STAR FORMATION PROPERTIES IN BARRED GALAXIES (SFB). I. ULTRAVIOLET TO INFRARED IMAGING AND SPECTROSCOPIC STUDIES OF NGC 7479

Zhi-Min Zhou1,2,3, Chen Cao4,5, Xian-Min Meng1, and Hong Wu1,3
1 National Astronomical Observatories, Chinese Academy of Sciences, Beijing 100012, China; zmzhou@bao.ac.cn, mengxm@bao.ac.cn, hwu@bao.ac.cn
2 Graduate School, Chinese Academy of Sciences, Beijing 100039, China
3 Key Laboratory of Optical Astronomy, National Astronomical Observatories, Chinese Academy of Sciences, Beijing 100012, China
4 School of Space Science and Physics, Shandong University at Weihai, Weihai, Shandong 264209, China; caochen@sdu.edu.cn
5 Shandong Provincial Key Laboratory of Optical Astronomy & Solar-Terrestrial Environment, Weihai, Shandong 264209, China

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ABSTRACT

Large-scale bars and minor mergers are important drivers for the secular evolution of galaxies. Based on ground-based optical images and spectra as well as ultraviolet data from the Spitzer Space Telescope, we present a multi-wavelength study of star formation properties in the barred galaxy NGC 7479, which also has obvious features of a minor merger. Using various tracers of star formation, we find that under the effects of both a stellar bar and a minor merger, star formation activity mainly takes place along the galactic bar and arms, while the star formation rate changes from the bar to the disk. With the help of spectral synthesis, we find that strong star formation took place in the bar region about 100 Myr ago. By comparing our results with the secular evolutionary scenario from Jogee et al., we suggest that NGC 7479 is possibly in a transitional stage of secular evolution at present, and it may eventually become an earlier type galaxy or a luminous infrared galaxy. We also note that the probable minor merger event happened recently in NGC 7479, and we find two candidates for minor merger remnants.

Key words: galaxies: evolution – galaxies: individual (NGC 7479) – galaxies: star formation – galaxies: structure

Online-only material: color figures

1. INTRODUCTION

The physical processes of galaxy evolution can be classified into fast and slow according to their timescales, and can also be divided into internal and external processes based on the origins of drivers (Kormendy & Kennicutt 2004). As the universe expands, internal secular processes become important. Secular evolution is different from the dissipative collapses and mergers of galaxies, which are rapid and violent (e.g., Sandage 1990, 2005). Secular processes can rearrange the energy and mass and can be driven by galactic structures such as bars, oval disks, spiral arms, triaxial dark halos inside galaxies (Athanassoula 2002; Kormendy & Kennicutt 2004; Kormendy & Fisher 2005; Kormendy & Fisher 2008), and by minor mergers and other environmental factors outside galaxies (Bournaud et al. 2005, 2007; Jogee et al. 2006).

Many observations and much research have shown that at low redshifts, especially in the local universe ($z \sim 0$), mergers are less common (e.g., Le Fèvre et al. 2000; Conselice et al. 2003), so secular evolution has important effects on galaxies (Kormendy & Kennicutt 2004). Pseudobulges, galactic structures produced by secular evolution, are common in disk galaxies (Kormendy & Fisher 2005; Kormendy 2008), and by minor mergers and other environmental factors outside galaxies (Bournaud et al. 2005, 2007; Jogee et al. 2006).

As important internal structures for secular evolution, galactic stellar bars have been discussed in many works, both theoretical and quantitative (e.g., Sellwood & Moore 1999; Barazza et al. 2007; Athanassoula et al. 2009). A bar is a common phenomenon in the universe; about 65% of nearby spiral galaxies have bars, among which over 30% have strong bars (Eskridge et al. 2000), and the percentage of bars remains high out to a redshift of $z \sim 1$ (Elmegreen et al. 2004; Jogee et al. 2004). Bars can provide intense nonaxisymmetry in the gravitational potential, which causes gas to lose angular momentum and then fall to the inner region of galaxies (Athanassoula 2003; Kormendy & Fisher 2005). Sheth et al. (2005) compared the molecular gas distribution in a sample of nearby galaxies from BIMA-SONG CO ($J = 1–0$) and found that more molecular gas is concentrated in the central kiloparsecs of barred spirals than that in other Hubble-type galaxies, which is consistent with radial inflow driven by a bar. After the gas density becomes supercritical in the central parts, the next step is to trigger circumnuclear star formation (Sheth et al. 2005); (pseudo)bulges also grow during this process (Kormendy & Kennicutt 2004). These processes have been proven by a large number of observations (e.g., Knapen et al. 2006; Shi et al. 2006; Gadotti 2010) and simulations (e.g., Athanassoula et al. 2009). Gadotti & dos Anjos (2001) also studied the broadband $UBV$ color profiles for 257 Sbc barred and nonbarred galaxies and found that the bulges of barred galaxies are bluer than others, indicating an increase in the star formation rate (SFR) in the central regions of these objects. Regan et al. (2006) found that 4 barred galaxies out of 11 spiral had strong central excess in both 8 $\mu$m and CO emission whereas Ho et al. (1997a) found the same effect only in early-type barred spirals using luminosity and the equivalent width of $H\alpha$ emission. Fisher (2006) found that some barred galaxies do not have higher star formation rates (SFRs) than those of other types in a sample of 50 galaxies spanning Hubble types E to Sc using Spitzer infrared color profiles.

Similar to stellar bars, minor mergers can also drive gas into the galactic central region and fuel nuclear activity (Jogee 2006). Observations and $N$-body simulations have shown that minor
mergers can lead to high SFRs (Ferreiro & Pastoriza 2004; Ferreiro et al. 2008; Kaviraj et al. 2009) and engender circum-
uclear rings (Knapen et al. 2004; Mazzuca et al. 2006). In ad-
dition, the evolution of stellar bars may relate to minor mergers
in numerical simulations (Berentzen et al. 2003; Romano-Díaz
et al. 2008). However, these correlations still need to be studied
further.

In order to better understand the effects of bars on the secular
 evolution of galaxies, it is essential to study the star formation
properties of nearby barred galaxies. Thus, we selected a barred
galaxy sample from three large Time Observer programs: the
Spitzer Infrared Nearby Galaxies Survey (SINGS; Kennicutt et al.
2003), the Local Volume Legacy Survey (Lee et al. 2008), and the Infrared Hubble Atlas
(Pahre et al. 2004). The sample consisted of 73 nearby (z < 0.02)
barrered galaxies (including Hubble types SB and SAB). One of
the most interesting objects in this sample was NGC 7479. NGC 7479 is an SBbc galaxy (de Vaucouleurs et al. 1991) with
a large stellar bar and two strongly asymmetric spiral arms,
among which the western one is much stronger. Its small and
bright nucleus is classified as a LINER (Keel 1983) and a Seyfert
1.9 (Ho et al. 1997a). Observations and simulations have been
made in studies of NGC 7479 (e.g., Martin & Friedli 1997; Laine
& Heller 1999; Aguerri et al. 2000; Huttemeister et al. 2000;
Laine et al. 2006; Laine & Beck 2008). There is an amount of
molecular gas along the stellar bar and in the central region of
NGC 7479, and it also has obvious dust lanes and large-scale
shocks along the bar (Laine & Gottesman 1998). Rozas et al.
(1999) showed that intense star formation regions can also be
found in the barred region. Huttemeister et al. (2000) found
that there may be a nuclear ring, a torus, a disk, or an inner bar
in the bulge of this galaxy. It seems that this galaxy has no
close companions although from its morphology it appears to
be an interacting system (Laine & Gottesman 1998; Saravia &
Benedict 2003), so it may have recently suffered a minor merger
(Laine & Beck 2008). Based on the facts above, the secular evolu-
tion simultaneously driven by the bar and the minor merger
makes NGC 7479 an interesting galaxy worthy of careful study.

In this paper, we study the properties of NGC 7479, mainly
focusing on the bar and star formation regions based on multi-
wavelength data from the ultraviolet (UV) to the infrared (IR).
This paper is organized as follows. Section 2 describes the data
we used and their reductions, Section 3 presents the main results
from this study, Section 4 provides some discussion, and we
present a summary in Section 5.

2. DATA ACQUISITION AND REDUCTION

We archived far-UV (FUV) and near-UV (NUV) images
(Gil de Paz et al. 2007) from the NASA Extragalactic Database
(NED) and IR images from the Spitzer Space Telescope data
archive (P.I.: G. Fazio) using Leopard software. In addition,
we observed NGC 7479 using a ground-based telescope and
obtained optical images and spectra. Detailed information is
given in Table 1.

### 2.1. UV Data

We obtained the UV images of NGC 7479 using the
Galaxy Evolution Explorer (GALEX; Martin et al. 2005). The
galaxy was imaged in both FUV (1350–1750 Å) and NUV
(1750–2750 Å) broadbands. These images are from the Nearby
Galaxies Survey (Gil de Paz et al. 2007), which includes obser-
vations of nearby galaxies of different types and environments
based on GALEX, and they are reduced through the GALEX
pipeline. We obtained a constant sky background subtracted
and flux calibrated using the keywords mean sky-background
level (SKY) and zero point in AB magnitude scale (ZP) in the
headers of the FUV and NUV images. The final images are char-
acterized by a point-spread function with an FWHM of ~6′
and a pixel size of 1.5′.

### 2.2. Optical Data

We observed NGC 7479 using the 2.16 m telescope at
Xinglong Observatory of the National Astronomical Observato-
ries of the Chinese Academy of Sciences. On 2009 September
12 observations were carried out by the BAO Faint Object Spec-
trograph and Camera with a Lick 2048 × 2048 CCD detector,
which has a field of view of about 10′ × 10′ and a pixel size of
0.′305. Four filters were used, of which the most important was
the narrowband interference filter centered near the redshifted
Hα emission line with the central wavelength at ~6610 Å and
an FWHM of 70 Å (marked as Hα2). The other three filters
were the broadband B, V, and R filters, respectively. The expo-
sure time was 1200 s in B, 1100 s in V, 600 s in R, and 3000 s in
Hα2.

We used the standard IRAF CCD reduction pipeline, in-
cluding checking the images, adding keywords to fits headers,
subtracting the overscan and bias, correcting bad pixels,

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**Table 1**

| Band  | Telescope | Instrument | λ$_{eff}$ (μm) | Exptime (s) | Obs-Date (UT) | FWHM (″) | Pixel Size (″ pixel$^{-1}$) |
|-------|-----------|------------|---------------|-------------|--------------|---------|--------------------------|
| FUV   | GALEX     |            | 0.1516        | 1606.05     | 2004 Oct 2   | 6.0     | 1.500                    |
| NUV   | GALEX     |            | 0.2267        | 1606.05     | 2004 Oct 2   | 6.0     | 1.500                    |
| Mid-IR| Spitzer   | IRAC       | 3.6/4.5/5.8/8.0 | 10 × 26.8 | 2004 Jul 5   | 2.3–2.6 | 1.220                    |
| Mid-IR| Spitzer   | MIPS       | 24            | 216 × 2.62  | 2005 Jun 27  | 6.0     | 2.500                    |

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### Archival observations

| Band  | Telescope | Instrument | λ$_{eff}$ (μm) | Exptime (s) | Obs-Date (UT) | FWHM (″) | Pixel Size (″ pixel$^{-1}$) |
|-------|-----------|------------|---------------|-------------|--------------|---------|--------------------------|
| B     | Xinglong 2.16 m BFOSC | 0.438 | 1200 | 2009 Sep 12 | 2.8 | 0.305 |
| V     | Xinglong 2.16 m BFOSC | 0.545 | 1100 | 2009 Sep 12 | 2.5 | 0.305 |
| R     | Xinglong 2.16 m BFOSC | 0.641 | 600 | 2009 Sep 12 | 2.2 | 0.305 |
| Hα2   | Xinglong 2.16 m BFOSC | 0.661 | 3000 | 2009 Sep 12 | 2.0 | 0.305 |
| Spectrum | Xinglong 2.16 m OMR | 0.38–0.85 | 2 × 3600 | 2009 Jul 2 | ... | ... |

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6. http://nedwww.ipac.caltech.edu/

7. http://www.xinglong-naoc.org/English/216.html
flat-fielding, and removing cosmic rays.\(^8\) The absolute flux calibration of broadband images was made using the standard star GD246, which was selected from the Landolt fields (Landolt 1992) and observed with the corresponding filters on the same night. The final flux conversion factors are 4.90, 1.16, and 1.25 \(\times 10^{-21}\) erg s\(^{-1}\) cm\(^{-2}\) \(\AA\)^\(-1\)/DN (DN is digital numbers) for the \(B, V,\) and \(R\) bands, respectively. The uncertainty is \(\sim 3\%\) for each band.

The removal of the stellar continuum contribution from the \(H_{\alpha}\) image is another critical part of the data reduction. We used a scaled \(R\)-band image as the stellar continuum; the scale factor was calculated using photometric count ratios of five unsaturated field stars in both filter images. After the continuum was removed, the \(H_{\alpha}\) image was flux calibrated following the conversion factor of the \(R\)-band image and the effective transmissions of narrowband and \(R\)-band filters. In this paper, we do not consider the \(H_{\alpha}\) emission that was lost in the process of continuum removal or the contribution of [N\(II\)] lines to the \(H_{\alpha}\) flux.

We also obtained optical spectra with the Optomechanics Research, Inc. Spectrograph using the same telescope on 2009 July 1. The spectra were taken with a 2\(''\) wide slit along the major axis of the stellar bar, covering a wavelength range from 3800 to 8500 \(\AA\) in the observer’s frame with the central wavelength at 6000 \(\AA\). We used the 200 \(\AA\) mm\(^{-1}\) grating, which resulted in a two-pixel resolution of 12 \(\AA\). The raw spectra were reduced with IRAF, and the preprocessing was similar to that of the images mentioned above except for the correction in the spatial and dispersion axis. After extraction, we applied the atmospheric absorption correction to the spectra using the IRAF task TELLURIC. Then they were wavelength calibrated using the spectrum of a He/Ar lamp and flux calibrated using the spectrum of standard star BD28+4211 observed on the same night.

2.3. Infrared Data

We obtained IR images of NGC 7479 taken with the Spitzer Space Telescope (Werner et al. 2004). As part of the Mid-IR Hubble Atlas of Galaxies (Fazio & Pahre 2004), NGC 7479 was imaged with the Infrared Array Camera (IRAC; Fazio et al. 2004) at 3.6, 4.5, 5.8, and 8.0 \(\mu\)m, and with the Multiband Imager and Photometer for Spitzer (MIPS; Rieke et al. 2004) at 24, 70 and 160 \(\mu\)m. After we obtained the Basic Calibrated Data (BCD), which were generated through the Spitzer data reduction pipeline version s14.0.0, MOPEX version 18.1.5 was used to produce mosaicked images from individual BCD frames. The final images have spatial resolutions of 2\(''\)3 \(\sim\) 2\(''\)6 and pixel sizes of 1\(''\)2 for the four IRAC bands, and spatial resolutions of 6\(''\) and pixel sizes of 2\(''\)5 for the MIPS 24 \(\mu\)m band. The pixel sizes of the MIPS 70 and 160 \(\mu\)m are 4\(''\)8 and 8\(''\), respectively, along with very low spatial resolutions, so they are not included.

There are mainly three components in the 8 \(\mu\)m band: polycyclic aromatic hydrocarbon (PAH) emission, dust-continuum emission, and stellar continuum. To obtain the properties of the dust emission, the contribution of the stellar continuum should be removed. We used a scaled IRAC 3.6 \(\mu\)m image as the stellar continuum with the assumption that the entire 3.6 \(\mu\)m band emission is from an old stellar population. The scale factor of 0.232 (Helou et al. 2004) was adopted, which has also been used many times by other authors (e.g., Cao et al. 2008; Zhu et al. 2008). This coefficient was derived with the assumption that the IRAC 3.6 \(\mu\)m emission is entirely due to stars and is based on the Starburst99 synthesis model (Leitherer et al. 1999). Occasional foreground stars located in the fields of NGC 7479 were almost removed by this technique, which suggests that this approach is fairly accurate in removing stellar emission. Although the 3.6 \(\mu\)m image is also somewhat contaminated by dust emission and red giant stars, particularly in the star-forming regions, this component only has an impact of less than a few percent on the stellar continuum subtraction process (Calzetti et al. 2005). Hereafter we refer to the 8 \(\mu\)m dust emission in which the stellar continuum has been removed as 8 \(\mu\)m (dust).

2.4. Object Masking

In order to obtain accurate results, we removed the foreground bright field stars and background galaxies in images from the optical \(B, V,\) and \(R\) bands and two of the IRAC bands. We performed object masking following the method in Muñoz-Mateos et al. (2009). First, we used SExtractor (Bertin & Arnouts 1996) to detect objects in each image. Then we selected the field stars and background galaxies using the parameters (FLUX and CLASS_STAR) yielded from the first step. Finally, we replaced the selected sources with their nearest background values to mask them. As for the UV images, there are a number of star formation regions located in them. It is hard to detect stars from these regions exactly, so masking was not performed on these images. This reduction was also not performed on 5.8 \(\mu\)m, 8.0 \(\mu\)m, and 24 \(\mu\)m images because the contribution from those masking objects could be negligible in the mid-IR.

Figure 1 shows the final UV, optical, and IR images. From the figure, a strong stellar bar can be found in optical and near-IR images, and a large asymmetry exists in UV and far-IR images.

3. ANALYSIS AND RESULTS

3.1. Surface Photometry and Radial Profile

In order to study the global properties of NGC 7479, we used the IRAF task ELLIPSE to produce the surface photometry of multi-band images. The radial surface brightness profile, ellipticity (\(e\)), and position angle (P.A.) were included in photometric results of each band. The bar structure was obviously identified by following the method in Jogee et al. (2004). The characteristic bar signature is that \(e\) increases continuously until reaching a maximum, \(e_{\text{max}}\), while the P.A. remains constant, and at the end of the bar, \(e\) falls rapidly and the P.A. changes accordingly. \(e_{\text{max}}\) was adopted as the ellipticity of the bar and the bar length was derived as the semimajor axis at which maximum ellipticity was reached. We also found a slight jump in the bar region from the radial surface brightness profile. Based on the \(R\)-band image, we found that the length of the bar is about 8.3 kpc and the ellipticity is 0.733; both are larger than their mean values in the local universe, \(\sim 3.5\) kpc and \(\sim 0.6\), respectively (Marinova & Jogee 2007; Gadotti 2010). The length is much larger than the mean bar size of Sbc galaxies, which is \(2.35 \pm 1.22\) kpc derived by Erwin (2005). The ellipticity is also in the upper range of those for Sb/Sbc galaxies, which lie in the range 0.35–0.80 as derived by Marinova & Jogee (2007).

Because different band images have different spatial resolutions as mentioned in Section 2, we determined the surface photometry using two sets of radial profiles: one radial step of 3\(''\)05 (for optical and IRAC images) and another of 6\(''\)1 (for UV and 24 \(\mu\)m images). In order to get the same regions in different

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\(^8\) IRAF is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.
bands and easily compare our results with previous findings, we used a fixed centric position, ellipticity, and P.A. from the values provided in the Third Reference Catalogue of Bright Galaxies (de Vaucouleurs et al. 1991). The result is shown in Figure 2. The properties of profiles are mainly three types.

1. **Mid-IR**. In the 24 μm band, there is a sharp inner cutoff at ~20′, and there are also cutoffs at smaller radii in 8 μm and 5.8 μm images. Two factors may cause the high IR brightness in the inner region. The first factor is that there is plenty of gas and dust reserved in the central region; these are traced by 24 μm and 8 μm (dust) emission, respectively. The second factor might be that the emission is affected by the active galactic nucleus (AGN), especially for the 24 μm flux (e.g., Bell et al. 2005).

2. **UV**. UV emission is mainly dominated by young stars. No strong peaks of UV profiles are found in the central region like those in the IR, which may be due to the strong dust attenuation.

3. **Optical and near-IR**. These profiles are relatively smooth and no obvious jumps can be found in the inner and outer disks. All the UV and optical photometric results have been corrected by the Galactic extinction with the assumption of the Cardelli et al. (1989) extinction curve and $R_V = 3.1$.

### 3.2. Morphological Asymmetry and Concentration Index

The rotational asymmetry as a tool of describing properties of nearby and distant galaxies has been used in many studies (e.g., Schade et al. 1995; Conselice et al. 2000). The asymmetry is calculated following Equations (12) and (13) in Muñoz-Mateos et al. (2009), i.e., by comparing the completely inverted image (the rotation angle is 180°) with the original counterpart:

$$
A = \frac{1}{2} \left[ \frac{\sum |I_{180°} - I_0|}{\sum |I_0|} \right] - \frac{2}{\sqrt{\pi}} \frac{\sigma_{sky} N_{pix}}{\sum |I_0|},
$$

where $I_0$ and $I_{180°}$ are intensities of the original and rotated images, $\sigma_{sky}$ is the sky noise, and $N_{pix}$ is the number of pixels.
The asymmetry is highest in the FUV at nearly 0.4 then drops to 0.11–0.12 in the optical. We obtained another maximal value, 0.27, at 5.8 μm and 8 μm as we moved toward longer wavelengths from the optical to the IR. This is consistent with Figure 1. The asymmetry of the Hα image is ~0.226, slightly smaller than the NUV value. The high asymmetry is probably due to the following reasons. The recent star formation regions traced by the UV have a clumpy and extended spatial distribution and these regions sprawl out not only in the galactic center but also in the disk, which is unlike that of middle- and old-aged stars traced by the optical and near-IR. The 5.8 μm and 8 μm emission are possibly due to 6.2, 7.7, and 8.6 μm PAH emission, although a large amount of dust is concentrated in the bulge and bar regions of which the obvious dust lane along the bar is proof, and there is also a certain amount of dust in the arms and disk.

The concentration indexes are the ratios of two radii containing a fixed fraction of the total galactic flux and they are widely used to identify structural properties of galaxies and to infer galactic morphological types (e.g., Strateva et al. 2001; Conselice 2003; Gil de Paz et al. 2007) since these indexes are relative parameters not affected by external factors. Here we adopt the index $C_{42}$ (Kent 1985) defined as

$$C_{42} = 5 \log_{10}(r_{80}/r_{20}),$$

where $r_{80}$ and $r_{20}$ are the radii along the semimajor axis containing 80% and 20% of the total luminosity. The bottom panel of Figure 3 shows the result along the wavelength, presenting a much different behavior. The index in the UV is very small (~2) due to the contribution of diffused young stars in the disk, and it is still small in optical wavelengths while in the IR, $C_{42}$ jumps to maximum values of 6.8 at 4.5 μm and 7.5 at 5.8 μm, and falls at 8.0 μm for the spatial distribution of dust. It rises again at 24 μm due to intense emission in the central region.

3.3. Star Formation Properties of Different Structural Regions

In the Hα image (Figure 1), we can see that most H II regions are located in the bar and two very asymmetric arms. These regions have been investigated in previous studies (e.g., Rozas...
Figure 4. Regional division on the Hα image. The ellipses overlapping in the image are regions we divided based on the Hα image, marked with the corresponding labels. The bulge and nucleus region is plotted with red color. Although there are overlaps for some adjacent regions, that has little effect on the results (see Section 3.3).

(A color version of this figure is available in the online journal.)

Table 2

Properties of the Hα Regions

| Regions Name (J2000.0) | R.A. (J2000.0) | Decl. (J2000.0) | Major r (arcsec) | Minor r (arcsec) | P.A. (deg) | FUV (mJy) | NUV (mJy) | B (mJy) | V (mJy) | R (mJy) | 3.6 μm (mJy) | 4.5 μm (mJy) | 5.8 μm (mJy) | 8.0 μm (mJy) | 24 μm (mJy) | Hα 10^40 (erg s⁻¹) |
|------------------------|---------------|----------------|------------------|------------------|------------|-----------|-----------|--------|--------|--------|-------------|-------------|-------------|-------------|-----------|-----------------|
| Center                 | 23:04:56.6    | +12:19:21.12   | 10.9             | 8.3              | 37.9       | 0.15      | 0.44      | 7.05   | 8.99   | 22.13  | 48.01       | 58.59       | 164.87      | 273.32      | 1894.25   | 7.79            |
| BN                     | 23:04:56.6    | +12:19:43.05   | 13.8             | 9.2              | 17.3       | 0.48      | 0.96      | 6.21   | 7.05   | 16.44  | 19.58       | 13.29       | 27.20       | 64.73       | 132.78    | 6.34            |
| BS                     | 23:04:56.5    | +12:19:00.23   | 12.3             | 7.7              | 17.3       | 0.19      | 0.42      | 4.85   | 5.68   | 12.96  | 15.94       | 10.48       | 23.48       | 58.95       | 119.63    | 5.12            |
| BAN                    | 23:04:56.7    | +12:20:13.61   | 20.3             | 14.9             | 37.3       | 0.68      | 1.21      | 7.52   | 7.69   | 16.62  | 17.77       | 11.78       | 31.09       | 83.49       | 72.07     | 7.97            |
| BAS                    | 23:04:56.3    | +12:18:37.17   | 12.3             | 9.2              | 37.9       | 0.29      | 0.52      | 3.54   | 4.02   | 8.45   | 9.66        | 6.14        | 15.95       | 45.03       | 10.65     | 3.68            |
| AE1                    | 23:04:58.5    | +12:20:24.48   | 13.9             | 10.8             | 42.7       | 0.19      | 0.32      | 2.30   | 2.33   | 4.96   | 4.76        | 2.85        | 8.30        | 23.55       | 22.30     | 2.12            |
| AE2                    | 23:04:59.5    | +12:19:54.73   | 20.0             | 19.0             | 37.9       | 0.46      | 0.79      | 5.09   | 5.74   | 11.39  | 9.64        | 5.88        | 16.88       | 43.09       | 46.73     | 3.23            |
| AE3                    | 23:04:59.6    | +12:19:15.35   | 20.0             | 18.4             | 2.9        | 0.34      | 0.35      | 4.32   | 4.89   | 9.52   | 8.11        | 5.05        | 13.90       | 38.33       | 56.33     | 3.13            |
| AW1                    | 23:04:54.3    | +12:18:19.07   | 24.6             | 12.3             | 71.9       | 0.73      | 1.23      | 6.41   | 6.86   | 13.24  | 14.47       | 9.68        | 34.17       | 96.42       | 97.97     | 12.46           |
| AW2                    | 23:04:51.6    | +12:18:29.46   | 21.6             | 15.4             | 32.1       | 1.13      | 1.56      | 5.24   | 4.93   | 8.55   | 7.03        | 4.42        | 13.83       | 37.16       | 36.98     | 9.38            |
| AW3                    | 23:04:51.3    | +12:19:02.55   | 12.3             | 11.7             | −3.1       | 0.28      | 0.40      | 1.68   | 1.63   | 2.78   | 2.28        | 1.37        | 3.92        | 11.01       | 10.50     | 3.12            |
| AW4                    | 23:04:51.7    | +12:19:29.02   | 13.9             | 12.3             | 22.9       | 0.25      | 0.33      | 1.60   | 1.64   | 2.81   | 2.31        | 1.41        | 3.87        | 11.01       | 17.15     | 3.76            |
| AW5                    | 23:04:52.8    | +12:19:57.60   | 18.5             | 9.2              | 37.9       | 0.23      | 0.32      | 1.52   | 1.48   | 2.76   | 2.19        | 1.39        | 2.76        | 7.60        | 9.37      | 2.02            |
| Entire                 | 23:04:56.6    | +12:19:22.40   | 123.0            | 93.0             | 95.6       | 13.70     | 129.01    | 156.09 | 288.11 | 286.33 | 205.20      | 452.25      | 1285.60     | 3531.18     | 110.17    |                 |

Notes. (1) name of the galactic region. (2) and (3) right ascension and declination in J2000.0. (4)–(6) the size and P.A. of each region; the angles run from 0 in the north, counterclockwise. (7)–(16) the photometric result of each wavelength band, in units of mJy. (17) the photometric result of the Hα narrowband, including the emission line [N II], in units of 10^40 erg s⁻¹.

et al. 1999; Zurita et al. 2000). Those studies were mainly focused on global properties of the Hα regions over the entire galaxy, from which the properties of star formation in different galactic structural regions cannot be clearly studied. Therefore, in order to analyze properties of star formation regions situated in different structures, we marked 13 different regions along the bar and arms in Figure 4. Because we focused on the entire properties of different regions and not just on separated star formation clumps, several clumps are always contained in one marked region, which has an aperture of different radii and shapes. It should be noted that the results from this step only make sense on average in each region along with a certain degree of uncertainty. In Figure 4 all regions are marked with boundaries and labels on the Hα image, including the southern and northern parts of the bar (noted as BS and BN), the bulge region (Center), three parts (AE1–AE3) along the eastern arm (i.e., the weaker one), four parts along the other arm (AW1–AW4), and two parts at the interface between the bar and arms (BAN and BAS). Detailed information about each part is listed in Table 2.
Figure 5. Total SED of NGC 7479 and SEDs of individual H\textsc{ii} regions noted in Section 3.3. The SEDs from the same galactic structures are plotted with lines of the same color.

(A color version of this figure is available in the online journal.)

### 3.3.1. UV to IR Spectral Energy Distributions

We determined photometry for the entire galaxy and each marked region using the ELLIPSE task in IRAF on multi-wavelength images. The results are listed in Table 2, and they are also plotted in Figure 5 as the spectral energy distributions (SEDs) along the wavelengths. To more accurately determine the SEDs, we also added the photometric results from near-IR bands (Skrutskie et al. 2006).

For the entire galaxy, the fluxes vary by a factor of two orders of magnitude from 0.01 Jy in the UV to above 3.5 Jy in 24 \( \mu \)m. The optical fluxes are similar to the flux at 3.6 \( \mu \)m and they are dominated by the stellar emission. There is a steep slope from UV to optical wavelengths, which is probably due to the Balmer jump or 4000 \( \AA \) break. It is clear that the highest IR flux and lowest UV emission lie at the galactic center in the 13 structural regions. In previous studies, the nucleus of NGC 7479 was classified as a Seyfert 1.9 (Ho et al. 1997b); thus, the emission from this region may be seriously affected by an AGN. In the eastern arm, western arm, bar, and central regions, the profiles of two regions in the bar also have higher IR emission than the regions in the two spiral arms. For other SEDs, the profiles of regions from the same galactic structures are similar to each other while all of their IR emission is much lower than that of the center.

### 3.3.2. Star Formation Rate

SFRs are very important for describing the activities of galactic star formation. Many tracers have been explored to estimate SFRs in different types of galaxies from the UV to the IR including broadband photometry and emission line luminosities (e.g., Kennicutt 1998; Wu et al. 2005; Zhu et al. 2008; Kennicutt et al. 2009; Calzetti et al. 2010; Panuzzo et al. 2010).

In order to calculate SFRs more accurately, we used three methods obtained from previous studies. Two were taken from Kennicutt et al. (2009; their Equation (11) and Table 4):

\[
\text{SFR}_{\text{H}\alpha+24 \ \mu\text{m}}(M_\odot \text{yr}^{-1}) = 7.9 \times 10^{-42} [L(\text{H}\alpha)_{\text{obs}} + 0.020L(24)] \text{(erg s}^{-1}),
\]

and

\[
\text{SFR}_{\text{H}\alpha+8 \ \mu\text{m}}(M_\odot \text{yr}^{-1}) = 7.9 \times 10^{-42} [L(\text{H}\alpha)_{\text{obs}} + 0.010L(8)] \text{(erg s}^{-1}).
\]

These equations were derived on the basis of data from the SINGS survey (Kennicutt et al. 2003) and Moustakas & Kennicutt (2006) and the calibration of Kennicutt (1998) with an assumption of solar abundance and a Salpeter initial mass function (0.1–100 \( M_\odot \)). These methods can be applied reliably to individual H\textsc{ii} regions and to galaxies as a whole (Kennicutt et al. 2009). The third model is from Fisher et al. (2009; their Equations (6) and (7)):

\[
\text{SFR}_{\text{FUV+24 }\mu\text{m}}(M_\odot \text{yr}^{-1}) = 2.21 \times 10^{-43} [L(\text{FUV})_{\text{obs}} + L(24)] \text{(erg s}^{-1}),$

which combines the 24 \( \mu \)m IR emission from warm dust with the FUV emission from young stars. This formula was derived on the basis of star-forming regions in nearby galaxies from Calzetti et al. (2007), in which luminosities were measured using elliptical apertures. This combination of FUV and 24 \( \mu \)m is also suitable for the regions in NGC 7479.

In the top of Figure 6, we plot our results as positions in the SFRFUV+24\( \mu \)m calculated using Equations (3) and (5) in the three regions are probably higher than their real values. In the galactic disk, the SFRs from Equation (5) are lower than those from Equations (3) and (4), likely due to the different IMFs used in these formulae. After our comparison, we adopt results from the composite tracer of H\alpha and 8 \( \mu \)m flux to perform the next analysis. Except for the central region, star formation activity is mainly located in the strong arm and at the end of the bar. The total SFRs are 0.95, 2.88, 1.24, and 1.36 \( M_\odot \) \text{yr}^{-1} in the eastern arm, western arm, bar, and central region, respectively.

In order to explicitly describe how the recent star formation contributes to galaxy growth for different regions, we investigated the specific star formation rate (SSFR), which is defined as the SFR per unit of stellar mass. Stellar masses are roughly determined with the luminosity of IRAC 3.6 \( \mu \)m using the method...
from Zhu et al. (2010; their Equation (2)):

$$\log_{10} M(M_\odot) = (-0.79 \pm 0.03) + (1.19 \pm 0.01) \times \log_{10} \nu L_\nu[3.6 \mu m](L_\odot).$$

(6)

This formula was deduced based on the sample cross-identified from the Spitzer Wide-area Infrared Extragalactic Legacy Survey field and the Sloan Digital Sky Survey. The result is plotted in the middle of Figure 6, where a large difference is revealed in all marked regions. The western spiral arm shows greater values than the other regions, while the SSFR is at its lowest value in the central region.

3.4. Stellar Population

We extracted optical spectra from nine regions in the spectroscopic long slit along the stellar bar including the nucleus with an aperture of 9$''$ (along the slit) $\times$ 2$''$ (the width of the slit). These regions are shown in Figure 7, and all positions are determined with the H$\alpha$ emission peak and are labeled as BN1-4 on the northern bar, BS1-4 on the southern bar, and Nucleus at the galactic center. The spectral synthesis code STARLIGHT (Cid Fernandes et al. 2005) is used to derive the stellar populations of different star formation regions along the bar. Previous studies have shown that this spectrum fitting code is a good tool for studying the properties of various types of galaxies (e.g., Meng et al. 2010; Lara-López et al. 2010; Martins et al. 2010). Our template spectra consist of simple stellar populations (SSPs) from Bruzual & Charlot (2003). Assuming that the stellar populations have instantaneous burst star formation history, these SSP spectra are computed with “Padov 1994” evolutionary tracks (Alongi et al. 1993; Bressan et al. 1993; Fagotto et al. 1994a, 1994b; Girardi et al. 1996) and Chabrier (2003) IMFs. We used templates with ages of 0.005, 0.025, 0.1, 0.29, 0.5, 0.9, 1.4, 2.5, 4, and 10 Gyr and metallicities of $Z = 0.0001$, $0.0004$, $0.004$, $0.008$, 0.02, and 0.05. Figure 8
Figure 7. Illustration of the optical spectrum long slit overplotted on the raw R-band image. The slit is signified by the blue line, the rectangles are the regions where spectra are extracted in the bar (red, labeled as BN and BS) and nucleus (blue, labeled as Nucleus), and the background used to subtract is located in the ends of the slit free from contamination of galaxies and stars. North is up, and east is left.

Figure 8. Spectral synthesis of the nucleus of NGC 7479. Top left: the observed spectrum (green), model spectrum (red), and error spectrum (blue) with gaps where the region is not involved in the fitting. Bottom left: the residual spectrum (purple). The spectra in the left two panels are normalized by the flux intensity at 4020 Å. Right: luminosity-weighted (top) and mass-weighted (bottom) stellar population fractions $x_j$ and $M_j$ (Cid Fernandes et al. 2005) as a function of ages of the stellar population templates. The basic results are also listed in the right panel.

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shows the nuclear spectrum fitting result as an example. In this figure, we see that the mean stellar age weighted by luminosity $\langle t_* \rangle_L$ (Cid Fernandes et al. 2005) is $\sim$100 Myr, and more than half of the luminosity is dominated by populations younger than 100 Myr. Besides young stellar populations, there is also an old population of $\sim$10 Gyr that serves as the background population. We summarize the results of our spectral synthesis in Table 3. These results indicate that strong star formation...
NGC 7479 is an interesting galaxy with a strong stellar bar that likely suffered a minor merger because of some of the features mentioned above. Its active star formation and dust lanes, and velocity gradients have complex relationships. The radio continuum emission at 21 cm in the galactic central region shows a behavior similar to the CO emission (Laine & Gottesman 1998). The distribution of star formation activity and gas in the bar may be a result of the concentration of gas flowing in from the disk under the influence of the bar because the gravitational torque of the large-scale bar can cause the gas to lose angular momentum, then drive it inward through the stellar bar (Athanassoula 1992; Sellwood & Wilkinson 1993).

In general, star formation is located in the circumnuclear regions and in the ends of bars, while bars are typically dominated by evolved stellar populations (Gadotti & de Souza 2006). In a study of the barred spiral NGC 5383, Sheth et al. (2000) found weak Hα emission in the bar between the bar ends and the central region despite the high gas column density in the bar dust lanes. Similarly, weak star formation in the bar takes place in NGC 1530, probably due to the inhibition of the shear and shock in the dust lanes (Reynaud & Downes 1998). How does the bar affect the evolution of NGC 7479? Quillen et al. (1995) found that the gas inflow rate along the stellar bar is about 4–6 $M_\odot$ yr$^{-1}$ in this galaxy, which is much larger than the SFR we derived in the bar region (1.24 $M_\odot$ yr$^{-1}$). Therefore, before turning into stars, a large percentage of gas will drop into the galactic central region and add to the bulge mass (Laine et al. 1999). In that case, this galaxy will possibly evolve toward a transitional stage.

4. DISCUSSION

NGC 7479 is an interesting galaxy with a strong stellar bar that likely suffered a minor merger because of some of the features mentioned above. Its active star formation and dust lanes, and velocity gradients have complex relationships. The radio continuum emission at 21 cm in the galactic central region shows a behavior similar to the CO emission (Laine & Gottesman 1998). The distribution of star formation activity and gas in the bar may be a result of the concentration of gas flowing in from the disk under the influence of the bar because the gravitational torque of the large-scale bar can cause the gas to lose angular momentum, then drive it inward through the stellar bar (Athanassoula 1992; Sellwood & Wilkinson 1993).

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| Region | log ($t_L$) | log ($t_M$) | Burst (%) | Young (%) | Median (%) | Old (%) | $A_v$ | $\chi^2$ |
|--------|------------|------------|-----------|-----------|------------|---------|------|--------|
| BN1    | 7.1        | 10.0       | 88.41     | 0.00      | 0.00       | 11.59   | 1.21 | 1.1474 |
| BN2    | 7.1        | 10.0       | 90.90     | 0.00      | 0.64       | 8.45    | 1.25 | 1.1573 |
| BN3    | 7.3        | 10.0       | 88.42     | 0.00      | 0.00       | 11.58   | 1.24 | 1.3180 |
| BN4    | 7.0        | 10.0       | 92.20     | 0.00      | 0.00       | 7.80    | 0.16 | 1.4435 |
| BS1    | 8.1        | 9.7        | 58.26     | 3.33      | 27.79      | 10.62   | 0.16 | 1.0284 |
| BS2    | 7.6        | 9.9        | 76.11     | 1.57      | 8.17       | 14.15   | 0.93 | 1.2923 |
| BS3    | 7.6        | 9.9        | 76.96     | 0.00      | 11.73      | 11.31   | 1.13 | 1.0580 |
| BS4    | 7.2        | 9.9        | 92.24     | 0.00      | 2.23       | 5.54    | 0.22 | 1.0427 |
| Nucleus| 8.1        | 9.9        | 53.50     | 14.83     | 15.33      | 16.33   | 1.12 | 1.4761 |

Notes. (1) positions of the spectra used, which are marked in Figure 7. (2) the average age weighted by luminosity (Cid Fernandes et al. 2005). (3) the average age weighted by stellar mass (Cid Fernandes et al. 2005). (4)–(7) the percentage of stellar population with different ages weighted by luminosity; ages are Burst ($<10^7$ yr), Young ($10^7$–$10^9$ yr), Median ($10^9$–$10^{10}$ yr), and Old ($>10^{10}$ yr) in Columns 4–7, respectively. (8) the extinction estimated by spectral synthesis. (9) the minimum variance of each spectral synthesis.
In order to explore the bar-driven secular evolution, Jogee et al. (2005) classified 10 different barred galaxies into three evolutionary stages based on their dynamical properties and dust morphology: (1) type I non-starburst, the early stages of bar-driven inflow, where large amounts of gas are located along the bar and there is low star formation efficiency in the inner few kiloparsecs; (2) type II non-starburst, the later stages of bar-driven inflow where most molecular gas is concentrated in the inner kiloparsec and star formation only occurs in regions with high gas densities; and (3) circumnuclear starburst, where a large fraction of molecular gas is concentrated in the galactic central region and intense star formation activity exists. Comparing our results with this scenario suggests that NGC 7479 may be in the type I non-starburst evolutionary phase based on its star formation and molecular gas properties. NGC 7479 is similar to NGC 4569, which is the prototype of a type I non-starburst galaxy in the work of Jogee et al. (2005). With a sample of barred galaxies, Verley et al. (2007) also put forward a scenario of bar-driven secular evolutionary sequence using properties of Hα emission in which they defined four main groups (i.e., Group E, a strong central peak in the Hα emission and no Hα emission in the bar; Group G, Hα emission in the bar; Group EG, a transition between the E and G groups; and Group F, less gas, a smoother morphology, and no central emission spot in Hα) and argued that the evolutionary sequence is \( G \rightarrow EG \rightarrow E \rightarrow F \). In their studies, NGC 7479 is classified as Group G. Similar results were also found by Martin & Friedli (1997); NGC 7479 is in the middle transitional type according to their three stages of evolutionary sequence.

Thus, as found by the above authors, NGC 7479 is in a temporal transitional phase. Due to the effects of its stellar bar, most of the molecular gas will be concentrated in the inner kiloparsec of the galactic center, a starburst can be triggered in the circumnuclear region when most of the gas exceeds a critical density, and pseudobulges are expected to be built in the inner kiloparsec. Later, NGC 7479 may become a galaxy with an earlier Hubble type. However, the increase in IR luminosity may also cause it to become a luminous infrared galaxy (LIRG); this may explain why some LIRGs are isolated barred galaxies but not interacting systems (e.g., Wang et al. 2006).

4.2. Minor Merger Event in NGC 7479

A minor merger event is a common phenomenon in the universe. According to statistics, each field spiral galaxy has more than one companion on average (Zaritsky et al. 1997). Thus, the interactions between galaxies and their companions are believed to be very common (Ostriker & Tremaine 1975). Several properties of NGC 7479 indicate the presence of a recent minor merger. First of all, as we mentioned in Section 4.1, star formation activity in the bar and bulge of this galaxy is stronger than in most common barred galaxies. The systems in minor mergers have higher SFRs than those found in normal H I regions of spiral galaxies (Ferreiro et al. 2008). Minor mergers also likely play a role in enhancing the IR luminosity for some low-luminosity galaxies (Kartaltepe et al. 2010). These features are likely caused by a large amount of gas that was driven into the host galactic disks when they swallowed gas-rich satellites, and the gas may also be transported into the galactic inner regions due to bars.

Second, in numerical simulations, the vertical impact of small companions can cause asymmetries in gas-rich barred galaxies (Berentzen et al. 2003). Walker et al. (1996) found that a minor merger can form significant disk asymmetry that is visible for at least 1 Gyr. Similarly, the simulations of Bournaud et al. (2005) indicate that in some conditions minor mergers can create a strong asymmetry when the galaxy appears to be “isolated,” once the most obvious merger-related features have disappeared. Through comparing the distribution of different compositions in Figure 1, we found that star formation regions of NGC 7479 are largely concentrated in the strong arm, and PAH emission is mostly distributed along the stellar bar and the strong spiral arm. Probably because of this, the asymmetry of NGC 7479 is much higher in the UV, mid-IR, and Hα bands \( (A \sim 0.3) \) than in the optical and near-IR bands.

Third, minor mergers are probably related to the triggering of stellar bars (Shumakova & Berczik 2005; Romano-Díaz et al. 2008). Since active star formation exists in the bar of NGC 7479, the intense gas concentration and young stars in the stellar bar are probably driven to some degree by a minor merger event besides by the stellar bar. The large percentage of burst population in the bar of NGC 7479 (Table 3) is evidently formed in the recent 100 Myr. Furthermore, as argued by Martin et al. (2000) there is strong evidence that the present morphology of NGC 7479 was acquired following a merging event with a small galaxy about 300 Myr ago. In addition, the radio continuum jet in NGC 7479 found by Laine & Beck (2008) is another signal of recent perturbation by a minor merger in this galaxy, and is similar to the cause of jets in NGC 1097 (Higdon & Wallin 2003). Through a comparison between the simulation model of a minor merger and observations, Laine & Heller (1999) suggested that NGC 7479 is the result of a minor merger that is still ongoing, and the remnant of the satellite galaxy is likely located within the bar. Besides a minor merger, there are likely other processes that contributed large amounts of gas in the evolution of NGC 7479 such as galaxy tidal encounters (Li et al. 2008) and external gas accretion (Bournaud & Combes 2002), which can also result in material infalling. In the simulation of Sellwood & Moore (1999), a tidal encounter or the accreted low angular momentum material could also strengthen the bar.

Although the morphological properties of NGC 7479 are consistent with characteristics of a minor merger, no companions have been found in the field of this galaxy (Laine & Gottesman 1998; Saraiva & Benedict 2003). To explore whether any remnant of merging companions still exists, we compared 0.2–12.0 keV X-ray images from the XMM-Newton telescope with high-resolution images from Hubble Space Telescope (HST) Proposal 6266 with the WFPC2 and the F814W filter. Since ultraluminous compact X-ray sources are probably dwarf companion galaxy nuclei (Makishima et al. 2000; Wu et al. 2002) and merger remnants, if they still exist, are also likely located in compact optical sources, we try to find possible candidates from these sources.

In Figure 9 we marked 10 candidates, among which there are four strong X-ray emission peaks (labeled as X1–X4) detected in the X-ray image and five intensive optical regions (labeled as O1–O5) in the HST image. The last one is a potential target pointed by Laine & Heller (1999) and marked with an L. Besides those 10 candidates, the nucleus of the host galaxy (marked as C) can also be clearly detected in XMM images. Target X4 is the nearest (~1 kpc) X-ray emission peak to the galactic nucleus C, and it lies in the most obscured region, which may be the reason it cannot be identified in optical wavelengths or distinguished from the nucleus. Therefore, we could not conduct further investigations for this source. Target X1 located in the north end of the bar has the most X-ray emission flux in the five peaks (assuming they are at the same distance), but it may
Figure 9. Potential remains of a minor merger. Ten potential positions are marked with green circles; four candidates (X1–X4) are identified with images from the XMM-Newton telescope, and five candidates (H1–H4) are identified using high-resolution images from HST. The target L is estimated by Laine & Heller (1999). C (red circle) is the host galactic nucleus, which also has strong X-ray emission and can be detected by XMM-Newton. The left panel is the image from the Xinglong 2.16 m telescope in the R band and the radii of the circles are 3′′. The right panel lists the zoomed images from HST with WFPC2 and the F814W filter and the radii of the circles are 2′′.

(A color version of this figure is available in the online journal.)

Table 4

| Name Label | R.A. (J2000.0) | Decl. (J2000.0) | $L_X$ (erg s$^{-1}$) | $\sum$ SFR (M$_\odot$ yr$^{-1}$ kpc$^{-2}$) | log$_{10}$ $F(24\mu m)/F(8\mu m)$ |
|------------|---------------|----------------|----------------|---------------------------------|---------------------------------|
| X1         | 23:04:57.62   | +12:20:28.70   | 5.35E+040        | 0.02                            | −0.12                           |
| X2         | 23:04:51.54   | +12:18:26.40   | 1.52E+040        | 0.23                            | −0.12                           |
| X3         | 23:04:52.10   | +12:19:42.40   | 5.69E+039        | 0.05                            | −0.09                           |
| X4         | 23:04:56.82   | +12:19:28.80   | 1.83E+040        | ...                             | ...                             |
| H1         | 23:04:54.49   | +12:18:21.32   | ...              | 0.36                            | −0.08                           |
| H2         | 23:04:51.84   | +12:19:36.43   | ...              | 0.51                            | −0.04                           |
| H3         | 23:04:52.67   | +12:19:49.45   | ...              | 0.33                            | 0.11                            |
| H4         | 23:04:53.00   | +12:19:59.15   | ...              | 0.04                            | 0.04                            |
| H5         | 23:04:56.66   | +12:19:41.13   | ...              | 0.03                            | −0.09                           |
| L          | 23:04:56.66   | +12:19:41.13   | ...              | 0.31                            | 0.31                            |
| C$^b$      | 23:04:56.69   | +12:19:21.80   | 2.95E+040        | 0.89                            | −0.77                           |

Notes.

$^a$ Including the emission from 0.2 keV to 12 keV.

$^b$ The nucleus of NGC 7479; it is not a remnant, but is listed here just for comparison with the potential remnants.

be the foreground star 2MASS J23045696+1220390 if we consider the pointing (the mean error of 8′′) and resolution errors (spatial resolution 6′′ FWHM) of XMM-Newton. Targets X2 and X3 are both located in the western strong spiral arm. X2 can be obviously detected from the high-resolution optical image from HST. In position X3, there is an optical counterpart with very weak emission, which is only ∼6′′ from the compact source H4 and also not far from two faint sources, H3 and H5. H1 and H2 are located on the strong arm and near the stellar bar, and H2 cannot be resolved even in HST images. The potential target L lies to the north of the galactic nucleus in the bar where there is little X-ray emission but a bright optical counterpart. Detailed information is listed in Table 4 (the coordinates of X-ray candidates are from XMM-Newton detection, and their luminosity ($L_X$) includes emission from 0.2 keV to 12 keV).

To further investigate the properties of candidates, we determined aperture photometry with a radius of 6′′ to obtain their SEDs (Figure 10). Due to low spatial resolution, we used the sum flux of X3 and H4 to plot their SEDs. We also obtained the VSG-to-PAH ratio using $F(24\mu m)/F(8\mu m)$ and surface SFR using Equation (4) with small photometric apertures (radii of ∼2′′) (see Table 4). We found that three sources have positive ratios and four sources have surface SFRs higher than 0.3 M$_\odot$ yr$^{-1}$ kpc$^{-2}$. By comparing these plots, we found that sources L and H3 have SEDs similar to the nucleus C, and they also have higher VSG-to-PAH ratios, which indicates they are more likely in the criteria region of AGNs (Wu et al. 2007). Thus, considering these two aspects, we suggest that sources L and H3 are more likely remnants of a minor merger event.

5. SUMMARY

In this paper, we present a multi-wavelength study of properties of the isolated barred galaxy NGC 7479 with ground-based optical images and spectra combining GALEX UV and Spitzer IR data. Our results are as follows.

1. We took the surface photometry from the FUV to the mid-IR, and obtained the radial profile of each band, and found
that these profiles show different behaviors in different wavelengths. Based on the R-band image, we found that the stellar bar in NGC 7479 is 8.3 kpc in length and 0.733 in ellipticity.

2. Calculating the morphological asymmetry and concentration index of NGC 7479, we found that the asymmetry of this galaxy is high in the UV and mid-IR as well as the Hα narrowband, while the concentration index is much smaller in the UV and has peak values of PAH emission.

3. The properties of star formation regions in NGC 7479 were analyzed using several tracers. Intense star formation activity was found to take place on the bar and in one strong spiral arm, which also has the highest special SFR in the disk. The star formation activity on this stellar bar is comparable with that in the central region and in the ends of the bar, while the growth time of the galactic bulge at a present-day SFR is also shorter than the typical value of Gyr derived by Fisher et al. (2009).

4. With the help of the stellar synthesis code STARLIGHT, we found that strong star formation took place in the bar about 100 Myr ago, and the stellar bar may be ~10 Gyr old as old stars contribute to a large fraction in mass.

5. By comparing our results with those from previous studies, we suggest that NGC 7479 is in a temporal and transitional phase of secular evolution. Due to the effects of its galactic bar, NGC 7479 may become an earlier-type galaxy or an LIRG.

6. The properties of active star formation and distinctive morphology in NGC 7479 also indicate that a minor merger event likely happened recently. If so, we measured 10 possible remnants of merger companions, among which two candidates have been found.

In order to understand the roles of large-scale bars and minor mergers in galaxy secular evolution, studies based on large samples are necessary. We plan to conduct further research using our galaxy sample in a subsequent series of papers.

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