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Structure and kinematics of the interacting group NGC 5098/5096

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Abstract. We analysed the system composed by two groups at $z \simeq 0.037$, NGC 5098, a group dominated by a pair of elliptical galaxies, and NGC 5096, a compact system which appears to be interacting with NGC 5098. We aim to describe its current dynamical state in order to investigate how it fits in our current cosmological framework. Our analysis is based on deep MegaCam/CFHT *g* and *r* imaging, archival *Chandra* X-ray data, and publicly available data of the galaxy redshift distribution. We conclude that NGC 5098 and NGC 5096 form a complex system, that may have collided in the past, producing a sloshing observed in X-rays and a large scale diffuse component of intragroup light as well as some important tidal debris.

Resumo. Analisamos o sistema composto por dois grupos situados em $z \simeq 0.037$: NGC 5098, um grupo dominado por um par de galáxias elípticas, e NGC 5096, um sistema compacto que parece estar interagindo com NGC 5098. Nosso objetivo é descrever o atual estágio dinâmico do sistema e investigar como se enquadra nas teorias cosmológicas. A análise é baseada em imagens profundas *g* e *r* obtidas pela MegaCam do CFHT e de observações em raios X pelo observatório *Chandra* (dados de arquivo), além de dados publicos da distribuição de redshifts das galáxias. Concluímos que NGC 5098 e NGC 5096 formam um sistema complexo que pode ter colidido no passado, produzindo o fenômeno de *slohing* - um movimento de agitação na região central do sistema - observado em raios X, além de uma componente de luz difusa intra-grupo e importantes detritos de maré.

Keywords. Galaxies: individual: NGC 5098, NGC 5096 – Galaxies: groups – Galaxies: photometry – X-ray

1. Introduction

Galaxies in groups are prone to interact with each other and with the intragroup medium (ICM). Since the velocity dispersion in groups is usually a few hundred kilometres per second, comparable to the stellar velocity dispersion in large galaxies, galactic encounters will have enough time to produce tidal forces that will act upon galaxy members. Moreover, galactic collisions in low velocity dispersion systems will often end in mergers after a few gigayears. An important consequence of tidal interactions in groups (and also clusters) is the build-up of a diffuse stellar component made of stars ripped away from galaxies which we call the *intracluster light* (ICL). This material spreads into the host group or cluster relaxing into the gravitational potential well (e.g., Contini 2021).

Here we describe a photometric and kinematic analysis of the galaxy group dominated by the pair of elliptical galaxies NGC 5098a and NGC 5098b, and its neighboring group centered on NCG 5096, based on the work of Lima Neto et al. (2025). This complex system shows features that suggest a recent dynamical interaction, which we explore here and describe below.

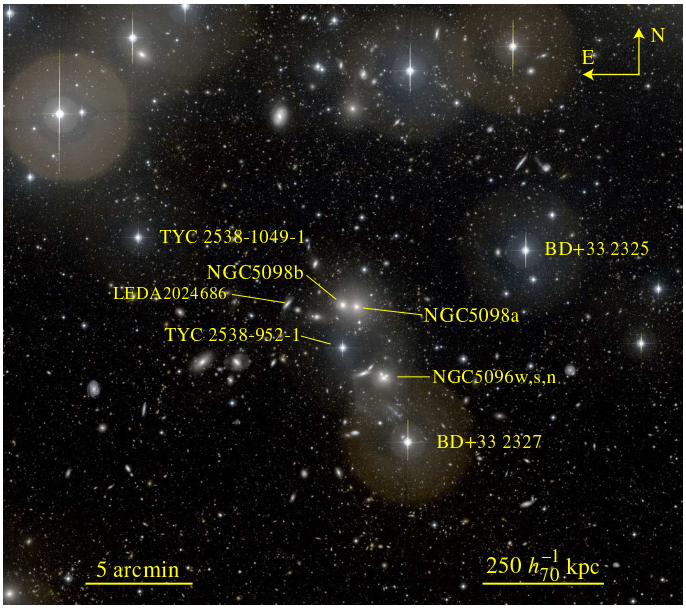

Figure 1. Colour image of the NGC 5098 Group based on MegaCam/CFHT images in the *g* and *r* bands. We show the galaxy pair NGC 5098a and b, and the three brightest stars on the field of view of the group core. NGC 5096 forms a subgroup with three galaxies: w (west), s (south) and n (north). LEDA2024686 is a foreground galaxy.

2. The NGC 5098/5096 group

NGC 5098 was discovered by John Herschel in 1827. Actually is a pair of early-type galaxies: in Fig. 1 NGC 5098a is the galaxy to the west, while NGC 5098b is to the east. NGC 5098a is an extended radio-galaxy with a moderately active galactic nucleus (AGN). Towards the south, about 3.6′ from NGC 5098a and b, there is a substructure dominated by the triple system of NGC 5096 (with the letters s, w, and n, for their relative positions, south, west, and north; see Fig. 1), which is considered a part of the NGC 5098 group . NGC 5096 is classified as a Hickson-like compact group (Zandivares et al. (2022)). The three central galaxies, NGC 5096s, n, and w (also shown in Fig. 1)

NGC 5098 was extensively studied in X-rays (Xue et al. (2004), Mahdavi et al. (2005), Randall et al. (2009)). Randall et al. (2009) analyzed a deep *Chandra* observation made with the ACIS-S3 detector. Thanks to the high spatial resolution, they

discovered the presence of a spiral-like arm due to gas sloshing in the centre, starting from the position of NGC 5098a, and unwinding outwards to the north and west. They argue that it is probably the galaxy NGC 5098b which is the perturber causing the sloshing.

We have reprocessed these *Chandra* exposures. Figure 2 shows the broad band *Chandra* image smoothed with an adaptive kernel with the r band isopleths superposed. The main X-ray emission comes from an extended halo centred on NGC 5098a, while a secondary extended, diffuse emission comes from the NGC 5096 substructure. The diffuse emission on both sources appears connected, showing some asymmetry, an excess westward from NGC 5098 and another X-ray excess eastward from NGC 5096. This is suggestive of a physical connection between both groups. The sloshing arm detected by Randall et al. (2009) can be seen as a faint X-ray excess to the north of NGC 5098b, spiralling outward clockwise, suggesting that this feature could be due to the arrival and gravitational interaction of NGC 5098b with NGC 5098a, the main galaxy of the group.

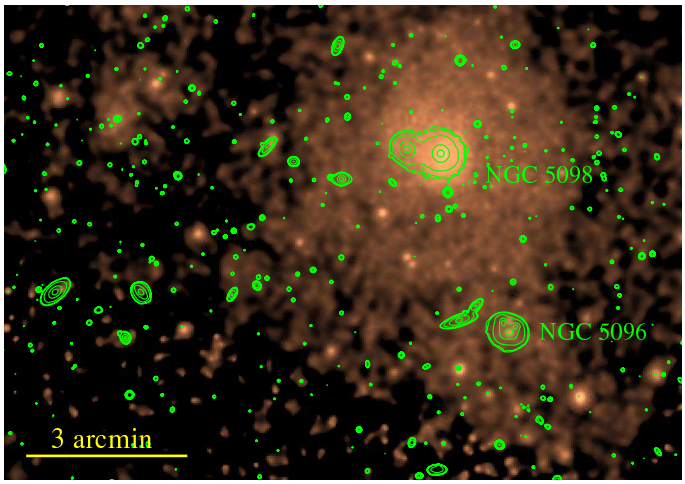

Figure 2. Exposure-map corrected image of the combined *Chandra* exposures in logarithmic scale in red tone. Green contours are isopleths from the r band image (without the bright stars). 3 arcmin corresponds to $147h_{70}^{-1}$ kpc.

We performed a detailed analysis of the light distribution, starting with the modelling of the circular halos around the bright point-like sources and then subtracting these halos from the g and r images. We then modelled the brightest galaxies taking in account the point-spread function obtained before (see details in Lima Neto et al. (2025)). The model was then subtracted from the CFHT image to obtain the diffuse light distribution detected in the field (see Fig. 3 where we highlight four structures with detected diffuse light).

The possible origin of these structures is discussed in detail in Lima Neto et al. (2025). We notice in particular structure C, which connects the central galaxies to NGC 5096. Region D to the south of NGC 5096 presents a blue bright diffuse intra-group light, extending southwards to a very blue object, [1] at the same redshift of the group. It is a very blue galaxy which we speculate is an extreme example of a jellyfish galaxy.

[1] WISEA J132005.90+330338.0 @ $z = 0.03815$ (NED); we estimated $g - r = 0.340 \pm 0.005$.

Table 1. Summary of the results

Subgroup	N_{gal}	σ_v(km.s^{-1})	$M_{200}(10^{13}M_\odot)$	$R_{200}(h_{70}^{-1}$Mpc)
NGC 5098a	82	318^{+43}_{-44}	3.93 ± 0.28	0.69 ± 0.02
NGC 5096	30	155^{+33}_{-27}	0.17 ± 0.02	0.24 ± 0.01

3. Kinematical & Dynamical Analysis

The photometric and spectroscopic data for the 748 galaxies with $r < 18^m$ projected a 50arcmin field centred at NGC 5098a were extracted from the SDSS/DR18 and the Hyperleda databases. We found that the completeness of our redshift sample relative to the SDSS photometric survey in the same area is $\gtrsim 60\%$ in the magnitude range $13 < r < 18$. The selection of galaxies kinematically belonging to the group was primarily made using the *shifting gapper* algorithm (SG) further refining the results by analysing the distribution of the data gaps. We end up with a list of 112 galaxy members of the group. We end up with a list of 112 galaxy members displaying a bimodal velocity distribution, with modes at the radial velocity of NGC 5098a and of NGC 5096. Fig. 4 summarize the main properties of the velocity distribution.

4. Masses and characteristic radius

The previous discussion suggests that the NGC 5098 group consists of two subsystems. Subgroup 1 with 82 members, is centred on the dominant pair of galaxies NGC 5098a-NGC 5098b, with a fairly regular distribution. Subgroup 2 is much poorer, with 30 spectroscopic members, and appears to have a spatial distribution where the majority of its galaxies lie in a line which includes the compact group around NGC 5096. We analysed the galaxy distribution in the projected phase space of the system using the method of caustics which relies on the determination of the caustic curves in the projected cluster phase-space (R, v_{pec}), as proposed by Diaferio & Geller (1997). Here R is the projected radial distance to the centre of the cluster and v_{pec} is the line-of-sight projected peculiar velocity (i.e. the velocity referenced to the cluster mean redshift).

We used the `CausticMass` code based on Gifford et al. (2013) [2] applied to subgroup 1 (phase space centred on NGC 5098a) and to subgroup 2 (phase space centred on NGC 5096). Figure 5 shows the the resulting caustic profiles together with the phase space positions of galaxies of both subgroups.

The characteristic mass and radius, M_{200} and R_{200}, were obtained by fitting a NFW profile (Navarro et al 1996) to the caustics profiles. As discussed by Gifford et al. (2017), this procedure produces more accurate values for these quantities. Table 1 summarizes the results we obtained.

5. Discussion

Both photometric and kinematic analyses show, at least, a bimodal structure, as already suggested in the literature Mahdavi et al. (2005). Ours new deep imaging shows several low surface brightness structures that may be the result of stellar stripping by tidal forces, either due to the encounter of galaxies or to interactions during the passage of a substructure through the main group of NGC 5098. Some features, such as the tidal arms shown in Region A of Fig. 3 (right panel) probably result from two-body interactions of galaxies near the core of the NGC 5098 group. In this same panel we notice a very faint diffuse stellar

[2] `https://github.com/giffordw/CausticMass`

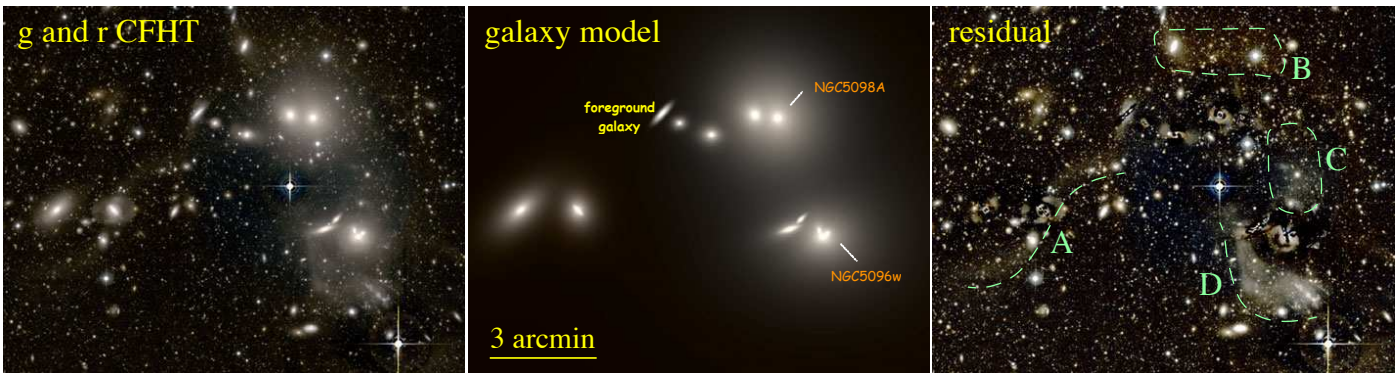

Figure 3. Left: "true colour" RGB image (after subtracting the stars models) using g, r and the the mean value of g and r bands. Middle: galaxies modelled with `galfit`, also in "true colour". Right: residual of the CFHT image minus the model image, showing the detected diffuse light. All images are in logarithmic scale (see Lima Neto et al. (2025) for details).

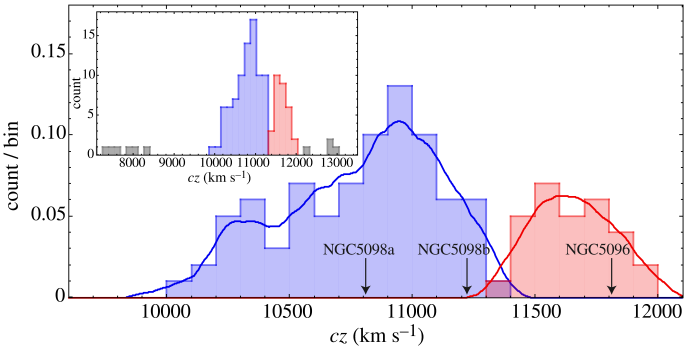

Figure 4. Velocity distributions of the two groups discussed in the text. The arrows point the radial velocities of the brightest galaxies, NGC 5098a and NGC 5098b, and NGC 5096. The continuous curves are adaptive kernel approximations for the distributions. The inset displays the $0.024 < z < 0.045$ redshift distribution of galaxies in the 50 arcmin cone centred on NGC 5098, with velocity bins of 150 km s^{-1}; grey bins indicate the galaxies that, although selected by SG, were discarded by the gap analysis.

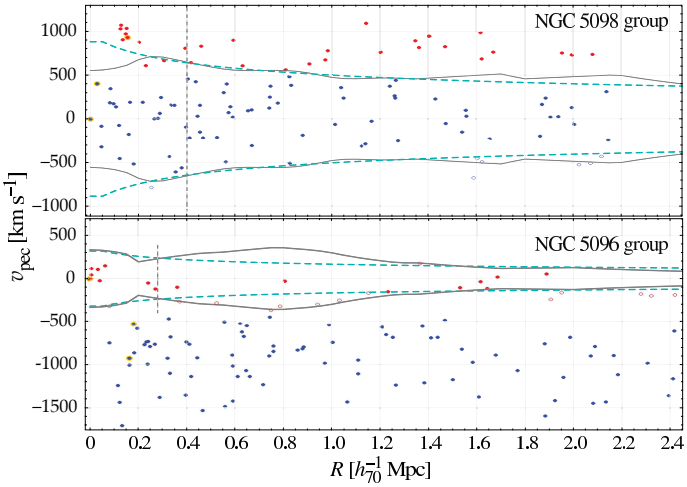

Figure 5. Projected phase space, $(R, v_{\rm pec})$, for the each of the two subgroups. Top panel: Projected phase space of subgroup 1 (NGC 5098a subgroup) ; Bottom panel: Projected phase space of subgroup 2 (NGC 5096 subgroup). The *Blue* points correspond to galaxies belonging to subgroup 1 and the *red* points to subgroup 2. The dominant galaxies are marked with *yellow haloes*. *open circles* are galaxies outside or very nearby the caustics lines and as so considered non-members of the group. The *grey* lines are the caustic lines, whereas the *green* dashed lines are the corresponding best fit NFW profile. The *dashed* vertical lines show R_{200}. Notice the compact group of galaxies around NGC5096 at $(R, v_{\rm pec}) \approx (0.1\, h_{70}^{-1}$Mpc, 1000 km s$^{-1})$ in the top panel (at the origin in the bottom panel).

emission between the core of the NGC 5098 group and the compact substructure of NGC 5096 (Region D). It has a bluer colour ($g - r = 0.44$) compared with the NGC 5098a and NGC 5098b pair, and also compared to the compact core of NGC 5096. There is no galaxy clearly linked to this structure, but its location suggests that it may have been produced by a past interaction between one or more galaxies pertaining to the NGC 5098 group and to the NGC 5096 compact group, assuming it has passed near the central region of the NGC 5098 group. The large-scale view of the NGC 5098 and NGC 5096 structure displayed in the left panel of Fig. 3, shows a large diffuse intragroup light component linking both substructures (corresponding to regions C and D in the right panel of this Figure) The blue colour of this diffuse component suggests it originates from the tidal stripping of galaxies.

This scenario, where NGC 5096 has passed near the core of the NGC 5098 group, is further corroborated by our dynamical analysis. We have clearly detected two structures in velocity space, separated by ≈ 700 km s^{-1}. The gap analysis done with a sample of 112 galaxies suggests that the groups are not isolated and may have undergone recent interactions. A further evidence for the past interaction between the groups comes from the X-ray analysis by Randall et al. (2009), where they detect a spiral arm feature which is typically related to a sloshing phenomenon. In Fig. 2 we show that the diffuse X-ray emission has a secondary component around NGC 5096, linked to the main emission from the NGC 5098 group.

6. Conclusions

We present the analysis of deep images in the g and r bands acquired with CFHT/MegaCam, as well as the redshift measurements available within a 50 arcminute radius around the galaxy NGC 5098a. Public X-ray data from the Chandra observatory were also used.

We confirm that NGC 5098 and NGC 5096 are two dynamically distinct groups, with a velocity difference about 700 km s^{-1} and we suggest that they are already interacting, with a possible previous passage of NGC 5096 near the core of NGC 5098. This conclusion comes from the intragroup light that we detect, which may be due to tidal stripping from galaxy members of both groups. We posit that this interaction may be the reason for the sloshing feature observed in X-rays and for the extended emission linking both groups. The skewness observed in the velocity distribution of the NGC 5098 group may also be a result of the perturbation induced by the passage of the NGC 5096 group.

Further work would greatly benefit from numerically modelling this complex system with customized hydrodynamical simulations.

Most of this report was based on the work of Lima Neto et al. (2025). Many details and discussions of the analysis presented here can be found in that work.

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