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Virgo cluster galaxies & signatures of Hubble flow

Varsha Gupta, G. K. Upadhyaya

Abstract— E. P. Hubble revolutionized cosmology by proving that galaxies recede from us in all directions. Hubble's work provides the first direct evidence of cosmic acceleration. His discovery had changed our understanding towards universe and opened the new way to investigate the; expanding, evolving and accelerating universe that engages today's burgeoning field of cosmology. Extensions of Hubble's work with advance technology have developed vast new arenas for explorations. Since Hubble several surveys have brought tremendous improvements in both quality and quantity. During the last two decades, the observational database on galaxies in a wide vicinity of the Virgo cluster has been grown significantly. Virgo cluster being the nearest and largest cluster of galaxies in the local super cluster has always been of great interest to astronomers and astrophysicists to carry out many systematic studies. It is evident that this cluster serves as an important reference for the determination of distance scale of the universe. In order to supplement Hubble's work and to find signatures of Hubble flow in Virgo cluster and its surrounding galaxies in the present paper Hubble diagram is plotted by using data of 180 galaxies (having redshift < 1), collected from SDSS-III DR9 database. From the diagram it is inferred that at smaller distances there is strong deviation from linear relation, also 3 galaxies (catalogued as dEs) are observed in this region possessing high redshift which is quite uncommon and therefore this gives an indication that either these galaxies are not dEs or something strange is happening inside the cluster that helps these galaxies to attain such high redshifts. Whereas at larger distances less scattering and a roughly linear relation is observed in the flow, making it resembles the global Hubble flow.

Index Terms— Galaxies, Redshift, Distance, Virgo cluster, Hubble diagram, Hubble flow

1 Introduction

Galaxies exist in clusters. Clusters of galaxies are among the largest gravitationally bound structures in the observable universe. The sites of these clusters provide venue for many exhaustive studies for eliciting valuable information about their formation and evolution. Among the major densely populated galaxy clusters in the nearby Local super cluster (like- Fornax, Abell 1367, Ursa Major, Virgo, Coma and others), the Virgo has been a very important celestial cluster for extra galactic astronomy. Cosmographically, it lies at the center of the Local Super clusters in whose outskirts 'Milky Way' in the Local group is situated [1]. It is the nearest and best studied, rich cluster of galaxies in the Nothern Hemisphere. In most respects, its properties are typical of large clusters. This cluster is a home of nearly 1500 and possibly up to 2000 galaxies of almost all known Hubble types; ranging from giant massive Elliptical galaxies and Spirals like our own 'Milky way' to dwarf galaxies, comparatively much smaller than their big brethren.

Earlier studies showed that, the structure of Virgo cluster is quite complex. It is an irregular cluster with significant sub structures. It mainly consists of two sub clusters (cluster A and cluster B) and few clouds (termed as W, W', M and, N clouds). Main cluster A containing M87/NGC4486 (considered as heart of the Virgo cluster), separated from cluster B containing M49/NGC4472.The clouds are considered as the separate entities, with distinct structural and kinematical properties. Mass estimates of this cluster vary significantly (0.15 – 1.5) × 10^{15} $M_\odot$ [2] [3] [4] [5] [6] [7] but generally fall within the range typical of rich clusters [8]. It contains vast quantities of X-ray emitting gas [3] [4] [9] and shows clear evidence for both substructure and nonvirialized motions [2] [10] [11].

Indeed, the property that sets Virgo aside from other clusters is its distance ≈ 17 Mpc [12] [13]. Its proximity allows its mapping to an unsurpassed level of depth and morphological detail, rendering it presently the most studied, richest cluster of galaxies in terms of number of known galaxies. In particular this cluster serves as an important reference for the determination of distance scale of the universe. The sites of this cluster serve as an ideal laboratory and provides ample opportunity to explore the wealth of morphological diversity and physical process and also motivates astronomers to carry out many systematic studies.

2 Expanding Universe: an important discovery

One of the greatest and most important discoveries of 20^{th} century is the concept of expanding universe which says that the dominant motion in the universe is the smooth expansion. Earlier everyone including astronomers had assumed that the universe was a stable unchanging stage, on which astronomical events played themselves out. During 1910s and 1920s several physicists and astronomers came up with several astonishing discoveries that defied easy explanations but at the same time opened new doors to explore the universe. Albert Einstein in 1915 developed the general theory of relativity in order to explain that how gravity works. When Einstein applied his theory to the whole universe, a strange result was obtained, that all of the space should be dynamic; either contracting or expanding. Einstein, himself did not believe this finding and thought that he could have committed some mistake. Like other astronomers, he too believed that the size of the universe is not changing. In 1920, a famous debate took place between Harlow Shapley and Heber D. Curtis over size and shape of the universe. Shapley argued for a small universe the size of the Milky Way galaxy and Curtis argued that the universe was much larger. This issue was resolved with Hubble's improved observations. Work by Alexander Fried-

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mann,1922[14]; Georges Lemaître, 1927[15] and several others provided hints of cosmic expansion; the Big Bang and Steady State theories of origin and evolution of universe were proposed.(However in modern cosmology the Big Bang model of the Universe is widely accepted).

Another important finding is by Vesto Slipher, who examined several faint fuzzy nebulae and measured their spectra. He observed that the spectra of nearly all of them were redshifted. Slipher knew that it is possible only when the object is moving away from earth and that the object's speed is proportional to the redshift. After calculating their speeds, he found that they all were moving away from us incredibly quickly. However the real breakthrough in understanding the universe came only after the publication of Edwin Hubble's 1929 article "A relation between distance and radial velocity among extra-galactic nebulae" through which he confirmed the expanding universe theory (considered as the first observational basis for the expanding space paradigm and today serves as one of the pieces of evidence most often cited in support of the Big Bang model) [16]. Hubble calculated distances to hundreds of galaxies by using the 100-inch Hooker Telescope. He combined his galaxy distances with Vesto Slipher [17] and Milton Humason's measurements of the redshifts of galaxies and made a famous plot which today, called as Hubble diagram. Through this diagram, Hubble showed that galaxies recede from us in all directions and more distant ones recede more rapidly in proportion to their distances. Hubble's work convinced the scientific community that we live in an expanding universe.

3. Hubble Law

According to Hubble the dominant motion in the universe is the smooth expansion. The equation that describes the linear fit is known as Hubble Law given by:

$$v = H_0 D$$

or $$cz = H_0 D$$

where,

v is the observed velocity of the galaxy away from us, usually in km/sec.

D is the distance to the galaxy in Mpc (1Mpc = 3.26 Million light years).

c is the speed of light.

z is redshift of galaxy.

& H_0 is proportionality constant known as Hubble's "constant" estimated from the slope of that line. The SI unit of H_0 is s^{-1} but it is most frequently quoted in (km/s)/Mpc. The reciprocal of H_0 is the Hubble time.

Hubble's Law can be easily depicted in a "Hubble Diagram". Figure 1 shows plot of velocity against distance (the original Hubble diagram) in which the velocity (assumed approximately proportional to the redshift) of an object is plotted with respect to its distance from the observer.

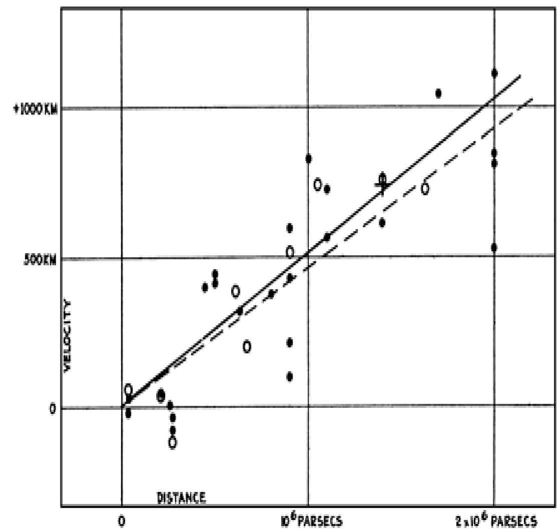

Fig. 1 Original Hubble Diagram: Velocity-Distance Relation among Extra-Galactic Nebulae (courtesy: E. Hubble, PNAS 1929)

A straight line of positive slope on this diagram is the visual depiction of Hubble's Law. This law has been considered as the first observational basis for the expanding space paradigm and today serves as one of the pieces of evidence most often cited in support of the Big Bang model.

Edwin Hubble proposed this law on the basis of the light received from the distant galaxies. He observed that the characteristic colors, or spectral lines (see figure 2) emitted by the stars in the galaxies do not have exactly the same wavelengths observed in the laboratory; rather they are systematically shifted to longer wavelengths, toward the red end of the spectrum i.e. redshifted. The redshift (or blueshift) of a galaxy is defined as shifting of its spectral features to longer (or shorter) wavelengths primarily due to the combination of Doppler motions and the general expansion of the Universe.

The Doppler Shift of Spectral Lines is illustrated below:

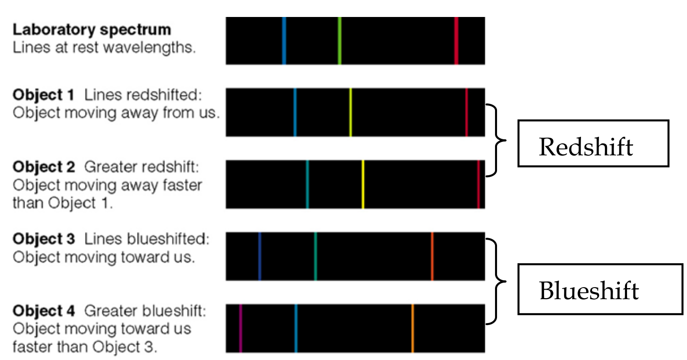

Fig.2 Doppler Shift of Spectral Lines (courtesy: http://ned.ipac.caltech.edu/help/zdef.html)

Redshift: An Example

Consider spectrum of a galaxy as shown below:

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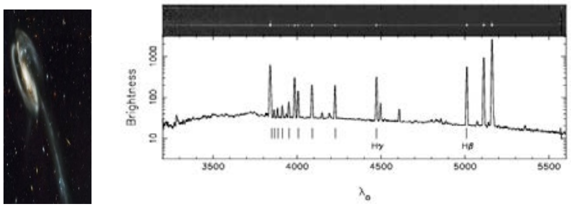

Astronomy picture of the Day [NASA]

The lines in this spectrum are all shifted by the same factor; for example:

Line	λ (Å)	λ_0 (Å)	Δλ (Å)	$z = \Delta\lambda / \lambda_0$	v = c z (km/sec)
Hβ	5009	4861	148	0.0304	9120
Hγ	4472	4340	132	0.0304	9120

Extensions to Hubble's work with today's technology have opened vast new arenas for exploration. Now if we accept expanding universe theory and consider that the whole universe is expanding, then this expansion could also be inferred in Virgo cluster: being very small part of this huge universe. Therefore to infer signatures of Hubble flow in Virgo cluster, Hubble diagram is plotted, using recent data of 180 galaxies obtained from SDSS III DR-9 database (appendix 1), which includes member and surrounding galaxies of Virgo cluster. Methodology used to plot Hubble diagram is as follows:

In order to plot Hubble Diagram two quantities are required first is the distance to galaxy and second is the velocity of galaxy. These values are estimated by using the following methods:

a. Estimating Distances to Galaxies

In astronomy it is very difficult to measure directly the real or absolute distances to galaxies. However, it is easier to calculate and compare their relative distances. For which the apparent magnitude of galaxy is compared with respect to a convenient but arbitrary standard like Andromeda galaxy, star Vega etc. Here we considered star Vega as standard and used galaxy's apparent magnitude value 'm' (obtained from SDSS database [18]) as a substitute for distance to calculate the relative distance to galaxy (as magnitude varies with distance).

SDSS database provides magnitudes in five different wavelengths of light namely; ultraviolet (u), green (g), red (r), two infrared wavelengths (i and z) and any of these magnitude values among u, g, r, i, z , could be used. We have selected 'r' magnitude values for our sample galaxies and assumed that galaxies emit same amount of light and the difference in their magnitudes are only due to their different distances from us. The normalized relative distances to 180 galaxies are calculated by using the following method:

Method:

Step 1: Record the 'r' magnitude value for each of our sample galaxies from SDSS database.

Step 2: Calculate the value of radiant flux 'F' by using formula $F = 2.51^{-m}$. Where, F is a relative number that compares the arriving radiant flux to the star Vega.

Step 3: Calculate the relative distance 'd' by using formula $d = 1/\sqrt{F}$.

Step 4: For simplification normalize these distance values such that $d_1 / d_2 = 1 / x$, for each galaxy.

where,

d_1 is the relative distance to the nearest galaxy.

d_2 is the relative distance to another galaxy.

x is the normalized distance to the other galaxy.

b. Estimating Redshift:

The velocity of a galaxy or other celestial object could be calculated by estimating the value of its Redshift (or blue shift) from its spectrum. A spectrum actually measures how much light an object gives off at different wavelengths. The spectra of stars and galaxies show a series of peaks and valleys called "spectral lines". These lines always appear at same wavelength, so they make a good marker for redshift or blue shift. If we look at a galaxy and see one spectral line at a longer wavelength than it would be on Earth, this would mean that the galaxy is red shifted and is moving away from us whereas, on the other hand if the same line is obtained at a shorter wavelength, this would mean that the galaxy is blue shifted and is moving toward us.

Here we considered redshift as a substitute of velocity. It is also considered that the degree of redshift or blue shift of light waves (obtained by using galaxy spectrum from SDSS database) is proportional to object speed in the direction we are looking. The method of estimating the redshift value is as follows:

Method:

Step 1: Obtain galaxy spectrum from SDSS database.

Step 2: Record the observed wavelength value corresponding to H_β line from spectrum.

Step 3: Calculate the shift of H_β line with respect to its expected wavelength by using formula:

$$z + 1 = \frac{\lambda observed}{\lambda rest} \quad \text{or,} \quad z = \frac{\lambda observed}{\lambda rest} - 1$$

where $(\lambda rest)\ H_\beta = 4862.7A^\circ$.

It is to be noted that positive 'z' values mean the galaxy has a Redshift; negative 'z' values mean the galaxy has a B lueshift.

Table2:

ObjID	RA	Dec.	Magni-tude 'm'	F =2.51-m	Relative distance 'd'	Normalized Relative Distance	λobs A°	Redshift $z = \lambda o/\lambda r - 1$ $\lambda r\,(H_\beta) = 4862.7$ A°
1237661812812873985	187.67892059	12.53960337	18.06	6.05191E-08	4064.935932	13.52311	5279.588	0.08571
1237661812812808373	187.58506469	12.58372373	18.14	5.62236E-08	4217.359798	14.03019	5290.54	0.08796
1237661950255693934	187.63645847	12.71917882	18.64	3.5488E-08	5308.344308	17.65965	5706.897	0.17358
1237661950255693850	187.64283239	12.75350231	17.41	1.10073E-07	3014.114495	10.02727	5314.96	0.09298
1237661950255693986	187.66555825	12.7929538	18.38	4.50814E-08	4709.789535	15.66839	5268.658	0.08346
1237661950255694330	187.63942988	12.90089779	18.02	6.27884E-08	3990.802453	13.27649	8466.424	0.74106
1237661813886550206	187.58423654	13.33841717	17.76	7.97618E-08	3540.810193	11.77947	5338.263	0.09778
1237661813886550213	187.58773072	13.43708591	18.07	5.99647E-08	4083.683483	13.58548	5269.871	0.08371
1237661813886615569	187.6412046	13.44915672	21.2	3.36447E-09	17240.16618	57.35409	7367.158	0.515
1237661813886615625	187.60420664	13.46206435	16.76	2.00202E-07	2234.939576	7.43513	5266.232	0.08296
1237661951329435676	187.64780631	13.62150414	20.41	6.9608E-09	11985.89111	39.87432	6047.836	0.24369
1237661068190613603	187.63872623	13.75811361	18.69	3.38921E-08	5431.889508	18.07065	5628.595	0.15748
1237661068190613592	187.62280247	13.78534984	18.28	4.9427E-08	4497.983048	14.96376	5627.299	0.15721
1237661068190613738	187.68592321	13.79943139	17.91	6.94774E-08	3793.832703	12.62121	4883.149	0.00418
1237661068190613700	187.62908823	13.81319962	17.93	6.82103E-08	3828.907839	12.7379	4975.079	0.02309
1237661068190613612	187.65372008	13.90792952	18.02	6.27884E-08	3990.802453	13.27649	5101.525	0.04909
1237664289392689370	187.62217555	13.94796204	17.91	6.94774E-08	3793.832703	12.62121	5349.338	0.10005
1237664289392689306	187.66645501	14.06159188	16.2	3.35186E-07	1727.257726	5.74619	5208.348	0.07106
1237661068727484463	187.61598497	14.16017778	15.08	9.39551E-07	1031.667763	3.43212	4960.209	0.02003
1237664289392689442	187.58498366	14.14011929	18.59	3.71591E-08	5187.609073	17.25799	6389.987	0.31406
1237661068727484560	187.68949665	14.26262527	19.35	1.84635E-08	7359.414351	24.48309	6287.819	0.29304
1237661068727484549	187.65161215	14.3068563	19.59	1.48044E-08	8218.718429	27.3418	6295.062	0.29453
1237661068727484507	187.68676809	14.34742898	19.1	2.32398E-08	6559.70094	21.82262	5868.134	0.20674
1237661069264290035	187.60655231	14.69190934	18.41	4.38538E-08	4775.25542	15.88618	5460.092	0.12283
1237664290466431099	187.62569307	14.95677501	17.39	1.12118E-07	2986.503364	9.93541	5425.003	0.11561
1237662525766959237	187.59691438	14.99331644	18.31	4.80811E-08	4560.504831	15.17176	5426.253	0.11587
1237662525767024716	187.67558509	15.04797282	18.09	5.88711E-08	4121.438378	13.71108	5081.594	0.04499
1237662525767024713	187.67202579	15.07430066	17.43	1.08065E-07	3041.980899	10.11997	5321.083	0.09424
1237662525767024687	187.66615439	15.12968378	15.03	9.83794E-07	1008.203073	3.35406	4861.833	-1.99E-04
1237662525767024822	187.72068356	15.1740636	18.71	3.3274E-08	5482.108977	18.23772	6011.737	0.23627
1237662525767024834	187.73722317	15.17343799	19.06	2.41112E-08	6440.069671	21.42464	6000.674	0.234
1237662525767024752	187.75523792	15.10413377	18.42	4.3452E-08	4797.278977	15.95945	5725.323	0.17737
1237662525766959207	187.5595623	14.99005054	18.74	3.23679E-08	5558.310071	18.49123	5766.337	0.18581
1237662525766893691	187.43574009	15.02478292	16.23	3.26058E-07	1751.266539	5.82606	4884.274	0.00442
1237662525766893633	187.36673563	14.99915597	17.79	7.75898E-08	3590.027312	11.9432	5142.804	0.05758
1237664290466300056	187.33846119	14.78931371	15.43	6.80823E-07	1211.944581	4.03186	5143.989	0.05782
1237661069264224401	187.31990349	14.73476503	17.94	6.75855E-08	3846.566825	12.79665	5136.887	0.05636
1237661069264158899	187.29305528	14.72869177	18.99	2.57156E-08	6235.940826	20.74555	6250.288	0.28533
1237661069264158851	187.26972728	14.62443213	17.93	6.82103E-08	3828.907839	12.7379	5260.173	0.08172
1237661069264158847	187.2629739	14.61357202	17.86	7.27491E-08	3707.544162	12.33415	5142.804	0.05758
1237664289929429097	187.28982081	14.52365769	17.05	1.53307E-07	2553.985784	8.49653	4961.352	0.02027
1237664289929429120	187.33074214	14.43754609	18.15	5.57086E-08	4236.810331	14.0949	5258.962	0.08147
1237664289929363608	187.24102252	14.41708778	17.15	1.39828E-07	2674.250968	8.89662	5349.338	0.10005
1237664289929363518	187.23260671	14.36981276	18.08	5.94154E-08	4102.517499	13.64814	5457.579	0.12231
1237661068727287971	187.29435514	14.31747249	16.62	2.27731E-07	2095.504634	6.97126	5066.406	0.04187
1237661068727353366	187.36059239	14.24242788	17.48	1.03206E-07	3112.779271	10.3555	5207.149	0.07081
1237664289392558378	187.35301537	14.14673377	20.55	6.11935E-09	12783.43267	42.52756	6698.846	0.37757
1237661068727222458	187.11442594	14.15538134	16.88	1.7927E-07	2361.81681	7.85722	8843.008	0.8185
1237664289392427011	186.98428499	14.12313161	20.72	5.23312E-09	13823.55531	45.98781	6629.793	0.36337
1237664289392427163	186.9616064	14.10645658	20.46	6.64776E-09	12264.84801	40.80234	6637.431	0.36494
1237664289392361716	186.9035708	14.00833796	19.18	2.15903E-08	6805.671602	22.64091	6014.507	0.23684
1237664289392361717	186.9016623	14.00986486	20.42	6.89704E-09	12041.17023	40.05822	6678.824	0.37345
1237664289392362261	186.92779429	13.99053903	20.42	6.89704E-09	12041.17023	40.05822	6675.749	0.37282
1237664289392427169	186.99892133	13.98128801	19.19	2.13925E-08	6837.059472	22.74533	5938.818	0.22128
1237661068190285935	186.97403963	13.92425728	19.21	2.10023E-08	6900.270163	22.95562	6089.758	0.25232
1237661068190351526	187.02829826	13.91175159	15.13	8.97298E-07	1055.678564	3.512	4980.81	0.02427
1237661068190351419	187.05221262	13.89922579	14.84	1.17177E-06	923.8022451	3.07328	4978.517	0.0238
1237661068190351587	187.02909307	13.7339277	18.17	5.46926E-08	4275.98093	14.22521	5422.505	0.1151
1237661951329173792	187.06074859	13.68765436	17.54	9.76614E-08	3199.915701	10.64539	5094.482	0.04764
1237661951329173752	187.09996956	13.61537998	21.01	4.00733E-09	15796.92092	52.55274	6759.273	0.39
1237661951329173624	187.03481987	13.60552351	18.56	3.81993E-08	5116.490067	17.02139	5659.786	0.16389
1237661951329173645	187.05649793	13.57057281	16.08	3.74323E-07	1634.469123	5.4375	4960.209	0.02003
1237661813886353551	187.08277267	13.52829618	17.99	6.45461E-08	3936.090948	13.09447	5658.483	0.16363

1237661813886353535	187.04432768	13.50448001	16.59	2.34106E-07	2066.776523	6.87569	5268.658	0.08346
1237661813886353615	187.07259239	13.44953363	18.72	3.29692E-08	5507.392554	18.32183	5570.575	0.14555
1237661813886419056	187.18147582	13.4330688	19.41	1.74716E-08	7565.427382	25.16845	6100.986	0.25462
1237661813886419019	187.24579377	13.37966863	18.54	3.89089E-08	5069.619891	16.86547	5706.897	0.17358
1237661813886550028	187.46803851	13.42746479	12.92	6.85828E-06	381.8495127	1.27033	4900.044	0.00766
1237661813886550159	187.51976443	13.44224697	17.65	8.8259E-08	3366.050227	11.19808	5266.232	0.08296
1237658629695537161	187.49625761	12.34867546	12.64	8.8741E-06	335.6896256	1.11676	4894.406	0.0065
1237661949718626441	187.1886768	12.41152959	18.68	3.42054E-08	5406.952554	17.98769	5610.48	0.15376
1237661949718561026	187.05964613	12.41815971	17.35	1.16322E-07	2932.03759	9.75422	5601.444	0.1519
1237658629695209653	186.79505416	12.38652722	18.72	3.29692E-08	5507.392554	18.32183	5657.18	0.16336
1237658629695144080	186.63810703	12.3875103	18.57	3.78494E-08	5140.087404	17.09989	5295.415	0.08896
1237658629695078609	186.49747394	12.37762232	17.35	1.16322E-07	2932.03759	9.75422	5286.887	0.08721
1237661949718298709	186.38592454,	12.41675623	16.89	1.77628E-07	2372.709548	7.89346	5310.067	0.09198
1237658629694881934	185.93478215	12.39248646	18.38	4.50814E-08	4709.789535	15.66839	5622.199	0.15616
1237658629694750884	185.70304983	12.35615027	18.21	5.27159E-08	4355.411907	14.48946	5310.067	0.09198
1237658629694750751	185.6842655	12.33946833	18.3	4.85256E-08	4539.568268	15.1021	5321.083	0.09424
1237658629694750797	185.62359472	12.34508414	19.36	1.82943E-08	7393.356091	24.596	5986.872	0.23116
123766194971797	185.57081316	12.39686724	16.09	3.70894E-07	1642.007322	5.46258	4967.067	0.02144
1237658629694619762	185.40717776	12.35821044	19.09	2.34546E-08	6529.58638	21.72244	5618.236	0.15535
1237658629694619805	185.3427675	12.34852022	19.43	1.7153E-08	7635.372056	25.40114	6065.966	0.24742
1237658629694488751	185.13618772	12.39185372	16.67	2.1749E-07	2144.274933	7.13351	4991.143	0.02639
1237658629694488714	185.09209971	12.34883394	17.51	1.00395E-07	3156.046778	10.49945	5337.034	0.09752
1237658629694488696	185.02652544	12.38108029	16.98	1.63508E-07	2473.032908	8.22721	5148.729	0.0588
1237661949717708877	184.94965204	12.42193433	14.85	1.16103E-06	928.0628364	3.08745	5153.473	0.05977
1237661949717643408	184.91952143	12.40549021	16.58	2.36271E-07	2057.288276	6.84413	5152.286	0.05953
1237661949717643394	184.91560656	12.39175524	16.66	2.19501E-07	2134.430902	7.10076	5146.358	0.05831
1237661949717643294	184.89186581	12.42072196	16.38	2.84017E-07	1876.410173	6.24239	5147.543	0.05856
1237661949717643488	184.80951551	12.37799219	19.18	2.15903E-08	6805.671602	22.64091	6058.987	0.24599
1237661949717577812	184.68313837	12.38581863	16.59	2.34106E-07	2066.776523	6.87569	4865.192	4.92E-04
1237661949717577822	184.68920607	12.36218143	17.47	1.0416E-07	3098.488989	10.30796	5314.96	0.09298
1237661949717512405	184.63157942	12.47111097	17.46	1.05123E-07	3084.264311	10.26064	5138.07	0.05661
1237661949717446734	184.48512316	12.46241641	18.69	3.38921E-08	5431.889508	18.07065	4861.833	-1.99E-04
1237661949717512325	184.49310957	12.38007561	18.13	5.67434E-08	4197.99856	13.96578	5328.439	0.09576
1237661949717446822	184.42602411	12.45274302	17.4	1.11091E-07	3000.277167	9.98124	5318.633	0.09374
1237661949717446772	184.39062142	12.38809375	14.92	1.0886E-06	958.442277	3.18852	4859.594	-6.59E-04
1237661949717381212	184.28867029	12.45393848	14.74	1.28472E-06	882.2574357	2.93507	4896.661	0.00696
1237661949717381378	184.18474855	12.41403117	18.34	4.67718E-08	4623.895665	15.38264	6112.234	0.25694
1237661949717315637	184.16504934	12.46822733	17.3	1.21799E-07	2865.350083	9.53236	5191.585	0.06761
1237661949717381357	184.20488604	12.38758636	18.69	3.38921E-08	5431.889508	18.07065	5565.446	0.14449
1237661949717250229	184.00985756	12.42877728	19.57	1.50794E-08	8143.429946	27.09133	6403.243	0.31678
1237661949717250075	183.9230868	12.46317685	18.53	3.92686E-08	5046.34606	16.78804	5490.35	0.12905
1237661949717184658	183.82051695	12.4202222	18.19	5.36951E-08	4315.513672	14.35673	5492.879	0.12957
1237661949717119083	183.67193858	12.37713816	18.58	3.75027E-08	5163.793572	17.17876	5583.416	0.14819
1237661949717053548	183.42459495	12.37285632	18.2	5.32033E-08	4335.416893	14.42294	5178.453	0.06491
1237661949716857000	183.09626126	12.46455349	17.64	8.90749E-08	3350.597217	11.14667	5445.027	0.11973
1237658630768820350	186.53213508	13.11362031	19	2.548E-08	6264.701089	20.84123	4866.313	7.22E-04
1237661813349220495	186.51594114	13.11212091	13.22	5.20371E-06	438.3724968	1.45836	4864.072	2.62E-04
1237661950792106283	186.59900892	13.14449594	18.15	5.57086E-08	4236.810331	14.0949	5117.997	0.05248
1237661950792106189	186.51731959	13.23961818	19.03	2.47862E-08	6351.780182	21.13092	6064.57	0.24714
1237661951328977125	186.53969251	13.67307469	17.68	8.58556E-08	3412.83819	11.35373	8970.156	0.84465
1237661068190089373	186.51070463	13.745641	18.06	6.05191E-08	4064.935932	13.52311	5380.22	0.1064
1237661068190154940	186.52537511	13.81258192	19.18	2.15903E-08	6805.671602	22.64091	5973.103	0.22833
1237661068190154956	186.55530879	13.87274064	19.97	1.04356E-08	9789.085212	32.56605	6432.799	0.32286
1237664289392230566	186.54704056	14.01019962	20.29	7.77356E-09	11342.00683	37.73226	6606.934	0.35867
1237661951329304590	187.28199266	13.69975516	17.9	7.01198E-08	3776.415811	12.56327	5461.35	0.12309
1237658629695733981	188.01211438	12.3733429	17.53	9.85643E-08	3185.225389	10.59652	5102.7	0.04933
1237658629695734017	188.05797548	12.33932996	17.95	6.69664E-08	3864.307255	12.85567	5303.957	0.09072
1237661949719085113	188.20376603	12.37672564	18.73	3.26671E-08	5532.792739	18.40634	5722.687	0.17683
1237661949719216267	188.5341265	12.40345399	18.78	3.11981E-08	5661.561701	18.83472	5985.494	0.23087
1237661951329042501	186.72816267	13.56617059	16.06	3.81276E-07	1619.496387	5.38769	4855.12	-0.00158
1237661951328977047	186.6349627	13.57877164	14.88	1.12942E-06	940.9628725	3.13037	4883.149	0.00418
1237658630231883978	186.3133465	12.71462394	14.68	1.35766E-06	858.2328143	2.85514	4857.357	-0.00112
1237661949718102040	185.93529176	12.47833535	14.11	2.29405E-06	660.2343339	2.19645	4855.12	-0.00158
1237664291002450113	185.71247927	15.27510559	17.57	9.5002E-08	3244.394401	10.79336	4854.003	-0.00181
1237661070337245213	185.68573654	185.68573654	17.03	1.56155E-07	2530.589714	8.41869	6395.875	0.31527
1237661950792040705	186.38972673	13.22721358	16.72	2.07709E-07	2194.1803	7.29954	4857.357	-0.00112
1237661950792040510	186.40505295	13.14372074	16.09	3.70894E-07	1642.007322	5.46258	4850.651	-0.0025
1237661950792040719	186.46048619	13.19764282	16.28	3.11395E-07	1792.025119	5.96166	4854.003	-0.00181
1237661812812415179	186.66589203	12.51353774	16.08	3.74323E-07	1634.469123	5.4375	4858.475	-8.89E-04
1237661950792171680	186.71353029	13.18294179	19.34	1.86342E-08	7325.628431	24.37069	4862.952	3.13E-05

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1237661950792171682	186.71436492	13.17302185	15.99	4.06647E-07	1568.163724	5.21692	4862.952	3.13E-05
1237662525766631444	186.72729378	15.05259471	14.37	1.80588E-06	744.1417801	2.47559	4861.833	-1.99E-04
1237661949181624903	186.84237672	12.0687089	17.98	6.51428E-08	3918.02097	13.03436	4859.594	-6.59E-04
1237658629695275533	186.84791201	12.33156985	18.08	5.94154E-08	4102.517499	13.64814	4842.839	-0.0041
1237661812275675183	186.92541762	12.08954419	16.32	3.00141E-07	1825.313926	6.0724	4865.192	4.92E-04
1237664289392558115	187.2769013	14.00491469	17.22	1.31105E-07	2761.790567	9.18785	4855.12	-0.00158
1237661813886484702	187.38341187	13.51042114	17.7	8.42898E-08	3444.390915	11.4587	4864.072	2.62E-04
1237661068190548092	187.46338805	13.86794401	15.92	4.33705E-07	1518.458136	5.05156	4852.885	-0.00204
1237658629158666270	187.47084075	11.962287	17.98	6.51428E-08	3918.02097	13.03436	4856.238	-0.00135
1237662525767024687	187.66615439	15.12968378	15.03	9.83794E-07	1008.203073	3.35406	4861.833	-1.99E-04
1237661950255759478	187.83094855	12.73798912	16.36	2.89293E-07	1859.22111	6.1852	4856.238	-0.00135
1237662526840897747	188.09511262	16.01887087	15.32	7.53353E-07	1152.127934	3.83287	4860.713	-4.29E-04
1237661950256021509	188.332409	12.85343083	14.91	1.09866E-06	954.0422185	3.17388	4854.003	-0.00181
1237662524694069565	189.50162538	14.17881935	17.6	9.2415E-08	3289.491352	10.94338	4862.952	3.13E-05
1237661974399484128	184.5600662	6.60364193	15.15	8.80933E-07	1065.438633	3.54447	4904.559	0.00859
1237654606947155983	184.84266267	6.09867794	12.59	9.29197E-06	328.0545584	1.09136	4891.026	0.0058
1237655126620045406	184.89898355	5.84675158	13.22	5.20371E-06	438.3724968	1.45836	4903.43	0.00836
1237661974399680630	184.97698705	6.64115942	18.59	3.71591E-08	5187.609073	17.25799	5644.169	0.16068
1237661971722469381	185.03117254	7.69184873	13.63	3.56818E-06	529.3908271	1.76116	4905.689	0.00882
1237655126083240130	185.10125194	5.57286483	14.36	1.82257E-06	740.7255417	2.46422	4877.531	0.00303
1237661970111922354	185.25354813	6.39525324	18.18	5.41916E-08	4295.701825	14.29082	5456.322	0.12205
1237655126620176584	185.28469625	5.90789419	17.99	6.45461E-08	3936.090948	13.09447	5232.389	0.076
1237654606410481727	185.23269225	5.83878824	18.21	5.27159E-08	4355.411907	14.48946	5330.893	0.09626
1237661971722797134	185.79510893	7.51137902	20.24	8.13962E-09	11084.03941	36.87406	4861.833	-1.99E-04
1237661970649055281	185.79404932	6.76528427	19.01	2.52466E-08	6293.593993	20.93735	6006.203	0.23513
1237661970112184751	185.77724019	6.42600859	21.2	3.36447E-09	17240.16618	57.35409	7483.418	0.53891
1237661970112185211	185.79038981	6.24603547	22.22	1.31598E-09	27566.08212	91.70605	8013.09	0.64783
1237662237468590245	190.04687567	9.89613023	15.61	5.7689E-07	1316.598622	4.38002	4894.406	0.0065
1237662526841749529	190.08197396	15.9352324	14.28	1.96182E-06	713.9542306	2.37516	4889.9	0.00557
1237661070872870923	182.65628346	16.03290574	12.4	1.10674E-05	300.5917613	1	4897.778	0.00719
1237661070872870999	182.64965722	15.993695	17.96	6.63529E-08	3882.129504	12.91496	5382.698	0.10691
1237661950790795288	183.47330837	13.172841	13.01	6.31313E-06	397.994947	1.32404	4902.301	0.00812
1237661971184812213	183.32653603	7.22471013	16.95	1.68086E-07	2439.129111	8.11442	5185.612	0.06638
1237674597852053622	182.21510797	9.13165117	15.51	6.325E-07	1257.389155	4.18305	4994.592	0.0271
1237662525765713987	184.592125	15.05426565	18.31	4.80811E-08	4560.504831	15.17176	5310.067	0.09198
1237662525765648620	184.54257276	15.06026801	18.15	5.57086E-08	4236.810331	14.0949	5173.685	0.06393
1237662525765517358	184.14071881	15.10962554	18.36	4.59188E-08	4666.644985	15.52486	5440.014	0.1187
1237662525765517399	184.13571657	15.11935005	18.29	4.89742E-08	4518.72782	15.03277	5435.006	0.11767
1237662525765451939	184.06100302	15.09142019	18.66	3.48408E-08	5357.421564	17.82292	5615.65	0.15482
1237662525765452020	184.04196555	15.12364455	17.52	9.94756E-08	3170.602518	10.54787	4873.04	0.00211
1237661069799588057	183.82665664,	15.05576573	17.68	8.58556E-08	3412.83819	11.35373	5633.782	0.15855
1237661069799522395	183.63282541	15.07729772	18.9	2.79362E-08	5982.967834	19.90396	6328.489	0.30141
1237661069799391384	183.31749804	15.05543609	20.42	6.89704E-09	12041.17023	40.05822	6565.987	0.35025
1237661069799325765	183.11999966	15.07090006	18.09	5.88711E-08	4121.438378	13.71108	5216.75	0.07279
1237661069799260259	182.97822539	15.11850857	18.72	3.29692E-08	5507.392554	18.32183	5440.014	0.1187
1237661975473291464	184.67584225	7.46526958	17.67	8.66494E-08	3397.170384	11.30161	5495.409	0.13009
1237661975473356952	184.71451566	7.48744288	20.41	6.9608E-09	11985.89111	39.87432	6525.293	0.34188

Column 1 - Object ID is the galaxy identity from SDSS-III DR9 database.

Columns 2 & 3 - Galactic position; Right Ascension (RA) & Declination (Dec.) in Degrees.

Column 4 - Galaxy magnitude ‘m’ by using ‘g’ filter value, directly lifted from SDSS DR9 database.

Column 5 - Apparent Flux of galaxy using $F = 2.51^{-m}$.

Column 6 -‘d’ is the Relative distance to galaxy.

Column 7 - Normalized Relative distance to galaxies.

Column 8 - λobs is the observed wavelength of H_β line through spectrum.

Column 9 - Calculated Redshift of galaxy ‘z’.

Finally by using the data tabulated in table 2 (above) and considering the relative distance values on X axis and the redshift values on Y- axis Hubble diagram is obtained as:

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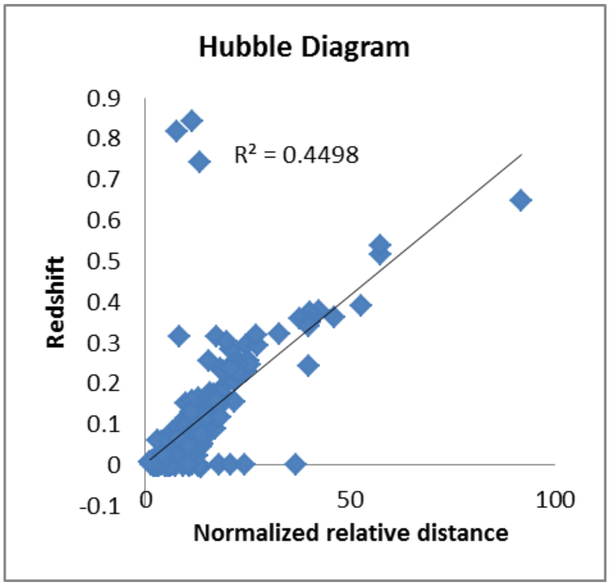

Fig. 3 Hubble Diagram of by considering 180 galaxies

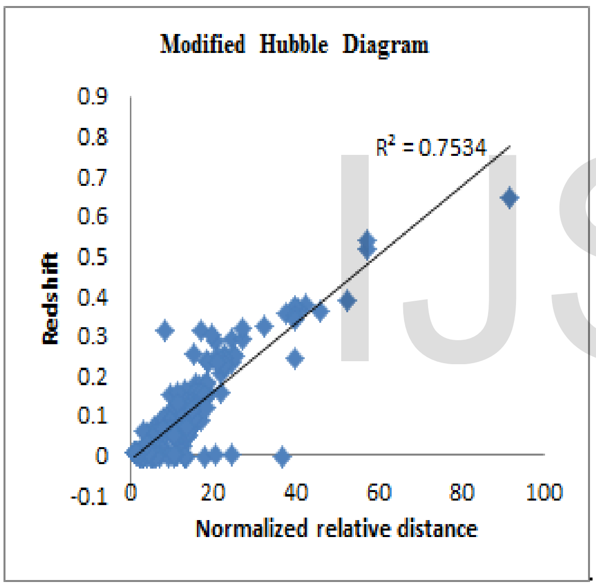

Fig. 4 Modified Hubble Digram by excluding 3 galaxies from our sample

RESULT

At smaller distances strong deviation from linear relation is observed (shown in figure 3 as we get $R^2 = 0.4498$). Here the galaxies are much more clustered and exhibit low redshift. In contrast to it three galaxies with higher redshifts are also observed in this region. If we exclude these galaxies from our Hubble diagram, then we get $R^2 = 0.7534$, i.e. lesser deviation (figure 4). This gives an indication that possibly that either these are those galaxies that fall into the cluster from its surrounding or from neighboring clouds, due to enormous mass of Virgo cluster. This larger mass provided gravitational pull for these galaxies or there is something strange happening inside the cluster that helps these galaxies to attain such high redshifts. However at larger distances, less scattering and a roughly linear relation is observed in the flow making it resembles the global Hubble flow.

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