# EXTRAGALACTIC BACKGROUND LIGHT IN THE INFRARED AND THE LOCAL FOREGROUNDS

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Mini-Array

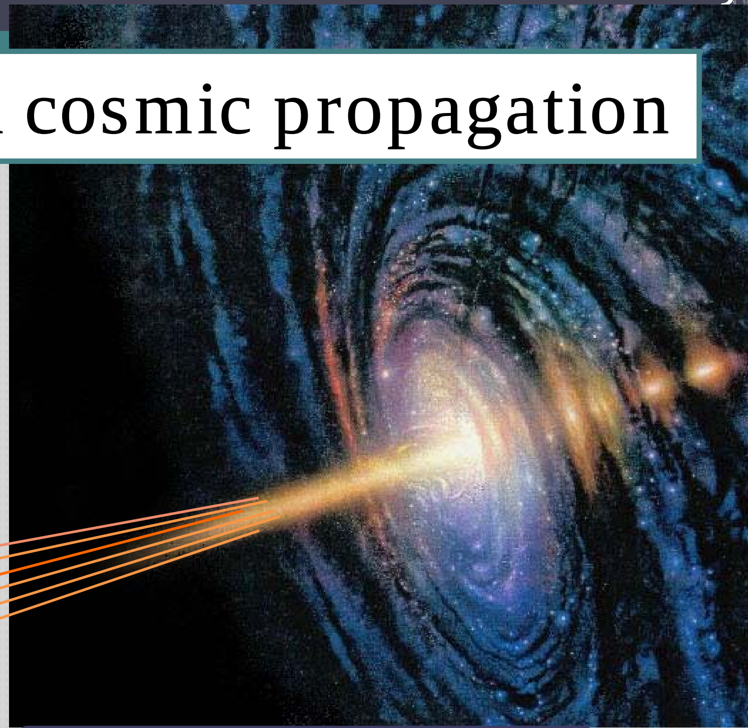
- $\gamma$–$\gamma$ interactions offer:
  - tests of the *Standard Model* of physics (LIV, ALPs)
    - cosmic opacities for particle and photon propagation
  - a bridge between high-energy and classical astrophysics
    - tests of the cosmic background radiations (EBL)
  - All this requires careful evaluation of the local photonic foregrounds

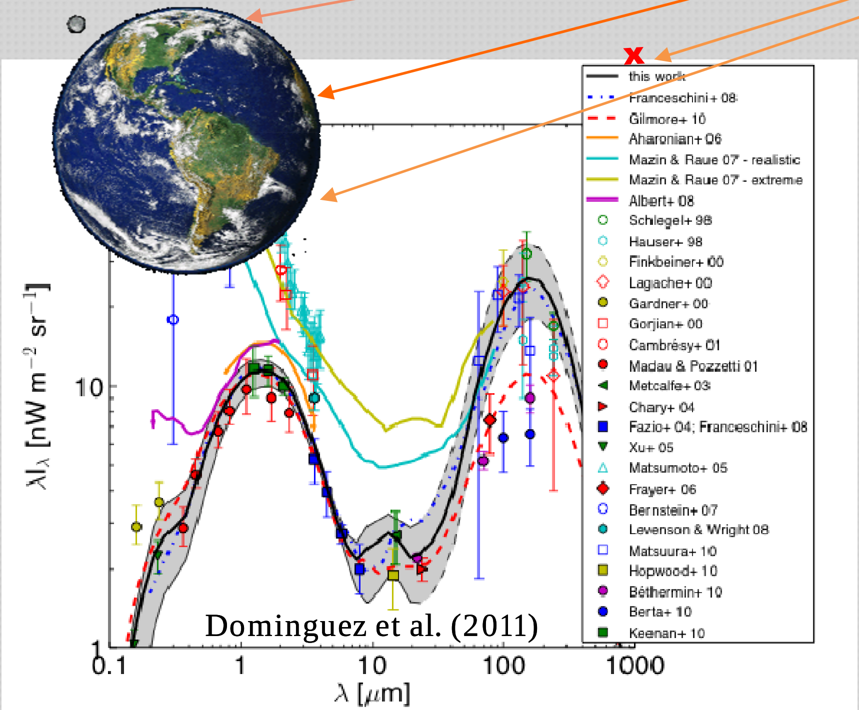
*Milano, Gamma2024*

# Photon-photon interactions and cosmic propagation

VHE photon + diffuse lights
→ electron-positron pair production $\gamma_{VHE}\gamma_{EBL} \rightarrow e^+e^-$

$$\lambda_{\max} \simeq 1.24 \times \varepsilon_{TeV}\ [\mu m]$$





Dominguez et al. (2011)

## Absorption effects:

$$\left.\frac{dF}{d\varepsilon}\right|_{OBS} = \left.\frac{dF}{d\varepsilon}\right|_{EM} e^{-\tau_{\gamma\gamma}},\ \tau_{\gamma\gamma} = \sigma_{\gamma\gamma} n_\gamma \cdot d$$

The interaction effects at the highest energies are maximized by looking at:

- the most luminous and brightest
- *extragalactic* VHE emitters (long baselines)
- at moderate distances (to avoid being killed by the EBL)

For LIVs and ALPs: see other contributions

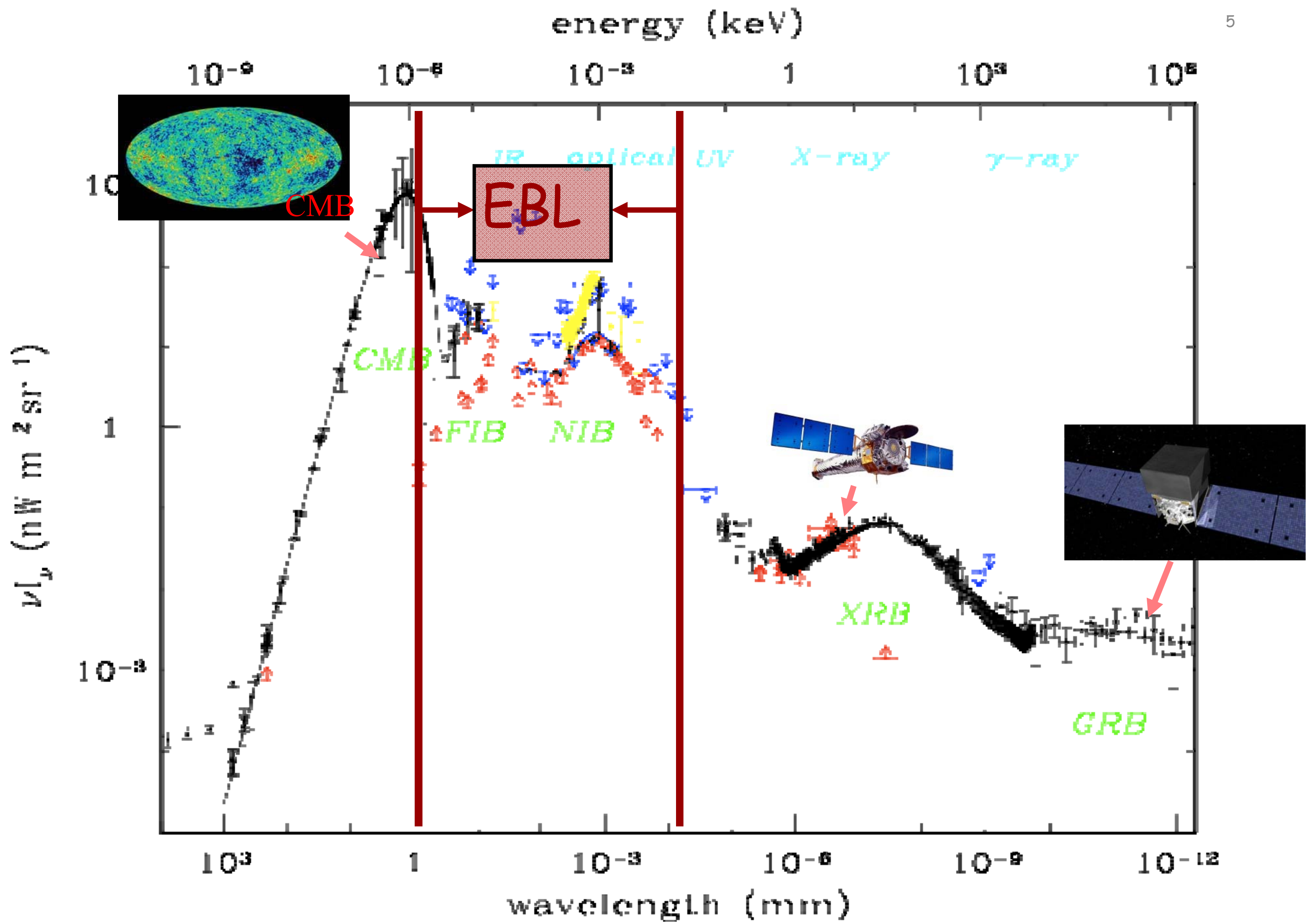
# Tests of the Extragalactic Background Light

- They are the repository of all radiant energy produced by cosmic sources and cosmic structures since the Big Bang
  - -- Point sources
  - -- Diffuse structures and components
- Background radiations concern the whole history of astrophysical sources,
- Essential data to understand how the Universe has taken shape and evolved.
- Three main physical processes for generating energy (and light):

  -- Thermonuclear reactions (in stars)

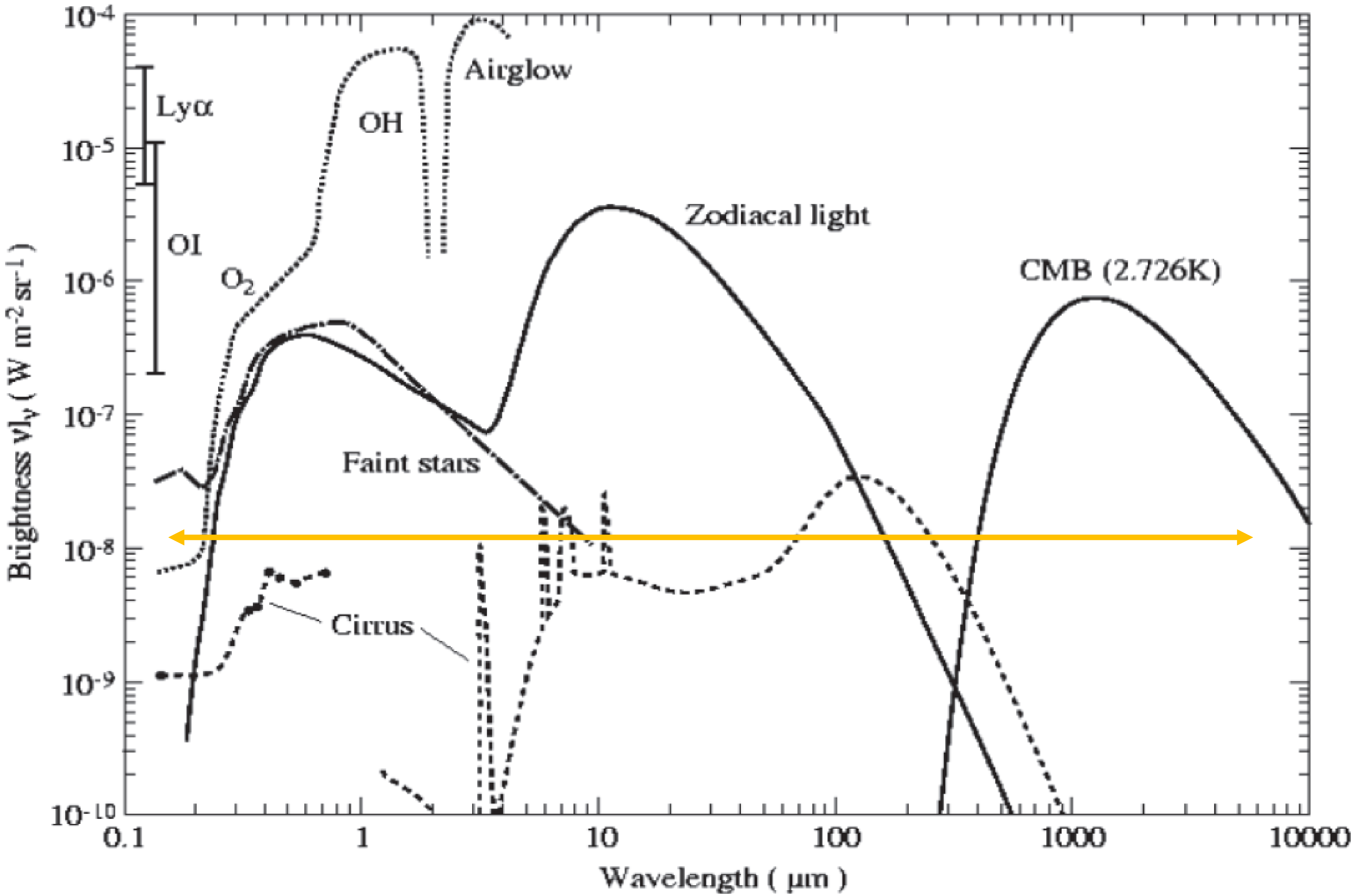
  -- Gravitational accretion (in galaxy nuclei – Active Galactic Nuclei)

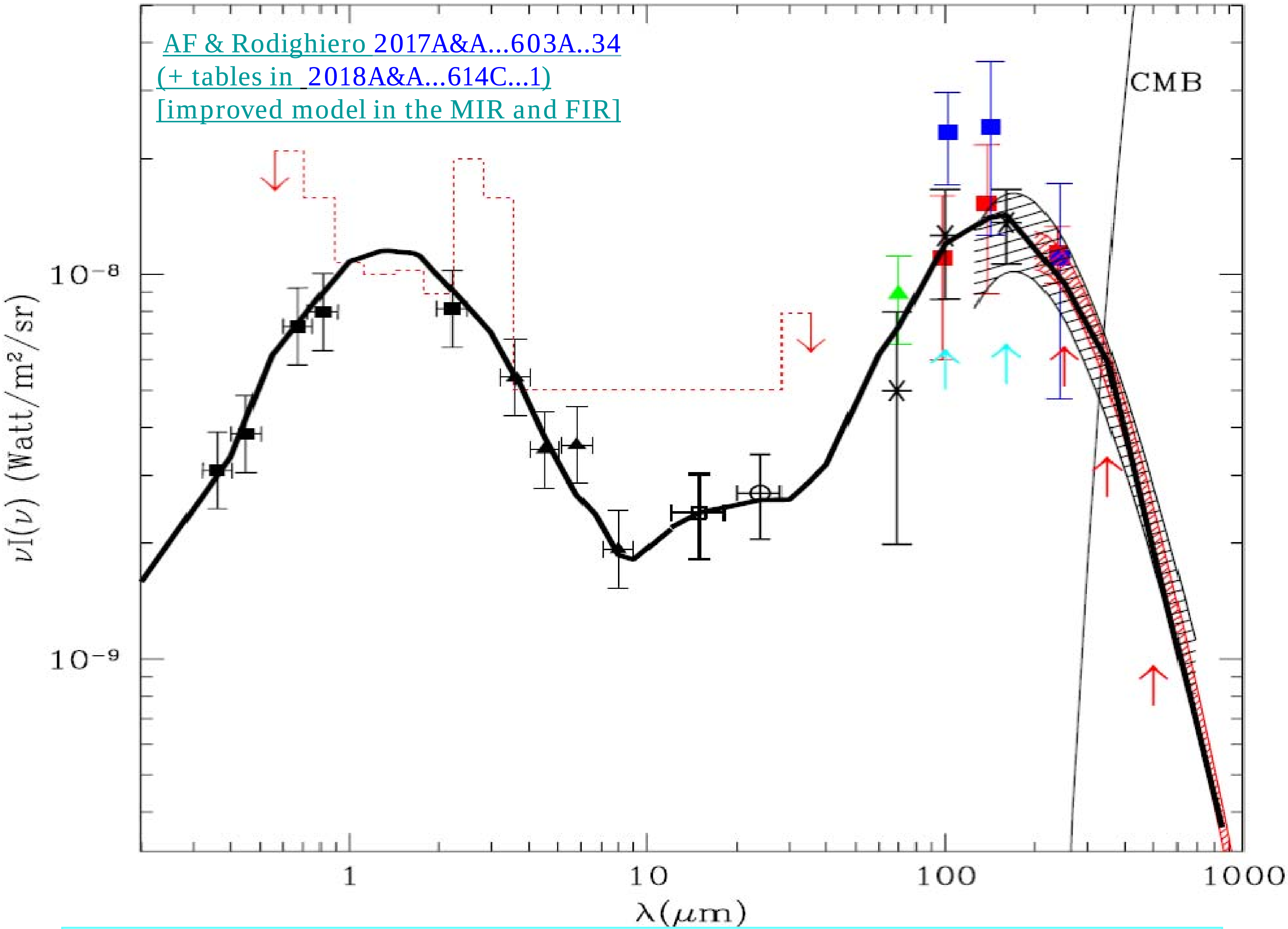
  -- Decaying particles (generated in the early phases of cosmic expansion - still speculative)



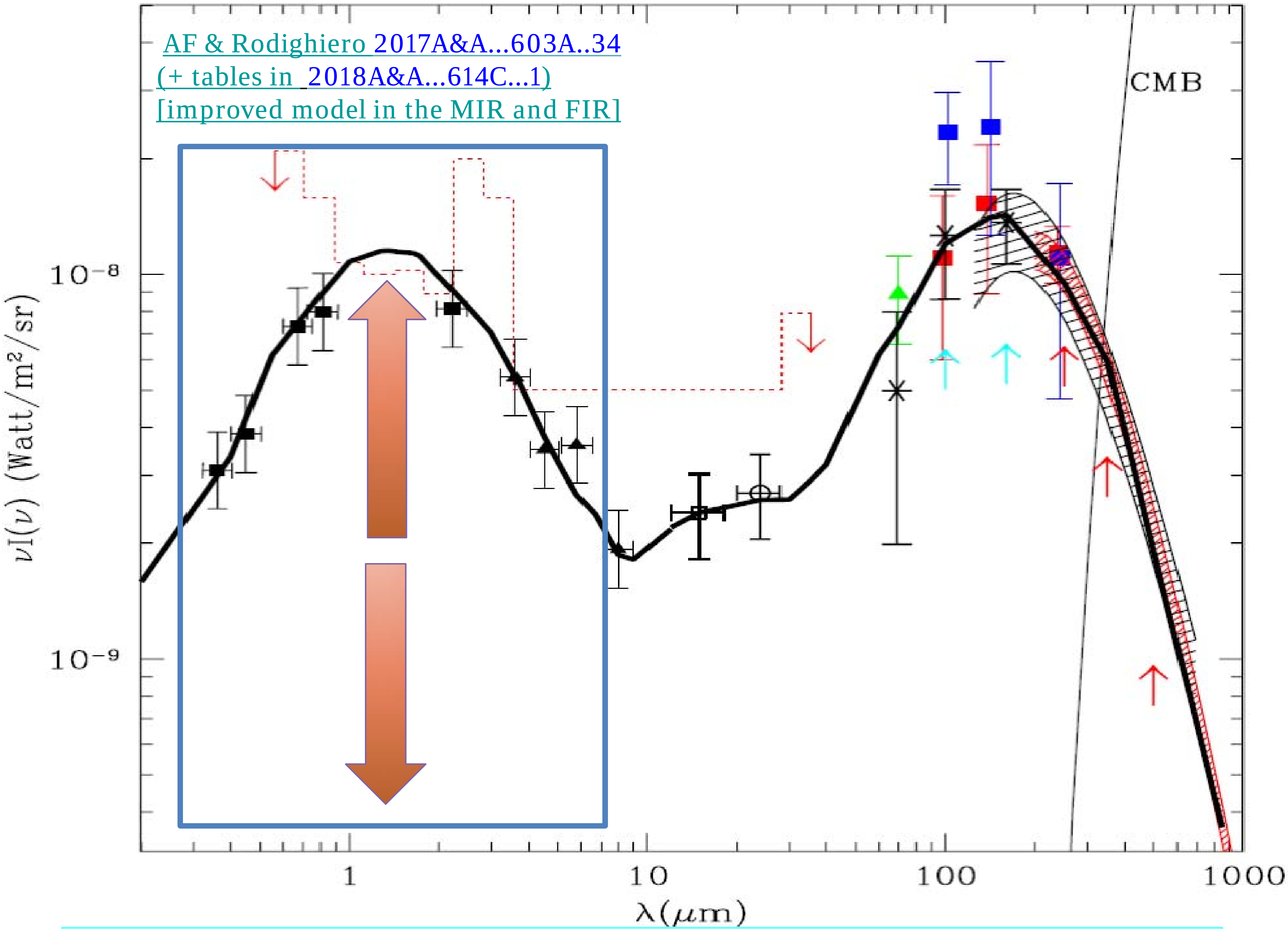

# The Global Background Radiation & the EBL

## Overview of the various components of the total night sky background at high galactic and ecliptic latitudes

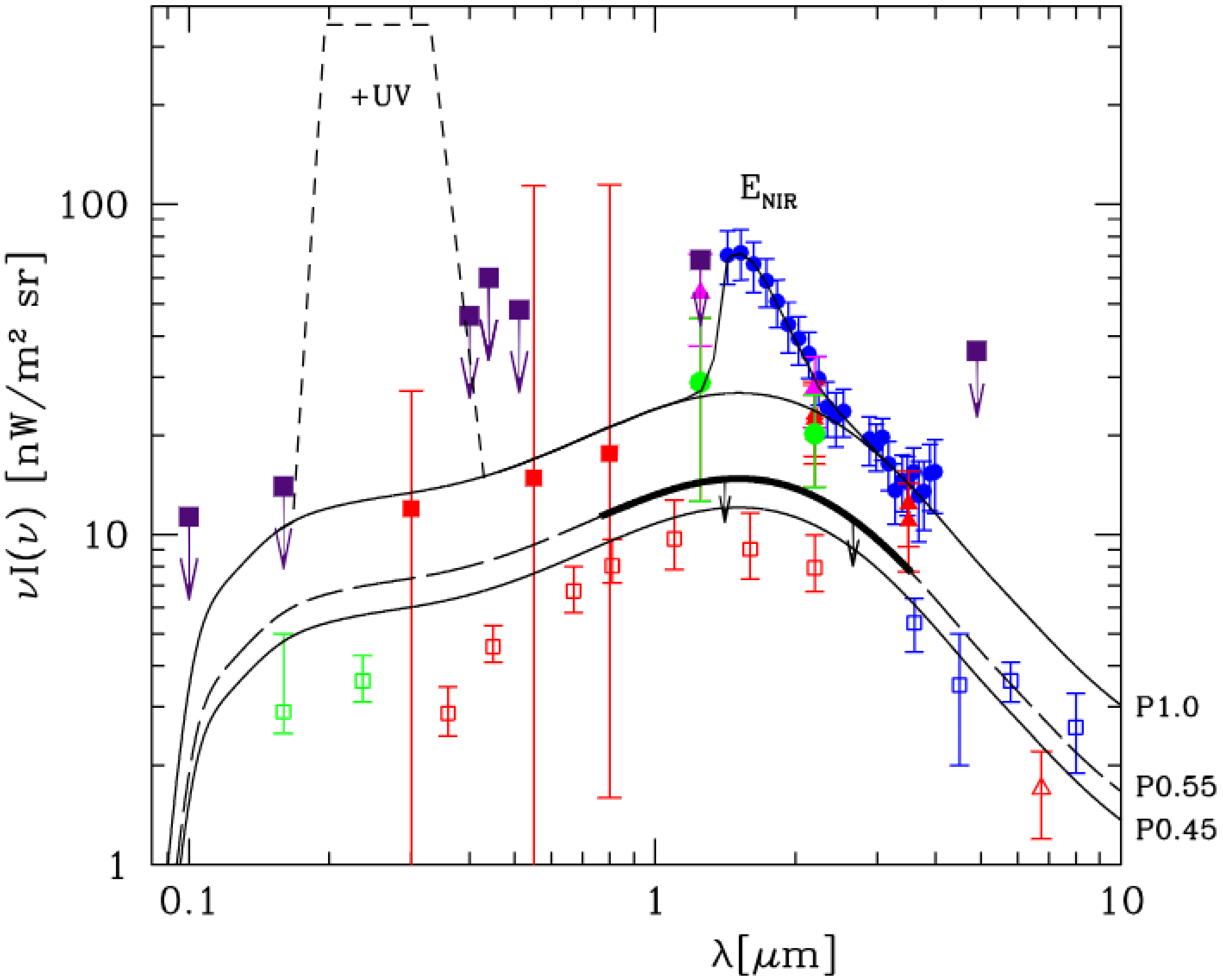




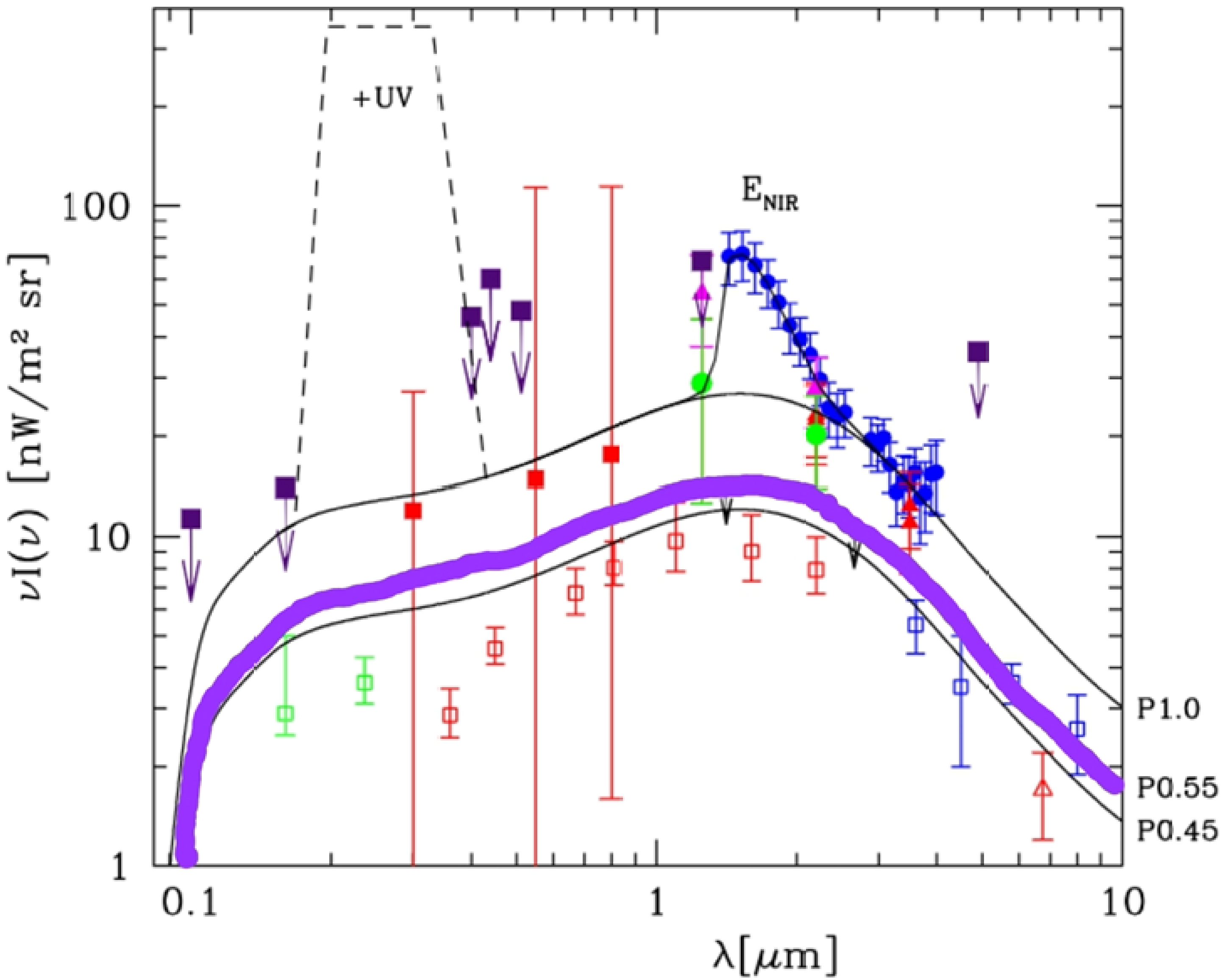

# Current view of the local EBL




# Current view of the local EBL




Aharonian et al., Nature, 2006 (based on H.E.S.S. data)

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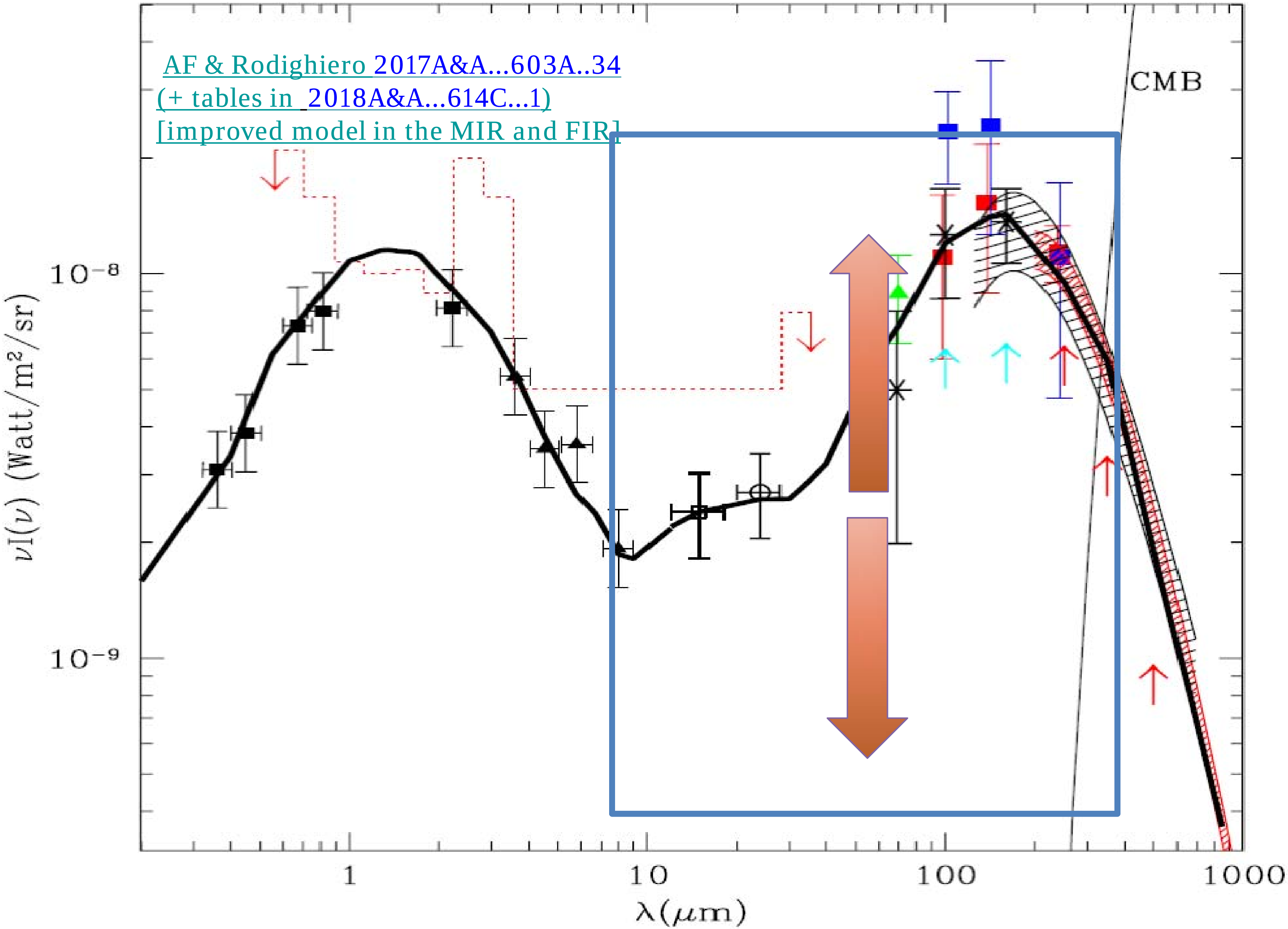


AF & Rodighiero 2017A&A...603A..34
(+ tables in 2018A&A...614C...1)
[improved model in the MIR and FIR]
CMB
$\nu I(\nu)$ (Watt/m²/sr)
$10^{-8}$
$10^{-9}$
1
10
100
1000
$\lambda(\mu m)$


Our target

# Dealing with the highest energy photons and their γ-γ interactions

- Constraining the EBL at long IR wavelengths via γ-γ opacity measurements not an easy task: going to long λ → high γ energies → strong opacity

- Requires to observe *VHE AGNs* at the highest VHE photon energies:

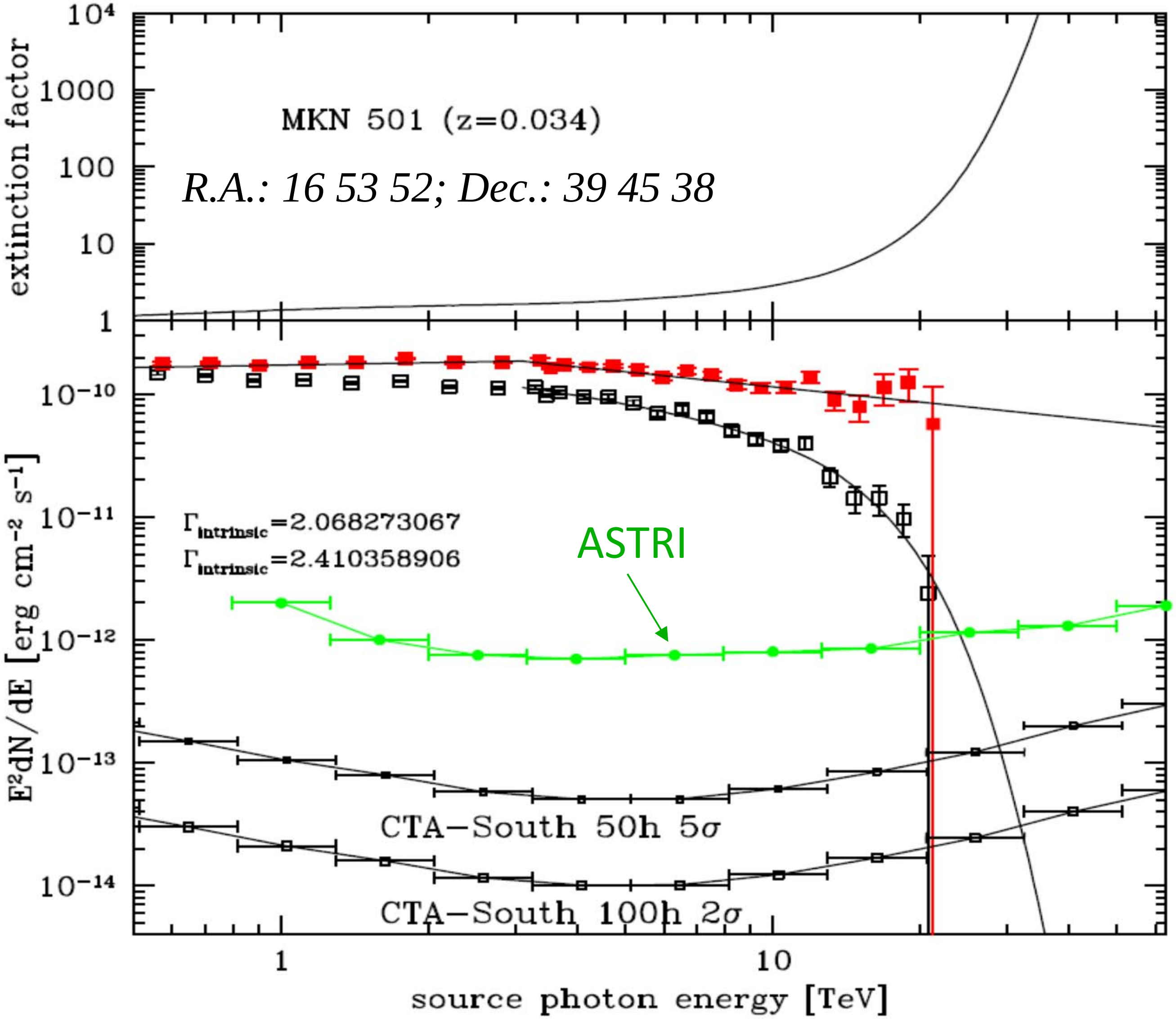
$$\lambda_{\max} \simeq 1.24 \times \varepsilon_{TeV} \ [\mu m]$$

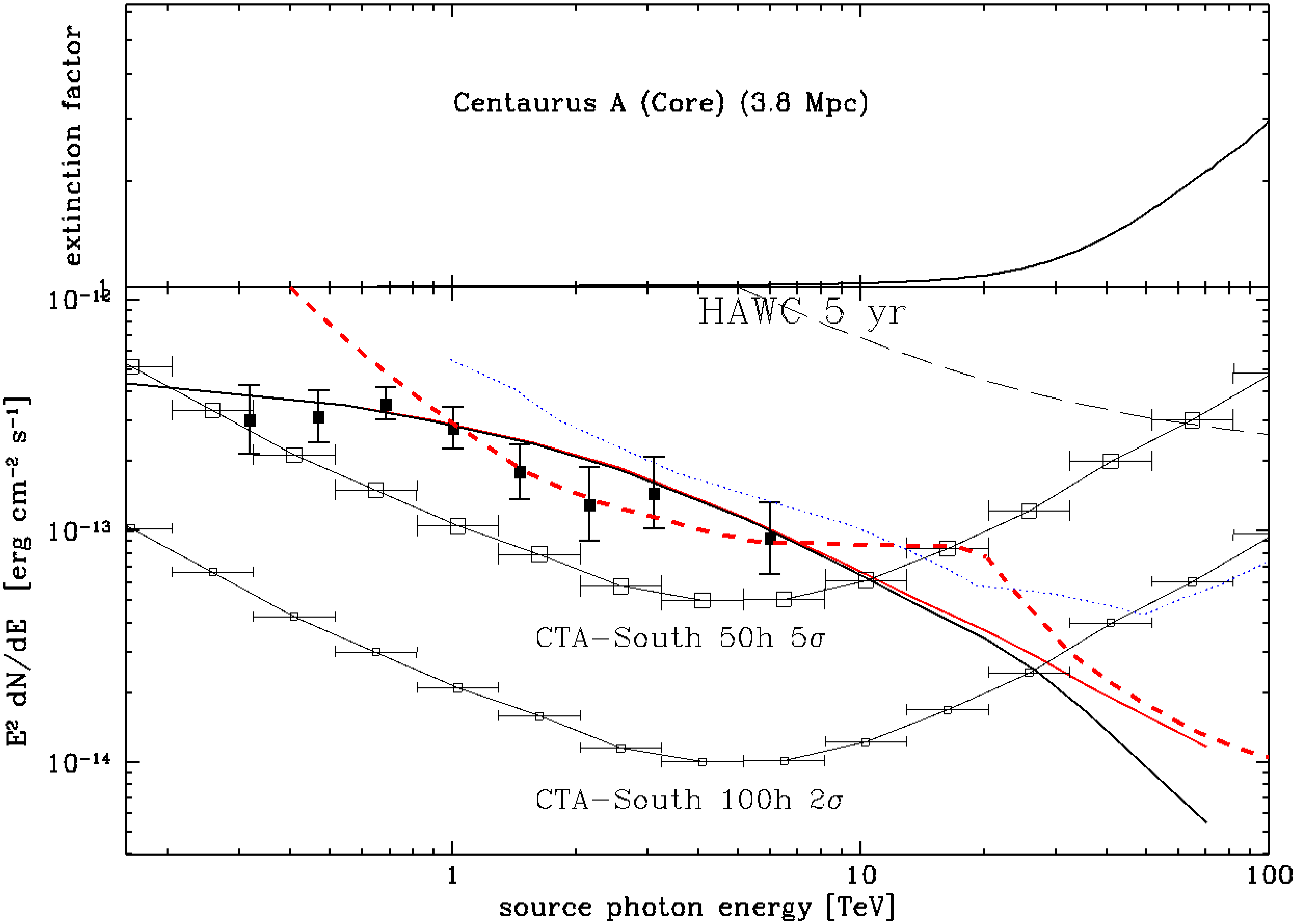
- → observations of the lowest redshift, most nearby, *VHE AGNs*

# Most promising local AGN

- Markarian 501
- Centaurus A core (too faint for CTA? but well suited for LHAASO)
- M 87
- IC 310
- NGC 4278 (VHE detection by LHAASO)
- NGC 1275
- + low-z starbursts

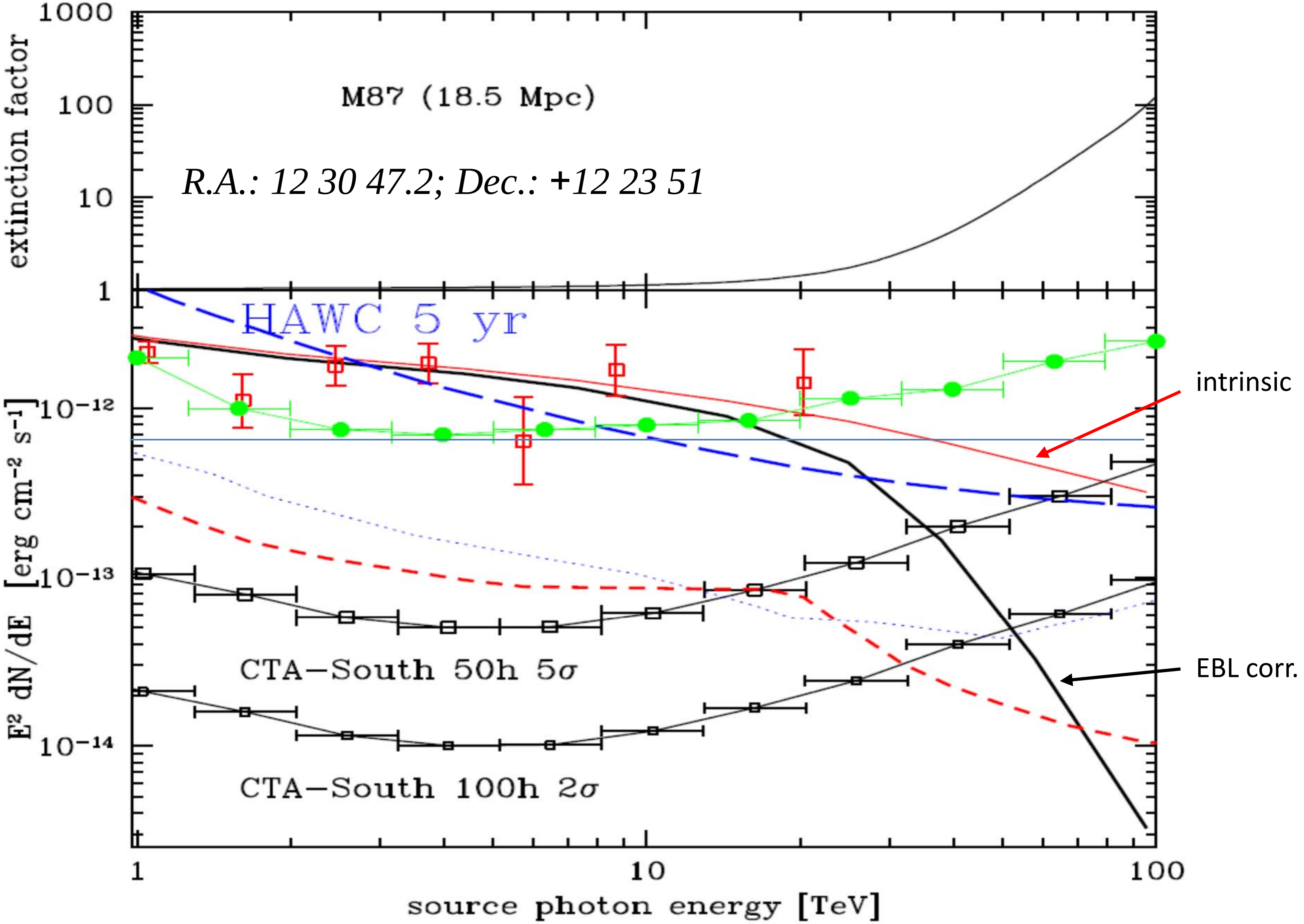
# Mkn 501 during famous 1997 outburst



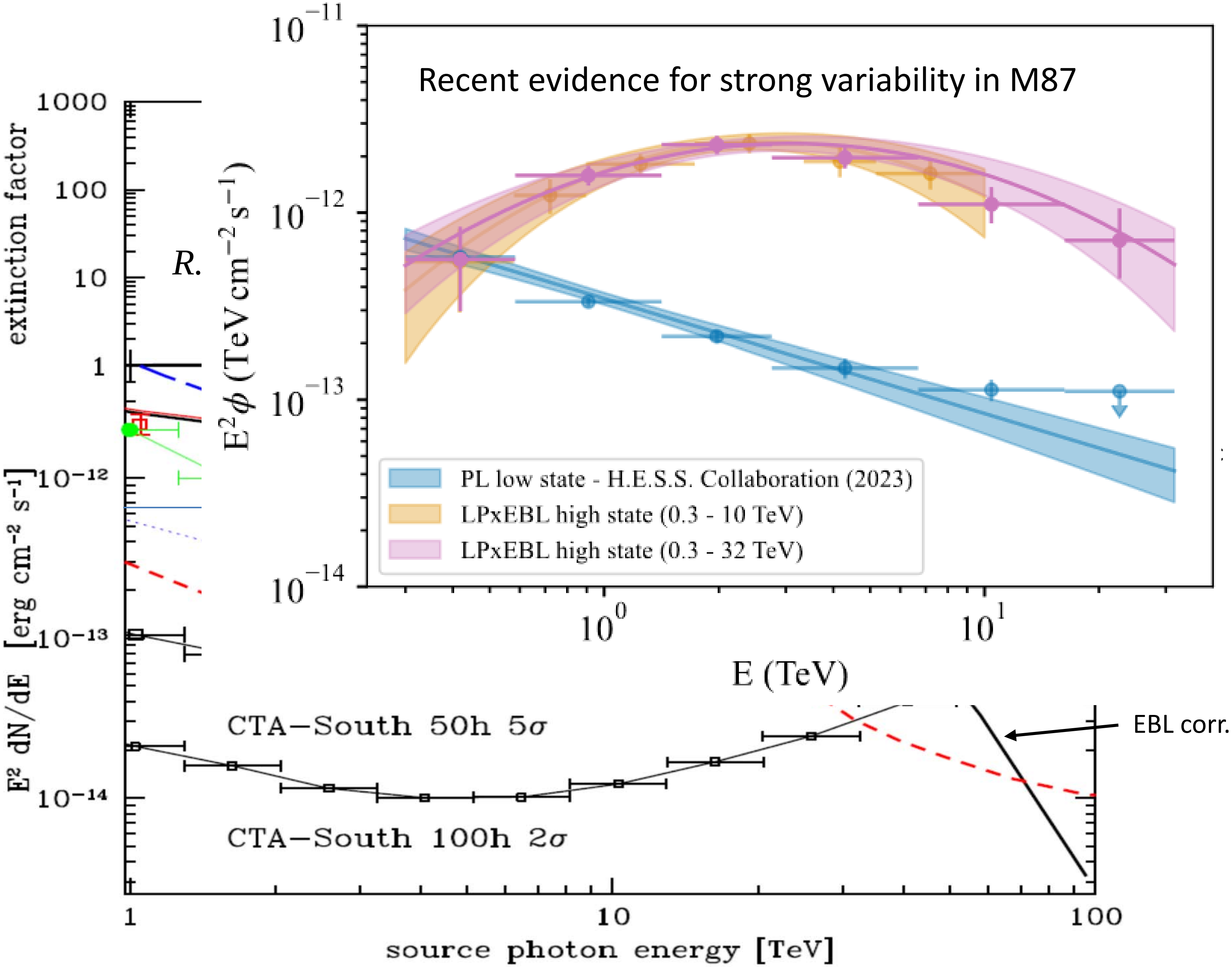


extinction factor
Centaurus A (Core) (3.8 Mpc)
1
HAWC 5 yr
$10^{-12}$
$10^{-13}$
$10^{-14}$
E² dN/dE [erg cm⁻² s⁻¹]
CTA-South 50h 5σ
CTA-South 100h 2σ
1
10
100
source photon energy [TeV]

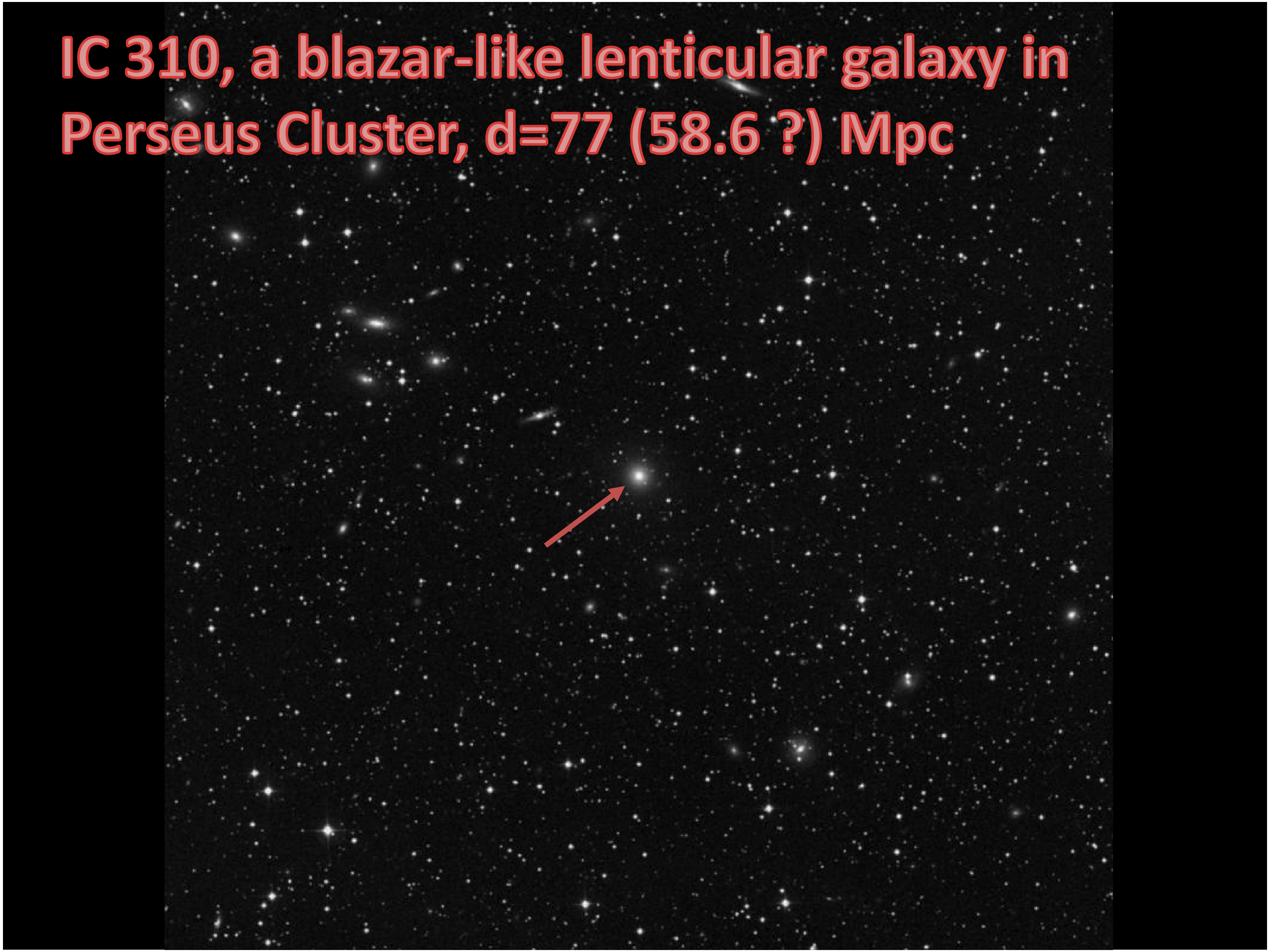
# M87: closeby source, better suited to CTA (and LHAASO!)



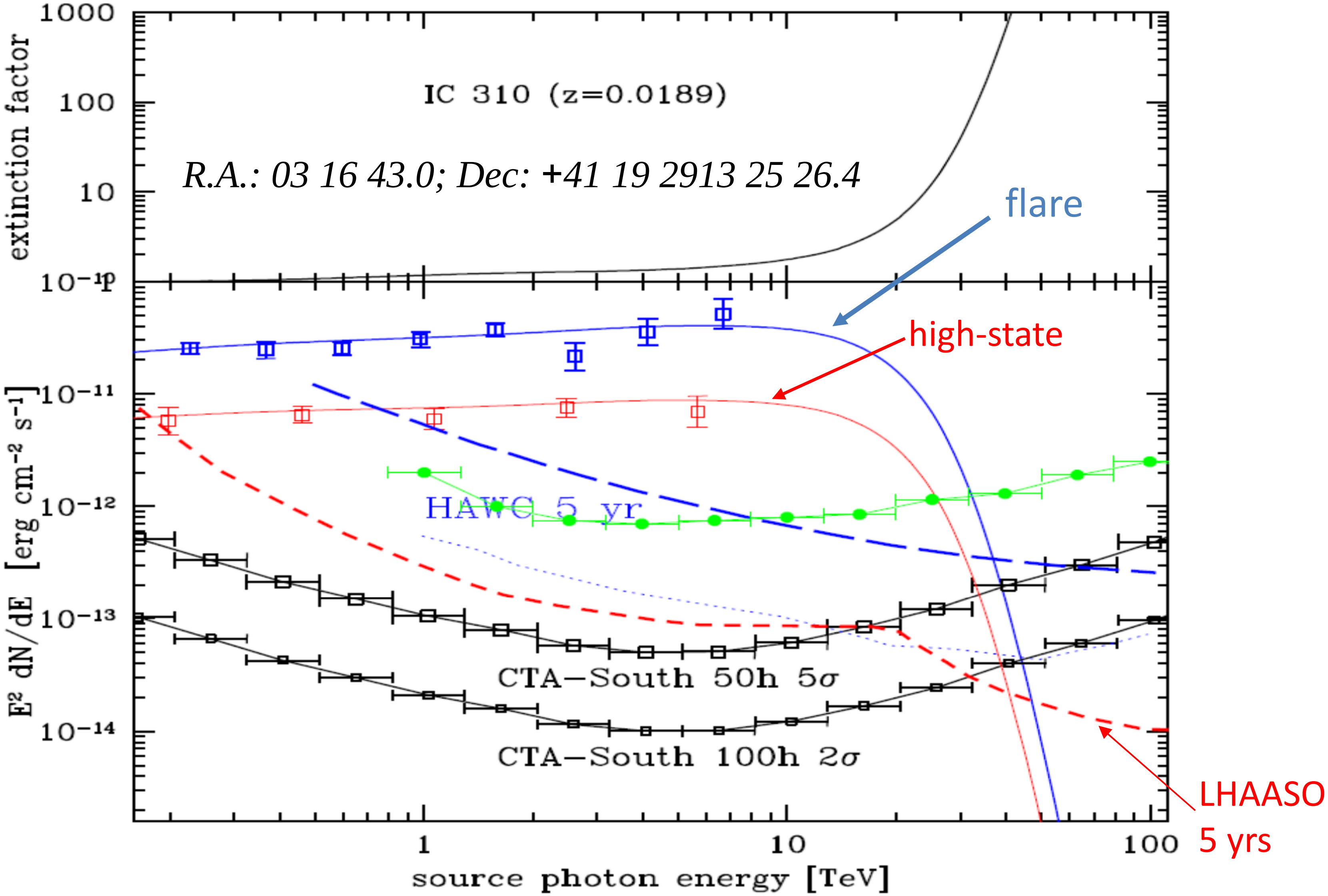
# M87: closeby source, better suited to



# IC 310, a blazar-like lenticular galaxy in Perseus Cluster, d=77 (58.6 ?) Mpc



# IC 310 showing strong variability and a months-long high-state in 2009-10



# LHAASO detection of renewed TeV activity from the radio galaxy IC 310

ATel #16540; ***Guangman Xiang (SHAO, IHEP), Min Zha (IHEP), Zhiguo Yao (IHEP), Jianeng Zhou (SHAO) and Yi Xing (SHAO) report on behalf of the LHAASO Collaboration***
*on* ***20 Mar 2024; 03:23 UT***
*Credential Certification: Jianeng Zhou (zjn@shao.ac.cn)*

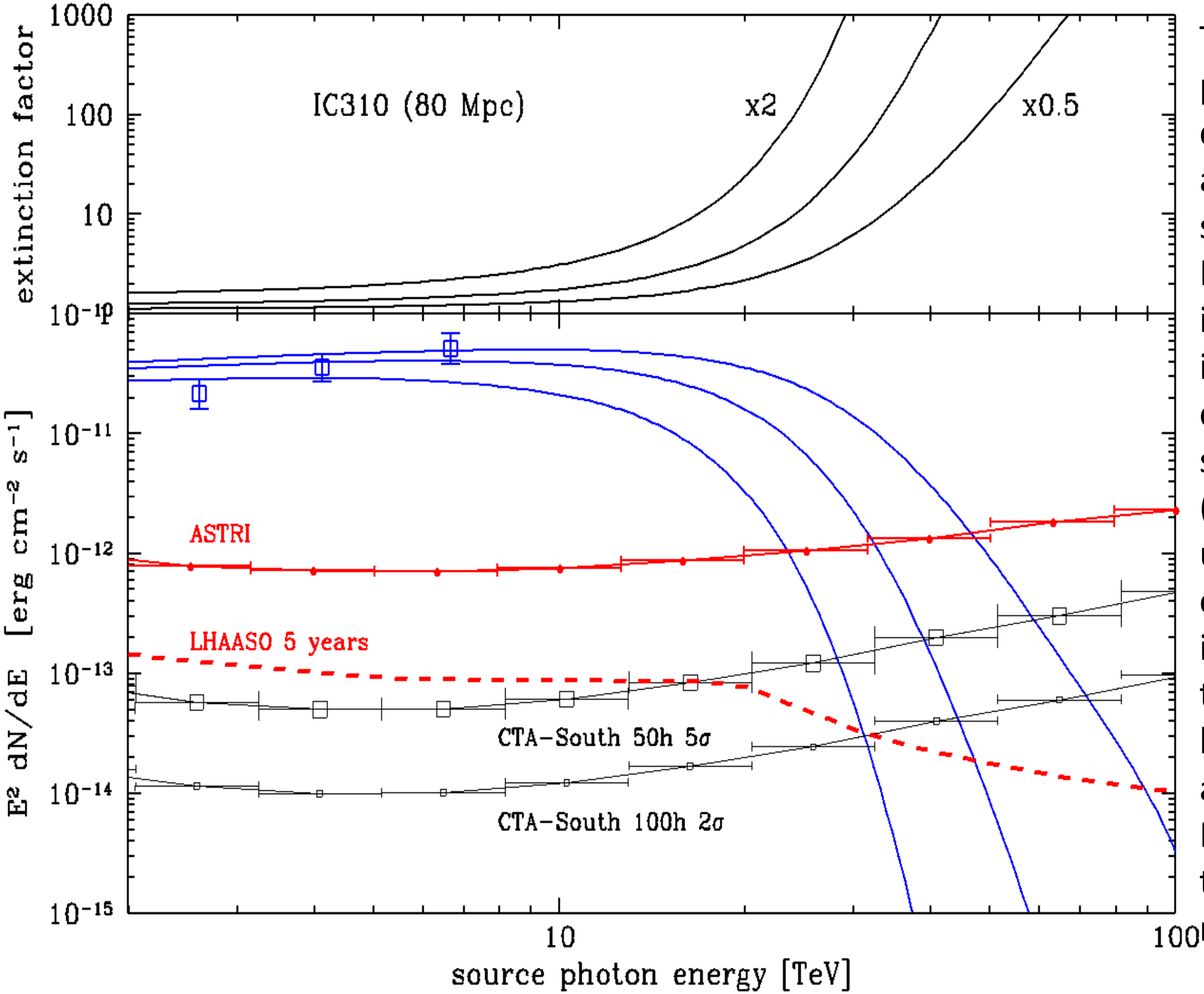
Subjects: Gamma Ray, TeV, VHE, AGN, Transient

Post

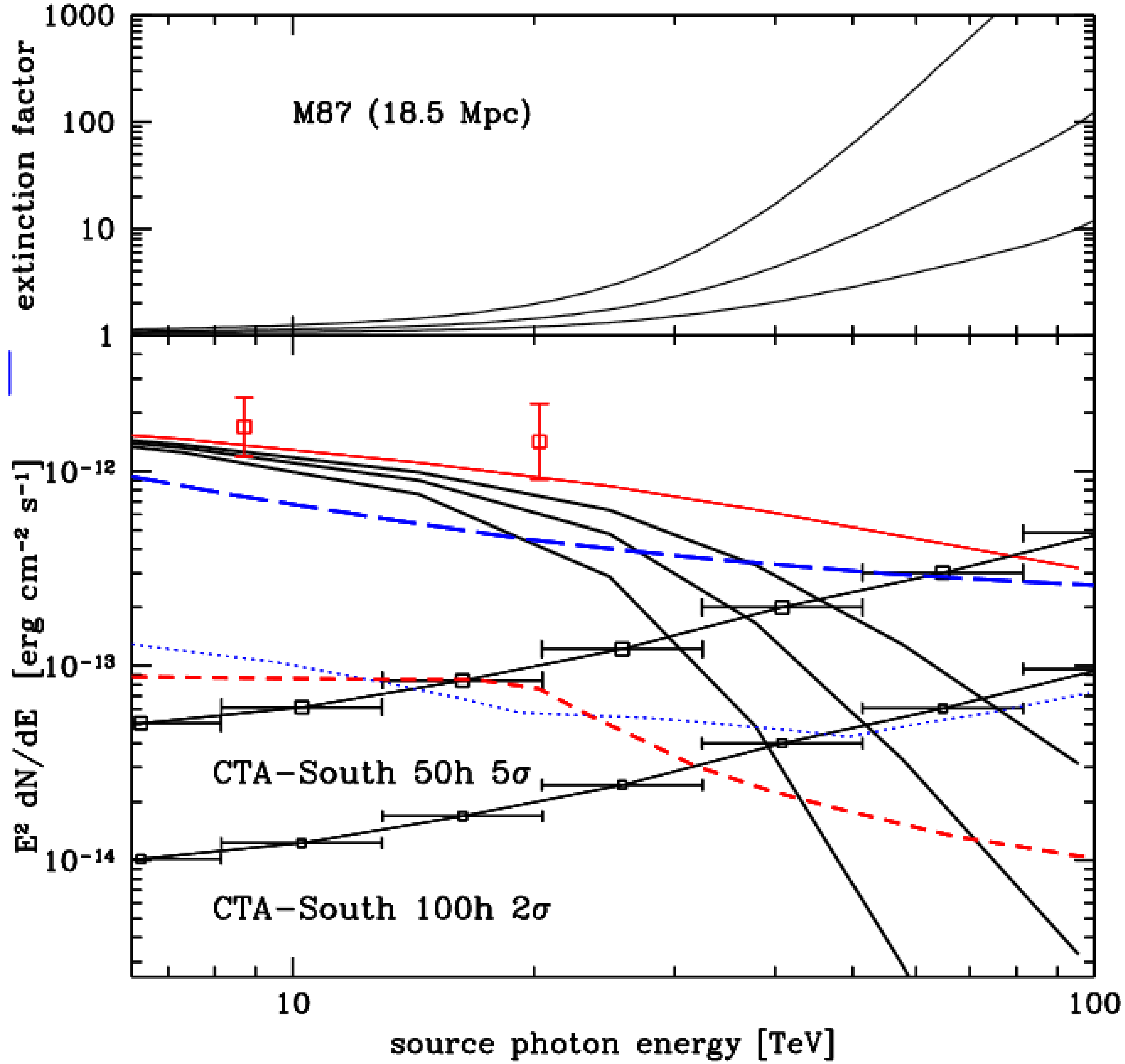
Utilizing the LHAASO-WCDA real-time alert system, we report the detection of renewed TeV gamma-ray activity from the galaxy IC 310. LHAASO-WCDA observed a gamma-ray flux enhancement from IC 310 initiated at MJD 60388.20. By MJD 60388.54, the accumulated significance reached 7.65 standard deviations, with a flux of approximately 1.3 Crab Unit above 1 TeV. The TeV gamma-ray activity had been alerted by LHAASO (ATel #16513) in March 6, 2024, VERITAS performed follow-up observations between March 10-13, 2024 (ATel #16535). We strongly encourage multi-band observation. LHAASO is a multi-purpose Extensive Air Shower (EAS) array designed to detect air showers induced by gamma-rays and cosmic rays across a wide energy range, spanning from sub-TeV to beyond 1 PeV.

!

# Simulation for x2 variation in IR-EBL




Top: Photon–photon absorption correction to be applied to the IC310 spectrum for three IR EBL adopted intensities. The intermediate curve corresponds to standard EBL (FR2017), and the upper and lower curves to IR EBL intensities a factor two higher and lower between 10 and 100 μm. Bottom: spectra for the three IR EBL models.

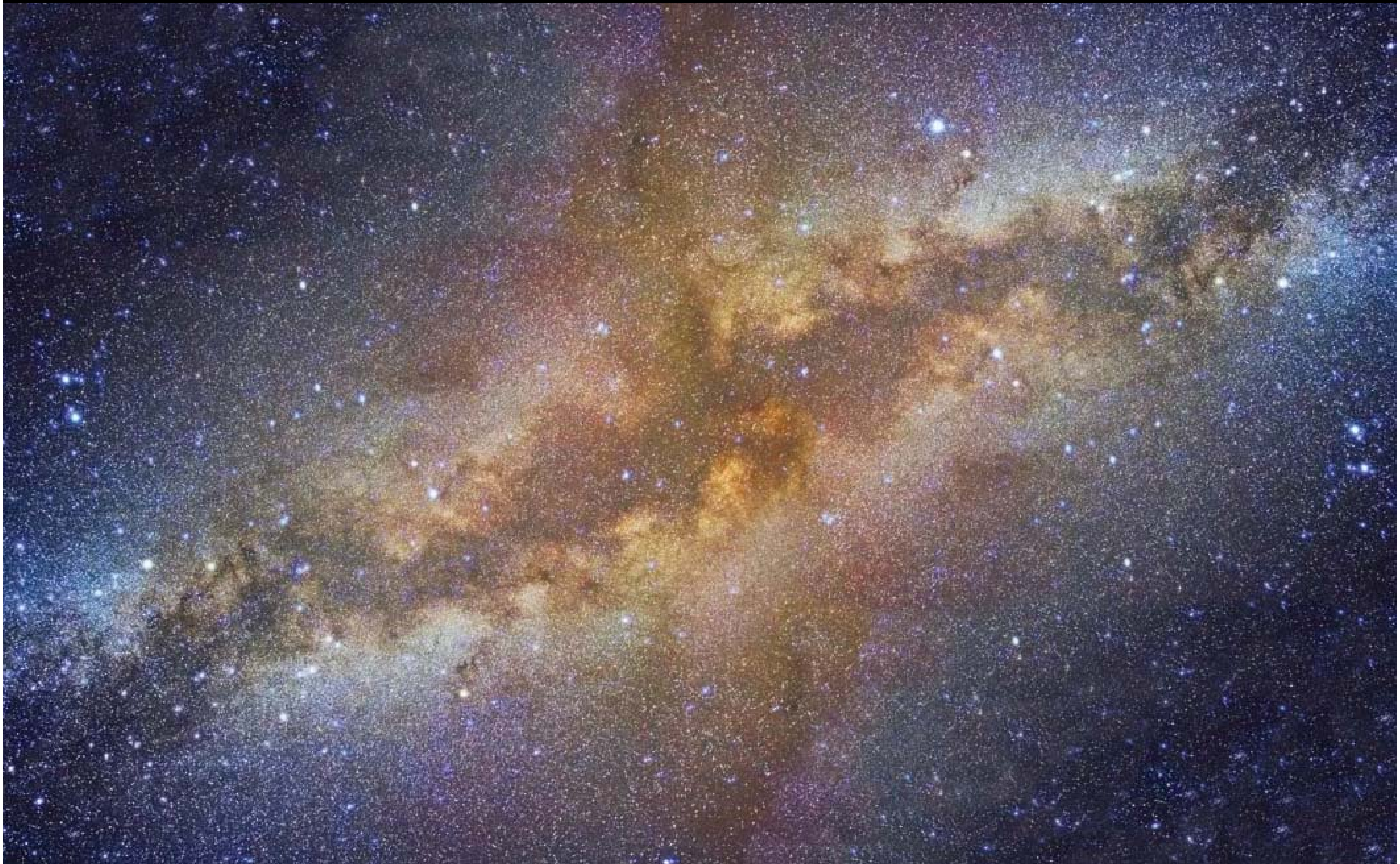



Top: Photon–photon absorption correction to be applied to the M87 spectrum for three IR EBL adopted intensities. The intermediate curve corresponds to the FR2017, and the upper and lower curves to IR EBL intensities a factor two higher and lower between 10 and 100 μm. Bottom: spectra for the three IR EBL models. The 50-hour 5σ and 100-hour 2σ sensitivity limits for CTA, and the HAWC and LHAASO five-year 5σ limits are also indicated.

# The problem of the Local Photonic Foregrounds for low-z VHE sources

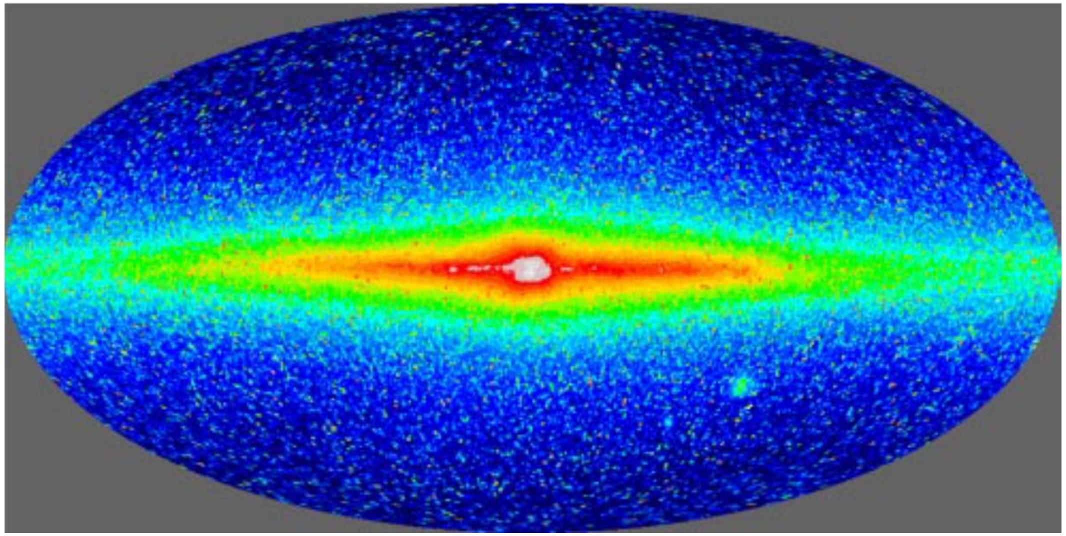
- Rich variety of foregrounds from the Milky Way
- Foregrounds from the local structure, like the hosting galaxy clusters
- Local radiation fields in the source itself (e.g. host galaxy)

# Photons from the Milky Way



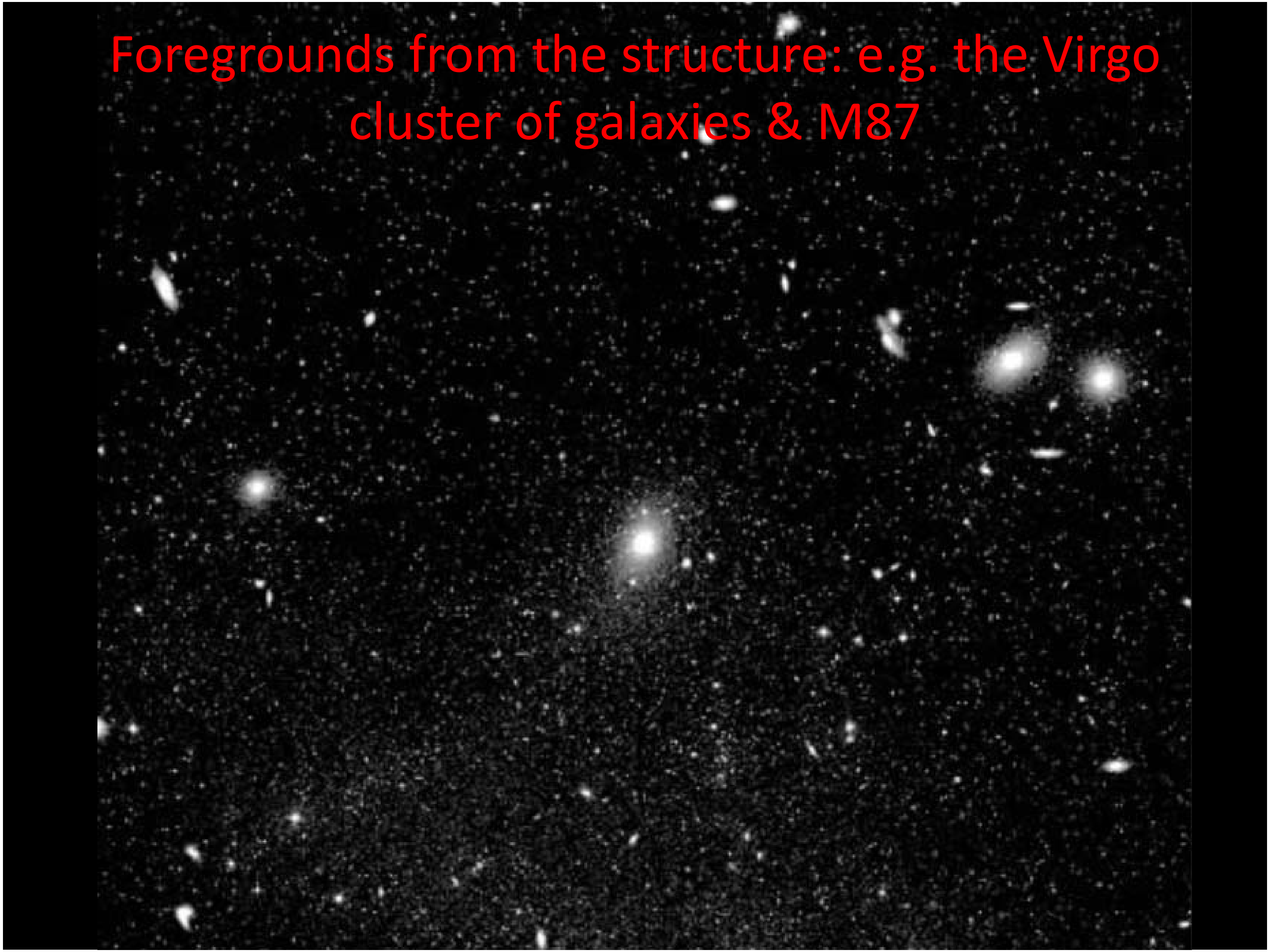
# Galactic spectral intensity data taken from Leinert et al. Astron. Astrophys. Suppl. Ser. 127, 1-99 (1998)

- Including integrated emissions from stars (bright & faint)



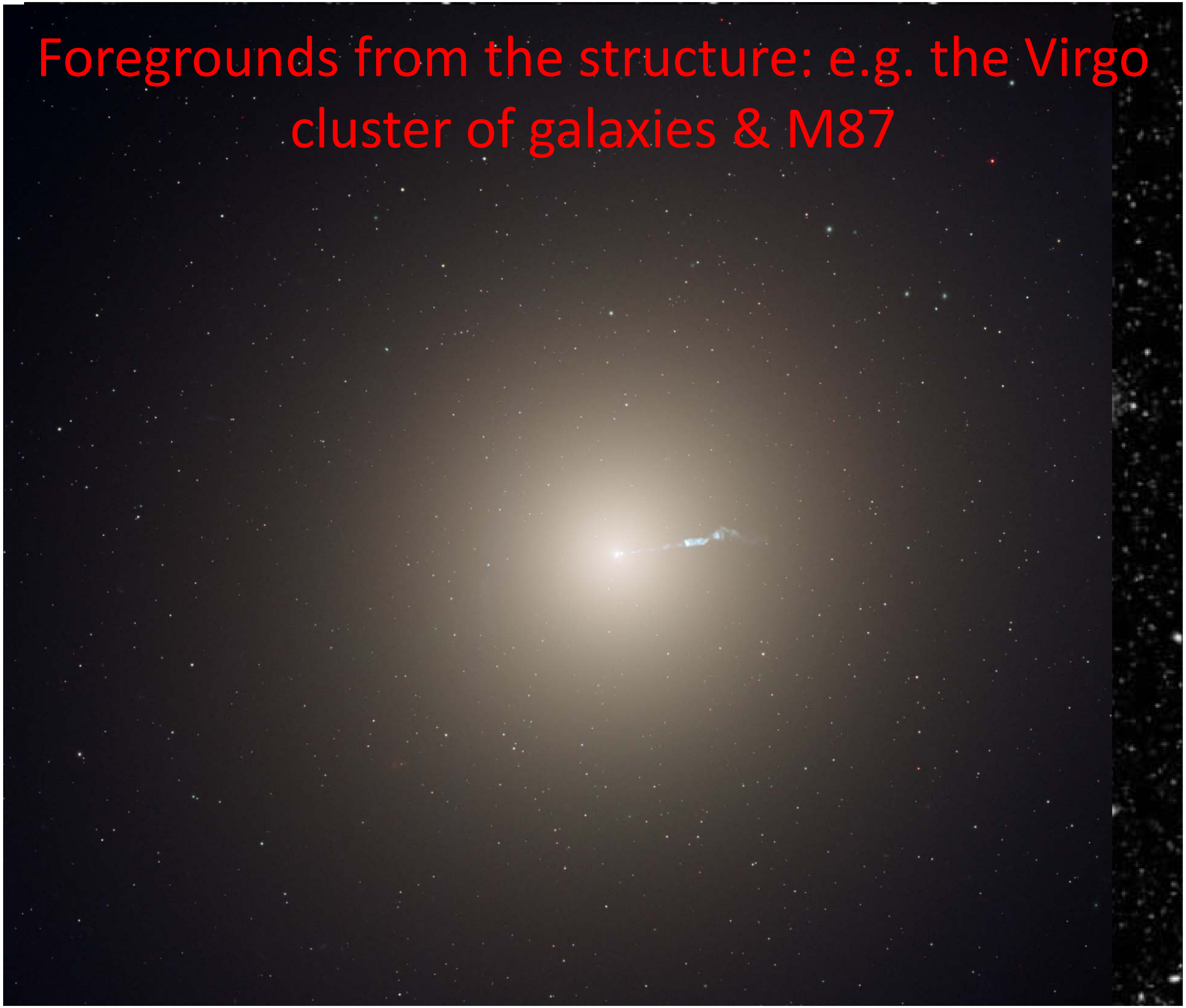
- Dust cirrus emission at high latitude all over the IR spectral region.

# Foregrounds from the structure: e.g. the Virgo cluster of galaxies & M87



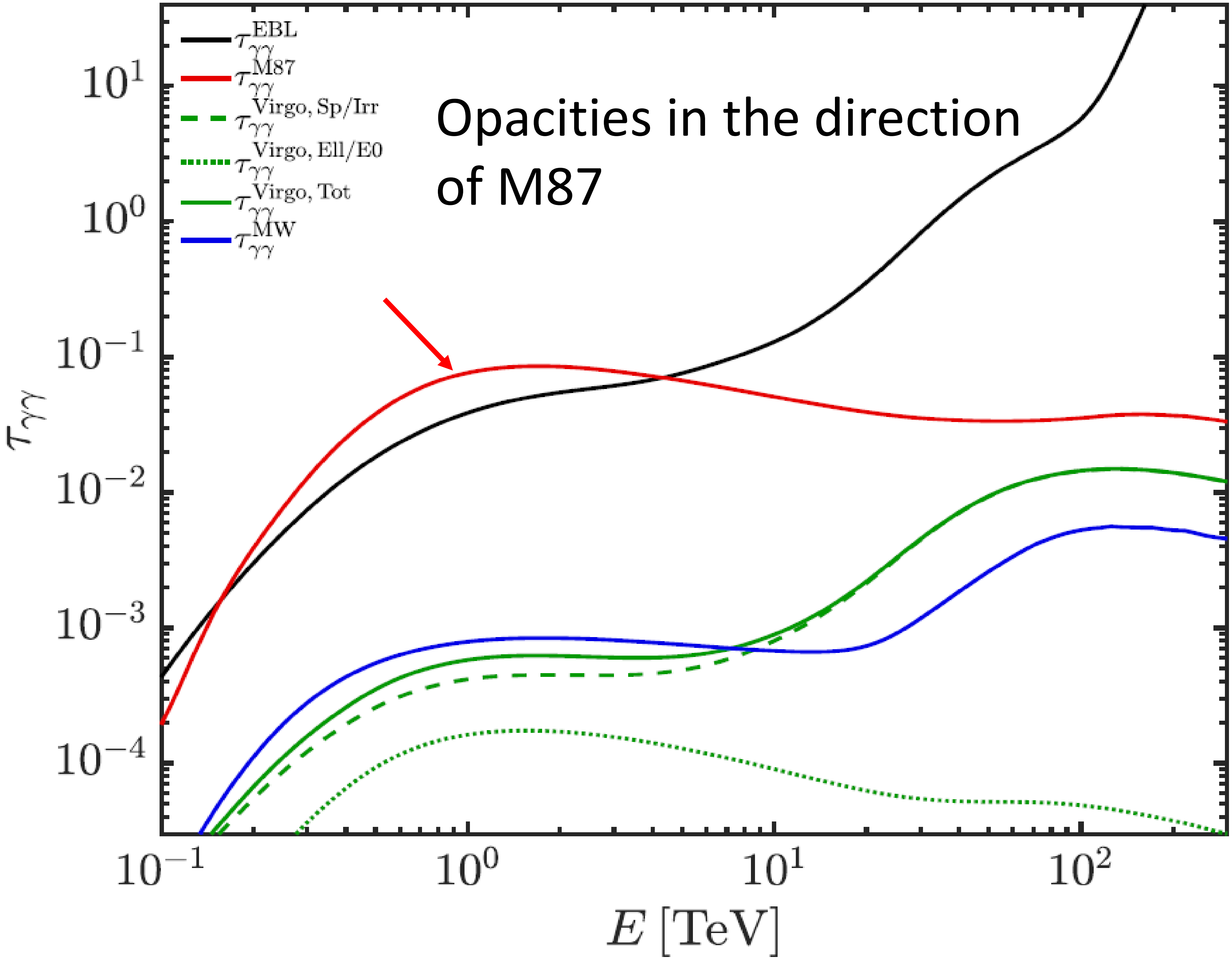
# Foregrounds from the structure: e.g. the Virgo cluster of galaxies & M87

# Foregrounds from the structure: e.g. the Virgo cluster of galaxies & M87

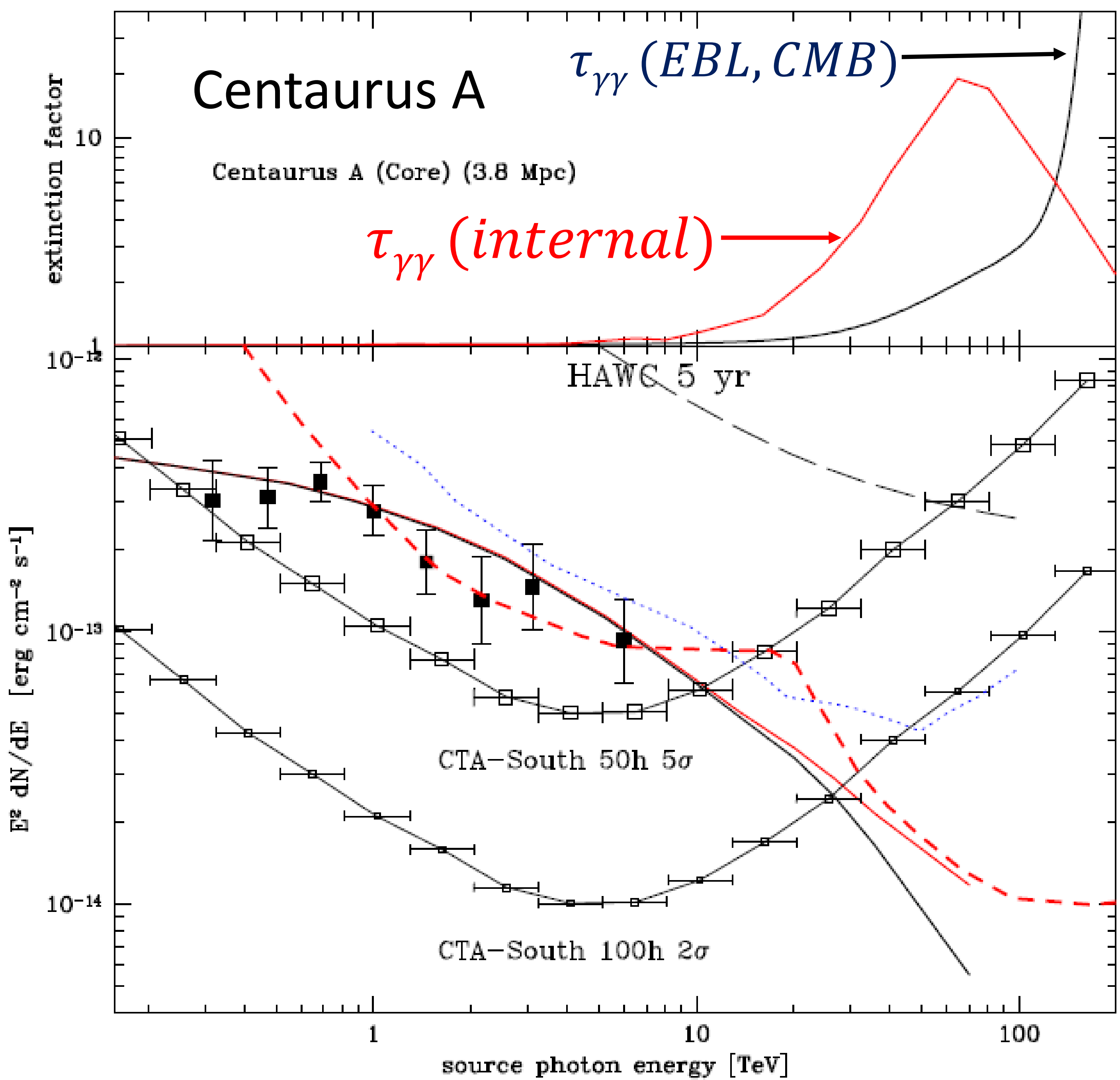


- Foreground radiations from the Virgo cluster:
  - We adopted the Extended Virgo Cluster Catalogue (Suk Kim et al 2014) to integrate the contributions of early-type (E/S0) and late-type (Sp/Ir) galaxies, + correction for diffure IntraCluster Light, and calculate $\tau_{\gamma\gamma}$

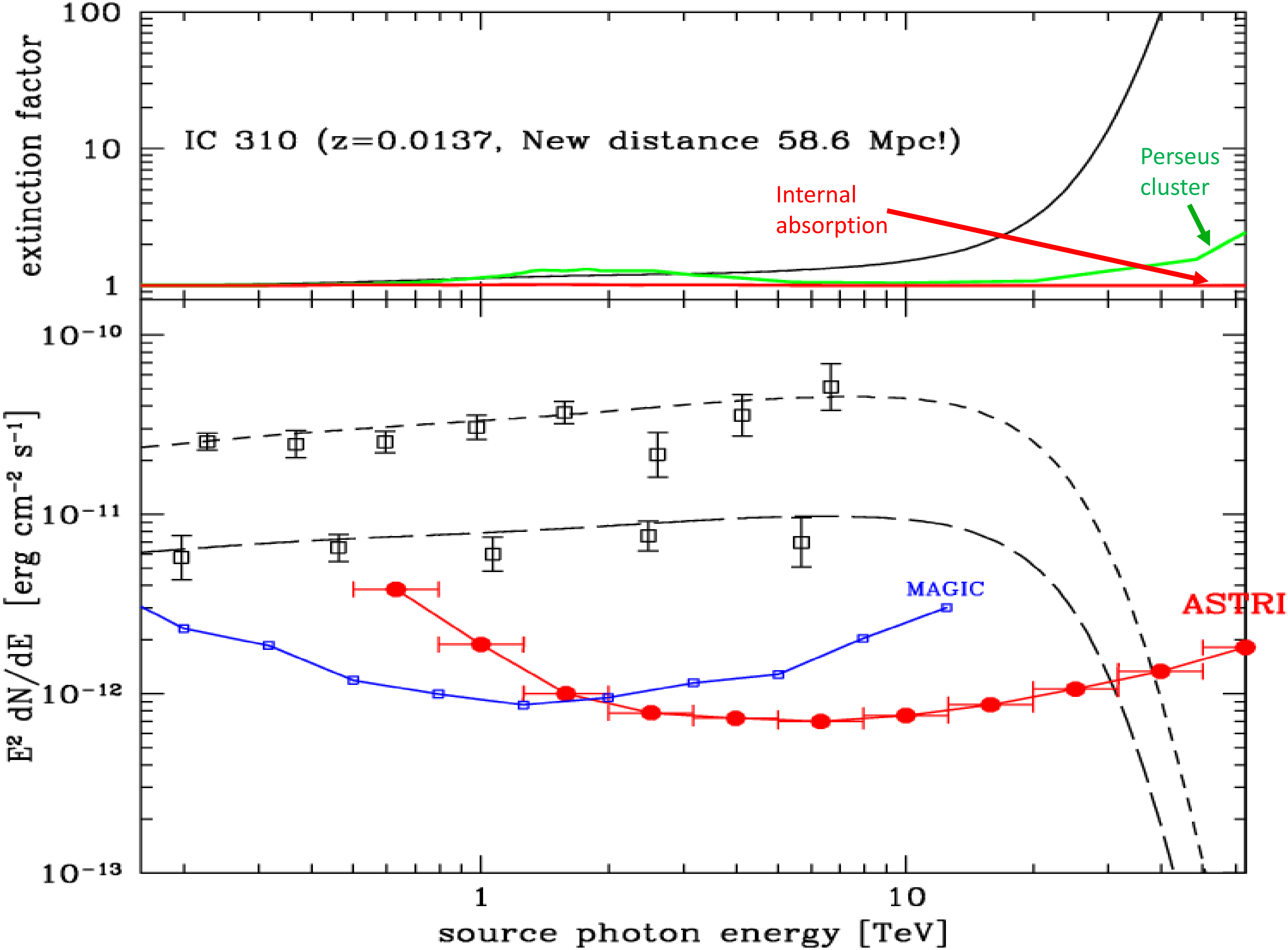
- For the internal emissions in the M87 halo:
  - We considered data on the surface brigthness distribution from the core out to external halo (100 kpc!) in the R band (Ying Liu et al AJ 129, 2005).
  - We have then used the integrated photometry from UV to the sub-mm (NASA/IPAC Extragalactic Database NED) to apply spectral corrections to the photon number density, and calculate $\tau_{\gamma\gamma}$



$\tau_{\gamma\gamma}^{\mathrm{EBL}}$
$\tau_{\gamma\gamma}^{\mathrm{M87}}$
$\tau_{\gamma\gamma}^{\mathrm{Virgo,\,Sp/Irr}}$
$\tau_{\gamma\gamma}^{\mathrm{Virgo,\,Ell/E0}}$
$\tau_{\gamma\gamma}^{\mathrm{Virgo,\,Tot}}$
$\tau_{\gamma\gamma}^{\mathrm{MW}}$
Opacities in the direction of M87
$\tau_{\gamma\gamma}$
$10^{1}$
$10^{0}$
$10^{-1}$
$10^{-2}$
$10^{-3}$
$10^{-4}$
$10^{-1}$
$10^{0}$
$10^{1}$
$10^{2}$
$E$ [TeV]

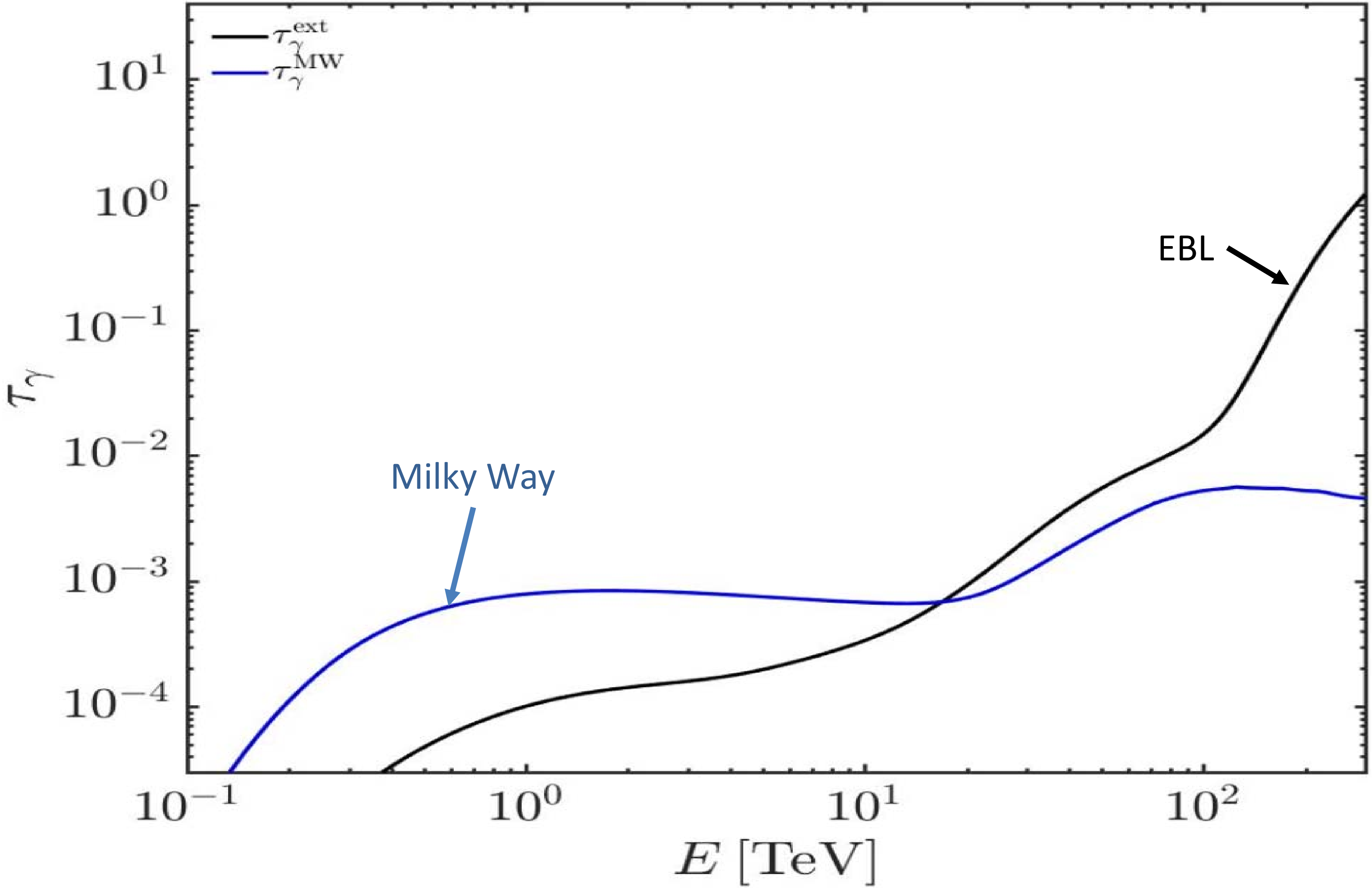


Centaurus A
$\tau_{\gamma\gamma}\,(EBL, CMB)$
$\tau_{\gamma\gamma}\,(internal)$
Centaurus A (Core) (3.8 Mpc)
extinction factor
10
1
HAWC 5 yr
CTA−South 50h 5σ
CTA−South 100h 2σ
E² dN/dE [erg cm⁻² s⁻¹]
$10^{-12}$
$10^{-13}$
$10^{-14}$
1
10
100
source photon energy [TeV]



100
10
1
extinction factor
IC 310 (z=0.0137, New distance 58.6 Mpc!)
Internal absorption
Perseus cluster
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^{-13}$
$E^2$ dN/dE [erg $cm^{-2}$ $s^{-1}$]
MAGIC
ASTRI
1
10
source photon energy [TeV]

# Absorption effects for VHE sources in LMC



# Conclusions

- Closeby extragalactic sources, like M87 and IC310 among others, offer best chances of both long baseline distances and access to VHE photons, to test:
  - non-standard fundamental physics (ALPs, LIV)
  - constraints on the IR extragalactic background IR-EBL.

- However, important effects are to be considered, and correct for, by the various local foreground radiations.