Bulletin de la Société Royale des Sciences de Liège, Vol. 80, 2011, p. 445 - 449

FUV and UVIS observations of circumnuclear star clusters in M83

Aida Wofford[1], Rupali Chandar[2] and Claus Leitherer[1]

[1] Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218, USA
[2] University of Toledo, Department of Physics and Astronomy, Toledo, OH 43606, USA

Abstract: We analyze archival *HST*/STIS/FUV-MAMA imaging and spectroscopy of 13 compact star clusters within the circumnuclear starburst region of M83, the closest such example. We compare the observed spectra with semi-empirical models, which are based on an empirical library of Galactic O and B stars observed with *IUE*, and with theoretical models, which are based on a new theoretical UV library of hot massive stars computed with WM-Basic. The models were generated with Starburst99 for metallicities of Z=0.020 and Z=0.040, and for stellar IMFs with upper mass limits of 10, 30, 50, and 100 $M_\odot$. We estimate the ages and masses of the clusters from the best fit model spectra, and find that the ages derived from the semi-empirical and theoretical models agree within a factor of 1.2 on average. A comparison of the spectroscopic age estimates with values derived from *HST*/WFC3/UVIS multi-band photometry shows a similar level of agreement for all but one cluster. The clusters have a range of ages from about 2 to 20 Myr, and do not appear to have an age gradient along M83's starburst. Clusters with strong P-Cygni profiles have masses of a few $\times 10^4$ $M_\odot$, seem to have formed stars more massive than 30 $M_\odot$, and are consistent with a Kroupa IMF from 0.1-100 $M_\odot$.

1 Introduction

Determining the ages, masses, and stellar initial mass functions (IMFs) of individual OB star clusters in the circumnuclear regions of nearby disk galaxies, is important for understanding the relation between the origin of the clusters, and galaxy dynamics and interactions. Messier 83 (M83, NGC 5236), which is a southern nearly face-on grand-design barred spiral galaxy of morphological type SAB(s)c, located at a distance of 4.6±0.09 Mpc (mean from NED using various indicators), hosts the closest example of an arc-shaped circumnuclear starburst region. The region is ∼200 pc in length and ∼35 pc in thickness, and is composed of several dozen compact OB star clusters, located within 200 pc of the galaxy's optical nucleus. M83 has a close dynamical companion in the dwarf irregular galaxy NGC 5253 (Rogstad, Lockhart, & Wright 1974), which harbors a nuclear starburst (Calzetti et al. 1997). The two galaxies are part of the M81 group, including the dust-rich starburst proto-type, M82.

M83's circumnuclear starburst region has been observed at wavelengths ranging from the radio to the X-rays (for references, see Dopita et al. 2010). Based on the analysis of CO absorption and Brγ emission-line data, Puxley, Doyon, & Wardy (1997) found that the northwestern end of the starburst's arc is the youngest, while the southeastern end is the oldest. Based on the statistical analysis of the *HST*/WFPC2 photometry of Harris et al. (2001), Díaz et al. (2006) found that the oldest cluster in the northwest is 5 Myr, and the oldest cluster in the southeast is 25 Myr, confirming the age gradient along the starburst. The above age gradient suggests that star formation occurs in an ordered manner, and supports the idea that the starburst is fed by the inflow of bar-driven material. If real, this gradient has profound implications for the formation and evolution of circumnuclear starbursts. For this reason, we re-visited M83's starburst's arc, and determined the ages and masses of 13 clusters within its northern portion, using three different techniques, i.e., by comparing archival *HST*/STIS FUV spectroscopy of the clusters with semi-empirical and new fully theoretical model spectra, and by deriving these properties from high spatial resolution *HST*/WFC3 multi-band optical photometry. We also studied the stellar IMFs of the clusters in our sample. Here, we focus on the analysis of the FUV spectroscopy, which is fully described in Wofford, Chandar, & Leitherer (2010), where we also studied field regions between the clusters. The description of the photometry and its analysis are summarized in the latter paper and presented in detail in Chandar et al. (2010), where the authors cover the entire field imaged by WFC3, which is larger than M83's circumnuclear region.

2 Model Spectra

We compared the observed FUV spectra with models generated with the widely used package Starburst99 (S99, Leitherer et al. 1999; Vázquez & Leitherer 2005). The main input parameters in S99 are 1) the star-formation law, 2) the IMF, 3) the metallicity and stellar evolution tracks, and 4) the stellar spectral library. Bresolin & Kennicutt (2002) ruled out continuous star formation within individual star clusters of M83's starburst region. Therefore, we fitted our cluster spectra with single stellar population (SSP) models. We tried IMFs with high mass limits of 10, 30, 50, and 100 $M_\odot$, and metallicities of Z=0.020 and Z=0.040, since the metallicity of M83 is intermediate between these two values (Bresolin & Kennicutt 2002). We used the stellar evolution tracks for non-rotating stars of Schaller et al. (1992) for masses $M<12\,M_\odot$, and of Meynet et al. (1994) for masses $M\geq12\,M_\odot$. Finally, we tried an empirical stellar library based on *IUE* observations of Galactic O and B stars (Robert et al. 1993), as well as a new high-resolution fully-theoretical UV library for massive stars, computed by Leitherer et al. (2010), with WM-Basic (Pauldrach, Hoffmann, & Lennon 2001). Figure 1 shows the age evolution from 1 to 20 Myr of models with a Kroupa IMF (Kroupa 2001), with Z=0.020, and based on the empirical and the theoretical stellar libraries, hereafter, the semi-empirical and the theoretical models, respectively.

The semi-empirical and theoretical models differ below 1240 Å because of the presence of Galactic interstellar Lyα but agree rather well in the range 1240-1700 Å, except for the O V 1370 Å line, which is stronger in the theoretical models at ages younger than $\sim$2 Myr, and the Si IV 1400 Å feature, which is stronger in the semi-empirical models at ages 3 and 4 Myr. Note that the empirical library is contaminated with interstellar lines.

3 Procedure

3.1 Reddening

We corrected the observed spectra for Galactic extinction based on the maps of Schlegel, Finkbeiner, and Davis (1998) and the extinction curve of Fitzpatrick (1999). We then fitted the FUV continuum with a power law of the form $F \sim \lambda^\beta$, and assumed that any deviation of β from the expected value for a dust free starburst (-2.6) was due to reddening. We used the obscuration law of Calzetti et al. (2000) to deredden the spectrum until $\beta = -2.6$ was reached.

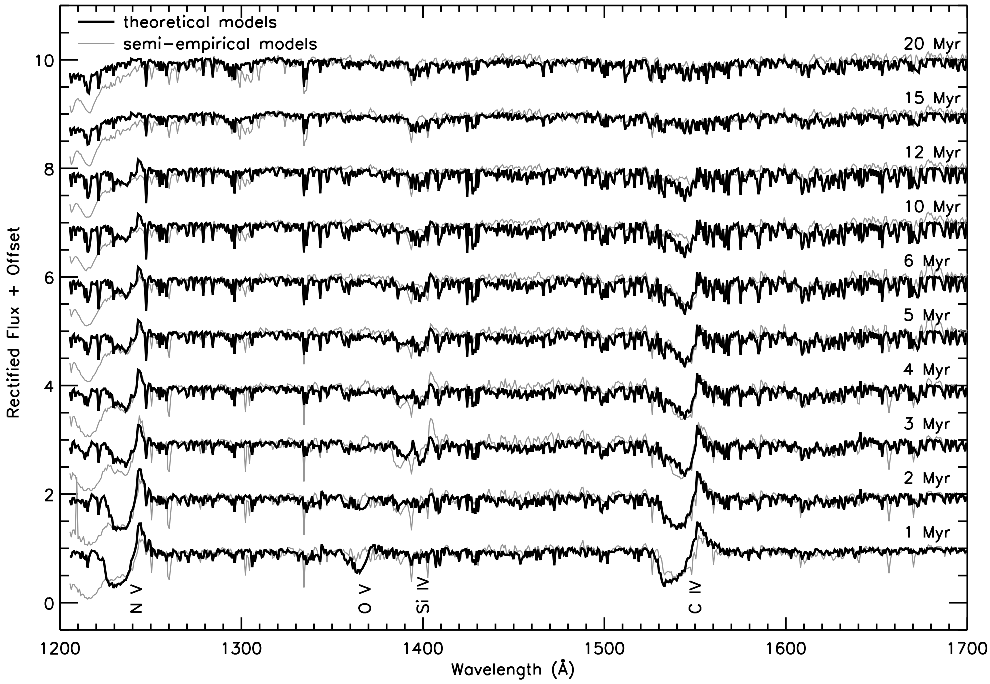

Figure 1: Evolution of SSP model spectra with time. The theoretical models are shown in black and the semi-empirical models are shown in grey. The models correspond to a metallicity of Z=0.020 and a Kroupa IMF from 0.1-100 $M_{\odot}$.

3.2 Spectroscopic Ages, Metallicity, and IMF

Figure 1 shows the sensitivity of the N V 1240, Si IV 1400, and C IV 1550 profiles to the age of the cluster. The metallicity of M83's starburst is intermediate between Z=0.020 and Z=0.040, but the age estimates from models corresponding to these two metallicities are very similar. Our clusters showing strong P-Cygni profiles in N V 1240, Si IV 1400, and C IV 1550 are consistent with having formed stars more massive than 30 $M_{\odot}$. This is illustrated in Fig. 2, where the observed spectra of two clusters (1 and 10) are compared against models having upper mass limits of 10, 30, 50, and 100 $M_{\odot}$. The presence of strong Si IV and C IV absorptions in the rest of clusters, suggests the presence of at least some B stars, assuming that the origin of these features is not mostly interstellar. We derived spectroscopic ages for the clusters in our sample by fitting their FUV spectra with models corresponding to a metallicity of Z=0.020 and a Kroupa IMF from 0.1-100 $M_{\odot}$. For this, we adopted the algorithm of Tremonti et al. (2001), which gives the most weight to the N V 1240, Si IV 1400, and C IV 1550 features and eliminates from consideration the interstellar lines. The goodness of the fit is characterized by χ^2, where $\chi^2 = (o_i - m_i)^2 w_i/\sigma_i^2$, and where o_i represents the observed data for the ith pixel, m_i the model data, σ_i the error in the observed spectrum, and w_i the assigned weight.

3.3 Spectroscopic Masses

The spectroscopic mass of each cluster was derived by comparing the mean luminosity of the best fit model to the data (corresponding to a stellar mass of 10^6 $M_{\odot}$), to the observed value.

Bulletin de la Société Royale des Sciences de Liège, Vol. 80, 2011, p. 445 - 449

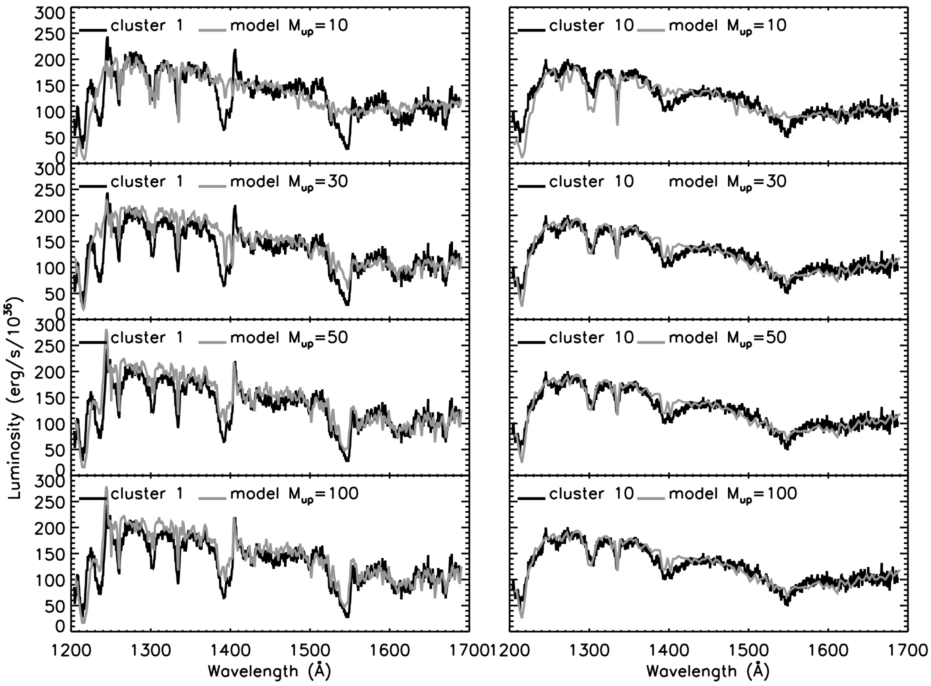

Figure 2: Observed spectra of clusters 1 and 10 (black curves) versus semi-empirical models corresponding to different upper mass limits to the IMF, M_{up}=10, 30, 50, and 100 $M_\odot$ (grey curves). The metallicity of the models is Z=0.020. The ages of clusters 1 and 10 are $\sim$4 Myr and $\sim$12 Myr, while their masses are $\sim 3\times10^4\,M_\odot$ and $\sim 10^5\,M_\odot$, respectively.

4 Cluster Properties

4.1 Masses

Optical photometry provides more leverage for determining the stellar mass than FUV spectroscopy. Therefore, our photometric masses (M_{phot}) are more reliable than our spectroscopic masses. Our most massive cluster has $M_{phot}=3.1\times10^5\,M_\odot$, which is comparable to the virial mass of the ionizing cluster of 30 Doradus, NGC 2070 ($4.5\times10^5\,M_\odot$, Bosch, Terlevich, & Terlevich 2009). According to Larsen (2010), young star clusters with masses larger than $10^5\,M_\odot$ can last an age comparable or exceeding the age of the universe. Therefore the latter cluster could be a globular cluster progenitor, while two other clusters, which have $M_{phot}\approx10^5\,M_\odot$, may also survive. One cluster has $M_{phot}=4\times10^3\,M_\odot$. Unfortunately, its spectrum is too noisy to reliably say whether stars more massive than 30 $M_\odot$ have formed in it. The rest of clusters have M_{phot} of a few $\times10^4\,M_\odot$.

4.2 IMF

Our clusters with strong P-Cygni profiles have M_{phot} $\sim10^4\,M_\odot$, seem to have formed stars with masses $> 30\,M_\odot$, and are consistent with a Kroupa IMF from 0.1-100 $M_\odot$. Clusters without P-Cygni profiles could be young clusters that did not form massive O stars, or older clusters whose O stars have died. The latter clusters are consistent with having formed at least some B stars.

4.3 Ages

The spectroscopic ages from semi-empirical and theoretical predictions are within a factor of 1.2 on average. The spectroscopic and photometric ages agree at a similar level. Our ages agree with those derived from *HST*/WFPC2 photometry by Harris et al. (2001), except for clusters 6, 7, and 10, which are older than 6 Myr in our case. Our ages for clusters 1-3 and 11-12 agree with the ages of regions A and B derived from STIS FUV spectroscopy by Bresolin & Kennicutt (2002). The clusters are $\sim$2-20 Myr old and were not all formed at the same time. We found no age gradient along M83's starburst, in disagreement with Puxley et al. (1997) and Díaz et al. (2006).

Acknowledgements

This work was supported by NASA grant N1317.

References

Bosch, G., Terlevich, E. & Terlevich R. 2009, AJ, 137, 3437
Bresolin, F. & Kennicutt Jr., R. C. 2002, ApJ, 572, 838
Calzetti, D., Meurer, G. R., Bohlin, R. C., Garnett, D. R., Kinney, A. L., Leitherer, C. & Storchi-Bergmann T. 1997, AJ, 114, 1834
Calzetti, D., Armus, L., Bohlin, R. C., Kinney, A. L., Koornneef, J. & Storchi-Bergmann, T. 2000, ApJ, 533, 682
Chandar, R., Whitmore, B. C., Kim, H., Kaleida, C., Mutchler, M., Calzetti, D., Saha, A., O'Connell, R., et al. 2010, ApJ, 719, 966
Díaz, R. J., Dottori, H., Aguero, M. P., Mediavilla, E., Rodrigues, I. & Mast D. 2006, ApJ, 652, 1122
Dopita, M. A., Blair, W. P., Long, K. S., Mutchler, M., Whitmore, B. C., Kuntz, K. D., Balick, B., Bond, H. E., et al. 2010, ApJ, 710, 964
Fitzpatrick, E. L. 1999, PASP, 111, 63
Harris, J., Calzetti, D., Gallagher III, J. S., Conselice, C. J. & Smith, D. A. 2001, AJ, 122, 3046
Kroupa, P. 2001, MNRAS, 322, 231
Larsen, S. S. 2010, RSPTA, 368, 867
Leitherer, C., Schaerer, D., Goldader, J. D., Delgado, R. M. G., Robert, C., Kune, D. F., de Mello, D. F., Devost, D., et al. 1999, ApJS, 123, 3
Leitherer, C., Ortiz Otálvaro, P. A., Bresolin, F., Kudritzki, R.-P., Lo Faro, B., Pauldrach, A. W. A., Pettini, M. & Rix S. A. 2010, ApJS, 189, 309
Meynet, G., Maeder, A., Schaller, G., Schaerer, D. & Charbonnel C. 1994, A&AS, 103, 97
Pauldrach, A. W. A., Hoffmann, T. L. & Lennon, M. 2001, A&A, 375, 161
Puxley, P. J., Doyon, R. & Wardy, M. J. 1997, ApJ, 476, 120
Rogstad, D. H., Lockhart, I. A. & Wright, M. C. H. 1974, 193, 309
Robert, C., Leitherer, C. & Heckman, T. M. 1993, ApJ, 418, 749
Tremonti, C. A., Calzetti, D., Leitherer, C. & Heckman, T. M. 2001, ApJ, 555, 322
Schaller, G., Schaerer, D., Meynet, G. & Maeder, A. 1992, A&AS, 96, 269
Schlegel, D. J., Finkbeiner, D. P. & Davis, M. 1998, ApJ, 500, 525
Vázquez, G. A. & Leitherer, C. 2005, ApJ, 621, 695
Wofford, A., Chandar, R. & Leitherer, C. 2010, ApJ, in press (arXiv:1011.4449)