The Taffy galaxy pair: optical and radio characterization of an interacting system

J. Saponara[1], A.V. Smith Castelli[2,3], F.R. Faifer[2,3], C.G. Escudero[2,3],
C. Mendes de Oliveira[4], A.C. Krabbe[5] & P. Benaglia[1]

[1] *Instituto Argentino de Radioastronomía, CONICET–CICPBA–UNLP, Argentina*
[2] *Instituto de Astrofísica de La Plata, CONICET–UNLP, Argentina*
[3] *Facultad de Ciencias Astronómicas y Geofísicas, UNLP, Argentina*
[4] *Instituto de Astronomia, Geofísica e Ciências Atmosféricas, Universidade de São Paulo, Brasil*
[5] *Departamento de Ciências Exatas e Tecnológicas, Universidade Estadual de Santa Cruz, Brasil*

Contact / jsaponara@iar-conicet.gov.ar

Resumen / El par de galaxias Taffy UGC 12915/4 constituye un excelente ejemplo de una fusión rica en gas en curso. La evidencia sugiere que las dos galaxias experimentaron una colisión frontal hace $25 - 30 \times 10^6$ años que originó un puente de gas atómico y molecular que conecta ambas galaxias. Dado que este sistema ha sido poco estudiado en el óptico y en el IR cercano, hemos comenzado un proyecto tendiente a caracterizar las propiedades de esta fusión en dicho rango espectral. Con tal objetivo hemos obtenido imágenes profundas del sistema Taffy utilizando el telescopio Gemini-Norte en las bandas g', r', i', z', Hα y H$_\alpha$C. Nuestro objetivo inmediato es caracterizar las contrapartes ópticas de varias fuentes ultra-luminosas en rayos-X (ULXs), detectar cúmulos de estrellas, regiones extragalácticas de formación estelar e identificar galaxias de baja masa de origen tidal. Esperamos que esta información adicional ayude a comprender mejor los procesos físicos involucrados en las interacciones de las galaxias.

Abstract / The Taffy galaxy pair UGC 12915/4 constitutes an excellent example of an ongoing major gas-rich merger. Evidence suggests that the two galaxies experienced a head-on collision $25 - 30$ Myr ago that raised an atomic and molecular gas bridge connecting both galaxies. This system has been poorly studied in the optical and near-infrared. Therefore, we observe the whole Taffy system with Gemini-North in g', r', i', z', Hα, and H$_\alpha$C bands. We aim to characterise the optical counterparts of several Ultra Luminous X-ray sources (ULXs), detect star clusters, extragalactic star-forming regions, and identify low-mass galaxies of tidal origin. We expect that this additional information will help to better understand the physical processes involved in galaxy interactions.

Keywords / methods: observational — galaxies: individual (Taffy) — galaxies: interactions

1. Introduction

In hierarchical cosmological models, interactions, mergers and accretion drive galaxy formation and evolution. In this scenario, massive galaxies form through major and minor mergers which leave imprints in their structural properties such as stellar population gradients (Hirschmann et al., 2015 and references therein). These processes might have also originated part of the globular cluster (GC) populations of those galaxies (Harris, 2009), as demonstrated by the existence of young and intermediat-age GC in post-merger bright elliptical galaxies (e.g. Sesto et al., 2018; Escudero et al., 2022).

In the same hierarchical framework mentioned above, low-mass galaxies are the building blocks from which massive galaxies form (e.g. White & Frenk 1991; Kauffmann et al. 1997). This picture is supported by the large number of low-mass galaxies observed in groups and clusters in comparison with massive galaxies (e.g. Binggeli et al. 1988), and by the low metallicities found in some of them (e.g. Lagos et al. 2014 and references therein). However, the transformation of massive progenitors through environmental effects, such as galaxy harassment or tidal stripping, is an alternative model for low-mass galaxy formation in dense environments (e.g. Penny & Conselice, 2008). In addition, it has been claimed that low-mass galaxies could be formed from the stellar and gaseous material pulled out in tidal interactions (e.g. Dabringhausen & Kroupa 2013; Duc et al. 2014).

The Taffy galaxy pair (UGC 12914; RA=00:01:38.32, DEC=+23:29:01.1 and UGC 12915; RA=00:01:41.93, DEC=+23:29:45.2, J2000), located at a distance of 62 Mpc (Appleton et al., 2015), constitutes an excellent example of an ongoing major gas-rich merger that can be completely imaged in a single Gemini field. A bridge of radio continuum emission between the galaxies was detected by Condon et al. (1993). Evidence suggests that the two galaxies experienced a head-on collision $25 - 30$ Myr ago in a way that their stellar distribution remains almost undisturbed, while most of their gas was stripped into a bridge connecting both galaxies. There is more molecular and atomic gas (7×10^9 M$_\odot$) in the bridge than in the two galaxies combined (Braine et al., 2003; Gao et al., 2003; Zhu et al., 2007). Despite the considerable amount of fuel for the star for-

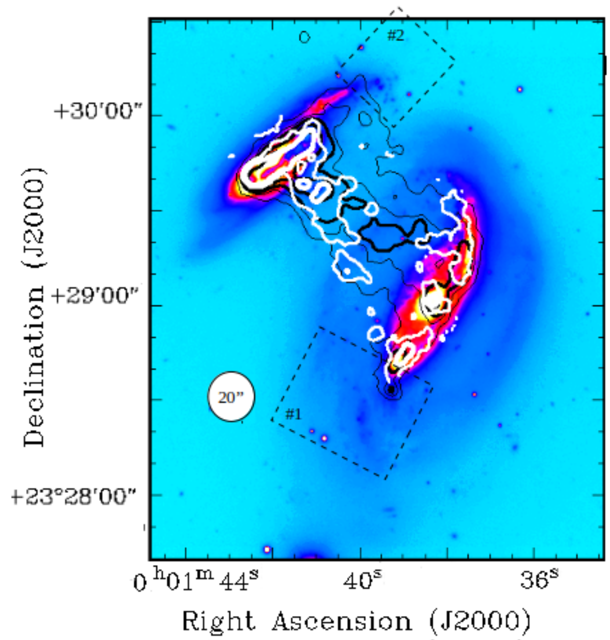

Figure 1: Gemini g', r', i', z' stacked image of the Taffy system. The black contours are showing the presence of the radio continuum at 1.49 GHz detected with the VLA, while the white contours depict the CO(1-0) emission detected with the IRAM telescope.

mation activity, the system is not a strong IR emitter ($L_{IR} = 4.5 \times 10^{10}$ $L_{\odot}$, indicating a low star formation efficiency (Appleton et al., 2015). Although optical images show interesting sub-structures like rings and loops, the Taffy galaxies have been poorly studied in optical bands. Recent X-ray studies revealed the presence of nine Ultra Luminous X-ray sources (ULXs). The brightest one is found in the bridge, and it is associated with an extragalactic HI region (Appleton et al., 2015), while the other eight might be massive accreting black-holes ($M_{BH} < 20$ $M_{\odot}$) associated with young star clusters (Zezas et al., 2007; Mineo et al., 2012).

In this contribution, we present the starting point of a study aimed at studying the Taffy galaxy system, complementing high-quality optical images with radio data. We expect that such study help to better understand the evolutionary path of the whole system and clarify the origin of several of their components.

2. Radio data

The Taffy galaxy pair was widely observed at radio frequencies through the years. Dressel & Condon (1978) observed the system at 2380 MHz using the Arecibo antenna. Some years later, Condon et al. (1993) published a detailed analysis using continuum and HI data, previously observed with VLA C configuration at 4.86 GHz and VLA B configuration at 4.86 GHz and 1.49 GHz. Datasets at 1.4 GHz were combined, achieving an r.m.s. of 0.03 mJy/beam and an angular resolution of 4.1 arcsec (Figure 1, white contours). To better understand the low star formation efficiency in the Taffy bridge, Vollmer et al. (2021) performed simulations and presented new CO(1-0) observations of the Taffy system obtained with the IRAM Plateau de Bure Interferometer. The r.m.s. of this CO observations is 5 mJy/beam and the angular resolution is 2.7 arcsec (see Figure 1, black contours).

3. Optical data

We have obtained deep g', r', i', z', Hα and HαC images of one field covering the whole Taffy galaxy system, with the Gemini Multi-Object Spectrograph (GMOS; Hook et al., 2004) of GEMINI-North, (Program: GN-2020B-Q-109, PI: A. Smith Castelli). GMOS consists of three CCDs with 2048×4096 pixels each, separated by 2.8 arcsec gaps, and with an unbinned pixel scale of 0.0727 arcsec pixel^{-1}. The field of view (FOV) is 5.5×5.5 arcmin. Figure 1 shows the g', r', i', z' stacked image in order to highlight the different features and low-brightness structures of the system. It is worth to be noticed that, up to date, optical investigations were carried out using images of the Sloan Digital Sky Survey (SDSS; 0.396 arcsec pixel^{-1}). Here, we present the first steps of a study using higher-quality (FWHM$\sim$ $0.45 - 0.70$ arcsec) deep optical Gemini-GMOS images.

4. Optical images inspection and preliminary results

Globular clusters and super star clusters are expected to be formed during the galaxy interactions, or soon after, as observed in the Antennae system (Johnson et al., 2015). Looking at the Hα image of the Taffy system, we found the presence of several faint and bright star-forming regions, in the outskirts of both

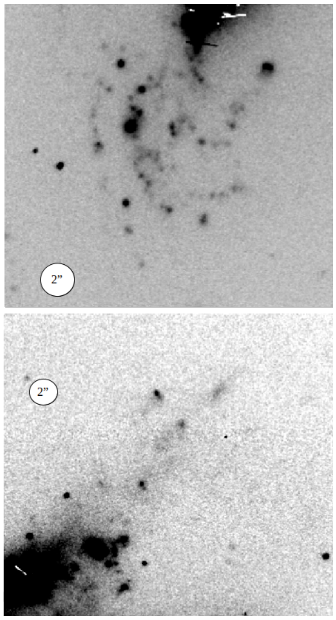

Figure 2: Gemini Hα image cutouts of the Taffy system. *Top panel*: the outskirts southern side of UGC 12914 (#1 RA=00:01:40, DEC=+23:28:24.4, J2000). *Bottom panel*: the outskirt northern side of UGC 12915 #2 RA=00:01:39.16, DEC=+23:30:16.4, J2000).

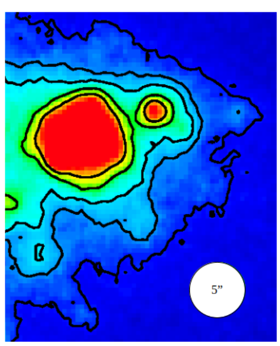

Figure 3: Gemini Hα image cutouts of the extragalactic HII region (X-HII, RA=00:01:40.9, DEC=+23:29:37.4, J2000). The Hα black contour levels are 1.6, 2.6, 3.6, 5.6, 7.6, in units of 10^{-16} erg s^{-1} cm^{-2} arcsec^{2}.

galaxies as well as in the bridge. In Figure 2, we show two of these regions. The outskirts of the southern side of the UGC 12914 galaxy (#1 RA=00:01:40, DEC=+23:28:24.4, J2000) and the outskirt of the northern side of UGC 12915 (#2 RA=00:01:39.16, DEC=+23:30:16.4, J2000). In particular, further analysis is required to determine if this latter region is linked or not to the galaxy. We also identified the extragalactic HII region (X-HII, RA=00:01:40.9, DEC=+23:29:37.4, J2000, Appleton et al. (2015)), see Figure 3. The total flux of this HII complex, measured within 6.5″aperture, is 3.5×10^{-14} erg s^{-1} cm^{-2}.

5. Future work

By performing photometry in all the observed bands, we expect that our images will allow us to detect young massive clusters and determine the properties of the HII regions that are already detected in our Hα image. We will complement our analysis with the HI and CO data for those regions where this information is available.

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