Mid-UV Spectroscopic Dating of LBDS 53W091

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Abstract. We have calibrated age-related spectral diagnostics in the mid-UV in terms of age and metallicity. We then make a preliminary application to dating the red galaxy, LBDS 53W091 at z = 1.55.

1. Introduction

For passively evolving stellar populations younger than about 5 Gyr, the hottest stars are at the main sequence turnoff (MSTO). These stars are the only source of significant flux in the mid-UV (2000 – 3200 Å) spectra of such galaxies; in fact, the spectra are remarkably similar to that of a single F-star. By determining the effective temperature of the MSTO stars, we can measure the age of the population.

This technique was first applied by Dunlop et al. (1996) and Spinrad et al. (1997) to LBDS 53W091, a very red galaxy at a redshift of z = 1.55. Observational evidence (colors, morphology, etc.) indicates that 53W091 is a normal giant elliptical galaxy, so its red color is likely due to an aged stellar population. Spinrad et al. (1997) used archival IUE low-dispersion spectra (R=6 Å) of F-type stars to calibrate the flux breaks at 2640 Å and 2900 Å in the spectrum of the galaxy in terms of T$_{\text{eff}}$, i.e. age.

Shortly thereafter, Heap et al. (1998) derived a younger age of 2 Gyr for 53W091 for a solar metallicity, based on model spectra tested against a STIS spectrum of the F-type star, 9 Comae. This observation was the first in a HST program (ID= 7433) to observe and analyze spectra of 12 F-type stars of known atmospheric properties and distance, and to use them to calibrate mid-UV features in the spectra of high-redshift galaxies. Now, two years later, we have nearly completed the observing program. The analysis and modelling are underway, so we report only preliminary observational results.

2. Observations

The 12 program stars were selected from the sample of Edvardsson et al. (1993) in order to sample an appropriate range of T$_{\text{eff}}$ and metallicity. Their atmospheric properties (T$_{\text{eff}}$, log g, abundances), Hipparcos distance, and ages are well known. The selected F4V - F9V stars have metallicities in the range [Me/H] = -0.75 to +0.24, and ages from 1 to 9 Gyr. We used STIS on HST to observe the mid-UV spectrum of each star at a resolving power of R = 30,000
or higher. The signal-to-noise per pixel is typically about 50 before binning to lower resolution (1 Å) for comparison to the spectrum of LBDS 53W091.

3. Diagnostics

*The spectral breaks, B2640 and B2900.* These breaks are defined as the flux ratios in two narrow-band filters located on both sides of $\lambda = 2640$ and 2900, respectively. Both become stronger toward later spectral type. However, our studies show that a prime age diagnostic, the spectral break at $\lambda 2640$, is degenerate: young, metal-rich stars have the same B2640 as do old, metal-poor stars. This $T_{\text{eff}} - Z$ degeneracy is illustrated in Figure 1, which shows that most of the program stars have values of B2640 like that of 53W091 (cross-hatched region), but their wide spread in ages demonstrates that this spectral feature by itself cannot constrain the age of a stellar population. The same comments apply to B2900, only this index has the further disadvantage that its strength cannot be reproduced by model-atmosphere calculations. Evidently, an important source of opacity is missing in the models.

![Figure 1](image)

**Figure 1.** Measurements of B2640 in the program stars. Each star is labelled by the value of [Me/H] as derived by Edvardsson et al. (1993). The cross-hatched region shows the observed B2640 for 53W091.

*The Mg I index and mid-UV color.* After a thorough analysis of F-type spectra, Lanz et al. (1999) found two spectral indices that can discriminate between effective temperature and metallicity among F-type stars. The Mg I index, which measures the strength of the Mg I $\lambda 2852$ resonance line rapidly becomes weaker with increasing temperature as Mg becomes ionized. The mid-UV color, defined as the difference between two magnitudes at 2310 Å and 3040 Å, becomes “bluer” with decreasing metallicity and increasing temperature. Taken together, these two indices appear capable of breaking the $T_{\text{eff}} - Z$ degeneracy. As shown in Figure 2, which plots the Mg I index against mid-UV color,
Figure 2. Calibrating Mg I and mid-UV color (see Lanz et al. 1999)

the high-metallicity program stars are clumped together, well away from the low-metallicity stars. A closer examination, however, shows that $T_{\text{eff}}$ is overestimated by about 200 K, which means that the age of a stellar population will be underestimated. In addition, the metallicities of the high-Z stars are overestimated (the derived metallicities of metal-poor stars are sufficiently accurate). These systematic errors will have to be accounted for before these spectral indices can be used with confidence for dating purposes. In any case, the observed Mg I index for 53W091 is much smaller than any of our model calculations. This is not the fault of our models, which reproduce the observed Mg I profiles of F-type stars almost exactly. Rather, the abnormally weak Mg I absorption in the galaxy spectrum is probably an artifact of imperfect subtraction of night-sky emission ($\lambda_{\text{obs}} = 7273$).

4. Estimating the age of LBDS 53W091

Because of the ambiguity of current spectral indicators, we can only estimate the age for an assumed metallicity, or we can assume an age and solve for the metallicity. Below, we discuss both approaches.

**Age for an assumed metallicity.** Recent models of the chemical evolution of galaxies suggest that a giant elliptical galaxy like 53W091 should contain stars having a variety of metallicities. To pursue this point, we calculated model spectra of galaxies allowing for a composite metallicity as specified by Kodama & Arimoto's (1997) infall model. Following Kodama’s advice, we assumed that 12% of the stars by number have a metallicity of $Z=0.005$, 31% have a solar metallicity, and 57% have $Z=0.04$. Figure 3 compares the calculated spectral indices, B2640 and mid-UV color, against the observations of 53W091. Both the mid-UV color and $\lambda$2640 break imply an age of about 1 Gyr for 53W091, if the extinction internal to the galaxy is $A_V = 0.6$. If the extinction is lower,
then the galaxy age implied by the mid-UV color can be up to 3 Gyr, in rough agreement with Spinrad et al.

![Graph](image)

**Figure 3.** Observations of LBDS 53W091 vs. Kodama & Arimoto's (1997) infall model. The isochrones we used are from Yi et al. (1999)

*Metallicity for an assumed age.* For currently favored cosmological parameters ($H_0 = 67$ km s$^{-1}$, $\Omega_m = 0.3$, $\Omega_L = 0.7$) and a 'reasonable' redshift of the most recent episode of star formation ($z_{SF}$), we can calculate the age of stars at $z = 1.55$, which can then be used to explore possible metallicities for the galaxy. Certainly, the last burst of star formation must have occurred after the first stars in the galaxy formed, say $z_{SF} = 15$. At the other extreme, the last major burst of star formation might have occurred as recently as $z = 3$, because some galaxies at this redshift have been observed to have star formation rates of up to $10^3 M_\odot$ yr$^{-1}$. For $z_{SF} = 3 - 15$, we obtain a wide range in times, from 2.1 to 4.1 Gyr, since the last major star-forming episode. Without a better knowledge of $z_{SF}$, we cannot place constraints on metallicity.

Both approaches are unsatisfactory. We are therefore broadening our study to include other observations such as the Balmer absorption lines.

References