Astron. Astrophys. 288, 705–712 (1994)

ASTRONOMY
AND
ASTROPHYSICS

H I deficiency in the Coma I cloud of galaxies

J.A. García-Barreto[1,2], D. Downes[3], and W. K. Huchtmeier[2]

[1] Instituto de Astronomía, Universidad Nacional Autónoma de México, Apartado Postal 70-264, México D.F. 04510 México
[2] Max Planck Institut für Radioastronomie, Auf dem Hügel 69, D-53121 Bonn, Germany
[3] Institut de Radio Astronomie Millimétrique, F-38406 St. Martin d' Hères, France

Received 10 November 1992 / Accepted 4 March 1994

Abstract. We present new H I observations of galaxies in the Coma I group. Of the 32 most probable members of the group, 16 are gas poor and 16 have normal H I contents. The 16 gas poor galaxies include 4 ellipticals, 5 S0s, and 7 spirals with a definite H I deficiency (more than a factor of four). Most of the 16 gas poor or H I deficient galaxies are concentrated within a radius of 500 kpc of a centroid near the galaxy NGC 4274, suggesting that this region contains a compact core of intergalactic matter that has stripped the gas from some of the galaxies. Seven gas poor galaxies are even within a projected radius of 130 kpc of this position. This possible existence of a dense core of intragroup gas may explain the large H I deficiency in the barred spiral NGC 4314. which has 100 times less H I mass than would be expected from its luminosity and stellar mass. In this galaxy the gas is 99% molecular, 1% atomic and nearly all in the central region. We suspect the extreme H I deficiency in NGC 4314 is due to two distinct causes: ram pressure stripping of the gas in its outer parts, plus action of its bar or an ancient tidal interaction with another galaxy that transferred gas from the inner parts of NGC 4314 to the center where H I was converted to H_2.

Key words: galaxies: clusters: Coma I group – galaxies: evolution – galaxies: interactions – galaxies: intergalactic matter – galaxies: interstellar matter – radio lines: galaxies

1. Introduction

The Coma I cloud is a small group of galaxies at a distance of 10 Mpc (de Vaucouleurs 1975, see distance review in Garcia-Barreto et al. 1991. The cloud has a size $4° \times 10°$ (0.7×1.7 Mpc), and contains 32 galaxies of which five are questionable members (Gregory & Thompson 1977). Unlike many small groups of galaxies, the Coma I group may be gravitationally bound (Turner & Sargent 1974). In numbers of galaxies, the Coma I cloud may be considered a poor cluster: there are only 19 bright galaxies in the Coma I group (Gregory & Thompson 1977), while there are about 130 galaxies in the Virgo cluster (Tully 1988). X ray observations of poor clusters (Price et al. 1991; Mulcahey et al. 1993) suggest they are scaled down versions of rich clusters.

In this paper we describe new H I observations of the galaxies in the Coma I group with the Effelsberg 100 m telescope which show definite H I deficiencies in seven of the spirals in this group. (Sect. 2). In particular one of the most spectacular H I deficiencies yet found in a spiral galaxy is that in NGC 4314, for which we combined Effelsberg and Arecibo data to constrain the size of the H I distribution and the H I mass (Sect. 3). We discuss ram pressure stripping in Coma I as the main cause of gas loss (Sect. 4). We still need, however, another mechanism to account for the situation in NGC 4314, where all the gas has ended up in the nucleus, in molecular form. We discuss the transformation of H I to H_2 in NGC 4314, after disk gas had been forced into the center of the galaxy by the bar or by a tidal interaction (Sect. 5).

Send offprint requests to: D. Downes

2. H I observations and results

We observed the Coma I galaxies with the Effelsberg 100 m telescope in 1991, with a half-power beamwidth of 9.3′, and a cooled two-channel HEMT receiver with 30 K system temperature. The 1024 channel autocorrelation spectrometer was split in four bands with a total width of 12.5 MHz and a velocity resolution of 21 km s^{-1} after Hanning smoothing. A typical integration of 10 min gave an r.m.s. noise of 4 mJy in the smoothed spectra, from which we subtracted linear baselines (Fig. 1). For the spectrum of NGC 4314, we integrated for 6^h on-source to get an r.m.s. noise of 0.6 mJy (Fig. 2).

Among the new detections are those of the elliptical galaxy NGC 4494 and the Sa spiral NGC 4448, both of which had eluded detection until now. Note that the line detected at the position of the elliptical NGC 4283 probably comes from NGC 4278, which was included in the 9.3′ beam, and not from NGC 4283 itself. The line has essentially the same profile as that of NGC 4278 observed with higher spatial resolution by Raimond et al. (1981).

Table 1. Galaxies of the Coma I Group, including probable and possible members

Galaxy NGC	Position h m s	(1950) ° ′ ″	Type	D_{25} arcmin	V_{hel} km s^{-1}	ΔV(H I) km s^{-1}	M(H I) 10^7 M$_\odot$	H I deficiency	H I reference
4020	11 56 21	+30 41 30	Sd	2.1	760	180	27	+0.67	
4062	12 01 30	+32 11 00	Sc(s)II-III	4.1	770	310	59	+0.49	HR393
4080	12 02 18	+27 16 14	Irr	1.2	569	176	7	+0.95	
4136	12 06 42	+30 12 00	Sc(r)I-II	4.0	607	105	96	+0.34	
4150	12 08 00	+30 41 00	S0(4)/Sa	2.3	244	177	≤ 1.0	—	HR249
4173	12 09 48	+29 28 00	SBd	5.0	1127	173	89	+0.04	S
4203	12 12 36	+33 29 00	S0(1)	3.4	1094	265	43	—	
4204	12 12 42	+20 56 18	SBdm	3.6	855	107	58	−0.18	
U7300	12 14 06	+29 00 00	Irr	1.4	1208	98	24	−0.12	
4245	12 15 05	+29 52 54	SBa(s)	2.9	890	230	0.8	+1.40	S
4251	12 15 36	+28 27 06	S0(8)	3.6	1014	—	≤9	—	HR27
4274	12 17 20	+29 53 18	Sa(s)	6.8	919	465	19	+0.77	
4278	12 17 36	+29 33 36	E1	4.1	630	292	26	—	HR519
4283	12 17 50	+29 35 12	E0	1.5	705	—	—	—	
4308	12 19 24	+30 20 00	E	0.8	606	—	≤ 23	—	
4310	12 19 54	+29 29 00	S0/SB0p	2.2	813	196	6	—	
4314	12 20 02	+30 10 25	SBa(rs)pec	4.2	980	190	0.4	+2.06	G
4359	12 21 36	+31 48 00	SBc	3.5	1242	216	43	−0.28	S
4393	12 23 18	+27 50 00	Sd/SBd	3.2	742	138	85	−0.08	HR373
4414	12 23 57	+31 29 54	Sc(sr)II.2	3.6	717	405	118	+0.46	HR373
4448	12 25 46	+28 53 48	Sa(late)	3.9	644	421	4	+1.33	
4455	12 26 14	+23 06 01	Sc	2.8	644	145	71	+0.08	
4494	12 28 55	+26 03 06	E1	4.8	1310	552	5	—	
U7673	12 29 30	+30 00 00	Irr	1.4	644	86	19	+0.05	
4525	12 31 18	+30 34 00	Sc	2.6	1174	162	18	+0.87	
4559	12 33 29	+28 14 06	Sc(s)II	10.7	819	249	778	+0.03	HR203
4562	12 33 06	+26 08 00	ScD	2.5	1354	147	17	−0.03	
4565	12 33 52	+26 15 36	Sb	15.9	1228	530	571	−0.04	HR183
1242+28	12 42 06	+28 45 00	Sd	0.7	940	82	12	+0.10	
4670	12 42 50	+27 23 58	S0	1.4	1068	164	24	—	
4725	12 48 00	+25 46 30	Sbb(r)II	10.7	1208	410	259	+0.26	
4747	12 49 19	+26 02 48	SBc	3.5	1191	189	64	+0.08	

Refs: Galaxies: Gregory & Thompson (1977); Types: Sandage & Tammann (1987), Tully (1988).
H I mass and radial velocities: HR: reference number in Huchtmeier & Richter (1989); S : Sage et al. (1994);
G : Garcia-Barreto et al. (1991); all others derived from the spectra in this paper (Fig. 1), with
assumed distance 10 Mpc and conversion factor 22 10^6 M$_\odot$(Jy km s^{-1})$^{-1}$ for sources smaller than the beam.
ΔV(H I) = H I linewidth measured at 20% of the peak.
H I deficiency = $\langle \log M_H/L_B \rangle - \log M_H/L_B$; the mean refers to isolated field galaxies of the same type (see Fig. 3).
H I deficiencies are not listed for S0 and E galaxies because the reference sample is not well defined.

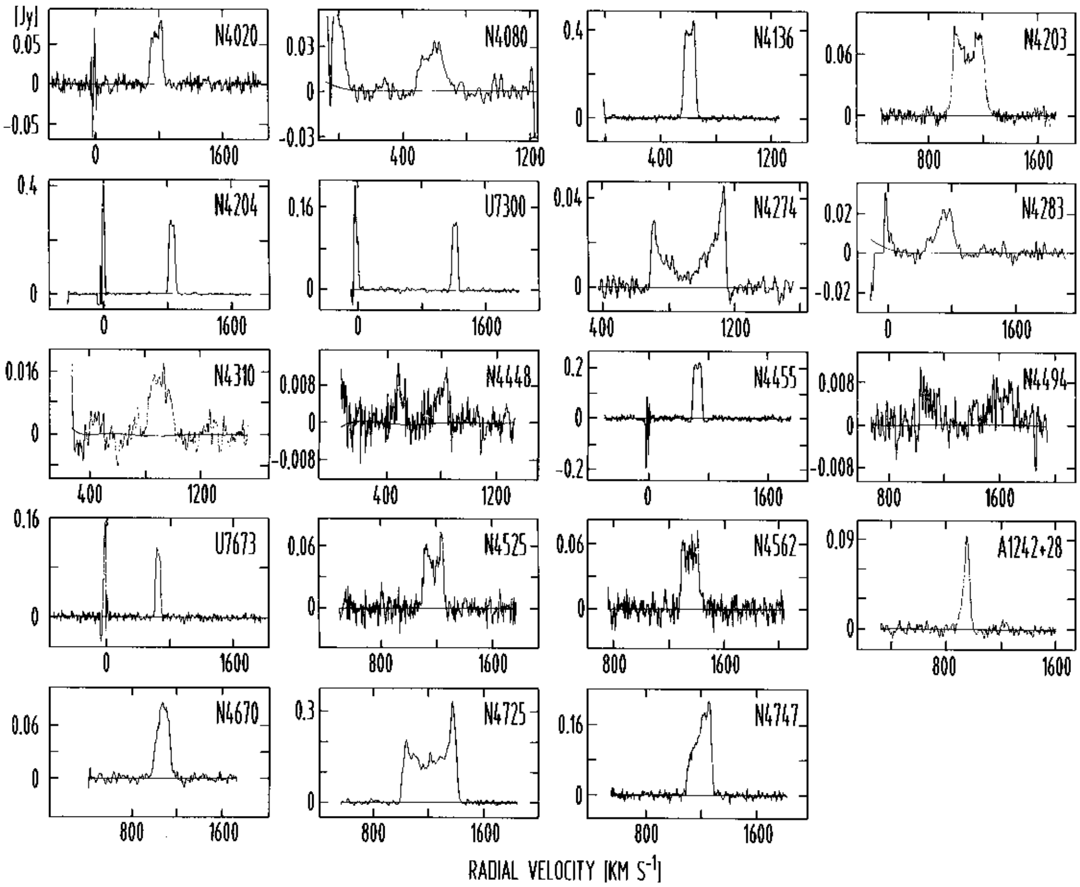

Fig. 1. H I profiles of galaxies in the Coma I group observed with the Effelsberg 100 m telescope

We define H I deficiency following Giovanelli et al. (1981) in terms of the ratio of H I mass to luminosity, that is, H I deficiency = $\langle \log M_{\rm H}/L_{\rm B}\rangle - \log M_{\rm H}/L_{\rm B}$, where the mean is for isolated field galaxies of the same type. We took the reference sample for type Sa from Huchtmeier (1982) and for types Sab to Irr from the Kraan-Korteweg & Tammann sample (Huchtmeier & Richter 1988). "Normal" galaxies are typically in the range -0.3 to 0.3, while values in the range 0.3 to 0.6 may be considered slightly deficient, but still within the scatter in any larger sample of spiral galaxies, especially Sc and irregular galaxies. Values greater than 0.6 indicate a definite deficiency in H I (greater than a factor of four). Galaxies earlier than Sa are more difficult to deal with. Observed values of the $M_{\rm H}/L_{\rm B}$ ratios of S0 and elliptical galaxies have a large scatter, and the "expected value" is not clear.

Figure 3 shows the ratio $M_{\rm H}/L_{\rm B}$ for galaxies in Table 1, with a smoothed median curve for the reference values. In general, including the S0s and ellipticals, we can say about half of the Coma I group members are gas poor, and specifically, seven of the spirals are definitely H I deficient: NGC 4314 with a deficiency of 2.0, NGC 4245 and NGC 4448 with deficiencies of 1.4 and 1.33 respectively, and NGC 4020 , NGC 4080, NGC 4525, and NGC 4274 with deficiencies greater than 0.6 .

3. The extreme H I deficiency in NGC 4314

A remarkable fact is that the barred spiral NGC 4314 is the galaxy with the highest known H I deficiency for its morphological type not only in Coma I, which is a poor cluster, but also for all clusters of galaxies, rich or poor.

For NGC 4314, the Effelsberg spectrum (Fig. 2a) agrees with that taken at Arecibo (Fig. 2b, from Garcia-Barreto et al. 1991). The line detected at Effelsberg has a half-power width of 190 km s^{-1} and an integrated flux of 0.18 Jy km s^{-1}, corresponding to an H I mass of 4 10^6 M$_\odot$, while the Arecibo line has $\Delta V \simeq 160$ km s^{-1} and 0.2 Jy km s^{-1}, corresponding to M(H I) $\simeq 4.4\ 10^6$ M$_\odot$. Because there is the same flux in the Effelsberg beam as in the nine times smaller Arecibo beam area, the H I line must come from a $< 2'$ region centered on the nucleus. The H I may be in the nuclear ring of radius $7''$, where the molecular gas and inner dust lanes are found (Garcia-Barreto et al. 1991; Combes et al. 1992; Benedict et al. 1992).

The Effelsberg and Arecibo data show NGC 4314 has an H I deficiency of +2.06, or more than 100 times less H I, relative to its luminosity, than expected for an early type spiral. If we allow for the range in the reference sample, and compare with the correlation of Huchtmeier & Richter (1988) for galaxies of the same type, then the spread due to the comparison galaxies' range of inclinations means NGC 4314 has 70 to 400 times

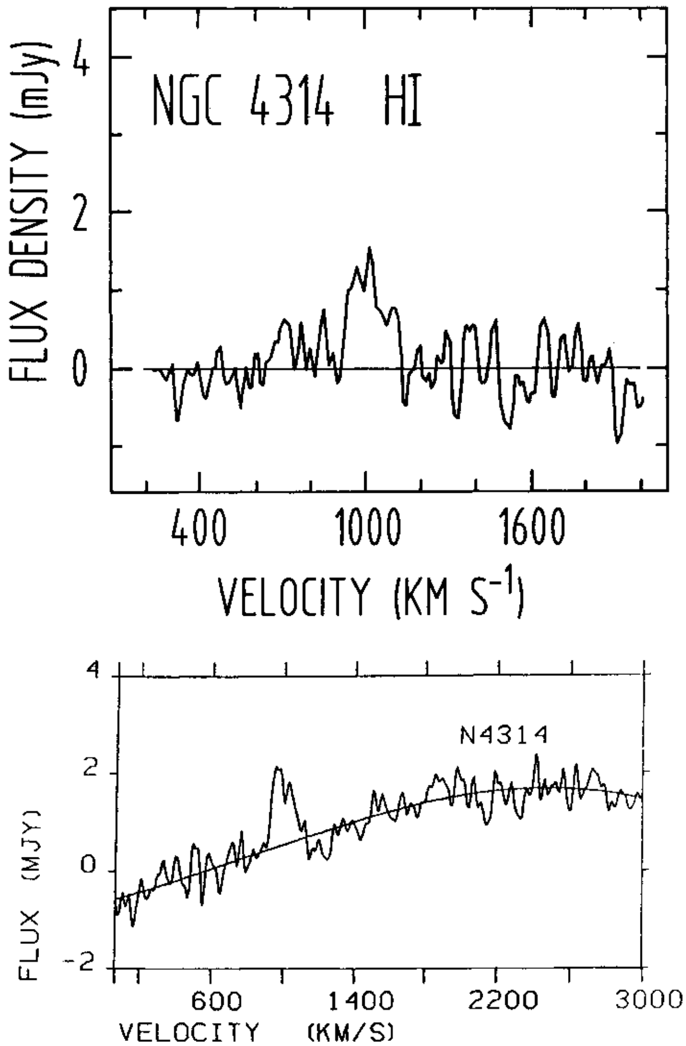

Fig. 2. *upper:* H I spectrum of the galaxy NGC 4314 from the Effelsberg 100 m telescope with a 9.3′ beam. *lower:* H I spectrum of the center of NGC 4314 from the Arecibo telescope with a 3.3′ beam (Garcia-Barreto et al. 1991)

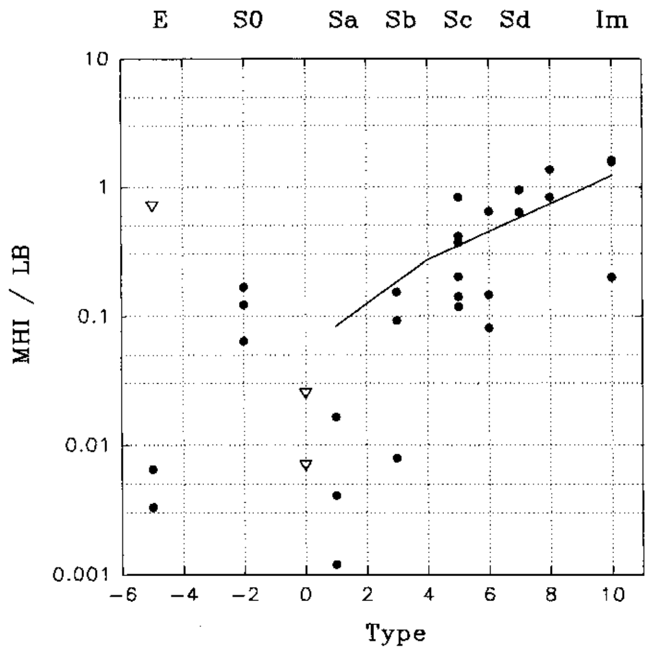

Fig. 3. $M_{\rm H}/L_{\rm B}$ values for Coma I group galaxies vs. morphological type; points = detections, triangles = upper limits. The line is the smoothed median for "normal" galaxies (the sample of nearby galaxies). The lowest points show the pronounced H I deficiencies of a few early type spirals in the Coma I group

less H I mass than expected. Even with this range, the H I deficiency in NGC 4314 is the most extreme value ever measured for an Sa spiral. If we normalize by area instead of luminosity, then M(H I)/D_{25}^2 is 70 times lower than the mean listed by Giovanelli et al. (1981, 1982) and Haynes et al. (1984). H I deficient galaxies are typically depleted by a factor of ten (Giovanelli & Haynes 1985), so even with this normalization, NGC 4314 is *highly deficient* in H I for an Sa galaxy.

In contrast, there is plenty of *molecular* gas in the center of NGC 4314; from the CO flux in the central region, $M(H_2) \simeq 3\ 10^8$ M$_\odot$ (Garcia-Barreto et al. 1991). Hence the gas in this galaxy is about 99% molecular, 1% atomic, and nearly all the gas is in the central region of radius 350 pc.

4. Ram pressure stripping

X rays from rich galaxy clusters yield intracluster gas densities consistent with ram pressure stripping of the outer parts of H I deficient spirals. Evidence for ram pressure stripping comes from the H I deficiency data in this paper. The Coma I galaxies that are gas poor are concentrated toward $12^{\rm h}20^{\rm m}$, +30° (Fig. 4). Indeed, seven gas-poor galaxies, including NGC 4314 and three ellipticals, fall within a circle with projected radius 130 kpc, centered near NGC 4274 (Fig. 4). Most of the gas rich galaxies are to the southeast of this zone. This compact group of gas poor galaxies may indicate the existence of a core of *intragroup gas*, which has stripped the gas from the spirals.

To strip the H I from the spirals, the ram pressure must exceed the gravitational pressure holding the gas in the galactic disk (Gunn & Gott 1972):

$$P_{\rm ram} \equiv \rho_{\rm m} v^2 \geq P_{\rm grav} \equiv 2G\pi\sigma_{\rm s}\sigma_{\rm g} \quad , \qquad (1)$$

with $\sigma_{\rm s}$ and $\sigma_{\rm g}$ = star and gas surface densities in the galaxy, v = velocity of the galaxy relative to the intragroup medium.

In NGC 4314, for example, from the mass model described by Garcia-Barreto et al. (1991), the total mass interior to a disk radius radius of 147″ (7.4 kpc) is 1.3 10^{10} M$_\odot$. The same value is obtained from the correlation of absolute magnitude and total mass (Huchtmeier & Richter 1988), for an absolute magnitude of −18.65 for NGC 4314. This yields a a stellar surface density of $\sigma_{\rm s} \simeq 1.7\ 10^{-2}$ g cm^{-2}. From the gas mass we get a gas suface density $\sigma_{\rm ring} \simeq 0.1$ g cm^{-2} for the gas within the nuclear ring

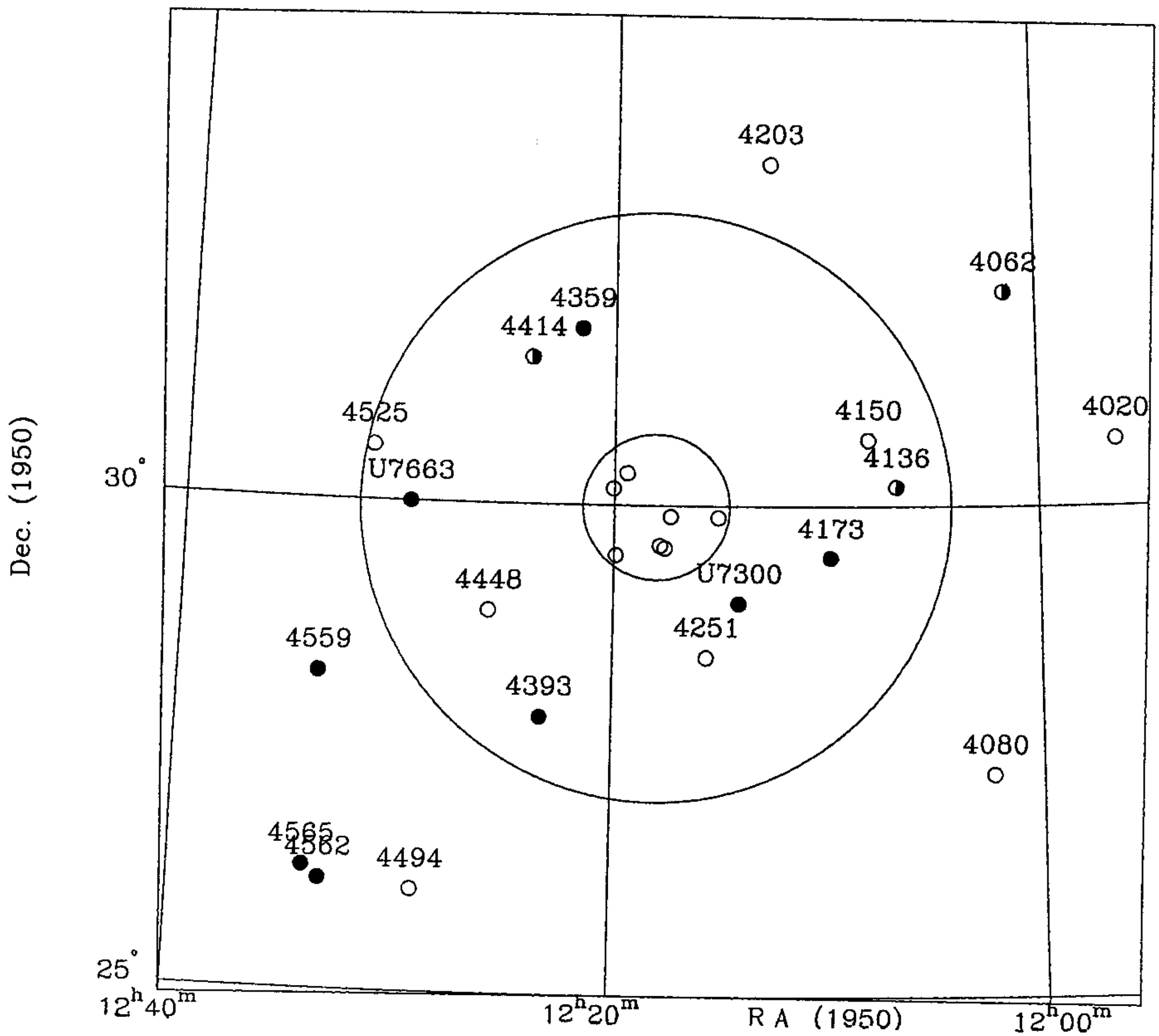

Fig. 4. Locations of gas rich and gas poor galaxies in the Coma I group. Filled circles = gas rich galaxies (H I deficiency < 0.3); half-filled circles = slightly deficient galaxies (0.3 < H I def. < 0.6); empty circles = gas poor galaxies (ellipticals, S0's, and spirals and irregulars with H I deficiencies > 0.6). The 7 gas poor galaxies in the central circle of projected radius 130 kpc are (in order of R.A.) NGC 4245, 4274, 4278, 4283, 4308, 4310 and 4314. The outer circle of a projected radius of 500 kpc includes 11 of the 16 gas poor galaxies in Coma I

and $\sigma_{\rm disk} \simeq 7\ 10^{-5}\ {\rm g\,cm^{-2}}$ for the gas in the stellar bar region (Garcia-Barreto et al. 1991). This yields:

1. $P_{\rm ring} \simeq 10^{-10}$ dyne cm^{-2} for the gravitational pressure within the nuclear ring;
2. $P_{\rm disk} \simeq 4\ 10^{-13}$ dyne cm^{-2} for the gravitational pressure in the bar and outer parts of NGC 4314.

From the Edge & Steward (1991) correlations between X ray and optical velocity dispersions of 36 clusters, the X ray luminosity is $L \simeq 10^{36.60}\sigma^{2.90}$ erg s^{-1}, and the temperature of the X ray emitting gas is $T \simeq 10^{-3.22}\sigma^{1.35}$ keV, where σ is the radial velocity dispersion. For the Coma I group with $\sigma \simeq 190$ km s^{-1} (Gregory & Thompson 1977), the predicted X ray luminosity would be $L \simeq 1.6\ 10^{43}$ erg s^{-1}, and the predicted X ray temperature would be 0.7 keV or 8 10^6K.

If the predicted X ray emission from Coma I comes from an isothermal sphere of radius 0.5 Mpc as in rich clusters of galaxies, then from the predicted temperature we derive an intracluster hydrogen density of $\sim 10^{-4}$ cm^{-3}. A similar density is obtained by assuming the intragroup medium has about the same mass as the sum all the galaxy masses in the group, 1.2 $10^{12}\ M_\odot$ (scaled to 10 Mpc). This is 10% of the virial mass (Gregory & Thompson 1977), and the X-ray emission from *clusters* does indeed correspond to intracluster gas masses of ~10% of the virial mass (Sarazin 1988, his Sect. 4.4.1).

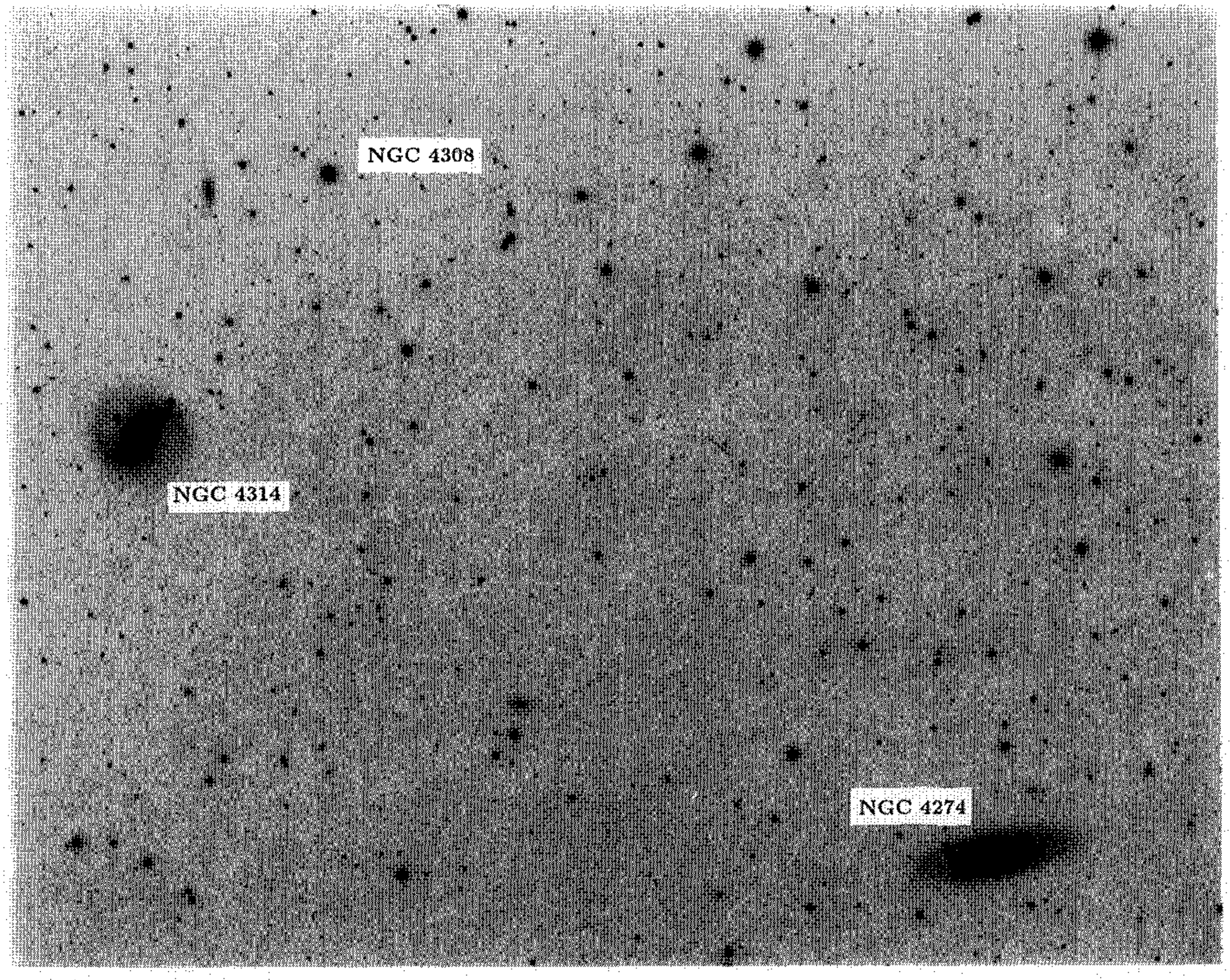

Fig. 5. Palomar Survey blue sensitive print of NGC 4314 field. North is at the top, and East is left. NGC 4314 is the barred spiral at the left. Above NGC 4314 in this print are the elliptical NGC 4308 and the small galaxy UGC 7438, which may not be a member of the Coma I cloud. The separation of NGC 4314 and the elliptical NGC 4308 is 736″. The Sa spiral at lower right is NGC 4274

With the observed velocity dispersion, we then derive a ram pressure of: $P_{\rm ram} \simeq 1\ 10^{-13}$ dyne cm^{-2}. Hence $P_{\rm ram} << P_{\rm ring}$, and the pressure of the intragroup medium is a thousand times too weak to remove gas from the nuclear ring. However, $P_{\rm ram}$ is comparable to $P_{\rm disk}$, so the intragroup medium may be able to strip the gas in the *outer* parts of NGC 4314 and possibly in the outer parts of other spirals in the group.

To summarize, for this ram pressure interpretation, we assumed the correlations found for rich clusters hold also for poor clusters, as is suggested by the work of Price et al. (1991), and that the X ray emitting region comes from an isothermal sphere of radius 500 kpc. For comparison, the mean radius of the X ray emitting regions in the poor clusters listed by Price et al. (1991) is about 400 kpc, so our assumption of a small core may be justified. There is to date no other evidence for an intragroup medium in Coma I: no X ray continuum, no X-ray iron lines, no optical line emitting filaments suggestive of a cooling flow. The best evidence is probably the concentration of gas poor galaxies, now supported by the H I measurements in this paper. How might the medium in Coma I be different than that in rich clusters of galaxies?:

1. *Lower temperature.* The gas temperature would be $T = \sigma^2/(k\mu m_{\rm p})$, where μ = mean molecular weight, $m_{\rm p}$ = proton mass, k = Boltzmann's constant, σ = line of sight velocity dispersion of galaxies in the group (Sarazin 1988, his Eq. 5.13). The dispersion in the line of sight component is 190 km s^{-1} observed, but could be as low as 160 km s^{-1} after allowing for 100 km s^{-1} redshift uncertainties (Gregory & Thompson 1977, their solution II). This corresponds to an intragroup gas temperature of 1.8 10^6 K, or only 0.15 keV, about a factor of 4 lower than estimated above, and probably difficult to detect in X rays.
2. *Short cooling time.* At this temperature, cooling by line radiation is more important than thermal bremstrahlung, un-

like the cooling of hot gas in clusters. The cooling rate is $6.2\ 10^{19}\ T^{-0.6} n_p^2$ erg cm^{-3} s^{-1} for $10^5 < T < 4\ 10^7$ K (McKee & Cowie 1977; Sarazin 1988, Eq. 5.22), so the cooling time is only a few $\times\ 10^7$ yr for densities $\sim 10^{-3}$ cm^{-3}, not a Hubble time as in the hot gas in clusters. Hence intragroup gas at such densities would not be hot enough to resist gravity, and should have been accreted by the Coma I galaxies long ago. The intragroup gas could stay hot for a few Gyr only if its density were $< 10^{-5}$ cm^{-3}.

3. *Shallow potential well.* The potential wells of individual galaxies are comparable with the potential well of the Coma I group. The radial velocity dispersion of galaxies in the group of only 160 km s^{-1} in the line of sight corresponds to a true space velocity dispersion of 270 km s^{-1}, comparable with the velocity dispersions of stars in galaxies. This is quite unlike the situation in clusters, where the velocity dispersions of galaxies are $\sim$ 1000 km s^{-1}, that is, the gravitational potentials of the clusters are ten times those of individual galaxies (Sarazin 1988, his Sect. 5.5). Thus individual galaxies will significantly perturb the distribution of any intragroup gas in Coma I.

5. H I $\Longrightarrow$ H_2 ?

It still remains to explain how most of the remaining gas in NGC 4314 ended up in its center (r < 350 pc), and nearly all of it in molecular form. Gas might be pushed from the outer regions of a galaxy to the inner regions by a non-axisymmetric potential (a bar), by a nearby companion or by both (e.g., Combes 1988). In a tidal interaction, nearly all of the gas and dust can be pushed to the center of the galaxy by dynamical friction (e.g. Barnes 1991), forming clouds of densities 10^2 —10^3 cm^{-3} at temperatures <100 K. In these central clouds, which are partly the atomic gas and partly those molecular clouds that existed before the bar was formed or before the tidal interaction occured, the gas and dust density are now both higher than before, and the H I is more rapidly transformed to H_2 by reactions on grain surfaces. For an H_2 formation rate (e.g., Spitzer 1978) of $3\ 10^{-17}$ cm^{-3} s^{-1}, and at densities $n_H \simeq 10^2 - 10^3$ cm^{-3}, temperature 100 K, and gas to dust ratio of 100, it would take only $\sim 10^8$ yr to convert 95% of the H I to H_2 by reactions on grain surfaces.

In this interpretation, the $3\ 10^8\ M_\odot$ of H_2 now observed in the center of NGC 4314 was made from disk H_2 and H I that was pushed to the center by the bar or by a tidal interaction. All this gas is now in a ring of radius 350 pc, possibly due to a resonance with the galaxy's bar. The H_2 may now be protected against photo-dissociation into H I by the high opacities of the galactic center clouds.

Although there is no current evidence for a collision or tidal interaction for most of the galaxies in Coma I, such an event may have happened in NGC 4747, which has a long plume to the northeast. The collision partner is probably NGC 4725, which is nearby and has a redshift of 1750 km s^{-1}, similar to that of NGC 4747. Could the H I deficiency in NGC 4314 also be explained by an interaction in the distant past with another member of the Coma I group? There are 31 probable neighbor galaxies of NGC 4314 in the Coma I cloud (Table 1). The closest galaxy to NGC 4314 is the small elliptical NGC 4308, at a projected distance of 38 kpc. The nearest spiral is the Sa galaxy NGC 4274 at a projected distance of 124 kpc (Fig. 5). The radial velocities relative to NGC 4314 are 374 km s^{-1} for NGC 4308, and 80 km s^{-1} for NGC 4274. Although the kinematic time (projected distance/relative velocity) for close interactions is 0.1 Gyr for NGC 4308 and 1.5 Gyr for NGC 4274, there is no observational evidence for a tidal interaction (plumes, tails or bridges) or galaxy – galaxy collision (a galaxy with two compact nuclei). With no tidal tails or other clues, it is impossible to say which galaxy might have interacted with NGC 4314.

6. Conclusion

The Coma I group of galaxies may provide an important clue to the process of H I removal, because although it is a poor cluster, it has a marked spatial concentration of gas poor galaxies. In addition, the spiral NGC 4314 shows some unusual properties:

1. the most extreme H I deficiency known for its type,
2. H I deficiency in its inner as well as its outer disk,
3. no obvious companion to sweep away the gas,
4. no tidal tail or sign of a recent interaction, and
5. it is the only extremely H I deficient Sa galaxy NOT in a rich cluster.

Ram pressure stripping could explain the H I deficiency in most of the gas poor spiral galaxies in the Coma I group if there is an intragroup medium concentrated in a core of radius 0.5 Mpc, with a density of 10^{-4} cm^{-3}, as in rich clusters of galaxies. That assumption needs to be confirmed with X ray observations of the Coma I group, but the concentration of gas-poor galaxies near NGC 4314 (circle in Fig. 4) may indicate that this compact core of intragroup gas really exists. In addition, a second mechanism, probably bar forcing or an ancient tidal interaction, seems necessary to explain how nearly all the gas in NGC 4314 ended up in its center, in molecular form.

Acknowledgements. We thank the referee, R.B. Tully, for helpful remarks and J. Franco for calculations of H I $\Longrightarrow$ H_2 conversion times. JAG-B acknowledges partial financial support from CONACYT (Mexico) grant PCCBBNA-022688 and a fellowship from the Alexander von Humboldt-Stiftung, Federal Republic of Germany.

References

Barnes, J.E. 1991, in Dynamics of Galaxies and their Molecular Cloud Distributions, IAU 146, ed. F. Combes, F. Casoli, Kluwer, Dordrecht, 363

Benedict, G.F., Higdon, J.L., Tollestrup, E.V., Hahn, J.M., Harvey, P.M. 1992, AJ 103, 757

Combes, F. 1988 in Galactic and Extragalactic Star Formation, ed. R.Pudritz and M.Fich, Kluwer, Dordrecht, 475

Combes, F., Gerin, M., Nakai, N., Kawabe, R., Shaw, M.A. 1992, A&A 259, L27

de Vaucouleurs, G. 1975, in Galaxies and the Universe, ed. A. Sandage, M. Sandage, J. Kristian, Univ. Chicago Press, 557

Edge, A.C.,Stewart, G.C., 1991, MNRAS 252,428
Garcia-Barreto, J.A., Downes, D., Combes, F. et al., 1991, A&A 244, 257
Giovanelli, R., Chincarini, G.L., Haynes, M.P. 1981, ApJ 247, 383
Giovanelli, R., Haynes, M.P. 1985, ApJ 292, 404
Giovanelli, R., Haynes, M.P., Chincarini, G.L. 1982, ApJ 262, 442
Gregory, S.A., Thompson, L.A. 1977, ApJ 213, 345
Gunn, J.E., Gott, J.R. 1972, ApJ 176, 1
Haynes, M.P., Giovanelli, R., Chincarini, G.L. 1984, ARA&A 22, 445
Huchtmeier, W.K. 1982, A&A 110, 121
Huchtmeier, W.K., Richter, O.-G. 1988, A&A 203, 237
Huchtmeier, W.K., Richter, O.-G. 1989, A&A 210, 1
McKee, C.F., Cowie, L.L. 1977, ApJ 215, 213
Mulcahey, J.S., Davis, D.S., Mushotzky, R.F., Burstein, D. 1993 ApJ 404, L9
Price, R., Burns, J.O., Duric, N., Newberry, M.V. 1991 AJ 102,14
Raimond, E., Faber, S.M., Gallagher III, J.S., Knapp, G.R. 1981, ApJ 246, 708
Sage,L.J., Huchtmeier, W.K., Westpfahl, D.J., Aufdenberg, J., 1994, A&A submitted
Sandage, A., Tammann, G.A., 1987, A Revised Shapley-Ames Catalog of Bright Galaxies, Carnegie Institution, Washington, D.C.
Sarazin, C.L. 1988, X-ray Emission from Clusters of Galaxies, Cambridge Univ. Press, Cambridge, U.K.
Spitzer, L. 1978, Physical Processes in the Interstellar Medium, Wiley, New York
Tully, R.B. 1988, Nearby Galaxies Catalog, Cambridge University Press, Cambridge, 201
Turner, E.L., Sargent, W.L.W. 1974, ApJ 194, 587

This article was processed by the author using Springer-Verlag LaTeX A&A style file version 3.