Photometric Analysis and Study of Cluster Radio Halo 0116+111

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Guided
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Jan − April, 2008

Acknowledgments

I would like to thank my guide Prof. Joydeep Bagchi (IUCAA) for allowing me to work on this project with him and for his encouragement and guidance through hour long discussions. I am also thankful to Prof. Bagchi, director IUCAA Prof. Dadhich and Prof. Chellathurai for availing me all the facilities needed, IUCAA computer centre, library, canteen facility, during the project period. I am grateful to Laxmikant sir, Dr. Sudhanshu Barve, Dr. Vijay Mohan and Mr. Nitin Wadnerkar for their invaluable help.

Jaydeep Sanjay Belapure

Contents

1 Introduction

Astronomy is the subject in which we have access to the largest laboratory i.e. the whole universe. A clear night sky full of stars is always fascinating, and it is also filled with all possible mysterious phenomena in physics. On a clear moonless night sky one may see ~ 2000 stars by naked eyes. Typically there are 10^{11} stars in a galaxy (diameter of 1-10 Kpc[1]) and also there are almost 10^{11} galaxies (separated by $\sim$ Mpc) in the observable universe. At large scales wes see many of these galaxies are locally gravitationally bound together to form a group of galaxies called as *cluster of galaxies*. These clusters may contain from ten to thousands of galaxies. A very rich cluster of galaxies, Abell 2218, is shown in the Fig. 1. The clusters themselves are often associated with larger groups called super-clusters. At the very largest scales of the visible universe, matter is gathered into filaments and walls surrounding vast voids. The study of cluster of galaxies is a key subject in understanding large scale structure formations in the universe.

The study of these clusters in various frequency bands reveals different interesting properties. When observed visually, clusters appear to be collections of galaxies held together by mutual gravitational attraction. However, their velocities are too large for them to remain gravitationally bound by their mutual attractions, implying the presence of either an additional invisible mass component, or an additional attractive force besides gravity. The missing component is known as dark matter and its nature is unknown. X-ray studies have revealed the presence of large amounts of intergalactic gas known as the intracluster medium (ICM). This gas is very hot, between 10^7K and 10^8K, and hence emits X-rays in the form of bremsstrahlung, inverse-compton and atomic line emission.

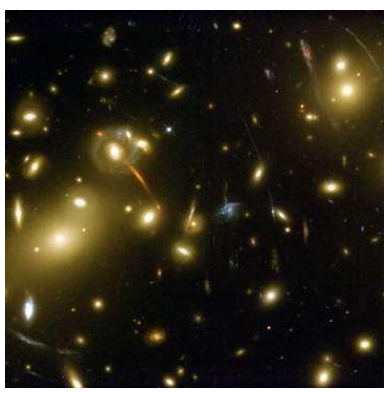


Figure 1: Galaxy Cluster Abell 2218 is a massive cluster of galaxies some 2 billion light years distant toward the constellation Draco.

In the last few decades, these are also found to be relevant sites of particle acceleration, a feature which has been discovered by observing the non-thermal diffuse radio emissions as Radio Halos and Radio Relics. Radio halos are large-scale areas of radio emission found in cluster of galaxies. They cannot be obviously associated with any individual galaxy, unlike radio galaxies which have AGN (Active Galactic Nuclei) counterparts.

[1] 1 parsec $= 3 \times 10^{16} m$

Hence radio halos are *not* same as radio galaxies. See Fig.2, the cluster region filled with diffuse extended radio emission and there is no sharp active center in the region, the image obtained by Mr Wadnerkar, one of our collaborators. These sources indicates the presence of relativistic particles and the non-thermal processes in the presence of magnetic fields in the intra cluster medium (ICM) (*Feretti, 2007*). These large scale radio features are also related to the properties in x-ray and optical domain and thus directly connected to the cluster history and evolution. The radio halos are very rare objects, there are not more than 5 such objects known. The cluster radio halo 0116+111 is of our interest here. It was first discovered using Ooty Radio Telescope, Ooty, in the Ooty Lunar Occultation Survey (*Joshi and Singal, 1980*). Here after in our study we will be referring to the radio halo 0116+111.

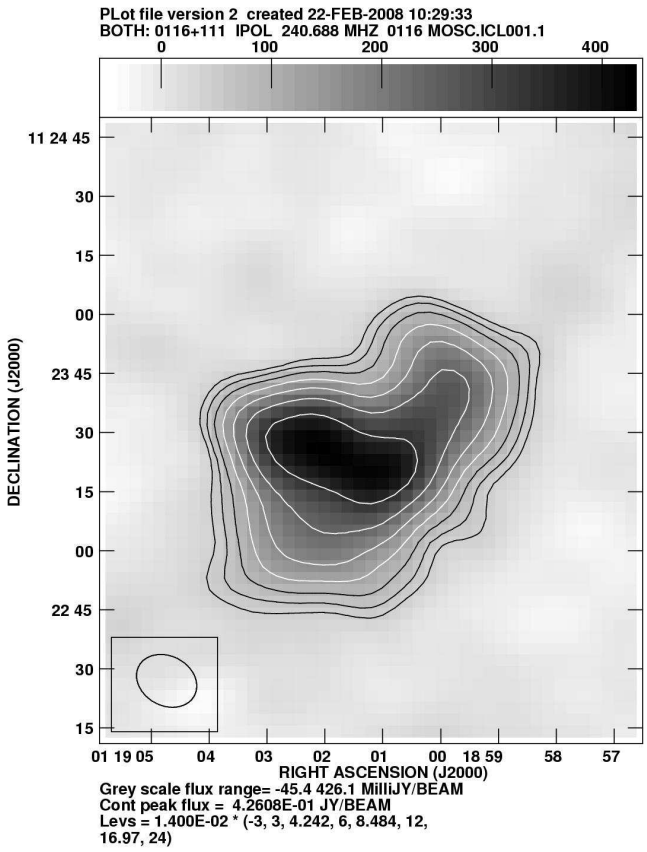


Figure 2: Galaxy Cluster 0116+111 observed at 244 MHz using GMRT, Pune.

In this project we mainly study the optical properties of the radio halo. The CCD photometric observations in optical band were taken using 2-m diameter telescope facility at IUCAA Girawali Observatory (IGO), Pune, India. The noise reduction in the images was done using standard packages in IRAF (Image Reduction and Analysis Facility).

For flux calibration we use Landolt's Standard Star Field Rubin149 (*Landolt, 1992*). Finally we estimate the absolute magnitudes of the two central galaxies. We find that the luminosity of the central galaxy is almost the same as that of our Milky Way galaxy. We also propose the discovery of a **'High Proper Velocity Star'**, but due to time limit only a preliminary analysis of the star properties is done. We plan to carry out detailed study in near future. At the end of the project, the different radiation mechanisms and interaction processes in the cluster medium such as synchrotron emission, bremsstrahlung, Inverse-Compton etc. were studied (Rybicki and Lightman).

The investigation of the radio halo in radio wavelengths (74 MHZ to 4.9 GHz) using GMRT (Giant Meter-wave Radio Telescope, Pune, India) and VLA (Very Large Array, New Mexico, USA) has been simultaneously carried out by Prof. Joydeep Bagchi (IUCAA, Pune), Mr. Wadnerkar (SRTMU, Nanded) and other collaborators. Although, it was previously planned to carry out some part of the radio analysis as a part of this project but due to time constraint it was not possible. The optical spectral study was done previously (*Gopal-Krishna et al, 2002*). Based on our optical as well as radio analysis, we have also proposed for x-ray observations using Chandra x-ray Telescope, which is crucial for understanding the properties of hot intra cluster medium (ICM). The analysis carried out under this project is also a part of the paper which will be published soon.

2 Observations

In observational astronomy it is not easy to get time for observation on any big telescope and it is very costly as well. Hence before observations it is very important to plan the observation session properly, e.g. while choosing a date of observation, first of all the object should be in the sky during that period, Moon phase and location, weather condition etc.

Before going to the observation details we first introduce some basic terminologies in observational astronomy which we may help us in understanding other concepts in later parts as well.

Coordinate system

Stars are very distant objects and therefore they appear at fixed relative positions on the celestial sphere. To locate any star on the surface of this celestial sphere we require two coordinates. It is similar to the longitude and latitude system on Earth. If we expand the longitude and latitude lines on the celestial sphere, they form the celestial coordinate system called as Right Ascension (RA or α) measured in hr:min:sec and Declination (Dec or δ) measured in deg:min:sec.

Magnitude scale

In astronomy the flux is measured in negative logarithmic scale, for historical reasons, called as *magnitude*. Usually the flux is measured in some wavelength band (λ), so the magnitude in that band is given as,

$$m_\lambda = -2.5log(flux) \tag{1}$$

So, higher the magnitude fainter is the star. If the distance to the object is know then we can calculate its absolute luminosity. But for comparison between different objects we then obtain its luminosity when observed from a standard distance i.e. 10 pc and the corresponding magnitude is called as absolute magnitude (M). Consider a star at a distance (R), so the flux received will be (F),

$$F = \frac{L}{4\pi R^2}$$

Hence, the apparent magnitude is,

$$m_\lambda = -2.5log(F)$$

Now assume the same star is located at a standard distance (R_o = 10 pc), so the flux we received will be (F_o),

$$F_0 = \frac{L}{4\pi R_o^2}$$

and the magnitude will be,

$$m_\lambda = -2.5log(F_o)$$

so,

$$\frac{F}{F_0} = \frac{R_o^2}{R^2}$$

Taking $\log_{10}$ of both sides and multiplying by (-2.5),
we get,

$$(-2.5log(F)) - (-2.5log(F_o)) = -5(log(R_o) - log(R))$$

i.e.

$$m_\lambda - M_\lambda = -5(log(R_o) - log(R))$$

i.e.

$$M_\lambda = m_\lambda + 5(log(R_o) - log(R))$$

i.e.

$$M_\lambda = m_\lambda - 5(log(R) - log(R_o))$$

Now, expressing the distances in units of 1 pc,

$$M_\lambda = m_\lambda - 5(log\left(\frac{R}{1pc}\right) - log(10))$$

Hence, the relation between apparent magnitude, distance and the Absolute magnitude is,

$$M_\lambda = m_\lambda - 5[log(D) - 1] \tag{2}$$

where, distance (D) is in parsecs.

Airmass (AM)

The star light has to pass through the earth's atmosphere before reaching us. The amount of atmosphere it has to covered is termed as *airmass* (AM). The amount of air column is least towards zenith and it is defined as 1 AM. As the angle (θ) of the star made with the zenith increases the airmass increases, it is defined as,

$$AM = sec(\theta) \qquad \ldots for \theta \leq 60^o$$

Hence when a star is at angle of 60° the airmass = 2.

Calibrator Star Field

The calibrator star field is different than the field of actual object of interest. The calibrator star fields contain standard stars whose magnitudes (in UBVRI) are known from the literature. So they help in calibrating the magnitudes of our object of interest. We use Landolt's Standard Star Field Rubin149 (*Landolt, 1992*).

2.1 Observations with IUCAA Girawali Observatory

The CCD photometric observations of the cluster 0116+111 (located in Pisces constellation) were taken on 1st Jan, 2008 night using 2-m diameter telescope facility at IUCAA Girawali Observatory (IGO), Pune, India see Fig.3. The Telescope is equipped with 'The Princeton Instruments CCD Camera (PI-CCD)' of 1340 x 1300 pixels, pixel size of 20 μm^2 and image scale of 0.3 arc sec/pixel. It also has standard UBVRI filter set. It also has spectroscopy facility.

Figure 3: The 2-m telescope facility at IUCAA Girawali Observatory (IGO), Pune.

The observations consists of two parts:
(i) the cluster 0116+111 and
(ii) the calibrator field Rubin149.
These two fields were observed alternately each in filter BVRI and the cycle was repeated over the night. The exposure times were suitably taken so as to avoid saturation of the CCD. Total around 150 images were taken.

During the twilight period just after the sunset and before the sunrise, the sky is equally illuminated. At this period we obtained images of the sky in BVRI filters, called as Flat frames. These are important for normalizing CCD pixel to pixel response. Also while CCD is readout it introduces some noise called as bias, to eliminate this, we take many zero seconds frames called as Bias frames. The CCD also generates noise due to thermal electrons called as Dark current, but it is very less ~ 3.6 e^-/pixel/hour at 153K (Typical), so it is completely neglected.

3 Noise Reduction of the Optical Images

As we have seen in last section, a CCD image consists of noise. It is mainly due to 3 reasons,
(i) Dark current,
(ii) Bias and
(iii) Due to unequal response of individual CCD pixels. The CCD is cooled at $\sim 110^o$C, so there are just $\tilde{3}$-4 thermally generated e^-s in 1 hour, so the Dark current is negligible. We use standard packages in the software IRAF (Image Reduction and Analysis Facility)

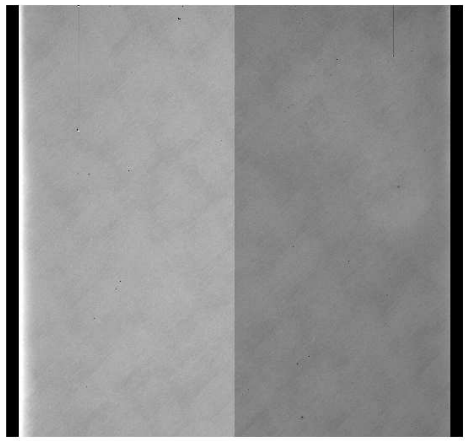


Figure 4: To remove bias noise CCD 0 sec bias frames are taken. Combining all bias frame a Master_Bias frame is obtained.

for cleaning all the images. The different stages of obtaining a clean image from a raw image are as follows -

Step 1] All bias frames are combined together to obtain a Master_Bias, see Fig. 4.
Step 2] Flat$_\lambda$ - Master_Bias = zFlat$_\lambda$ (Bias subtracted flat frame)
Step 3] All zFlat$_\lambda$ frames of same filter are combined together to obtain a Master_Flat$_\lambda$ of that filter.
Step 4] $\frac{zFlat_\lambda}{median} = nzFlat_\lambda$. (This is called as normalized master flat frame.)
See Fig.5 raw object image.
then,
Step 5] Object$_\lambda$ - Master_Bias = zObject$_\lambda$
Step 6] $\frac{zObject_\lambda}{nzFlat_\lambda} = nzObject_\lambda$ (Complete clean image)
Step 5 and 6 is followed for our cluster field images as well as calibrator (Rubin149) field images to obtain clean images of both cluster and calibrator fields in each filter.

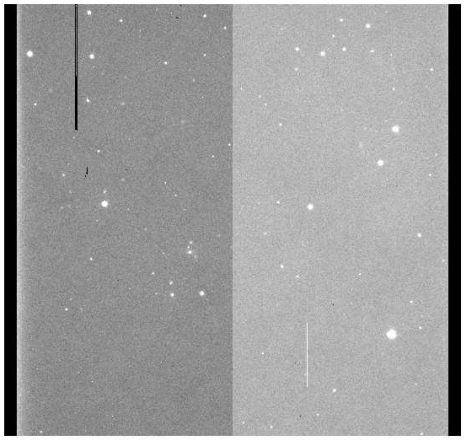


Figure 5: A raw object image observed in B filter.

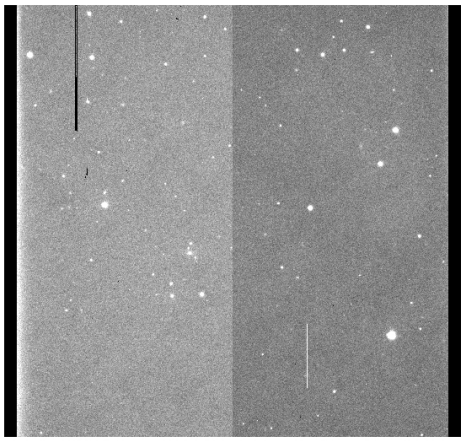


Figure 6: A bias subtracted object image observed in B filter.

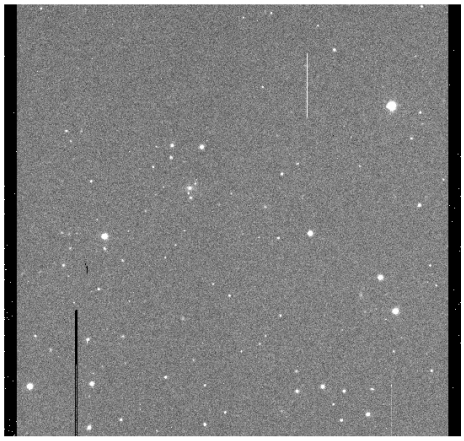


Figure 7: A cleaned object image observed in B filter.

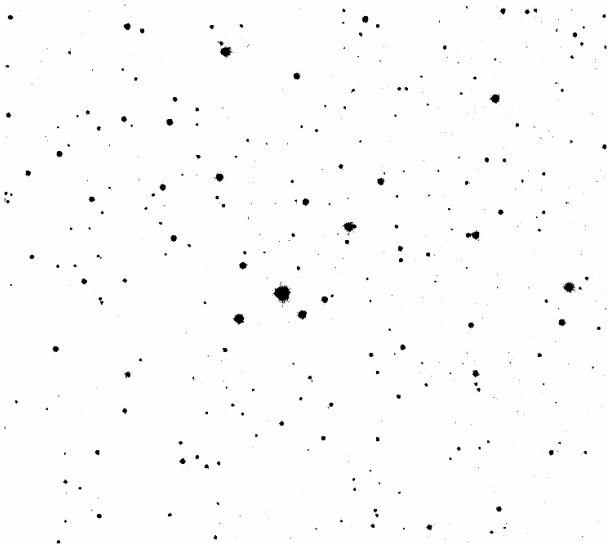
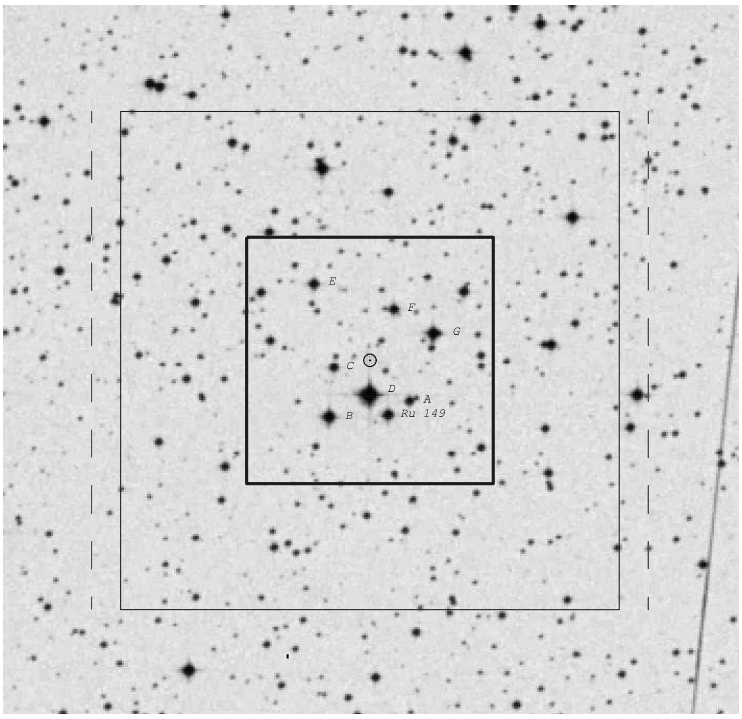


Figure 8: The standard calibrator star field Rubin149, in inverted gray scale, IGO image in B filter.

Ru 149

RA = 07:24:15 DEC = -00:32:21 (2000.0)



	V	B-V	U-B	V-R	R-I	V-I
Rubin 149	13.866	-0.129	-0.779	-0.040	-0.068	-0.108
A	14.495	0.298	0.118	0.196	0.196	0.391
B	12.642	0.662	0.151	0.374	0.354	0.728
C	14.425	0.195	0.141	0.093	0.127	0.222
D	11.480	-0.037	-0.287	0.021	0.008	0.029
E	13.718	0.522	-0.007	0.321	0.314	0.637
F	13.471	1.115	1.025	0.594	0.538	1.132
G	12.829	0.541	0.033	0.322	0.322	0.645

Figure 9: The standard calibrator star field Rubin149, Landolt's catalogue.

4 Analysis

4.1 Atmospheric Extinction

Whenever light passes through larger and larger atmospheric column more and more light gets scattered. It is mostly Reighley scattering, and the scattering is inversely proportional to λ^4. So the extinction in B filter will be larger than V filter. Extinction coefficient is given as change in magnitude per unit airmass (mag/AM). We use the cleaned calibrator (Rubin149) images to find the extinction. The procedure for obtaining extinction coefficient and extinction corrections is as below,

Step 1] Select single filter (say B) images out of all calibrator images and arrange them according to increase in airmass.

The calibrator field contains 8 standard stars namely rub149, A, B, C, D, E, F and G.
Step 2] Select any one star (say A) and obtain its flux value in each frame using IRAF.

The flux value is some digital number dependent on the instrument used but it is proportional to the actual flux. Divide it by the observation time (t).
Step 3] calculate the corresponding magnitude. m_b.

$$m_b = -2.5log(F_b/t)$$

Step 4] plot m_b verses airmass.
Step 5] extinction coefficient (η_b) = The slope of the least square fit to above plot.
Step 6] The Y-intercept gives zero-airmass i.e. the magnitude obtained above the earth's atmosphere, called as instrumental magnitude m_{b0}^A.

Repeat the steps 2 to 6 for all 8 stars and obtain their zero airmass magnitudes m_{b0}^{rub149}, m_{b0}^A ..., m_{b0}^G. And the average extinction coefficient is obtained (η_b). Hence the zero-airmass magnitude can now be obtained for any star at any airmass as,

$$m_{b0} = m_b - \eta_b \times AM$$

The corresponding catalogued magnitudes for the stars are denoted as m_{B0}^{rub149}, m_{B0}^A ..., m_{B0}^G.
Step 7] Plot instrumental magnitudes verses catalogued magnitudes for the stars, we expect the slope close to 1. Obtain a least square fit to get relation between m_{B0} and m_{b0} as,

$$m_{B0} = a \times m_{b0} + c$$

Repeat all the steps from 1 to 7 for all the filters and obtain corresponding set of equations.

The set of three relations obtained are given below -

I] For filter B:

$\eta_b = 0.5 mag/AM$

$$m_b = -2.5 log\left(\frac{F_b}{t}\right) \tag{3}$$

$$m_{b0} = m_b - 0.5 \times AM \tag{4}$$

$$m_{B0} = 0.98 \times m_{b0} + 23.92 \tag{5}$$

See Fig.10,11, similar graphs for all the 8 stars are obtained.

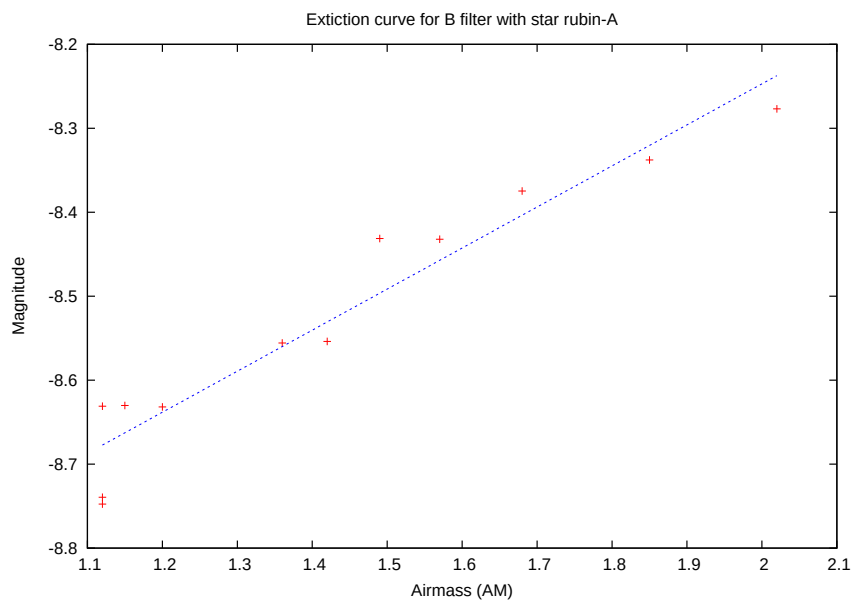


Figure 10: Extinction curve for B filter using star Rubin-A

II] For filter V: $\eta_v = 0.25 mag/AM$

$$m_v = -2.5 log\left(\frac{F_v}{t}\right) \tag{6}$$

$$m_{v0} = m_r - 0.25 \times AM \tag{7}$$

$$m_{V0} = 0.99 \times m_{v0} + 23.64 \tag{8}$$

See Fig.12, 13, similar graphs for all the 8 stars are obtained.
III] For filter R: $\eta_r = 0.19 mag/AM$

$$m_r = -2.5 log\left(\frac{F_r}{t}\right) \tag{9}$$

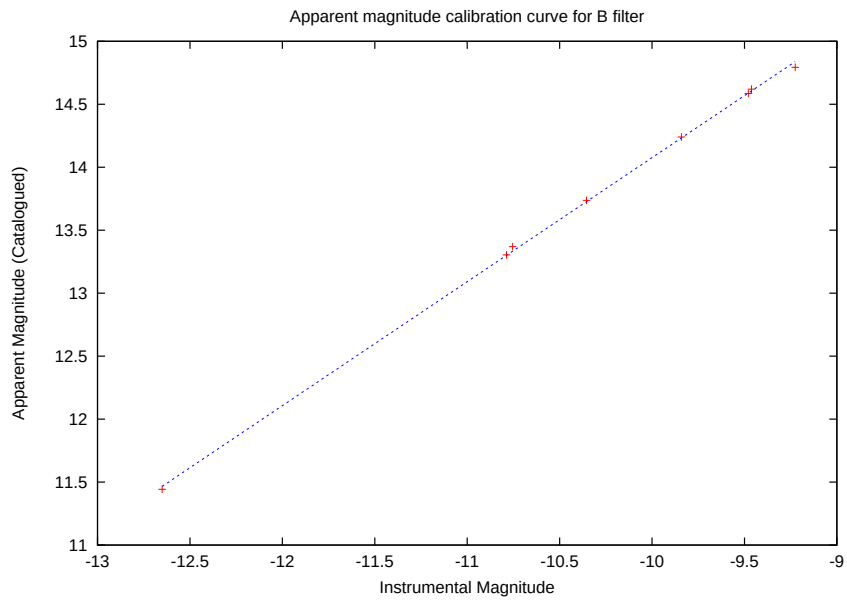


Figure 11: Magnitude calibration curve for B filter using 8 stars from Landolt's Rubin149 star field.

$$m_{r0} = m_r - 0.25 \times AM \tag{10}$$

$$m_{R0} = 1.01 \times m_{r0} + 23.89 \tag{11}$$

See Fig.14,15, similar graphs for all the 8 stars are obtained.

4.2 Estimating Absolute Magnitude

The absolute magnitude can be obtained if the distance to the object is know. The distance to the galaxy can be found by studying its spectra.

4.2.1 Theoretical methodology for calculating the Luminosity Distance (D_L)

It is observed that the galaxies are moving away from each other, the more distant galaxies have larger receding velocities. The empirical relation was first given by E. Hubble as,

$$V = H_o D \tag{12}$$

where, H is called as Hubble's constant. Its current value H_o = 71 km/sec/Mpc.

But there is no specific centre from which all the galaxies are moving away. It is just because the universe is expanding and hence each galaxy is moving away from every other galaxy, i.e. the distance between any two objects is scaled by a factor called as expansion factor a(t). Because of the expansion of the universe, the light waves coming towards us

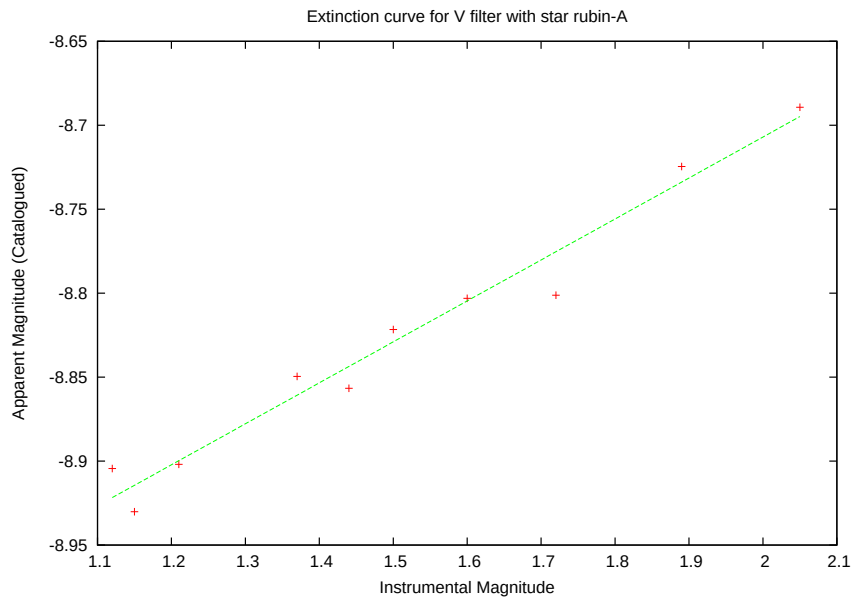


Figure 12: Extinction curve for v filter using star Rubin-A

get redshifted. We define a quantity called as cosmological redshift (z) as the ratio of expansion factor at t=t_o i.e. today to t=t at some time in the past,

$$\frac{a_o}{a} = (1+z) \tag{13}$$

Because of the expansion of the universe the light waves coming towards us get redshifted, hence,

$$\begin{aligned} \frac{\lambda_o}{\lambda_e} &= \frac{a_o}{a} = (1+z) \\ \frac{\Delta\lambda}{\lambda} &= z \end{aligned} \tag{14}$$

The value of z can be obtained by studying the spectrum of the object. The redshift (z) of the central galaxy of the cluster under study is obtained as 0.1316 (*Gopal-Krishna et al., 2002*).

As the cluster of galaxies are very distant objects, cosmology plays important role in any calculation. Imagine a scale printed on a rubber sheet, now if the rubber is expanded, the distance between any two marks (r) is not changed, and it is called as comoving distance (r), but to find out proper distance we have to multiply the comoving distance by the scale factor, it is called as proper distance (D). Consider an object with luminosity (L) at a distance (r), the flux received is simply,

$$F = \frac{L}{4\pi r^2} \tag{15}$$

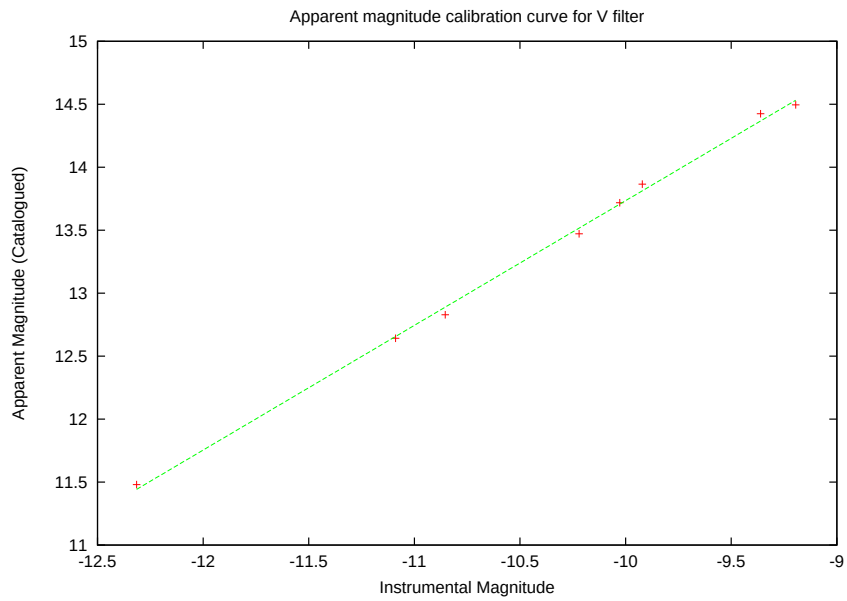


Figure 13: Magnitude calibration curve for V filter using 8 stars from Landolt's Rubin149 star field.

But as the universe is expanding, the distance (r) is scaled by a factor a_o, so,

$$D = a_o r$$

where,

r $\rightarrow$ comoving distance

$a_o \rightarrow$ expansion factor or scaling factor

D $\rightarrow$ proper distance

As the light coming towards us from the galaxy gets redshifted, the flux observed becomes,

$$F = \frac{L}{4\pi D^2 (1+z)^2} \tag{16}$$

Where,

$$D_L = a_o r (1+z) \tag{17}$$

called as Luminosity distance.

We right the Friedmann-Robertson-Walker (FRW) metric,

$$ds^2 = c^2 dt^2 - a(t)^2 \left(\frac{dr^2}{1-kr^2} + r^2 \left(d\theta^2 + sin^2(\theta) d\phi^2 \right) \right) \tag{18}$$

where,

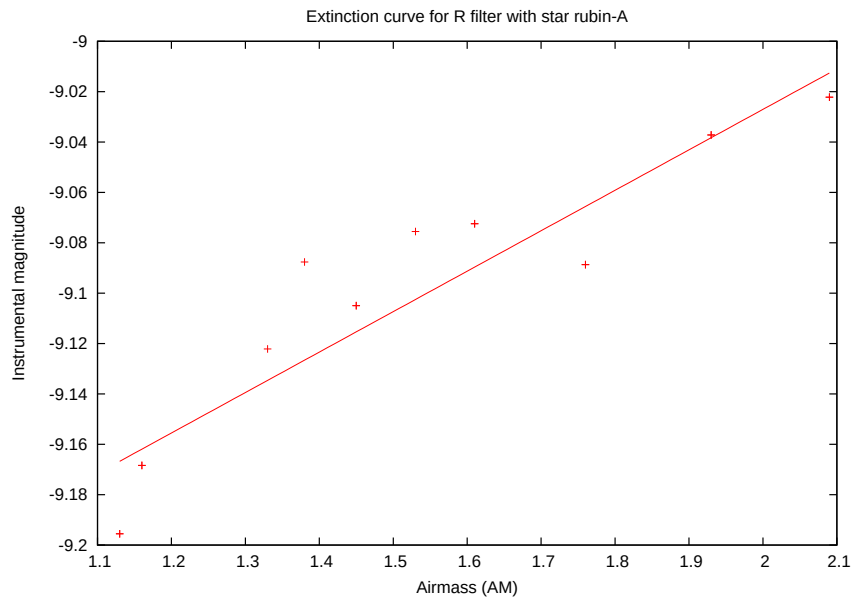


Figure 14: Extinction curve for R filter using star Rubin-A

k $\rightarrow$ curvature parameter, it can take values 0, $\pm$ 1 and,
k=0 $\Rightarrow$ Flat Universe
k=+1 $\Rightarrow$ Close Universe
k=-1 $\Rightarrow$ Open Universe

Consider a light ray emitted from a galaxy $G_1(r,\theta,\phi)$ towards our galaxy $G_o(0,\theta,\phi)$, as light follows geodesics, so we have $ds^2 = 0$, it implies,

$$\begin{aligned} c^2dt^2 &= a(t)^2\frac{dr^2}{1-kr^2} \\ cdt &= \frac{adr}{\sqrt{1-kr^2}} \\ for, k = 0 & \\ cdt &= a(t)dr \\ \int dr &= \int \frac{cdt}{a(t)} \\ r &= \int \frac{cdt}{a(t)} \end{aligned} \tag{19}$$

Now, we write Einstein equation directly (*Narlikar J.V., Gravitation and Cosmology*), because it is very lengthy and tedious process to derive it.

$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G\rho}{3} - \frac{k}{a^2} \tag{20}$$

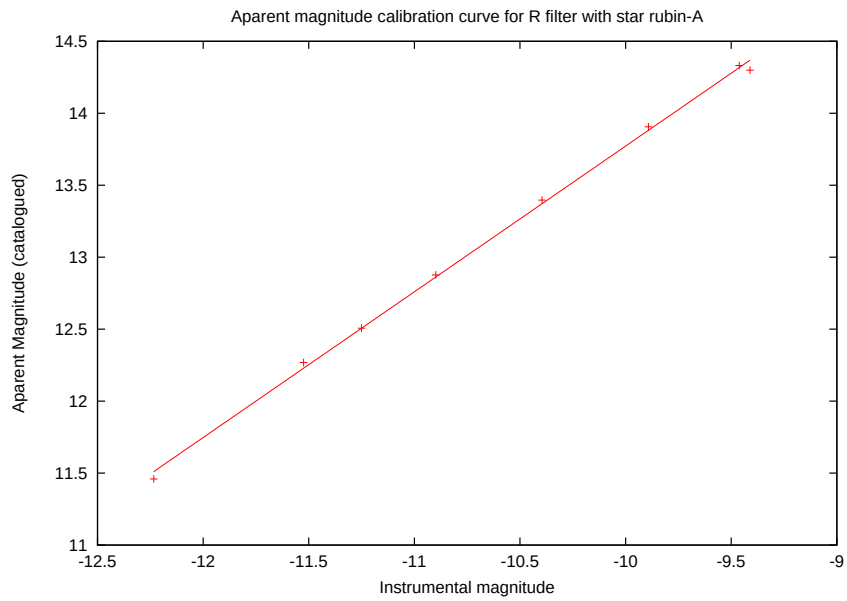


Figure 15: Magnitude calibration curve for R filter using 8 stars from Landolt's Rubin149 star field.

where,

$$H(t) = \left(\frac{\dot{a}}{a}\right)$$

i.e. Hubble's constant.

$\rho \rightarrow$ energy density of the universe. The density (ρ) may have components other than baryonic matter (ρ_b), mainly dark matter (ρ_{DM}) and dark energy (ρ_{DE}), which are completely unknown components. The relative fractions of matter (baryonic + dark matter) and and dark energy are conventionally denoted respectively by (*Hartle, Gravity*),

$$\Omega_m = \frac{\rho_m(t_o)}{\rho_{crit}}, \qquad \Omega_\Lambda = \frac{\rho_\Lambda(t_o)}{\rho_{crit}} \tag{21}$$

The present day values of these constants are, $\Omega_m = 0.27$, $\Omega_\Lambda = 0.73$.

Solving Einstein equation eq. 20 for two component universe Ω_m and Ω_Λ, we get,

$$H(z) = H_o\sqrt{\Omega_m(1+z)^3 + \Omega_\Lambda} \tag{22}$$

also consider eq. 13,

$$\frac{a_o}{a} = (1+z)$$

Differentiating above equation,

$$\frac{dz}{dt} = -\frac{a_o}{a}\frac{\dot{a}}{a}$$

$$
\begin{aligned}
&= -(1+z)H(z) \qquad\qquad \ldots from \quad eq.13,\ 20 \\
dt &= -\frac{dz}{(1+z)H(z)} \qquad\qquad (23)
\end{aligned}
$$

Substituting eq. 23 in eq.19 we get,

$$
\begin{aligned}
r &= -\int_z^0 \frac{cdz}{a(1+z)H(z)} \\
&= \int_0^z \frac{cdz}{a_o H(z)}
\end{aligned}
$$

$$
let \quad h(z) = \frac{H(z)}{H_o}, \quad therefore,
$$

$$
r = \frac{c}{a_o H_o}\int_0^z \frac{dz}{h(z)} \qquad (24)
$$

Now, substituting the eq.24 in eq.17 we get,

$$
\begin{aligned}
D_L &= a_o(1+z)r \\
&= a_o(1+z)\frac{c}{a_o H_o}\int_0^z \frac{dz}{h(z)} \\
substituting \quad eq.22, \\
&= (1+z)\frac{c}{H_o}\int_0^z \frac{dz}{\sqrt{\Omega_m(1+z)^3+\Omega_\Lambda}} \qquad (25)
\end{aligned}
$$

Where, c/H_o is called as Hubble's radius.

Above equation is very difficult to solve analytically, hence we calculate the luminosity distance D_L) by using NED Wright's cosmological calculator (*NED Write's cosmology*) using the values of constants - H_o = 71 km/sec/Mpc, z= 0.13.16, $\Omega_m = 0.27$, $\Omega_\Lambda = 0.73$, and we get,

$$
D_L = 611.5 Mpc
$$

Before obtaining the absolute magnitude, the apparent magnitudes are corrected for galactic extinction using the NASA/IPAC extra galactic data base (*NED extinction database*).

The galactic extinction corrections are,

$$
\begin{aligned}
&for \quad B(0.44\ \mu m) \quad \rightarrow \quad 0.18\ mag. \\
&for \quad V(0.54\ \mu m) \quad \rightarrow \quad 0.139\ mag. \\
&for \quad R(0.65\ \mu m) \quad \rightarrow \quad 0.112\ mag. \\
&for \quad I(0.80\ \mu m) \quad \rightarrow \quad 0.081\ mag. \qquad (26)
\end{aligned}
$$

The absolute magnitude are calculated by using eq. (2). The apparent magnitudes and absolute magnitudes obtained for central galaxy (G1) and the companion galaxy (G2), see Fig.17 are given below,

Table 1: Apparent and Absolute magnitudes of the central galaxies

Galaxy	z	m_b	m_v	m_r	M_b	M_v	M_r
Central galaxy (G1)	0.1316	18.79	17.69	16.69	-20.32	-21.38	-22.23
Companion galaxy (G2)	$\tilde{0}$.1316	19.86	18.5	17.72	-19.25	-20.57	-21.20

4.3 Fitting world coordinates

For referring to any object in the frame we require its standard coordinates i.e. RA and Dec. For this purpose we use USNO standard catalogue (*USNO B1 catalogue*) of stars. We select 5-6 stars which are common in both the frame and the catalogue. We note down their pixel coordinates (x,y) and the world coordinates (RA,Dec). Using standard package in IRAF we obtain a relation between the coordinates (x,y) and (RA,Dec). Using these solutions we superimpose world coordinates on our final cleaned cluster images in B, V and R.

4.4 B-V-R colour image

Initially we have B, V and R filter cleaned images, which are in gray scale scheme i.e. shades from black to white for low to high flux values. First we convert the image in logarithmic scale. We convert then this gray shade scale to respective false colour shade scales, i.e B to blue, V to green and R to red colour shade scales. Then these images were open in GIMP graphics package as transparent layers. These layers then merged together to obtain BVR false colour composite image. Fig.16. shows a complete field of the cluster and Fig.17 shows the central part of the cluster.

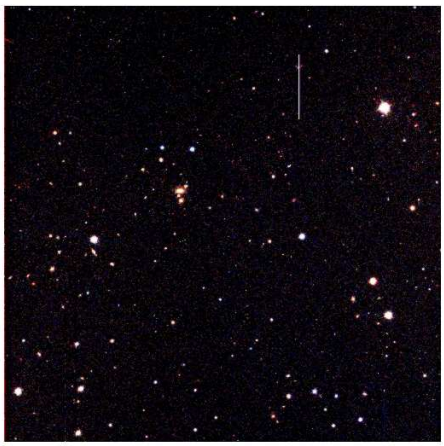


Figure 16: The BVR false colour image of the cluster.

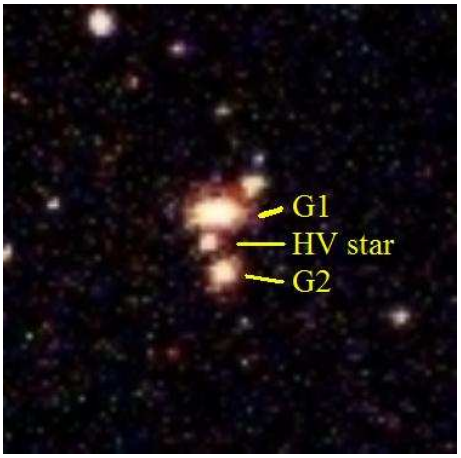


Figure 17: Central part of the cluster.

5 Serendipitous Discovery of a High Proper velocity Star

While analyzing the optical images, we noted that a star in our field has slightly shifted from its initial position. Initially we suspected that it must be some artifact in image display, because stars are very distant objects. We then compare different star's patterns in the field and conclude that the star has actually moved from its initial location. The images of the same field at two different epochs, DSS1 (Digital Sky Survey-1, 1952) (*Skyview*) and IUCAA Girawali (2008) are shown in Fig.18 and 19 respectively. The shift in position of the central star is easily seen.

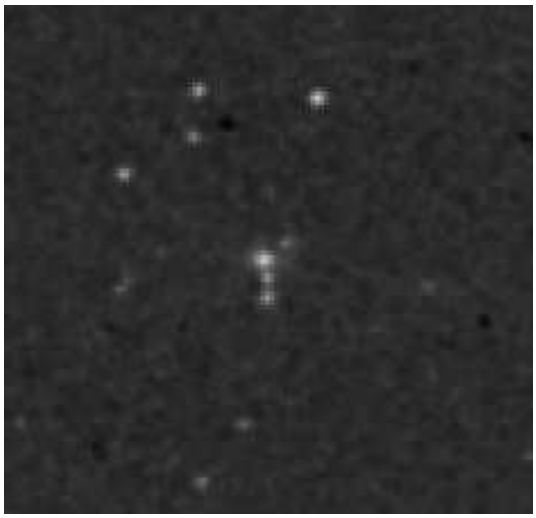


Figure 18: The image taken from Digital Sky Survey (DSS1) in the year 1952, shows the central star on right side of central galaxies G1 and G2

As a part of initial analysis we aim to find out the projected proper velocity of the star. The steps are given below,
Step 1] Calculate the angle A in the sky, a telescope of diameter D and focal length f, is looking at, as,

$$A = \frac{D}{f}$$

Step 2] Calculate the plate scale i.e. angle per mm on the photographic plate or CCD frame,

$$Platescale = \frac{A}{D}$$

size of 1 CCD pixel is 4.47 μm. Using the specification parameters given for the IUCAA telescope we obtain, (plate scale $\times$ pixel size) = Image scale in (angle/pixel) and it is calculated as,

$$Image \quad scale = 0.3 \quad arcsec/pixel.$$

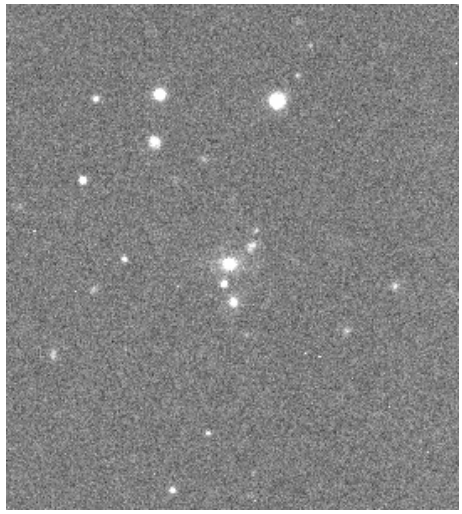


Figure 19: The central star (marked in Fig.17) has moved to left from its initial position in Fig.18

Step 3] Image of the same field from Digital Sky Survey-1DSS1 is taken in year 1952.946. Comparing the DSS1 image and our IUCAA telescope (IGO) image in 2008.00, We calculate the shift in pixels over the baseline of 55.054 years. as ($\Delta x = 3.85$ pixels) and ($\Delta y = 6.48$ pixels). The net displacement is obtained as,

$$\Delta s = (\Delta x^2 + \Delta y^2)^{\frac{1}{2}} = 7.54 pixels$$

Step 4] Using image scale (0.3 arcsec/pixel) we get,

$$\begin{aligned} Angular \quad displacement(\theta) &= 0.3 \times 7.54 \quad arcsec \\ &= 1.09 \times 10^{-5} \quad radians \end{aligned}$$

The baseline time $\Delta t = 55.054$ years $= 1.73 \times 10^9$ sec. As no spectral information of the star is available, we can not estimate its distance. But assuming the star to be at 1 kpc, i.e. typically distance of such a halo star.
Step 5] Hence, the projected distance covered (d) is calculated as,

$$\begin{aligned} d &= (1 \times 10^{19}) \times (1.09 \times 10^{-5} meters) \\ &= 3 \times 10^{14} m \end{aligned}$$

Step 5] The projected proper velocity (V) is then calculated as,

$$V = \frac{d}{\Delta t}$$

$$= \frac{3 \times 10^{14}}{1.73 \times 10^{9}}$$
$$= 2 \times 10^{5} meters/sec$$

Typical proper velocity of stars is few tens of km/sec. This implies that our star is certainly high proper velocity (HV) star. But it should be noted that if the distance of the star is just greater than or equal to $\sim$ 5 kpc then the proper velocity would be extremely high, $\sim$ **1000 km/sec**, a hyper velocity star. There is no physical theory currently exists which can explain these hyper velocities. But few authors suggested that this could be explained by dynamical ejection from a massive black hole (*Hills et al., 1988*). There has been surveys for detecting these hyper velocity stars (*Brown et al, 2006*).

5.1 Photometric study of the star

The flux values of the star in BVR filters are measured using IRAF package, and then we obtain the corresponding apparent magnitudes corrected for instrumental and atmospheric extinction using the set of eq.3 to eq.11. The values obtained are,

Table 2: Apparent magnitudes of the HV star

	m_b	m_v	m_r
HV Star	20.77	18.88	17.59

The magnitudes obtained in BVR tells us about the colour of the star and the colour of the star is related to its temperature (T). The colour index calculated from its magnitude are,

(B-V) = 1.89

(V-R) = 1.29

An approximate empirical relation between the colour index (B-V) and its temperature is,

$$B - V = -3.684 log(T) + 14.551 \tag{27}$$

Hence we obtain the temperature to be of the order of **3000 K**. To study further properties, spectroscopic observations of the star are required. We propose to carry out further studies in near future.

6 Conclusions

Under this project work we learned the optical observational techniques and analysis using IRAF. Cleaning and calibrating the images is very important part for further photometric analysis. The absolute magnitudes obtained for the central two galaxies are same as the absolute magnitudes of typical elliptical galaxies, the high colour index value of the galaxies implies the old population of stars, which is consistent with the properties of elliptical galaxies observed.

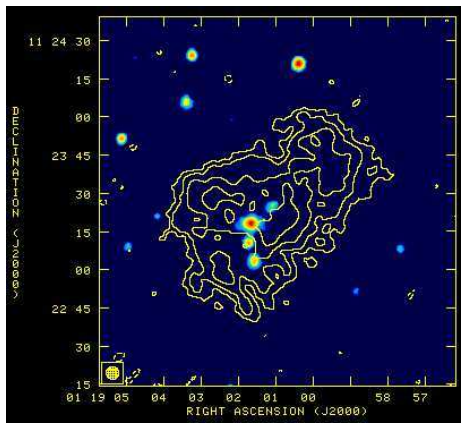


Figure 20: The optical image superimposed with 1.4 GHz radio contour image

The optical image shows spatial correlation with the radio observation taken with GMRT see Fig.20, there there is no evidence of direct link between the central galaxies of the cluster and the radio halo, which implies that the activity or pumping of energy into the intracluster medium may have stopped some time back, but the observations in radio shows of presence of relativistic electrons responsible for radio emission, which tells us that there must be some local acceleration mechanisms. But to understand the complete nature one should study the properties of this cluster in optical, radio and x-rays together. Based on the analysis (of the object 0116+111) done till now we have also proposed for x-ray observations over a 0.5 to 2 keV band using Chandra x-ray Telescope, which would be our future part of the study.

References

[1] Bagchi et al., 1998, MNRAS, 000,1-6

[2] Brown et al., 2006, ApJ, 640:L35

[3] Feretti and Giovannini, 2007, arXiv:astro-ph/0703494

[4] Gopal-Krishna et al, 2002, IAU Symp., 199,159.

[5] Hartle, Gravity, Pearson edu., I edition, 2006.

[6] Hills et al., 1988, Nature, 331, 687

[7] Joshi and Singal, 1980, Mem. Astr. Soc. India, 1, 49

[8] Landolt, A. U. 1992, AJ, 104, 340.

[9] NED extinction database : http://nedwww.ipac.caltech.edu/forms/calculator.html

[10] NED Write's cosmology: http://www.astro.ucla.edu/ wright/DlttCalc.html

[11] Rybicki and Lightman,Radiative processes in Astrophysics, John Wiley & Sons, 1979

[12] Skyview: www.skyview.gsfc.nasa.gov

[13] USNO B1 catalogue: http://www.nofs.navy.mil/data/fchpix/