What about the far-infrared background?

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The near-IR background
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The extragalactic background light (EBL)

SED of the extragalactic background light (Dole & Béthermin, in prep.)

**S** Far-infrared background: second background after CMB

**S** Relic emission of dust emission across cosmic times

**S** Far-IR 3 times lower than near-IR/optical in the local Universe

=> quick evolution of galaxy properties
The far-infrared: a tracer of star formation

- **UV emissions of galaxies dominated by massive, hot, short-lived stars** => tracer of recent star formation.

- **PROBLEM:** UV strongly absorbed by dust around the regions of star formation.

- **Re-emission of UV by dust in the far-IR is a good tracer of this reprocessed UV.**

Spectral energy distribution of a galaxy (Noll +09)
Absolute measurements of the far-infrared background

Puget et al. (1996) detected for the first time the absolute level of the far-IR background in FIRAS data.

Was confirmed by DIRBE (Hauser+98) and FIRAS (Fixsen+98).

Spectrum of the far-infrared background measured with FIRAS (Puget+96)
Resolving the CIB: the problem of confusion

Spitzer 160 microns

CIB 15% résolved (Béthermin+10a)
A new picture of the infrared Universe with Herschel and Planck

Herschel (credits: ESA)

Observed between 60 and 600 micron
“Good” angular resolution: 4.5” (70 microns) to 36” (500 microns)
Scanned only a part of the sky following a wedding cake strategy

Planck (credits: ESA)

Launched together in 2009
Observed between 350 and 3000 microns (for HFI instruments)
Low angular resolution: ~5 arcmin but very stable at large scale
Scanned the full sky
Resolving the CIB: the problem of confusion

Herschel 500 microns

CIB 6% résolved (Oliver+10)
Digging into confusion using stacking analysis

24 microns Spitzer

250 microns Herschel

MIPS Stacking Analysis
Dole et al., 2006

stacking analysis

24µm
70µm
160µm
P(D) analysis

If Poisson distribution, histogram of a map depends on the source counts.

Pixel histogram of Herschel maps can be used to determine faint source counts.

Illustration of the link between the counts and the pixel histogram of a confusion limited infrared map.
Dusty galaxies explain the CIB level

Galaxy number counts observed by SPIRE (Béthermin+12b)

Cumulative contribution to the CIB as a function of the flux cut (Béthermin+12b)

Fixsen+98, Lagache+00

Béthermin+10b

Oliver+10

Béthermin+10b
Redshift distribution of the CIB

Counts per redshift slice

CIB build-up with $z$

CIB contribution below a given $z$

Béthermin+12b

redshift
SED of the CIB

Total CIB: $27^{+7}_{-3}$ nW m$^{-2}$ sr$^{-1}$

- PACS (resolved)
- SPIRE (stacking)
- MIPS (stacking)
- MIPS (resolved)
- IRS (resolved)

$\nu I_{\nu}$, [nW m$^{-2}$ sr$^{-1}$]

Wavelength [$\mu$m]

Béthermin+12b
Lots of very bright IR galaxies at high-z

**Herschel** revealed a quick evolution of the infrared luminosity function with redshift:
- in density (decreasing with z)
- in luminosity (increasing with z)

Evolution of the far-infrared (8-1000 microns) luminosity function (Gruppioni+13)
Fluctuation of the cosmic infrared background

Fluctuations of the cosmic infrared background (Planck collaboration et al.)

Simulation of large scale structures (Pichon, Teyssier)
Anisotropies of the far-infrared/millimeter background fluctuations between bands measured between 100 and 1400 microns (3000 to 217 GHz).

Longer wavelengths are dominated by higher redshift.

The cross-correlations help to disantangle between various scenarios.

Power spectrum of CIB anisotropies (Planck collaboration XXX)
Obscured star formation and host halos

S Linear model based only on large scales. Use several wavelength to break degeneracies between redshifts.

S Star formation history:
- good agreement with extrapolation of Herschel luminosity functions
- Uncorrected UV significant at z>3

S Clustering of galaxies dominating the CIB compatible with halos of few $10^{12} M_{\text{sun}}$

Evolution of the star formation rate density and the effective bias with redshift (Planck collaboration XXX)

\[ P_{\text{gal}} = \text{bias}^2 P_{\text{DM}} \]
A more detailed modeling approach...

**THEORY**

- Halo mass function including sub-structures (Tinker+08, Tinker+09)
- Abundance matching

**OBSERVABLES**

- Mass function spitted in star-forming and quenched galaxies (from Ilbert+10)
- SFR-Mstar model for star forming galaxies (Béthermin+12c)
- Neglect the IR outputs of quenched galaxies

Main hypotheses:
- same Mstar-Mhalo relation in main and sub-structures
- same Mstar-Mhalo relation for SF and quenched galaxies
- the probability to be quenched depends only on the halo mass
- starburst and main-sequence lies in the same halos

Béthermin+13
Procedure of abundance matching

From Béthermin +13
Model of IR galaxy evolution

- Mass function of star-forming galaxies
- Evolution of the “main-sequence”: $<\text{SFR}> = f(M_\star, z)$
- Scatter of SFR-$M_\star$ relation
- Dust attenuation of galaxies vs $M_\star$ and $z$
- New templates of “main-sequence” and starburst galaxies
- Cosmology (for volume and luminosity distance only)

- SFR function
- Infrared luminosity function

- Statistical properties of infrared sources:
  - number counts
  - redshift distribution
  - CIB redshift distribution

Béthermin+12c
Redshift distribution of the CIB and its anisotropies

CIB spectral energy distribution splitted by redshift slices

Redshift distribution of CIB fluctuation at $l=1000$

Redshift distribution of the CIB from Béthermin+13 model
Results

Model A: Fiducial model
Model B: Lowest density, high sSFR
Model C: Lowest density, high, sSFR + no star-formation around passive central galaxies

Reproduce also: SPIRE cross power spectra, ACTxSPIRE, Planck CIBxlensing, clustering of PACS detected sources

CIB power spectrum and galaxy counts (B+13)
Star formation history and host halos

Instantaneous halo mass

Mass extrapolated at $z=0$

Relative contribution of various halo masses as a function of redshift (B+13)
Star formation efficiency of dark matter halos

Mean ratio between SFR and BAR as a function of halo mass at various redshift (Béthermin+13)

Baryon Accretion Rate (BAR) = Mean halo growth (Fakhouri +10) × Ωb / Ωm

S Instantaneous efficiency of the system {halo+galaxy(ies)}: SFR/BAR (neglect reservoir effects)

S Maximum efficiency (~50%) for DM halos close to ~10^{12} M_{sun} at all z.

S Low efficiency at low(SN feedback?) and high(AGN feedback? Hot halo?) mass.

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Interpreting the evolution of far-IR galaxies at first order

Evolution of the star formation rate density and contribution of various infrared luminosities (Magnelli+13)
The far-infrared background intensity can be explained by known IR galaxy populations.

We have also constrained the redshift distribution of the far-infrared background.

The anisotropies of the far-infrared background are now measured very accurately by Planck and Herschel.

These measurements put constraints on the dark-matter halos hosting the obscured star formation at different cosmic epochs.