Faint Blue Counts from Formation of Dwarf Galaxies at z≈1

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1. Introduction.

The nature of faint blue objects (FBOs) has been a source of much speculation since their detection in deep CCD images of the sky (Cowie *et al.* 1988; Tyson 1988). Their high surface density argues against them being progenitors of present-day bright galaxies and since they are only weakly clustered on small scales (Efstathiou *et al.* 1992), they cannot be entities that merged together to form present-day galaxies. Babul & Rees (1992) have suggested that the observed faint blue counts may be due to dwarf elliptical galaxies undergoing their initial starburst at $z \approx 1$. In generic hierarchical clustering scenarios, however, dwarf galaxy haloes ($M \sim 10^9\, M_\odot$) are expected to form at an earlier epoch; for example, typical $10^9\, M_\odot$ haloes will virialize at $z \approx 2.3$ if the power-spectrum for the density fluctuations is that of the standard $b = 2$ cold dark matter (CDM) model. Under "ordinary conditions" the gas would rapidly cool, collect in the cores and undergo star-formation. Conditions at high redshifts are far from "ordinary". The intense UV background will prevent the gas in the dwarf haloes from cooling, the haloes being released from their suspended state only when the UV flux has diminished sufficiently.

2. Haloes in Stasis.

We begin by assuming that the redshift evolution and the spectrum (for frequencies greater than ν_L, the Lyman limit) of the intergalactic ionizing flux can be modeled as

$$J_{21}(z) = J_{21}\left(\frac{\nu_L}{\nu}\right)\left(\frac{1+z}{3}\right)^4 \times 10^{-21}\,(\nu_L/\nu)\,\mathrm{erg\,cm^{-2}\,Sr^{-1}\,Hz^{-1}\,s^{-1}}. \tag{1}$$

Such a model is consistent with the limits for the UV flux derived from studies of the optical depth for the absorption of photons in a quasar spectrum shortward of $Ly\alpha$:

$J_{21} \gtrsim 1.6$ at $z \approx 2.6$ ($\tau \lesssim 0.05$, Steidel & Sargeant 1987)
$J_{21} \gtrsim 9$ at $z \approx 4.1$ ($\tau \lesssim 0.04$, Webb *et al.* 1992)

The UV background will photoionize the intergalactic medium, heating it to temperature $T \sim 3\times10^4$ K. Under such conditions, baryons in virialized dark haloes with $V_c \approx 30\,\mathrm{kms^{-1}}$ will be stably confined, neither able to escape not able to collapse.

Inside the halo, the gas will be in ionization equilibrium: $dn_R/dt = dn_I/dt$, where

$$\frac{dn_R}{dt} \approx 4.36\times10^{-13}\left(\frac{T}{10^4\,\mathrm{K}}\right)^{-3/4}\Omega_b^2\left[\frac{\rho_x(r)}{\mu_H m_p}\right]^2[1-\chi(r)]^2\,, \tag{2a}$$

$$\frac{dn_I}{dt} \approx 4\pi\Omega_b\left[\frac{\rho_x(r)}{\mu_H m_p}\right]\chi(r)\int_{\nu_L}^{\infty}\frac{\sigma_\nu J_\nu e^{-\tau_\nu(r)}}{h\nu}\,d\nu. \tag{2b}$$

In the above equations, $\chi(r)$ is the neutral fraction, $\sigma_\nu = 6.7\times10^{-18}(\nu_L/\nu)^3\,\mathrm{cm^{-2}}$ is the ionizing cross-section for hydrogen, and $\tau_\nu(r) = \int_r^R n_{HI}(r)\sigma_\nu\,dr$ is the optical depth for absorption for photons penetrating from the surface.

3. Epoch of Dwarf Galaxy Formation

As the background UV flux intensity decreases with redshift, the gas in the central regions of the haloes will become increasing neutral. To determine the corresponding epoch, we model the virialized dark haloes as a truncated isothermal sphere of radius R, with a core of radius r_c such that $r_c \approx 1\,\mathrm{kpc}$:

$$\rho_x(r) = \begin{cases} \rho_{xo}(R/r_c)^2, & \text{if } 0 \le r \le r_c \\ \rho_{xo}(R/r)^2, & \text{if } r_x \le r \le R, \end{cases} \tag{3}$$

where z_v is the redshift of virialization,

$$\rho_{xo} \approx 7.5\times10^{-27} h_{50}^2 \left(\frac{1+z_v}{3}\right)^3 \mathrm{g\,cm^{-3}}, \quad \text{and} \quad R \approx 12.2 h_{50}^{-1} \left(\frac{V_c}{30\,\mathrm{km\,s^{-1}}}\right) \left(\frac{1+z_v}{3}\right)^{-3/2} \mathrm{kpc},$$

The density distribution of the stably confined gas is $\Omega_b \rho_x(r)$.

Solving the equation for ionization equilibrium at each radii, we find that gas in a $V_c \approx 30\,\mathrm{km\,s^{-1}}$ halo that virialized at $z_v \approx 2$ (as in the standard $b = 2$ CDM model) will develop a warm ($T \sim 10^4$) neutral centre ($\chi \approx 0.95$) soon after virialization. Further cooling of a neutral metal-poor gas is only possible if H_2 molecules form. The declining intensity of the UV flux coupled with the increasing efficiency in shielding of the central regions suggests that by $z \approx 1.2$ the conditions for the formation of molecular hydrogen will be in place. As noted by Shapiro & Kang (1987), the gradual onset of shielding from the ionizing radiation will, in fact, enhance the formation of H_2 molecules. Cooling by H_2 molecules will cause the temperature to rapidly plummet down to to $\sim 10^2$ K, allowing the central regions to collapse.

Meanwhile, the hot gas in the ionized envelope will remain in hydrostatic equilibrium until an expansion wave signaling the loss of pressure-support due to the collapse of the neutral region propagates upstream. The response of the envelope under such conditions has been studied by Shu (1977). The envelope will collapse in $\Delta t \approx 8\times10^8$ yr. If the gas experience starburst upon collapse, the projected epoch of starburst is $z \approx 1$.

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