



The Magnetic Tail of Mars

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Overview



- Planetary magnetospheres
- Mars' magnetic space environment
- Using MAVEN to explore the Mars magnetic tail
- MAVEN data and simulation results
- Magnetic reconnection at Mars
- Mars magnetotail and atmospheric escape

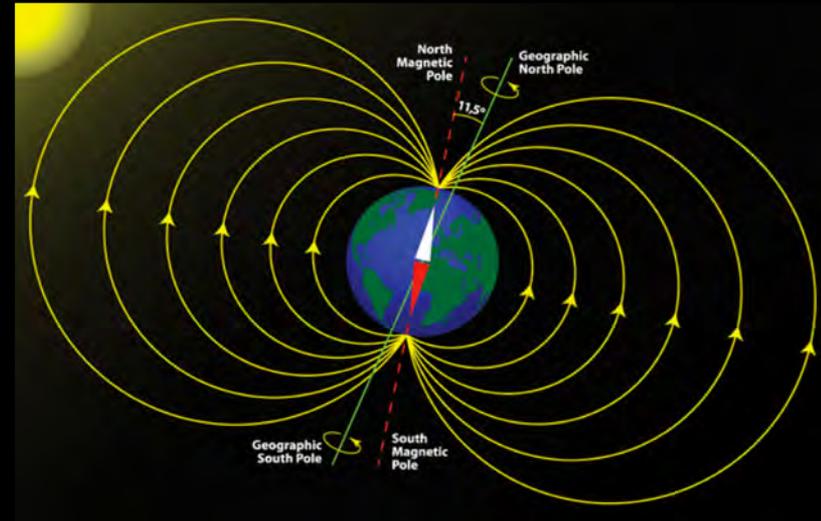
How does a planet's magnetic tail form?

First, let's talk about planetary magnetospheres...

Planetary Magnetic Fields



Some planets have a global magnetic field, generated through a conductive core.



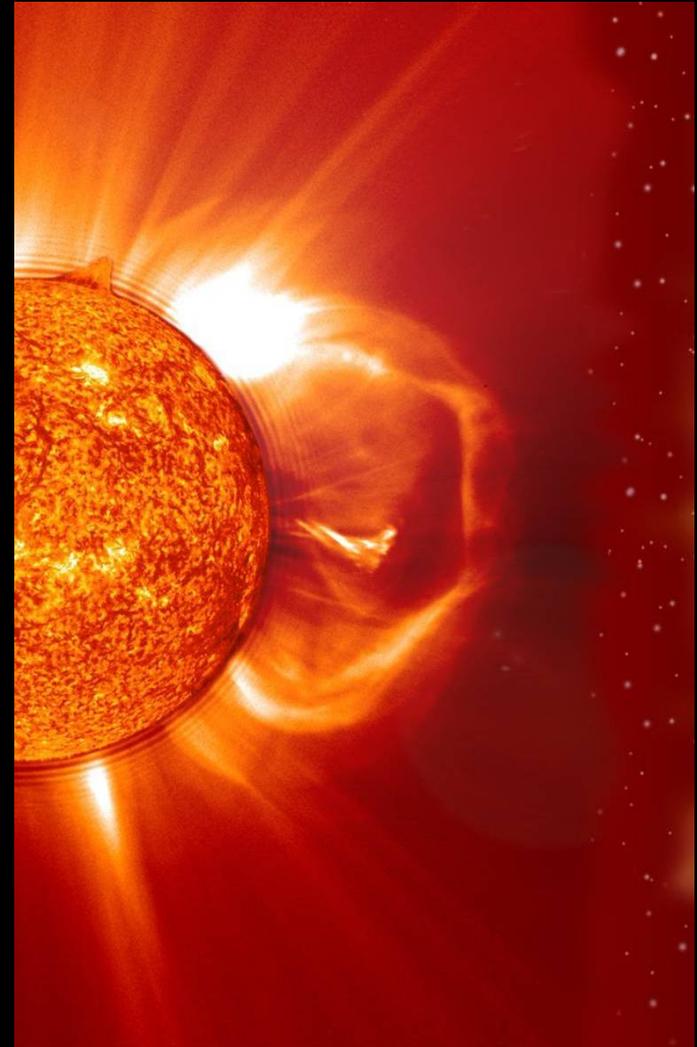
And other planets have no magnetic field, although one may have existed in the past.



The Sun's Solar Wind



- The solar wind is a plasma (gas filled with charged particles) produced in the Sun's atmosphere.
- It streams out from the Sun at extremely high speeds around 1,000,000 mph (450 km/s).
- The solar wind also carries the Sun's magnetic field, called the Interplanetary Magnetic Field (IMF).



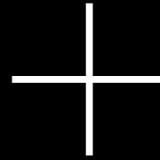
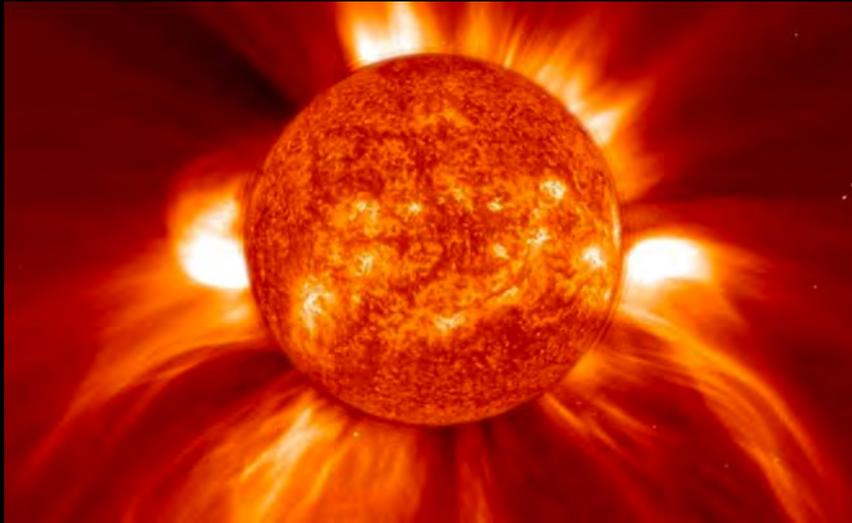
What happens when the solar wind and the Sun's magnetic field interact with a planet's magnetic field?

It creates a planetary magnetosphere.

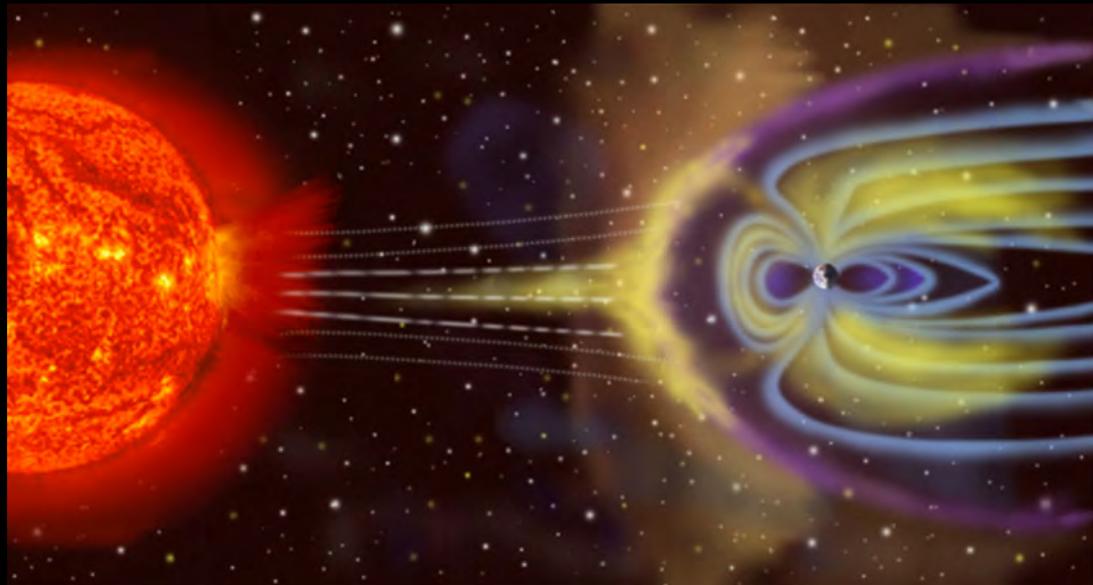
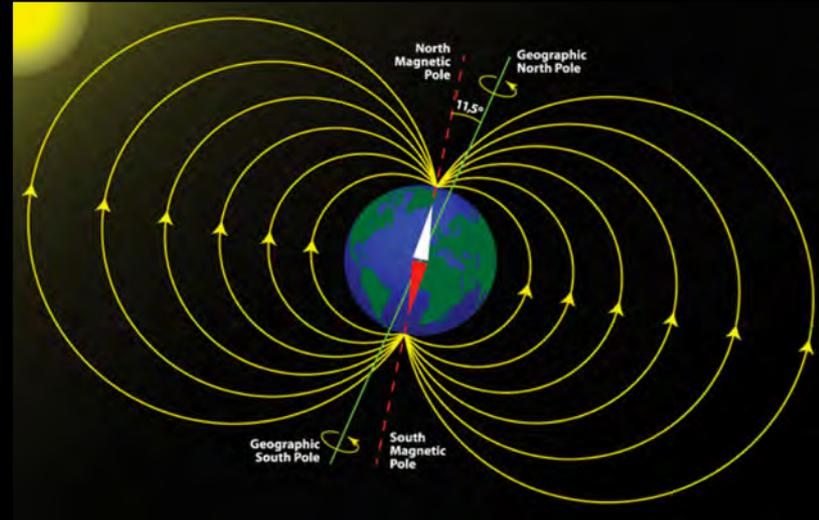
Intrinsic Magnetospheres



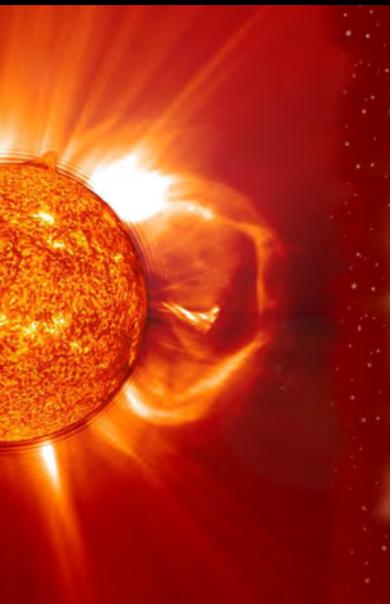
Solar wind from the Sun



Planetary magnetic field



Earth's Magnetosphere



Not to scale

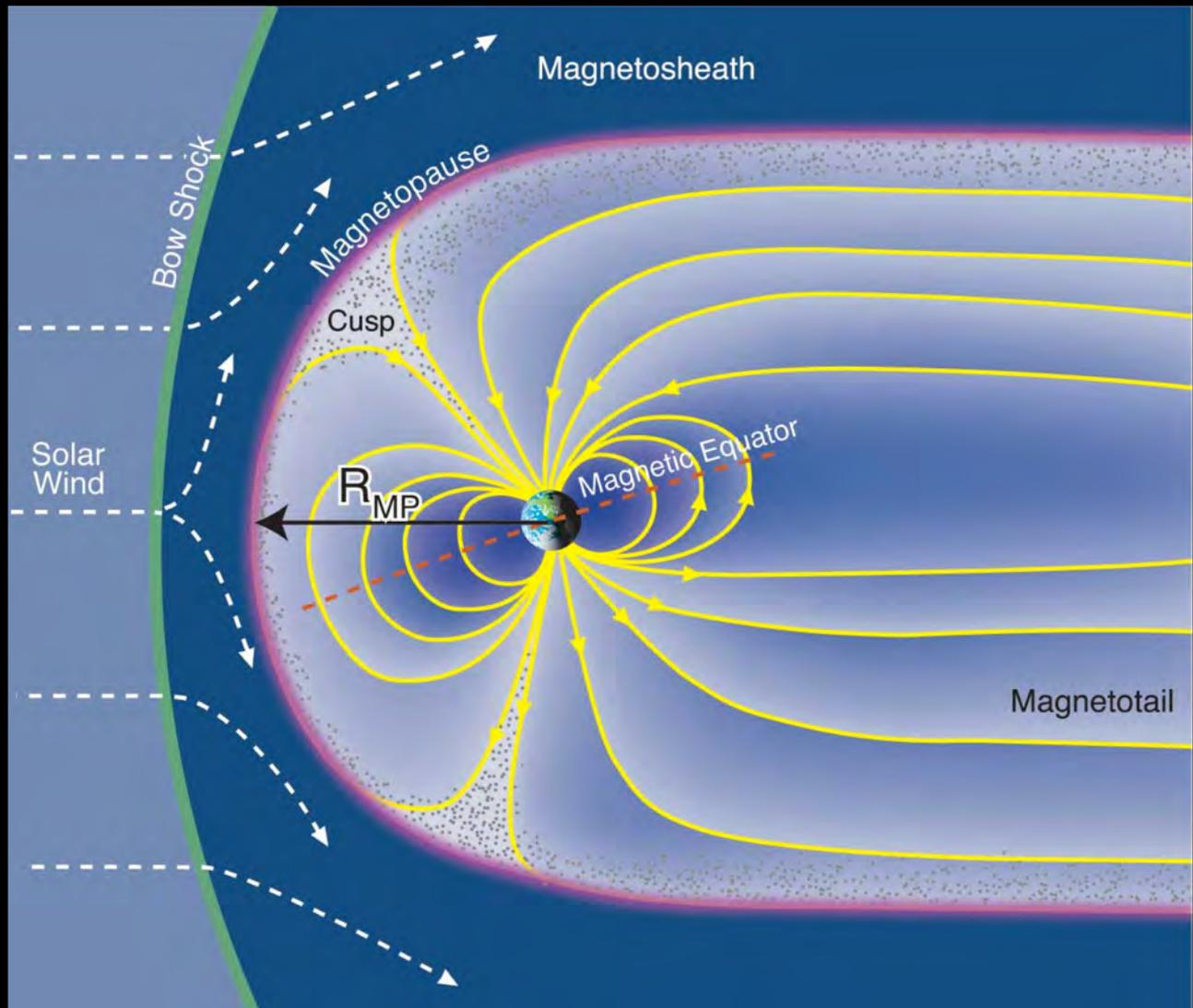
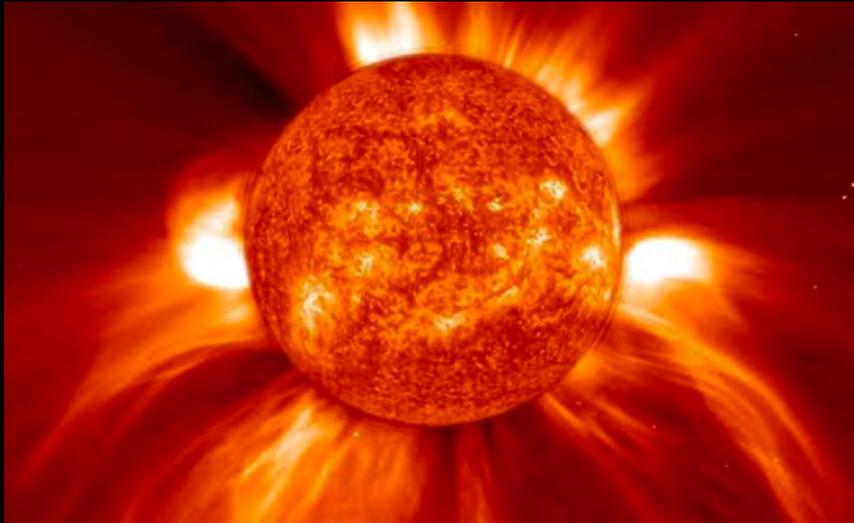


Image Credit: CU LASP

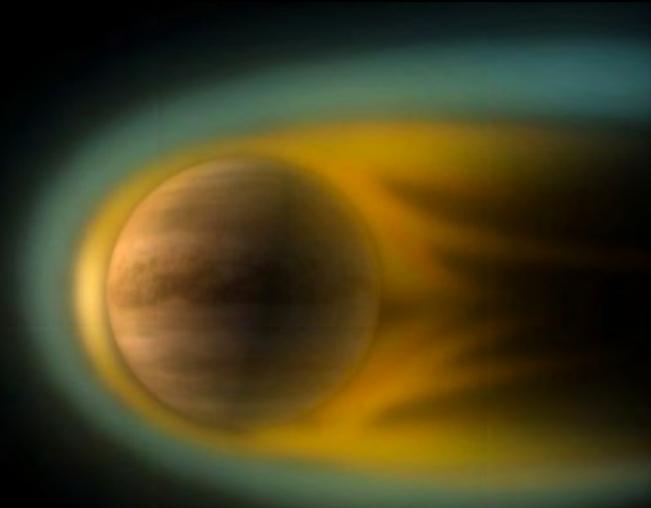
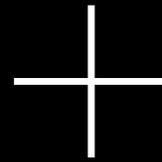
Induced Magnetosphere



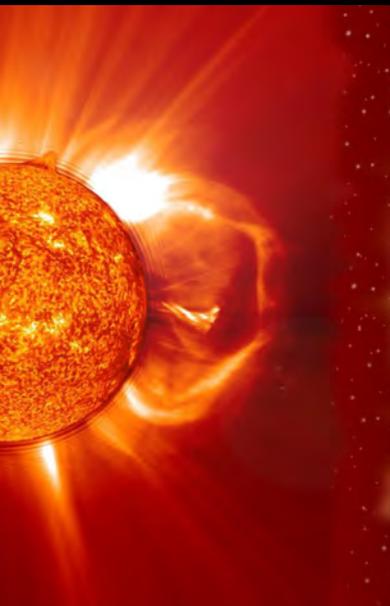
Solar wind from the Sun



Unmagnetized Planet



Venus' Magnetosphere



Not to scale

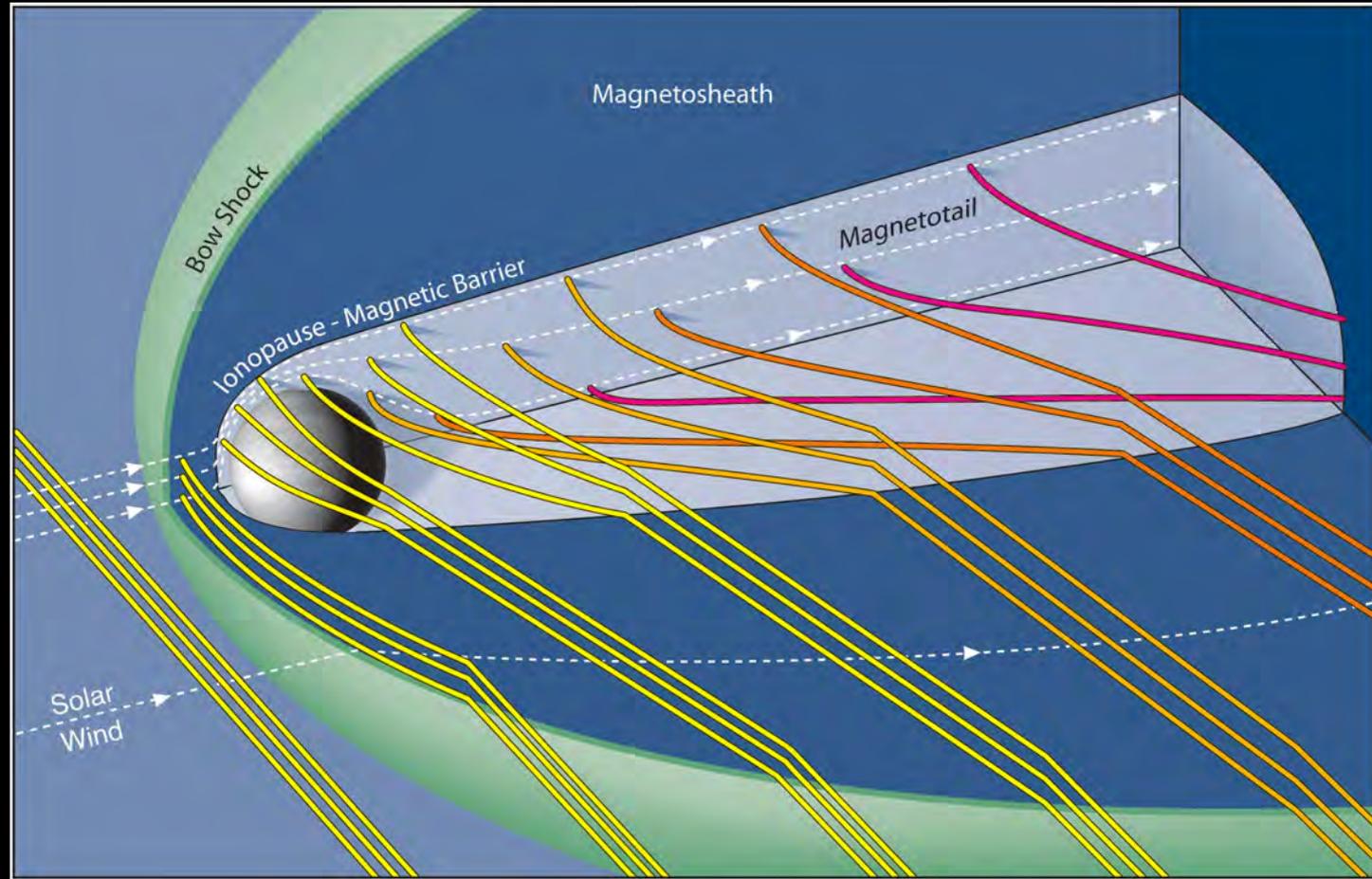


Image Credit: CU LASP

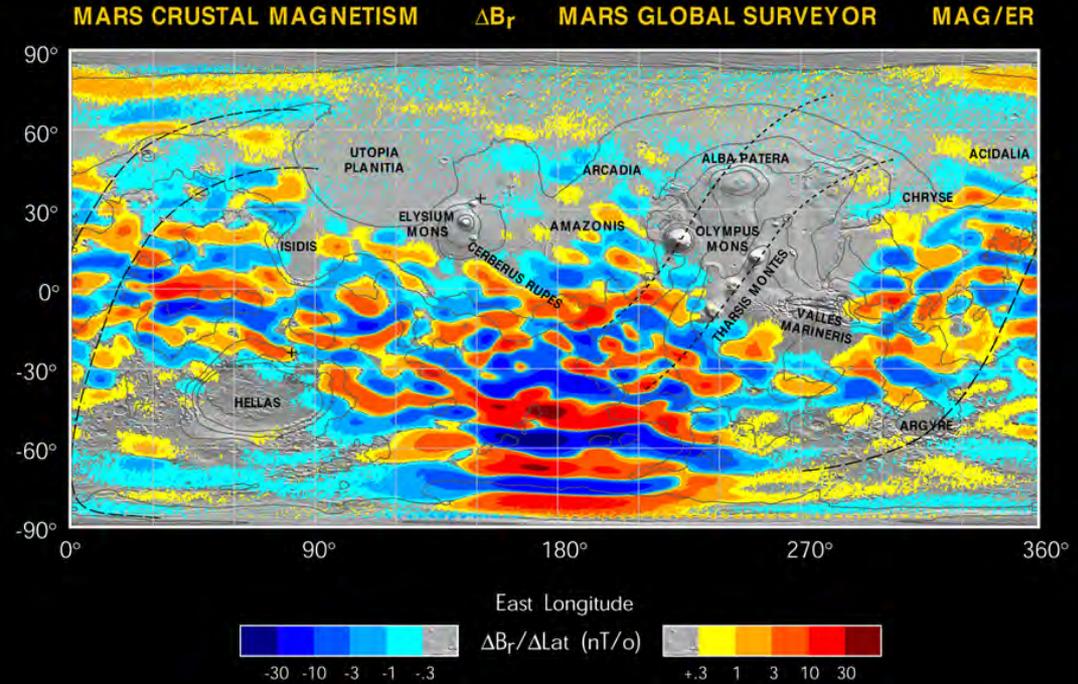
But what about Mars?

Mars is even more complicated...

Mars Crustal Magnetic Fields



- Mars does not have a global magnetic field.
- Instead, Mars has localized crustal magnetic fields that are a fossil of the global field that once existed.



Connerney et al., *PNAS*, 2005

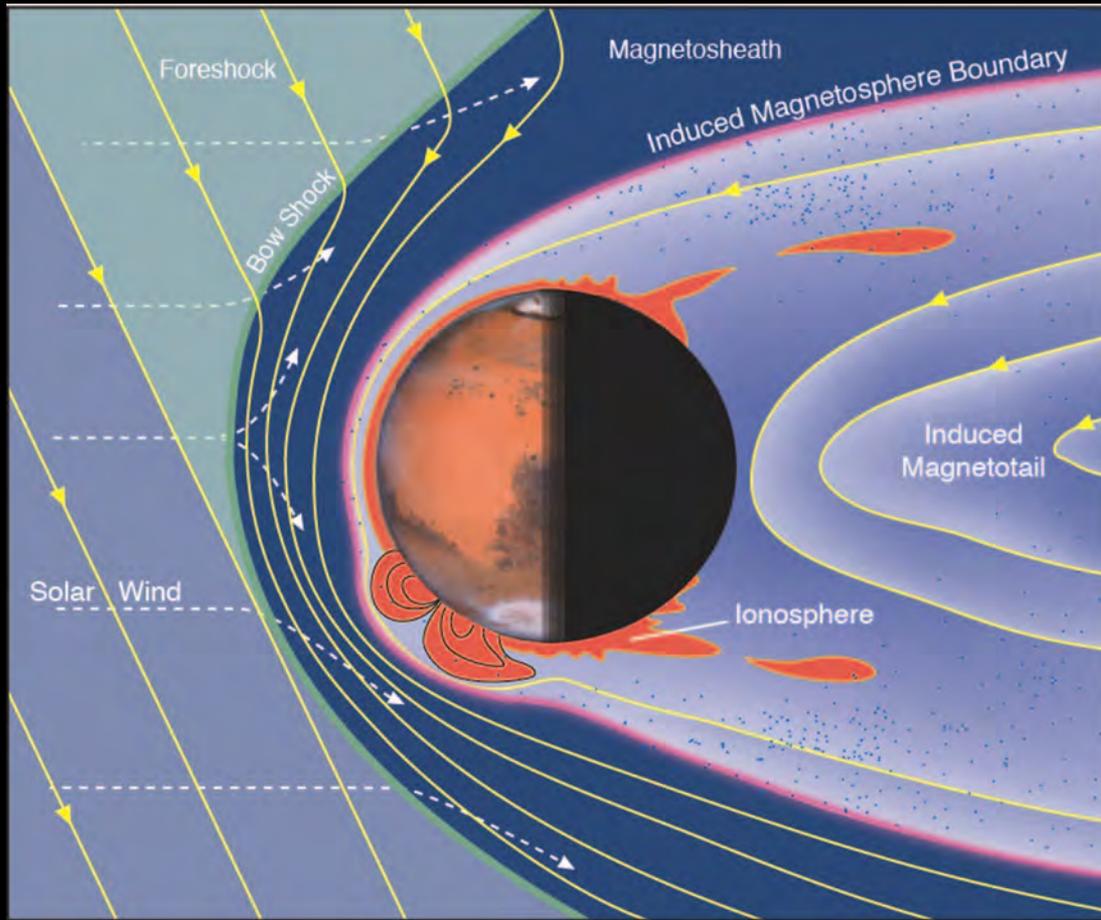
- The strongest Martian crustal fields are located at 180° E Longitude in the southern hemisphere.

Mars Crustal Magnetic Fields



NASA GSFC SVS

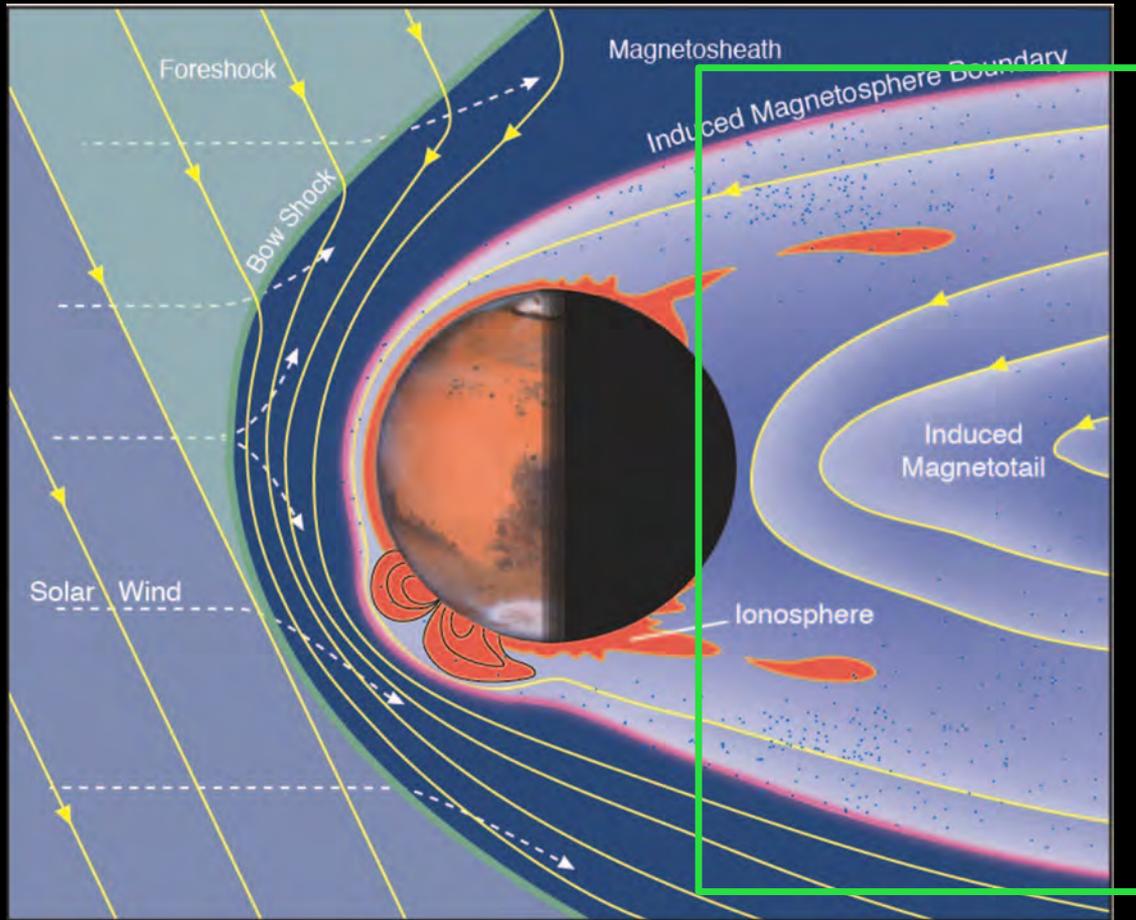
Martian Magnetosphere



Brain et al. [2015]

- Mars presents a complicated induced magnetosphere.
- The planet and crustal magnetic fields create an ever-changing obstacle to the solar wind.
- Many of the same processes occur in the Martian magnetosphere compared to Earth but they have different effects.

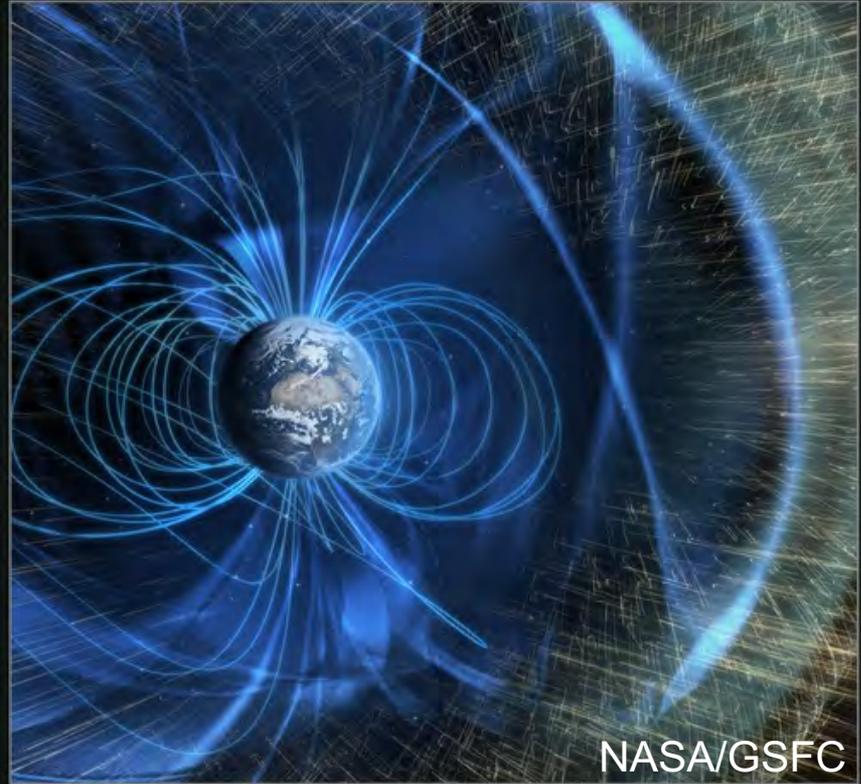
Martian Magnetotail



Brain et al. [2015]

- Mars' magnetic tail, called the "magnetotail," is the region of the Martian magnetosphere that extends behind the planet.
- The magnetotail consists of two magnetic lobes:
 - One directed *towards* Mars
 - One directed *away from* Mars

Magnetospheres of Mars and Earth



- Localized crustal magnetic fields
- Induced magnetosphere
- Sun's magnetic field influences magnetotail field direction
- Global magnetic field
- Intrinsic magnetosphere
- Planetary field dictates magnetotail field direction

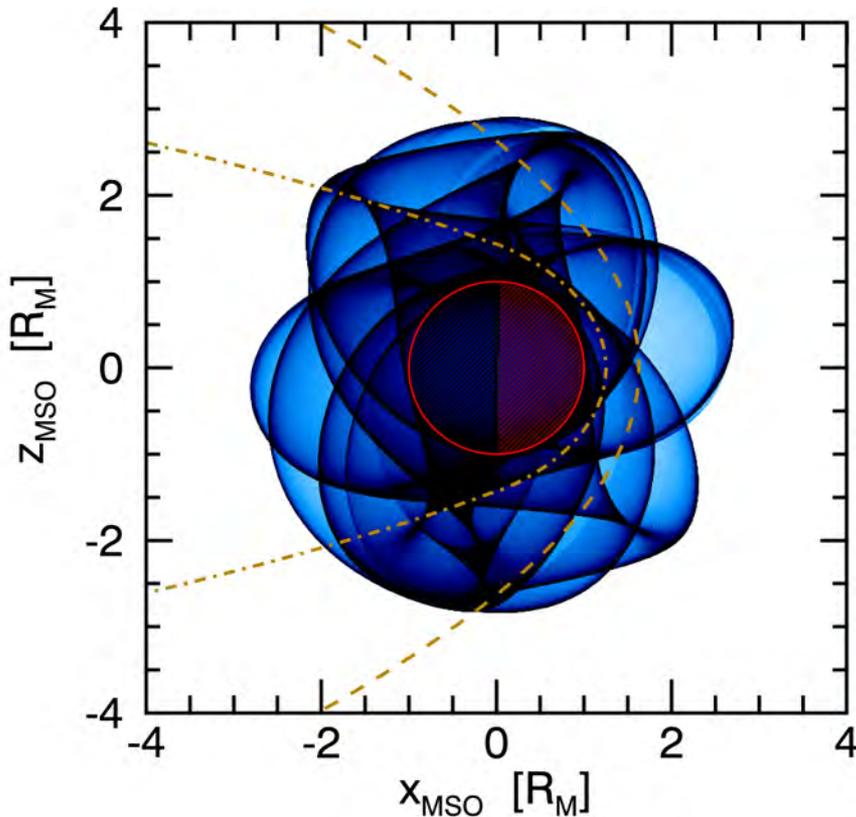
How do we observe the Martian magnetotail with MAVEN?

This depends on MAVEN's orbit and the available measurements.

MAVEN's Orbit



MAVEN's orbit (side view)



Gruesbeck et al. [*JGR*, 2018]

- MAVEN's orbit precesses about Mars to sample different regions of the Martian atmosphere and magnetosphere.
- Observations of solar wind enable monitoring of upstream parameters and solar activity.
- In order to determine how the magnetotail responds to changes in solar wind, we look for orbits where MAVEN measures the solar wind and the magnetotail.

MAVEN's Magnetometers



Magnetometers are instruments that measure magnetic fields.



MAVEN's Magnetometers are located on the end of the solar arrays.



MAVEN's two Magnetometers were provided by the NASA Goddard Space Flight Center.

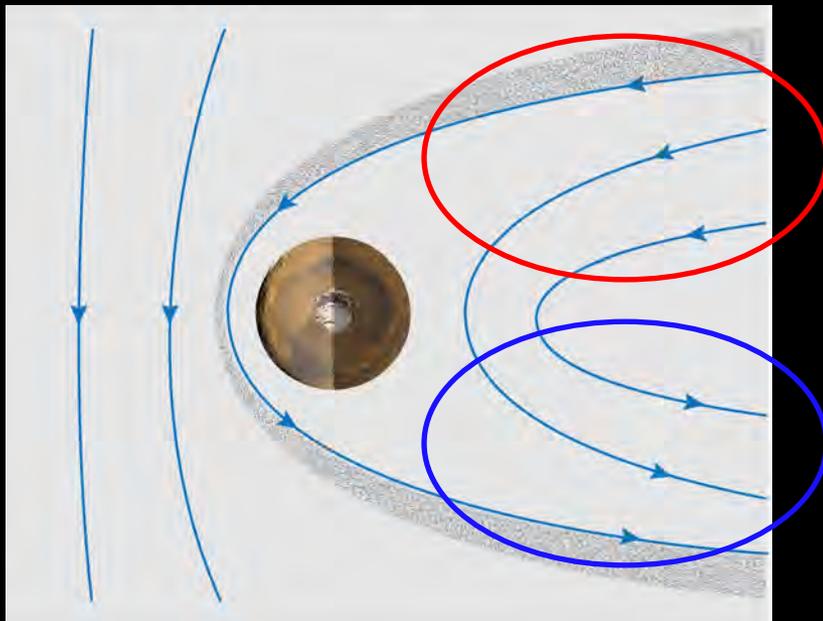
What is MAVEN telling us about the Martian magnetotail?

MAVEN is showing us that the
magnetic tail of Mars is twisted from
the orientation that we expect it to be.

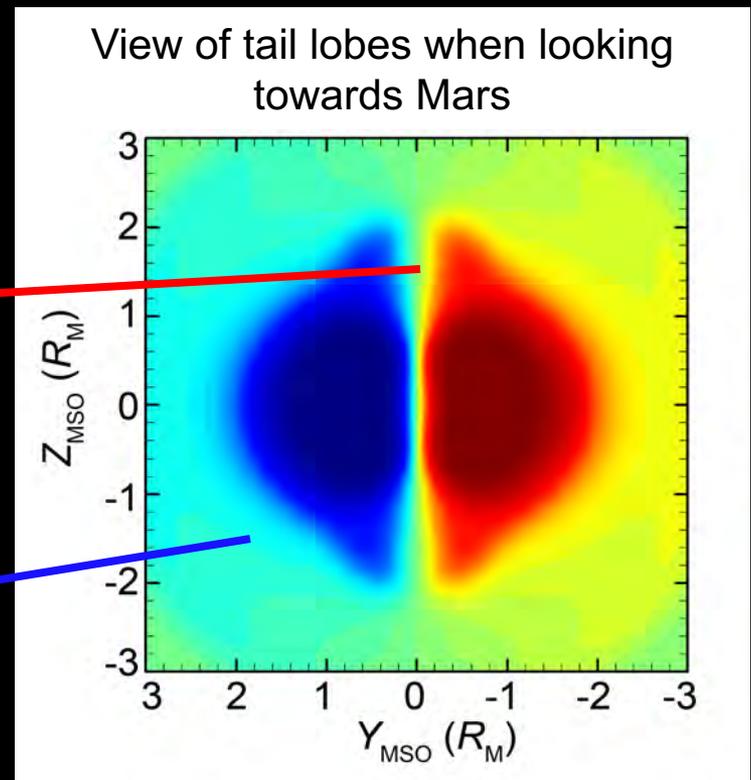
Expected Tail Orientation



Assuming that the Sun's magnetic field drapes perfectly around Mars, it is expected that the tail would consist of two symmetric lobes.



DiBraccio et al. [*JGR*, 2017]



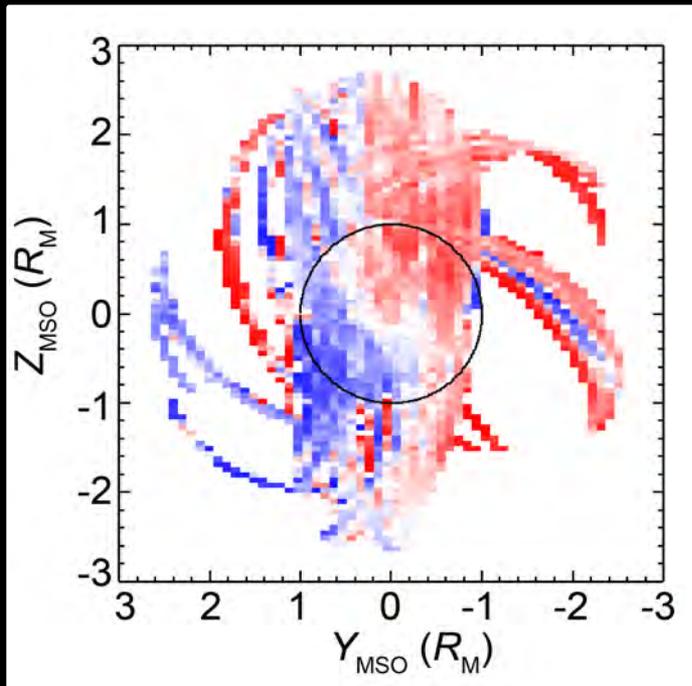
Simulation Credit:
Yingjuan Ma/UCLA

MAVEN Tail Observations



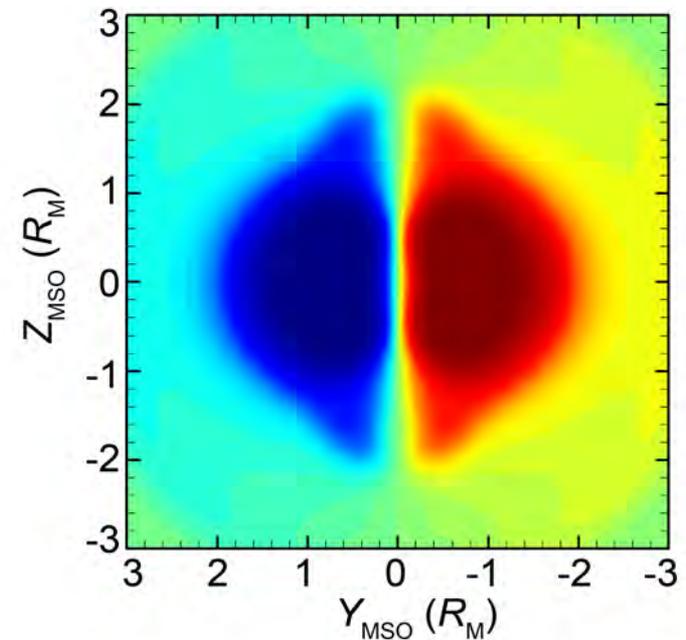
When comparing MAVEN magnetic field data to the simulation results we find that the lobes are not oriented as expected.

The tail has a twist!



DiBraccio et al. [*GRL*, 2018]

View of tail lobes when looking towards Mars



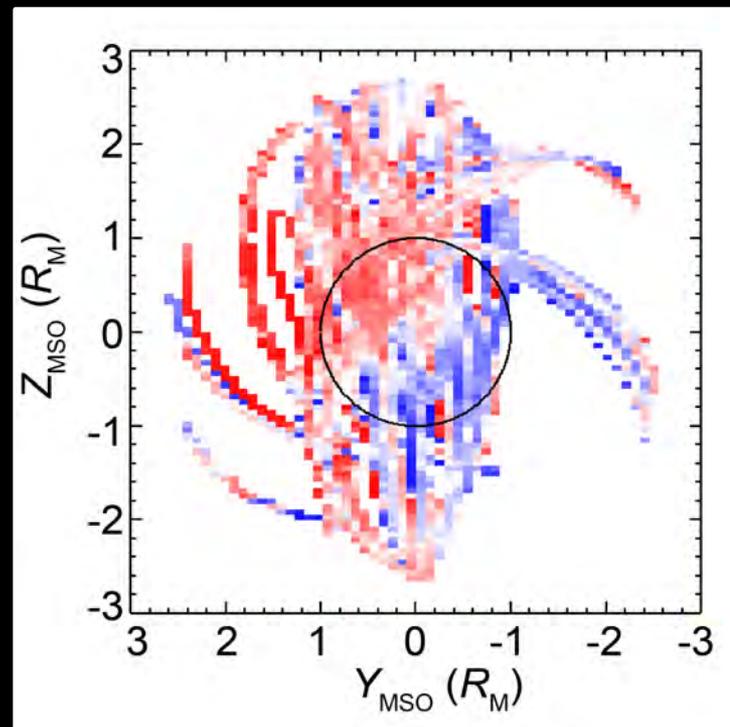
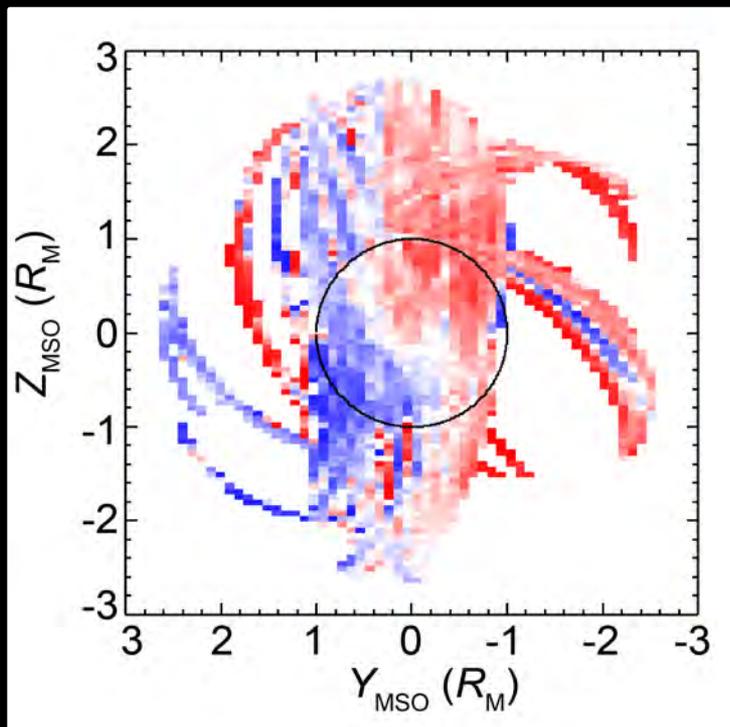
Simulation Credit:
Yingjuan Ma/UCLA

MAVEN Magnetotail Results



MAVEN observations reveal that the tail twist switches as the Sun's interplanetary magnetic field (IMF) changes direction.

← IMF Direction →



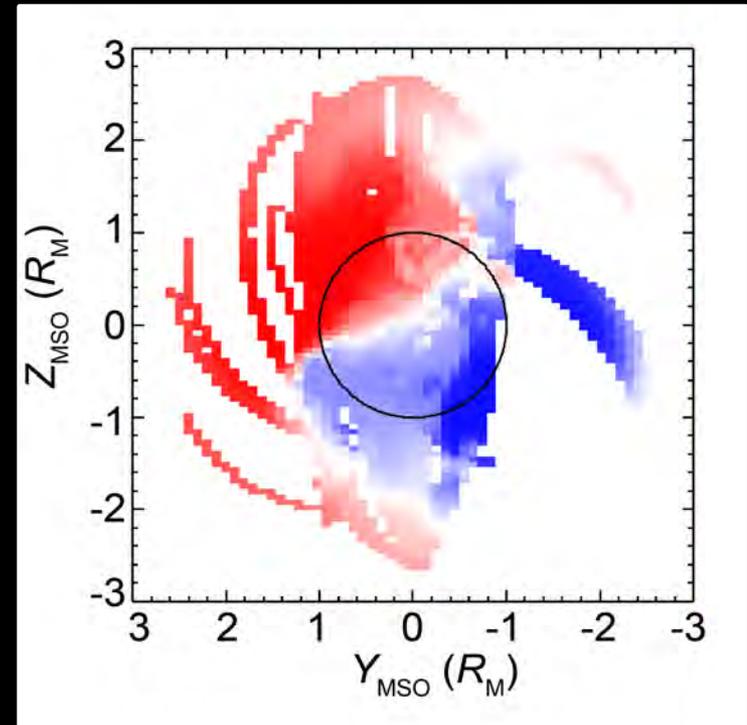
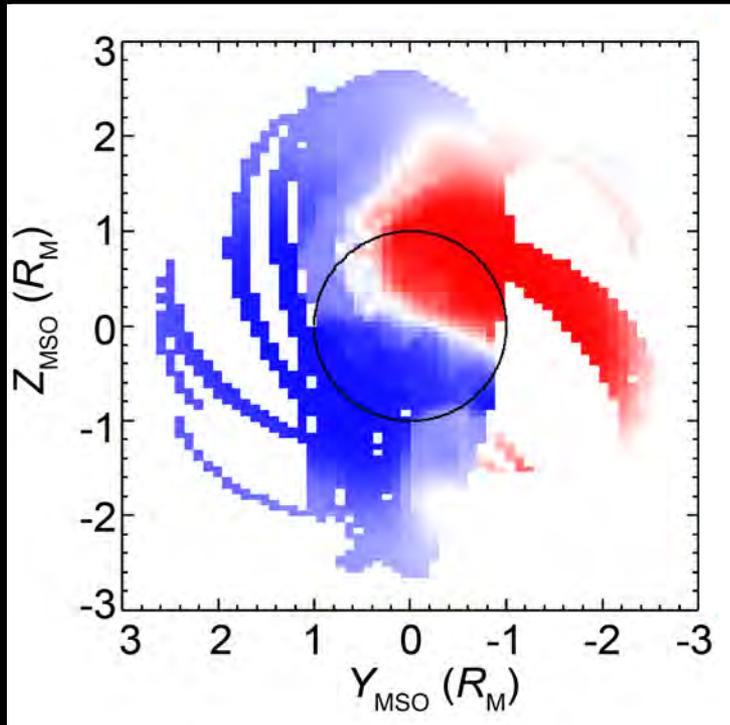
DiBraccio et al. [*GRL*, 2018]

Model Magnetotail Results



Simulation results support MAVEN observations that the Mars magnetic tail is twisted.

← IMF Direction →



DiBraccio et al. [*GRL*, 2018]

What is causing the Mars magnetic tail to twist?

A process called magnetic reconnection.

Magnetic Reconnection at Mars



Magnetic reconnection is a plasma process that combines magnetic fields.

At Mars, reconnection can combine:

Sun's magnetic field + **Martian crustal fields** = **Open magnetic fields**

These new, open fields are connected to Mars and open to space.

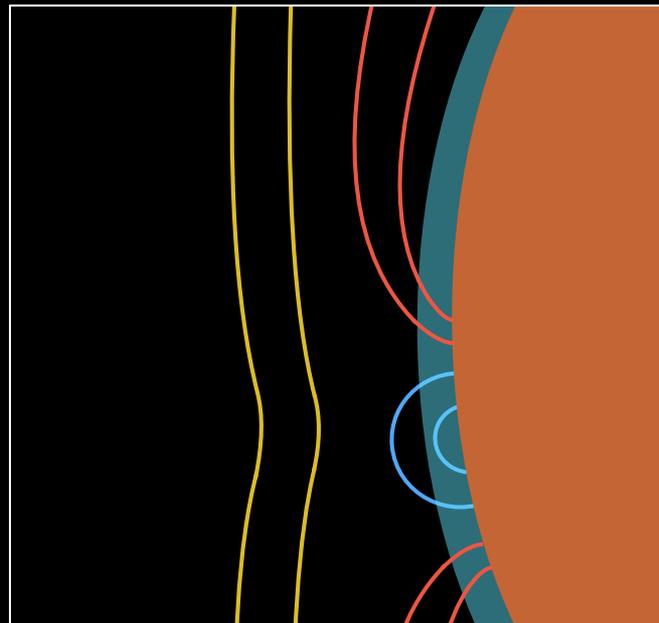


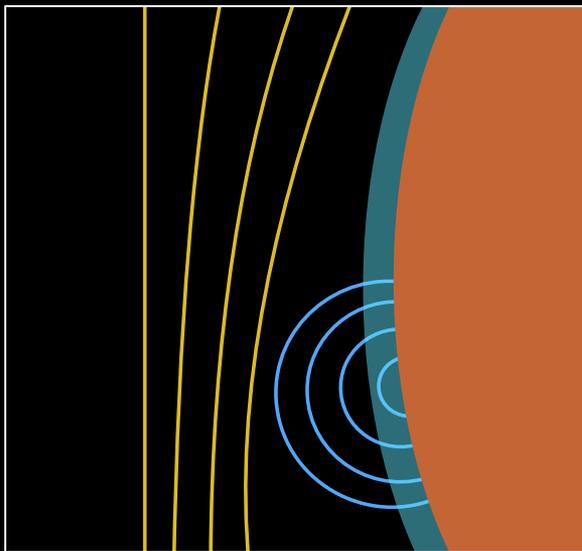
Image Credit:
Tristan Weber/University of Colorado

Magnetic Reconnection at Mars

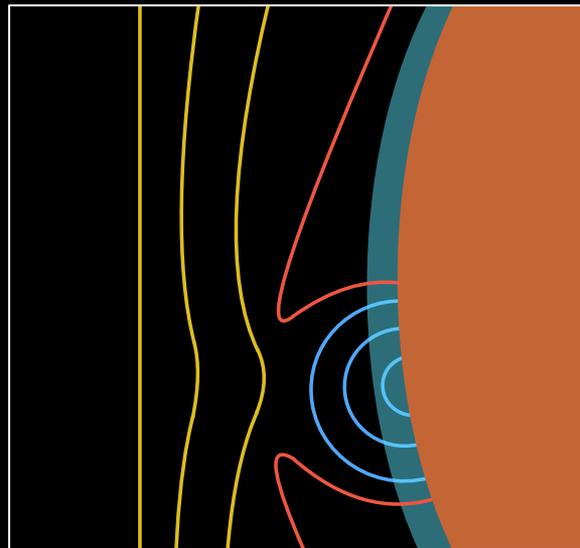


Sun's magnetic field + Martian crustal fields = Open magnetic fields

Before



During Reconnection



After

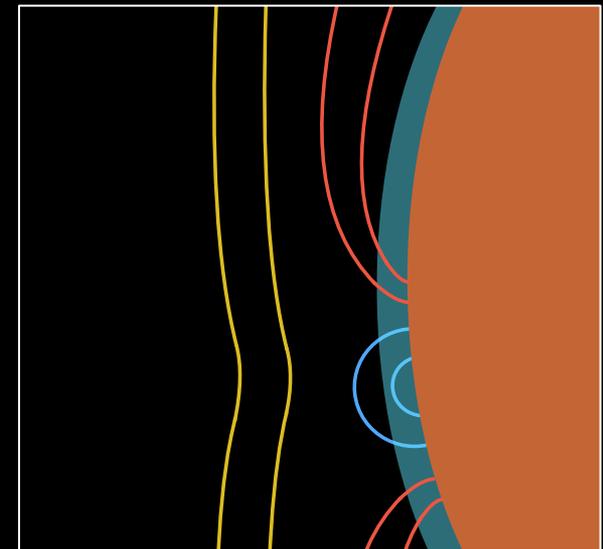


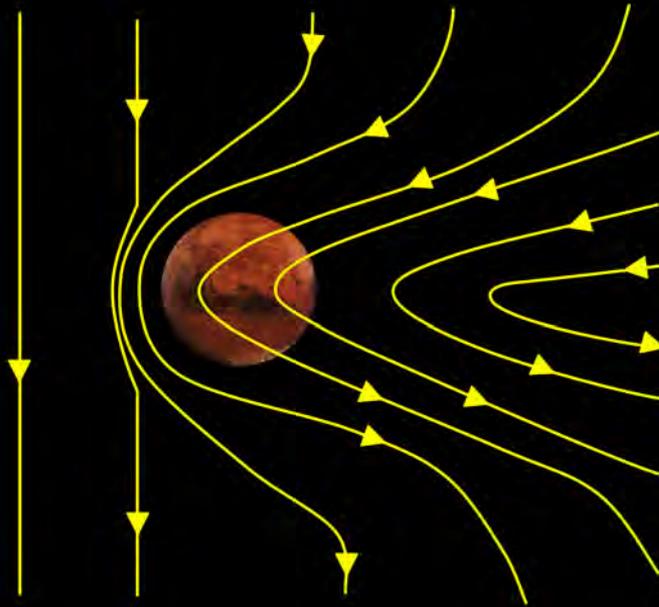
Image Credit:
Tristan Weber/University of Colorado

Updated Tail Structure



By considering the effects of magnetic reconnection, we have a new understanding of the Martian magnetic tail structure.

Prior Understanding



New Understanding

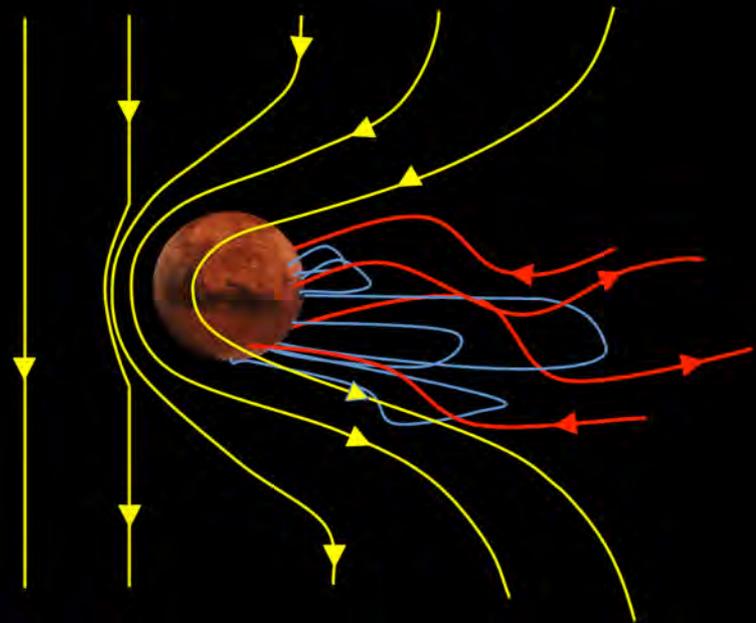


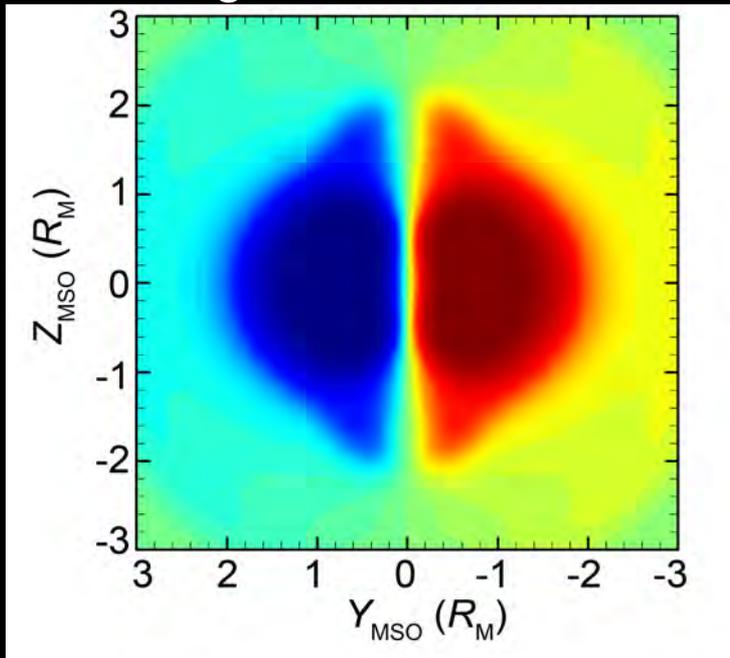
Image Credit: NASA/GSFC

Testing Mars Tail Twist



- The original simulation of Mars magnetic tail did not include magnetic reconnection.

No Magnetic Reconnection



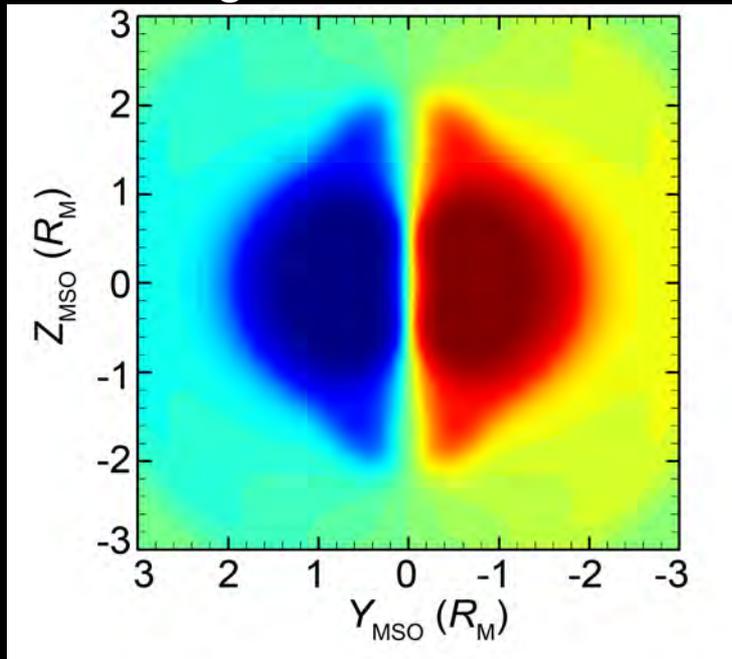
Simulation Credit: Yingjuan Ma/UCLA

Testing Mars Tail Twist

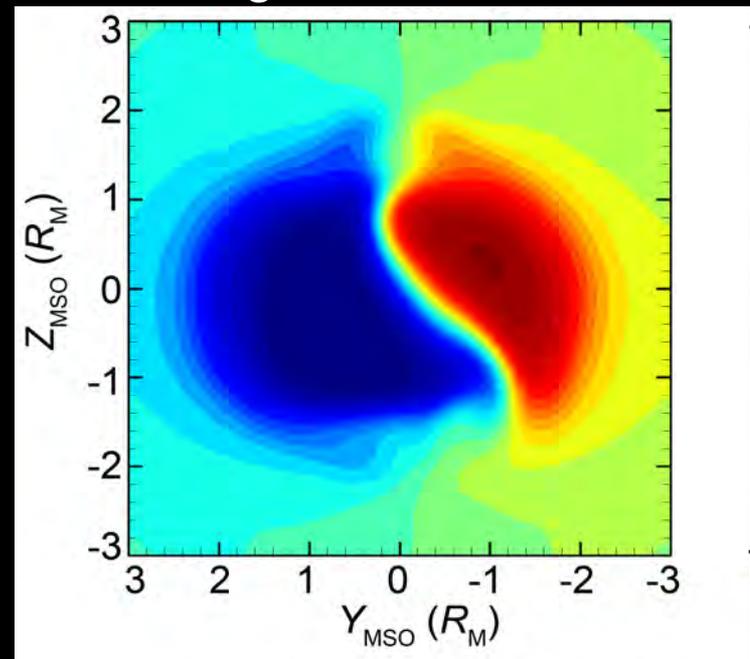


- The original simulation of Mars magnetic tail did not include magnetic reconnection.
- When reconnection is added in, the twist is observed!
- This supports the idea that magnetic reconnection contributes to the tail twist.

No Magnetic Reconnection



With Magnetic Reconnection



Simulation Credit: Yingjuan Ma/UCLA

Why does the tail twist matter?

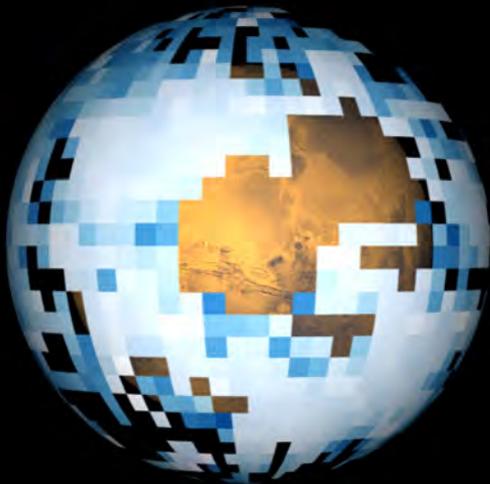
Understanding the tail structure can help us to understand atmospheric loss at Mars.

Atmospheric Escape in the Tail



The magnetotail is a major source of atmospheric loss to space.

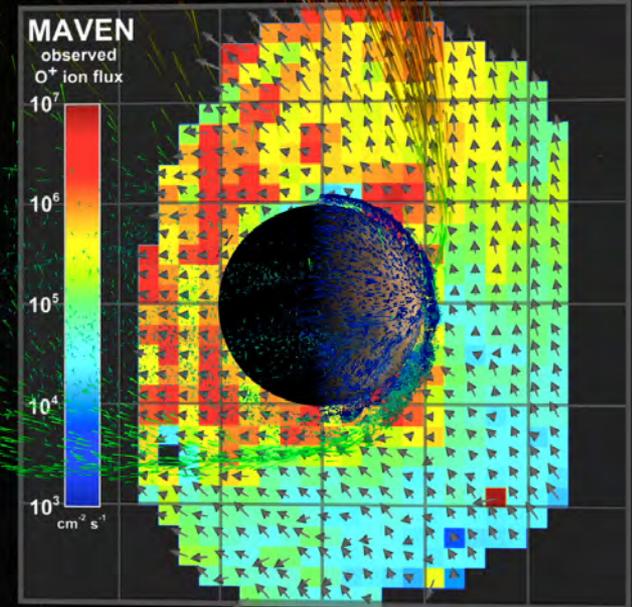
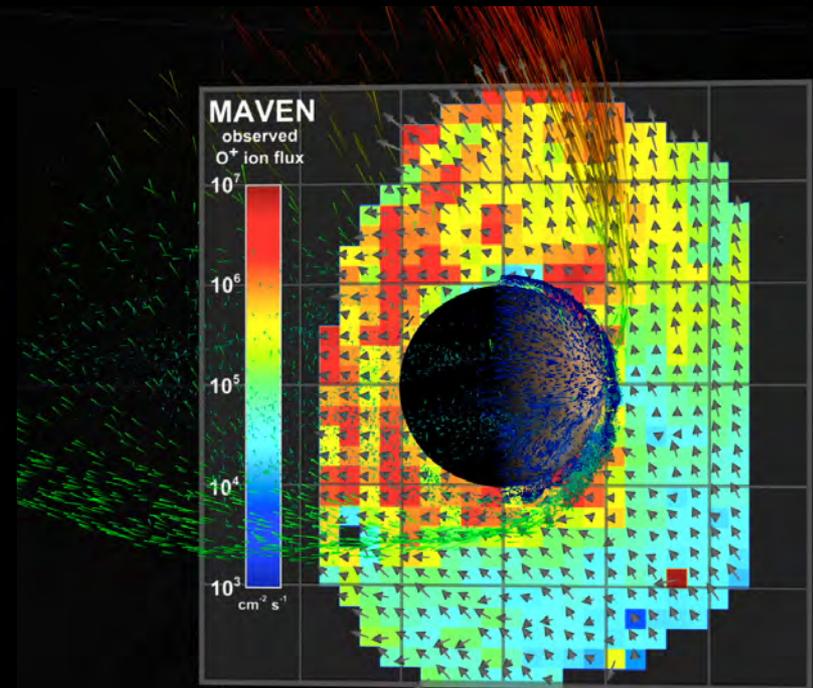
By understanding the tail twist, it is possible to determine factors affecting atmospheric escape in the tail.



DAY SIDE



NIGHT SIDE



Brain et al. [*GRL*, 2015]

Dong et al. [*GRL*, 2015]

Conclusions



- Together, MAVEN observations and simulations have indicated that the Martian magnetic tail is twisted as a result of a process called magnetic reconnection.
- The tail twist changes direction with the Sun's magnetic field and can help us to understand changes in atmospheric loss through the Martian magnetotail.

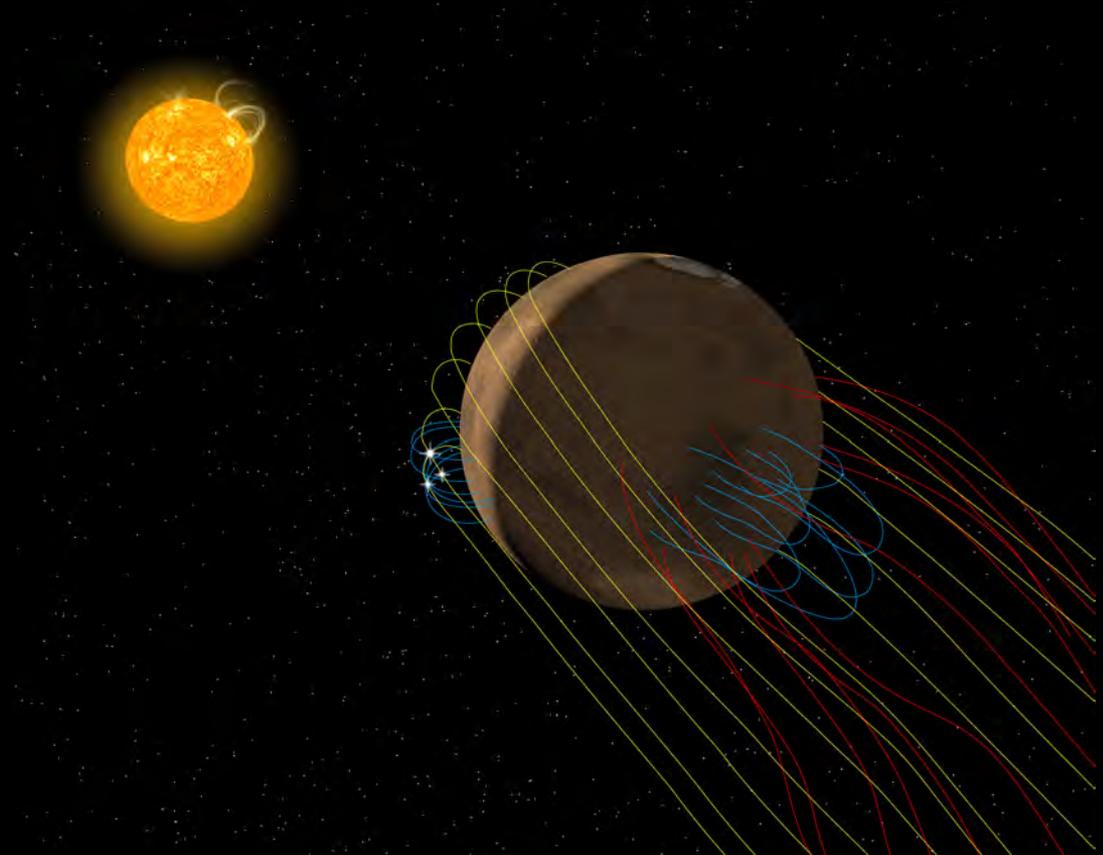


Image Credit: Anil Rao/Univ. of Colorado/NASA/GSFC