The Mars magnetotail: Currents, composition, and crustal fields

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At the IsraDynamics Conference
April 26, 2018
The solar-terrestrial relationship

- Our magnetic field keeps the solar wind at bay
Unmagnetized Planets

- Canonical schematic is this: Mars and Venus

Nagy et al., *Space Sci Rev*, 2004
A global view of the Mars tail

• Xu et al., *JGR Space*, 2016
First, Venus: asymmetric tail lobes

- Dusk lobe is almost always bigger
- Seen in models as well as data

Tail current sheet is shifted to $-y$ values (towards dawn)

Ma et al., JGR Space, 2013

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At Venus, explained by IMF

- McComas et al, *JGR Space*, 1986, using Pioneer Venus Orbiter data, came up with this schematic
  - Tail current sheet offset towards dawn
Mars: same thing

- At solar maximum, the tail lobes of Mars have a Venus-like asymmetry
  - Note: no crustal B in this MHD simulation

Tail current sheet is shifted toward dawn

Dusk lobe is bigger than dawn lobe
But not at solar minimum

- The lobe structure flips
  - Now the dawn lobe is bigger!
  - Identical solar wind inputs as the solar max run
- Again: no crustal B

Tail current sheet is shifted towards dusk

Dawn lobe bigger than dusk lobe
Stop and assess: what do we have?

• Two multi-fluid MHD simulations
  – Identical upstream solar wind and IMF conditions
  – Identical numerical scheme and grid structure
  – No crustal fields or planetary tilt influences

• The only difference: solar EUV flux applied to ionization rates
  – And changes to assumed neutral density values in the thermosphere and exosphere
  – Solar EUV flux changes by a factor of ~3 from min to max

• How can the thermosphere-ionosphere change the tail lobes and current sheet?
It’s the pileup region in the ionosphere

- Magnetic pile-up region $|B|$ values are bigger at solar min than at solar max

Solar min: Aphelion

Solar max: Aphelion

More $|B|$ lower down, getting into the ionosphere
Mars at solar minimum: different than Venus

- McComas et al, 1986, idea relies on fast slippage of IMF past planet
- Mars @ solar min: magnetic field remains close to planet much longer
Mars has Crustal fields?

- Mars has the strongest crustal fields in the solar system, 10x bigger than on Earth
Currents in the Tail

• Influence of Crustal Fields
  – The small addition of crustal fields twists the tail

1.1 $R_M$ downtail

2.0 $R_M$ downtail

Li et al., PSS, 2013
What about measurements?

- From MAVEN observations at $X=[-1.0, -1.5] \, R_M$

Bx looks like it should

Bz looks close to expected

By looks like it should, but only in the north

$|B|$ is kind of asymmetric

Harada et al., GRL, 2015
Composition in the tail

- Lots of planetary ions leaving down the tail
- From Mars Express
  - Sees more $O_2^+$ than $O^+$ in the central tail

Barabash et al., Science, 2007
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The polar plume of escaping ions

- Leaving in the direction of $+E_{SW}$
  - Circles are a disk at $4 R_M$ downtail, 3 energy ranges

Strong fields on dayside

Strong fields on dawnside

No crustal fields

Fang et al., JGR Space, 2008
Evidence of the +E plume

- Mars Express can see it, sometimes
  - This took a lot of work to extract from the H\(^+\) noise

MAVEN sees it very well and essentially all the time that it is in the +E direction.

Liemohn et al., JGR Space, 2014
Summary

• Mars is an interesting planet with a complicated space environment
  – Localized crustal fields: more difficult than Venus

• Missions have made critical observations
  – Especially Mars Global Surveyor, Mars Express, and Mars Atmosphere Volatile EvolutioN

• Modeling with both fluid and kinetic treatments have advanced our understanding of these observations
  – Still much to do
Thanks to others

• With help from my friends:
  – Shaosui Xu, Chuanfei Dong, Steven Bougher, Raluca Ilie, Blake Johnson, and Darren De Zeeuw
  – At Berkeley, Princeton, Michigan, and Illinois

• And funding agencies
  – NASA and NSF

• Full citation of my 2 most recent Mars papers: