Pop III, Gravity Waves and ^{6}Li … oh my!

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Journal Club

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Notes

- Definition of z:

$$z = \frac{\lambda - \lambda_0}{\lambda_0}$$

$$z = \frac{H_0 d}{c}$$

$$z = e^{v/c} - 1$$

$$z = \left(1 - \frac{v}{2c}\right)^2 - 1$$

Event	*Redshift*	*Time (yrs)*
Big Bang	Z=∞	0
Pop III stars	Z=12-20	3-1 x 10^8
First 0.02% of metals	Z=14	2 x 10^8
Pop II stars	z<10	>4 x 10^8
Galaxy Clusters	Z=2	3 x 10^9
Milky Way	Z=1	5 x 10^9

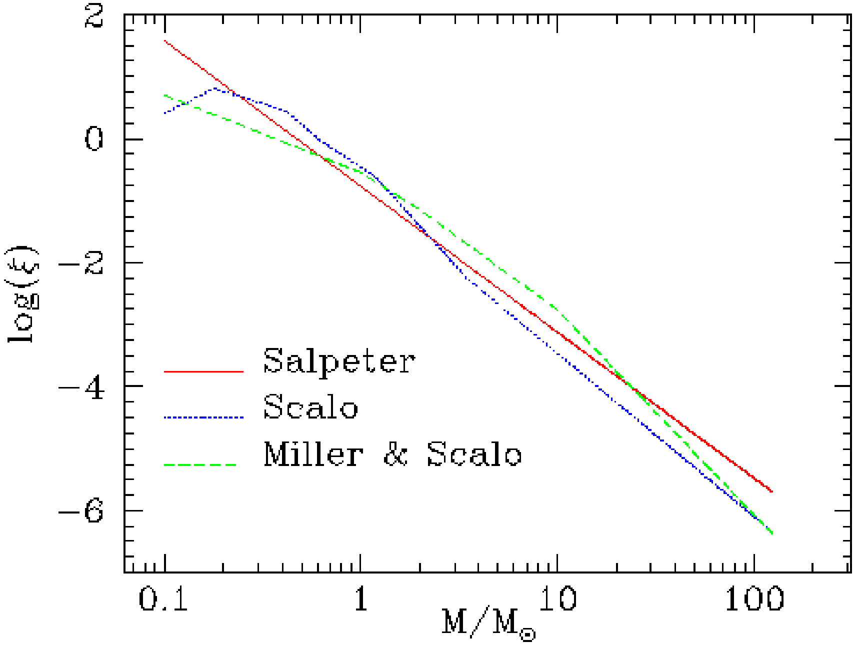
Lepp and Stancil (1998), adapted partially from Peebles (1993)

Notes

- Initial Mass Function
  - Generally, a power law describing the distribution of mass
- Populations of Stars
  - Pop. I – the Sun, metal rich, in the plane of the galaxy
  - Pop. II – metal poor, in globular clusters
  - Pop. III – no metals, minihalos?

Cosmic rays

  - relativistic protons, alpha-particles ejected from almost every energetic object in the universe



Bruzual and Charlot, 1993

Gravitational wave background from Population III black hole formation

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Gravitational Waves

- What are they?
  - Think GR (which I've never had)
    - Gravity can be expressed as the curvature of space time
    - A changing mass distribution can create ripples in space-time which propogate away at the speed of light.
    - No detection YET… but indirect influence has been measured in the binary neutron star system PSR1913+16

Gravitational Waves

- Where are they generated?
  - SNe, collapsing stars to form black holes, coalesence of compact binaries, rotating neutron stars, cosmic strings etc etc… etc….
- Araujo et. al. consider *only* the waves generated during core collapse of Population III stars to black holes

Gravitational Wave Production-
Formalism

- GWs are characterized by their dimensionless amplitude and frequency

- Spectral Density:

$$F_\nu = \int_{z_{cf}}^{z_{ci}} \int_{m_{min}}^{m_u} f_\nu(\nu_{obs})\, \mathrm{d}R_{BH}(m, z),$$

  - For the AST531 folks: This not what we did on the homework
  - Rather, it is a relationship which determines the total amount of energy emitted as GWs over the entire range of redshifts (~10 - ~50)and from progenitor masses of interest (here 25-125 M_{Sol})

Gravitational Wave Production-

Formalism

- Dimension Amplitude
  - A way to incorporate redshifts, i.e. expansion of the universe on these scales

$$h_{\rm BG}^2 = \frac{(7.4\times 10^{-20}\alpha)^2 \varepsilon_{\rm GW}}{\nu_{\rm obs}}$$

$$\times \left[\int_{z_{\rm cf}}^{z_{\rm ci}} \int_{m_{\rm min}}^{m_{\rm u}} \left(\frac{m}{\rm M_\odot}\right)^2 \left(\frac{d_{\rm L}}{1\,{\rm Mpc}}\right)^{-2} \dot{\rho}_{\star}(z) \times \frac{{\rm d}V}{{\rm d}z} \phi(m)\,{\rm d}m\,{\rm d}z \right].$$

- Necessity of *h*
  - Reduces the complexity of the background flux graphs
  - Models are useful iff they predict the location (in “z-space”) of the Pop. III collapse

Determining z

- The importance
  - There is a non-negligible time between the generation of Pop. III stars (and their associated Stromgren spheres) and reionization
  - Determining ages of Pop. III will put an upper limit before which re-ionization would not have occurred.

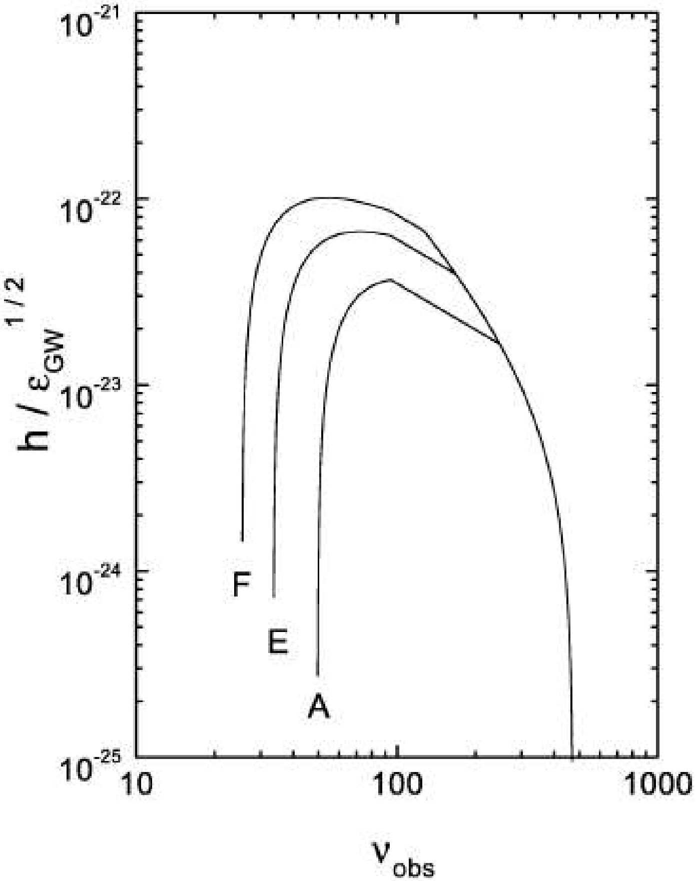
The model

- Authors accept that there exist a number of variables
  - Efficiency of gravity wave production
  - IMF
  - Condensation of baryons in stars
  - Range of z during which P.III stars were produced…
- Most of these variables are inherent to the problem due to lack of observables
- Taking the risk:
  - P. III stars could be
    - Directly responsible for ionizing Hydrogen
    - Account for the metallicity found in Lyman- α Forest Clouds

The model

Table 1. The redshifts of collapse for our models and the corresponding GW frequency bands. The cosmological parameter $h_{100}^2 \Omega_B = 0.019$ (see the text), $\alpha = 0.1$, $f_\star = 0.01$ (our fiducial value) and the standard IMF are adopted.

Model	z_{ci}	z_{cf}	$\Delta\nu$ (Hz)
A	20	10	50–470
B	30	20	34–250
C	40	30	25–170
D	50	40	20–130
E	30	10	34–470
F	40	10	25–470
G	50	10	20–470
H	15	5	65–870



Guidelines for detectors:

the background amplitude

Detection

- LIGO I: no
- LIGO II: maybe
- LIGO III: “more optimistic”

Model		S/N	
	LIGO I	LIGO II	LIGO III
A	8.3×10^{-3}	1.6	6.6
B	8.5×10^{-3}	2.3	26
C	8.7×10^{-3}	2.7	47
D	8.1×10^{-3}	2.5	51
E	2.7×10^{-3}	5.7	37
F	5.0×10^{-3}	12	120
G	7.7×10^{-2}	21	260
H	4.6×10^{-3}	0.5	1.7

-To make matters worse, there could be overlap. This could occur anywhere in the bandwidth

-LISA wouldn’t detect background GWs

Population III Generated Cosmic Rays and the Production of ^{6}Li

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Legend has it…

- ^{7}Li from BBN, ^{6}Li from GCRN
- The bulk of Population II ^{7}Li abundance is produced by BBN, with 10% supplied by GCRN
  - Basis for "Spite Plateau"s
- ^{6}Li should show strong (log-linear) correlation to Fe

Survey says …

- WMAP (2006) data:
  - $\Omega_b * h^2 \sim 0.02233$
    - $n \sim 6.12 \times 10^{-10}$
      - $4.15 \times 10^{-10} < {}^{7}Li/H < 4.97 \times 10^{-10}$
      - A factor of 1-2 time greater than observed abundances
- Observations of 6 Li (Asplund *et. al.)*
  - [^{6}Li] independent of metallicity.
  - ^{6}Li plateau about 1000 times above the BBN predicted abundance

Paper I vs. Paper 2

- Paper 1-not so realistic
  - 2005
  - Considered initial burst of CCRs correlated to a very early generation of Population III stars at redshift z_s
- Paper 2-realistic
  - 2006
  - Considered more linear (on log-linear plot) SF on log-linear

Birthrates

-Phi functions:

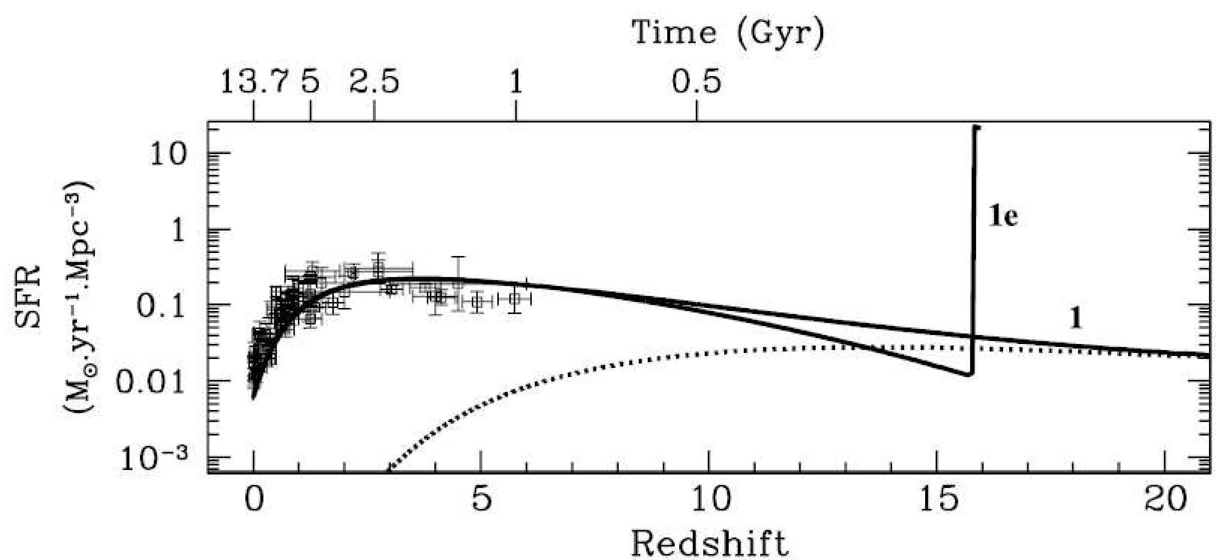
both are power laws (individually normalized) with a near Salpeter slope

-Psi functions:

SFR rates, mediated by either:

a) time for the massive component

b) the metallicity of the IGM for the normal component



Deathrates, Cosmic Rays

- Assumptions:
  - Massive component: $40 < M_{Sol} < 100$
  - 100 M_{Sol} is the greatest mass, (Daigne et al. looked at 140-260M_{Sol} , 270-500M_{Sol})
  - All stars > 8 M_{Sol} go supernova

Deathrates, Cosmic Rays

- Energy of Core Collapse:
  - Stars with mass 30-100 MSol generate black holes of mass equal to the star's helium Helium Core Mass approximated by core (Heger *et al.,* 2003)

$$M_{He} = \frac{13}{24}(m - 20M_{Sol})$$

  - Parameterization of the energy injected in cosmic rays per supernova

$$\varepsilon_{CR}(m) = \frac{\epsilon E_{cc}(m)}{100}$$

where:

epsilon = 0.01-0.3 (poorly confined)

$$E_{cc} = 0.3M_{He}$$

Deathrates, Cosmic Rays

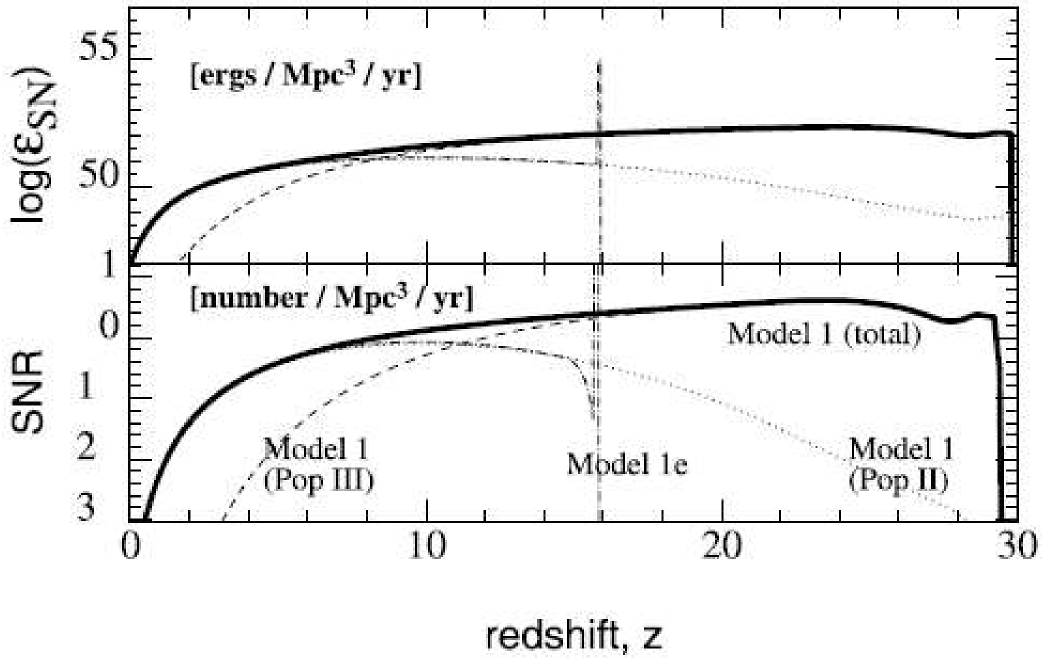
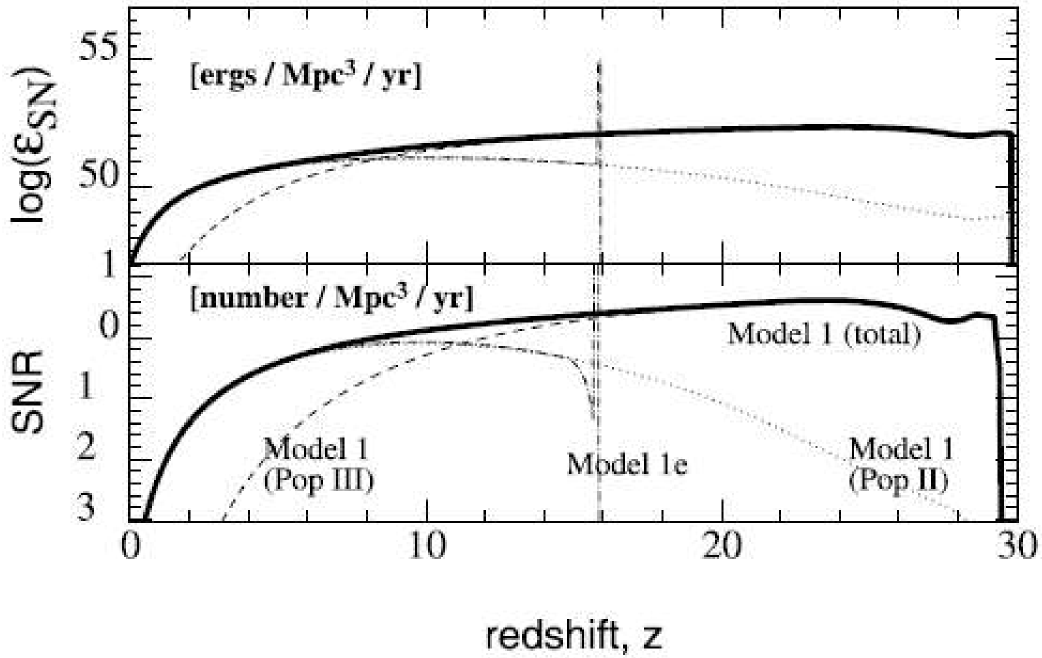


FIG. 2.—CR history predicted by Daigne et al. (2006). The SNR (*bottom panel*) and energy density in cosmic rays (*top panel*, eq. [9]) are shown in the case of model 1 for Population III (*dashed line*), Population II (*dotted line*), all SN (*solid line*), and in the case of the model 1e (*dot-dashed line*). The fraction of energy deposited in cosmic rays, ϵ, (defined in eq. [8]), is 0.15 and 0.04 in model 1 and 1e, respectively.

Deathrates, Cosmic Rays



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Cosmic Rays and the production of Lithium in the IGM

- Difference between Paper 1 and 2 characterized well in terms of the CR energy density:

- In contrast to Daigne et al., assume all CRs are ejected
- Flux of alpha particles:

$$\Phi_{\alpha,H}(E,z) = \beta N_{\alpha,H}(E,z)$$

Results

(that I'm comfortable with)

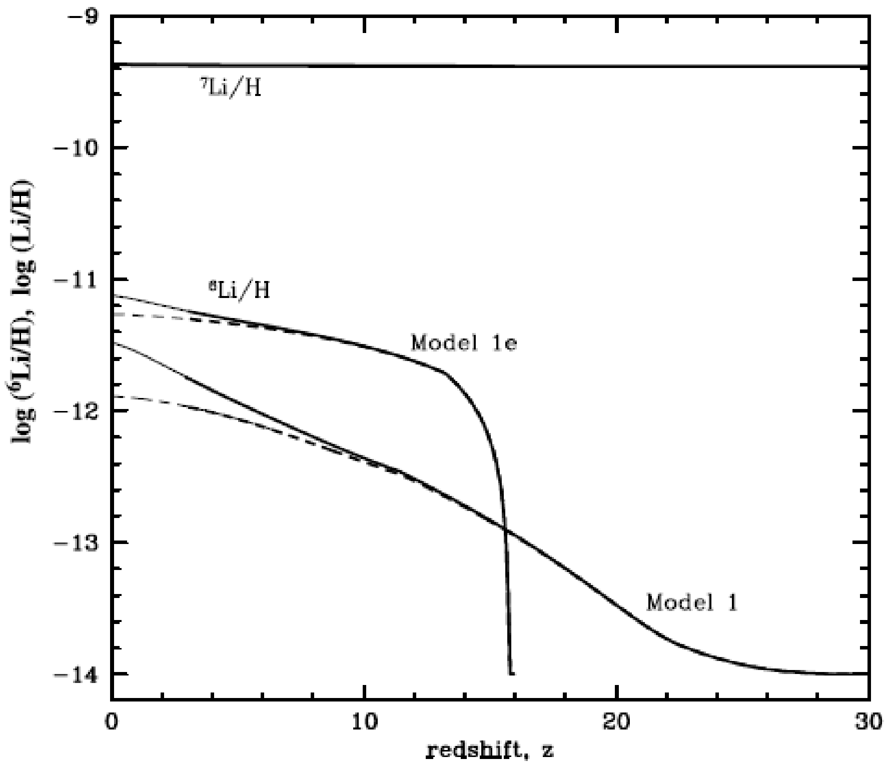


FIG. 4.—Production of lithium in the IGM by CCRs assuming $E_{cut} < 10$ MeV and $\epsilon_{esc} = 1$ as a function of redshift for both isotopes in both models 1 and 1e. Here, ϵ is fixed at 0.04 so that model 1e produces $\log(^6\mathrm{Li/H}) = -11.2$ at $z = 3$. Since the ^{6}Li abundance scales with ϵ, adopting $\epsilon = 0.15$ would increase the model 1 abundance to -11.2 as well. The contribution to the Li abundance from Population III stars alone is shown by the dashed curves.

Results

(that I'm not comfortable with)

- Many observations (of quasars) set "conservative" upper limit on T_{IGM} of 10^5 K
- Rollinde et. al. find strong correlation between induced T_{IGM} and CR energy cutoff

Results
(that I'm not comfortable with)

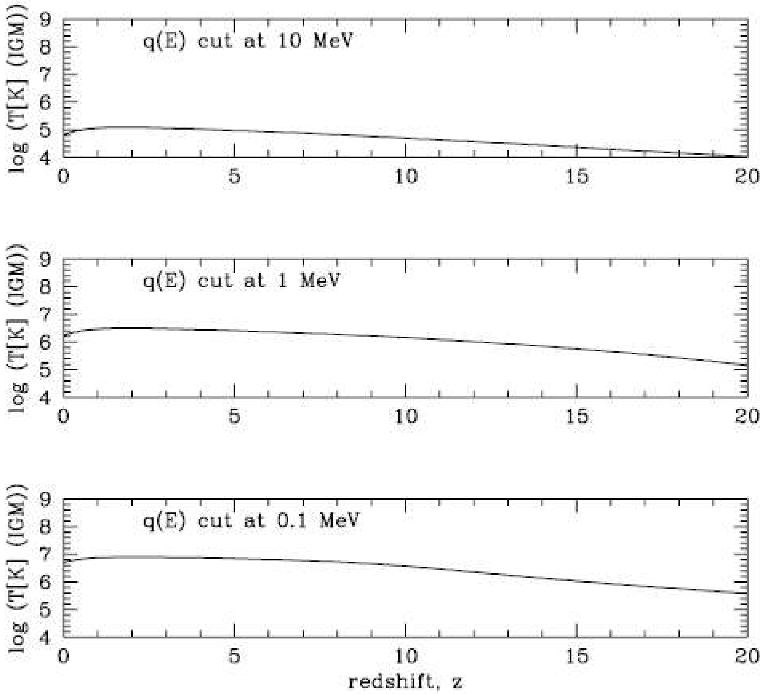


FIG. 5.—Induced temperature by CCR heating in the IGM for model 1 for three choices of the CR cutoff energy, E_{cut}, as indicated.

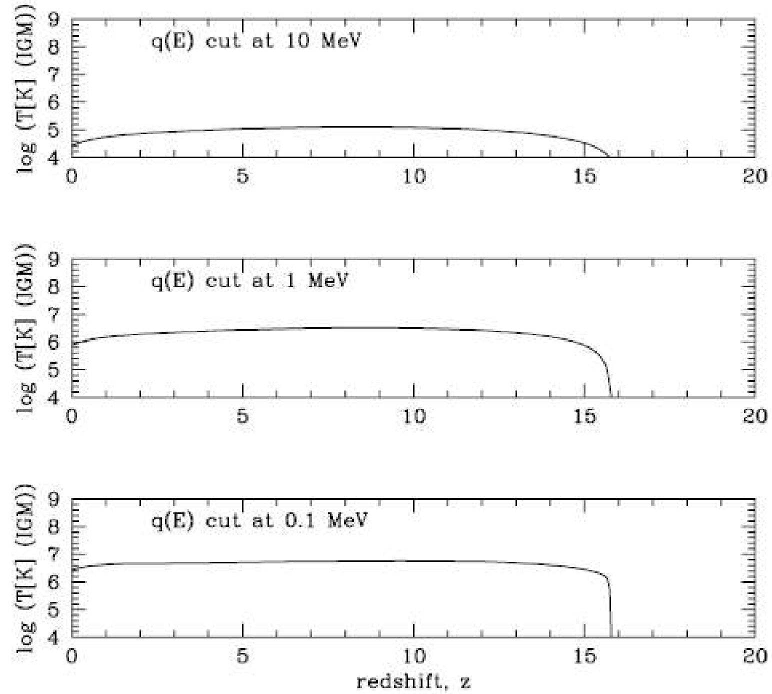


FIG. 6.—As in Fig. 5, but for model 1e.

Results

(that I'm not comfortable with)

- To their credit:
  - Model assumes epsilon = 1.0 for *all* z
  - Temperatures in the warm-hot IGM is of the same magnitude (Cen and Ostriker, 1999; Simcoe et al. 2002).

Production of Lithium in ISM

- Similar to production, in mathematical terms, to IGM production
- But!
  - Structure exists
  - Presence of strong magnetic fields
  - Presence of “characteristic column density” that can/will affect epsilon

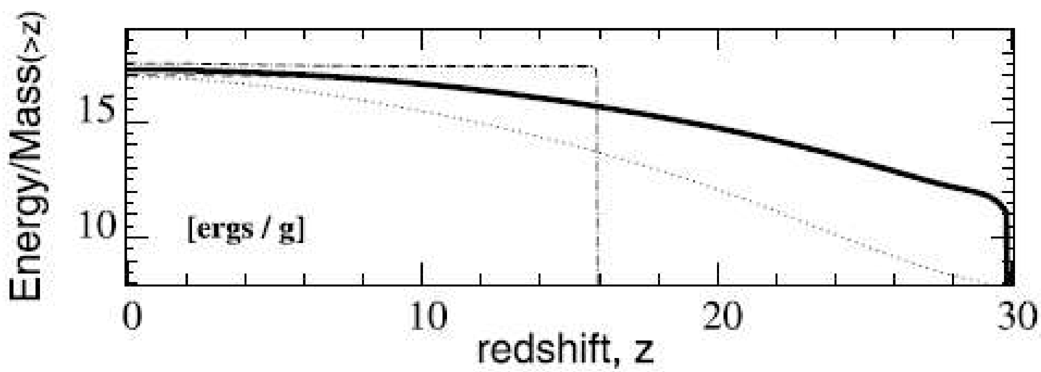
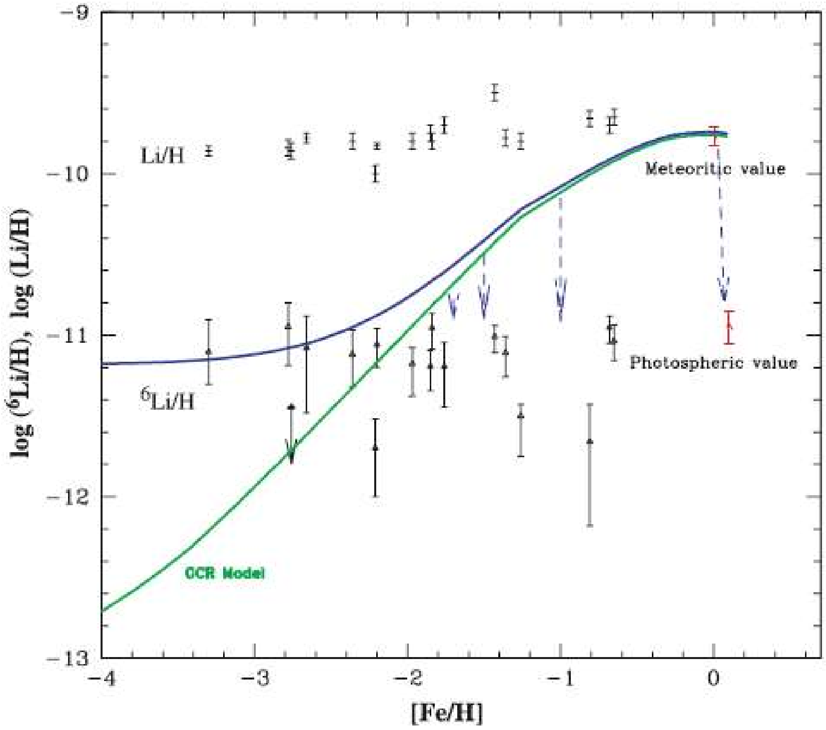


FIG. 8.—Cumulative ratio of the energy deposited in CRs to the mass of the structure as determined by the integral in eq. (22) (curves are as in Fig. 2).

Summary

- Further support for the necessity of Population III
- Can be used to produce the ^{6}Li plateau
- Provides some insight into mass density in old star forming regions
- Model is more robust, allows for:
  - Reionization at z ~ 11
  - Observed SFR at z </= 6



Papers of Interest

- Observational:
  - Asplund et. al. “Lithium Isotopic Abundances in Metal Poor Halo Stars” 2006
- Theoretical:
  - Daigne et. al. “Hierarchical Growth and Cosmic Star Formation: Enrichment, Outflows, and Supernova Rates” 2006

Summaries of the two papers

- Paper b)
- Paper a)
  - Use core collapse of Pop. III stars to model the environment of the old universe
  - Find an upper limit to z for the reionization