Asymmetric Star Formation Triggered by Gas Inflow in a Barred Lenticular Galaxy PGC 34107

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Abstract

Comparing the inactive and gas-poor normal lenticular galaxies (S0s) in the local universe, we study a barred star-forming S0 galaxy, PGC 34107, which has been observed by the Centro Astronómico Hispano Alemán 3.5 m telescope and the Northern Extended Millimeter Array. The spatially resolved ionized gas and molecular gas traced by CO(1–0), hereafter CO(1–0), and CO(0–0), show similar distribution and kinematics to the stellar component with an off-center star-forming region, ∼380 pc away from the center. The resolved kinematics of molecular CO(1–0) emission reveals that there is a blueshifted (redshifted) velocity component on the receding (approaching) side of the galaxy along the stellar bar. This might provide plausible evidence of noncircular motion, such as the bar-induced molecular gas inflow. The velocity of the molecular gas inflow decreases when approaching toward the peak of the off-center star formation in the north, which might be associated with the inner Lindblad resonance. In addition to CO(1–0), we also detect the isotopic line of 13CO(1–0). For most Hα, CO(1–0) and 13CO(1–0) emissions are concentrated on this northern star-forming region. We find that PGC 34107 follows the local stellar mass–metallicity relation, star-forming main sequence, and the Kennicutt–Schmidt law. The resolved and integrated molecular gas main sequence suggests that there is a higher gas fraction in the central region of the galaxy, which supports a scenario that the bar-induced gas reservoir provides the raw material, and subsequently triggers the central star formation.

Unified Astronomy Thesaurus concepts: Galaxies (573); Elliptical galaxies (456); Active galaxies (17); Galaxy evolution (594); Galaxy formation (595)

1. Introduction

Lenticular galaxies (S0s) are traditionally considered to be at an intermediate position between elliptical and spiral galaxies (Hubble 1936). S0s not only display the disk-like structure seen in spirals, but also contain a red bulge with old stellar populations typically found in ellipticals. Thus, normal S0s, as a class of early-type galaxies (ETGs), are usually gas-poor and inactive (e.g., Bregman et al. 1992; Caldwell et al. 1993; Blanton & Moustakas 2009). PGC 34107 shows an early-type morphology, and active star formation in its center (e.g., Contini et al. 1998; Xiao et al. 2016; Zhou et al. 2020). Based on the Canada–France–Hawaii Telescope r-band image, Zhou et al. (2020) analyzed the structure of PGC 34107 from the 1D profile and 2D multicomponent decomposition, and found that PGC 34107 is a barred S0 galaxy with a disk-like pseudo-bulge (Sérsic index n = 1.29), which is consistent with other star-forming S0s, as found by Xiao et al. (2016) and Mishra et al. (2017). At the meantime, Alatalo et al. (2013) detected a limited amount of molecular gas in PGC 34107. Therefore, PGC 34107 is a special and promising candidate of S0s with signs of star formation and cool gas. However, we cannot completely rule it out as a possibly misclassified normal spiral galaxy.

A commonly accepted scenario of the formation of S0s is that they are the end product of the evolution of spiral galaxies stripped of gas (Spitzer & Baade 1951; Dressler 1980; D’Onofrio et al. 2015). The increasing fraction of S0s with decreasing redshift (e.g., Postman et al. 2005; Desai et al. 2007) and the observation of gas stripping of spirals (e.g., Vollmer et al. 2009; Sivanandam et al. 2010) can support the transformation of S0s from spiral galaxies. In S0s, their globular cluster specific frequency (e.g., Barr et al. 2007), mass–metallicity trends (e.g., Prochaska Chamberlain et al. 2011), and stellar kinematics inferred from planetary nebulae (e.g., Cortesi et al. 2011) are consistent with those observed and derived in spiral galaxies, which is also in favor of the transformation from spiral galaxies. During the transformation, the environment may play an essential role of stripping out gas from spiral arms (e.g., Dressler 1980; Postman & Geller 1984). In comparison to the field galaxies, the higher frequency of normal S0s in groups/clusters hints that S0s prefer to form in dense environment by interactions, such as galactic winds (e.g., Ho et al. 2014), ram pressure stripping (Gunn et al. 1972), strong tidal interactions and mergers (e.g., Barnes & Hernquist 1992; Mazzei et al. 2014a, 2014b), and galaxy harassment (e.g., Moore et al. 1996). Based on the Mapping Nearby Galaxies at APO Data Release 15 (MaNGA-DR15) survey, Fraser-McKelvie et al. (2018) and Domínguez Sánchez et al. (2020) supplemented that S0s with different masses...
may be formed through different physical processes. They proposed that the spiral-to-S0 fading scenario likely formed less massive (<10^9 M_\odot) S0s by the bulge rejuvenation (Fraser-McKelvie et al. 2018) or in situ star formation (Domínguez Sánchez et al. 2020), while massive (>10^9 M_\odot) S0s transformed via morphological/inside-out quenching (Fraser-McKelvie et al. 2018) or gas-rich mergers (Domínguez Sánchez et al. 2020).

However, there are arguments against the spiral-to-S0 fading scenario. If S0s are stripped spirals whose star formation has been quenched, we expect the bulges of S0s to be connected to those of spirals. Gao et al. (2018) performed multicomponent decomposition of S0s by using high-quality optical images from the Carnegie-Irvine Galaxy Survey and found that the bulges of late-type spirals and S0s were intrinsically different, which implied that spirals were not the plausible progenitors of S0s. Similarly, Burstein et al. (2005) pointed out that if S0s were gas-stripped spiral galaxies, the absolute K magnitudes of S0s would be expected to be ~0.75 mag less luminous than early-type spirals in models, but they did not find this difference. Meanwhile, Sil'chenko et al. (2012) found the higher metallicity in the outer disks of nearby S0s, and Holden et al. (2009) suggested that there is no evolution in the overall distribution of bulge-to-disk ratios for cluster ETGs from z ~ 0 to z ~ 1. All results suggest that there may exist other physical processes that can form S0s (e.g., Kormendy & Kennicutt 2004; Barway et al. 2009; van den Bergh 2009).

Although S0s are often thought to be inactive, the nuclear star formation in S0s has been found by some studies (Kaviraj et al. 2007; Schawinski et al. 2007; Xiao et al. 2016; Fraser-McKelvie et al. 2018). Welch & Sage (2003) and Welch et al. (2010) detected the cool neutral and/or molecular gas in more than 50% of normal S0s. If this reservoir of gas accreted from the environment (Dressler et al. 2013; Sil'chenko et al. 2019) provides the raw material, then galaxy interactions or gas-rich mergers can trigger the star formation of S0s (Thilker et al. 2010; Davis et al. 2015; Xiao et al. 2016; Ge et al. 2020). With the expansion of the universe and the virialization of galaxy clusters, major mergers become less common and the internal secular processes gradually become dominant with the cosmic time (Kormendy & Kennicutt 2004). The relevant secular processes can generally shape many distinct substructures of S0s in low-density environments, such as bars, ovals, and lenses (e.g., Laurikainen et al. 2005, 2009). Bars have been proven to trigger the secular evolution of disk galaxies by theory and numerical simulations (Athanassoula 1992; Sellwood & Wilkinson 1993; Piner et al. 1995; Knapen et al. 2000; Athanassoula 2003). More spatially resolved observations of the cool molecular gas can help reveal the kinematics of the gaseous bar and infer the formation of S0s.

In this work, PGC 34107 is a nearby (z = 0.00471) barred S0 galaxy at a distance of ~20.2 Mpc, which corresponds to 1″~97 pc. PGC 34107 is one of the star-forming S0 galaxies (SFS0s) from Xiao et al. (2016). Based on the cross-matching between the two catalogs Sloan Digital Sky Survey Data Release 7 (SDSS DR7) and the Third Reference Catalog of Bright Galaxies (RC3), Xiao et al. (2016) found that SFS0s with lower Sérsic indices and stellar masses mainly live in a sparse environment. What kind of secular processes triggers the nuclear star formation of S0s in the sparse environment, resulting in the difference between SFS0s and normal S0s? Unlike SFS0s triggered by a gas-rich minor merger such as PGC 26218 and PGC 38025, which have been studied by Ge et al. (2020) and Chen et al. (2021), respectively, our target PGC 34107 has a stellar bar and two bright regions, which are also called double nuclei by Zhou et al. (2020), where they presented long-slit spectroscopy along the major axis, and concluded that the double nuclei may be formed and evolved by secular processes driven by the stellar bar or the external accretion of gas. Here we present the spatially resolved optical observation with the Centro Astronómico Hispano Alemán (CAHA) 3.5 m telescope and millimeter observation with the NOttene Extended Millimeter Array (NOEMA), respectively, which can help reveal the kinematics of the stellar component, as well as ionized and molecular gas. Compared to previous works, what is important is that tentative signs of inflow along the bar traced by the molecular gas are found due to the high quality of the NOEMA data, which provides possible evidence of the star formation induced by the stellar bar in PGC 34107. Table 1 summarizes the global parameters derived from different works. Figure 1 shows the Sloan Digital Sky Survey (SDSS) gri image of PGC 34107. The optical center of PGC 34107 is marked with a black cross. There are two obvious bright regions, i.e., the northern blue and southern red regions, seen near its center, while the bright point in the northwest is a foreground star.
This paper is laid out as follows. Sections 2 and 3 show the observations and simple data analyses of the optical integral field unit (IFU) and millimeter data, respectively. In Section 4, we present the discovery of gas inflow, gas distributions (i.e., H$_\alpha$, $^{12}$CO(1–0) and $^{13}$CO(1–0)), the global mass–metallicity relation (MZR) and star-forming main sequence (SFMS), and the Kennicutt–Schmidt (K–S) law and molecular gas main sequence (MGMS) by combining the 2D spectroscopic observation with the millimeter observations, respectively. In Section 5, we present our summary. Throughout this paper, we assume a flat $\Lambda$CDM cosmology with $\Omega_M = 0.3$, $\Omega_\Lambda = 0.7$, and $H_0 = 70 \text{ km s}^{-1} \text{ Mpc}^{-1}$ and a Salpeter (1955) initial mass function (IMF).

2. CAHA Optical Data

2.1. CAHA 2D Spectroscopic Observation

We started a program to obtain integral field spectroscopy (IFS) data of SFSOs in Xiao et al. (2016), with the Potsdam Multi Aperture Spectrograph (PMAS)/PPak configuration mounted on the CAHA 3.5 m telescope in the Calar Alto observatory. The observations were performed during 2016 March and 2017 April. The optical IFU spectroscopic observation of PGC 34107 was carried out on 2017 March 31 with the low-resolution (V500) setup, covering a hexagonal field of view (FoV) of $78'' \times 73''$, and a wavelength of 3745–7500 Å at a spectral resolution of 6 Å ($R \sim 850$). After examining the internal vignetting effect of the blue and red parts of spectra from fibers around the FoV center, a wavelength range from 4240 to 7140 Å is adopted in this work (Husemann et al. 2013). In order to reach a filling factor of 100% across the entire FoV, a three-pointing dithering scheme has been taken, thus the final 3D datacube is composed of 4221 spectra at a sampling of $1'' \times 1''$ per spaxel. The exposure time per pointing is 900 s. The atmospheric seeing is about 2'', but it is not a limiting factor of spatial resolution because the final spatial resolution of the Calar Alto Legacy Integral Field Area Survey (CALIFA) data is set by fiber size and the dither scheme together with the adopted image reconstruction algorithm (García-Benito et al. 2015).

We used an upgraded python-based pipeline (García-Benito et al. 2015; Sánchez et al. 2016) to reduce the PPak IFU data. The data were reduced though a series of processes, including (1) the removal of electronic signatures and realignment of the frames; (2) spectral extraction, wavelength calibration, and fiber transmission correction; (3) sky subtraction; (4) flux calibration; (5) spatial rearranging and image reconstruction; (6) differential atmospheric refraction; and (7) absolute flux recalibration. More detailed data reduction processes are described in Sánchez et al. (2012), Husemann et al. (2013), García-Benito et al. (2015), and Sánchez et al. (2016). Finally, the reprocessed spectral data are stored in a 3D datacube. In the ATLAS3D project, PGC 34107 had been observed for 2 hours by Spectroscopic Areal Unit for Research on Optical Nebulae (SAURON) IFU mounted on the William Herschel Telescope on La Palma (Cappellari et al. 2011), which had an FoV of $34 \times 41$ arcsec$^2$, a spectral resolution of 4.2 Å, and a wavelength range of 4800–5380 Å. Compared to the SAURON observation, although our exposure time and spectral resolution were shorter and lower, we have a longer wavelength range, including the H$_\alpha$, [N II]λ6548, 6583 and [S II]λ6717, 6731, which are important emission lines to understand the photoionization.

As shown in Figure 1, there are two bright regions in the central region of PGC 34107. For each bright region (north or south), we can compare a spectrum derived from the central spaxels with a spectrum derived from the periphery. If the bright region is a nucleus experiencing a mass concentration, the contribution from stellar continuum could be detected in the residual spectrum obtained by subtracting the outer bright region spectrum from the inner bright region. Conversely, if only the emission lines are left, it suggests that this bright region is only from recent star formation events rather than nuclei. Therefore, we first stack the spectra of nine spaxels in the northern and southern brightness peaks shown in Figure 1, and take their average spectra to be the local spectrum. Next, we stack 12 spectra around the northern/southern brightness peaks, and take the average to represent the surrounding spectrum. After subtracting the surrounding spectrum from the local spectrum, the residual spectra in the north (blue) and south (red) are shown in Figure 2. Both spectra have been normalized to the $\sim 5100$ Å flux of the central spaxel of PGC 34107, and the position of the central spaxel is shown as a black cross in Figure 1. As shown in Figure 2, the stellar continua are almost subtracted and only emission lines are left, which imply that both blue and red bright regions in PGC 34107 tend to be the star-forming regions rather than mass concentrations or nuclei.

2.2. Full Spectral Fitting

For each spectrum in the datacube of PGC 34107 we adopted a public code, the penalized pixel-fitting (pPXF), to decompose stellar and emission-line components via full spectral fitting (Cappellari & Emsellem 2004; Cappellari 2017). Following Ge et al. (2020), for each spaxel we adopt the average flux and the standard deviation of the flux covering a wavelength range of 5075–5125 Å as the signal and noise as
The residual spectrum in blue (red) between the average stacked spectrum of 9 spaxels in the north (south) and the average stacked spectrum of 12 spaxels around those 9 spaxels. The corresponding positions of the nine northern (southern) spaxels are shown with the blue (red) dots from the Figure 1. The spectra are normalized to \( \sim 5100 \) Å flux of the central spaxel of PGC 34107, and the signal-to-noise ratio (S/N) of each spaxel spectrum is larger than 10. The upper panel (A) presents the full spectra, while the zoom-in spectra in the H\( \beta \) and H\( \alpha \) ranges are shown in bottom panels (B) and (C), respectively. There are only emission lines left in the residual spectra, which implies that they are two star-forming regions, and not star-forming nuclei.

Figure 2. The residual spectrum in blue (red) between the average stacked spectrum of 9 spaxels in the north (south) and the average stacked spectrum of 12 spaxels around those 9 spaxels. The corresponding positions of the nine northern (southern) spaxels are shown with the blue (red) dots from the Figure 1. The spectra are normalized to \( \sim 5100 \) Å flux of the central spaxel of PGC 34107, and the signal-to-noise ratio (S/N) of each spaxel spectrum is larger than 10. The upper panel (A) presents the full spectra, while the zoom-in spectra in the H\( \beta \) and H\( \alpha \) ranges are shown in bottom panels (B) and (C), respectively. There are only emission lines left in the residual spectra, which implies that they are two star-forming regions, and not star-forming nuclei.

well, because such a range can avoid contamination of emission and absorption lines. The signal-to-noise (S/N) ratio of the most spaxels of PGC 34107 within the effective radius (<Re) is more than 10, which is high enough so that no more information can be provided using the Voronoi binning method (Cappellari & Copin 2003). So in this work, a spectral fitting of each spaxel with S/N >10 is performed separately, without Voronoi binning.

With emission lines being masked out, the stellar component in the rest-frame spectrum is fitted with simple stellar population (SSP) templates of Medium resolution INT Library of Empirical Spectra (MILES; Sánchez-Blázquez et al. 2006; Vazdekis et al. 2010), assuming a Salpeter (1955) IMF and a Calzetti et al. (2000) dust extinction law. The SSP templates evenly distribute on the age–metallicity grid, with 25 ages ranging from 0.06 Gyr to 15.85 Gyr and 6 different metallicities (log \( Z/Z_\odot \) = −1.71, −1.31, −0.71, −0.4, 0.0, 0.22). Figure 3 shows the distributions of the physical properties of a stellar population derived by fitting, including the stellar velocity (panel (A)), the stellar velocity dispersion (panel (B)), the surface mass density (panel (C)), the light-weighted age (panel (D)), and the light-weighted metallicity (panel (E)). The stellar velocity map (panel (A)) shows a characteristic rotating disk–shape structure, and the rotation of the galaxy should be counterclockwise on the sky in order for the spiral arms to be trailing. The average stellar velocity dispersion shown in panel (B) is about \( \sim 97 \) km s\(^{-1}\). Panel (C) shows a higher stellar mass surface density along the bar than on the outskirt of galaxy. The position and length of the bar is indicated by a black dashed ellipse in panel (C), which is derived by performing a 2D multicomponent decomposition of an r-band SDSS image with GALFIT (Peng et al. 2002, 2010).

Following Zhou et al. (2020), we adopt three Sérsic models for the bar, bulge, and disk of PGC 34107, respectively. The position angle (PA\(_{\text{bar}}\), in degrees east of north) and radius (\( R_{\text{bar}} \)) of bar are −15°97 ± 0°03 and 8°4 ± 0°03, respectively, which are consistent with results (PA\(_{\text{bar}}\) = −17°58 and \( R_{\text{bar}} = 10°22 \)) of Zhou et al. (2020). The total stellar mass is estimated to be about \( 4.0 \times 10^9M_\odot \), which is summarized in Table 1. It is \( \sim 0.27 \) dex lower than that from the Max Planck for Astrophysics and Johns Hopkins University (MPA–JHU) DR7 catalog, but \( \sim 0.47 \) dex higher than that from Zhou et al. (2018), which is derived by using Wide-field Infrared Survey Explorer (WISE) 3.4 \( \mu \)m luminosity. Note that stellar masses in the MPA–JHU DR7 catalog are based on the Kroupa (2001) IMF, while we adopt the Salpeter (1955) IMF in this work. The stellar mass listed in Table 1 has been converted to the Salpeter (1955) IMF. Maps of the light-weighted age and
metallicity are shown in panels (D) and (E), respectively. The distribution of metallicity is relatively uniform, while the central distribution of age is younger than that in the outskirts, which suggests that there is active star formation in the central region of the galaxy. Note that when fewer available spaxels with the wavelength range from 3750 to 7500 Å are used to fit the pPXF, the light-weighted age near the center is still younger than the outer region of the galaxy.

For the emission lines, we subtract the best-fit synthesized stellar continuum from the observed spectrum to get the pure emission-line spectrum. Subsequently, each emission line is fitted with one single Gaussian profile with the IDL package MPFIT (Markwardt 2009). Following Xia et al. (2016), the Hβ and [O III]λλ4959, 5007 lines are fitted simultaneously, while Hα and [N II]λλ6548, 6583 are fitted together. The S/N for each emission line is then estimated using the method introduced by Ly et al. (2014), where the flux is determined by

$$\text{Flux} = \sum_{-2.5\sigma_{G}}^{+2.5\sigma_{G}} [f(\lambda - l_c) - \langle f \rangle] \times l',$$  

and the noise is estimated by

$$\text{Noise} = \sigma(f) \times l' \times \sqrt{N_{\text{pixel}}},$$

where the median $\langle f \rangle$ and standard deviation $\sigma(f)$ of the flux densities are estimated within a 200Å-wide region, avoiding the effect of sky lines and emission lines. $\sigma_G$ represents the width of the Gaussian profile, $l_c$ represents the emission-line center, $l'$ is the spectral dispersion ($l' = 1$ Å spaxel$^{-1}$), and $N_{\text{pixel}}$ equals $5 \times \sigma_G/l'$. After checking each spectrum, we find that spaxels closer to the northern star-forming region have stronger emission lines of ionized gas, including Hα, Hβ, [N II]λλ6548,

Figure 3. Distributions of the physical parameters color coded by panel (A) the stellar velocity, panel (B) the stellar velocity dispersion, panel (C) the surface mass density ($M_\odot$·pc$^{-2}$), panel (D) the light-weighted age (LWage), panel (E) the light-weighted metallicity (LWZ), panel (F) the corrected Hα flux, panel (G) the Hα velocity, and panel (H) the Hα velocity dispersion, respectively. The zoomed-in map of panel (F) is shown in panel (I) for a better view. The black dashed ellipse in panel (C) represents the position and length of the stellar bar, which is obtained by performing a 2D multicomponent decomposition of r-band SDSS image with GALFIT (Peng et al. 2002, 2010). The white circle in the northwest is corresponding to the position of the foreground star. The S/Ns of emission lines, including Hα and Hβ, are imposed to be larger than 5 (panels (G) and (H): S/N_{Hα} > 5, panels (F) and (I): S/N_{Hα,Hβ} > 5). The map center, marked with a black cross, is set at 168.166 (R.A.), +09.056 (decl.).
Panels (G) and (H) of Figure 3 show the distributions of the H\textalpha
diversity and H\textalpha
dynamics, respectively. The rotation of the ionized gas is consistent with that of the stellar component. The average velocity dispersion of the ionized gas in the central region is $\sim 140 \text{ km s}^{-1}$. Considering the nebular extinction, H\textalpha
diversity is corrected by assuming the “case B” recombination model, (i.e., $H\beta/H\alpha = 2.86, T = 10^4 \text{K}$, and $n_e = 10^5 \text{cm}^{-3}$) and the Calzetti et al. (2000) extinction law, which means that the corrected H\textalpha
diversity should satisfy S/N$_H\alpha > 5$ and S/N$_{H\beta} > 5$ simultaneously. The distribution of the corrected H\textalpha
diversity is shown in panel (F) of Figure 3. For a better view, we present a zoomed-in image in panel (I). Due to the weak H\beta
edition near the southern star-forming region, a few spaxels (S/N$_{H\alpha, H\beta} > 5$) in the south are left and most of the corrected H\textalpha
diversity concentrates on the northern, blue star-forming region. Based on the extinction-corrected H\textalpha
diversity, the extinction-corrected star formation rate (SFR) can be derived using the formula given by Kennicutt (1998a):

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

where $L(\text{H}\alpha)$ is the extinction-corrected H\textalpha
diversity luminosity. Within the H\textalpha
diversity region of panel (I), the estimated SFR is about 0.27 $\pm$ 0.05 $M_\odot \text{ yr}^{-1}$. After totaling the spectra of all available 1792 spaxels in PGC 34107, the total SFR listed in Table 1 is estimated about 0.33 $\pm$ 0.01 $M_\odot \text{ yr}^{-1}$, which is between the results from the MPA–JHU DR7 catalog and Zhou et al. (2018). Their SFRs shown in Table 1 have been converted to the Salpeter (1955) IMF. Most of the SFR is mainly contributed by the northern star-forming region. We adopt the axial ratio of the inner disk ($q = 0.84$) from Zhou et al. (2020) to derive the inclination angle by

$$\cos^2 i = \frac{q_0^2 - q^2}{1 - q_0^2},$$

where $q_0 = 0.25$ for classical S0 galaxies (Sandage et al. 1970). The derived inclination is estimated to be $i = 34^\circ$. Thus, within the H\textalpha
diversity region of panel (I), the inclination-corrected surface density of SFR is about $0.31 \pm 0.06 M_\odot \text{ yr}^{-1} \text{ kpc}^2$, which is listed in Table 1. Overall, the IFU 2D spectroscopic data clearly reveals that the star formation occurs near the central region of the galaxy, and is mainly concentrated in the northern region, which is $\sim 380 \text{ pc}$ away from the galactic center.

3. NOEMA Millimeter Data

3.1. NOEMA Millimeter Observation

PGC 34107 was observed twice in the $^{12}$CO(1–0) transition, hereafter CO(1–0), with NOEMA on 2019 December 15 and 2020 January 3, respectively (project W19BJ; PI: Xue Ge). The observations were carried out with 10 antennas in the C configuration with a 6.0 hour total on-source time. In the first 3 hour observation on 2019 December 15, 1055+018 was used as the receiver bandpass (RF) and the phase/amplitude calibrators simultaneously, while 1038+064 was used as the absolute flux calibrator. In the second 3 hour observation on 2020 January 3, 1055+018 was used as the phase/amplitude calibrators, while the RF and the absolute flux calibrators of 3C273 were used instead. The antennas are equipped with dual polarizations for the 3 millimeter atmospheric window (93.4–116.0 GHz). Each polarization covers a bandwidth of $\sim 7.8 \text{ GHz}$ at a spectral resolution of 2 MHz.

The calibrations of CO(1–0) were performed using Continuum and Line Interferometer Calibration (CLIC), including the RF, phase, and amplitude calibrations. Cleaning and imaging of the data were done using MAPPING. Both CLIC and MAPPING are modules of the available GILDAS software package. The redshifted CO(1–0) frequency is 114.731 GHz, given its redshift of $z = 0.00471$ ($v_{\text{sys}} = 115.271 \text{ GHz}$). After subtracting the continuum in the $uv$ plane, we image a CO(1–0) datacube, which covers a velocity range of -480–500 km s$^{-1}$ at a velocity resolution of 20 km s$^{-1}$. The synthesized beam size is $2.96 \times 1.50$ with a position angle of 13°70. The final datacube consists of 512 $\times$ 512 pixels for a map cell of 0″29 $\times$ 0″29, covering a FoV of 43″9 $\times$ 43″9. The ATLAS3D project, the Combined Array for Research in Millimeter Astronomy (CARMA) CO imaging survey of ETGs (Alatalo et al. 2013) also included PGC 34107, which was observed in 3.75 hours with a CO-synthesized description beam of 3″8 $\times$ 3″3 and pixels of 1″ $\times$ 1″. Compared to the CARMA CO observation, our NOEMA observation has a longer exposure time and smaller beam size, which is helpful to find the gas inflow along the stellar bar (see Section 4.1).

Besides CO(1–0), we also find a strong isotopic line of $^{13}$CO(1–0) in the upper inner baseband, which was detected by Crocker et al. (2012) using IRAM 30 m telescope at Pico Veleta, Spain. We use CLIC and MAPPING to clean and image the $^{13}$CO(1–0) datacube. The redshifted (rest) $^{13}$CO(1–0) frequency is 109.685 (110.201) GHz. The synthesized beam size is 3″07 $\times$ 1″36 with a position angle of 13°47. The final $^{13}$CO(1–0) datacube is made up of 512 $\times$ 512 pixels for a map cell of 0″31 $\times$ 0″31, covering a FoV of 45″9 $\times$ 45″9. The integrated NOEMA fluxes are in the units of Jy km s$^{-1}$, including the CO(1–0) and $^{13}$CO(1–0).

3.2. CO(1–0) Distribution

We use a threshold of 17.40 mJy ($\sim 5\sigma_{\text{rms}}$) to output moment maps of the CO(1–0) emission. Figure 4 shows the moment maps of CO(1–0) emission, including the integrated intensity (panel A), velocity (panel B), and velocity dispersion (panel C), respectively. Most of the CO emission is concentrated in the central region, but its flux peak is off-center and closer to the northern star-forming region, similar to H\textalpha
diversity emission. We measure the position angles of CO(1–0) and stellar velocity fields using the IDL package KINEMETRY (Krajnovi\v{c} et al. 2006), where the kinematic position angle is defined as the clockwise angle between north and a line with the velocity field of gas or stars on the redshifted side. The position angle of the molecular gas CO(1–0) and stars with a 3σ error is $\text{PA}_{\text{gas}} = 12°9 \pm 38°6$ and $\text{PA}_{\text{star}} = 12°9 \pm 6°4$, respectively. There is no kinematic misalignment between the molecular gas and stars, which is consistent with that of Davis et al. (2011). The misalignment between the molecular gas and stellar bar ($\text{PA}_{\text{bar}} = -15°97 \pm 0°03$) is observed in $\Delta \text{PA} (\text{mol, bar}) = 28°87 \pm 38°6$. The molecular gas of PGC 34107 is mainly located as the...\footnote{http://www.iram.fr/IRAMFR/GILDAS}
concentrated in a small central region, which makes the derived position angle have a large error. Considering the error, the molecular gas could be aligned with the stellar bar, as shown in panel (B) of Figure 4. In panel (C), the velocity dispersion shows an increase from the outside to the inside, which may be caused by the gas turbulence near the star-forming region. Here, we have adopted the 3D BAROLO code (Di Teodoro & Fraternali 2015) to perform a 3D fitting on the CO(1–0) datacube to check the effect of beam smearing on the velocity dispersion. Figure 5 shows the channel maps of CO(1–0) with a velocity range of $-100 \text{ km s}^{-1} < v < 80 \text{ km s}^{-1}$ and a velocity interval $\Delta v = 20 \text{ km s}^{-1}$. The corresponding value of the velocity is shown in the upper right corner. The beam size is marked with a black ellipse in the bottom left corner. The intensity in all maps is scaled by the same level, as shown by the color bar.

We extract the CO emission of each pixel within the moment0 map, i.e., panel (A) of Figure 4, to construct a stacked spectrum, as shown in black histogram of Figure 6. We find that the CO(1–0) line shows an asymmetric profile, then we fit the spectrum with two Gaussian components shown by the orange solid lines. One stronger component is the primary component of the rotation of molecular gas, while the other is the residual due to the asymmetry of the distribution and the difference of the flux intensity for the extracted pixels. This secondary component might hint that the molecular gas may have weak signatures of noncircular motion, which will be discussed in Section 4.1. The best-fit line is the superposition of the two Gaussian profiles as the best-fit model.

Figure 5. Channel maps of the CO(1–0) emission with a velocity range of $-100 \text{ km s}^{-1} < v < 80 \text{ km s}^{-1}$ and a velocity interval $\Delta v = 20 \text{ km s}^{-1}$. The corresponding value of the velocity is shown in the upper right corner. The beam size is marked with a black ellipse in the bottom left corner. The intensity in all maps is scaled by the same level, as shown by the color bar.

Figure 6. Decomposition of the CO(1–0) line profile with a velocity interval of $20 \text{ km s}^{-1}$. The black line represents the original stacked spectrum within the moment0 map, and the orange lines represent the Gaussian models. The green line is the superposition of the two Gaussian profiles as the best-fit model.

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Solomon & Vanden Bout (2005),

\[ L_{\text{CO}} = 3.25 \times 10^7 S_{\text{CO}} \Delta \nu \nu_{\text{obs}}^{-2} D_L^{-2} (1 + z)^{-3}, \]

where \( S_{\text{CO}} \Delta \nu \) is the CO integrated flux density in units of Jy km s\(^{-1}\), \( \nu_{\text{obs}} \) is the observed frequency in gigahertz at a given redshift, and the luminosity distance is \( D_L = 20.2 \) Mpc. The CO luminosity is about \( (3.80 \pm 0.26) \times 10^7 \) K km s\(^{-1}\) pc\(^2\), shown in Table 1. The corresponding mass of the molecular hydrogen \( M_{\text{HI}} \) can be estimated by adopting the conversion factor \( (\alpha_{\text{CO}}) \) between CO(1–0) and H\(_2\).

\[ M_{\text{HI}} = \alpha_{\text{CO}} \times L_{\text{CO}}. \]

where \( \alpha_{\text{CO}} \) is adopted to be 4.3 \( (M_\odot \text{km s}^{-1}\text{pc}^2)^{-1} \) for the inner disk of our galaxy (Bolatto et al. 2013). The molecular hydrogen mass \( M_{\text{HI}} \) is estimated to be \( (1.66 \pm 0.50) \times 10^8 M_\odot \), within the moment0 map \( (\sim 0.63 \text{ kpc}^2) \) at \( D_L = 20.2 \) Mpc. Using the IRAM 30 m telescope, Young et al. (2011) obtained the \( M_{\text{HI}} \) of \( 1.90 \times 10^8 M_\odot \) at \( D_L = 20.2 \) Mpc, which is consistent with the result from Young et al. (2011), considering the 10% absolute flux uncertainties for NOEMA at 3mm. Covering a larger moment0 map \( (\sim 2.51 \text{ kpc}^2) \) where some pixels extend beyond the primary beam of the IRAM 30 m telescope, Alatalo et al. (2013) derived the \( M_{\text{HI}} \) of \( 2.29 \times 10^8 M_\odot \) at \( D_L = 20.2 \) Mpc. Under a similar coverage \( (2.4 \text{ kpc}^2) \), orange contours in panel (A) of Figure 4, we estimate that the \( M_{\text{HI}} \) is \( (2.51 \pm 0.77) \times 10^8 M_\odot \), which agrees with Alatalo et al. (2013). Note that here \( M_{\text{HI}} \) from a different work has been converted by adopting the same \( \alpha_{\text{CO}} \) and \( D_L \) as this work. In summary, our estimated \( M_{\text{HI}} \) is consistent with previous work. Below we adopt the estimated \( M_{\text{HI}} \) within \( \sim 0.63 \text{ kpc}^2 \) at \( D_L = 20.2 \) Mpc to discuss. The inclination-corrected surface mass density of H\(_2\) is about \( (2.19 \pm 0.65) \times 10^3 M_\odot \text{pc}^{-2} \). We calculate the star formation efficiency (SFE) by the ratio of the SFR within the H\(_2\) region in panel (I) of Figure 3 to the \( M_{\text{HI}} \) of \( (1.66 \pm 0.50) \times 10^8 M_\odot \). The SFE is about \( (1.63 \pm 0.57) \times 10^{-9} \text{ yr}^{-1} \), which is similar to that of spirals \( (1.5 \times 10^{-9} \text{ yr}^{-1} \) (Kennicutt 1998b) but higher than that of ETGs \( (4 \times 10^{-10} \text{ yr}^{-1} \) (Davis et al. 2015). Assuming a constant consumption of gas, the depletion time is about 600 Myr.

### 4. Discussion

#### 4.1. The Inflow of Molecular Gas CO(1–0)?

The high quality of NOEMA gives us a chance to identify weak signatures of noncircular motion. As shown in panel (II) of Figure 8, we separately extract three-pixel molecular spectra at equal spacing along the bar on the northern and southern sides of the galaxy, which are marked with 3N, 2N, 1N, and 1S, 2S, 3S, respectively. Here we consider that the space of pixels is symmetric along the stellar bar, and each spectrum possesses a high enough S/N (gray arrow) to obtain a reliable secondary component, simultaneously. In panels (a) through (g) of Figure 8, we show the corresponding observed CO(1–0) line profiles in the north, center, and south of the galaxy with black histograms, respectively. The asymmetry of the line profiles can be found, thus we adopt two Gaussian profiles to fit all of the observed CO profiles except the central one. The orange lines represent the primary components for the local rotation of molecular gas, while the lines in a series of blue (red) colors represent the secondary velocity components, which are corresponding to the blueshifted (redshifted) parts of the local CO line profiles. Here the centroid of the primary Gaussian component of each observed CO(1–0) spectrum has been subtracted in order to compare the blueshifted and redshifted secondary components clearly. The S/Ns of all secondary components are \( >3 \sigma_{\text{rms}} \), except the 3S spectrum \( (>2 \sigma_{\text{rms}}) \) in panel (g). The darker the color, the closer it is to the center of the galaxy. The green line is the superposition of the two Gaussian profiles. In the bottom of panel (h) in
Figure 8, all of the secondary components in blue and red are shown together.

In Figure 8, we find that three pixels in the north (i.e., 3N, 2N, and 1N) are corresponding to the receding side of the galaxy seen in panel (I2) of Figure 8, while their secondary Gaussian components are blueshifted. It is inverse in the three southern pixels. Three southern pixels in the approaching side of the galaxy exhibit redshifted secondary components, compared to their local CO line profiles, suggesting that there might be an inflow of molecular gas along the bar. The location...
of those extracted pixels is within the radius ($8''–10''$, $<1$ kpc) of the bar (Zhou et al. 2020). Panel (h) of Figure 8 clearly shows that as the pixel approaches the center of the galaxy, the velocity of the gas inflow decreases and the flux intensity increases. Previous studies of barred galaxies have found for decades that the linear bar-like gas morphology in the central regions does not last all the way into the nucleus (Ishizuki et al. 1990; Kenney et al. 1992). It indicates that the inflow may be slowed down or stopped at certain radii, such as inner Lindblad resonances (ILR; Combes 1988; Shlosman et al. 1989; Combes 2001), which are located inside the bar with a radius of a few hundred parsec as seen in CO(1–0) (Kenney et al. 1992; Schinnerer et al. 2000; Walter et al. 2002; Olsön et al. 2010). The location of our extracted pixels within $\sim 300–550$ pc is connected to the peak of the star formation ($\sim 380$ pc), and the position of the flux peak might be related to ILR, which seemingly provides a reliable explanation as to why the velocity of gas inflow decreases gradually with the decreasing distance, finally resulting in an active star formation.

Based on the observations of the CO(1–0) line made with the Berkeley–Illinois–Maryland Association (BIMA) millimeter array, Regan et al. (1999) studied the kinematics of the dense molecular gas in a set of seven barred spiral galaxies. By extracting the spectrum along the bar, they found the two velocity components near the joint of the dust lanes and nuclear ring. The one velocity component corresponds to gas on circular orbits, and the other one is attributed to the gas flowing down the bar dust lane, which is similar to what we found here. This implies that it is easier to detect gas inflows at such joint locations. For PGC 34107, we have tried to adopt 3D BAROLO software to perform a 3D tilted-ring fitting on the CO(1–0) emission-line database (Di Teodoro & Fraternali 2015), considering the variation of inclination, position angle, rotation velocity, and velocity dispersion (see the Appendix for details). The position–velocity diagrams along major and minor axis indicate the existence of a weak noncircular motion compared to the circular model. Generally, the contribution of the radial inflow motions is small (Di Teodoro & Peek 2021), while our existing velocity and spatial resolutions are not high enough to resolve the weak noncircular motion completely, and a higher resolved observation is needed in the future. Thus, here we explore the possibility that the observed velocity structure is due to radial inflow.

Assuming that the noncircular motion is due to the bar-induced gas inflow, we plot a simple schematic view about the kinematics and spectra in the stellar bar (elliptical shape) of PGC 34107, shown in Figure 9. The filled red/blue colors imply the receding/approaching rotation in the north/south. As the gas (white cloud) is closer to the ILR (dashed line), its velocity (blue/red arrows) gradually decreases. The gas gradually slows down and accumulates near the ILR, providing raw materials for star formation. Panels (a) and (b) of Figure 9 show the sketch of molecular gas along a line-of-sight (LOS) direction. The spectrum in panel (a) is corresponding to the 3N, 2N, and 1N spectra in panels (a–c) of Figure 8, while panel (b) is for the 1S, 2S, and 3S ones in panels (e–g) of Figure 8. Compared to the local circular rotation (orange lines), the blueshifted/redshifted components (blue/red lines) can be observed on the receding/approaching sides of stellar bar in PGC 34107. In Figure 8, the flux intensity for a secondary component is higher in the north than that in the south. It might explain why the star formation is concentrated at the northern side. (see the star formation region of Figure 9). The hydrodynamics simulations of barred galaxies suggested that a thin bar with an axis ratio (b/a) of $\sim 0.2$ can produce mass inflows of $0.25 M_\odot$ yr$^{-1}$ into the inner $\sim 100$ pc (Piner et al. 1995). PGC 34107 has a thin bar with an axis ratio of 0.24, derived by Zhou et al. (2020). We convert Equation (4) of the mass outflow rate from García-Burillo et al. (2014) to simply derive the mass inflow rate as

$$\frac{dM}{dt} = 3 \times V_{\text{in}} \times \frac{M_{\text{mol}}}{R_{\text{in}}} \times \tan \alpha,$$  

where $V_{\text{in}}$ and $R_{\text{in}}$ are the projected velocity and radial size of inflow, respectively. $M_{\text{mol}}$ represents the molecular gas of inflow. From panel (h) of Figure 8, the mean gas-infalling velocity is about 35 km s$^{-1}$. $M_{\text{mol}}$ is derived by summing the secondary components at these six pixels in the north and south. Assuming an angle between the inflow and the LOS of $40^\circ$, and a projected radial size of 550 pc (corresponding to the position of 3N or 3S pixel), the mass inflow rate ($dM/dt$) is about $0.11 M_\odot$ yr$^{-1}$, which is in the same order of magnitude as found in Piner et al. (1995). Note that although in a barred galaxy the noncircular motions are elliptical streaming motions induced by the bar, the actual inflow is a small fraction of the noncircular velocity and is difficult to measure directly (Di Teodoro & Peek 2021). So the assumed $V_{\text{in}}$ is overestimated and the current $dM/dt$ is the upper limit based on existing observations and assumptions.

4.2. Gas Distributions: H$\alpha$, CO(1–0), and $^{13}$CO(1–0)

Since the spatially resolved optical and millimeter maps have been obtained by CAHA and NOEMA, respectively, we can overlay CO(1–0) and $^{13}$CO(1–0) over a noncorrected H$\alpha$ mosaic map to compare their different distributions, as shown in Figure 10. The previous spatially resolved optical data did not cover the longer wavelength (Cappellari et al. 2011), so in
this work we could combine the resolved Hα with CO. It clearly shows that most ionized and molecular gas distribute at the central region, especially concentrated on the northern star-forming region, while the 13CO isotopes mainly assemble in the central region, especially concentrated on the northern star-forming region. Figure 4 and the Hα region is shown in the (dashed - solid) black polygon, same as panel (C) of Figure 3. The blue contours represent the 13CO(1–0) integrated intensity, same as in panel (A) of Figure 7. The red contours correspond to 10%, 40%, and 70% of the CO(1–0) flux peak. The polygon covered by the corrected Hα and CO(1–0) simultaneously is displayed as a solid black line (∼40 arcsec). The optical center is marked with a black cross.

4.3. MZR and SFMS

Panel (A) of Figure 11 shows the relationship between gas-phase metallicity and stellar mass (MZR). The contours and gray dots represent the sample of 113 CALIFA galaxies from Sánchez et al. (2013), where the gas-phase metallicity was also derived using the O3N2 index. The black dashed and solid lines are from Sánchez et al. (2013) as well. Panel (B): the SFMS relation. The contours and gray dots represent the sample of 775,473 galaxies from the MPA–JHU DR7 catalog (Kauffmann et al. 2003; Brinchmann et al. 2004). The SFMS for local star-forming galaxies is derived by Elbaz et al. (2007), shown by the black solid and dashed lines. The red star represents our target SFS0 PGC 34107.

Inflows can not only arrange the metallicity of a galaxy, but can also provide the raw material for star formation. By stacking the spectra of all pixels in PGC 34107, we can also derive the global gas-phase metallicity. Here the gas-phase metallicity is calculated by the linear relation between oxygen abundance and the O3N2 method, modified by Marino et al. (2013) as

$$12 + \log(O/H) = 8.533 - 0.214 \times \text{O3N2},$$

(Eq. 8)
where $O3N2 = \log \left( \frac{[O iii] \lambda 3007}{H\alpha} \right) \times \frac{H\alpha}{[N ii] \lambda 6583}$ was first introduced by Alloin et al. (1979), after considering the extinction correction. Given the intrinsic scatter (0.18 dex) of this linear relation from Marino et al. (2013), the global gas-phase metallicity and its scatter ($8.58 \pm 0.18$) are plotted in Figure 11. Based on the IFS data provided by the CALIFA survey, Sánchez et al. (2013) explored the MZR of local spirals and adopted an asymptotic function to fit it. Their CALIFA galaxies are shown in contours and gray squares, while the best-fitting MZR is shown in the black solid and dashed lines in panel (A) of Figure 11. Note that Sánchez et al. (2013) calculated the gas-phase metallicity based on the relation $(12 + \log(O/H) = 8.73 - 0.32 \times O3N2)$ from Pettini & Pagel (2004). This relation was updated to Function (8) by Marino et al. (2013).

Panel (A) of Figure 11 suggests that PGC 34107 follows the stellar mass–metallicity relation of local spirals.

The global SFMS of PGC 34107 is shown in panel (B) of Figure 11. The background gray dots and contours represent the 775,473 galaxies from the MPA–JHU DR7 catalog (Kauffmann et al. 2003; Brinchmann et al. 2004), which provided the SFR and stellar mass based on a Kroupa (2001) IMF, whereas we adopt a Salpeter (1955) IMF in this work. Therefore, we convert the SFR and stellar mass from the MPA–JHU DR7 catalog by multiplying them by a factor of 1.5 (Bell et al. 2003). The black solid and dashed lines represent the local SFMS from Elbaz et al. (2007), who obtained the SFR and stellar mass from the MPA–JHU DR4 catalog. The SFS0 PGC 26218 (Ge et al. 2020) and PGC 38025 (Chen et al. 2021) are marked with the red plus and multiplication symbols, respectively. Similar to the other two SFS0s, PGC 34107 basically follows the local SFMS relation within the errors. Combining the MZR and SFMS with the plausible gas inflow for PGC 34107, it seemingly supports the fact that the bar-induced gas inflow from the galactic disk supplies the raw material for the central star formation in PGC 34107. This could explain why the MZR and SFMS of PGC 34107, a lenticular galaxy, are comparable to spiral or star-forming galaxies.

### 4.4. K–S Law and MGMS

Panel (A) of Figure 12 shows the relationship between $\Sigma_{\text{gas}}$ and $\Sigma_{\text{SFR}}$, i.e., the K–S law, within the same region of ionized and molecular gas (i.e., the solid black polygon in Figure 10), considering the correction of the inclination simultaneously (see Section 2.2). Here we have already considered the contribution from the $\Sigma_{HI}$, which is derived from the gas-phase metallicity by utilizing the empirical formula given by Schruba et al. (2018). The final $\Sigma_{\text{gas}}$ of PGC 34107 is about $2.52 \pm 0.14 \, M_\odot \, \text{pc}^{-2}$, listed in Table 1. As shown in Figure 12, the K–S law for the local ETGs (orange squares; Davis et al. 2014), spirals (green triangles/contours; Shi et al. 2018), and the nuclear regions of U/LIRGs (indigo squares; Shi et al. 2018) is displayed, and the K–S law for the high-redshift integrated main-sequence galaxies (red circles; Shi et al. 2018) are given as well. The best-fitting K–S law for Shi et al. (2018) sample is

$$\log \Sigma_{\text{SFR}}[M_\odot \, \text{yr}^{-1} \, \text{kpc}^{-2}] = 1.41 \times \log \Sigma_{\text{gas}} - 3.97,$$

where $\log \Sigma_{\text{gas}}$ is in units of $M_\odot \, \text{pc}^{-2}$. Considering the effect of the adopted IMF for comparison, here the $\Sigma_{\text{SFR}}$ from different works has been calibrated based on a Salpeter (1955) IMF instead of a Kroupa (2001) IMF. Simultaneously, we also ensure that here the $\Sigma_{\text{gas}}$ from all works is calculated by adopting the same $\alpha_{CO}$ as in this paper. But note that our results
may be biased because the SFR and gas measurements are limited to a small region and the physical area adopted by the literature makes a difference. In the Davis et al. (2014) sample, most of the ETGs are S0 galaxies, and distribute below the K–S law (black line) of Shi et al. (2018), while PGC 34107 is consistent with it. This means that the northern star formation of PGC 34107 is enhanced compared to normal ETGs, and it basically follows the K–S law of star-forming galaxies. Within the same region of ionized and molecular gas, the SFE is about $(1.74 \pm 0.65) \times 10^{-2}$ yr$^{-1}$, and it may take about 580 Myr to exhaust the gas if assuming a constant gas consumption without a gas inflow. The depletion time of gas is much smaller than that $(\sim 2.5$ Gyr) of normal ETGs (Davis et al. 2015). If we adopt the total molecular gas (see Section 3.2; $(3.6 \pm 1.1) \times 10^{9} M_{\odot}$) and the total SFR (see Section 2.2; $(33 \pm 0.01 M_{\odot}$ yr$^{-1}$), the gas depletion time is about $(1.02 \pm 0.34) \times 10^{9} yr$, which is consistent with that of Bigiel et al. (2008), which is converted to be $(1.26 \pm 0.5) \times 10^{9}$ yr based on a Salpeter (1955) IMF.

In addition, panel (B) of Figure 12 shows the molecular gas main sequence (MGMS; Lin et al. 2019). The resolved MGMS (rMGMS) of PGC 34107 is shown by brown diamonds/ contours and the corresponding total MGMS is shown as a red star, covering the same central region between the molecular gas and stellar mass. A constant molecular gas fraction log($f_{H_2}$) = −1 (defined as log($f_{H_2}$) = log($\Sigma_{gas}$) - log($\Sigma_{s}$)) is shown as a black line for reference. At a fixed log($\Sigma_{s}$), the rMGMS and its integrated MGMS of PGC 34107 show higher log($\Sigma_{gas}$), which means that there is a higher gas fraction in the center of PGC 34107, which is similar to the rMGMS of 12 local spirals of Shi et al. (2018). We note that PGC 34107 lives in a low-density environment (Xiao et al. 2016; Zhou et al. 2020), so we propose a secular evolutionary scenario where the bar-induced molecular gas inflow accumulates the central gas reservoir and supplies the raw materials for the current star formation, then further promotes the star formation.

5. Summary

Based on 2D optical spectroscopy from CAHA and millimeter observation from NOEMA, we study a barred lenticular galaxy PGC 34107 with central star formation. The spatially resolved ionized and molecular gas provide us an opportunity to reveal the trigger and evolution of star formation in the center of S0s. Our main results are summarized as follows.

1. Based on the IFU spectroscopic observation, PGC 34107 with a normal rotation disk shows younger age in the central region and higher surface mass density along the stellar bar. Most of the star formation is off-center and concentrated on the northern star-forming region, $\sim 380$ pc away from the center.

2. Revealed by the NOEMA observation, the distribution of molecular gas CO(1–0) also mainly traces the northern star formation. The rotation of molecular gas is consistent with the rotation of a stellar disk. Thanks to the high-resolution observations of NOEMA, a blueshifted (redshifted) velocity component on the receding (approaching) side of galaxy is discovered along the stellar bar, which might suggest that there is a molecular gas inflow along the bar. The location of gas inflow (300–550 pc) is connected to the peak of the off-center star formation ($\sim 380$ pc), while the peak position might be associated with the ILR, which can probably explain why the velocity of gas inflow gradually declines along the bar to the northern star-forming region. The plausible gas inflow provides evidence that this kind of secular internal process leads to the ongoing star formation.

3. We also find the existence of the isotopic line of $^{13}$CO(1–0). Combining optical and millimeter observations, most H, CO(1–0), and $^{13}$CO(1–0) emissions are found to be concentrated on the northern star-forming region. The integrated intensity line ratio $R_{10} = CO(1–0)/^{13}$CO(1–0) for the whole galaxy is estimated about 7.52 ± 0.01, which is generally consistent with the ranges observed in spirals. The $R_{10}$ value is related to the intensity of the star formation.

4. PGC 34017 follows the local MZR and SFMS. Within the northern star-forming region covered by ionized and molecular gas simultaneously, its star formation also follows the K–S law, and the SFE is comparable to that of spirals. Based on rMGMS, PGC 34107 shows a higher gas fraction in the central region. This might support a scenario that the gas inflow along the bar gradually accumulates the gas reservoir and provides the raw material of star formation, then triggers the star-forming activity and arranges the gas-phase metallicity, resulting in the active star formation similar to spirals.

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Software: KINEMETRY (Krajnović et al. 2006), GILDAS (Pety 2005; Gildas Team 2013), MPFIT (Markwardt 2009), GALFIT (Peng et al. 2002, 2010), 3D BAROLO (Di Teodoro & Fraternali 2015).

Appendix

Position–Velocity Diagram

To model the rotation of molecular gas, we adopt 3D BAROLO software to perform a 3D tilted-ring fitting on the CO(1–0) emission-line datacube (Di Teodoro & Fraternali 2015). We set the position angle (PA), inclination (i), rotation velocity ($v_{rot}$), and velocity dispersion ($v_{disp}$) to be free after giving initial values (PA = 0°, i = 80°, $v_{rot} = 100$ km s$^{-1}$, $v_{disp} = 20$ km s$^{-1}$). The 3D BAROLO code fits a pure circular rotation model, so the noncircular motions, such as radial motion due to bar-induced gas inflow, can be reflected by comparison to the circular rotation model on the position–velocity diagram (PVD: Athanassoula & Bureau 1999; Bureau & Athanassoula 1999). In Figure 13, we show the results of PVDs from the 3D BAROLO
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Figure 13. Position–velocity diagrams for the CO(1–0) emission line along the major axis (upper) at PA = 2° and the minor axis (bottom) at 92°. The definition of the position angle is same as that derived by KINEMETRY. The blue contours represent the observed velocities. The best-fit models from 3DBAROLO are shown as red contours, considering the corrections of both the inclination and position angle. The levels of both contours are at 2σ from the mean of observed velocities. Generally, the whole observed rotation follows a rotating orbit by comparing the shape of the model (red contours) with that of observation (blue contours). But specifically, the blue contours for the major axis in the north shift slightly lower than the red contours, and the situation is inverse in the south, where blue ones tend to distribute above red ones, indicating that it is not a pure circular rotation along the major axis, which is also implied by the comparison of the minor axis between model and observation.

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