

Weighing Neutrinos Using High Red Shift Galaxy Luminosity Functions

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August 10, 2010

Neutrinos and Cosmology

- ▶ Second most abundant species in the universe. Total matter density in the universe due to neutrinos is

$$\Omega_\nu = \frac{\Sigma m_\nu}{94h^2 eV}$$

- ▶ Neutrinos free stream and escape density perturbations resulting in a suppression in the growth of density perturbations below the free streaming scale.
- ▶ Reduced abundance of dark matter halos
- ▶ Particle physics limit on absolute mass scale $\rightarrow \Sigma m_\nu < 2.05 \text{ eV}$ (95 % C.L.)

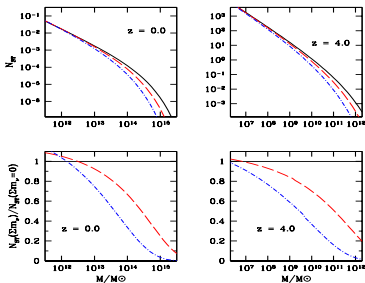
*Jose C., Samui S., Subramanian K. and Srianand R., Phys.Rev.D, **83** (2011), 123518.*

The abundance of objects: The ST mass function

- ▶ Comoving number density of halos with mass between M $M + dM$

$$N_{ST}(M, z)dM = \frac{\rho}{M} A \sqrt{\frac{2a}{\pi}} \left[1 + \left(\frac{\sigma^2}{a\delta_c^2} \right)^p \right] \frac{\delta_c}{\sigma} \left(\frac{-1}{\sigma} \frac{d\sigma}{dM} \right) \exp \left(\frac{-a\delta_c^2}{2\sigma^2} \right)$$

- ▶ $\Sigma m_\nu = 0.0\text{eV}$ $\Sigma m_\nu = 0.5\text{eV}$ $\Sigma m_\nu = 1.0\text{eV}$



- ▶ Counting Galaxies at high z may constrain neutrino mass \rightarrow Galaxy Luminosity functions (LF) at high z .

Model for Luminosity Function

- ▶ The Star formation rate in a halo at a time 'T' after collapse is

$$\dot{M}_{SF}(T) = f^* M_b \left(\frac{T}{t_{dyn}^2} \right) \exp[-T/t_{dyn}], \quad T(z, z_c) = t(z) - t(z_c)$$

Chiu W. A. & Ostriker J. P., ApJ, 2000, 534, 507.

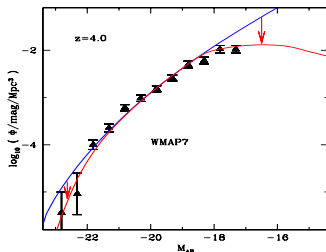
- ▶ SFR \rightarrow Luminosity \rightarrow Magnitude(M_{AB}).
- ▶ Observed luminosity $\rightarrow L_0 = L/\eta$
- ▶ The quantity f^*/η is the light to mass ratio of the galaxy and is a free parameter.
- ▶ Galaxies of different masses forming at different redshifts can have same luminosity at some redshift.

High Redshift UV Luminosity Functions of LBG's

- ▶ LF is the total number of galaxies of a particular absolute magnitude at z . It is a directly observable quantity.

$$\Phi(M_{AB}, z) dM_{AB} = \int_z^\infty dz_c \frac{dN_{PS}(M, z_c)}{dz_c} \frac{dM}{dL_{1500}} \frac{dL_{1500}}{dM_{AB}} dM_{AB}$$

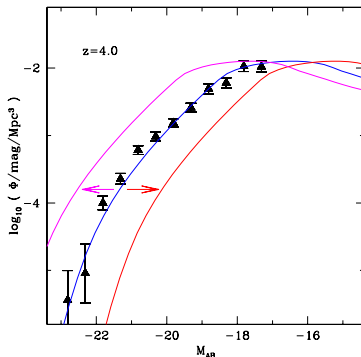
S. Samui, R. Srianand and K. Subramanian, MNRAS, 377 (2007), 285.



- ▶ Radiative feedback: Linear suppression in galaxy formation from 0 to 1 for halos with circular velocity in the range $35 \leq v_c \leq 95$ (in kms^{-1}).
- ▶ Suppression factor due to AGNs $[1 + (M/M_{AGN})^3]^{-1}$. $M_{AGN} \propto 10^{12} M_{\odot}$.

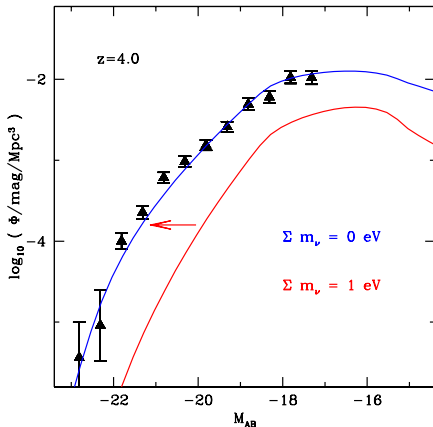
High Redshift Galaxy LF

- ▶ Changing mass to light ratio f^*/η moves curve parallel to the X-axis.
- ▶ The best fit LF is obtained by varying f^*/η as a free parameter.



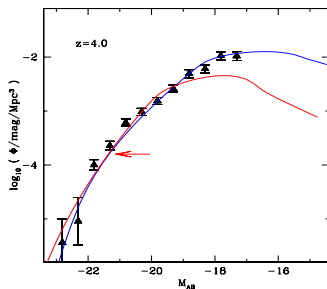
Massive neutrinos and LF

- ▶ The presence of massive neutrinos reduce the number density of galaxies and under predict LF.
- ▶ This effect is degenerate with f^*/η . LF can still be fitted by increasing f^*/η .



Contd..

- ▶ A difference in shape of LFs in massive neutrino models. Here the low luminosity end is under predicted.
- ▶ Increasing f^*/η brings small mass galaxies into observable range which are suppressed by radiative feedback. This results in the above feature.



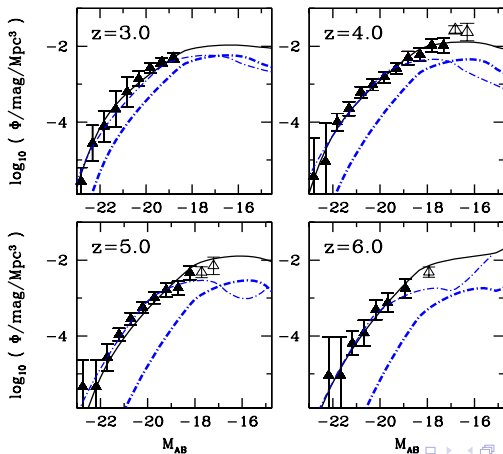
Shape of the LF can tell about Mass of Neutrinos

Massive neutrinos and LF

The effect of Massive Neutrinos on LF at various redshifts.

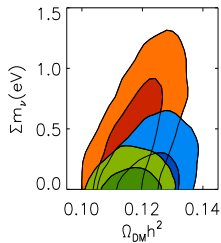
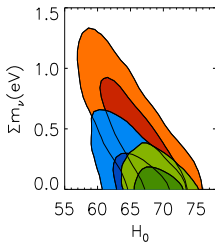
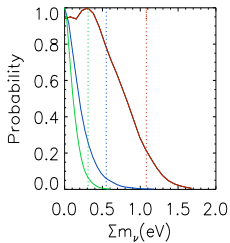
$$\Sigma m_\nu = 0 \text{ eV}$$

$$\Sigma m_\nu = 1 \text{ eV}$$



Limits on Σm_ν .

- ▶ MCMC analysis using COSMOMC. Combined $z = 4$ UV LF data with other cosmological data.
- ▶ Used the previous radiative feedback. $M_{AGN} = 1.5 \times 10^{12} \odot$.
- ▶ 1D and 2D distributions of Σm_ν against other parameters.



WMAP7 WMAP7+LF WMAP7+LF+HST

Limits on Σm_ν

- ▶ The WMAP 7 year data $\rightarrow \Sigma m_\nu < 1.1$ eV.
- ▶ WMAP7 + LF data $\rightarrow \Sigma m_\nu < 0.52$ eV
- ▶ WMAP7 + HST data $\rightarrow \Sigma m_\nu < 0.54$ eV
- ▶ WMAP7 + HST + LF data $\rightarrow \Sigma m_\nu < 0.29$ eV
- ▶ WMAP7 + HST + SNe + LRG data $\rightarrow \Sigma m_\nu < 0.28$ eV
- ▶ WMAP7 + HST + SNe + LF data $\rightarrow \Sigma m_\nu < 0.23$ eV
- ▶ M_{AGN} is varied as a free parameter. Results remained almost the same.

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Limits on Σm_ν .

- ▶ Combined $z=3$ LF data with $z=4$ LF data and other data. M_{AGN} varied as a free parameter.
- ▶ WMAP7 + LF data $\rightarrow \Sigma m_\nu < 0.32$ eV
- ▶ WMAP7 + LF + HST data $\rightarrow \Sigma m_\nu < 0.23$ eV
- ▶ WMAP7 + LF + HST data + SNe $\rightarrow \Sigma m_\nu < 0.2$ eV
- ▶ $\Sigma m_\nu < 0.2$ is among the current best limit from cosmology.

Summary..

- ▶ Demonstrated that LF data can potentially constrain neutrino mass.
- ▶ Obtained a limit of $\Sigma m_\nu < 0.2 \text{ eV}$
- ▶ Improvement of UV LF data especially at fainter end can improve this limit.
- ▶ Having a better understanding of astrophysics of Galaxy formation one can use all high redshift LF to improve this limit.

THANK YOU