From planetesimals to planets

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Introduction

- Computing the chemical composition of planet is a growing need for planetary formation models and for the search of habitable planets as they are probably related.
- Previous works have been investigating the chemical composition of planet, combining dynamical process of planetary formation and chemistry. However, either these studies have only focused on the volatile content of the planets (CO, H_2O, CO_2, CH_4) either the composition of the planets have been determined in a non self-consistent manner.
- We present here results of calculations of chemical compositions of planets with the combination of a planet formation model for both refractory and volatile compounds. Combination has been carried self-consistency with the planetary formation model.

Models

Planet formation model

- Initial planet formation model of Alibert et al. (2005) based on the core accretion theory of Pollack et al. (1996)
- Calculations of population synthesis (Mordasini et al 2009a,b)
- Accretion rate of planetesimals improved in Fortier et al. (2013)
- Addition of 10 planetary embryos in each disc in Alibert et al. (in prep.)
- Surface density of the dust in the disc computed with :

$$\Sigma = \Sigma_0 . (\frac{r}{a_0})^{-\gamma} . e^{(\frac{r}{a_{core}})^{2-\gamma}} \quad (1)$$

where a_0 is equal to 5.2 AU, a_{core} is the characteristic scaling radius (in AU), γ is the power index, r is the distance to the star (in Astronomical Units [AU]), and $\Sigma_0 = (2-\gamma)\frac{M_{disc}}{2\pi a_{core}^{2-\gamma} a_0^{\gamma}}$ (in g.cm^{-2}).

Refractory components

Table : List of Inorganic refractory phases considered in the calculations (Bond et al., 2010)

Al_2O_3	$FeSiO_3$	$CaAl_2Si_2O_8$
C	Fe_3P	TiC
$CaAl_{12}O_{19}$	$NaAlSi_3O_8$	SiC
Ti_2O_3	Fe_3C	Cr_2FeO_4
$CaMgSi_2O_6$	$CaTiO_3$	Fe
$Ca_2(PO_4)_2$	FeS	Fe_3O_4
TiN	$Ca_2Al_2SiO_7$	Ni
AlN	$MgAl_2O_4$	P
CaS	Mg_2SiO_4	Si
Cr	Fe_2SiO_4	$Mg_3Si_2O_5(OH)_4$
MgS	$MgSiO_3$	

- Composition ruled by chemical equilibrium => condensation sequence.
- HSC Chemistry (v.7.1) computes this condensation sequence and requires assumption of an isobaric system.
  - Gibbs Energy Minimization.
  - P(r) = mean(P_j(r)).
  - Initial composition = atoms in the gas phase, abundances of Lodders (2003).

Two models
  - with formation of organic compounds.
  - without formation of organic compounds.

Volatile Component

- Condensation or trapping during the cooling of the stellar nebula.
- Depends on T(r) and P(r).
- Abundances are determined following the cooling curves of the disc.

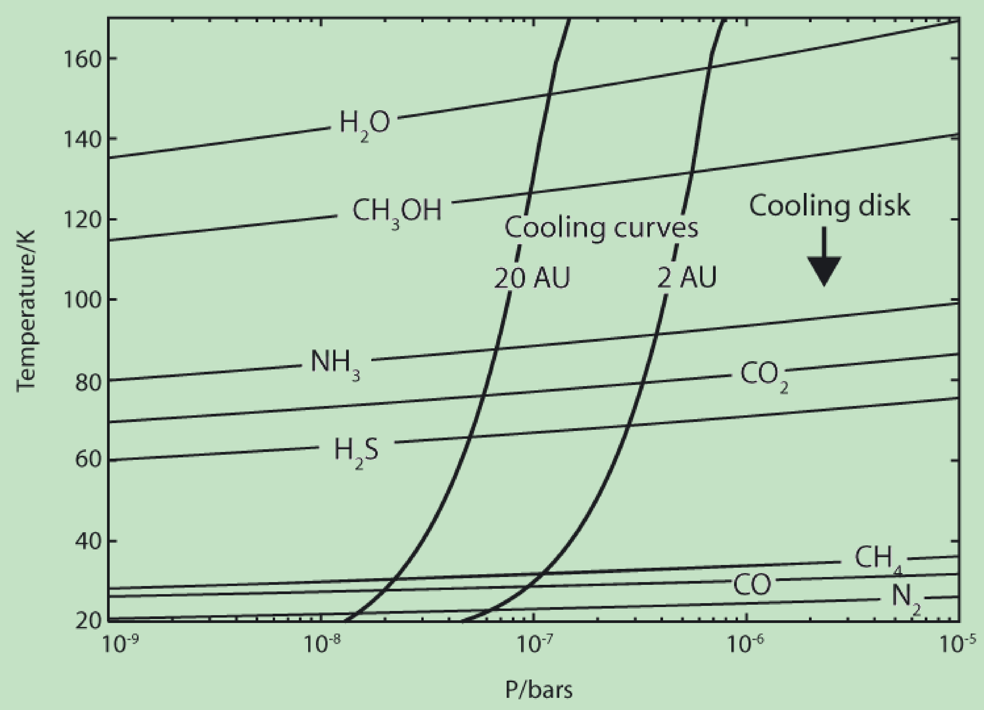
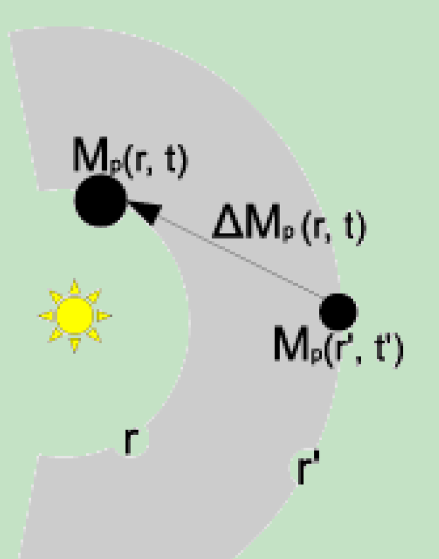


Figure : Cooling curves at 2 AU and 20 AU and stability regions of volatile molecules.

Combining chemistry and formation



- Disc extends from 0.04 AU to 30 AU.
- A radial grid of composition is computed. The chemical composition of planetesimals (as wt %) at a given radius is computed by interpolation on this grid.
- We follow the growth of each planet predicted by the planet formation model during its lifetime, i.e we compute its composition.
- The composition of the disc and the mass gained by the planet between two time steps t and t' gives us the mass of each molecule and element in the planet.

Results

Disk composition

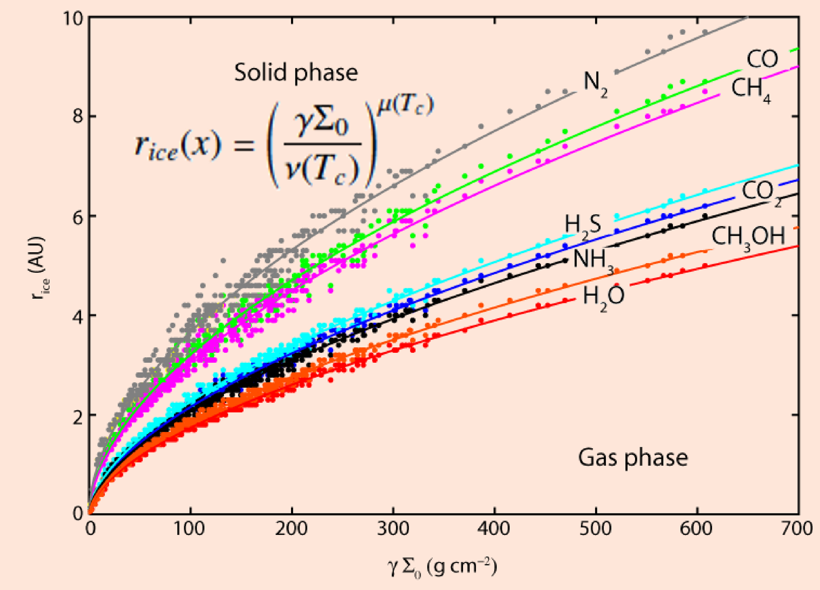


Figure : Iceline position versus $\gamma\Sigma_0$ for volatile molecules.

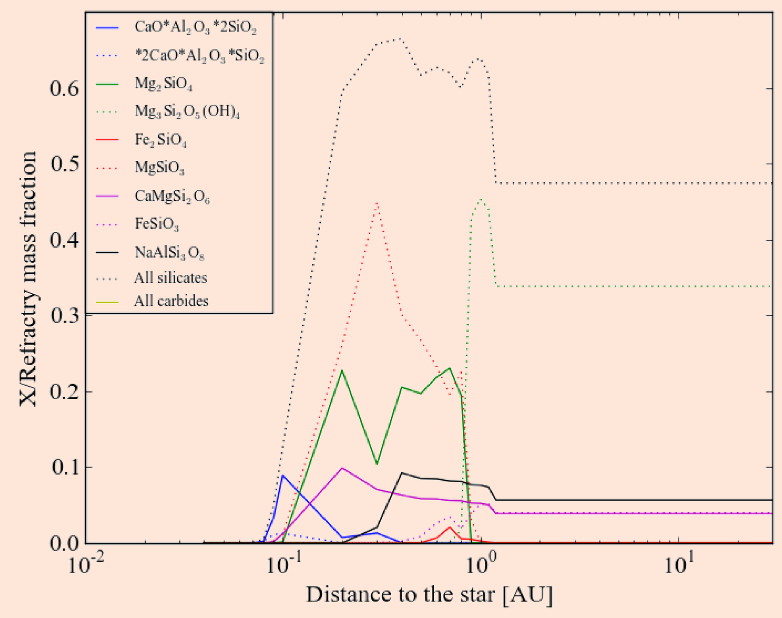
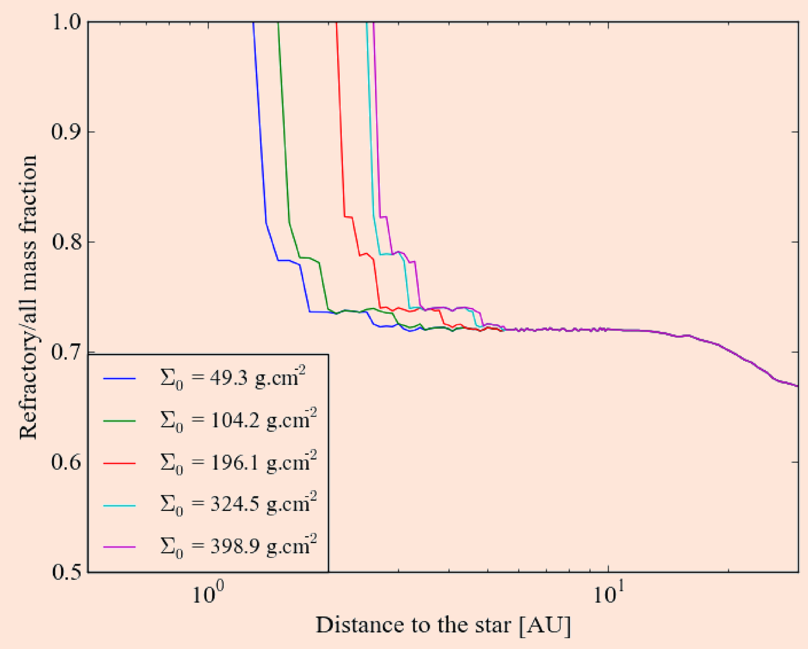


Figure : Distribution of carbides and silicates relative to all condensed refractory molecules in one of the simulated discs (Σ_0=95.844 g.cm^{-2}, a_{core}=46 AU and γ=0.9) for the model "with" organic compounds.

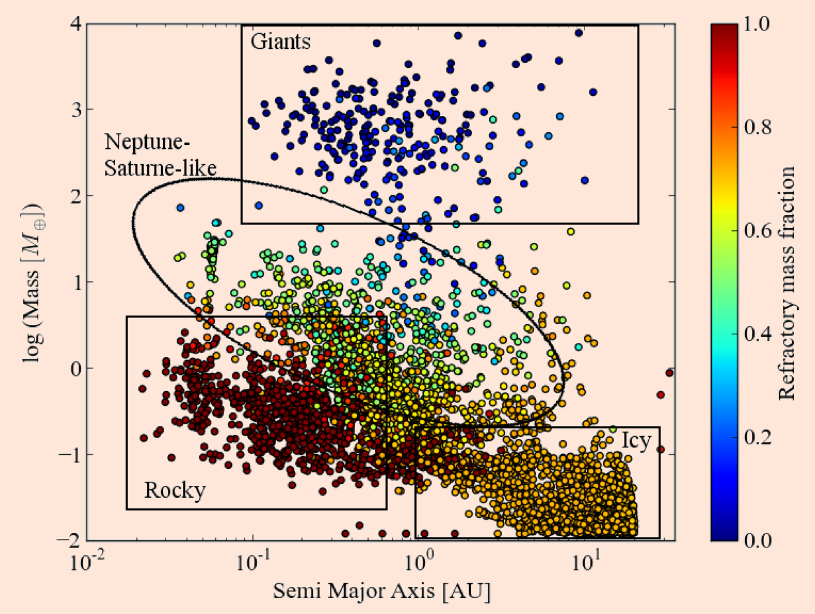
Chemical diversity

Figure : Evolution of the mass fraction of refractory elements in 5 discs of different masses (a_{core} = 14 AU and γ = 0.8, fixed). The position where the ratio drops is the position of the ice line.



Planets formed

Figure : Mass fraction of refractory elements incorporated into planets as a function of their final position and mass.



Planet composition

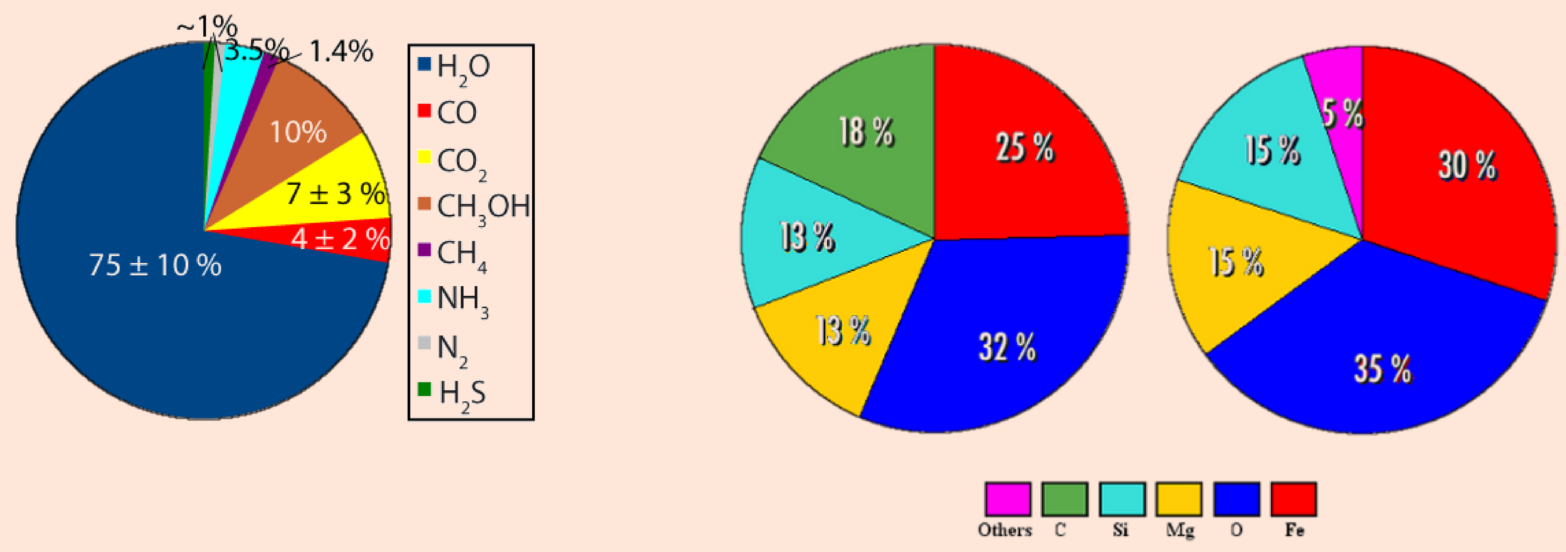


Figure : Abundance (in wt % of the mass of solids accreted by the planet) in volatile elements in giant, icy and Neptune/Saturn-like planets (right panel) and in refractory elements for rocky planets (left panel).

Summary and conclusions

- Every planet of the Solar System can be chemically reproduced.
- Results of the model without organic compounds are closer to what is observed in the Solar System.
- Organic material can represent up to 30 wt % of a planet.
- Giant planets are depleted in volatile elements, compared to icy or Neptune/Saturn-like planets.
- A relation between the disc parameters and the position of the ice line is derived.
- The use of self-consistent models, with a population of discs, is needed to form a large diversity of planets.

Aknowledgements

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