

# First stars contribution to the near-infrared background fluctuations

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## ABSTRACT

We show that the emission from the first, metal-free stars inside Population III objects (Pop IIIs) is needed to explain the level of fluctuations in the near-infrared background (NIRB) recently discovered by Kashlinsky et al., at least at the shortest wavelengths. Clustering of (unresolved) Pop IIIs can in fact account for the entire signal at almost all the  $\sim 1\text{--}30$  arcsec scales probed by observations in the  $J$  band. Their contribution fades away at shorter frequencies and becomes negligible in the  $K$  band. ‘Normal’, highly clustered,  $\langle z \rangle \simeq 3$  galaxies undergoing intense star formation such as those found in the *Hubble Deep Fields* can ‘fill in’ this gap and provide for the missing signal. It is in fact found that their contribution to the intensity fluctuations is the dominant one at  $\lambda = 2.17 \mu\text{m}$ , while it gradually loses importance in the  $H$  and  $J$  bands. The joint contribution from these two populations of cosmic objects is able, within the errors, to reproduce the observed power spectrum in the *whole* near-infrared range on small angular scales ( $\theta \lesssim 200$  arcsec for Pop III protogalaxies). Signals on larger scales detected by other experiments instead require the presence of more local sources.

**Key words:** galaxies: clustering – galaxies: infrared – cosmology: theory – large-scale structure of Universe – cosmology: observations.

## 1 INTRODUCTION

Different authors have reported the discovery of an excess in the near-infrared background (NIRB) which cannot be accounted for by normal galaxies (see Hauser & Dwek 2001, and references therein). This unaccounted excess can be well fitted by the redshifted light of the first population of stars born inside the so-called Population III objects (Pop IIIs) (Santos, Bromm & Kamionkowski 2002; Salvaterra & Ferrara 2003, hereafter SF03). More recently, Kashlinsky et al. (2002) have observed small-scale NIRB fluctuations in the  $J$ ,  $H$  and  $K$  bands, which cannot be due to local or low redshift sources.

The aim of this paper is to show that Pop IIIs are indeed required to account for the observed small-scale ( $\theta \lesssim 200$  arcsec) background fluctuations at least in the  $J$  band. Their contribution – dominant for  $\lambda = 1.25 \mu\text{m}$  – is found to rapidly decrease at longer wavelengths until it becomes negligible for  $\lambda = 2.17 \mu\text{m}$ . We will also show that ‘normal’, high ( $\langle z \rangle \simeq 3$ ) redshift and highly clustered star-forming galaxies of the kind found in the *Hubble Deep Fields* can provide for the ‘missing’ power in the  $H$  and  $K$  bands, so that the joint contribution from these two populations can reproduce, within the errors, the observed power spectrum of intensity fluctuations at all NIR wavelengths. Note that, owing to the high redshifts of the two candidate populations ( $z \gtrsim 8.8$ , as found by SF03, for Pop IIIs and  $z \gtrsim 2$  for ‘normal’ star-forming galaxies), this is only true at small

angular scales. Signals on intermediate-to-large scales detected by other experiments ( $\theta \sim 0.7^\circ$ ; see e.g. Kashlinsky & Odenwald 2000; Matsumoto et al. 2000) are instead expected to require populations of more local sources.

The outline of the paper is as follows: in Section 2 we briefly describe the adopted model for the birth and evolution of Pop III protogalaxies. Section 3 presents our predictions for the intensity fluctuations of the NIRB owing to the clustering of Pop III sources, while Section 4 compares such predictions with the available data and discusses the results. Finally, Section 5 summarizes our conclusions.

## 2 THE MODEL

SF03 have shown that the NIRB data (see e.g. Hauser & Dwek 2001, and references therein) are well fitted by a model in which the contribution from Pop IIIs is added to the ‘normal’ galaxy background light as obtained from the *Hubble Deep Field* (Madau & Pozzetti 2000) or from the *Subaru Deep Field* (Totani et al. 2001). We now briefly summarize some of the many aspects of the SF03 model.

The mean specific intensity of the background arising from Pop IIIs  $I(\nu_0, z_0)$ , as seen at a frequency  $\nu_0$  by an observer at redshift  $z_0$ , can be written as

$$I(\nu_0, z_0) = \frac{1}{4r\pi} \int_{z_0}^{z_{\text{max}}} \epsilon_\nu(z) e^{-\tau_{\text{eff}}(\nu_0, z_0, z)} \frac{dI}{dz} dz \quad (1)$$

(Peebles 1993). Here  $\nu = \nu_0(1+z)/(1+z_0)$ ,  $\tau_{\text{eff}}(\nu_0, z_0, z)$  is the effective optical depth at  $\nu_0$  of the IGM between redshift  $z_0$  and  $z$ ,

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$dl/dz$  is the proper line element, and  $z_{\max}$  is the redshift when the sources begin to shine;  $\epsilon_\nu(z)$  is the comoving specific emissivity in units of  $\text{erg s}^{-1} \text{Hz}^{-1} \text{cm}^{-3}$ , given by

$$\epsilon_\nu(z) = l_\nu(z) f_* \frac{\Omega_b}{\Omega_M} \int_{M_{\min}(z)}^{\infty} n(M, z) M dM, \quad (2)$$

where  $l_\nu(z)$  is the specific luminosity of the population at redshift  $z$ , computed using the spectra for metal-free stars obtained by Schaerer (2002);  $n(M, z)$  is the comoving number density of dark matter haloes of mass  $M$  at redshift  $z$  given by the Press & Schechter formalism (Press & Schechter 1974). The integral gives the dark matter mass per unit volume contained in dark matter haloes with mass greater than  $M_{\min}(z)$ , where  $M_{\min}$  (computed by Fuller & Couchman 2000) is a cut-off mass below which haloes cannot form stars owing to the lack of cooling.  $\Omega_M$  and  $\Omega_b$  are the total matter and baryon density<sup>1</sup> in units of the critical density  $\rho_c = 3H_0^2/8\pi G$ . The ratio  $\Omega_b/\Omega_M$  converts the integral into baryonic mass which is then turned into stars with an efficiency  $f_*$ . This latter quantity is constrained by the contribution of the redshifted light of Pop IIIs to the NIRB (SF03). The Pop III star formation efficiency required to match the NIRB data depends essentially only on their initial mass function (IMF), being in the range  $f_* = 10$ –50 per cent (the top-heaviest requiring lowest efficiency). The redshift at which the formation of metal-free stars ends is tightly constrained to be  $z_{\text{end}} \simeq 8.8$  by the  $J$  band data (SF03).

### 3 CONTRIBUTION OF CLUSTERING TO BACKGROUND FLUCTUATIONS

The angular correlation function of intensity fluctuations  $\delta I$  owing to inhomogeneities in the space distribution of unresolved sources (i.e. with fluxes fainter than some threshold  $S_d$ ) is defined as

$$C(\theta) = \langle \delta I(\theta', \phi') \delta I(\theta'', \phi'') \rangle, \quad (3)$$

where  $(\theta', \phi')$  and  $(\theta'', \phi'')$  identify two positions on the sky separated by an angle  $\theta$ . The above expression can be written as the sum of two terms,  $C_P$  and  $C_C$ , the first one owing to Poisson noise (i.e. fluctuations given by randomly distributed objects), and the second one owing to source clustering (see De Zotti et al. 1996; Magliocchetti et al. 2001 for a detailed discussion). In the case of strongly clustered sources, as the NIR data seems to indicate (Kashlinsky et al. 2002), the Poisson term  $C_P$  is found to be negligible when compared with  $C_C$  (see e.g. Scott & White 1999). We can therefore safely assume  $C \simeq C_C$  [hereafter simply called  $C(\theta)$ ], and its expression in the case of Pop III sources is given by

$$C(\theta) = \left( \frac{1}{4r\pi} \right)^2 \int_{z_0}^{z_{\max}} dz \frac{\epsilon_\nu^2(z)}{(1+z)^2} e^{-2\tau_{\text{eff}}} \left( \frac{dx}{dz} \right) \times \int_{-\infty}^{\infty} du \xi_g(r, z), \quad (4)$$

where  $x = l(1+z)$  is the comoving radial coordinate,  $r = (u^2 + x^2\theta^2)^{1/2}$  (for a flat universe and in the small angle approximation),  $\epsilon_\nu(z)$  is the comoving specific emissivity at the frequency  $\nu$ , and  $z_0$  and  $z_{\max}$  are defined as in Section 2.

The spatial two-point correlation function of a class of galaxies ‘ $g$ ’,  $\xi_g(r, z)$ , in general results from a complicated interplay between

the clustering properties of the underlying dark matter and physical processes associated to the formation of such galaxies (see e.g. Peacock & Smith 2000; Scoccimarro et al. 2001; Magliocchetti & Porciani 2003). However, at high enough ( $z \gtrsim 0.5 - 1$ ) redshifts, the probability for a dark matter halo to host more than one galaxy is negligible (see e.g. Somerville et al. 2001), and one can write:

$$\xi_g(r, z) = \xi(r, z) b_{\text{eff}}^2(M_{\min}, z), \quad (5)$$

where  $\xi(r, z)$  is the mass–mass correlation function and  $b_{\text{eff}}^2(M_{\min}, z)$  the bias associated to all dark matter haloes massive enough to host a galaxy at redshift  $z$ .

In equation (5),  $\xi(r, z)$  has been obtained following the work by Peacock & Dodds (1996, see also Moscardini et al. 1998; Magliocchetti et al. 2000), which provides an analytical way to derive the trend of the dark matter correlation function both in the linear and non-linear regime. Note that  $\xi(r, z)$  only depends on the underlying cosmology and on the normalization of  $\sigma_8$ . The effective bias factor  $b_{\text{eff}}^2$  of all haloes with masses greater than some threshold  $M_{\min}$  (quantity that generally may depend on the look-back time) is instead obtained by integrating the quantity  $b(M, z)$  – representing the bias of individual haloes of mass  $M$  – opportunely weighted by their number density  $n(M, z)$ :

$$b_{\text{eff}}(z) = \frac{\int_{M_{\min}}^{\infty} dM b(M, z) n(M, z)}{\int_{M_{\min}}^{\infty} dM n(M, z)}, \quad (6)$$

where, in this case, the mass function is obtained according to the Press & Schechter (1974) approach and we take the functional form for  $b(M, z)$  from Jing (1998) (but see also Scannapieco & Barkana 2002).

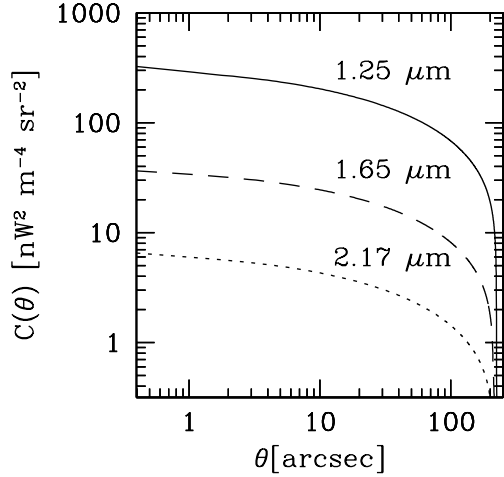
If we then plug into equation (4) the expressions obtained by SF03 (see Section 2) for the specific emissivity  $\epsilon_\nu(z)$ , the halo cut-off mass  $M_{\min} \equiv M_{\min}(z)$ , and use as the minimum redshift at which these sources contribute to the background the value  $z_{\text{end}} = 8.8$  (corresponding to the epoch at which metal-free star formation ends – note that we are making the reasonable assumption that no such a source can be resolved by current observations), then, by also making use of expressions (5) and (6), we can derive predictions for the contribution of the clustering of (unresolved) Pop IIIs to the background fluctuations at different wavelengths.

The cases for  $\lambda = 1.25 \mu\text{m}$ ,  $\lambda = 1.65 \mu\text{m}$  and  $\lambda = 2.17 \mu\text{m}$  (respectively corresponding to  $J$ ,  $H$  and  $K$  bands) are represented in Fig. 1 by the solid, dashed and dotted lines. Since these wavelengths at the redshifts under examination are always greater than the rest-frame Ly $\alpha$ , the contribution from the  $e^{-2\tau_{\text{eff}}}$  term in equation (4) can be neglected in the calculation of  $C(\theta)$  (see SF03).

The first feature to be noticed in the plot is the sharp drop of all the curves at  $\theta \simeq 200$  arcsec. This is owing to the fact that such an angular scale corresponds to distances  $r \gtrsim 8.6$  Mpc (with the minimum value corresponding to  $z_{\text{end}} = 8.8$  in the adopted cosmology), where the spatial correlation function has already steepened from its power-law behaviour and rapidly approaches the zero value. As a first conclusion of this work we can then say that the clustering of unresolved Pop III sources cannot account for any of the observed fluctuations on scales  $\gtrsim 200$  arcsec, which instead require much more local objects (for the Matsumoto et al. 2003 results the maximum acceptable redshift turns out to be  $z \sim 1$ –2).

The second point to stress is the remarkably different amplitude of the intensity fluctuations as evaluated at different frequencies. More specifically,  $C(\theta)$  is found to decrease by about two orders of magnitude when going from  $\lambda = 1.25 \mu\text{m}$  to  $\lambda = 2.17 \mu\text{m}$ . As already argued by SF03, the reason for this decrement has to be

<sup>1</sup> We adopt the ‘concordance’ model values for the cosmological parameters:  $h = 0.7$ ,  $\Omega_M = 0.3$ ,  $\Omega_\Lambda = 0.7$ ,  $\Omega_b = 0.038$ ,  $\sigma_8 = 0.9$ , and  $\Gamma = 0.21$ , where  $h$  is the dimensionless Hubble constant,  $H_0 = 100h \text{ km s}^{-1} \text{ Mpc}^{-1}$ .



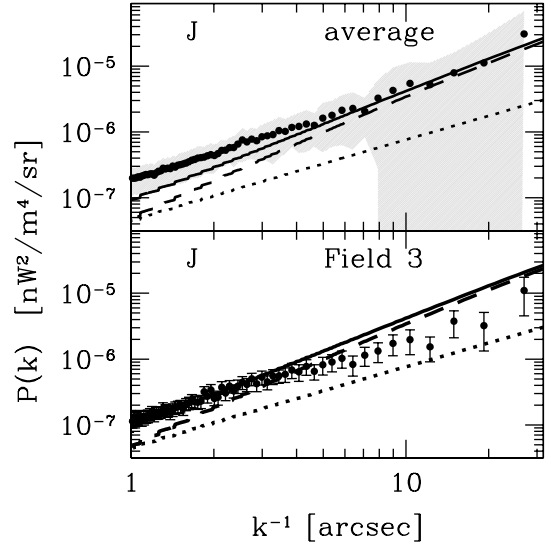
**Figure 1.** Predictions for the correlation signal owing to intensity fluctuations of Pop III sources. The solid line represents the contribution in the *J* band, while dashed and dotted lines respectively illustrate the case for the *H* and *K* bands.

found in the extremely strong Ly $\alpha$  nebular emission line – responsible for a considerable fraction of the Pop III emissivity – which, once redshifted to the present time, gives its maximum contribution in the *J* band and rapidly disappears at the other two wavelengths under exam. We discuss the implications of these findings in the next section.

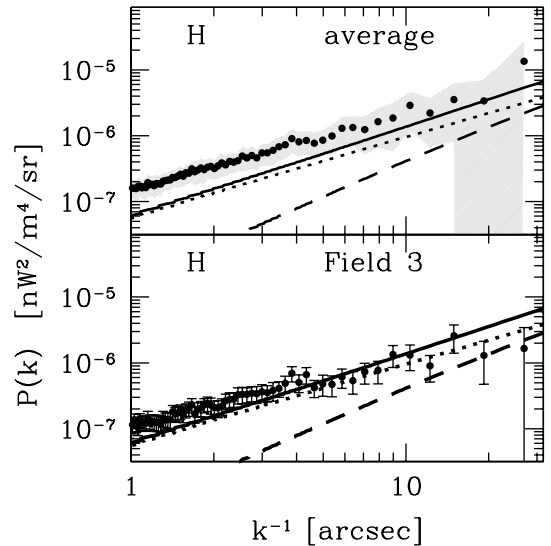
#### 4 COMPARISON WITH THE DATA

Kashlinsky et al. (2002) and Odenwald et al. (2003) have recently reported the first detection of small angular scale fluctuations in the near-infrared background. Their measurements were obtained by using long integration data constructed from 2MASS (Two Micron Sky Survey) observations and by then coadding images in order to produce a  $8.6 \text{ arcmin} \times 1^\circ$  field, divided into seven square patches  $512 \text{ arcsec}$  on a side. In each patch, individual stars and galaxies were removed down to a magnitude limit that varied slightly from patch to patch, owing to variations in the background level and associated noise. The clipping algorithm was applied for a mesh size of  $3$  by  $3$  pixel (corresponding to  $9 \text{ arcsec}^2$ ). However, in order to test for its stability, the above procedure was also repeated with increasing mask sizes (up to  $5$  by  $5$  pixel) and the corresponding results were found in agreement with each other (S. Kashlinsky, private communication). Such an approach ensures the effective removal of entire galaxies at all redshifts but the lowest ones, in which case more extended objects were identified by eye and removed by the clipping algorithm regardless. The remaining diffuse light was then Fourier-transformed, with the resulting power spectrum showing a positive signal at all  $1$ – $30 \text{ arcsec}$  scales and in all the seven patches.

The authors estimate contributions to the observed power spectrum from possible non-cosmological components such as atmospheric fluctuations, remaining Galactic stars, cirrus emission, zodiacal light (expected to be the largest source of uncertainty in the treatment of NIRB data), instrument noise and extinction, and conclude that they all have different slopes and negligible amplitudes when compared with the observed signal. Odenwald et al. (2003) and Kashlinsky et al. (2002) identify the measured power spectrum as arising from clustering of faint ( $K \geq 18.5$ – $19 \text{ mag}$ ), high-redshift, galaxies undergoing significant star formation.

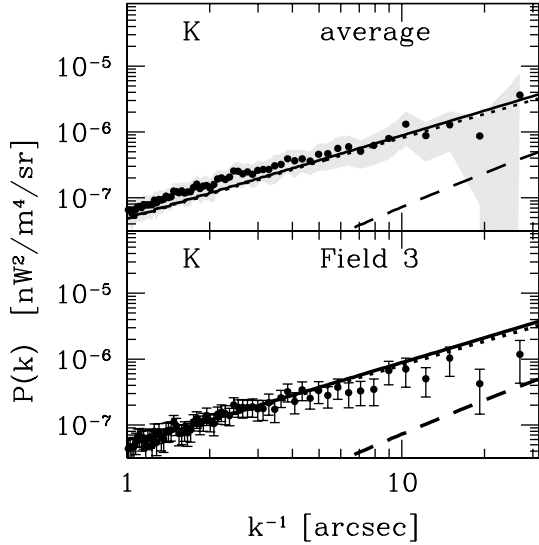


**Figure 2.** Power spectrum of NIRB fluctuations at  $\lambda = 1.25 \mu\text{m}$ . The data are the results obtained by Kashlinsky et al. (2002) after atmospheric subtraction; the lower panel reproduces measurements from their Field 3 (considered by the authors as the most representative one), while the upper panel shows the signal obtained by averaging all the seven fields. The shaded area corresponds to uncertainties in the power spectrum arising from both statistical errors and field-to-field variations. In both panels, the dashed line represents the predicted contribution to NIRB fluctuations in the *J* band as due to clustering of Pop IIIs, the dotted line that of ‘normal’, highly clustered, ( $z \sim 3$ ) star-forming galaxies and the solid line is the sum of both components (see text for details).



**Figure 3.** As in Fig. 2, but for  $\lambda = 1.65 \mu\text{m}$ .

Their results (kindly provided by S. Kashlinsky in electronic form) are presented in Figs 2, 3 and 4 respectively for the *J*, *H* and *K* bands. The lower panels show the power spectrum as measured at the different wavelengths from Field 3, considered by Odenwald et al. (2003) as the most representative one owing to its depth (limiting magnitudes for sources removal:  $J = 20$ ,  $H = 19.2$ ,  $K = 19$ ). The upper panels instead report the signal obtained by averaging measurements in all their seven fields. The shaded areas illustrate the levels of uncertainty owing to both statistical (Poissonian) errors



**Figure 4.** As in Fig. 2, but for  $\lambda = 2.17 \mu\text{m}$ .

(corresponding to the error bars in the lower panels) and field-to-field variations, found to be the dominant effect possibly because of the small area covered by each of the patches (cosmic variance). Note that the data have already been corrected for the atmospheric contribution.

In order to compare these measurements with predictions from Section 3, we have converted our results for the intensity fluctuations  $C(\theta)$  arising from Pop IIIs into the corresponding signal in the angular wavenumber  $k$  space,  $P(k)$ , where

$$P(k) = 2\pi \int_0^\infty C(\theta) J_0(k\theta) \theta d\theta, \quad (7)$$

with  $J_0$  the zeroth-order Bessel function.

The resulting power spectrum at the different wavelengths is illustrated in Figs 2, 3 and 4 by the dashed lines. As it is clear by comparing data with model predictions in both panels of Fig. 2, the clustering properties of Pop IIIs can nicely explain the observed fluctuations in the  $J$  band, even though there seems to be some discrepancy at the smallest angular scales. The situation however becomes increasingly worse when one goes to longer wavelengths and it is found that, while in the  $H$  band this class of sources can only (possibly) account for the observed spectrum at the highest angular scales probed by the data, their contribution in the  $K$  band falls short by at least one order of magnitude. Also, especially in the  $H$  and  $K$  bands, the predicted slopes for the power spectrum are too steep when compared with the measured ones.

The missing ingredient to this analysis has to be searched amongst ‘normal galaxies’ which can at least partially account for the extragalactic light emitted at the wavelengths under examination (see Madau & Pozzetti 2000; Totani et al. 2001). In their work, Kashlinsky et al. (2002) and Odenwald et al. (2003) remove from the maps all resolved sources up to  $K \simeq 19$  mag which, they claim, corresponds to the removal of possibly all resolvable galaxies to redshifts  $z \simeq 1$  (with some allowance made for low-surface-brightness systems). However, we argue that the population of galaxies responsible – together with Pop IIIs – for the observed NIRB fluctuations must reside at redshifts  $z \gtrsim 2$ .<sup>2</sup> The argument supporting this conclusion goes as follows.

<sup>2</sup>The possibility for a non-negligible part of the unaccounted signal to be caused by residual disc emission from low-redshift galaxies, the nuclei of

The power spectrum of fluctuations as measured by 2MASS features a remarkable power-law behaviour down to angular scales of 1 arcsec. Under the hypothesis for this signal to be generated by large-scale structure, one has that – since the correlation function of dark matter haloes (see equation 5) must drop to  $-1$  on distances smaller than two virial radii owing to spatial halo–halo exclusion (see e.g. Magliocchetti & Porciani 2003) – the power-law trend exhibited by the data down to 1 arcsec sets a strong limit on the minimum redshift at which these ‘normal galaxies’ appear. More in detail, one has that for masses of the order of  $10^8 M_\odot$  (value taken as a reasonable lower limit for the kind of objects under examination) and the cosmology adopted in this paper, the condition for a power-law behaviour to hold at the minimum scales probed by the data is only met for redshifts  $z \gtrsim 2$ .

What are then these  $z \gtrsim 2$  ‘normal galaxies’, faint enough not to be resolved by a  $K \lesssim 19$  survey, which can significantly contribute to the observed fluctuations of the NIRB, especially in the  $H$  and  $K$  bands? A natural candidate can be found in the population of high- $z$ , star-forming galaxies detected in the *Hubble Deep Fields* to  $I_{AB} = 29$ . Magliocchetti & Maddox (1999) have measured the clustering signal for this class of galaxies and shown that they are indeed strongly clustered, with an amplitude  $A \simeq 7 \times 10^{-3}$  (where the angular correlation function was parametrized as  $w(\theta) = A\theta^{-0.8}$ ), constant within the errors at all redshifts  $2 \lesssim z \lesssim 4.8$ .

The contribution of this class of galaxies to intensity fluctuations in the NIRB can then be written as  $C_{\text{gal}}(\theta) \simeq I_B^2 w(\theta)$ , where  $I_B$  is the residual background intensity after source removal. Suitable values for  $I_B$  at the wavelengths relevant to this work can be obtained by taking the estimates for the total extragalactic light emitted in the  $J$ ,  $H$  and  $K$  bands from Madau & Pozzetti (2000), and by then subtracting the contributions from resolved sources as given in Kashlinsky et al. (2002). Note that the resulting  $I_B$  values can in principle only be considered as upper limits, since the Kashlinsky and collaborators figures were given by assuming source removal up to  $z \simeq 1$ , while we are considering background fluctuations made by  $z \gtrsim 2$  galaxies.

The power spectrum of intensity fluctuations in the NIRB obtained for these ‘normal’ galaxies in the  $J$ ,  $H$  and  $K$  bands is shown in Figs 2, 3 and 4 by the dotted lines. The solid lines instead illustrate the *total* signal stemming from the sum of the contribution of this class of sources with the one deriving from Pop IIIs. ‘Normal’, faint, high-redshift galaxies are able to reproduce the observed power spectrum at all angular scales in the  $K$  band, both in its amplitude and its slope. Their contribution however becomes less and less important as one moves towards shorter wavelengths and – at  $\lambda = 1.25 \mu\text{m}$  – not only can it account for  $\sim 10$  per cent of the observed signal, but it also has a different (shallower) dependence on the angular scale than the data indicate.

It is then found that, since Pop IIIs and ‘normal’ galaxies seem to be responsible for the observed fluctuations with a different relevance at the different wavelengths (Pop IIIs mainly appearing in the  $J$  band, ‘normal’ galaxies giving the strongest contribution in the  $K$  band), their sum is able to reproduce the data within the errors at *all* wavelengths (with some allowance made in the  $H$  band). In more

which have been removed, can be discarded with a high confidence level both on the basis of the arguments introduced in this section re the clipping procedure and also by noticing that (relatively local) galaxies up to the clipping threshold  $K \simeq 19$  mag contribute only a very small fraction of the cosmic infrared background (CIB) at this wavelength (see e.g. Kashlinsky et al. 2002). Even if some (outer) parts of these galaxies were to remain, therefore, their contribution to the observed signal would be extremely small.

detail, by considering both populations we can give account for the observed (roughly constant) amplitude of the observed power spectrum at the different wavelengths, and can also naturally explain the steepening of its slope when moving to shorter wavelengths as arising from the intervening contribution of Pop III sources. Note that the match is particularly good, especially if one considers that *there are no free parameters in the model*. Our predictions do not depend on the exact functional form for the chosen IMF and star formation efficiency  $f_*$ , as long as their combination is able to reproduce the observed NIRB (SF03). Obviously, one of the main uncertainties of this work is associated with the determination of the slope of the predicted power spectrum. This is owing to the lack of solid determinations of the two-point correlation function, from both an observational and a theoretical point of view, at the high redshifts and small masses under exam. The fact that our predictions result – within the errors – in agreement with the observed trend, however, gives us some confidence that the assumptions made in the course of our analysis are (at least) plausible.

As a last remark we note that, even if in the above analysis we have considered  $I_B$  in the different bands as an upper limit of the true background intensity, the fact that the data at  $\lambda = 2.17 \mu\text{m}$  is perfectly reproduced by the population of ‘normal’ galaxies suggests this upper limit to be very close to the real value for otherwise the curves would have fallen below the observations. Under this assumption, there is then no need for the emergence of a third, still-unknown, population of objects, since Pop IIIs, together with high-redshift/star-forming ‘normal’ galaxies, can fully explain the observed level of fluctuations.

## 5 CONCLUSIONS

In this paper we have used the model of SF03 to derive the expected contribution of the clustering of (unresolved) Pop IIIs to the intensity fluctuations of the NIRB. Comparisons with the recent observations by Odenwald et al. (2003) show that this class of sources can indeed account for the observed level of fluctuations at almost all the  $\sim 1\text{--}30$  arcsec scales probed by the data, at least in the  $J$  band where the  $\text{Ly}\alpha$  nebular emission line – responsible for most of the Pop III emissivity – once redshifted to the present time gives its maximum contribution. Their relevance however rapidly fades away for shorter frequencies and becomes negligible in the  $K$  band.

‘Normal’, highly clustered,  $2 \lesssim z \lesssim 5$  galaxies undergoing intense star-formation such as those found in the *Hubble Deep Fields* can ‘fill in’ this gap and provide for the missing signal. If we in fact assume these objects to produce a clustering signal as measured by Magliocchetti & Maddox (1999) and associate them to a background intensity in the  $J$ ,  $H$  and  $K$  bands as taken from Madau & Pozzetti (2000) (after source removal), we find that their contribution to the intensity fluctuations is the dominant one at  $\lambda = 2.17 \mu\text{m}$ , while it gradually loses importance in the  $H$  and  $J$  bands.

The sum of the two Pop IIIs and ‘normal’ galaxy components is able, within the errors, to reproduce the observed power spectrum of intensity fluctuations in the *whole* near-infrared range on small angular scales ( $\theta \lesssim 200$  arcsec for Pop III sources). The match is particularly good, especially if one considers that our model is not associated with any free parameter. Signals on larger scales as detected by other experiments (see Hauser & Dwek 2001, for review) are instead expected to require populations of more local sources.

The present results strongly support the scenario presented by Schneider et al. (2002) (see also Scannapieco, Schneider & Ferrara 2003), in which the first stars were biased towards high masses, thus producing copious amounts of ionizing photons and heavy elements which caused cosmic reionization and enrichment of the otherwise pristine intergalactic medium. It is only when the gas metallicity reached a critical value (still subject to uncertainties owing to the complicated physics of molecular cloud fragmentation) in the range  $Z = 10^{-6}\text{--}10^{-4} Z_\odot$  that a relatively abrupt transition to the ‘normal’ star formation mode took place. This epoch has left a remarkable imprint both in the intensity and the fluctuations of the NIRB that we have here isolated for the first time.

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