Early Preheating as Global Feedback, and the Resulting Luminosity function.

Jamie Cohen
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1.Introduction

The ΛCDM paradigm has been very successful in explaining various observations, but it has not seen the same success in explaining the formation of galaxies and simulations thereof (R. Somerville, private communication). ΛCDM simulations suggest that cooling in clusters should be very efficient and baryons should collapse to the centers of halos at high redshifts ($z \geq 3$), since the cooling time is shorter than the Hubble time, and be found in the form of cold gas and stars. Contrary to predictions, only about 5-10% of the baryons expected are seen condensed at the centers of clusters (Bell et al. 2003a, Fukugita & Peebles 2004), and x-ray spectroscopy shows that gas is not cooling to the extent it should (Peterson et al.2003). Another such related discrepancy arises in the galaxy luminosity function of simulations, which does not reproduce the observed flatness of slope at the faint end. This paper will try to examine some of the techniques that are employed to help ΛCDM to better match observations.

2. Feedback

Feedback in various forms is invoked to try to remedy the disparity between predictions of ΛCDM and observations. Photoionization by supernovae and winds driven by massive stars will increase gas pressure and suppress cooling which will prevent collapse in smaller halos. This sort of feedback is local to the galaxy that the events occur in and it seems unlikely that they alone produce enough energy to prevent collapse in massive halos (Benson et al. 2003).

Another feedback mechanism that has been more recently applied is that of pre- or sub- galactic outflows, which is also called preheating. Populations of subgalactic star systems and accreting black holes (the possible massive remnants of populations III stars) at redshifts of 10-15 would produce enough energy through outflows, such that in the shallow potential wells of these subgalactic systems, they could cause the blow out of metal rich baryons and thus enrich the IGM at early times. This enrichment can in turn quench star formation and inhibit the growth of early galaxies by raising gas pressure and also by increasing the cosmological Jeans mass through increasing the temperature (Benson & Madau 2003). Preheating is thus inherently different than the local supernova feedback previously mentioned which acts in the galaxy the event occurred in, whereas preheating acts globally in heating the IGM.

3. Constraints

In Benson and Madau's 2003 paper, semi-analytic models were used to examine several different preheating scenarios. Their method involves a preheating prescription to evolve gas properties in the IGM, while varying both the redshift of preheating and the amount of preheating. The energy was added over a short period of time centered about $z_{preheat}$, where $z_{preheat}$ is some chosen redshift of injection, but was shown to not affect the luminosity functions obtained so long as Δz was not close to the value of $z_{preheat}$, in which case the effects of preheating were essentially removed. Observational constraints were placed on the energy and redshift of deposition by looking at temperature measurements of the Lyα forest at $z\sim3$, and from making sure that models were consistent with the Compton y-distortion measurements of the COBE satellite. The former restricts preheating scenarios to those that do not preheat at late times or to too high temperatures so that the IGM has time to cool down by $z\sim3$. Models of the first stars and galaxies were use as guides for choosing specific energies and redshifts, giving a range from $E_{preheat}$ =0.05-0.3keV, and $z_{preheat}$ =6-12.

Two other constraints that I will not get into any further in this paper are the ionized/neutral fractions of hydrogen and helium which arise naturally from preheating due to an increase of temperature, and the abundance of local group satellites whose predicted luminosity function can be compared to observations

4. Temperature Evolution

The thermal history of the IGM for Benson and Madau's models are shown in figures 1 and 2. Both figures show the values for no preheating, while figure one shows several values for redshift at $E_{preheat}$=0.3keV and figure 2 shows several values for the energy plotted at $z_{preheat}$=9. The models are compared to observations (circles and triangles in the figures) to narrow down the possible values for $E_{preheat}$ and $E_{preheat}$. These figures show that models with T_{IGM} >(about greater) 10^6K, and $z_{preheat} \leq 10$ are inconsistent with the data and so are disregarded for the rest of their paper.

5. Filtering Mass

Because the temperature of the IGM is greater than zero, gas pressure exists and will oppose gravitational collapse. For gas of a constant temperature (say in a non-expanding universe) the Jean's mass describes the effects of pressure on density perturbation growth such that any mass perturbation below the Jean's mass cannot collapse. The Jean's scale, k_J, given by the comoving wave number is considered the filtering scale in this situation since baryonic matter density perturbations are suppressed relative to dark matter perturbations.

For an expanding universe the fact that temperature is a function of time needs to be considered and leads to a filtering scale k_F where the gas is suppressed for comoving wave #'s $k>k_F$, with k_F related to k_J by,

$$\frac{1}{k_{\mathrm{F}}^2(t)} = \frac{1}{D(t)} \int_0^t \mathrm{d}t' a^2(t') \frac{\ddot{D}(t') + 2H(t')\dot{D}(t')}{k_{\mathrm{J}}^2(t')} \int_{t'}^t \frac{\mathrm{d}t''}{a^2(t'')},$$

where k_J is given by,

$$k_J = a\left(4\pi G\bar{\rho}_{\rm tot}\frac{3\mu m_H}{5k_B\overline{T}_{\rm IGM}}\right)^{1/2}$$

For a homogeneous IGM temperature, T_{IGM}, we can determine T_{IGM} by using a volume weighted mean temperature and averaging over the temperature at each density. Preheating however can cause homogeneities in the IGM so it may be useful to compute filtering masses by using a density dependent temperature.

The hottest models considered by Benson and Madau have a temperature of $T_{IGM}\approx 4000K$ that gives a virial temperature of $10^8 h^{-1}$M_sun. The virial temperature gotten from the filtering mass is a few times $10^{11} h^{-1}$M_sun which means that the filtering mass leads to a greater suppression of galaxy formation and thus affects the galaxy luminosity function.

6. Luminosity Function

Benson and Madau present luminosity functions predicted by their semi-analytic model using the aforementioned filtering mass for some values of $z_{preheat}$ and $E_{preheat}$. First, as shown in figure 3, the situation where the volume weighted mean temperature was used was considered and some models seemed to match the faint end very well but over produced in the bright end, while other models did fairly well in the bright end but then overproduced in the faint. Next, in figure 4, the case where the temperature was a function of density was considered and the results are that more energetic preheating is necessary to match the luminosity function.

7. Conclusion

In conclusion, preheating in the universe caused by feedback from an early group of subgalactic star systems and accreting black holes is a viable solution for remedying some of the problems of the ΛCDM paradigm. Depending on the details of the thermal history of the IGM, preheating can flatten out the faint end slope of the galaxy luminosity function to match observations without calling on typically used feedback mechanisms such as supernovae. While preheating cannot on its own match some of the observational constraints it might reduce or replace the need for other standard feedback mechanisms.

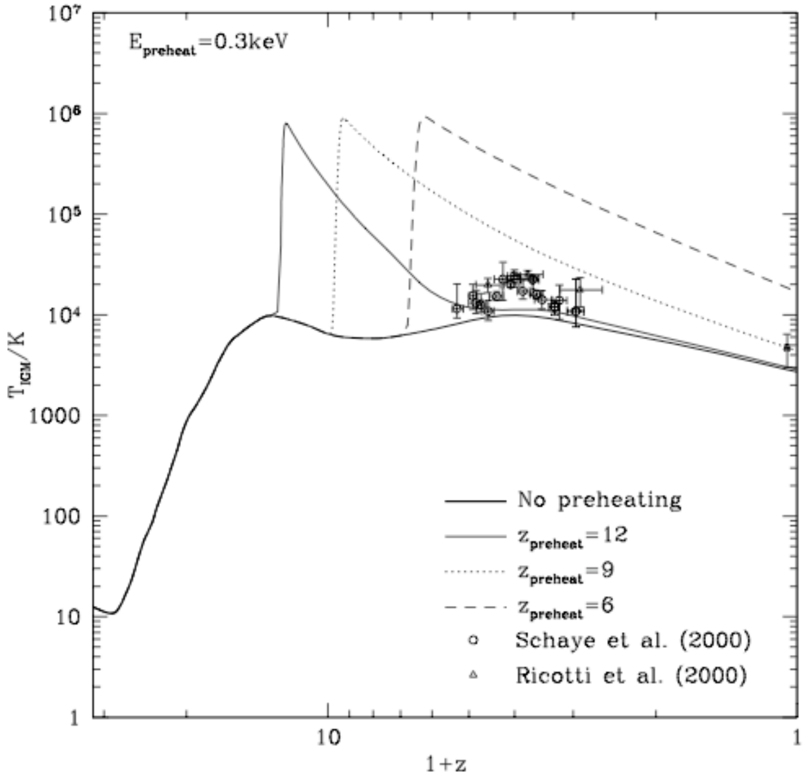

Figure 1.

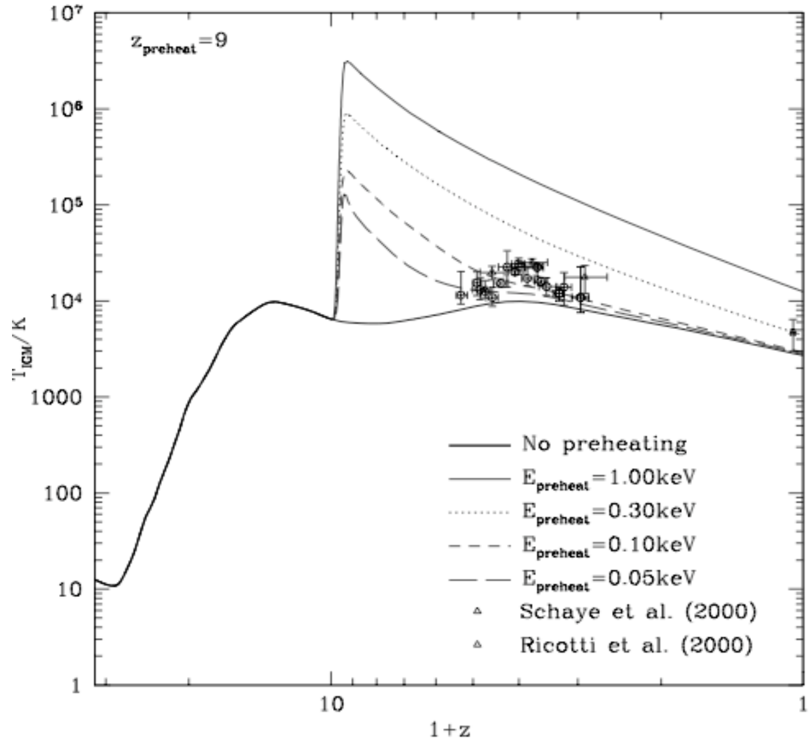

Figure 2.

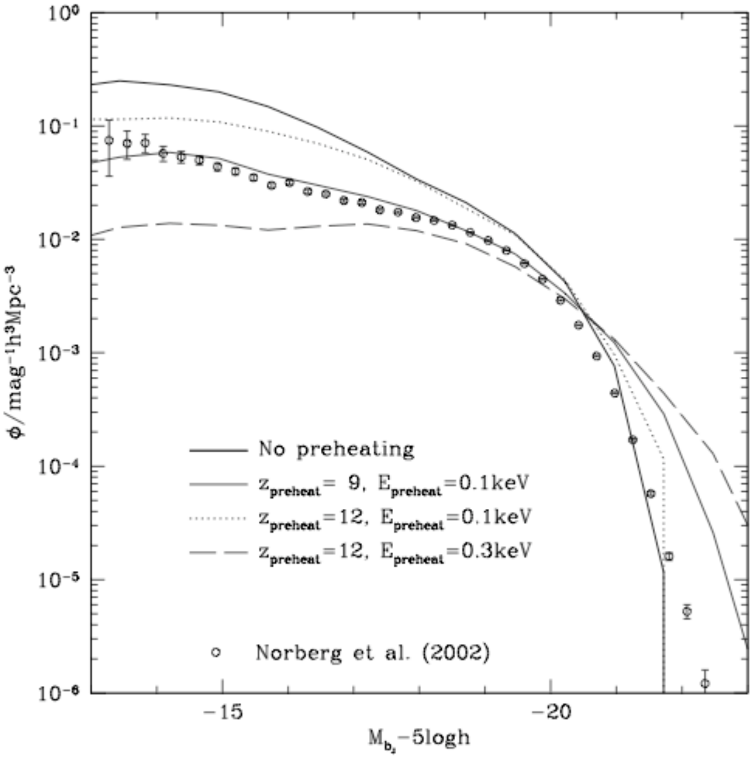

Figure 3.

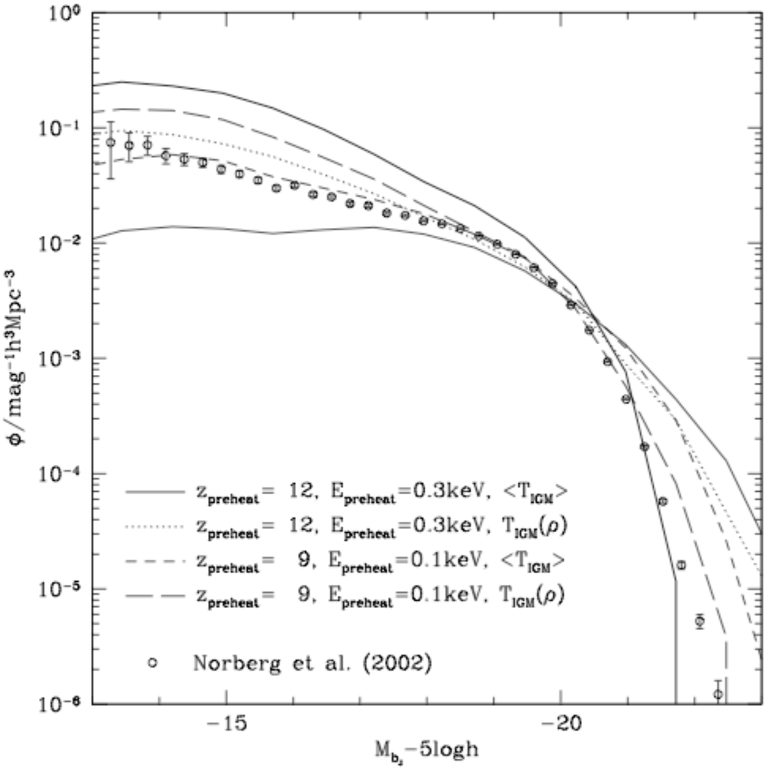

Figure 4.

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