The Merging System AM 2049–691

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ABSTRACT. We present photometric and spectroscopic observations of the peculiar object AM 2049–691, whose most remarkable features are (1) two distinct nuclei connected by a bridge and (2) two tails. We studied seven zones and found that they have spectral features typical of H II regions of low excitation, electron temperatures and densities in the range of normal values for such regions, and quite high internal reddening. The derived Hα+N II equivalent widths suggest enhanced star formation formation in both galaxies, especially in the northeast nucleus; the equivalent width of the integrated spectrum reflects starburst activity in the whole object, which is compatible with a merger of two disk galaxies. We detected a comparative overabundance of nitrogen relative to oxygen in the southwest nucleus, which has the most evolved population. The bridge between the nuclei was also observed in Hα emission. B−V colors of the nuclei, after correction for internal absorption, also indicate that they are star-forming regions. The central radial velocity dispersions at the nuclei suggest that the most massive galaxy might be the progenitor of the southwest component. The observed radial velocity distribution shows the presence of two subsystems, each one associated with a different nucleus.

1. INTRODUCTION

Gas fueling induced by galaxy collision has been considered to be a very important mechanism in the triggering of nuclear starbursts (see, e.g., Noguchi 1988; Shlosman, Begelman, & Frank 1990). Starburst nuclei are often observed in interacting systems, particularly in those with heavily disturbed morphologies (see, e.g., Keel et al. 1985; Dahari 1985). Numerical simulations have shown that a strong dynamical perturbation caused by a merging partner induces an inflow of gas into the central regions of the perturbed galaxy and, subsequently, star formation in both galaxies (see, e.g., Olson & Kwan 1990; Mihos & Hernquist 1994). Constraints on the models can be obtained from the detailed observation of individual merger candidates, the search and determination of the connections between interactions and different levels of activity (e.g., from nuclear activity to star formation; see the models by Mihos & Hernquist 1996), and properties such as the separation and size of the components, spatial velocity distributions, global or local star formation activity, infrared emission, etc.

In that sense, the little studied system AM 2049–691 (ESO 074-IG 020, IRAS 20494−6913) (Fig. 1 and Table 1) is an interesting example of interaction or merger; it has a quite symmetric appearance, mainly because of the tidal tails disposition. This could be understood as the consequence of the interaction of two quite similar progenitors, plus a more or less symmetric geometry for the encounter. Therefore, in this particular case the observed physical properties of the system should be easier to reproduce with the state-of-the-art models and thus contribute to a better understanding of the nature of this kind of objects.

Arp & Madore (1987) classified AM 2049–691 as an interacting double object (category 2), but they did not give a definitive statement about its probable merger condition. Laur- berts & Valentijn (1989) considered it to be composed of two galaxies of morphological types Sh-c and Sb.

In this paper we present a spectroscopic and photometric study of AM 2049–691, in order to determine some of the properties of the progenitor galaxies as well as the age of the ongoing starbursts.

2. OBSERVATIONS AND REDUCTIONS

2.1. CCD Photometry

Broadband B, V, R, and I observations of AM 2049–691 were performed on 1999 July 6 and 7 with the 2.15 m Ritchey-Chrétien telescope of the Complejo Astronómico El Leoncito (CASLEO), San Juan, Argentina. The detector used was a CCD Tek 1024 × 1024; the scale was 0′′27 pixel−1. The total exposure times in each band were 960 s in B, 660 s in V, and 120 s in R and I. The seeing during the observations was ≈2″ (FWHM). The obtained data were corrected for atmospheric extinction and calibrated with standard stars from Graham (1982).
2.2. Spectra

Spectroscopic observations were carried out on 1999 June 15 and 16 with a REOSC spectrograph attached to the CASLEO telescope and the same detector as above. The seeing was also ≈2" (FWHM). Two sets of spectra were obtained through a slit 2.2 wide and 348" long, along P.A. = 30°. For the first set a 1200 line mm⁻¹ grating was used over the wavelength range 6415–7030 Å (total exposure time was 2400 s). For the second set a 300 line mm⁻¹ grating was used to cover the wavelength range 3797–7216 Å (total exposure time was 3600 s). The resolutions were 2.5 and 10 Å, respectively. The angular scale was 1"pixel⁻¹. The spectra were corrected for atmospheric and Galactic extinction ($A_B = 0.15$; Burstein & Heiles 1984) and were flux calibrated with stars from Stone & Baldwin (1983). Data reduction of images and spectra was accomplished using the standard methods in the IRAF reduction package.³

### Table 1

| Parameter                  | Value          |
|----------------------------|----------------|
| R.A. (J2000.0)             | 20°54'10"     |
| Decl. (J2000.0)            | 19°02'19"     |
| Radial velocity (GSR) (km s⁻¹) | 10956 ± 20   |
| Distance ($H_0 = 75$ km s⁻¹ Mpc⁻¹) (Mpc) | 146          |
| Total $B$ magnitude (mag)  | 14.40          |
| FIR luminosity ($L_\nu$)  | $5 \times 10^{10}$ |
| FIR color $\alpha(60, 25)$ | -2.5          |
| FIR color $\alpha(100, 60)$ | -1.5          |

**Note.**—Far-infrared data were extracted from the IRAS Point Source Catalog 1988; the far-infrared luminosity was calculated following Lonsdale et al. 1985.

³ Image Reduction and Analysis Facility, distributed by the National Optical Astronomy Observatories.
detected here in Hα emission. The system shows two tails; the first one emerges from the SW extreme point of the main body (0.6 × 0.2) and is seen up to ≈41 kpc from the center of the system, whereas the other tail stems from the NE extreme point and reaches a distance of 58 kpc. At the end of this last tidal tail there is a likely dwarf galaxy, as it has been observed out of the debris of merging disk galaxies (Mirabel, Dottori, & Lutz 1992).

3.2. Magnitudes and Colors

The $B$ magnitude and the $B−V$, $V−R$, and $R−I$ colors of AM 2049−691 were derived, after removing the field stars, using circular apertures of increasing radii centered on a point equidistant from the two nuclei. The photometrically useful frames were smaller than the total estimated system size, so asymptotic extrapolations of the obtained values were used to derive the total magnitudes. The results are $B = 14.40 ± 0.02$, $B−V = 0.52 ± 0.05$, $V−R = 0.47 ± 0.06$, and $R−I = 0.59 ± 0.06$. The $B$ and $R$ magnitudes here obtained are consistent with those by Lauberts & Valentijn (1989: $B_∗ = 14.50$, $R_∗ = 13.62$), which are values derived from the individual total magnitudes of each component. The total color $B−V$ corresponds to an Sc–Scd galaxy (Robert & Haynes 1994) and to a spectral type of F7 for the integrated stellar population. The resulting absolute blue magnitude of AM 2049−691, $M_B = −21.42 ± 0.03$, together with its far-infrared (FIR) luminosity (Table 1), lead to $L_{FIR}/L_B ≈ 6.6$; this luminosity ratio is higher than in isolated spirals but typical of interacting systems (Bussighthouse, Lamb, & Werner 1988).

Within 5° radii, the $B$ magnitudes and $B−V$ colors of the NE and SW nuclei are, respectively, $16.28 ± 0.02$ and $16.66 ± 0.02$, and $0.75 ± 0.05$ and $0.87 ± 0.05$. After correcting these values for internal absorption by adopting $A_λ = E_{B−V} × X(λ)$ and the extinction curves given by Seaton (1979), the $B−V$ colors for the NE and SW nuclei become $−0.25 ± 0.05$ and $0.19 ± 0.05$, which correspond, respectively, to average integrated populations of about B1 and A6 types. These colors clearly reflect that the two nuclei are star-forming regions.

4. SPECTROSCOPY

The photometric information of both nuclei was complemented with their spectroscopic data and those of their neighboring zones. For the seven studied regions the measured and corrected line intensity ratios $F_{λ}/F_0$ and $I_{λ}/I_0$ are listed in Table 2, as well as the errors estimated from the noise level around each line. The values of $c$ and the corrected Hβ fluxes are given at the bottom of the table (regions 3 and 6 correspond to the centers of the NE and SW nuclear regions, respectively). The intensities were derived by fitting Gaussians to the line profiles. The interstellar extinction curves given by Seaton (1979) were used to correct for internal reddening, under the assumption that the optical properties of the dust in AM 2049−691 are similar to those of the dust in the Galaxy. To derive the values of $c$, the logarithmic extinction at Hβ, a value of 2.85 was adopted for the intrinsic ratio Hα/Hβ (Osterbrock 1989).

The spectra of all these regions present strong emission lines in the red zones (Fig. 2); their features are typical of low-excitation H II regions. The excitation in region 3 appears to be considerably lower than that in region 6. The principal excitation mechanisms might be photoionization by young massive stars. The internal reddening is quite high, especially in region 3.

4.1. Abundances, Physical Conditions, and Equivalent Widths

Abundance ratios, electron temperatures $T_e$, and densities $N_e$ were obtained for regions 1–7. The average values of $N(O)/N(H)$ derived from the empirical calibrations of Edmunds & Pagel (1984) were adopted. The $N(N)/N(H)$ abundances were derived by making the usual assumptions valid for H II regions. Expressions given by Díaz (1985) were used for the involved ionic abundances. The electron temperatures were obtained by searching the required values of $T_e$ for the adopted $N(O)/N(H)$ abundances; the electron densities were derived from the [S II] λ6717/λ6731 ratios (Osterbrock 1989). The results are presented in Table 3. The electron temperatures are rather low, but they are in the range of normal values for H II regions; electron densities are also within that range.

The derived nitrogen and oxygen abundances present two maxima corresponding to region 3 (NE nucleus) and region 6 (SW nucleus), the abundances of both elements being higher in the NE nucleus than in the SW one. The relative line flux uncertainties were propagated through all the calculations considering the minimum and maximum possible values in each step; thus the estimated uncertainties of N are 20% for region 3 and 15% for region 6, whereas the estimated uncertainties of O are 15% for region 3 and rise to 20% for region 6. The $N(N)/N(O)$ ratios (whose typical estimated uncertainty is about 25%) in region 3 and toward the NE are practically coincident with those of the Galactic emission regions (Shaver et al. 1983). These ratios increase toward the SW, being in region 6 about twice those of Galactic regions; this indicates a comparative overabundance of N with respect to the O, which is reflected in the relatively high [N II] λ6584/Hα ratios. The difference in the $N(N)/N(O)$ ratio is more than twice the estimated uncertainty, so it seems a significative excess. If this excess is due to an enhancement of nitrogen abundance after a succession of short starbursts (Contini, Considère, & Davoust 1998), that overabundance suggests that the SW nucleus has undergone previous bursts.

The equivalent widths EW(Hα + [N II]) also show two maxima at the two nuclei (Fig. 3), reaching values of 67 and 48 Å for the NE and SW nuclei, respectively. All the obtained values indicate enhanced star formation activity compared with isolated galaxies, especially in the NE nucleus. The equivalent
width $\text{EW}(\text{H}\alpha + \text{[N II]}) = 58 \text{ Å}$ derived from the integrated spectrum of AM 2049–691 reflects star formation activity in the whole object, which could be favored with the usually large amounts of gas that spiral galaxies have, and it is compatible with a merger of two disk galaxies (Liu & Kennicutt 1995). This differs from the results of Joseph et al. (1984), who found evidence of this activity in only one member of their observed pairs.

The H$\alpha$ equivalent widths determined for the NE and SW nuclei are 44 and 25 Å, respectively. The observed differences in equivalent widths seem not to be due to variations in the continuum from one nucleus to the other: the red continuum profiles along P.A. = 30° are similar, but there is a significative difference in the H$\alpha$ flux of each nucleus (Fig. 4b). Ages of $\sim 9 \times 10^6$ yr are derived for their bursts of star formation, according to the standard model for instantaneous bursts with metallicities of about 2 $Z_\odot$ and 1 $Z_\odot$ (Leitherer & Heckman 1995), respectively.

The integrated spectrum H$\alpha$ luminosity along P.A. = 30°, which includes most of the emission of both starburst nuclei (see Fig. 4b), is $L_{\text{H}\alpha} \sim 4.9 \times 10^7 L_\odot$. Thus, AM 2049–691 is at least 40% H$\alpha$ brighter than the starburst galaxies in the Schmidt objective-prism survey of Gallego et al. (1995). H$\alpha$ luminosity can be used as a direct estimator of the current star formation rate (SFR), since it is directly related to the number of massive stars (see, e.g., Kennicutt 1992); following the results of Gallego et al. (1995) the observed H$\alpha$ luminosity corresponds to an SFR $\geq 3 M_\odot$ yr$^{-1}$ (assuming case B recombination theory to predict the luminosity of the H$\alpha$ emission line and a Scalo 1986 initial mass function).

It is accepted that the known correlation between IR and H$\alpha$ emission fluxes for interacting and merging galaxy systems (see, e.g., Bushouse, Telesco, & Werner 1998) implies that both of them have the same origin in the observed starbursts. Van den Broek (1992) found a ratio $\log (L_{\text{FIR}}/L_{\text{H}\alpha}) \sim 1.9$; Agüero et al. (1994) and Lipari, Bonatto, & Pastoriza (1991) found a ratio of $\sim 2.5$. The lower limit in the H$\alpha$ luminosity of AM 2049–691 leads to $\log (L_{\text{FIR}}/L_{\text{H}\alpha}) < 3$, which is consistent with the general view of a common origin for the IR and H$\alpha$ emissions in the present starburst of AM 2049–691.
4.2. Radial Velocities

Radial velocities were derived from the spectra obtained with the 1200 line mm$^{-1}$ grating by measuring the centroids of Gaussian curves fitted to the profiles of the strongest emission lines. The resulting heliocentric radial velocities of the nuclei are $V_{\text{NE}} = 10,977 \pm 18$ km s$^{-1}$ and $V_{\text{SW}} = 11,144 \pm 13$ km s$^{-1}$, respectively. The average velocity was adopted as the systemic velocity (Table 1). The survey of Sekiguchi & Wolstencroft (1992) reports for the AM 2049–691 system the nuclear velocities $V_{\text{NE}} = 11,004 \pm 30$ km s$^{-1}$ and $V_{\text{SW}} = 11,092 \pm 43$ km s$^{-1}$, without giving any detailed kinematical analysis.

The Mg $\text{i}$ λ5175, Na $\text{i}$ λ5893, and TiO band absorption lines were also detected in the continuum emission of each nucleus, with average velocities $V_{\text{NE}} = 10,977 \pm 20$ km s$^{-1}$ and $V_{\text{SW}} = 11,141 \pm 20$ km s$^{-1}$. The average measured radial velocity dispersions were $\sigma_{\text{NE}} = 290 \pm 34$ km s$^{-1}$ and $\sigma_{\text{SW}} = 342 \pm 30$ km s$^{-1}$. The instrumental line width was measured in the night sky emission lines, $\sigma_{\text{instr}} = 192 \pm 10$ km s$^{-1}$, and through the relation $\sigma_{\text{inst}}^2 = \sigma_{\text{obs}}^2 + \sigma_{\text{inst}}^2$ we derived average values for the intrinsic stellar radial velocity dispersions at the center of each subsystem: $\sigma_{\text{NE}} = 217 \pm 35$ km s$^{-1}$ and $\sigma_{\text{SW}} = 280 \pm 32$ km s$^{-1}$.

Assuming a Maxwellian velocity distribution for the stars contributing to the integrated light of each nucleus, we can consider, at first approximation, that the central velocity dispersions are indicative of the relative masses of the original

| TABLE 3 | RELATIVE ABUNDANCES AND PHYSICAL CONDITIONS |
|---------|---------------------------------------------|
| Parameter | Region 1 (0°) | Region 2 (20°) | Region 3 (0°) | Region 4 (−20°) | Region 5 (−12°) | Region 6 (−14°) | Region 7 (−16°) |
| N(O)/N(H) $\times 10^3$ | 7.2 | 11.6 | 14.6 | 9.1 | 7.6 | 7.7 | 6.6 |
| N(N)/N(H) $\times 10^3$ | 4.9 | 8.3 | 10.9 | 9.1 | 7.0 | 7.7 | 8.1 |
| N(N)/N(O) | 0.07 | 0.07 | 0.07 | 0.10 | 0.09 | 0.13 | 0.12 |
| T_e (K) | 7080 | 6140 | 5720 | 6250 | 7030 | 6670 | 6940 |
| N_e (cm$^{-3}$) | 10 | 160 | 270 | 400 | 140 | 10 | 140 |

Note.—Distances are as in Table 2.
systems. Thus the progenitor galaxy of the SW component would be the most massive one. Caution is necessary here regarding the use of the absorption lines, since it has been shown that the Na i λ5893 interstellar line is strong in about half of the FIR-bright starburst galaxies and can reflect the macroturbulent gas motions triggered by winds and supernovae (see, e.g., Heckman et al. 2000). As the stellar population of the AM 2049–691 system is quite hot, this stellar line is expected to be weak and the intrinsic stellar dynamics could be masked by the interstellar absorption line. Nevertheless, the Na i line does not appear to have a blueshifted component, and the observed line widths are similar in all the observed absorption lines; therefore this effect could be neglected in the present case.

The stellar radial velocity dispersion allows us to estimate the mass and tidal radius of each nuclear-bulge component (see, e.g., Bowers & Deeming 1984). They turn out to be roughly $5.5 \times 10^{10} M_\odot$ and 5.9 kpc, and $9.6 \times 10^{10} M_\odot$ and 8.6 kpc, for the NE and SW nuclei, respectively. Following the results of Kormendy & Illingworth (1983) about the $L \propto a^n$ relation for disk-galaxy bulges, the values presented here are roughly consistent with the progenitor systems being early-type spiral galaxies with $M_\phi \approx -21$. These values are in accordance with the global photometric properties presented in § 3.2 and the spectrophotometric results above discussed.

The velocity distribution of the emission lines along P.A. = 30° is illustrated in Figure 4a. The radial velocity curve along the line that joins both nuclei shows the presence of two different components separated by a velocity discontinuity of $\approx 100$ km s$^{-1}$, and a glance at the curve suggests that each one is associated with a different nucleus. A close inspection of the spectra shows that the Hα emission has a minimum between both nuclei at about a half of the distance from the NE nucleus to the SW one. Then the three points after the velocity discontinuity have photometric continuity with the NE emission complex, as it is shown in Figure 4b. The NE system has the smallest tidal radius ($r_\perp \approx 6$ kpc), so the feature could have been produced by tidal disruption of the NE gaseous system, part of which would have become gravitationally bound to the SW body, which apparently is the most massive one.

The global appearance of the rotation curve resembles a solid body (SB) in 70% of the observed positions. This SB aspect does not necessarily correspond to a spherical halo mass distribution, since recent numerical simulations have shown that an appropriate combination of perturbation and dust obscuration in the disk can explain the SB appearance of an interacting galaxy rotation curve at a wide range of radii (Díaz et al. 2000).

As a whole system, AM 2049–691 shows a velocity amplitude of $\approx 330$ km s$^{-1}$, and the total Keplerian mass inside a radius of 11.5 kpc is $\sim 1.4 \times 10^{11} M_\odot$; this is only a rough estimation because the orientation is unknown and the system is far from relaxation, but it is consistent with the estimated progenitors properties.

5. CONCLUDING REMARKS

AM 2049–691 has two components whose separation is comparable to their sizes, and its tidal interactions apparently have not produced very high IR emission compared with the IR luminosity of typical mergers. Its far-infrared colors are relatively low (Table 1), indicating that it is a nonactive object, consistent with the information derived in this paper. The integrated total color $B-V$ corresponds to an Sc–Scd galaxy with an F7 integrated population type. All the observed zones are low-excitation dusty H ii regions and reveal inhomogeneous obscuration, and the Hα+[N ii] equivalent width of the integrated spectrum reflects global starburst activity.

The photometric and spectroscopic data suggest that the observed star formation bursts in the nuclei of both progenitor galaxies were triggered at about the same time: $\sim 9 \times 10^6$ yr. This age is at least 1 order of magnitude shorter than a galactic rotation or the dynamical evolution time of the merger of two disk galaxies ($\sim 10^8$ yr; see, e.g., Barnes 1992; Hernquist 1992), so the observed star formation bursts have been triggered during the present (advanced) merger phase. Moreover, Mihos & Hernquist (1994) found that galaxies with dense central bulges

![Figure 4](image-url)

Fig. 4.—(a) Radial velocity distribution along P.A. = 30°. The values correspond to the weighted average velocities from the Hα, [N ii] λ6548, 6584 lines. Open circles correspond to the nuclei, and bars indicate uncertainties. Symbols and distances are as in Fig. 3. (b) Hα emission profile (continuum subtracted) along P.A. = 30°.
prove stable against strong starbursts until the final merger, providing a natural explanation for the discrepant merging and starburst timescales. These numerical results are consistent with the derived progenitor properties (§ 4.2) and starburst age (§ 4.1) in AM 2049–691.

The most intense starburst activity and the highest obscuration is observed at the NE nucleus. The SW one presents a relative overabundance of nitrogen with respect to oxygen, has the most evolved stellar population, has the shortest tidal tail, and would be the most massive one.

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