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ABSENCE OF LYMAN-ALPHA EMISSION FROM THE COMA CLUSTER OF GALAXIES

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ABSTRACT

The redshifted Lα flux from the Coma cluster of galaxies is determined to be less than 6000 photons cm^{-2} s^{-1}, leading to severe (and perhaps fatal) new restrictions on hot ionized gas models for the gravitational binding of the cluster.

I. INTRODUCTION

An intriguing problem regarding clusters of galaxies is the question of their gravitational stability. Neyman, Page, and Scott (1961) show by application of the virial theorem that there may be substantially more matter present in at least some clusters of galaxies than can be accounted for by summing the masses of the individual galaxies. Woolf (1967) discussed this problem for the Coma cluster of galaxies, and suggested that ionized matter might account for the additional mass needed to satisfy the virial theorem. He placed limits on the temperature and clumpiness of such gas. Turnrose and Rood (1970) discussed the stability against gravitational collapse of gas in the Coma cluster, and the problems associated with heating such gas. They concluded that models involving ionized gas face substantial difficulties.

Meekins *et al.* (1971) detected X-rays (in the 3–17 Å wavelength band) from the direction of the Coma cluster of galaxies, and concluded that if the X-rays represent thermal emission from hot gas in the cluster, the amount of such gas is not nearly sufficient to bind the cluster gravitationally. Noerdlinger (1971) showed, however, that if the Hubble parameter H were as low as 38 km s^{-1} Mpc^{-1}, a binding mass could still be present and consistent with Meekins *et al.* A value of H this low apparently cannot be excluded. Gursky *et al.* (1971) showed that the X-ray emission is diffuse, and concluded that if the source is emission from gas at 73×10^6 ° K, the mass involved is 3×10^{13} $M_\odot$, about 1 percent of the mass needed to stabilize the cluster. A value $H = 100$ was apparently used. It is easy to show that for a binding mass to be present, and consistent with their observation, H must be 4.5, a value that can surely be excluded. Thus the Coma cluster is not bound by gas at 70×10^6 °K.

The question of intergalactic gas in the Coma cluster has at least one broader ramification. Gott and Gunn (1971) have argued that unless the Coma cluster of galaxies does contain gas in some quantity, then there can be no dense (10^{-5} cm^{-3}) general intergalactic gas, for such general gas should fall into the cluster over a period of 10^9 years.

Goldsmith and Silk (1971) have made a model for the Coma cluster of galaxies involving a "binding" mass in the form of hot "blobs" in the temperature range around 10^5 ° K. They suggest searching for such gas by looking for the Lα recombination radiation that would be produced. We have performed this experiment, obtaining an upper limit to possible Lα emission that is low enough to restrict severely or even to eliminate ionized gas as the explanation of the mass discrepancy in the Coma cluster. This there-

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fore suggests that the conclusion of Gott and Gunn (1971) referred to above may be correct.

II. EXPERIMENT

An Aerobee rocket, launched from White Sands Missile Range at 0400 UT 1970 March 1, carried an ultraviolet-sensitive Geiger-counter detector to an altitude of 210 km. The detector had a CaF_2 window and was filled with 10 mm of NO and one atmosphere of neon, resulting in a bandpass of 1225 Å to 1340 Å. Lyman-α radiation (1216 Å) from the Coma cluster of galaxies would be redshifted 27 Å to 1243 Å, a wavelength that is transmitted by the gas of our own Galaxy, and a wavelength that is within the detector passband. The efficiency of the detector was measured before and after flight and was 10.7 percent at 1243 Å and 4.2 percent at 1304 Å. The detector viewed the sky through a mechanical collimator having a field of view of 0.02 sterad. Pulses from the detector proceeded to a scaler, and the state of the scaler was telemetered to Earth. The area of the detector was 0.62 cm^2.

The rocket was despun at an appropriate altitude to a maintained rate of about one rotation in 11 s; thus one field-of-view element (9°10′ full width at half-maximum transmission) was scanned in $0^s.28$ s. The precession of the rocket resulted in a scan of essentially the whole galactic-anticenter hemisphere. High voltage was turned on to the detector 10 s before a metal door covering the detector was opened. During this 10-s period, a cosmic-ray counting rate of a few counts per second was obtained. After the door opened, the CaF_2 detector indicated a roughly isotropic ultraviolet background, presumably due to λ1304 O I resonance radiation (which will be discussed in detail elsewhere). (A second detector sensitive only near 1450 Å gave a signal above cosmic-ray background only when pointed in the upward direction.) The CaF_2 detector did clearly respond to ultraviolet sources (stars), and the signal on both detectors declined when, at the end of the flight, the experiment fell below 130 km so that Shumann-Runge absorption by atmospheric molecular oxygen became effective.

The aspect pointing of the experiment was obtained by using onboard magnetometers and stellar photomultiplier tubes. An accuracy of about $\pm 2°$ was obtained. One scan passed directly across the position of the Coma cluster of galaxies, allowing an upper limit of 30 counts to be obtained for the contribution from the Coma cluster to the observed signal on the CaF_2 detector. This would correspond to an intensity of 1700 photons cm^{-2} s^{-1} at 1443 Å, the wavelength at which redshifted Lα photons are expected. Previous experience with these detectors suggests that the absolute calibration might be in error by almost a factor of 2; we therefore take 3×10^3 photons cm^{-2} s^{-1} for the observed upper limit to the redshifted Lα flux as seen at Earth. Outside the dust of the galactic plane, this would be about 6×10^3 photons cm^{-2} s^{-1} from the cluster of galaxies itself.

III. DISCUSSION

The flux of Lα photons from the Coma cluster of galaxies will be

$$F(\mathrm{L}\alpha) = \frac{n_e^2(fV)\alpha(T)}{4\pi R^2} \text{ photons cm}^{-2}\text{ s}^{-1}, \tag{1}$$

where f is the fraction of the total cluster volume occupied by the hot clouds, V is the volume of the cluster, R is the distance to the cluster, $\alpha(T)$ is some appropriate recombination coefficient, and n_e, the electron density in the clouds, is equal to N_e/fV where N_e is the total number of electrons in all of the clouds.

Let M equal the number of "binding masses" that are present in the form of hot clouds. Turnrose and Rood (1970) give 1.2×10^{15} $M_\odot$ for the binding mass (if the cloud distribution follows that of the galaxies). Then equation (1) gives

$$F(\mathrm{L}\alpha) = \frac{\alpha(T)(N_e/h)^2}{(fV/h^3)4\pi(R/h)^2} \tag{2}$$

TABLE 1

LIMITS ON THE CLUMPINESS OF HOT GAS IN THE COMA CLUSTER OF GALAXIES

	$H=100$		$H=50$	
T(° K)	$f>$	$\log(1/f)<$	$f>$	$\log(1/f)<$
6×10^4......	...	...	0.212	0.65
1×10^5......	...	...	0.113	0.95
3×10^5......	0.307	0.51	0.034	1.41
1×10^6......	0.084	1.08	0.010	1.98

NOTE.—The quantity f is the fraction of the cluster occupied by hot clouds. Limits on f are given for two values of H, the Hubble parameter (in km s^{-1} Mpc^{-1}).

where h is the ratio of the true value of the Hubble constant to 100 km s^{-1} Mpc^{-1}; or

$$F(L\alpha) = 4.15 \times 10^{17} M^2 h^3 \alpha(T)/f\,, \tag{3}$$

where a cluster distance of 70 Mpc and a cluster diameter of 45′ (Gursky *et al.* 1971) have been adopted.

For α, we will use the recombination rate to the $n = 2$ level (Seaton 1959). Some of those recombinations will be to the $2s$ level, but on the other hand the $2p$ level will be populated an additional amount by cascades from higher levels; this roughly compensates.

The result, for $M = 1$, is given in Table 1 in the form of limits on the clumpiness of the hypothetical gas for assumed values of the temperature and the Hubble constant. The Lα observation provides a much more stringent limit than do the free-free emission and Hβ upper limits described by Woolf (1967). The X-ray observations (Meekins *et al.* 1971) at 44 Å can easily be shown to require that the gas temperature be below about 3×10^5 ° K (for a binding mass present), so the final result is an extremely restricted region in the (f, T)-plane which could still be occupied by the cluster. For a Hubble constant of 50 km s^{-1} Mpc^{-1}, the clouds must be roughly in the temperature range 3×10^4 ° to 3×10^5 ° K, and must occupy more than 4 percent the total volume of the cluster. However, Goldsmith and Silk (1971) have argued that the clumping must be considerably greater than this to avoid dissipation of the clouds by collisions. If this is correct, then we can conclude that no binding mass of hot intergalactic gas is present in the Coma cluster of galaxies.

IV. CONCLUSION

By obtaining an upper limit on the redshifted Lα flux from the Coma cluster of galaxies, we have been able to place severe new restrictions on models which assume that the cluster is gravitationally bound by hot ionized intergalactic gas. The present observation was of very low sensitivity because of the short observing time ($0^s.28$) and the presence of an airglow "noise" background. It should be a simple matter in the future to observationally confirm or eliminate the few remaining conceivable distributions for hot gas.

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