

Single-Seismometer Imaging of Planetary Interiors: *A Way Out with Global Inter-Source Correlations*

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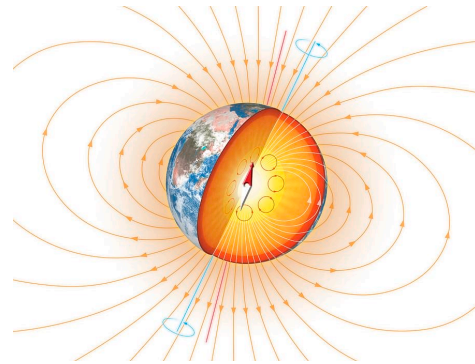
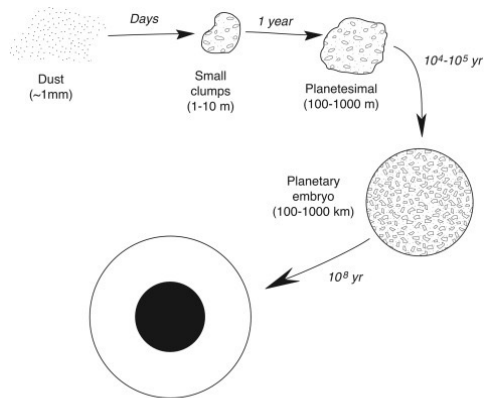
LGWA

A one/multi-billion question

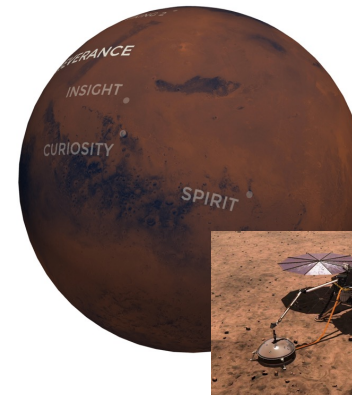
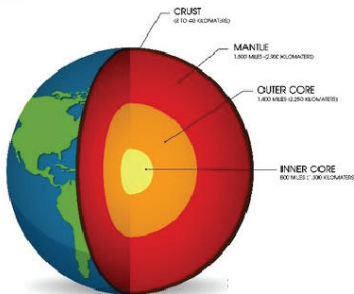
Urgent need for the study of planetary interiors

Vs.

Extremely expensive and challenging planetary facilities



Understanding the formation and evolution of planetary bodies, surface-interior interactions for habitability and resource exploration....

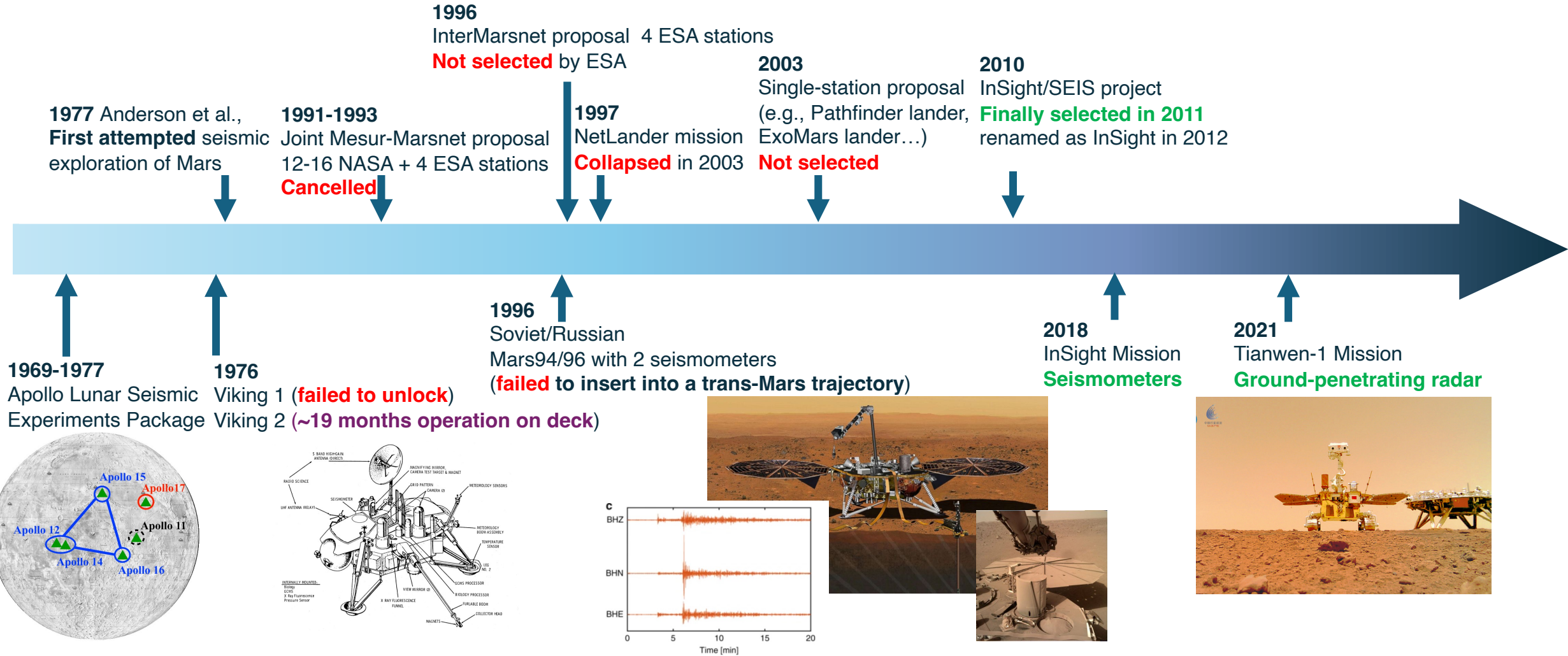


Aircraft Development	\$596.3 million
Lift Vehicle (Atlas V 401)	\$163.4 million
Science Operations (2 years)	\$53.9 million
U.S. Total	\$813.6 million
International Contributions	\$180 million
Total	\$993.6 million

The ~1 billion InSight station on Mars

(Lognonné et al., 2019; Banerdt et al., 2020; SEIS raw data, InSight Mission 2019; Mars Seismic Catalogue, InSight Mission 2022;)

Past Missions and InSight Pre-selection Efforts



Past Missions and InSight Pre-selection Efforts

It is unlikely the “astronomical” expenses and challenges in planetary missions will change in the coming decades or even within this century!



1969-1977
Apollo Lunar Seismic Experiments Package

1976

Viking 1 (failed to unlock)

1996

Soviet/Russian

Mars94/96 with 2 seismometers

(failed to insert into a trans-Mars trajectory)

2018

InSight Mission
Seismometers

2021

Tianwen-1 Mission
Ground-penetrating radar

How can we use the extremely limited (or even a single) planetary instruments to illuminate planetary interiors?

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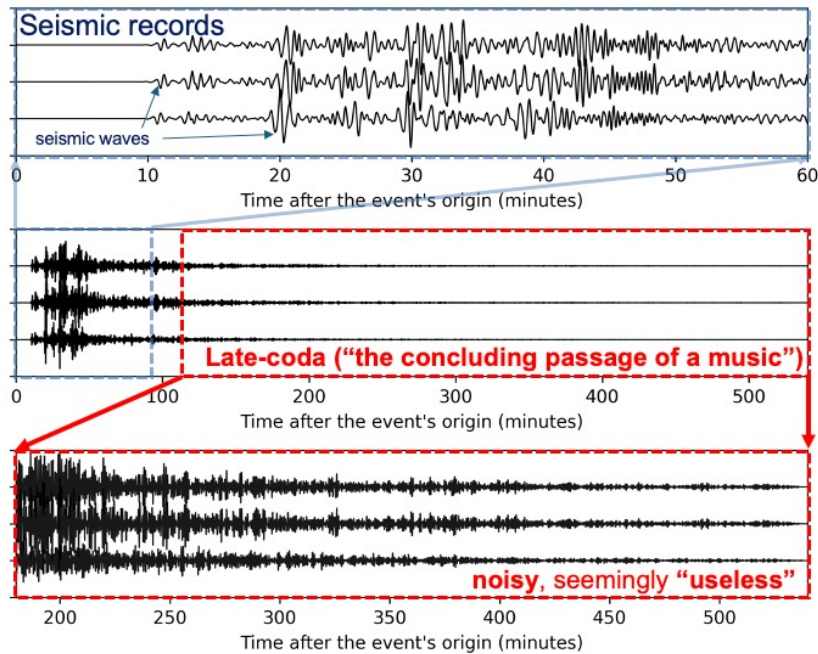
Ground-penetrating radar

How can we use the extremely limited (or even a single) planetary instruments to illuminate planetary interiors?

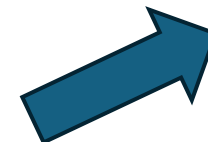
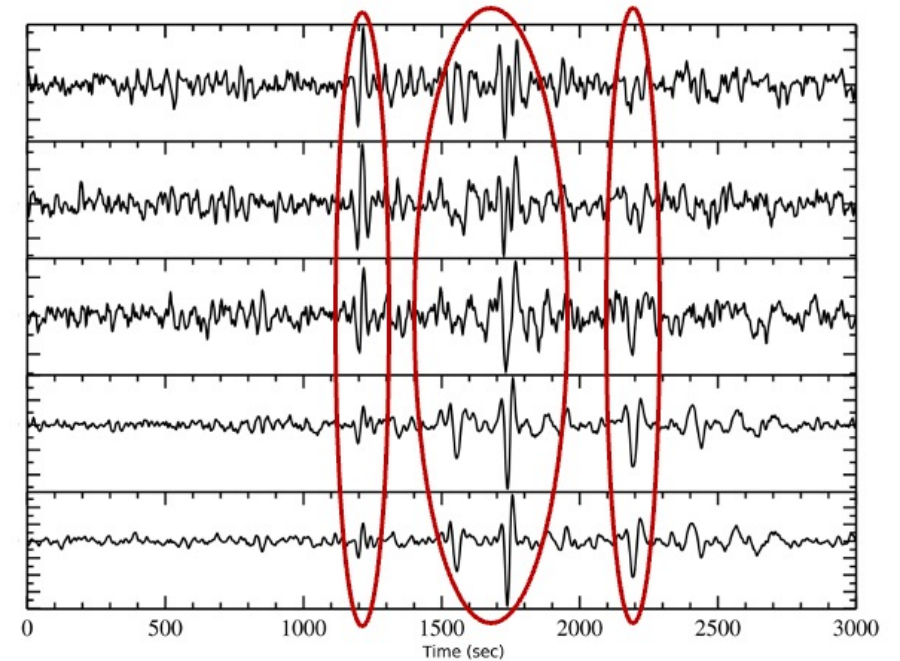
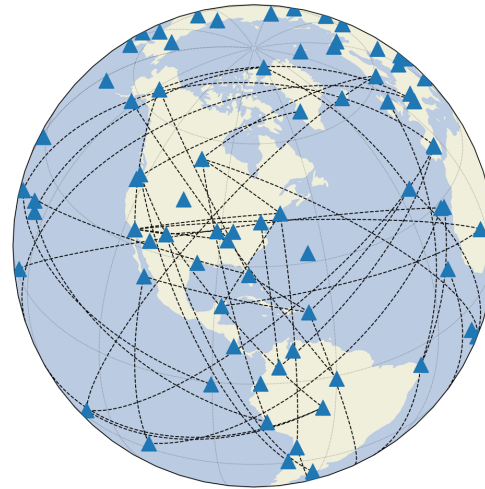
“A Way Out: Global Inter-Source Correlations”

Global inter-source correlation

Global inter-source correlation ← Global inter-receiver correlation

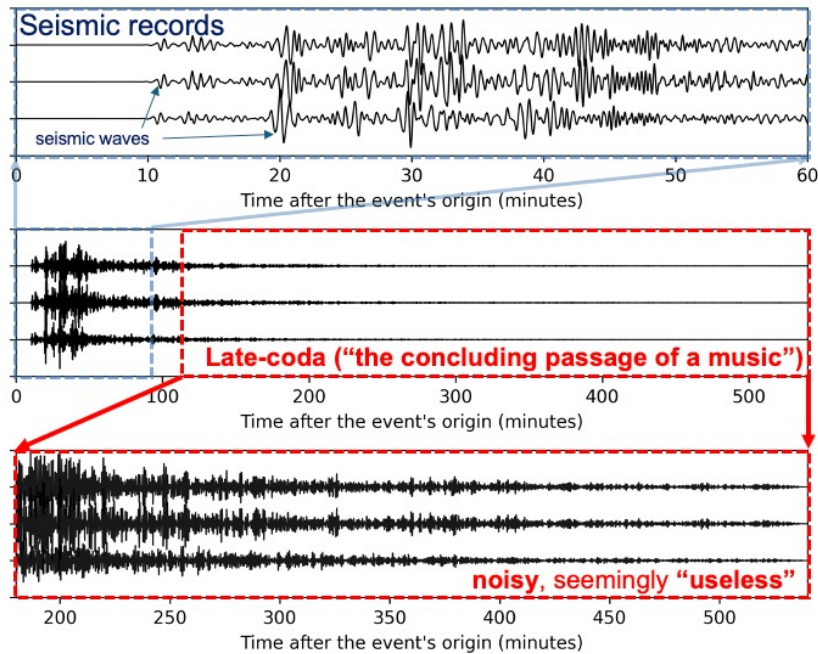


Seismic event late coda

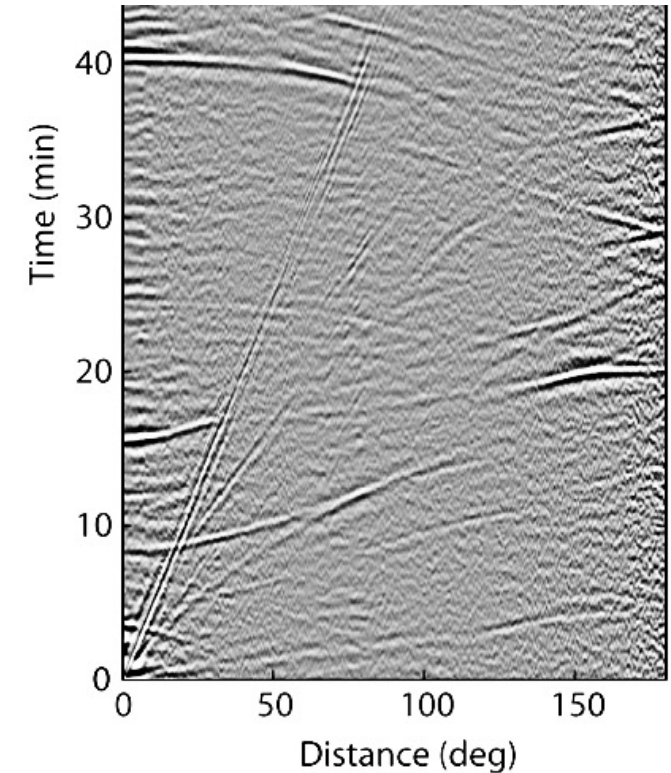
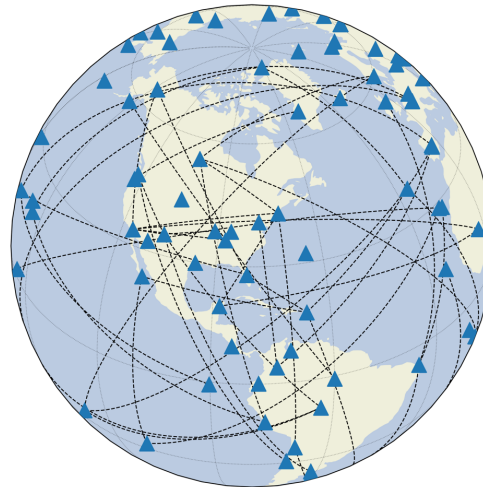


(Boué et al., 2014; Lin and Tsai, 2013; Nishida, 2013; Phạm et al., 2018; Poli et al., 2017; Wang et al., 2015;)

Global inter-source correlation ← Global inter-receiver correlation

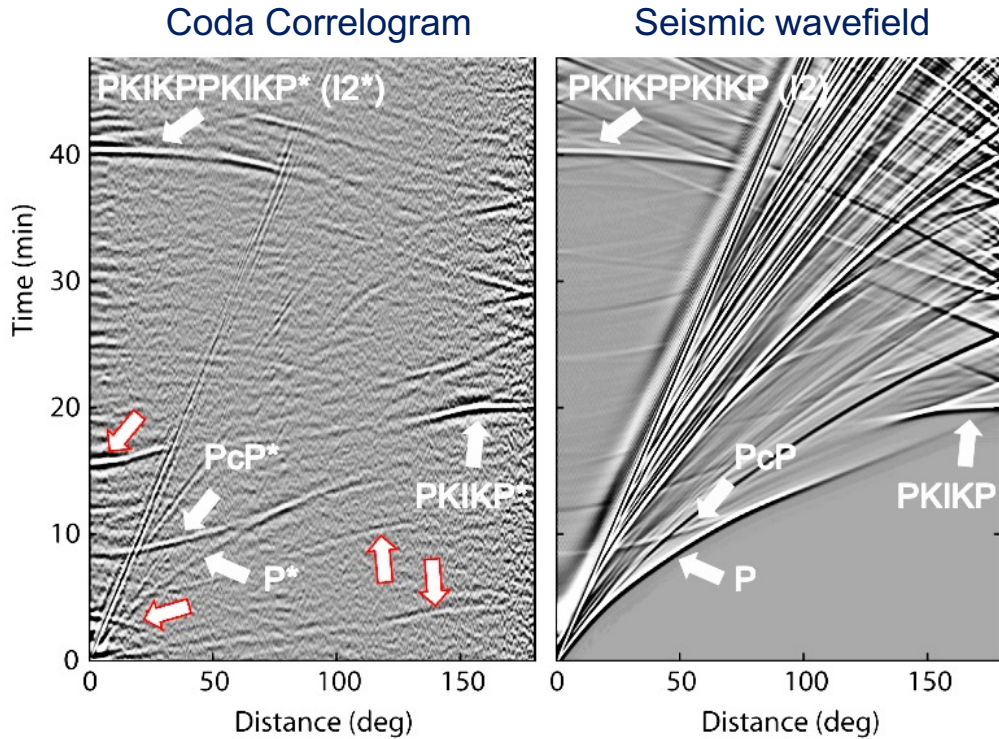


Seismic event late coda

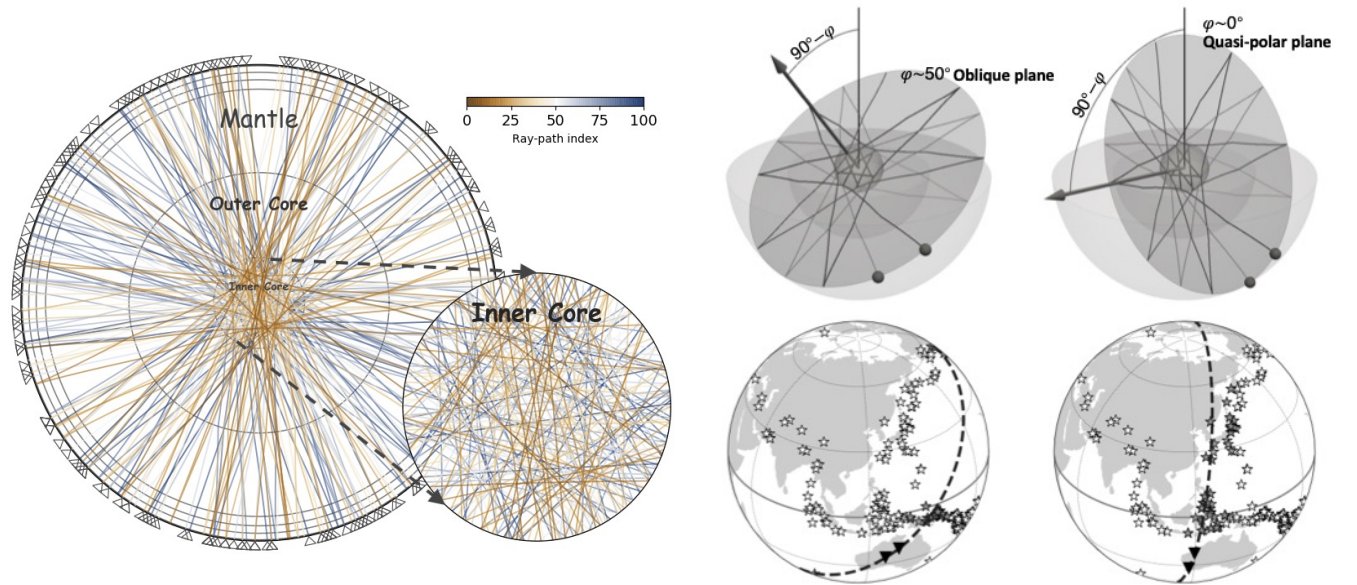


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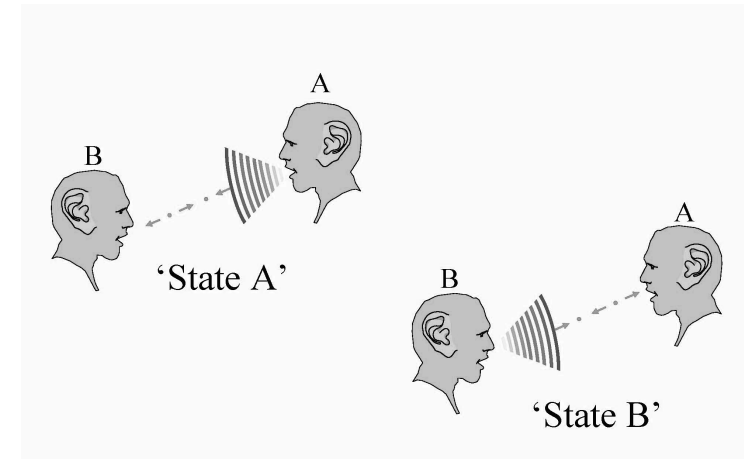
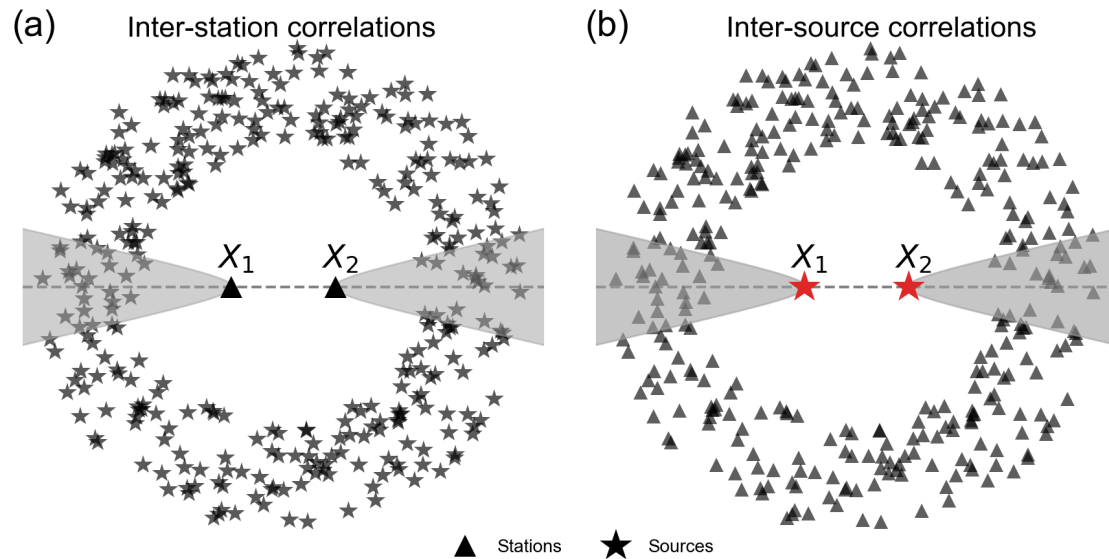
Global correlation features **are not** reconstructed seismic waves!



Earthquake-coda tomography boosts illumination of the deep Earth
&
Observation of shear wave anisotropy in the Earth's inner core

Global inter-source correlation \leftarrow Global inter-receiver correlation

- The principle of cross correlation can be extended to the correlations between sources – *inter-source correlations*.

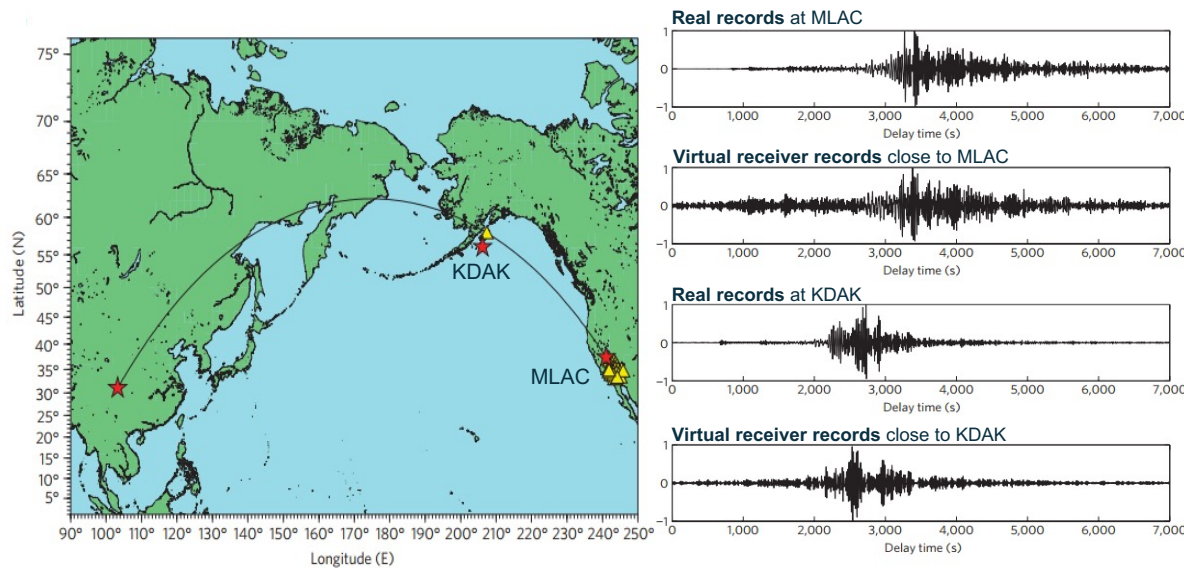


$$G(t; x_A \rightarrow x_B) = G(t; x_B \rightarrow x_A)$$

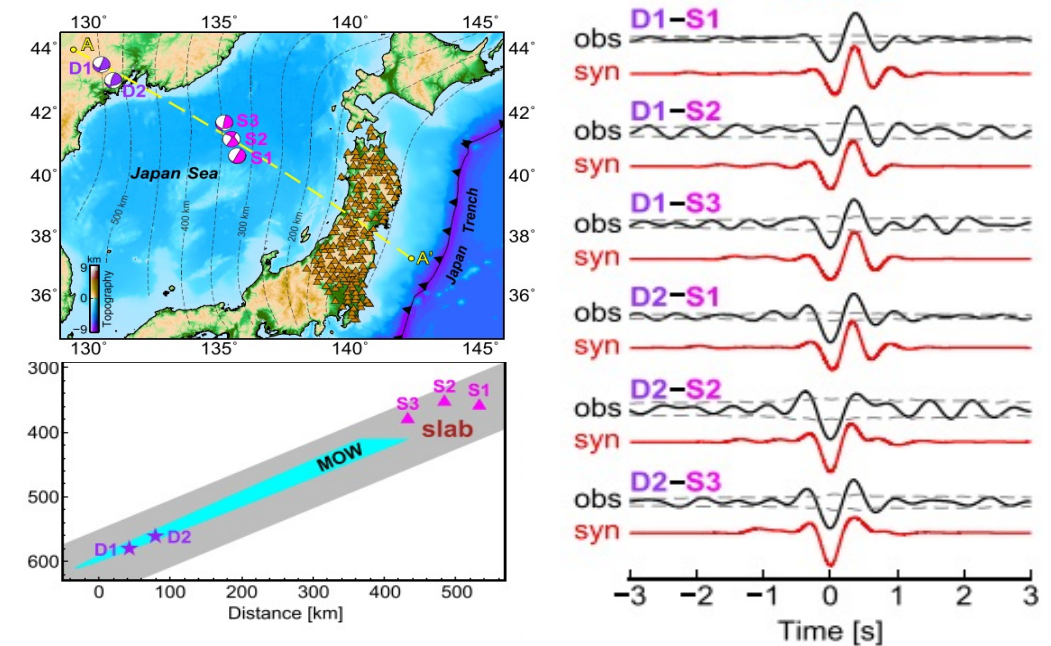
Reciprocal Theorem: *Exchanging the locations of the source and the receiver does not alter waveforms.*

Virtual receivers via inter-source correlations

- Form virtual seismometers in areas where no seismometers are deployed.
- Allows for a recovery of subsurface structure via avoiding the influence of near-surface heterogeneities.



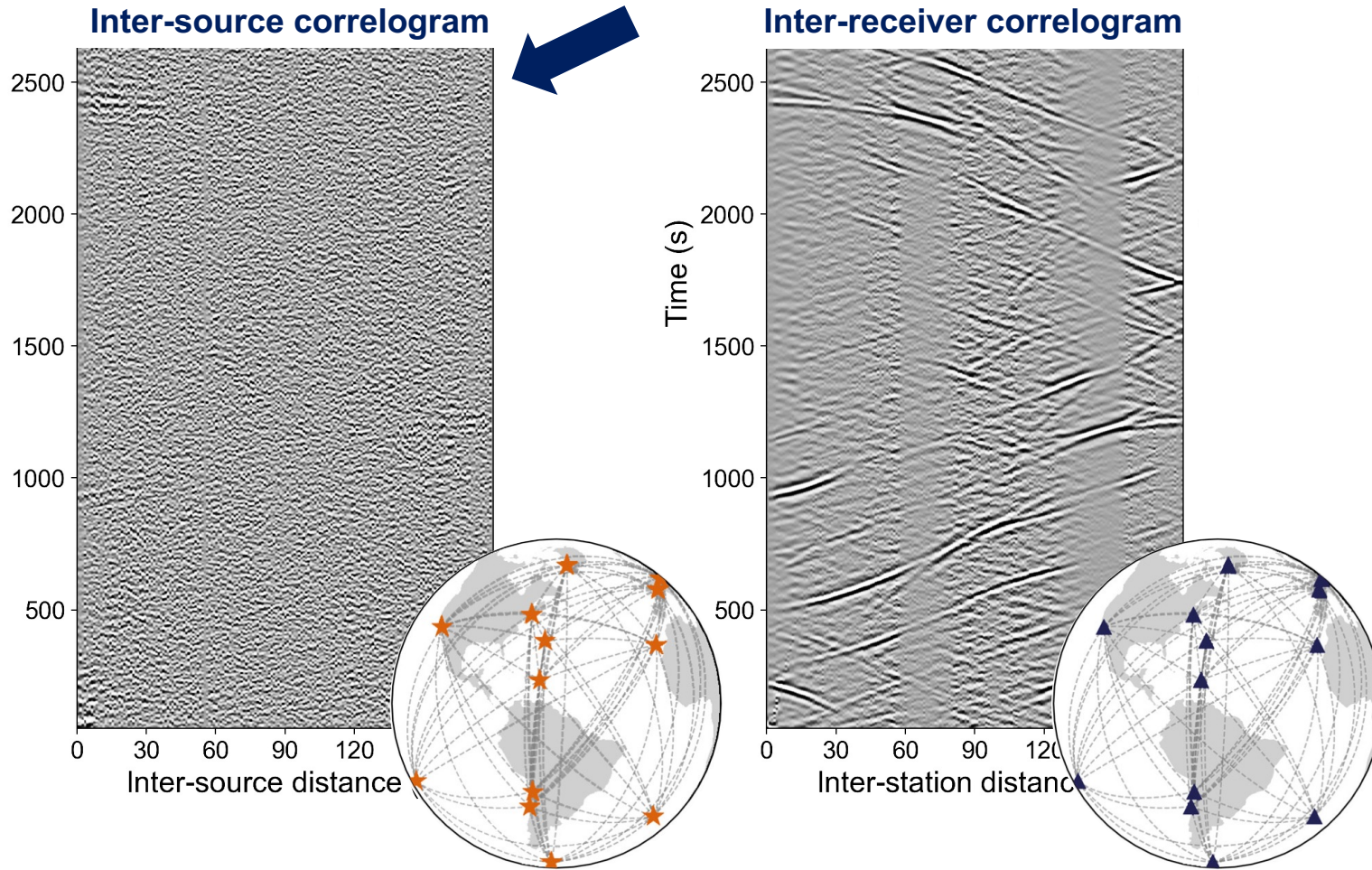
(Curtis et al., Nature Geoscience, 2009)



(Shen and Zhan, GRL, 2020; Shen et al., GRL, 2021)

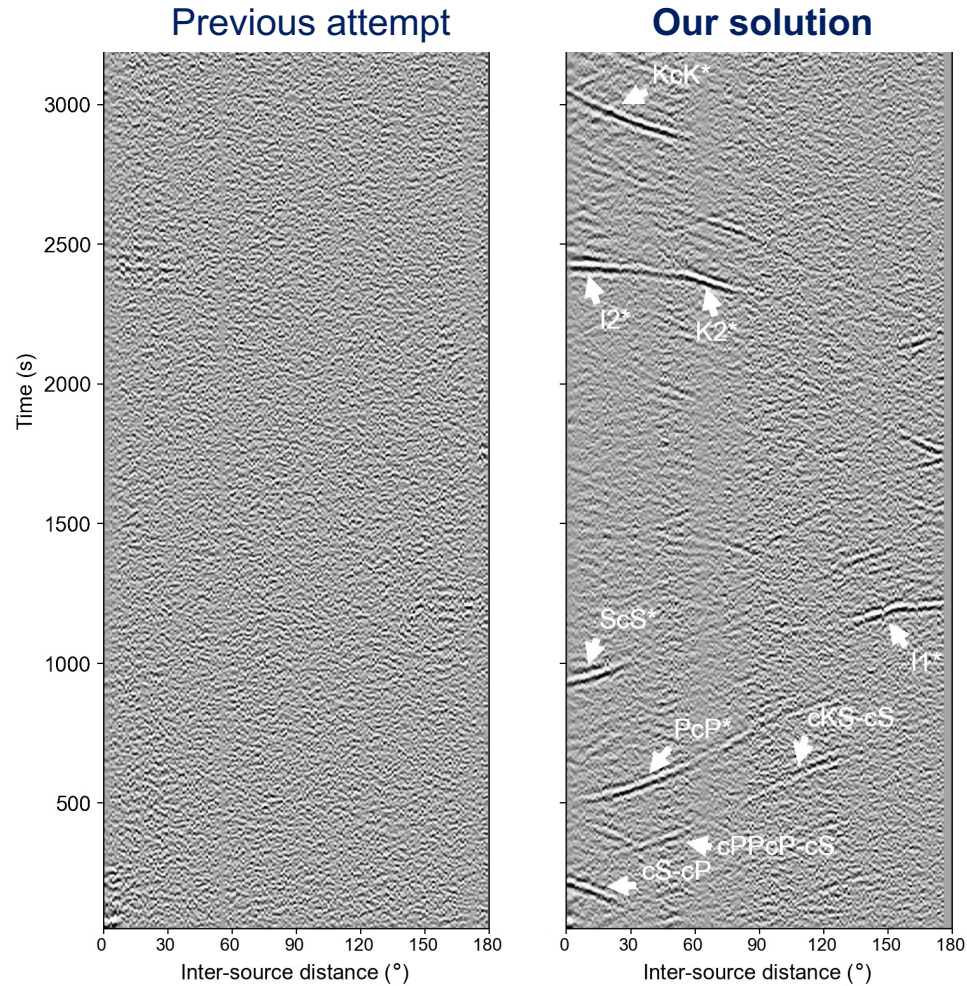
There are very limited inter-source correlation/interferometry publications/reports!

However...



- **No inter-source correlation feature exists!**
- **Realistic global inter-source observation contradicts theoretical expectations!** (Inter-source correlogram should resemble the inter-receiver one.)

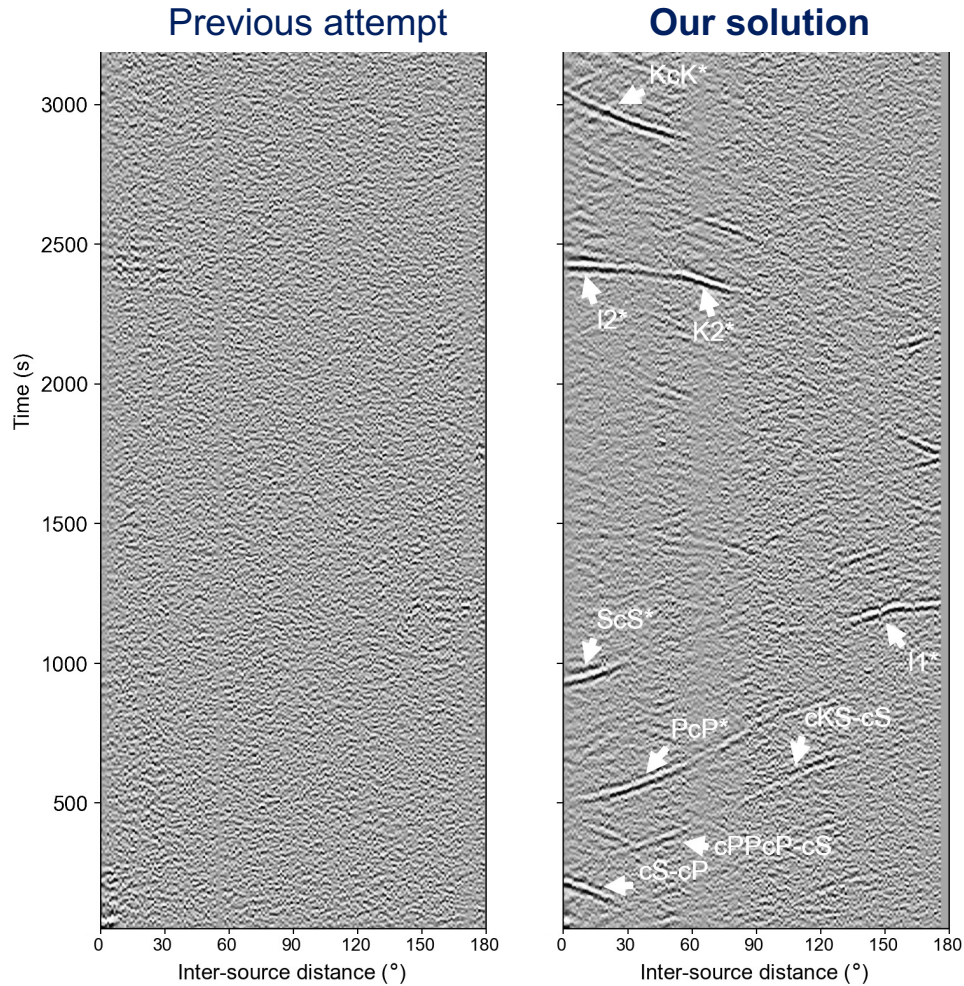
Solution



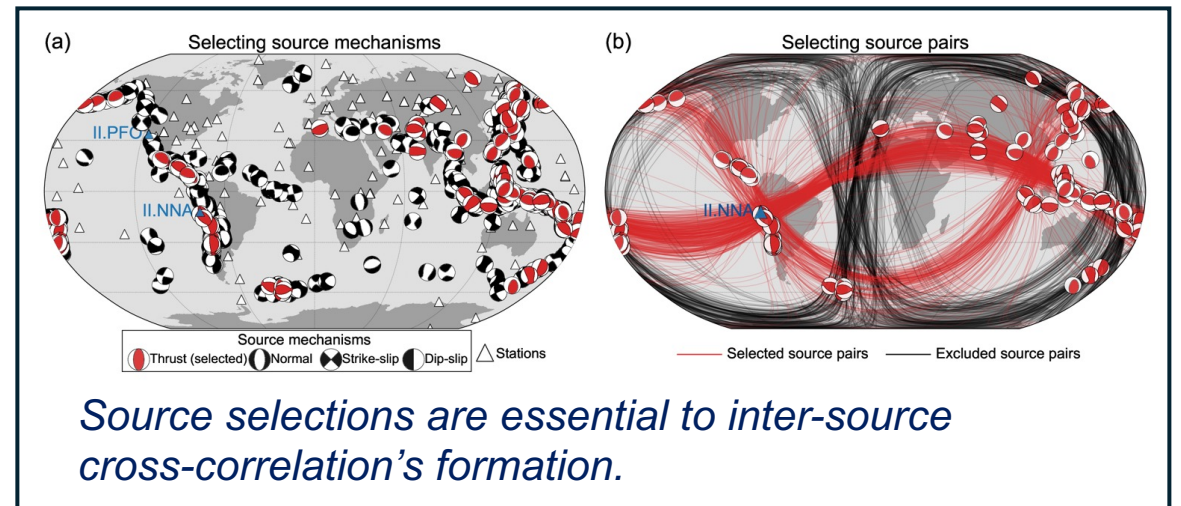
- *Multiple inter-source correlation features emerge!*
- *The problem is **solved!***

(Wang and Tkalčić, JGR-SE 2023)

Solution



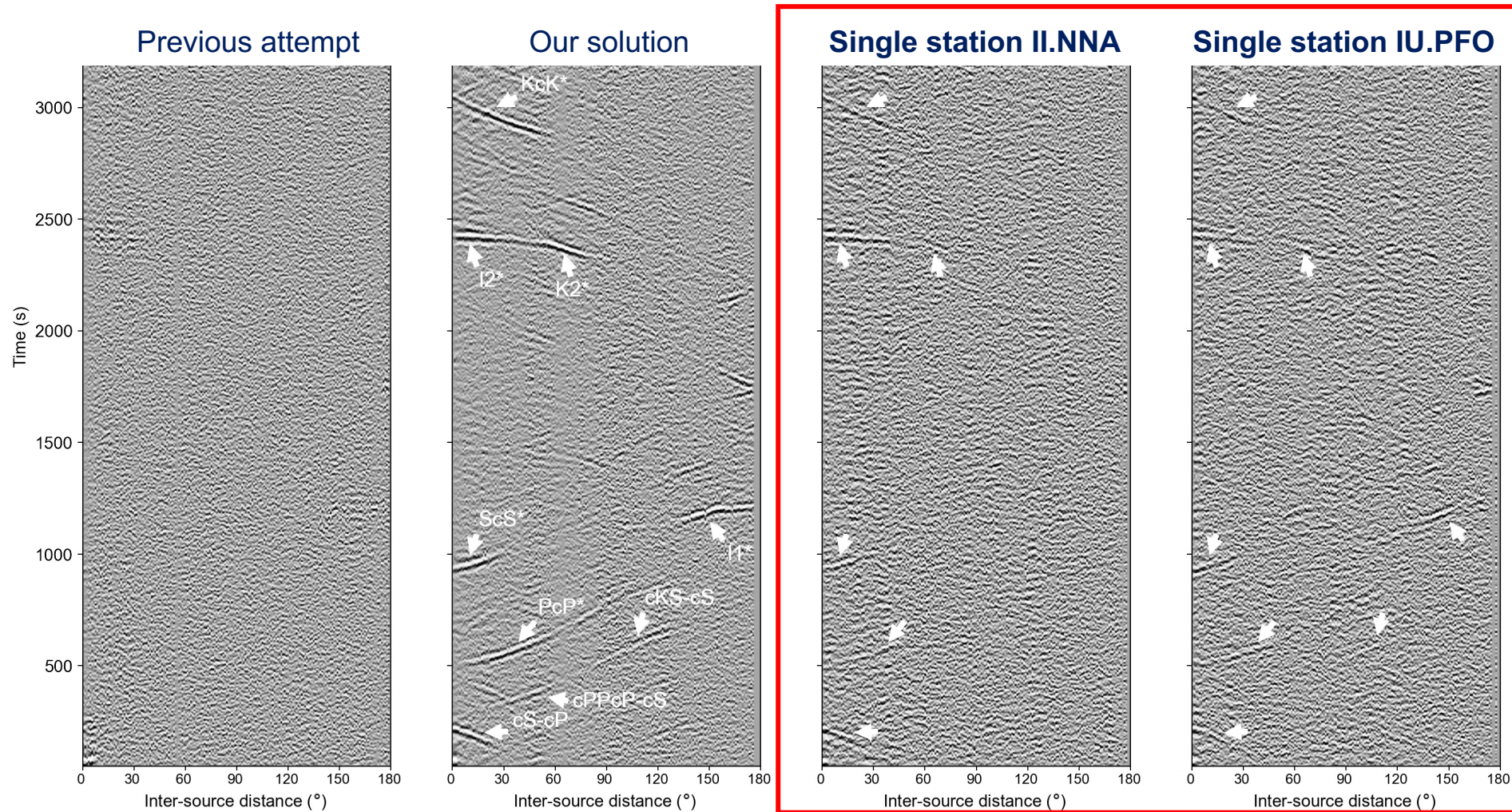
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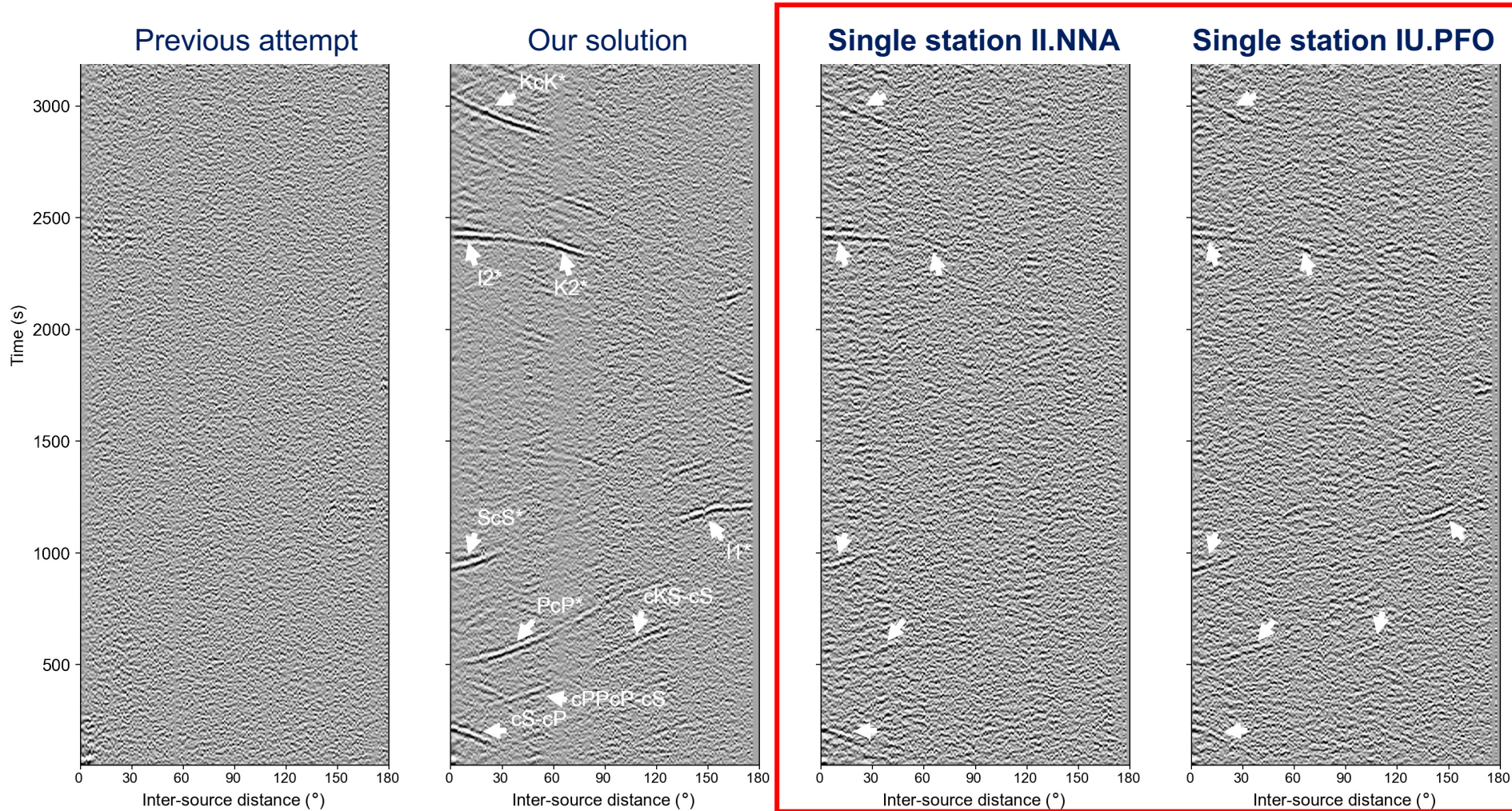
(sheng.wang@eaps.ethz.ch)

Single-station inter-source correlation



A single station is sufficient for forming global correlograms!

Single-station inter-source correlation



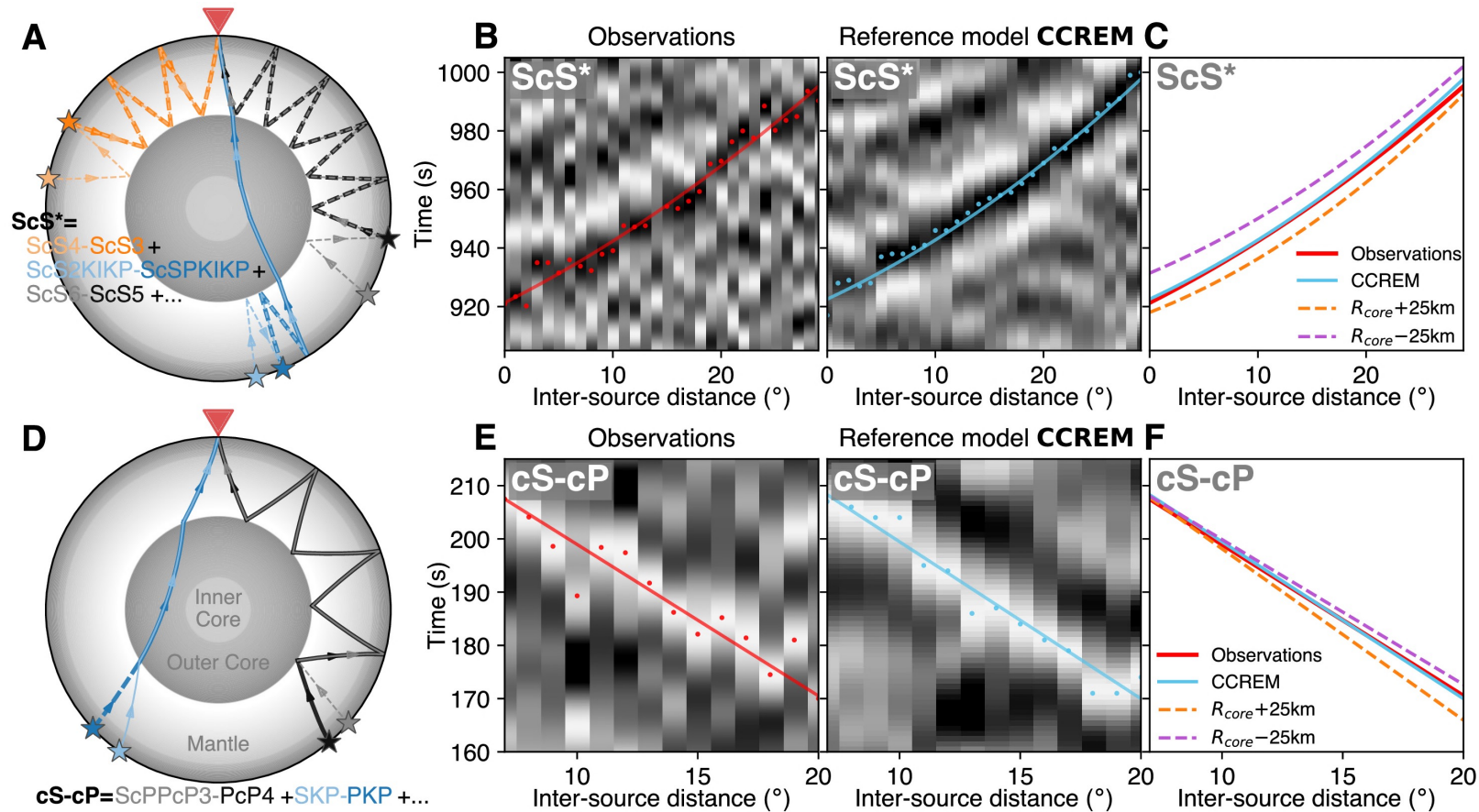
We can use the single-station correlogram:

- the appearance of different correlation features;
- the timing, amplitude, distance-time relationship of the correlation features;

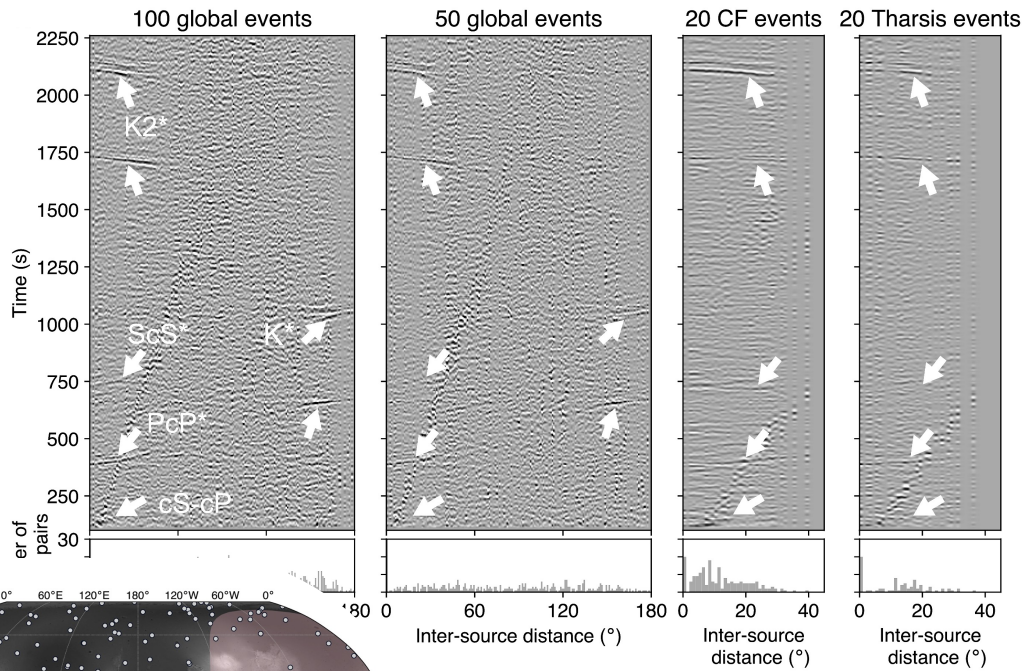
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Single-station Probing of the Earth's interior

- The single-station correlation features, ScS^* , PcP^* , $cS-cP$ can be used to constrain the CMB depth.

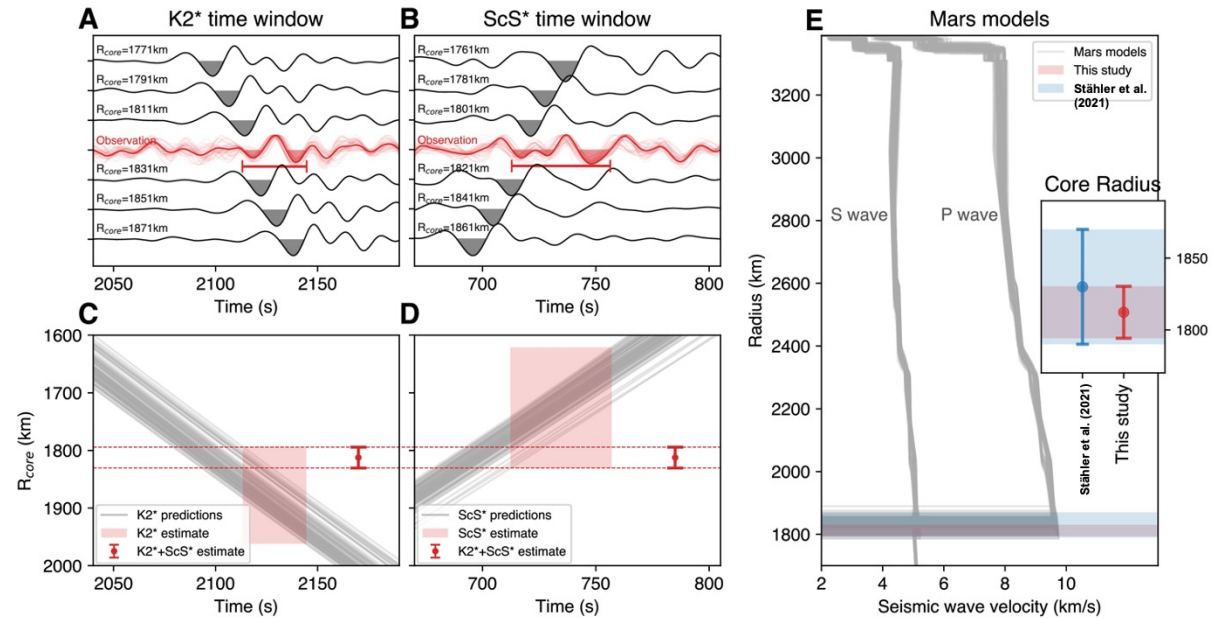


Single-station Scanning for the Martian core



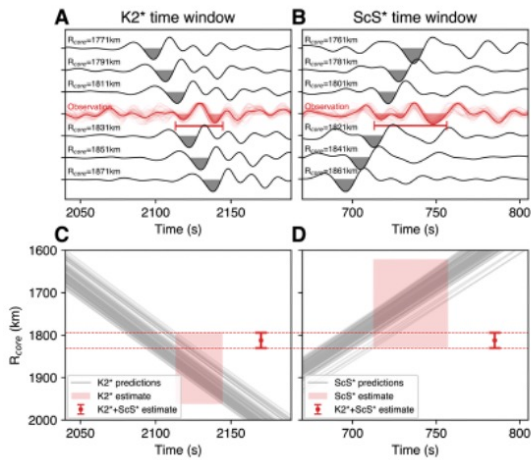
Synthetic single-station inter-marsquake correlograms

(Wang and Tkalčić, Nature Astronomy, 2022)

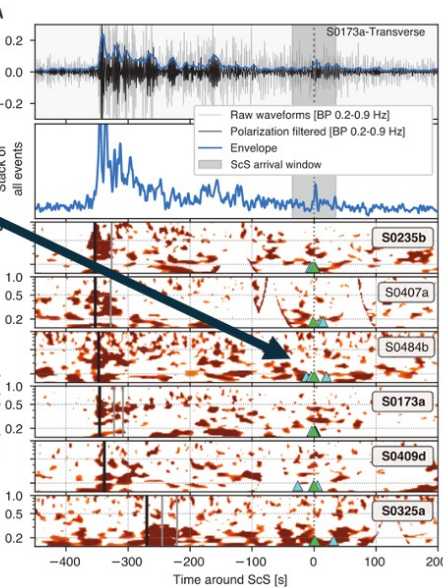
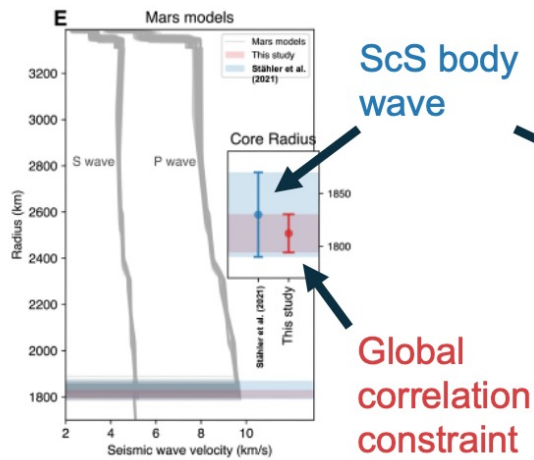


Scanning for the existence of the Martian core and its radius size

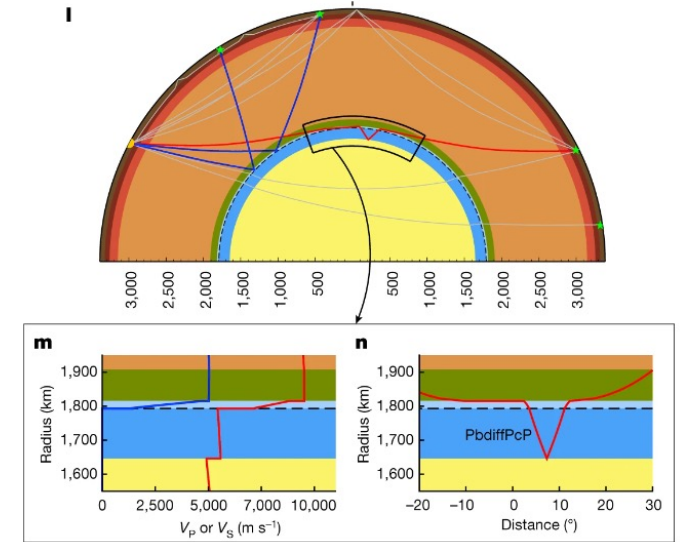
Single-station Scanning for the Martian core



(Wang and Tkalčić, Nature Astronomy, 2022)



(Stähler et al., Science, 2021)



(Samuel et al., Nature, 2023; Khan et al., Nature 2023)

What is next:

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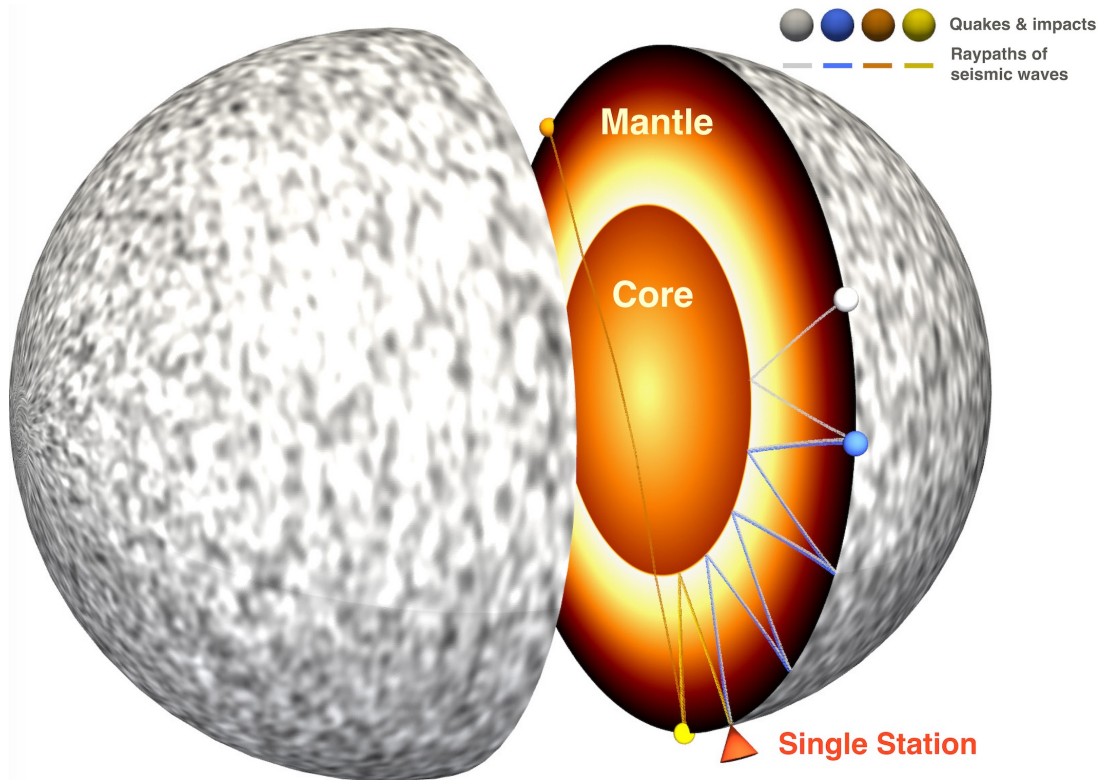
Single-station Illumination of  interiors



My research homepage

What is next:

Single-station Illumination of _____ interiors



- The observed global inter-source correlations have not exhibited the theoretical features; here, we resolve this problem;
- Global inter-source correlograms for a single receiver can be formed via the reciprocity principle and a rigorous selection of sources;
- A way out for single-station illumination of the interiors of planetary bodies with global inter-source correlations.

Thank you!
Questions and Comments!