Inferring Mars' Internal Structure from a Probabilistic Inversion of Complementary Geophysical Data

M Drilleau[1] (drilleau@ipgp.fr), Henri Samuel[1], Olivier Verhoeven[2], Attilio Rivoldini[3], Max Collinet[4], Raphaël Garcia[5], & Philippe Lognonné[1]

[1] Université Paris Cité, Institut de Physique du Globe de Paris, CNRS, Paris, France, [2] Nantes Université, Université d'Angers, Le Mans Université, CNRS, UMR 6112, Laboratoire de Planétologie et Géosciences, UAR 3281, Observatoire des Sciences de l'Univers de Nantes Atlantique, Nantes, France, [3] Royal Observatory of Belgium, Brussels, Belgium, [4] Namur University, Namur, Belgium, [5] Institut Supérieur de l'Aéronautique et de l'Espace ISAE-SUPAERO, Toulouse, France

Framework

- Which 1D interior structure models of Mars are compatible with different and complimentary geophysical observables? What can we deduce about the evolution of Mars' interior?
- We adopt a synergetic strategy in which multiple types of geophysical data (body wave arrival times, electrical conductivity, Love number k_2, moment of inertia MoI) are simultaneously inverted to infer the interior structure models of Mars.

Method

- Our models depend on quantities that influence the thermo-chemical evolution of the planet (Samuel et al., 2019, Drilleau et al., 2022): The mantle rheology (effective activation energy, volume, reference viscosity), the initial thermal state (temperature below the lithosphere and core-mantle boundary temperature), the core radius, the equation of state of the core
- We assume Mg# dependent variations of the mantle composition models of Sanloup et al. (1999) EH45, Taylor (2013) TA, and Yoshizaki & McDonough (2020) YM
- The mantle mineral proportions and elastic properties are computed using Perple_X (Connolly, 2005) employing the thermodynamic formulation and database of Stixrude & Lithgow-Bertelloni (2021)
- We consider models with and without a basal mantle layer (BML) (Samuel et al., 2023)
- Inversion scheme: Bayesian inversion using Monte Carlo Markov chains

Results: Correlation between Mg# and potential temperature

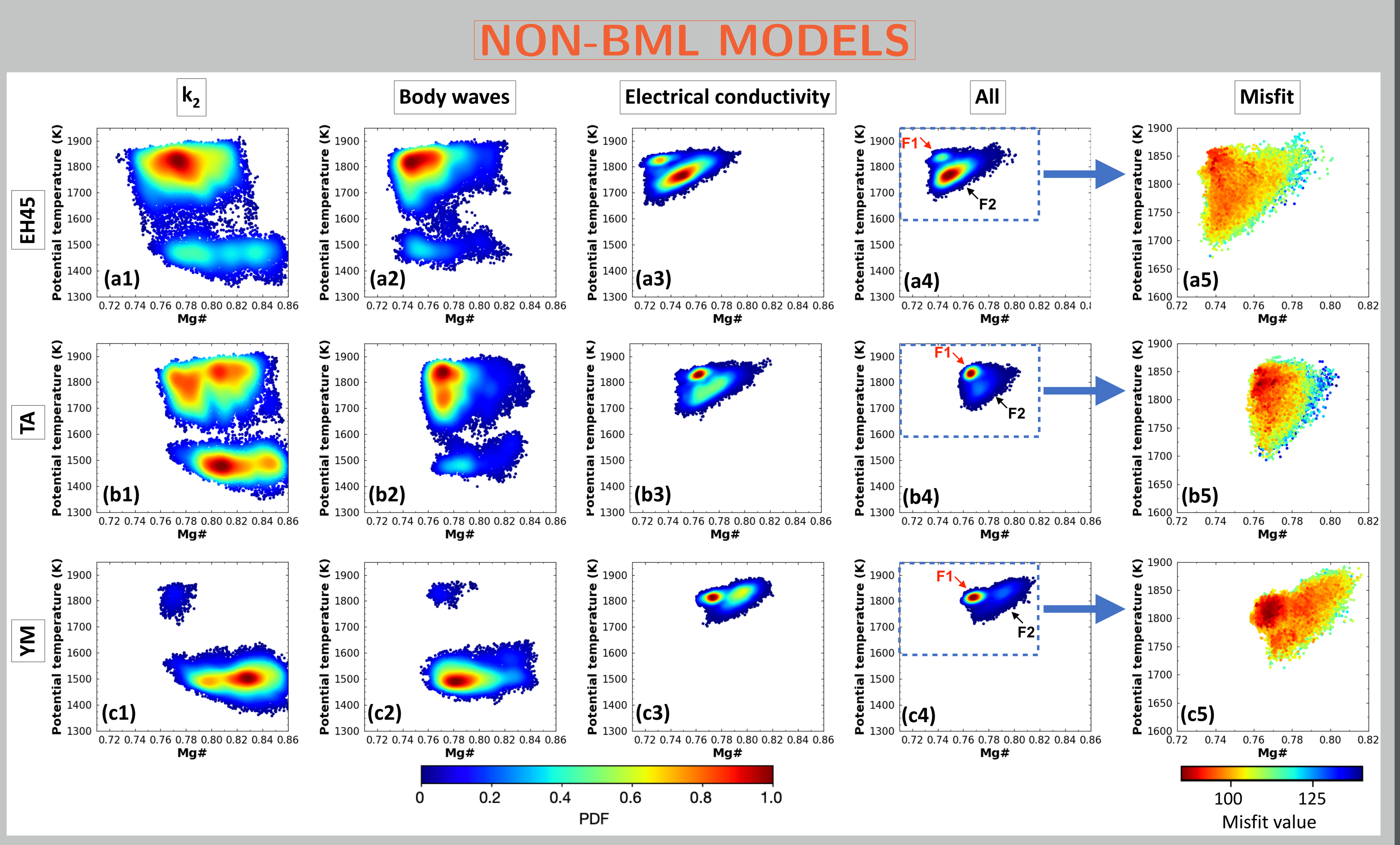

Figure 1: Correlations between Mg# and potential temperature, and datafit (last column) for **non-BML models**.

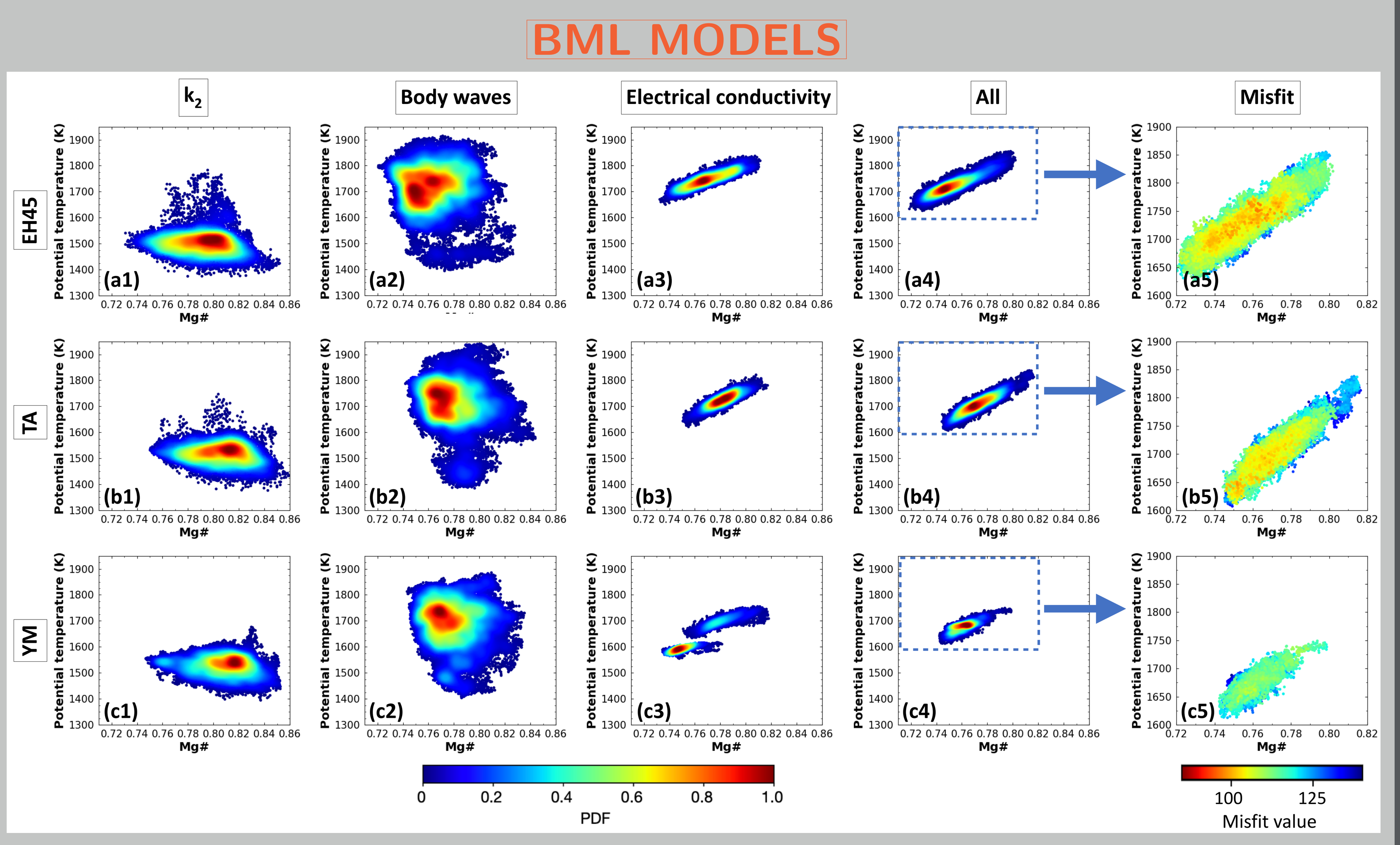

Figure 2: Correlations between Mg# and potential temperature, and datafit (last column) for **BML models**.

- Models with Mg#<0.72 are not compatible with the MoI
- Models inferred with mantle electrical conductivity data favour larger potential temperatures
- **Non-BML**: Models based on either of the considered mantle composition with Mg#>0.72 agree with the geophysical data at the same level
- **BML**: Models based on the YM mantle composition are less compatible with seismic data
- **BML**: The models agree less with electrical conductivity data

Data

- Body waves data set of 31 seismic events: P, S, PP, SS, PPP, SSS, pP, sP, sS, ScS, SKS, Pdiff or PbdiffPcP (Samuel et al., 2023, Drilleau et al., 2024)
- k_2 Love number and moment of inertia MoI (Konopliv et al., 2020)
- 1D electrical conductivity profile (Civet & Tarits, 2014)

Results: Inferred seismic velocity and electrical conductivity profiles

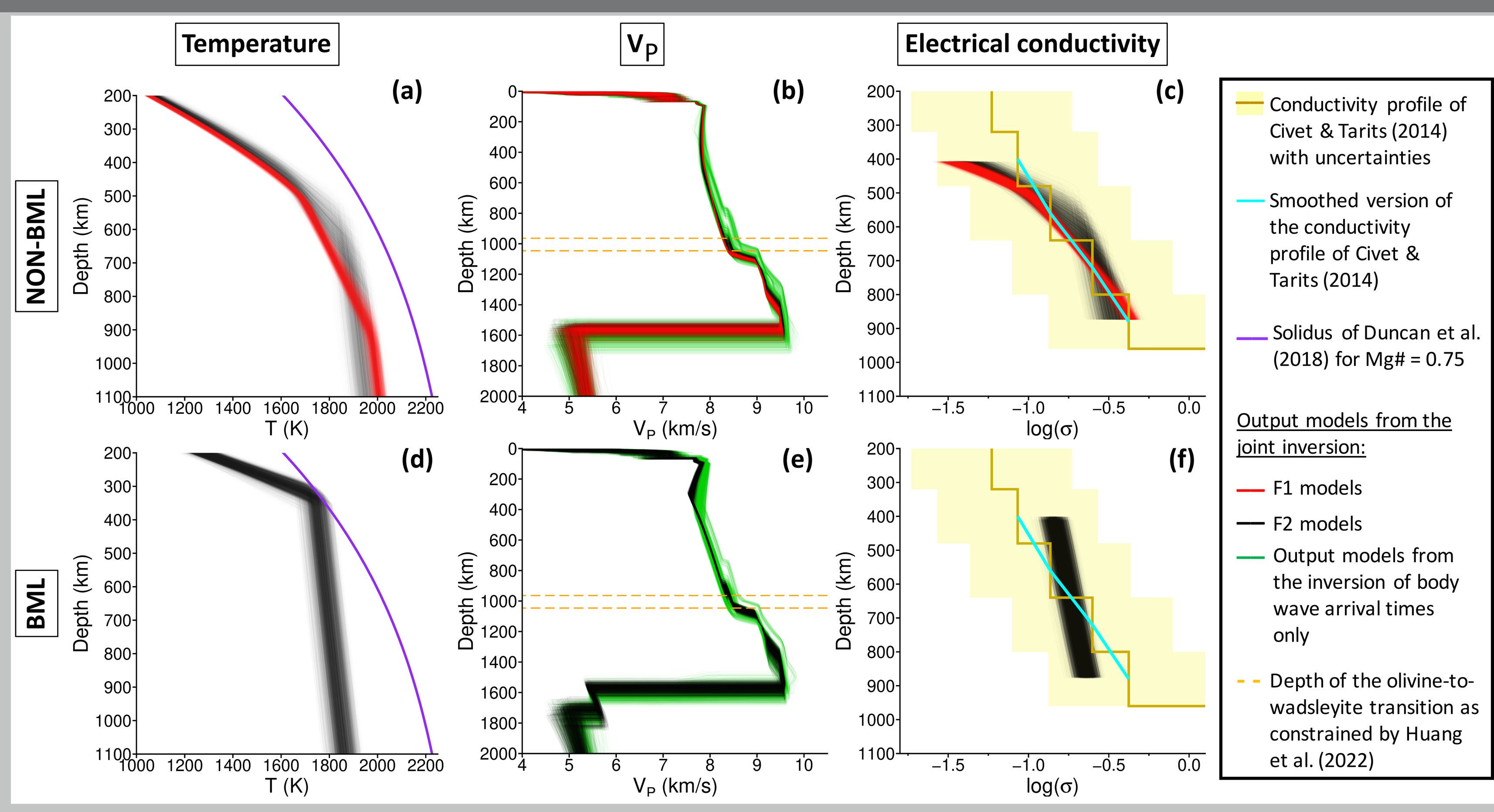

Figure 3: Output profiles of temperature, electrical conductivity, and V_P, considering the TA mantle composition.

- **non-BML:** The mantle electrical conductivity profile of Civet & Tarits (2014) favours models with thick thermal lithospheres (>800 km)
- **BML:** Models have colder present-day mantle temperatures and thinner lithospheres, and agree less well with the mantle electrical conductivity profile of Civet & Tarits (2014)
- Models inferred from electrical conductivity data favour larger mantle temperatures than those inferred body wave arrival times only
  ⇒ The seismic velocity profiles are shifted toward smaller values

Results: Influence of the thermodynamical database

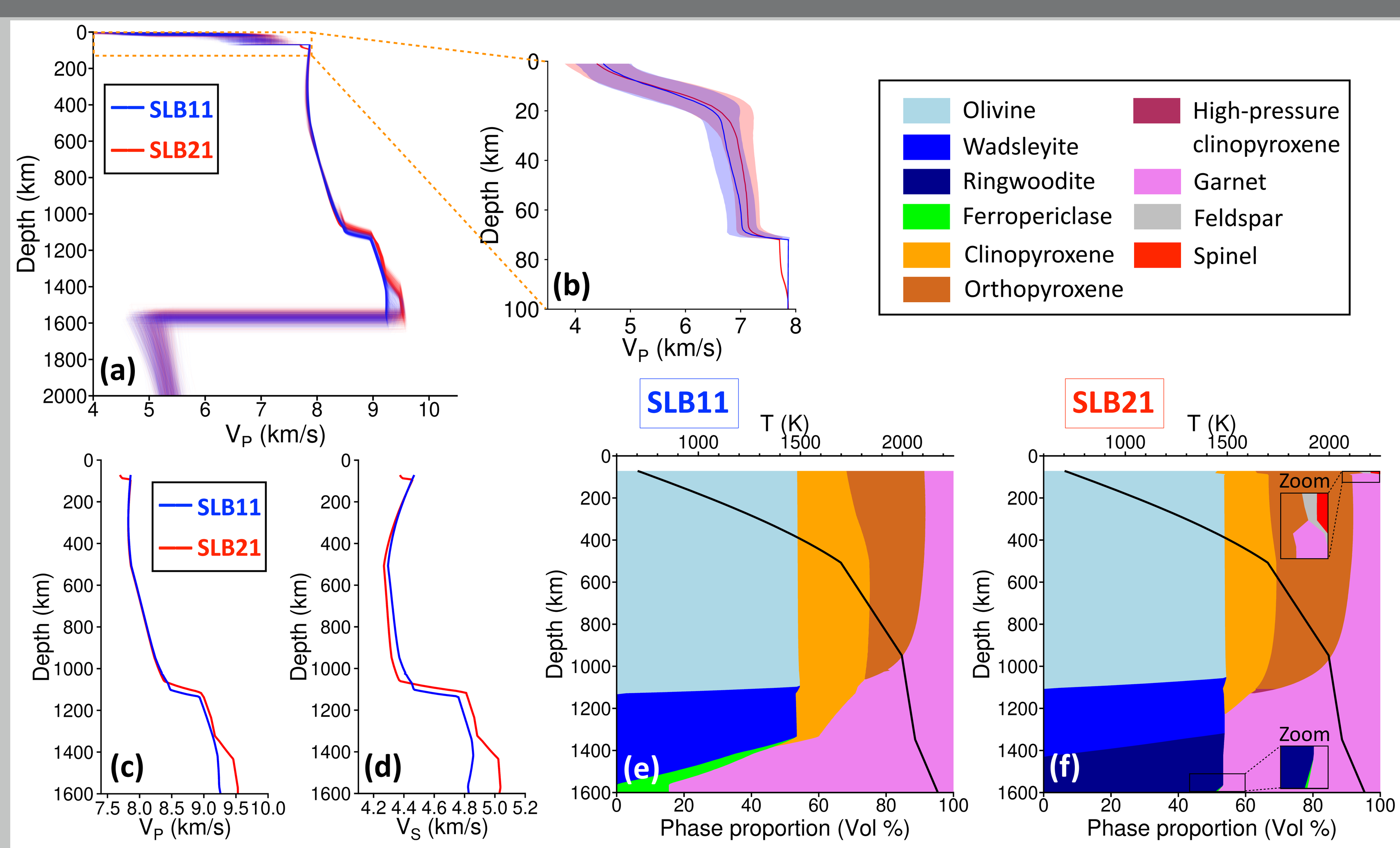

Figure 4: Comparison of seismic velocities and mineralogical phase diagrams between SLB11 and SLB21 (Stixrude Lithgow-Bertelloni, 2011, 2021), considering the TA mantle composition for non-BML models.

- All the published models using InSight data rely on the thermodynamical database of SLB11
- The use of SLB21 introduces several differences:
  ⇒ An additional discontinuity appears below the Moho (∼80 km depth)
  ⇒ The location/amplitude of seismic discontinuities or velocity gradients associated with mineralogical phase transitions are significantly modified in the lower part on the mantle
- The datafit is comparable between SLB11 and SLB21!

Main findings and discussion

- By using electrical conductivity data, the range of plausible mantle temperature profiles is reduced and hot mantle profiles are favoured
- For BML models, whose temperature at the top of the convecting mantle is close to the solidus, a good estimation of the solidus is critical
- The ambiguity in the interpretation of the slope of the Civet & Tarits (2014)'s profile can significantly influence model selection
- A better knowledge of the depth of the seismic discontinuities in the mantle associated with mineralogical phase transitions could further help discriminate between competing interior models