Interior of Mars and its habitability

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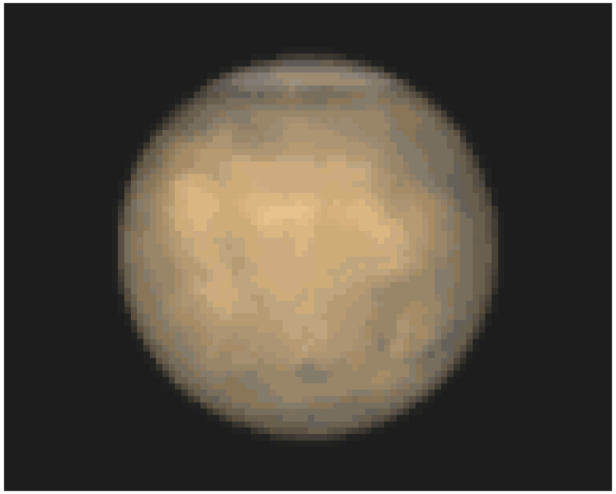

INTRODUCTION:

what do we know about Mars' interior?

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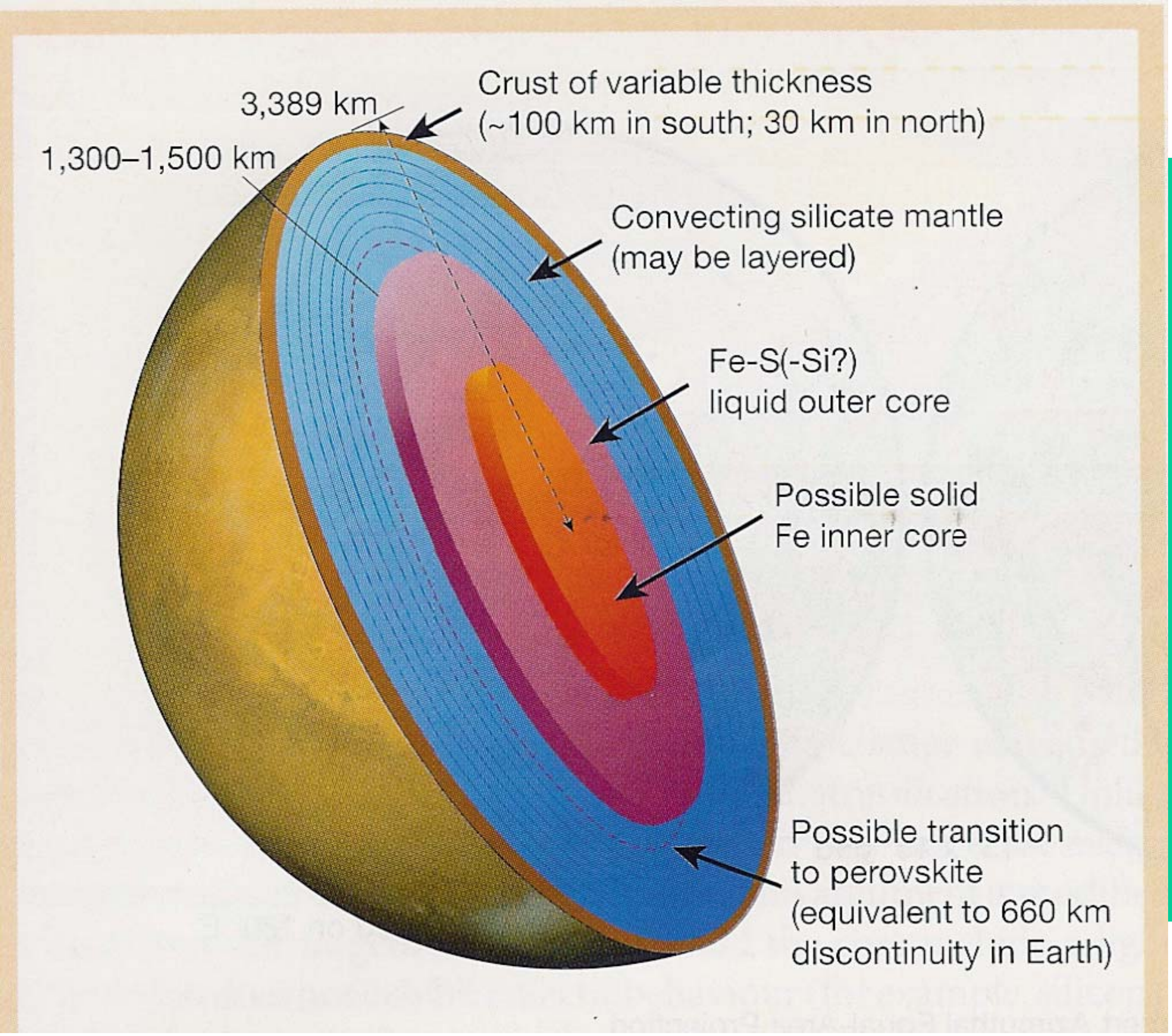
MARS INTERIOR



Core:

– Many questions for Mars (size, state)
– Important for the understanding of origin, evolution, and dynamics of terrestrial planets

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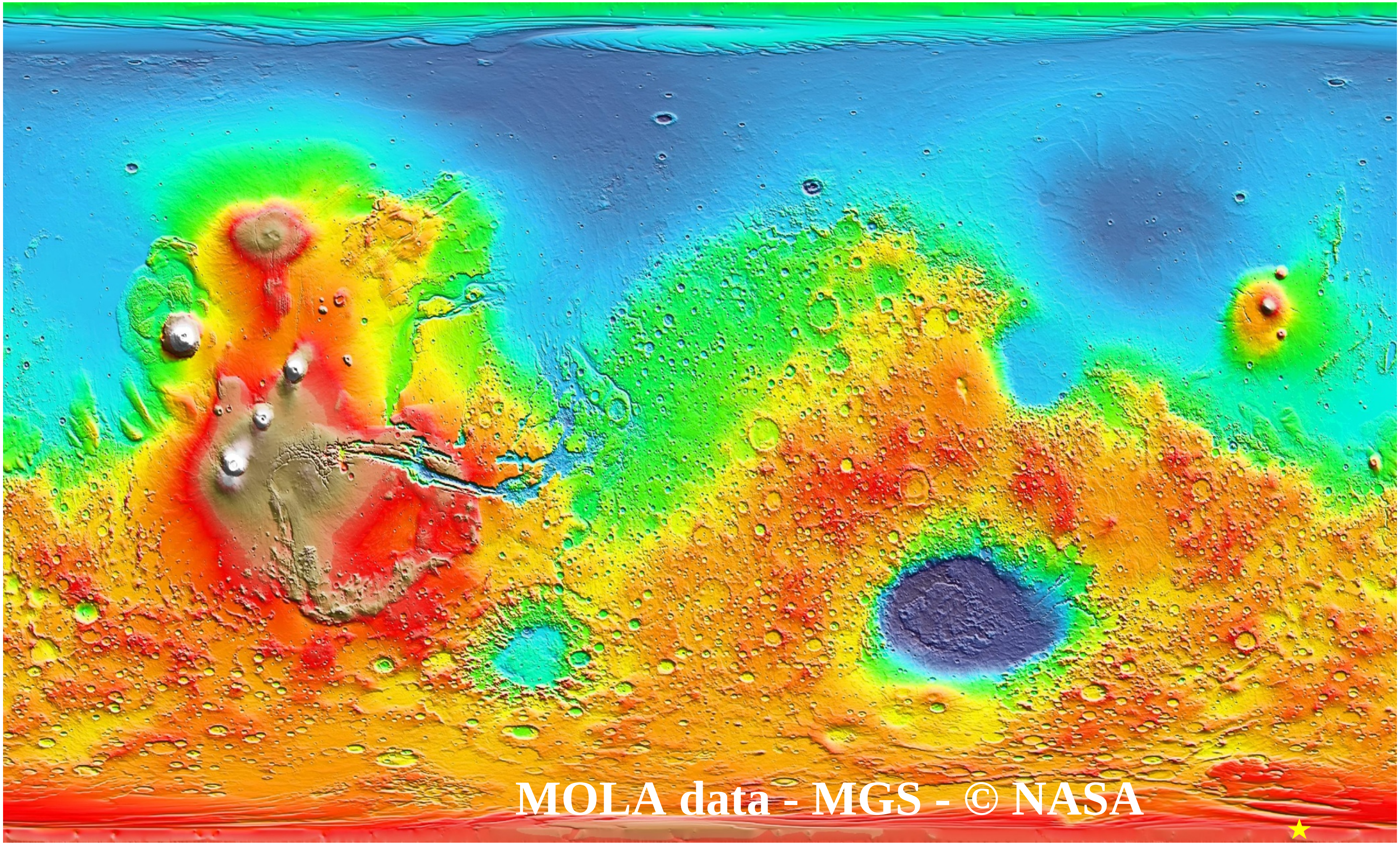
TOPOGRAPHY OF MARS (SCALE -8 A 25 KM ALT.)



BLUE : LOW ALTITUDES, RED : HIGH ALTITUDES

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From Breuer et al.

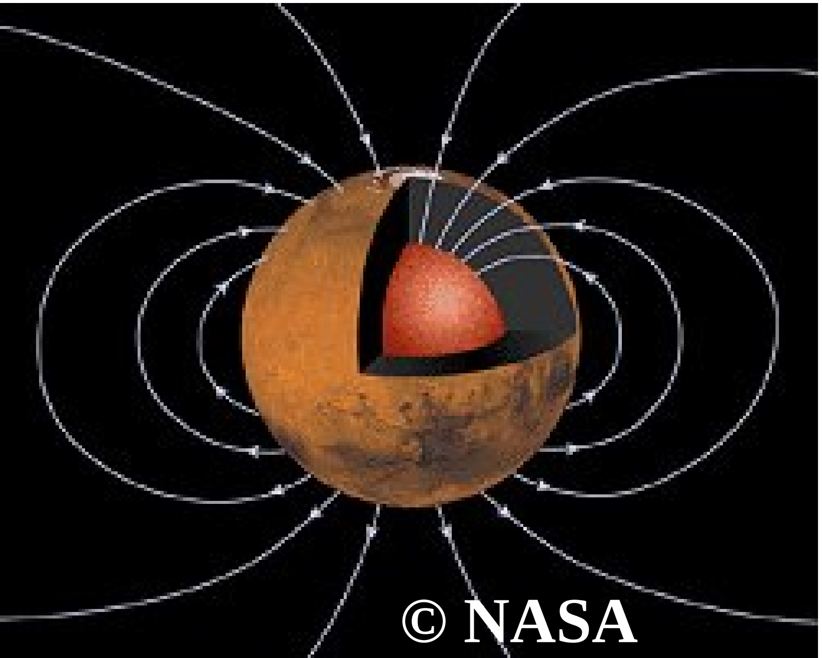
Mantle convection sustains plumes, which can persist. Difficult to maintain a one-plume convection, but possible explanation related to partial melt and/or phase transition inside the mantle.

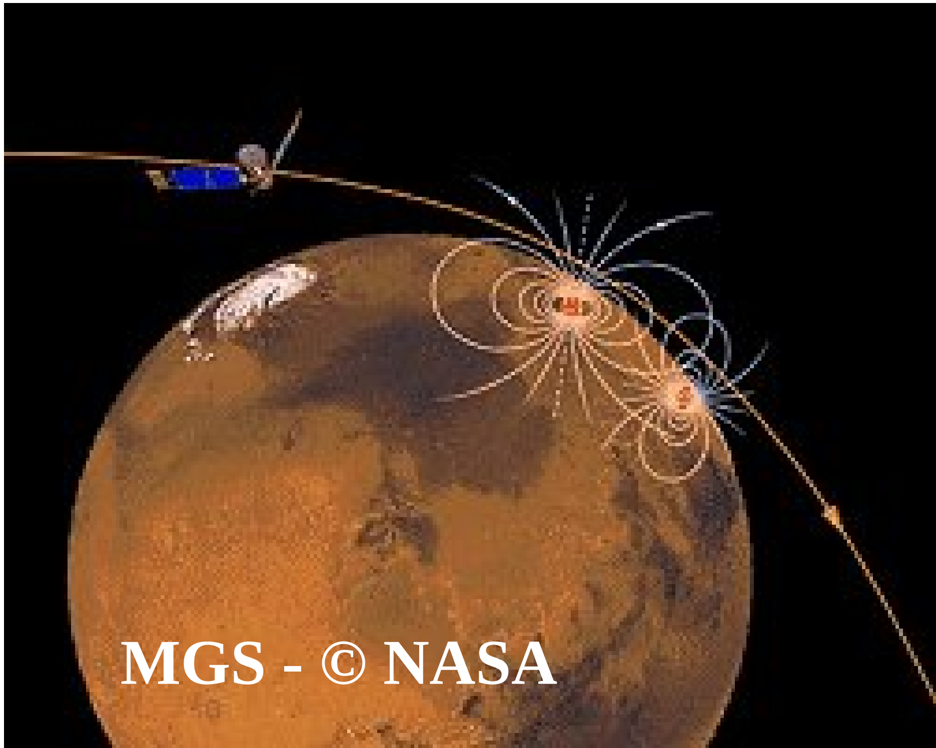
Magnetic field

Earth: global field, mainly dipole

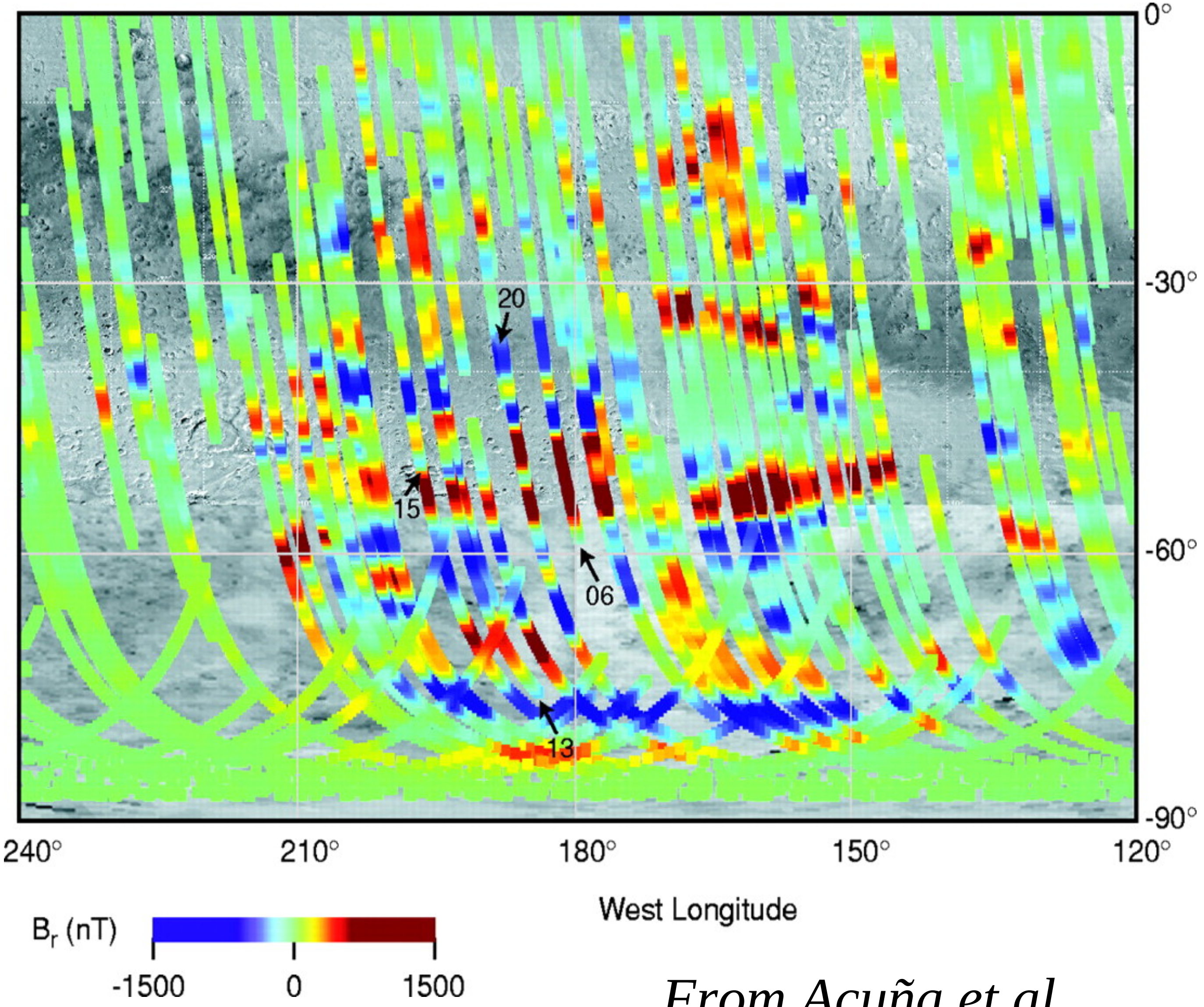
Mars:
No present global field
Only traces of an ancient global field

geodynamo

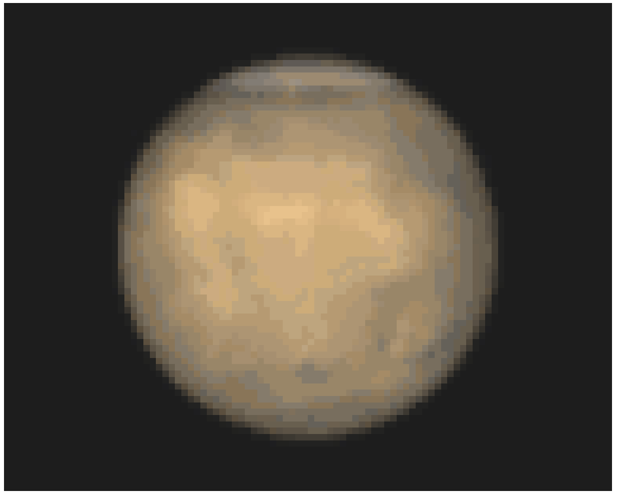




Remanent magnetism on Mars



From Acuña et al.



CONTEXT:

habitability

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Habitability conditions:

- Energy source (solar, volcanism, tidal energy, natural radioactivity…)
- Stable liquid water
- C, H, N, O, P, S, amino-acides … nutriments

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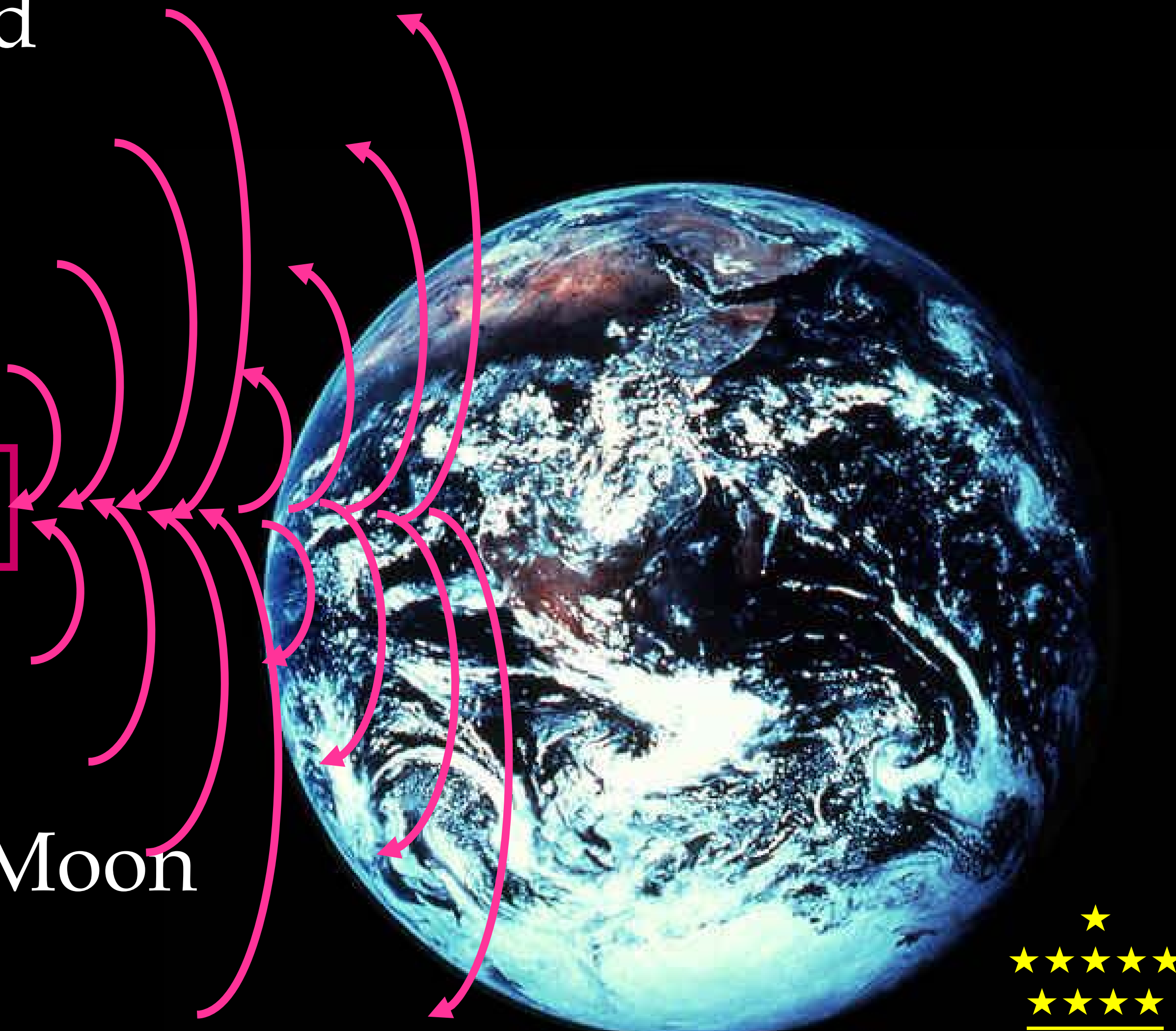
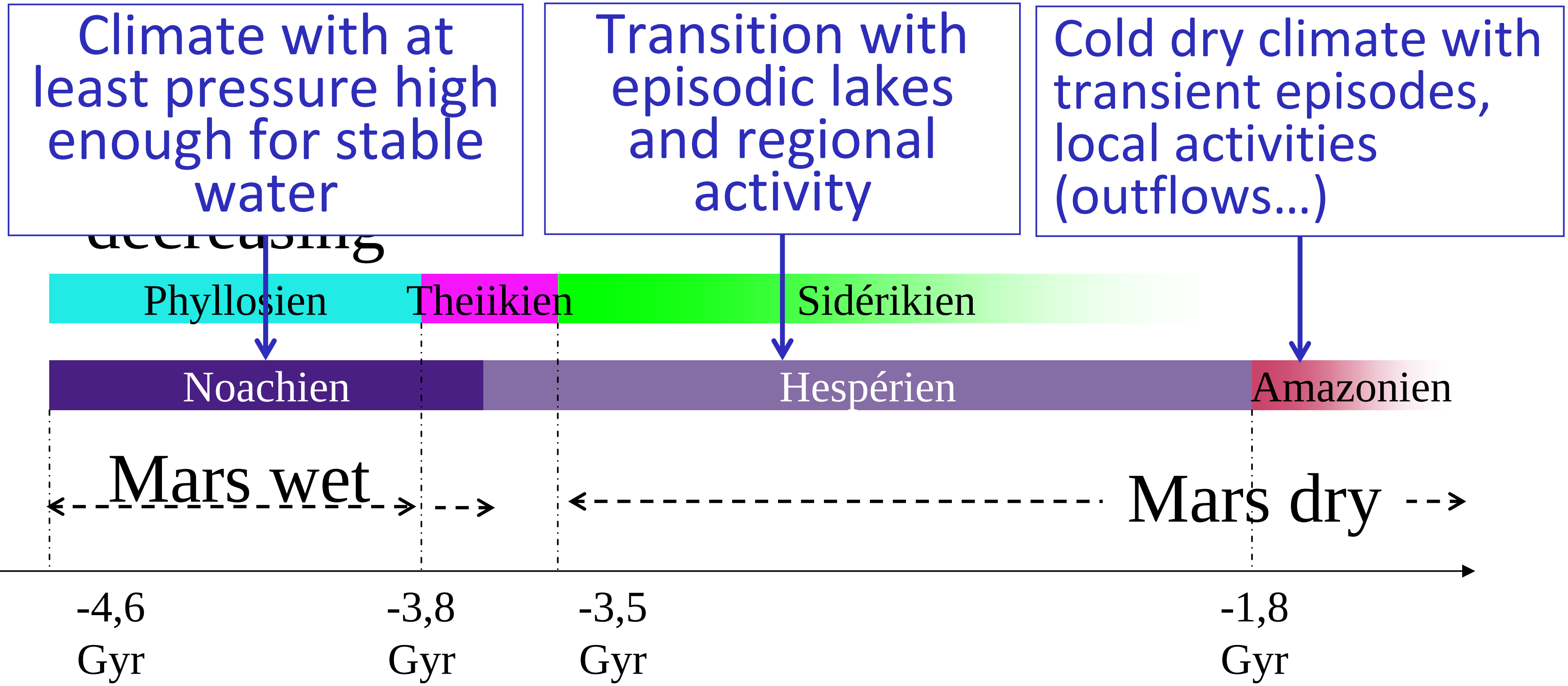
Earth criterias for habitability:

- Magnetic field
- Plate tectonic
- Volcanism
- Atmosphere
- Liquid water
- Gravity
- Carbon cycle
- Satellite: the Moon
- Impacts

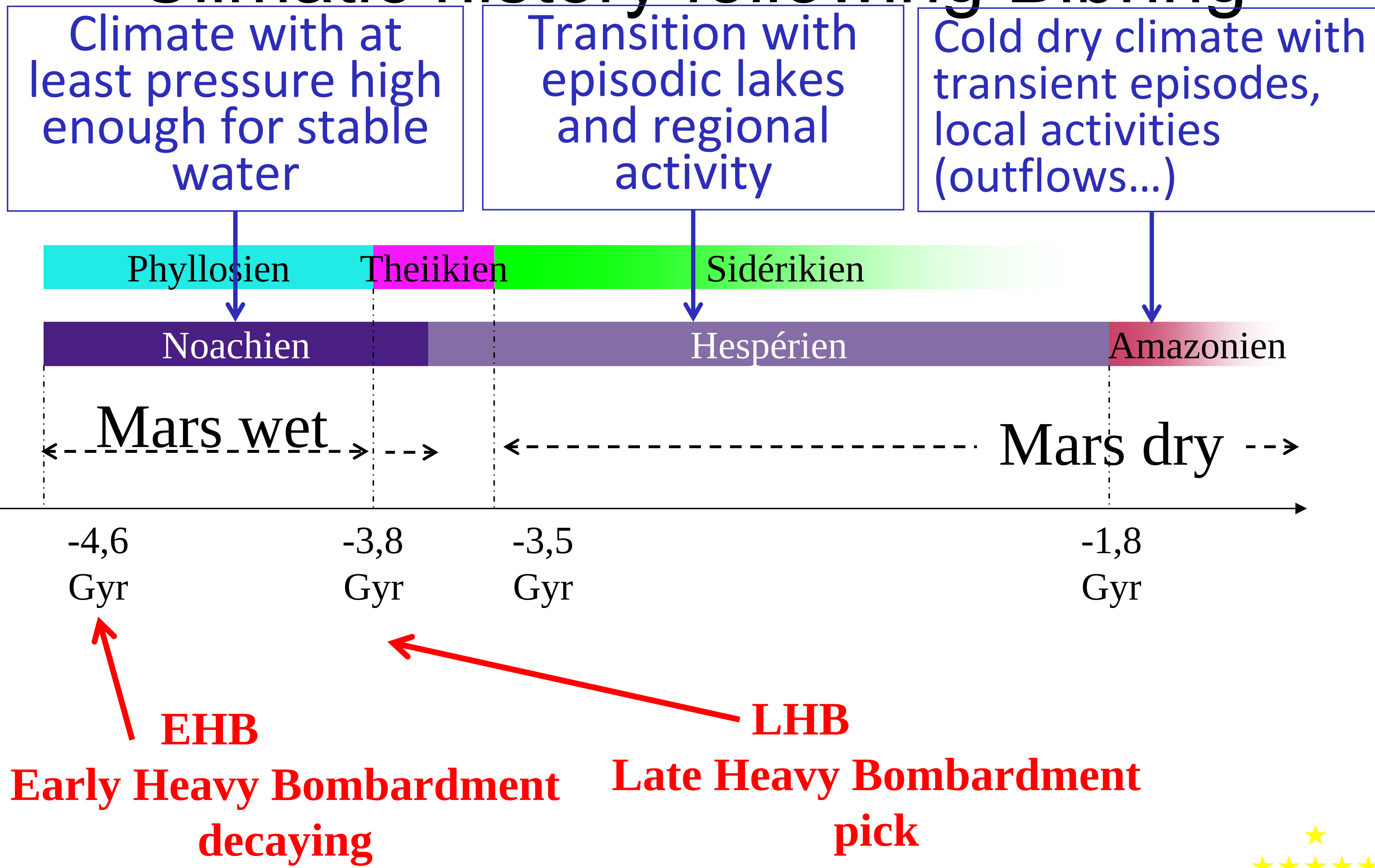


Climatic history following Bibring's talk



Geological findings such as Mangold's talk also Clifford et al., etc…

Climatic history following Bibring



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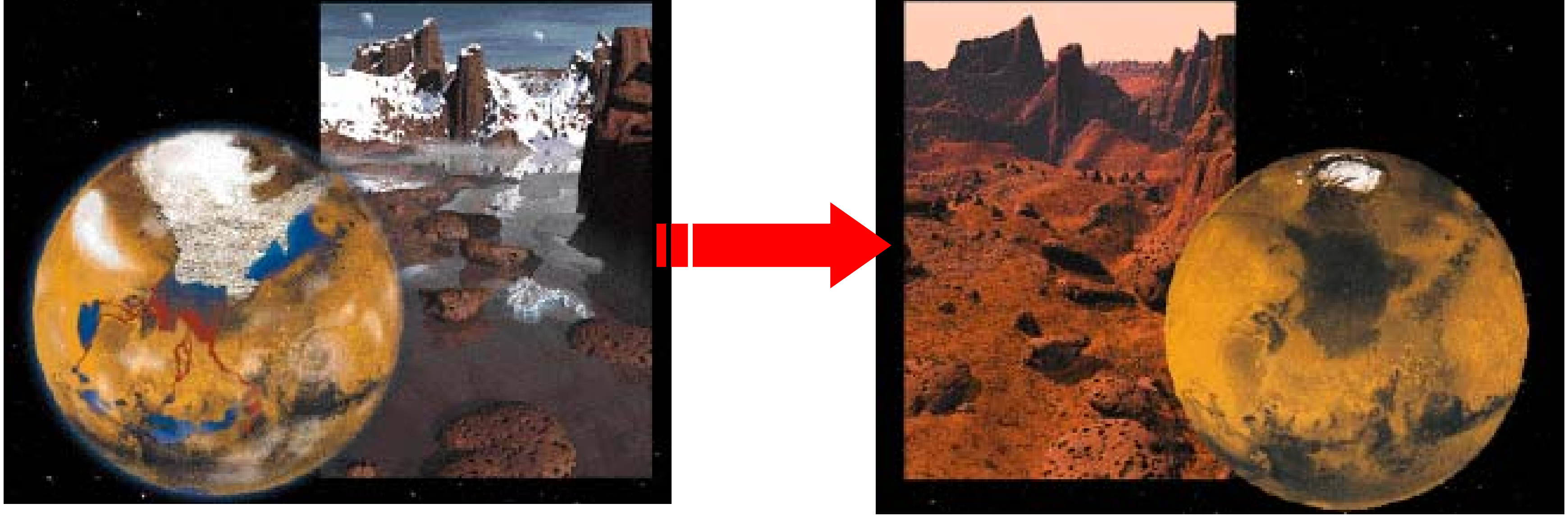
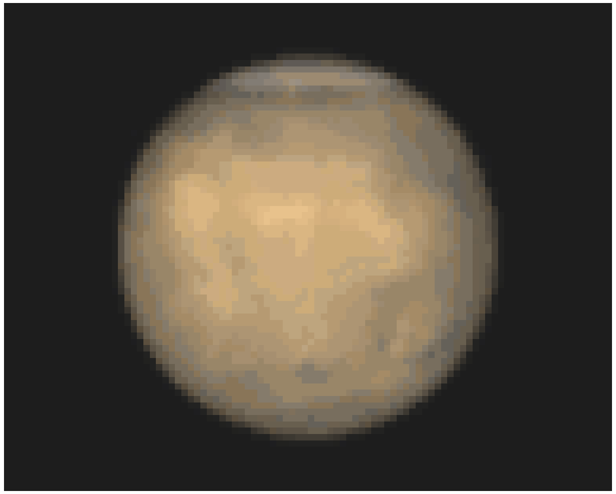


- **Mars at present 7 mbar atmosphere; may not be the atmosphere in the early stage**
- **Mars lost its early atmosphere during the (pre-)Noachian**
- **Escape, Erosion? Sputtering, ion pick-up etc…**
- **(Sun was different at the beginning of Mars' life)**



Relation with interior?

Habitability in the frame of geophysics

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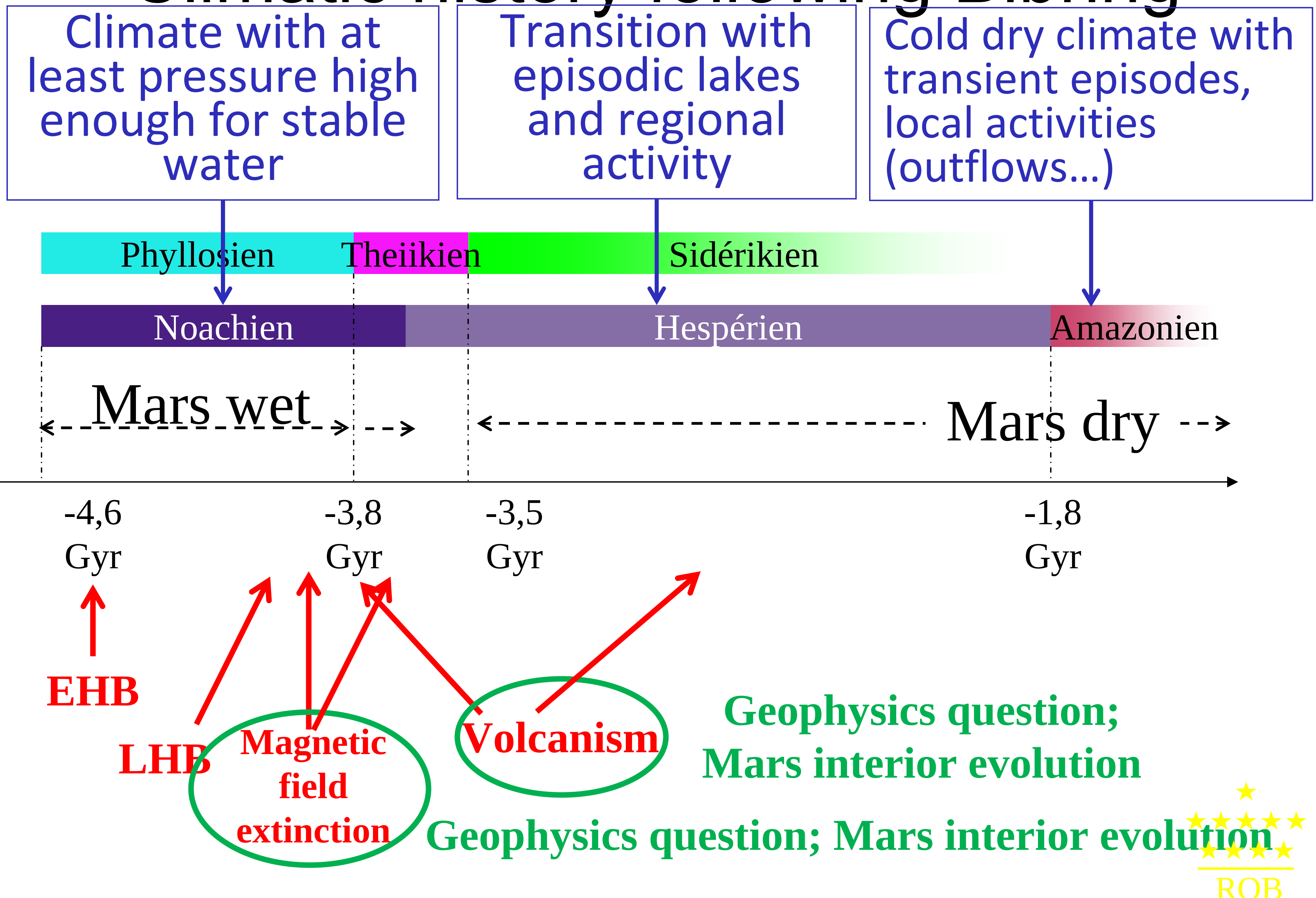
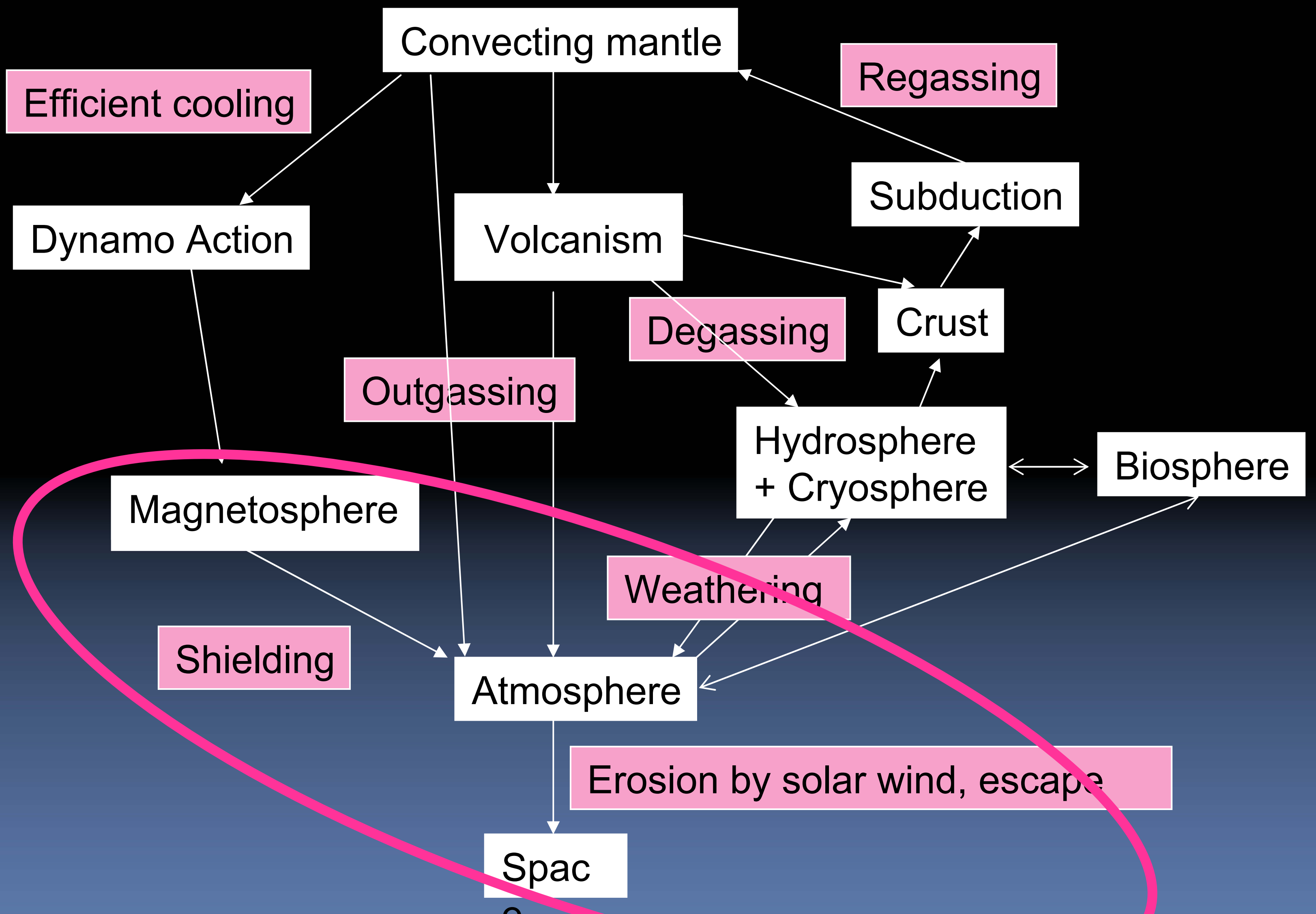
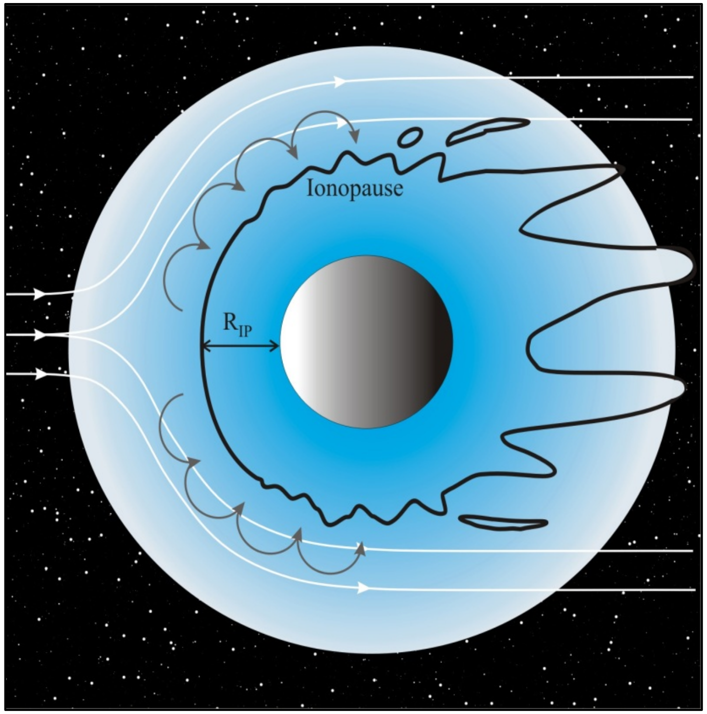
Climatic history following Bibring

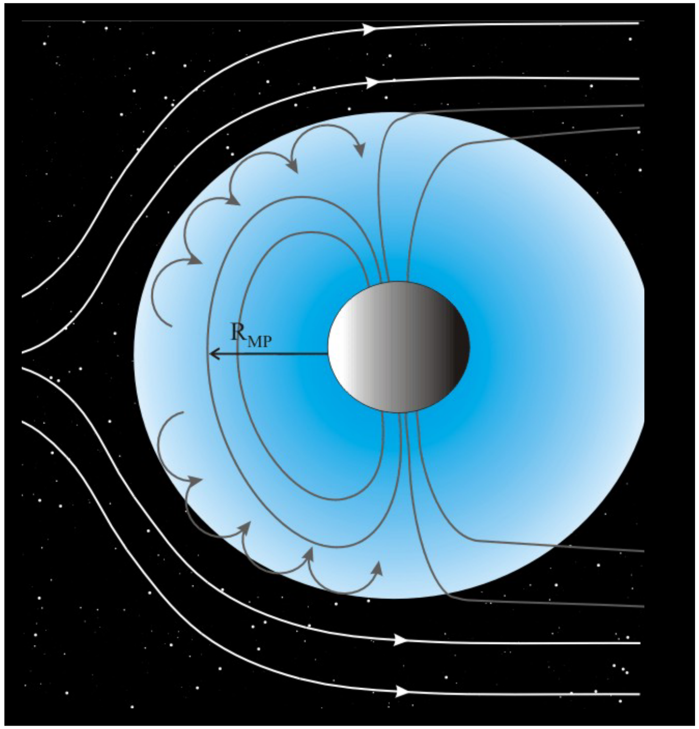


Planet with plate tectonics adapted from *Spohn et al.* and *Lammer et al.*



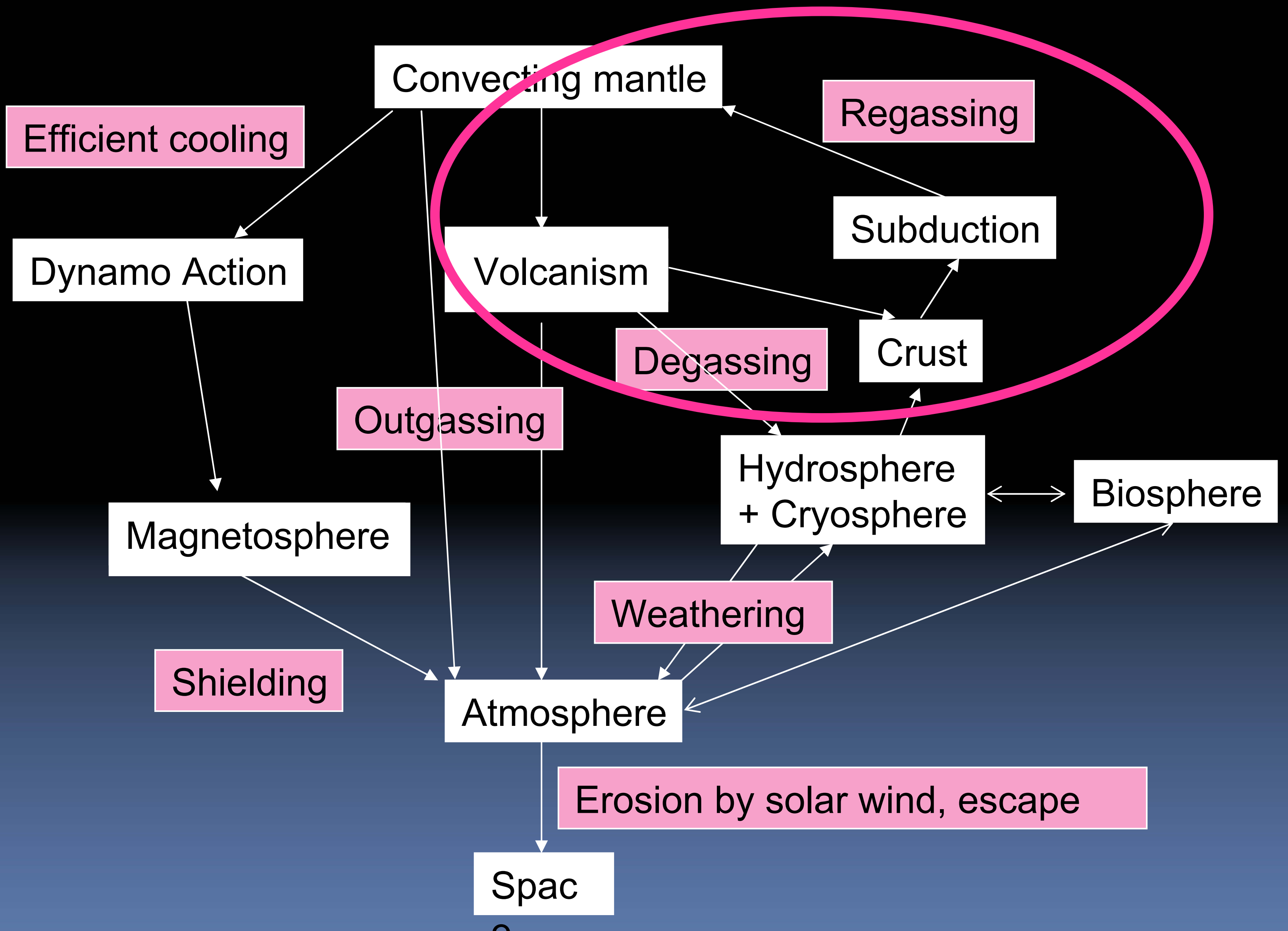
The presence of a magnetic field is important for these phenomena:





From Lammer et al.

Planet with plate tectonics adapted from *Spohn et al.* and *Lammer et al.*

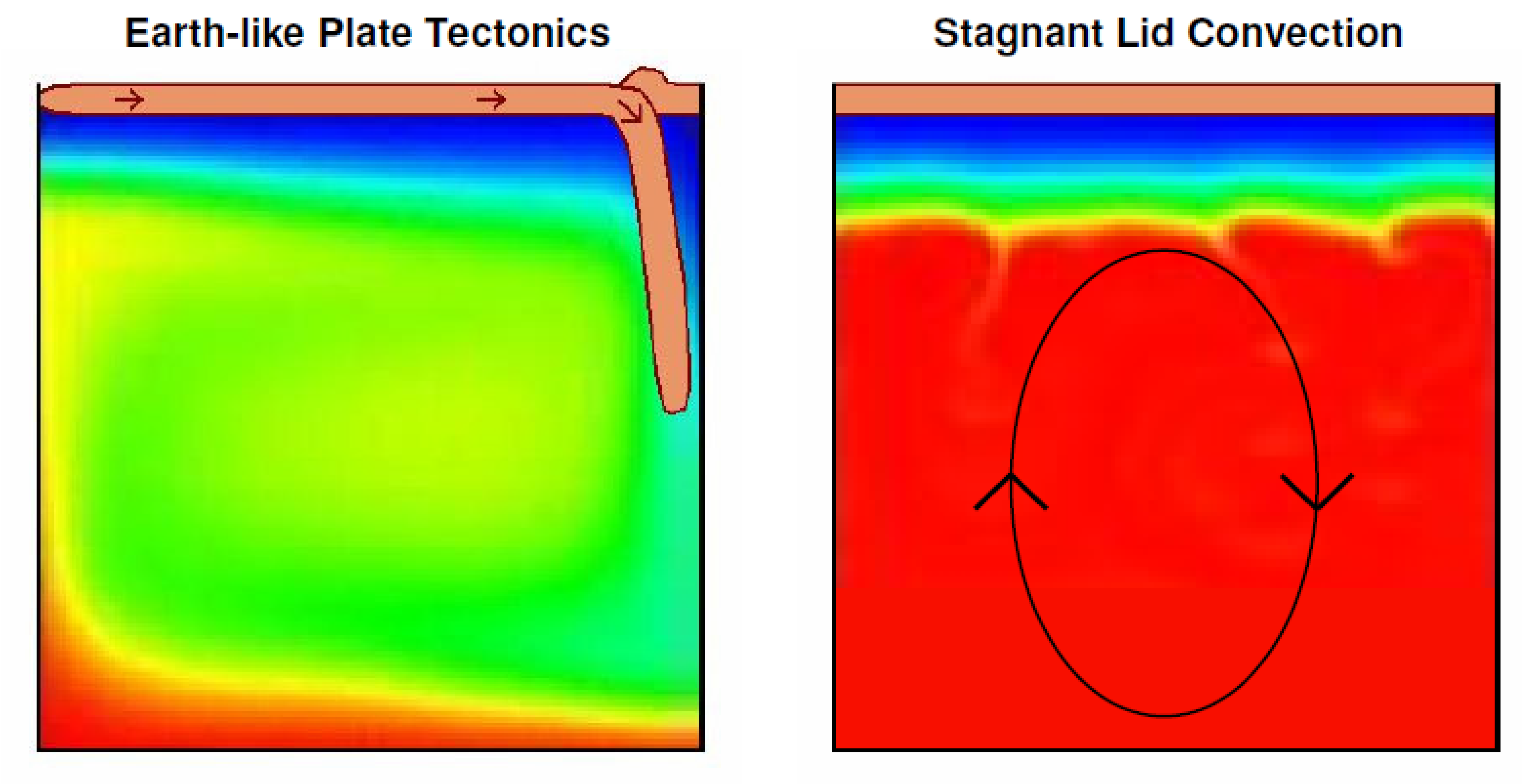


Why is surface mobilization and convection important?

- Recycling of crust
- Replenishing of nutrients
- Global carbon cycle/ water cycle
- Cooling of the interior → Magnetic field maintained

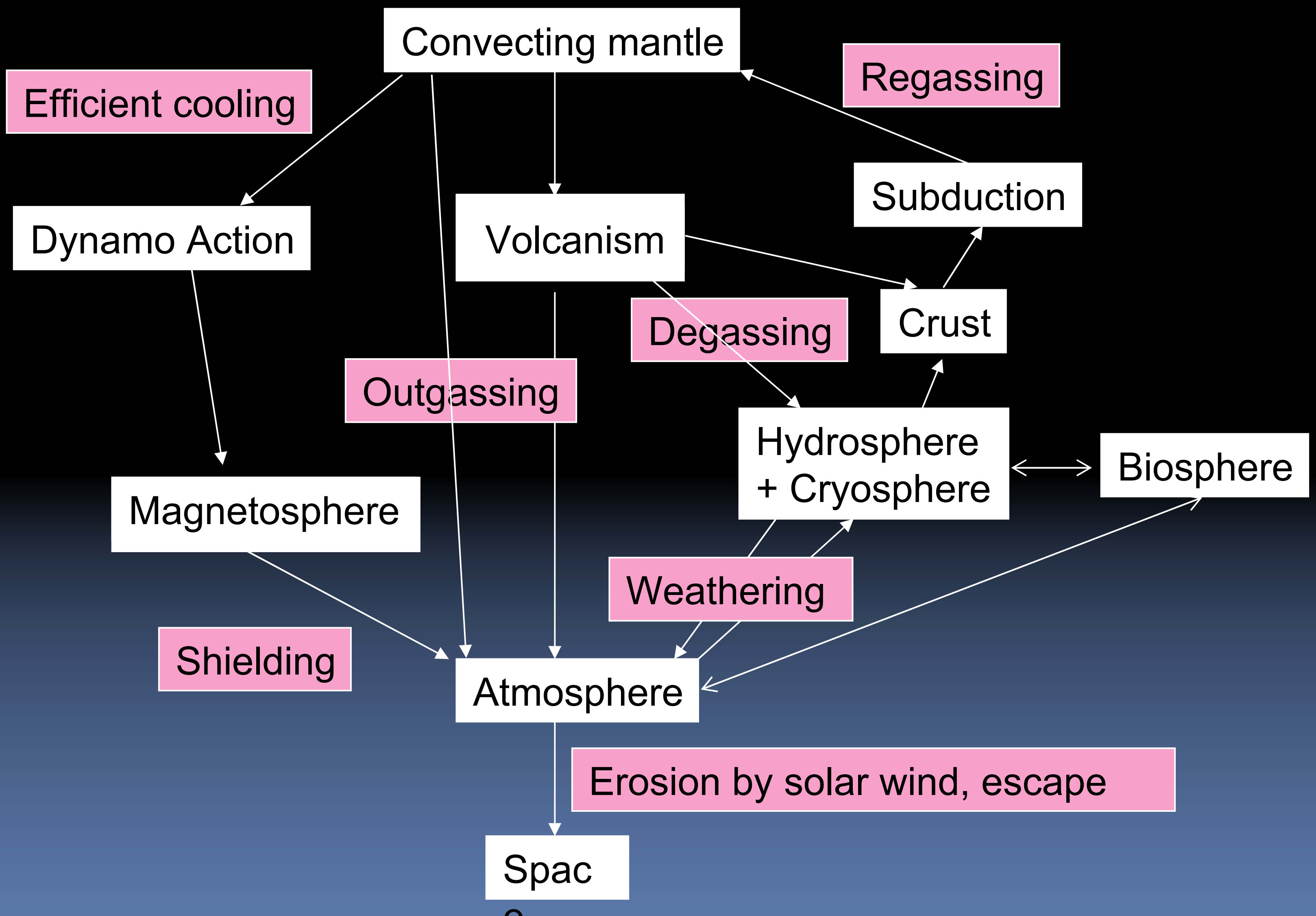
Important for enhancing habitability

The temperature inside Mars depends on the tectonics regime

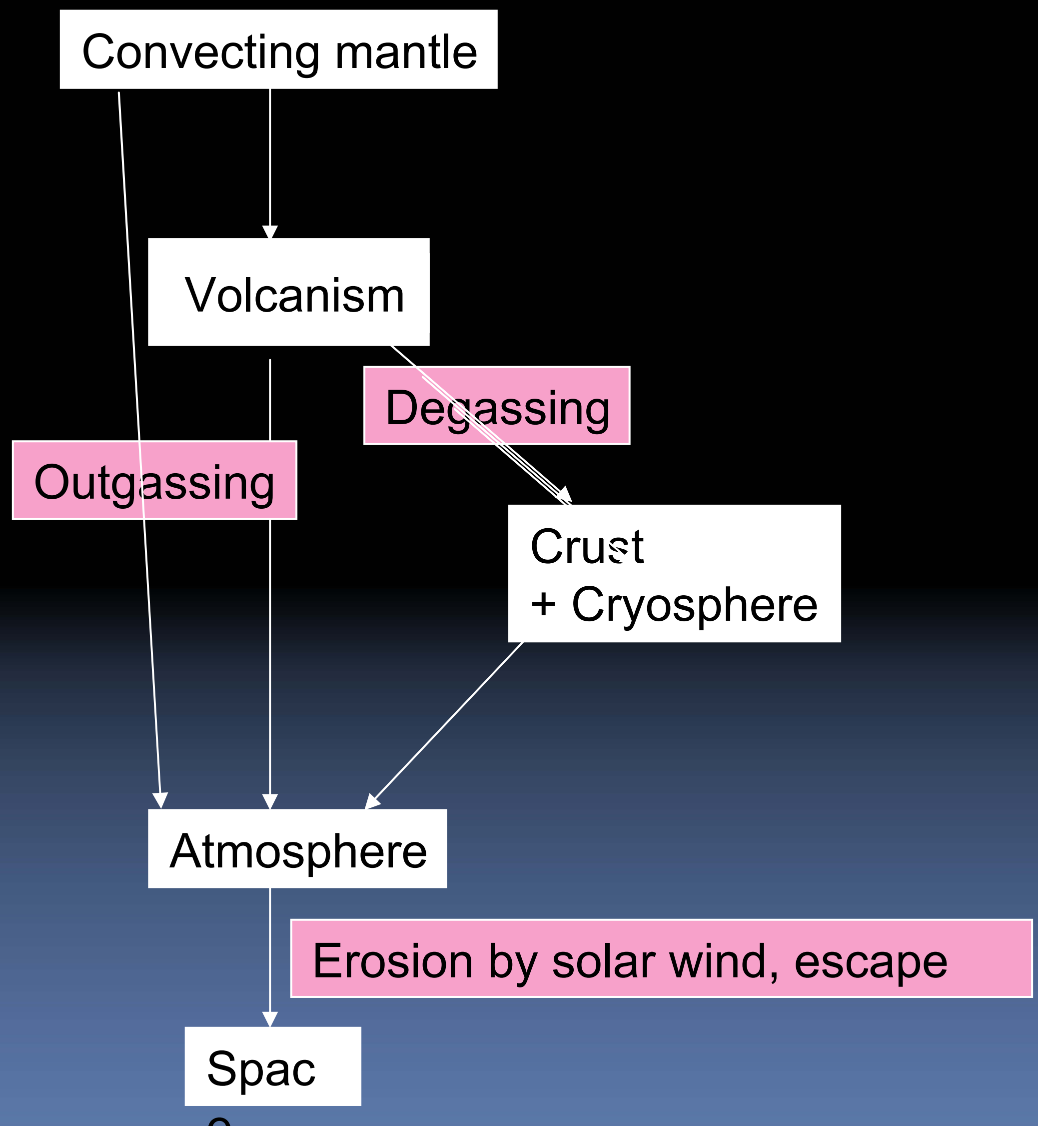


From Noack et al.

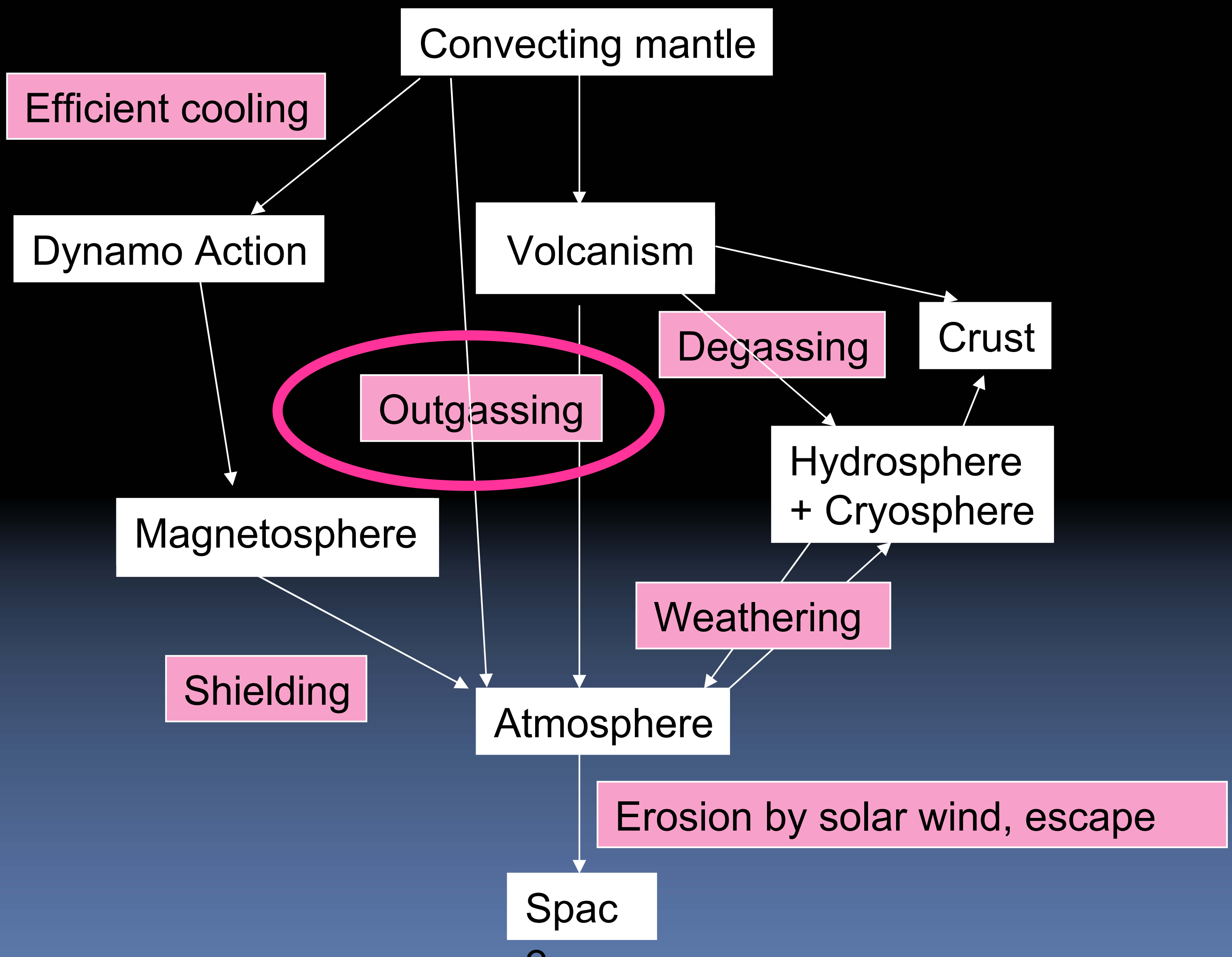
Planet with plate tectonics adapted from *Spohn et al.* and *Lammer et al.*



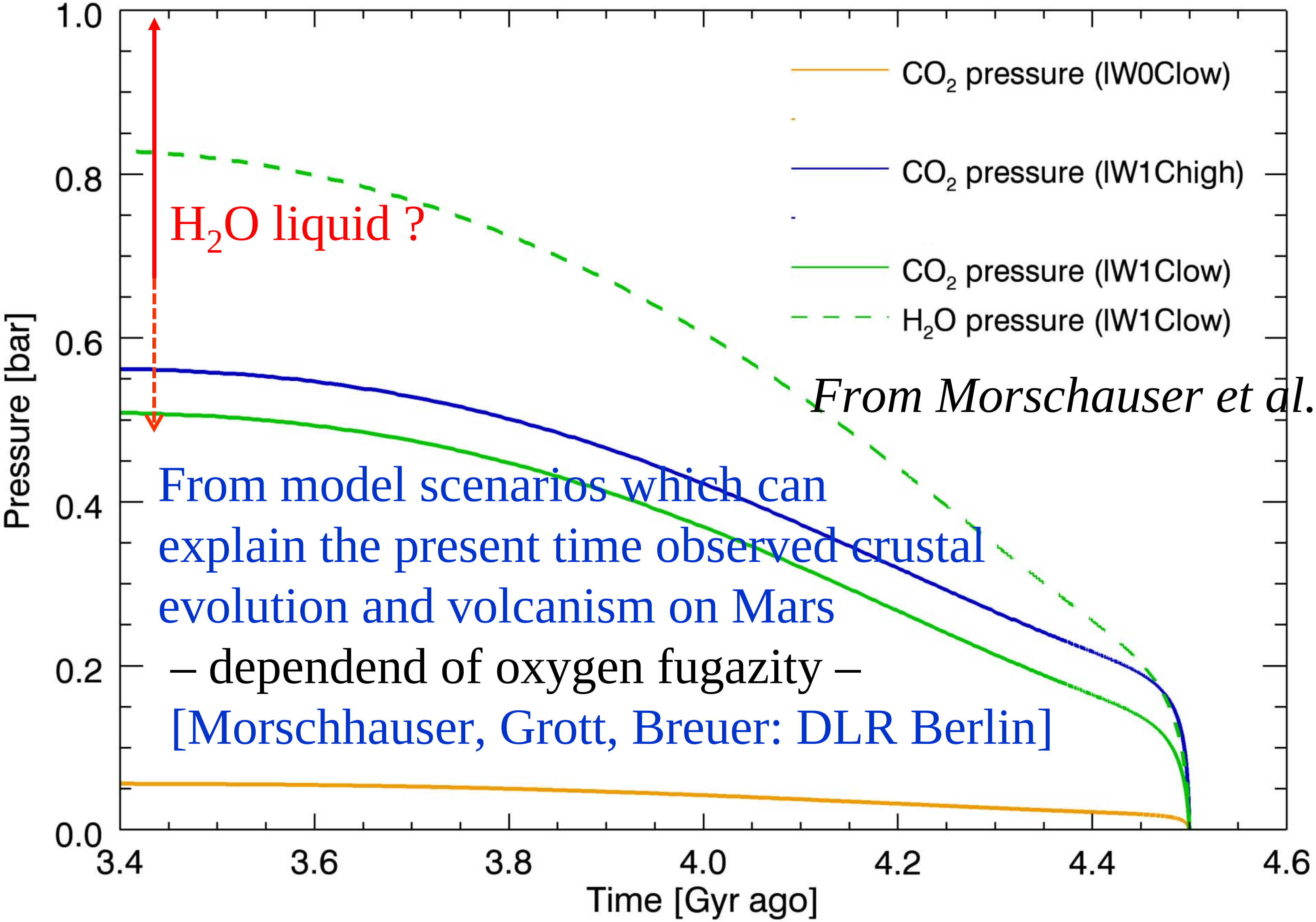
Monoplate for present Mars



Monoplate for Mars in the past



CO_2 outgassing and build-up of early Mars atmosphere (without escape)



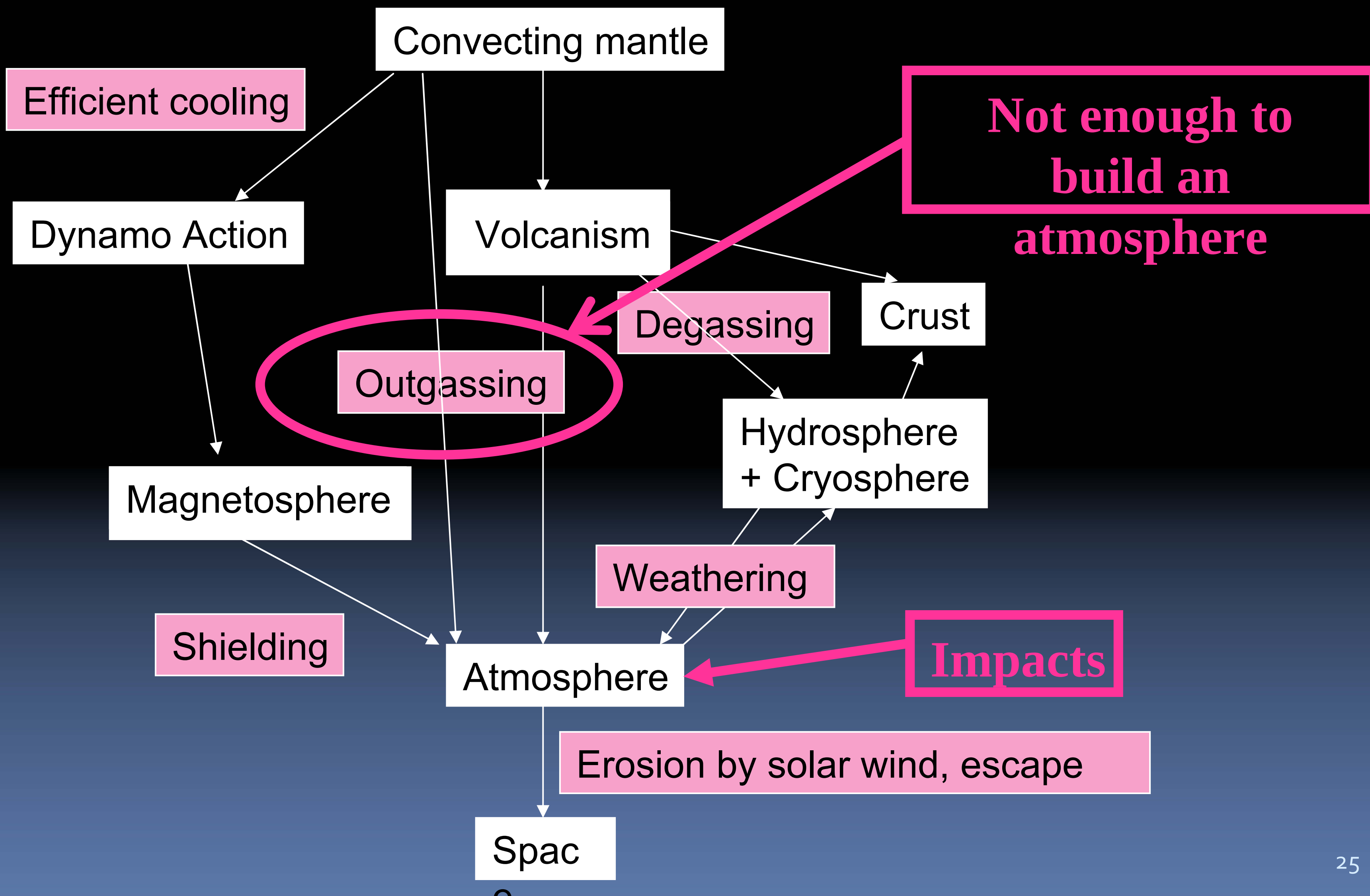
From Morschauser et al.

From model scenarios which can explain the present time observed crustal evolution and volcanism on Mars

– dependend of oxygen fugazity –

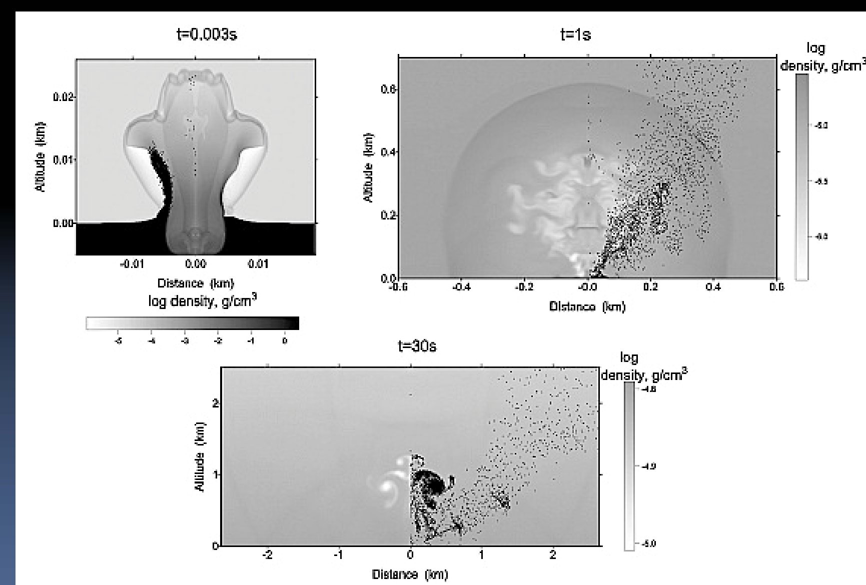
[Morschhauser, Grott, Breuer: DLR Berlin]

Monoplate for Mars in the past



Models of impact and atmospheric erosion

Simulations by hydrocodes in which equations of motion and equations of state (EoS) are solved.

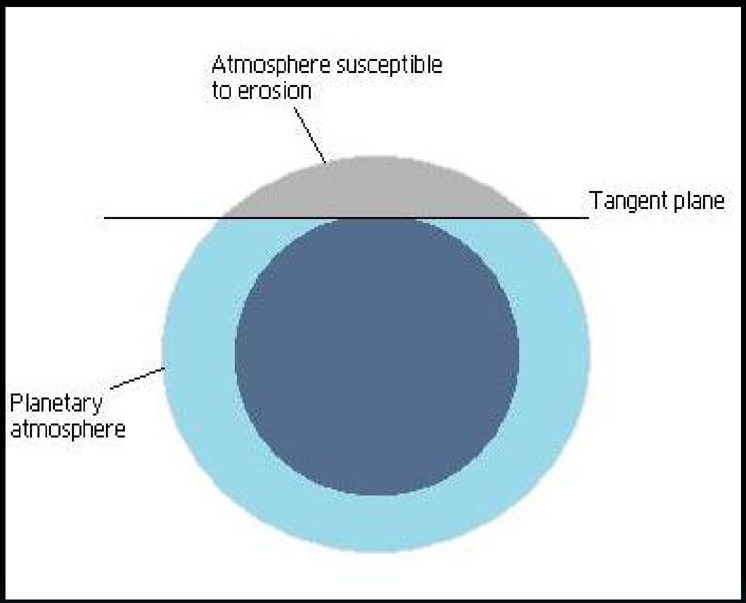


Nemtchinov et al. 2002

Difficulties:

- Choice of an appropriate EoS
- A proper model of the vapor cloud dynamics
- Expensiveness in time and calculations

A simplified model: the "tangent plane model"



From Melosh and Vickery

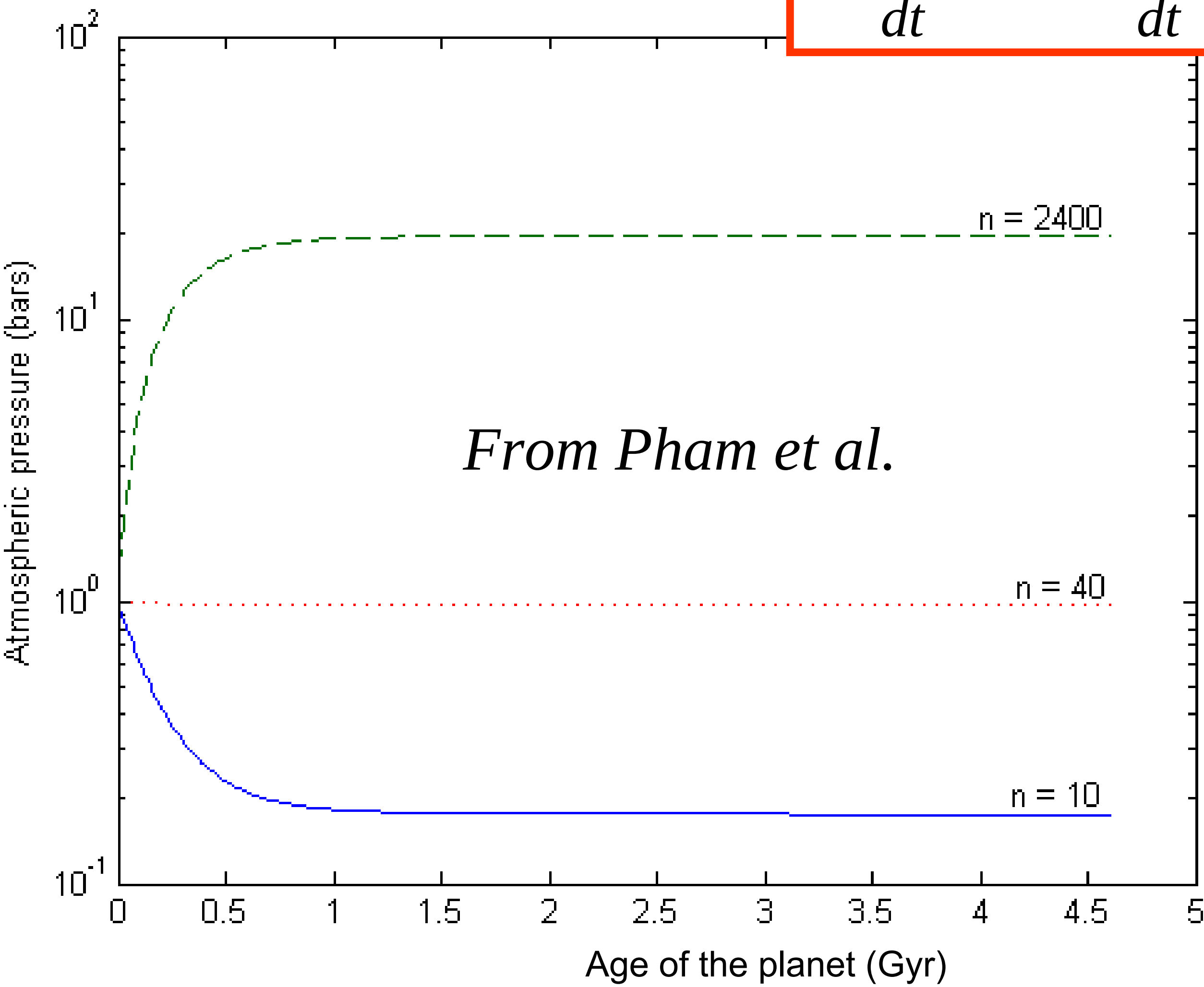
- $\boldsymbol{m_{tan}}$ = atmospheric mass above the plane tangent of the impact surface
- $\boldsymbol{m_{crit}}$ = minimal impactor mass that can eject a mass equivalent to $m_{\tan}$

$$m_{crit} \geq m_{\tan} = \frac{m_{atm} H}{2R}$$

The critical mass (above which erosion occurs) m_{crit} mainly determines the magnitude of impact erosion ($n = m_{crit} / m_{tan}$)

Impact atmospheric mass evolution on Mars

$$\frac{dM_{atm}(t)}{dt} = \frac{dM_{del}(t)}{dt} - \frac{dM_{esc}(t)}{dt}$$



Starting from n ~ 19-22 on Mars, impacts constitute a volatile source de volatiles

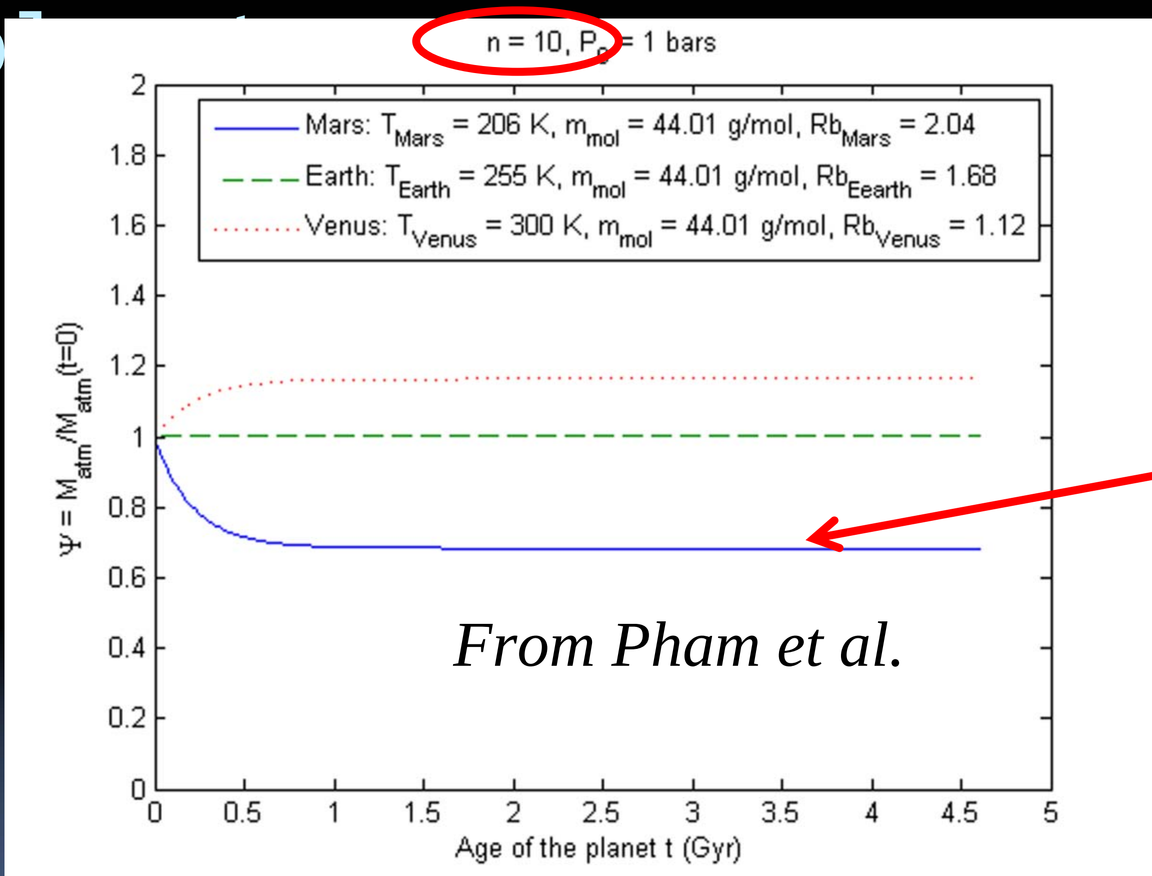
(n ~ 9-10 for the Earth and n ~ 6-7 for Vénus)

Inclusion of other parameters effects

- Types of the impactors population (asteroid, comet); rate of volatiles
- Impact velocity
- Vaporized fraction of the impactor, following its energy (impact velocity and mass range)
- Impact obliquity
- Late Heavy Bombardment (LHB)

Inclusion of these factors in the model decreases the variation of the atmospheric mass through the time

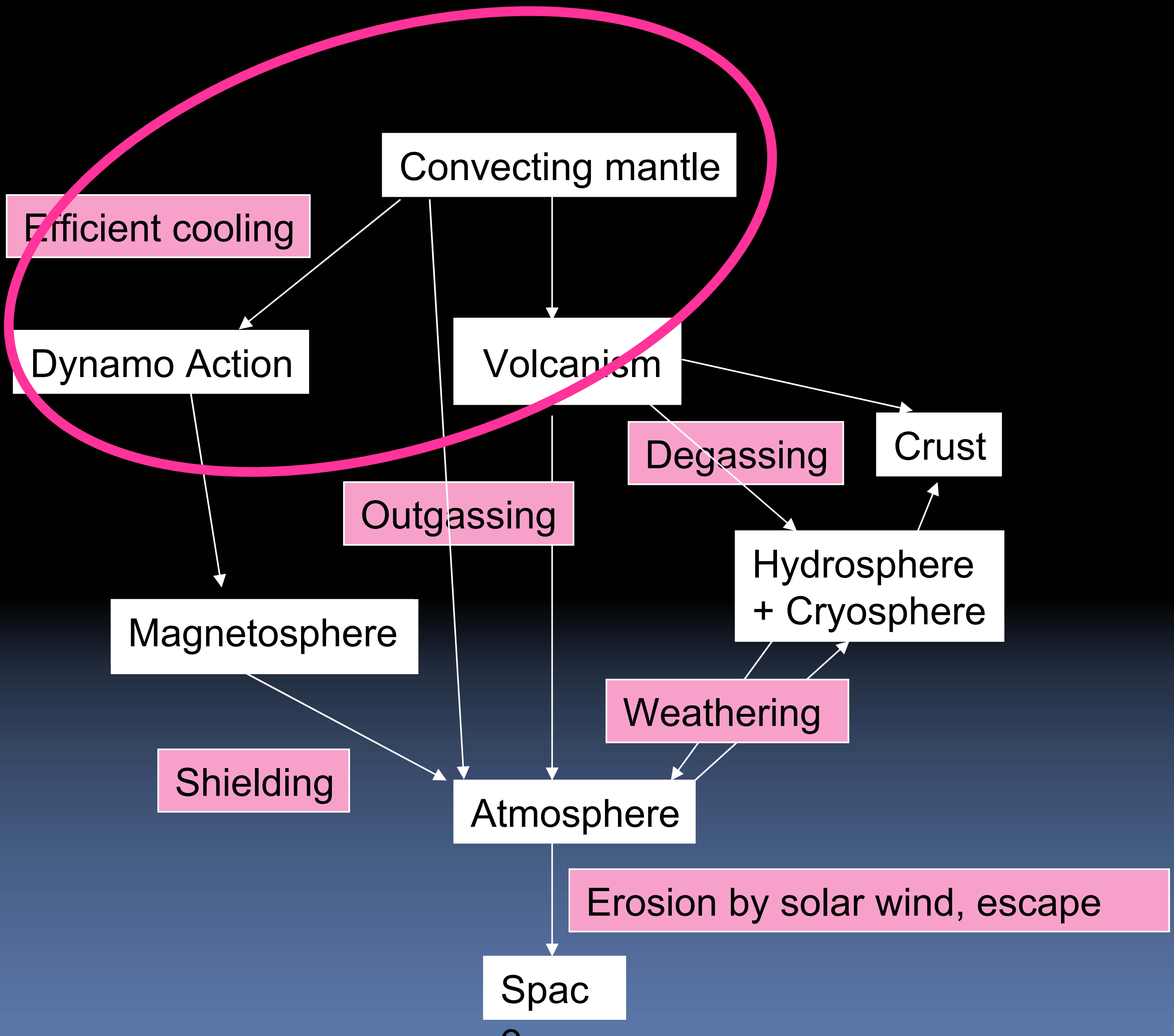
Comparison between Mars, Earth, and Venus for y_{imp} varying for each pl



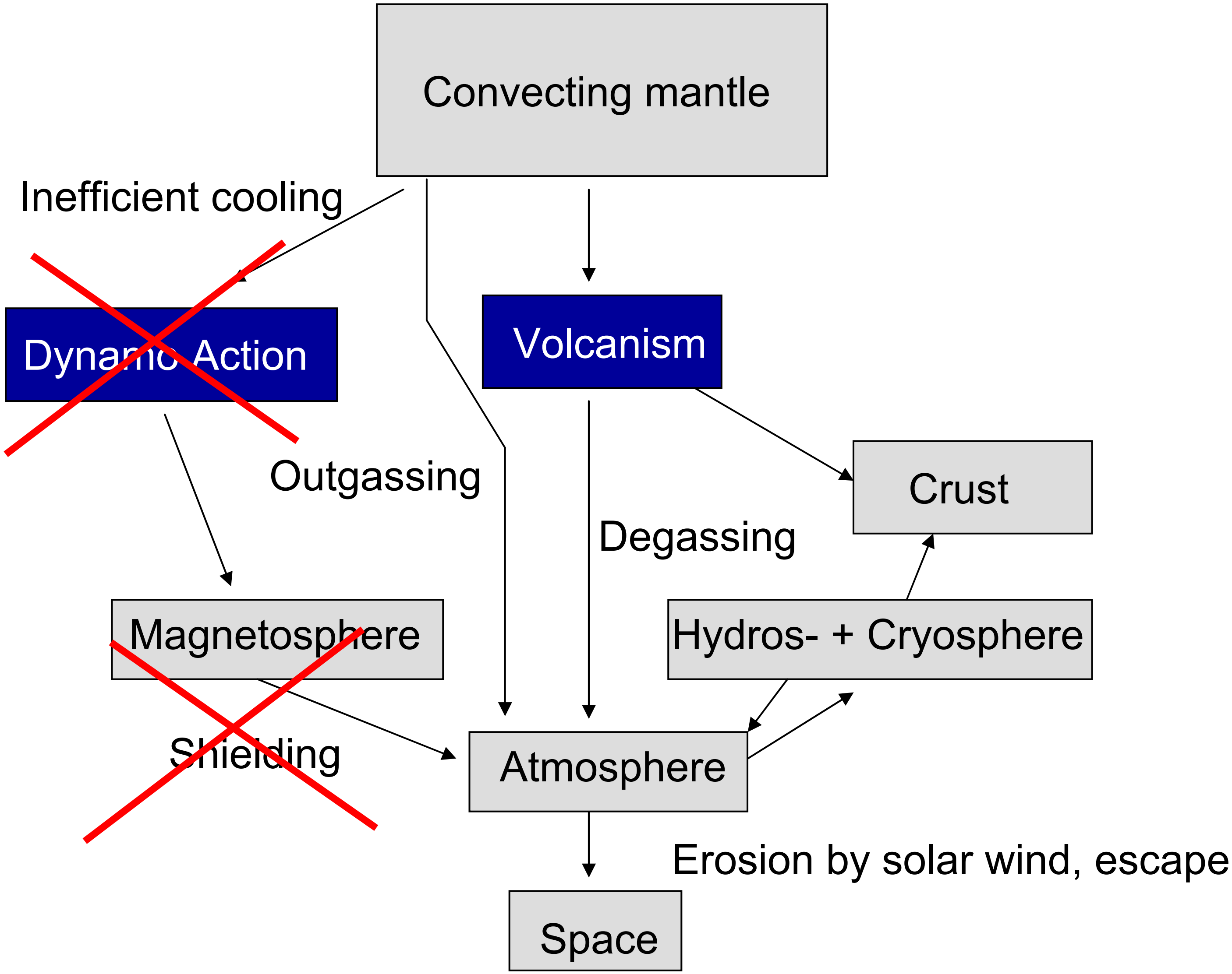
A significant part of the primordial atmosphere (with Ps> 150mb) can be eroded by impacts only during LHB period and for a doubtfully low values of *n* (*n*<10).

Impacts can hardly explain a large atmospheric escape on Mars unless specific conditions are met such as small values of n and LHB: needs escape and thus extinction of magnetic field!

Monoplate for Mars in the past



One plate planet



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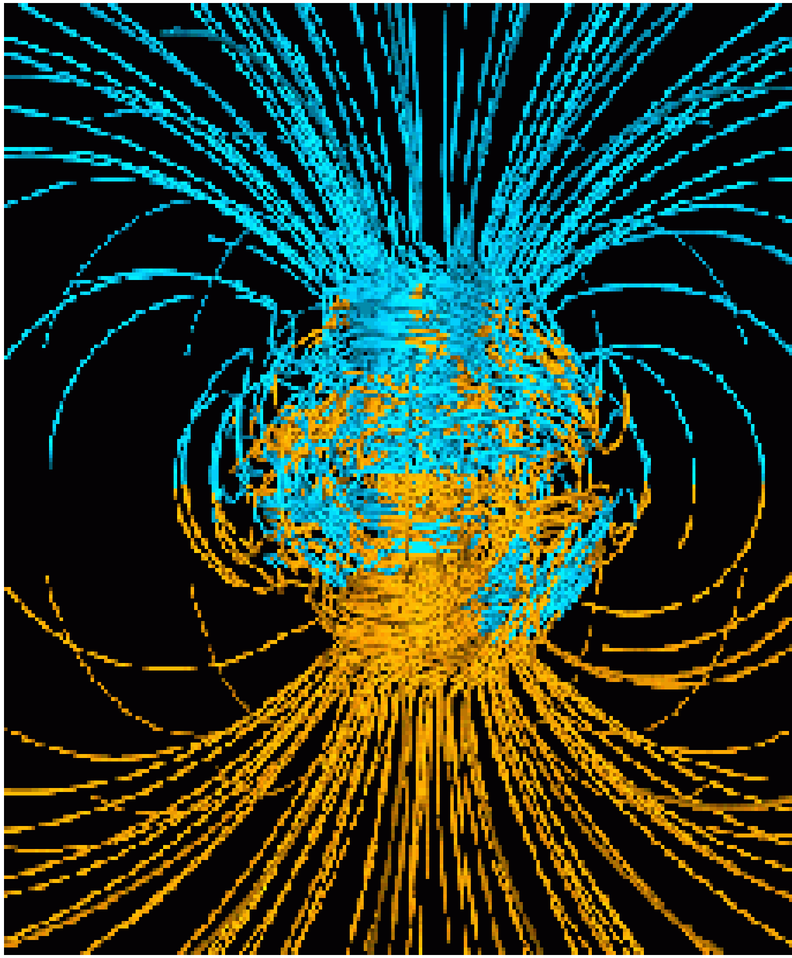
Dynamos

Electromagnetic dynamos

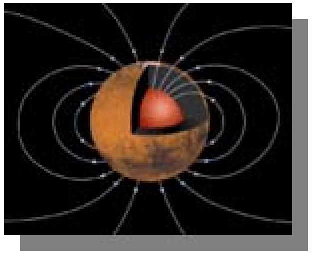
1. Thermal dynamos

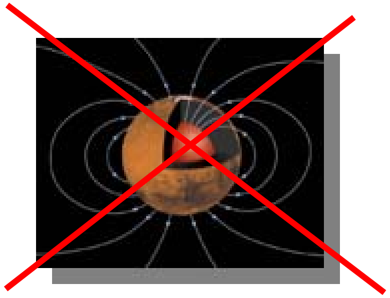
2. Chemical dynamos



Glatzmeier's Dynamo model for Earth

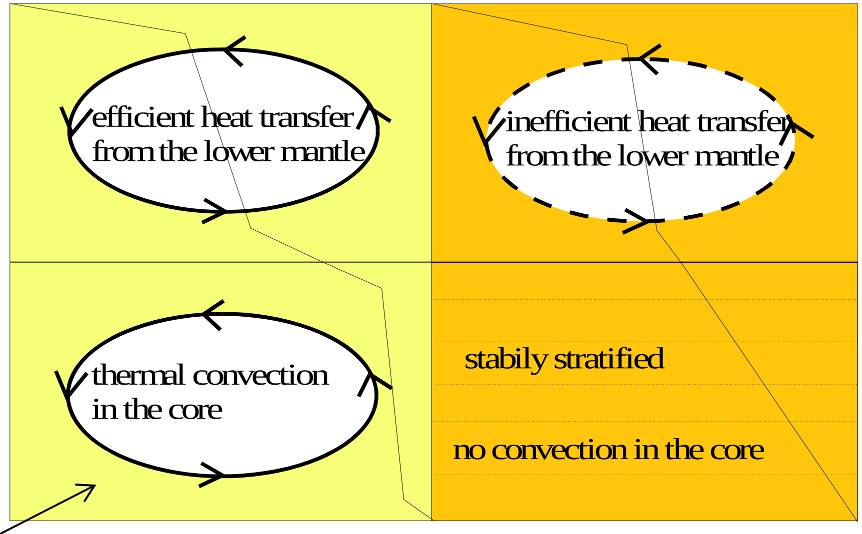
1. Thermal dynamos





- Fluid motion in the liquid iron core due to thermal buoyancy
(cooling from above)

- Critical heat flow out of the core

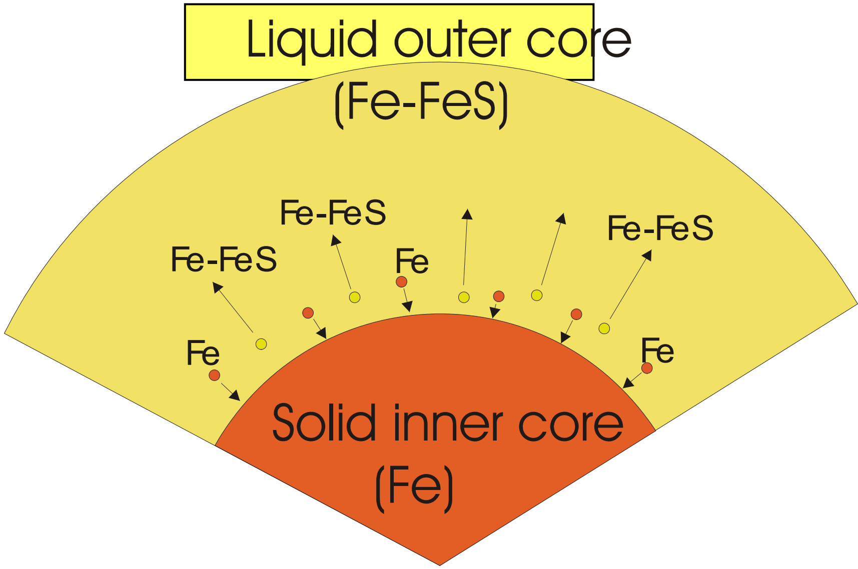


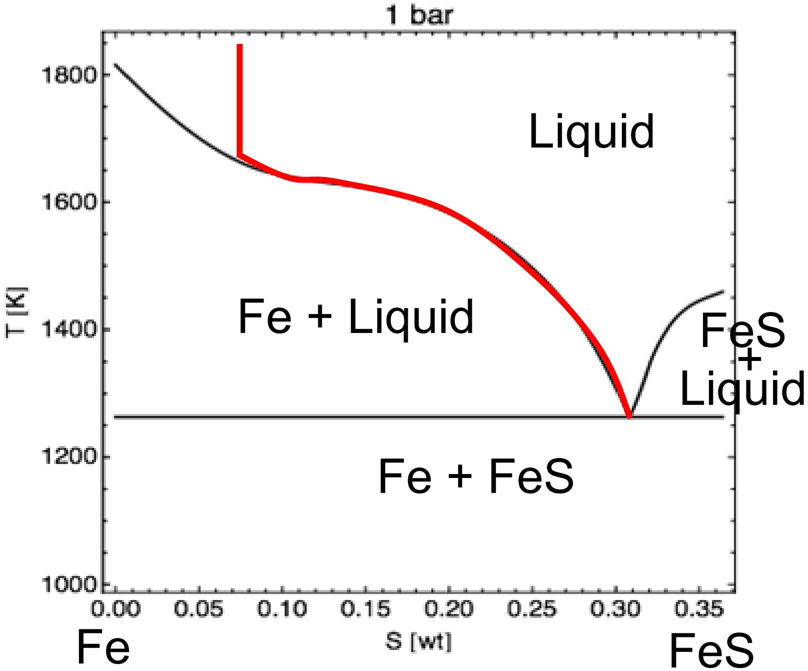
A sufficiently large ΔT between the core and the mantle is required in order to drive thermal convection in the core

If ΔT is too small than the core will be cooling by conduction

2. Chemical dynamos

- Existence of light alloying elements in the core like S, O, Si
- Core temperature between solidus and liquidus
- Compositional buoyancy released by inner core growth
- Difficult to stop operating



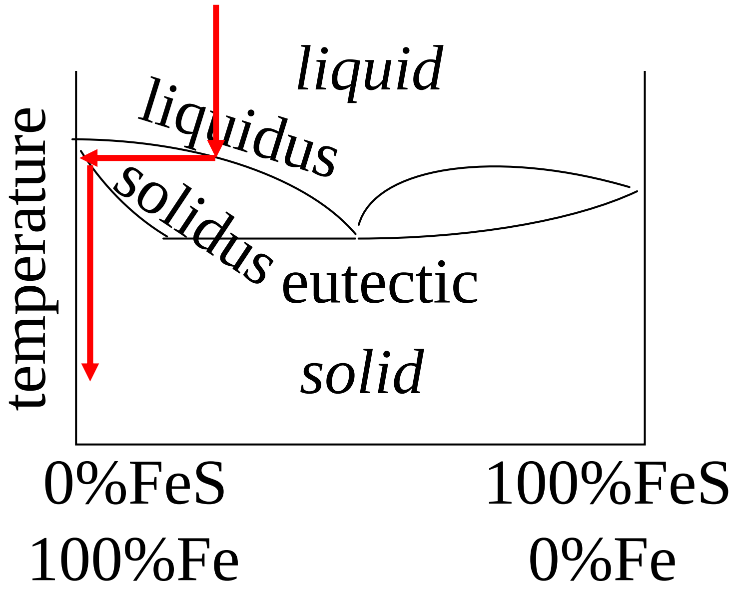


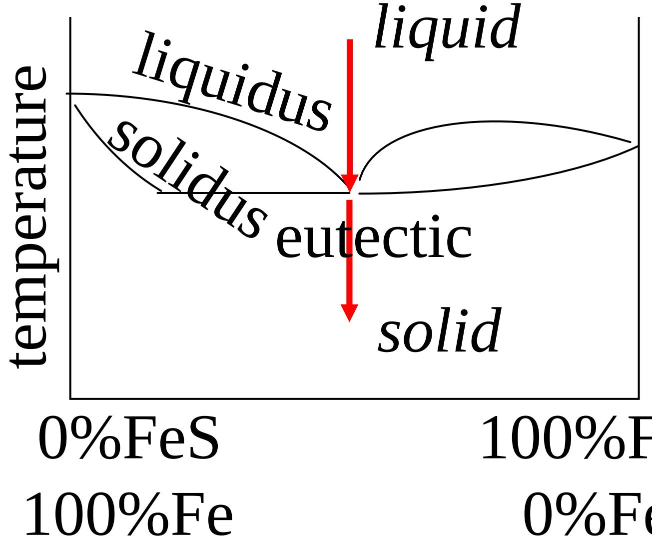
Adjustment of the liquid core and solid inner core densities

The growth of the inner core is modeled as follows:

- At the **beginning**, the inner core is created by **precipitation of iron** contained in the liquid core and thus has the density of pure solid iron;

- **After the eutectic point is reached**, the inner core grows by **solidification (freezing)** of the liquid outer core and thus the newly formed outer layers have the same concentration in light element as the remaining liquid core.





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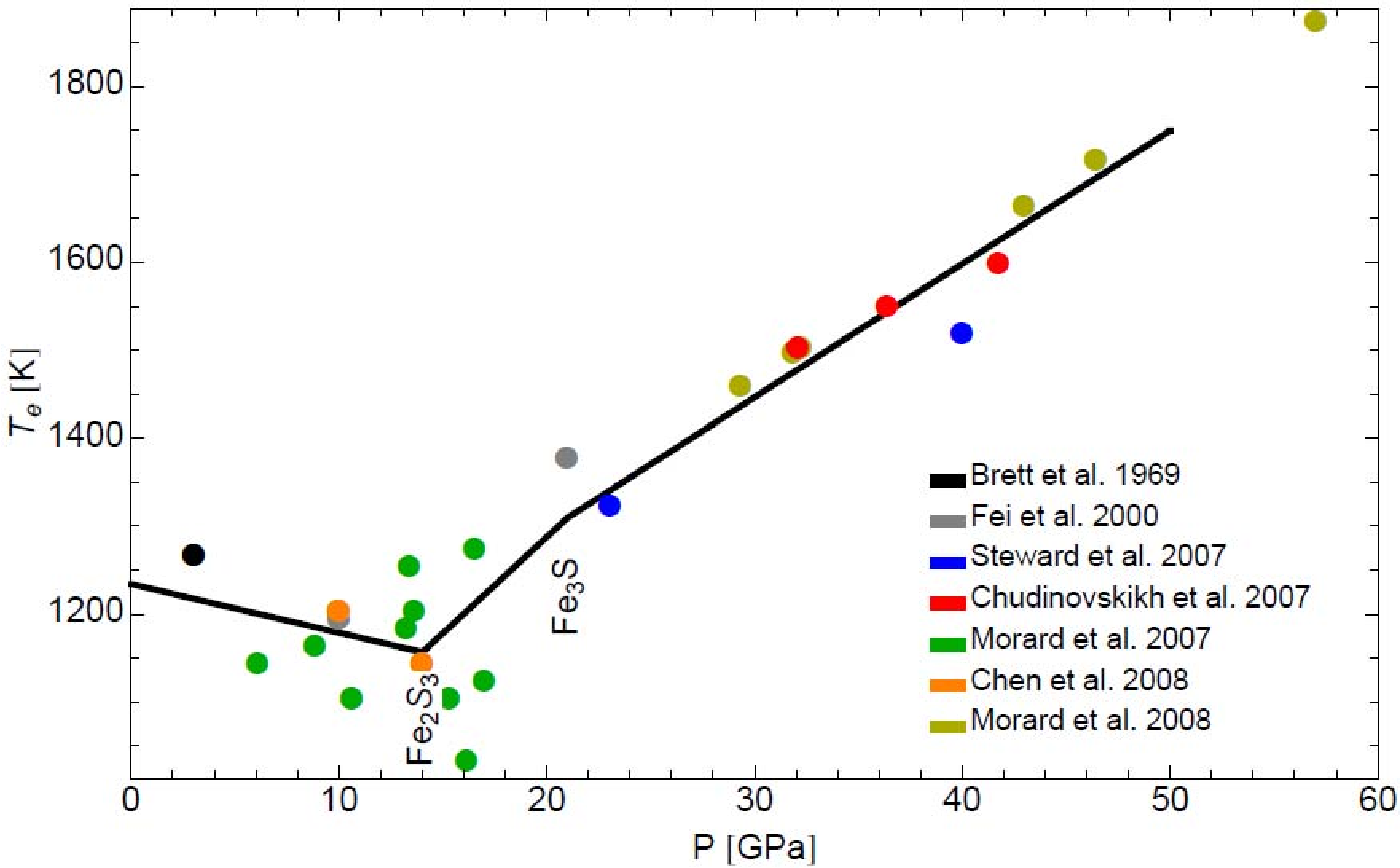
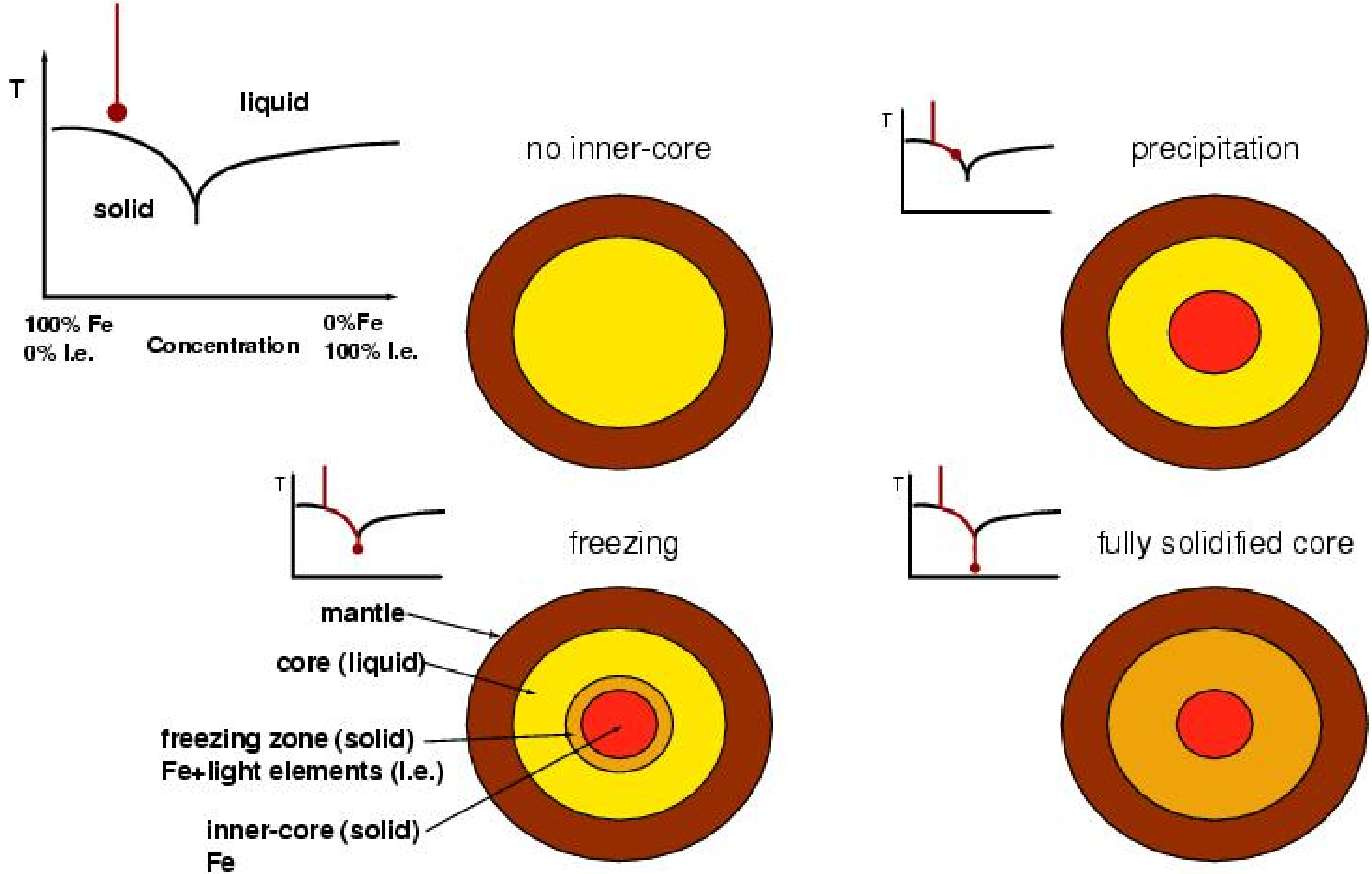
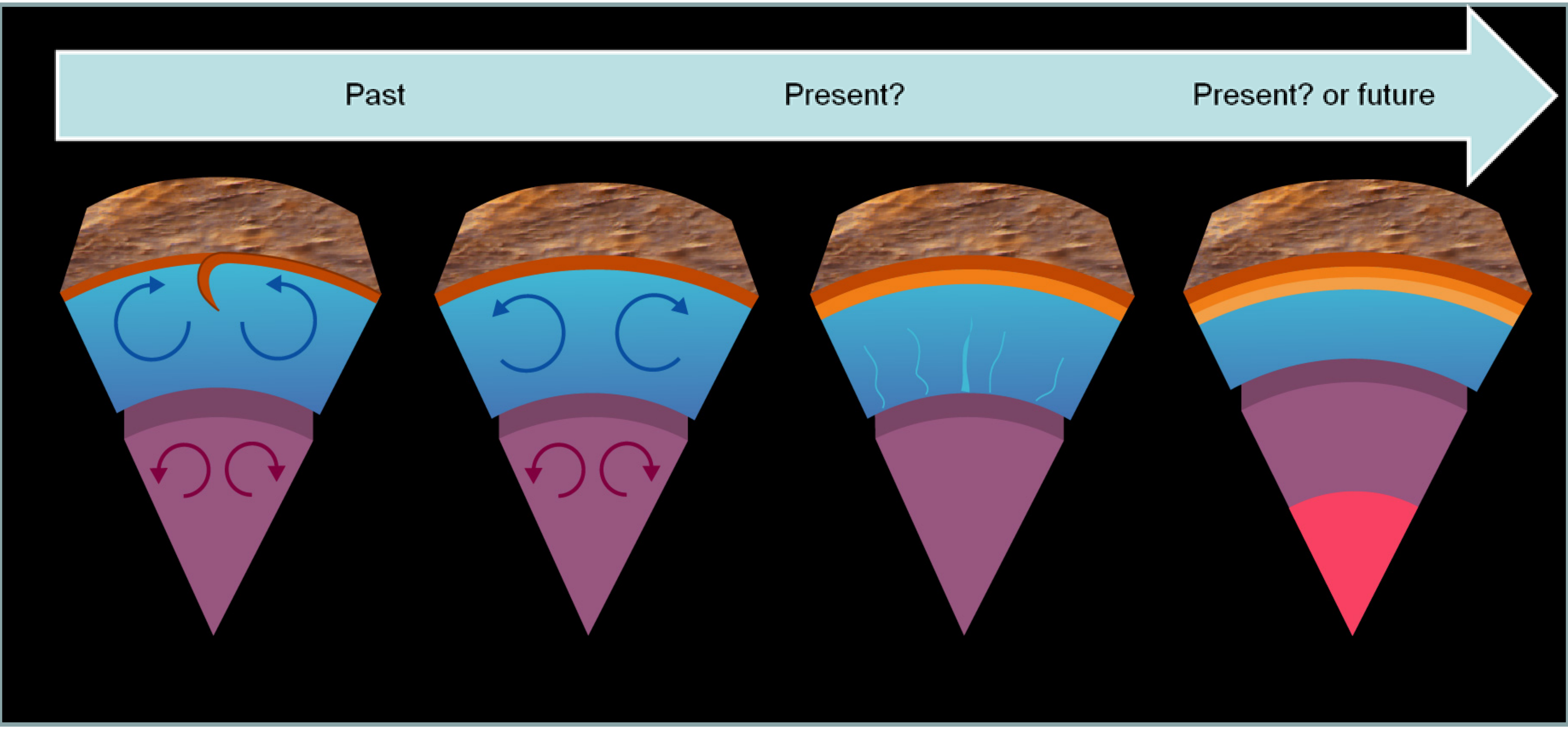


From Rivoldini et al.

Adjustment of the liquid core and solid inner core densities



Many open questions!



– Many questions about Mars' core (size, state, inner core?)
– Important for the understanding of origin, evolution, and dynamics of Mars

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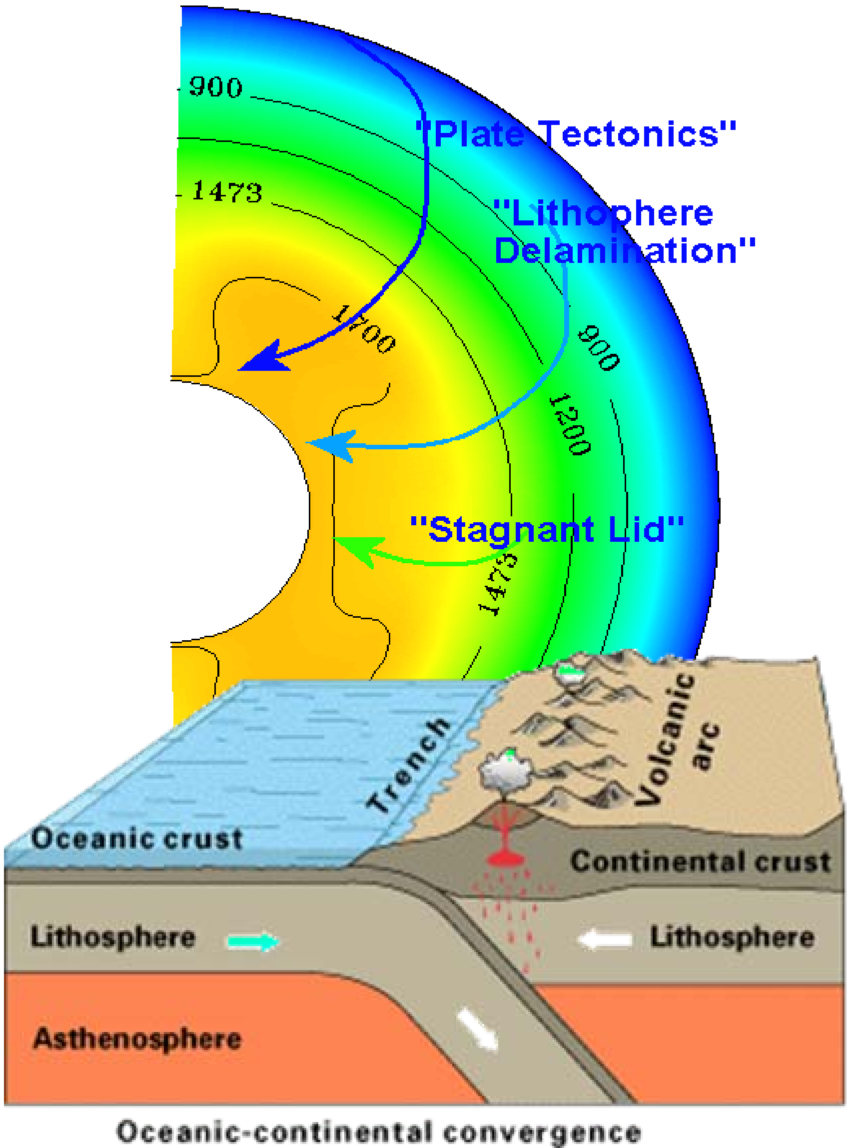
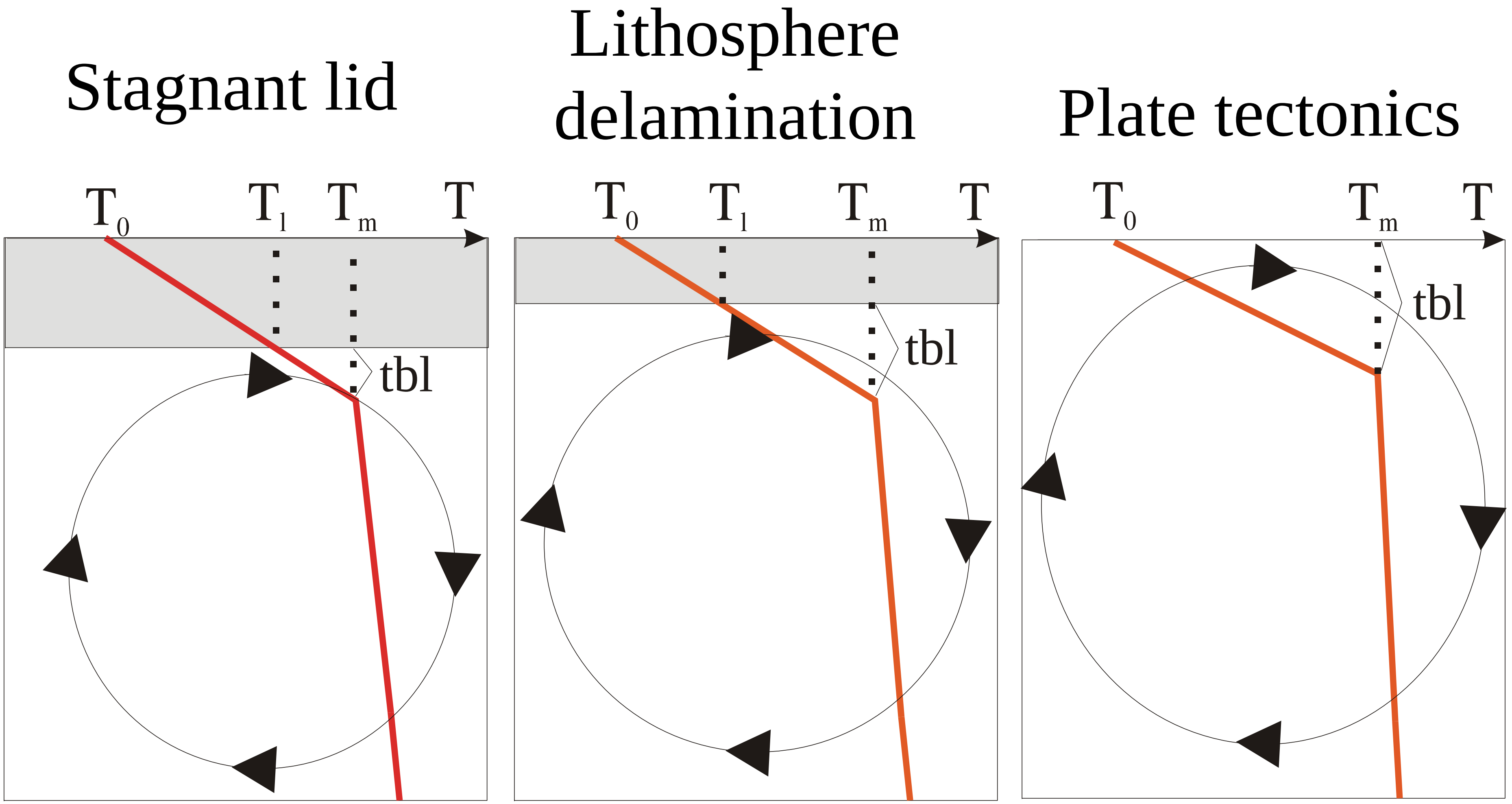
Heat Transport Mechanisms

- Plate tectonics (Earth, early Mars?, early Venus?)
- Stagnant lid convection (Mercury, Venus?, Mars, Moon
- Lithosphere delamination (Venus?)

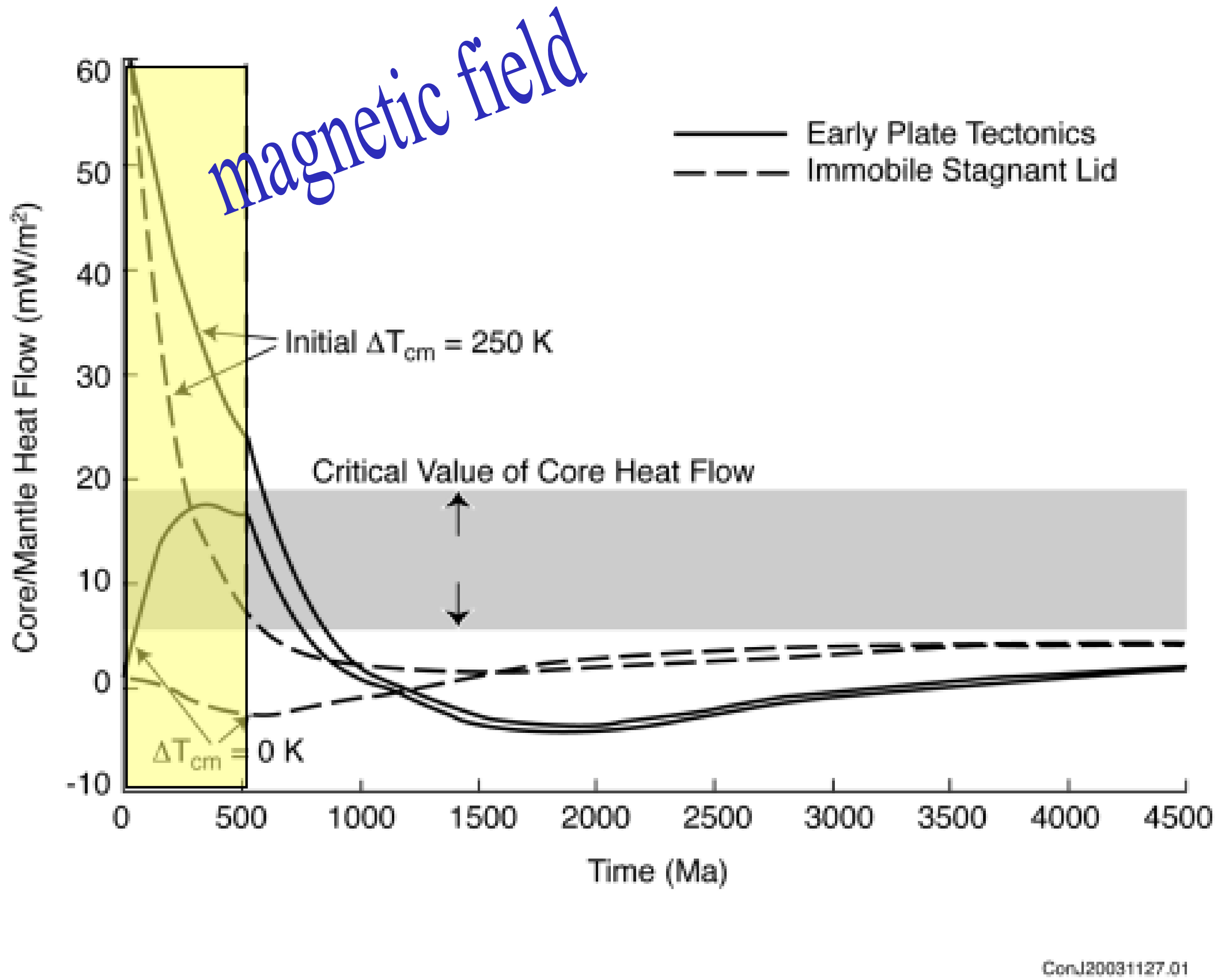


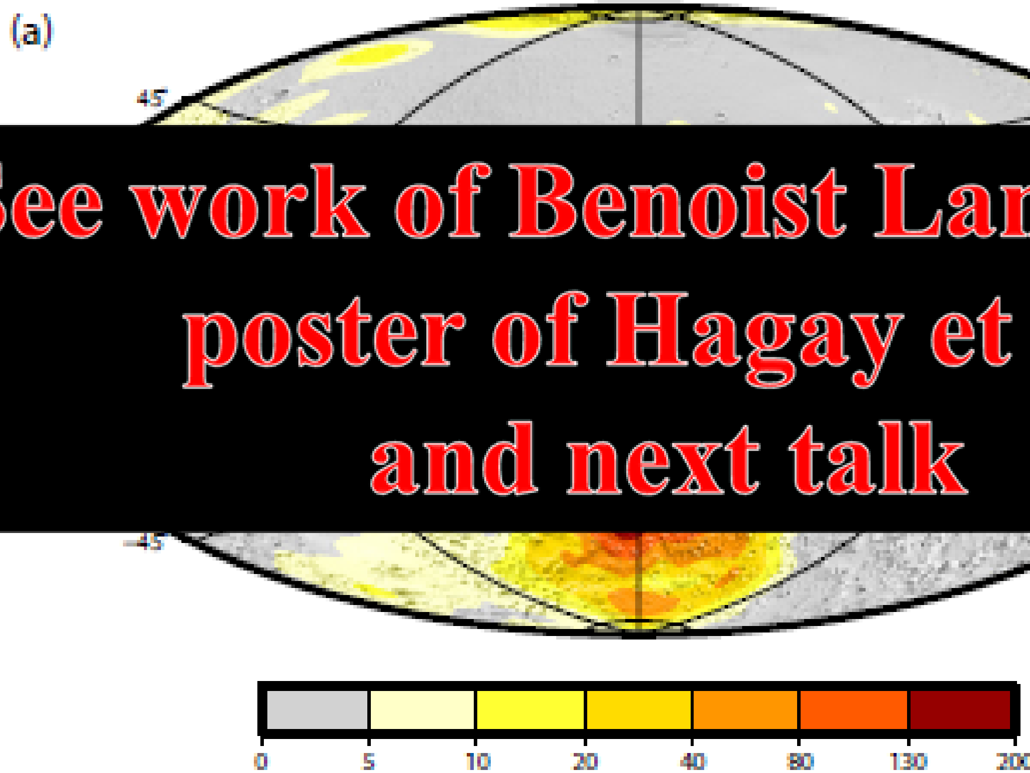
Magma transport (volcanism)


Stagnant lid
Lithosphere delamination
Plate tectonics
T0
T1
Tm
T
tbl
T0
T1
Tm
T
tbl
T0
Tm
T
tbl

Early Martian (thermal) dynamo possible with a superheated core

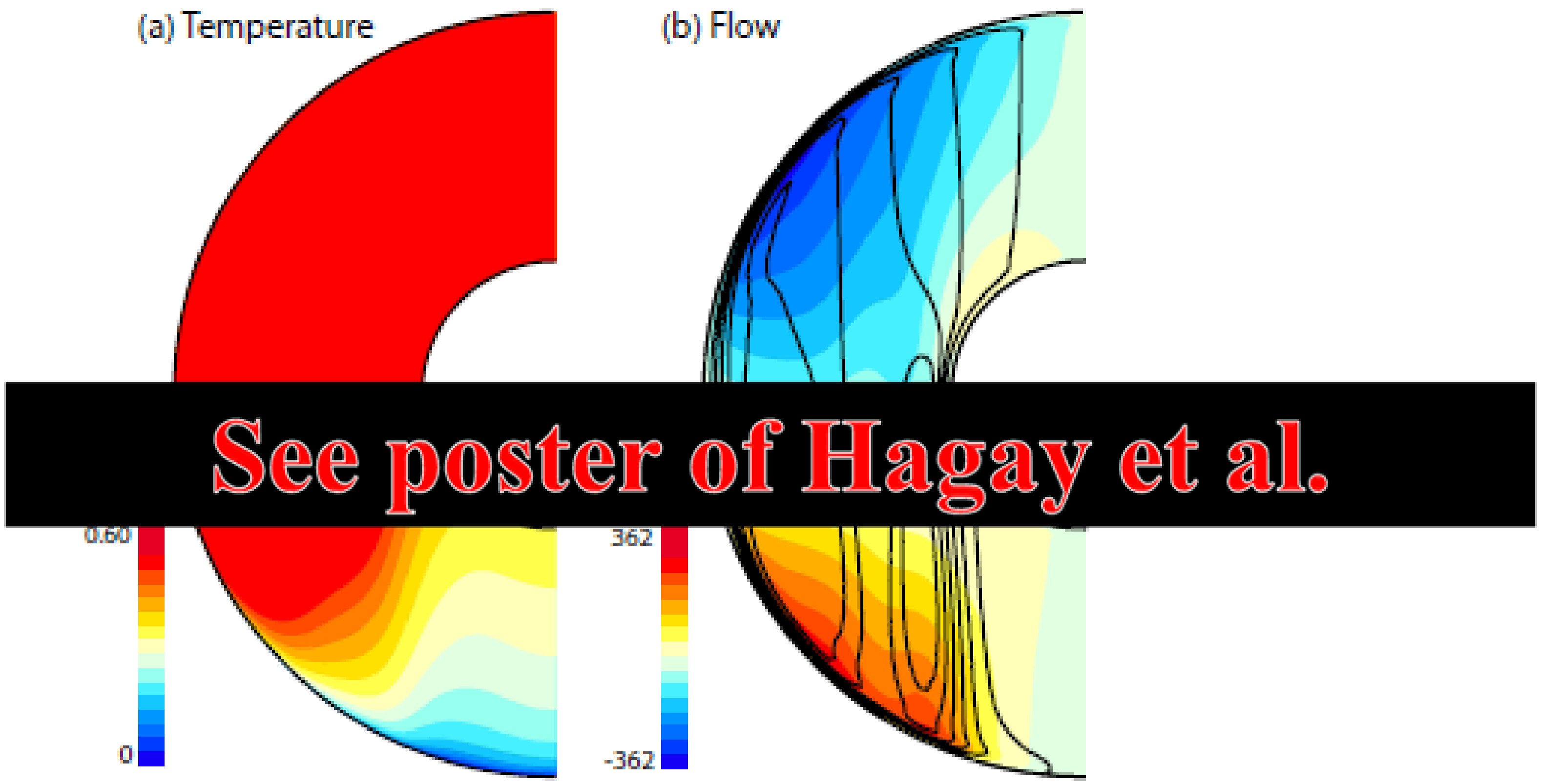
From Breuer et al.





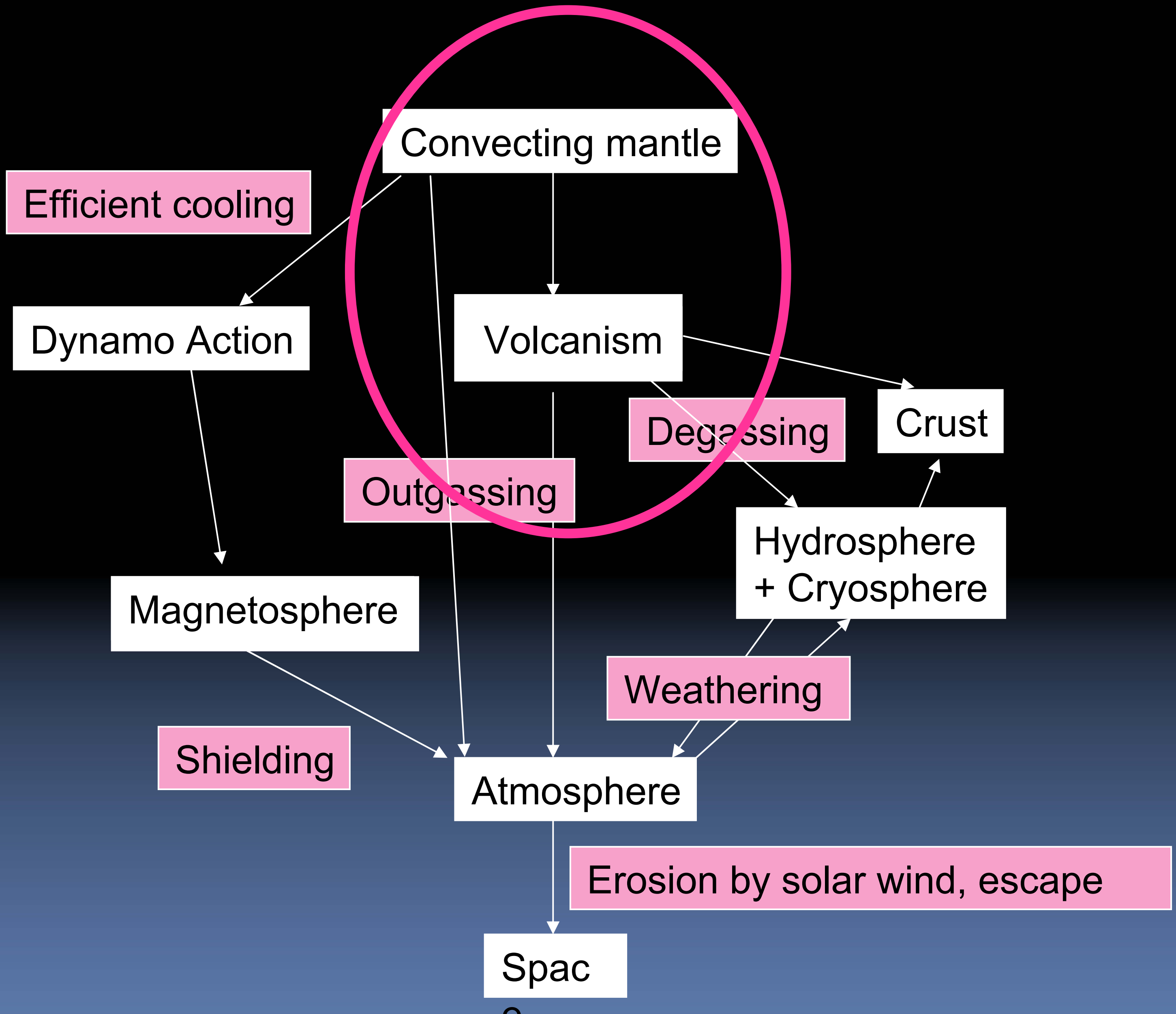
See work of Benoist Langlais in poster of Hagay et al. and next talk

The present Martian crustal magnetic field intensity exhibits a strong dichotomy between the strong field in the southern hemisphere to the weak field in the northern hemisphere.



Hagay et al. use numerical dynamos driven by purely volumetric internal heating with imposed degree-1 heat flux heterogeneities to study mantle control on the past dynamo of Mars. They show that, because of the excitation of a strong equatorial upwelling in the dynamo, a mantle heterogeneity centered at the geographical pole related to a heat dichotomy is efficient in producing the observed magnetic anomalies.

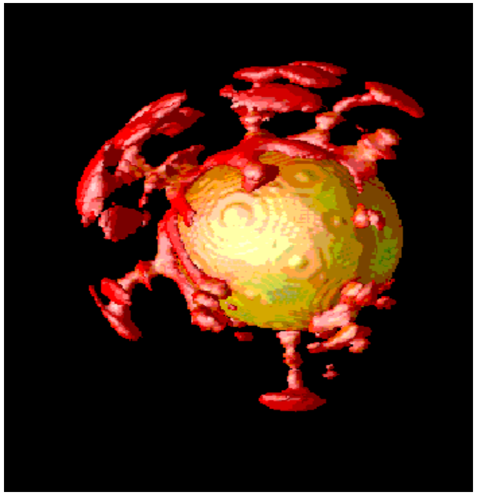
Monoplate for Mars in the past

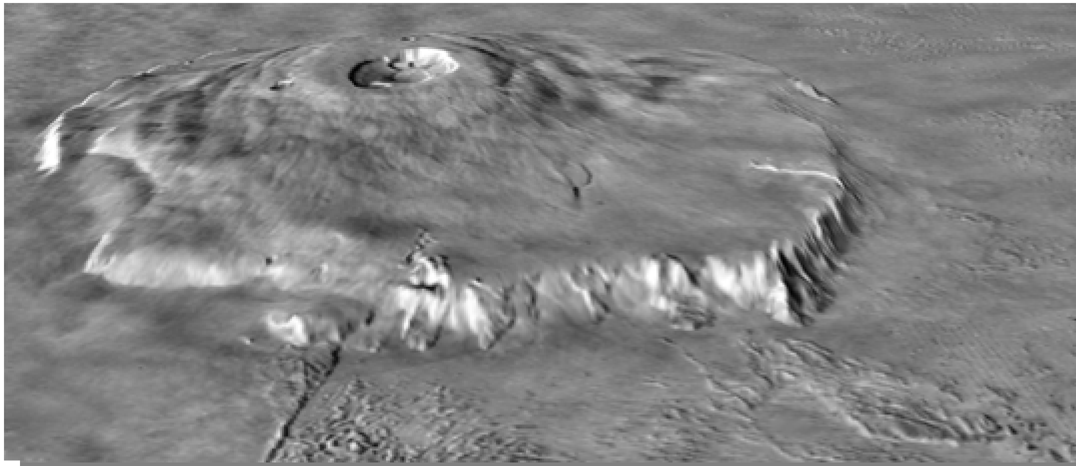


Plume Volcanism on Mars?

Early global volcanic activity reduces during the evolution in mainly one or two regions: Tharsis & Elysium

Significant signal in the gravity field





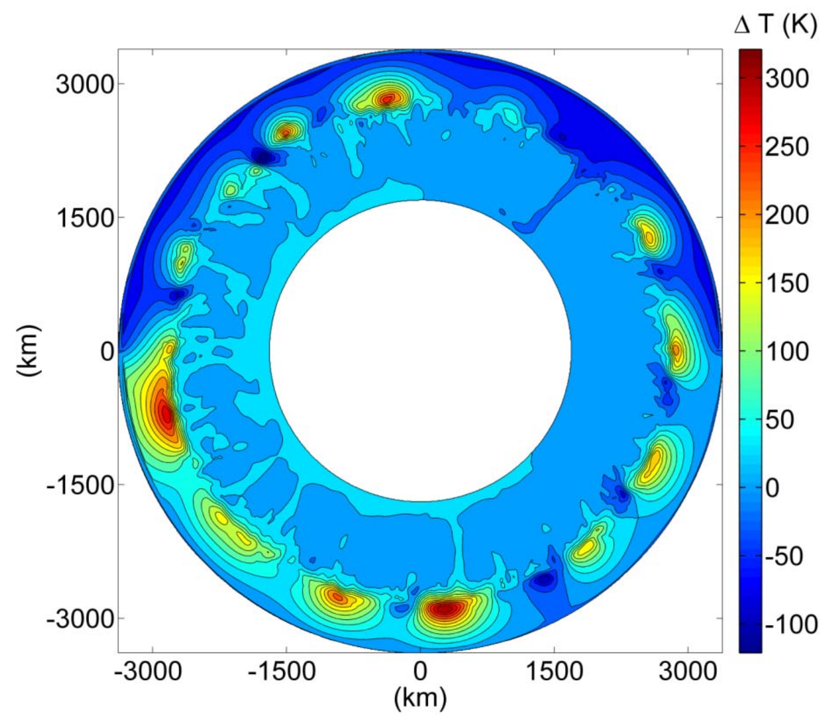
Conditions required to sustain plumes

- Perovskite layer
  - With a perovskite layer close at the core-mantle boundary it might be possible to generate a large plume early in the evolution but this will be very weak if existent after about 1Ga.

from Schumacher et al. and Van Thienen et al.

- Partial melting
  - After a first plume and temperature difference, partial is enhanced and volcanism is maintained.

from Plesa et al.



Martian mantle convection without phase transition

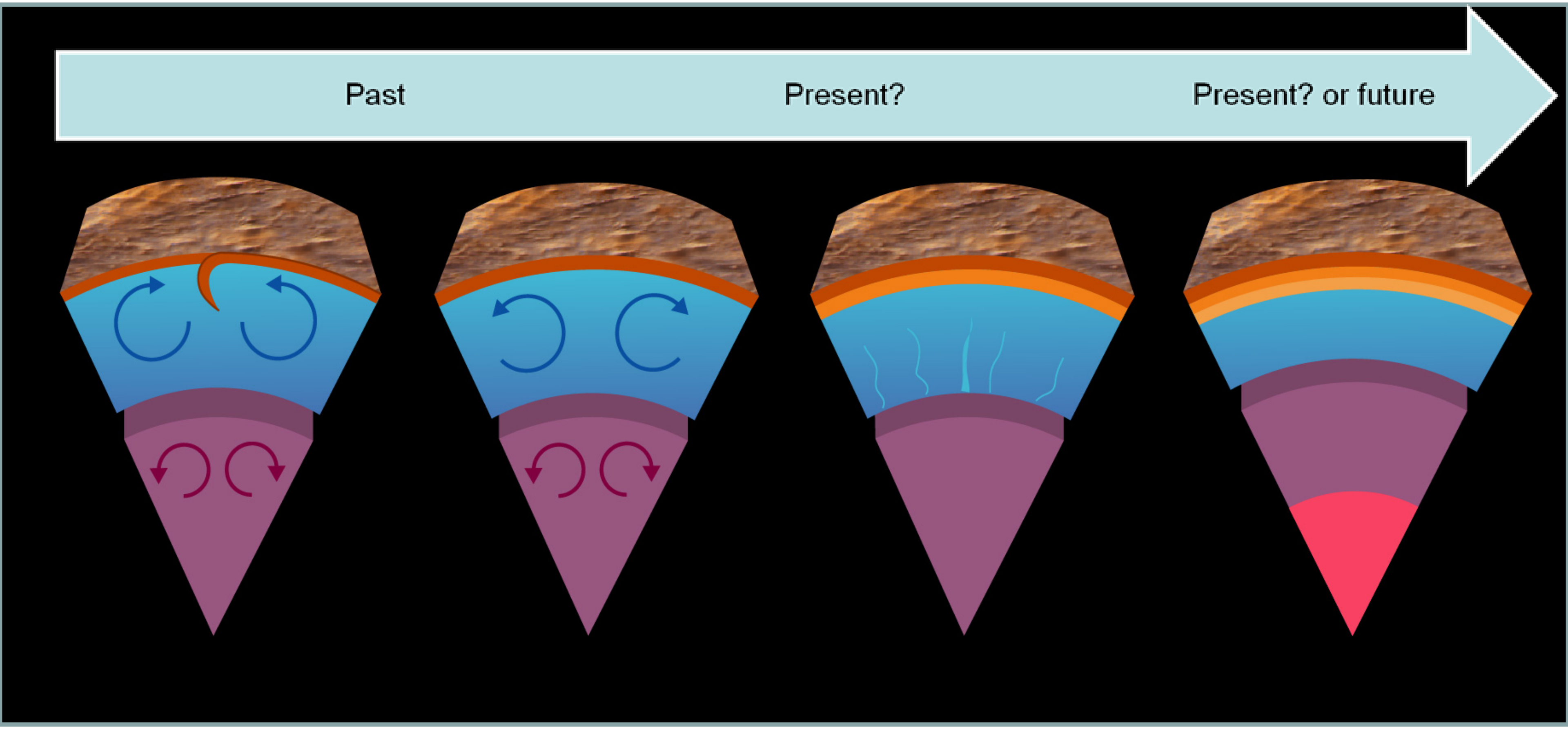
See poster Anna Plesa et al.

Difficult to maintain large plumes, but not difficult if partial melting.

Thermo-chemical evolution of a one-plate planet like Mars strongly influences its atmospheric evolution via volcanic outgassing.

Convection, partial melt, outgassing, dehydrating stiffening are related to thermal evolution and early chemical reservoirs.

Many open questions!



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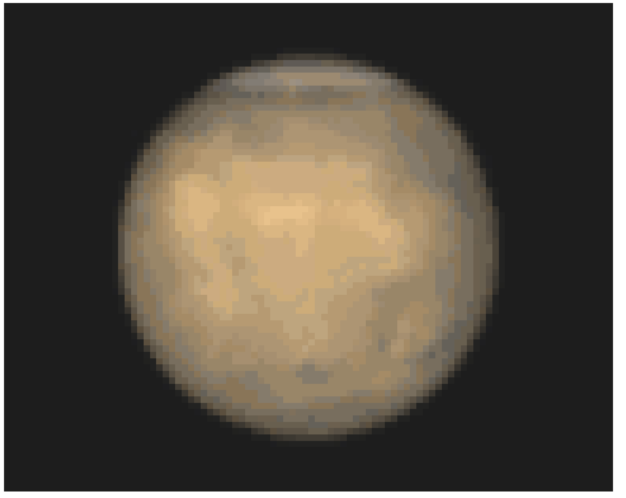

GEODESY:

Importance of the core in the context of habitability

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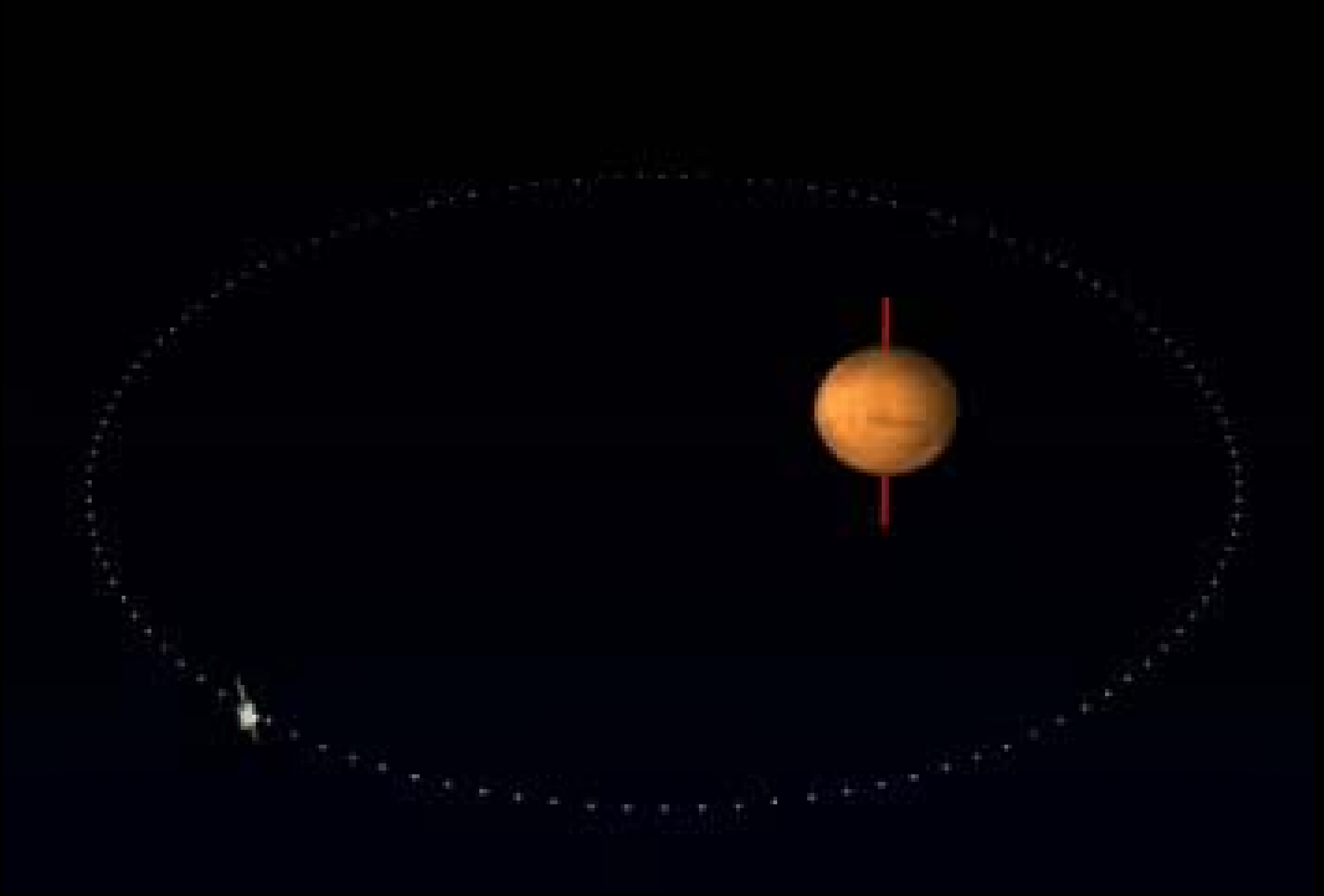


Using mass and moment of inertia

- 2 constraints: mean density ρ and MoI factor I/MR^2.

$$\rho = \rho_m + (\rho_c - \rho_m)\left(\frac{r_c}{R}\right)^3$$

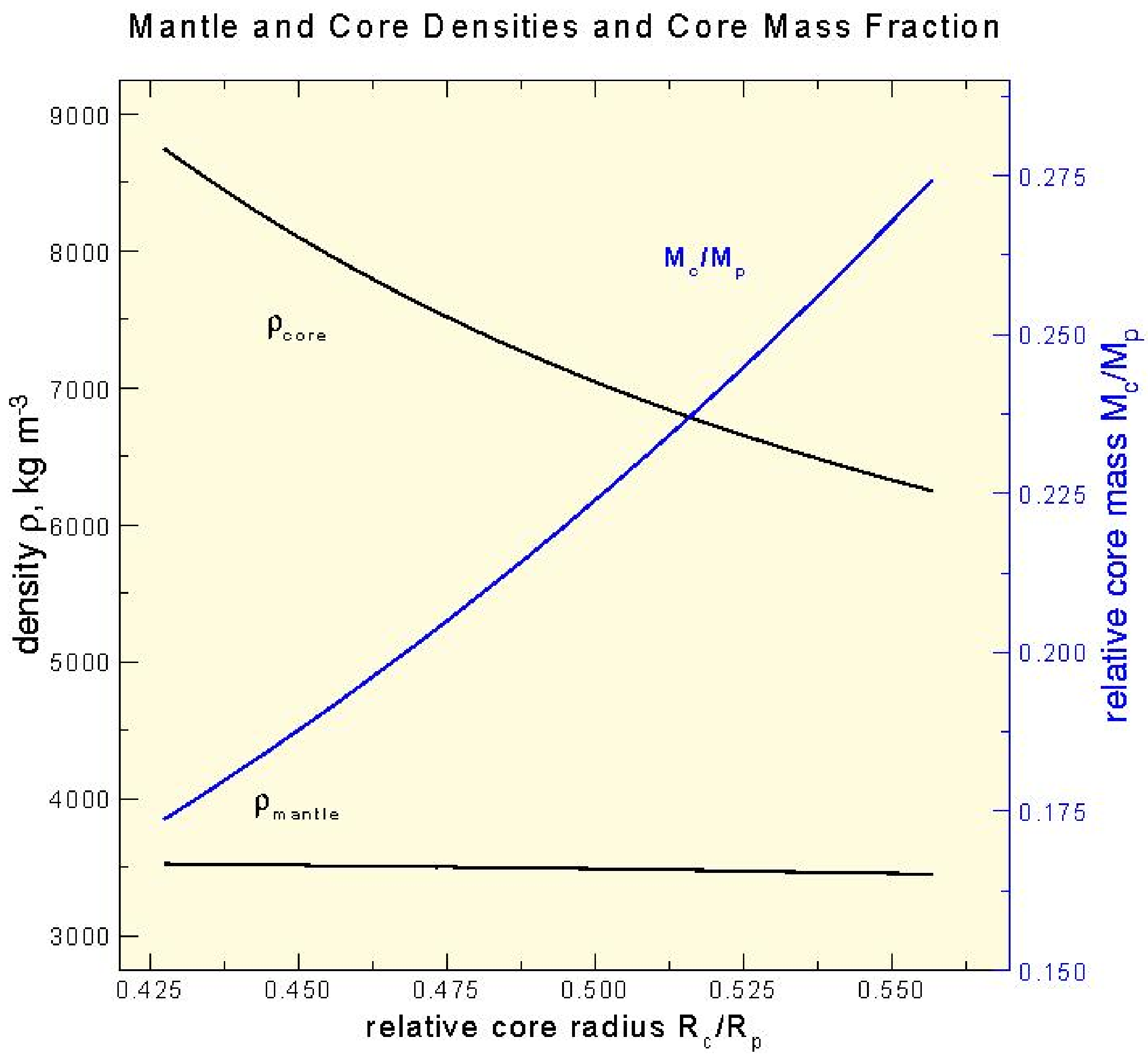
$$\rho\left(\frac{I}{MR^2}\right) = \frac{2}{5}\left[\rho_c\left(\frac{r_c}{R}\right)^5 + \rho_m\left\{1 - \left(\frac{r_c}{R}\right)^5\right\}\right]$$

- 3 unknowns: core radius r_c, mantle density ρ_m, core density ρ_c.

Simple two layer structure

2 knows:
M mass
 I   moment of inertia

3 unknows:
R_c core radius
ρ_m mantle density
ρ_c core density



Three-layer structural models

- 2 constraints: mean density ρ and MoI factor I/MR^2.

$$\rho = \rho_s + (\rho_c - \rho_m)\left(\frac{r_c}{R}\right)^3 + (\rho_m - \rho_s)\left(\frac{r_m}{R}\right)^3$$

$$\rho\left(\frac{I}{MR^2}\right) = \frac{2}{5}\left[\rho_s + (\rho_c - \rho_m)\left(\frac{r_c}{R}\right)^5 + (\rho_m - \rho_s)\left(\frac{r_m}{R}\right)^5\right]$$

- 5 unknowns: core radius r_c, crust-mantle radius r_m, crust density ρ_s, mantle density ρ_m, core density ρ_c.

Interior structure relevant data

- size and mass

r_a=3389km, m_a=6.4185 10^{23} kg

- average moment of inertia

MOI=0.3655±0.00086 (Konopliv et al. 2010)

- crust density and thickness

ρ=2900±200kg/m^3, d=50±12km (Wieczorek et al. 2004)

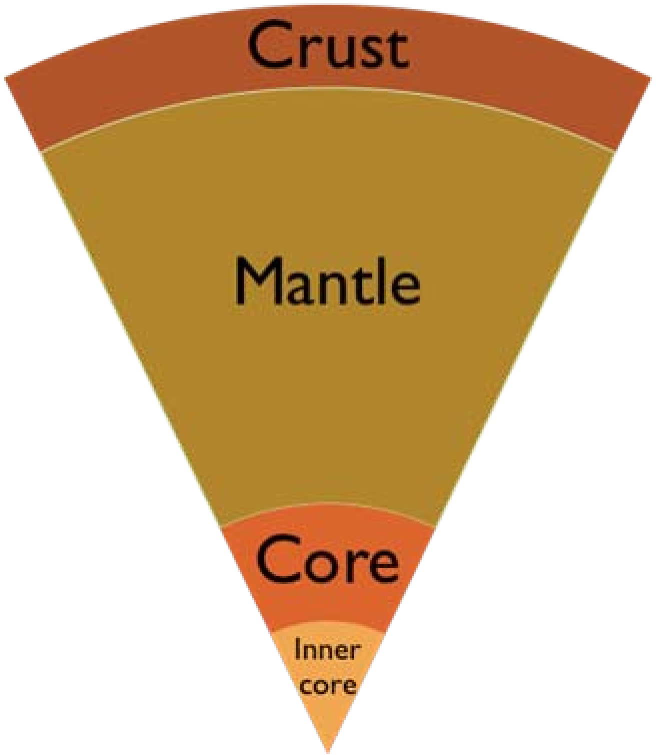
- phase diagrams of mantle minerals and core constituents

- high pressure and temperature thermoelastic data

New geophysical observations

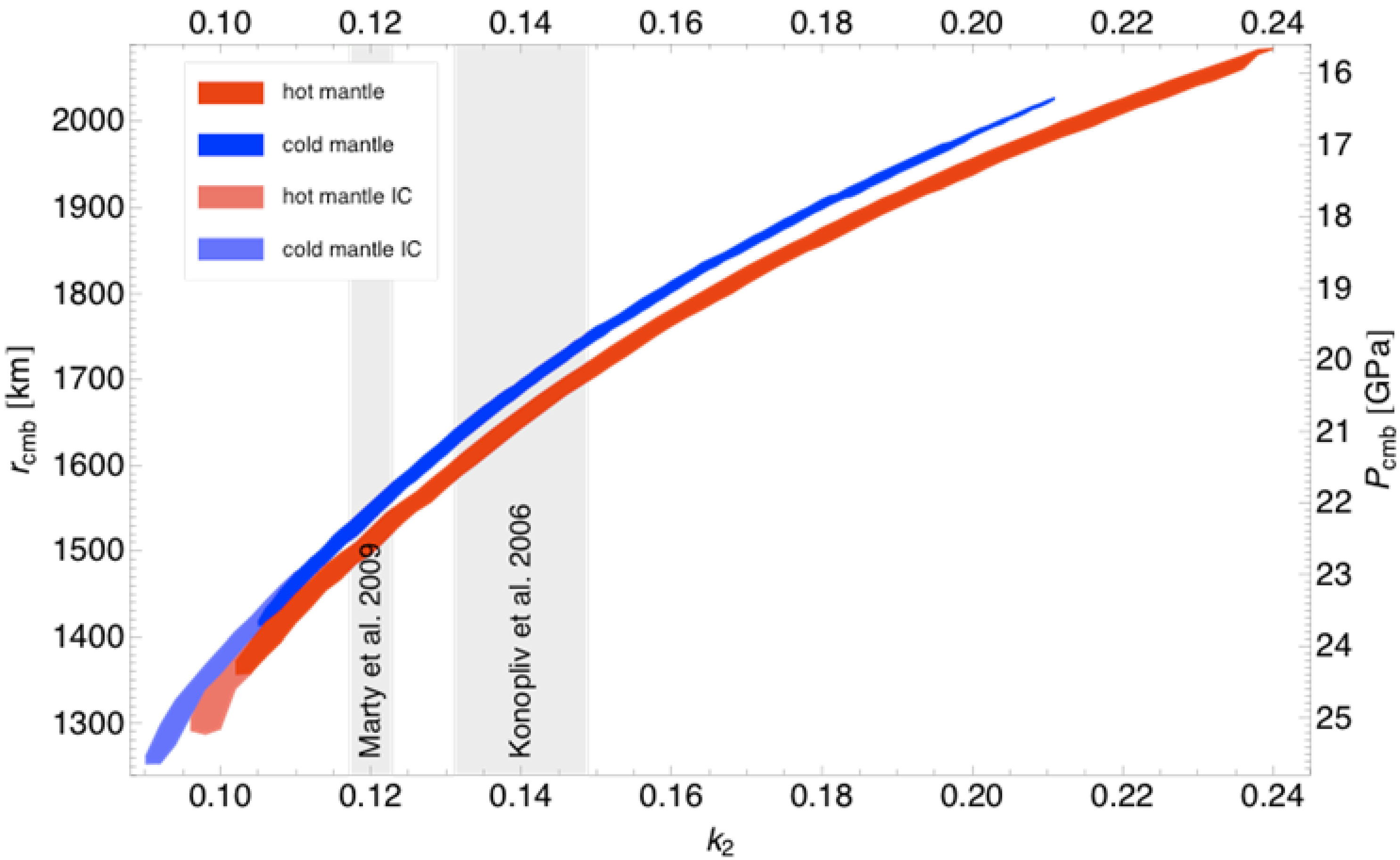
- Re-analysis of MGS tracking and MPF & VL ranging resulted in $C/MR^2 = 0.3650 \pm 0.0012$ (Yoder *et al.*, 2003).
  → significantly lower than most often used value $C/MR^2 = 0.3662 \pm 0.0017$ (Folkner *et al.*, 1997).
  → implies stronger central mass concentration ex: Martian crust is several tens of km thicker than previously thought if crust & mantle density and core size are given
- Tidal potential Love number $k_2 = 0.153 \pm 0.012$ (Yoder *et al.*, 2003) and $k_2 = 0.15 \pm 0.01$ (Konopliv *et al.*, 2006) suggests hot interior with liquid (outer) core.
- Tidal potential Love number $k_2 = 0.12 \pm 0.01$ (Marty *et al.*, 2009) suggests smaller liquid core.

Interior structure model of Mars as recently derived at ROB (*Rivoldini et al. Poster*)

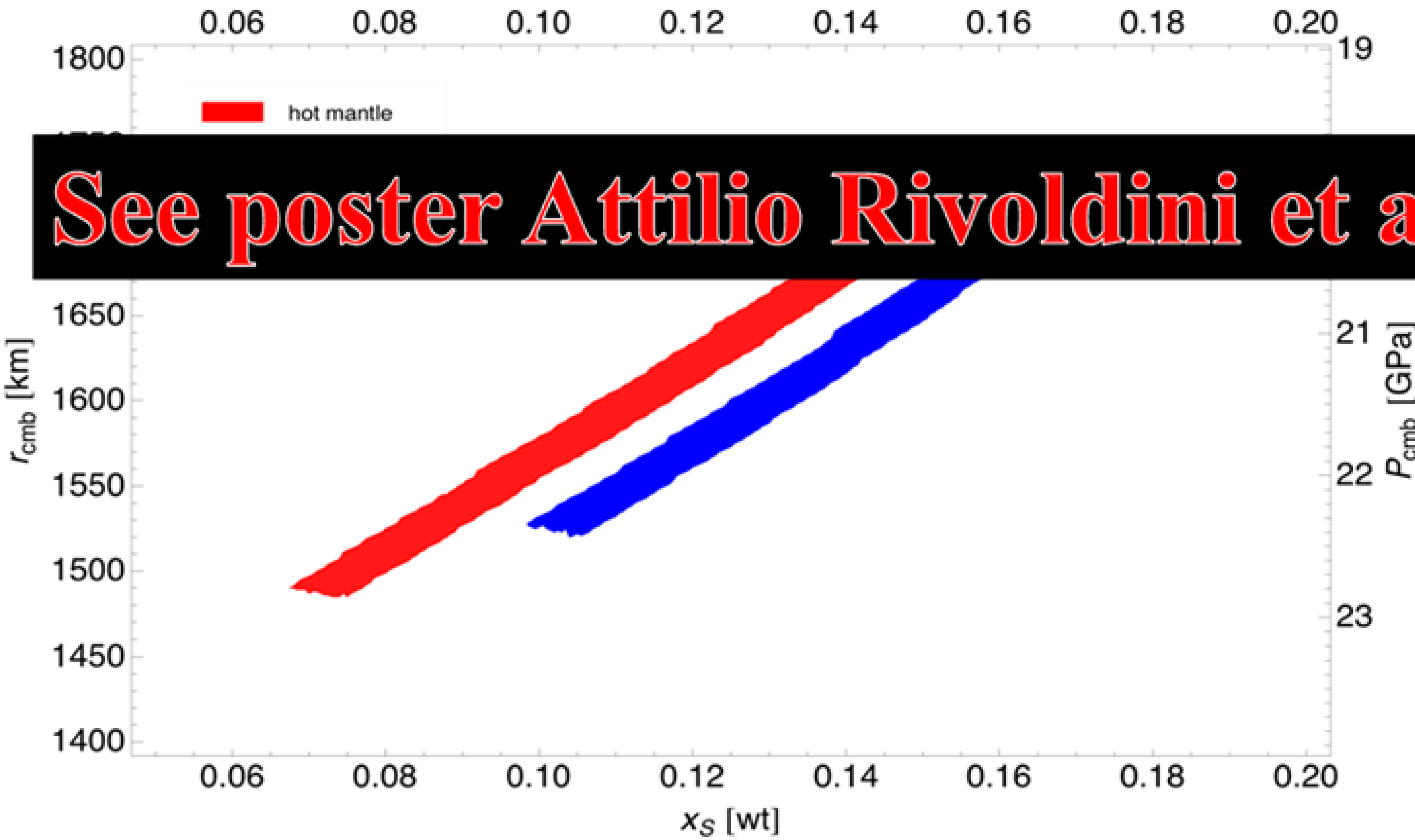


- spherical symmetric, hydrostatic and elastic
- homogeneous crust
- depth dependent thermoelastic properties in mantle and core
- convecting liquid Fe-S core
- solid γ-Fe inner core (melting data dependent)

k_2 as a function of core size

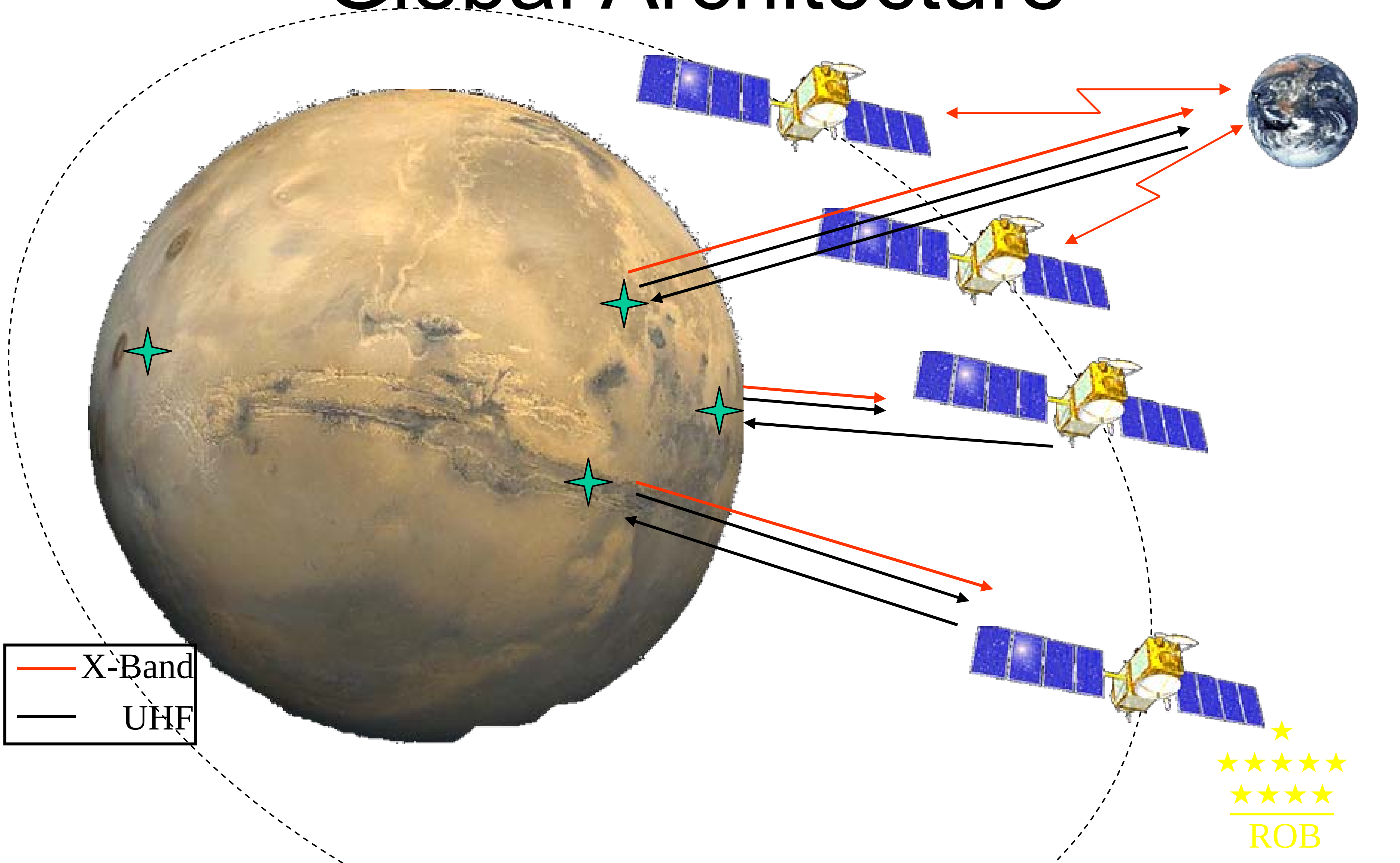


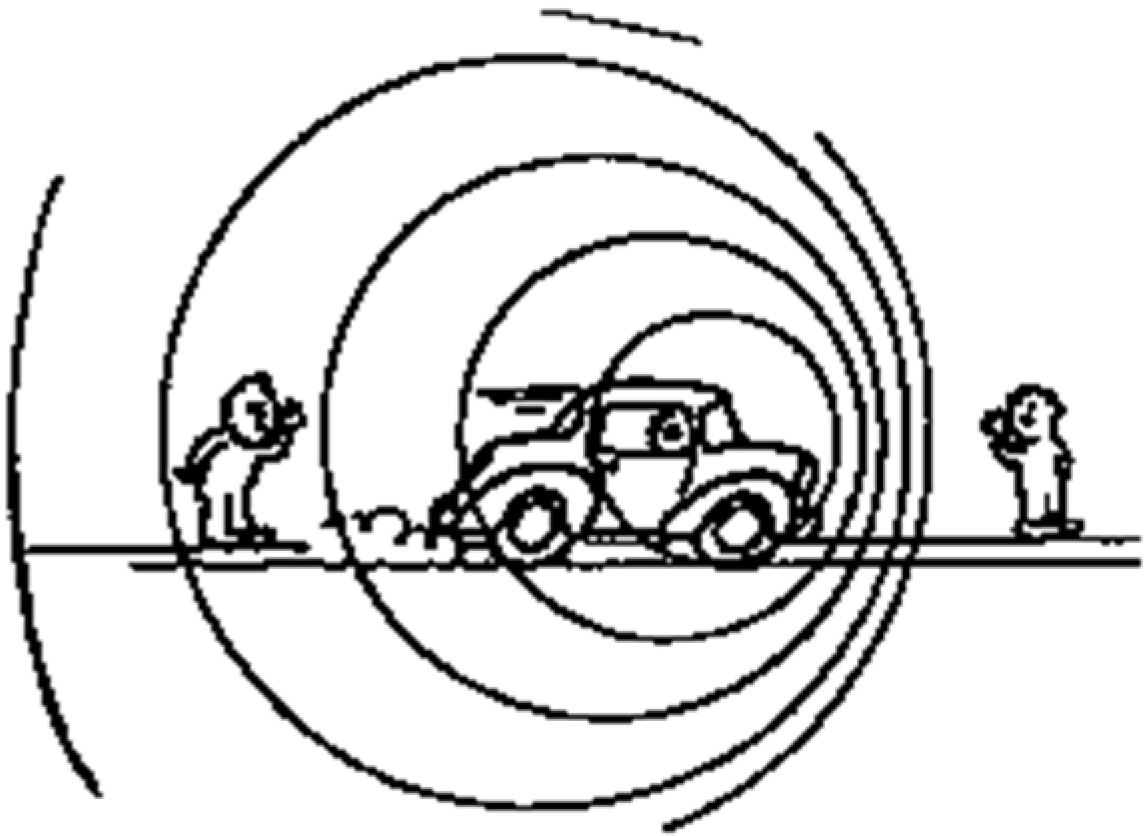
Core size-core vs sulfur concentration (compatible with MoI and k_2 ranges)



See poster Attilio Rivoldini et al.

Global Architecture



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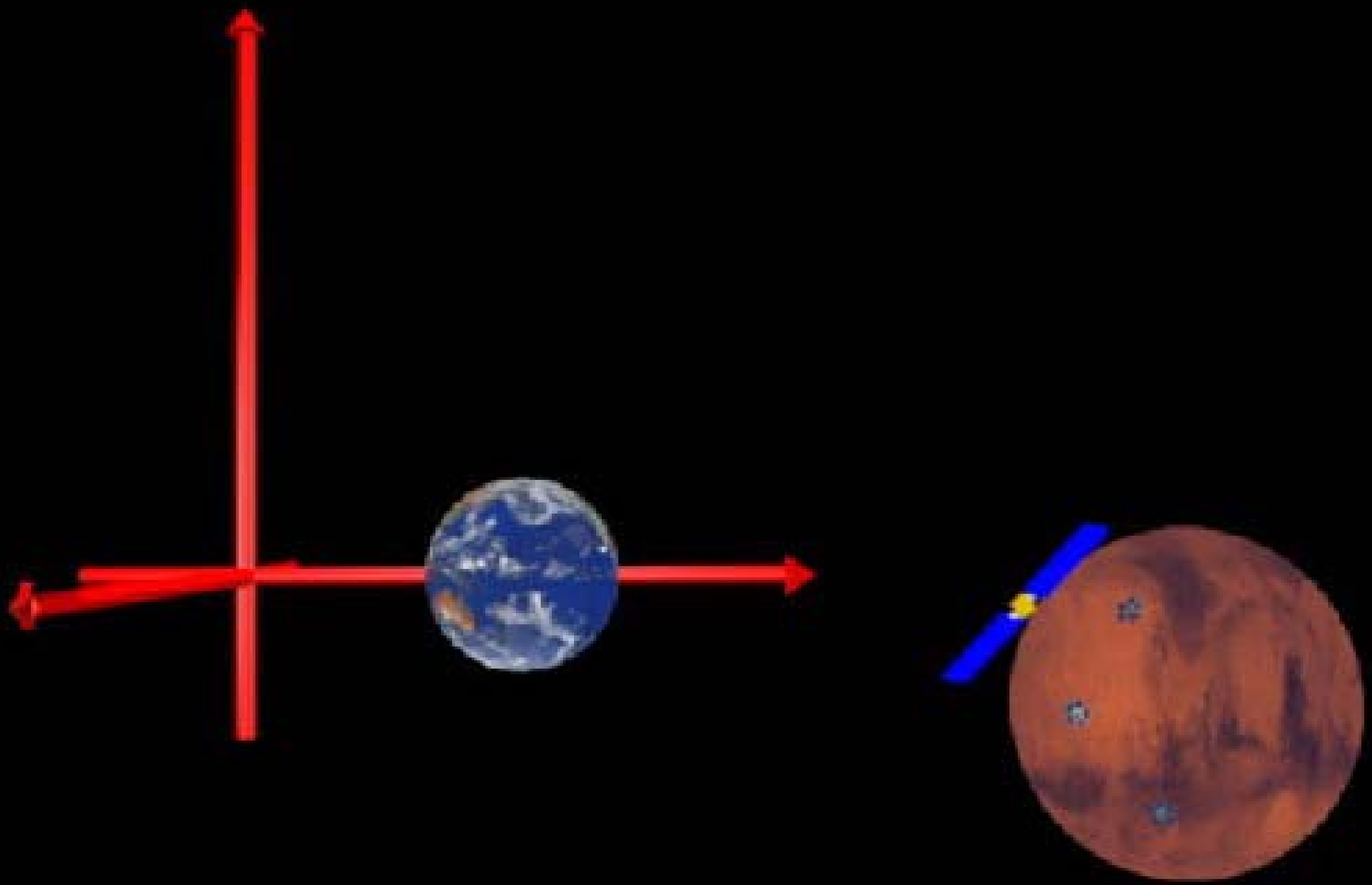
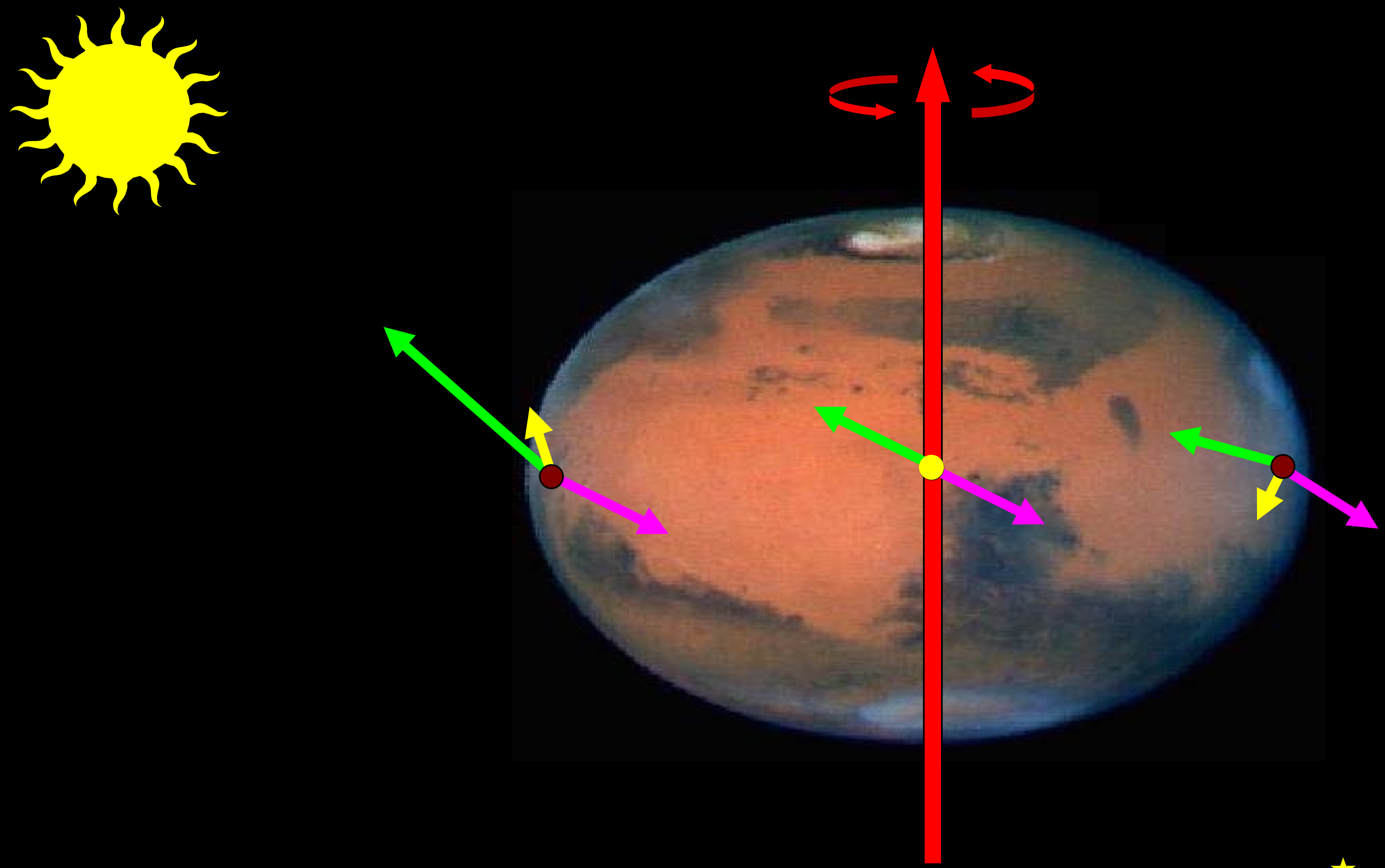


Precession and nutation of Mars

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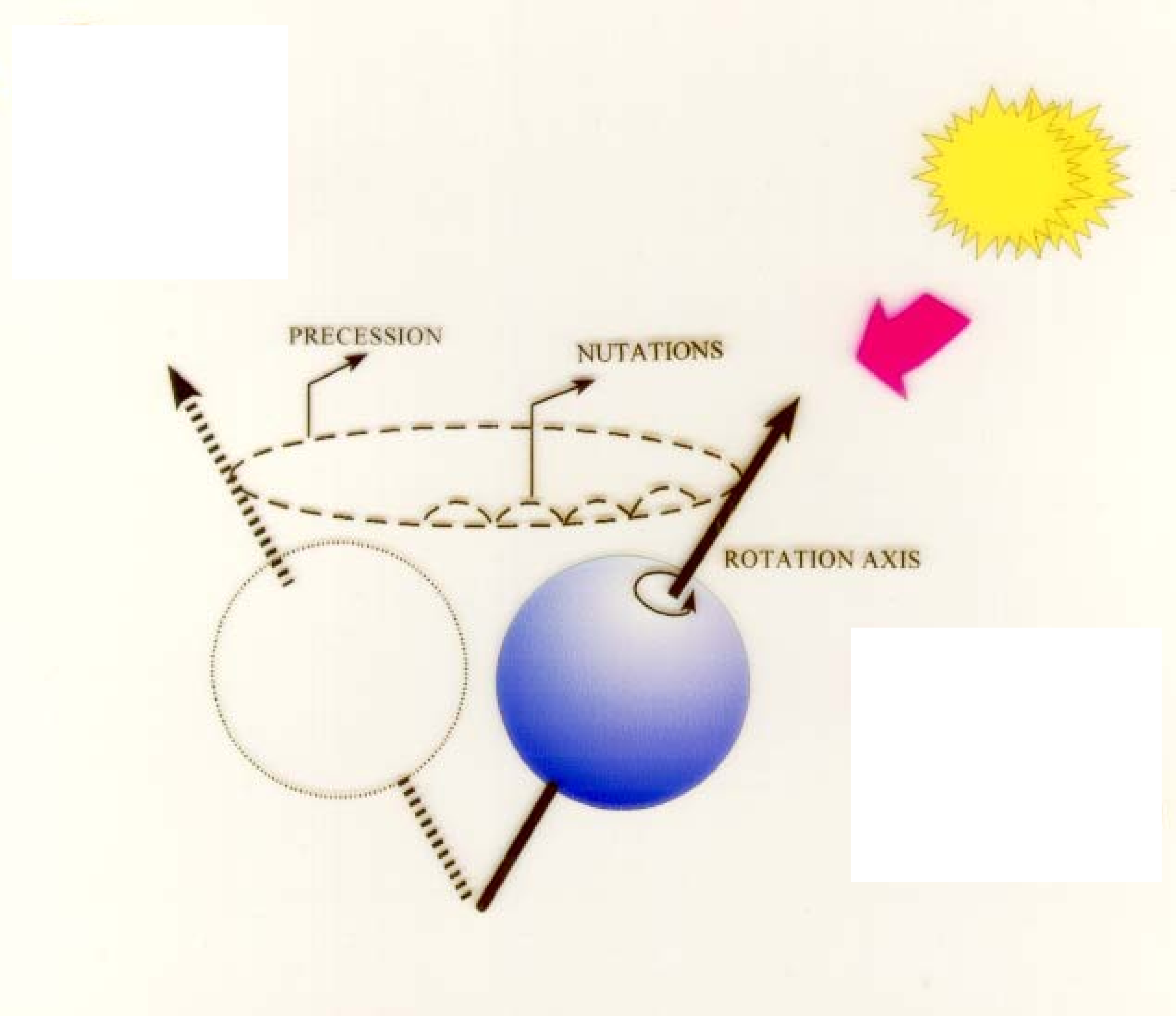

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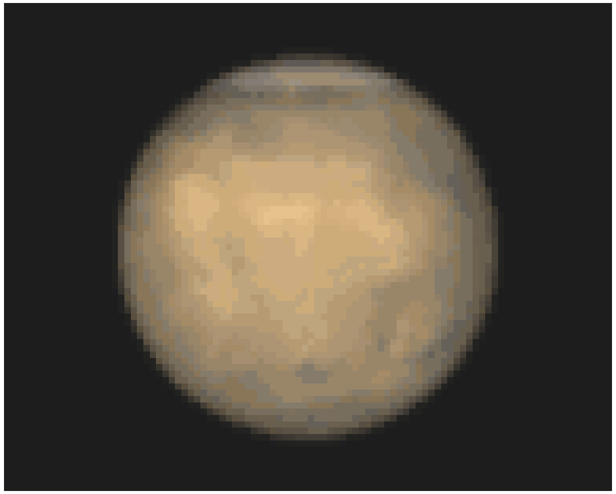

Conclusions

ROB

Conclusions

- The interior of Mars plays an important role in the context of habitability.
- Mantle convection, phase transition inside the mantle, core dynamo are examples.
- In order to address these characteristics: GEMS (GEophysical Monitoring Station), Mars Network Science,
  - including seismology, geodesy, heat flow measurements, magnetism:
  - next talks!