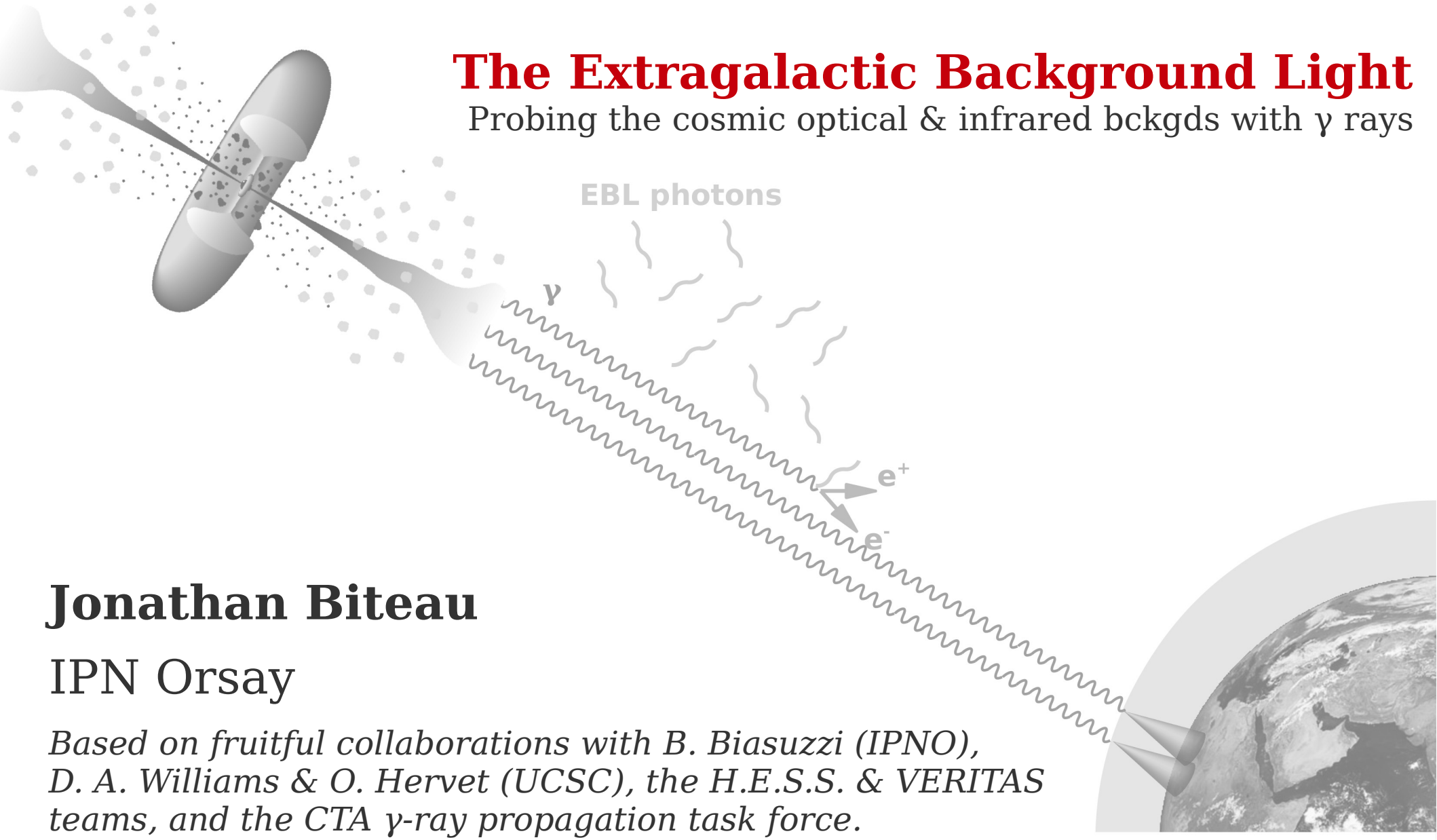
The Extragalactic Background Light

Probing the cosmic optical & infrared bckgds with γ rays

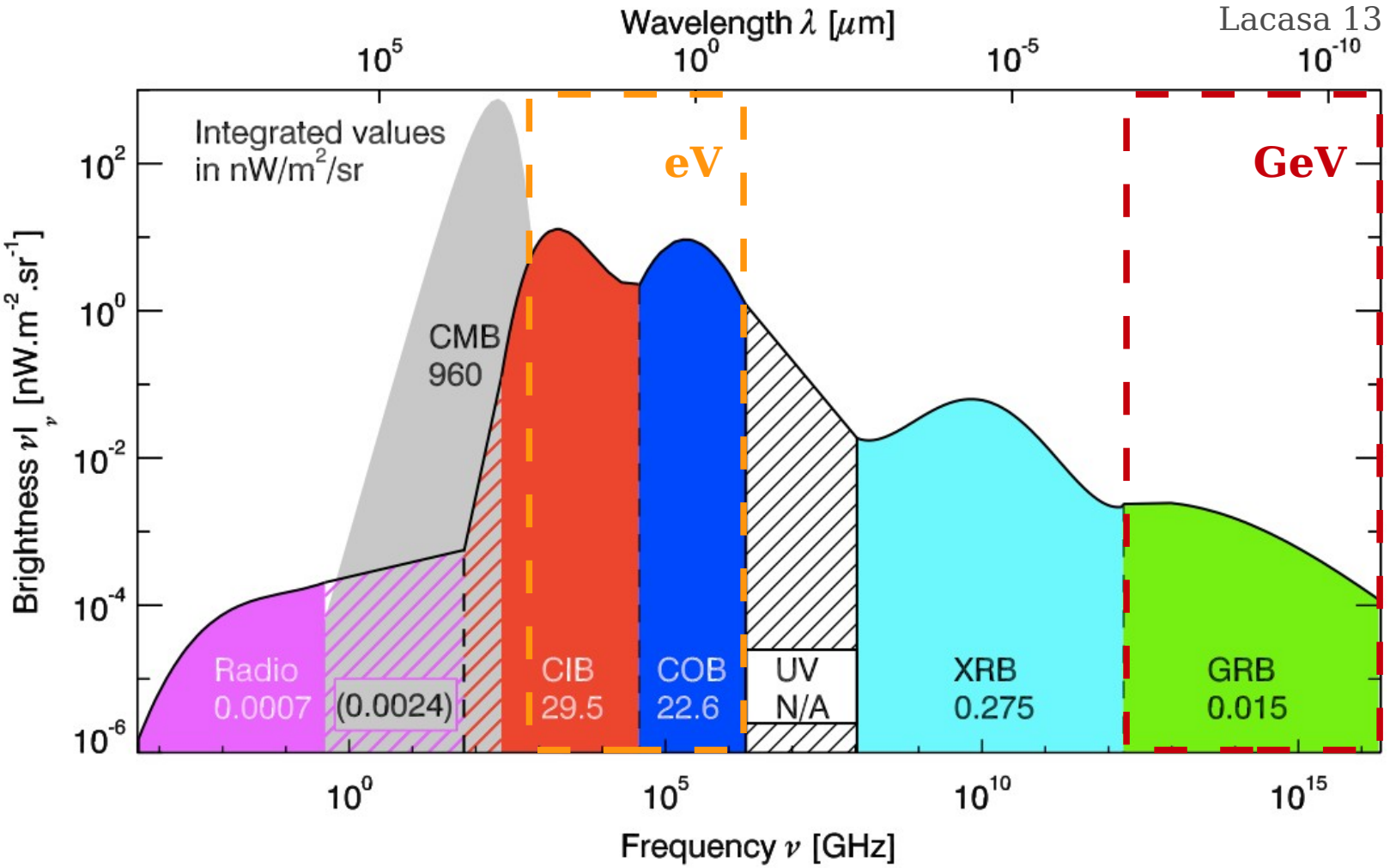


Jonathan Biteau

IPN Orsay

Based on fruitful collaborations with B. Biasuzzi (IPNO), D. A. Williams & O. Hervet (UCSC), the H.E.S.S. & VERITAS teams, and the CTA γ-ray propagation task force.

The Extragalactic Sky



Synchrotron from radio-galaxies (AGN & extended)

Dust emission & Direct starlight

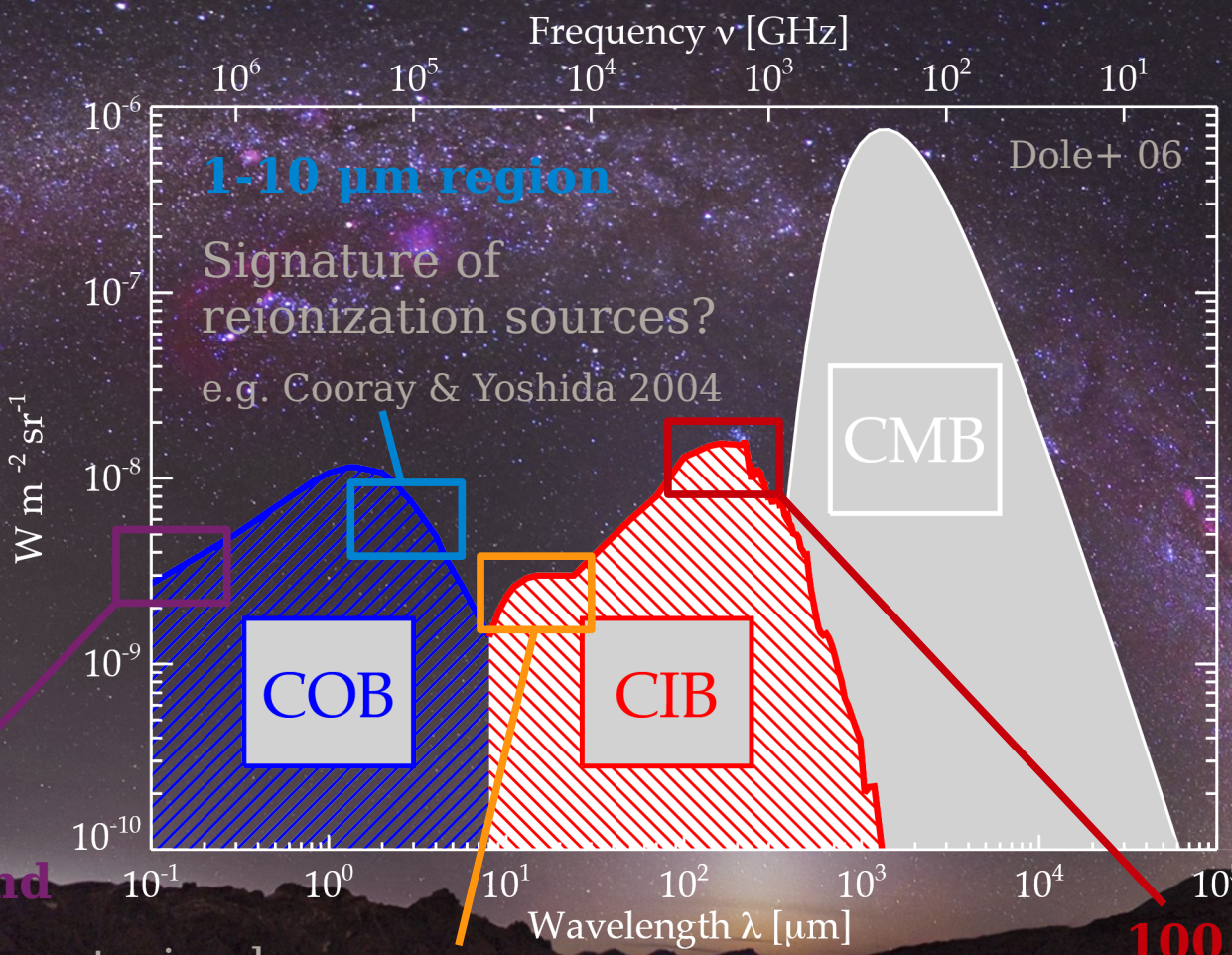
Accretion in AGN

AGN & starbursts

Extragalactic Background Light Spectrum

On top of source populations: lines? truly diffuse components? line-of-sight interactions?

What's the EBL & where does it come from?



UV background

Largely underconstrained by theory and experiments

e.g. Haardt & Madau 2012

10-30 µm region

Polycyclic aromatic hydrocarbons / amorphous carbons ?

e.g. Dominguez+ 2011

100 µm region

Census of the CIB sources up to high z ?

e.g. Viero+ 2015

Daniel López
cielosdelteide.com

“Dark patches” observations

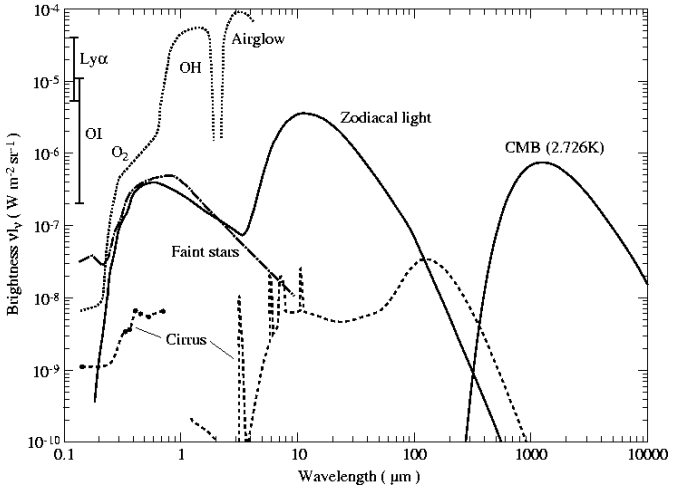
Direct measurement of the night-sky brightness

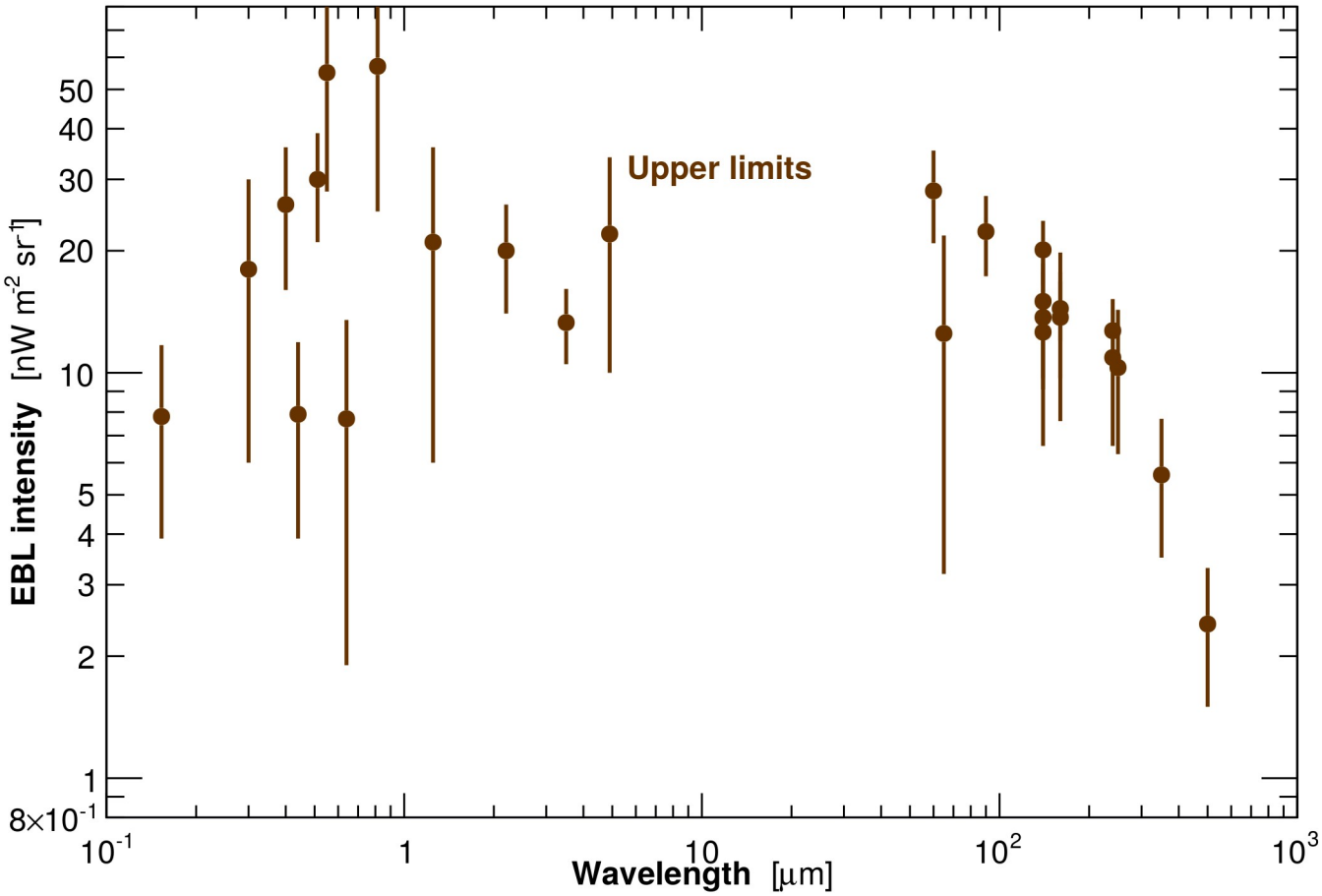
But bright local environment (e.g. zodiacal light) suggests foreground contamination, particularly for the COB → overestimation of the EBL.

> 100 µm: cleaner

COBE (FIRAS/DIRBE) measurements less prone to contamination

Leinert+ 1998

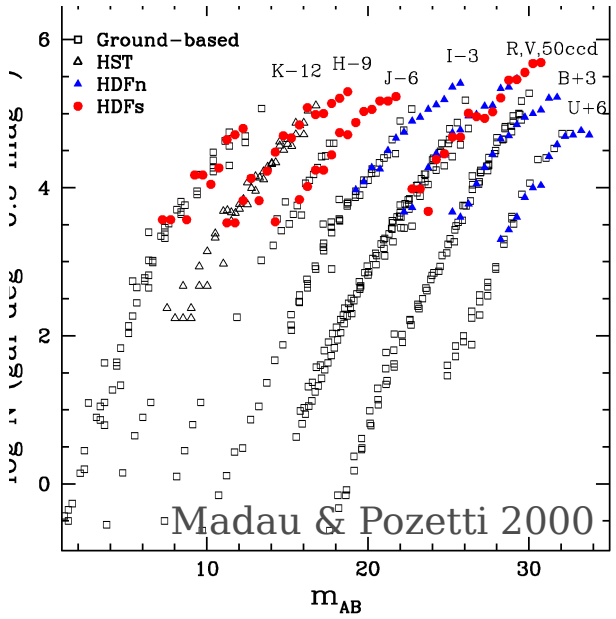




Galaxy Counts

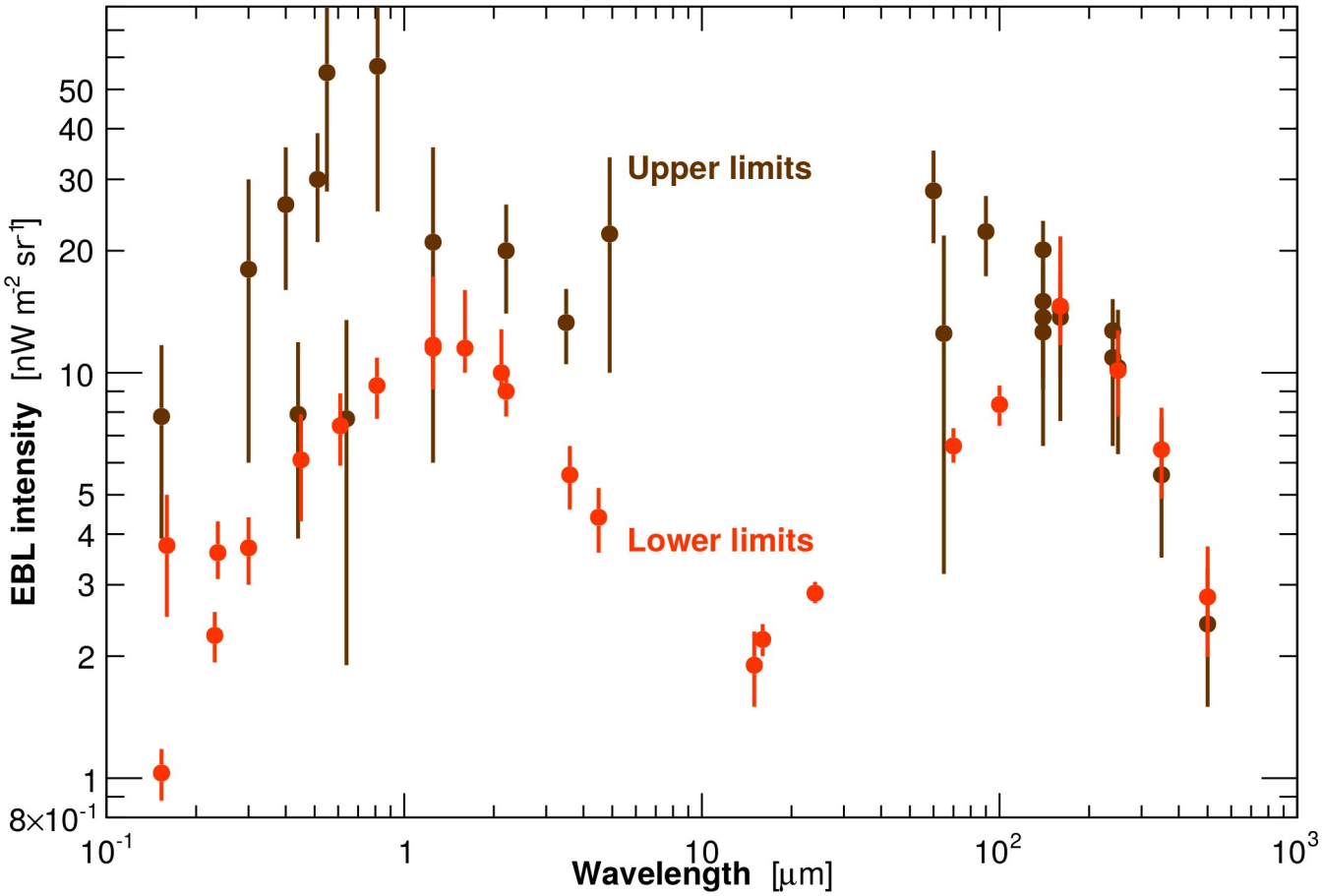
Counting the number of objects per magnitude band

Faint end of the distribution function must drop below a given slope for the integral to converge (completeness). Does not account for unknown populations of sources or truly diffuse component → underestimation.

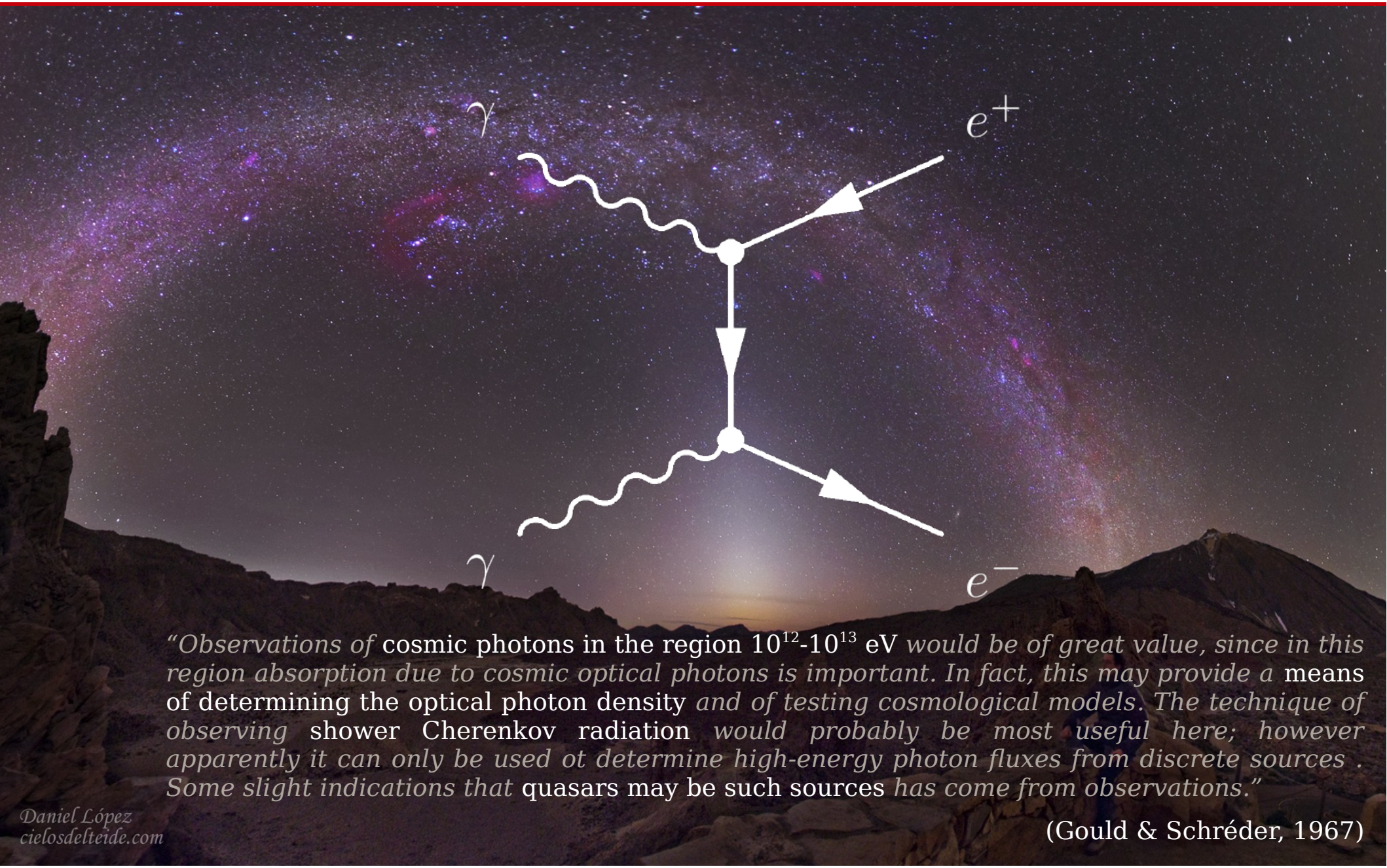


+ stacking e.g. Viero +13

+ fluctuations
e.g. Zemcov +14



The 60s' brilliant idea

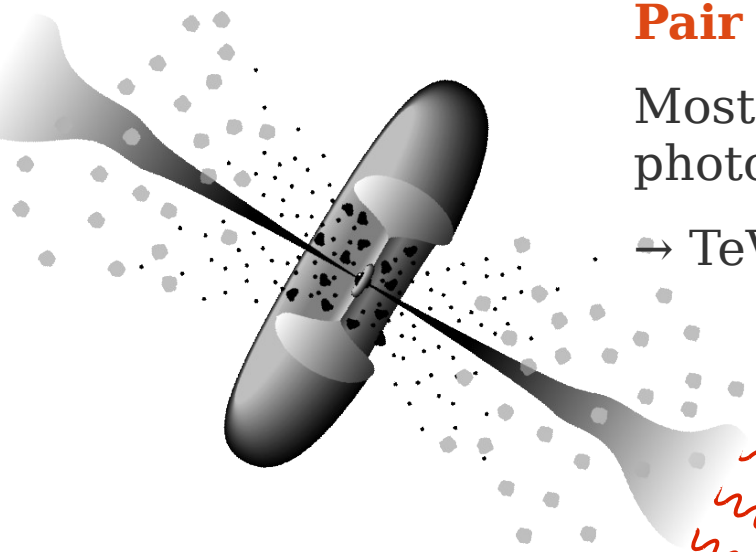


"Observations of cosmic photons in the region 10^{12}-10^{13} eV *would be of great value, since in this region absorption due to cosmic optical photons is important. In fact, this may provide a* means of determining the optical photon density *and of testing cosmological models. The technique of observing* shower Cherenkov radiation *would probably be most useful here; however apparently it can only be used ot determine high-energy photon fluxes from discrete sources . Some slight indications that* quasars may be such sources *has come from observations."*

(Gould & Schréder, 1967)

Daniel López
cielosdelteide.com

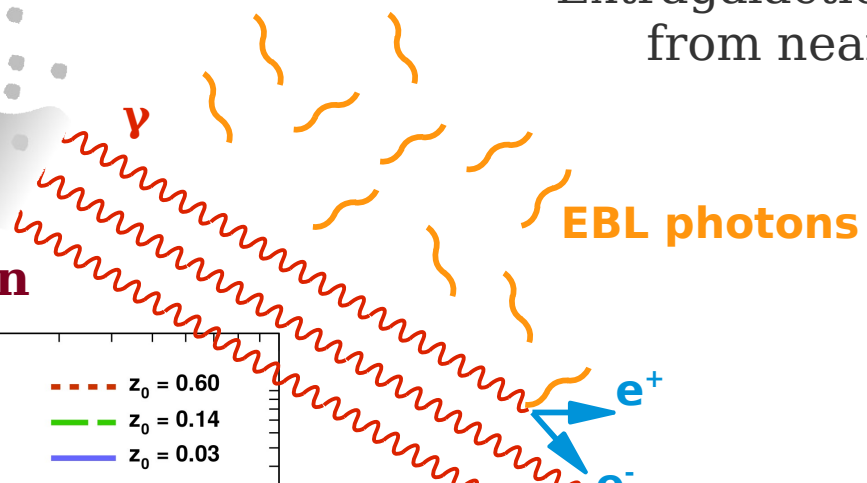
Gamma-ray Absorption



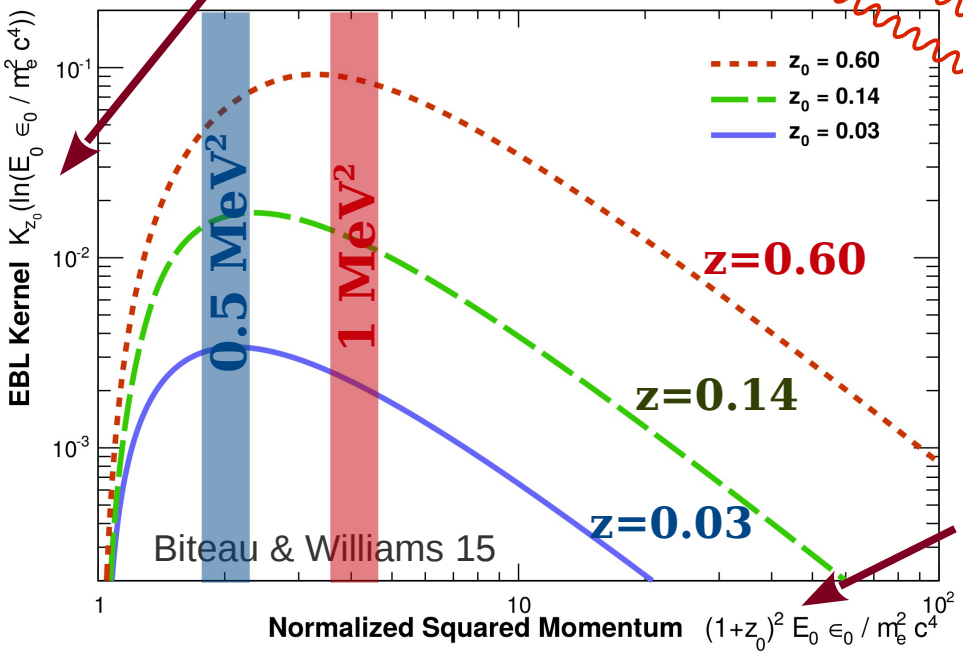
Pair creation along the line of sight

Most likely when gamma-ray energy times diffuse photon field energy equals 0.5–1 MeV^2

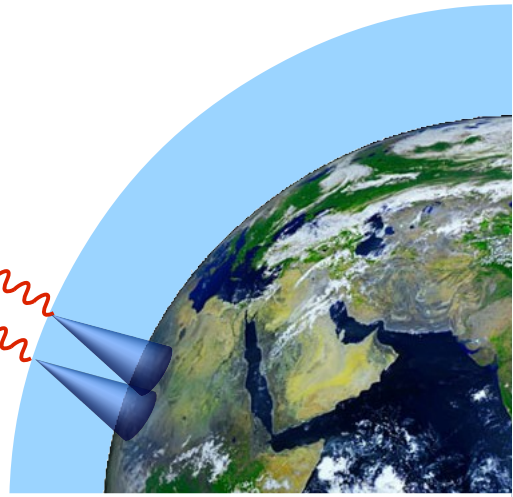
→ TeV gamma-rays interact with eV photons i.e. with the Extragalactic Background Light from near UV to far infrared



Probability of interaction



Product of EBL photon and γ-ray energies



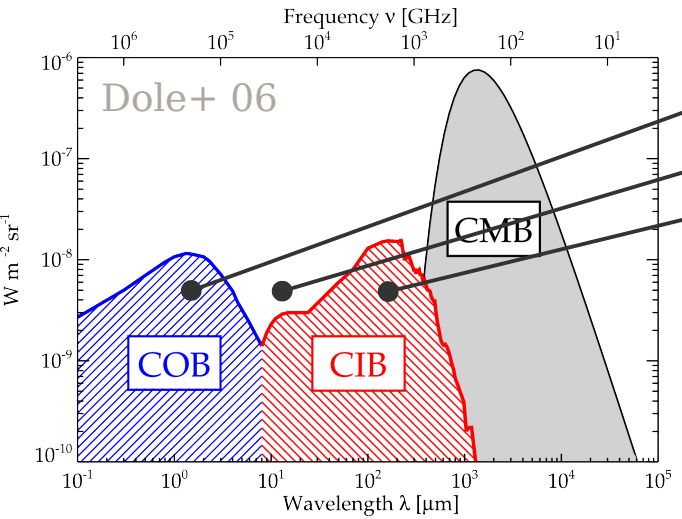
The EBL imprint on gamma-ray spectra

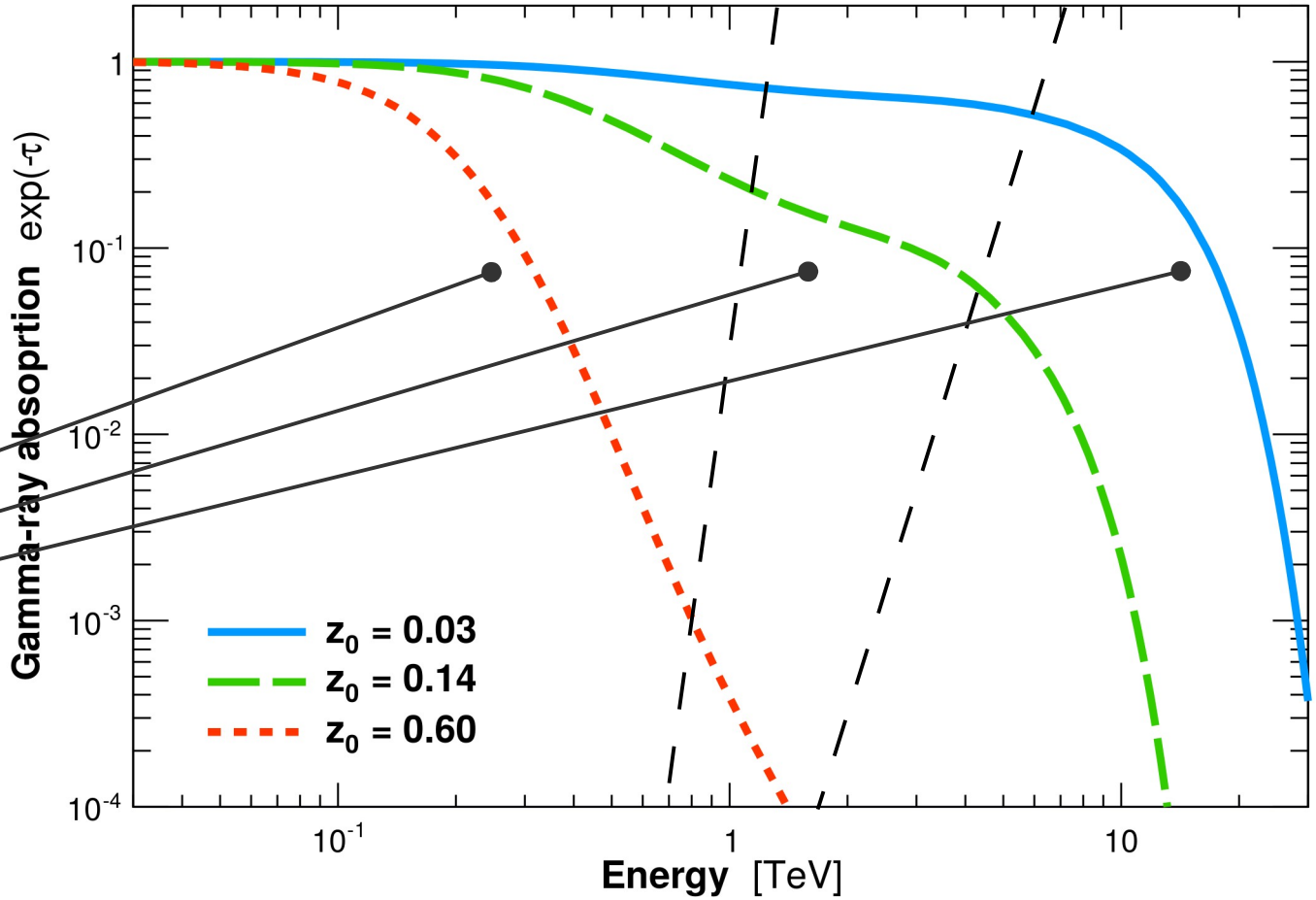
Gamma-ray disappearance imprints the spectra > 100 GeV

Near sources (z<0.05) mostly affected by the CIB

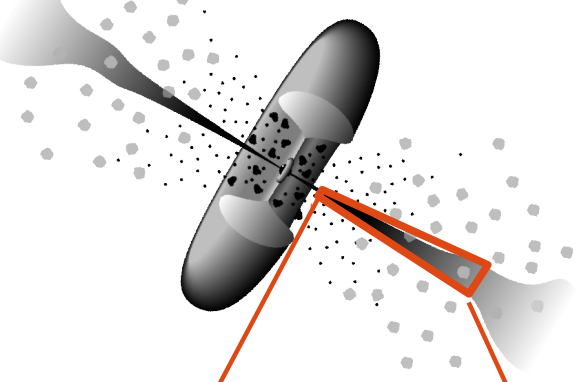
Far sources (z>0.3) mostly affected by the COB

Specific imprint enabling a reconstruction of the EBL spectrum, combining data from multiple sources, and accounting for the expected intrinsic spectral curvature.





Understanding TeV blazars

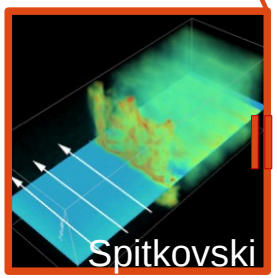


Emission at the source: intrinsic spectrum

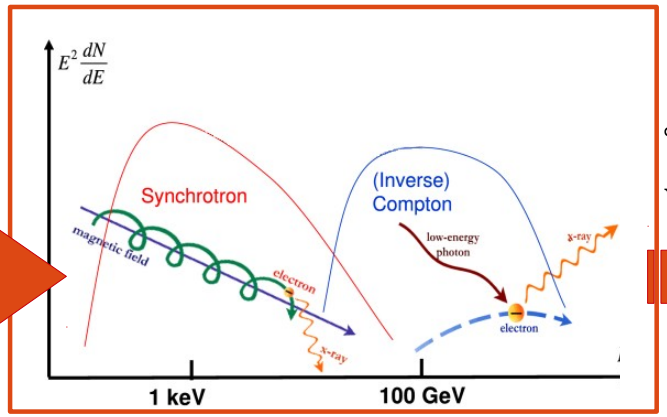
Curvature, smooth cut-offs expected from acceleration and radiative processes → disentangle from EBL effect?

Magnetic reconnection

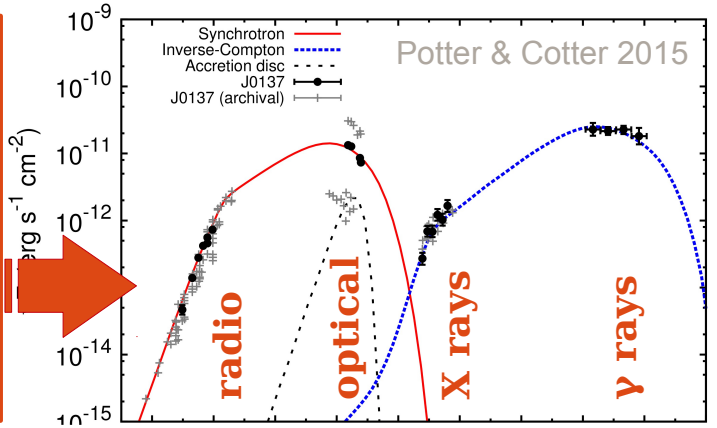
Shock acceleration



PIC simulations



Radiative models



Multiband observations

Model-dependent approaches

Broad-band modeling of "average" spectra (SSC) → fixed intrinsic spectrum e.g. Dominguez+ 13

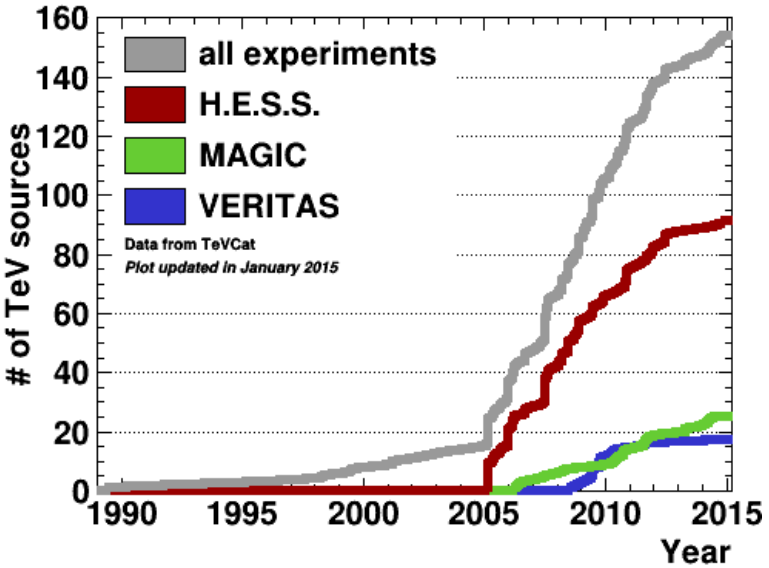
Fixed-parameter approaches

Curvature fixed to average value over pop. e.g. Sanchez+ 13
Extrapolation of the low-energy, unabsorbed spectrum e.g. *Fermi*-LAT+ 12, Armstrong+ 17

Maximum-likelihood approaches

Free-parameter hypothesis testing with increasing complexity (PWL → LP/EPWL → …)
e.g. H.E.S.S. 13, Biteau & Williams 15

Detecting GeV-TeV blazars



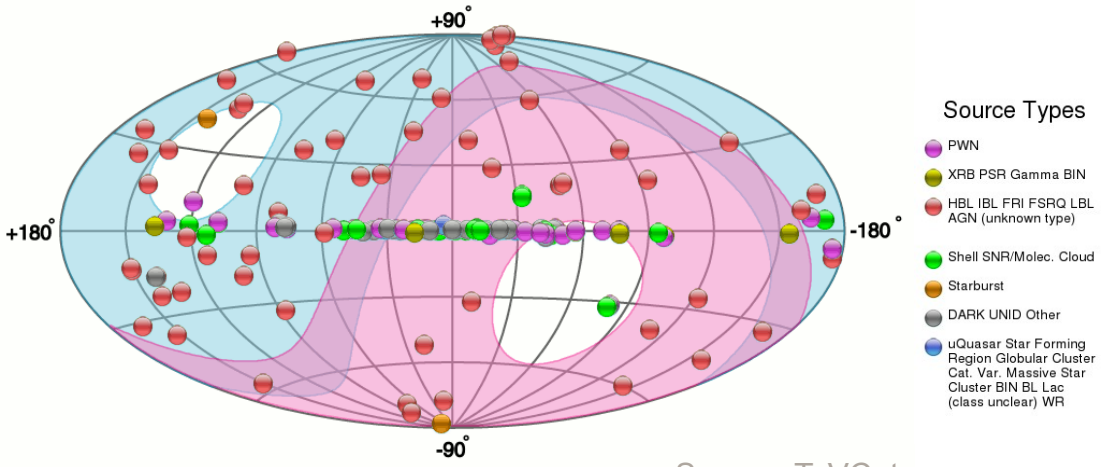
Ground based (>100 GeV)

In particular: H.E.S.S., MAGIC, VERITAS

~ 200 sources (~70 extragalactic – 35%)

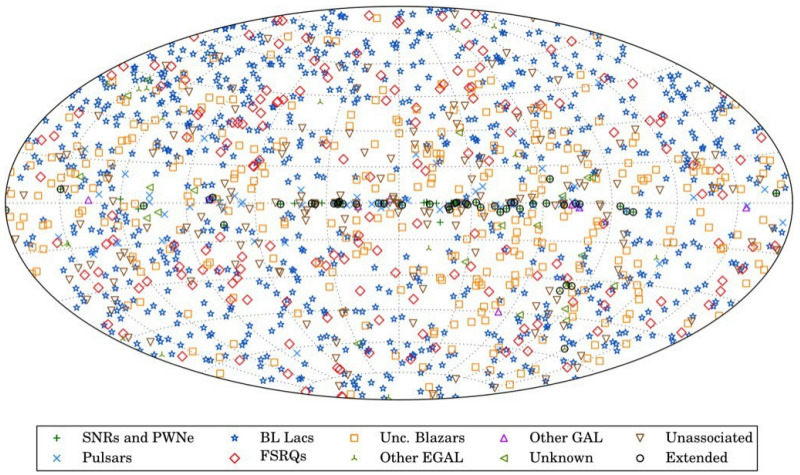
Fermi-LAT (>10 GeV - 3FHL)

~ 1600 sources (~1200 extragalactic – 80%)



Source: TeVCat

Source: *Fermi*-LAT 2017



EBL-Model-Dependent Constraints

Using template EBL model

1 free EBL parameter: normalization α

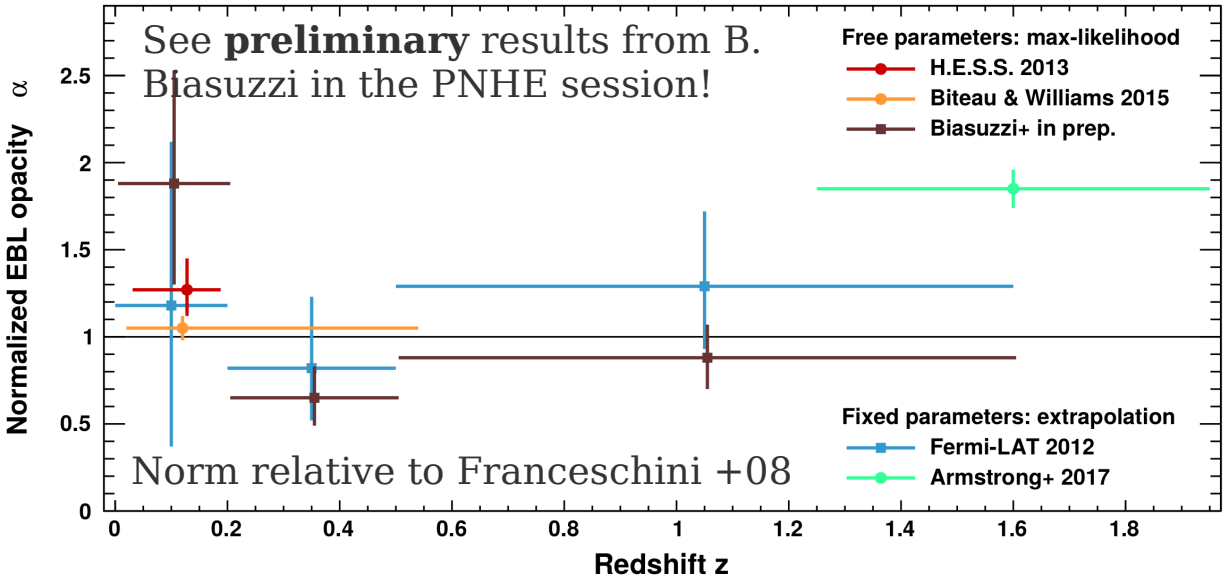
$\phi_{observed}(E,z) = \phi_{intrinsic}(E) \times \exp[- \alpha \times \tau_{template}(E,z)]$

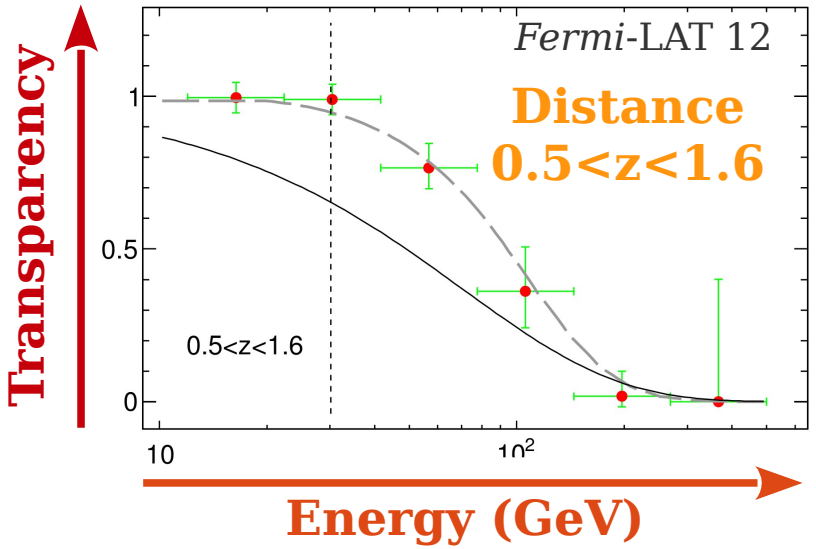
Fermi-LAT ~ 100 GeV

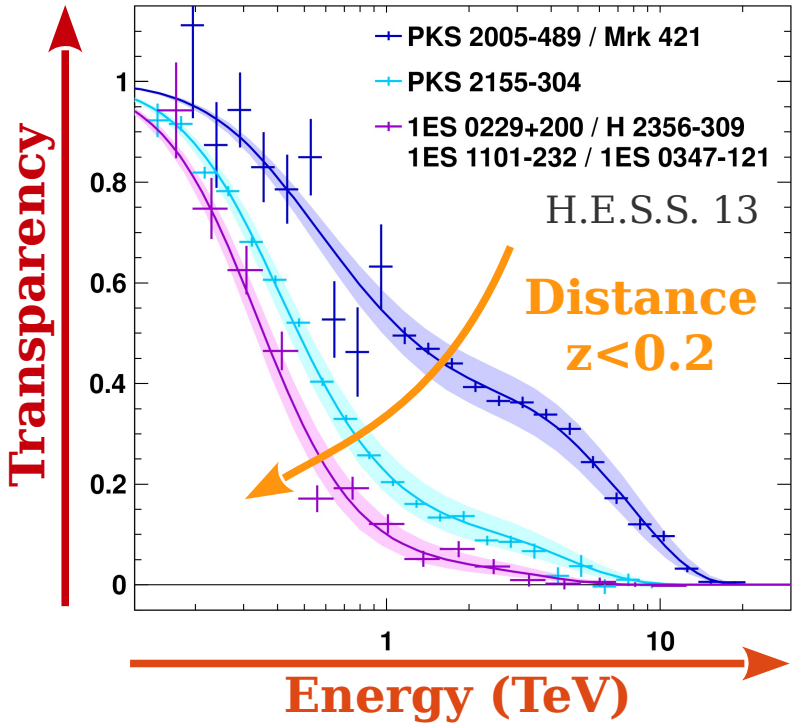
1st det. in 2012: 6σ detection, mostly from z ~ 1

H.E.S.S. ~ 1 TeV

1st det. in 2013: 9σ detection, mostly from z ~ 0.1







Model-Independent Gamma-ray Constraints

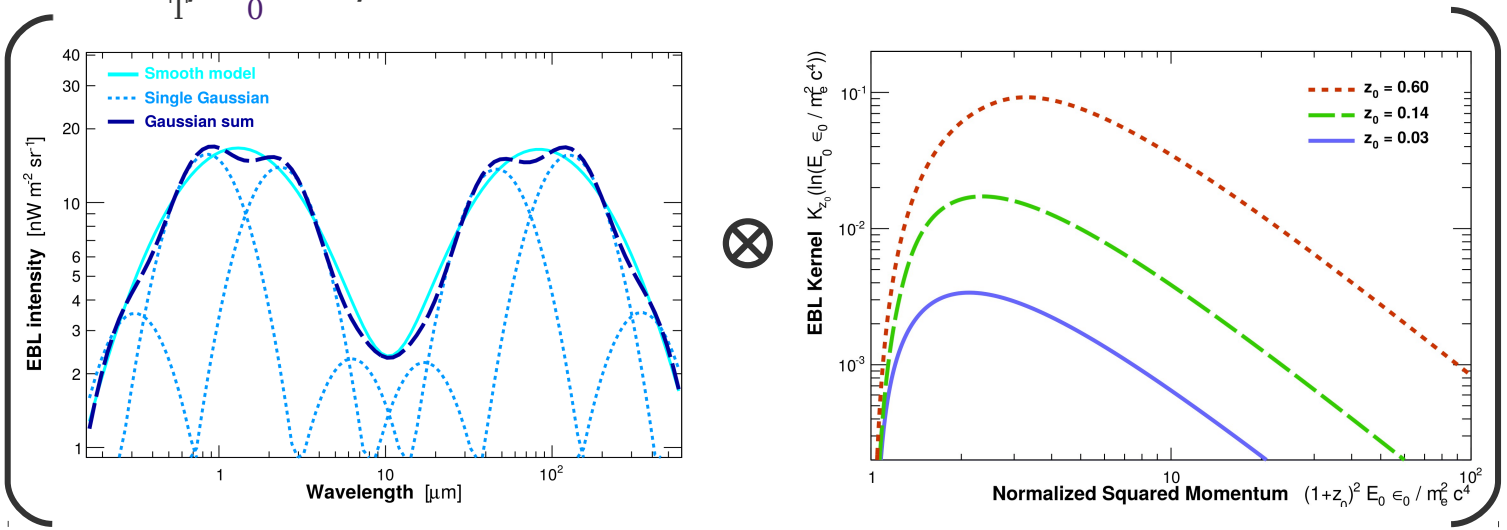
Optical depth: $\tau(E,z)$ = Target density x Distance x Cross section

→ 3D integral over: energy of target photons, redshift, gamma-to-target angle

→ 2D integral after analytical reduction of the integral over the angle

If Target density(ε,z) = Target density(ε,z=0) x Evolution(z), then

→ $\tau(E,z) = 3\pi\sigma_T/H_0 \times E/m^2c^4 \times$



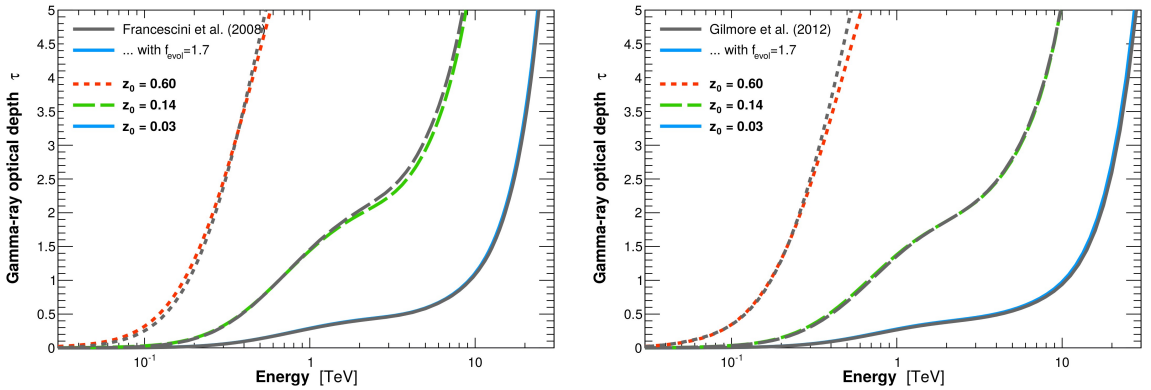
$\ln(E/mc^2)$

Evolution:

Evolution(z) = $(1+z)^{3\text{-fevol}}$

Decoupling hypothesis:

impact on τ of about ~2%



UV-IR Spectral Imprints

Combining (almost) all TeV spectra

Biteau & Williams 15

Model-independent 11σ detection

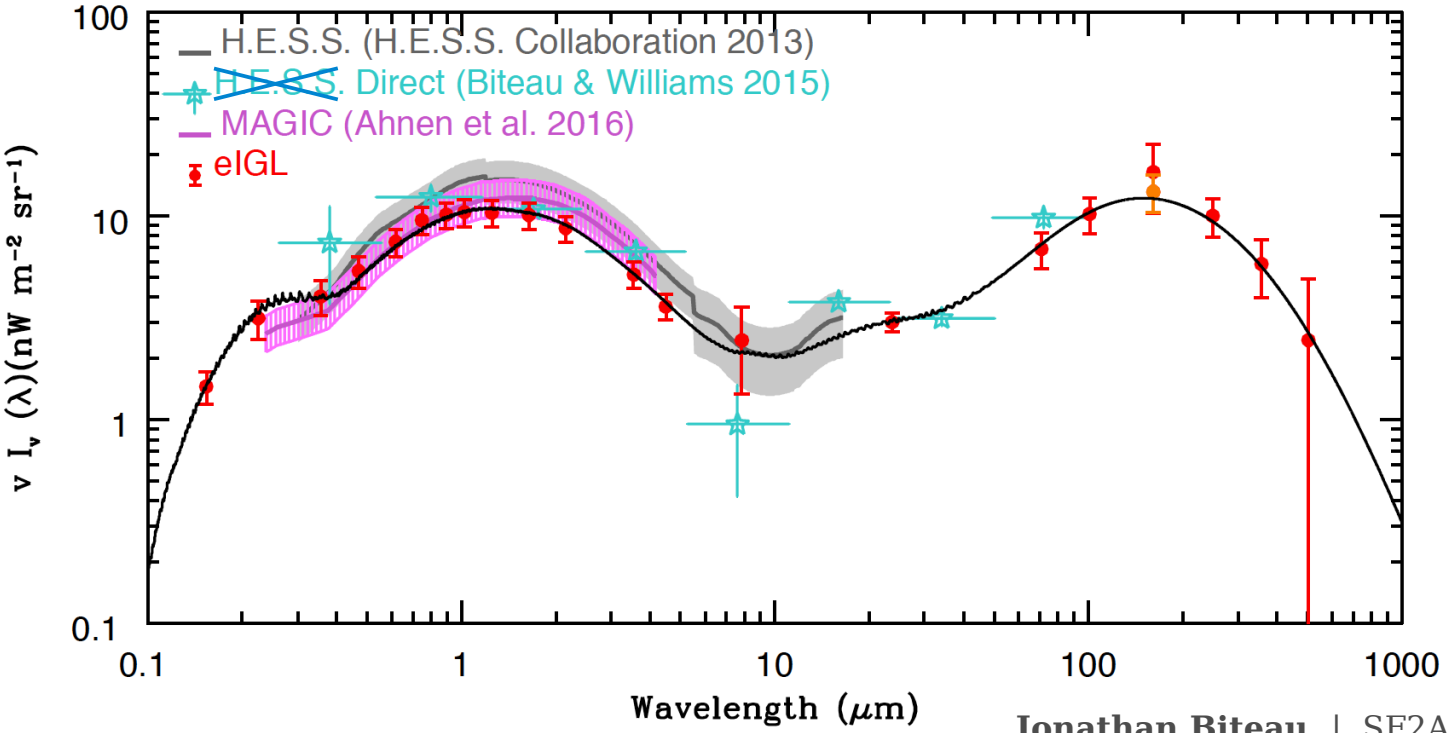
Overall 20% accuracy from NUV to FIR

Excellent agreement with galaxy counts, excluding most of direct observations (contamination by foregrounds)

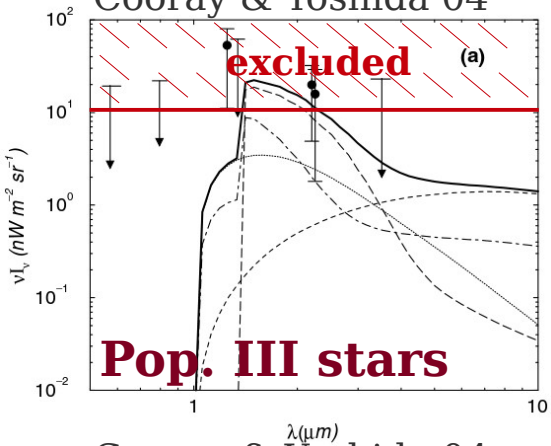
3 EBL models still ok (Franceschini+ 08, Dominguez+ 11, Gilmore+ 12)

Extreme reionization models excluded (eV overproduction)

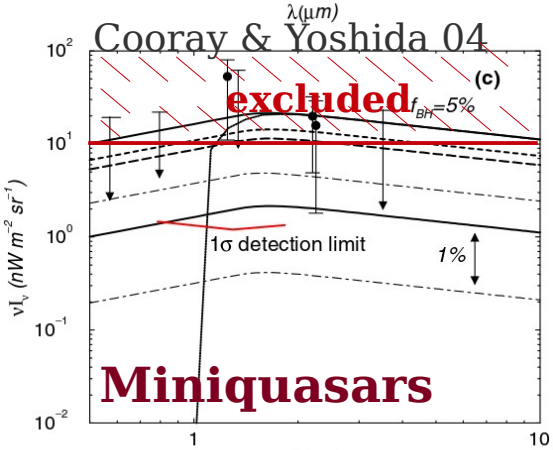
Driver+ 16

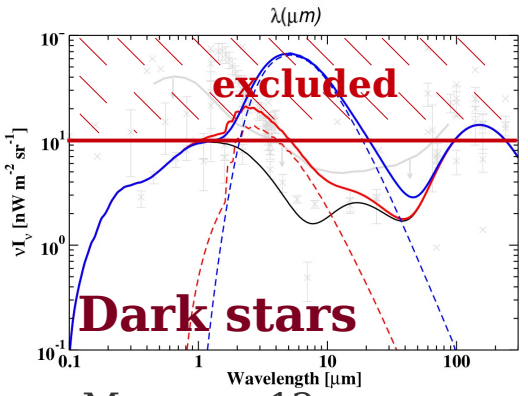


Cooray & Yoshida 04



Cooray & Yoshida 04





Maurer+ 12

Distance Modulus

Some constraining power on H_0

γ-ray optical depth ∝ EBL / H_0

Galaxy counts (if integral) → EBL

Two measurements on the market

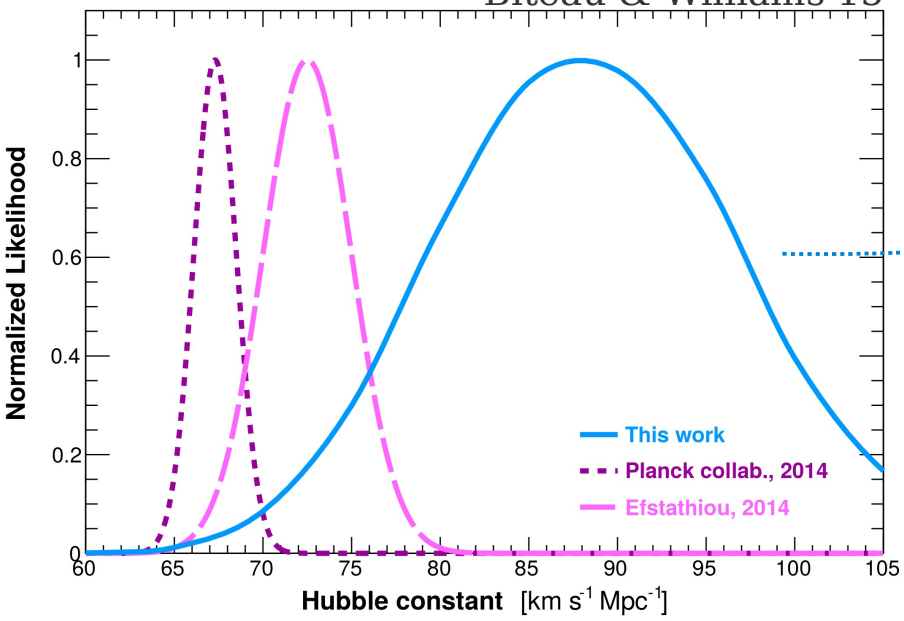
$h_0 = 0.71 \pm 0.05 \pm 0.11$ Dominguez & Prada 13

$h_0 = 0.88 \pm 0.13 \pm 0.13$ Biteau & Williams 15

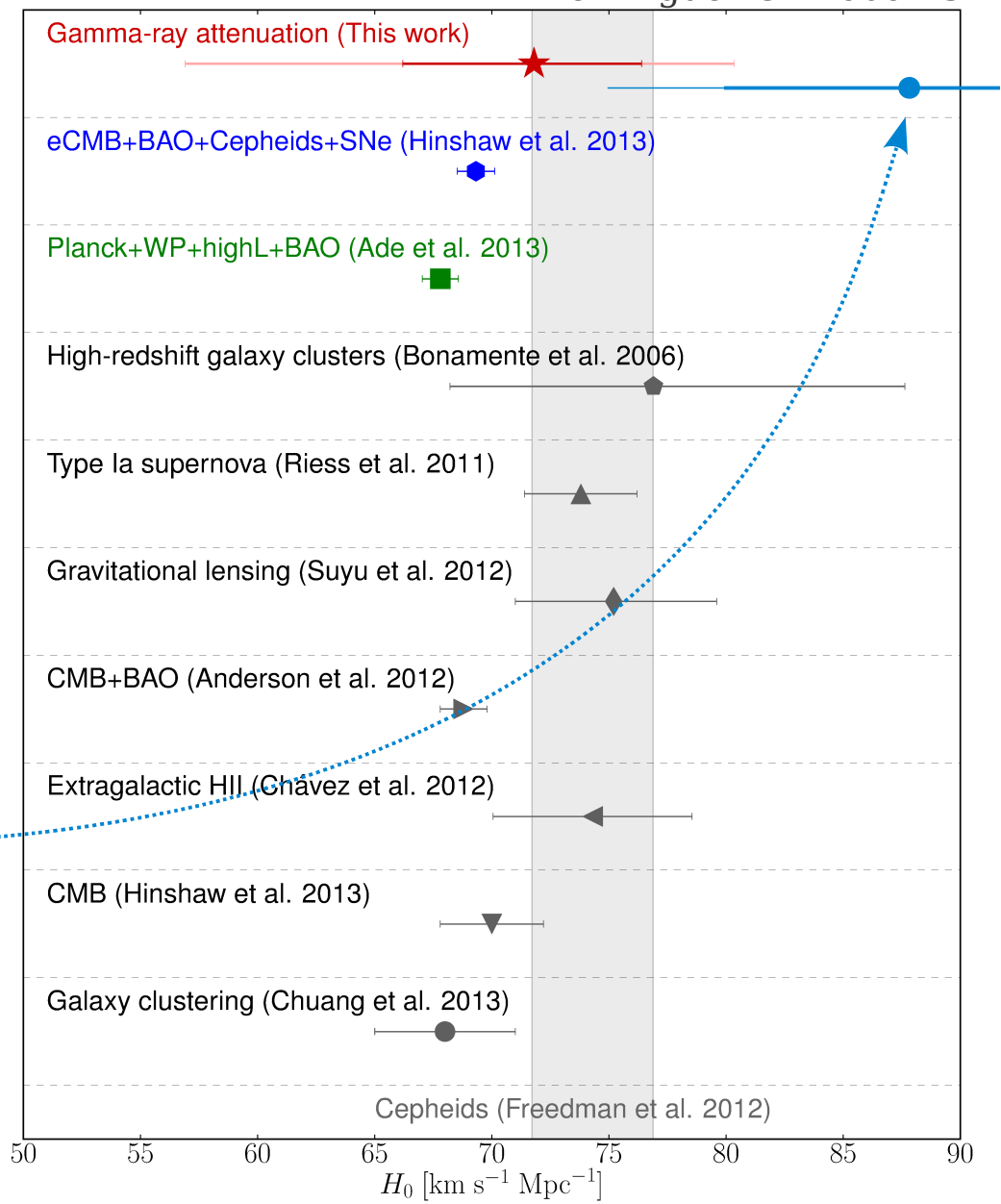
< 2σ tension with best measurement

Much less constraining power for other parameters

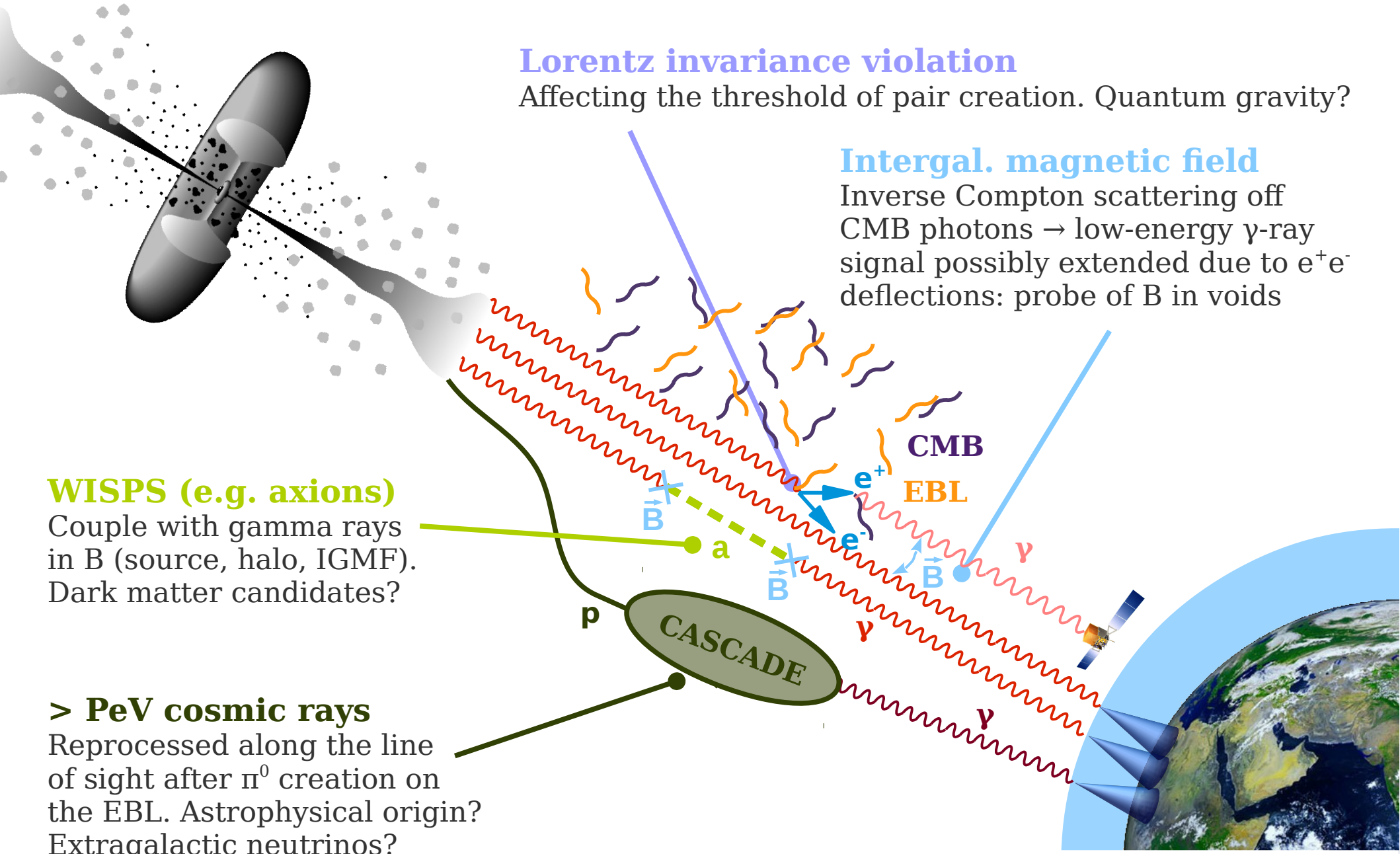
Biteau & Williams 15



Dominguez & Prada 13



Gamma-ray cosmology: EBL + [...]



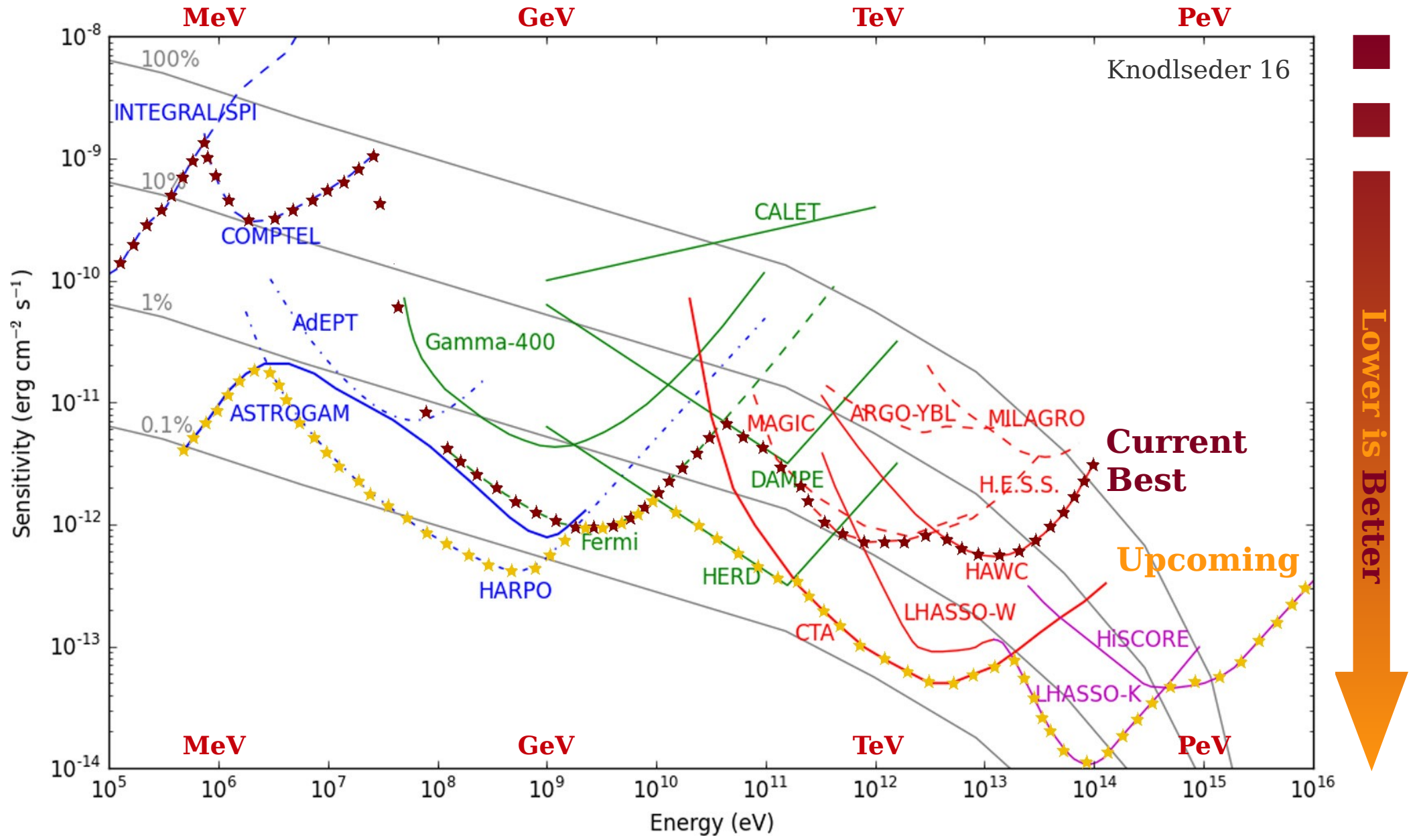
Lorentz invariance violation
Affecting the threshold of pair creation. Quantum gravity?

Intergal. magnetic field
Inverse Compton scattering off CMB photons → low-energy γ-ray signal possibly extended due to e^+e^- deflections: probe of B in voids

WISPS (e.g. axions)
Couple with gamma rays in B (source, halo, IGMF). Dark matter candidates?

> PeV cosmic rays
Reprocessed along the line of sight after π^0 creation on the EBL. Astrophysical origin? Extragalactic neutrinos?

Current & Future γ-ray Landscape



2020 perspective: the Cherenkov Telescope Array

10× sensitivity + energy extensions < 100 GeV and > 10 TeV

Northern and Southern Arrays in the Canary Islands and in Chile, ~ 100 telescopes total

Vast Key Science Program

(Extra)Galactic surveys, AGN, Clusters, GRBs, Pulsars, PWN, SNRs, Dark Matter, Fundamental physics...

See upcoming “Science with CTA”

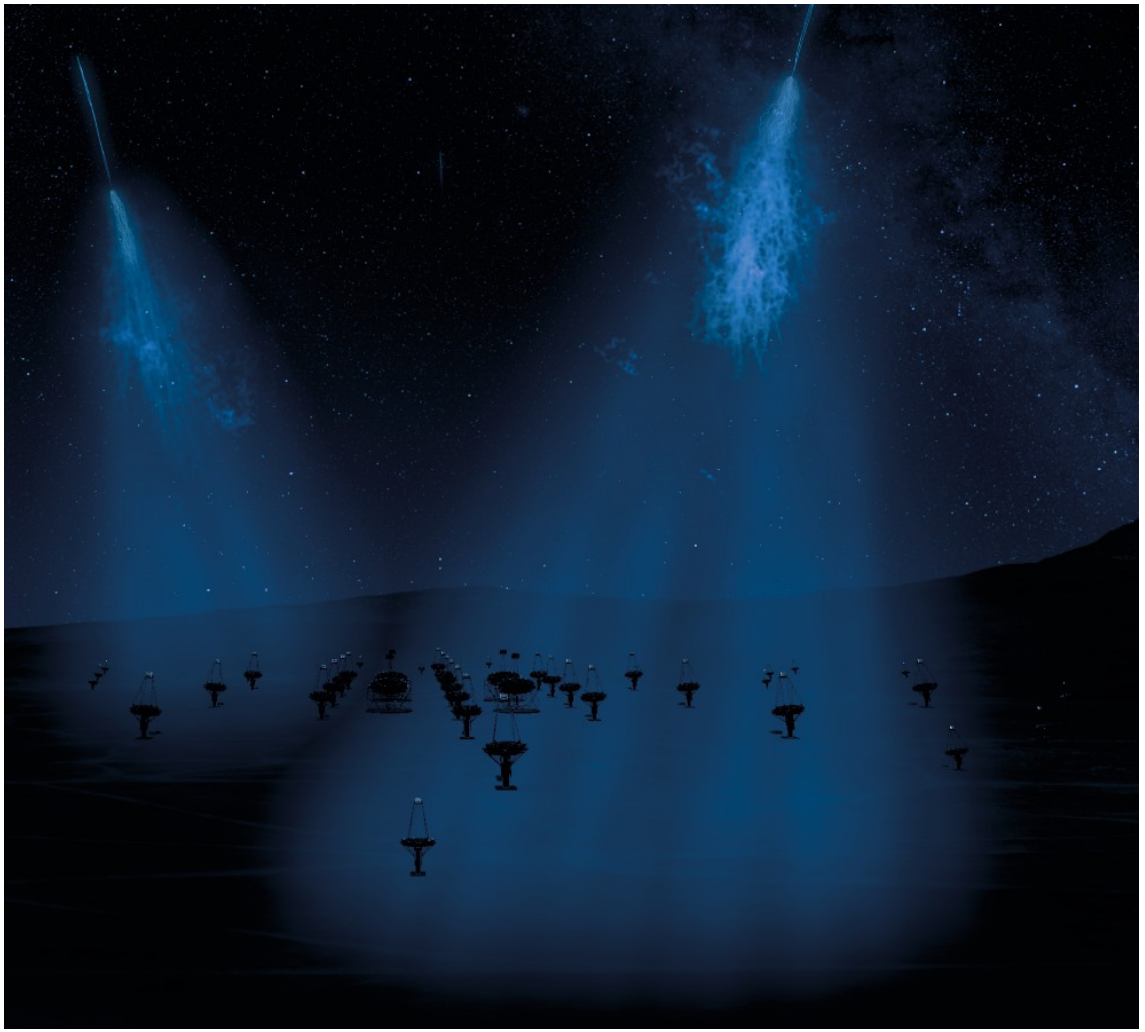
Including γ-ray cosmology

Dedicated task force created in 2016 to jointly address the classical and exotic physics that can be probed using γ-ray propagation.

Leads: JB (IPNO), M. Meyer (SLAC)

~70 people signed in, strong French contributions to the simulation and analysis (APC, LAPP, Meudon)

First results from simulations at ICRC2017. Stay tuned!



Conclusions

γ-ray Cosmology: an Active Field with already Fantastic Discoveries!

γ-ray discovery of the EBL imprint in 2012-2013 by *Fermi*-LAT and H.E.S.S.

Since then, about a publication a month on this and related topics

Probe of "Standard" Physics

Now able to measure the EBL spectrum in a model-independent way

Amount of EBL known within 20%, already constraining reionization models

Shrinking allowed parameter space for the IGMF, pinpoints areas to be studied

Probe of "Exotic" Physics

Hints of beyond-the-standard-model particles (WISPs) not confirmed, improving constraints on the coupling to γ-rays

New LIV constraints close to the Planck scale.

A Bright Future with Strong French Contributions

VERITAS, H.E.S.S., MAGIC, *Fermi*-LAT: incremental improvements to be expected

CTA, the ultimate tool: exciting discoveries for classical (and BSM?) physics