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REDSHIFT-MAGNITUDE BANDS IN CLUSTERS OF GALAXIES

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Les bandes V_o-m sont discutées pour trois amas de galaxies.

This paper presents new material and analysis for three clusters of galaxies. We assume familiarity with the initial Coma work (Tifft 1972,3). Redshifts and nuclear magnitudes are now available for 108 Perseus galaxies. The sample is nearly complete to $0^{\circ}\!.75$ radius and V(6)=16.8 (6" scaled from $4''\!.8$ in Coma). No field galaxies are seen, not surprising in view of field studies in the Coma region (Tifft and Gregory 1976). Table 1 shows average data. The central $0^{\circ}\!.3$ field has a mean redshift 700 km/s less than the outer part, a difference independent of magnitude and significant at the 99.9 confidence level. A redshift excess appears around N1275 and N1265. Excluding these radio regions the difference exceeds 1000 km/s.

Table 1 Perseus Redshift Analysis

Number	R°	$\overline{V}_o \pm$ me	Disp	ΔV_o	t	p
108	<0.75	5480 ± 126	1307			
59	<0.3	5160 ± 178	1358	705	2.9	0.001
49	>0.3	5865 ± 163	1128			
29	<0.3, <9'N1275	5595 ± 242	1281	855	2.5	0.01
30	<0.3, >9'N1275	4740 ± 241	1296	1038	3.8	<0.001
42	>0.3, >9'N1265	5778 ± 153	982	621	1.35	0.1
7	>0.3, <9'N1265	6399 ± 682	1670			

Number	R°	m	$\overline{V}_o$	V_o
30	<0.3	14-15	5169	19
29	<0.3	16	5150	
28	>0.3	14-15	5833	75
21	>0.3	16	5908	

Redshifts: 61 Tifft, 47 Chincarini and Rood (1971)
Magnitudes: From iris smoothing of Weedman (1975)

Now consider redshift-magnitude diagrams in radial zones. Fig. 1 is the central zone where three bands are seen. Half the sample is new. As in Coma the central field shows bands very clearly. Open circles are galaxies near N1275. Radio galaxies (+) appear to associate with band heads and a vertical scattering of objects furthest from bands is suggested below band heads. Fig. 2 shows larger regions. Note the radio association. The

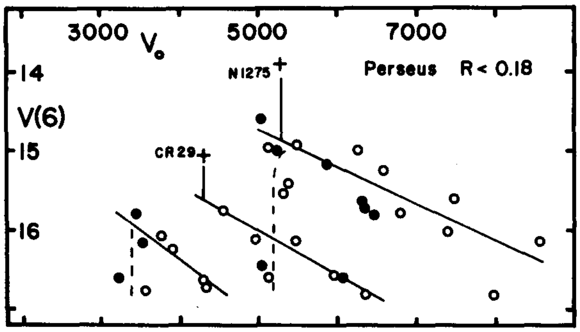

Fig. 1 V_o-V(6) diagram for central Perseus galaxies. 15 V_o are new.

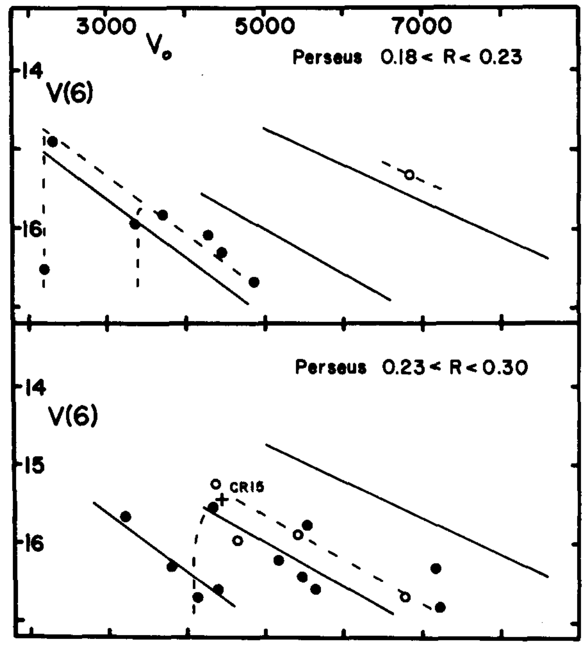

Fig. 2 V_o-V(6) diagrams for radial zones in Perseus. Solid lines from fig. 1. Bands brighten with radius and radio sources (+) associate with band heads. 15 V_o are new.

bands also appear to brighten with radius at a rate close to 1.2 màgnitudes per degree. We will see more of this later. If we remove the radial drift with a linear relationship we obtain fig. 3. Forty of the 59 galaxies with R<0°.3 fall in the outlined regions which are drawn convergent to V_o=0 in accord with Coma. The upper band head redshifts also match Coma (lc,mc).

Outer Perseus data are shown in fig. 4. Open circles are objects near N1265. The radio association is present and the bands are 0.6 magnitudes brightened. Two remarkably sharp vertical sequences appear below the band heads which are now shifted to higher redshift. There is no spatial clumping of the vertical sequences, they distribute throughout outer Perseus.

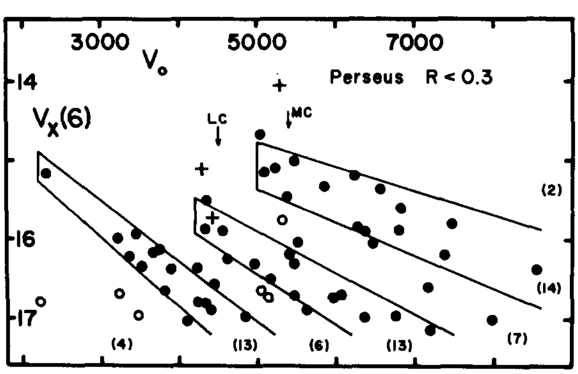

Fig. 3 Composite V_o-V(6) diagram for Perseus to 0°.3. V_x^o=V+1.2R° removes the radial brightening. Radio (+), vertical sequence candidates (o). Band and interband populations along margins. Bands converge to V_o=0.

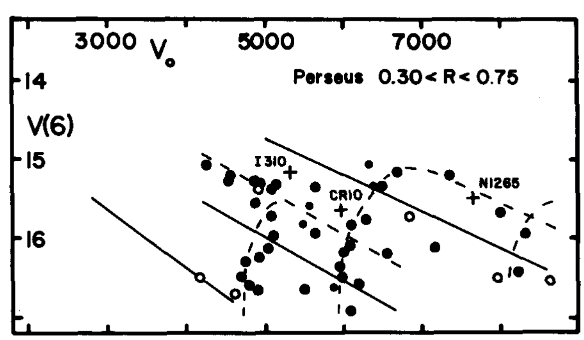

Fig. 4 V_o-V(6) diagram for outer Perseus. Small dots for R>0°.6. 31 V_o are new. Distinct vertical sequences lie below band heads, with a possible one at 8000 km/s. The bands are 0.6 magnitudes bright.

Using Perseus we now propose an explanation of bands based upon galaxy evolution. Fig. 5 shows a model where galaxies appear in a narrow redshift interval which moves to bluer redshift with time. Galaxies rise in luminosity, forming vertical sequences, until a critical maximum is reached. At this point radio source activity is likely. The galaxy then fades with time by expansion and dissipation, to produce down sloping bands. The cluster core is further advanced in evolution, hence it shows bluer vertical sequences and fainter bands at a given redshift (greater fading time).

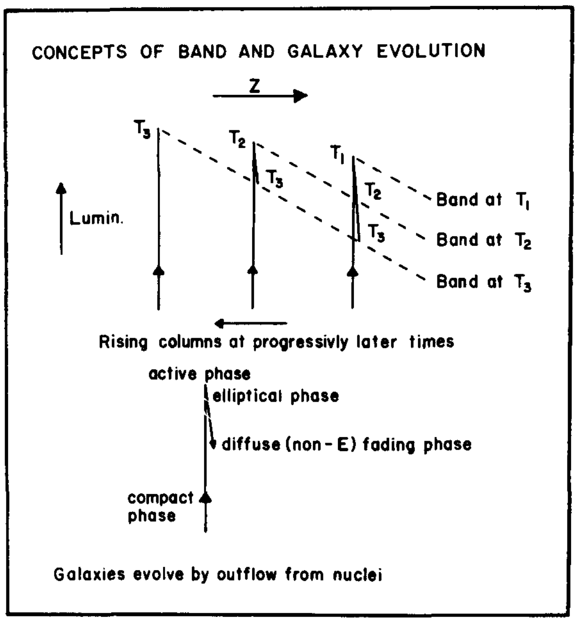

Fig. 5 A model of galaxy-band evolution which is consistent with vertical sequences, band brightening with radius, and morphological correlations. More evolved high redshift objects should tend toward non-elliptical morphology as shown in Coma. The evolution requires expansion from faint "cores" with luminosity peaking in the elliptical phase and then fading slowly as the galaxies dissipate. This model is consistent with the two redshift expanding stream model for individual galaxies (Tifft 1976).

We now turn to the Coma cluster. The total Zwicky sample of more than 200 galaxies within 3° of the center is available. Two subsamples are the emission line and radio galaxies. Fig. 6 shows that radio and strong emission galaxies clump in two areas of the V_o-m diagram. The clumps match the upper and lower Coma bands defined by central field galaxies. No spatial clumping is present, the galaxies distribute quite uniformly throughout the central parts of Coma. The groups differ appreciably from the mean redshift of the cluster and also differ in emission properties. Fifteen of the 17 high V_o galaxies show $H\beta > 5007$ [OIII], while 4 of the 5 low V_o objects have $H\beta \lesssim 5007$. Fig. 7 shows weak emission line galaxies. They populate the middle Coma band and are widely distributed in the outer parts of the cluster. They are also brighter than the centrally defined band indicating the same radial luminosity effect seen in Perseus. Table 2 compares Coma samples.

Finally we consider the entire sample of outlying bright Coma galaxies and transform their magnitudes, as in Perseus, by 0.35 mag/$^{\circ}$. Fig. 8 shows the original and transformed sample of all single galaxies with transformed

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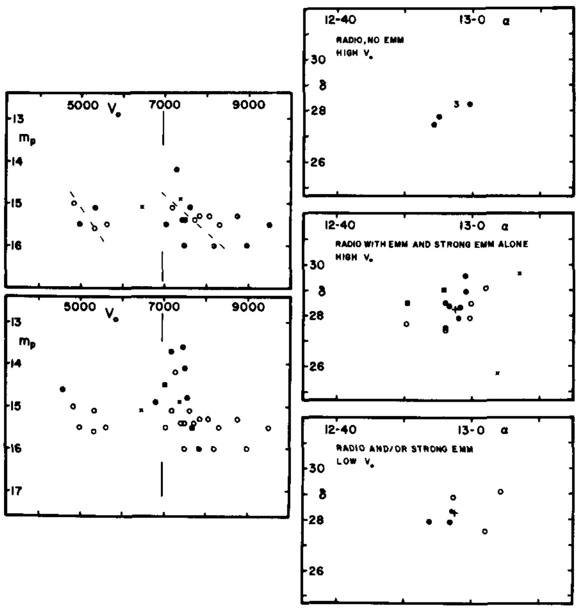

Fig. 6 V_o-m and spatial distribution of strong emission line galaxies in Coma. The upper left panel shows all the strong emission line galaxies. The dot symbol is filled for radio and half filled for possible radio. The vertical line marks the mean Coma redshift and x marks galaxies with $R>2^o$. The lower left repeats the upper panel (o,x) and adds radio galaxies without emission (•) or weak emission (squares). Coma bands are shown dashed. On the right the spatial distributions are shown. The cluster center is marked (+). Radio sources have filled symbols and the small symbol identifies the non-emission galaxy. Otherwise symbols are as on the left.

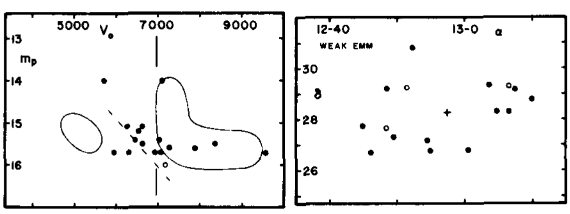

Fig. 7 V_o-m and spatial distribution of weak emission line galaxies in Coma. On the left (o) marks a faint companion. On the right (o) marks the three high V_o galaxies.

Table 2 Coma Redshift Deviations

Sample	N	$\overline{V}_o$ ± me	Disp	ΔV_o	t	p
Total Coma (1)	226	6952 ± 61	909			
Total hi-z group	25	7669 ± 136	668	+717	3.8	<0.001
Str emm alone	17	7806 ± 185	739	+854	3.8	<0.001
Radio alone	18	7708 ± 169	697	+756	3.4	<0.001
Best radio (2)	16	7612 ± 174	672	+660	2.8	0.001
Total lo-z group	6	5124 ± 156	350	-1828	4.9	<<0.001
Wk emm group (3)	13	6623 ± 129	447	-329	1.3	0.1

(1) Tifft and Gregory 1976 (2) omits doubtful sources
(3) omits 3 hi-z objects and 2 companions in doubles

magnitudes brighter than 15.6, plus the radio (large o) and emission line (o,x) galaxies previously discussed. The bands are now readily seen and are a rather striking confirmation of the concepts introduced via Perseus.

As a further example we can consider the N545 cluster (Zwicky and Humason 1964). Fig. 9 shows the cluster before and after radial transformation using the same coefficient as in Perseus which is similar in V_o. The Coma band pattern is superimposed at about the expected modulus difference. This cluster, plus Coma, Perseus, and A2199 (Tifft 1974), provide a case for the band phenomenon which is not easily dismissed.

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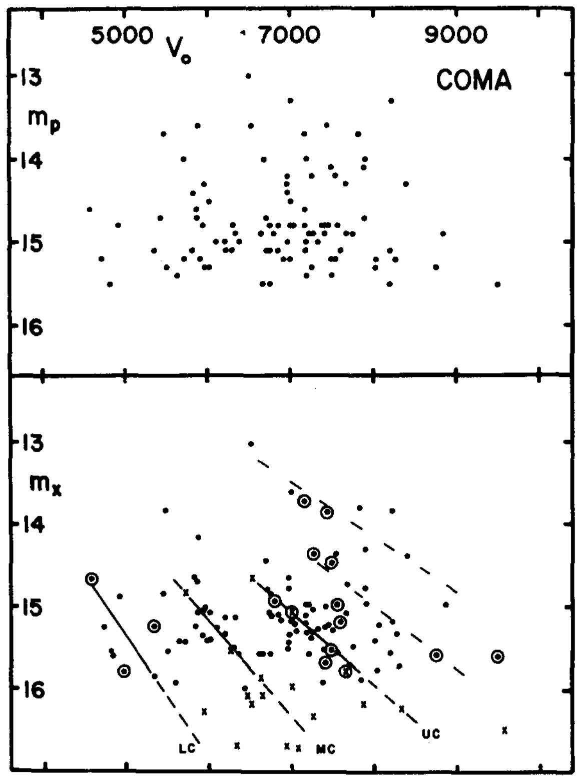

Fig. 8 V_o-m diagram for Coma cluster. $m_x=m_p+0.35R^o$ is the transformation to remove radial brightening. Emission (o) in the upper panel is distinguished as weak (x) or strong (o) below. Radio (large o) is also shown. All single galaxies $R<3^o$ and $m_x<15.6$ are shown. The lower panel adds fainter emission and radio galaxies to $m_p=15.7$. Lc, mc and uc denote the central Coma bands. Higher remnants are suggested.

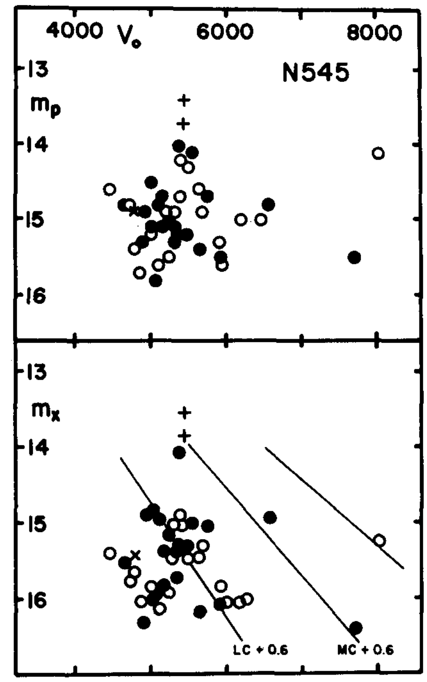

Fig. 9 V_o-m diagrams for N545 cluster. $m_x=m_p+1.2R^o$ gives the magnitude free of radial effects. The bright optical pair (+), ellipticals (•), spirals (o) and unclassified (x) objects shown. The Coma bands are shown shifted 0.6 magnitudes. Note the trend in morghology on the strongest band.

Limited space prevents discussion of the redshift as a discrete variable (Tifft 1976, 1977) which is at fundamental variance with interpretation of the redshift as a velocity. Details are given elsewhere.

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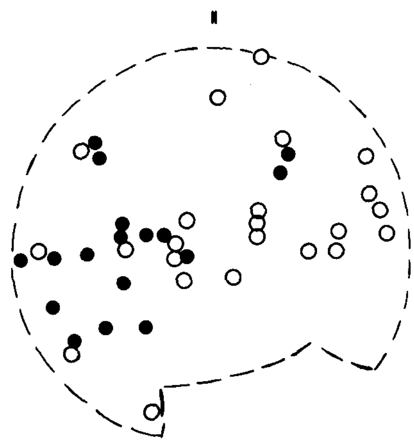
DISCUSSION

L. NOTTALE: Do you not think that there might be some relation between bands in clusters and the spatial distribution of galaxies? Indeed here is a plot of the distribution of galaxies in the core of the Coma cluster for two different bands, and some kind of separation can be noticed which has shown to be statistically significant.



Spatial distribution of galaxies belonging to Tifft's bands 3 and 4 in the core of the Coma cluster.

W.G. TIFFT: In the center of Coma there could be some slight spatial separation. When the larger outer region is considered, using emission line galaxies for example, the same bands are present. On the larger scale I do not believe one can spatially distinguish the separate bands. Each band appears to overlay the entire cluster region or a very large part of it.

H. ARP: Disregarding the bands for a minute, the average of the redshifts of radio galaxies in Coma is significantly higher than the mean of the redshifts of non-radio galaxies. Does this also apply to the new clusters you have analyzed?

W.G. TIFFT: The number of radio galaxies in Perseus is too small to get a significant determination but a slight effect could be present. The location of radio sources appears to relate to band location and is not simply a general redshift "excess" compared to normal galaxies.

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J.M. BARNOTHY: In a paper published in Astrophys. J. 189,11, 1974, I have shown that the redshift bands discovered by Tifft in the Coma cluster have no statistical significance, and in 20 random samples 8 showed a similar banding. I have also shown that the apparent magnitude distribution of the galaxies in the cluster suggests the presence of an absorbing cloud in the central part of the cluster, which may contribute to the appearance of a redshift banding.

W.G. TIFFT: I will refer this question to my paper in Astrophys. J., 188, 221, 1974 where I show your band pattern to be entirely different in character and significance. I also wish to point out that additional samples in Coma itself (emission line, radio, outer galaxies) are independent samples but confirm the same bands. The significance of the band rests on far more then the original sample you discussed. Other clusters now clearly show the same effects.

J.P. VIGIER: I am not convinced by your answer that spatial (velocity) separation is out since subgroups could cover a wider region. However, a big mystery remains: why is it that in all these bands (and also in the Virgo cluster as shown by Holmberg and de Vaucouleurs) there is always a difference between Sc and elliptical galaxies.

W.G. TIFFT: I agree that in general morphology varies systematically along a band with higher redshift tending toward spiral morphology. It is important, however, to distinguish effects along a band from the overall mean effect in a cluster since the bands are shifted and overlap. The cluster average might not show an effect even when separate bands do.

B.M. LEWIS: Is it true that all the clusters you have investigated and found banding structure in (Coma, Perseus, A 2199 etc.) are within much the same velocity range.

W.G. TIFFT: Perseus: 3000 - 8000; Coma: 4500 - 9000; A 2199: 9500 - 10 000. The total redshift range over the three clusters is wider than a single cluster and the mean concentrations in such cluster are narrower still. The clusters by no means are identical.

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