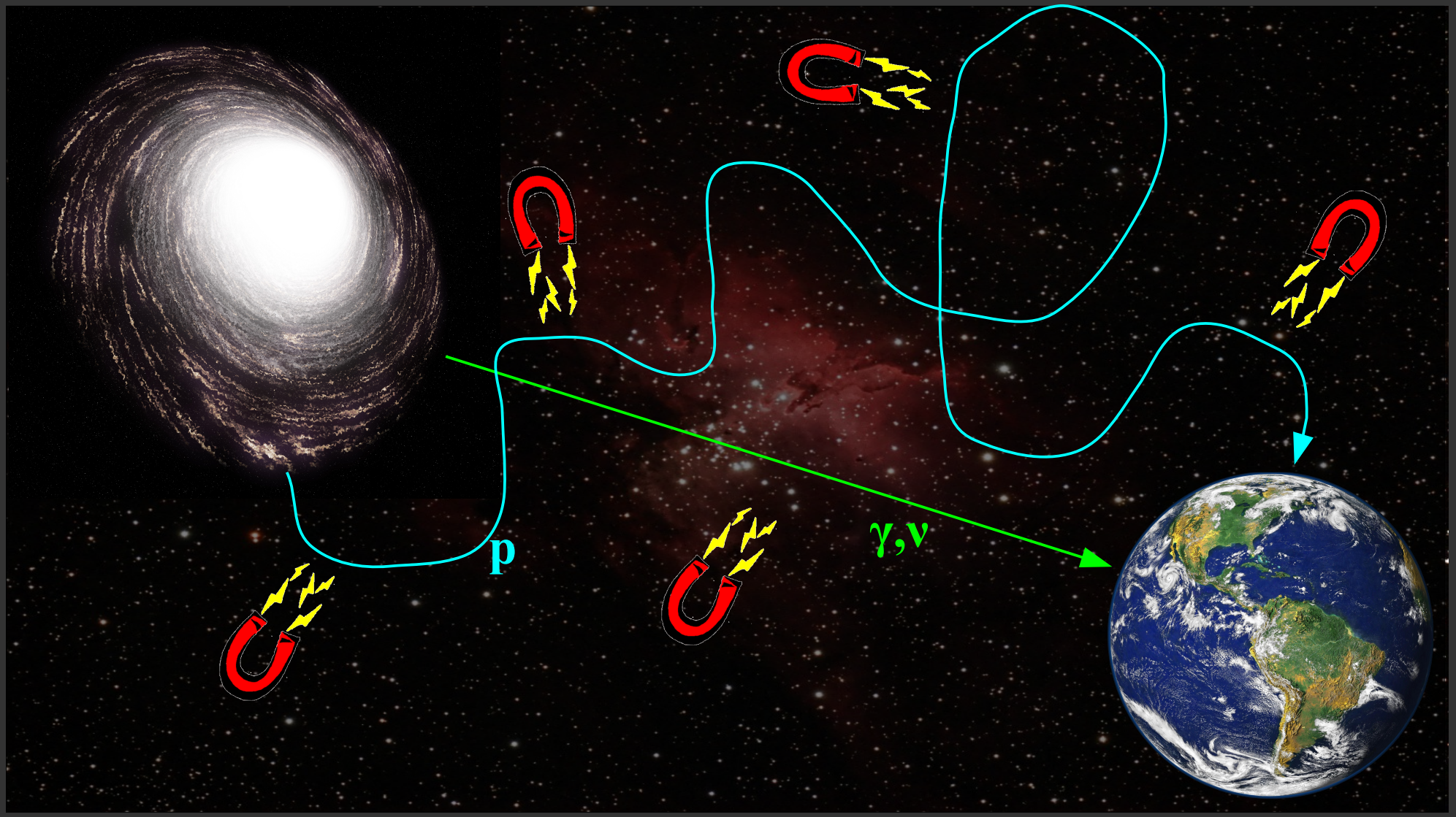
VHE photon propagation and determination of the cosmological constants

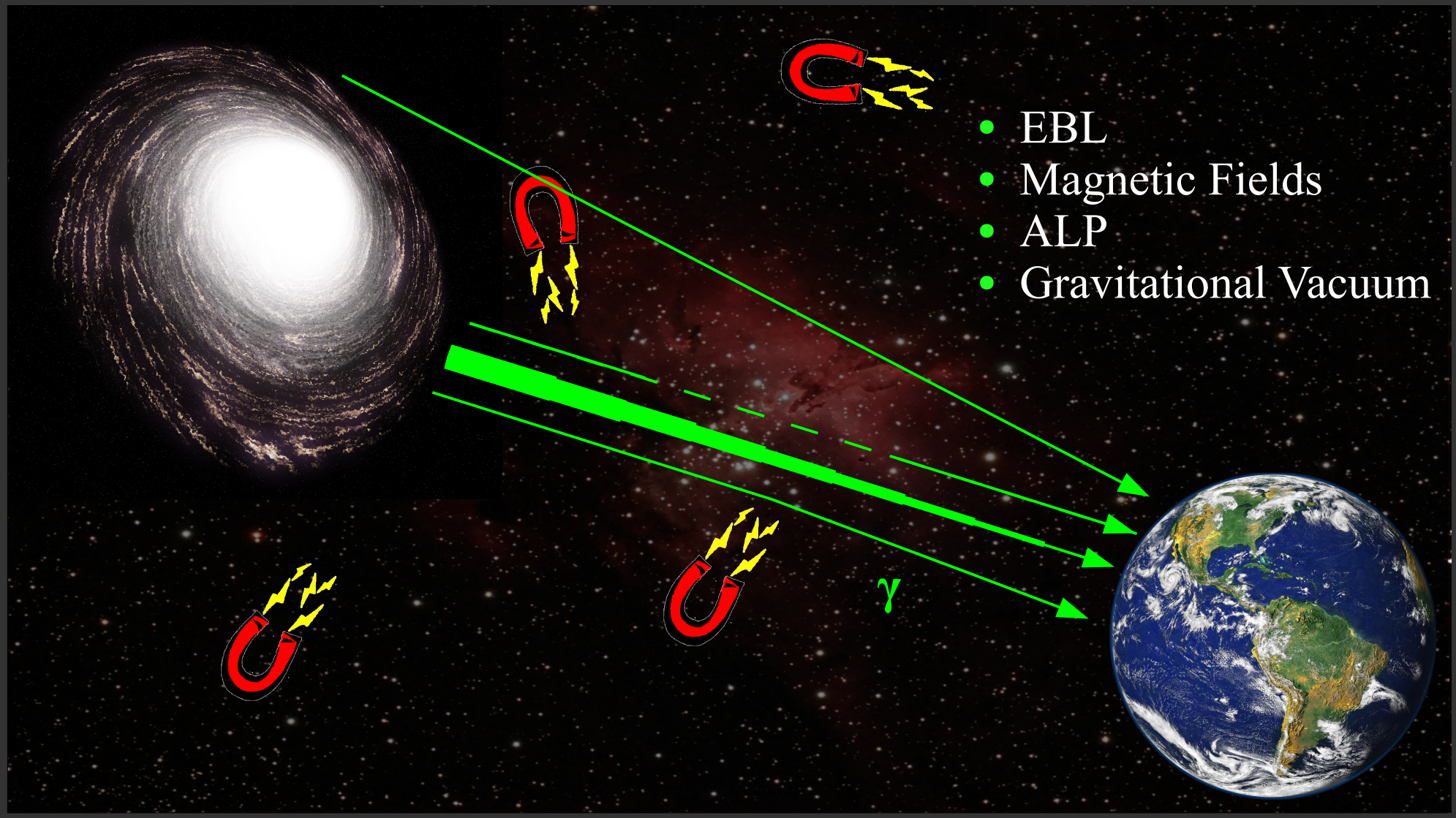
Oscar Blanch Bigas
IFAE, Barcelona
SciNeGHE 2014, Lisboa

Propagation through the Universe



VHE gammas keep original direction → Most energetic phenomena

VHE photon Propagation



VHE gammas reaching the Earth also have information about the their propagation through the Universe → Cosmology and Fundamental Physics

Interaction with Vacuum

- Quantum Gravity Theories: General Relativity + Quantum Theories
  - Loop Quantum Gravity
  - Superstring theory
  - Effective theories
  - Standard-Model Extension
  - …

Amelino-Camelia et al, Nature 393 (1998)

- VHE photons should notice the "quantum fluctuations" in the gravitational vacuum
  - Deformed dispersion relation for photons: $c^2p^2=E^2(1+f(E/E_{QG}))$
  - At small energies ($E<<E_{QG}$) a series expansion of dispersion relation should be applicable:

$$c^2 p^2 = E^2 \quad \rightarrow \quad c^2 p^2 = E^2\left(1+\xi\left(\frac{E}{E_{QG}}\right)+\zeta\left(\frac{E^2}{E_{QG}^2}\right)+\ldots\right)$$

Test Lorentz Invariance

- VHE photons will travel through the universe with a propagation speed different than the "speed of light: c"
  - ➔ Leading order on dispersion relation : $(E/E_{QG})^{\alpha}$
  - ➔ Energy detected at Earth: $E/(1+z)$

$$v = \frac{dE}{dp} = c\left[1 + \xi\frac{1+\alpha}{2}\left(\frac{E_\gamma(1+z)}{E_{QG}}\right)^{\alpha}\right]$$

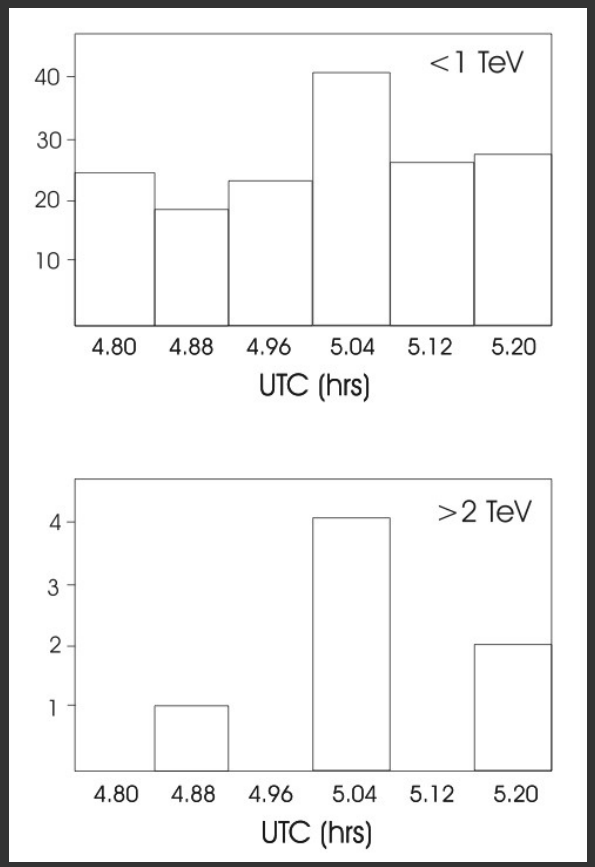
- VHE photons with different energy will need different time to travel from the source to the Earth → Arrival times of fast burst of VHE photons provide excellent sensitivity

$$t - t' = \int\left(\frac{c}{v_{E_\gamma}} - \frac{c}{v_{E'_\gamma}}\right)\frac{dt}{dz}\,dz$$

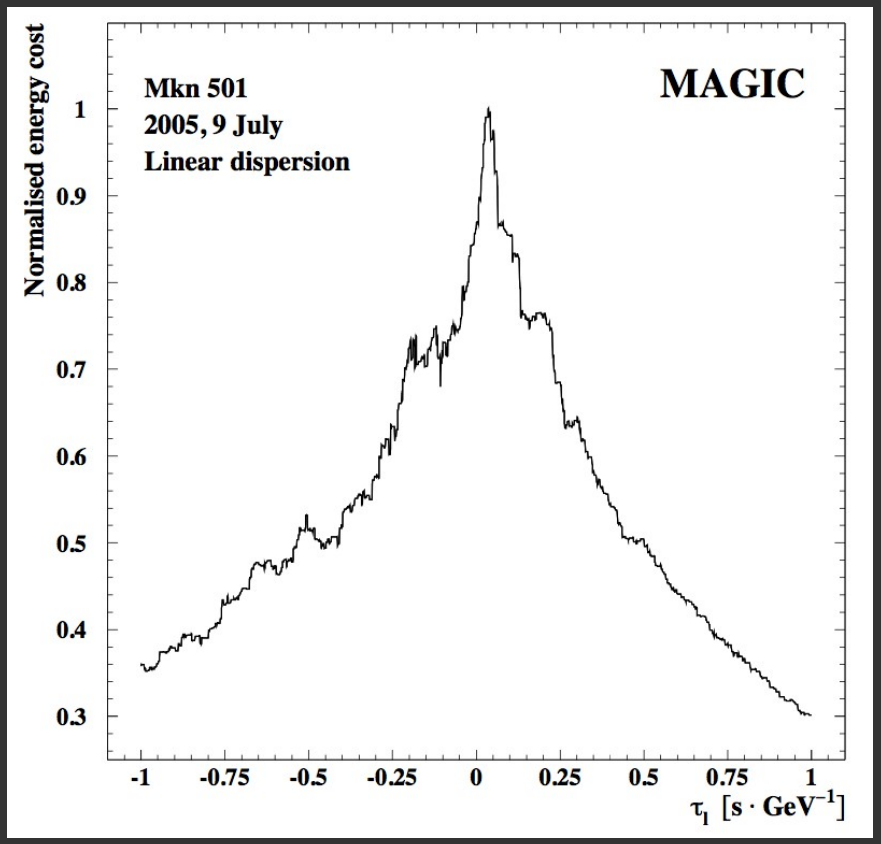
LIV Results from VHE photons

Fast flares of AGNs detected with Cherenkov Telescopes

Mkn 421 (Whipple, 1996)



Biller et al, Phys.Rev.Lett. 83 (1999)



MAGIC, Phys.Lett.B 668 (2008)

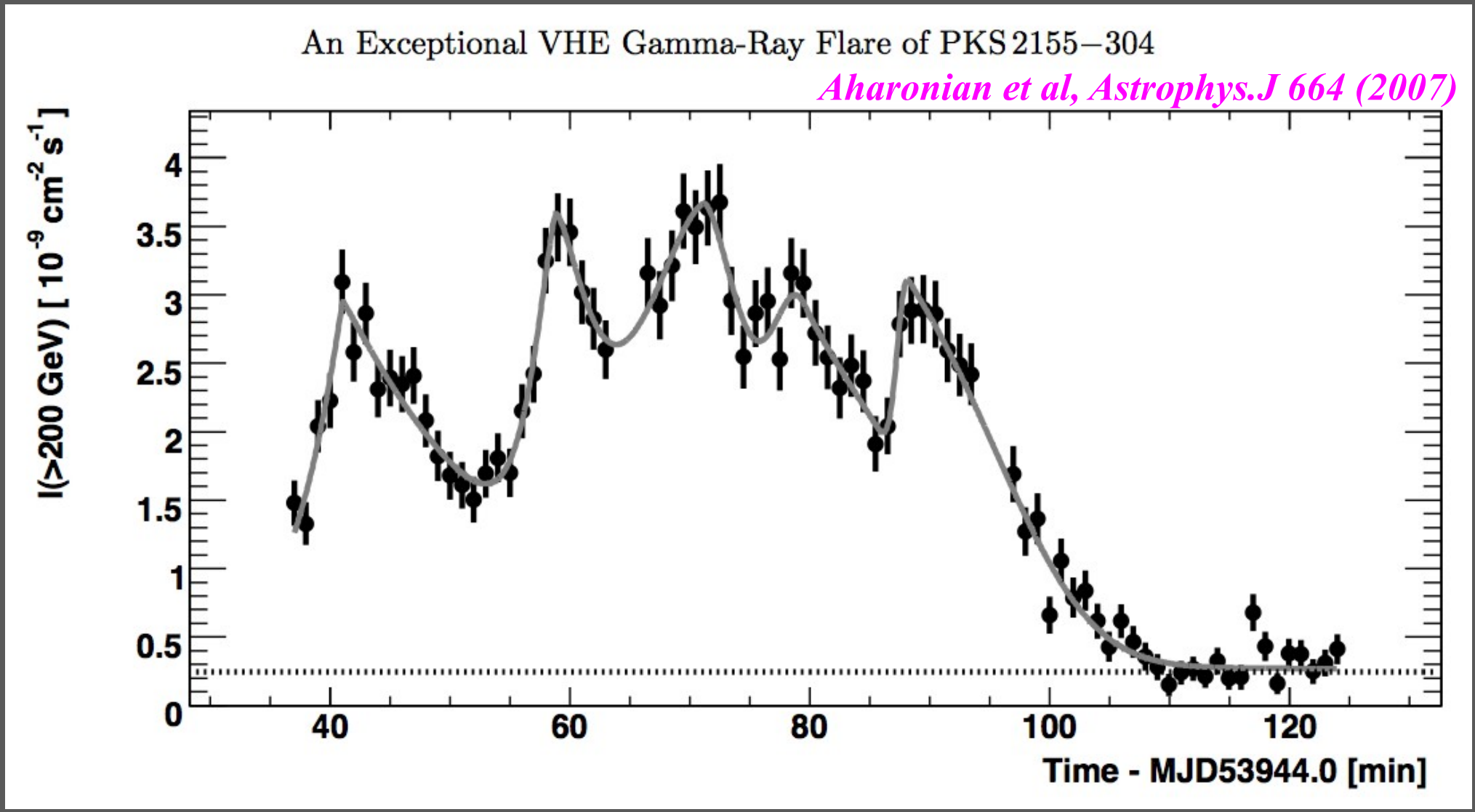
PKS2155-304 (HESS,2006)

HESS, Astropart.Phys. 34 (2011)

$E_{QG} > 2.1 \cdot 10^{18}$ GeV (α=1) – $E_{QG} > 2.6 \cdot 10^{10}$ GeV (α=2)

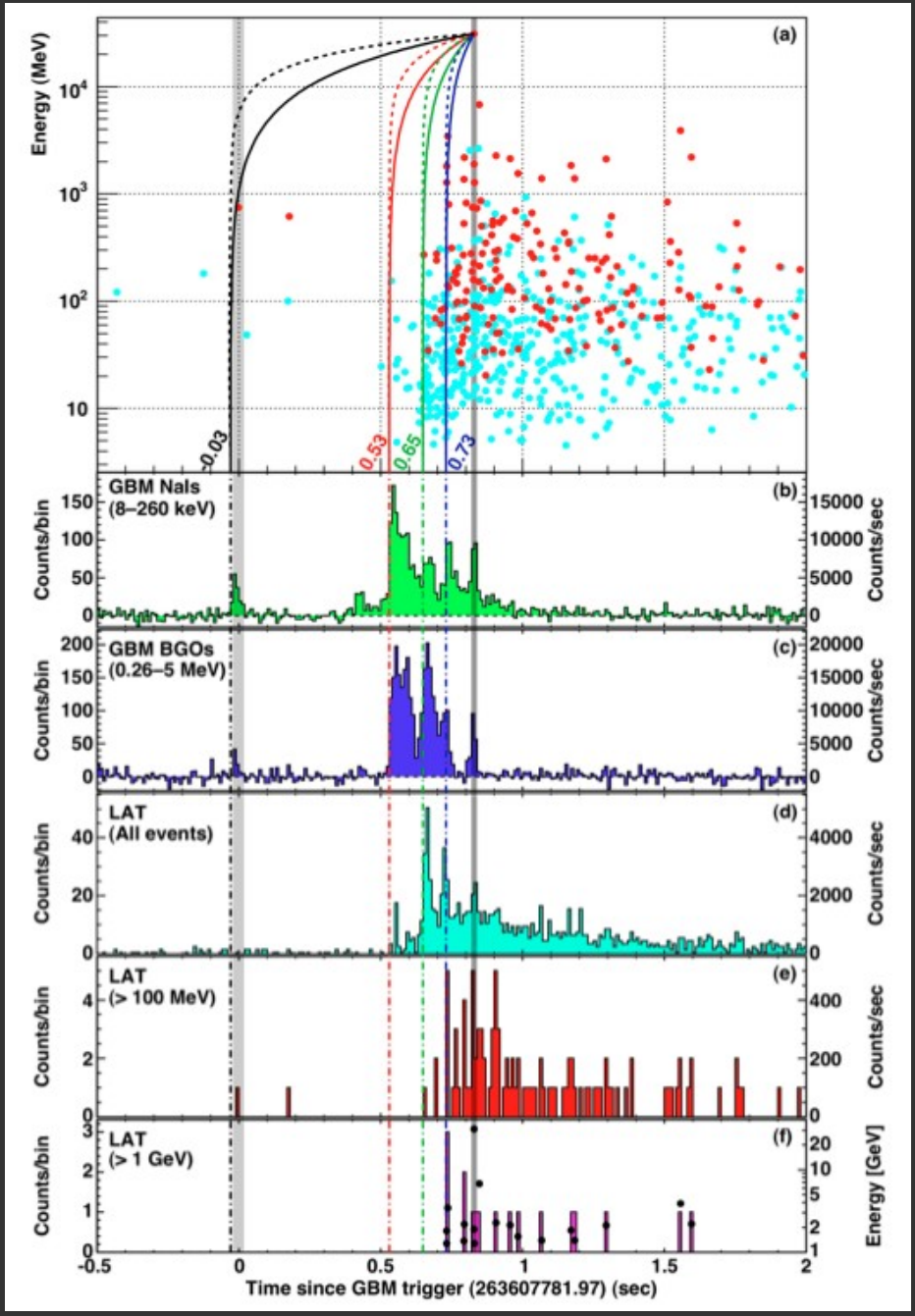
LIV Results from VHE photons

Fast flares of AGNs detected with Cherenkov Telescopes



$E_{QG} > 2.1 \cdot 10^{18}$ GeV (α=1) – $E_{QG} > 2.6 \cdot 10^{10}$ GeV (α=2)

HE photons and CTA-HAWC



GRB090510 (Fermi)

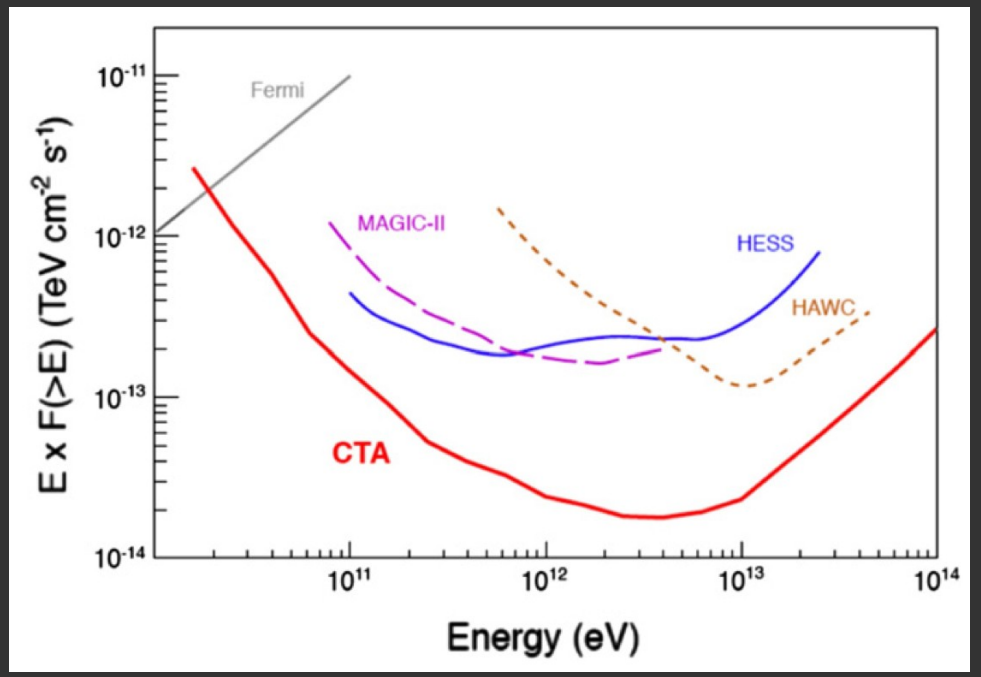
Abdo et al, Nature 462 (2009)

$E_{QG} > 1.5 \cdot 10^{19}$ GeV (α=1)

up to $1.2 \cdot 10^{21}$ *GeV*

$E_{QG} > 3.0 \cdot 10^{10}$ GeV (α=2)

up to $2.8 \cdot 10^{11}$ *GeV*

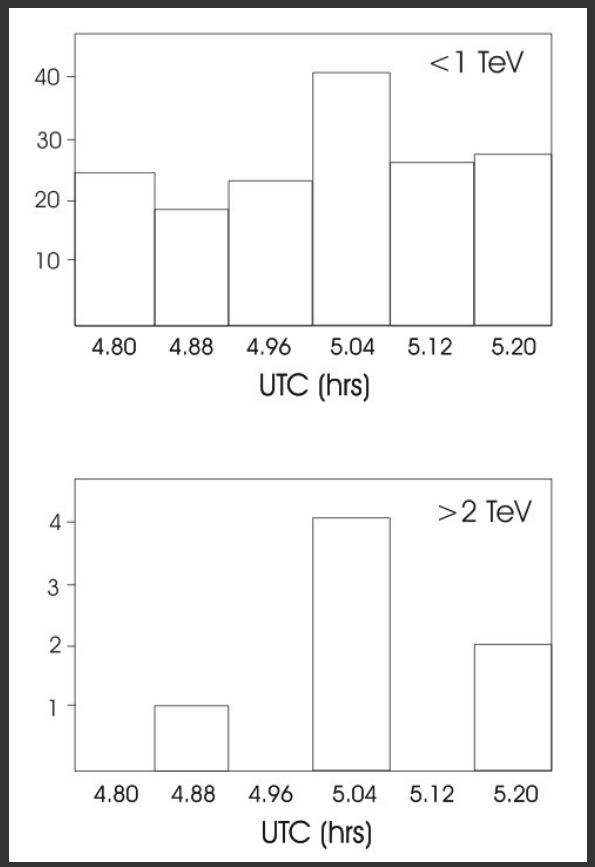


Acharya et al, Astropart.Phys. 43 (2013)

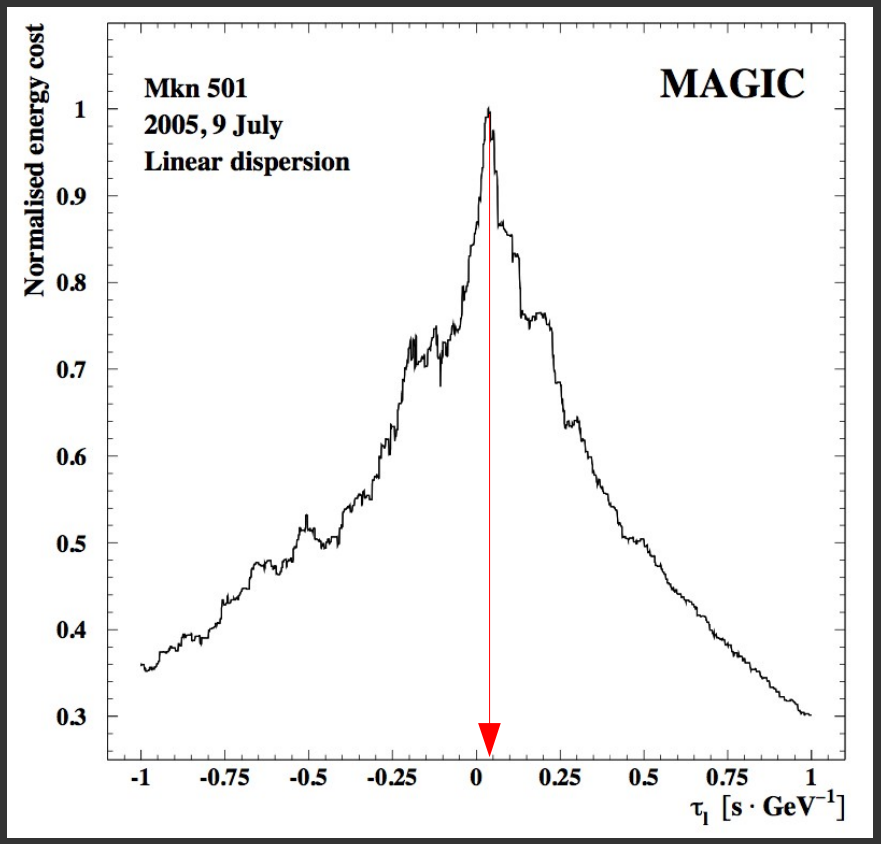
LIV Results from VHE photons

Fast flares of AGNs detected with Cherenkov Telescopes

Mkn 421 (Whipple, 1996)



Biller et al, Phys.Rev.Lett. 83 (1999)



MAGIC, Phys.Lett.B 668 (2008)

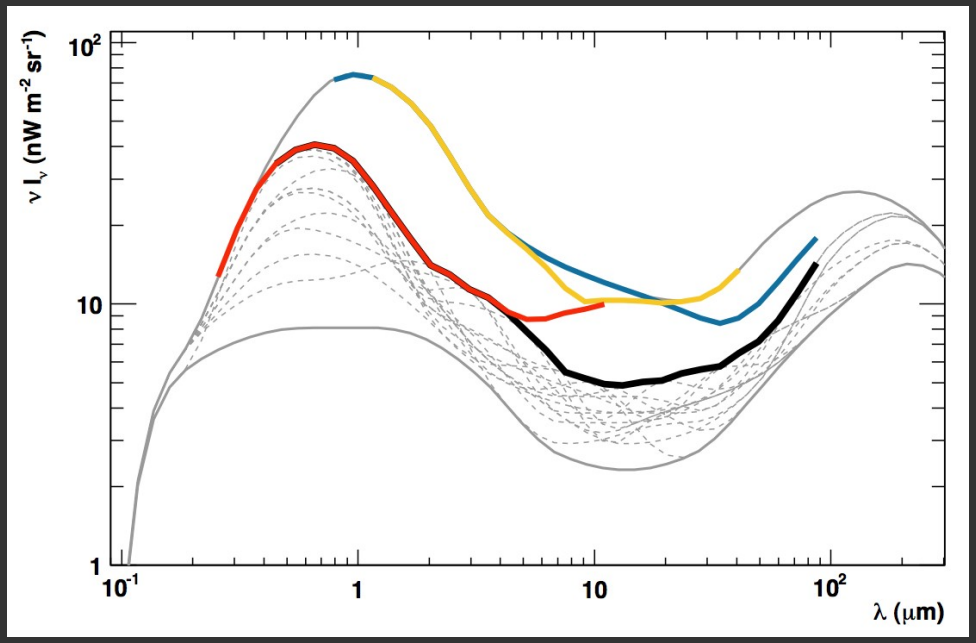
PKS2155-304 (HESS,2006)

HESS, Astropart.Phys. 34 (2011)

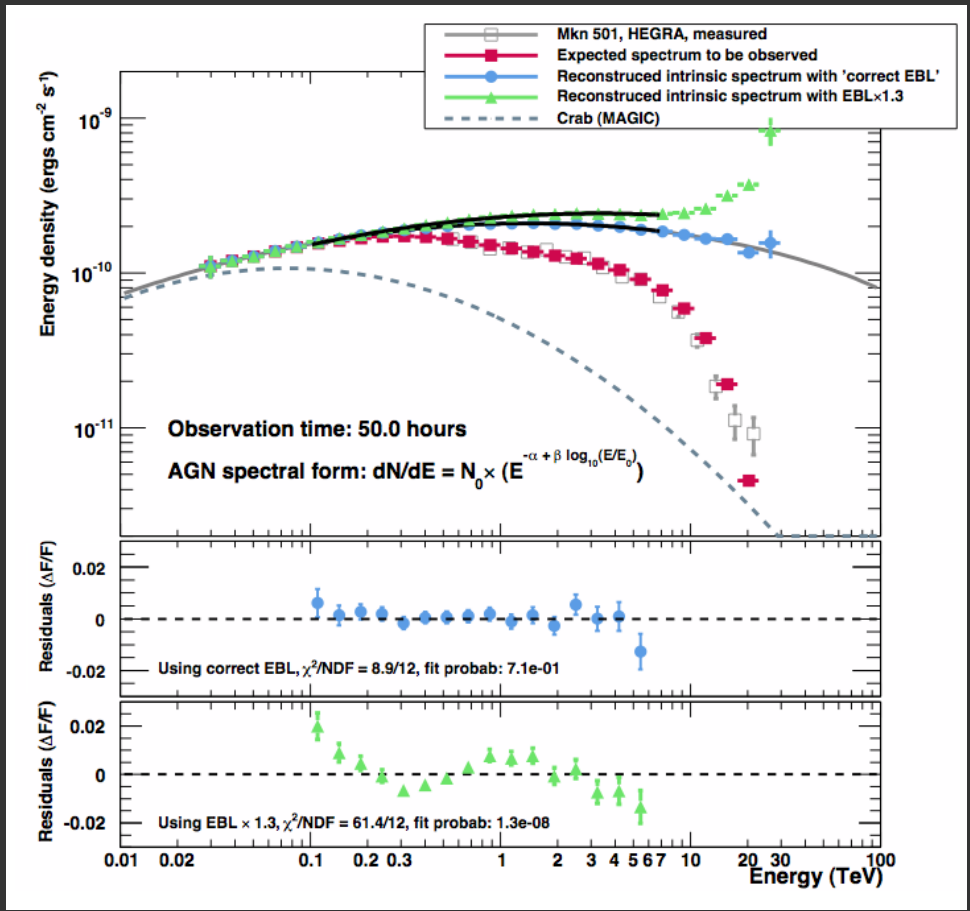
$E_{QG} > 2.1 \cdot 10^{18}$ GeV (α=1) – $E_{QG} > 2.6 \cdot 10^{10}$ GeV (α=2)

EBL → Cosmology

- Fluxes of VHE photons reaching the Earth have been attenuated due to the interaction with the Extragalactic Background Light
  - ➔ Extract EBL density from observed spectra
  - ➔ Determine Cosmological Constants from observed spectra



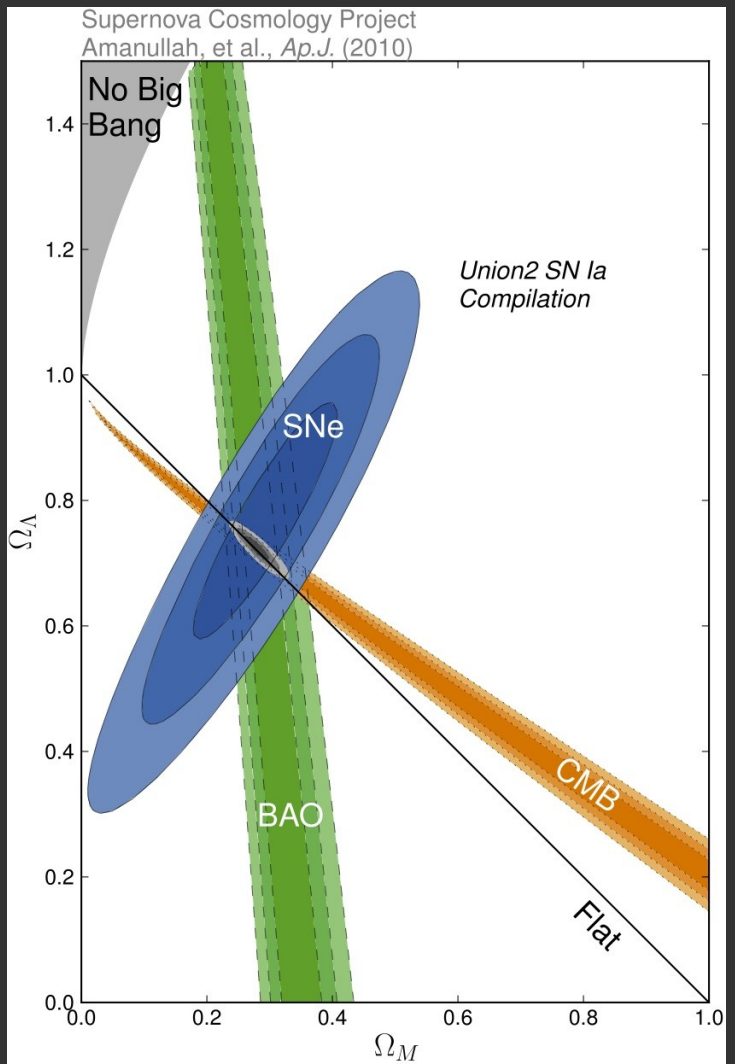
Mazin & Raue, A&A 471 (2007)

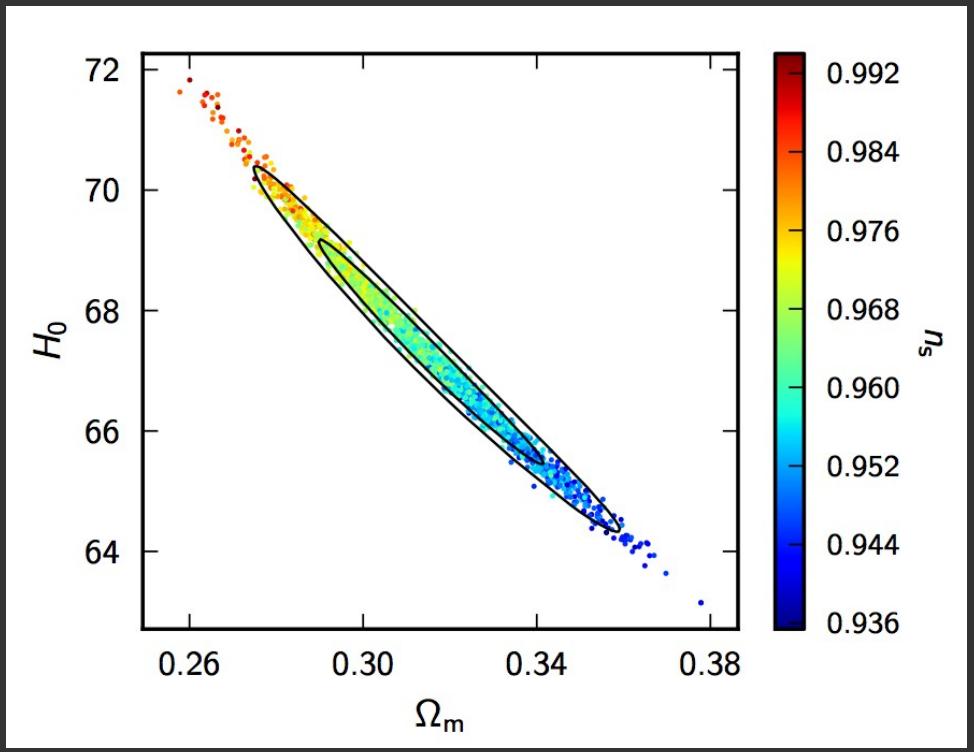


Acharya et al, Astropart.Phys. 43 (2013)

EBL → Cosmology

- Fluxes of VHE photons reaching the Earth have been attenuated due to the interaction with the Extragalactic Background Light
  - ➔ Extract EBL density from observed spectra
  - ➔ Determine Cosmological Constants from observed spectra



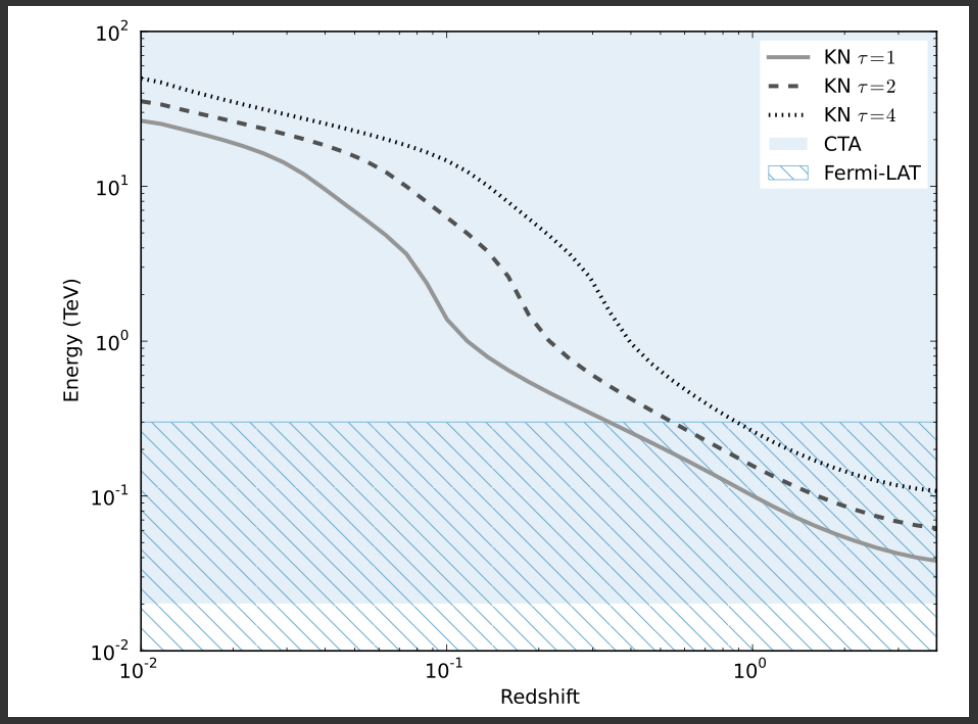


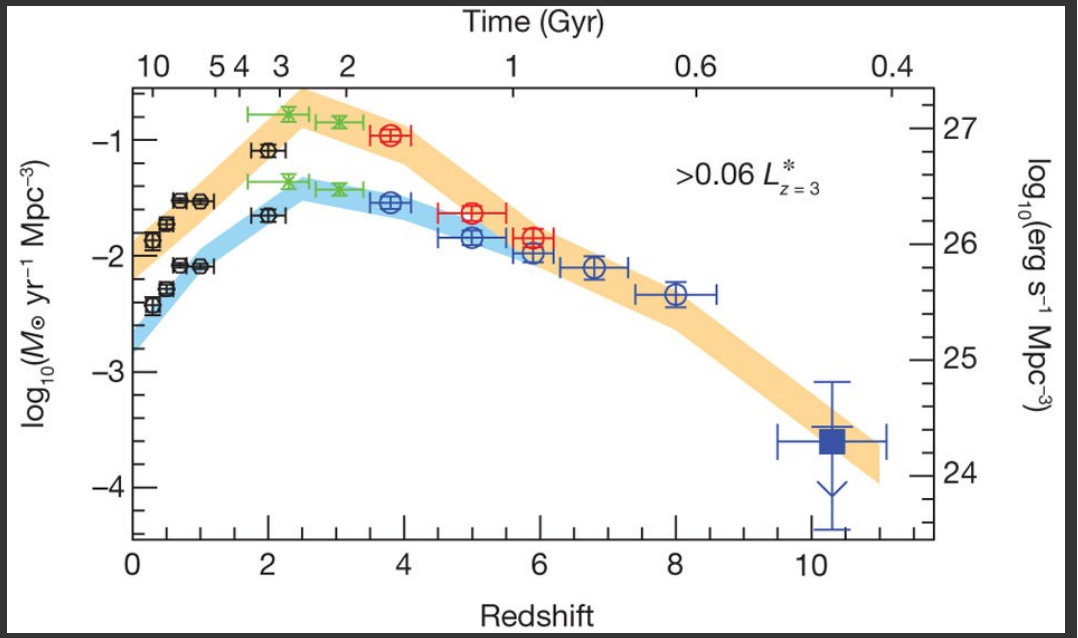
Planck 2013, accepted A&a (2014)

Amanullah et al, Ap.J 716 (2010)

The Gamma-ray Horizon

$$\tau(E,z)=\int_0^z dz'\frac{dl}{dz'}\int_{-1}^{1} dcos\,\theta\,\frac{1-\cos\theta}{2}\int_{E_{thr}}^{\infty} d\,\epsilon(z)\,n_\epsilon(\epsilon(z),z)\,\sigma(E(z),\epsilon(z),\theta)=1$$



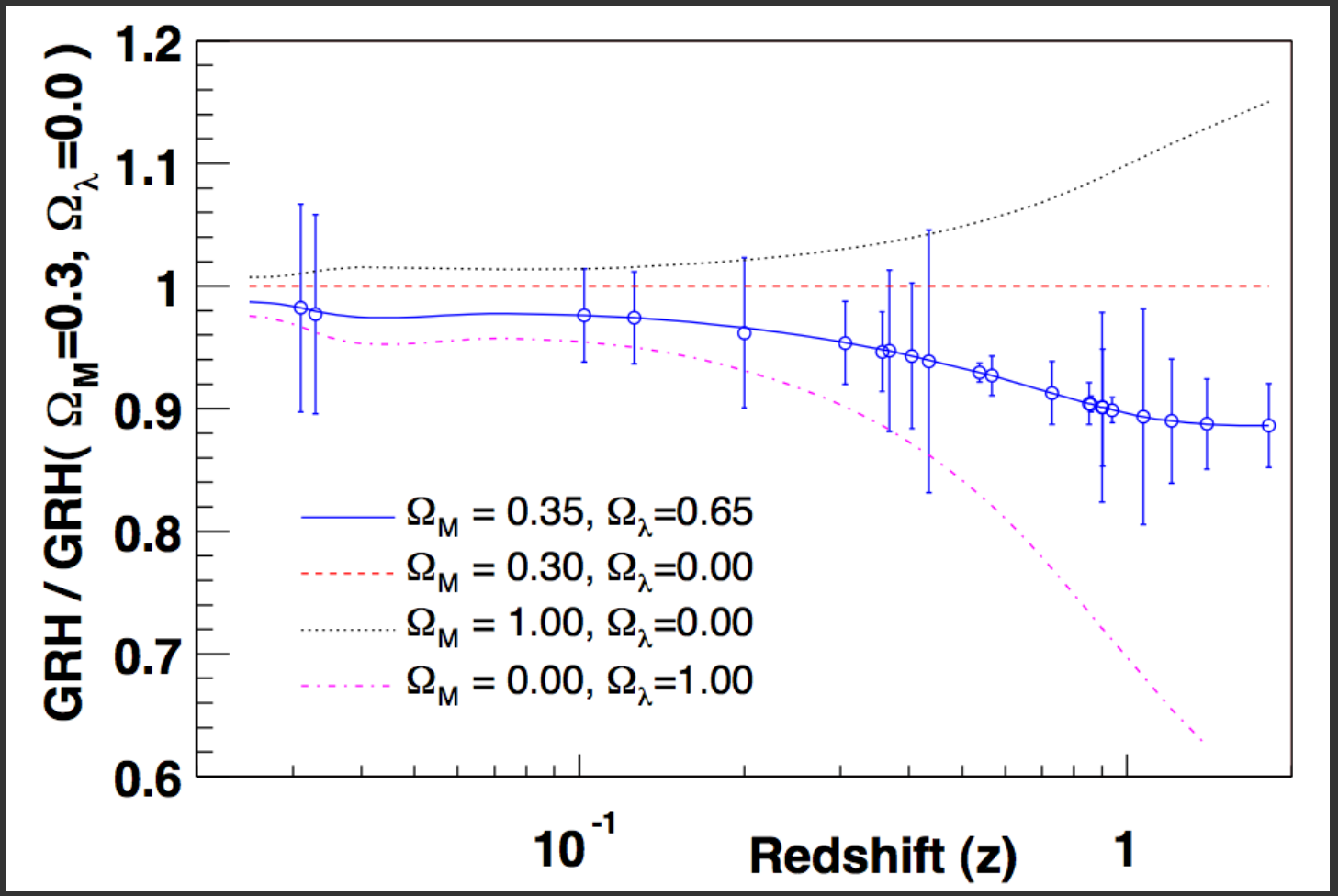


Acharya et al, Astropart.Phys. 43 (2013)

Bouwens et al, Nature 469 (2011)

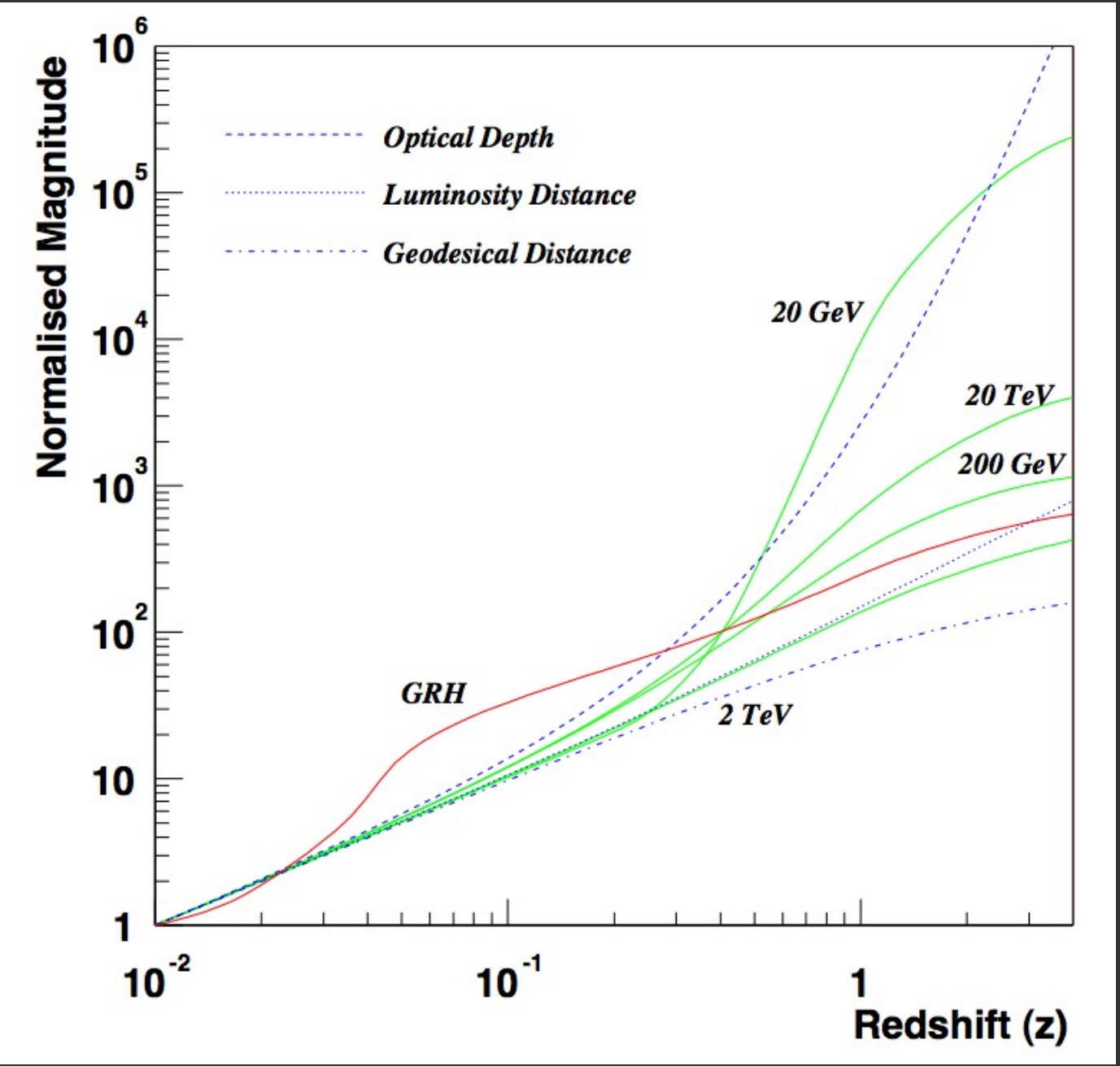
The Gamma-ray Horizon

$$\tau(E,z)=\int_0^z dz'\,\frac{dl}{dz'}\int_{-1}^{1} dcos\,\theta\,\frac{1-\cos\theta}{2}\int_{E_{thr}}^{\infty} d\,\epsilon(z)\,n_\epsilon(\epsilon(z),z)\,\sigma(E(z),\epsilon(z),\theta)=1$$

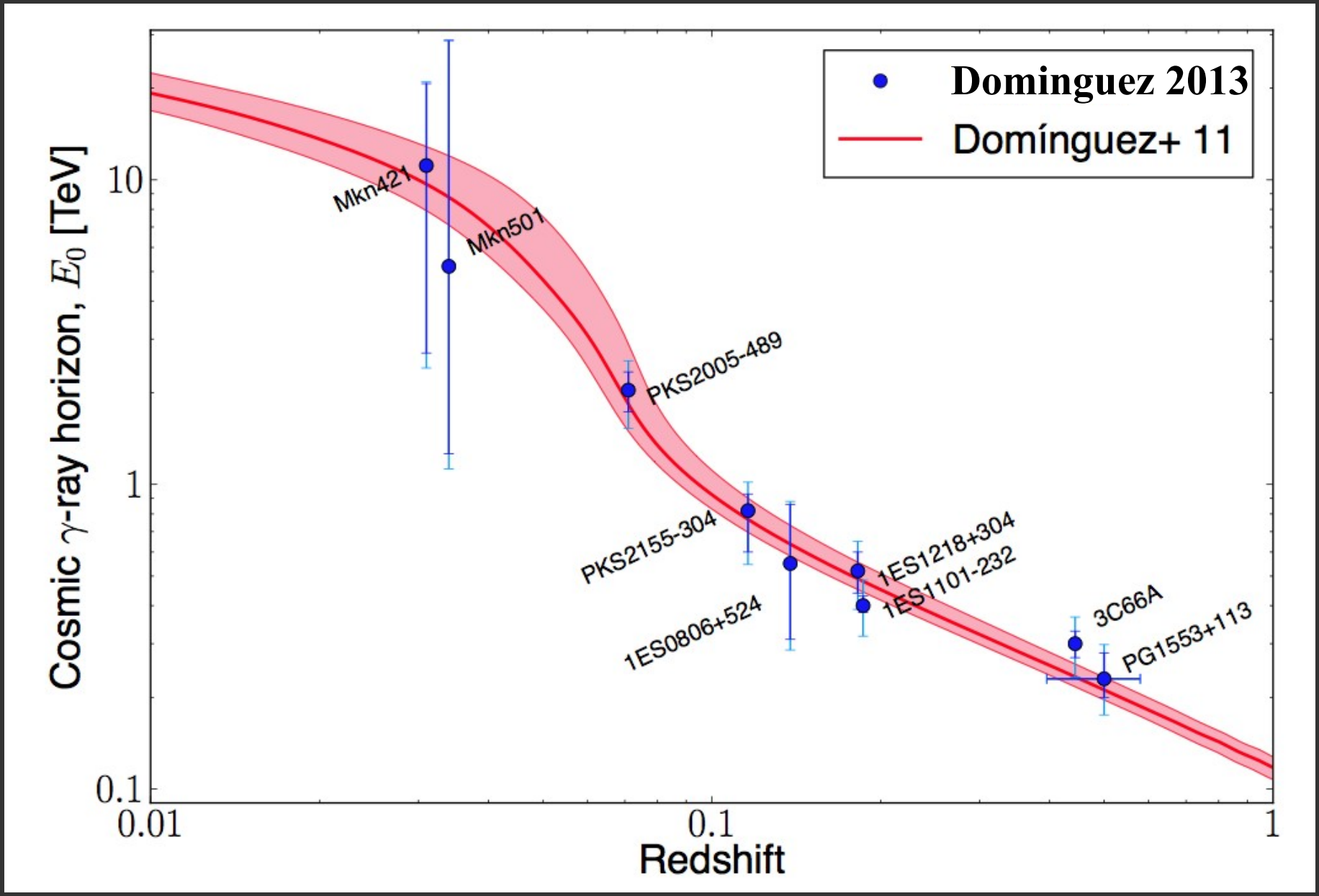


Blanch&Martinez, Astropart.Phys. 23 (2005)

An independent observable



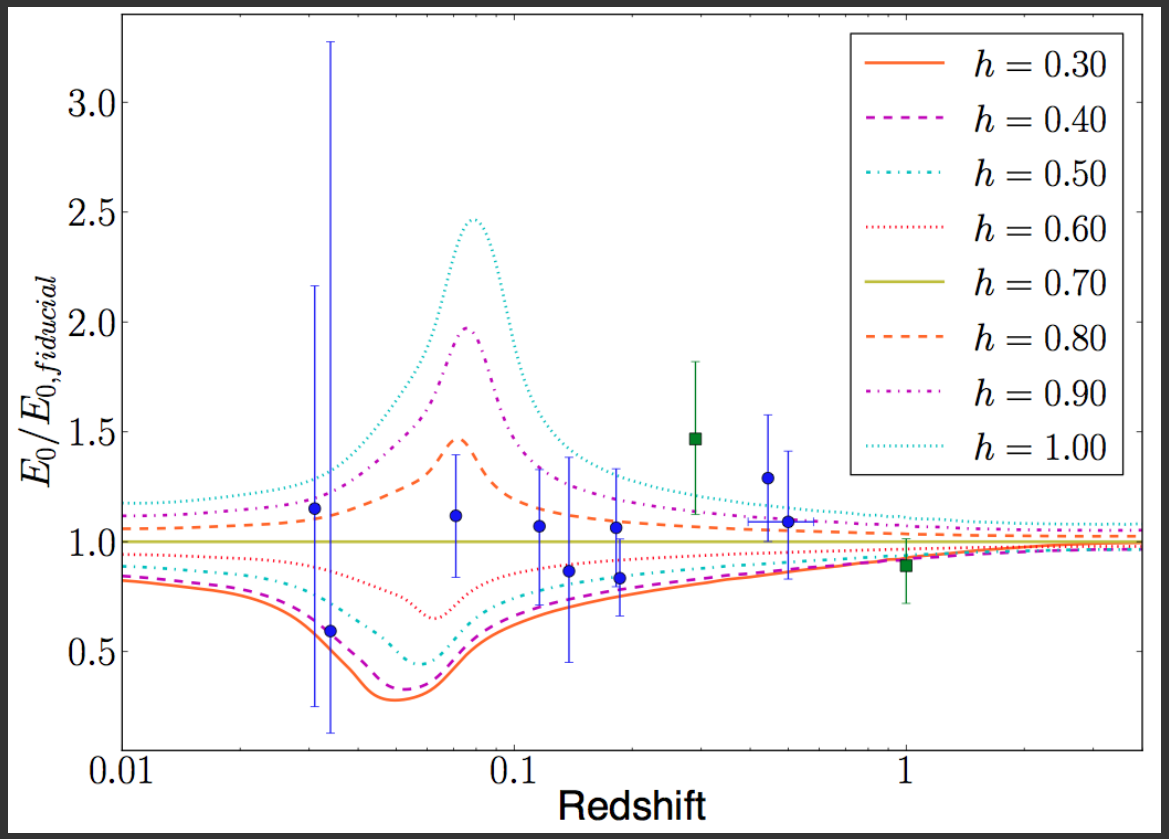
The “current” Gamma-ray Horizon

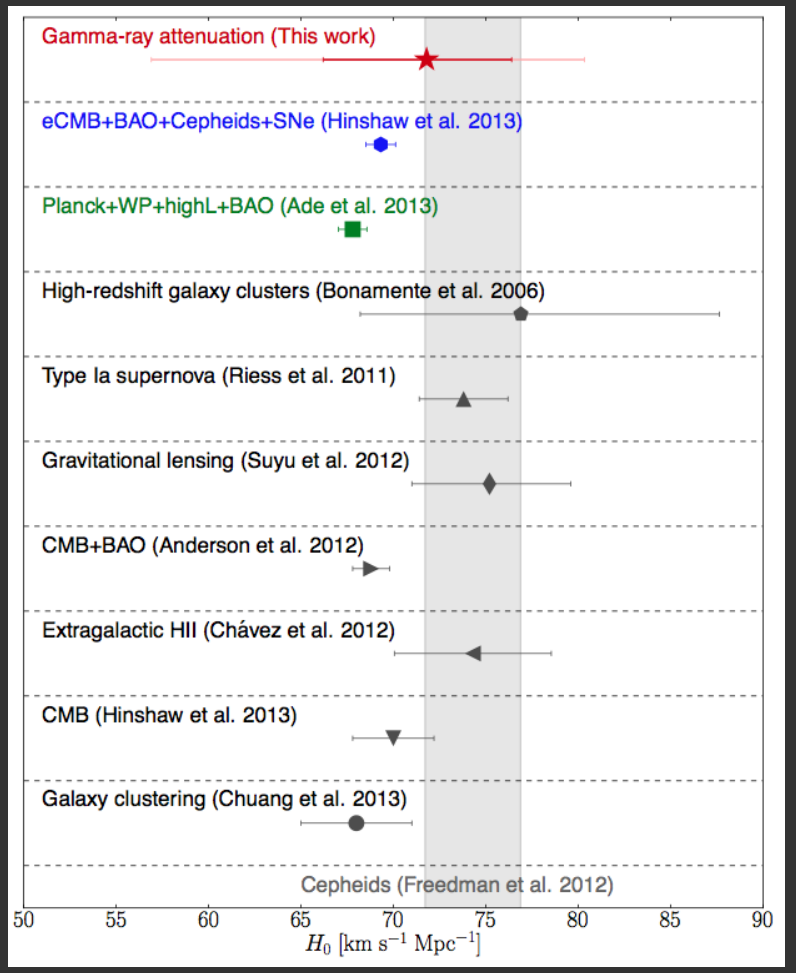


Dominguez et al, Astrophys.J 770 (2013)

Measurement of the Hubble constant

Gamma-ray Horizon measurement → Hubble constant



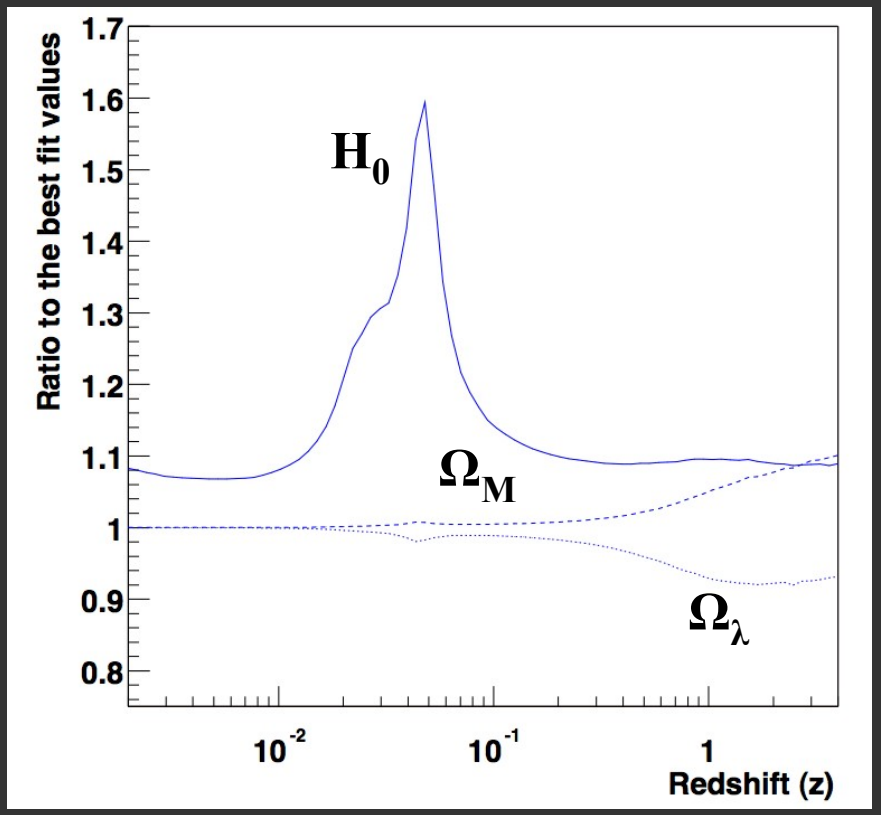


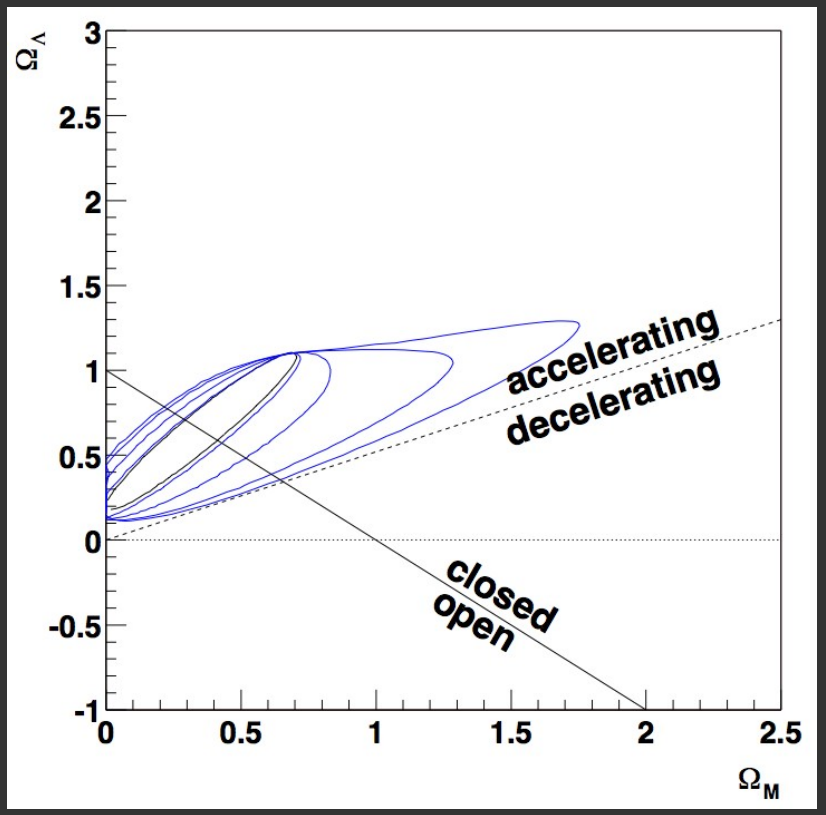
$$H_0 = 71.8^{+4.6}_{-5.6}(stat)^{+7.2}_{-13.8}(sys)$$

Dominguez&Prada, arXiv1305.2163 (2013)

Limitations to measure cosmological constants

- Systematics
  - ➔ Systematics from current generation of Cherenkov telescopes
  - ➔ Knowledge of Extragalactic Background Light
- Intrinsic source energy spectra
- Sources at large redshift ($z \geq 1$) needed for cosmological densities

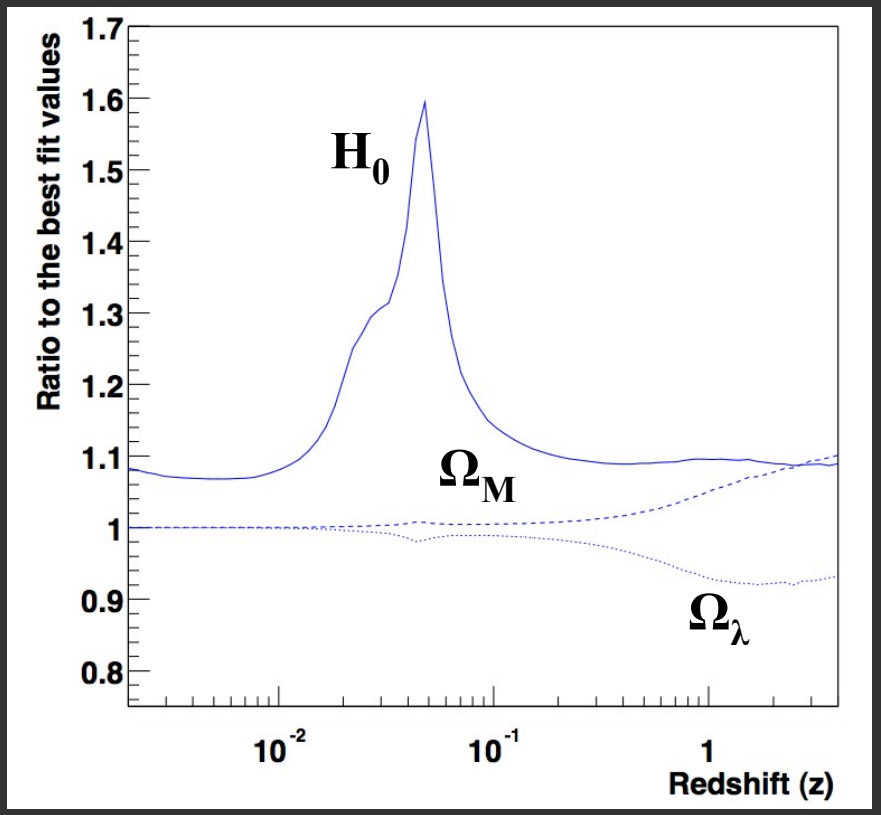


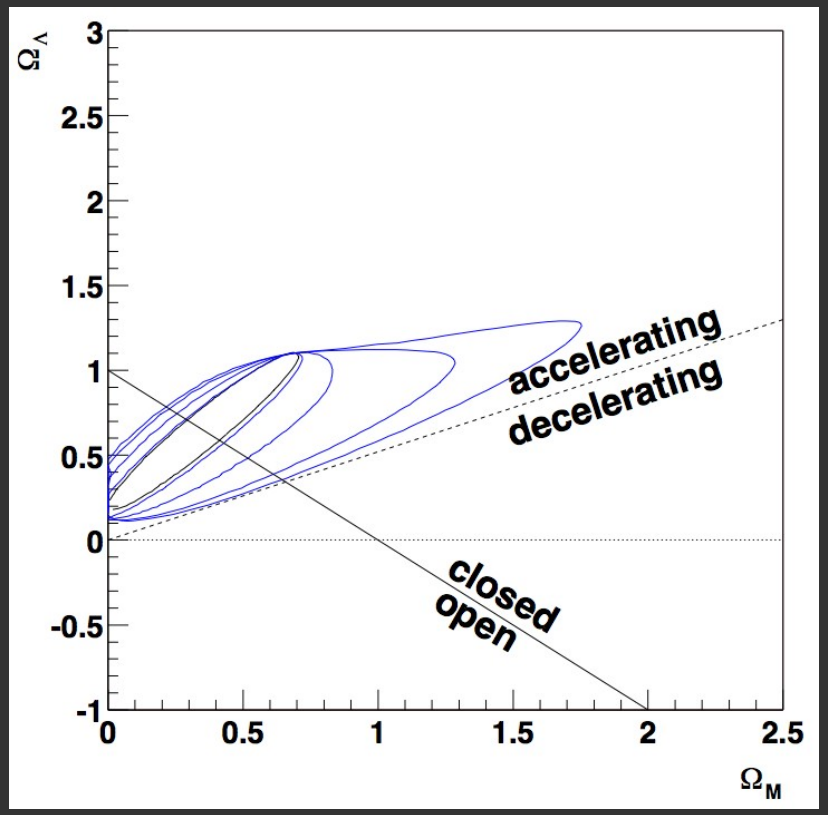


Blanch&Martinez, Astropart.Phys. 23 (2005)

Limitations to measure cosmological constants

- Systematics
  - ➔ Systematics from current generation of Cherenkov telescopes
  - ➔ Knowledge of Extragalactic Background Light
- Intrinsic source energy spectra
- Sources at large redshift ($z \geq 1$) needed for cosmological densities





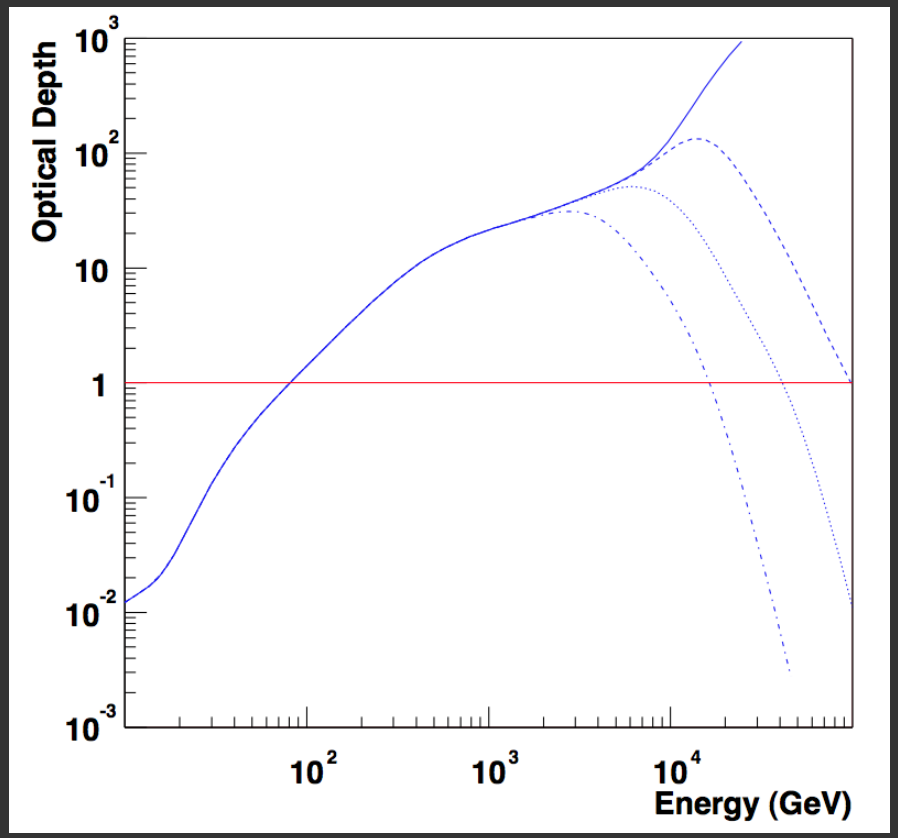
Blanch&Martinez, Astropart.Phys. 23 (2005)

Modified GRH due to LIV

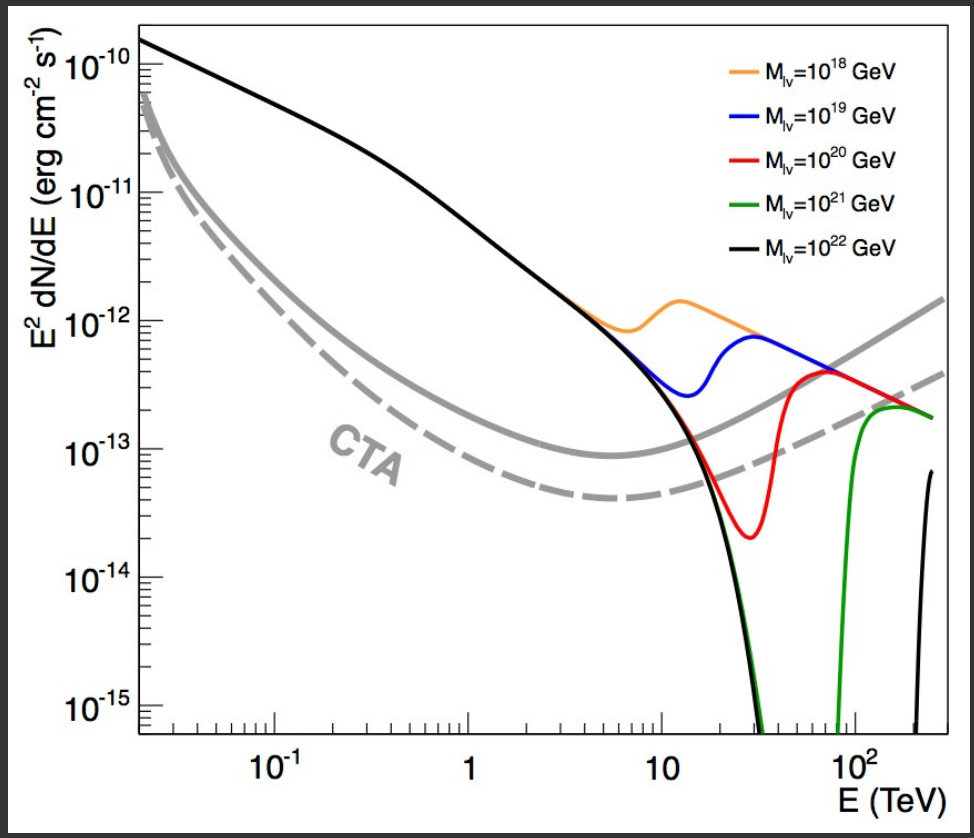
LIV provides effective mass to photons →

$$m_\gamma^2 = \xi \frac{E_\gamma^{2+\alpha}}{E_{LIV}^{\alpha}}$$

Protheroe&Meyer, Phys.Lett.B 93 (2000)



Blanch et al, Astropart.Phys. 19 (2003)



Fairbairn et al, arXiv:1401.8178 (2014)

Summary

- VHE photon propagation through the universe provide insights on fundamental physics:
  - Extragalactic Background Light
  - Axion Like Particles
  - Intergalactic magnetic fields
  - Lorentz Invariance Violation
  - Cosmological constants

- VHE and HE photon propagation has provided strong limit on the the effective mass for LIV (Quantum Gravity) , reaching values above the Planck mass.

- Attenuation of gamma-ray fluxes with the EBL depends on the travelled by the photons → Cosmological constants

Next generation of VHE detectors will provide data to improve measurements on Quantum Gravity scale and cosmological constants

END TALK