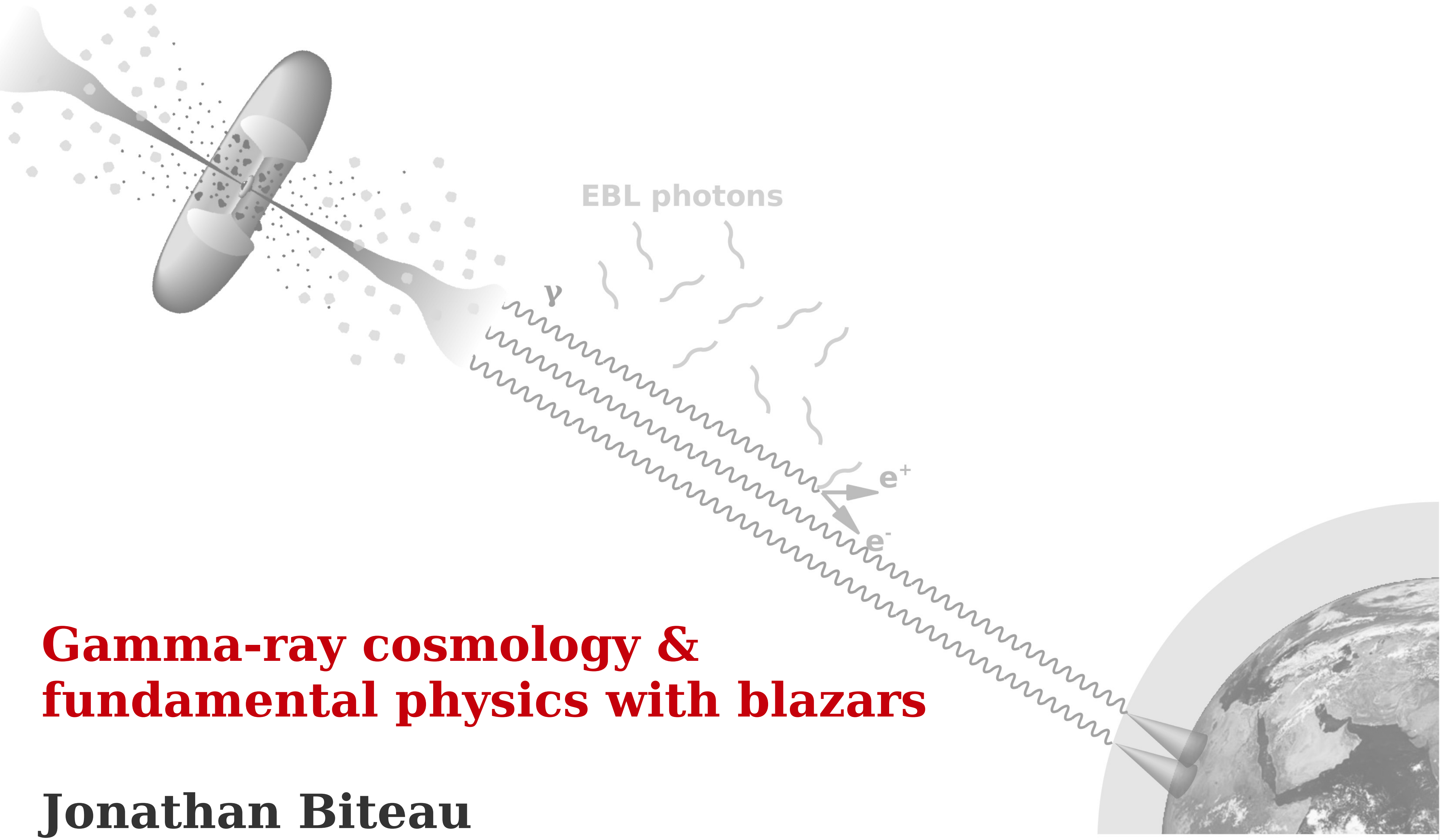
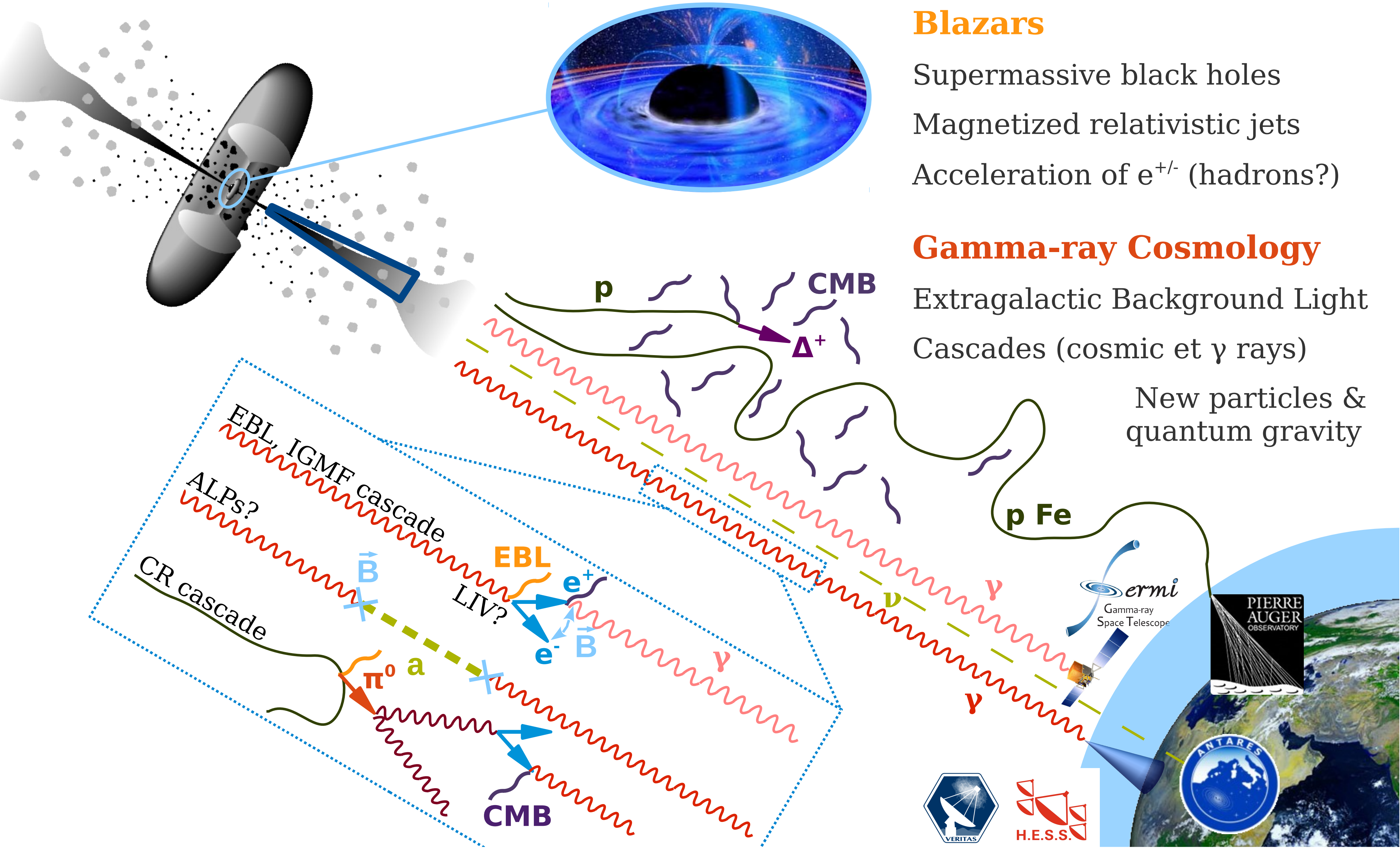


Gamma-ray cosmology & fundamental physics with blazars

Jonathan Biteau

Observing the Extreme Universe with Blazars



Blazars

Supermassive black holes

Magnetized relativistic jets

Acceleration of $e^{+/-}$ (hadrons?)

Gamma-ray Cosmology

Extragalactic Background Light

Cascades (cosmic et γ rays)

New particles & quantum gravity

Outline of this talk

→ **Observing blazars in the gamma-ray band**

Detecting gamma rays - emission from blazars

→ **Blazars as cosmological beacons**

Gamma-ray absorption - the extragalactic background light

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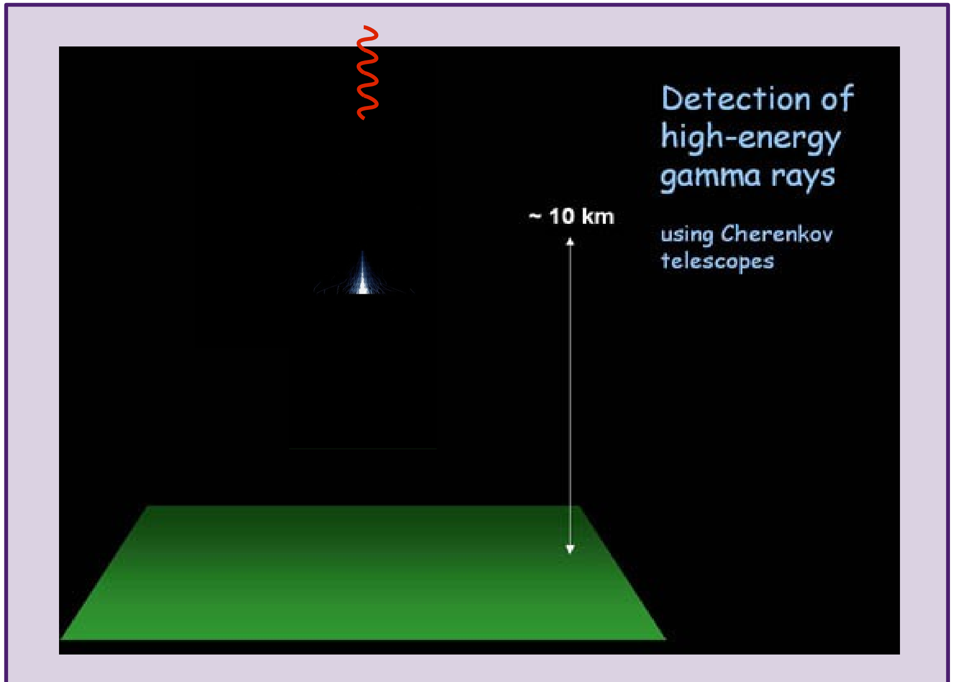
→ **What remains to be done**

Fermi-LAT, H.E.S.S., MAGIC, VERITAS, and CTA

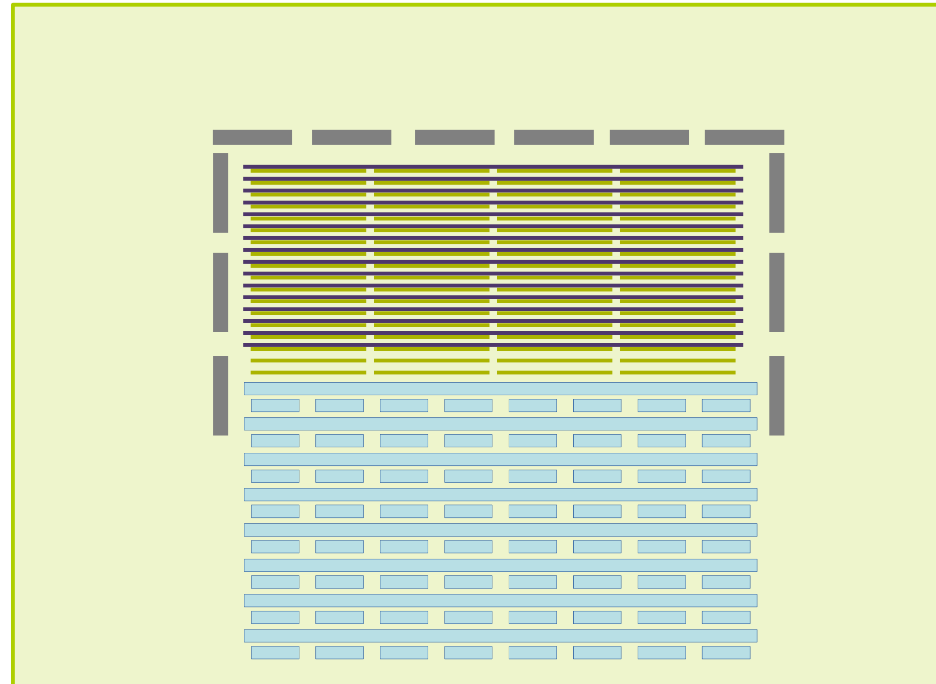
→ **Conclusion**

Summary, CNRS research project

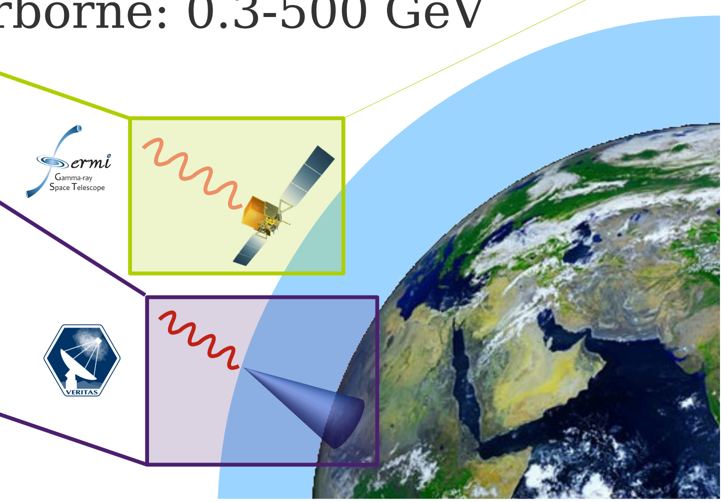
Detecting TeV and GeV gamma rays



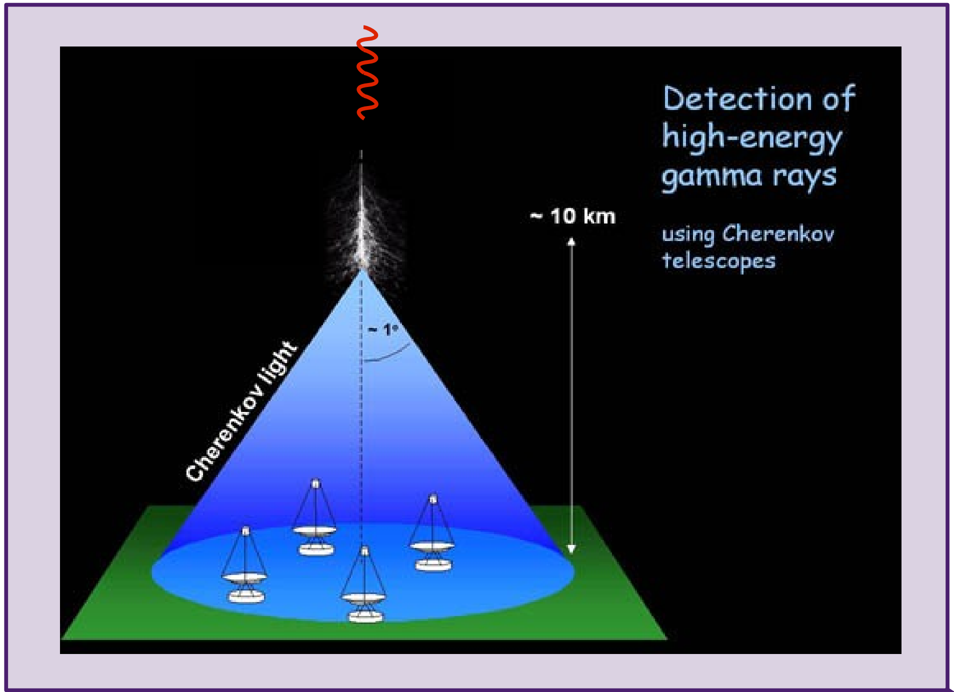
Ground based: 0.1-30 TeV



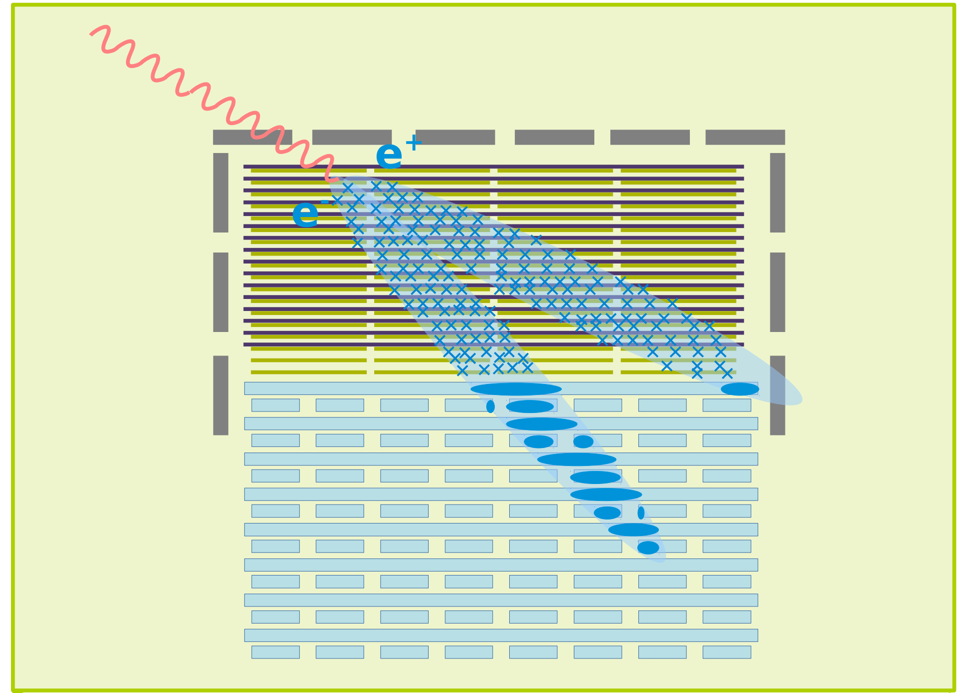
Airborne: 0.3-500 GeV



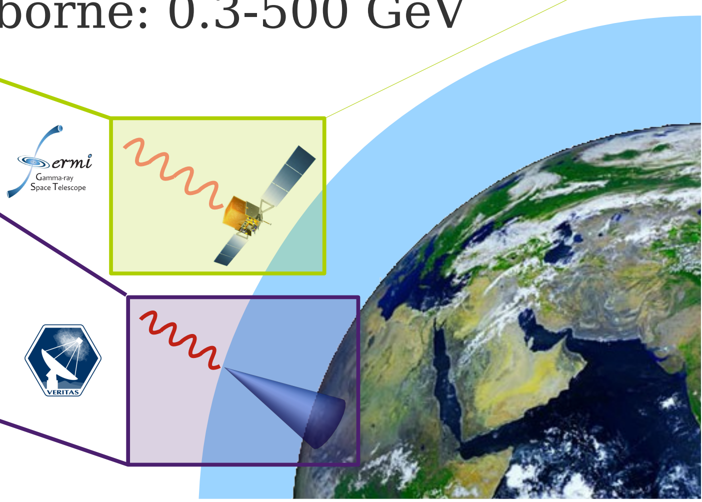
Detecting TeV and GeV gamma rays



Ground based: 0.1-30 TeV



Airborne: 0.3-500 GeV



- → **Angular resolution Δθ~0.1º**
- → **Calorimetric measurements ΔE~15%**

H.E.S.S., MAGIC, VERITAS… & CTA

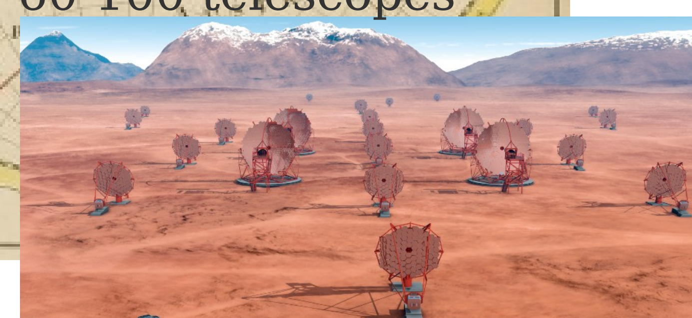
VERITAS
4 x 12m

MAGIC
2 x 17m

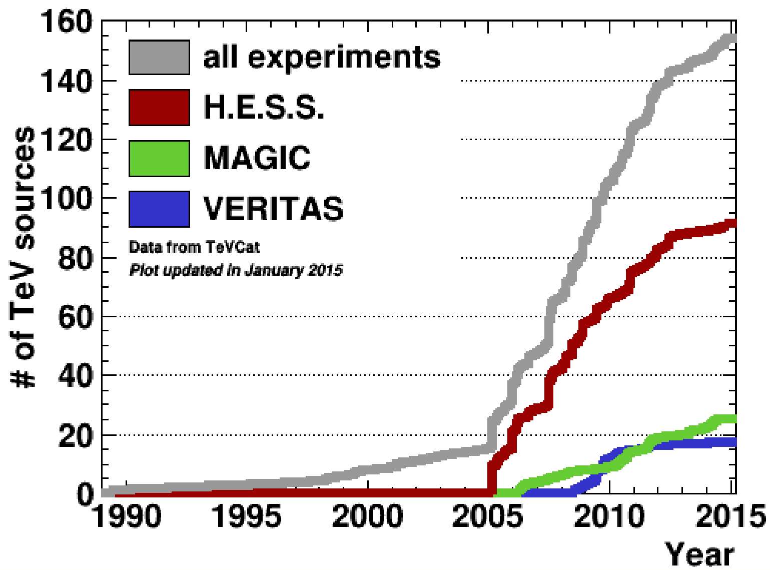
H.E.S.S. II - 4 x 12m + 1 x 28m

CTA North
n_1 x 12m + n_2 x 24m
20-30 telescopes

CTA South
n_1 x 5m + n_2 x 9-12m
+ n_3 x 24m
60-100 telescopes



Detecting GeV-TeV blazars



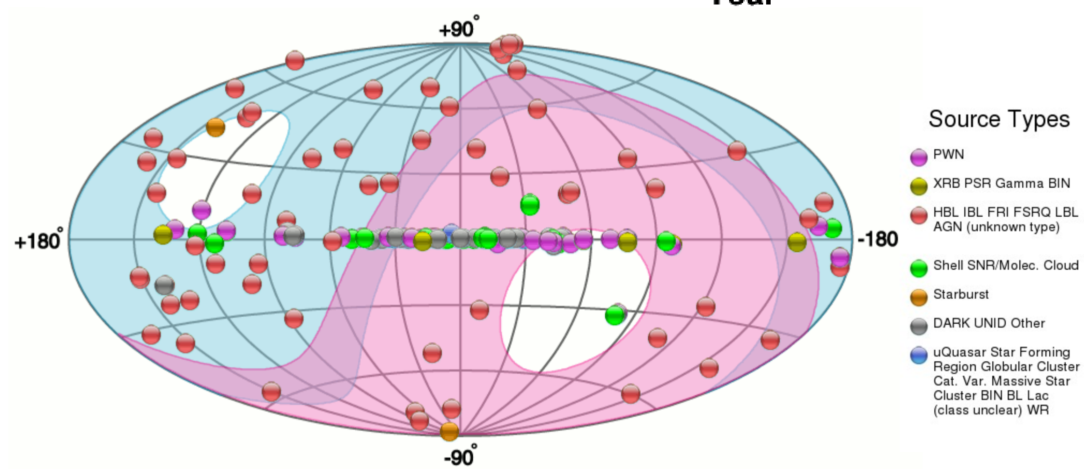
Ground based (>100 - 200 GeV)

~ 160 sources (~60 extragalactic – 40%)

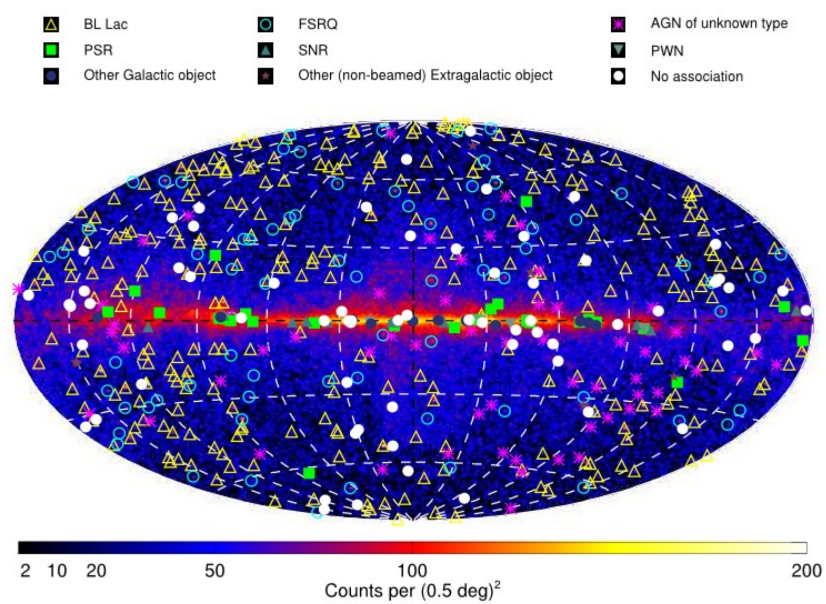
Fermi-LAT (>10 GeV - 1FHL)

~ 500 sources (~400 extragalactic – 80%)

Source: Ackermann et al. 2013



Source: TeVCat



First Author :

. **Flux upper limits for 47 AGN observed with H.E.S.S. in 2004-2011**, H.E.S.S., A&A 564, 9 (2014)

. **H.E.S.S. and Fermi-LAT discovery of gamma-rays from the blazar 1ES 1312-423**, H.E.S.S., MNRAS 434, 1889 (2013)

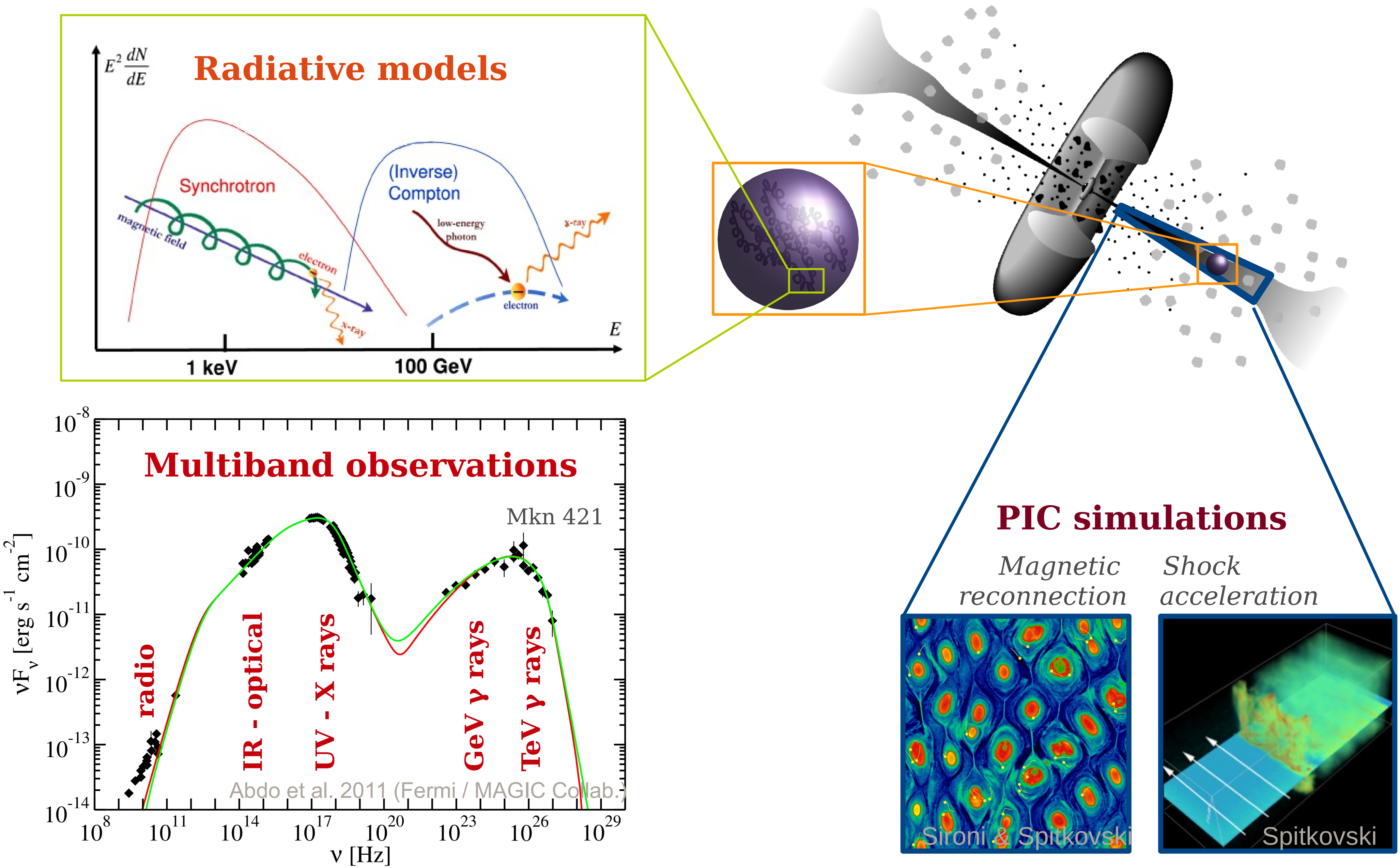
Second Author :

. **The high energy gamma-ray emission of AP Librae**, H.E.S.S. and *Fermi*-LAT, A&A 573, 31 (2015)

. **Discovery of high and very high energy emission from the BL Lac object SHBL J001355.9-185406**, H.E.S.S., A&A 554, 72 (2013)

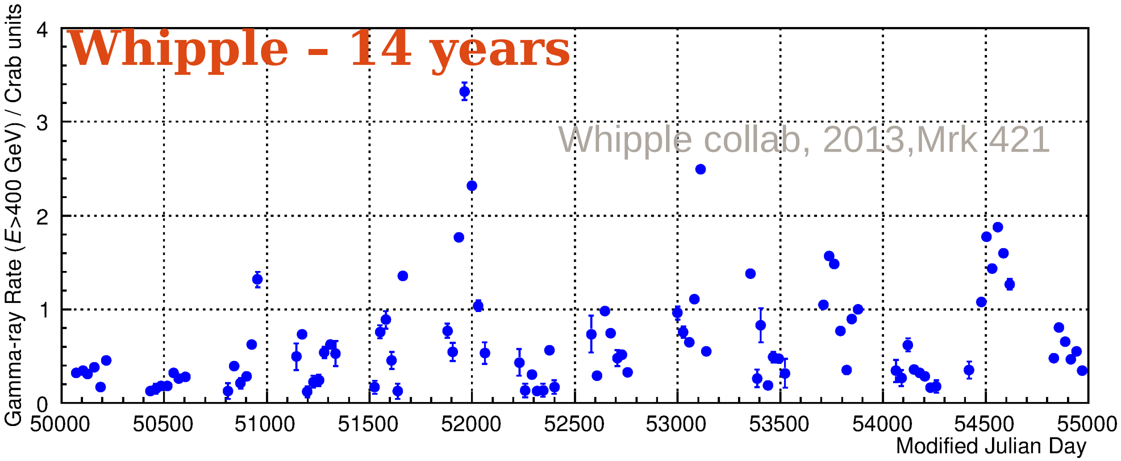
+ Referee pour ApJ, MNRAS, referee interne à H.E.S.S. et VERITAS

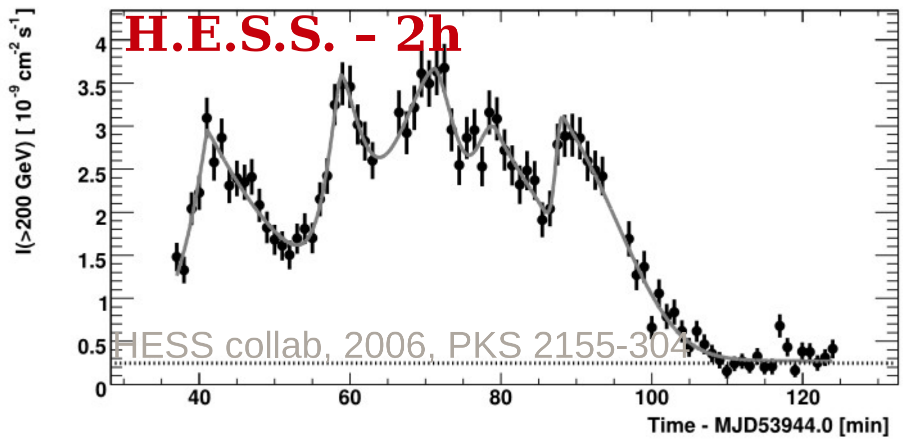
Emission of TeV blazars (HSPs/HBLs in particular)



The Conundrum: Variability of Electromag. Emission

Blazars, variable sources from radio wavelengths to TeV energies





Numerous observables

Multiwavelength variability (cross correlation, fractional variation vs wavelength)

Intra-band variability (flux distribution, moments of flux correlations, Fourier analysis)

But theoretical framework still open

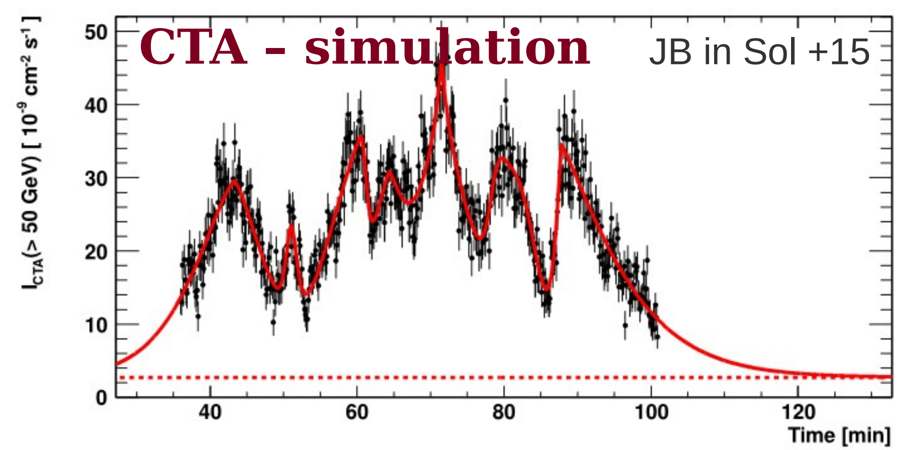
Magnetic reconnection highly promising

First Author:

. **The minijets-in-a-jet statistical model and the RMS-flux correlation,** Biteau & Giebels, A&A 548, 123 (2012)

Second Author :

. **Active Galactic Nuclei under the scrutiny of CTA**, Sol et al. for CTA, Astropart. Phys. 43, 215 (2015)



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→ **Blazars as cosmological beacons**

Gamma-ray absorption - the extragalactic background light

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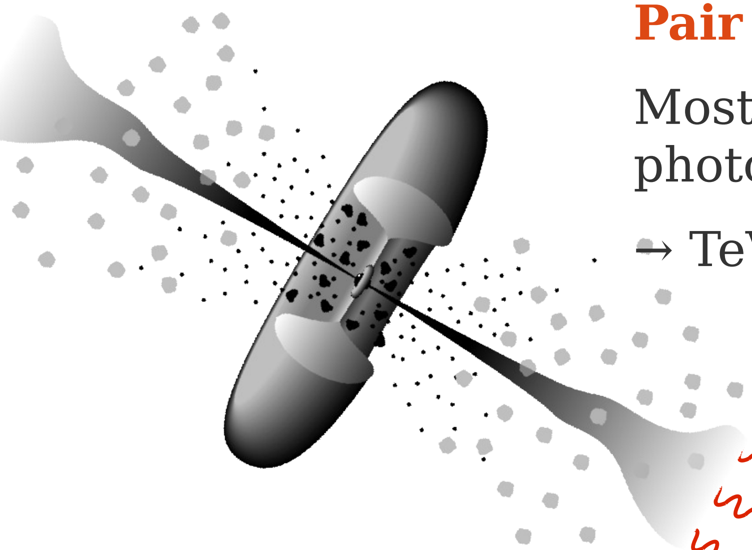
Summary, CNRS research project

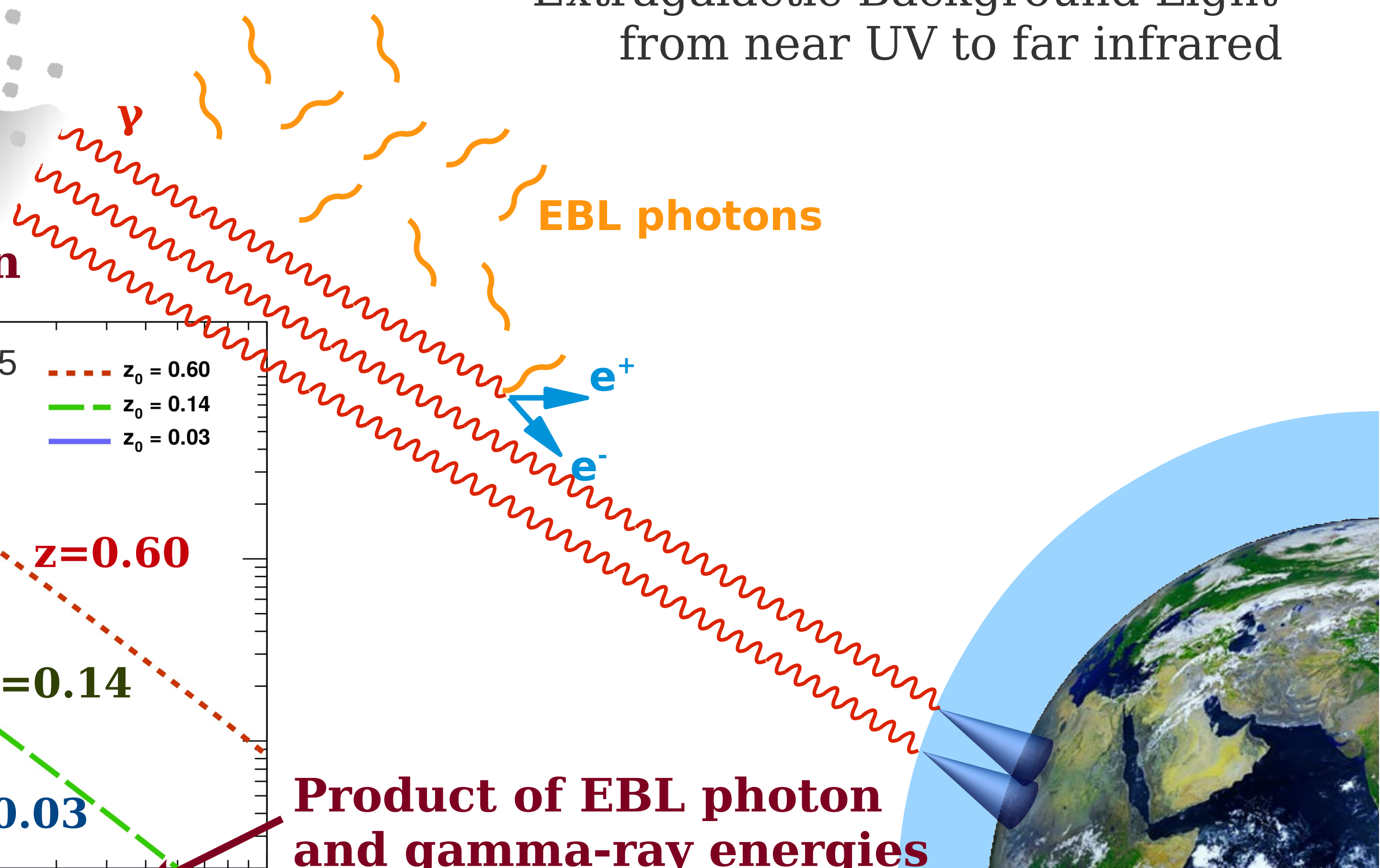
Gamma-rays and the EBL



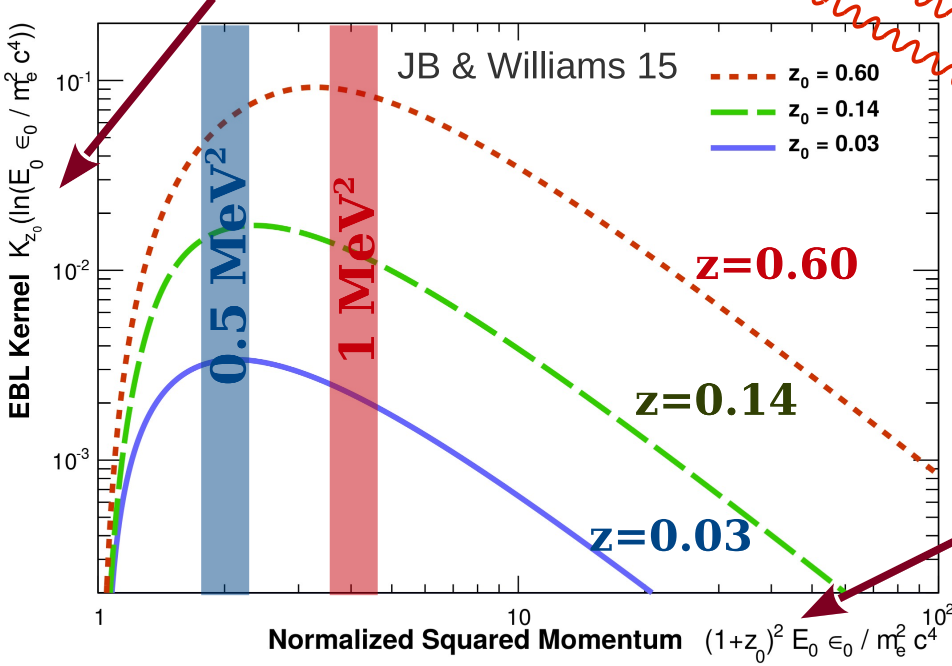
Pair creation along the line of sight

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

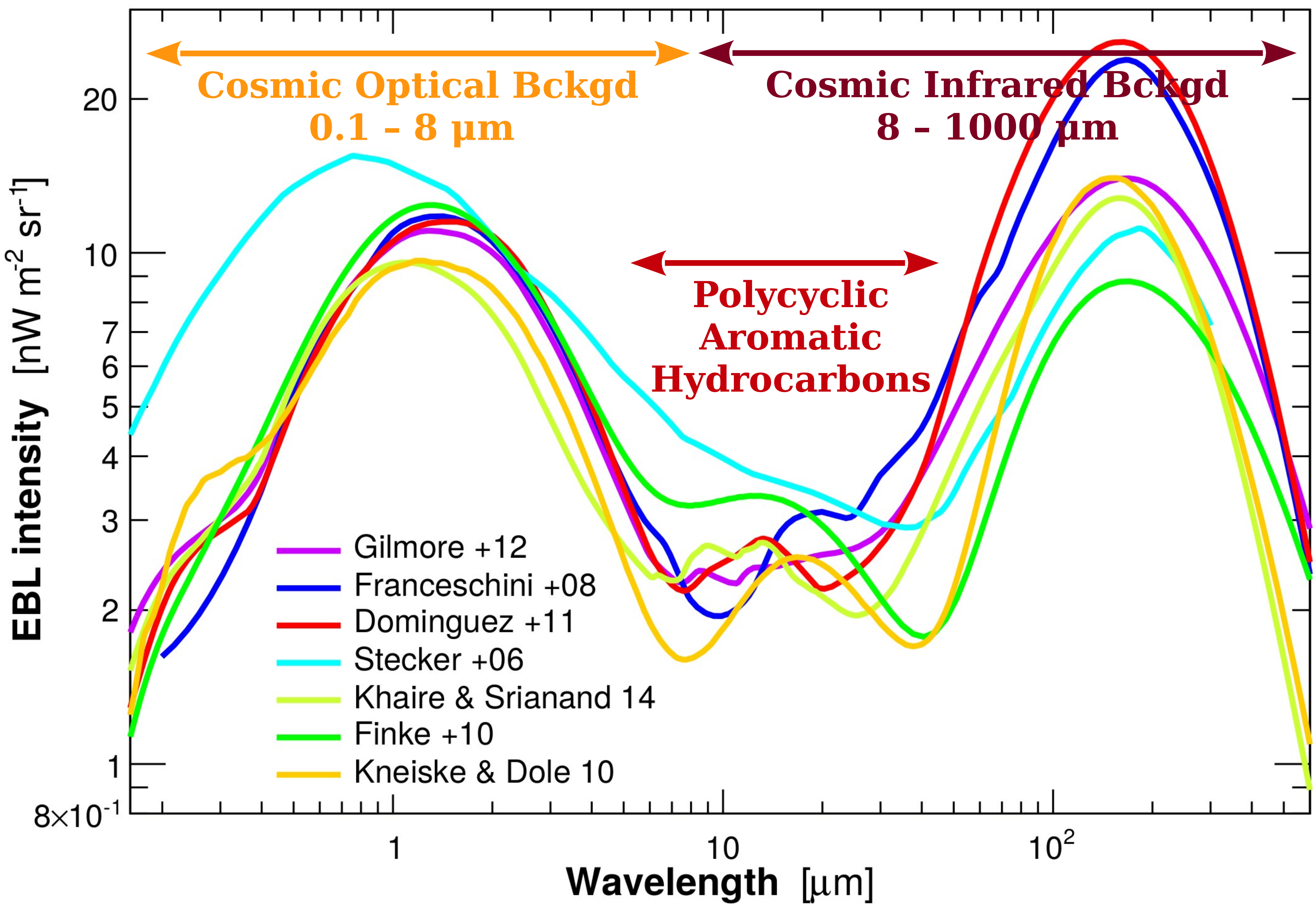


Probability of interaction



Product of EBL photon and gamma-ray energies

The Extragalactic Background Light

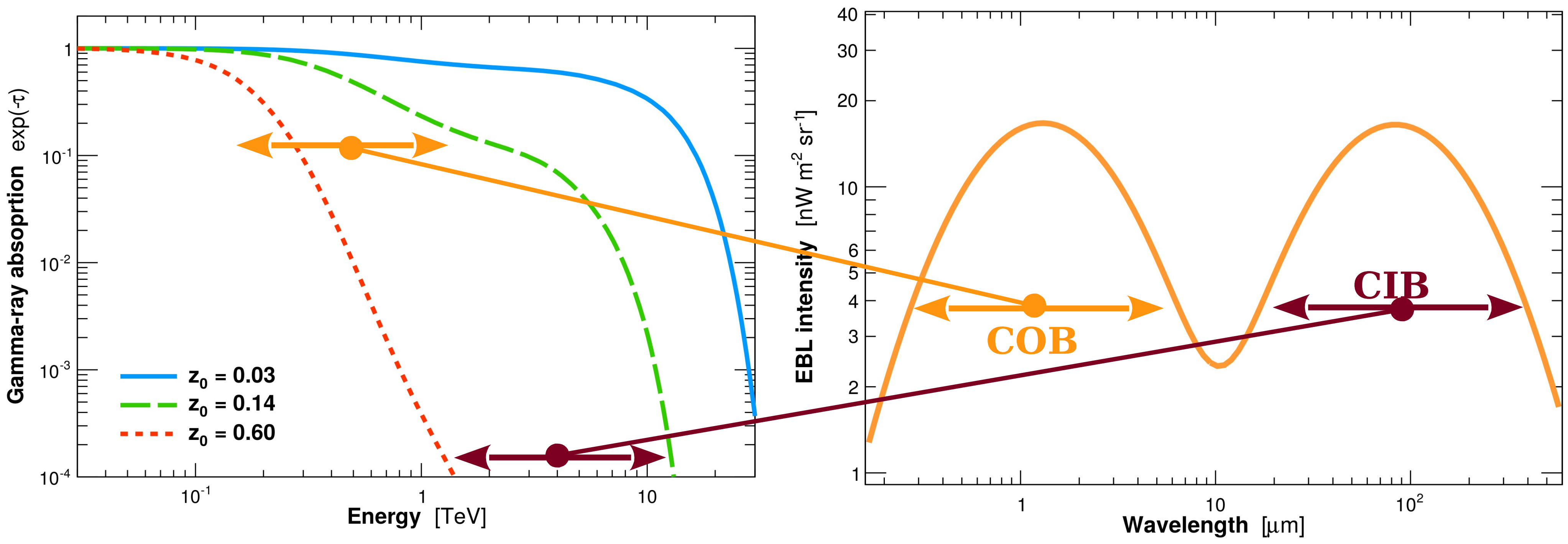


Gamma-ray Absorption by the EBL

Gamma-ray absorption by the EBL: exp(- τ)

with optical depth: τ(E,z) = Target density x Distance x Cross section

On the first order: τ(E,z) ~ E / E_0(z) where E_0 decreases with redshift
+ <u>modulations depending on the EBL spectrum</u>



EBL: what was known so far

Local constraints on the EBL: *see Dwek & Krennrich (2013)*

Direct observations: tend to be contaminated by foregrounds → upper limits

Galaxy counts: corrected for the lack of completeness but do not include unresolved populations or truly diffuse components → lower limits

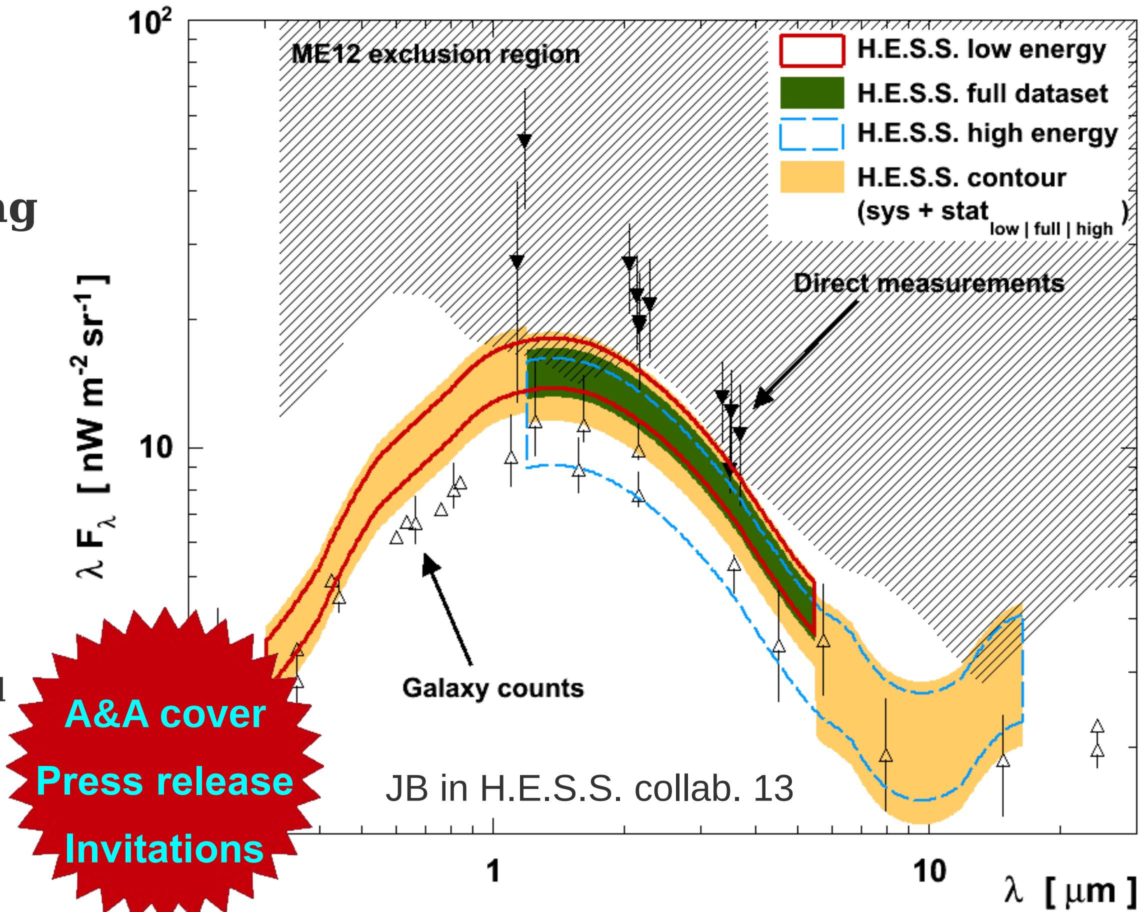
Gamma-ray constraints on the EBL:

Difficulty so far had been **disentangling intrinsic curvature from absorption by the EBL**

By means of **hypothesis testing** and **accounting for intrinsic curvature**, model-dependent detections by Fermi-LAT (6σ) and **H.E.S.S. (9σ)**

First Author :

. **Measurement of the extragalactic background light imprint on the spectra of the brightest blazars observed with H.E.S.S.,**
H.E.S.S., A&A 550, 4 (2013)



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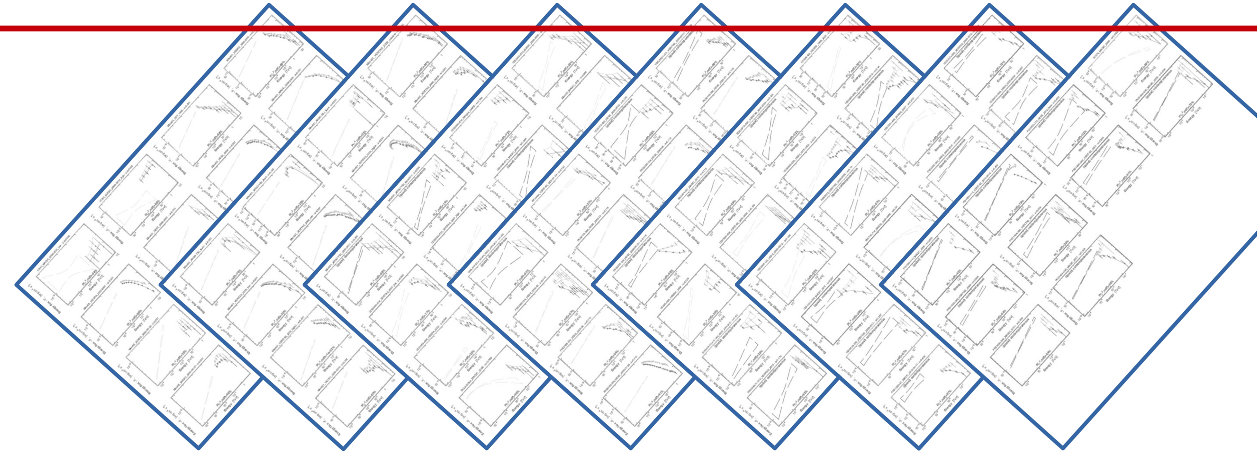
  Summary, CNRS research project

Dataset and Hypotheses



Dataset

. 106 TeV spectra from 38 sources, i.e. ~80% of published data

. GeV spectral index when contemporaneous GeV-TeV observations

Going public

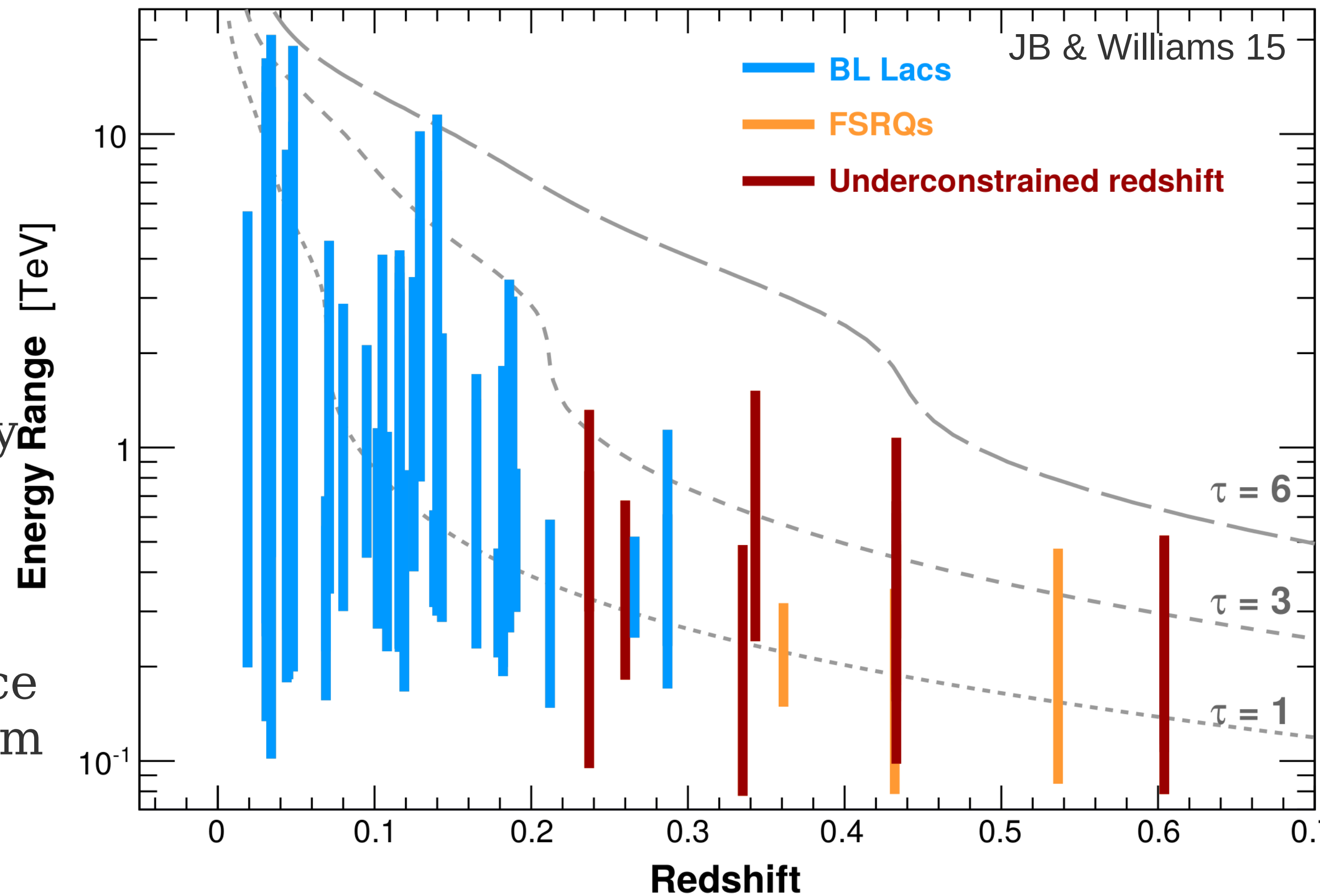
. Interest from MWL community (P. Giommi, ASDC SED builder)

. Most data out in Apr.-May

Hypotheses

. TeV softer than GeV

. TeV emission at the source = smooth concave spectrum (PWL, LP, EPWL, ELP)



Computing the optical depth

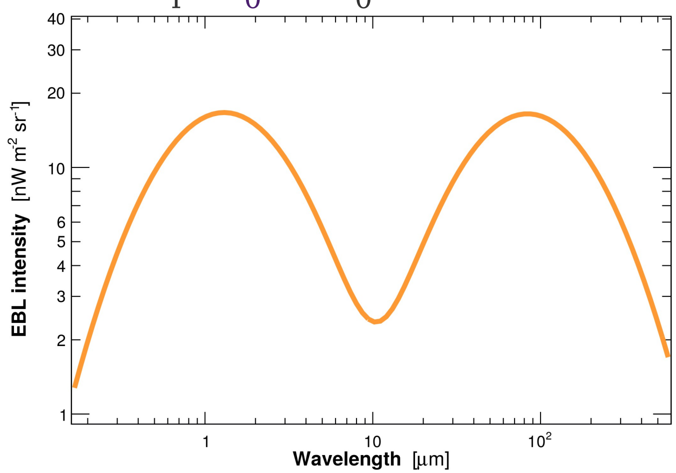
Optical depth: $\tau(E_0,z_0)$ = Target density x Distance x Cross section

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

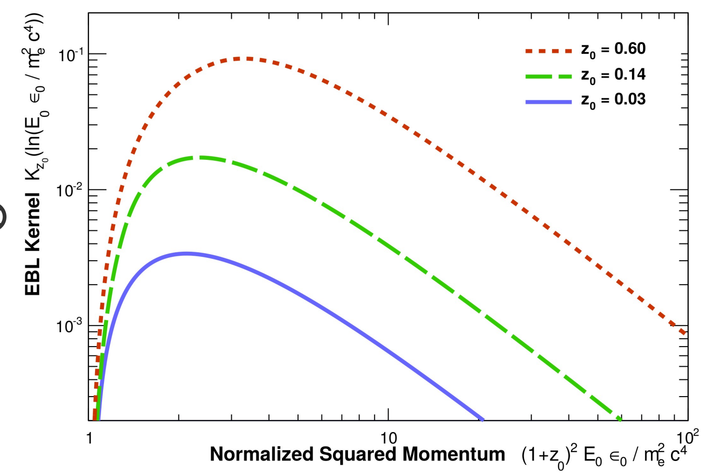
→ 2D integral after analytical reduction of the integral over the angle

If Target density(ϵ_0,z_0) = Target density(ϵ_0,z_0=0) x Evolution(z_0), then

→ $\tau(E_0,z_0) = 3\pi\sigma_T/H_0 \times E_0/m^2c^4 \times$



⊗



$\ln(E_0/mc^2)$

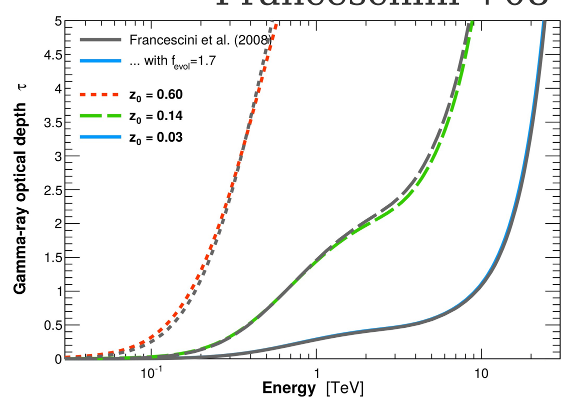
Evolution:

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

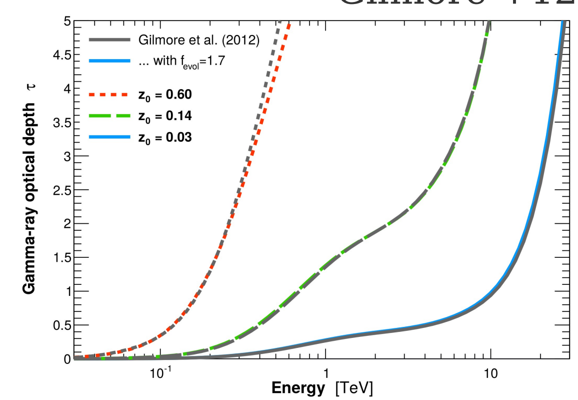
Decoupling hypothesis:

impact on τ of about ~2%

Franceschini +08

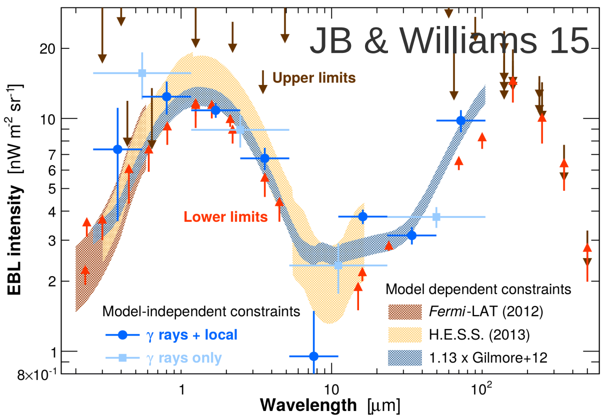


Gilmore +12

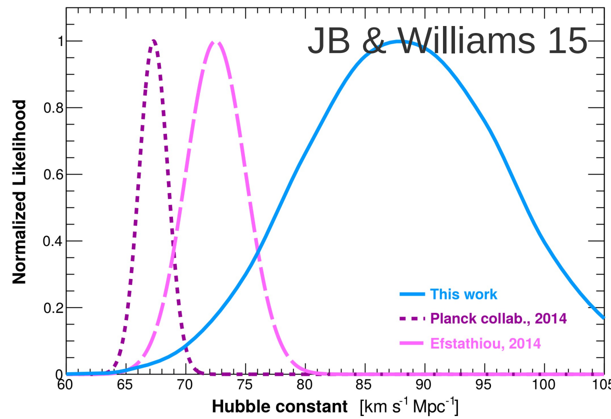


Some Scientific Topics of Gamma-ray Cosmology

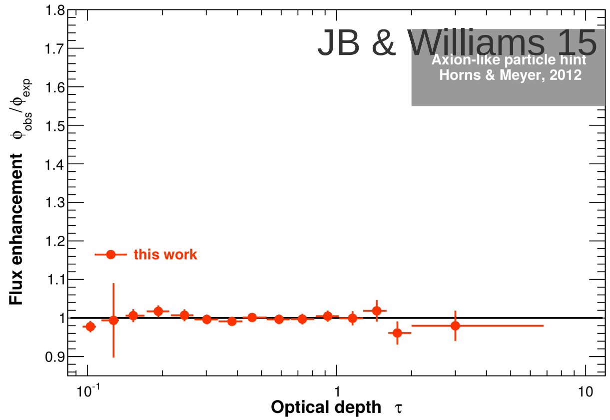
EBL Spectrum

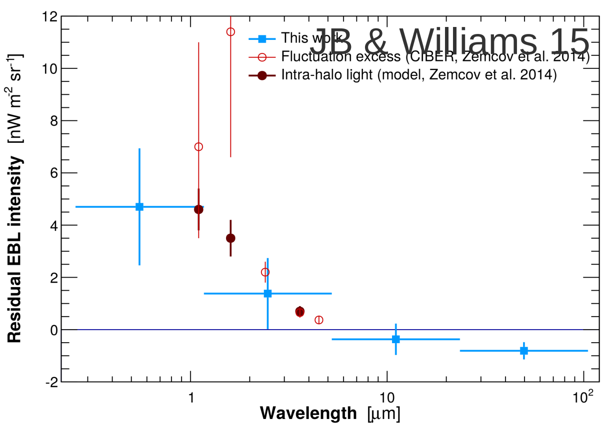


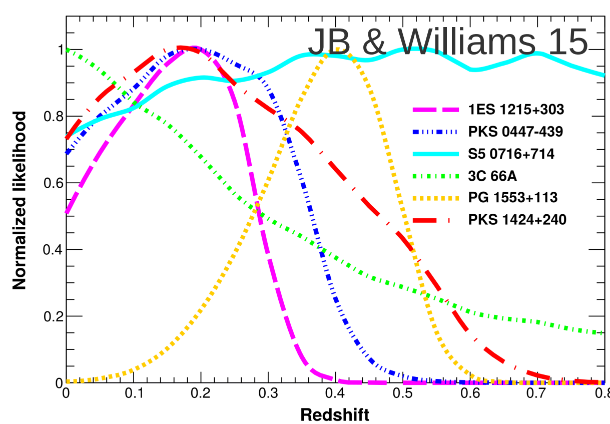
Hubble Constant

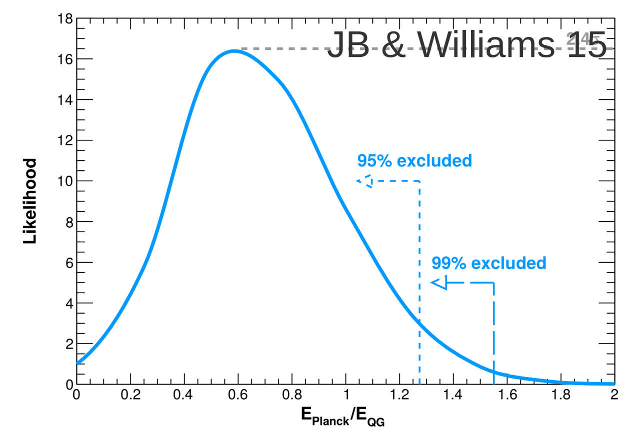


Axion-Like Particles









Unresolved Sources & Reionization

Sources distance

Lorentz Invariance

+ (partly) unaddressed topics: UHECR cascades, IGMF, heating of the IGM...

Modeling the EBL spectrum

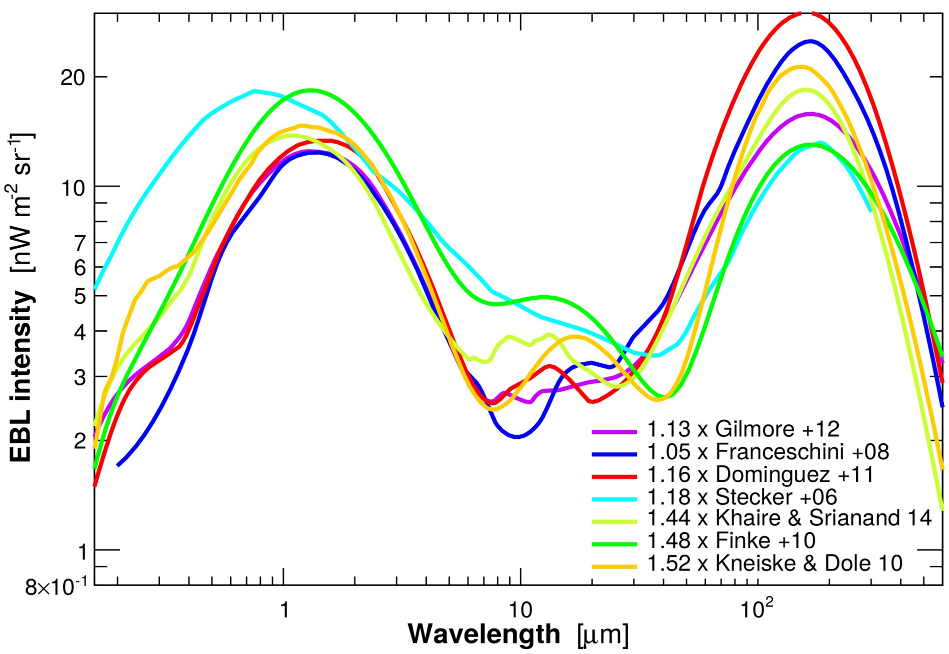
Model-dependent approach:

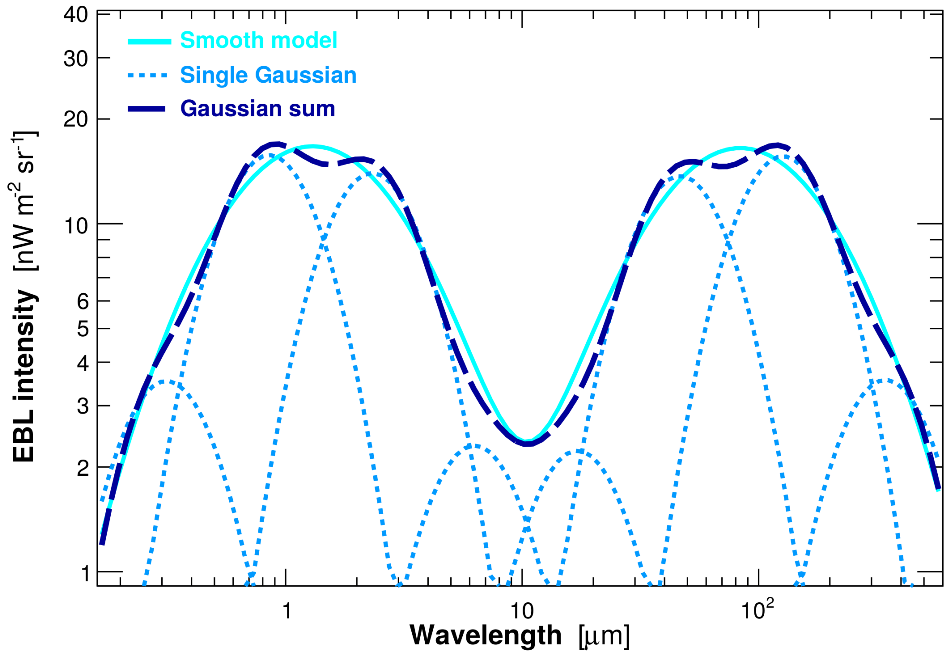
As for the H.E.S.S. and Fermi-LAT measurements, a free normalization factor for each model tested (Franceschini+08, Gilmore+12, Dominguez+11...)

Model-independent approach:

Sum of Gaussians of fixed widths and means, with free amplitudes

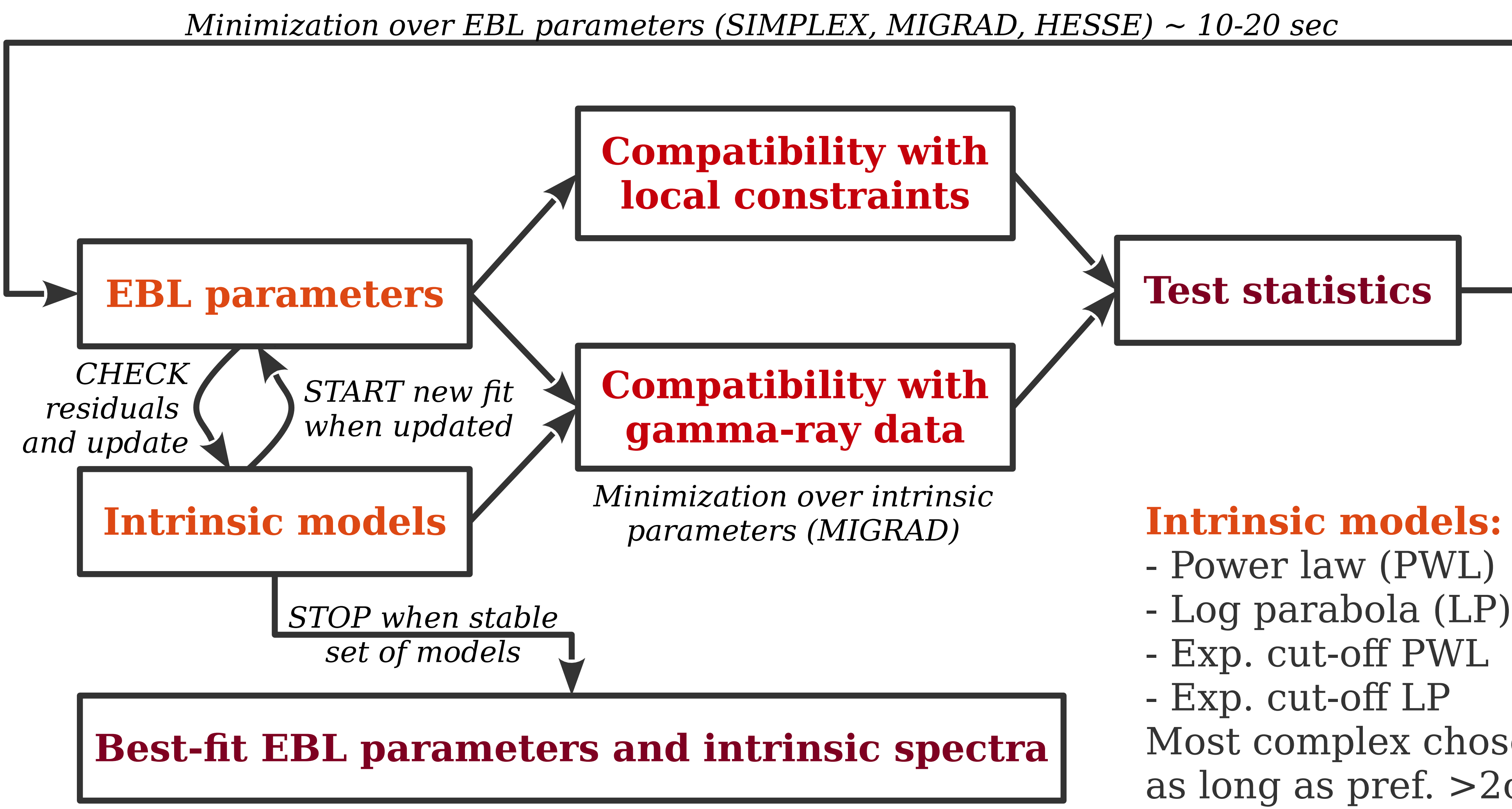
→ In both cases, optical depth linearly depends on the free parameters





Methodology

Fitting algo. accounting for gamma-ray data and local EBL constraints:



Intrinsic models:
- Power law (PWL)
- Log parabola (LP)
- Exp. cut-off PWL
- Exp. cut-off LP

Most complex chosen as long as pref. $>2\sigma$

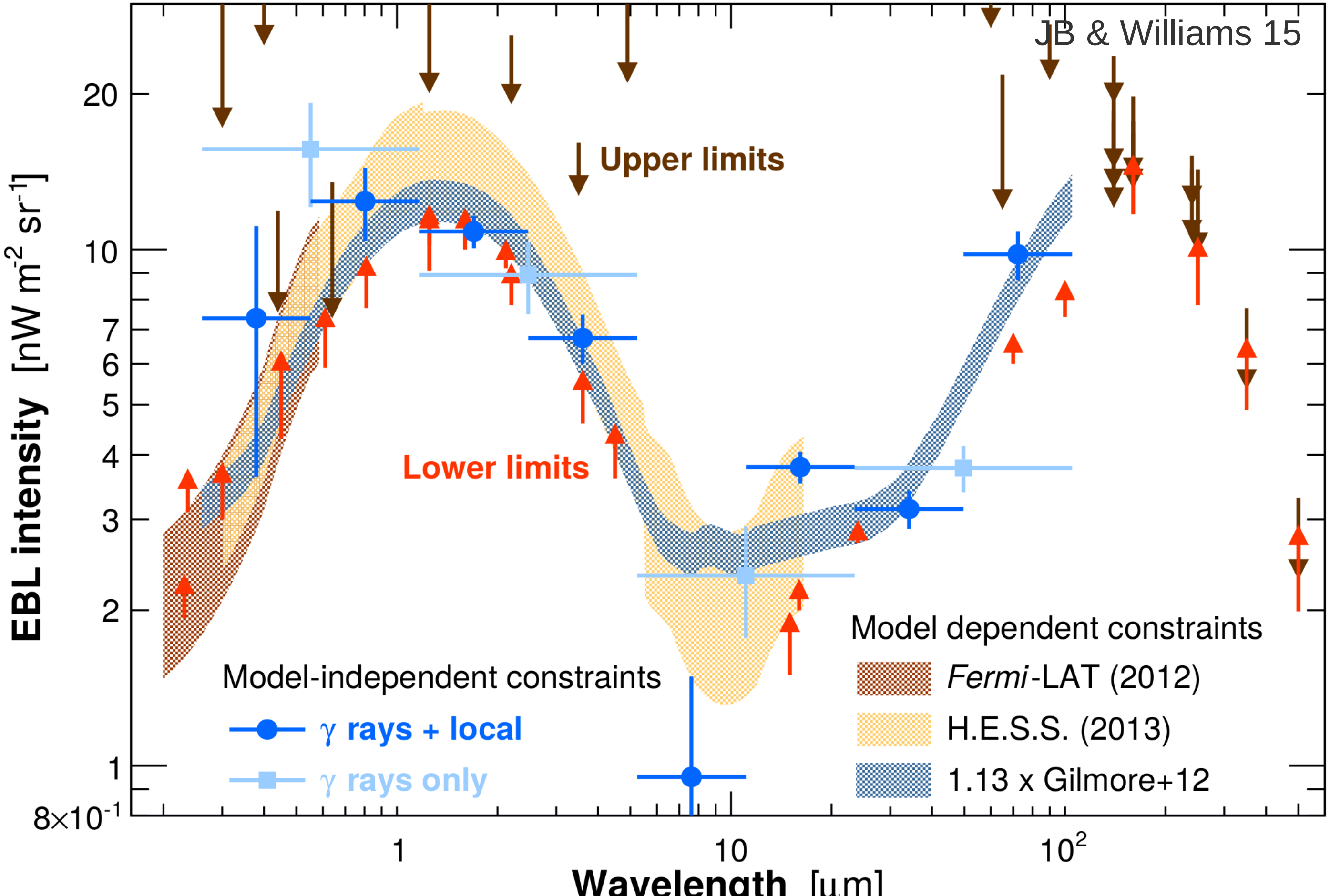
The Extragalactic Background Light

Hypothesis:

. Parametrization of EBL evolution up to z~0.8

Method: χ^2 minimization

. TeV points, GeV-TeV hardness, (local EBL constraints)



Results

. 11σ detection both for model-dependent & independent methods

. Study of 7 models, 4 ruled out, 3 ~as good as model-independent

. EBL (0.1 - 1000 μm): 62±12 nW m-2 sr-1 6.5±1.2% of the CMB

. No significant tension with galaxy counts

Gamma-ray inferred EBL is NOT too low wrt expectations from UV-IR observations!

Unresolved Sources & Reionization

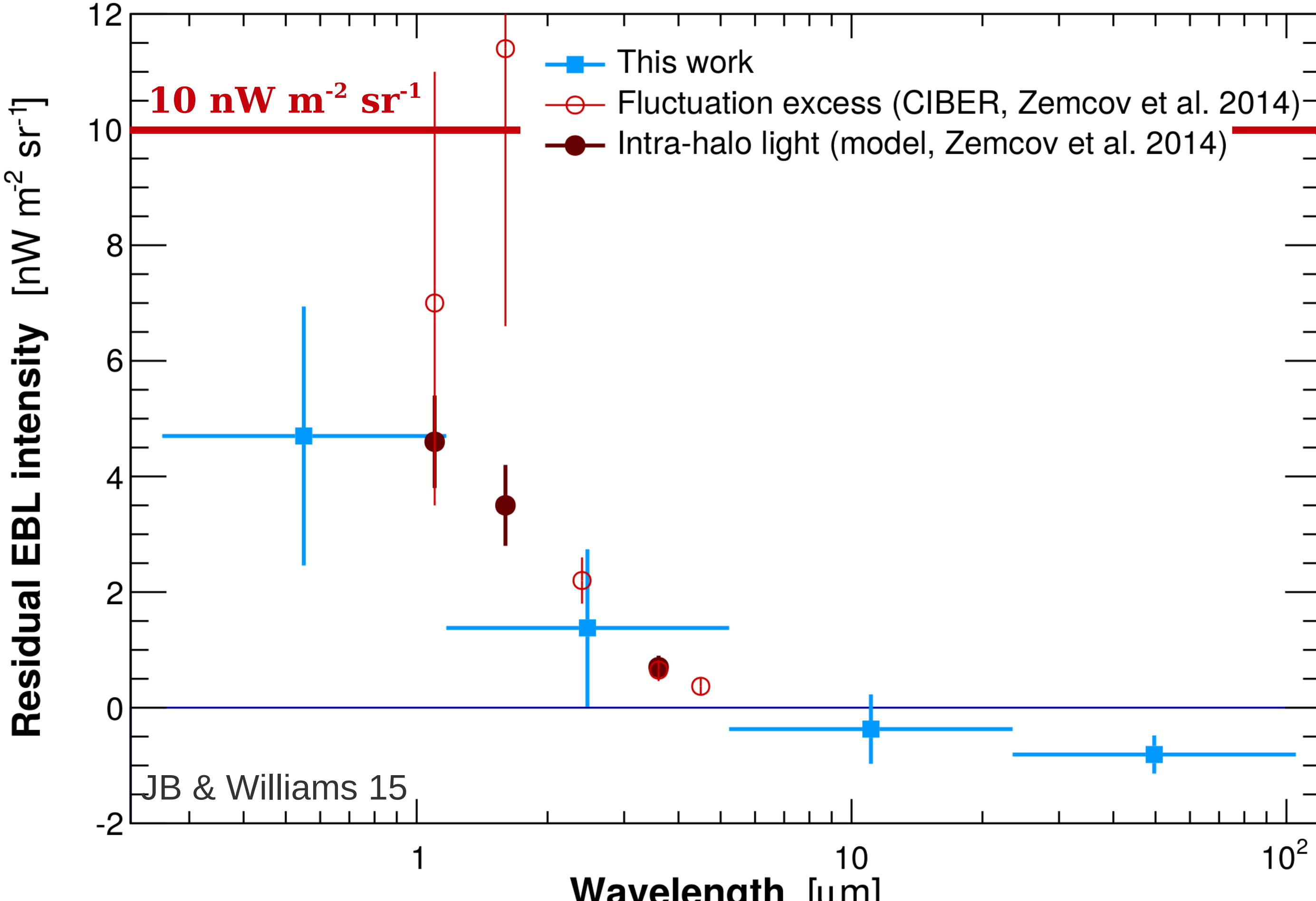
Method: gamma-ray inferred EBL – galaxy counts

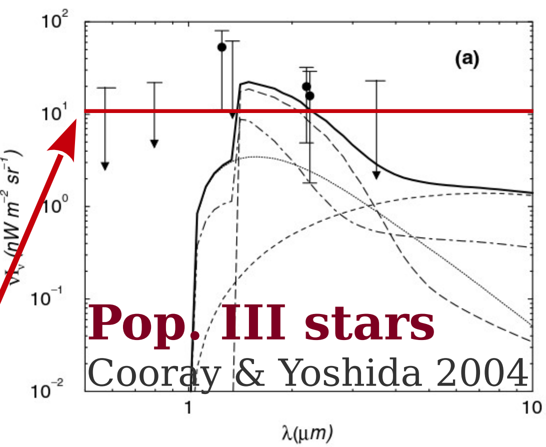
. Using the EBL derived with gamma-ray data only

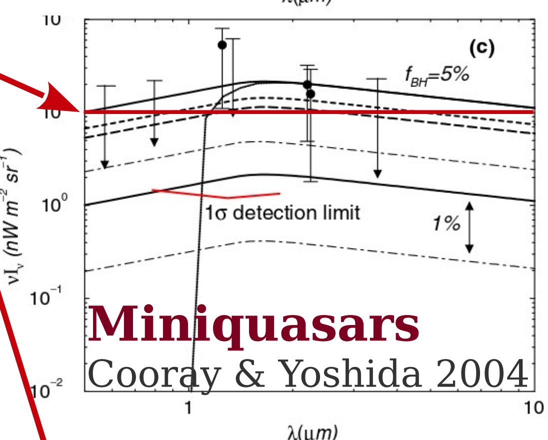
Results:

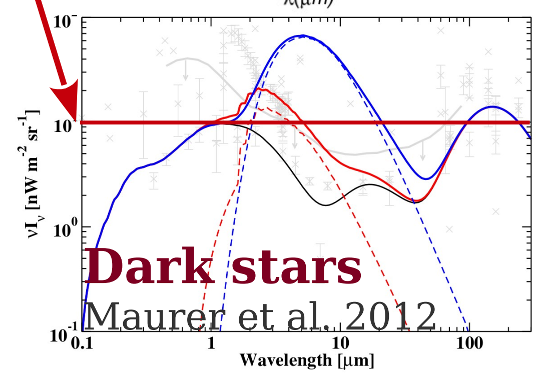
. Optimistic models of reionization rejected

. Good agreement, room left for intra-halo light (CIBER)









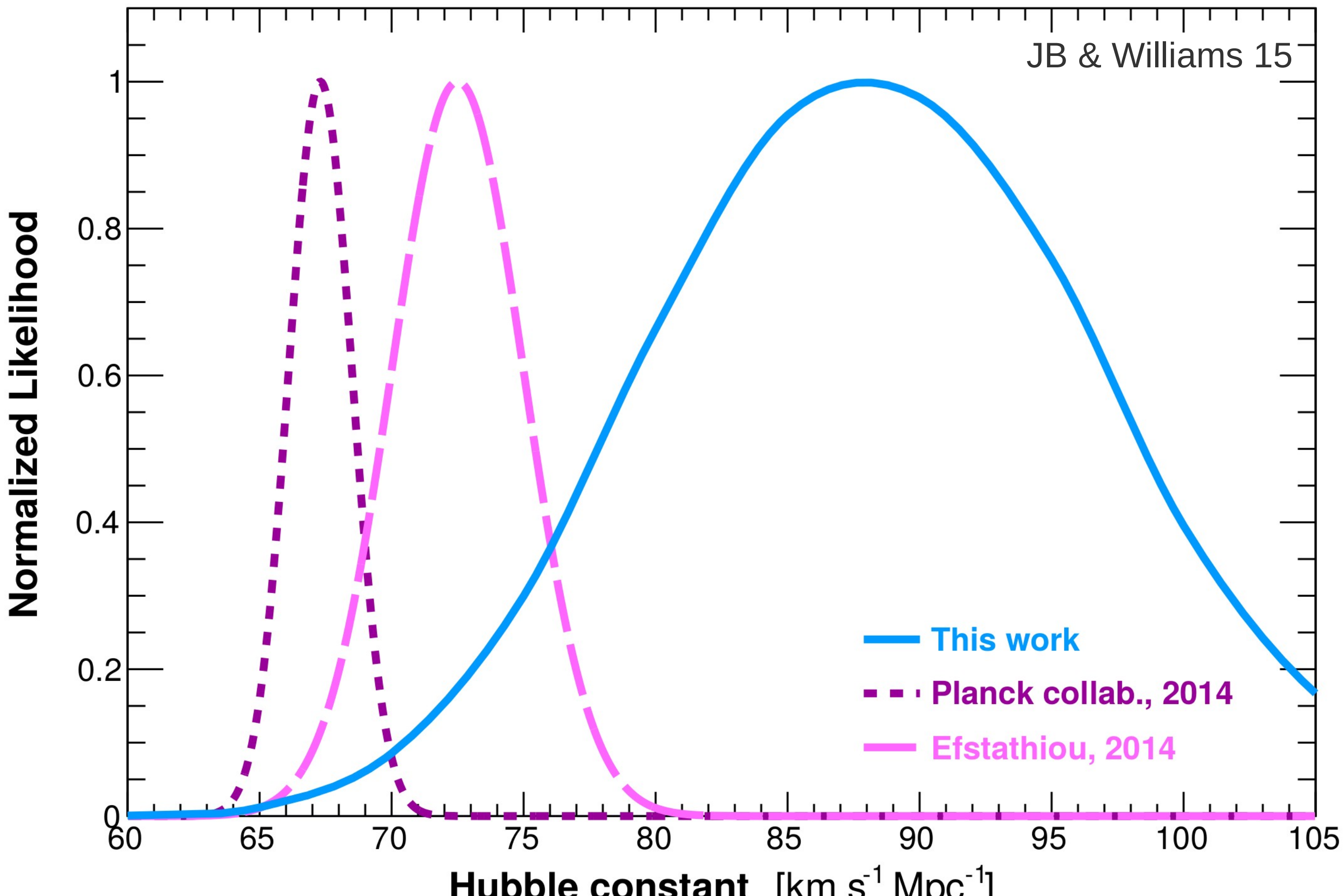
The Hubble Constant

Hypothesis: No unresolved population

. EBL from gamma-rays only = EBL from galaxy counts

Method: gamma-ray infered EBL ∝ I_{EBL}/H_0

. Marginalized likelihood accounting for correlations between gamma-ray inferred EBL spectral points



Approach similar to:

. Bi & Yuan 2008
. Barrau 2008
. Dominguez & Prada 2013

Result

. $H_0 = 88 \pm 8_{stat} \pm 13_{sys}$

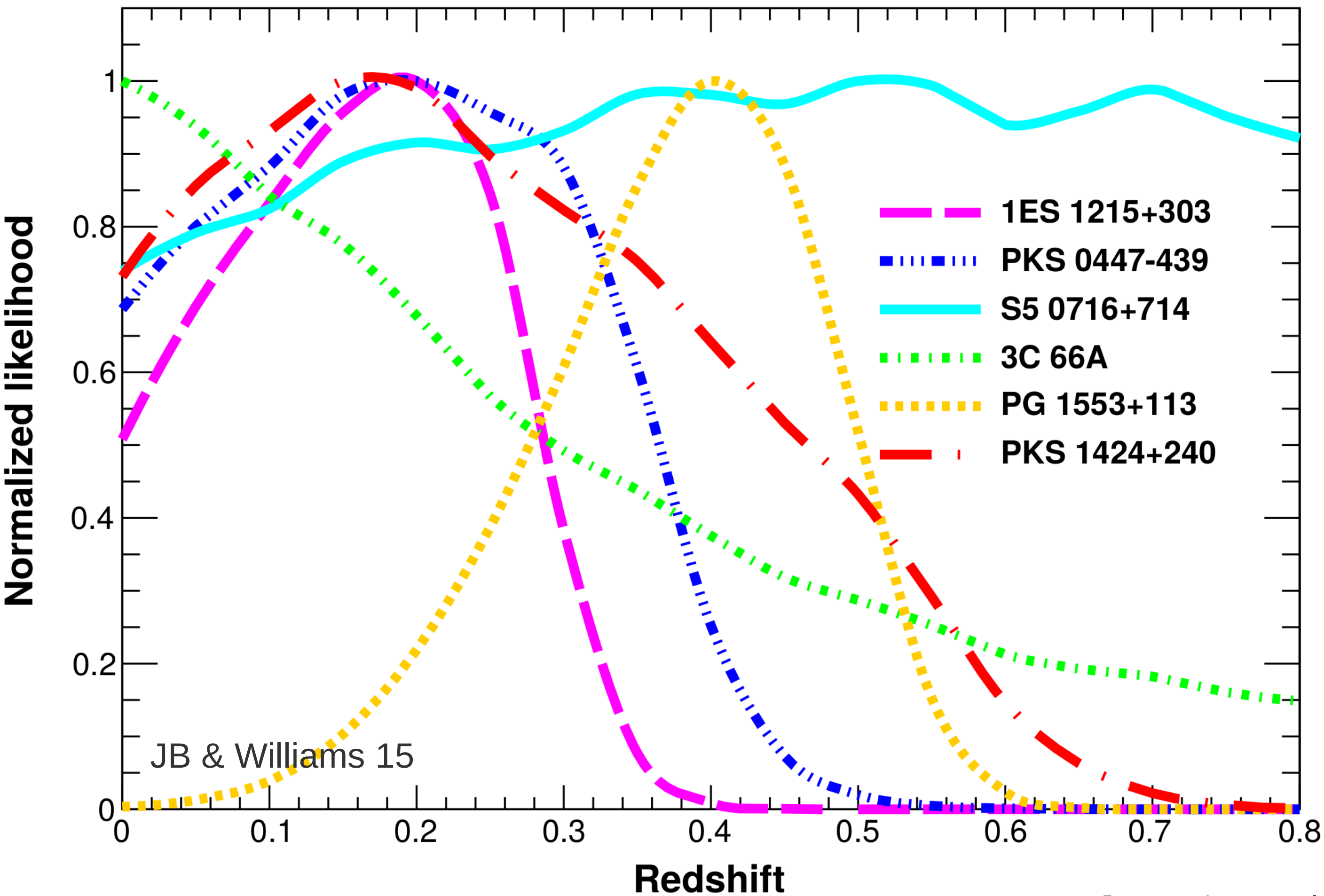
. Systematic driven by unresolved populations

Consistent with CMB and cosmic ladder estimates of H_0

Redshifts of TeV blazars

Method: Marginalized likelihood accounting for correlations between gamma-ray inferred EBL points

. Combining all the spectra from sources with underconstrained distance



Results

. Only the spectra from PG 1553+113 show significant absorption. 3.4σ effect with z = 0.41-0.11+0.08

. Most constraining gamma-ray upper limits (99%) for
1ES1215+303 (<0.35)
PKS0447-439 (<0.45)
3C66A (<0.58)
PKS1424+240 (<0.64)

. 1-2σ tensions with spectroscopic lower limits for these last two srcs. **Need data!**

Gamma-ray Absorption + Axion-Like Particles

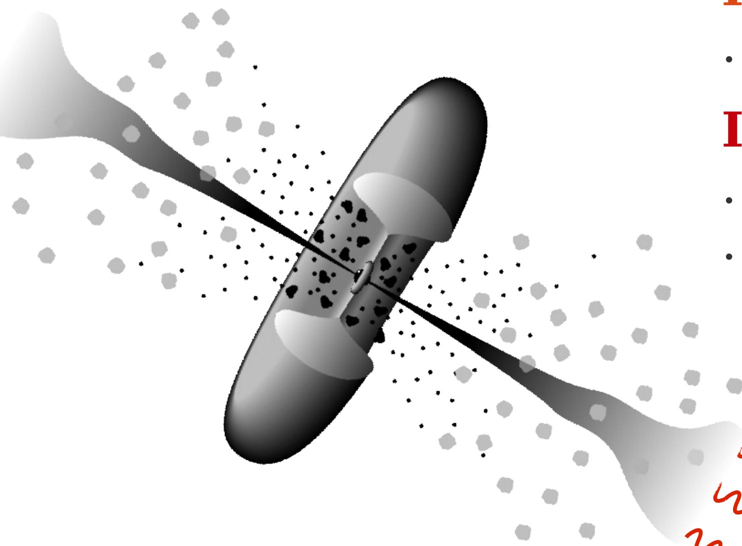
Hypothetical particles coupling with γ rays: ALPs

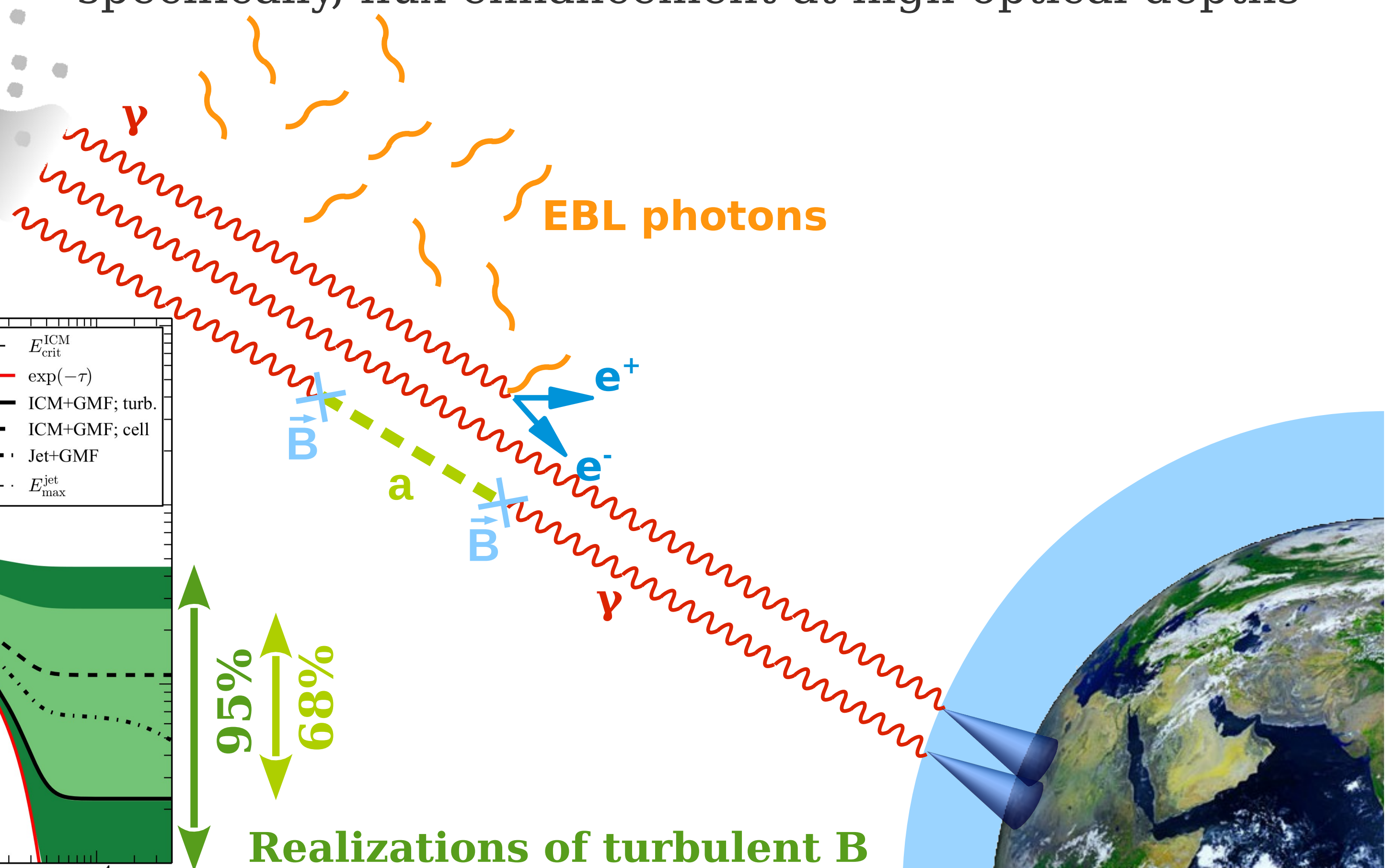
. Inspired from QCD axion, but free mass and coupling

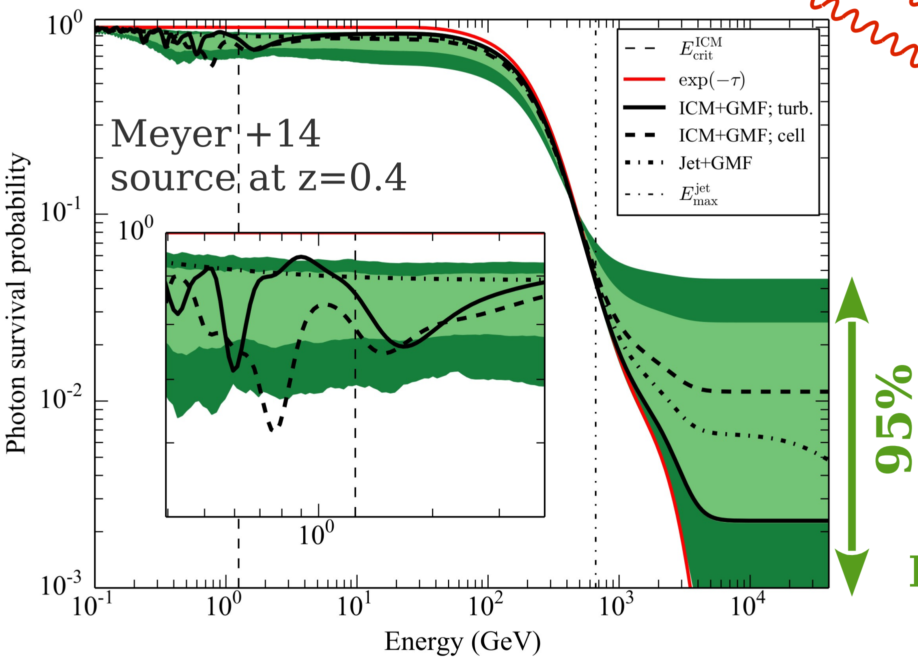
Impact on TeV spectra:

. Point-to-point fluctuations at low energies

. Reduction of absorption at large energies, or more specifically, flux enhancement at high optical depths



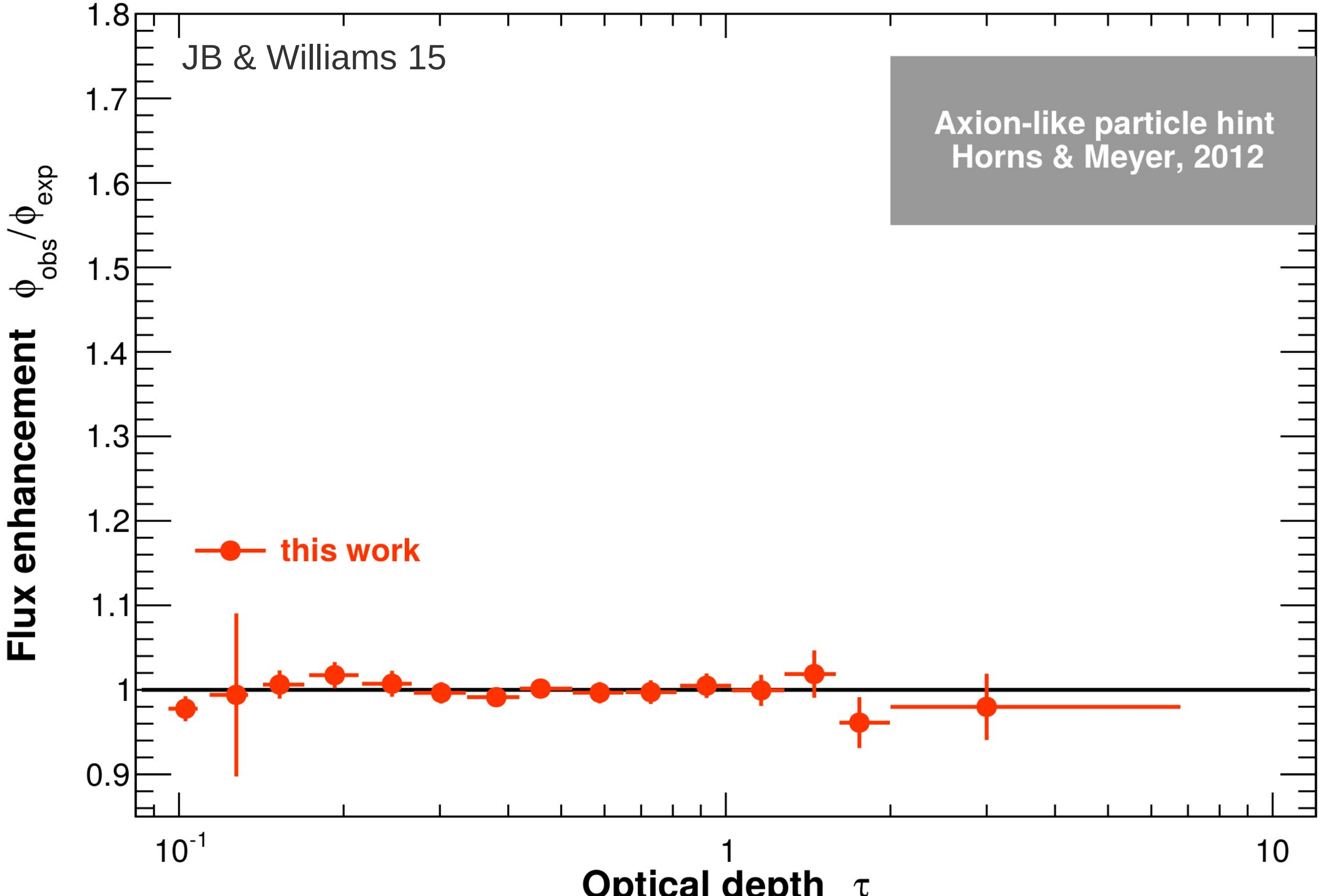




Axion-Like Particles

Method: Flux residuals as a function of optical depth

- Horns & Meyer 2012, Meyer et al. 2013 found a 3-4σ flux enhancement above τ=2, interpreted as a coupling of gamma rays with hypothetical ALPs
- Flux enhancement computation in τ-bins, accounting for flux uncertainties



Results

- All the spectra are well fit by classical EBL absorption
- Flux enhancement above τ=2 smaller of **-2 ± 4%** vs ~70% inferred from Horns & Meyer 2012

No anomaly correlating with optical depth (or energy) detected!

Lorentz Invariance - Principle

Principle:

. Modified dispersion relation around $E_{QG} \sim E_{Planck} \sim 10^{28}$ eV

. Modified threshold of pair creation (Jacob & Piran 08)

. Probe of the > 15-20 TeV energy range

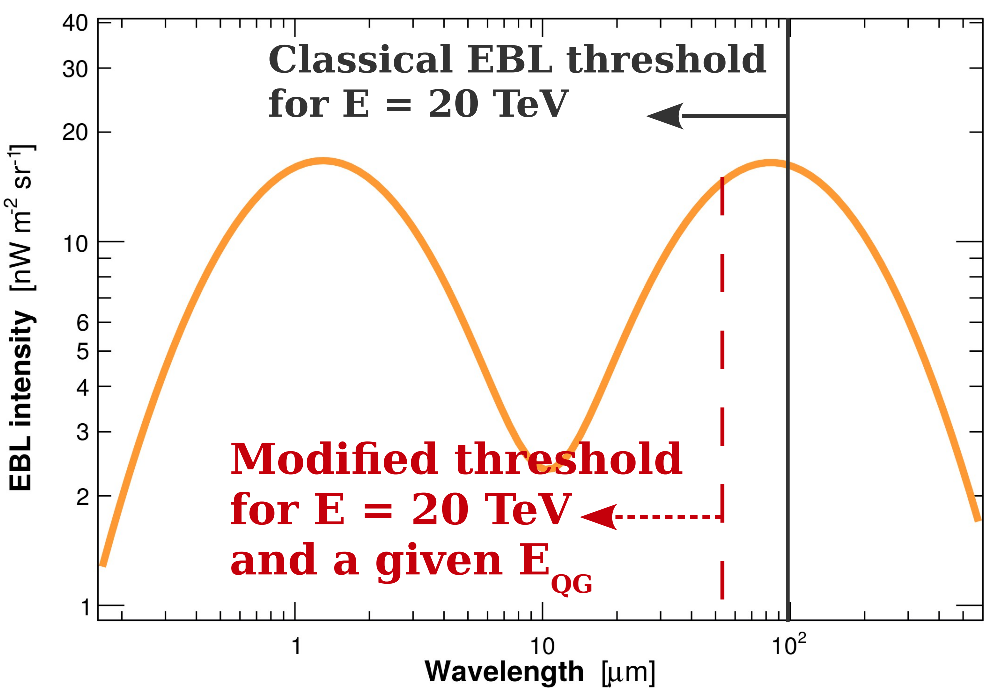
1 $$E^2 = p^2 + m^2 - E^2 \times \frac{E}{E_{\mathrm{QG}}}$$

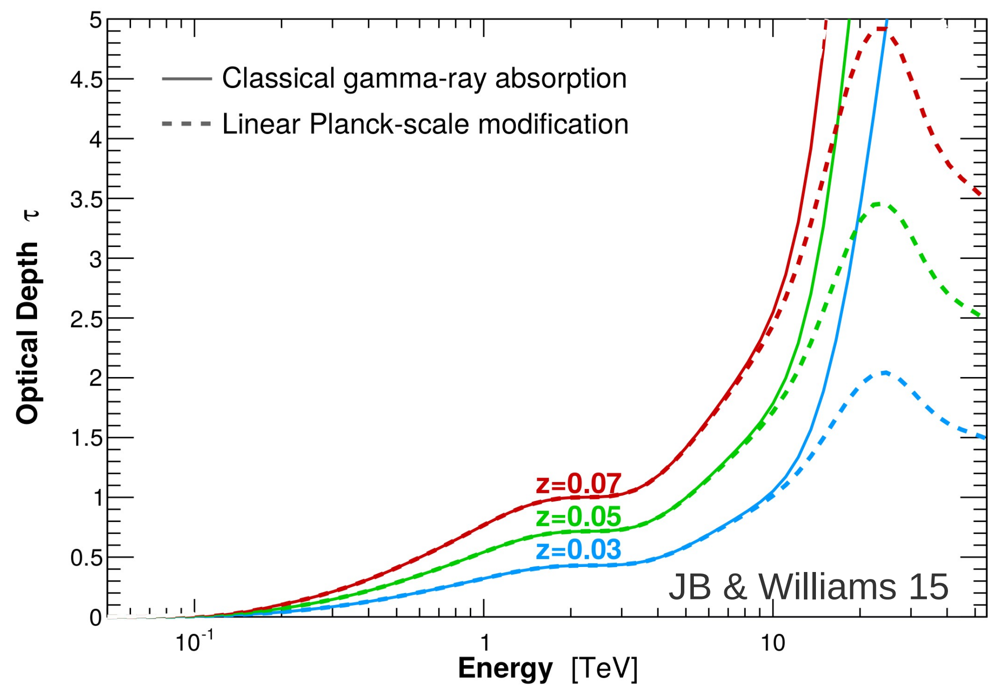
2a: 4-P conservation
2b: speed of light

2a $$\epsilon_{thr} = \frac{m_e^2}{E_\gamma} \times \left[1 + \left(\frac{E_\gamma}{E_{\gamma,\mathrm{LIV}}}\right)^3\right]$$

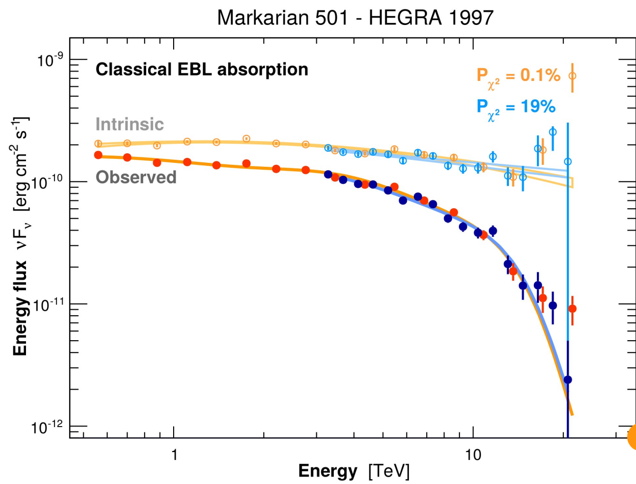
2b $$v = \frac{\partial E}{\partial p} = 1 - \frac{E_\gamma}{E_{\mathrm{QG}}}$$

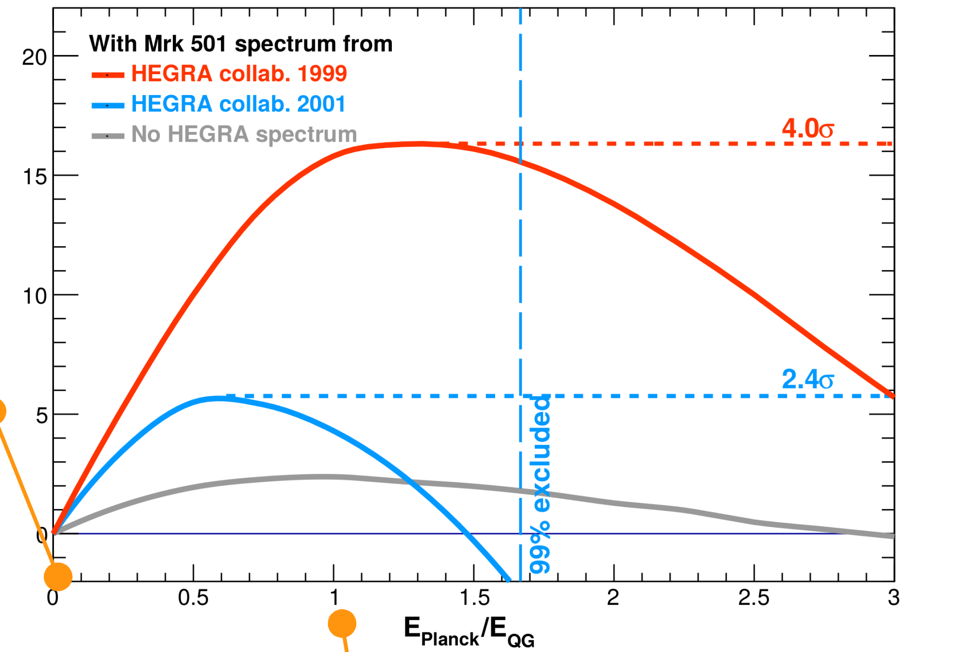
3a $$E_{\gamma,\mathrm{LIV}} = \left(8 m_e^2 E_{\mathrm{QG}}\right)^{1/3} = 29.4\,\mathrm{TeV} \times \left(\frac{E_{\mathrm{QG}}}{E_{\mathrm{Planck}}}\right)^{1/3}$$



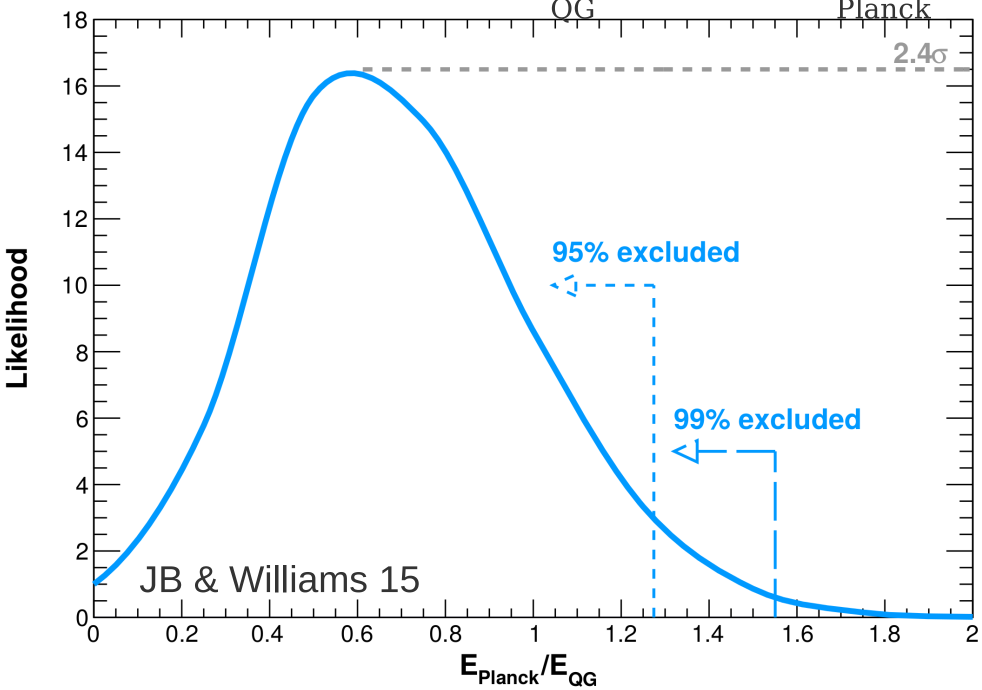


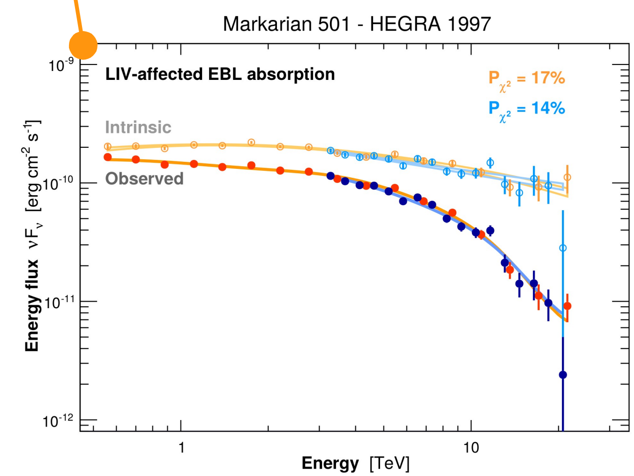
Lorentz Invariance - Results





2.4σ prevents exclusion of Planck scale,
99% lower limit: $E_{QG} > 0.6 \times E_{Planck}$





Revisiting the common wisdom...

- **"Gamma-ray constraints on the EBL are below galaxy counts"**

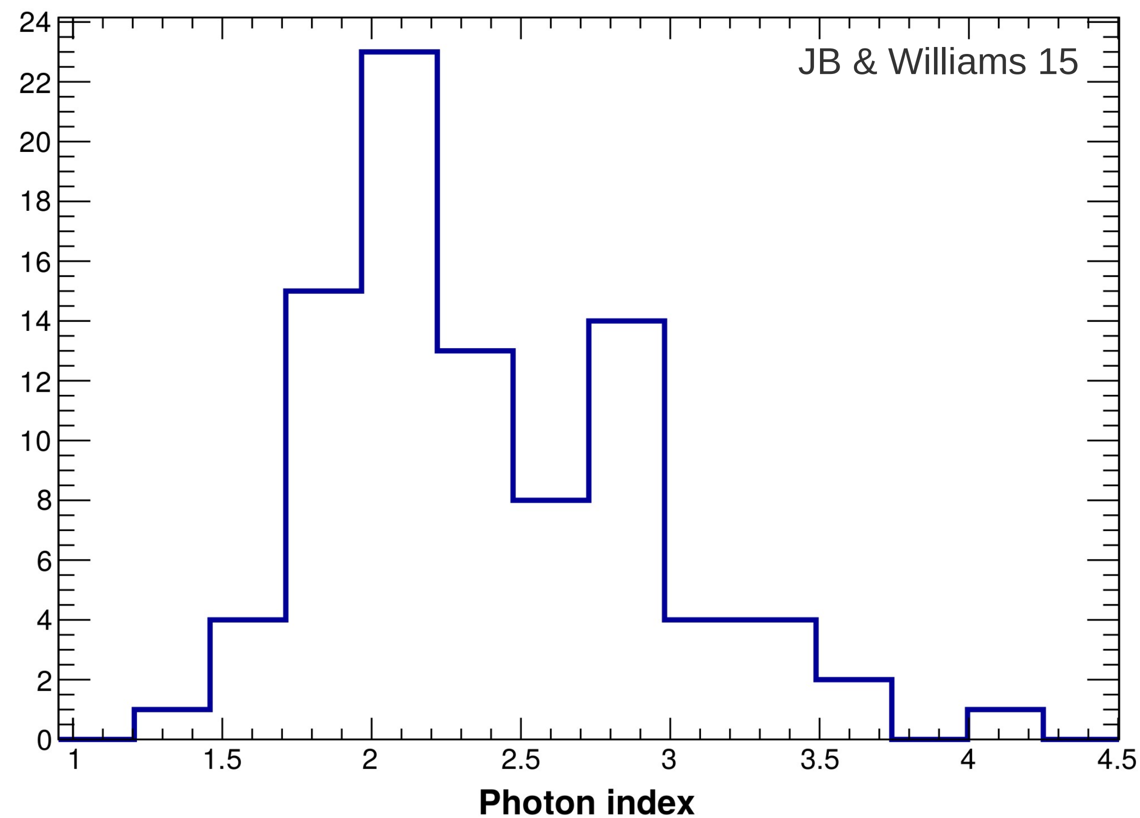
  WRONG! model-independent approach even shows a slight excess from gamma rays

- **"TeV intrinsic spectra are too hard"**

  WRONG! no tension with Fermi-LAT hardness for contemporaneous observations
  no tension with photon index > 1.5 (↔ electron index of 2), minimum at 1.3±0.3

- **"GeV extrapolation does not match TeV flux"**

  PARTLY WRONG!
  Good match for 25/31 quasi-contemporaneous spectra.
  2 (4) spectra have a larger (smaller) VHE flux than GeV extrapolated. Easily explained: blazars are variable and their GeV and TeV flux are not recorded simultaneously...



- **"Flux excess correlated with optical depth"**

  WRONG!

What remains to be done

Refined EBL spectrum between 0.2 and 90 µm

Sources with $0.05<z<0.3$, signature of polycyclic aromatic hydrocarbons?

Probing further the EBL in the FUV and FIR regions

FIR: $z<0.05$, high stats above 10 TeV – FUV: distant sources, underconstrained region

Evolution of the EBL

Current study does up to $z=0.3$ – need more lever arm to probe the evolution

Hubble constant

Improved gamma-ray constraints in 0.5-50 µm. Improved direct observations, JWST...

Anomalies

Upper-limit on UHECRs & coupling with ALPs still to be determined.

Fate of the electron-positron pairs

Probe of the intergalactic magnetic field? Heating of the intergalactic medium?

Intrinsic emission

Characterization of the GeV-TeV gamma-ray bumps (blazar sequence)

What we can do with Fermi-LAT

Absorption starts to be significant above z=0.5

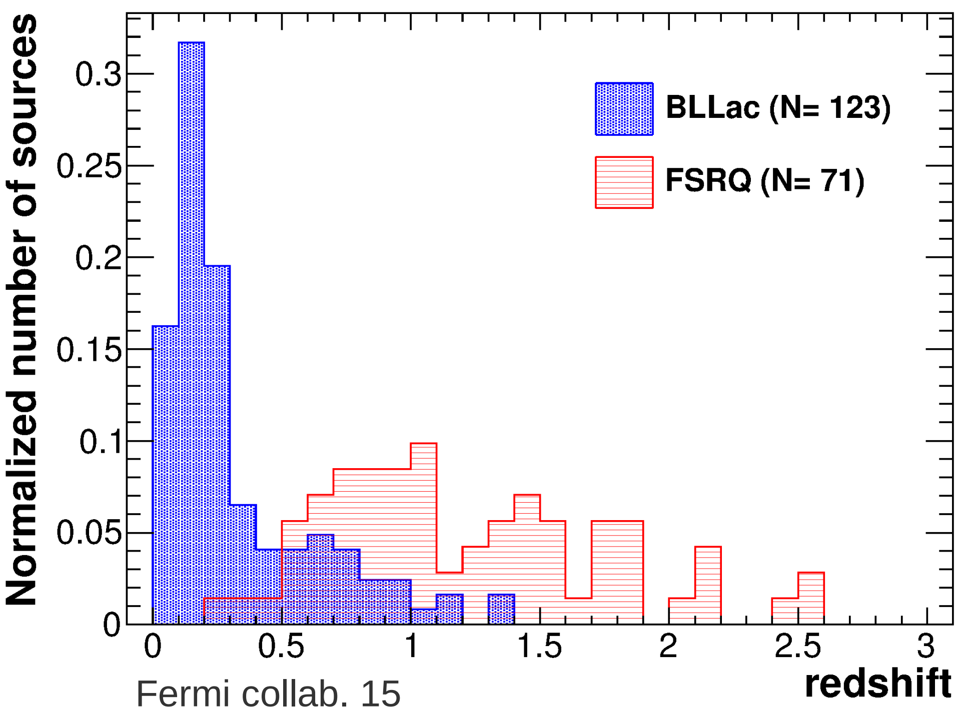
Lots of potential with Pass 8 and 7 years of data (wrt Pass 7 / 4 years for the Fermi paper)

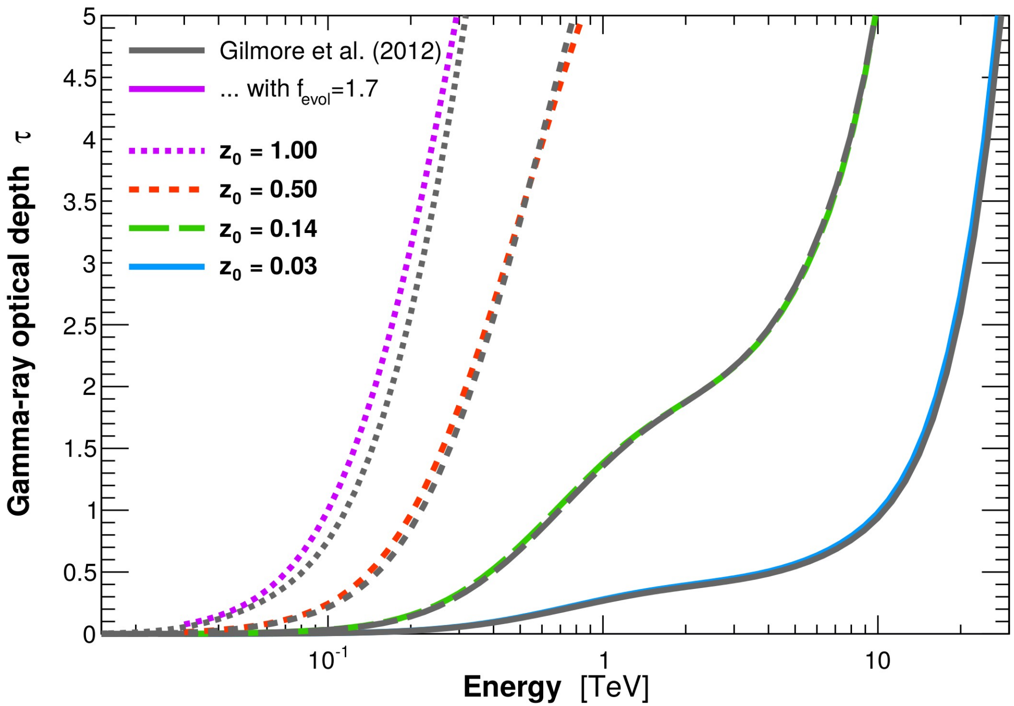
Need of a new evolution parametrization above z=0.8

Current parametrization fails for large redshifts, where most of the Fermi sources are

Fermi GI proposal submitted

Work with David Williams – parametrization and testing 1st year, full analysis 2nd year





What we can do with VERITAS, H.E.S.S., and MAGIC

Upgrade of the three instruments in 2012/2013

First MAGIC camera / 5th telescope for H.E.S.S. / High QE photomultipliers for VERITAS

Aim: as low an energy threshold as possible

Better handle on the intrinsic spectra – bridge the gap between 0.3<z<0.5

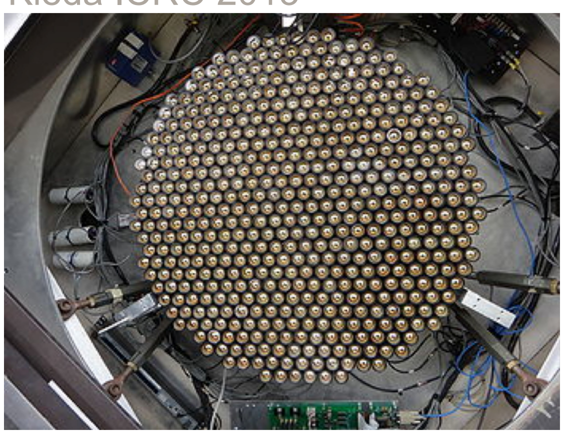
Ongoing work within VERITAS

Reconstruction of the EBL with long-term spectra, constraints on LIV with Mrk 421

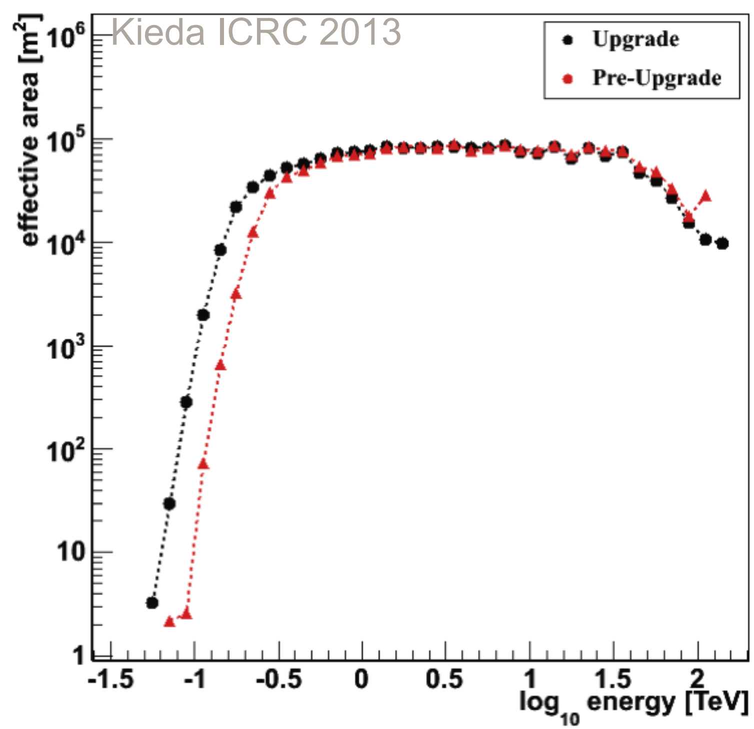
Nice potential of joint analyses at the event level

Tools such as 3ML (HAWC) or GammaLib (CTA) could open such possibilies

Kieda ICRC 2013



Mirzoyan ICRC 2013



2020 perspective: the Cherenkov Telescope Array

Ten fold increased sensitivity + extensions < 100 GeV and > 10 TeV

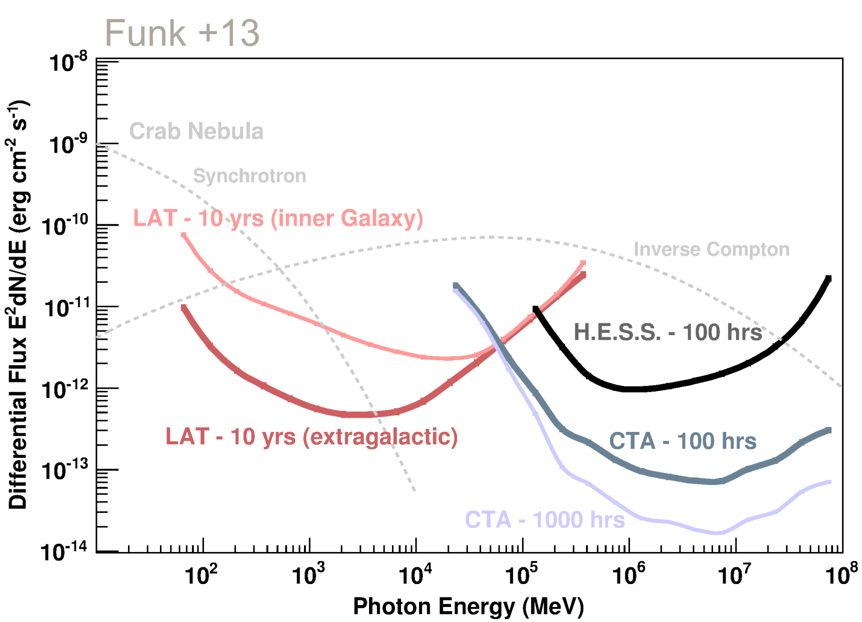
Northern and Southern Arrays (4 large, 25+24(US) medium, >20 small covering 3km^2)

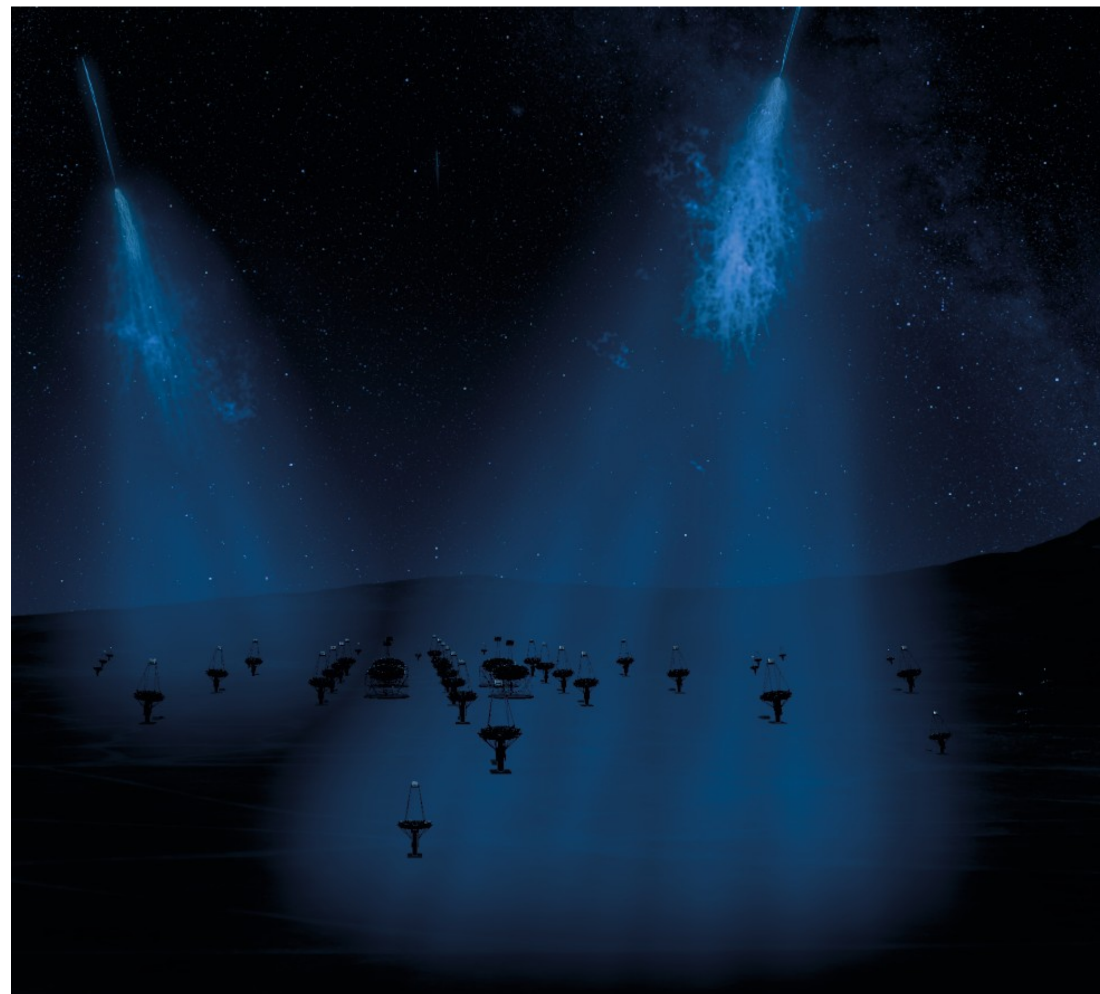
Vast Key Science Program

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

Including gamma-ray cosmo.

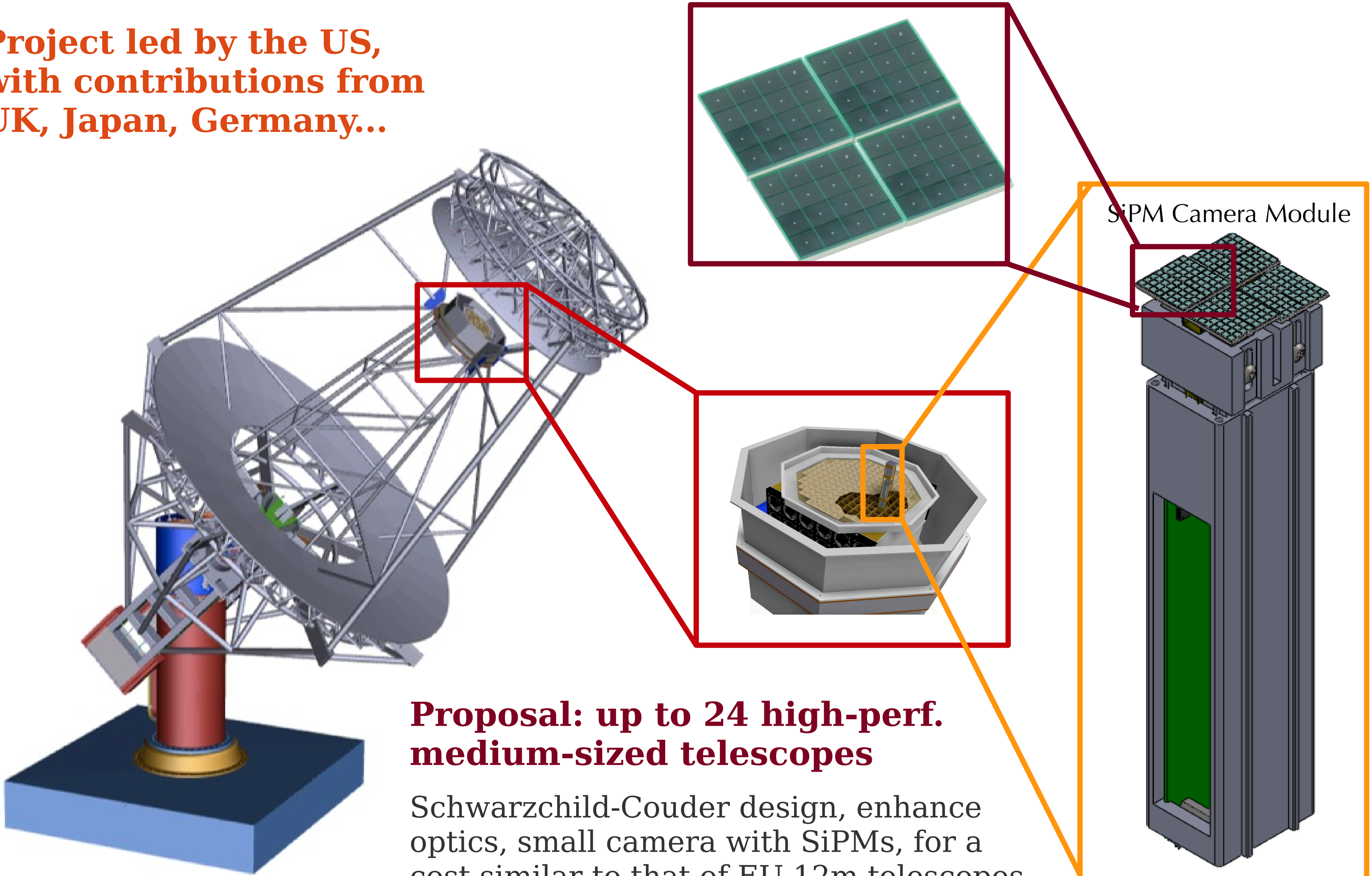
EBL, IGMF, ALPs, LIV...





SCT contribution to CTA

Project led by the US, with contributions from UK, Japan, Germany...



Proposal: up to 24 high-perf. medium-sized telescopes

Schwarzchild-Couder design, enhance optics, small camera with SiPMs, for a cost similar to that of EU 12m telescopes.

SiPMs vs PMTs

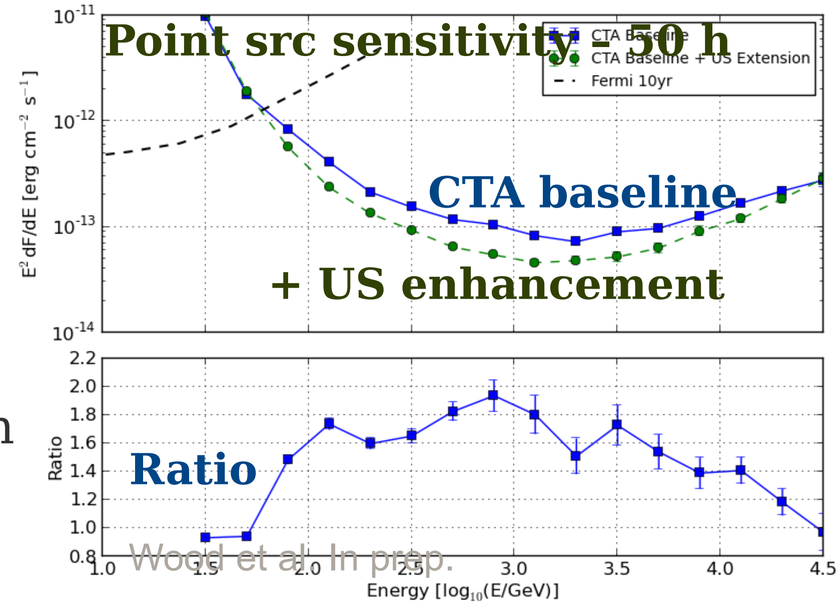
Impact of SCT contribution

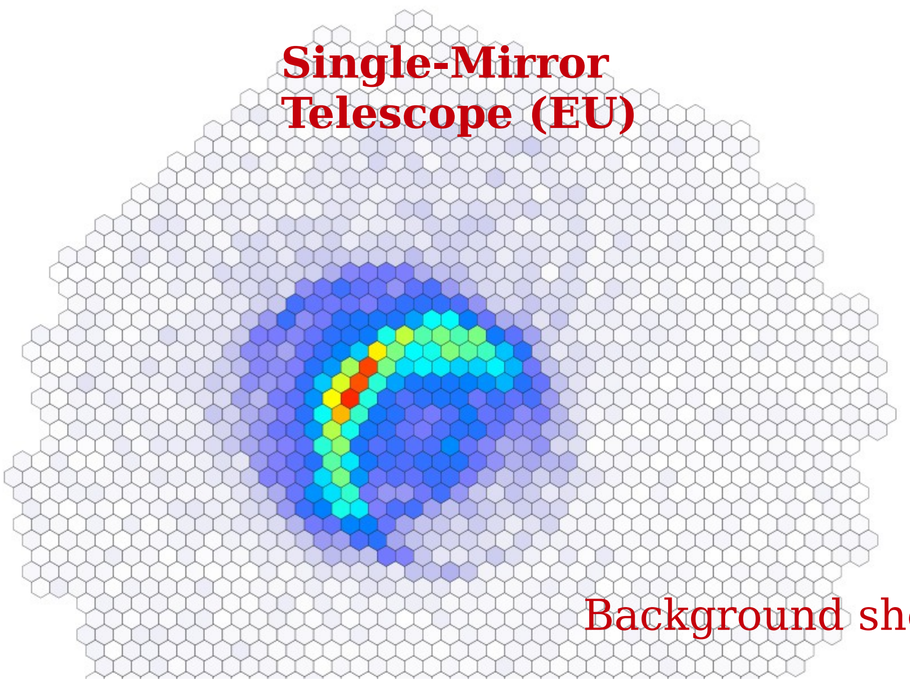
. Addition results in ~2x better sensitivity in the core energy range of CTA (0.1-10 TeV)

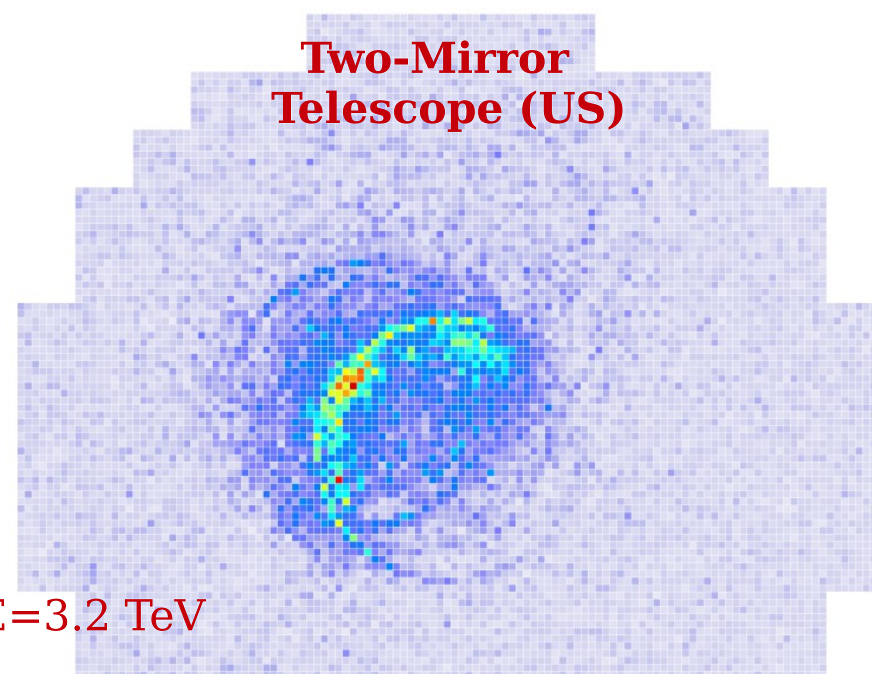
→ Crucial for EBL studies in 0.1-10µm (PAH) in conjunction with the JWST

. > 0.3 TeV: 30-40% better angular resolution

→ Crucial studies of the intergalactic magnetic fields and galactic science







Background shower, E=3.2 TeV

from Bouvier

Conclusions

Computation of gamma-ray absorption becomes easier!

Reduction of 3D integral to a mere convolution production of the EBL intensity with a kernel. Negligible impact of underlying assumptions up to z~0.6-0.8.

Joint fit of gamma-ray spectra and local EBL constraints

11σ preference for best-fit EBL spectrum (0.26-105µm). Few room left for unresolved populations or truly diffuse components above 1 µm.

Model-indep. measurement of the Hubble constant, promising for JWST/CTA.

Pair-production anomaly as obtained by Horns & Meyer 2012 ruled out

Motiavations for ALPs and reprocessed CR signal strongly undermined

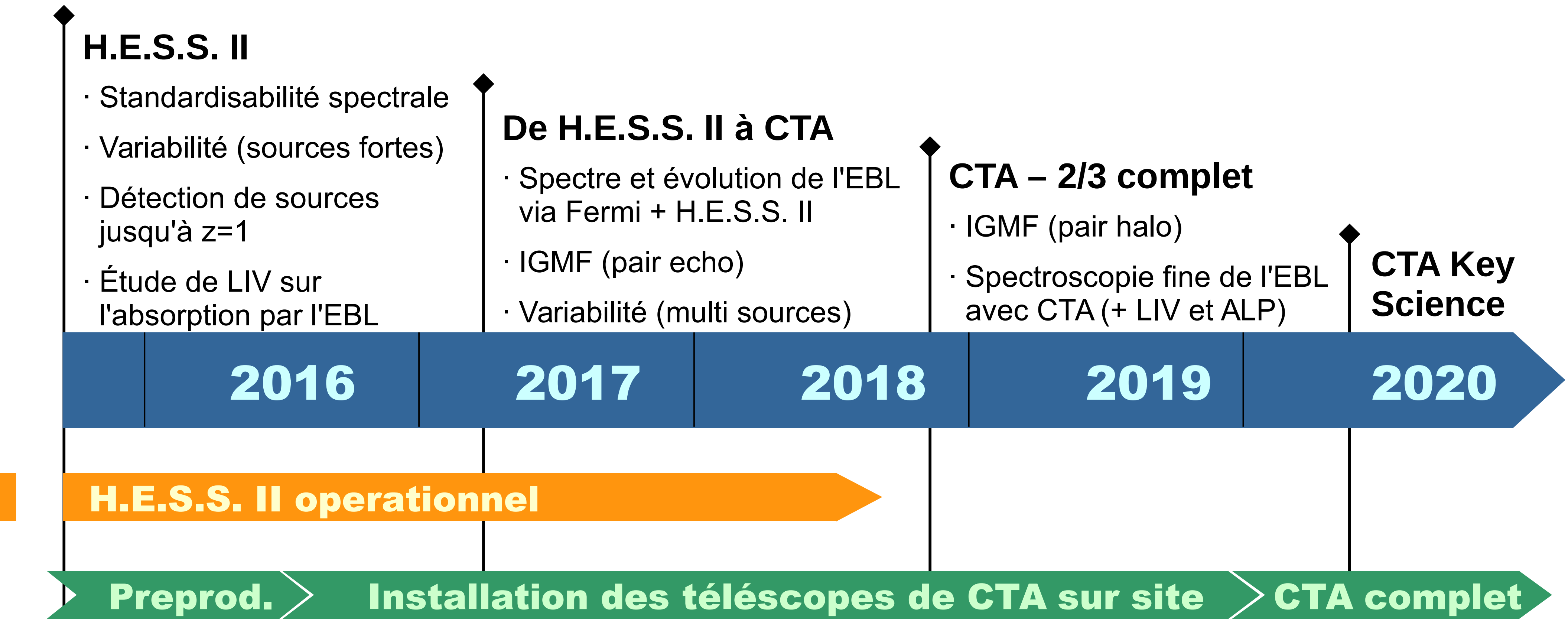
Vast science case to be addressed with current and upcoming instruments

Fermi-LAT: FUV spectrum and evolution of the EBL, IGMF

VERITAS, H.E.S.S. II, MAGIC: improved O-NIR spectrum of the EBL, LIV

CTA, the ultimate tool: blazar sequence, MUV-FIR EBL, EBL evolution, H_0, IGMF, LIV, UHECR

Projet de recherche - CNRS

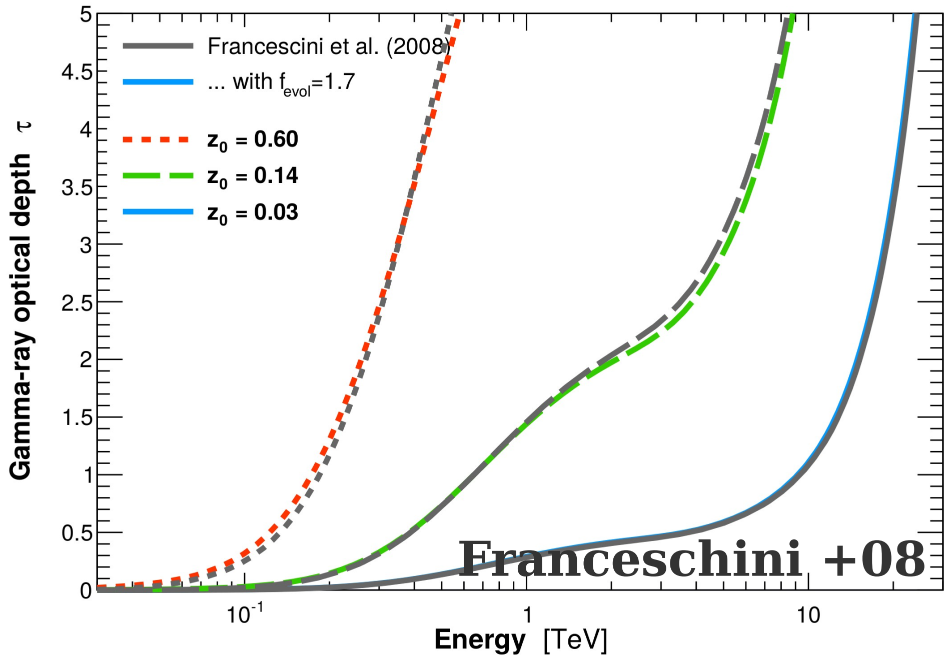


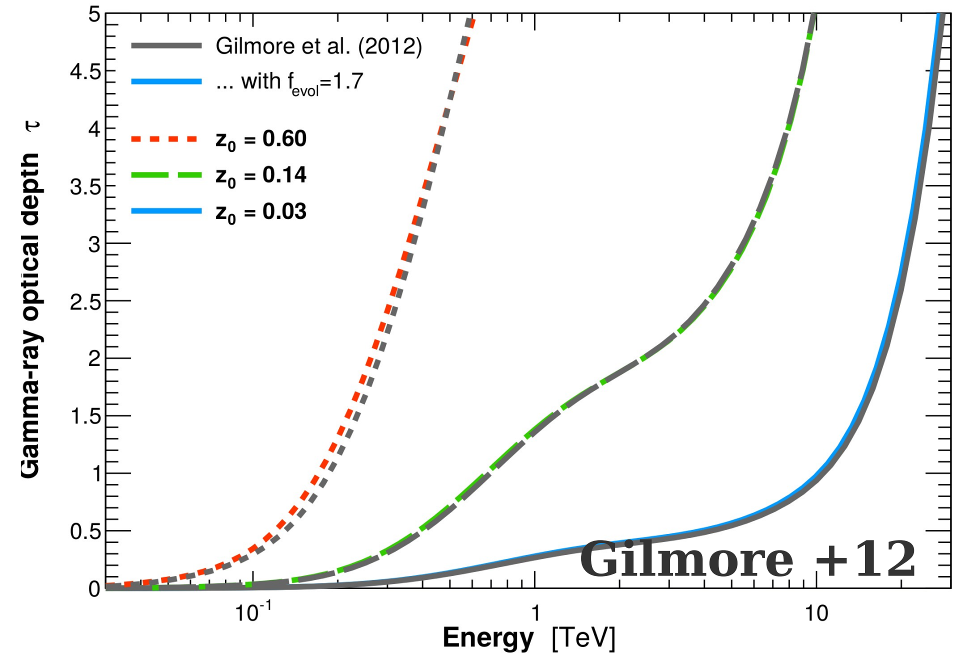
EBL (*extragalactic background light*) : fond diffus cosmologique optique et infrarouge
IGMF (intergalactic magnetic field) : champ magnétique sub nG peuplant les vides cosmiques
ALP (*axion like particles*) : particules de faible masse, candidates matière/énergie noire
LIV (*Lorentz invariance violation*) : vitesse de la lumière variant avec l'énergie des photons

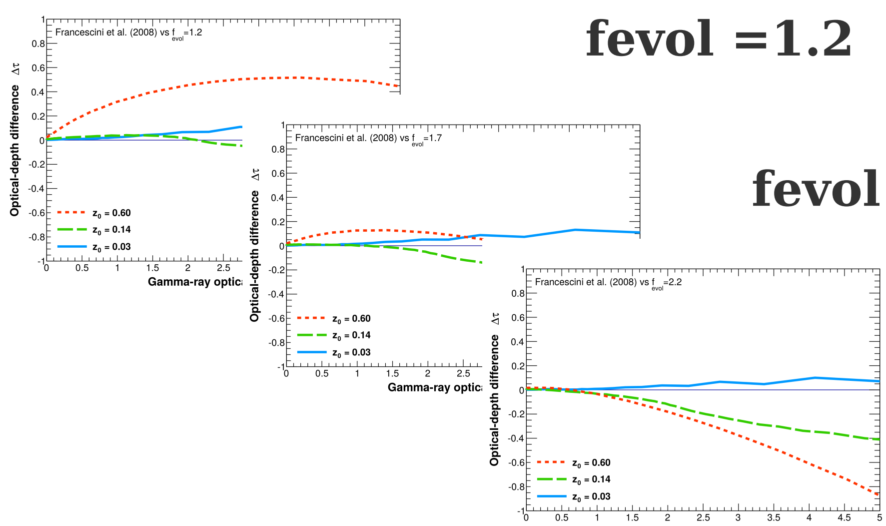
Backup

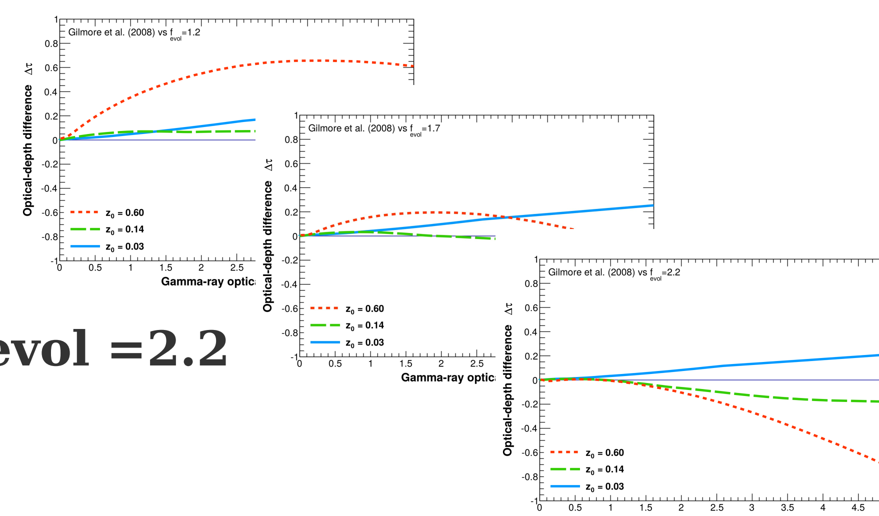
Evolution

$$\mathrm{d}\epsilon \frac{\partial n}{\partial \epsilon}(\epsilon, z) = \mathrm{d}\epsilon_0 \frac{\partial n}{\partial \epsilon_0}(\epsilon_0, 0) \times (1+z)^{3-f_{evol}}$$









fevol =1.2

fevol =1.7

fevol =2.2

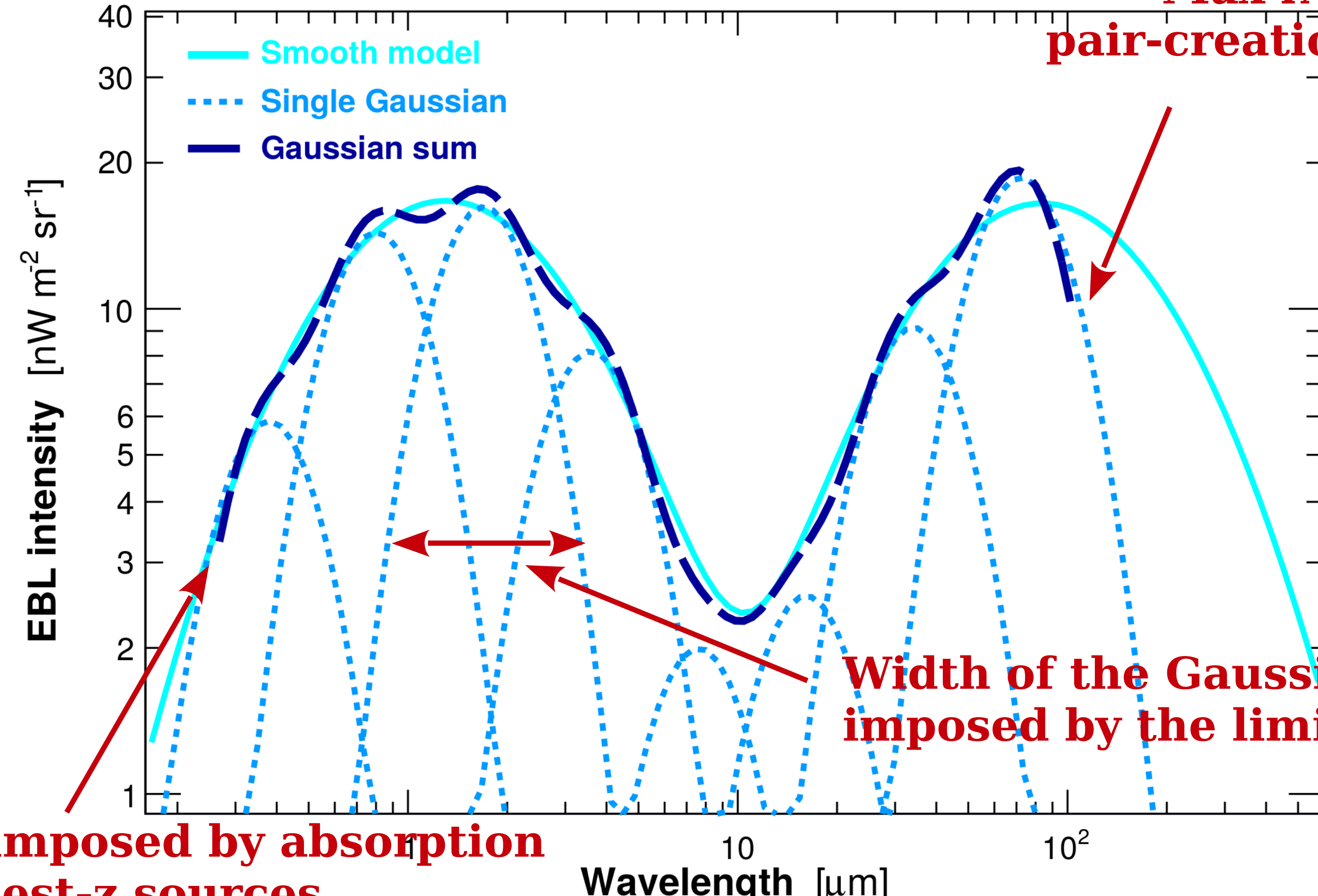
Spectral parametrization

Model-independent approach:

. Sum of Gaussians of fixed widths and means, with free amplitudes

→ optical depth linearly depends on the free parameters

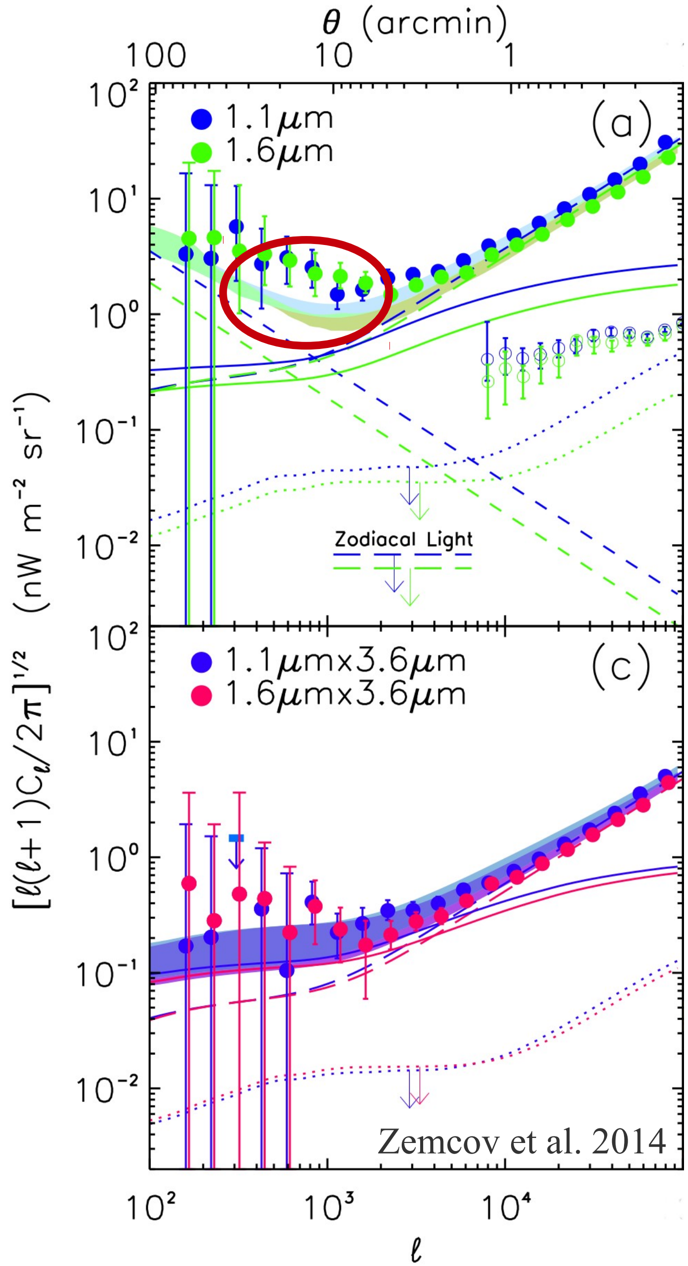
Max λ imposed by pair-creation threshold



Width of the Gaussians (binning) imposed by the limited statistics

Min λ imposed by absorption of highest-z sources

A word about CIBER



Other means of detection: 2^{nd} moment (fluctuations) instead of 1^{st} moment (brightness)

A fluctuation excess in NIR ?
Science publication in November 2014

Attributed to IHL
- Diffuse galactic light below l<500
- Low-z galaxies above l>2000
- Unknown excess in between to which intra-halo light from stars stripped from their parent galaxies could contribute.

Excess fluctuations → EBL intensity

Table 1. Contributions to near-infrared EBL anisotropy and intensity. At each wavelength, we list the measured fluctuation amplitude at large angular scales; the model-dependent ratio of EBL intensity to EBL anisotropy; the IGL determined by previous measurements; the ratio of the IHL and IGL intensities; and finally, the inferred total background intensity from both components. We also list the background intensity that would arise assuming the measured fluctuations are entirely due to high-redshift EOR galaxies.

λ (μm)	Measured $\delta\lambda I_\lambda$* (nW m^{-2} sr^{-1})	$\frac{\lambda I_{\lambda,IHL}}{\delta\lambda I_\lambda}$	$\lambda I_{\lambda,IHL}$‡ (nW m^{-2} sr^{-1})	$\lambda I_{\lambda,IGL}$§ (nW m^{-2} sr^{-1})	$\frac{\lambda I_{\lambda,IHL}}{\lambda I_{\lambda,IGL}}$	$\lambda I_{\lambda,IHL} + \lambda I_{\lambda,IGL}$ (nW m^{-2} sr^{-1})	$\lambda I_{\lambda,EOR}$‖ (nW m^{-2} sr^{-1})
1.1	$1.4^{+0.8}_{-0.7}$	5	$7.0^{+4.0}_{-3.5}$	$9.7^{+3.0}_{-1.9}$	0.7	$16.7^{+5.0}_{-4.0}$	28
1.6	$1.9^{+0.9}_{-0.8}$	6	$11.4^{+5.4}_{-4.8}$	$9.0^{+2.6}_{-1.7}$	1.3	$20.4^{+6.0}_{-5.1}$	38
2.4	0.32 ± 0.05†	7	2.2 ± 0.4	$7.8^{+2.0}_{-1.2}$¶	0.3	$10.0^{+2.0}_{-1.3}$	6.4
3.6	$0.072^{+0.019}_{-0.021}$	9	$0.65^{+0.17}_{-0.19}$	5.2 ± 1.0	0.1	5.9 ± 1.0	1.4
3.6#	$0.049^{+0.021}_{-0.007}$	9	$0.44^{+0.19}_{-0.06}$	5.2 ± 1.0	0.1	5.6 ± 1.0	1.0
4.5	0.053 ± 0.023†	7	0.37 ± 0.16	3.9 ± 0.8	0.1	4.3 ± 0.8	1.0

*RMS fluctuation amplitude computed as averages of measured data over $500 < l < 2000$, except for those marked †, which are determined at $l = 3000$ using fainter mask cuts due to restricted field size (see also note ‖). ‡The IHL background from the product of columns 2 and 3. §The IGL background as compiled by (*28*). ‖Computed EOR background assuming EOR fluctuations with $\lambda I_\lambda/\delta\lambda I_\lambda = 20$. ¶Determined at *K* band corresponding to 2.2 μm. #Computed using the measurements of (6) averaged over $500 < l < 5000$.

Axion-like particles

If "anomaly" due to ALP

- Complex shaped dark pink "TeV transparency" region

Meyer and Horns 2013

Caveats

- no anomaly seen by more complete studies

Biteau & Williams 2015

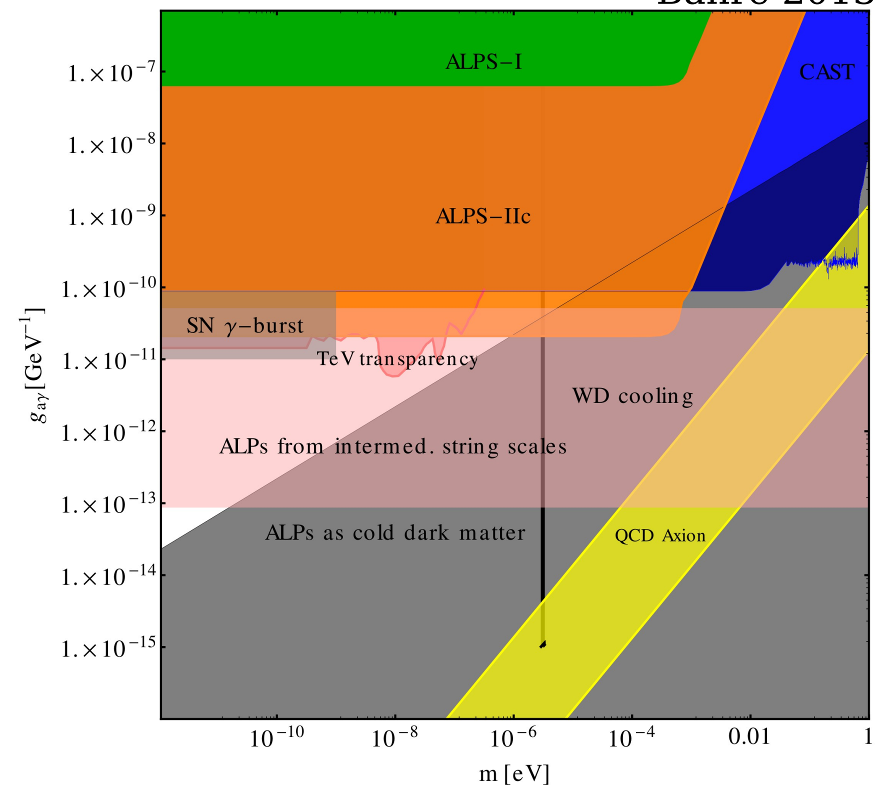
- large fraction of the ALP param. space excluded from H.E.S.S. observations of PKS 2155-304

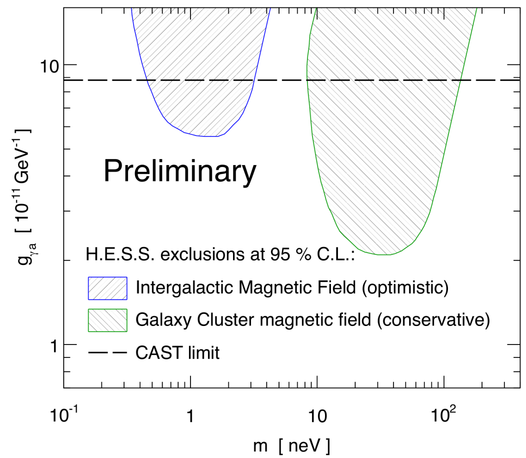
Brun et al. 2013 (H.E.S.S. Collab.)

- Uncertainties in EBL > 5 μm
- Treatment of uncertainties and correlation between points

See e.g. discussion in Biteau 2013

Bahre 2013





Brun et al. 2013 (H.E.S.S.)

Inter-Galactic Magnetic Field

IGMF constraints

- First constraints B > 10^{-16} G

  Neronov and Vovk 2010

- Releasing steady assumption B > 10^{-17} - 10^{-18} G

  Taylor et al. 2011, Dermer 2011

- Studying the hypotheses on the intrinsic emission, B=0 rejected at the 3σ level

  Arlen et al. 2012

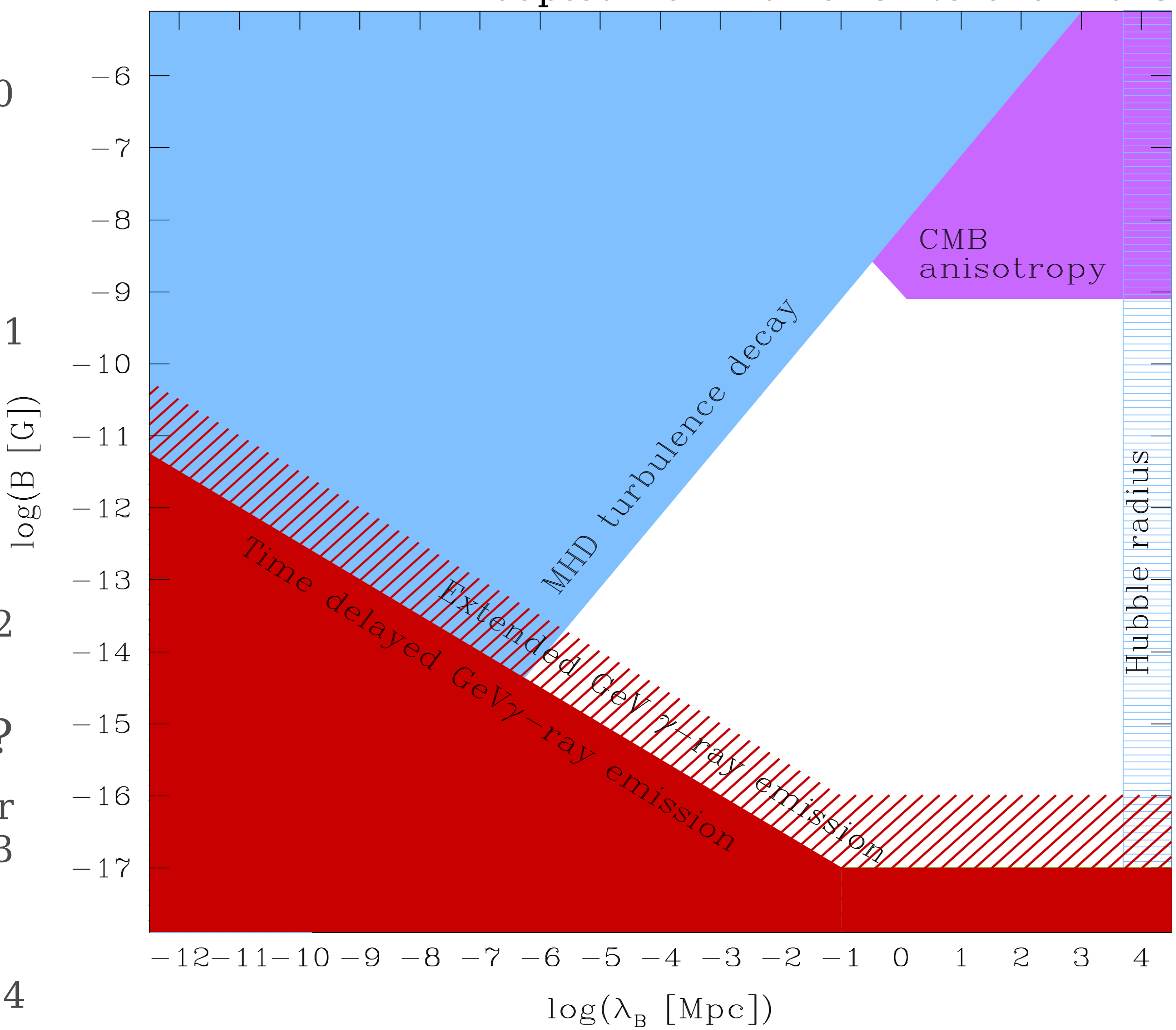
- Caveats from plasma physics?

  Broderick et al. 2012, Schlickeiser et al. 2012 vs Miniati & Elyiv 2013

  Not confirmed by PIC simu.

  Sironi & Gianios 2014

Adapted from Durrer & Neronov 2013



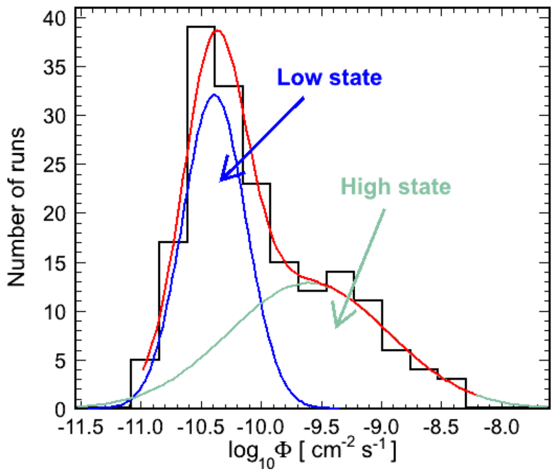
Blazars' variability

→ **Statistical observables during the ~week of high-flux « state »**

Skewed flux distribution – Log-normal?

The brighter, the more variable – Linear RMS-flux relation

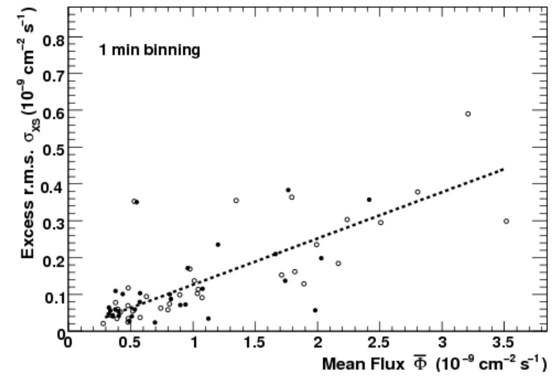
Power-law Fourier spectrum – Red noise behavior



→ **Fractal behaviors?**

Noah effect – Rare-events domination. Tailed distribution?

Joseph effect – Long-term memory. Fractional Fourier index?

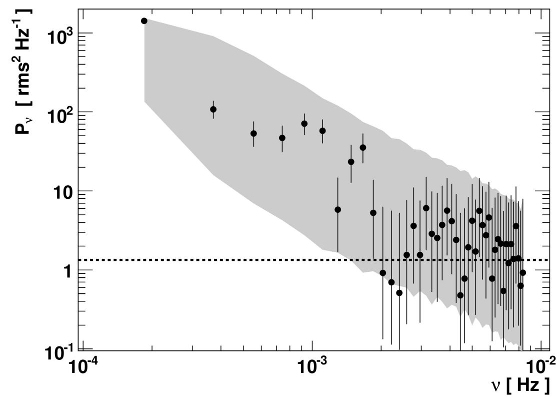


→ **Signature of the disk modulation?**

Disk fluctuations might modulate jet emission
suggested e.g. in McHardy 2010

Red noise from inward-going outward disk fluctuations
cellular automaton Mineshige et al. 94, alpha disk Lyubarski 1997

Log-normal behavior from multiplicative process
Disk avalanche-like process ⇒ multiplicative flux
⇒ additive log flux ⇒ log flux is normal (Central Limit Theorem)



Minijet model

→ **Long-term variability originated from the disk?**

Would explain long-term statistical properties, but...

→ **Fast variability must originate from the jet!**

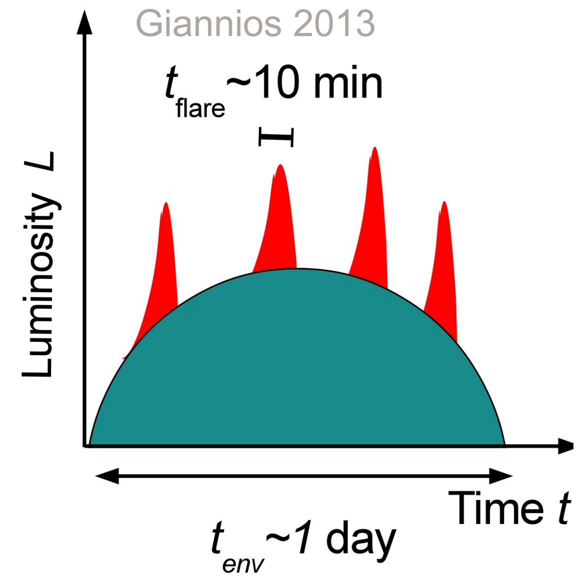
Minute variations vs hour black-hole light crossing time :

a) engine and emitting region move towards the observer

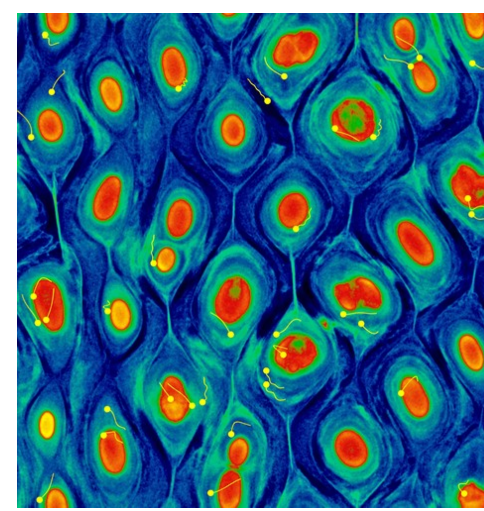
b) emitting region alone moves rapidly and variability caused by some local instability

c) supermassive BH 50 times less massive than estimated

Narayan & Piran 2012



Sironi & Spitkovski



→ **Minijets-in-a-jet models**

Reconnection-powered plasmoids
reproduce timescales and luminosity

→ **Problem with additive scenarios...**

Sum of plasmoids emission ⇒ normal flux (Central Limit Th.)
⇒ no more-variable-when-brighter behavior (gaussian prop.)

My kinematic minijet model

→ **From spherical cow to herd of ovoidal cows**

Plasmoids (or reconnection layers) modeled as boosted regions within a boosted medium

Analytic computation of the Doppler factor

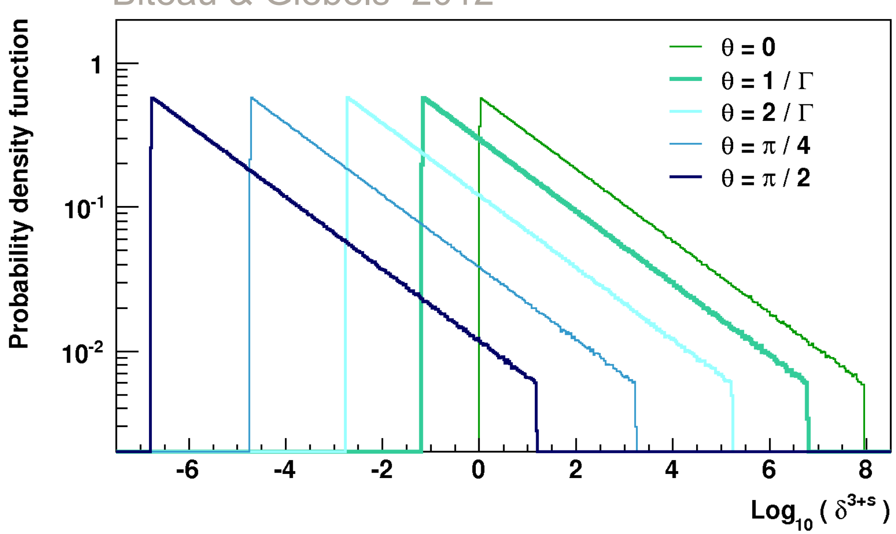
Power-law flux distribution for each minijet assuming isotropy IN the jet frame

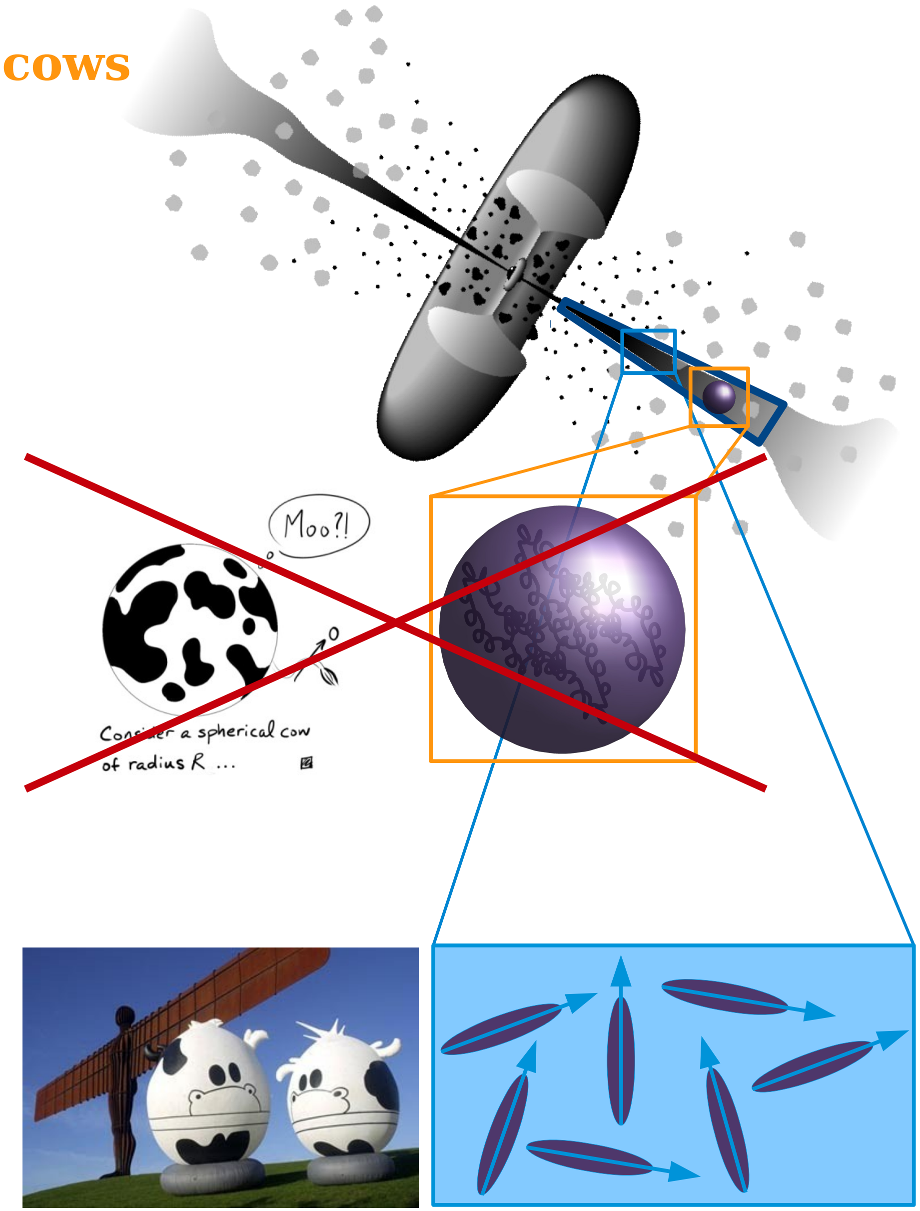
→ **Fractal behavior!**

Noah effect – Pareto flux distribution

Central Limit Theorem does not hold!

Biteau & Giebels 2012





My kinematic minijet model

→ **When the CLT goes nuts!**

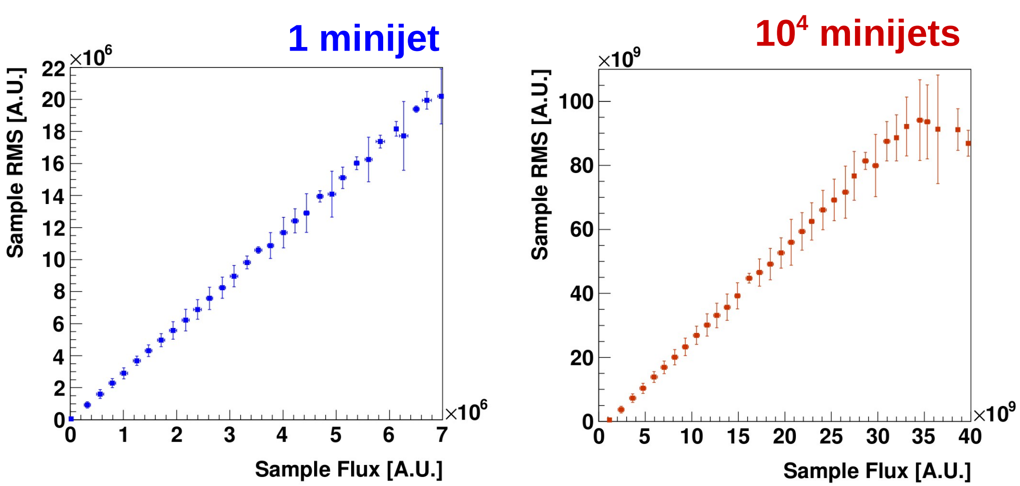
Sum of Pareto variables NOT asymptotically gaussian

Tend to alpha (or Levy) stable distribution, highly skewed, looking similar to lognormal

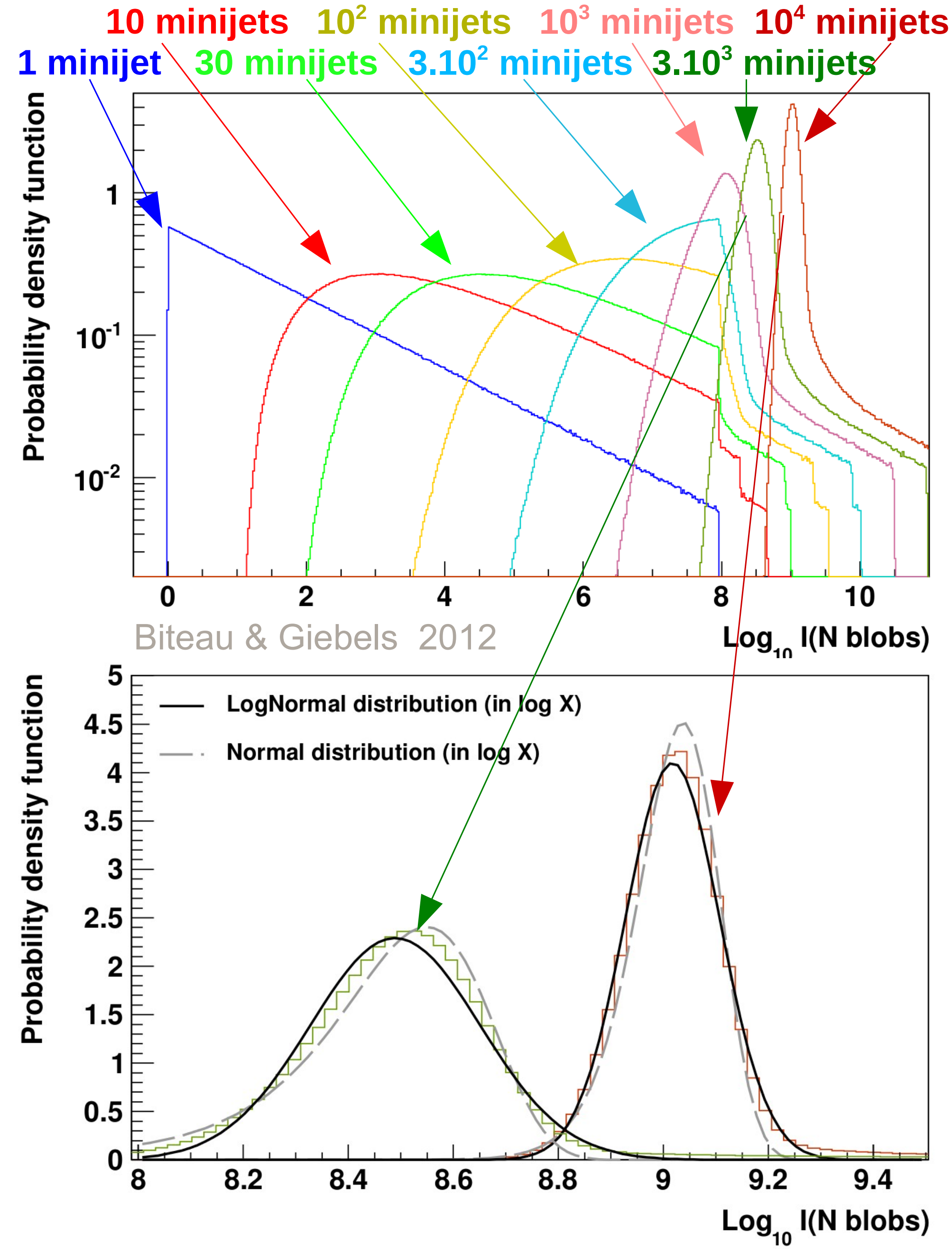
→ **The brigther, the more variable**

Linear RMS-flux for Pareto distribution

… and also for alpha-stable distributions



Biteau & Giebels 2012

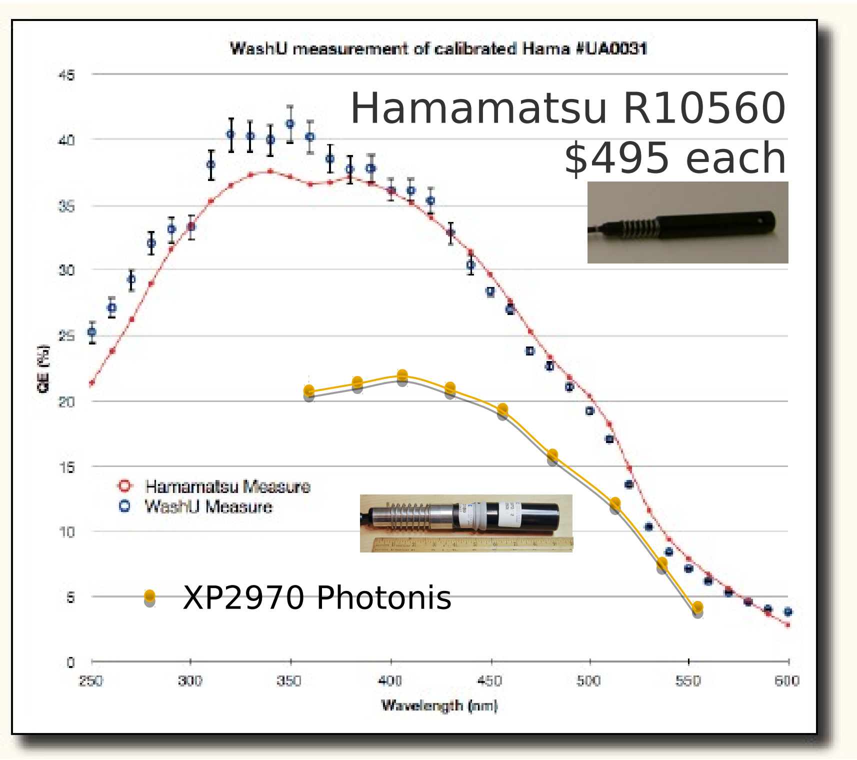


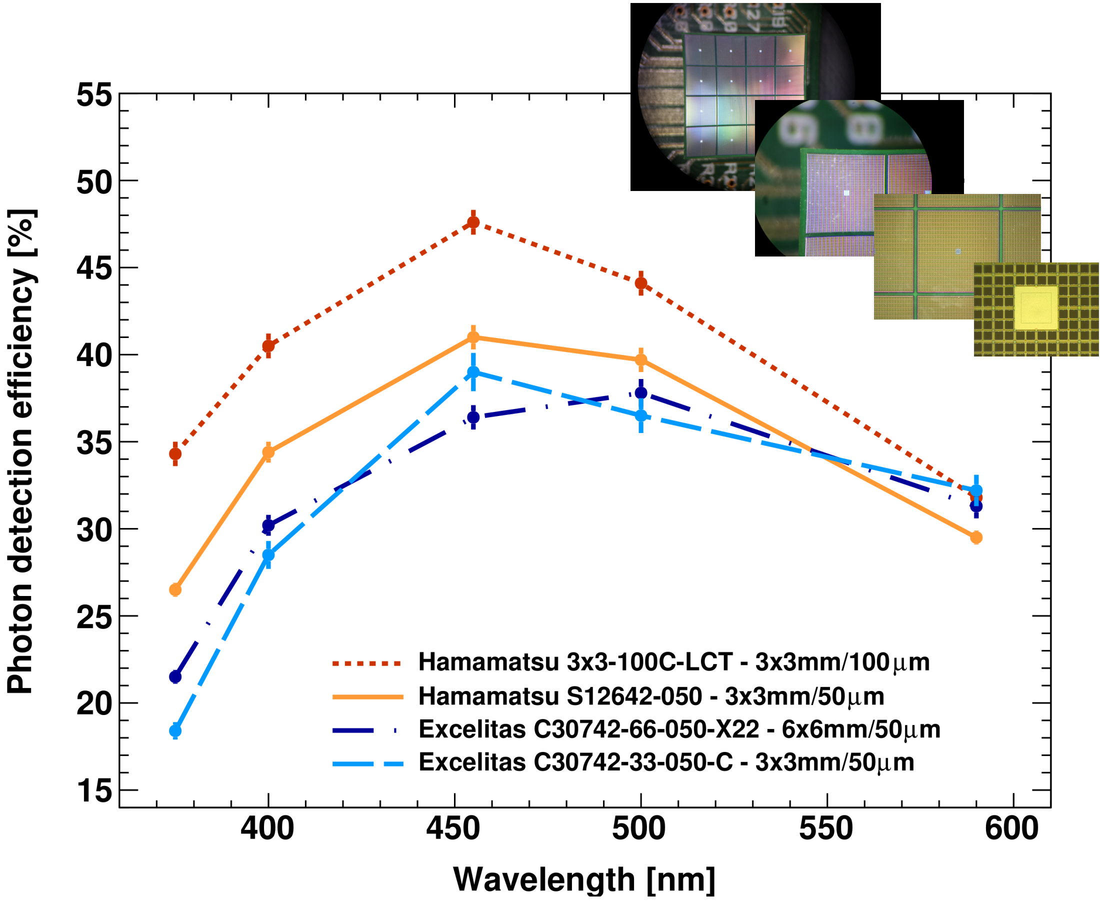
PMTs vs SiPMs

→ **Pros and cons of SiPMs :**

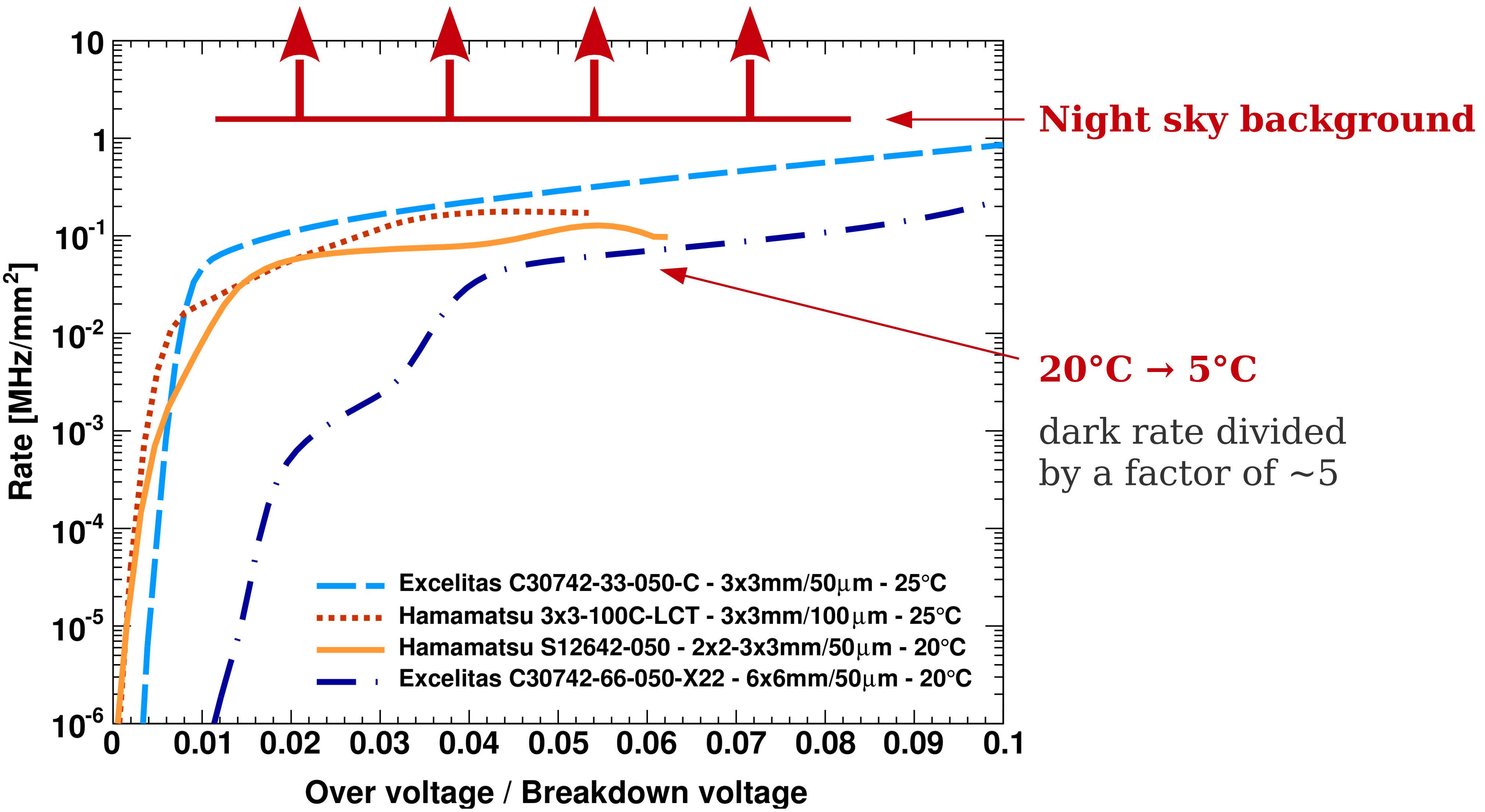
Pros : High efficiency, low cost, low V operation, high luminosity operation

Cons : Optical cross talk and afterpulse, need of temperature monitoring





Dark rate



dark rate divided
by a factor of ~5