A pass to the Deep Earth

Henri-Claude NATAF

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ISTerre
Université Grenoble Alpes
cnrs

A pass to the Deep Earth

outline

- Pressing questions about the Deep Earth at the time of my *grand-parents*
- The incredible wealth of data on the Deep Earth *today*
- Back to the future: how was the Earth *4 Ga ago?*
- Pressing questions about the Deep Earth at the time of my *grand-children*

Pressing questions about the Deep Earth

at the time of my *grand-parents*

- Is there a liquid core deep inside the Earth?
- Is the Earth really only 100 million years old?
- What physical mechanism can explain the magnetic field of the Earth?
- Does the solid Earth deform?
- What causes the « ring of fire »?
- Has the magnetic field reversed in the past?
- What does the bottom of the ocean look like?

The tools available at that time

The incredible wealth of data on the Deep Earth

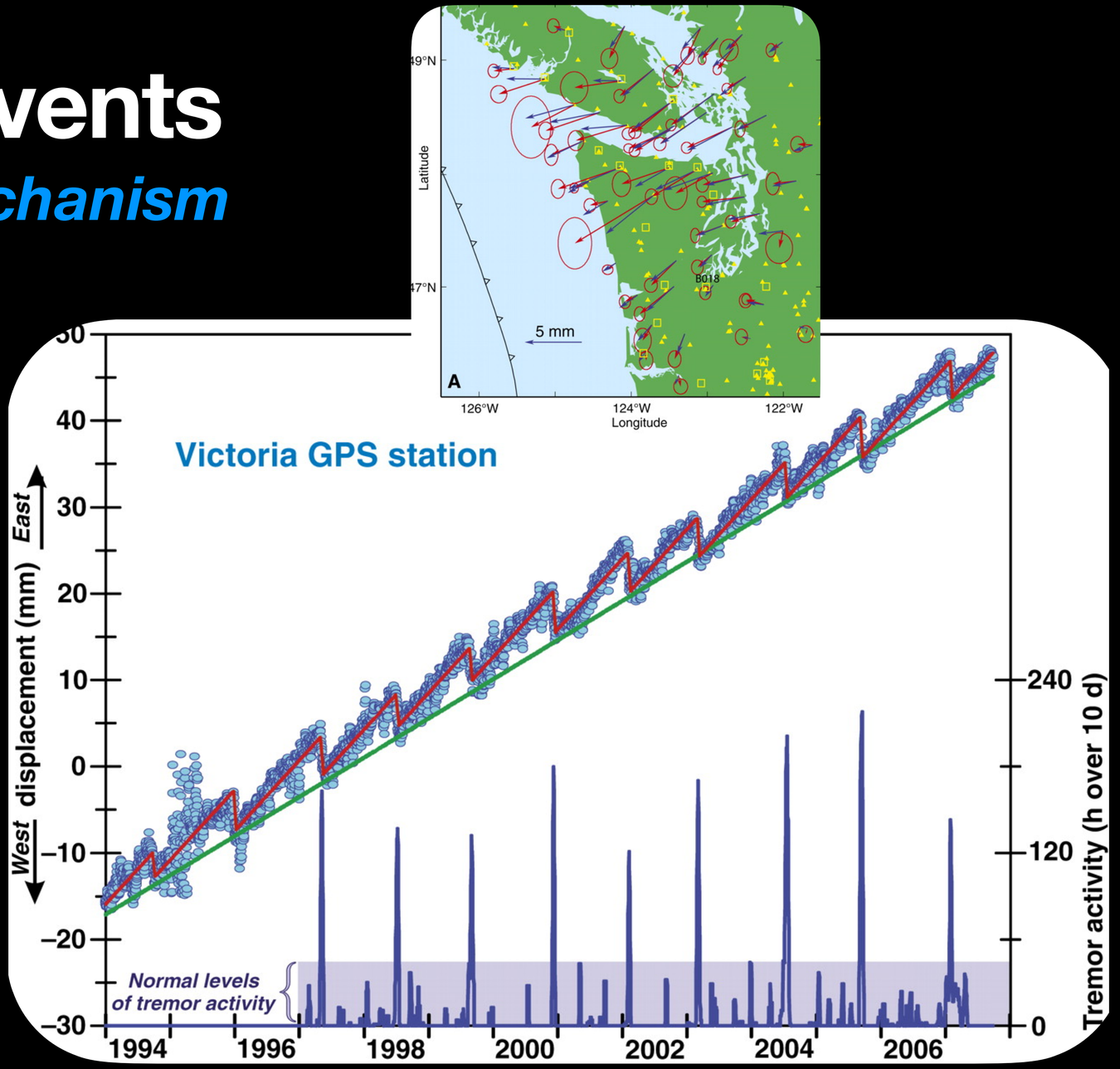
today

- A unique opportunity to discover or unravel *processes* and to place constraints on *material properties*.
- Three illustrations:
  - GPS and Slow Slip Events
  - 3D structure of the mantle and the geoid
  - Alfvén waves in the core and Length-of-Day

GPS and Slow Slip Events

A new kind of deformation mechanism

- The serendipitous discovery of ‘slow slip events’ in the Cascadian subduction zone (Dragert *et al*, 2001), associated with intense ‘tremor’ activity, has revealed new deformation mechanisms.
- GPS continuous recording was key for this discovery.



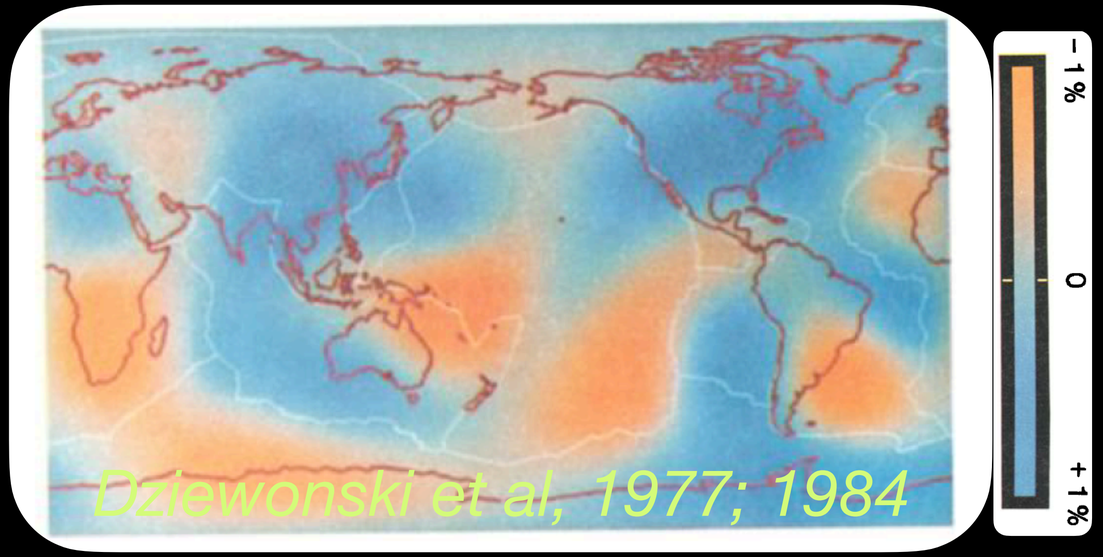
Gomberg et al, 2010

3D structure of the mantle and the geoid

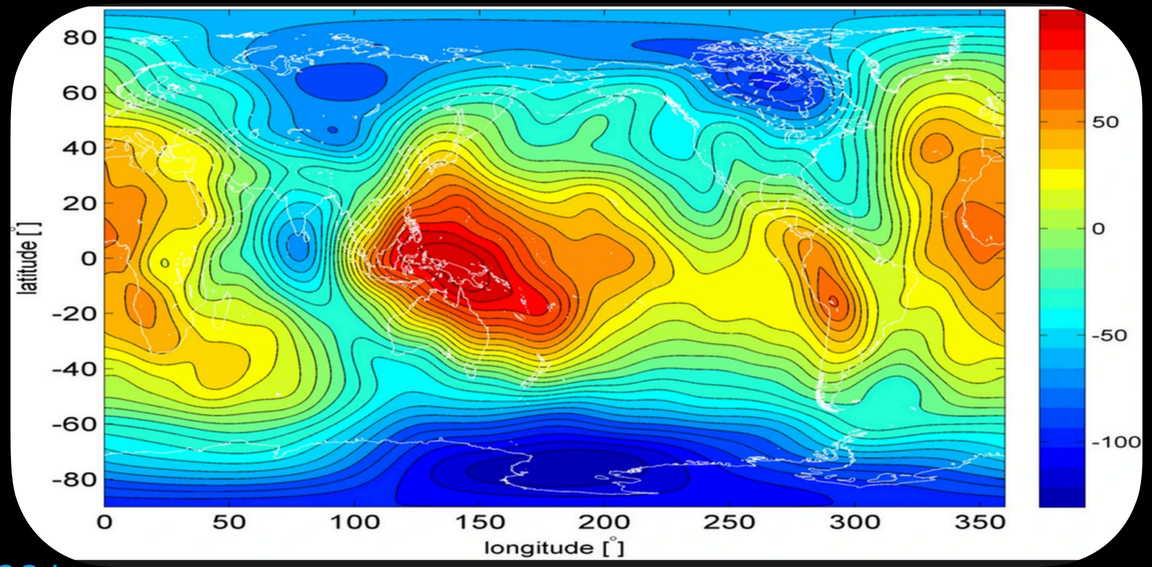
Constraints on mantle viscosity

- Seismology probably best illustrates the wealth of data available today.
- The first tomographic models of the lower mantle revealed a dominant large-scale pattern of heterogeneities just above the CMB.
- The pattern shows some correlation with the hydrostatic geoid, but with a *sign opposite* to the expected one.

V_P near the CMB



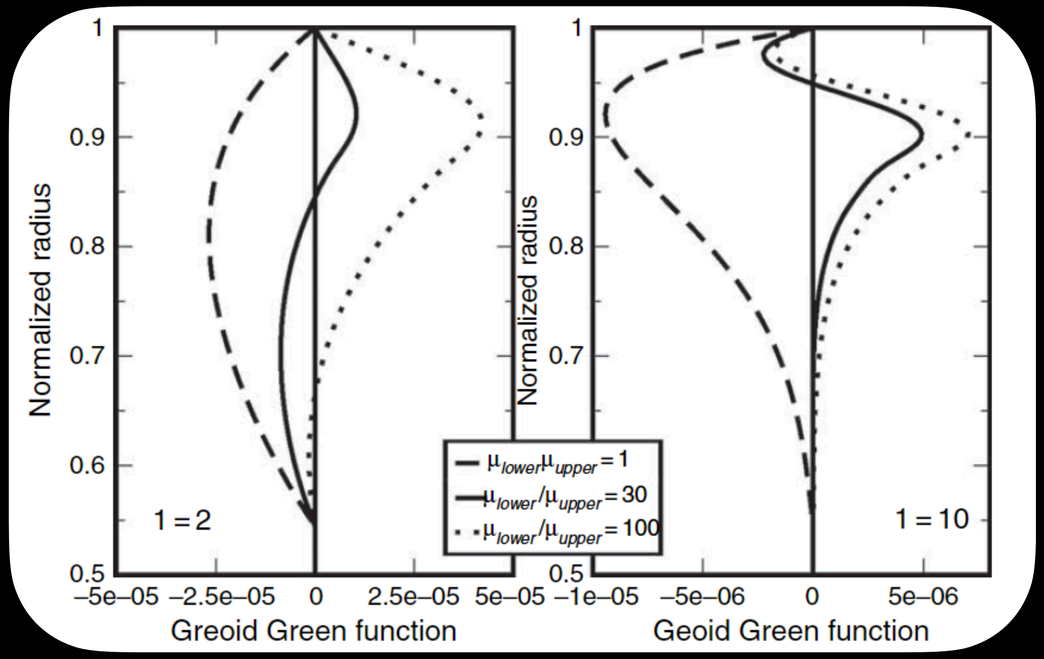
Non-hydrostatic geoid



3D structure of the mantle and the geoid

Constraints on mantle viscosity

- This paradox prompted the development of dynamic models of the mantle (Richards & Hager, 1984; Ricard *et al*, 1984).
- In these models, dynamic topography can add a hidden mass anomaly.
- Depending on the viscosity layering of the mantle, this effect can change the sign of the expected geoid.
- The anti-correlation revealed by seismic models requests a high-viscosity lower mantle.

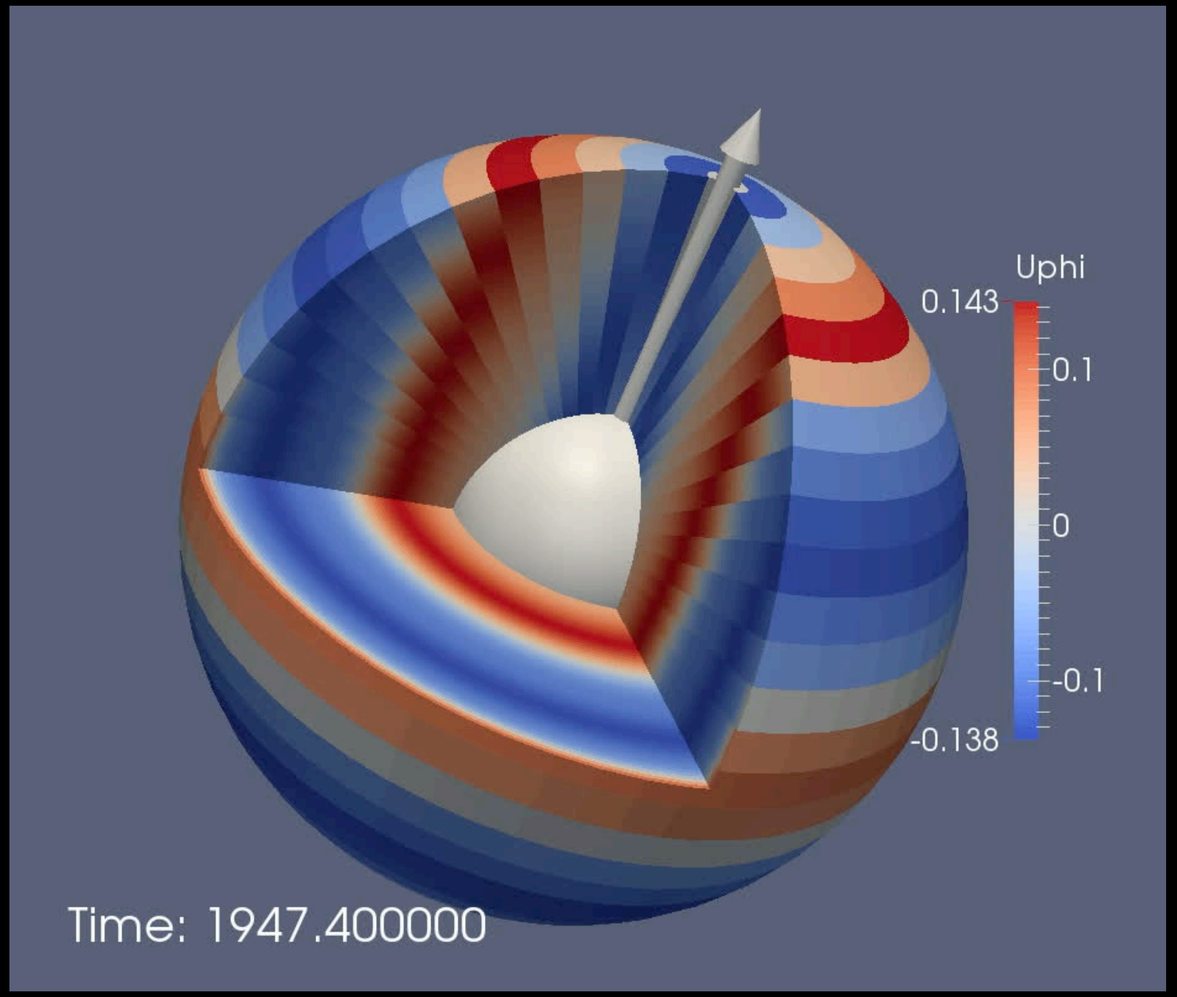


Ricard, 2007

Alfvén waves in the core and Length-of-Day

Accessing the magnetic field hidden in the core

- Fluid flow inside the core can be inferred from the secular variation of the magnetic field observed at the surface of the core.
- Geostrophic Alfvén waves have thus been discovered.
- Their travel time across the core (~3 years) constrains the intensity of the magnetic field hidden inside the core (~4 mT).

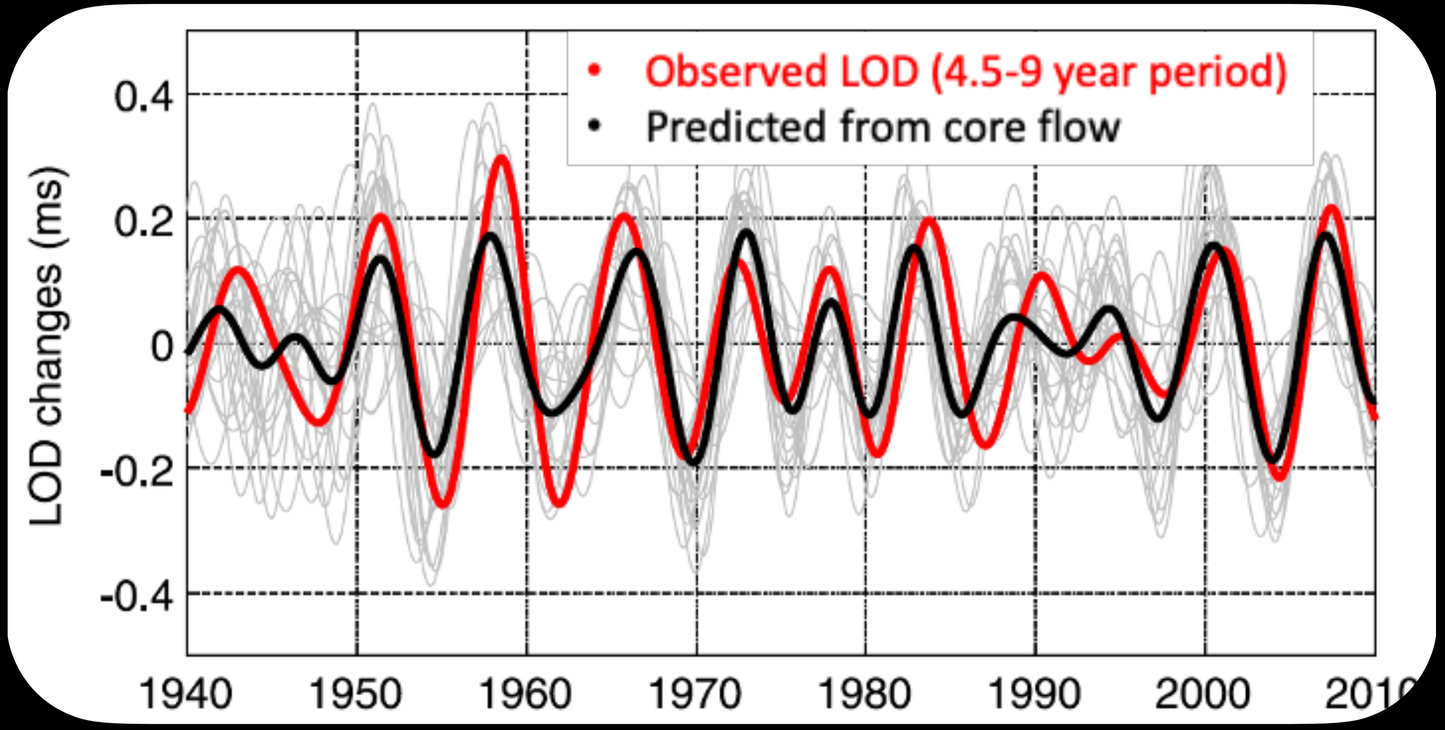


Gillet et al, 2010

Alfvén waves in the core and Length-of-Day

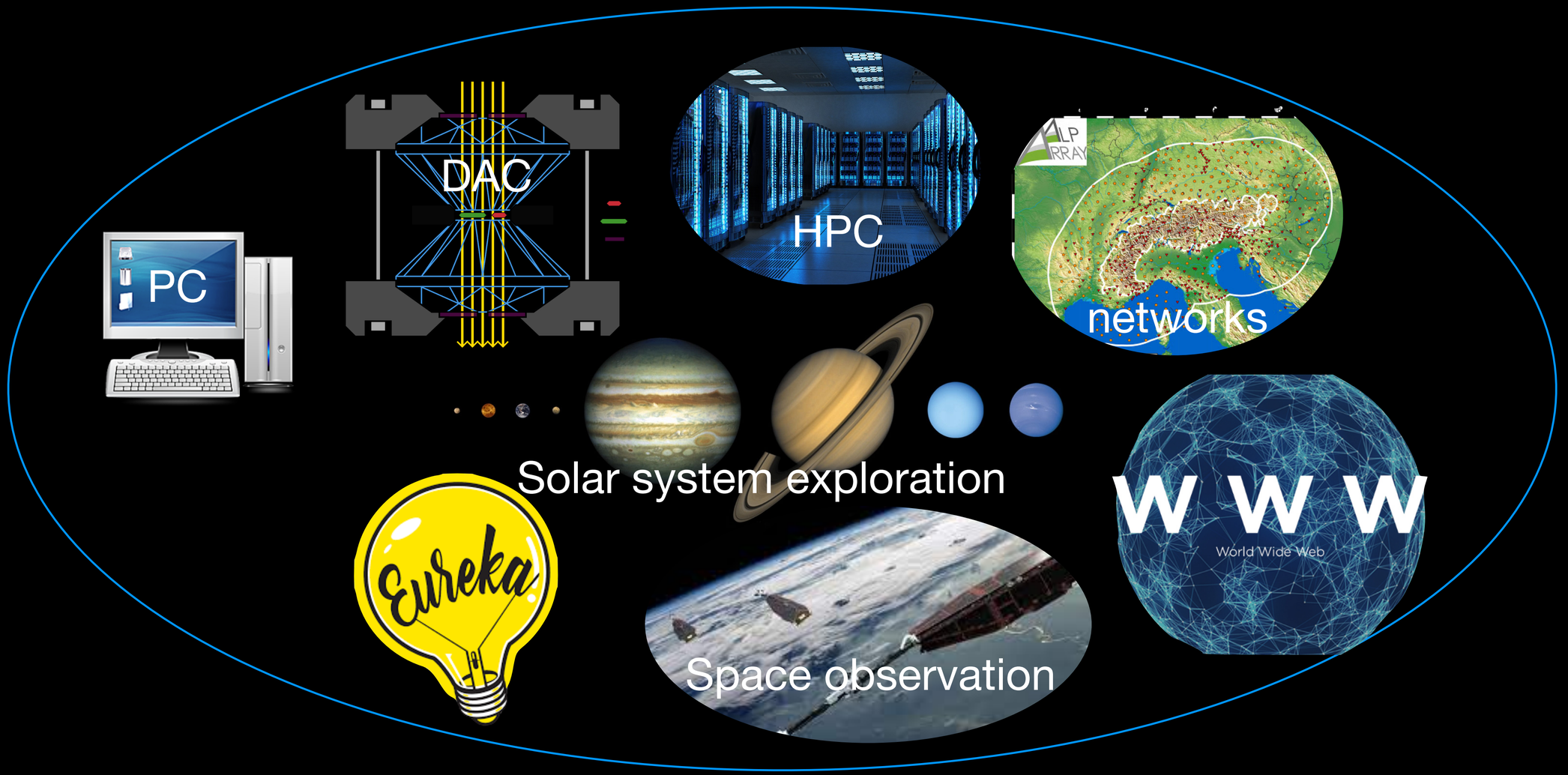
Accessing the magnetic field hidden in the core

- The discovered geostrophic Alfvén waves transfer angular momentum.
- This produces minute changes in the length-of-day (LOD), which can be computed and compared with observed LOD.



Gillet et al, 2015

The tools that made this possible



Back to the future

How was the Earth 4 Ga ago?

- One danger about having so much data about the Earth today is to forget that the Earth has been very different in the past.
- Understanding the present state of the Earth can shed light on how it evolved, but finding out how was the Earth in the past is essential to understand the present Earth.

Back to the future…

Back to the future…

600 Ma

Late Precambrian

1 day = 22h

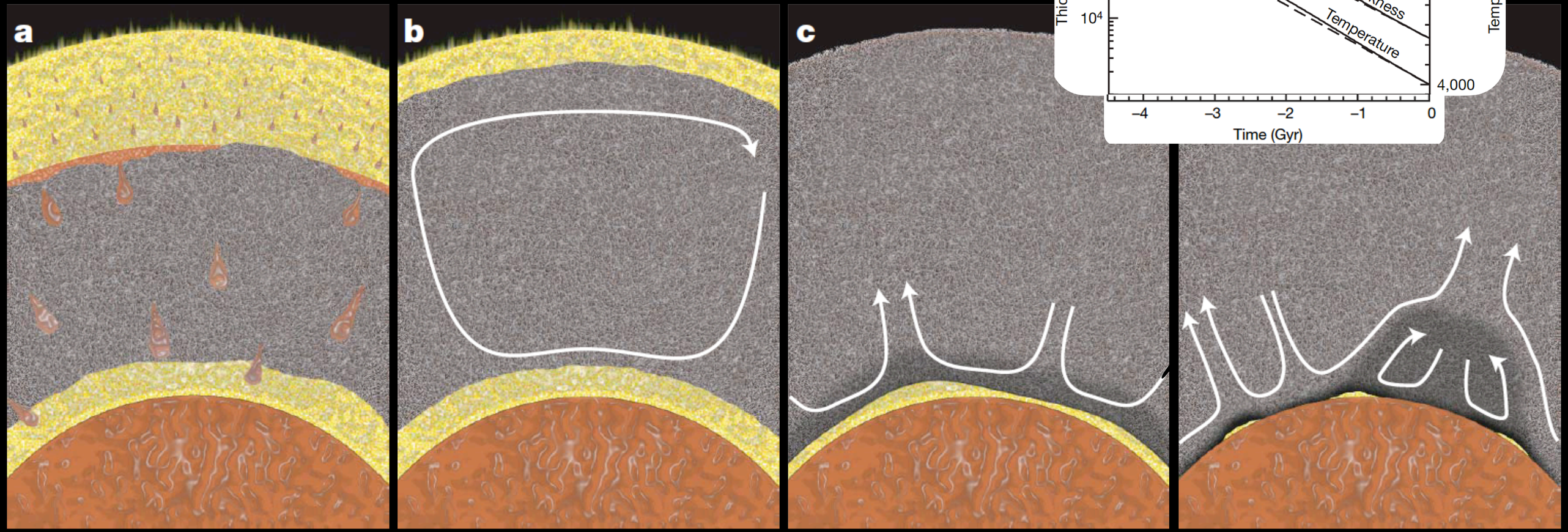
400 days/year

Back to the future

How was the Earth 4 Ga ago?

- The core was entirely liquid.
- At the base of the mantle lied a 4700K 300km-thick magma ocean.

Mantle basal magma ocean



Labrosse et al, 2007

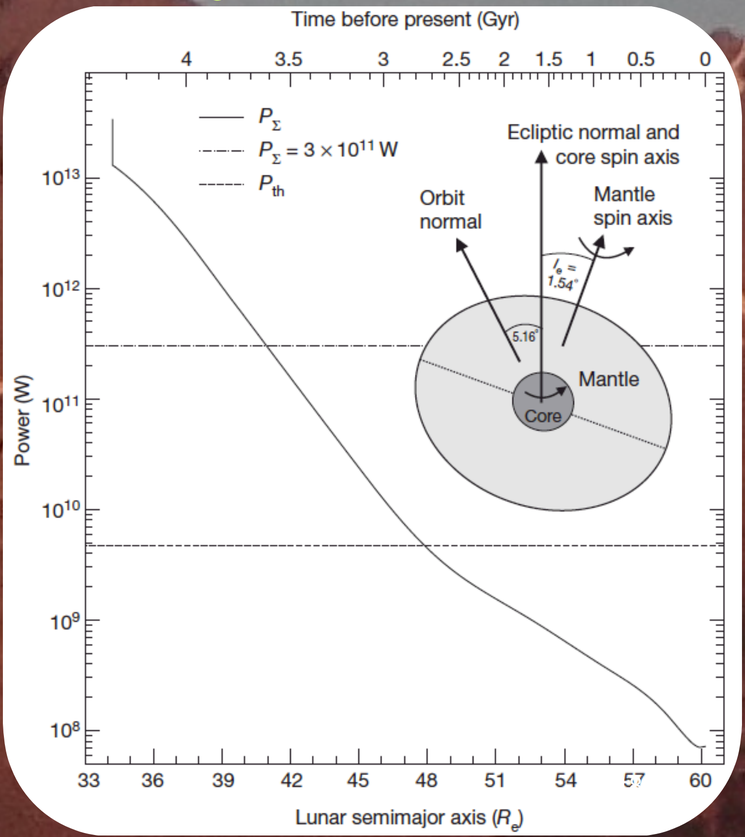
Back to the future

How was the Earth 4 Ga ago?

- There was no continental crust.
- Radioactive heating was 4 times larger.
- The Moon was 38 Earth radius away (instead of 60 today).

The Moon was *1.6 times closer*

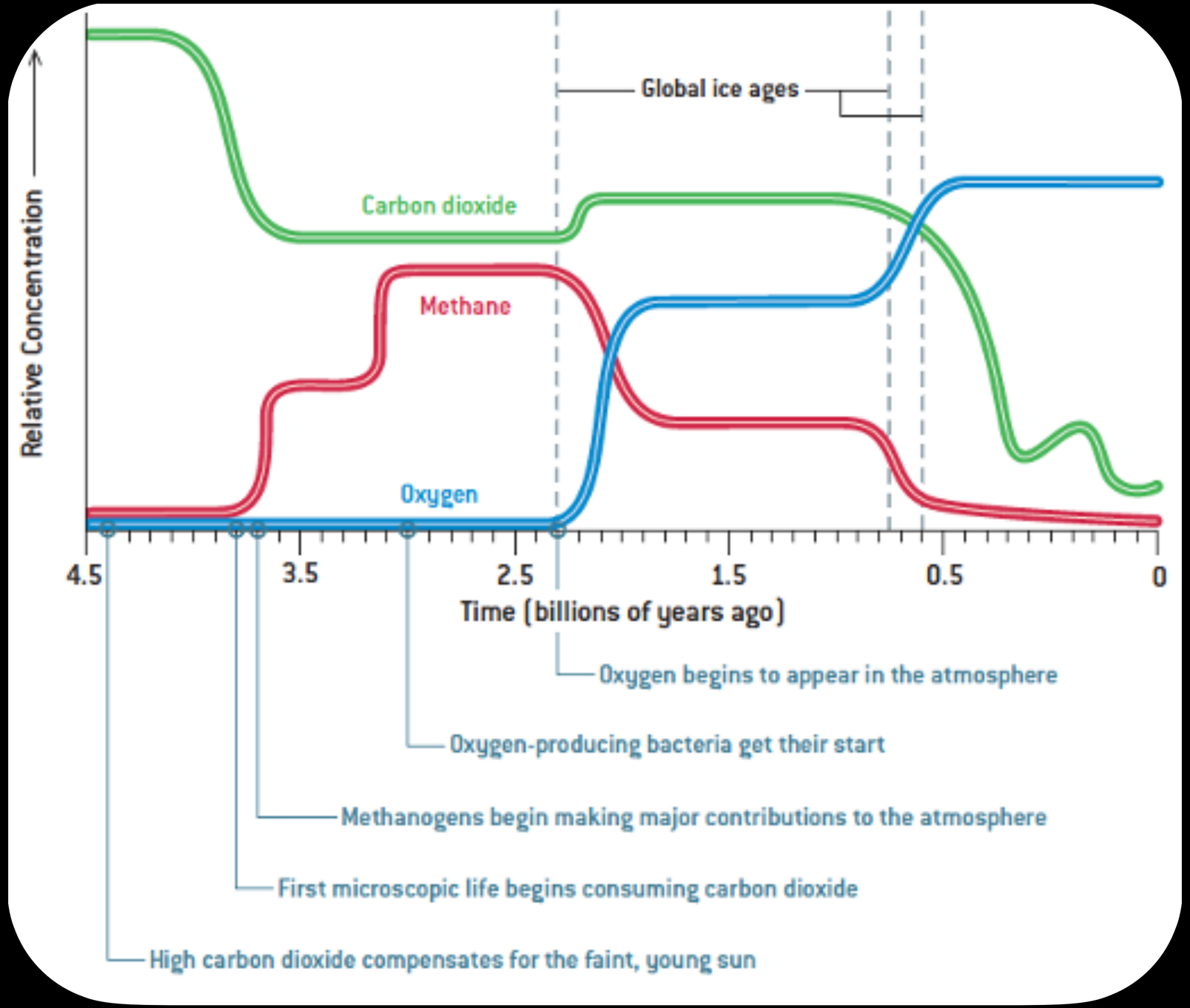
Dwyer et al, 2011



Back to the future

How was the Earth 4 Ga ago?

- The Sun was 25% times fainter.
- The atmosphere was carbon dioxide.
- Life was on the start.



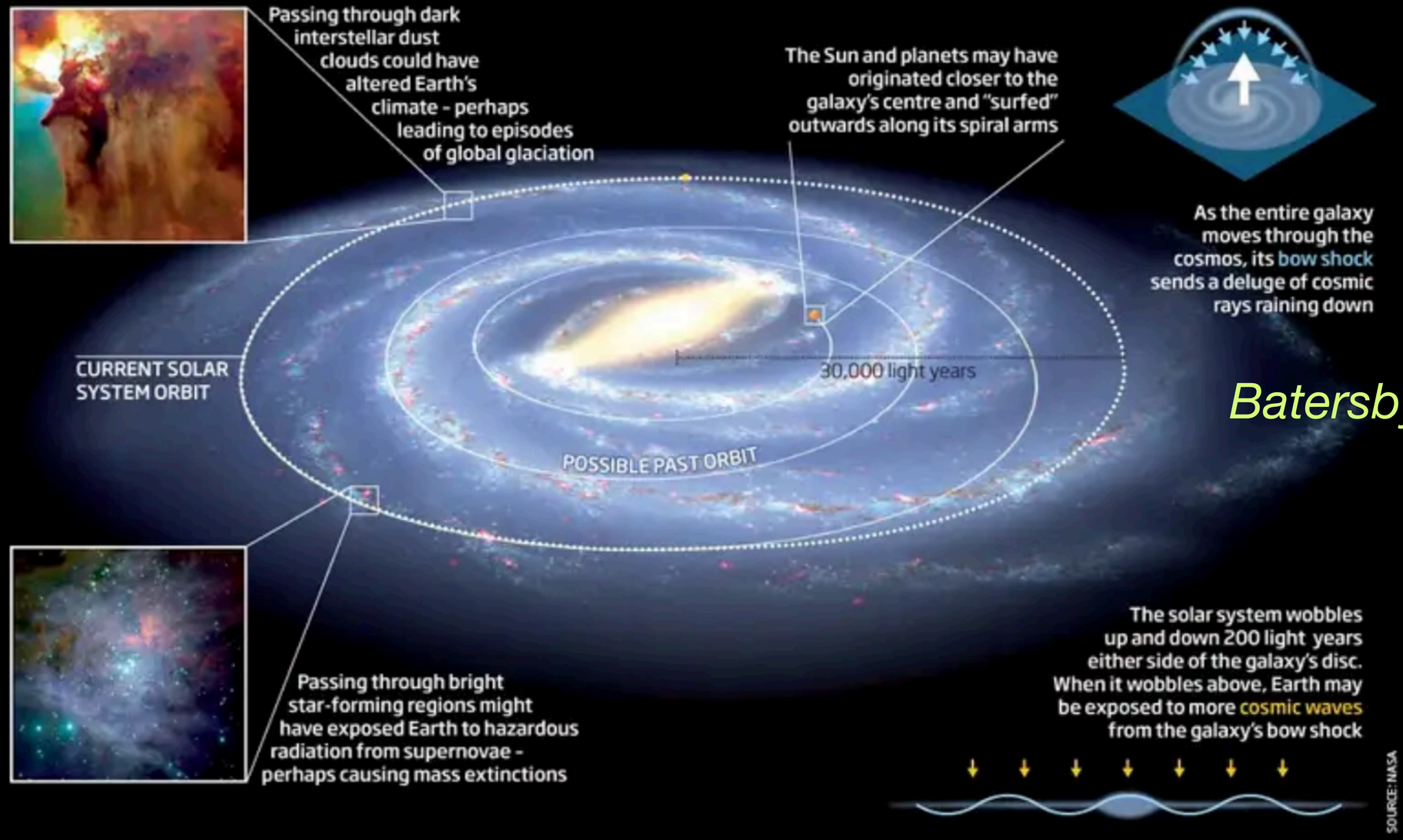
Kasting, 2004

Back to the future

How was the Earth 4 Ga ago?

- The Solar system was somewhere else in the galaxy…

Somewhere in the galaxy…



Batersby, 2011

Back to the future

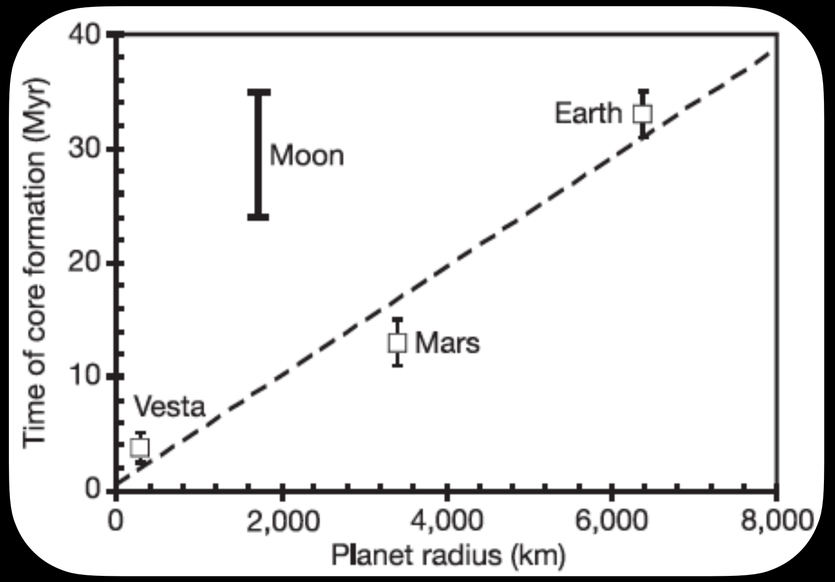
Messengers from the past

Messengers from the past

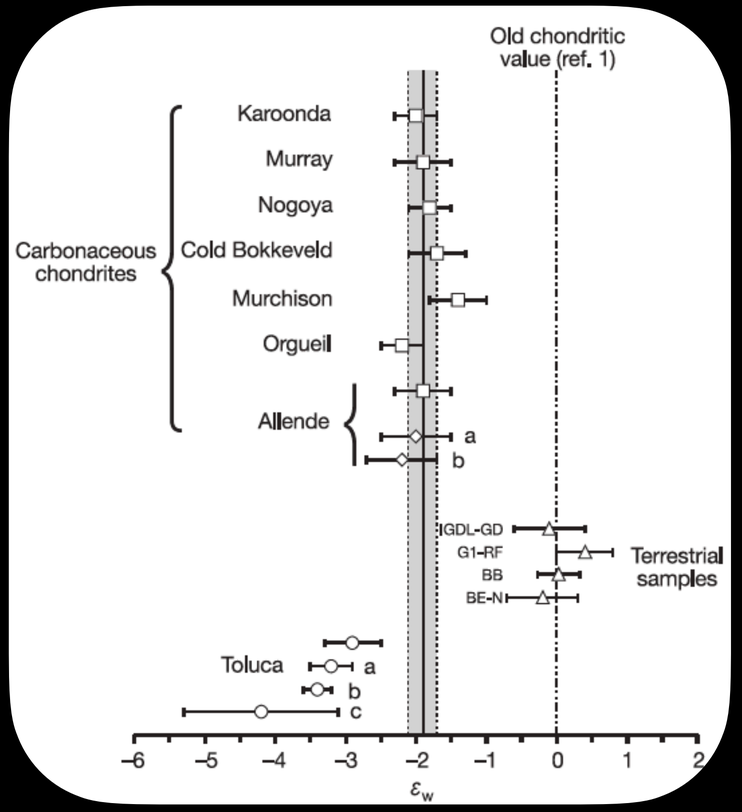
The core of the Earth formed ~30 Ma after the Solar system

$^{182}Hf \rightarrow {}^{182}W$

$T_{1/2} = 8.88$ Ma



Kleine et al, 2002

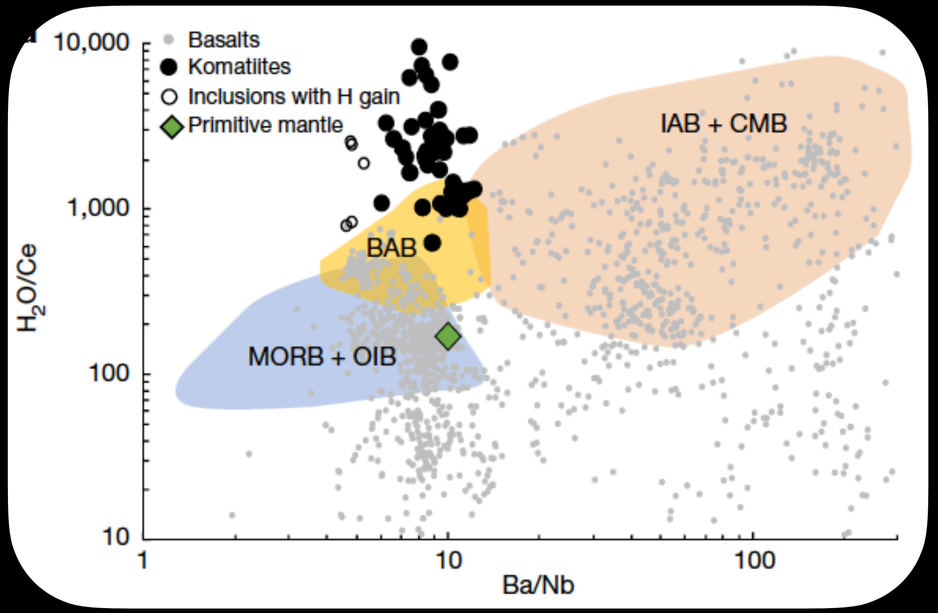


^{182}W / ^{184}W

Messengers from the past

Crustal recycling started before 3.3 Ga ago

« Together with an excess of chlorine and depletion of lead in the mantle sources of komatiites, these results indicate that seawater-altered lithosphere recycling into the deep mantle, arguably by subduction, started before 3.3 billion. »



Sobolev et al, 2019

Pressing questions about the Deep Earth

at the time of my *grand-children*

- Can we construct a 3D Reference Earth Model (at last)?
- Date(s) of birth of plate tectonics?
- Mantle plumes and hotspots: sharpen the view!
- Stratification in the mantle: where? how much? origin? evolution? role?
- Can we express, measure, and model the rheologies of the solid Earth?

Pressing questions about the Deep Earth

at the time of my *grand-children*

- What is going on at the core-mantle boundary?
- History of heat flow at the CMB?

Pressing questions about the Deep Earth

at the time of my *grand-children*

- How large is thermal conductivity in the core?
- How old is the inner core? How viscous?
- Stratification in the core: where? how much? origin? evolution? role?
- Can we map the magnetic field inside the core?
- What causes magnetic reversals?
- Flows due to orbital forcings in the core?

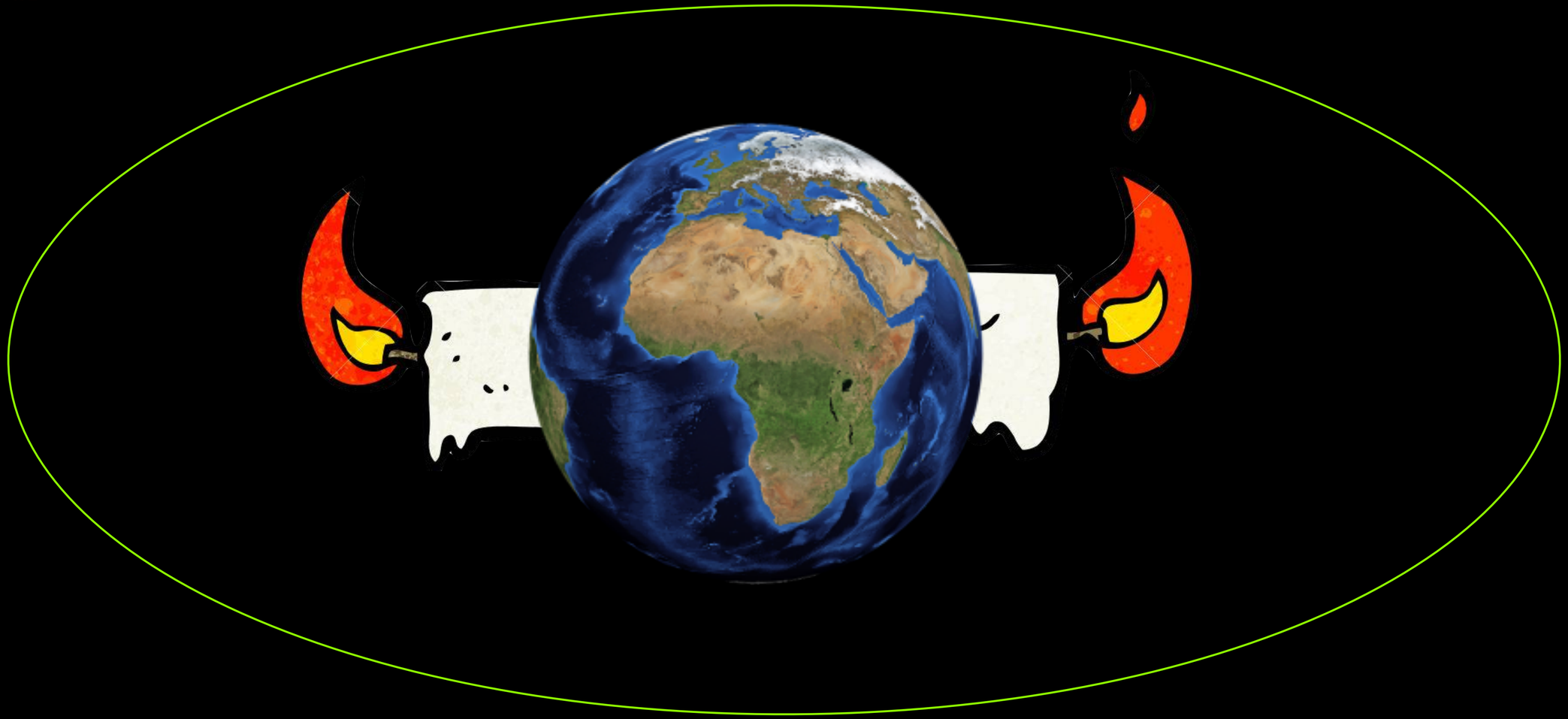
Pressing questions about the Deep Earth

at the time of my *grand-children*

- Origin(s) of life on Earth?
- Has Venus had a magnetic field? An inner core?
- Elsewhere in the Solar system…
- Elsewhere in the galaxy…

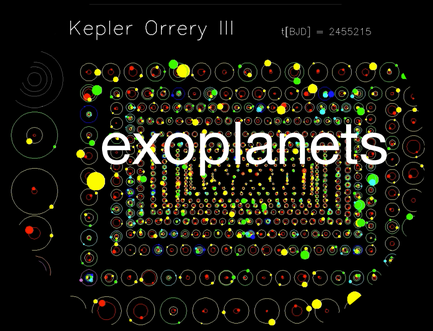
The new tools that they (you) will have

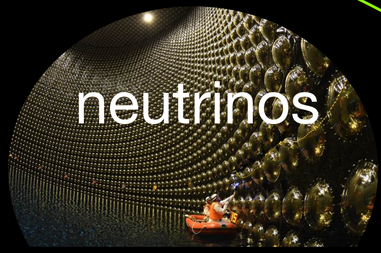
Caveat!

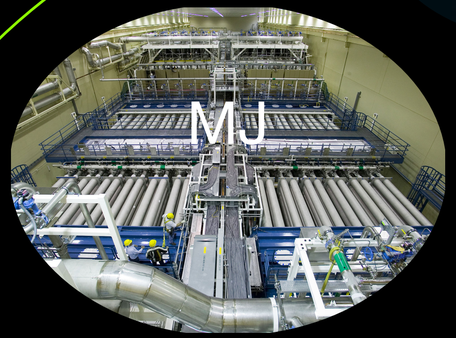


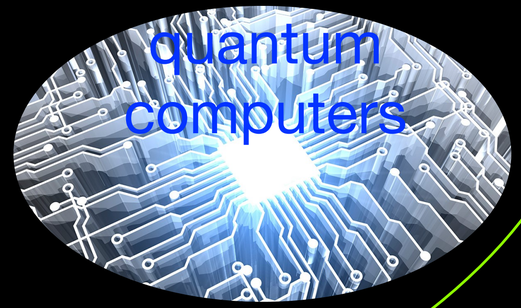
The new tools that they (you) will have

perhaps…









Thank you

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to delve further…

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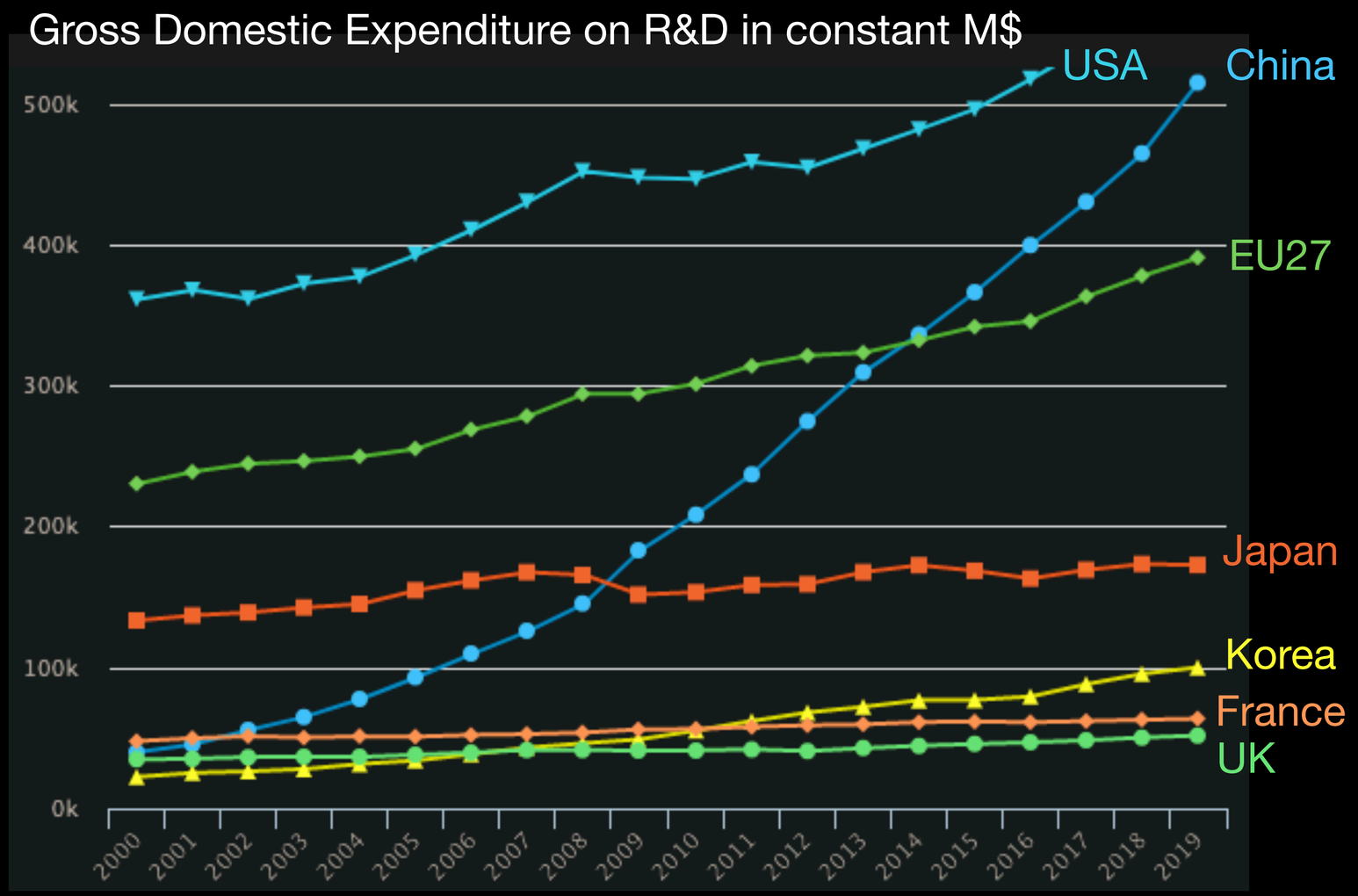
to delve further…



https://www.oecd.org/sti/scoreboard.htm