Cosmic IR Backgrounds

by

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http://www.astro.ucla.edu/~wright/intro.html

See:

• http://www.astro.ucla.edu/~wright/cosmolog.htm

• http://www.astro.ucla.edu/~wright/DIRBE

• http://www.astro.ucla.edu/~wright/CIBR

• http://sirtf.caltech.edu
• $I_\nu$ - specific intensity, energy per 
  (area\times time\times frequency\times solid angle).
  $10^{-20}$ W/m$^2$/Hz/sr = 1 MegaJansky/sr [MJy/sr].
• $I = \int I_\nu d\nu$ - bolometric intensity, energy per 
  (area\times time\times solid angle).
  1 nW/m$^2$/sr.
• $\nu I_\nu$ - intensity per octave, energy per 
  (area\times time\times logarithmic bandwidth \times solid angle).
  1 nW/m$^2$/sr.
• $J_\nu = (4\pi)^{-1} \int I_\nu d\Omega$: mean intensity – the angle averaged 
  intensity.
• $F_\nu = \int I_\nu \cos \theta d\Omega$: monochromatic flux, energy per 
  (area\times time\times frequency).
  $10^{-20}$ W/m$^2$/Hz = 1 MegaJansky [MJy].
Wide window on the CBR
Backgrounds

- Microwave – the CMB is 10,000 times brighter than the galactic foreground & the spectrum is very close to a blackbody.
- Far Infrared – the FIRB is 10 times fainter than the galaxy with a spectrum similar to the galaxy.
- Near IR and Optical – also 10 times fainter than galaxy.
- X-ray – the XRB is 10 times brighter than the galaxy.
In a homogeneous unchanging Universe every line of sight will end on a star. So why is the night sky not as bright as the surface of a star? The Cosmic Infrared Background is what remains after this Olbers’ paradox is resolved.
Sources of the CIRB
Expanding Mirrored Box

- The Universe is *homogeneous* & *isotropic*.
- Reflections in a mirrored box look like the Universe.
- Expanding mirrored box gives a redshift with $\lambda \propto a(t)$. 
Consider a mirrored box, where the mirrors move with the galaxies in the Hubble flow, and define the comoving luminosity density:

\[
\ell(t) = \frac{\sum_{\text{in box}} L_{gal}(t)}{V_{box}(t_0)}
\]

For a static, unchanging Universe the energy density in the box now is

\[
u(t_0) = \frac{4\pi J}{c} = \int_{-\infty}^{t_0} \ell(t_0)dt \rightarrow \infty \quad \text{[Olber's Paradox]}
\]

In an expanding Universe with scale factor \( a(t) \), and \( 1 + z = a(t_0)/a(t) \), then:

\[
u(t_0) = \frac{4\pi J}{c} = \int_{0}^{t_0} \frac{\ell(t)}{1 + z}dt
\]
The total energy produced, $\int \ell(t)\,dt$, is more than the CIRB energy density because it does not have the $(1 + z)$ factor in the denominator. For the baryon density given by Big Bang Nucleosynthesis, $\Omega_B h^2 = 0.02$, if 1% of the baryons are converted from hydrogen to helium releasing 0.7% of their mass into energy, then

$$\int \ell(t)\,dt = 0.02 \times 0.01 \times 0.007 \times 10539.4 \frac{\text{eV}}{\text{cm}^3} = \frac{1}{68} \frac{\text{eV}}{\text{cm}^3}$$

$c/[4\pi]$ times this energy density is 56 nW/m$^2$/sr.
The relationship between time and redshift is

\[ t = \frac{2}{3H_0(1 + z)^{1.5}} \]

so

\[ \frac{dt}{dz} = -\frac{1}{H_0(1 + z)^{2.5}} \]

for the Einstein-de Sitter Universe with \( \Omega = 1 \), and the Hubble constant is \( H_0 = (2/3)/t_\circ \).

Thus if \( \ell(t) \) is CONSTANT, the energy density of the CIRB would be

\[ u = \frac{1}{H_0} \int \frac{\ell(t_\circ)}{(1 + z)^{3.5}} dz = \frac{3}{5} \int \ell(t) dt = 0.6\ell(t_\circ)t_\circ \]

If \( \ell(t) \) is proportional to \( (1 + z) \), then the energy density of the CIRB would be

\[ u = \frac{1}{H_0} \int \frac{(1 + z)\ell(t_\circ)}{(1 + z)^{3.5}} dz = \frac{1}{3} \int \ell(t) dt = \ell(t_\circ)t_\circ \]
Luminosity density vs. redshift
$L/(1+z)$ vs. time
DIRBE Beam Size

0.7°
DMR COVERAGE
ONE ORBIT,
DAY 45
DMR COVERAGE
ONE ORBIT,
DAY 135
Bump Chart: Where is the CIRB?

Wavelength [μm]

Ecliptic Poles @ 1 au

Intensity [nW/m²/sr]
Note the triangles of zodiacal emission along the ecliptic on either side of the solar exclusion hole.
Extrapolation to Outside Solar system?

- Observe same spot on the sky through different amounts of interplanetary dust.

- Fit a model to the change in intensity vs. elongation (or time).
Still no CIRB Bump:
We want $\nu J_\nu$ at B but sit at A
Extrapolation to NO Galaxy?

- Galaxy is a *very* thin disk
- Average column density $\propto \csc |b|$
Extrapolation to $\csc|b| = 0$ in Far IR
Atomic Hydrogen Map

21 cm H I emission

Color scale: 33.3 - 126.8 - 233.1 - 373.3 - 839.8 - 7057.5


## DIRBE Team IRB Results


<table>
<thead>
<tr>
<th>$\lambda$ [$\mu$m]</th>
<th>$\nu I_\nu$ [nW m$^{-2}$ sr$^{-1}$]</th>
<th>$I_\nu$ [MJy sr$^{-1}$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.25</td>
<td>&lt; 75.</td>
<td>&lt; 0.031</td>
</tr>
<tr>
<td>2.2</td>
<td>&lt; 39.</td>
<td>&lt; 0.029</td>
</tr>
<tr>
<td>3.5</td>
<td>&lt; 23.</td>
<td>&lt; 0.027</td>
</tr>
<tr>
<td>4.9</td>
<td>&lt; 41.</td>
<td>&lt; 0.067</td>
</tr>
<tr>
<td>12.</td>
<td>&lt; 468.</td>
<td>&lt; 1.87</td>
</tr>
<tr>
<td>25.</td>
<td>&lt; 504.</td>
<td>&lt; 4.2</td>
</tr>
<tr>
<td>60.</td>
<td>&lt; 75.</td>
<td>&lt; 1.5</td>
</tr>
<tr>
<td>100.</td>
<td>&lt; 38.</td>
<td>&lt; 1.27</td>
</tr>
<tr>
<td>140.</td>
<td>25.0 ± 6.9</td>
<td>1.17 ± 0.32</td>
</tr>
<tr>
<td>240.</td>
<td>13.6 ± 2.5</td>
<td>1.09 ± 0.2</td>
</tr>
</tbody>
</table>

$I_\nu \approx (1.3 \pm 0.4) \times 10^{-5} (\nu/100)^{0.64\pm0.12} B_\nu (18.5 \pm 1.2 \text{ K})$

Extrapolation to \( \csc|b| = 0 \) at 3.5 \( \mu m \)
Detecting the Cosmic Infrared Background at 2.2μm with Ground Based and Space Based Observations

A dissertation submitted in partial satisfaction of the requirements for the degree Doctor of Philosophy in Physics and Astronomy

by

Varoujan Gorjian
1998
DIRBE vs. 2MASS Fits at K

The diagram shows scatter plots comparing DIRBE and 2MASS intensity measurements, with the y-axis representing the DIRBE intensity in kJy/sr and the x-axis representing the 2MASS intensity in kJy/sr. The plots are arranged in a 3x3 grid, each showing a linear trend line indicating the relationship between the two measurements.
DIRBE at L vs 2MASS at K
DIRBE-2MASS at J, K & L

CIRB [kJy/sr]

csc|β|
DIRBE-2MASS Residuals at K: $\sigma = 1.83 \text{ kJy/sr}$
DIRBE-2MASS Residuals at L: $\sigma = 1.43 \text{ kJy/sr}$
## RESULTS

<table>
<thead>
<tr>
<th>Region</th>
<th>$I_\nu(2.2)$ kJy/sr</th>
<th>$I_\nu(3.5)$ kJy/sr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dark Spot</td>
<td>16.4 ± 2.3</td>
<td>12.8 ± 1.8</td>
</tr>
<tr>
<td>NGP</td>
<td>16.7 ± 0.4</td>
<td>15.0 ± 0.3</td>
</tr>
<tr>
<td>SGP</td>
<td>18.9 ± 0.5</td>
<td>17.7 ± 0.3</td>
</tr>
<tr>
<td>HQB ($</td>
<td>b</td>
<td>&gt; 60^\circ$, $</td>
</tr>
<tr>
<td>B45 ($</td>
<td>b</td>
<td>\approx 45^\circ$, $</td>
</tr>
<tr>
<td>NEP</td>
<td>14.9 ± 2.0</td>
<td>11.9 ± 1.2</td>
</tr>
<tr>
<td>Mean</td>
<td>16.9 ± 0.6</td>
<td>14.2 ± 0.9</td>
</tr>
<tr>
<td>Systematic error</td>
<td>±4.4</td>
<td>±3.7</td>
</tr>
</tbody>
</table>
2.2 $\mu$m CIRB Results
Near IR Decomposition
Discrepancy between Counts & Measurements

• Rebecca Bernstein gets about $2 \times$ more optical extragalactic background light than one derives from the sum of the galaxy counts:

$$I_{counts} = \int S dN = \int S \left| \frac{\partial N}{\partial \ln S} \right| d\ln S$$

$$I_{obs} \approx 2 \times I_{counts}$$

• Wright gets about $(2 \pm 0.5) \times$ more near infrared cosmic background light than is expected from deep $K$-band counts.

Both measurement involve difficult and uncertain zodiacal light corrections but they use entirely different techniques.
2.2 $\mu$m Galaxy Counts

- K counts from Figure 1 of Madau & Pozzetti, MNRAS, 312, L9-L15 (2000)
- CADIS counts from Huang et al astro-ph/0101269
- Integral under fit gives 6.3 kJy/sr or 8.6 nW/m$^2$/sr
Undercount of Faint, Fuzzy Edges

- SDSS from astro-ph/0012085
- 2dF redshifts with 2MASS photometry from astro-ph/0012429
- Need to multiply IR values by 2 to 2.6 for continuity with SDSS
Local Luminosity Density

\[ \frac{L_v}{h} \text{ [erg/sec/Hz/Mpc]} \]

\[ \lambda [\mu m] \]

- SDSS
- 2.3*2dF/2MASS
- LCRS
- 2dF
- 2dF/2MASS
- CFRS
- Gardner

UV tail
1.7*Dwek et al '98
Dwek et al '98
L* causes 55% of jump

\[ n(L) dL = \left( \frac{L}{L^*} \right)^\alpha e^{-\frac{L}{L^*}} \frac{dL}{L^*} \]

Total = L*  \( \phi^* \)  \( \Gamma(\alpha+2) \)
Spitzer
I am the PI on a MIDEX proposal for WISE, an all-sky survey in 4 bands from 3 to 24 μm. WISE will find and study the closest stars to the Sun, the most luminous galaxies in the Universe, and also map the large-scale structure out to redshift \( z=0.7 \), covering the peak of the galaxy \( S^2dN/dS \).

Now in phase B, WISE will fly in 2009.
WISE and the distant Universe

WISE detects very distant QSOs

WISE detects very distant QSOs
\textbf{\(\gamma\)-Ray Connection}

- The reaction \(\gamma_1 + \gamma_2 \rightarrow e^+ + e^-\) has a threshold of \(E_1E_2 > (m_e c^2)^2\).
- The peak cross-section of \(1.7 \times 10^{-25}\) cm\(^2\) occurs at twice the threshold energy.
- 1 MJy/sr corresponds to a photon density of 0.63 cm\(^{-3}\) oct\(^{-1}\).
- Expect absorption of \(\gamma\)-rays over distance of 3 Mpc for 1 MJy/sr, or \(450/\lambda[\mu\text{m}]\) Mpc for 20 nW/m\(^2\)/sr, at \(E \approx 400\lambda[\mu\text{m}]\) GeV.
- Only 3 extragalactic \(\gamma\)-ray sources are observed at \(E \gtrsim 300\) GeV with mean distance of 160 Mpc.
- NEED MORE SOURCES!!
Solar Tower Atmospheric Cherenkov Effect Experiment

- Collecting area of 100 m diameter telescope
- Optical Quality: Don’t Ask!
Ablaze in the distance

- Blazar H1426+428 has a flux of $4 \times 10^{-12}$ erg/cm$^2$/sec at $E > 1$ TeV.
- $z = 0.129$
- 96% absorption at 1 TeV for my CIRB
- This is definitely a caveat to remember!
HESS is going great
Claimed limit on CIRB

Fig1 of astro-ph 0508073. Based on only 2 AGNs.
Blue points: Matsumoto et al.

- Scanned a line on sky.
- Correlated signal with zodiacal light model.
- Extrapolated to the model zeropoint.
- Scale factor of the correlation often off by 10% or more.
Zodi dominates the total signal

Fig 11 of Matsumoto et al, astro-ph/0411593

\[ \nu I_\nu \text{[nW/m}^2\text{/sr]} \]

\[ \lambda \text{[\mu m]} \]

Total

Zodi

CIBR?

Stars
Zodi errors underestimated

• A 7% error in the zodi, as suggested by the 7% change in the correlation scale factor when moving off the DIRBE datum at 2.2 \(\mu\)m, reduces the CIRB by \(0.07 \times 260 = 18\) nW/m\(^2\)/sr.

• This would be a systematic reduction in the rise at 1.5 \(\mu\)m, bringing Matsumoto et al more in line with my values, but these are still higher than the H.E.S.S. limits.
Cosmic Optical & IR Background

![Graph showing the mean intensity of cosmic optical & IR background across different frequencies and wavelengths. The graph includes data points and curves indicating the distribution of intensity.]
Discussion: CIRB

• The CIRB has been detected in both the far IR and the near IR windows through the interplanetary dust, but measurements between 5-60 μm are impossible from 1 AU

• Bolometric OIR background is about 100 nW/m²/sr

• Ratio of optical plus near IR to the far IR is about 2:1 but γ-ray data says more like 1:1
Discussion: $\Delta X$

- For UVO “Madau” curve, fuel burn over current energy density ratio is $f/U_0 = 1.9$
- Current CIRB bolometric energy density is about 100 nW/m$^2$/sr
- Therefore $\Delta X = -0.033$
- Madau curve with Rowan-Robinson addon at high $z$ burns more fuel at high redshift, so $f/U_0 = 2.3$, $\Delta X = -0.04$
- At 1/3 solar from cluster gas, $\Delta X = -0.02$
- Do we need more baryons [CMB], more AGN, or less CIRB [zodi]?
White Dwarf Helium Reservoir?

• Oppenheimer *et al.* (2001) claim 3% of local halo in old WDs

\[ \Delta X = -0.04h \frac{f_{WD}}{0.03} \frac{M_H}{5 \times 10^{11}} \frac{\ell_{ONIR}}{5.6h \times 10^8} \frac{3 \times 10^{10}}{L_{MW}} \]

• BUT Richer on 2 Apr 2001 withdrew the claimed detection of faint, high proper motion stars in the HDF [astro-ph/9908270]

• The Oppenheimer *et al.* objects do not have a halo velocity distribution, and can not be part of a spherical halo.
CONCLUSION

• CIRB is 7-10% of CMB energy density.
• Zodiacal dust (interplanetary dust) is the major foreground source, and uncertainties in modeling it are the major uncertainty in the near-IR background.
• HESS, STACEE, MAGIC and VERITAS are measuring the interplanetary dust cloud by observing Active Galactic Nuclei in $\gamma$-rays.
REFERENCES

COSMOLOGY TUTORIAL:
http://www.astro.ucla.edu/~wright/cosmolog.htm
http://www.astro.ucla.edu/~wright/CIBR

- DIRBE: http://www.astro.ucla.edu/~wright/DIRBE/
- SIRTF: http://sirtf.caltech.edu/