ANOMALOUS FLUX IN THE COSMIC OPTICAL BACKGROUND DETECTED WITH NEW HORIZONS

OBSERVATIONS. Tod R. Lauer[1], Marc Postman[2], John R. Spencer, Harold A. Weaver, S. Alan Stern, G. Randall Gladstone, Richard P. Binzel, Daniel T. Britt, Marc W. Buie, Bonnie J. Buratt, Andrew F. Cheng, W.M. Grundy, Mihaly Horanyi, J.J. Kavelaars, Ivan R. Linscott, Carey M. Lisse, William B. McKinnon, Ralph L. McNutt, Jeffrey M. Moore, J. I. Nunez, Catherine B. Olkin, Joel W. Parker, Simon B. Porter, Dennis C. Reuter, Stuart J. Robbins, Paul M. Schenk, Mark R. Showalter, Kelsi N. Singer, Anne. J. Verbiscer, & Leslie A. Young. [1]NSF's National Optical Infrared Astronomy Research Laboratory, P.O. Box 26732, Tucson, AZ 85726; tod.lauer@noirlab.edu, [2]Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218; postman@stsci.edu.

Summary: The cosmic optical background (COB) is the visible-light analogue of the famed cosmic microwave background. It provides a measure of the total photon production by all stars, accreting black holes, and any unknown mechanisms, over the age of the Universe. To observe it we used New Horizons LORRI images to measure the optical-band ($0.4 \lesssim \lambda \lesssim 0.9 \mu m$) sky brightness within a high galactic-latitude field selected to have reduced diffuse scattered light from the Milky Way galaxy (DGL), as inferred from the IRIS all-sky 100 μm map. We also selected the field to significantly reduce the scattered light from bright stars (SSL) outside the LORRI field. Suppression of DGL and SSL reduced the large uncertainties in the background flux levels present in our earlier New Horizons COB results [1]. The raw total sky level, measured when New Horizons was 51.3 AU from the Sun, is 24.22 ± 0.80 nW m^{-2} sr^{-1}. Isolating the COB contribution to the raw total required subtracting scattered light from bright stars and galaxies, faint stars below the photometric detection-limit within the field, and the hydrogen plus ionized-helium two-photon continua. This yielded a highly significant detection of the COB at 14.67 ± 1.47 nW m^{-2} sr^{-1} at the LORRI pivot wavelength of 0.608 μm. This result [2] is in strong tension with the COB flux inferred from the attenuation of very-high energy γ-rays over cosmological distances, and the hypothesis that the COB only comprises the integrated light of external galaxies (IGL). Subtraction of the estimated IGL flux from the total COB level leaves a flux component of unknown origin at 8.06 ± 1.95 nW m^{-2} sr^{-1}.

**Observations:** The field selected for observation is at J2000 α = 0.0756°, δ = −21.5451°; the galactic latitude is b = −77.1°. The estimated flux from IR-cirrus in the field is 0.252 ± 0.055 MJy sr^{-1}. With the Zemcov [3] scaling coefficient, the implied DGL flux is only 2.22 ± 1.00 nW m^{-2} sr^{-1}. We obtained 16 images with 65s exposures using New Horizons' LORRI instrument [4,5]. The images were reduced with a custom pipeline designed to ensure high accuracy recovery of low-level flux backgrounds [1,2]. The average sky value of the 16 images is 1.058 ± 0.035 DN, or a V-band surface brightness of 26.4 mag/arcsec^2. This corresponds to 24.22 ± 0.80 nW m^{-2} sr^{-1} in flux units at the LORRI pivot wavelength of 0.608 μm.

COB Isolation: Isolating the COB flux from the total sky requires correcting for a number of foreground sources. We describe these in detail in [1,2], but summarize the decomposition of the total sky in the Table and Figure 1. The COB includes the integrated light of all faint galaxies in the field, but is corrected for faint stars below the photometric detection limit. The present detection of the COB at 10σ is the most significant measurement of this component to date.

Component	nW m^{-2} sr^{-1}
Total Sky	**24.22 ± 0.80**
Scattered Starlight (SSL)	5.17 ± 0.52
Scattered Milky Way Light (DGL)	2.22 ± 1.00
Faint Stars (FSL)	1.16 ± 0.18
Two-photon continuum (2PC)	0.93 ± 0.47
Scattered Galaxy Light (SGL)	0.07 ± 0.01
Cosmic Optical Background (COB)	**14.67 ± 1.47**
Integrated Galaxy Light (IGL)	6.61 ± 1.28
Anomalous Flux (dCOB)	**8.06 ± 1.95**

The figure shows the decomposition of the present field (leftmost column) as compared to the 7 fields in [1]. The reduced DGL and SSL contributions in the present field are evident.
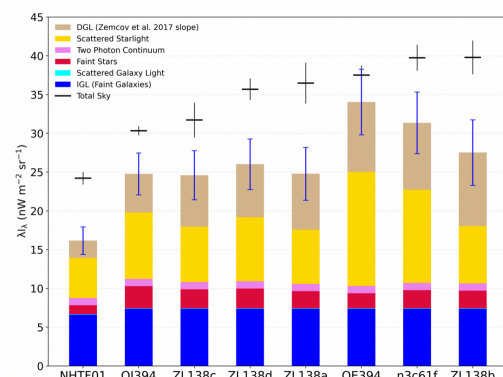
Anomalous Flux in the COB : The anomalous flux is evident in the figure above as the gap between the total sky (black crosses) and all known components, including the IGL, which is nominally part of the COB measurement for each field. Isolation of this component also includes a complete audit of all potential foregrounds associated with the spacecraft, itself. The figure below shows the anomalous component in the present field in blue, with that from the 7 fields from [1] in gray. In [1] we could only constrain the anomalous component at 2σ significance. The anomalous component in the present field is clearly consistent with the earlier work, but is now at $> 4\sigma$ significance.
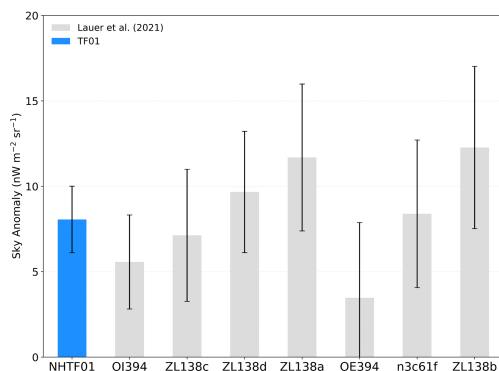

What It Means: The present COB measurement is plotted in the Figure below. Its drastically smaller error bars, as compared to measures made in Earth-space, such as those done with HST [6] or CIBER [7] (we also show an upper limit from the first attempt to measure the COB with New Horizons [3]), is due to simply having a camera far enough away from the Sun that zodiacal light doesn't matter anymore.

Despite this improvement, however, our COB flux is in strong conflict with the flux of integrated galaxy light and the COB flux inferred from the attenuation of very-high energy γ-rays [8,9]. The implied anomalous sky component in fact is slightly greater than the IGL flux, itself. We discussed this conflict in detail in [1]. In brief, [10] has argued that the galaxy counts on which the IGL is based are strongly incomplete. [11,12,13] have argued that the COB incudes a substantial component of light from stars tidally removed from galaxies, or a population of faint sources in extended halos, which would not be accounted for in standard galaxy counts.

The very-high energy γ-rays [8,9] constraints are based on the observations of very-high energy (~ 1 TeV) γ-rays from cosmologically distant AGN, which show that γ-rays are absorbed as a function of the distance of the source and the energy of the γ-ray photons. The γ-ray photons interact with optical photons

to produce e−/e+ pairs. [14] notes that if the ubiquitous dark matter in the universe is composed of axions, or axion-like particles, the γ-ray photons may mix with the particles and thus reduce the attenuation of the γ-rays over cosmological distances. This might allow for the higher COB flux found in the present study, in contrast to the [8,9] inferences.
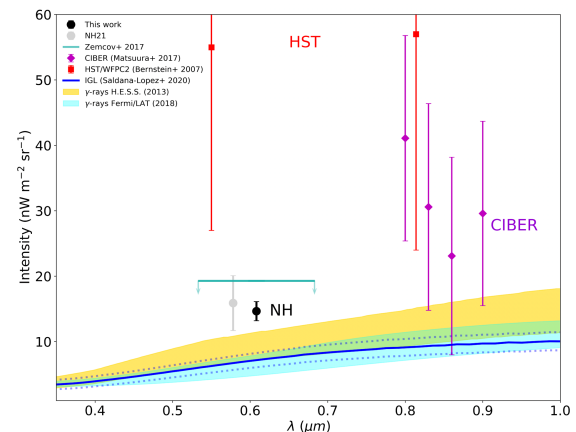
References: [1] Lauer, T. R., et al. 2021, ApJ, 906, 77. [2] Lauer, T. R., et al. 2022, ApJL, submitted. [3] Zemcov, M. et al. 2014, Science, 346, 732. [4] Cheng, A. et al. 2008, SSRv, 140, 189. [5] Weaver, H. A. et al. 2020, PASP, 132, 035003. [6] Bernstein, R. A. 2007, ApJ, 666, 663. [7] Matsuura, S. et al. 2017, ApJ, 839, 7. [8] H. E. S. S. Collaboration et al. 2013, A&A, 550, A4. [9] Fermi-LAT Collaboration et al. 2018, Science, 362, 1031. [10] Conselice, C. J. et al. 2016, ApJ, 830, 83. [11] Cooray, A. et al. 2012, Nature, 490, 514. [12] Zemcov, M. et al. 2014, Science, 346, 732. [13] Matsumoto, T. & Tsumura, K. 2019, PASJ, 71, 88. [14] Ringwald, A. 2014, arXiv:1407.0546.