On the Age Estimation of LBDS 53W091

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Abstract. We present a summary of our recent paper (Yi et al. 1999).

The recent spectral analysis of LBDS 53W091 by Spinrad et al. (1997) has suggested that this red galaxy at $z = 1.552$ is at least 3.5 Gyr old. This imposes an important constraint on cosmology, suggesting that it formed at $z > 6.5$, assuming recent estimates of cosmological parameters. While their analysis was heavily focused on the use of some UV spectral breaks as age indicators, we have performed $\chi^2$ tests to the continuum of this galaxy using its UV spectrum and photometric data ($R$, $J$, $H$, & $K$: $2000 - 9000$ Å in rest-frame). We have used the updated Yi models (Yi et al. 1997) that are based on the Yale tracks. We find it extremely difficult to reproduce such large age estimates, under the assumption of the most probable input parameters. Using the same configuration as in Spinrad et al. (solar abundance models), our analysis suggests an age of approximately $1.4 - 1.8$ Gyr, which is in good agreement with those of Bruzual & Magris (1997) and of Heap et al. (1998).

The large difference in age estimate from Spinrad et al. and from this study is mainly due to the significant difference in the model integrated spectrum. Figure 1 shows the comparison between the latest Jimenez models (downloaded from Jimenez’ ftp site in May, 1999), the preferred models in the analysis of Spinrad et al., and the Yi models, both for the solar composition. The Jimenez models shown here are the more recent ones than those used in Spinrad et al. At the time of this study, only his new models were made available to us.

In Figure 1, it is apparent that the new Jimenez ("J99") models are much bluer than the Yi models. Each model is denoted by the age (Gyr) and source (J: Jimenez, Y: Yi). One can easily understand why Spinrad et al. and we are achieving such different age estimates. An open diamond is an approximate relative flux of LBDS 53W091 normalized at 3150 Å. This relative flux of LBDS 53W091 is closely reproduced by the $1.4^{+0.1}_{-0.1}$ Gyr model when Yi’s models are used or the $1.9^{+0.2}_{-0.1}$ Gyr models when new Jimenez models are used (based on the reduced-$\chi^2$ tests).

Also plotted are the relative fluxes from the earlier version Jimenez ("J97") models (horizontal dashed lines) used in Spinrad et al. (1997), read off from the Figure 14 of Spinrad et al. (1997). The three dashed lines are from the top his 1, 3, and 5 Gyr models, respectively. Note that the J97 models are substantially bluer than the J99 models, which are already bluer than the Yi models. One can
see that the J97 models match the LBDS 53W091 data approximately at 3 Gyr, as Spinrad et al. (1997) suggested. The Yi models are in reasonable agreement with the 1999 version Bruzual & Charlot ("BC") models. If the new Jimenez models are the improved ones over his previous version used by Spinrad et al., all three groups now suggest rather consistent age estimates, between 1 and 2 Gyr. The fit to the UV spectrum using the new Jimenez models, which suggests an age estimate of 1.9 Gyr, is shown in Figure 2. Readers are encouraged to compare Figure 2 to Figure 14 of Spinrad et al. (1997).

Figure 1 also shows that, in the visible – IR, the difference between the J99 models and the Yi models is even larger, which contributed to the difference in the photometry-based age estimates of Spinrad et al. and Yi et al. This difference, however, is not the only cause for Spinrad et al. to get a larger age estimate, i.e., 2.5 Gyr, than ours. It was also caused by the fact that they used only \( R - K \), omitting \( J \) and \( H \) magnitudes, in their analysis. Figure 2 shows that even the Jimenez models would have suggested a substantially smaller age if the whole photometric data had been used. When we use the new Jimenez models and the reduced-\( \chi^2 \) test on all of the four photometric data points, the best model indicates \( 1.9^{+0.5}_{-0.7} \) Gyr, which is in good agreement with the estimate from the UV analysis. Then again, all three groups that have performed continuum fits are suggesting consistent age estimates of 1 – 2 Gyr (c.f., 1.5 Gyr from Yi et al., 1.4 Gyr from Bruzual & Magris). Such an agreement, at least on the age of
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Figure 3. The solar UV spectrum is matched by the Yi models at its accepted age.

LBDS 53W091, is possible because, for small ages (< 2 Gyr), the new Jimenez models differ from the Yi and the BC models only slightly.

One may then say that the age discrepancy on LBDS 53W091 has been resolved. Despite this apparent resolution, it is still quite disturbing to know that there is a significant disagreement between the Jimenez models and the Yi (and the BC) models at larger ages. It is extremely difficult to directly compare different population models and find a more realistic model, but it should be viable to test models by matching the observational properties of the objects whose ages are known a priori. Good examples include the sun, M32, and Galactic globular clusters. A sample test on the sun is shown in Figure 3. In a solar-age (4.5 – 4.7 Gyr), solar abundance population, most of the UV light is still produced by MS stars. Thus, such a population should exhibit a UV spectrum similar to that of the sun. Figure 3 shows the fits to the theoretical solar spectrum (2000 – 3500 Å) from the Kurucz library using the Yi models and the new Jimenez models. The best fitting model is a 5.0 ± 0.1 Gyr model when the Yi models are used. This slight disagreement in the age estimate from the generally accepted solar age is perfectly expected, because we are matching a single stellar spectrum with those of composite (containing MS, red giants, and etc.) stellar populations. The proximity of this age estimate to the accepted age of the sun once again demonstrates the high reliability of the UV-based age estimates for intermediate-age, composite populations. However, when the new Jimenez models are used, much larger ages are indicated (10 Gyr giving the best fit). This was already evident in Figure 1, where the Jimenez models appeared much bluer than the Yi models. If the continua of G-type stars in the Kurucz library are significantly inaccurate, an effort to achieve the right age of the sun using population synthesis models and a theoretical spectrum would not be appropriate. Yet, such tests would still serve as sanity checks for the population synthesis computations. Similar tests can be performed on different objects whose ages are independently known.

We have further improved our estimates over conventional ones by adopting convective core overshoot (OS) and realistic metallicity mixtures. The inclusion of OS has little effect on the UV-based age estimates, but it raises the age estimates based on the visible data normalized to the UV by 20 – 50%. Adopting realistic metallicity distributions is also important because different metallicity
groups dominate different parts of the integrated spectrum. If we assume that the majority of stars in LBDS 53W091 are already as metal-rich as those in nearby giant elliptical galaxies, the photometric data of LBDS 53W091 indicate up to a factor of two larger ages when metallicity mixtures are adopted.

When we use Yi's chemically composite models with OS included, the photometric data of LBDS 53W091 indicate $1.5 \pm 0.2$ Gyr, while the UV data suggest $1.9 \pm 0.2$ Gyr. The slightly larger estimates from the UV continuum fit would be consistent with this photometry-based one if we include a small amount of reddening and/or if the core of this galaxy is somewhat older or more metal-rich than its outskirt, all of which are quite plausible. It may also indicate that there is no substantial age spread among the stars in LBDS 53W091.

There is no doubt that precise age estimates of high-$z$ galaxies would be very useful for constraining cosmology. In order to fully take advantage of the power of this technique, however, we first need to understand the details of the population synthesis, which are currently creating a substantial disagreement in age estimate. We propose to carry out a comprehensive investigation on the various population synthesis models through a series of standard tests on the objects whose ages have been independently determined. Such objects may include the sun, M32, and Galactic globular clusters. Our models (the Yi models) currently pass these tests reasonably.

Our age estimates indicate that LBDS 53W091 formed approximately at $z = 2 - 3$. However, our smaller age estimate for this one galaxy does not contradict work that suggests galaxies generally formed at high redshifts, regardless of the rarity of massive ellipticals at $z \approx 1.5$. Furthermore, we are just beginning to expand our observations of galaxies to high redshift, and so the existence of a few old galaxies at high redshifts does yet prove any galaxy formation scenario, although it can potentially constrain cosmological parameters (in the sense that the ages of a few objects can provide lower limits on the age of the Universe at that redshift). Finding no old galaxies at high redshift would support a low $z_f$ for the general population. Building a larger database of observations is therefore crucial to achieve a unique and statistically significant solution.

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References

Section C.
Deep Field Surveys