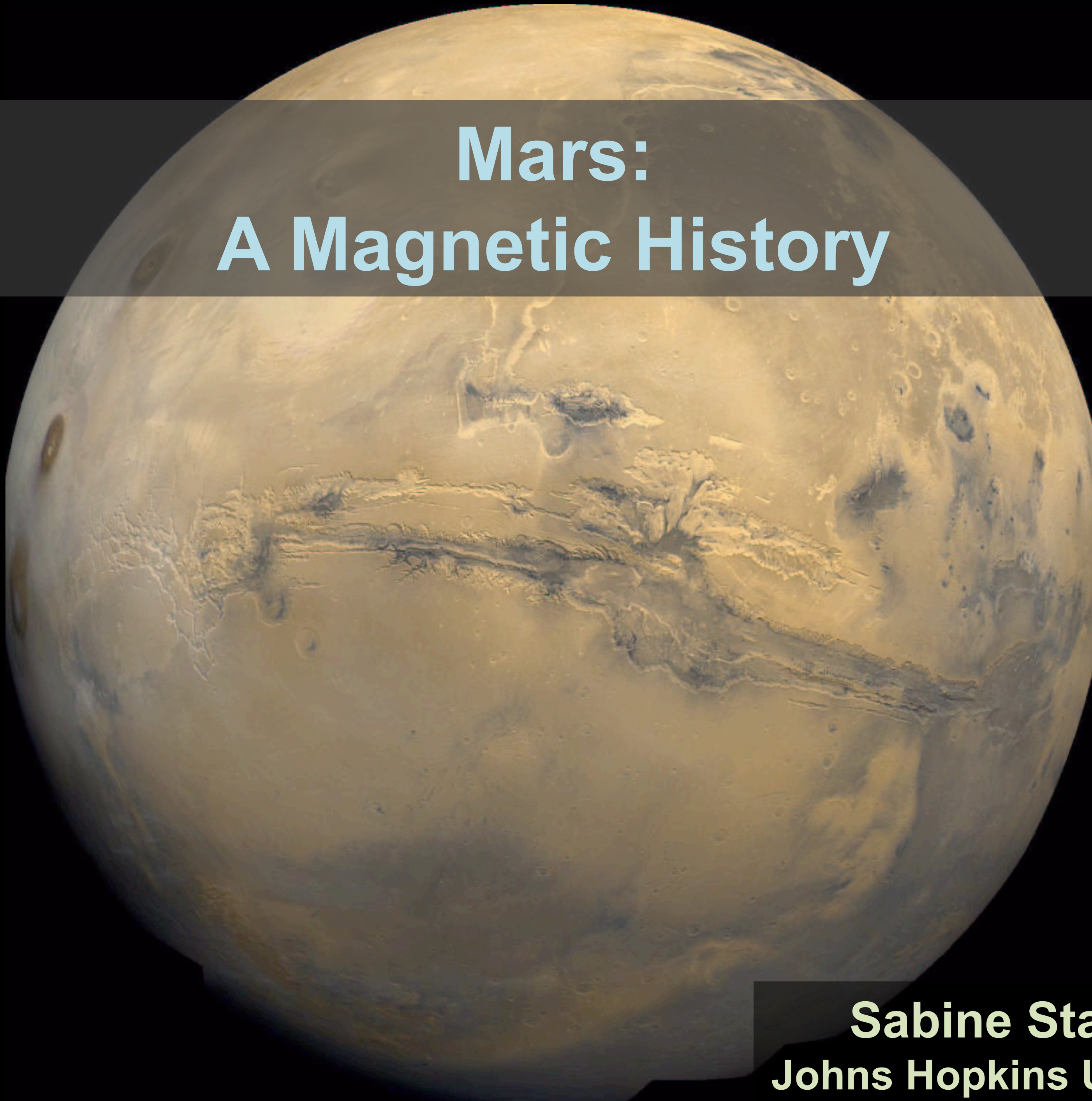
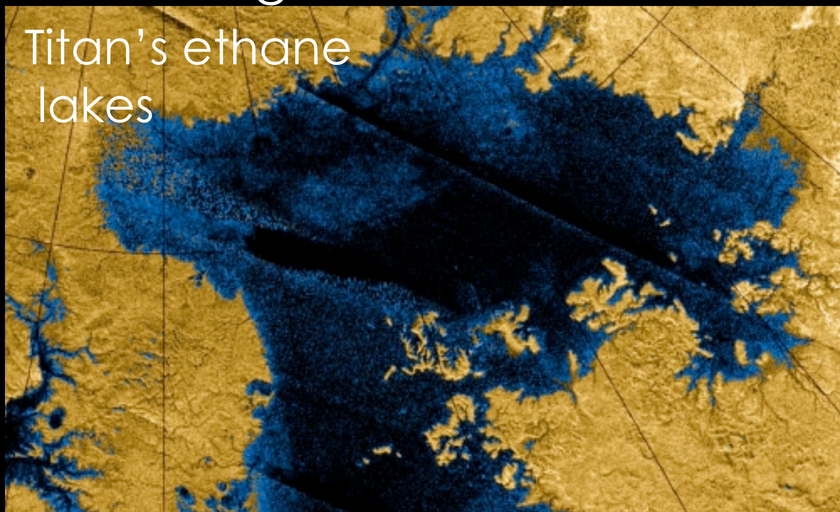
Mars: A Magnetic History



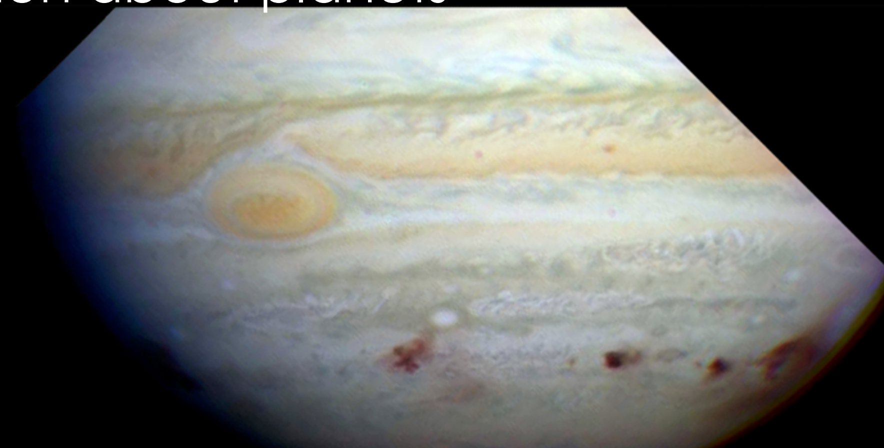
Sabine Stanley
Johns Hopkins University

Planetary Science

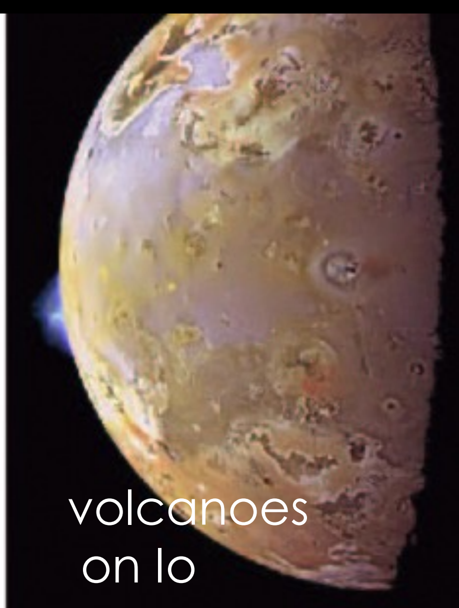
- over the past few decades, spacecraft missions have provided stunning observations and information about planets



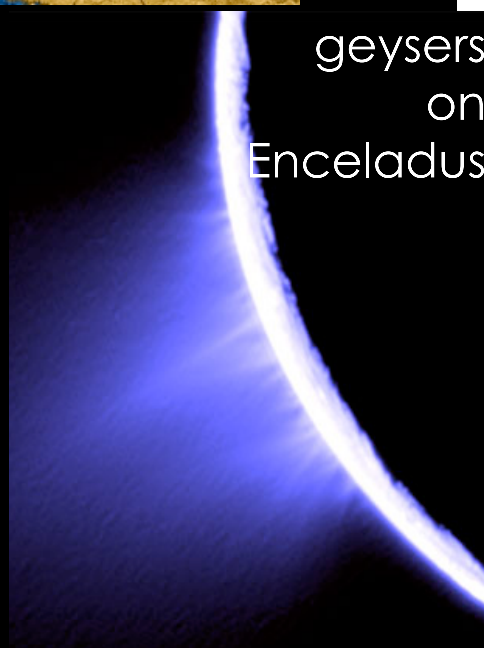
Titan's ethane lakes



Shoemaker-Levy 9 impacting Jupiter



volcanoes on Io

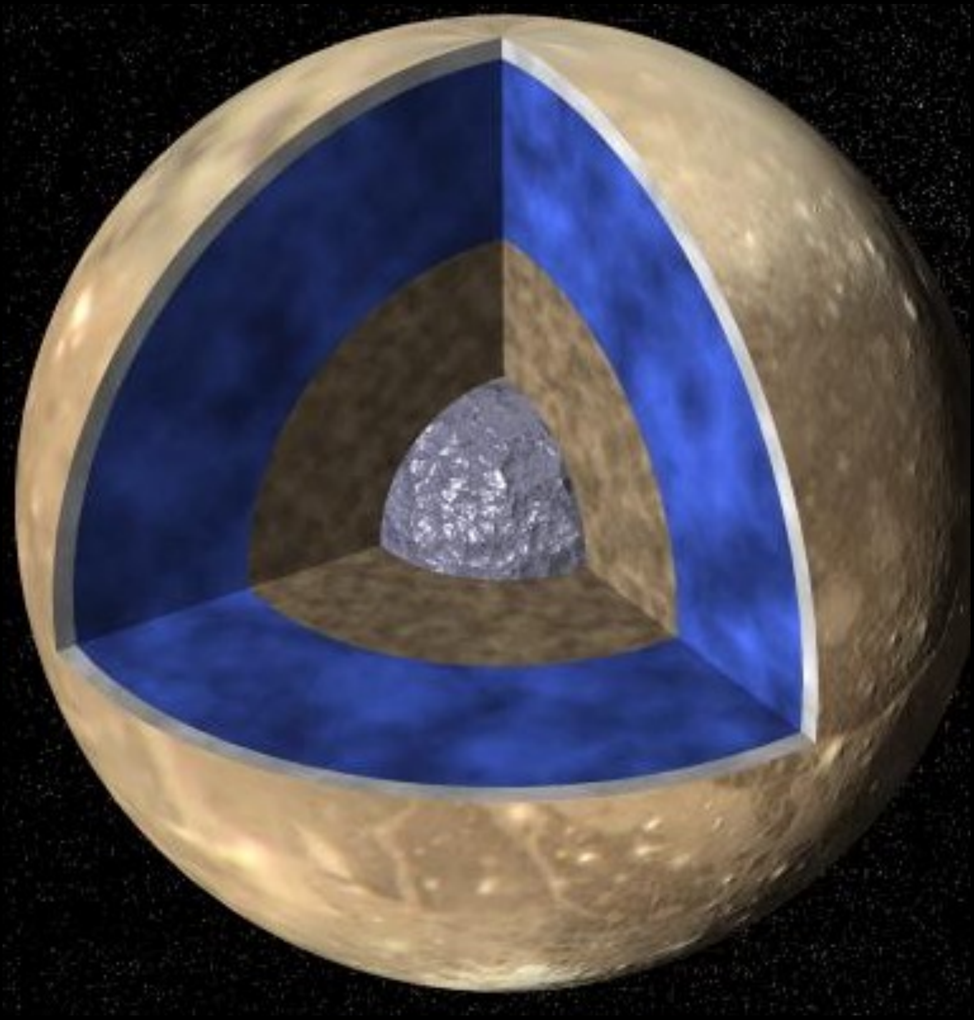


geysers on Enceladus

water on Mars

Planetary Science

- most of the information is about features & physical processes near the surface
- the deeper inside the planet, the less we know



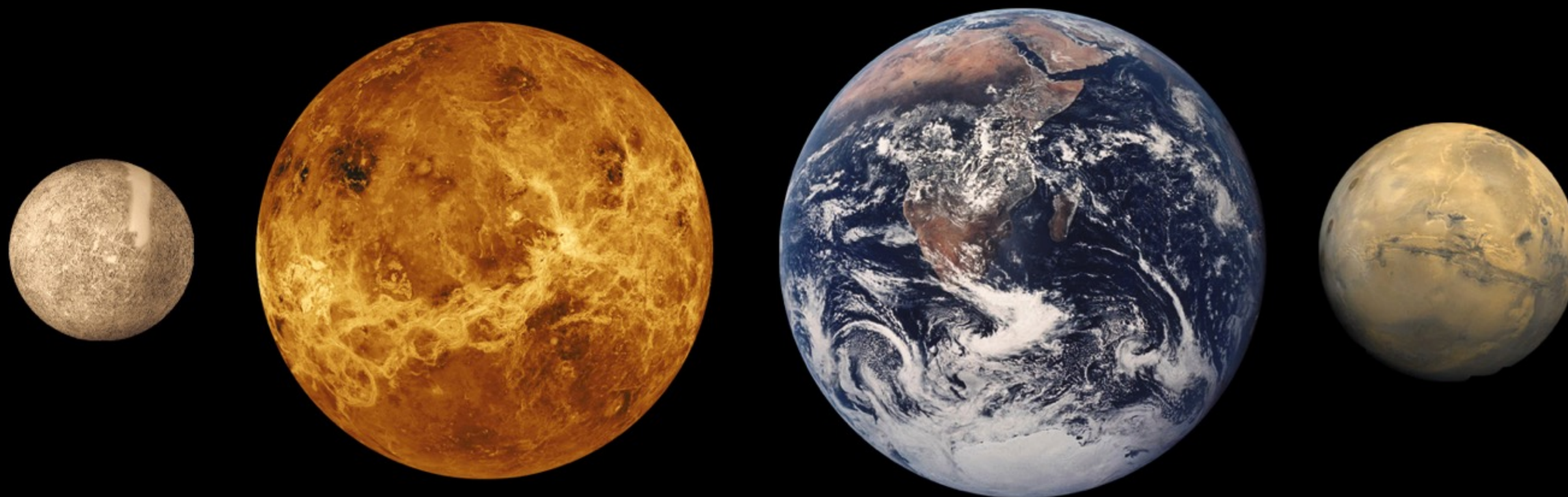
- its HARDER to get info on the deep interior, because we need processes in the interiors to produce observables at the surface

- one process that occurs in the deepest regions of some planets and is observable is:

magnetic field generation

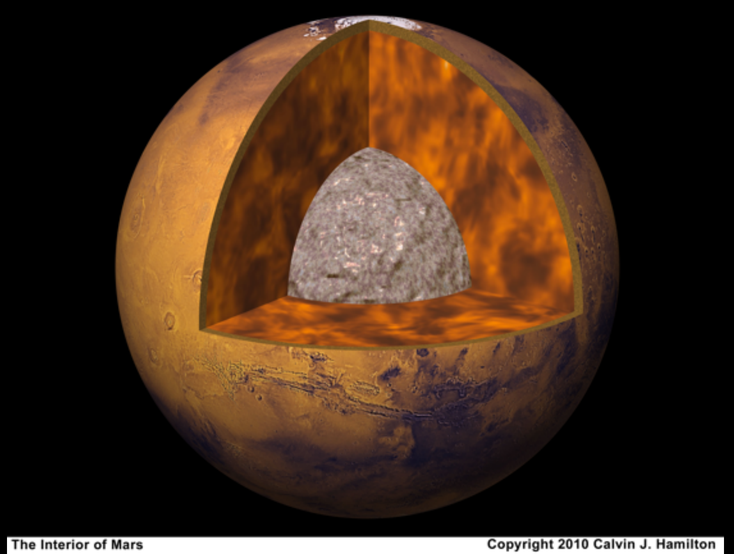
Terrestrial planet comparison

•about half the size of Earth



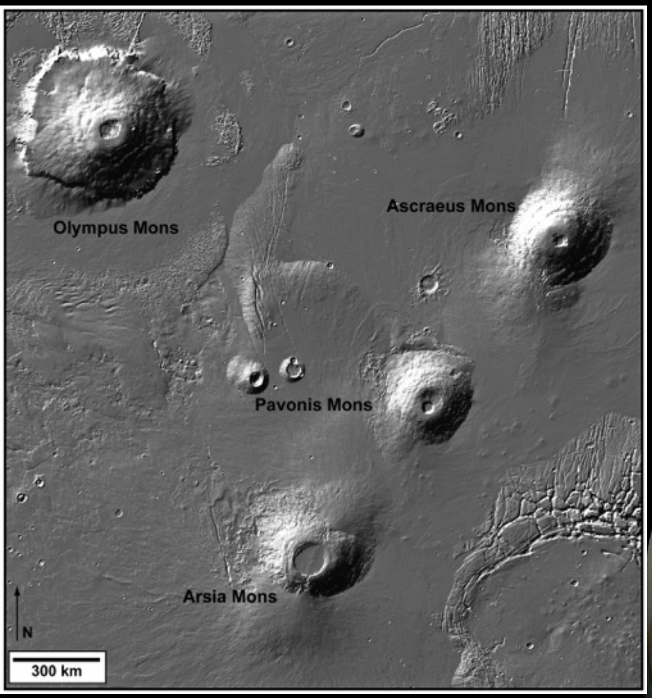
Mars has a core, mantle and crust like
other terrestrial planets

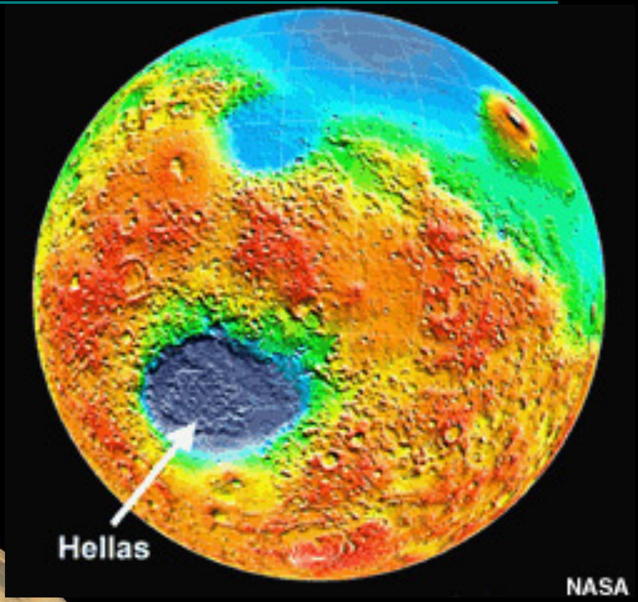
and although its small…



XL surface features

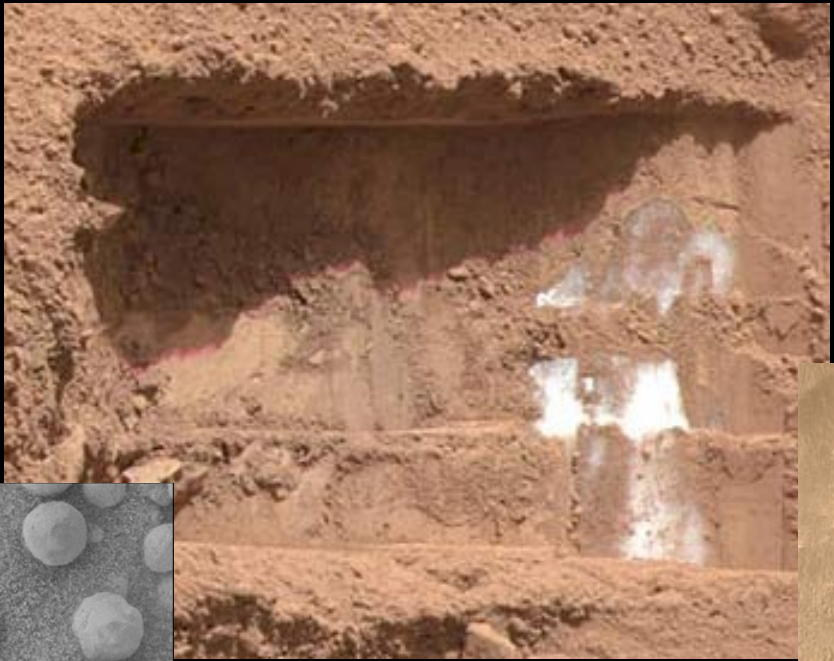
- large impact craters: Hellas & Argyre
- Tharsis volcanic province
- Valles Marineris

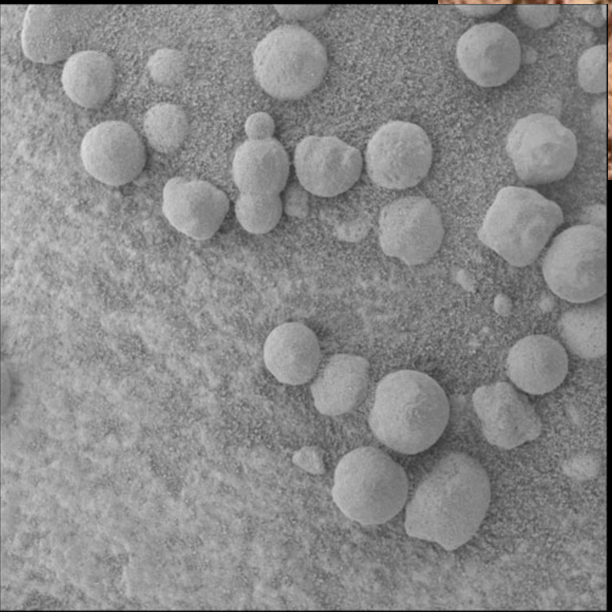




Lots of new data

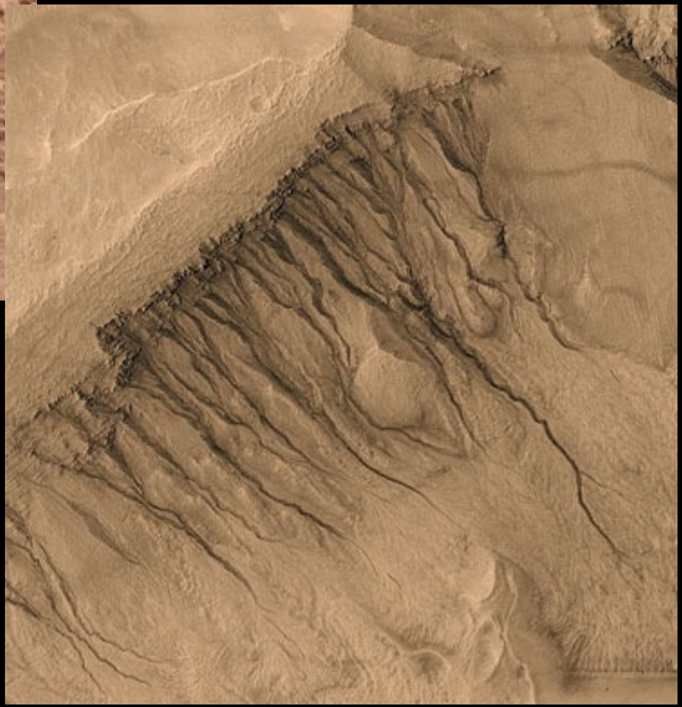
- recent missions: MGS, Mars Express, rovers, MAVEN, …
- mapping of topography, gravity, surface composition, magnetic fields
- local in-situ analysis of rocks, ice





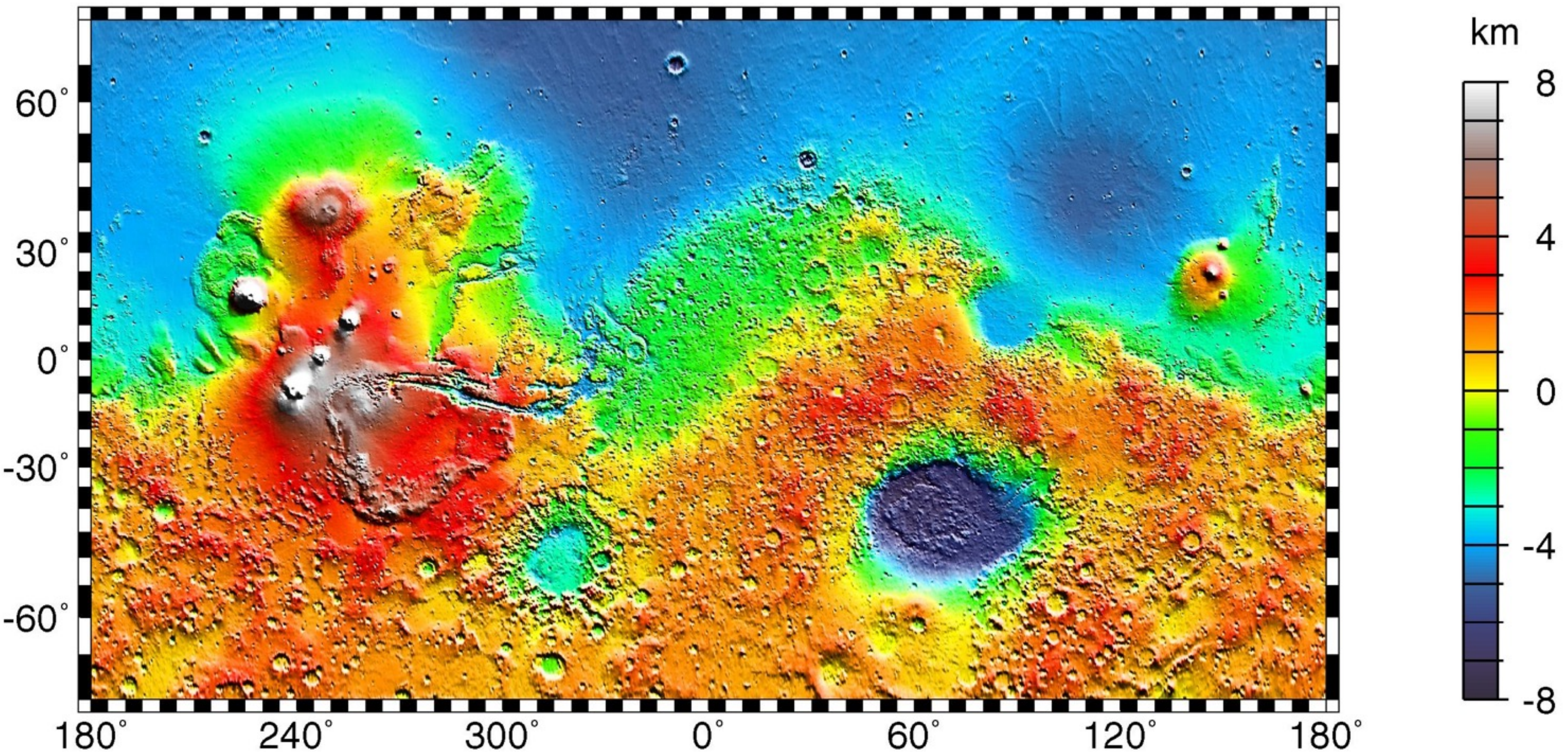
Mars today:
no surface liquid water, thin atmosphere

Mars in early history:
surface liquid water, thick atmosphere

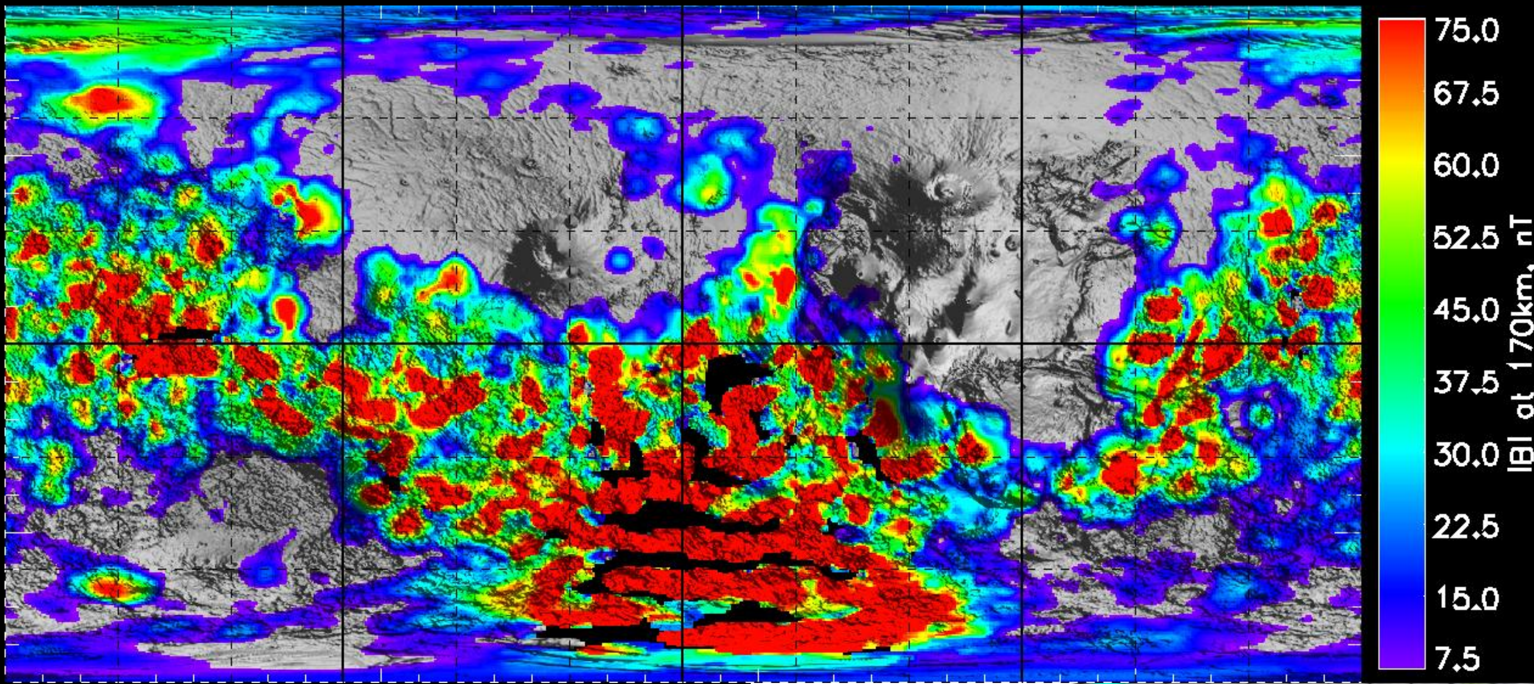


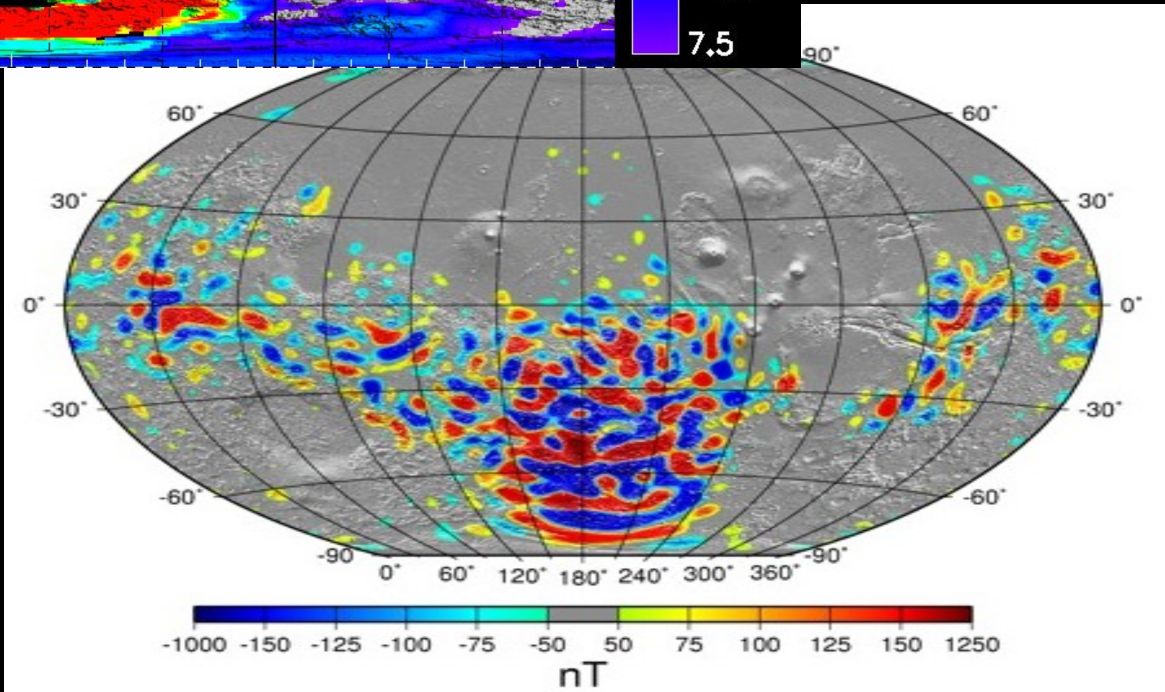
Mars topography

- hemispheric crustal dichotomy: north: low
  south: high
- can also see Tharsis, Valles Marineris, large impact craters



Mars magnetic field





- extremely strong localized crustal magnetism

Mars: A Magnetic History

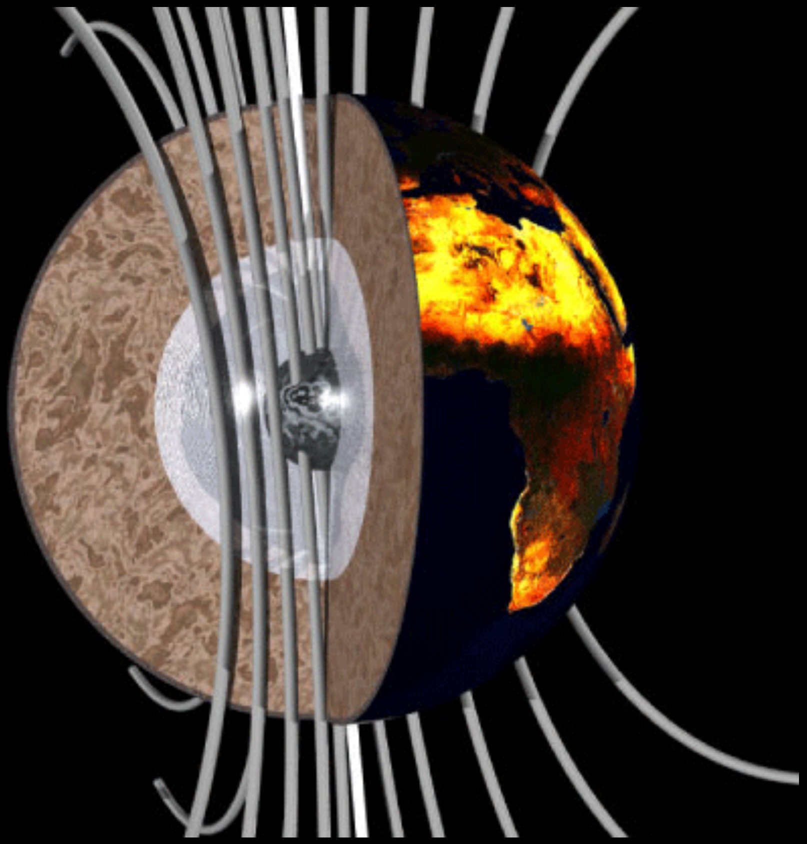
•magnetic fields especially useful because:

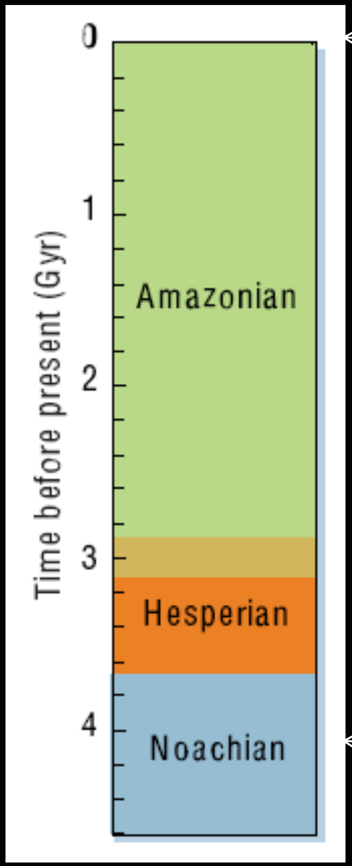
(1) source is deep, but can be observed with spacecraft

→ can probe deep interior

(2) rocks can record past magnetic fields

→ can probe history

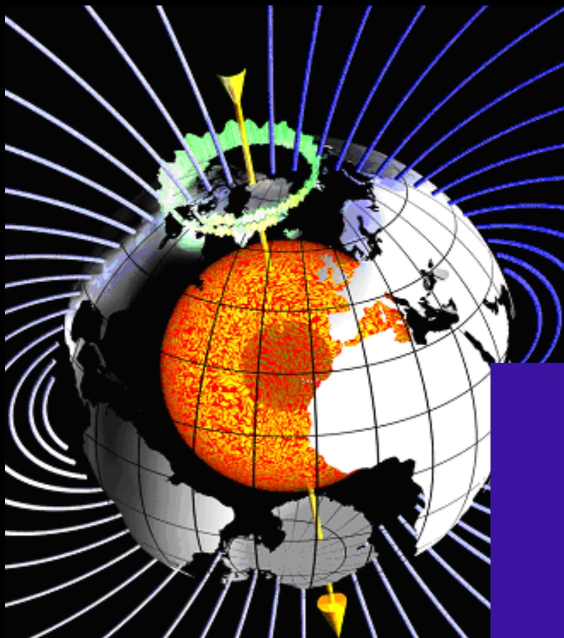




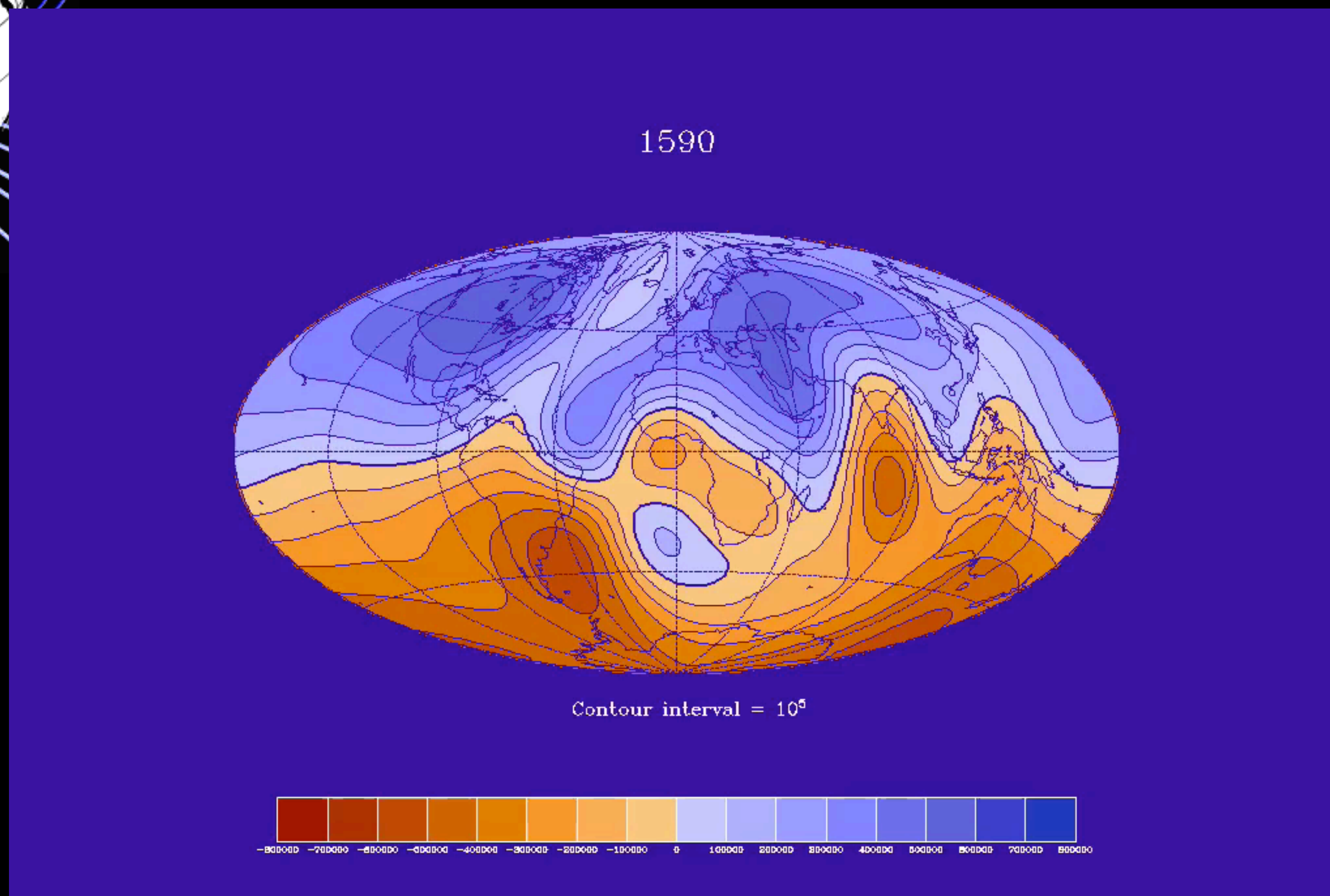
magnetic fields observed here

magnetic fields generated here

Earth magnetism

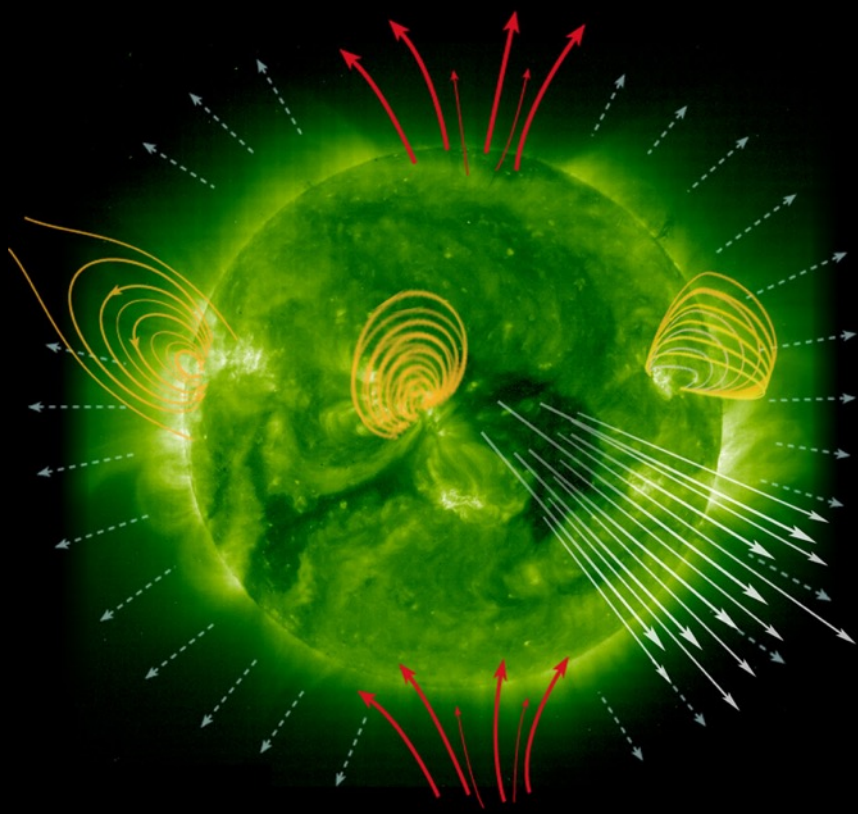


- axial dipole dominated
- reversals
- variable in time

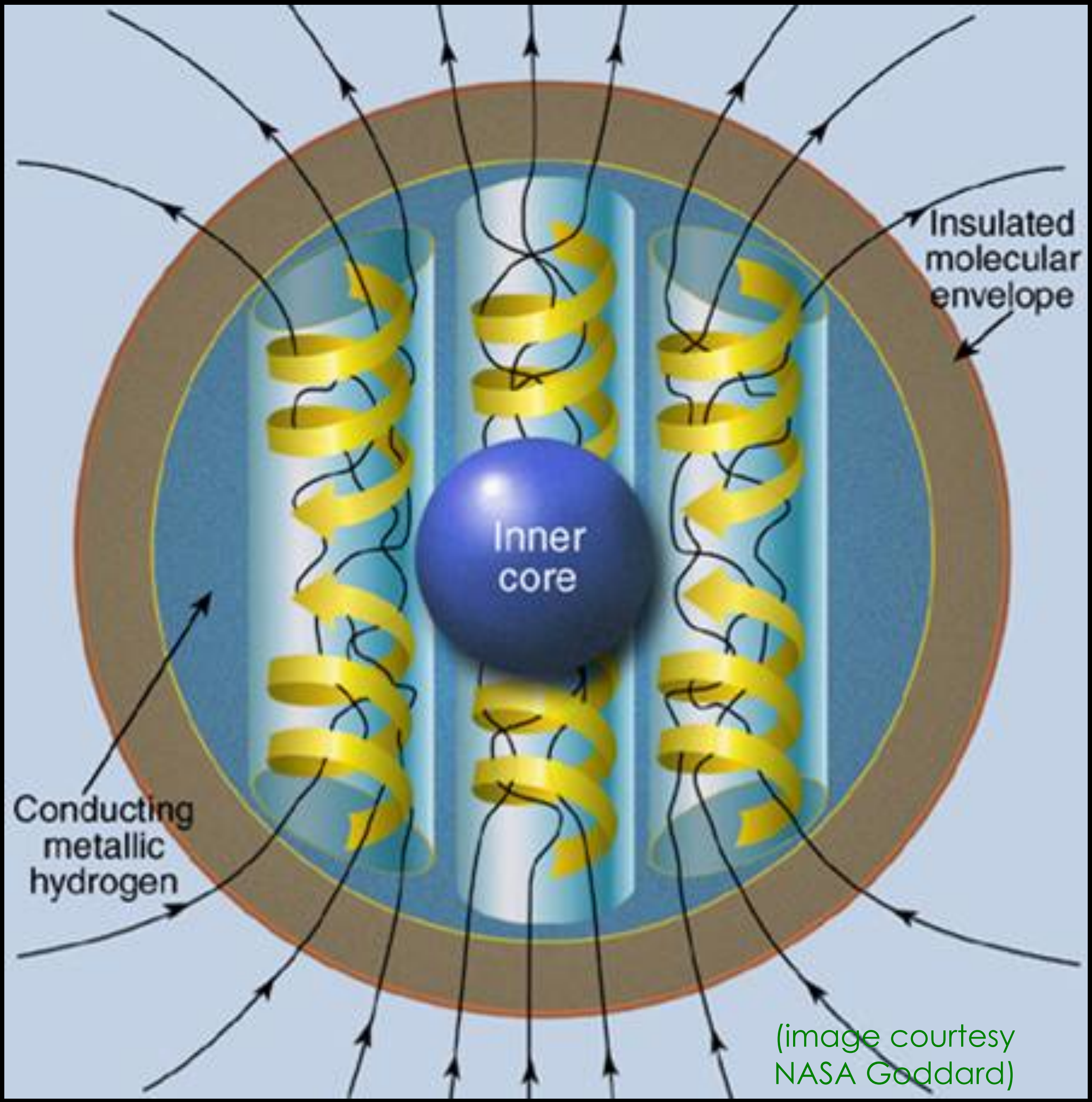


Dynamo generation

- conversion of mechanical energy (motion) into electromagnetic energy
- occurs in some planets, stars, galaxies, generators, bicycles…



Planetary Dynamo Ingredients



complex motions

+

electrically conducting fluid

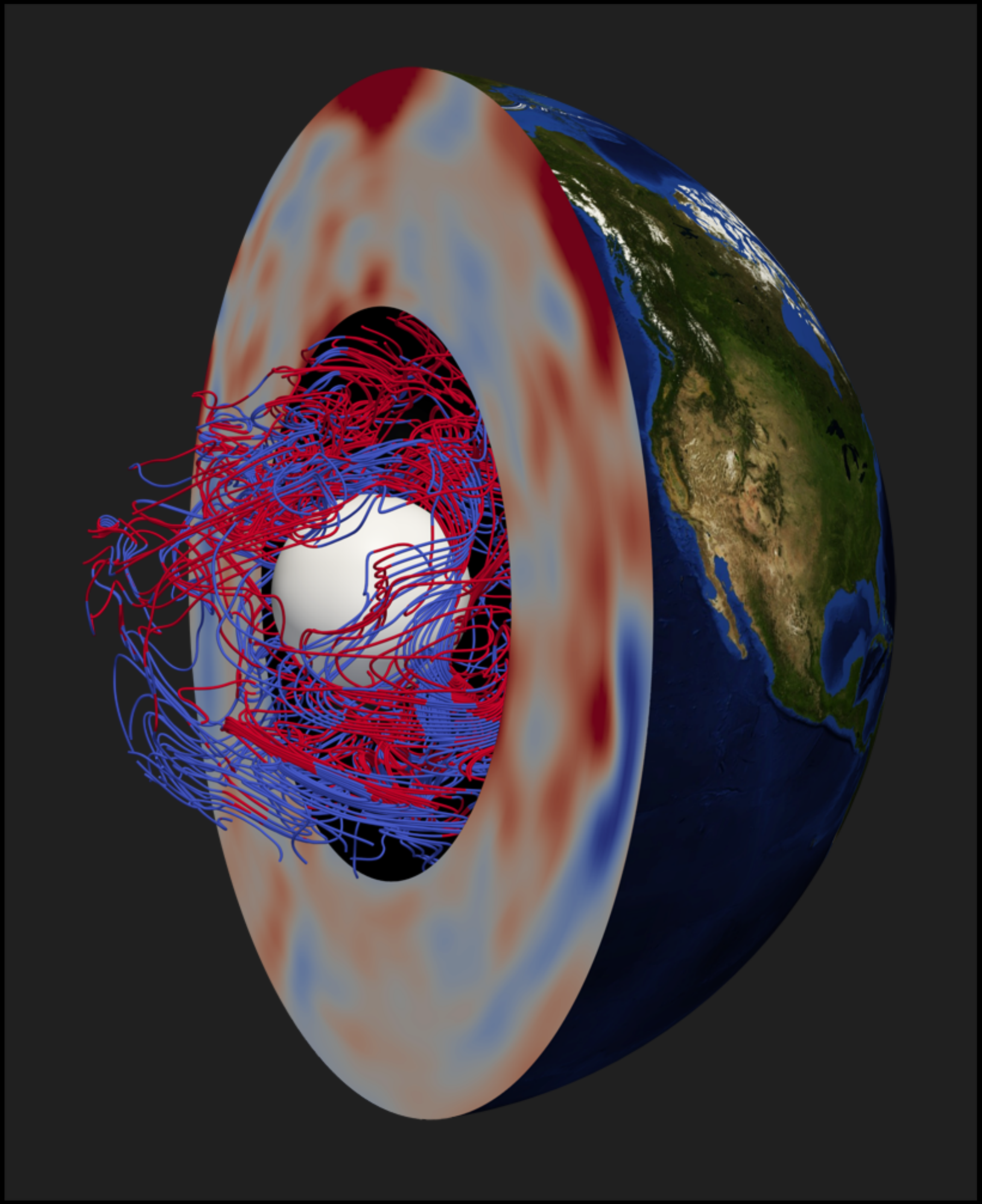
+

presence of a magnetic field

⇓

maintain field against Ohmic decay

Dynamo generation



(1) electrically conducting fluid

- liquid iron (terrestrial planets)
- metallic hydrogen (gas giants)
- ionized water (ice giants)

(2) fluid must have complex motions

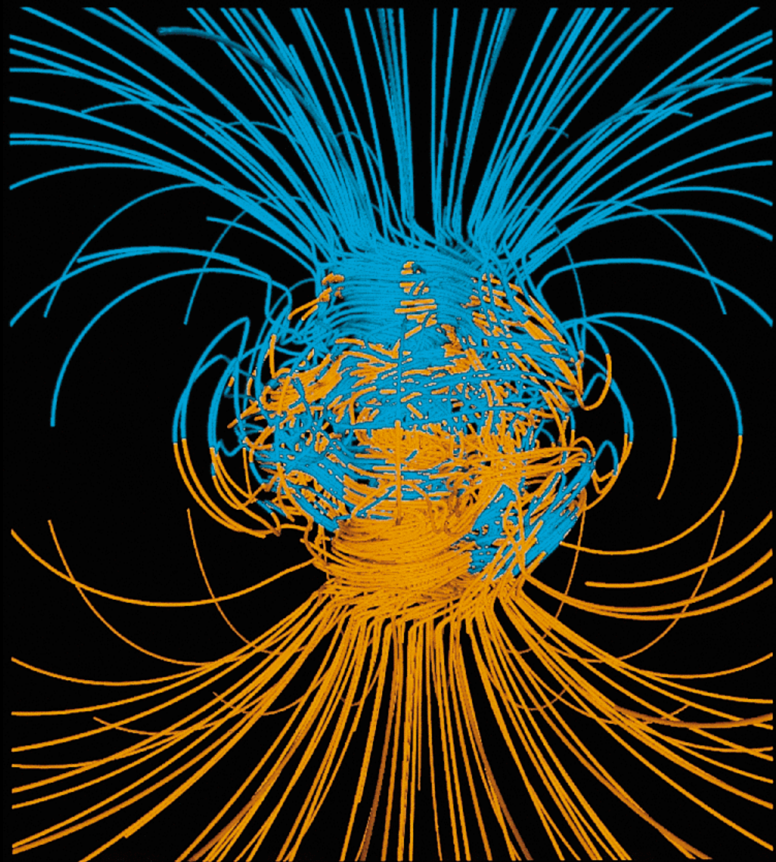
- lots of twisting, helical
- rotation not required, but helpful in producing large-scale field

(3) motions must be vigorous enough

- Velocity * Size * Conductivity must be big enough

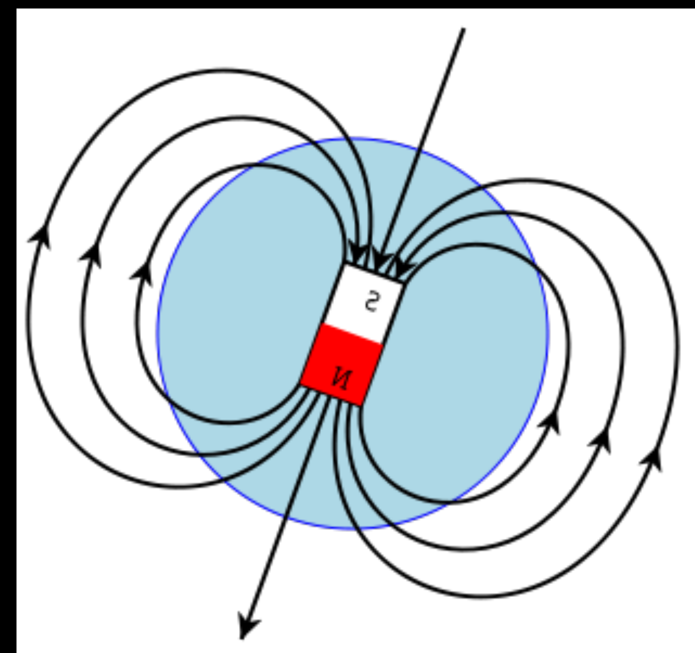
Earth's Magnetic Field

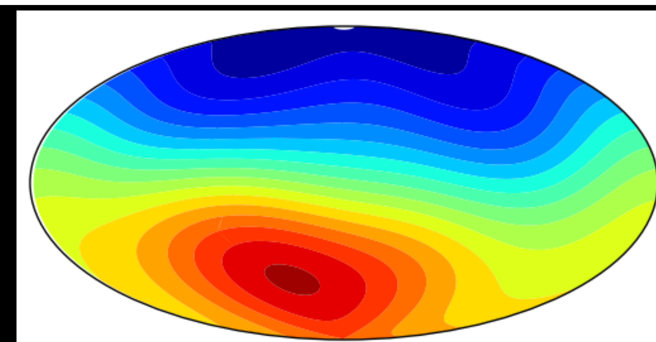
- We can only observe the field outside the surface.
- We try to infer what goes on in the dynamo source region



http://www.es.ucsc.edu/~glatz/index.html

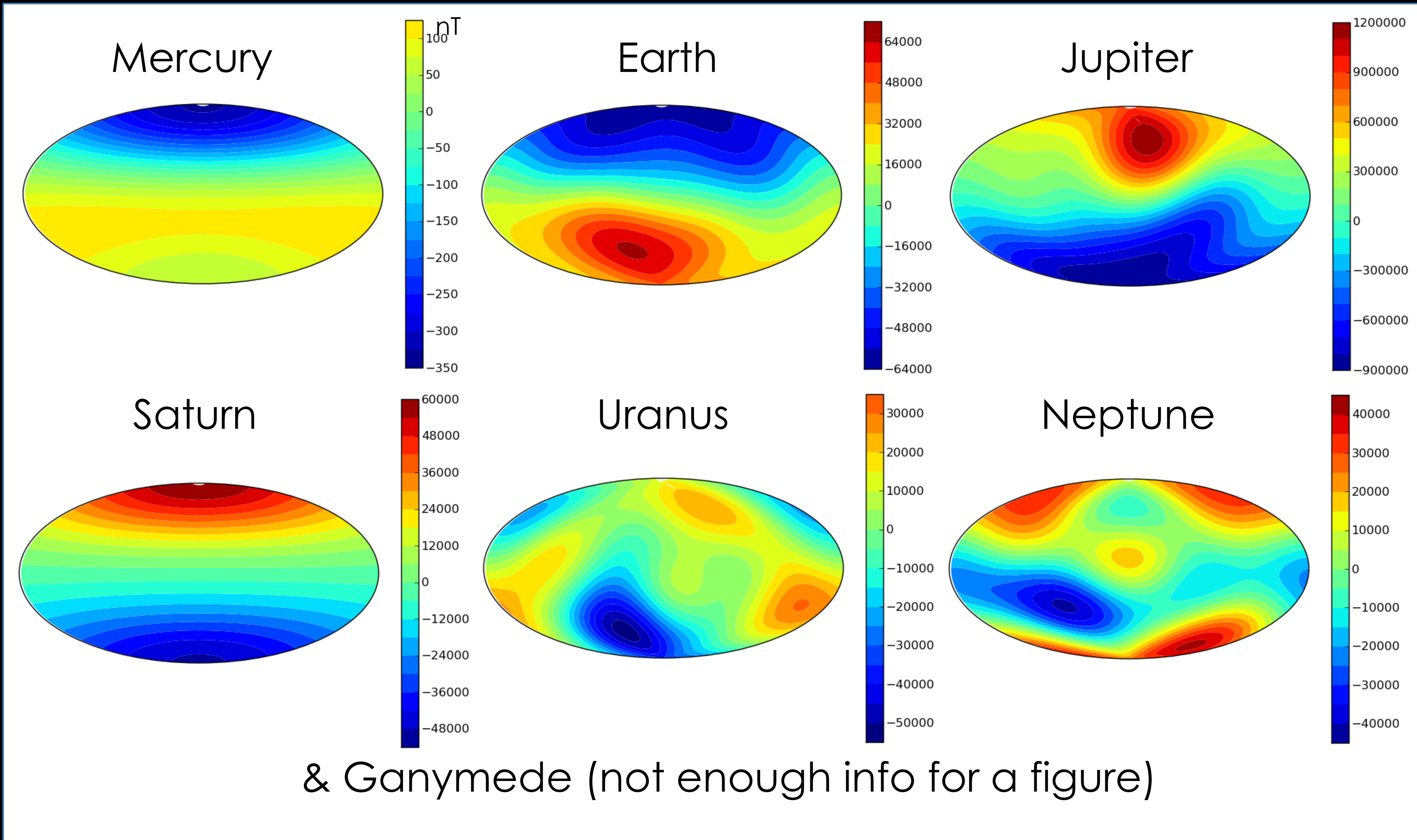
- field in the source region likely very complicated





- observed field at the surface very dipolar

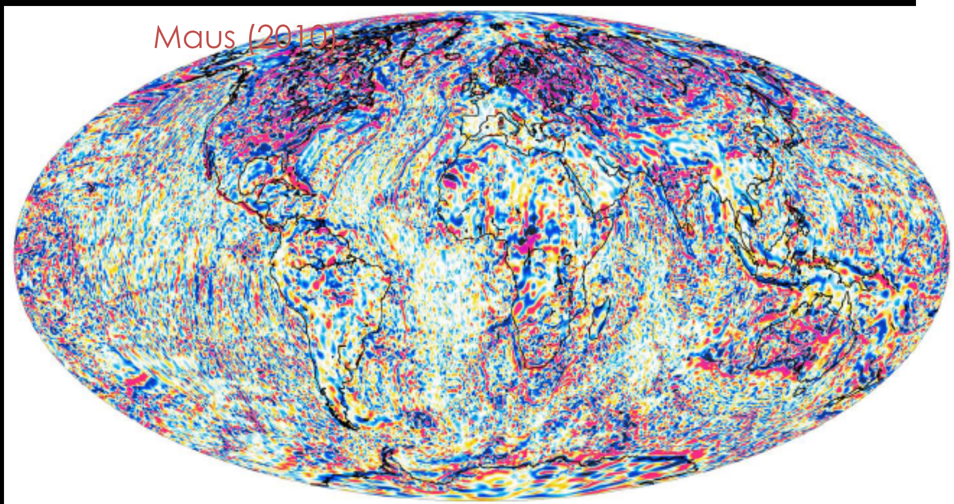
Magnetic Field Diversity



- there are similarities & differences which are linked to interior properties

Evidence of Past Dynamos

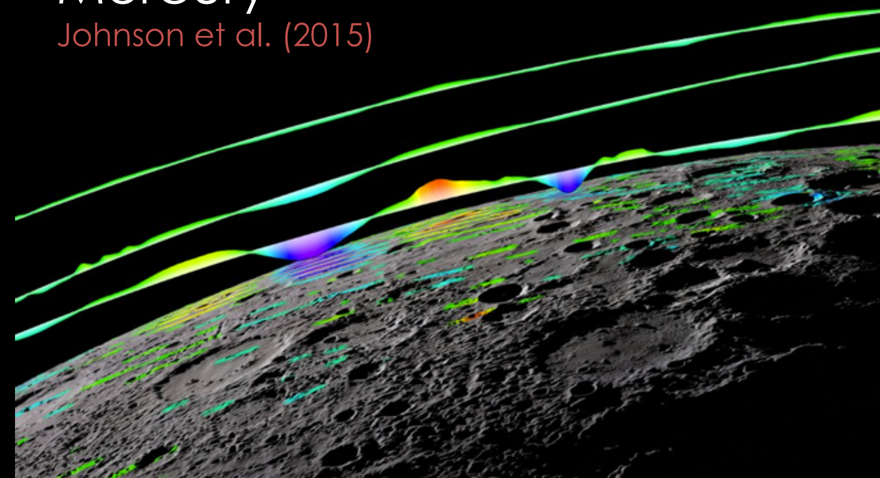
Earth @ surface



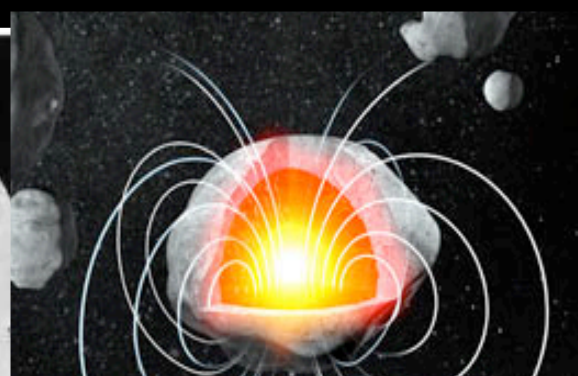
Maus (2010)

Mercury

Johnson et al. (2015)

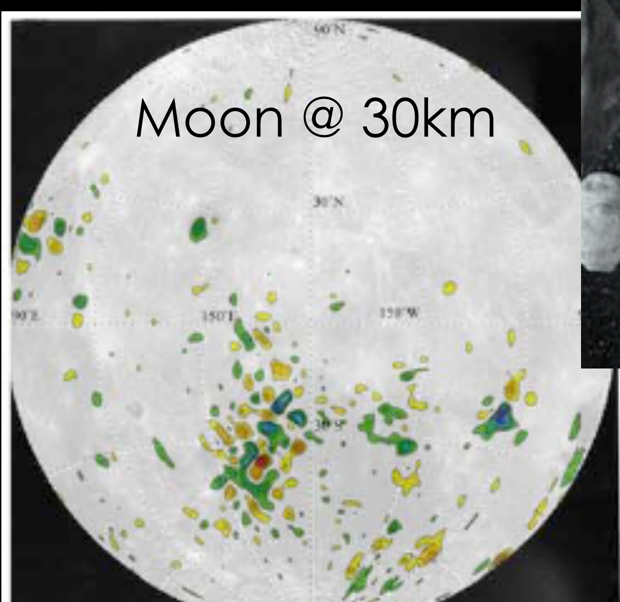


Planetesimals & Asteroids



Weiss et al. (2008)

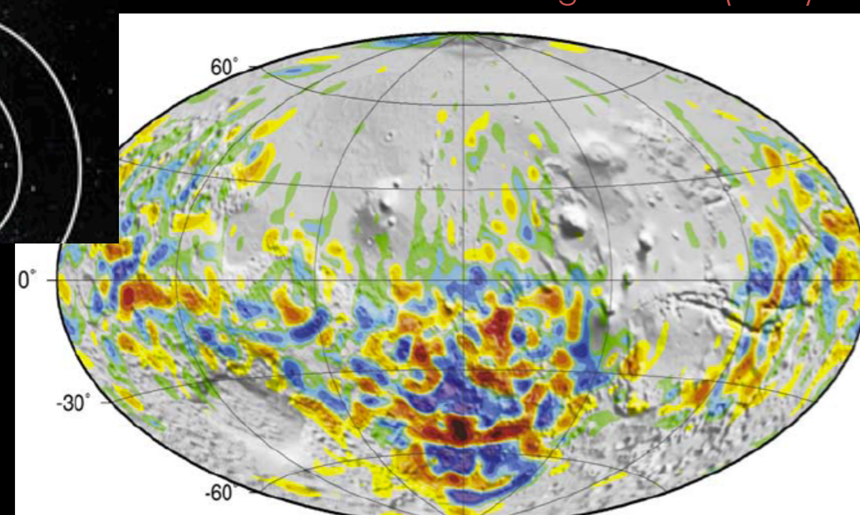
Moon @ 30km



Richmond & Hood (2008)

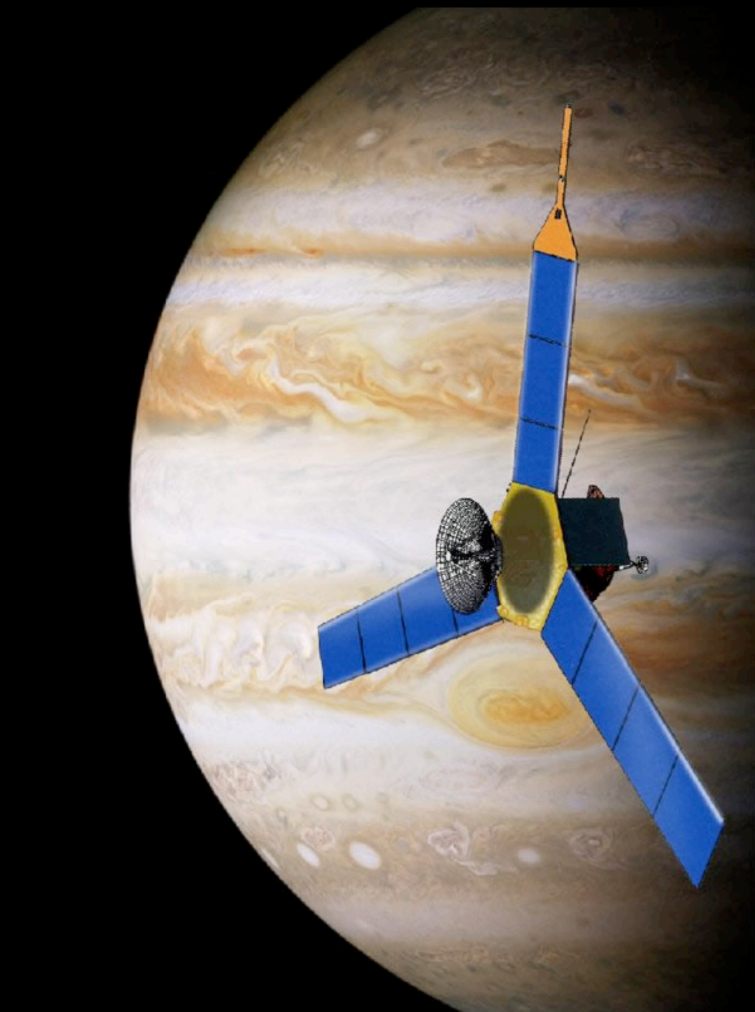
Mars @ 200km

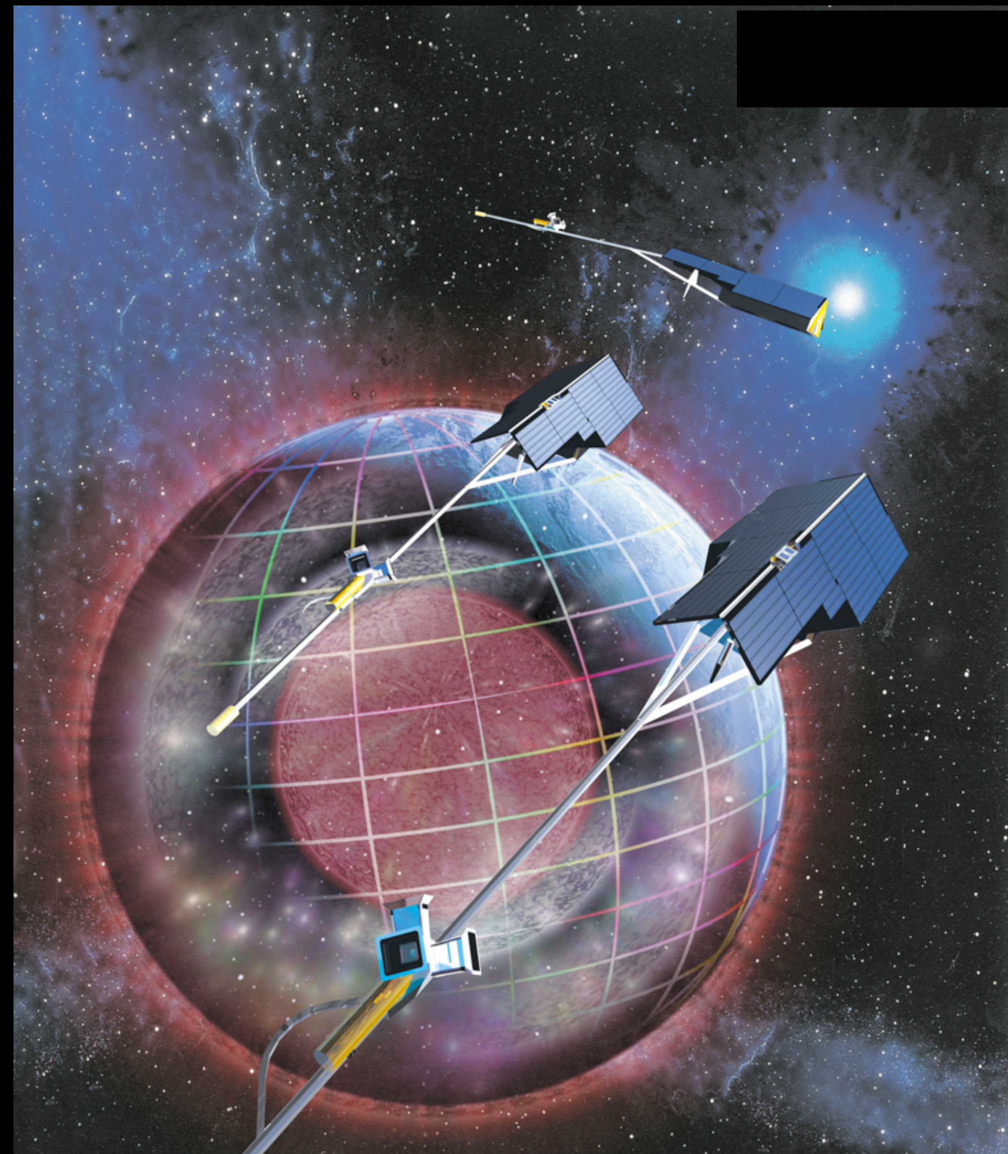
Langlais et al. (2004)



Studying Planetary Magnetic Fields

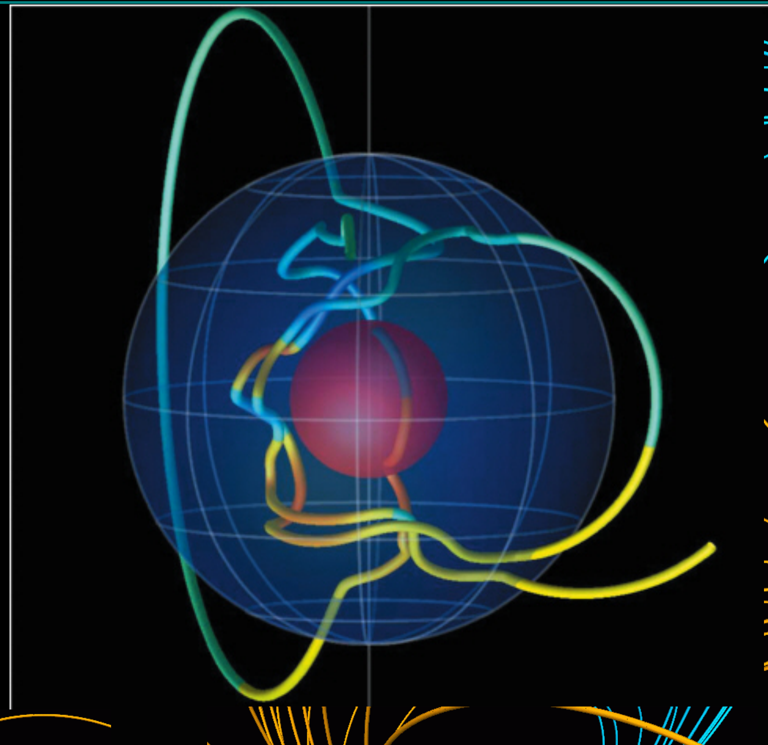
- observations from spacecraft

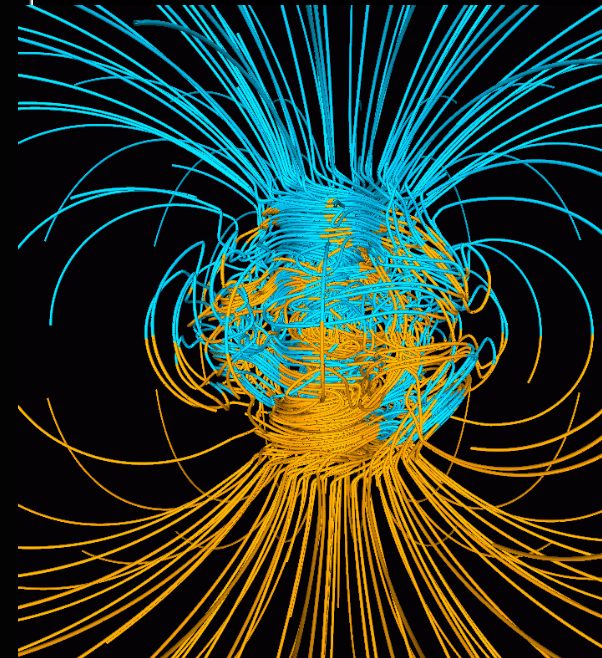


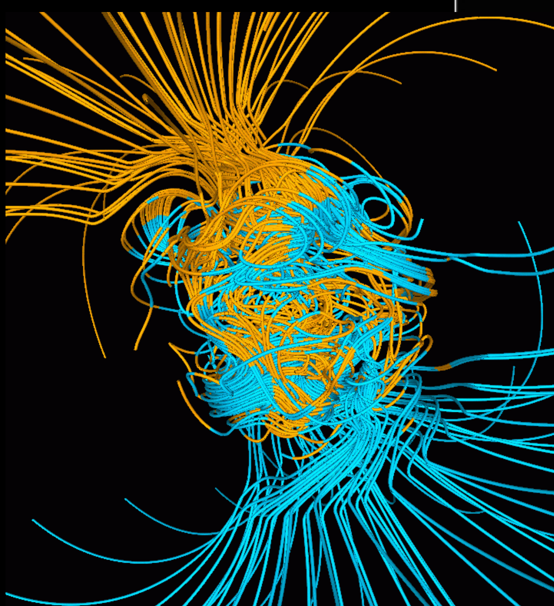


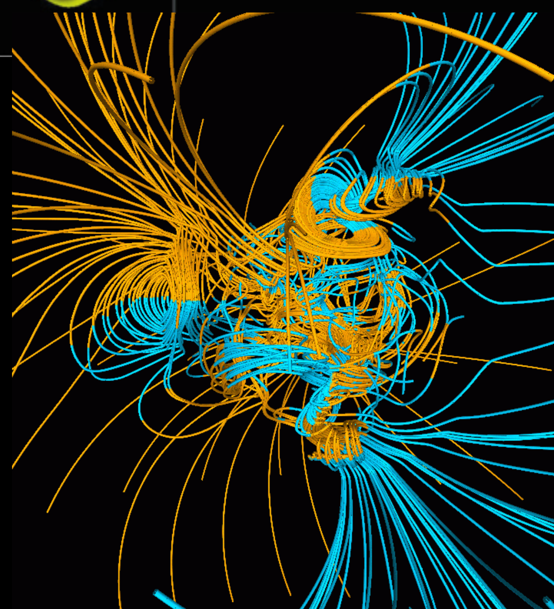
Studying Planetary Magnetic Fields

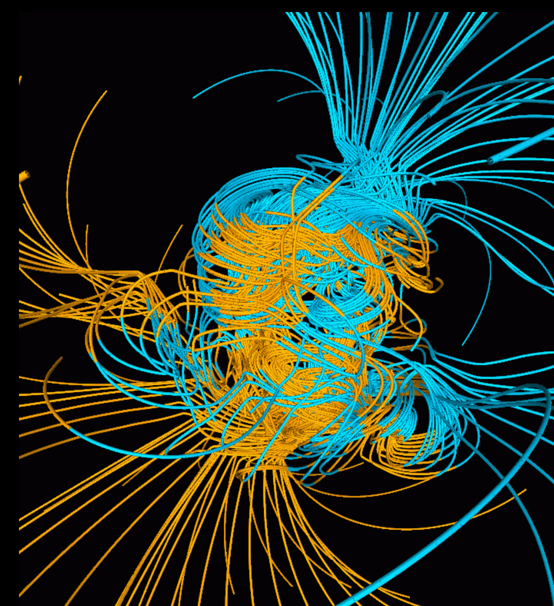
Computer simulations of dynamo generation





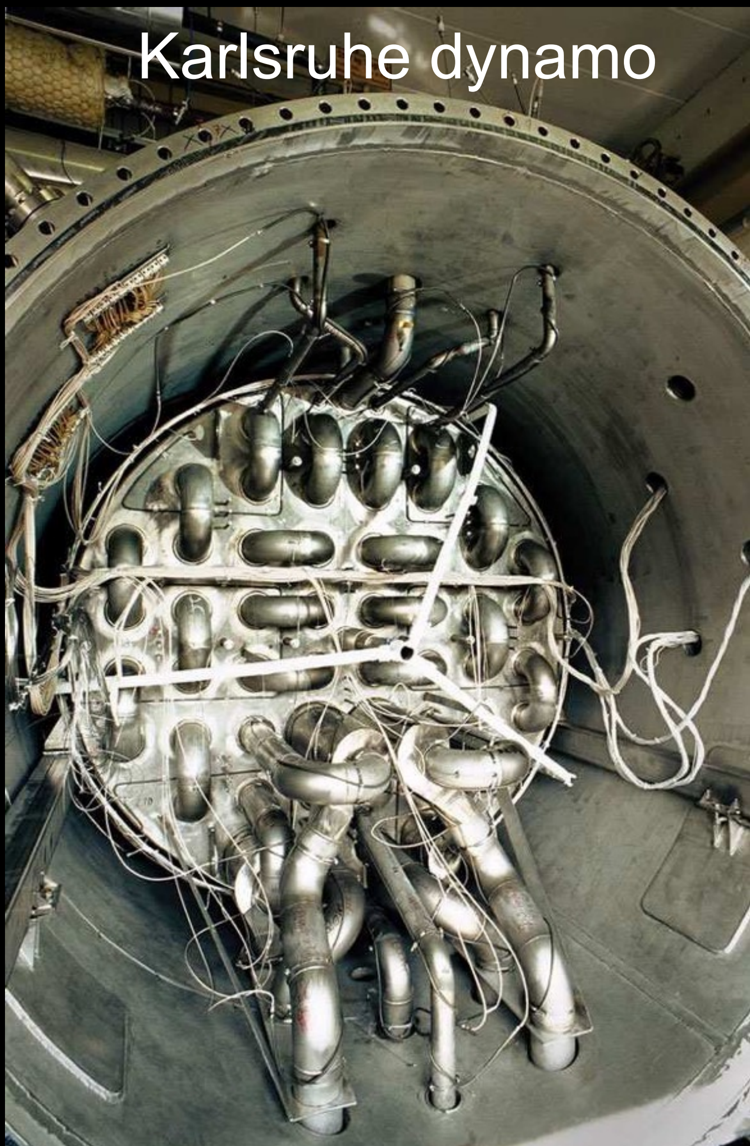




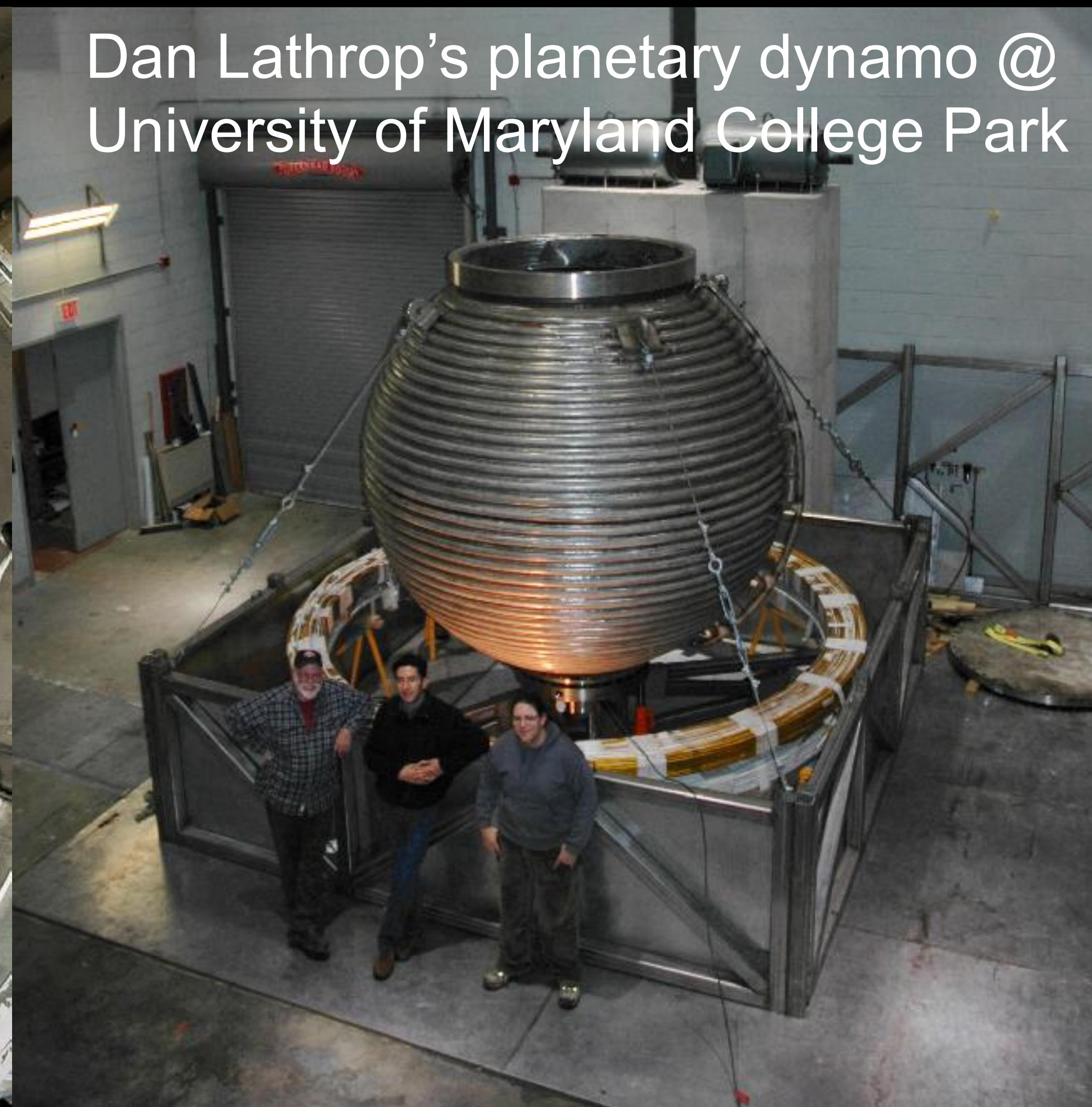


Studying Planetary Magnetic Fields

Dynamo Experiments:



Karlsruhe dynamo



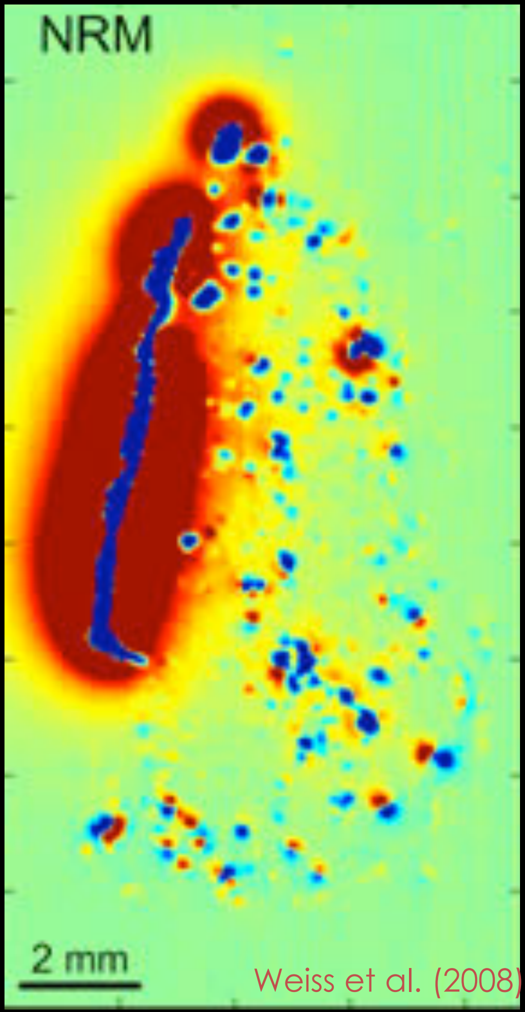
Dan Lathrop’s planetary dynamo @ University of Maryland College Park

Studying Planetary Magnetic Fields

Paleomagnetism: investigating magnetic fields frozen into rocks

Martian meteorite ALH84001 sample

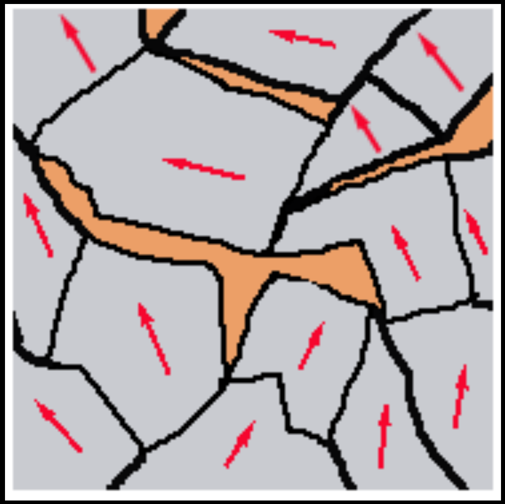
SQUID microscope scan of magnetic field in sample



Weiss et al. (2008)

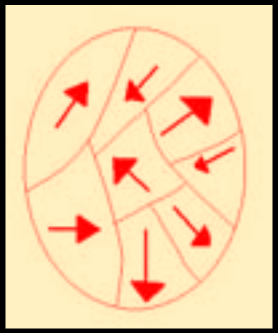
Rock Magnetization

•rocks are made up of different minerals
•broken up into grains
•some are magnetic

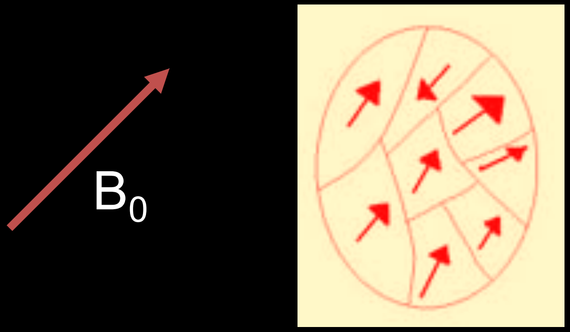


•when rocks cool from lava, they align their grains' dipoles with the field present at that time

•if there is no dynamo-generated field, magnetic fields will be random and cancel on average over the rock



•if there is a dynamo-generated field, magnetic fields will preferentially align with background field and we observe a crustal remanent field

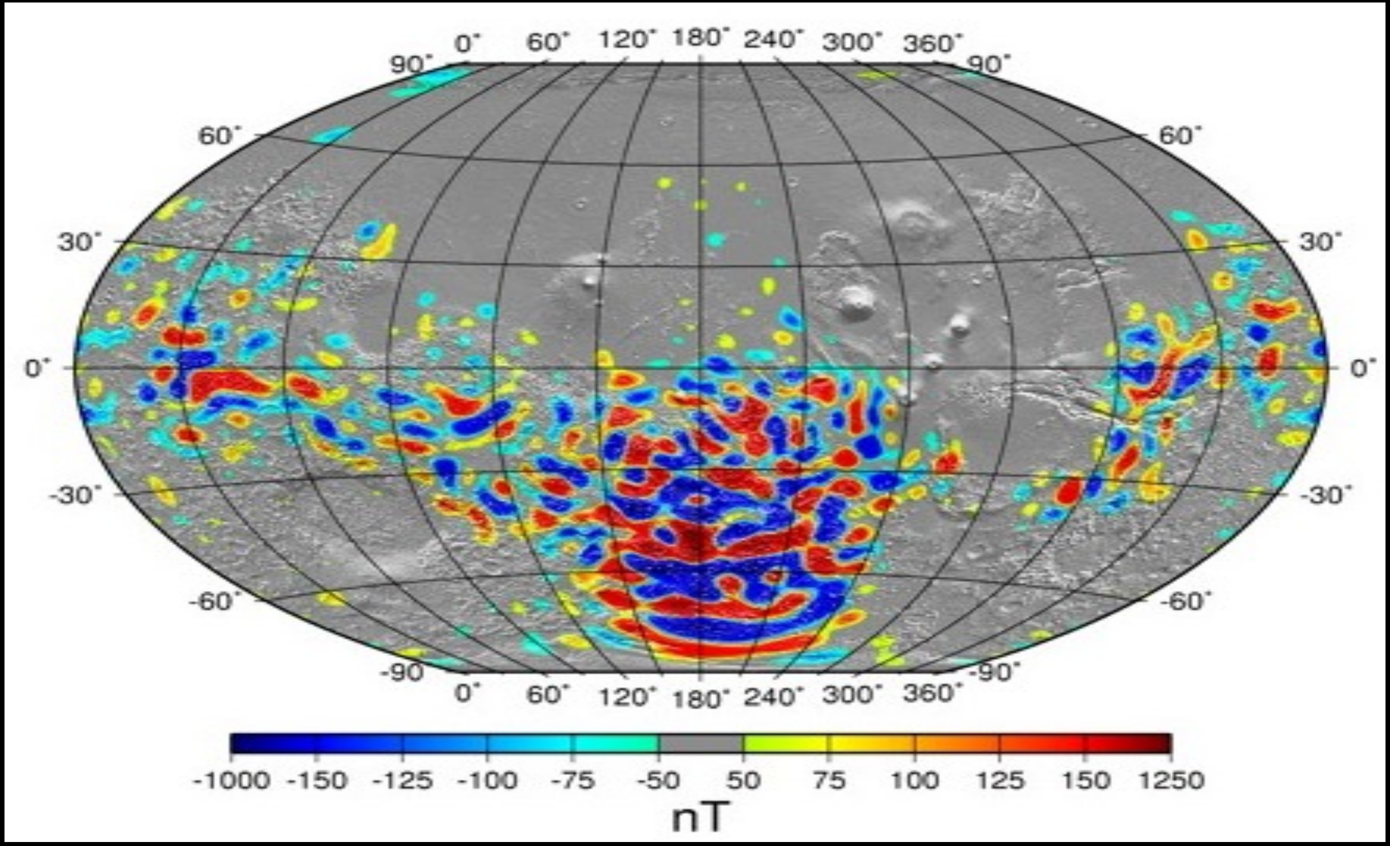


Mars' crustal magnetic field

•magnetic fields frozen into rocks as they cooled in presence of a dynamo

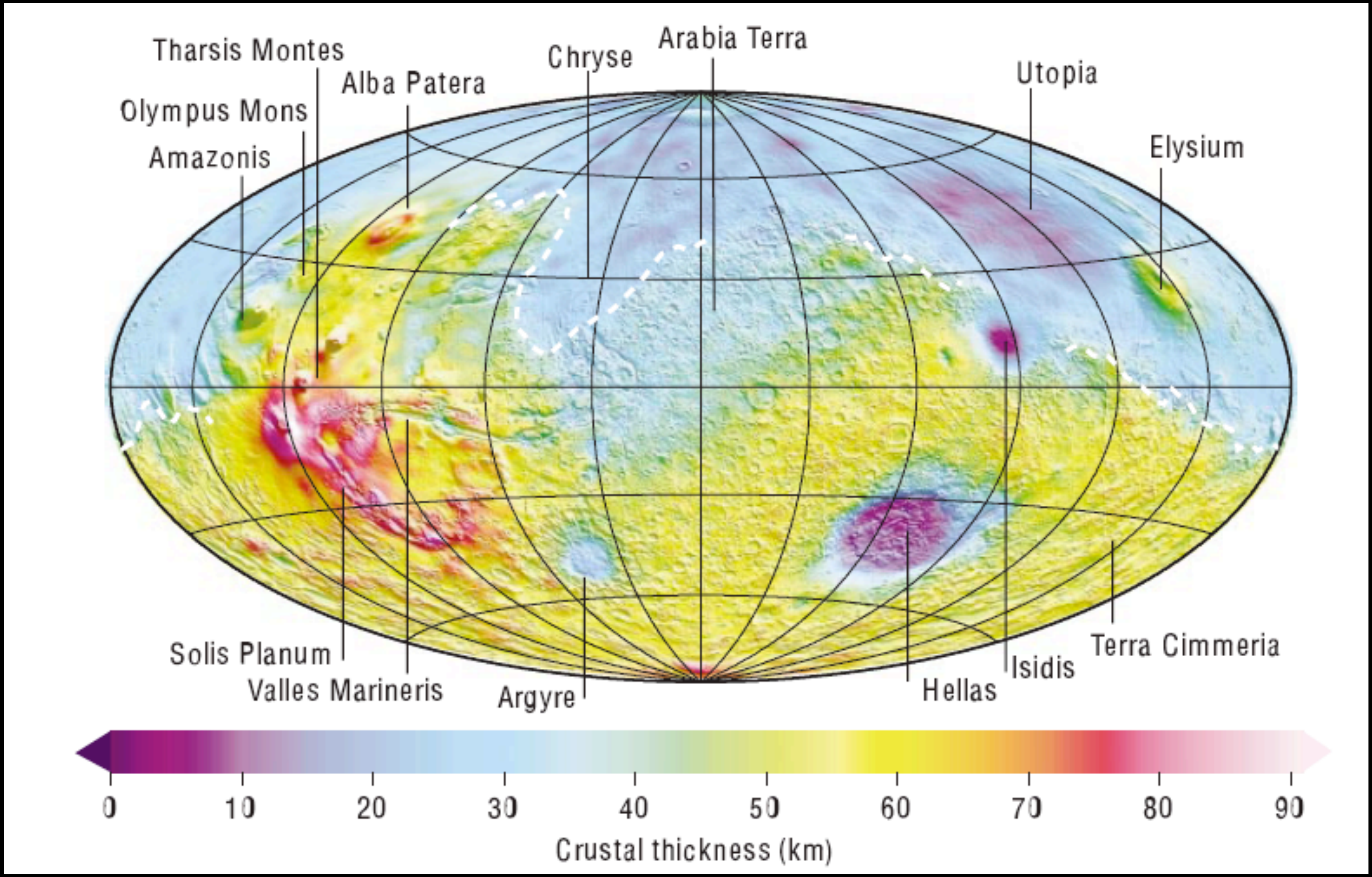
•fields missing in large impact craters and on Tharsis → dynamo was 'off' by 3.9Ga

•crustal fields are ancient, strong and <u>concentrated in southern hemisphere</u>



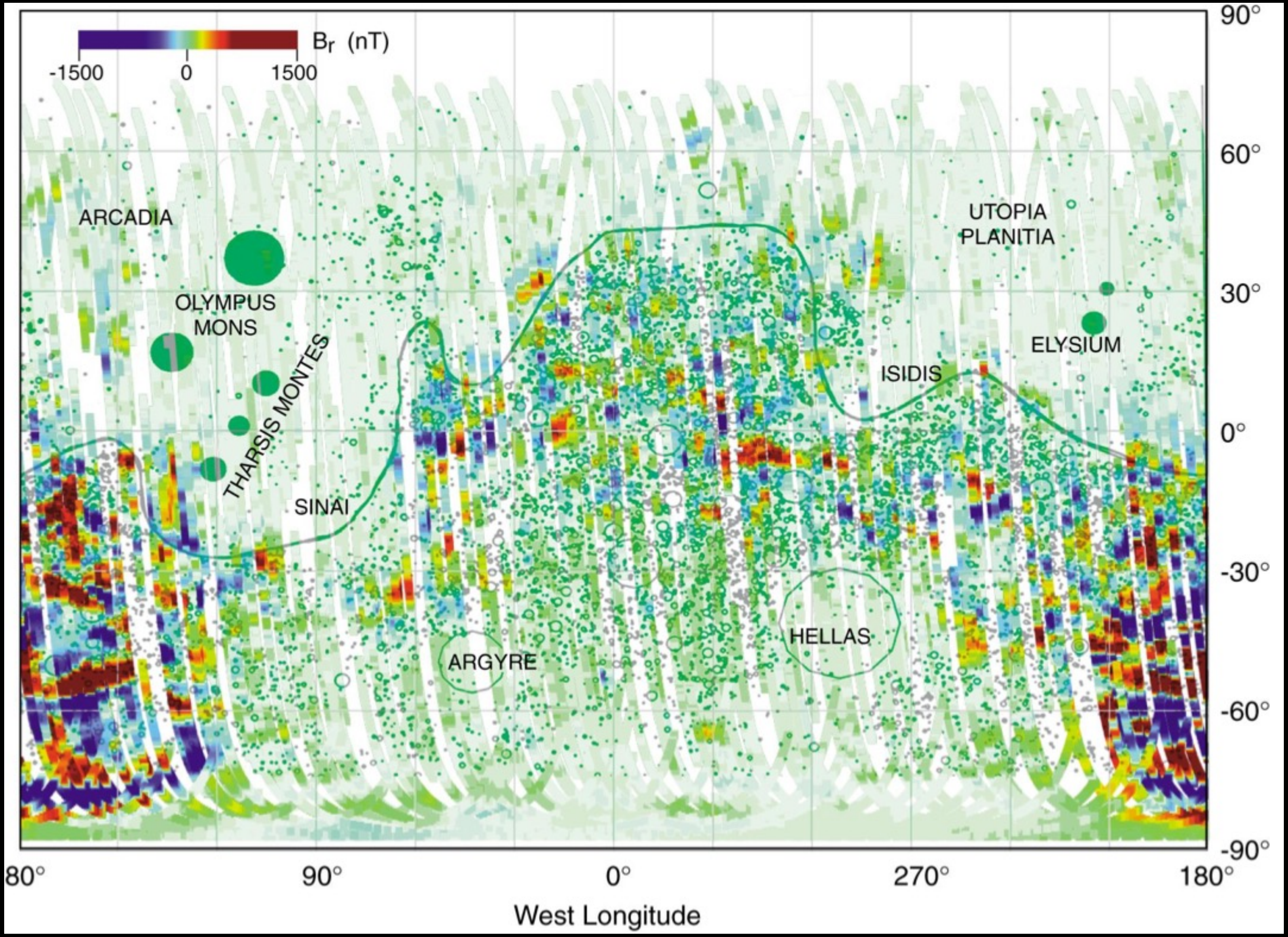
Mars' crustal dichotomy

- northern hemisphere: low, crust is thin, covered in sediments
- southern hemisphere: high, crust is thick, devoid of sediment cover



Magnetism/Dichotomy correlation

crustal magnetic field appears to correlate with the dichotomy boundary

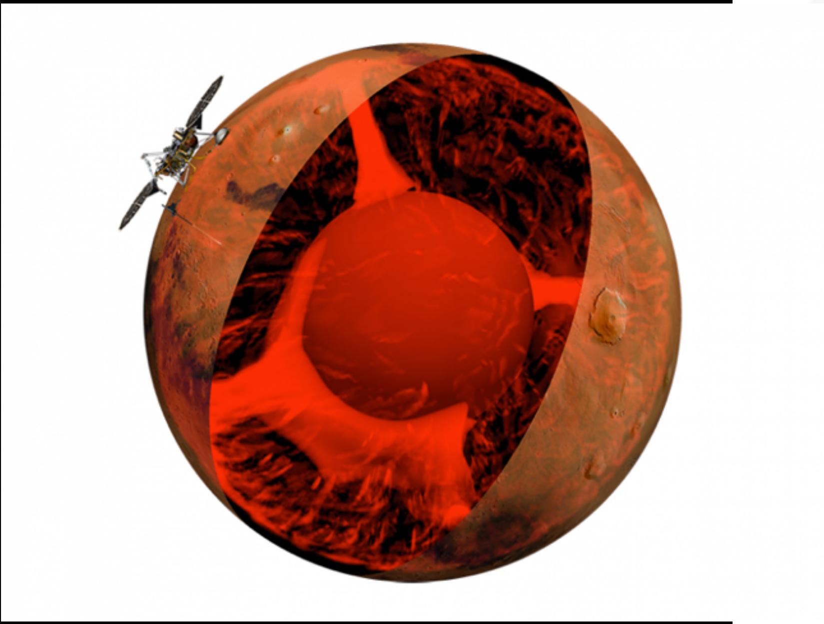


- We asked the question: can the formation mechanism for the crustal dichotomy explain the magnetic field?

Mars dichotomy formation

•2 possibilities:

(1) hemispheric convection



DLR/NASA/JPL

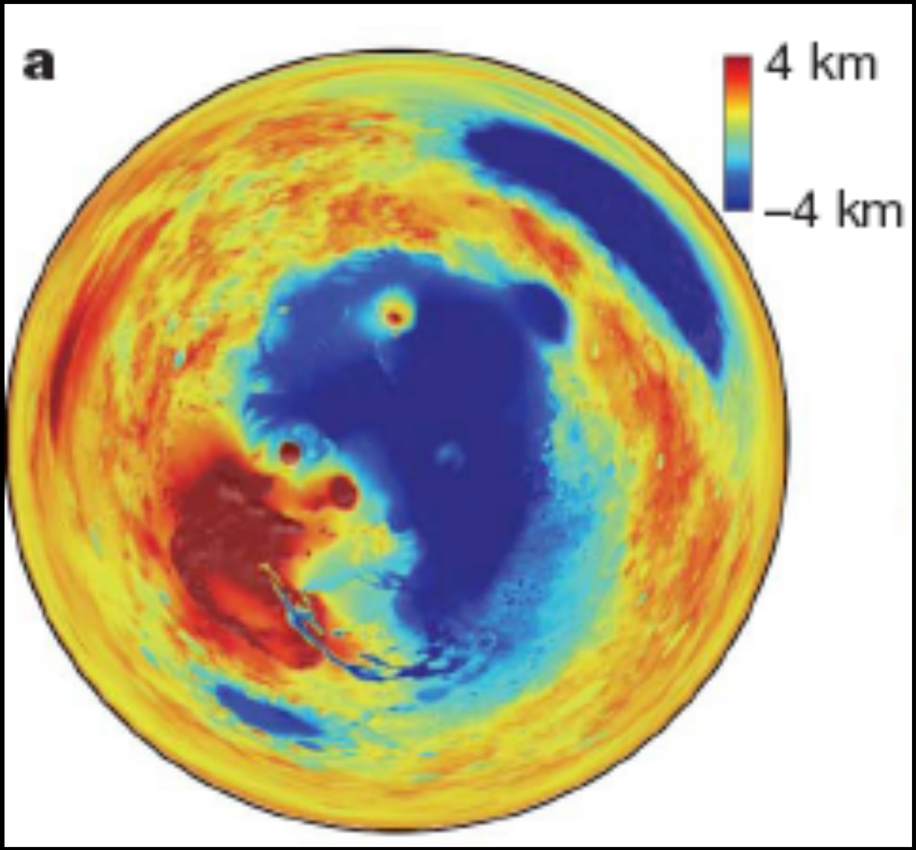
(only upwelling shown)

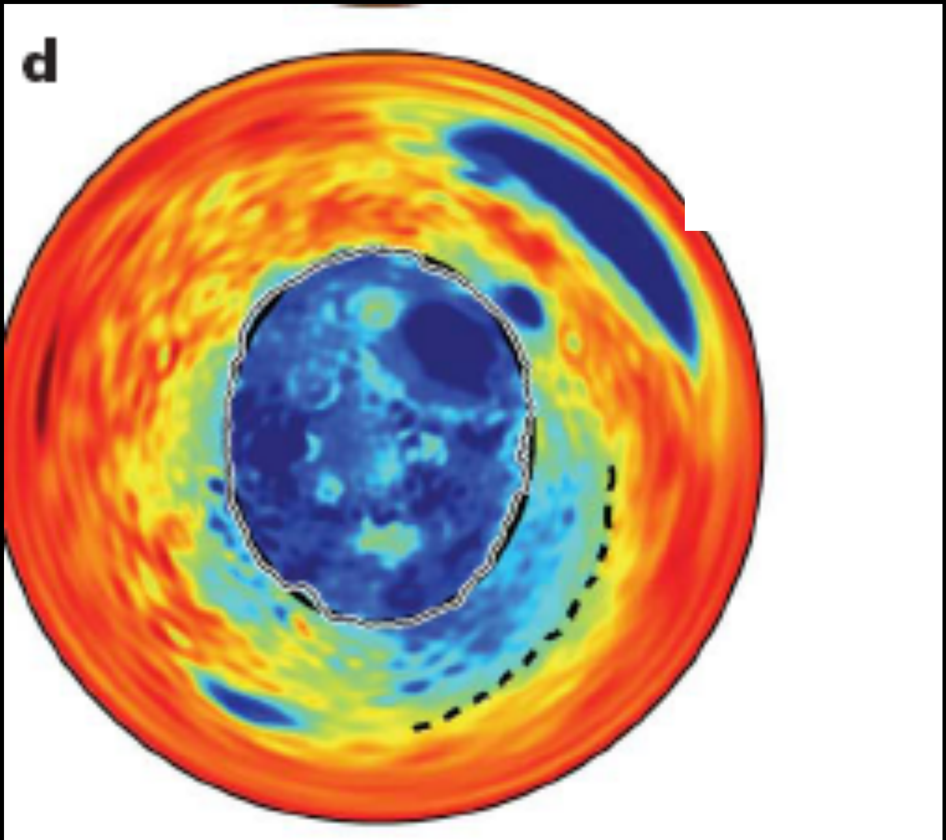
Mars dichotomy formation

(2) Giant Impact

Topography today

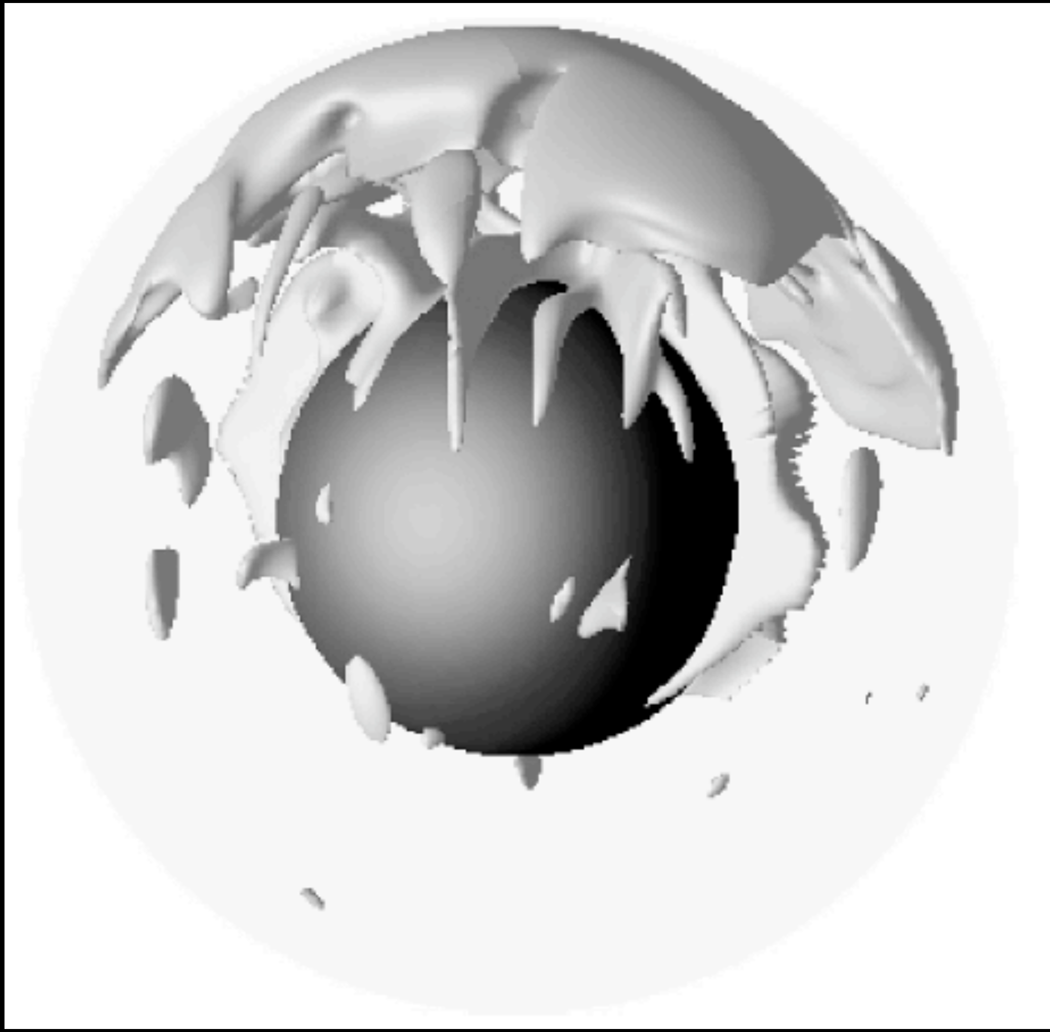
removing effects of Tharsis

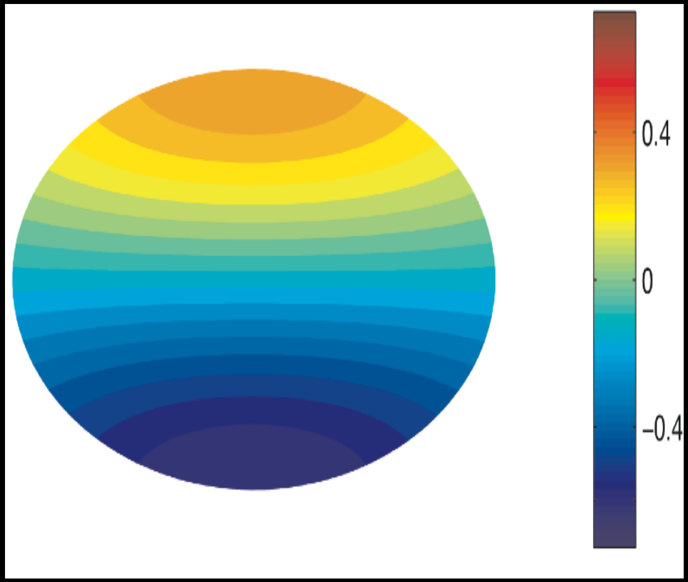




Implications for interior temperature

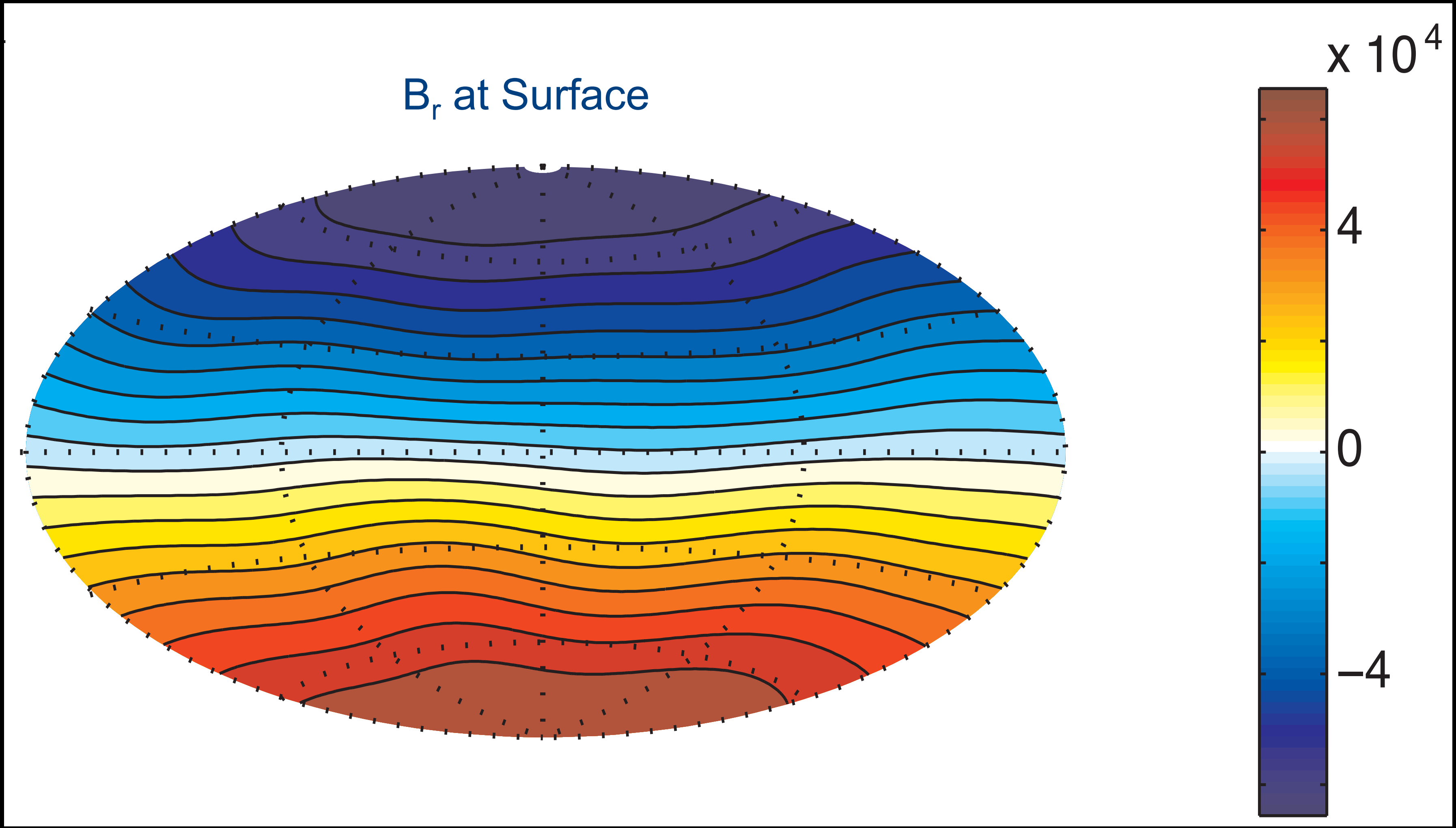
- Why does the dynamo care?





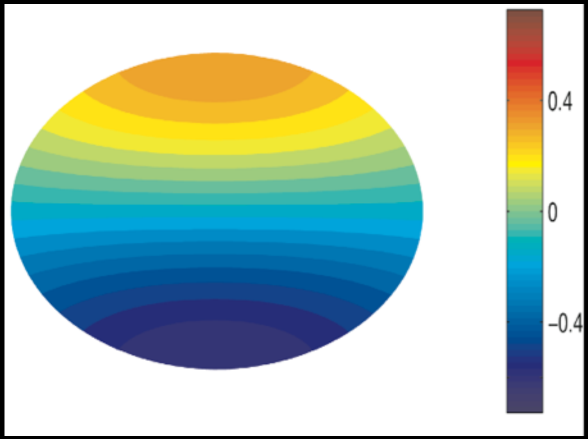
‘Normal’ planetary dynamos

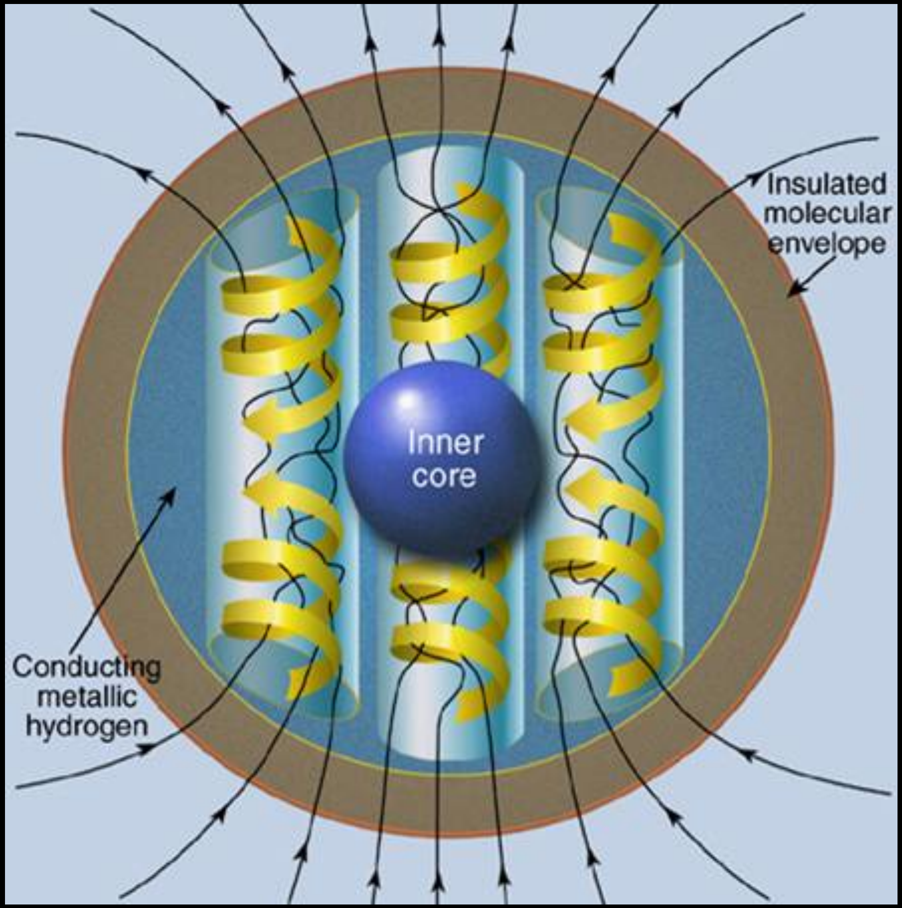
- Normal dynamos produce dipolar fields aligned with rotation axis
- field intensity ~equal but opposite direction in each hemisphere



Mars dynamo model

- Asked: what effect would a hemispheric outer boundary thermal condition have on the dynamo?



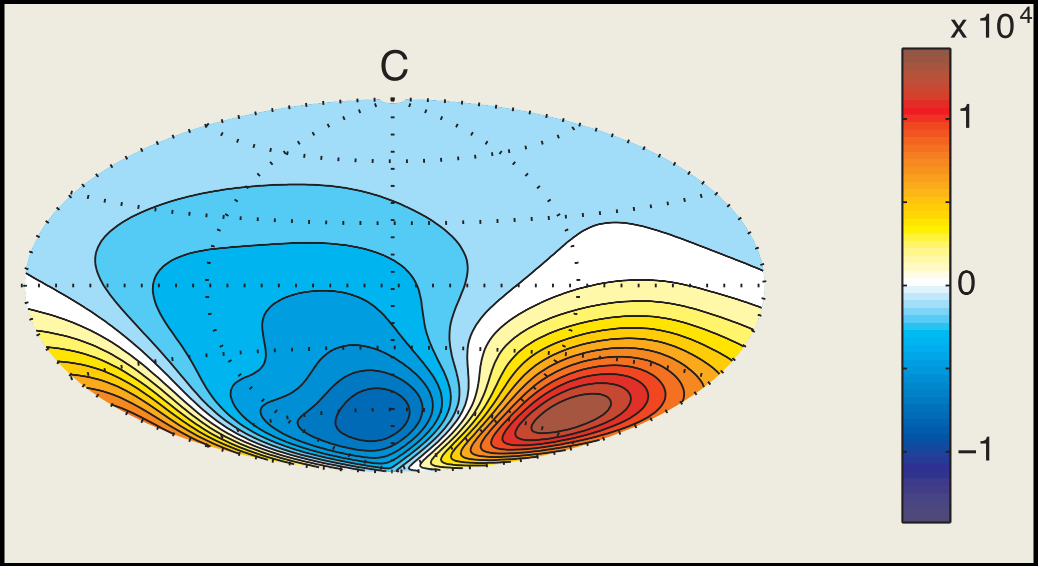


- Why do we think this might have effect?

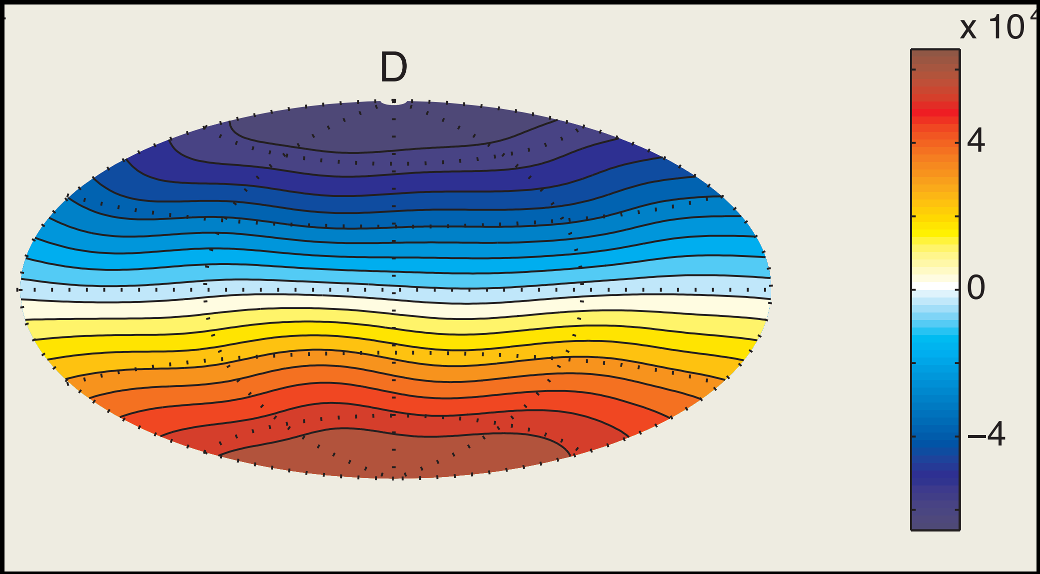
- Convective motions in core driven by temperature differences

Results: magnetic field

Mars dynamo

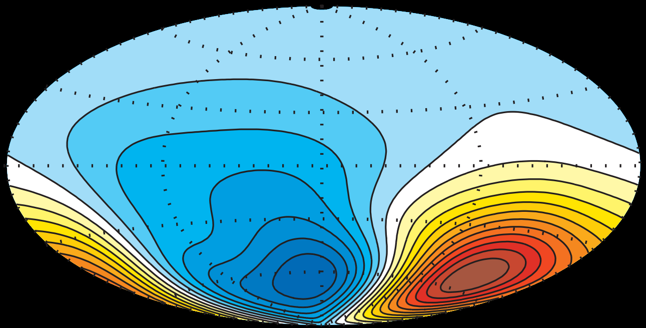


normal dynamo

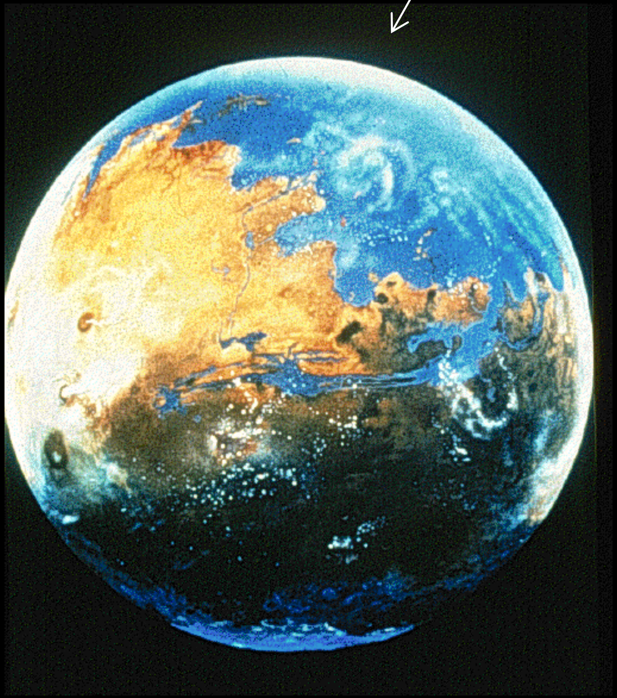


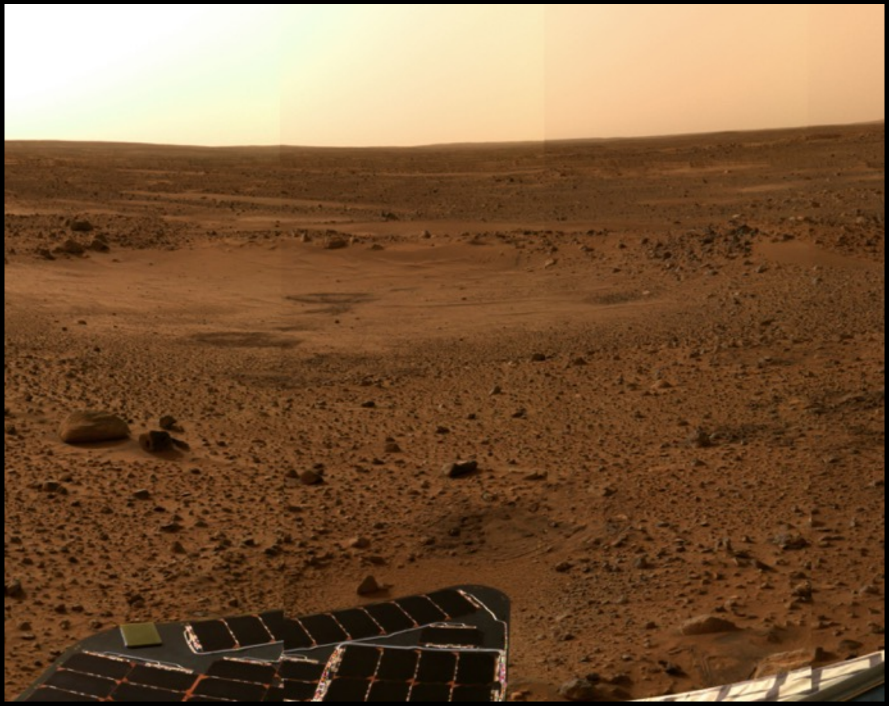
Implications:

If Mars' ancient dynamo produced a magnetic field with this morphology:



are there implications for Mars' ancient atmosphere/water/life?
How did Mars go from to





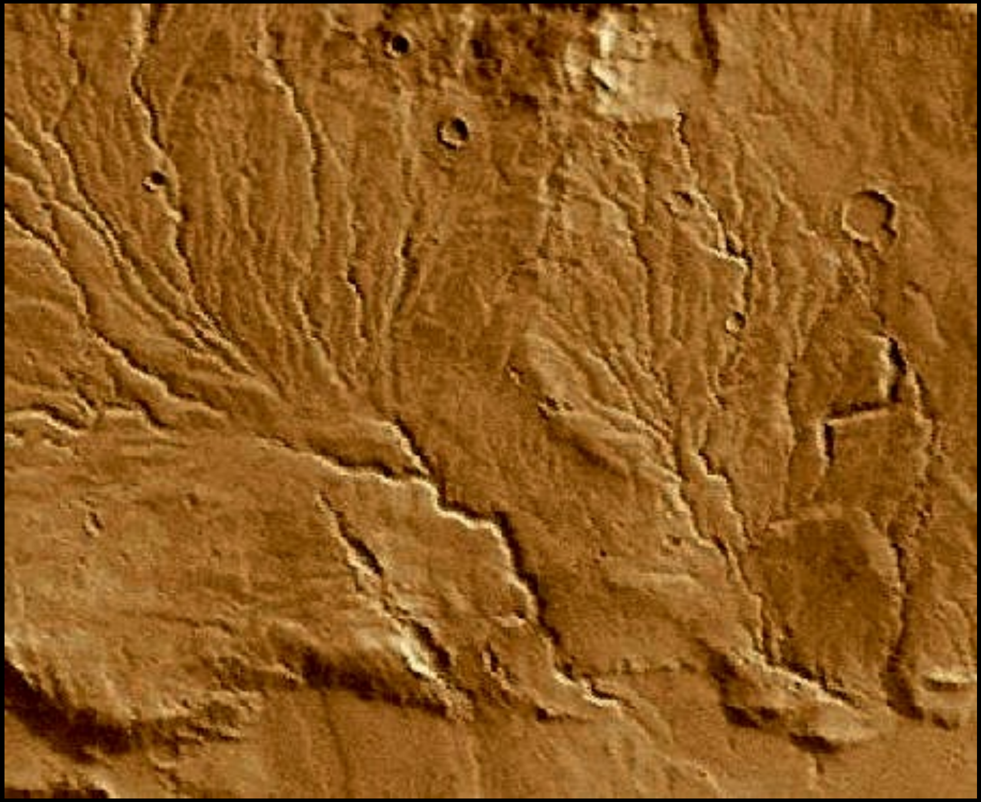
Atmosphere and Water

- currently, low atmospheric pressure → liquid water not stable at surface

- signs of ancient flowing surface water require a higher atmospheric pressure (a ‘thicker’ atmosphere) in past

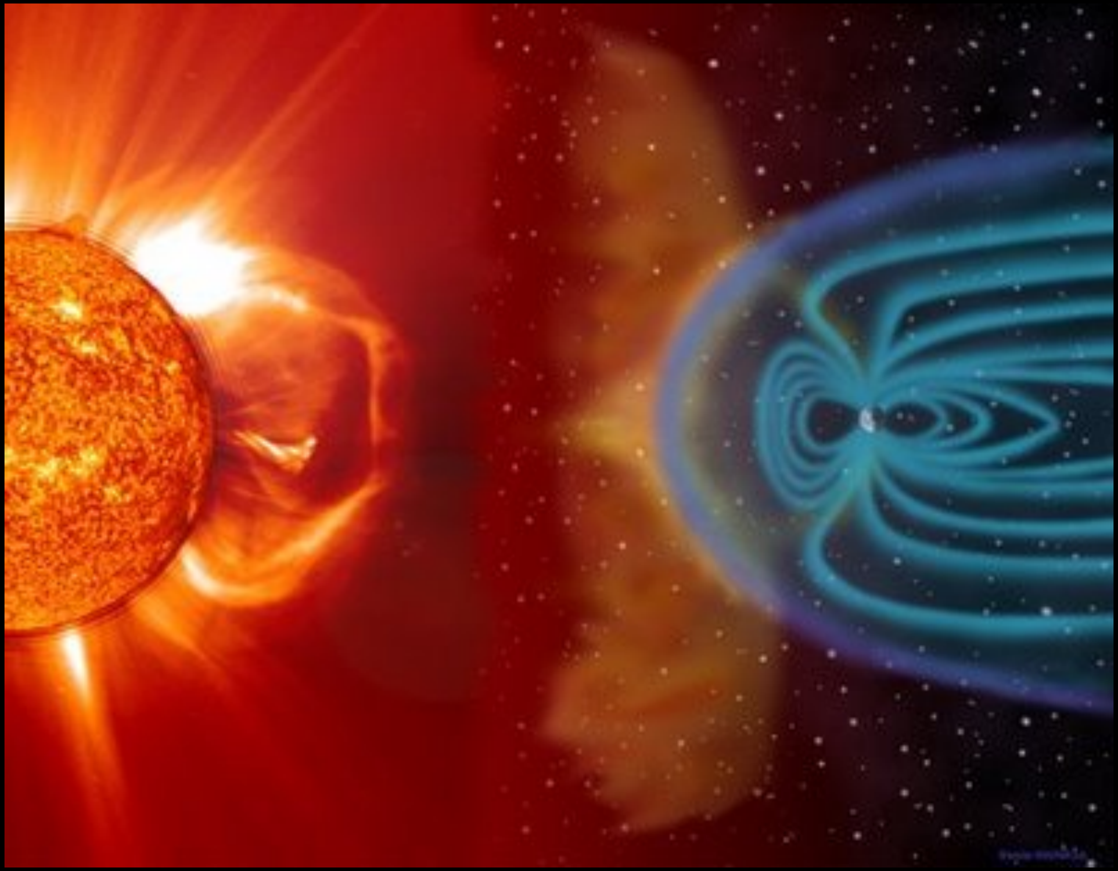
- the atmosphere must have eroded away to produce the current thin atmosphere

- atmospheric erosion processes:
    - solar wind erosion
    - impact erosion



Magnetic Fields & Erosion

•when dynamo active, magnetic field shields atmosphere and reduces solar wind erosion



•it may not be a coincidence that Mars had a dynamo when it had a thick atmosphere

When the dynamo died

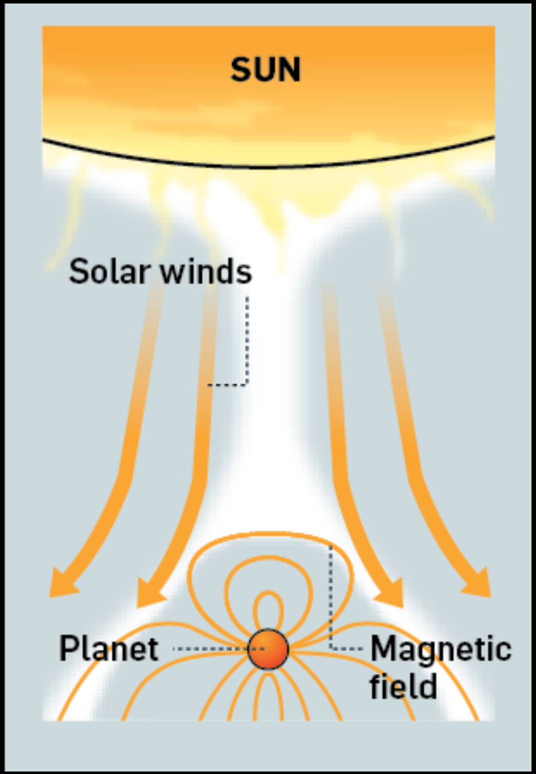
•when dynamo died, atmosphere began to erode

BUT

•models suggest you can’t remove enough atmosphere from 4 Ga to now

•very young Sun was more active → easier to erode atmosphere earlier in Mars history

•atmospheric people want no magnetic field shielding on early Mars so that young Sun (more active) could more efficiently erode atmosphere



BUT

•planetary magnetists want strong magnetic field on early Mars to create strong crustal fields

How our model helps

•in our model, the magnetic field is only strong in the southern hemisphere

SO

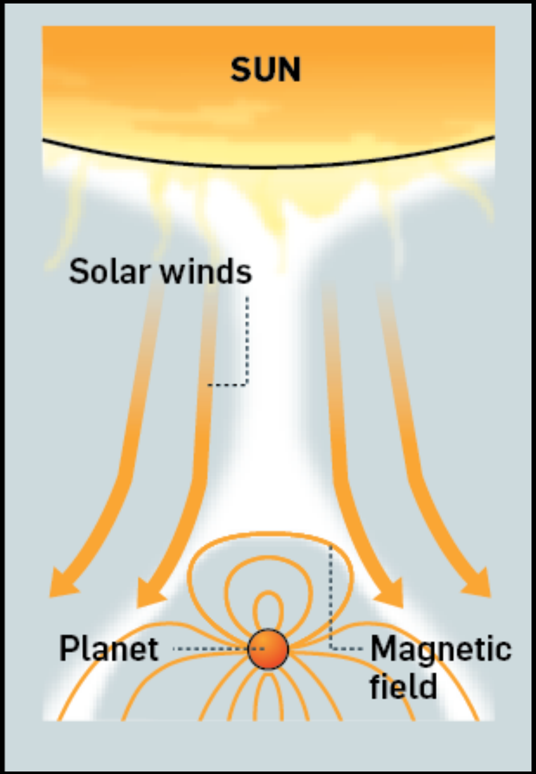
•can have efficient early atmospheric removal (in the northern hemisphere)

AND

•strong magnetic fields for the rocks to magnetize (in the southern hemisphere)

•we need to model this atmospheric loss process

•to do that, we need data on Mars' atmosphere …



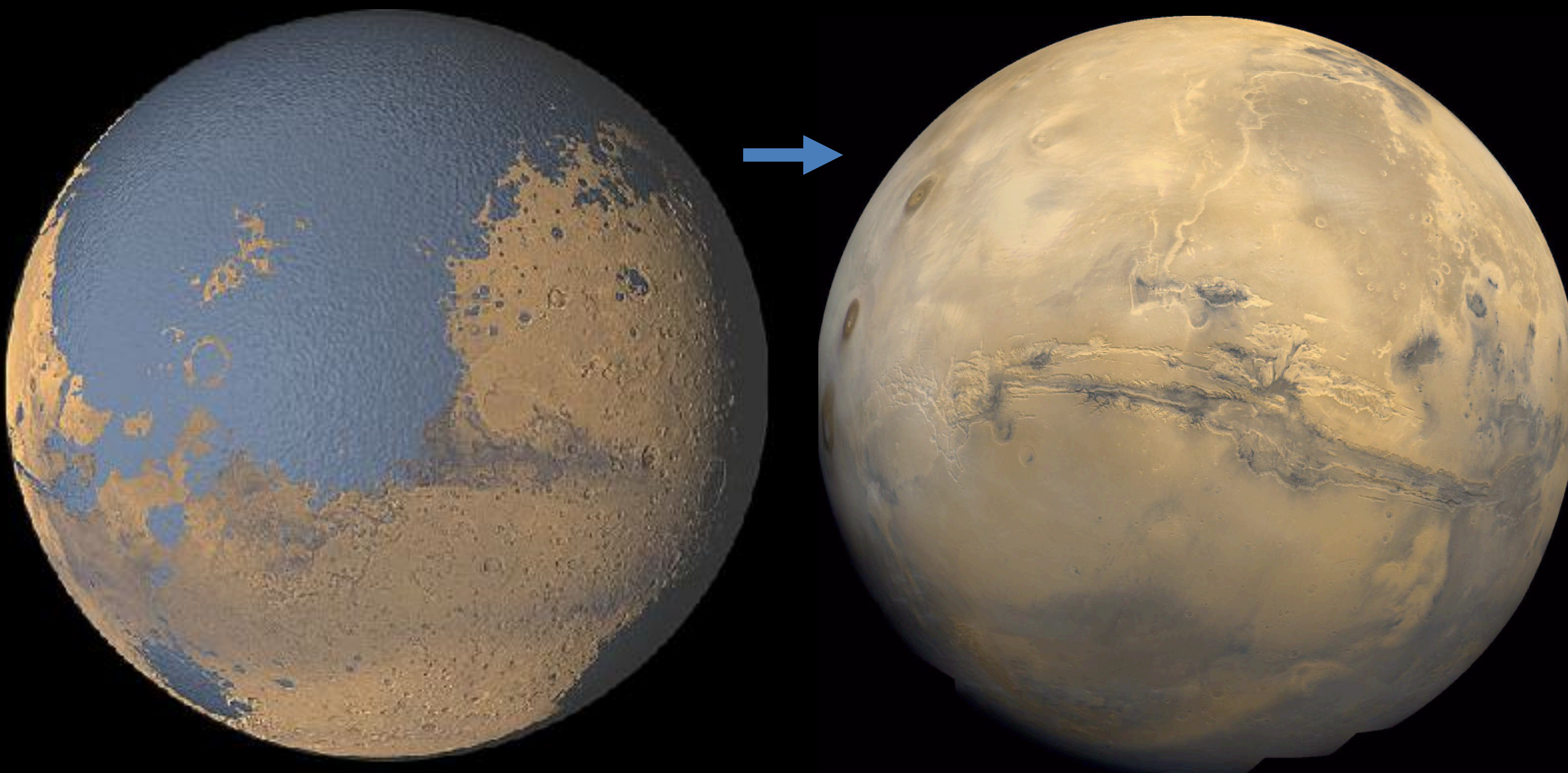
Mars MAVEN Mission

"Mars Atmosphere and Volatile EvolutioN"

- launched Nov 18, 2013
- arrived Sep 22, 2014

MAVEN objectives:

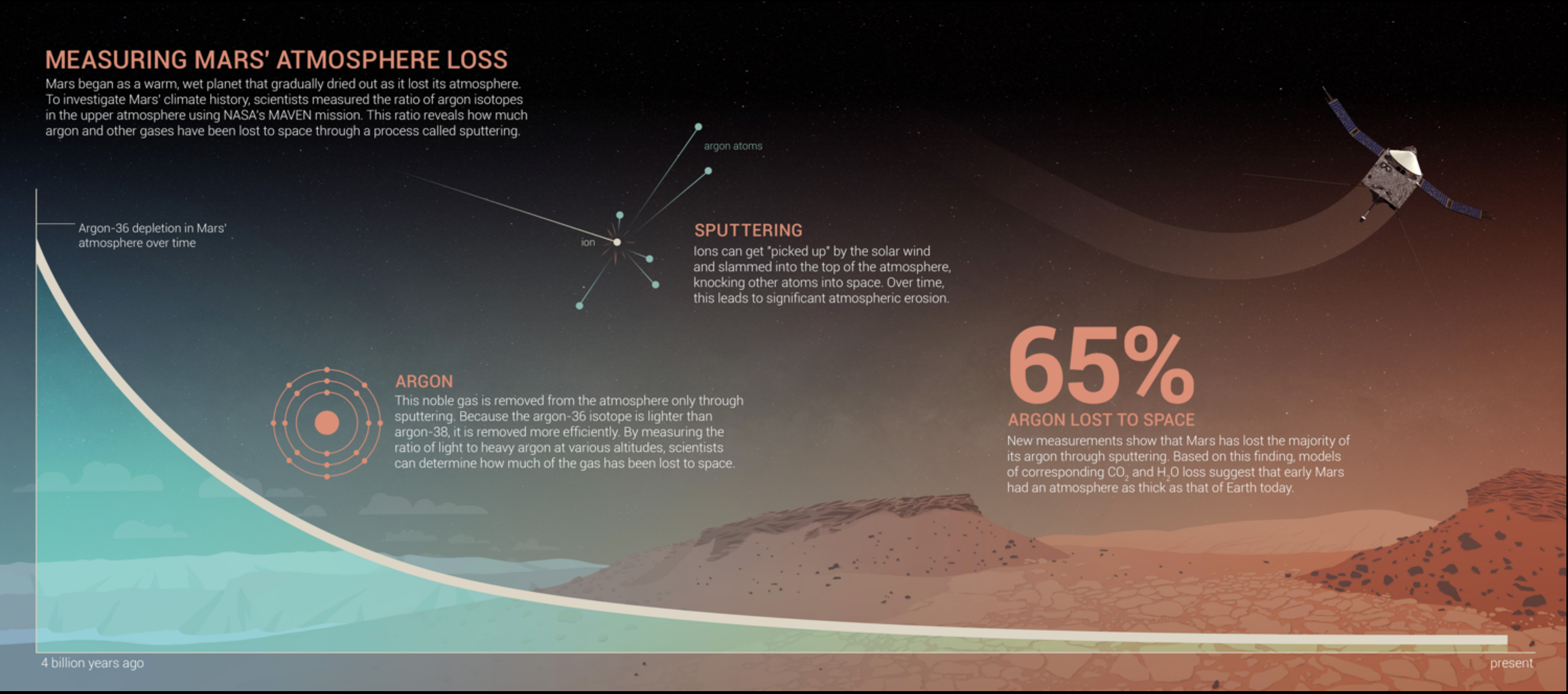
- Determine the current state of Mars' atmosphere
- Determine atmosphere escape rates today
- Determine total loss of atmosphere to space over time
- How did Mars go from wet/warm to dry/cold?



MAVEN Spacecraft

Cool Maven Results

- Solar wind & radiation responsible for most of the atmospheric loss on Mars
- Depletion was enough to transform Martian climate



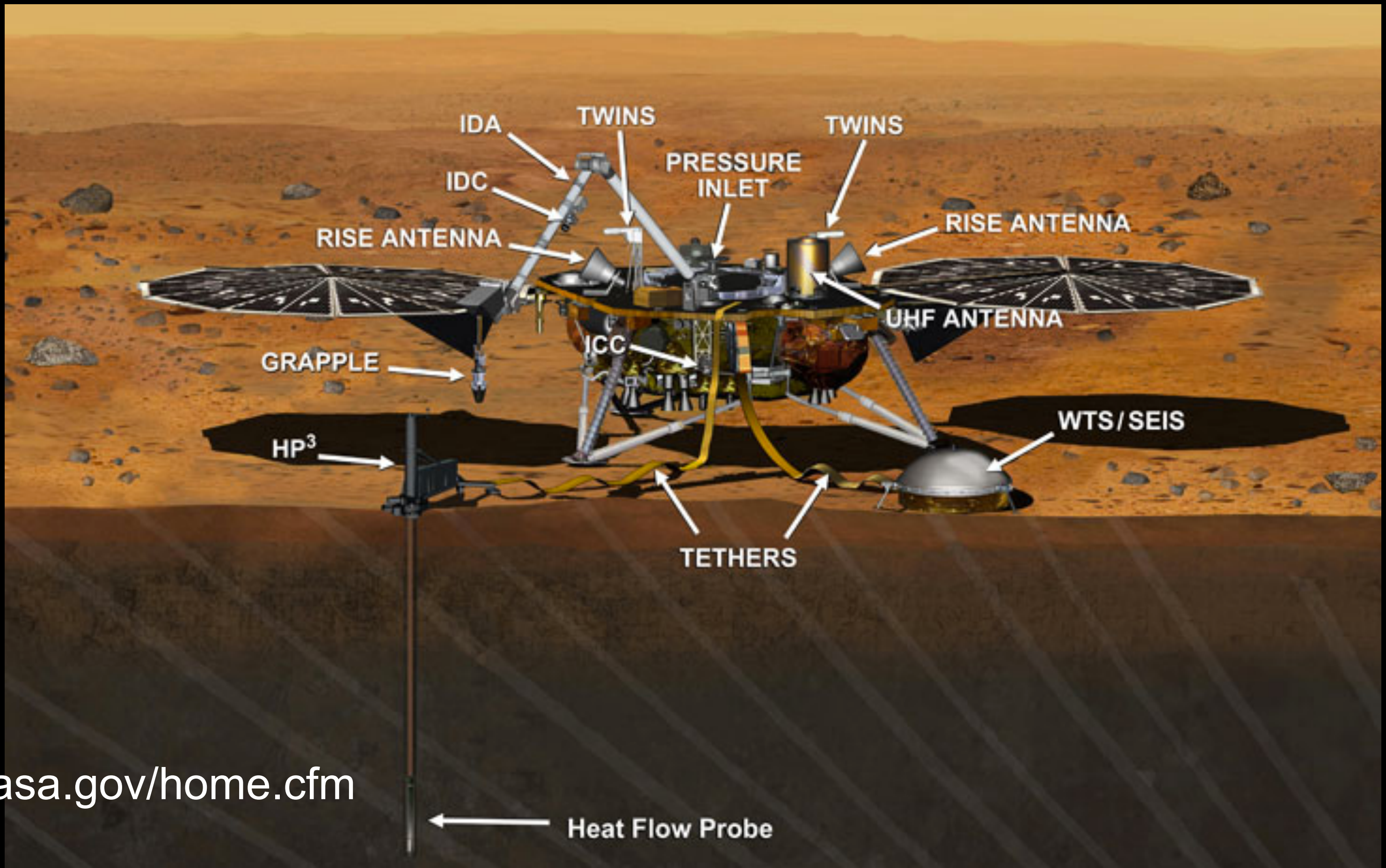
https://www.nasa.gov/press-release/nasas-maven-reveals-most-of-mars-atmosphere-was-lost-to-space

Mars InSight

INterior exploration using **S**eismic **I**nvestigations, **G**eodesy and **H**eat **T**ransport

Science Goals:

- Determine size, composition, physical state of Martian core
- Determine thickness and structure of Martian crust
- Determine thermal state of Mars' interior
- ...



https://insight.jpl.nasa.gov/home.cfm

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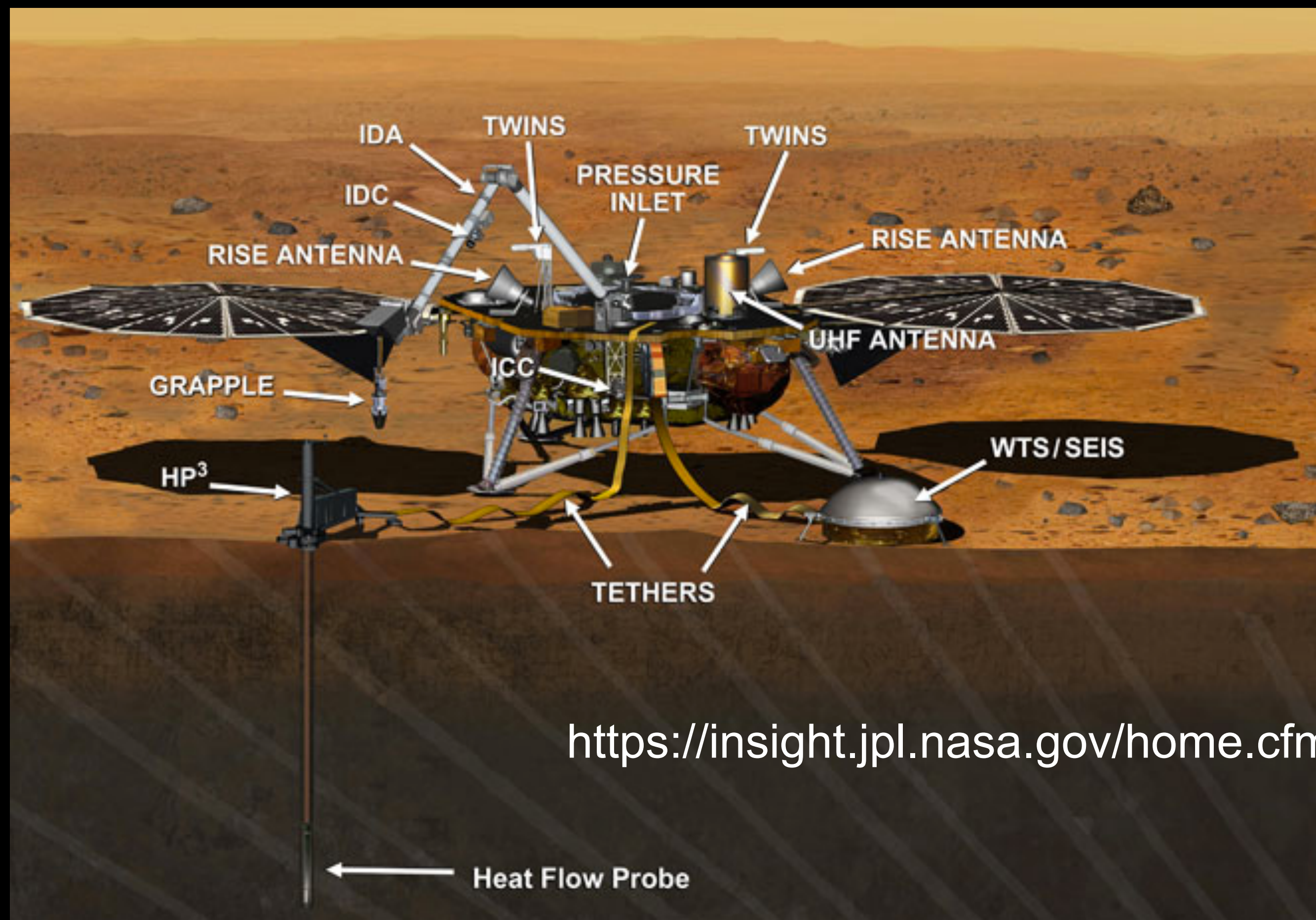
- ...

Launch:
May 5 2018
(was originally planned for Mar 2016, but scrapped)

Landing:
Nov 26 2018



https://insight.jpl.nasa.gov/home.cfm

Conclusions

•want to understand how Mars got its wacky magnetism and what it tells us about Mars’ past

•Mars’ dichotomy formation mechanisms can result in a single hemisphere dynamo

•this can explain why crustal rocks are most strongly magnetized in the southern hemisphere

•implications for the atmosphere are interesting and need to be studied further

Thank you