Minimum Mass Solar Nebulae,

Nice model,

& Planetary Migration.

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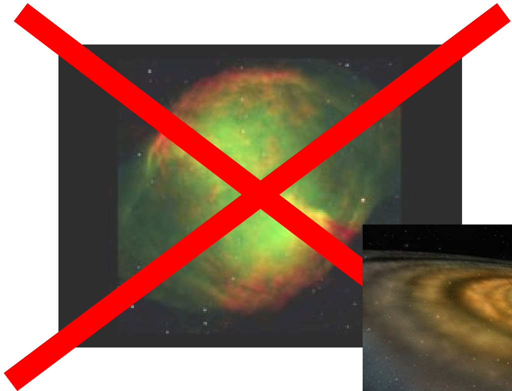
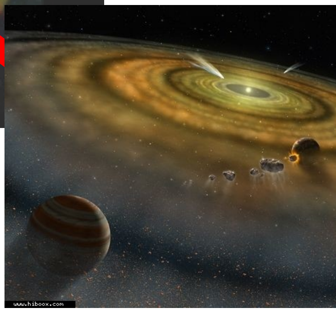
Minimum Mass Solar Nebula





Little reminder :

It is *not* a nebula,
but a protoplanetary disc.

Solar : from which the Solar System is born.

Minimum Mass :
just enough solid material to build the 8 planets.

Importance :

Density used in basically **all** processes of planet formation.

1) MMSN : definition, recipe

Recipe of the Minimum Mass Solar Nebula

Ingredients for 8 planets :

~ 60 Earth masses of solids (chondritic composition).

~ 0.01 solar mass of the famous mixture H (75%), He (25%).

Preparation :

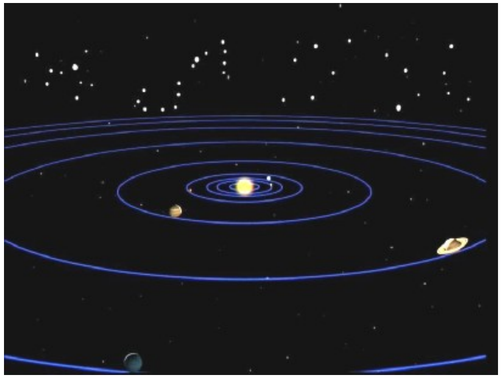
Spread the appropriate mass of solids around the orbit of each planet.

Multiply the obtained density by 100 (add gas).

Cover with a power law profile.

Dispose around the Sun for 10 million years.

You get the Solar System. Enjoy !



1) MMSN : definition, recipe

Weidenschilling (1977), Hayashi (1981) :

$$\Sigma(r) = 1700 \left(\frac{r}{1\mathrm{AU}}\right)^{-1.5} \mathrm{g.cm^{-2}}$$

<u>Main assumptions :</u>

The planets accreted **all** the solids (therefore «minimum»).

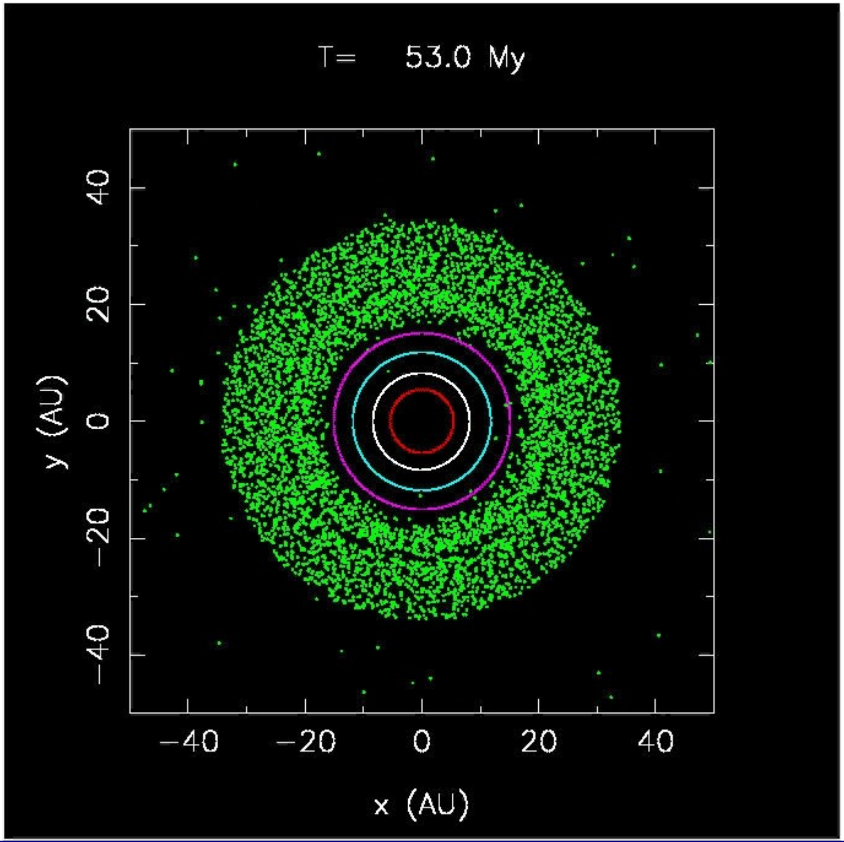
They formed **where they presently orbit**.

... did they ?

2) The Nice model

After the protoplanetary disc dispersal, the giant planets were on **circular** orbits, in a **compact** configuration, surrounded by a disc of **planetesimals**.

(Gomes et al. 2005 ; Tsiganis et al, 2005)



Planetesimal scattering perturbs the orbits of the planets.

When Jupiter and Saturn reach their 2:1 resonance,
the system is destabilized :

→ Late Heavy Bombardement.

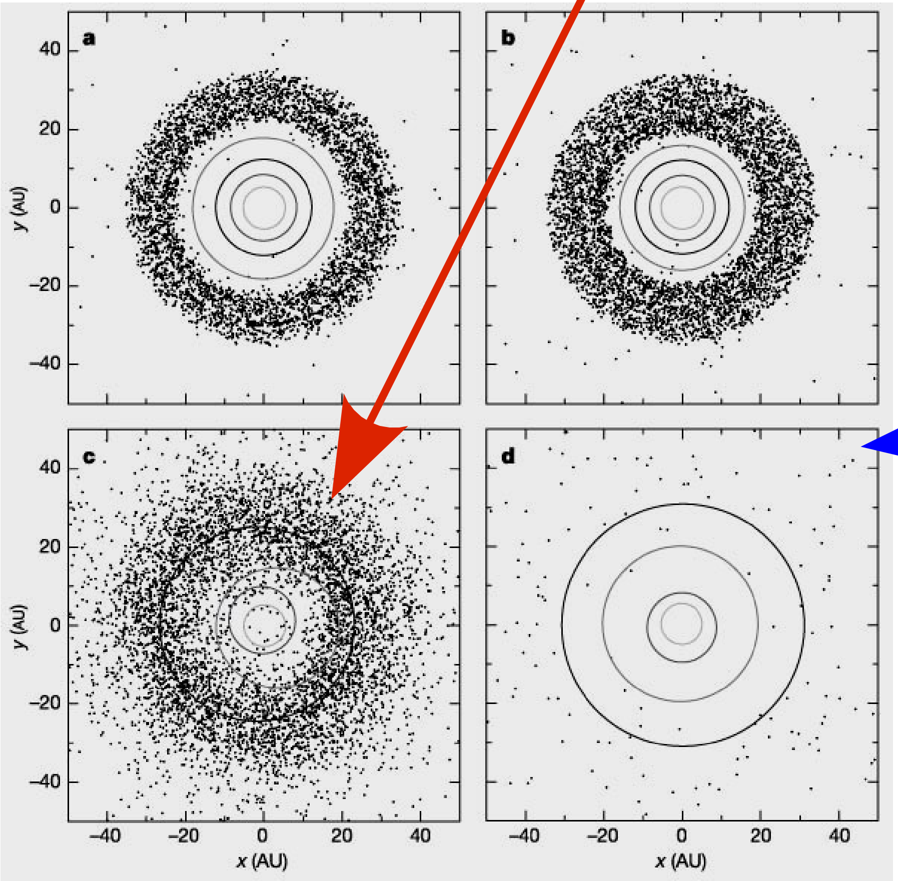
→ The planets reach their present orbits.

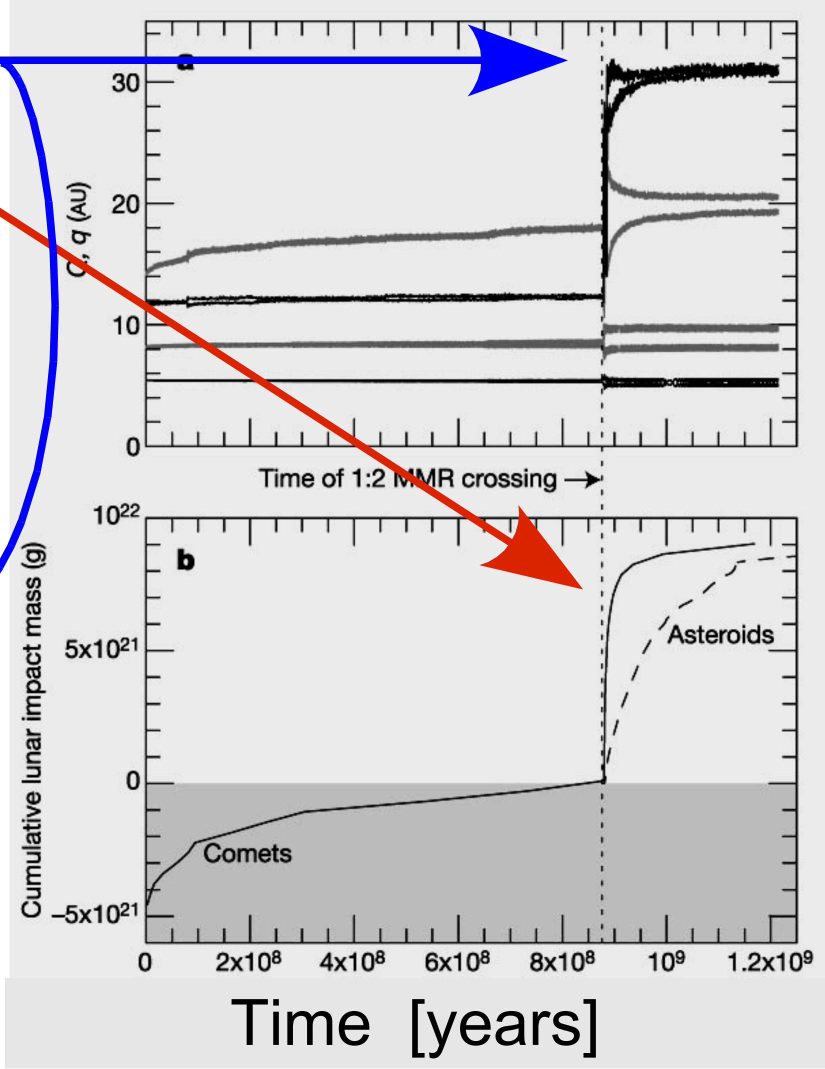
2) The Nice model

The Nice model explains :

The **eccentricities** of the giants

the **Late Heavy Bombardement**.





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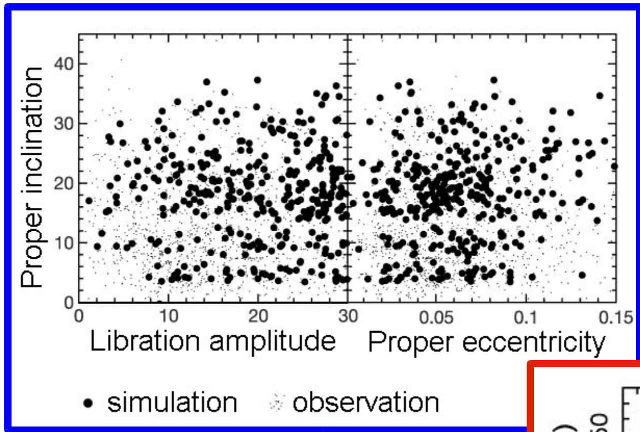
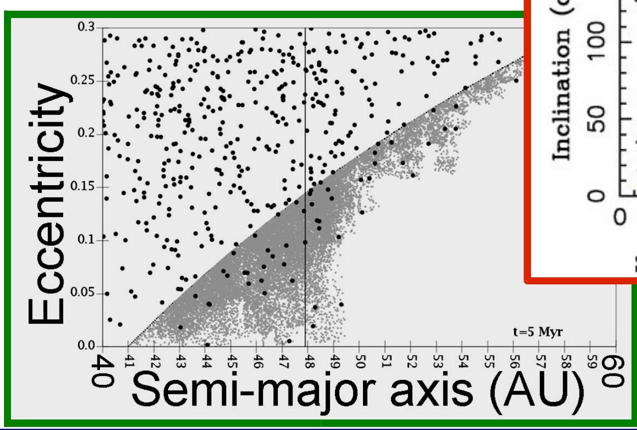
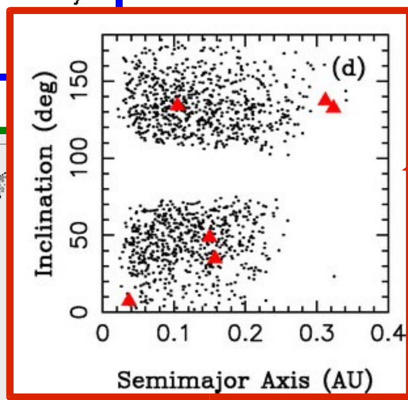






And also :

- The capture of Jupiter's Trojans on **inclined** orbits (Morbidelli et al, 2005).
- The Hildas and D-type asteroids (Bottke et al, 08).
- The capture of the irregular satellites by the giants (Nesvorny et al, 2007).
- The Kuiper Belt architecture (Levison et al, 2007).

3) Return of the MMSN

If the Nice model holds, **the giant planets didn't form where they now orbit**.

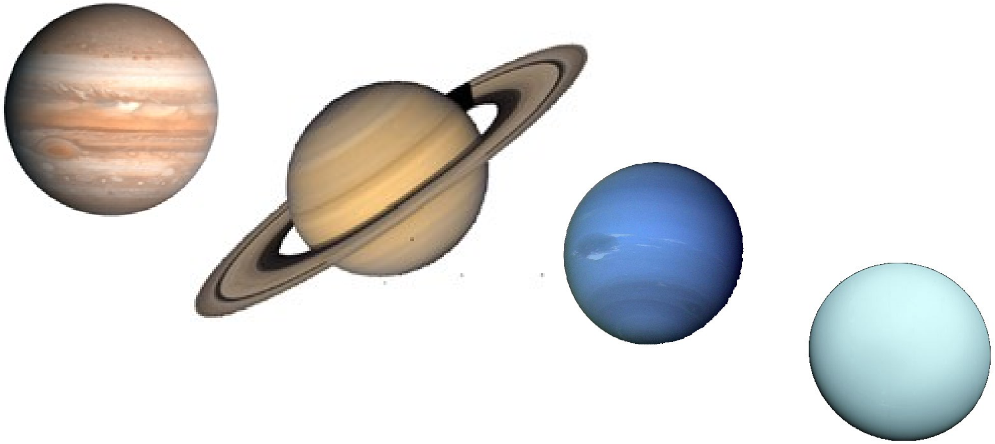
After the gas disc phase, they were located at :

Jupiter : 5,45 AU ;

Saturn : ~8,2 AU ;

Neptune: 11-12 AU ;

Uranus: 14-17 AU.



Then, the Hayashi density profile is out of date.

Desch applied the recipe with these positions (and improved the cooking).

3) Return of the MMSN

Desch (2007) : a MMSN based on the Nice model

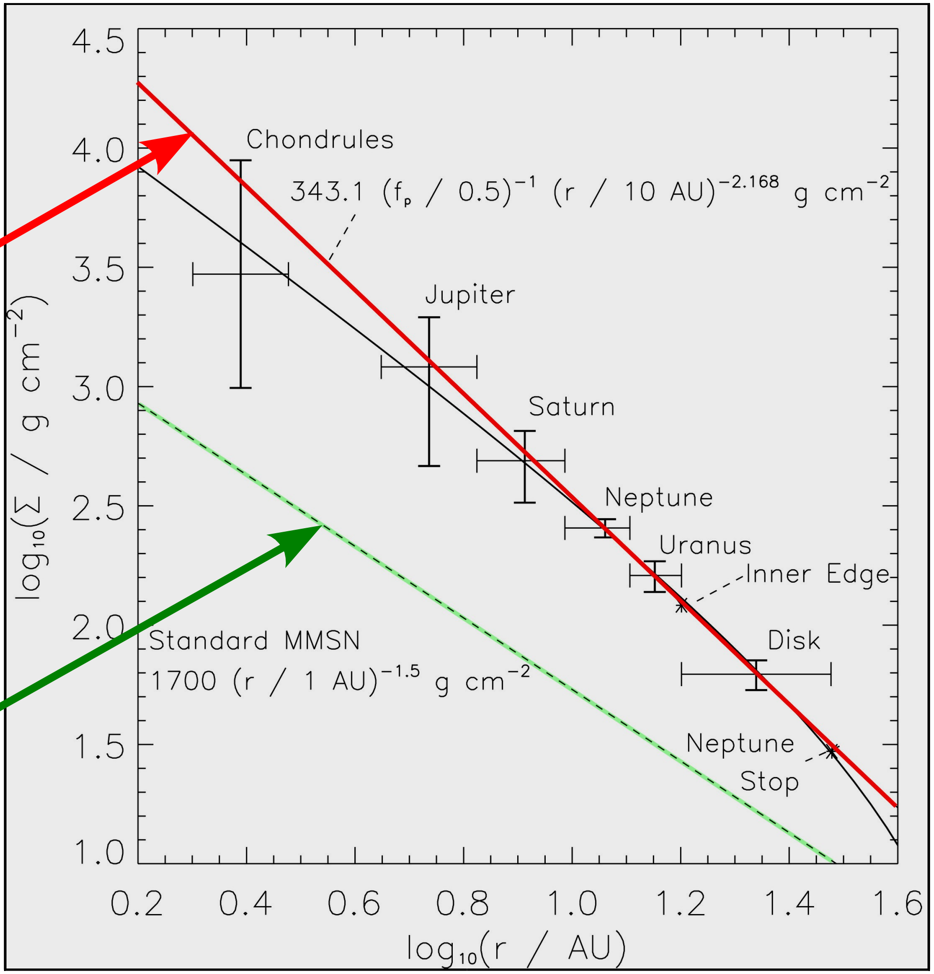
- Compact configuration,
- Uranus ↔ Neptune,
- Disc of planetesimals,

→ Excellent fit with :

$$\Sigma(r) = 50500 \left(\frac{r}{1\mathrm{AU}}\right)^{-2.168} \mathrm{g.cm^{-2}}$$

10 times more dense at 5 AU than Hayashi's MMSN.

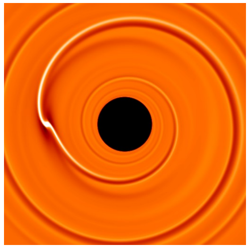
Much steeper slope.



Migration, did you say migration ?

The orbital radius may change through 3 different processes :

- Small size bodies (<km) : **radial drift** (or type 0) through gas drag.
- Planets in a gaseous disc : **migration** (type I, II, III) through tidal interaction (this session).
- Planets after the gas disc : discontinuous change through scattering (ex: in the Nice model).



None is taken into account in the Hayashi (1981) MMSN.

Only the 3rd one is considered in the Desch (2007) MMSN.

How about migration inside the MMSN ?

4) Migration strikes back

Jupiter, Saturn, Neptune & Uranus in Desch (2007) disc.

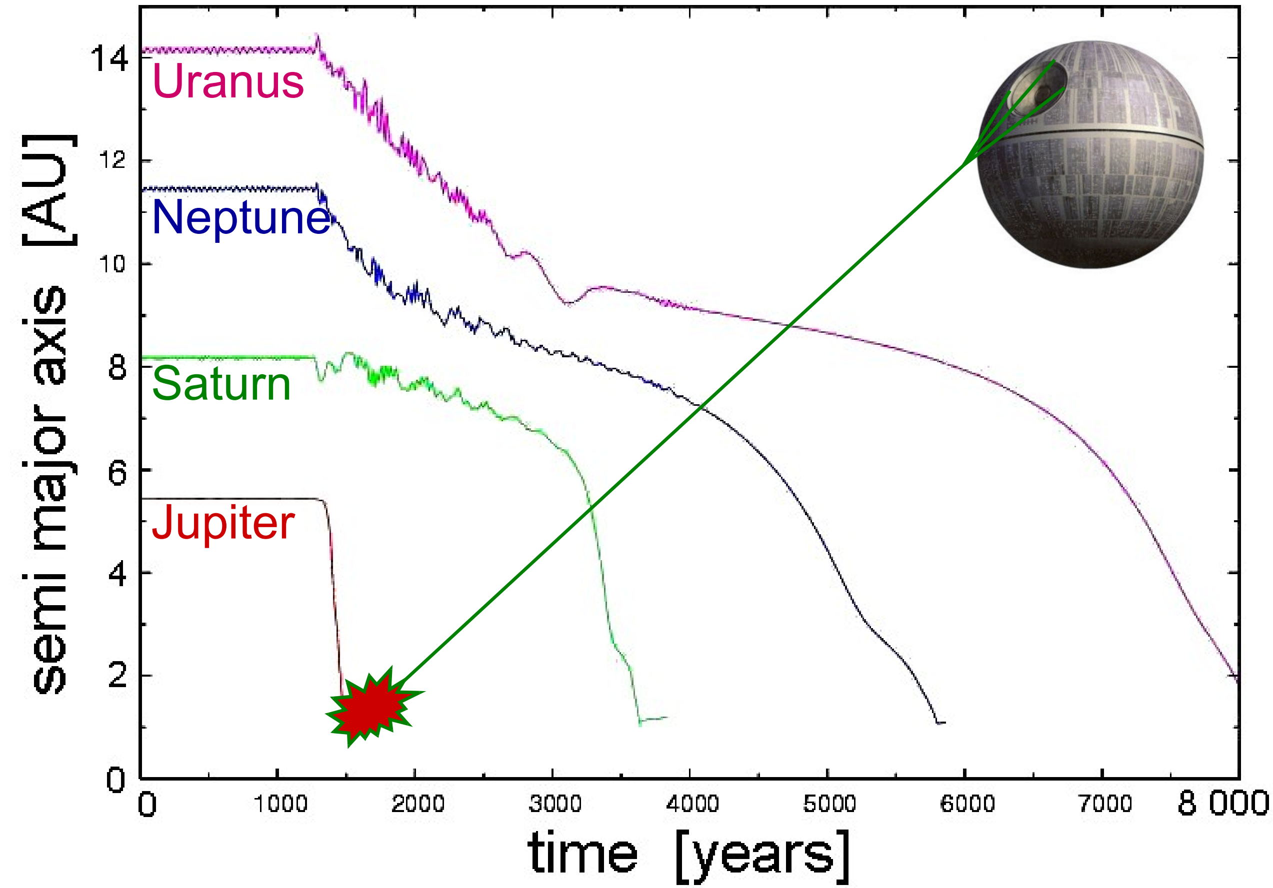
100 Jupiter orbits on a fixed orbit, then released.

Jupiter: runaway, type III migration, lost.

Saturn : type I, then type III migration, lost.

Neptune : type I, lost.

Uranus : type I, lost.



4) Migration strikes back

Jupiter, Saturn, Neptune & Uranus in Desch (2007) disc.

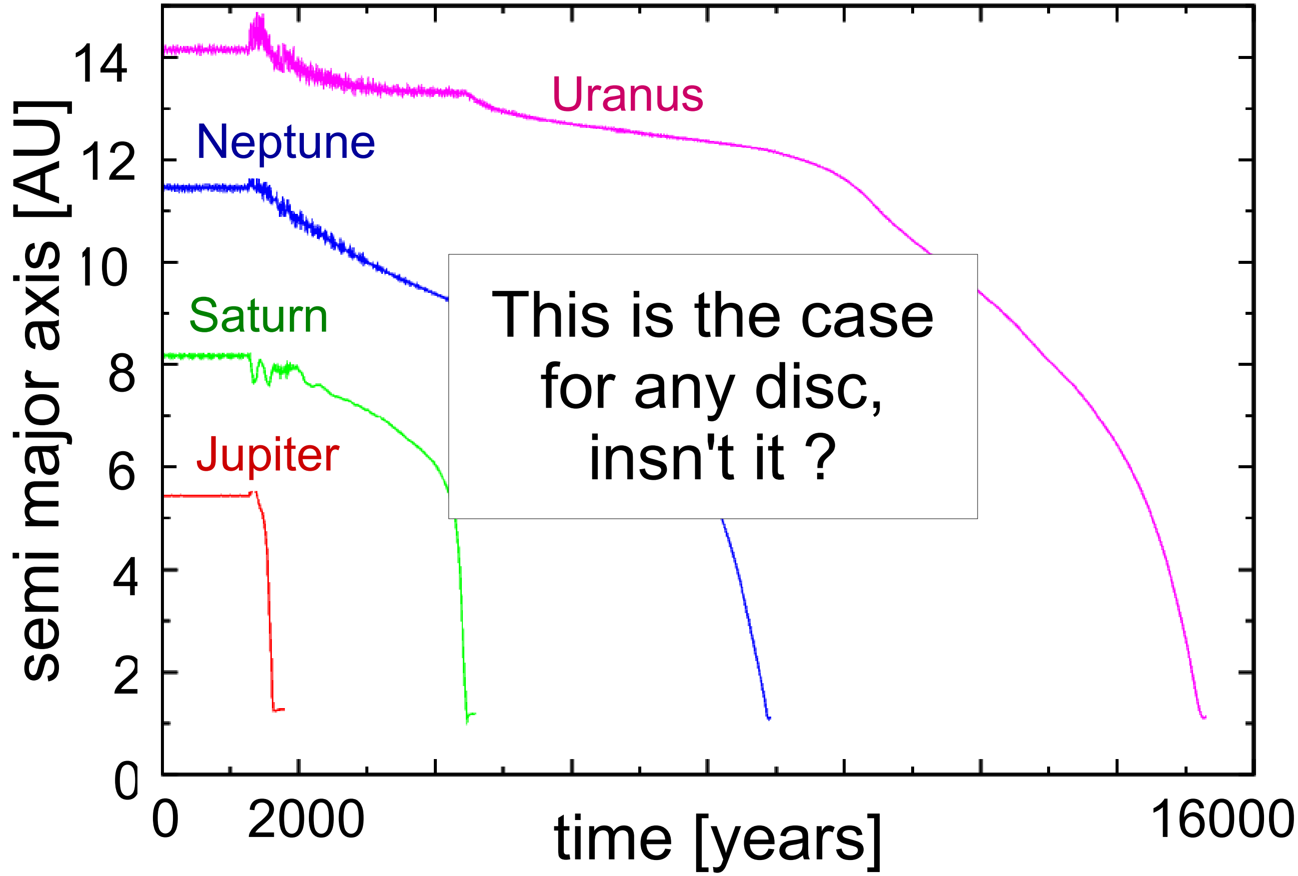
Non localy isothermal EOS: viscous heating, radiative cooling.

Jupiter: runaway, type III migration, lost.

Saturn, Neptune, Uranus, lost.

The planets can't survive more than 20 000 yrs.

(Crida, 2009, ApJ, submitted)



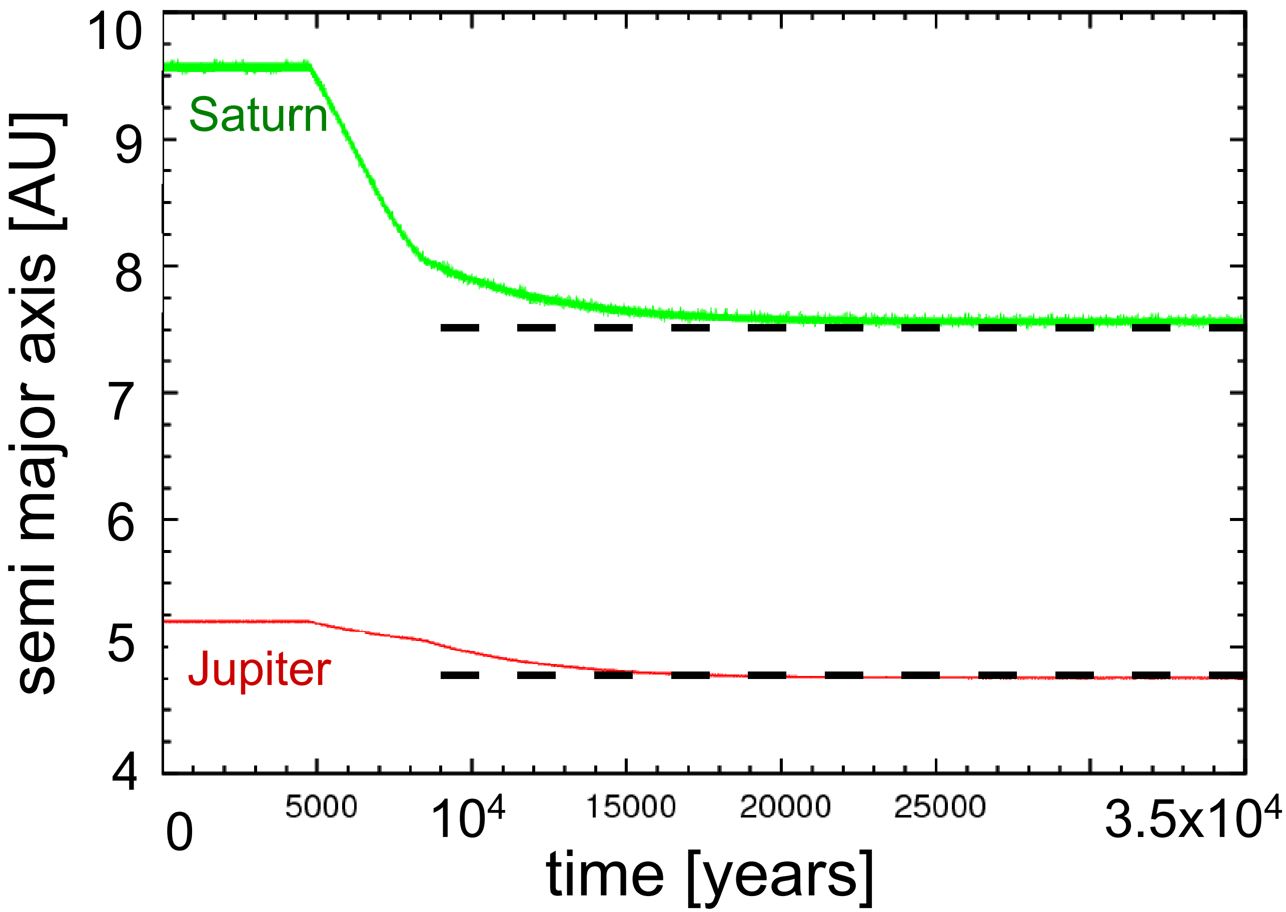
4) Migration strikes back

Jupiter & Saturn in Hayashi (1981) density profile,
with same H/r, α as in Desch (2007), localy isothermal EOS.

No type III,
no runaway.

Jupiter, Saturn
enter in 3:2
mean motion
resonance,

and stop !



4) Migration strikes back

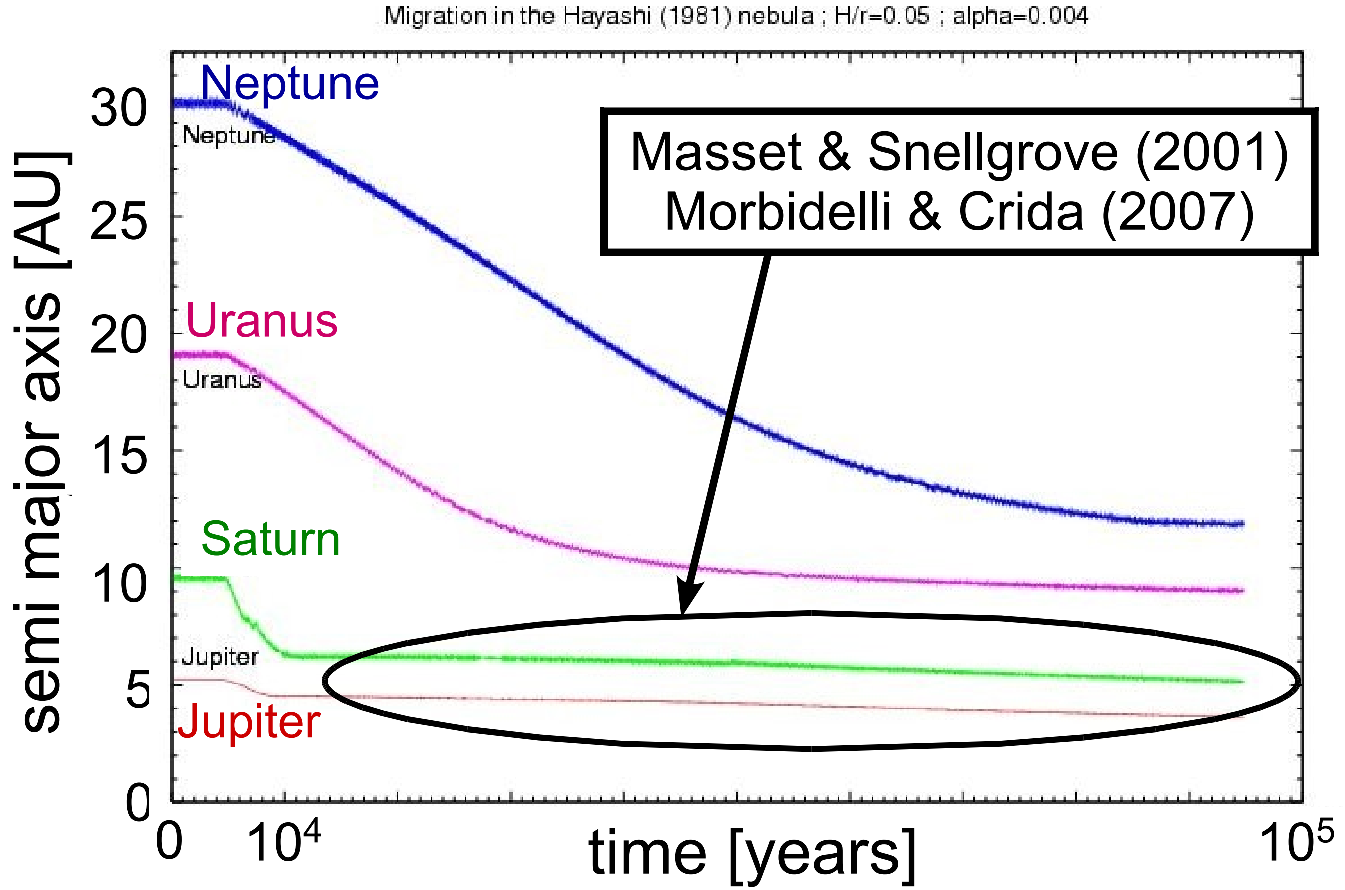
Jupiter, Saturn, Neptune & Uranus in Hayashi (1981) disc.

On longer term, with other disc parameters :

Jupiter-Saturn: in resonance, stop.

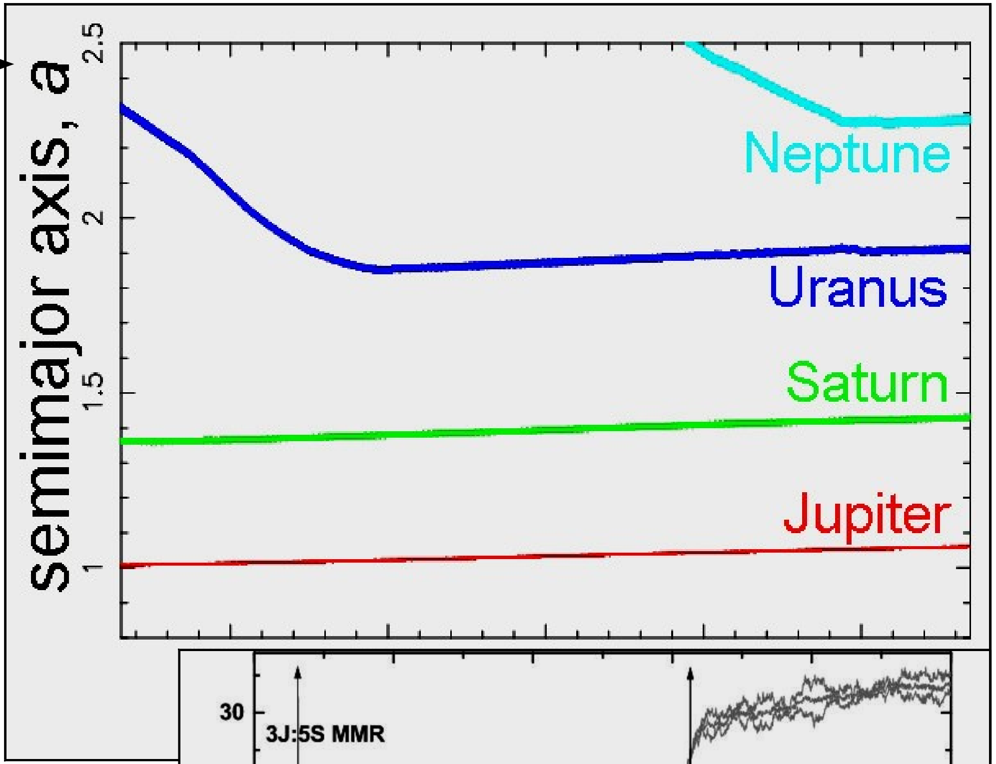
Neptune,Uranus, also caught in resonance, after type I migration.

(Crida, 2009, ApJ, submitted)



5) A new hope

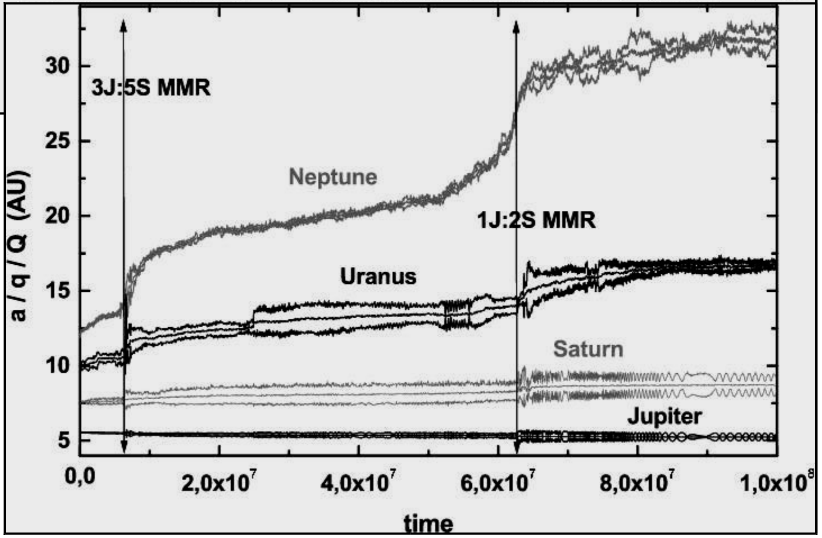
Morbidelli et al. (2007) :



6 possible resonant configurations in the gas disc.

2 are stable over $10^{8\text{-}9}$ yrs without gas disc.

With a planetesimals disc, a (late) global instability can take place.

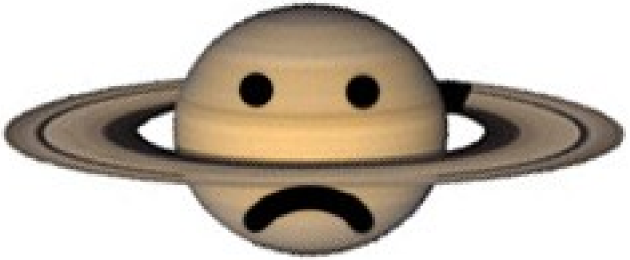


This is the « Nice model II ».

CONCLUSION

Neither the standard MMSN (Hayashi, 1981), nor the newer one (Desch, 2007), are consistent with planetary migration.

In a very dense disc, the giants can't survive (runaway migration of Jupiter and Saturn, no resonance).



Formation of the giant planets
over a **wide radial range**, in a **low density** disc,

then, **migration**, approach, and resonances,

then, **Nice model II**.

Radial drift and **migration** make
the recipe of the MMSN **irrelevant**.