HALOGAS: Strong Constraints on the Neutral Gas Reservoir and Accretion Rate in Nearby Spiral Galaxies.

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ABSTRACT

Context. Galaxies in the local Universe are thought to require ongoing replenishment of their gas reservoir in order to maintain the observed star formation rates. Cosmological simulations predict that such accretion can occur in both a dynamically hot and cold mode, depending on the redshift, halo mass and the details of the included feedback processes. However, until now observational evidence of the accretion required to match the observed star formation histories is lacking.

Aims. Within the framework of the Hydrogen Accretion in LOcal GalaxieS (HALOGAS) survey, this paper attempts to determine whether galaxies in the local Universe possess a significant reservoir of cold neutral gas and what would be the accretion rates derived from such reservoirs. Additionally, with this moderately sized sample we can start to investigate whether the observed accretion is connected to intrinsic properties of the galaxies like Hubble type, star formation rate or environment.

Methods. We search the vicinity of 22 nearby galaxies for isolated H I clouds or distinct streams, that are not yet connected to the galaxy's disk, in a systematic and automated manner. The HALOGAS observations were carried out with the Westerbork Synthesis Radio Telescope and represent one of the most sensitive and detailed H I surveys to date. These observations typically reach column density sensitivities of $\sim 10^{19}$ cm^{-2} over a 20 km s^{-1} width.

Results. We find 14 secure H I cloud candidates without an observed optical counterpart in the entire HALOGAS sample. These cloud candidates appear to be analogues to the most massive clouds detected in the extensive cloud distributions around the Milky Way and M 31. However, on average their numbers seem significantly reduced compared to these galaxies. Within the framework of cold accretion, we constrain upper limits for H I accretion in the local Universe. The average H I mass currently observed in a state suggestive of accretion onto the galaxies amounts to a rate of 0.05 $M_{\odot}yr^{-1}$ with a stringent upper limit of 0.22 $M_{\odot}yr^{-1}$, confirming previous estimates. This is much lower than the average star formation rate in this sample. Our best estimate, based on the Green Bank Telescope detection limits of several galaxies in the sample, suggests that at most another 0.04 $M_{\odot}yr^{-1}$ of neutral hydrogen could be accreted from clouds and streams that remain undetected.

Conclusions. These results show that in nearby galaxies neutral hydrogen is not being accreted at the same rate as stars are currently

Проблема

- Эволюция SFR в галактиках требует включения аккреции, компенсирующей потерю газа. Однако прямых свидетельств аккреции, сопоставимой с SFR, мы не видим.

Три канала аккреции:

- Облака HI, спутники, богатые газом, и разреженный газ низкой пов.плотности.
- In the local Universe, a global Hi accretion rate of 0.2 Ms/yr was estimated by Sancisi et al. (2008) based on observational findings. This accretion rate includes both the accretion of pure gas clouds as well as gas-rich dwarf galaxies and is based on the literature of single target studies.

- We used the Westerbork Hydrogen Accretion in LOcal GAlaxieS (HALOGAS) survey to investigate general characteristics of gaseous halos and accretion in a significant sample). For this purpose, we obtained deep (10 -12 hours) HI observations using the Westerbork Synthesis Radio Telescope (WSRT), reaching typical column density sensitivity levels of 10^{18} cm-2.
- We used the SOurce Finder Application (SoFiA, Serra et al. 2015). Тестирование (подгружены облака к datacube).
- Из 36 облаков найдено 36+1.
- Depending on the distance of the cloud, this translates to a detection threshold in the range 0.5-3 10^{6} Ms.

Наблюдения

- Из 22 одиночных галактик отдельные облачка HI найдены в 14.

Galaxy (1)	ID (2)	RA [hms] (3)	Dec [dms] (4)	Class (5)	S_p [mJy bm^{-1}] (6)	F_i [Jy km s^{-1}] (7)	F_i,pbcorr [Jy km s^{-1}] (8)	W20 [km s^{-1}] (9)	Vel. [km s^{-1}] (10)	Dist. to target [kpc] (11)
NGC 0925	2	2h27m5.62s	33d43m13.73s	CC	0.871	0.048	0.056	45.1	579.1	22.6
NGC 1003	2	2h39m12.94s	40d55m51.93s	CC	0.893	0.086	0.088	36.3	593.9	12.3
NGC 4258	3	12h19m2.16s	47d6m52.02s	CC	0.830	0.067	0.088	41.5	252.9	24.5
NGC 4258	8	12h18m34.75s	47d32m46.60s	CC	1.174	0.088	0.141	42.0	570.7	33.8
NGC 4274	9	12h20m18.55s	29d18m48.96s	CC	1.082	0.032	0.069	30.3	791.7	108.4
NGC 4274	10	12h20m18.47s	29d22m2.91s	CC	0.962	0.045	0.077	32.9	979.4	91.3
NGC 4274	11	12h20m0.86s	29d34m26.72s	CC	1.224	0.110	0.112	42.2	998.7	19.8
NGC 4414	2	12h26m26.93s	31d21m20.80s	CC	0.888	0.045	0.051	36.0	622.0	42.8
NGC 4565	3	12h36m49.28s	25d55m49.89s	CC	0.799	0.058	0.065	50.4	1017.6	24.6
NGC 4565	6	12h35m39.69s	25d55m58.35s	CC	1.092	0.025	0.031	25.9	1327.0	30.2
NGC 4565	7	12h35m59.96s	26d8m16.66s	CC	0.785	0.057	0.070	37.3	1381.8	30.0
NGC 4565	8	12h38m11.61s	25d36m44.94s	CC	0.991	0.030	0.411	98.2	1576.6	107.5
NGC 5055	2	13h16m59.56s	42d6m39.26s	CC	0.981	0.309	0.462	48.6	534.6	36.3
NGC 5585	1	14h21m24.29s	57d4m47.70s	CC	0.916	0.020	0.076	63.1	111.0	62.0

- CC- кандидаты в облака
- C-компаньоны
- T – target galaxy

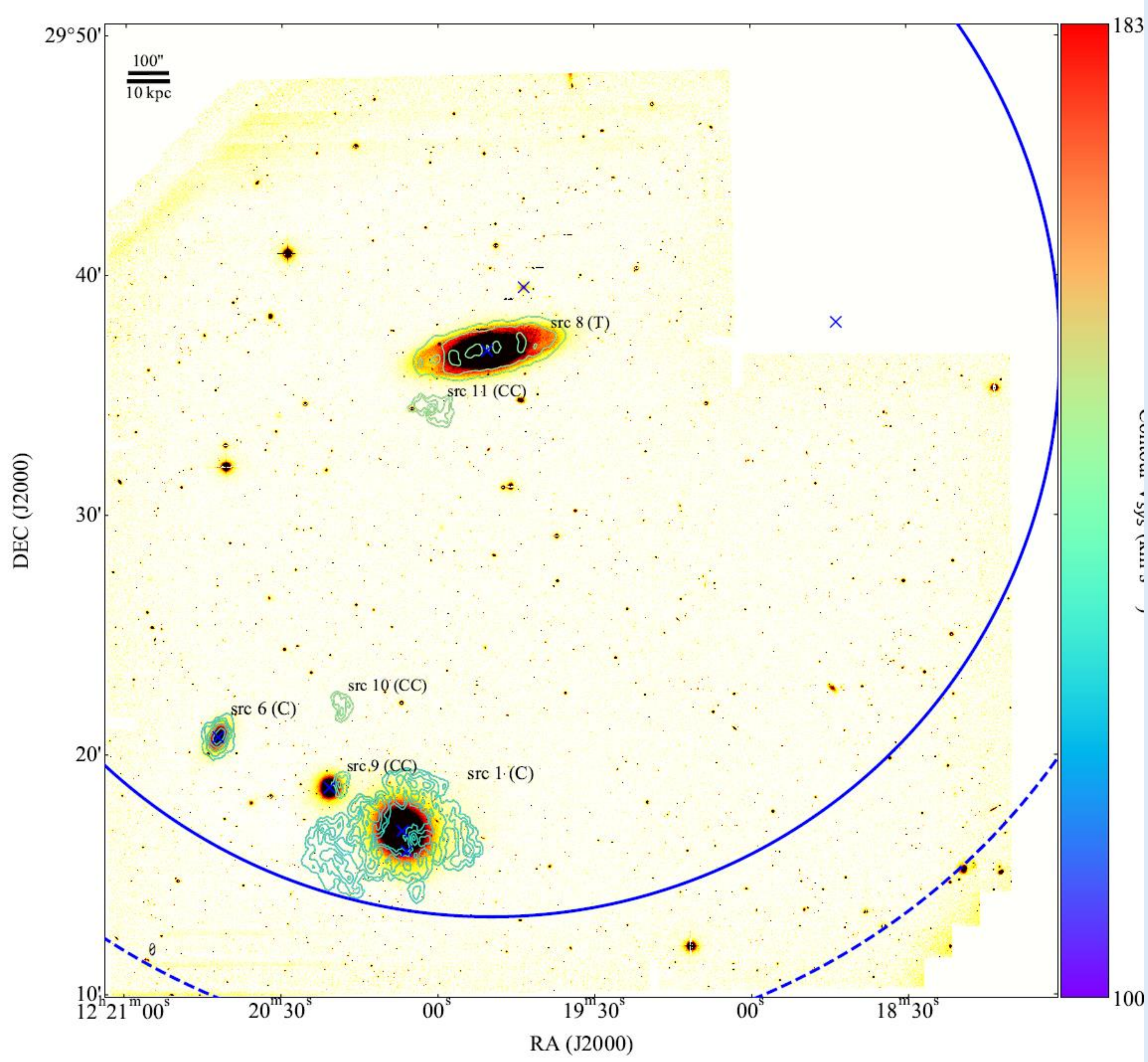


Fig. B.6. As Figure B.1 but for the NGC 4274 field.

- Верхний предел для темпов аккреции определялся по времени свободного падения облака или спутника на край диска (t_{ff1}) или на центр (t_{ff2}) галактики с динамической массой M_{dyn}.

$$M_{\rm dyn} = \frac{(0.5 \times W_{20})^2 \times R}{\sin(i)^2 \times G}$$

Calculating the accretion rate as described above we find mean neutral gas accretion rates onto the disk of the host galaxies of 0.03 Ms/yr for all cloud candidates, 0.18 Ms / yr for all companions within the virial radius.

Host Galaxy	Source	v_{esc} km s^{-1}	t_{ff1} 10^7 yr	t_{ff2} 10^7 yr	$\dot{M}_1$ $M_\odot yr^{-1}$	$\dot{M}_2$ $M_\odot yr^{-1}$
NGC 0925	2	216.4	16	6	0.007	0.016
NGC 0925	4	132.9	69	51	0.02	0.02
NGC 1003	2	300.7	6	3	0.04	0.08
NGC 2541	1	79.1	227	198	0.02	0.02
NGC 3198	2	140.6	149	137	0.18	0.19
NGC 4258	3	353.7	10	2	0.01	0.04
NGC 4258	4	240.3	33	24	0.13	0.18
NGC 4258	6	329.7	13	8	0.28	0.45
NGC 4258	8	301.1	17	7	0.01	0.03
NGC 4258	10	501.2	3	1	0.02	0.06
NGC 4274	9	146.3	113	107	0.005	0.006
NGC 4274	10	159.5	87	81	0.008	0.008
NGC 4274	11	342.4	8	5	0.11	0.18
NGC 4414	2	341.9	19	8	0.02	0.05
NGC 4565	1	389.1	12	10	0.02	0.03
NGC 4565	3	434.6	8	4	0.02	0.04
NGC 4565	4	335.0	18	16	0.92	1.03
NGC 4565	5	529.1	4	3	0.82	1.30
NGC 4565	6	392.3	11	10	0.007	0.009
NGC 4565	7	393.6	11	6	0.02	0.03
NGC 5055	2	379.7	14	5	0.05	0.14
NGC 5055	4	300.1	29	19	0.29	0.44

- Кружки – аккреция облаков
- Звездочки – аккреция облаков

+ спутников

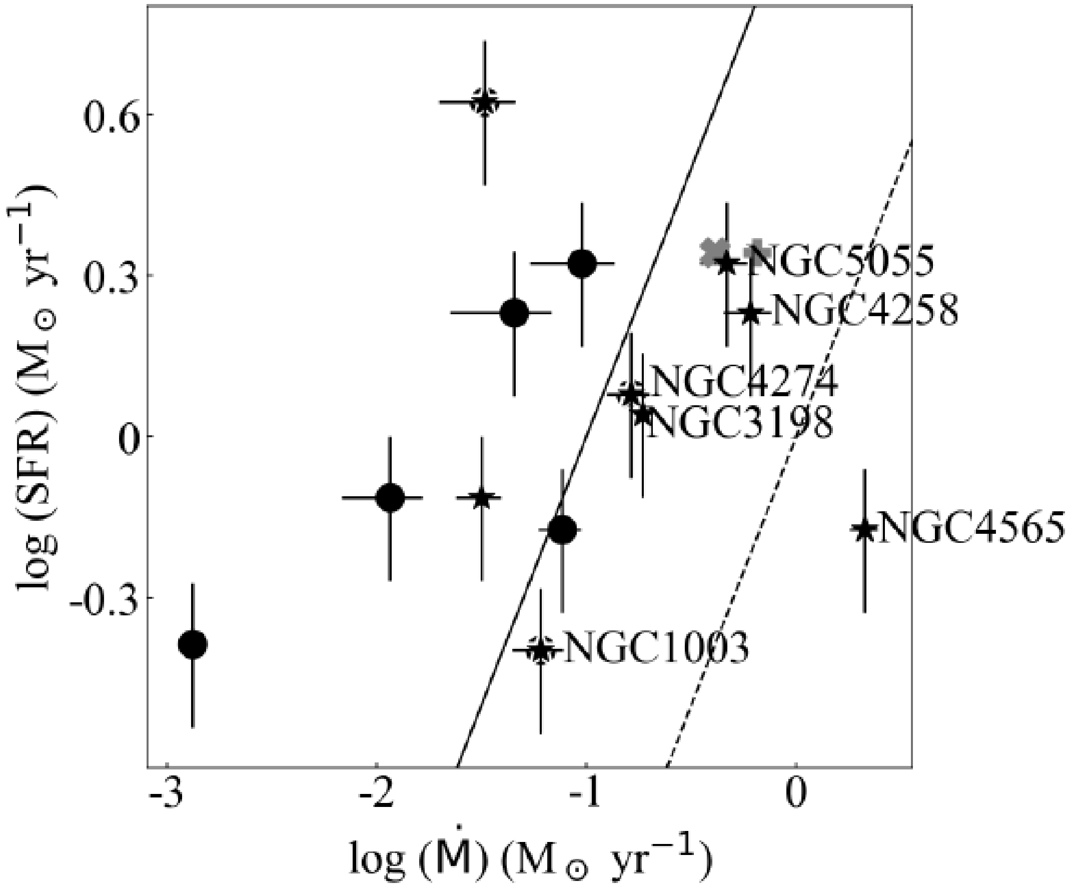


Fig. 2. $\dot{M}$ vs SFR of host galaxies. Solid circles represent the average of accretion rates with a timescale of t_{ff1} (infall on center) and a timescale of t_{ff2} (infall on edge of disk) for galaxies with cloud candidates, with the horizontal error indicating the distance to these upper limits. The errors on the SFR indicate the assumed 30% error.

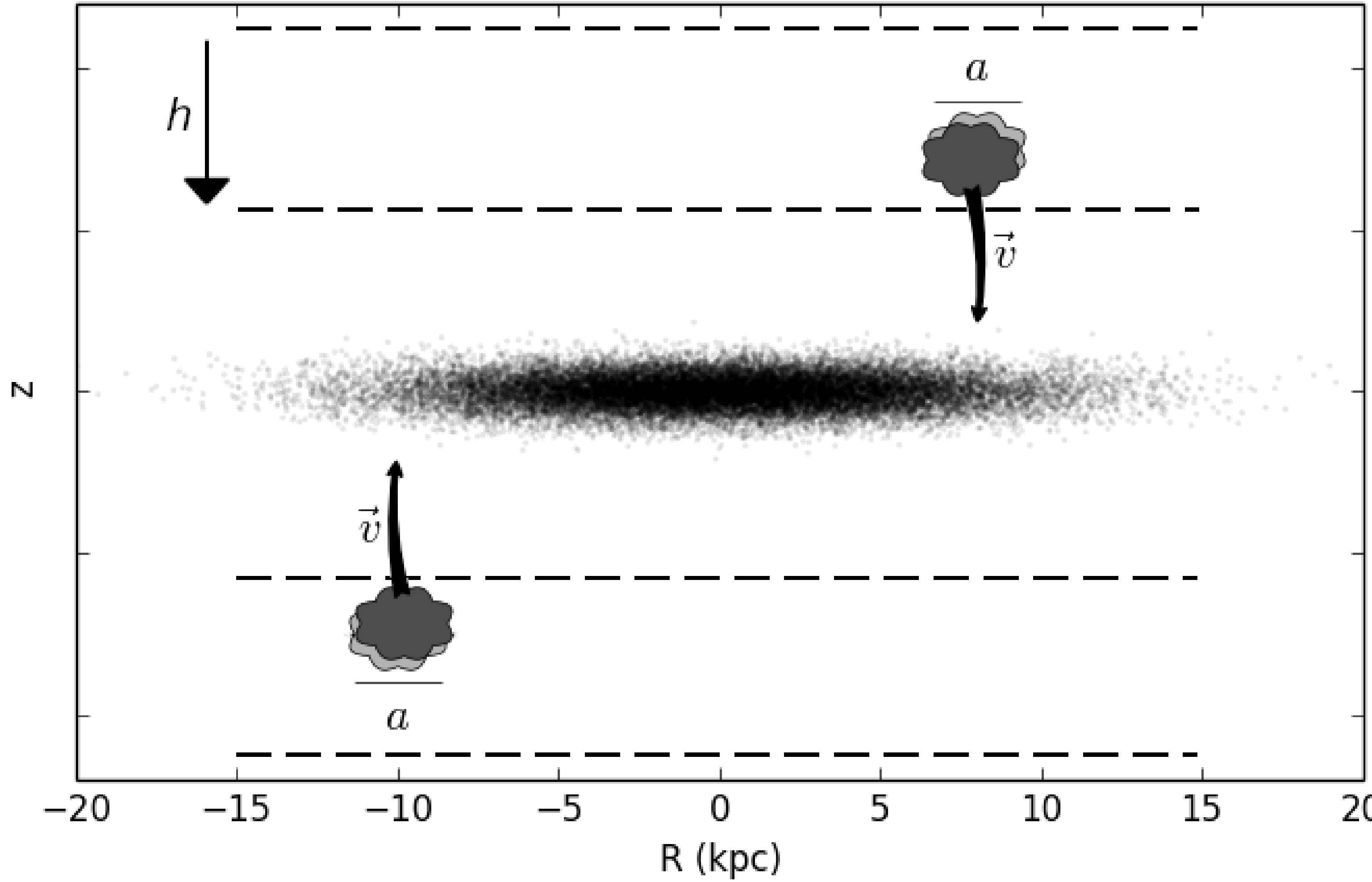
Учет более разреженного газа

- Although HALOGAS provides the deepest resolved survey of nearby galaxies to date, there is still potentially a large amount of undetected gas at low column density. Such a reservoir was recently claimed to have been detected in sensitive Green Bank Telescope (GBT) measurements for NGC891 and NGC4565 (Das et al. 2020). Here we attempt to estimate the neutral hydrogen gas reservoir that could still be hiding below our sensitivity limits.
- Taking 5 10^{17} cm2 with a line width of 20 km s as an indicative upper limit on the detection from the GBT we can obtain a limiting maximum mass.

$$t_{cross} = \frac{h}{v_{cross}}$$

$$\dot{M}_{upper} = \frac{M_{boundary}}{t_{cross}}$$

Host Galaxy	$\dot{M}_{GBT}$ $M_{\odot}yr^{-1}$
NGC0925	0.034
NGC0949	0.010
NGC1003	0.014
NGC2541	0.023
NGC3198	0.037
NGC4062	0.034
NGC4244	0.024
NGC4258	0.074
NGC4274	0.106
NGC4414	0.021
NGC4448	0.037
NGC4559	0.035
NGC4565	0.122
NGC5023	0.017
NGC5055	0.032
NGC5229	0.004
NGC5585	0.009
UGC2082	0.025
UGC4278	0.021
UGC7774	0.019



• Сравнение с HVC- облаками M31 и MW.

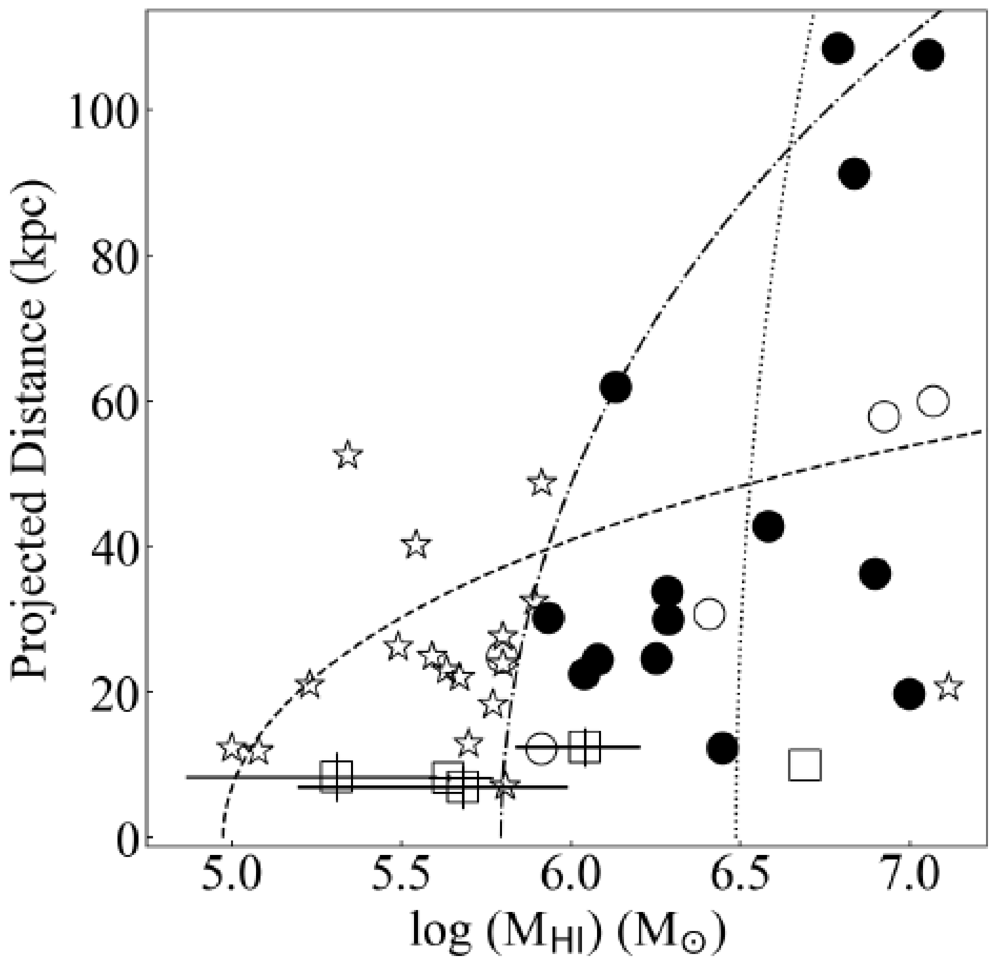


Fig. 7. Mass vs Projected Distance to host for the clouds surrounding M 31 (stars, Westmeier et al. 2008) and our detections. Filled circles are the cloud candidates, open circles are our detections with a stellar counterpart. Open squares indicate the Milky Way HVC complexes with their errors the actual detected ranges. The dashed, dot-dashed and dotted lines indicate the minimum, median and maximum detection limits in the survey galaxies. The limits are primary beam corrected and hence increase with increased distance to the host. The axes are not adjusted to show the companions hence only a few are visible.

Основные выводы

- The cloud detections account for an average accretion rate of 0.03 Ms/ yr over the whole sample. If we simply compare this to the average SFR in the sample, 0.8 Ms/ yr this would not be sufficient to replenish the gas used in star formation.
- When we consider all detections within the virial radius of our host galaxies, we obtain the observed accretion rate to 0.05 Ms/ yr.
- There are hints that galaxies with closer companions have more clouds. If this trend could be confirmed in a larger sample it is likely that our cloud candidates have a tidal origin instead of being primordial accretion. For now the question of why some galaxies display a HVC population and others do not remains open.
- Our study can not exclude that other forms of gas accretion, such as those provided by direct infall of ionized intergalactic gas or the condensation of coronal gas, triggered by galactic fountain activities, are at work