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New measurements of radial velocities in clusters of galaxies (*)

D. Proust (1), A. Talavera (2), E. Salvador Sole (3), A. Mazure (1) and H. V. Capelato (4)

(1) Observatoire de Paris, Section de Meudon et Université Paris VII, Département d'Astrophysique Fondamentale, F-92195 Meudon Principal Cedex, France
(2) I.U.E. Observatory, European Space Agency, P.O. Box 54065, Madrid, Spain
(3) Departamento de Fisica de la Tierra y del Cosmos, Universidad Central de Barcelona, Av. Diagonal 647, Barcelona 28, Spain
(4) IAG-USP, Caixa Postal 30627, 01051 São Paulo, Brazil

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Summary. — We have obtained 101 new redshifts for 100 galaxies in ten clusters of galaxies. Data for individual galaxies are presented and the accuracy of velocities determined using four different instrumentations (located at Calar Alto, La Palma, ESO and Hawaï) is discussed.

Key words: redshifts of galaxies — clusters of galaxies.

1. Introduction.

From recent developments of observational astronomy, the overall view of the structure of the universe appears to be very different from the homogeneous and isotropic one claimed by the traditional cosmology. The scheme of long, interconnected linear filaments (of size $\simeq 100\ h^{-1}$ Mpc, where $h = H_0/100$ and H_0 is the Hubble constant) formed by concentration of galaxies seems now well established (e.g. Fontanelli, 1984), these regions being separated by large voids empty of bright galaxies.

One of the fundamental aspects of the understanding of such large structures is to accede to the third dimension in order to modify their « projected view ». For instance, the spatial correlation function $\xi(r)$ of galaxy pairs (Dekel, 1984) estimated from the Center for Astrophysics (CFA) survey shows unobserved structures from estimates made on the basis of catalogues which use only projected positions. The use of percolation applied to a sample of three-dimensional galaxies is also a powerful way to explain the reality of large structures.

If the redshift determination is the only way to have access to the third dimension, it is also essential for the understanding of the dynamics because it leads to the determination of the velocity dispersion in particle systems. The cosmic virial theorem (Peebles, 1980) using two and three points spatial correlation functions gives estimates of the cosmological parameter Ω_0.

The radial velocities are also essential for the understanding of structures like clusters of galaxies, their dynamical analysis leading to their mass and to an estimate of the missing mass in the universe.

Analyses of some Abell clusters have been recently published: Gregory and Thompson (1984) for A 2197 and A 2199 ; Geller *et al.* (1984) for A 1142 ; Mazure *et al.* (1985) for A 496, and in this paper, we present 101 new redshifts for 100 galaxies in ten clusters. The data for individual galaxies are presented and the accuracy of velocities determination using four different instrumentations is discussed.

2. Observations.

The program of radial velocity measurements was carried out between March 1984 and March 1985, i) at the 2.2 m telescope at Calar Alto (Spain), ii) at the 2.5 m Isaac Newton telescope at La Palma (Canary Islands) and iii) at the 1.50 m telescope at ESO (Chile). We also include results of observations made during a technical run at the 3.60 m Canada-France-Hawaii (CFH) telescope at Mauna Kea.

2.1 OBSERVATIONS AT CALAR ALTO. — Observations were made in two observing runs of six nights each with the 2.20 m telescope in March 1984 and March 1985.

(*) Based on observations made at Calar-Alto Observatory (Spain), La Palma Observatory (Canary Islands), European Southern Observatory — La Silla (Chile) and Canada — France — Hawaii Telescope operated by the National Research Council of Canada, the Centre National de la Recherche Scientifique of France, and the University of Hawaii.

Fifty per cent of the nights were suitable for observations because of wheather conditions and Moon light.

We used the Boller & Chivens Spectrograph with an effective dispersion of 89 Å/mm. The spectral region covered was from 3900 Å to 7200 Å with a 600 line/mm grating blazed at 5500 Å. The slit was 180 μm widened, the resolution was about 8 Å FWHM. A two-stage EMI9916 image intensifier of 40 mm cathode diameter was used, cooled at –18°. Spectrograms were obtained on IIa0 Kodak plates and the wavelength calibration was made using a Fe-Ne Source before and after each spectrum. Exposure times used ranged between 1800 and 3600 s, depending on magnitude and weather conditions. The resulting signal to noise ratio was between 8 and 12.

Spectrograms were recorded with the PDS1010G microphotometer of the Institut d'Optique at Orsay (using a 20 μm square aperture). The observations were reduced using the STII interactive data processing programs developed at the Meudon observatory. The resulting redshifts are listed in table I referenced as CA1 and CA2 for the first and the second run respectively. The galaxy number is from Dressler (1980).

2.2 CALAR ALTO DATA REDUCTION. — Wavelength calibration was carried out using the Fe-Ne comparison source and night sky lines on each spectrum. Usually these set of lines are used in a fifth order polynomial fit of the wavelength solution with typical r.m.s. residuals of 0.6 Å.

The redshift computations were made using the H and K lines, the Ca1 4226.70 Å one, the G band, H_γ, H_β, H_α, Mg Ib triplet and Na ID doublet, and all these lines in the best case. Note that the [OII] 3727.30 Å line was not observed because of its position at the extreme edge of the spectral range.

Each line was fitted using a Gaussian profile so that a set of redshift was obtained depending upon the number of useful lines for each spectrum. The final redshift was determined following Balkowski *et al.* (1981), the principles of which are in de Vaucouleurs and de Vaucouleurs (1967). In order to check the accuracy of the procedure, we have observed three known galaxies in the Coma cluster (Tab. I) : the results are in a very good agreement with previous values. The centroid determinations of the features measured is more or less uncertain, depending on the noise in the spectrum. This source of error is reflected for each galaxy by the dispersion of redshifts from individual lines. This dispersion is noted in table I.

2.3 OBSERVATIONS AT LA PALMA. — Observations were made during three nights (two nights were suitable for observations because of technical and clouds problems) with the 2.5 m Isaac Newton telescope in July 1984.

We used the Intermediate Dispersion Spectrograph (IDS) with a dispersion of 66.5 Å/mm. The spectral region covered was from 3500 to 5600 Å with a 632 line/mm grating blazed at 4500 Å - two slit apertures were used : 180 and 360 μm. The Image Photon Counting System (IPCS) (Boksenberg, 1982) was used as the detector with the 235 mm camera. The spectral resolution was 2 Å FWHM. The exposure time was 1000 s so that the average signal to noise ratio measured was 15. For each galaxy, a comparison spectrum was made using a Cu-Ar source before and after each spectrum. In order to use a cross-correlation procedure for data reduction, we have taken every night two spectra, one of the G8III giant HD210807 ($V_r = -14.8 \pm 0.5$ km/s) and one of the G9III giant HD213009 ($V_r = -39.7 \pm 0.6$ km/s) using a 55 μm slit. In order to check possible mechanical flexure and instabilities the zero-points of the two stellar spectra were checked against each other, and agreed to within 20 km/s.

2.4 IPCS REDUCTIONS. — Reduction of the IPCS spectra followed the SPICA standard procedure similar to that used by many other observers (e.g. Davies, 1981 ; Sadler, 1982). After correction of distorsion, each spectrum was flat-fielded using a normalized flat field. The comparison spectra taken immediately before and after each galaxy observation were checked for a shift and then added together. No significant shift was found.

Wavelength calibration was performed by fitting a fifth order polynomial to each arc spectrum to a wavelength scale and checking the position of several lines. Each galaxy spectrum was rebinned to a log λ scale using the corresponding calibration polynomial, then sky subtracted and normalized. After filtering to remove noise and pixel to pixel sensitivity variations the spectrum of a given galaxy is then cross-correlated with the two stars above mentioned, the measured shift Δ log λ being easily converted to a velocity shift by :

$$v = c\left(e^{\Delta \log \lambda} - 1\right) .$$

In order to estimate the accuracy of the radial velocities measured in this observing program, we have fit a Gaussian profile to the correlation peack displayed after a cross correlation procedure. The accuracy of the redshift determination is obtained from the width of the half height of the peak. Because of the response of the IPCS in the blue region (as for IDS at ESO) we cannot provide information on the [OII] 3727.30 Å line, specially for galaxies having Hβ and Hα in emission.

2.5 OBSERVATIONS AT ESO. — Observations were made during five nights with the 1.52 m telescope at La Silla in november 1984. We used the Image Dissector Scanner (IDS) mounted on a Boller & Chivens spectrograph which ends with an output phosphor readed by a scanning device dividing the one-dimensional image into 2048 pixels. The dispersion was 114 Å/mm so that the spectral region covered was from 3830 to 6150 Å with a 600 line/mm grating blazed at 5000 Å. The slit width was 200 μm widened and the spectral resolution was about 6 Å at FWHM. The average exposure time was 3600 s so that the measured signal to noise ratio was ranging around 12. For each galaxy, a comparison was made before and after each spectrum using an He-Ar source. In order to obtain the redshift by cross-correlation procedure, we have also taken every night two spectra, one of the G3IV star HD6655 ($V_r = 15.5 \pm 0.5$ km/s) and one of the K1III giant CD-43°2527 ($V_r = 13.1 \pm 0.3$ km/s); both stars are classical IAU Standards.

2.6 ESO DATA REDUCTION. — Data reduction was performed at Garching using the software package IHAP in order to obtain radial velocities with a cross correlation procedure. The different steps of the reduction are analogous to the IPCS ones.

2.7 OBSERVATIONS AT HAWAII. — Three galaxies have been observed at Hawaii in April 1985 with the CASS-HAWEC spectrograph installed at the Cassegrain focus of the 3.60 m telescope. The dispersion was 38 Å/mm centred to observe the MgIb triplet either on the galaxy and on the reference star, the giant K2III HD90861 ($V_r = 39.8 \pm 0.4$ km s^{-1}). The detector was a 236 × 236 px photon counting system with a Fe-Ne comparison source. The data reduction has been made using the cross correlation procedure, identical to the above IPCS one.

3. Estimate of errors.

In order to test the accuracy of our velocities, we have made a comparison of our redshift determinations with data available in the literature (see e.g. Palumbo *et al.*, 1983) for the same set of galaxies. The results of the comparison between the two sets of observations are summarized in table II, where we list the velocity differences between our measurements and other determinations. We have excluded three galaxies for which the discrepancy between redshift determinations was too large : A496-57, A1142-41 and A2589-17 ; we find that our velocities are shifted by + 4.0 km s^{-1} in the average with respect to the published data. The standard deviation in the difference is 89.7 km s^{-1}, which is consistent with the rms of redshift measurements mentioned in table II, ranging from 50 to 100 km/s. A valuable comparison can be made for the twelve galaxies of A496.

From the comparison of our redshifts with those of Quintana *et al.* (1985), we find that our velocities are shifted by -6.2 km s^{-1} in the average. The standard deviation in the differences is 91.3 km s^{-1} which is consistent with the rms uncertainty of 96.3 km s^{-1} derived from Quintana *et al.* (1985). Note that our velocities are not as homogeneous as those measured usually, since they come from different telescopes, but all velocities in the present study agreed with those quoted by authors mentioned in table II to within +/− 180 km/s (2 σ level) except for the three galaxies above mentioned, which were not included in the error calculations.

4. Conclusion.

In this paper, we have reported new redshift measurements for 100 galaxies in ten Abell clusters. These redshifts represent the initial results of the observational group on clusters of galaxies of Meudon. However, the number of redshifts collected in our survey is too much dependent of the observing time allocated and weather conditions.

The recent development of multi-object spectrographs associated with large telescopes will be a powerful tool to increase the number of redshifts collected. We are doing a major effort in this direction.

Let us emphasize that, in addition to redshifts, a lot of data like reliable magnitudes, X observations... are also required in order to improve our knowledge on clusters of galaxies and large scale structures.

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TABLE I. — *Heliocentric redshifts for galaxies.*

(1)	(2)	(3)	(4)	(5)	(6)	(7)		(8)
A 151								
5	01 06 28.7	-16 19 04	S0	15	ESO	11909	100	
10	01 06 37.7	-16 16 00	S	14	"	16111	75	
41	01 09 16.3	-15 48 47	S+S	15	"	11865	100	1
						16371	100	
42	01 08 13.1	-15 47 09	SB0	15	"	9947	60	
43	01 07 37.8	-15 46 11	S	15	"	16425	100	
44	01 07 36.7	-15 47 07	S	15	"	16530	55	2
46	01 06 42.8	-15 45 44	S	15	"	15554	100	
51	01 04 30.6	-15 45 51	S0	15	"	11740	75	
52	01 07 39.4	-15 45 16	S0/S	15	"	16609	120	
61	01 06 22.8	-15 40 20	D	14	"	15445	60	
62	01 06 22.2	-15 40 29	E	15	"	15980	60	
63	01 06 21.3	-15 40 09	E	15	"	16166	100	
69	01 06 03.1	-15 39 48	E	15	"	16535	75	
A 496								
13	04 32 27.8	-13 35 09	E	14	ESO	9983	60	
25	04 31 51.4	-13 28 19	E	14	"	10489	100	
26	04 31 23.6	-13 26 35	E	14	"	10290	75	
32	04 30 33.8	-13 28 50	S0	14	"	9338	75	
33	04 30 10.0	-13 29 54	S0	14	"	8501	60	
34	04 29 56.8	-13 30 21	S0	14	"	9107	60	
42	04 32 51.8	-13 20 39	SBAB	14	"	10462	60	
46	04 31 18.8	-13 21 52	CD	13	"	9705	60	
56	04 31 22.2	-13 16 22	SB0	14	"	9851	60	
57	04 31 12.9	-13 16 28	E	14	"	9470	60	
59	04 30 17.2	-13 18 12	S0	14	"	8937	100	
63	04 30 57.4	-13 15 17	S0	14	"	9819	60	
75	04 29 21.8	-13 01 58	SBC	14	"	10336	100	
77	04 30 30.9	-13 00 49	E/S0	14	"	10468	100	
78	04 29 38.0	-12 55 24	SA	14	"	10100	60	
A 957								
31	10 10 56.5	-00 45 00	E	15	CA2	12417	103	
33	10 11 44.2	-00 42 13	S0	16	"	13756	86	
34	10 11 26.4	-00 40 33	S0	16	"	12801	65	
35	10 11 13.5	-00 39 53	SC	14	"	13947	165	
					CFH	13875	50	
37	10 11 13.0	-00 42 07	S0	15	CA2	13801	48	
39	10 11 04.9	-00 40 34	D	13	CA1	13438	76	
42	10 10 52.3	-00 39 41	S0	15	CA2	12628	78	
43	10 11 52.3	-00 37 20	S0	15	"	14476	72	
44	10 11 54.5	-00 39 10	SB0	15	"	13556	74	
46	10 11 35.9	-00.36 57	S0	16	"	13941	92	
47	10 11 22.4	-00.38.13	S0	15	"	12241	65	
50	10 11 06.8	-00.36.53	S0	16	"	13551	167	
54	10 10 25.7	-00.38.39	SB0	15	"	13485	103	
56	10 12 06.0	-00 34 50	SBB	14	"	14630	60	
58	10 12 00.8	-00 35 12	S0	16	"	13176	98	
59	10 10 50.9	-00 35 40	SB0	16	"	12756	50	
63	10 12 14.6	-00 30 49	SA	15	"	14480	95	
75	10 12 12.2	-00 05 28	E/S0	14	CA1	9953	139	
A 1142								
19	10 58 49.2	+10 29 54	S0/A	14	CA1	10414	55	
20	10 59 44.5	+10 30 45	E/S0	14	"	10572	73	
29	10 58 23.2	+10 35 01	S0	14	"	11045	64	
35	10 58 38.3	+10 45 00	0	14	"	12538	37	
41	10 58 20.9	+10 46 34	E	14	"	10576	65	
A 1656								
43	12 56 10.3	+27 52 01	S0P	13	"	7704	64	
105	12 56 58.7	+28 10 59	E	14	"	4660	65	
179	12 56 55.3	+28 21 22	S0	13	"	6847	63	
A 1913								
23	14 23 40.3	+16 45 37	E	15	CA2	17526	90	
25	14 24 55.2	+16 40 48	S0	15	"	16224	149	
29	14 24 35.8	+16 49 34	S0	16	"	16722	68	
32	14 24 22.8	+16 51 30	S0	15	"	15834	123	
33	14 24 07.9	+16 49 55	E/S0	15	"	16009	110	
38	14 24 52.0	+16 55 29	S	16	"	15899	98	
39	14 24 29.0	+16 54 04	SBC	16	"	15559	129	
40	14 24 20.2	+16 54 17	S0	16	CFH	15809	50	
41	14 24 17.3	+16 54 46	E	15	CA2	15937	86	
48	14 24 11.3	+16 59 06	E	14	CA1	15400	225	
50	14 24 07.2	+16 59 19	E	16	CA2	16318	75	
54	14 24 55.0	+17 03 23	E	14	CA1	14853	177	
55	14 24 12.4	+17 02 40	S0/E	15	CA2	15769	90	
59	14 23 57.7	+17 01 23	SBAB	15	"	16027	162	
60	14 25 15.2	+17 07 29	E	14	CA1	15000	114	
70	14 22 31.4	+17 15 54	S0/D	14	CFH	14775	50	
A 1983								
2	14 48 36.5	+16 18 42	SC	15	LPA	13615	60	
5	14 49 33.0	+16 25 30	S	15	"	10539	60	
15	14 52 02.5	+16 33 12	E	13	CA1	13787	80	3
28	14 52 59.6	+16 42 08	SA/0	13	LPA	6340	60	
39	14 50 47.5	+16 47 33	EP	14	"	13988	60	
61	14 48 54.4	+16 54 02	SP	13	CA1	13754	41	2
70	14 46 06.4	+16 57 03	SC	14	"	11272	100	
71	14 47 56.1	+16 55 33	SC	14	"	11037	72	
84	14 50 23.6	+17 06 20	E	14	"	13777	88	
97	14 50 13.1	+17 15 54	SA	14	"	13401	85	
102	14 47 41.9	+17 15 12	SBB	14	"	11479	59	
105	14 50 03.9	+17 19 27	S0	14	"	13358	90	
114	14 58 51.1	+17 23 35	SC	14	"	13494	68	
116	14 49 54.1	+17 27 06	S0	14	"	13601	92	
A 2063								
24	15 22 03.6	+08 39 59	SBB	14	CA1	11033	66	
36	15 19 29.1	+08 36 08	E/S0	13	"	11602	55	
60	15 20 39.5	+08 47 14	D	13	"	10699	47	
114	15 21 10.7	+09 31 22	E	13	"	10859	85	2

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TABLE I (*continued*)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
		A 2256					
37	17 07 50.4	+78 43 57	S0	--	LPA	17773	60
		A 2589					
17	23 21 26.0	+16 28 28	S0	--	LPA	12200	60
21	23 21 27.8	+16 29 01	E	--	"	12524	60
28	23 21 45.1	+16 30 38	S	--	"	12406	60
30	23 21 32.6	+16 30 21	S0	--	"	12476	60
31	23 21 29.7	+16 32 46	E	--	"	12626	60
32	23 21 28.7	+16 32 13	S0	--	"	12653	60
33	23 21 26.0	+16 31 32	E	--	"	12320	60
35	23 21 17.8	+16 29 38	S0/A	--	"	14031	60
45	23 21 29.0	+16 35 43	E	--	"	12000	60
46	23 21 28.5	+16 35 59	E	--	"	12675	60

Notes to table I:

Column 1: Galaxy number in the cluster.
Column 2 *and 3*: Right ascension and declination (1950).
Column 4: Morphological type.
Column 5: Estimated total apparent visual magnitude.
Column 6: Observatory. CA1 and CA2 are observations made at Calar Alto in 1984 and 1985 respectively, LPA at La Palma in 1984, ESO at La Silla in 1984 and CFH at Mauna Kea in 1985.
Column 7: Galaxy heliocentric velocity and estimated error.
Column 8: Notes: 1- Results are derived from two correlation peaks. 2- Hα and Hβ in emission. 3- 3C 306.

TABLE II. — *Comparison with published redshifts.*

GALAXY	V-V(REF)	REFERENCE
A 151 - 61	+5	HUMASON ET AL. (1956)
62	-77	"
A 496 - 13	+58	QUINTANA ET AL. (1985)
25	-36	"
26	+90	"
32	+98	"
33	-4	"
34	-13	"
42	-93	"
46	-55	"
56	+21	"
57	+390*	"
59	+137	"
63	-146	"
77	-132	"
A 1142 - 19	-133	GELLER ET AL. (1984)
20	-98	"
29	-35	"
35	+71	"
41	-370*	"
A 1656 - 43	+143	KENT AND GUNN (1982)
105	-47	"
179	+80	"
A 1983 - 15	+117	TRITTON (1972)
114	-87	RUBIN ET AL. (1976)
A 2063 - 60	+156	HUMASON ET AL. (1956)
A 2256 - 37	+53	FABER AND DRESSLER (1977)
A 2589 - 17	+1045*	HINTZEN (1980)
28	+13	"
32	+23	"
<V-V(REF)>	+4.0	
σ	+89.7	

* NOT INCLUDED IN THE CALCULATIONS