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THE STELLAR CONTENT OF LOW REDSHIFT BL LAC HOST GALAXIES FROM MULTICOLOUR IMAGING

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RESUMEN

Presentamos imágenes en las bandas UBV de 18 objetos BL Lac de bajo corrimiento al rojo ($z \leq 0.3$). Estos datos se usan para investigar los colores rojo-azul-infrarrojo y gradientes de color de galaxias huésped. La distribución del color integrado azul/cercano-infrarrojo y el gradiente de color de las galaxias huésped de objetos BL Lac es más amplia que la que tienen las elípticas no-activas, y la mayoría de los objetos BL Lac tienen galaxias huésped más azules y gradientes de color más empinados que los de las elípticas no-activas. Los colores azules parecen ser causados por una componente de la población estelar joven, e indican una conexión entre la formación estelar causada por un evento de interacción/fusión, y el encendido de la actividad nuclear. Este resultado es apoyado por los modelos de población estelar, que indican que existe una población estelar joven/intermedia en la mayoría de los objetos de la muestra.

ABSTRACT

We present UBV-band imaging of 18 low redshift ($z \leq 0.3$) BL Lac objects. These data are used to investigate the blue-red-near-infrared colours and colour gradients of the host galaxies. The distributions of the integrated blue/near-infrared colour and colour gradient of the BL Lac hosts are much wider than those for inactive ellipticals, and most BL Lac objects have bluer hosts and/or steeper colour gradients than those in inactive ellipticals. The blue colours are likely caused by a young stellar population component, and indicates a link between star formation caused by an interaction/merging event and the onset of the nuclear activity. This result is supported by stellar population modelling, indicating a presence of young/intermediate age populations in the majority of the sample.

Key Words: BL Lacertae objects: general — galaxies: active — galaxies: interactions — galaxies: nuclei — galaxies: photometry

1. INTRODUCTION

BL Lac objects are an extreme class of active galactic nuclei (AGN) characterized by luminous, variable and polarized continuum emission across the electromagnetic spectrum and strong core-dominated radio emission (Kollgaard et al. 1992). A number of optical (Falomo & Kotilainen 1999; Urry et al. 2000; Heidt et al. 2004) and near-infrared (NIR) (Kotilainen et al. 1998; Scarpa et al. 2000; Cheung et al. 2003; Kotilainen & Falomo 2004; Kotilainen et al. 2005) imaging studies have shown that virtually all nearby ($z < 0.5$) BL Lac objects are hosted in large and luminous elliptical galaxies. Until recently, however, imaging of BL Lac hosts was obtained in one band only and, therefore, little colour information exist for them.

Kotilainen & Falomo (2004) found that low redshift ($z < 0.3$) BL Lac host galaxies appear to be systematically bluer, have a much wider distribution of R-H colour and steeper colour gradient than those for inactive elliptical galaxies (Peletier et al. 1990). The blue colours are most likely indicating a recent star formation (SF) episode, possibly triggered by interaction or merging between galaxies. Blue band observations are paramount to assess whether their blue colours are caused by a young stellar population. We obtained UBV-band imaging of a sample of 18 BL Lac objects for which high resolution R- and H-band imaging exists (Kotilainen et al. 1998; Scarpa et al. 2000; Cheung et al. 2003; Kotilainen & Falomo 2004).

Combining UBV-band imaging with the existing R- and H-band data, the colours and colour gradients can be derived over an extended wavelength range to trace the contribution from young stellar populations. Also, the obtained $UBVRH$ broad band colours are used in conjunction with stellar synthesis population models to estimate the ages of the

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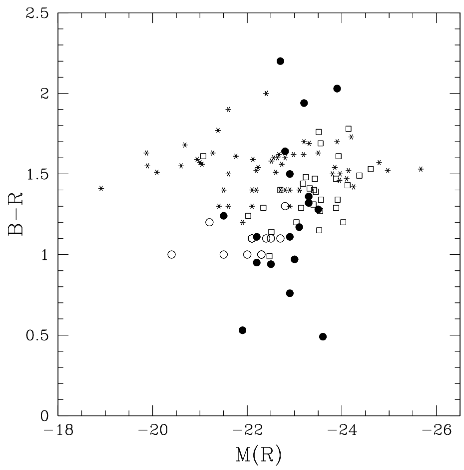

Fig. 1. The *B-R* vs. *R* colour-magnitude diagram for BL Lac host galaxies (filled circles), low redshift quasars (from Jahnke et al. 2004, open circles), radio galaxies (from Govoni et al. 2000, open squares) and inactive ellipticals (from Peletier et al. 2000, and Colbert et al. 2001, asterisks).

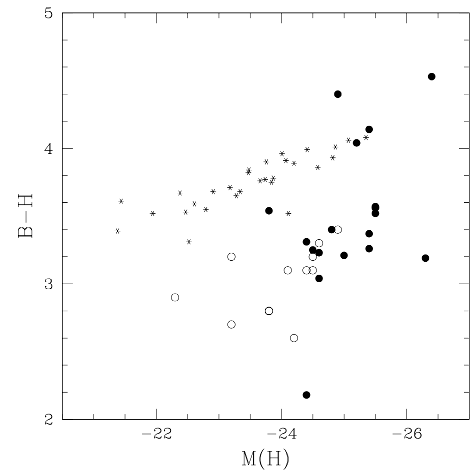

Fig. 2. The *B-H* vs. *H* colour-magnitude diagram for BL Lac hosts, low redshift quasars and inactive ellipticals. Symbols are as in Figure 1, except asterisks are from Bower et al. (1992).

most recent SF episode in the host galaxies. For full discussion, see Hyvönen et al. (2007).

2. OBSERVATIONS, DATA REDUCTION, AND ANALYSIS

The observations were carried out during several observing runs with different telescopes, with most of the observations done at the 2.5 m Nordic Optical Telescope (NOT) using Bessel U, B and V broad band filters. Nine targets were observed only in the B-band, five in the UBV-bands and four in the UB-bands. To derive the properties of the host galaxies, azimuthally averaged 1D radial luminosity profiles were extracted for each BL Lac object. The luminosity profiles were decomposed into a point source and an elliptical galaxy components. The data were fit using the $r^{1/4}$ de Vaucouleurs law for elliptical galaxies to represent the host galaxy.

3. RESULTS

3.1. *Host galaxy colours*

The average *B-H* colour of BL Lac hosts (B-H=3.5 ± 0.5) are slightly redder than that of quasar hosts (Jahnke et al. 2004) but slightly bluer than that of inactive elliptical galaxies (Colbert et al. 2001). In fact, the optical colours of BL Lac hosts are very similar to those of Sb – Sbc inactive galaxies with significant ongoing SF (Fioc & Rocca-Volmerange 1999).

The *B-R* vs. *R* and *B-H* vs. *H* colour-magnitude diagrams for BL Lac hosts and comparison samples are presented in Figures 1 and 2. It is evident that BL Lac hosts do not follow the relatively tight colour-magnitude relation of inactive ellipticals. Instead, they have a significantly broader colour distribution and the majority of them appear to be bluer than inactive ellipticals of similar luminosity. Indeed, such colours are more similar to those found in intermediate/late-type inactive galaxies that have significant recent SF. This result is consistent with the colours of low redshift radio galaxies (Govoni et al. 2000) and quasar hosts (Jahnke et al. 2004). A likely explanation for the blue colours of BL Lac hosts is that they have experienced recent SF and the wide colour distribution indicates a range of timescale since the latest SF episode.

3.2. *Colour gradients of the host galaxies*

It is well known that nearby inactive elliptical galaxies have negative colour gradients (e.g., Peletier et al. 1990). These colour gradients have been widely interpreted as due to radial variations in the dust content and/or SF history of the galaxies. For BL Lac host galaxies, we derived the radial *U-B*, *B-R* and *B-H* colour gradients using the *R*- and *H*-band host galaxy luminosity profiles (Kotilainen et al. 1998; Falomo & Kotilainen 1999; Scarpa et al. 2000; Kotilainen & Falomo 2004). As expected for early-type galaxies, most BL Lac host galaxies exhibit a negative colour gradient with average $\Delta(B\text{-}R)/\Delta(log\ r) = -0.14 \pm 0.75$. The same negative trend was also found for the *R-H* colour gradients of BL Lacs by Kotilainen & Falomo (2004). The amplitude of the *B-R* colour gradients of the BL Lac hosts is consistent with the average B-R gradient of radio galaxies ($\Delta(B\text{-}R)/\Delta(log\ r) = -0.16 \pm 0.17$; Govoni et al. 2000) and inactive ellipticals ($\Delta(B\text{-}R)/\Delta(log\ r) = -0.09 \pm 0.07$; Peletier et al. 1990), but the distribution is much wider than that of the radio galaxies and inactive ellipticals. A similar distribution was also obtained for the R-H gradient of BL Lac hosts by Kotilainen & Falomo (2004).

However, some BL Lac host galaxies have little evidence for colour variation or even have a positive colour gradient, e.g. 1ES1426+428 and MRK501. Similarly steep positive R-H colour gradient for 1ES1426+428 was previously observed by Kotilainen & Falomo (2004). Since the B-H colour is more sensitive to dust content than the R-H colour, it indicates that the positive B-R and R-H gradients of this target are due to spatial variations in the dust content of its host galaxy. On the other hand, dust is not a reasonable explanation for e.g. MRK 501 which has a positive B-R but a negative R-H gradient. In this case, the inverted profiles may indicate SF in the inner region of the host galaxy. That indication is also supported by recent spectroscopic observations of ongoing SF in the nuclear regions of the BL Lac object PKS 2005-489 (Bressan et al. 2006).

3.3. *Stellar population model fits*

The UBV colours combined with the previously observed R- and H-band data can be used in conjunction with stellar synthesis population models to estimate the approximate ages of the recent SF episodes in BL Lac host galaxies. Comparing fits made for different model spectra gives an estimate of the ages of the dominant stellar population components in the host galaxy. For the analysis we used the PEGASE2 evolutionary model (Fioc & Rocca-Volmerange 1997) and a single stellar population (SSP) model of solar metallicity with Scalo (1986) initial mass function. We used instantaneous burst models which assume that the young stellar population is formed in a short burst with an IMF and evolves passively thereafter.

The best fitting models are generally consistent with a young/intermediate age stellar population. These results are in excellent agreement with similarly young stellar populations found by Jahnke et al. (2004) for quasar host galaxies obtained from population synthesis model. None of the elliptical BL Lac hosts were best modeled with the 14 Gyr model as would be expected for early-type host galaxies. On the other hand, for both types of AGN, there is also little evidence for massive ongoing starbursts with a significant very young population (age $\ll$ 1 Gyr). Together these results are in good agreement with the colour information and strongly support the idea that the blue colours of the early-type host galaxies of moderately luminous AGN are caused by them having experienced a relatively recent SF episode. This indicates a link between SF and the onset of the nuclear activity, both likely triggered by a tidal interaction or a minor or major merger. However, the lack of obvious signs of interaction in the close environment of the large majority of the host galaxies may require a significant time delay (at least hundreds of Myr) between the event with associated SF episodes and the start of the nuclear activity.

4. CONCLUSIONS

The blue colours and steep colour gradients of the BL Lac host galaxies are most likely caused by a young stellar population, and indicate a link between SF caused by an interaction/merging event and the onset of the nuclear activity. This result is corroborated by stellar population modelling, indicating young/intermediate age populations in the majority of the sample, in agreement with low redshift quasar hosts. Future work in this area should address the correlation between colour and statistics of companion galaxies and morphological disturbances as an indicator for the interaction.

In a forthcoming paper, we shall present NIR spectroscopy of BL Lac hosts and RGs with blue colours, to analyze their stellar content and SF properties, based on emission and absorption line diagnostics, in more detail than is affordable with imaging.

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