Role of dust in Galactic Chemical Evolution

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Outline

1. Introduction
2. Galactic chemical evolution model
   - Ingredients
     - Infall
     - Star formation
     - Ejecta
   - Dust life cyle
     - Dust formation
     - Dust destruction
3. Results

Introduction

- Galactic chemical evolution analyses the time evolution of the different chemical species
- Dust grains play a major role in galactic because they are the main mechanism of molecular hydrogen formation
- They also shield the molecular clouds from photodissociation

Model

We have created a galactic chemical evolution model including the effects of the lifecycle of dust

Our model considers that the galaxy has three phases:

- Atomic phase ($T = 100$K)
- Ionized phase($T = 10000$K)
- Molecular phase ($T = 10$K)

Model

- We have taken into account the different processes that change the phase of particles:
  - Photoionization
  - Photodissociation
  - Recombination
  - Molecular hydrogen formation

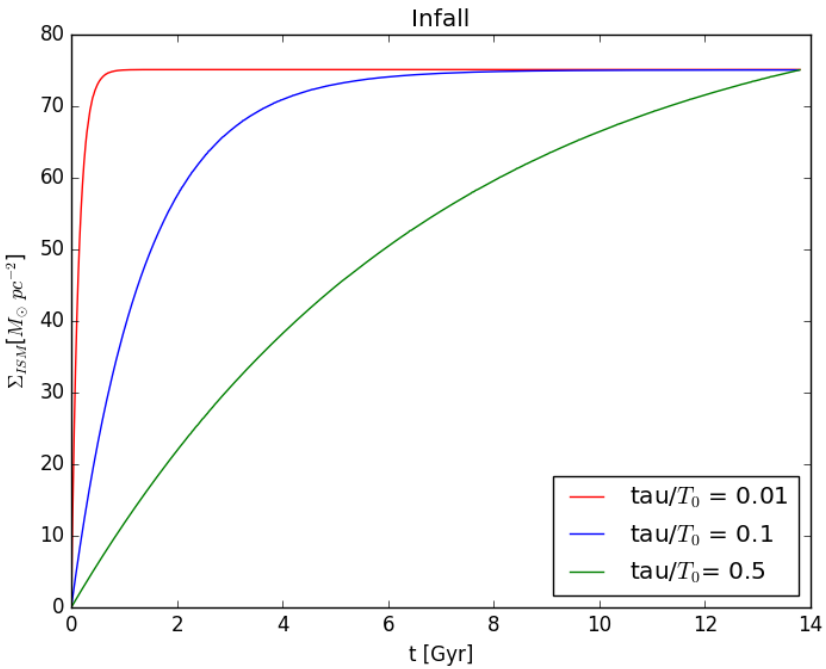
Model equations

- The evolution of the surface density of the different phases is:
  - $\dot{\Sigma}_a = \frac{\Sigma_i}{\tau_{rec}} - \eta_{ion}\Psi(t) - \frac{\Sigma_a}{\tau_{cloud}} - \frac{\Sigma_a}{\tau_{nodust}} + \eta_{diss}\Psi(t)$
  - $\dot{\Sigma}_i = -\frac{\Sigma_i}{\tau_{rec}} + E(t) + \eta_{ion}(t)\Psi(t) + I_i(t)$
  - $\dot{\Sigma}_m = \frac{\Sigma_a}{\tau_{cloud}} + \frac{\Sigma_a}{\tau_{no\ \ dust}} - \Psi(t) - \eta_{diss}(t)\Psi(t)$
  - $\dot{\Sigma}_* = \Psi(t) - E(t)$
- The time evolution of the individual chemical elements are:
  - $\dot{\Sigma}_X = -\frac{\Sigma_X}{\Sigma_{\rm ISM}}\Psi(t) + E_X(t) + X_0 I_i(t)$
  - $\dot{\Sigma}_Y = -\frac{\Sigma_Y}{\Sigma_{\rm ISM}}\Psi(t) + E_Y(t) + Y_0 I_i(t)$
  - $\dot{\Sigma}_Z = -\frac{\Sigma_Z}{\Sigma_{\rm ISM}}\Psi(t) + E_Z(t) + \frac{\Sigma_{\rm dust}}{\tau_{\rm destruction}}$

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Infall



- We have simulated an isolated galaxy that accretes gas from the IGM
- $I(t) = \frac{\Sigma_I e^{-\frac{t}{\tau}}}{\tau(1-e^{\frac{T_0}{\tau}})}$

Star formation

- Tradionally, the SFR of a galactic region was chracterized using the Kennicutt-Schimdt law $\Psi(t) \propto \Sigma_{gas}^{n}$ where $n = 1.4$
- However, there are evidences that SFR is proportional to the molecular gas density
- $\Psi = \frac{\Sigma_m}{\tau_\Psi}$ where $\tau_\Psi = 3 Gyr$

Phase change

- Photoionization $\eta_{ion}(t) = \int_0^t dt' \ Q_i(t', Z(t'))$
- Recombination $\tau_{rec} = \frac{1}{n_i(t) \ <\sigma \ v>}$
- Photodissociation $\eta_{diss}(t) = 0.4 \ \ 0.15 \ \int_0^t dt' \ Q_d(t', Z(t'))$
- Molecular hydrogen formation
  $k_{dust} = 2.2 \ 10^{-19} \ \frac{D \ S \ n(H)[n(H)+2n(H_2)]}{<\rho> \ <a>} \ \left(\frac{T}{300}\right)^{0.5} \ [cm^3 \ s^{-1}]$ (Le Bourlot et al. 1995)

Ejecta

- The stars eject part of their initial mass to the ISM when they die
- There are three types of ejecta depending on the type of star that dies: low and intermediate mass star, high mass star and white dwarf with a companion star
- The ejection rate of an element j is
$E_j(t) = E_{j,\mathrm{AGB}}(t) + E_{j,\mathrm{SNcc}}(t) + E_{j,\mathrm{SNIa}}(t)$

Ejecta

- Low and intermediate mass stars end up their lifes in the AGB phase(Mollá et al. 2015)
- $E_{j,\mathrm{AGB}}(t) = \int_{M_{\mathrm{limit}}(t,Z)}^{M_{\mathrm{max}}} \Psi(t-\tau_M(M,Z))\ \Phi(M)\ e_{j,\mathrm{AGB}}(M, Z_{\mathrm{ISM}}(t-\tau_M(M,Z))\ dM$
- High mass stars' fate is to explode as core collapse supernovae (Woosley Weaver 1995)
- $E_{j,\mathrm{SNcc}}(t) = \int_{8}^{M_{\mathrm{max}}}\ dM\ \Psi(t-\tau_M(M,Z(t)))\ \Phi(M)\ e_{j,\mathrm{SNcc}}(M,Z(t))$
- Type Ia supernovae eject material to the ISM(Iwamoto et al. 1999)
- $E_{j,\mathrm{SNIa}}(t) = e_{j,\mathrm{Ia}} R_{\mathrm{SNIa}}$

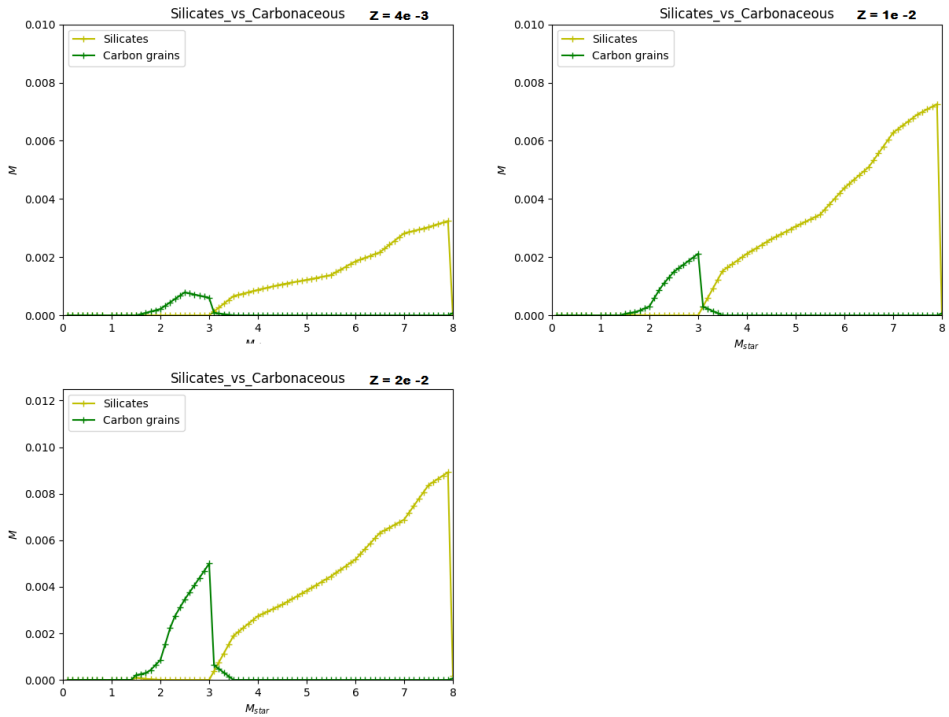
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Life cycle equations

- Our model considers the following dust species: Olivine, Pyroxene, Quartz, Carbonaceous materials, Silicon Carbide and Iron
- The time evolution of the surface density of a dust species j is:
- $\dot{\Sigma}_{d,j} = -\frac{\Sigma_{d,j}}{\Sigma_{\rm gas}}\Psi(t) + E_{d,j} - \frac{\Sigma_{d,j}}{\tau_{Destruction}}$

Dust formation



- Dust grains are formed in: the Asymptotic giant branch(AGB) phase of low mass stars and the last phases of supernova shock waves
- The type of grain of the AGB ejecta depends on the $\frac{C}{O}$ ratio inside the stellar atmosphere

Dust formation

- Even though SN shock wave is the main destruction mechanism of the grains, dust grains are created during the last phase of a supernova shock waves (Bianchi Schneider 2007)
- As the composition of the progenitors of a type Ia SN is very similar, the main difference of the ejecta is the exact mechanism that triggers the explosion (Nozawa et al. 2011)

Dust destruction

- Dust grains are mainly destroyed by supernova shock waves (Asano et al. 2015)
- $\Gamma_{destruction,SNe,j} = -\frac{\Sigma_{d,j}}{\tau_{destruction}}$ where $\tau_{destruction} = \frac{\Sigma_{\rm ISM}}{\epsilon \; f_{SN} \; M_{swept,j} \; R_{SN}}$ and $M_{sweept} = 1535 \; n^{-0.202} \left(\frac{Z}{Z_{\odot}} + 0.0039 \right)^{-0.289} M_{\odot}$
- Dust is also destroyed via star formation $\Gamma_{destruction,SF,j} = -\frac{\Sigma_{d,j}}{\Sigma_{\rm ISM}} \Psi(t)$

Using tables

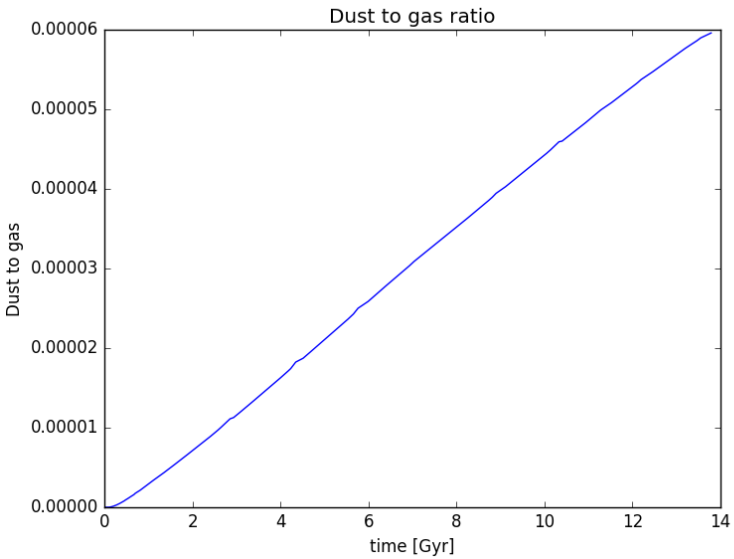


Figure: Dust to gas ratio evolution

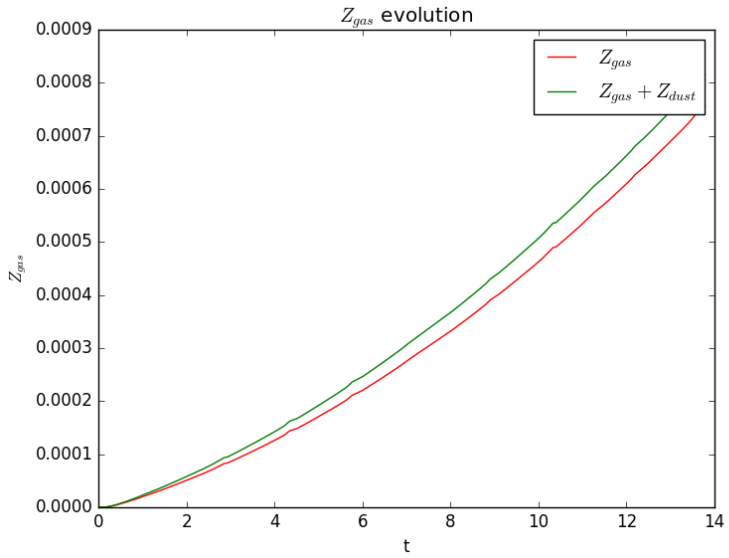


Figure: Evolution of the metallicity

Using tables

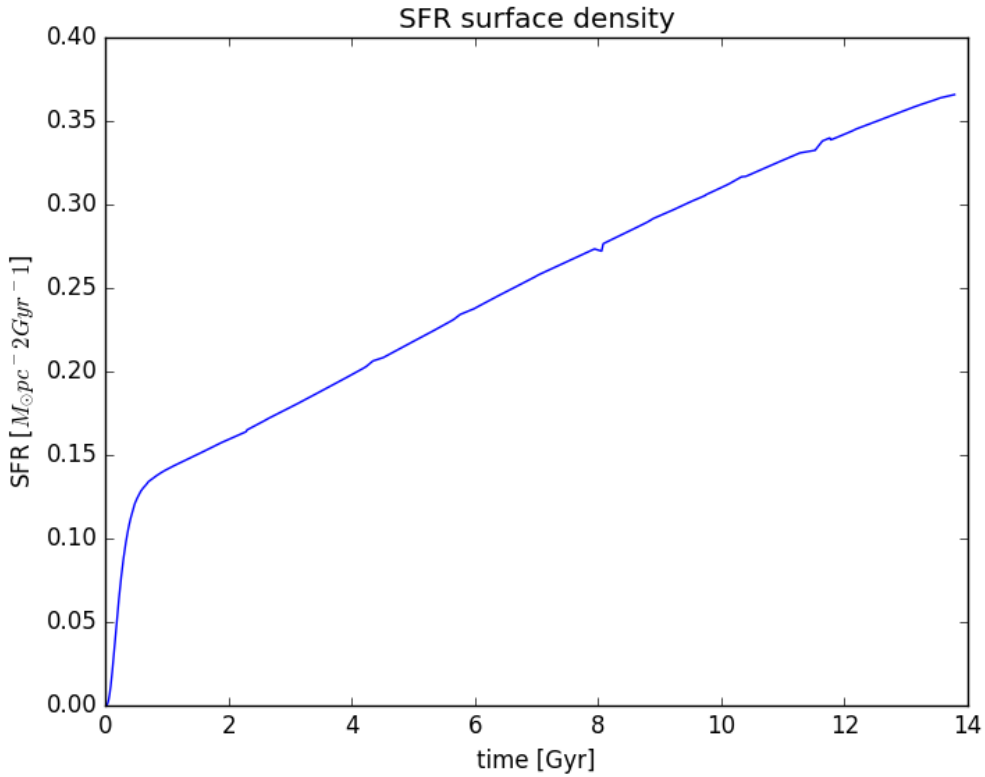


Figure: SFR surface density evolution

Maximal depletion

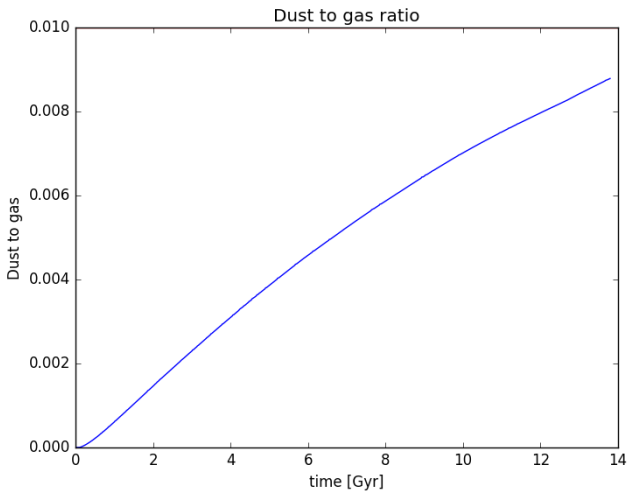


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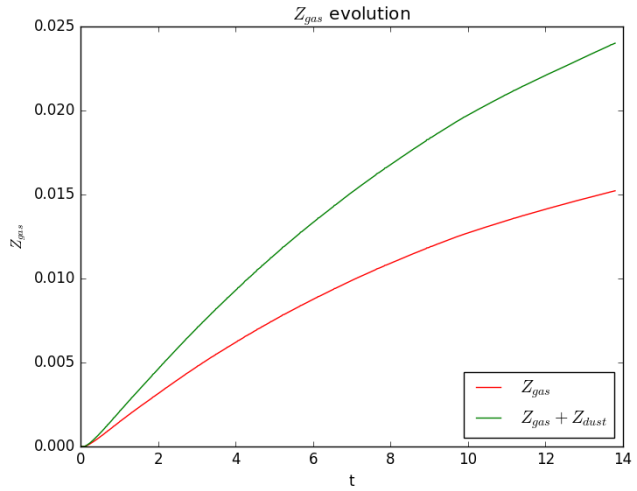


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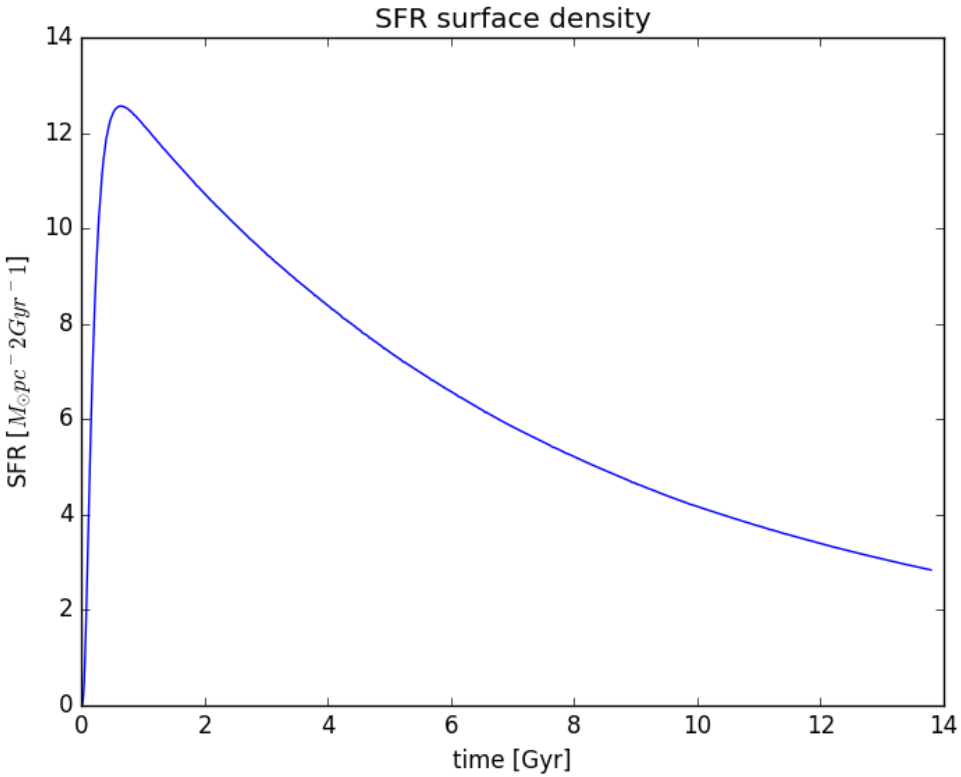


Figure: SFR surface density evolution

Summary

- Dust grains play an important role in several processes that are critical to chemical evolution
- There is a choke point at the first stages of the galaxy using the values of the tables
- Ejecting the maximum dust that stars can eject and deactivating the destruction via supernova explosions we approximately reproduce the dust to gas ratio but we underestimate the metallicity of the gas