



THE MINIMUM MASS SOLAR NEBULA: A 3 MILLION YEAR-OLD DISK

Kevin Baillie

► To cite this version:

Kevin Baillie. THE MINIMUM MASS SOLAR NEBULA: A 3 MILLION YEAR-OLD DISK. European Planetary Science Congress / Division of Planetary Science, Sep 2019, Geneve, Switzerland. hal-03018587

HAL Id: hal-03018587

<https://hal.science/hal-03018587>

Submitted on 23 Nov 2020

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

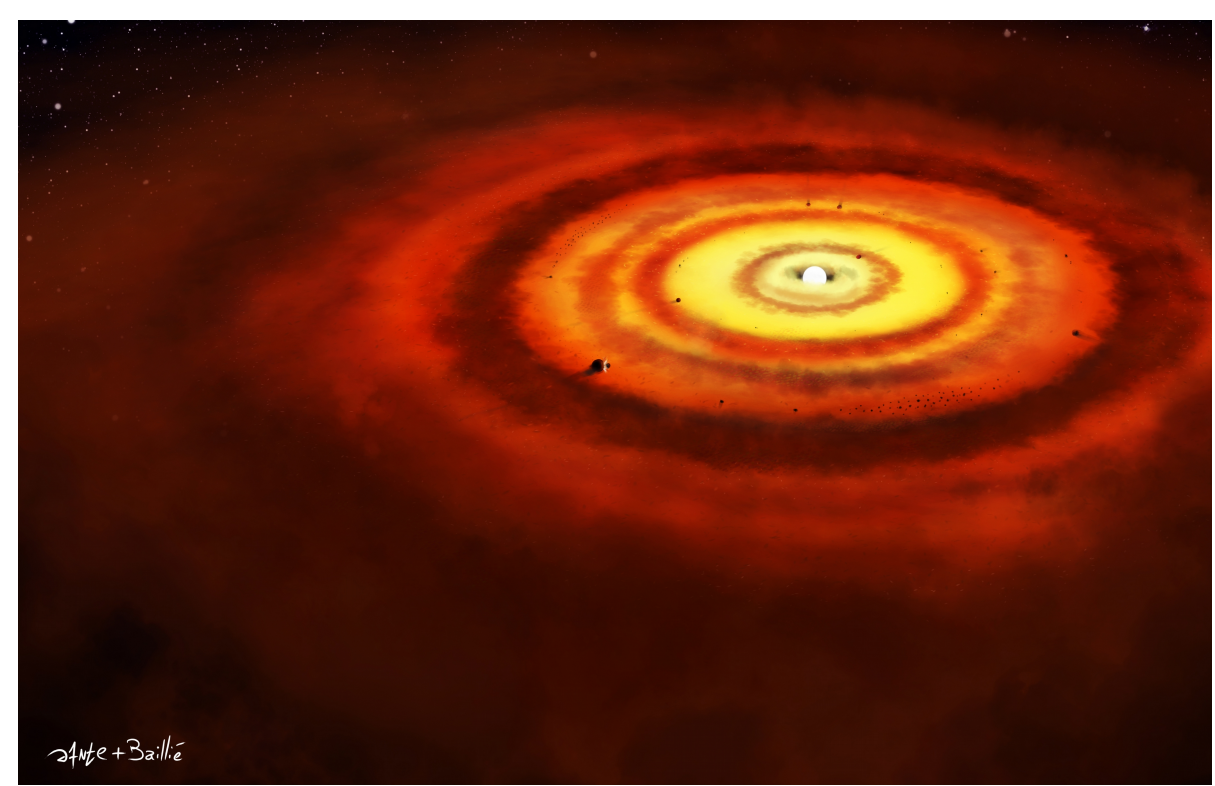
THE MINIMUM MASS SOLAR NEBULA: A 3 MILLION YEAR-OLD DISK.

LP5 - L2.116



K. Baillié - kevin.baillie@obspm.fr

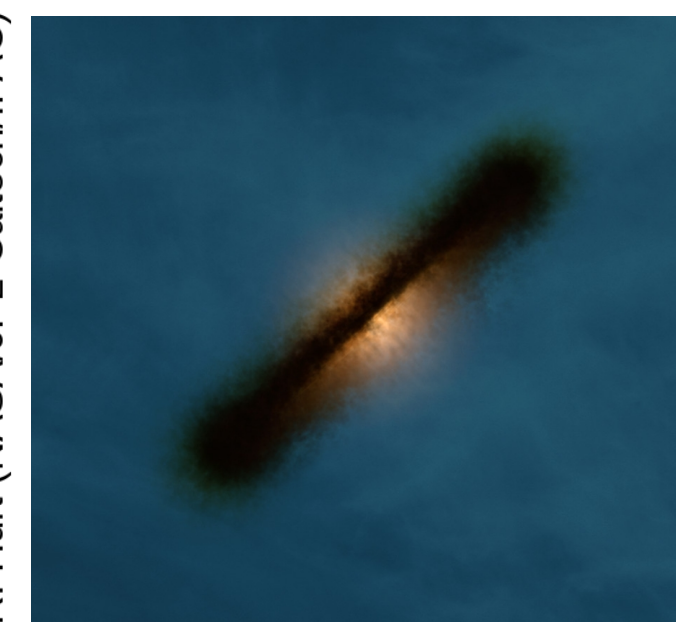
IMCCE, Observatoire de Paris, PSL Research University, CNRS, Sorbonne Universités, UPMC Univ Paris 06, Univ. Lille, 77 Av. Denfert-Rochereau, 75014 Paris, France.



Abstract

Most planetary formation simulations rely on simple protoplanetary disk models evolved from the usual, though inaccurate, Minimum Mass Solar Nebula. Here, we suggest a new consistent way of building a protoplanetary disk from the collapse of the molecular cloud: both the central star and the disk are fed by the collapse and grow jointly. We then model the star physical characteristics based on pre-calculated stellar evolution models. After the collapse, when the cloud initial gas reservoir is empty, the further evolution of the disk and star is mainly driven by the disk viscous spreading, leading to radial structures in the disk: temperature plateaux at the sublimation lines of the dust species and shadowed regions that are not irradiated by the star. These irregularities in the disk surface mass density or midplane temperature may help trap planetary embryos at these locations, eventually selecting the composition of the planet cores. In addition, we redefine the disk timeline and describe the stages that lead to the MMSN model.

R. Hurl (NASA/JPL-Caltech/IPAC)



Problematic Where and when can planetary embryos be saved ? With what size and composition ?

Cloud & star model

We interpolate the stellar physical properties from tables of pre-calculated stellar evolutions (Piau et al., 2002, 2011, Marques et al., 2013).

The disk gains mass from the molecular cloud.
The star gains mass from the molecular cloud and accretion by the disk viscous spreading.

Figure 1 : Star and disk mass evolution.

Figure 2 : Stellar temperature, radius and luminosity evolution.

Disk model

1D + 1D numerical viscous spreading (Lynden-Bell, 1974) hydrodynamical code from Baillié et al., 2014, 2015, 2016 :

- heating : irradiation + viscous + cloud
- + radiative cooling + disk self-shadowing
- coupling dynamics \rightleftharpoons thermodynamics (v_{turb})
- coupling temperature \rightleftharpoons geometry (α_{gr})
- coupling temperature \rightleftharpoons composition (opacity)

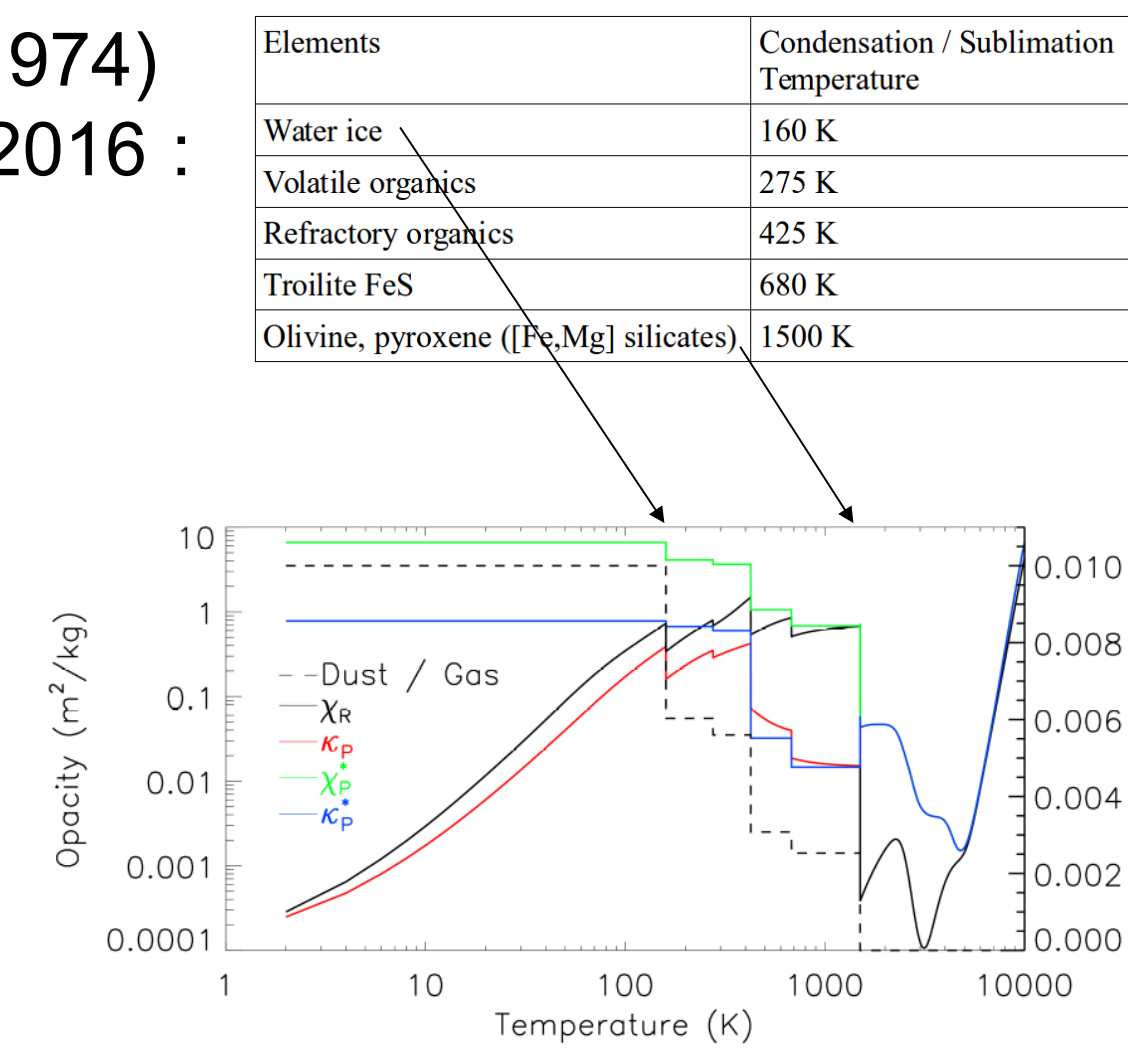
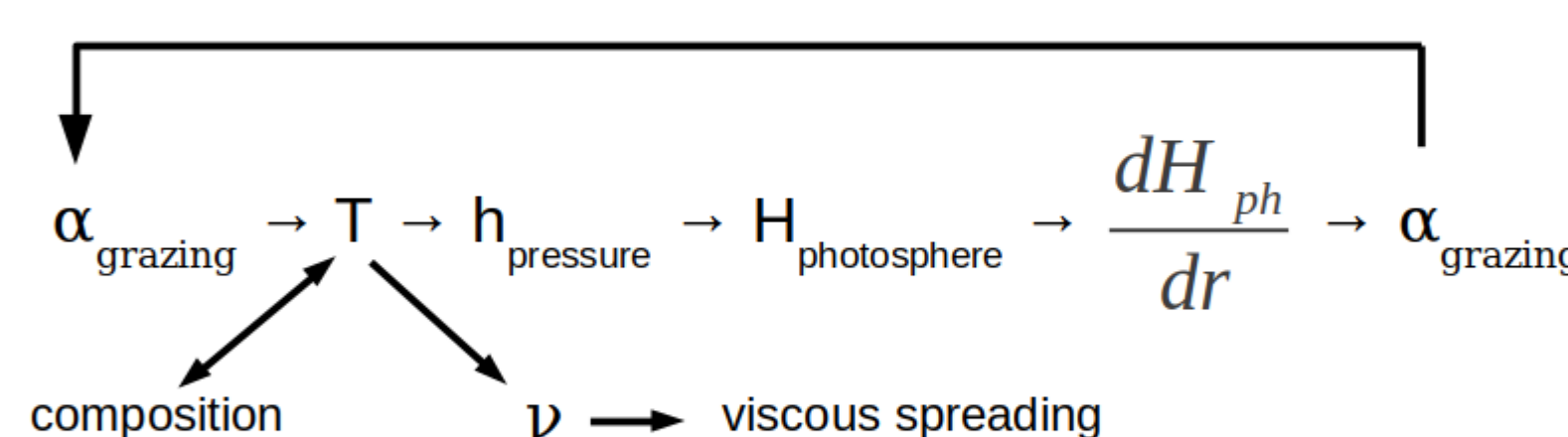


Figure 3 : Opacity variations with local temperature (from Semenov et al., 2003)

Disk structure and evolution

- The disk grows for **170 kyr** before emptying on the star by viscous spreading
- It gets hotter until the end of the collapse phase and then cools down
- Sublimation lines migrate as the disk evolves

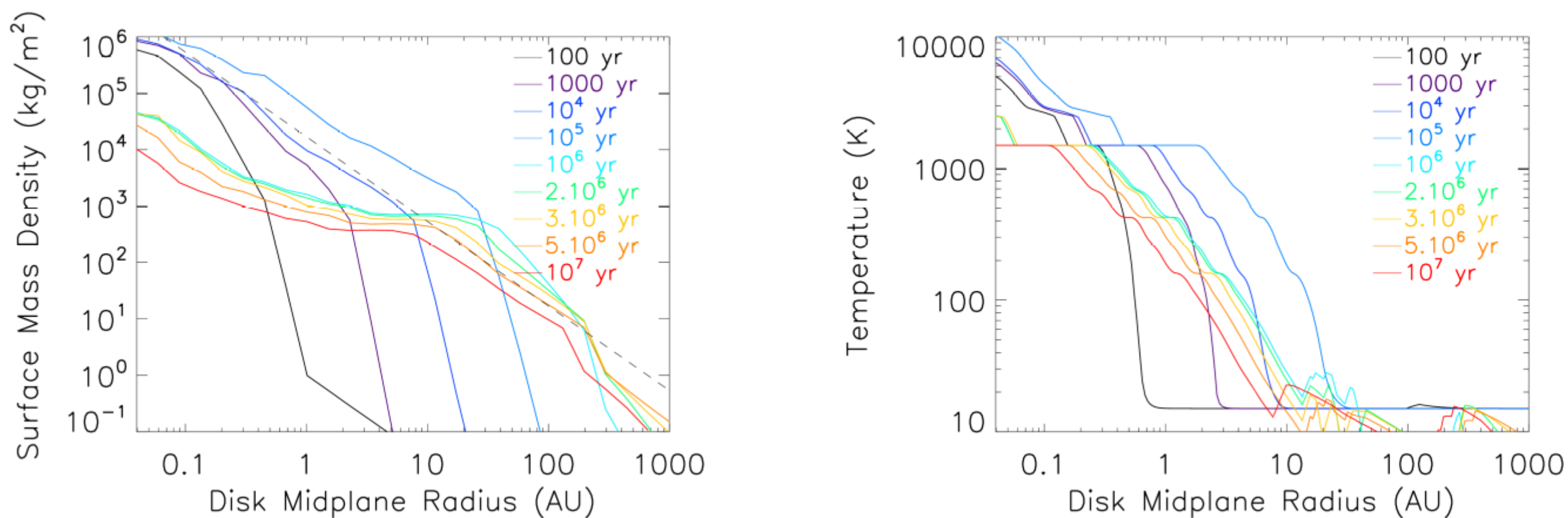


Figure 4 : Evolution of the surface-mass density and temperature radial profiles for disk fed by collapse of the molecular cloud.

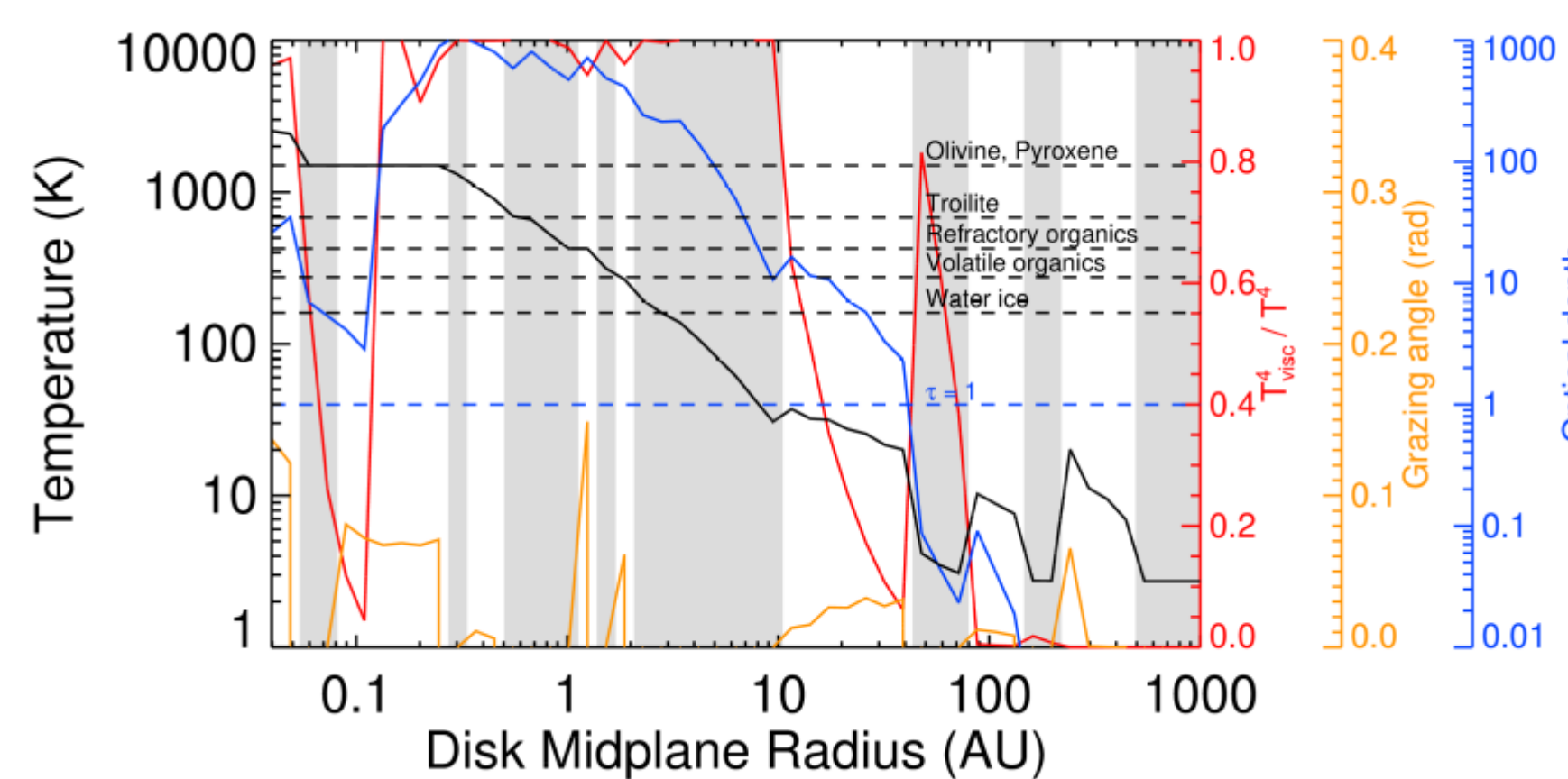


Figure 5 : Mid-plane temperature radial profile after 1 Myr. Shadowed regions in gray. The ratio of the viscous heating contribution over the total heating is presented in red, the grazing angle profile in yellow and the optical depth profile in blue.

- Most of the **inner disk is self-shadowed** (up to the heat transition barrier)
- Sharp edge and positive temperature gradient at the heat transition barrier
- **Enlarged snow and sublimation zones at the temperature plateaux**

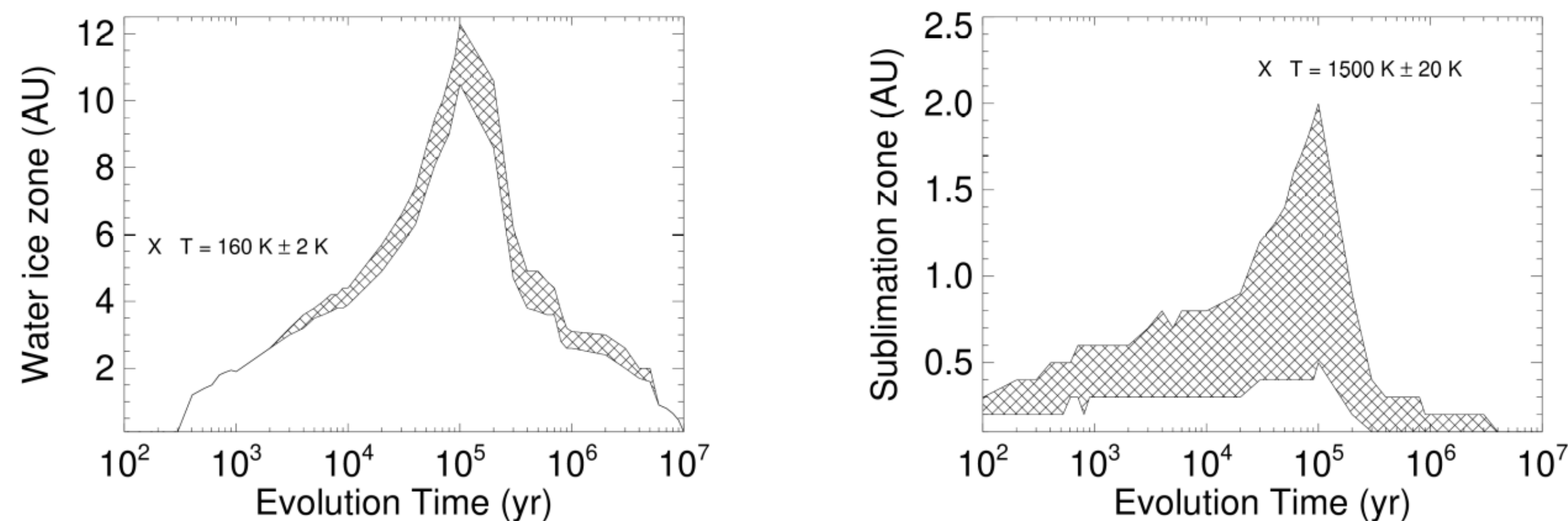


Figure 6 : Time evolution of the snow region and silicates sublimation zone.

Sublimation lines and therefore traps migrate outward at first and inward after the end of the collapse phase

Conclusions

- The disk forms in 170 kyr and reaches an MMSN-like stage in 2-3 Myr
- Planet traps follow the sublimation lines \rightarrow « trapped migration »
- Modeling the disk formation by the cloud collapse allows to understand the multiple trapping possibilities in the first million years of planet formation

References

K. Baillié and S. Charoz: Time Evolution of a Viscous Protoplanetary Disk with a Free Geometry: Toward a More Self-consistent Picture. *A&A*, 786:35, May 2014.
K. Baillié, S. Charoz and E. Pantin: Time Evolution of Snow Regions and Planet Traps in an Evolving Protoplanetary Disk. *A&A*, 577 : A65, May 2015.
K. Baillié, S. Charoz and E. Pantin: Trapping planets in an evolving protoplanetary disk: preferred time, locations, and planet mass. *A&A*, 590 : A60, May 2016.
K. Baillié, J. Marques and L. Piau: Building protoplanetary disks from the molecular cloud: redefining the disk timeline. *A&A*, 624 : A93, Apr. 2019.
D. Lynden-Bell and J. E. Pringle: The evolution of viscous disks and the origin of the nebular variables. *MNRAS*, 188:953-957, Sep. 1974.

Planetary migration maps

Torques are very sensitive to Σ and T gradients.

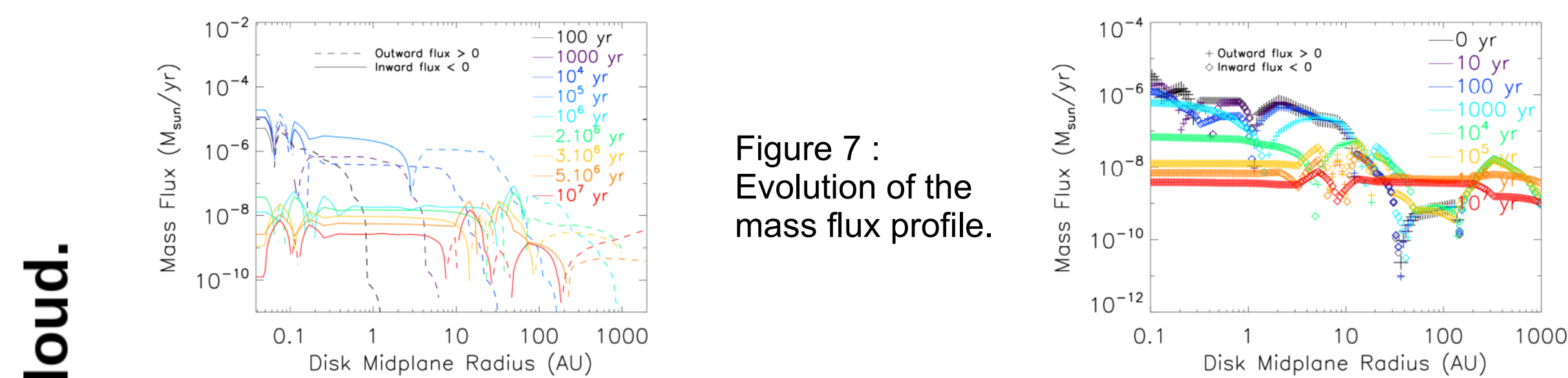
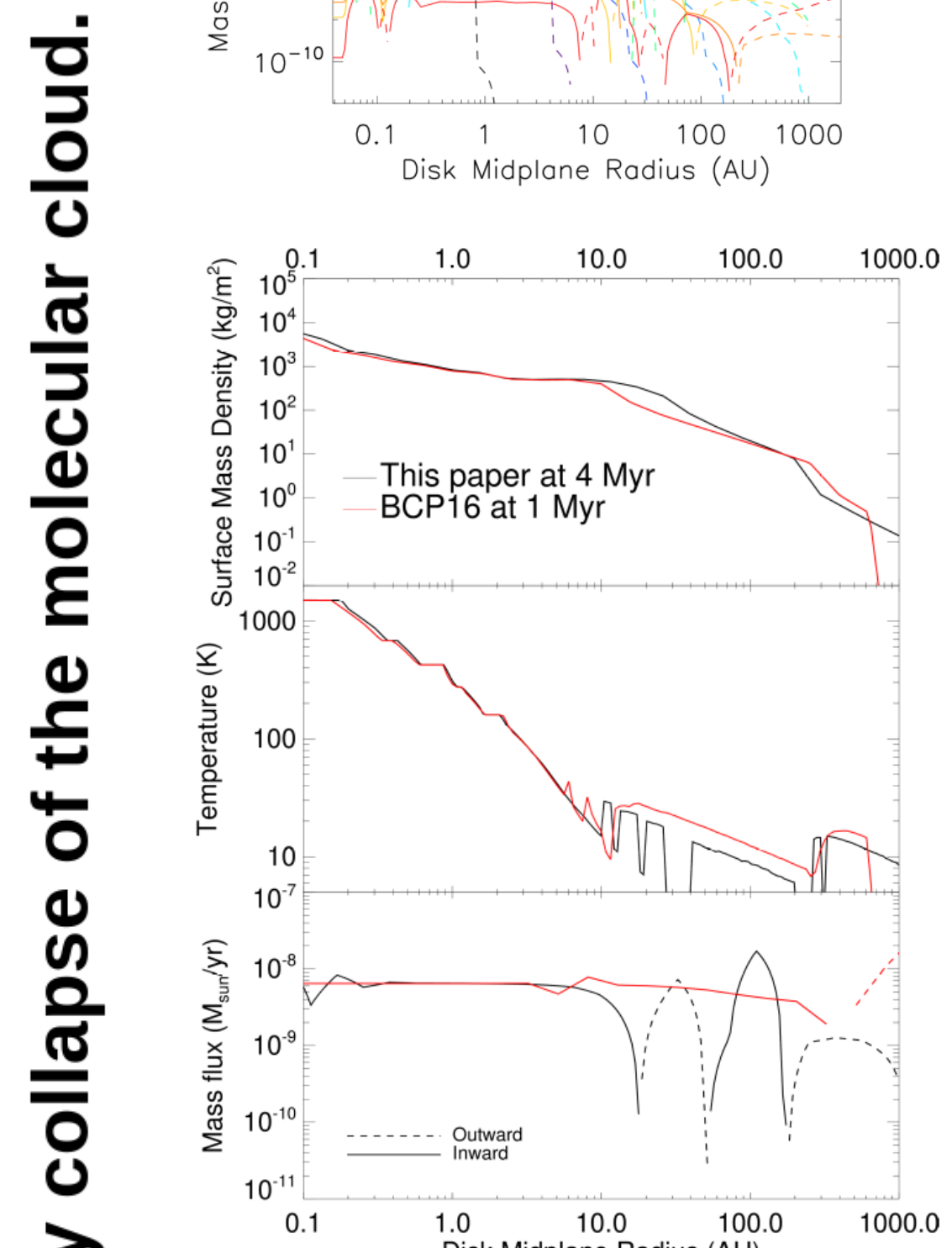


Figure 7 : Evolution of the mass flux profile.

Disk evolved from an initial MMSN.



Disk formed by collapse of the molecular cloud.

Assuming that **disks of similar ages have similar mass accretion rates**, we can rescale the MMSN timeline to fit the timeline of the disk formation by collapse.

The evolution from the disk formation to an MMSN-like stage seems to require about 2-3 Myr. Though the MMSN evolves faster, **disks of similar mass accretion rates will present similar planet traps and deserts at the sublimation lines and heat transitions**

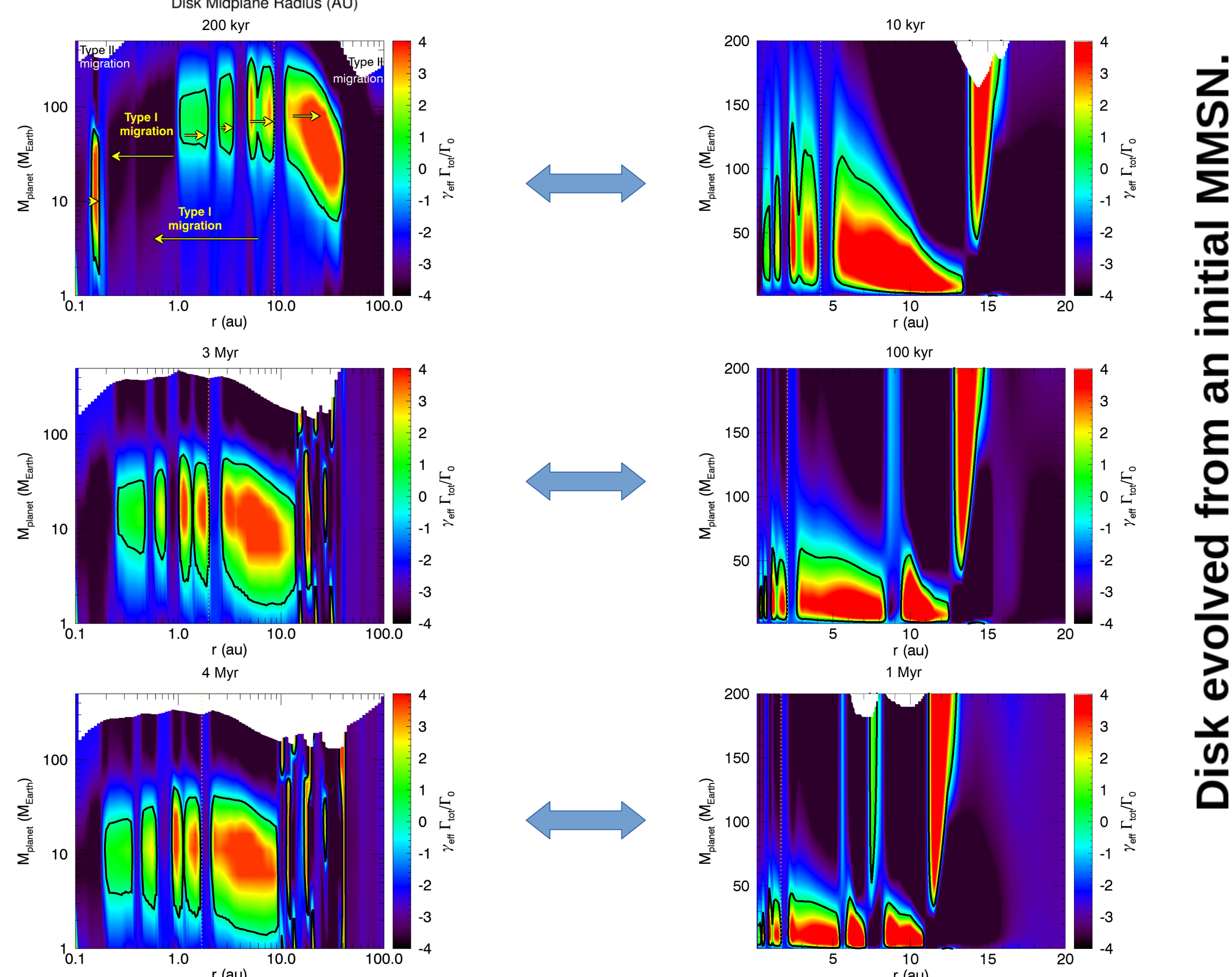
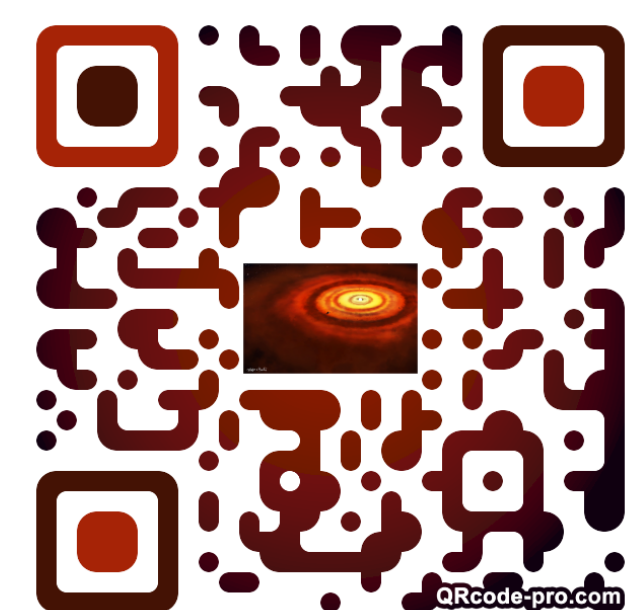


Figure 8 : Migration maps showing the direction and intensity of the migration of planetary embryos wrt location and mass. **Super-Earths can get trapped very early in the inner disk.**

Perspectives

- Photoevaporation
- Planetary growth, multiple-planet interactions
- Variable turbulent viscosity, deadzones
- Separate treatment of gas and dust flux



https://perso.imcce.fr/kevin-baillie/migrationmap_movie.html