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The HI content of Early-Type Galaxies in an evolutionary context

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di Serego Alighieri et al. 2007, A&A 474, 851

Grossi et al. 2009, A&A in press, arXiv:0903.0602

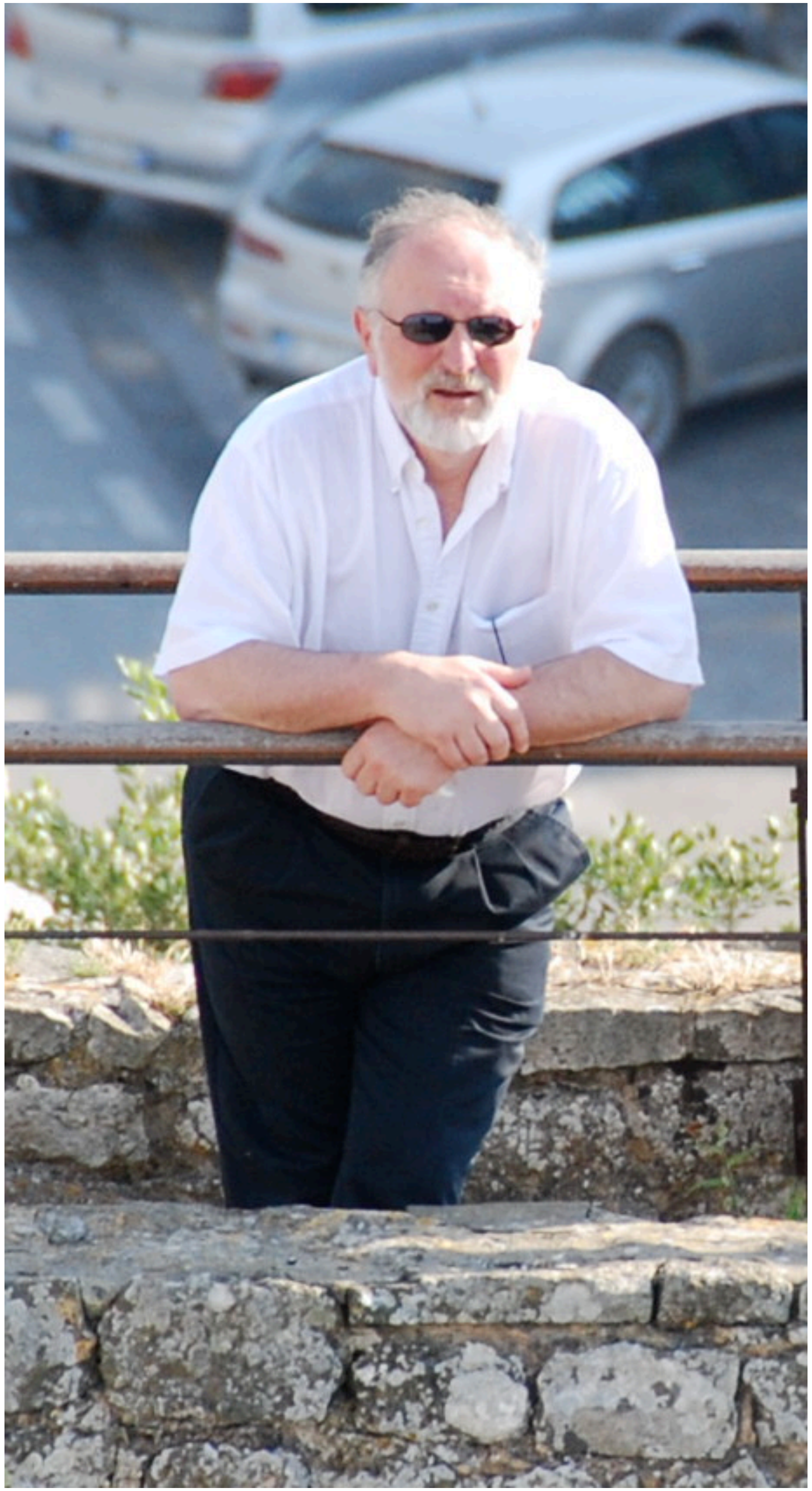
See also *http://www.arcetri.astro.it/~sperello*

The ISM in ETG

- The massive ETG contain large quantities ($M \sim 10^{10} M_{\odot}$) of hot gas ($T \sim 10^7 K$), which has been well studied in the X-rays.
- Several ETG also contain smaller amounts of warm ionized gas ($T \sim 10^4 K$, $M \sim 10^5 M_{\odot}$), which has been observed through emission line surveys.
- Cold neutral gas ($T \sim 10^2$-$10^3 K$, $M \sim 10^8 M_{\odot}$) has been detected in a number of ETG from HI 21 cm observations.
- However a deep unbiased survey of the HI 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 ($M_{HI} \geq 10^8 M_{\odot}$), suffers from source confusion and does not discuss the influence of the environment.
- The presence of HI in ETG can be the consequence of a recent accretion of a gas rich satellite, or of a merging process between similar-size galaxies, or of gas inflow from the intergalactic medium. The absence of HI can be due to gravitational interactions or ram pressure stripping, which can lead to the suppresion of star formation in ETG. The properties of the gas, also in other phases, can discriminate between these possibilities, and therefore give clues on their evolution.
- Our goal is therefore to study the HI content of ETG in a uniform and unbiased way, as a function of galaxy mass and environment, down to $M_{HI} \approx 10^7 M_{\odot}$

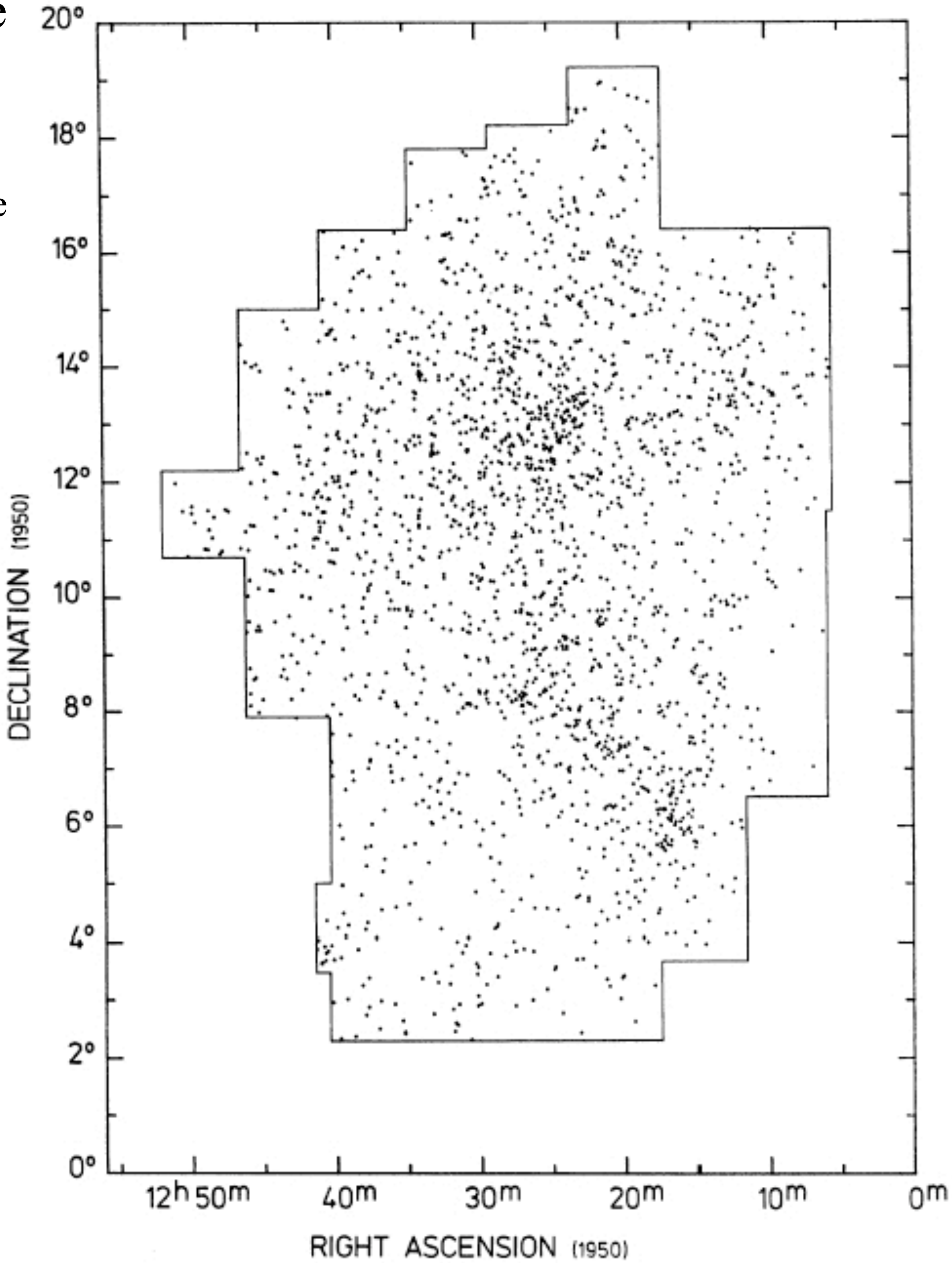
Arecibo Legacy Fast ALFA Survey

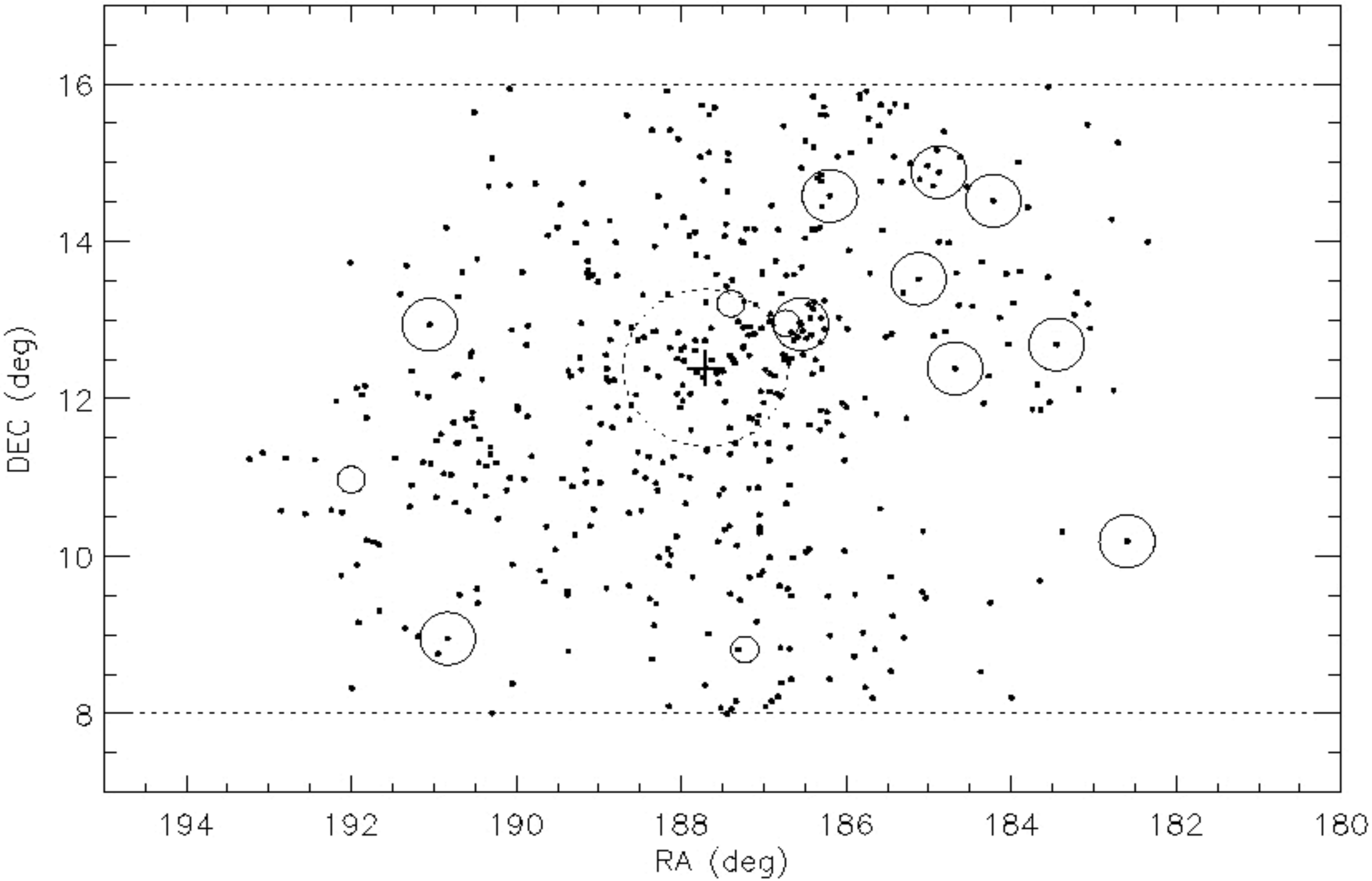
- ALFALFA is surveying 7074 sq. deg. (~17% of the sky) at 21 cm for HI sources brighter than ~ 0.5 Jy km s^{-1}, corresponding to ~ 3×10^7 $M_\odot$ at the distance of the Virgo cluster (Giovanelli et al. 2005, 2007).
- We are using ALFALFA to study the HI content of ETG in a uniform and unbiased way, 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, both by crosscorrelating our sample lists with the Catalogue of detected HI sources, produced by the ALFALFA group, and by directly searching the ALFALFA data-cubes at the position and velocity of each ETG in the optical samples.



The high-density-environment sample

- On the Virgo cluster we select a sample of 939 ETG from the Virgo Cluster Catalogue (VCC, Binggeli et al. 1985) in the declination strip from 8 to 16 deg., which contains more than 70% 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.
- Our sample contains 457 ETG brighter than B_T=18.0, the completeness limit of the VCC.
- By crosscorrelating the VCC sample with the ALFALFA Catalogue we find 13 ETG with HI, 9 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 2.3% (9 out of 387).
- 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 800 ETG (378 with $B_T \leq 18.0$) in the VCC have been observed but not detected, so they have $M_{HI} \lesssim 3.5\text{-}7.6\times10^7 M_\odot$.

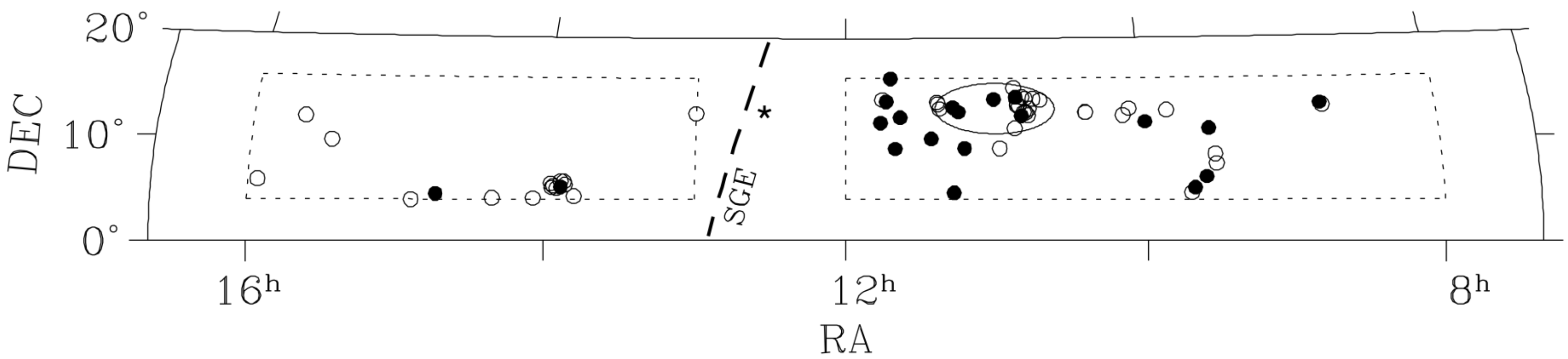
The low density environment sample

• We have selected from the SDSS catalog all 307 galaxies with v<3000 km/s in the sky area already covered by ALFALFA (4°<Dec.<16°, 8h<RA<16h) avoiding the Virgo region.

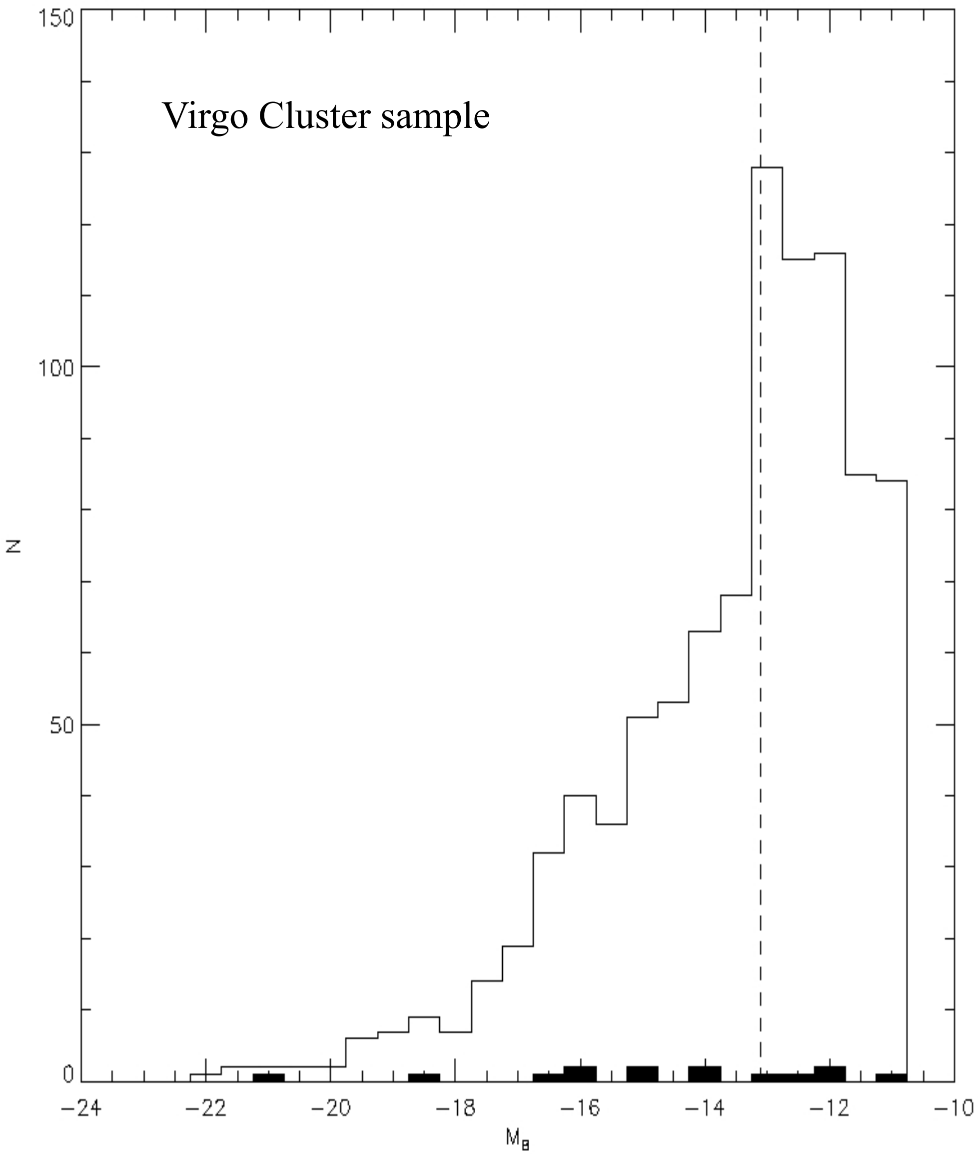
• Since the SDSS parameters *FracDev* and *eclass* used to select ETG (e.g. Bernardi et al. 2003) would not produce results similar to the standard morphological classification (dwarfs with exponential profiles and ETG with emission lines are missed), we classified the 307 galaxies by visual inspection of the color SDSS images and got a sample of 50 ETG.

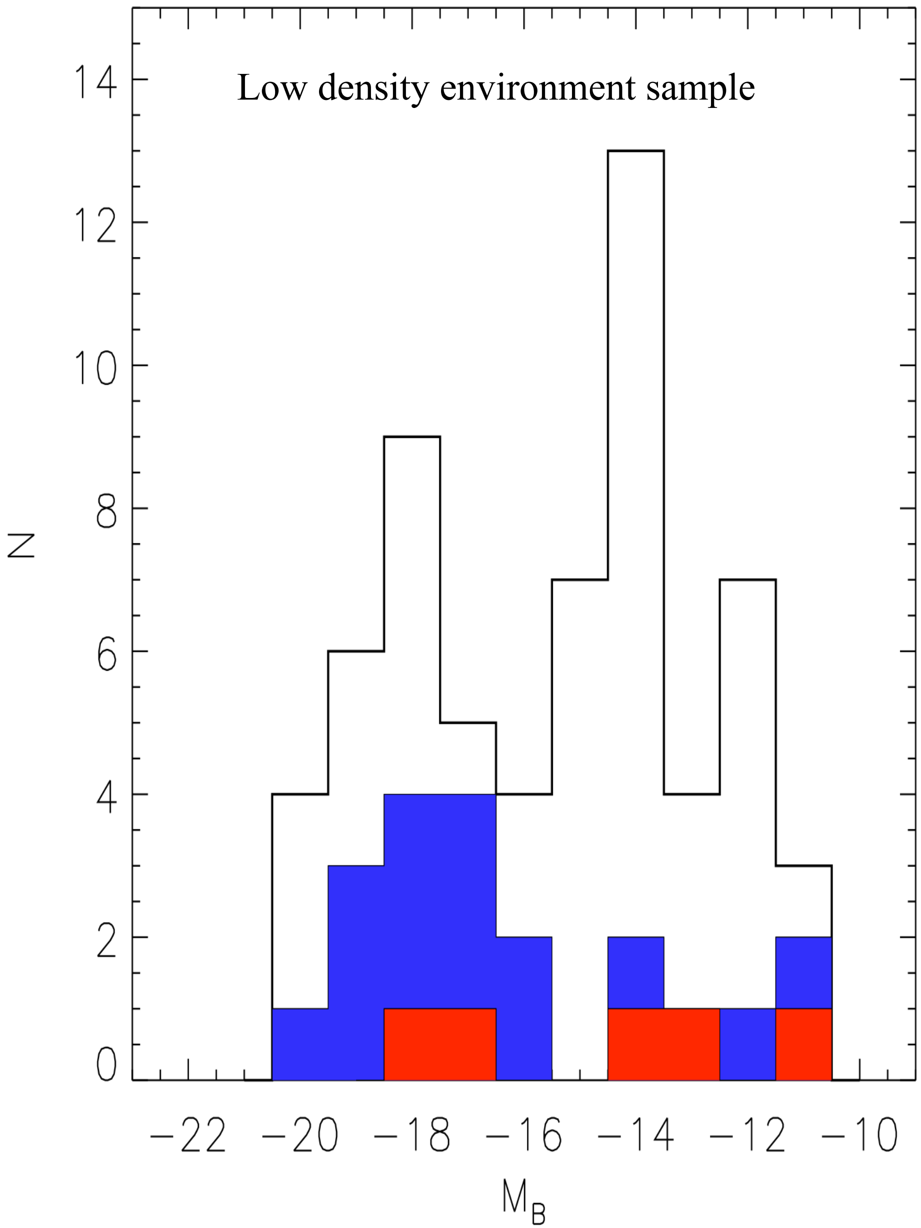
• The SDSS spectroscopic sample is complete down to r<17.77 and to half-light surface brightness μ_{50}<24.5. However it also misses some (~5%) bright galaxies (r>15) because these have substructures which fool the automated deblender (Strauss et al. 2002). We have therefore searched the RC3 catalog and found 10 bright ETG according to our criteria. We also found a faint dwarf (LeG14) and the nearby resolved dwarf LeoI from NED. The total field sample has 62 ETG.

•Searching this sample in the ALFALFA datacubes we found 15 safe HI detections (code 1 and 2) and 5 at lower S/N(code 4). The overall HI detection rate is then 32% (20 out of 62).



HI detection rates in field vs. cluster ETG





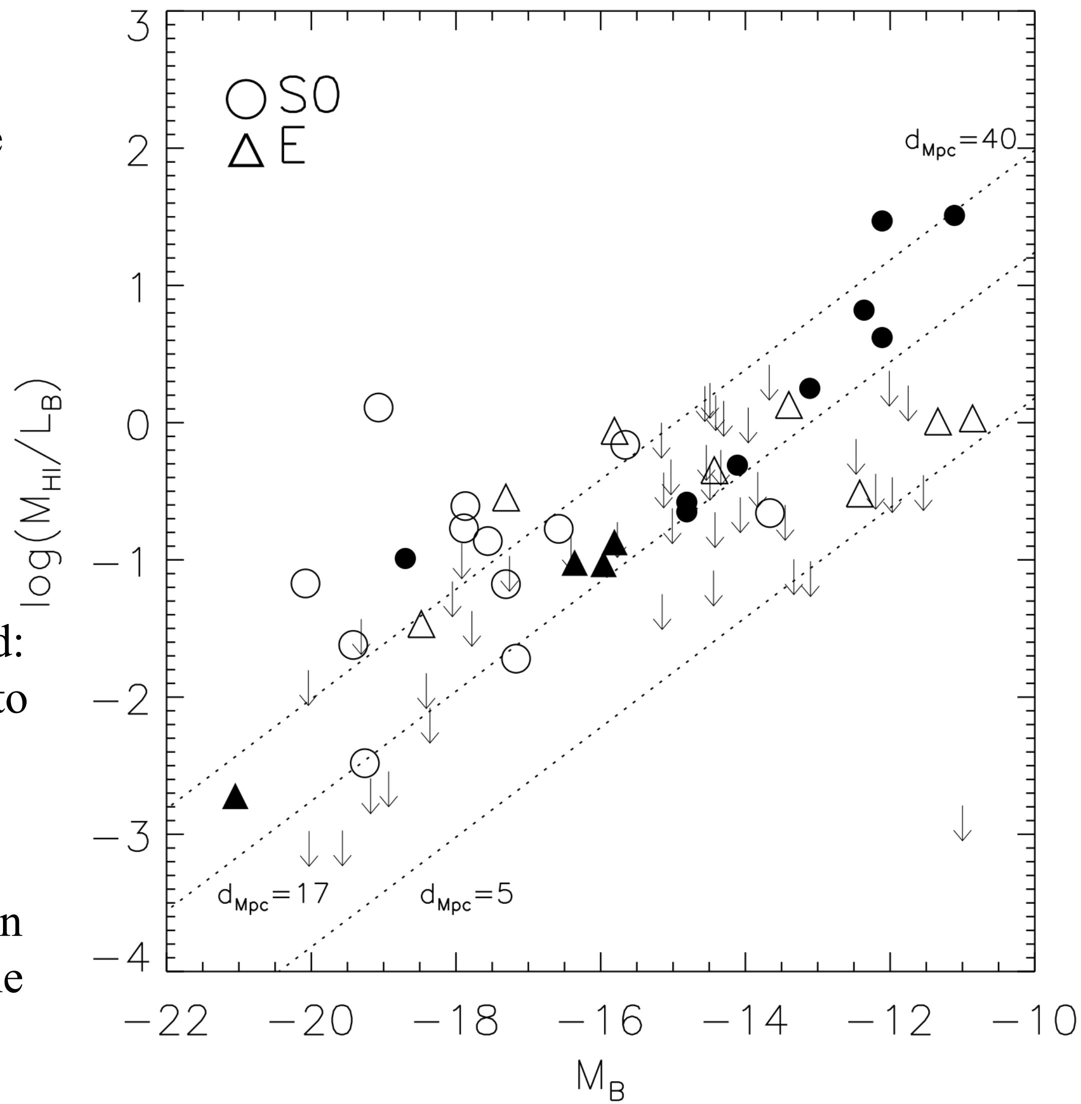
How much neutral gas per stellar light?

• 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 much 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

HI content vs. mass and environment

Environment	Total HI Detection rate	MB<-17.0	MB>-17.0
Virgo Cluster	2.3 ± 0.7 %	3.6 ± 2.5 %	1.7 ± 0.7 %
LDE	32 ± 7 %	48 ± 14 %	23 ± 8 %

- 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 may be 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.

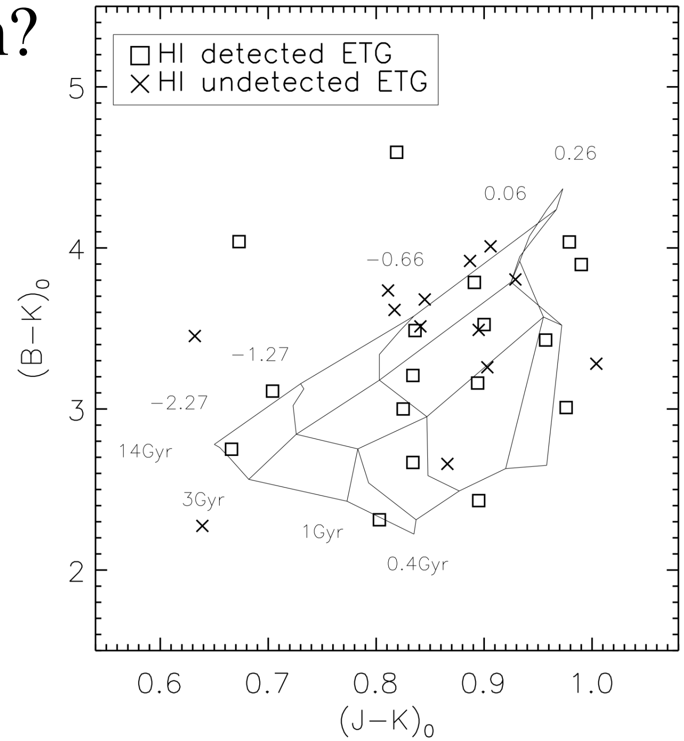
Do HI rich ETG show signs of star formation?

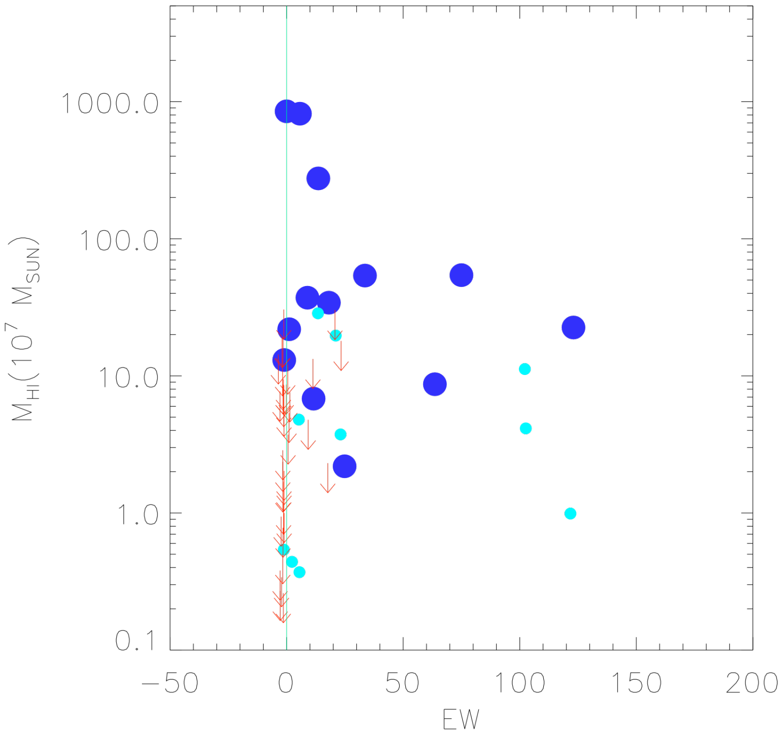
• It is conceivable that galaxies with HI have, or have recently had, more star formation than those without.

• In order to find out if this is the case for field ETG we have looked at a two-color diagram, which can discriminate between age and metallicity: although the majority of ETG without HI appear old, some of them seem a lot younger, and HI rich ETG have a wide range of ages.

• As a possible sign of star formation activity, we have also looked at the Hα equivalent width, as measured on SDSS nuclear spectra: although most of the HI rich ETG have Hα in emission, and most of the ETG without HI detected have Hα in absorption, there is no clear correlation between the Hα equivalent width and the amount of neutral gas.

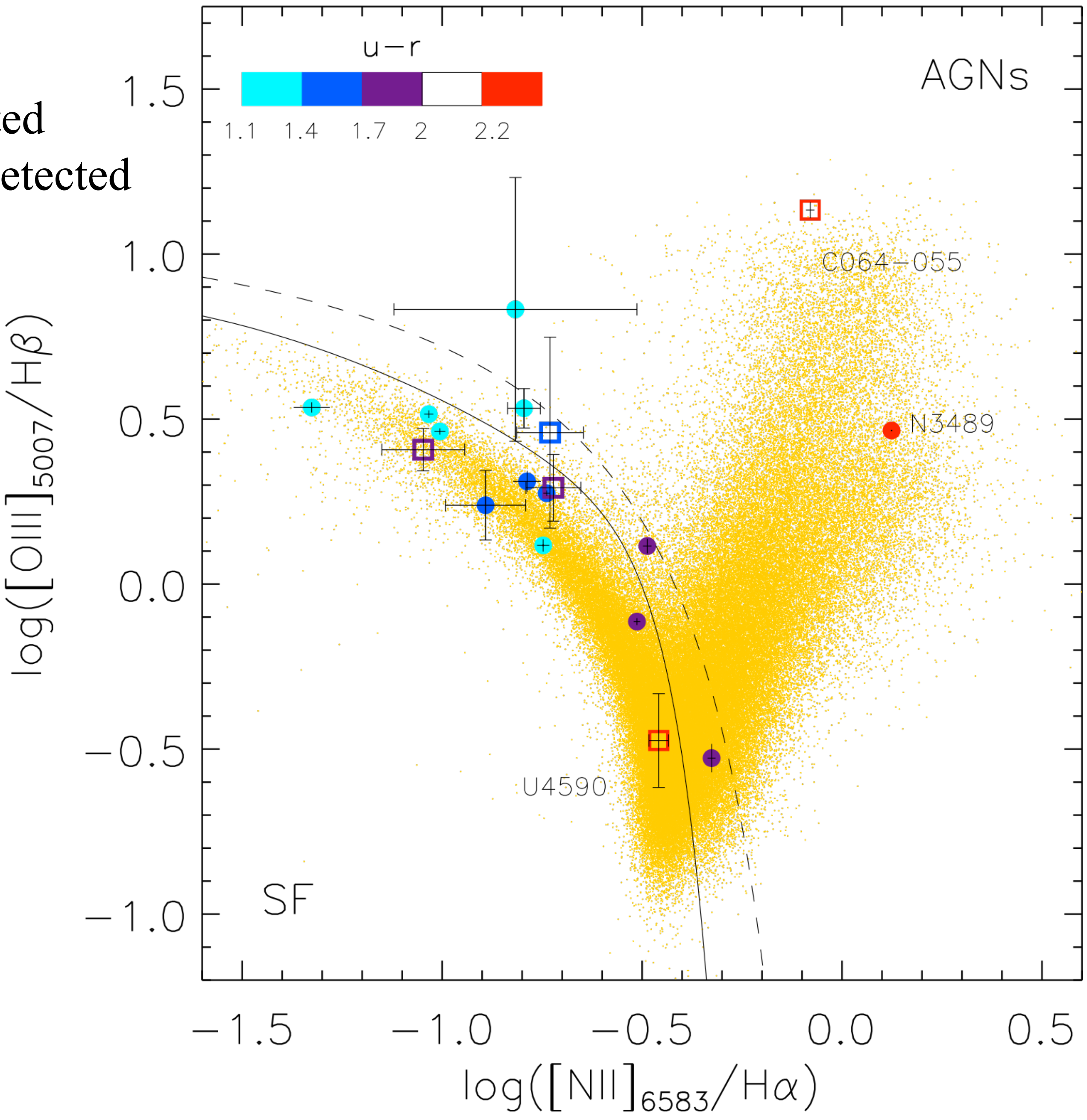
• However one should be careful in relating Hα emission with star formation in ETG, because it has been shown that old hot stars (PAGB, hot HB) can easily ionize the observed line-emitting gas (di Serego Alighieri 1990, Binette et al. 1994).



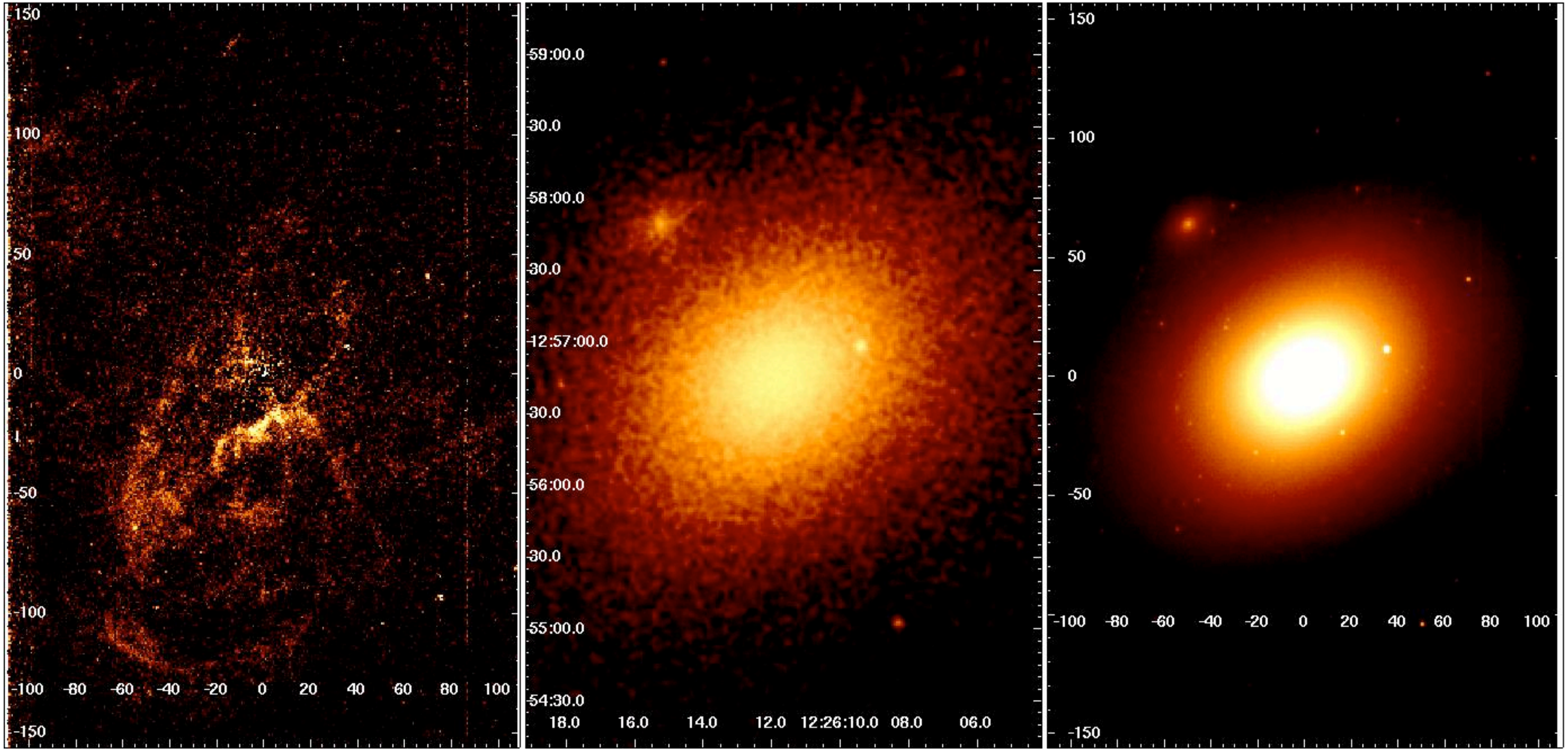


Emission lines diagnostic diagramme

Filled symbols: HI detected
Empty symbols: HI not detected

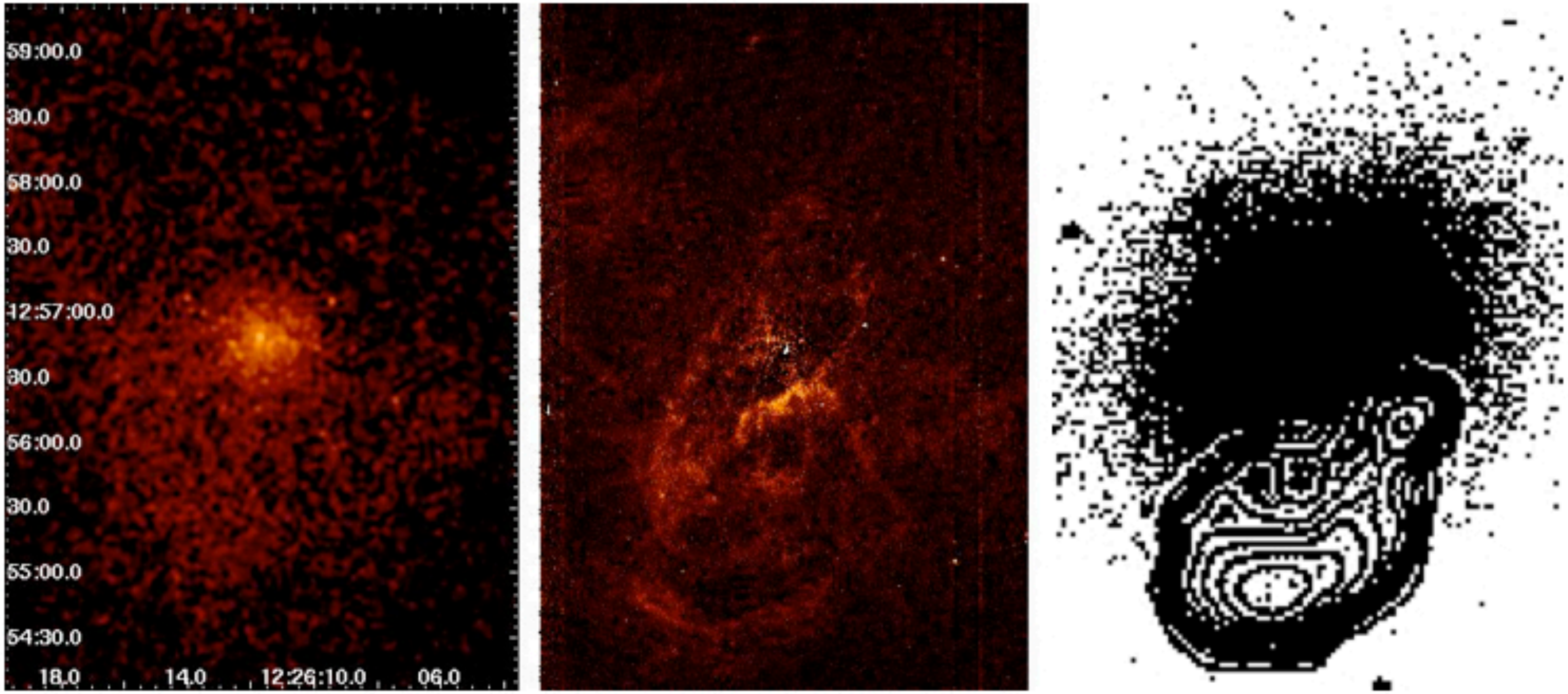


Interaction between gas phases in M86

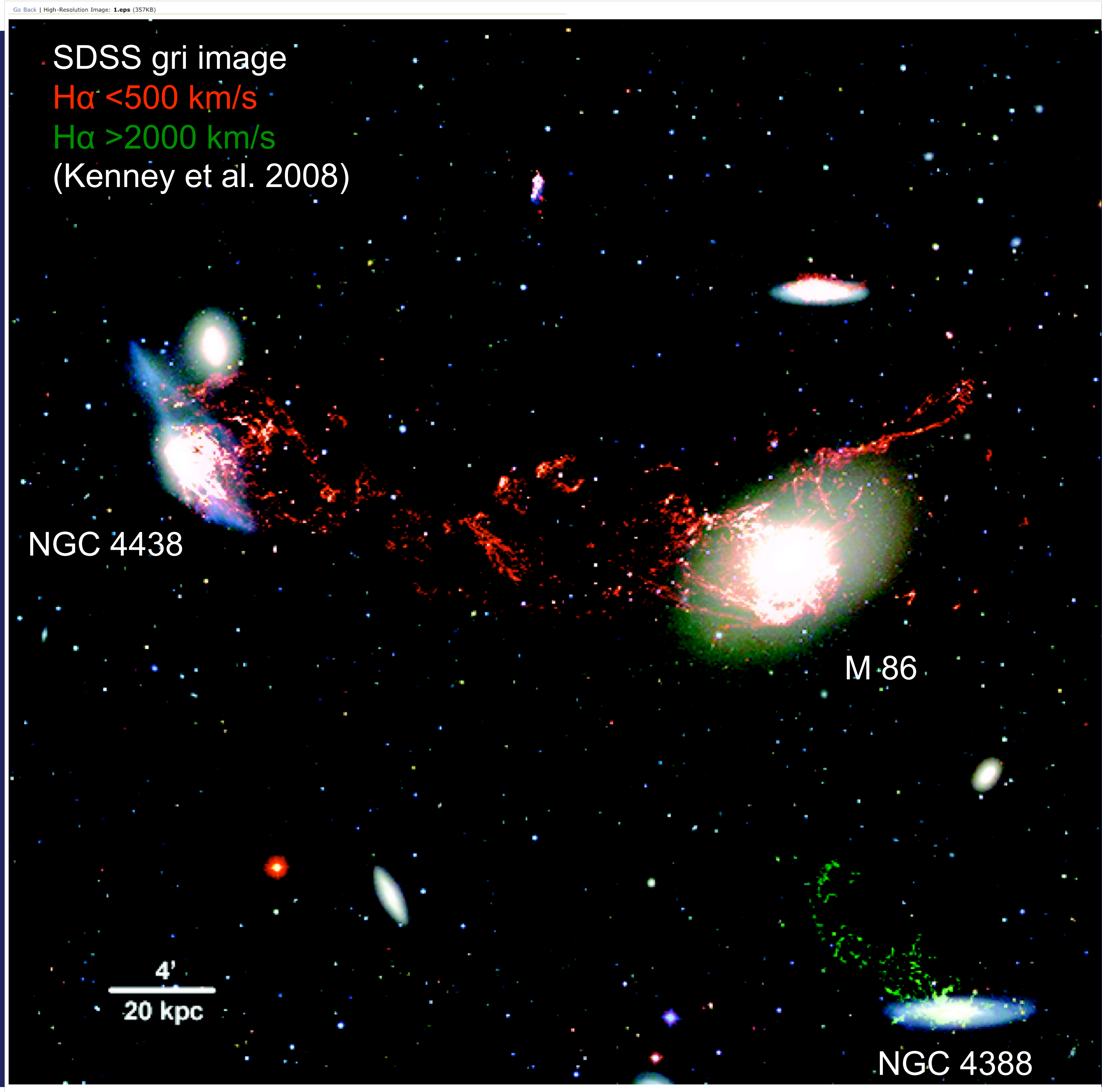


- M86=NGC4406: S0/E3 galaxy with M_B=-21.05, the brightest with HI in Virgo.
- It has warm ionized gas seen in Hα (log $L_{H\alpha}$=40.58 erg/s, $M_{I.G.}$~$10^6 M_\odot$, Trinchieri & di Serego Alighieri, 1991). The rings and filaments suggest that the ionized gas might result from a recent interaction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

Interaction between gas phases in M86

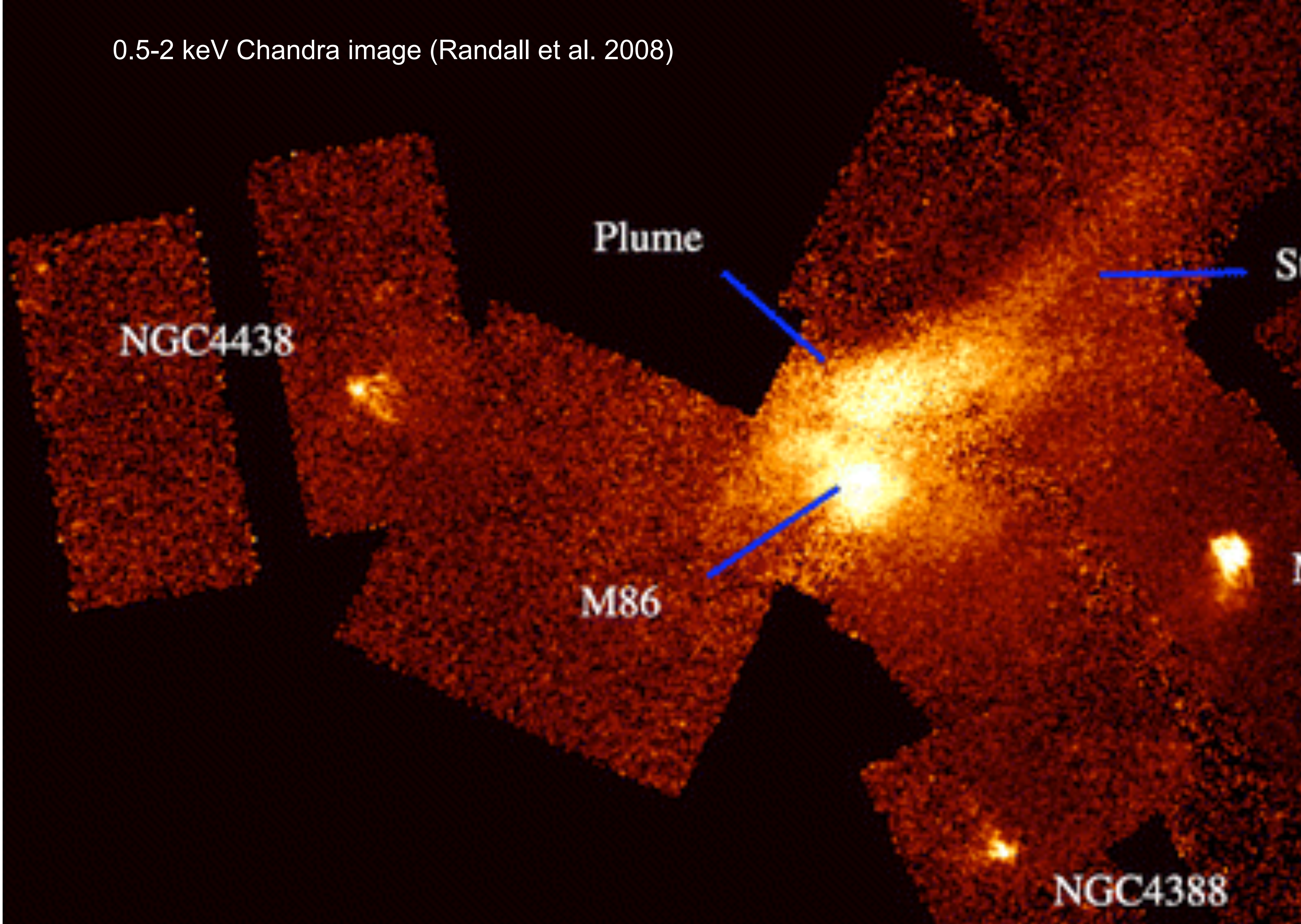


- It has hot gas, with a long plume of X-ray emission to the North-West, which is thought to be due to hot gas swept back by the ram pressure caused by the motion of M86 through the Virgo intracluster medium.
- It has neutral cold gas ($M_{HI} = 8\times10^7\ M_\odot$): see the VLA 21cm map (Li & van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



Go Back | High-Resolution Image: 1.eps (357KB)
SDSS gri image
Hα <500 km/s
Hα >2000 km/s
(Kenney et al. 2008)
NGC 4438
M 86
NGC 4388
4'
20 kpc

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



Conclusions & questions

- 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) 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.
- This dependence of the HI detection rate on the galaxy mass, which is contrary to what would be expected for residual primordial hydrogen, and the presence of structures, such as discs and rings, in some cases, point to an external origin for the neutral gas also in the field.
- Could the suppression of star formation in ETG, which is necessary to explain their passive evolution after the strong initial starburst, be due to heating up of residual cold gas to hot halo temperatures?
- Can dry mergers really exist, given the widespread presence of ISM in ETG, particularly in LDE?