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

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

Connerney et al., *PNAS*, 2005
Mars Crustal Magnetic Fields

NASA GSFC SVS
Martian Magnetosphere

- 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.

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 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.

Gruesbeck et al. [JGR, 2018]
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]

View of tail lobes when looking towards Mars

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!

View of tail lobes when looking towards Mars

DiBraccio et al. [GRL, 2018]

Simulation Credit: Yingjuan Ma/UCLA
MAVEN observations reveal that the tail twist switches as the Sun’s interplanetary magnetic field (IMF) changes direction.

DiBraccio et al. [GRL, 2018]
Simulation results support MAVEN observations that the Mars magnetic tail is twisted.
What is causing the Mars magnetic tail to twist?

A process called magnetic reconnection.
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
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

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Testing Mars Tail Twist

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

Brain et al. [GRL, 2015]

Dong et al. [GRL, 2015]

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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.