Hello!

Please find a poster of this presentation in the next page and contact me if you have questions.

Regarding the **simulation videos**, feel free to scan the QR codes as indicated on the poster, or follow the following links:

- **Results with motionless boundary - temperature:** https://www.dropbox.com/s/xth5jzq4jpprvsl/Fixed_boundary_movie_temp.avi?dl=0
- **Results with motionless boundary - FeO:** https://www.dropbox.com/s/0781wblcq82nhcl/Fixed_boundary_movie_FeO.mp4?dl=0
- **Results with moving boundary:** https://www.dropbox.com/s/ymqnrkv8obo1isn/Moving_boundary_movie_temp.mp4?dl=0

I invite you to **take a look on my paper** (under review) about timescales of chemical equilibration between a solid mantle and a magma ocean: https://www.solid-earth-discuss.net/se-2020-49/

Happy EGU 2020 everyone!
Daniela Bolrão

Daniela Bolrão[1] (daniela.bolrao@erdw.ethz.ch),

Maxim Ballmer[2], Adrien Morison[3], Antoine Rozel[1], Stéphane Labrosse[3], Paul Tackley[1]

1 ETH zürich 2 UCL 3 ENS DE LYON

EGU General Assembly 2020

From a Magma Ocean to a Solid Mantle: Implications for the Thermo-Chemical Evolution of Mars

1. Motivation

WHAT WE KNOW ABOUT MARS[1, 2]:

✓ Early **Magma Ocean (MO)** due to accretion;

✓ **MO** crystallizes from the bottom up to the surface and originates the **Solid mantle (S)** in few Myr - see Fig. 1;

✓ Fractional crystallization can lead to an unstable density profile and overturn;

✓ Overturn can occur before the entire crystallization of the **MO**;

✓ Today we observe crustal dichotomy and chemical heterogeneities in the **solid mantle**.

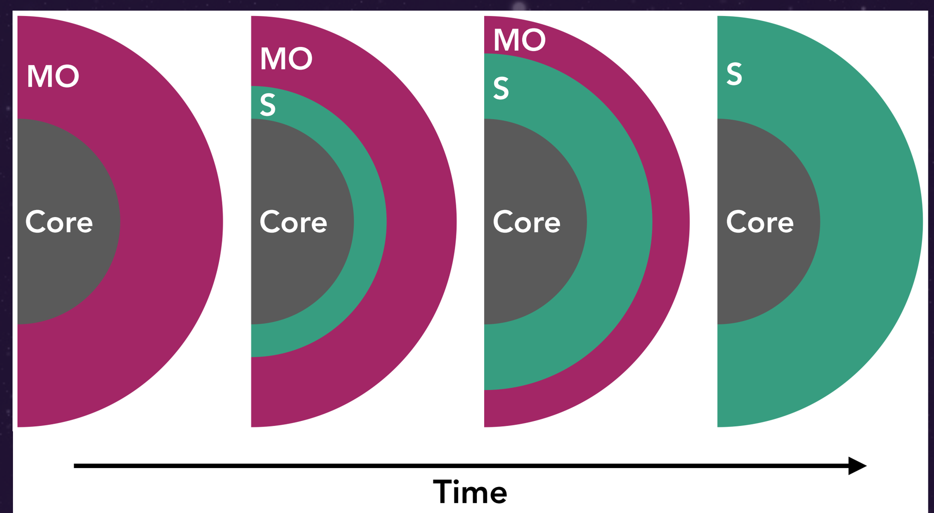

Fig. 1 Bottom-up **Magma Ocean (MO)** crystallization originates the **solid mantle (S)**.

WHAT WE DON'T KNOW ABOUT MARS AND WANT TO INVESTIGATE:

Considering fractional crystallization and melting processes at the **solid mantle**–**magma ocean** boundary:

- What happens to the dynamics and composition of the **solid mantle** during the **MO** crystallization?
- What is the timescale for chemical equilibration between the **solid mantle** and the **magma ocean**?

2. Methods

Code StagYY[3]: models the convection in the **solid mantle (S)**; we run simulations with **motionless** and **moving** boundary between **S** and **magma ocean (MO)**. **Geometries**: **S** is a 2D spherical annulus and the **MO** is a 0D object at the boundary. **Composition**: only FeO and MgO; Fe partitioning: $K_D = 0.3$; initial FeO content: 0.224; for moving boundary cases: solidus curve[4]. **Temperature**: 0.0 and 1.0 at top and bottom **S** boundaries, respectively. **Boundary condition**: phase change BC to allow exchange of solid and liquid matter at the boundary between **S** and **MO**. **Other**: dimensionless equations, $Ra = 10^6$, isoviscous mantle, MO dimensions: 1000 km, phase change number = 10^{-1}.

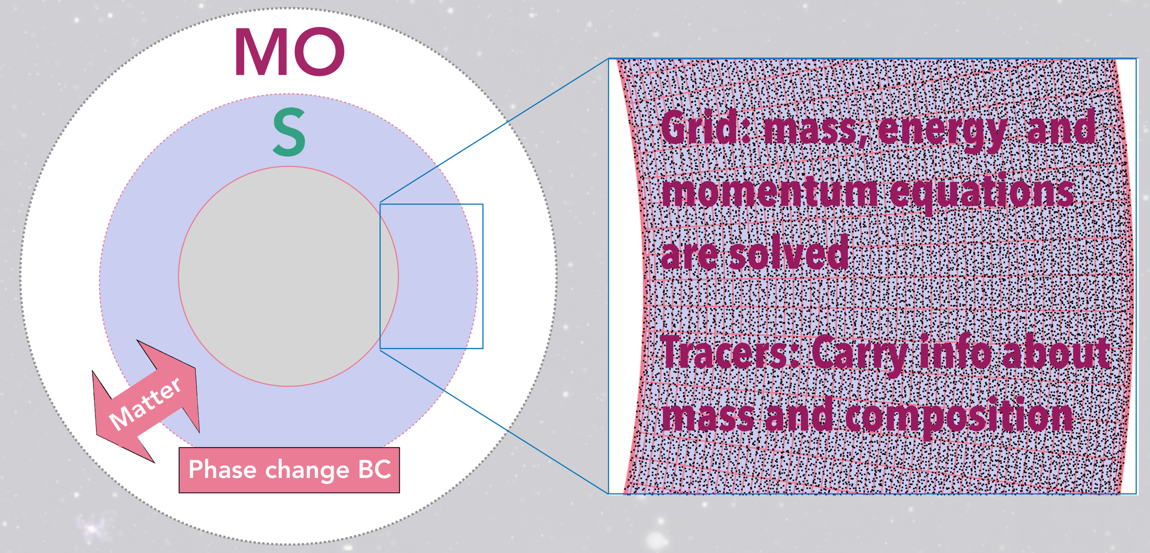

Fig. 2 Geometry of the **Solid mantle (S)** with zoom of the grid and tracers. Solid and liquid matter can be exchanged at the boundary between **S** and the **Magma Ocean (MO)** due to the phase change Boundary Condition (BC).

3. Results

3.1. Results with motionless boundary between solid mantle and magma ocean

Scan the QR codes to see the simulations!

Evolution of temperature and FeO content in the solid mantle

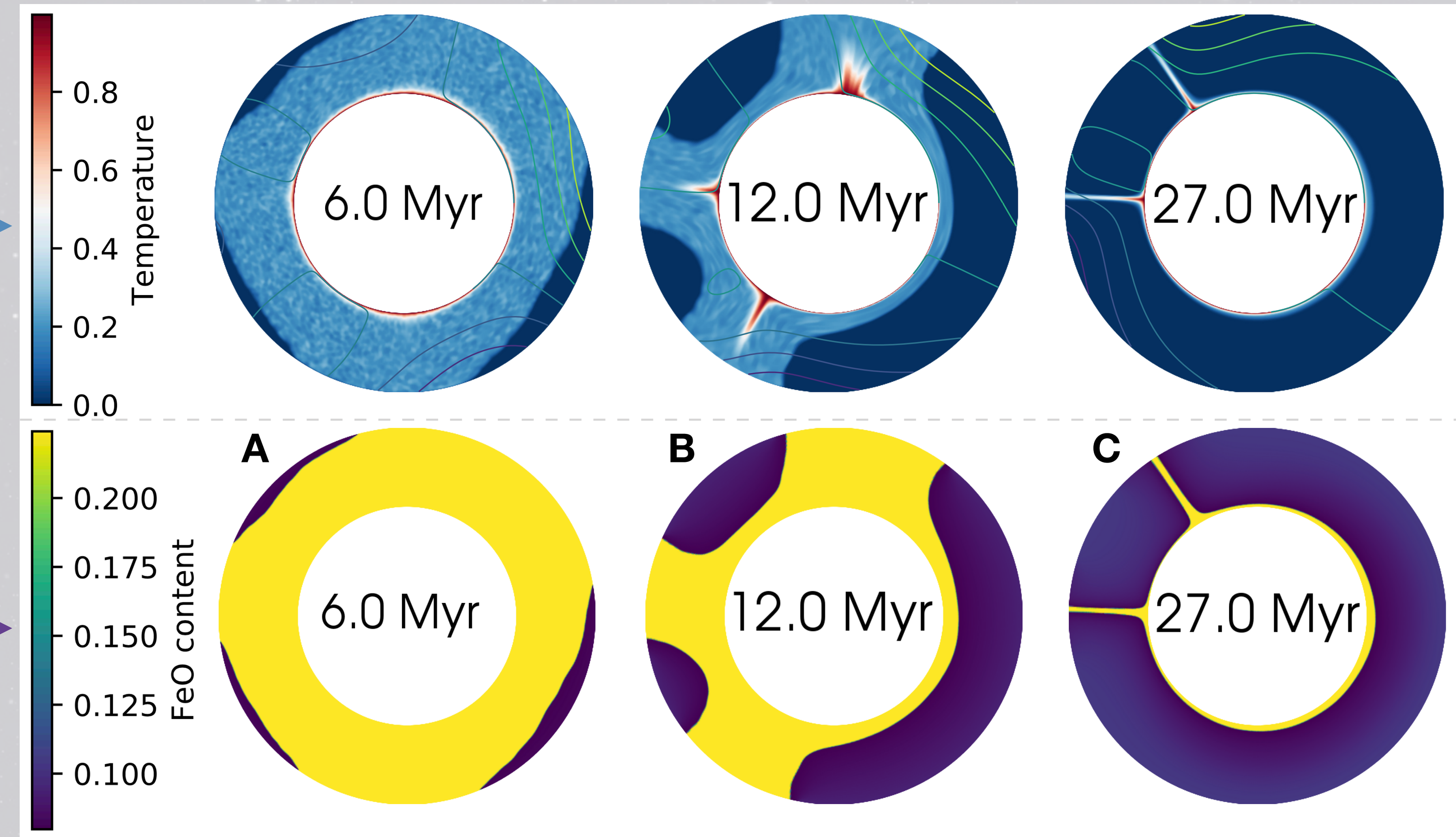

Fig. 3 Snapshots of the evolution of temperature (top panel) and FeO content (bottom panel - **A**, **B** and **C** correspond to the points in **Fig. 4**) in the **solid mantle**. Scan the QR codes on the left to see the simulation movie of each field. **Overturn** of the **solid mantle** occurs with degree-1. A layer with **primordial material enriched in FeO** stays at the bottom of the mantle.

Evolution of FeO content in the magma ocean and solid mantle

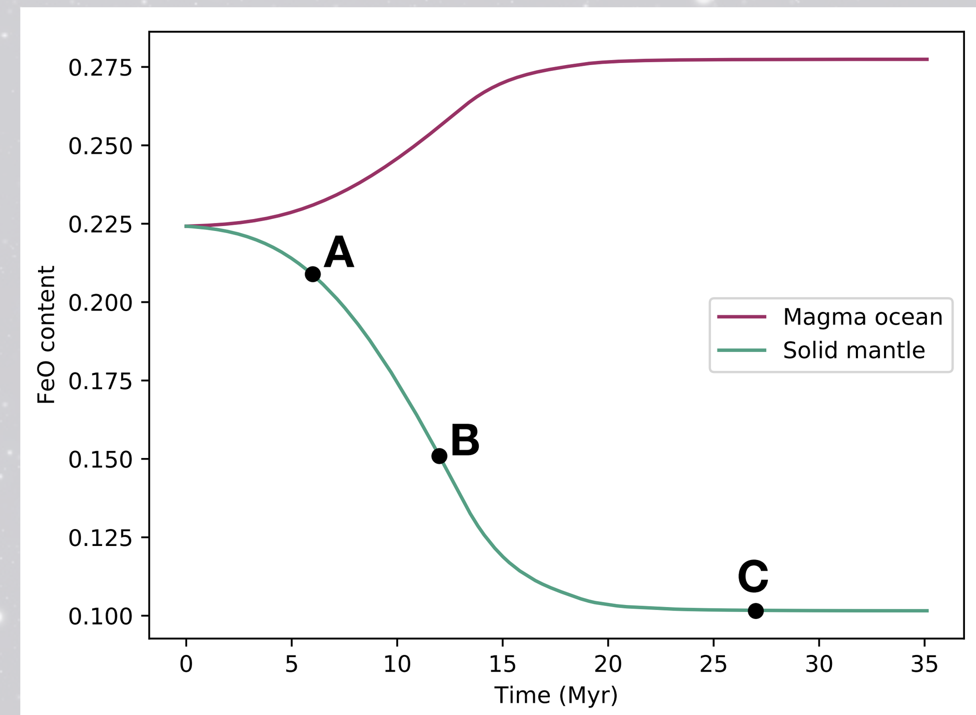

Fig. 4 Evolution of FeO content in the **magma ocean** and **solid mantle**. Points **A**, **B** and **C** correspond to the snapshots of FeO content in **Fig. 3, bottom panel**. FeO content decreases in the **solid mantle** and increases in the **magma ocean** towards **chemical equilibration**. This starts around 25 Myr (>> than crystallization timescale of few Myr).

3.2. Results with moving boundary between solid mantle and magma ocean

Preliminary results!

Scan the QR code to see the simulation!

Evolution of temperature in the solid mantle

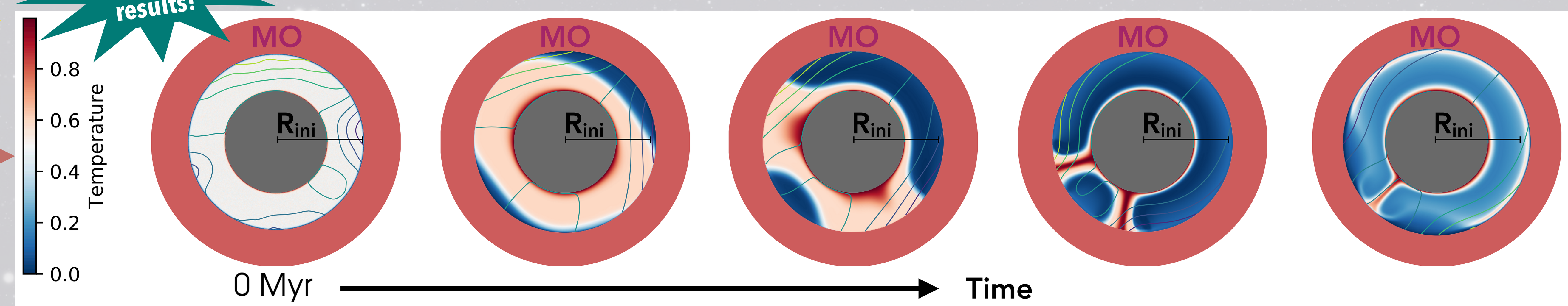

Fig. 5 Snapshots of the evolution of temperature in the **solid mantle** in contact with the **magma ocean (MO)**. Scan the QR code on the left to see the simulation movie. R_{ini} is the initial radius of the **solid mantle**–**magma ocean** boundary and it is depicted here to make it easier to see the growth of the **solid mantle** with time. While the **solid mantle** grows, there's an **overturn** before the end of **MO** crystallization. Note: **MO** is not fully crystallized because the simulation takes time to run. Also, don't associate these snapshots in terms of time with the ones of **Fig. 3** (ask me why!).

4. Conclusion

DYNAMICS: overturn of the **solid mantle** occurs with degree-1 before the end of the **magma ocean** crystallization. **COMPOSITION:** chemical equilibration between the **magma ocean** and the **solid mantle** can take longer than **magma ocean** full crystallization (~25 Myr vs. few Myrs, respectively). This may explain mantle chemical heterogeneities observed in present day.

REFERENCES: [1]Elkins-Tanton, L.T., Parmentier, E.M. and Hess, P.C. (2003), *Magma ocean fractional crystallization and cumulate overturn in terrestrial planets: Implications for Mars*. Meteoritics & Planetary Science, 38: 1753-1771. [2]Morison, A., Labrosse, S., Deguen, R., Alboussière, T. (2019). *Timescale of overturn in a magma ocean cumulate*. Earth and Planetary Science Letters. 516. 25-36. [3]Tackley, P. J. *Modelling compressible mantle convection with large viscosity contrasts in a three-dimensional spherical shell using the yin-yang grid*. Phys. Earth Planet. Inter., 171(1-4):7–18, 2008. [4]Duncan, M. S., Schmerr, N. C., Bertka, C. M., & Fei, Y. (2018). *Extending the solidus for a model iron–rich Martian mantle composition to 25 GPa*. Geophysical Research Letters, 45, 10,211– 10,220.

ACKNOWLEDGMENTS: This work has received funding from the project **MaCoMaOc – Convection in planetary mantles interacting with magma oceans**, SNSF grant 200021E-164337.