An Improved Method for Determining the Integrated Properties of Nuclear Rings: NGC 1512

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Abstract

The integrated properties of nuclear rings are correlated with the secular evolution and dynamics of the host galaxies of the rings, as well as with the formation and evolution of the rings’ star cluster population(s). Here we present a new method to accurately measure the spectral energy distribution and current star formation rate (SFR) of the nuclear ring in the barred spiral galaxy NGC 1512, based on high-resolution Hubble and Spitzer Space Telescope images. Image degradation does not have a significant negative effect on the robustness of the results. To obtain the ring’s SFR for the period spanning ~3–10 Myr, we apply our method to the continuum-subtracted Hα and 8 μm images. The resulting SFR surface density, \( \Sigma_{\text{SFR}} = 0.09 M_\odot \text{ yr}^{-1} \text{ kpc}^{-2} \), is much higher than the disk-averaged SFR densities in normal galaxies. We also estimate the ring’s total stellar mass, \( \log (M/M_\odot) = 7.1 \pm 0.11 \), for an average age of ~40 Myr.

Key words: galaxies; evolution – galaxies: fundamental parameters – galaxies: individual (NGC 1512) – galaxies: star formation – methods: observational

1. Introduction

Circumnuclear starburst rings, which are usually found within 1 kpc of galactic nuclei, are interesting substructures that are often subject to intense starbursts. They are mostly found in barred spiral galaxies, since they are the natural products of bar-induced dynamics, although it has been reported that merger events and other non-axisymmetric structures—such as oval/elliptically shaped density enhancements and strong spiral arms—in some unbarred galaxies can also generate nuclear rings (e.g., NGC 7217 and NGC 7742; Shlosman et al. 1990; Athanassoula 1994; Combes 2001; Kormendy & Kennicutt 2004; Mazzuca et al. 2006; Síl’chenko & Moiseev 2006). The gravitational torque from the asymmetric bar potential causes gas infall toward the nucleus along the dust lanes at the leading edges of the bar (e.g., Byrd et al. 1994; Knapen et al. 1995; Regan & Teuben 2003; Kim et al. 2012a). The inflowing materials, which lose most of their angular momentum, spiral in toward the ring region at the two “contact points” between the dust lanes and the ring, where the accumulated gas proceeds to move in nearly circular orbits and forms a luminous, compact ring around the galactic center (e.g., Athanassoula 1992; Buta & Combes 1996; Maciejewski 2004; Kim et al. 2012b).

The high gas density (e.g., Wild et al. 1992; Mazzuca et al. 2008; Comerón et al. 2010), the unusually short crossing timescale, and the enhanced collision rate in the ring may consequently trigger violent starburst episodes, which often dominate the entire star formation history of the host galaxy (e.g., Genzel et al. 1995; Knapen et al. 2006; Mazzuca et al. 2011). Comprehensive studies of nuclear rings are therefore paramount to understand the secular evolution and dynamics of spiral galaxies. Over the course of several decades, many theoretical and observational studies have contributed significantly to our knowledge of nuclear ring properties (e.g., Burbidge & Burbidge 1960; Sandage 1961; Hummel et al. 1987; Buta & Crocker 1993;Englmaier & Shlosman 2000; van der Laan et al. 2013). Owing to the close connection between rapid star formation and the presence of young star clusters, nuclear rings are prime regions in nearby disk galaxies where young massive star clusters are found in abundance (e.g., Barth et al. 1995; Maoz et al. 1996; de Grijs & Anders 2012; Hsieh et al. 2012; van der Laan et al. 2013; de Grijs et al. 2017).

The properties of nuclear rings are also good diagnostics to constrain the host galaxy’s structural parameters (e.g., Weiner et al. 2001; Kormendy & Kennicutt 2004; Li et al. 2015). They thus serve as important features connecting galaxy-scale properties to the star cluster population. Since our ultimate purpose is to explore how the ring environment (or the integrated ring properties) affects the evolution of the young cluster population, it is of great importance to derive the integrated ring parameters, such as their total luminosities and their star formation rates (SFRs). Traditional approaches for calculating the global ring SFR (e.g., Buta et al. 1999; Maoz et al. 2001; Mazzuca et al. 2008) usually follow Kennicutt (1998):

\[
\text{SFR} (M_\odot \text{ yr}^{-1} ) = 7.9 \times 10^{-42} [L(\text{H}\alpha)_{\text{obs}}],
\]

where \( L(\text{H}\alpha)_{\text{obs}} \) represents the Hα emission-line luminosity, which is usually directly derived from the imaging. However, as readily recognized by these authors, application of this equation can result in large uncertainties of up to 50% (e.g., Kennicutt 1998), because of the presence of variable extinction across the ring, although some investigators have tried to minimize this effect by adopting a representative ring cluster extinction value (e.g., Buta et al. 2000; Benedict et al. 2002). To circumvent the dust attenuation problem, it is indispensable to combine observations of ultraviolet or optical SFR tracers with complementary infrared measurements, to account for missing flux caused by the dust absorption and scattering (for a review, see, e.g., Kennicutt & Evans 2012 and references therein).

Mazzuca et al. (2008) have shown that nuclear rings are coplanar with their disks and retain nearly circular shapes after deprojection. Since these structures are embedded in the galactic disk and bulge of their host galaxy, the total, intrinsic
ring luminosities measured are unavoidably contaminated by contributions from the host galaxy. However, few studies have taken background corrections into account when calculating the total ring flux, except for Maoz et al. (1996), who measured the total ring flux by integrating all counts above the background over the entire ring region. Note that their background measure is, in fact, a constant value, determined in an “empty” corner of the image. This thus only provides a simple approximation to the often highly complex background in the ring region. Consequently, the main motivation for this paper is to demonstrate the feasibility of a newly devised method to obtain clean ring luminosities based on galaxy light-profile-fitting using the GALFIT algorithm (Peng et al. 2002, 2010).

As a test case, we will obtain the spectral energy distribution (SED) and SFR of the luminous nuclear ring in the galaxy NGC 1512, while simultaneously allowing for inherent dust attenuation and background correction. Our analysis is based on multi-waveband Hubble Space Telescope (HST) imaging data, combined with observations obtained with the Infrared Array Camera (IRAC) on board the Spitzer Space Telescope. NGC 1512 is located at high Galactic latitude and is hence barely affected by Galactic foreground extinction, $E(B-V) = 0.011$ mag (Schlegel et al. 1998); we will hence ignore any correction for Galactic foreground reddening. The remainder of this paper is organized as follows. In Section 2, we describe the observational data used as well as our data reduction approach. Section 3 presents in detail our improved procedure for calculating the ring flux, and addresses a series of technical issues. Finally, we provide a brief summary and our main conclusions in Section 4.

2. Observations and Data Reduction

Broadband HST/Wide Field Camera-3 (WFC3; pixel size $\sim 0\farcs04$) images of NGC 1512 were acquired from the HST Legacy Archive (HLA), observed as part of program GO-13364 (PI: Calzetti). Our multi-wavelength imaging data set included observations through the F336W (roughly corresponding to the Johnson–Cousins $U$ band), F438W ($B$), F555W ($V$), and F814W ($I$) filters, which were pipeline-processed and calibrated using the standard HLA reduction software. They were already aligned to the same orientation and field of view, covering the inner galactic region (see Figure 1). In this paper we assume a distance modulus\(^3\) of $(m-M)_0 = 30.48 \pm 0.25$ mag, which corresponds to a distance of 13 Mpc. This results in a pixel scale of 2.4 pc pixel$^{-1}$. Since the circumnuclear starburst ring represents a small fraction of the full image, for convenience we cropped the ring-dominated area in the original four exposures to yield a final, common science image of $585 \times 585$ pixels\(^2\) (or $1400 \times 1400$ pc$^2$), as shown in Figure 1.

We used Kennicutt et al.’s (2009) calibration of the local SFR:

$$\text{SFR} (M_\odot \, \text{yr}^{-1}) = 5.5 \times 10^{-42} [L(\text{H}$\alpha$)_{obs} + 0.011 L(8 \, \mu m)],$$

where $L(\text{H}$$\alpha$)$_{obs}$ is expressed in units of erg s$^{-1}$ prior to any internal dust attenuation correction, and $L(8 \, \mu m)$ is the Spitzer 8 $\mu m$ polycyclic aromatic hydrocarbon (PAH) emission-line luminosity, also in erg s$^{-1}$. This calibration was derived assuming a Kroupa initial mass function (IMF) with stellar masses in the range $0.1$–$100 M_\odot$ (Kroupa & Weidner 2003) and solar chemical abundance; Allard et al. (2006) and Sarzi et al. (2007) showed that circumnuclear regions of barred galaxies can be modeled well by adopting solar metallicity. $\text{H}$\alpha emission is dominated by young massive stars and is commonly used as an instantaneous SFR indicator, tracing stars with lifetimes of $\sim 3$–10 Myr and masses greater than $40 M_\odot$ (e.g., Kennicutt et al. 2009; Hao et al. 2011).

Since HST observations of the NGC 1512 circumnuclear ring in H$\alpha$ line emission are also available in the HLA, we additionally retrieved a narrowband F658N (H$\alpha$) image (GO-6738; PI: Filippenko), observed with the WFPC2/Planetary Camera (PC). The PC chip has a pixel size of $\sim 0\farcs05$. The pixel scale of the H$\alpha$ image was resampled to match that of the WFC3 images ($\sim 0\farcs04$) and then aligned to the F555W frame, using standard IRAF/STSDAS routines. Observational information for all HST images used in this paper can be found in Table 1.

The aligned H$\alpha$ band is actually a combined emission line plus a continuum image. To remove the underlying stellar continuum, we used the scaled F555W and F814W images on both the short-wavelength and long-wavelength sides of the F658N filter bandpass to linearly interpolate a continuum image at the reference H$\alpha$ wavelength. Since the WFC3 and WFPC2/PC detectors have almost the same PSF size, FWHM $\sim 0\farcs07$ (i.e., they have comparable spatial resolutions), we did not apply PSF matching. Next, the continuum image thus generated was subtracted from the F658N image, after converting both images from counts s$^{-1}$ to the physical flux units of erg s$^{-1}$ cm$^{-2}$ $\mu$m$^{-1}$ using the calibration parameter PHOTFLAM (i.e., the inverse sensitivity, contained in the image header), also listed in Table 1. This provides us with a reliable continuum subtraction without generating any conspicuous

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3 http://hla.stsci.edu/hlaview.html
4 This value, computed from values collected in the NASA Extragalactic Database (NED; https://ned.ipac.caltech.edu/), presents the geometric mean of 10 individual distance measurements from the literature.
5 The Image Reduction and Analysis Facility (IRAF) is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the US National Science Foundation.
negative-flux regions, as shown in the bottom left panel of Figure 1. As a consistency check, we compared our continuum-subtracted Hα image to Figure 1 of Maoz et al. (2001). The latter was generated based on their WFPC2/F547M and F814W images. We changed the display colors, inverted the associated color map, and adjusted the scale limits to match the appearance of Maoz et al.’s image as closely as possible. Although both images are indeed very similar, our new, higher-resolution image shows additional details in the form of dust lanes. However, this will not cause any problems in measuring the ring flux, since the faint continuum structure forms part of the background flux, which must be subtracted from the image (see below). We prefer to use the WFC3/F555W filter rather than WFPC2/F547M, because the more recently installed WFC3 camera is characterized by better spatial resolution and improved efficiency. Moreover, the F555W image reaches fainter photometric limits and hence it shows more detailed structures compared with F547M. Note that our continuum-subtracted Hα image includes adjacent [N II] lines redshifted to λλ6558,6604 Å. We adopted a redshift of 0.0029 (Koribalski et al. 2004).

However, the possible effects of dust extinction in the Hα filter significantly undermine its reliability for measuring the SFR. Dust particles in the interstellar medium absorb a fraction of the Hα flux; the attenuated Hα luminosity is subsequently re-radiated at infrared wavelengths. To more robustly estimate the dust-corrected SFRs, a better solution involves combining Hα with infrared observations. We used the Spitzer/IRAC post-basic calibrated data (“post-BCD”) images (3.6 and 8 μm bands, with a pixel scale of 0′′6; see Table 1) taken from the Spitzer Heritage Archive and observed as part of the Spitzer Infrared Nearby Galaxies Survey (SINGS; Kennicutt et al. 2003). To derive the pure 8 μm PAH emission, needed as input in Equation (2), we had to remove the stellar continuum contribution from the 8 μm image. Since the 3.6 μm band traces stellar mass in nearby galaxies (e.g., Elmegreen & Elmegreen 1984; Eskew et al. 2012; Meidt et al. 2012), a continuum-free PAH emission image at 8 μm can be obtained by subtracting a scaled 3.6 μm band image from the original 8 μm image, following the recipe of Helou et al. (2004) and employing a scale factor of 0.255. This approach results in highly accurate continuum-subtracted images, and has been widely demonstrated and used in the literature (e.g., Calzetti et al. 2007; Kennicutt et al. 2009; Zhou et al. 2015). The bottom right panel of Figure 1 shows the continuum-subtracted 8 μm image cropped to focus on the inner ring area only.

3. Measuring the Integrated Ring Luminosities

To characterize the ring structure, we employed GALFIT to simultaneously fit the two-dimensional stellar light distributions of multiple galactic components using analytical functions. It generates a final model image based on the best-fitting structural parameters. The optimal solution for the model parameters is obtained using the iterative Levenberg–Marquardt algorithm (e.g., Bevington & Robinson 2003). Since the standard statistical uncertainties returned by GALFIT tend to underestimate the true uncertainties, we evaluated the goodness-of-fit based on both the χ² values given by GALFIT and visual inspection of the residual images.

3.1. HST Image Analysis

With regard to optical HST images, we have developed an improved approach to derive the total ring luminosity, based on inspection of the radial surface brightness profiles. To start with, we performed a test using the F336W image, which contains the most luminous nuclear ring component among our optical HST bands.

We plotted the radial surface brightness profile in the F336W image, shown as the red dotted line in the left panel of Figure 2. The presence of the nuclear ring introduces a prominent peak at radii between 118 and 250 pixels, corresponding to a radial range from 47.6 to 96.8. Therefore, we adopted this annulus to define the ring region in this paper. Based on the shape of the observed radial profile, we assume that our observed image consists of the host galaxy’s background contribution and a nuclear ring, and we intend to model all galactic components in the original image. The nuclear ring can be quantified by a truncation function, and the background contribution in the image can be fitted by adopting a mixture of Gaussian and Sérsic functions. This approach yields a good fit with minimal residuals. The truncation function is, in essence, a hyperbolic tangent function. In GALFIT these functions are commonly used to modify the light profiles of galactic components, such as Sérsic profiles, to produce ring-like structures (for a detailed description, see Peng et al. 2010).

To limit the degrees of freedom in the fits, we (only) fixed the center position; the other parameter were left as free parameters.
We found a good match between the best-fitting model and the real data. The middle panel of Figure 3 presents our best-fitting model based on the improved method, and the relevant radial profile is shown in the left panel of Figure 2 (blue dotted line; the red line represents the actual data). It is clear that a three-component model could entirely recover the observational profile with high accuracy. Using this method, the total ring luminosity can be derived by adding the flux in all pixels of the predefined ring region: see the right panel of Figure 3, which shows the truncation component (designed to model the nuclear ring). We determined $m_{\text{ring}}(U) = 14.83_{-0.05}^{+0.17}$ mag.

We also investigated how the use of different PSF images affected our fit results. We ran GALFIT using an empirical PSF, a theoretical PSF, and without any input PSF, respectively. We verified that the effect of changing the PSF is negligible, because the three conditions employed accurately reproduced the model image with the same structural parameters and the same resulting ring luminosity. This can be readily understood given the significant difference between the ring and the PSF sizes: the typical WFC3/UVIS stellar PSF of $\sim 0\arcsec 08$ (e.g., Calzetti et al. 2015) is much smaller than the ring radius $\sim 8\arcsec$.

To find the best fits faster, we opted to neglect the PSF when dealing with our HST images.

We subsequently applied our method to the other HST filters. The measured total ring magnitudes in the other filters in our data set are listed in Table 2. Note that no attempt was made to obtain a definitive model for the bulge. Our main goal was just to measure the proper, localized ring structure, with the remaining parts of the image together considered the image’s (i.e., the ring’s) background.

To determine the observed ring’s H$\alpha$ luminosity, we applied our method to the continuum-subtracted H$\alpha$+[N II] image produced in the previous section. We found $L(\text{H}$\alpha$+\text{[N II]}) = 5.61 \times 10^{39}$ erg s$^{-1}$, with a fractional uncertainty of $\sim 10\%$. This is very close to the luminosity $(6 \times 10^{39}$ erg s$^{-1}$) derived by Maoz et al. (2001), although those authors did not actually define a clear-cut ring region. Next, we corrected for the contributions of the [N II] lines using the theoretical [N II] flux line ratio (1/3; Osterbrock & Ferland 2006) and the observed [N II]6584/H$\alpha$ flux line ratio of NGC 1512 obtained from Calzetti et al. (2007). $L(\text{[N II]})$ was removed as a function of transmission efficiency of the F658N filter at the position of the lines. We obtained $L_{\text{obs}}(\text{H}$\alpha$) = 4.74 \times 10^{39}$ erg s$^{-1}$, which will be used to calculate the ring’s SFR, together with $L(8 \mu\text{m})$, discussed in the next subsection.

3.2. Spitzer Image Analysis

A caveat regarding the Spitzer/IRAC image is that the IRAC image resolution for a typical PSF FWHM $\sim 2\arcsec$ is much lower than that of the HST PSF. As illustrated in the bottom right panel of Figure 1, such a resolution is comparable to the radius of the ring, and hence we cannot ascertain whether or not the measured ring luminosity would be affected by the lower Spitzer resolution. To clarify this issue, our strategy consisted of artificially degrading the HST/WFC3 F336W image to the resolution of Spitzer/IRAC to simulate the conditions pertaining to low resolution. We subsequently ran GALFIT on the degraded F336W image to verify whether we could recover the same result as that derived before image degradation. To construct the simulated image, we first changed its pixel size to that of Spitzer ($\sim 0\arcsec 06$ pixel$^{-1}$), as shown in the middle panel of Figure 4. It was then broadened by convolution with a Gaussian kernel to match the smoothness of the Spitzer image, as shown in the right panel of Figure 4. We found that the ring magnitude derived from our simulated image is $m_{\text{ring}}(U) = 14.83_{-0.05}^{+0.17}$ mag, which is in very good agreement with that obtained prior to image degradation, supporting the application of our method to Spitzer images.

We next applied our method to the continuum-subtracted Spitzer 8 $\mu$m image, with the input PSF image artificially created by the STinYTIm package (Krist et al. 2005, which is a new version of TINyTim developed specifically for Spitzer data). It is important to note that the ring is morphologically rather extended in the infrared compared with its extent in the optical images, but we chose the ring region according to that defined in the previous subsection to obtain its PAH emission-line luminosity, an essential parameter to determine the ring’s SFR. In essence, our standard ring region was defined on the basis of the HST/F336W image, which traces the young stellar population. The equation we used to determine the SFR is also sensitive to the age range (roughly from 3 to 10 Myr).

The resulting luminosity is $L(8 \mu\text{m}) = (8.857 \pm 0.6) \times 10^{41}$ erg s$^{-1}$. Substituting $L(8 \mu\text{m})$ and $L(\text{H}$\alpha$)_{\text{obs}}$ into Equation (2), we derive an extinction-corrected $L(\text{H}$\alpha$)_{\text{corr}} = (1.445 \pm 0.17) \times 10^{40}$ erg s$^{-1}$, which is within the estimated range of H$\alpha$+[N II] luminosity given by Maoz et al. (2001), who provided an order-of-magnitude estimation in the range from $\sim 10^{40}$ to $10^{41}$ erg s$^{-1}$. This indicates a total SFR of 0.08 $M_\odot$ yr$^{-1}$ based on Equation (2). The area of the ring is 0.879 kpc$^2$, so the SFR surface density (i.e., the star formation per unit area) is $\Sigma_{\text{SFR}} = 0.09$ $M_\odot$ yr$^{-1}$ kpc$^{-2}$, which is about an order of magnitude higher than the disk-averaged SFR densities in normal galaxies (e.g., Kennicutt 1998).

For comparison, we also explored the performance of a simpler method to determine the ring flux. Here, we tried to
obtain the best-fitting ring background profile. Like before, the background can be modeled by Sérsic and Gaussian functions. However, the ring region was masked to prevent over-estimation of the background before running the fit. The blue dotted line in the right panel of Figure 2 shows the best-fitting background in the F336W data, which matches the real background nicely. The total ring luminosity can be derived by subtracting the model from the data across the ring region, yielding $m_{\text{ring}}(U) = 14.76^{+0.13}_{-0.11}$ mag. The associated uncertainties were estimated by considering both the fitting errors and the influence of different masking annulus radii applied to the ring. This is, within the uncertainties, consistent with the value resulting from our more elaborate method; see Table 2 for comparison.

We note that the integrated ring luminosity returned by our improved method (see Section 3.1) is derived completely based on adequate model assumptions, including the use of a truncation function to model the ring, but for this simpler method the luminosity is directly derived from the “real” image. The fact that our two different approaches reach the same conclusion for this particular image featuring a very luminous ring component demonstrates the feasibility of our more elaborate method and the robustness of the results under such circumstances. The ring magnitude is a function of wavelength and age, however. The nuclear ring gradually becomes less prominent toward redder wavelengths, and it is almost undetectable in the radial profile of the F814W image, as shown in Figure 1. Application of our simple method would hence lead to unreasonably large uncertainties. It is therefore only suitable for blue filters and/or very luminous rings.

Because of the remarkably luminous ring seen in our continuum-subtracted 8 μm, Hα+[N II], and 8 μm images, as evidenced in both Figures 1 and 5, we proceeded to fit their backgrounds based on application of the simple model as well (see Figure 5 for an example). We found that the resulting flux values and the SFR derived were consistent with those found using the more elaborate method; see Table 2. Table 2 also includes the best-fitting ring parameters (see below).

### 3.3. SED Modeling

We next modeled the observed SED using Flexible Stellar Population Synthesis models (FSPS; Conroy et al. 2009; Conroy & Gunn 2010) to derive the ring’s average age and total stellar mass. We did not correct for emission-line contamination to the broadband magnitudes, because this minor effect can be ignored. The stellar population synthesis model templates were internally generated over a grid of stellar population parameters, with the metallicity again fixed to the solar value. We assumed a Kroupa (2001) IMF, and left the age, mass, and dust parameters free in the fits. In FSPS models, the (dimensionless) dust parameters dust1 and dust2 describe the attenuation of young and old stellar light, respectively (for a detailed description, see Conroy et al. 2009), corresponding to $\tau_V$ and $\tau_I$ in Charlot & Fall’s (2000) prescription (their Equation (5.8)). The priors of our free parameters were $6.0 < \log (M_*/L_*) < 9.0$, $6.0 < \log (t/yr) < 10$, $0.1 < \text{dust1} < 2.0$, and $0.1 < \text{dust2} < 2.0$. For each parameter, a posterior probability distribution was constructed by employing Markov chain Monte Carlo methodology.

Figure 6 shows our best-fitting result; the photometry is represented by the blue dots, while the solid line is the model spectrum based on the best-fitting parameters. The best-fitting stellar mass is $\log (M_*/L_*) = 7.1 \pm 0.11$, and the error bars

### Table 2

Photometry and Physical Properties of the NGC 1512 Ring

| $H\alpha$+[N II] | F336W | F438W | F555W | F814W | 8 μm | Continuum-subtracted 8 μm |
|-----------------|-------|-------|-------|-------|------|--------------------------|
| $13.93 \pm 0.06$ | 14.83 ± 0.05 | 15.23 ± 0.08 | 16.12$^{+0.12}_{-0.10}$ | 17.14 ± 0.17 | 5.58 ± 0.27 | 5.60 ± 0.28 |
| $13.87^{+0.10}_{-0.09}$ | 14.76$^{+0.13}_{-0.12}$ | ... | ... | ... | 5.66 ± 0.31 | 5.69 ± 0.31 |

**Note.** We do not provide the photometric results from the simple method for redder optical filters, because of the intrinsically large uncertainties (see the text). The logarithmic mass estimates, based on the $M/Ls$ calculated, are also given as a function of filter/wavelength. dust1 and dust2 are dimensionless parameters.
are the 16th and 84th percentiles of the model posteriors. This mass value corresponds to approximately 0.004% and 0.2% of the total dynamical and the H1 masses of NGC 1512 (e.g., Koribalski & López-Sánchez 2009), respectively. To further examine the reliability of the derived mass, we calculated the mass-to-light ratio ($M/L$) based on the best-fitting parameters. The mass can then be estimated approximately by multiplying by our observed photometry. As shown in Table 2, we found that the derived masses based on the best-fitting $M/L$ ratios are consistent within the 1σ error ranges in our four HST filters, with the 8 μm band being the only outlier. This is mainly due to the larger observational uncertainty in that filter. This reflects the robustness of our mass determination. The best-fitting average age is log ($t$ yr$^{-1}$) = 7.63 ± 0.15, in agreement with the young-starburst characteristics of the ring. Given the present-day SFR derived above and the ring’s average age, the total stellar mass formed over its 40 Myr lifetime, assuming a constant SFR, would amount to $\sim 3.8 \times 10^6 M_\odot$. This only accounts for approximately one-quarter of the best-fitting total ring mass. This insight thus demonstrates that the nuclear ring’s star formation history is likely more complex. There is some evidence that the observed emission lines in the ring might be best modeled by adopting multiple starburst episodes of varying intensity rather than by a constant SFR (e.g., Allard et al. 2006; Sarzi et al. 2007).

4. Summary and Conclusions

Based on the publicly available optical HST/WFC3 and infrared Spitzer/IRAC images, we have presented an improved method (based on the Galfit code) to derive the SED and SFR of the conspicuous nuclear ring in the barred spiral galaxy NGC 1512. The good agreement between the results from our improved method with that from a simple two-component method indicates that it is possible to accurately measure the integrated ring properties. We derived the SFR following the prescription given by Kennicutt et al. (2009). Based on Equation (2), this offers a composite (multi-wavelength), Hα + 8 μm-based SFR that is attenuation-corrected (composite methods provide more robust SFRs than any of the single-wavelength methods). We treated the contribution of the background intrinsic to the host galaxy more carefully, through modeling the light profile in the observed images. These two aspects represent the most important novel aspects of our study, since they enable us to obtain more realistic SFRs characterized by smaller uncertainties than those derived in previous studies.

All nuclear components of the galaxy in the image were modeled using analytical functions. To derive the ring’s current SFR, we constructed high-quality continuum-subtracted Hα and 8 μm images. The resulting SFR surface density ($\Sigma_{SFR}$) is 0.09 $M_\odot$ yr$^{-1}$ kpc$^{-2}$. Our approach represents a significant improvement in measurement accuracy compared with previous efforts in the literature, which are often based on simple assumptions. Finally, we compared the observed ring’s SED with SPS model SEDs to derive its physical properties, including its average age and total stellar mass. The NGC 1512 ring has a total stellar mass of $\sim 10^7 M_\odot$ and a young average age of around 40 Myr.

We have compiled a catalog of nuclear rings that have already been observed and are well resolved by both the HST (in at least four filters, ideal for further star cluster analysis) and Spitzer telescopes. In an extensive follow-up study, we are working on application of our improved method to a statistically carefully selected sample of nuclear rings. We will combine these results with the detected cluster populations to explore possible relationships between ring star formation properties and those of the young cluster populations (e.g., cluster luminosity and mass functions, the cluster mass fraction, and cluster formation efficiencies). Our main objective in this paper was therefore to develop essential technical tools for our follow-up statistical study.

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