A Measurement of the Extragalactic Background Light with NASA's New Horizons

Dennis Houlihan
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The extragalactic background light (EBL) offers a window into various ongoing processes in the universe and understanding it could potentially lead to profound discoveries. The EBL is the total light emitted from sources outside of the Milky Way Galaxy. A good measurement of the EBL can be used as a benchmark test where summed emission from point sources are compared to its intensity. Any discrepancies would imply the presence of new diffuse emission sources and can lead to major discoveries. In this project, we will be using data from the Linear Etalon Imaging Spectral Array (LEISA) aboard the New Horizons spacecraft to measure the EBL at the near-infrared range. The New Horizons spacecraft is one of very few outer solar system probes with astronomical viewing capabilities. Its location provides a unique vantage point where local foregrounds are mitigated, enabling an exciting chance at measuring the EBL.

Introduction

The universe is home to a large host of diffuse astrophysical backgrounds that if measured accurately, can yield tremendous knowledge on the emission processes that cause them. One of the most notable backgrounds is the Cosmic Microwave Background (CMB), which was emitted shortly after the Big Bang. It has shown to be a prime example of how fruitful diffuse background studies can be as it is a major source of information about the early universe[1].

The particular background of interest for this project is the extragalactic background light (EBL), which is the total emission of all light outside of our Milky Way Galaxy. It is believed that the EBL in UV, optical, and near infrared wavelengths consists mainly of redshifted starlight from unresolved galaxies[2]. Just as the CMB provides information on the early nature of the universe, a good measurement of the EBL could potentially provide new information on these processes as well as reveal other sources of emission[3].

Prior ground-based measurement of the EBL has proven to be extremely difficult as there are numerous diffuse foregrounds that must be taken into account, as well as atmospheric disturbances. The New Horizons spacecraft and its instruments provide an exciting opportunity to measure the EBL from an outer solar system vantage point that is free from any atmospheric noise[3]. The affect of other diffuse foregrounds are greatly mitigated as well. For this project, we will be measuring the EBL in the near infrared spectral range. To do this, we will be using data from the New Horizons instrument known as the Linear Etalon Imaging Spectral Array (LEISA).

Measuring the EBL

The formation of stars and galaxies release large amounts of photons. Therefore, diffuse background radiation in various parts of the electromagnetic spectrum are an expected result of these processes. One such background is the extragalactic background, which is defined as the total emission of all light of all wavelengths outside of the Milky Way. In this project, we will be focusing on the near-IR range, which is thought to be mainly from redshifted light emitted by nuclear processes within stars of other galaxies.

A good measurement of the EBL can be used as a valuable test, where integrated light from point sources such as all galaxies can be compared. Any discrepancies among comparisons would therefore indicate the presence of other sources of emission. It could also potentially lead to exciting discoveries such as diffuse photons associated with dark matter annihilation, the signature of recombination from the epoch of reionization, and the presence of intra-halo light in the intragalactic medium[3].

Local Foregrounds

Despite the interest in the EBL, direct measurements of it are extremely difficult due to bright diffuse foregrounds including the integrated star light (ISL), zodiacal light (ZL), and the diffuse galactic light (DGL). While the New Horizons location alone will mitigate most of these foregrounds, we still must take them into account when making our measurements.

The integrated star light is the total sum of light emitted from stars within the Milky Way Galaxy. It is easy to account for brighter stars, however, there are faint stars that telescopes cannot detect directly that still contribute to this foreground.

The zodiacal light is caused by solar light scattered by interplanetary dust particles within the plane of the ecliptic. This dust originates from many sources such as comets, asteroids, and Edgeworth-Kuiper Belt objects[1] and spread out after they are ejected from their parent bodies. The ZL is concentrated within the plane of ecliptic and is less appreciable outside of it. Furthermore, interplanetary dust (IPD) in general is more prominent within the inner solar system, as measurements from Helios, Galileo, and Pioneers 8/9 show a steep decline in

IPD density outside of 1AU[3]. From this, we can infer that IPD population at the location of measurements is small and decreasing with distance. Fortunately for us, New Horizons will be out of the plane of the ecliptic, so the zodiacal light is not expected to appreciably contribute to the sky brightness. The spacecraft's outer solar system location would also lead us to infer that we should not suffer from strong IPD contamination in our measurements.

In a similar way to the interplanetary dust, dust along the plane of the galaxy scatters light from stars within the galaxy. The resulting foreground is known as the diffuse galactic light (DGL). As the ZL is brightest along the ecliptic, the DGL is brightest in the galactic plane and fainter at higher galactic latitudes[4]. It is important to note that it the DGL is due to dust in interstellar space, not interplanetary space. Therefore, outer-solar system location does not mitigate this light contribution and no where in the sky can we ignore this foreground.

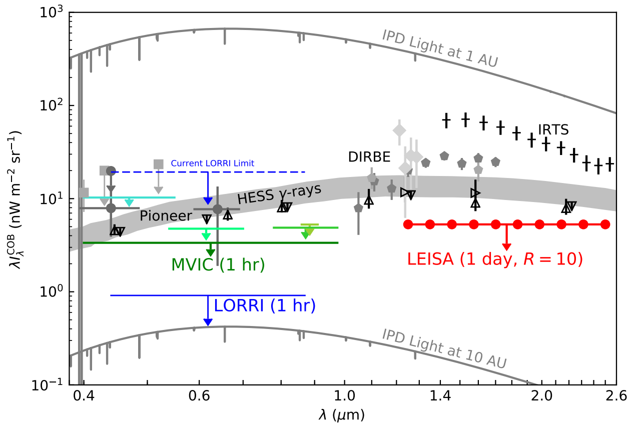

FIG. 1:[3]Measurements of the EBL surface brightness λI_λ^{EBL} in the optical and near-IR. The filled in data points represent direct photometric measurements while the open symbols represent the integrated galactic light. The shaded region indicates the HESS γ-ray constraints on the extragalactic background light. The red bar shows the wavelength range of LEISA and expected sensitivity for an integration time of t_{int}= 1 day.

LEISA

The main purpose of New Horizons and its instruments is to map the surface geology and composition of objects in the Pluto/Charon system and the Kuiper belt[5], but its instruments can double as astronomical telescopes. One such instrument is Ralph, a visible/near-IR multispectral imager. It consists of a telescope that feeds two sets of focal planes. One of these focal planes is LEISA, a wedged filter infra-red spectral imager that creates spectral maps in the 1.25–2.5 micron short wave infrared spectral region[5], and the instrument of choice for this project.

LEISA Instrument Parameters	
FOV:	0.9°x0.9°
Single Pixel FOV:	60.83μrad x 60.83μrad
Pixel Size:	40μm x 40μm Pixels
Telescope Aperture:	75mm
Focal Length:	657.5mm
Spectral Resolution:	$\lambda/\Delta\lambda = 240$
Dark Current:	40 counts/second
Sensitivity:	2.45 x 10^{-3} DN/photon
SNR:	32

TABLE I: Tabulated parameters for LEISA. All values were found in the Ralph instrument paper[5]. The SNR is the average of two scans.

Figure 1 shows the sensitivities of three New Horizons instruments (MVIC, LORRI, and LEISA) as compared to current measurements of the optical and near-IR backgrounds. Compared to MVIC and LORRI, LEISA has a much higher wavelength range (1.25 - 1.5μm), which helps in detecting fainter objects such as redshifted galaxies. LEISA also has a large field of view (0.9° x 0.9°), which is good since the EBL is spread throughout the sky. Having a large field of view means measuring a larger area in the sky, which will help get a better sense of the nature of the EBL. LEISA's wavelength range is also important as measurements from 1-3μm have been very challenging on Earth due to the bright foregrounds mentioned prior.

Although it is in a good vantage point, LEISA's parameters are not optimal for measuring the EBL. In Table I, LEISA's parameters are listed. For example, LEISA's small aperture (75mm) and spectral resolution (R = 240) means that it has a poor per-pixel sensitivity. This in turn requires a significantly longer integration time (1 day as compared to 1 hour for MVIC and LORRI) to make a constraining measurement of the EBL. As a result, LEISA's measurements of the EBL will be both very interesting as well as very challenging.

Budget

There are no planned expenses for this project.

Timeline

Capstone I

- Learn about LEISA (3 weeks)
- Data quality assessment and preliminary cuts (6 weeks)

- Analysis pipeline validation and checks (4 weeks)
- Write Paper and Presentation (2 weeks)

Capstone II

- Finalize data cuts (1 week)
- EBL Analysis (4 weeks)
- Systematics and error assessment (6 weeks)
- Scientific Interpretation (2 weeks)
- Write paper and presentation (2 weeks)

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* Rochester Institute of Technology, School of Physics and Astronomy, Faculty Advisor: Dr. Michael Zemcov

[1] Proposal

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