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The HDF, The Arizona View

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Abstract. We present an initial analysis of the star formation rates in the deep NICMOS field of the Hubble Deep Field. The analysis utilizes template photometric redshift and extinction techniques on the combination of six optical and near infrared fluxes available for this region from observations with both NICMOS and WFPC2. Our results are consistent with a constant star formation rate for a redshift range of 1 to 6.

1. Introduction

The history of star formation in the universe is a matter of intense current study. Early observations eg. Madau et al. 1996 found an order of magnitude increase in star formation from the present epoch to a redshift range of approximately 1.5 then a decrease in star formation out to a redshift of 4. Since that analysis used the 1500 Å flux as a star formation indicator it is subject to uncertainty due to extinction. Far infrared studies in the HDF eg. Hughes et al. 1998 detected several far infrared sources and suggested that significant amounts of star formation can be hidden by dust obscuration. The combined NICMOS and WFPC observations cover a factor of 5 (0.3 - 1.6 microns) in wavelength, therefore, it is possible to determine both the redshift and the extinction by photometric means. The data for this analysis comes from the HDF observations of Williams et al. 1996 and Thompson et al. 1999.

2. Methodology

Since there are no good polynomial fits for very high redshift galaxies and near infrared fluxes we utilize the template fitting method of photometric redshifts. We take 11 different spectral energy distribution templates that span the range from early galaxies to very recent starbursts. The templates also include two low metallicity templates. Each template is then numerically redshifted and extincted to provide a very large grid of templates. The extinction law is taken from Calzetti et al. 1994.

The observed fluxes are then matched against the template fluxes to determine the fit with the minimum chi squared value. The redshift and extinction for that template is then considered the correct redshift and extinction for the source.

The chi squared value for the fit is given by

$$\chi(z,E)^2 = \sum_{i=1}^{6} \frac{(f_i - A \cdot fmod(z,E)_i)^2}{\sqrt{\sigma_i^2 + f_i^2}} \quad (1)$$

where i is the flux band, f_i is the observed flux, $fmod(z,E)$ is the template flux numerically altered for the redshift z and extinction E and A is the normalization that minimizes the chi squared value given by

$$A = \sum_{i=1}^{6} \frac{f_i \cdot fmod(z,E)_i}{\sigma_i^2 + f_i^2} / \sum_{i=1}^{6} \frac{(fmod(z,E)_i)^2}{\sigma_i^2 + f_i^2} \quad (2)$$

Note that in addition to the usual errors given by σ_i we also divide through by the flux f_i. This takes into account that at larger fluxes the main error is a systematic fraction of the flux rather than the formal 1 σ error from the noise.

3. Star Formation Rates

Following Madau, Pozzetti and Dickinson 1998 we determine the star formation rate from the 1500 Å flux by

$$SFR = 8.0 \times 10^{27} \cdot UV_{1500} M_{\odot}/yr \quad (3)$$

In our case we utilize the UV flux from the unextincted template since we wish to correct for the extinction effects. The star formation rate as a function of redshift for the NICMOS deep observations of the HDF appear in Figure 1.

The error bars on this figure are determined from an analysis of the effect of photometric errors on the star formation rate not by number statistics. This is appropriate since we are measuring the star formation rate that exists in the NICMOS region of the HDF and are not trying to extrapolate it to other regions of the sky. Except for the excess near a redshift of 2 the star formation rate is roughly constant at all z values out to 6. The bump at redshift 2 is probably due to the very narrow line of sight passing through a z = 2 cluster of galaxies. We do not try to determine the star formation rate at low redshifts due to the very small number of galaxies in our sample at low redshifts. The inclusion of extinction raises the rate by roughly a factor of two at all redshifts.

4. Conclusions

Our observations do not show a decrease in the star formation rate as a function of z out to a redshift of 6. This conclusion is not due to the inclusion of extinction but extinction does reduce the rate determined by optical means by about a factor of two at all redshifts. These results are consistent with the recent results of Steidel et al. 1999 that find no fall off in star formation rate out to a redshift of 5.

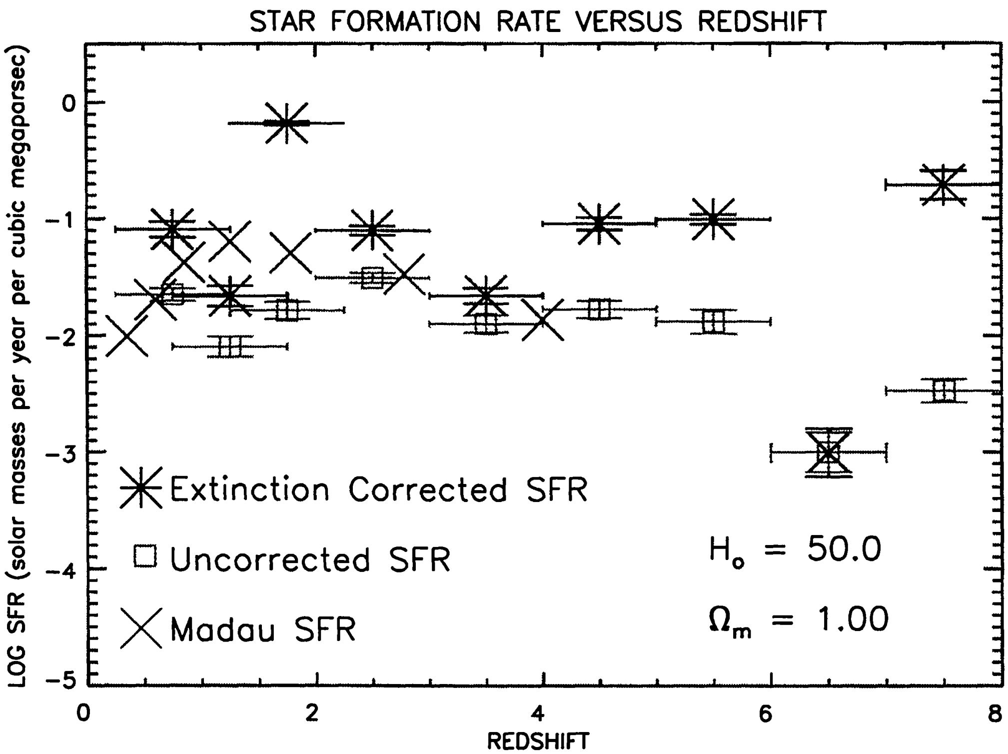

Figure 1. Star formation rate per comoving volume as a function of redshift

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