Planetary Magnetospheres

Mercury

Earth

Jupiter

Heliosphere
Which topic is (probably, at this point in time) your primary interest?

1. Solar physics – & other stars
2. Heliosphere – solar wind
3. Earth ionosphere/magnetosphere
4. Planetary space physics
5. Hummmm…. not sure
Planetary Magnetic Dynamos
De Magnete 1600
William Gilbert
"May the gods damn all such sham, pilfered, distorted works, which do but muddle the minds of students"
**Planetary Dynamos**

Volume of electrically conducting fluid 1 which is convecting 2 and rotating

All planetary objects probably have enough rotation - the presence (or not) of a global magnetic field tells us about 1 and 2

Earth dynamo model - From Glatzmeier and Roberts
### Table: Comparative Values

<table>
<thead>
<tr>
<th></th>
<th>Ganymede</th>
<th>Mercury</th>
<th>Earth</th>
<th>Jupiter</th>
<th>Saturn</th>
<th>Uranus</th>
<th>Neptune</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_p/R_E$</td>
<td>0.41</td>
<td>0.38</td>
<td>1</td>
<td>11</td>
<td>9.5</td>
<td>4.0</td>
<td>3.9</td>
</tr>
<tr>
<td>$R_{core}/R_p$</td>
<td>0.3</td>
<td>0.6-0.8</td>
<td>0.55</td>
<td>0.9</td>
<td>0.6</td>
<td>0.8</td>
<td>0.8</td>
</tr>
<tr>
<td>Magnetic Moment /$M_E$</td>
<td>$5 \times 10^{-4}$</td>
<td>$5 \times 10^{-4}$</td>
<td>1</td>
<td>20,000</td>
<td>600</td>
<td>50</td>
<td>25</td>
</tr>
</tbody>
</table>

- Orange clouds: Blue because methane absorbs red sunlight.
- Liquid Metallic Hydrogen
- Liquid Iron
- Ionic Water

- Blue because methane absorbs red sunlight.
Offset Tilted Dipole (poor) Approximation
Magnetic Potential
3-D Spherical harmonics

\[ V = R_p \sum_{n=1}^{\infty} \sum_{m=0}^{n} \left( \frac{R_p}{r} \right)^{n+1} P_n^m (\cos \theta) \left( g_n^m \cos m\lambda + h_n^m \sin m\lambda \right) \]

- **functions**
  - \( P_0^0 (\cos \theta) = 1 \)
  - \( P_1^0 (\cos \theta) = \cos \theta \)
  - \( P_1^1 (\cos \theta) = -\sin \theta \)
  - \( P_2^0 (\cos \theta) = \frac{1}{2} (3 \cos^2 \theta - 1) \)
  - \( P_2^1 (\cos \theta) = -3 \cos \theta \sin \theta \)
  - \( P_2^2 (\cos \theta) = 3 \sin^2 \theta \)
  - \( P_3^0 (\cos \theta) = \frac{1}{2} (5 \cos^3 \theta - 3 \cos \theta) \)

- **coefficients - constants**
  - \( n=0 \)
  - Dipole
  - Quadrupole
  - \( n=1 \)
  - \( n=2 \)
  - \( n=3 \)
  - \( n=4 \)
  - \( n=5 \)
  - \( m=0 \)
  - \( m=1 \)
  - \( m=2 \)
  - \( m=3 \)
  - \( m=4 \)
  - \( m=5 \). . .
Modeling Uranus’ & Neptune's non-dipolar fields with a thin-shell dynamo over a stratified core.

Multipole coefficients / Dipole coefficient indicates degree of complexity.
<table>
<thead>
<tr>
<th>Planet</th>
<th>Rcore / Rplanet</th>
<th>Bo [µT]</th>
<th>Tilt</th>
<th>Quad / Dipole</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earth</td>
<td>0.55</td>
<td>31</td>
<td>+9.92°</td>
<td>0.04</td>
</tr>
<tr>
<td>Jupiter</td>
<td>0.84</td>
<td>428</td>
<td>-9.6°</td>
<td>0.10</td>
</tr>
<tr>
<td>Saturn</td>
<td>0.6</td>
<td>21</td>
<td>&lt;-1°</td>
<td>0.02</td>
</tr>
<tr>
<td>Uranus</td>
<td>0.7</td>
<td>23</td>
<td>-59°</td>
<td>1.3</td>
</tr>
<tr>
<td>Neptune</td>
<td>0.8</td>
<td>14</td>
<td>-47°</td>
<td>2.7</td>
</tr>
</tbody>
</table>

**Dipolar**

**Irregular**

Stanley & Bloxham 2006
Earth's Magnetic Field

When you look closer there's more complexity

Earth's field extrapolated down to the top of the outer core dynamo region
Br through a reversal
Polarity reversals:

1. variable in duration and
2. rate

rapid rate
~ 5/million years
~ every 200,000 yrs
Where are the Earth's magnetic poles - and where are they headed?

Note that the north pole is moving towards the rotation pole, the south pole is moving away from the rotation axis…

What's the difference?

Magnetic Poles = where $B = Br$

Geomagnetic Poles = best fit dipole
• Juno's first few passes are showing deviations from previous simple models

• Hints that the dynamo region is closer to the surface?
Juno-based magnetic field model

Big N-S asymmetries!
Heavy elements mixed with metallic H to ~40% radius

This can arise during accretion and be augmented by convective stirring -core erosion- as Jupiter cools over geologic time

Wahl et al. 2017
Implications for Dynamo

Earth: Dynamo deep in core – outer field ~dipole

Saturn: Deeper core, zonal flows in resistive layer makes symmetric dipolar field

Glatzmeier 2002

Glatzmeier 2005
Implications for Dynamo

How to get basically dipole field with some N-S asymmetry?

What's happening here?

Dynamo cylinders

Heavy elements dissolved

Different from here?

Dynamo cylinders

Duarte et al. 2018

Heimpel & Aurnou
WHICH HAVE ACTIVE MAGNETIC DYNAMOS?

Why Don't Venus or Mars have Dynamos?
• Enough rotation – even for Venus
• Conducting fluid core – probably
• Lack of convection in core?
  1. If...Mantle convection controls heat flow from core. Then....Lack of plate tectonics suggests less efficient cooling of interior and lower heat flux from core
  2. No inner core means no latent heat of solidification and no enhancement of lighter material in the outer core

Need geophysics missions that address interior structure

Stevensen 2010
Moon & Mars: All Crustal Remanent Magnetization

- Did Moon ever have dynamo?
- Mars' dynamo died >3.5 BYA.
Mars:
Weak, irregular field
-> bumpy surface + changing topology

MGS mission
MAVEN mission

David Brain
Solar Wind Interaction
Atmosphere Escape

- Ionization of outer atmosphere
- Plasma-atmosphere interaction
- Similar scale!
- Similar loss! few kg/s
- Comets up to ton/s

Brain et al. 2016
Magnetosphere Sizes
Bow Shock:
- Kinetic energy -> thermal energy
- Flow diverted around obstacle
- ~11% less pressure at MP than in upstream SW

Supersonic

\( R_{BS} \approx 1.3 \, R_M \)

1930s
Small Magnetospheres

**Mercury**
- Mariner 10
- MESSENGER
- In solar wind m'sphere
- No atmosphere
- aurora

**Ganymede**
- Galileo
- In Jupiter
- Atmospheric

**B_{surface} \sim 1/100 \text{ Earth}**

Jia et al. 2014, 2015
Mercury

- Small magnetosphere
- No atmosphere/ionosphere
- Currently close via crust
- Very rapid Dungey cycle
- Sputtered Na\(^+\) escape

Extreme solar wind conditions -> exposed planet

Slavin et al.
Chapman-Ferraro Current

- Internal magnetic field pressure $\frac{B^2}{2\mu_0}$
- Balances the solar wind dynamic pressure $\rho_{sw} U_{sw}^2$
- Assumes northward Interplanetary Magnetic Field – IMF

Chapman-Ferraro current must provide $\mathbf{j} \times \mathbf{B}$ force integrated across magnetopause
Chapman-Ferraro Current

- Creates closed magnetosphere
- Limits size of magnetosphere
- Current pattern over the whole magnetopause.
\[ B_{\text{dipole}} = B_0 \left( \frac{R_p}{r} \right)^3 \]

SW ram pressure \( \Leftrightarrow \) internal magnetic field pressure

\[ \rho_{sw} U_{sw}^2 = B_0^2 \left( \frac{R_p}{r} \right)^6 / 2 \mu_o \]

BUT what about currents at the magnetopause? \( \Rightarrow 2B_{\text{dipole}} \)

\[ \rho_{sw} U_{sw}^2 = (2B_0)^2 \left( \frac{R_p}{r} \right)^6 / 2 \mu_o \]

Solve for \( r \Rightarrow R_{\text{MP}} \)

\[ \frac{R_{\text{MP}}}{R_{\text{planet}}} = 2^{1/3} \left[ \frac{B_0^2}{2 \mu_o \rho_{sw} U_{sw}^2} \right]^{1/6} \]
Dipole Magnetic Field in Solar Wind

Chapman-Ferraro Distance

SW Ram Pressure $\sim 1.2 \left[ \frac{B_0^2}{2 \mu_0 \rho_{SW} V_{sw}^2} \right]^{1/6}$

Walker & Russell 1995
\[
\frac{R_{CF}}{R_p} \sim 1.2 \left\{ \frac{B_0^2}{(2 \mu_0 \rho_{sw} U_{sw}^2)} \right\}^{1/6}
\]

Quick chat with your neighbors….

- How does \( \rho_{sw} \) vary with distance \( D \) from Sun?  
  \( \sim \frac{1}{D^2} \)

- How does \( U_{SW} \) vary with distance \( D \) from Sun?  
  \( \sim \text{constant} \)

- How does \( \left\{ \frac{1}{\rho_{sw}} U_{sw}^2 \right\}^{1/6} \) vary with distance?  
  \( \sim D^{1/3} \)

- Move Earth from 1 AU to 8 AU – How big is the magnetosphere?  
  \( \times 2 \)
\( \frac{R_{\text{CF}}}{R_p} \sim 1.4 \left\{ \frac{B_0^2}{2 \mu_0} \rho_{\text{sw}} V_{\text{sw}}^2 \right\}^{1/6} \)

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<tbody>
<tr>
<td>Bo surface</td>
<td>0.3 µT</td>
<td>31 µT</td>
<td>430 µT</td>
<td>22 µT</td>
<td>23 µT</td>
<td>14 µT</td>
</tr>
<tr>
<td>R_{\text{CF}} Calculated</td>
<td>1.4 ( R_M )</td>
<td>10 ( R_E )</td>
<td>46 ( R_J )</td>
<td>20 ( R_S )</td>
<td>25 ( R_U )</td>
<td>24 ( R_N )</td>
</tr>
<tr>
<td>R_{M} Observed</td>
<td>1.4-1.6 ( R_M )</td>
<td>8-12 ( R_E )</td>
<td>63-92 ( R_J )</td>
<td>22-27 ( R_S )</td>
<td>18 ( R_U )</td>
<td>23-26 ( R_N )</td>
</tr>
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</table>
Jupiter’s magnetic field extends beyond 4 big moons

Io ejects 1 ton/s volcanic gases
Mega-Amp currents couple Io to Jupiter

John Spencer (SwRI)
Dynamics
Which Form of Coupling Dominates
-> Controls Dynamics
Earth

Solar Wind

Magnetosphere

Ionosphere

A - Dungey Circulation

*Reconnection-Driven Global Circulation
Open Magnetosphere

Now flip Interplanetary Magnetic Field direction

Reconnection
**Dungey Cycle**

Dynamics at Earth driven by the solar wind coupling the Sun's magnetic field to the Earth's field

- Variable opening & closing rates
- Must be equal over time to conserve magnetic flux

**Plasmapause** = boundary between corotation and convection

**Opening reconnection**

**Closing reconnection**

**Rotating Plasmasphere**
The Dungey Cycle

Solar wind driven magnetospheric convection*

\[ E_{\text{convection}} = - \zeta V_{SW} \times B_{SW} \]

\( \zeta \)~ efficiency of reconnection
\( \sim 10-20\% \)

crude approximation!!

\( E_{\text{conv}} \sim \text{constant in m'sphere} \)

\( V_{\text{convection}} \sim \zeta V_{SW}(R/R_{MP})^3 \)

(where 3 power assumes a dipole - in reality, the flow is not uniform and the power somewhat less)

(*strictly speaking not convection but advection or circulation)
Solar Wind

Polar view

Connected to solar wind

Closed magnetic field

Solar Wind

Magnetosheath

Magnetopause

Wind Direction
\[ V_{co} \sim \Omega \times R \]
\[ V_{\text{convection}} \sim \zeta V_{SW}(R/R_{MP})^3 \]

Fraction of planetary magnetosphere that is rotation dominated...

- increases with planetary spin
- increases with field strength
- decreases with solar wind strength
Solar-wind vs. Rotation-dominated magnetospheres

Assumptions:
1. Planet’s rotation coupled to magnetosphere
2. (Large-scale) Reconnection drives solar wind interaction
Reality = Messy & 3D
Plasma Sources
## Plasma Sources

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<tbody>
<tr>
<td>$N_{\text{max}}$ cm$^{-3}$</td>
<td>$\sim 1$</td>
<td>1-4000</td>
<td>$&gt;3000$</td>
<td>$\sim 100$</td>
<td>$\sim 3$</td>
<td>$\sim 2$</td>
</tr>
<tr>
<td>Composition</td>
<td>H$^+$</td>
<td>O$^+$</td>
<td>O$^{n+}$</td>
<td>O$^+$</td>
<td>H$^+$</td>
<td>H$^+$</td>
</tr>
<tr>
<td>Solar Wind</td>
<td>H$^+$</td>
<td>Ionosphere</td>
<td>Ionosphere</td>
<td>H$_2$O$^+$</td>
<td>Ionosphere</td>
<td>H$^+$</td>
</tr>
<tr>
<td>Source kg / s</td>
<td>?</td>
<td>5</td>
<td>700-1200</td>
<td>70-200</td>
<td>$\sim 0.02$</td>
<td>$\sim 0.2$</td>
</tr>
</tbody>
</table>
Earth Sources of Plasma (5 kg/s): Solar Wind + ionosphere mixed (over the poles) into magnetotail and convected sunward
Earth Plasma Flux  5 kg/s

Ionosphere: H⁺  He⁺  O⁺
Solar Wind: H⁺  He++
**Io Plasma torus**

- Total mass 2 Mton
- Source 1 ton/s
- Replaced in 50 days
• Strong electrodynamic interaction
• Mega-amp currents between Io and Jupiter

• Plasma interaction with Io's atmosphere
• Heated atmosphere escapes
• ~20% plasma source
• The magnetic field couples the plasma to the spinning planet
• Ion gains large gyromotion -> heat
Spectral diagnosis of plasma conditions Ni, Ne, Te
Radial Transport

In rotating magnetosphere: If fluxtube A contains more mass than B – they interchange

Interchange of A and B does not change field strength for $\beta \ll 1$

Margy Kivelson

Bagenal 1994
• As plasma from Io moves outwards its rotation decreases (conservation of angular momentum)

• Sub-corotating plasma pulls back the magnetic field

• Curl $\mathbf{B}$ $\rightarrow$ radial current $J_r$

• $J_r \times \mathbf{B}$ force enforces rotation

Field-aligned currents couple magnetosphere to Jupiter’s rotation

Khurana 2001

Cowley & Bunce 2001
\( \nabla \times B_{\text{observed}} \rightarrow J \)

Configuration

\( \nabla \cdot J = 0 \rightarrow J_{||} \)

Expands, stretches field

Side View

Looking Down

Azimuthal Current

Radial Current

Plasmasheet

Bends field back
Aurora
$R_{MP}$ 60-100 $R_J$

Main Aurora 20 $R_J$
The aurora is the signature of Jupiter’s attempt to spin up its magnetosphere

• Outward transport of Io-genic plasma
• $J$ transfers load to ionosphere
• Transfer of angular momentum limited by ionospheric conductivity

Cowley et al. 2002
• Empirical field + plasma model
• Sub-cortoring plasmasheet 20 - 60 $R_J$
• Knight relation
• $E \parallel \sim 100 \text{ kV}$
• Upward current $\sim 1 \mu A/cm^2$
• 1 narrow auroral oval

Parallel electric fields: potential layers, $\phi_\parallel$, “double layers”

Downward ???

Upward ~ OK
How is information transmitted along magnetic field lines?

How is a stress from the outside communicated to the planet?

How does a blob of plasma here communicate with the planet?

Alfven waves!
Ionosphere  

Solar Wind  

Magnetosphere  

B – Rotating Plasmasphere

Radial Transport  
• Fluxtube interchange  
• Mass flux out  
• Empty magnetic flux in  
• Decoupling  
\[ S_p, E_\parallel \text{ and/or } V_r \sim V_A \]

Communication breaks down \( \sim 25R_J \). Magnetosphere & atmosphere stop talking > 60 \( R_J \)
Jupiter's 3 Types of Aurora

Steady Main Auroral Oval

Variable Polar Aurora

Aurora associated with moons
Satellite auroral emissions

- Plasma-moon electrodynamic interaction
- Mega-amp current systems
- Analogous to Earth auroral processes

Papers by Su, Ergun, Lysak, Hess, Bonfond
Main Aurora

- Shape constant, fixed in magnetic co-ordinates
- Magnetic anomaly in north
- Steady intensity
- $\sim 1^\circ$ Narrow

Clarke et al., Grodent et al. HST
Jupiter's Aurora: Structured & Dynamic

Same region – very different structure in UV vs. IR

Reveals energy of bombarding electrons & atmospheric chemistry

Gerard et al. 2018
Juno is testing ideas of how charged particles that bombard Jupiter's atmosphere are accelerated.
Alfven Wave Heating – Both Ions and Electrons

Heats Electrons $T_\parallel$

Heats Ions $T_\perp$

Saur et al. 2018
• Electrons reach >1 MeV
• Acceleration processes unclear: solitary waves, electrostatic potentials, plasmasheet turbulence

Mauk et al. 2018
- Waves?
- Electrostatic Voltages?
- Field-aligned coupling currents
- Turbulence?

- System quasi-stable?
- Strong coupling currents unstable?
- Fluxtube interchange non-continuous – local force imbalance
- Turbulence cascades to small scales?
- Stochastic accelerations
Plasma $\beta$ increases ballooning replaces interchange

Transport:

Outward: Plasma heats up - Tapping rotation via field-aligned currents

Inward: Adiabatic heating. Injection/depolarization after plasmoid release

$\beta = \frac{n k T}{B^2/2\mu_0}$

$\beta > 100$

Nichols 2011
High Plasma Pressure Makes Magnetosphere Larger & Compressible

\[ \rho_{sw} V_{sw}^2 = nkT + \frac{B^2}{2\mu_0} \]
How Compressible with Solar Wind Pressure?

**Earth** ~ Dipole

\[ R_{mp} \sim (\rho V^2)^{-1/6} \]

10 R\(_E\)

**Jupiter**

\[ R_{mp} \sim (\rho V^2)^{-1/4} \]

100 R\(_J\)

Solar wind \( \rho V^2 \)

Slavin 1985
Huddleston et al. 1998
Joy et al. 2002
Earth ~ Dipole

\[ R_{mp} \rightarrow 0.7 R_{mp} \]

solar wind \( \rho V^2 \)

Jupiter

\[ R_{mp} \rightarrow 0.5 R_{mp} \]

solar wind \( \rho V^2 \)

x10 Solar wind pressure

observed 100-50 \( R_J \) dayside magnetosphere
Drizzle?

Intermittant Tail

Reconnection

Cross-magnetopause Transport of mass & momentum

Kelvin-Helmholtz Instability

Draped IMF

“chicken wings” – closed field

Ionosphere

Magnetosphere

Solar Wind

C - Viscous Interaction

Delamere & Bagenal 2013
Masters 2017
• Not open Dungey cycle
• Viscous interaction
• Shear instabilities
• Small-scale, intermittent reconnection
• Boundary layers

“Candy wrapper”
Is Jupiter Really Just a Colossal Comet?

Delamere & Bagenal 2013
Time for Solar Wind to Flow Nose-Terminator

\[ V_{\text{solar wind}} \approx 400 \text{ km/s} \]

Probability of \( B_{\text{IMF}} \) staying \( B_z > 0 \) or \( B_z < 0 \) (i.e. N or S) for 5 hours is \( \sim 10^{-3} \)

Earth vs. Jupiter

10 \( R_E \) < 3 minutes

100 \( R_J \) \( \sim \) 5 hours

Bob McPherron
Margy Kivelson

McComas & Bagenal 2007
Earth

- Modest plasma source
- Residence time ~hours
- Taps solar wind
- Global convection
- Small, dynamic magnetosphere

Jupiter

- Strong plasma source
- Residence time ~weeks
- Taps rotation
- Local dynamics
- Large, hot plasma disk
Future at Jupiter: Clipper & JUICE

Particle & field measurements key for science goals
Why so different?

<table>
<thead>
<tr>
<th></th>
<th>Jupiter</th>
<th>Saturn</th>
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<tbody>
<tr>
<td>Planet Radius</td>
<td>70,000 km</td>
<td>58,000 km</td>
</tr>
<tr>
<td>M'pause Distance</td>
<td>63-92*  $R_J$</td>
<td>22-27#  $R_S$</td>
</tr>
</tbody>
</table>

Note: Both bimodal

* Joy et al. 2002  # Achilleos et al. 2008
Why so different?

1. Weaker Magnetic Field
2. Weaker Plasma Source

Jupiter

Saturn

Rc/Rp=0.9
Rc/Rp=0.6

Mass: Saturn = 1/3 Jupiter
- lower pressures
- smaller region metallic hydrogen
- 1/30 weaker magnetic field

Io

1/2 ton/s

Enceladus

50 kg/s

270 eV

58 eV

O\(^+\) pickup energy
Plasma Torus Mass Flux

**Jupiter**
- Half lost as fast neutrals
  - -> extended neutral cloud
- Half transported out to plasma disk

**Saturn**
- MOST lost as fast neutrals
  - -> extended neutral cloud
- Few% transported out to plasma disk

**Charge Exchange = CHEX**

\[
\text{O}^+ + \text{O} \rightarrow \text{O}^* + \text{O}^+
\]

- rotating
- stationary
- Energetic Neutral Atom
- Pickup Ion

Delamere et al. 2007
Plasma Torus Energy Flux

**Jupiter**
- Heating: Half pick-up, Half hot electrons
- Cooling: UV emissions

**Saturn**
- Heating: Charge exchange pick-up
- Cooling: Charge exchange escape

Delamere et al. 2007
### Why so different?

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<tr>
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<tbody>
<tr>
<td>Neutrals</td>
<td>70 kton</td>
<td>1 Mton</td>
</tr>
<tr>
<td>Plasma</td>
<td>1.5 Mton</td>
<td>85 kton</td>
</tr>
<tr>
<td>Disk Heating</td>
<td>10,000 GW</td>
<td>300 GW</td>
</tr>
<tr>
<td>Auroral Power</td>
<td>500 GW</td>
<td>20 GW</td>
</tr>
</tbody>
</table>

*• Plasma source less, cooler
• Less heating
• More CHEX*
• Enceladus closer to planet - slower relative motion
• LESS ENERGY,
• LESS IONIZATION

• Weaker magnetic field
• Weaker plasma source

Neutral density 100x ion density
Uranus & Neptune

They're Totally Weird!
Uranus and Neptune have much less mass

- Lower pressures
- No metallic hydrogen
- Weak & irregular magnetic fields produced in water layer, deep below gas envelope
Modeling Uranus & Neptune non-dipolar fields with thin-shell dynamo over a stratified core

Stanley & Bloxham 2006
Need to go back to Uranus & Neptune

- Voyager got quick glimpse!
- Saw irregular, changing field
- How do m'spheres respond to solar wind?

Hints of aurora with HST

Lamy et al. 2017
Explore weird configurations at different seasons

- Full coverage from orbit
- Modern instrumentation
- Onboard data-processing

Voigt et al. 1987

Cao & Paty 2017
Long Cruise
Sample Trajectory to Uranus:
Earth-Venus-Earth-Earth-Jupiter
Gravity Assist
May 2031 – May 2043
12 years

Orbit insertion ∆V high
Neptune: 2.3-3.5 km/s
Uranus: 1.5-2.5 km/s

Plus aerocapture capability, enables very lowers flight times
Uranus < 5 yr
Neptune < 7 yr
Delivers more mass....

We'll have the Pu-238

Ice Giants

SLS Falcon
## Comparative Planetary Magnetospheres

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<td>Moment $/M_E$</td>
<td>5x10^{-4}</td>
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<tr>
<td>Coupling Process</td>
<td>Ionosphere</td>
<td>Ionosphere</td>
<td>Jup. M'Sphere</td>
<td>Ionosphere</td>
<td>Magnetosphere</td>
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<td>Magnetosphere</td>
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<tr>
<td>Timescale</td>
<td>mins</td>
<td>mins</td>
<td>hrs</td>
<td>wks</td>
<td>days</td>
<td>??</td>
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Summary

• Diverse planetary magnetic fields & magnetospheres
• Earth, Mercury, Ganymede magnetospheres driven by reconnection
• Jupiter & Saturn driven by rotation & internal sources of plasma
• Uranus & Neptune are complex – need to be explored!

Stay tuned…. MAVEN mission to Mars
Juno mission to Jupiter
Bebi-Columbo to Mercury
Go Juno!
Planetary Magnetic Dynamos – Questions:

A. What controls amount of non-dipole field?
B. Are dynamos of Earth, Jupiter, Sun similar – or completely different?
C. What controls variation in time?
D. Why do some dynamos die out?
Earth Auroral Current Region
Does same physics apply at Jupiter?
Spacecraft & Payload

Orbit Insertion 4th July 2016

SPACECRAFT
DIAMETER: 66 feet, 20 meters
Power 400 W
Spin period 30 sec

Gravity Science

Magnetometer

Waves
Radio & plasma

JunoCam
camera

UV spectrometer

UVS

JIRAM
IR spectrometer

MWR
Microwaves

JEDI
High-energy particles

JADE
Low-energy particles

JEDi
High-energy particles

Jade
Low-energy particles


Guillot, Tristan; Stevenson, David J.; Hubbard, William B.; Saumon, Didier, The interior of Jupiter, Jupiter. The planet, satellites and magnetosphere. Edited by Fran Bagenal, Timothy E. Dowling, William B. McKinnon. Cambridge, UK: Cambridge University Press,


