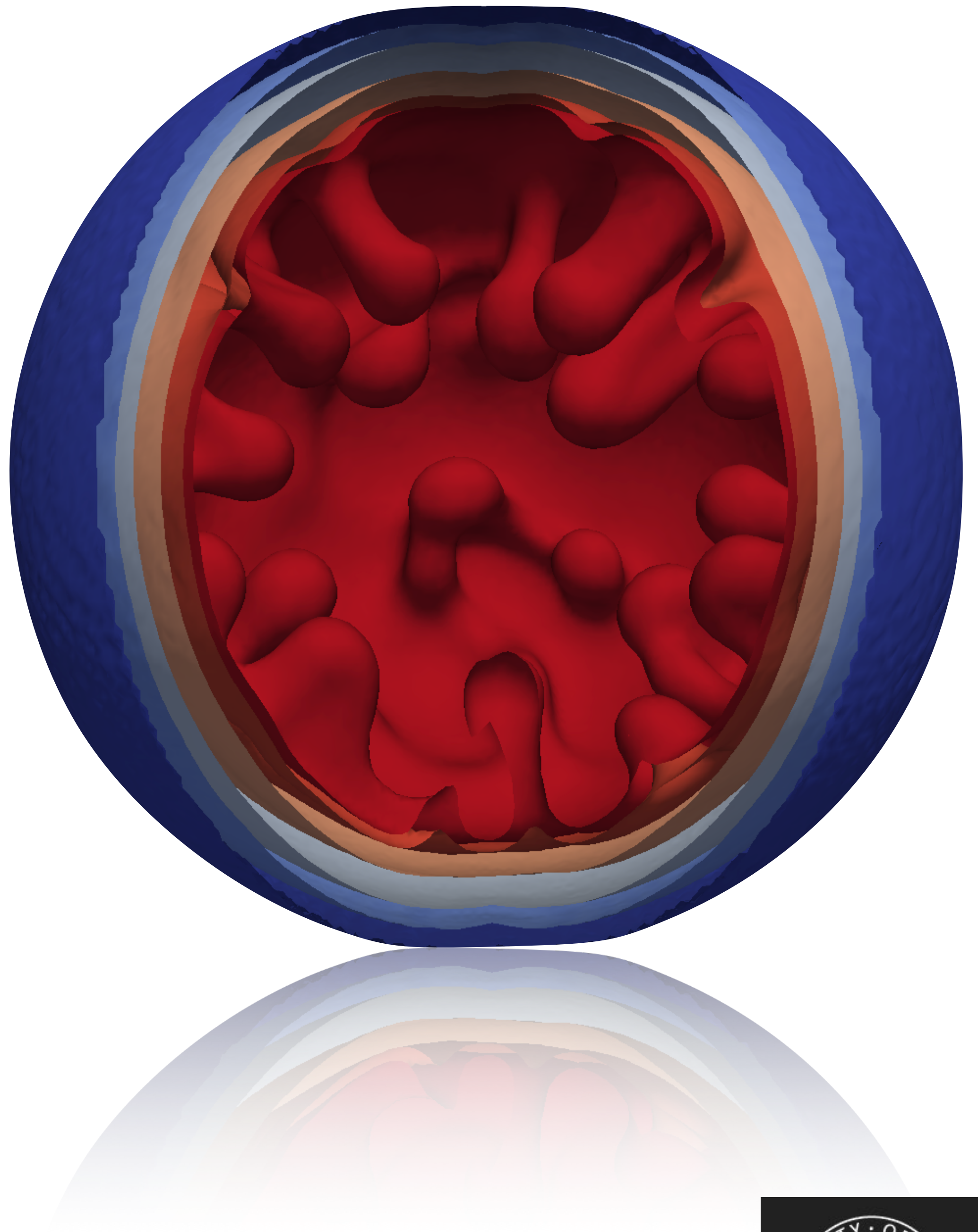
Magma ascent in planetesimals: control by grain size

Tim Lichtenberg (ETH Zurich / U Oxford)

Tobias Keller (Stanford)
Richard Katz (U Oxford)
Gregor Golabek (BGI Bayreuth)
Taras Gerya (ETH Zurich)



arXiv:1802.02157

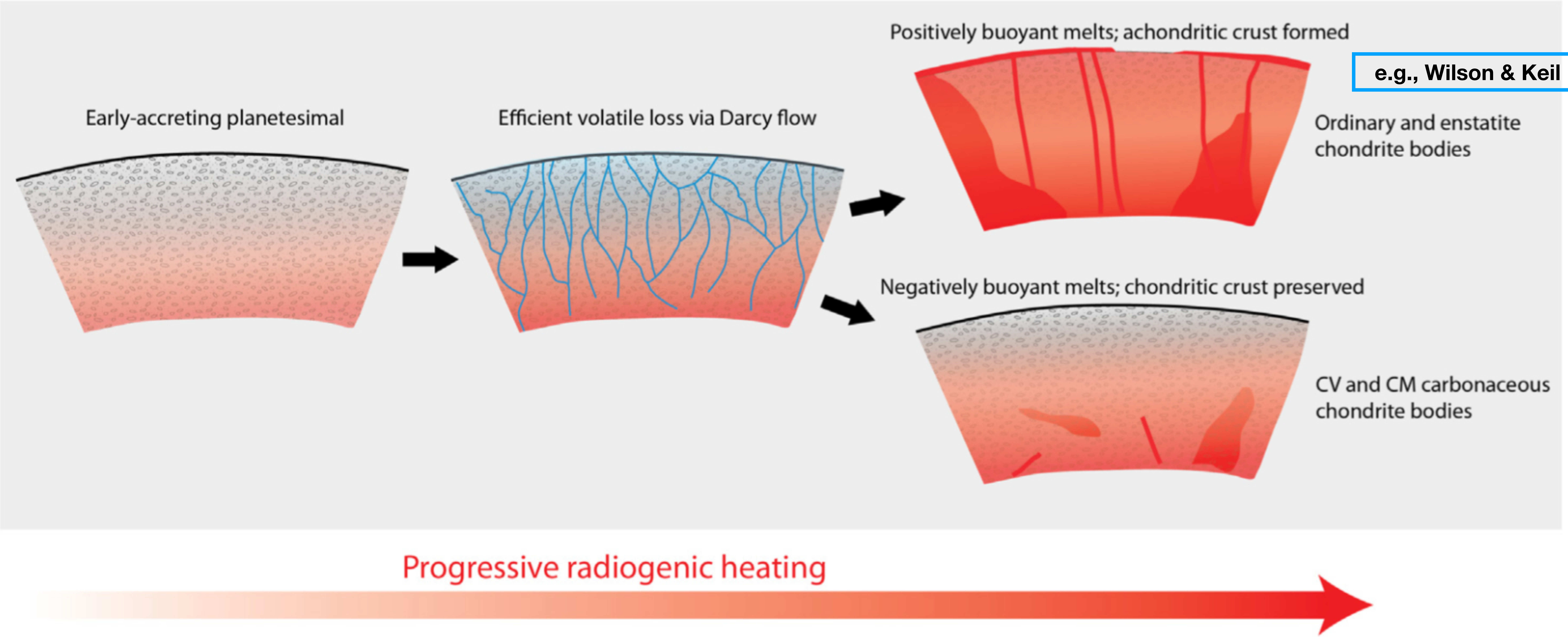
ETHzürich

EPSC 2018, Berlin, 18 Sep 2018

Since Aug 2018

UNIVERSITY OF OXFORD

Thermal inversions due to melt segregation?



e.g., Wilson & Keil 17

Fu & Elkins-Tanton 14

Steady-state melt ascent scaling

Melt segregation number

$$\boxed{R_{\mathrm{seg}} = \log_{10}\left(\frac{\tau_{\mathrm{heat}}}{\tau_{\mathrm{segr}}}\right) = \log_{10}\left(\frac{k_\phi \Delta\rho g_0 c_{\mathrm{p}} \Delta T_0}{R_{\mathrm{P}} \mu H_{0,{}^{26}\mathrm{Al}}}\right)}$$

Permeability: $k_\phi = \frac{a_0^2}{b}\frac{\phi^{\mathrm{n}}}{(1-\phi)^{\mathrm{m}}}$

$\Delta\rho$: Solid-melt density contrast

ΔT: T contrast

$H_{0,26Al}$: ^{26}Al decay power

ϕ: Melt fraction (porosity)

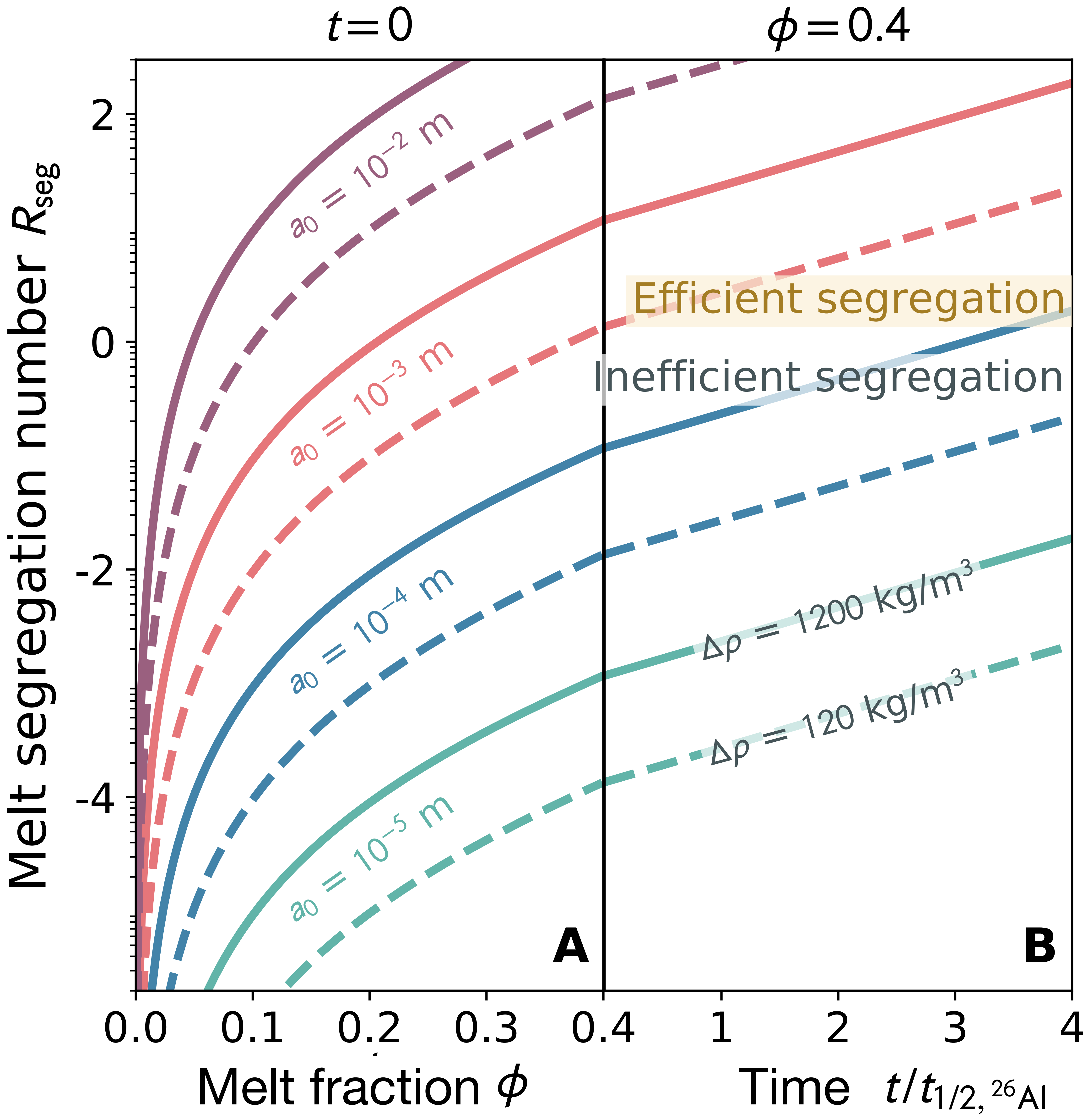
a_0: Grain size

c_p: Specific heat

μ: Melt viscosity

R_P: Planetesimal radius

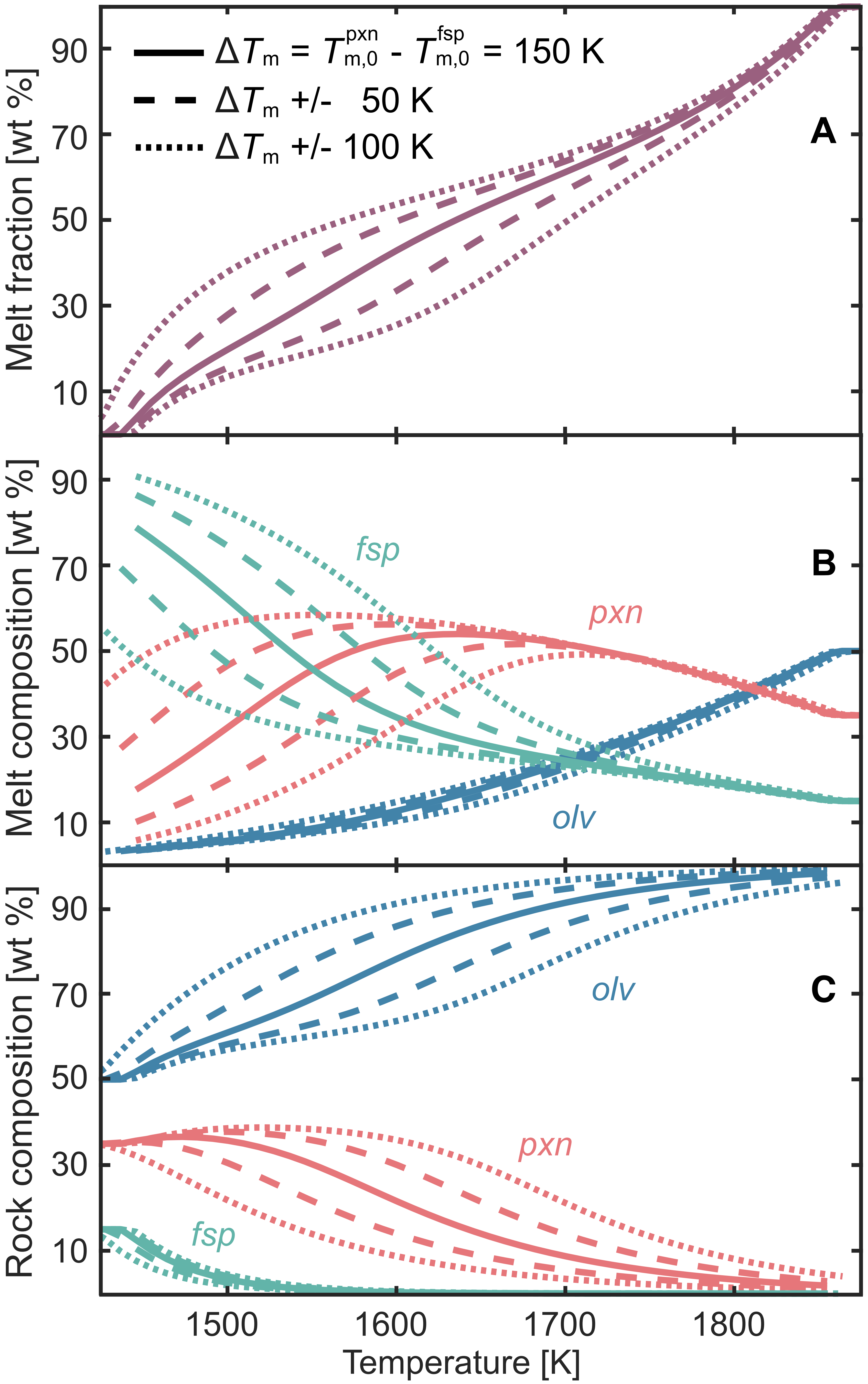
g_0: Surface gravity



Lichtenberg+, arXiv:1802.02157

Two-phase magma dynamics + multi-component thermo-chemistry

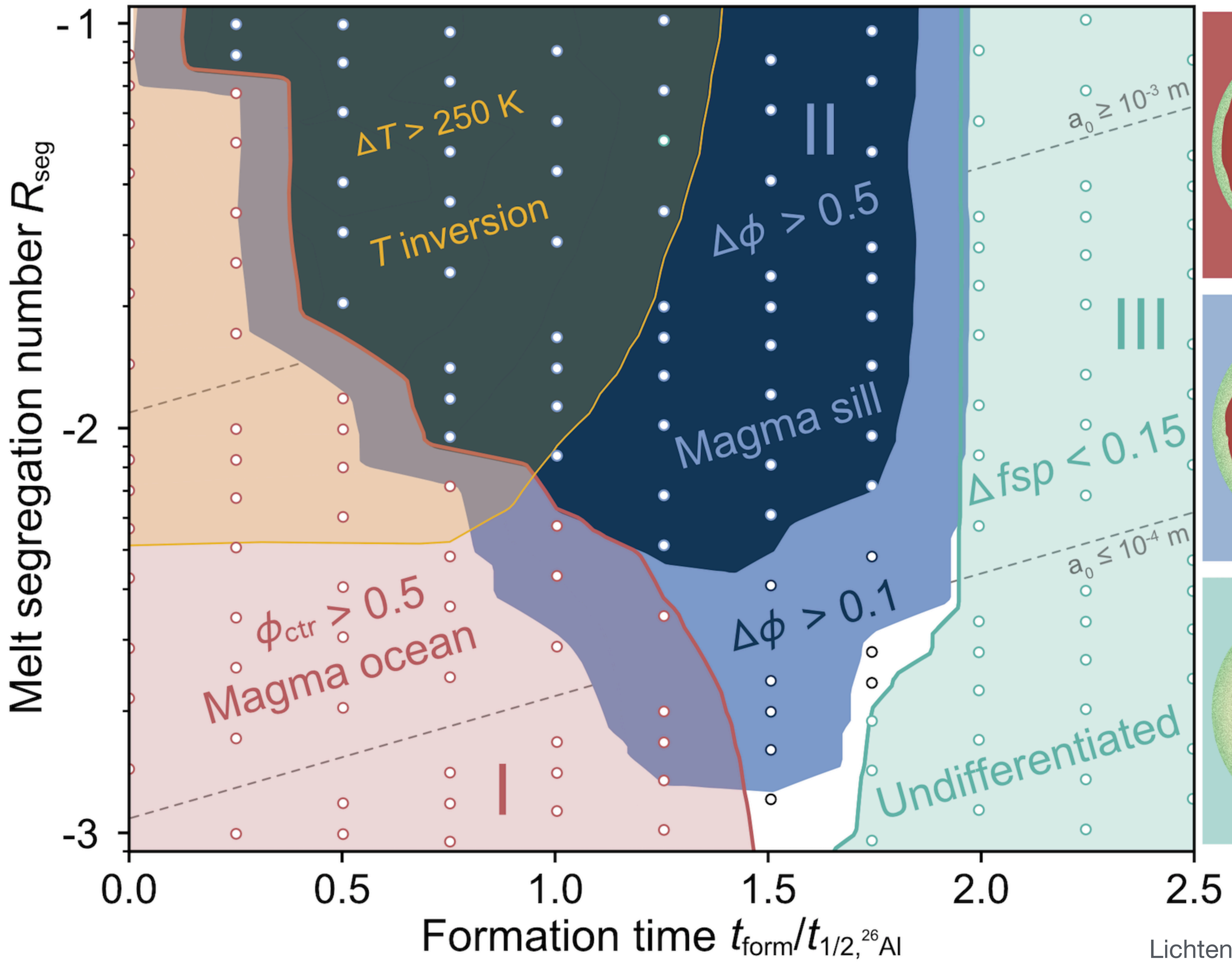
- Split up planetesimal rock body into multiple components, follow individually
- **Two-phase, thermo-chemical** evolution in 1D column setup (*Keller & Katz 16*)
- 'Dry' compositional setup:
  - Olivine/***olv*** (~50%, refractory)
  - Pyroxene/***pxn*** (~35%, fertile)
  - Feldspar/***fsp*** (~15%, ^{26}**Al**)
- Parameter study of solid-melt density contrast, grain sizes (permeability), formation time

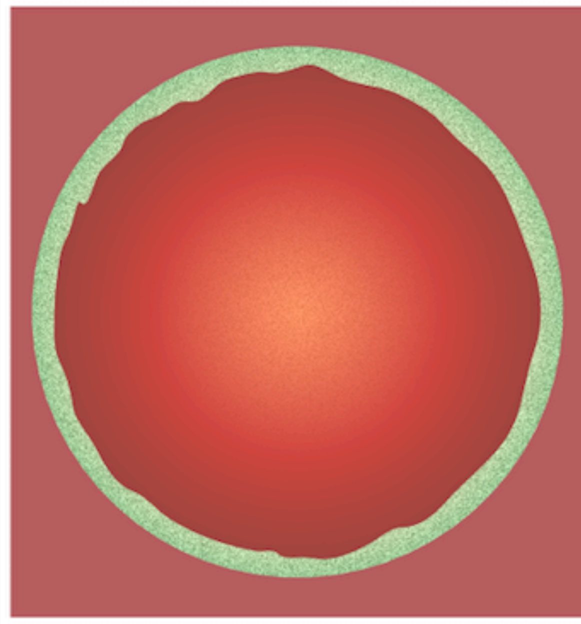


Lichtenberg+, arXiv:1802.02157

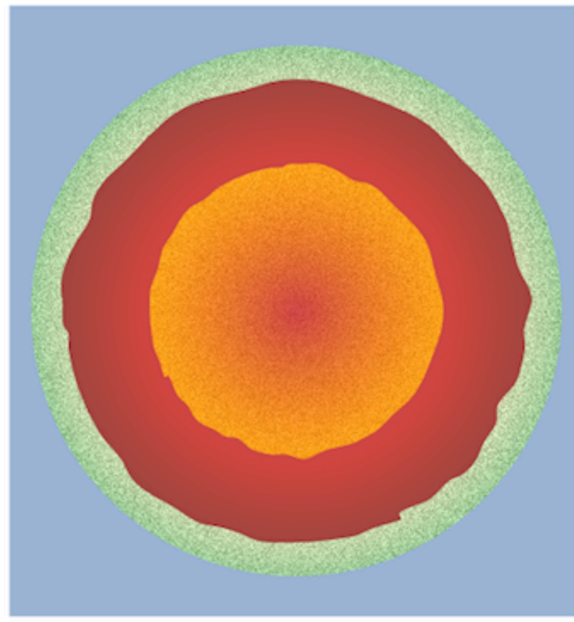
Melt segregation regimes

$$R_{\mathrm{seg}} = \log_{10}\left(\frac{\tau_{\mathrm{heat}}}{\tau_{\mathrm{segr}}}\right) = \log_{10}\left(\frac{k_{\phi}\Delta\rho g_0 c_{\mathrm{p}}\Delta T_0}{R_{\mathrm{P}}\mu H_{0,{}^{26}\mathrm{Al}}}\right)$$

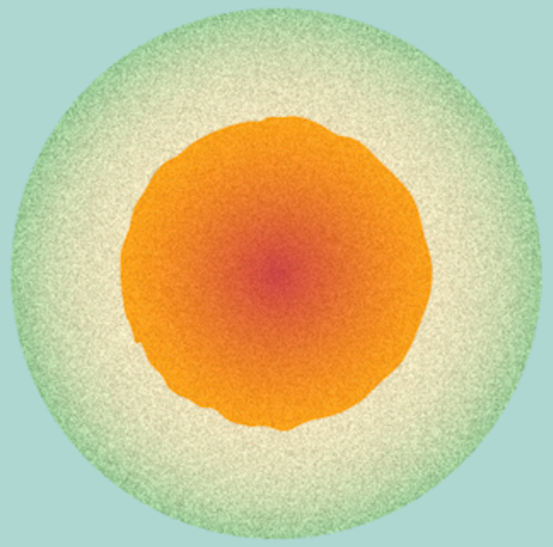




I Magma ocean
- Global interior magma ocean
- Chemical & isotopic equilibration
- Shallow chondritic lid at surface
- Adiabatic interior *T*



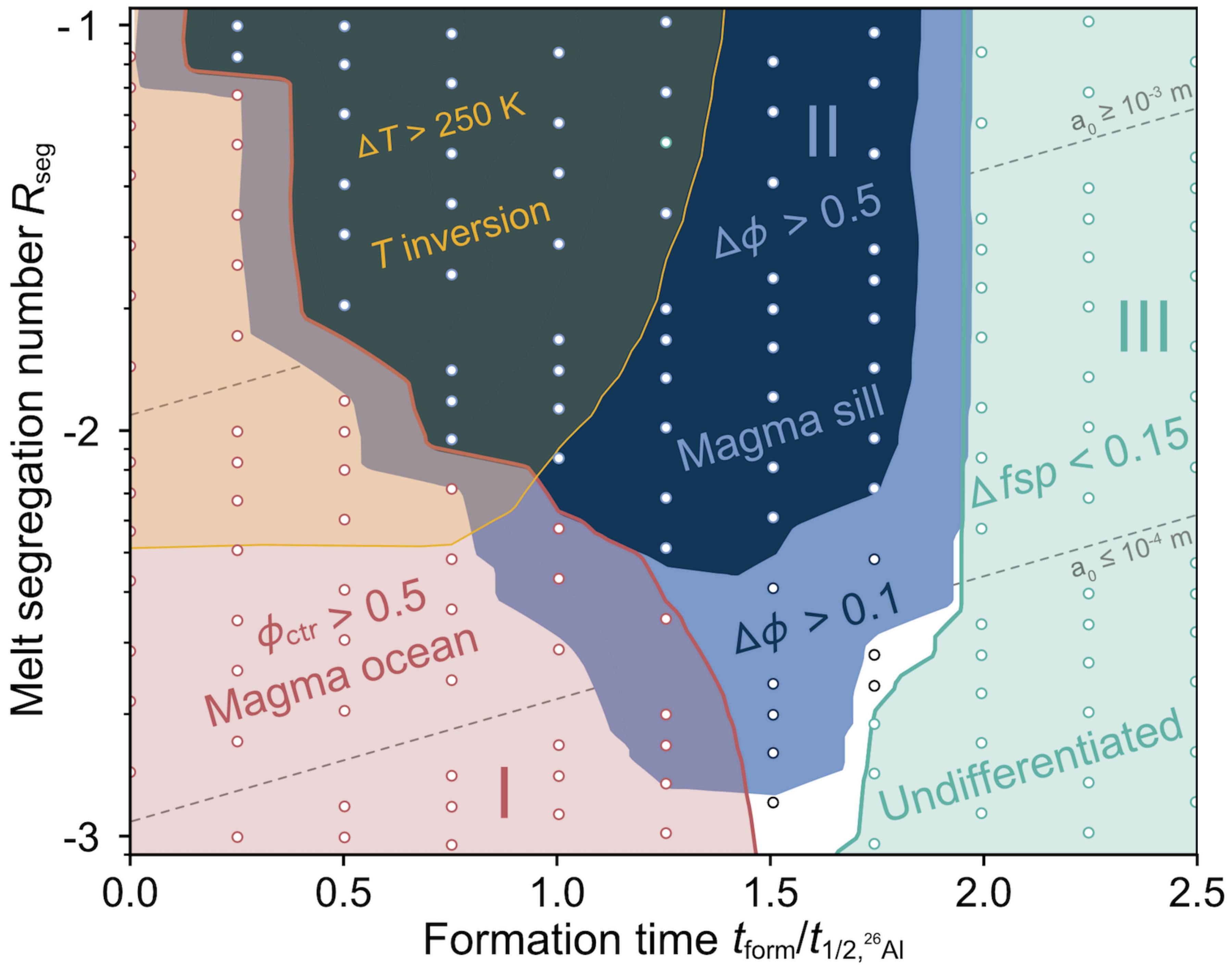
II Magma sill
- Efficient magma segregation
- Chemical differentiation
- Shallow chondritic lid at surface
- Potential *T* inversion



III Undifferentiated
- Zero to partial silicate melts
- Primordial chemical signature
- Thick chondritic lid
- Inside-out *T* decrease

Lichtenberg, Keller, Katz, Golabek, Gerya (E&PSL, in revision, **arXiv:1802.02157**)

Summary & Conclusions



Melt ascent in planetesimals: control by grain size
Lichtenberg, Keller, Katz, Golabek, Gerya
E&PSL, in revision, arXiv:1802.02157

- **Two melting regimes:**
    - ➡ **Control: grain size, formation time, $fO_2/\Delta\rho$**
        - (i) global magma ocean ($t_{\mathrm{form}} < t_{26,\mathrm{Al}}$)
        - (ii) magma sill (t_{form} ~ 1 Myr + grain size > 1 mm)
- **Temperature inversions limited in parameter space (< 250 K)**
    - Questions use of simple thermal models for age dating
- **Constrains possible core formation regimes**
- Consistent with/implications for:
    - Paucity of olivine on Vesta’s surface; ‘missing olivine’
    - Time gap between basalts and CAIs/youngest irons