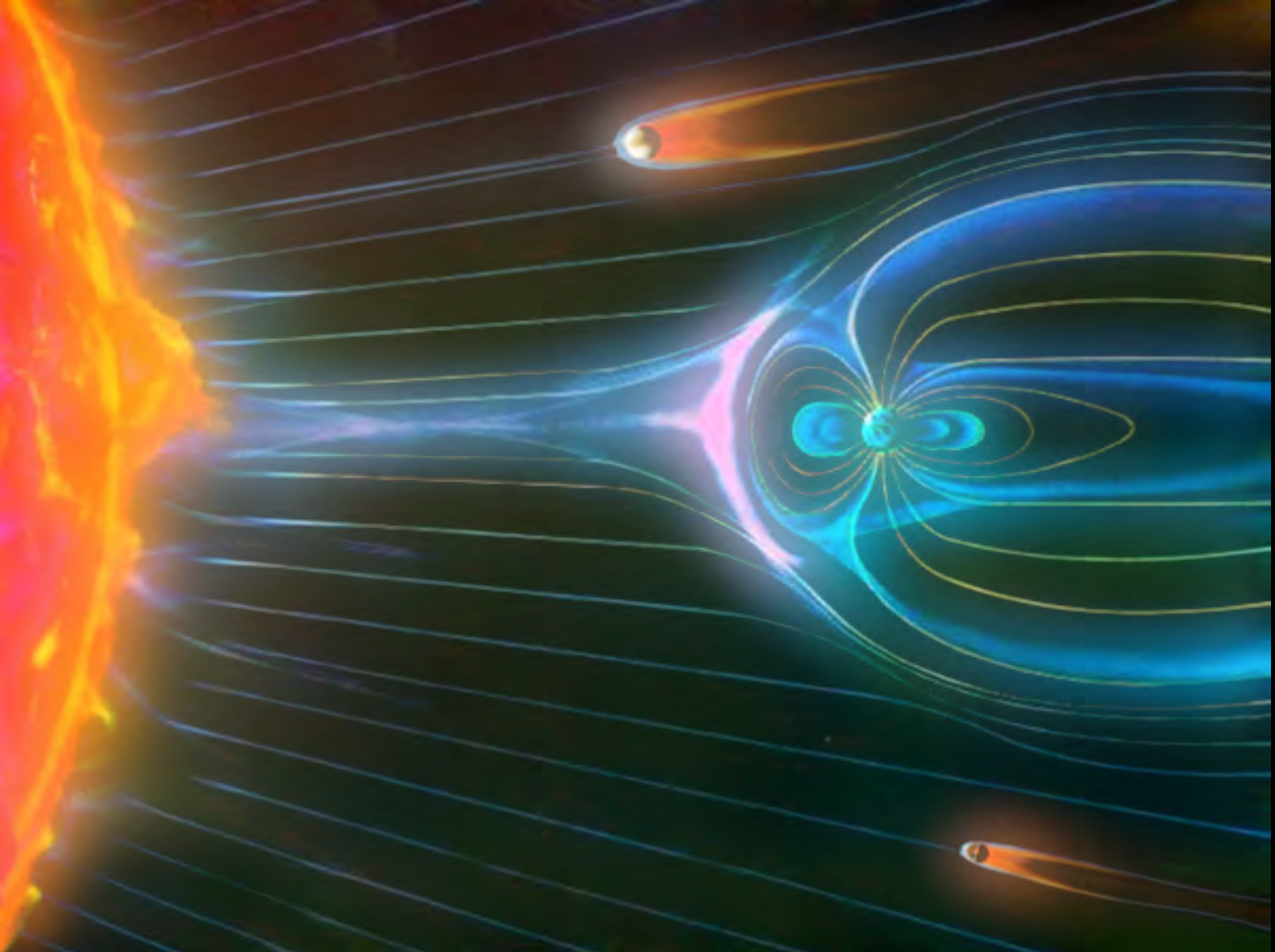


Do Habitable Worlds Require Magnetic Fields?

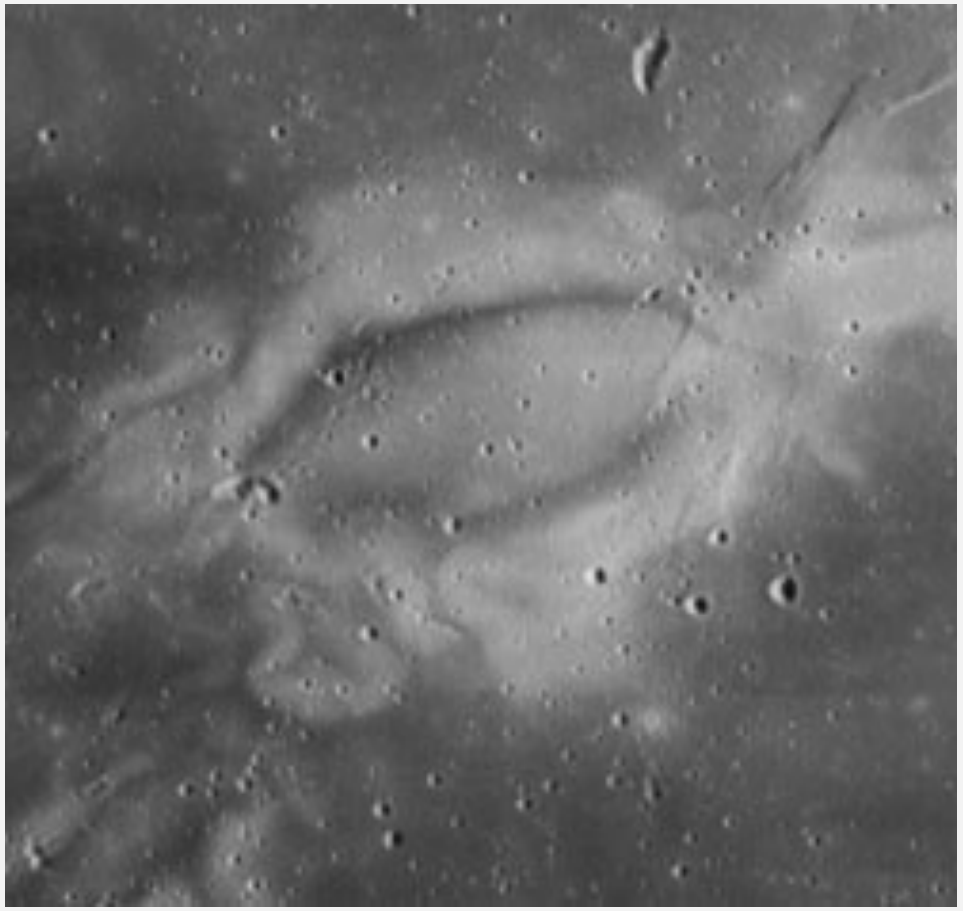
Dave Brain

University of Colorado

MAVEN Outreach Webinar
18 April, 2018

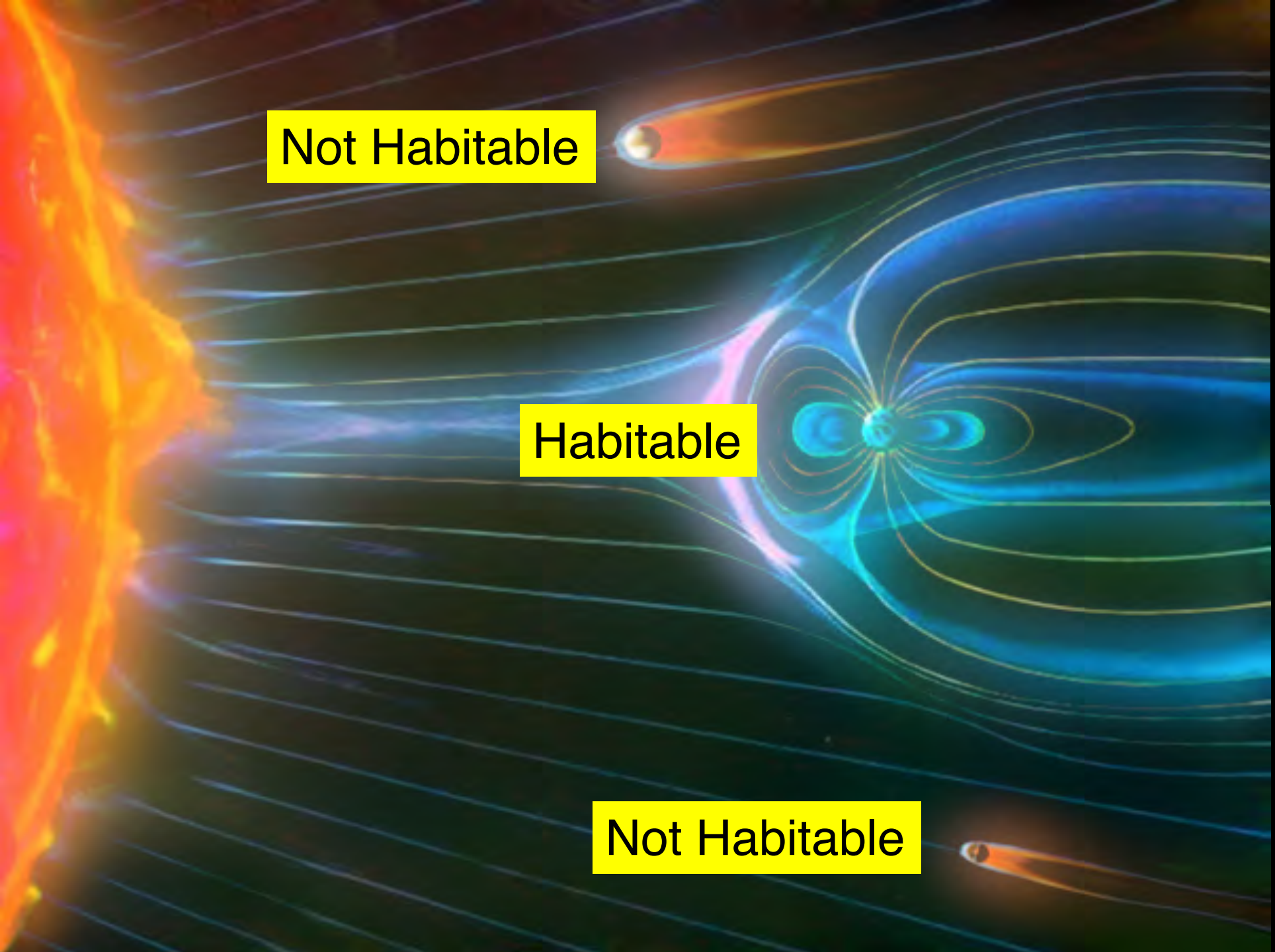
Do Magnetic Fields Affect Planets?

Ganymede



Moon

Do Magnetic Fields Affect Atmospheres?



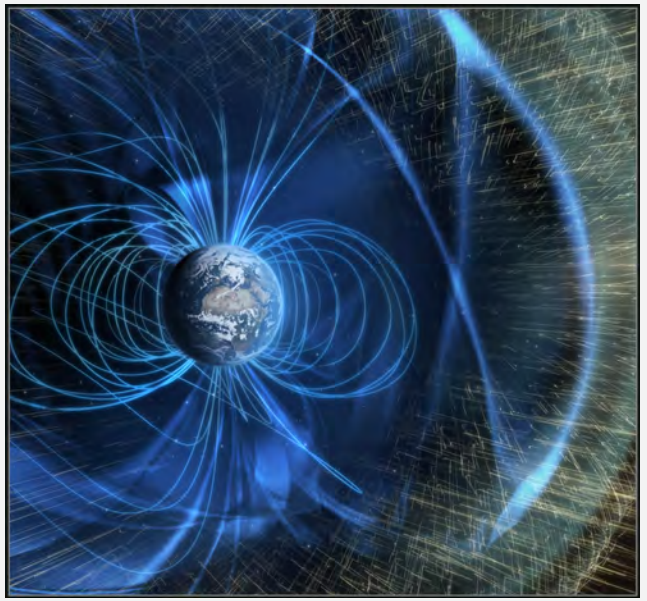
Do Habitable Planets Require Magnetic Fields?

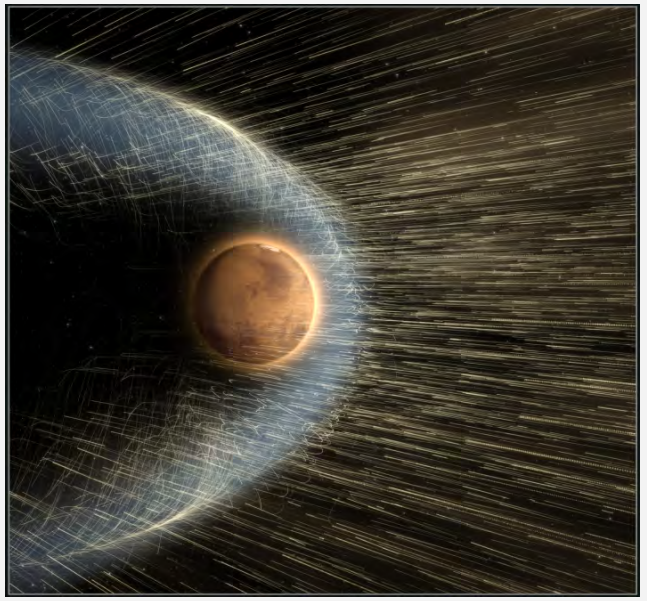
Empirical evidence suggests “Yes”

What Does Life Need?

Motivation

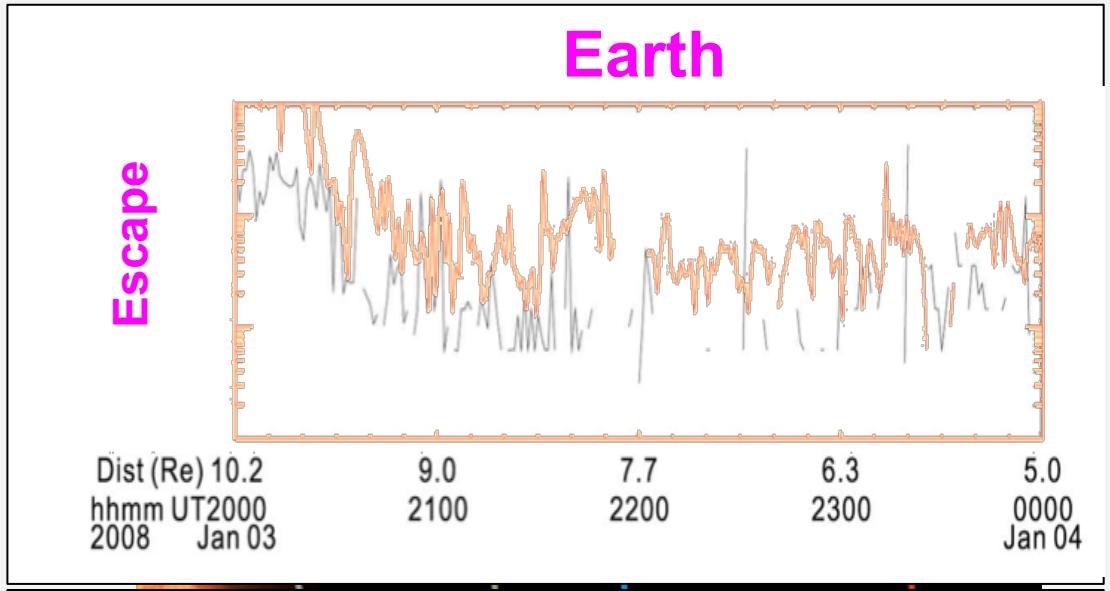
- Life requires liquid water
- An atmosphere is required for stable liquid water at the surface
- It is often assumed that a planet's magnetic field prevents its atmosphere from escaping to space
- There is reason to question this assumption, and evaluate it critically

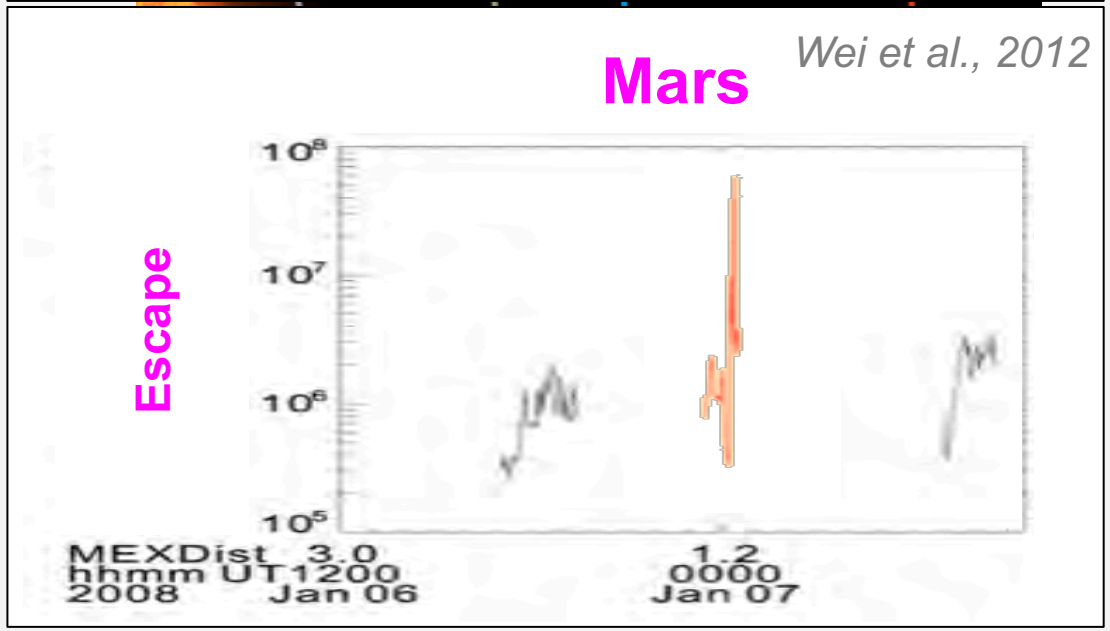




* Disclaimer: Here I neglect magnetic field influence on surface radiation

Magnetic Fields Should Protect Atmospheres





Wei et al., 2012

Simple physics: A magnetized planet deflects solar wind charged particles far from the atmosphere

- Solar wind can't hit atmosphere
- Less energy for top of atmosphere

→ Atmosphere can't escape efficiently

Qualitative support:

- Chemical signatures in atmospheres of Venus and Mars suggest they lost atmosphere relative to Earth
- Earth and Mars respond differently to the same event*

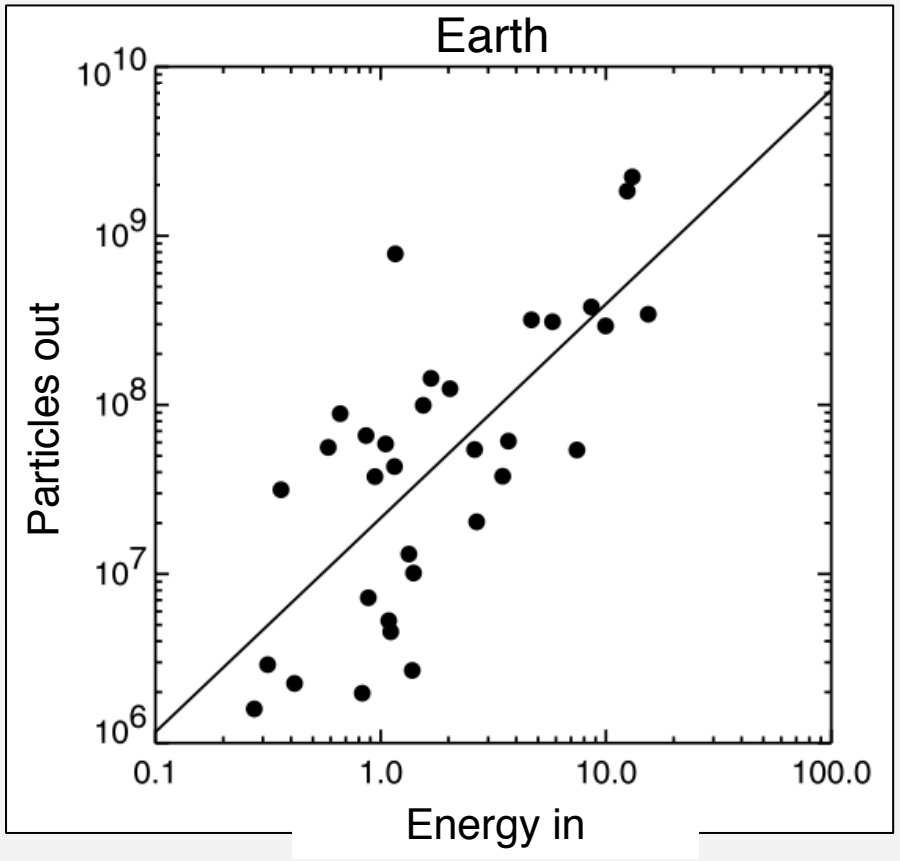
Magnetic Fields Should Not Protect Atmospheres

Simple physics: A magnetized planet captures more energy from the solar wind

- A magnetic field gives a larger cross-section
- Energy transferred to the atmosphere along magnetic field (e.g. aurora!)
- Escape is efficient, but non-global

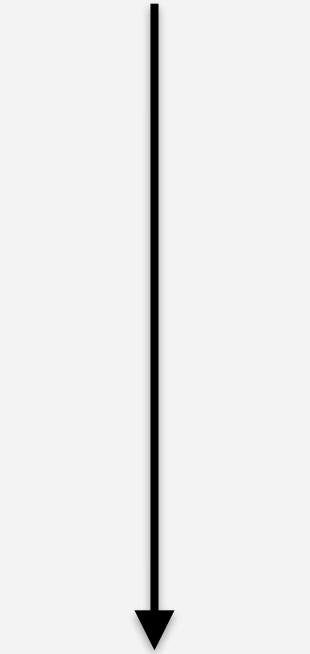
Qualitative support

- V, E, M all lose roughly the same amount of charged particles today
- Energy of solar wind proportional to ion escape at Earth



Strangeway et al., 2005

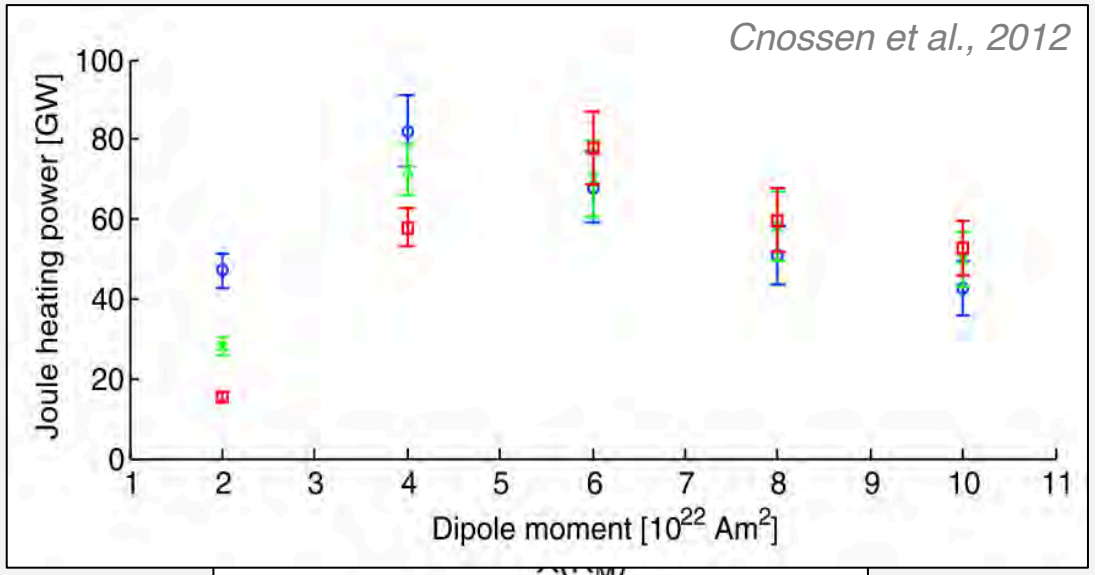
Key Questions

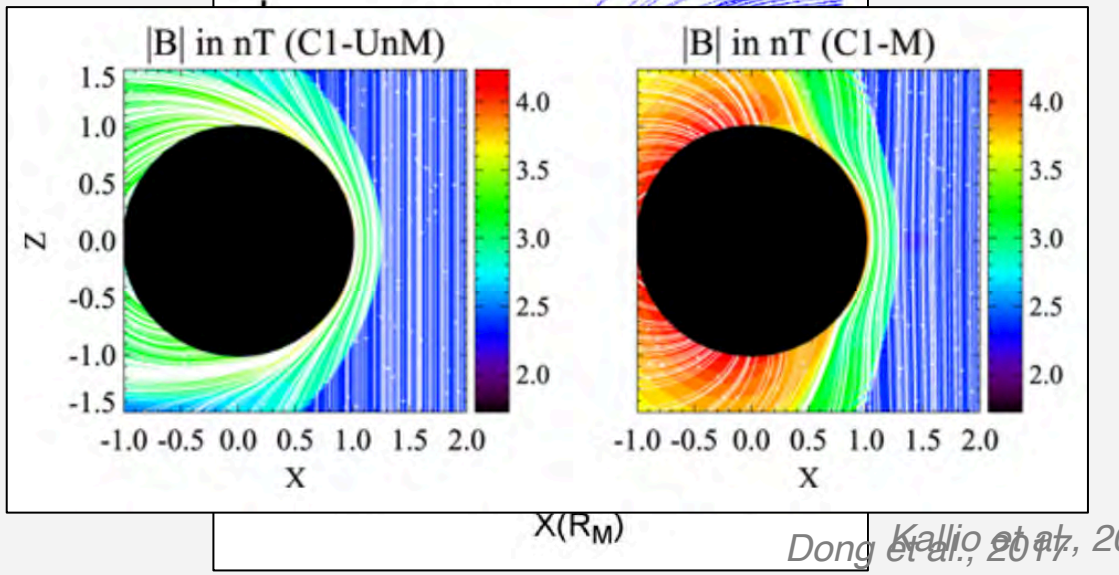


- All other things being equal, does a planet with a magnetic field lose less atmosphere than a planet without?
- If so, is this reduction substantial enough to account for a difference in habitability on some timescale?
- Is it highly likely or even required that a planet that retains a habitable atmosphere has a magnetic field?

How can we bring data and/or models to bear on these questions?

Global Plasma Models





Dong et al., 2017

Kallio et al., 2008

All other things being equal, do planets with magnetic fields lose less atmosphere than planets without?

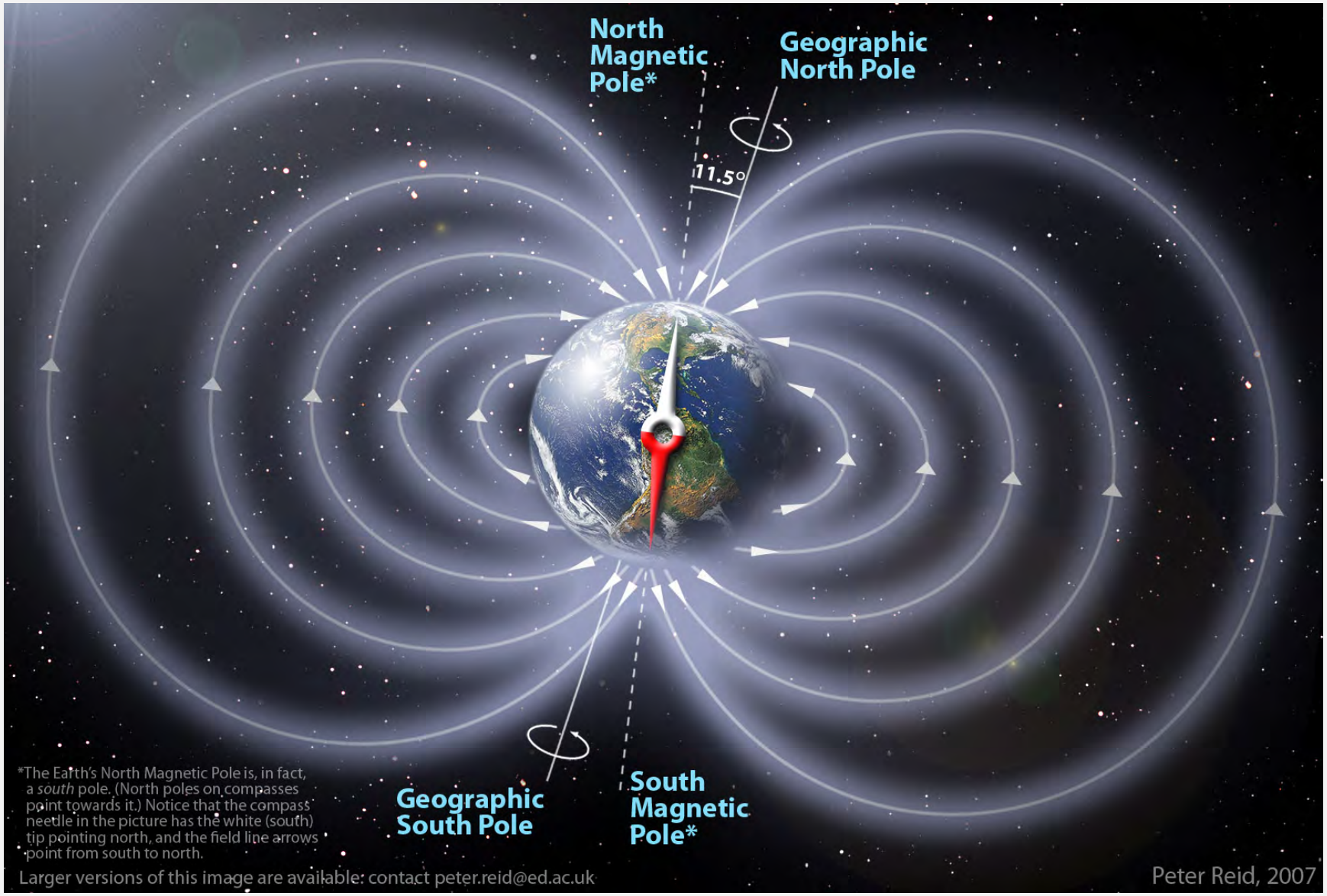
Simulations can turn global dipoles on and off

- Morphology of magnetosphere changes
- Ion escape rates change

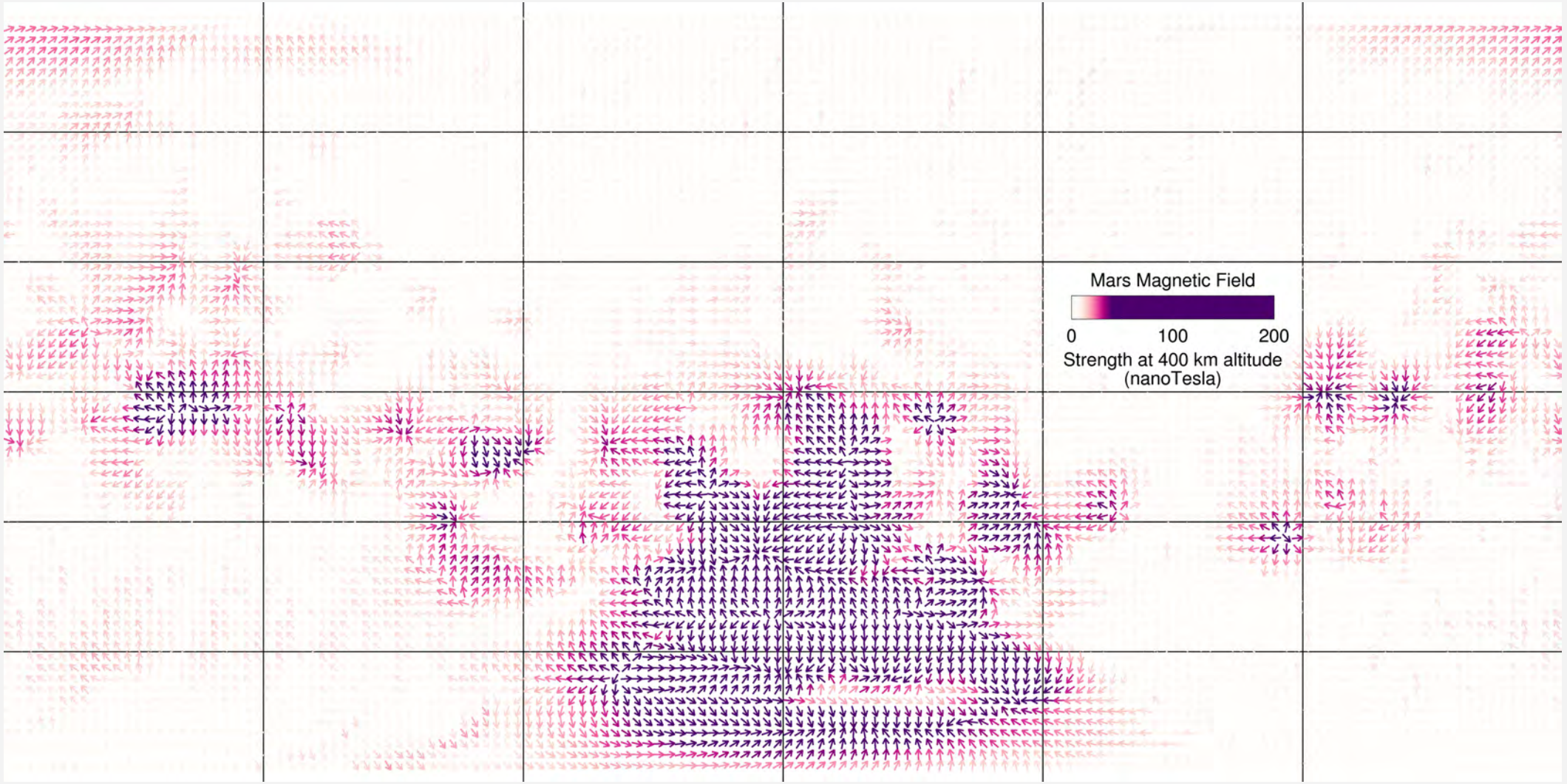
Caveats

- How to validate results?
- Are results sensitive to other parameters, or model physics?
- Ion escape is one of several loss processes
- Strong magnetic fields present major challenges for global simulations

Earth's Magnetic Field

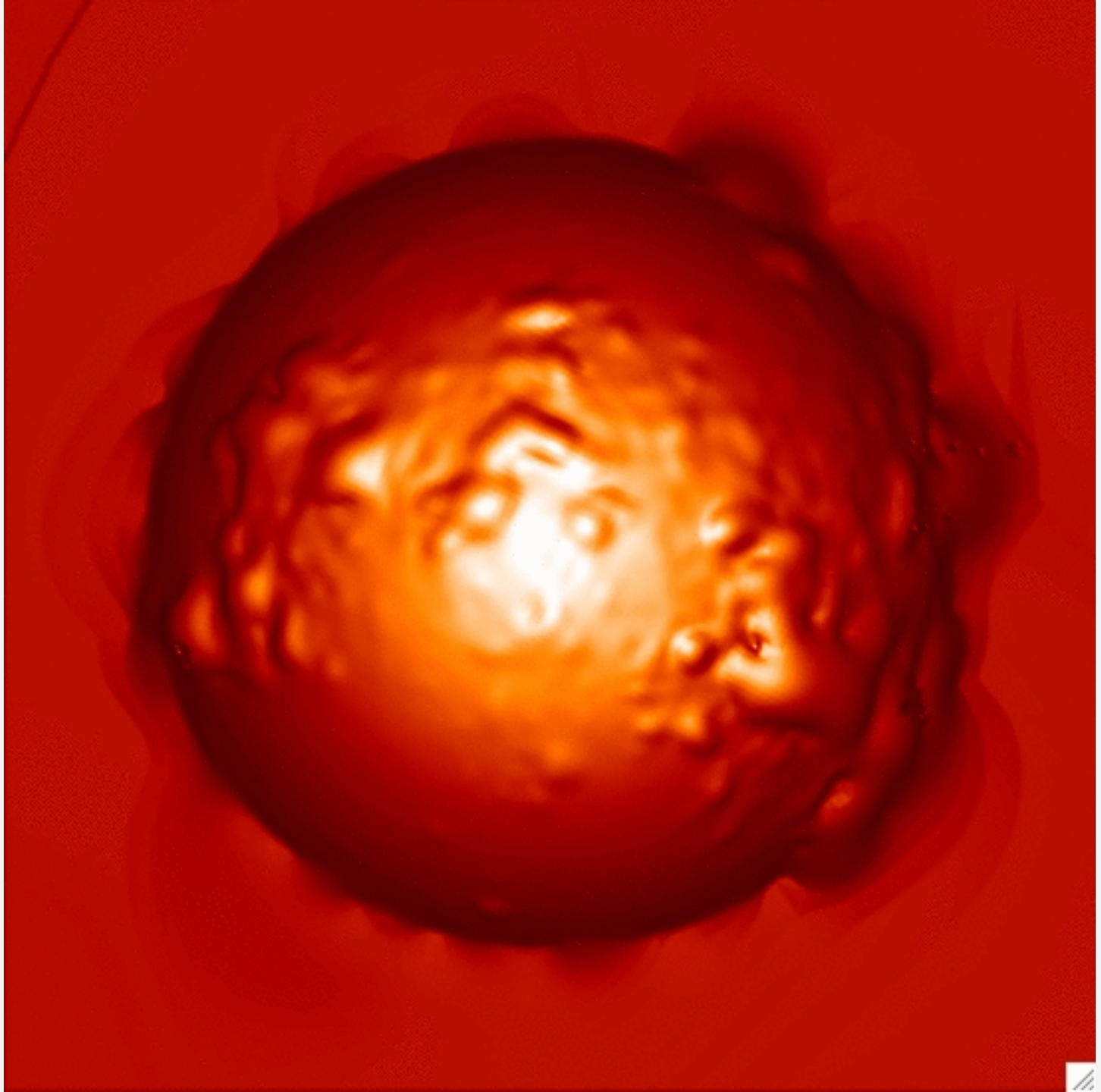


‘Global Compass Maps’



Latitude

Longitude



A Possible Rosetta Stone?

Martian crustal magnetic fields

All other things being equal…

Mars has a built-in control experiment

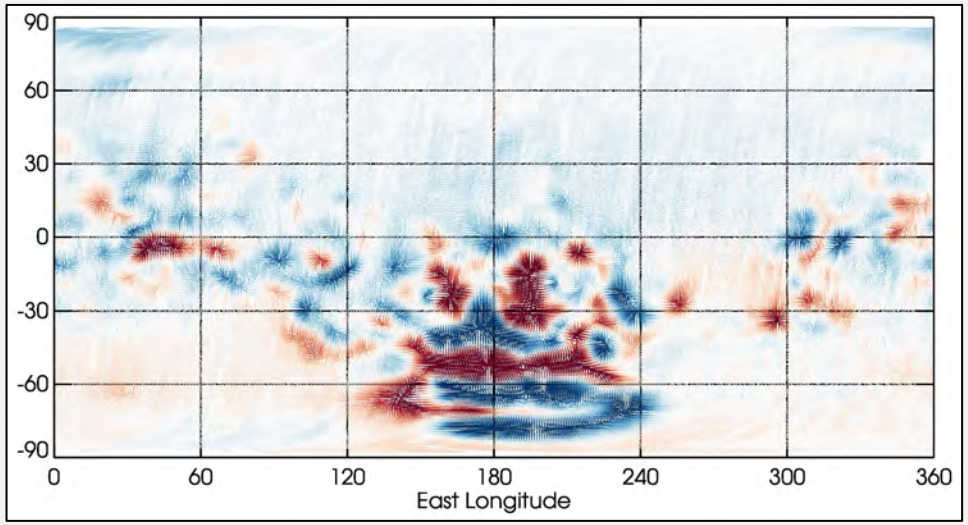
- Both magnetized and unmagnetized regions
- Should host all escape processes that occur on both kinds of objects

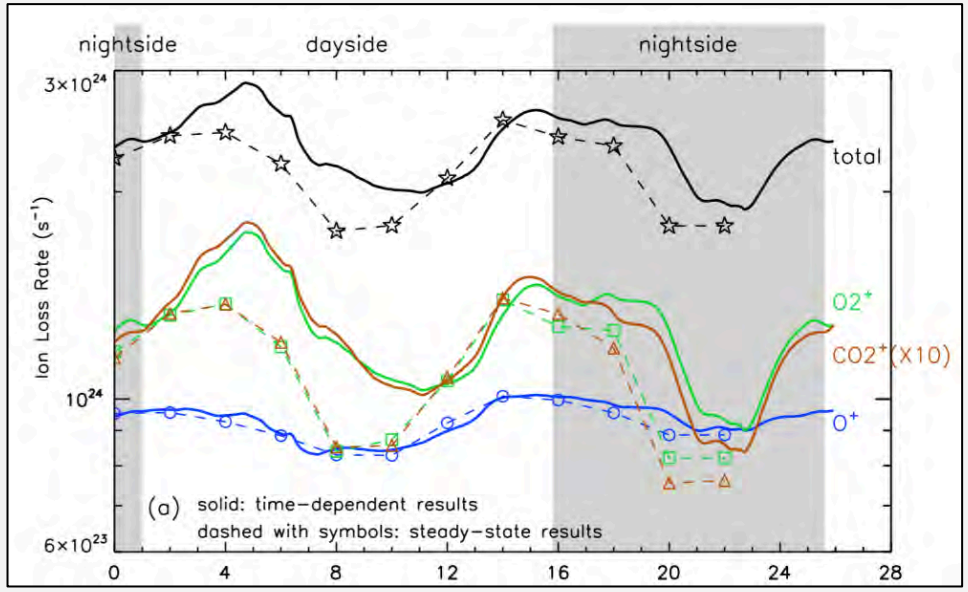
When simulations add crustal fields:

- Ion loss changes by 0.1 – 30×

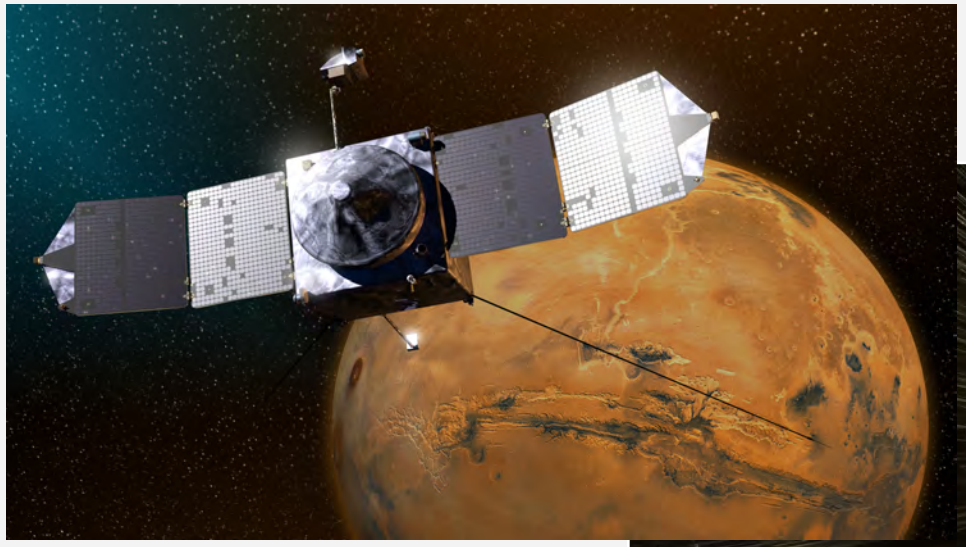
When simulations rotate crustal fields through a day

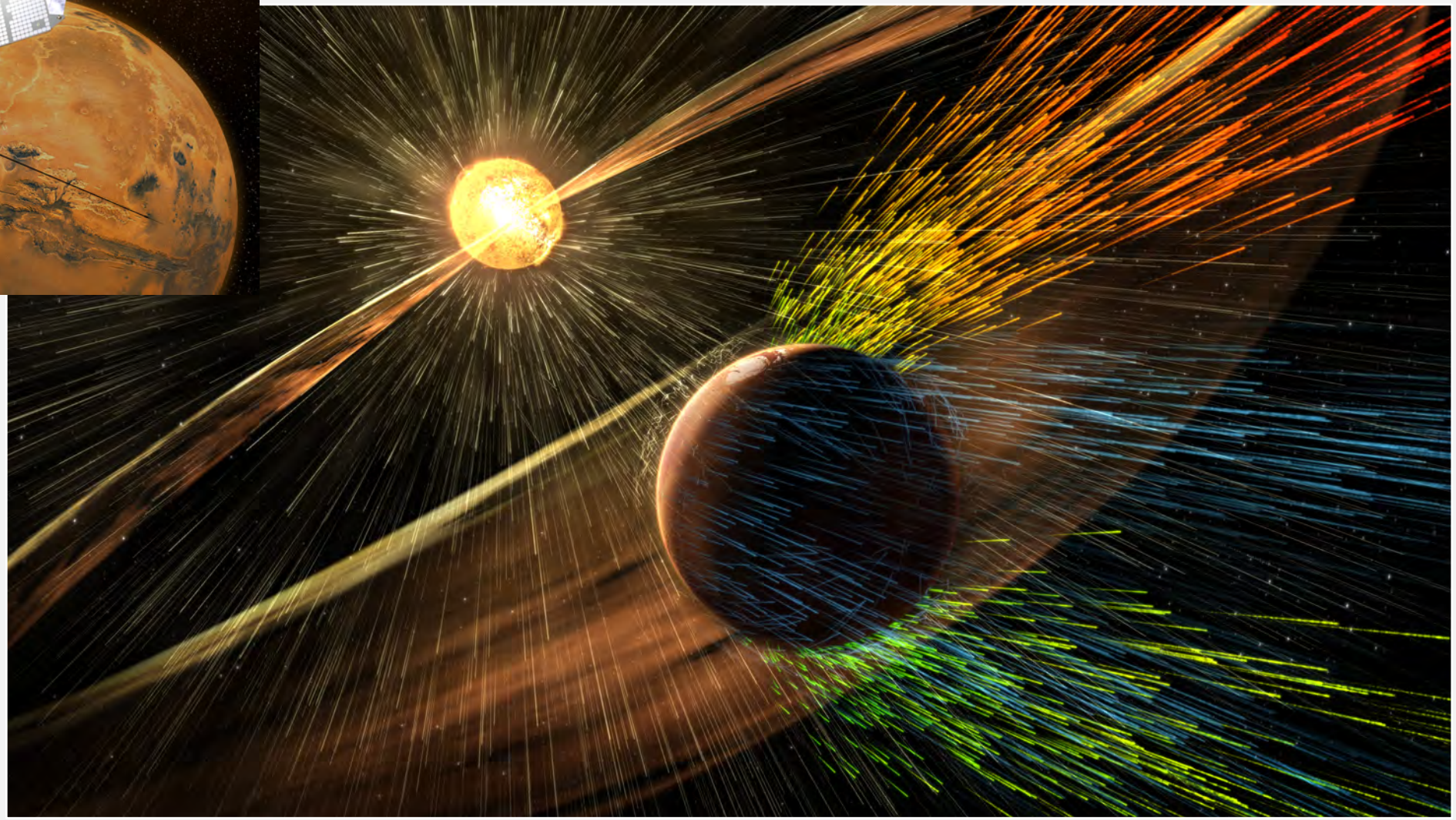
- Ion loss changes by 15 – 50% (or more)



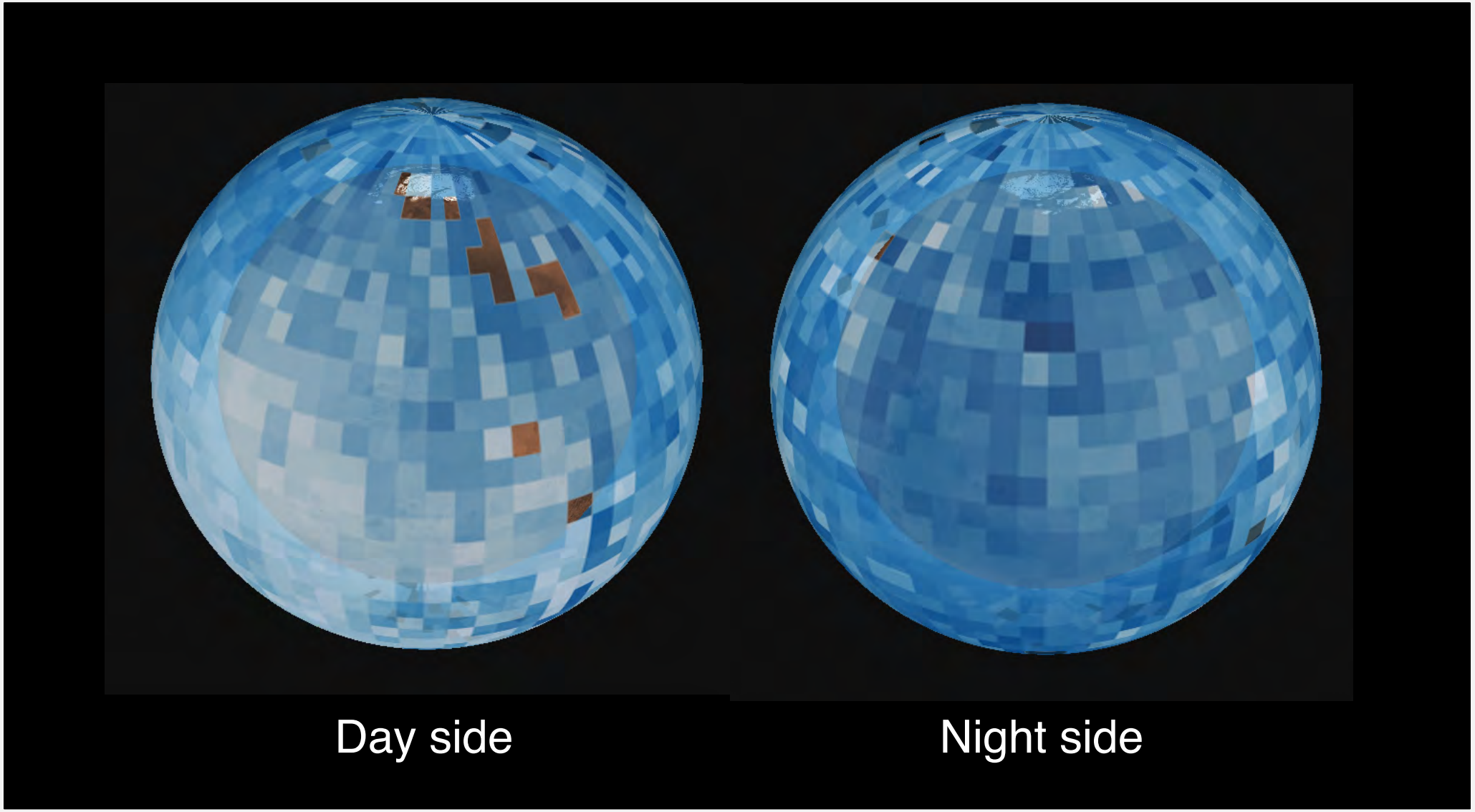


Mars Atmosphere and Volatile EvolutioN



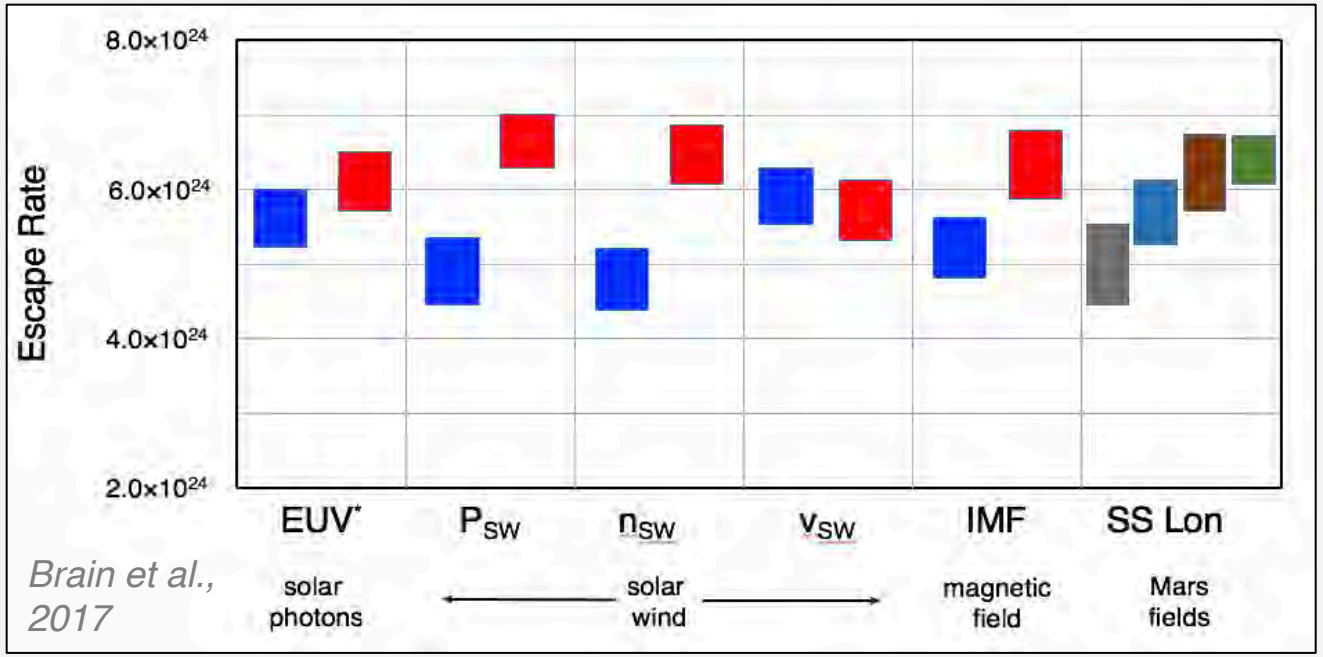


Loss of Charged Atmospheric Particles

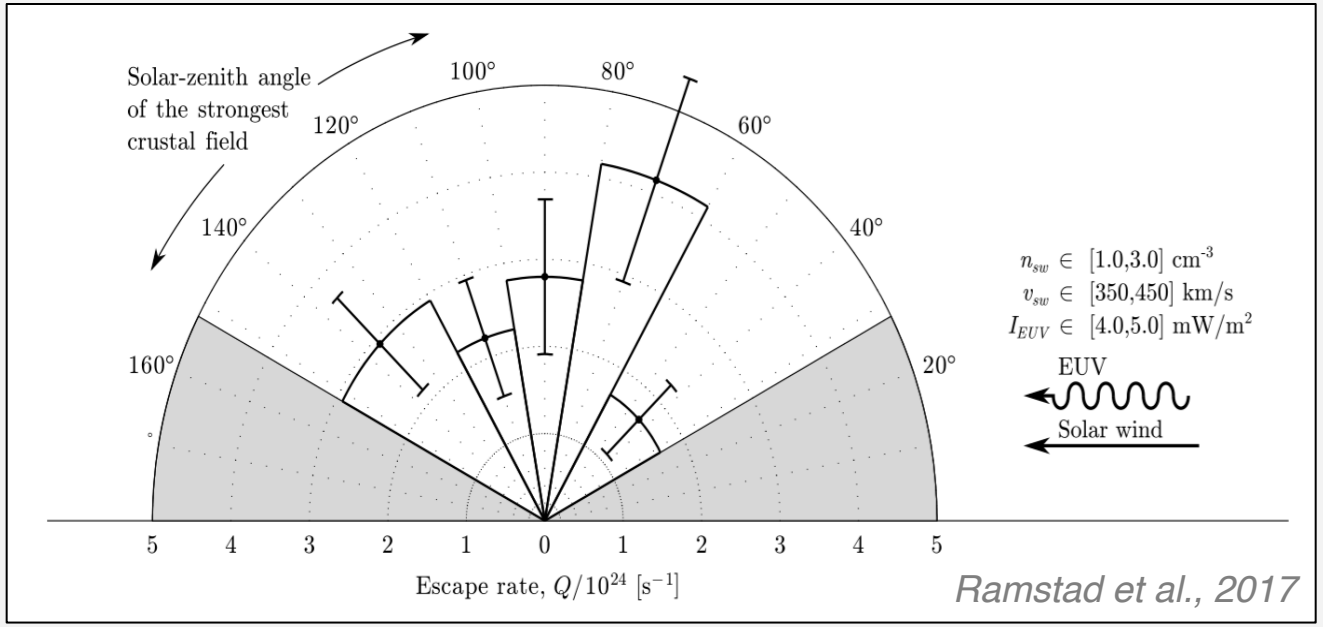


Brain et al., 2015, 2017

Observations from Mars



Brain et al., 2017



Ramstad et al., 2017

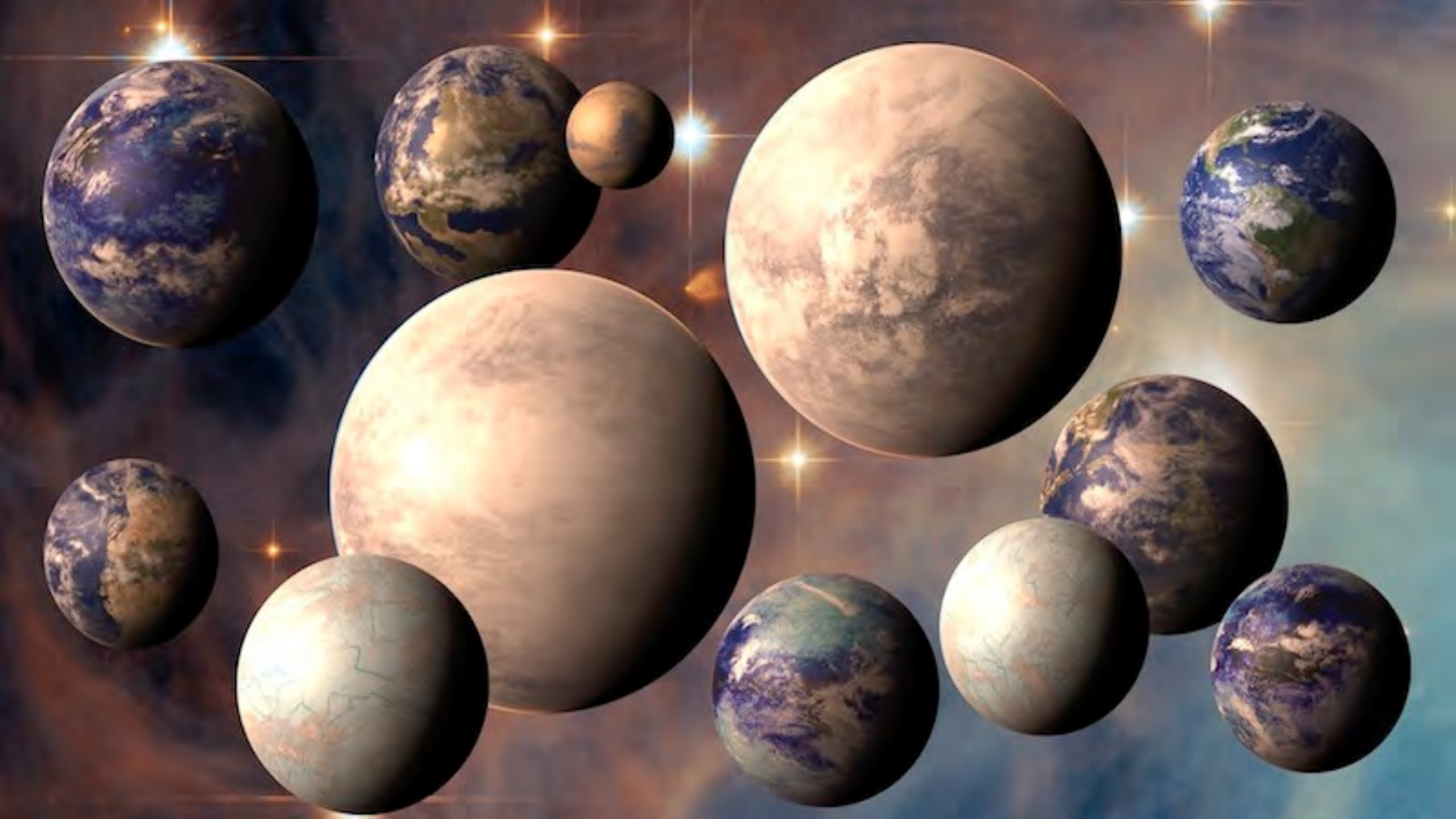
Measured global ion loss:

- MAVEN: Varies 30% as Mars rotates*
- Mars Express: Varies 2.5×

Needed:

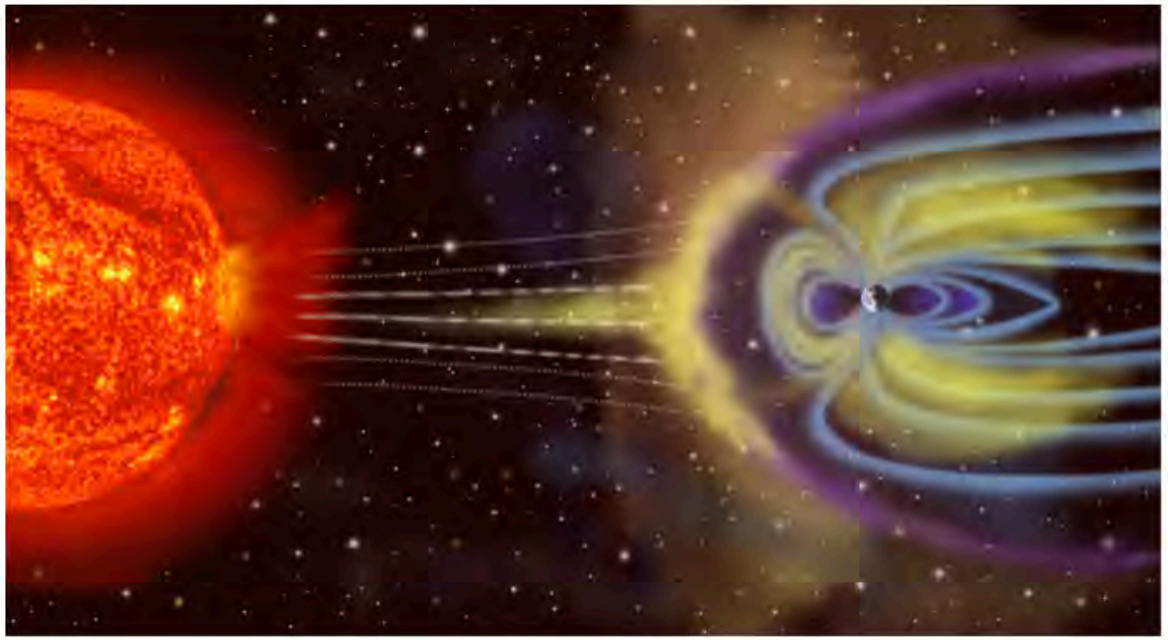
- Measured ion loss from different geographic regions
- Variation in other loss processes as Mars rotates or from different regions

*Coverage is still sparse



NEWS | September 28, 2015

Earth-like exoplanets may have magnetic fields capable of protecting life



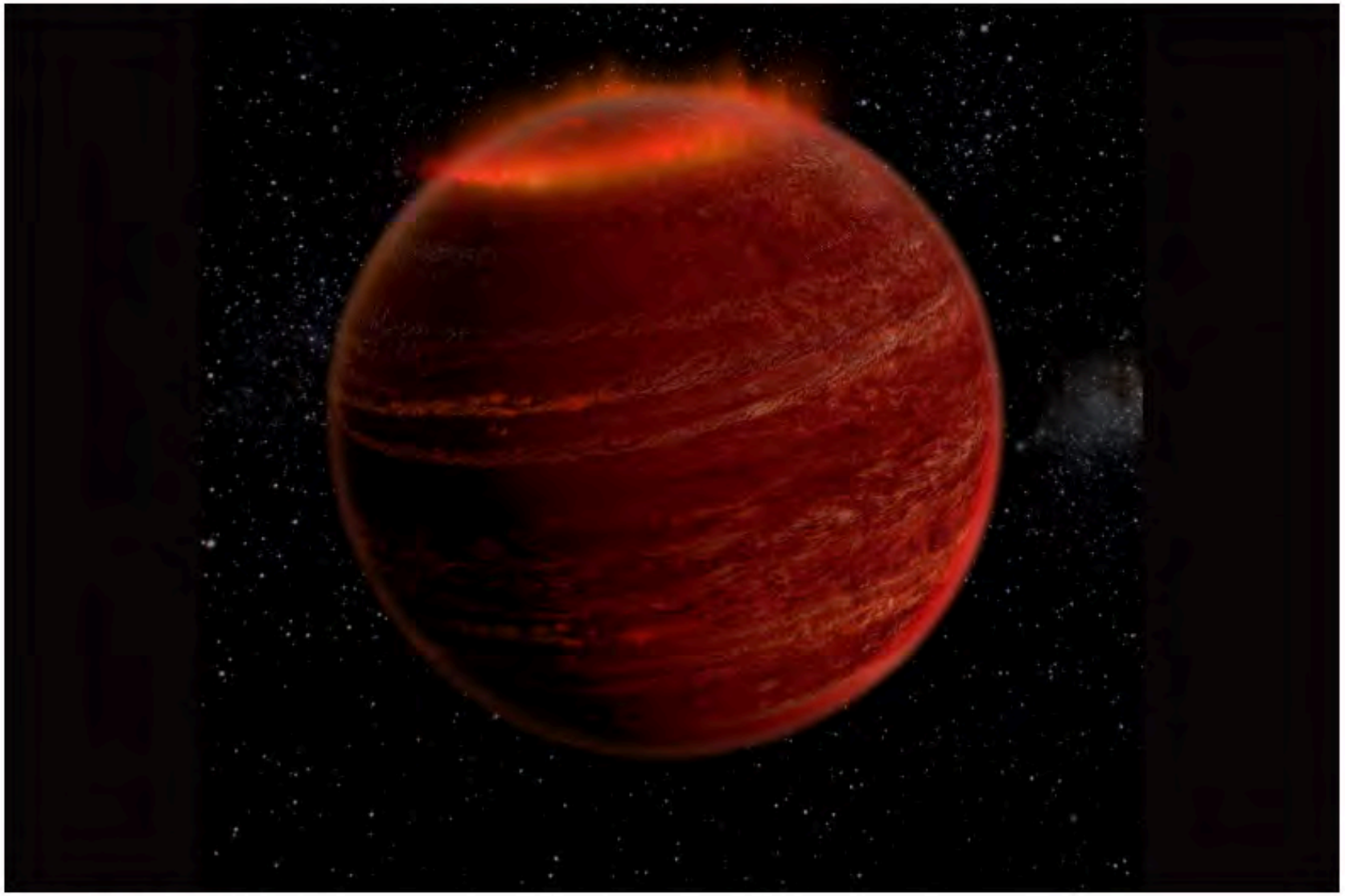
Exoplanets orbiting close to small stars may have magnetic fields that could protect life on the planet's surface: NASA

From University of Washington

Earth-like planets orbiting close to small stars probably have magnetic fields that protect them from stellar radiation and help maintain surface conditions that could be conducive to life, according to research from astronomers at the University of Washington.

A planet's magnetic field emanates from its core and is thought to deflect the charged particles of the stellar wind, protecting the atmosphere from being lost to space. Magnetic fields, born from the cooling of a planet's interior, could also protect life on the surface from harmful radiation as the Earth's magnetic field protects us.

Brown dwarfs have strong magnetic fields just like real stars



Chuck Carter and Gregg Hallinan/Caltech

Key Questions

Dave's Guesses

More strict

- All other things being equal, does a planet with a magnetic field lose less atmosphere than a planet without?

  Yes

- If so, is this reduction substantial enough to account for a difference in habitability on some timescale?

  Depends

- Is it highly likely or even required that a planet that retains a habitable atmosphere has a magnetic field?

  No

How can we bring data and/or models to bear on these questions?