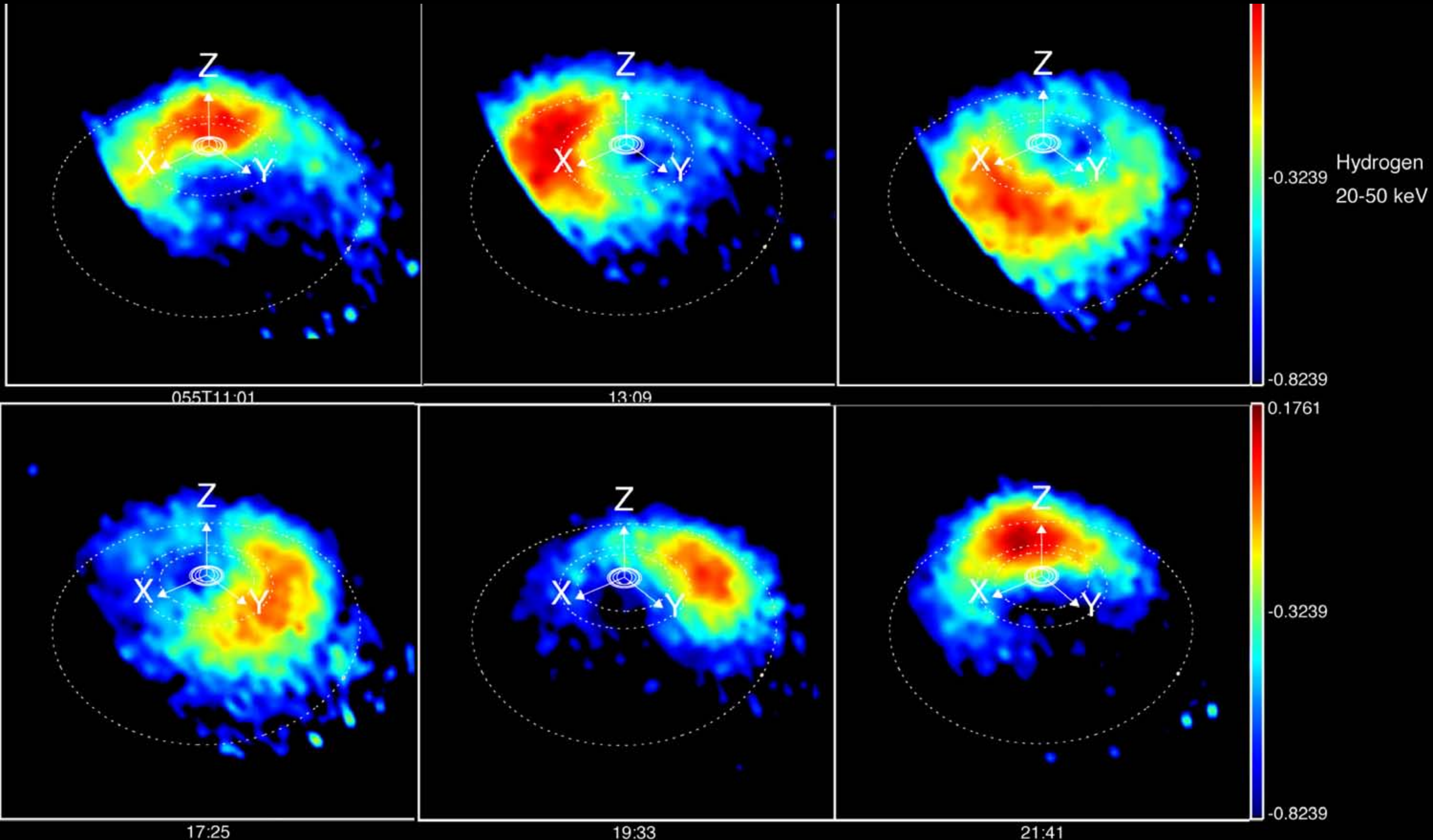
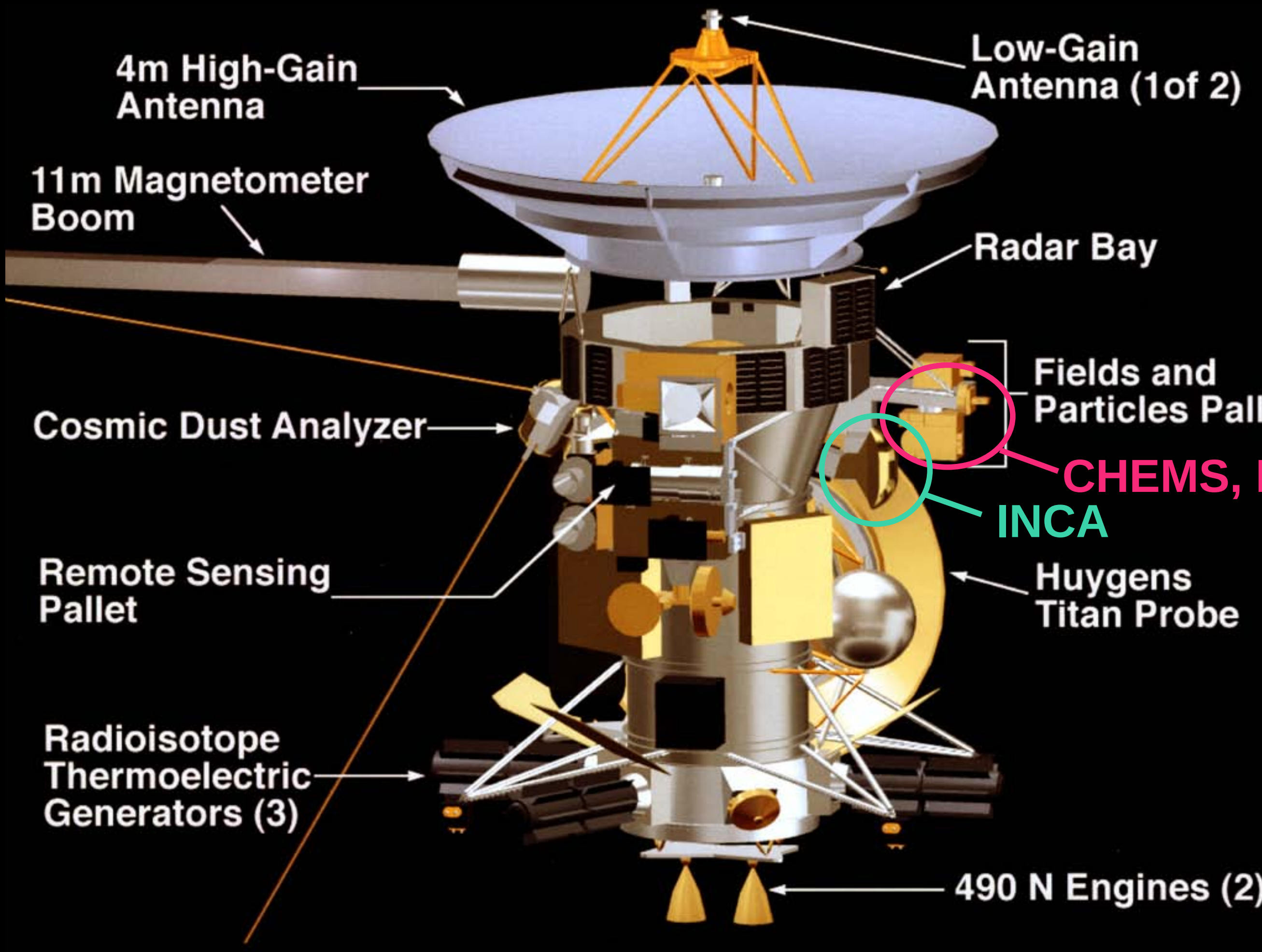
Energetic Particles in Saturn's Rotating Magnetosphere

Don Mitchell and the MIMI Team (S. M. Krimigis, PI)



Cassini Spacecraft



Spacecraft Specs

Height: 6.8 m (22 ft)

Diameter: 4 m (13 ft)

Mass: 2500 kg (2.8 tons)
(fueled): 5600 kg (6 tons)

Power: 700 Watts at SOI

12 Instruments
- 4 Optical Remote Sensing
- 6 MAPS
- 2 microwave

3.5 GB Solid State Recorder

The Saturn System

Magnetosphere

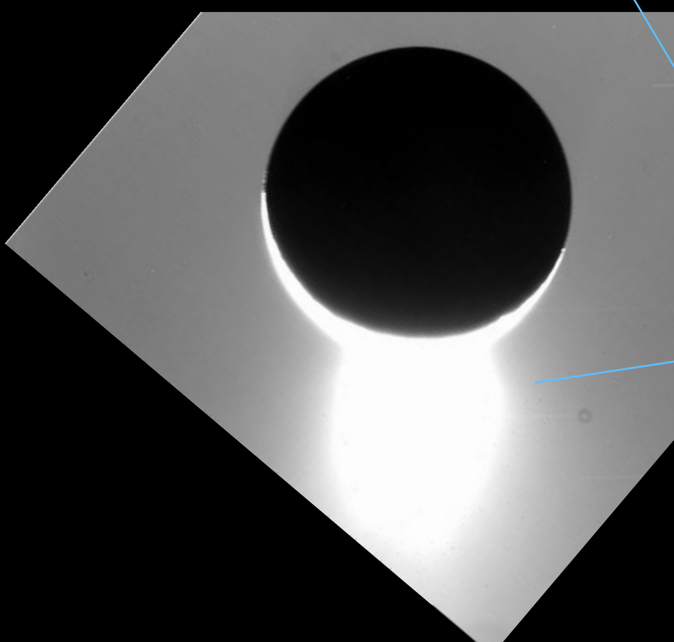
- The Magnetosphere is a giant magnetic bubble surrounding the planet Saturn.

- There is a very complex interaction between the icy satellites and rings of Saturn, the plasma trapped in the magnetic field, the neutral gases in the bubble, and the solar wind (a stream of ionized particles flowing from the Sun, which blows the magnetosphere into a blunt-nosed, long-tailed windsock).

- The icy moon Enceladus, with its strong emission of water into the magnetosphere at 4Rs, dominates the neutral and ionized gas populating the magnetosphere inside 10Rs, while Saturn's atmosphere and ionosphere also contribute in the outer regions.

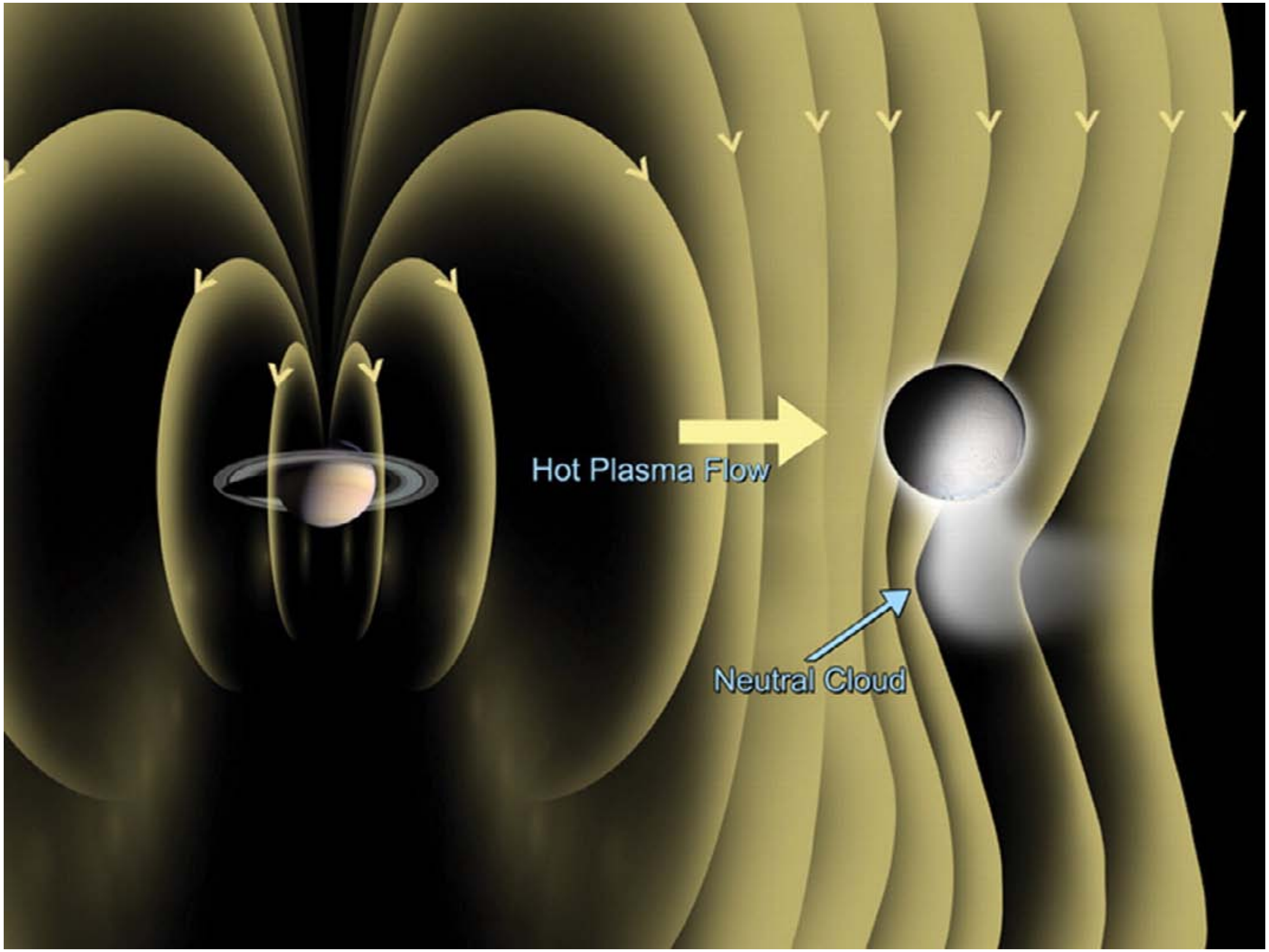
- Typical constituents found in the system are O, H_2, H, OH, CH_4 , in both neutral and charged states, and from the solar wind, He^{++}.

As Io is to Jupiter, Enceladus is the dominant influence on Saturn’s magnetosphere



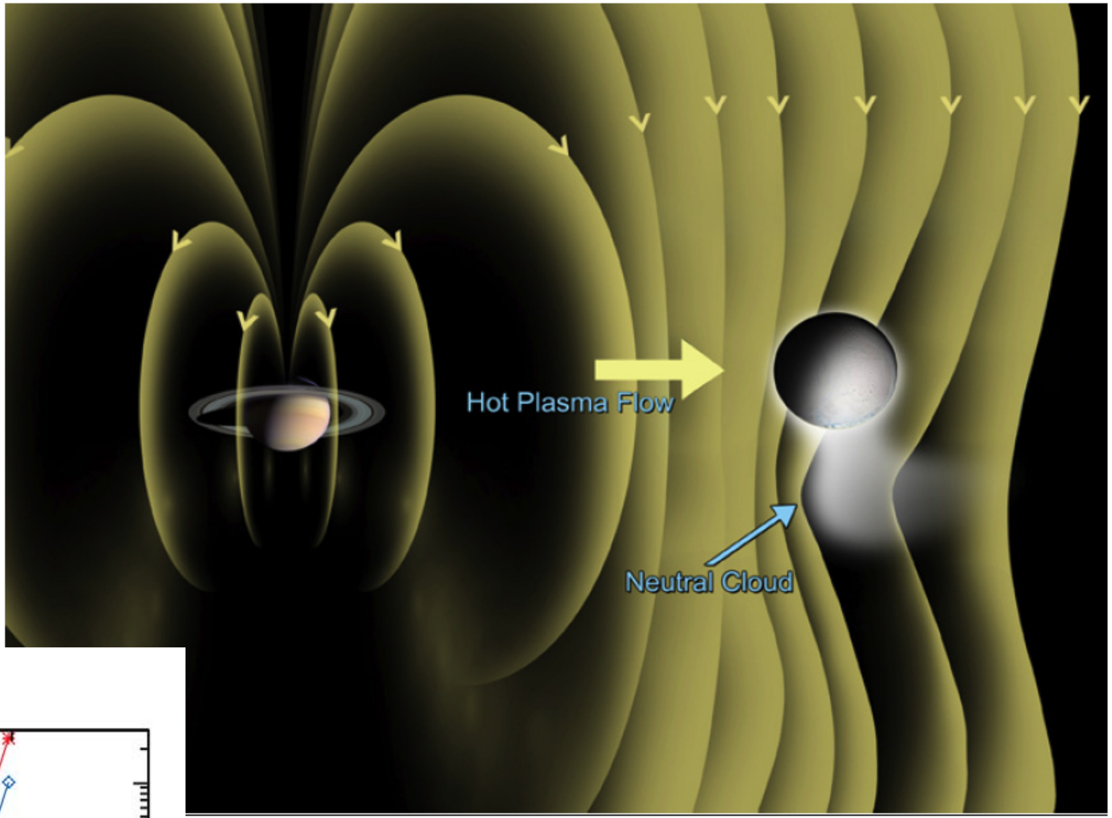
Gas (mostly water) and micron-size ice particle jets emerge from these cracks

Fig. 4. A schematic (where Saturn and Enceladus are not to scale) showing the corotating Saturn magnetic field and plasma being perturbed by the neutral cloud that is produced by a polar plume generated close to the south pole of Enceladus

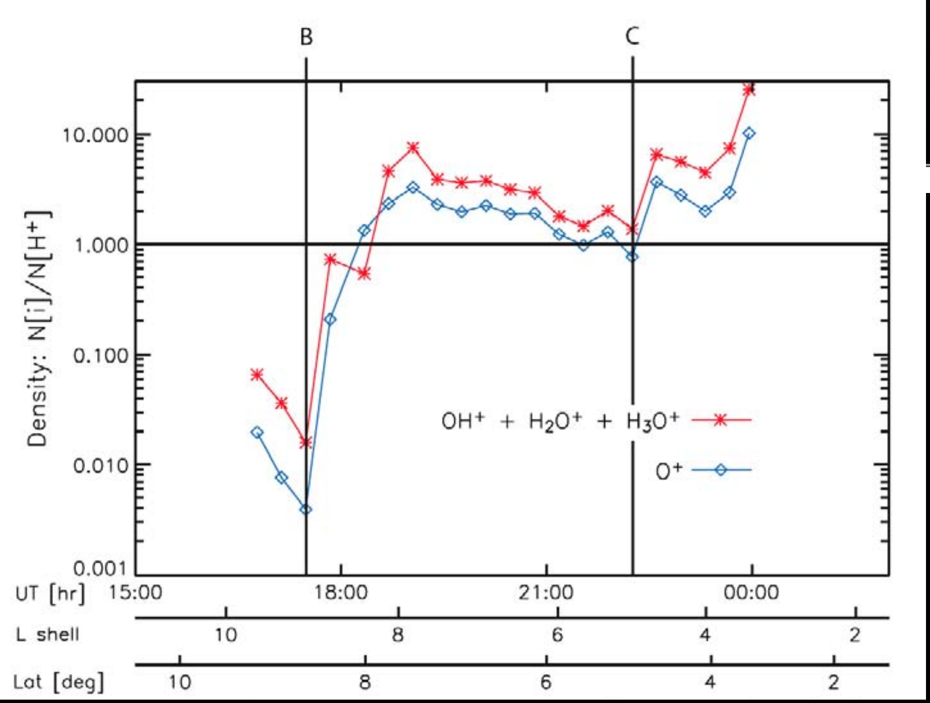


M. K. Dougherty et al., Science 311, 1406 -1409 (2006)

From Dougherty et al. 2005

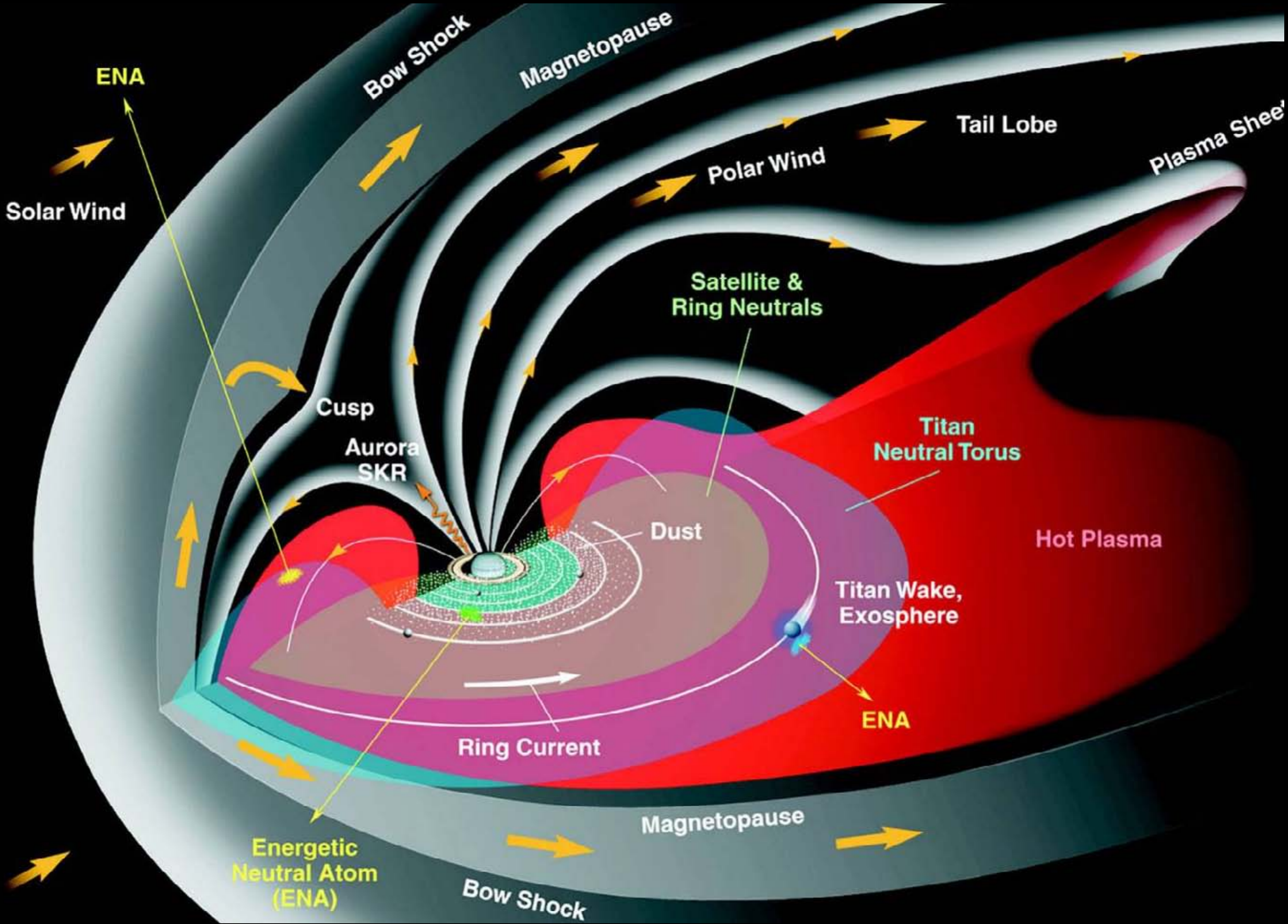


Young et al., Science, Feb. 25, 2005 -- Cassini CAPS

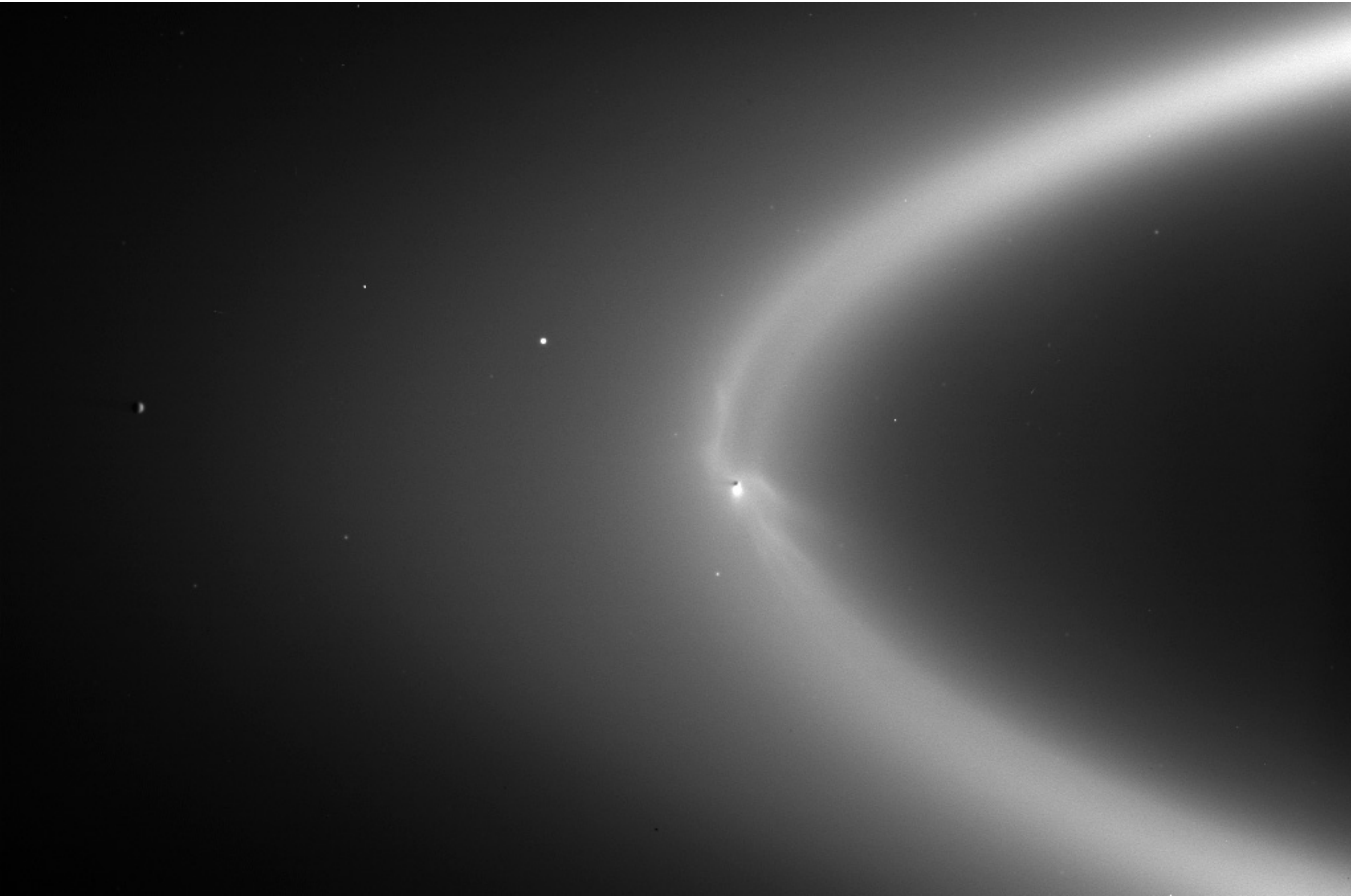


Enceladus probably dominates the plasma and gas sources and composition throughout most of Saturn’s magnetosphere

Saturn’s Magnetosphere

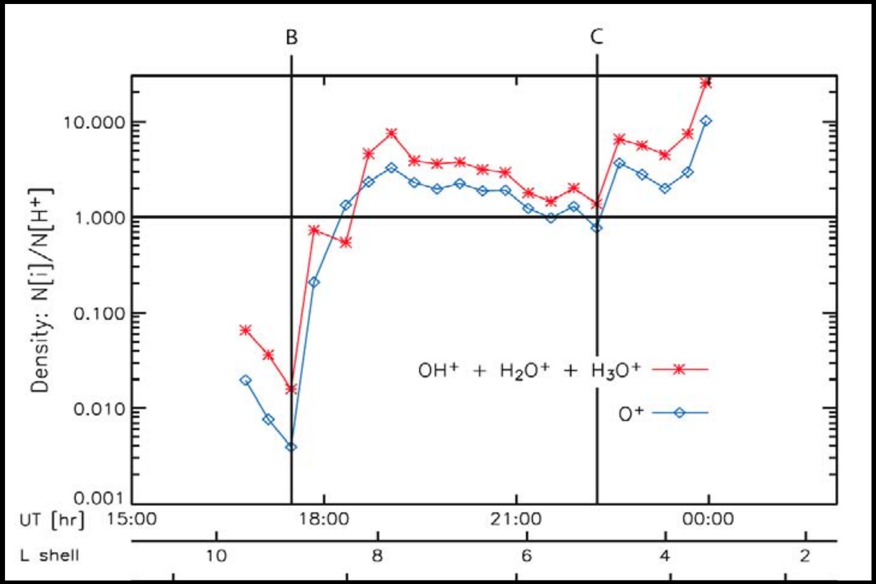


Enceladus creating the E-Ring, and the water products gas cloud



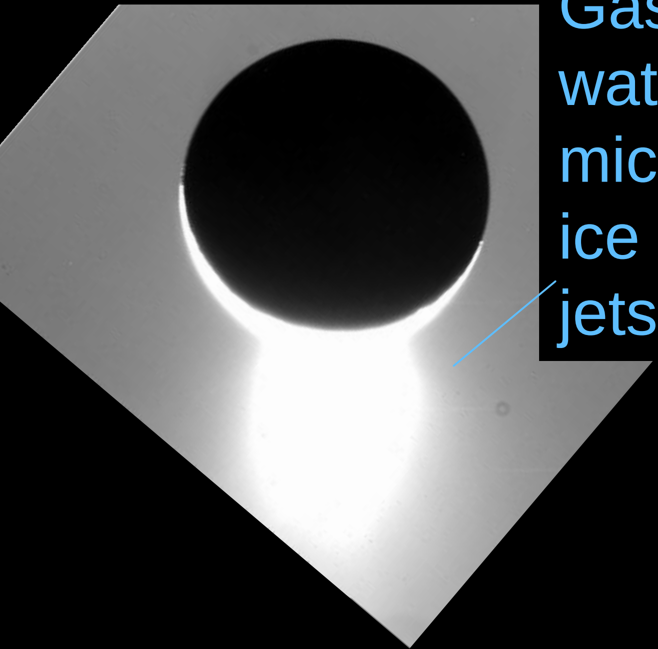
As Io is to Jupiter, Enceladus is the dominant influence on Saturn's magnetosphere.

Water-product plasma

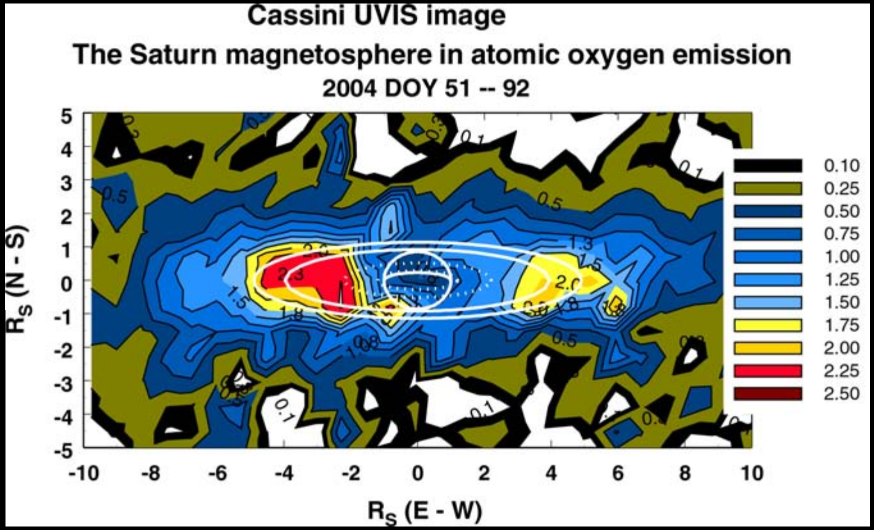


Young et al., Science, Feb. 25, 2005 -- Cassini CAPS

Gas (mostly water) and micron-size ice particle jets

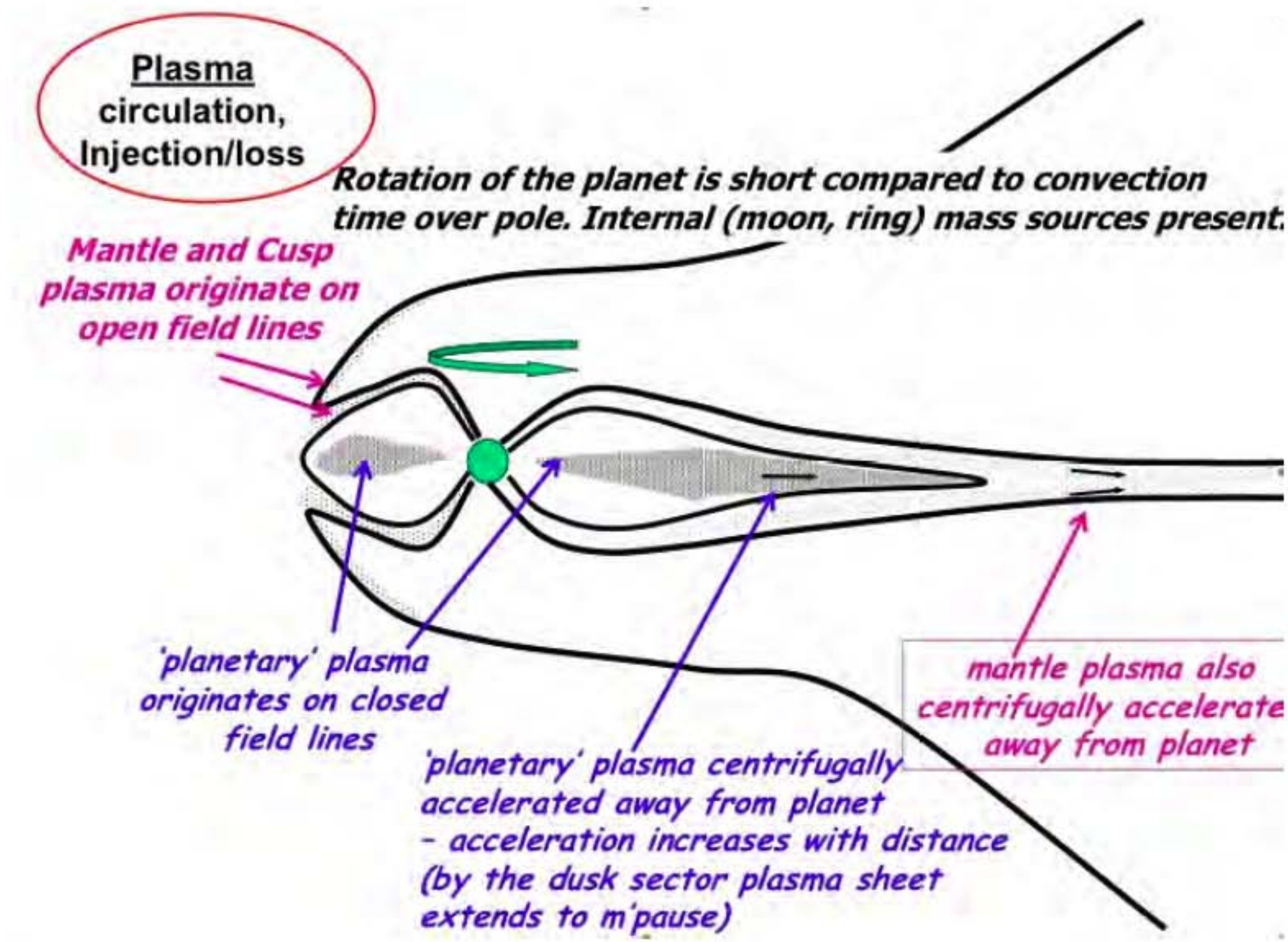


Water-product gas

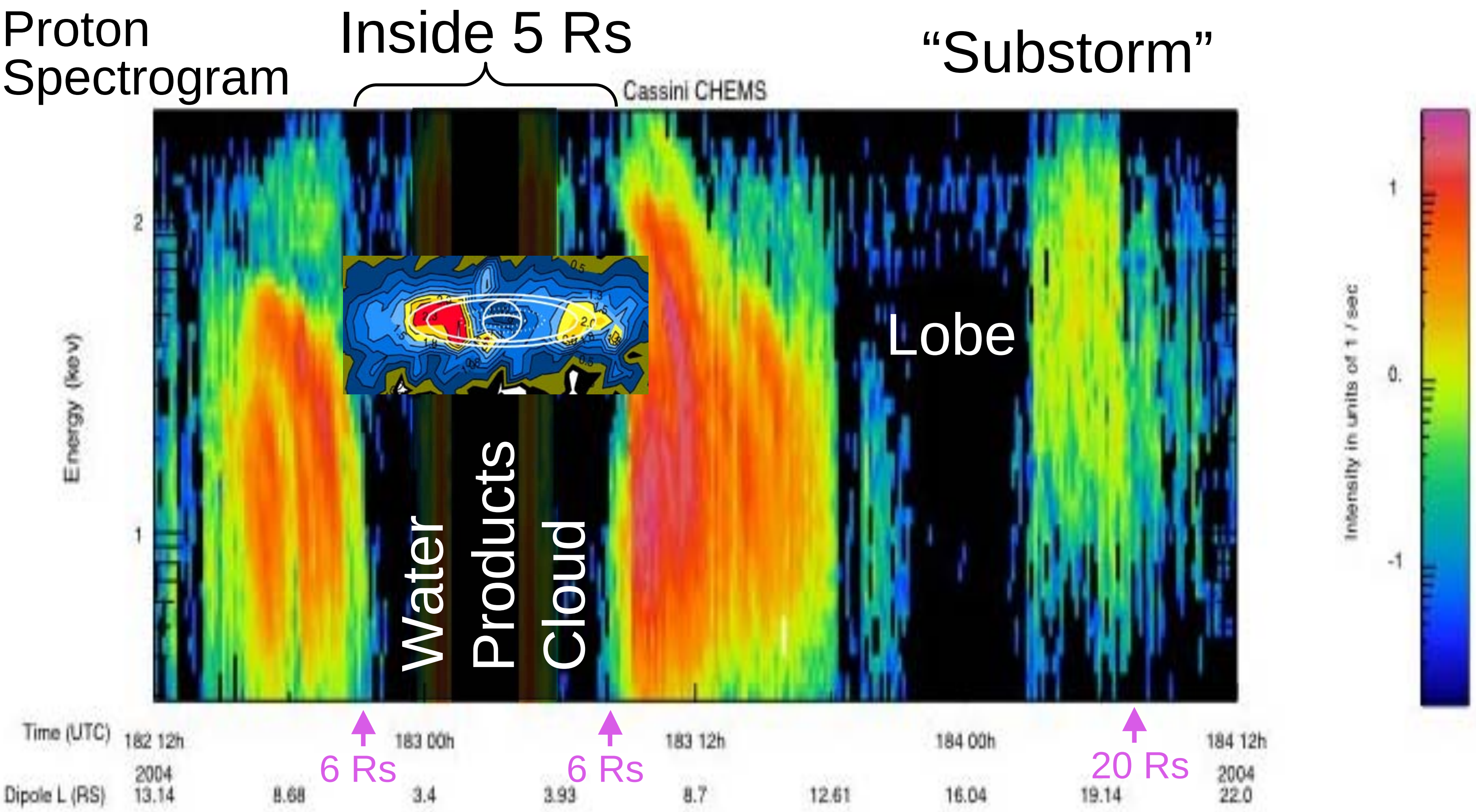


Esposito et al., Science, Feb. 25, 2005 -- Cassini UVIS

Magneto-tail formation & circulation <u>for giant planets</u> where centrifugal forces are important



Proton Spectrogram



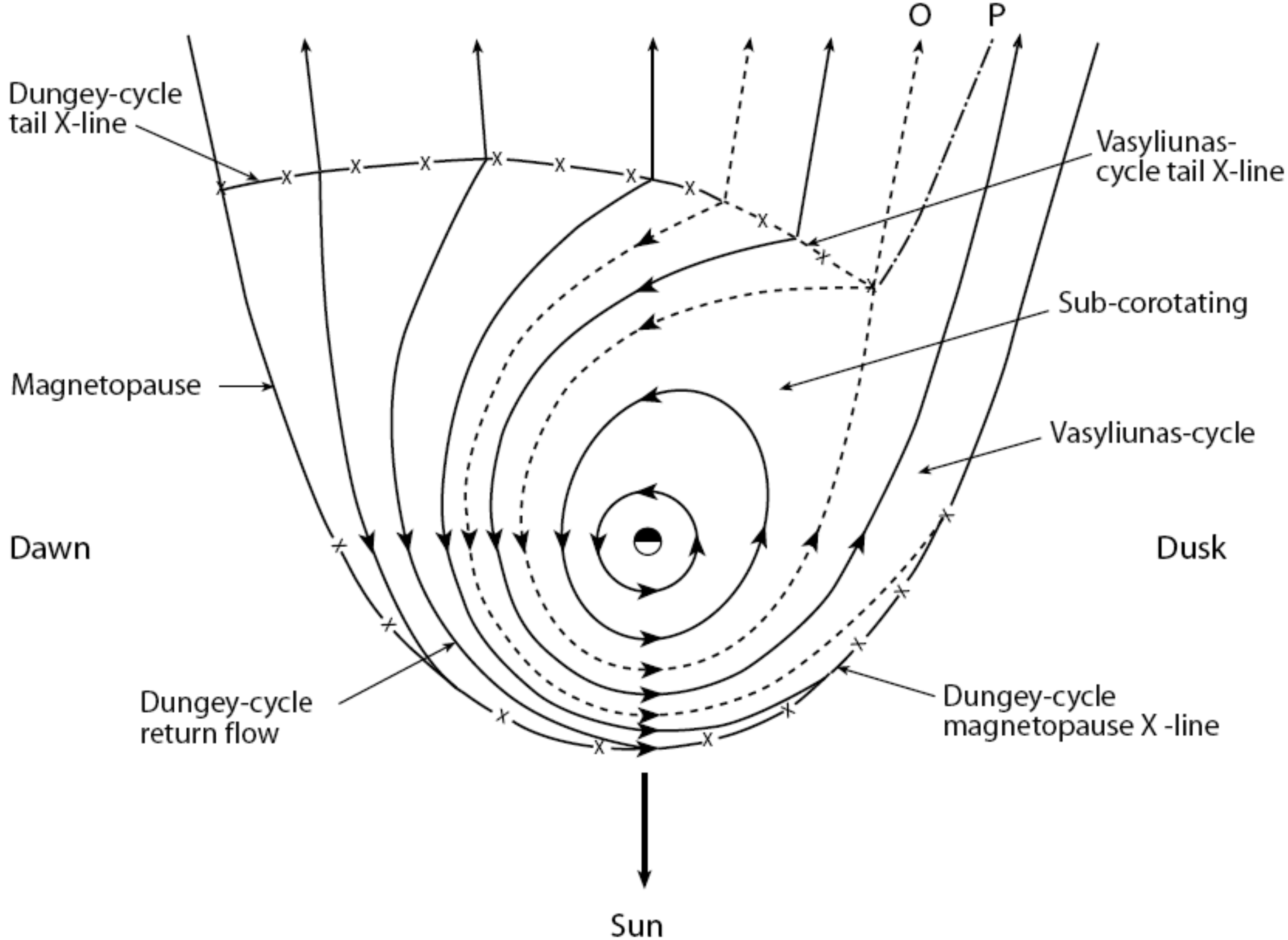


Fig. 2. Sketch of the plasma flow in the equatorial plane of Saturn's magnetosphere, where the direction to the Sun is at the bottom of the diagram, dusk is to the right, and dawn to the left. Arrowed solid lines show plasma streamlines, arrowed short-dashed lines the boundaries between flow regimes (also streamlines), the solid lines joined by Xs the reconnection lines associated with the Dungey cycle, and the dashed lines with Xs the tail reconnection line associated with the Vasyliunas cycle. The two tail reconnection lines are shown as being contiguous, but this is not necessarily the case. The line indicated by the "O" marks the path of the plasmoid O-line in the Vasyliunas-cycle flow (also a streamline), while "P" marks the outer limit of the plasmoid field lines, which eventually asymptotes to the dusk tail magnetopause.

How Long Is the Day on Saturn?
Agustín Sánchez-Lavega
SCIENCE VOL 307 25 FEBRUARY 2005

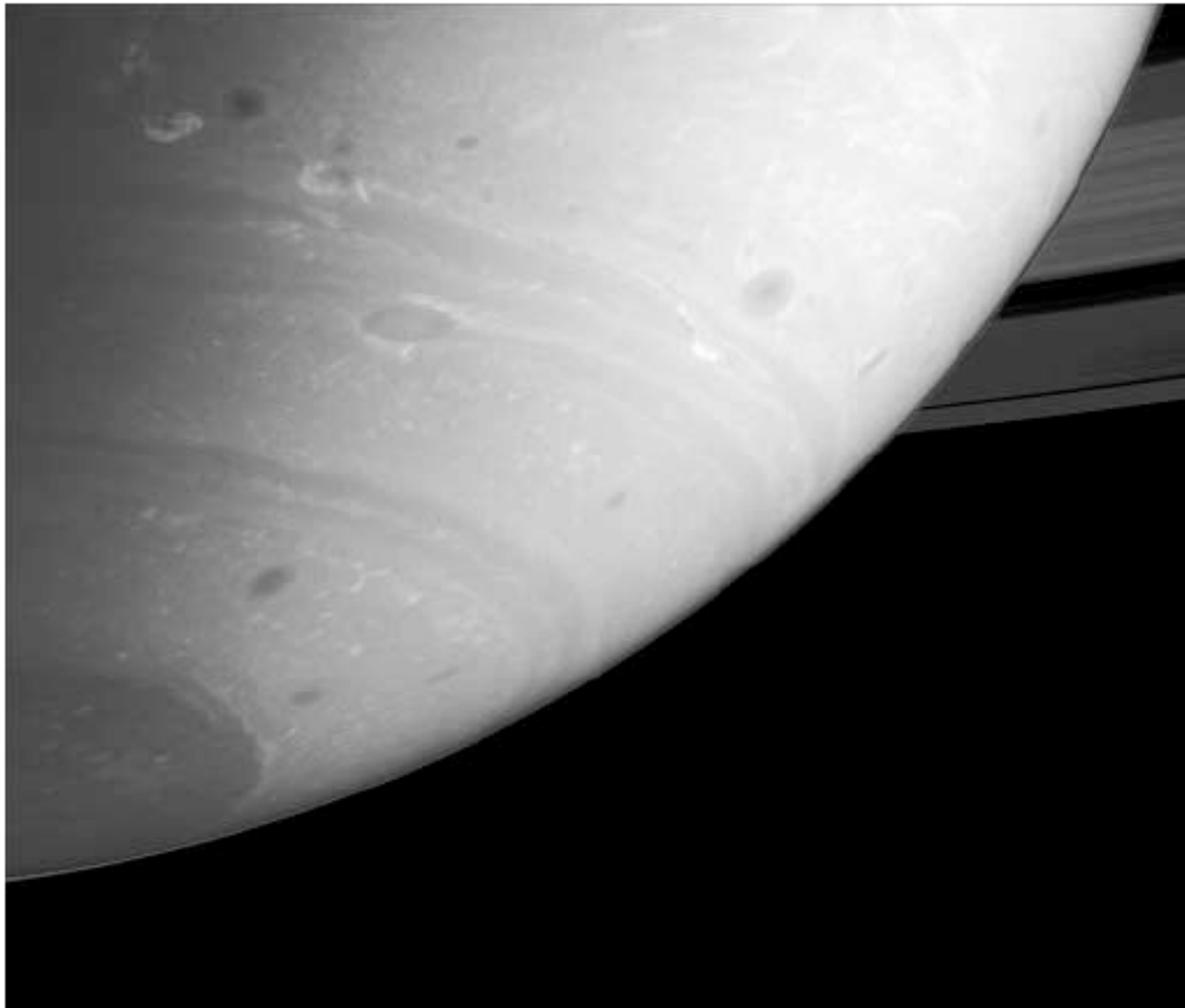


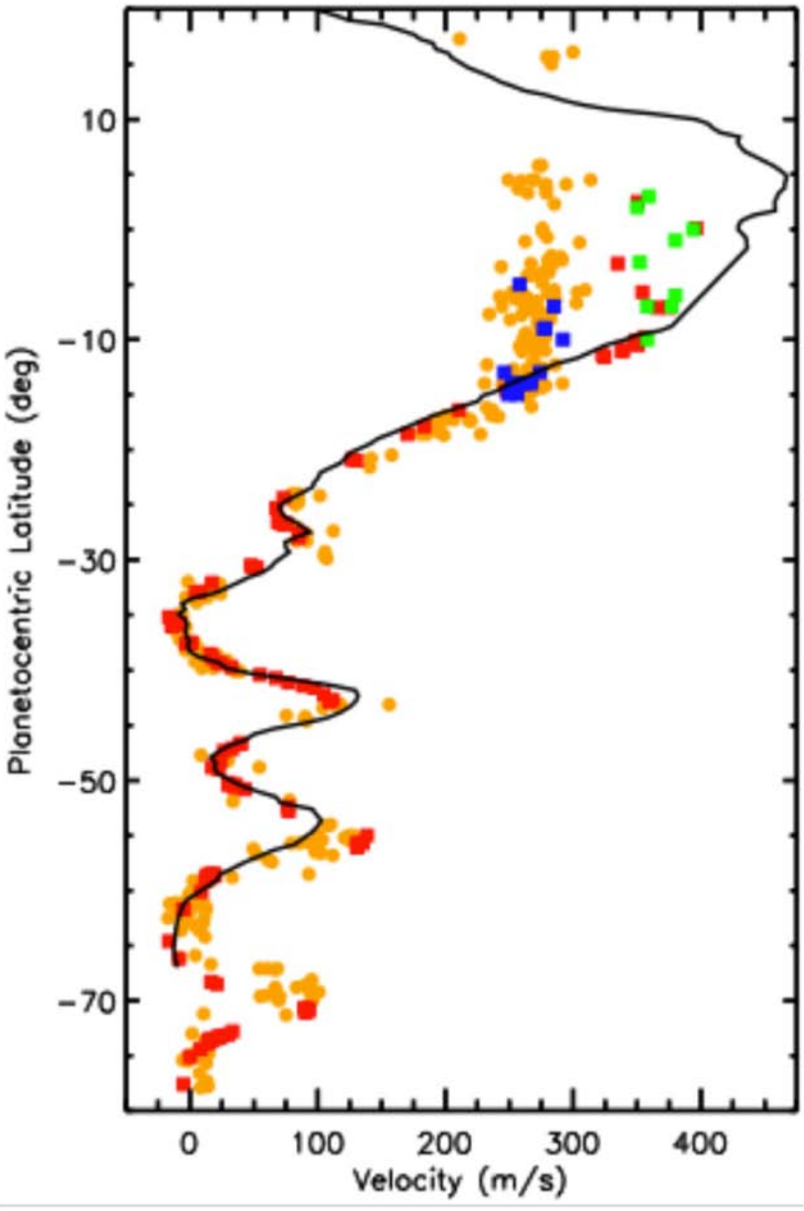
Fig. 2. Saturn's atmosphere. This Cassini image of the planet's southern hemisphere shows dark storms ringed by bright clouds. It was taken with the Cassini narrow-angle camera on 19 September 2004 at a distance of 8.3 million km through a filter sensitive to infrared light at 750 nm. [Image: NASA/ESA]

Line: Voyager

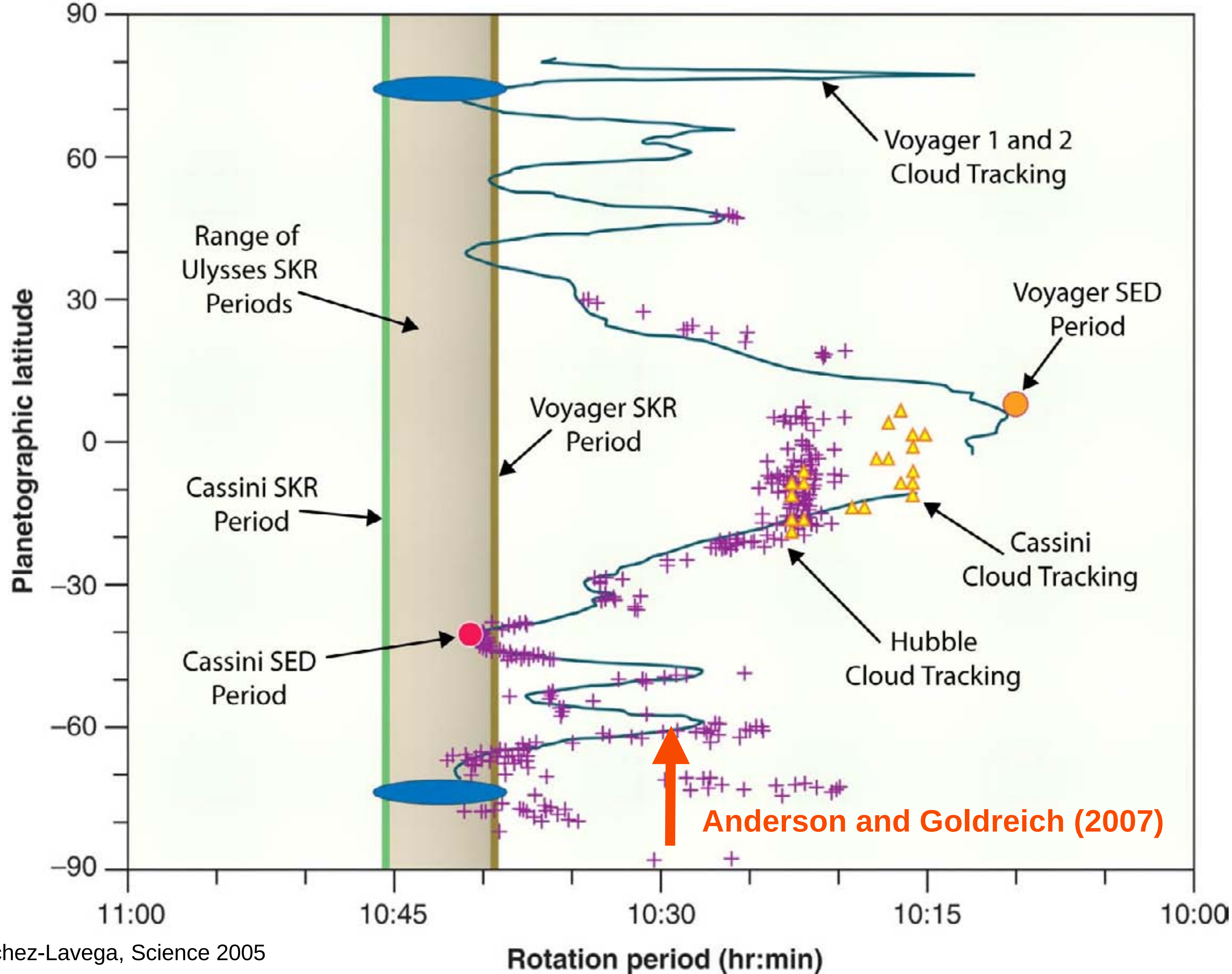
Yellow: HST

Red & Green: ISS Cassini continuum

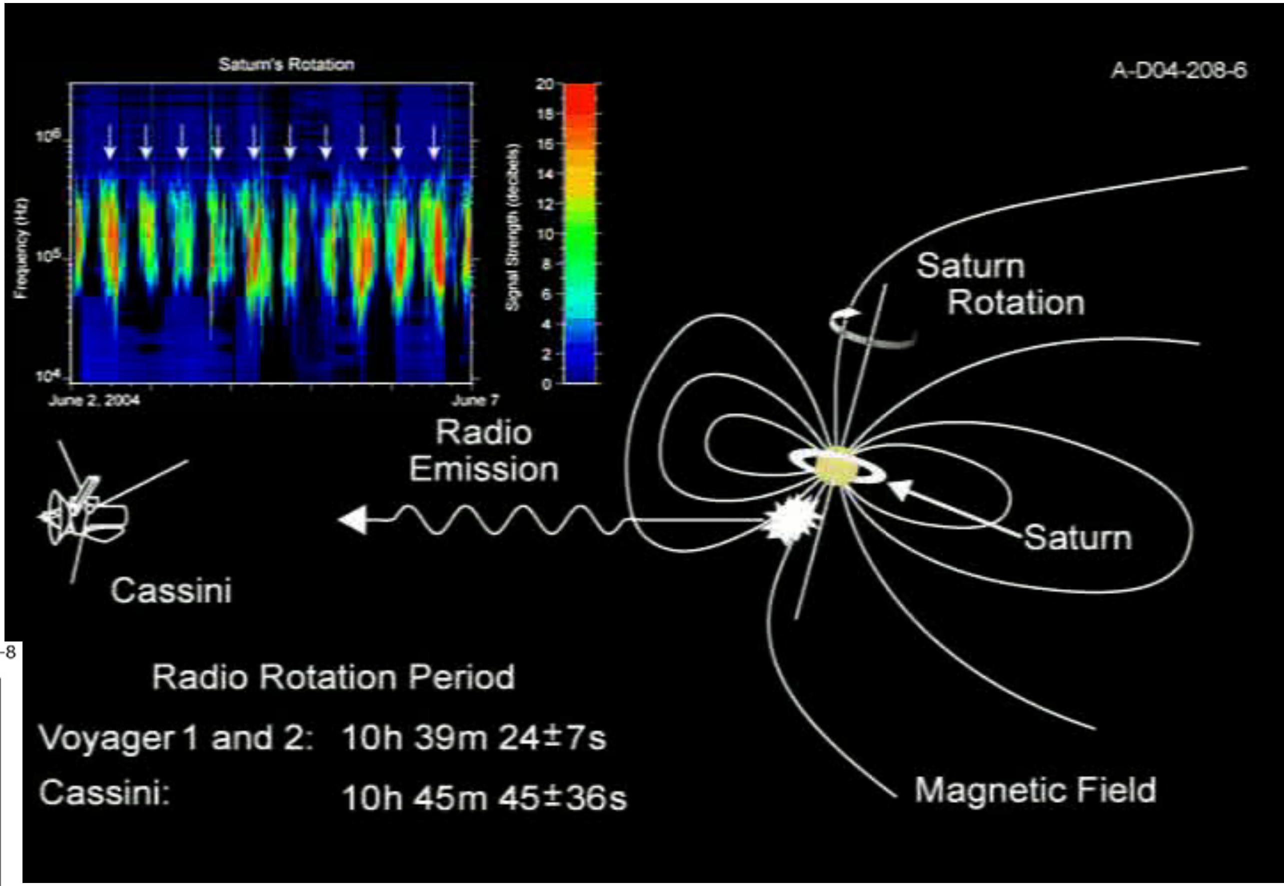
Blue: ISS Cassini methane

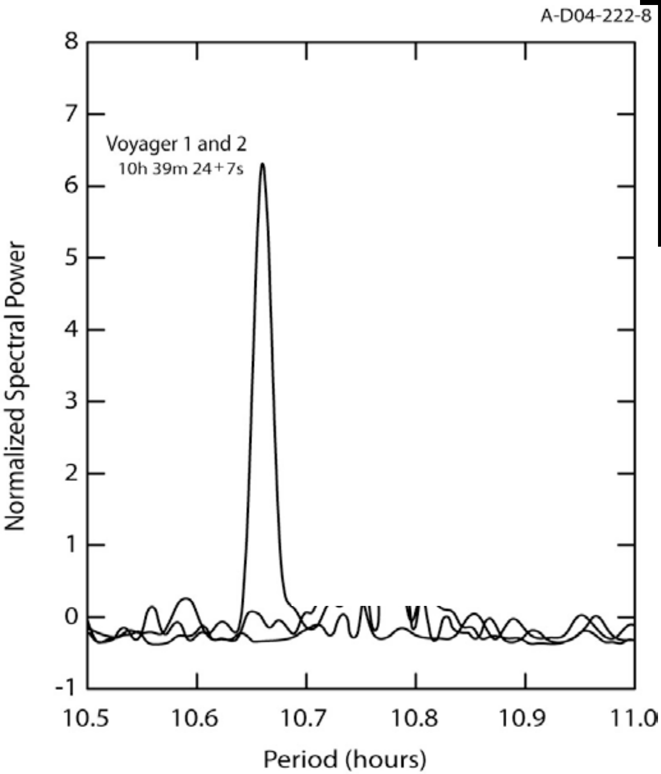


Various Measurements of Saturn's Rotation Period



from Sanchez-Lavega, Science 2005





Cassini has found a different radio period than Voyager. The radio period is usually used to determine the rotation period of gas giant planets. A major mystery for Cassini to solve is the reason for the variation of the radio period. Once this mystery is solved, it will be possible to accurately determine the rotation period of the deep interior of Saturn.

Summary of Saturn Rotation Period Measurements

Period (h:m:s)	Period (h)	Dates of Measurement	Method of Measurement	Reference
10:39:24 ± 7s	10.657 ± 0.002	Jan 1980 – Sep 1981	SKR harmonic analysis (Vgr)	Kaiser & Desch (1981)
10:21:00 ± 48m	10.35 ± 0.80	Nov 1980 – Aug 1981	Electron spectral index peaks (Vgr)	Carbary & Krimigis (1982)
10:39:22	10.656	1980 – 1981	Radio periods (IAU)	Davies et al. (1996)
10:45:45	10.763	Nov 1994 – May 1996	SKR harmonic analysis (Ulysses)	Galapeau & Lecacheux (2000)
10:45:45 ± 36s	10.760 ± 0.010	Apr 2003 – June 2004	SKR harmonic analysis (Cassini)	Gurnett et al. (2005)
10:47:06 ± 40s	10.785 ± 0.011	Jul 2004 – Aug 2005	Lomb periodogram of perturbation Br	Giampieri et al. (2006)
10:47:34 + $A_0+A_1t+A_2t^2+A_3t^3$	10.793 + $A_0+A_1t+A_2t^2+A_3t^3$	Jan 2004 – Aug 2006	SKR phase analysis	Kurth et al. (2007)
10:53 ± 31m	10.88 ± 0.52	Jul 2004 – Jul 1006	Wavelet analysis of 20-300 keV electrons	Carbary et al. (2007A)
10:48:36	10.80	Jan 2005 – Dec 2006	Lomb periodogram of charged particles	Carbary et al. (2007B)
10:51 ± 14m	10.85 ± 0.23	Aug 2004 – Jun 2007	Lomb periodogram of oxygen ENA	Paranicas et al. (2007)

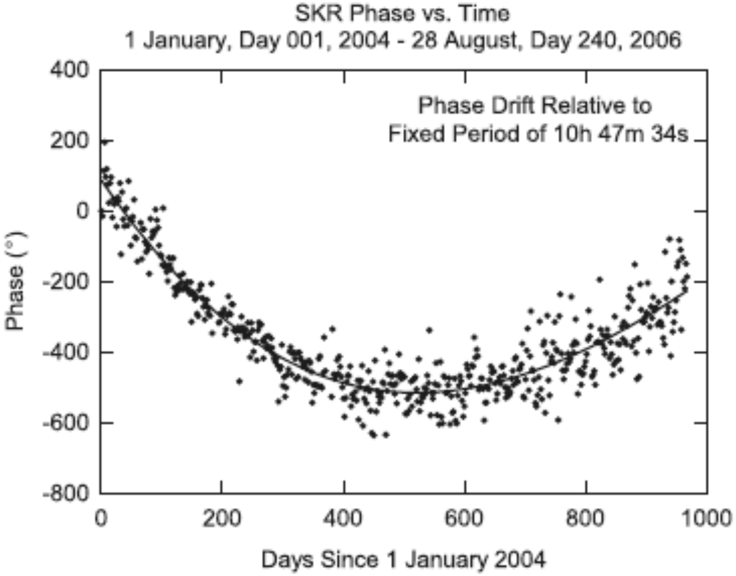
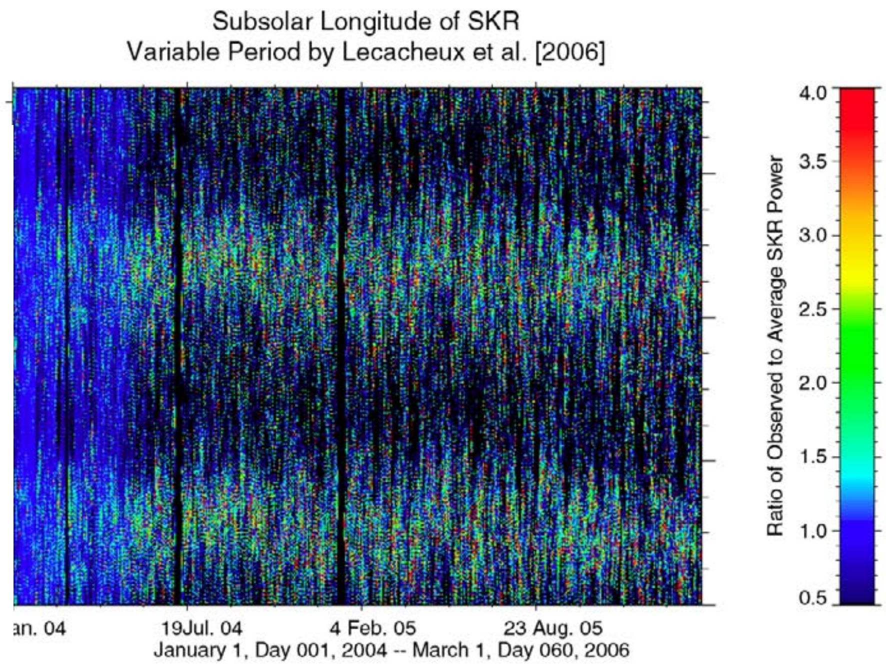


Figure 2. The dots are 4-rotation average determinations of the peak in the SKR intensity using an arbitrary fixed period of 0.4497 days. The phase was determined by fitting the ratio of the SKR intensity and a 1-rotation average intensity with a sine wave and determining the phase of the peak. The line is a third-order polynomial fit to the data using equation (1).

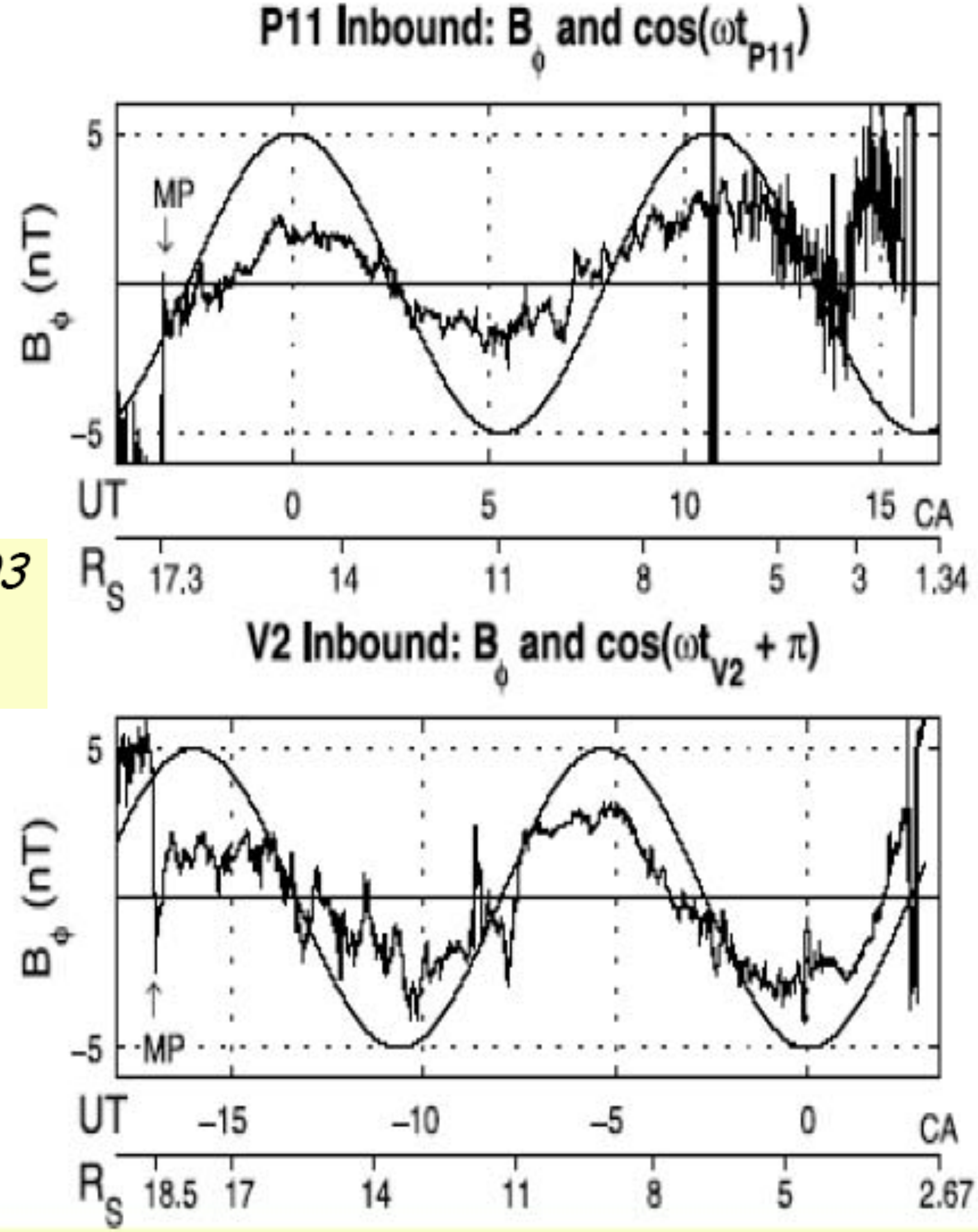


A Saturnian Longitude System Based on a Variable Kilometric Radiation Period

W. S. Kurth , A. Lecacheux , T. F. Averkamp ,
J. B. Groene , and D. A. Gurnett

GEOPHYSICAL RESEARCH LETTERS, VOL. 34, L02201, doi:10.1029/2006GL028336, 2007

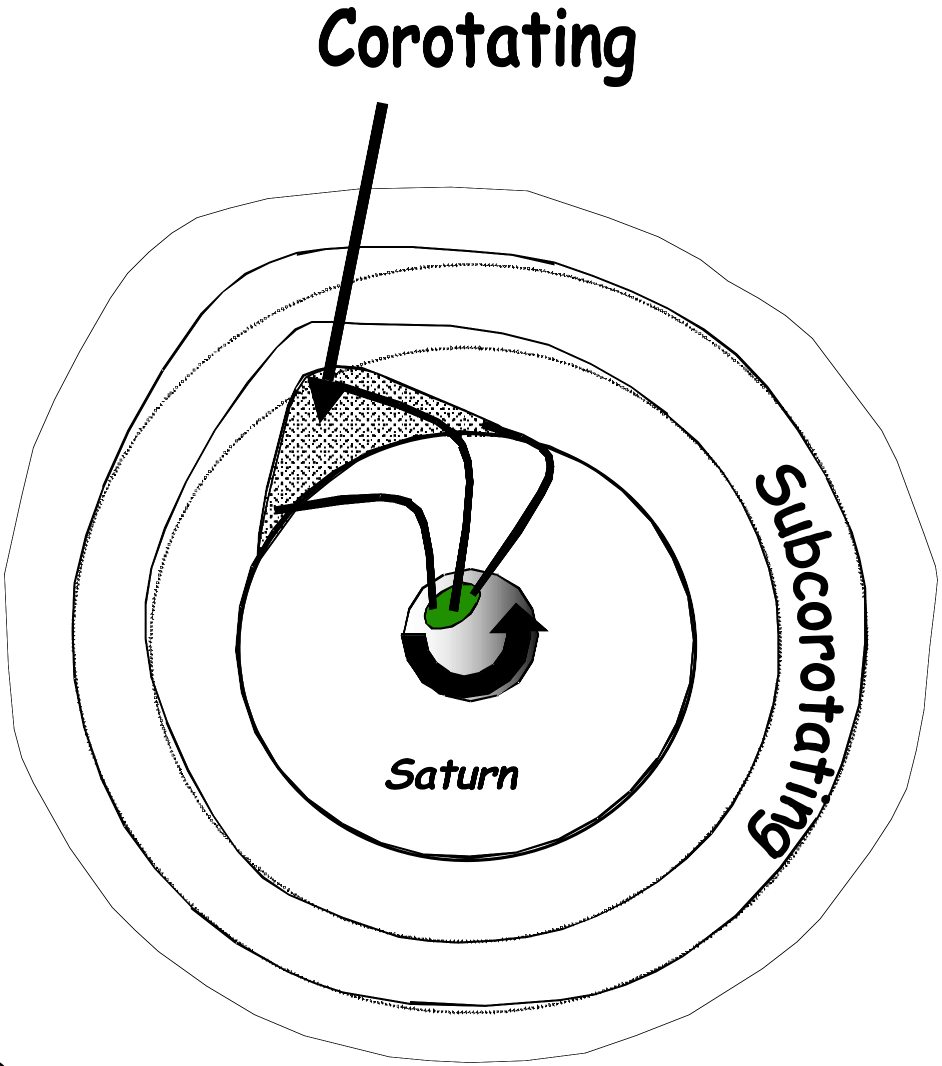
How well does the coordinate system based on the SKR modulation organize the outer magnetosphere?



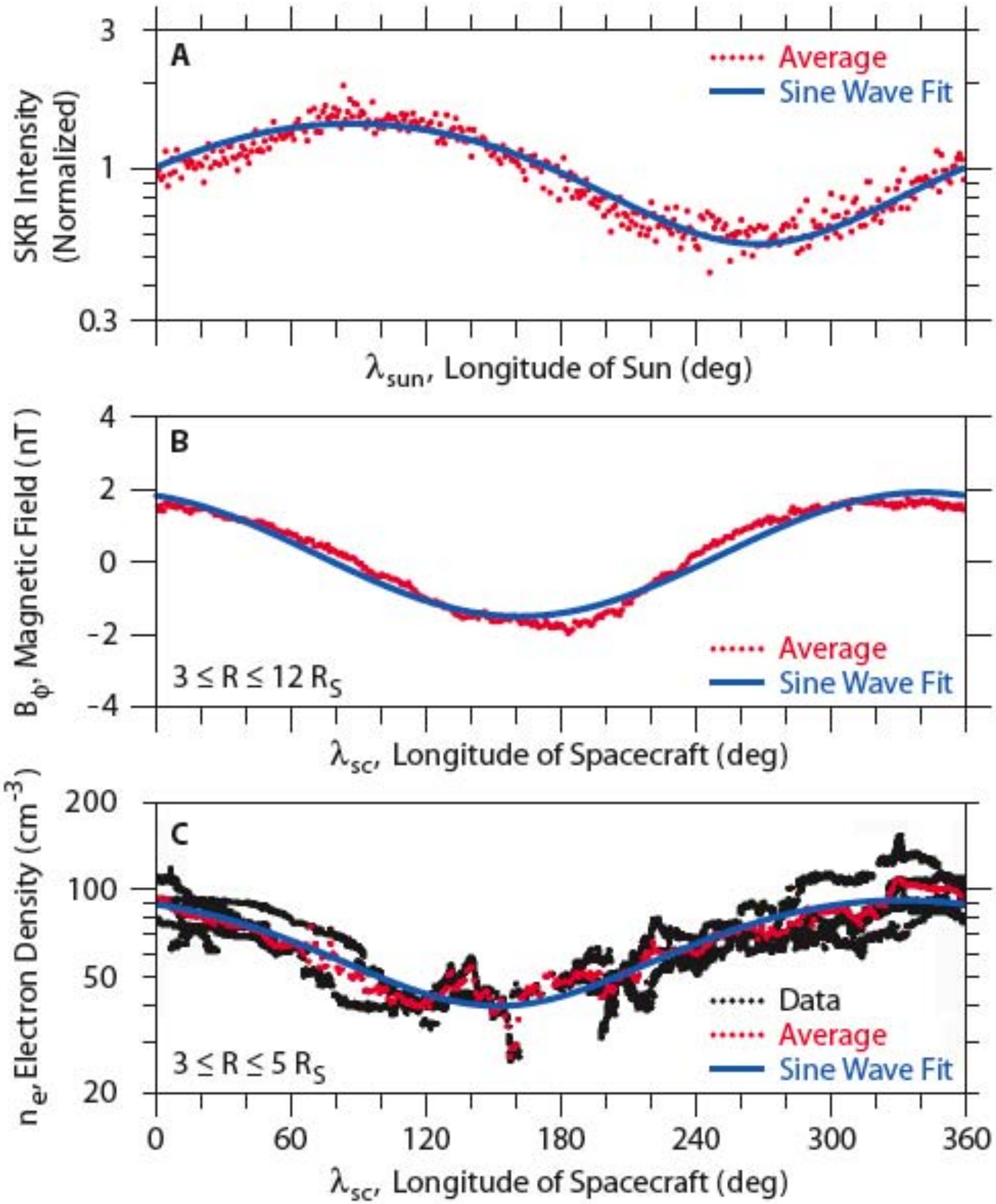
Espinosa et al. 2001/2003

Led to "Camshaft" model

Camshaft

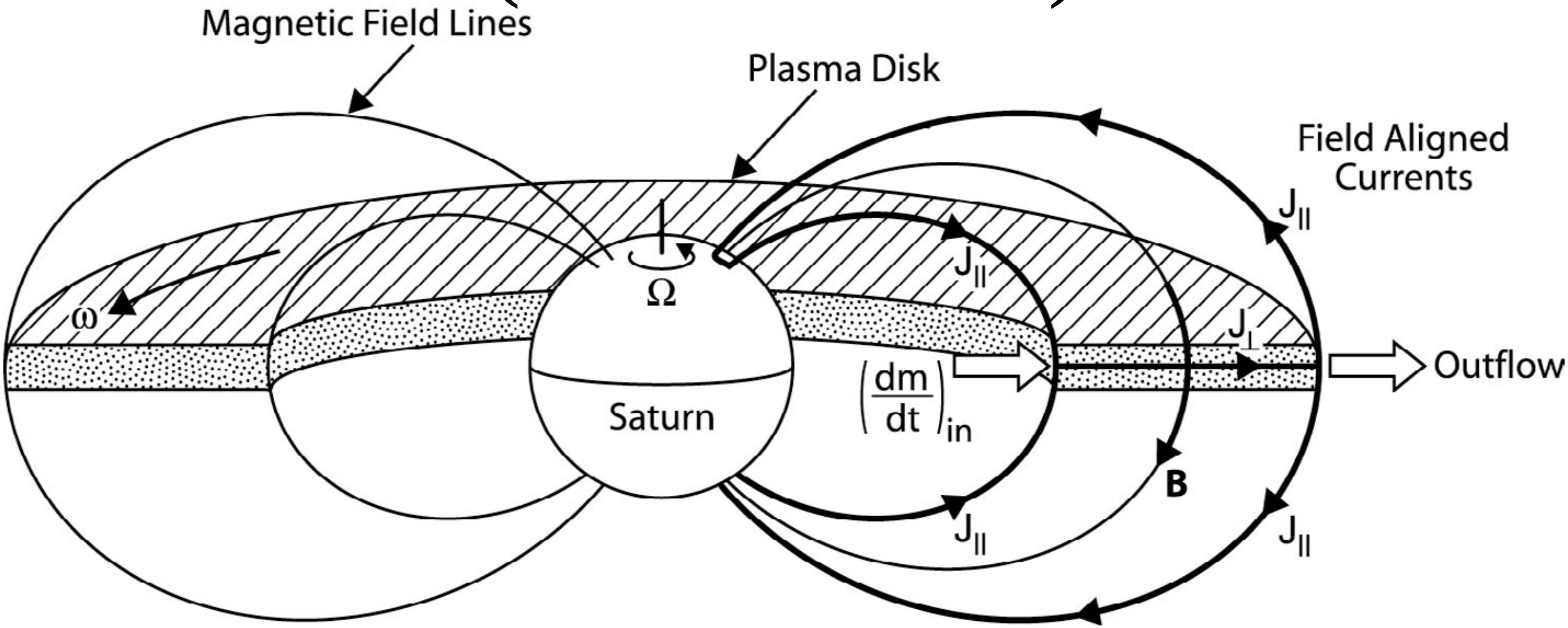


(D. Southwood)

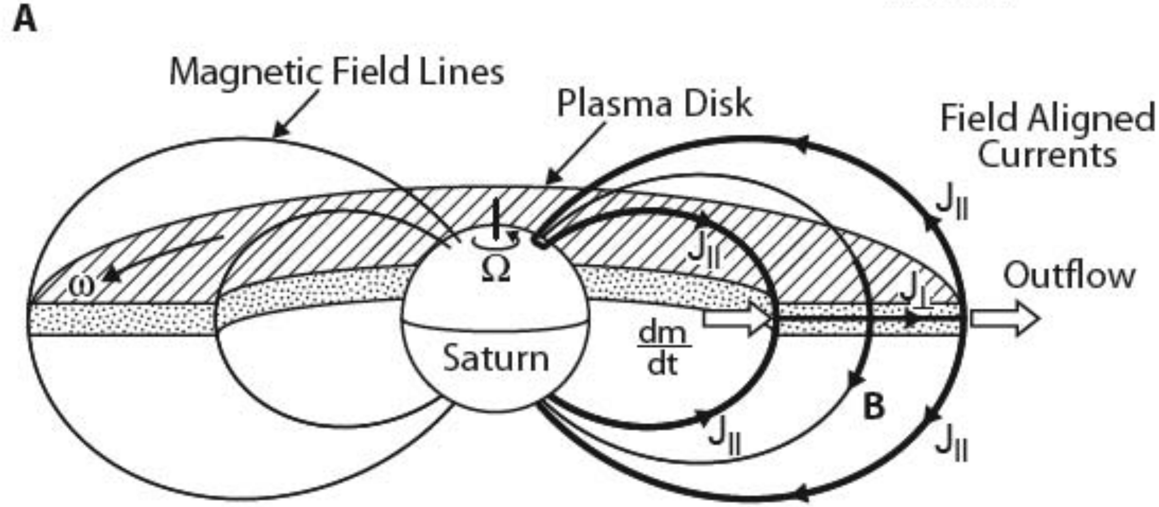


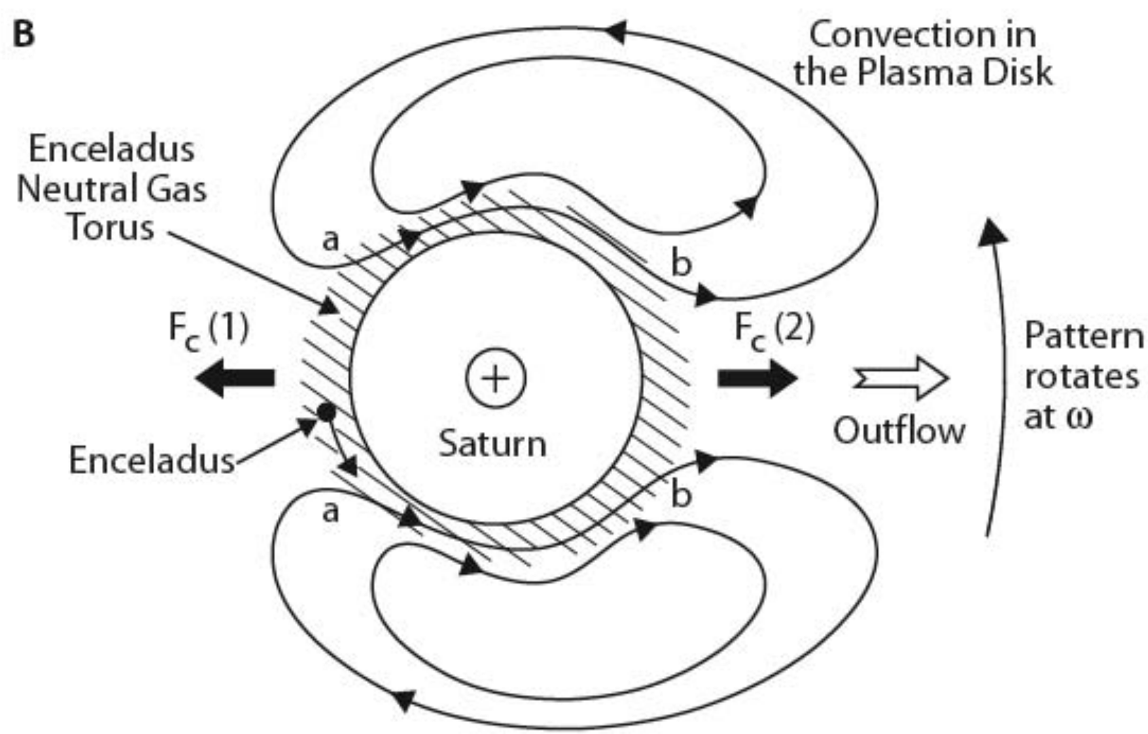
A
Average
Sine Wave Fit
SKR Intensity (Normalized)
3
1
0.3
λ_{sun}, Longitude of Sun (deg)
B
B_ϕ, Magnetic Field (nT)
4
2
0
-2
-4
$3 \leq R \leq 12\ R_S$
Average
Sine Wave Fit
λ_{sc}, Longitude of Spacecraft (deg)
C
n_e, Electron Density (cm^{-3})
200
100
50
20
$3 \leq R \leq 5\ R_S$
Data
Average
Sine Wave Fit
0
60
120
180
240
300
360
λ_{sc}, Longitude of Spacecraft (deg)

The Rotational Slippage Model (Gurnett et al.)



- Hypothesis: the SKR rotation period is determined by a variable slippage of the magnetosphere relative to Saturn's upper atmosphere.
- Possible reason: mass loading from the Enceladus gas torus.


A
Magnetic Field Lines
Plasma Disk
Field Aligned Currents
$J_{\parallel}$
$J_{\parallel}$
$J_{\perp}$
Outflow
ω
Ω
Saturn
$\frac{dm}{dt}$
B
$J_{\parallel}$
$J_{\parallel}$


B
Convection in the Plasma Disk
Enceladus Neutral Gas Torus
a
b
F_c (1)
F_c (2)
Pattern rotates at ω
Saturn
Outflow
Enceladus
a
b

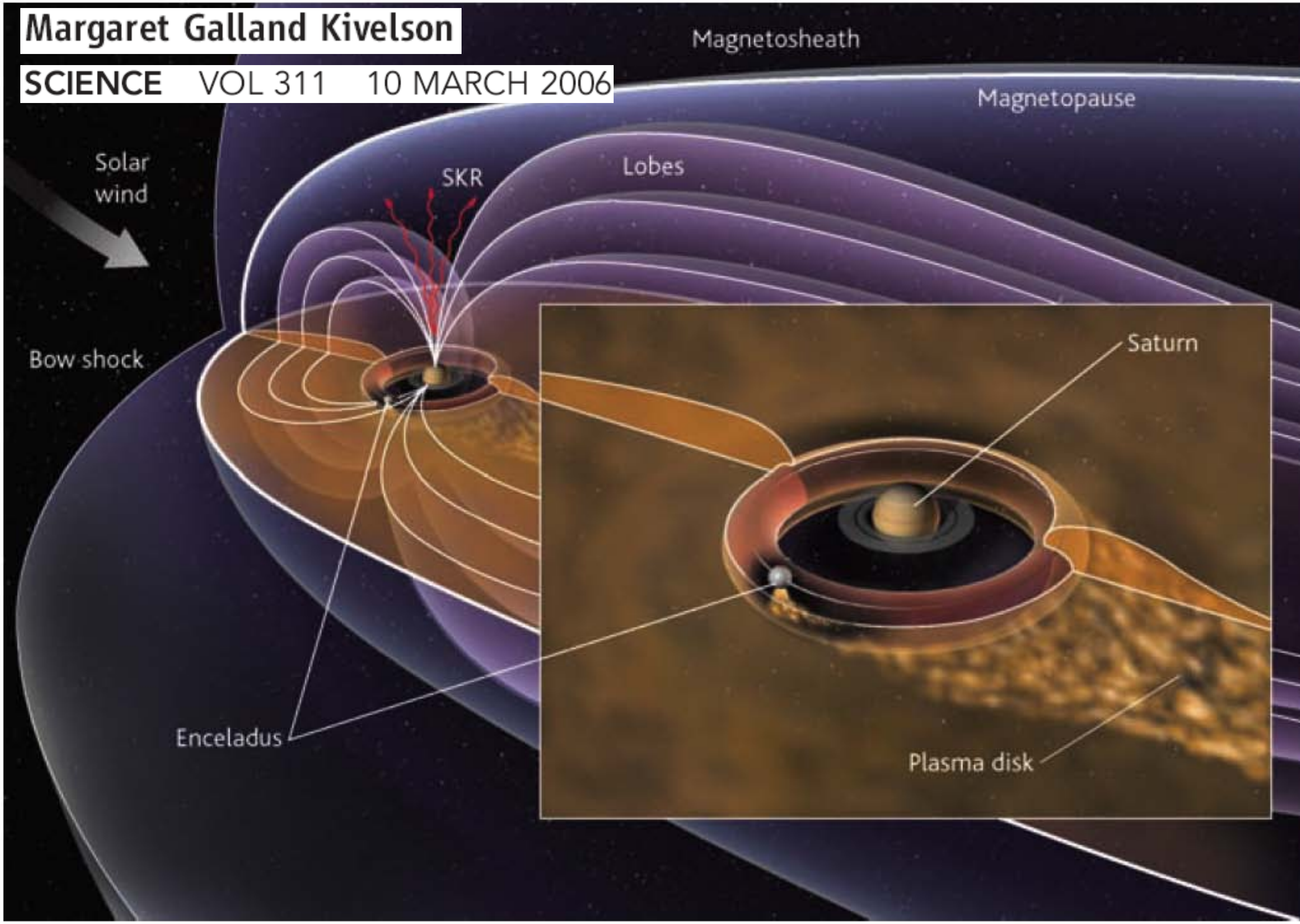
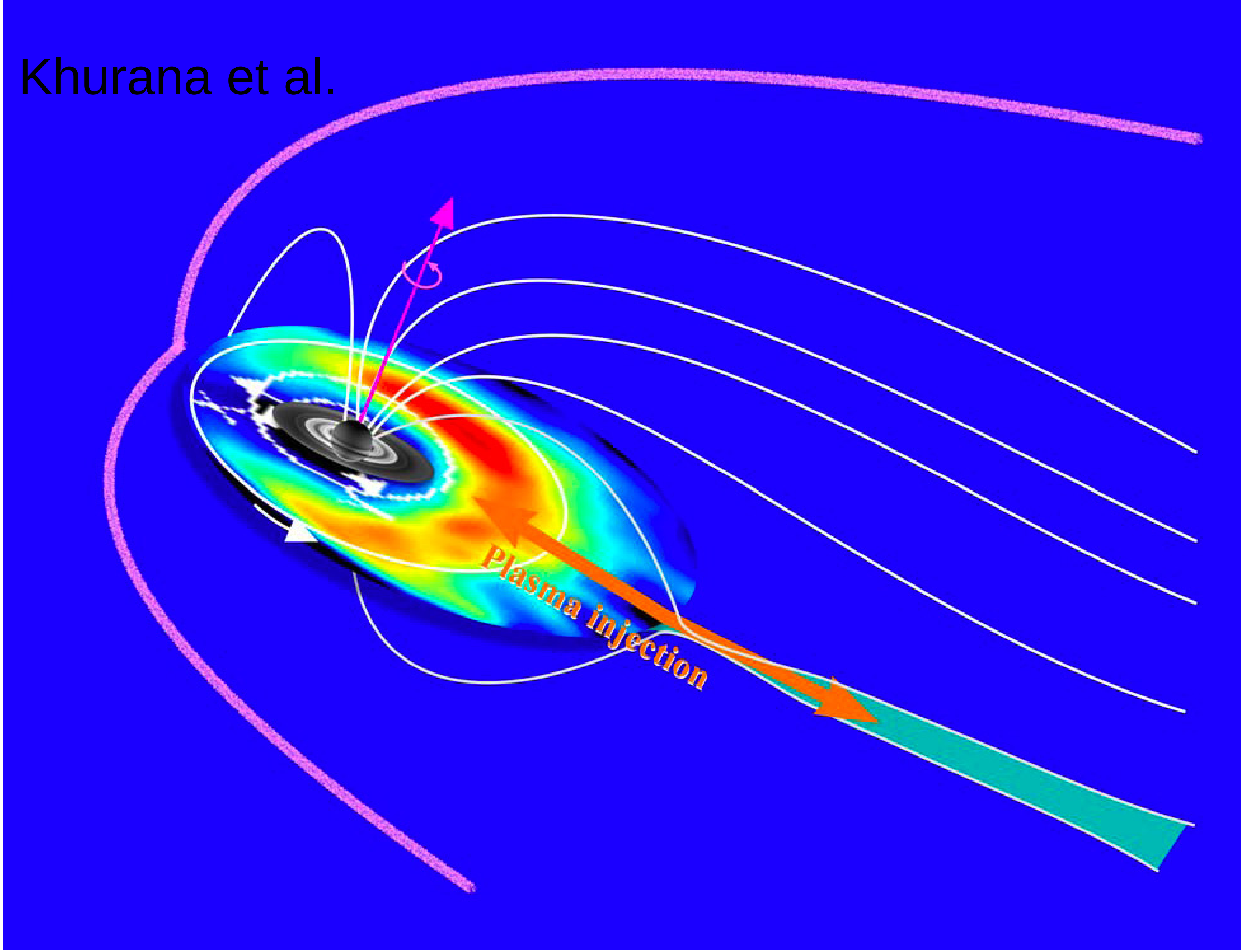


Fig. 1. Schematic of Saturn's magnetosphere showing the plume at Enceladus as the source of plasma and outflowing plasma on the night side in a region linked magnetically to a region of lower-than-average ionospheric conductance. Red arrows indicate kilometric radiation emitted from Saturn's polar region (SKR). Diagram is not to scale.



Synchronous plasma injection process. When the prime sector with an enhanced ring current and energetic particle distribution faces the magnetotail, the field lines in the magnetotail become extremely stretched and prone to reconnection and reconfiguration. The resulting particle injections and bursty bulk flows would reinforce the existing particle asymmetries.

Energetic particles in-situ

1. Energetic particles are those non-thermal (non-plasma) particles in Saturn's magnetotail with energies greater than ~10 keV for electrons and greater than ~5 keV for ions.

2. Saturn's magnetotail begins at a radial distance of ~20 R_S (the orbit of Titan) and extends far into the anti-Sun direction. Cassini did not travel much beyond ~60 R_S down the tail.

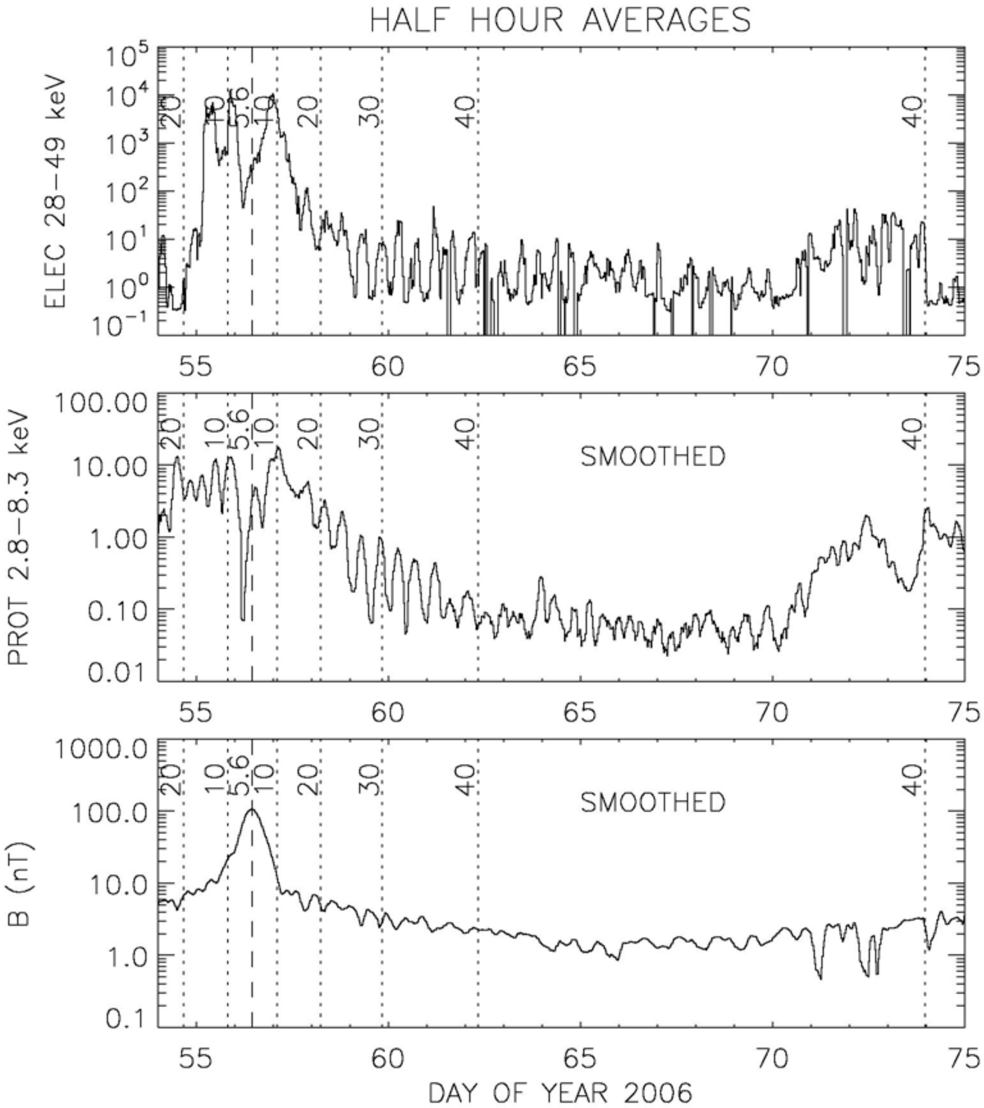
This part of the talk will cover:

- The "typical" behavior of energetic particles in the tail current sheet;
- The high latitude extension of those populations;
- The appearance of low altitude-accelerated ion (and electron) beams in the tail;
- Reconnection accelerated energetic particle jetting and acceleration.

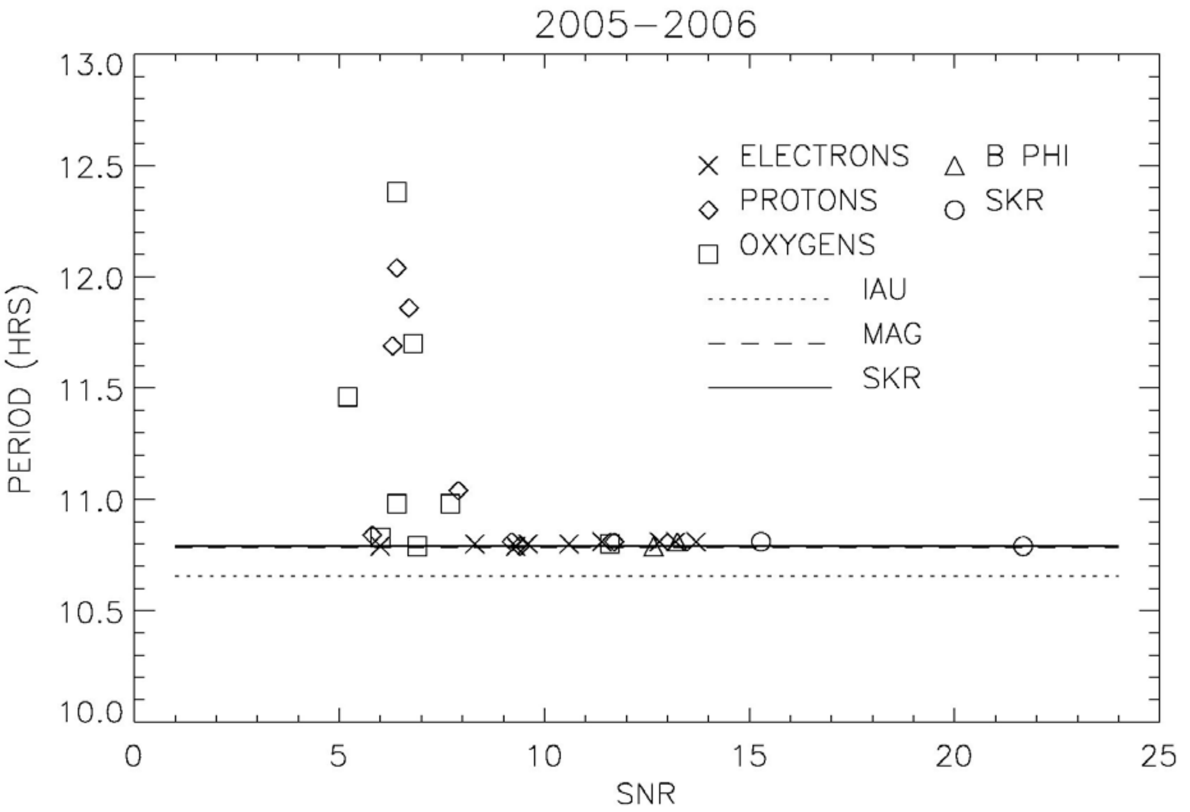
Time Profiles – 1

This figure shows energetic particle rate and magnetic field profiles as a function of time for one low-latitude pass through the magnetotail. For most of this pass, the spacecraft was close to Z=0 (equatorial plane).

Vertical dotted lines indicate radial distances.

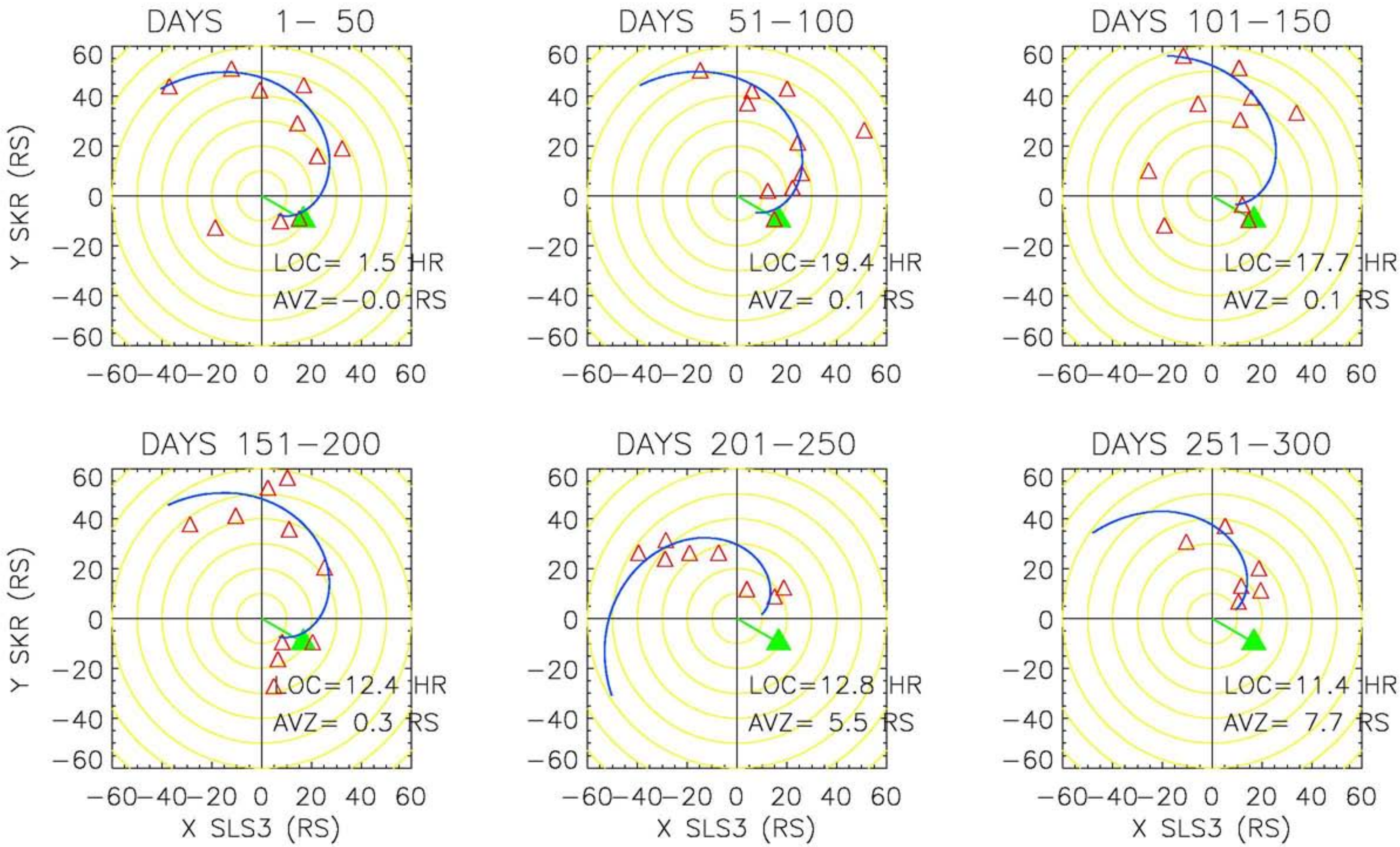


Summary of Magnetotail Periodicities



This summarizes all the Lomb periodicities for 2005-2006. The periodicity begins to break down when the signal to noise ratio degrades as a result of poor statistics. Otherwise, the mean period is 10.80 hours, which is about the same as the SKR “base” period of 10.793 hours.

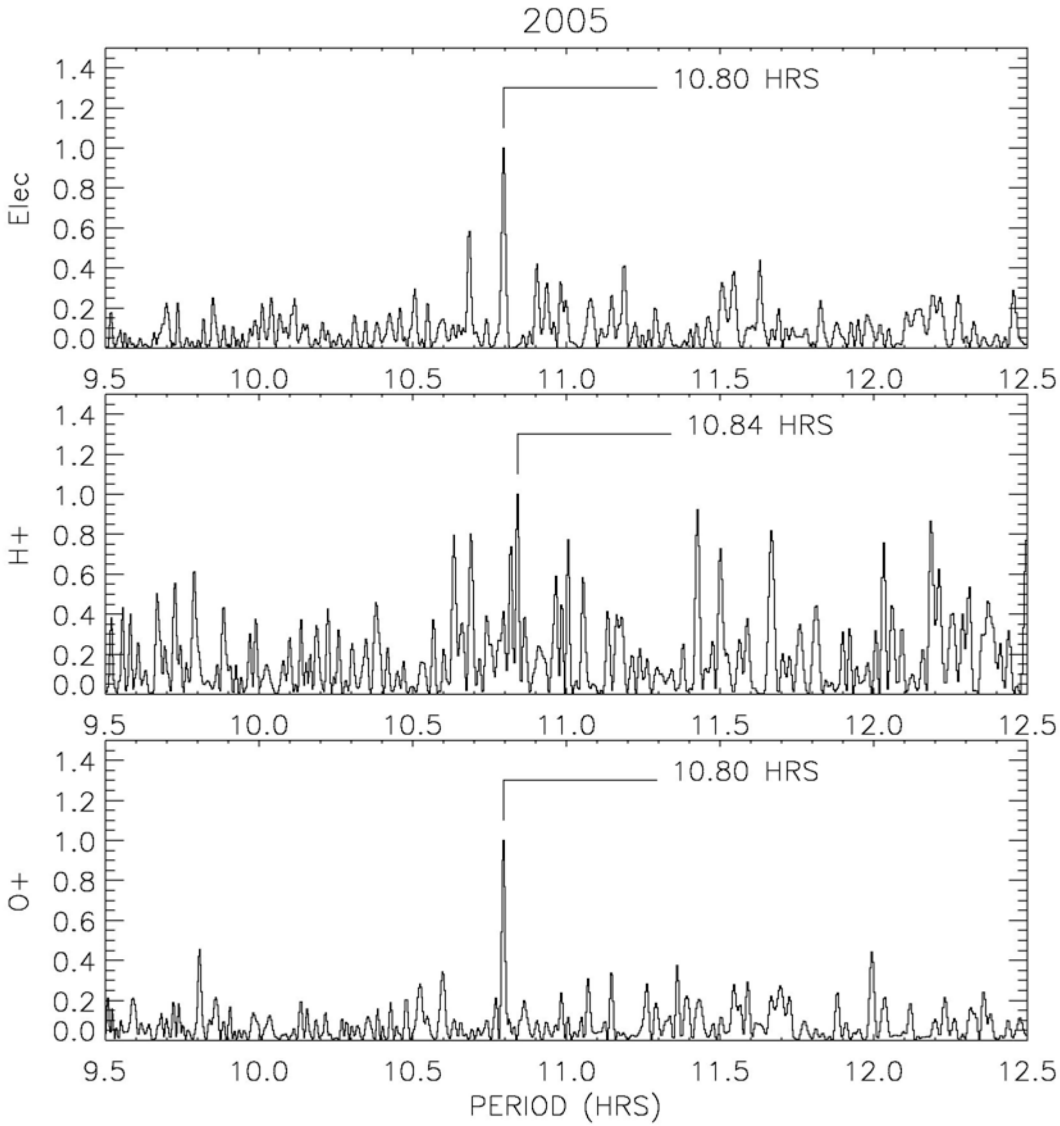
A Spiral Pattern in SLS-3 Longitude (2006 Data)



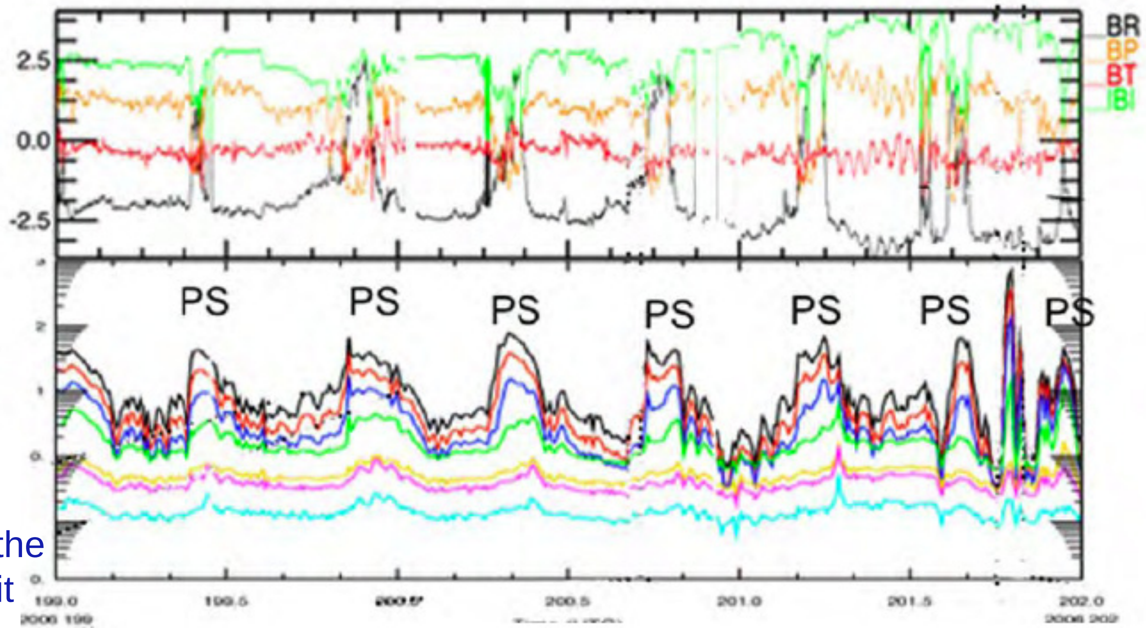
Since the charged particle periodicities are so regular, suppose we organize them into longitude bins, using the new (fifth-order polynomial) SLS-3 (SKR) system? Spiral patterns emerge (see blue line fits). Green arrow indicates “outflow” identified by Gurnett et al. (2007). Cassini was a low latitudes during the first four periods, and at high latitudes during the last two. The “base” of the spirals consistently appears near the green arrow. 28-49 keV electron data were used.

Lomb Periods of Magnetotail

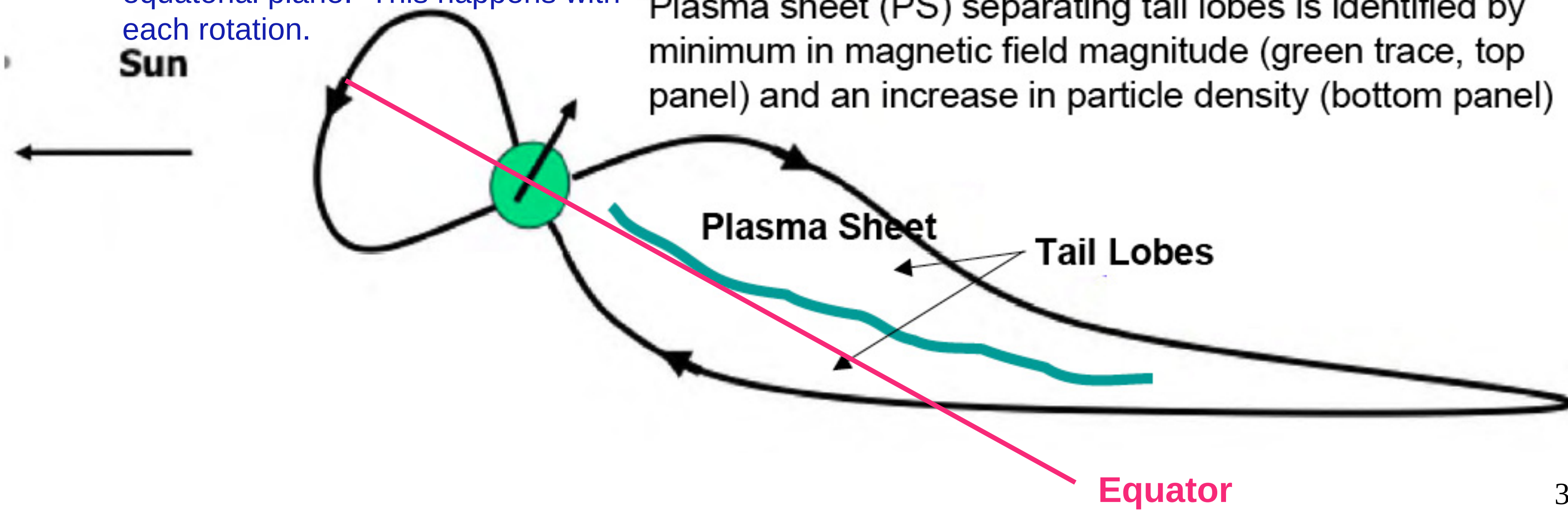
A Lomb periodogram analysis of all the charged particle data in the magnetotail ($r > 20\ R_S$) reveals very strong and regular periodicities. All the charged particles, regardless of species or energy, have basically the same period. Usually, the signal to background ratio is very strong (above ~8). There are especially strong periodicities in the energetic oxygens.



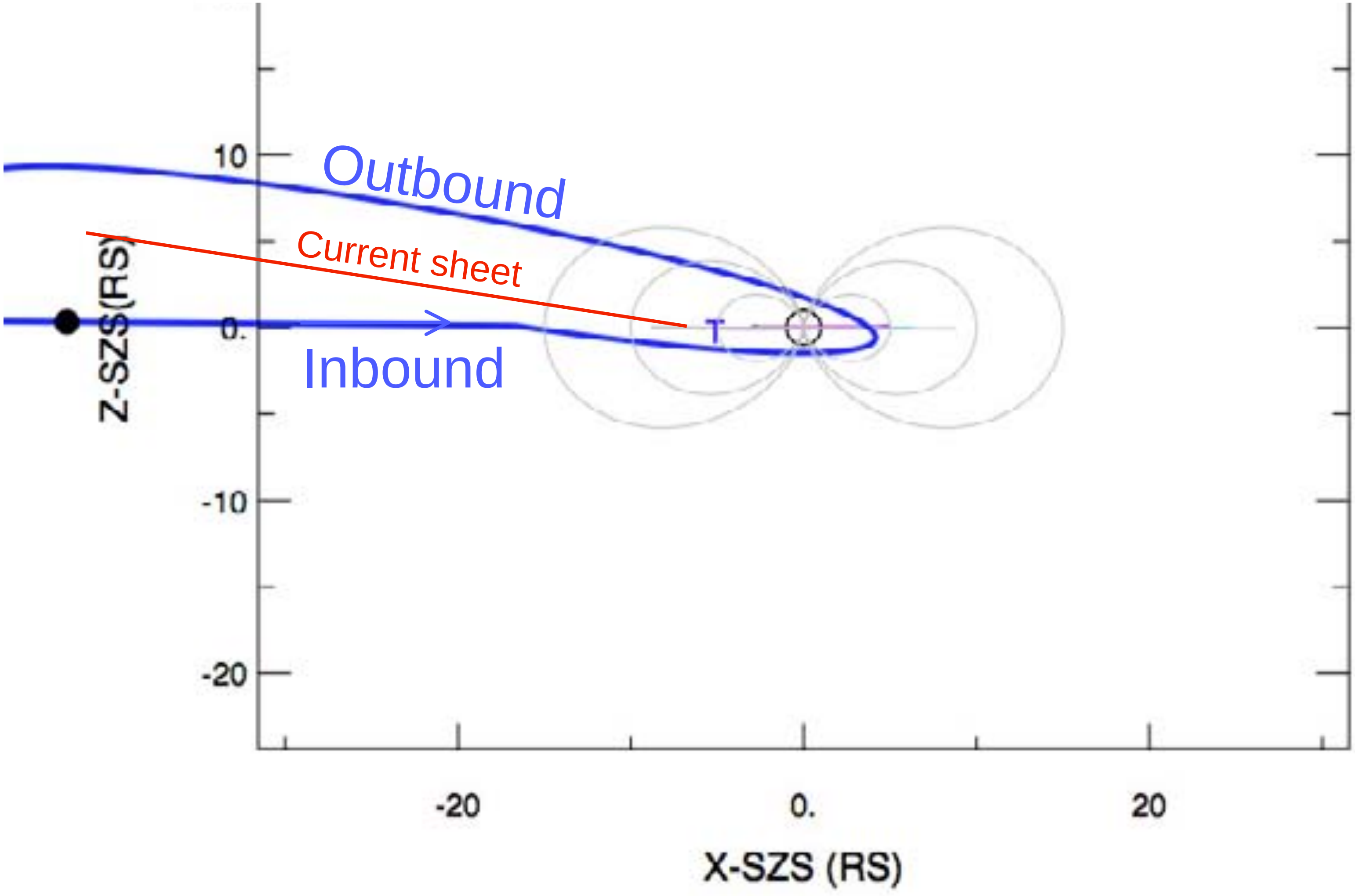
- Though the rotational axis and the dipole axis are aligned, Saturn's rotational axis is tiled with respect to the ecliptic.
- Figure shows an example of MAG and MIMI data from a recent tail pass
- Cassini was in the equatorial plane during this night-side orbit leg; since the plasma sheet bends away from the plane, Cassini would not encounter it unless it was displaced toward the equatorial plane. This happens with each rotation.

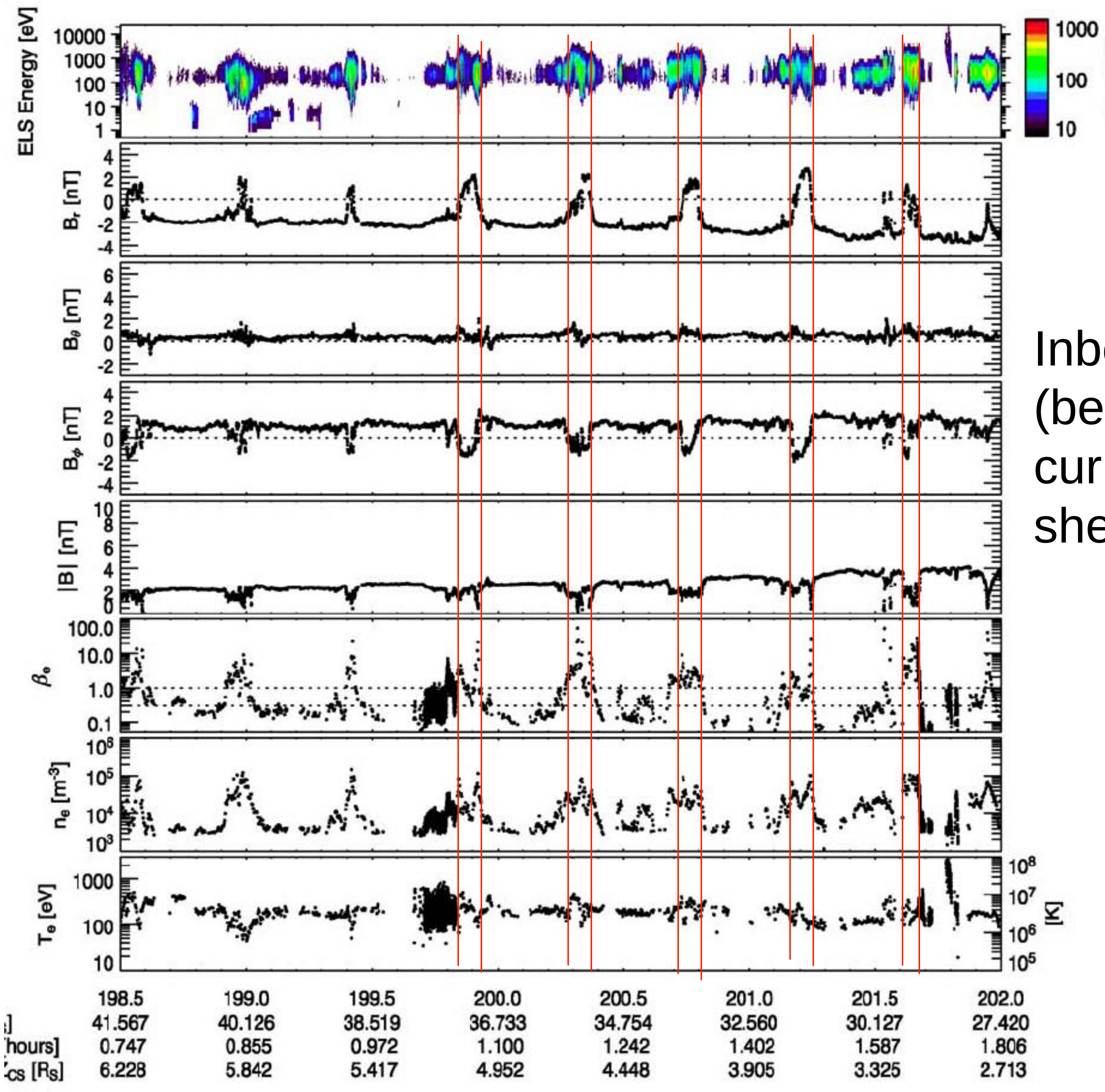


Plasma sheet (PS) separating tail lobes is identified by minimum in magnetic field magnitude (green trace, top panel) and an increase in particle density (bottom panel)



Rev 26: Inbound below nominal current sheet, outbound above nominal current sheet



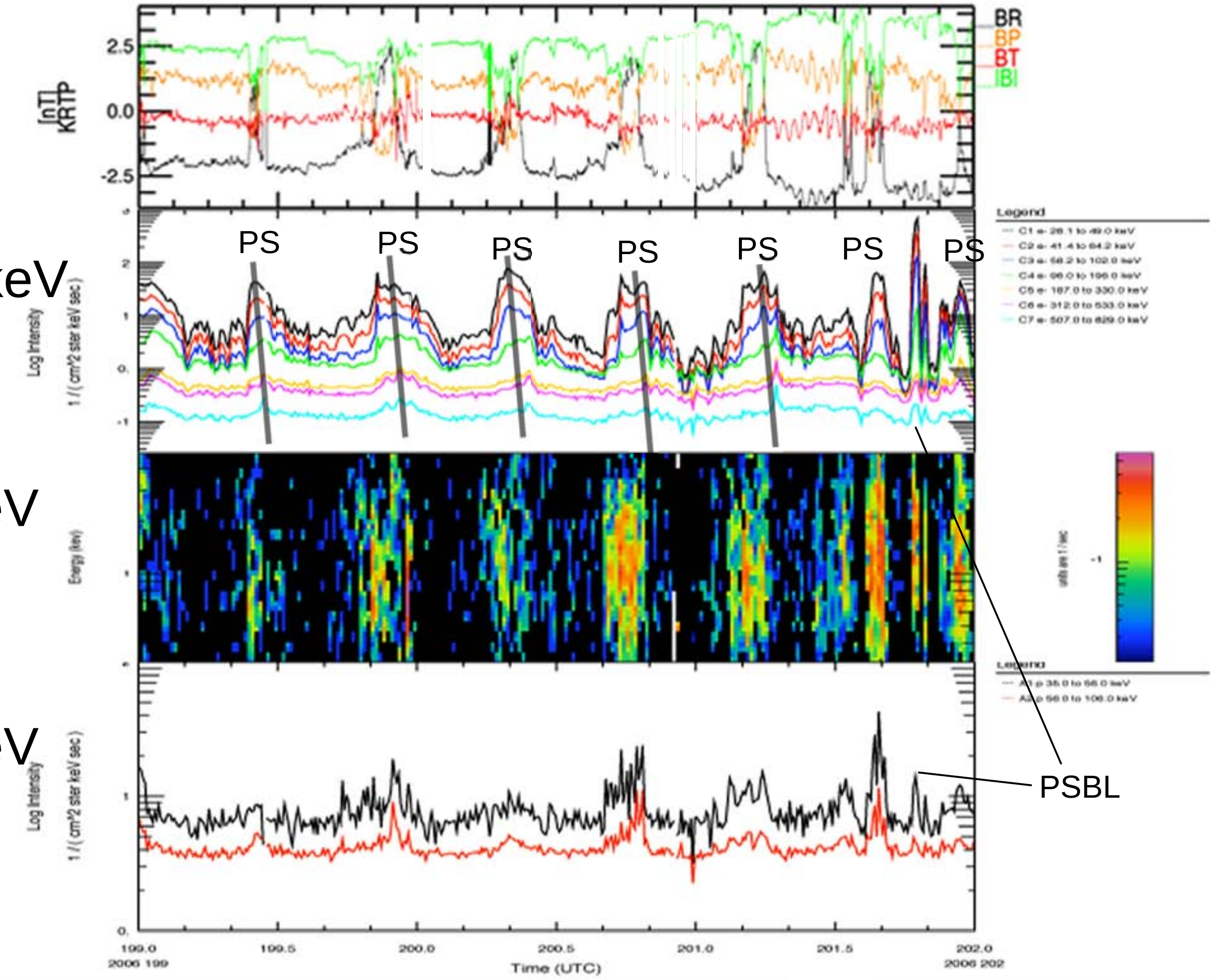


Inbound (below current sheet)

30 to 600 keV electrons

3 to 230 keV protons

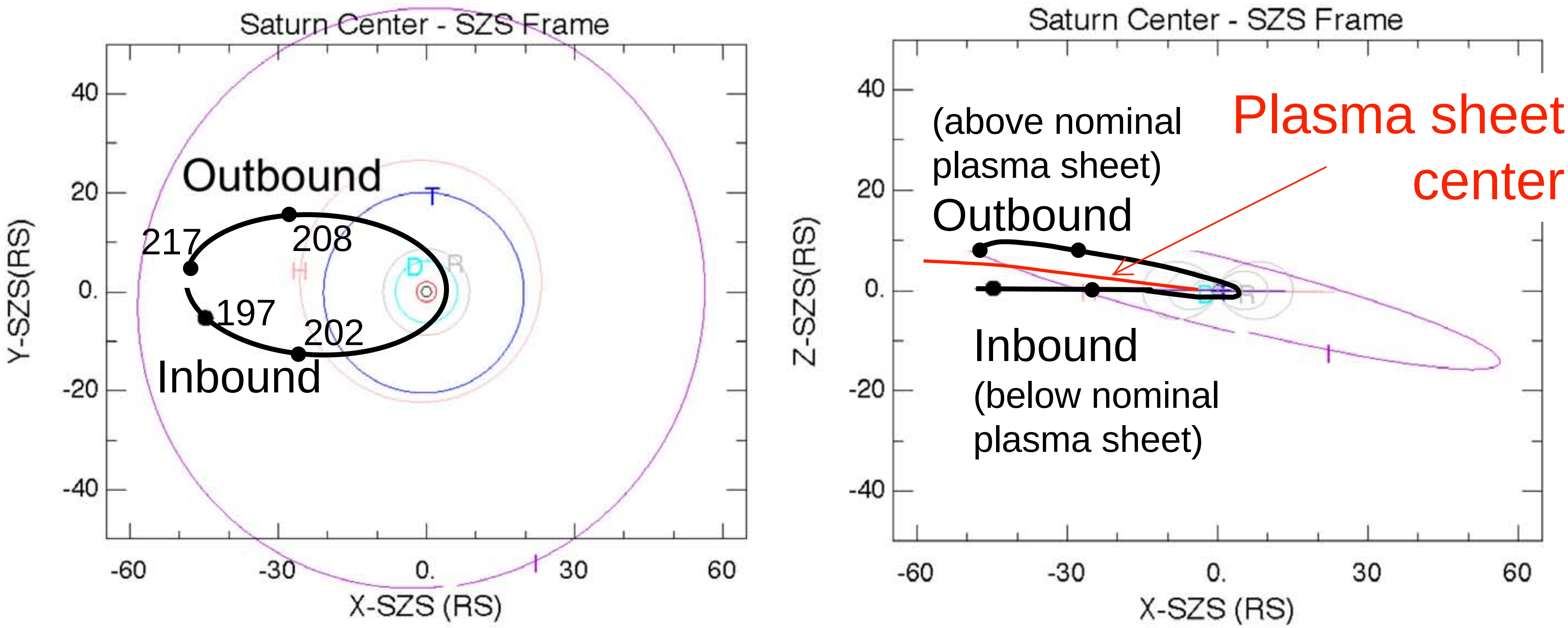
40 to 80 keV ions



Typical plasma sheet encounters in Saturn’s magnetotail, recurrent at the planetary rotation period.

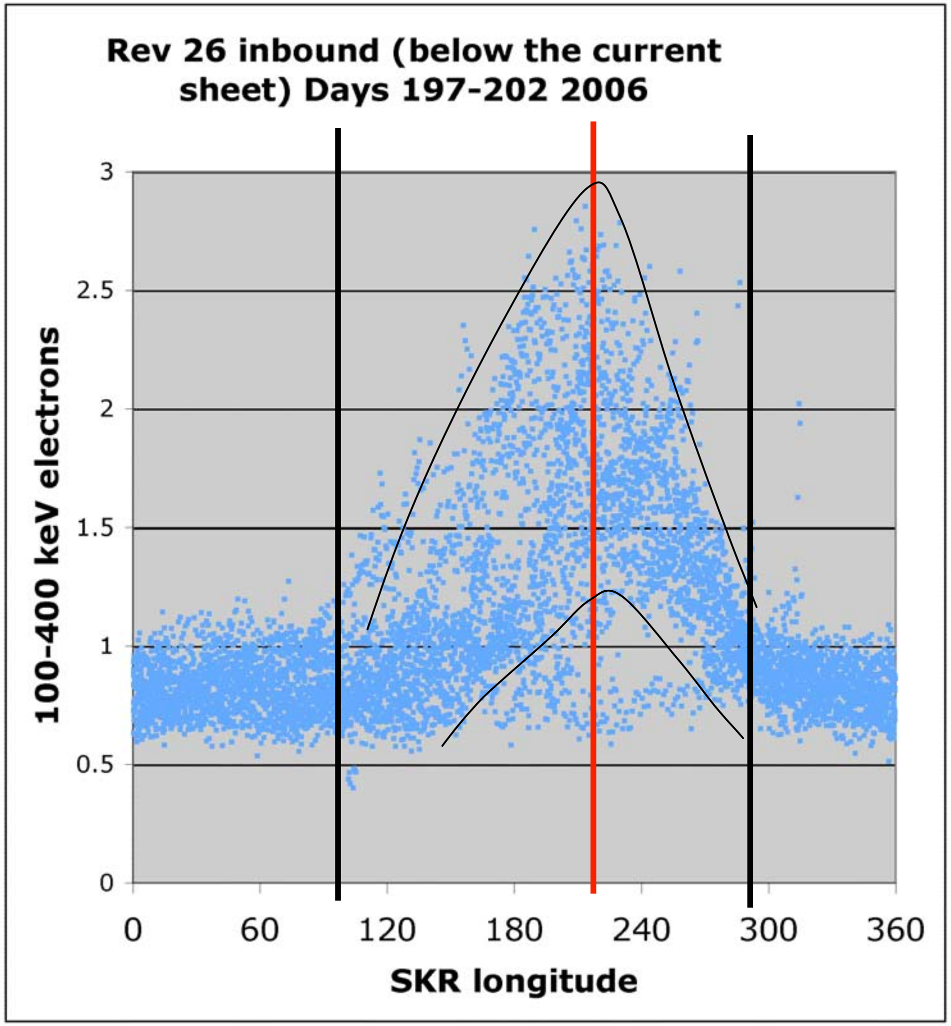
Day 202, 2005 (Inbound, below nominal current sheet)

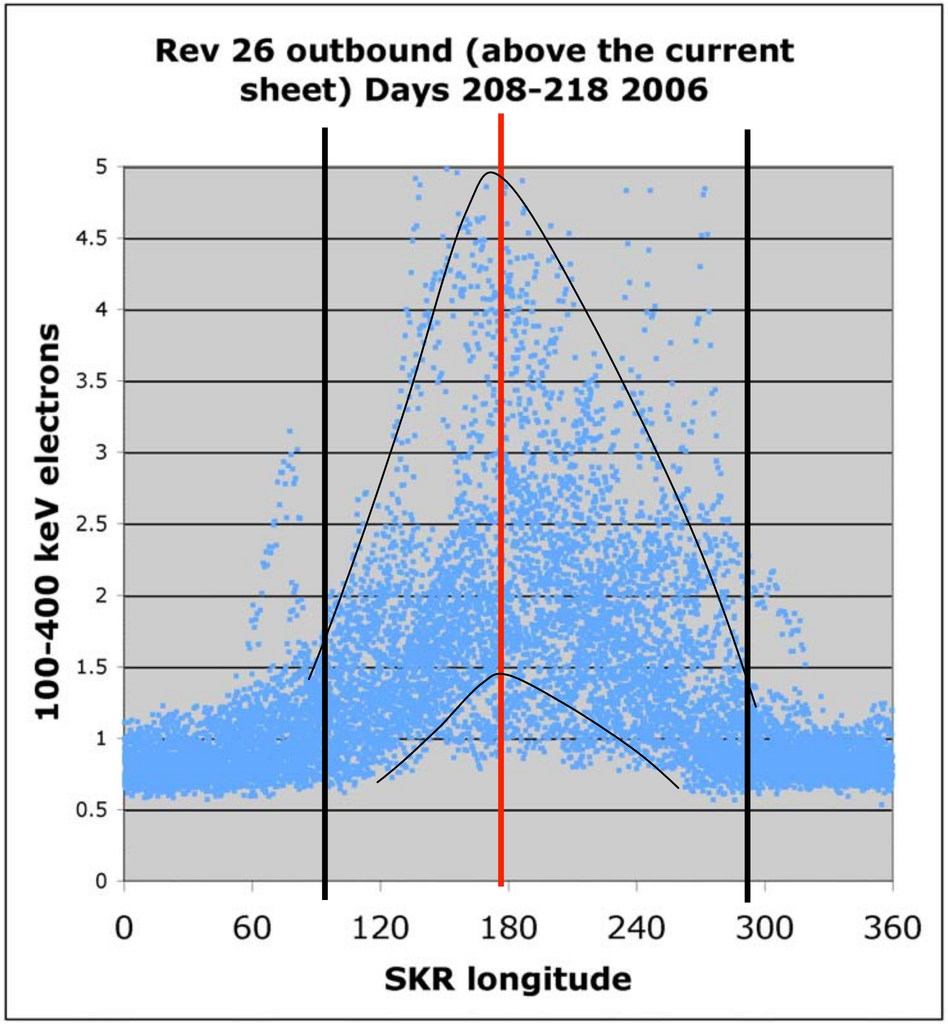
Comparison of magnetotail electron events for south-to-north and north-to-south current sheet encounters.



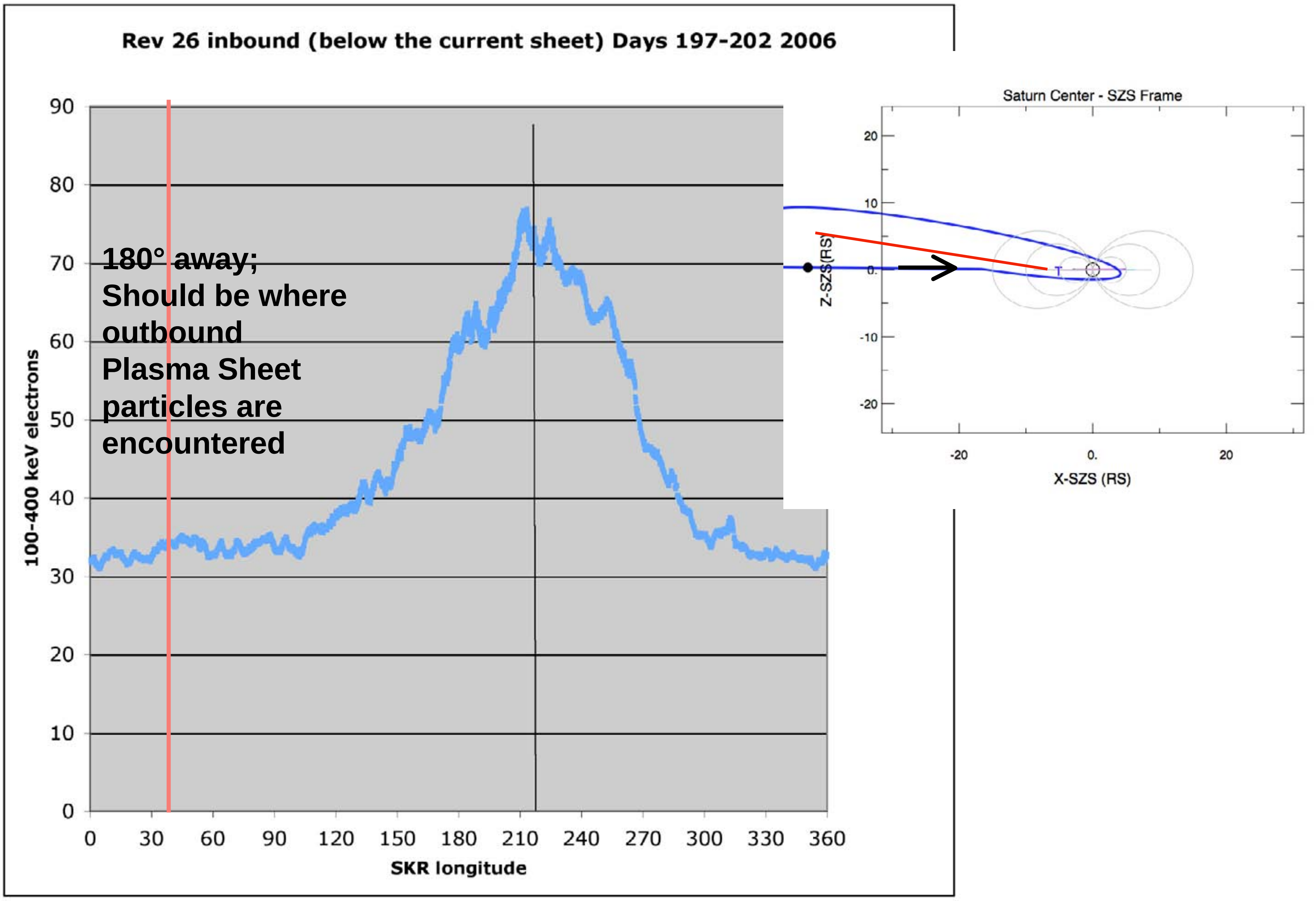
If a mechanism similar to Jupiter were in effect (tilted dipole ==> current sheet crossings driven by rotating tilted disk), we should see a 180° phase shift between the SKR longitudes of inbound and outbound encounters.

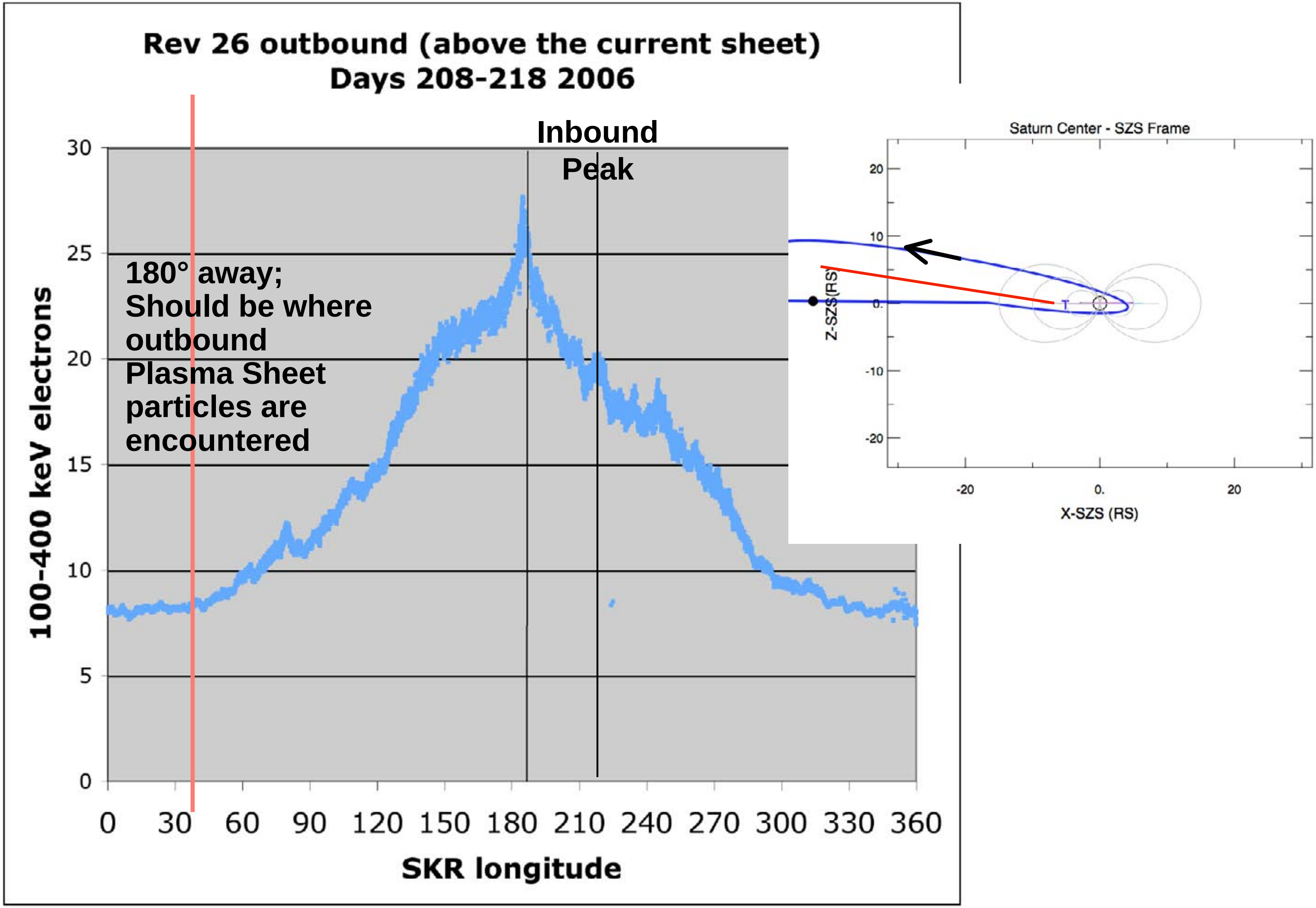
Comparison of magnetotail electron events for south-to-north and north-to-south plasma sheet encounters.





SKR longitude of energetic electron enhancement associated with plasma sheet encounters shifts only slightly between entries from the southern hemisphere toward the northern (Rev 26 inbound) and from the northern hemisphere toward the southern (Rev 26 outbound).

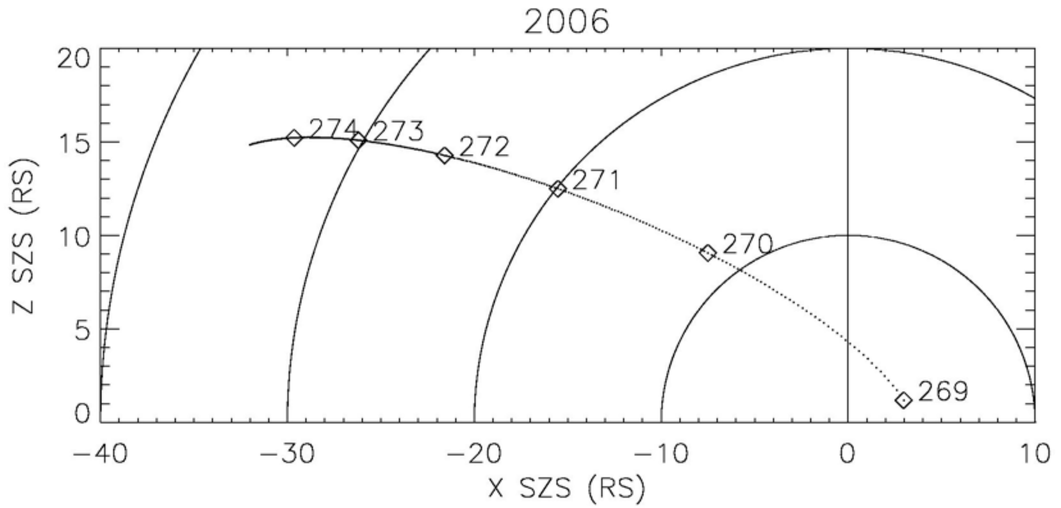

Rev 26 inbound (below the current sheet) Days 197-202 2006
180° away;
Should be where
outbound
Plasma Sheet
particles are
encountered
100-400 keV electrons
SKR longitude
Saturn Center - SZS Frame
Z-SZS (RS)
X-SZS (RS)



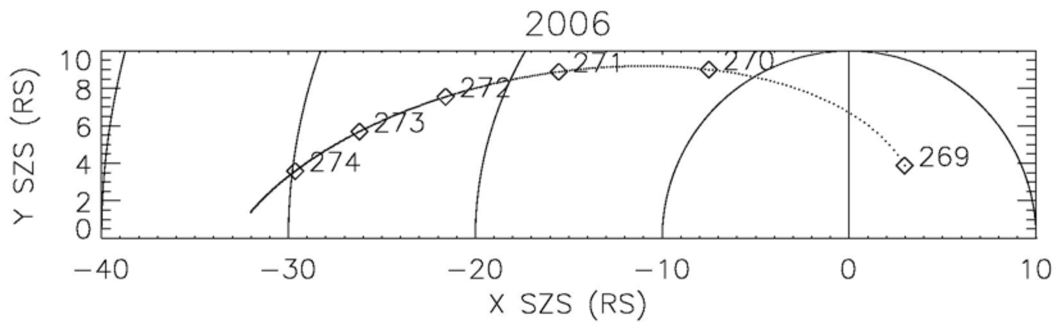
Rev 26 outbound (above the current sheet)
Days 208-218 2006
Inbound Peak
180° away;
Should be where outbound Plasma Sheet particles are encountered
100-400 keV electrons
SKR longitude
0 30 60 90 120 150 180 210 240 270 300 330 360
0 5 10 15 20 25 30
Saturn Center - SZS Frame
Z-SZS (RS)
X-SZS (RS)
-20 0. 20
20 10 0. -10 -20

Sample Trajectory, days 269-275, 2006

Projection into plane perpendicular to the equatorial plane; night-side.

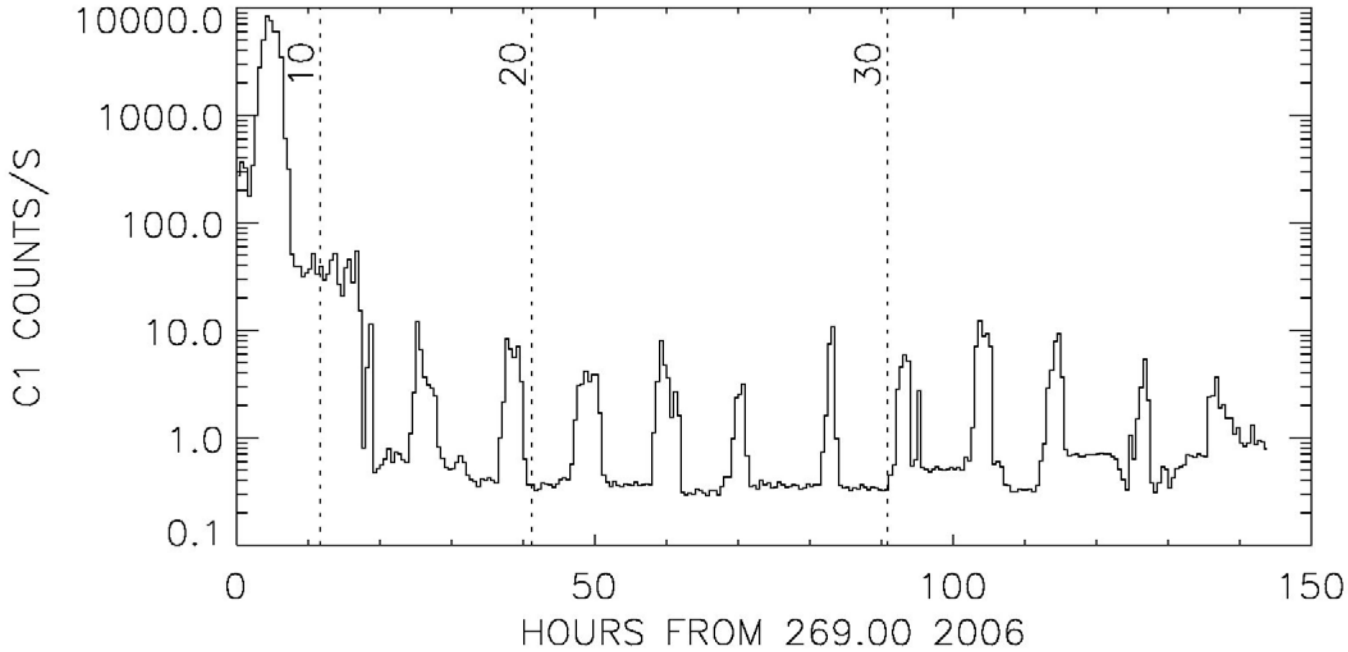


Projection into equatorial plane



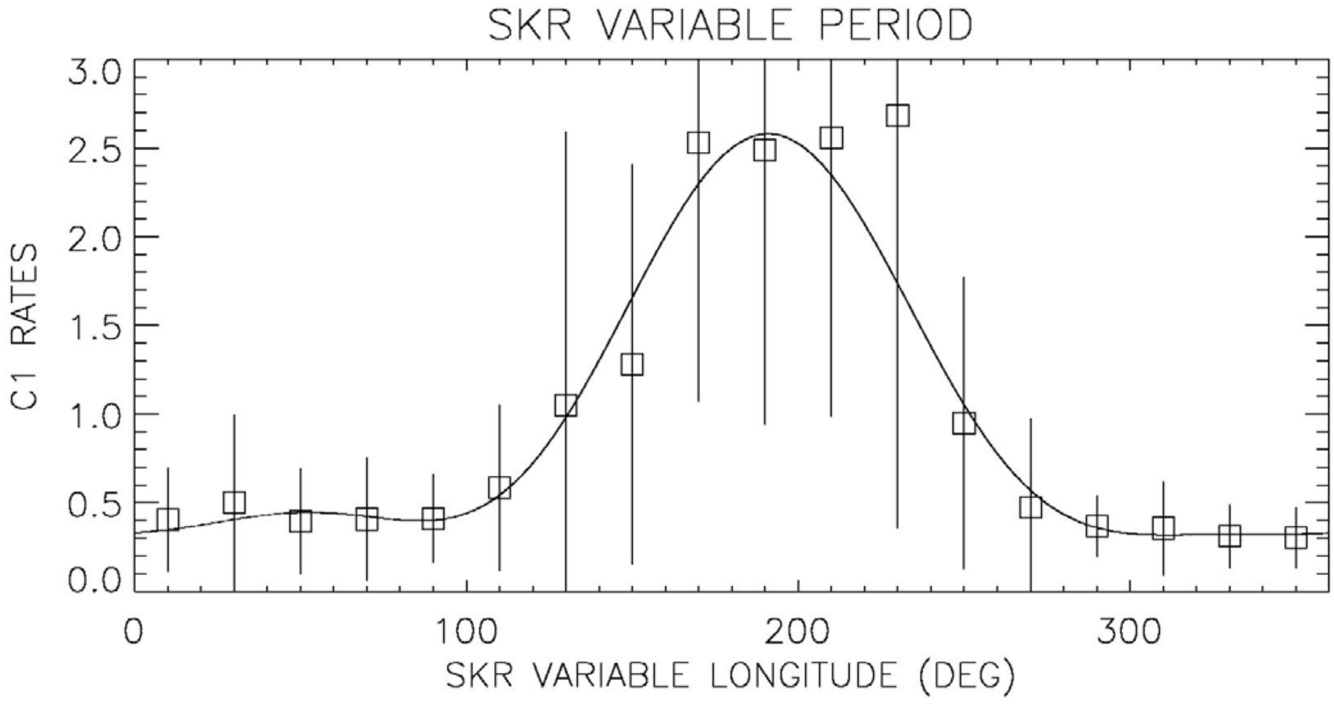
Projections of Cassini trajectory in SZS coordinates for a high latitude (~30°) orbit.

Count Rate vs Time for 30° Latitude Pass



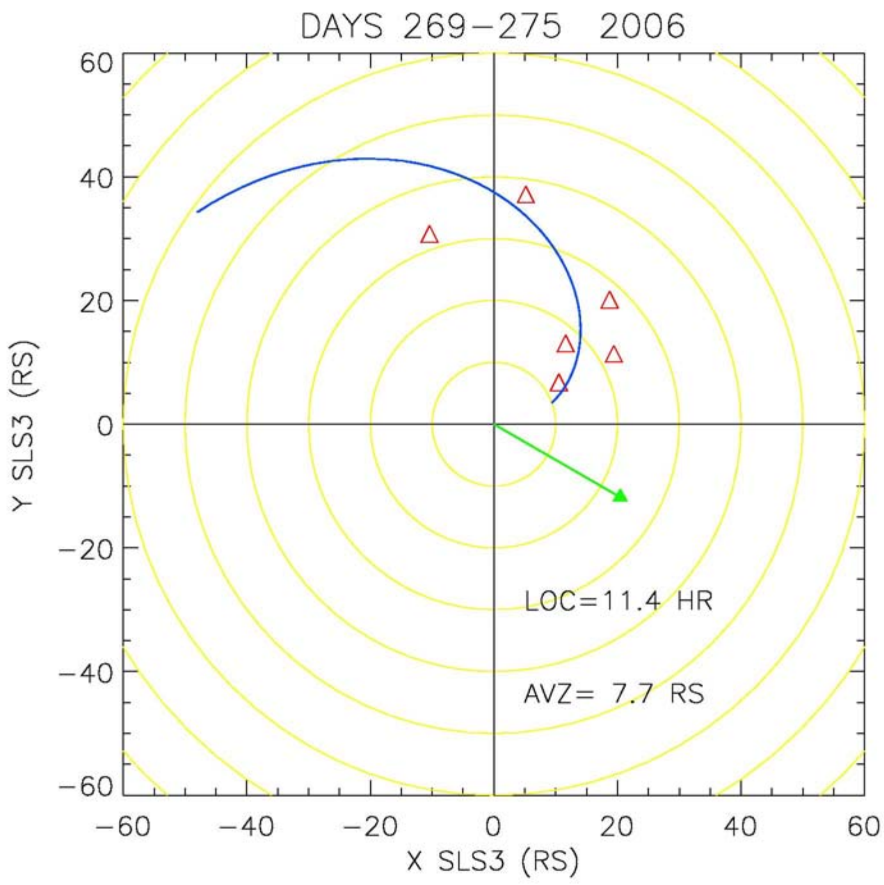
Strong periodicities are observed in the ~70 keV electron count rates (and similarly for other LEMMS electron channels).

Longitude-Binned Sample Count Rates with Harmonic Fit

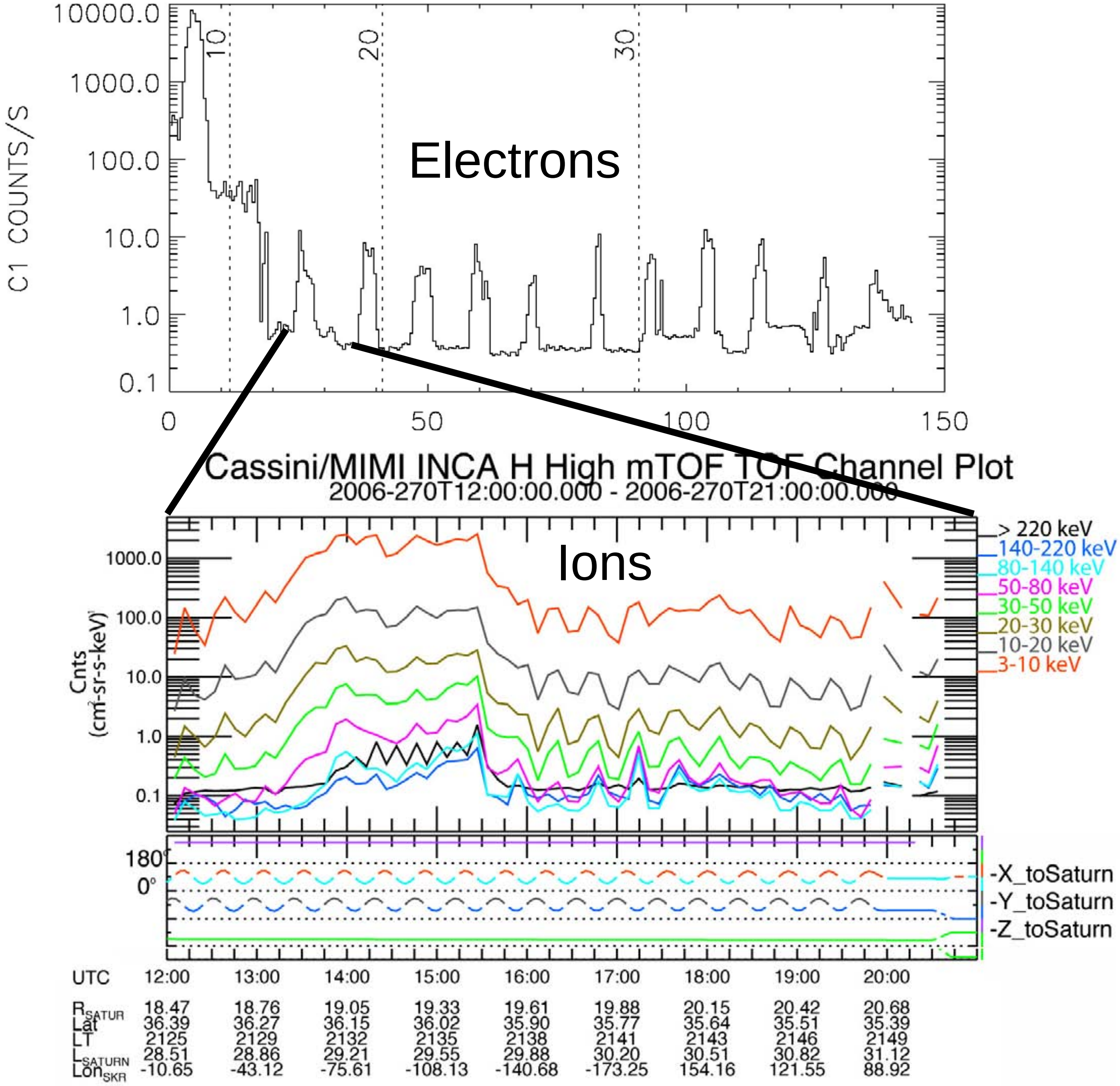


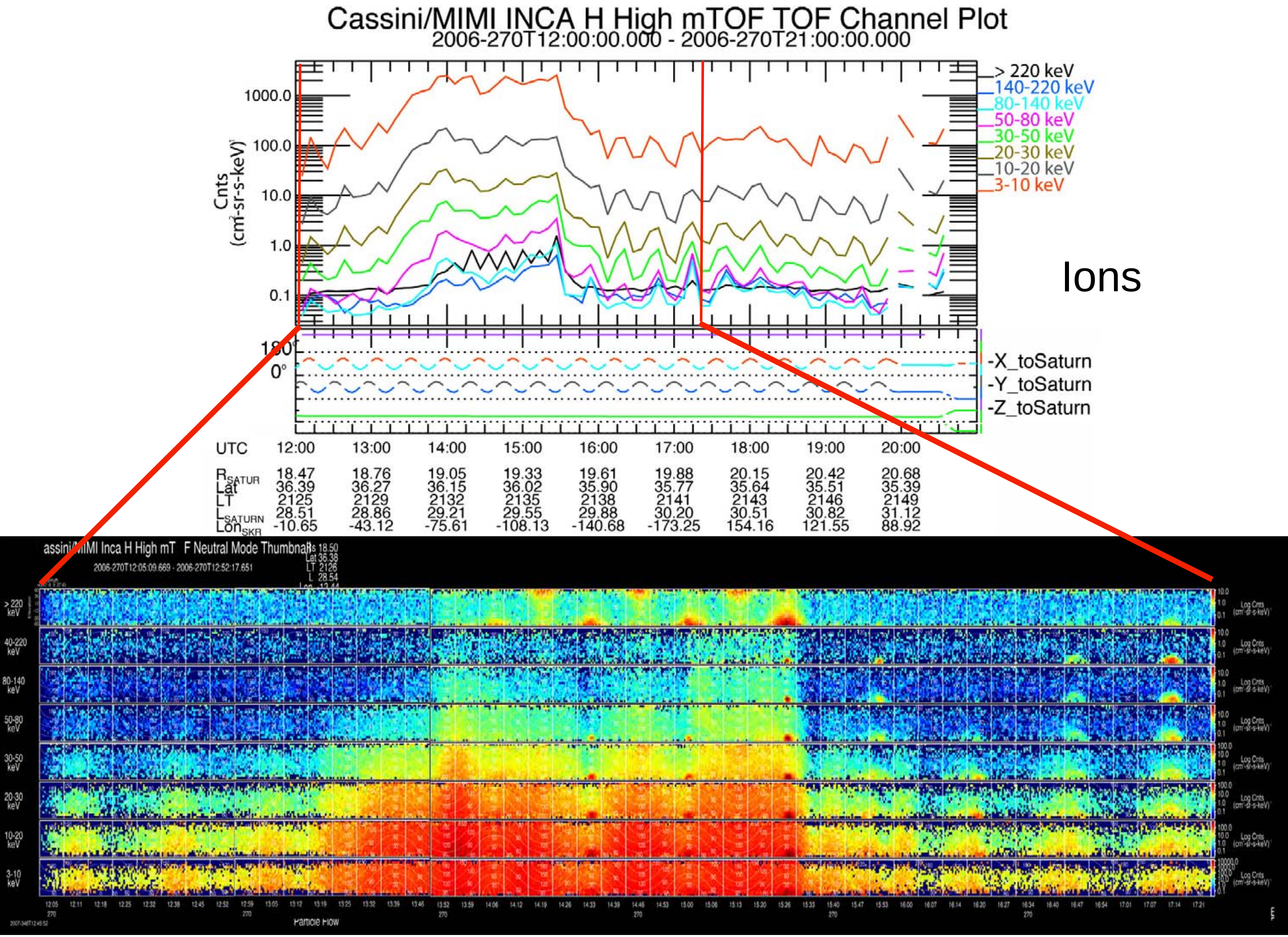
The squares represent averages of the normalized count rates into 20° longitude bins. The extended lines show the standard deviations of these averages. The solid line shows a 3-order harmonic fit. The fit has a first order amplitude of 0.959 and a first order angle of 189°.

Spiral Pattern for 1 High Latitude Pass



The spiral pattern persists for this one high-latitude pass (30°) during 2006. But the base of the spiral is shifted ~40° from the green outflow arrow. SLS-3 longitude was used to organized the data.

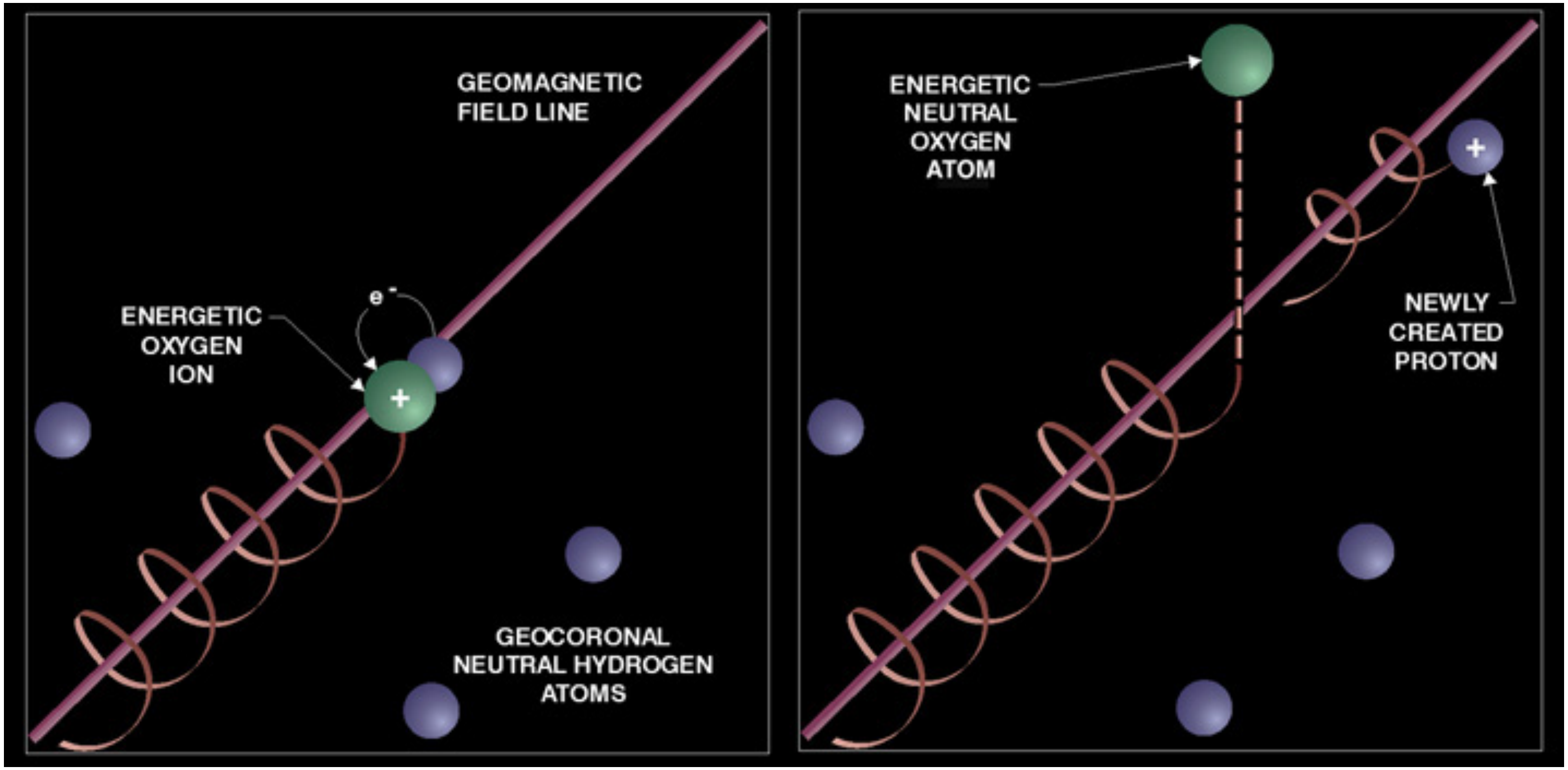

Electrons
C1 COUNTS/S
Cassini/MIMI INCA H High mTOF TOF Channel Plot
2006-270T12:00:00.000 - 2006-270T21:00:00.000
Ions
Cnts (cm²-sr-s-keV)
> 220 keV
140-220 keV
80-140 keV
50-80 keV
30-50 keV
20-30 keV
10-20 keV
3-10 keV
-X_toSaturn
-Y_toSaturn
-Z_toSaturn
UTC 12:00 13:00 14:00 15:00 16:00 17:00 18:00 19:00 20:00
R_SATUR 18.47 18.76 19.05 19.33 19.61 19.88 20.15 20.42 20.68
Lat 36.39 36.27 36.15 36.02 35.90 35.77 35.64 35.51 35.39
LT 2125 2129 2132 2135 2138 2141 2143 2146 2149
L_SATURN 28.51 28.86 29.21 29.55 29.88 30.20 30.51 30.82 31.12
Lon_SKR -10.65 -43.12 -75.61 -108.13 -140.68 -173.25 154.16 121.55 88.92


Cassini/MIMI INCA H High mTOF TOF Channel Plot
2006-270T12:00:00.000 - 2006-270T21:00:00.000
Cnts (cm²-sr-s-keV)
1000.0
100.0
10.0
1.0
0.1
> 220 keV
140-220 keV
80-140 keV
50-80 keV
30-50 keV
20-30 keV
10-20 keV
3-10 keV
180°
0°
-X_toSaturn
-Y_toSaturn
-Z_toSaturn
UTC 12:00 13:00 14:00 15:00 16:00 17:00 18:00 19:00 20:00
R SATUR 18.47 18.76 19.05 19.33 19.61 19.88 20.15 20.42 20.68
Lat 36.39 36.27 36.15 36.02 35.90 35.77 35.64 35.51 35.39
LT 2125 2129 2132 2135 2138 2141 2143 2146 2149
L SATURN 28.51 28.86 29.21 29.55 29.88 30.20 30.51 30.82 31.12
Lon SKR -10.65 -43.12 -75.61 -108.13 -140.68 -173.25 154.16 121.55 88.92
Ions
2006-270T12:05:09.669 - 2006-270T12:52:17.651
> 220 keV
40-220 keV
80-140 keV
50-80 keV
30-50 keV
20-30 keV
10-20 keV
3-10 keV
Log Cnts (cm²-sr-s-keV)
Particle Flow

Conclusions about Charged Particles in Saturn's Magnetotail

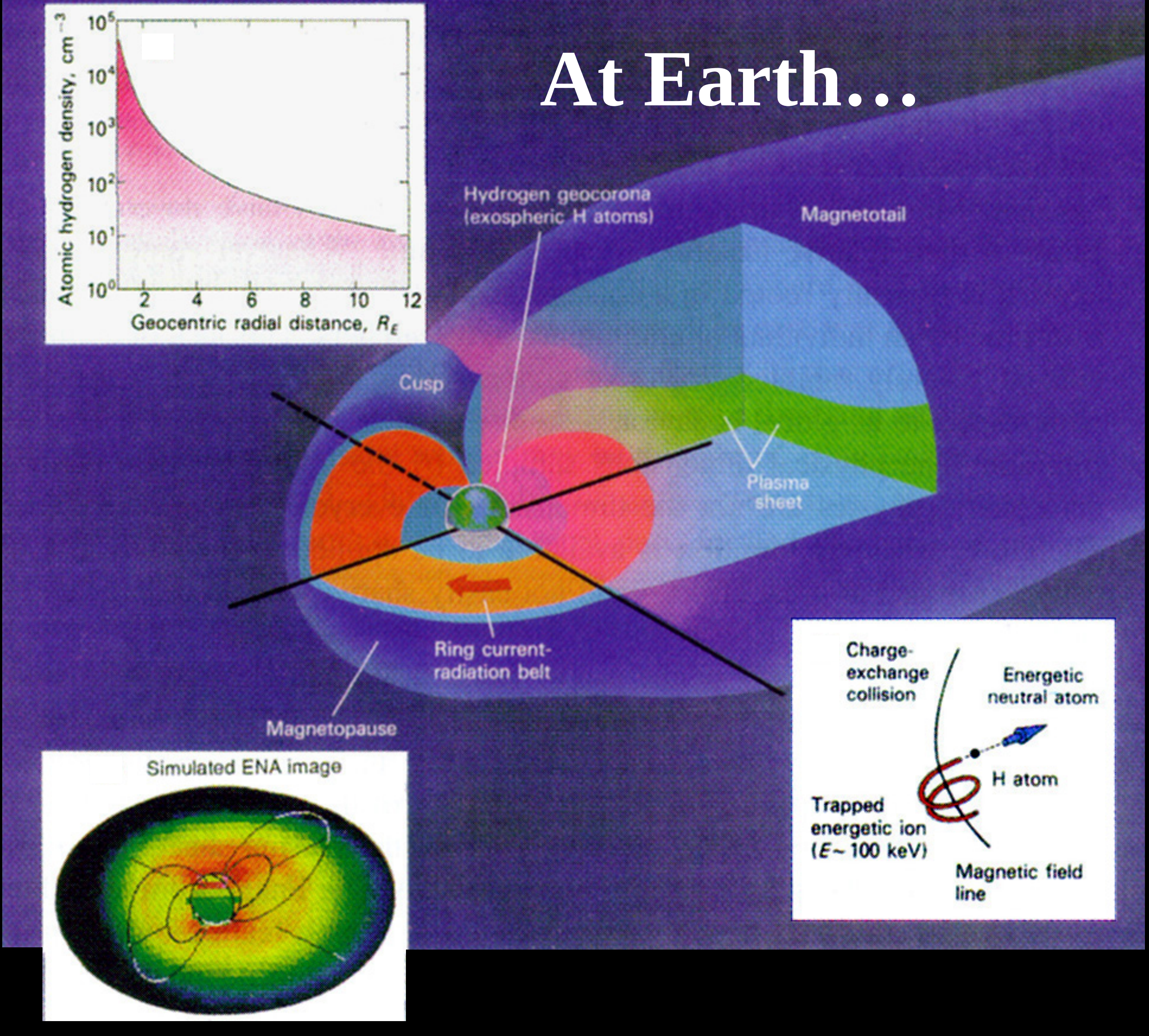
1. All the charged particles regardless of species exhibit strong periodicities at 10.80 hours
2. The periodicities are evident over time periods of more than a year.
3. The periodicities are evident at both low and high latitudes.
4. A regular spiral pattern appears in the 28-49 keV electrons (and probably in the other charged particles as well) in the SLS-2 and SLS-3 longitude systems.
5. Quiet time flows in the magnetotail are predominantly cross-tail, in the same direction as corotation, but well below rigid rotation velocity. Reconnection floows are much stronger, with strong field aligned, tailward components.
6. Field aligned ions (and electrons), probably accelerated in the auroral and sub auroral zones, appear independent of the 10 hour 45 minute periodicity (generally for L > 9).
7. Plasmoid release can take place as close to Saturn as 20 Rs (+/- 5).

Now we change gears, and look at remote sensing of Energetic Particles, using the technique of Energetic Neutral Atom imaging

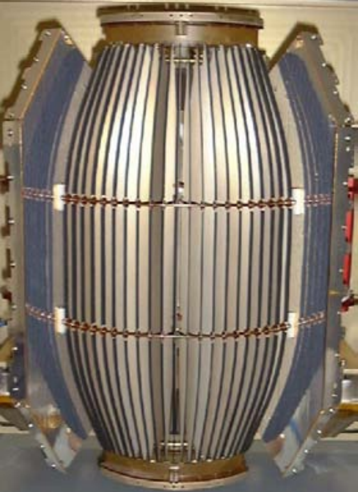


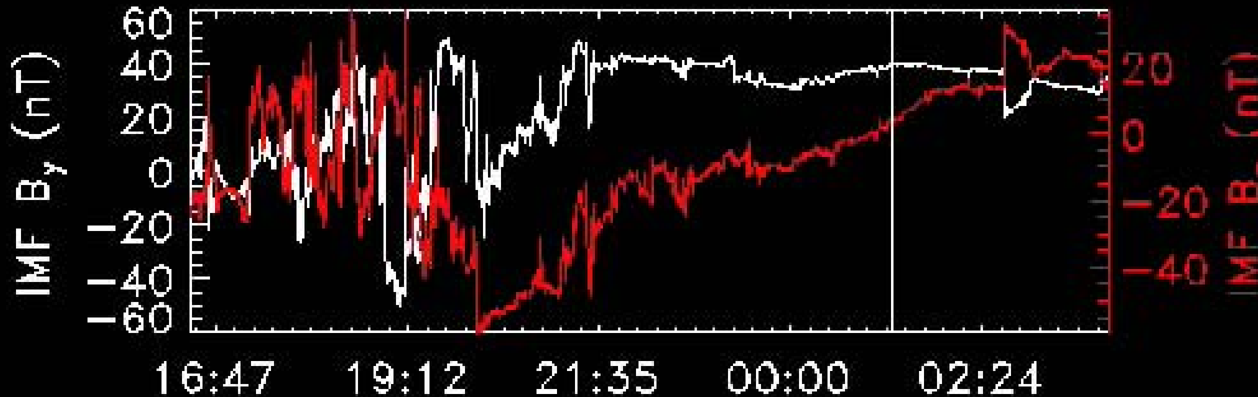
ENA generation mechanism

At Earth…

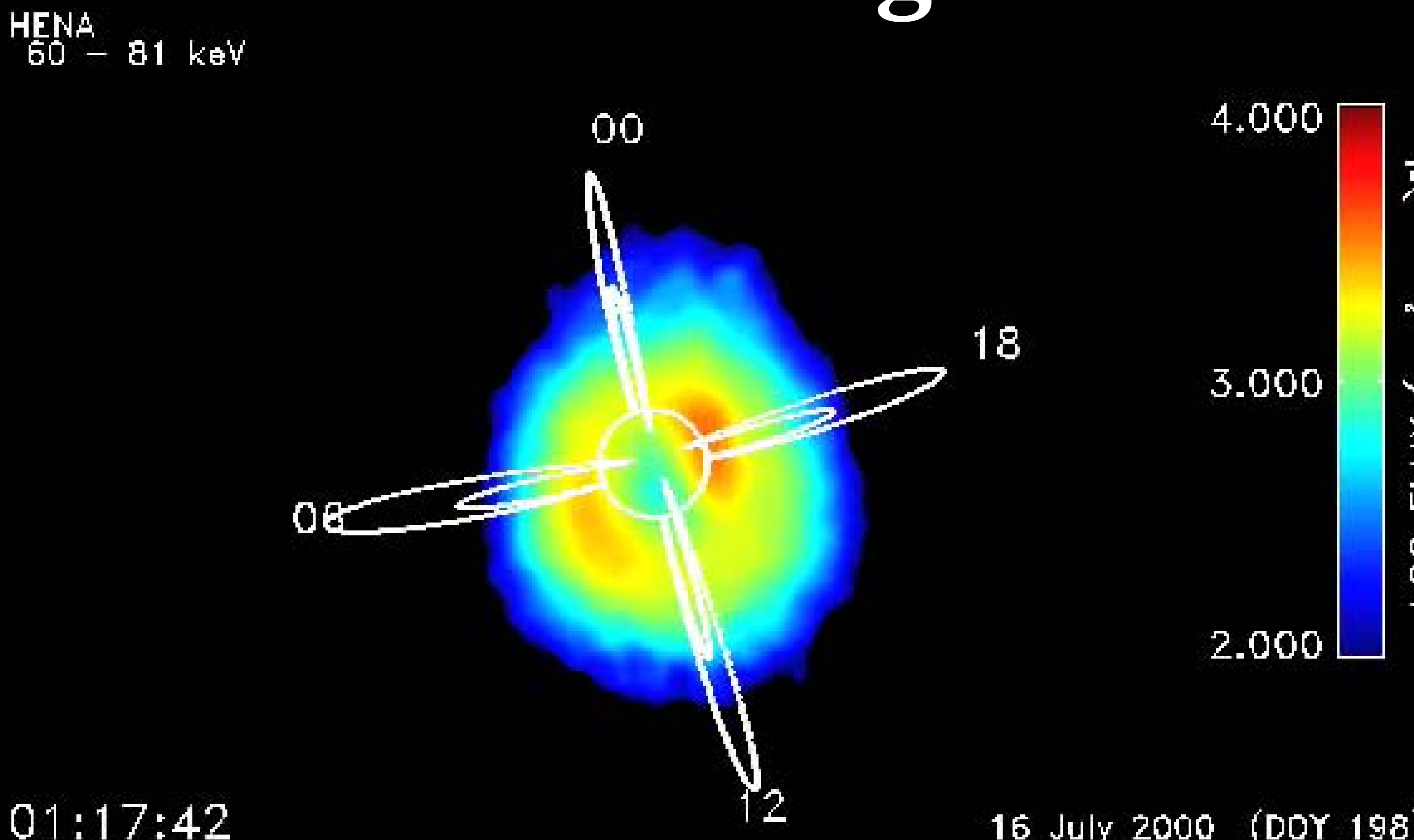


Atomic hydrogen density, cm⁻³
10⁵
10⁴
10³
10²
10¹
10⁰
2
4
6
8
10
12
Geocentric radial distance, R_E
Hydrogen geocorona
(exospheric H atoms)
Magnetotail
Cusp
Plasma
sheet
Ring current-
radiation belt
Magnetopause
Charge-
exchange
collision
Energetic
neutral atom
H atom
Trapped
energetic ion
($E \sim 100$ keV)
Magnetic field
line
Simulated ENA image

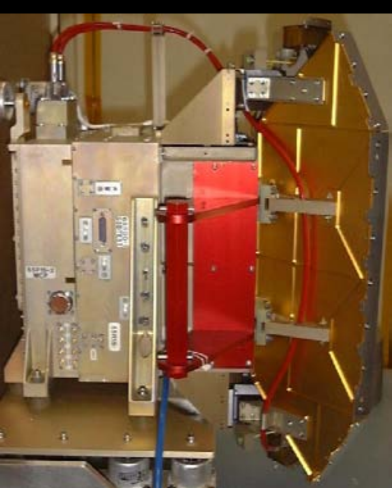




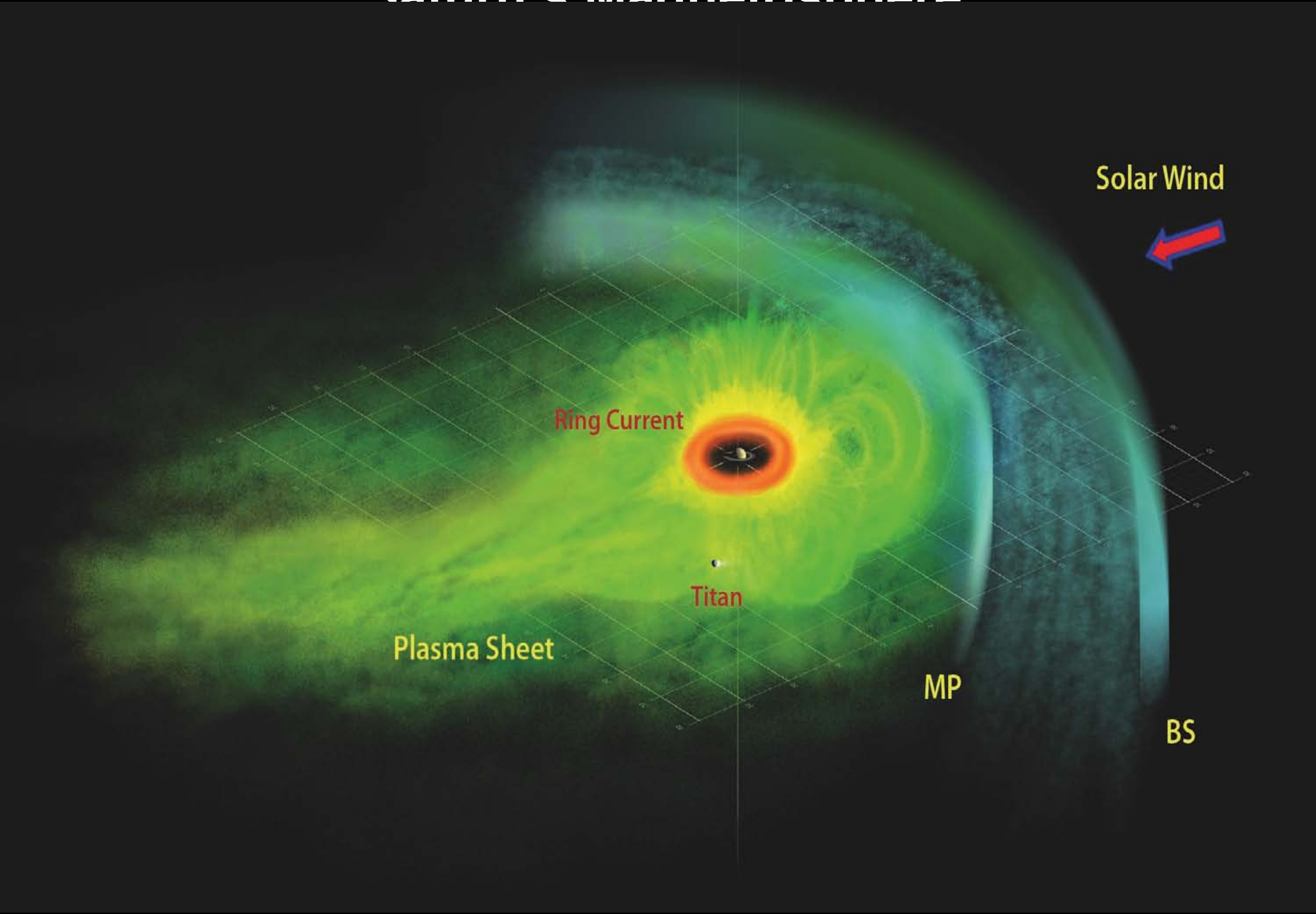
Movie-Earth Ring Current



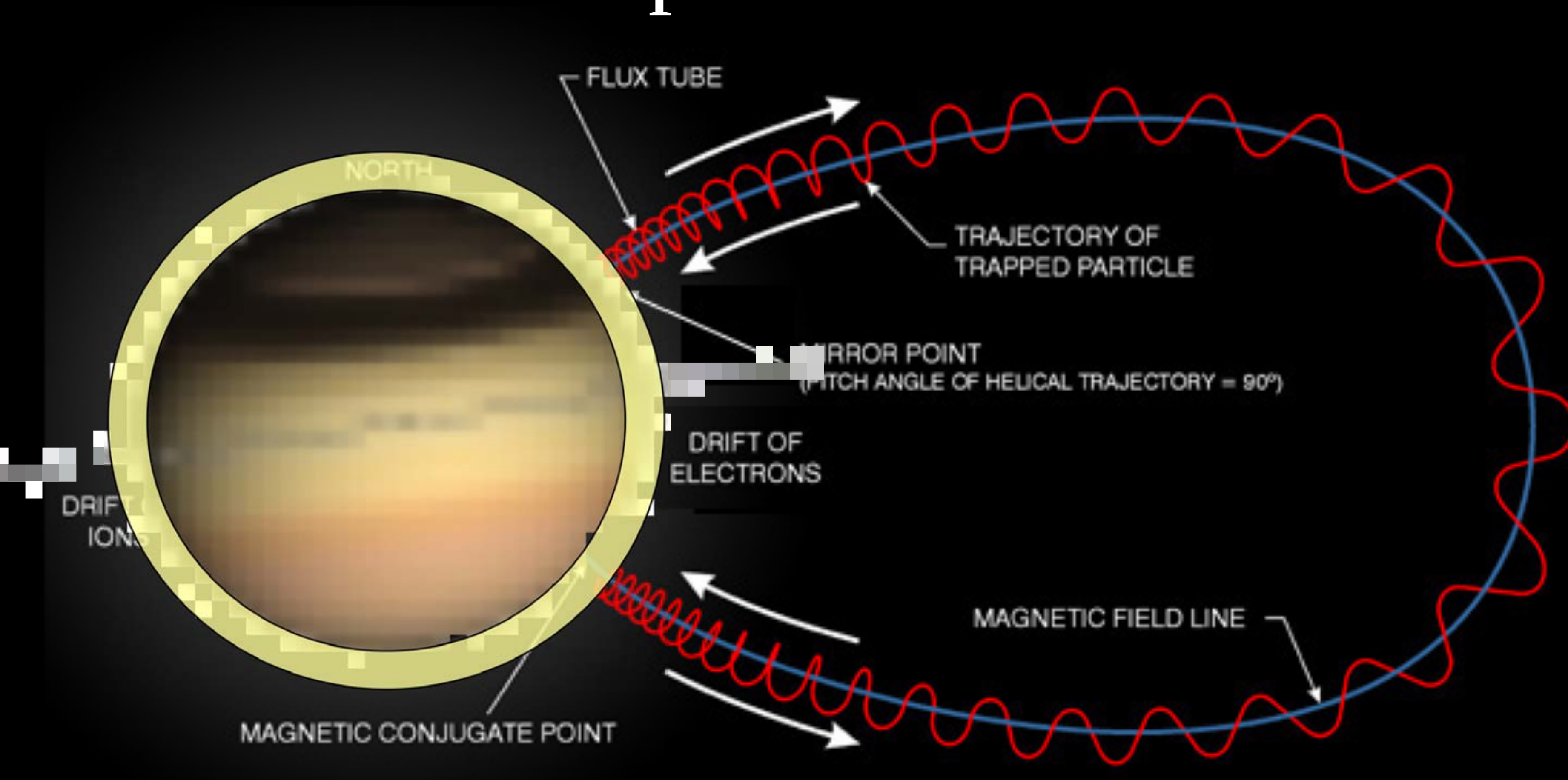
Ring Current



Saturn's Magnetosphere



Saturn’s magnetic field traps particles



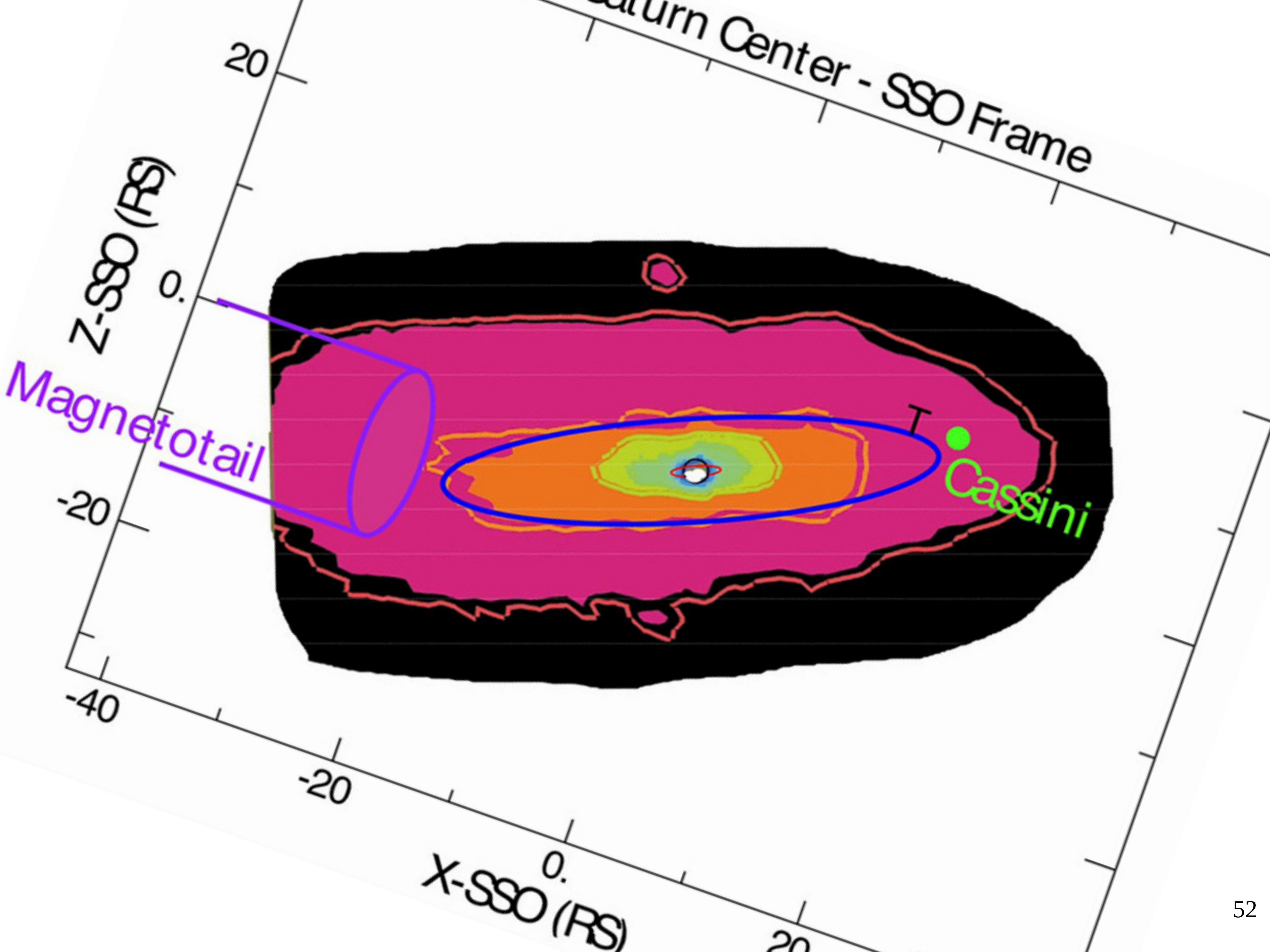
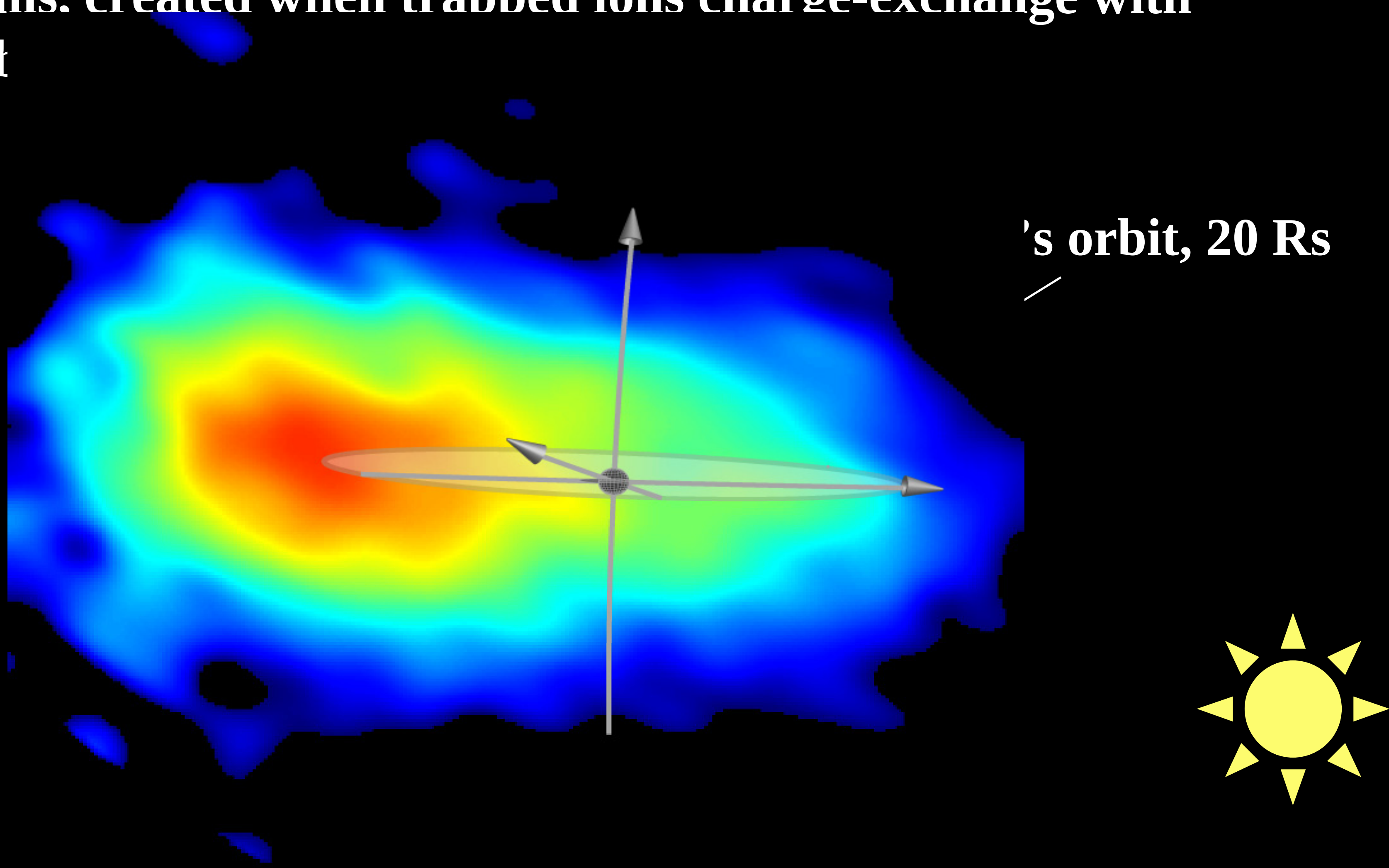
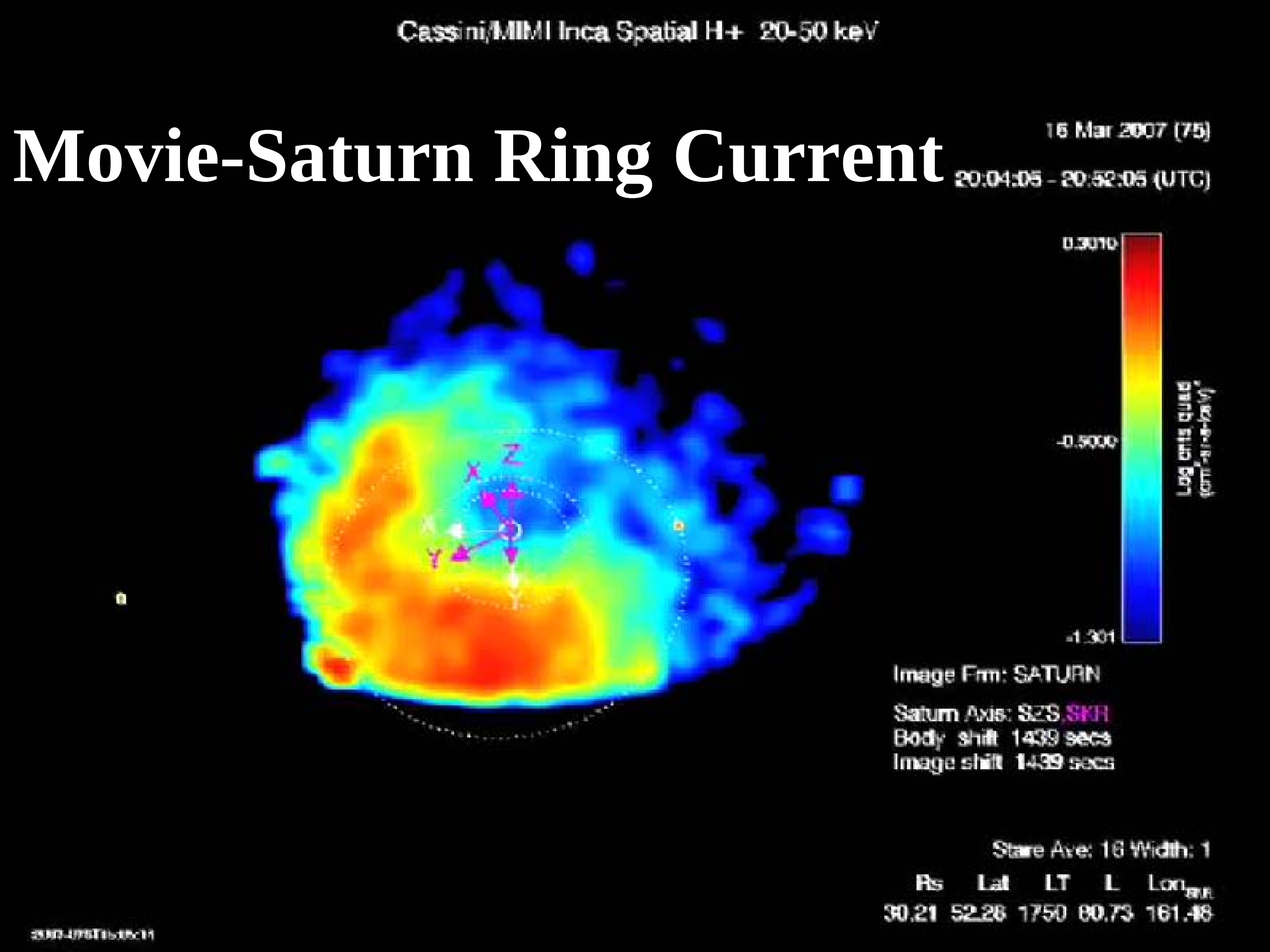
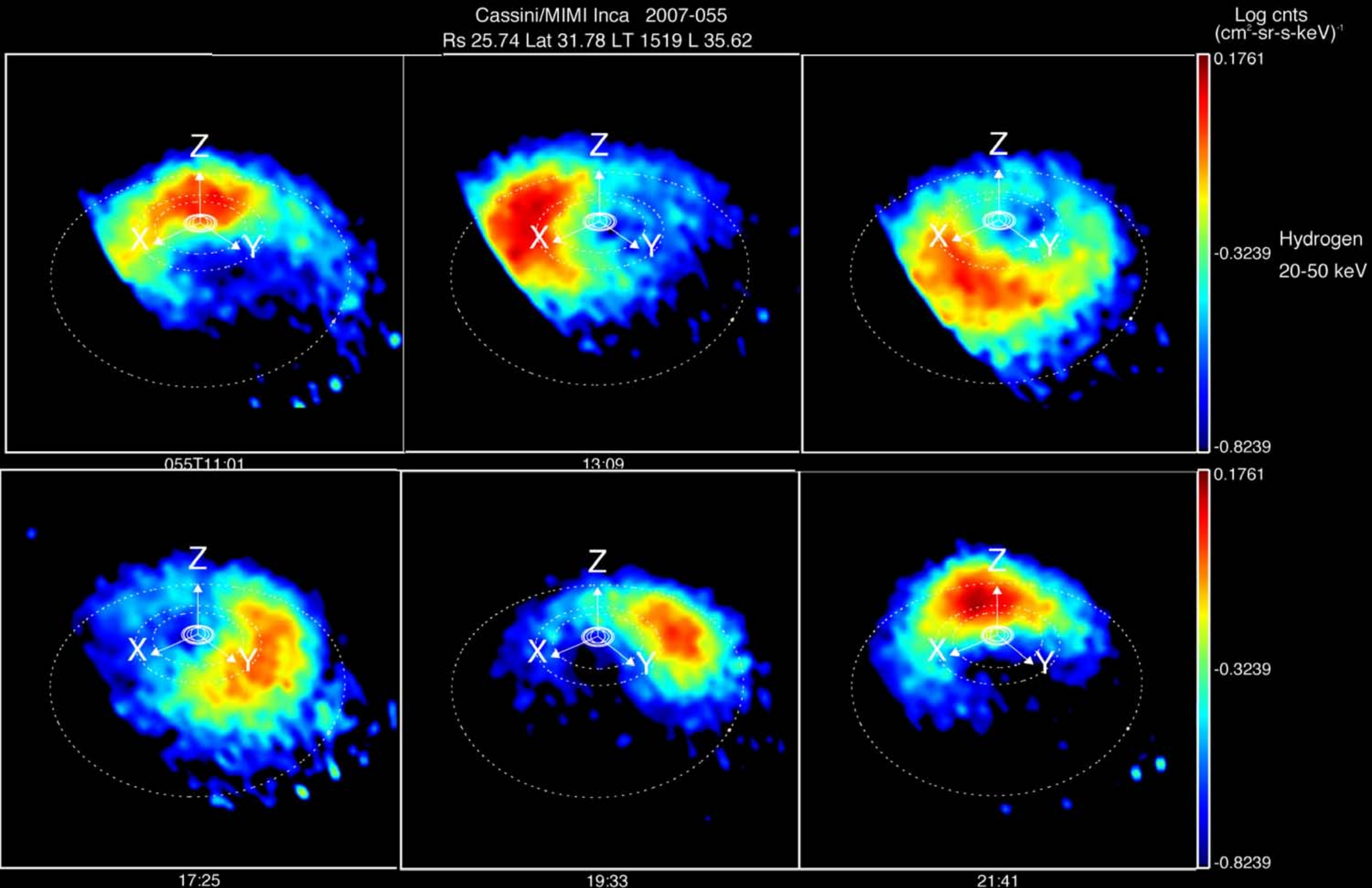

urn Center - SSO Frame
Z-SSO (RS)
20
0.
-20
-40
X-SSO (RS)
-20
0.
20
Magnetotail
Cassini

Image of the magnetosphere in the emission of energetic neutral atoms, created when trapped ions charge-exchange with amb



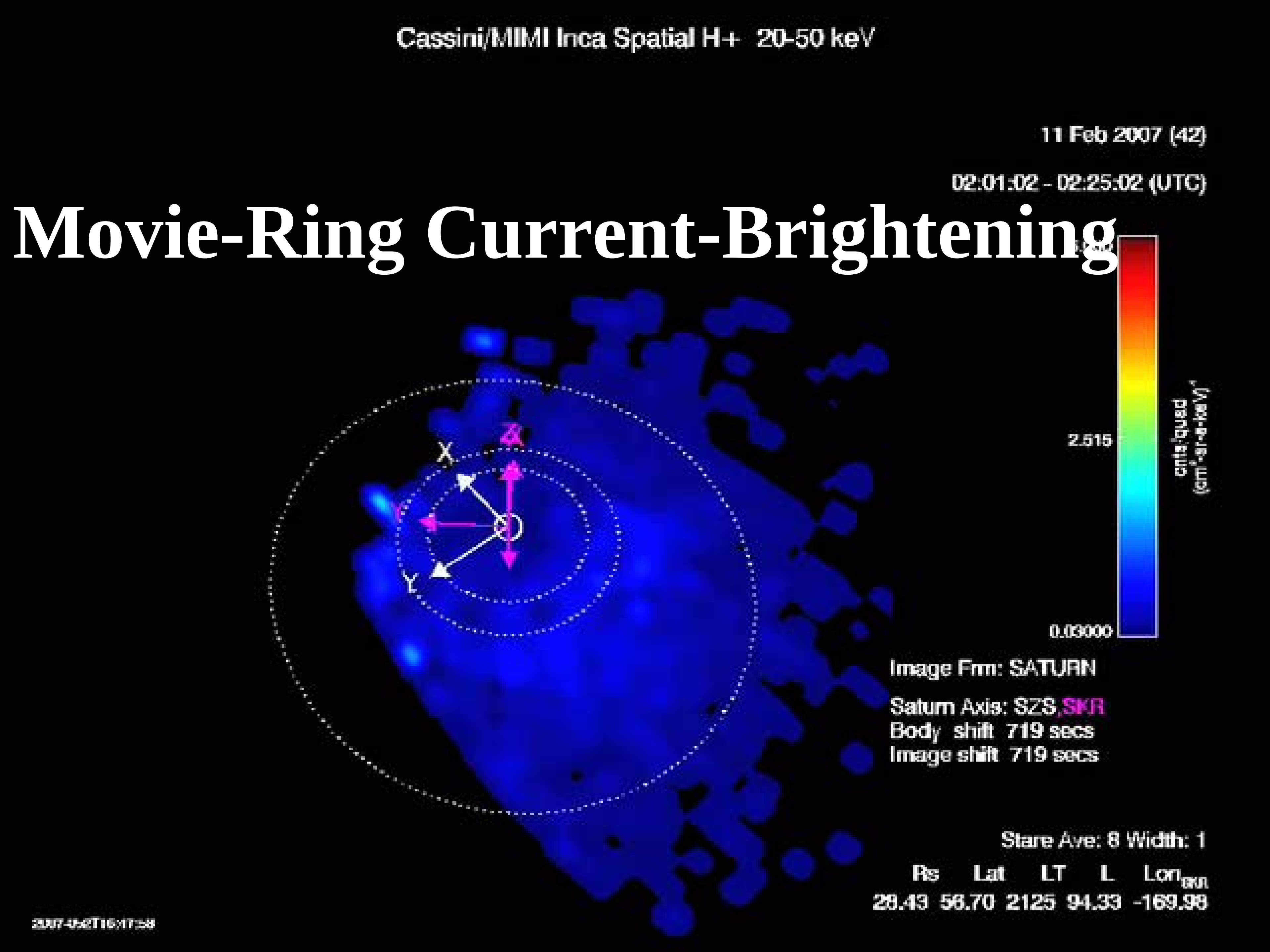
Movie-Saturn Ring Current





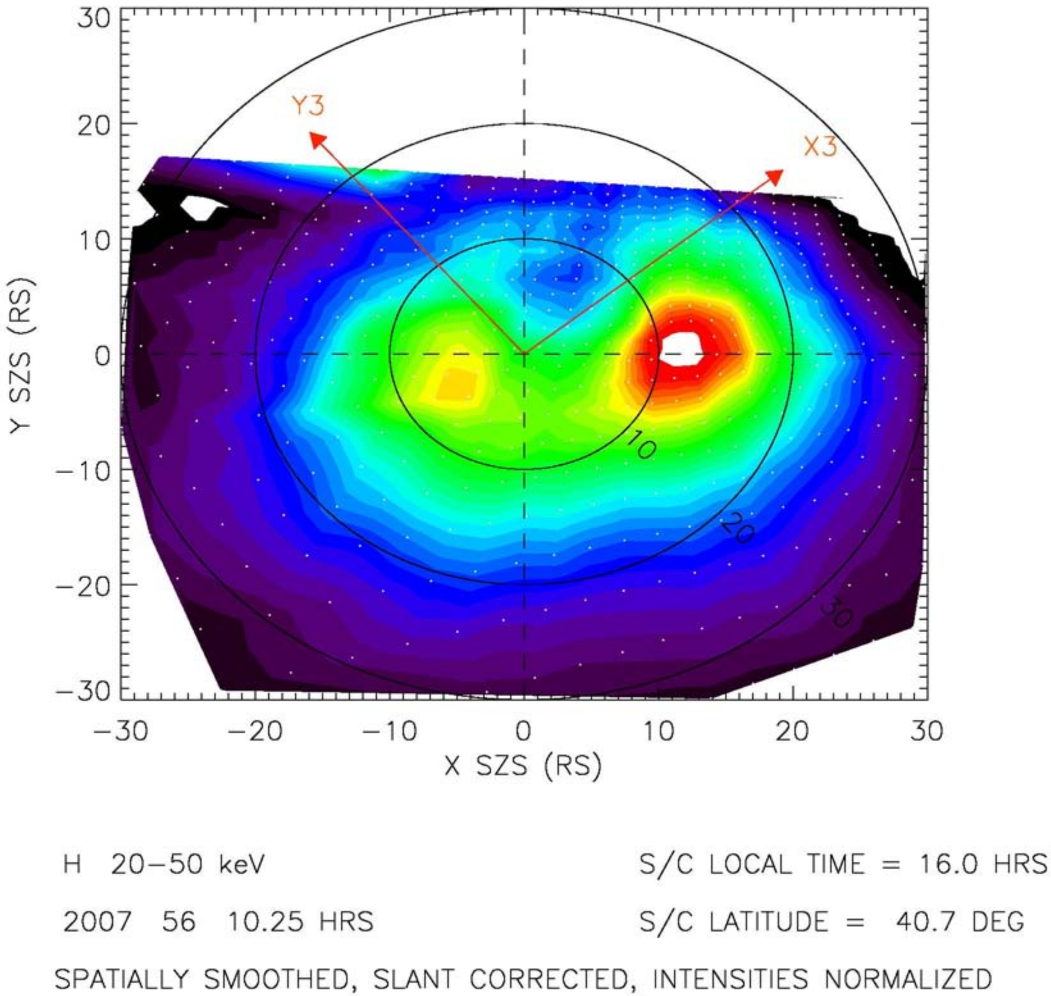
Cassini/MIMI Inca 2007-055
Rs 25.74 Lat 31.78 LT 1519 L 35.62
Log cnts
(cm²-sr-s-keV)⁻¹
0.1761
-0.3239
-0.8239
Hydrogen
20-50 keV
Z
X
Y
055T11:01
13:09
17:25
19:33
21:41

Movie-Ring Current-Brightening



ENA Movie Format

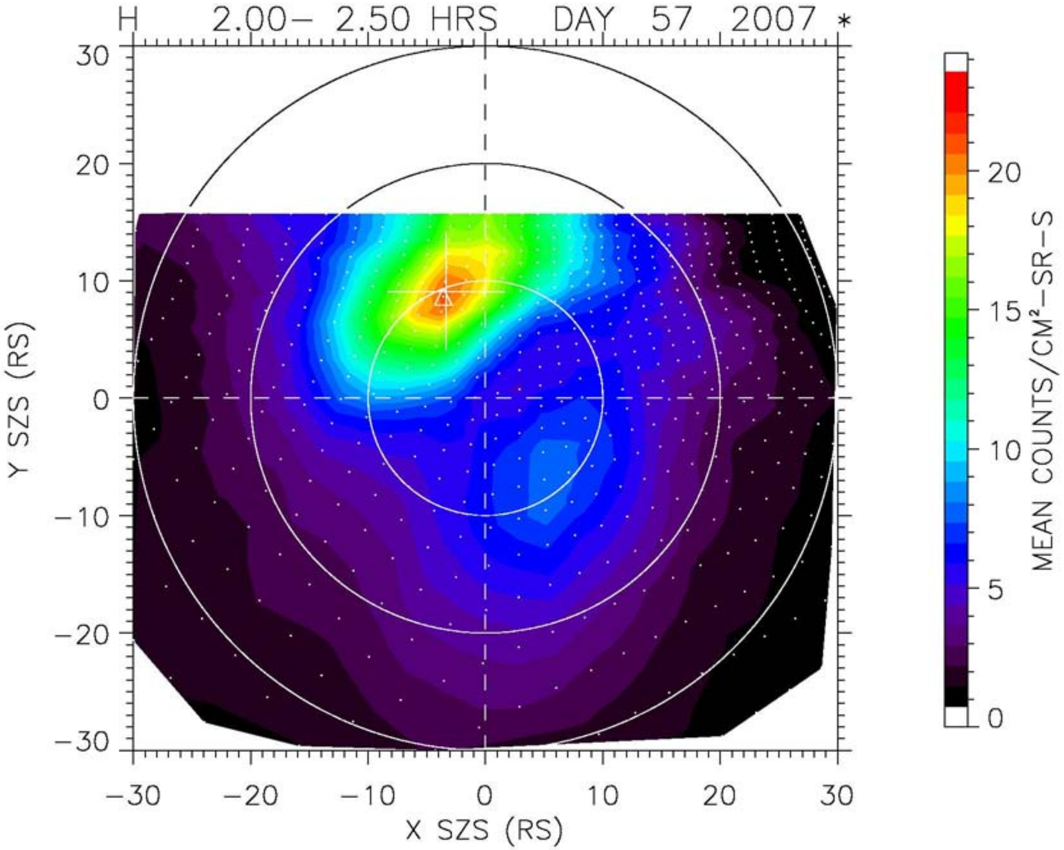
Watching a movie is one of the best ways to visualize Saturn’s rotational dynamics. This image shows the frame format for energetic neutral atom emissions under the assumption that the emissions can be projected onto Saturn’s equatorial plane. Here, the X axis (right) points toward the Sun; the Y axis points toward dusk, and the Z axis (toward viewer) is along spin axis. X3 and Y3 show the SLS3 coordinate axes (the revised SKR longitude system of Kurth et al., 2007B). ENA radiances were smoothed, corrected for slant geometry, and normalized to maximum in each frame. Only data for observer latitudes above 40° north were used.



Tracking the ENA Blobs

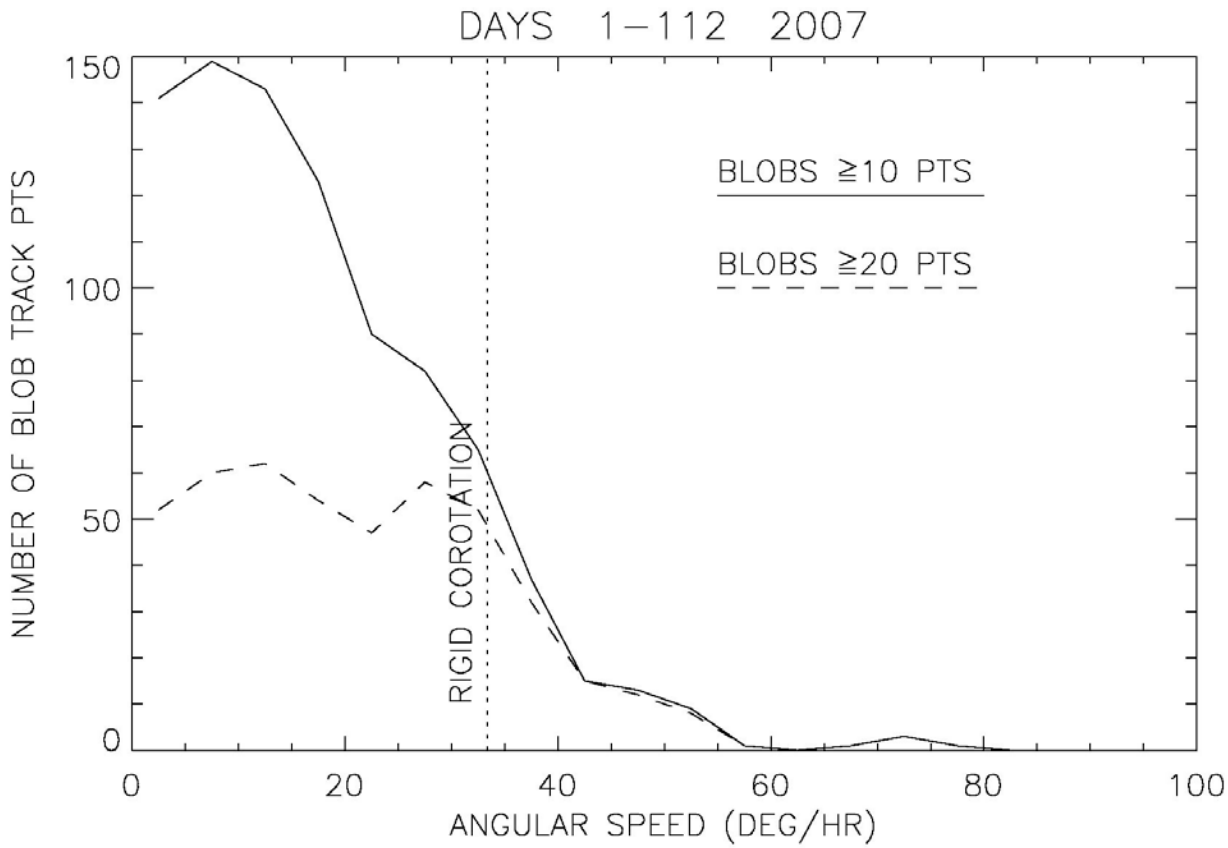
The movies show how ENA “blobs” move around Saturn but they do not quantify the motion. To quantify the motion, find the locations of each ENA blob using a centroid algorithm. The white cross in this sample shows the intensity peak of the blob. Then follow the blob’s centroid position through time.

The blob track analysis concentrates on the energetic hydrogen neutrals (20-50 keV).



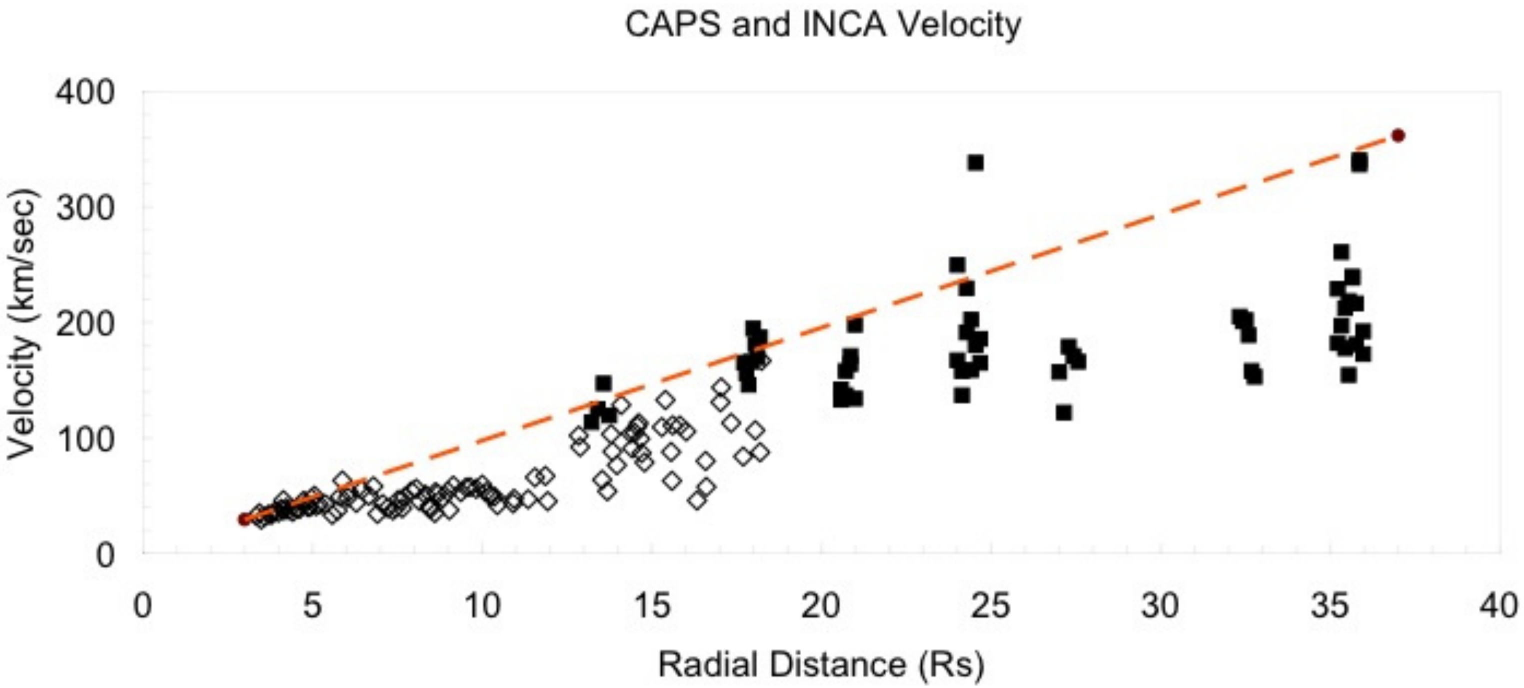
Angular Speed Statistics

ΔT	# blobs	# points
>5 h	61	873
>10 h	22	458



This shows the distribution of blob speeds for those blobs tracked when observations were above 40°N. Blobs are divided into two categories: those lasting at least 10 points (5 hours) and those lasting at least 20 points (10 hours). For the longer-lasting blobs, there appears to be a cut-off at the rigid corotation speed. Table at upper left give numerical statistics of the distribution.

Convection Speeds Using Fit to Charged Particles

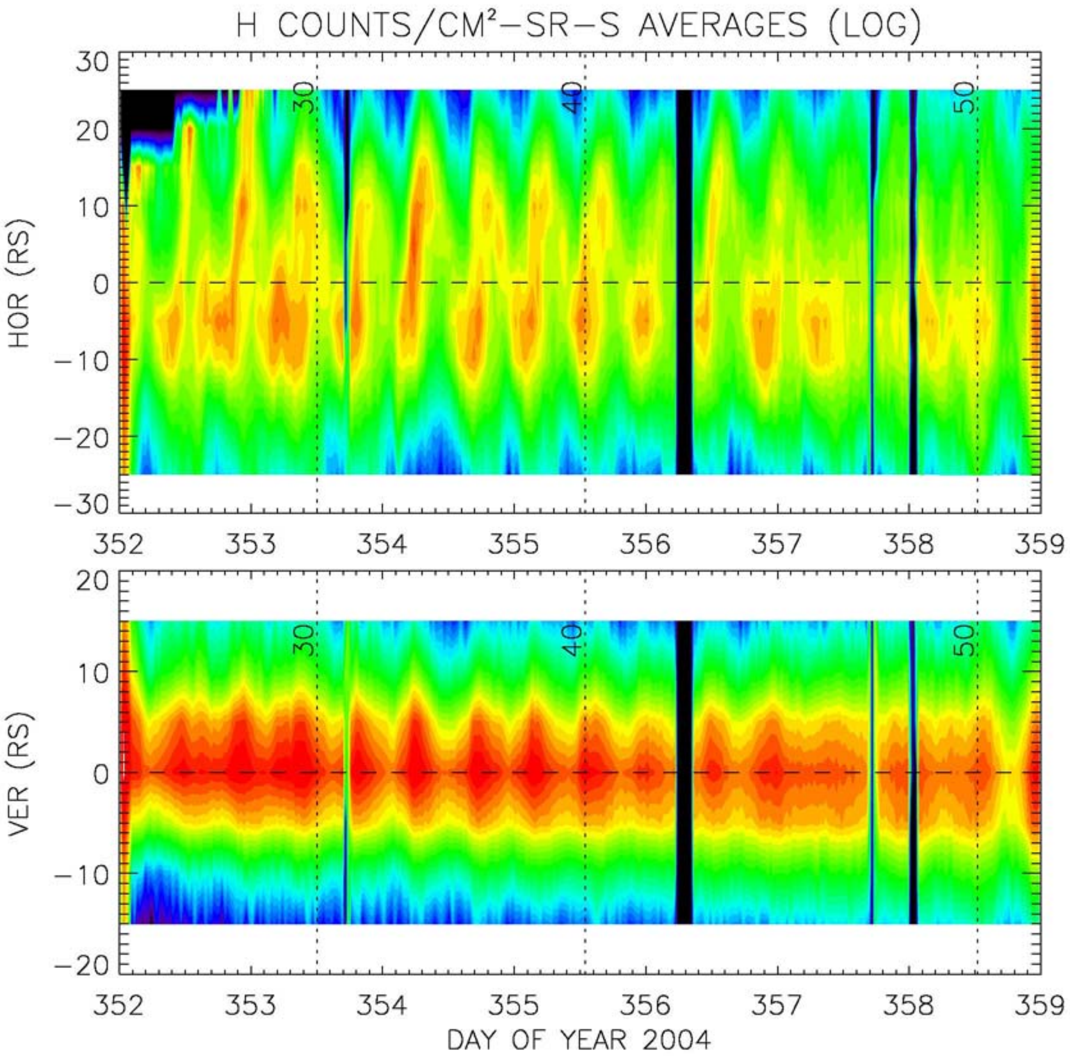


The results– convection speeds as a function of radial distance. The solid squares indicate the convection speeds from the convected κ fits, while the diamonds indicate speeds from a moment analysis of plasma data. The orange dashed line is rigid corotation. Most of the speeds tend to lag corotation, although there are some interesting variations.

Stacked Profiles for H (20-50 keV)

This shows 1/2 hour averages of the ENA "stacked" profiles: the top panel shows the horizontal profiles resulting from vertical summation, while the bottom panel shows the vertical profiles resulting from horizontal summation. These data come from the same time period examined by Paranicas et at (2005).

Periodicities are clearly evident. A type of "cork screw" pattern emerges in the horizontal profiles. Similar patterns emerge for other time periods, although gaps in the coverage tend to obscure them.

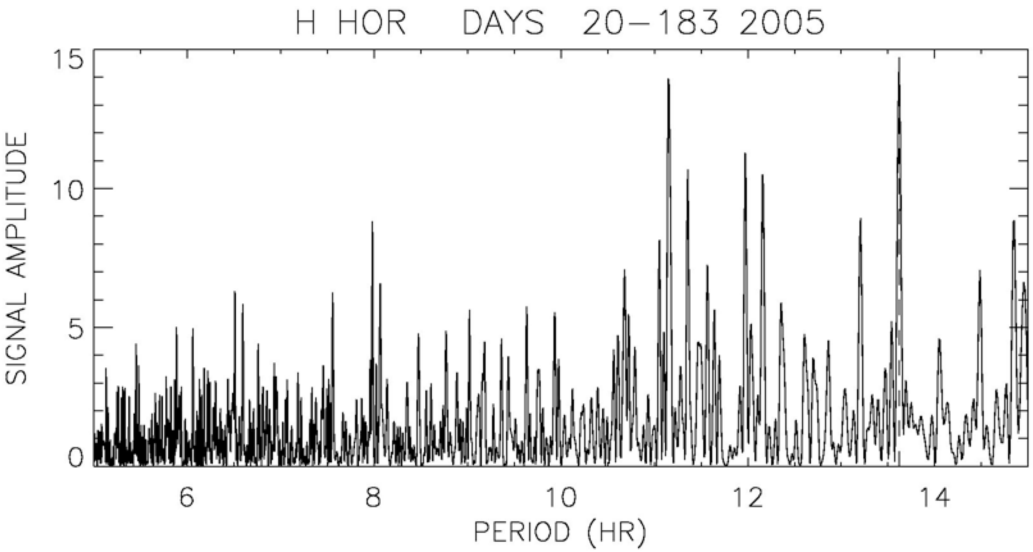


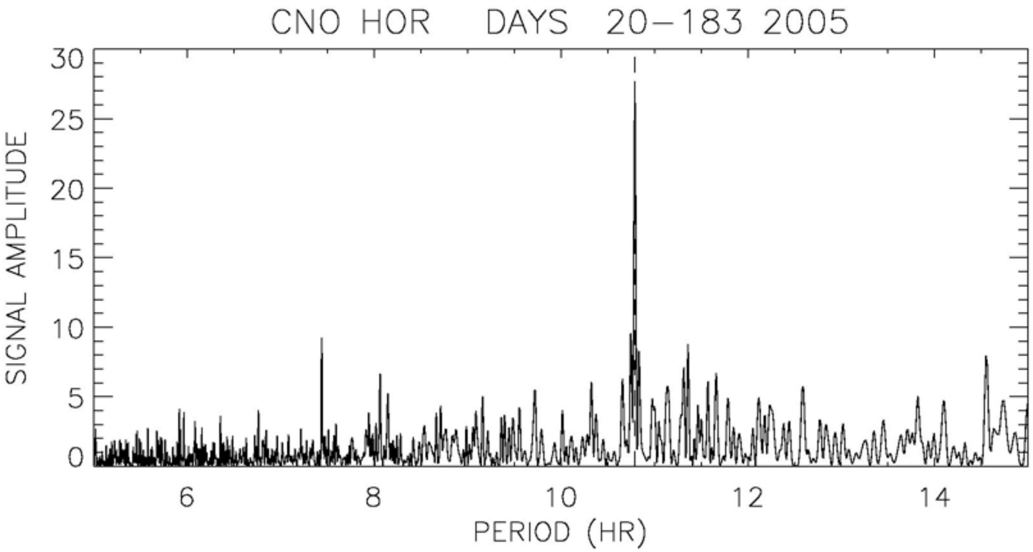
Lomb Periodograms of the Stacked Profiles

What periodicities emerge from these stacked profiles? Apply a Lomb analysis to long time periods. In this case, use the "center" the horizontal stacks (where, in theory, the Compton Getting effect should vanish because θ=90°).

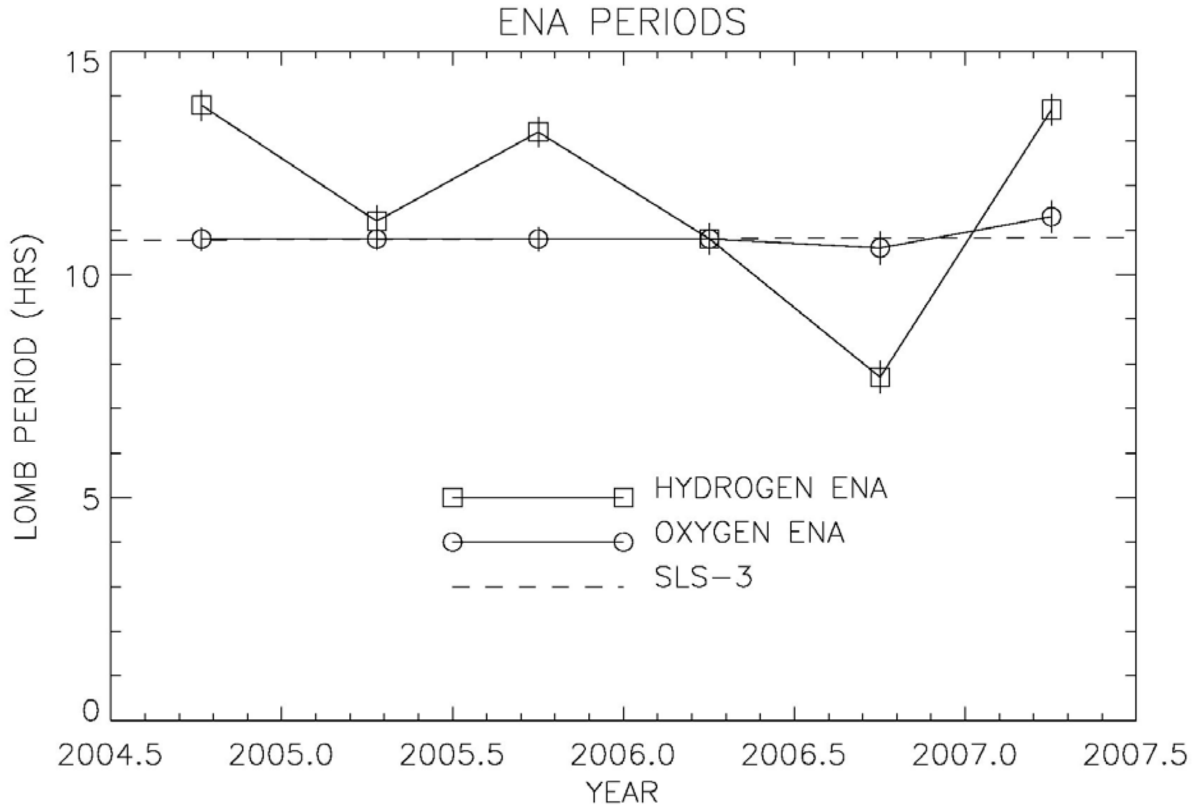
Top panel shows the Lomb periodogram for 20-50 keV H for the first half of 2005. NO strong periodicity emerges, just a lot of noise. Strongest peak is at 13.6 hours.

Bottom panel shows Lomb periodogram for 64-144 keV O for same interval. A VERY strong peak emerges with a period of 10.8 hours— exactly the same as charged particles in outer magnetosphere.





ENA Periods



This figure summarizes the H and O periodicities from Lomb analyses from the middle of 2004 through the middle of 2007. For comparison, the SLS-3 (SKR) period is plotted as a dashed line. The O periods are very close to the SKR period of ~10.8 hours, while the H periods are scattered wildly about this value. Basically, the H has no single period, while O has!

Questions/Comments

Why do the ENA signatures (as well as many others--SKR, energetic particles 20-60 Rs, magnetic field 3-12 Rs, plasma density between 3-5 Rs) show a persistent periodicity at a well defined, slowly varying frequency*?

* SKR results now show two periods present at the same time.

The driving mechanism must be only loosely coupled to the interior.

The driving mechanism is likely not bound to the magnetosphere (i.e., the plasma velocity does not keep pace with the disturbance).

This leaves the ionosphere; but given the variation in coupling coefficient between the atmosphere and the ionosphere with latitude, how does a disturbance in the ionosphere affect a broad range of radii/latitudes at the same period?

Questions/Comments

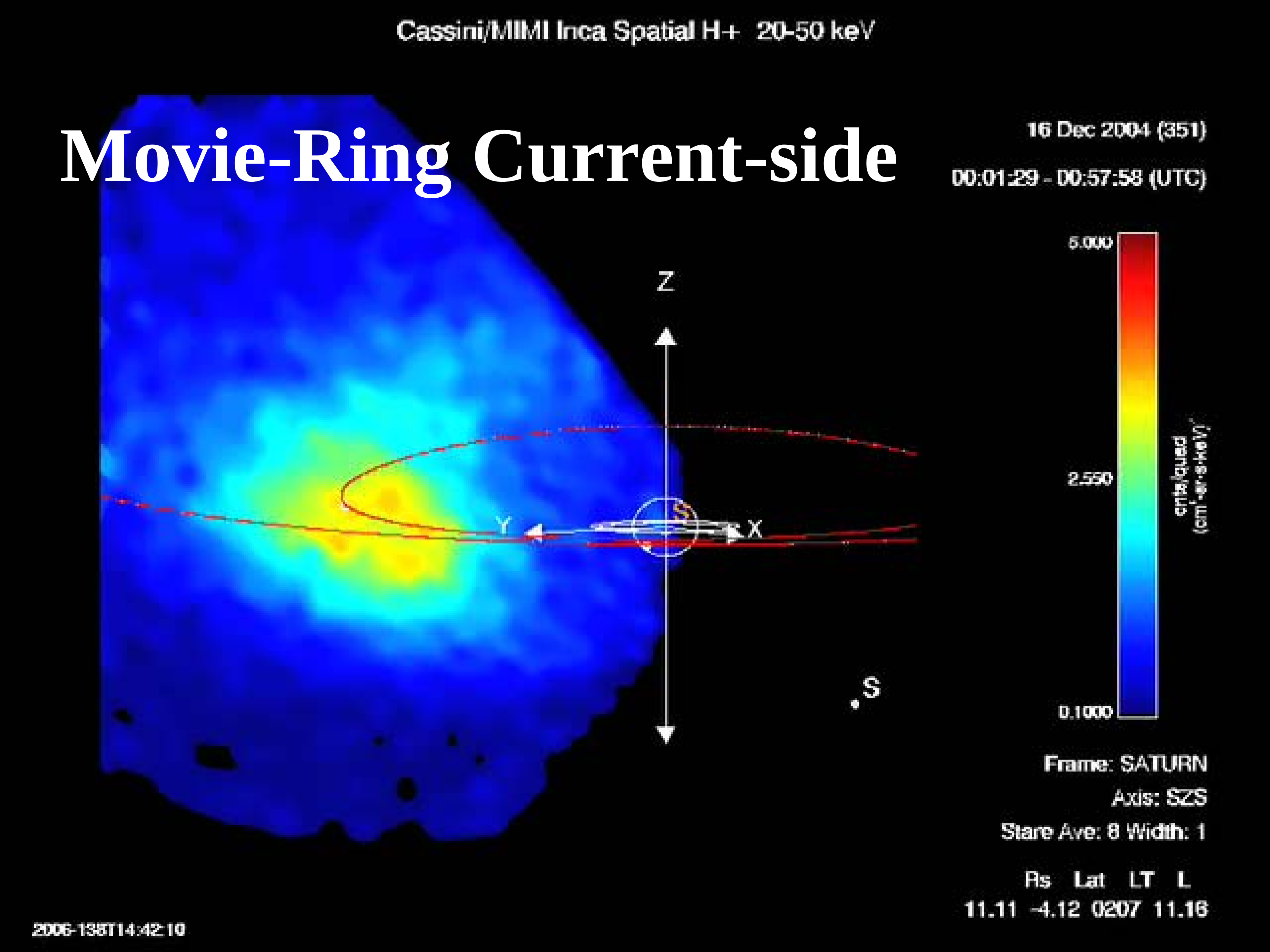
Is there a preferred latitude in the ionosphere that couples closely to a magnetospheric feedback loop, that then reinforces the disturbance at that latitude (Kivelson)?

Is the “unbalanced load” the driver (Gurnett)?

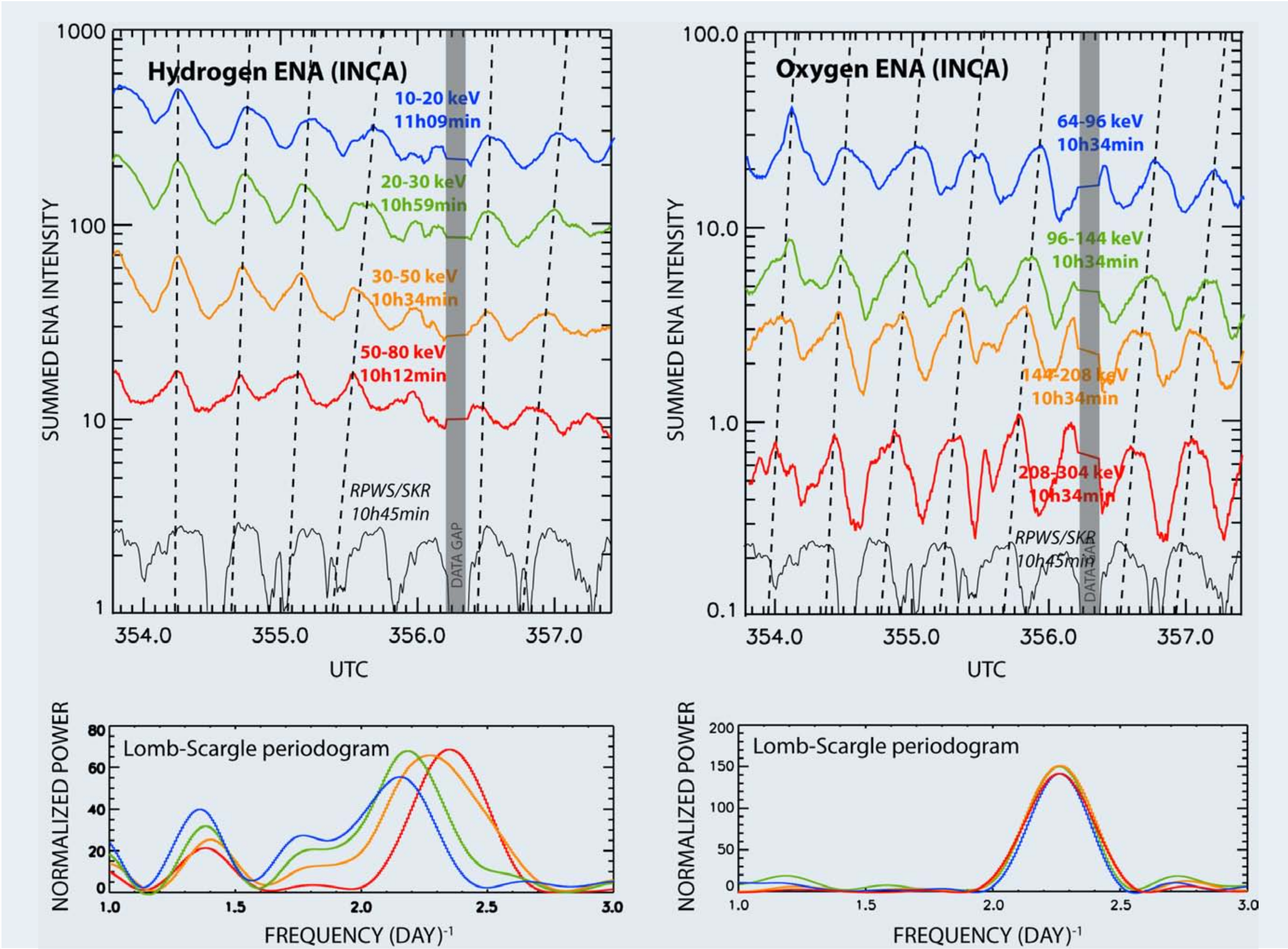
Is there another mechanism (Southwood; Khurana)?

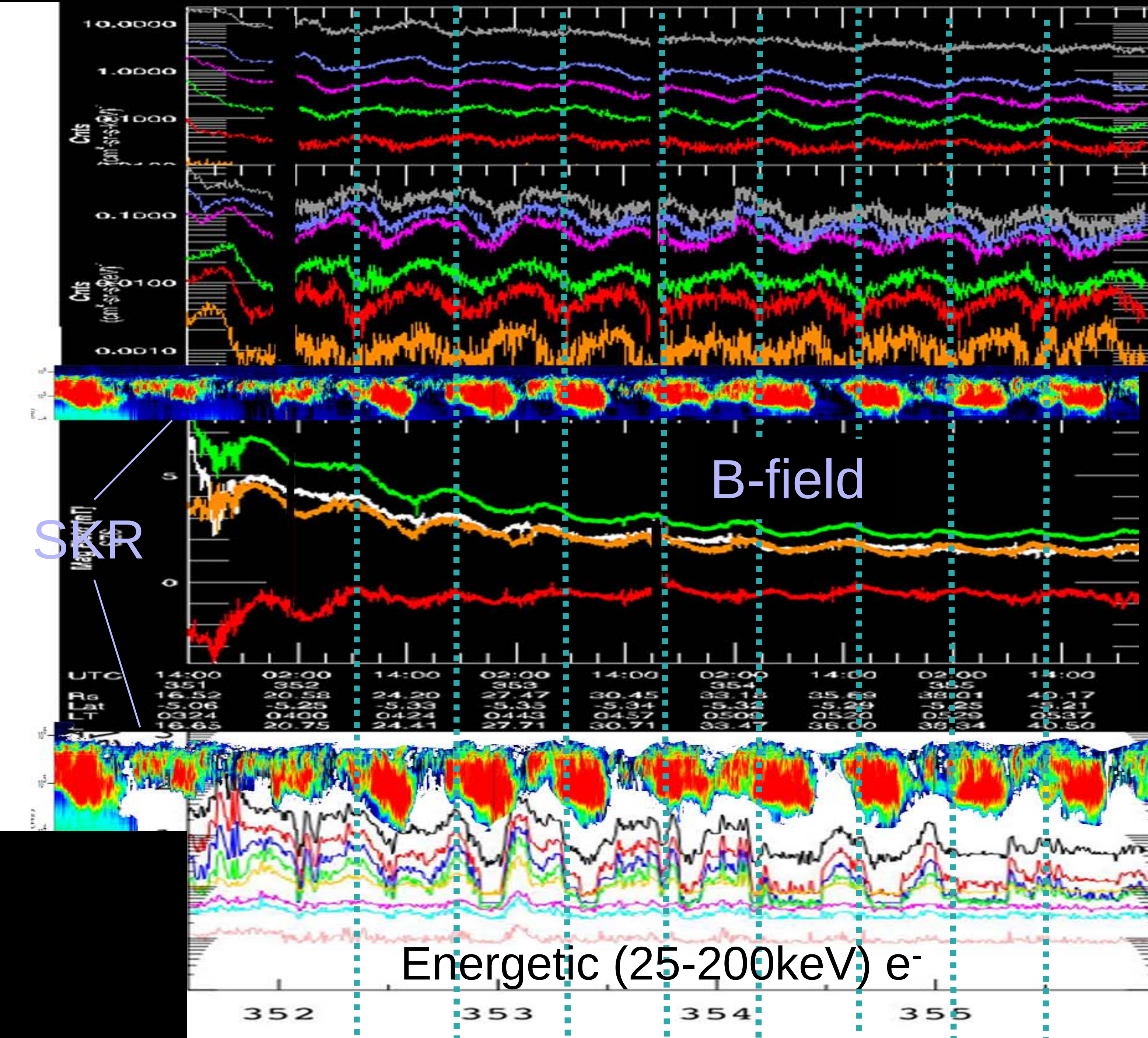
We still don’t have an answer, but energetic particles (particularly oxygen) tend to be energized on every rotation, preferentially at a particular SKR longitude *and* local time. This is likely caused by a current structure in the magnetosphere set up by (your choice--ionosphere, unbalanced load, probably not a magnetic anomaly) that triggers an instability in the middle magnetosphere (10-20 Rs) and energizes particles.

Movie-Ring Current-side



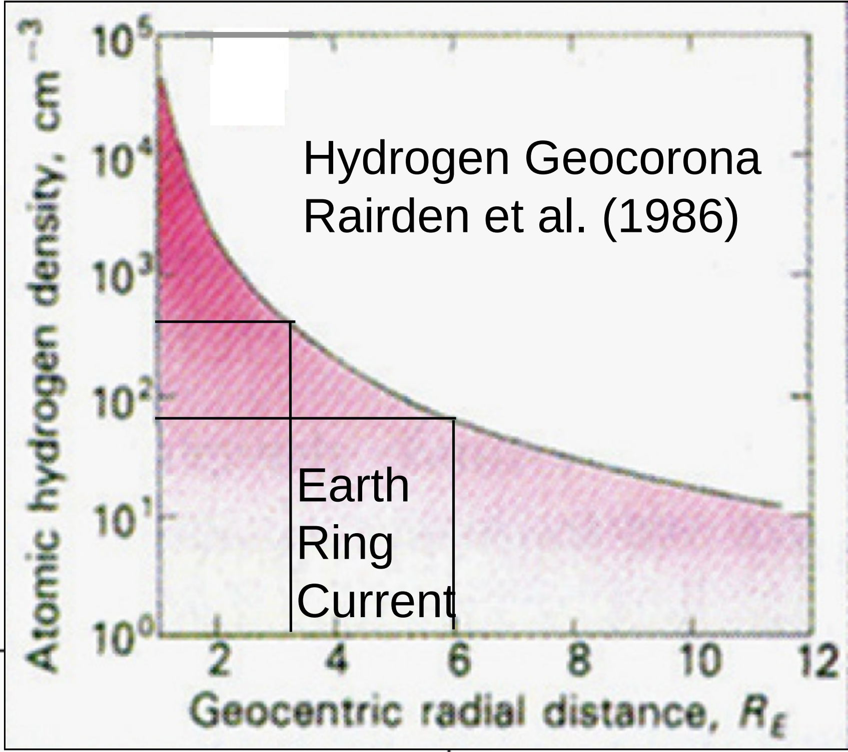
OXYGEN Period is about the same over the energy range consistent with the observed constant dispersion.

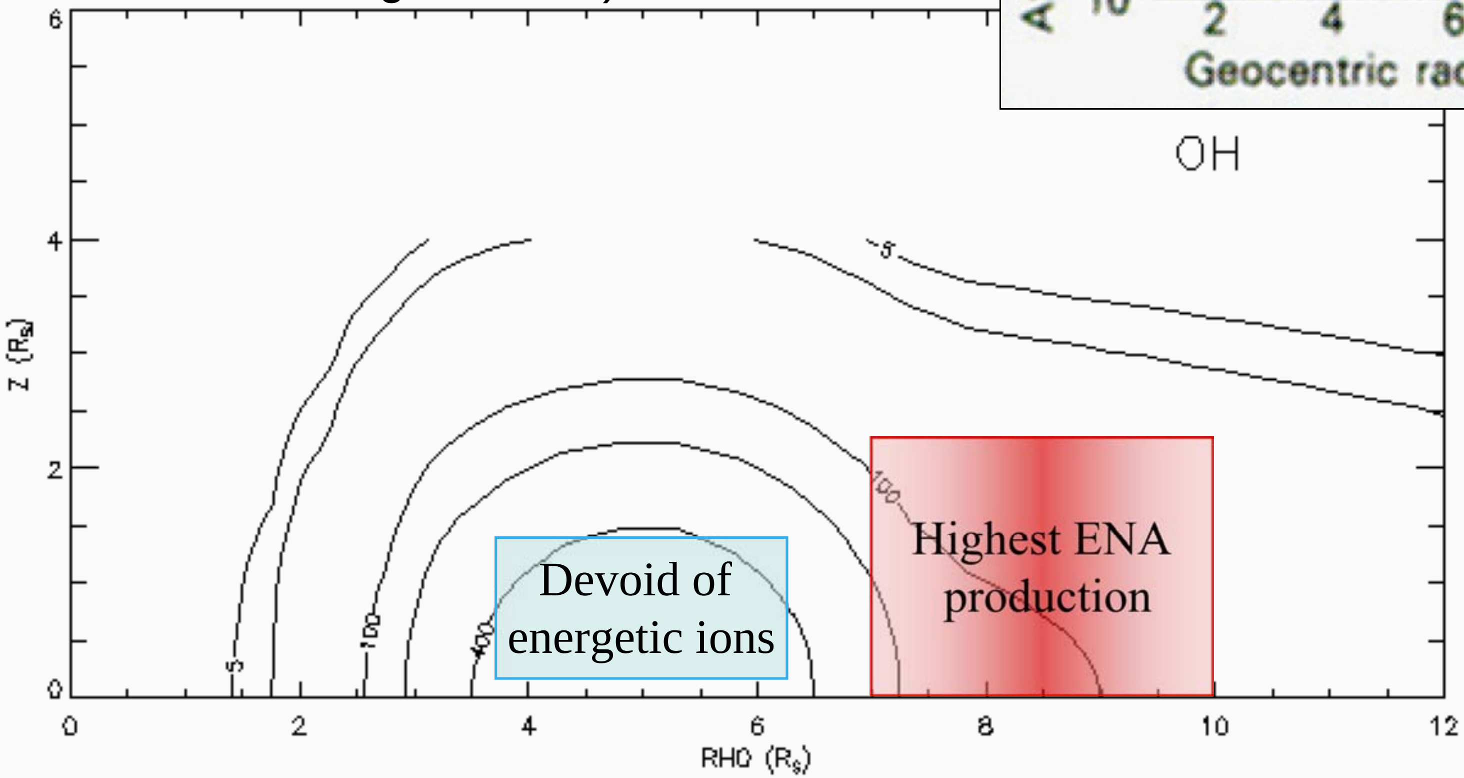




With what else does the ENA oscillation correlate?

The density of OH in the 6-10 Rs region is comparable to H density in the Geocorona. O is probably about the same as OH. O+ lifetime in the Earth's ring current is ~ 8h. O+ lifetime in the inner Saturn magnetosphere could be much shorter, depending on its radial placement (O, OH charge-exchange cross-section is larger than H)

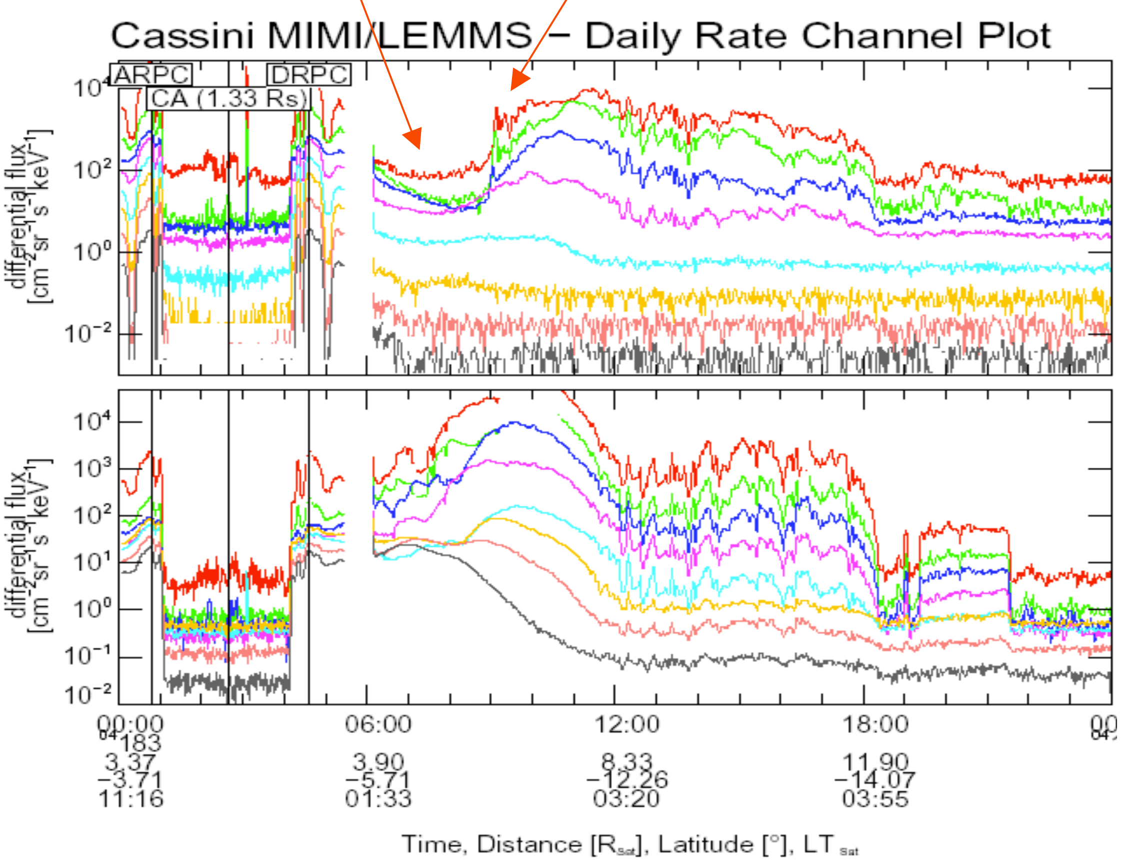


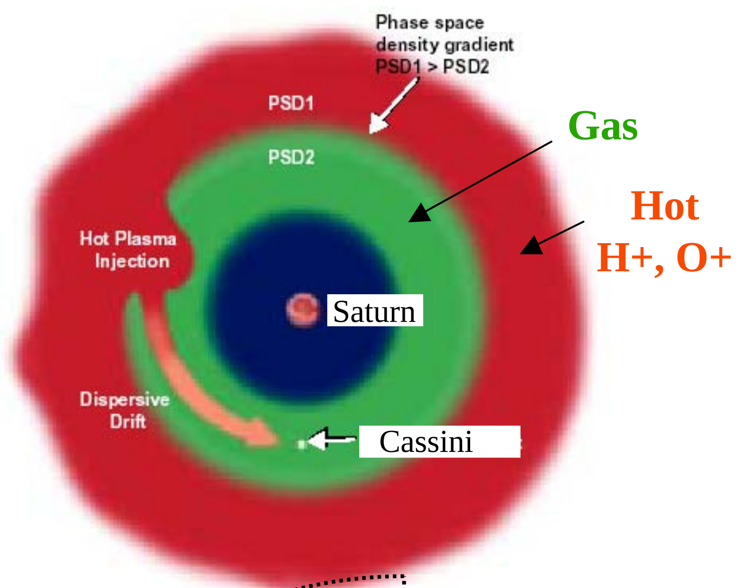


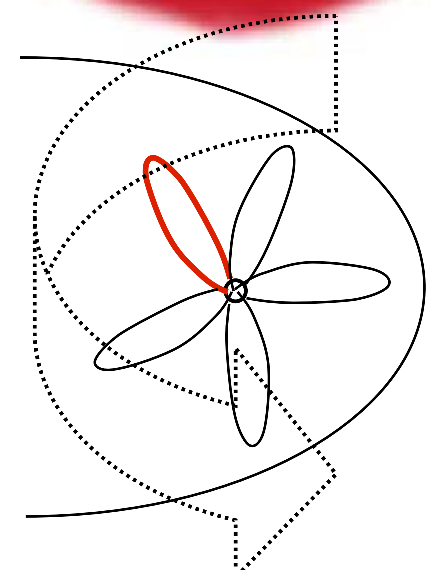
Modulation persistence and phase lock suggest an “active” longitude (could be a quadrant) coupled with a preferred local time for ion injection

Neutral Gas?

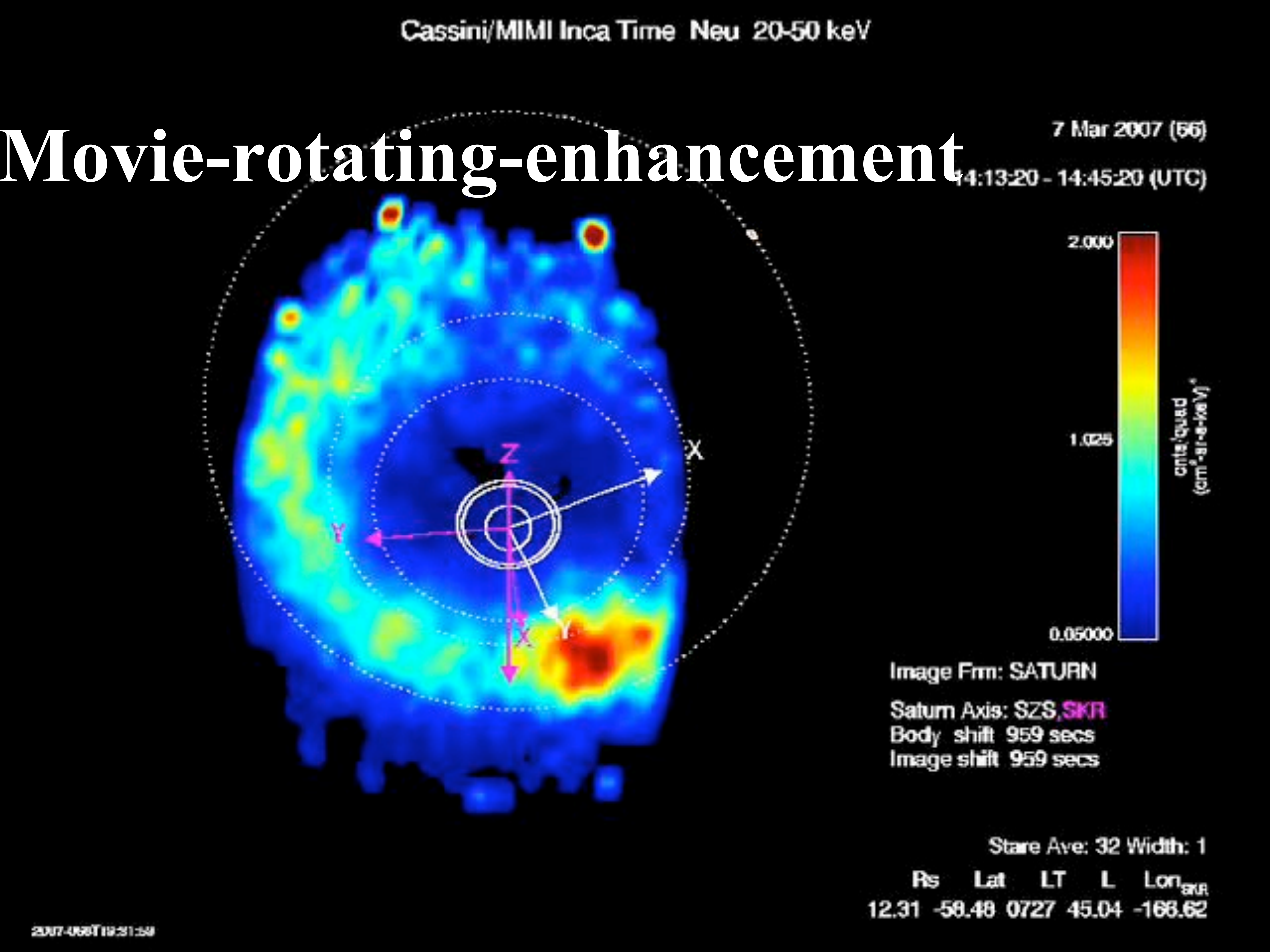
Ion Dispersion Event

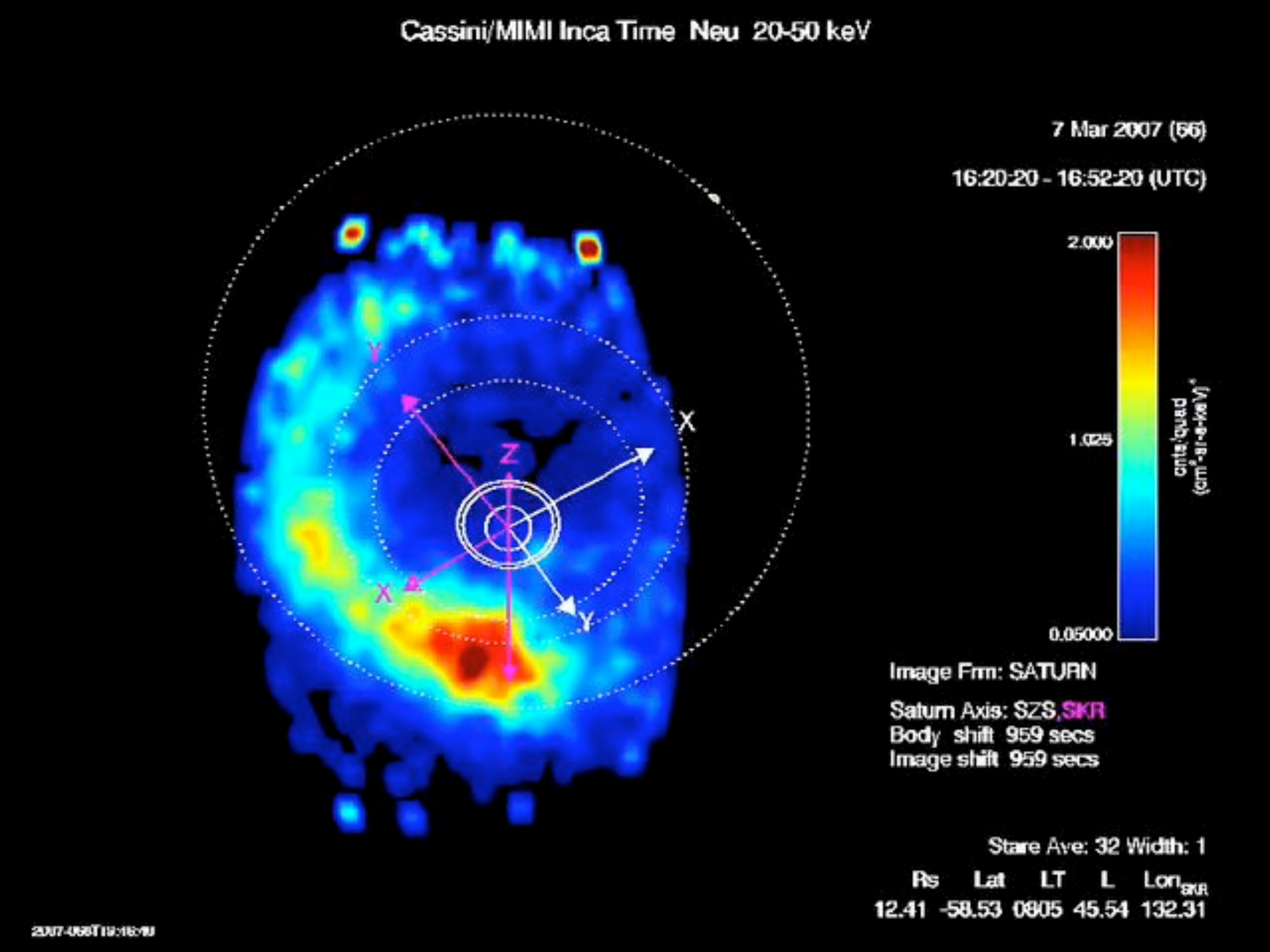


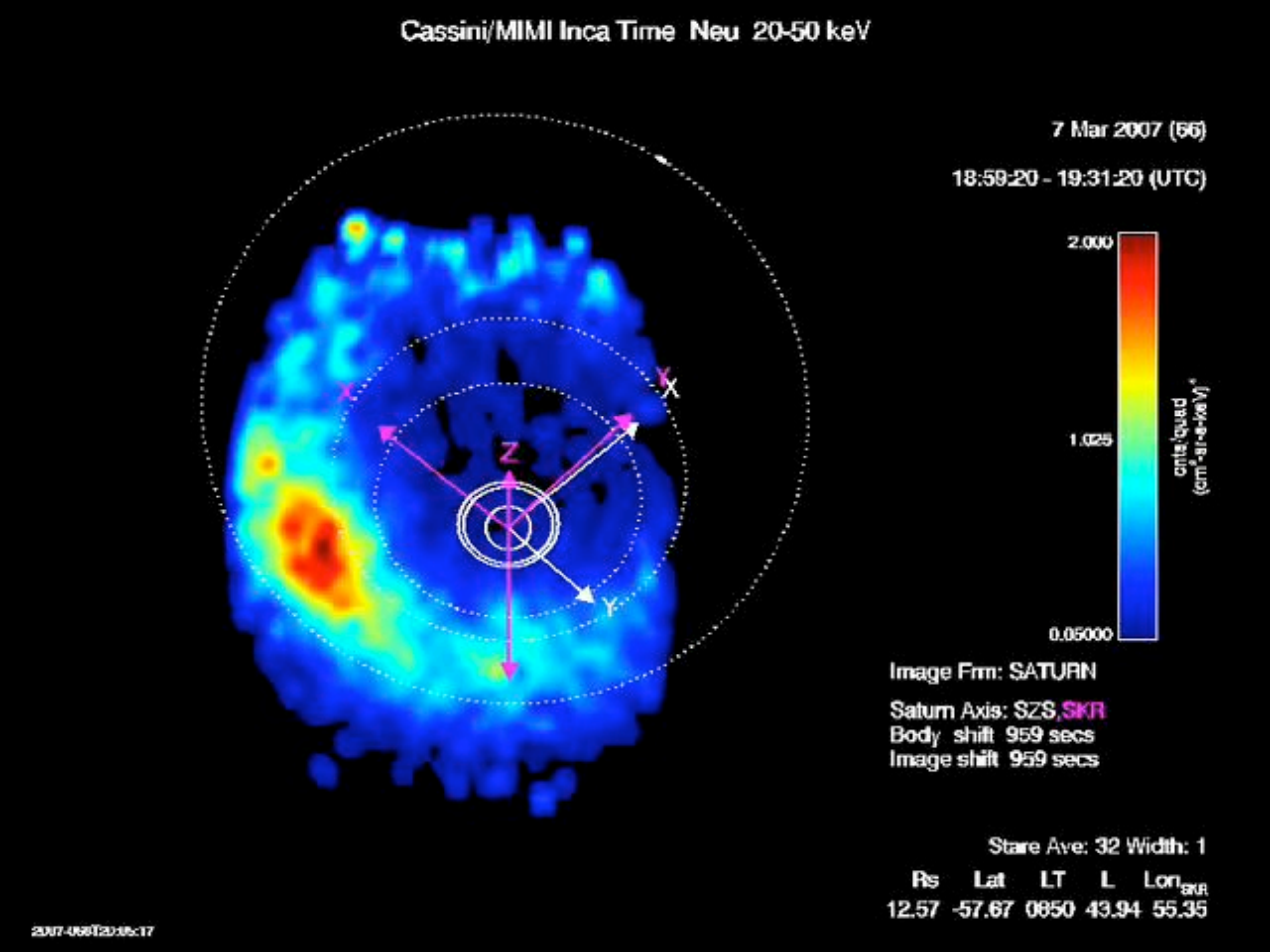




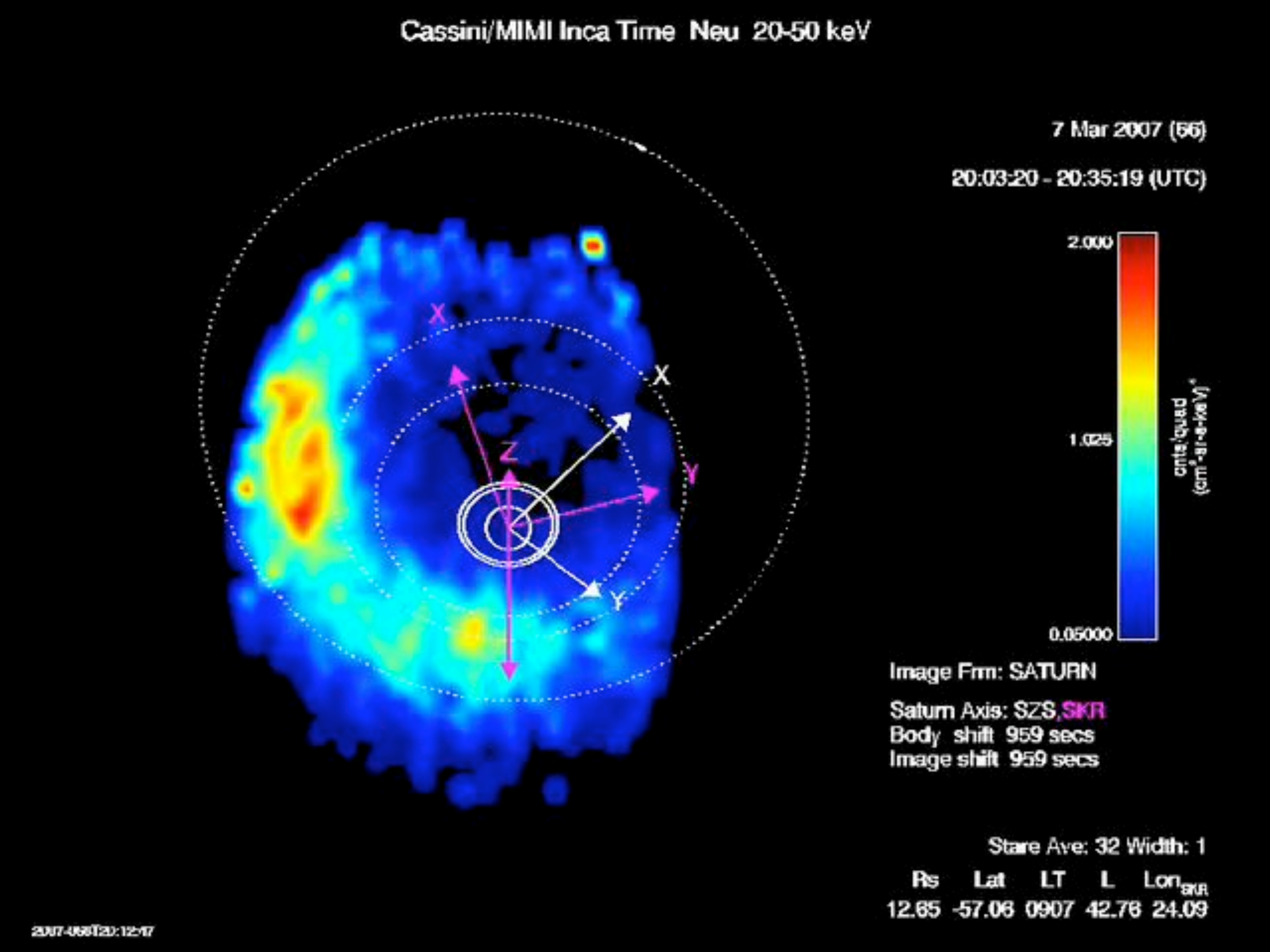
Movie-rotating-enhancement




Cassini/MIMI Inca Time Neu 20-50 keV
7 Mar 2007 (66)
16:20:20 - 16:52:20 (UTC)
2.000
1.025
0.05000
Y
X
Z
X
Y
Image Frm: SATURN
Saturn Axis: SZS,SKR
Body shift 959 secs
Image shift 959 secs
Stare Ave: 32 Width: 1
Rs Lat LT L Lon SKR
12.41 -58.53 0805 45.54 132.31

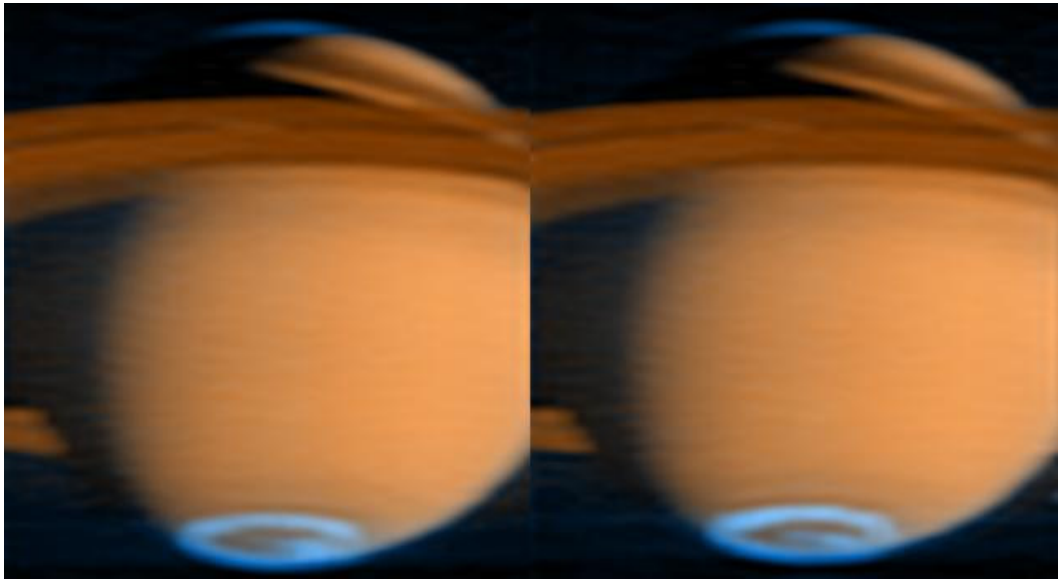


Cassini/MIMI Inca Time Neu 20-50 keV
7 Mar 2007 (66)
18:59:20 - 19:31:20 (UTC)
2.000
1.025
0.05000
cnts/quad
(cm²-sr-s-keV)⁻¹
Z
X
Y
Image Frm: SATURN
Saturn Axis: SZS,SKR
Body shift 959 secs
Image shift 959 secs
Stare Ave: 32 Width: 1
Rs Lat LT L Lon SKR
12.57 -57.67 0850 43.94 55.35

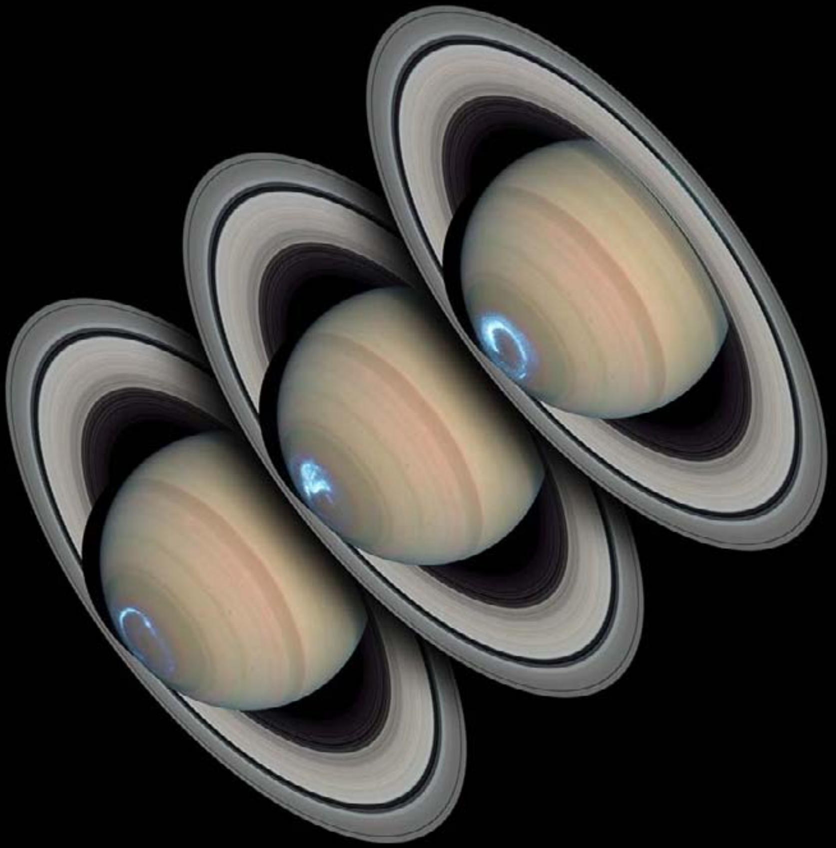

Cassini/MIMI Inca Time Neu 20-50 keV
7 Mar 2007 (66)
20:03:20 - 20:35:19 (UTC)
2.000
1.025
0.05000
X
Y
Z
Image Frm: SATURN
Saturn Axis: SZS,SKR
Body shift 959 secs
Image shift 959 secs
Stare Ave: 32 Width: 1
Rs Lat LT L Lon$_{SKR}$
12.65 -57.06 0907 42.76 24.09

Science Highlights - Aurora

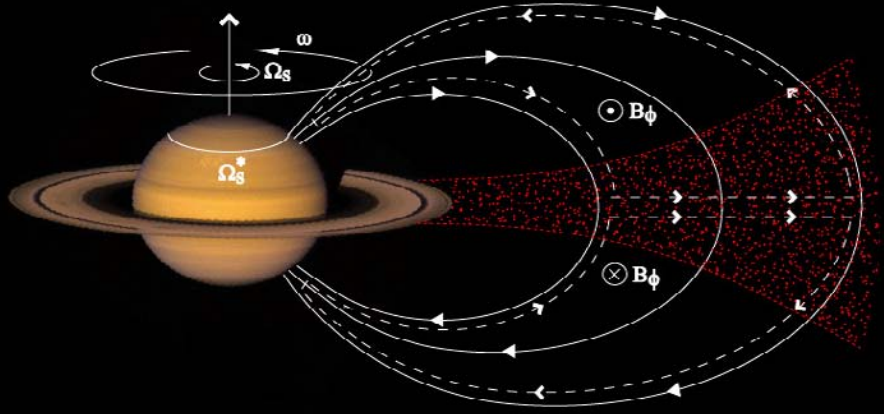
- Images taken on June 21, 2005, with Cassini's Ultraviolet Imaging Spectrograph (UVIS) are the first from the mission to capture the entire "oval" of the auroral emissions at Saturn's south pole. In the side-by-side, false-color images, blue represents aurora emissions from hydrogen gas excited by electron bombardment, while red-orange represents reflected sunlight. The images show that the aurora lights at the polar regions respond rapidly to changes in the solar wind. Changes in the emissions inside the Saturn south-pole aurora are visible by comparing the two images, taken about one hour apart. The brightest spot in the left aurora fades, and a bright spot appears in the middle of the aurora in the second image.



Aurora



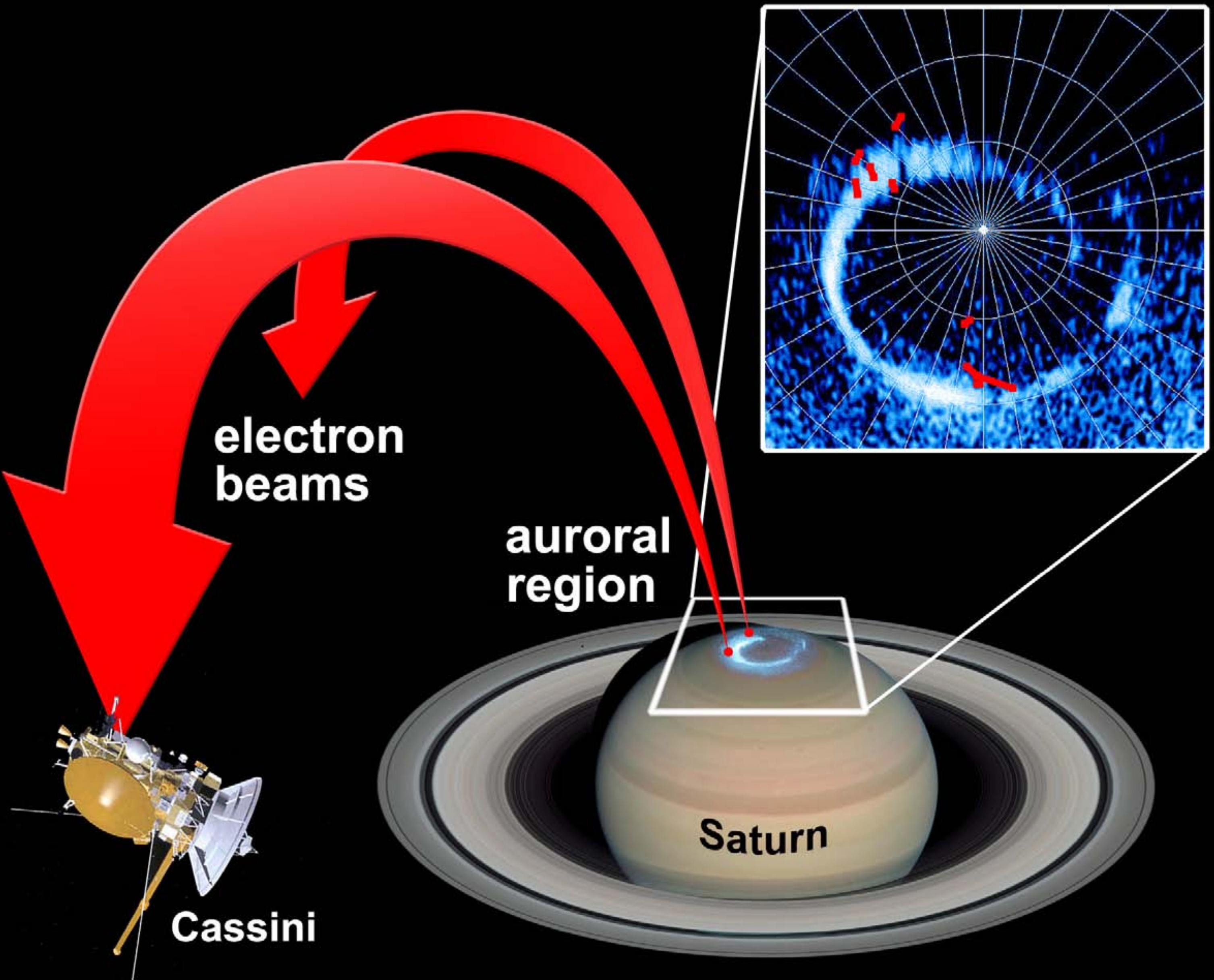
Clarke et al.

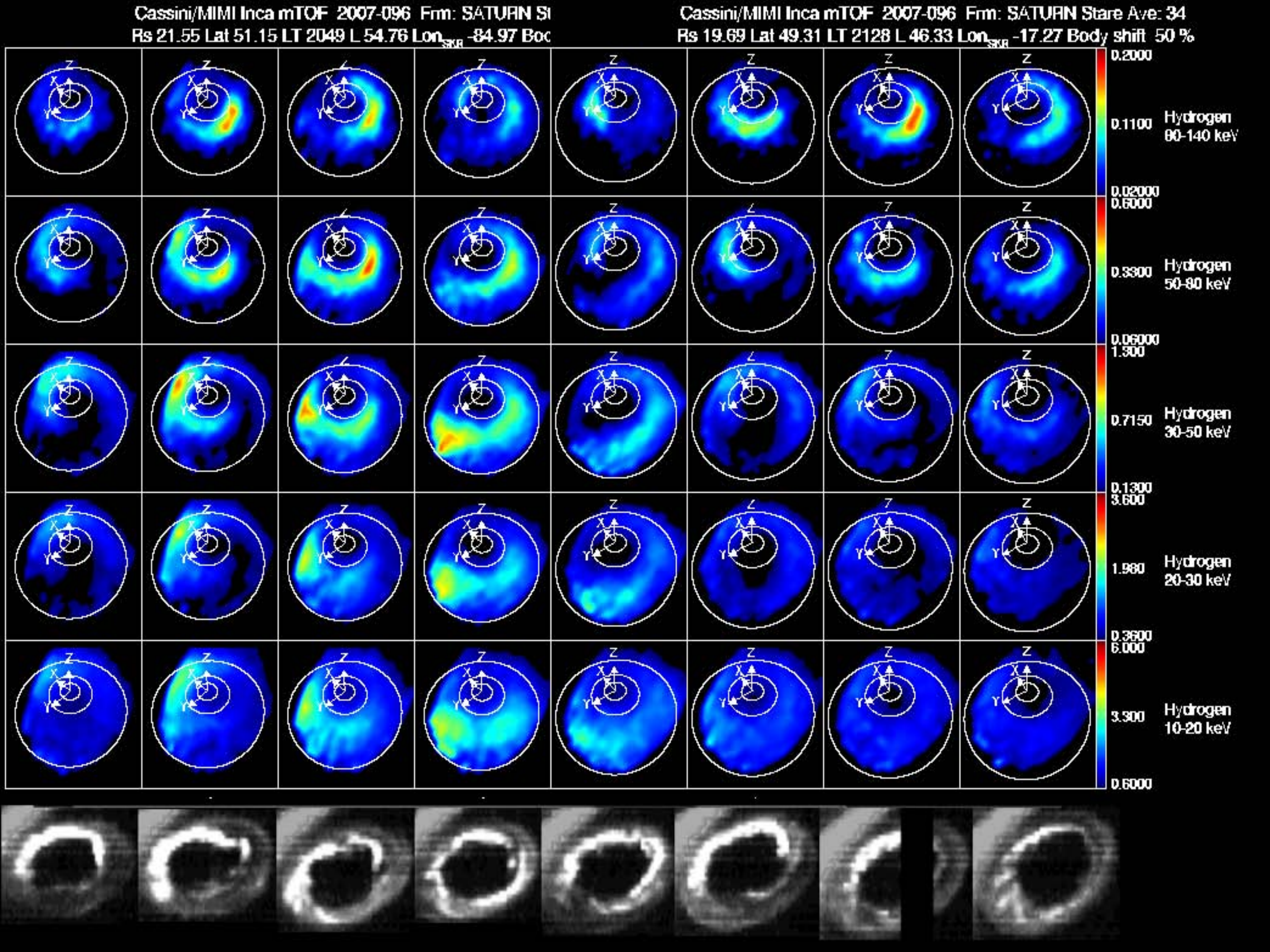


Field-aligned currents associated with precipitating particle fluxes are responsible for the aurora.
The MAPS instruments (CAPS, MAG, MIMI, RPWS) did find these precipitating beams.

Electron Beams moving away from Saturn

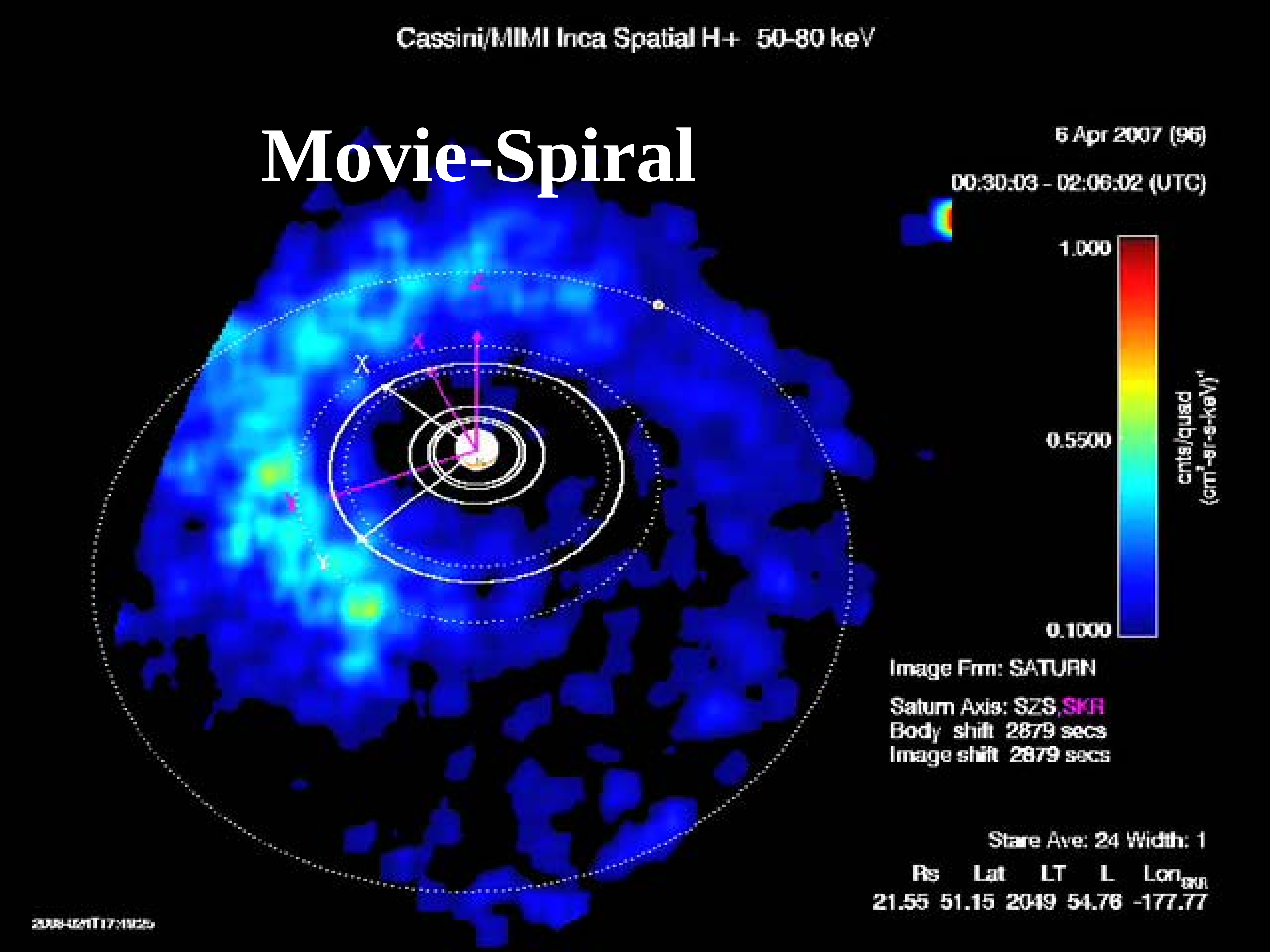
(Saur et al, Nature, Feb. 9, 2006)

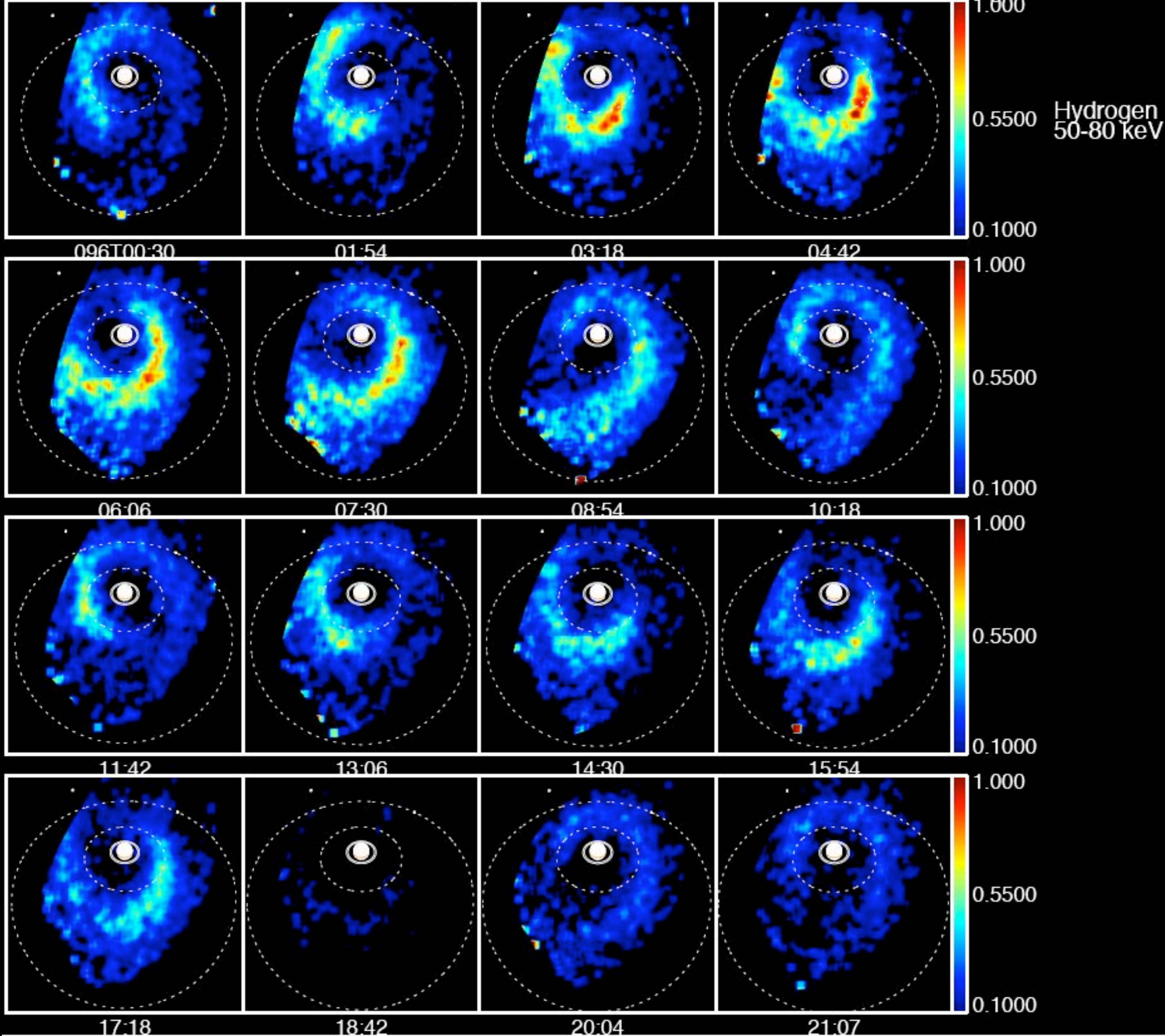




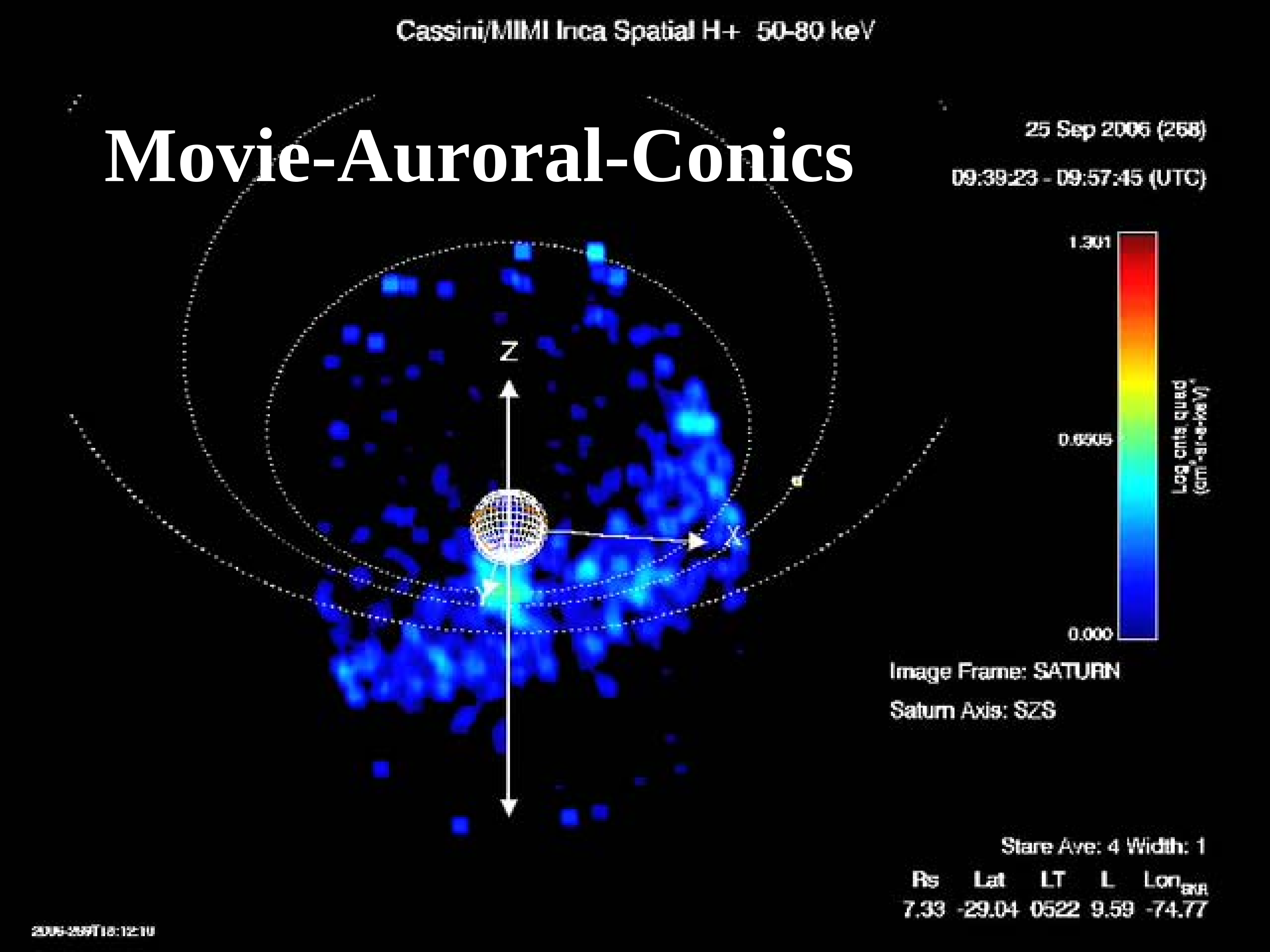
Cassini/MIMI Inca mTOF 2007-096 Fm: SATURN St
Rs 21.55 Lat 51.15 LT 2049 L 54.76 Lon$_{SKR}$ -84.97 Boc
Cassini/MIMI Inca mTOF 2007-096 Fm: SATURN Stare Ave: 34
Rs 19.69 Lat 49.31 LT 2128 L 46.33 Lon$_{SKR}$ -17.27 Body shift 50 %
0.2000
0.1100
0.02000
Hydrogen 80-140 keV
0.6000
0.3300
0.06000
Hydrogen 50-80 keV
1.300
0.7150
0.1300
Hydrogen 30-50 keV
3.600
1.980
0.3600
Hydrogen 20-30 keV
6.000
3.300
0.6000
Hydrogen 10-20 keV

Movie-Spiral




Hydrogen
50-80 keV
1.000
0.5500
0.1000
096T00:30
01:54
03:18
04:42
06:06
07:30
08:54
10:18
11:42
13:06
14:30
15:54
17:18
18:42
20:04
21:07

Movie-Auroral-Conics



- For the rotation modulation of the various magnetospheric observables, we favor an explanation based on a rotating ionospheric conductance anomaly, coupled to the atmosphere, but slipping relative to the clouds. Changes in the observed rotation frequency may be explained by variations in coupling, as the conductance varies in response to solar UV and feedback from the magnetosphere in the form of field-aligned currents.

- Manifestations of that rotation seen throughout the magnetosphere are probably communicated via field-aligned currents, and propagate as a standing wave in the otherwise symmetric dipole field.

- There are many clues to the mechanism, but no one has yet combined them all into a generally accepted model.

Speeds from Charged Particles