

LGWA Meeting 2026
28 Sep—2 Oct, 2026, University of Liège

Modeling the Lunar Response to GW in the Era of China's Chang'E Mission

Xian Chen (陈弦)

Department of Astronomy, School of Physics, Peking University
& Kavli Institute for Astronomy and Astrophysics, Peking University

In collaboration with: Han Yan (PKU), **Lei Zhang (IGG-CAS)**, **Jinhai Zhang (IGG-CAS)**,
Mengyao Wang (BNU), **Fan Zhang (BNU)**, Lijing Shao (PKU)



2026 Sino-Europe Workshop on Lunar Gravitational Wave Detection

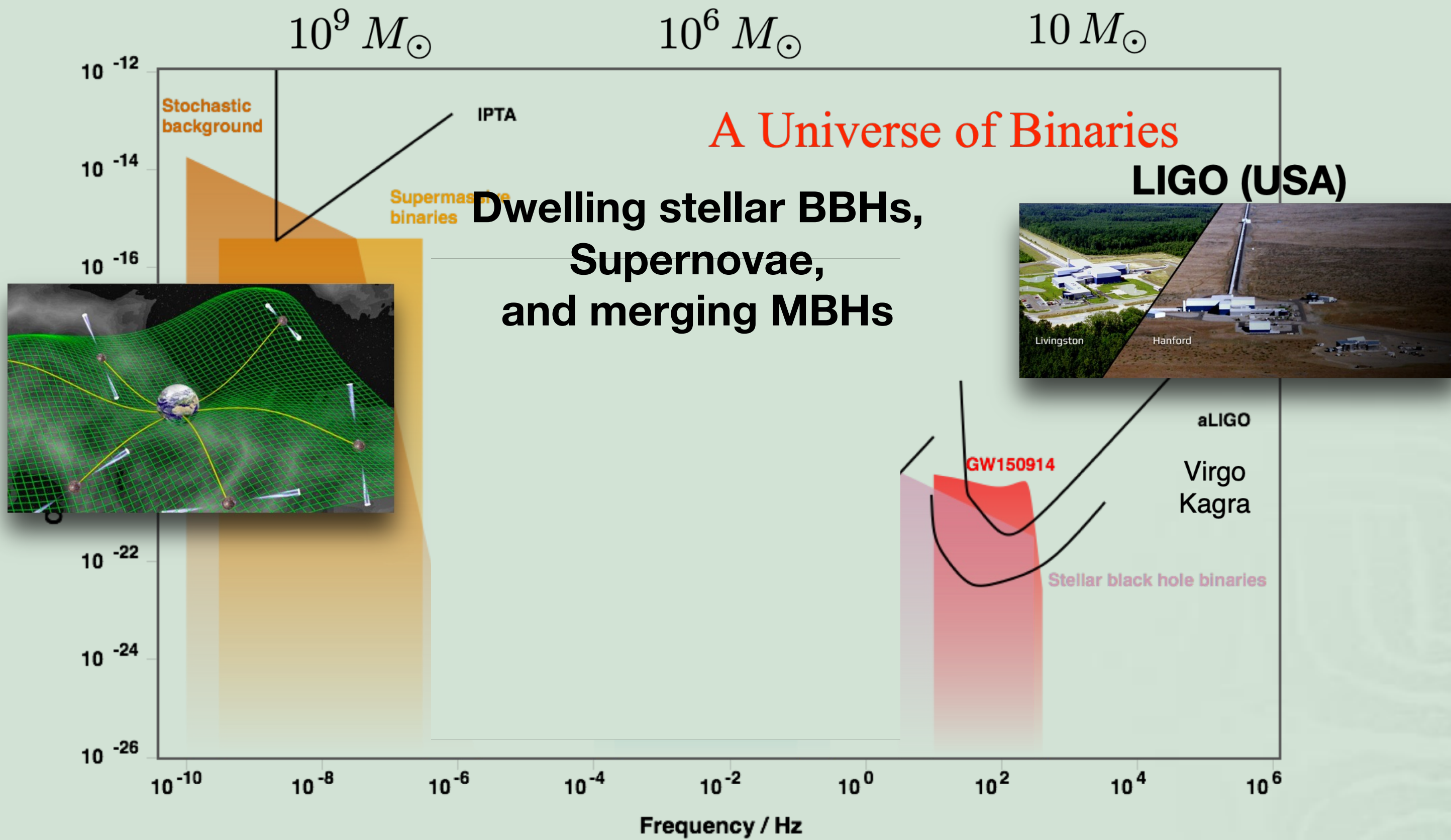
Dunhuang, China July 27, 2026



Prepare for **Chang'E 7** lunar seismology

Aiming for low frequency GW: 10^{-3} -1 Hz

Observational evidence of GW



$$f = \frac{1}{\pi} \sqrt{\frac{GM}{a^3}} \propto \frac{1}{M} \text{ because } a_{\min} \sim GM/c^2$$

CHINA'S CHOICES

Chinese researchers have proposed several ways to detect gravitational waves in space.

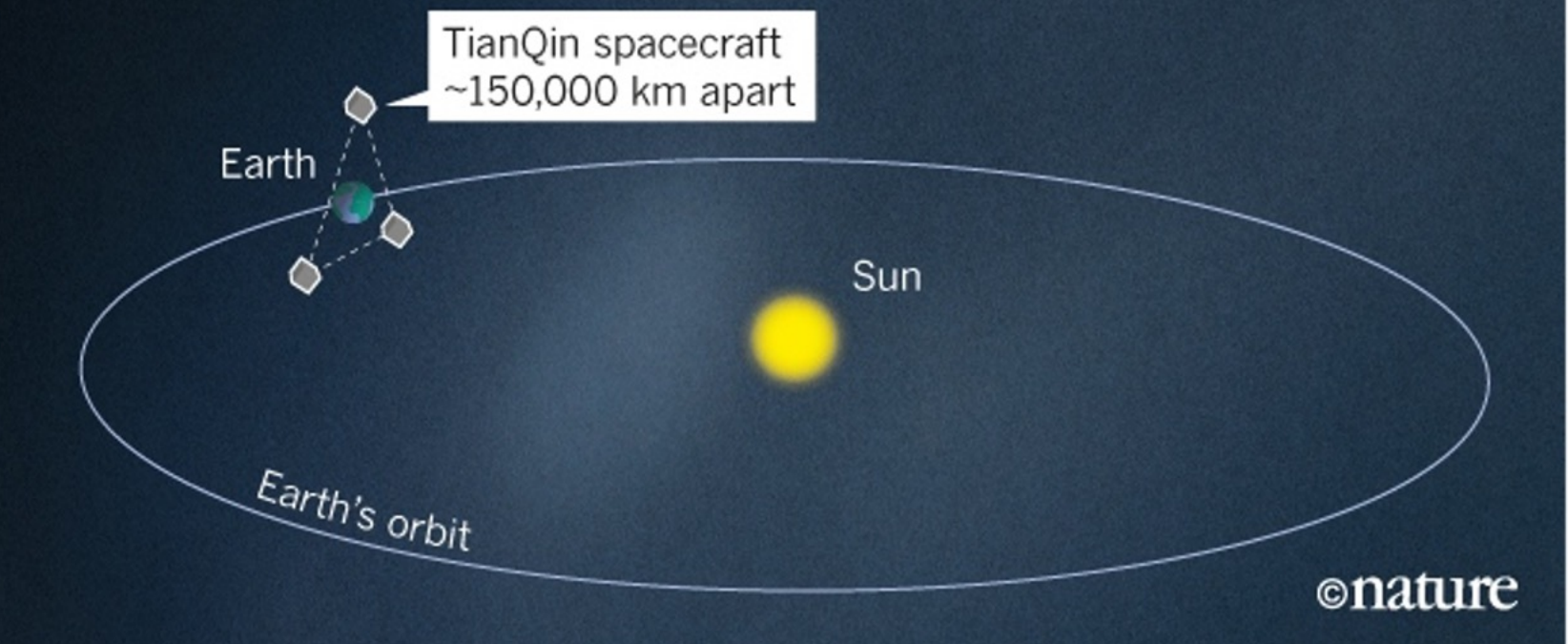
TAIJI

The most ambitious proposal uses three spacecraft in a triangle that orbits the Sun and detects gravitational waves from a range of objects, like Europe's eLISA proposal. The spacecraft are farther apart than in eLISA, giving Taiji access to different frequencies.



TIANQIN

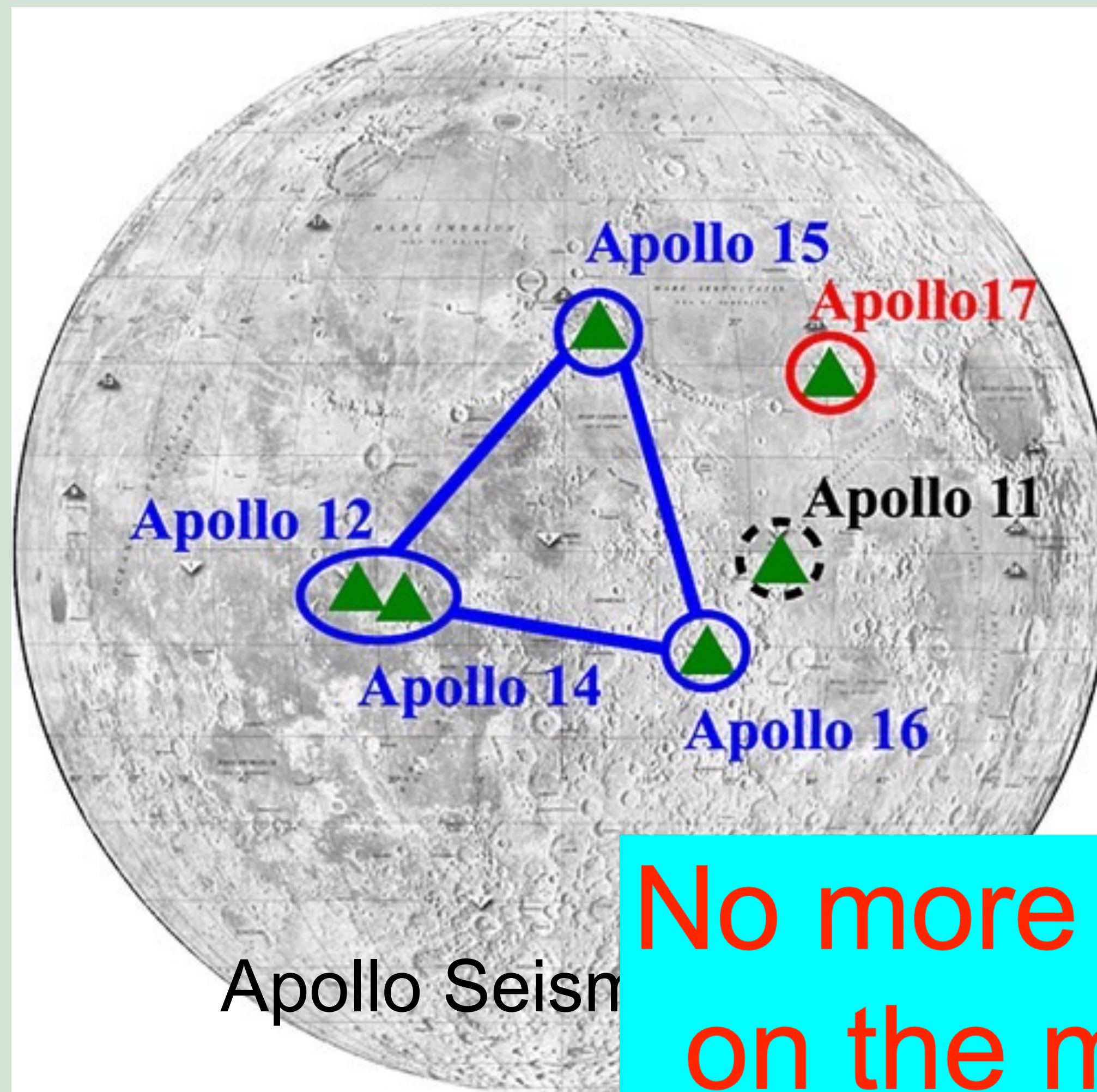
A cheaper proposal puts three spacecraft in orbit around Earth, and much closer to each other than in Taiji. This would target the gravitational waves emitted by HM Cancri, a pair of white dwarf stars.



History of GW experiments on the moon



- Idea proposed by Weber 1960 Physical Review, 117, 306
- Lunar Surface Gravimeter by Apollo 17 (Dec 1972)
- Apollo Seismic Array for GWs (Coughlin & Harms 2014 PRD)



12-2

APOLLO 17 PRELIMINARY SCIENCE REPORT

the lunar and terrestrial records should allow searches for simultaneous sudden surface accelerations. By delaying one recording relative to the other one, the rate of chance coincidences may be measured. A significant excess of zero-delayed as compared to time-delayed (chance) coincidences can establish the existence of correlations.

Experiments have been conducted in the kilohertz region using aluminum cylinder masses of several thousand kilograms that are isolated from terrestrial effects. The existence of such coincidences has been established using antennas at the University of Maryland and at the Argonne National Laboratory near Chicago, Illinois. The high frequency (seismic output) of the LSG will be compared with the records of the aluminum cylinder experiments in an effort to find numbers of coincident amplitude increases over and above the chance rate.

The LSG was also designed to measure the tidal effects on the Moon and to serve as a one-axis seismometer. The lunar orbit is slightly elliptical, and the Moon undergoes librations. For these reasons, the gravitational fields of the Earth and Sun sensed by a given part of the lunar surface will vary with time. This variation results in time-dependent tidal forces

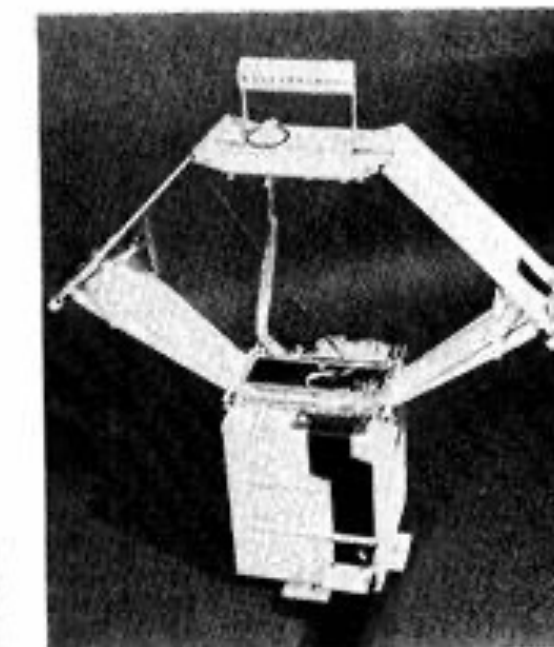


FIGURE 12-1. Lunar surface gravimeter.

See report by Giganti, Larson, Richard, Weber 1977

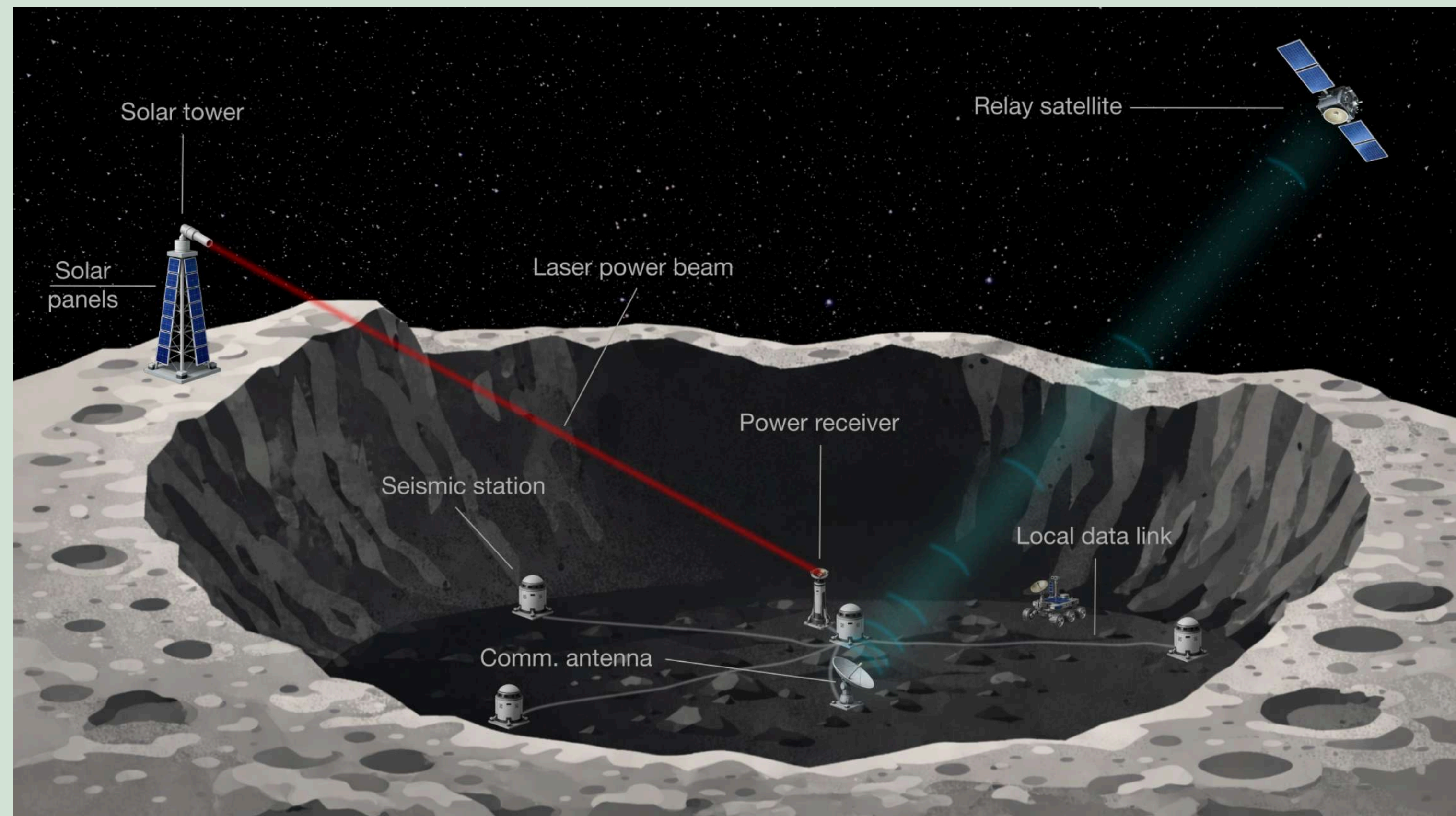
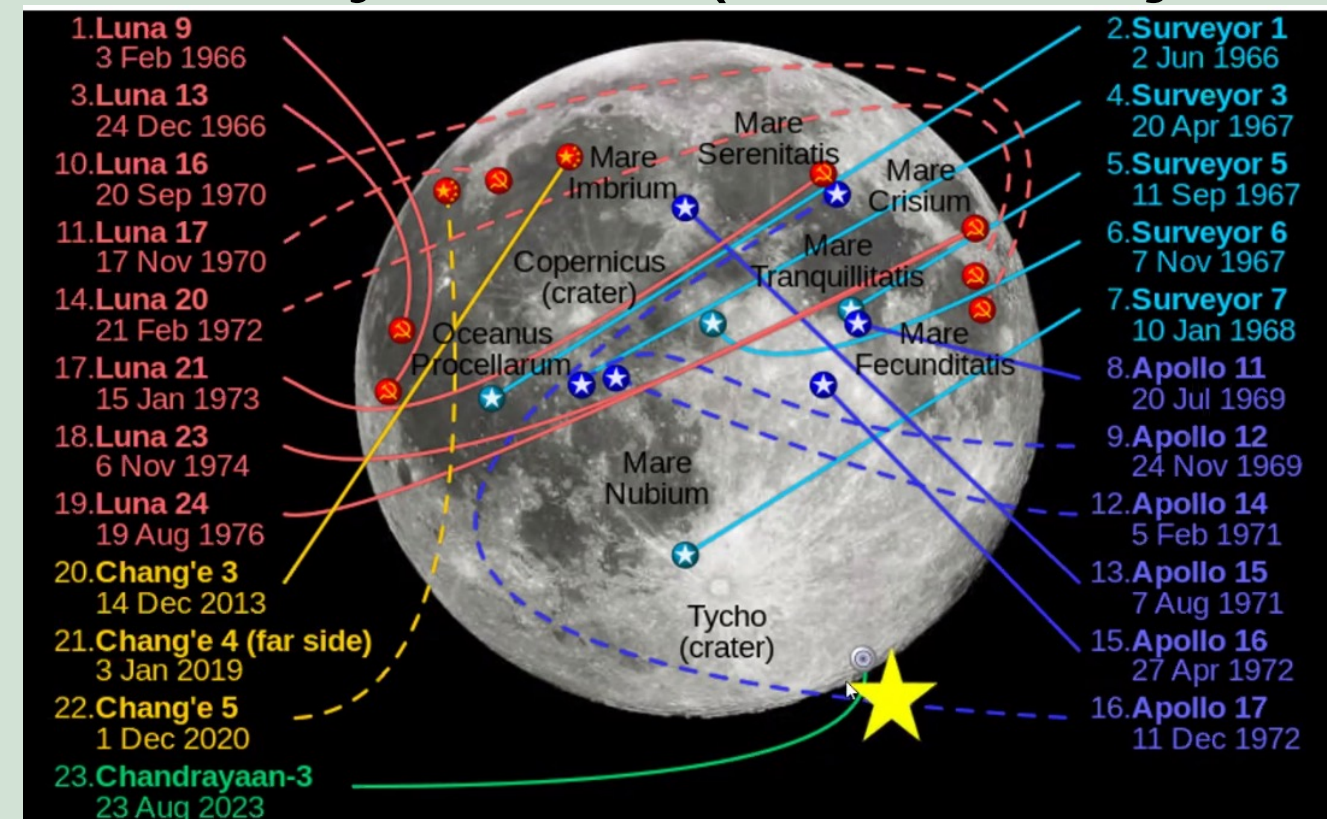


No more seismometer on the moon, until...



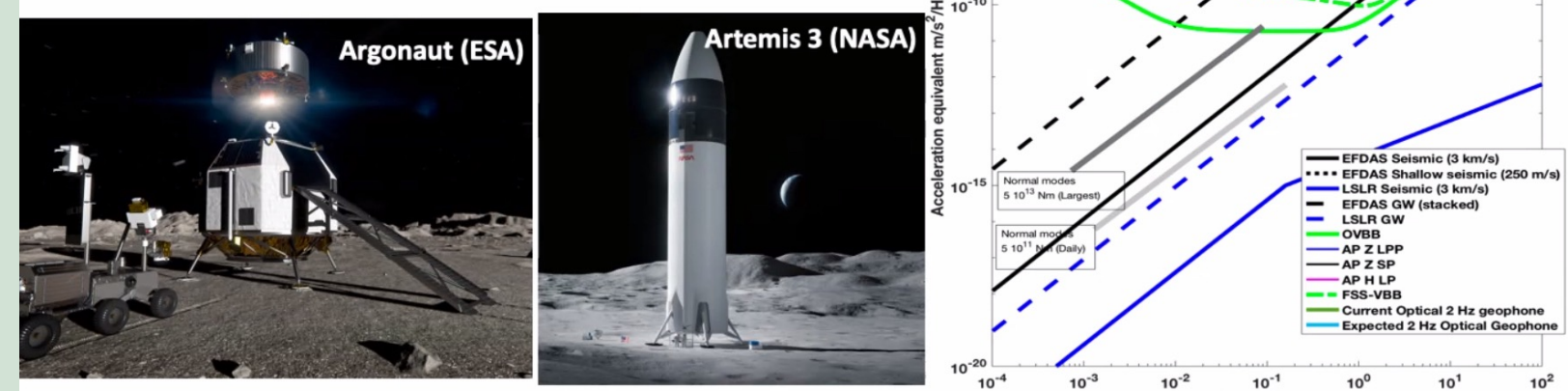
Lunar Seismometers in Development

Chandrayaan 3 (Credit: Jiju John)



Existing Opportunities

- NASA
 - Farside Seismic Suite: Launch previewed in 2025
 - Artemis 4
 - CLPS
- ESA
 - Argonaut (former European Large Logistics Lander): 2030s
- JAXA
 - LEAD: 2028
 - Mid-Class Lander: 2030s



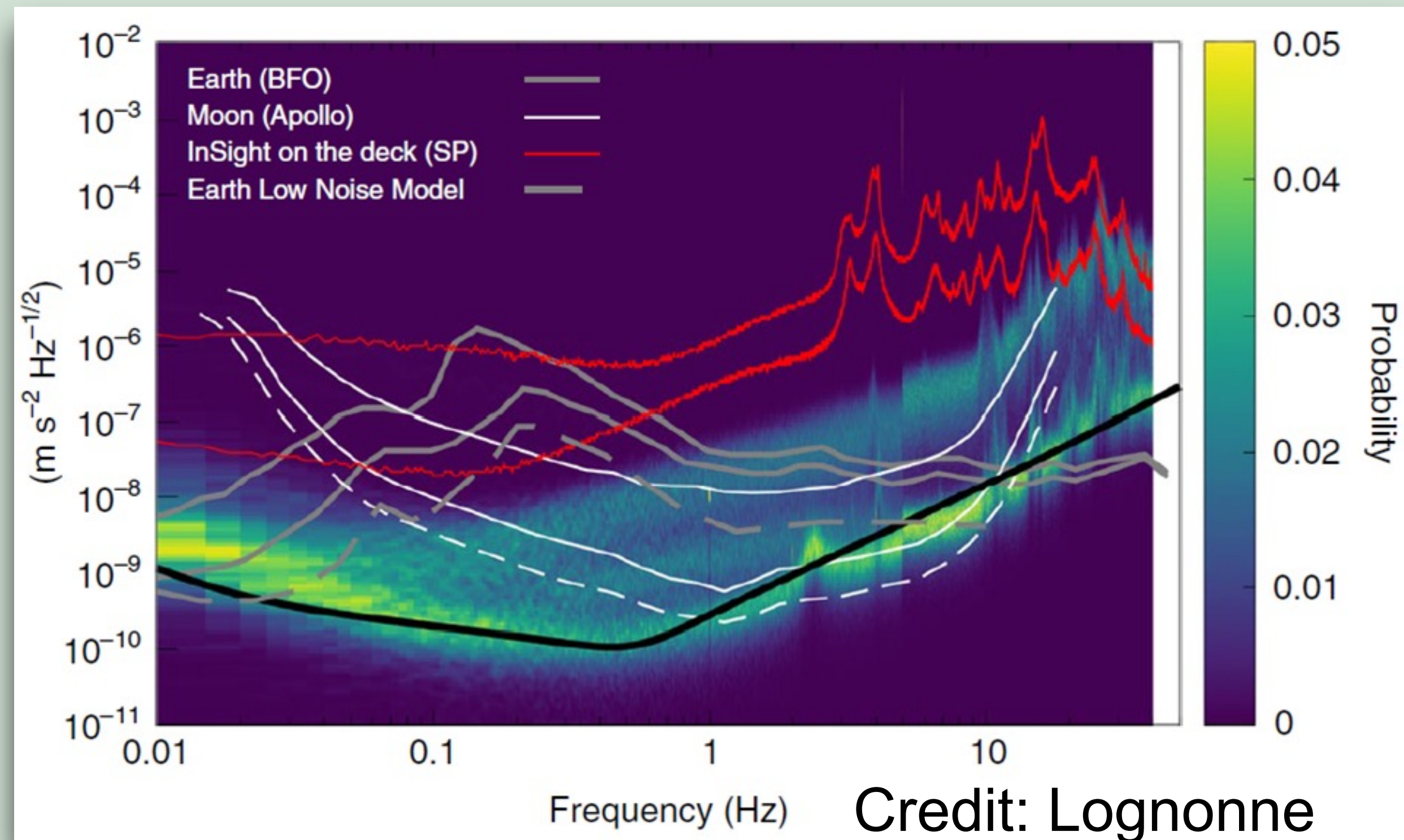
Lunar Gravitational Wave Antenna (LGWA)

Accelerometers, cryogenically cooled, 2035 ETA
(also see J. Harms et al. 2021 white paper)

Credit: Taichi Kawamura

Lunar Seismometers in Development

Chang'E-7 Mission (~2027)



**Urgent to study the
response of the moon!**

Chang'E-7 Seismograph (expected in 2026)

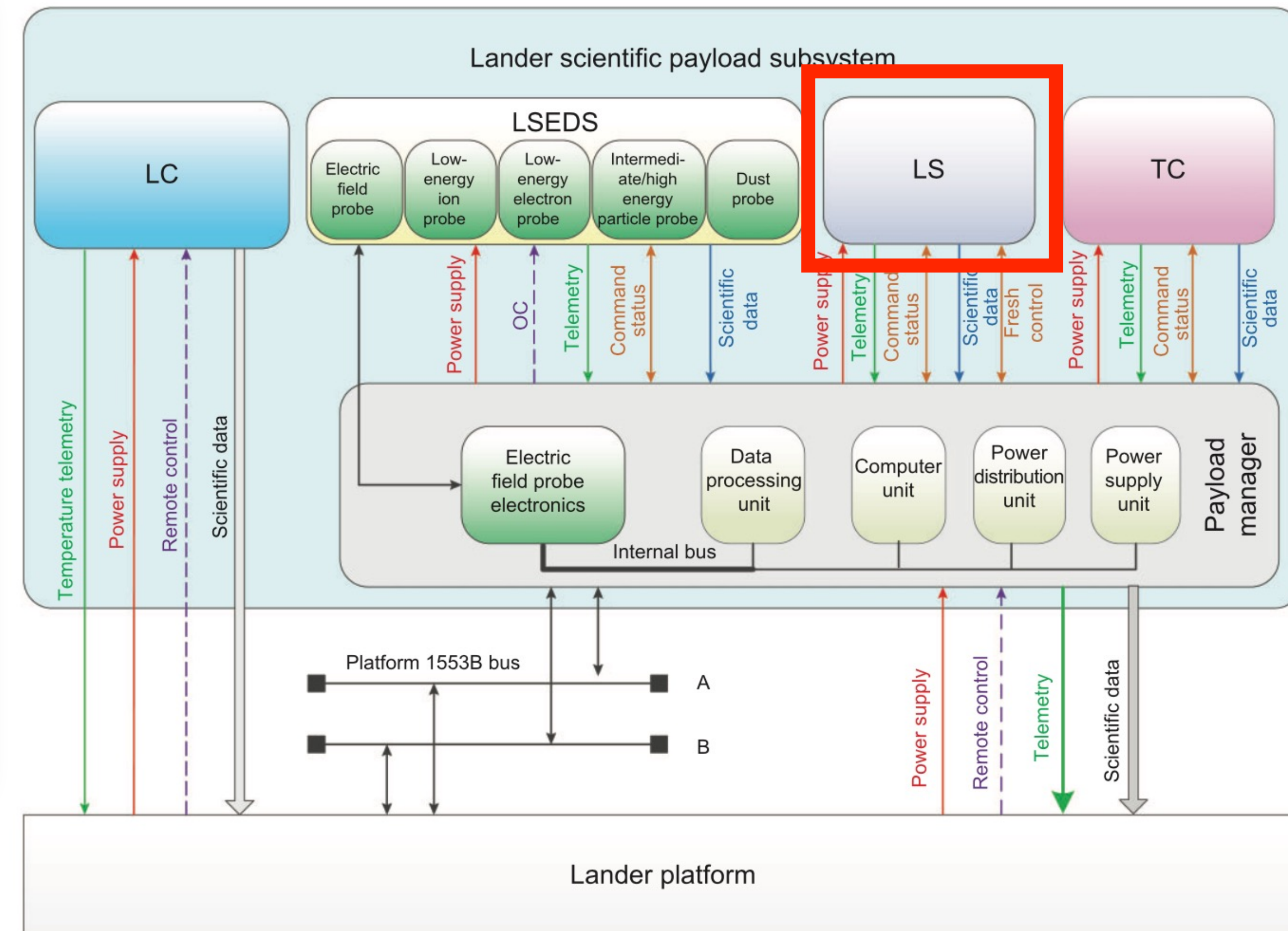
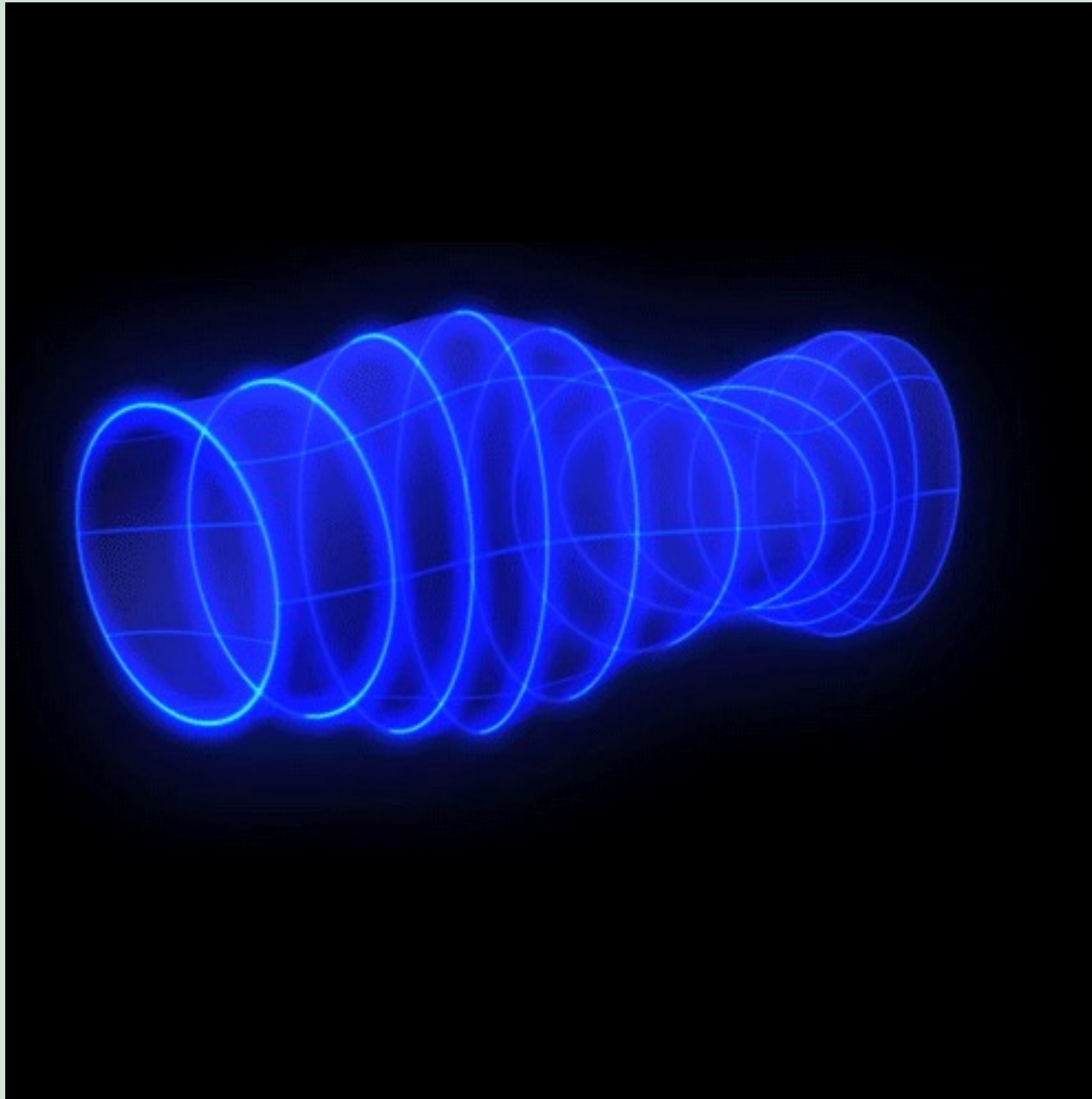


Fig. from Wang et al. 2024 Nation Science Review

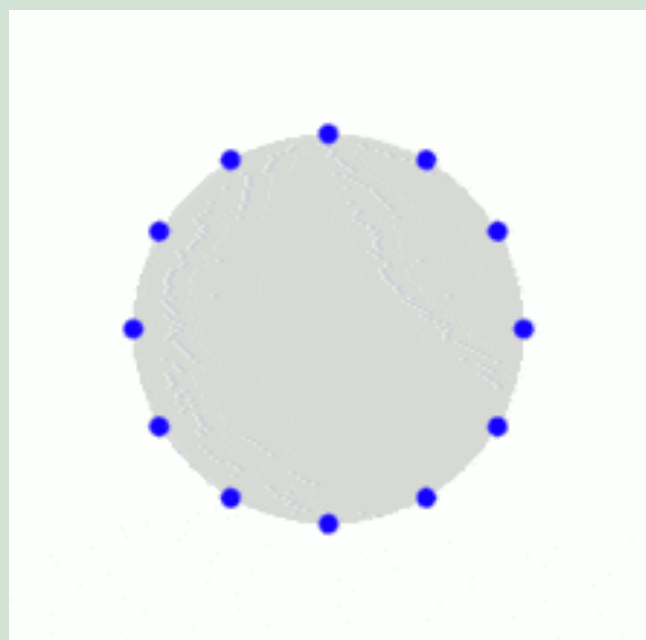
From Physical Picture to Theory



GW imposing on the moon
(0.1Hz ~ 3e6km >> 1750 km)



Basic Theory



Elastic body under forced vibration

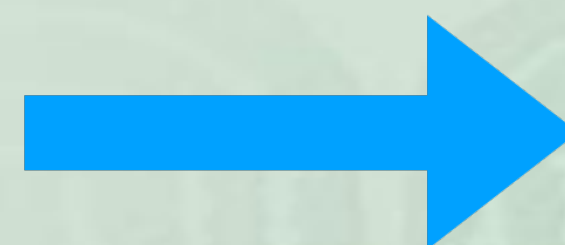
$$\rho \frac{\partial^2 \xi^i}{\partial t^2} = \frac{\partial \sigma^{ij}}{\partial x^j} + \text{GWStress}$$

Two views:

- TT coordinate: (**A**) not change, metric changes

$$ds^2 = (\eta_{\mu\nu} + h_{\mu\nu}^{TT}) dx_A^\mu dx_A^\nu$$

geodesic eq.: $\frac{\partial^2 x_A^i}{\partial t^2} = 0$



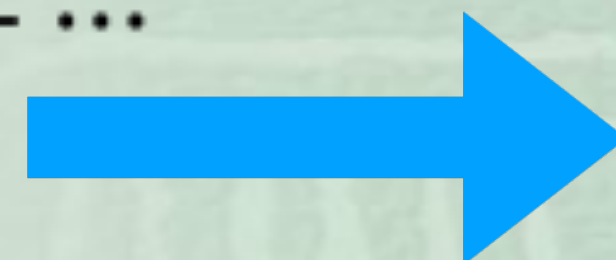
From Dyson 1969, or “Dyson force”

$$\vec{f}_A = \nabla \cdot \left(\mu \vec{\dot{h}} \right)$$

- Lab coordinate: (**B**) changes, metric not change

$$ds^2 = \eta_{\mu\nu} dx_B^\mu dx_B^\nu + O(1) \times (R_{\mu l \nu m} x_B^l x_B^m) dx_B^\mu dx_B^\nu + \dots$$

geodesic eq.: $\frac{\partial^2 x_B^i}{\partial t^2} = \frac{1}{2} \ddot{h}_j^i x_B^j$

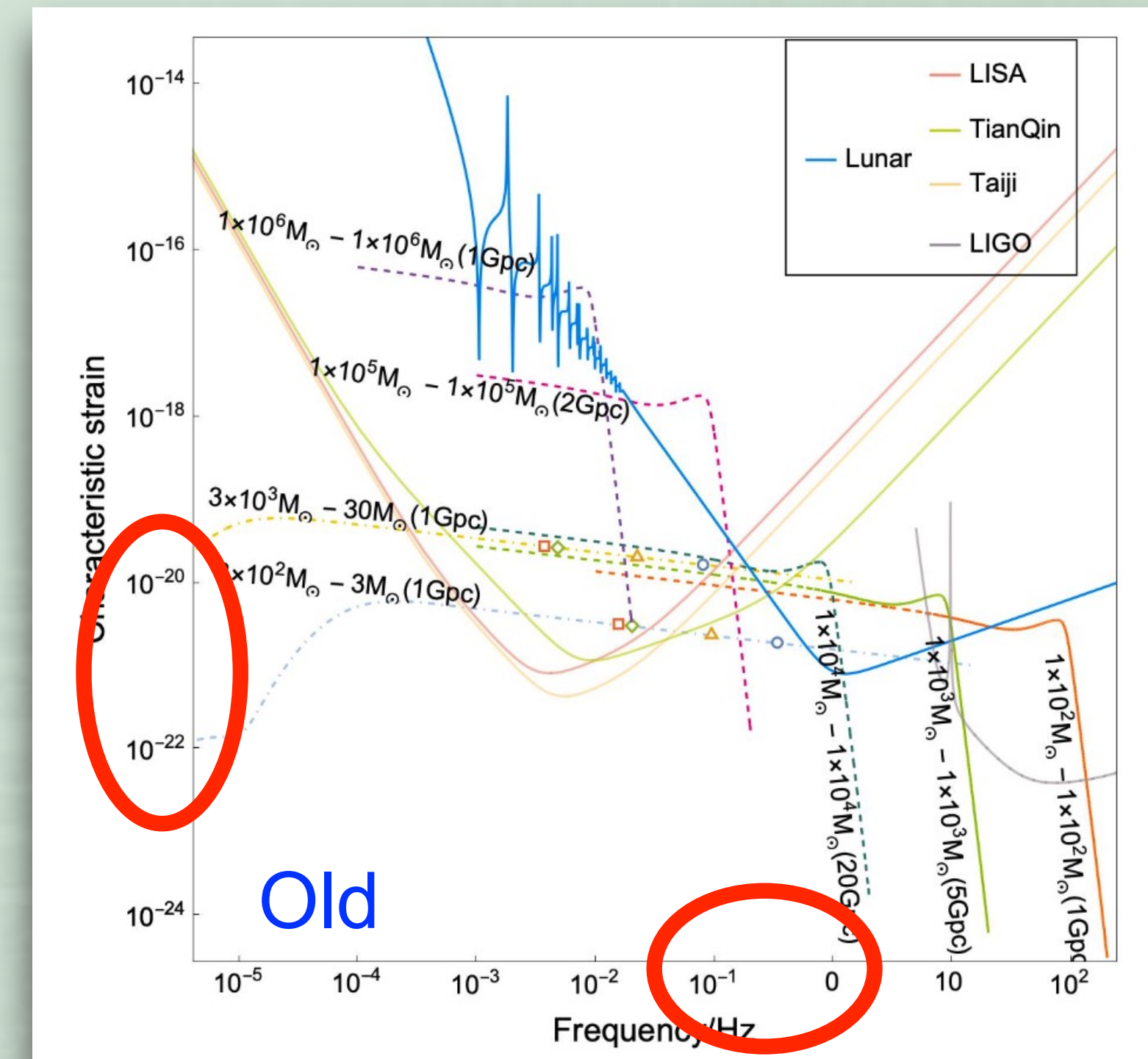
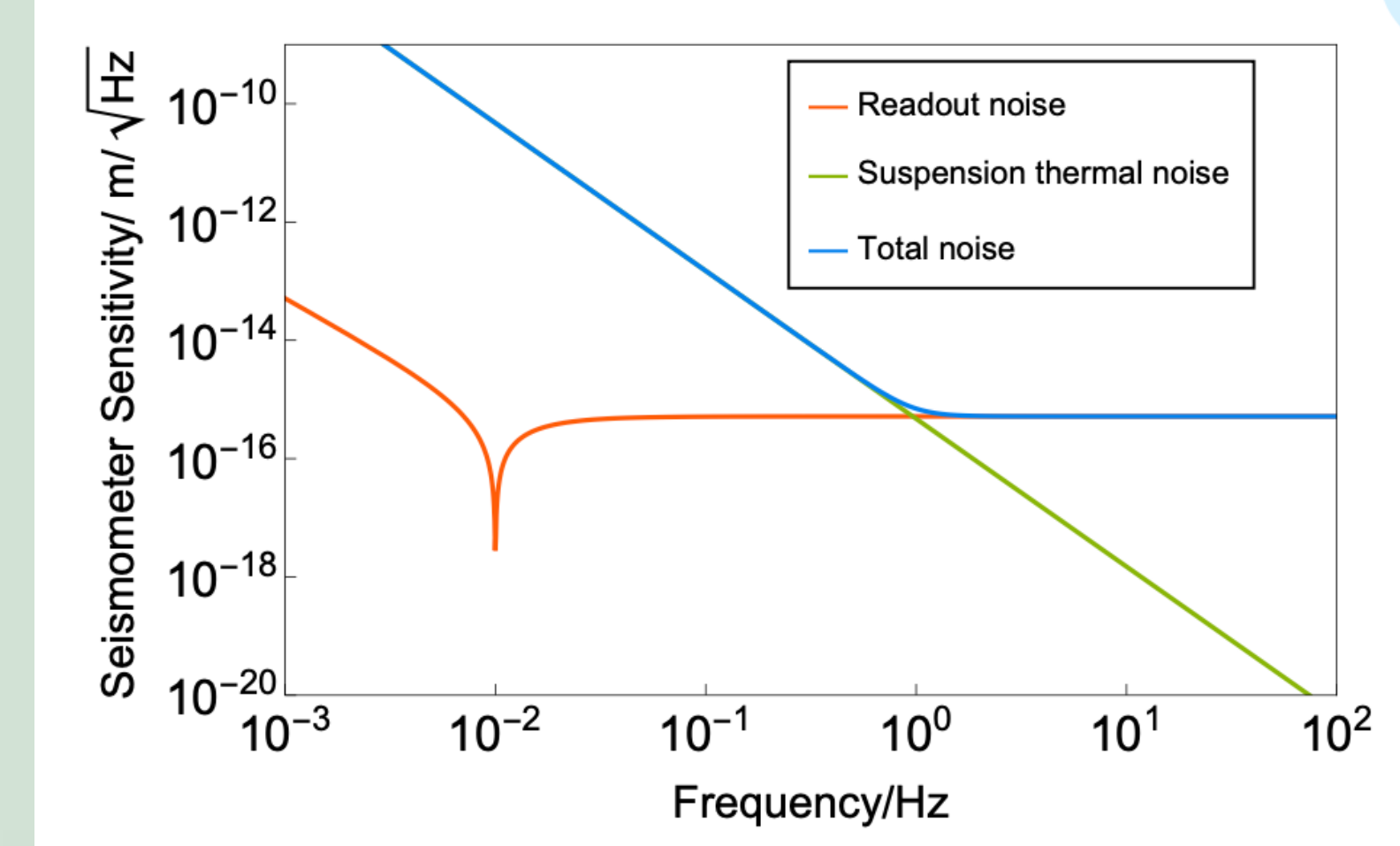
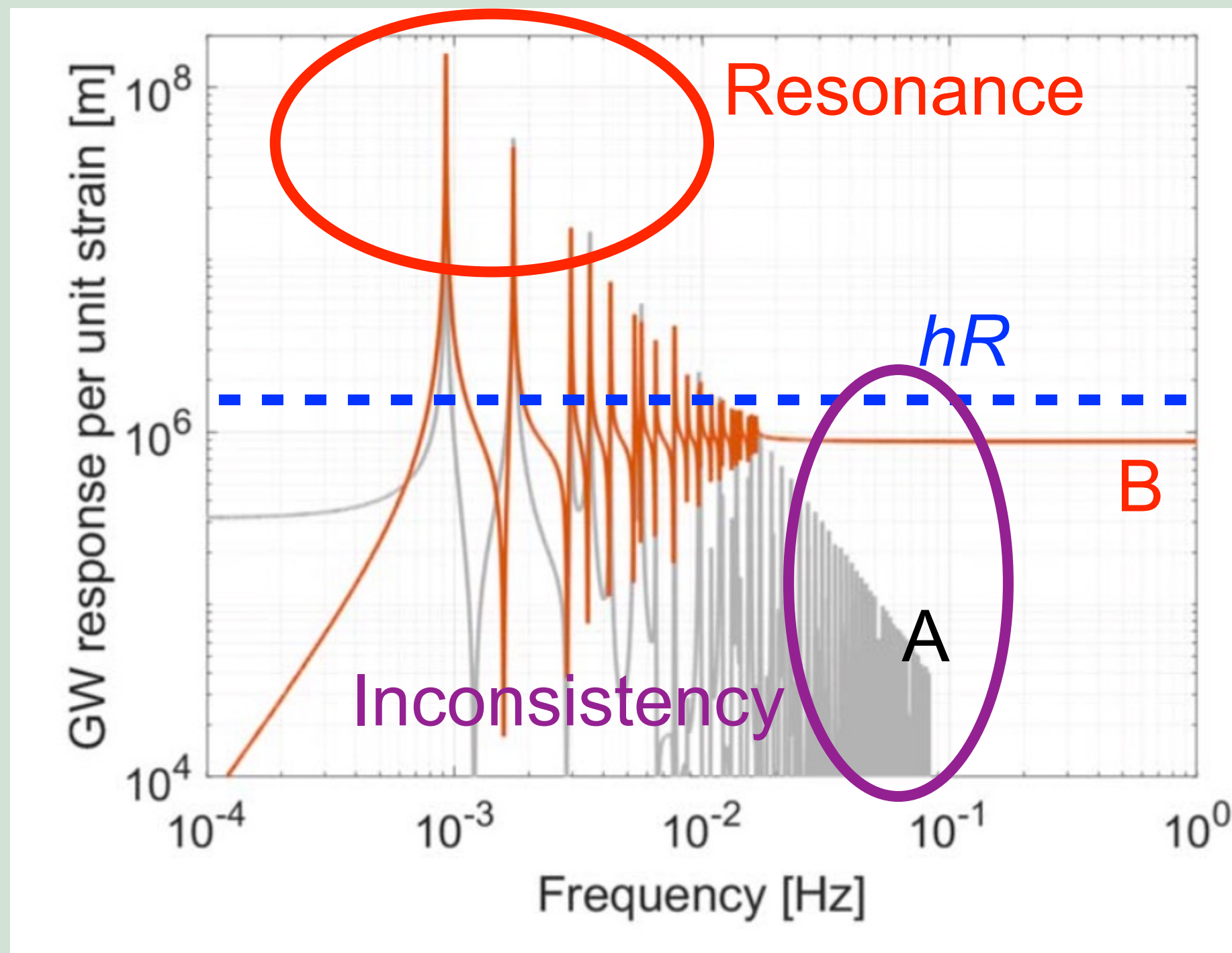


From Weber 1960, or “tidal force”

$$\vec{f}_B = \frac{\rho}{2} \ddot{\vec{h}} \cdot \vec{r}$$

Inconsistency in the Literature

Transfer function if $h=1$

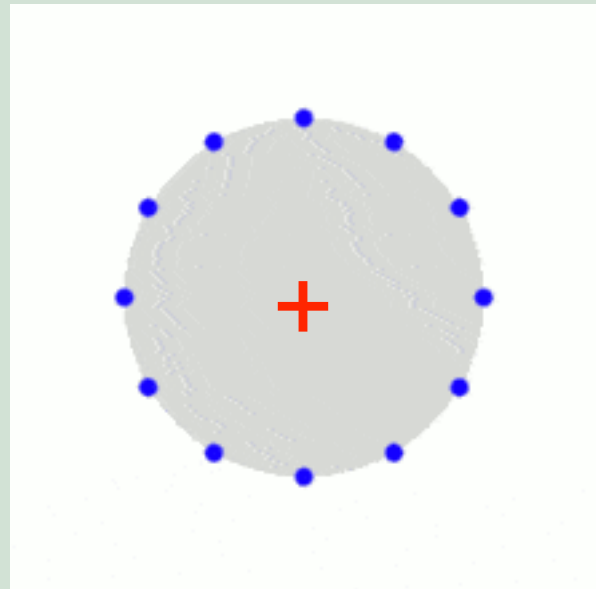


From Harms+21, LGWA White Paper

$$\text{Sensitivity} \sim \frac{\text{Instrument noise}}{f^{3/2} \times \text{Transfer function}}$$

Our Interpretation: Physical Insight

Put the moon back



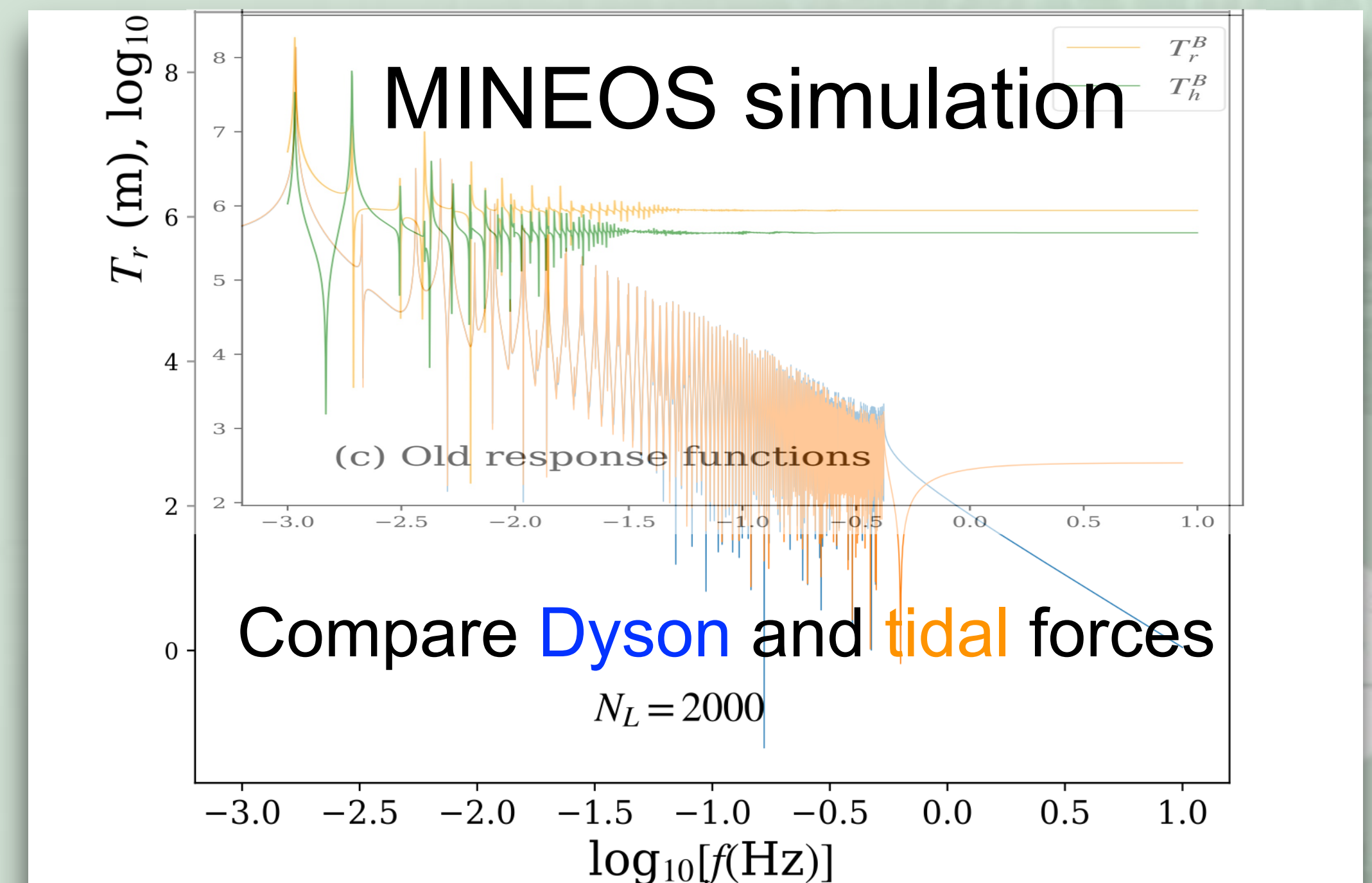
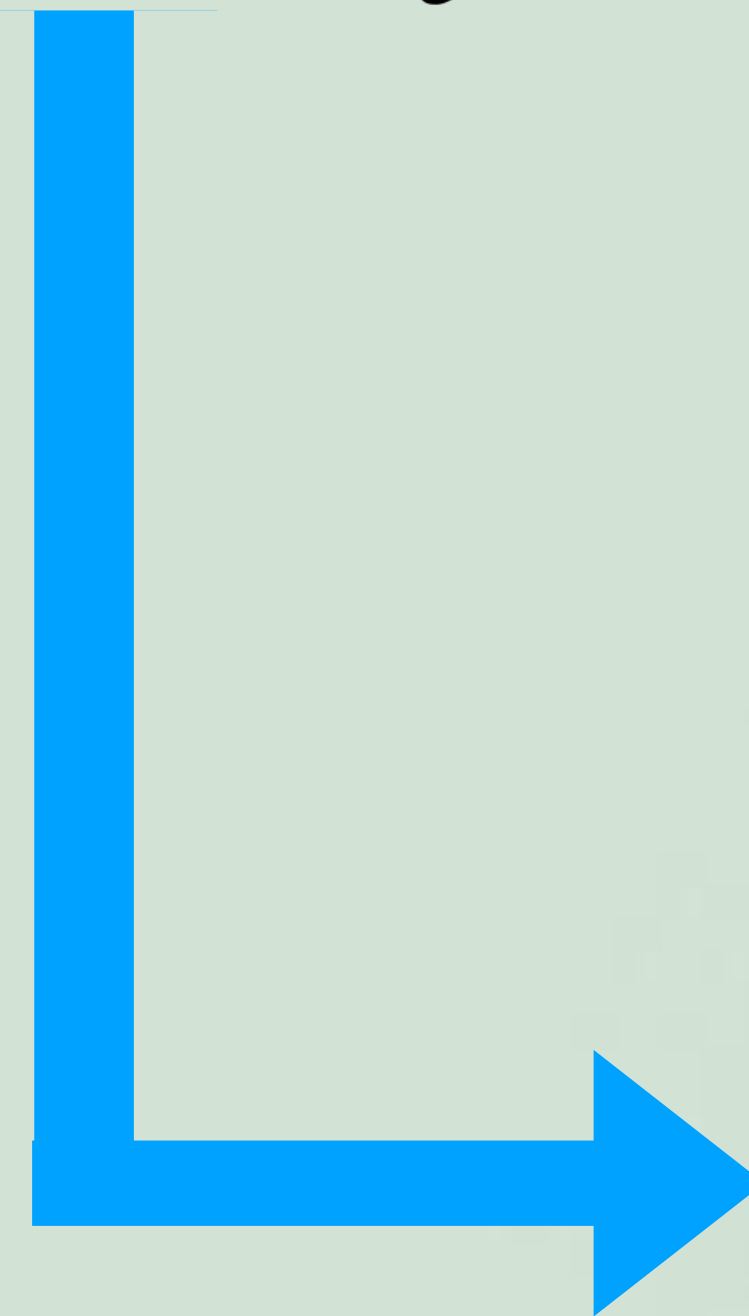
$$\vec{\xi}_\zeta^A = \vec{\xi}_\zeta^B - \frac{1}{2} \overleftrightarrow{h} \cdot \vec{x}_{eq}$$

Coord. of LIF

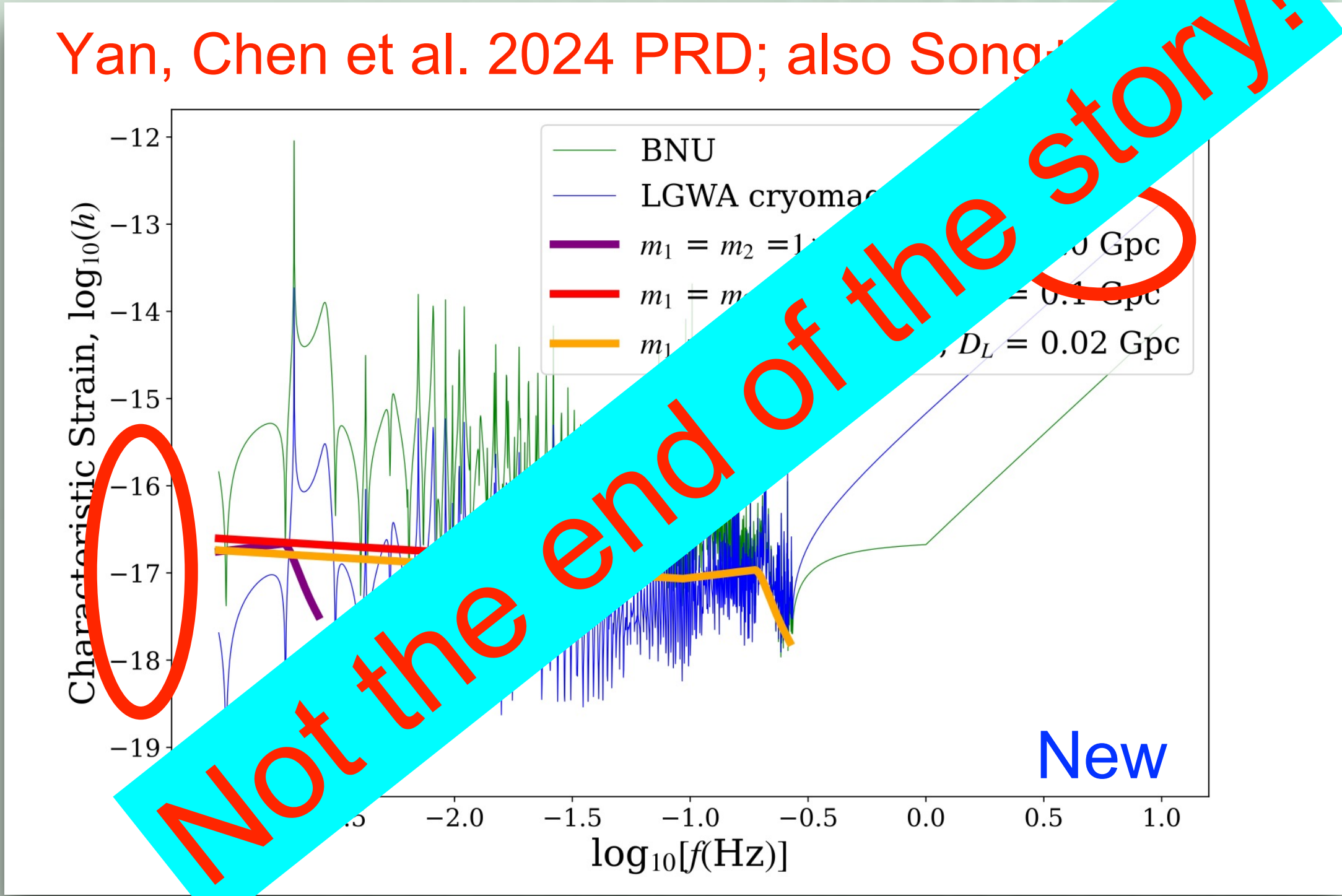
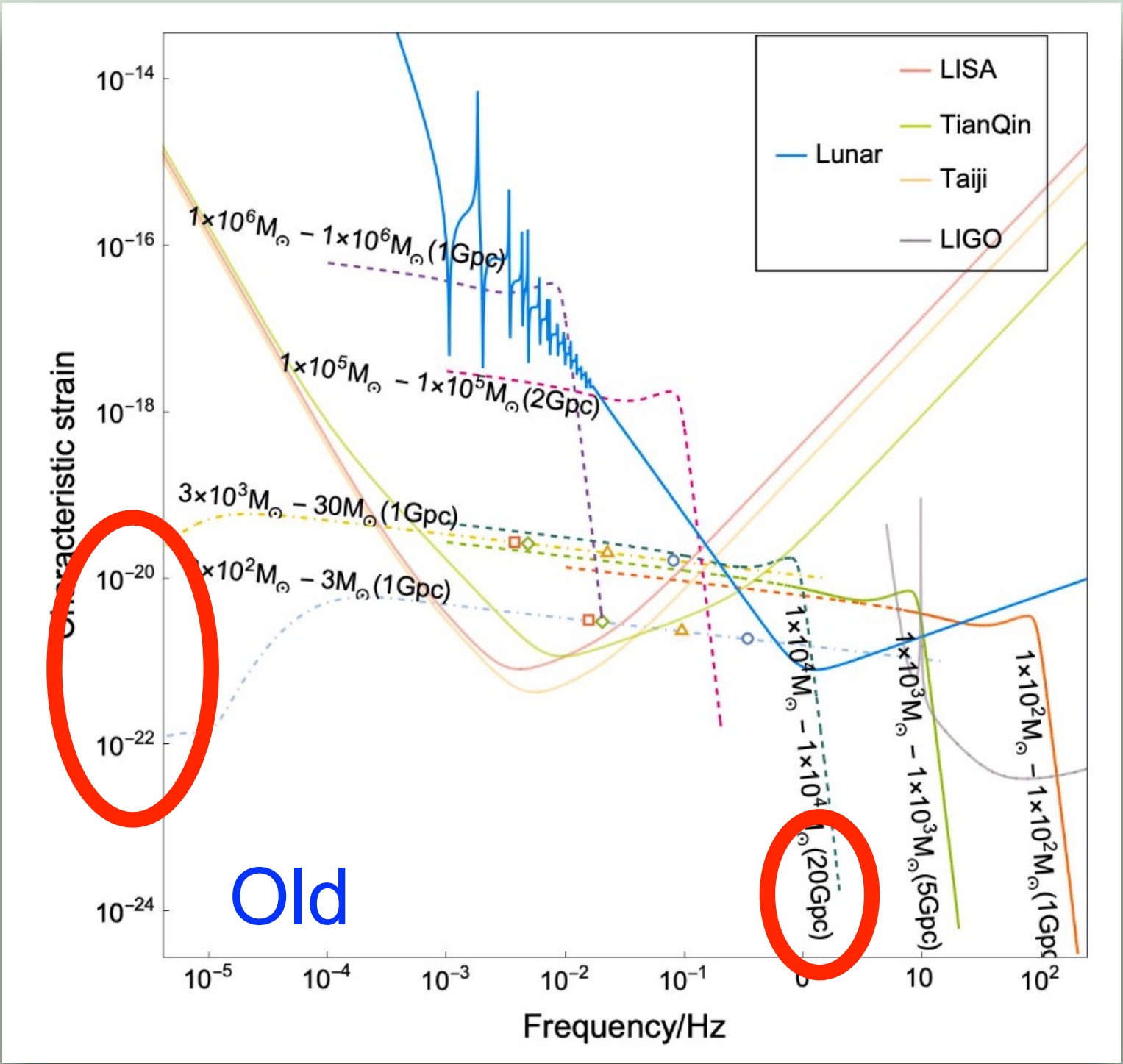
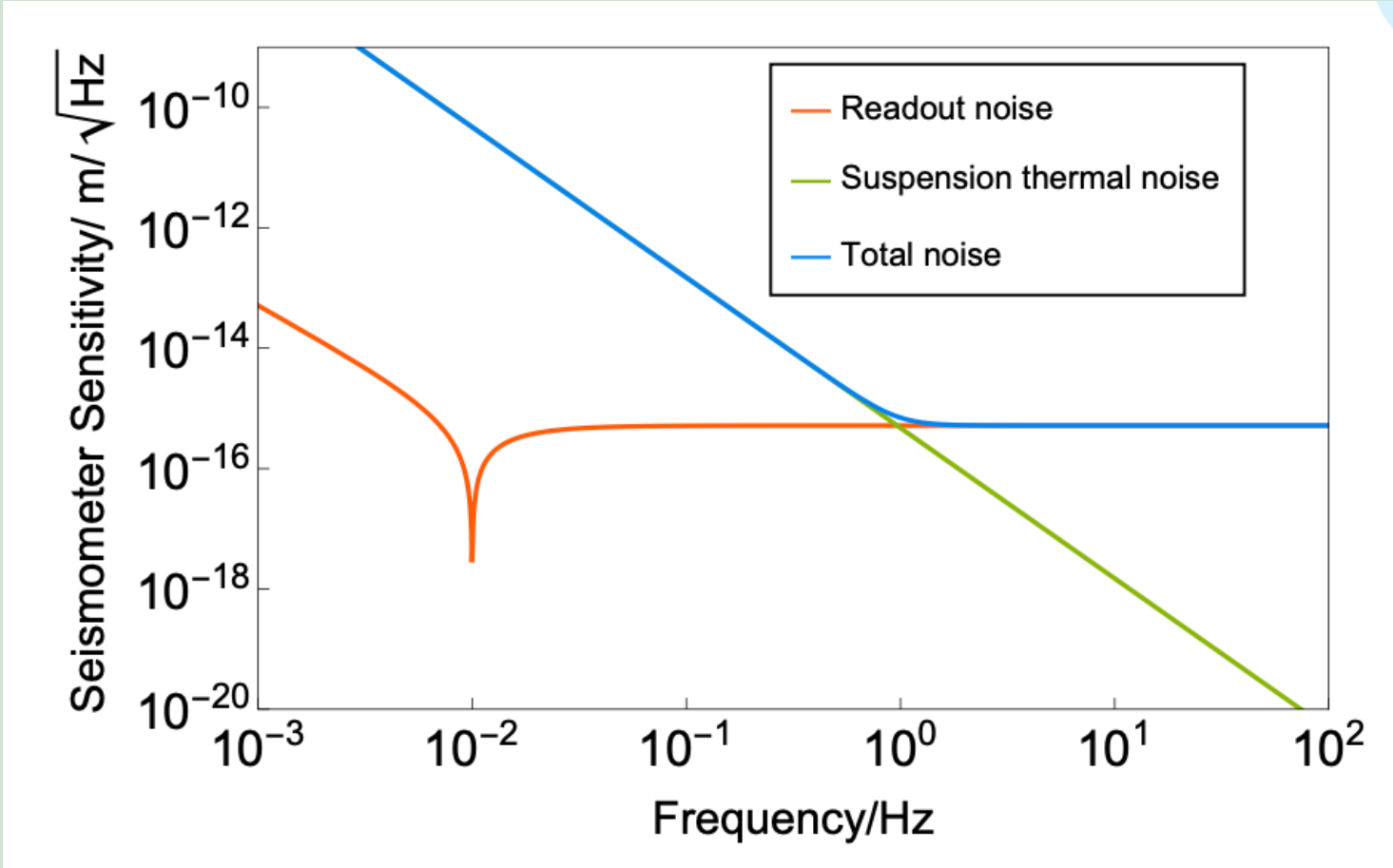
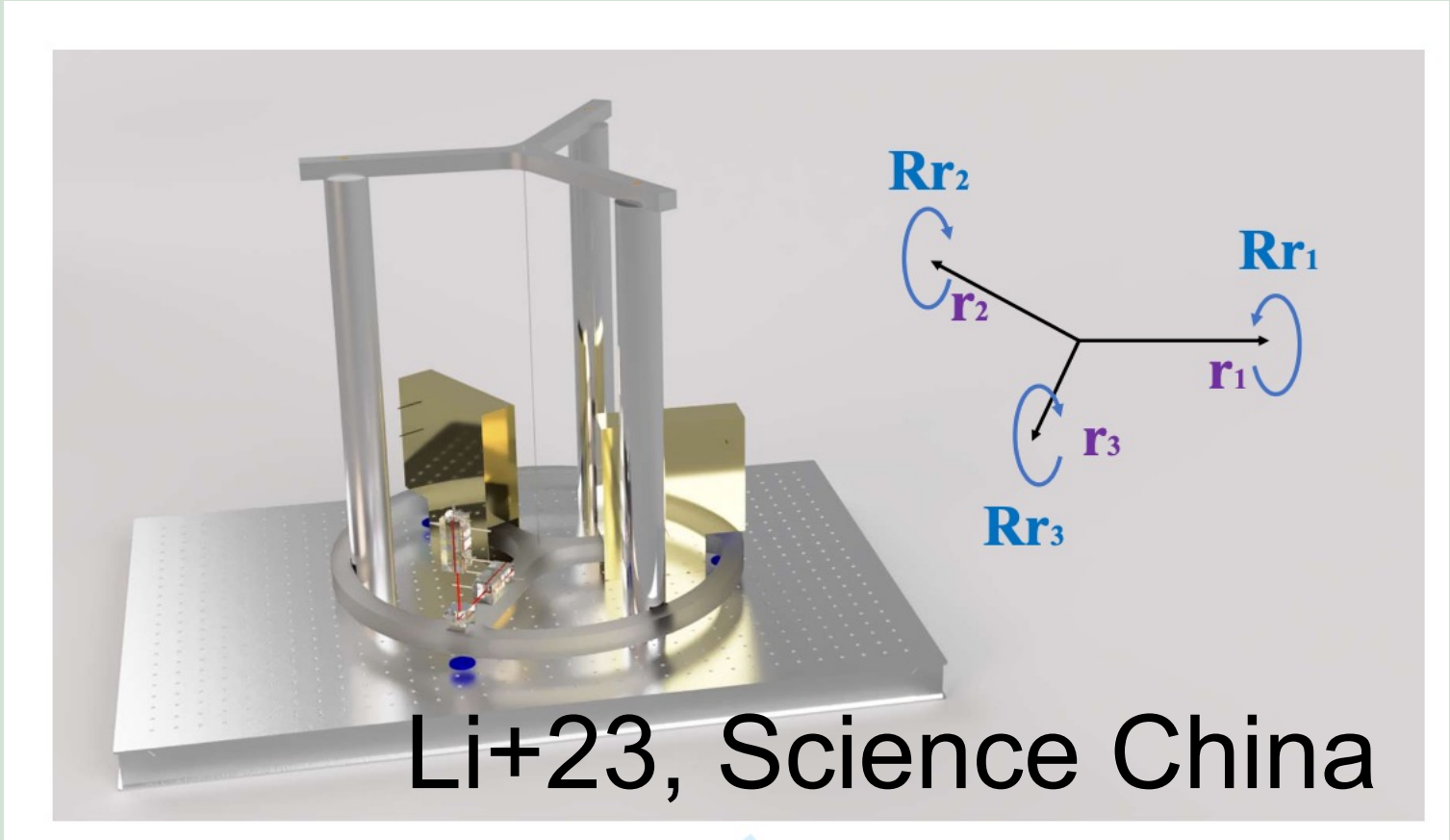


Meaning of B coord.

- Ignore moon for a while
- Proper distance from center
- But free falling, no acceleration
- No readout on seismometer
- No acc. relative to *local inertia frame* (LIF)
- Coordinate A proportional to acceleration with respect to LIF (Yan, Chen et al. 2024 PRD)



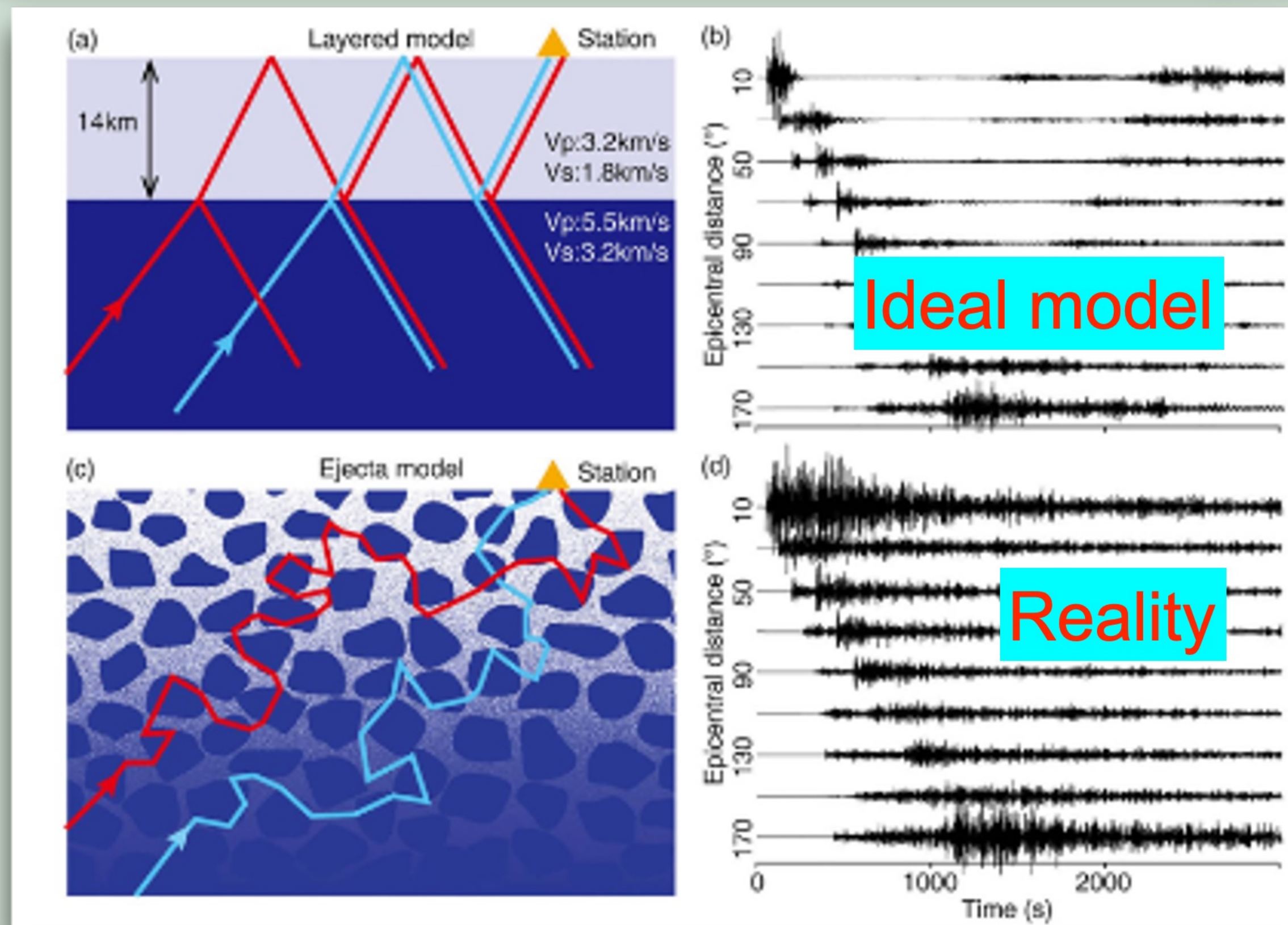
Potential: Beijing Normal Univ. seismometer



Not the end of the story!

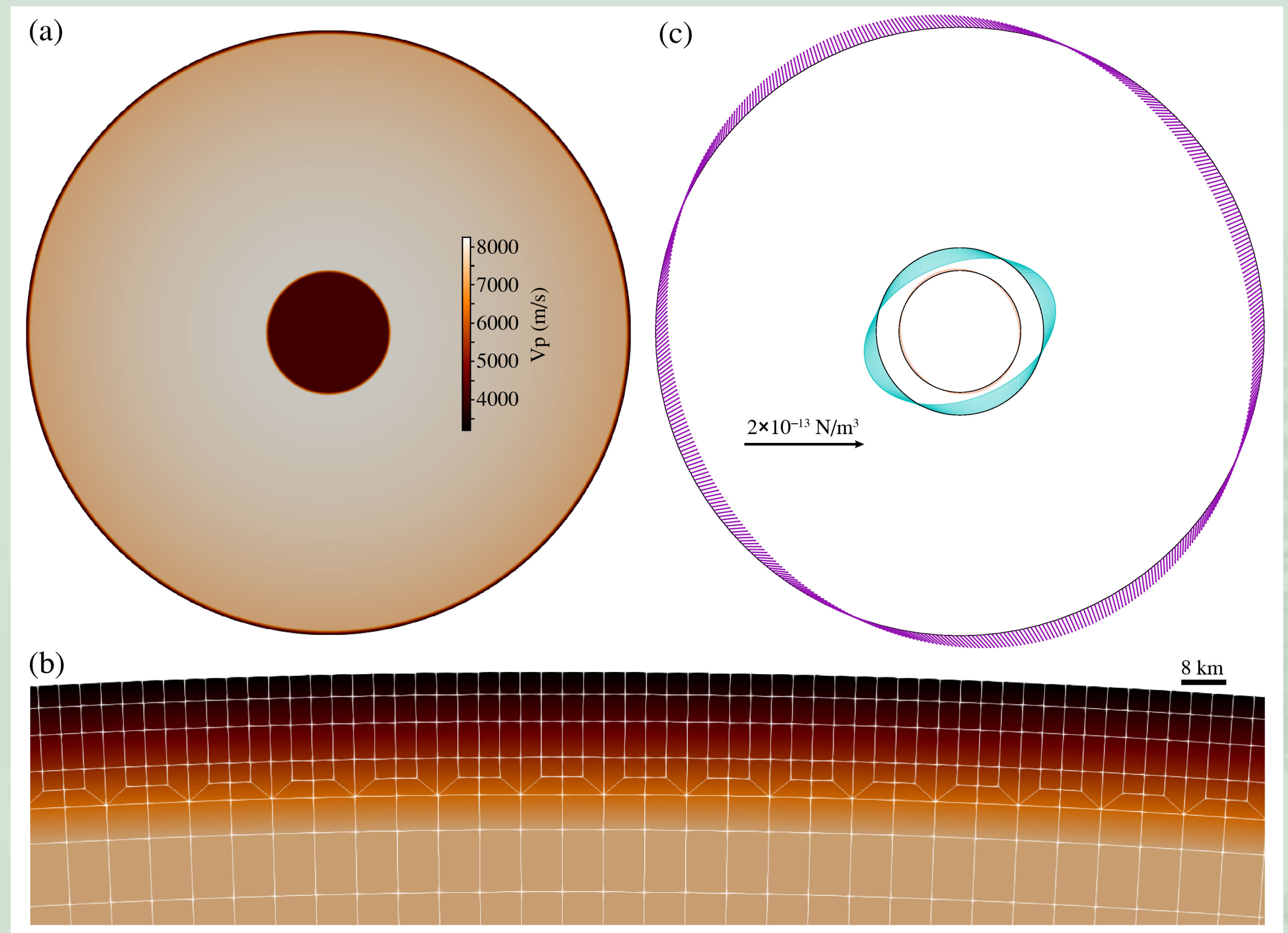
Importance of lunar structure/physics

Not the end of the story!



Surface Effect. Ref: Zhang22

First 2D finite-element simulation



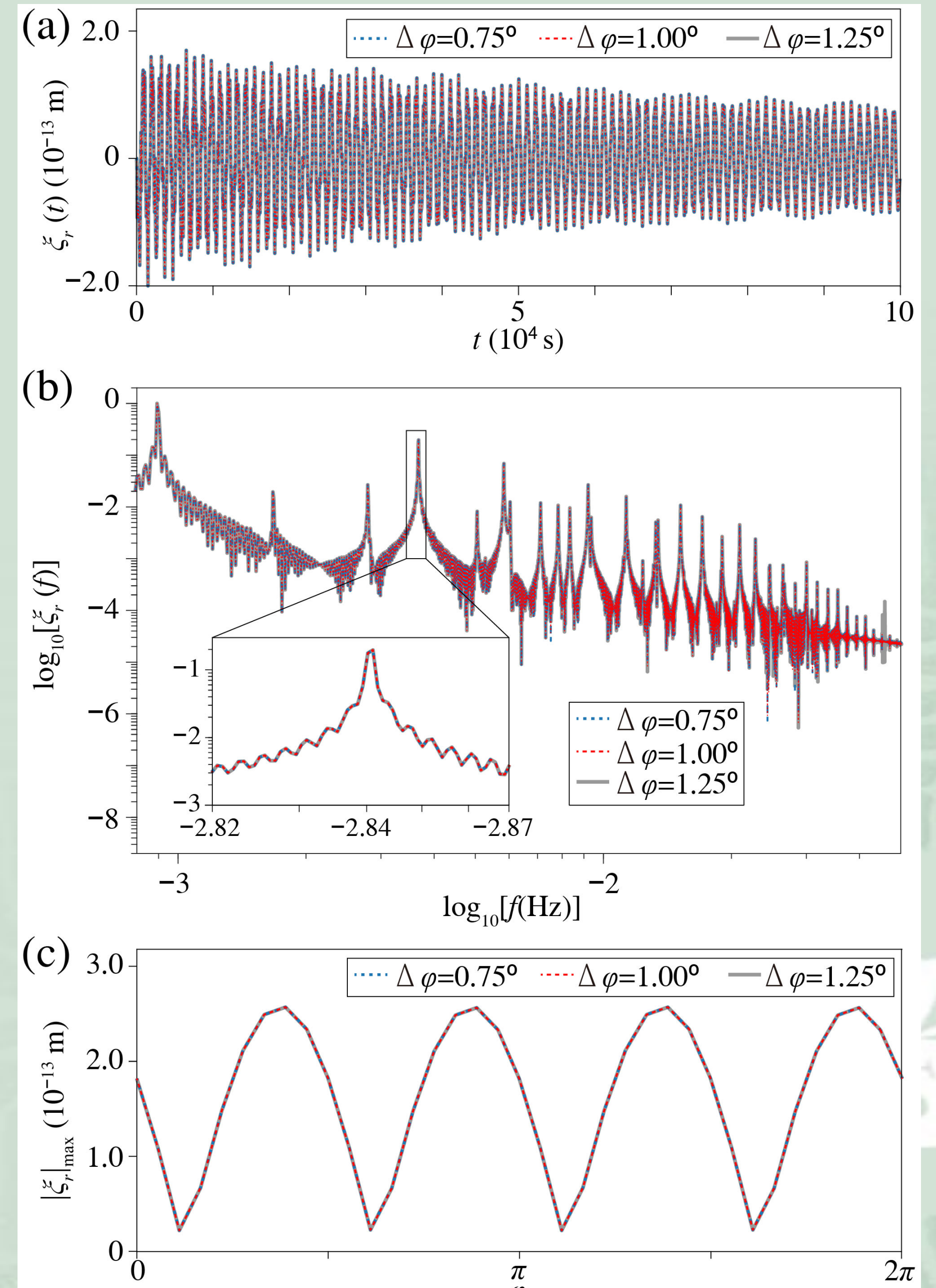
12k CPU cores, km-size resolution

First finite-element 2D simulation

First 2D finite-element simulation

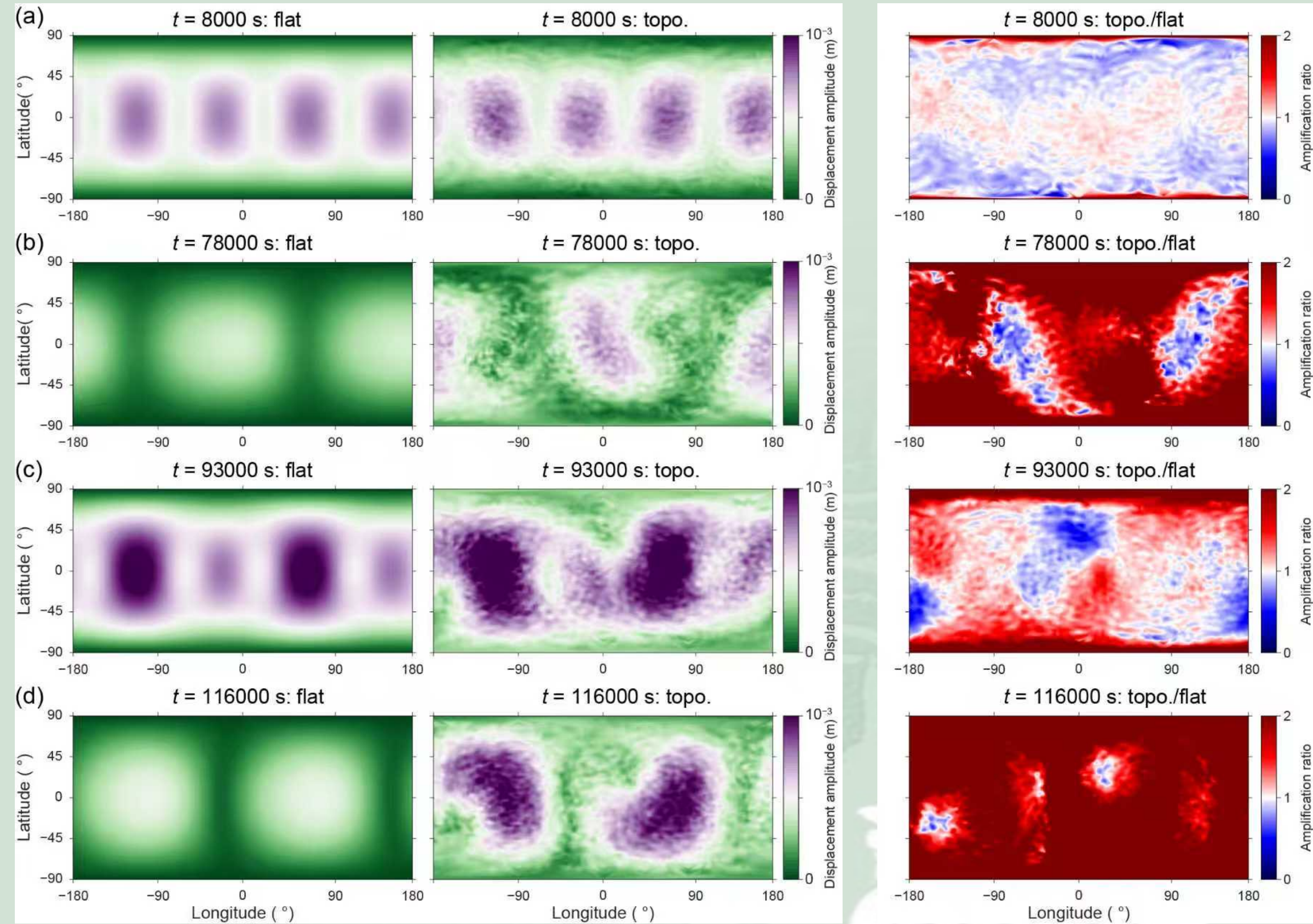
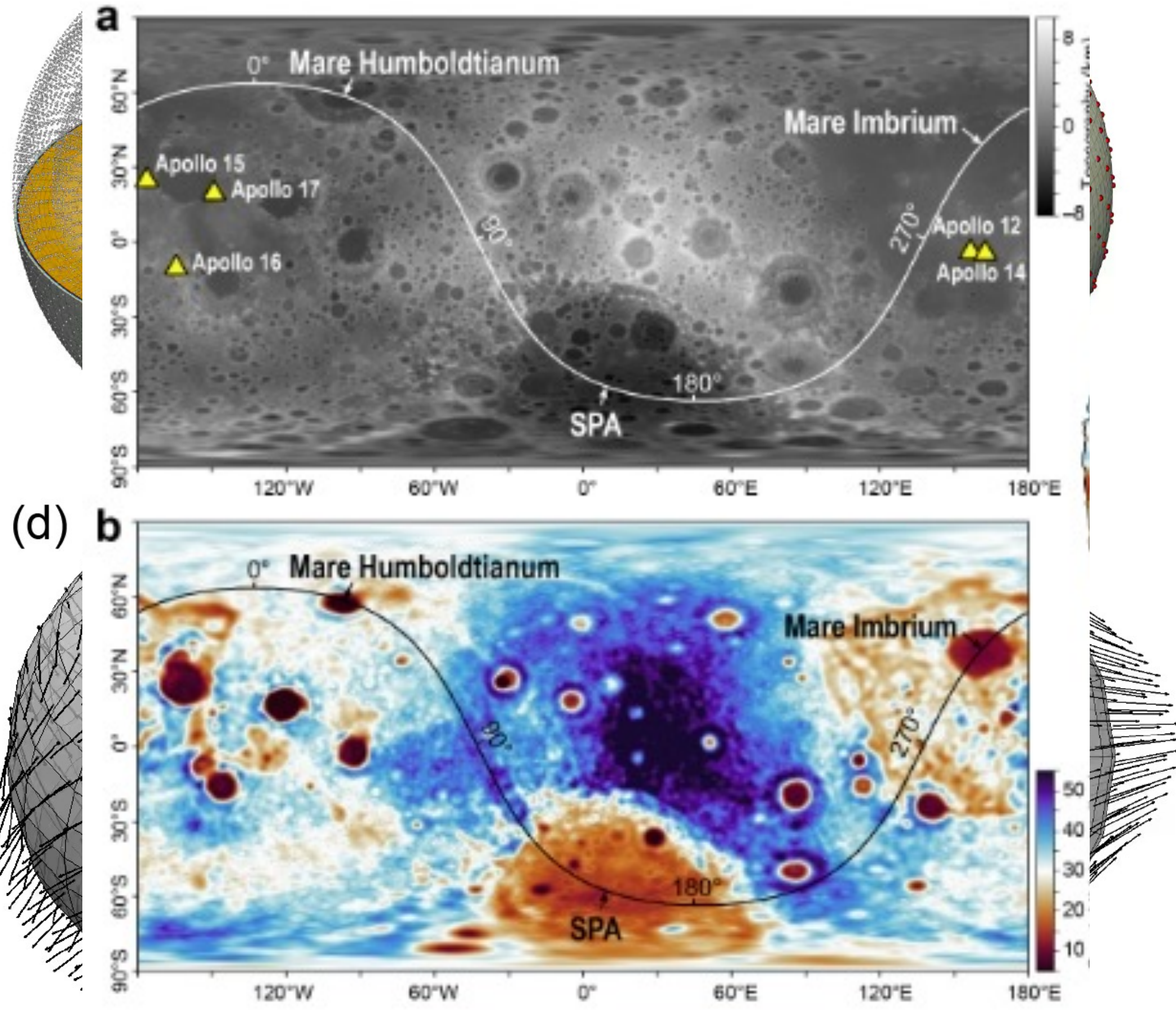


(Zhang, Yan, Chen, Zhang, 2025, PRD)



Full 3-D simulation and signal amplification

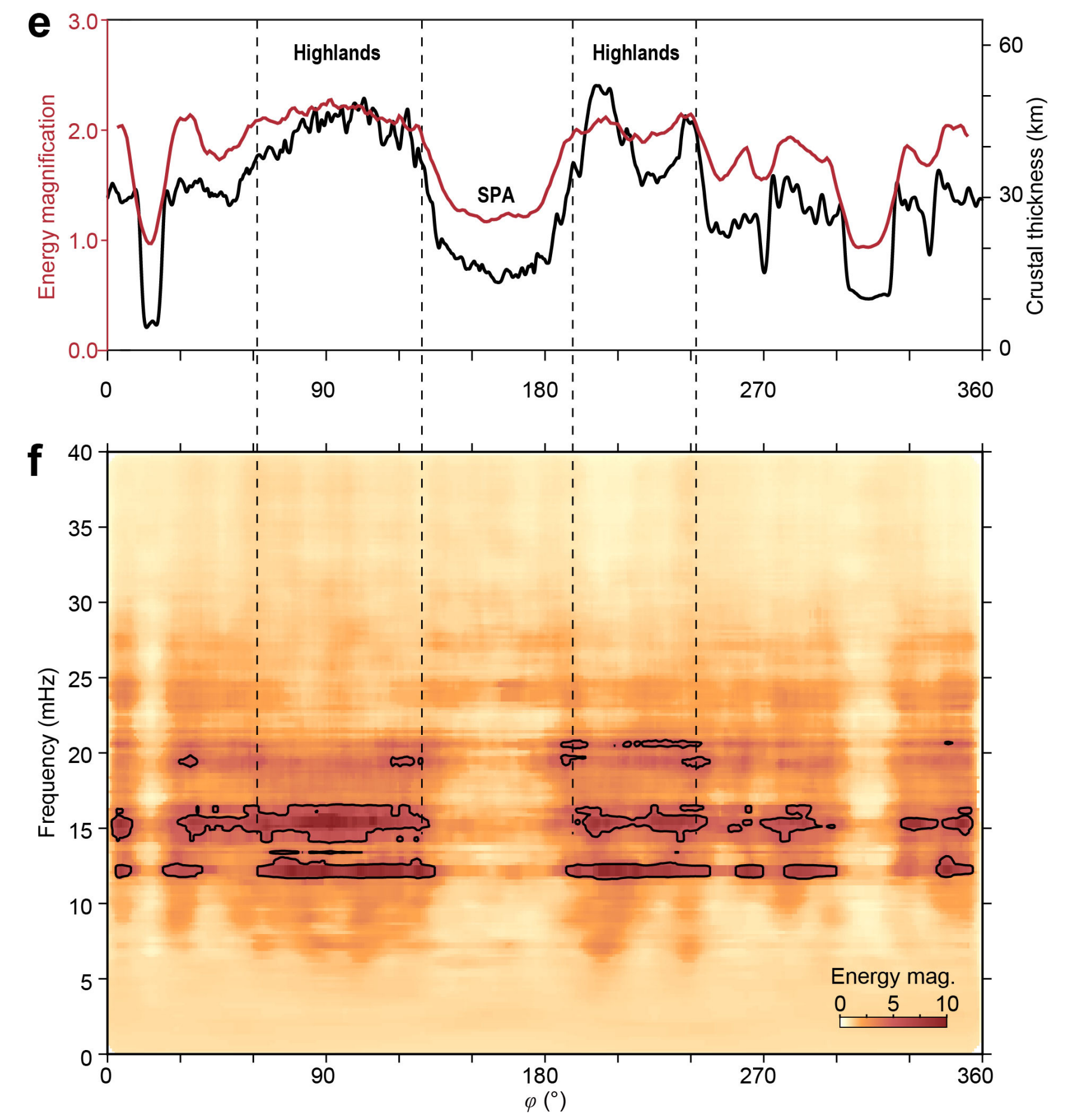
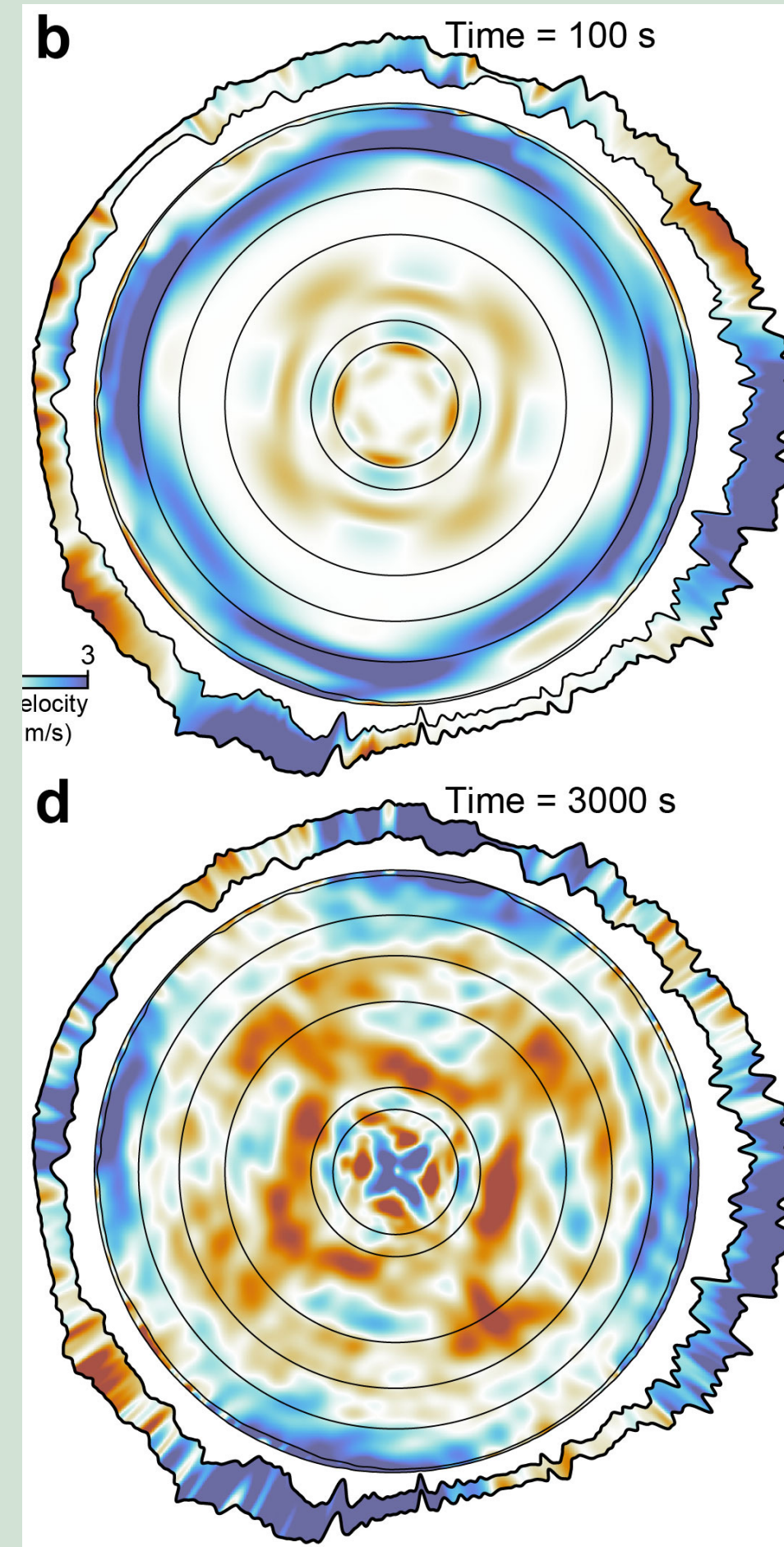
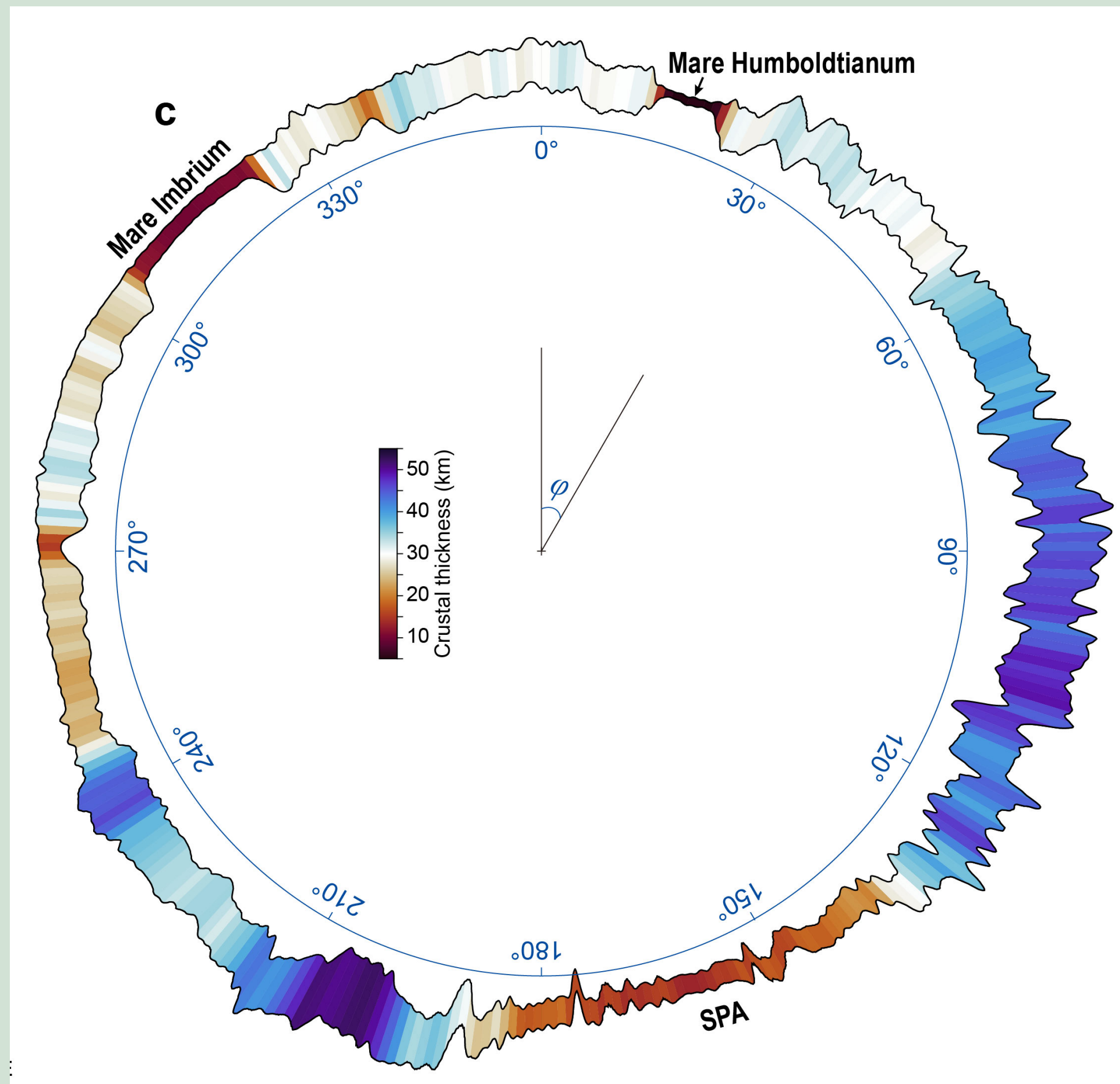
Real terrain (3D simulation)



(Zhang, Yan, Zhang, Chen 2026, PRD, 113, 023031)

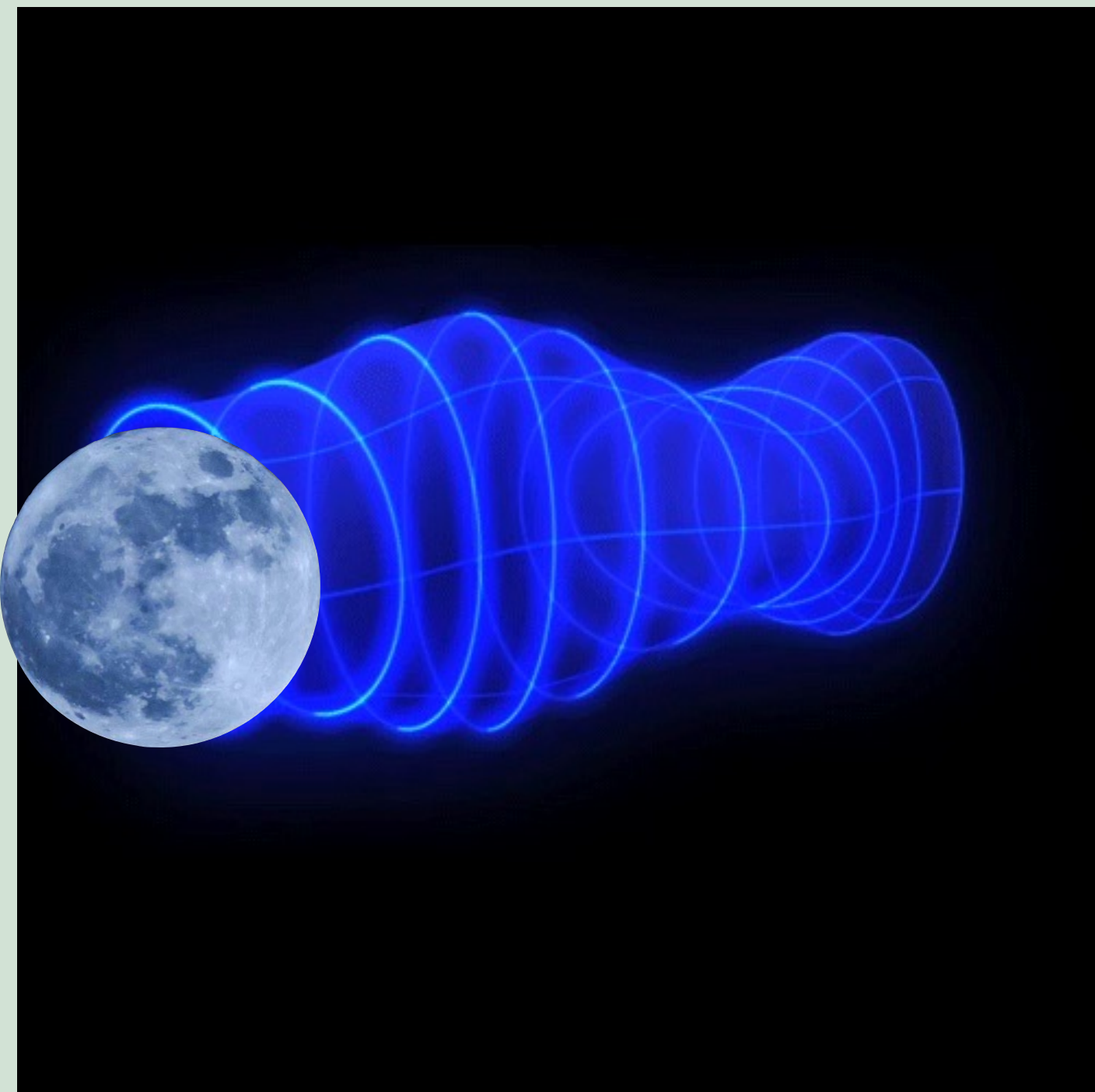
Thick crust amplifies GW signal

Real terrain & crust structure



(Zhang, Yan, Chen, Zhang 2026, PRL cover paper, Editor's Suggestion)

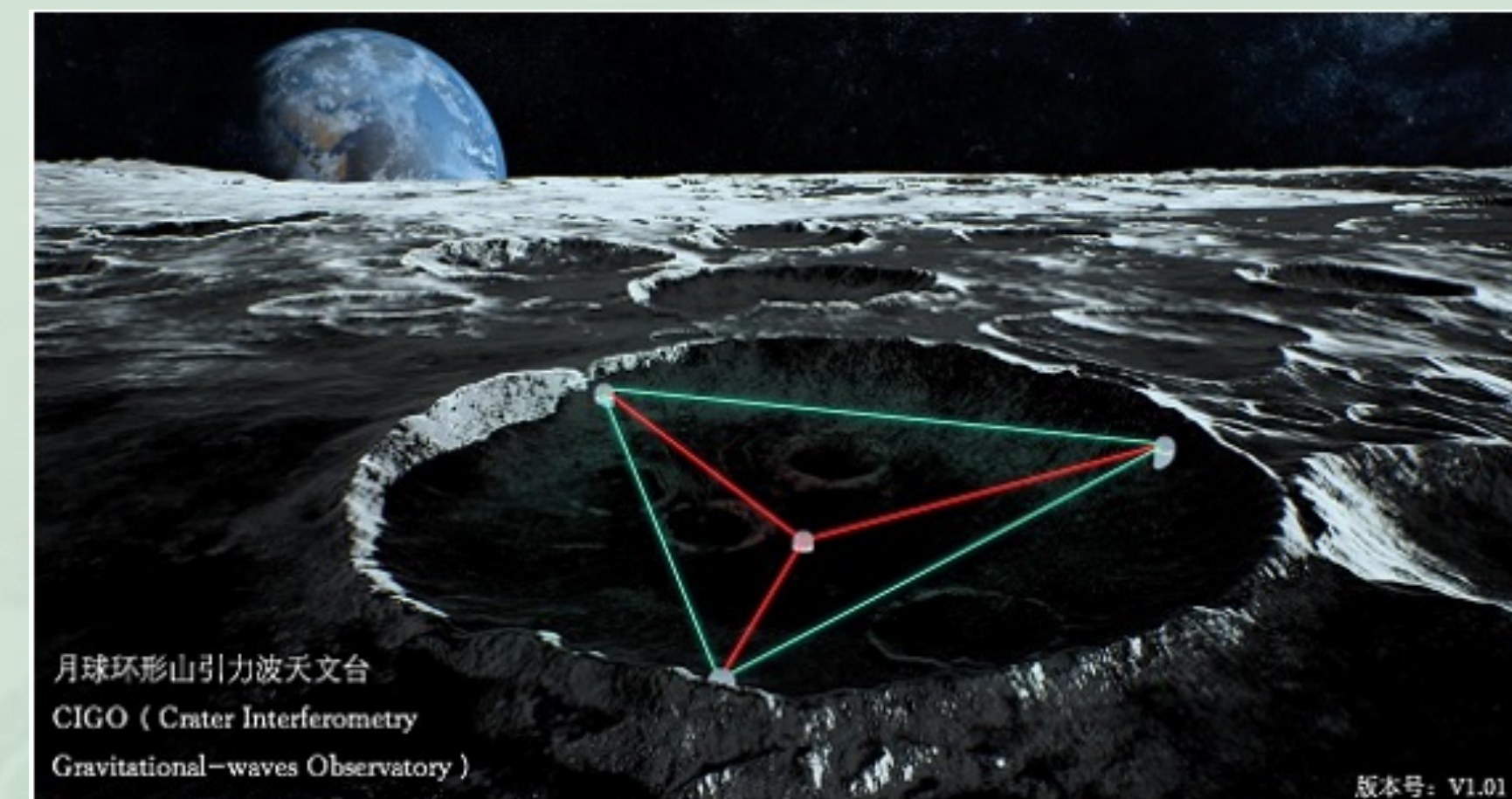
Different Schemes



GW imposing on the moon
(0.1Hz ~ 3e6km >> 1750 km)



Lunar Seismology
Accelerometers
Cryogenically cooled
(LGWA)



Measure strain h
Laser interferometers
No tunnel, no vacuum tube
(CIGO, GLOC/LILA, LION, LSGA)

Summary

- Derived self-consistent lunar response function
- First numerical simulation of lunar response to GWs
- Sensitivity to GW background by different lunar seismometers
- Cosmology, astrophysics, seismometer deployment plan...
on the way