New Synoptic Observations of the Cosmic Optical Background with New Horizons

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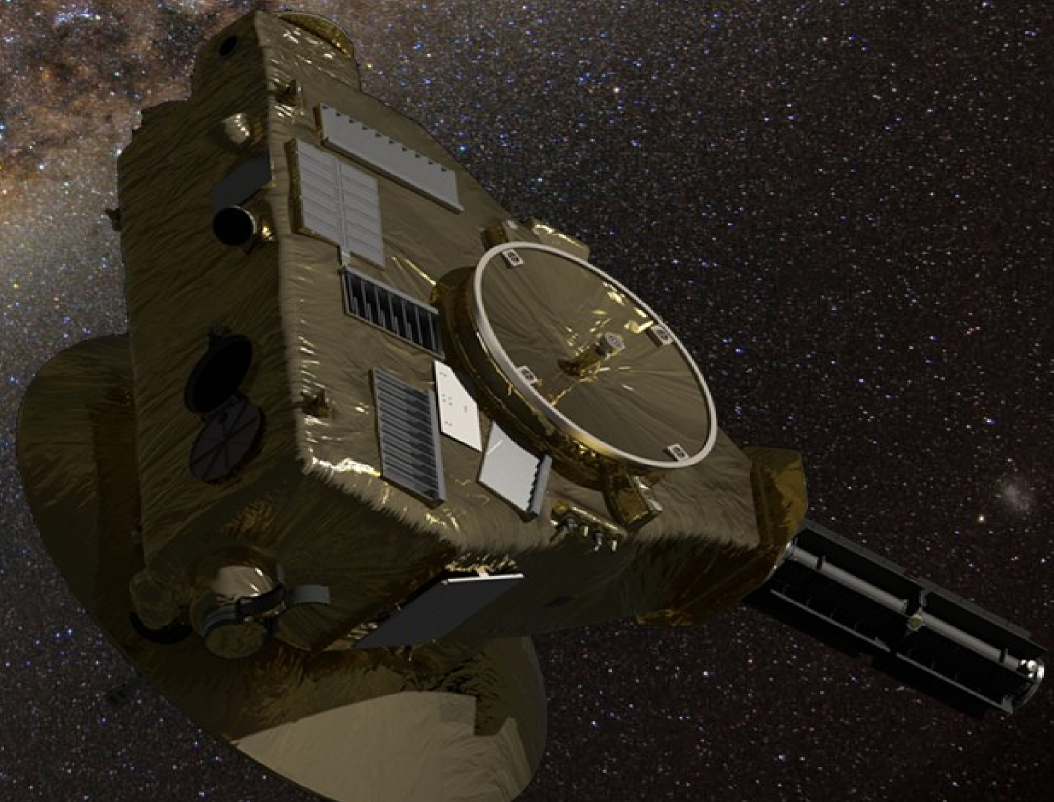
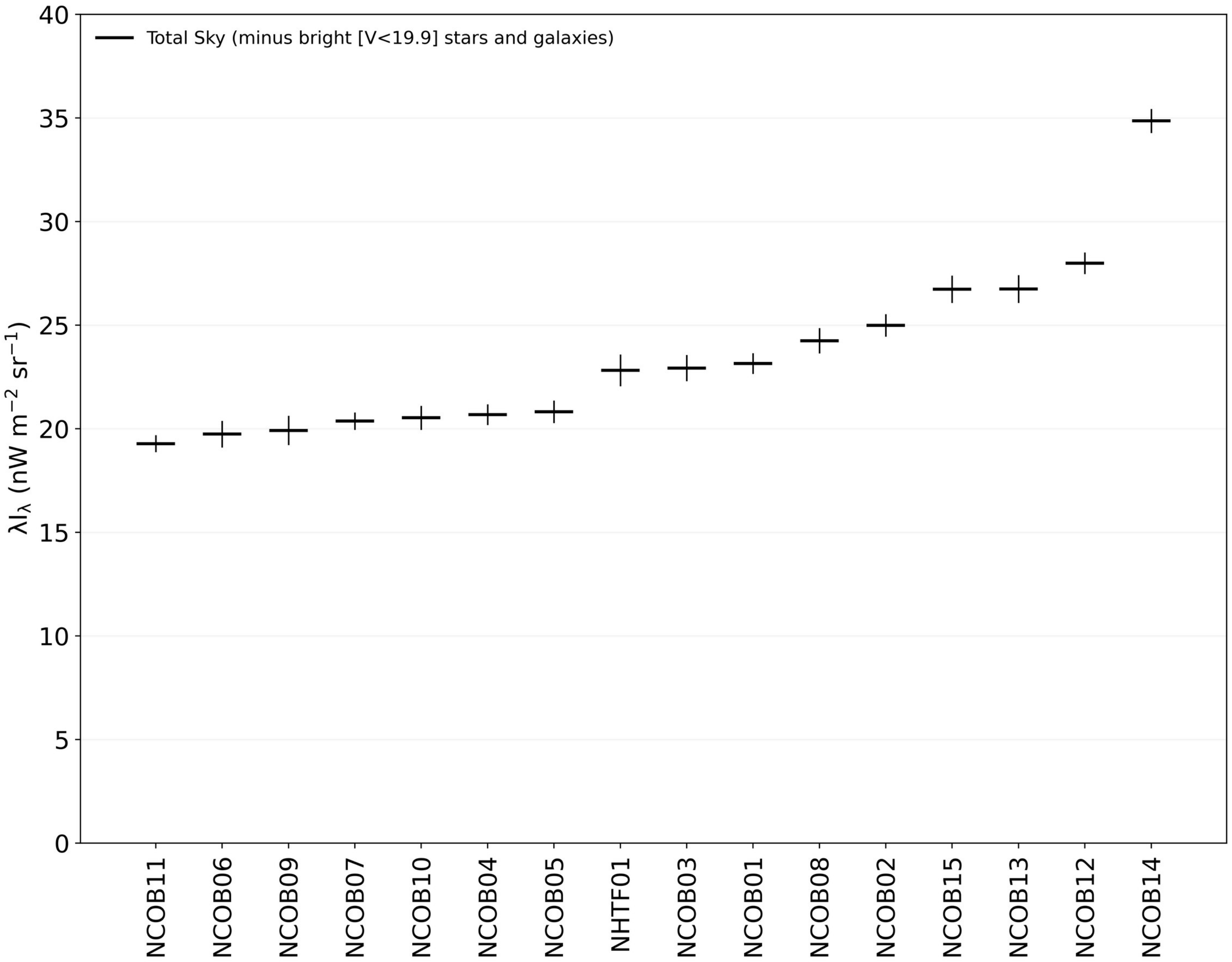


Diffuse Cosmic Backgrounds and the Low Surface Brightness Universe
Aspen Center for Physics, April 2024

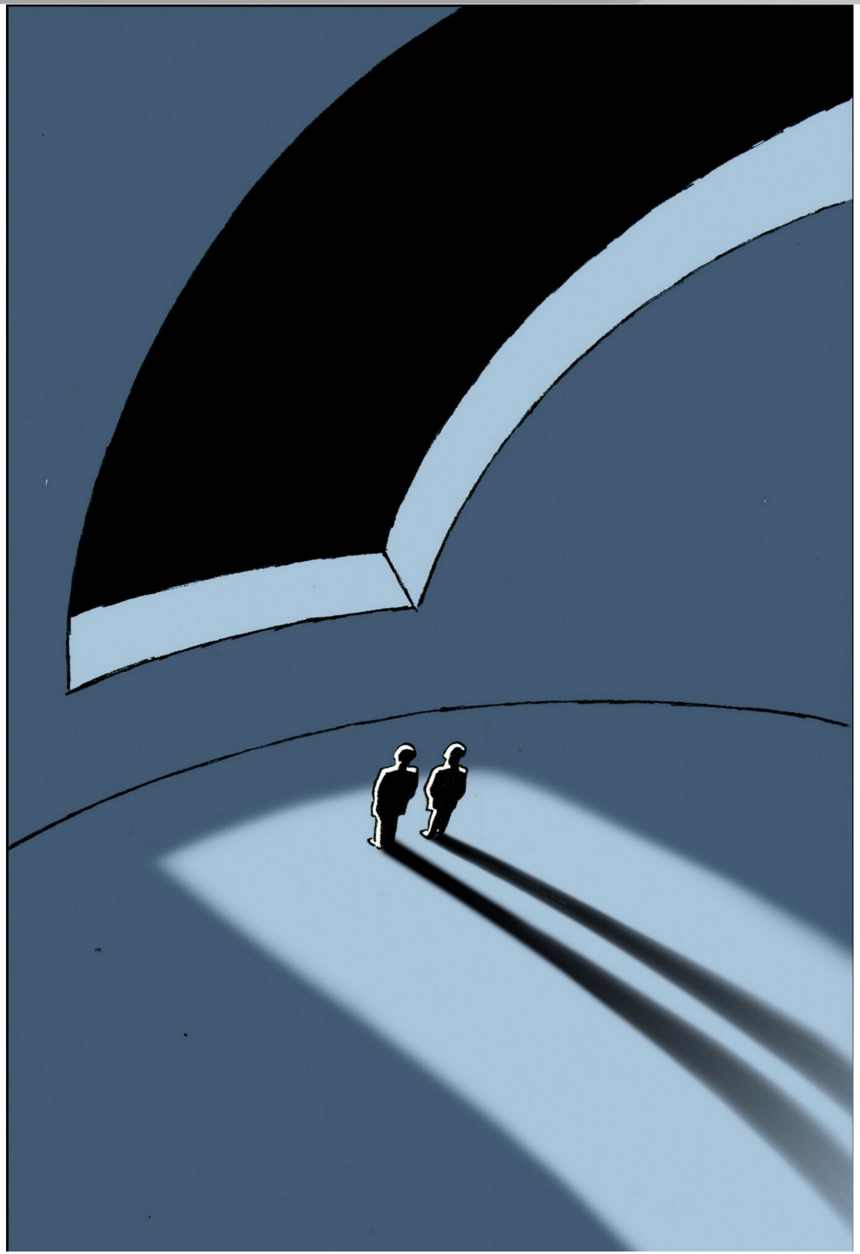
Detection of the Cosmic Optical Background



Can we account for all the flux in every field from known instrumental and astrophysical sources?

If so, then the source of the COB is the known census of galaxies.

Detection of the Cosmic Optical Background



Preview of results:

COB = 11.08 ± 1.65 (6.7σ)
COB – IGL = 2.81 ± 2.03 (1.4σ)

Where IGL = integrated light from known galaxies with V ≤ 30 mag (8.17 ± 1.18)

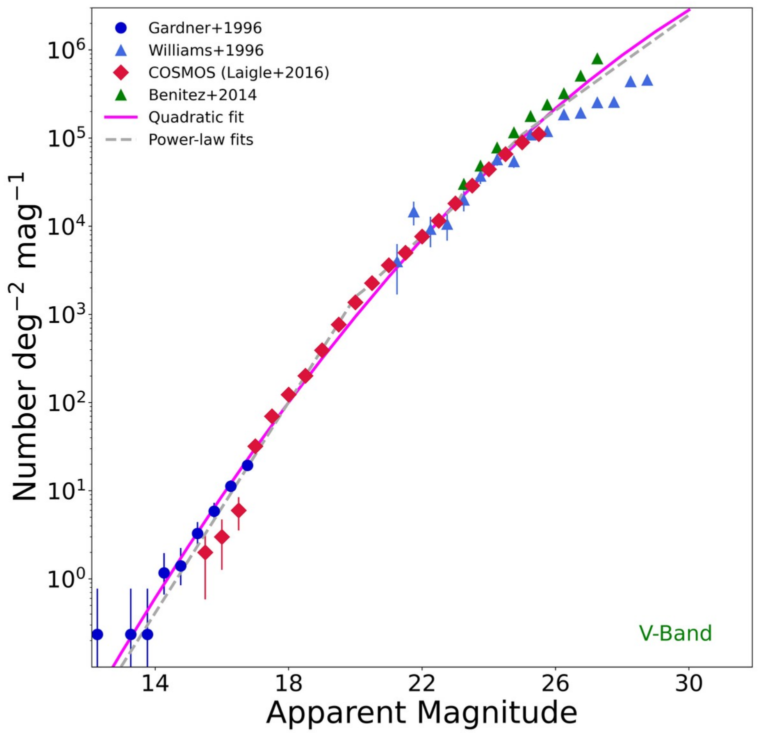
We thus cannot falsify the hypothesis that the COB is due entirely to the integrated light from galaxies.

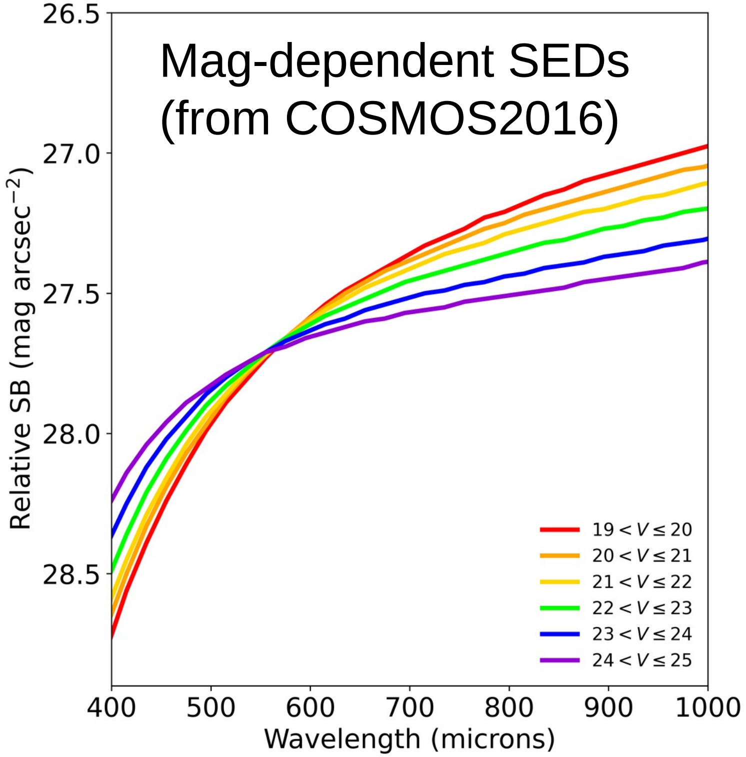
The Components of the Detected Sky Level

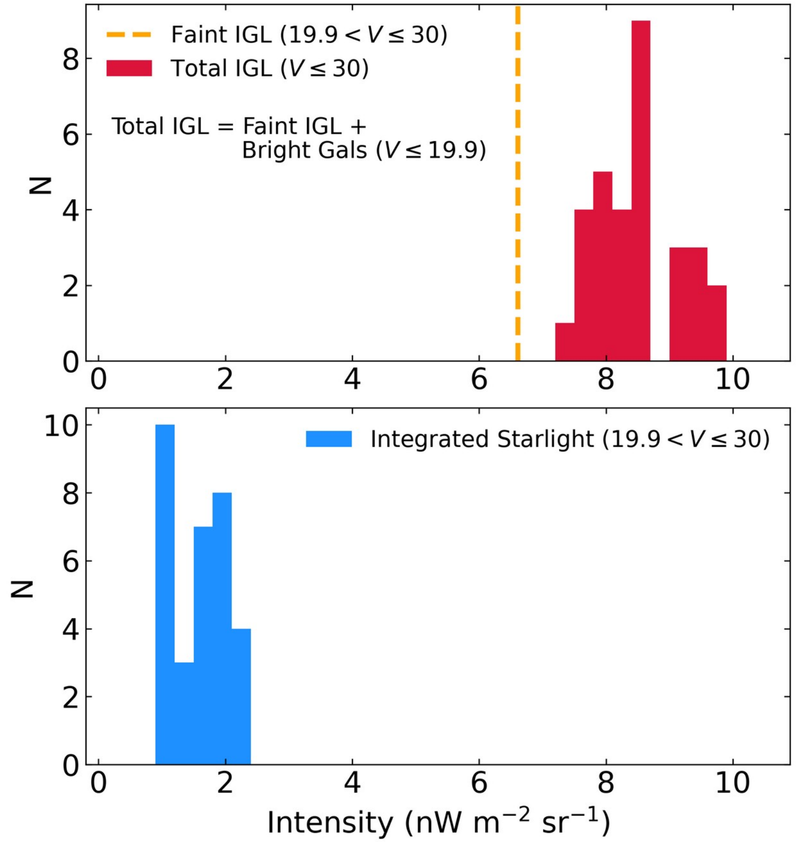
- Integrated Starlight (ISL) = light from faint stars below the LORRI detection limit (V=19.9).
- Integrated Galaxy Light (IGL) = light from faint galaxies below the LORRI detection limit (V=19.9).
- Diffuse Galactic Light (DGL) = optical starlight reflected/scattered off of dust in the Milky Way.
- H-alpha emission from the interplanetary and interstellar medium (from WHAM survey).
- Scattered Light (SSL + SGL) = light that is scattered into the LORRI detector from off-axis stars and bright galaxies.
- Stars and galaxies within the LORRI FOV that are above the detection limit (V=19.9) are masked out and excluded from total sky signal.

Integrated Star and Galaxy Light

- Source counts are computed over range $19.9 < V \leq 30$ based on power law fits to either observed or simulated source counts. We then compute the integrated V-band SB from these sources on the sky over that flux range.
- SEDs are derived using UBVRIZJHK photometry as a function of magnitude, normalized to the above SB.
- For galaxies: we use COSMOS2016 and a variety of other catalogs. For stars: we use TRILEGAL simulations.
- The IGL and ISL are then computed using normalized SEDs over the LORRI response (weighted by N(m)).
- Total IGL shown below includes bright ($V \leq 19.9$) galaxies (from DESI / DECam Legacy Survey data).

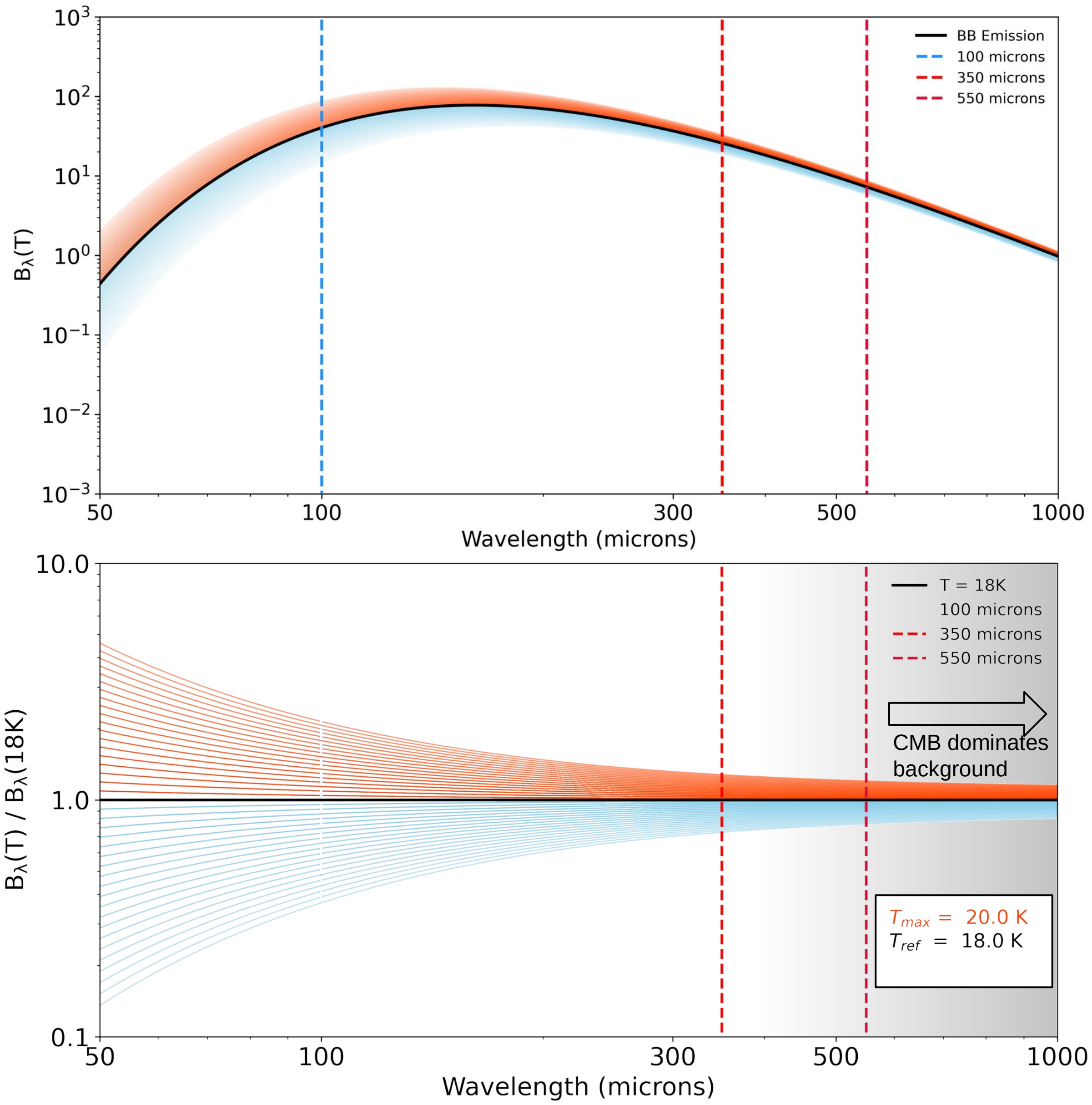






The Diffuse Galactic Light – FIR Intensity Relation

- We use FIR emission to estimate the amount of diffuse optical light that scatters off of dust in the Milky Way.
- This diffuse optical light can account for 30% - 50% of the total sky signal we detect with LORRI.
- We initially used the 100 μm data from IRAS but we switched to 350 μm and 550 μm data from Planck for the current work:
  - 100 μm lies on the Wien side of the BB curve for interstellar dust whereas 350, 550 μm lie on the Rayleigh-Jeans side.
  - 350, 550 μm flux is less susceptible to dust temperature variations than 100 μm flux.



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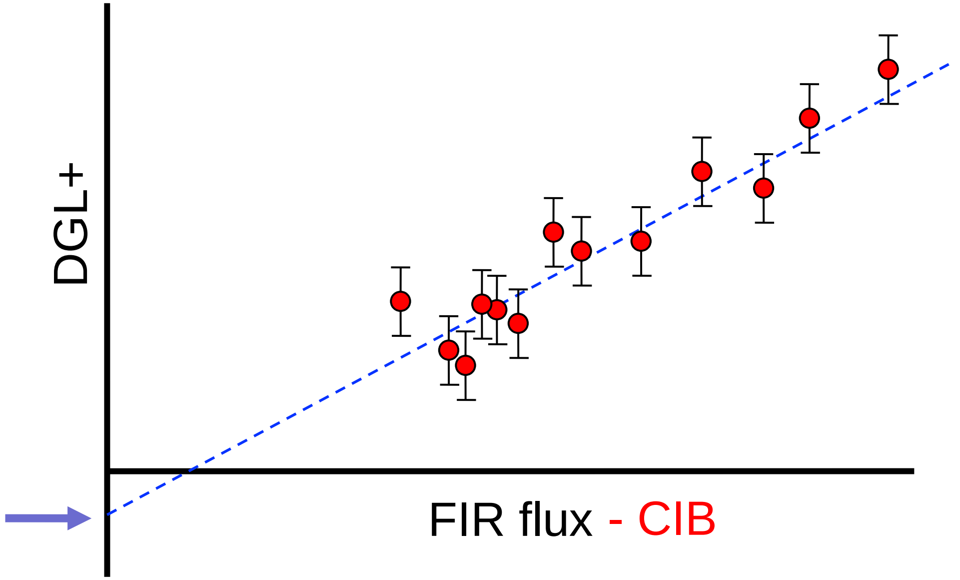
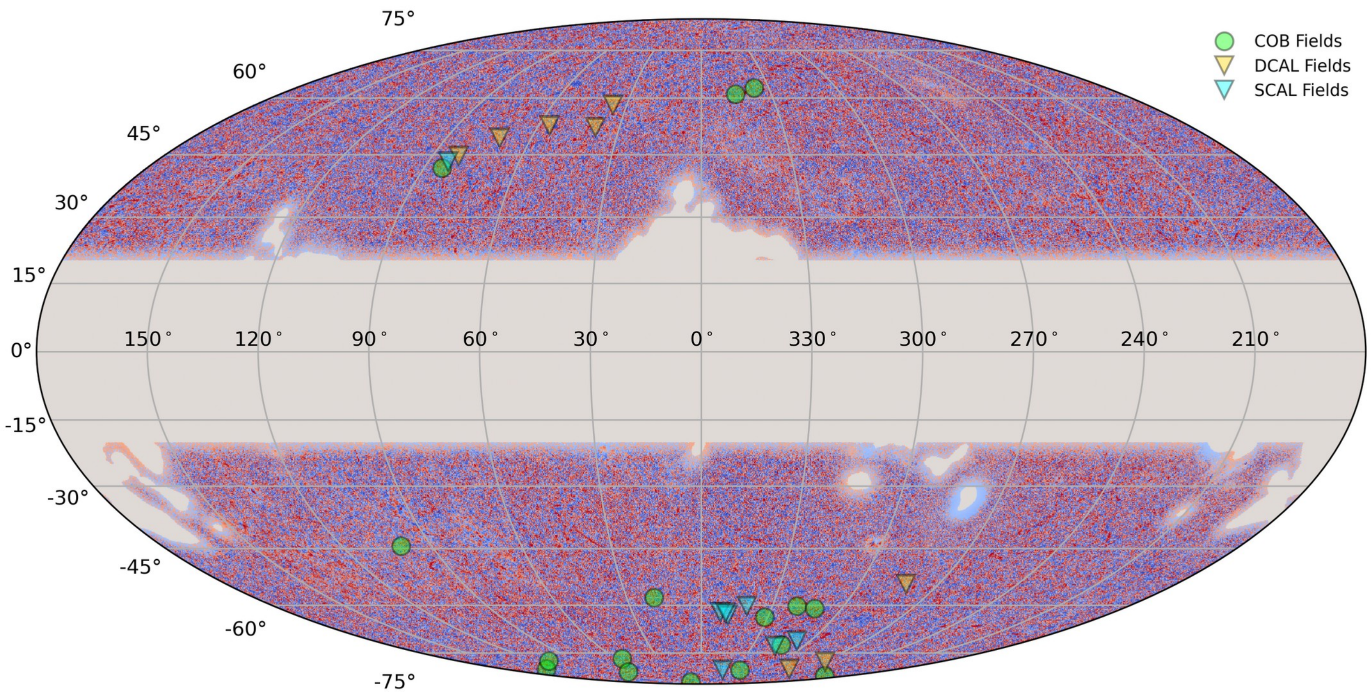
- We initially used the 100 μm data from IRAS but we switched to 350 μm and 550 μm data from Planck for the current work:
  - The mean cosmic infrared background (CIB) level is more precisely measured at these longer wavelengths. The CIB level must be subtracted from all FIR fluxes to get the MW dust component.

DGL+ = Total Sky – IGL – ISL – SSL – SGL - Hα

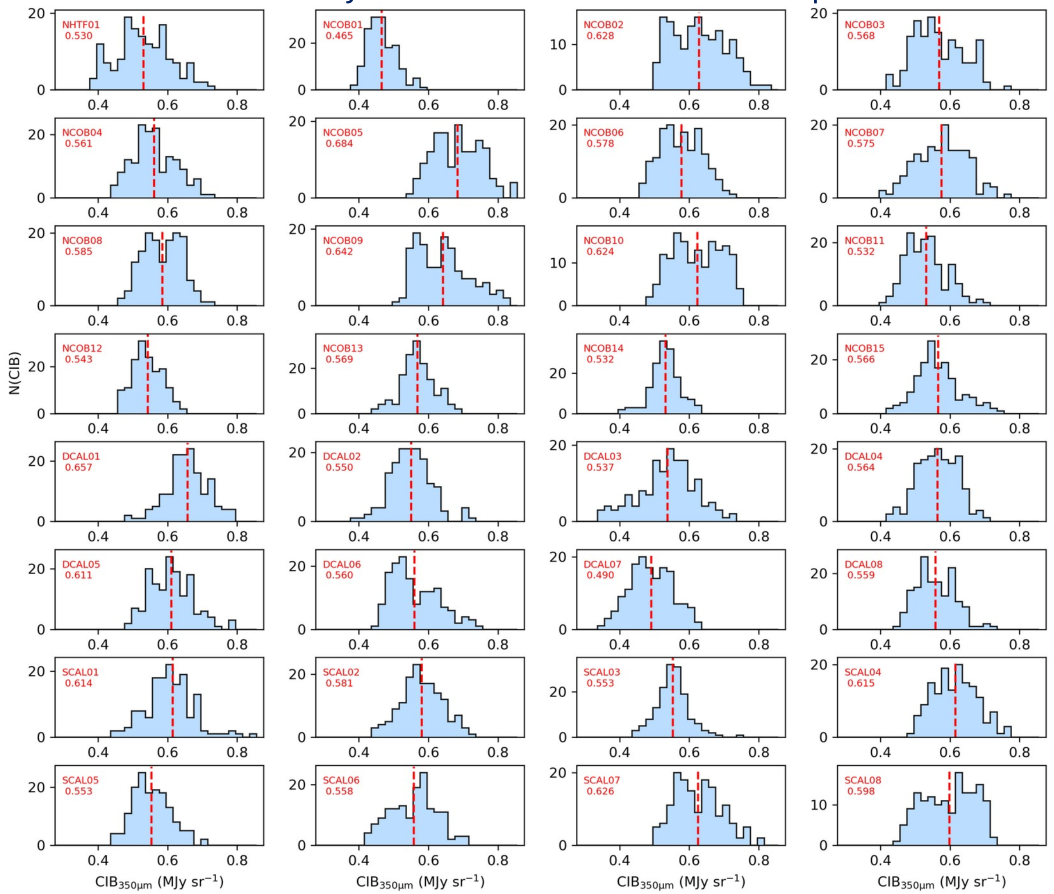
where
IGL = light from faint galaxies below detection limit
ISL = light from faint stars below detection limit
SSL = Scattered light from off axis bright stars
SGL = Scattered light from off axis bright galaxies
Hα = local emission from ISM (<0.3 nW m^{-2} sr^{-1})



Determining the Cosmic IR Background (CIB) level for each field



CIB intensity distribution at each KEM2 field position

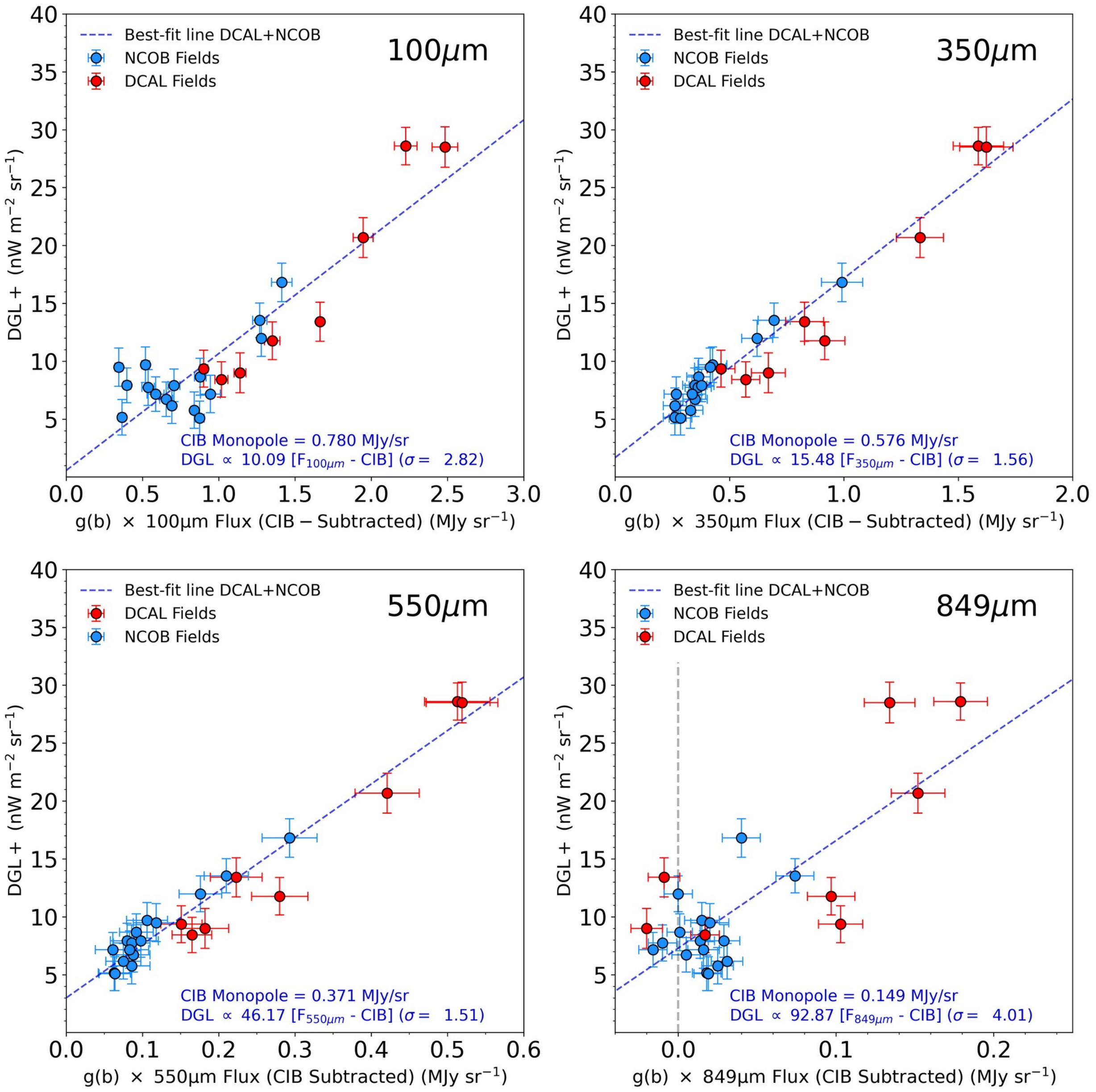


- Adopt the 857 GHz (350 μm) monopole value = 0.576 ± 0.034 MJy/sr
- Adopt the 545 GHz (550 μm) monopole value = 0.371 ± 0.009 MJy/sr

} Odegard et al. 2019

- Use Planck GNILC CIB residual maps to add the observed deviations from these monopole levels.
  - GNILC = Generalized Needlet Internal Linear Combination (Planck Collaboration 2016)

The Diffuse Galactic Light – FIR Intensity Relation



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Lowest scatter at 550 microns with next best trend at 350 microns.

Wavelength (μm)	RMS Scatter
100	2.82 nW m^{-2} sr^{-1}
350	1.56 nW m^{-2} sr^{-1}
550	1.51 nW m^{-2} sr^{-1}
849	4.01 nW m^{-2} sr^{-1}

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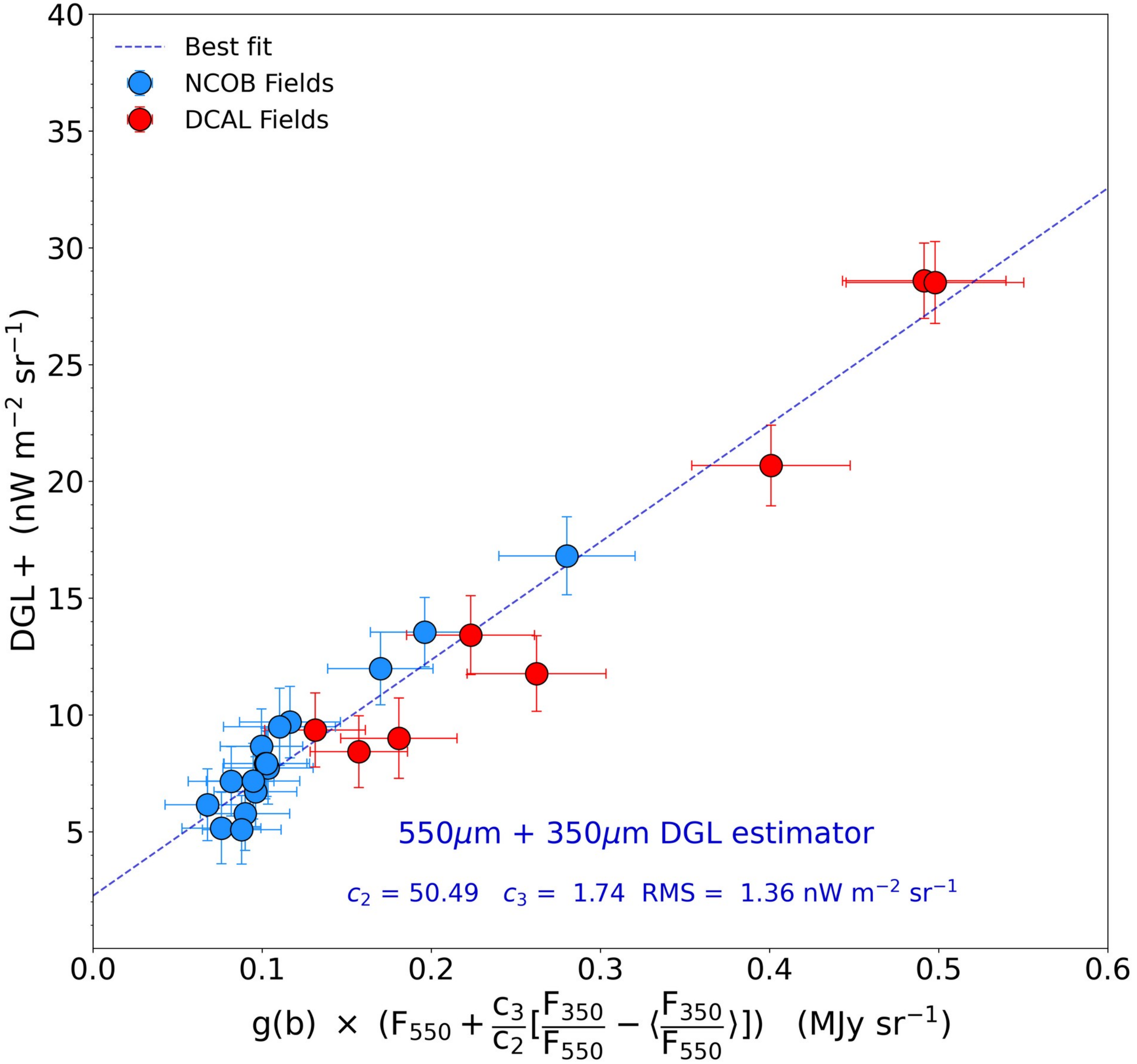

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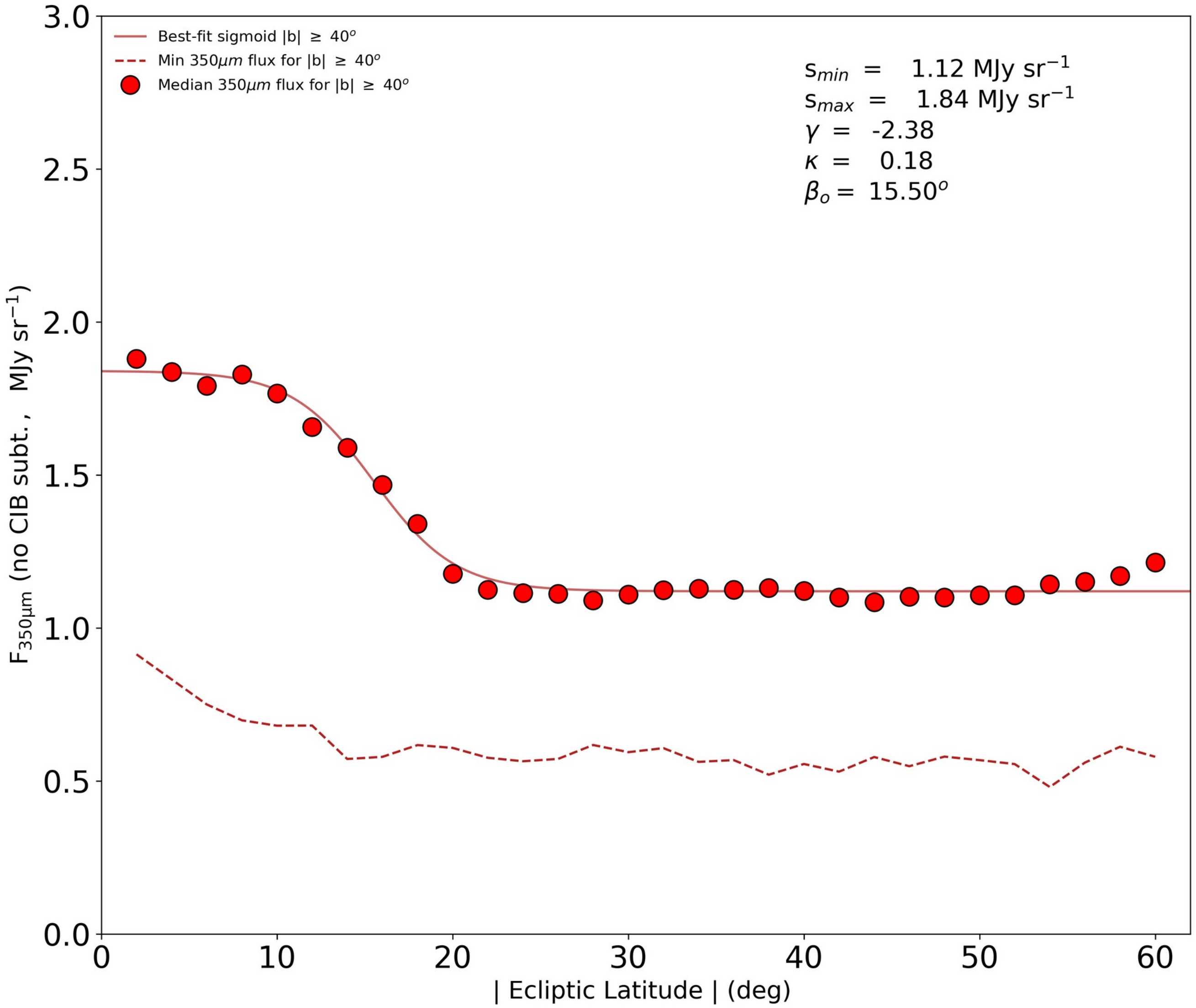
DGL+ Estimator:
)

where = geometric phase function and best fit coefficients are:

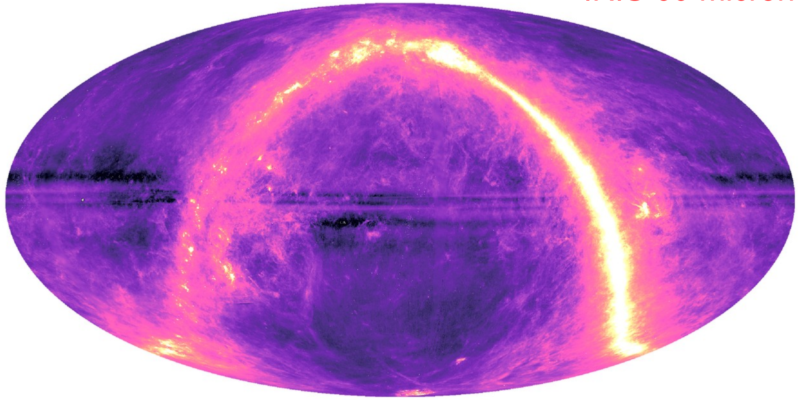
c_1 = 2.26 nW m^{-2} sr^{-1}
c_2 = 50.49 (nW m^{-2} sr^{-1})/(MJy sr^{-1})
c_3 = 1.74 nW m^{-2} sr^{-1}
RMS = 1.36 nW m^{-2} sr^{-1}

Is there an excess zodi signature in the FIR sky map?



Selecting data at high galactic latitude reveals a rise in the median FIR flux at low ecliptic latitude.

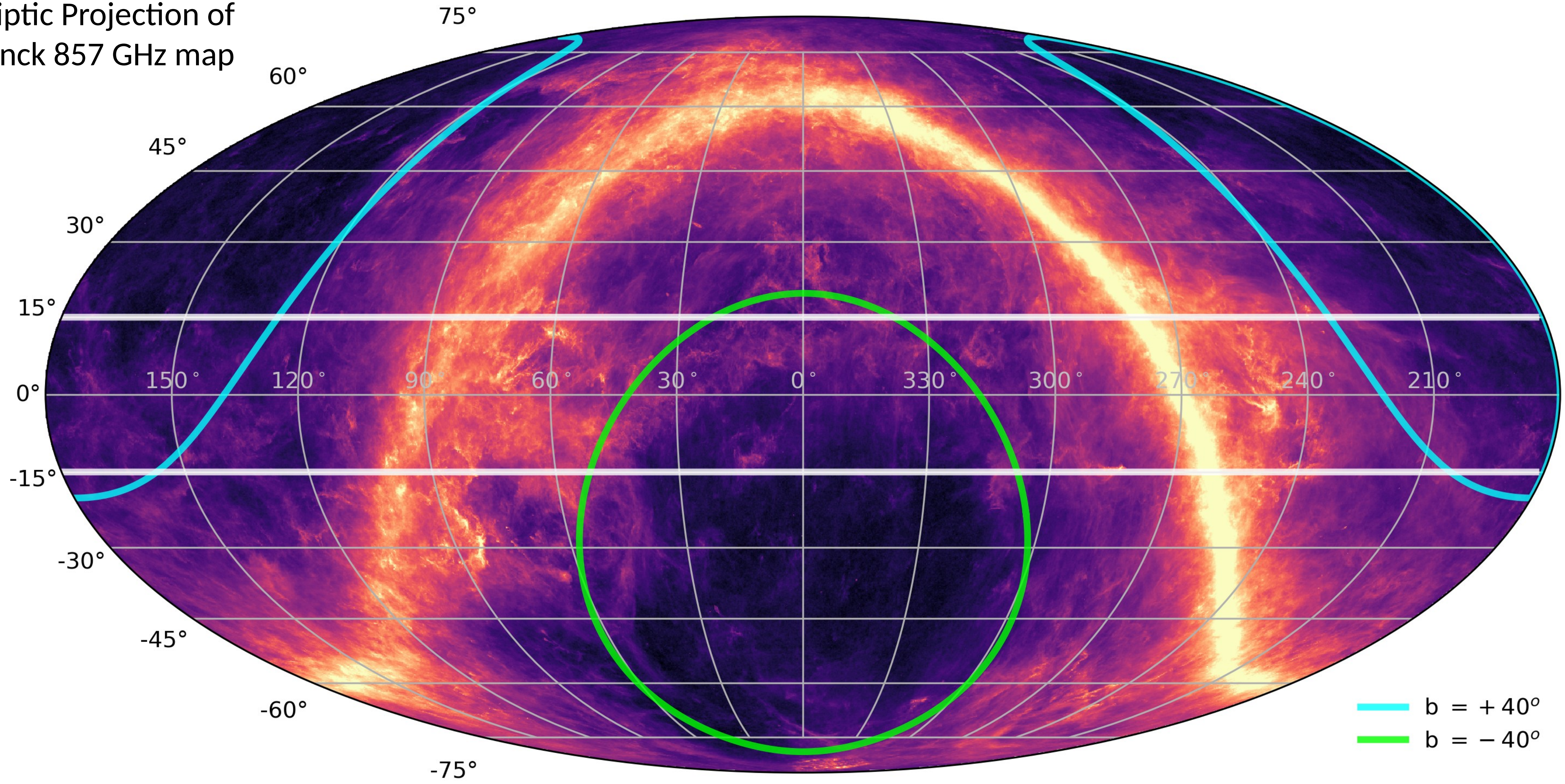
IRIS 60 micron map



Is this effect in the 100 micron and 350 micron maps real or is it due to a residual in the model used to subtract the zodiacal light from the FIR sky survey?

Answer: it is real and not a residual signal.

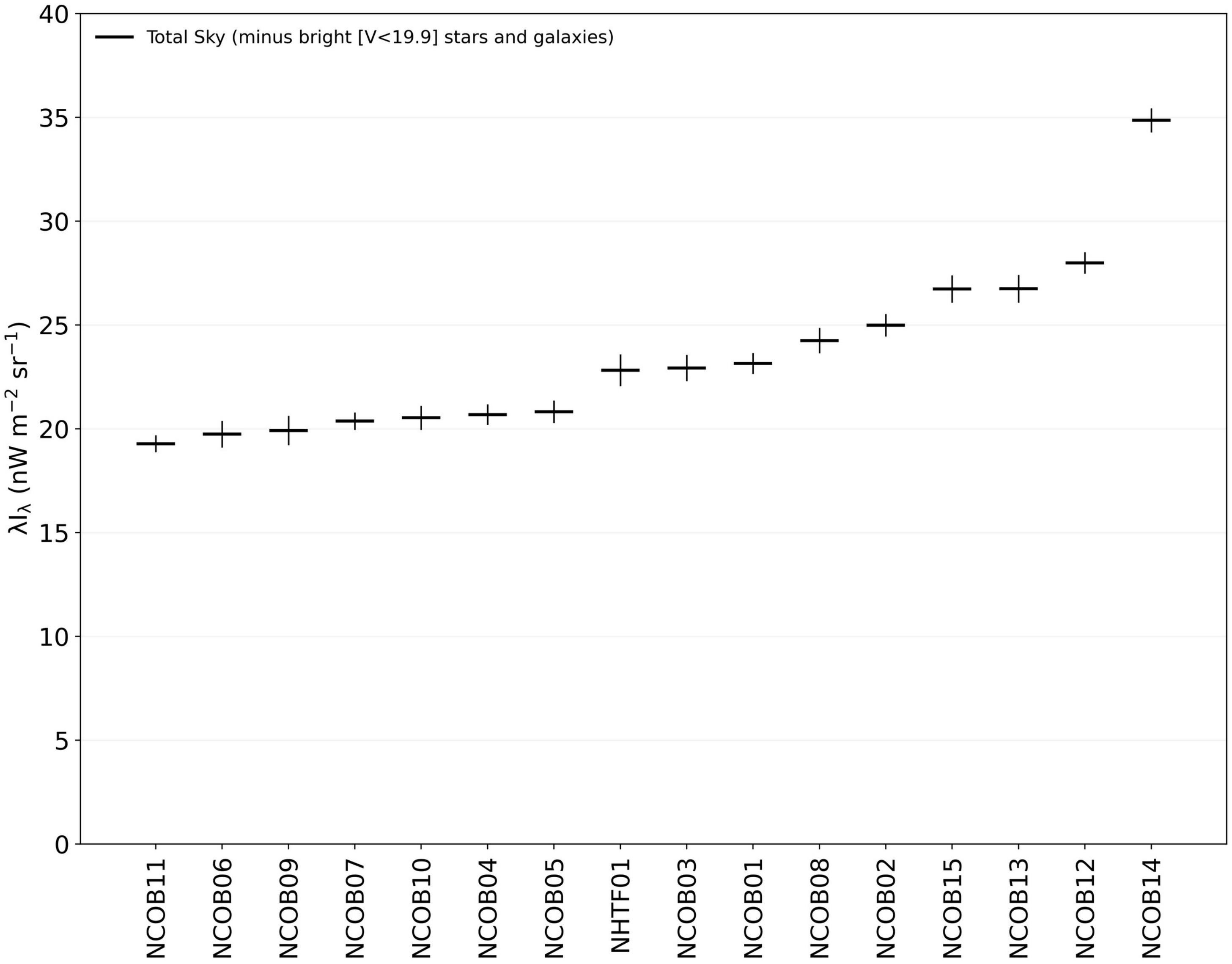
Ecliptic Projection of
Planck 857 GHz map



The amplitude of any zodiacal light subtraction residual in the 350 micron map is small. The rise in median flux with decreasing ecliptic latitude at high galactic latitude is due to real structure in the Milky Way dust distribution.

A ZODI RESIDUAL CORRECTION IS NOT REQUIRED

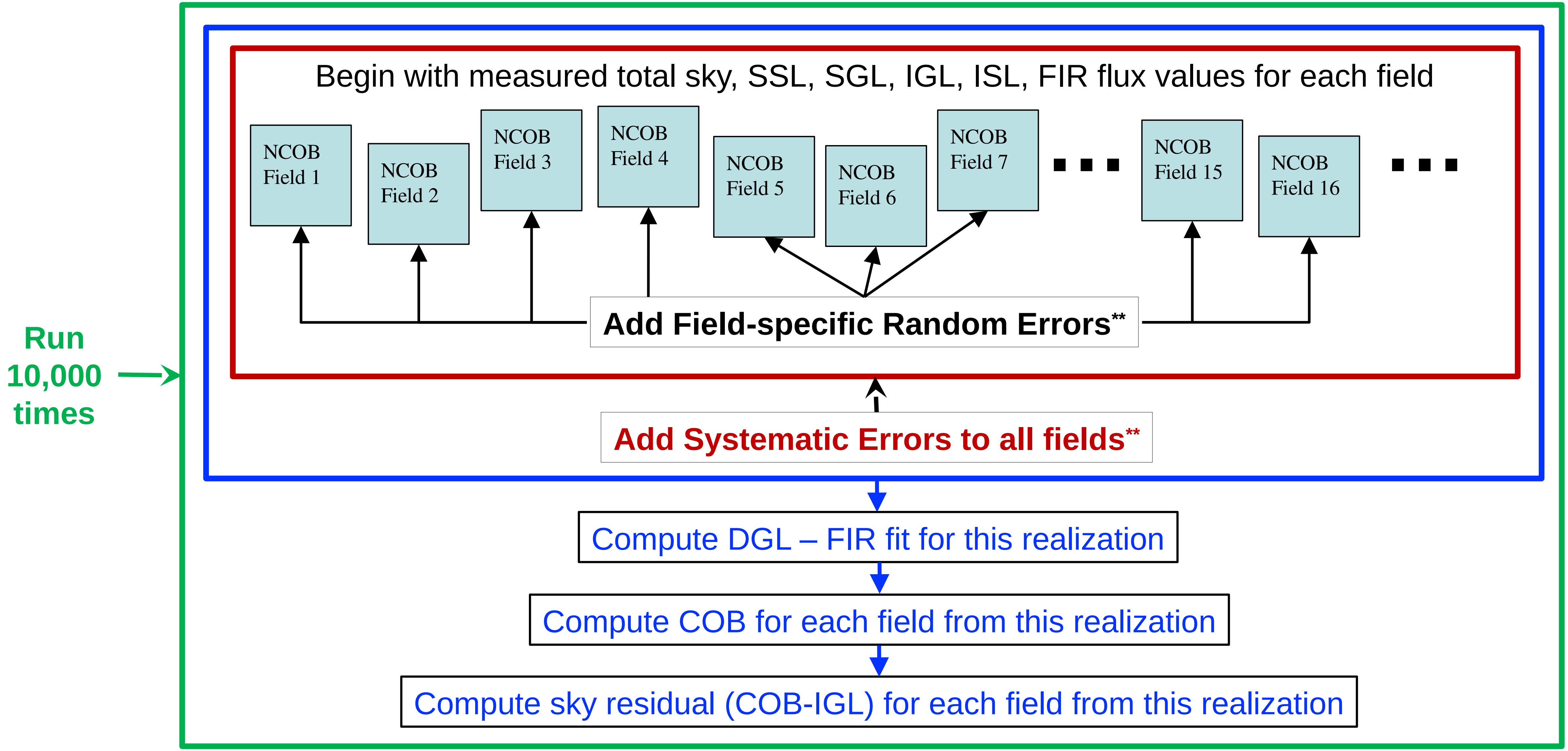
The Components of the Detected Sky Level



Propagation of the systematic and random errors

Parameter	Random Error	Systematic Error
Integrated faint galaxy light (IGL)	✓	✓
Integrated faint star light (ISL)	✓	✓
Scattered starlight (SSL)	Negligible	✓
Scattered galaxy light (SGL)	Negligible	✓
Total sky level	✓	✓
Diffuse Galactic light (DGL)	✓	✓
H-alpha intensity	✓	Negligible
FIR photometry	Negligible	✓
CIB monopole value	Negligible	✓
DGL – FIR Relation	✓	✓

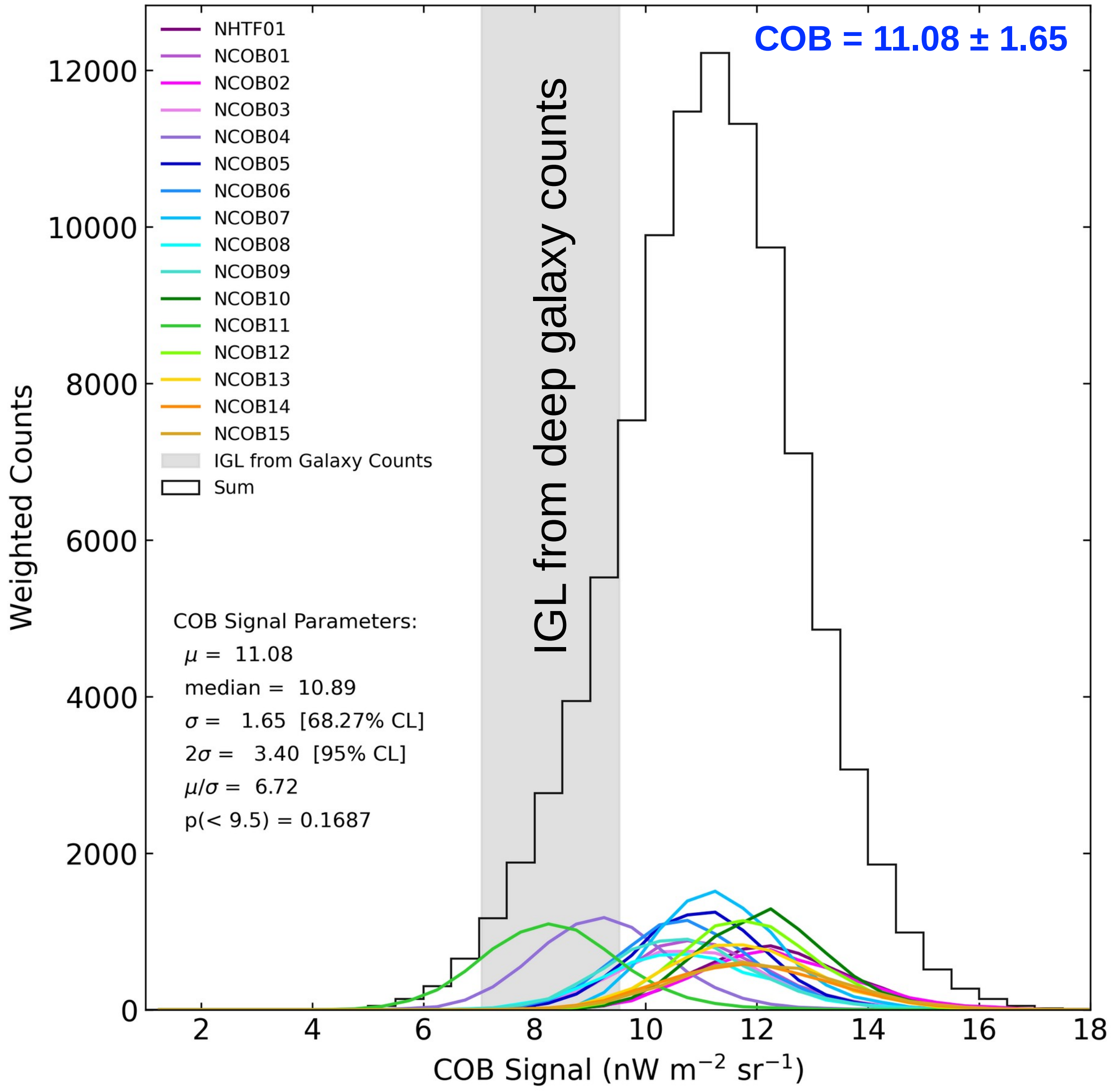
Propagation of the systematic and random errors

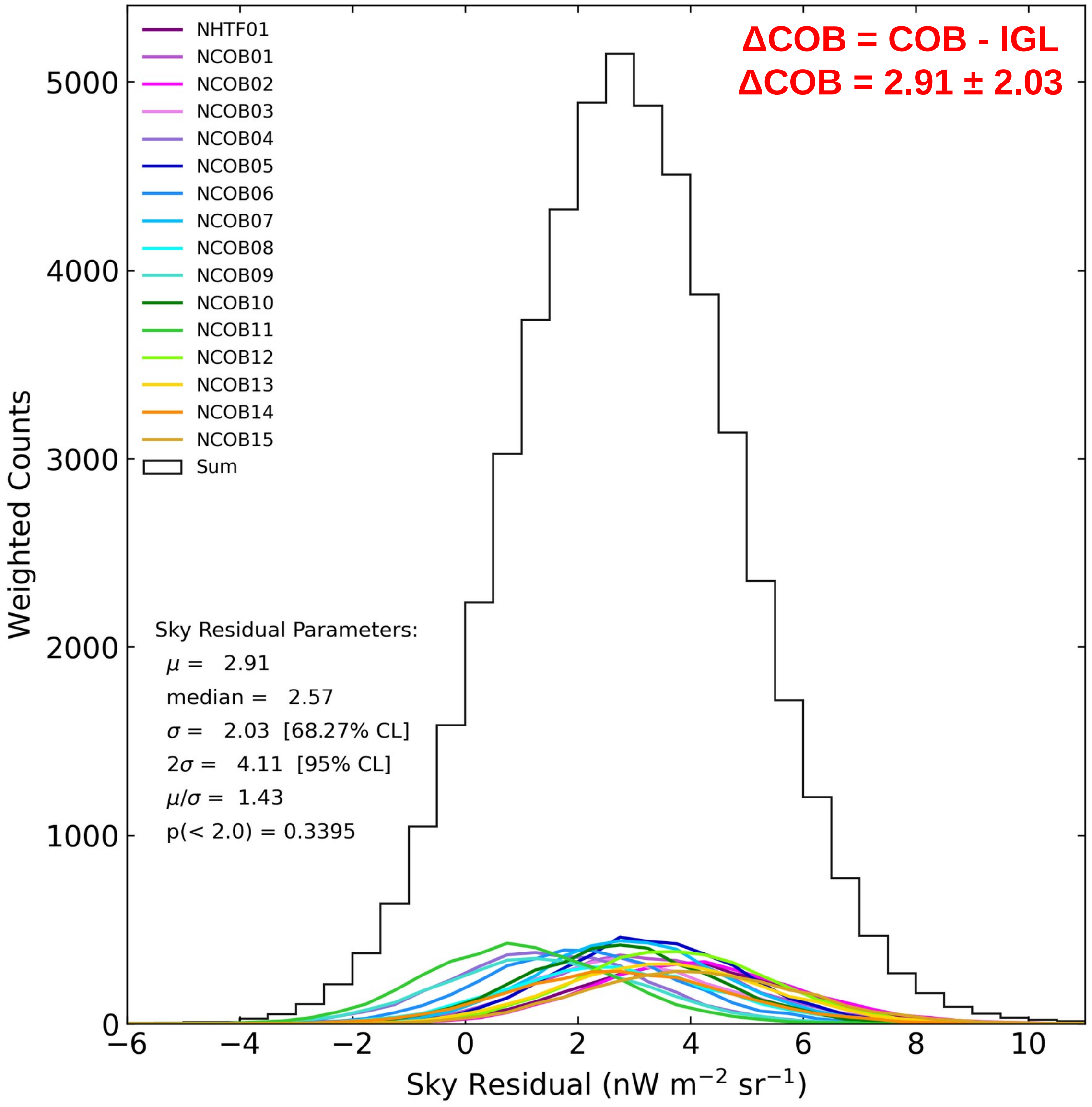


**Random and systematic error values are randomly drawn from Gaussian distributions with the appropriate dispersions.

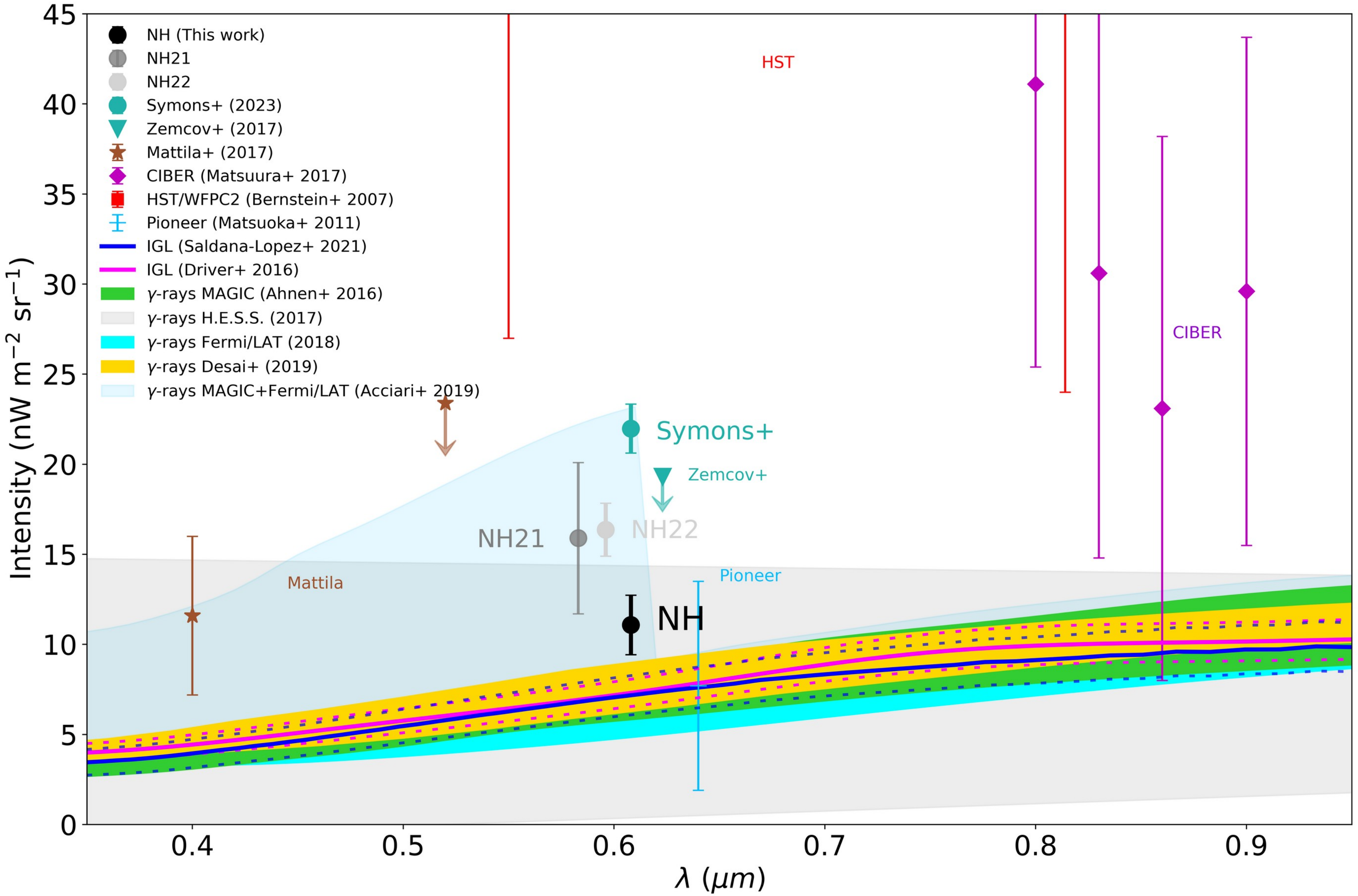
NH Results: COB detected at 6.7 sigma

Individual field probability distributions are weighted by the inverse square of the uncertainties in COB and ΔCOB





Comparison to Previous Results



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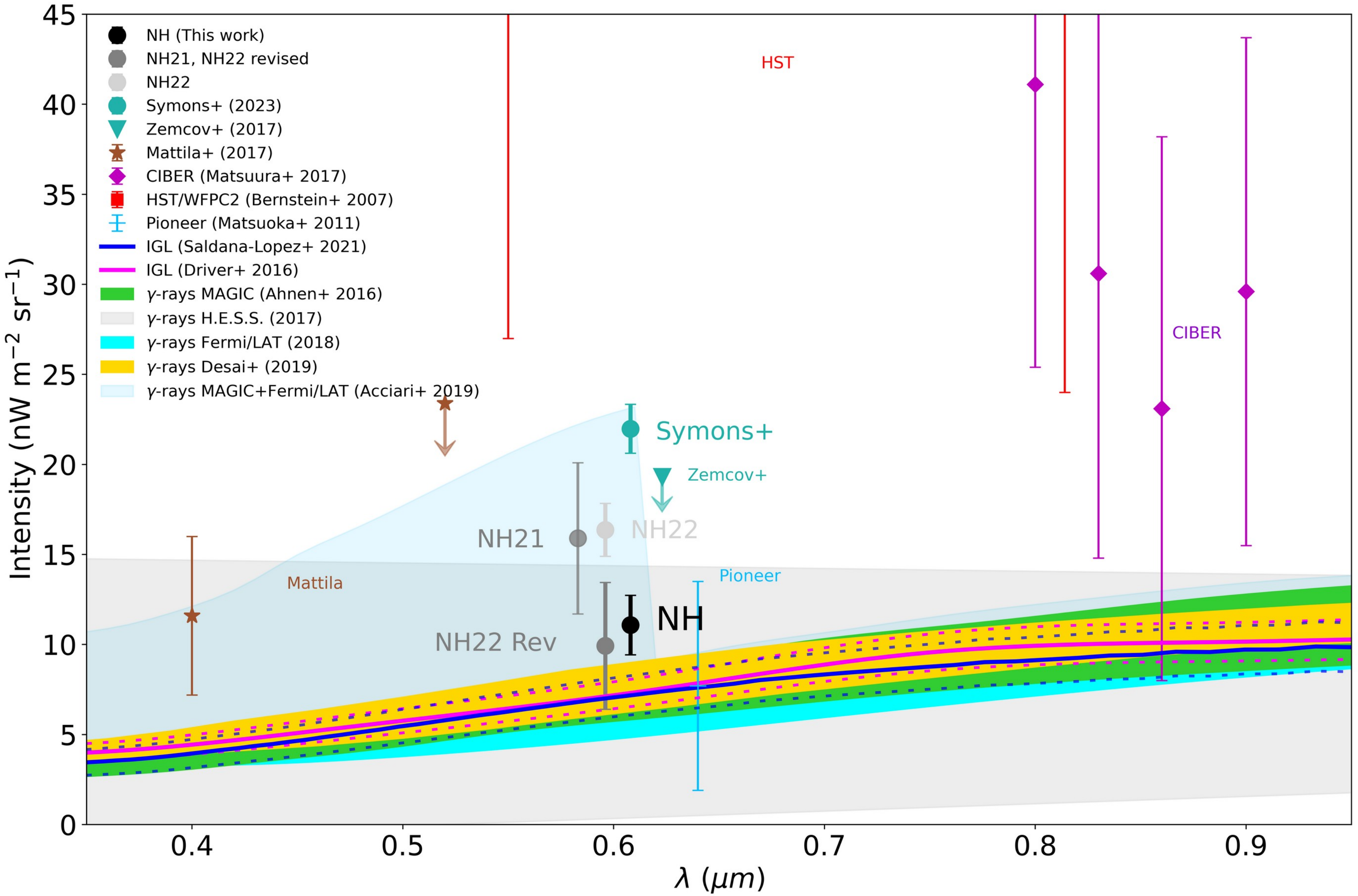

Summary

- **We have developed a DGL estimator using 350 and 550 micron imaging from the Planck satellite. Scatter is 1.36** Potentially useful for studies of LSB objects or other EBL surveys as well.
- We have definitively detected (6.7 sigma) the cosmic optical background in the LORRI bandpass (0.4 – 0.9 microns):

COB = 11.08 ± 1.65

- Our derived COB is higher than that predicted from deep galaxy counts (8.17 ± 1.18) but the difference is not significant (1.4 sigma):

ΔCOB = (COB – IGL) = 2.91 ± 2.03

- To explain the above residual as extragalactic in origin would require a ~30% increase in light from galaxies or intergalactic space. Driver et al. (2016) suggested a diffuse component to the optical EBL could be present at the 20% level, possibly due to low surface brightness galaxies and/or intrahalo light.