TeV BLAZAR Observations, Background Radiations & the Cosmic Photon-Photon Opacity
Summary

- Diffuse backgrounds in the optical & infrared
  - Attempts to measure it, and difficulties
  - Origin of the radiations, the discrete-source contribution
- Radiations in the optical, UV and near-IR
- Radiations in the mid- and far-IR
- Modelling the background radiation and its evolution with cosmic time
- Computation of photon-photon opacity for any-z sources
- A few illustrative applications and first considerations
The Global Background Radiation

\[ \gamma + \gamma \rightarrow e^+ + e^- \]

\[ \lambda_{\text{max}} \approx 1.24(E_\gamma [\text{TeV}]) \mu\text{m} \]
Can we measure the Extragalactic Background Light in the optical?

Foreground emission sources in the optical, upper limits on the EBL, and lower limits based on the integrated flux from resolved galaxies (V555 > 23 AB mag) in the HDF (Williams et al. 1996). The spectral shape and mean flux of zodiacal light and of diffuse galactic light (DGL) are shown. The effective bandpasses for our HST observations are indicated.
"A critical discussion is presented of the data analysis applied by Bernstein, Freedman, & Madore (2002a,b) in their measurement of the Extragalactic Background Light. **There are questionable assumptions in the analysis of the ground-based observations of the Zodiacal Light.** The modeling of the Diffuse Galactic Light is based on an underestimated value of the dust column density along the line of sight. Comparison with the previously presented results from the same observations reveals a puzzling situation: in spite of a large difference in the atmospheric scattered light corrections the derived Extragalactic Background Light values are exactly the same. **Then the claim of the paper of a “detection of the Extragalactic Background Light” appears premature.**

Bernstein R., 2007ApJ...666, 663:

“We revise the measurements in our previous work of foreground zodiacal light (ZL) and diffuse Galactic light (DGL) that were used to measure the extragalactic background light (EBL). These changes result in a decrease of 8 and an increase of 5 in units of ergs s$^{-1}$ cm$^{-2}$ sr$^{-1}$ Å$^{-1}$ (“cgs” units) in the ZL and DGL flux, respectively. We therefore obtain revised values for the EBL of 0.07, 0.04, and 0.01 cgs in the HST WFPC2 $U$ (F300W), $V$ (F555W), and $I$ (F814W) bands, respectively, from sources fainter than 22 AB mag.”

No optical background detection, only an upper limit!
Plot of the NIRBE flux from Matsumoto et al. (2005) shown as asterisks. The squares are object fluxes from Madau & Pozzetti (2000), the triangles are the NUDF object fluxes from Thompson et al. (2006), the plus signs are those fluxes corrected for the expected missing flux from faint galaxies and regions of galaxies and the diamonds are the quoted backgrounds from Kashlinsky (2005). The crosses with error bars are the DIRBE fluxes.
Discovery of the Cosmic Infrared Background (CIRB)

(Puget et al. 1996; Hauser et al. 1998)
CIRB measurement: a dramatic challenge

Foreground contributions in the Lockman Hole area: observed sky brightness (*open circles*), interplanetary dust (*triangles*), bright Galactic sources (*squares*), faint Galactic sources (*asterisks*), and the interstellar medium (*diamonds*). (*Solid circles*)

The residuals after removing all foregrounds from the observed brightness.

(Hauser & Dwek ARAA)
CIRB in the far-infrared

Direct measurements of CIB with COBE/DIRBE
Stacking analysis for Spitzer MIPS 24um sources
Integrated flux of galaxy counts with Spitzer & AKARI.

Only ~5% of CIRB is resolved into individual sources.
Our aim is to know what the unresolved sources are.

THE BASIC TOOL TO MEASURE THE CIRB

Boulanger et al. 1996

**Fig. 1.** Correlation between IR and HI emission at 100 $\mu$m (DIRBE data, smoothed to 7° resolution) and at 736 $\mu$m (FIRAS LLSS data, averaged between 600 and 900 $\mu$m). The lines represent fits to data at $W_{\text{HI}} < 250$ K km s$^{-1}$.
Far-IR spectrum of the Galaxy emission from COBE-FIRAS, normalized to \(10^{20}\) HI/cm\(^2\)

\(T \sim 20\) K

Summary of CIRB measurements and limits

(Dwek & Hauser ARAA)

(Puget et al. 1996)
Spheroidal Galaxies

Disk Galaxies

The Extragalactic Background in the optical resolved into sources!
Left: Differential UBV IJHK galaxy counts as a function of AB magnitudes. The sources of the data points are given in the text. Note the decrease of the logarithmic slope $d \log N/dm$ at faint magnitudes. The flattening is more pronounced at the shortest wavelengths. Right: Extragalactic background light per magnitude bin, $i = 10^{-0.4(m_{AB}+48.6)}N(m)$, as a function of U (filled circles), B (open circles), V (filled pentagons), I (open squares), J (filled triangles), H (open triangles), and K (filled squares) magnitudes. For clarity, the BV IJHK measurements have been multiplied by a factor of 2, 6, 15, 50, 150, and 600, respectively.

Madau & Pozzetti 2000
Galaxy number counts and the cosmic background emissivity

\[ I = \int_0^{S_\Delta} \frac{dN}{dS} S dS = \frac{1}{4\pi} \frac{c}{H_0} \int_{z(S_d, L_{\min})}^{z_{\max}} \frac{dz}{(1 + z)^6(1 + \Omega z)^{1/2}} j_{\text{eff}}(z) \]

\[ j_{\text{eff}}(z) = \int_{L_{\min}}^{\min[L_{\max}, L(S_d, z)]} d\log L \ L \ n_c(L, z) K(L, z) \]

\[ S_{\Delta \nu} = \frac{L_{\Delta \nu} K(L, z)}{4\pi d_L^2} \]
Great progress in the study of the star formation and assembly in galaxies by the Spitzer Space Telescope.

Spitzer's IRAC & MIPS photometric cameras
The Extragalactic Background at 3 to 10 $\mu$m resolved into sources!

IRAC Spitzer
GOODS CDFS 3.6$\mu$m image
Dickinson et al., Rodighiero et al.

$S_{3.6\mu m} > 1 \mu$Jy,
160 arcmin$^2$
Spitzer/IRAC: issues about photometry, comparison of completely different analyses of independent teams
The Extragalactic Source Number Counts at 3.6 & 2.2µm!
Spitzer provided a very accurate assessment of the 24 µm statistics... but what about SCUBA galaxies?...

Red: SWIRE data (Shupe et al., 2008)

...tricky interpretation...
The Modellistic Scheme

- The most adherent possible to the multi-wavelength data
- Basic split into the *photospheric stellar* component (0.1 – 10 μm) and the *dust-reradiation* (10 – 1000 μm) parts
- Each section identifies fundamental galaxy categories with reference to their different cosmic evolutionary properties: non-evolving spirals, spheroidal (elliptical) galaxies, fast-evolving starburst galaxies, Active Galactic Nuclei and quasars
- For all components we consider both **luminosity** and **comoving density** evolution:
  - density evolution to treat the galaxy merging and hierarchical assembly
  - luminosity evolution following the *aging stellar populations* and the evolution of the *rate of star formation* (typically much larger at $z \geq 1$ than locally)
Let us concentrate on the far-IR part, an excellent tracer of SF in (local &) distant galaxies.

Spitzer provides accurate assessment of the far-IR statistics.
We know how far-IR sources distribute locally and how they evolve in cosmic time.

The SWIRE/VVDS sample in the XMM/LSS area + GOODS-South & North.

Includes 1494 24µm sources with $S_{24}>400$ µJy, spectroscopic redshifts by VIMOS/VVDS + photo-z by Arnouts et al. 2007.

+948 24µm sources in HDFS
+908 24µm sources in HDFN

Rodighiero et al. in prep.
We start knowing the far-IR source emissivity and its time evolution.

FIDEL includes 322 24µm sources with S_{70}>3 mJy, +44 70µm sources in GOODS-S +119 in GOODS-N +195 in ECDFS (Magnelli B. et al. in prep.)
Luminosity functions of extragalactic sources at 3.6 µm

(A.F. et al. 2006)
From all this we then know well the source local emissivity and how it evolves in cosmic time.

The source volume emissivity

\[ j[\nu_0, z] = \int_{L_{\min}}^{L_{\max}} d\log L_{\nu_0} \frac{dn}{dL_{\nu_0}} \times K(L_{\nu_0}, z) \times L_{\nu_0} \]

where \( K(L_{\nu_0}, z) \) is the K–correction

\[ K(L_{\nu_0}, z) = (1+z) \cdot \frac{L_{\nu_0(1+z)}}{L_{\nu_0}} \]
The Model Local Extragalactic Background intensity from 0.1 to 1000 µm vs. data
The redshift-dependent photon number density in the comoving volume.

Red: $z=0, 0.2, 0.4$;
Green: $z=0.6, 0.8, 1.0$;
Blue: $z=1.2, 1.4, 1.6$;
Cyan: $z=1.8, 2$.

\[
\rho(z^*, \nu_0) = \frac{4\pi}{c} (1 + z^*)^3 \cdot I_{\nu_0}(z^*) =
\]
\[
= \frac{1}{H_0} (1 + z^*)^3 \cdot \int_{z^*}^{z_{\text{max}}} \frac{dz^* [\nu_0(1+z),z]}{(1+z)[(1+z)^2(1+\Omega_m z)-z(2+z)+\Omega_\Lambda]^{1/2},}
\]
Comparison of the evolutionary proper photon number density (continuous lines) with the density corresponding to a non-evolving population (dashed lines). Black, red, blue and green lines correspond to $z=0, 0.6, 1.2, 1.8$. Evolution effects make the $\gamma$-density much lower at high-$z$ ($z > 0.6$) than the no-evolution prediction, particularly in the optical.
The optical depth for $\gamma\gamma$ collision of a high-energy photon with $E_\gamma$ from a source at $z_e$:

$$\tau(E_\gamma, z_e) = c \int_0^{z_e} \frac{dz}{dz} \int_0^2 dx \frac{x}{2} \int_{\frac{2m_e^2c^4}{E_\gamma(1+z)}}^{\infty} \frac{d\varepsilon}{d\varepsilon} \sigma_{\gamma\gamma}(\beta)$$

$$\sigma_{\gamma\gamma}(E_\gamma, \varepsilon, \theta) = \frac{3\sigma_T}{16} \cdot (1 - \beta^2) \times \left[ 2\beta(\beta^2 - 2) + (3 - \beta^4) \ln\left(\frac{1 + \beta}{1 - \beta}\right) \right],$$

$$\beta \equiv (1 - 4m_e^2c^4/s)^{1/2}, \quad s \equiv 2E_\gamma\varepsilon x(1 + z); \quad x \equiv (1 - \cos \theta),$$

For a flat universe, the differential of time to be used in eq. 1 is:

$$\frac{dt}{dz} = \frac{1}{H_0(1 + z)} \left[ (1 + z)^2(1 + \Omega_m z) - z(z + 2)\Omega_\Lambda \right]^{-1/2}.$$

$\varepsilon$: energy of the background photon,

$E_\gamma$ that of the high-energy colliding one,

$\theta$ being the angle between the colliding photons.
Relationship of γ-γ optical depth, energy & source redshift

N.B.: closer to Kneiske at low-z high-$E_\gamma$
closer to Primack at high-z low-$E_\gamma$

See [http://www.astro.unipd.it/background/](http://www.astro.unipd.it/background/)
another view of the relation

\[ z = 0.003, 0.01, 0.03, 0.1, 0.3, 0.5, 1, 1.5, 2, 2.5, 3, 4 \]
First applications:

how does all this information match with current TeV BLAZAR observations?
Aharonian et al. (2005) and (2006) report two among the highest redshift studies of objects...
... two among the best studies local objects...
The most distant TeV source known, 3C 279!

(Albert et al. 2008 & the MAGIC collaboration, astroph/0807.2822)

*Top:* spectral correction for $\gamma - \gamma$ opacity.

*Bottom:* the observed (open black) and absorption-corrected (filled red) spectrum, the best-fit value of $\Gamma_{\text{intrinsic}} = 2.55$ refers to the intrinsic unattenuated spectrum.

Fair power-law fit, again some tendency for high-energy upturn, marginal fit …
First (tentative) conclusions ...

- Are there striking inconsistencies requiring new physics?

- The analysis of the TeV spectra of well-known Blazars indicates that the present model of the backgrounds produces intrinsic spectra fairly consistent with natural power-laws and realistic ($\Gamma>1.5$) spectral slopes.

- (Marginal) indication of a problem may arise at the highest TeV energies of the most studied Blazars (Mkn 421 & 501), perhaps requiring a lower background at $\lambda>10\mu m$, which would be difficult to reconcile with astrophysical observations (Spitzer & ISO @ 24 & 15 $\mu m$). => observations at $E_{\gamma}=10$ TeV => synergy with Fermi Observatory.

- The fit to the highest-redshift AGN (3C279) is marginally consistent with a power-law => Improve the far-UV section with GALEX data.
Plot of the NIRBE flux from Matsumoto et al. (2005) shown as asterisks. The squares are object fluxes from Madau & Pozzetti (2000), the triangles are the NUDF object fluxes from Thompson et al. (2006), the plus signs are those fluxes corrected for the expected missing flux from faint galaxies and regions of galaxies and the diamonds are the quoted backgrounds from Kashlinsky (2005). The crosses with error bars are the DIRBE fluxes.
Inclusion in the Local Background of a truly diffuse flux from primeval sources (Pop-III stars)
The effect on the spectrum of the source 1ES 1101-232 of the inclusion of a truly diffuse background in addition to that from resolved sources. The excess background is assumed to have the same spectrum as estimated by Matsumoto et al. (2005), but is down-scaled by a factor of 5.

**Top:** spectral correction for $\gamma - \gamma$ opacity.

**Bottom:** the observed (open black) and absorption-corrected (filled red) spectrum, the two best-fit values of $\Gamma_{\text{intrinsic}} = 1.15$ and 1 refer to the lower and higher energy portions of the spectrum.

$I_{\text{excess}} < 6 \ \text{nW/m}^2/\text{sr} \ [1 - 4 \ \mu\text{m}] < 0.5\%$ of baryons in Pop-III stars (also Aharonian et al. 2006)
More details in:

A.F., G. Rodighiero, M. Vaccari, A&A...487..837F
Final considerations

- In spite of some previous expectations by astronomers, it is more and more clear that the direct measurement of truly diffuse photon backgrounds in the UV/near-IR frequency range (so critical for cosmology) is both extremely difficult and prone to systematic errors.

- The only promising approach at the moment: to exploit estimates of the $\gamma\gamma$ cosmic opacity in TeV AGN spectra to constrain the diffuse light.

- Already important results obtained (Aharonian et al. 2006; A.F.2008) concerning possible signatures of primeval stellar populations indicated on the basis of COBE and IRTS maps: Current data show that only <20% of the IRTS signal is consistent with the data (<0.5% of baryons in Pop-III stars).

- These preliminary analyses, however, based on heuristic approach => more extensive AGN spectral modelling & data required.

- We expect dramatic improvements in this field by the combination of ground large Cherenkov telescopes and the Fermi Observatory.