Investigations of the galaxies of the LCV

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0.3 TODO **Units in the plots**

Abstract

The paper investigates the properties of galaxies in the Local Cosmological Volume (LCV), using the Catalogue of Neighboring Galaxies[2] and its updated version from the "Catalog & Atlas of the LV galaxies" database[1]. The properties studied include the galaxy types, their various masses, the star formation rates (SFRs) and the star formation timescale τ, gas depletion timescale τ_g and the star formation time t_{sf}. The paper aims to understand the distribution and correlation of these properties in the sample of galaxies in the LCV, and how they relate to current astrophysical theories.

1 The Galaxies in the Local Cosmological Volume (LCV)

The Catalogue of Neigbouring Galaxies (Karachentsev, Igor D. and Makarov et al. 2013[2]) and its updated version from the "Catalog & Atlas of the LV galaxies" database[1] are used to extract the B-band, FUV $\setminus$ K-band luminosities[1] , the types of the galaxie[2]s, the mass within the Holmberg radius (M26), the Hydrogen masses of the galaxies (M_{HI}) and the SFRs based on integrated H and far-ultraviolet (FUV) measurments for galaxies within a distance of $\approx$ 11 Mpc. Some of those values contain limit flags, which we exclude from our present analysis. This gives a sample of 793 galaxies from 1248. From the remaing galaxies we have

Measurment	Number of Galaxies
Name	793
FUVmag	687
TType	793
Tdw1	580
Tdw2	568
Bmag	790
SFR_{Ha}	566
SFR_{FUV}	688
K	789
MHI	643
color	686

The K-band values are converted to the total Stellar Masses of each galaxy according to the mass-to-light ratio of 0.6 ([5]), and the M_{HI} can be converted to the total mass of the gas of the galaxy using the equation $M_g = 1.33\, M_{HI}$

The total SFR of each galaxy can be calcuated by

$$SFR_o = \frac{SFR_{FUV} + SFR_{Ha}}{2}$$

if both $SFR_{H\alpha}, SFR_{FUV}$ measurments are available. If only one only one of them is given, then the SFR is equal to the given SFR value

$$SFR_o = SFR_i, \text{ if } SFR_j = 0, i \neq j,\ i, j = FUV, H_a$$

[1] We use the FUV and B measurments to calculate the B-FUV color index.

[2] TType=Morphology type code according to the classification by de Vaucouleurs/ Tdw1=Dwarf galaxy morphology/ Tdw2=Dwarf galaxy surface brightness morphology

The condition $SFR_o \geq 10^{-3} M_{\odot} yr^{-1}$ leaves 579 galaxies. This condition is applied due to the reasons given in the P. Kroupa,M. Haslbauer, I. Banik, S. T. Nagesh and J. Pflamm-Altenburg et al. 2020 [4]

2 Types of galaxies

Using the dataset of 1248 galaxies, do before using the condition and removing the galaxies with the flags, the below histograms can be plotted.

Most of the galaxies in the LCV are Irregular galaxies followed by lenticular galaxies

Out of the 1248 galaxies the 1022 are dwarf galaxies RODO

2.1 TODO **write a table with the types**

Most dwarf galaxies have low brightness and are irregulars followed by Dwarf spheroidal.

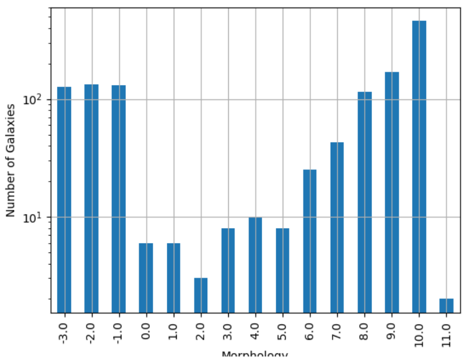


Figure 1: The classification by de Vaucouleurs et al. (1991) is used for the morphology of the galaxies

3 Delayed-τ model

According to P. Kroupa et al. 2020[4] current star formation rates of galaxies can be described by the 'delayed-τ' model as

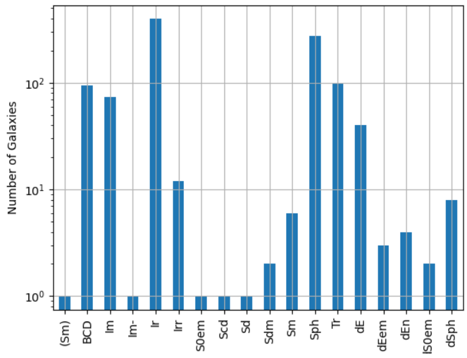


Figure 2: Dwarf galaxy morphology

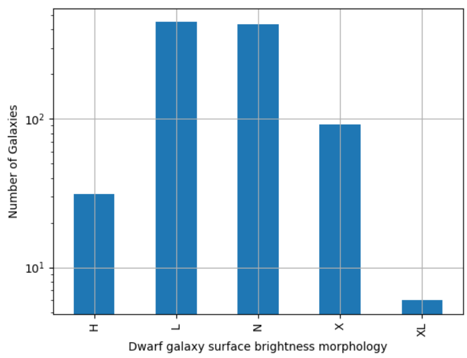


Figure 3: Dwarf galaxy surface brightness morphology, where: H = high; N = normal; L = low; X = extremely low.

$$SFR_{0,del} = \frac{A_{del} x e^{-x}}{\tau}, \text{ where } x = \frac{t_{sf}}{\tau} \quad (1)$$

where τ is the star formation time-scale, t_{sf} is the real time of star formation in a given galaxy and A_{del} a normalization constant.

The average SFR is

$$\overline{SFR_{del}} = \frac{A_{del}}{t_{sf}}[1 - (1 + x)e^{-x}] \quad (2)$$

and can also be defined by the present day stellar mass

$$\overline{SFR} = \frac{\zeta M_*}{t_{sf}} \quad (3)$$

where ζ accommodates for mass-loss through stella evolution and $\zeta \approx 1.3$

This is a system of 2 equations and 3 variables, since A_{del} has never been calculated

3.1 Constant t_{sf}

The observed ages of galactic discs are $t_{sf} \approx 12$ Gyr[3], so assuming an approximation of $t_{sf} = 12.5$ Gyr, the $\overline{SFR_{del}}$ can be calcuated, from the equation (**??**).

After that the equation of ratio

$$\frac{\overline{SFR_{del}}}{SFR_{0,del}} = \frac{e^x - x - 1}{x^2} \quad (4)$$

can be solved numerically for x and using the equations (**??**) and (**??**) the A_{del} and τ of each galaxy are found.

	A_{tsf}	tau	x_{tsf}
count	578	579	579
mean	2.24715e+12	1.08958e+11	1.853
std	3.93675e+13	1.04132e+12	1.476
min	2.47798e+07	1.93205e+09	0.001
25%	1.40573e+08	4.18098e+09	0.565
50%	6.83764e+08	7.79265e+09	1.604
75%	5.70379e+09	2.21327e+10	2.99
max	9.10088e+14	2.23774e+13	6.47

$$\log(A_{del}|_{tsf}) = (9.6(4) \times 10^{-1}) \cdot \log(M_t) + (8(4) \times 10^{-1})$$
with correlation $R^2 = 48\%$ (5)

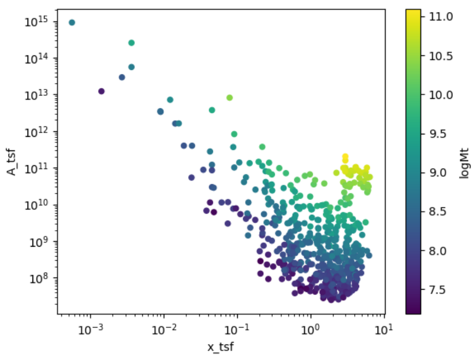


Figure 4: $A_{del} = f(x)$ for constant t_{sf}

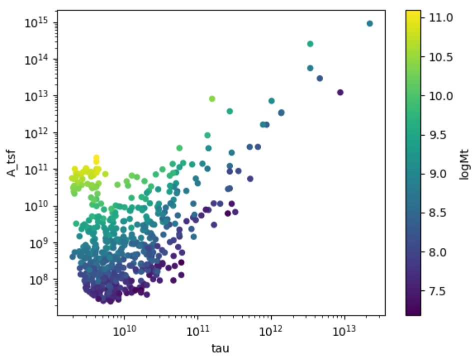


Figure 5: $A_{del} = f(\tau)$ for constant t_{sf}

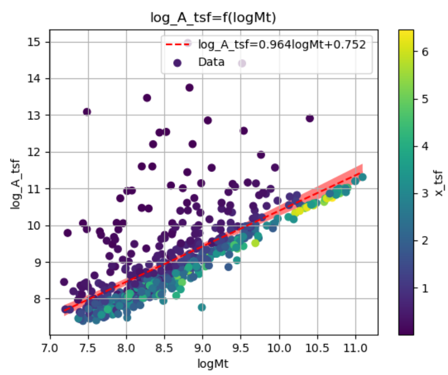


Figure 6: Total Mass M_t - $A_{del}|_{t_{sf}}$

3.2 Constant τ

Assuming for an constant $\tau = 3.5$ Gyr, we cannot use the same $\overline{SFR}$ since it depends on t_{sf}. Using the equations~(**??**) and (**??**)

$$\frac{\overline{SFR_{del}}}{SFR_{0,del}} = \frac{e^x - x - 1}{x^2} \Leftrightarrow \frac{e^x - x - 1}{x} = \frac{\zeta M_*}{SFR \cdot \tau}$$

using this equation x and A_{del} can be calculated numerically.

	$\mathrm{A_{tau}}$	$\mathrm{x_{tau}}$	ts
count	579	579	579
mean	4.58667e+09	2.54057	8.89201e+09
std	1.49896e+10	0.956554	3.34794e+09
min	9.87003e+06	0.406787	1.42376e+09
25%	6.50497e+07	1.87165	6.55079e+09
50%	2.36667e+08	2.43871	8.5355e+09
75%	1.11526e+09	3.07972	1.0779e+1(
max	1.0577e+11	5.77102	2.01986e+1(

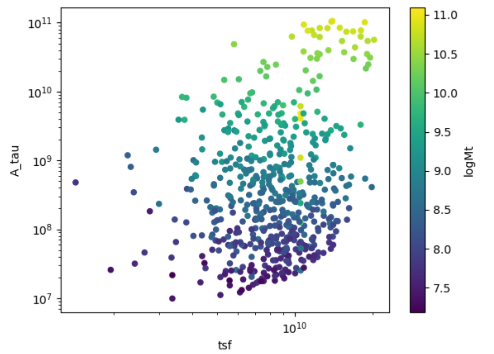


Figure 8: $A_{del} = f(t_{sf})$ for constant τ

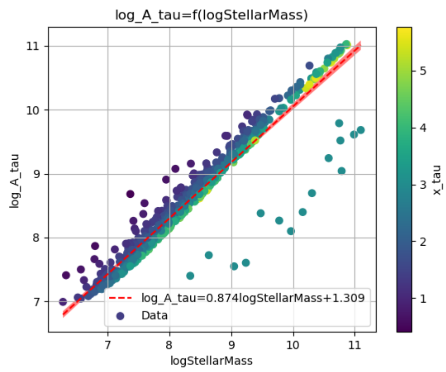


Figure 9: Total Mass M_t - $A_{del}|_\tau$

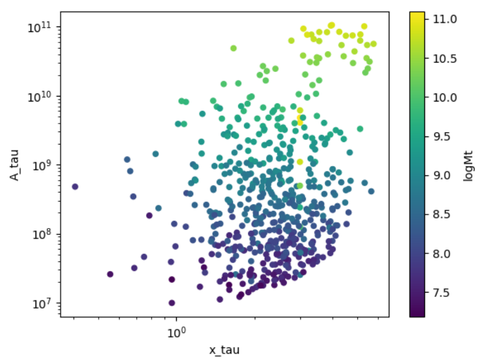


Figure 7: $A_{del} = f(x)$ for constant τ

	x_tau	x_tsf
count	5.79E+02	5.79E+02
mean	2.54E+00	1.85E+00
std	9.57E-01	1.48E+00
min	4.07E-01	5.59E-04
25%	1.87E+00	5.65E-01
50%	2.44E+00	1.60E+00
75%	3.08E+00	2.99E+00
max	5.77E+00	6.47E+00

$\log(\mathrm{A}_{del}|_\tau) = (8.74(12) \times 10^{-1}) \cdot \log(\mathrm{M}_t) + (1.31(10) \times 10^0)$
with correlation $R^2 = 90\%$ (6)

3.3 Comparing the two results

3.3.1 Comparing the x's

Comparing the two different results for x, we see that the $x|_\tau$ has a lower σ

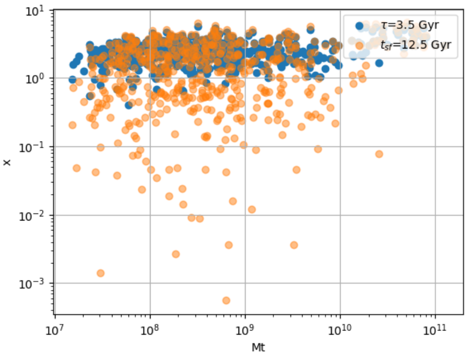


Figure 10: Comparing the two x's, According to their total masses

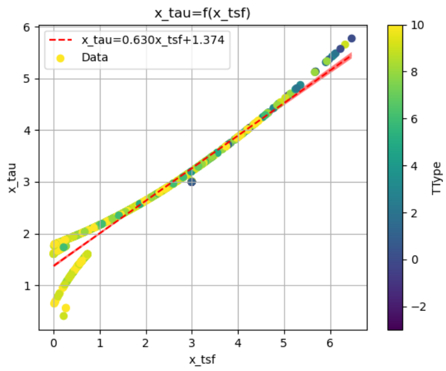


Figure 13: Comparing the two x, according to their type

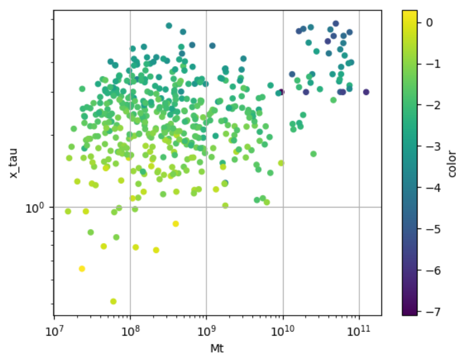


Figure 11: $x|_\tau = f(M_t)$, with their color index

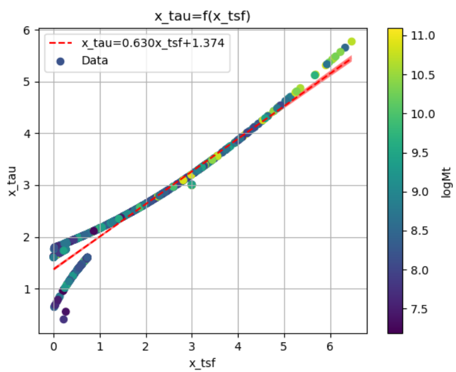


Figure 12: Comparing the two x, according to their total mass

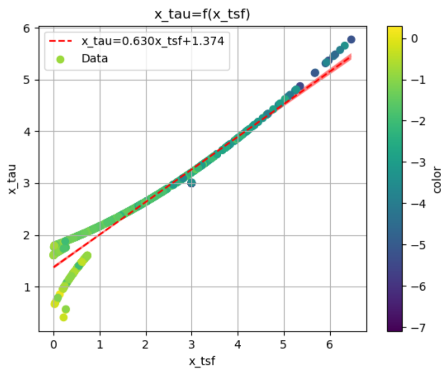


Figure 14: Comparing the two x, according to their color index

The two results are interrelated through the equation:

$$x|_\tau = (6.30(6) \times 10^{-1}) \cdot x|_{tsf} + (1.374(15) \times 10^0) \\ \text{with correlation } R^2 = 94\% \tag{7}$$

and from the plots the following conclusions can be drawn:

1. The galaxies with a higher total mass deviate less from the linear fit and are older.
2. The younger galaxies are mainly later types of galaxies
3. For lower x's, the galaxies have a lower color index which indicates that they are younger. So the values are inline with the experimental values.

3.3.2 Comparing the normalization constants

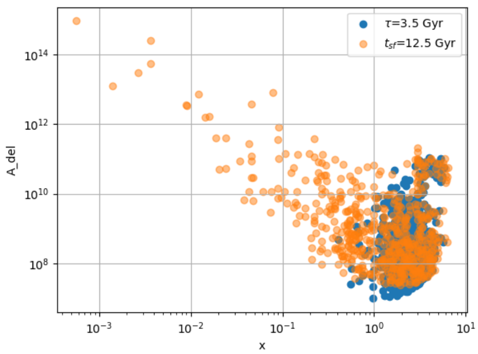


Figure 15: Comparing the two A_{del}

For high x and high masses the two A_{del}s have a high correlation. Specifically:

1. For high x the $A_{del}|_\tau - A_{del}|_{t_{sf}}$ plot follows a $y = x$ trend, which means that for older stars and stars with a low star formation timescale τ, the normalization constant is the same despite the method used to calculate it.
2. The same is true for more massive galaxies, since they deviate less from the $y = x$ line

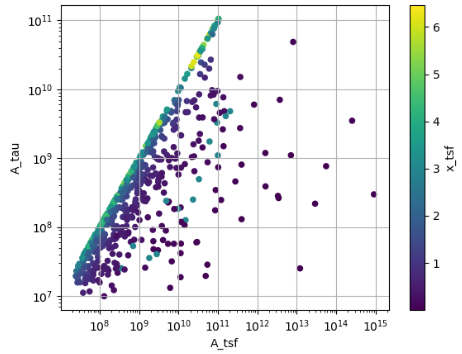


Figure 16: Comparison of the 2 A_{del}s according to their x

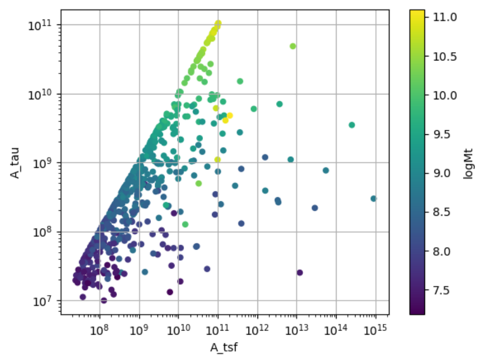


Figure 17: Comparison of the 2 A_{del}s according to their total masses

3.3.3 Trying to make the A_{del} cloud more compact

Having found $x|_{t_sf}$ and $x|_\tau$ we can find a relation between these two values

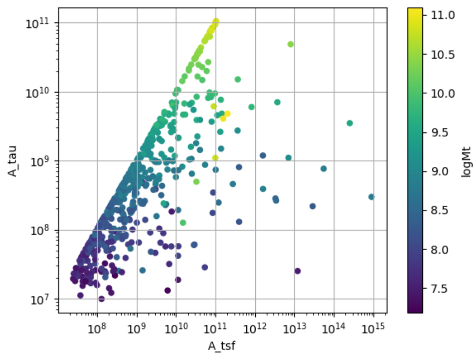


Figure 18: Comparison of the 2 A_{del}s according to their total masses

3.4 Int SFR to find the A_{del}

If we integrate equation (**??**) we get:

$$
\begin{aligned}
\int_0^{t_{sf}} SFR_{del} dt_{sf} &= \int_0^{t_{sf}} \frac{A_{del} t_{sf} e^{-t_{sf}/\tau}}{\tau^2} dt_{sf} \\
M_* &= -A_{del} \frac{(t_{sf}\tau + \tau^2) e^{\left(-\frac{t_{sf}}{\tau}\right)}}{\tau^2} + A_{del} \\
M_* &= -A_{del} \frac{\tau^2 (x+1) e^{-x}}{\tau^2} + A_{del} \\
M_* &= A_{del}(1 - (x+1)e^{-x}) \\
A_{del} &= M_* \frac{e^x}{e^x - x - 1}
\end{aligned}
\tag{8}
$$

From the plots

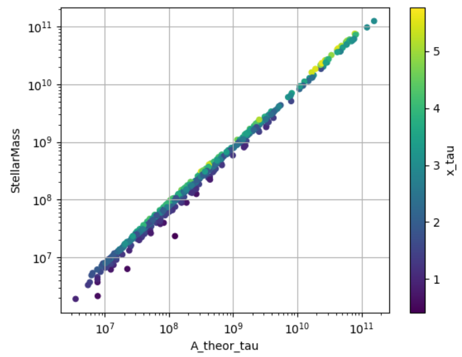


Figure 19: Comparison of the 2 A_{del}s according to their total masses

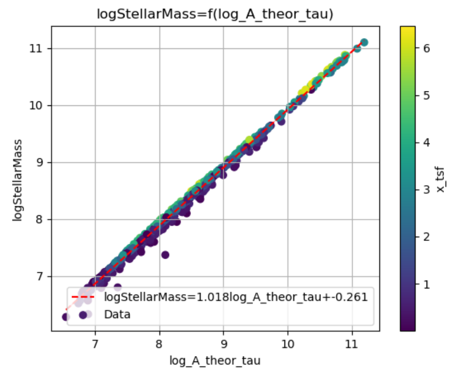


Figure 20: Comparison of the A_{del} according to their Stellar Mass

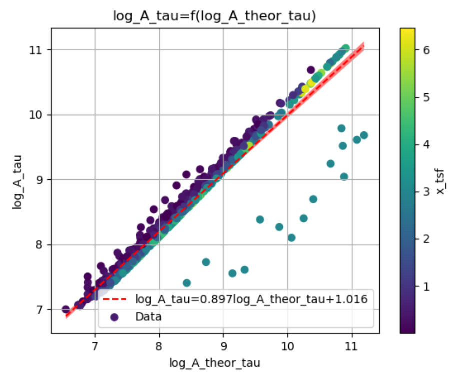


Figure 21: Comparison of the 2 $A_{del}|_{\tau=const.}$s (theoretical and experimental)

4 The gas depletion timescale τ_g

The gas depletion timescale τ_g measures the time taken by a galaxy to exhaust its gas content Mg given the current SFR[6, 7].

$$\tau_g = \frac{M_g}{\dot{M}_*} = \frac{M_g}{SFR} \tag{9}$$

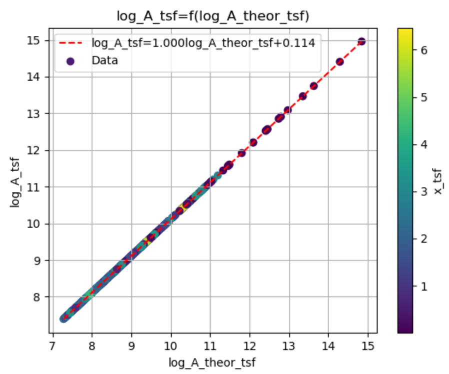


Figure 22: Comparison of the 2 $A_{del}|_{tsf=const.}$s (theoretical and experimental)

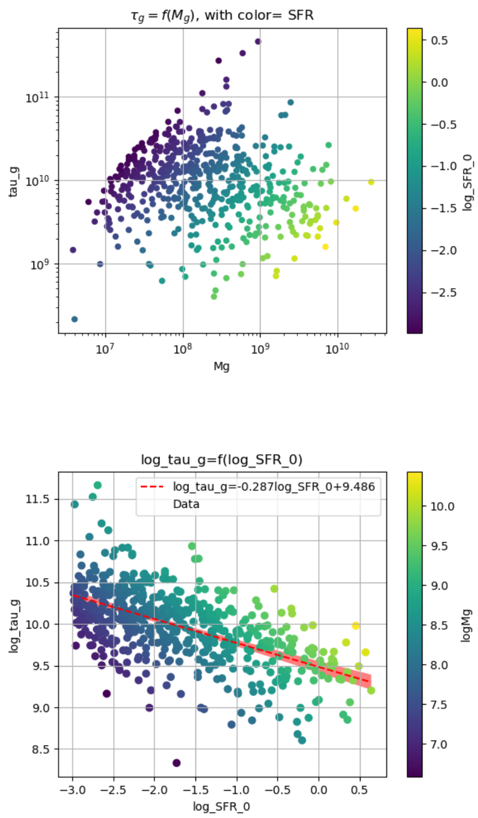


Figure 23: Correlation of the τ_g with the SFR and the gas mass

Despite a weak logarithmic correlation (as indicated by $R^2 = 32\%$), there is a noticeable trend of decreasing τ_g with increasing SFR and M_g.

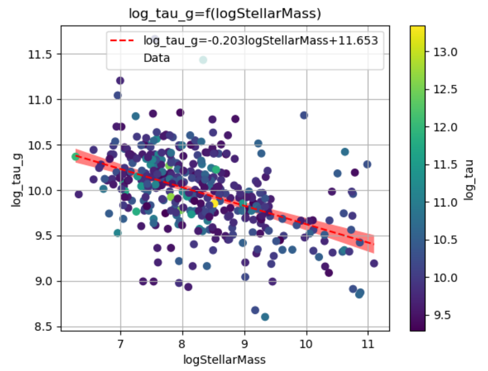


Figure 24: Correlation of the τ_g with the SFR and the Stellar mass

The logarithmic correlation between $\tau_g - M_*$ is low ($R^2 = 21\%$), there seems to be a pattern wherein the decrease of τ_g corresponds to an increase in the values of the Stellar Mass, but there does not seem to be one for $\tau_g - \tau$

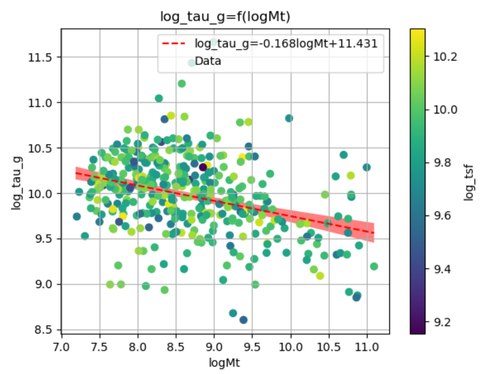


Figure 25: Correlation of the τ_g with the total mass and the mass of the gas

Again it can be observed that as the τ_g decreases, the corresponding values of M_t increase, but the logarithmic correlation is again low ($R^2 = 11\%$), and there is no clear correlation between $\tau_g - t_{sf}$

There is a notable trend, wherein for high masses we have a shorter timescale.

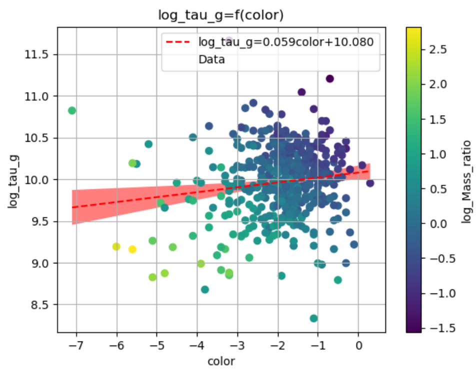


Figure 26: Correlation of the τ_g with the color index

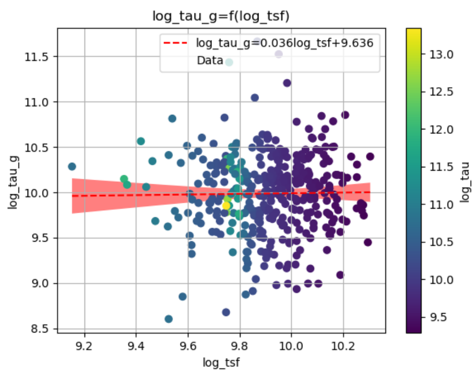


Figure 27: Correlation of the τ_g with the color index

5 Mass relations

Many of the galaxies masses have a high correlation with each other, and also help us understand the previous calculations.

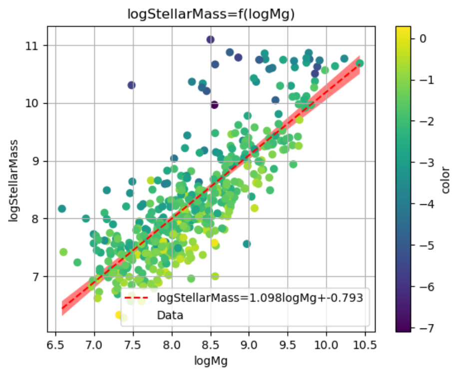


Figure 28: Gas Mass-Stellar Mass plot

For the plot **??**:

$$M_g = (1.098(35) \times 10^0) \cdot M_* + (-7.9(2.9) \times 10^{-1})$$
$$\text{with correlation } R^2 = 64\% \tag{10}$$

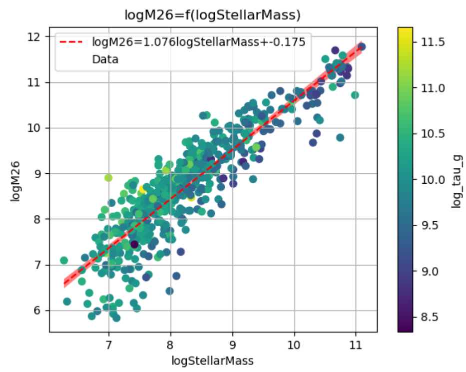


Figure 29: Mass inside the Holmberg radius-Stellar Mass plot

For the plot **??**:

$$M26 = (1.076(23) \times 10^0) \cdot M* + (-1.8(1.9) \times 10^{-1})$$
$$\text{with correlation } R^2 = 80\% \tag{11}$$

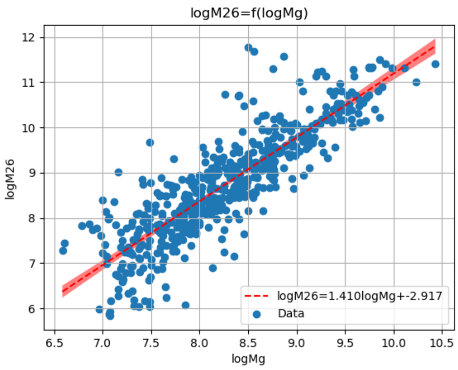


Figure 30: Mass inside the Holmberg radius-Gas Mass plot

For the plot **??**:

$$M26 = (1.41(4) \times 10^0) \cdot Mg + (-2.92(30) \times 10^0)$$
$$\text{with correlation } R^2 = 74\% \tag{12}$$

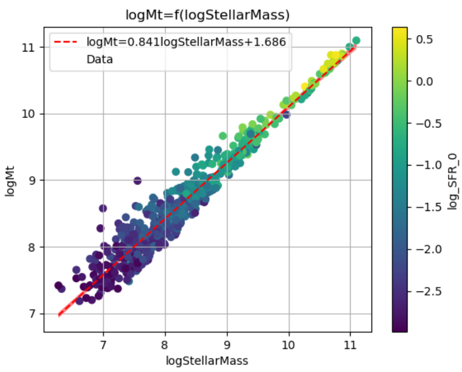


Figure 31: Stellar Mass-Total Mass plot

For the plot **??**:

$$M_t = (8.41(9) \times 10^{-1}) \cdot M_* + (1.69(8) \times 10^0)$$
$$\text{with correlation } R^2 = 94\% \tag{13}$$

For the plot **??**:

$$M_t = (1.065(23) \times 10^0) \cdot M_g + (-1.5(1.9) \times 10^{-1})$$
$$\text{with correlation } R^2 = 81\% \tag{14}$$

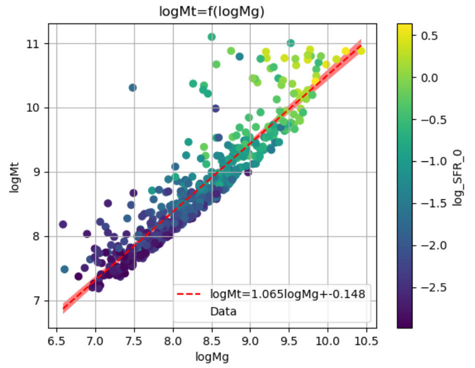


Figure 32: Total Mass - Gas Mass plot

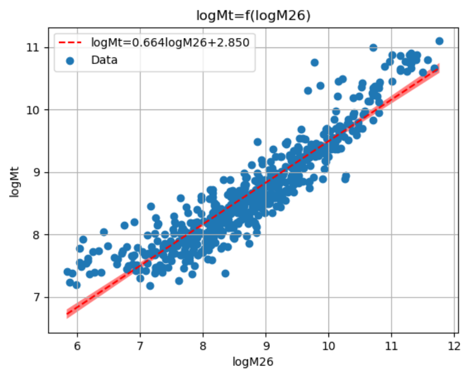


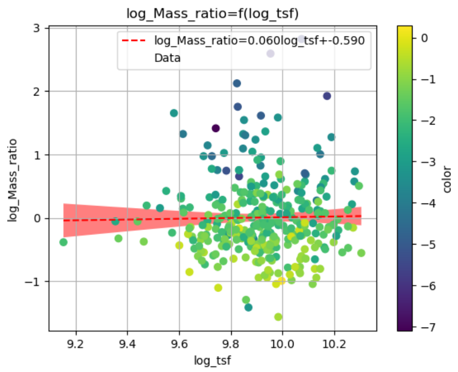
Figure 33: Mass inside the Holmberg radius-Total Mass plot

$$M26 = (6.64(12) \times 10^{-1}) \cdot \mathrm{M}_t + (2.85(11) \times 10^0) \quad \text{with correlation } R^2 = 85\% \tag{15}$$

There are many plots exhibiting a correlation of $R^2 > 80$

The $M_t - M_*$ (**??**) plot is particularly noteworthy, displaying a correlation of $R^2 = 94\%$. This plot also indicates that galaxies with greater total and stellar masses tend to have higher SFR, consistent with the findings in section **??** where τ_g decreases with increasing masses.

This phenomenon is likely due to the fact that galaxies with higher masses possess greater potential energy, which accelerates the star formation process. The galaxies with a high Mass ratio M_r could also help the process due to their dense regions and the resulting strong local gravitational potential.



From the **??**, we conclude that when the color index is higher the Mass ratio decreases, which is to be expected, since the higher the B-FUV the more active the star formation of the galaxy.

6 Variations in Star Formation Rate Across the Different Masses

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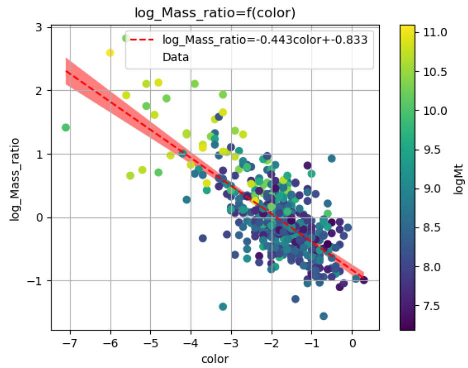


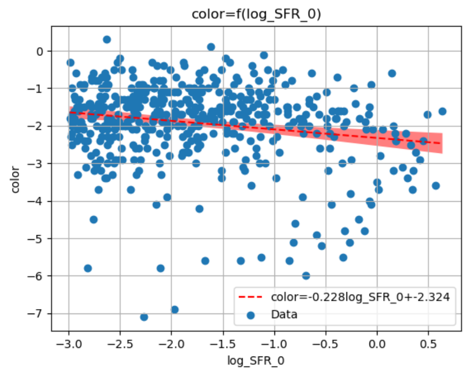


Figure 36: None

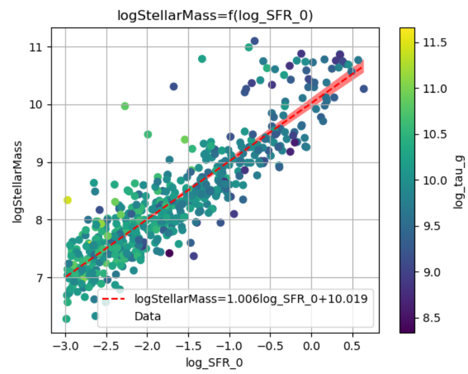


Figure 37: None

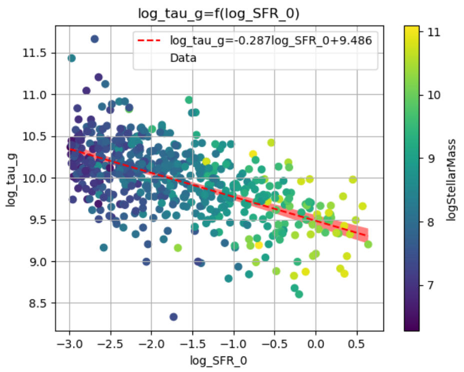


Figure 38: None

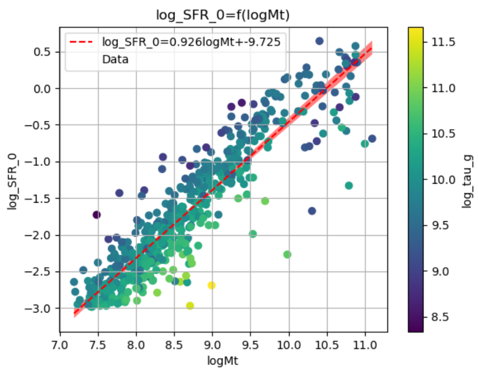
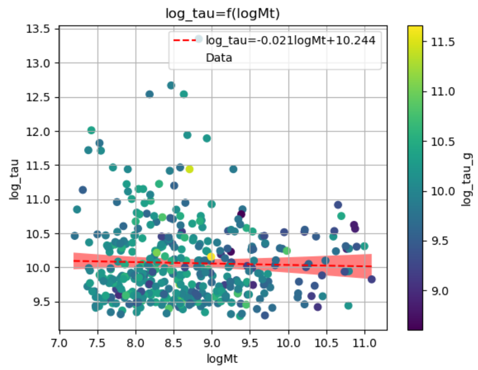


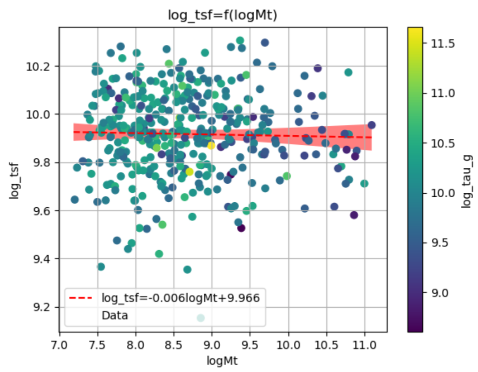
Figure 39: None

fig:None #+caption:None#+ATTR$_{\LaTeX}$: :placement [!htpb]



’, ’logMt-log$_{tau}$-color$_{logtaug}$’)

(<statsmodels.regression.linear$_{model.RegressionResultsWrapper}$ object at 0x7f4adf0bd6d0>, ’#+name: fig:None #+caption:None#+ATTR$_{\LaTeX}$: :placement [!htpb]



’, ’logMt-log$_{tsf}$-color$_{logtaug}$’)

6.1 TODO **put that tau and tsf dont have a correlation with Mt**

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