory (IIB compactification: at least 2 axions at intermediate scale [e.g. 1209.2299]

# ALPs coupling/mass

[1310.1256]

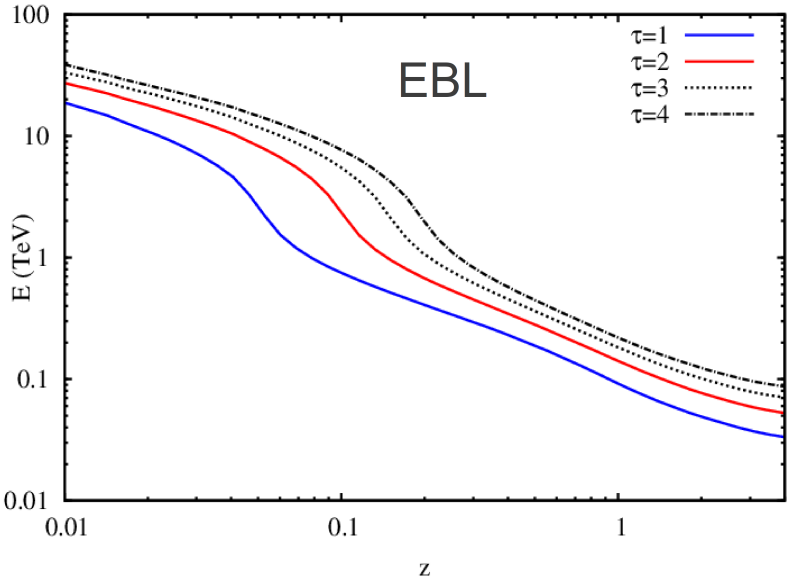


# Gamma-ray attenuation via pair-production




$$\tau_\gamma(E, z_0) = \int_0^{z_0} d\ell(z) \int_{-1}^{+1} d\mu \frac{1-\mu}{2} \int_{\epsilon_{\rm thr}}^{\infty} d\epsilon' n_{\rm EBL}(\epsilon', z) \sigma_{\gamma\gamma}(E, \epsilon', \mu)$$

$$\frac{dN_{\rm obs}}{dE} = \frac{dN_{\rm int}}{dE} \times \exp\left[-\tau_\gamma(E, z_0)\right]$$



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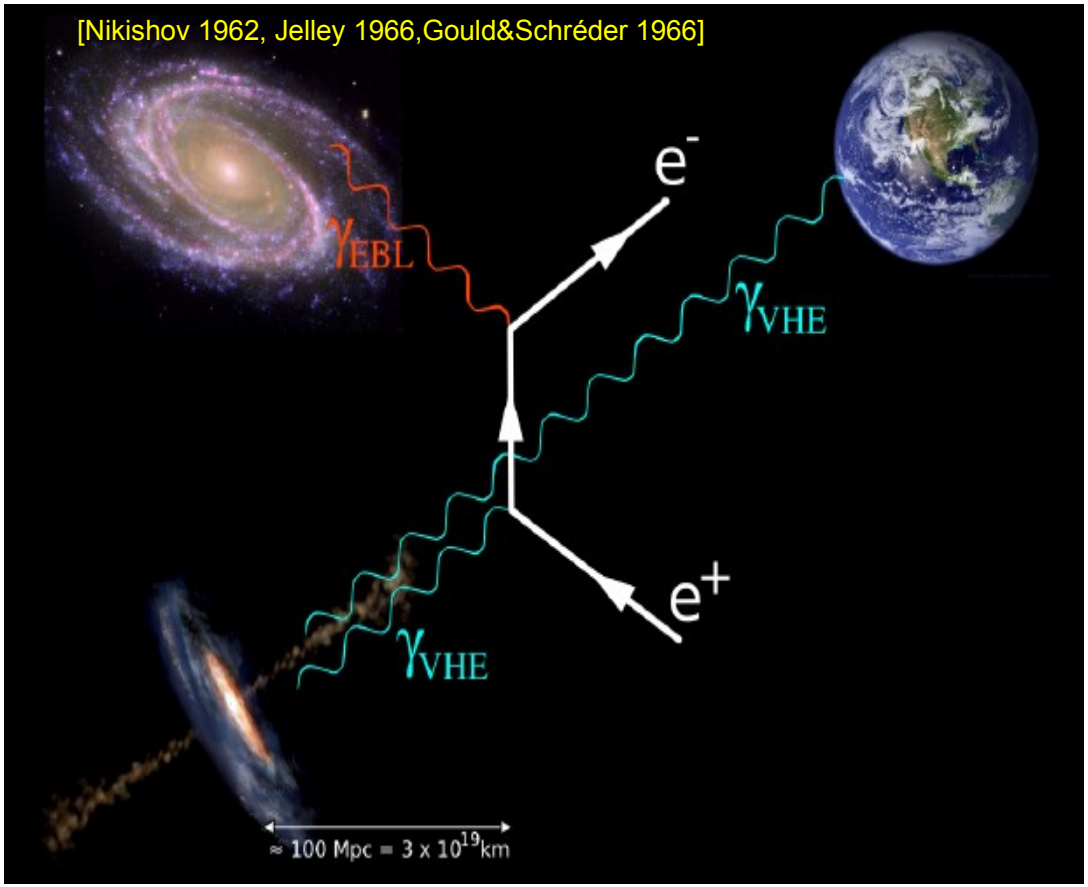


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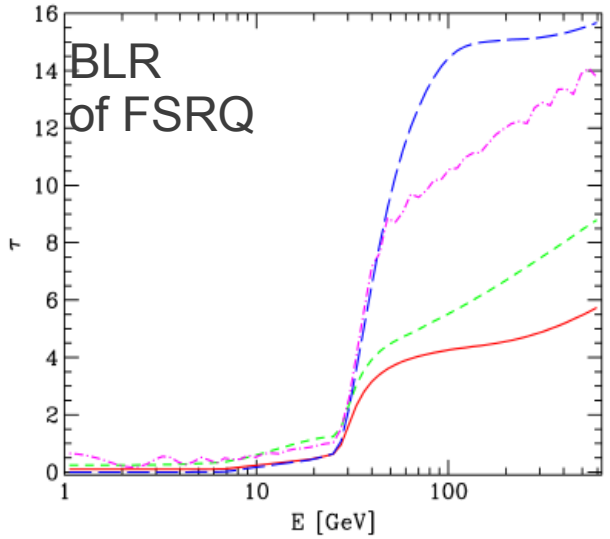
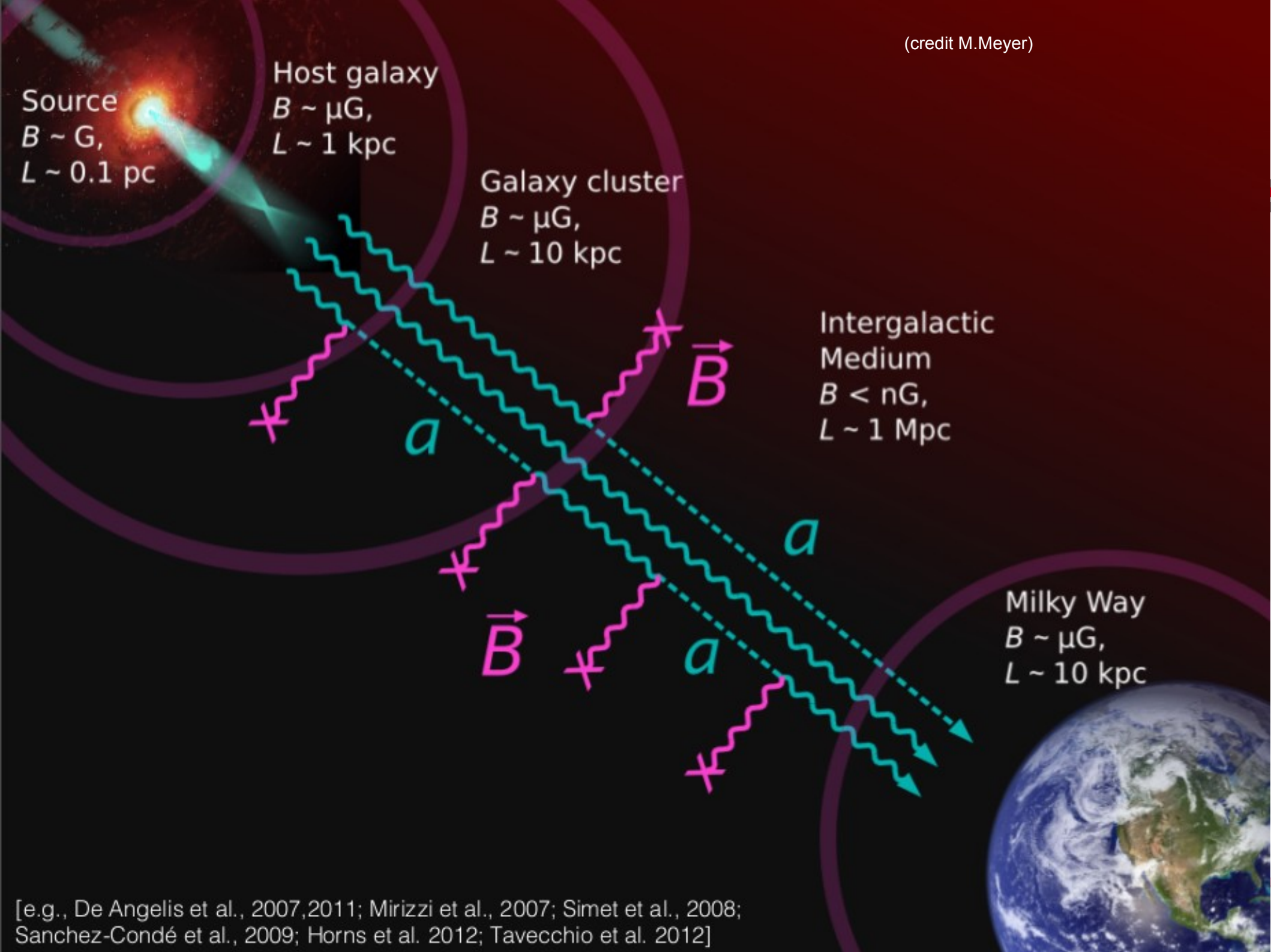
Tavecchio et al.

PHYSICAL REVIEW D **86,** 085036 (2012)

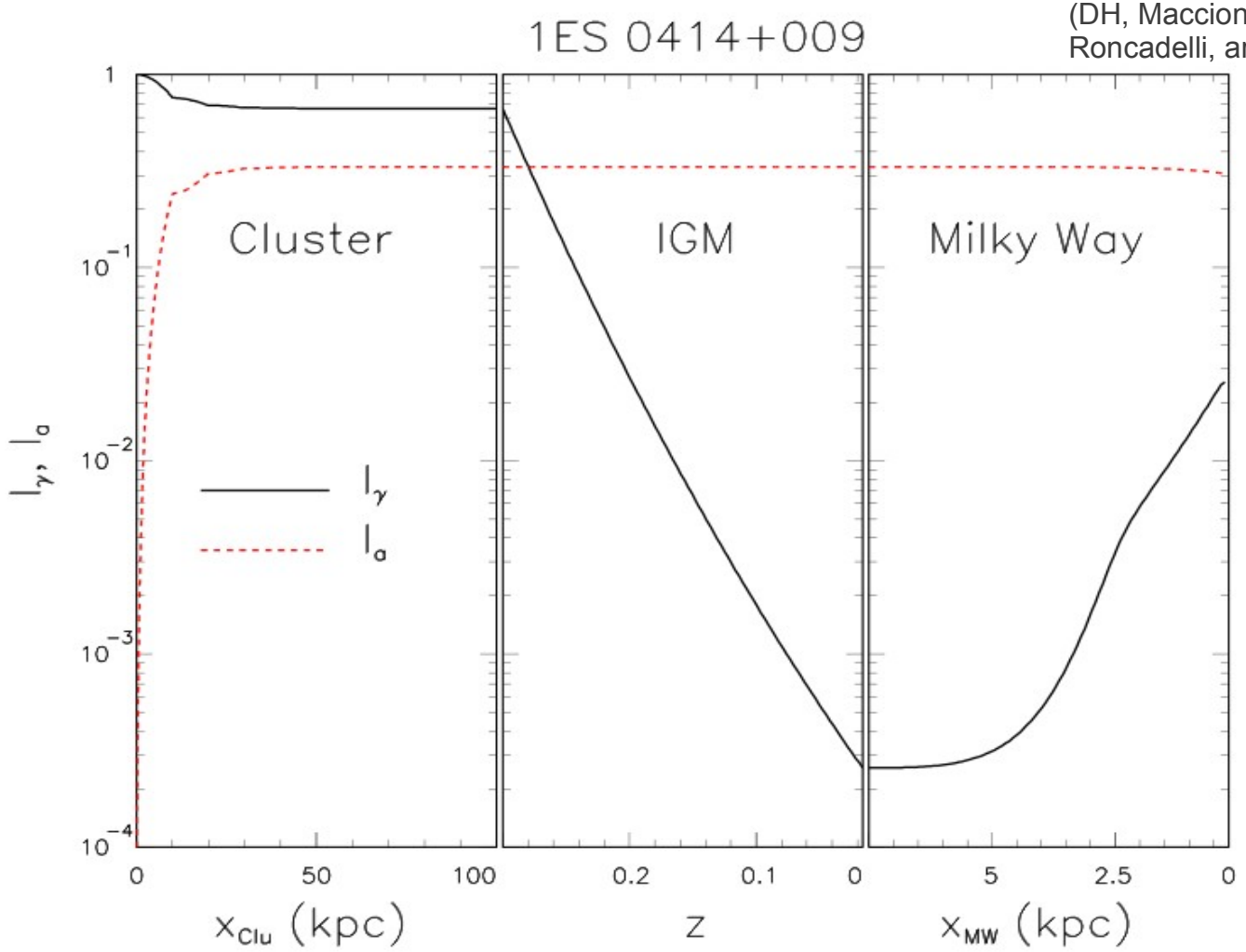



Next talk


(credit M.Meyer)
Source
B ~ G,
L ~ 0.1 pc
Host galaxy
B ~ μG,
L ~ 1 kpc
Galaxy cluster
B ~ μG,
L ~ 10 kpc
Intergalactic
Medium
B < nG,
L ~ 1 Mpc
Milky Way
B ~ μG,
L ~ 10 kpc
B
a
a
B
a
[e.g., De Angelis et al., 2007,2011; Mirizzi et al., 2007; Simet et al., 2008;
Sanchez-Condé et al., 2009; Horns et al. 2012; Tavecchio et al. 2012]

# Effect of gamma-ALPs mixing on propagation

(DH, Maccione, Meyer, Mirizzi, Montanino, Roncadelli, arXiv: 1207.0776)



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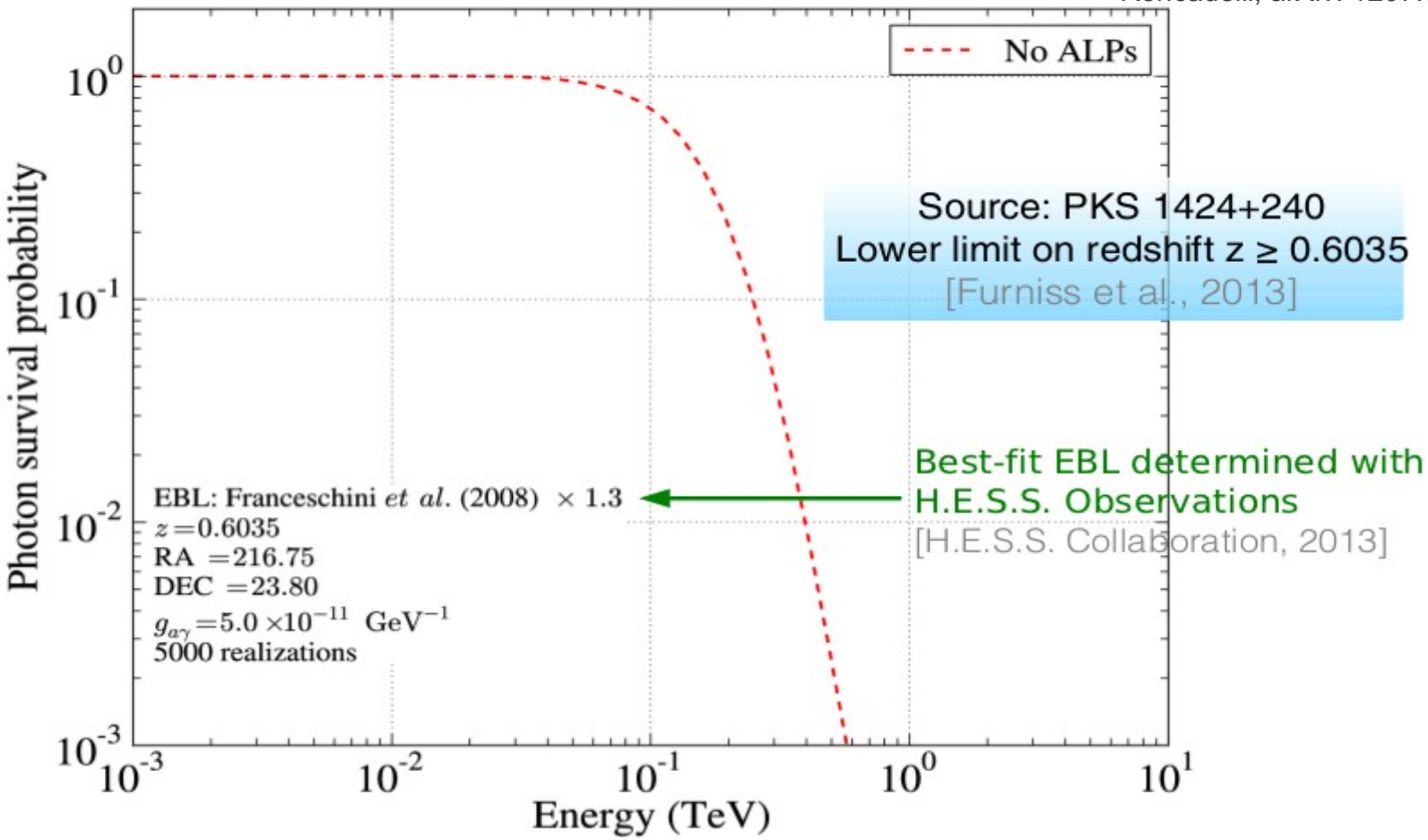

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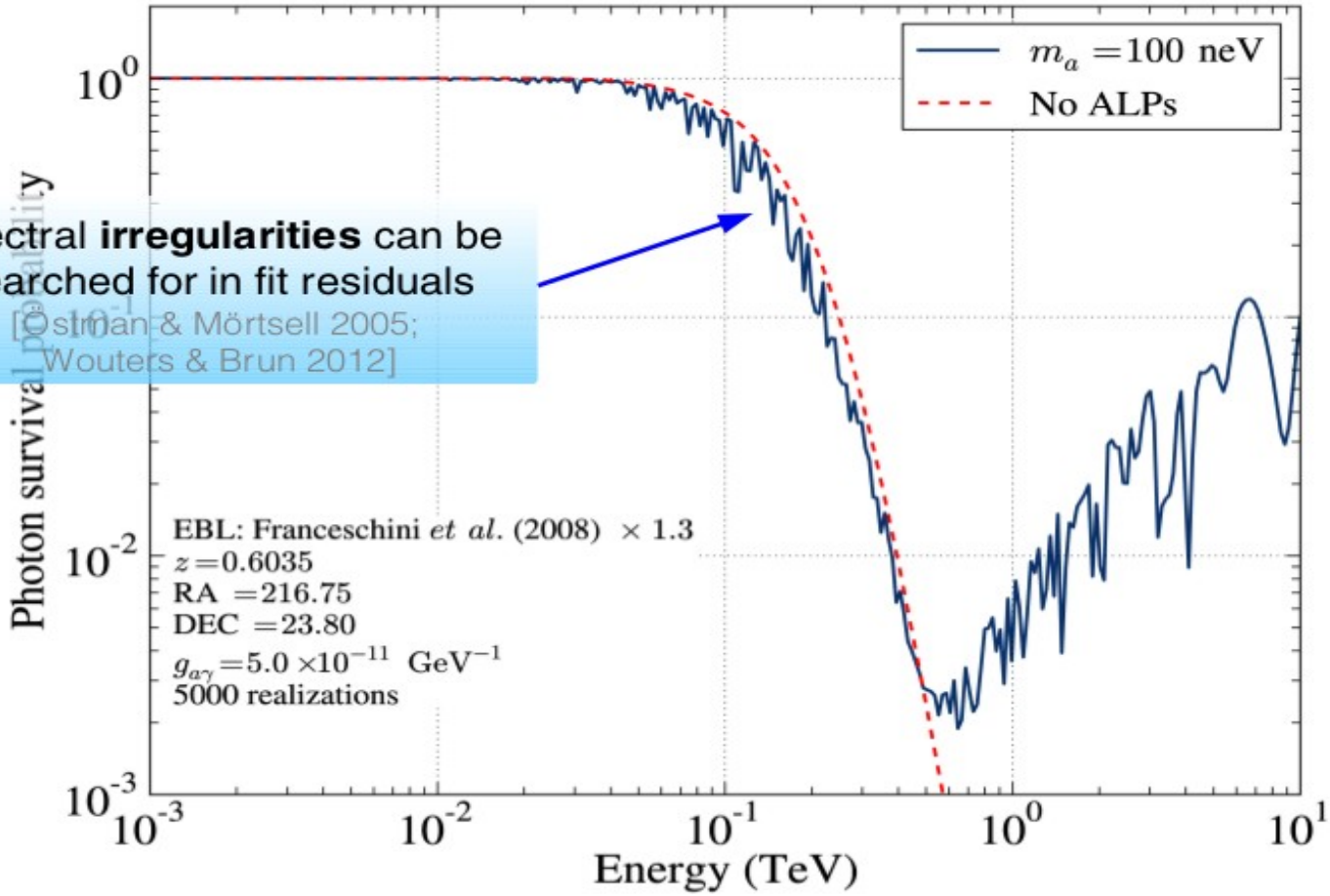


Spectral **irregularities** can be searched for in fit residuals
[Östman & Mörtsell 2005; Wouters & Brun 2012]

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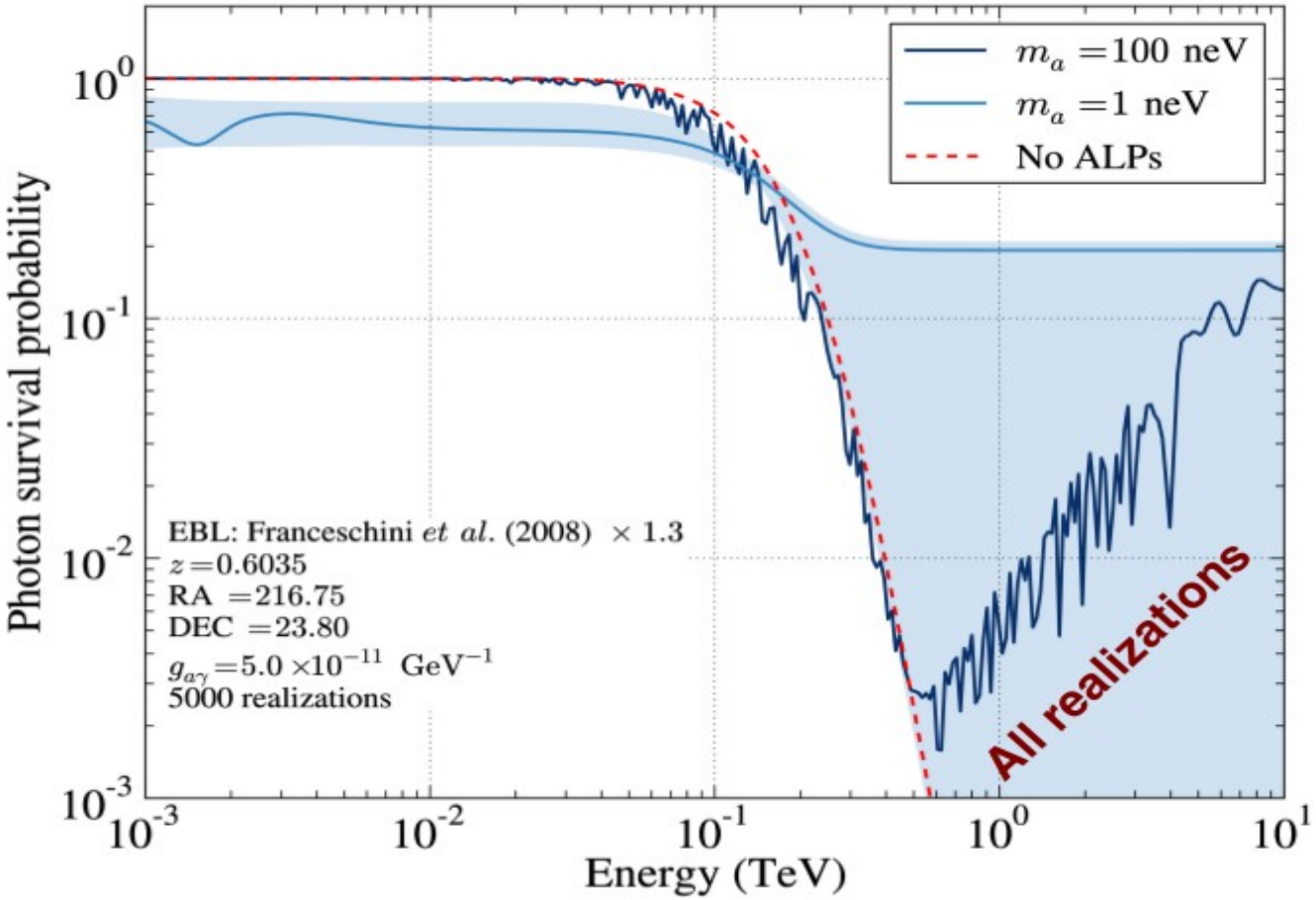
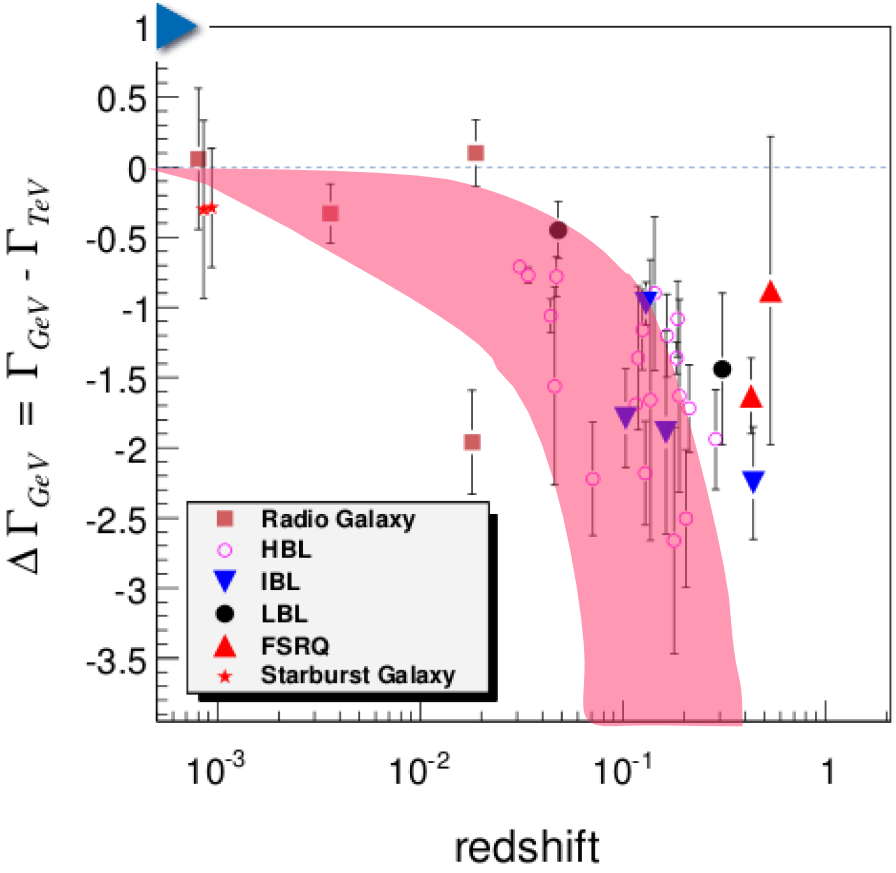


# Indications for modified optical depth

- De Angelis et al. 2007, 2009, 2011, 2013, Simet et al. 2008, Sanchez-Conde 2009:

  The observed TeV spectra are too hard.

Adapted from Dwek&Krennrich 2012



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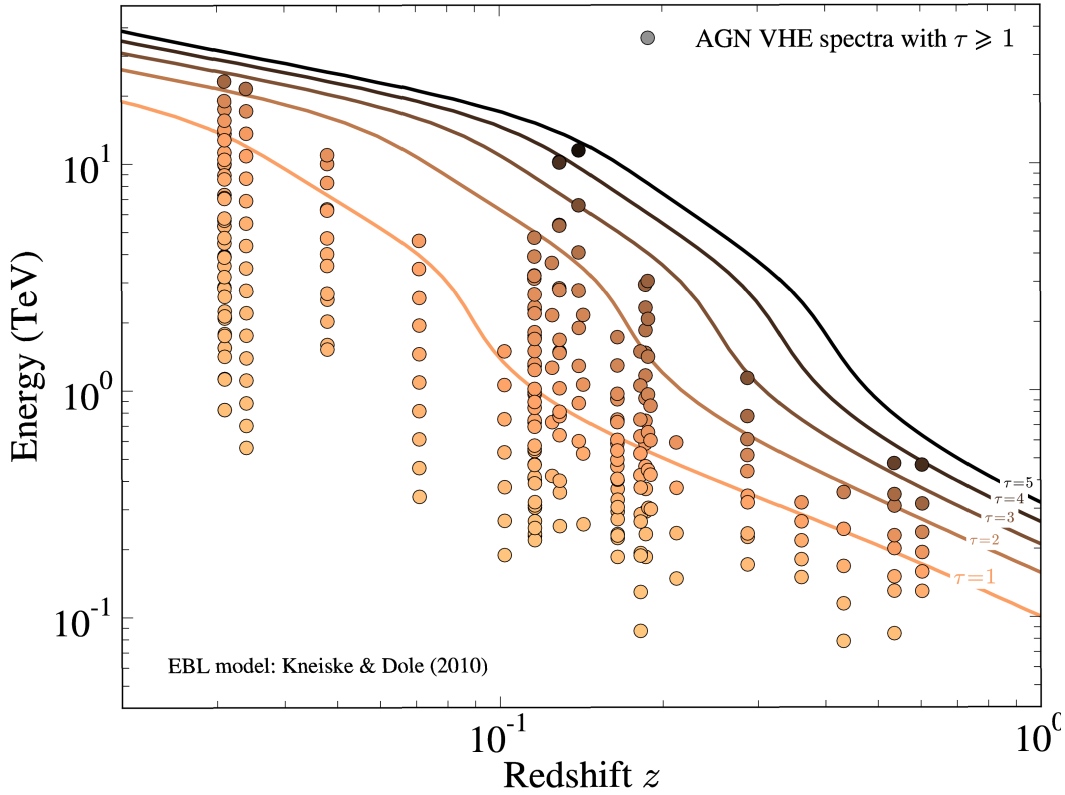

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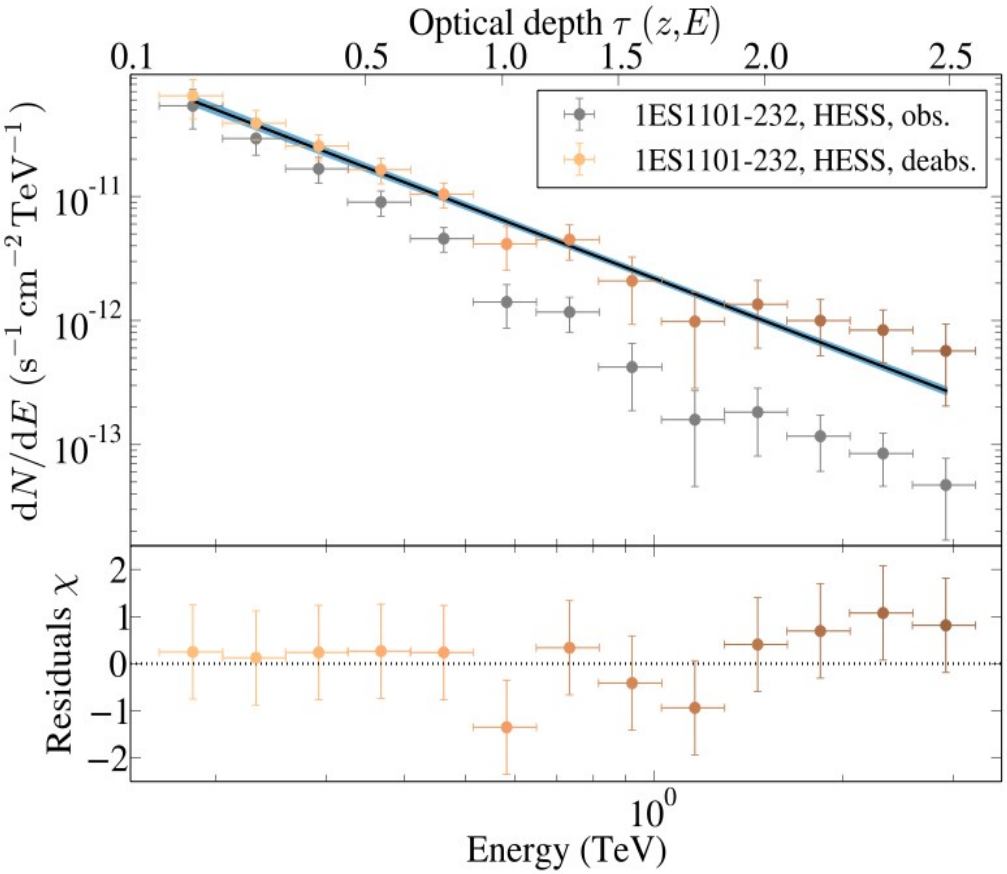

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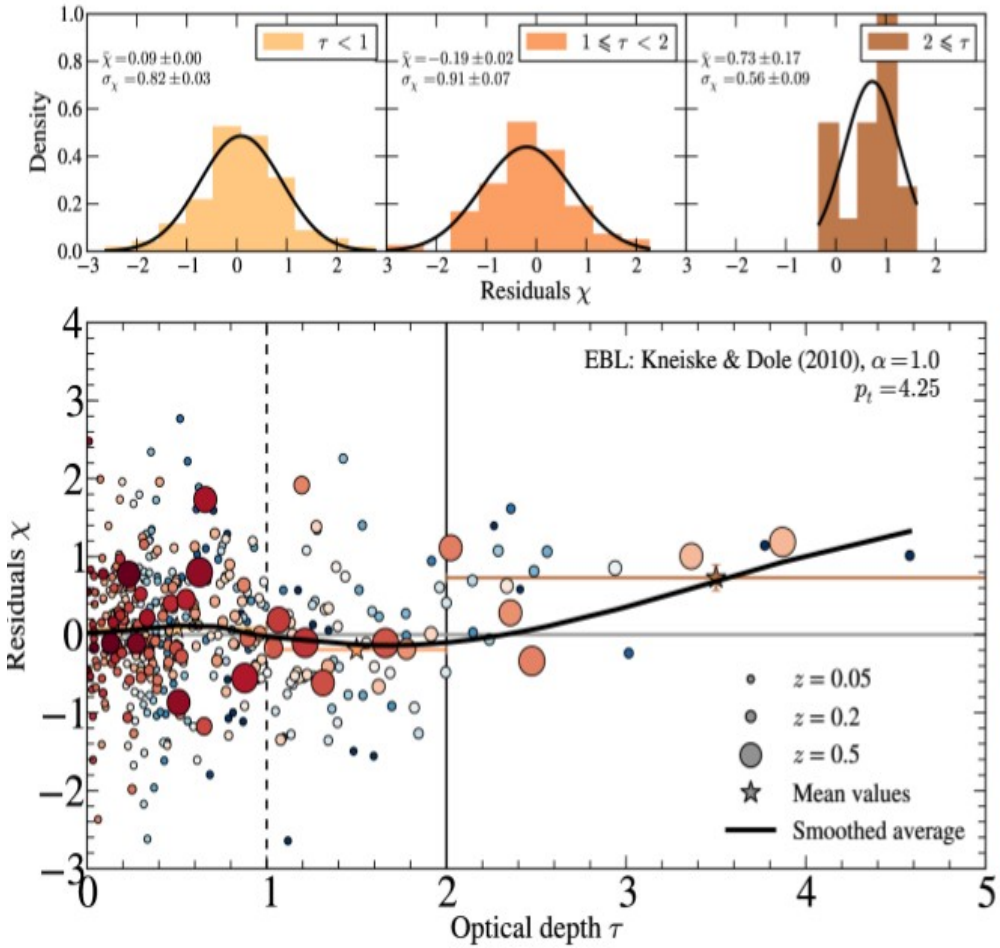
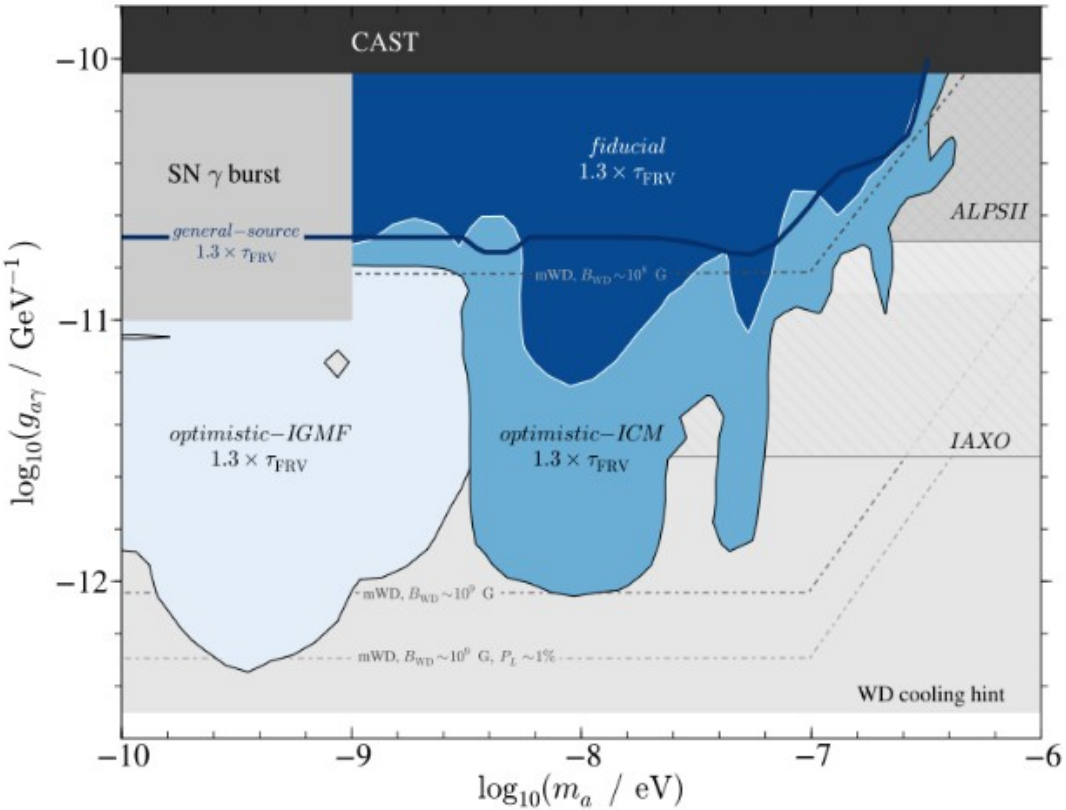


# Lower limit on coupling $g_{a\gamma}$




[Meyer, DH, Raue arXiv:1302.1208]

- Coupling within reach of future helioscope IAXO (Irastorza et al. 2013), light-shining-through the wall ALPS-II (Bähre et al. [arXiv:1302.5647])
- Coupling consistent with anomalous cooling of WD (Isern et al. 2008)
- Coupling consistent with soft X-ray excess from Coma cluster (Angus et al. 2013)
- Coupling consistent with FSRQ/absorption (Tavecchio et al. 2012)
- Coupling consistent with FSRQ/spectral break (Mena&Razzaque 2013)

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  The attenuation of VHE spectra at τ>2 is too small (at ~4 σ)
- Meyer 2013 (desy-thesis 2013-33),
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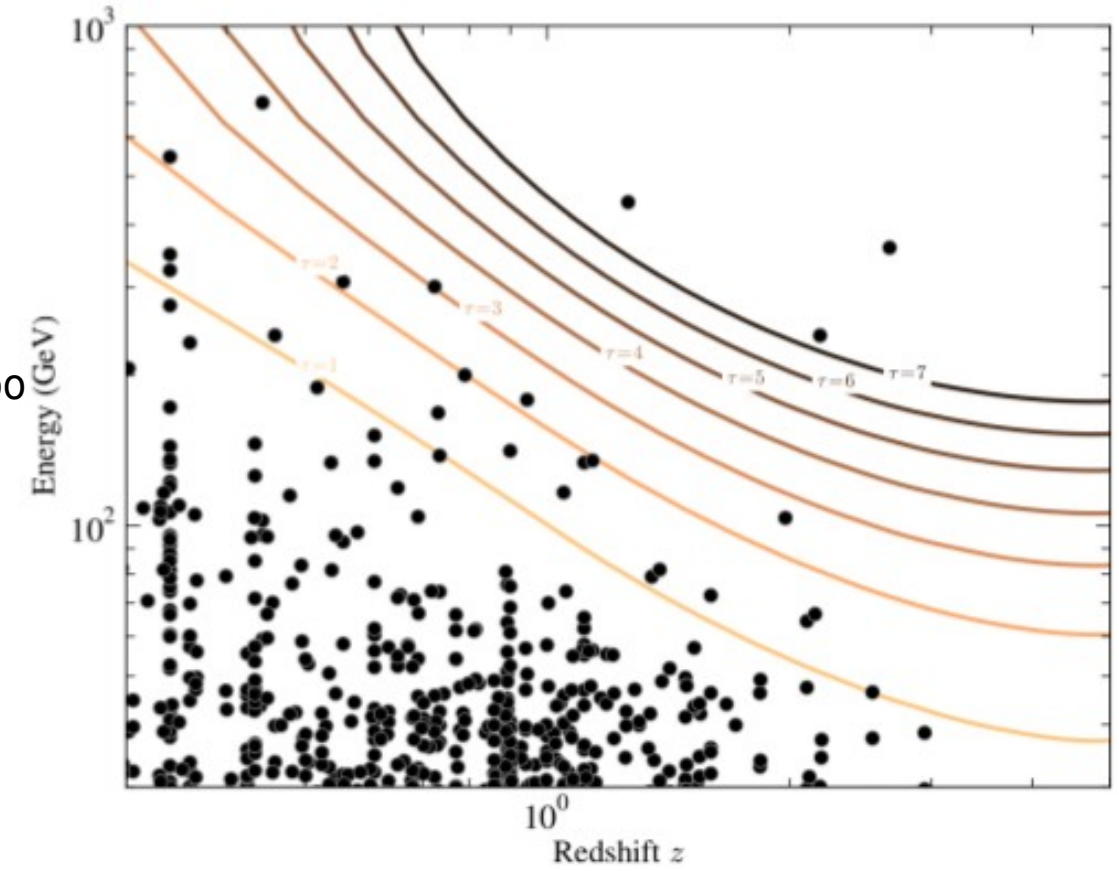
  Fermi-LAT photon (~3.5σ) excess at τ>2
  (similar: [arXiv:1207.1962]



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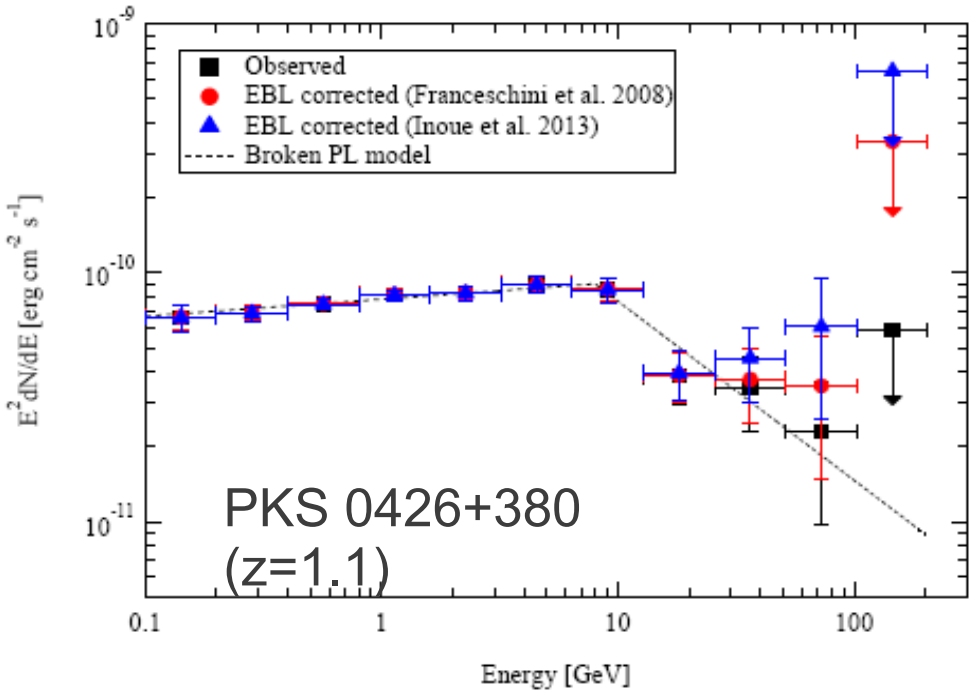
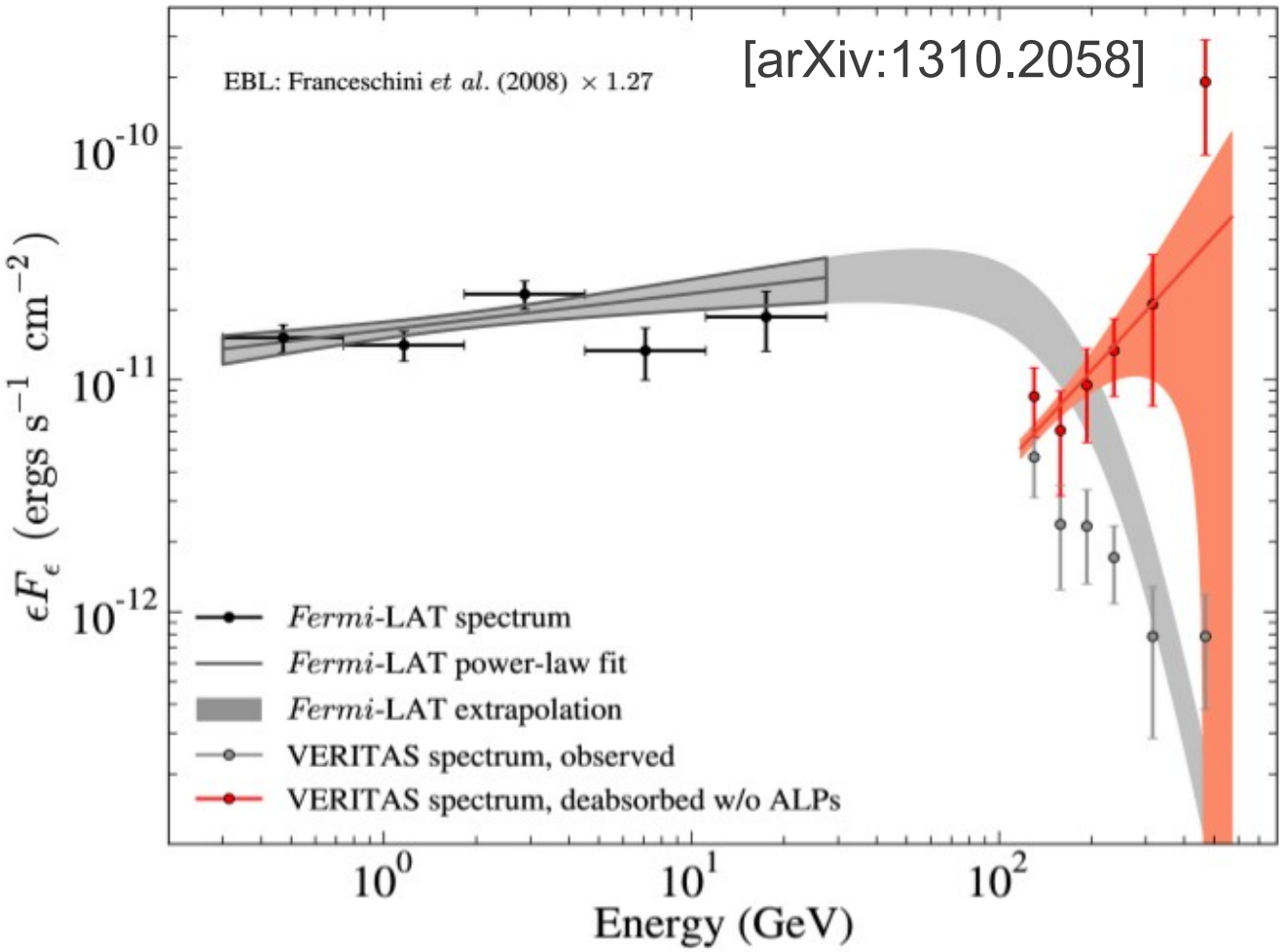
- Very similar results with individual spectra
  (e.g. [arXiv:1308.380])



# A closer look on PKS 1424+240



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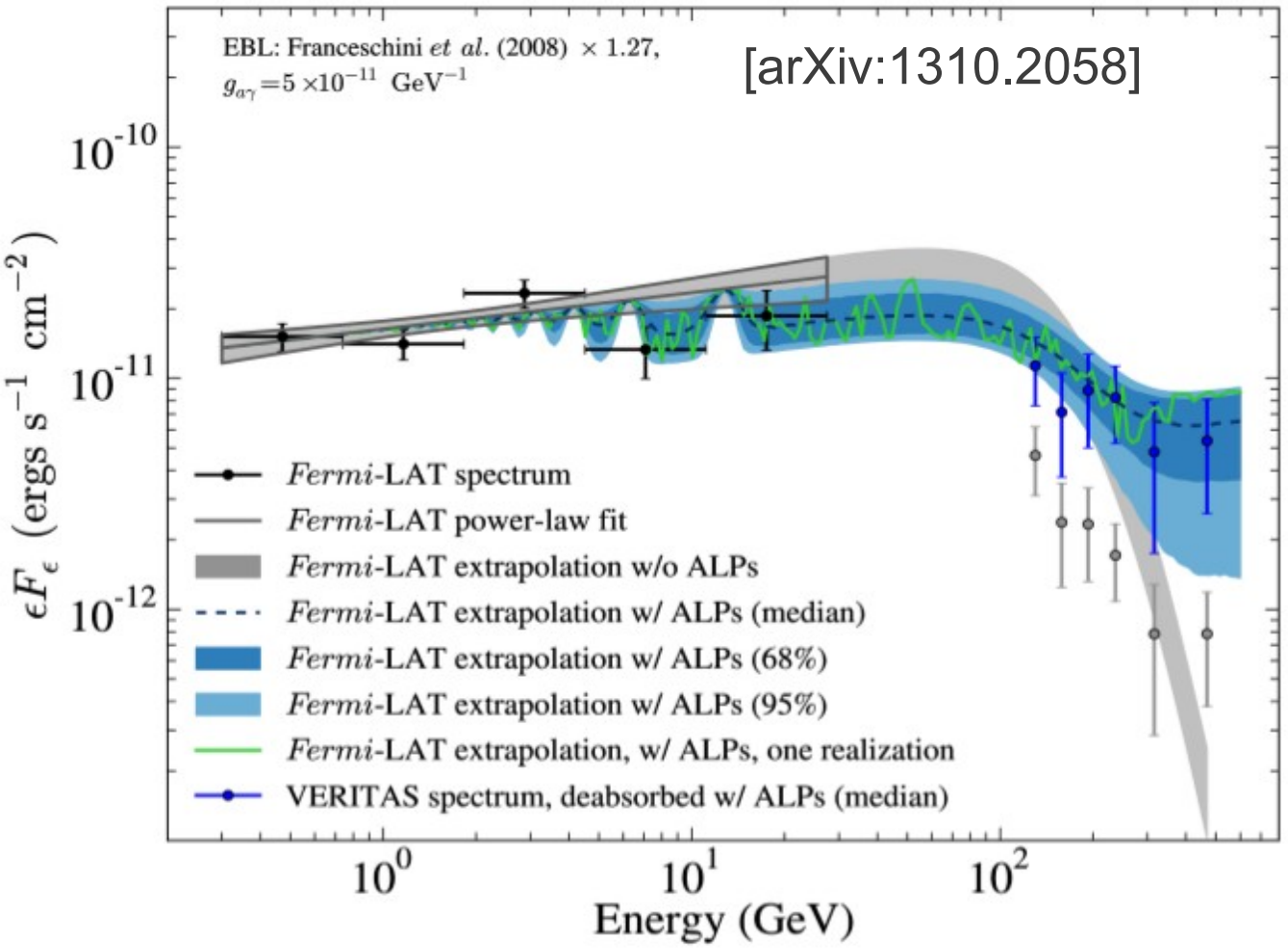
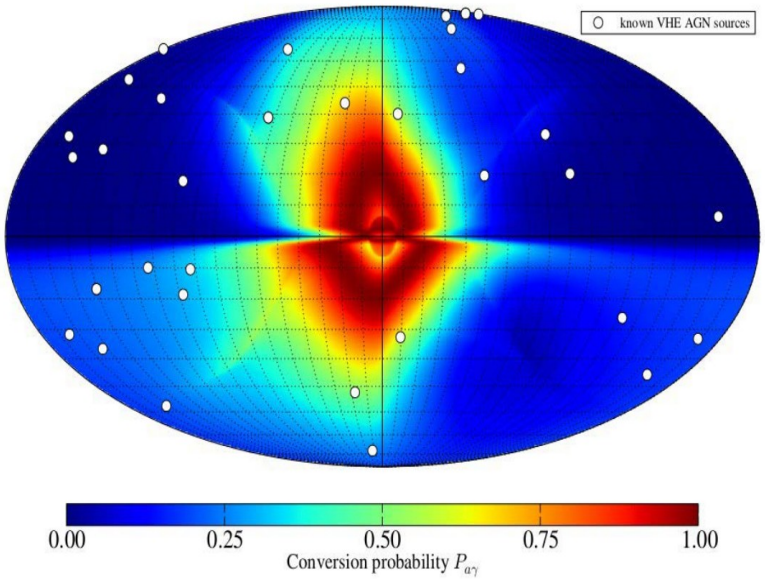


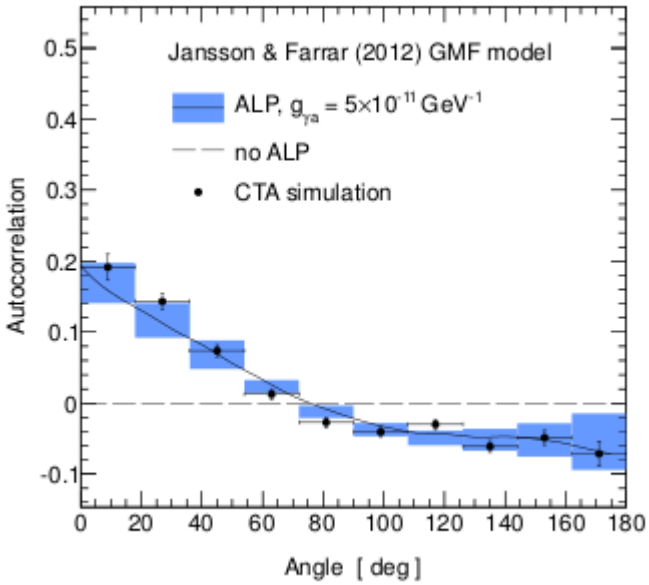
# Latest result [arXiv:1406.0239]

- Similar study to 1201.4711: Extended source list including Fermi-LAT spectra
- Looking at upward-turn in de-absorbed spectra (using Dominguez et al. EBL)
- Looking at the \Delta \Gamma of the index as a function of z → claim 12σ detection
- Authors favor a ALP reconversion scheme

# Anisotropic re-conversion [Simet et al. 08, Wouters&Brun 13]




Autocorrelation
Of Spectral changes



# Relevance of Gamma-ray observations on ALPS-physics

- Discovery potential of anomalous transparency with CTA: excellent
- ALPs specific (unique) spectral and angular signatures: Demonstrate existence of ALPs
- Opportunity to measure mass and coupling of ALPs
- Similar range of coupling and mass accessible as IAXO, ALPS-II

# Observational strategies for AGN:

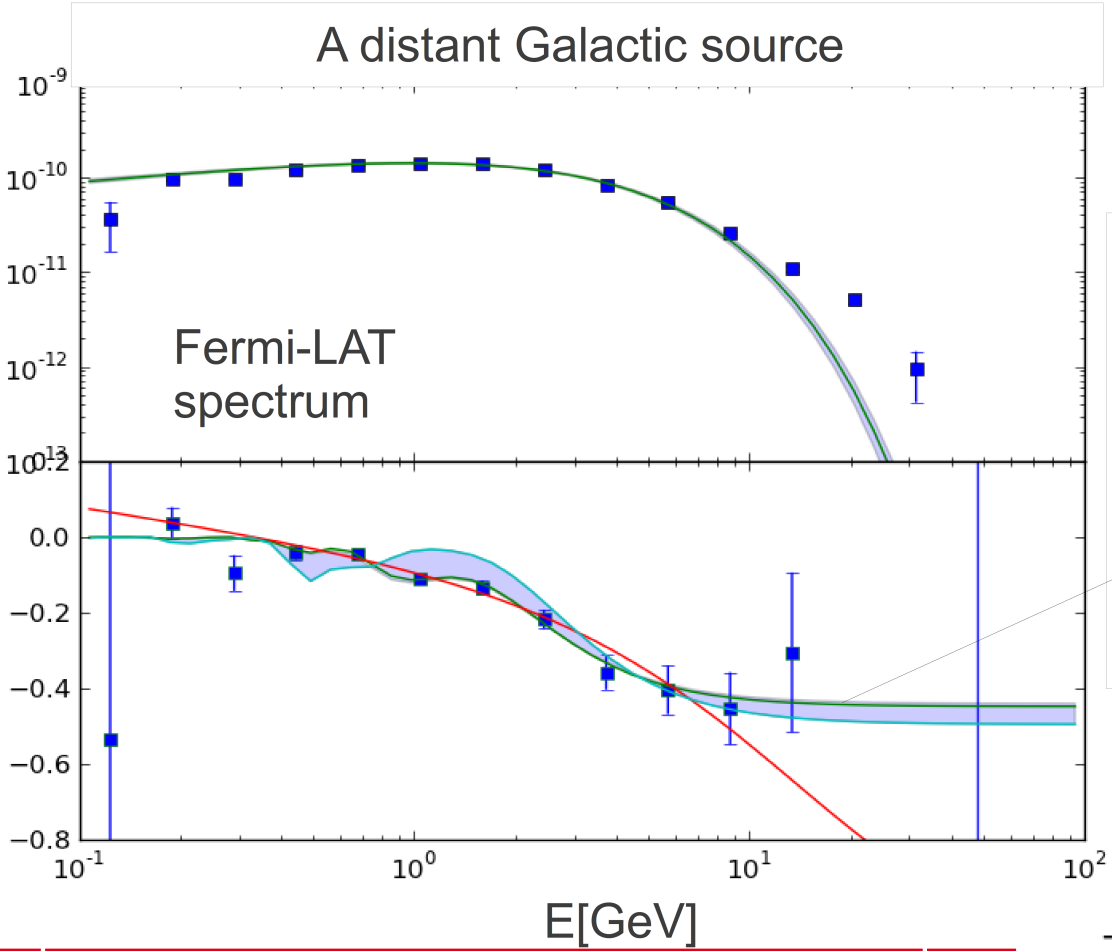
- High S/N spectra (bright and flaring AGN)
  - Search for additional noise
  - Spectral features from ALPS/photon conversion in jet
- Deep observations of nearby AGN (large zenith angle)
  - Search for anomalies in transparency at E>10 TeV
  - (Constrain EBL at λ>10 μm)
- Push ethreshold down for z>0.5 AGN
  - Search for anomalies in transparency at E>100 GeV
  - (Constrain EBL at λ<1 μm)
- Target AGN in $P_{ag}$-large region of sky

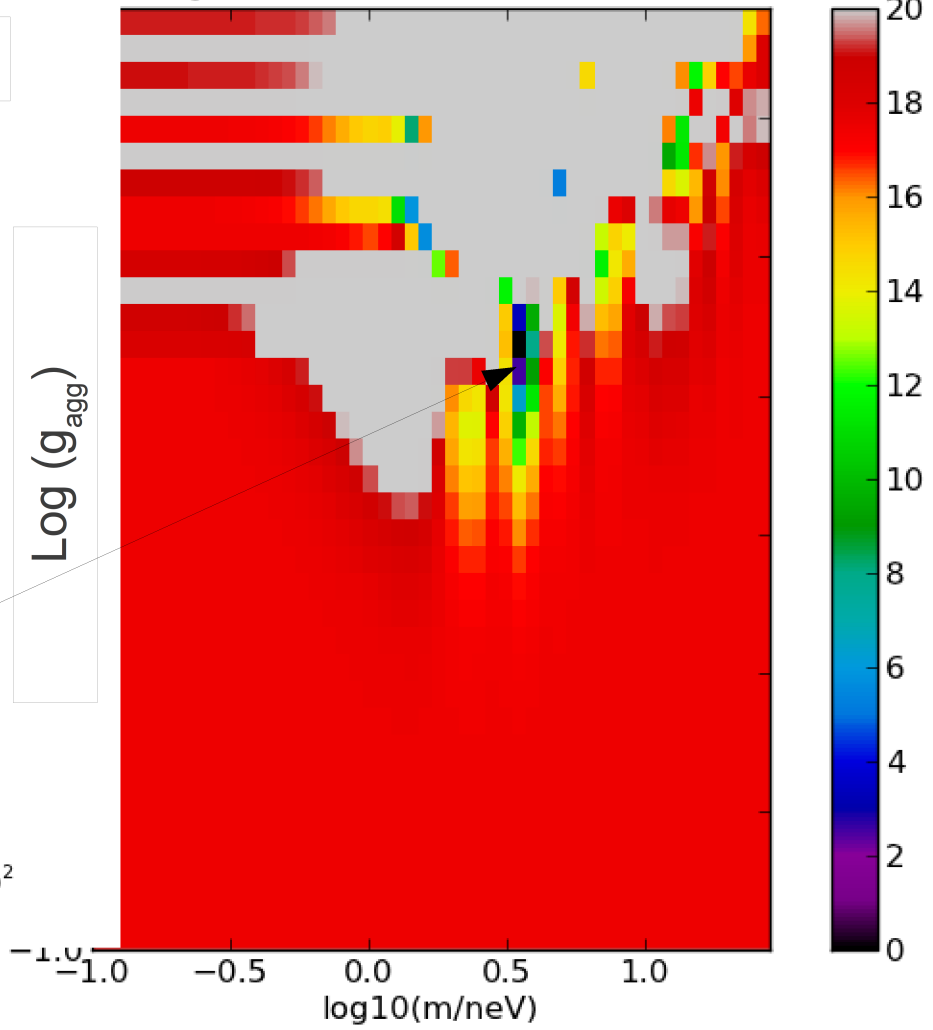
# Additional opportunities

- Galactic sources:
  - Binary systems (high tau)
  - Broad spectral coverage → spectral features from disappearance channel (e.g. pulsars) (see next slide)

- Galaxy clusters:
  - Dark radiation claim (X-rays) requires better understanding of non-thermal particles in Galaxy clusters [arXiv:1312.3947]

# Something new...(work in progress)



# Summary

- Modification of Universe transparency: Evidence is increasing
- Interpretation: Split between cascade and ALPs oscillation
- Decisive observational tests:
  - Irregularities in the spectra
  - Variable re-conversion probability over the sky
  - Disappearance channel from Gal. sources
- Finally: Excellent chances with ALPS-II and IAXO to confirm/reject the ALPs interpretation of the pair-production anomaly

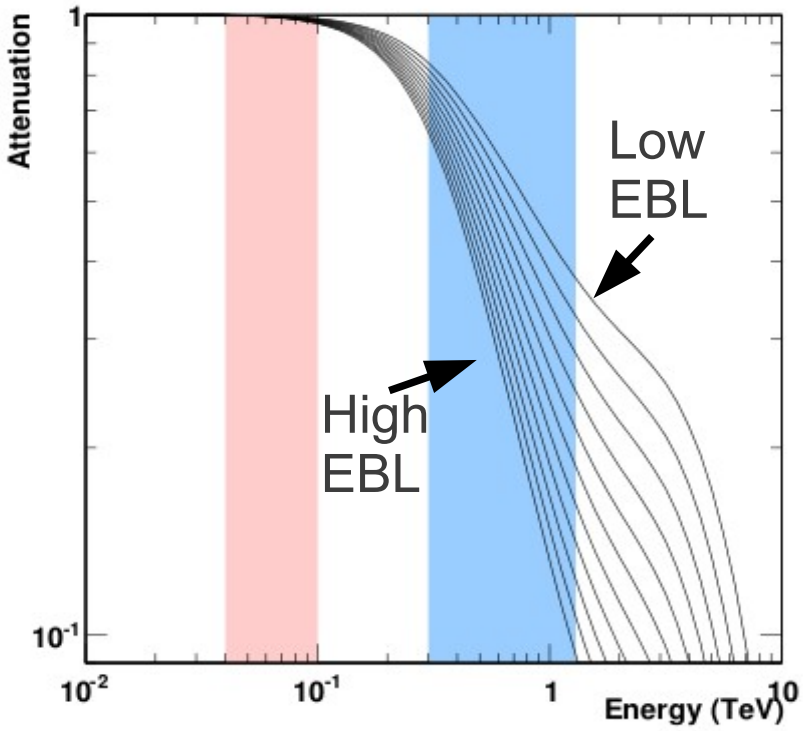
# End of presentation – beginning of discussion

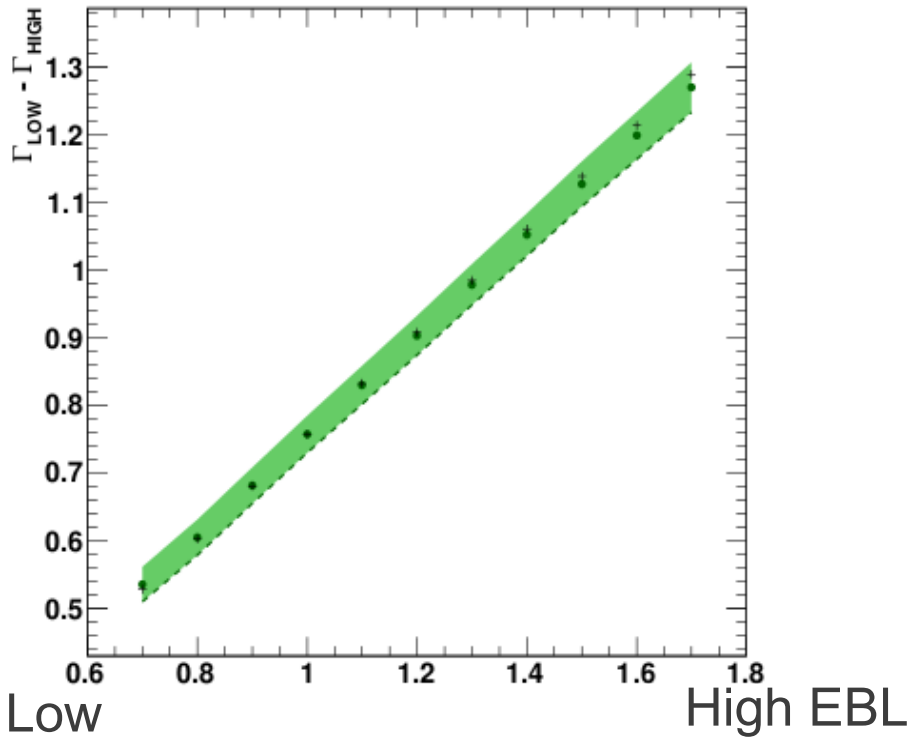
- Backup on EBL measurements

# Measuring the EBL with VHE gamma-ray attenuation

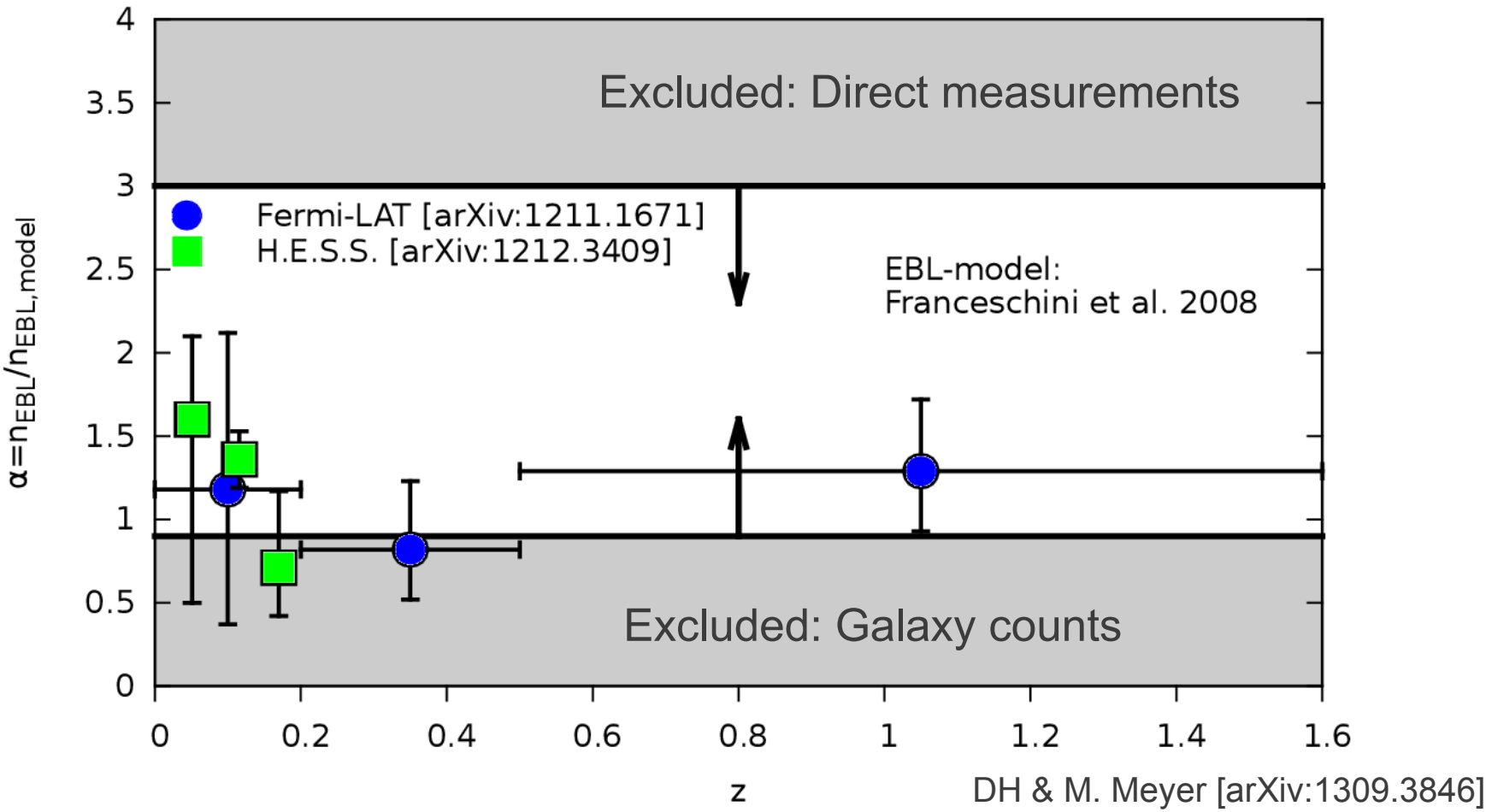
Raue & Mazin 2010
[arXiv:1005.1196]

z=0.116



# Consistency of the EBL-measurements




DH & M. Meyer [arXiv:1309.3846]