Atomic hydrogen deficiency in spiral galaxies in clusters

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We consider the new method for atomic hydrogen deficiency estimations. The main idea is to use the empirical relation between total HI mass and specific angular momentum of the disk for isolated galaxies. The method was compared with the standard one, based on dependence of HI mass on optical diameter and galaxy type. They both were applied to Virgo and Coma cluster galaxies and to Local Volume galaxies. Also we investigated possible mechanisms responsible for HI deficiency in cluster spirals.

Introduction

In the dense regions of rich clusters galaxies interact with gravitational field of cluster, with each other and with intergalactic medium. These interactions may affect physical properties and evolution of galaxies. In different works several mechanisms were investigated which may be responsible for HI deficiency in cluster galaxies (see, e.g., [1, 2, 8, 11, 20], [13]-[17]).

Cluster galaxies have, in average, a lower atomic gas content than their isolated counterparts. HI deficiency parameter was for the first time defined in [7] as logarithmical difference between observed HI mass and expected one. The latter is estimated by empirical relation between HI mass and luminosity, type, and optical linear diameter of the disk. This relation was obtained for isolated galaxies from Karachentseva catalog [10]. Galaxies with $|\mathrm{def\,HI}| < 0.3$ are considered as normal.

In our work we used semi-empirical relation between M_{HI} and specific angular momentum of the disk considered in [9],[22]-[24]:

$$(\lg M_{\mathrm{HI}})_{exp} \approx a + b \lg V_R D_C, \tag{1}$$

where D_C is optical linear diameter of the disk or scalelength, V_R is rotational velocity of the disk on the radius $D_C/2$, a and b are some constants, and $b \approx 1$.

Isolated and neighbouring galaxies

We obtained the dependence of HI mass on specific angular momentum of the disk for isolated galaxies from AMIGA catalog [21] and for neighbouring isolated galaxies from Karachentsev et al. catalog [9] with types from Sbc and later (Fig. 1).

We used galaxies with inclination angles not less than 30°, and types from Sbc and later ($t \geq 3.5$, according to de Vaucouleurs [3]). We obtained the following empirical relation with correlation coefficient $R = 0.94$:

$$(\lg M_{\mathrm{HI}})_{exp} = (1.06 \pm 0.02) \lg V_R D_C + (5.94 \pm 0.06), \tag{2}$$

where D_C is diameter of galactic disk up to isophote 25 mag/arcsec^2, in kpc, corrected for inclination and extinction, V_R is maximum deprojected rotation velocity (km/s) of the gas calculated from both the 21-cm line widths at different levels and/or the available rotation curves (generally H_α rotation curves) and corrected for inclination, M_{HI} is HI mass, obtained from corrected for self-absorption effect HI line magnitude, in solar masses. All used quantities were taken from Hyperleda database [25].

This relation is also valid for Sab and Sbc galaxies. However galaxies with S0a-Sab ($t = 0 - 2$) types show, on average, significant lack of HI compared with later type galaxies. Hence we cannot apply considered relation for most part of these galaxies.

The HI deficiency parameter is defined as logarithmical difference between observed HI mass and expected:

$$(\mathrm{def\,HI})_{VD} = (\lg M_{\mathrm{HI}})_{exp} - (\lg M_{\mathrm{HI}})_{obs}, \tag{3}$$

where $(\lg M_{\rm HI})_{exp}$ is logarithm of expected HI mass (in solar masses) of galaxy according to (2) and $(\lg M_{\rm HI})_{obs}$ is logarithm of observed HI mass (in solar masses) of galaxy.

We estimated HI deficiency for non-isolated galaxies from Karachentsev et al. catalog [9] and found no correlation with the isolation degree. Therefore, processes responsible for HI deficiency in cluster galaxies, are not significant in nearby groups.

HI deficiency in cluster galaxies

For galaxies in Virgo and Coma clusters we estimated $(\mathrm{def\,HI})_{VD}$ using relation (2), obtained for isolated galaxies. In Virgo we used galaxies from inner region of cluster, up to 1.8 Mpc; in Coma we used galaxies up to 6 Mpc from cluster center, but within accepted cluster limits [12]: $V = 5300 - 9000$ km/s, $\alpha = 12^h30^m - 13^h30^m$, $\delta = 26^\circ - 31^\circ$). $M_{\rm HI}$, V_R and D_C were taken from Hyperleda database [25]; we used galaxies with inclination angles $i > 30^\circ$.

Diagrams "$(\mathrm{def\,HI})_{VD}$–$(\mathrm{def\,HI})_{Gavazzi}$" for Virgo and Coma cluster galaxies are presented in Fig. 2. $(\mathrm{def\,HI})_{VD}$ is HI deficiency obtained on the basis of HI mass dependence on specific angular momentum of the disk, $(\mathrm{def\,HI})_{Gavazzi}$ is HI deficiency from [5] (for Virgo) and [6] (for Coma).

Also we obtained a well-known relation between the mean HI deficiency and clustercentric distance for our method of HI deficiency estimation (Fig. 3). In Virgo cluster we see a substantial HI deficiency up to nearly 2 Mpc from the cluster center, in Coma – up to $3 - 4$ Mpc from the cluster center. Many galaxies have normal hydrogen content at all distances.

The condition of disk gas stripping by ram pressure is given by the equation:

$$P_{ram} \geq 2\pi G \Sigma_{star} \Sigma_{gas}.$$

Ram pressure P_{ram} is given by:

$$P_{ram} = \rho_{IGM} V_{gal}^2.$$

Typical ram pressure on distances where substantial HI deficiency is observed (2 Mpc for Virgo and $3-4$ Mpc for Coma) for typical values $V_{gal} = 1000$ km/s, $\rho_{IGM} = 10^{-4}$ cm^{-3} (see [4, 18]) is $P_{ram} \simeq 10^{-12}$ dyn/cm^2.

But this value of ram pressure is not sufficient by order of magnitude for sweeping the considerable amount of gas (see [19]). These galaxies either passed through the dense core of the cluster or HI deficiency is related with other reasons, for example with starvation effect.

Results and conclusions

1. Application of semi-empirical relation between total HI mass and specific angular momentum of the disk for isolated Sab-Irr galaxies allowed us to estimate HI deficiency in cluster galaxies without taking into account their morphological types.
2. Neighboring galaxies from Karachentsev et al. (2004) catalog show no systemic HI deficiency. Mean deviation of HI mass from "normal" one is small and shows no correlation with isolation degree.
3. The relation between HI deficiency and distance from cluster center was confirmed for Virgo and Coma cluster galaxies. We found out the existence of substantial HI deficiency up to nearly 2 Mpc from cluster center in Virgo, and up to $3 - 4$ Mpc from cluster center in Coma.
4. In Virgo cluster at distances where galaxies with substantial HI deficiency are being observed the ram pressure is not sufficient for sweeping off considerable amount of gas. These galaxies either passed through the dense core of the cluster or HI deficiency is related to other reasons, for example with starvation.

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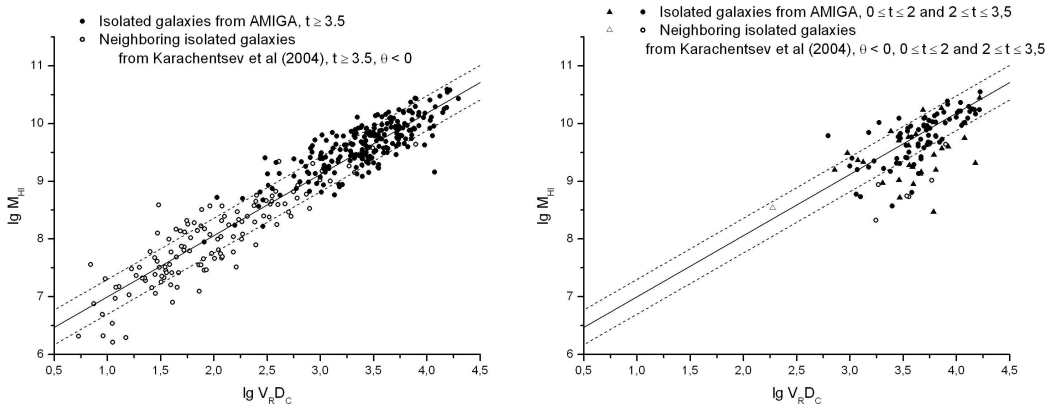

Figure 1: Diagrams "HI mass – specific angular momentum" for isolated galaxies with $t \geq 3.5$ (left) and $t = 0-3.5$ (right).

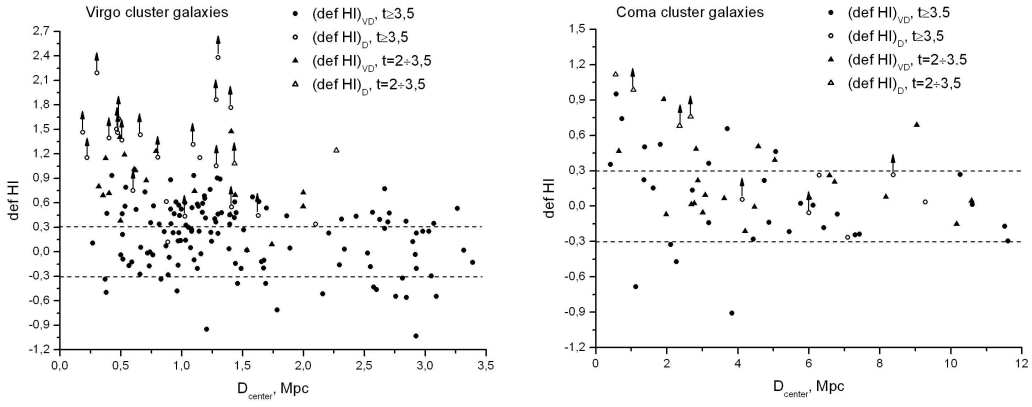

Figure 2: Diagrams "$(\mathrm{def\,HI})_{VD} - (\mathrm{def\,HI})_{Gavazzi}$" for Virgo (left) and Coma (right) cluster galaxies. Straight line corresponds to the equality of values.

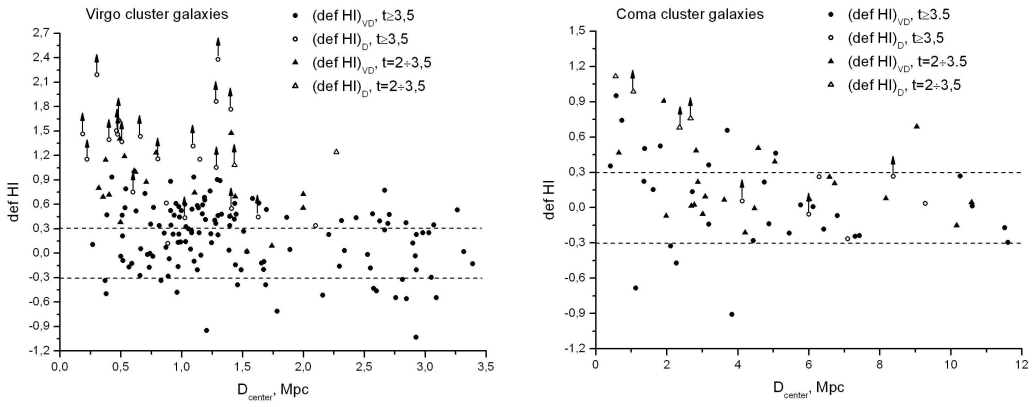

Figure 3: Diagrams "def HI – distance from the cluster center" for Virgo (left) and Coma (right)

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