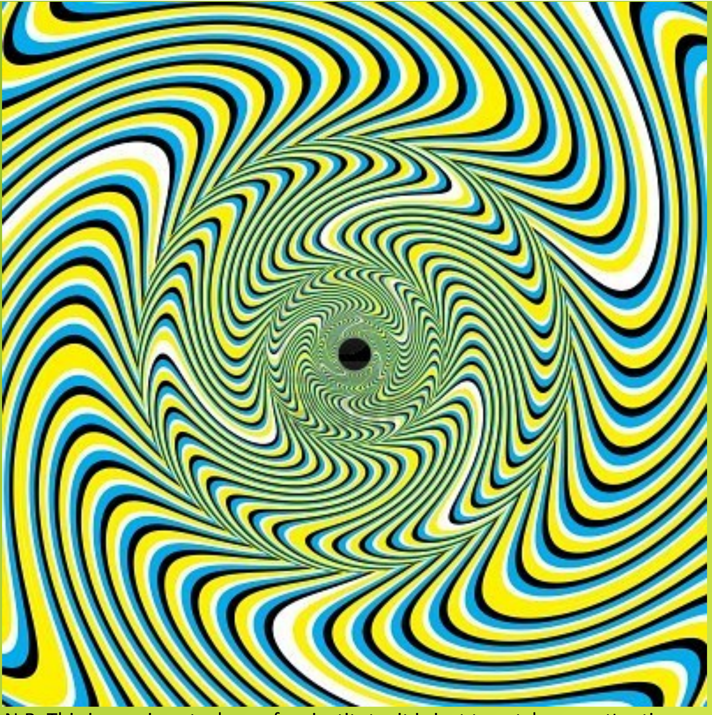
# Molecular and dust distribution in Virgo spiral galaxies



N.B. This image is not a logo of an institute, it is just to catch your attention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loosely based on Pappalardo et al. 2012 (accepted in A&A)


## Abstract

The evolution of a galaxies is set by a complex mechanism of recycling between the stellar and the gaseous components, but the picture is even more complicated, because galaxies are not isolated system, they are preferentially found in cluster. For that cases the environment through hydrodynamical and gravitational effects, can drastically modify the gas distribution within galaxies. In Pappalardo et al. 2012 we investigate how the environment affects the various components of the interstellar medium. To quantify this effects I considered a sample of spiral galaxies in the Virgo cluster, because at the Virgo distance (about 17 Mpc) we can resolve spatially the galaxy and investigate radial variations along the disks.

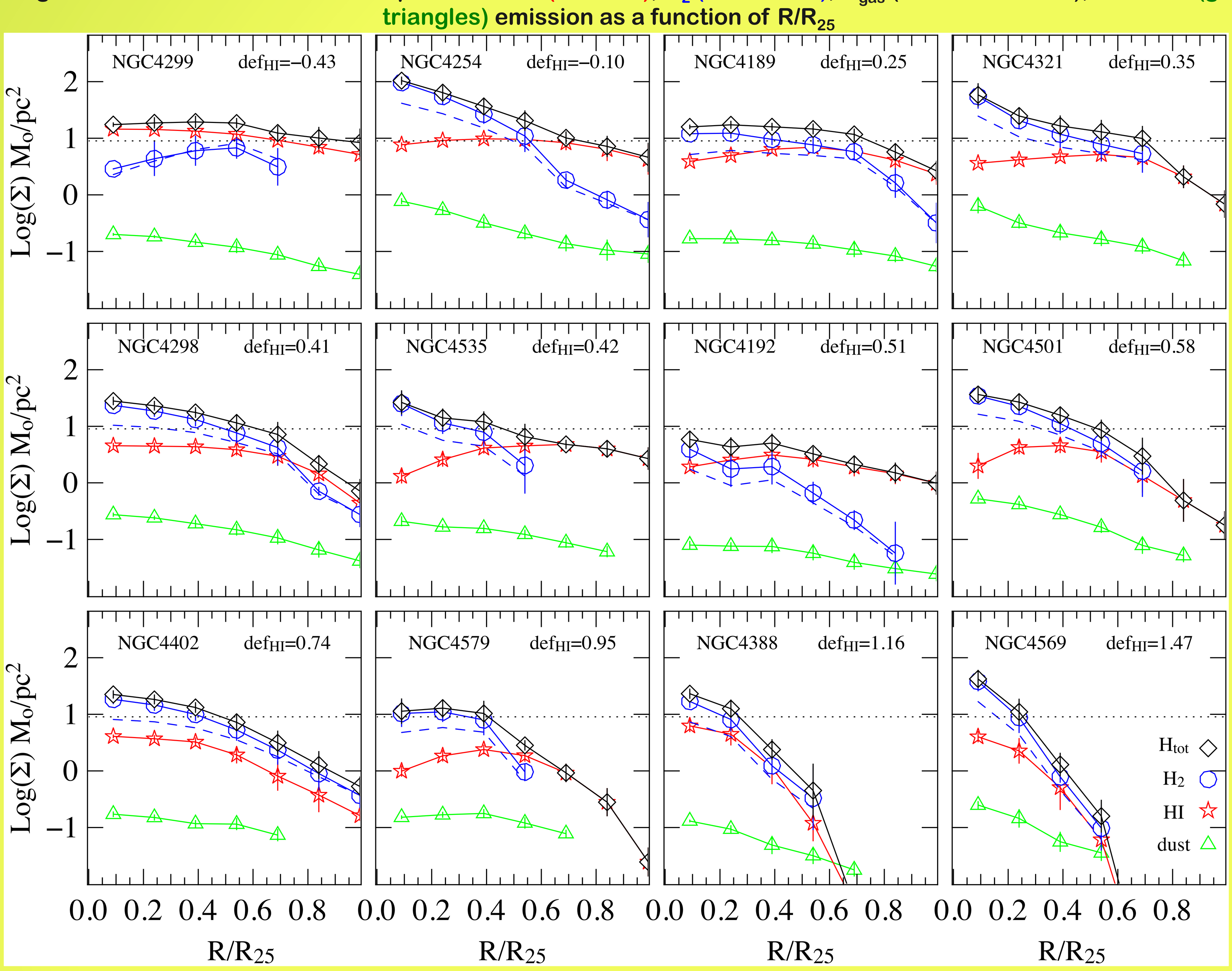
For the galaxies samples we use the following data:

HI = the atomic has been mapped by Chung et al. 2009 with VLA interferometer

$H_2$ = the molecular gas is not traced directly. We use the intensity of the CO(J=1-0) emission line and we convert it into molecular hydrogen column density through a conversion factor $X_{CO}=2\times10^{20}$ cm$^{-2}$ [K km s$^{-1}$]$^{-1}$ calibrated in the Milky Way. For a subset of the sample the CO line has been mapped by Kuno et al. 2007 with the Nobeyama Telescope. The other galaxies has been mapped by us using the IRAM 30m telescope (maps shown in Pappalardo et al. 2012)

Dust = dust emission has been mapped at 5 wavelengths (100, 160, 250, 350, and 500 micron) with Herschel within the Herschel Virgo Cluster Survey (HeViCS, Davies et al. 2010) consortium.

In the Figure below are shown the radial profiles of HI (red star), $H_2$ (blue circle), $H_{gas}$ (black diamonds), and dust (green triangles) emission as a function of R/R$_{25}$

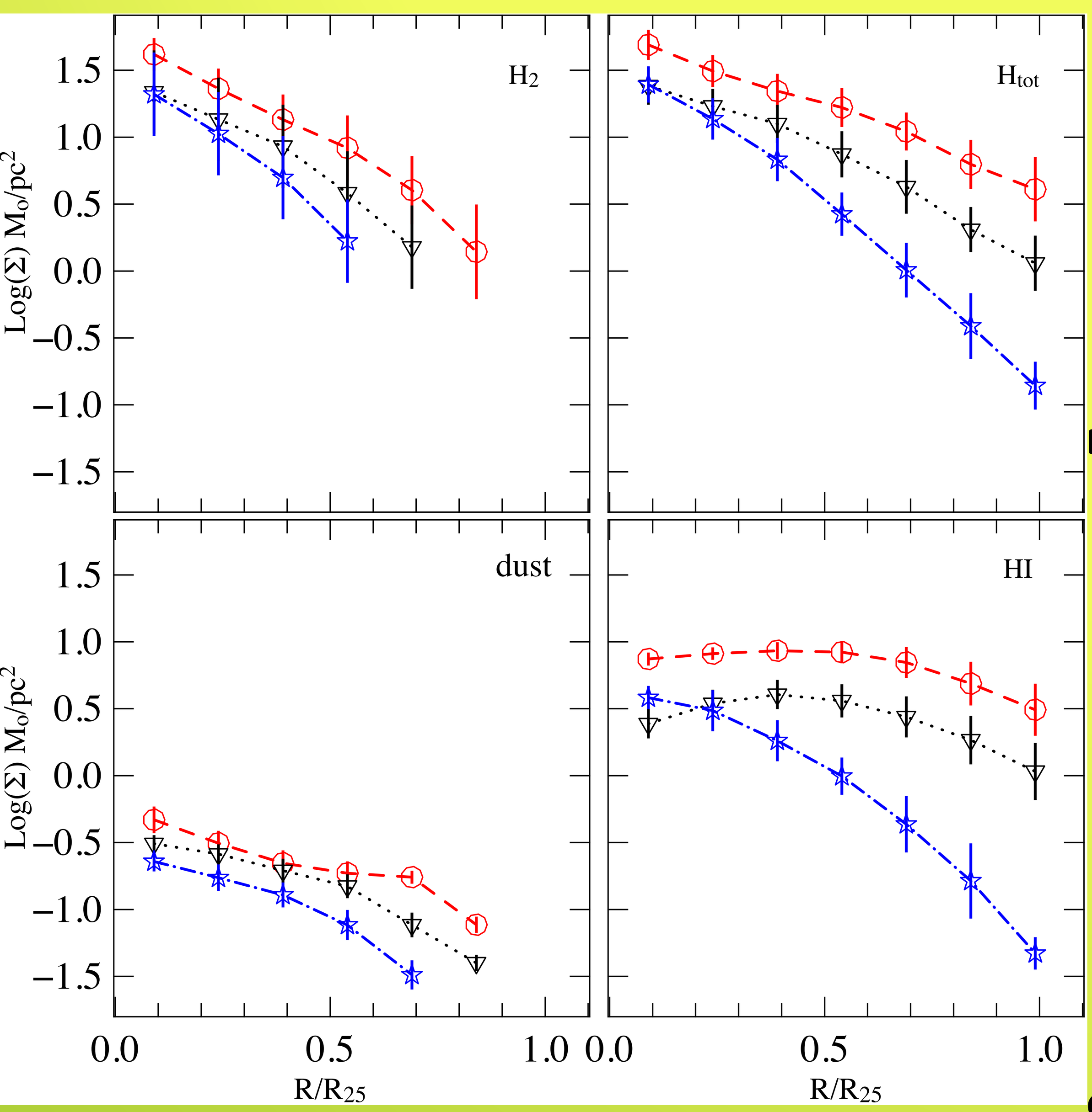

## Does the environment affects the dust and gas distribution?

The galaxies in the Figure above are classified according to the HI deficiency, i.e. the logarithmic difference between the observed HI mass and the expected value in isolated objects of similar morphological type and linear size.

Each row in the Figure represents:

A. FIRST ROW = galaxies unperturbed with def$_{HI}$ > 0.3
B. SECOND ROW = galaxies slightly perturbed with 0.3 < def$_{HI}$ < 0.7
C. THIRD ROW = galaxies strongly perturbed with def$_{HI}$ > 0.7

To characterize the environmental effects we calculate the bin averaged profiles of the dust and ISM components for each subset defined above. The Figure below shows the results (colors corresponds to each subset):




RED CIRCLE = UNPERTURBED GALAXIES

BLACK TRIANGLES = SLIGHTLY PERTURBED GAL

BLUE STARS = STRONGLY PERTURBED GALAXIES

### Results

A. Galaxies with higher HI deficiency have steeper profiles and lower surface mass densities, indicating that the lack of atomic hydrogen affects the formation of the molecular gas, and thus the total gas component. However this trend is not so obvious, because the HI deficiency is a condition necessary but not sufficient for the molecular gas deficiency, as shown in Fumagalli et al. (2009).
B. Increasing the HI deficiency we find lower surface mass densities for all the ISM components. However, for the atomic hydrogen in the central regions of the disks of HI-deficient galaxies, the surface mass density appears somewhat higher than that of slightly perturbed galaxies. This effect could be explained as ram-pressure-induced compression of the gas in the inner region of the disk (Tonnesen & Bryan 2009) that could increase locally the gas density (Byrd & Valtonen 1990).
C. Dust radial profiles of perturbed galaxies (blue stars) decrease steeply at R/R$_{25}$ > 0.4, with respect to the unperturbed galaxies (red circles), but have comparable radial slopes in the inner parts of the disk, since the dust is more confined to the disk where ram pressure is less efficient in the ISM removal. This trend has already been found by Cortese et al. (2010).

## Does the environment affects the Dust-to-gas ratio?

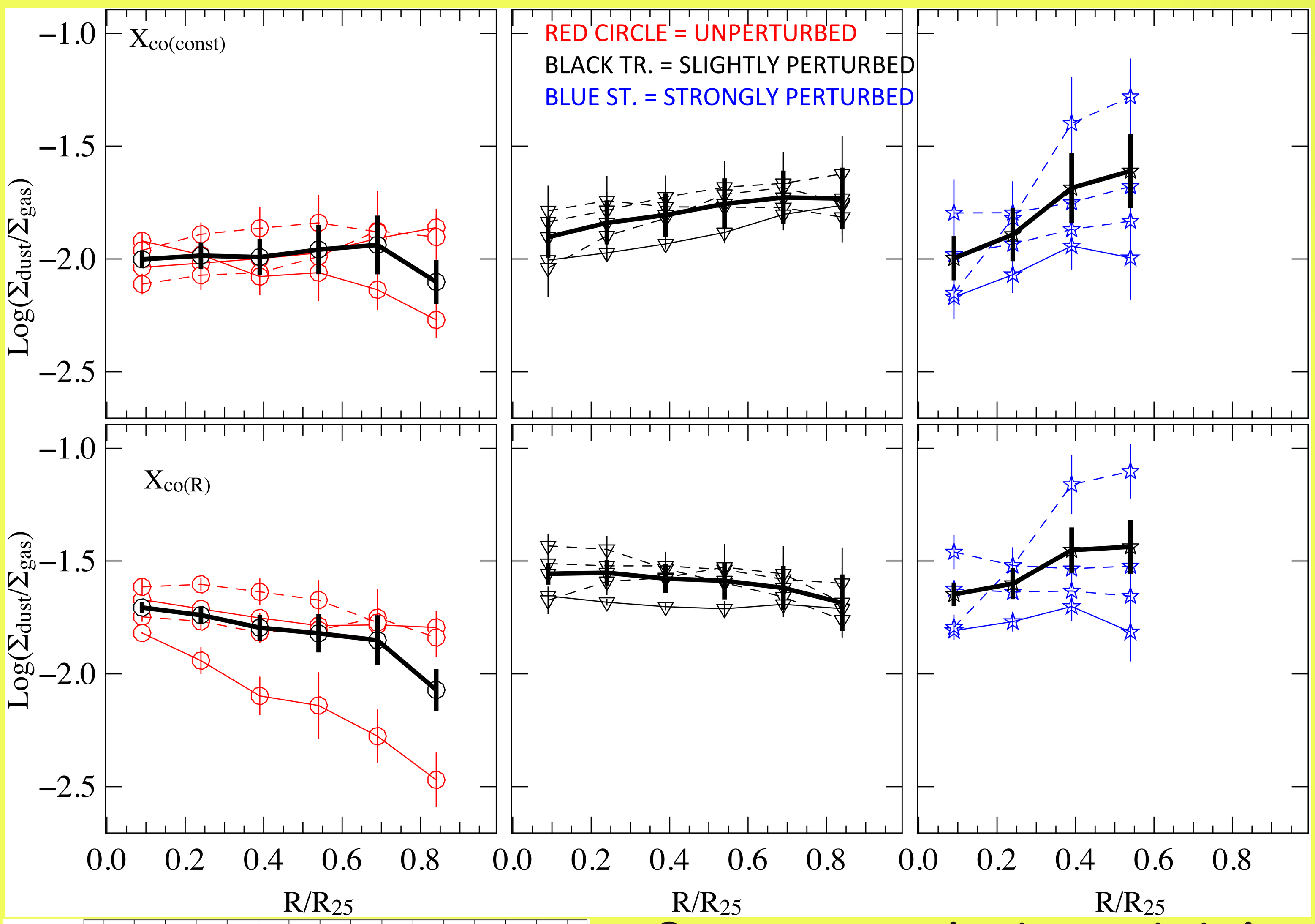
Since we have the gas and dust component now we can investigate the effect of the environment in the dust-to-gas ratio. The molecular gas estimation strongly depends on the assumption about the $X_{CO}$ factor. While we have used so far the Galactic solar neighborhood value, there is ample evidence that $X_{CO}$ varies in other galaxies as a function of physical conditions. Thus, we consider an alternative conversion factor, which depends on the metallicity, and varies radially following the metallicity gradient along the disk.

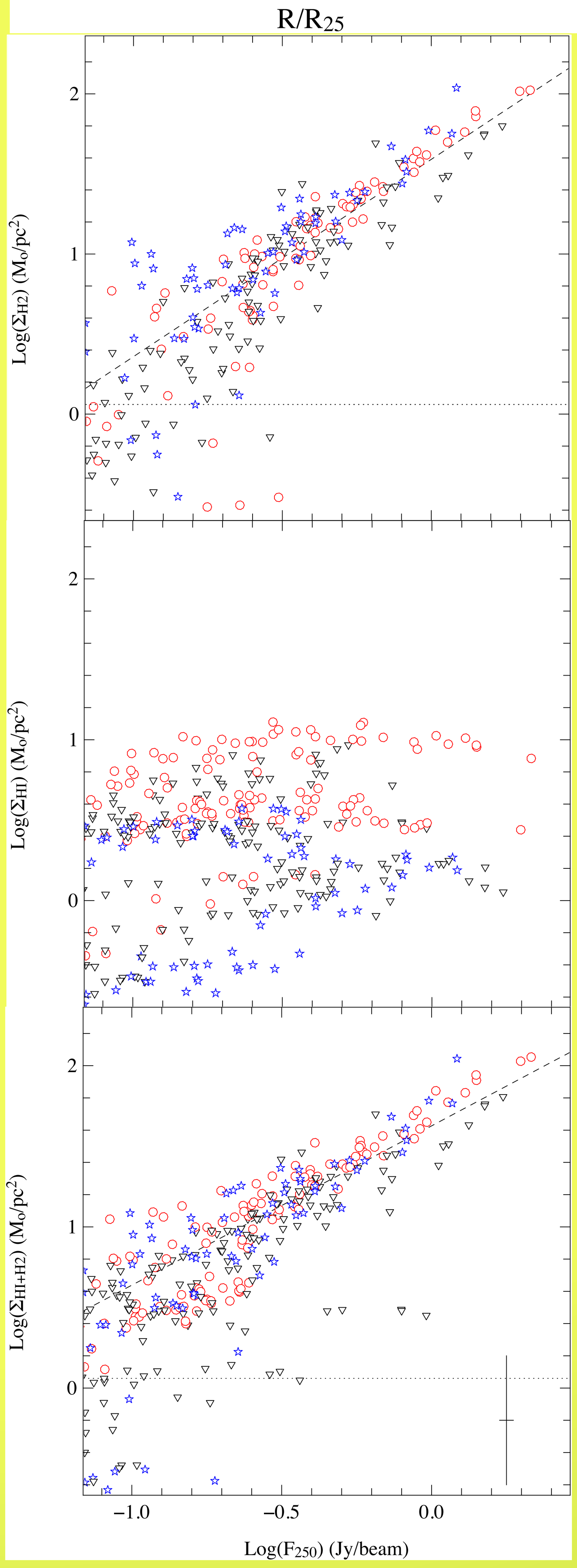
The Figure below shows the radial profiles of the dust-to-gas ratio for the three subsamples of galaxies defined in the previous Figure. The black solid line in each panel shows the bin-averaged profile for each subset.

In the top panels of the Figure we use the standard Galactic conversion factor, and in the bottom panels we use the alternative conversion factor which depends on the metallicity.

### Results

The averaged profiles show only moderate change with HI deficiency; the dust-to-gas ratio is almost constant throughout the disk for non-deficient galaxies (top left panel of Figure), while it increases with radius for the strongly HI-deficient subset (top right panel of Figure). As shown in the bottom left panel of the Figure, this effect is more evident for non-deficient objects, confirming what was already found by Magrini et al. (2011). Simple considerations want the dust- to-gas ratio to follow linearly the metallicity (both dust-to-gas and metallicity tracing metals, the former in the solid and the latter in the gaseous phase; Draine et al. 2007); thus, a lower- than-Galactic $X_{CO}$ in a galaxy's center appears to be necessary for the dust-to-gas ratio to have the same gradient observed for the metallicity. Indeed, in the case where the surface mass density is dominated by the atomic gas at all radii the dust-to-gas ratio decreases with radius, similarly to the metallicity gradient (see e.g. Bendo et al. 2010 for NGC 2403).




## Can we use dust as a total gas tracer?

An alternative to the standard CO/21cm method to estimate the mass of the interstellar medium is to measure the dust emission. This idea, proposed in 1983 by Hilderbrand, is at present of topical interest mainly for two reasons:

1. The Herschel Space Observatory is measuring dust emission of thousands of galaxies spanning a timescale of ≈ 10 Gyr
2. It is unfeasible to measure the 21cm and the CO emission line for all the galaxies detected in optical bands, even using ALMA facilities.

But is this method reliable?

An encouraging result has been found in Corbelli et al. 2011, where they showed that in a sample of galaxies of the Virgo cluster dust mass correlates better with the total gas than a single gas component.

Eales et al. 2012 applied this method to a sample of nearby galaxies. Their conclusion is that the method is potentially useful with a upper limit error of 30%.

The Figure on the left of this panel shows the surface mass density of $H_2$ (top), HI (middle), and $H_{tot}$ = HI+$H_2$ as a function of the surface brightness at 250 micron, in a pixel by pixel analysis. The dotted line shows the 3σ level in each panel and the dashed line shows the best linear fit.

### Results

For the molecular component we find a best linear fit:

$$\text{Log}\,\Sigma_{H2} = 1.23\,\text{Log}\,F_{250} + 1.59$$

With a Pearson correlation of r = 0.86.

The relation is tighter for galaxies for unpertubed galaxies (red circles) with respect to galaxies HI-deficient (blue stars). For the HI component there is no clear correlation. For the total gas we have:

$$\text{Log}\,\Sigma_{gas} = 0.99\,\text{Log}\,F_{250} + 1.63$$

With a Pearson correlation of r = 0.87, not significantly different from the correlation obtained for the molecular component.

This is in contrast with Corbelli et al. 2011, that found a better correlation for the total gas.

Why if we considered integrated properties we found a better correlation with the total gas but if we proceed to a resolved analysis a better correlation is found with the molecular component?

A possible explanation is that when we consider resolved analysis we are intrinsically biased toward the central regions of the galaxy, rich in molecular gas, and when we consider the integrated properties we extend our analysis towards the outskirt of the disk, but still the question is not closed.

## Conclusions

1. Galaxies with high HI deficiency have steeper radial profiles, as a consequence of the combined effect of HI and H2 deficiency, in agreement with previous studies (Fumagalli et al. 2009; Cortese et al. 2012). The average radial profiles of the dust surface mass density in HI- deficient galaxies is steeper than in HI-normal galaxies. This is consistent with the results found by Cortese et al. (2010), on the radial distribution of the flux density at 250, 350 and 500 micron.
2. The dust-to-gas ratio for non-deficient galaxies has a radial trend which depends on the $X_{CO}$ conversion factor, as already discussed by Magrini et al. (2011). This ratio decreases radially only if $X_{CO}$ increases radially due to metallicity gradients. For HI-deficient galaxies instead, the dust-to-gas ratio stays constant or increases radially independently of the $X_{CO}$ factors used. This indicates that atomic gas is stripped more efficiently than the dust in a cluster environment. Since both dust and gas radial profiles truncate sharply well inside the optical disk, the dust-to-gas ratio cannot be traced at large galactocentric radius in highly perturbed galaxies.
3. We observe a tight pixel-by-pixel correlation between the mass surface density of the molecular hydrogen and the 250 micron surface brightness. In HI-deficient galaxies, the environment is efficient in perturbing both gas and dust, introducing a large scatter. Adding the atomic gas to the molecular component, the correlation with the 250 micron surface brightness becomes linear, but the correlation coefficient does not change significantly. Thus it is not clear if the dust emission at large FIR wavelengths can be used as a tracer of the total gas surface mass density, or of the molecular gas only.