Chemical evolution of dwarf galaxies with dust

Galactic surveys: New results on Formation, Evolution, Structure and Chemical Evolution of the Milky Way

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PhD student:
Lorenzo Gioannini

University of Trieste

Supervisors:
Francesca Matteucci
Giovanni Vladilo

Outline of presentation

- **Introduction**
- What is cosmic dust?
- What we want to study?
- Dust cycle

Model prescriptions

- Dust sources
  AGB stars
  Type II SNe
- Dust processing
  Accretion
  Destruction

Modeling chemical evolution with dust

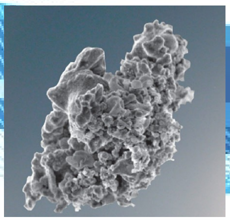
- Chemical evolution equations
- Dust prescriptions

Results

- Following dust mass evolution
- Dust in dwarf galaxies: comparison with dust amount and elemental depletion in DLAs

Cosmic dust

Dust particles are grains of size of the order of 0.1 um

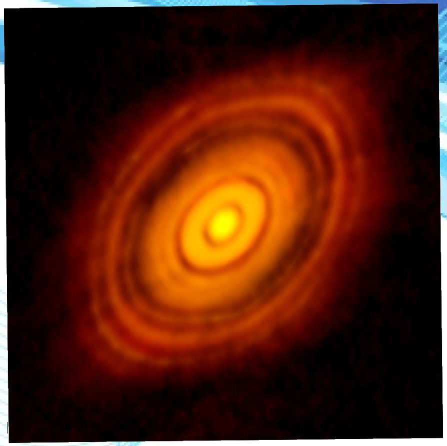


Its presence deeply changes the spectral energy distribution of background sources (flux reduction and reddening)

What we want to study:

- Chemical evolution of the dust
- Constrain on dust chemical composition

Test on new prescriptions on dwarf galaxies

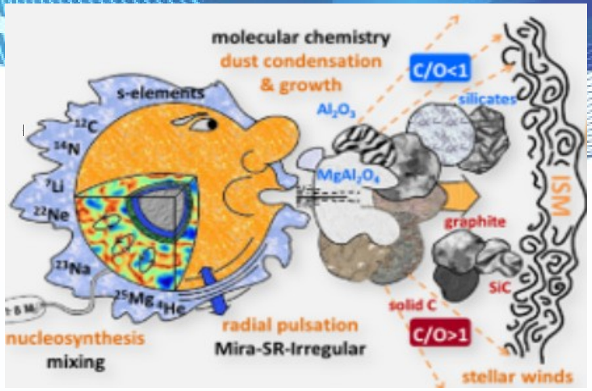


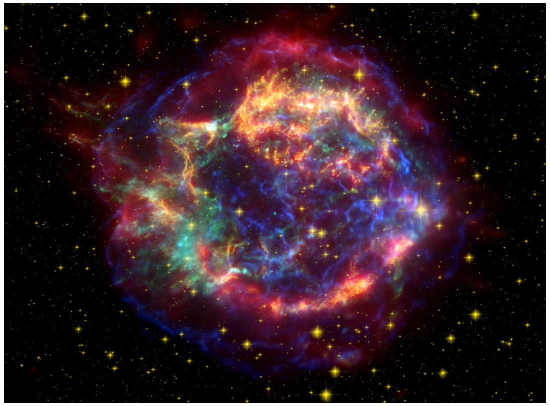
Dust formation from AGB and Type II SNe

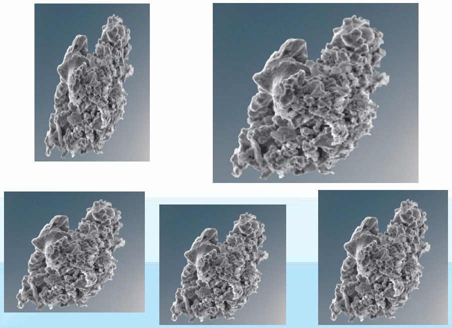
Dust processing in the ISM (destruction and outflow)

Dust accretion in Molecular clouds

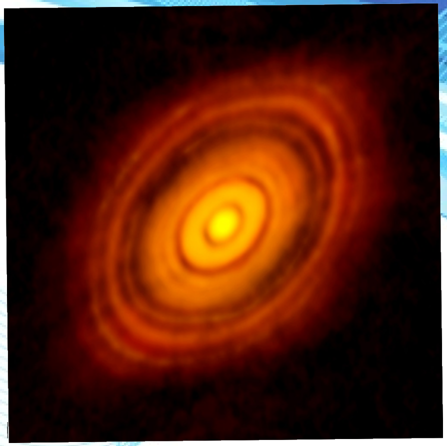
Dust astration

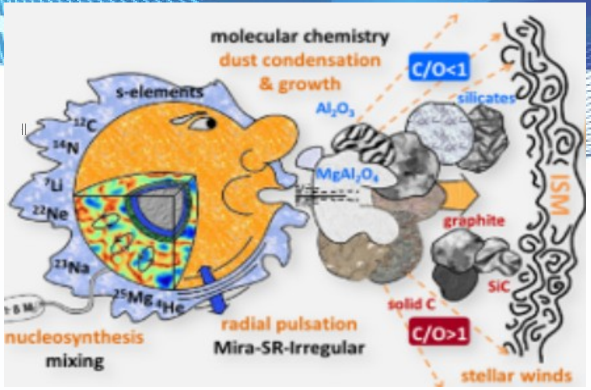


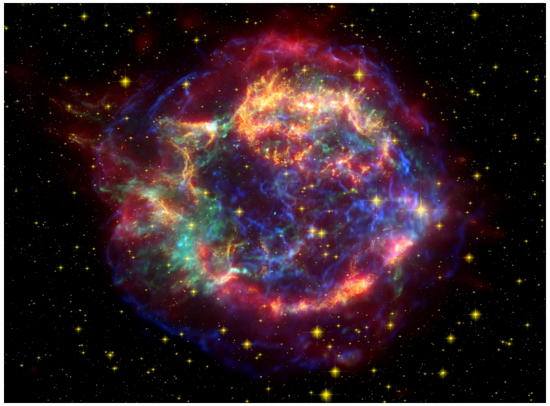


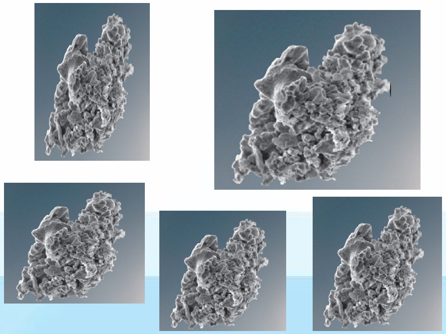


Dust cycle




molecular chemistry
dust condensation & growth
C/O<1
s-elements
^{12}C
^{14}N
^{7}Li
^{22}Ne
^{23}Na
^{25}Mg
^{4}He
Al_2O_3
silicates
$MgAl_2O_4$
ISM
graphite
SiC
solid C
C/O>1
radial pulsation
Mira-SR-Irregular
nucleosynthesis
mixing
stellar winds





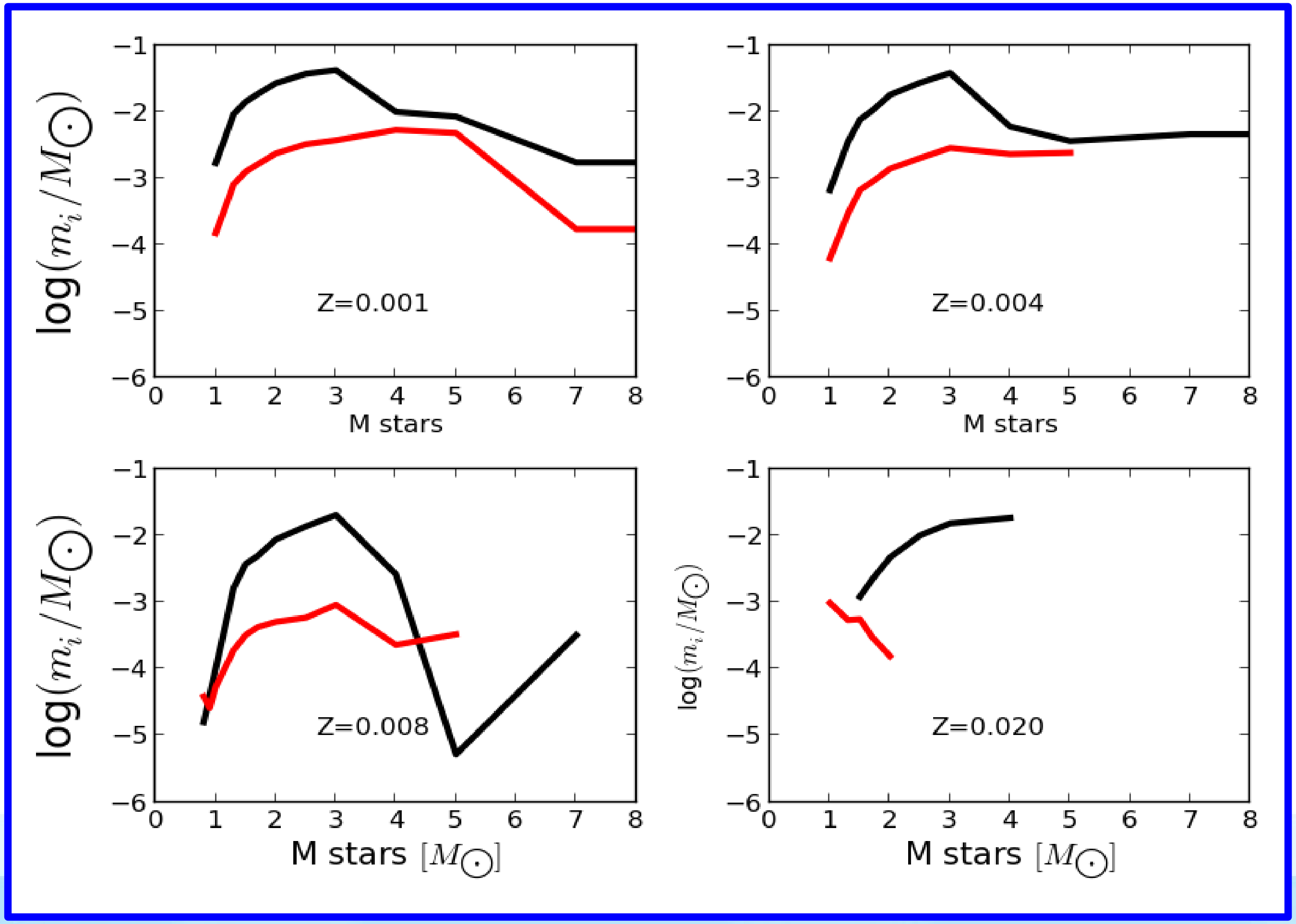
Dust production by AGB stars

Stellar yields

(van den Hoek & Groenewegen 1997)

Carbon

Oxygen



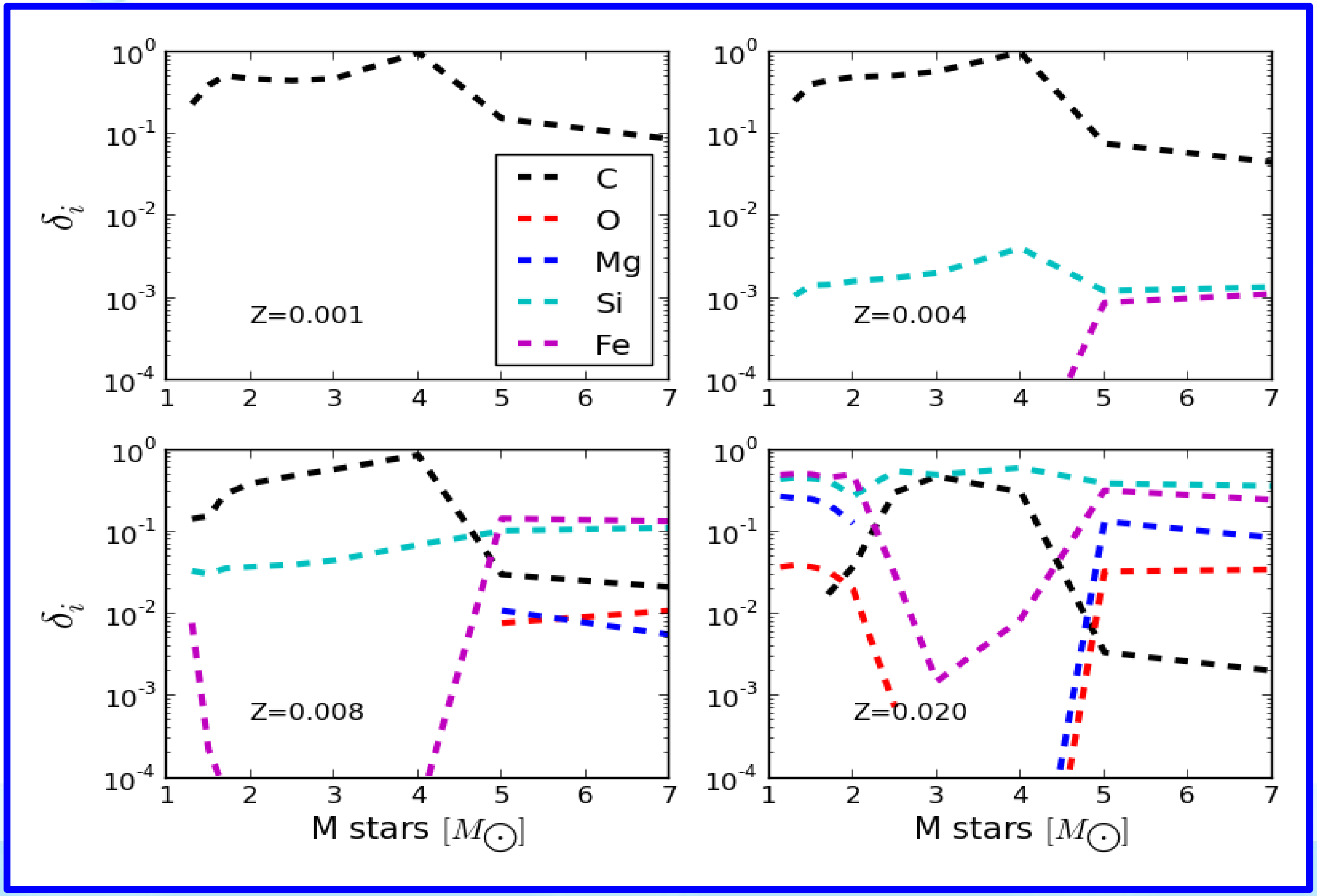
Dust production by AGB stars

Dust condensation efficiencies:

Represent the efficiency of how much of a single element in the gas phase condenses in dust phase

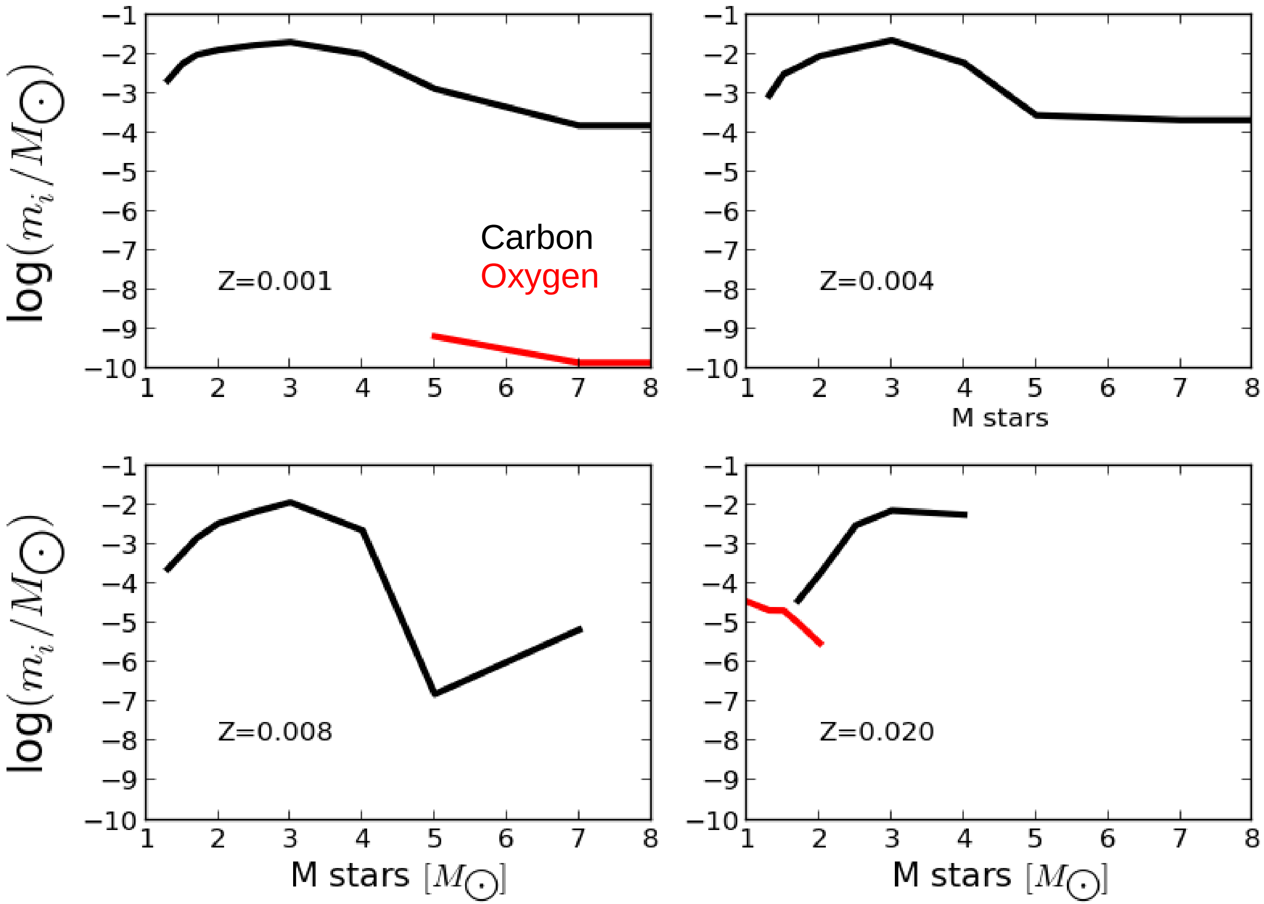
Condensation efficiencies were obtained by the comparison between theoretical studies and observational data.

Values from Piovan et al. 2011



Dust production by AGB stars

Dust yields



Dust amount produced is consistent with predictions of Dwek 1998, Zhukovska et al. 2008, Valiante et al. 2009: $M_d \leq 10^{-2}$ M_O and picked between 2-3 M_O

Overabundance of carbon dust with respect to silicates

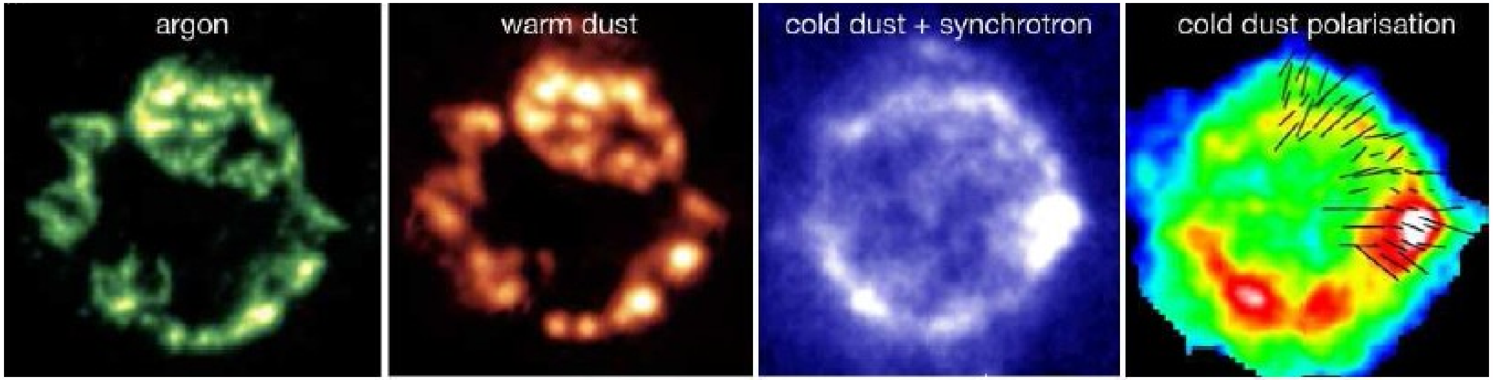
- Good agreement with carbon dust.
- Lower silicates and iron dust mass produced

Dust production by Type II SNe

Type II SNe are believed to cover an important role in dust production as witnessed by observation:

- Presence of dust in historical SNe (SN1987 (First by Danziger et al. 1989), Crab Nebula, Cas A, Gomez 2013 and reference therein)
- Presence of dust in High-redshift objects requires an efficient and quick source, i.e. Type II SNe (Carilli & Walter 2013, Dwek et al. 2011)

Cassiopea A
(Spitzer IRS, Rho et al. 2008)
(SCUBA, Dunne et al. 2003)

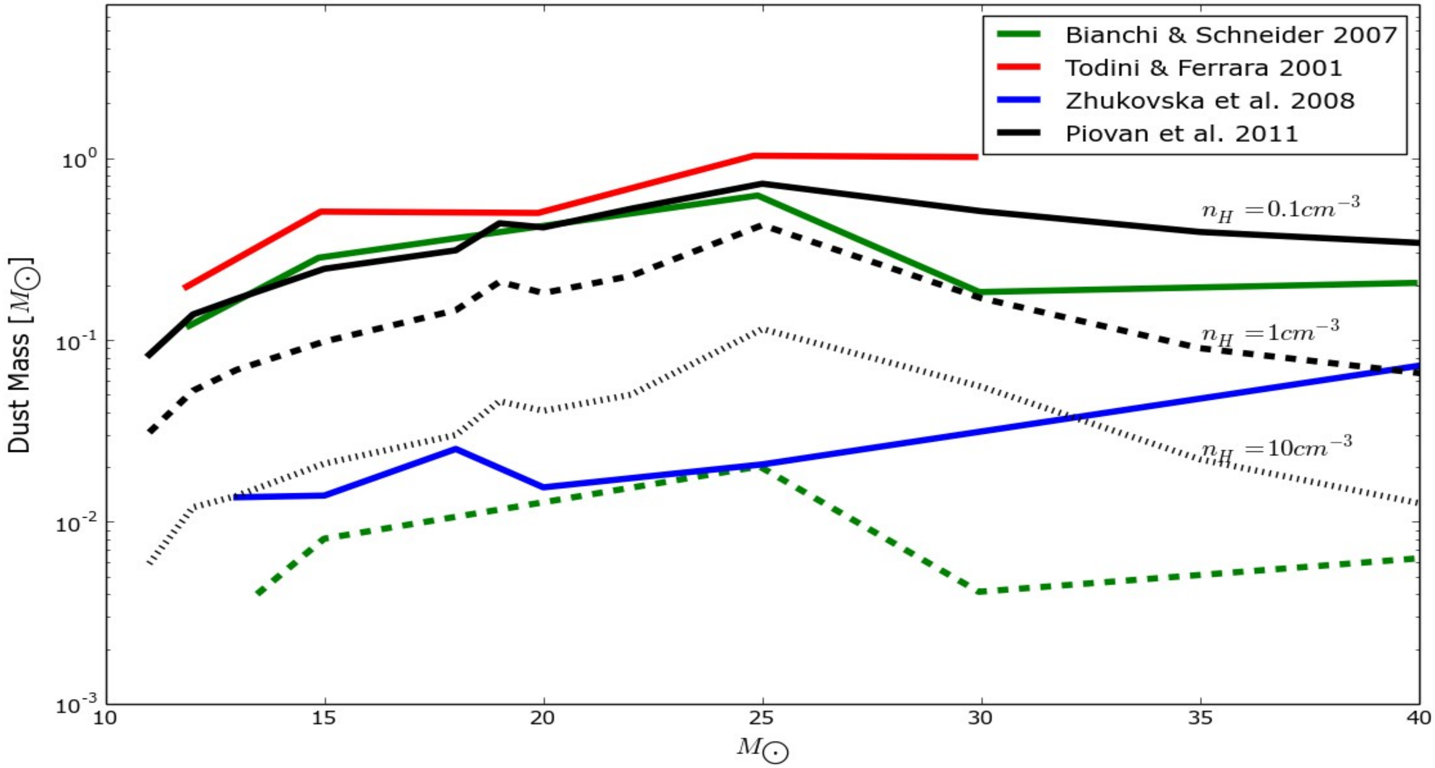


SCUBA, Herschel and recently ALMA have detected a total mass of dust between 0.1 and 0.7 M_o in the ejecta of core-collapse SNe

One of the main uncertainties stays in the role played by the reverse shock:
Up to the 20% of the total amount of dust can be destroyed. in SNe which can destroy by thermal sputtering up to 20% the dust produced.

Dust production by Type II SNe

Piovan 2011 condensation efficiencies depend on the density of the ISM in which the shock propagates: higher is the density more resistance the shock will encounter and more dust will be destroyed.

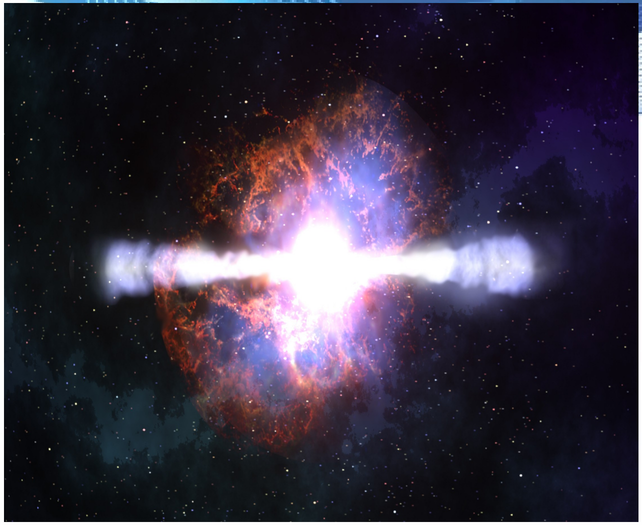


- Bianchi & Schneider 2007 (green)considered also the presence of reverse shock.
- Zhukovska et al. 2008: studies with observational data (IR emission, pre-solar grains in meteorites).

Dust destruction

Destruction processes:
Thermal sublimation, evaporation in grain-grain collision, thermal sputtering, desorption.

Grain **destruction by SNRs** is the most important mechanism for cycling the dust back to the gas phase.



$$\left(\frac{G_{i,dust}}{dt}\right)_{destr} = \frac{M_{dust}}{T_{destr}}$$

$$T_{destr} = \frac{M_{ISM}}{(\epsilon \cdot M_{SNR})SN_{rate}}$$

M_{SNR} = 6800 M_{O} [McKee 1989]:
amount the mass swept up by remnant.
ε = 0.2 (1300M)

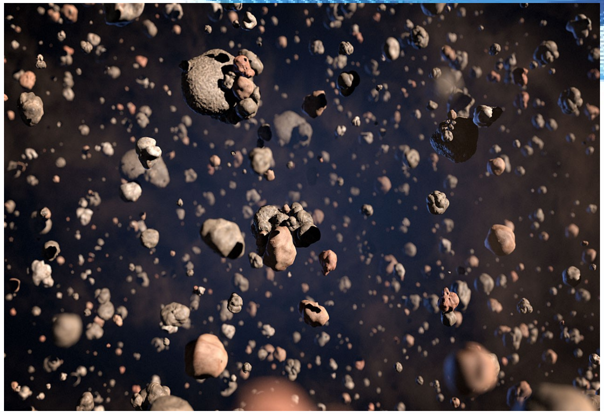
We tested new prescriptions (De Bennassuti et al. 2014, Asano et al. 2013)

Relation between metallicity and the swept up mass:

$$M_{Swept} = 1535 \cdot R_{SN}^{-0.202} \cdot [Z/Z_{\odot} + 0.039]^{-0.289} [M_{\odot}]$$

Dust accretion

Accretion processes:
Dust coagulation, accretion onto pre-existing dust grains.
(Ref. Hirashita et al. 2000, Asano et al. 2013, De Bennassuti et al. 2014)



$$\left(\frac{G_{i,dust}}{dt}\right)_{accr} = M_{dust}\frac{(1-\delta_i)}{T_{accr,i}}$$

Estimated time-scale: $\tau_{accr,i} = 5 \times 10^{7}$ yr.

Finer prescriptions take into account:
Fraction of molecular clouds (amount and mass)
Dust amount in MC
Desorption mechanisms

We tested new prescriptions (De Bennassuti et al. 2014, Asano et al. 2013)

$$\tau_{acc} = 20 Myr \times \frac{a}{0.1\mu m}\left(\frac{n}{100cm^{-3}}\right)^{-1}\left(\frac{T}{50K}\right)^{3/2}\left(\frac{Z}{Z_{\odot}}\right)^{-1} = 4 \times 10^{4} yr Z^{-1}$$

Modeling chemical evolution with dust

- Evolution of elemental abundances in the gas and dust phase

How?

Studying simultaneously the chemical evolution of:

- Gas in interstellar medium
- Dust

Chemical evolution of the ISM

$$\dot{M}_{\mathrm{g},i}(t) = \underbrace{-X_i(t)\psi(t)}_{\mathrm{SF}} + \underbrace{R_i(t)}_{\mathrm{yields}} - \underbrace{W_i(t)}_{\mathrm{outflow}} + \underbrace{A_i(t)}_{\mathrm{infall}}$$

Chemical evolution of the ISM

$$\dot{M}_{\mathrm{g},i}(t) = \underbrace{-X_i(t)\psi(t)}_{\text{SF}} + \underbrace{R_i(t)}_{\underline{\text{yields}}} - \underbrace{W_i(t)}_{\text{outflow}} + \underbrace{A_i(t)}_{\text{infall}}$$

$$\begin{aligned}
\underline{R_i(t)} = & + \int_{M_L}^{M_{B_m}} \psi(t-\tau_m)Q_{mi}(t-\tau_m)\phi(m)dm \\
& + A\int_{M_{B_m}}^{M_{B_M}} \phi(m) \\
& \chi\left[\int_{\mu_{min}}^{0.5} f(\mu)\psi(t-\tau_{m2})Q_{mi}(t-\tau_{m2})d\mu\right] dm \\
& + (1-A)\int_{M_{B_m}}^{8M_\odot} \psi(t-\tau_m)Q_{mi}(t-\tau_m)\phi(m)dm \\
& + (1-A)\int_{8M_\odot}^{M_{B_M}} \psi(t-\tau_m)Q_{mi}(t-\tau_m)\phi(m)dm \\
& + \int_{M_{B_M}}^{M_U} \psi(t-\tau_m)Q_{mi}(t-\tau_m)\phi(m)dm
\end{aligned}$$

Enrichment rate due to low mass stars

Enrichment by SN Ia

Massive stars that explode as type II SNe

Chemical evolution of dust

$$\dot{G}_{i,dust}(t) = -\underline{\phi(t)\,X_{i,dust}(t)} + \underline{R_{i,dust}(t)} + \underline{\left(\dot{G}_{i,dust}(t)\right)_{accr}} - \underline{\left(\dot{G}_{i,dust}(t)\right)_{destr}} - \underline{\left(\dot{G}_{i,dust}(t)\right)_{w}}$$

Chemical evolution of dust

$$\dot{G}_{i,dust}(t) = -\phi(t)X_{i,dust}(t) + \underline{R_{i,dust}(t)} + (\dot{G}_{i,dust}(t))_{accr} - (\dot{G}_{i,dust}(t))_{destr} - (\dot{G}_{i,dust}(t))_{w}$$

Condensation efficiencies

$$R_{i,dust}(t) =$$

$$+ \int_{M_L}^{M_{B_m}} \psi(t-\tau_m)\delta_i^{AGB} Q_{mi}(t-\tau_m)\phi(m)dm$$

$$+ A \int_{M_{B_m}}^{M_{B_M}} \phi(m) \cdot [\int_{\mu_{min}}^{0.5} f(\mu)\psi(t-\tau_{m2})\delta_i^{Ia} Q_{mi}(t-\tau_{m2})d\mu]dm$$

$$+ (1-A) \int_{M_{B_m}}^{8M_\odot} \psi(t-\tau_m)\delta_i^{AGB} Q_{mi}(t-\tau_m)\phi(m)dm$$

$$+ (1-A) \int_{8M_\odot}^{M_{B_M}} \psi(t-\tau_m)\delta_i^{II} Q_{mi}(t-\tau_m)\phi(m)dm$$

$$+ \int_{M_{B_M}}^{M_U} \psi(t-\tau_m)\delta_i^{II} Q_{mi}(t-\tau_m)\phi(m)dm$$

Represent the efficiency of how much of a single element in the gas phase condenses in dust phase

δ^{Ia} → Type Ia SNe

δ^{II} → Type II SNe

δ^{AGB} → AGB stars

Chemical evolution of dust

$$\dot{G}_{i,dust}(t) = -\phi(t)X_{i,dust}(t) + R_{i,dust}(t) + (\dot{G}_{i,dust}(t))_{accr} - (\dot{G}_{i,dust}(t))_{destr} - (\dot{G}_{i,dust}(t))_{w}$$

Condensation efficiencies

Adopted values values for **this** work:

SNe Ia are not considered dust factories (Nozawa et al. 2011)

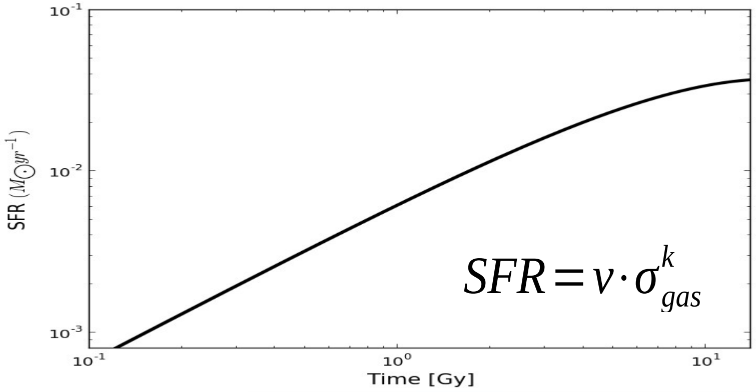
$\delta^{I}=0$

δ^{II}, δ^{AGB} from AGB stars and Type II SNe values from Piovan et al. 2011.

Test and comparison with others widely adopted in literature.

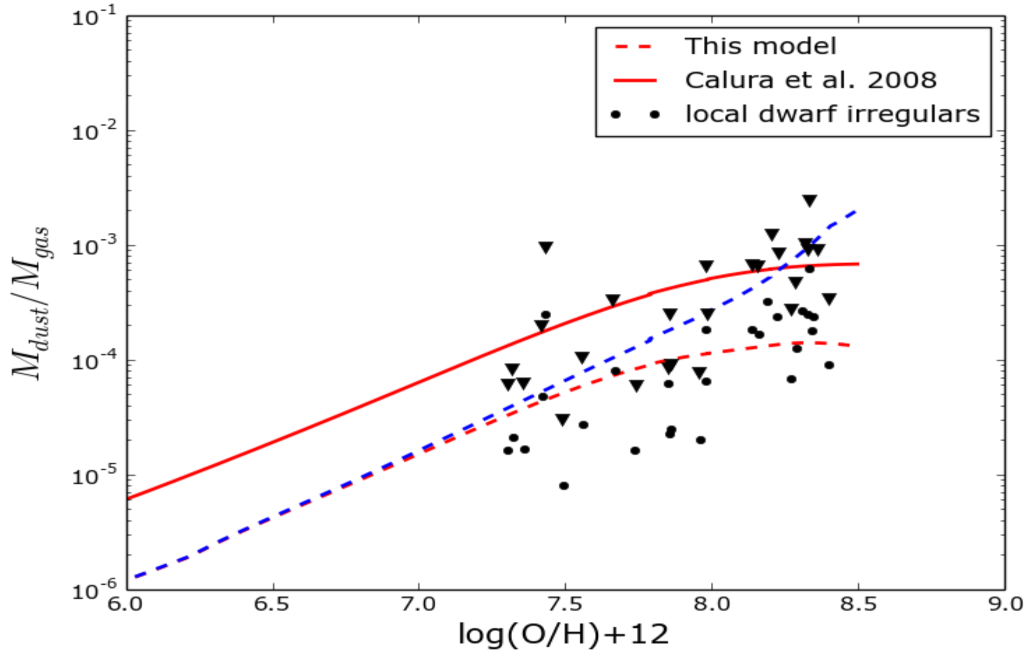
Dust ratio in dwarf irregulars

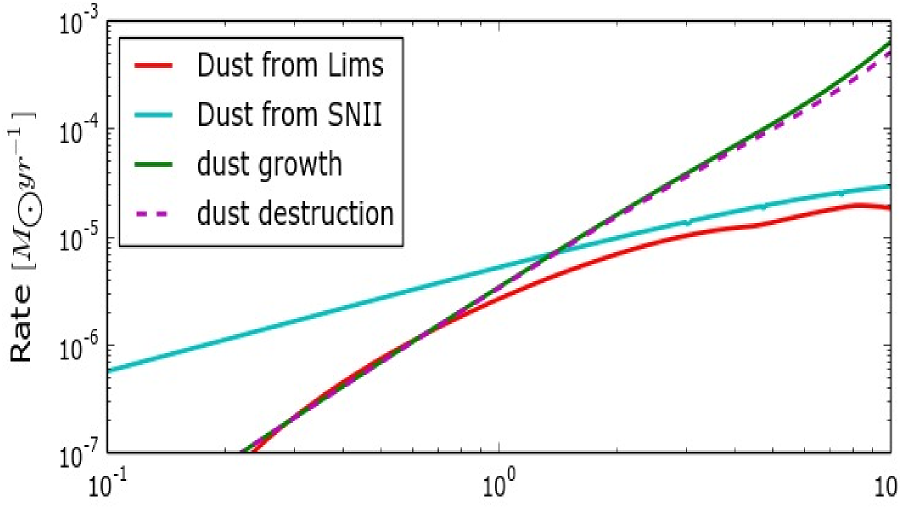
Ref. Model Calura et al. 2008
$M_{infall} = 1 \times 10^{9}\ M_{O}$
$T_{infall} = 10$ Gy
ν = 0.050 [Gy^-1] (star formation efficiency)
Continuum star formation rate



New dust condensation efficiencies
without dust accretion - - - - -

De Bennassuti et al. 2014
prescriptions - - - - -





Following dust evolution

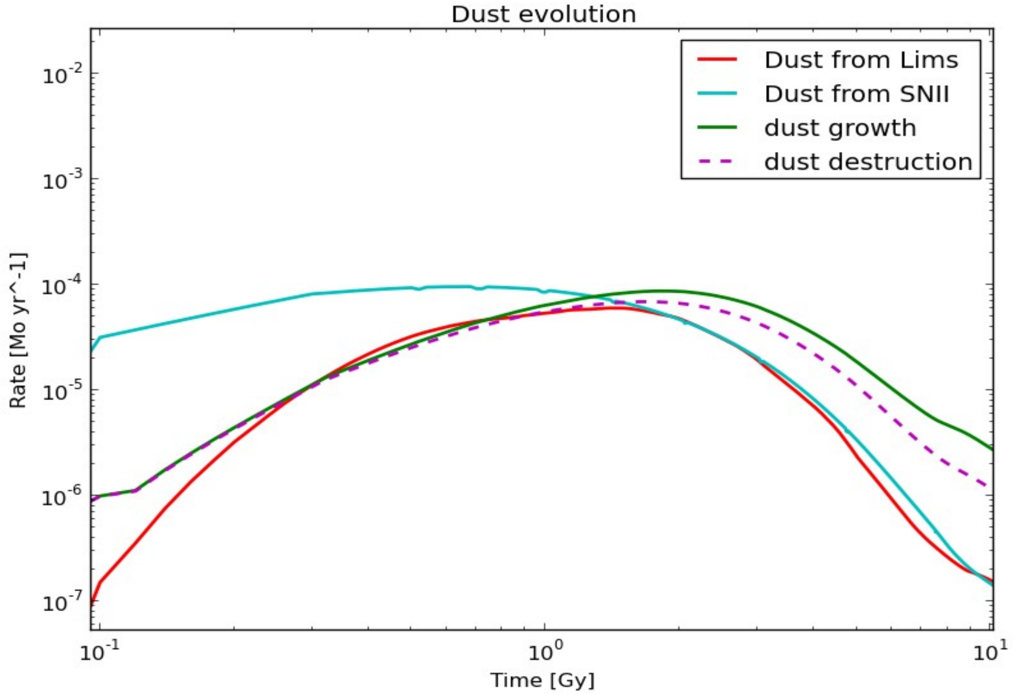
$M_{infall} = 10^9\ M_O$

T_{infall} =1 Gy

ν = 0.4 [Gy^-1]

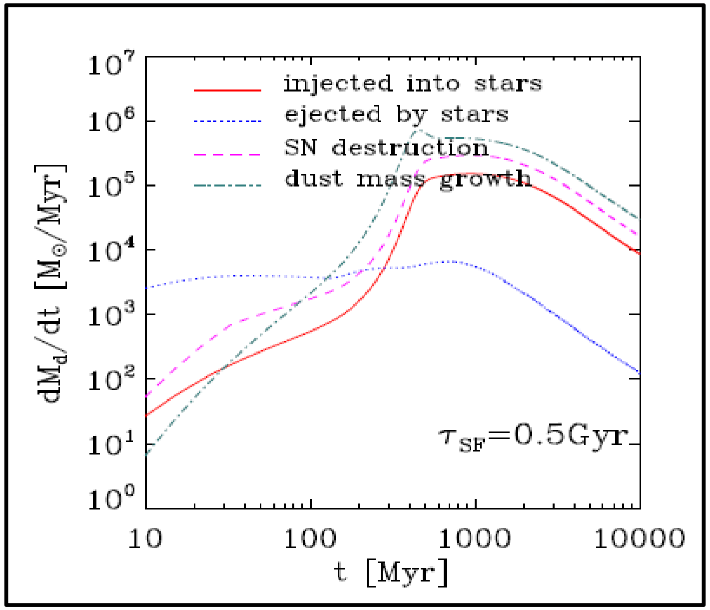
w=1.5

This work



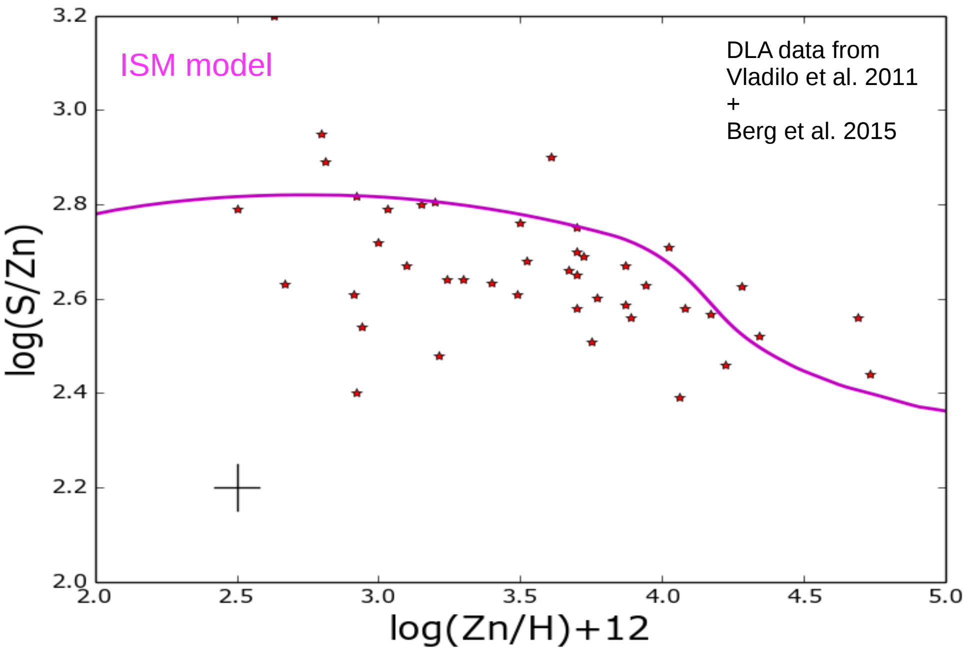
Ref. **Asano et al. 2013**

Critical metallicity at which dust accretion dominates on dust formation



Comparison with Damped Lyman alpha system

Volatile elements
Zinc and Sulfur
(low condensation temperature, less affinity with dust)
Constrain on the model

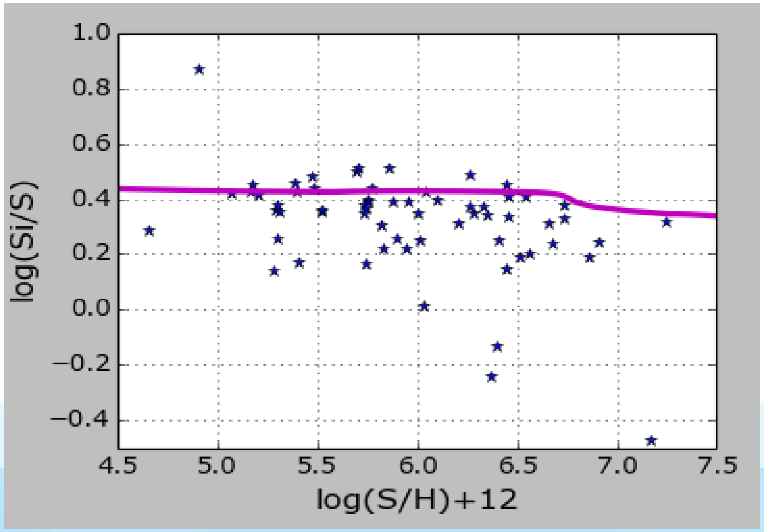


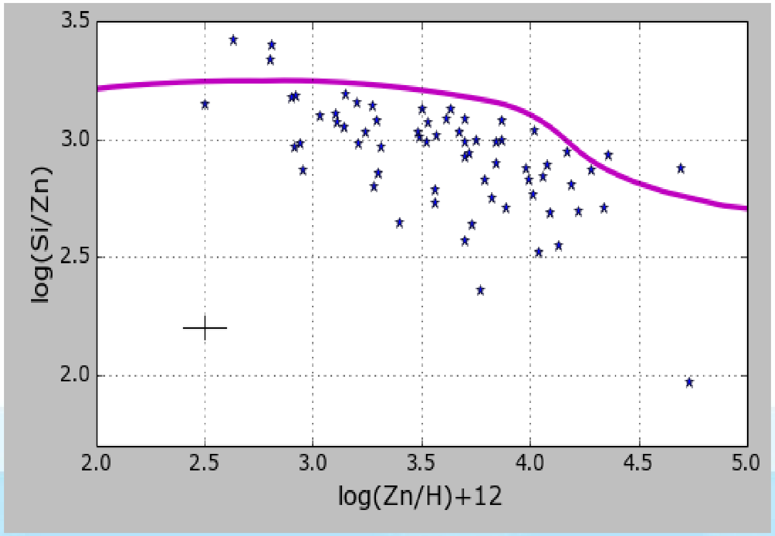
DLAs are best associated to dwarf irregular galaxies (Matteucci, Vladilo, Molaro 1997)

Model parameters:
$M_{infall} = 5 \times 10^{9}\ M_{O}$
T_{infall} =1 Gy
ν = 0.70 [Gy^-1]
w= 3.5

Ref. Vladilo et al. 2011

Refractory elements
Si, Mg, O...
Data lie below model prediction because of **dust depletion**





Conclusions

A chemical evolution model with new prescriptions has been shown

- Dust mass yields are consistent with other works (Dwek 1998, Zhukovska et al. 2008, Valiante et al. 2009)

- Dust evolution
  With this method is possible to follow the evolution of dust to know which are the dominant processes during the cosmic time

- Comparison with dwarf irregulars:
  Total amount of dust produced is in good agreement with observations (in particular with new prescriptions).
  Dust accretion and destruction are fundamental in describing dust evolution).

- DLA system:
  Dust-corrected chemical evolution models where shown in order to reproduce depletion pattern in refractory elements (Si case)
  With this model is possible to calculate elemental depletion and constrain chemical dust composition (future work).

- Comparison with dust depletion pattern in the interstellar medium of the solar neighborhood