Acceleron Aerospace Journal || AAJ.11.2106-2503
Volume 4, Issue 1, pp (831-846)
Review Paper
E-ISSN- 2583-9942 || DOI: 10.61359/11.2106-2503

Exploring the Formation, Dynamics, and Structure of Galaxy Clusters: A Comprehensive Analysis

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Abstract: This study explores the formation, structure, and dynamics of galaxy groups and clusters, highlighting their significance in the cosmic web. Galaxy clusters are massive, self-gravitating systems that display complex interactions influenced by dark matter and the intracluster medium (ICM). Recent advancements in X-ray and optical observations have significantly improved our understanding of the morphology and kinematics of these clusters, shedding light on the processes governing their evolution. The research employs the virial theorem to determine mass distributions and examines gravitational lensing effects to probe the mysterious nature of dark matter. Key challenges addressed include understanding how galaxy clusters form, analyzing the dynamics of the galaxies within them, and identifying the missing mass that holds these structures together. By combining observational data with theoretical models, this investigation aims to enhance our comprehension of the Universe's large-scale structure and the fundamental forces driving galaxy group dynamics.

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1. Introduction

The Galaxies clustering range from small groups, to large clusters containing hundreds and thousands of galaxies, to the structures of enormous scales, forming the filaments of the Cosmic Web. Clustering can occur on all scales and the probability of an isolated galaxy is very low. Rich clusters of galaxies are the largest self-gravitating bound systems in the Universe and are therefore of particular interest. These systems of size ranges from $13h^{-1}Mpc$ and mass $\sim 10^{14}-10^{15}h^{-1}M_{\odot}$. Their composition accounts for dark matter ($\sim 75\%$), intracluster medium ($\lesssim 20\%$) and a small fraction of stellar bodies, dust and MACHOs, of them mostly situated in galaxies. By comparing various properties of clusters like, velocity dispersion, hot gas luminosity, mass distribution suggests that various components of the galaxy clusters are in dynamical equilibrium inside the deep potential wells of the systems. The extremely deep gravitational potential barrier of clusters can be detected directly using the X-ray bremsstrahlung emission of ICM gas which forms an atmosphere of hydrostatic nature inside the cluster. In any case, spatially inhomogeneous thermal and non-thermal emission of the Intracluster medium (ICM), saw in certain clusters in the X-ray and radio groups, and the kinematic and morphological isolation of galaxies are a mark of non-gravitational procedures, progressing cluster merging and interactions. In the as of now acknowledged 'base up' situation for the formation of structures, where minute variances of the in any case early-stage field of (S. Schindler et al., 2008) homogeneous densities are exaggerated by gravity. Galaxy clusters are the most extensive hubs of the giant filamentary structure of the vast cosmic web and structure by anisotropic and irregular accumulation of mass, as per the greater part of the observational proof. In this model of the universe ruled by cool dark matter (CDM), right now most baryons are expected to be in an uncoalesced part as opposed to be in galaxies; Moreover, $\sim 60\%$ of this diffused marks temperature of $\sim 0.01-0.09keV$, permeating the distribution of the dark matter in the filaments. In correspondence with the neighborhood densities, the temperature of this Warm-Hot Intergalactic Medium (WHIM) shifts in the external locales of clusters and areas of low density has been the chase of much late observational exertion.

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** Received: 07-December-2024 || Revised: 17-December-2024 || Accepted: 28-January-2025 || Published Online: 30-January-2025.

2. Problem Statement

In the study on galaxy clusters conducted several key problems and questions arise. These problems serve as the foundation for the research project and drive the investigation into the nature and properties of galaxy clusters. The statement of problems includes:

1. Understanding Galaxy Cluster Formation: One of the primary problems addressed in this study is the understanding of how galaxy clusters form. While it is known that clusters are massive, self-gravitating systems, the specific mechanisms and processes involved in their formation remain a mystery. Investigating the formation of galaxy clusters is crucial for unraveling the larger picture of cosmic structure and evolution.

2. Exploring the Morphology and Kinematics of Galaxy Clusters: Another problem addressed in this research is the exploration of the morphology and kinematics of galaxy clusters. By studying the spatial distribution, shapes, and motions of galaxies within clusters, the researcher aims to gain insights into the underlying dynamics and interactions. Understanding the morphology and kinematics of clusters is essential for deciphering their evolutionary history and the physical processes at work.

3. Constraining the Mass Distribution of Galaxy Clusters: The accurate determination of the mass distribution within galaxy clusters is a significant problem in astrophysics. By applying the virial theorem and comparing the results with radiation data, the researcher aims to constrain the mass distribution and gravitational potential of the clusters. This problem is crucial for understanding the overall structure and stability of galaxy clusters.

4. Investigating the Nature of Dark Matter: Dark matter, which constitutes a significant portion of the mass in galaxy clusters, presents a fundamental problem in astrophysics. The researcher aims to investigate the nature of dark matter by studying its effects on dynamics and gravitational lensing within the clusters. Understanding the properties and behavior of dark matter is essential for comprehending the formation and evolution of galaxy clusters.

5. Identifying the Missing Mass Holding Clusters Together: The majority of the mass in galaxy clusters is composed of dark matter, which cannot be directly observed. The problem of identifying and understanding this missing mass is crucial for unraveling the gravitational forces that hold the clusters and their constituent galaxies together. By studying the dynamics and interactions within the clusters, the researcher aims to shed light on the nature and properties of this missing mass.

3. Classification and Morphology of Clusters

As has been referenced earlier in this content galaxies are not thrown arbitrarily all through the universe; instead about all galaxies settle in association, either in groups or in clusters. In both the types, galaxies are bound gravitationally to each other and orbit the barycenter (center of mass) of the system.

Groups usually have less than 60 members and are about $1.4h^{-1}Mpc$ across. The constituent galaxies in a group have a velocity dispersion of about $160kms^{-1}$ and the mass of an average group is on the order of $2 \times 10^{13}h^{-1}M_{\odot}$, calculated using the virial theorem. Moreover, an average group have the mass-to-light ratio of about $260h\, M_{\odot}/L_{\odot}$, which is suggestive of copious amounts of dark matter.

Clusters on the contrary may contain from 60 galaxies (a poor cluster) to thousands of galaxies (a rich cluster), within a field of space about $6h^{-1}Mpc$ across. The characteristic galaxies motion in a cluster is more rapid with respect to other members than those of galaxies inhabit in a group. The characteristic velocity dispersion of a galaxy cluster is $700kms^{-1}$, exceeding $1000kms^{-1}$ for extremely rich clusters. An average cluster's virial mass is approximately $1 \times 10^{15}h^{-1}M_{\odot}$ and its mass-to-light ratio is about $400h\, M_{\odot}/L_{\odot}$, once more suggestive of huge amounts of dark matter (S. Schindler et al., 2008).

Rich clusters may be further classified as regular, intermediate and irregular. To explain the morphological depiction of clusters, different characterization plans have been proposed to describe various aspects of their properties (Table-1) (Bahcall, Neta, 1977) These include:

- **Bautz–Morgan types I, II, III:** In clusters of type I, there is a main central galaxy, which is much brighter than the next brightest individual cluster galaxy and is usually a cD galaxy. In type III, there is no dominant galaxy.

- **Galaxy content:** The various types of galaxies in a cluster can be characterized by the associated number of S0, elliptical and spiral galaxies.
- **Symmetry:** The clusters can have shapes like spherical, intermediate or irregular.
- **Central concentration of the galaxy distribution:** Described as very little, moderate or high.
- **Central profile:** The radial gradient of the cardinal density of galaxies can be characterized as steep, intermediate or flat.
- **Mass segregation:** Generally, in case of some clusters, the most prominent galaxy at the center is massive due to continued merging; in others there is little or no mass separation as a function of radius.

Table 1: Rich galaxy cluster properties (Bahcall, 1977)

Property/Class	**Regular**	**Intermediate**	**Irregular**
Bautz–Morgan type	I, I–II, II	(II), II–III	(II–III), III
Galaxy content	Elliptical/S0 rich	Spiral-poor	Spiral-rich
E : S0 : S ratio	3 : 4 : 2	1 : 4 : 2	1 : 2 : 3
Symmetry	Spherical	Intermediate	Irregular shape
Central concentration	High	Moderate	Very little
Central profile	Steep gradient	Intermediate	Flat gradient
Mass segregation	Marginal evidence for m − m(1) < 2	Marginal evidence for m − m(1) < 2	No segregation
Examples	Abell 2199, Coma	Abell 194, 539	Virgo, Abell 1228

Rich clusters of galaxies are of particular importance in astronomy. Much of the initial work was carried out by George O. Abell, who was one of the key observers for the 48-inch STPOSS. Abell named clusters are correlated, both with one another and with the distribution of the galaxies. These associations were at first described in terms of the super clustering of galaxies by Zwicky and Abell. Some impression of the connection between the average distribution of galaxies in the Universe and the clusters of galaxies we can get from the 'Cone Diagram' of the distribution of galaxies acquired from the AAT 2dF Galaxy Survey (Fig. 1) (Colless et al., 2003). If the distribution of galaxies in space were homogeneous, the points would be scattered uniformly over the region within which the sample is complete. On the contrary, the observation shows that the distribution is eminently inhomogeneous, with the galaxies concentrated into filaments with huge voids in between. This distribution is somewhat ‘sponge-like’ and is often hinted as the cosmic web. The rich cluster of galaxies are generally found in the high-density regions of the Cosmic Web i.e. where the walls intersect. These features of the galaxy distribution can be quantified in terms of cross-correlation functions between the distribution of clusters and galaxies in general.

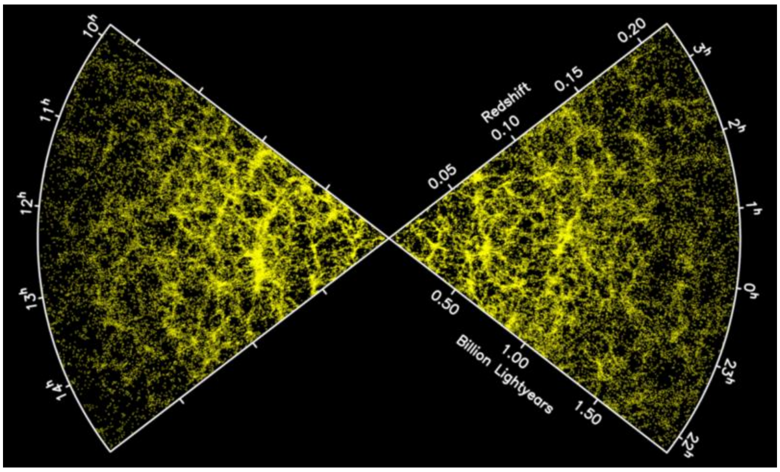

Figure-1 From 1995 and 2002, the 2dF redshift study utilized the two-degree field spectroscopic facility on the Anglo-Australian Telescope to quantify the redshifts of around 220,000 galaxies. (Colless, Matthew, et al., 2003).

4. Methodology of Study

In this study on galaxy clusters, aims to explore various aspects of these massive, self-gravitating systems. The methodology employed in this research involves a multi-faceted approach, combining observational research, theoretical analysis, and data comparison.

1. Observational Research: The first step in the methodology is to conduct extensive observational research on galaxy clusters. This involves gathering data from X-ray and optical observations conducted over the past decade. By analyzing these observations, the researcher aims to gain a comprehensive understanding of the morphology and kinematics of galaxy clusters. This step is crucial in establishing a baseline understanding of the clusters and identifying key areas for further investigation.

2. Theoretical Analysis: Building upon the observational research, the researcher then proceeds to perform theoretical analysis. This involves applying established principles of plasma physics to study the behavior of the intracluster medium (ICM) gas within the clusters. By examining the thermal and non-thermal emissions of the ICM, as well as the kinematic and morphological characteristics of galaxies within the clusters, the researcher can gain insights into the underlying physical processes at work. This step is essential in unraveling the dynamics and interactions within the clusters.

3. Application of Viral Theorem: To further understand the mass distribution of the clusters, the researcher applies the viral theorem. By analyzing the motions and velocities of galaxies within the clusters, the researcher can estimate the mass distribution and gravitational potential of the systems. This analysis provides valuable information about the equilibrium and stability of the clusters. By comparing these results with the mass distribution inferred from radiation data, the researcher can validate the findings and refine the understanding of the clusters' structure.

4. Comparison with Radiation Data: The next step in the methodology involves comparing the mass distribution obtained from the virial theorem with the mass distribution inferred from radiation data. Specifically, the researcher examines the bremsstrahlung emissivity, which is the X-ray radiation emitted by the ICM gas. By analyzing this radiation, the researcher can further refine the understanding of the mass distribution and the presence of dark matter within the clusters. This step provides crucial insights into the nature of the clusters and the role of dark matter in their formation and evolution.

5. Investigation of Missing Mass: Lastly, the researcher focuses on investigating the majority of missing mass that holds the galaxy clusters and their constituent galaxies together. This missing mass, known as dark matter, poses a significant mystery in astrophysics. By studying the dynamics, gravitational lensing effects, and kinematic behavior of galaxies within the clusters, the researcher aims to shed light on the nature and properties of dark matter. This investigation involves analyzing the gravitational effects and interactions within the clusters, providing valuable insights into the overall structure and composition of the clusters.

5. Results and Discussion

Group of Galaxies

5.1 The Local Group

Around 30 galaxies are known to be residing in approximately $1Mpc$ of the Milky Way (Figure 2) (Grebel, E. K., 2001," Microlensing 2000) This assortment of galaxies is referred to as the local group. Its zero-velocity surface and is about $1.2Mpc$from the barycenter. Its most salient members are the three spiral galaxies: Milky Way galaxy, M31 (Andromeda galaxy), and M33. The next most luminous are The Large and Small Magellanic Clouds which are two of the 13 irregular galaxies group. The rest of the galaxies are dwarf (ellipticals or spheroidal) which are quite faint and very small. It is clear from Figure 2 that most of these galaxies have concentrated around the Milky Way and Andromeda galaxies which are on opposite sides of the Local Group and about $r = 770kpc$ apart from each other. The Magellanic Clouds and 9 of the dwarf ellipticals and dwarf spheroidal are found near the Milky Way. Moreover, several of them are found in the Magellanic Flow (the long filament of hydrogen gas that was stripped tidally from the Magellanic Clouds around $150 million years ago$). Interestingly, it should also be noted that the three principal spiral galaxies have warped disks that resemble an integral sign ($\oint$) when viewed edge on. In fact, the line of sight from Earth passes twice through some parts of the disk of M33.

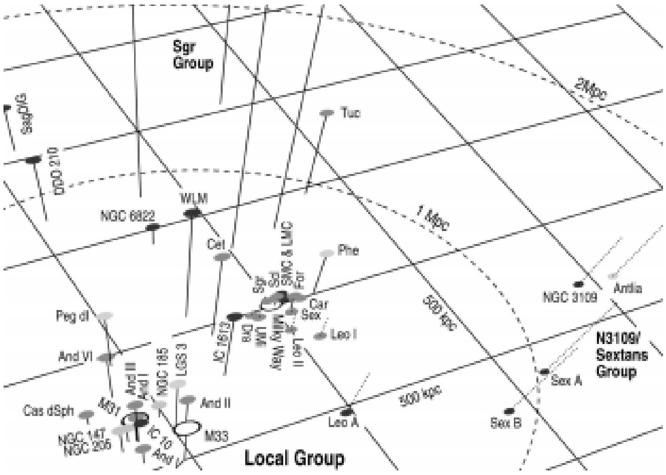

Figure-2 The Local Group (Grebel, E. K., 2001," Microlensing 2000: A New Era of Microlensing Astrophysics",239,280)

Apparently, the gravitational attraction between the Andromeda and Milky Way galaxies has overcome their tendency to expand along with the Hubble flow and are advancing towards each other with a relative velocity of $v = 120kms^{-1}$. As a result, the collision is eminent in approximately $t_c = \frac{r}{v} = 6.3billionyrs$. Indeed, it can be said that the entire Local Group is still in a state of collapse.

Because the M31 and Milky Way reign the Local Group, generating some 92% of its luminosity, their movement toward one another gives a chance to evaluate their united mass. Here we can assume that leading the Big Bang the two newly formed system of galaxies were initially moving apart and at some time in the past their gravitational attraction grew weak, halted and reversed their original recessional motion. The Milky Way and Andromeda are therefore orbiting each other with an eccentricity $e \simeq 1$ (i.e. on a collision course). From conservation of energy the separation and orbital velocity are related by,

$$v^2 = GM\left(\frac{2}{r} - \frac{1}{a}\right) \tag{5.1}$$

where M is the combined mass of the two galaxies. By Kepler's third law, the orbit's semimajor axis $a$is related to its period, P by:

$$P^2 = \frac{4\pi^2}{GM}a^3 \tag{5.2}$$

Combining these relations to eliminate a and leads to

$$v^2 - \frac{2GM}{r} + \left(\frac{2\pi GM}{P}\right)^{\frac{2}{3}} = 0 \tag{5.3}$$

We input the values, $r = 770kpc \wedge v = 119kms^{-1}$ to obtain the total mass M we need an estimate of the orbital period, P. When the galaxies finally combine in the future, they will have returned to their initial configuration, and one orbital period will have elapsed since the Big Bang. Let us therefore use,

$$P = t_H + t_c\ , \tag{5.4}$$

where $t_c = r/v$ is roughly the time until they collide. This is however an overestimate of the period as the Milky Way and M31 will accelerate as they approach their fate.

MY WORK WITH PUBLICLY AVAILABLE DATA:

From the WMAP (Wilkinson Microwave Anisotropy Probe) value $h = 0.71$ (so $H_0 = 71 kms^{-1} Mpc^{-1}$) the total mass is calculated to be

$$M = 7.0 \times 10^{42} kg = 4.0 \times 10^{12} M_{\odot}.$$

This measurement of the mass of the Local Group is significantly more than the luminous mass saw in these galaxies. The luminosity of the Milky Way is about $2.3 \times 10^{10} L_{\odot}$ in B- band and M31 is roughly twice of Milky Way. Thus, the mass to light ratio is estimated to be $M/L = 57\ M_{\odot}/L_{\odot}$. Note that a smaller period gives a larger mass. This means that, because the value of P was overestimated, M/L has been underestimated. These numbers are much larger than the value of $M/L \simeq 3\, M_{\odot}/L_{\odot}$ for the luminous matter in the Milky Way's thin disk and central bulge. Our WMAP result of $M/L \simeq 57\, M_{\odot}/L_{\odot}$ with the estimates when the Milky Way's dark halo is included. Apparently, astronomers are consistent and have seen less than approximately 10% of the matter that makes up the Milky Way and Andromeda galaxies.

5.2. The Coma Cluster

The Coma cluster is the closest, rich distinctive cluster and it is in the constellation Coma Berenices, 15° north (in declination) of Virgo cluster. It consists of approximately 10,000 galaxies with majority of them being dwarf-ellipticals, too faint to be seen (Fig. 3) (Coma Cluster in Visible and Infrared, NASA/JPL-Caltech/GSFC/SDSS). It is about 90 Mpc away from Earth or 5.4 times farther away than the Virgo cluster. The angular diameter of the cluster is about 4° or linear diameter of 6 Mpc. Generally, in a rich, cluster most of the galaxies are ellipticals and S0's and so, is the case for the Coma Cluster. The cluster's center is home to two bright cD elliptical galaxies but out of the thousand bright galaxies, only 10% are spirals and irregulars.

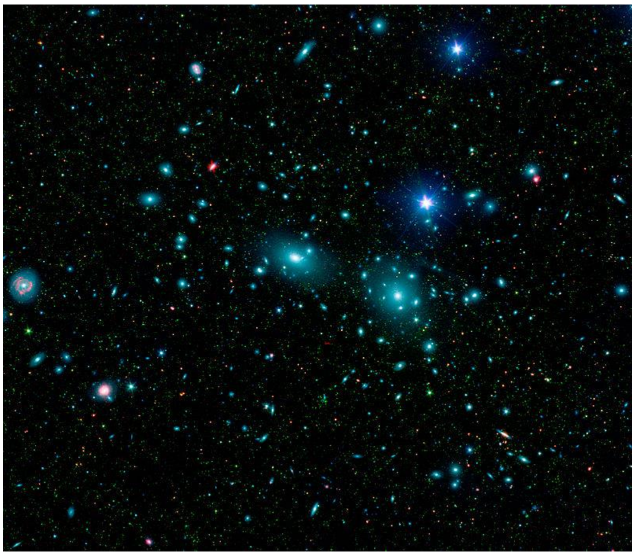

Figure-3 The Coma Cluster in short-wavelength infrared (green), long-wavelength infrared (red), and visible light (Image Courtesy: NASA/JPL-Caltech/GSFC/SDSS)

The transcendence of early type galaxies in a cluster might be because of the greater probability of interactions (the relation of morphology-density). Maybe before, more spirals existed in the Coma cluster and other rich, customary clusters, however tidal interactions and mergers pulverized the winding morphology leaving behind ellipticals and S0's. Then again, early type of galaxies may essentially exist as a result of various hierarchical leveled mergers of protogalaxies close to the base of the cluster's gravitational well, in districts where dark matter would normally gather.

In 1933 Fritz Zwicky estimated the line of sight (radial) velocities of galaxies in the Coma cluster (Zwicky, Fritz, 1933). Using those observations of Doppler-Shift spectra, he determined the dispersion in their radial velocities, presently known to be $\sigma_r = 977kms^{-1}$. Zwicky at that point utilized the virial hypothesis to estimate and calculate the mass of the Coma cluster. By and large the Coma cluster's intensity profile, $I(r)$, follows a distinctive $1/r^4$ law like those that portray the intensity profiles of elliptical galaxies and the Milky Way's halo and bulge. Apparently, similar to the stars that make up elliptical galaxies and the spheroidal parts of spirals, the galaxies in the Coma cluster have become dynamically relaxed and are in a equilibrium condition. This makes the virial theorem a suitable strategy to use.

MY WORK WITH PUBLICLY AVAILABLE DATA:

For the Coma cluster the dispersion in the radial velocity is $977kms^{-1}$ and the cluster radius $R = 3Mpc$ which leads to a mass of

$$M \approx \frac{5\sigma_r^2 R}{G} = 3.3 \times 10^{15} M_\odot$$

for the Coma cluster. Since the visual luminosity of the Coma cluster is about $5 \times 10^{12} L_\odot$, the mass to light ratio of the cluster is $M/L \approx 660\, M_\odot/L_\odot$

Zwicky realized the criticalness of this result and expressed that in the Coma cluster, "the combined mass ... impressively exceeds the aggregate of the majority of individual galaxies." He understood that there isn't sufficient visible (baryonic) mass to bind the cluster together. If not for the presence of a huge quantity of hidden matter the galaxies in the Coma cluster would have dispersed long ago. After forty years when the rotation curve of the Andromeda galaxy was estimated, astronomers understood the significance of Zwicky's observations.

A fraction of Zwicky's "missing mass" was found with the High Energy Astronomical Observatory (HEAO) arrangement of satellites that first went operational in 1977. They uncovered that numerous clusters of galaxies discharge X-rays from a significant part of the cluster's volume. These satellites along with optical data showed that clusters of galaxies contain an intracluster medium (ICM). The intracluster medium has two segments. One is a diffuse, irregular dispersion of stars, the other segment is a hot intracluster gas that is spread pretty much homogeneously, consuming the space between the galaxies and filling the cluster's gravitational potential well. The X-ray radiances lie in the range $10^{36} 10^{38} W$, with more rich clusters radiating more brilliantly in X-rays. The center of the Coma cluster holds $3 \times 10^{31} M_\odot$ of X-ray producing gas, and the center of the Virgo cluster contains around $5 \times 10^{13} M_\odot$. Figure 4 reflects the emission of X-rays from the hot gas that permeate the Coma cluster (Briel, Ulrich, et al., 2000). Generally, the mass of the hot gas is several times greater than the total visible stellar masses in the cluster

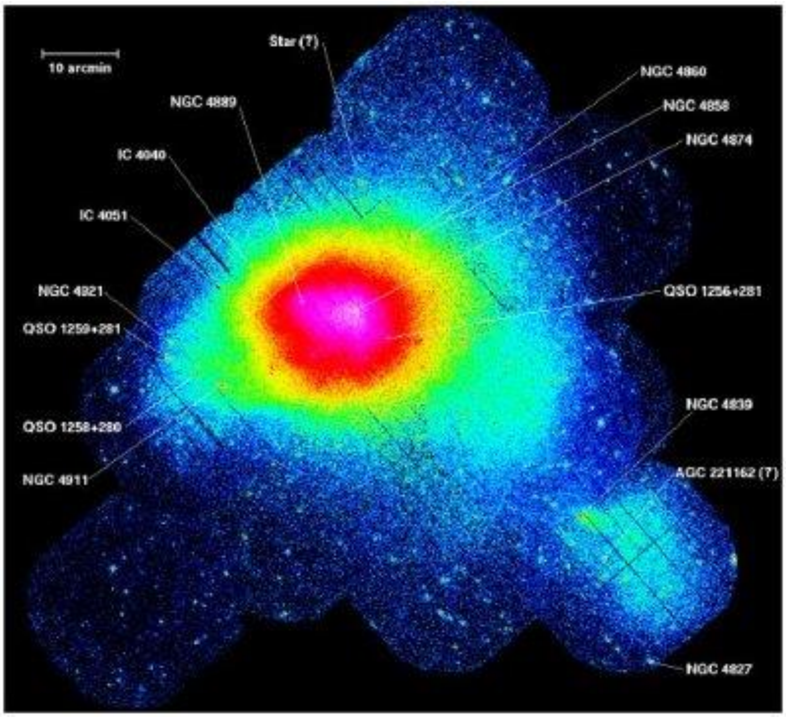

Figure-4 The Coma Cluster in X-ray spectrum captured by XMM(X-ray Multi Mirror) Newton Observatory.

(Image courtesy: U. Briel, Max Planck Institut fur extraterrestrische Physik Garching Germany and the European Space Agency.)

Thermal bremsstrahlung, a similar component that producing the X-rays originating from the hot gas inside individual galaxies (portrayed for M87 in the Virgo cluster also), is also at work here. For completely ionized hydrogen gas, the energy transmitted per unit volume per unit time between frequencies ν and $\nu + d\nu$ is given by,

$$l_\nu d\nu = 5.44 \times 10^{-40}(4\pi n_e^2)T^{-1/2}e^{\frac{h\nu}{kT}}d\nu W m^{-3} \tag{5.5}$$

where n_e is the number density of electrons and T is the gas temperature. One of the versions of this spectra for the Coma cluster is shown in Figure 5 (Henriksen and Mushotzky, 1986). The aggregate sum of energy transmitted per second per unit volume at all frequencies (the luminosity density L_{vol}) is calculated by integrating l_ν frequency. This outcomes in

$$L_{vol} = 1.42 \times 10^{-28} n_e^2 T^{\frac{1}{2}} W m^{-3} \tag{5.6}$$

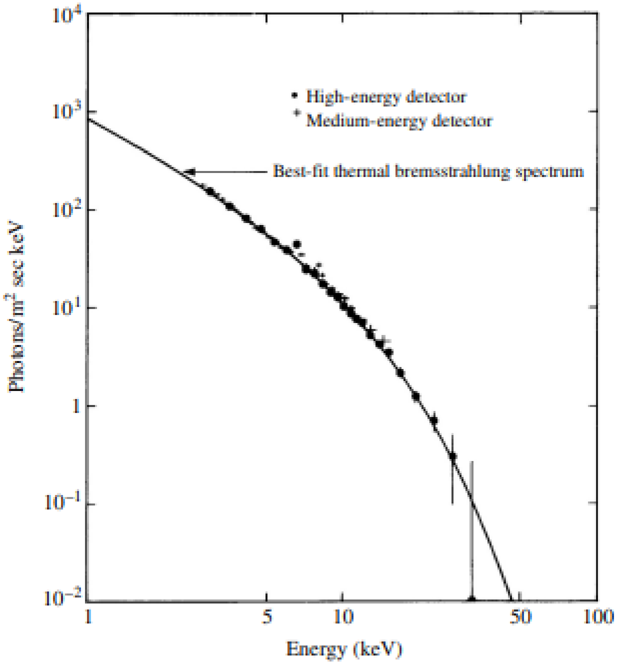

Figure-5 Thermal bremsstrahlung spectrum (line) for 88 million K. The points are observations of X-rays from the Coma cluster's intracluster gas. Photon energy is plotted on the horizontal axis. (Figure adapted from Henriksen and Mushotzky, Ap J., 302, 287,1986.)

MY WORK WITH PUBLICLY AVAILABLE DATA:

Equation (4.6) can be used to calculate the mass of the Coma cluster's intracluster gas. The cluster can be imagined as a sphere of constant surface temperature (isothermal) of hot ionized hydrogen gas for simplicity. Figure 4 indicates that the central core radiates most strongly, the radius can be taken to be $R = 1.5Mpc$ (half of the cluster's actual radius). Majority of photons emitted along the line of sight can be observed due to the gas being optically thin. The gas temperature comes from the X-ray spectrum of the gas, shown in Figure 4. The best aligned to the data (the dots on the Figure 4) is obtained with a temperature of $8.8 \times 10^7 K$.

Using (3.6) L_x can be expressed as,

$$L_x = \frac{4}{3}\pi R^3 L_{vol} \tag{5.7}$$

The X-ray luminosity of the gas is $L_x = 5 \times 10^{37} W$, so the value of n_e, the number of free electrons per m^{-3}, is

$$n_e = \tag{5.8}$$

The intracluster gas is several million times less dense than the giant molecular clouds for which $n_{H_2} 10^8 10^9 m^{-3}$

For an ionized hydrogen atom, there is one proton for every electron, so the total combined mass of the gas is,

$$M_{gas} = \frac{4}{3}\pi R^3 n_e m_H = 1.05 \times 10^{14} M_\odot \tag{5.9}$$

It's a slight overestimate of the value of $3 \times 10^{12} M_\odot$ quoted previously.

Now we can compare the up to this point obtained mass of the intracluster gas with the luminous mass of the Coma cluster.

Utilizing the mass-to-light ratio for the stellar bodies in the Milky Way's Galactic thin disk and bulge, $M/L \simeq 3\, M_\odot/L_\odot$, and the visual luminosity of the Coma cluster, $L_v = 5 \times 10^{12} L_\odot$, the visible baryonic mass of the Coma cluster is approximately $1.5 \times 10^{13} M_\odot$. As indicated by this estimate, there is approximately multiple times more intracluster gas in the Coma cluster than there is in its galaxies' stars. However, the $10^{14} M_\odot$ of intracluster gas is still just a small portion of the total mass of the cluster (Bradley W. Carroll, Bradley W).

5.3 The Hydra Cluster

Hydra cluster (Abell 1060) of galaxies is a Class III Bautz-Morgan irregular, rich cluster. It can be traced in the Hydra Constellation, with a declination $-12°05'$. The Hydra cluster consists of approximately 160 bright galaxies. At the center there are three prominent galaxies: one blue spiral (NGC 3312) and two ellipticals (NGC 3309, NGC 3311). It is about $58.3Mpc$ away from Earth and one of the three large galaxy cluster within 200 million light years. The number density distribution decreases from center to boundary.

MY WORK WITH PUBLICLY AVAILABLE DATA:

The mean velocity of the cluster is calculated to be $3230kms^{-1}$ (Mayall and de Vaucouleurs 1962), and a standard deviation of $796kms^{-1}$ (Vidal and Peterson, 1975). The radial velocity is independent of the distance from the center or on the position angle. The outcome was $3340 \pm 818kms^{-1}$ and along these lines no critical change in the two qualities. We received the broader worth referenced above, to be specific, $3233 \pm 796kms^{-1}$, as the mean velocity and dispersion. The issue of deciding the blunder on the mean velocity and in the velocity scattering isn't straightforward. Solinger and Tucker used error of ± 10 and ± 15 percent, separately, for all the clusters. With an end goal to make our mistake assessed increasingly certain, we embraced the t and χ^2 circulations for small examples, by which we used the 70 percent cutoff points of certainty of our inferred mean and standard deviation. Clearly these techniques consider both the way that we are managing a small example, and that the quantity of observed galaxies in each cluster is not same. Utilizing these statistical techniques, we are accepting a typical normal distribution for example just as for the methods and standard deviations of the various examples taken from the cluster population. Unmistakably, our example of 15 galaxies in Hydra Cluster is excessively small to show a reasonable distribution.

(Table-2). Moreover, a few experiments with 15 galaxies picked up randomly from the Coma cluster yielded identical distribution. Utilizing the χ^2 circulation, we found that the 70 percent certainty cutoff points of the velocity dispersion of A1060 are 685 and $1060kms^{-1}$ Table-2 and Figure-6

REDSHIFTED VELOCITIES OF GALAXIES IN ABELL 1060

Cass. Plate	Galaxy	Identification (NGC)	Date	Dispersion (Å mm^{-1})	V_r	s.d.	vCa II K	Lines
2413.......	A	3311	1972 April 14	100	3835	103	3846	K,g,5175,5269
2438.......	B	3309	1972 April 17	200	4118	98	4218	K,H,g
2422.......	C	3308	1972 April 15	100	3513	23	3502	K,H,g,5269
2416.......	D	3312	1972 April 14	100	2780	50	...	H,4959(em),5007(em)
2431.......	E	3316	1972 April 16	200	3960	54	3980	K,H,Hβ,Hα
2430.......	F	...	1972 April 16	200	2916	120	...	3727(em),Hβ(em),Hα(em)
2440.......	J	...	1972 April 17	200	2389	96	2446	K,5175,5268
2415.......	L	...	1972 April 14	100	2772	59	2782	K,H,g,5175,5269,5892
2423.......	M	...	1972 April 15	100	4927	133	4875	K,Hδ,g,Hβ,4383,5175
2424.......	O	...	1972 April 15	100	2742	56	2686	K,H
2439.......	S	...	1972 April 17	200	4829	25	4865	K,5175,5892
2887.......	2	...	1973 March 1	100	3970	...	3946	K,g
2884.......	5	...	1973 March 1	100	3030	103	2944	K,g,4383,Hβ,5269
2885.......	8	...	1973 March 1	100	2753	16	2748	K,H,Hδ,Hβ,5892
2886.......	10	3305	1973 March 1	100	3971	75	4076	K,H,5175,5269

Table-2 The radial velocities of the 15 observed galaxies in Hydra Cluster.

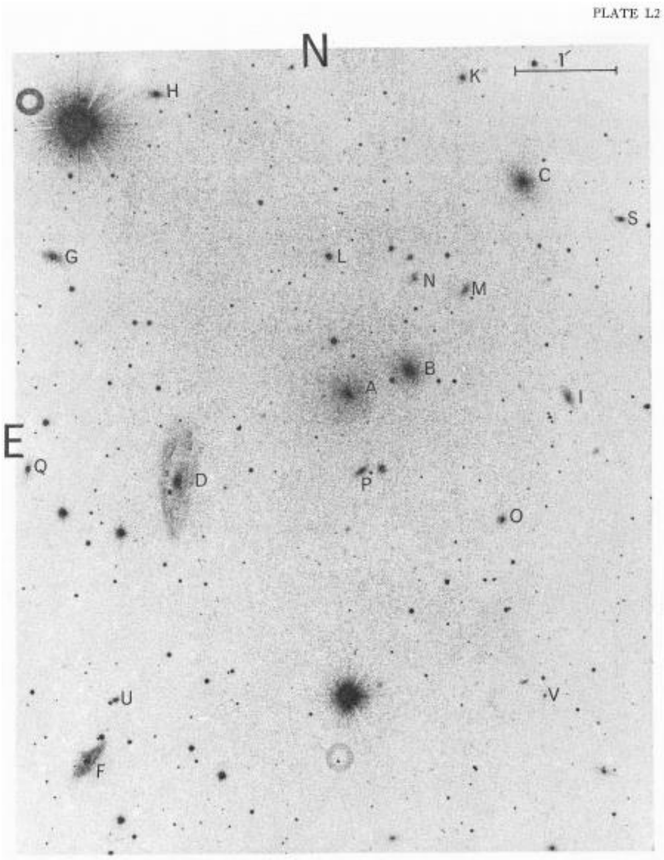

Figure-6 Abell 1060 identification sheet 1

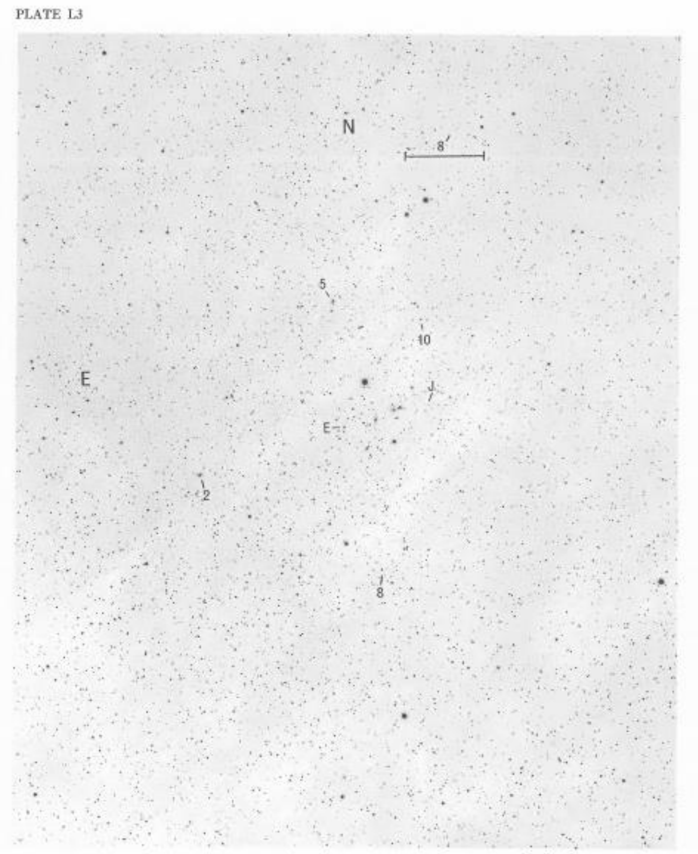

Figure-7 Abell 1060 identification sheet 2 (Vidal and Peterson, 1975)

Therefore,

$$\bar{v}_{radial} = 3230 \pm 228 kms^{-1} \quad (5.10)$$

Radial velocity dispersion,

$$\sigma_r = 796 kms^{-1} (limits of 685 - 1060 kms^{-1}) \quad (5.11)$$

The virial mass of the cluster can be calculated by,

$$M \approx \frac{5\sigma_r^2 R}{G}$$

The calculated Virial mass is shown in Table-3

MASS AND LUMINOSITIES VERSUS RADIUS FOR THE HYDRA A CLUSTER

R (Mpc)	L_x(ergs s^{-1})	$M_{gas}(M_\odot)$	$L_v(L_\odot)$	$M_{vir}(M_\odot)$	$M/L(M_\odot/L_\odot)$
<0.5..........	3.3×10^{44}	1.3×10^{13}	8.2×10^{11}	1.7×10^{14}	210
<1.0..........	4.1×10^{44}	4.3×10^{13}	1.3×10^{12}	3.5×10^{14}	270

NOTE.—The integrated X-ray luminosity L_x, gas mass M_{gas}, galactic luminosity L_v, total gravitating mass M_{vir}, and mass-to-light ratio M/L for the Hydra A cluster at two separate radii.

Table-3 Luminosity and Mass of the Cluster at different radius of the cluster

The visual luminosity of the Hydra Cluster within 0.5 Mpc radius is about $8.25 \times 10^{11} L_\odot$ and within $1 Mpc$radius is about $1.36 \times 10^{12} L_\odot$ is significantly less compared to rich clusters visual luminosities (David, L.P., et al., 1990). However, the X-ray luminosity of the Hydra Cluster is 10 times greater than the standard L_x for the poor clusters. The visible mass-to-light ratio is calculated to be $270\, M_\odot/L_\odot$, which suggests huge proportion of dark matter. The mass of the hot gas (X-ray) constitutes merely 7% of the total self-gravitating virial mass of the cluster.

5.4 Gravitational Lensing by Galaxy Cluster Systems

A possible method to measure the distribution of mass in a cluster can be done by analyzing the gravitational lensing of the background structures. In case of galaxy clusters, these comprise of stretched arcs about the center of the system (Figure 6) (Abell 2218, NASA) in the same manner as background galaxies are lensed due to singular galaxies of the cluster. In 1915, Einstein in his General Theory of Relativity gave us an equation to measure the bending of light rays around a mass distribution.

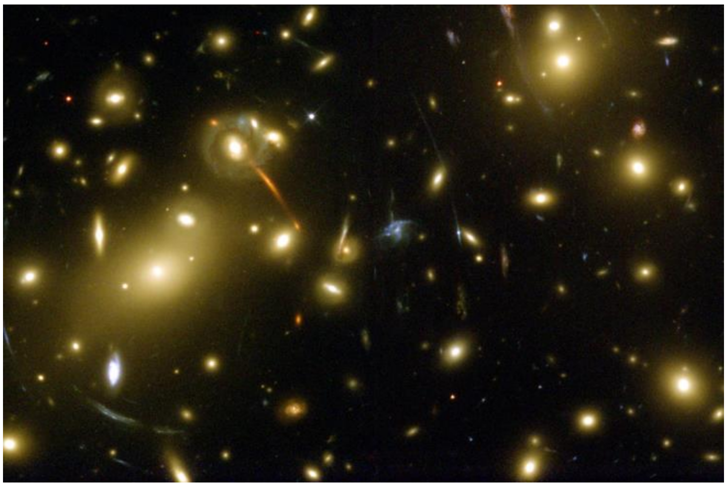

Figure-8 Abell 2218 (rich cluster). There is a supergiant cD galaxy in the centre. The image additionally shows the lensing effect of the distribution of matter in the cluster. (Courtesy NASA, ESA and the Space Telescope Science Institute.)

This equation was given as,

$$\alpha = \frac{4GM}{\xi c^2} \tag{5.12}$$

where M is the 'mass of the deflector' and ξ is the 'distance of nearest approach' (Fig. 9a) (Wambsganss, Joachim, 1998). Individually, Einstein (1915) and Chwolson (1924) understood that, the lensing effect would form a circular ring if the background source was lined up to the symmetric mass distributed deflector similar to the glass lens. Such rings are referred to as 'Einstein Rings' and their radius is worked out computationally. The angular radius of the Einstein ring can be denoted by θ_E. At any point along the axis of the observer, since all the angles are very small, θ_E is,

$$\theta_E = \alpha\left(\frac{D_{LS}}{D_S}\right) = \frac{4GM}{\xi c^2}\left(\frac{D_{LS}}{D_S}\right) \tag{5.13}$$

where α is the deflection produced, D_{LS} is the distance between background mass and lens, D_L is the distance between lens and observer and D_S is the distance between source and the observer.

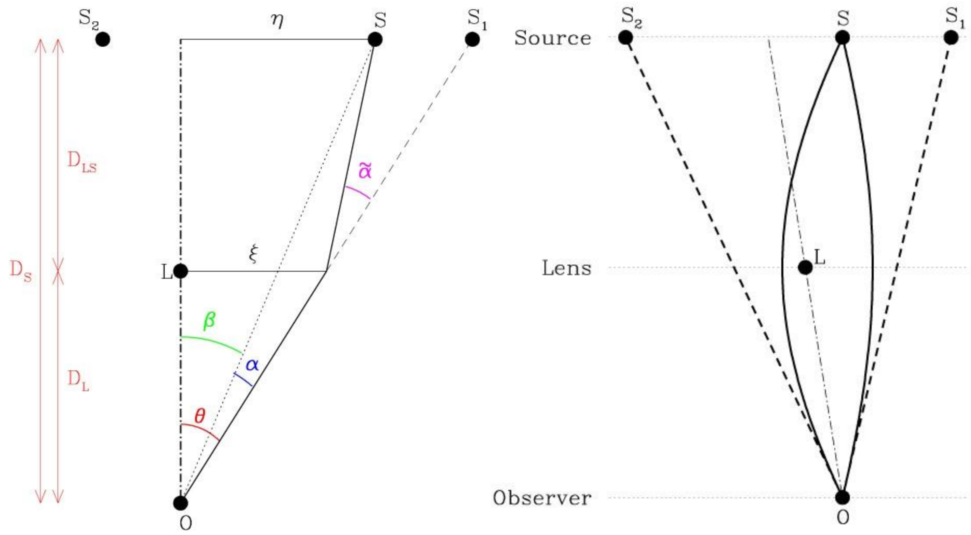

Figure-9 The left image (a) illustrates the arrangement to find deflection by lens of mass M and the right image (b) illustrate the formation of multiple images from a single lens (Wambsganss, 1998).

Since $\xi = \theta_E D_L$,

$$\theta_E^2 = \frac{4GM}{c^2}\left(\frac{D_{LS}}{D_S D_L}\right) = \frac{4GM}{c^2}\frac{1}{D} \tag{5.14}$$

here, $D = \left(\frac{D_S D_L}{D_{LS}}\right)$.

Thus, the Einstein angle θ_E can be calculated as,

$$\theta_E = \left(\frac{4GM}{c^2}\right)^{\frac{1}{2}}\frac{1}{D^{\frac{1}{2}}} \tag{5.15}$$

The above result yields precise results at very vast, or D_S should be very large. Let us represent equation (4.14) in units of solar masses $M_\odot$ and the separation D in Mpc,

$$\theta_E = 3 \times 10^{-6} \left(\frac{M}{M_\odot}\right)^{\frac{1}{2}} \frac{1}{D_{Gpc}^{\frac{1}{2}}} arcsec \tag{5.16}$$

Examples such as Abell 2218 observed by HST by Kneib et al. (Figure 10) shows beautiful partial Einstein Rings. The ellipticity and the partiality of the rings mirror the fact that the gravitational capability of the cluster isn't decisively circularly symmetric and additionally the background distribution is also not aligned precisely. This is only demonstrating the capacity of strong and weak gravitational lensing to give key astrophysical and cosmological data about the dark matter in the Universe.

Strong lensing of background sources possibly happens in the event that they exist in the Einstein point θ_E of the axis of the focal point of lens. Gravitational lensing isn't accurate lensing rather it forms cusps and caustics as shown in (Figure 10) (Kneib, 224, 2008). For clusters of galaxies, the precise masses are satisfactory simultaneousness with the qualities gained by assessing the velocity scattering of the cluster galaxies and with the X-ray technique for evaluating absolute masses.

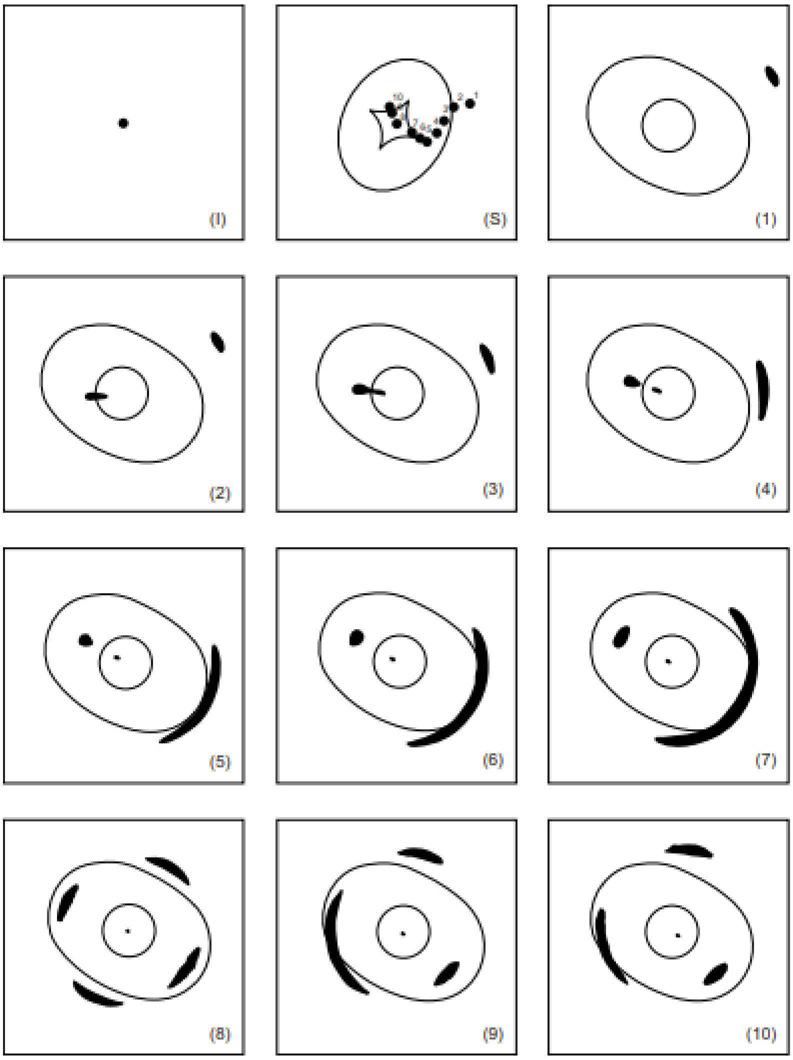

Figure-10 Lensing effect at various axis points (Kneib, 1993)

Gravitational lensing tests straightforwardly the combined distribution of mass, without depending on the distribution of baryonic matter, thus can be utilized to address various key astrophysical mysteries. Strong lensing impacts, for example, those represented in Figure 10 empower the scattered mass to be resolved at the same time on the inside caustic surfaces, likewise, statistically weak lensing can be identified for huge radii.

6. Conclusion

Clusters of galaxies are virialized, bound, high over-density frameworks of galaxies, held together by the clusters self-gravity. The dispersion of dark matter characterizes the generally found deep potential well of the clusters, the mass of which (DM) incredibly exceeds that of the baryonic matter, for example, that contained in the stars in galaxies and the related interstellar gas and the hot Intracluster gas. The profound gravitational wells of clusters can be analyzed straightforwardly through the X-ray bremsstrahlung emission of hot intracluster gas which forms a hydrostatic equilibrium inside the cluster. Gravitational lensing has end up being an incredible asset for characterizing the distribution of dark matter in clusters, just as in the halos of singular galaxies. Clusters of galaxies, therefore, give researchers to considering various aspects of galactic evolution and the role of high energy astrophysical phenomena within rather well-defined astronomical environments.

7. Acknowledgement

Thanks to friends for helps and sharing knowledge and experience during preparation of the manuscript.

8. Data Availability Statement

The data available in the manuscript is available online for open access.

9. Conflict of Interest

The author declares no conflict of interest.

11. Funding

This work is not supported by any external funding.

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