Chemical evolution of galaxies: emerging dust and the different gas phases in a new multiphase code

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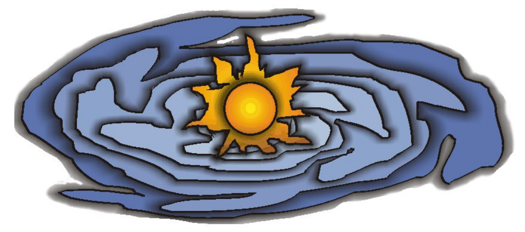
Abstract: Dust plays an important role in the evolution of a galaxy, since it is one of the main ingredients for efficient star formation. Dust grains are also a sink/source of metals when they are created/destroyed. Therefore, its self-consistent treatment is key to correctly model chemical evolution. In this work, we discuss the implementation of dust physics into our current multiphase model, which also follows the evolution of atomic, ionised and molecular gas. Our goal is to model the conversion rates among the different phases of the interstellar medium, including the creation, growth and destruction of dust, based on physical principles rather than phenomenological recipes as much as possible. We calibrate our model against observations o fthe Milky Way Galaxy and compare its predictions with extant data. Our results are broadly consistent with the observed data for intermediate and high metallicities, but the models tend to produce more dust than observed in the low metallicity regime.



Context

Dust is a very small amount of the mass of a galaxy, e.g., the dust mass is just ≈ 1% of the ISM of the Milky Way.

Dust plays a indispensable role in key processes in the evolution of galaxies, such as, molecular gas creation, molecular cloud shielding, …

Furthermore, the adequate determination of the dusty content of a galaxy is crucial to determine correctly the abundance of the element that are depleted inside dust grains.

In order to model self-consistently the chemical evolution of the galaxy it is necessary to simulate appropriately the structure of the ISM including all the processes that affect the equilibrium between the phases of the ISM.

The dust cycle goes as follows:

1- Dust grains form in the AGB phase of small and intermediate mass stars and late phase of supernovae

2- Dust grows in the densest parts of the ISM

3- Grains are destroyed due to the shock waves of the initial phases of supernovae

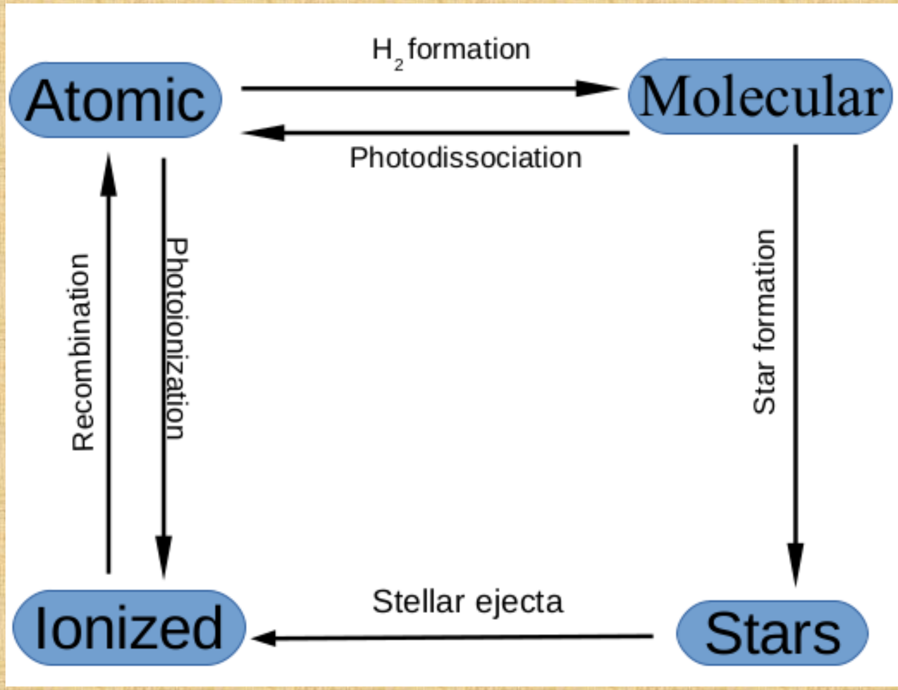
Description of the model

We have created a program to compute the galactic chemical evolution that includes the vital modelling of dust creation and destruction.

Moreover, our code simulates the multiphase structure ISM that includes 3 phases: atomic, ionised and molecular.

We do not use any free parameter to model the multiphase structure of the ISM, just rely on physical principles and observational data.

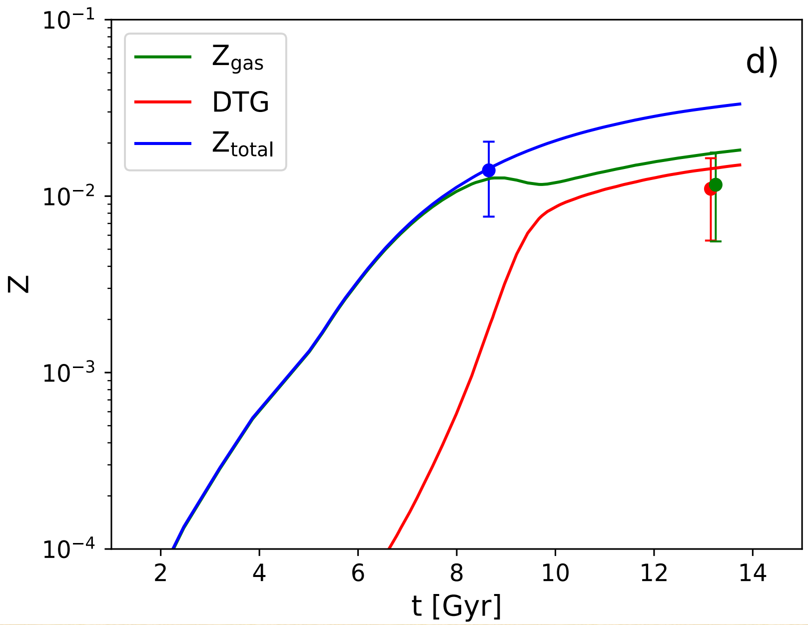
$$
\begin{aligned}
\dot{\Sigma}_{\rm X} &= -\frac{\Sigma_X}{\Sigma_{\rm ISM}}\Psi(\rm t) + E_X(\rm t) + X_0 I_i(\rm t) \\
\dot{\Sigma}_{\rm Y} &= -\frac{\Sigma_Y}{\Sigma_{\rm ISM}}\Psi(\rm t) + E_Y(\rm t) + Y_0 I_i(\rm t) \\
\dot{\Sigma}_{\rm Z} &= -\frac{\Sigma_Z}{\Sigma_{\rm ISM}}\Psi(\rm t) + E_{Z_{gas}}(\rm t) + \frac{\Sigma_d}{\tau_{dest}} - \left(1 - \frac{\Sigma_d}{\Sigma_Z}\right)\frac{\Sigma_d}{\tau_g} f_m \\
\dot{\Sigma}_{\rm dust} &= -\frac{\Sigma_{dust}}{\Sigma_{\rm ISM}}\Psi(t) + E_{dust}(\rm t) - \frac{\Sigma_d}{\tau_{dest}} + \left(1 - \frac{\Sigma_d}{\Sigma_Z}\right)\frac{\Sigma_d}{\tau_g} f_m,
\end{aligned}
$$



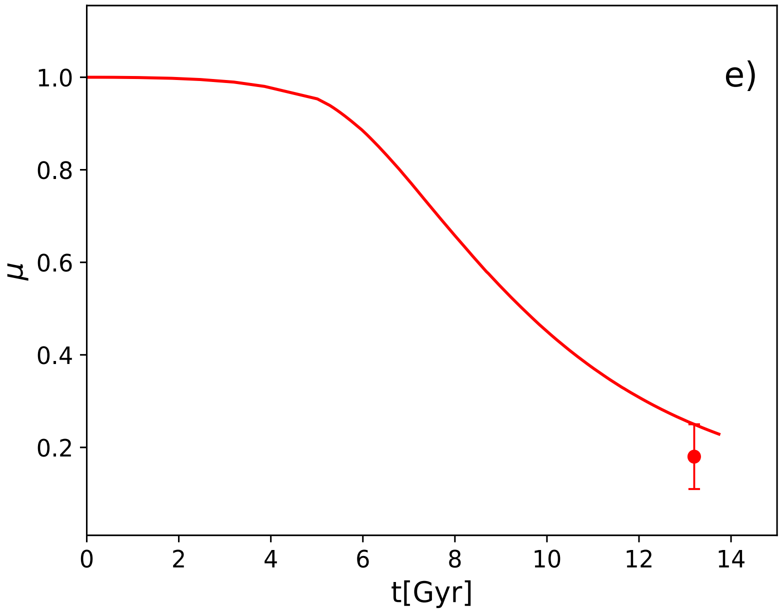
The diagram summarizes all the phases and processes we consider for the ISM and stars:

- Atomic
- Ionized
- Molecular

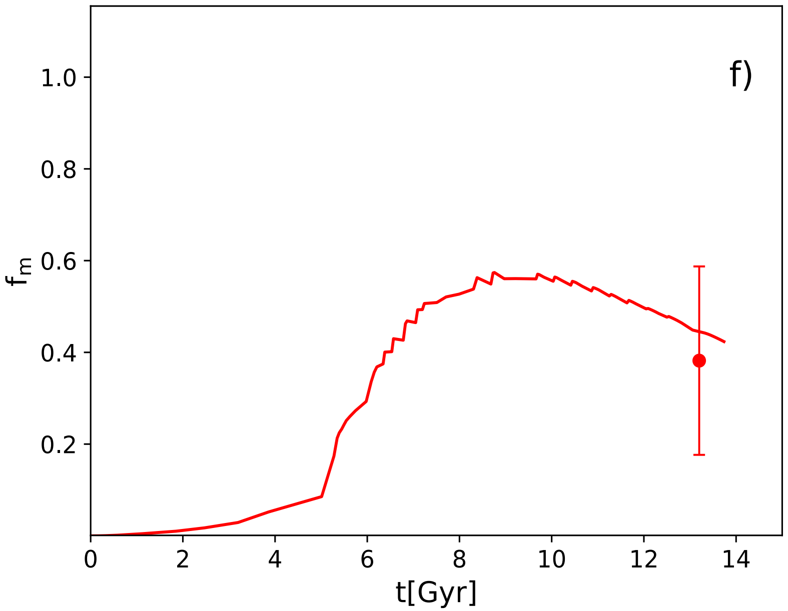
Results



The total metallicity 4.5 years ago matches the metallicity of the Sun. Gas metallicity and dust to gas ratio (DTG) of the solar neighbourhood reached observed values.



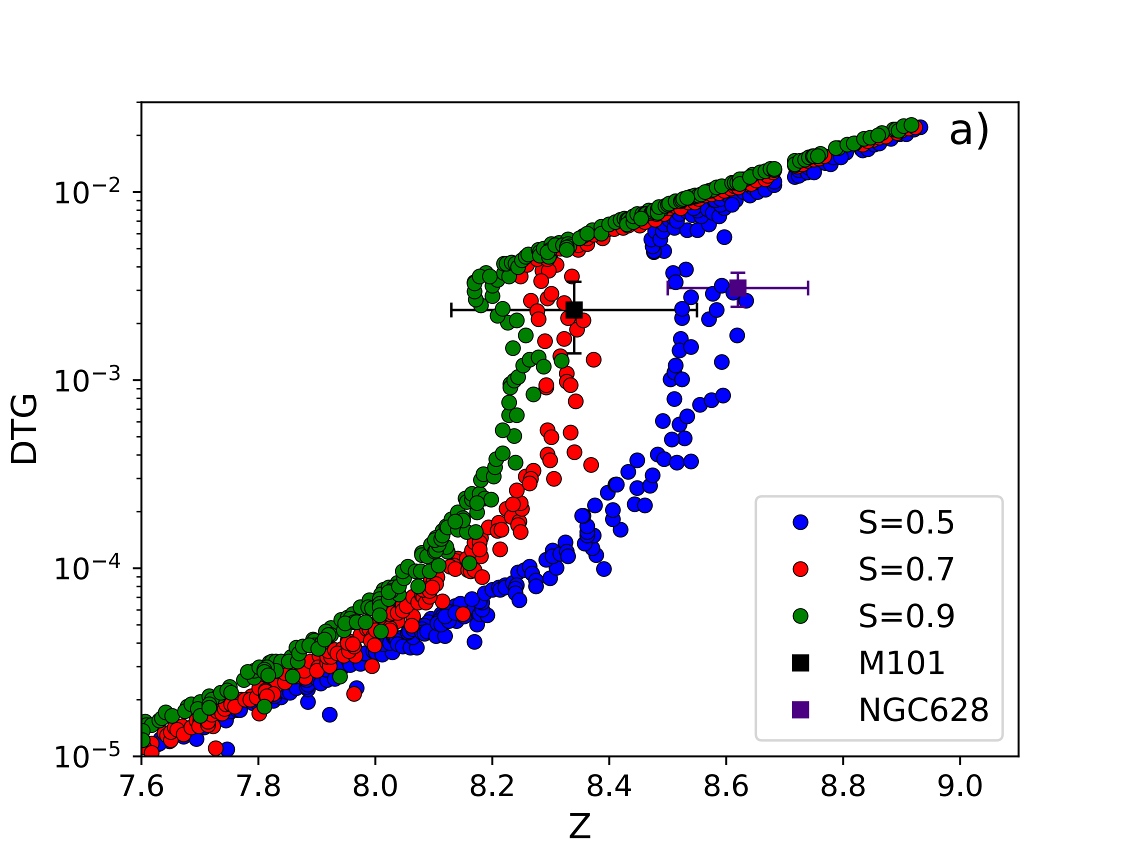
Gas fraction reaches the values of the solar neighbourhood within the error bars.

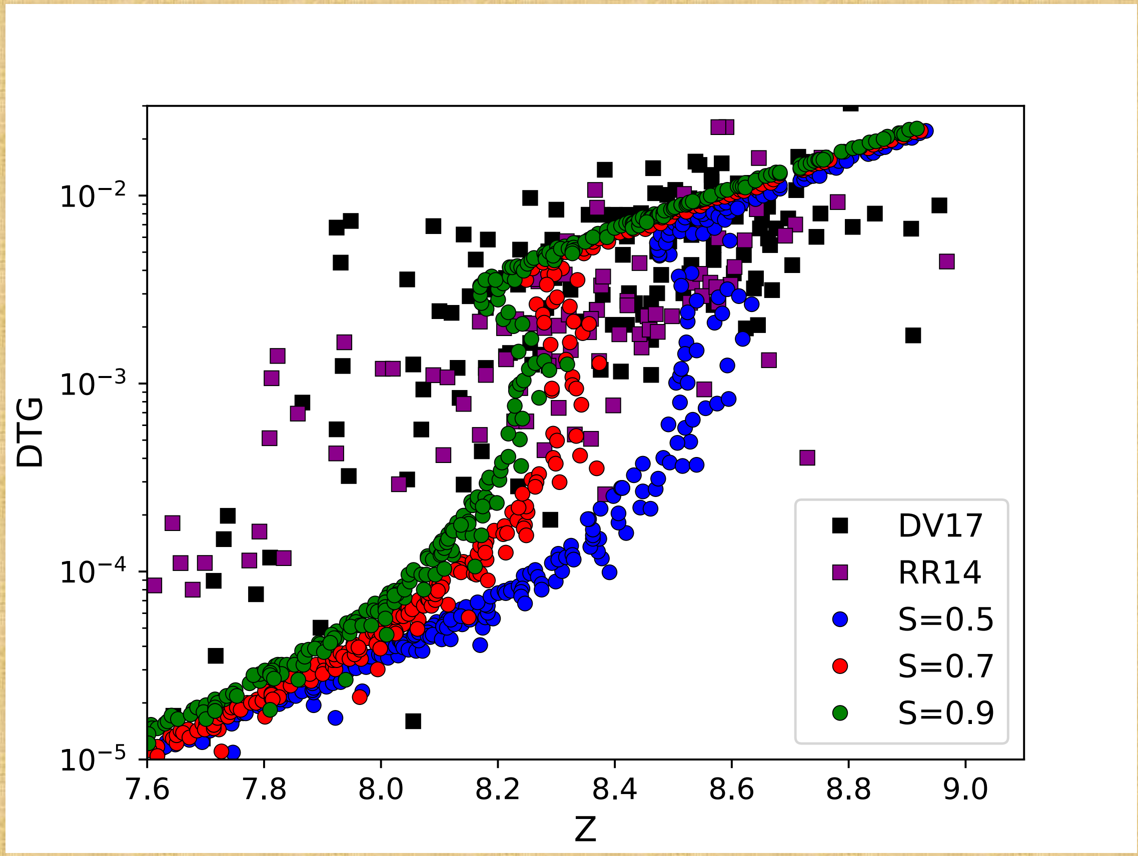


Molecular gas fraction of our models get the expected values.

Our models were tested with solar neighbourhood observational data.
We reproduced correctly all the data:
Z, DTG, supernova rate, star formation rate, stellar mass surface density and total surface density.

Results





Our models have been compared with the IFU data of M101 and NGC628 obtained by Vilchez et al. 2019. The mean DTG and Z of both galaxies are consistent with our models.

We have compared with observations of large galaxy samples of Remy-Ruyer et al. 2014 (RR14) & De Vis et al. 2017(DV17). We reproduce the observed values of DTG-Z diagram at medium and high metallicities. However, the low metallicity range is not well reproduced. This is due to modelling limitation at the early stages of the galaxy and uncertainties of dust yields at low metallicity.

Conclusions

- We have created a galactic chemical evolution model that computes the evolution of the metals and dust inside a galaxy that includes the evolution of a multiphase ISM.
- Our models have been tested with Solar neighbourhood data.
- Our models reproduce the DTG-Z relationship in medium and high metallicity regime, but have some discrepancies at the low metallicity regime.
- This discrepancy is probably due to uncertainties of dust ejecta in low metallicity stars and, more important, to the limitations at the early stages of the galaxy when the metallicity is low: the formation of dust needs other mechanism independent of the metal content.
- Our next goal is to expand our model to follow the evolution of the main dust grain species.