K-LUMINOUS GALAXIES AT Z ~ 2

Metallicity and B Stars

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Abstract
We present the results from the analysis of the composite spectrum of five near-IR luminous (K < 20) galaxies at z ~ 2. Several of the strongest absorption lines are present in the merging galaxy NGC 6090 UV spectrum and are not present in the spectra of Lyman Break Galaxies at z ~ 3. They were identified as SiIII 1296, CIII 1428, SiII 1485, and Fe ~1380 Å which are photospheric lines typical of B stars. A metallicity higher than solar is suggested by comparing the pure photospheric lines known as the 1425Å index (SiIII, CIII, FeV) with Starburst99 models. The evidence of high metallicity, together with the high masses, high star-formation rates, and possibly strong clustering, suggest that these galaxies are candidates to become massive spheroids.

1. Introduction - The K20 Survey
A key open question in galaxy evolution is the epoch of formation of massive spheroidal galaxies. As the rest-frame optical–near-infrared traces the galaxy mass, the $K_s$-band allows a fair selection of galaxies according to their masses up to $z \sim 2$. Based on this, a VLT spectroscopic survey of about 500 galaxies with $K_s < 20$ in the GOODS southern field was conducted (Cimatti et al. 2002). In this contribution (see also de Mello et al. 2004), we analyze the average spectrum of five K20 galaxies at $1.7 < z < 2.3$ with the highest S/N ratio among the ones presented in Daddi et al. (2004). These K< 20 galaxies at $z \sim 2$ appear to be massive ($\geq 10^{11} M_\odot$) and have high star-formation rates (SFR 100–500 M$_\odot$/yr) (Daddi et al. 2004), thus qualifying as good candidates for assembling/forming massive early-type galaxies.
2. Local starbursts and B stars

We have compared the K20 average spectrum with the local starburst galaxies NGC 1705, NGC 1741, NGC 4214, and NGC 6090. The best match is obtained with NGC 6090 which is an interacting system at $v \sim 9062$ km/s in the process of merging. It is a luminous infrared galaxy ($\log L_{\text{IR}} = 11.51$; Scoville et al. 2000) with a number of luminous clusters triggered by the galaxy-galaxy interaction. The Sloan Digital Sky Survey $r$-band image (Fig.1) shows tidal tails that extend several arcminutes from the two merging objects. NICMOS/HST images of NGC 6090 (Scoville et al. 2000) show the inner site of the interaction in more detail, where a less massive galaxy seems to be merging with a disk. The spectrum of NGC 6090 taken by the HUT during the Astro-2 mission (Gonzalez Delgado et al. 1998) is shown in Fig.2. It has several absorption lines which are similar in strength to the K20 composite spectrum, such as the photospheric lines SiIII 1295 Å, CIII 1430 Å and SiII 1485 Å and a marginally weaker FeV 1380 Å line.

In order to search for the stellar population which contains these photospheric lines, we have examined a far-UV (IUE) library of Milky Way OB stars (de Mello et al. 2000). The similarity between the spectra of B stars and the K20 composite spectrum is remarkable. In Fig.3 and Fig.4 we show the average spectrum of two main sequence stars (B0V and B8V) and a supergiant (B3I) where the main photospheric lines are identified. B stars live longer than
K-luminous galaxies at $z \sim 2$

Figure 3. The spectrum of a B3I star (dashed) and the K20 composite spectrum.

Figure 4. The spectrum of a B8V (dashed) star and a B0V (dotted) star and the K20 composite spectrum. Photospheric lines are marked with $\ast$.

the more luminous short-lived O stars and become a major source of the UV flux in the integrated spectrum of starbursts. The photospheric lines found in the spectrum of K20 galaxies and in NGC 6090 are stellar features of B stars.

3. **Lyman Break Galaxies and Metallicity**

We have also compared the K20 average spectrum with the average Lyman Break Galaxies (LBGs) spectrum (Shapley et al. 2003) at $z \sim 3$. The best match is obtained with the LBGs without Lyman-\(\alpha\) emission (Fig.5). The most striking differences between the LBG composite spectra and the K20 average spectrum are the photospheric lines described above. One caveat that one has to have in mind, before further interpreting this comparison, is the fact that the LBGs’ average-spectrum contains several hundred spectra, whereas the spectrum we are presenting here is the average of only 5 objects. Therefore, a few peculiar objects could be present and co-addition of a larger number of spectra is desirable for the future in order to smooth out the contribution of individual objects. Nevertheless, they comprise an interesting class of objects that might be important in the galaxy evolution scenario.

We have used the pure photospheric lines known as the 1425Å index (SiIII, CIII, FeV) (Leitherer et al. 01) to estimate metallicity (Fig.6), since it does not strongly depend on age. The equivalent width of the index is 2.3±0.4 Å, a value much larger than in Starburst99 models (Leitherer et al. 1999) for solar (1.5Å) and LMC metallicity (0.4Å). It corresponds to models with continua...
ous star formation, fewer massive stars and metallicities larger than solar (Fig. 11 in Rix et al. 2004). Recently, Shapley et al. (2004) also suggested that K< 20 galaxies at 2.1 < z < 2.5 have at least solar metallicity from near-IR spectroscopic measurements of seven galaxies. Near-IR spectroscopy of a larger sample of K20 galaxies is needed in order to confirm the metallicities and estimate the relative importance of O and B stars in these objects.

Figure 5. The spectrum of Lyman Break Galaxies (dotted) and the K20 composite spectrum.

Figure 6. The 1425Å index region of the K20 composite spectrum. Starburst99 models for solar metallicity (dashed) and 0.25 Z⊙ (dotted).

Notes

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