The Nearby QSO Host I Zw 1: NIR Probing of Structural Properties and Stellar Populations

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The likely merger process and the properties of the stellar populations in the I Zw 1 host galaxy are analyzed on the basis of multi-wavelength observations\textsuperscript{4} and N-body simulations. The data give a consistent picture of I Zw 1, with properties between those of ultra-luminous infrared galaxies (ULIRGs) and QSOs as displayed by transition objects in the evolutionary sequence of active galaxies.

1 Introduction

The formation and evolution of active galactic nuclei (AGN) and the associated star-formation activity are conditioned by the rate at which gas is supplied from the surrounding host galaxy. Interactions and mergers are identified as one possible mechanism to provide the transport of gas towards the central regions of a galaxy ([1] and references therein). The hypothesis of a merger-driven evolution of active galaxies from ULIRGs to unobscured QSOs is motivated by the spectral energy distributions of template objects showing a sequence of decreasing far-infrared excess and increasing UV brightness [4]. In accordance with the assumption that the evolution is triggered by interactions, the vast majority of ULIRGs show evidence for ongoing merger processes [3]. Merger signs are less clear in the case of objects close to the QSO phase. These transition objects are important sources to confirm the evolutionary sequence. As a nearby representative (\(z = 0.0611\), [9]) of a template transition object in the original evolutionary sequence (Fig. 17 in [4]), I Zw 1 is suitable to address the merger properties, the structural composition, and the starburst activity using near-infrared (NIR) and molecular line observations at sub-kpc angular resolution.

\textsuperscript{4} With the ISAAC camera at the Very Large Telescope (VLT/UT1) of the European Southern Observatory (ESO), Chile (Paranal), with the interferometer of the Berkeley-Illinois-Maryland Association (BIMA), USA (Hat Creek/California), and with the IRAM Plateau de Bure Interferometer (PdBI), France
2 Observations and Results

2.1 Merger Process

The J-band image of I Zw 1 (Fig. 1), obtained with ISAAC at a median seeing of 0.6" ($\approx 0.7$ kpc), provides a detailed view of the host galaxy with its two-armed spiral, its likely western companion galaxy, and the northern foreground star. The ongoing merger process with the companion is indicated by the tidal bridge towards the companion and by the tidal tail and the elongated shape of the companion [5]. The parameter space of this interaction is investigated with the help of restricted stellar-dynamical N-body simulations. As suggested by the surface-brightness profile of the companion, the study focuses on companions with less than 10% of the total mass of I Zw 1. On a bound elliptical orbit, even a companion with only 3% of the total mass of I Zw 1 can evoke a two-armed spiral structure similar to the one observed in the J-band image (Fig. 1).

![Fig. 1. J-band image of I Zw 1 (left panel), taken with the ISAAC camera at the VLT of ESO, and a snapshot of a restricted N-body simulation for the interaction between I Zw 1 and the companion (right panel). The companion in the simulation has a mass of 3% of the total mass of I Zw 1 and orbits I Zw 1 at an eccentricity of 0.2 and with a pericentric distance of 15.3 kpc.](image)

2.2 Hydrogen Emission and Stellar Absorption Lines

The K-band spectrum of I Zw 1 shown in Fig. 2 was obtained with the 1" long-slit of ISAAC and extracted in a 3" aperture centered on the I Zw 1 nucleus. It is characterized by strong hydrogen emission lines (Pa $\alpha$, Br $\gamma$, Br $\delta$). In agreement with I Zw 1 being classified as a narrow-lined Seyfert 1,
the hydrogen lines are narrow with a full width at half maximum of about 1,000 km s\(^{-1}\). The narrow lines with broad wings indicate a mixture of emission from narrow-line regions and from broad-line regions in the surroundings of the AGN. The flux ratio of the Pa\(\alpha\) and the Br\(\gamma\) line is about 11, as expected for HII regions. The overall fluxes and line widths are in good agreement with the results from previous K-band spectroscopy of I Zw 1 [8]. There are indications for the \(^{12}\)CO(2-0) bandhead (inset in Fig.2) which is mainly coming from late-type giants and/or super-giants. The preliminary analysis of the depth of this bandhead suggests a stellar contribution of about 20% to the total nuclear NIR flux of I Zw 1. This is in good agreement with the results presented in [8], which are based on the analysis of the \(^{12}\)CO(6-3) overtone bandhead in the H-band spectrum of I Zw 1. By comparing stellar and dynamical masses, it becomes evident that such a high stellar flux contribution can only be produced by a massive starburst (see [8]).

![Fig. 2. K-band spectrum of I Zw 1 taken with a 1" long-slit and extracted in a 3" aperture centered on the I Zw 1 nucleus. Stellar absorption features are magnified in the inset and compared to the synthetic spectrum of an M2 super-giant.](image)

### 2.3 Circum-Nuclear Molecular Gas

The circum-nuclear \(^{12}\)CO(1-0) emission in I Zw 1, observed with the BIMA interferometer at an angular resolution of 0.7" (\(\approx 0.8\) kpc), has a ring-like structure with a radius of about 1.5 kpc (see [10]). The comparison of the BIMA \(^{12}\)CO(1-0) measurements with PdBI \(^{12}\)CO(2-1) data indicates that
the molecular gas in the disk region is cold or subthermally excited while
the gas in the circum-nuclear region is warm and optically thick. The large
molecular clouds in the ring-like structure are most probably the sites of the
massive starburst activity discussed in [2], [8], and Sect. 2.2.

2.4 Structural Decomposition and Mean Stellar Populations
Mass-to-light (M/L) ratios of the mean stellar populations in the bulge and
disk components of the I Zw 1 host are derived by decomposing the J-band
surface-brightness profile and the gas rotation curve (see [5], [6], [7]). The disk
component and, in particular, the bulge component, show sub-solar M/L
ratios. In accordance with the findings of starburst activity, the low M/L
ratios indicate young mean stellar populations with an enhanced fraction of
hot stars and super-giants.

3 Conclusion
The multi-wavelength data converge to a consistent picture of I Zw 1 as a
transition object. A merger-driven evolution is suggested by the J-band image
and the N-body simulations showing evidence for a merger process with the
companion. The decomposition, together with the large stellar contribution to
the nuclear NIR flux, indicates young mean stellar populations and starburst
activity which is most likely located in the giant clouds of the circum-nuclear
molecular ring.

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