Cosmic Optical Background: The View from Pioneer 10/11

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COB: The View from Pioneer 10/11

- Cosmic optical background (COB) = Optical component of the extragalactic background light (EBL)
- UV and optical light of all radiation sources in the Universe (↔ integrated brightness of galaxies)

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FIRST STARS IV

Bernstein 07

Dominguez et al. 2011
NASA’s Pioneer 10/11 spacecrafts
• “the first to be sent to the outer solar system and the first to investigate the planet Jupiter, after which followed an escape trajectory from the solar system”
• Launched: May 1972 (Pioneer 10)
  Apr 1973 (Pioneer 11)
• Comm. Stop: Jan 2003 (P10; D = 82 AU)
  Nov 1995 (P11; D = 45 AU)
• Scientific instruments:
magnetometer; plasma analyzer; charged particle detector; ionizing detector; non-imaging telescopes; sealed pressurized cells of Ar and N gas; UV photometer: IR radiometer; imaging photopolarimeter
**Imaging Photopolarimeter (IPP)**
- 2.5-cm Maksutov telescope
- Wollaston prism
- multilayer filters
- dual-channel Bendix channeltrons

- measures two orthogonal polarization components in the two wave bands (blue; 3900 – 5000 Å, red; 5950 – 7200 Å)

- Instantaneous FOV: 2.29° x 2.29°
- takes 64 exposures per one spacecraft spin (12.5 sec)
  → **effective FOV**: 2.29° x (2.29° + 5.625° sin L) ~ 10 deg²

- L: “look angle” between the IPP pointing and spacecraft spin axis
- 1 data cycle = 10 rolls (8 for sky measurements, 1 for photometric calibration, 1 for dark-current and offset measurement)
• **ZL and COB measurements by the IPP**

  - Hanner et al. (1974)
    - monitored the sky brightness during the cruise phase of the Pioneer 10 at the heliocentric distances 2.4 – 4.8 AU.
    - \( ZL @ 2.4 \text{ AU} < 10\% \ ZL @ 1 \text{ AU} \)
    - \( ZL \text{ undetectable} @ > 3.3 \text{ AU} \)

• **Toller (1983)**

  - attempted to detect the COB in the Pioneer 10 IPP data taken at the heliocentric distances > 3.3 AU (i.e., outside the ZL clouds)
  - \( \text{COB} < 4.5 \times 10^{-9} \text{ erg s}^{-1} \text{ cm}^{-2} \text{ sr}^{-1} \text{ Å}^{-1} \text{ at 4400 Å} \)
  - … comparable to the HST results by Bernstein et al. (2002-2007)
  - BUT the starlight subtraction is the fatal problem in his analysis.
<table>
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<th>date</th>
<th>R (AU)</th>
<th>all #</th>
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Quality Assessment

Comparison between data subgroups (spacecraft, distance to the Sun, ...)

Comparison between two polarization components

Comparison of differential brightness: IPP measured vs. stellar magnitudes
• IPP Blue-band brightness maps (north/south Galactic hemispheres at \(|b| > 35^\circ\))
• IPP Red-band brightness map (north/south Galactic hemispheres at $|b| > 35^\circ$)
**Contribution of faint stars**
- Bright \( m_V < 6.5 \) stars in the Yale Bright Star Catalog and the USNO Photoelectric Catalog have already been subtracted.

**Fainter stars... all-sky catalogs:**
- Tycho-2 Catalog (6 – 10 mag),
- GSC-II Catalog (9 – 20 mag) and Galactic star-count model:
- TRILEGAL (> 20 mag) are used to derive the starlight contributing to each IPP FOV

“Diffuse emission map”
COB: The View from Pioneer 10/11

- Final foreground component: Diffuse Galactic Light
- "Since the DGL is mostly the scattered starlight by the interstellar dust, its brightness correlate with far-IR brightness which traces the thermal emission of dust heated by the starlight."

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\[
\begin{align*}
S_{\text{IPP}}^{\text{diffuse}} & = S_{\text{IPP}} - S_{\text{IPP}}^s \\
& = S_{\text{DGL}} + S_{\text{COB}} \\
& = a_{\text{DGL}} (S_{100\mu m})
\end{align*}
\]
COB: The View from Pioneer 10/11

• **DGL subtraction**
  IPP diffuse emission map at $|b| > 35^\circ$
  \[ \downarrow \]
  IRAS/DIRBE 100 $\mu$m emission map (Schelgel et al. 1998)
  - Derived DGL/100 $\mu$m brightness ratios are in good agreement with the previous measurements.

• **Residual COB**
  - $7.9 \pm 4.0$ nW m$^{-2}$ sr$^{-1}$ at Blue band
  - $7.7 \pm 5.8$ nW m$^{-2}$ sr$^{-1}$ at Red band
  (\(I_{\text{CIB}} = 0.78 \pm 0.21\) MJy sr$^{-1}$ at 100$\mu$m ; Lagache et al. 2000)
Dominguez et al. 2011

this work

\[ \lambda_{\lambda} \text{[nW m}^{-2} \text{sr}^{-1}] \]

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

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Summary

- We have re-analyzed the all-sky imaging data taken by IPPs on board Pioneer 10/11 spacecrafts.
- The new constraints on the optical EBL (COB) are obtained, which are
  - $7.9 \pm 4.0 \text{ nW m}^{-2} \text{ sr}^{-1}$
  - at $0.39 - 0.50 \mu\text{m}$,
  - $7.7 \pm 5.8 \text{ nW m}^{-2} \text{ sr}^{-1}$
  - at $0.60 - 0.72 \mu\text{m}$.
- The derived COB is consistent with the integrated brightness of galaxies in the Hubble deep field.