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Universal Star-Formation History from 2dF Galxy Redshift Survey spectra.

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Abstract. We present results on the star-formation history of the Universe as reconstructed from the 2dF Galaxy Redshift Survey. We analyse the local 'Cosmic Spectrum', i.e. the ensemble emission of local stellar populations of different ages, to derive allowed ranges for the star-formation rate over $0 < z < 5$. A comparison with UV based measurements of high-z galaxies shows good agreement and indicates that the star-formation rate is $\simeq$ constant for $z > 1$.

1. Introduction

The analysis of the comoving star-formation rate density as a function of redshift has been the subject of much recent work. The onset of large redshift surveys at $z < 1$ (Lilly et al. 1996) and $z > 3$ (Steidel et a. 1999) has allowed the volumetric emission of luminosity in different bands to be traced with redshift. In particular from these studies there is now good evidence for a rise in star-formation rate by a factor of about 8 between $z = 1$ and $z = 0$ (Hogg 2002) and either a $z > 1$ decline (Madau et al. 1996) or plateau (Pettini et al. 1998).

Popular tracers of star-formation rate include: the UV 1500–3000Å continuum (Connolly et al. 1997; Madau et al. 1998); the radio continuum (Mobasher et al. 1999); emission in the Hα and Hβ lines (Glazebrook et al. 1999), and; other line emission such as Lyα (Kudritzki et al.(2000) or OII (Colless et al. 1990, Hogg et al. 1998). The far-IR thermal dust emission has also been used to trace star-formation rate (Hughes et al. 1998) although so far without the benefit of redshift information. All these measures have in common the use of some kind of luminosity per unit volume whose change is proportional to the star-formation rate (with corrections). The debate over the $z > 1$ slope reflects the uncertainty in the dust correction to the UV continuum measurements, which are the easiest to measure at high redshift but most affected by dust. The other indicators are harder to measure and are affected by small number statistics.

2. Our approach

We describe our new constraints on the history of star formation based on the ensemble stellar populations of relatively nearby present day galaxies ($z < 0.3$).

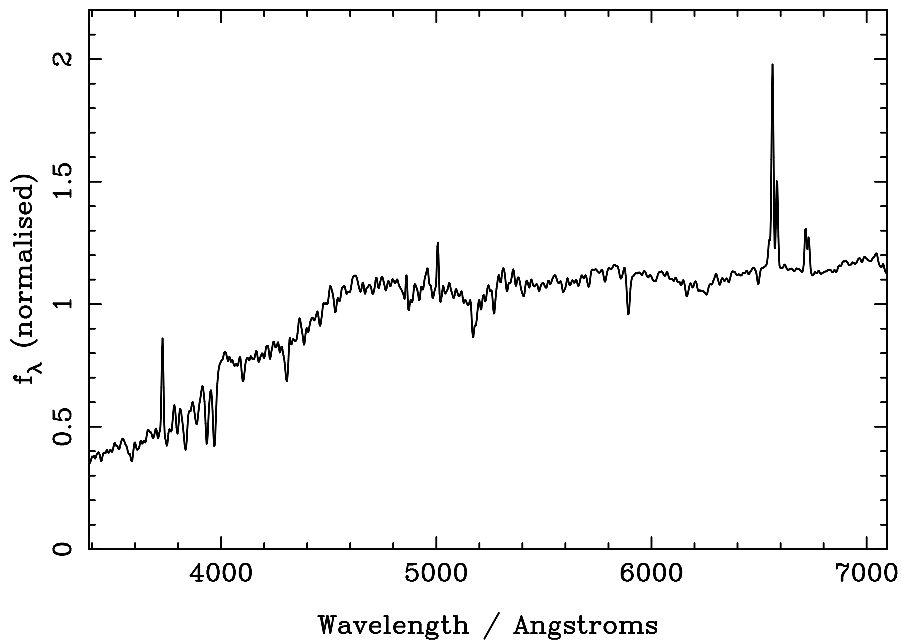

Figure 1. The 'Cosmic Spectrum' at z=0.1 from the 2dF Galaxy Redshift survey. This reprensents the volumetric emission of all the starlight in the survey at this redshift.

The concept is to use the average spectrum of nearby galaxies to constrain the earlier history of star formation leading up to that stellar population. The average spectrum contains absorption features for stars of all ages and probes look-back times of 0.2–10 Gyr. With the advent of the large galaxy redshift surveys, such as the Two-degree Field Galaxy Redshift Survey (2dFGRS) and the Sloan Digital Sky Survey, it has become feasible to combine the spectra of 10^4–10^5 galaxies to form very high signal-to-noise intermediate resolution spectra that represent the average emission of the universe at various redshifts ($0.03 \lesssim z \lesssim 0.25$). Effectively, the surveys can be regarded as having a series of apertures on the cosmic background emission rather than apertures on individual galaxies. We form what we call 'The Cosmic Spectrum', i.e. the volumetric, spectroscopic emission with redshift.

What is novel about this method is that it is not based on any luminosity output with time of the Universe, unlike all the other indicators discussed above. The method uses an integral over the star-formation history rather than attempting to track the derivative (the star-formation rate) and uses the whole visible spectrum at intermediate resolution.

3. Our Results

Figure 1 shows the Cosmic Spectrum at z=0.1 from the 2dFGRS. The relative units are energy per unit wavelength per Mpc^3. It it this spectrum we must fit

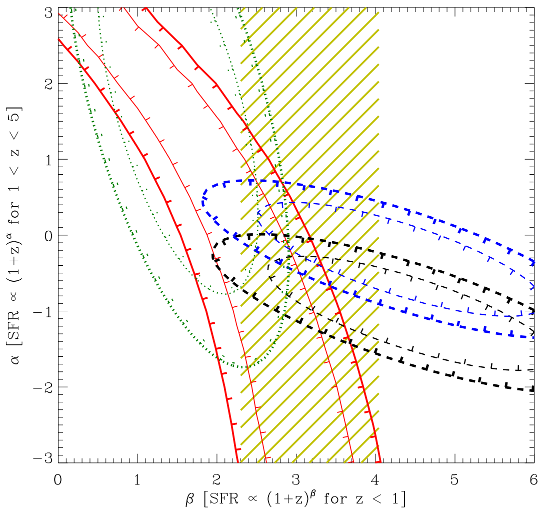

Figure 2. Confidence limits in α versus β. The *solid contours* represent the 2σ and 3σ confidence limits from this paper. The *dashed contours* represent the UV compilation (with and without extinction correction) of Steidel et al. The *dotted contours* UV compilation of Cowie et al (overlapping studies excluded). The vertical shaded region shows the line/far-IR/radio compilation of Hogg (which lie at $z < 1$).

with a model of star-formation history. In a sense we can think of this approach as applying 'evolutionary synthesis' on the Univerese as a whole, rather than on individual galaxy spectra. This has the advantage that the Cosmic Spectrum has a very high signal:noise, and that peculiar variations in star-formation histories in individual galaxies (e.g. starbursts) are averaged out.

For comparison with the literature on star-formation histories we adopt a simple double power-law for the star-formation rate, i.e for $z < 1$ we have $SFR \propto (1+z)^{\beta}$ and for $z > 1$ we have $SFR \propto (1+z)^{\alpha}$. The normalisation is adjusted to match at the break at $z = 1$ (this is where a break is commonly seen in the literature). We start the scenario at $z = 5$ (i.e. $SFR = 0$ for $z > 5$). Our spectral evolution models use PEGASE.2 for the underlying evolutionary synthesis (Fioc & Rocca-Volmerange 1997). Spectra are generated with time and fitted to the Cosmic Spectra in the 2dFGRS redshift range at low redshift.

For robust comparison of data with models we choose figures of merit (FOM) which are insensitive to small errors in the 2dF spectrophotometry. To do this we smooth the spectra with a 200Å top hat filter to generate a low-pass filtered spectrum. We then divide the original spectrum by the smoothed version in order to generate a high-passed filtered spectrum. The latter is particularly insensitive to low order variations due for example to spectro-photometric errors or incorrect extinction estimates. Our primary FOM is based on the reduced χ^2 of the high-pass filtered spectrum. The regions with strong nebular emission lines are excluded from this analysis as they represent the instantaneous star-formation rate rather than the past rate (i.e. we just use the relative strengths of the absorption features).

We have explored a range of IMFs and dust extinction scenarios, we find our results are insensitive to these. For the results presented here we just use the Salpeter IMF.

4. Results

Figure 2 shows our results in the (α, β) plane, in to which we have also transformed results from the literature. The Cosmic Spectrum results are degenerate, this is no surprise and includes the classical age-metallicity degeneracy. However robust upper limits at $z > 1$ are produced, we can not have arbitrarily high star-formation at $z > 1$ (which in principle is allowed by the UV data as the extinction and completeness are difficult to account for) because this would produce too high a ratio of old stars in the Cosmic Spectrum today (i.e. large α). All the allowed regions agree at the 2σ level, which we consider good given the dominant source of uncertainty in comparing the different methods is likely to be systematic. In particular there is a global region of agreement at $\beta \simeq 2.5, \alpha \simeq 0$, i.e. a scenario in which the star-formation rate rises by a factor of $\sim 6\times$ up to $z = 1$ and is $\simeq$ constant over $1 < z < 5$. This is in agreement with the *extinction corrected* results of Steidel et al. 1999, indicating that the Balmer decrement method of Pettini et al. 1998 is giving reasonable extinction values. Finally, it is also further evidence for the Copernican principle in cosmology, i.e. that the star-formation rates measured in the distant high-redshift Universe are in agreement with that inferred in the local Universe in the distant past.

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