Analysis of possible open field lines as origins for Jovian auroras

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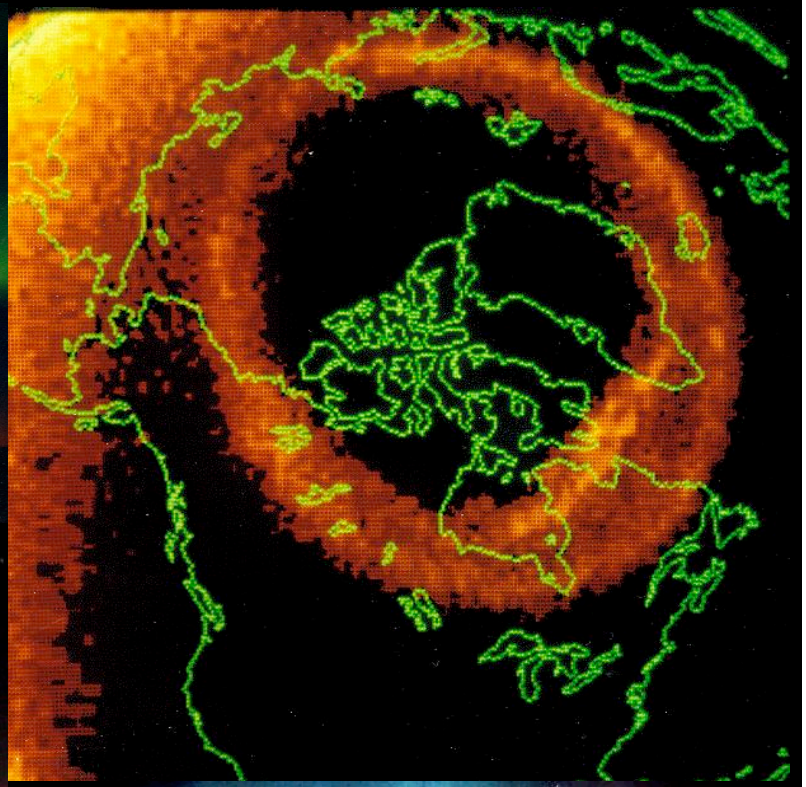
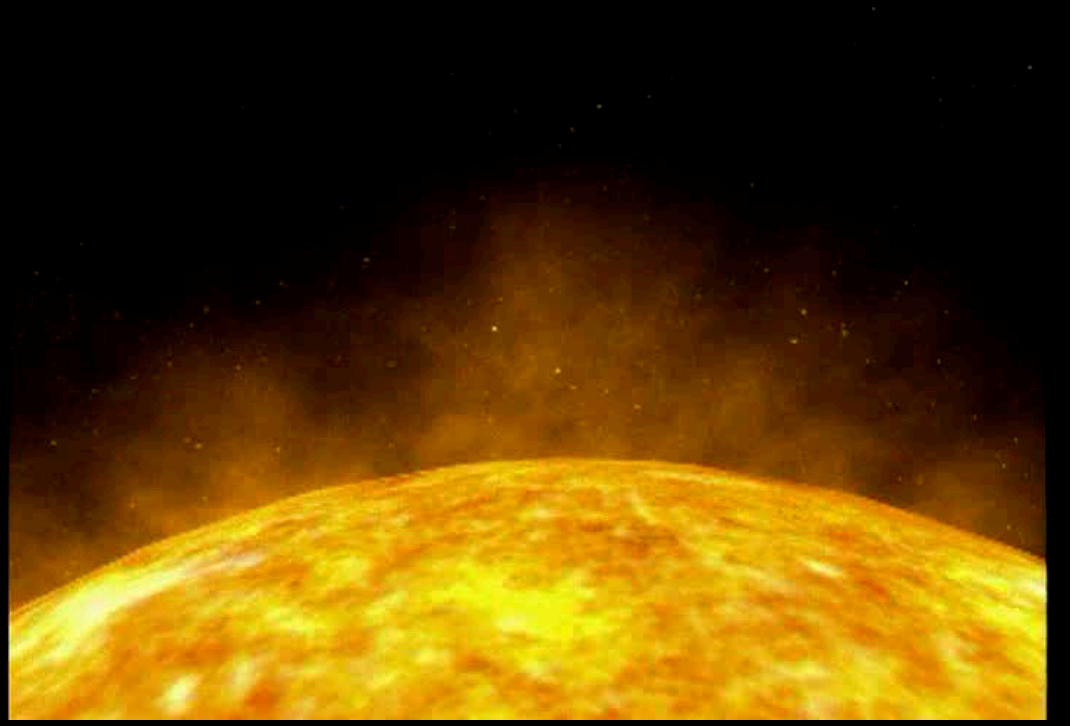
We Know That Auroras Occur on Earth



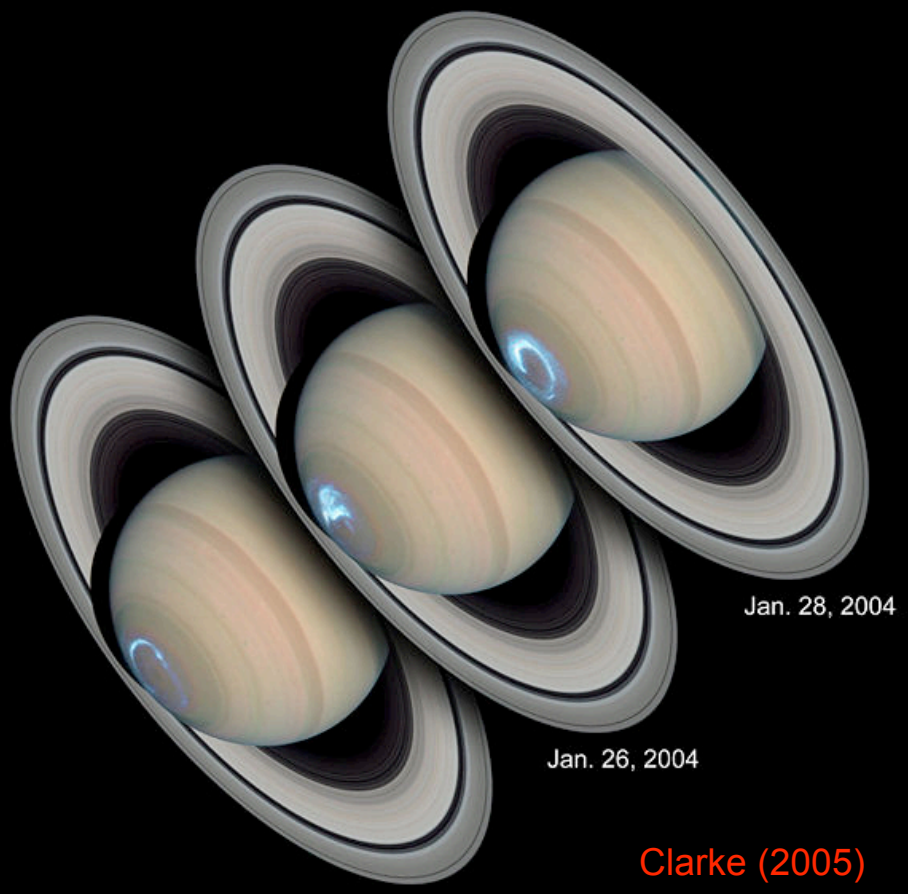
What Causes Earth's Auroras?

- CME fields can connect with Earth's magnetic field if at the right orientation
- These opened field lines convect back towards the magnetotail
- Here the field lines are compressed and magnetic reconnection can occur
- This springs charged particles back along the closed field lines toward the poles



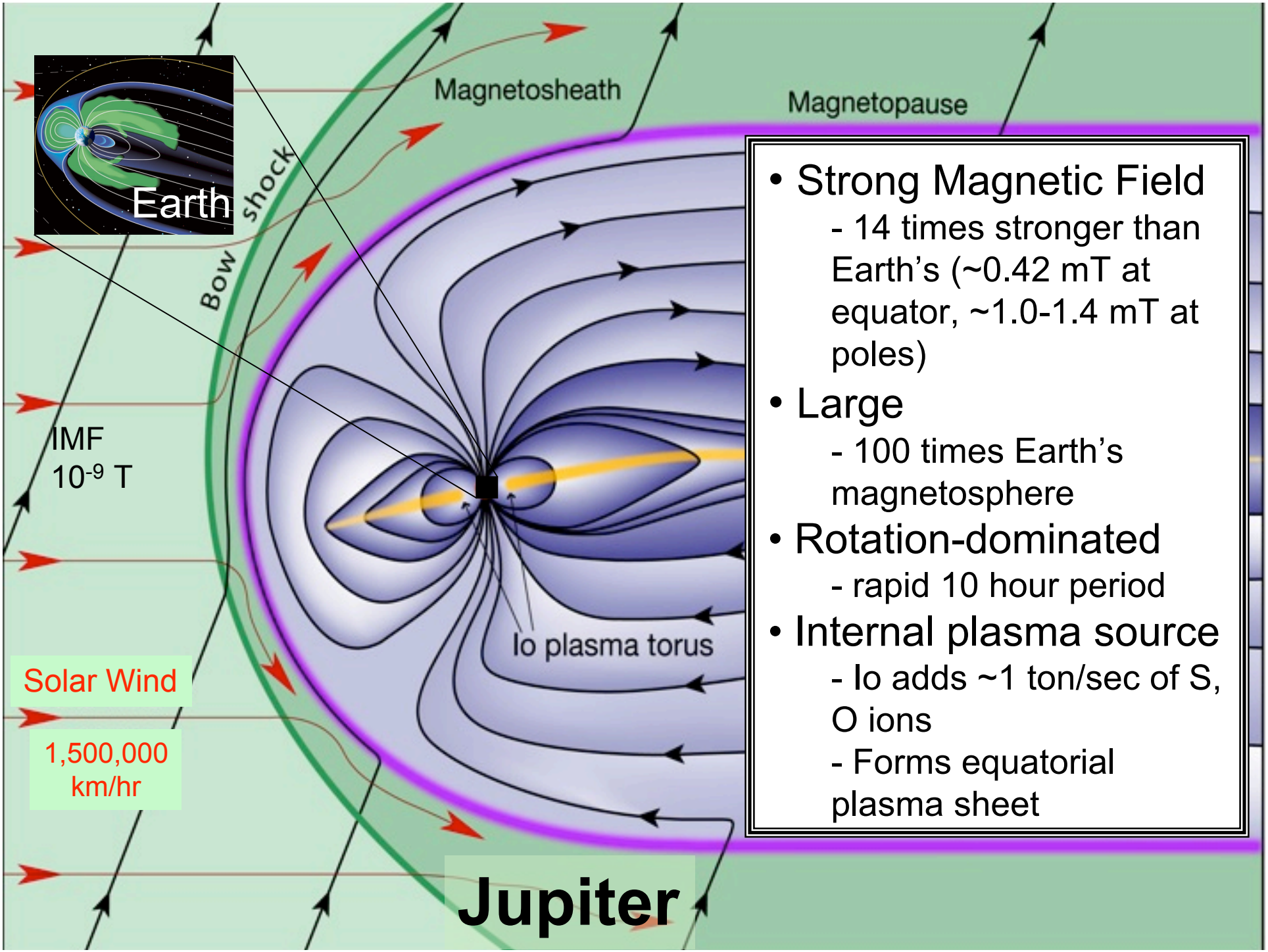
Earth Isn't Alone

- We have found that all of the gas giants have aurora
- Observing and modeling the aurora on these planets allows us to compare and contrast with the processes here on Earth



Clarke (2005)

BOSTON UNIVERSITY



- Strong Magnetic Field
  - 14 times stronger than Earth's (~0.42 mT at equator, ~1.0-1.4 mT at poles)
- Large
  - 100 times Earth's magnetosphere
- Rotation-dominated
  - rapid 10 hour period
- Internal plasma source
  - Io adds ~1 ton/sec of S, O ions
  - Forms equatorial plasma sheet

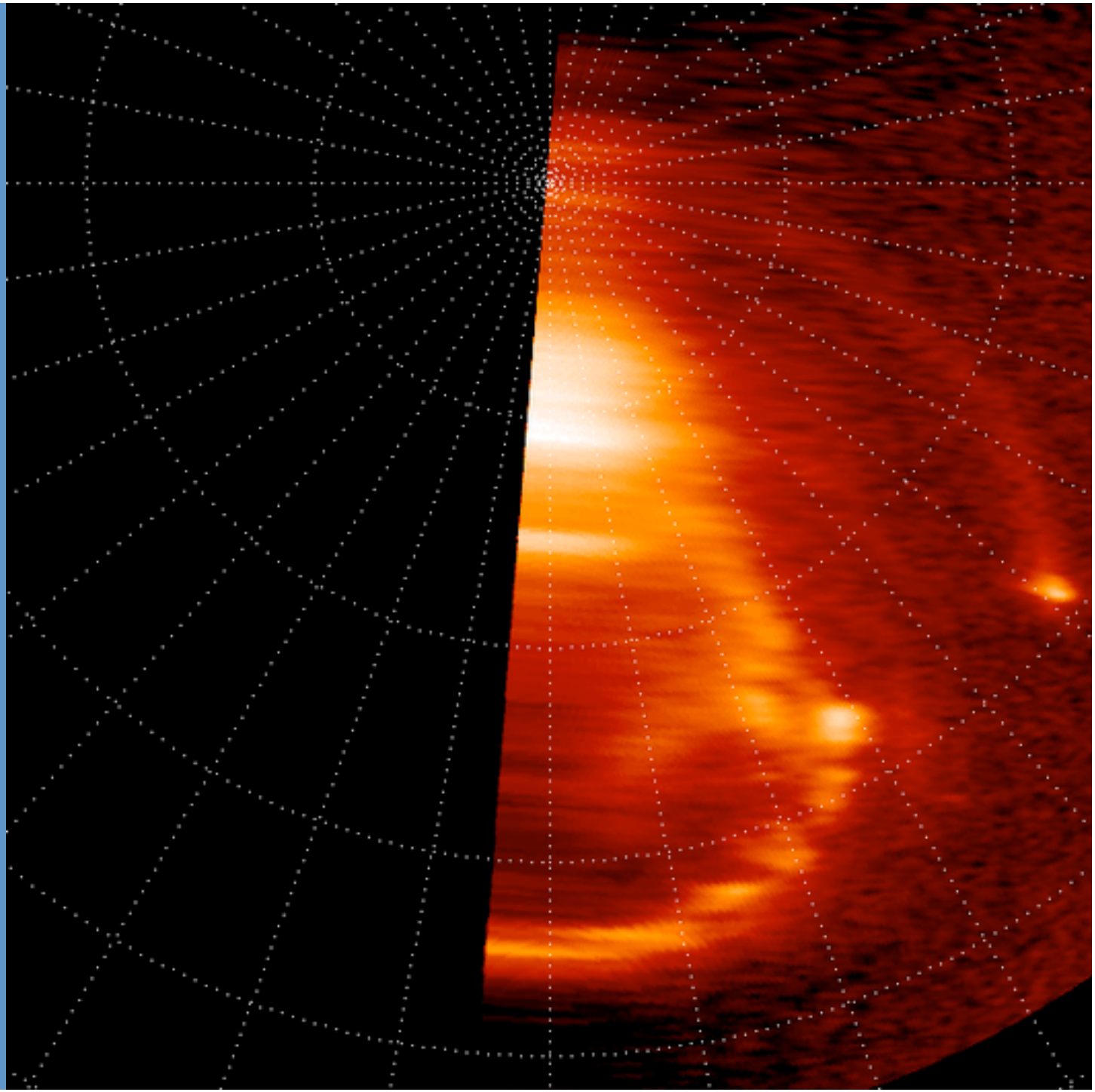
s Aurora: The Movie

Fixed magnetic coordinates rotating with Jupiter

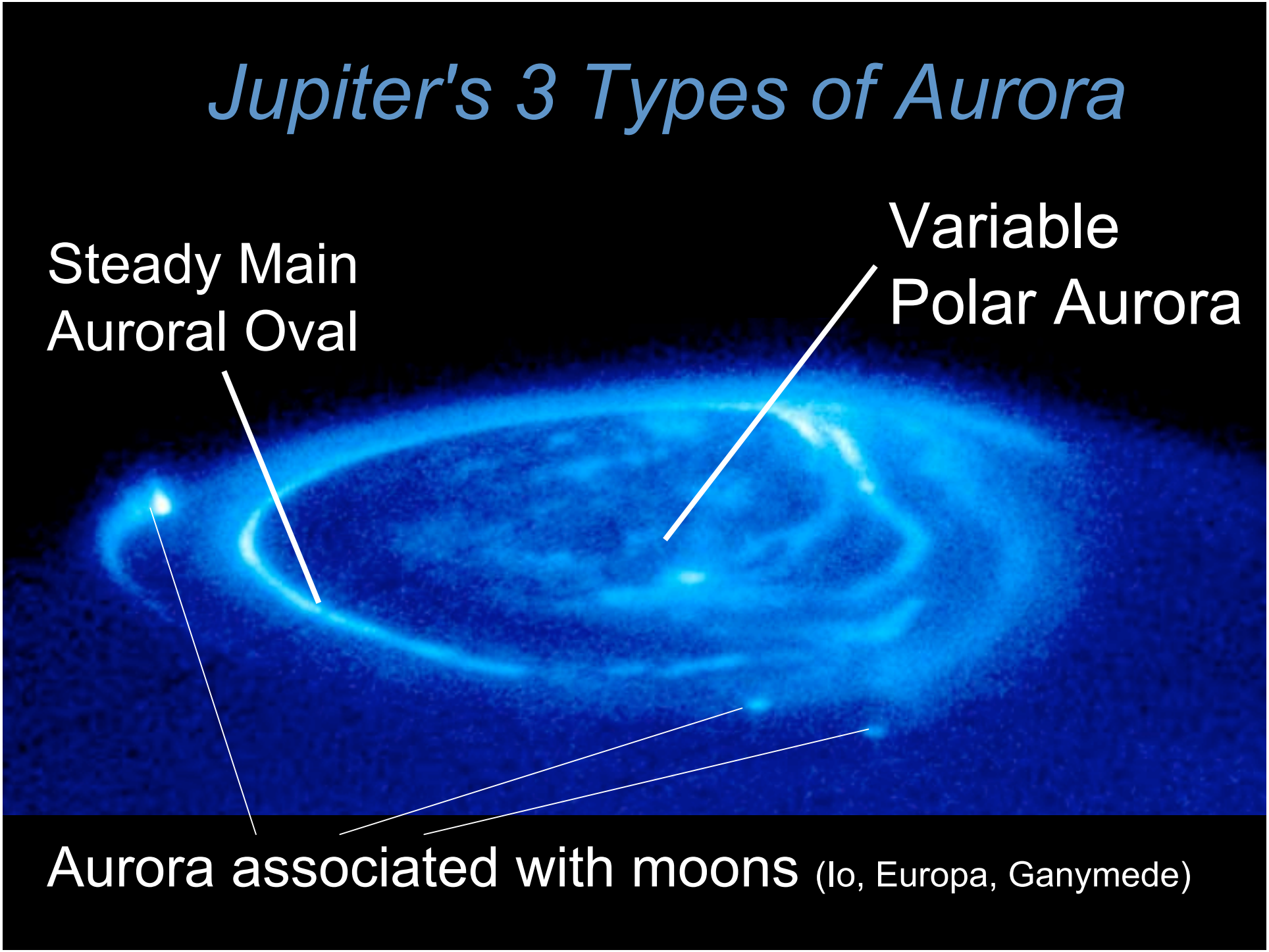
Clarke et al.

Grodent et al.

HST

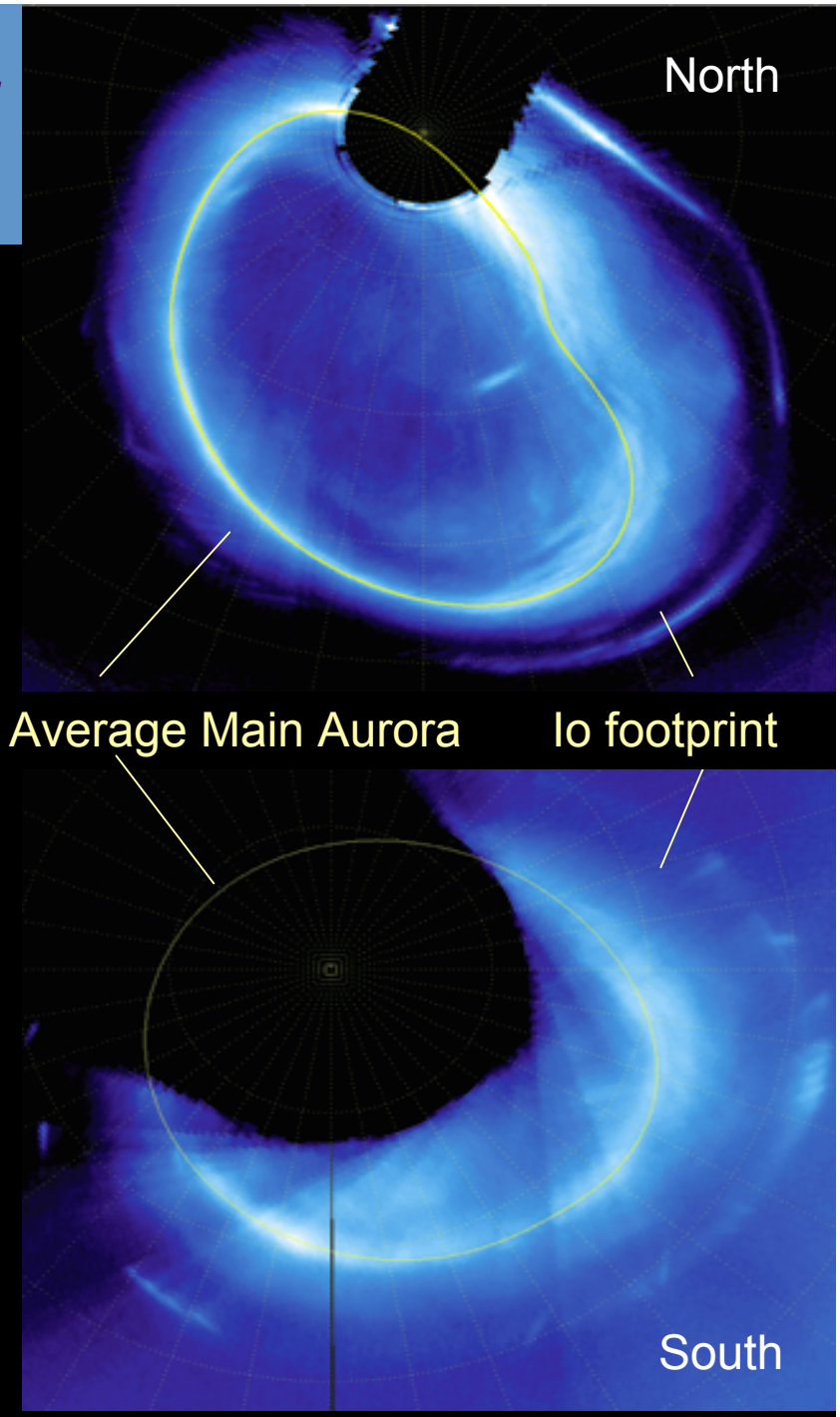


Jupiter's 3 Types of Aurora



Main Auroral Oval

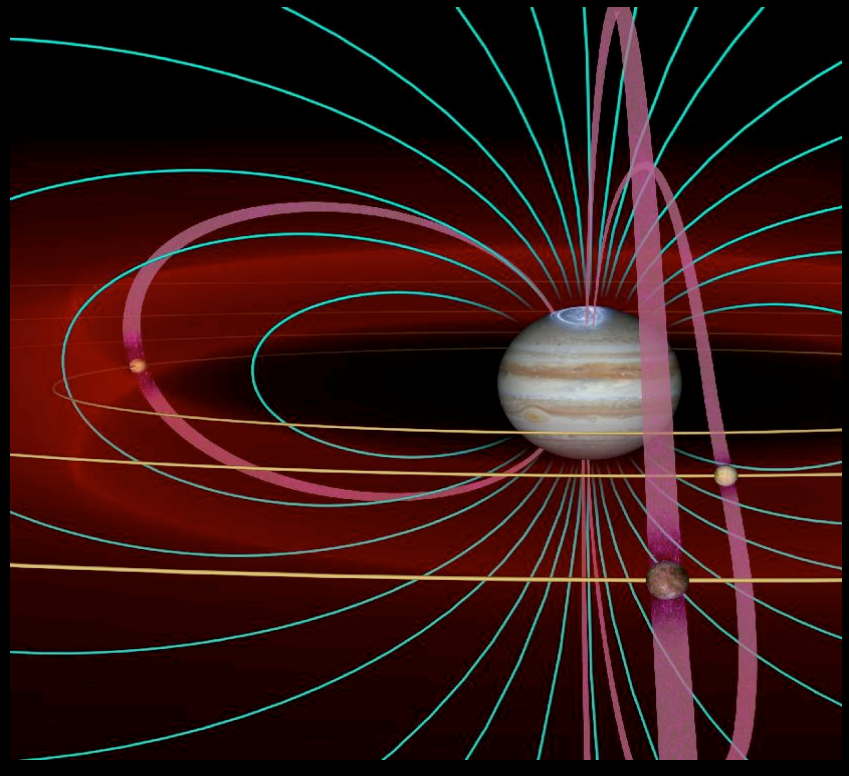
- Shape constant, fixed in magnetic coordinates, rotates with magnetic dipole
- Steady intensity
- Possible magnetic anomaly in Northern Hemisphere, causing kink in oval
- Not caused by same connection with IMF like at Earth, but by outward transport of plasma

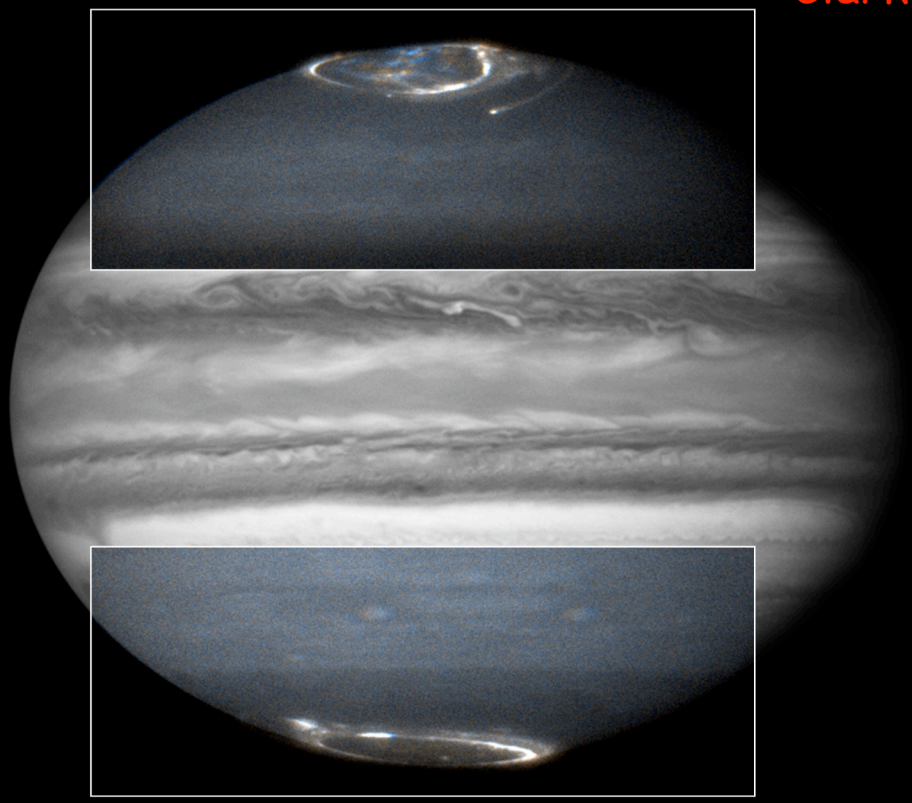


Satellite Auroral Emissi

Clarke

HST Observations of Auroral Emissions from Io's Magnetic Footprint

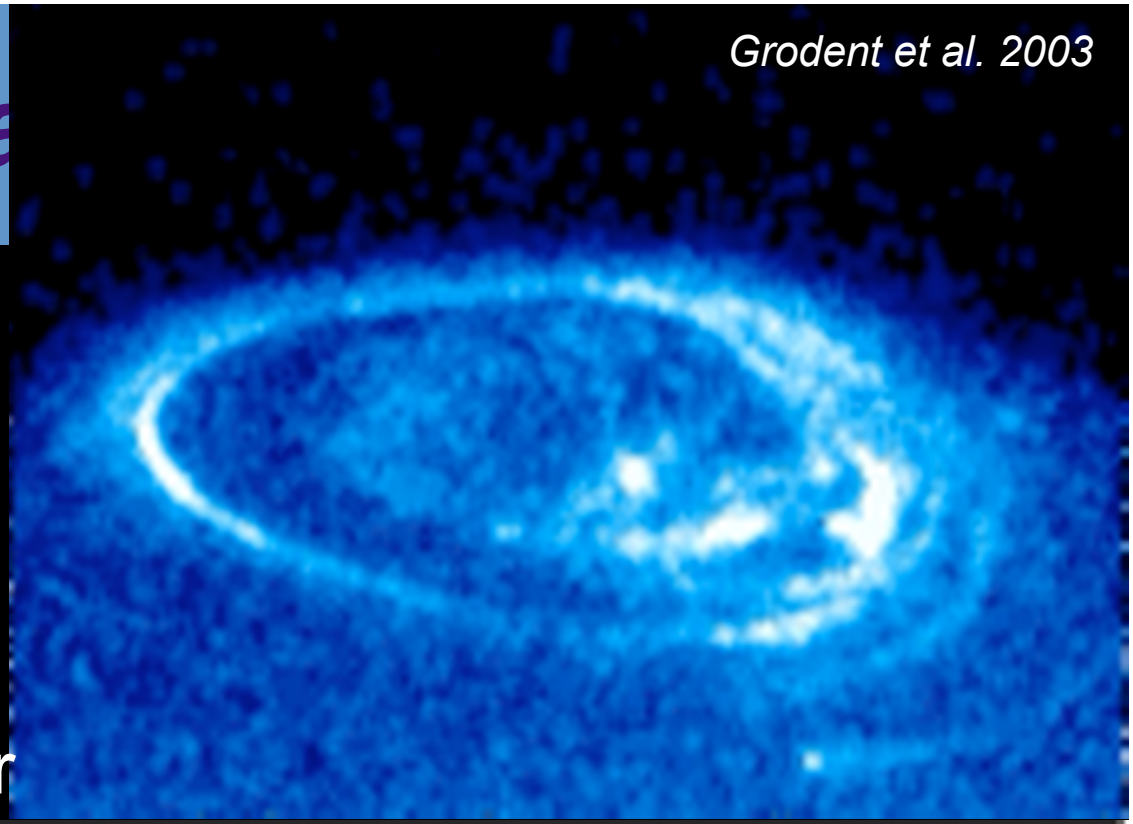


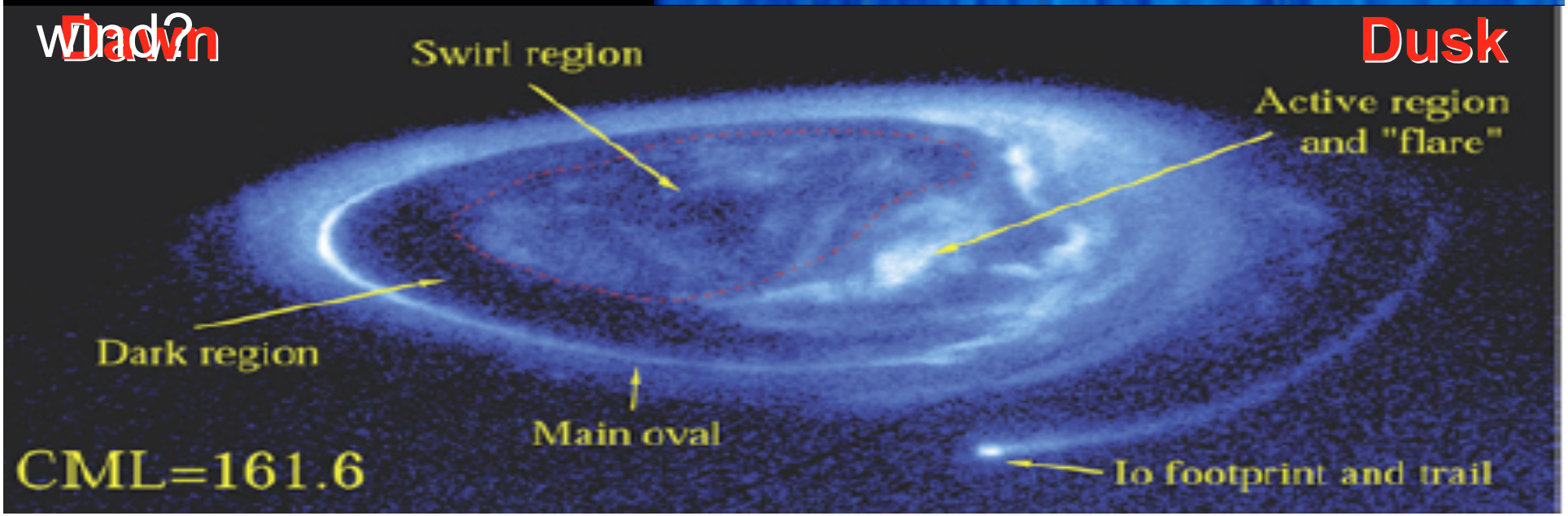


- Caused by plasma-moon electrodynamic interaction
- Mega-amp current systems
- Analogous processes to Earth's, but different drivers

Polar Aurora

- Highly variable
- Local time controlled
- Solar wind modulated? Possibly caused by reconnection with solar wind?



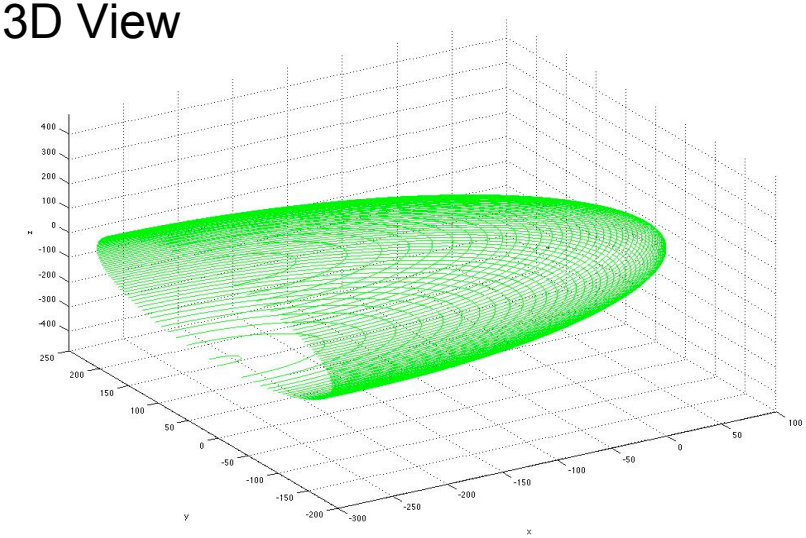


Is the Jovian Aurora Like Earth's?

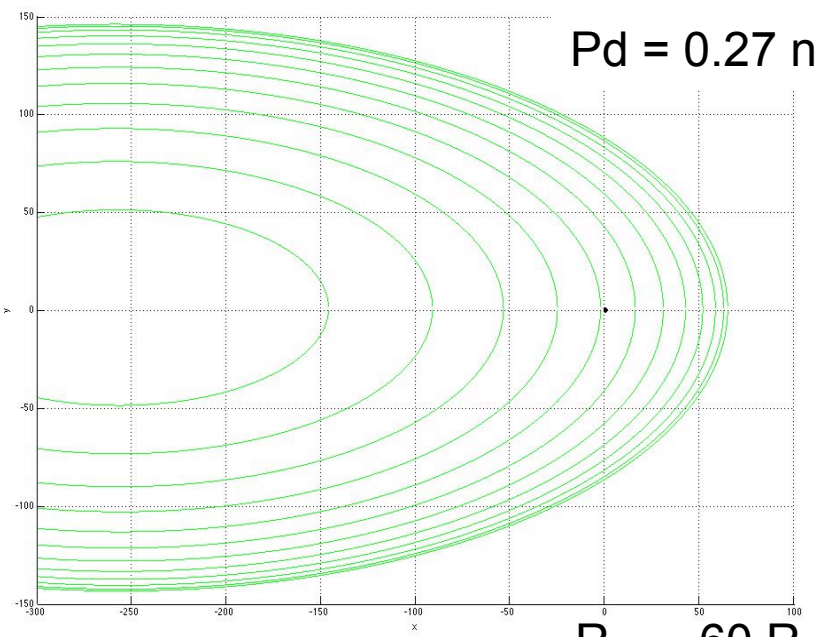
- On Earth, field lines open to the Solar Wind and IMF are where auroras occur
- Most Jovian aurora is caused by the inner magnetosphere and has no correlation to the solar wind or IMF (main auroral oval and satellite footprints)
- The variable aurora seen inside the main oval is highly variable and may be more like the auroras seen
- Using the *Khurana* model of the Jovian magnetic field and a model of the Jovian magnetopause we want to plot where the field lines that are opened to the IMF by magnetic reconnection exist
- We want to try to show that the region where the variable aurora exists is a region of open field lines

The Magnetopause

3D View

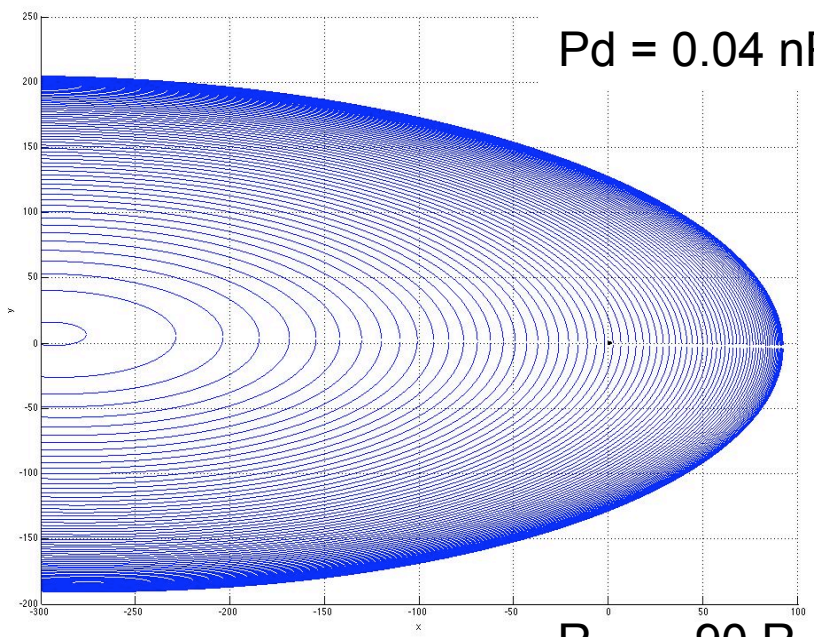


- Defined by Joy et. al (2002)
- Described by function
  $z^2 = A + Bx + Cx^2 + Dy + Ey^2 + Fxy$
- Variable with magnitude of solar wind dynamic pressure (P_d)
- Fluctuates in distance from planet from ~60 R_J to ~90 R_J



Pd = 0.27 nPa

R_{MP} ~60 R_J



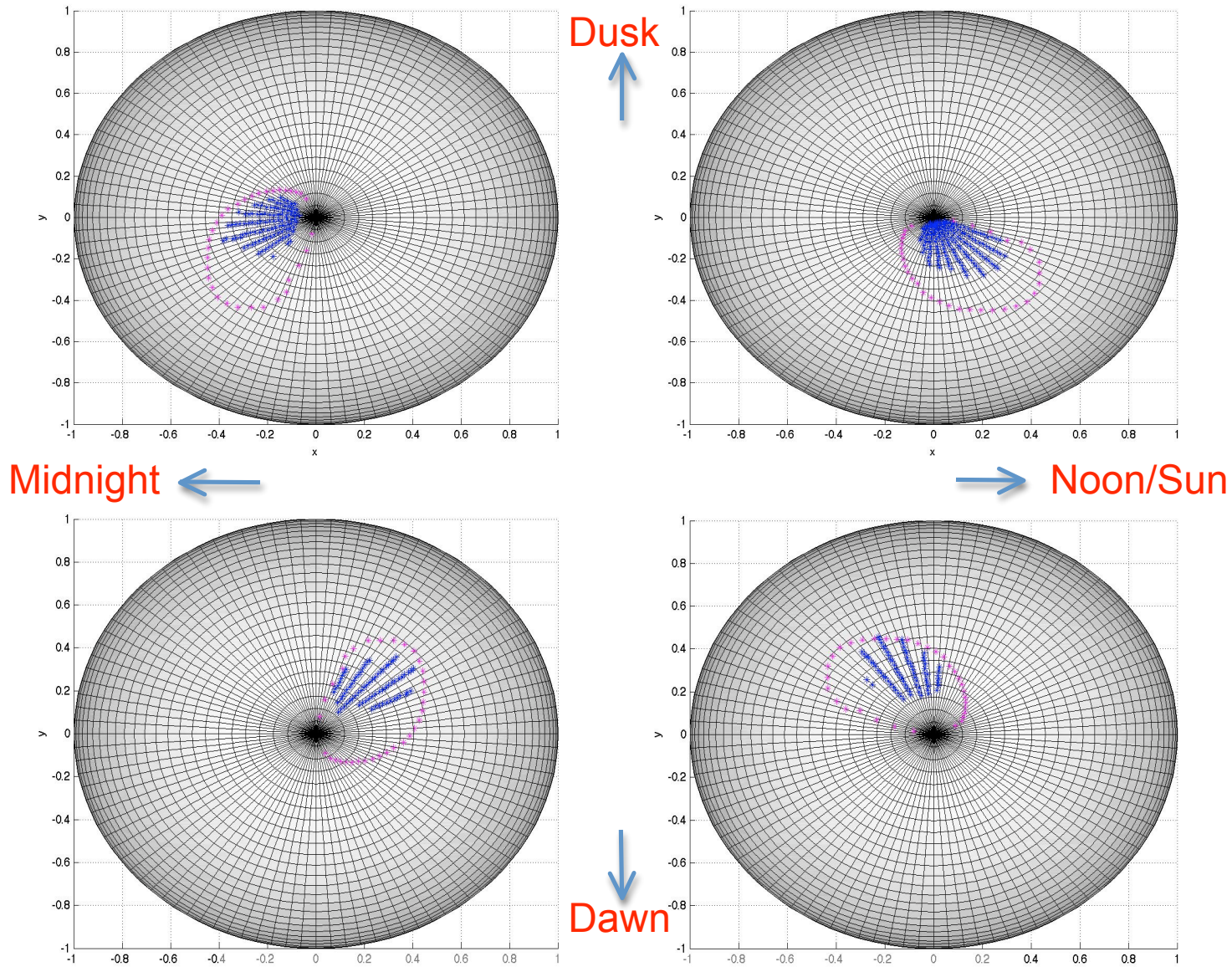
Pd = 0.04 nPa

R_{MP} ~90 R_J

How Jovian Magnetic Reconnection Works

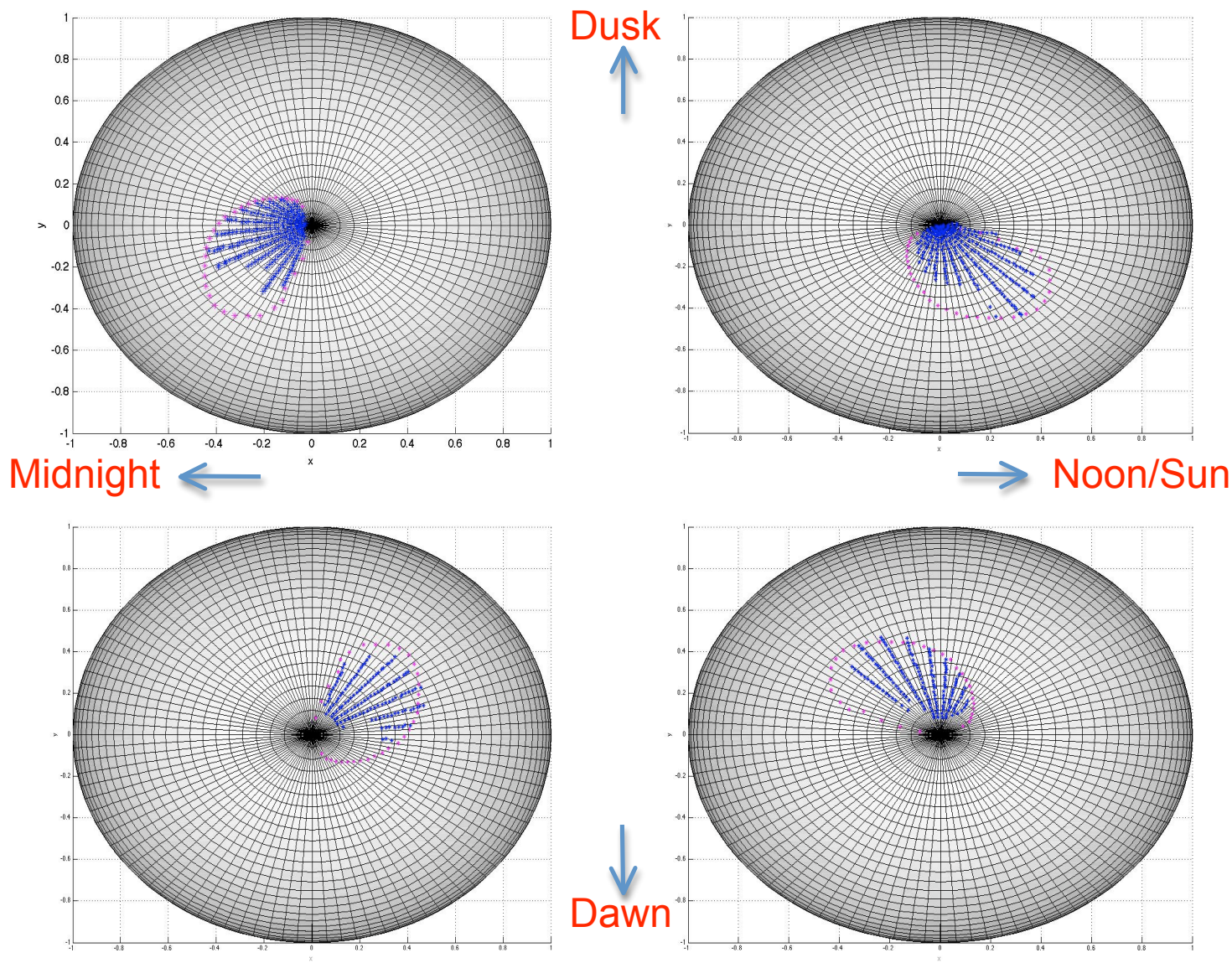
- Assume an IMF with an arbitrary orientation in the xy (equatorial) plane
- As the IMF encounters the Jovian magnetic field it forms a bow shock that contours to the shape of the magnetopause
- This creates a sunward field line on one side of the planet (dawn or dusk) and a magnetotail-facing line on the opposite side
- The bend-back of the Jovian field (a clockwise pinwheel effect caused by the planet's rapid rotation) can cause the IMF and Jovian field lines to be locally anti-parallel
- If this occurs, then magnetic reconnection can occur in the *equatorial plane* where Jovian field lines connect to the IMF, exposing the planet to solar variability effects

Where Do Field Lines That Cross the Magnetopause Come From?



Shown for magnetopause with radius ~90 R_J, P_d = 0.04 nPa

How Does the Region of Possible Open Field Lines Vary With Different Dynamic Pressures?



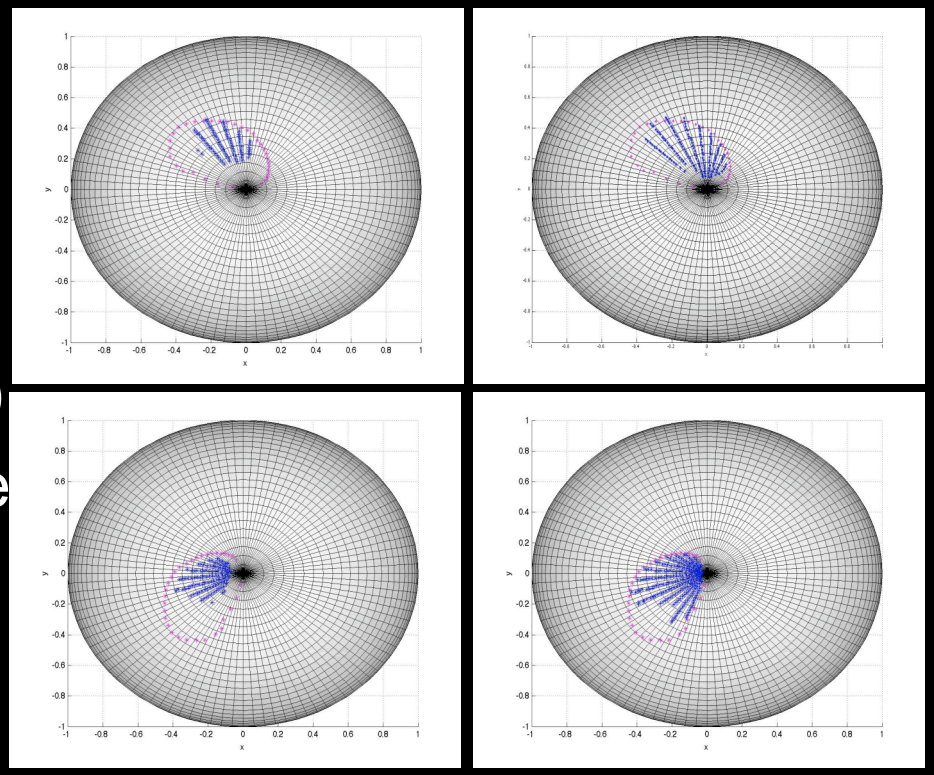
Shown for magnetopause with radius ~60 R_J, P_d = 0.27 nPa

The Region of Open Field Line Candidates Expands in Both Latitude and Longitude

<u>Comparison of dynamic pressures at 0.04 and 0.27 nPa</u>

- The region of open line candidates spreads in longitude and latitude (as much as 30° farther from the pole in some instances)
- All open line candidates are still well within the main auroral oval
- The noon and dusk orientations lack candidates close to the pole for the smaller value of P_d

P_d = 0.04 nPa P_d = 0.27 nPa



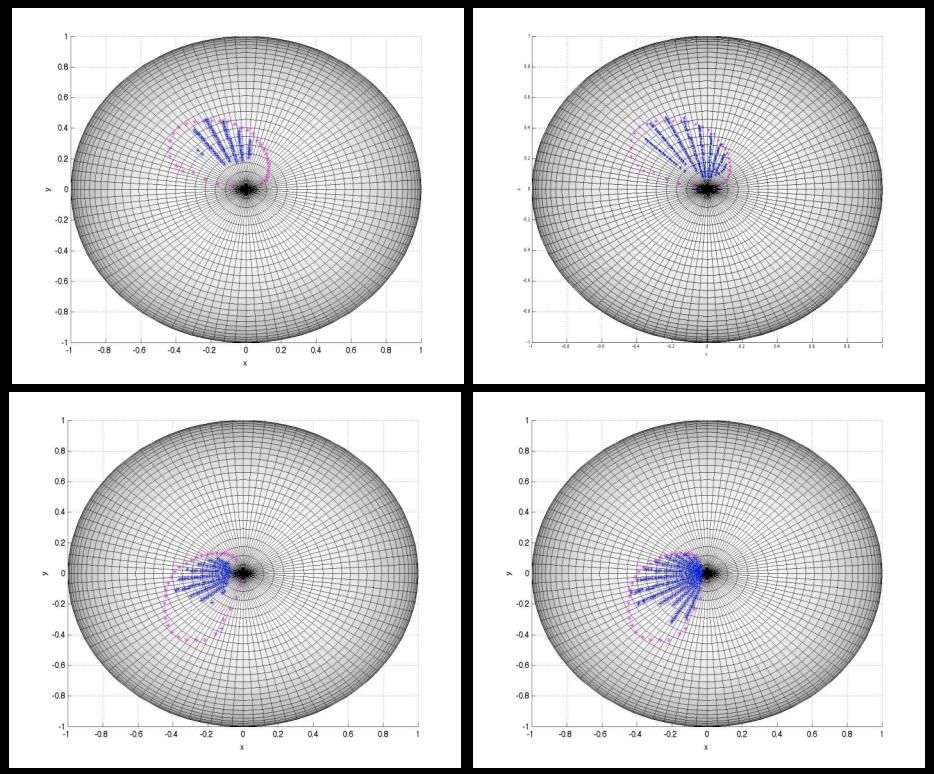
Top row : Dusk Dipole Orientation

Bottom row : Midnight Dipole Orientation

Why the change?

- For the noon and dusk dipole orientations, clockwise bend-back of the Jovian field causes the high latitude field lines to bend back into the magnetotail, where they can avoid intersecting with the magnetopause boundary
- As the P_d increases, the magnetopause is compressed, leaving less room for field lines to exist without crossing the boundary (even the high latitude lines that were

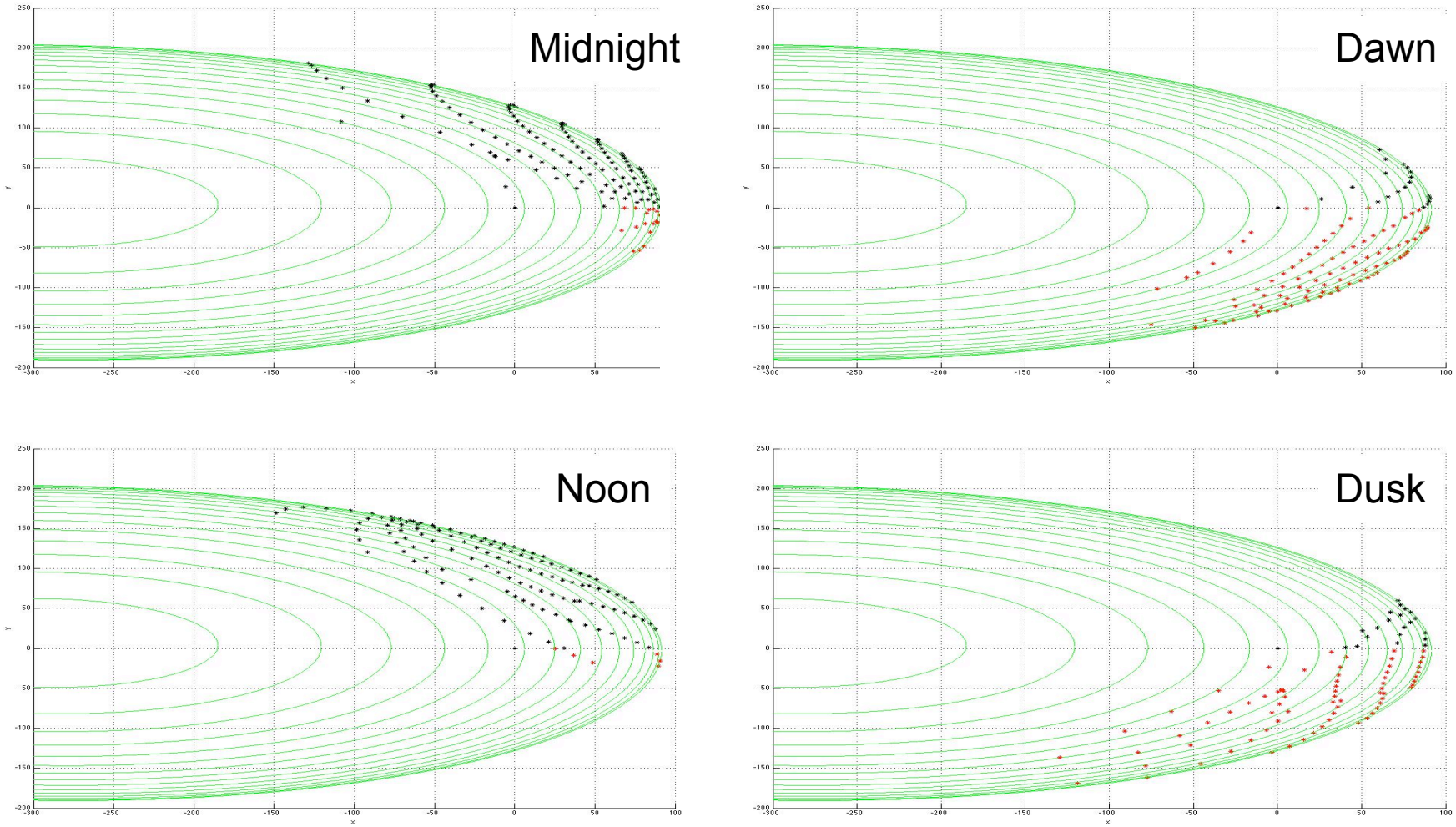
P_d = 0.04 nPa P_d = 0.27 nPa



Top row : Dusk Dipole Orientation

Bottom row : Midnight Dipole Orientation

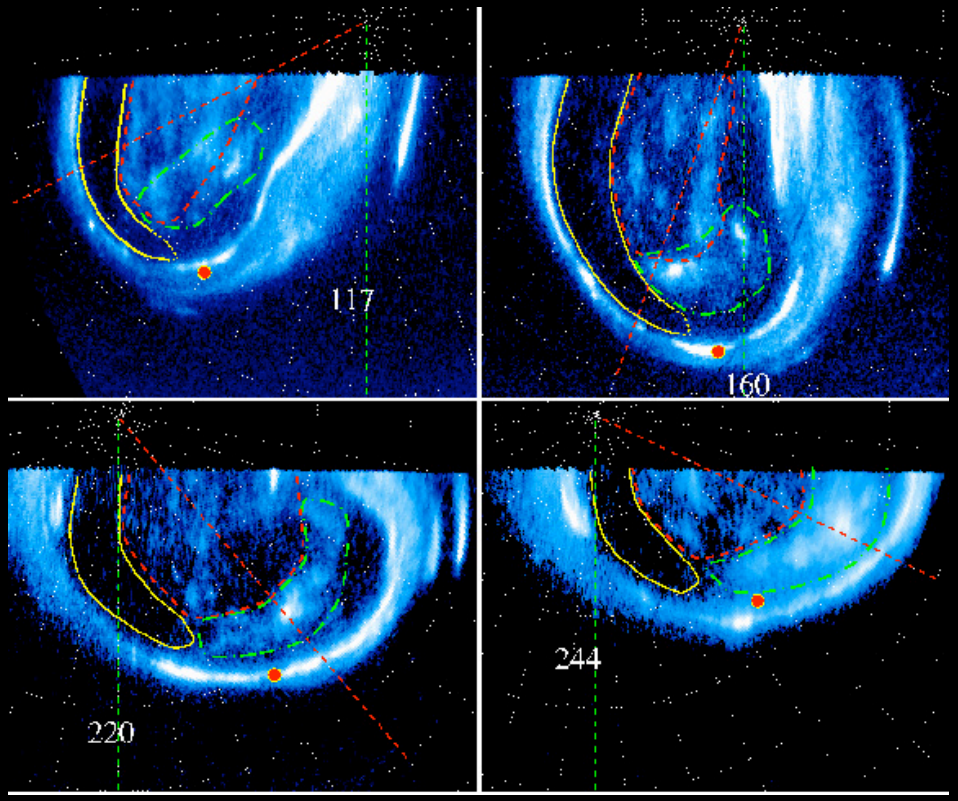
Where Do The Field Lines Cross?



Pd = 0.04 nPa, red indicates +y (dusk side), black indicted –y (dawn side)

The Dark Region

- In all four dipole regions (for both values of P_d) there is a noticeable lack of open field line candidates in the dawn-most region of the auroral oval
- This agrees with HST STIS observations made by *Grodent et al.* [2003]



The yellow solid line in this image shows the consistent dark region of variable polar emission on the dawn side of the main auroral oval

Conclusions

- Magnetic reconnection occurring and opening the area within the main auroral oval to the IMF and solar wind seems very promising.
- There remains some speculation if the *Khurana* model can be effectively applied to the polar regions because it is based on data collected near the equator
- If the field lines within the region where we observe the variable polar emission are in fact open to the IMF, then it can be postulated that solar-related activity does drive the variability in the emission.
- The agreement between the observations by *Grodent et al.* and the lack of open field line candidates at the dawn extremes in our investigation indicates a correlation between our possibly open field lines and the appearance of the variable emission.
- Further study might require calculating the dot product of the magnetic field line vectors as they cross the magnetopause with the vector of the IMF that would be streaming along the outer edge of the Jovian magnetopause.

Final Thought

- If a large enough anti-parallel component exists between the bent-back Jovian field lines and the IMF lines at the magnetospheric bow shock, then it is highly probable that magnetic reconnection could occur that would open the field lines within the main auroral oval to the IMF and solar wind, creating the variable emission in a process very similar to that which causes aurora on Earth.