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Research Article

Dynamical Study of a Trio-Clusters of Galaxies: A2550-A2554-A2556

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Abstract: In this paper, we share the analysis results of Trio-Clusters of galaxies in the heart of Aquarius constellation. Super clusters are dense regions of the sky; close passages and mergers are highly probable. Thus, the line of sight images of A2550-A2554-A2556 looks like a trio-structure. We search for dynamical relations and the mutual gravitational effects on the structural evolutions by using *ASCA*, and *Chandra* archival data. The Newtonian gravitational binding criterion shows no clear bound by considering the potential and kinetic energy of the system. It looks like the Trio-Cluster is very close due to projection effects and hasn't started its cosmic gravitational dance.

Keywords: galaxy, clusters, intracluster gas, X-ray, cosmology

1. INTRODUCTION

Galaxies gravitationally gather to form clusters, and clusters form superclusters. Superclusters of galaxies are the largest known structures in the Universe. Since they are composed of multiple structures at the same redshift distance, they are the best cosmic laboratories. By characterizing the observed properties, it is possible to further understand the formation and evolution of galaxies and the Universe.

First studies of the gravitational structures from the Aquarius region were carried by Ciardullo et al. (1985). They studied the optical spectroscopic redshifts of the brightest cluster galaxies (BCGs) to pinpoint the galaxy clusters and listed 22 members within $0.08 < z < 0.24$ redshift intervals A more extensive research was done by Batuski et al (1999) for the Aquarius field. By using the all-available redshift data Batuski et al (1999) found a filamentary structure along the clusters, and also reported five intersection point about 150 times more crowded and denser than the mean field. Our goal in this work is to study gravitational relation numerically between Abell 2550, Abell 2554 and Abell 2556. Figure-1 top panel shows the merged X-ray image of 0.3-2.4 keV soft energy band *ASCA* on left, and 0.3-7 keV all energy band *Chandra* on right. *Chandra* ACIS chip configuration is overlaid on ASCA image for visual aid.

2. TRIO CLUSTER MEMBERS

The portion of Aquarius region for this study is (see Figure-1) composed of three clusters of galaxies: A2550, A2554 and A2556. Due to projection effects the field exhibit a clear three-body structure and thus named as *Trio cluster*. Individual X-ray brightness maps show elongations towards each other. The X-ray contours of A2556 are not symmetrical, rather elongated in the northwest-southwest direction, which is the direction of A2554 at 12.5 arcmin. In order to understand further gravitational relations and dynamical interactions of these members, one needs to analyze the binding conditions numerically. In this section, we present brief notes on individual clusters, mainly from the previous studies based on the X-ray gas properties.

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Abell 2550: The cluster located at the heart of the Trio filamentary structure (R.A.=$23^h11^m33^s.0$, decl.=$-21^d44^m42^s$, J2000, at $z = 0.122$, Abell at al. 1989, Batuski et al. 1999). X-ray contours (Figure-1 bottom right) show a quite relaxed system with no clear elongation. There is a faint X-ray clump south of A2550's core, which was also reported by Sun et al. (2009).

Abell 2554: A2554 (J2000; R.A.: $23^h13^m20^s.7$, decl.: $-21^d30^m02^s$) is a non-relaxed cluster at redshift $z = 0.1108$ (Caretta et al. 2002) with an X-ray luminosity $L_X = 1.78{\times}10^{44} erg\ s^{-1}$ (Jones & Forman 1999). Based on the redshift information radial velocity is reported to be $v_r = 33246 \pm 175\ km\ s^{-1}$ and velocity dispersion is $\sigma_r = 827\ km\ s^{-1}$ by Zabludoff et al. (1990).

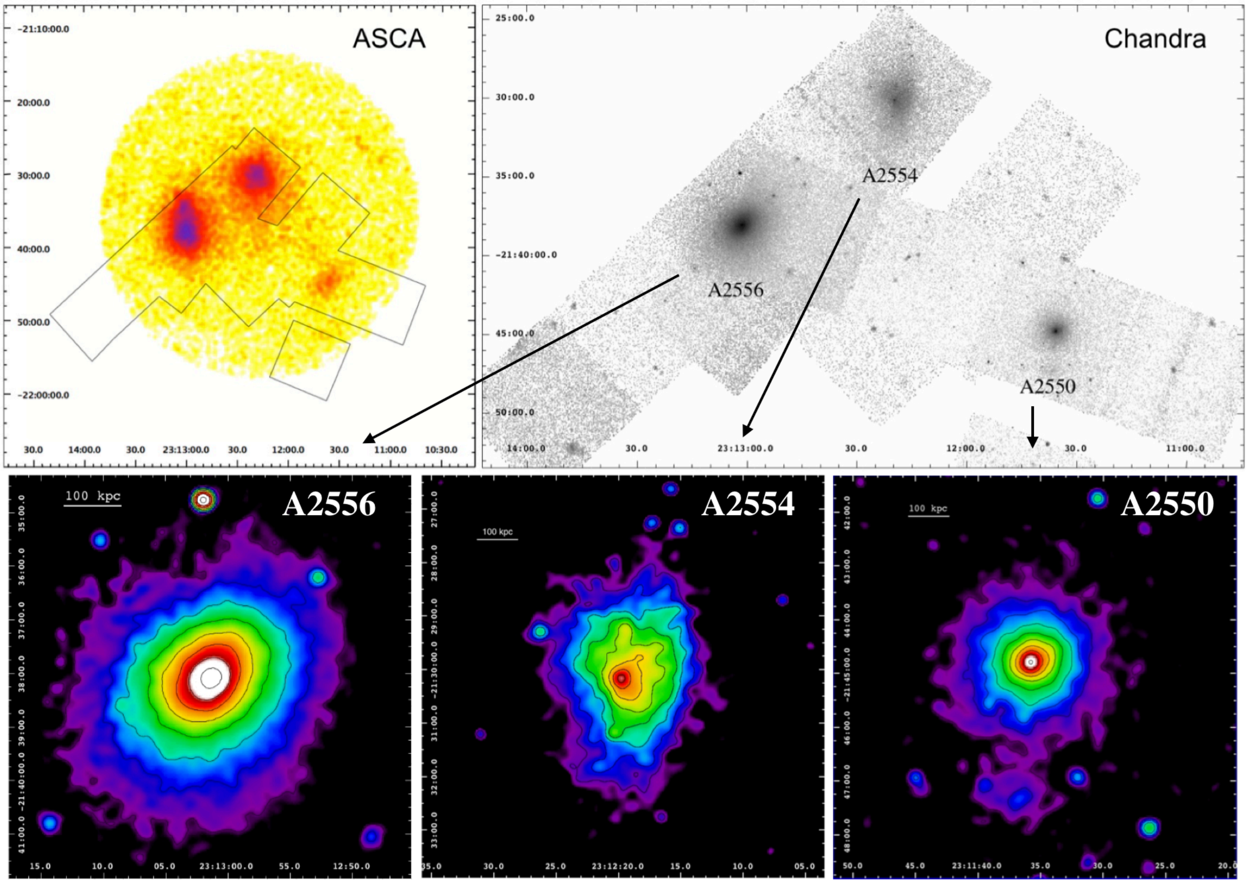

Figure-1**.** Left: the 0.3-2.4 keV low band *ASCA* GIS image of A2550-A2554 & A2556. Right: the 0.3-7 keV background subtracted, exposure corrected *Chandra* mosaic image. *Chandra* merged field of view is overlaid on *ASCA* image for visual aid.

There is a clear brightness edge in Figure-1, which was studies extensively by Erdim et al. (2019) and a cold front is defined at the southeast of A2554 core. It is noteworthy that the direction of the cold front is aligned with the neighboring cluster A2556. Elongated X-ray image is considered as a potential evidence for an ongoing merger.

Abell 2556 (R.A.=$23^h13^m03^s.3$, decl.=$-21^d37^m40^s$, J2000) is located at $z = 0.0871$ (Batuski et al. 1999). The cluster is moderately bright in X-rays, $L_X = 2{\times}10^{44} erg\ s^{-1}$ (Ebeling et al. 1996). The system has a velocity dispersion of $\cong 872\ km\ s^{-1}$ (White et al. 1997) and a virial mass of $\cong 2.5 \pm 0.1{\times}10^{15} M_{\odot}$ (Reimers et al. 1996). High energy Chandra X-ray data was studied in detail and by Zhenzhen Qin et al. (2013) and a weak shock front is reported at approximately 160-kpc northeast of the cluster center.

3. A DYNAMICAL MODEL FOR THE STRUCTURE

We use the Newtonian gravitational binding criterion by comparing the gravitational potential energy and the kinetic energy of the clusters, in order to test numerically whether these multiple structures are physically connected. The two body dynamics are well defined by Beers et al. (1982) and Gregory & Thomson (1984). There are many successful applications to the binary systems in the literature; e.g. A1367 (Cortese et al. 2004), A3716 (Andrade-Santos et al. 2015), and A3653 (Caglar et al. 2018).

This model allows us to evaluate the dynamical state of clusters. Based on the results we can estimate the probability that (i) the system merging, (ii) the system is gravitationally bound but going away from each other, or (iii) the structures are unbound. By using the Newtonian dynamics and Gravitational potential energy of a system.

$$V_r^2 R_p \leq 2GM \sin^2\alpha \ \cos\alpha, \tag{1}$$

The radial velocity difference, V_r, and the projected separation, R_p, are related to the velocity and separation by

$$V_r = V \sin\alpha \, , R_p = R \cos\alpha, \tag{2}$$

The angle α is the projection angle between the plane of the sky and the line connecting the two systems (i.e., if the clusters are at the same distance the angle is zero). The values of V and R are true (3D) velocity and positional separation between the two structures. The solutions to the equation of motion for gravitationally bound systems are given by Beers et al. (1982):

$$t = \left(\frac{R_m^3}{8GM}\right)^{1/2} (\chi - \sin\chi), \tag{3}$$

$$R = \frac{R_m}{2}(1 - \cos\chi), \tag{4}$$

$$V = \left(\frac{2GM}{R_m}\right)^{1/2} \frac{\sin\chi}{(1 - \cos\chi)} \tag{5}$$

Here, R is the separation at time t, R_m is the separation at the maximum expansion, M is the total mass of the system, and χ is the developmental angle. Similarly, the parametric solutions for an unbound case are also described by Beers et al. (1982). For gravitationally unbound systems, the parametric equations are

$$t = \frac{GM}{V_\infty^3}(sinh\,\chi - \chi), \tag{6}$$

$$R = \frac{GM}{V_\infty^2}(cosh\,\chi - 1), \tag{7}$$

$$V = V_\infty \frac{sinh\,\chi}{(cosh\,\chi - 1)} \tag{8}$$

where V_∞ is the asymptotic expansion velocity.

Table-1. The physical parameters: mass, velocity and distance for the clusters.

	A2550	**A2554**	**A2556**
Mass ($M_\odot$)	0.08×10^{15}	0.66×10^{15}	2.50×10^{15}
Velocity ($km\ s^{-1}$)	36755	33217	26112
Distance (Mpc)	465	426	343

Using the parameters previously for the cluster from the archival data: the masses are $0.08{\times}10^{15}M_{\odot}$ (Sun et al. 2009), $0.66{\times}10^{15}M_{\odot}$ (Pierson & Batuski, 2013) and $2.5{\times}10^{15}M_{\odot}$ (Krick & Bernstein, 2007), the velocities are 36755 $km\ s^{-1}$, 33217 $km\ s^{-1}$ and 26112 $km\ s^{-1}$, the distances are 465 Mpc, 426 Mpc and 343 Mpc for A2550, A2554 and A2556, respectively. The important parameters values, which are used for binding calculations, are listed in Table-1. By considering the radial velocities (V_r) as a function of projection angle (α) between the binary systems are solved by bound and unbound states (Gregory & Thomson 1984),

$$\tan\alpha = \frac{tV_r}{R_p}\frac{(\cos\chi - 1)^2}{\sinh\chi\,(\chi - \sinh\chi)}, \tag{9}$$

$$\tan\alpha = \frac{tV_r}{R_p}\frac{(\cos\chi - 1)^2}{\sinh\chi\,(\sinh\chi - \chi)}, \tag{10}$$

respectively. We compute A2550-A2554 and A2554-A2556 relative binding probabilities. Figure-2 shows the projection angle (α) as a function of the relative radial velocity difference (V_r). The black vertical lines represent the relative radial velocities. The blue and green curved lines represent bound incoming and outgoing solutions, respectively. And the orange line is the unbound solution. As it is clearly seen, the physical values of the relative radial velocities (black-lines) do not match with the bound solutions (the curved lines) for both systems. Only the unbound solutions are possible.

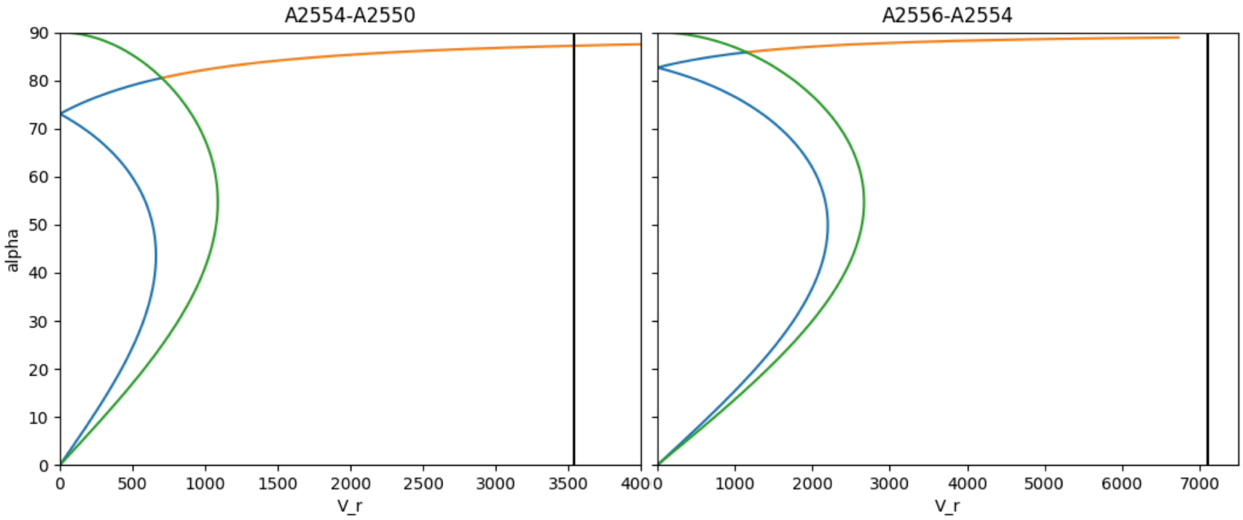

Figure-2. Projection angle (α) as a function of the relative radial velocity difference (V_r) of the clusters A2554-A2550 on the left, and A2556-A2554 on the right. The straight vertical black lines represent the relative radial velocities. The blue and the green lines represent bound incoming and outgoing solutions. The orange line is the unbound solution.

4. SUMMARY and CONCLUSION

We present the X-ray analysis results of a multiple cluster system: A2550-A2554-A2556. The X-ray brightness maps reveal elongations towards the close neighbors, which can be considered as the traces of the mutual gravitational awareness. Two-body Newtonian Dynamical models suggest unbound-incoming solutions for the systems. The trio structure members are moving towards each other, but gravitationally not bounded strongly.

The results suggest that in highly dense part of the sky (e.g. superclusters) the systems may look very close to each other due to the projectional affects. Although the close passages and merger events are highly possible, detailed numerical analysis can judge whether the systems are gravitationally related or not.

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