Constraints on Extragalactic Background Light from Cherenkov telescopes: status and perspectives for the next 5 years

Daniel Mazin\textsuperscript{1}

and

Martin Raue\textsuperscript{2}

\textsuperscript{1}: IFAE, Barcelona

\textsuperscript{2}: MPIK, Heidelberg

This research of D.M. is supported by a Marie Curie Intra European Fellowship within the 7th European Community Framework Programme.
Contents

• Extragalactic Background Light
• Blazars
• H.E.S.S. limits on EBL
• Overall limits on EBL (until 2007)
• MAGIC limits on EBL (2008)
• Wrong AGN assumptions or just low EBL?
• Future perspectives (Fermi and CTA)
Extragalactic Background Light
Spectral Energy Distribution of the EBL

- Unique imprint of the history of the universe
- Test of star formation and galaxy evolution models
- Cosmological evolution models have to explain current EBL
- Opacity source of GeV-TeV photons
EBL: status of the measurements

• Direct measurements are difficult
• Lower limits from source counts and stacking
• Upper limits from fluctuation analyses and direct

Probing EBL with VHE γ-rays

XLIVth Rencontres de Moriond
AGN emission passes through EBL

- Direct measurements of the EBL in UV to IR are difficult (foregrounds)
- Imprint of the EBL density and shape in the measured GeV-TeV spectra
- GeV-TeV spectra can be used to test EBL density under certain assumptions about the intrinsic GeV-TeV spectra

\[ \lambda_{\text{max}} = 1.24 \mu\text{m}(E/\text{TeV}) \]
Blazars
Active Galactic Nuclei, TeV blazars

- Factories of violent, broad band (up to high energy) non-thermal radiation
- Blazars: relativistic plasma jet, highly variable
- TeV blazars (above 100 GeV): 18 out of 24 are HBL (High-peaked BL Lacertae)
- Models: leptonic vs. hadronic origin

![Diagram of AGN](image)

**leptonic acceleration**
- $e^{-} (\text{TeV})$
- Synchrotron $\gamma (\text{eV-keV})$
- $\gamma (\text{eV})$ Inverse Compton

**hadronic acceleration**
- $p^{+} (\gg \text{TeV})$
- Matter
- $\pi^{+}$ $\gamma\gamma (\text{TeV})$

Probing EBL with VHE $\gamma$-rays

XLIV$^{th}$ Rencontres de Moriond
AGNs, TeV blazars, leptonic models

- Leptonic models favored due to:
  - X-ray/TeV correlation found in some objects (Mkn501, Mkn421)
  - Fast flaring: down to minutes!
- We still do not know:
  - Variability scales
  - Other correlations
- Open questions:
  - Origin of $\gamma$-rays
  - Physical conditions in the jet
  - Reason for the variability
- No wonder: only 6 known VHE blazars in 2004

Self-Synchrotron-Compton (SSC)
- Free parameters: electron spectrum, electron density, magnetic field, Doppler factor, size of the region

Probing EBL with VHE $\gamma$-rays

XLIV$^{th}$ Rencontres de Moriond
EBL constraints
Previous problems

- A: TeV crisis (pile-up at high energies)
- B: Too hard spectra (spectral index < 1.5)
HESS results: 1ES1101-232 and H2356

Probing EBL with VHE γ-rays
EBL model independent constraints (2007)


![Graph showing UV flux (\(\nu \lambda\)) in nW m\(^{-2}\) sr\(^{-1}\) versus wavelength (\(\lambda\) in \(\mu m\)) with two scans: extreme scan (\(\Gamma < 2/3\)) and realistic scan (\(\Gamma < 1.5\)).
Probing new range of the EBL

**Green line**: model of Kneiske et al., tuned to the 3C 279 spectrum using the $\Gamma=1.5$ criterion

Albert et al., Science (2008) 320, 1752
Taking into account internal absorption

- BLR: spherical shell of thickness \( \Delta R \), negligible disk radiation
- Latest CLOUDY code, which includes not only lines but also continuum emission
- Moderate change of the VHE MAGIC spectrum
- No change of the EBL limits

With realistic Broad Line Regions and Disk re-emission: no change in the EBL limits

Probing EBL with VHE \( \gamma \)-rays

XLIV\textsuperscript{th} Rencontres de Moriond
EBL constraints from VHE $\gamma$-rays

- Upper limits using VHE spectra + assumptions about AGN physics
- Recent constraints are already very tight
- HESS II, MAGIC II and Fermi will remove these uncertainties
- Constraints above 10$\mu$m rely on a single measurement of Mkn 501 done by HEGRA in 1997: need more!

References:
- Aharonian et al, Nature 440
- Mazin&Raue, AA 471
- Aharonian et al., AA 475
- Albert et al., Science 320
Only narrow band left between galaxy counts and the IACT constraints.
Population III stars


- used the recent EBL limits to derive constraints on the PopIII stars
- account for the time evolution of the emissivity of a stellar population
- results:
  - Zero metallicity stars: peak SFR of 0.6 - 3 M_☉ / year (for z = 7 - 14)
  - Low metallicity stars: peak SFR of 0.3 - 1.5 M_☉ / year (for z = 7 - 14)
Open issues and solutions

The EBL limits are (very) good, but:

- Hardness of the VHE spectrum depends on:
  - Emission mechanism (hadronic or leptonic)
  - Details on acceleration and cooling
  - Target photon fields
  - Environment of low energy radiation fields, which can absorb VHE $\gamma$-rays (e.g. Aharonian et al. 07, Liu et al. 08, Sitarek & Bednarek 08, Tavecchio & Mazin 09):
    - Are these radiation fields there?
    - Are VHE $\gamma$-rays emitted behind these fields?

- More complicated: intrinsic absorption is redshift dependent and can/will mimic the EBL evolution (A. Reimer 07)
- Energetics of VHE $\gamma$-ray emitters: low EBL preferred
- Need sources at different redshifts with well measured SED, from radio to TeV. Especially in the Fermi energy range (100 MeV - 100 GeV), where no or very little EBL absorption is expected
Future perspectives:
Fermi
IACTs
CTA
Goal 1: EBL evolution

- Star and galaxy evolution is largely unknown
- Fermi (CTA) can measure blazar spectra up to redshift $z \sim 1$ ($z \sim 2$)
- Such sources are behind the main star formation epoch ➞ beacons
- Using sources with $z<1$, the EBL evolution can be resolved!
- Need >100 sources
- Need to know intrinsic evolution of the sources (BH masses, internal radiation fields, see A. Reimer 07)

Madau, 1998
Goal 2: EBL at Mid- and Far-Infrared

- EBL in mid- and far-infrared are crucial for understanding star and galaxy formation:
  - How much dust?
  - What is dust contents?
  - How many galaxy populations?
- No direct measurement in the near future
- CTA (high energy array!!) is the only experiment to test Mid + Far-Infrared
- Need a few sources (e.g. Mrk 501, PKS2155-304, H1426+428)

COBE data (Hauser & Dwek, 2001)
Goal 3: distance = Hubble parameter

- If one knows
  - Intrinsic AGN spectrum and
  - EBL density
- determine distance to the sources using the EBL signature in the measured spectra
- Can cover range from $z=0.004$ to $z > 1$

Based on Blanch & Martinez, 2001
Goal 3: distance = Hubble parameter

Based on Blanch & Martinez, 2001

- Determination of cosmological parameters
- Independent method
- Required precision: 5-10% \((\text{in } dz/z)\)
- High potential to determine evolution of Hubble parameter
- need >100 sources
- There are already some simplistic attempts to constrain \(H_0\): Barrau et al. 08, Bi & Yuan 08

Probing EBL with VHE \(\gamma\)-rays
• Assuming toy sensitivity for the CTA project
• Generate synthetic AGN spectra
• Check the power of the CTA to distinguish between different EBL models (left) and $H_0$ parameters (right)
Conclusions

- EBL carries essential cosmological information
- VHE spectra put strong limits on the EBL density, suggesting an EBL on the level of galaxy counts
- In the next 5 years:
  - H.E.S.S. II, MAGIC II and VERITAS will provide 10-20 more AGNs with well measured spectra.
  - Fermi will measure 100s of AGNs in 100MeV - 50GeV range;
  - With common sources one can resolve the hard spectra issue
- In the next 10 years CTA will
  - disentangle AGN physics from propagation effects
  - provide beacons behind the main galaxy formation epoch (z>1)
  - measure Mid and Far-infrared EBL
  - independent distance measurements
  → cosmology, Hubble parameter
EBL: all stars

Probing EBL with VHE $\gamma$-rays

XLIV$^{th}$ Rencontres de Moriond
3C279 (z=0.536): the most distant VHE $\gamma$-ray source

2006 February: MAGIC measures clear signal from the quasar 3C 279 at energies 80 - 300 GeV. Albert et al., Science (2008) 320, 1752
CTA: toy MC

- Assuming toy sensitivity for the CTA project
- Generate synthetic AGN spectra
- Check the power of the CTA to distinguish between different EBL models (left) and $H_0$ parameters (right)

CTA: source at $z = 0.212$; flux level = 0.2 crab units; 20 h live time

**Work in progress**

Probing EBL with VHE $\gamma$-rays

XLIV$^{\text{th}}$ Rencontres de Moriond
CTA: toy MC

- Assuming toy sensitivity for the CTA project
- Generate synthetic AGN spectra
- Check the power of the CTA to distinguish between different EBL models (left) and $H_0$ parameters (right)

Probing EBL with VHE $\gamma$-rays