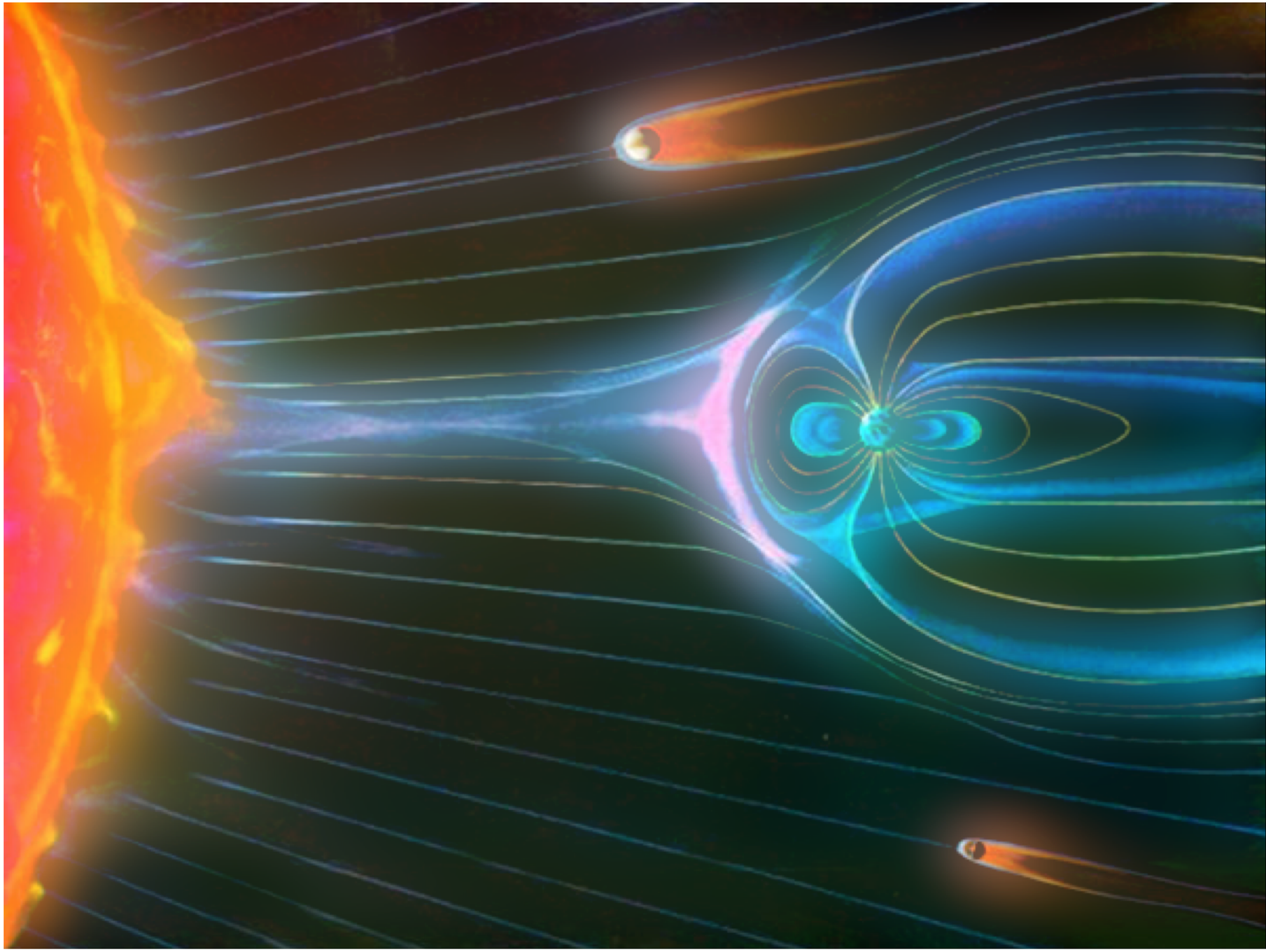
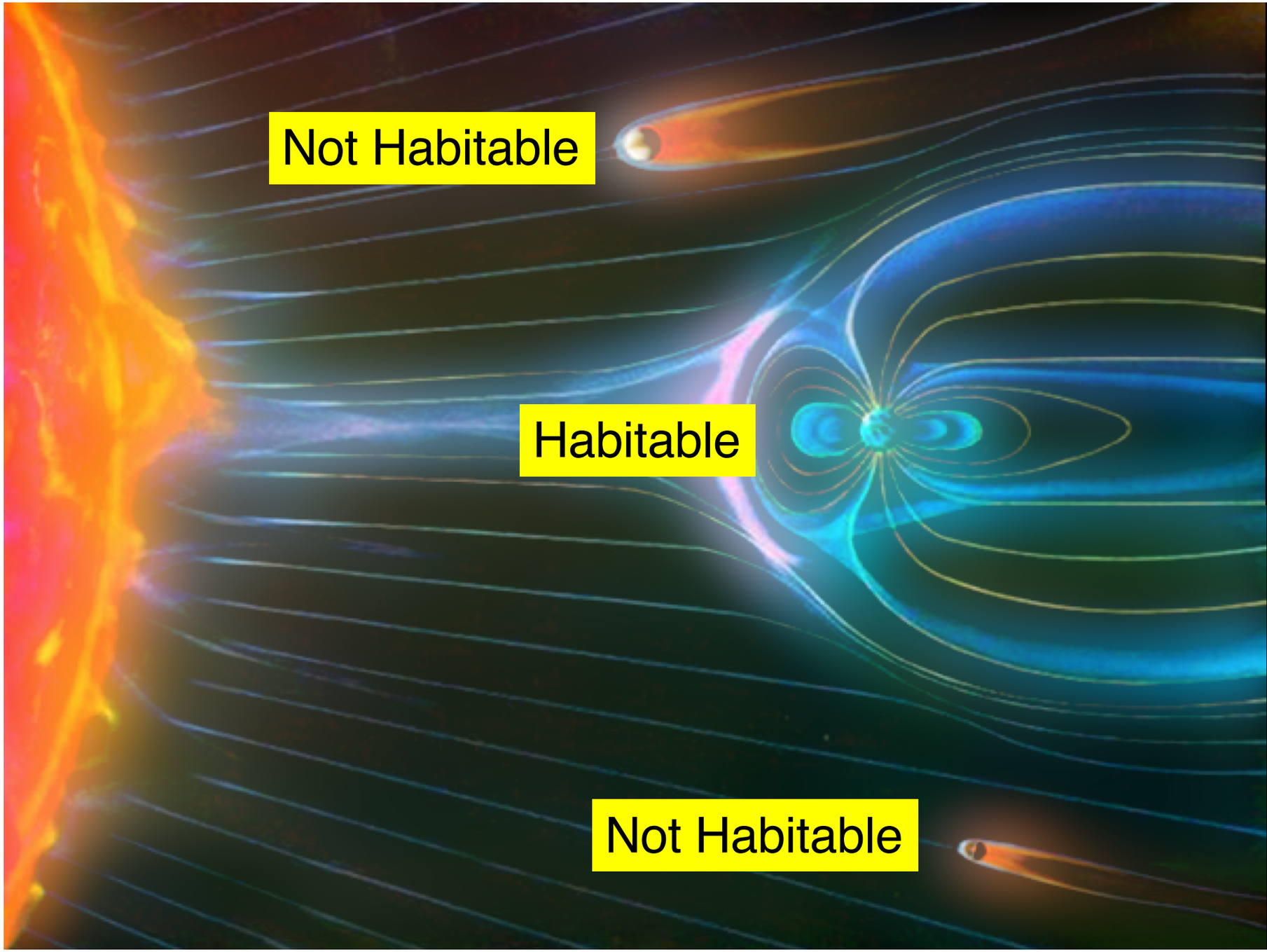


Do Habitable Worlds Require Magnetic Fields?

Dave Brain[1,2], K. Seki[2], H. Egan[1], R. Jarvinen[3], Y. Ma[4], M. Hölmstrom[5], R. Ramstad[1], T. Weber[1], R. Jolitz[1]

[1]U. Colorado, [2]U. Tokyo, [3]FMI, [4]UCLA, [5]IRF

SPS2019 – Sendai
20 February, 2019



Do Habitable Worlds Require Magnetic Fields?

Empirical evidence suggests “Yes”

Motivation

life

↓ Earth type

liquid water

↓ surface

atmosphere

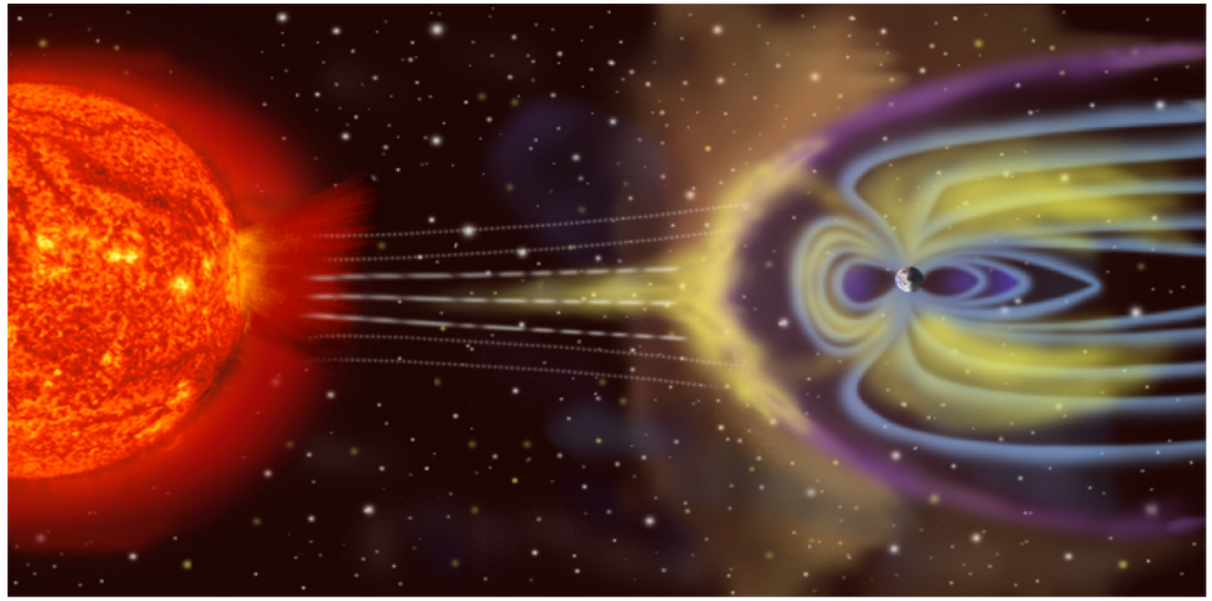
↓ ???

magnetic field

Can we safely assume (exo)planetary magnetic fields improve chances for habitability?

NEWS I September 28, 2015

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



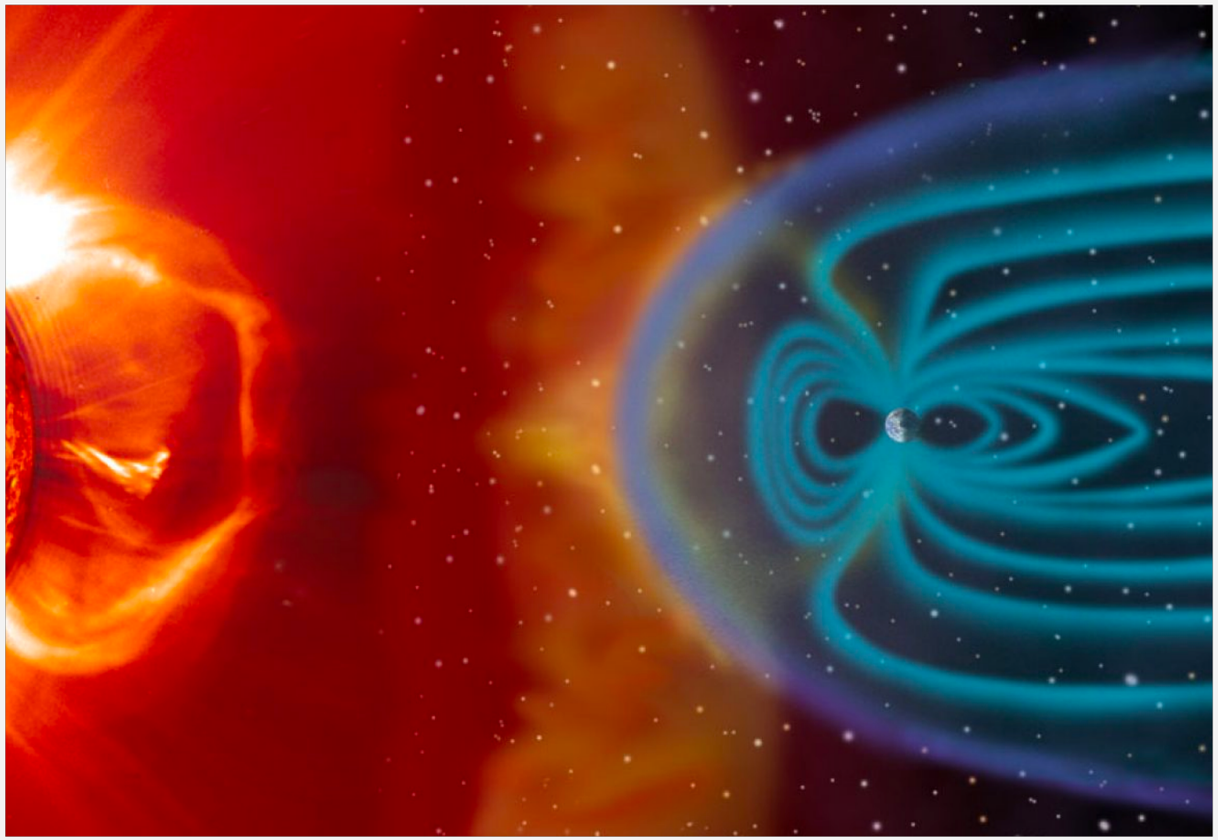
Exoplanets orbiting close to small stars may have magnetic fields that could protect life on the planet's surface: NASA

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.

Magnetic Fields Should Protect Atmospheres



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

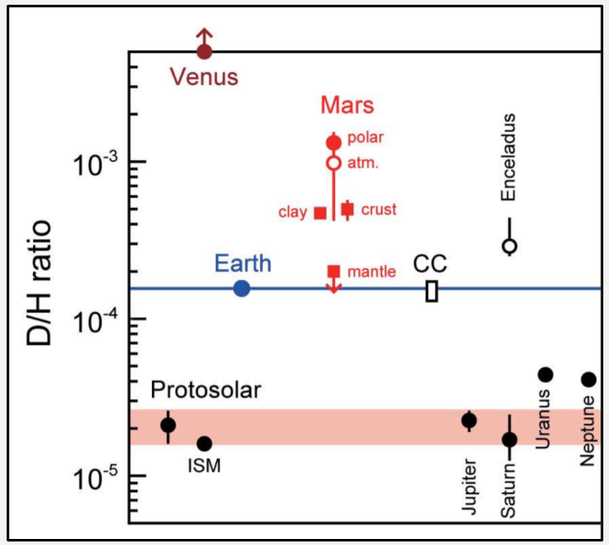
- Solar wind can't hit atmosphere
- Less energy for top of atmosphere

→ Atmosphere can't escape efficiently

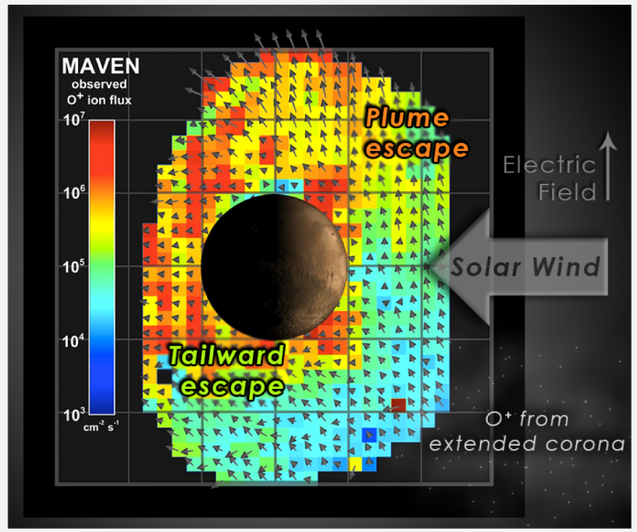
Observational support:

- Isotopes at Venus and Mars suggest they lost atmosphere relative to Earth
- MAVEN observations indicate Mars lost substantial atmosphere over time
- Earth and Mars respond differently to the same event*

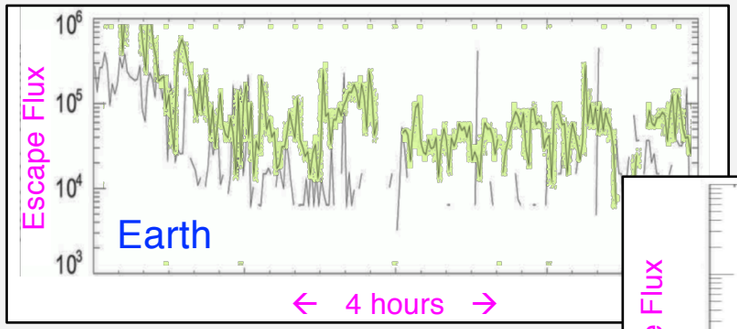
Magnetic Fields Should Protect Atmospheres

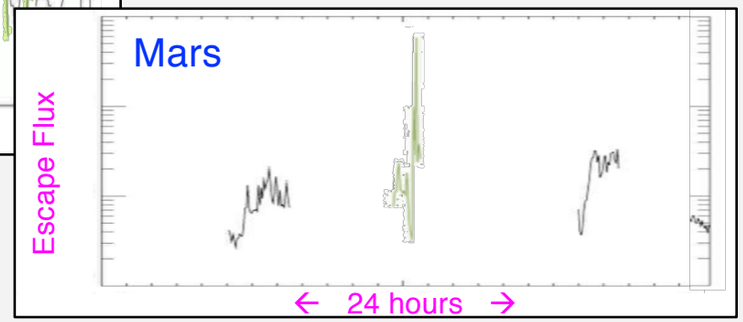


Genda, 2015



Dong et al., 2015





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

Observational support:

- Isotopes at Venus and Mars suggest they lost atmosphere relative to Earth
- MAVEN observations indicate Mars lost substantial atmosphere over time
- Earth and Mars respond differently to the same event*

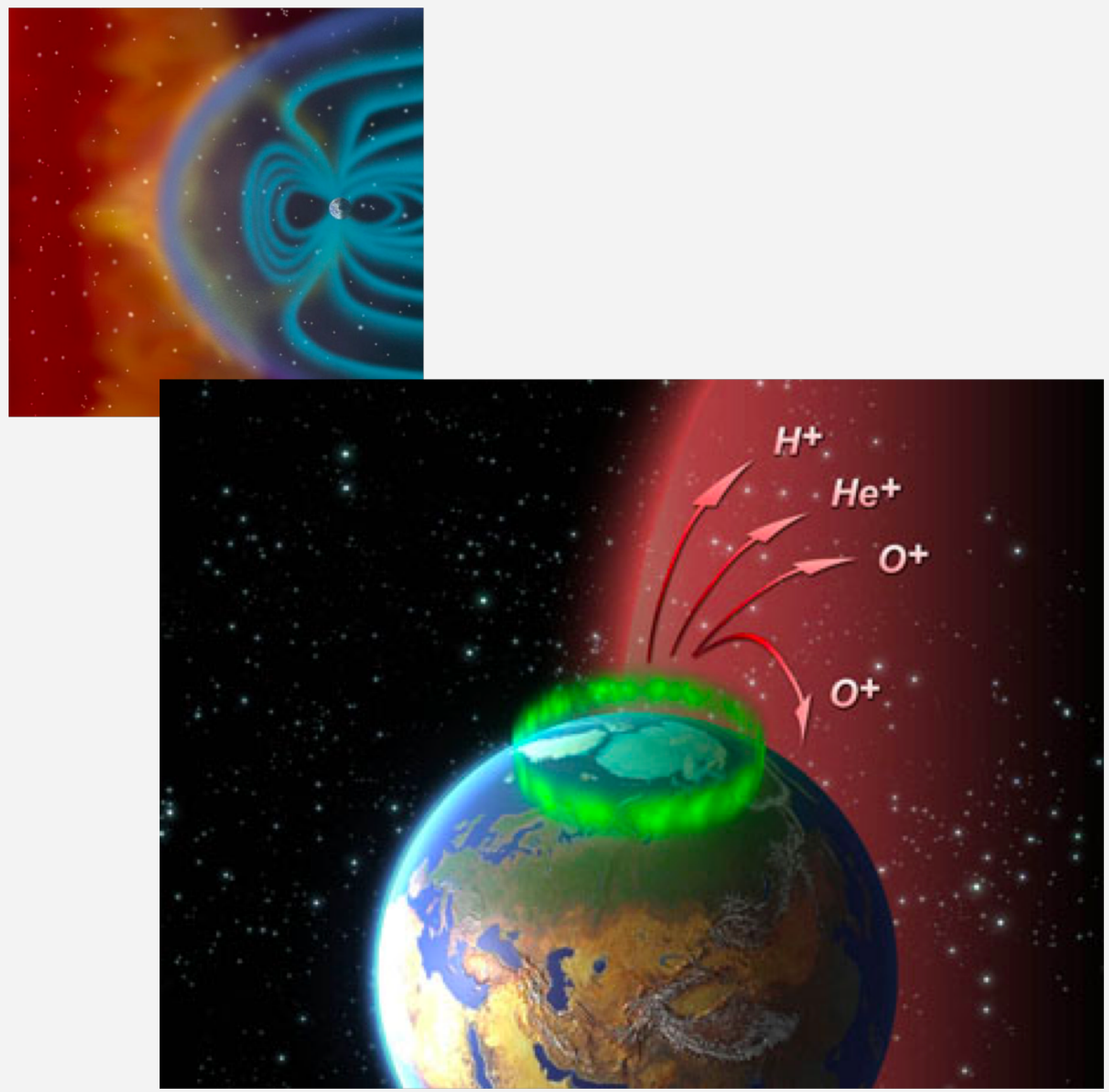
Magnetic Fields Should Not Protect Atmospheres

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

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

Observational support

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



Magnetic Fields Should Not Protect Atmospheres

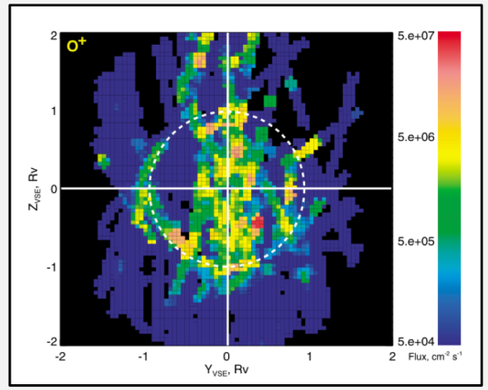
Simple physics: A magnetized planet captures more energy from the solar wind

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

Observational support

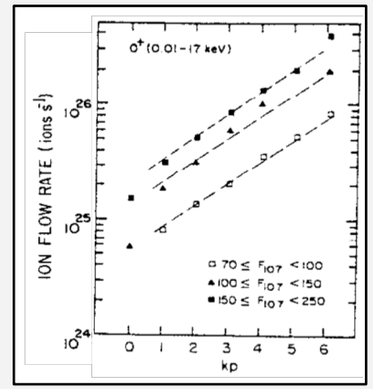
- V, E, M all lose roughly the same amount of charged particles today*
- Energy of solar wind is proportional to ion escape at Earth*

Venus



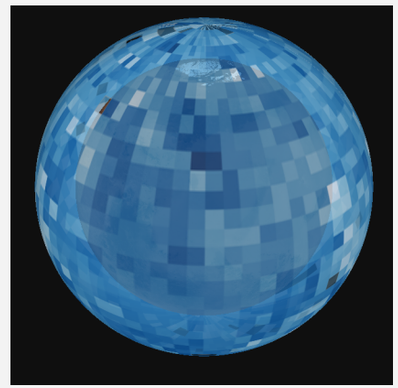
Fedorov et al., 2011

Earth

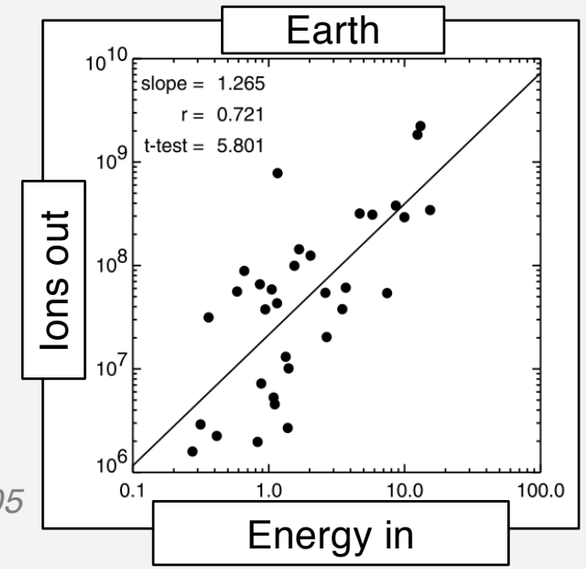


Yau et al., 1998

Mars



Brain et al., 2015



Strangeway et al., 2005

One Effort: Modeling Magnetized ExoMars

Global Hybrid Model

- Assumed present-day Mars
- 7 runs, varying only magnetic field strength (all weak!)

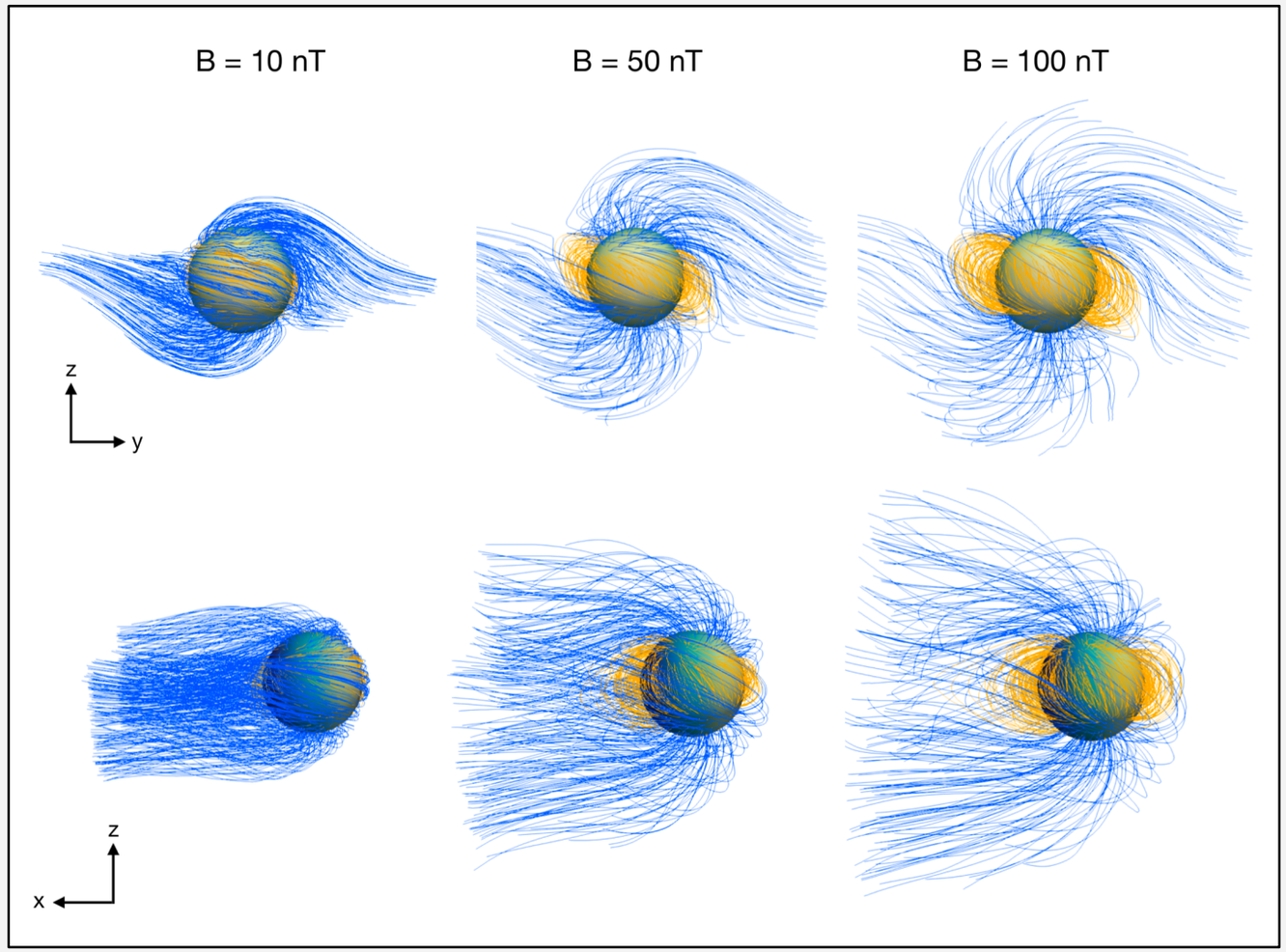
Explored:

Plasma environment

- Magnetic topology
- IMF vs. dipole influence
- Tail twisting

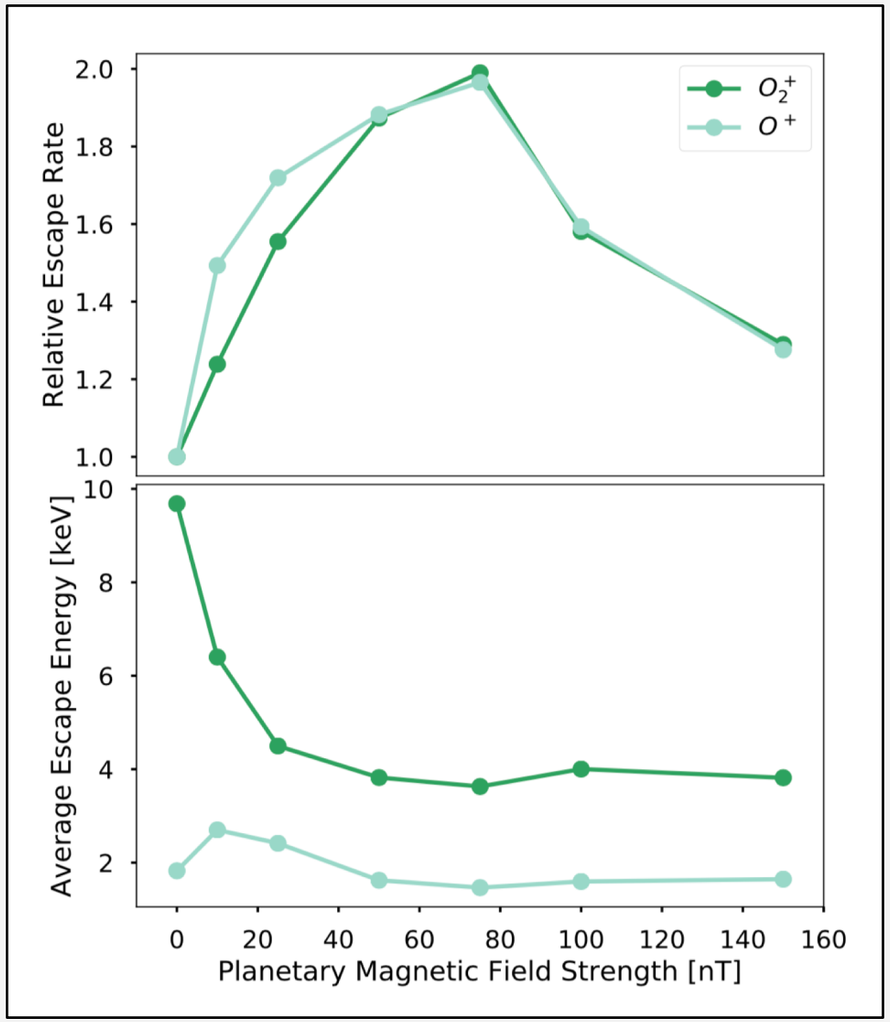
Ion Escape

- Escape rates and energies
- Magnetic shielding
- Plasmasphere trapping
- Power coupling to solar wind



Egan et al., 2019

Modeled Scaling Laws for Ion Escape



Egan et al., 2019

Escape Rates

- A weak field <u>increases</u> escape
  - Fewer particles crash into planet
- A strong field <u>decreases</u> escape again
  - Increased trapping of newborn ions
- Balance point occurs when planetary field can balance solar wind pressure

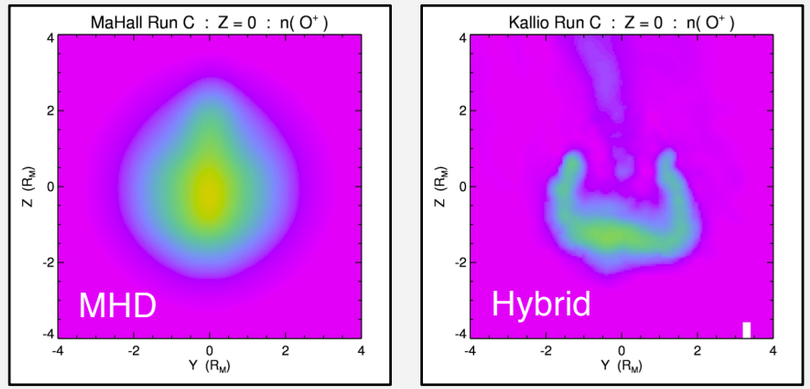
Escape Energies

- Adding magnetic field <u>decreases</u> escaping particle energy
  - Fewer particles accelerated directly by solar wind
  - Less important for lighter species

A Few Challenges

Models

- Have trouble with strong magnetic fields
- May be sensitive to other parameters, or model physics
- Are difficult to validate
- Don't include all escape processes



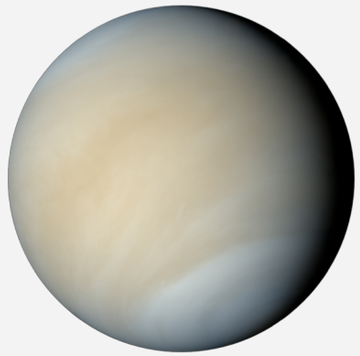
Brain et al., 2014

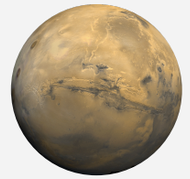
Experiment

- It's difficult to turn a planetary field off or on
- I'd be labeled an evil supervillain if I tried (especially with this last name)

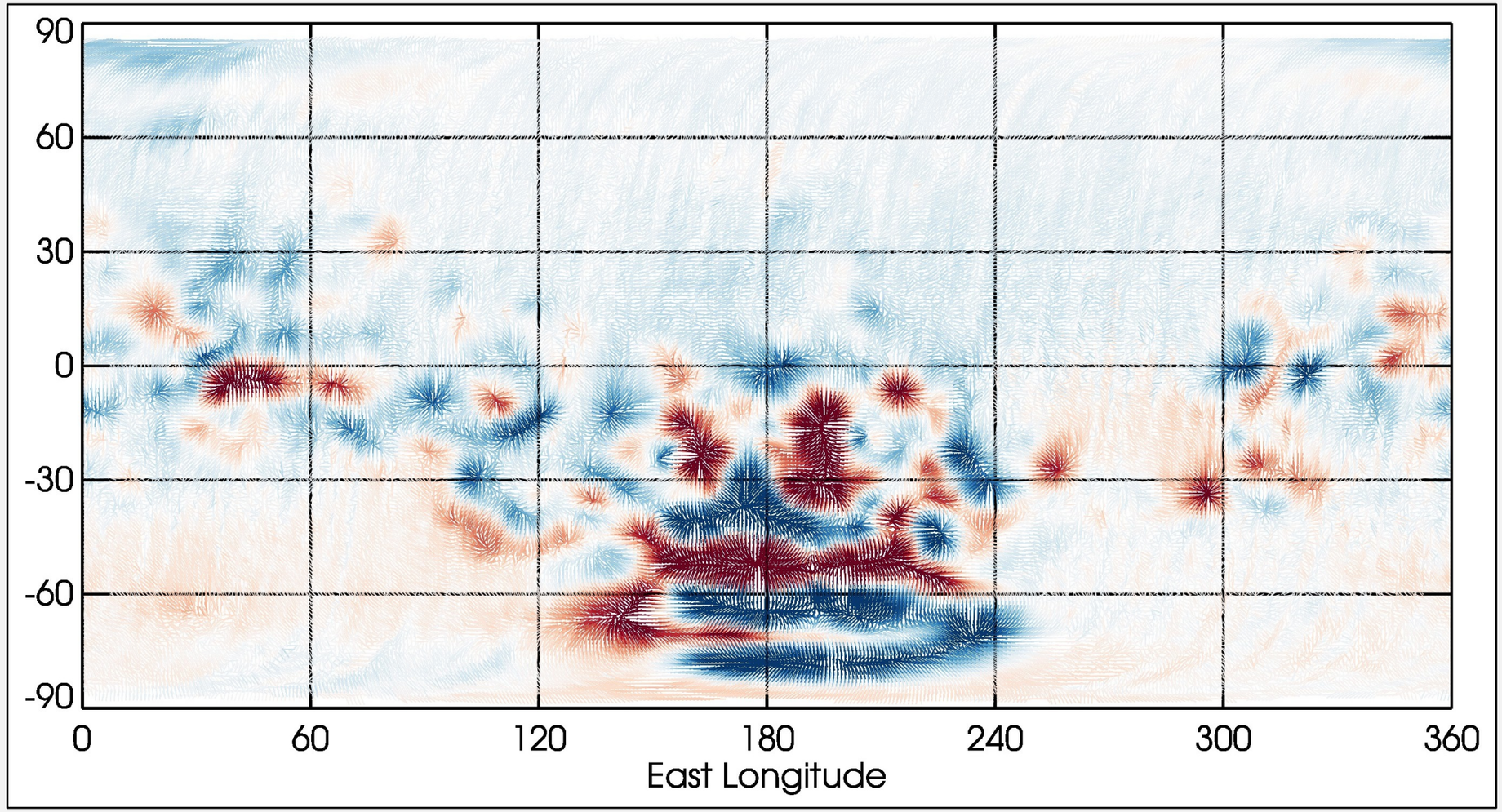
Data

- Comparing escape rates for Venus, Earth, and Mars in an "apples to apples" way hasn't been done
- Venus, Earth, and Mars differ in other ways, which might influence measured escape rates



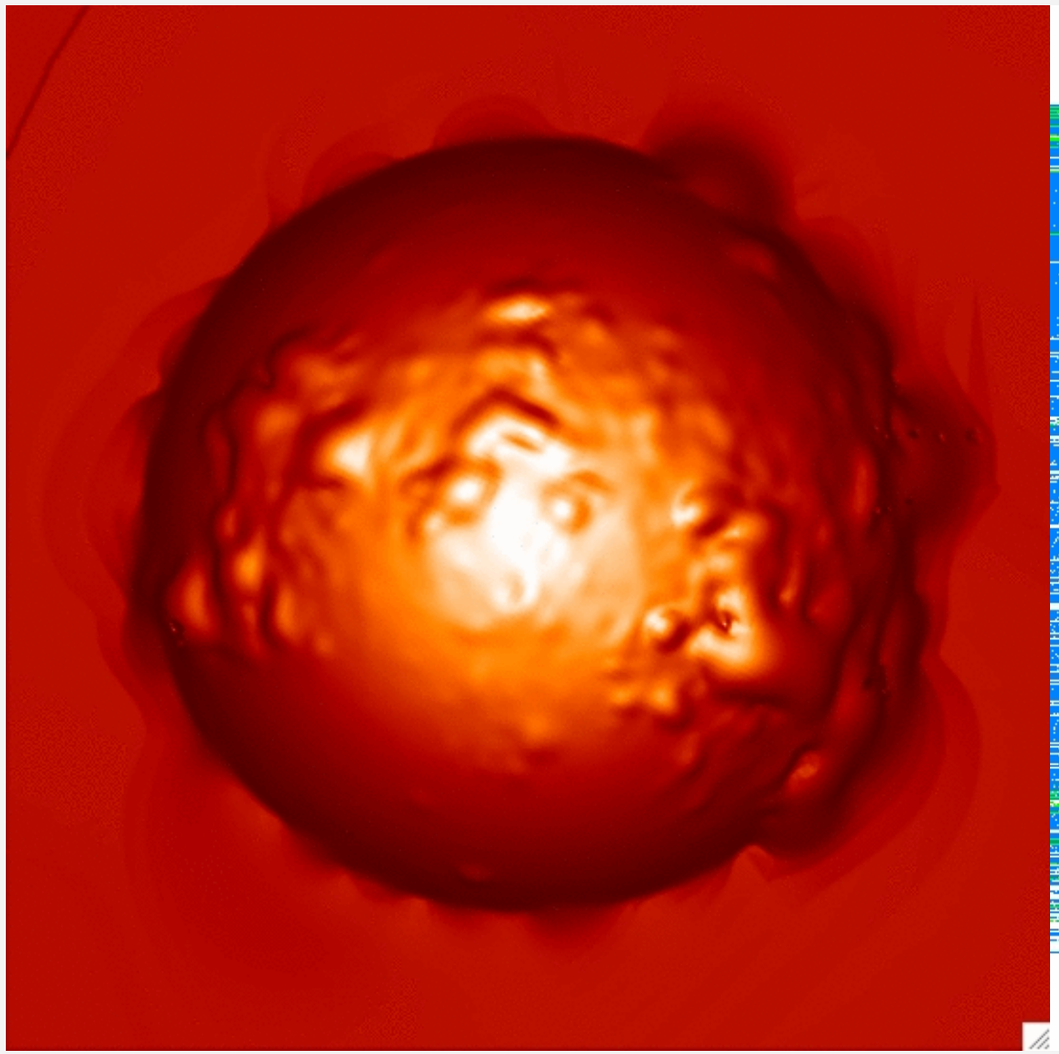


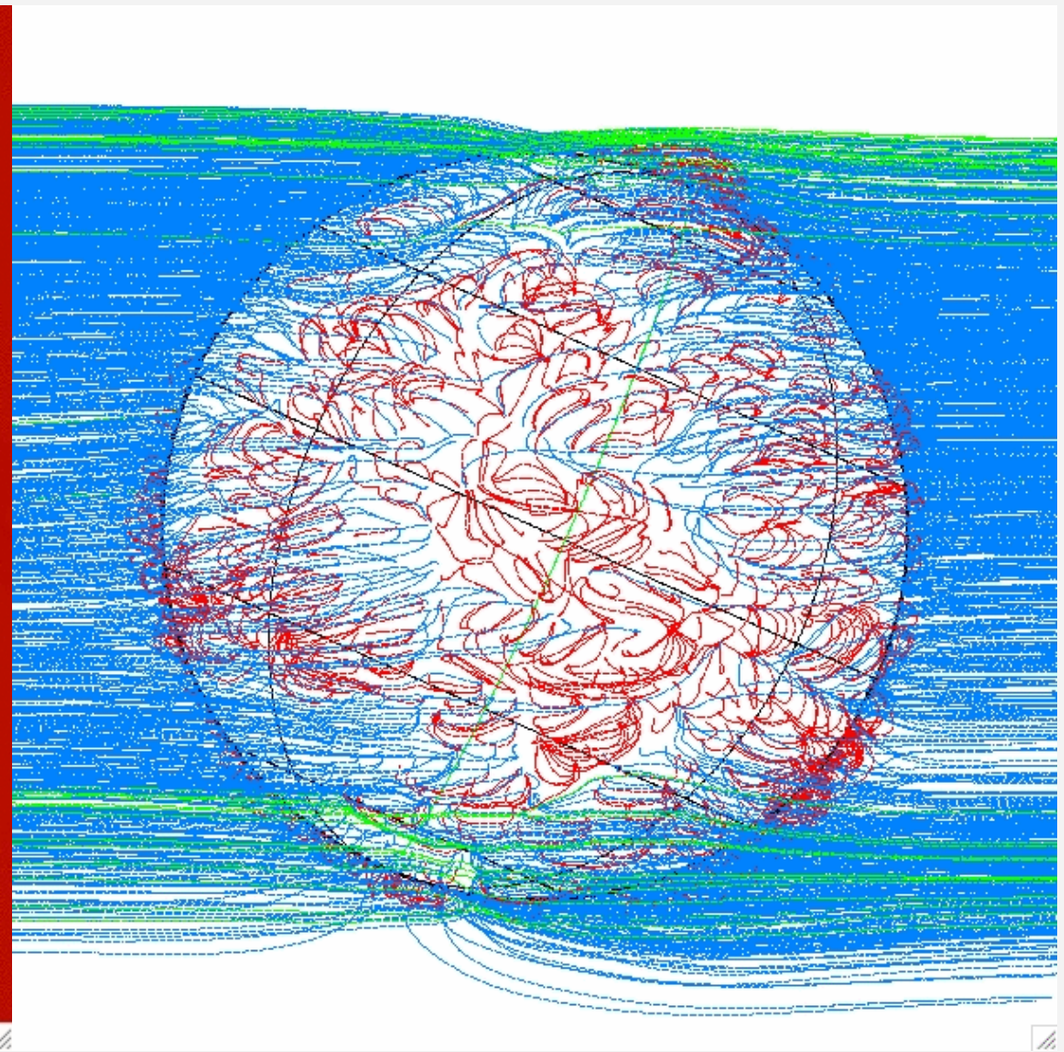
Mars Crustal Fields: A Built-in Control Experiment



Brain et al., 2003, 2018

Mars Crustal Fields: A Built-in Control Experiment





Brain et al., 2003, 2018

Simulations with Crustal Fields

When simulations *add* crustal fields:

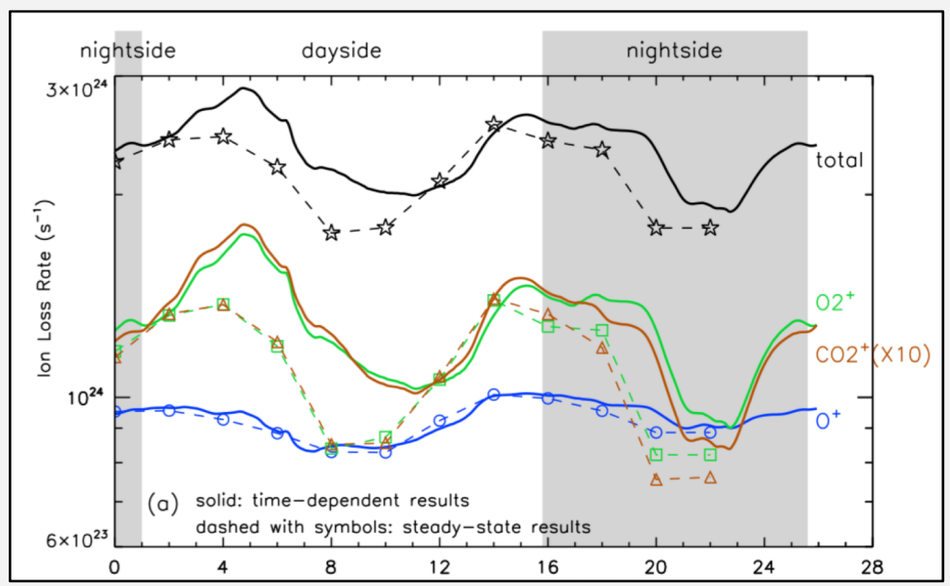
- Global ion loss changes by 0.1 – 30×

	Unmagnetized	Magnetized
O_2^+	2.72×10^{25} s^{-1}	1.88×10^{25} s^{-1}
O^+	0.47×10^{25} s^{-1}	0.36×10^{25} s^{-1}
Total	3.19×10^{25} s^{-1}	2.24×10^{25} s^{-1}

Ma et al., 2002

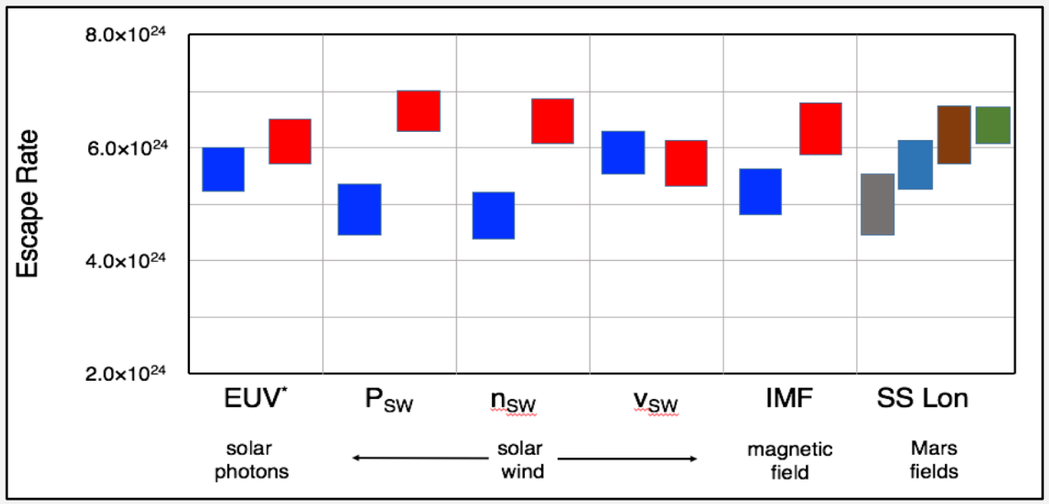
When simulations *rotate* crustal fields through a day

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

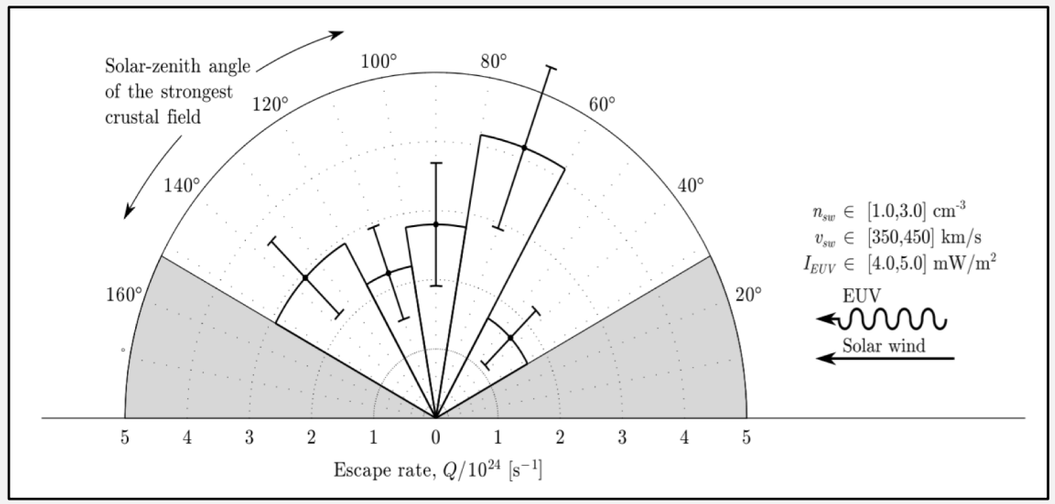


Fang et al., 2016

Observations with Crustal Fields



Brain et al., 2017



Ramstad et al., 2017

Ion loss varies 30% as Mars rotates*

Infer: Crustal Fields <u>not</u> very important

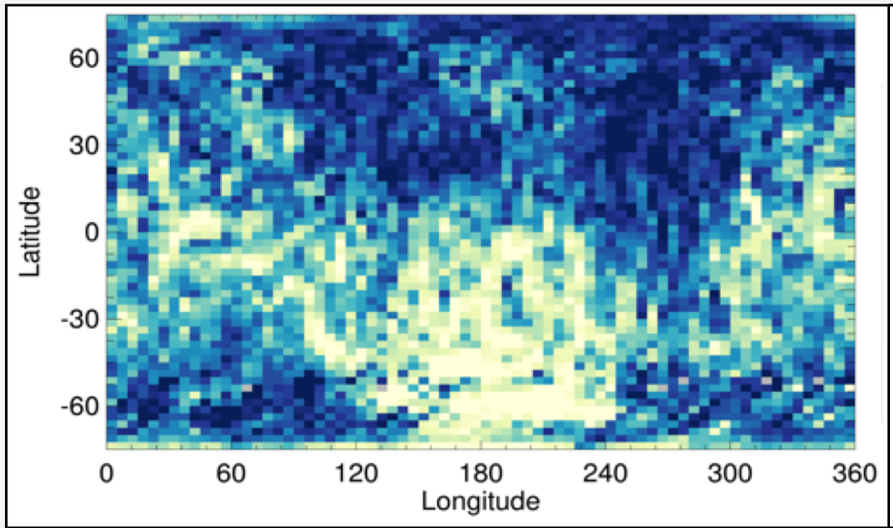
Ion loss varies 2.5x as Mars rotates*

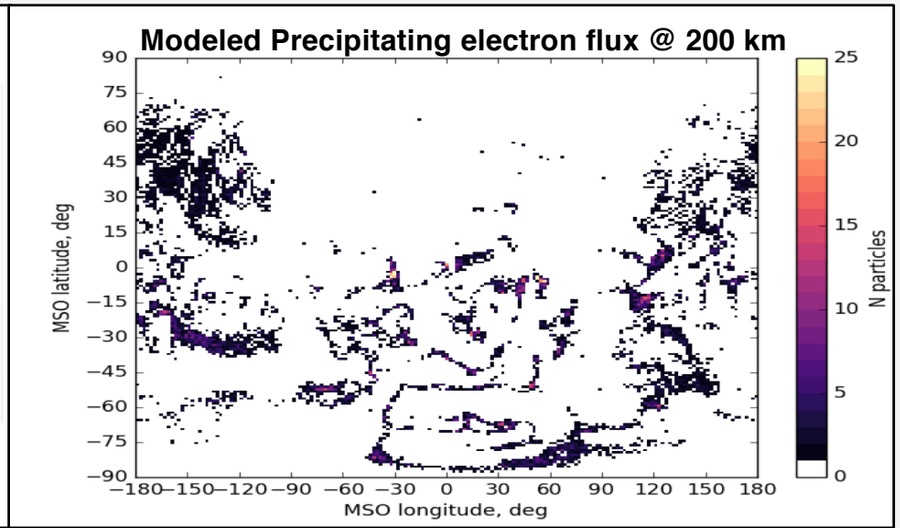
Infer: Crustal Fields fairly <u>important</u>

Ongoing Efforts in Our Group

Compute local outflow

Tristan Weber (Grad)



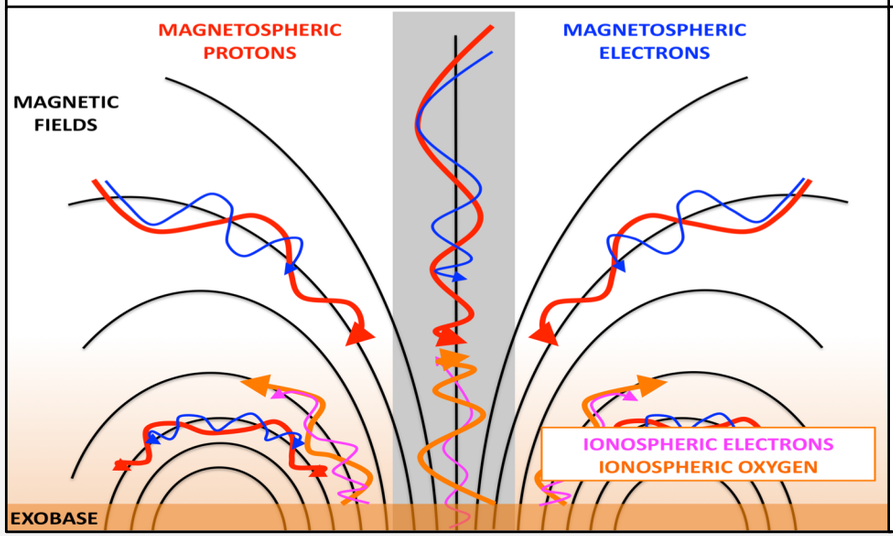


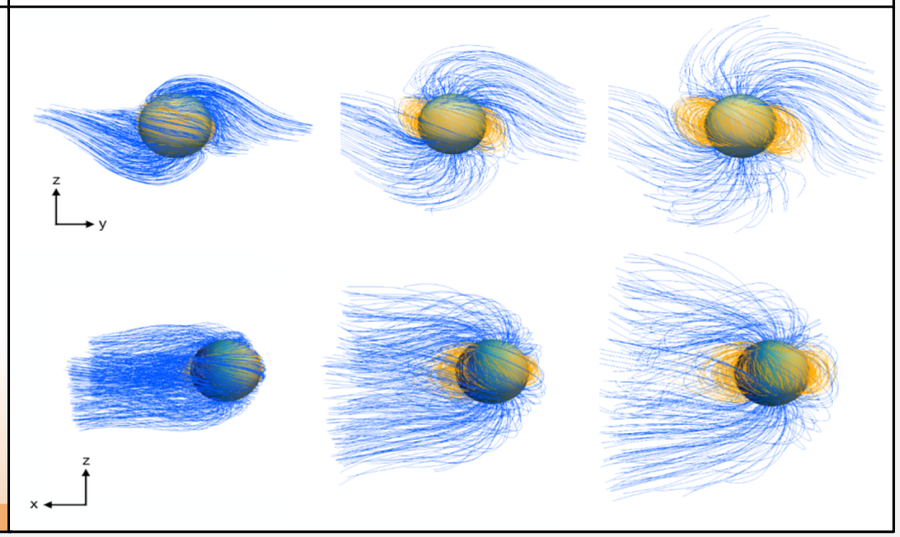
Model incident electrons

Rebecca Jolitz (Grad)

Simulate cusp kinetics

Yaxue Dong (RS)



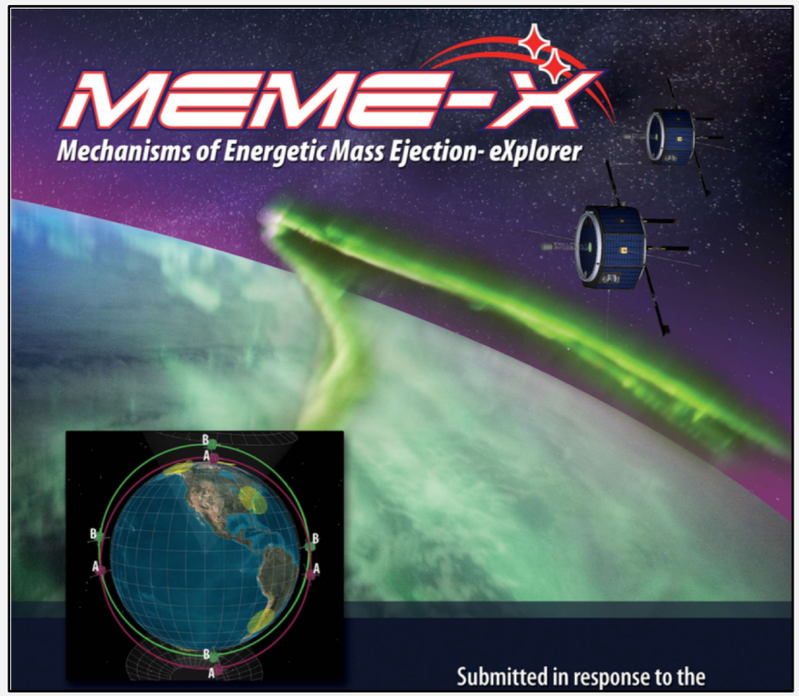


Simulate magnetized (Exo)Mars

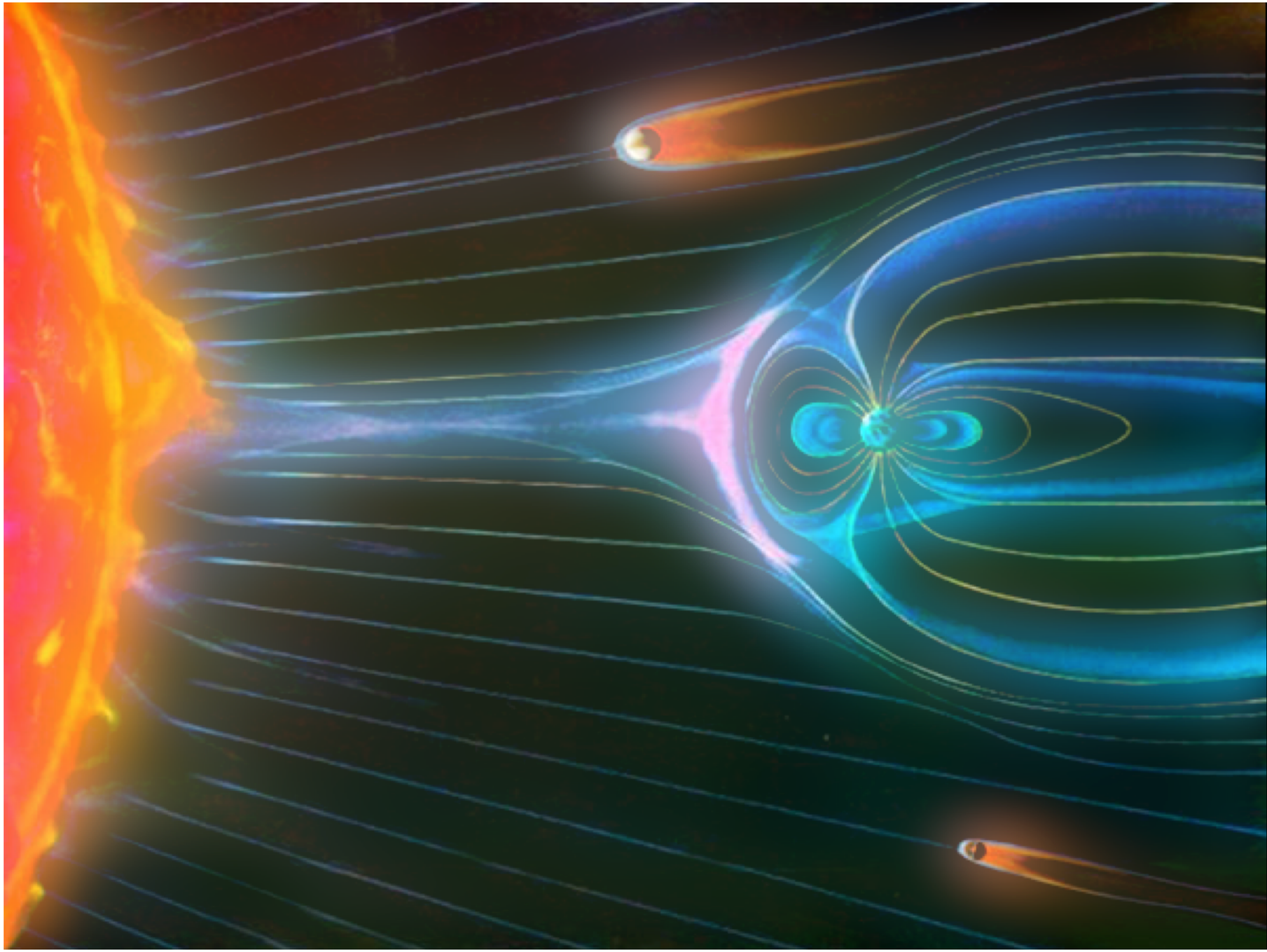
Hilary Egan (Grad)

What's Next?

(That's why I'm here!)



- Resolve the Mars discrepancy
- Put V / E / M observations on a common footing
- Acquire new observations
- Advance simulations
- Propose a Chapman Conference (or equivalent)
- Start a coordinated effort that brings together expertise from V / E / M, simulations, theory



Do Habitable Worlds Require Magnetic Fields?

It depends

planet properties
field strength
space environment