Neutral/ Plasma Interactions (in a magnetosphere)

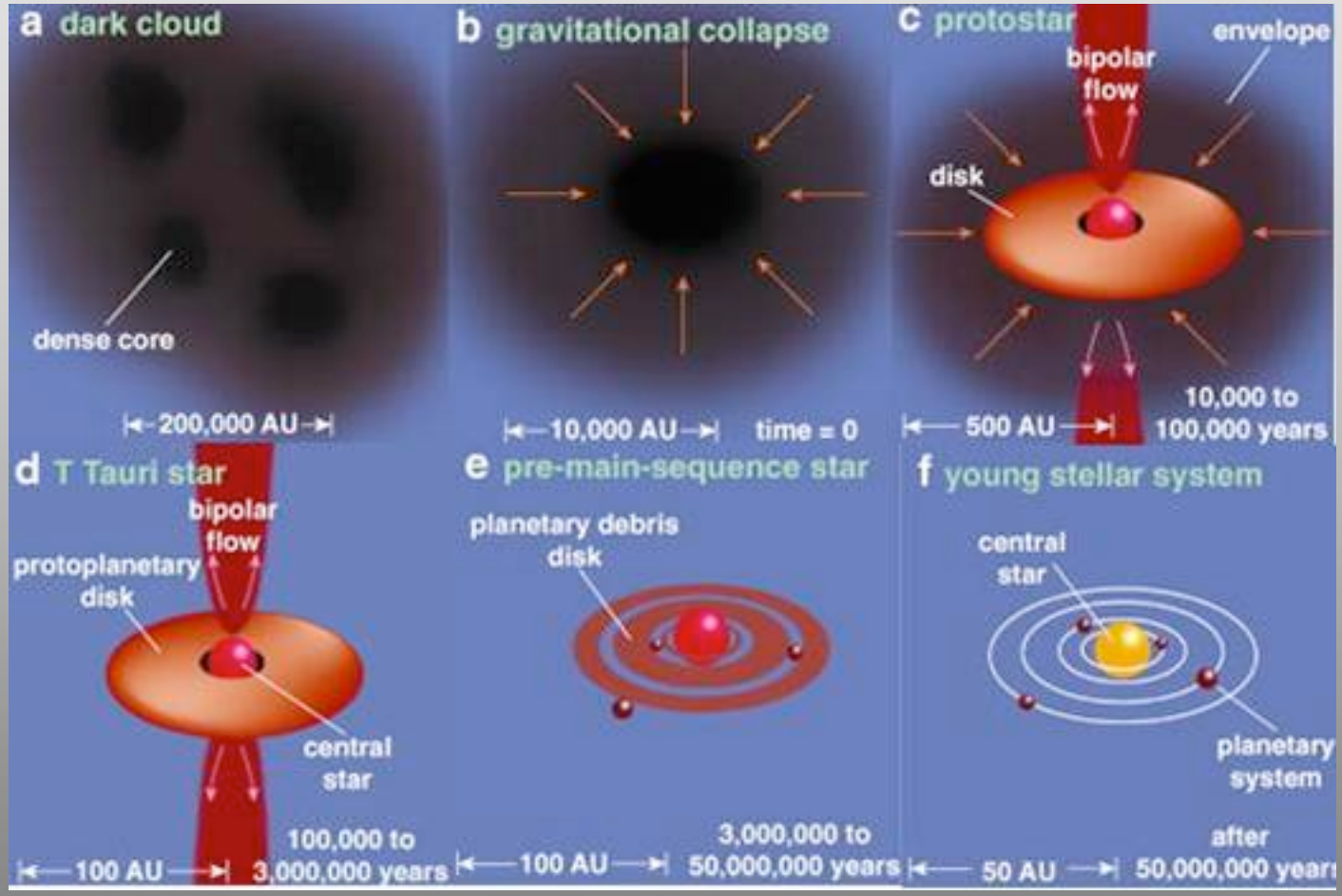
Bob Johnson

University of Virginia + NYU

Recalibrate yourselves!

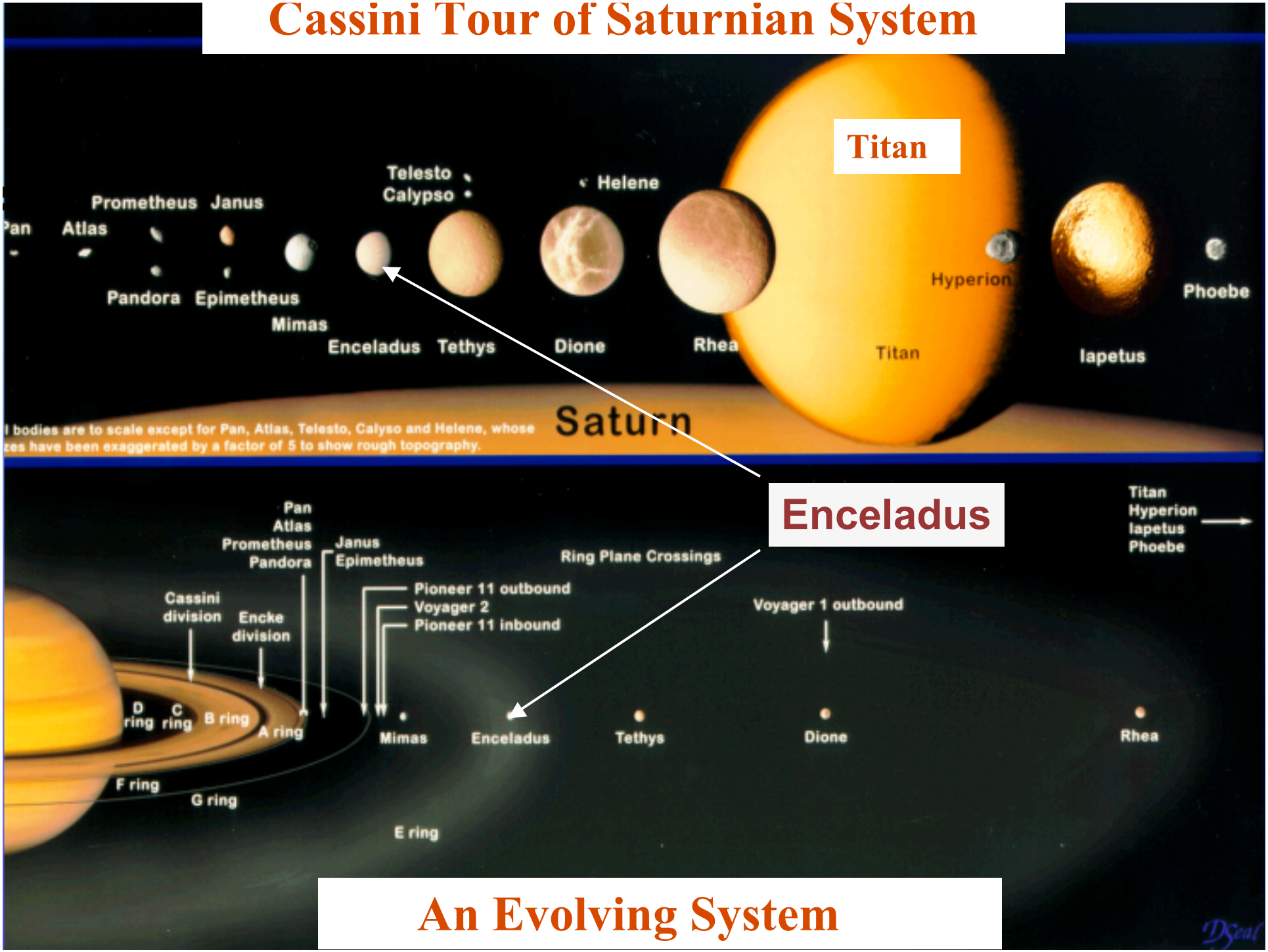
10^{51} ergs → eV- keV

Star + Planet Formation

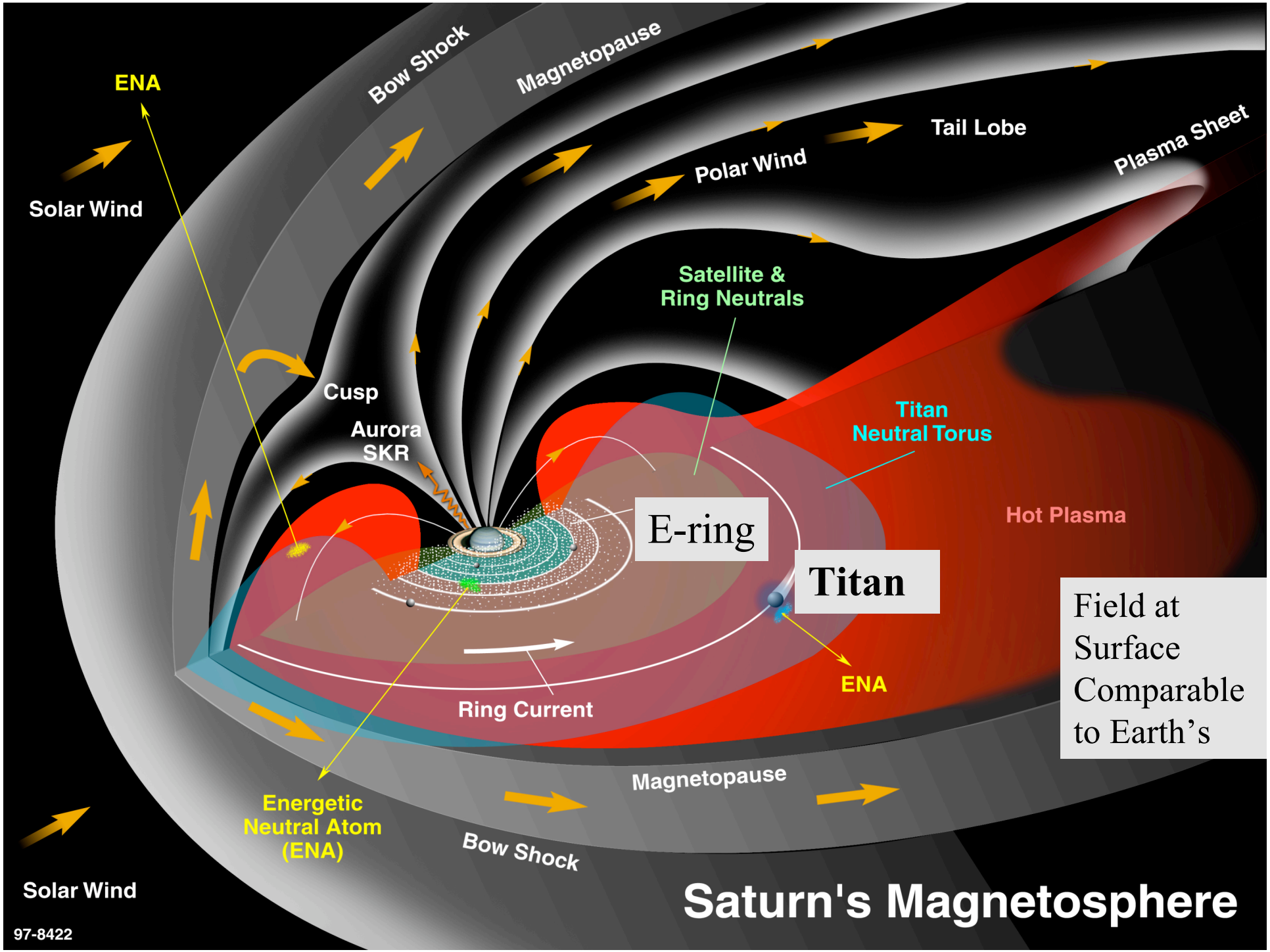


Debris and Gas Disks in a Magnetic Field

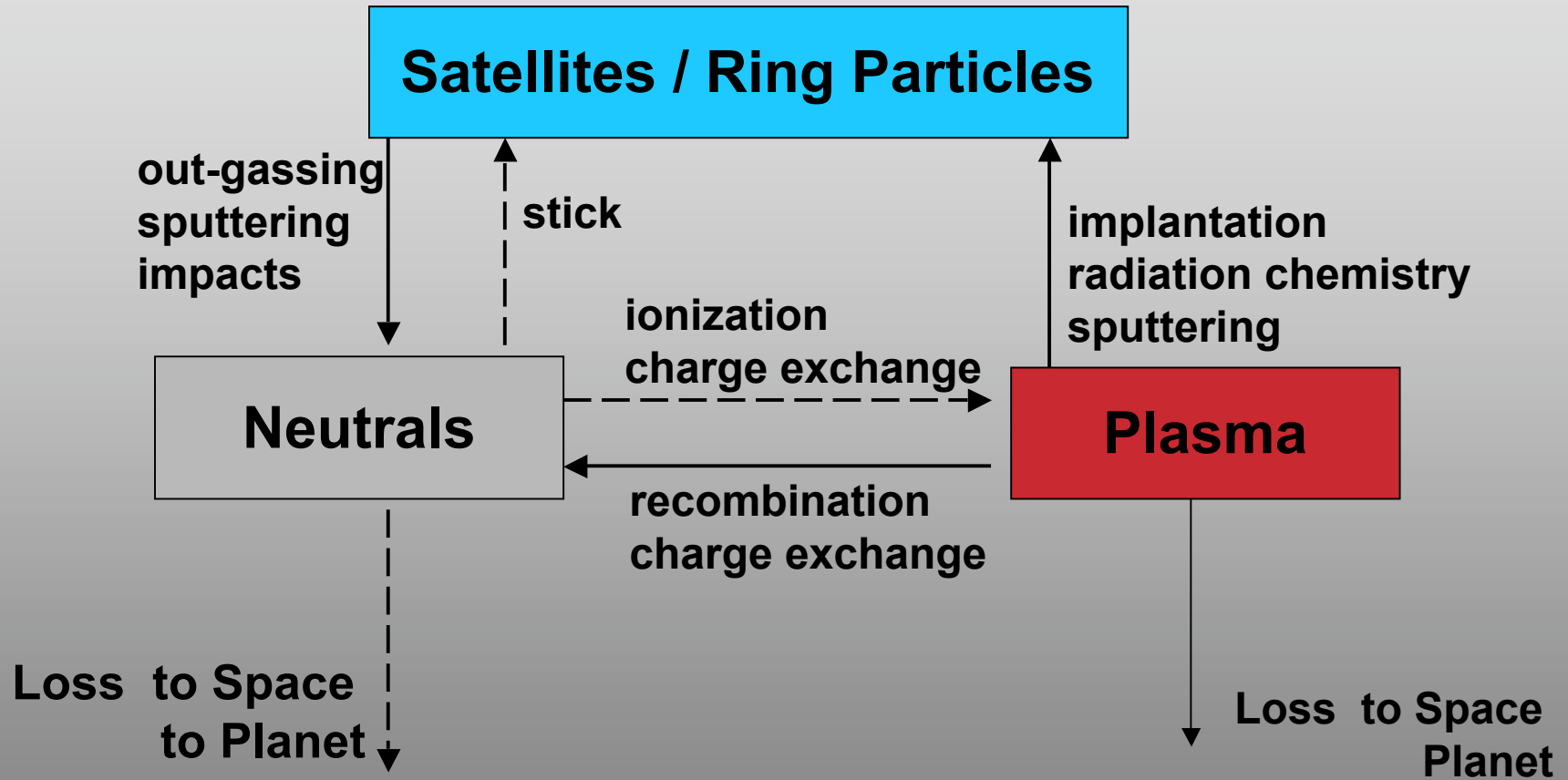
Cassini Tour of Saturnian System



An Evolving System


ENA
Bow Shock
Magnetopause
Solar Wind
Polar Wind
Tail Lobe
Plasma Sheet
Satellite &
Ring Neutrals
Cusp
Aurora
SKR
Titan
Neutral Torus
Hot Plasma
E-ring
Titan
Field at
Surface
Comparable
to Earth's
ENA
Ring Current
Magnetopause
Energetic
Neutral Atom
(ENA)
Bow Shock
Solar Wind
97-8422
Saturn's Magnetosphere

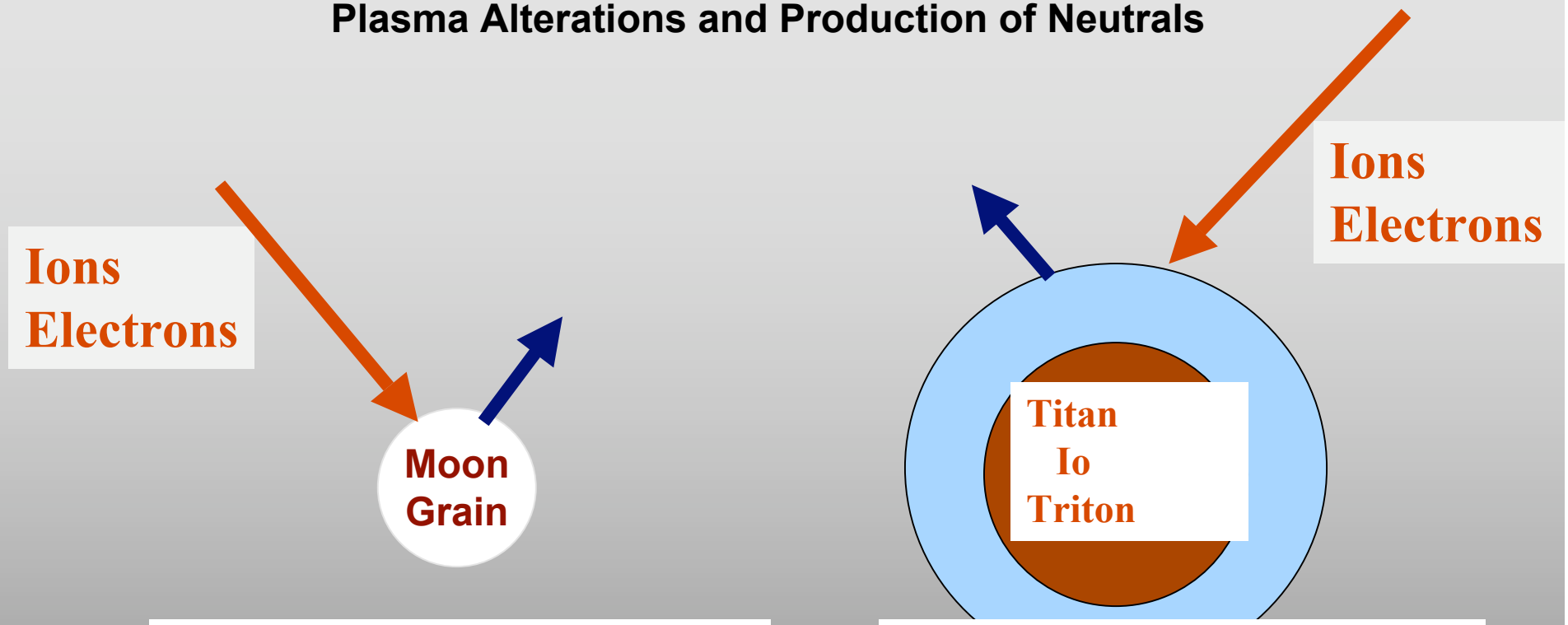
Neutrals in a Magnetosphere



Plasma Composition → Imbedded Material

Plasma Neutral Interactions Clear out Magnetosphere

Plasma Alterations and Production of Neutrals



Sputtering/ Chemistry on a Surface

Heating/ Sputtering of an Atmosphere

Collision Cross Sections, Radiation Chemistry Simulations for Gases and Surfaces

Plasma-Induced Removal of Satellite Atmospheres

Large Moons	Plasma Pressure 10^{-9} N/m^2	Atmospheric Loss* (Titan Atmos.)
Jovian		
Io*	1800	30
Europa	140	2
Ganymede	20	0.3
Callisto	2	0.03
Saturnian		
Titan*	0.2	0.01

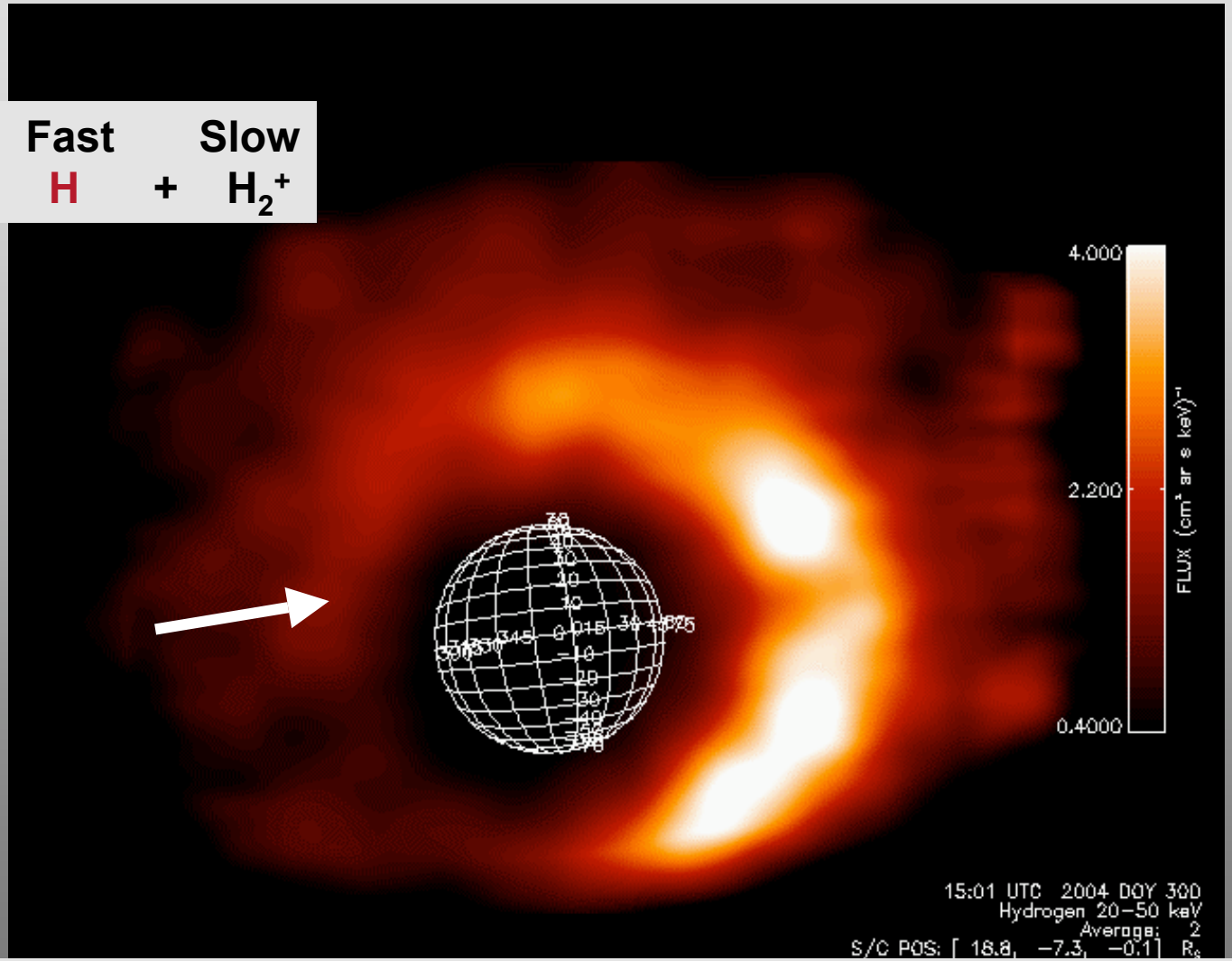
Johnson Ap.J. L. 2004

Energetic Neutral Image of Titan's Escaping Corona

Cassini: MIMI-INCA

Dandouras et al. 2006

Fast		Slow		Fast		Slow
H^+	+	H_2	→	H	+	H_2^+

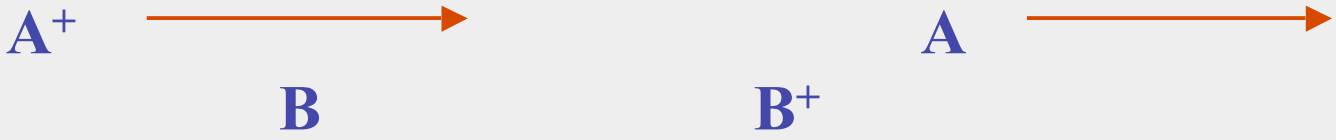


H = 8000 km 20 keV < *E* < 50 keV t_{expo} = 8 minutes

Redistribution by Charge Exchange

v = *Relative Speed Between Ion and Neutral*

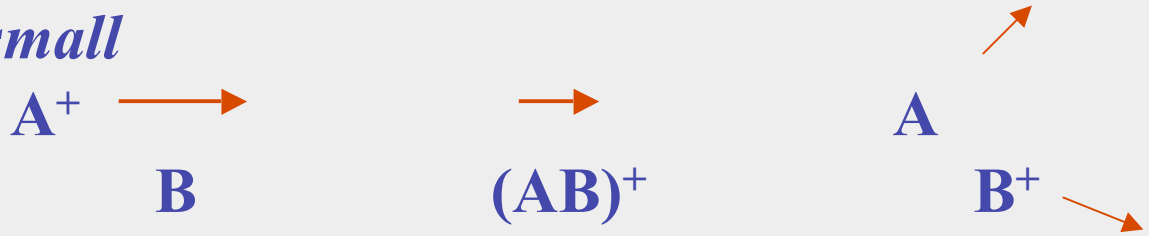
v *large*



A can escape: $R > 2^{1/3} R_{kepler}$ ~ Edge of Main Rings

Plasma Clearing of a disk of gas

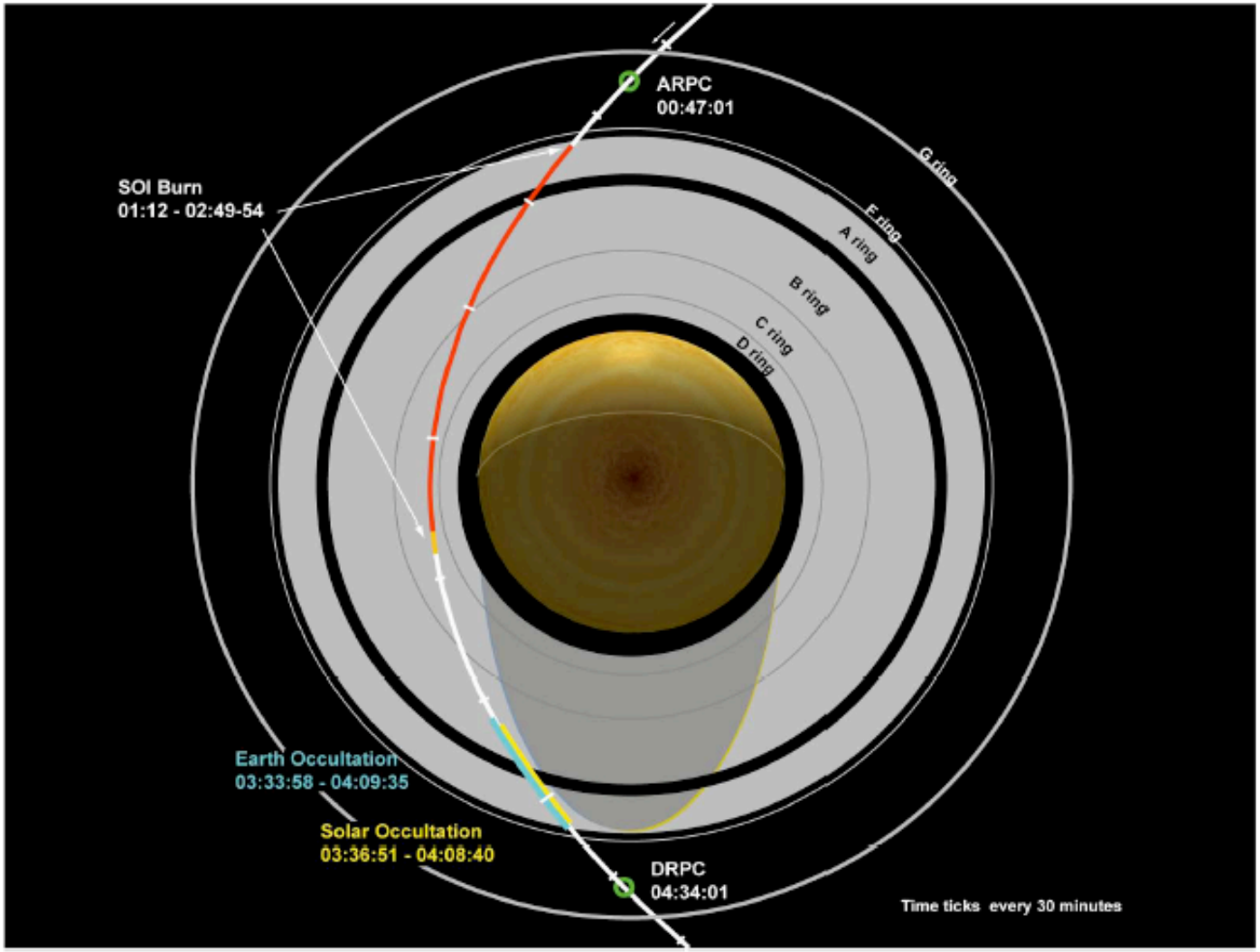
v *small*



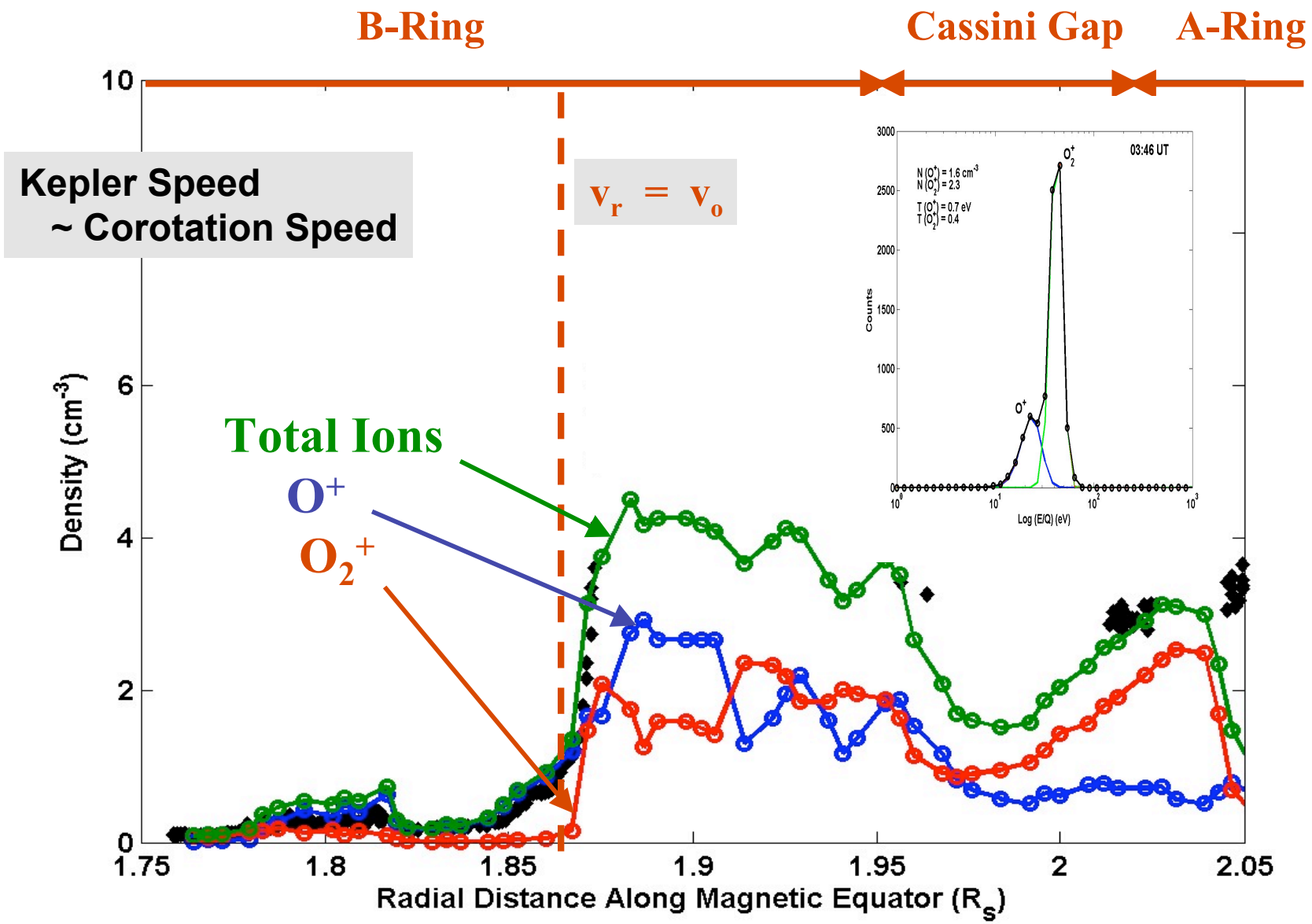
Charge Ecchange → An Ion-Molecule Reaction

Imporxant in inner magnetosphere

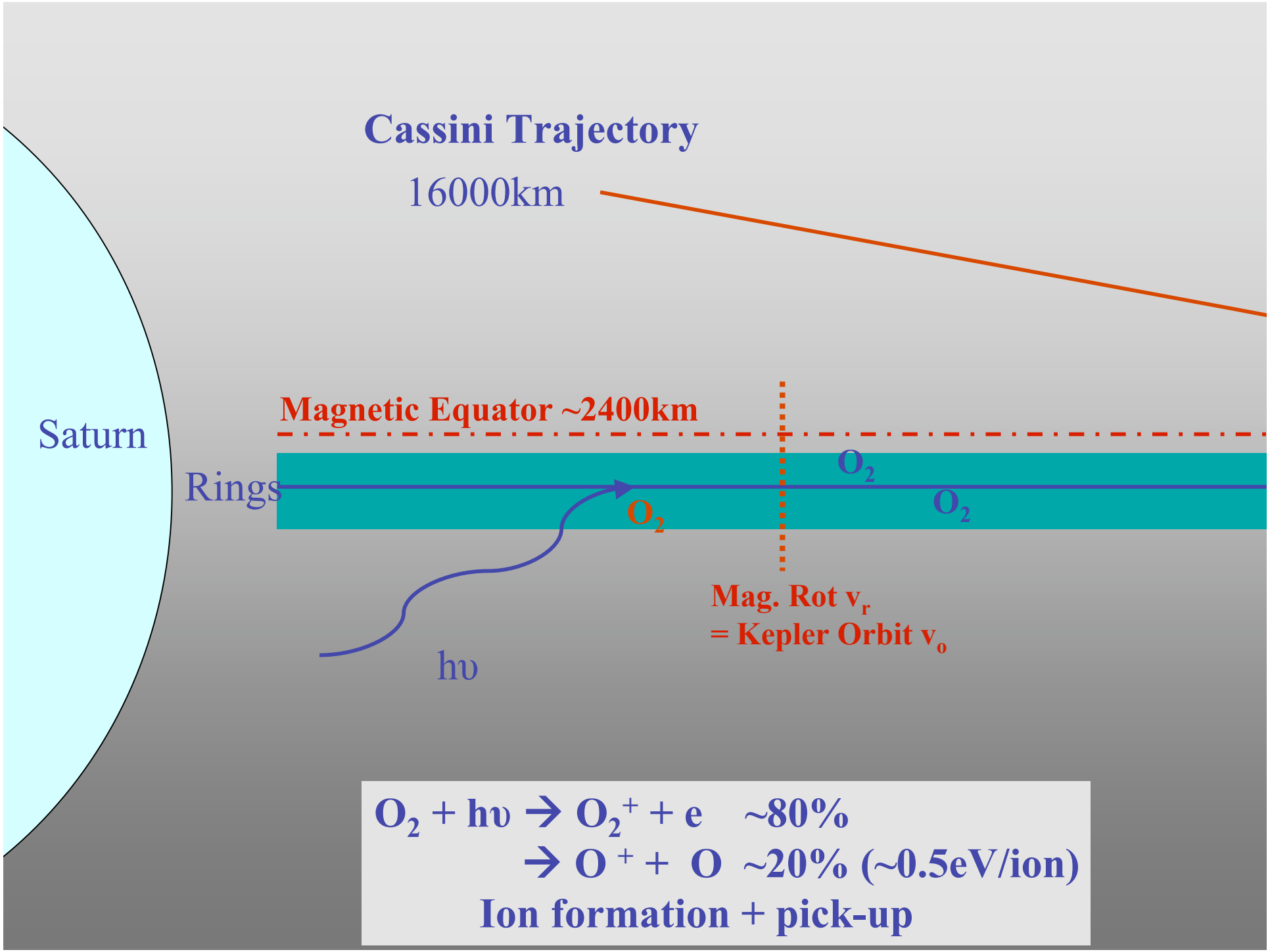
Cassini's trajectory over the rings



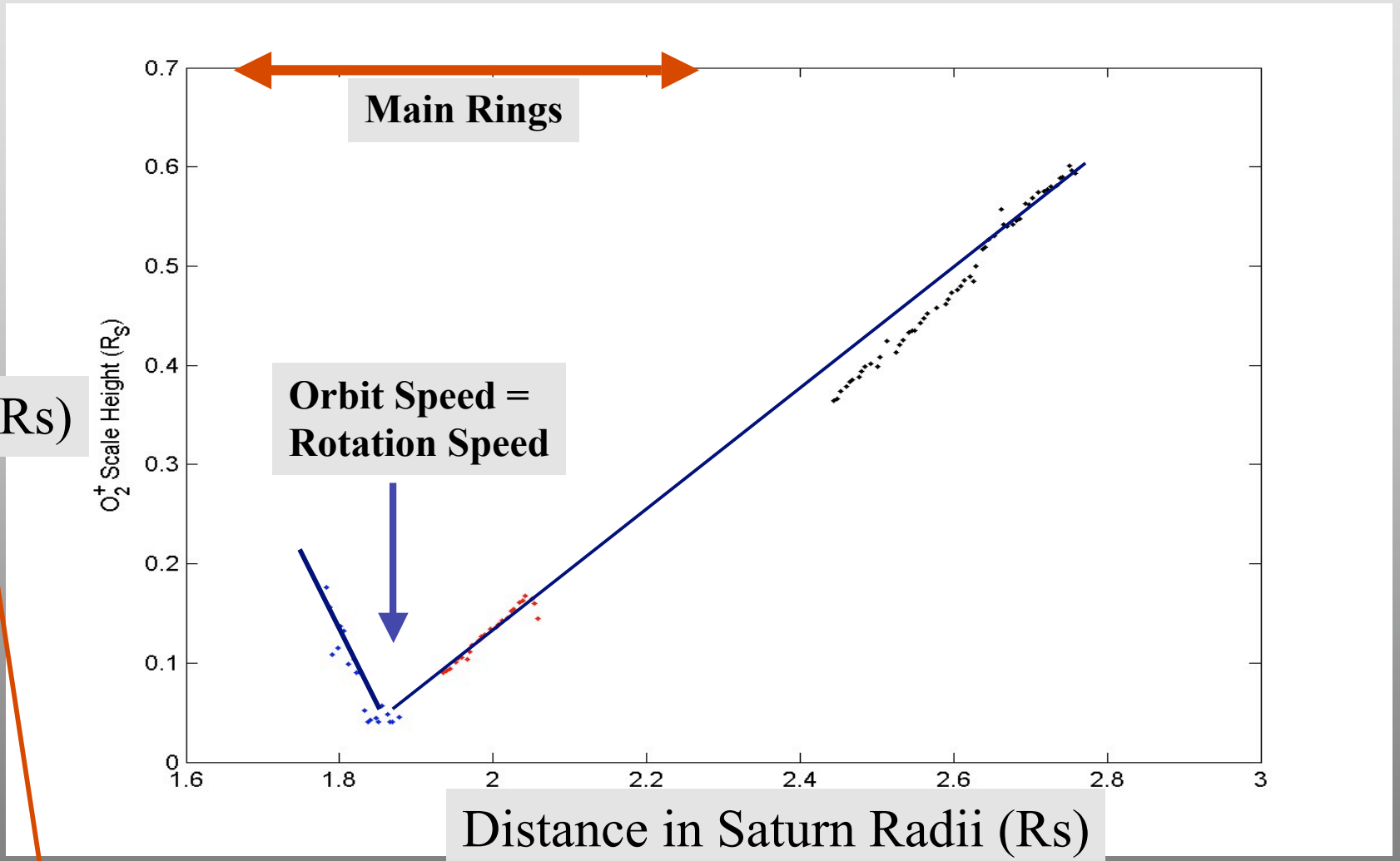
Ring Ionosphere



Cassini CAPS Data: Tokar et al. 2005; Young et al. 2005


Cassini Trajectory
16000km
Saturn
Magnetic Equator ~2400km
Rings
O_2
O_2
O_2
Mag. Rot v_r
= Kepler Orbit v_o
hυ
$O_2 + h\upsilon \rightarrow O_2^+ + e$ ~80%
$\rightarrow O^+ + O$ ~20% (~0.5eV/ion)
Ion formation + pick-up

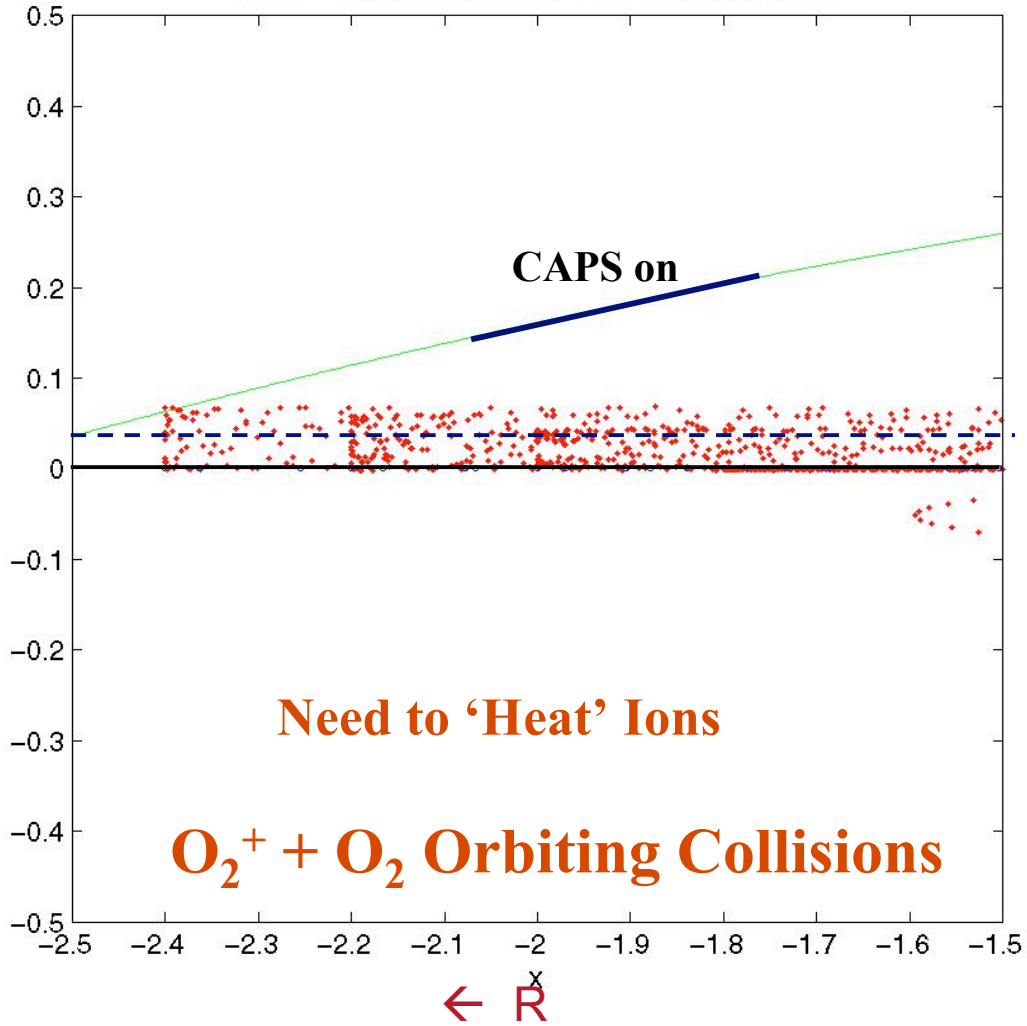
O_2^+ Temperature (Pick-up Energy) Shown as a Scale Height, H



Simulations

O_2^+ Motion: Rotating Magnetic Field + Gravity

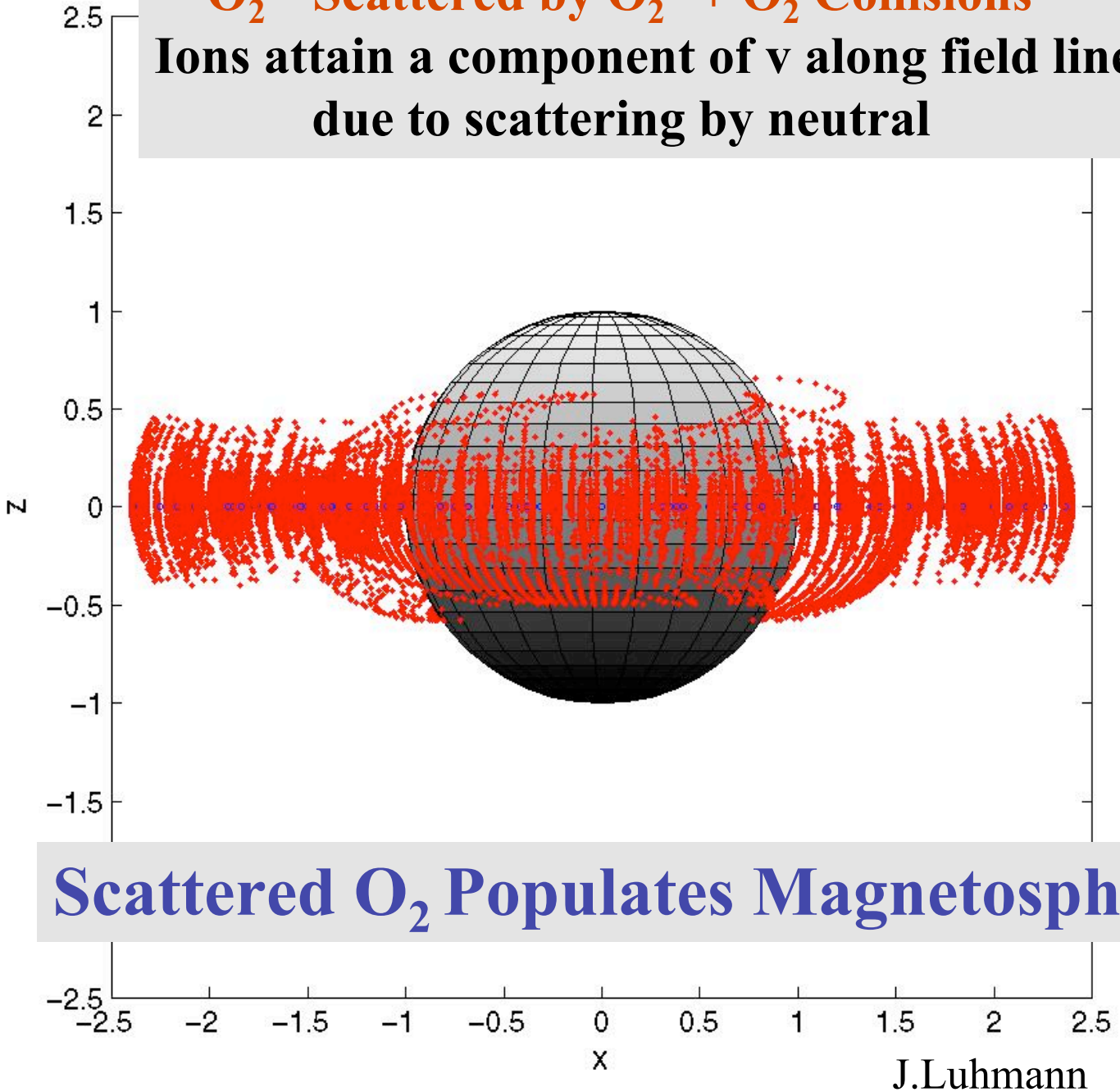
O_2^+ formed north of ring plane



Saturn

O_2^+ Scattered by $O_2^+ + O_2$ Collisions

Ions attain a component of v along field lines due to scattering by neutral



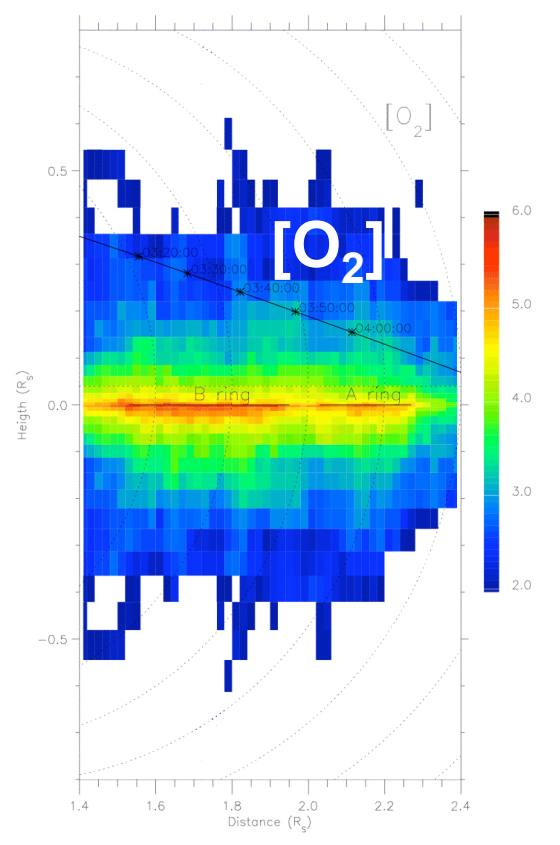
Scattered O_2 Populates Magnetosphere

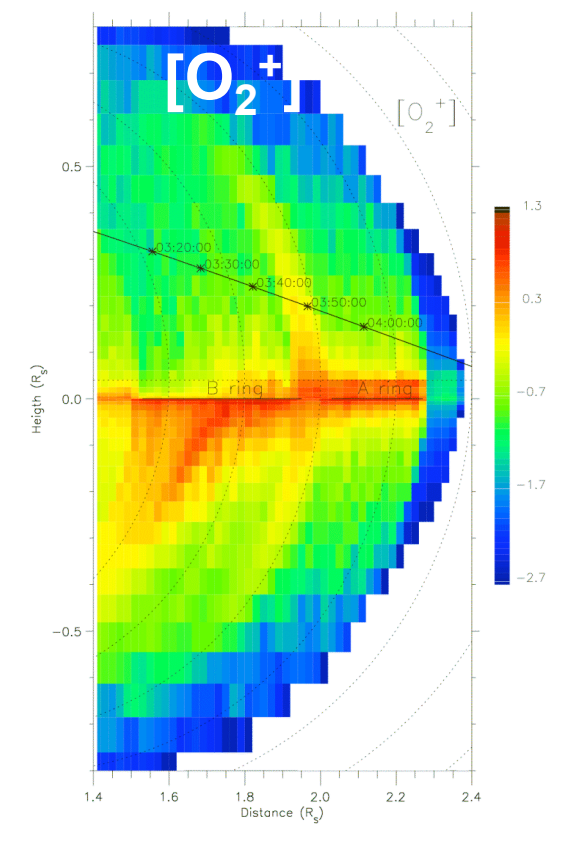
J.Luhmann

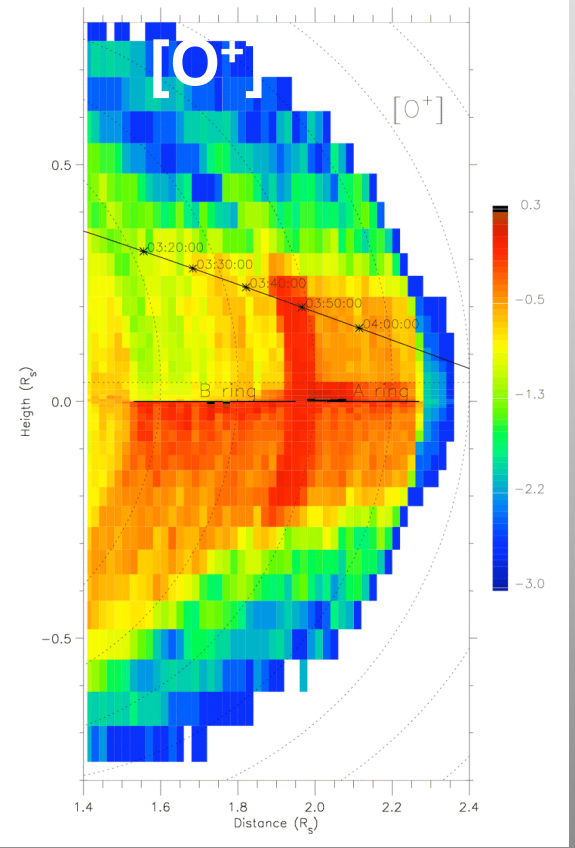
Saturn's O_2 Ring Atmosphere

Photo-Sputtering

(Bouhram et al. 2006: Model)







How efficiently do ions pass through the ring plane?
If at all.

Enceladus (Saturn) and Io (Jupiter)

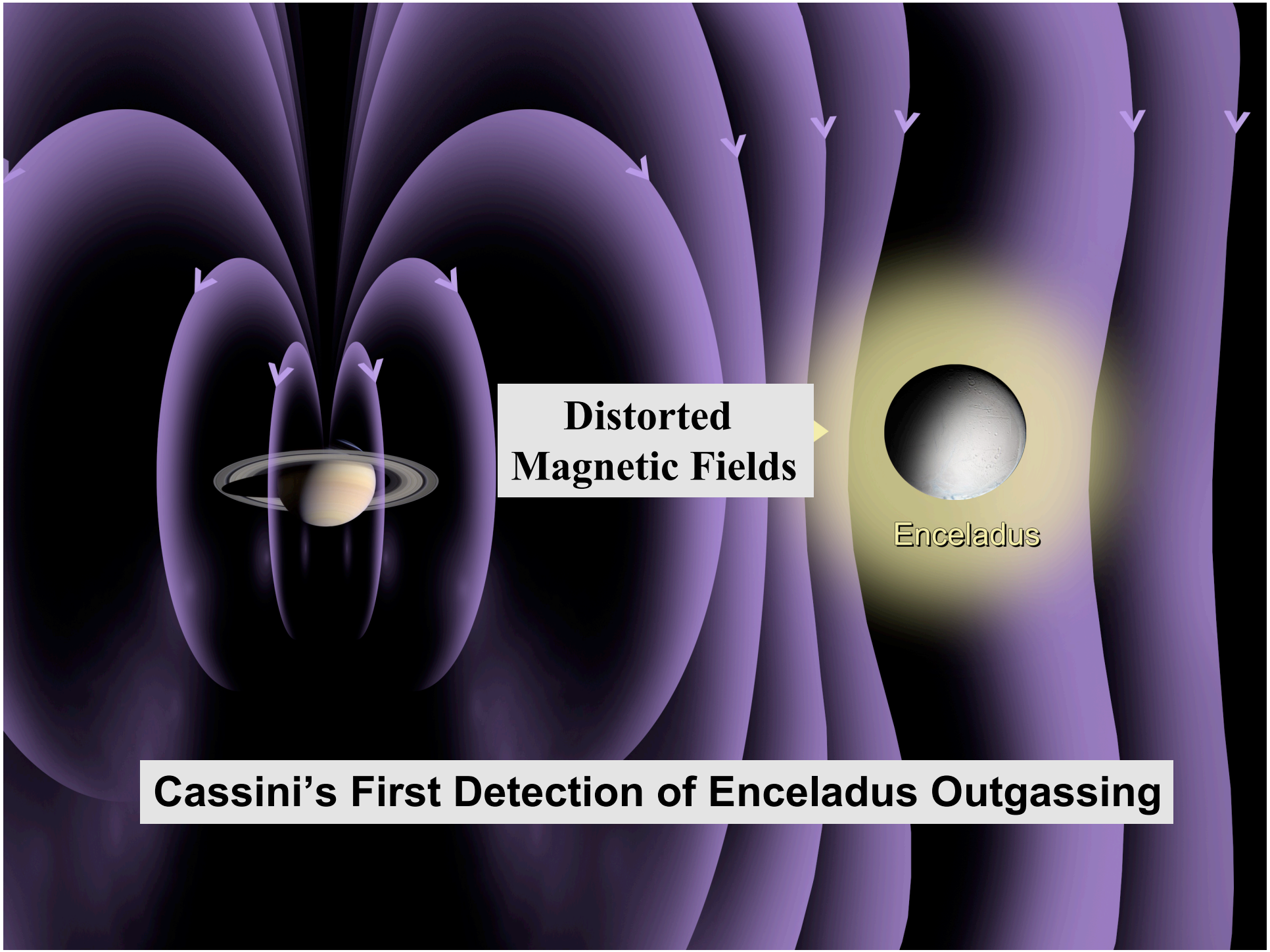
Active Moons

Sources of Neutrals/ Plasma Tori

Inner Magnetosphere

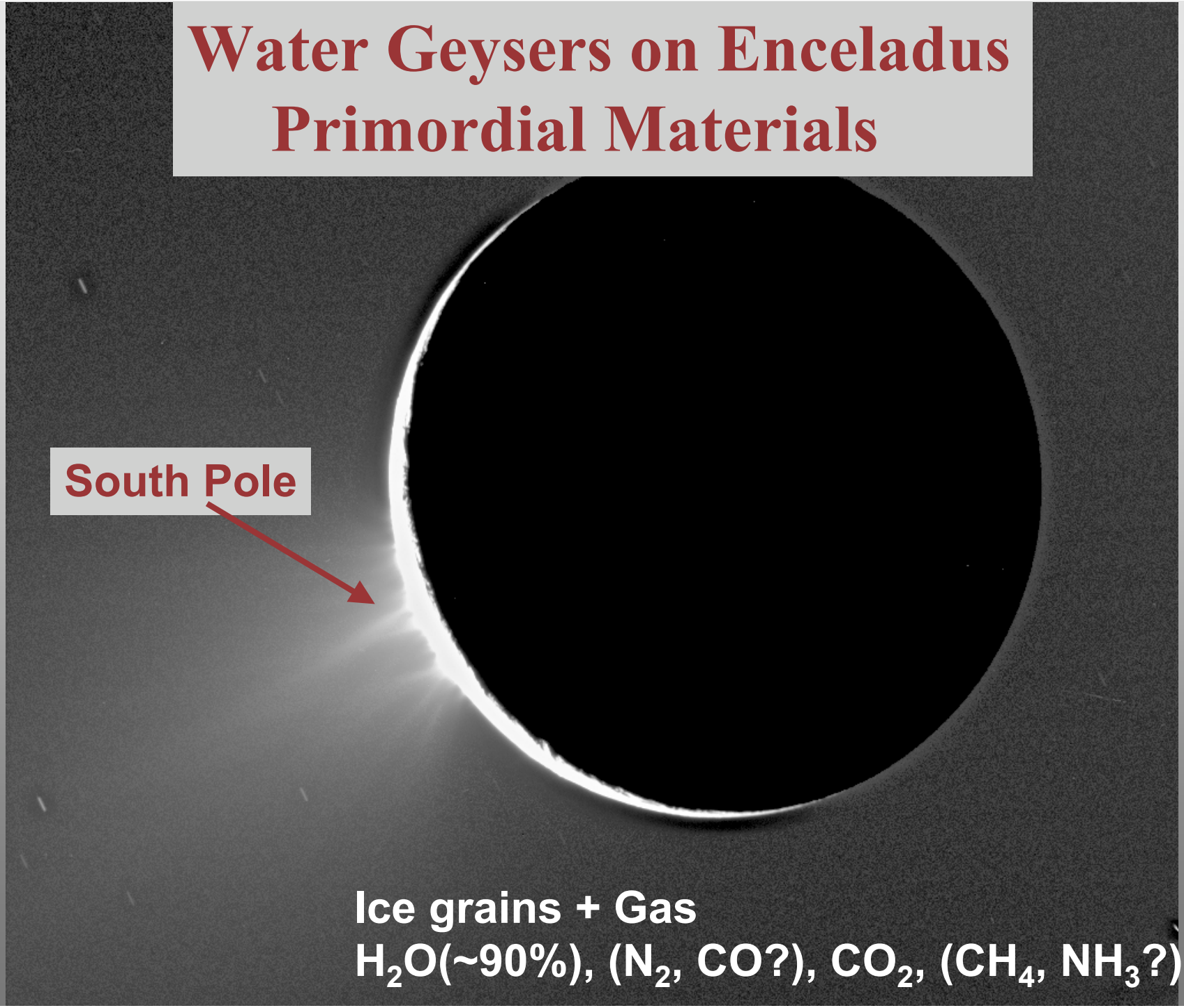
Saturn: Neutrals >> Ions

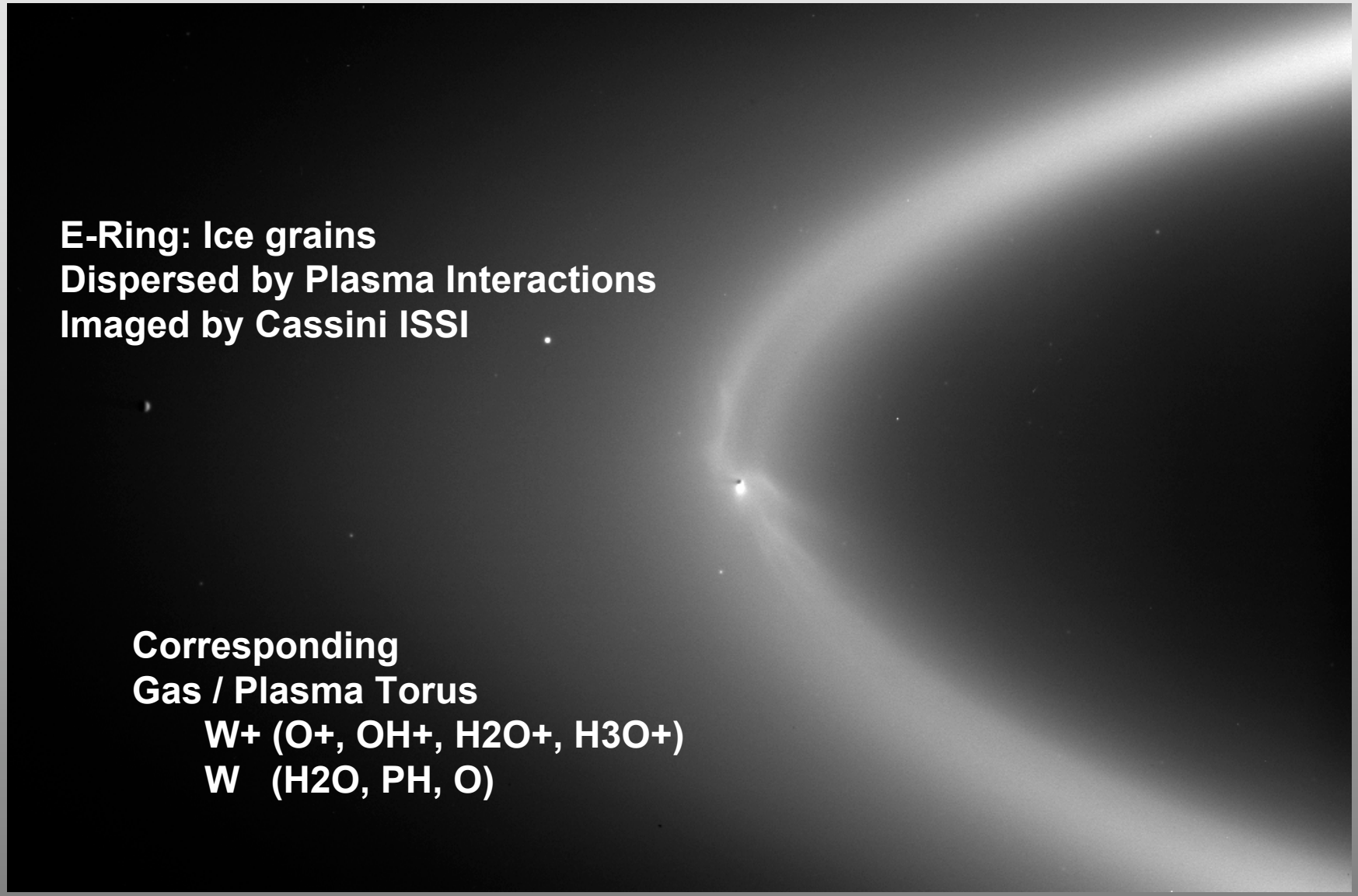
Jupiter: Ions >> Neutrals



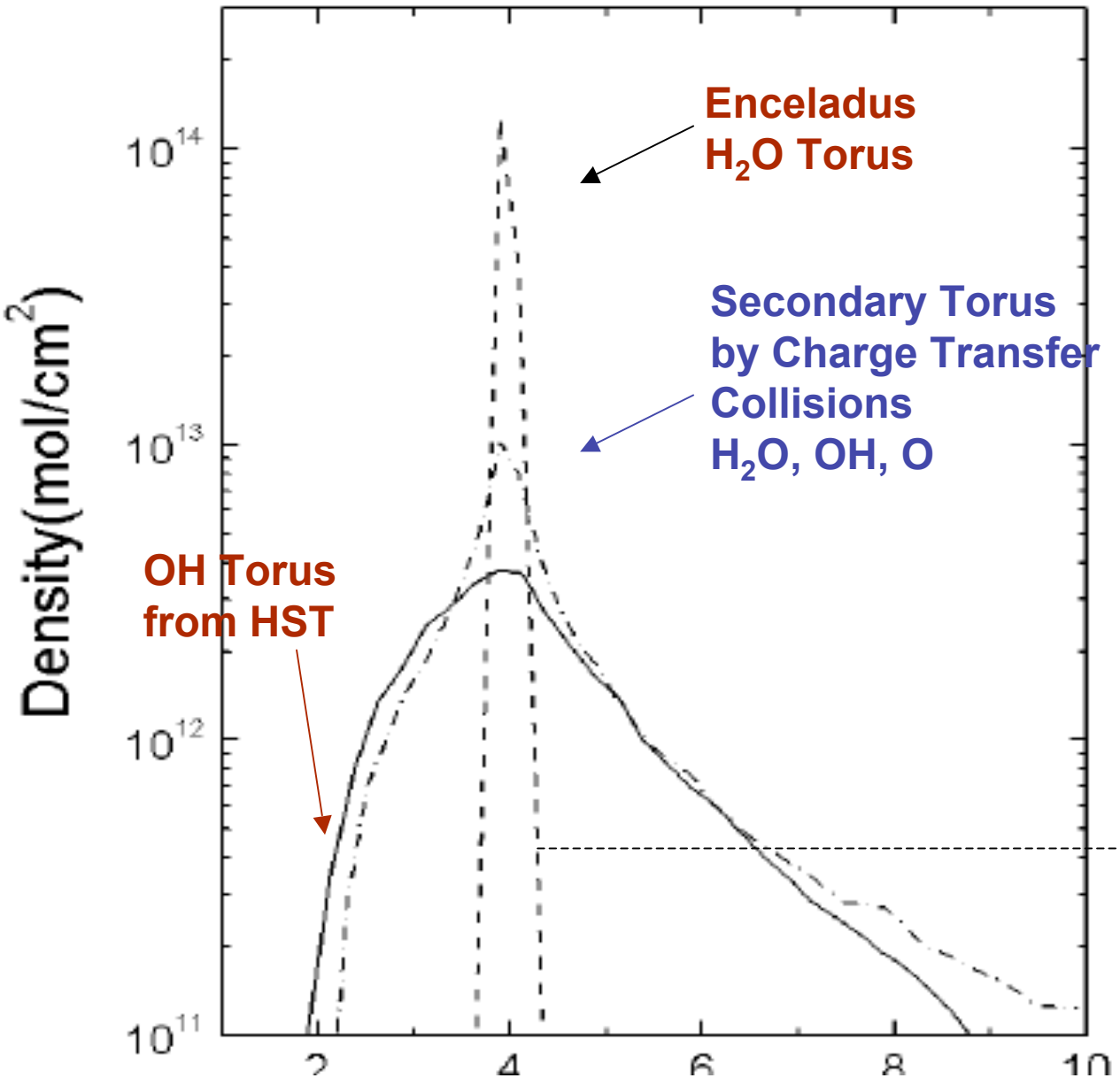
Cassini's First Detection of Enceladus Outgassing

Water Geysers on Enceladus
Primordial Materials

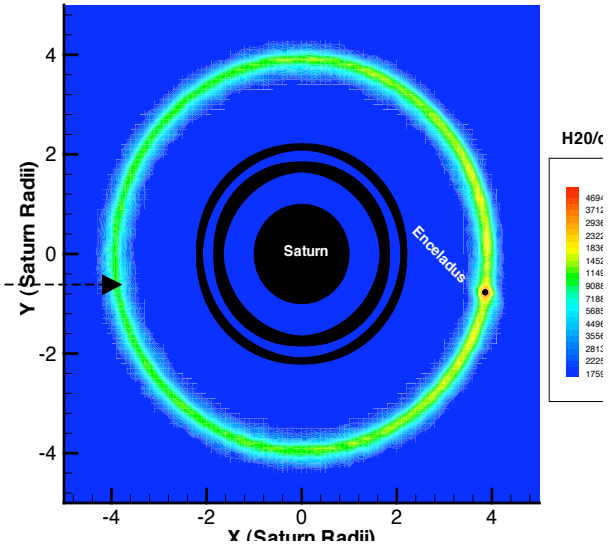



E-Ring: Ice grains
Dispersed by Plasma Interactions
Imaged by Cassini ISSI
Corresponding
Gas / Plasma Torus
W+ (O+, OH+, H2O+, H3O+)
W (H2O, PH, O)

Enceladus Neutral Tori

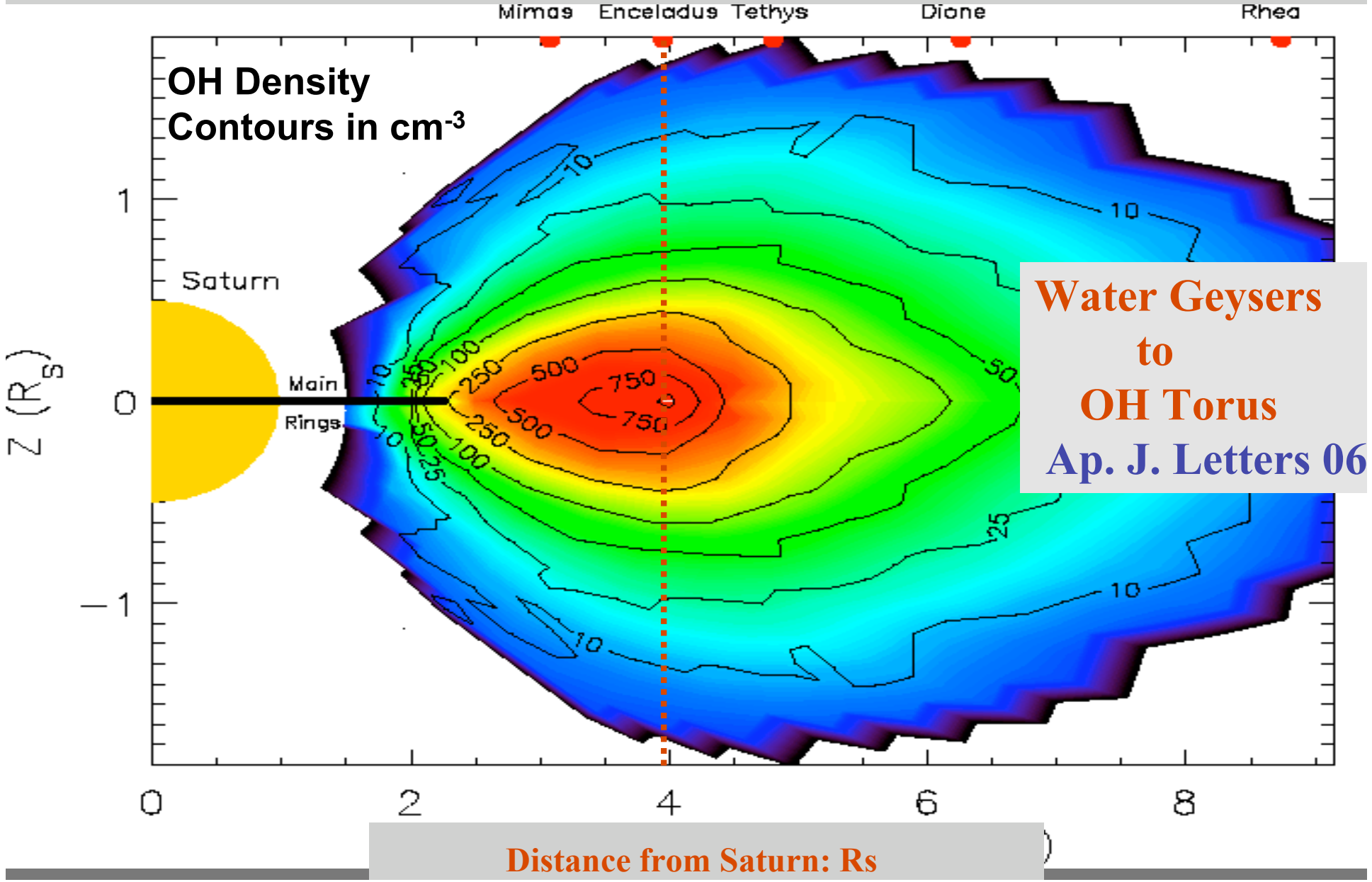


Track Ejected H_2O
South Pole Emission
Source rate ~ 10^{28}/s
Charge Trans. Coll.
Lifetime = $6x10^6$s
T_I = 35eV
T_e = 1.5eV
Loss fraction
60-70%



Toroidal OH Atmosphere

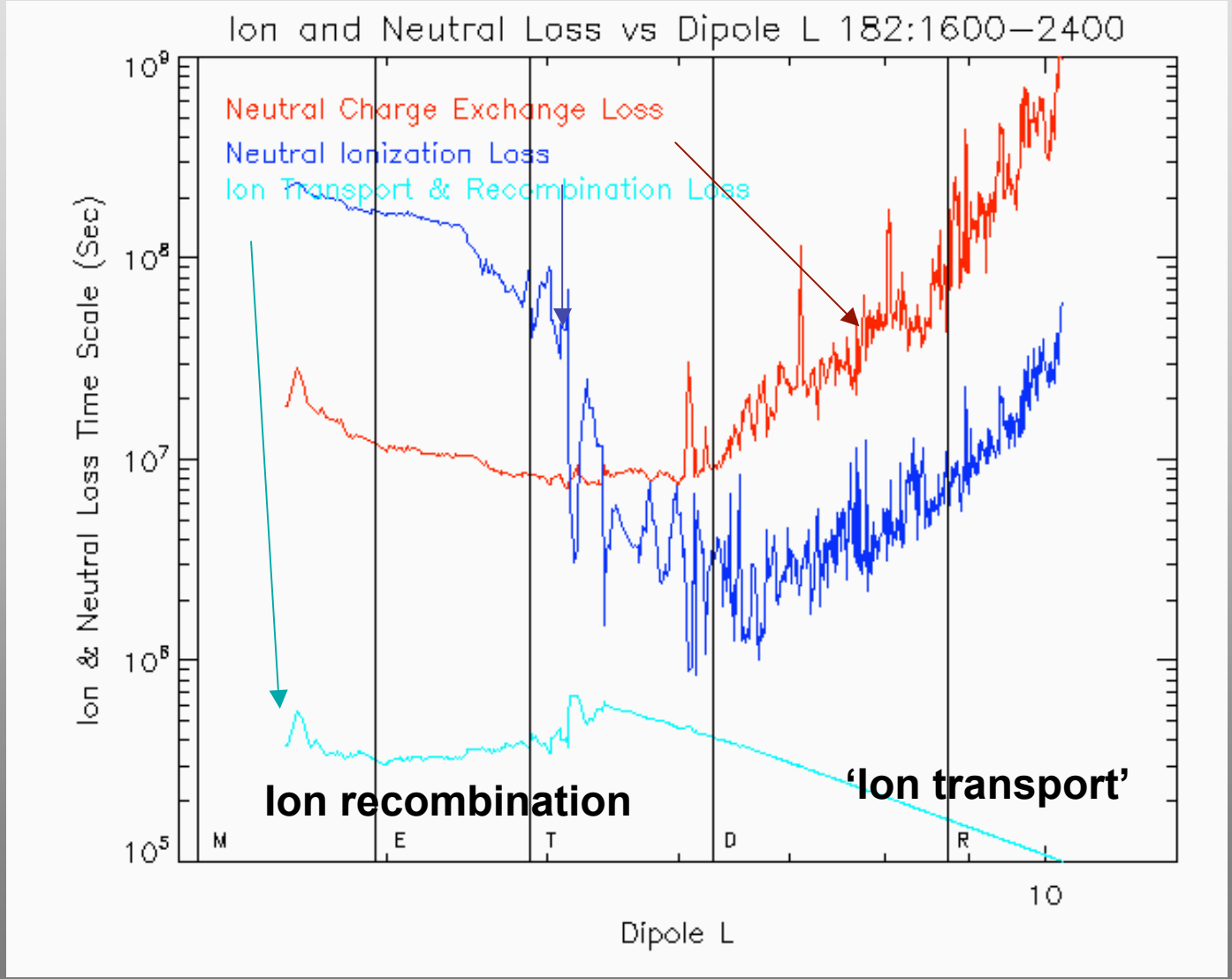
from Hubble Space Telescope Observations



Water Geysers to OH Torus

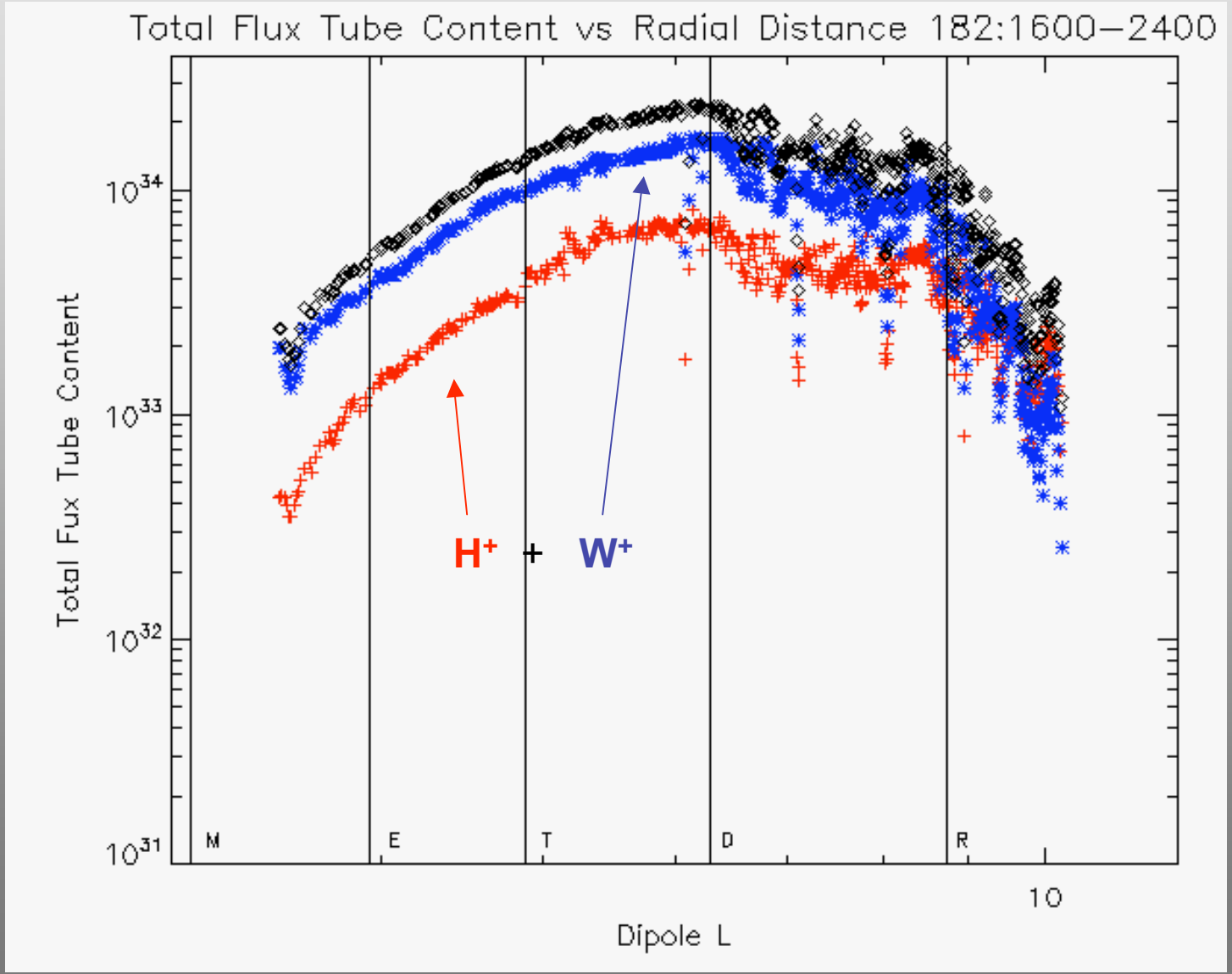
Ap. J. Letters 06

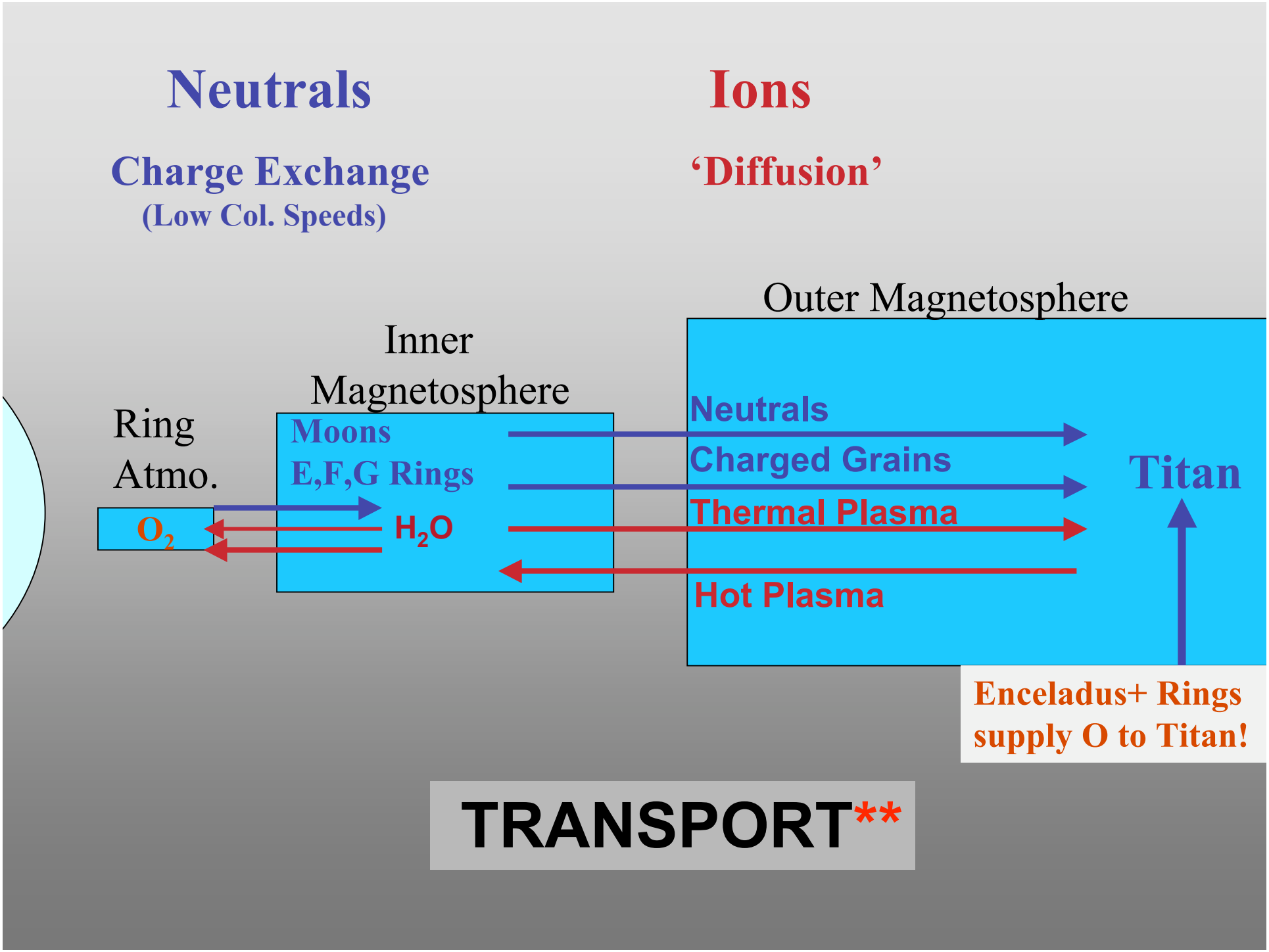
Water Neutral-Ion Loss Time Scales



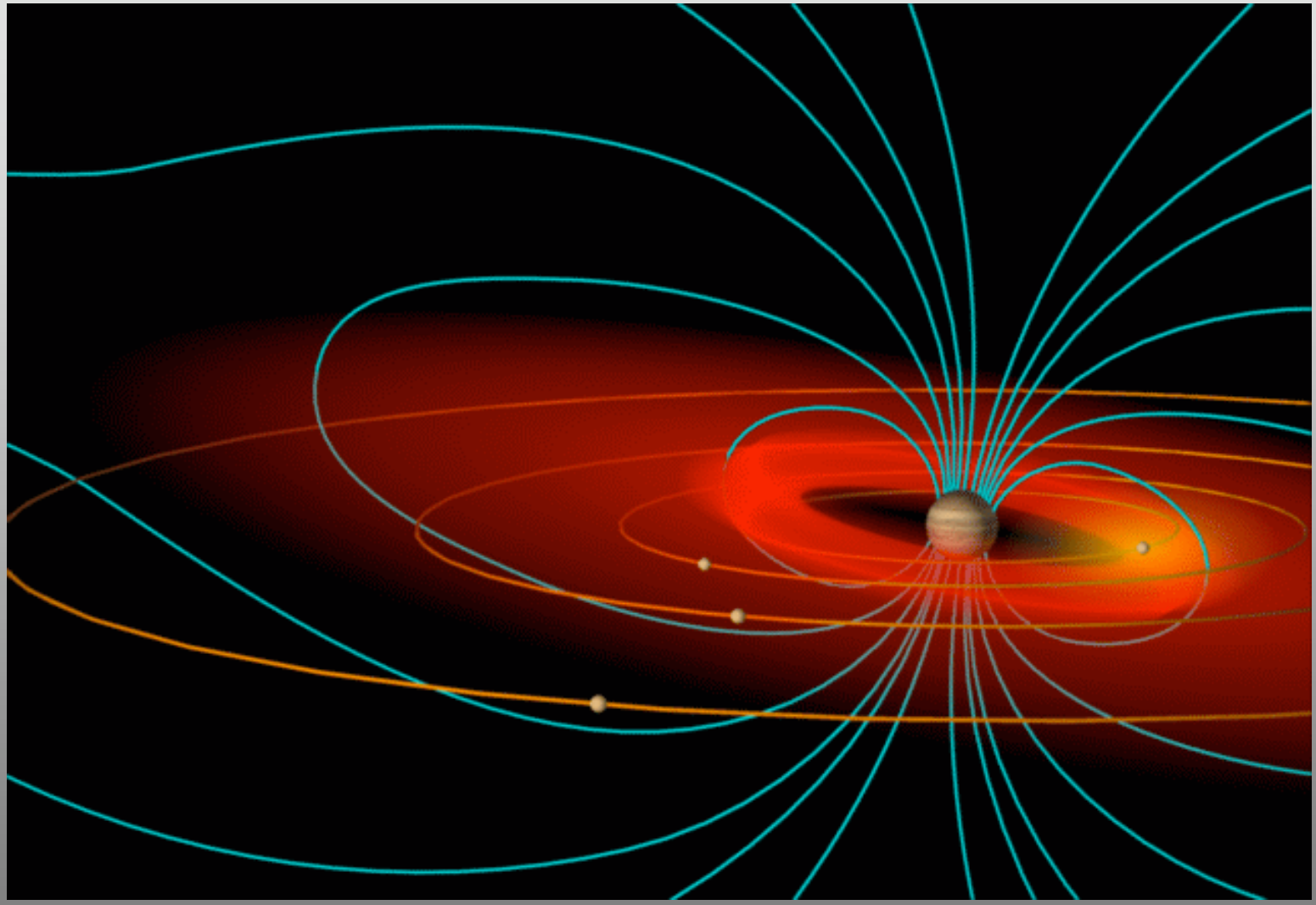
Neutral Dominated Plasma

Flux Tube Content: nL^2

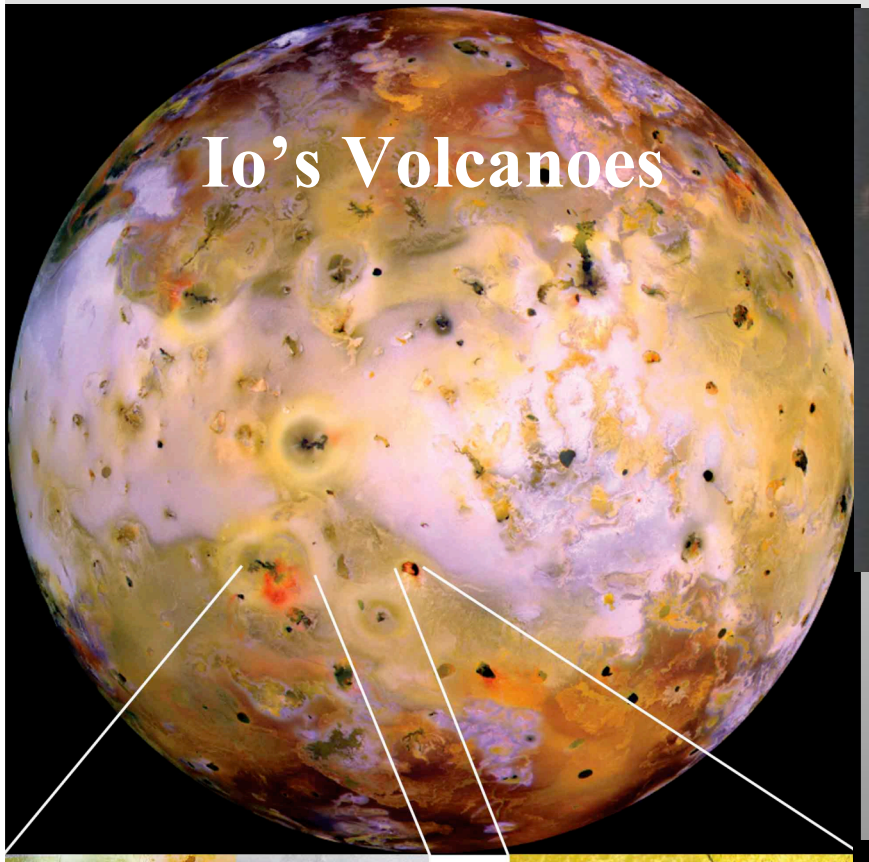


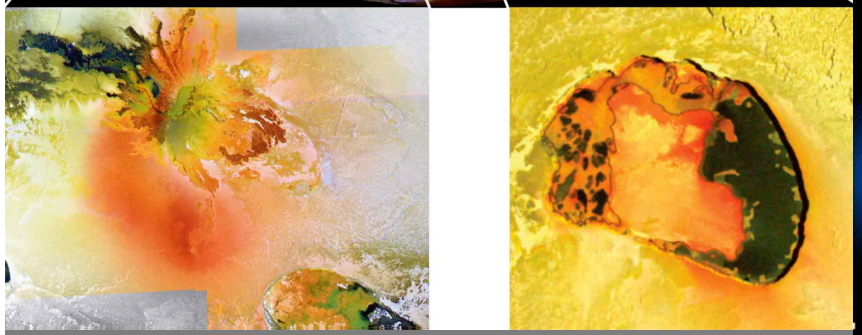

Neutrals
Ions
Charge Exchange
(Low Col. Speeds)
'Diffusion'
Outer Magnetosphere
Inner
Magnetosphere
Ring
Atmo.
Moons
E,F,G Rings
O_2
H_2O
Neutrals
Charged Grains
Thermal Plasma
Hot Plasma
Titan
Enceladus+ Rings
supply O to Titan!
TRANSPORT**

Jupiter: Magnetic Field, Satellites and Plasma Torus

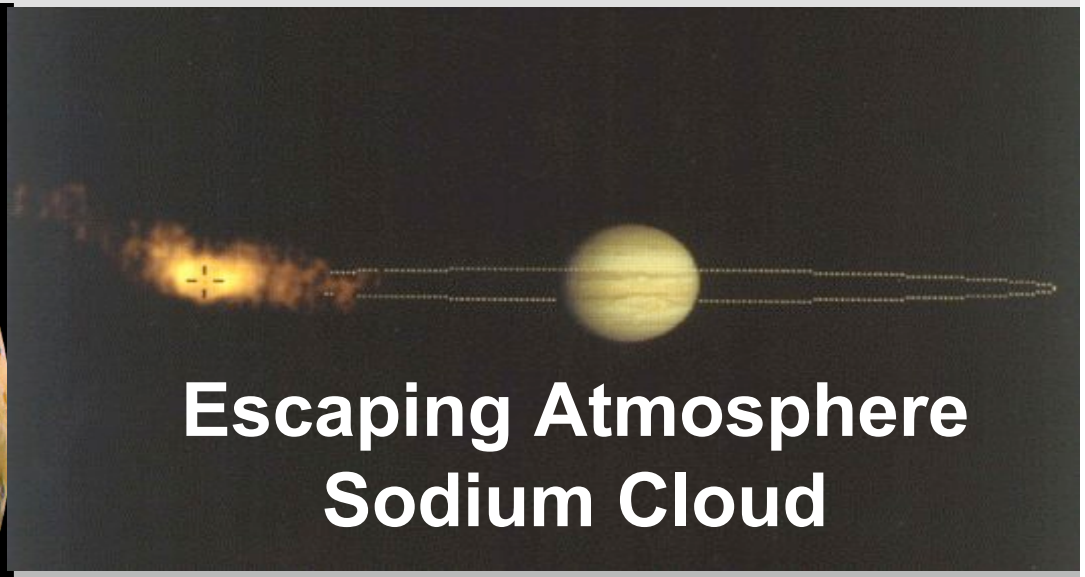


Jupiter's Moon Io



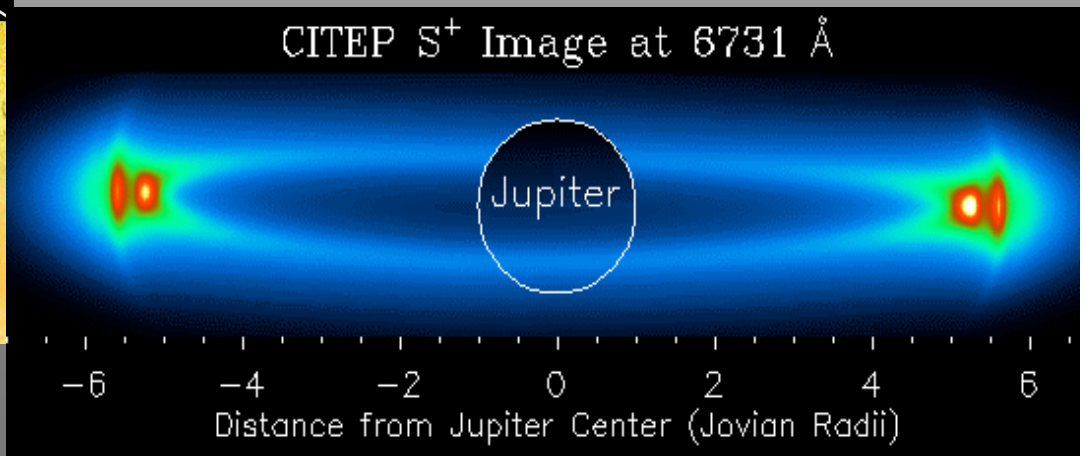


SO_2,S_x, Na, K, Cl, Silicates

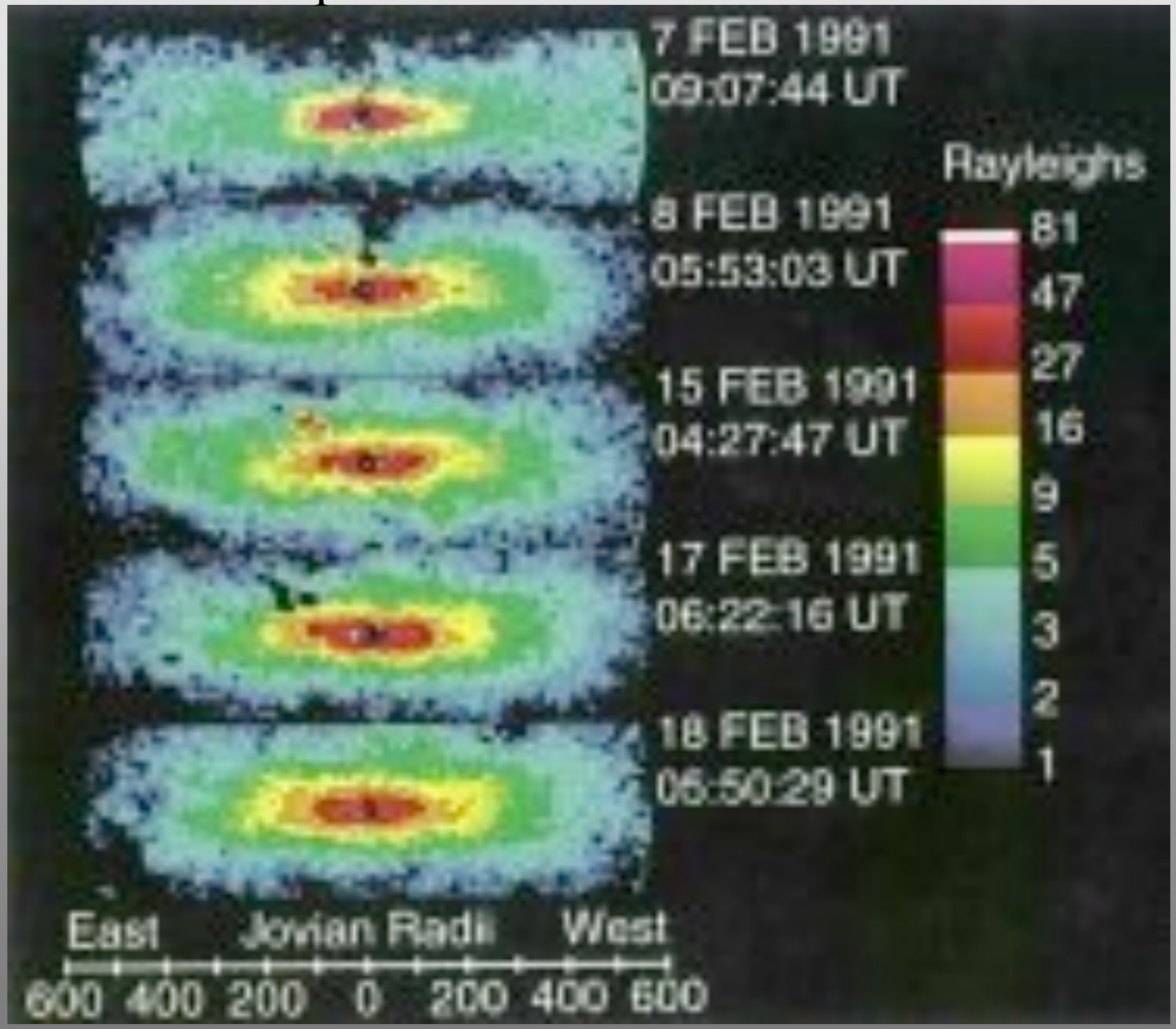


Escaping Atmosphere Sodium Cloud

Io's S^+ Torus



Jupiter's Giant Sodium Corona



Enceladus vs. Io

	Enceladus	Io
Neutral Source Rate	~0.3 tons/s	~1 ton/s
(vco – vo)	26km/s	57km/s
n_e	70/cc	~2500/cc
n_{eh}/n_e	0.3	0.3
Te	~1.5eV	~ 6eV
Ti	~ 35eV	~150eV

Delamere et al. 2007:

Difference in $(v_{co} - v_o)$ → difference in T_e

What about:

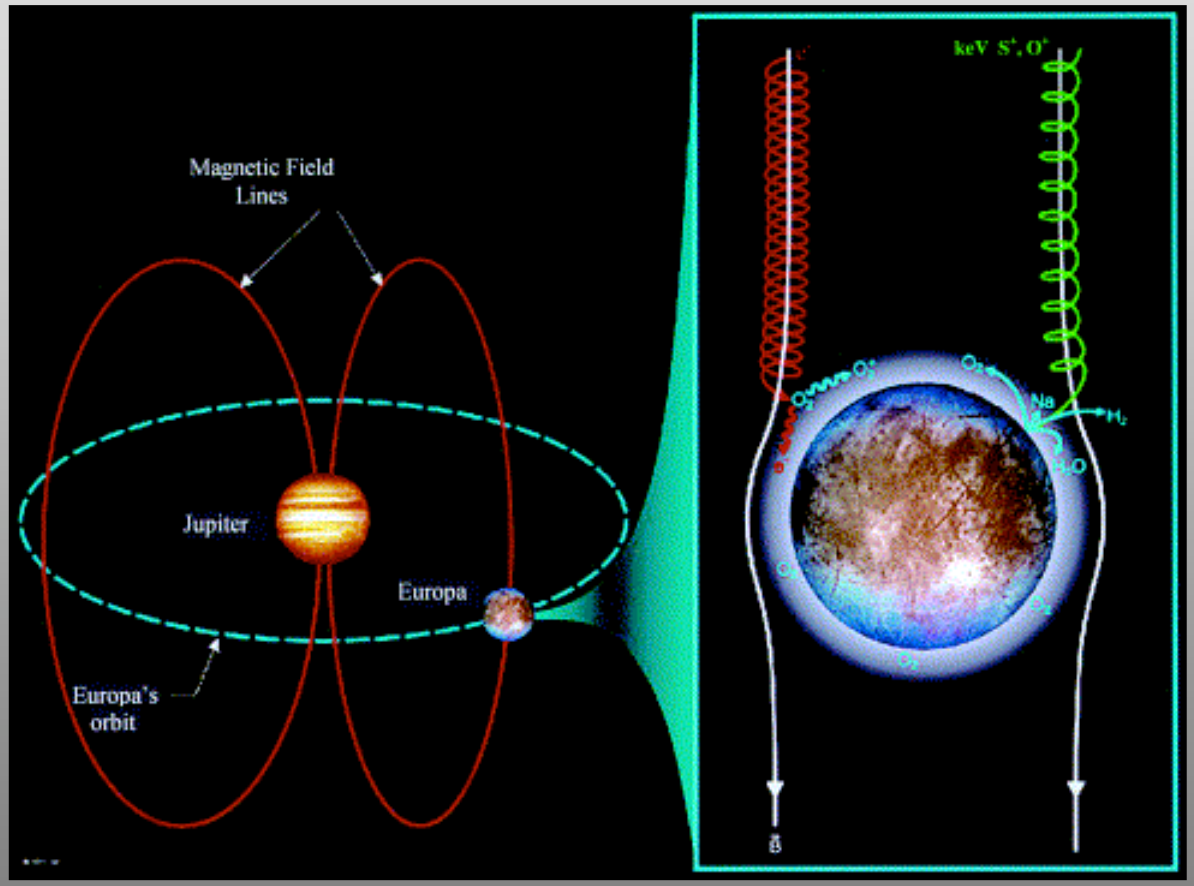
Differences in charge exchange redistribution of neutrals?

Saturn's much weaker magnetic field?

Other?

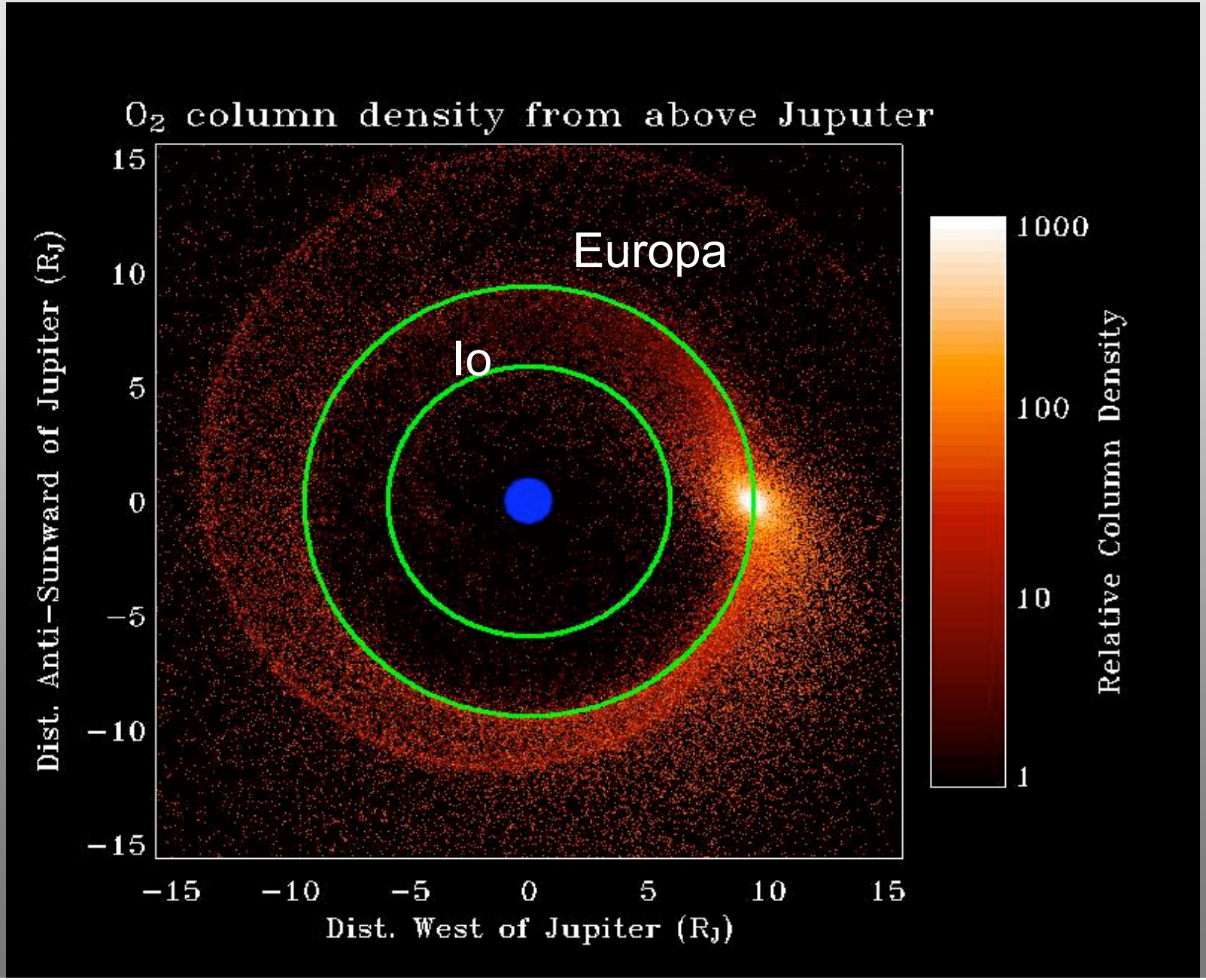
Europa in the Jovian System

Radiation Effects



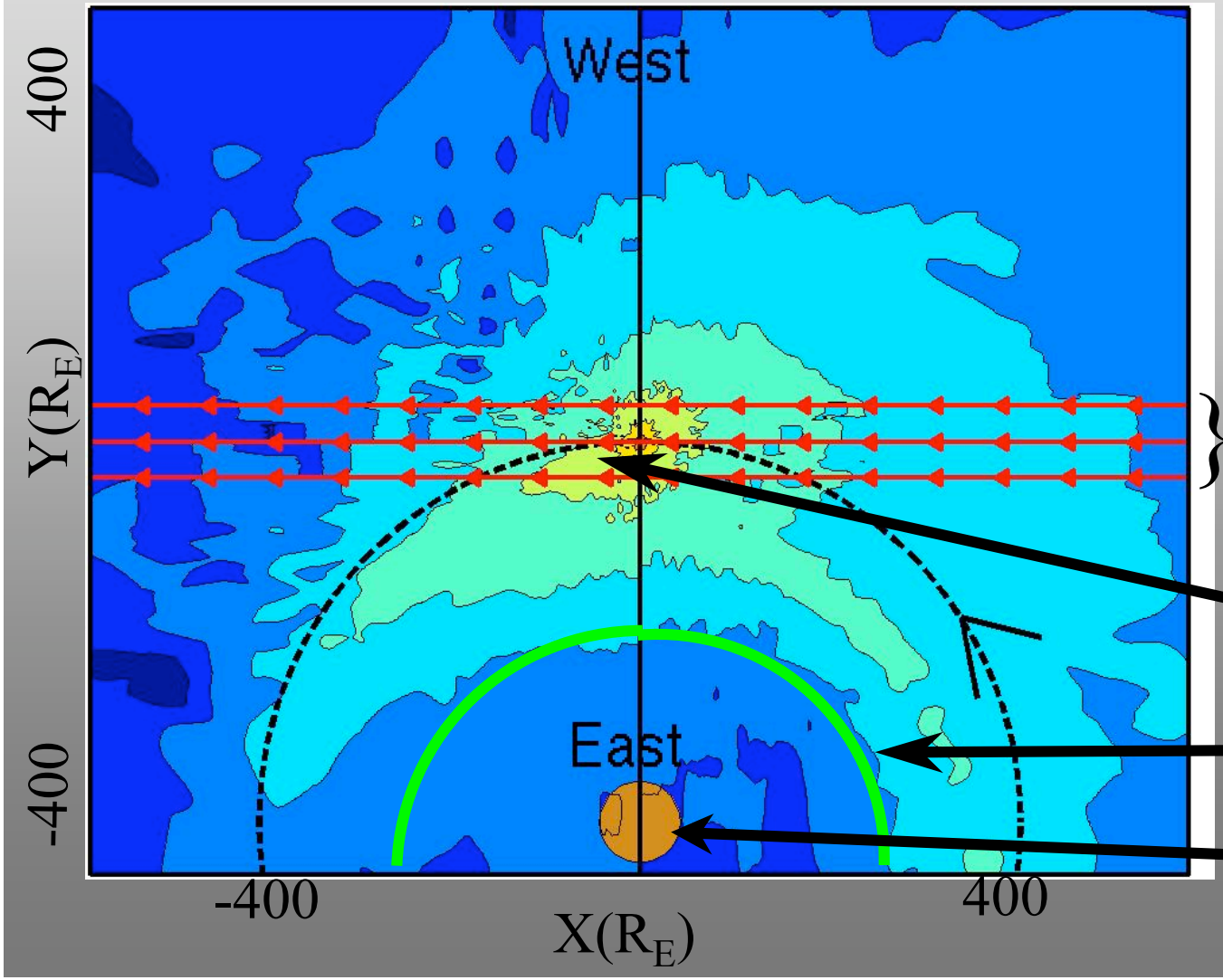
Europa Mission?
T.A. Cassidy

Europa's O_2 Torus
(Burger and Johnson 2005)



Europa's Sodium Atmosphere

(Leblanc et al. 2002; 2005)



Sun/Earth

Observations
(Brown 2001;
Potter, Killen)

Europa

Io

Jupiter

Do we understand the differences between the Jovian and Saturn magnetospheric plasmas?

Do erosion processes in these magnetospheres have much in common with magnetic field driven processes at other debris disks?

Do these material transfer processes have much in common with such processes elsewhere?

Can we detect tori of extra-solar planets?

- **Many must have neutral and plasma tori**
- **Such features can be larger than planet's disk**
- **Is this a way of detecting moons or rings?**

Johnson and Huggins 2006