

## THE VELOCITY DISPERSION OF THE CLUSTER OF GALAXIES ABELL 1060 (3U 1044-30)

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Received 1974 November 11

### ABSTRACT

Radial velocity measurements of 15 galaxies in the cluster A1060 give an average velocity of  $3233 \text{ km s}^{-1}$  and a dispersion velocity of  $799 \text{ km s}^{-1}$ . The X-ray luminosity is  $1.5 \times 10^{43} \text{ ergs s}^{-1}$ . The correlation of velocity dispersion and X-ray luminosity is reviewed.

*Subject headings:* galaxies, clusters of — redshifts — X-ray sources

Kellogg *et al.* (1973) identified the Abell 1060 cluster of galaxies with 3U 1044-30. Burbidge (1972) reviewed the different mechanisms that could generate X-rays from such systems and concluded that the scarcity of observations does not allow a definite mechanism to be preferred. From recent published works (Harris and Romanishin 1974; Owen 1974; Guthrie 1974) the emergent picture is that the very presence of an appreciable radio flux would always obscure the contribution of thermal bremsstrahlung produced by kinematic heating to the total X-ray flux (Solinger and Tucker 1972). However, there are at least two cases in which the X-ray emission does not seem to be related to the radio flux: (a) In a high-resolution study of the X-ray morphology of the Perseus cluster, Wolff *et al.* (1974) found that the structure-rich radio galaxy IC 310 does not contribute any significant X-ray flux to the total flux from this cluster. (b) The Centaurus cluster (3U 1247-41) is known to be an extended X-ray source (Kellogg and Murray 1974) while the radio source is compact and located inside NGC 4696 (Eckers 1969). Even if the X-ray emission can be explained by Compton scattering, as in the case of the Coma and the Abell 401 clusters (Harris and Romanishin 1974), the alignment of several clusters in the X-ray luminosity versus velocity dispersion diagram, if true, seems to supply compelling evidence for the kinematic heating mechanism.

Burbidge (1972) doubted the existence of such an empirical relation between the X-ray luminosity and velocity dispersion of these clusters on the ground that the ranges of these parameters are too small to be significant. However, if more observations show the same tendency, it would be difficult to reject it. Since one of us (B. A. P.) had a collection of spectra of the X-ray cluster Abell 1060 (all taken on the 74-inch [1.9 m] at Mount Stromlo), we thought it would be of considerable interest to study the velocity dispersion and thus to add one more point on the yet ill defined relation between X-ray luminosity and velocity dispersion. The sample of 15 galaxies studied in this cluster is by no means complete, but the consistent small-sample statistical treatment we adopted gives some confidence in the results.

All spectra were measured and reduced by one of us

(N. V. V.). The computer program yielded the plate mean velocity and its (formal) standard deviation using all lines that have not been rejected in the process of identification. Table 1 presents the spectroscopic material and the resulting reductions. The galaxies are identified in figures 1 and 2 (pls. L2 and L3). Redshifts of three of these galaxies have been reported in the literature. Table 2 presents the values reported by Peterson (1970, 200-inch Hale) and Mayall and de Vaucouleurs (1960, Lick). While the difference of about  $100 \text{ km s}^{-1}$  between Mount Stromlo and Hale may be acceptable (one galaxy in common only), the high differences of 247 and  $351 \text{ km s}^{-1}$  between Mount Stromlo and Lick show a definite systematic shift. (Dr. K. C. Freeman of Mount Stromlo reports that spectra of globular clusters taken with the same equipment did not show any systematic effects.) A much larger sample of objects in common is needed to investigate this point.

The mean velocity of the cluster from all lines is  $3233 \text{ km s}^{-1}$  (corrected for galactic rotation, see Mayall and de Vaucouleurs 1962), with a standard deviation of  $799 \text{ km s}^{-1}$ . Since we are interested primarily in this velocity dispersion, we have calculated also the mean velocity and its dispersion from the Ca II K-line only (since systematic effects on each line may be different). The result was  $3342 \pm 824 \text{ km s}^{-1}$  and therefore no significant change in both values. We adopted the more general value mentioned above, namely,  $3233 \pm 799 \text{ km s}^{-1}$ , as the mean velocity and dispersion for the cluster.

The problem of determining the error in the mean velocity and in the velocity dispersion is not simple. Solinger and Tucker adopted rough error estimates of  $\pm 10$  and  $\pm 15$  percent, respectively, for all clusters. In an effort to make our error estimates more confident, we adopted the  $t$  and  $\chi^2$  distributions for small samples, by which we estimate the  $\sim 68$  percent limits of confidence of our derived mean and standard deviation, respectively, which is at least more objective. Obviously these methods take into account both the fact that we are dealing with a small sample, and that the number of observed galaxies in each cluster is different. Using these statistical methods, we are assuming a normal distribution for our sample as well as for the means and

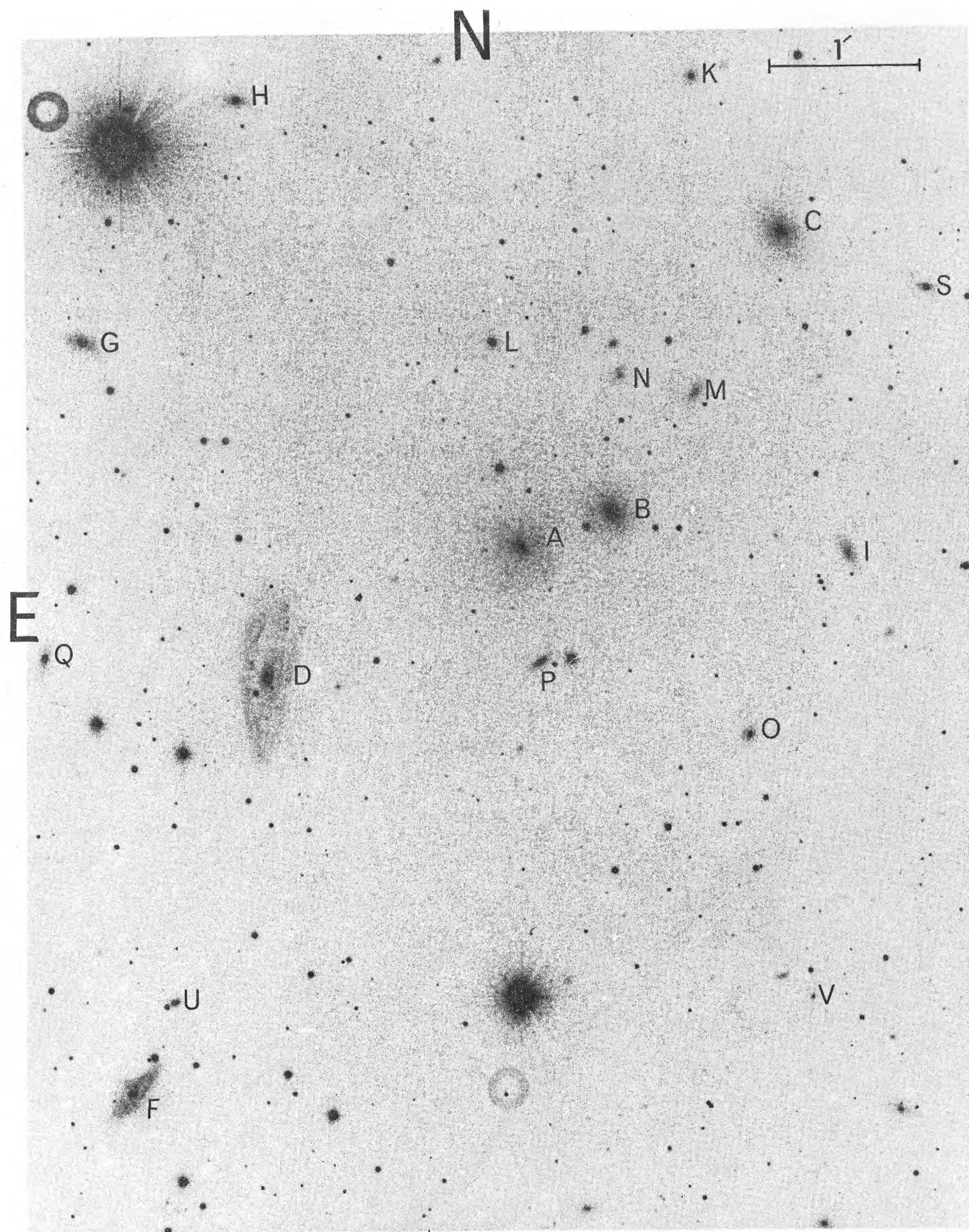


FIG. 1.—Identification chart for galaxies in Abell 1060 (see table 1)

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PLATE L3



FIG. 2.—Same as fig. 1

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TABLE 1  
REDSHIFTED VELOCITIES OF GALAXIES IN ABELL 1060

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

TABLE 2  
VELOCITIES OF GALAXIES IN COMMON  
WITH HALE AND LICK  
IN ABELL 1060

	NGC 3311	NGC 3312	NGC 3316
MS.....	3835	2780	3960
Hale.....	3720	...	...
Lick.....	...	2533	3609
$\Delta$ .....	115	247	351

standard deviations of the different samples drawn from the cluster population. Clearly, our sample of fifteen galaxies in A1060 is too small (compared to the velocity dispersion) to show a clear normal distribution. However, several experiments with 15 galaxies drawn in a random manner from the Coma cluster (which has almost the same velocity dispersion) yielded similar distributions. We believe that our sample is not far from representing a larger one.

Using the  $\chi^2$  distribution, we found that the  $\sim 68$  percent confidence limits of the velocity dispersion of A1060 are 687 and 1059  $\text{km s}^{-1}$ . Adopting  $\sqrt{3}$  as a conversion factor from radial to space velocity, we have the final kinematical results:

$$\bar{v}_{\text{radial}} = 3233 \pm 228 \text{ km s}^{-1};$$

radial velocity dispersion

$$= 799 \text{ km s}^{-1} \text{ (with limits of 687–1059 km s}^{-1}\text{);}$$

space velocity dispersion

$$= 1382 \text{ km s}^{-1} \text{ (with limits of 1190–1834 km s}^{-1}\text{);}$$

$$\bar{z} = 0.0108 \pm 0.0007.$$

Following Kellogg *et al.* (1973), the X-ray luminosity is

$$L_x = 5.7 \times 10^{46} z^2 R_x = 1.5 \times 10^{43} \text{ ergs s}^{-1},$$

and its limits up to 1 standard deviation are  $8.1 \times 10^{42}$  and  $2.3 \times 10^{43}$   $\text{ergs s}^{-1}$ .

We have plotted in figure 3 the X-ray luminosity of several X-ray clusters as functions of their velocity dispersions. The kinematic data were extracted from Noonan (1973) and Tammann (1972), and the X-ray fluxes from the 3U catalog. All error bars were estimated by the  $t$  and  $\chi^2$  distributions for small samples in the

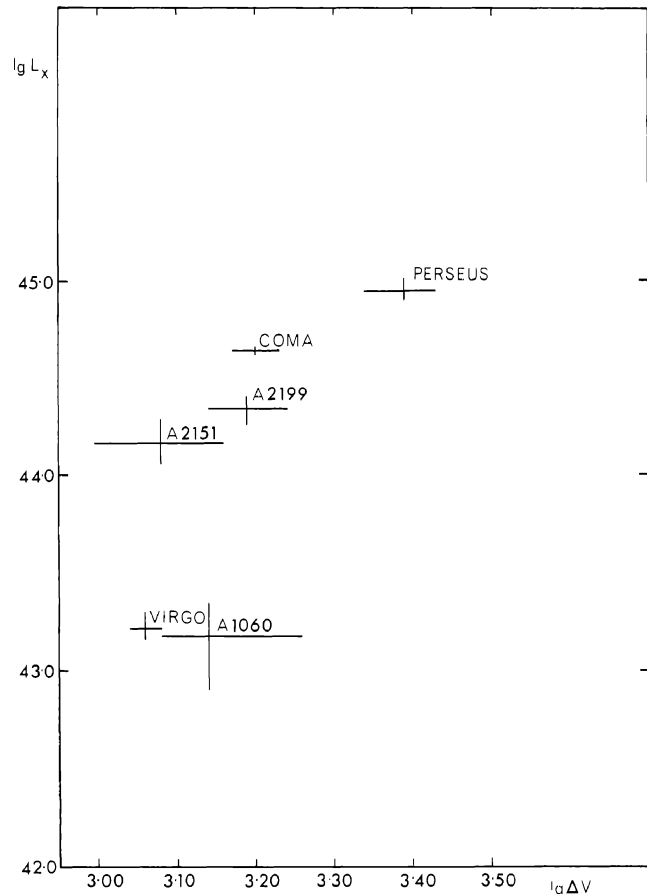


FIG. 3.—The X-ray luminosity ( $\text{ergs s}^{-1}$ ) versus velocity dispersion ( $\text{km s}^{-1}$ ) for X-ray clusters.

same manner as we treated A1060 above. It is seen that rich clusters of galaxies are located in the upper part of the diagram (and may form a separate group) whereas the Virgo and A1060 clusters, of lower richness, are in the lower part. However, both groups together may fit the "curved" model (Solinger and Tucker 1972, fig. 1):

$$L_x \sim \Delta V \exp[-A(\Delta V^{-2})],$$

in which the kinematic heating of the intergalactic medium is not related to the binding mass in clusters. At this stage, it would be premature to stress this point further.

In conclusion, our work on A1060 supports the suggestion that the X-ray luminosity in clusters is correlated with richness (Kellogg *et al.* 1973). Many more points are needed to confirm any of the models of kinematic heating as suggested by Solinger and Tucker. At the same time, radio observations of X-ray clusters of galaxies are needed to check whether the Compton scattering model is not less applicable to the same clusters, as has been shown for Coma (Harris and Romanishin).

We thank Dr. K. C. Freeman for helpful discussions.

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