PROCEEDINGS OF SCIENCE

Understanding the Cosmic Infrared Background

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The Cosmic Infrared Background (CIB) can provide information about stars and galaxies at high redshifts. We will discuss the constraints that can be attained from observations of the near infrared background. Information about background light provides the benefit of giving information of the stellar population as a whole, rather than just bright or common sources, however, it is often very difficult to observe. We will discuss the theory and what properties of stars and galaxies can be constrained by current and future observations, as well as the state of observations.

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1. Introduction

It is now possible to begin to observe star and galaxy formation in the high redshift ($z > 6$) universe. This era of the universe is important to understand, for it signals the beginnings of galaxy formation, reionization, and possibly the transition from Population III (metal-free) to Population II (metal-poor) stars.

One way to observe high redshifts ($z > 6$) is by using high redshift galaxy surveys. Surveys that locate Lyman-alpha emitters or Lyman break galaxies, for instance, are indispensable to understand specifics of galaxy properties. However, they probe only a small fraction of the galaxy population - those galaxies that are bright enough and common enough to be seen in galaxy surveys.

A complimentary method to observe high redshift stars is to measure the Near Infrared Background (NIRB). Most of the ionizing radiation emitted by stars at high redshifts (6 < z < 30) is absorbed by photoionizing hydrogen and re-processed into nebular emission like Lyman alpha lines, following recombination in the absorbing gas, then redshifted into the near-IR, along with some of the original starlight that was emitted below the 13.6 eV ionization threshold of hydrogen. The NIRB has the benefit of probing star formation as a whole. Therefore, those galaxies that are too few or faint to be seen in galaxy surveys will contribute to the NIRB. We discuss how studying both the mean and fluctuations of the NIRB can lead to information about these early stars and galaxies.

2. The Mean Infrared Background

Observations of the mean infrared background are difficult to obtain. All foreground contaminants must be completely removed. Zodiacal light is a troublesome foreground, and one that is poorly understood. In addition, there are always some galaxies below the detection limits of surveys, as well as the contribution from the faint wings of known galaxies. Both of these sources of emission must somehow be taken into account.

However, observations of the mean NIRB can be invaluable in interpreting the condition of early star formation. The mean NIRB is a direct measure of the star formation rate, and does not depend heavily on the properties of the stars themselves (metallicity and stellar mass). This is because the nuclear burning efficiency depends only slightly on the mass and metallicity of the stars. While larger stars emit more ionizing radiation, the radiation is eventually reprocessed into nebular emission, either within the halo or in the IGM. Smaller stars have less ionizing radiation, but have a larger contribution from their stellar blackbody emission than their larger counterparts. Therefore, the cumulative light is nearly independent of the source or type of this light [1]. Since the mean of the NIRB constrains the star formation rate, it can then be used to find the star formation efficiency. In figure 1, we show the level of the mean NIRB expected for different values of the star formation efficiency f_* (or the fraction of baryons incorporated into stars). Current observations suggest that the mean NIRB is probably less than 3 nW $m^{-2}sr^{-1}$. This rules out star formation efficiencies above $f_* \sim 0.2$ [2].

3. The Fluctuations in the Near Infrared Background

Fluctuations of the NIRB are easier to observe and interpret. Unlike the mean, they do not

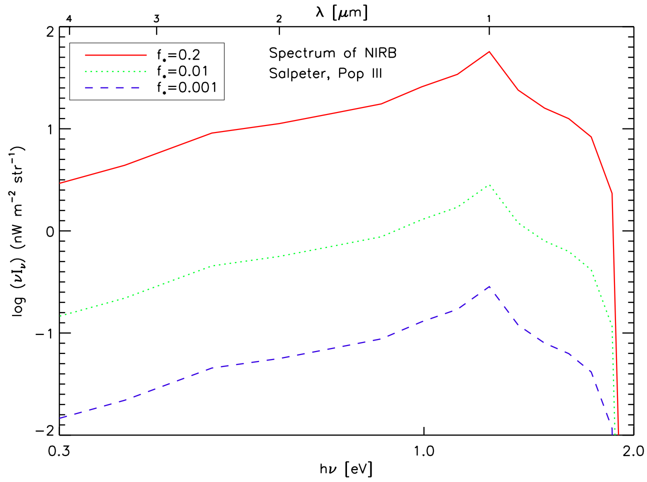

Figure 1: The mean infrared background predicted from various values of the star formation efficiency f_*. Current observations rule out $f_* \gtrsim 0.2$ [2].

need a zero point. In addition, they give information about primordial structures such as halos and their surrounding HII regions - and hence give information regarding reionization. In addition, it can provide information about the escape fraction and about stellar populations.

We used several N-body simulations combined with radiative transfer: one with coarse resolution with a minimum halo mass of $2.2 \times 10^9\ M_\odot$ and a box size of 100 h^{-1} Mpc (100-coarse) [3, 4, 5] and several with finer resolution with a minimum mass of $10^8\ M_\odot$ and a box size of 114 h^{-1} Mpc and 37 h^{-1} Mpc (114-fine and 37-fine respectively) [6, 7]. These were then combined with analytical formulas to obtain the total luminosity from the halos and the ionized IGM. To be consistent with reionization, we had to constrain the parameter f_γ:

$$f_\gamma = f_* f_{esc} N_i. \tag{3.1}$$

Within this limit, we were free to change the population of stars (which affects the number of ionizing photons produced per stellar atom N_i) , the escape fraction f_{esc}, and the star formation efficiency f_*. For 100-coarse, we calculated the angular power spectrum of a various populations of halos integrated over $6 < z < 30$, shown in figure 2. The angular power spectrum of Population II stars with a Salpeter (normal, non-massive) IMF with a high star formation efficiency ($f_* = 0.5$) provide the highest angular power spectrum for halos of all our models, while Population III stars with a Larson (heavy) IMF and a low star formation efficiency ($f_* = 0.01$) gives the lowest. Both are consistent with reionization. The two models are separated by several orders of magnitude. In all cases, the angular power spectrum of the IGM is at least two orders of magnitude below the halo angular power spectrum, and therefore will be difficult to detect [2].

Observations, such as with IRAC, NICMOS, and AKARI, and CIBER [8, 9, 10, 11, 12, 13, 14, 15, 16], are able to observe our predicted models with a bright angular power spectrum. However, many of our models still lie below their detection limits.

The minimum mass in this simulation was $2 \times 10^9 M_\odot$, which is quite large. In order to see the affect of halo mass size on the angular power spectrum, we calculated the angular power spectrum

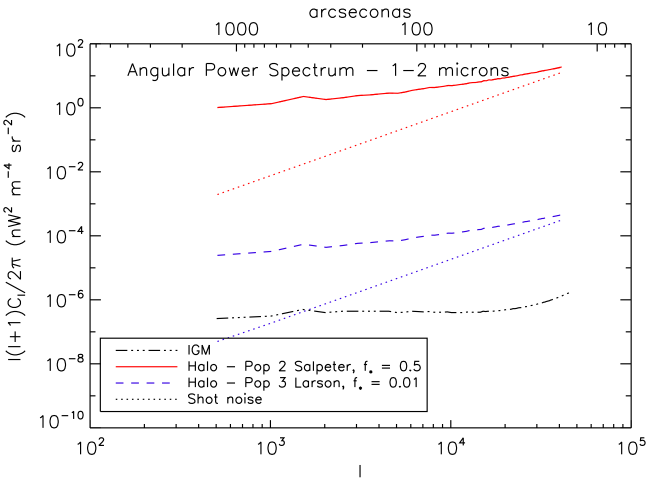

Figure 2: The angular power spectrum of various stellar populations consistent with reionization. The angular power spectrum shown is for a rectangular bandpass from 1-2 microns from the 100-coarse simulation. [2]

for the simulations 114-fine and 37-fine for cases with varying minimum halo mass. We also measured the effect of suppression of small-mass halos that form inside H II regions of the intergalactic medium on the angular power spectrum. Both of these are shown in figure 3. We computed the angular power spectrum for a case with only large halos (all those halos above $10^9 M_\odot$), including large and small halos (greater than $10^8 M_\odot$), and where these small halos were suppressed if they were formed inside an ionized patch of the universe.

In general, when the minimum mass is smaller, the angular power spectrum decreases. Similarly, when small halos are suppressed, the angular power spectrum decreases. This is a result of increasing the number of halos, but decreasing each halo's luminosity to be consistent with reionization. The only exception is when large halos are dim (when they are populated with Pop III stars with a Larson IMF and a low value of the star formation efficiency). We do not see a turnover in the angular power spectrum at high values of l [17].

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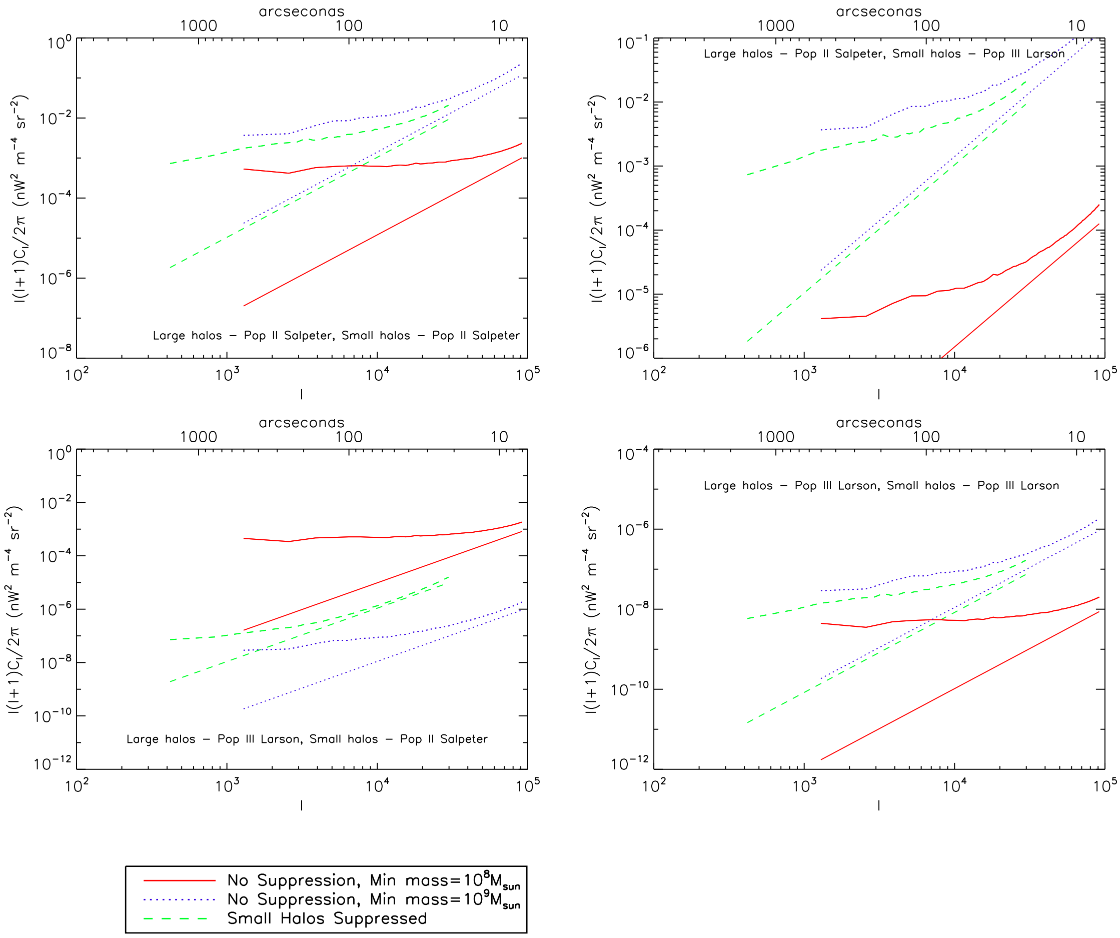

Figure 3: The angular power spectrum for various minimum masses, and for cases with and without suppression from the 114-fine and 37-fine simulations. Plots are shown for the J band (1.1 to 1.4 microns). [17]

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