Gas and Dust in Early-Type Galaxies

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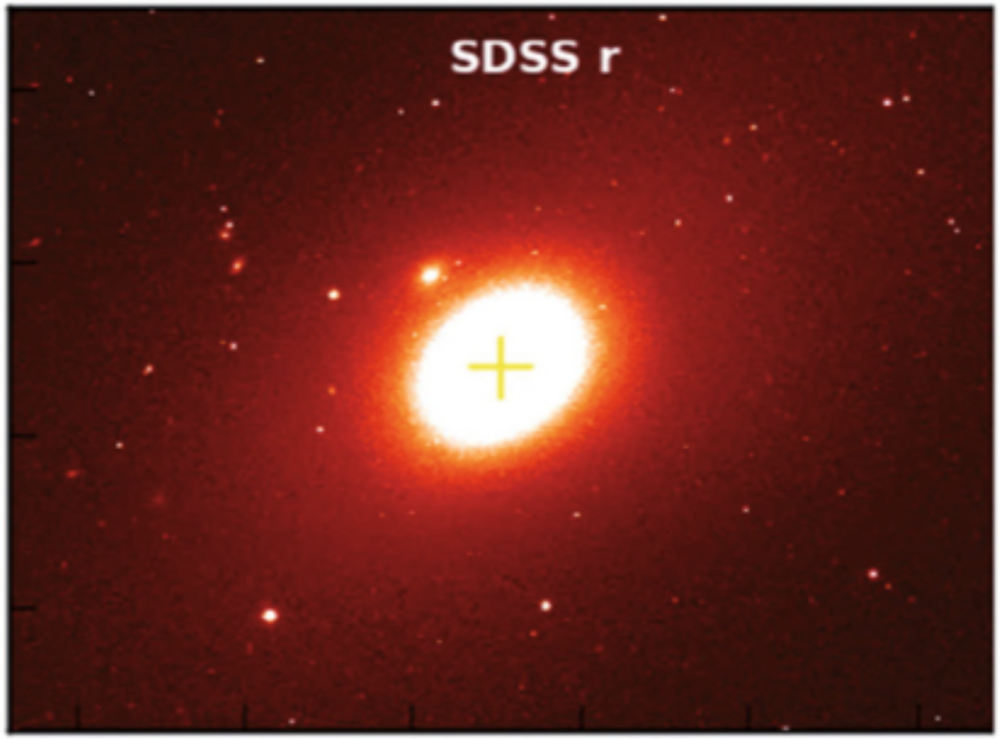
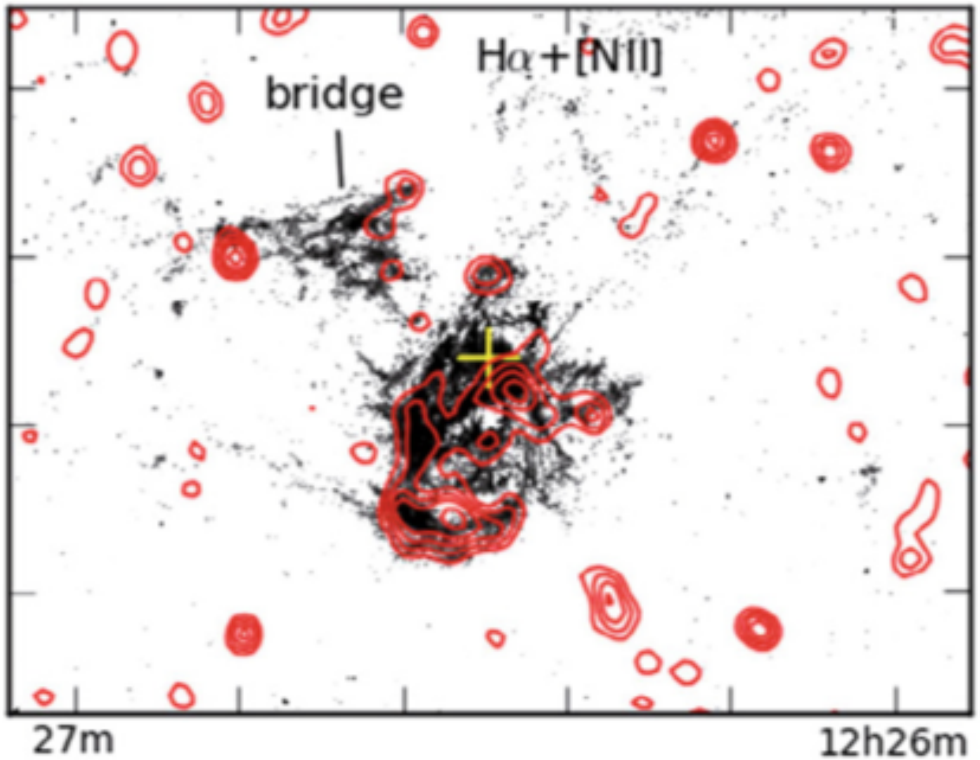


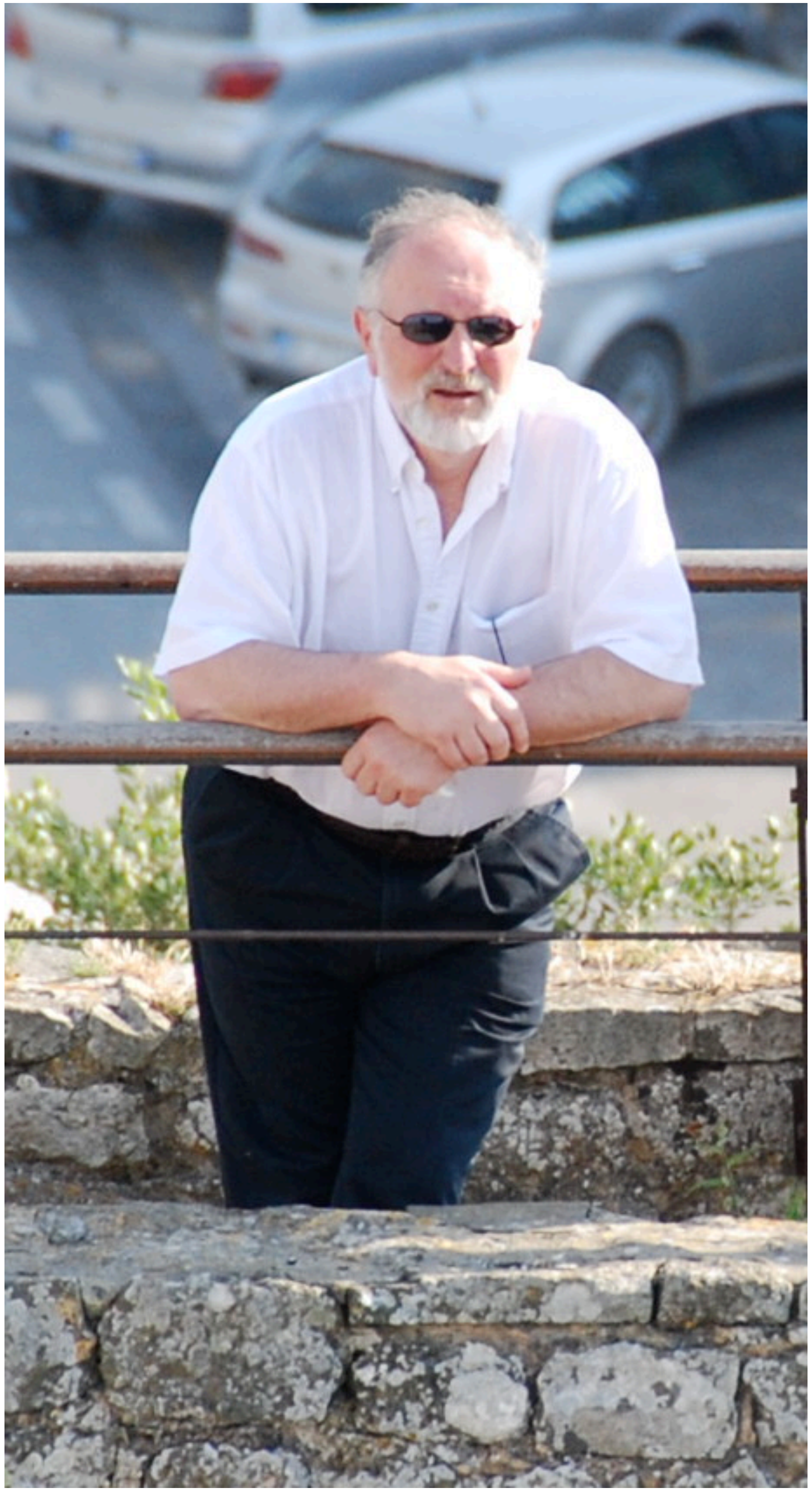


The ISM in ETG

- The massive ETG contain large quantities ($M\sim10^{10}M_\odot$) of hot gas ($T\sim10^7K$), which has been well studied in the X-rays.
- Several ETG also contain smaller amounts of warm ionized gas ($T\sim10^4K$, $M\sim10^5M_\odot$), which has been observed through emission line surveys.
- Cold neutral gas ($T\sim10^2$-10^3K, $M\sim10^8M_\odot$) has been detected in a number of ETG from HI 21 cm observations.
- However a deep unbiased survey of the HI and dust content in ETG is still lacking.
- Previous estimates of the HI detection rate in ETG vary between 15% (Knapp et al. 1985, Conselice et al. 2003) and more than 50% (Morganti et al. 2006, Bregman et al. 1992).
- The HI Parkes All-Sky Survey HIPASS has surveyed for HI a sample of 2500 southern ETG from the RC3 and found HI in the 6% of E and 13% of S0 (Sadler, 2001), but the survey is shallow ($M_{HI}\geq10^8$ $M_\odot$) and does not discuss the influence of the environment.
- The presence of HI and dust in ETG can be of internal origin, or the consequence of a recent accretion of an ISM rich satellite, or of a merging process between similar-size galaxies, or of ISM inflow from the intergalactic medium. The properties of the gas and dust, also in other phases, can discriminate between these possibilities, and therefore give clues on the evolution of these objects.
- Our goal is then to study the HI and dust content of ETG in a uniform and unbiased way, as a function of galaxy mass and environment, down to $M_{HI}\approx10^7$ $M_\odot$ and $M_{dust}\approx10^5$ $M_\odot$.

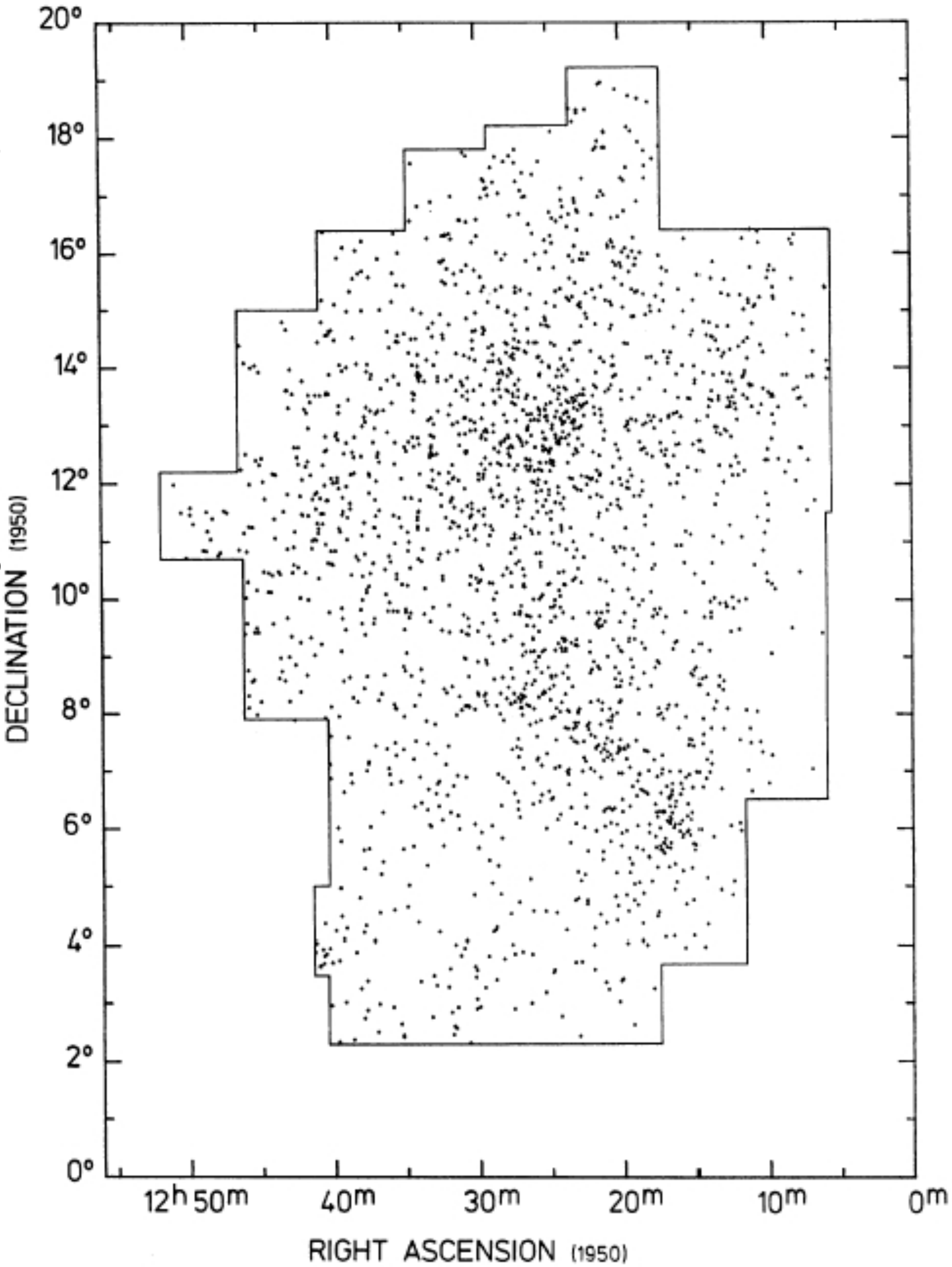
Arecibo Legacy Fast ALFA Survey

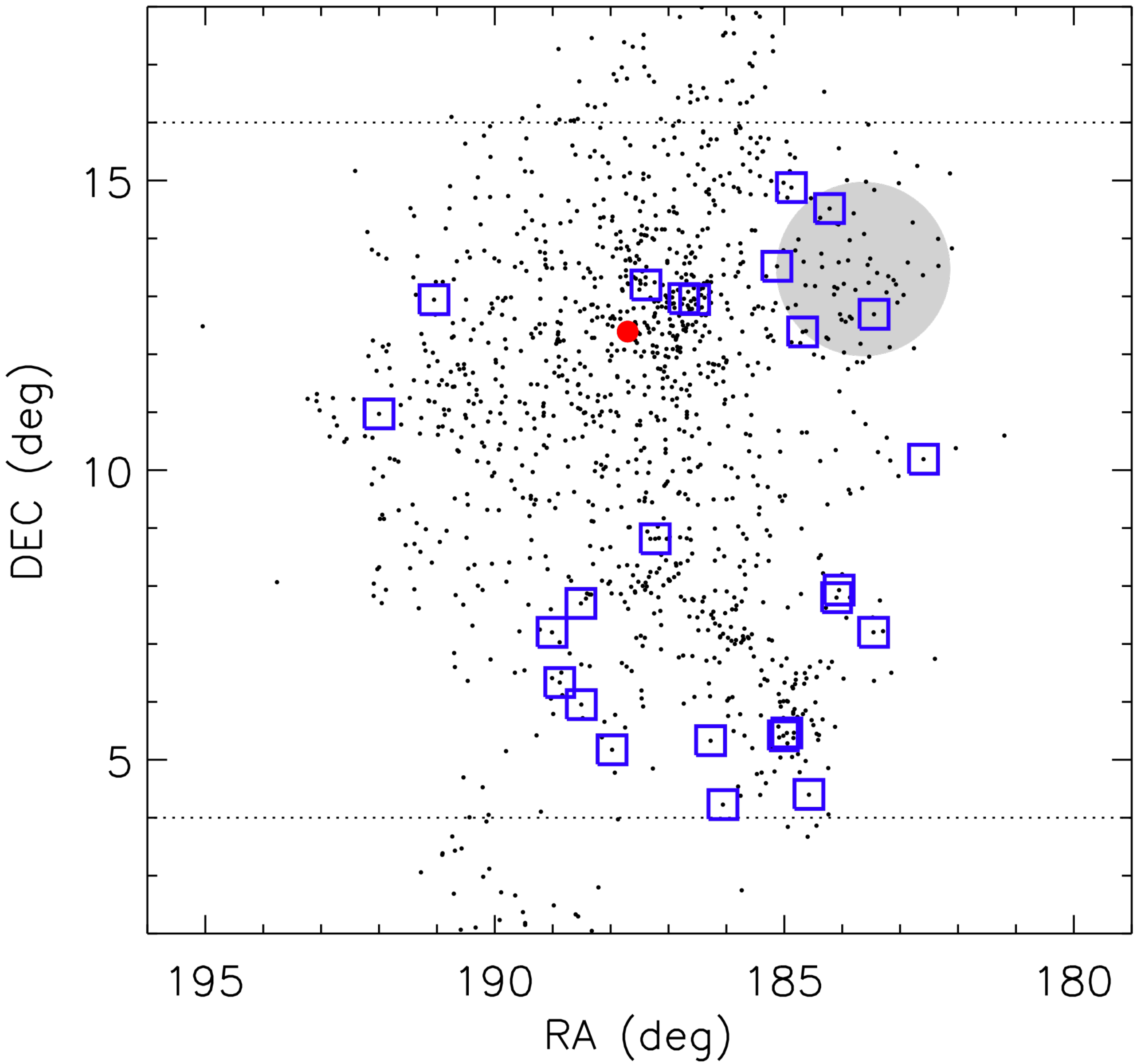
- ALFALFA is surveying 7074 sq. deg. (~17% of the sky) at 21 cm for HI sources brighter than ~ 0.5 Jy km s^{-1}, corresponding to ~ 3×10^7 $M_\odot$ at the distance of the Virgo cluster (Giovanelli et al. 2005, 2007).
- We are using ALFALFA to study the HI content of ETG in a uniform and unbiased way, as a function of galaxy mass and environment.
- Our strategy is to define a-priori both a high- and a low-density environment samples of ETG, selected at optical wavelengths to be as uniform and complete as possible.
- Then we analyze the HI content of each sample using ALFALFA in a two-step approach.
- First we crosscorrelate our samples with the Catalogue of HI sources produced blindly by the ALFALFA group.
- Then we search the ALFALFA data-cubes at the position and velocity of each ETG in the optical samples, hoping to find lower S/N HI detections.



The high-density-environment sample

- On the Virgo cluster we select a sample of 1164 ETG from the Virgo Cluster Catalogue (VCC, Binggeli et al. 1985) in the declination strip from 4 to 16 deg., which contains more than 90% of the VCC galaxies.
- We adopt the galaxy type from the GOLDMine compilation (Gavazzi et al. 2003), including E, E/S0, S0, dE, dE/dS0, dS0 and S0a-S0/Sa.
- Our sample contains 577 ETG brighter than B_T=18.0, the completeness limit of the VCC.
- By crosscorrelating the VCC sample with the ALFALFA Catalogue we find 26 ETG with HI, 21 of which are brighter than B_T=18.0.
- The HI completeness limit depends on the velocity width and is 3.5 and 7.6 × 10^7 $M_{\odot}$ for dwarfs and giants, respectively.
- If one considers the low ALFALFA sensitivity region within 1 deg. of M87 and a correction for background galaxies, the detection rate of HI for VCC ETG with $B_T \leq 18.0$ is 5.2% (21 out of 503).
- An accurate search in the data-cubes at the positions and velocities of the ETG in the VCC sample has not yielded any additional HI source, confirming the accuracy of the blind analysis which has produced the ALFALFA Catalog.





The detected ETG tend to lie at the periphery of the Virgo cluster.

Most importantly, more than 1000 ETG (503 with $B_T \leq 18.0$) in the VCC have been observed but not detected, so they have $M_{HI} \lesssim 3.5\text{-}7.6 \times 10^7 M_\odot$.

ETG in the Virgo cluster detected in HI by ALFALFA

S. di Serego Alighieri et al.: Dust in Early Type Galaxies

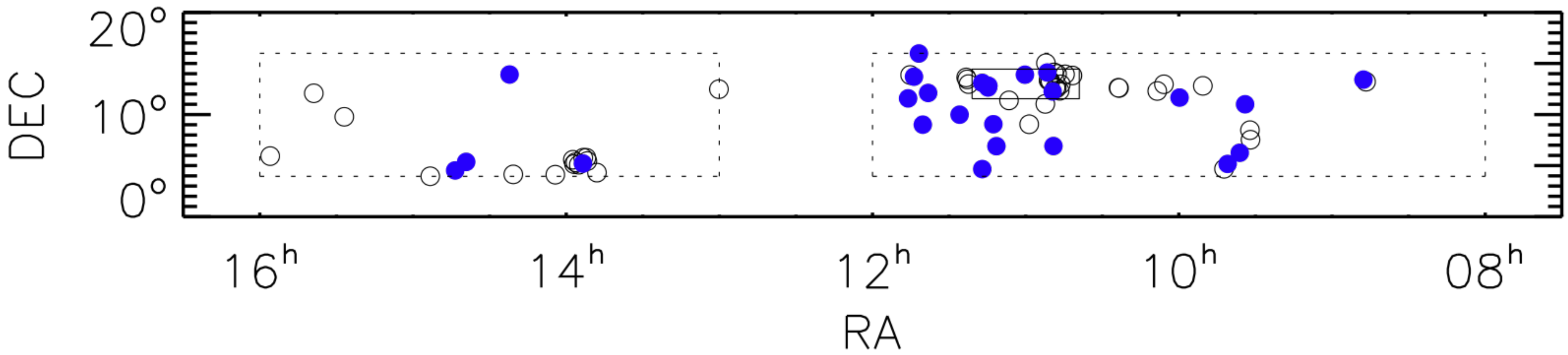
Table 1. Virgo ETG detected in ALFALFA40 ($4^o < Dec < 16^o$)

ID	Other Name	B_T	Type GM[a]	Type VCC	Opt. Pos. RA - Dec	$cz_{opt.}$ km/s	cz_{HI} km/s	D Mpc	M_{HI} $10^7 M_\odot$	M_B	$\log(M_{HI}/L_B)$ $M_\odot/L_\odot$
VCC 21	IC 3025	14.75	-3	dS0(4)	121023.0+101118	506	485	17	5.9	-16.49	-1.02
VCC 93	IC 3052	16.3	-1	dE2	121348.1+124126	910	841	32	13.3	-16.36	-0.61
VCC 94	NGC 4191	13.57	2	S0/a	121350.3+071203		2659	32	180.2	-19.04	-0.55
VCC 180		15.3	1	S0 pec	121613.0+075545	2232	2239	32	6.5	-17.32	-1.31
VCC 190		18.0	-1	dE4	121623.5+074756		2352	32	13.8	-14.63	0.09
VCC 209	IC 3096	15.15	-3	dS0?	121652.4+143055	1208	1263	17	3.9	-16.14	-1.06
VCC 282		17.0	-1	dE5?	121817.9+042407	2014	1985	32	11.8	-15.60	-0.36
VCC 304		16.3	-1	dE1 pec?	121843.8+122308	155	132	17	3.5	-15.01	-0.66
VCC 355	NGC 4262	12.41	1	SB0	121930.6+145238	1359	1367	17	58.9	-18.89	-0.98
VCC 375	NGC 4270	13.11	1	$S0_1(6)$	121949.4+052749		2377	32	49.9	-19.50	-1.30
VCC 390		16.9	-1	dE3	122004.0+052452	2479	2474	32	21.2	-15.71	-0.15
VCC 421		17.0	-1	dE2	122030.7+133109		2098	17	3.7	-14.33	-0.36
VCC 710		14.9	-3	dS0:	122414.5+041333	1175	1182	17	7.8	-16.41	-0.86
VCC 764		14.83	1	$S0_2(6)$	122505.6+051945	2044	2020	17	6.8	-16.33	-0.89
VCC 881	NGC 4406	10.06	0	$S0_1(3)$/E3	122611.8+125646	-244	-302	17	8.9	-21.22	-2.73
VCC 956		18.75	-1	dE1,N:	122656.4+125741		2151	17	10.3	-12.52	0.81
VCC 1142		19.0	-1	dE	122855.2+084855		1306	23	9.2	-12.89	0.62
VCC 1202		20.0	-1	dE?	122933.6+131146		1215	17	16.5	-11.26	1.52
VCC 1391		18.5	-1	dE	123153.9+051020		2308	17	2.6	-12.75	0.12
VCC 1533		18.0	-1	dE2,N	123401.5+055710		648	17	2.9	-13.25	-0.02
VCC 1535	NGC 4526	10.61	1	$S0_3(6)$	123403.1+074157	448	560	17	1.4	-20.64	-3.31
VCC 1617		15.0	-3	d:S0(4) pec?	123530.9+062002		1600	17	3.8	-16.25	-1.11
VCC 1649		15.7	-1	dE3,N:	123602.8+071200	1038	972	17	1.4	-15.54	-1.28
VCC 1993		15.3	0	E0	124412.0+125631	875	925	17	5.0	-15.96	-0.88
VCC 2062		19.0	-1	dE:	124759.9+105815	1146	1141	17	38.5	-12.32	1.46
CGCG100011	NGC 4710	11.6	2	SA(r)0+? sp	124938.7+150954	1129	1100	17	5.7	-19.68	-2.31

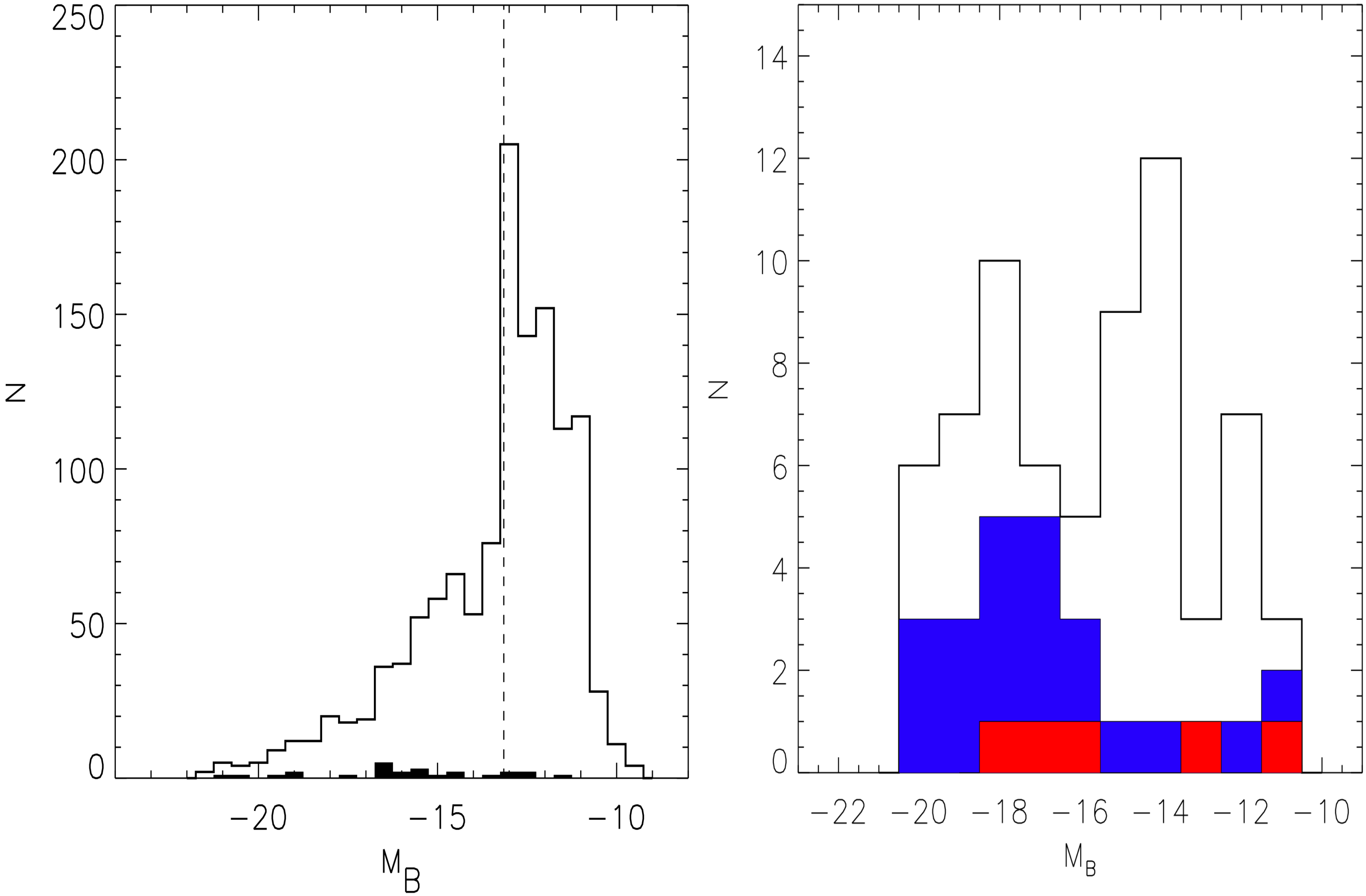
[a] GOLDMine type: -3=dS0 -2=dE/dS0 -1=dE(d:E) 0=E-E/S0 1=S0 2=S0a-S0/Sa

The low density environment sample

- We have selected from the SDSS catalog all 325 galaxies with v<3000 km/s in the sky area already covered by ALFALFA (4°<Dec.<16°, 8h<RA<16h) avoiding the Virgo region.
- Since the SDSS parameters *FracDev* and *eclass* used to select ETG (e.g. Bernardi et al. 2003) would not produce results similar to the standard morphological classification (dwarfs with exponential profiles and ETG with emission lines are missed), we classified the 325 galaxies by visual inspection of the color SDSS images and got a sample of 56 ETG.
- The SDSS spectroscopic sample is complete down to $r<17.77$ and to half-light surface brightness $\mu_{50}<24.5$. However it also misses some (~5%) bright galaxies ($r>15$) because these have substructures which fool the automated deblender (Strauss et al. 2002). We have therefore searched the RC3 catalog and found 10 bright ETG according to our criteria. We alsofound a faint dwarf (LeG14) and the nearby resolved dwarf LeoI from NED. The total field sample has 68 ETG.
- Searching this sample in the ALFALFA datacubes we found 20 safe HI detections (code 1 and 2) and 5 at lower S/N(code 4). The overall HI detection rate is then 37% (25 out of 68).



HI detection rates in field vs. cluster ETG

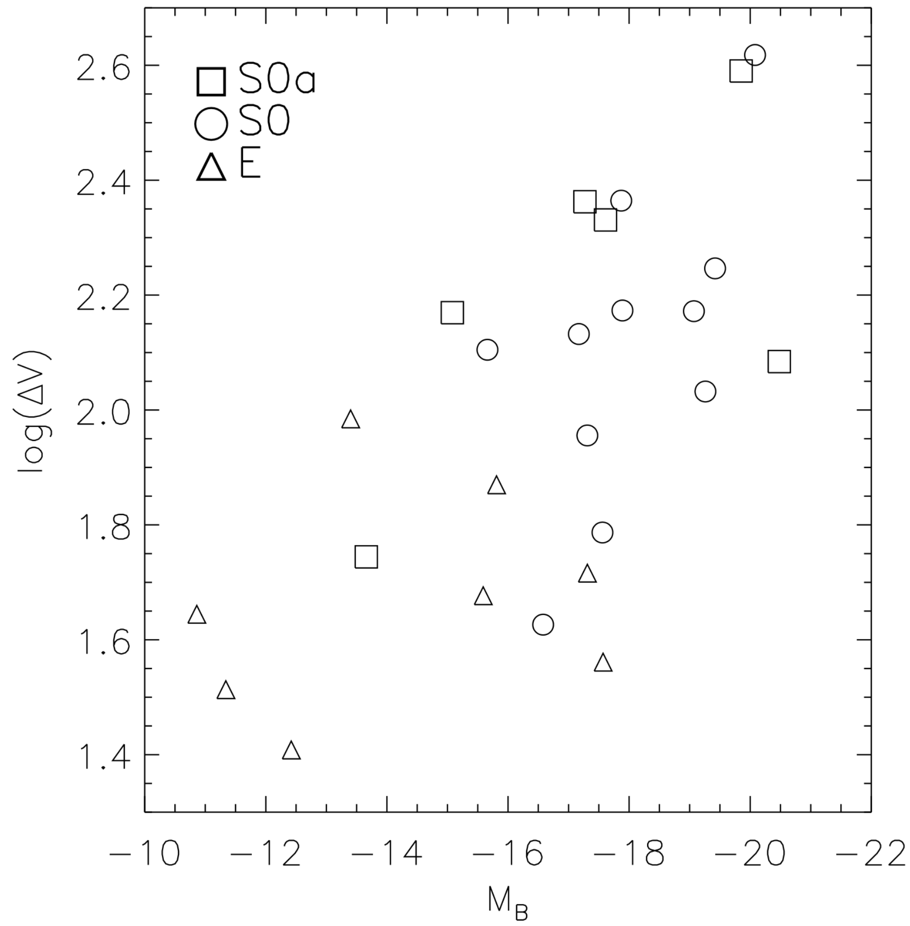


HI content vs. mass and environment

- In the Virgo cluster, considering the accuracy allowed by poissonian statistics for the small number of HI detected galaxies, the HI detection rate likely depends on galaxy luminosity: it is 5.9±2.0% and 1.8±0.4% for ETG with $M_B<-17.0$ and $M_B>-17.0$, respectively.
- The HI detection rate depends more clearly on luminosity for the field sample: it is 54±13% and 25±8% for ETG with $M_B<-17.0$ and $M_B>-17.0$, respectively.

- The HI detection rate can be compared between the Virgo and the field samples only for $M_B<-17.0$: it is about 10 time higher in the field than in the cluster. This so called *HI deficiency* is well known for later type galaxies (e.g. Haynes et al. 1984).

- The dependence on galaxy mass can be studied also looking at the HI velocity width ΔV_{50}:
- All E galaxies have $\Delta V<100$ km/s. Most S0 and S0a galaxies have $\Delta V>100$ km/s.



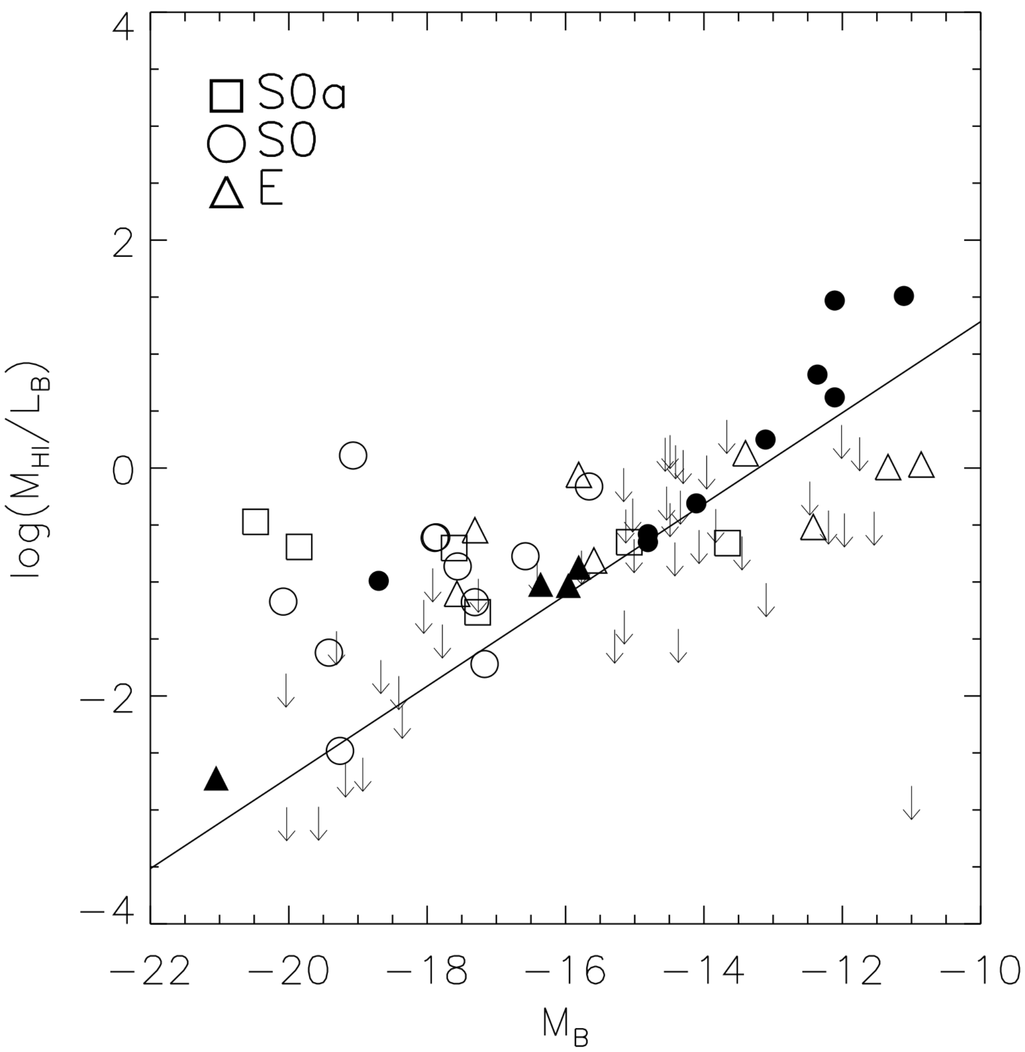
How much neutral gas per stellar light?

• In Virgo we note the lack of bright ETG with a large M_{HI}/L_B, similar to that of some dwarf ETG.

• In the field the M_{HI}/L_B ratio covers a smaller range and depends less on luminosity, as would be expected if the gas has an external origin.

• We also note again the paucity of bright ETG with HI in Virgo, compared to the field: neutral hydrogen in the field is more likely to survive for a relatively long period even in more massive galaxies.

• Bright elliptical galaxies are not detected in HI. The exception is M86 (NGC 4406) in the Virgo cluster (see later).



Filled symbols: Virgo
Empty symbols: field

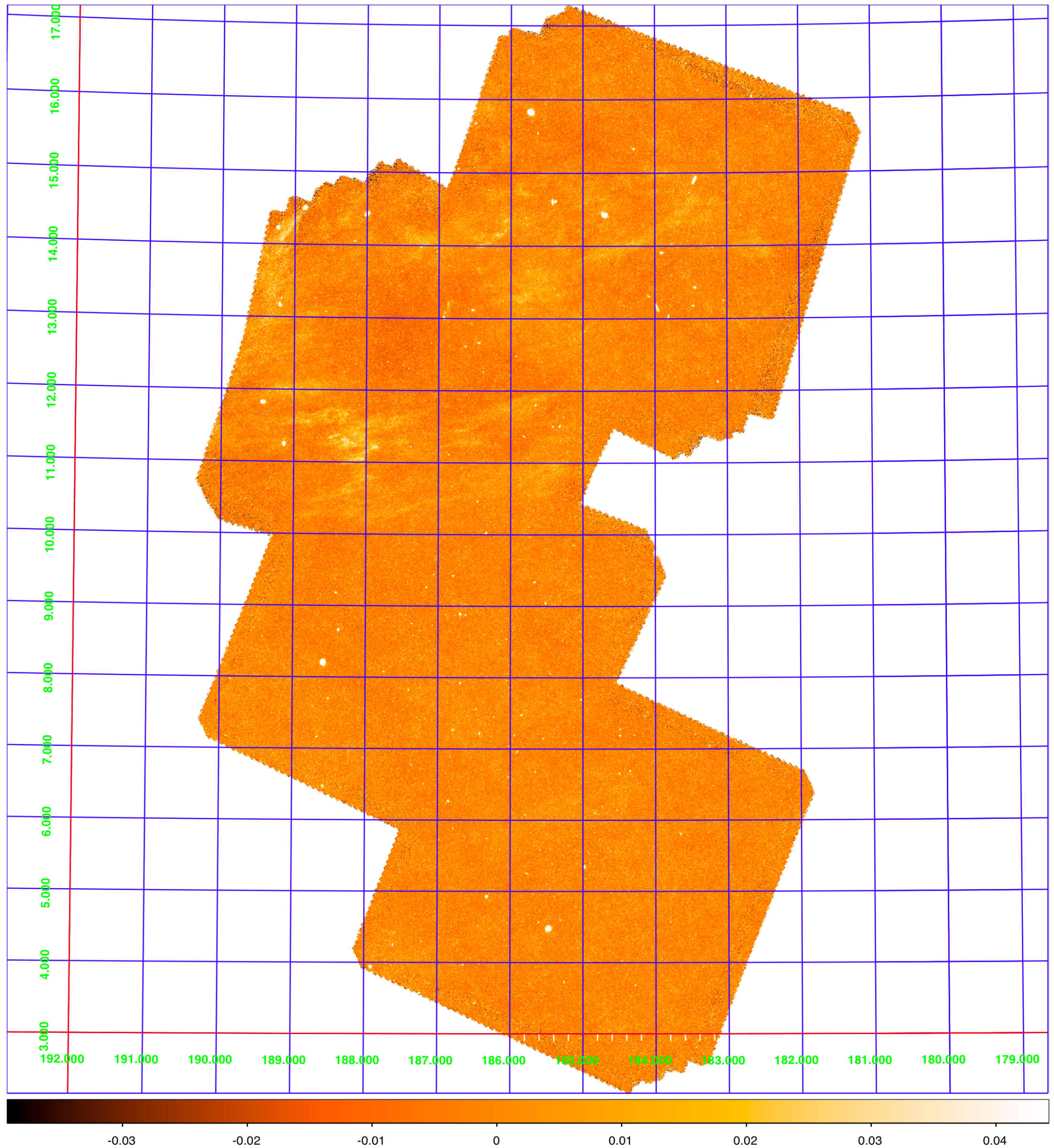
Why are cluster ETG HI deficient?

- The mechanisms used to explain the HI deficiency for spiral galaxies in clusters relate to the more frequent encounters (tidal stripping) and to the hot ICM (ram pressure stripping, evaporation induced by heat conduction), with the latter thought to be more efficient (e.g. Haynes et al. 1984).
- In fact the evaporation time due to heat conduction for a cold gas cloud of ~500 pc in radius and a density of ~1 cm^{-3} embedded in a Virgo-like hot ICM is estimated to be a few 10^8 years. This mechanism would be efficient also for Virgo ETG. Then the only HI that can be found in Virgo ETG should have been recently accreted in an encounter with a gas-rich dwarf.
- For the cluster region within 6° of M87 we estimate from the VCC that the density of gas-rich dwarfs is 10 Mpc^3 with a velocity dispersion of ~700 km/s. An estimated cross section diameter of 100 kpc for the capture by a giant ETG translates into an encounter rate of ~0.05 Gyr^{-1}. This means that for each bright ETG the average time between collisions with a gas rich dwarf is ~20 Gyr. If the cold gas survival time in the bright ETG is a few 10^8 Gyr, then the HI detection rate should be a few %, as we have observed.
- However the evaporation mechanism should also be efficient in the field ETG which have an individual hot halo. In fact the evaporation time of a cold gas cloud in a typical ETG hot halo is estimated to be ~1 Gyr. This could be the reason why we have not detected HI in any bright field elliptical galaxy.
- Unfortunately X-ray data exist only for a handfull of the ETG in our field sample and only two (NGC 3379 without HI and NGC 3593 with HI) have been detected.

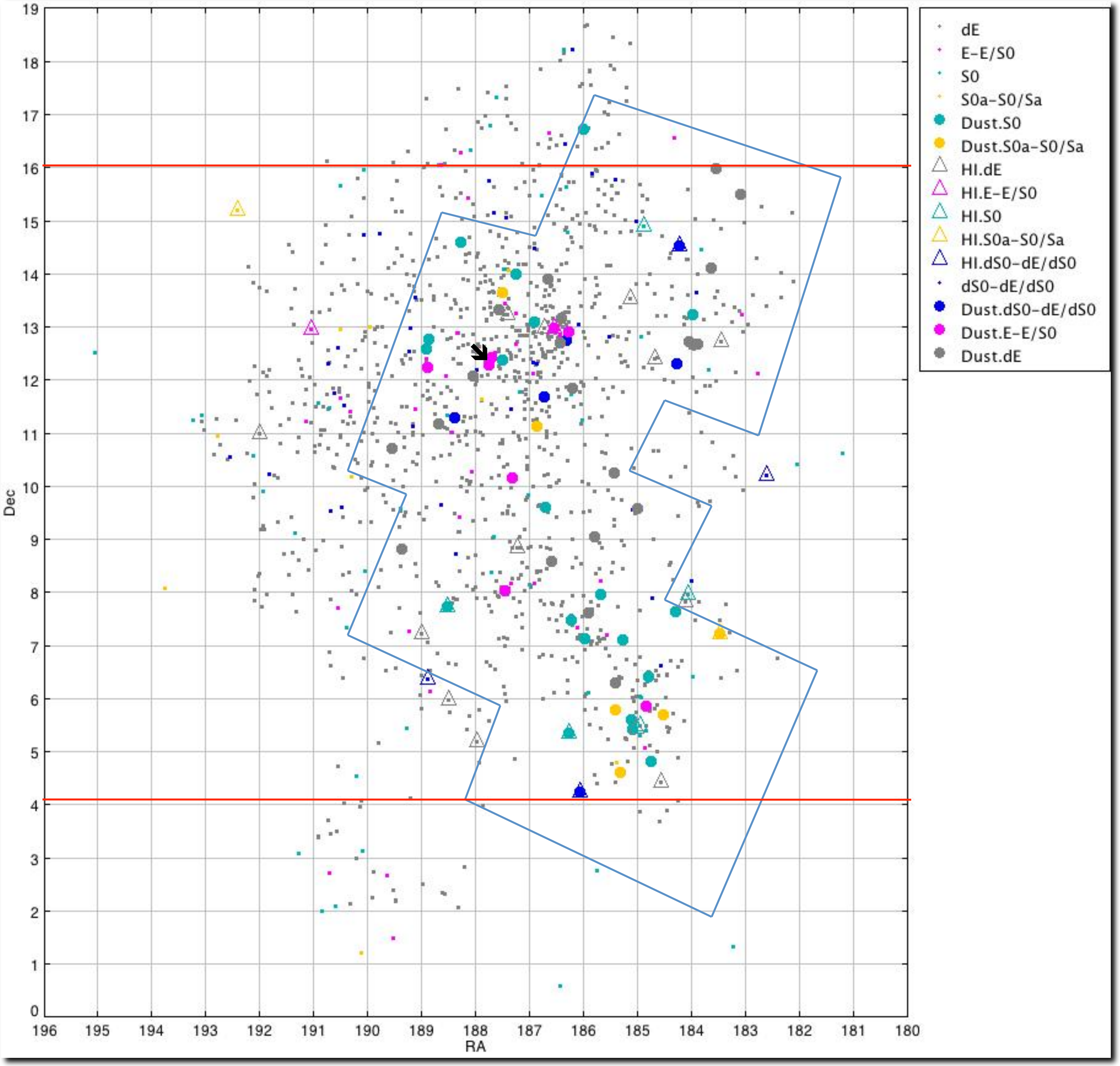
Dust detection procedures in HeViCS and preliminary results

- Virgo ETG selected from GoldMine (VCC): Goldmine types from -3 to 2, v_{Hel}<3000 km/s, inside the 4 HeViCS fields ➔ 928 ETG (448 ETG are within the VCC completeness limit, m_{pg}<18.0).
- At the optical positions we have searched for detections in the HeViCS 8-scan 250 μm mosaic image with Hipe and with a 30 arcsec aperture. We have examined individually all detections with "quality">2, also superimposing them with an optical image, rejecting the spurious and uncertain ones. For some larger objects we have enlarged the aperture.
- The result is 60 ETG safely detected at 250 μm, 48 of which have m_{pg}<18.0 (10.7%).
- We have measured the flux of the 60 detected ETG also in the other SPIRE (and PACS) bands, using the same apertures.
- Only 8 of the 60 dust-detected ETG have also been detected in HI (all these are in the VCC complete sample).

HeViCS 250 μm image

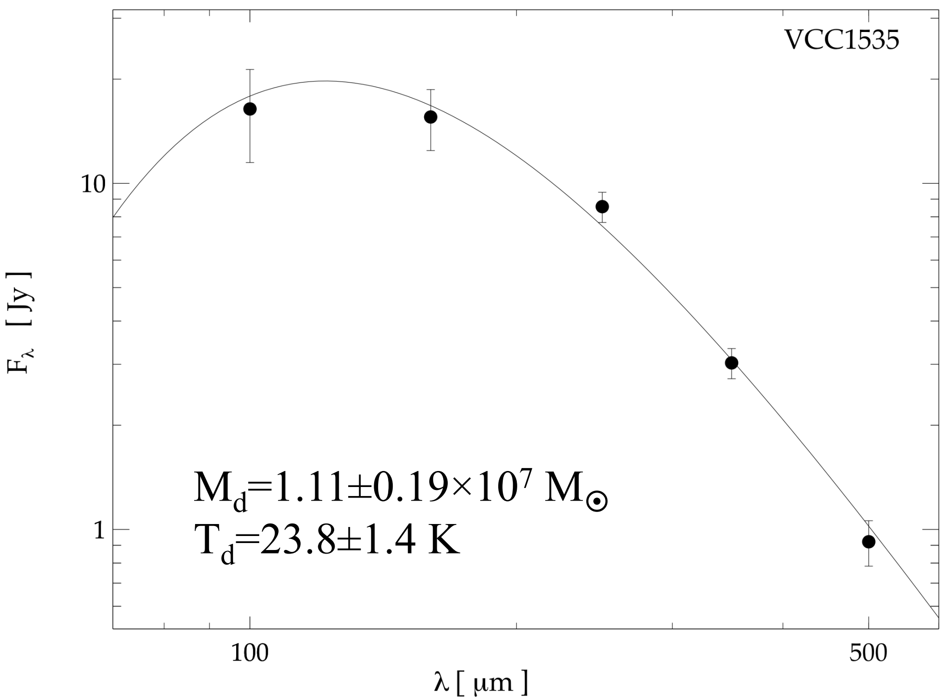


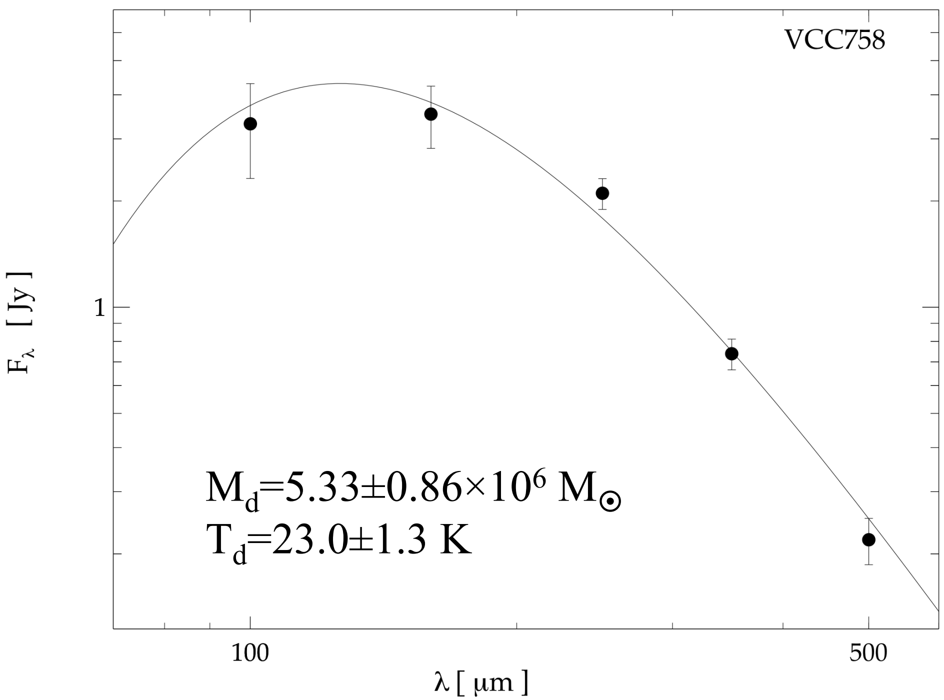
HI- and dust-detected ETG in the Virgo cluster. While HI detections seem to avoid the centre of the cluster, the same is not true for dust detections.



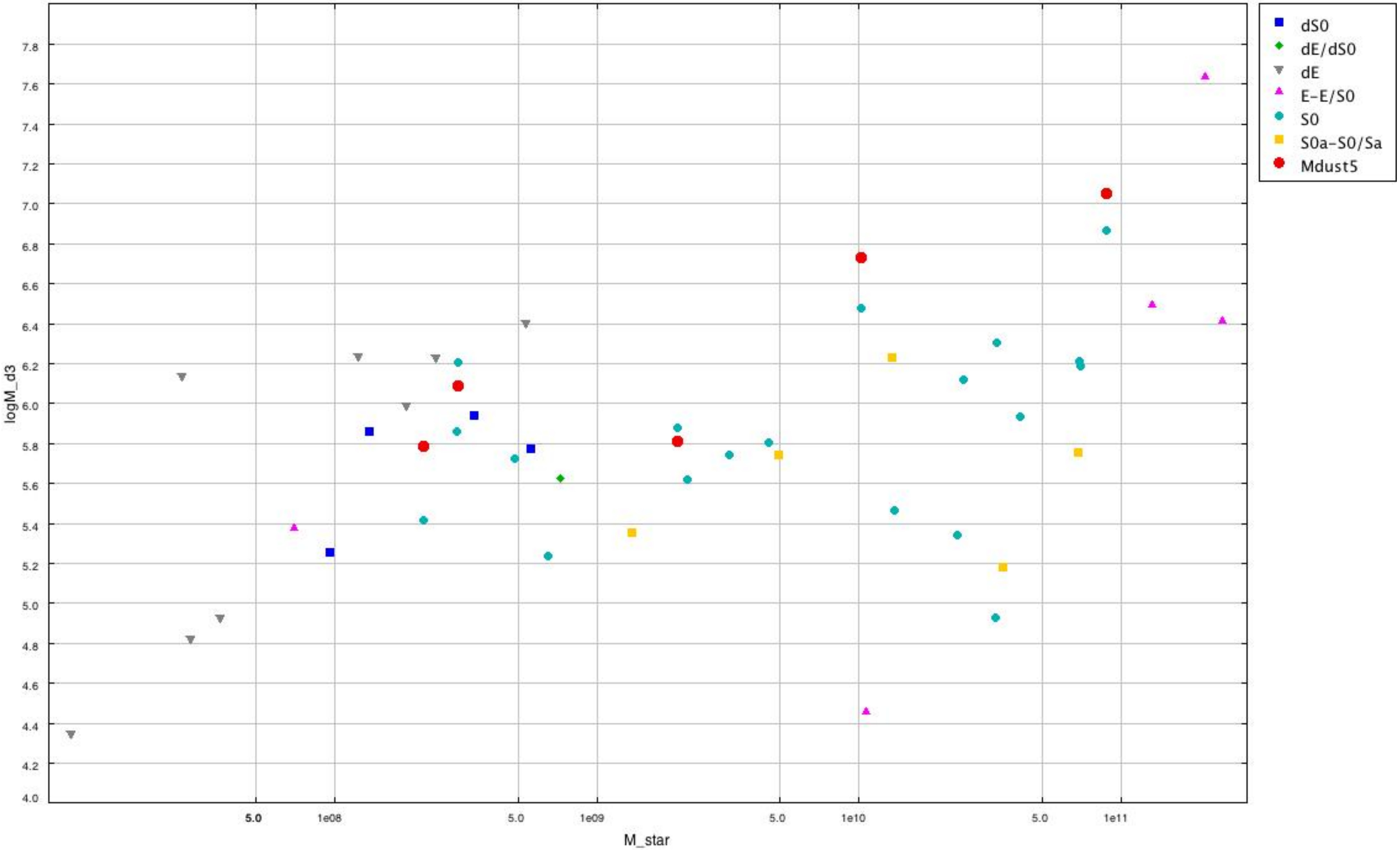
Mass estimates

- Dust mass has been estimated for all detected ETG by Luca using his method with the 3 SPIRE bands.
- For a few ETG in V3 we have also estimated dust masses with modified BB fits on all 5 bands.
- Stellar masses have been estimated by fits to optical/IR luminosities by Stefano Zibetti.

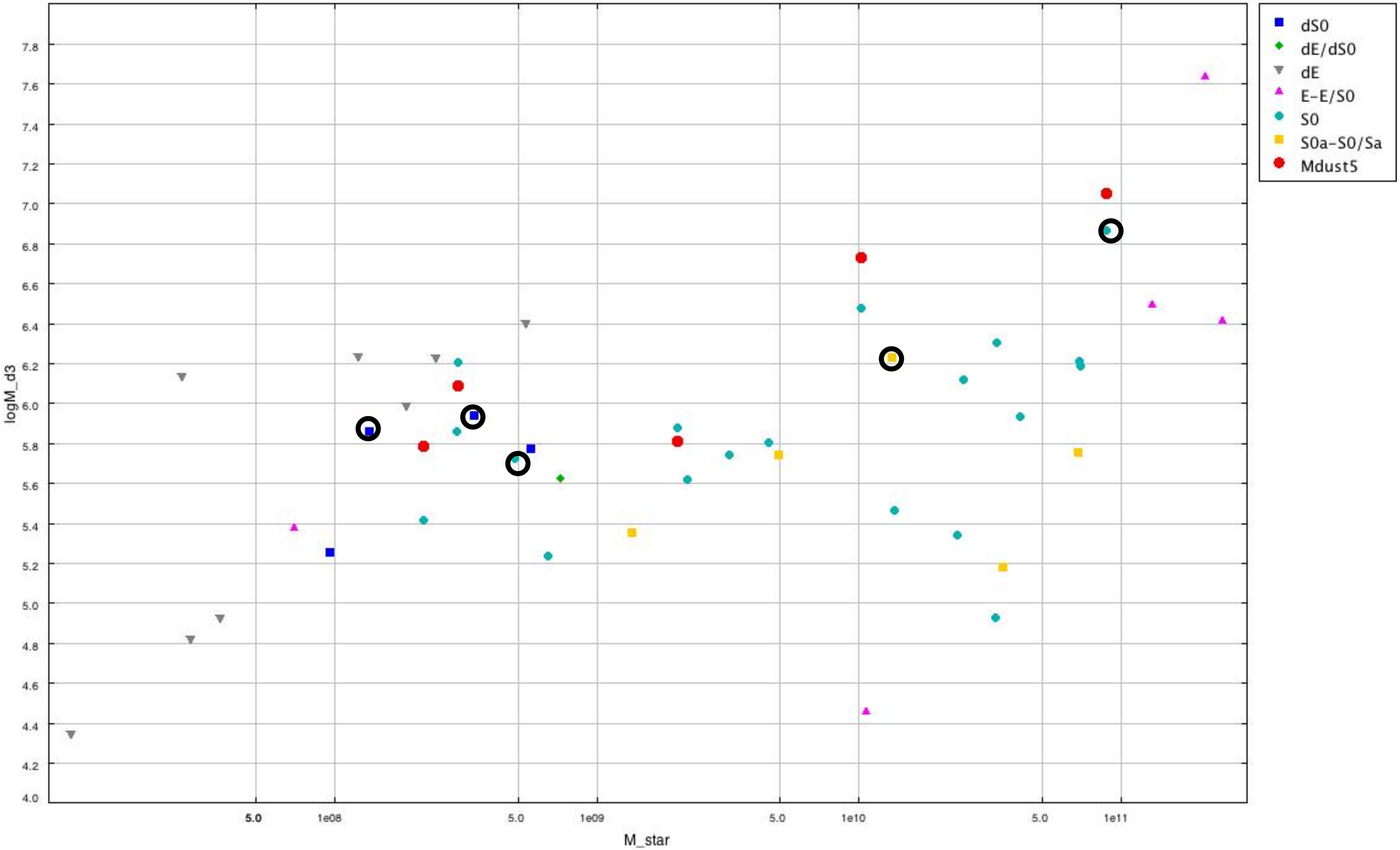




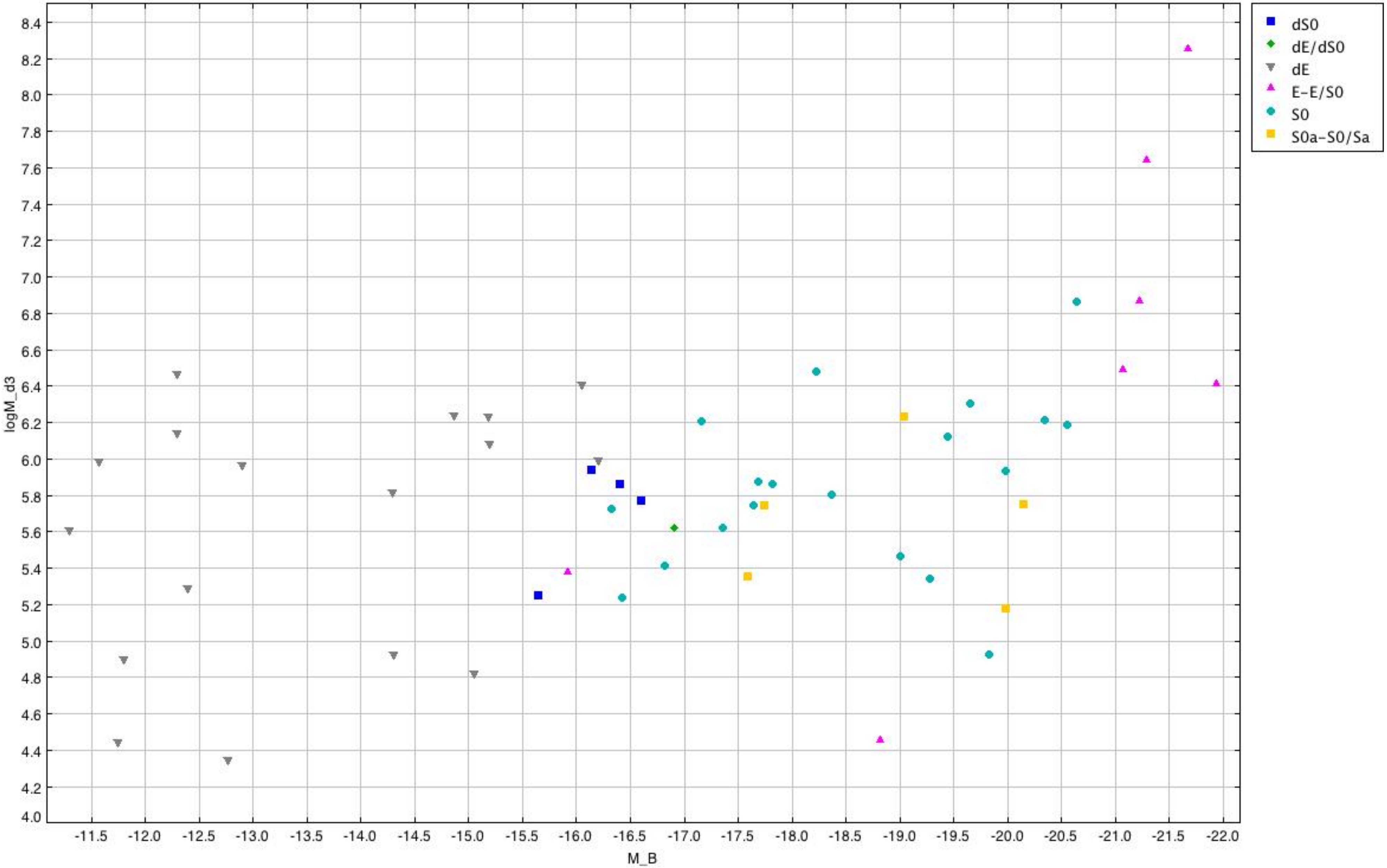
Dust mass vs. stellar mass



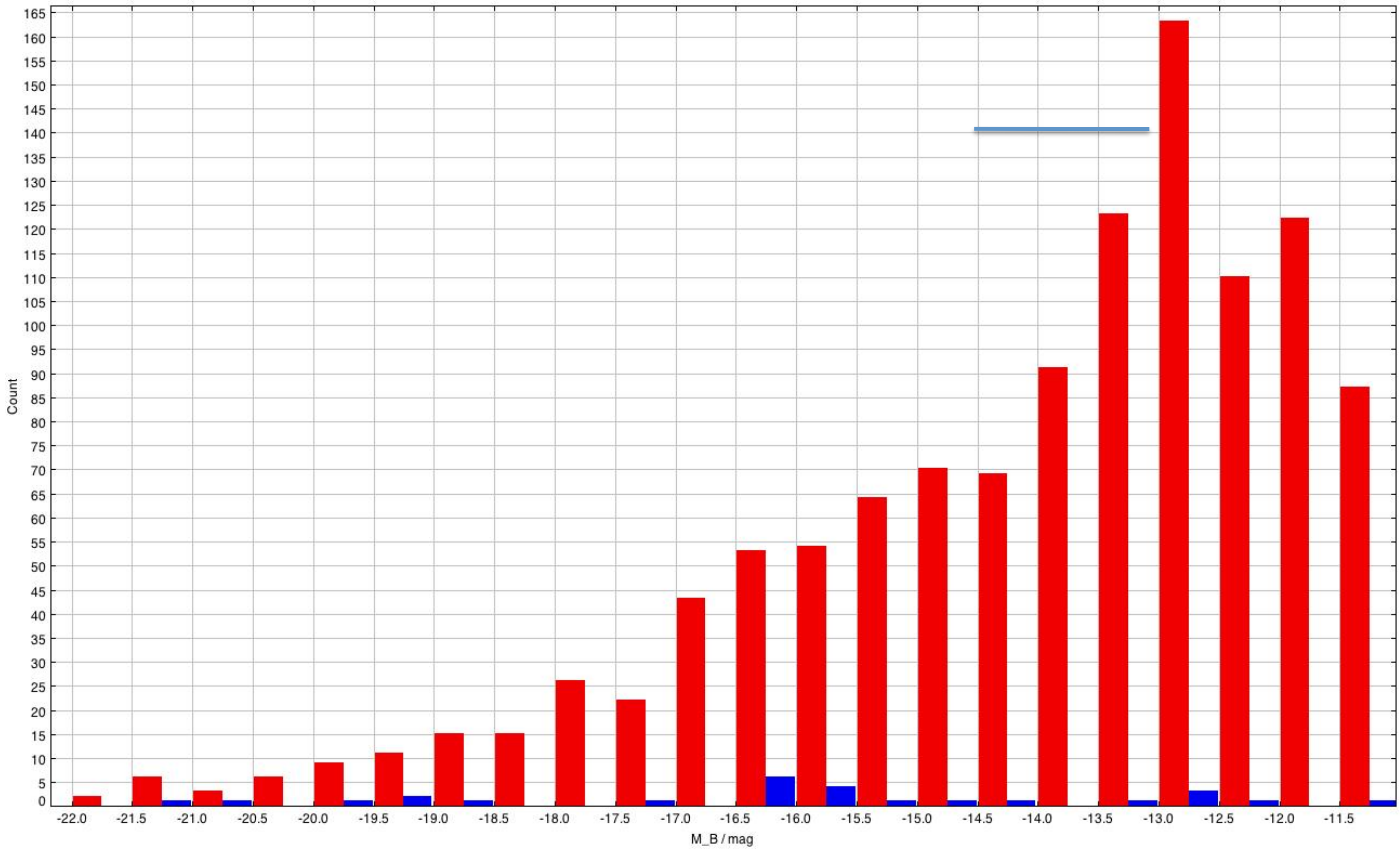
ETG also detected in HI



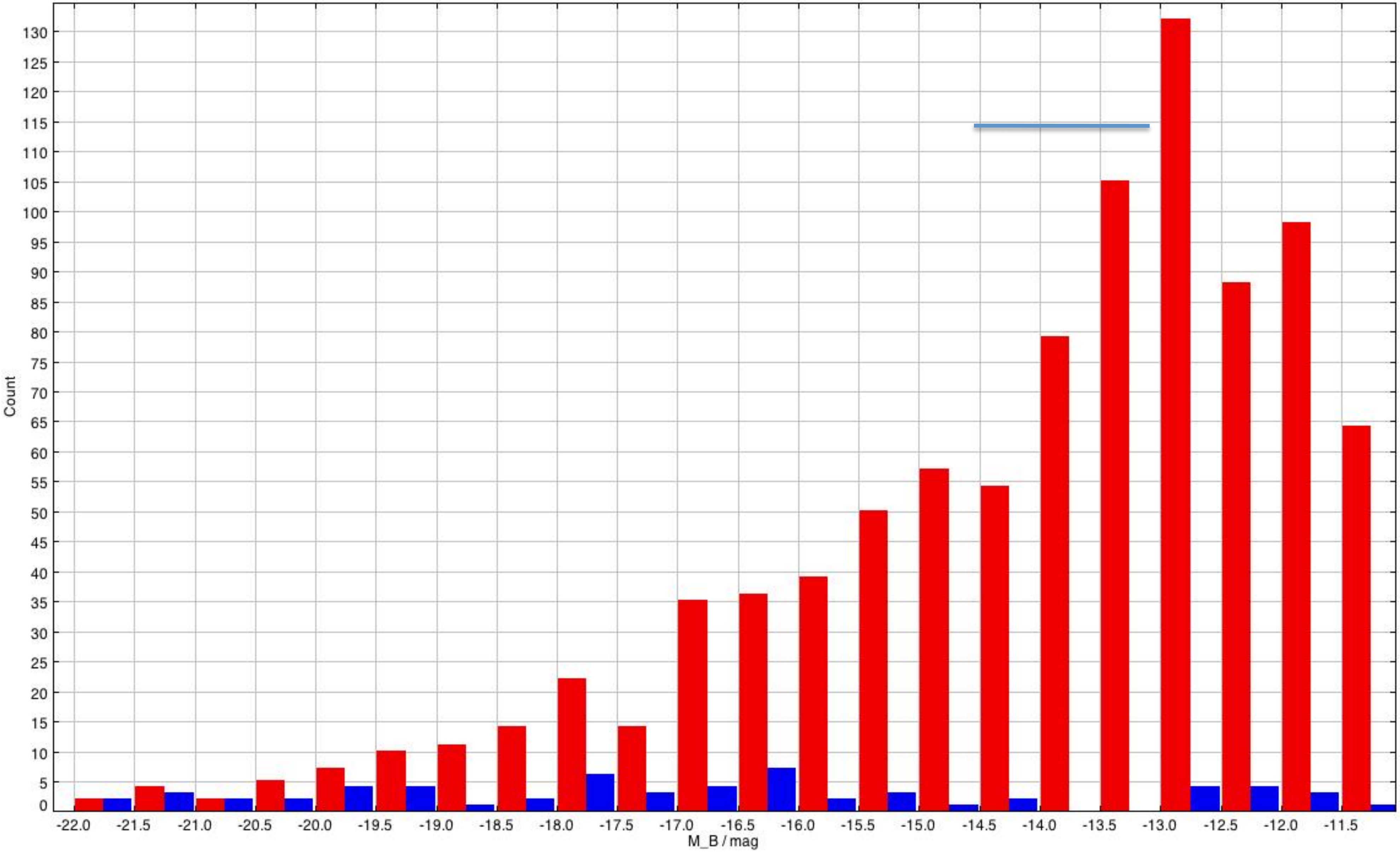
Dust mass vs. B-band luminosity



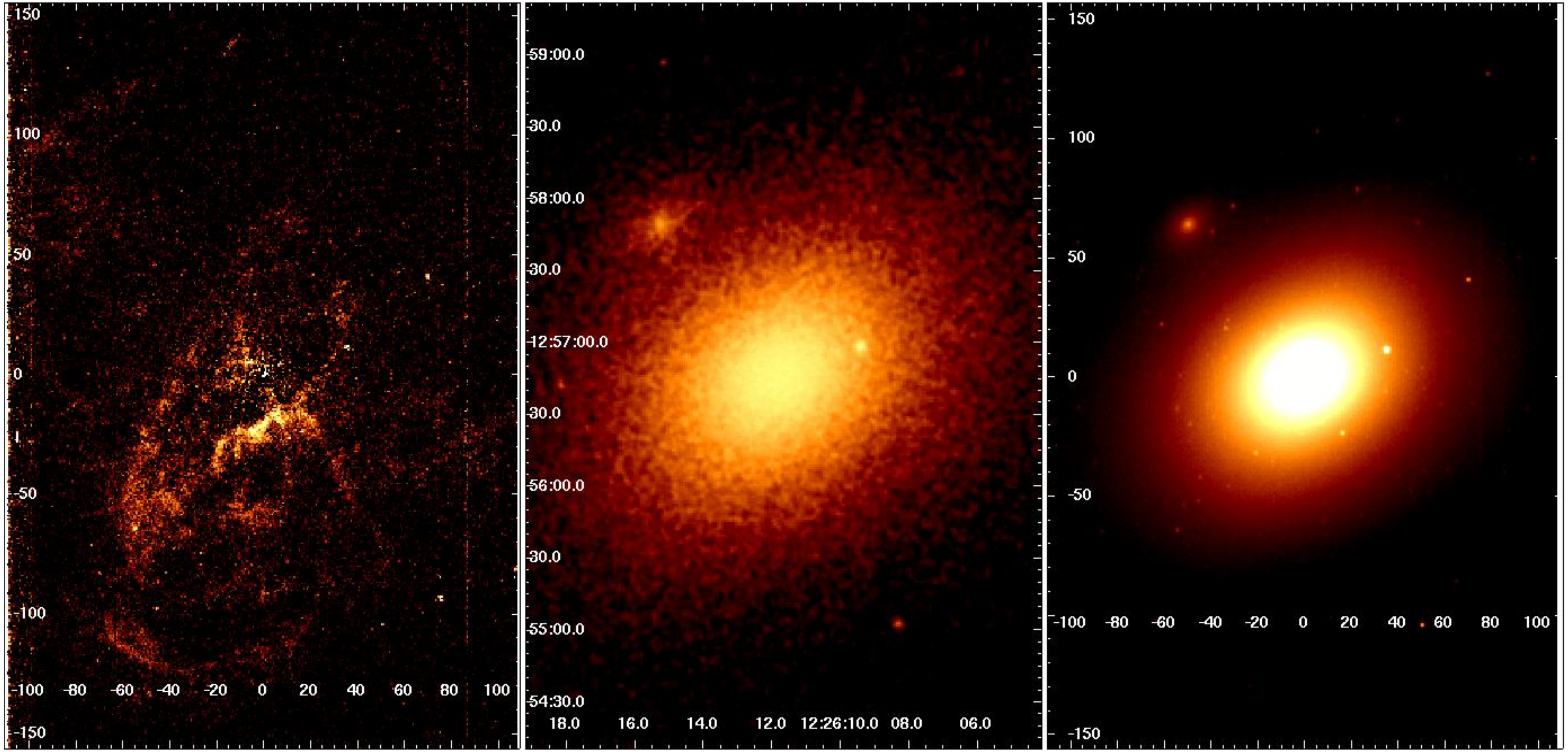
M_B distribution for HI detected ETG in Virgo



M_B distribution for dust detected ETG in Virgo

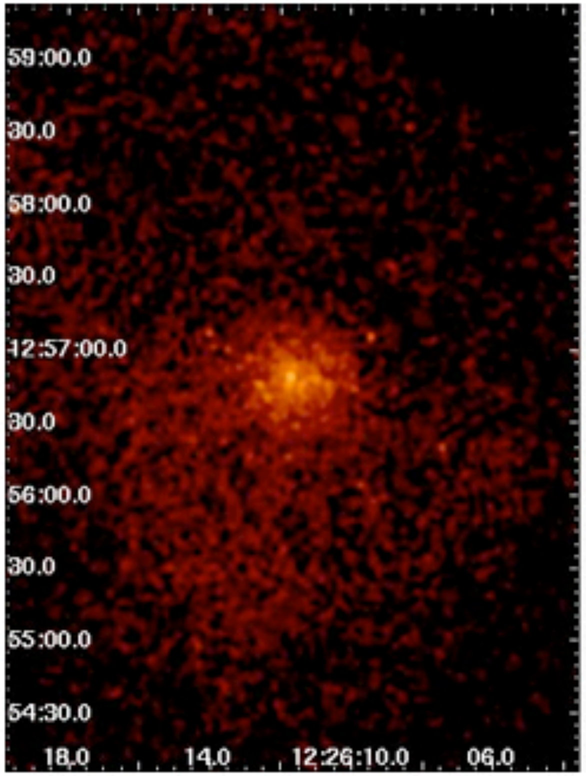


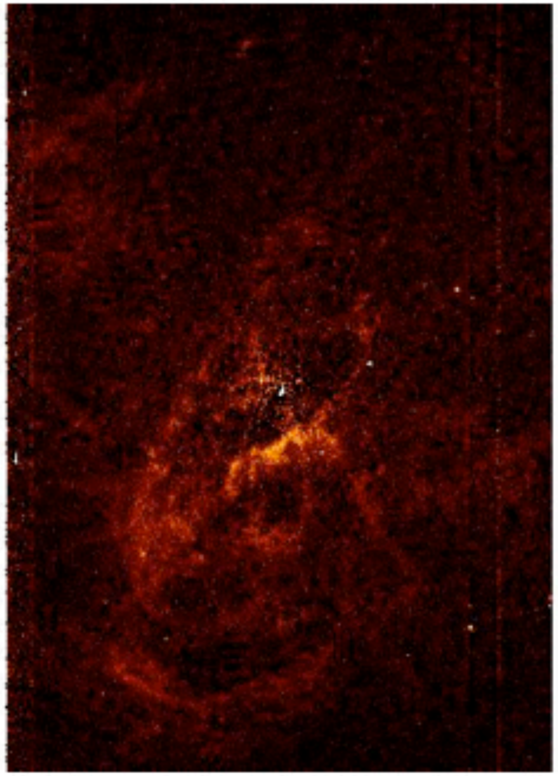
Interaction between gas phases in M86



- M86=NGC4406: S0/E3 galaxy with M_B=-21.05, the brightest with HI in Virgo.
- It has warm ionized gas seen in Hα (log $L_{H\alpha}$=40.58 erg/s, $M_{I.G.}$~$10^6 M_\odot$, Trinchieri & di Serego Alighieri, 1991). The rings and filaments suggest that the ionized gas might result from a recent interaction with a gas rich object (e.g. NGC4406B, a dE at 1.4 arcmin to the North-East).

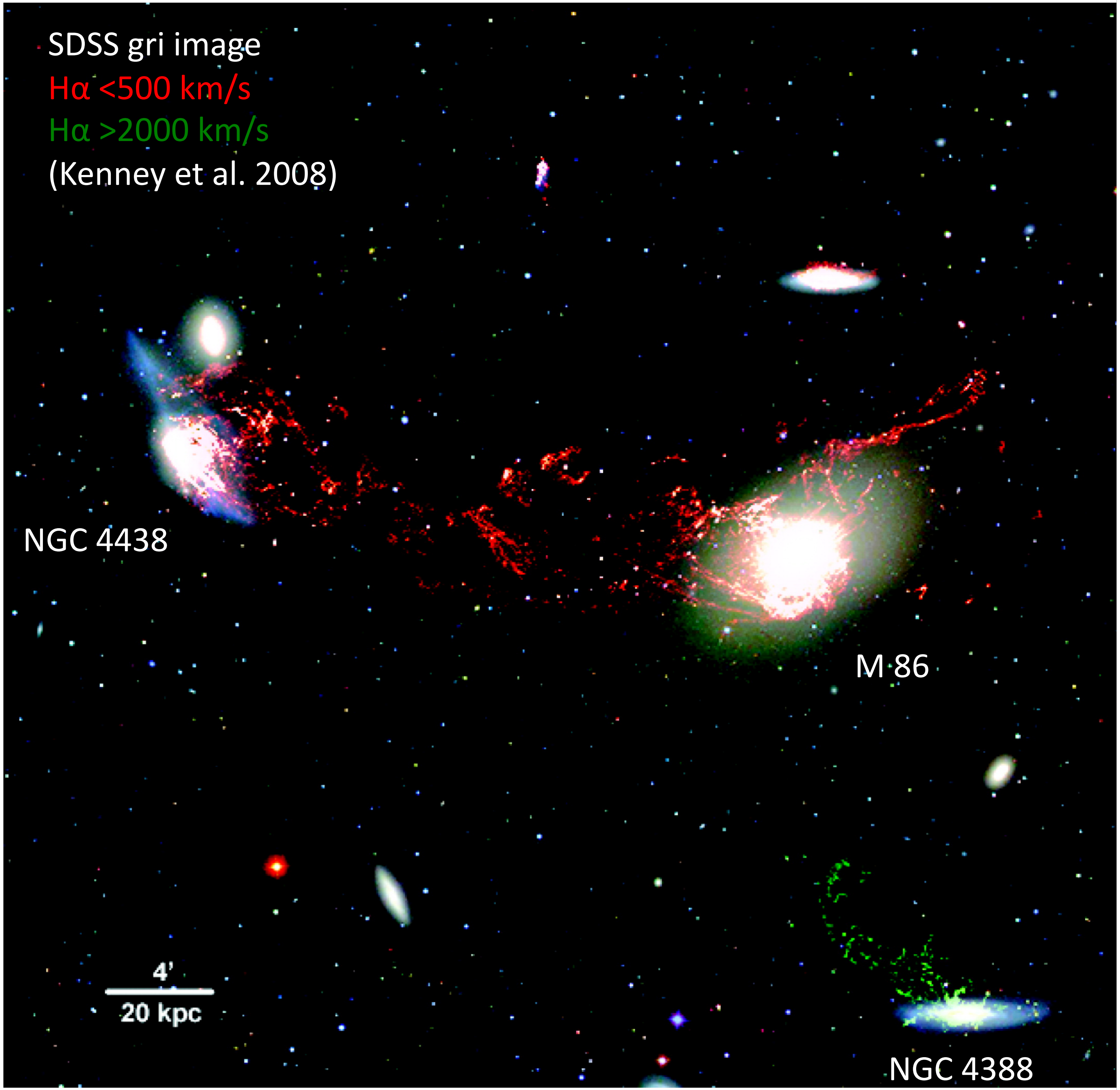
Interaction between gas phases in M86



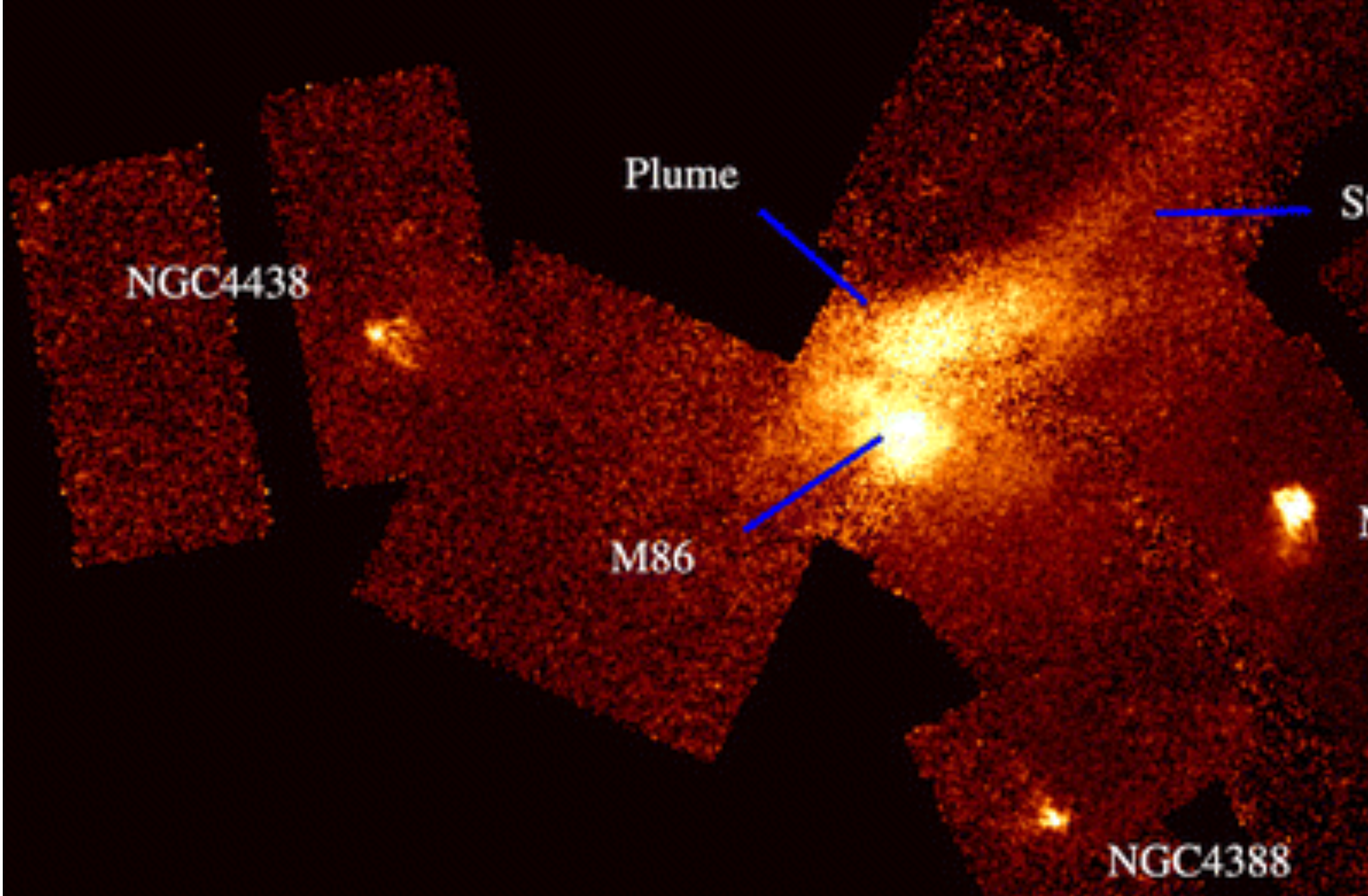


- It has hot gas, with a long plume of X-ray emission to the North-West, which is thought to be due to hot gas swept back by the ram pressure caused by the motion of M86 through the Virgo intracluster medium.
- It has neutral cold gas ($M_{HI} = 8\times10^7\ M_\odot$): see the VLA 21cm map (Li & van Gorkom 2001)

Go Back | High-Resolution Image: **1.eps** (357KB)



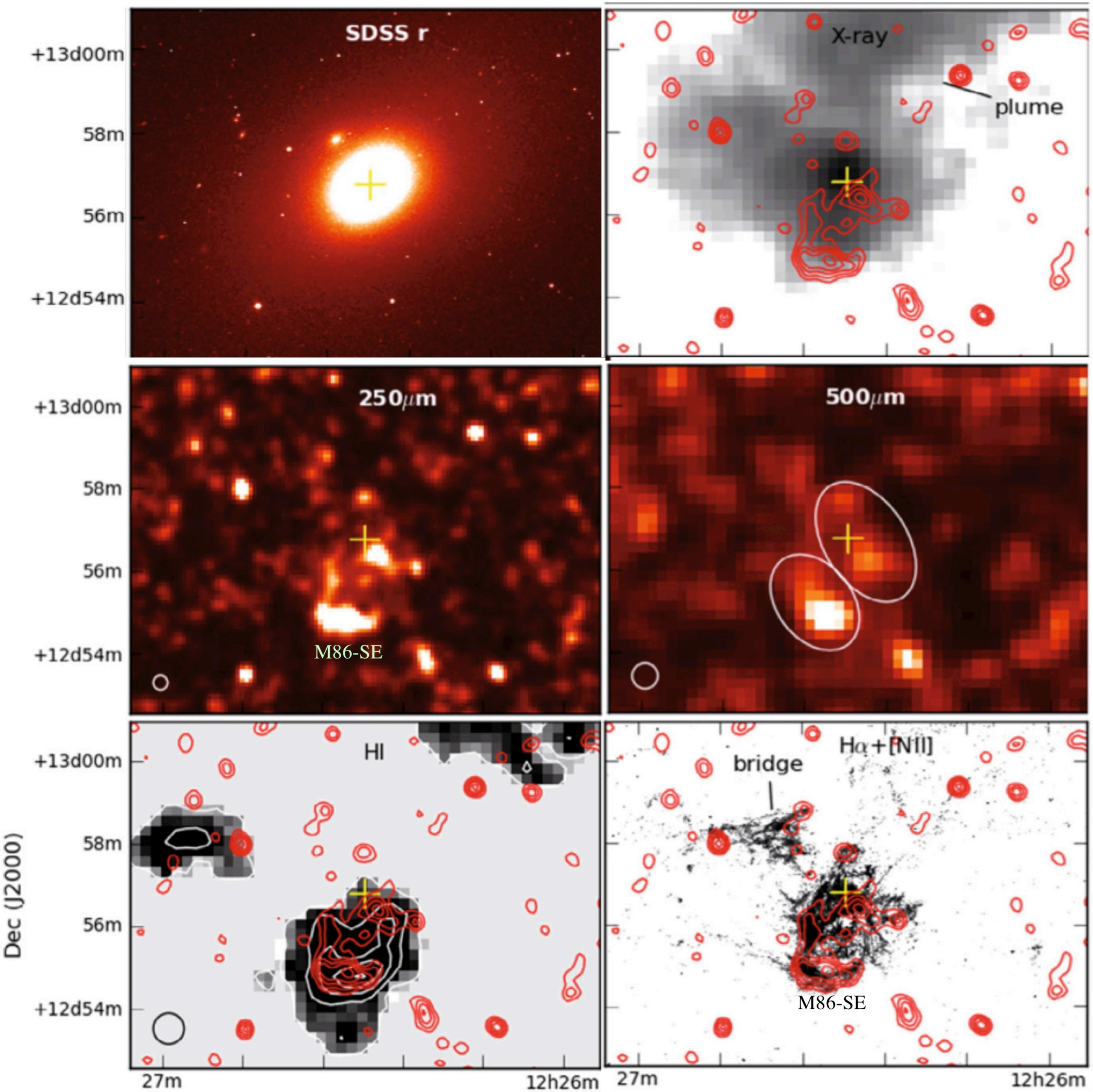
0.5-2 keV Chandra image (Randall et al. 2008)



Stars in r band
Hot gas in X-rays

Cold dust emission at
250 and 500 μm

HI emission at 21 cm
Ionized gas in Hα



Conclusions

- Cluster ETG contain very little or no neutral gas. The few exceptions are peculiar dwarf elliptical galaxies, which are at the edge of the ETG morphological classification, and very few larger galaxies, for which the gas might have a recent external origin.
- On the other hand, about half of the bright (M_B<-17) ETG in low-density environments (only S0 and S0a) contain neutral hydrogen with masses between 10^7 and 10^{10} $M_\odot$, while the HI detection rate for fainter field ETG is considerably smaller.
- Cold dust is preliminarly detected in 10.7% of the Virgo ETG (VCC complete sample), predominantly in the bright ones.
- The overlap of the HI-detected ETG with the dust-detected ETG is surprisingly small.

Open issues

- PACS fluxes have to be obtained, and then better dust masses estimated.
- Contamination by background sources in the HeViCS images, particularly the one at 250 μm.
- Comparison with molecular gas.
- Estimate gas-to-dust ratios.