JEO Spacecraft Environments

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Spacecraft Environments

- **SUN**
  - **Solar Wind**
  - **Solar Proton Events**
- **JUPITER**
  - **Magnetic Field**
  - **Radiation Belts**
  - **Heavy Ions**
  - **Plasma**
- **GCR**

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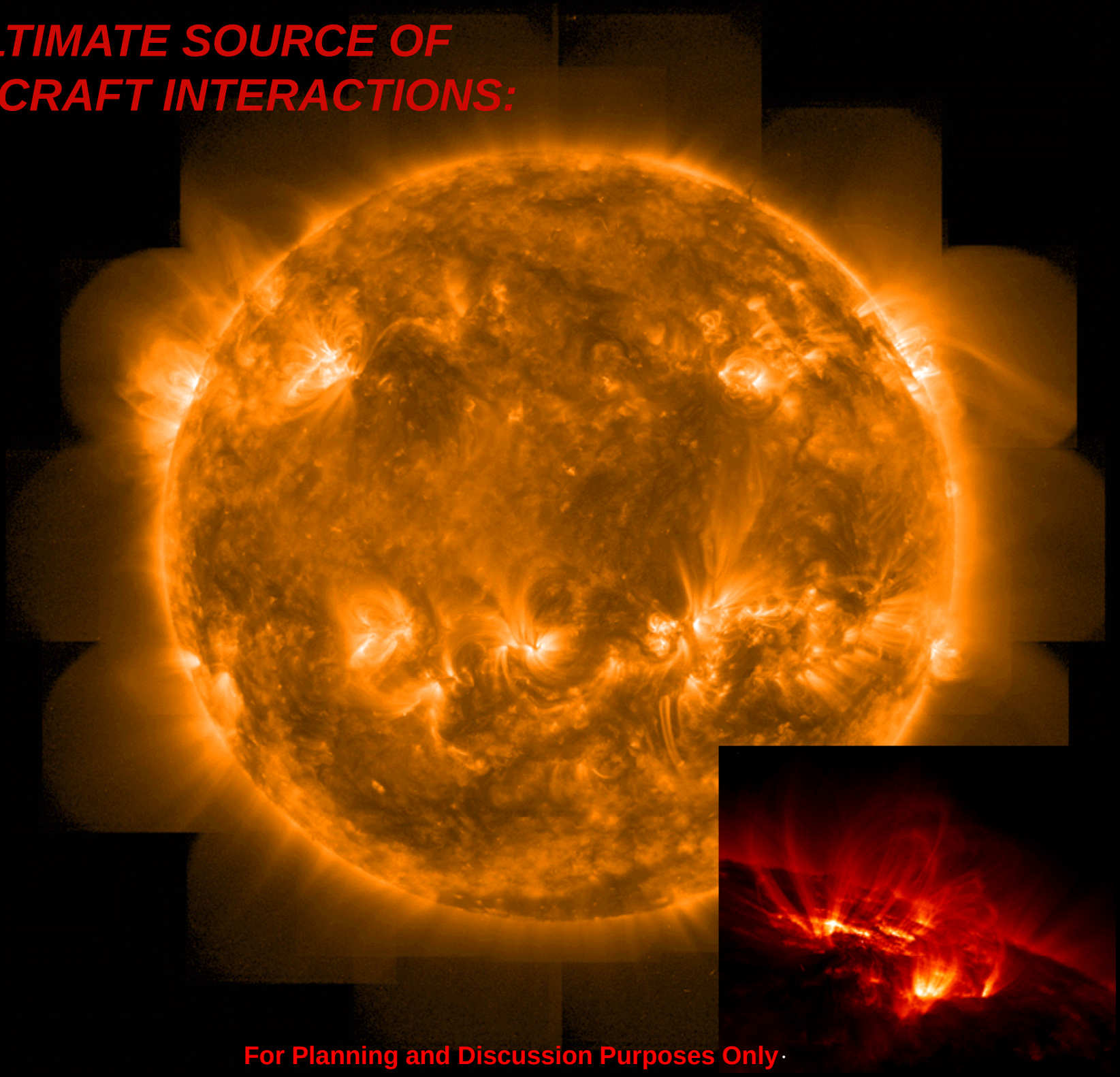
THE ULTIMATE SOURCE OF SPACECRAFT INTERACTIONS:



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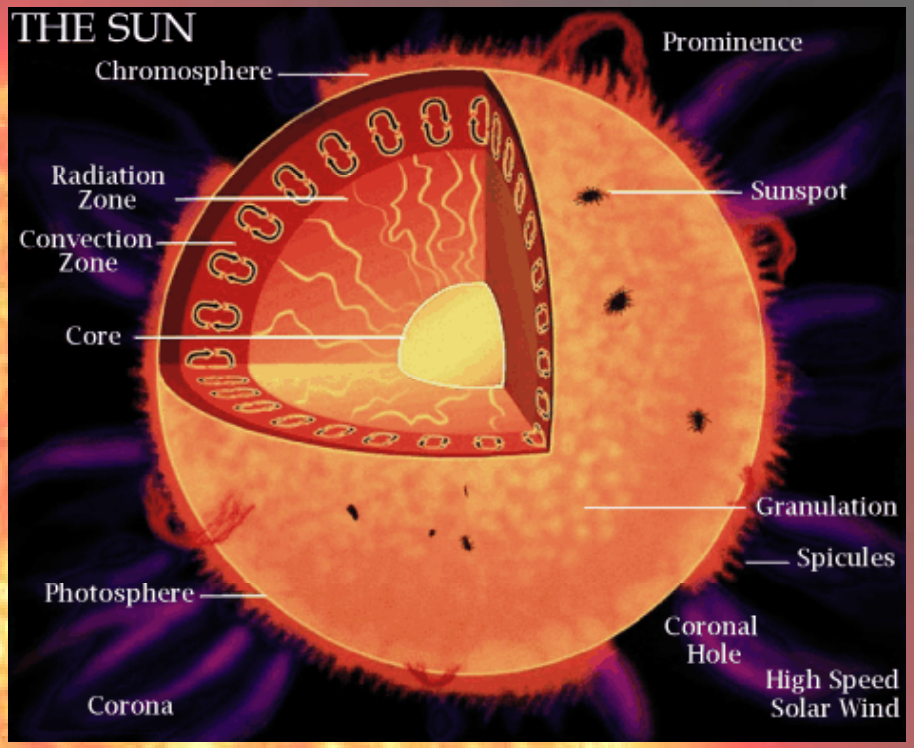
THE SUN....



THE SUN

PHYSICAL CHARACTERISTICS:

- **Blackbody Temperature:** 5570 ^{o}K
- **Flux at 1 AU:** 1368 W/m^2
- **Mass:** 1.99 x 10^{30} Kg
- **Radius:** 6.96 x 10^5 Km
- **Mean Density:** 1.41 g/cm^3

ATMOSPHERIC REGIONS:

- **Photosphere:** Source of continuous spectrum; "Surface" ~500 Km thick; "Granulation" and "Sunspots"
- **Chromosphere:** Region of glowing gas; density falls from ~10^{-6} to 10^{-13} g/cm^3; Temperature rises from ~4000 ^{o}K at top of Photosphere to ~20,000 ^{o}K at ~2,000 Km Marked by "Spicules"
- **Transition Region:** Thin region between Corona and Chromosphere; Temperature rises from ~25,000 ^{o}K to 2x10^6 ^{o}K; Density falls from 10^{-13} g/cm^3 at 2000 Km to 10^{-16} g/cm^3 at 2500 Km.
- **Corona:** Marked by sharp rise in temperature to 2x10^6 ^{o}K in 2000 Km. Density falls to ~10^{-18} g/cm^3 transitioning to Solar Wind

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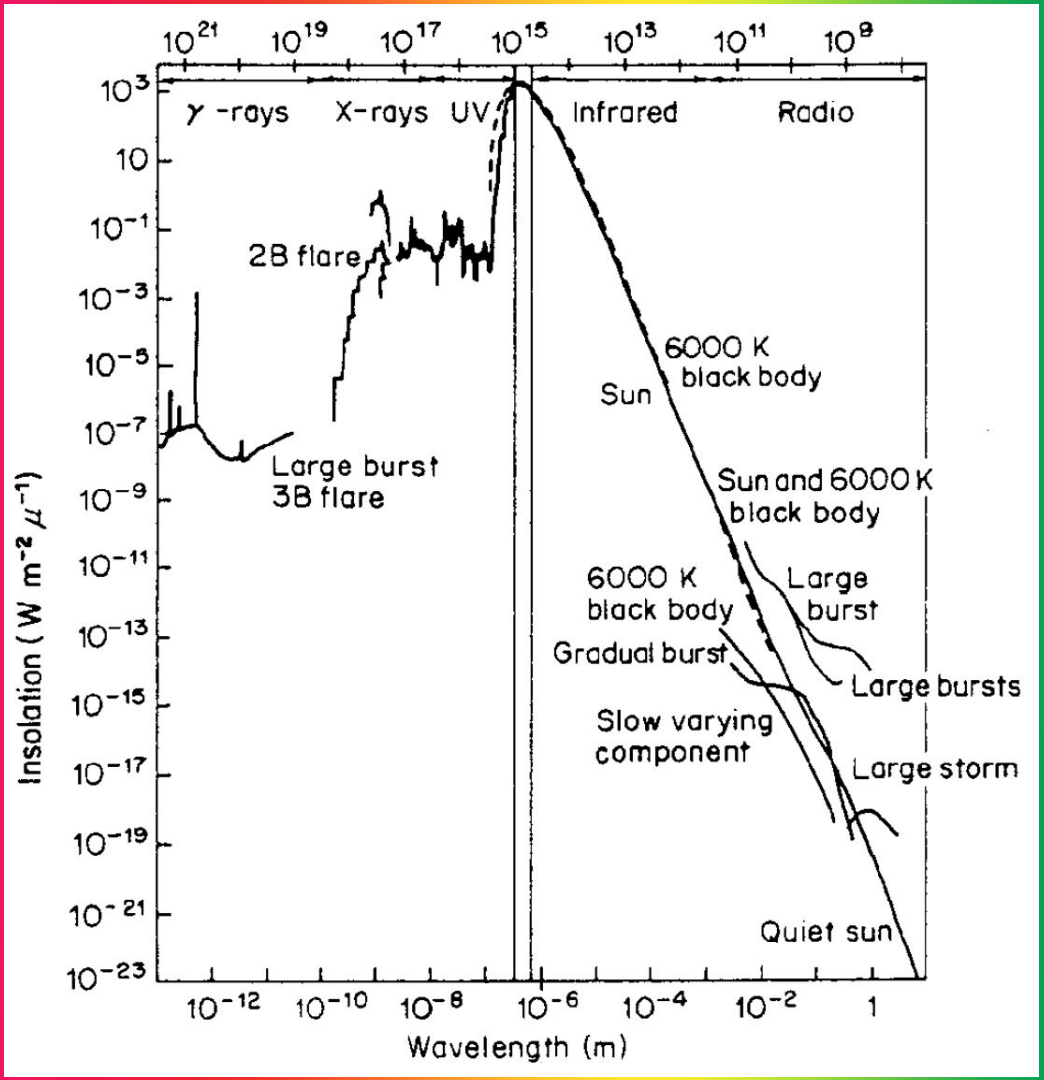
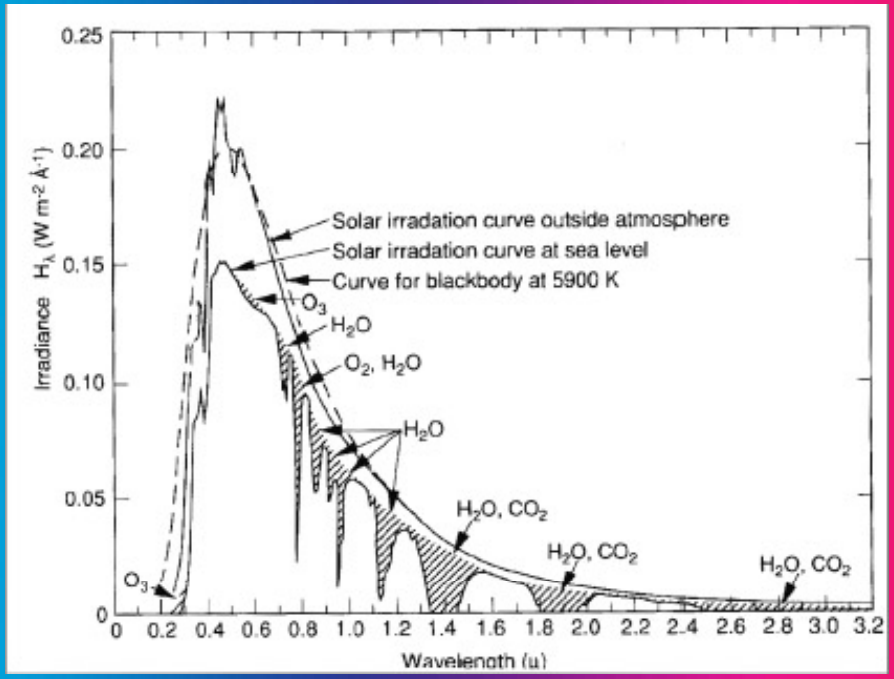
SOLAR PHOTON ENVIRONMENT:

RADIO TO γ-RAY





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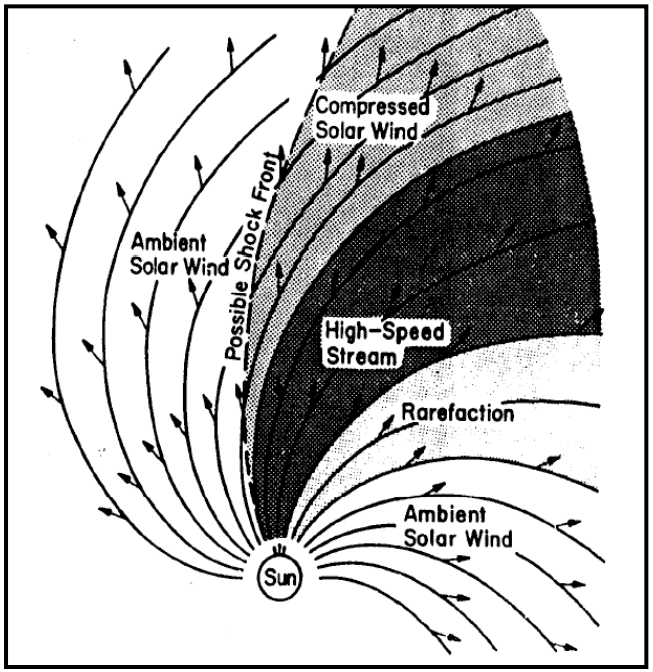
The Solar Wind Environment

Equatorial Plane View

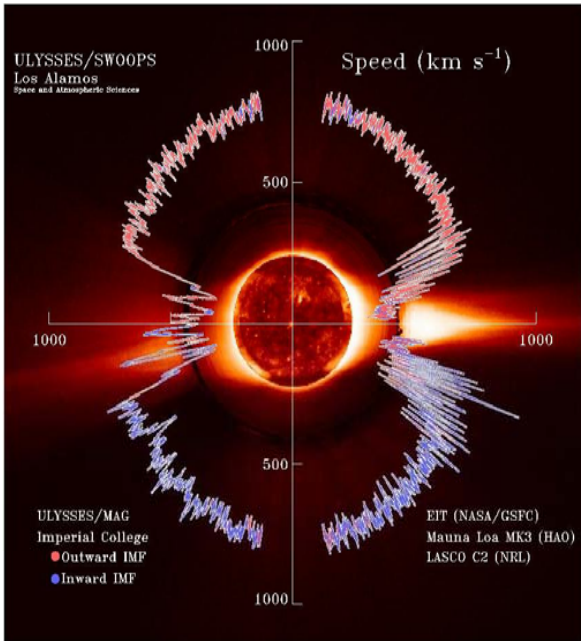


SOLAR WIND PARAMETERS AT 1 AU

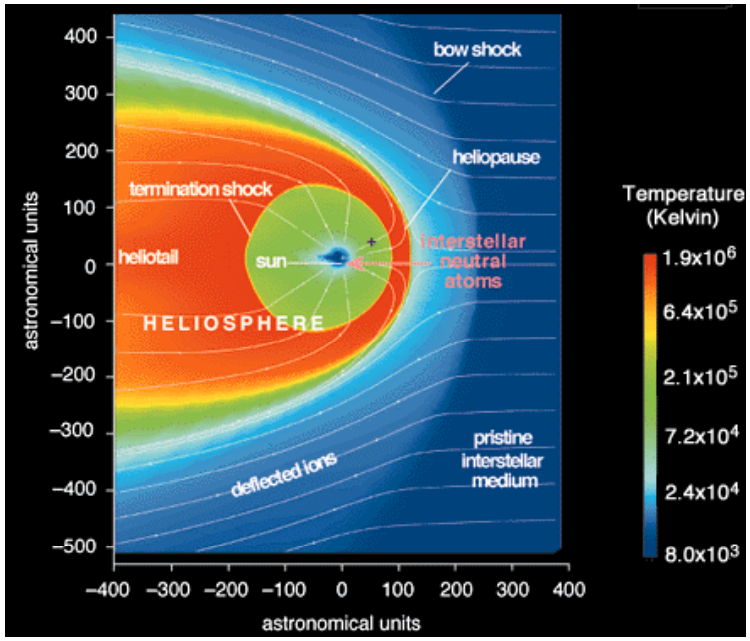
	MIN	MAX	AVG
FLUX (NO#/CM^2-S)	10^8	10^{10}	2-3X10^8
VELOCITY (KM/S)	200	2500	400-500
DENSITY (NO#/CM^3)	0.4	80	5-10
T (eV)	0.5	100	20
T_{max}/T_{avg}	1.0*	2.5	1.4
HELIUM RATIO (N_{He}/N_H)	0.0	0.25	0.05
FLOW DIRECTION	±15° from radial;		~2° East
ALFVEN SPEED (KM/S)	30	150	60
B (γ)	0.25	40	6
B VECTOR			
	POLAR COMPONENT:	AVG IN ECLIPTIC PLANE	
	PLANAR COMPONENT:	AVG SPIRAL ANGLE ~45°	

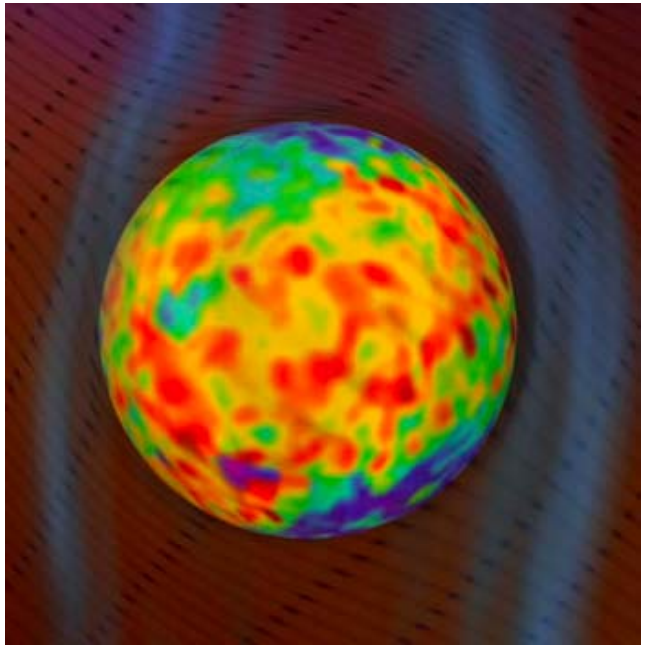
*isotropic

Meridional View



Two Models of the Heliopause





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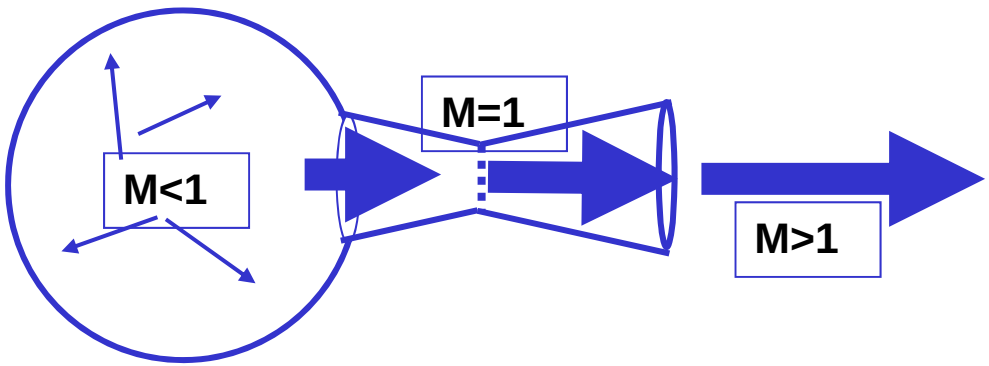
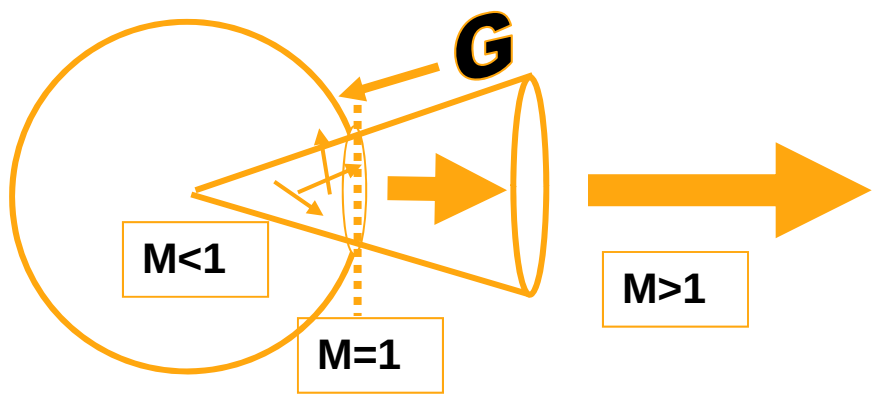
The Solar Wind Environment



De Laval Nozzle



The Solar "Gravity" Nozzle

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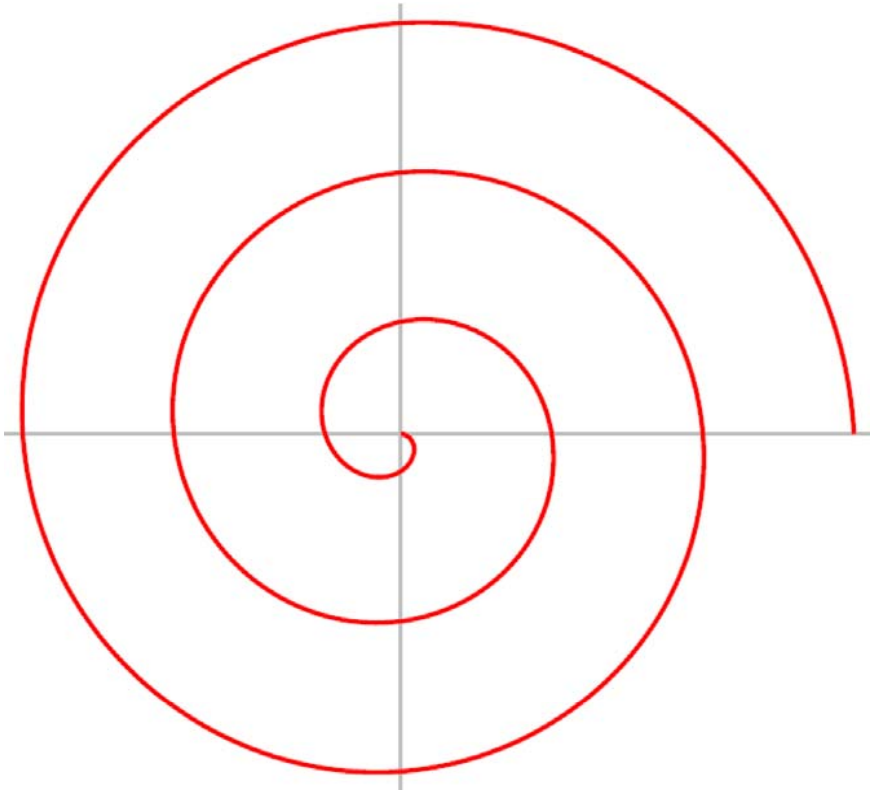
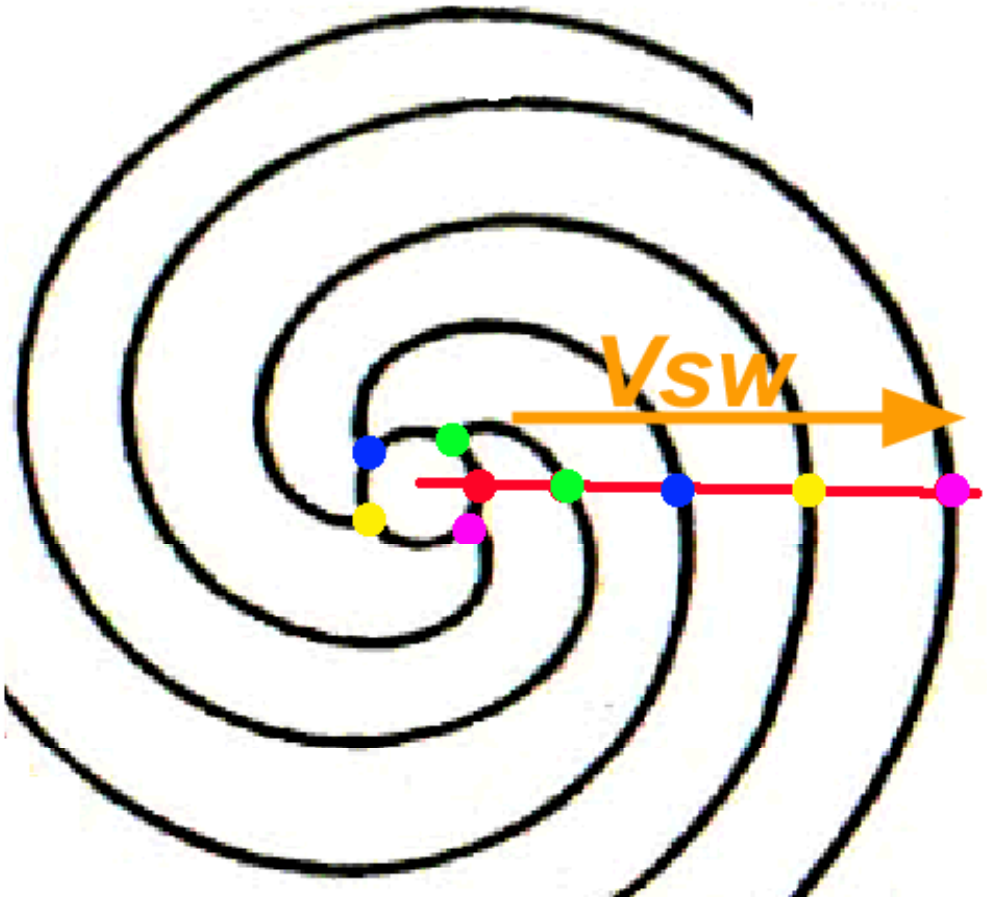
The Solar Wind Environment





Archimedean Spiral

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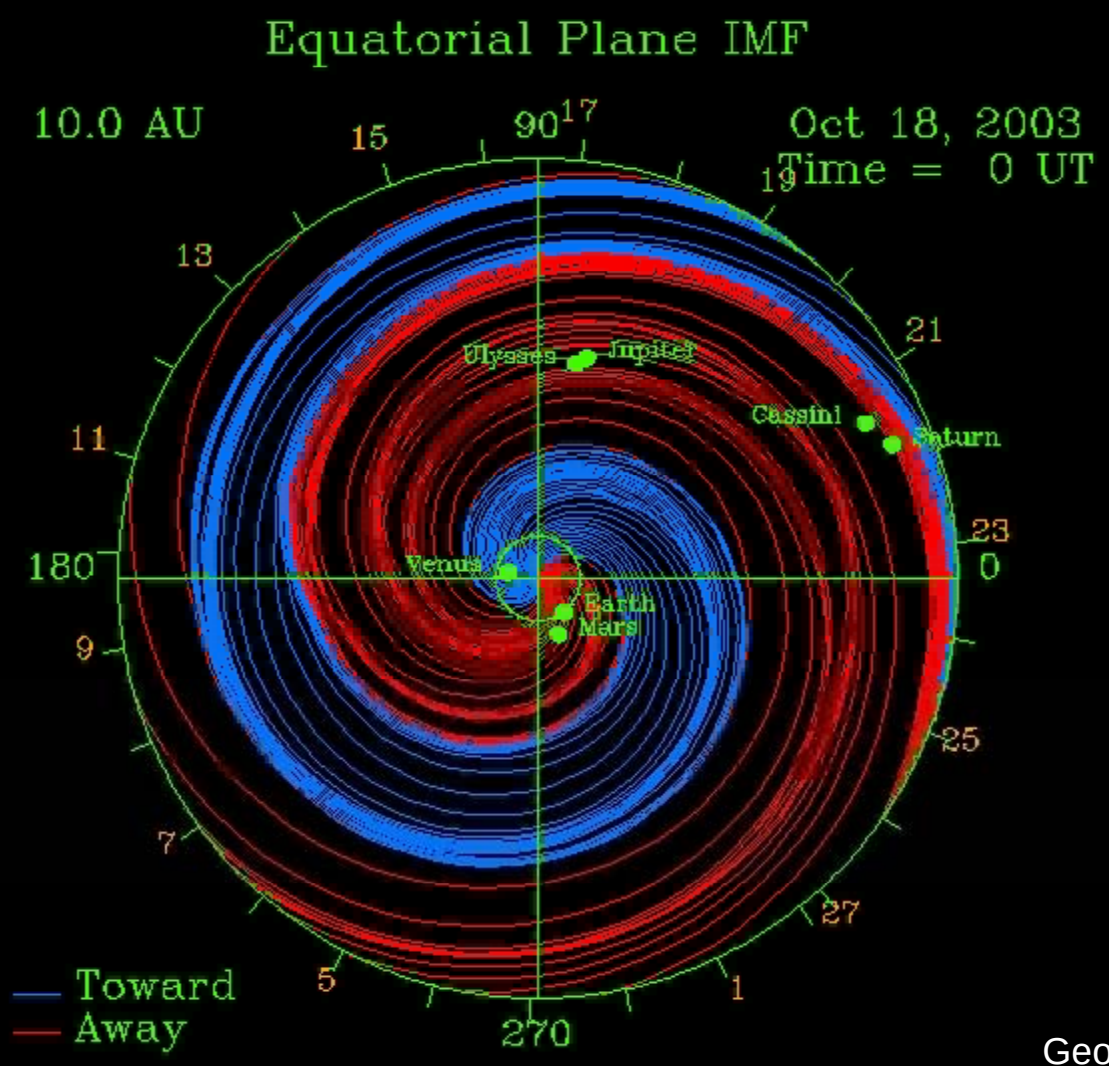
The Solar Wind—The Breeze in Space Weather



Geophysical Institute
University of Alaska

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The Sun

ACTIVE FEATURES:

SUNSPOTS:	Dark features in Photosphere; ~4600 °K. Most visible form of Solar Activity. Vary with ~11 (22) year cycle. Occur in magnetic pairs/ "Active Regions". Have dark central Umbra surrounded by a brighter Penumbra. Magnetic fields range from 100-4000 G.
PROMINENCES:	Large clouds or loops of gas high in Chromosphere. Appear as bright flame like objects.
CORONAL MASS EJECTIONS (CMEs):	Sudden massive release of plasma and embedded solar magnetic field from the Sun. Now believed to be a major source of geomagnetic storms and Solar Proton Events (SPEs).
SOLAR FLARES:	Sudden brightening in white light, X-ray, and radio. <u>May</u> occur in conjunctions with CME. A source of SPEs.
CORONAL HOLES:	Regions (usually near poles) of open field lines and high velocity streams.

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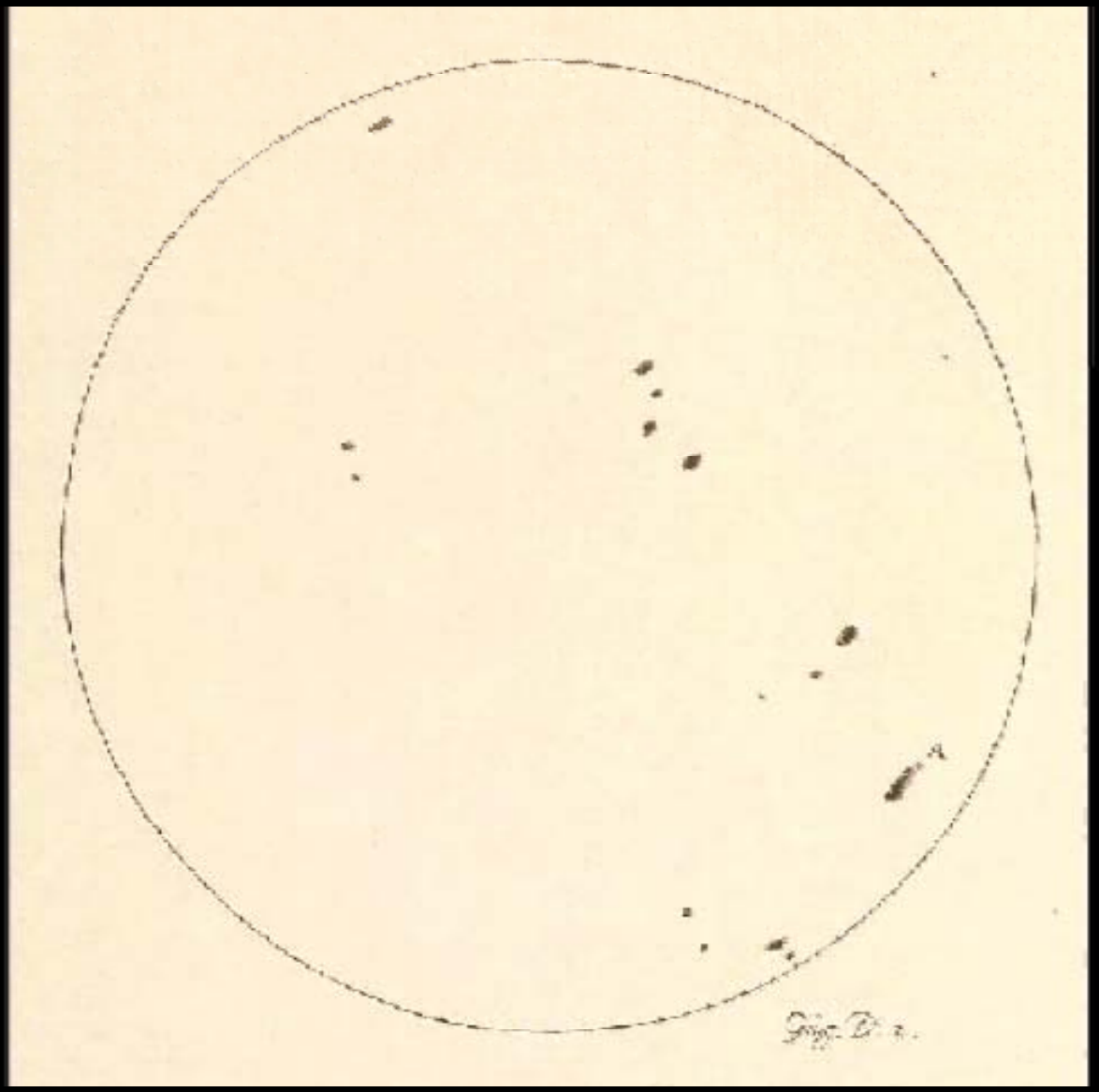
Sunspot Drawings by Galileo



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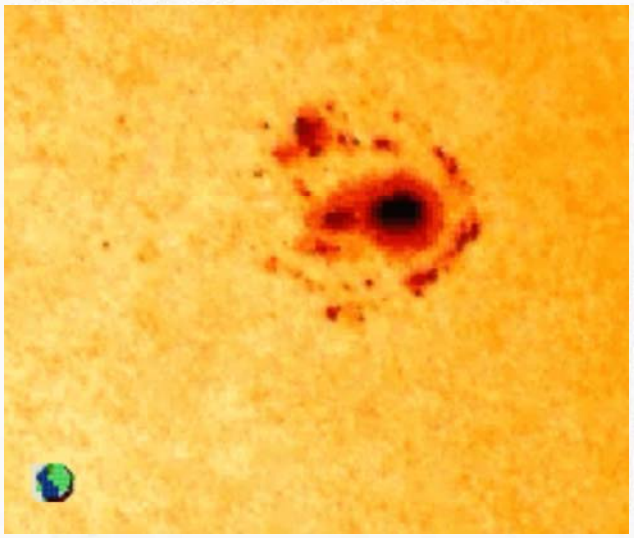
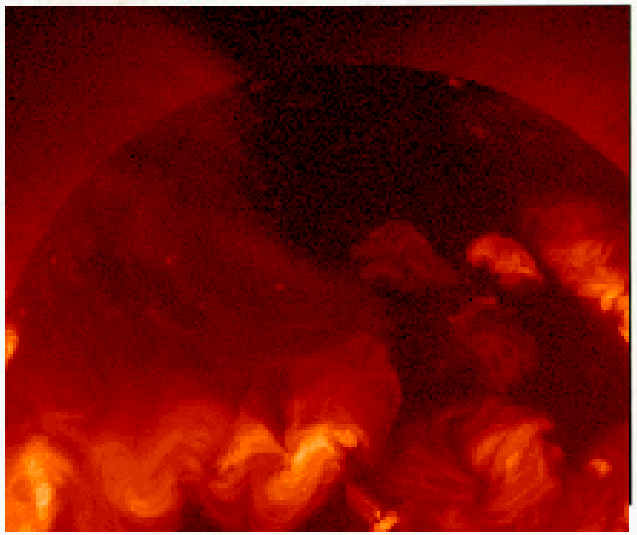
SOLAR ACTIVITY

SUNSPOT GROUP

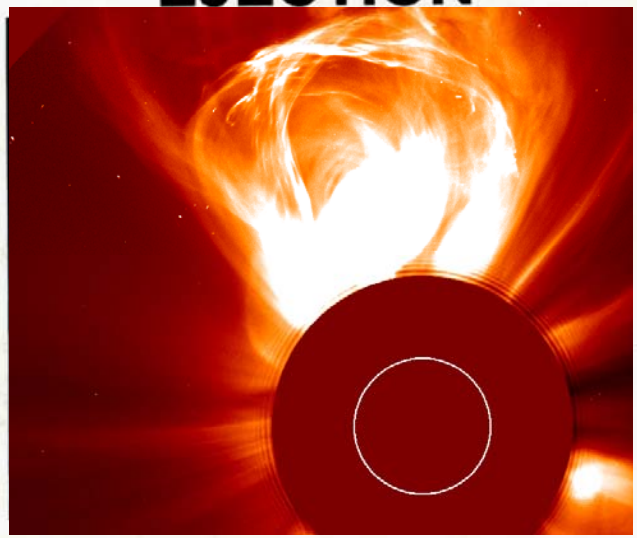


CORONAL HOLE



PROMINENCE

CORONAL MASS EJECTION



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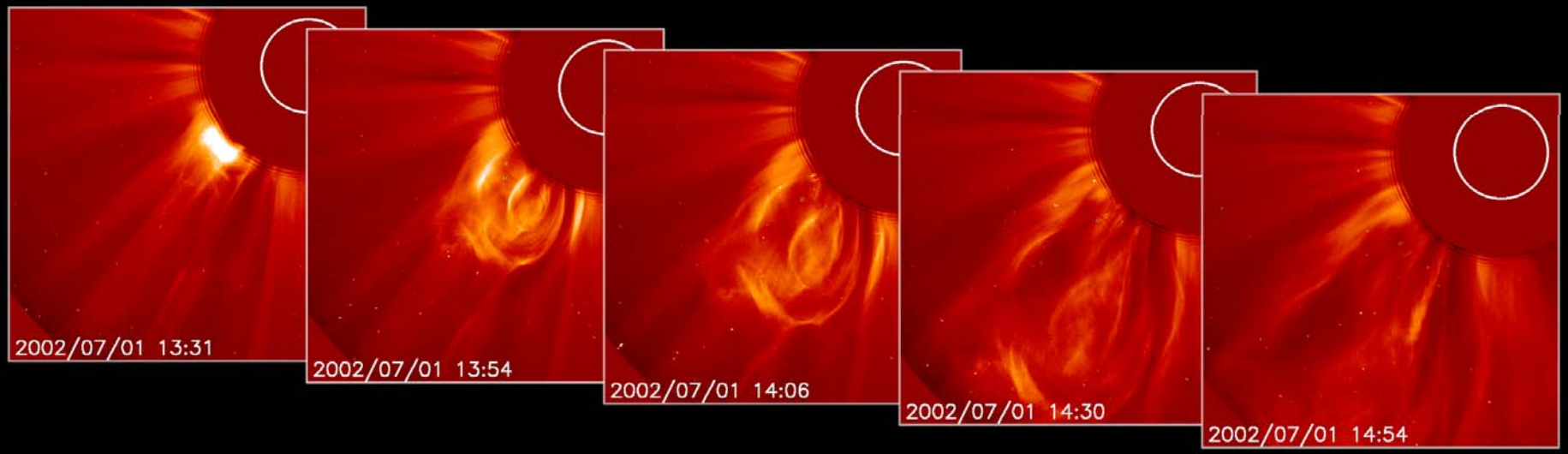
Coronal Mass Ejections: Space "Hurricanes"



Solar and Heliospheric Observatory

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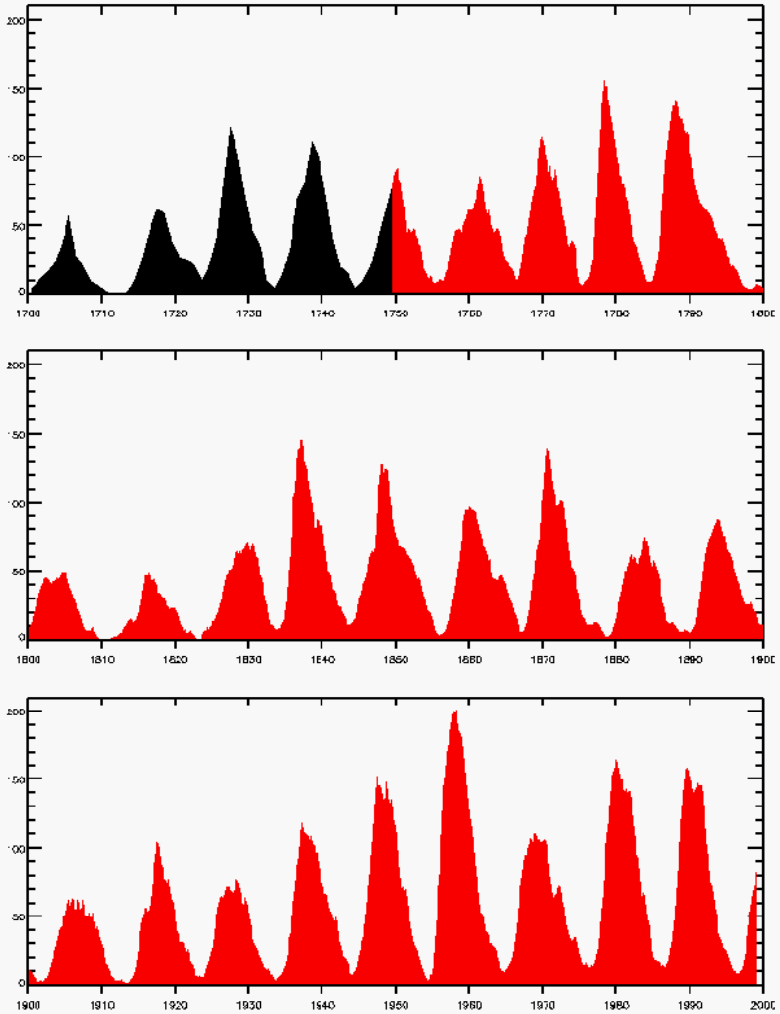
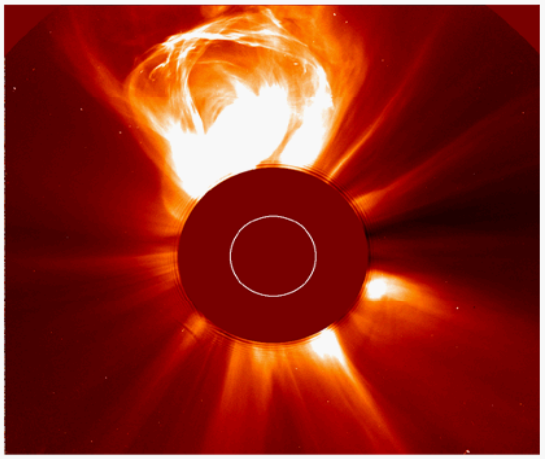
SOLAR ACTIVITY

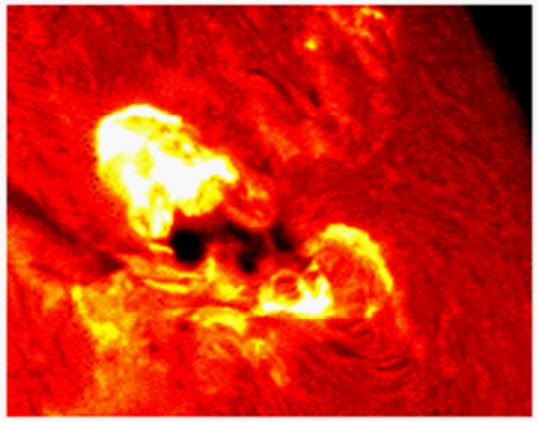
SUNSPOT CYCLE



CME



FLARE



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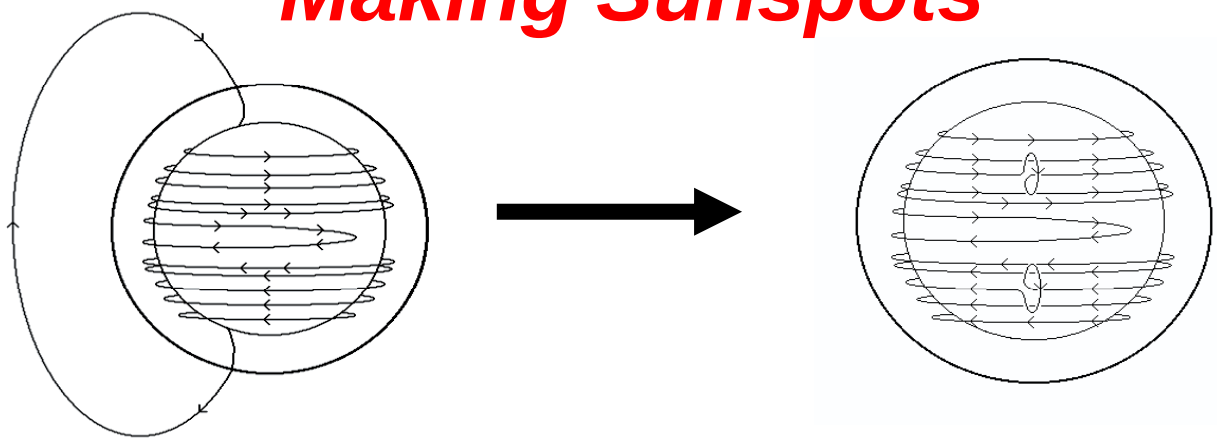
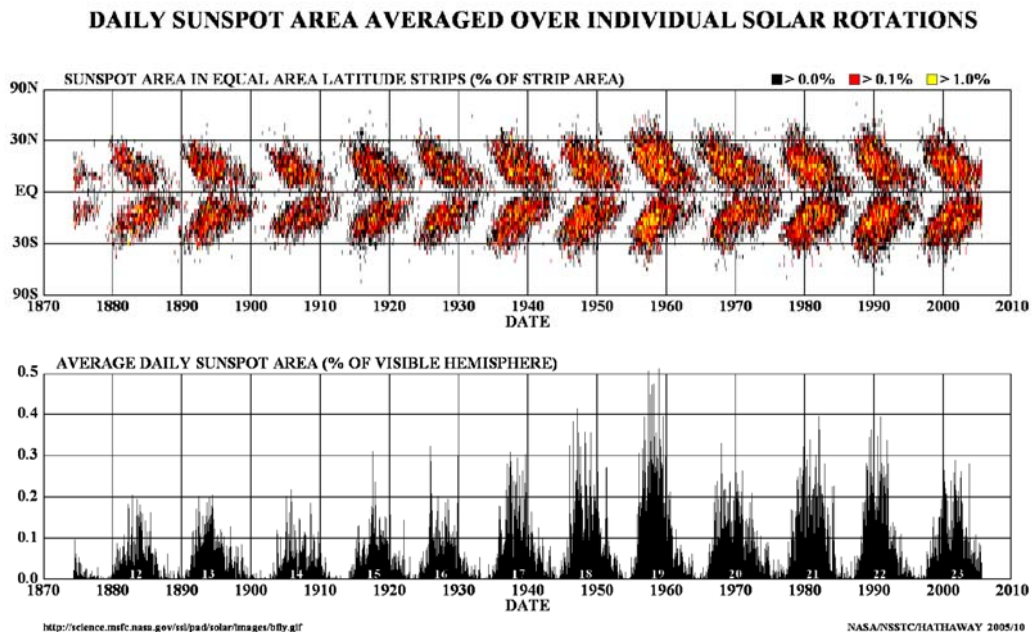
Making Sunspots



How Sunspots Migrate



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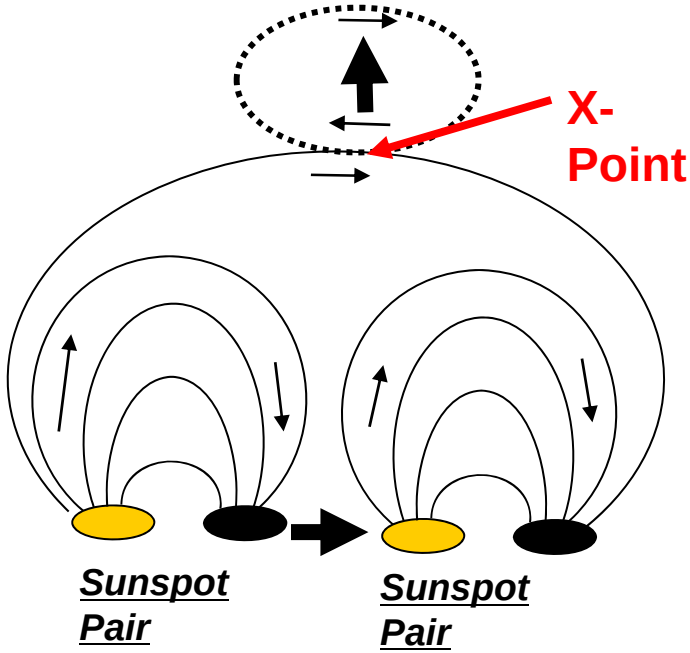
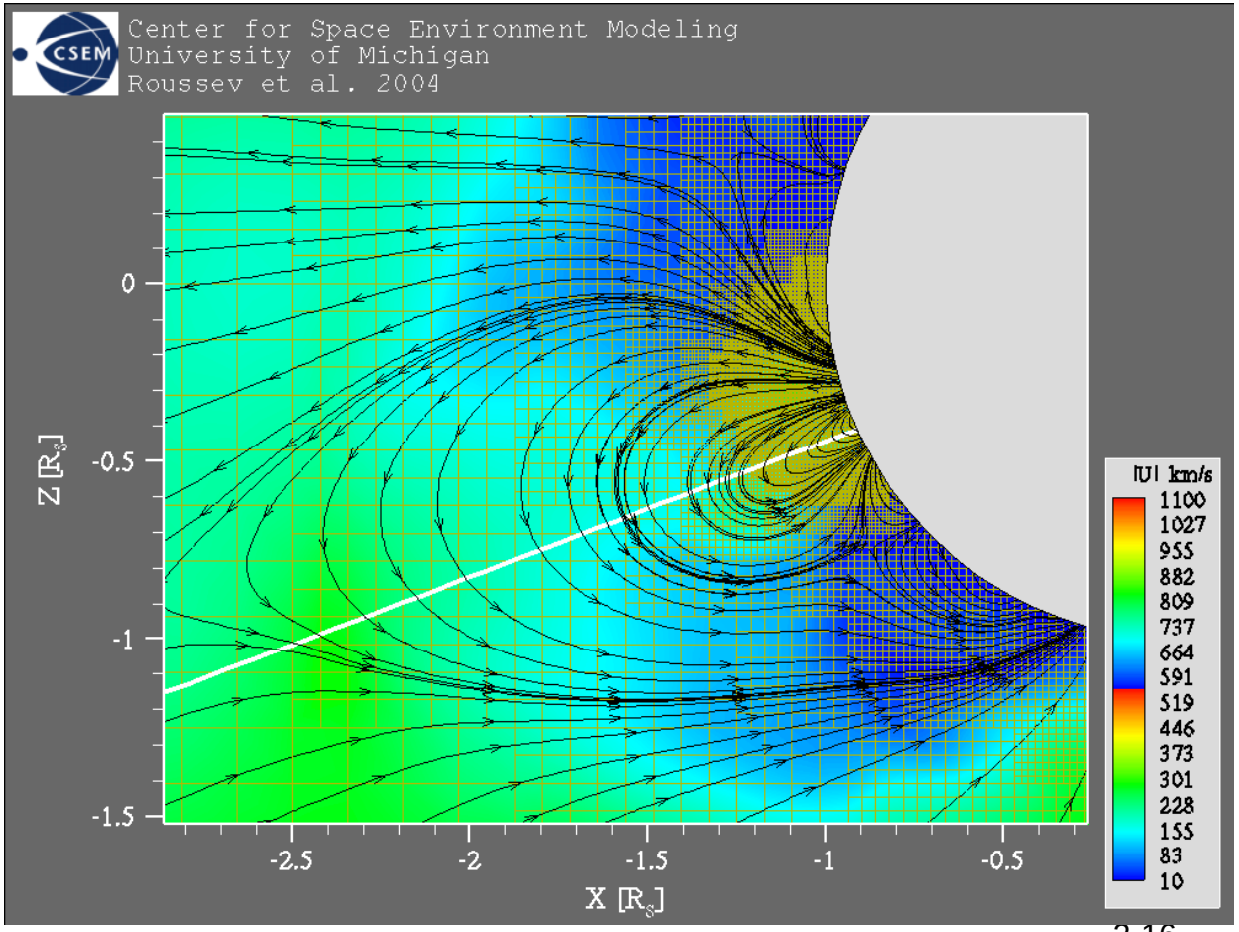
Magnetic Field Merging





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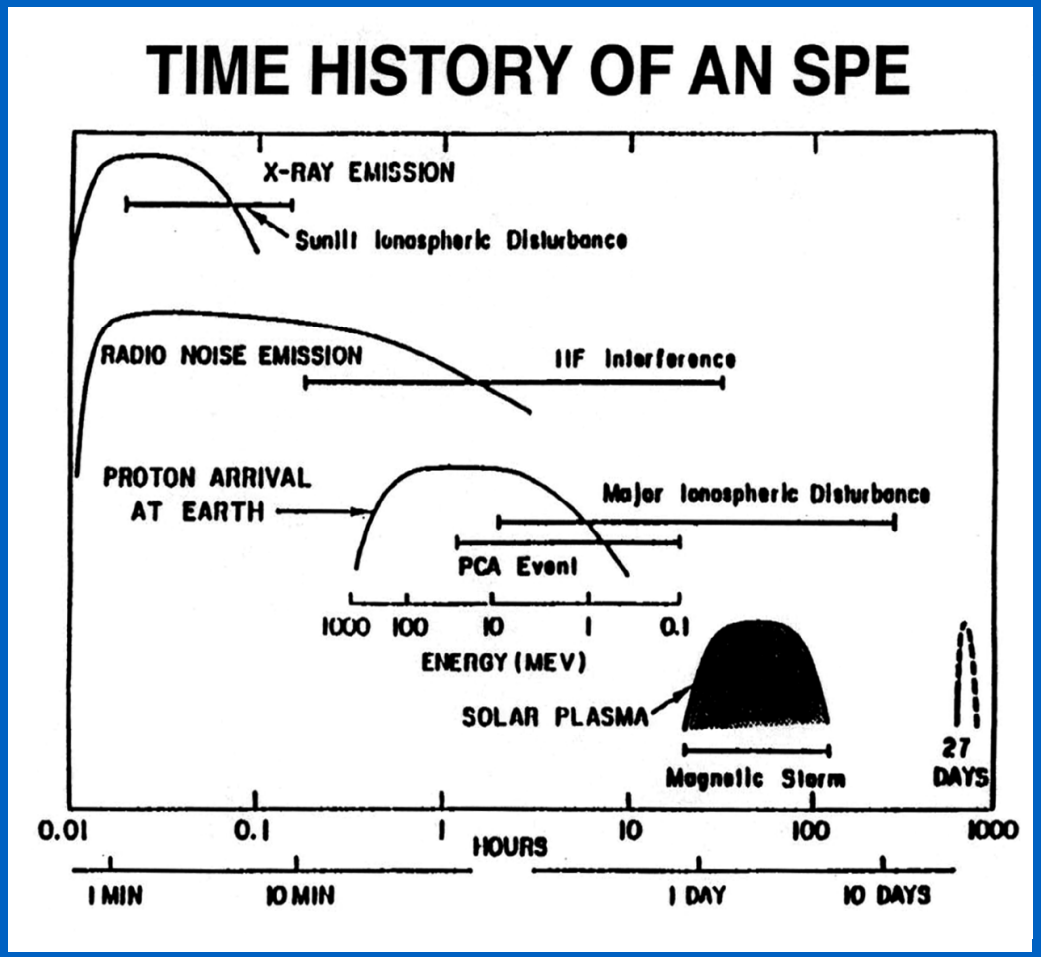
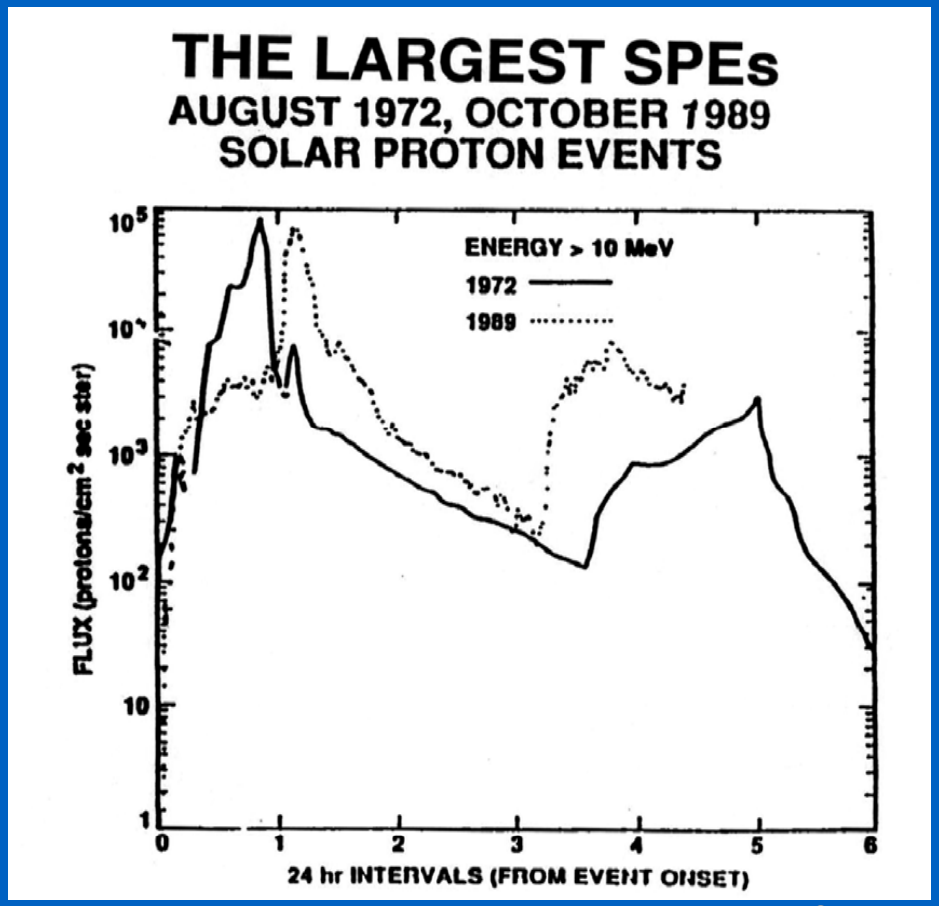
Solar Proton Events: Space "Rain"





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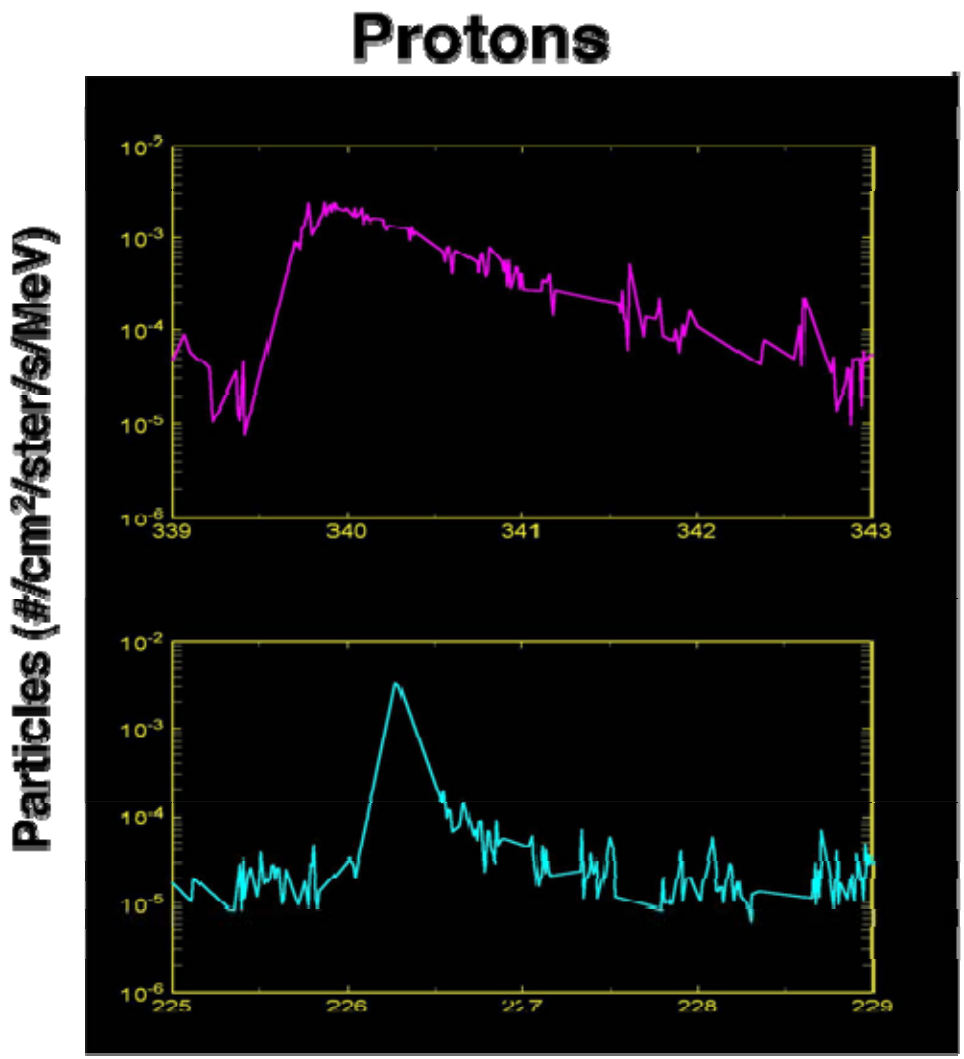
Solar Proton Events

REAMES SPE PARADIGM:

- 2 TYPES OF EVENTS
  - GRADUAL EVENT (~10/YEAR)
    - -CME DRIVEN SHOCK ACCELERATED
    - -ABUNDANCES SIMILAR TO CORONA AND SOLAR WIND PLASMA
    - LARGEST PROTON EVENTS
    - SHARP RISE/SLOW DECAY OVER HRS
    - WIDE LONGITUDE DISTRIBUTION
  - IMPULSIVE EVENT (~1000/YEAR)
    - -PARTICLES FLARE ACCELERATED
    - -ABUNDANCES CHARACTERISTIC OF FLARE PLASMA
    - RICH IN HEAVY IONS
    - SHARP PEAK IN X-RAYS
    - CONCENTRATED IN LONGITUDE



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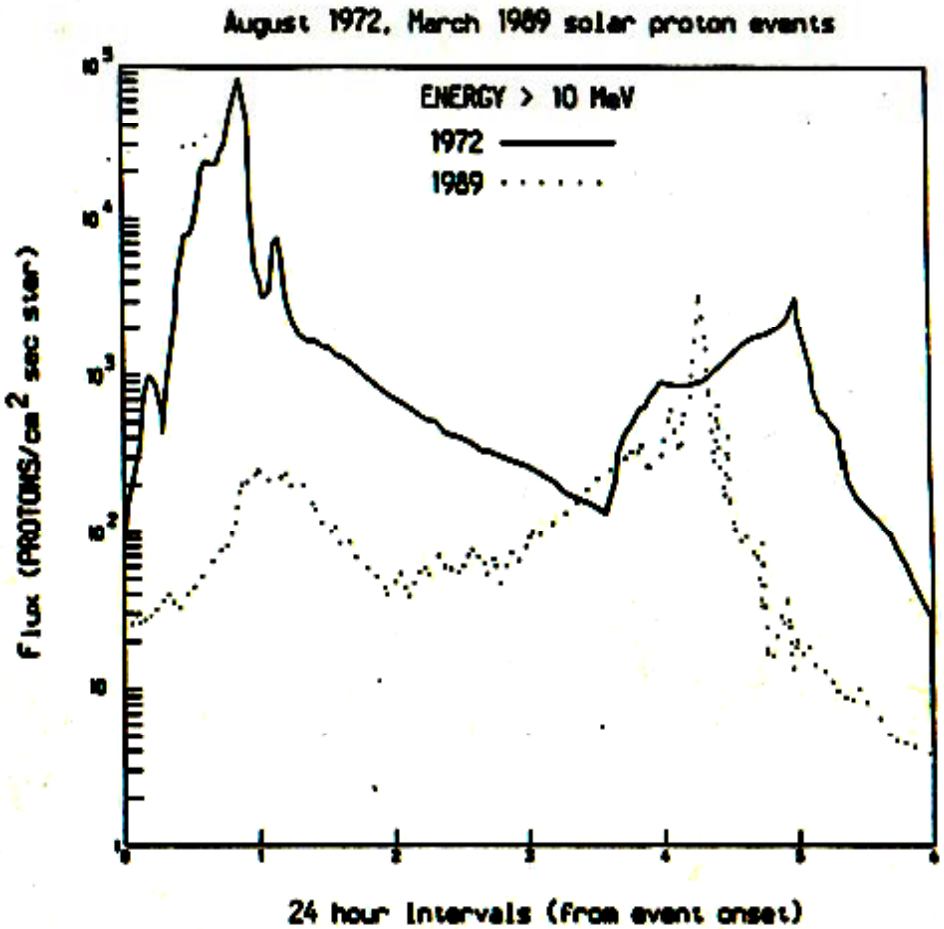
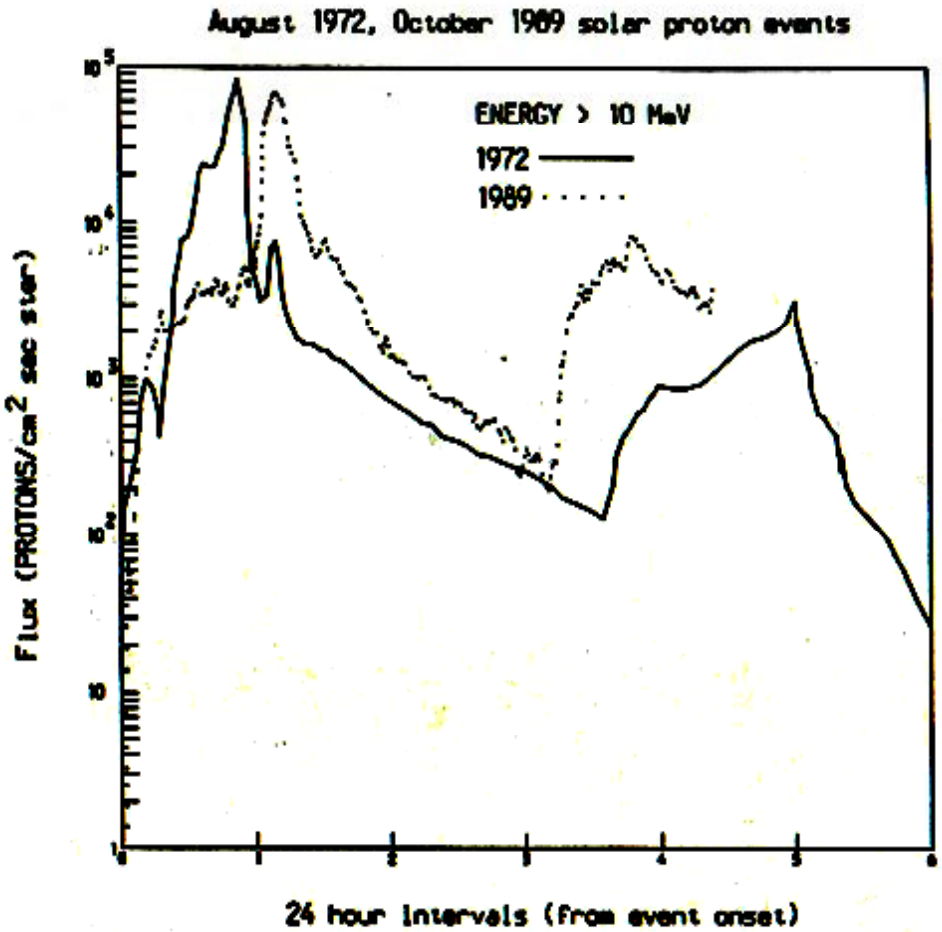
March–October 1989 Solar Proton Events Compared with August 1972 Event for E>10 MEV





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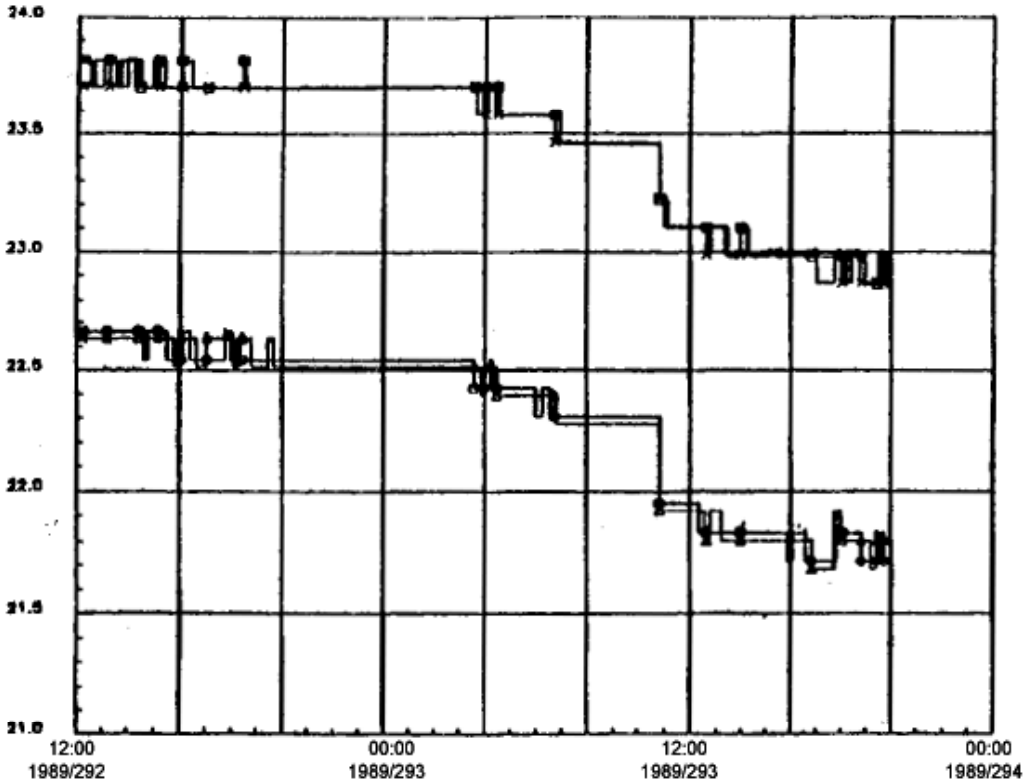
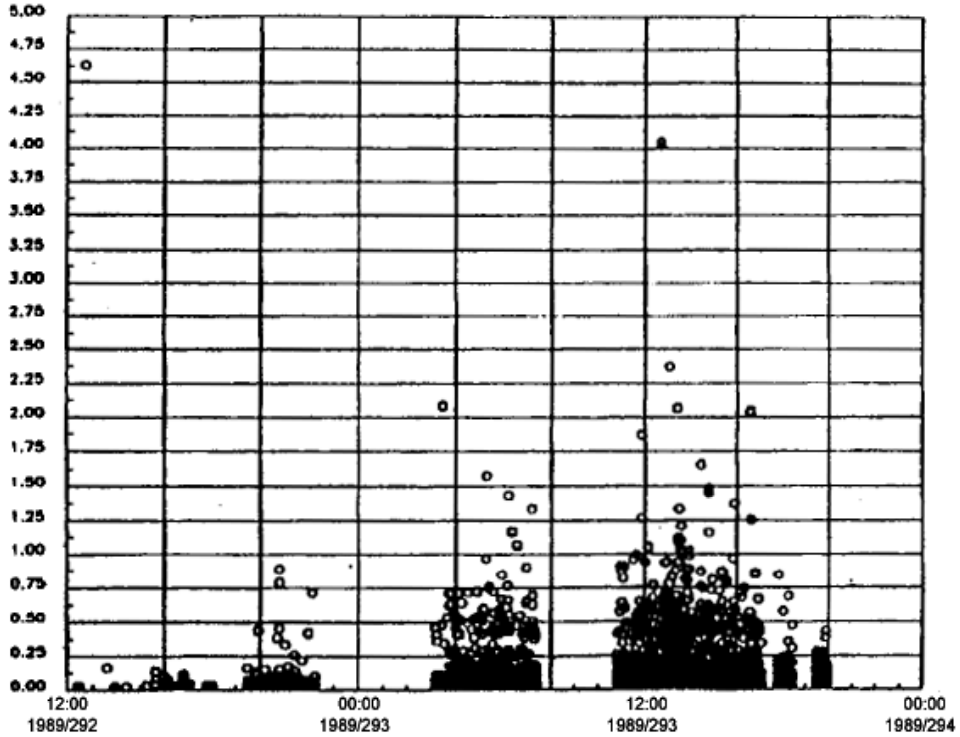
1989 Solar Proton Event Effects on Magellan

SOLAR ARRAY CURRENT



STAR SCANNER VOLTAGE



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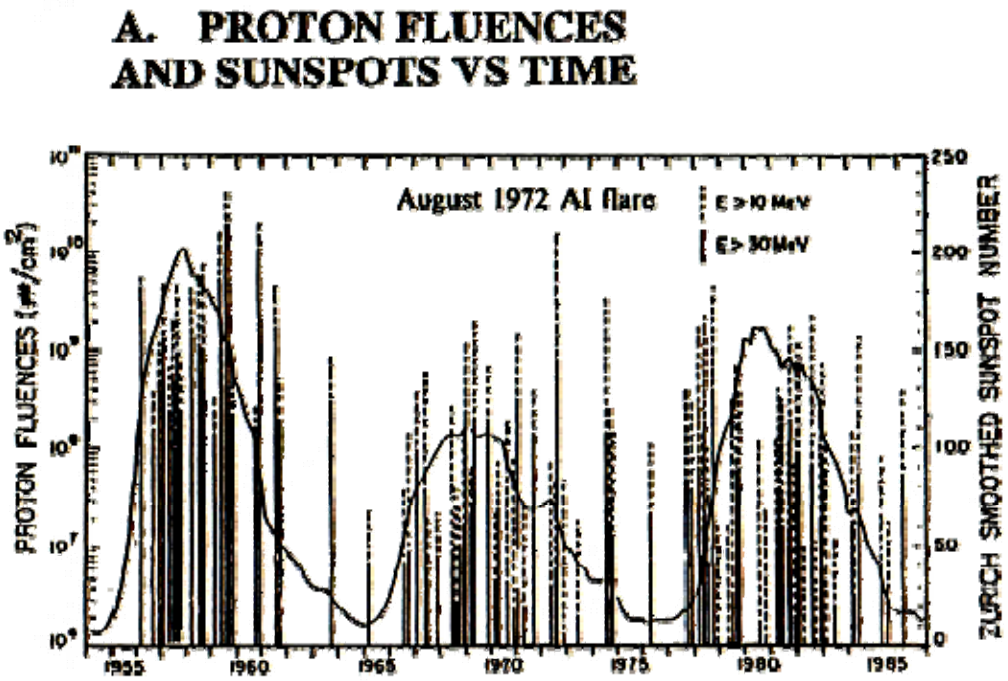
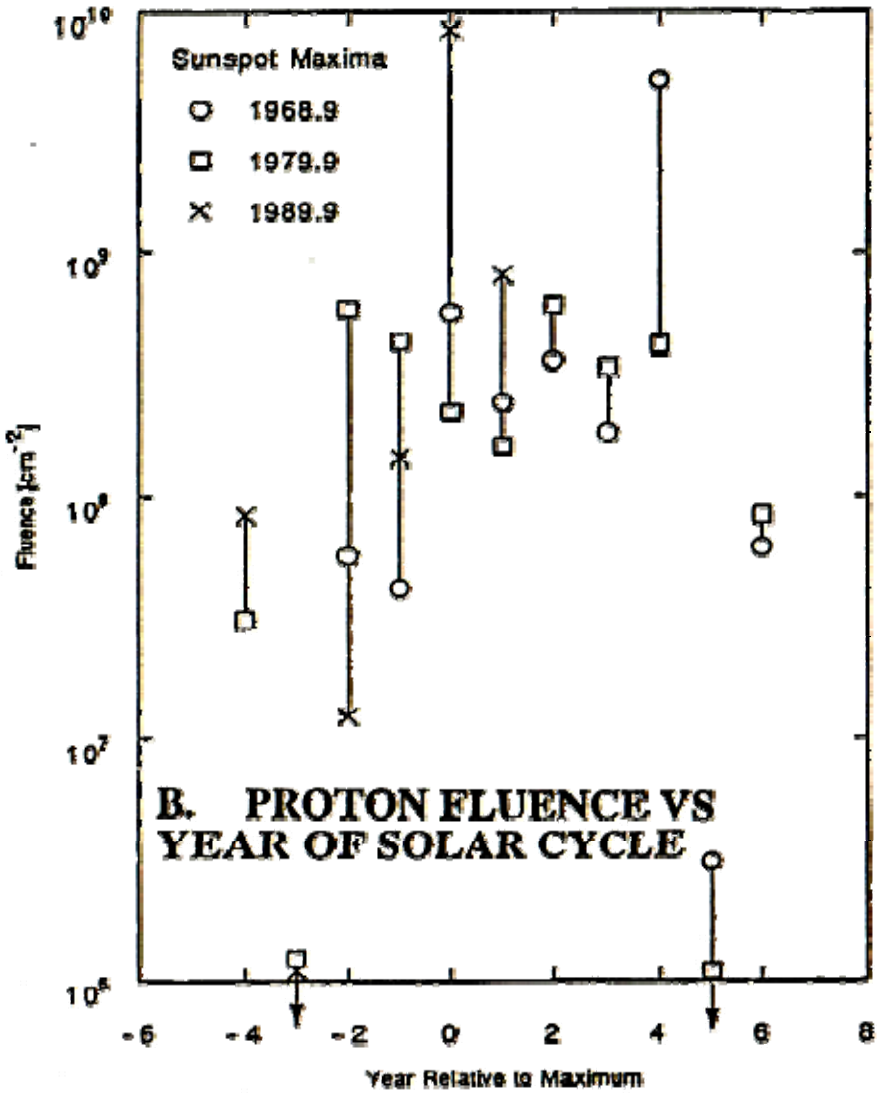
Frequency of Major Solar Proton Events





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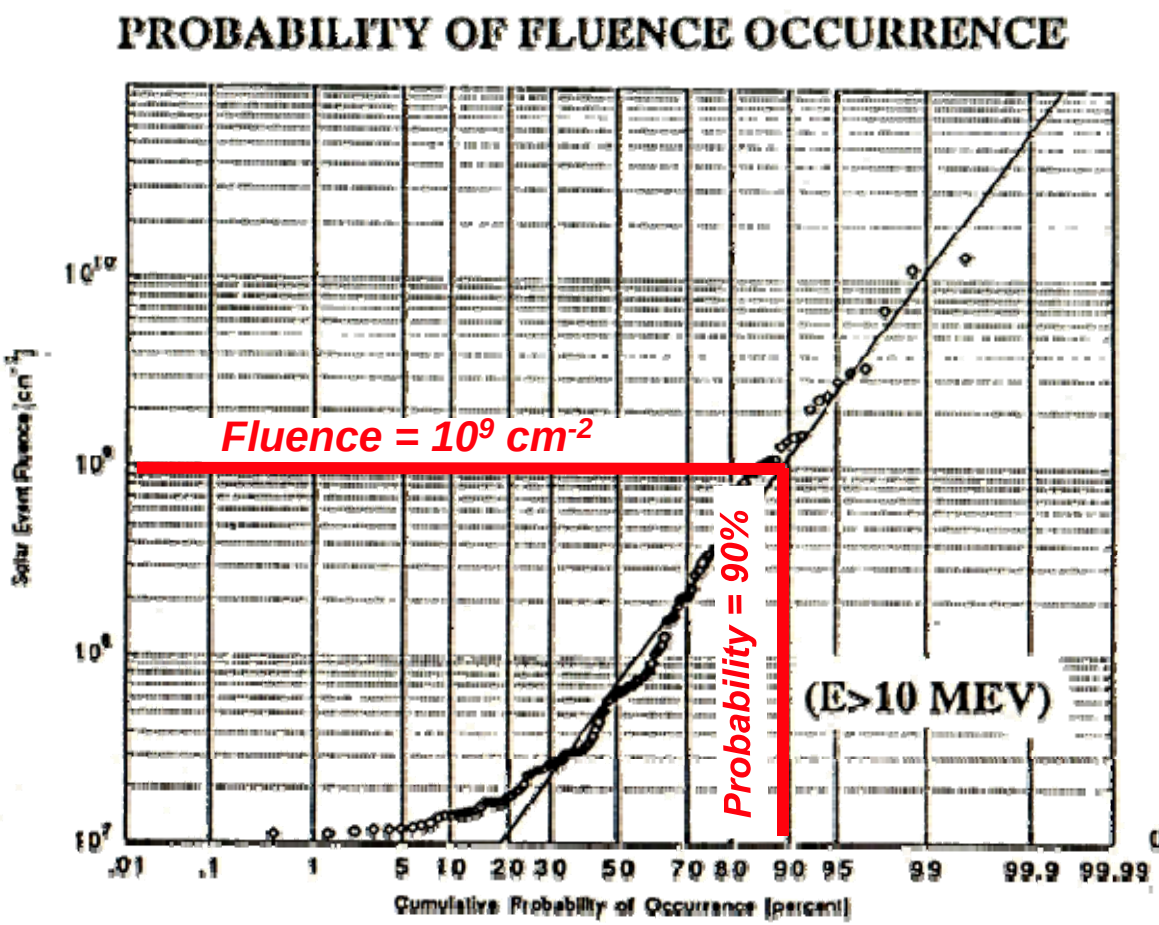
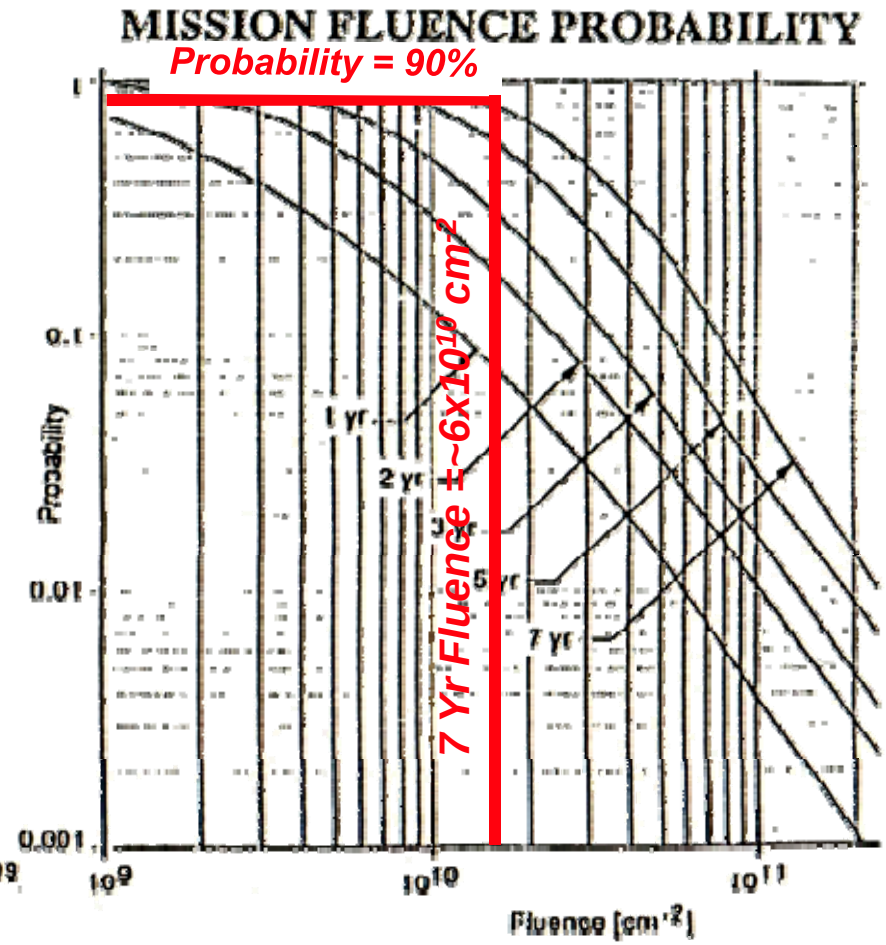
The JPL Model of Solar Proton Events





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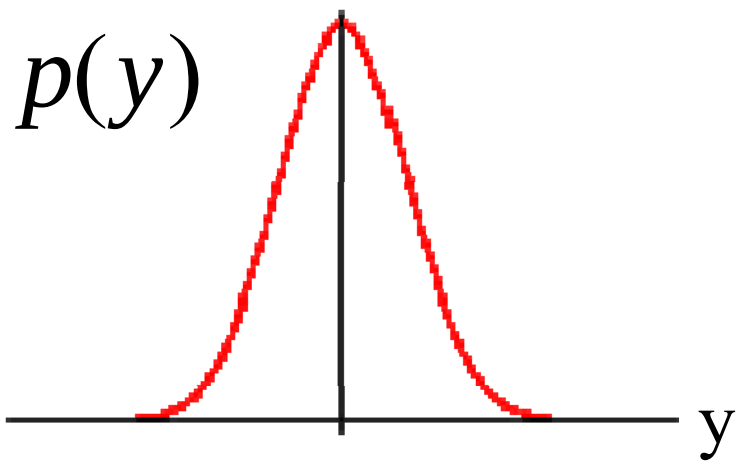
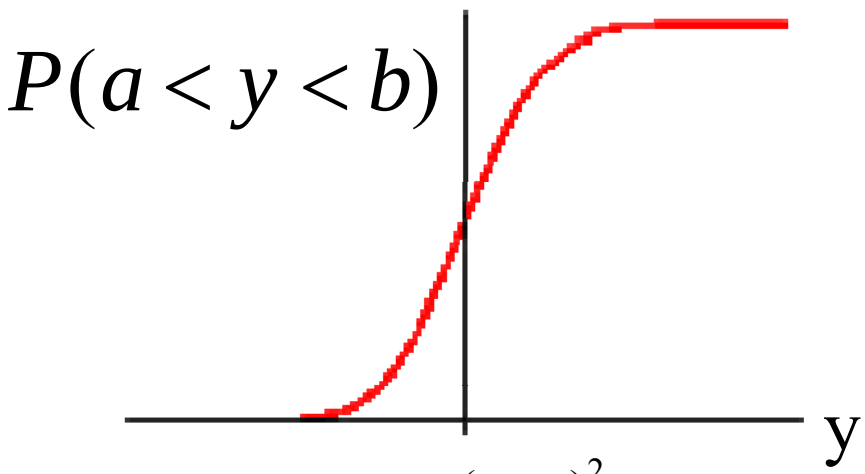
SPE Probability Curves

$$p(y) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(y-\mu)^2}{2\sigma^2}}$$

μ = mean of distribution
σ^2 = variance of distribution
y = continuous variable ($-\infty \le y \le \infty$)
= Log(SPE Fluence)





$$P(a < y < b) = \int_a^b p(y)dy = \frac{1}{\sigma\sqrt{2\pi}} \int_a^b e^{-\frac{(y-\mu)^2}{2\sigma^2}} dy$$

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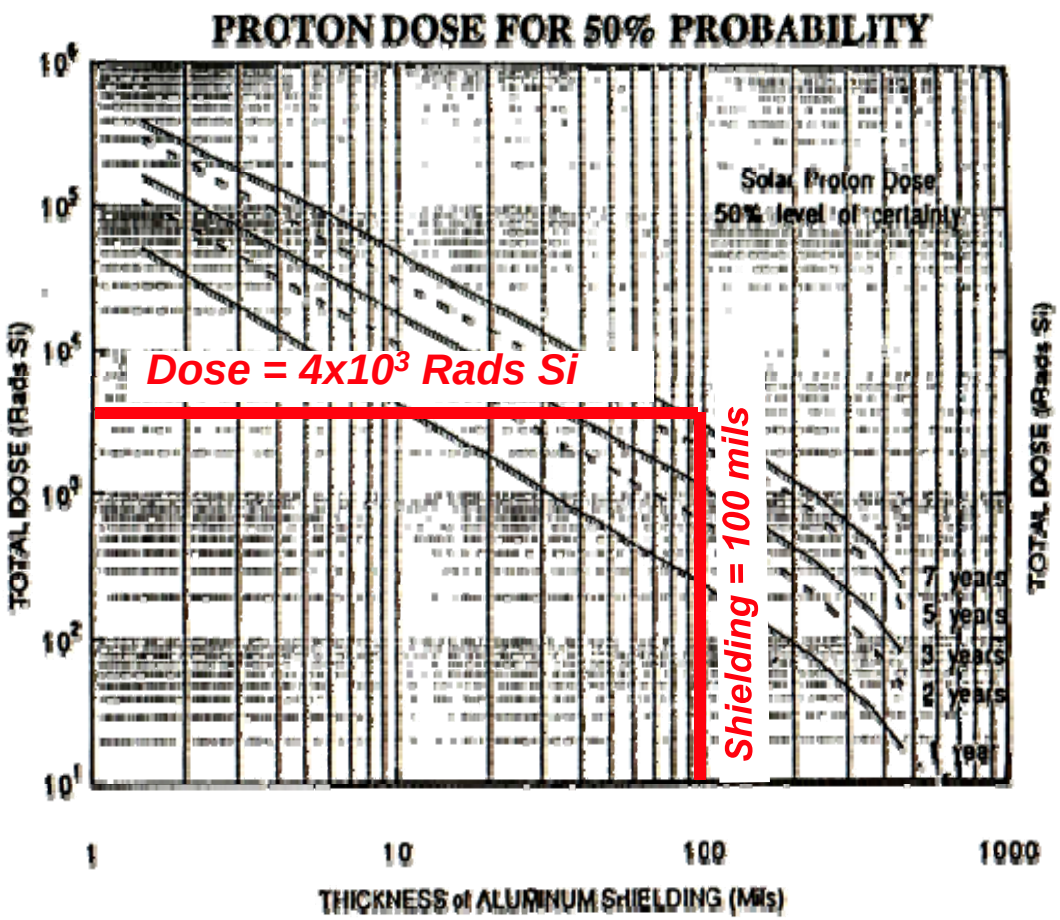
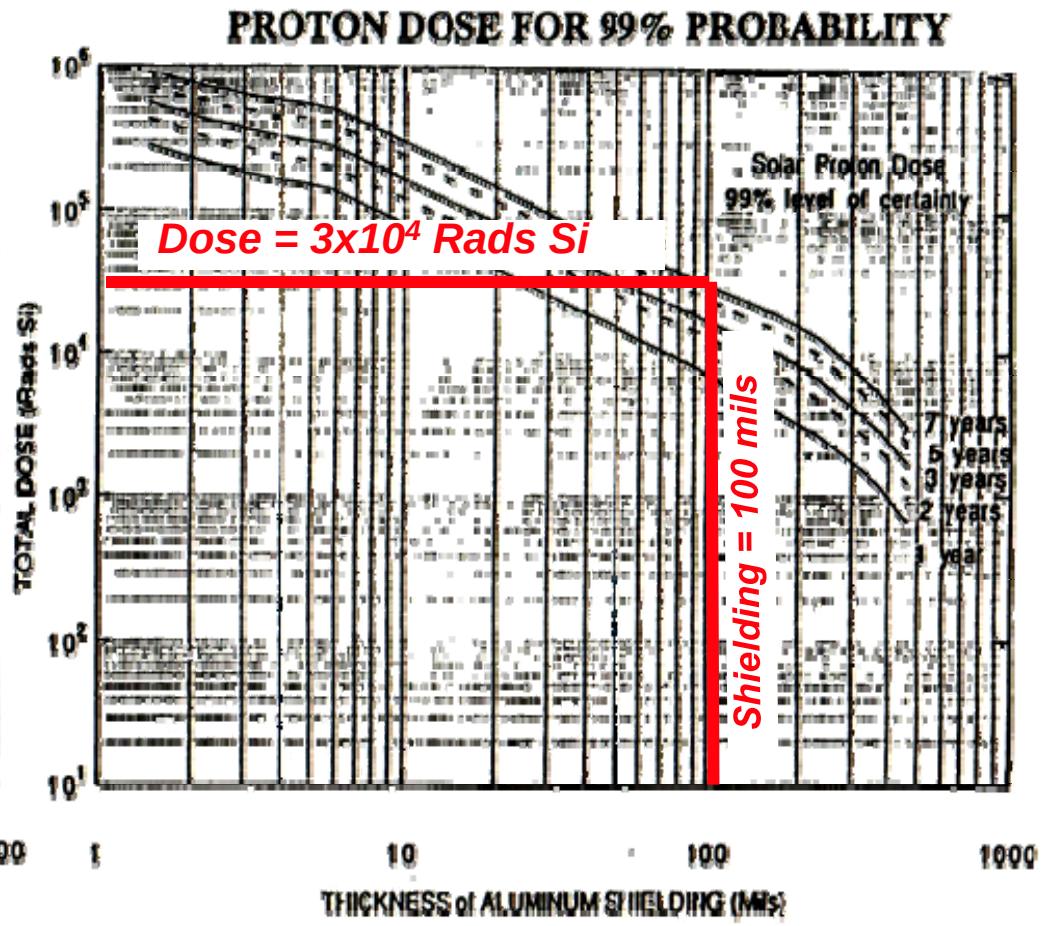
The JPL Model 1 AU DOSE Predictions





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Solar Particle Event Ionic Composition

Mean and Worst-Case Solar Particle Event Composition for Low Z Ions.[3]

Element	Mean case	Worst case	Element	Mean case	Worst case
H	1	1	P	2.3×10^{-7}	1.1×10^{-6}
He	1.0×10^{-2}	3.3×10^{-2}	S	8.0×10^{-6}	5.0×10^{-5}
Li	0	0	Cl	1.7×10^{-7}	8.0×10^{-7}
Be	0	0	Ar	3.3×10^{-6}	1.8×10^{-5}
B	0	0	K	1.3×10^{-7}	6.0×10^{-7}
C	1.6×10^{-4}	4.0×10^{-4}	Ca	3.2×10^{-6}	2.0×10^{-5}
N	3.8×10^{-5}	1.1×10^{-4}	Sc	0	0
O	3.2×10^{-4}	1.0×10^{-3}	Ti	1.0×10^{-7}	5.0×10^{-7}
F	0	0	V	0	0
Ne	5.1×10^{-5}	1.9×10^{-4}	Cr	5.7×10^{-7}	4.0×10^{-6}
Na	3.2×10^{-5}	1.3×10^{-5}	Mn	4.2×10^{-7}	2.3×10^{-6}
Mg	6.4×10^{-5}	2.5×10^{-4}	Fe	4.1×10^{-5}	4.0×10^{-4}
Al	3.5×10^{-6}	1.4×10^{-5}	Co	1.0×10^{-7}	5.5×10^{-7}
Si	5.8×10^{-5}	1.9×10^{-4}	Ni	2.2×10^{-6}	2.0×10^{-5}

Mean Solar Particle Event Compositions for High Z Ions.[3]

Element	Mean case	Element	Mean case	Element	Mean case
Cu	2.0×10^{-8}	Sn	2.0×10^{-10}	Lu	2.0×10^{-12}
Zn	6.0×10^{-8}	Sb	1.4×10^{-11}	Hf	8.0×10^{-12}
Ga	2.0×10^{-9}	Te	3.0×10^{-10}	Ta	9.0×10^{-13}
Ge	5.0×10^{-9}	I	6.0×10^{-11}	W	1.0×10^{-11}
As	3.0×10^{-10}	Xe	2.7×10^{-10}	Re	2.0×10^{-12}
Se	3.0×10^{-9}	Cs	2.0×10^{-11}	Os	3.0×10^{-11}
Br	4.0×10^{-10}	Ba	2.0×10^{-10}	Ir	3.0×10^{-11}
Kr	2.0×10^{-9}	La	2.0×10^{-11}	Pt	6.0×10^{-11}
Rb	3.0×10^{-10}	Ce	5.0×10^{-11}	Au	1.0×10^{-11}
Sr	1.0×10^{-9}	Pr	8.0×10^{-12}	Hg	1.0×10^{-11}
Y	2.0×10^{-10}	Nd	4.0×10^{-11}	Tl	9.0×10^{-12}
Zr	5.0×10^{-10}	Pm	0	Pb	1.0×10^{-10}
Nb	4.0×10^{-11}	Sm	1.0×10^{-11}	Bi	6.0×10^{-12}
Mo	2.0×10^{-10}	Eu	4.0×10^{-12}	Po	0
Tc	0	Gd	2.0×10^{-11}	At	0
Ru	9.0×10^{-11}	Tb	3.0×10^{-12}	Rn	0
Rh	2.0×10^{-11}	Dy	2.0×10^{-11}	Fr	0
Pd	6.0×10^{-11}	Ho	4.0×10^{-12}	Ac	0
Ag	2.0×10^{-11}	Er	1.0×10^{-11}	Th	2.0×10^{-12}
Cd	7.0×10^{-11}	Tm	2.0×10^{-12}	Pa	0
In	9.0×10^{-12}	Yb	9.0×10^{-12}	U	1.2×10^{-12}

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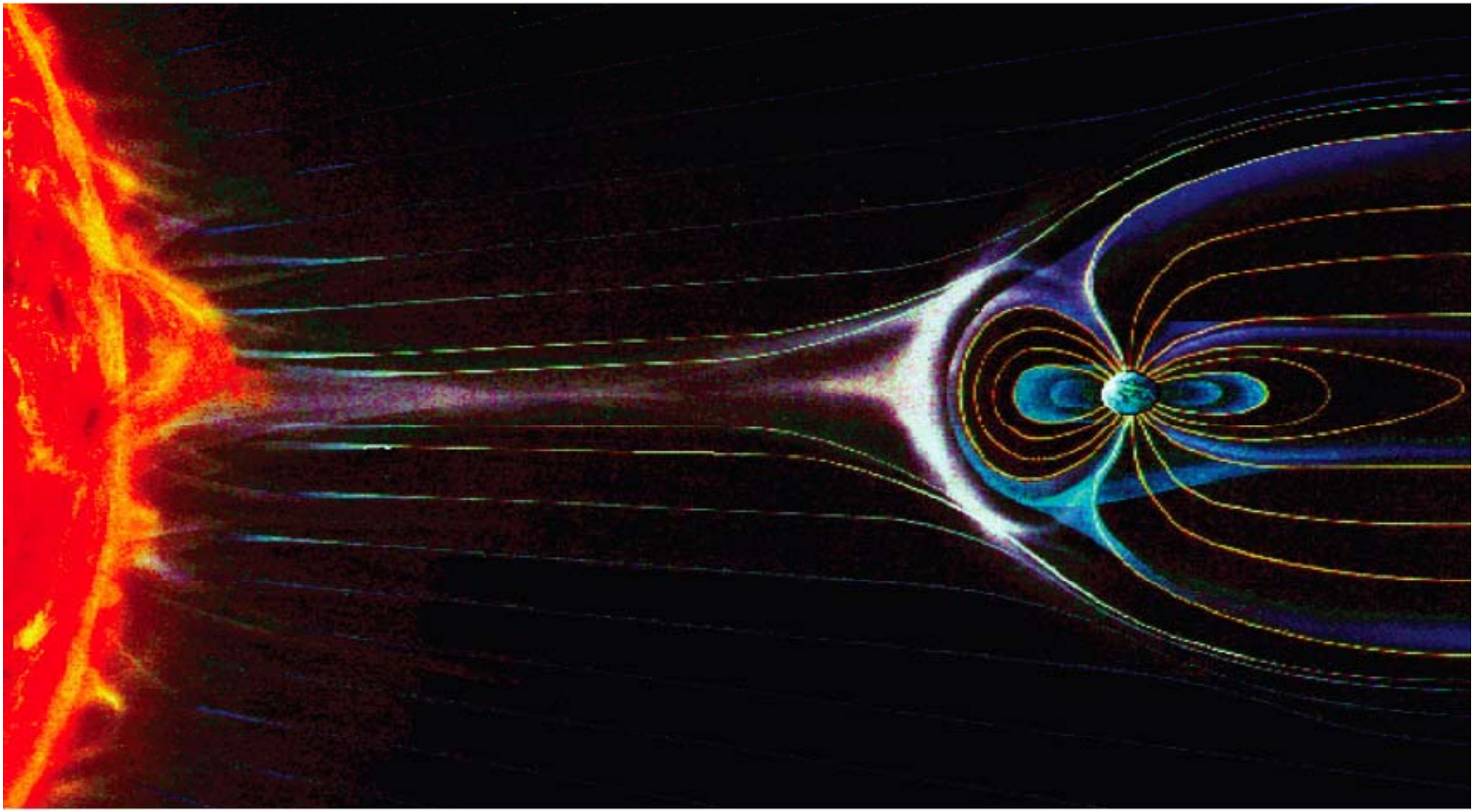
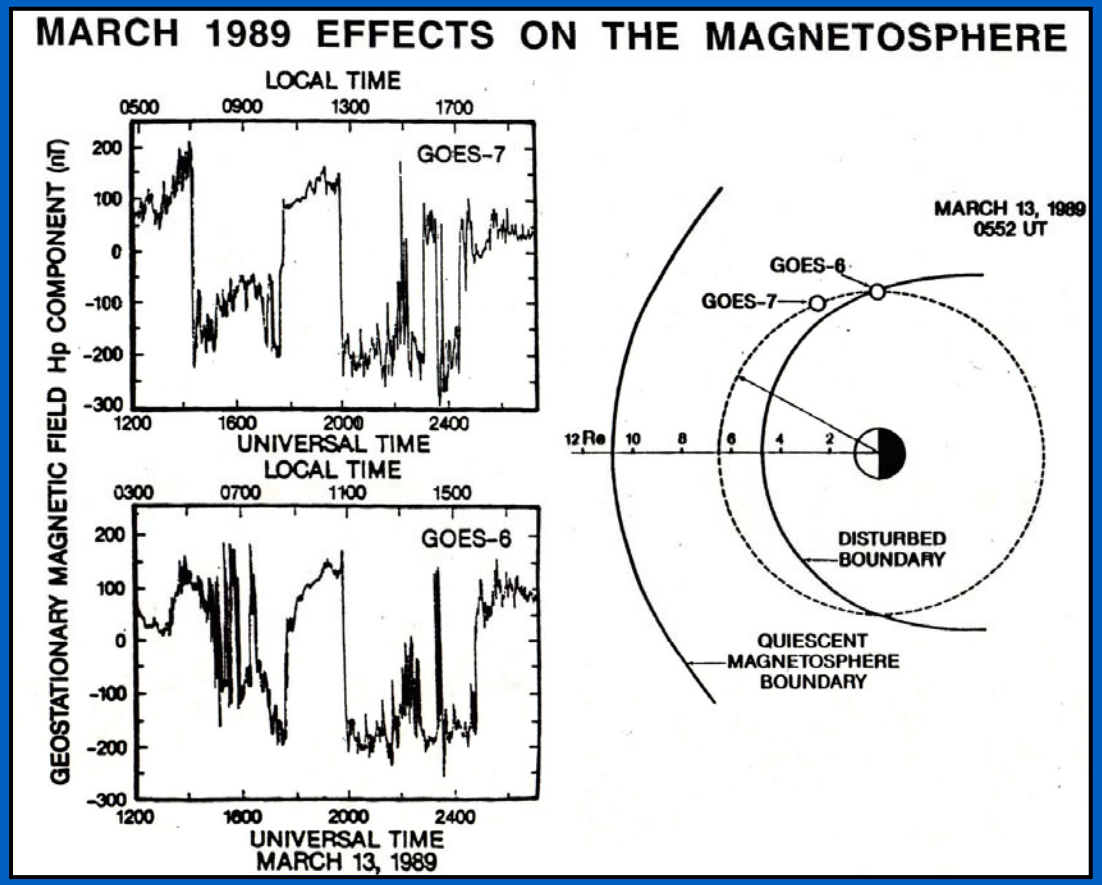
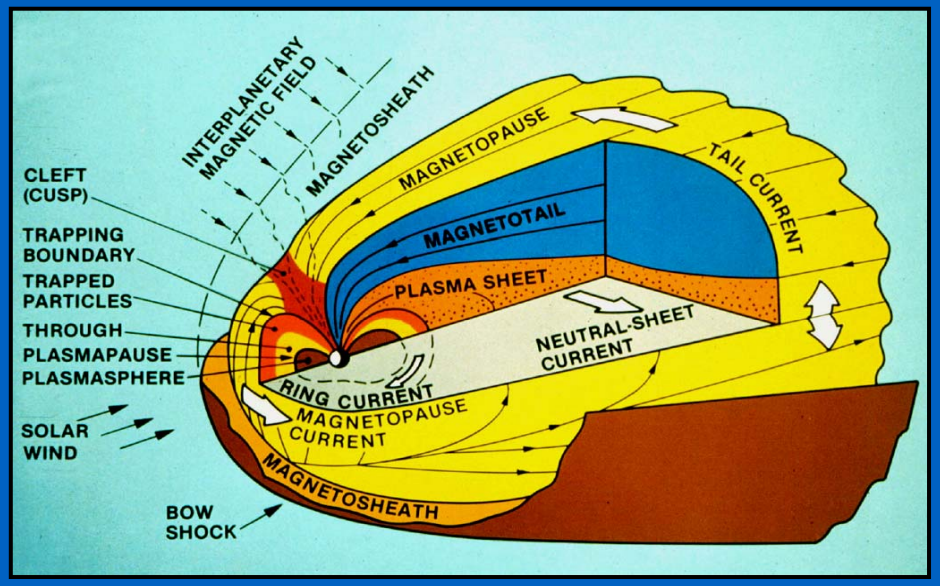
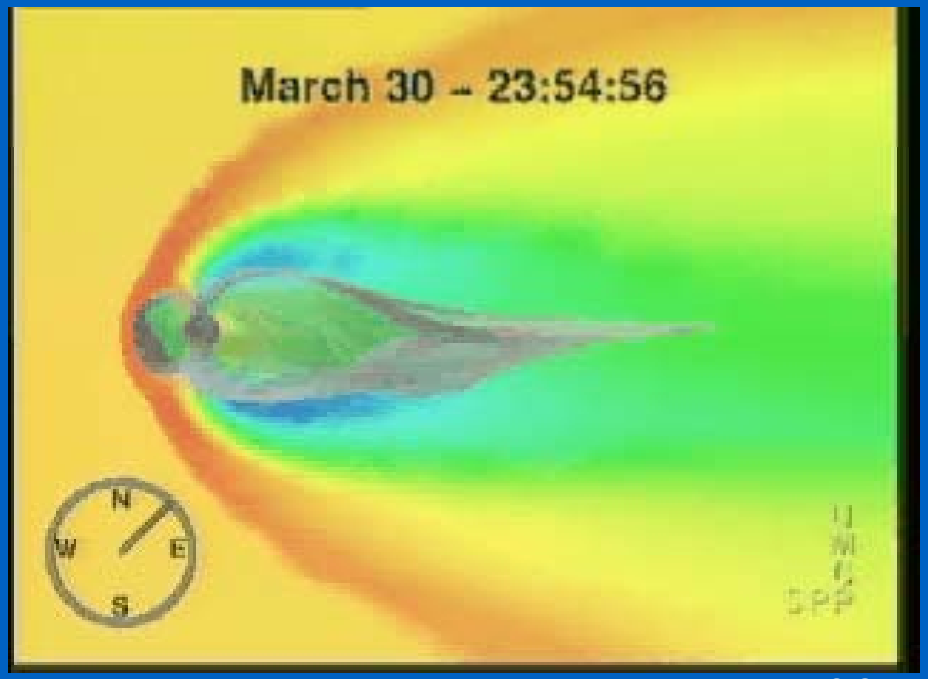
Magnetospheres are created when the Solar Wind interacts with planetary magnetic fields:



Effects of a Coronal Mass Ejection on the Earth's Magnetosphere







Charged Particle Motions in Electric and Magnetic Fields

FORCES:

$$\overline{F}_E = q\overline{E}$$

$$\overline{F}_M = \frac{q}{c}\overline{V} \times \overline{B}$$

CYCLOTRON RADIUS:

$$R_c = \frac{\gamma m_o V_\perp c}{qB}$$

CYCLOTRON FREQUENCY:

$$\omega_c = \frac{qB}{\gamma m_o c}$$

PITCH ANGLE:

$$\sin\alpha = V_\perp / V = \left(B/B_m\right)^{1/2}$$

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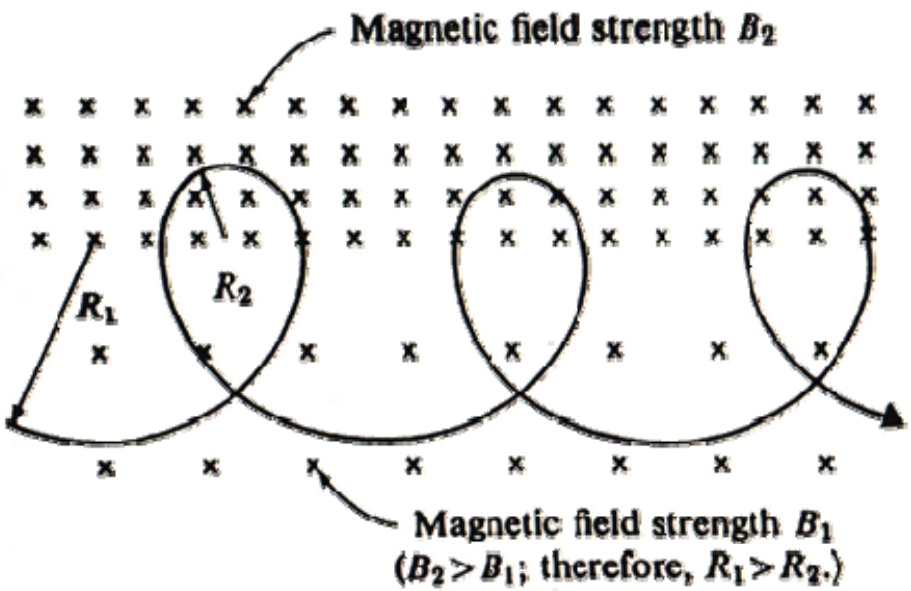
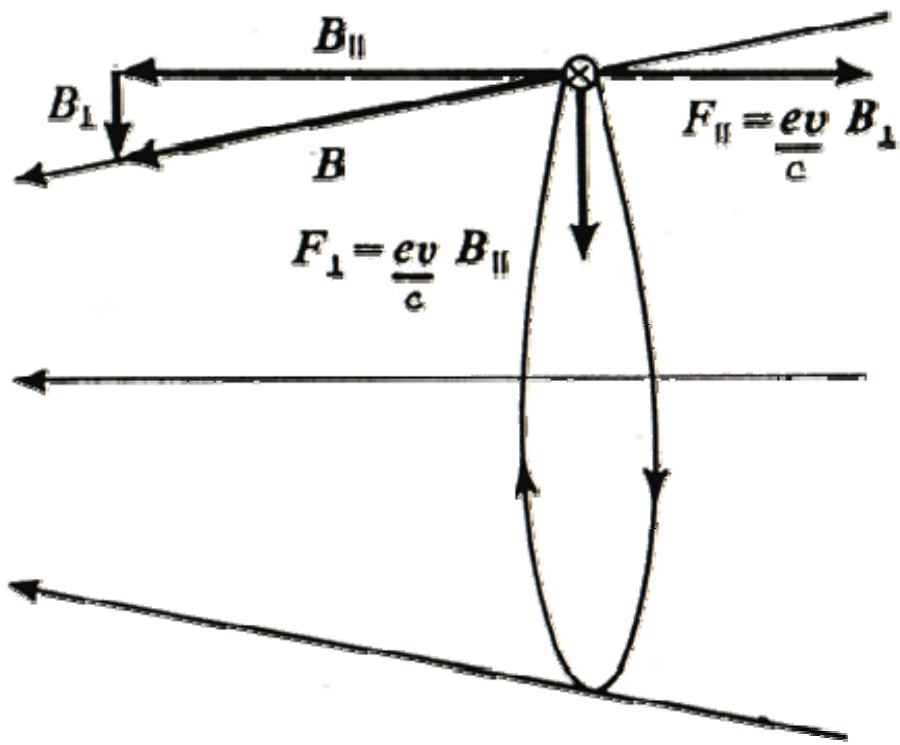
Motion in a Magnetic Field

GRADIENT EFFECT



MIRROR EFFECT



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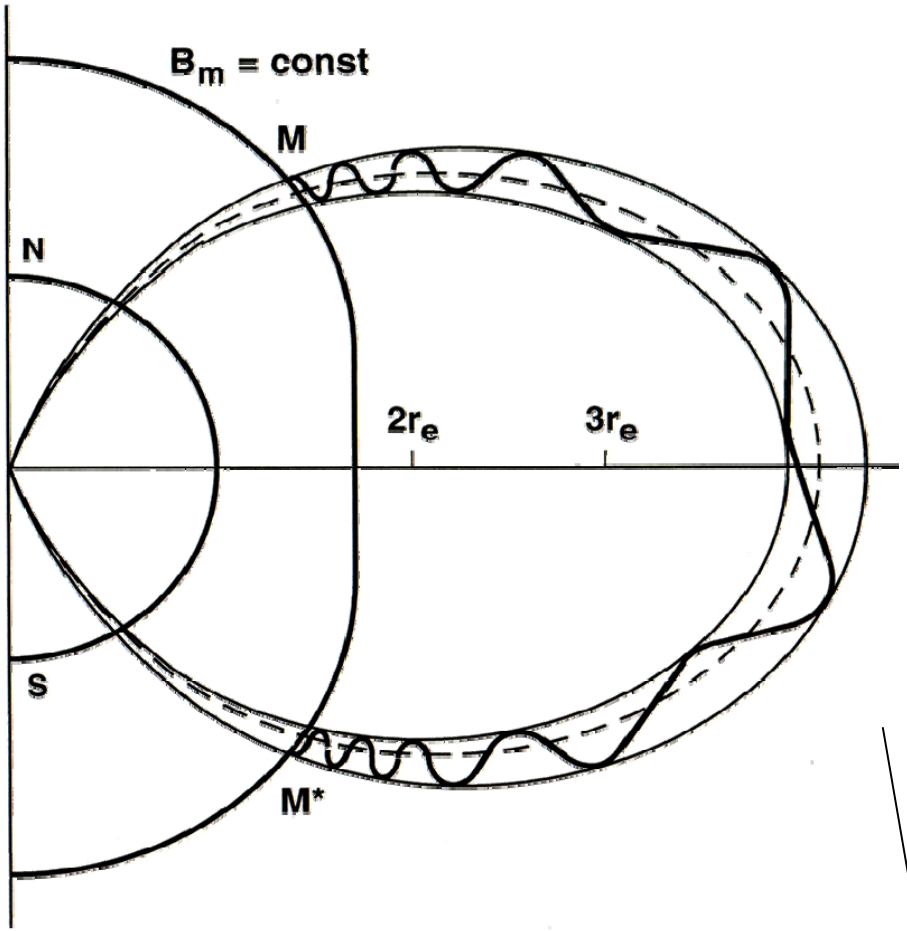
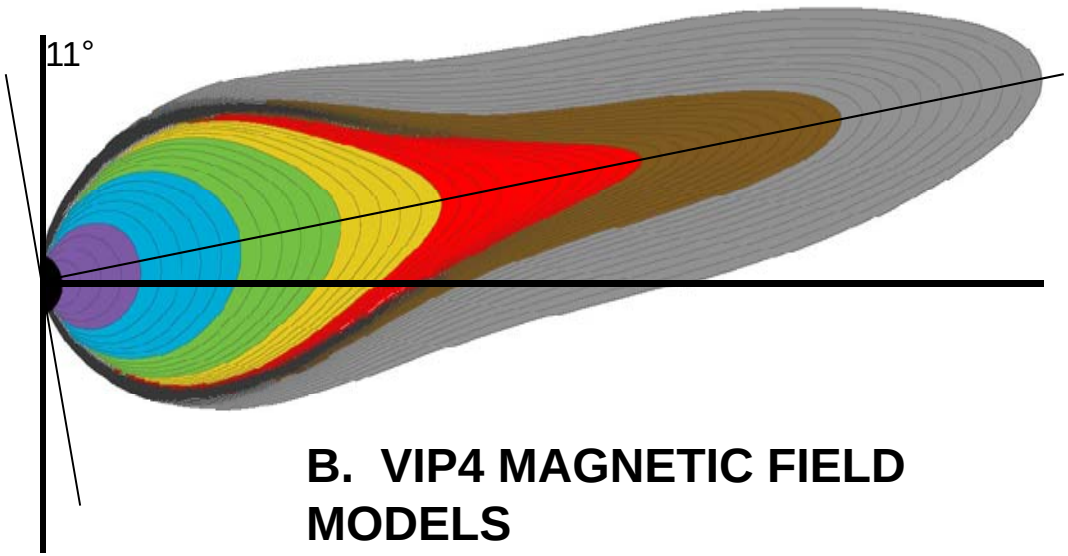
Particle Trapping at Jupiter

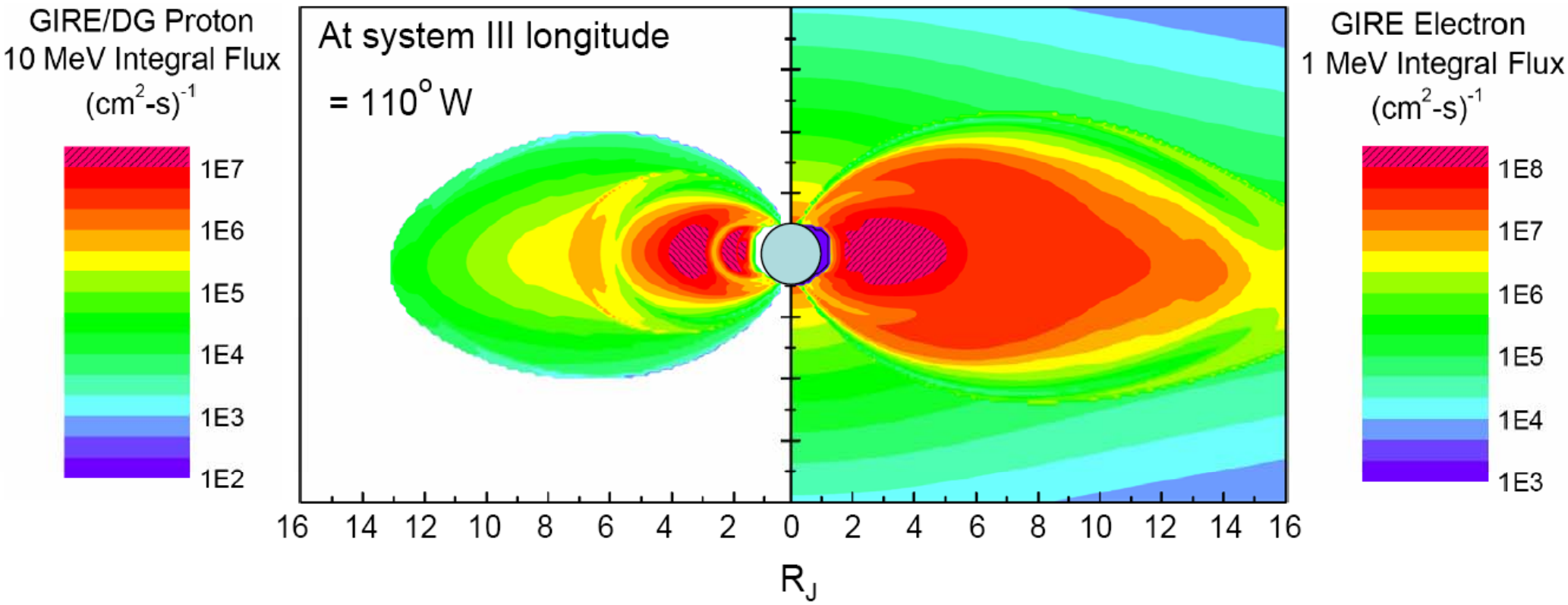
A. PARTICLE TRAPPING





B. VIP4 MAGNETIC FIELD MODELS

Divine/GIRE Jovian-Trapped Radiation Models



Contour plots of ≥1 MeV electron and ≥10 MeV proton integral fluxes at Jupiter. Coordinate system used is jovi-centric. Models are based on Divine/GIRE models. Meridian is for System III 110° W.

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Characteristic Time Scales of Geophysical Events

GEOPHYSICAL EVENT	TIME PERIOD
1. Solar Cycle	11 Years
2. Geomagnetic Storms	1-10 Days
3. Substorms	1-3 Hours
4. Magnetic Pulsations	Sec-Min
5. Plasma Boundary Crossings	Sec-Min
6. Plasma Waves	ms-μs

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The Jovian Space Environment

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Outline:

- Status of current models of Jovian radiation environment
  - Jovian magnetosphere overview (magnetic field, plasma torus/disc, aurora)
  - Divine radiation model, GIRE (Galileo Interim Radiation Electron) model update, and Inner Belts update for electrons
  - Statistical variations of electron environment with R_j
  - HIC (Heavy Ion Counter) model of high energy O, S, and C ions
- Europa and Ganymede radiation environments
  - Overview of Europa's and Ganymede's interactions with Jupiter's magnetosphere
  - Radiation at surface of Europa and Ganymede
- Outstanding radiation environment issues

Planetary Characteristics

OBJECT	EQUATORIAL RADIUS [km]	MASS [kg]	DIPOLE MAG MOMENT [G-cm^3]	$\vec{E} = (10^{-8})(\vec{V}_s \times \vec{B})$ ⇓ INDUCED E-FIELD AT SURFACE [V/cm]
SUN	6.960×10^5	1.991×10^{30}	$\sim 3.4 \times 10^{32}$	$\sim 4.4 \times 10^{-1}$
MERCURY	2.439×10^3	3.303×10^{23}	5×10^{22}	1.0×10^{-5}
VENUS	6.050×10^3	4.870×10^{24}	~ 0	—
EARTH	6.378×10^3	5.976×10^{24}	8.1×10^{25}	2.5×10^{-3}
MOON	1.738×10^3	7.353×10^{22}	0	—
MARS	3.398×10^3	6.421×10^{23}	$< 10^{22}$	$< 10^{-6}$
IO	1.82×10^3	8.916×10^{22}	$\sim 6.5 \times 10^{17}$	$\sim 2 \times 10^{-10}$
SATURN	6×10^4	5.686×10^{26}	4.3×10^{28}	5.0×10^{-3}
TITAN	2.56×10^3	1.359×10^{23}	—	—
URANUS	2.6145×10^4	8.66×10^{25}	$\sim 1.9 \times 10^{28}$ (?)	$\sim 1.6 \times 10^{-2}$ (?)
COMETS	~1-10	$\sim 10^{12}$-10^{17}		

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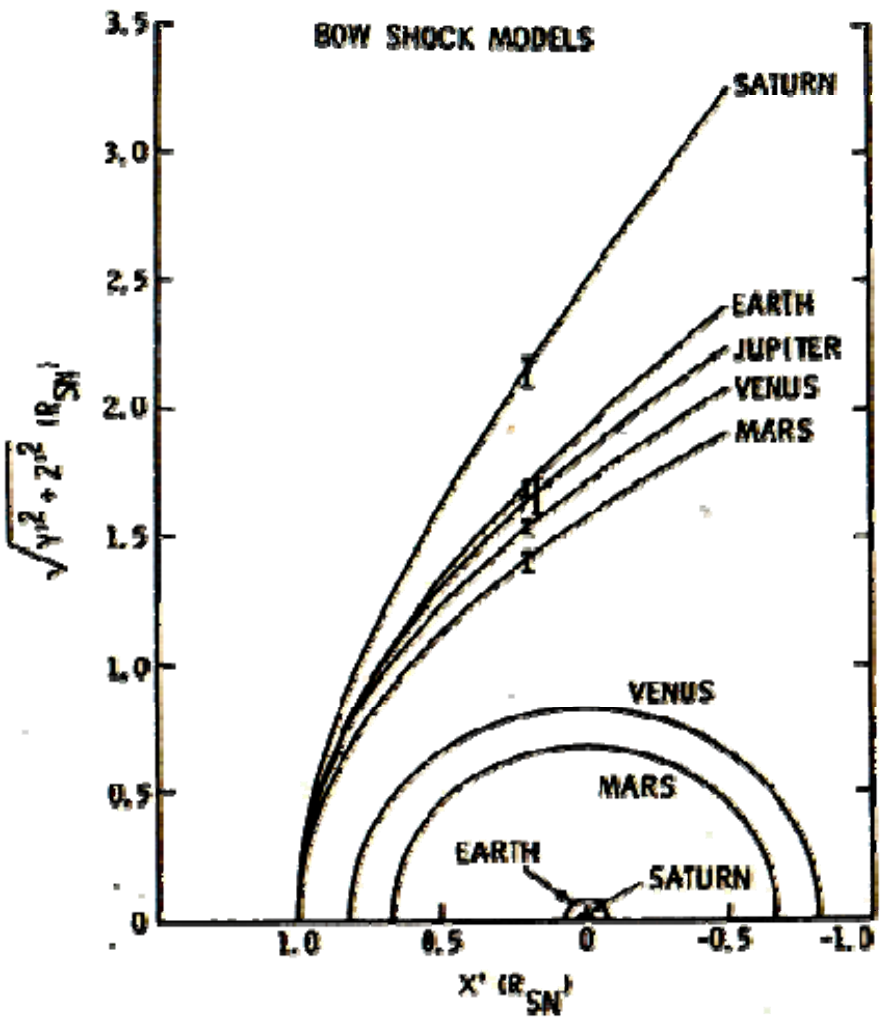
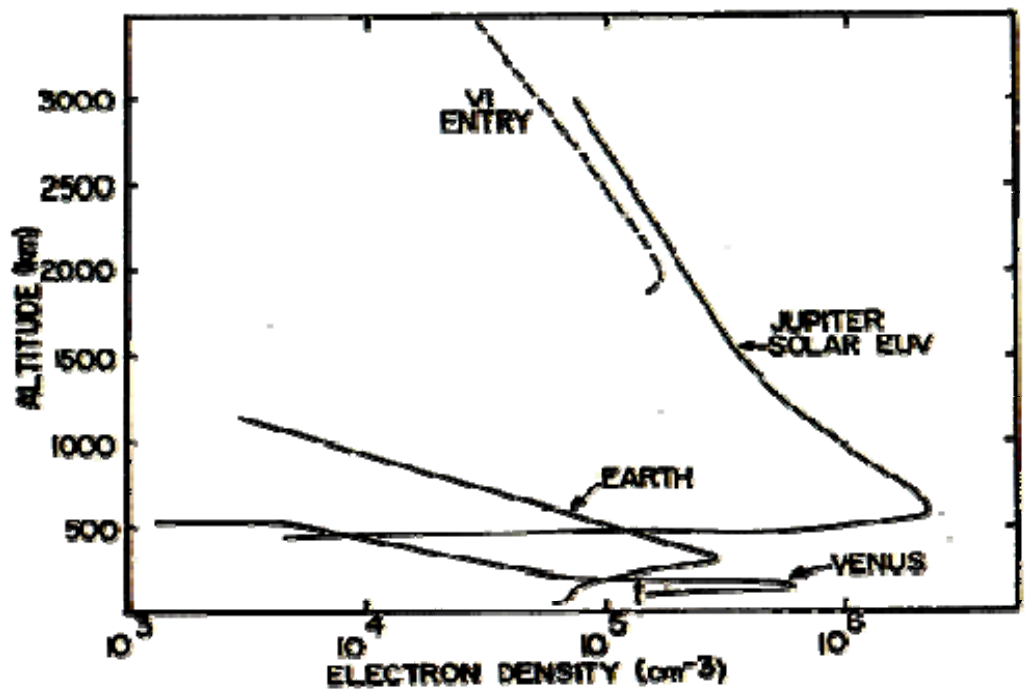
Planetary Magnetosphere/Ionosphere Comparisons

MAGNETOSPHERES



IONOSPHERES



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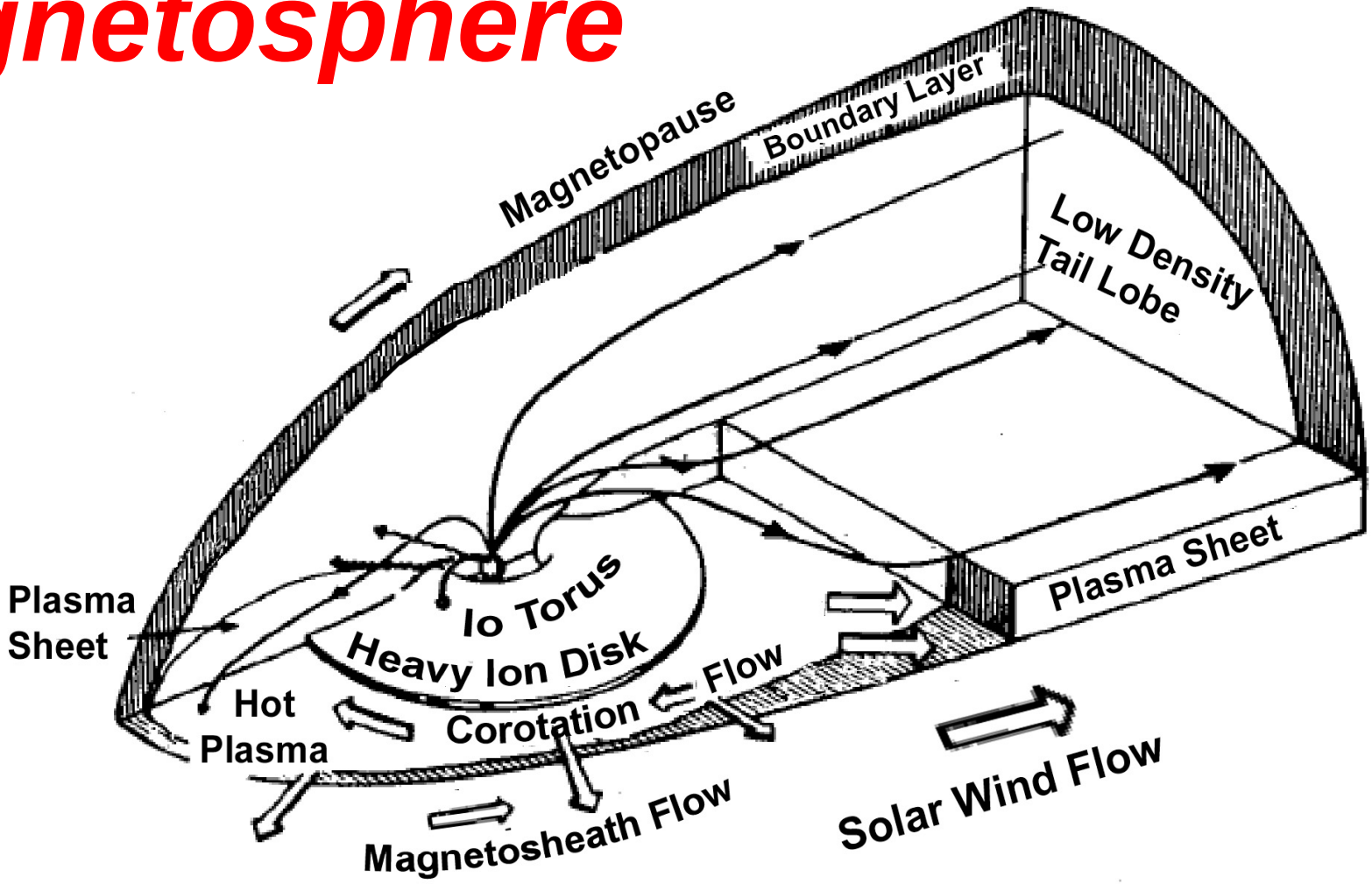
Modeling the Jovian Magnetosphere



Physics of the Jovian and Saturian Magnetospheres:
Highlights of a Conference at APL 1981 perprint cover.

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Jupiter's Magnetosphere

Characteristics	***Earth***	***Jupiter***
Equatorial radius (km)	6.38×10^3	7.14×10^4
Magnetic moment (G-cm^3)	8.1×10^{25}	1.59×10^{30}
Rotation period (hr)	24.0	10.0
Aphelion/perihelion (AU)	1.01/0.98	5.45/4.95

- Jupiter is roughly 10 times the size of the Earth while its magnetic moment is 2×10^4 larger.
- As the magnetic field at the equator is proportional to the magnetic moment divided by the cube of the radial distance, the Jovian magnetic field is proportionally ***20 times*** larger than the Earth's.
- The energy and flux levels of trapped particles in the Jovian system can be much higher than those at the Earth or in the interplanetary space.

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The Jovian Radiation Environment

Current Radiation Models:

Divine Electron and Proton Models

- Divine, N. T., Garrett, H. B., "Charged Particle Distributions in Jupiter's Magnetosphere", J. Geophys. Res., 88, 6889-6903, 1983

Galileo Interim Radiation Electron Model

- Garrett, H. B., I. Jun, J. M. Ratliff, R. W. Evans, G. A. Clough, and R.W. McEntire, “Galileo Interim Radiation Electron Model”, JPL Publication 03-006, 72 pages, The Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, 2003.
  - http://www.openchannelfoundation.org/projects/GIRE/

Salammbô

- Sicard, A., and S. Bourdarie, “Physical Electron Belt Model from Jupiter’s surface to the orbit of Europa” J. Geophys. Res., 109, A02216, doi:10.1029/2003JA010203, 2004.

JOSE

- Sicard-Piet, A., and S.Bouradrie, “JOSE (JOvian Specification Environment)”, TN-CCN/13279 DESP, ONERA-DESP, The French Aerospace Lab, pp. 134, February 2010.

Divine "Family" of Radiation Models

- Jupiter radiation modeling based on original "Divine" model--de-facto standard Jupiter radiation environment model since 1983.
  - Pioneer and Voyager in-situ data plus Earth-based Synchrotron observations
  - Limited in temporal and spatial coverage
- Galileo orbited Jupiter starting in 1995
  - Total 35 orbits
  - Extensive scientific data return
- New Jupiter radiation environment models derived from:
  - Energetic Particle Detector (EPD) for high energy trapped electrons
  - Heavy Ion Counter (HIC) for heavy ions

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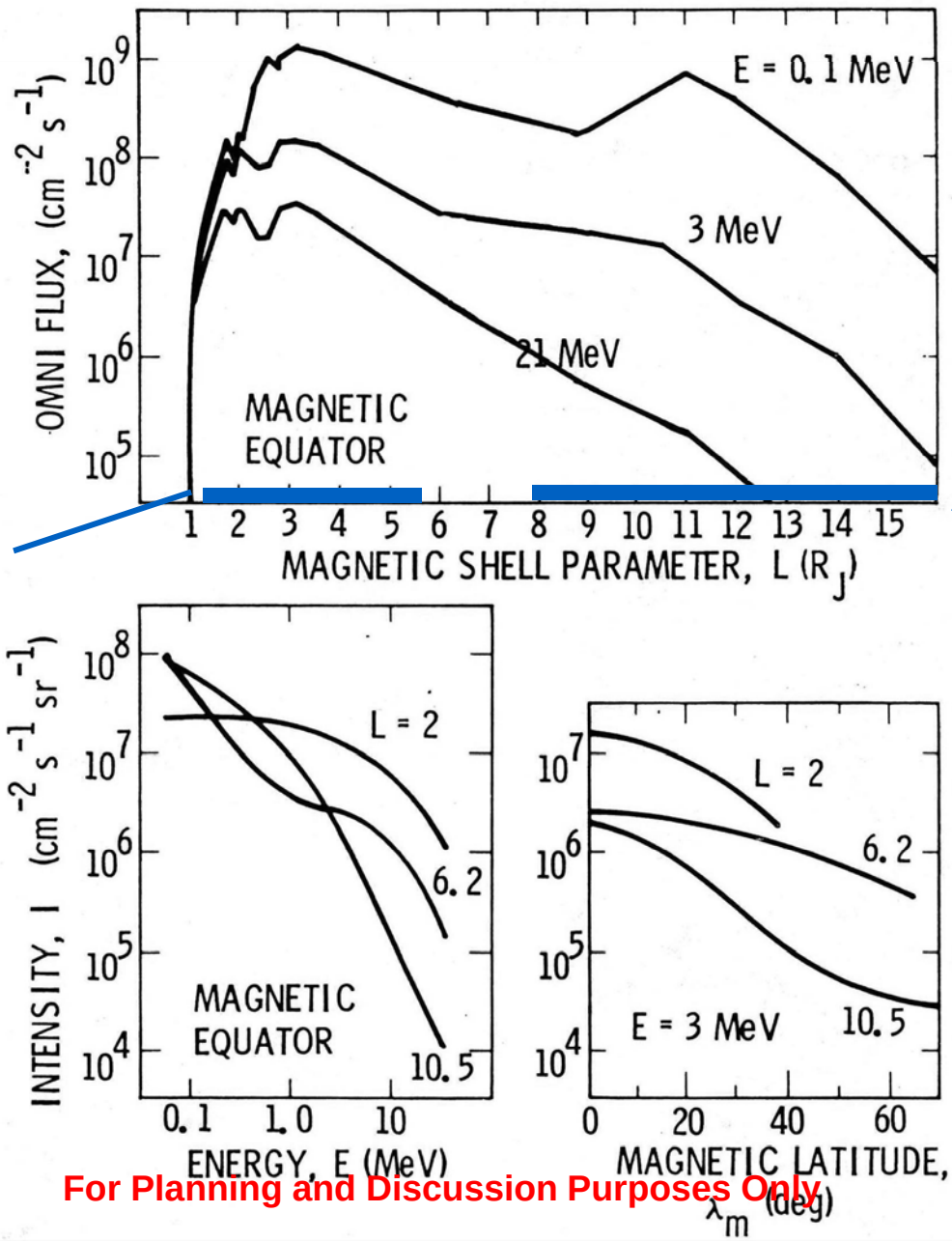
ORIGINAL DIVINE HIGH ENERGY ELECTRON MODEL

SYNCHROTRON UPDATE

GIRE UPDATE



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GIRE Model*

- GIRE is a significant improvement over the Divine electron model.
- Uses in-situ data from 35 Galileo orbits--based primarily on EPD data
- Updated to fit synchrotron data within 5 Rj.
- Covers radial distance 1-4 and 8-16 Rj.
- Defines the trapped electron environment.
- Assumes Divine pitch angle distributions.
- Covers energy range 0.1 MeV to ~30 MeV.
- Assumes Divine proton model.

*Garrett et al., JPL Pub. 03-006 (2003)

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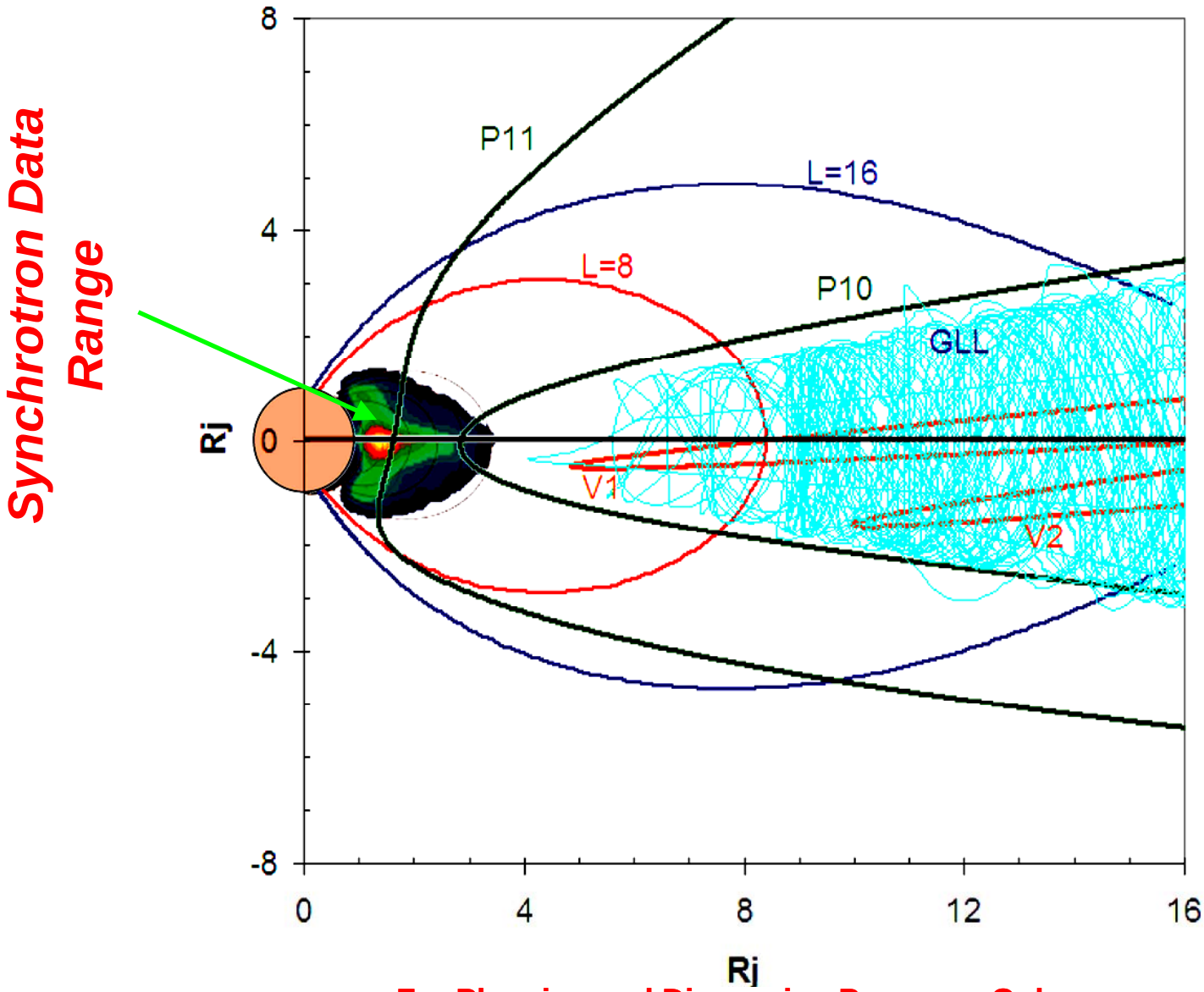
Pioneer 10-11, Voyager 1-2, and Galileo Trajectories



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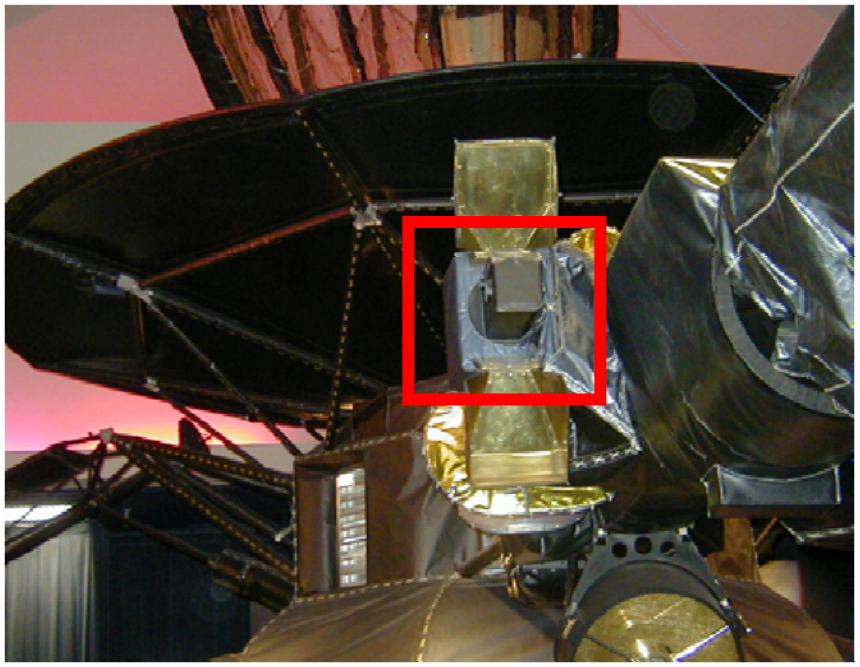
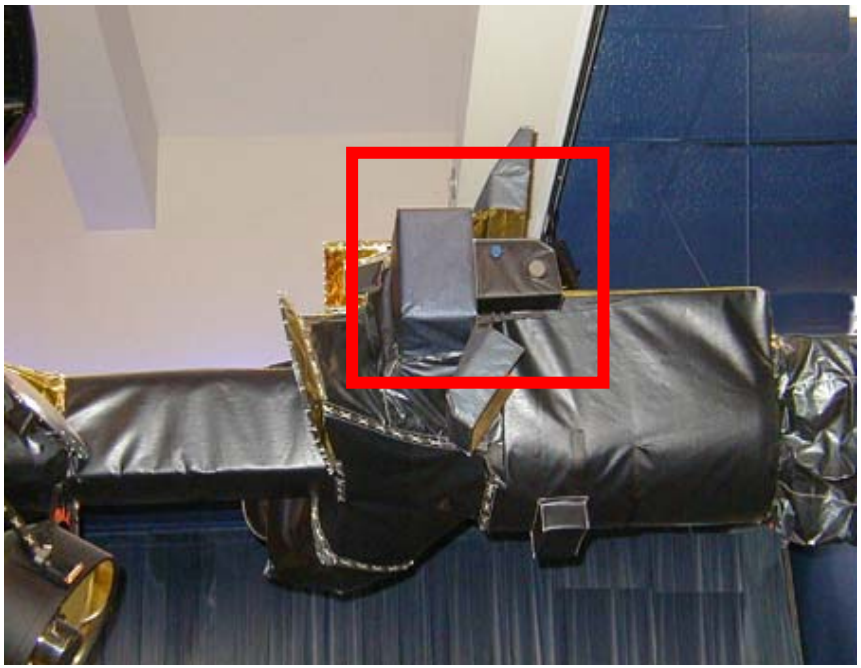
EPD (LEMMS)





Channel Name	Nominal Energy Range (MeV)
F1	0.174-0.304
F2	0.304-0.527
F3	0.527-0.83
B1	1.5 – 10.5
DC2	≥ 2.0
DC3	≥11.0

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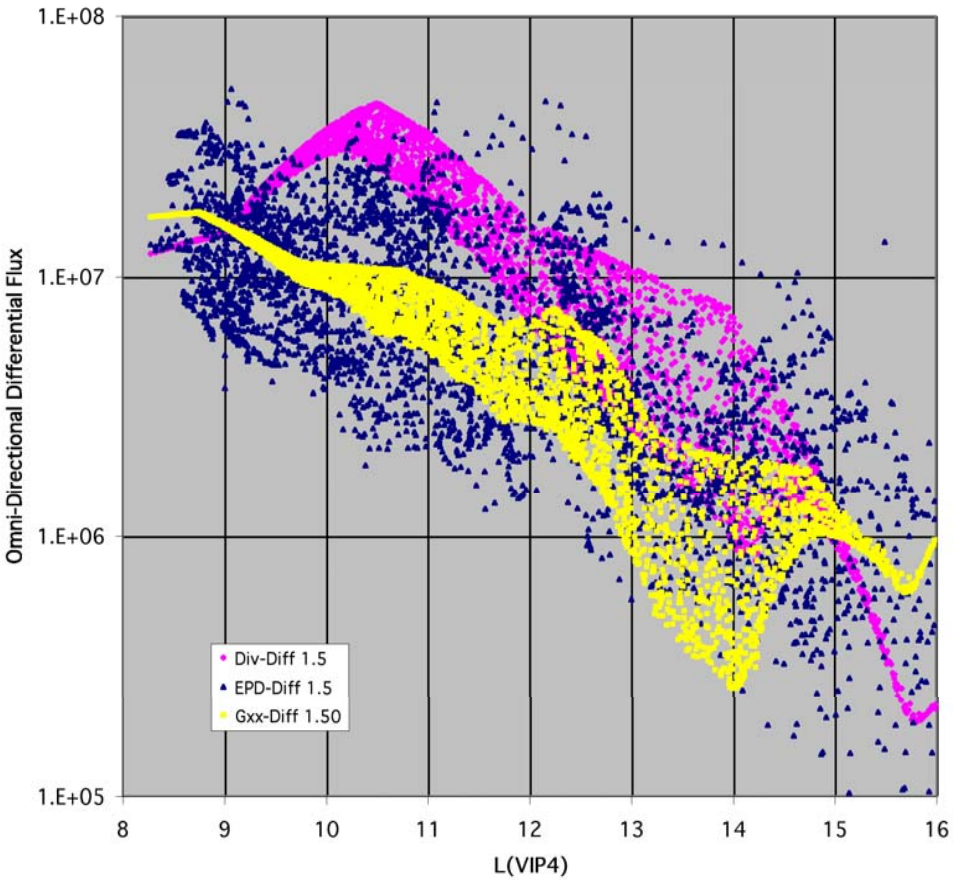
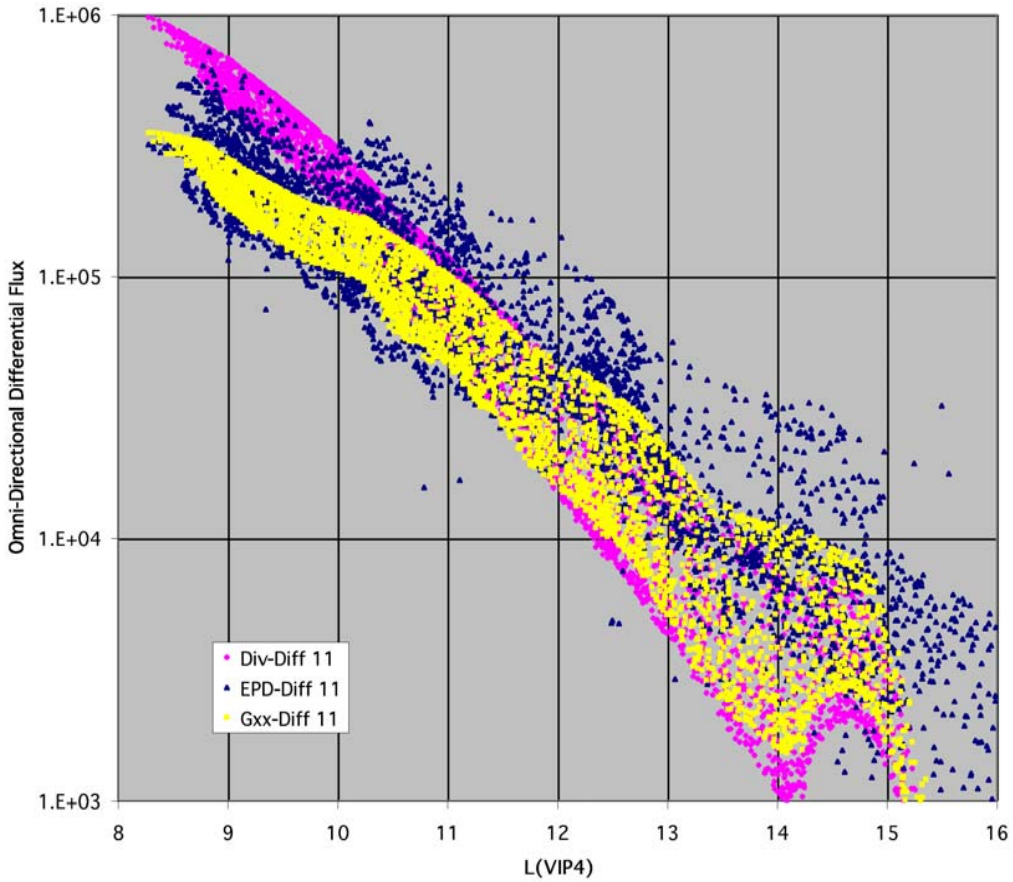
Divine Model, GIRE Model, EPD Data

Comparisons between observed EPD (blue) fluxes and Divine (pink) and GIRE (yellow) predictions



1.5 MeV ELECTRONS



11 MeV ELECTRONS

Pink = Divine; Yellow = GIRE; Blue = EPD data

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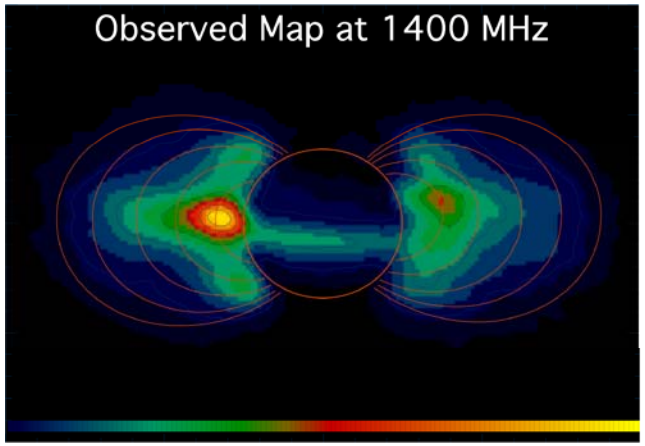
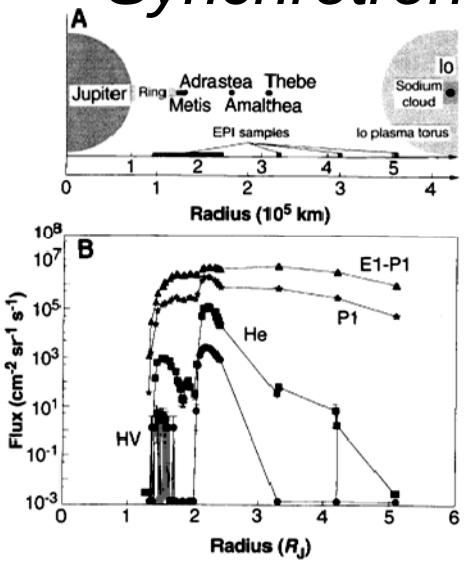
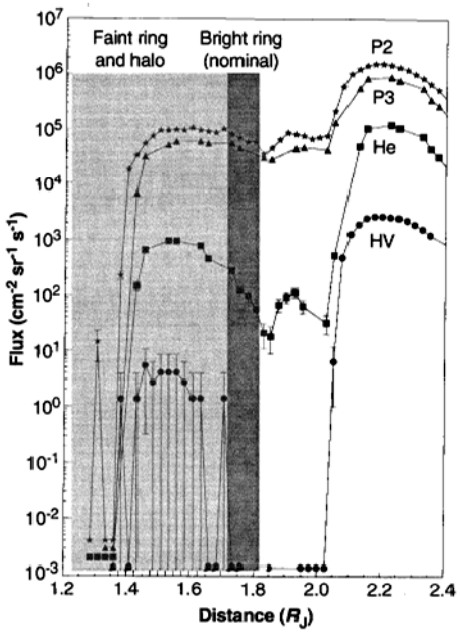
Update of Inner Radiation Belt Model



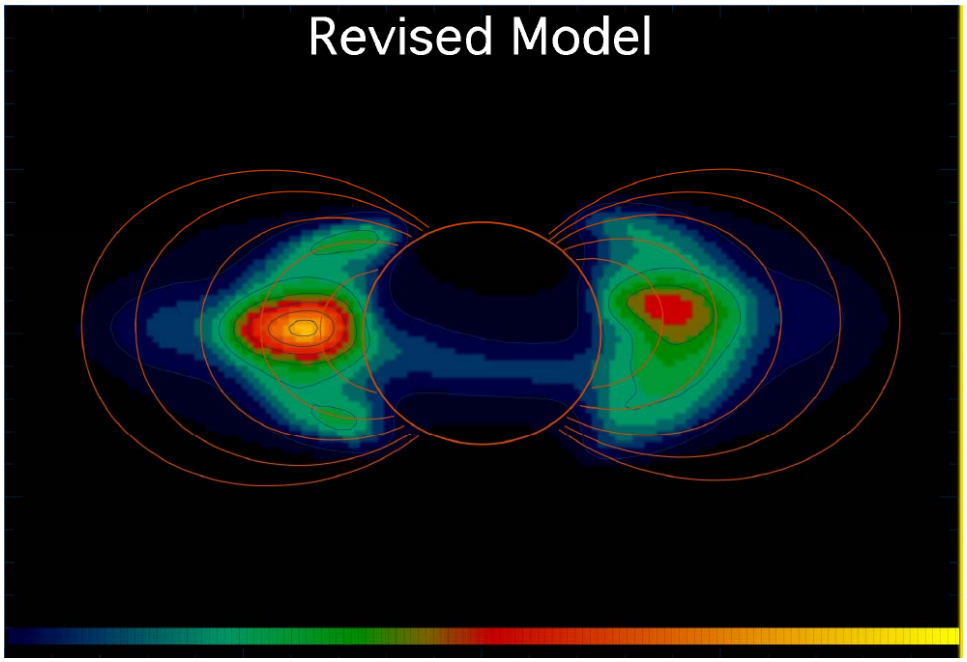
Synchrotron predictions based on update to Divine Model

Synchrotron Observations





Galileo Probe Observations



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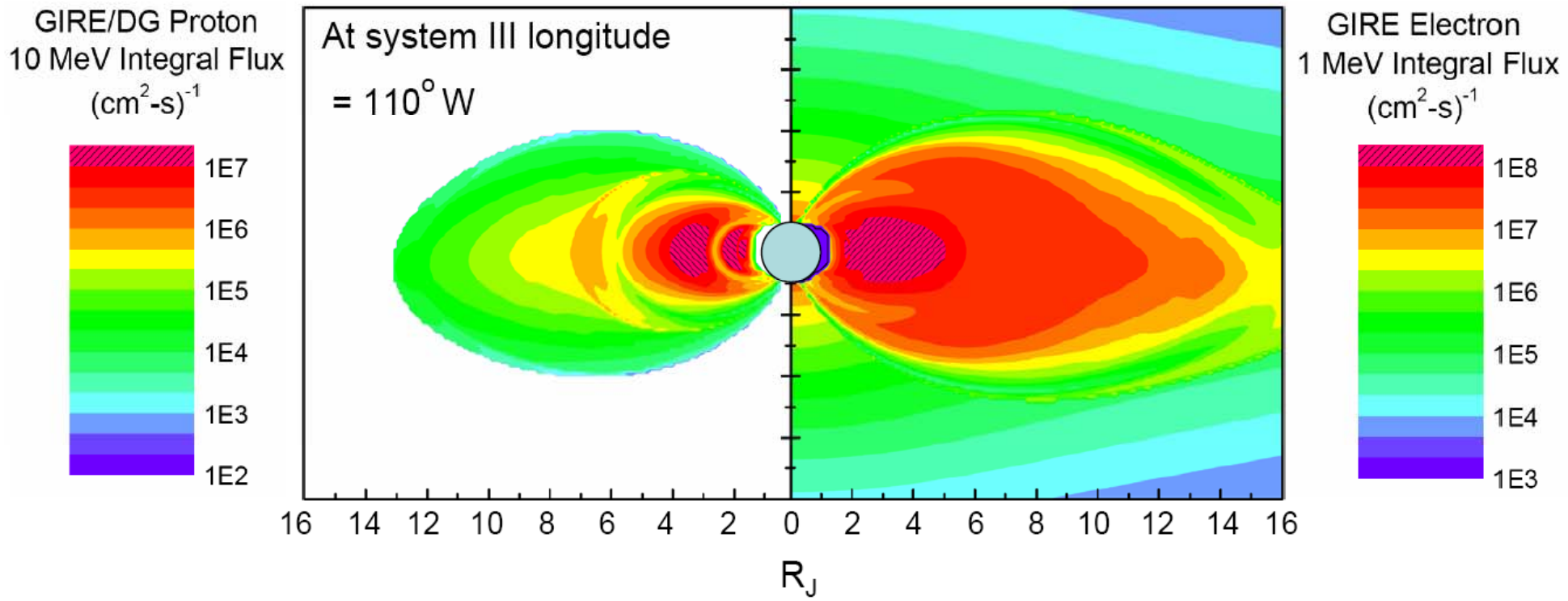
DIVINE + GIRE JOVIAN RADIATION MODELS



Contour plots of ≥1 MeV electron and ≥10 MeV proton integral fluxes at Jupiter. Coordinate system used is jovi-centric. Models are based on Divine/GIRE models. Meridian is for System III 110° W.

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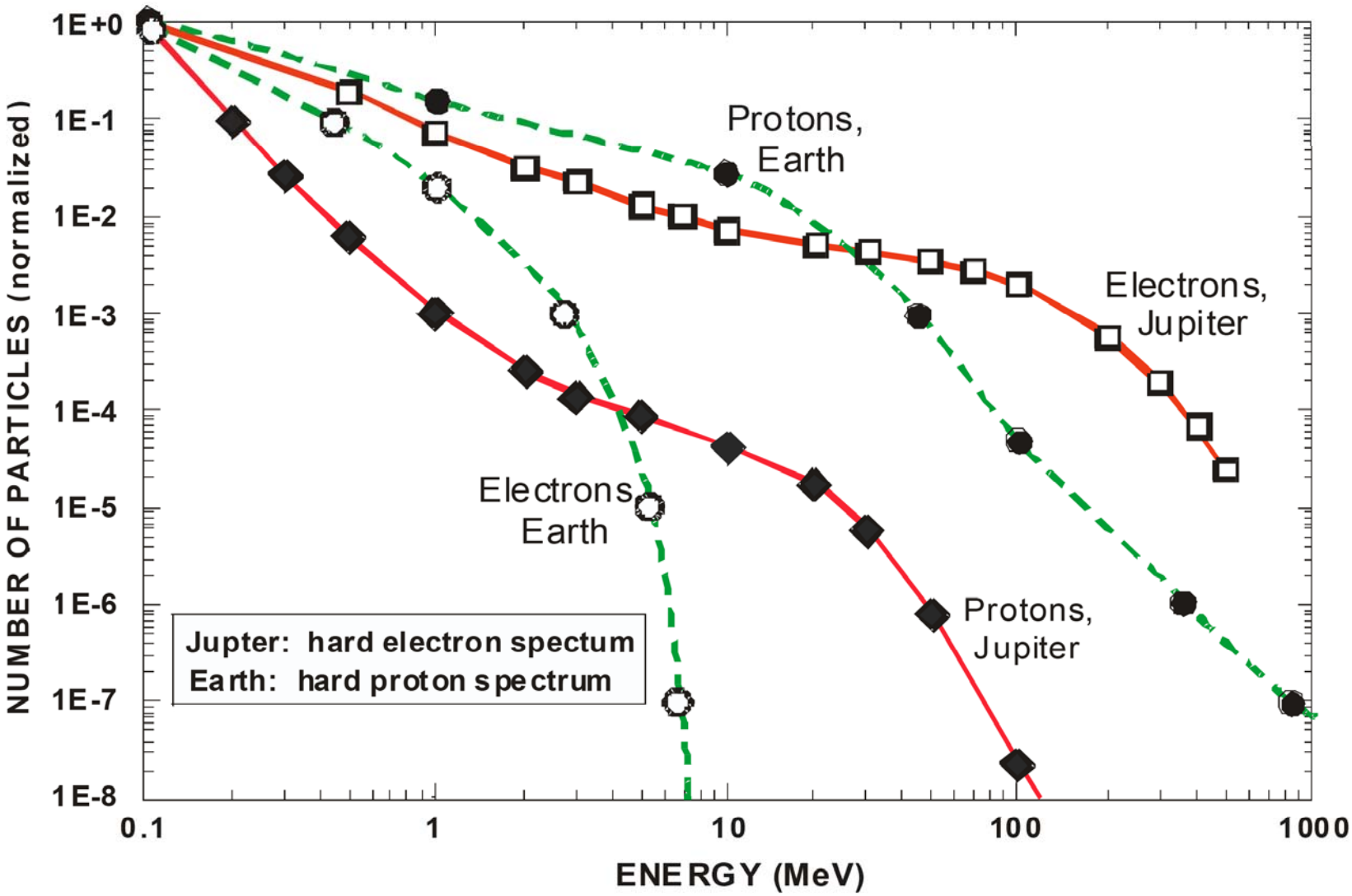
Comparisons Between Jovian and Terrestrial Radiation Spectra



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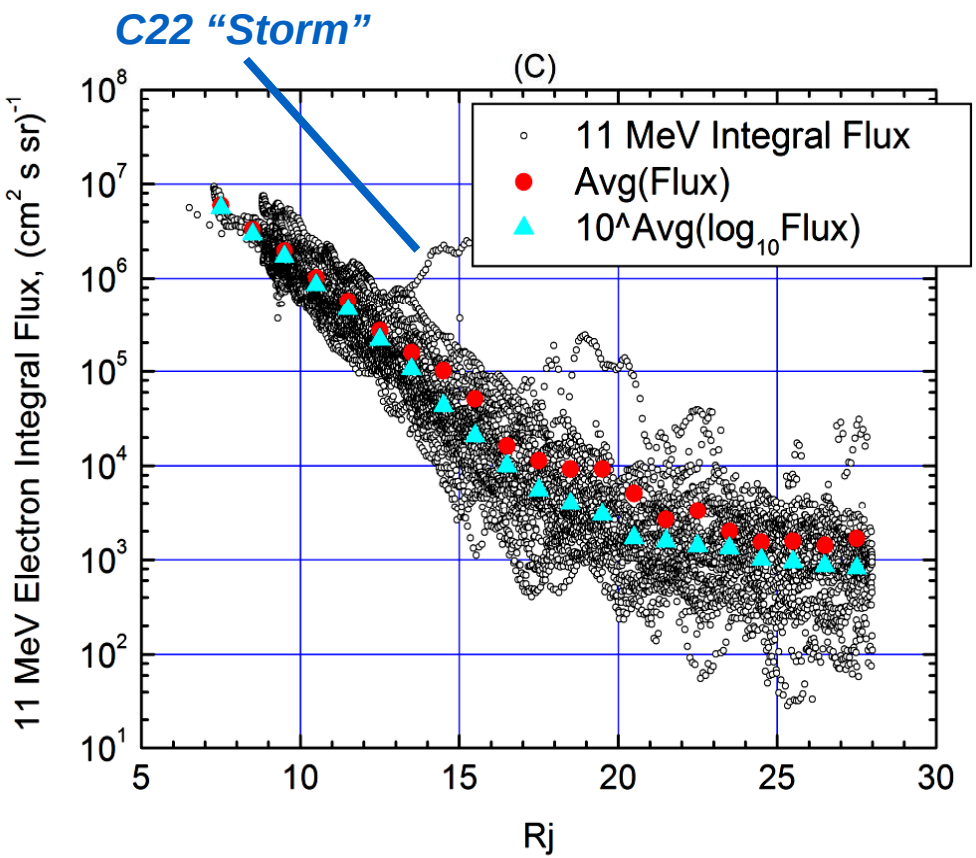
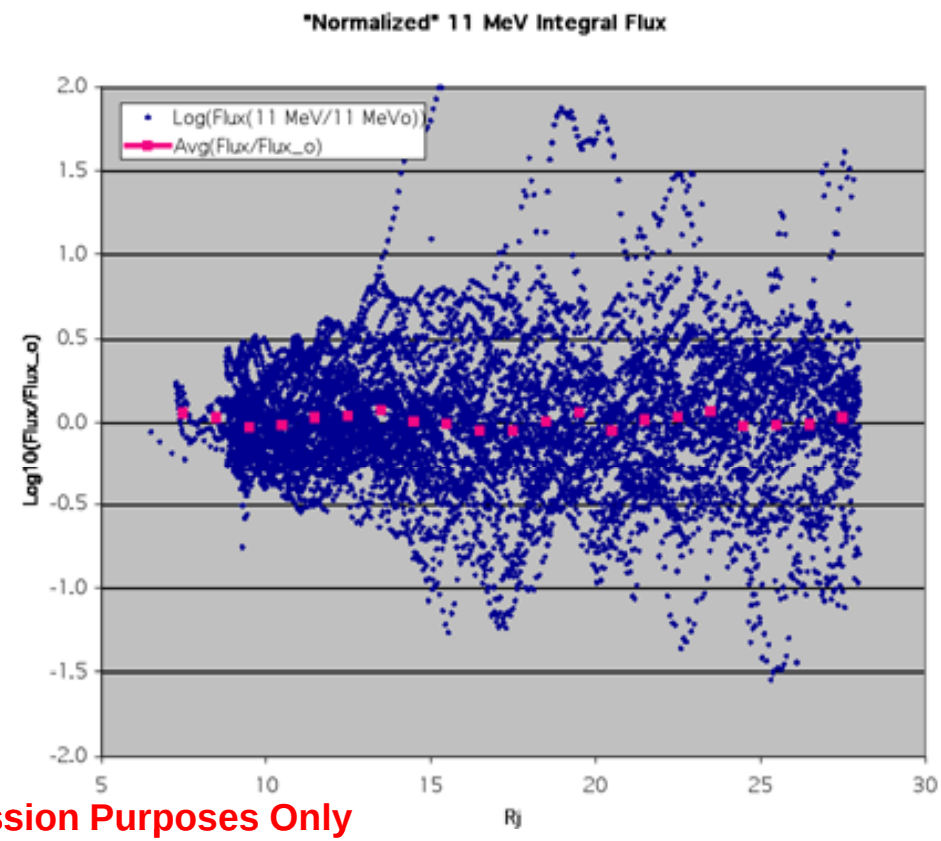
Statistical Variations in EPD Fluxes* with distance from Jupiter showing "average" and "storm" variations



Galileo EPD 11 MeV particle fluxes vs radial distance

Logarithms Of Ratio Of EPD To Average Flux Vs L-shell



*Jun et al., Icarus (2005)

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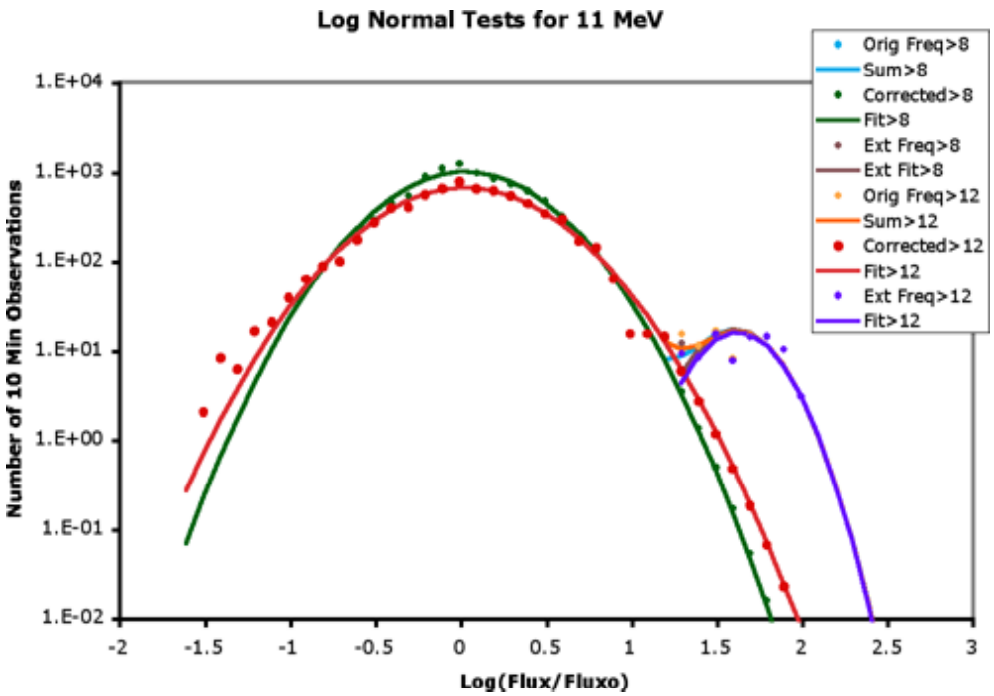
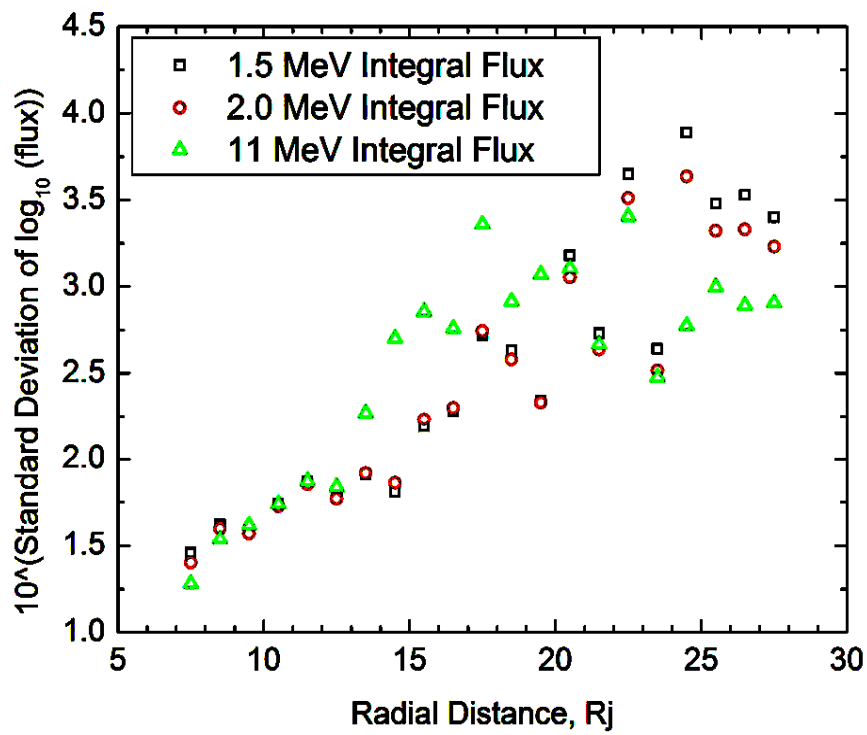
Statistical Variations of Jovian Particle Fluxes

Examples of log-normal fits to the Galileo electron fluxes



Log-Normal fits to 11 MeV Electrons

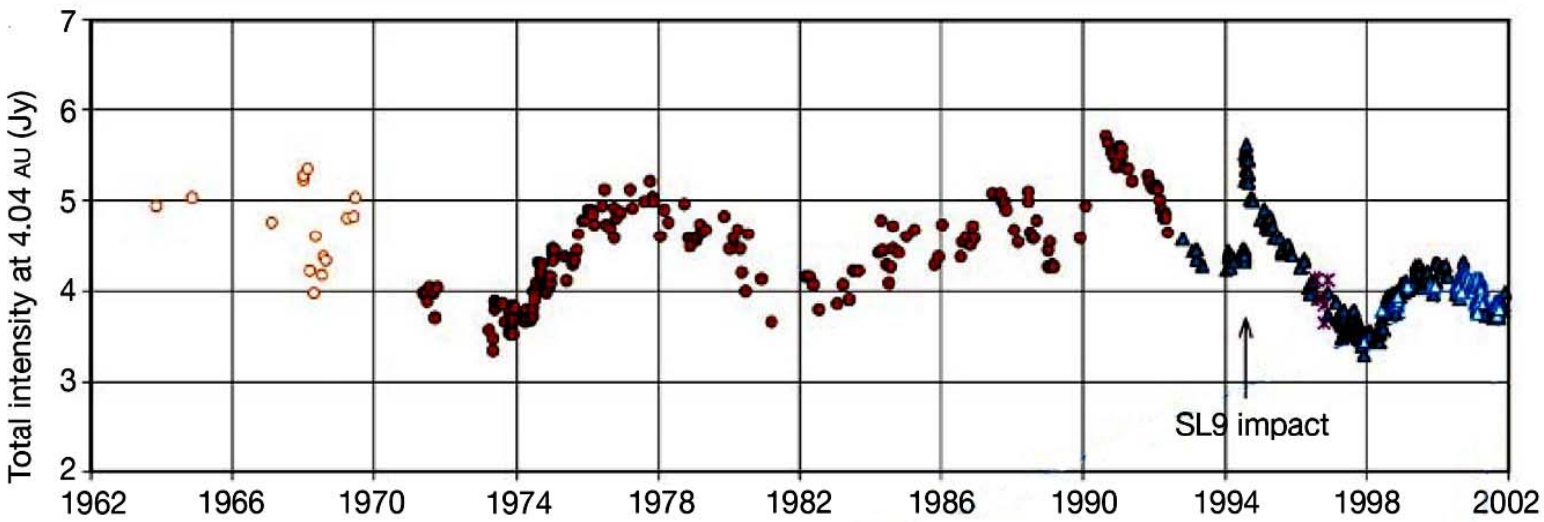
Standard Deviations of Electron Fluxes versus Rj



Jovian Radiation "Climatology"

QUESTION: How does the jovian environment change on the time scale of years to decades?

- The "climate", based on the Pioneer (Dec 1973, Dec 1974) and Voyager encounters (Mar 1979, July 1979) versus Galileo (1995-2003), implies variations of ***2-3*** (Divine vs GIRE).
- The Earth-based Goldstone Apple Valley Radio Telescope (GAVRT) study of the jovian synchrotron radiation shows variations of ***~2*** in the trapped, relativistic electron populations over 4 decades in inner electron belt (~1.5-2 L).



Caltech Galileo Heavy Ion Counter Radiation Model

- **Used data from 31 of the 35 Galileo orbits.**
- **Covers radial distance from 2.5 Rj to 30Rj.**
- **Models three ions: Oxygen, Carbon, and Sulfur.**
- **Covers energy range ~6-200 MeV/nucleon.**
- **Average model**
  - **Model is useful for defining heavy ion spectra for SEE evaluations.**

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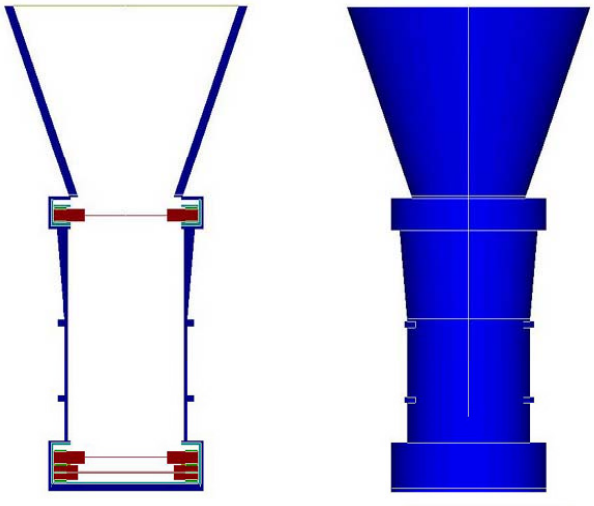
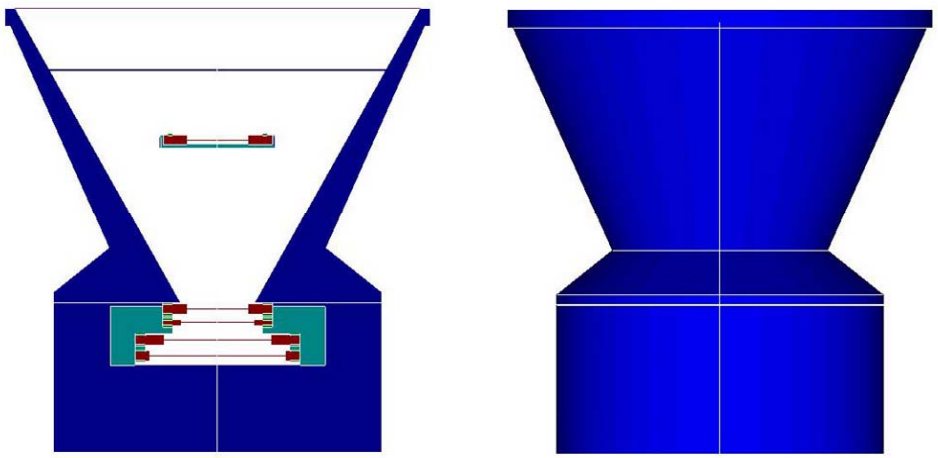
Caltech HIC (Heavy Ion Counter)

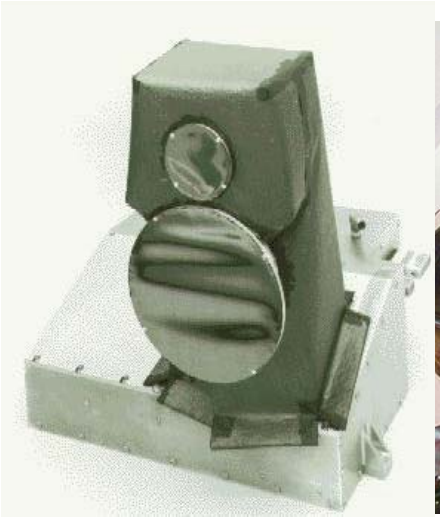


LET B

- Two solid-state dE/dx vs energy Low Energy Telescopes (LET B and LET E).
- Measured ~6 to >200 MeV nucl^{-1}, heavy ions from $_{6}$C to $_{28}$Ni.
- Returned data for all but 2 of the 35 orbits of the Jupiter system from 1995 to 2003.



LET E



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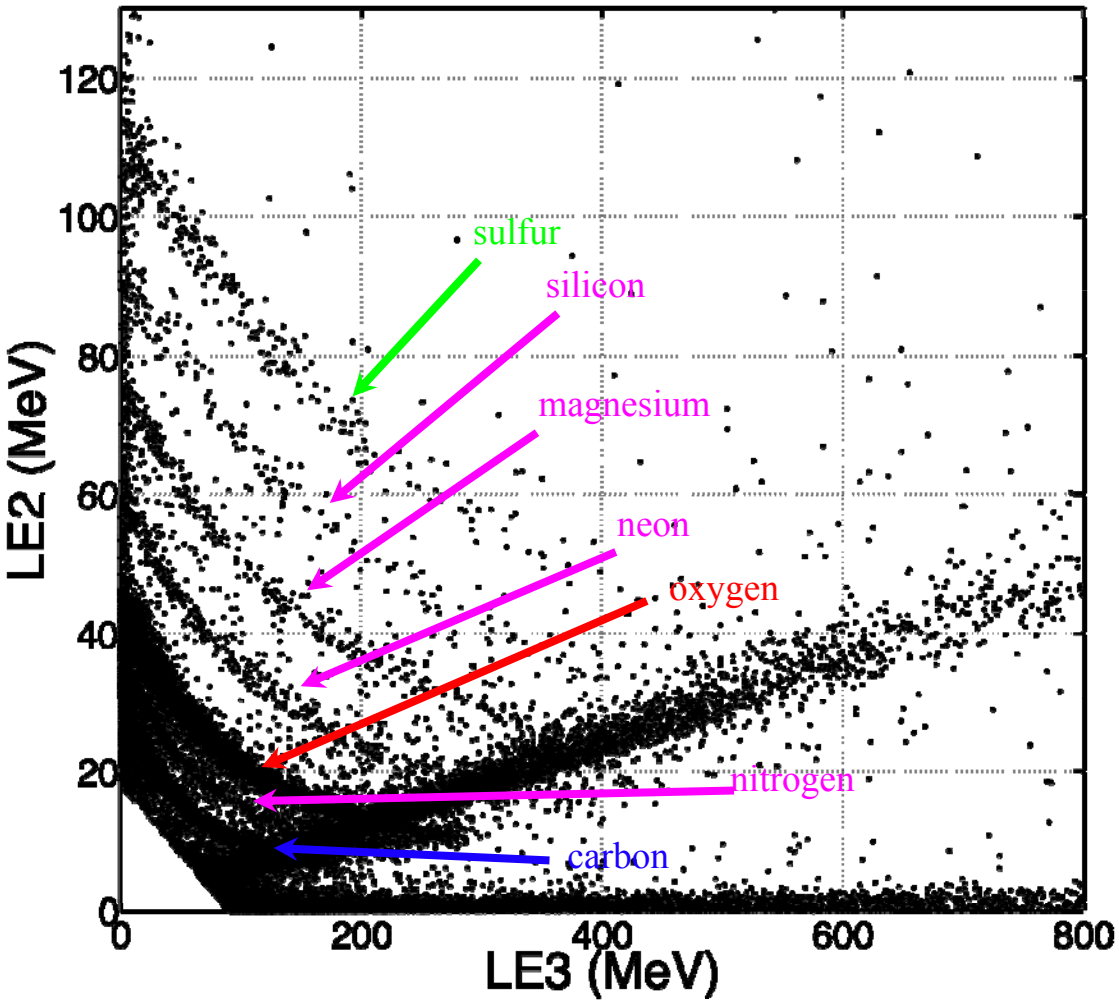
Ion Species Observed by HIC

TLETB Data



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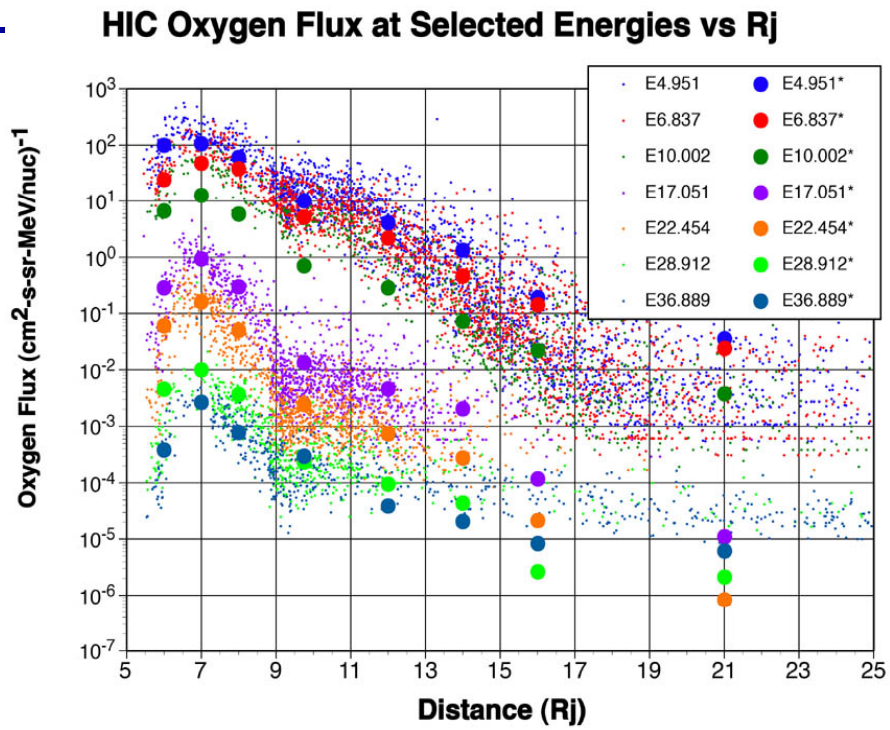
HIC Observations

HIC fluxes at selected energies (small symbols; designated “E4.359”, etc.) in units of MeV/nuc vs radial distance. Also plotted are the averages for selected radial intervals and energies (large symbols; designated “E4.359*”, etc.).



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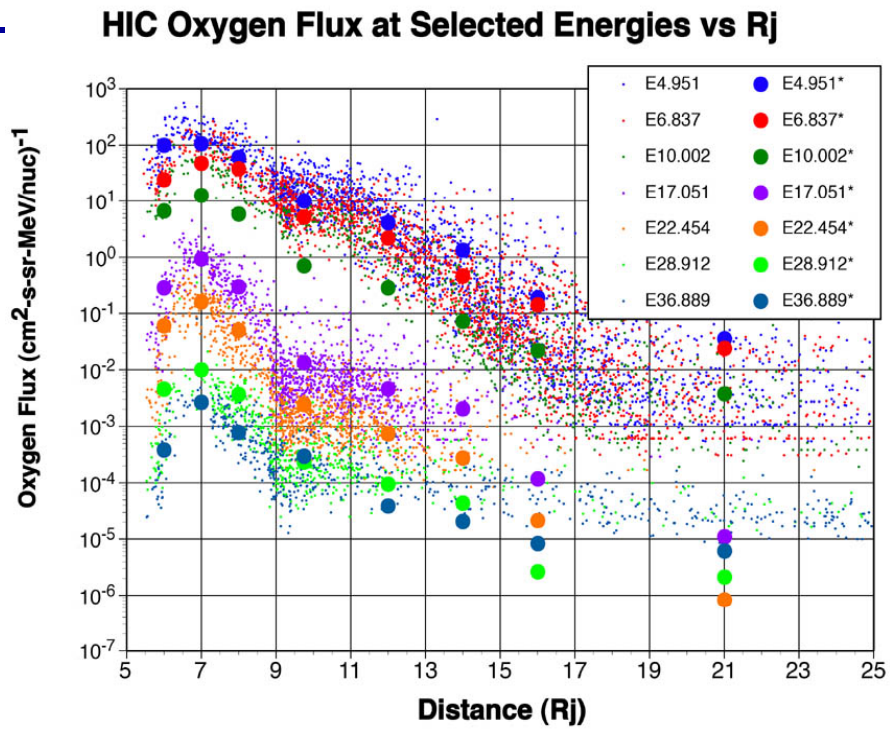

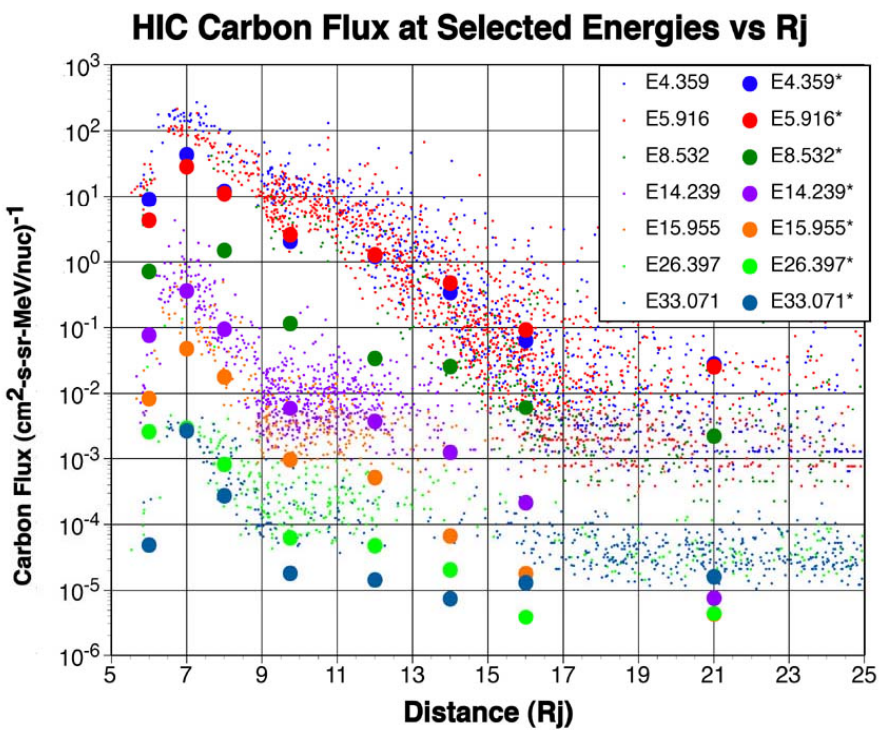

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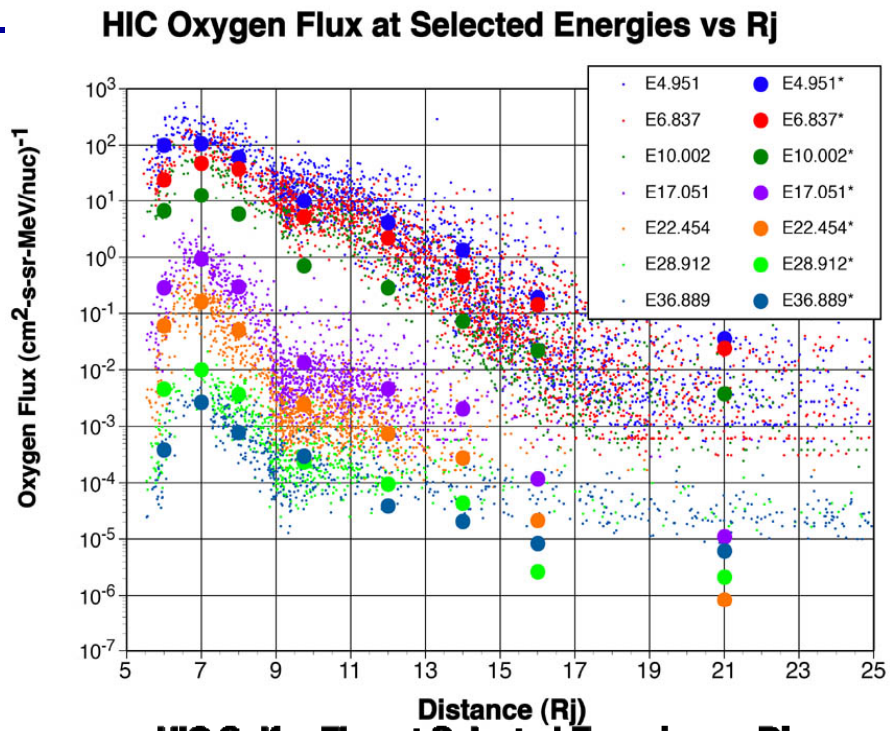
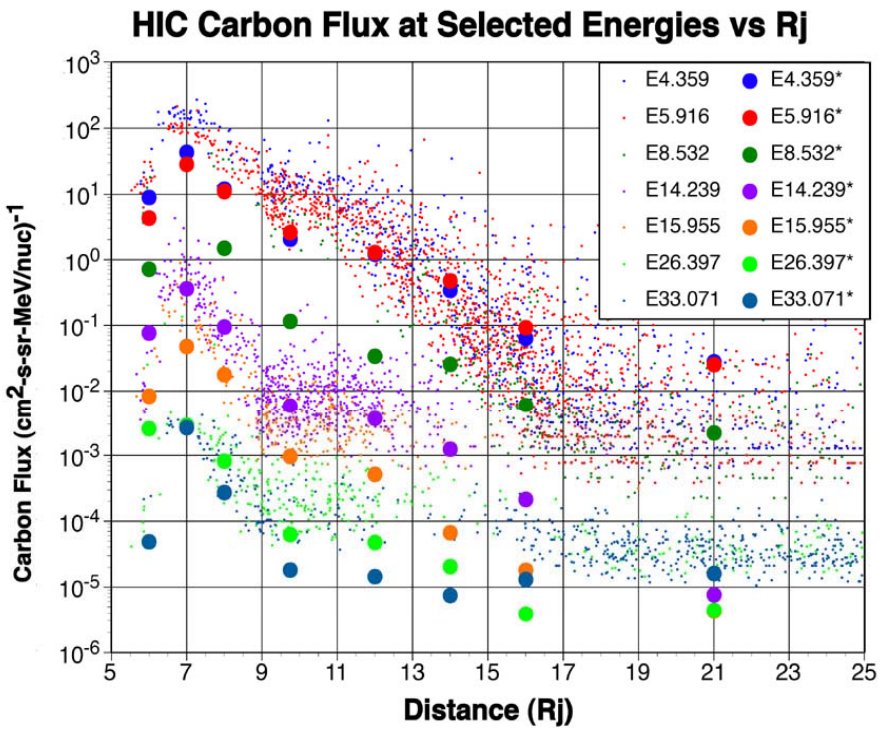
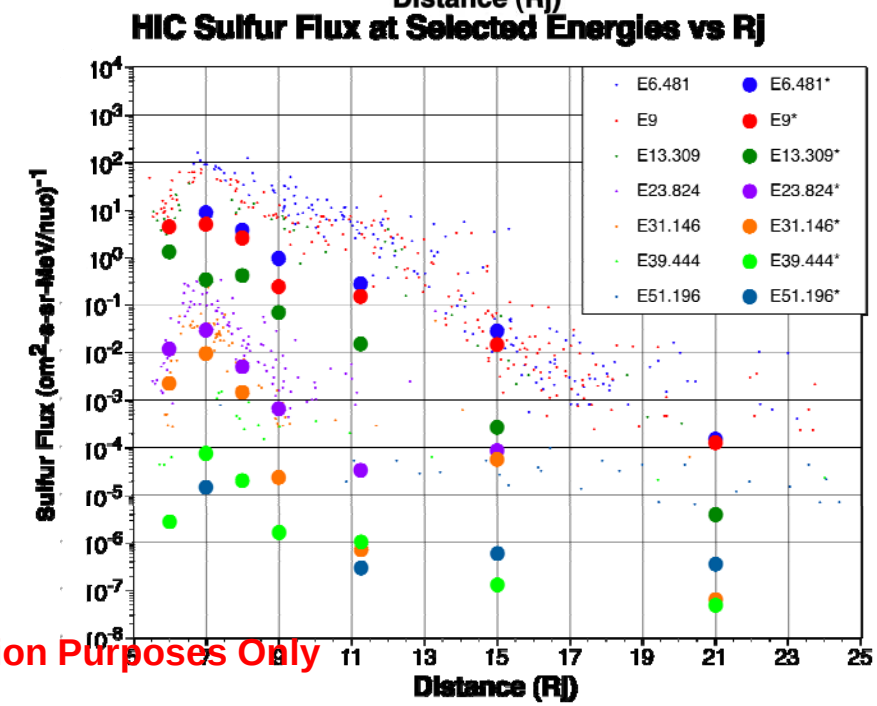
HIC fluxes at selected energies (small symbols; designated “E4.359”, etc.) in units of MeV/nuc vs radial distance. Also plotted are the averages for selected radial intervals and energies (large symbols; designated “E4.359*”, etc.).







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HIC Data Fits vs Equatorial Radius/Energy

Carbon

A	B	E_0	R^2				
5.52566	0.00894115	0.92756	0.9476				
Radius	6	7	8	9.75	12	15	21
F_0	230955	450115	48497	7068.14	3969.56	985.138	457.0051

Oxygen

A	B	E_0	R^2					
-10.2806	18.2221	1.55683	0.97463					
Radius	6	7	8	9.75	12	14	16	21
F_0	1749081	4287791	1795300	189749	61673	21854	3212.96	632.823

Sulfur

A	B	E_0	R^2				
-20.9041193	38.70714854	6.44416	0.8818				
Radius	6	7	8	9	11.25	15	21
F_0	1.96042E-05	8.7001E-05	3.19029E-06	9.56586E-07	9.65935E-07	2.75922E-07	2.25412E-09

$$F_j(E, R_j) = F_{0j}(R_j) \cdot E^{-A_j} \left(1 + \frac{E}{E_{0j}}\right)^{-B_j}$$

Where:

F_j = Flux ($n^{\#}/cm^2$ s sr MeV/nuc)

E = Energy (MeV/nuc)

R_J = Equatorial distance (jovian radii) at the center of the interval*

A_j, B_j = Fit constants

E_{0j} = Fit constant (MeV/nuc)

j = Species (C, O, S)

*Assumes linear interpolation of $\log_{10}$ of flux in R_j at other distances

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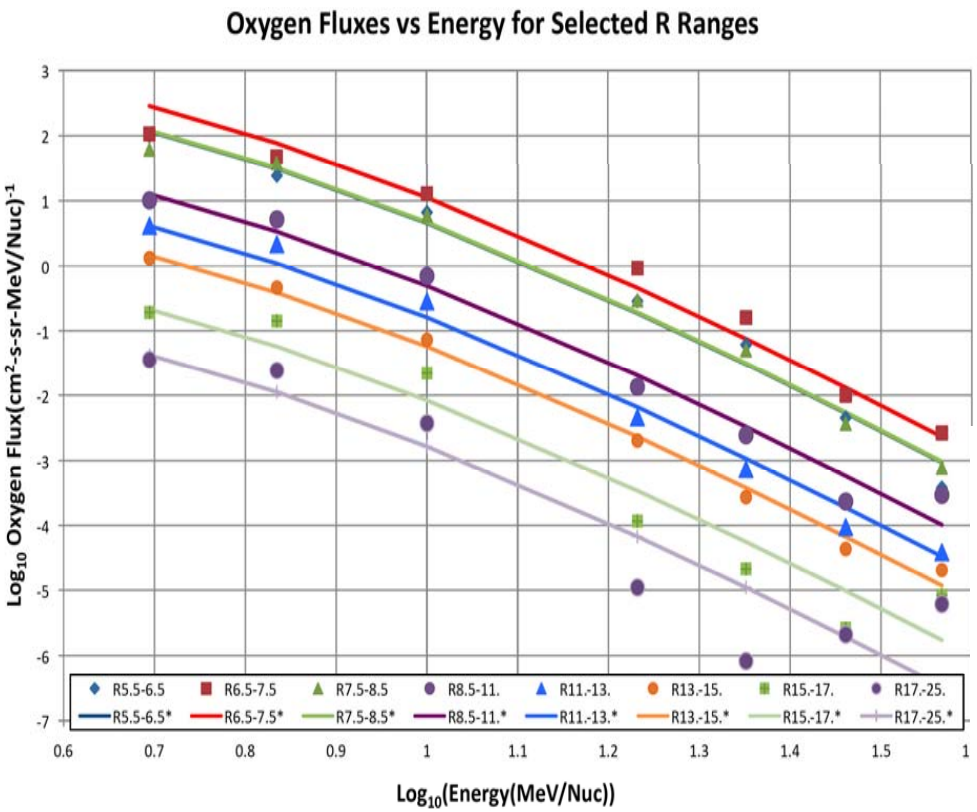
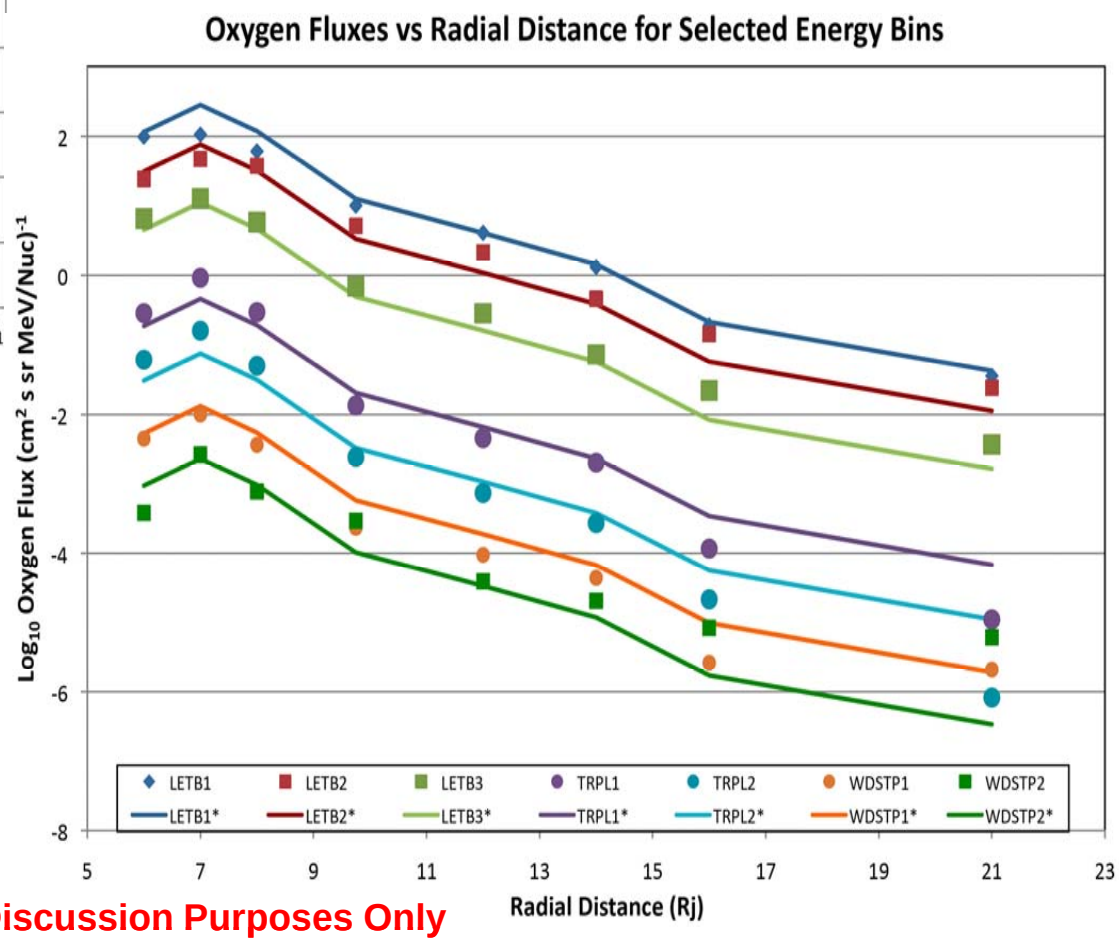
Oxygen Fits





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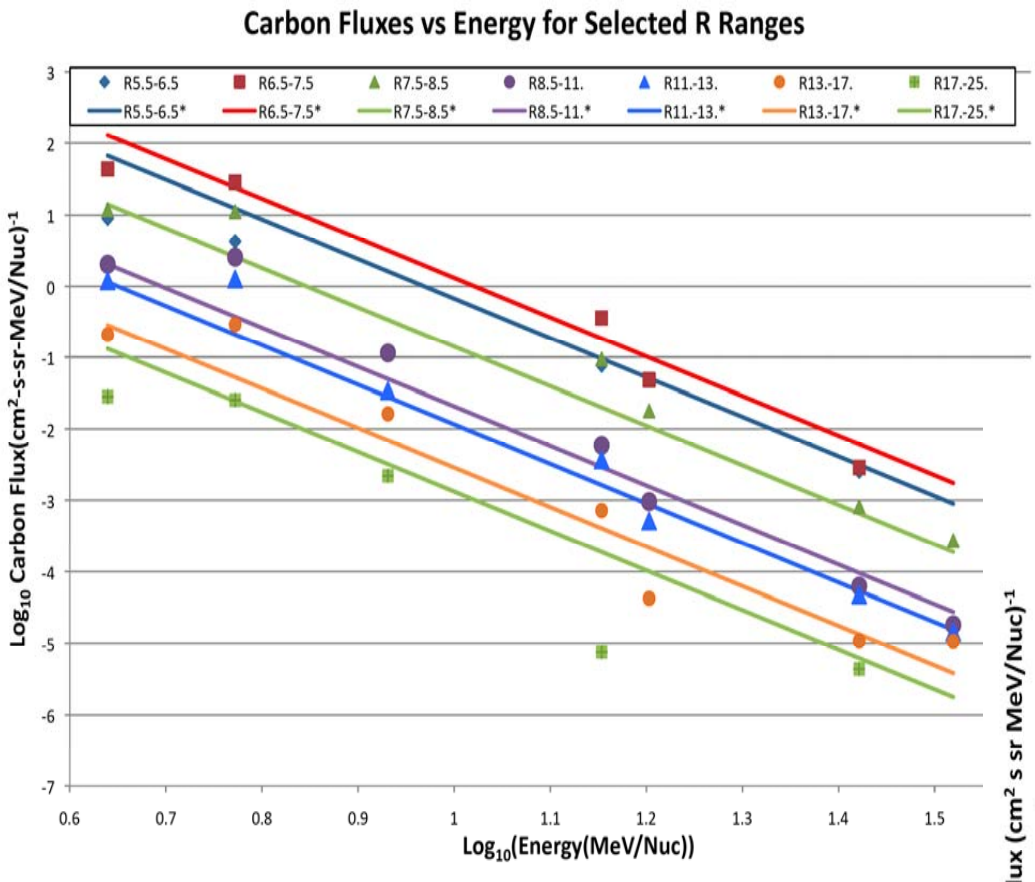
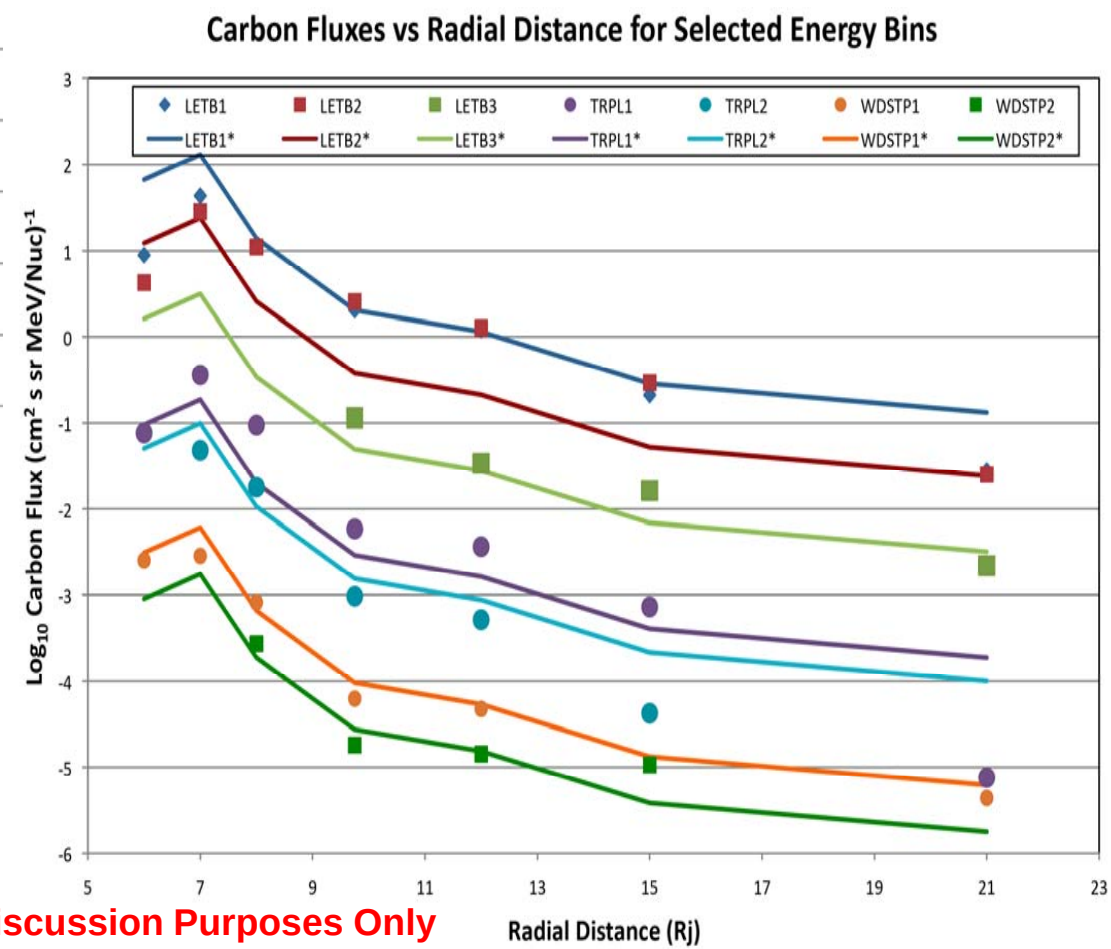
Carbon Fits





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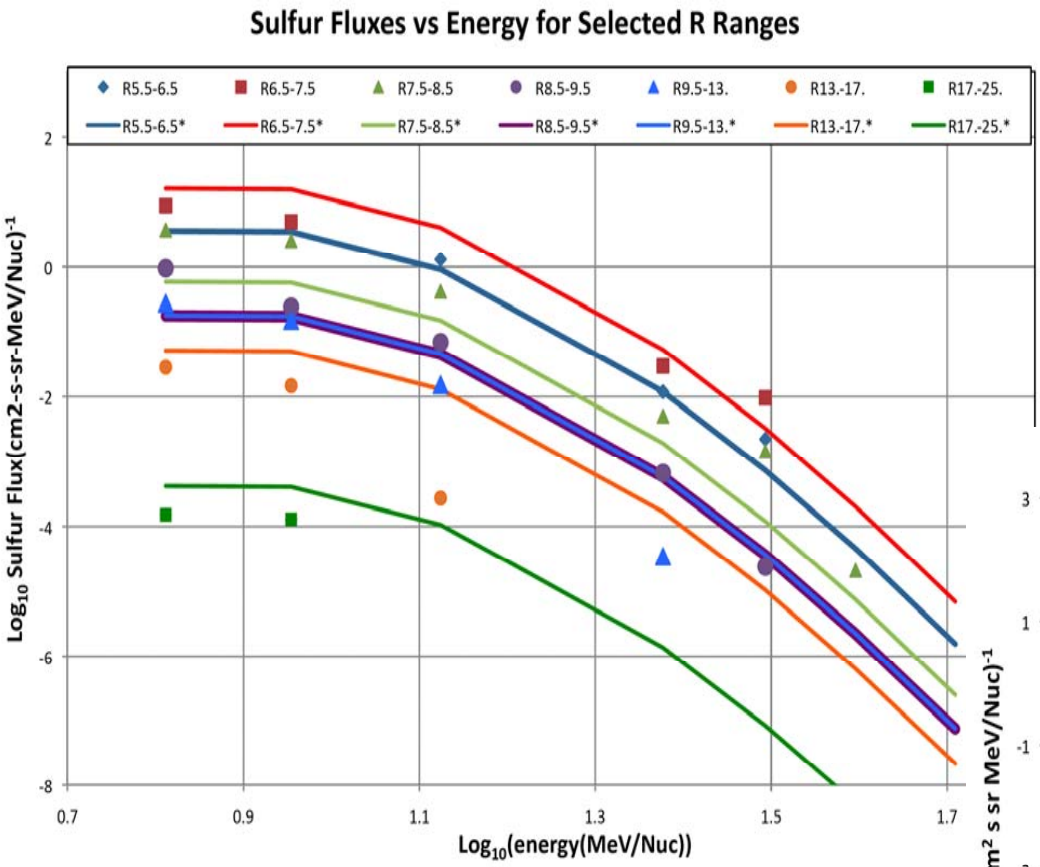
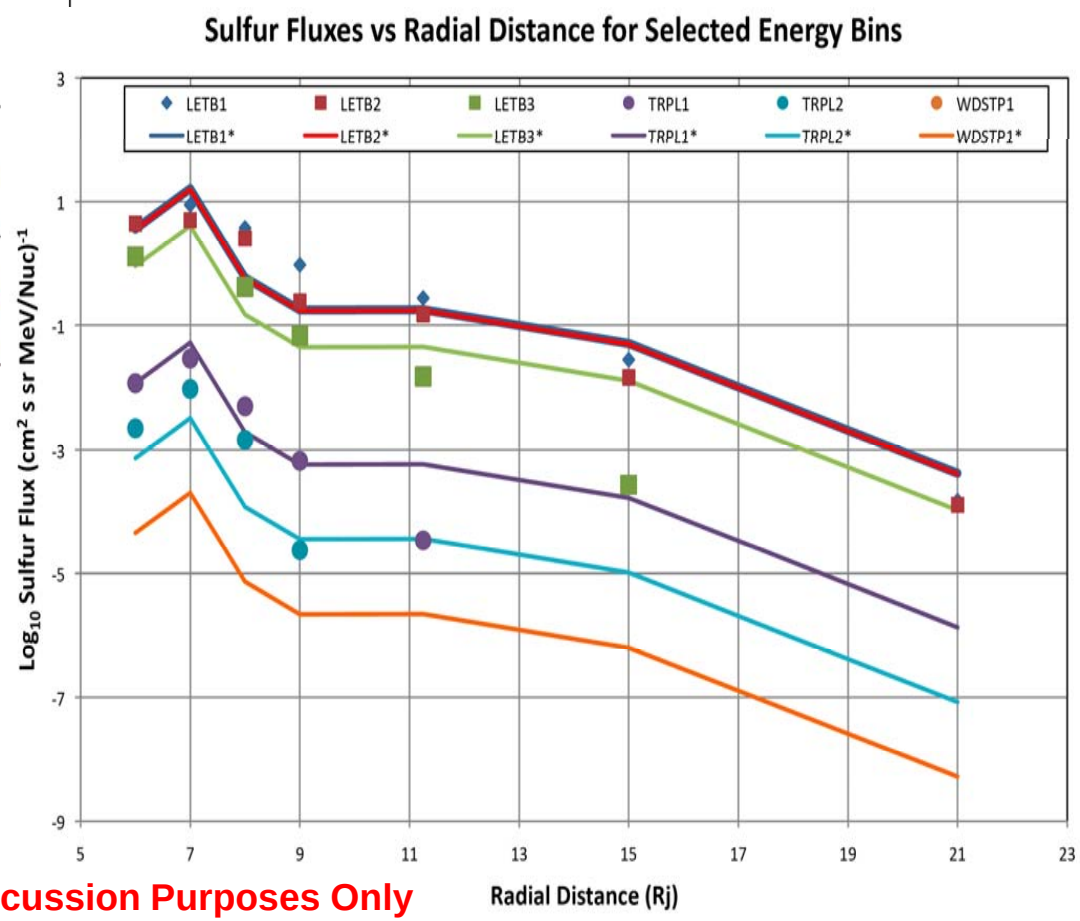
Sulfur Fits





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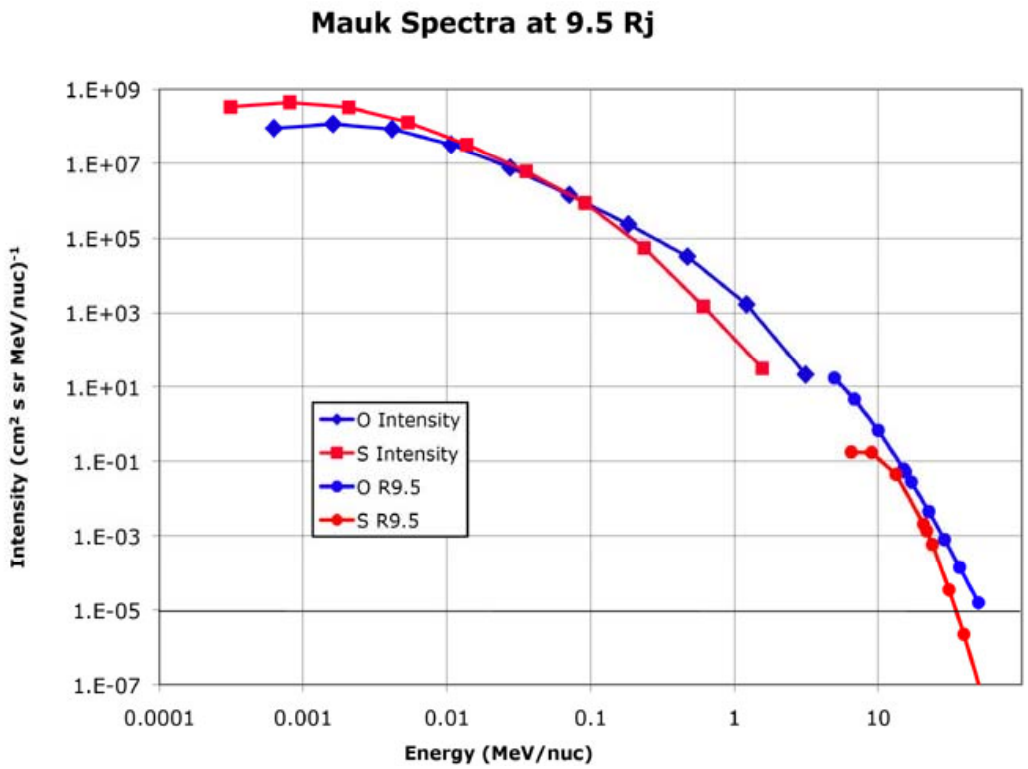
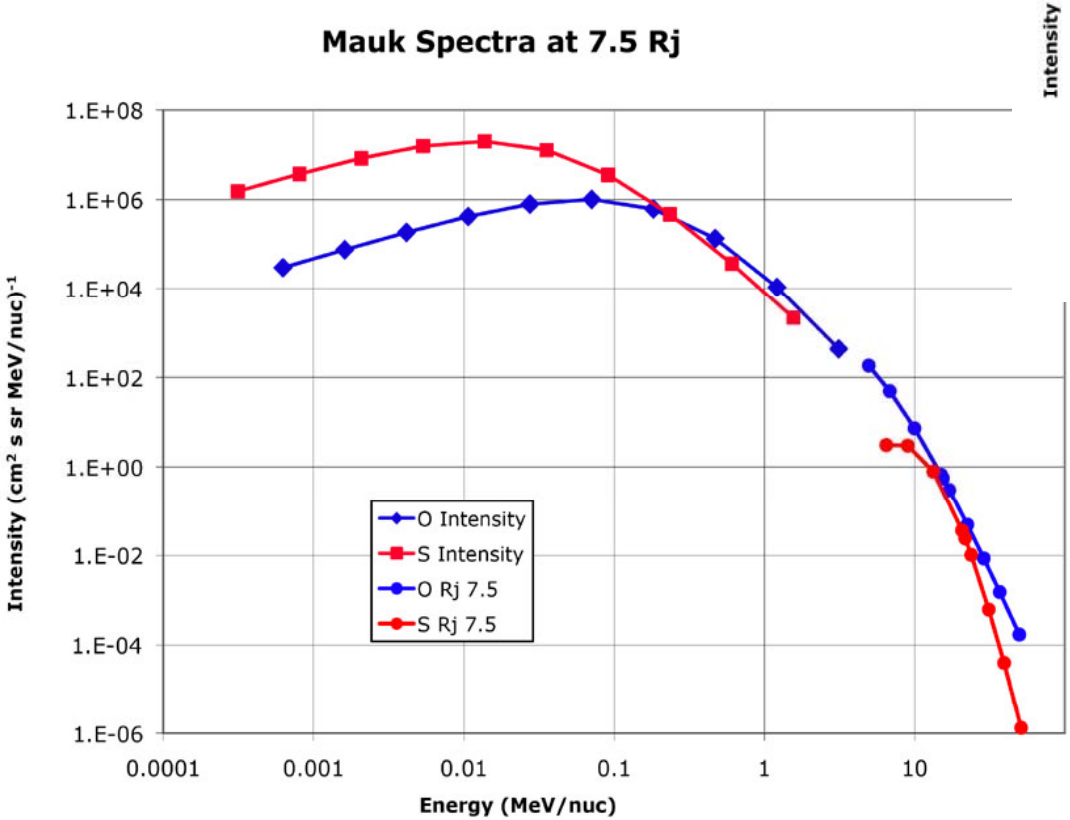
Comparisons to Mauk et al. (2004)





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Summary of HIC Model

- Used data from 31 of the 35 Galileo orbits.
- Covers radial distance from 2.5 Rj to 30Rj.
- Models three ions: Oxygen, Carbon, and Sulfur.
- Covers energy range ~6-200 MeV/nucleon.
- Model is useful for:
  - Provides baseline estimates for Sulfur (believed to be of iogenic origin), Oxygen (both iogenic and solar origins), and, for the first time, Carbon (solar origin)
  - Can be used to define heavy ion spectra for SEE evaluations

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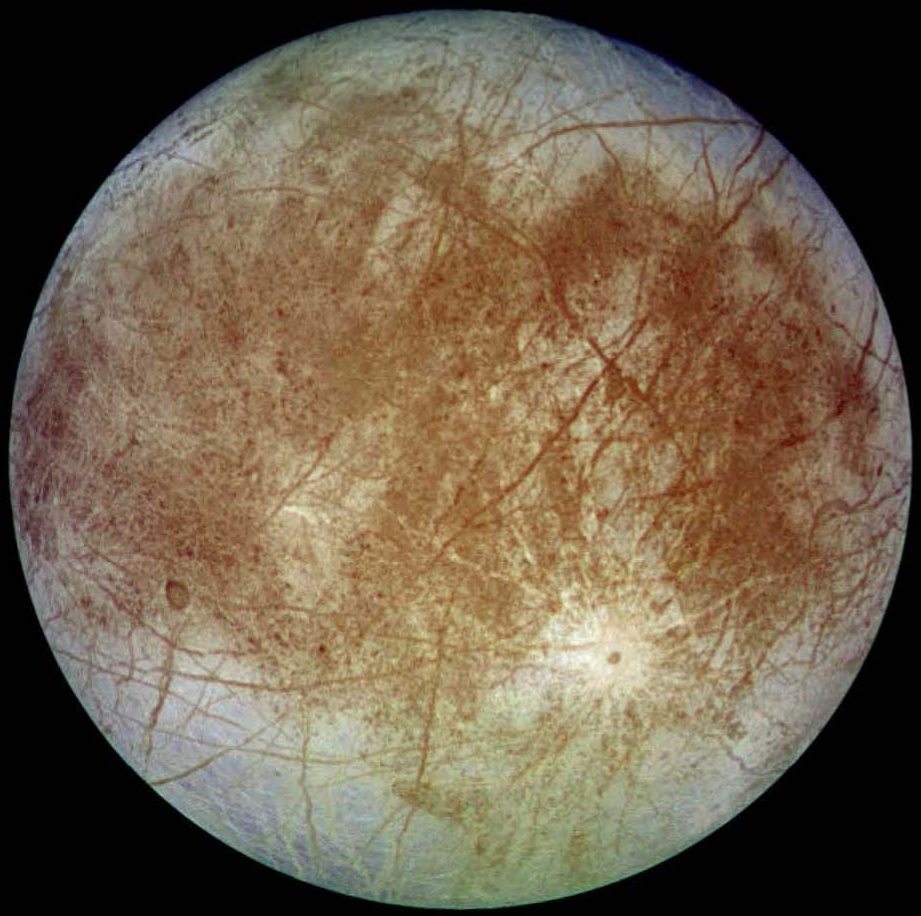
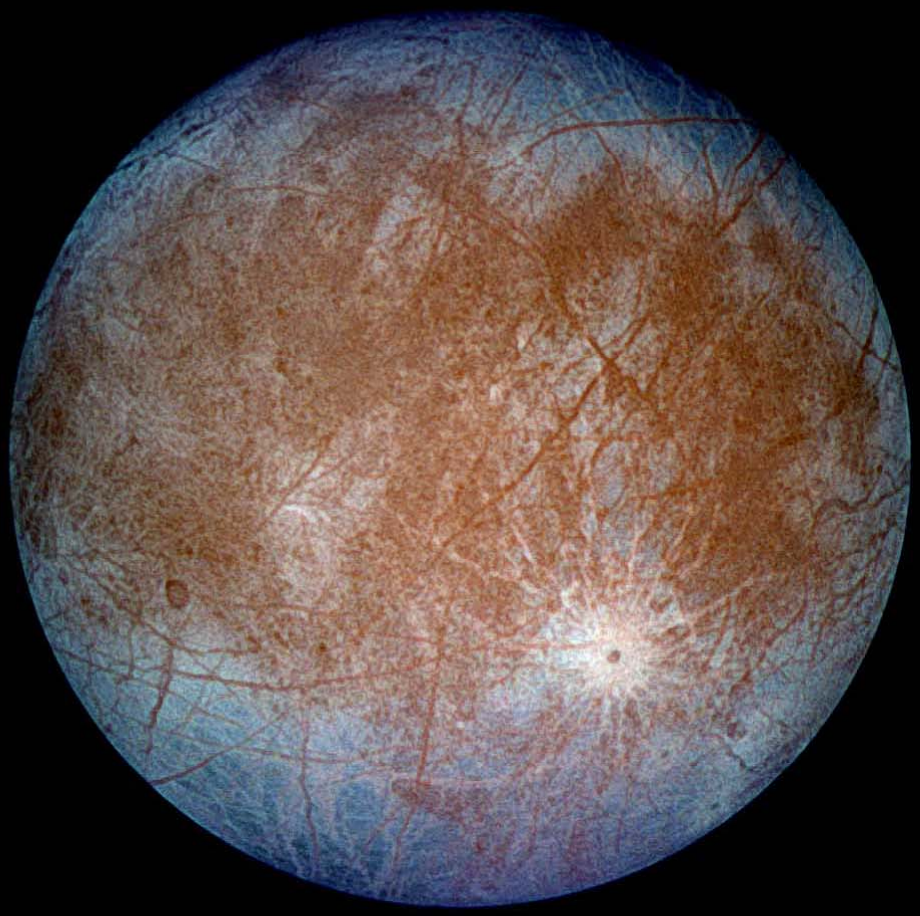
Europa





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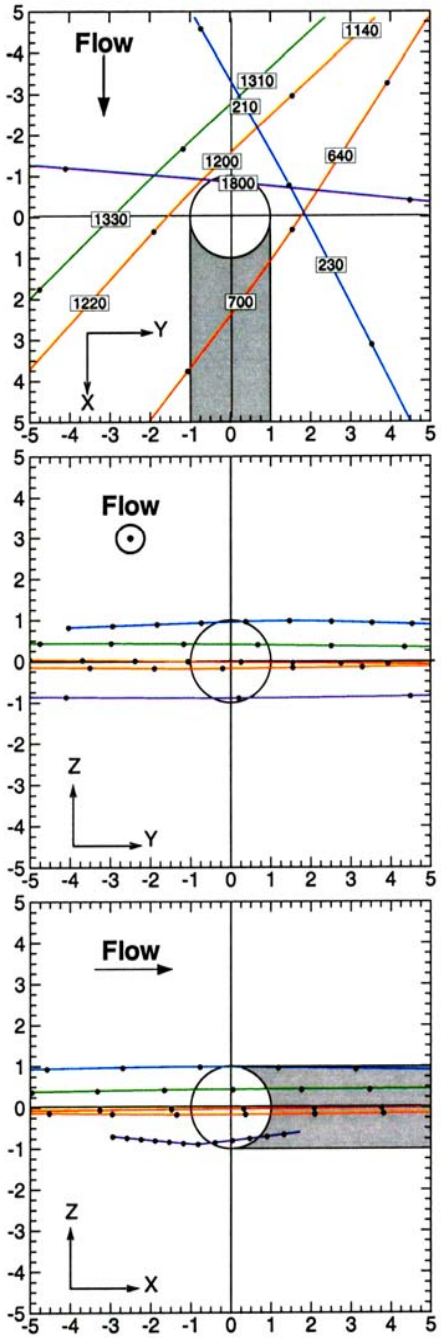
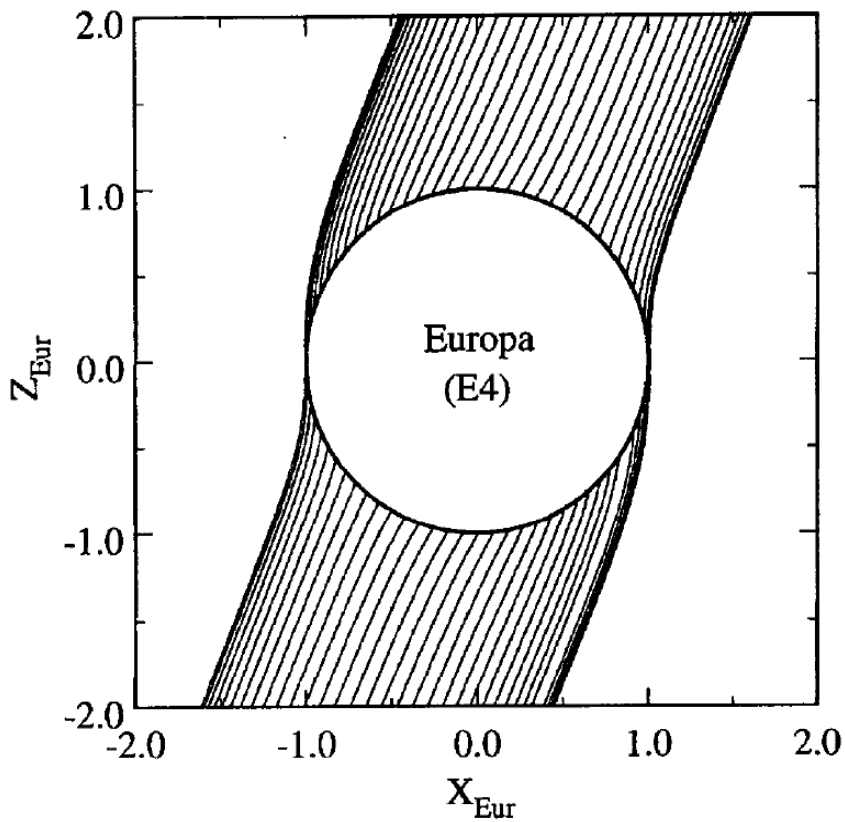
Europa's Magnetic Field Environment



Europa flybys E4 (red), E12 (orange), E14 (green), E19 (blue), and E26 (purple) by Europa. Cartesian Coordinates: X along flow direction, Y along Europa-Jupiter vector, Z along spin axis.



E4 magnetic field line configuration in X_s-Z_s plane from vacuum superposition of external jovian magnetic field (Khurana, 1997) for System III location.

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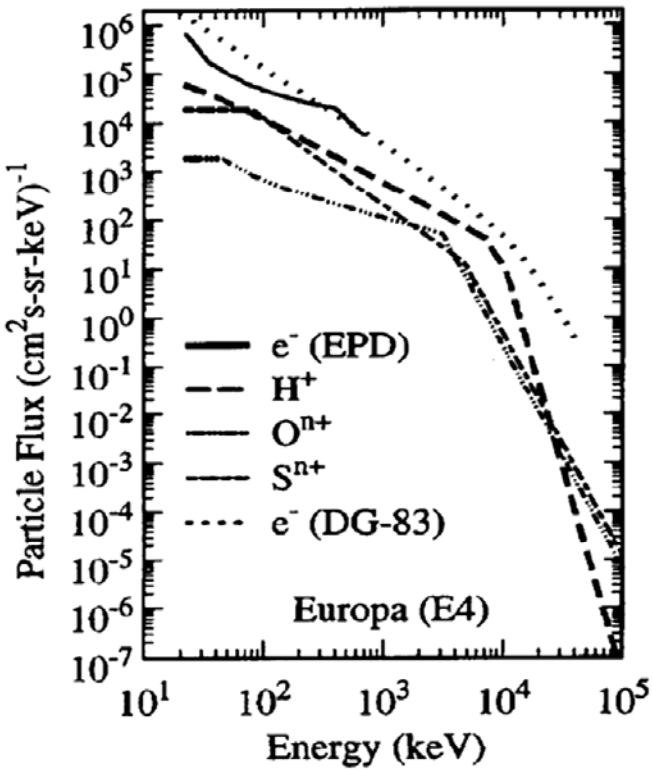
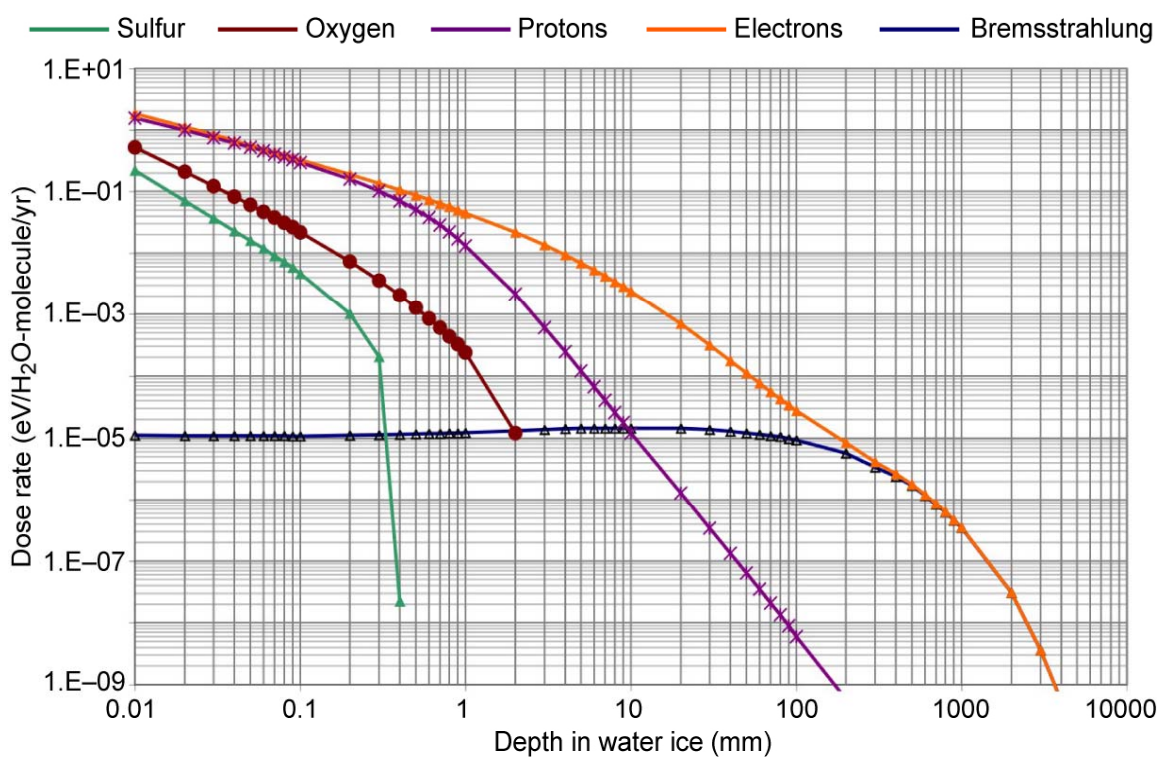
Radiation Environment at Europa's Surface



Flux spectra from EPD measurements at Europa during E4 encounter (Cooper et al., 2001). Electron spectra from EPD at 20-700 keV and from Divine and Garrett (1983).

Dose rate (rad(H_2O)/s) vs depth curves for, electrons, protons, oxygen, and sulfur at apex of Europa's trailing hemisphere.



Paranicas et al. (2002)

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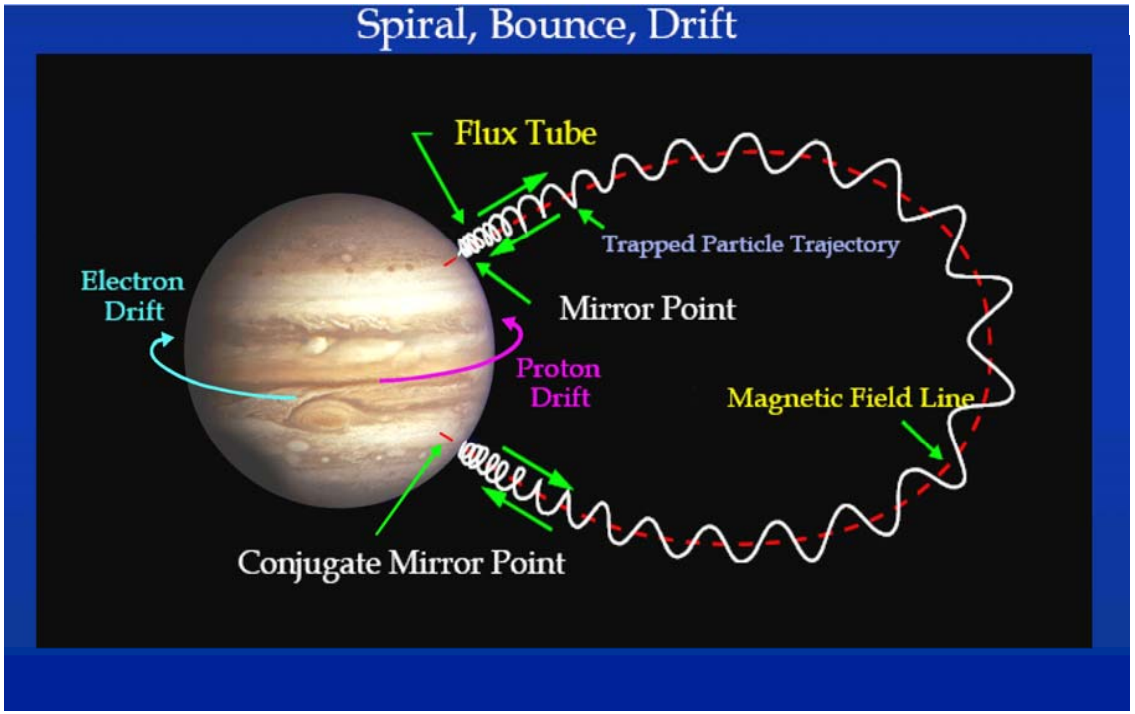
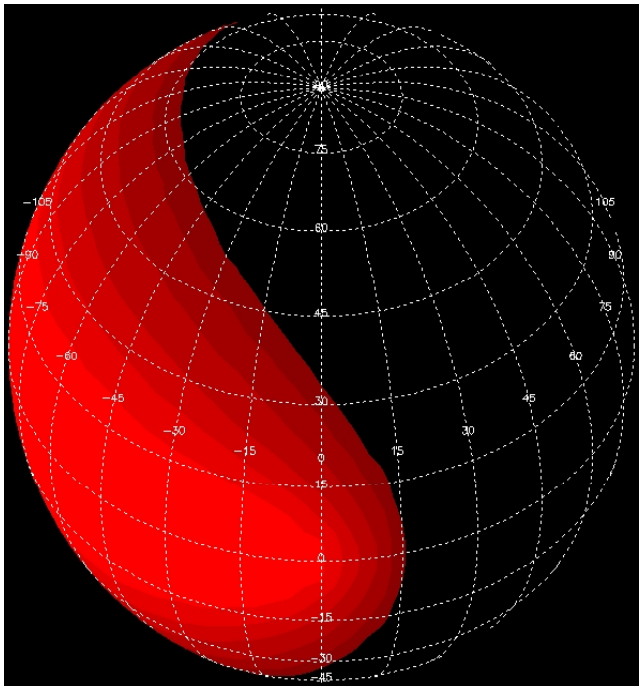
Trapped Particle Motion at Jupiter

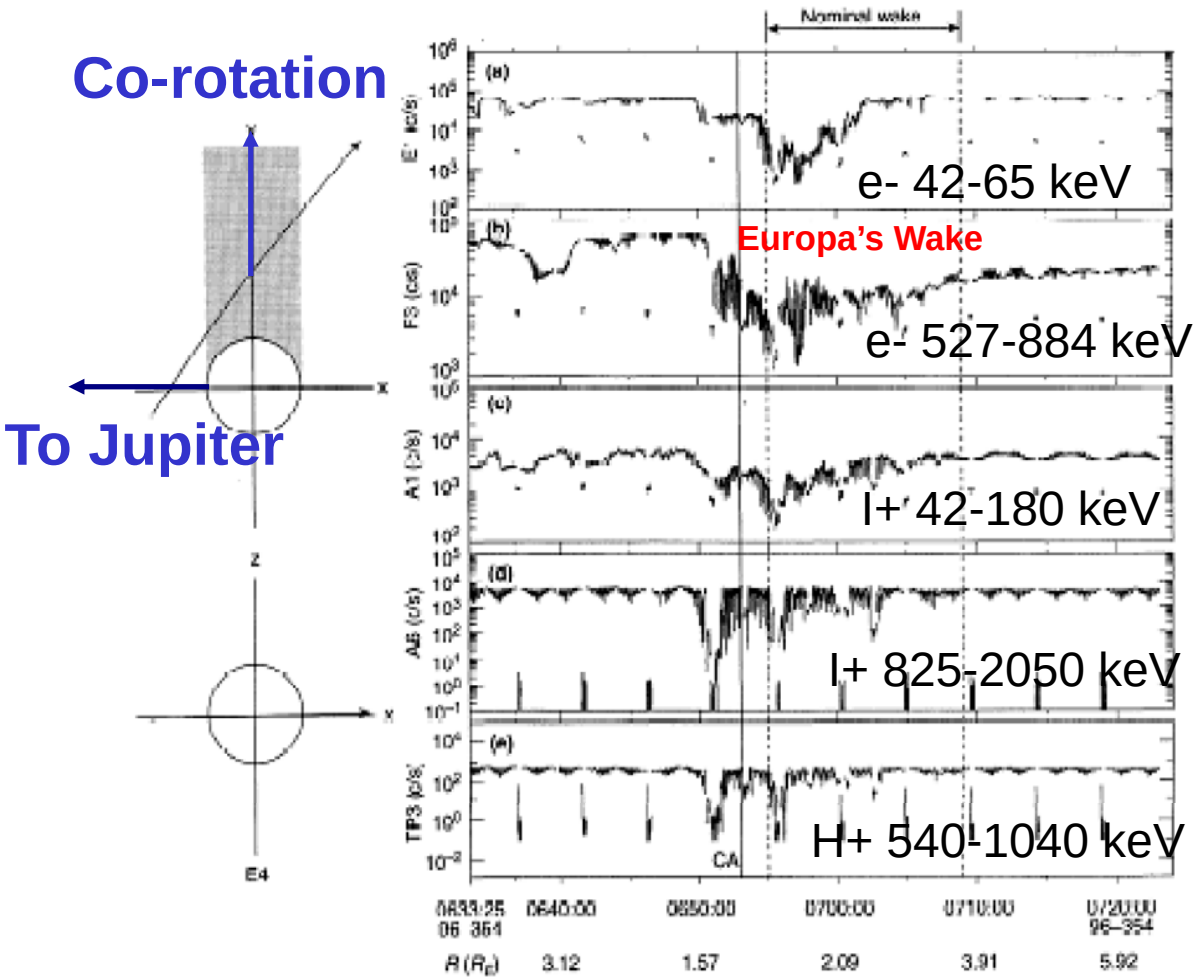


- If the magnetosphere of Jupiter is rigidly co-rotating, plasma flow speed at Europa's orbit (9.5 Rj) is about 118 km/s.
- Europa travels about 14 km/s in its orbit, so that charged particles are overtaking the satellite at all times.

Particles impacting the trailing hemisphere leave regions above poles and leading hemisphere depleted of MeV electron flux (creating wake).



Measurements of Flux Reductions at Europa



EPD observed flux reductions in wake for orbit E4

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EPD B1 (1.5-10.5 MeV) Electron Channel

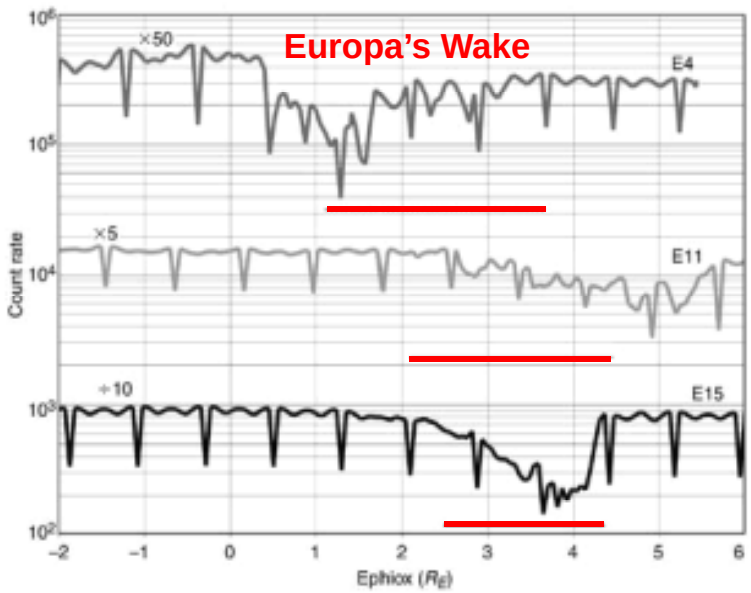
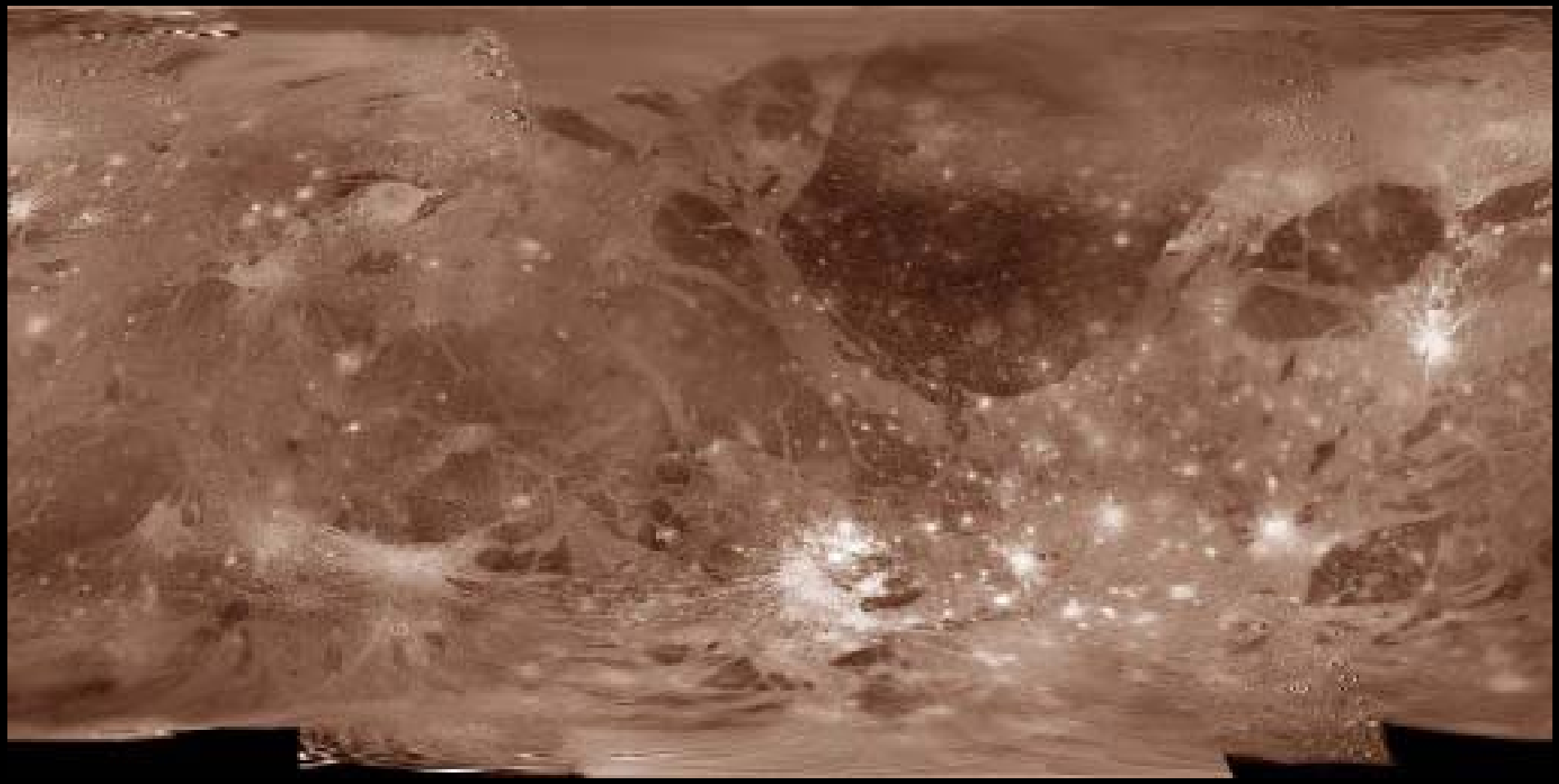


Figure 3. Spin-averaged count rates from the ~1.5–10.5 MeV electron channel on EPD plotted as a function of ephiox, the x-axis of the ephio system. The horizontal lines correspond to the nominal geometric wakes in ephio coordinates.

Paranicas et al., 2007)

GANYMEDE



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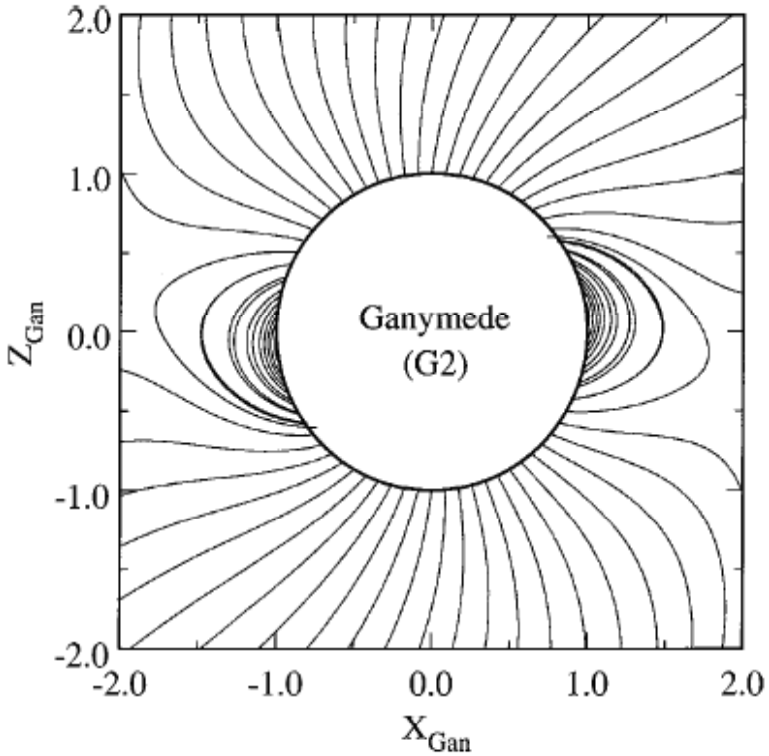
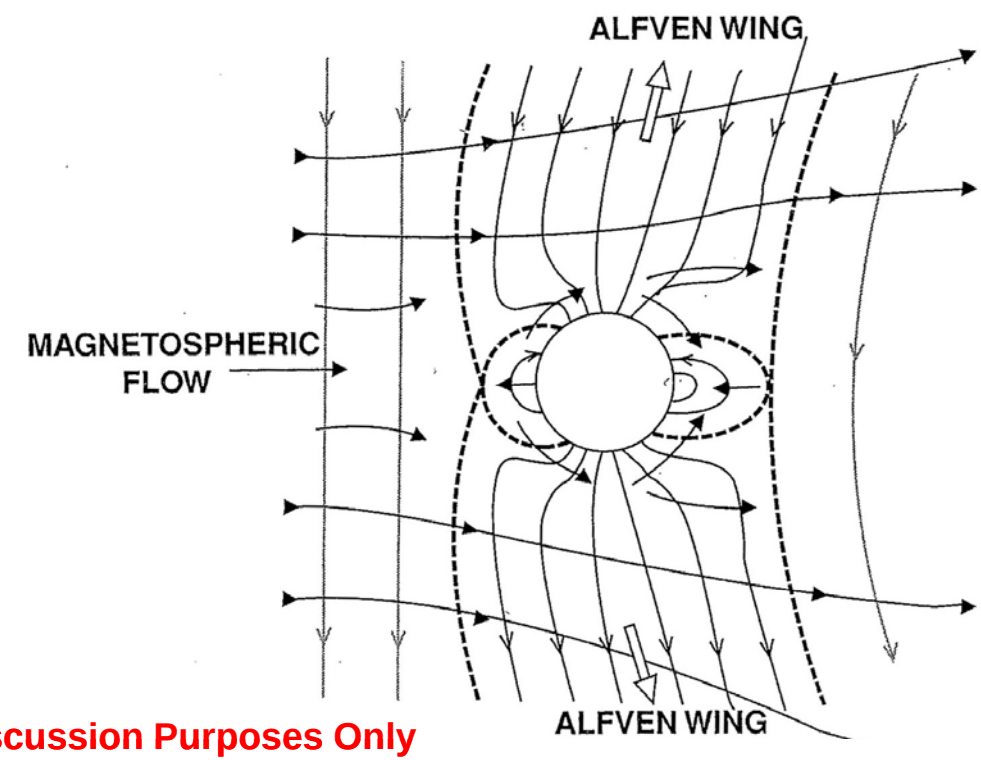
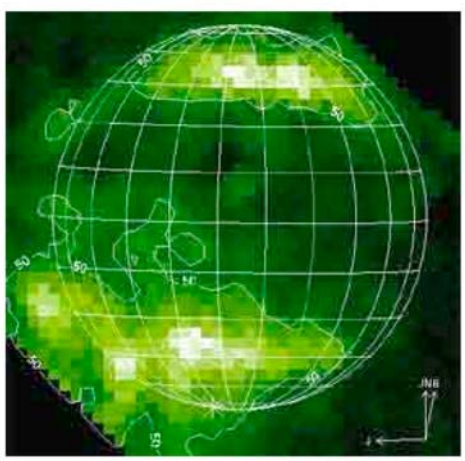
Ganymede's Magnetosphere



Magnetic field configuration at Ganymede (Cooper et al., Icarus, 2001)

Magnetospheric regions at Ganymede.





Aurora at Ganymede.

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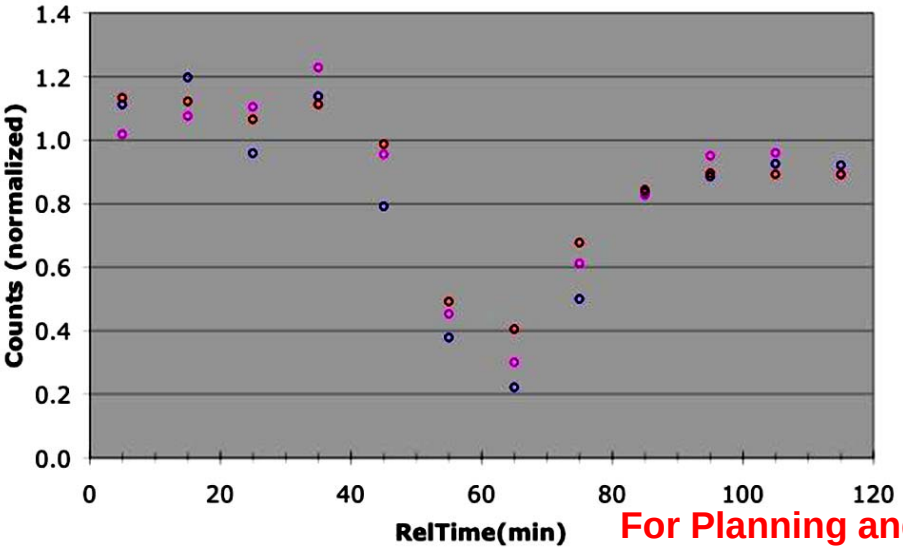
Flux Reductions at Ganymede

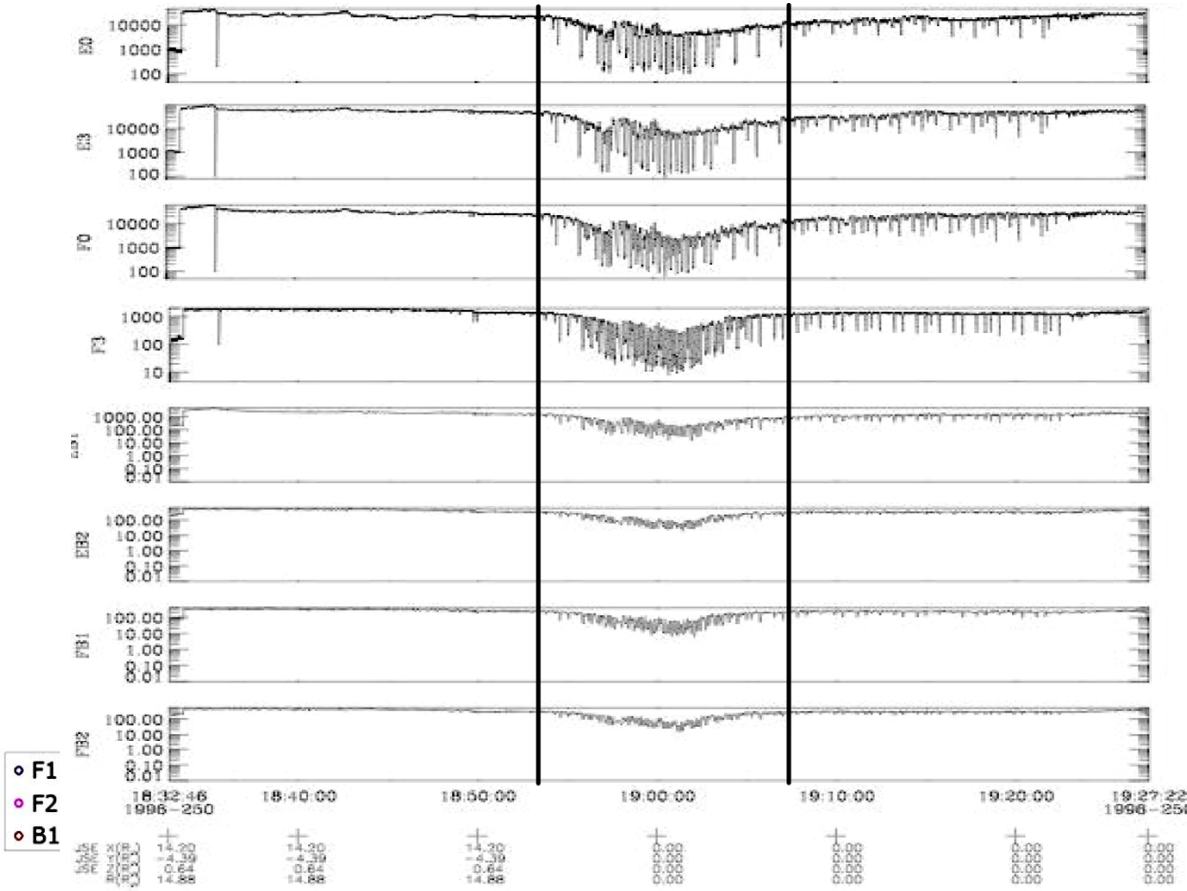
Galileo observed reductions in the particle fluxes as at Europa

Ganymede Flybys:

G1	838.0 km (EPD off)
G2	***264.4 km***
G7	3104.9 km
G8	1606.2 km
G28	808.7 km

G2 High F1, F2, B1 Electron Fluxes





G2 Ganymede encounter EPD low-energy channel counts

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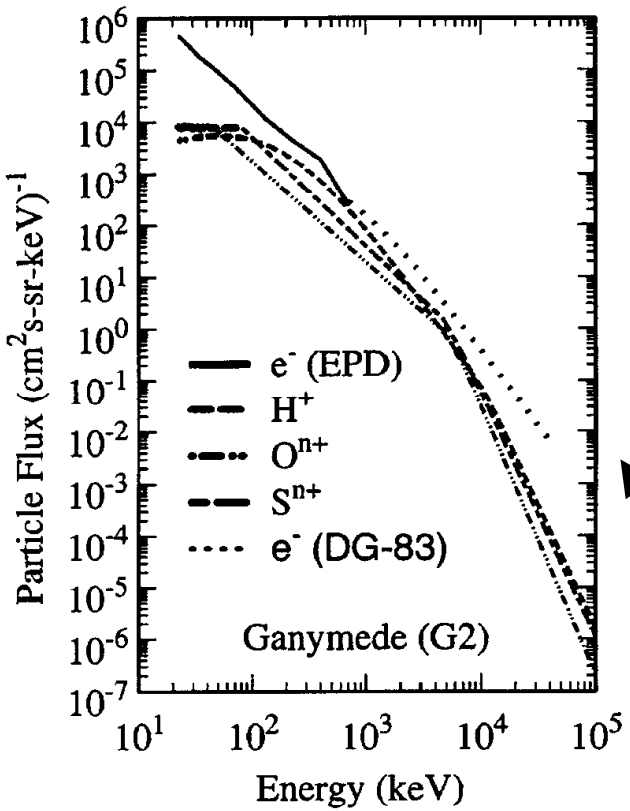
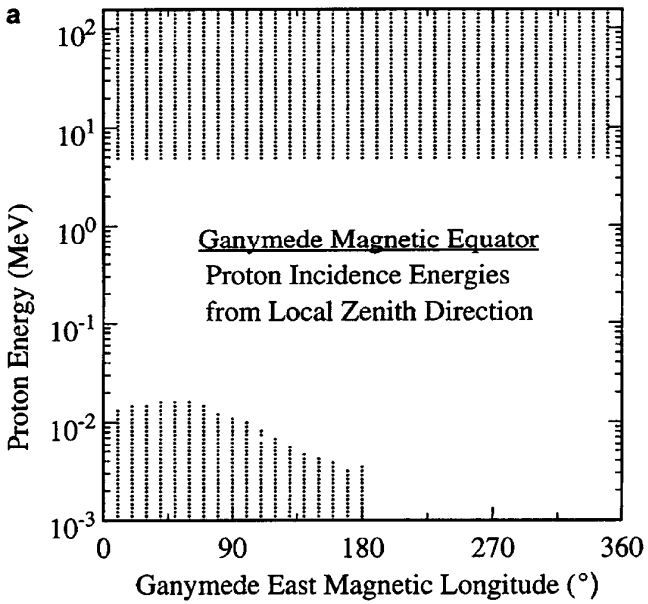
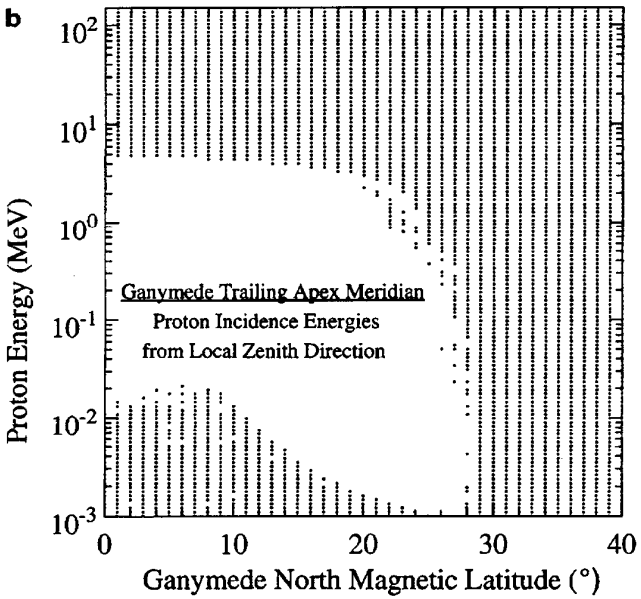
Radiation Environment at Ganymede



Magnetic (a) east longitude and (b) north latitude for allowed trajectories incident from zenith onto Ganymede's surface. From Cooper et al. (2001)





From Cooper et al. (2001)

Flux spectra represent energetic particle environment upstream of Ganymede from EPD measurements during G2 encounter compared with Divine-Garrett (1983). From Cooper et al. (2001).

Radiation Modeling

Issues:

- Continued updates to Galileo-based electron/proton models will further the understanding of the jovian radiation environment
- Understanding the time-dependent, statistical variations of the jovian radiation belts provides better insight into the risk posture (effects of “storms”…)
- Heavy ion SEU rates at Jupiter may impact design choices (lessons learned from Galileo)
- Improved models of the local Ganymede and Europa environments can take advantage of the “shielding” effects of the moons.

What's different about the Jovian Environment?

- Expected mission total ionizing doses are substantially higher compared to other planetary or deep space missions

Shielding strategy needs system level attention to optimize the use of shielding mass

- The Jovian radiation environment is dominated by high-energy electrons in addition to other usual radiation effects
  - Internal ESD due to high-energy electrons is an important design consideration
  - Transients or background noise due to secondary particles due to high-energy electrons will drive the performance of detectors and sensors

Special attention will be required to mitigate the radiation effects due to the high energy electron environment.

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Jupiter Charging/Plasma Environment

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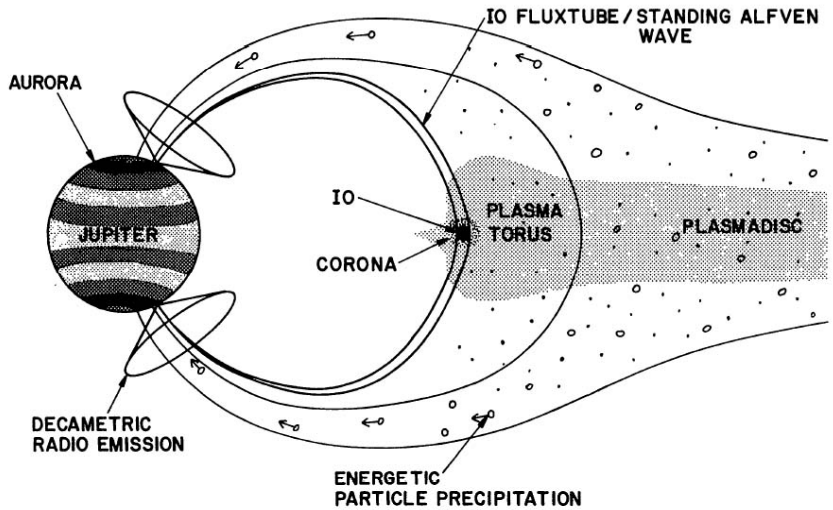
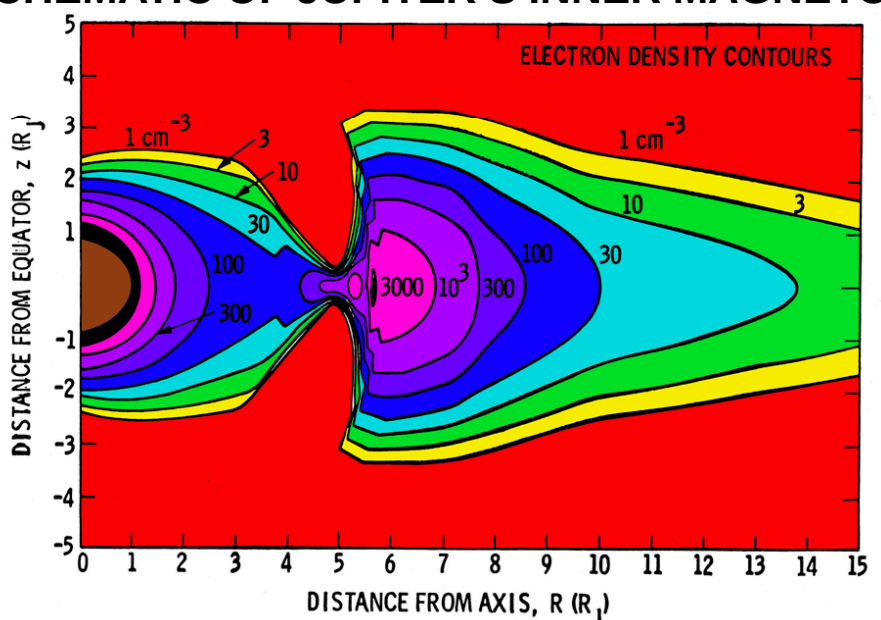
Jupiter's Plasma Environment and Aurora



SCHEMATIC OF JUPITER'S INNER MAGNETOSPHERE



JUPITER'S LOW ENERGY PLASMA ENVIRONMENT

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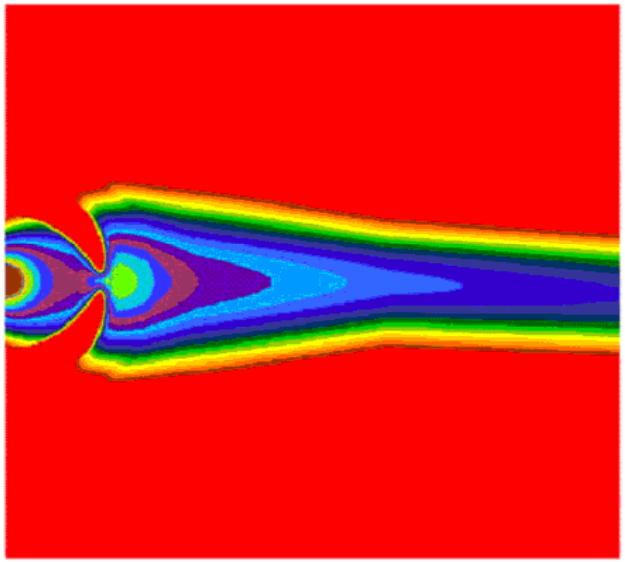
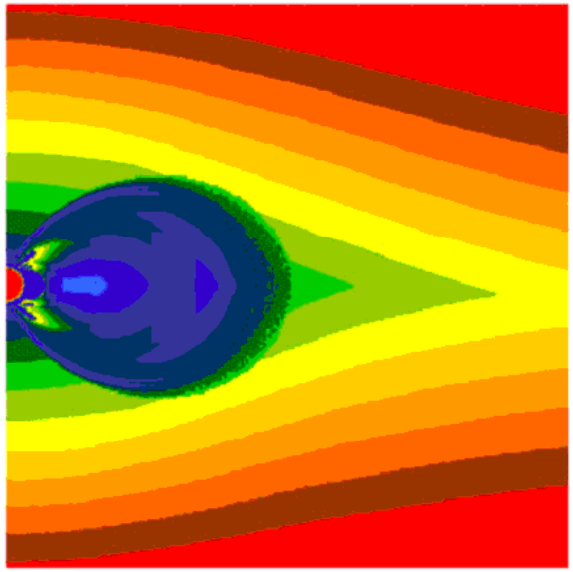
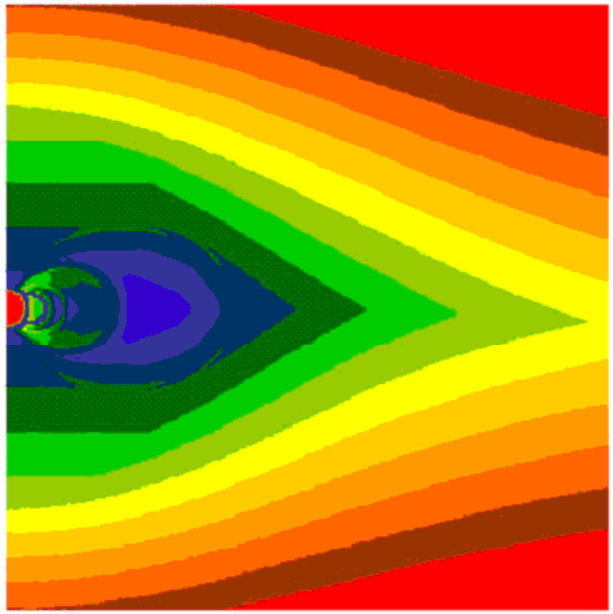
Jovian Plasma Densities



Cold Plasma Density



Hot Electron Density



Hot Proton Density

Divine and Garrett, 1983

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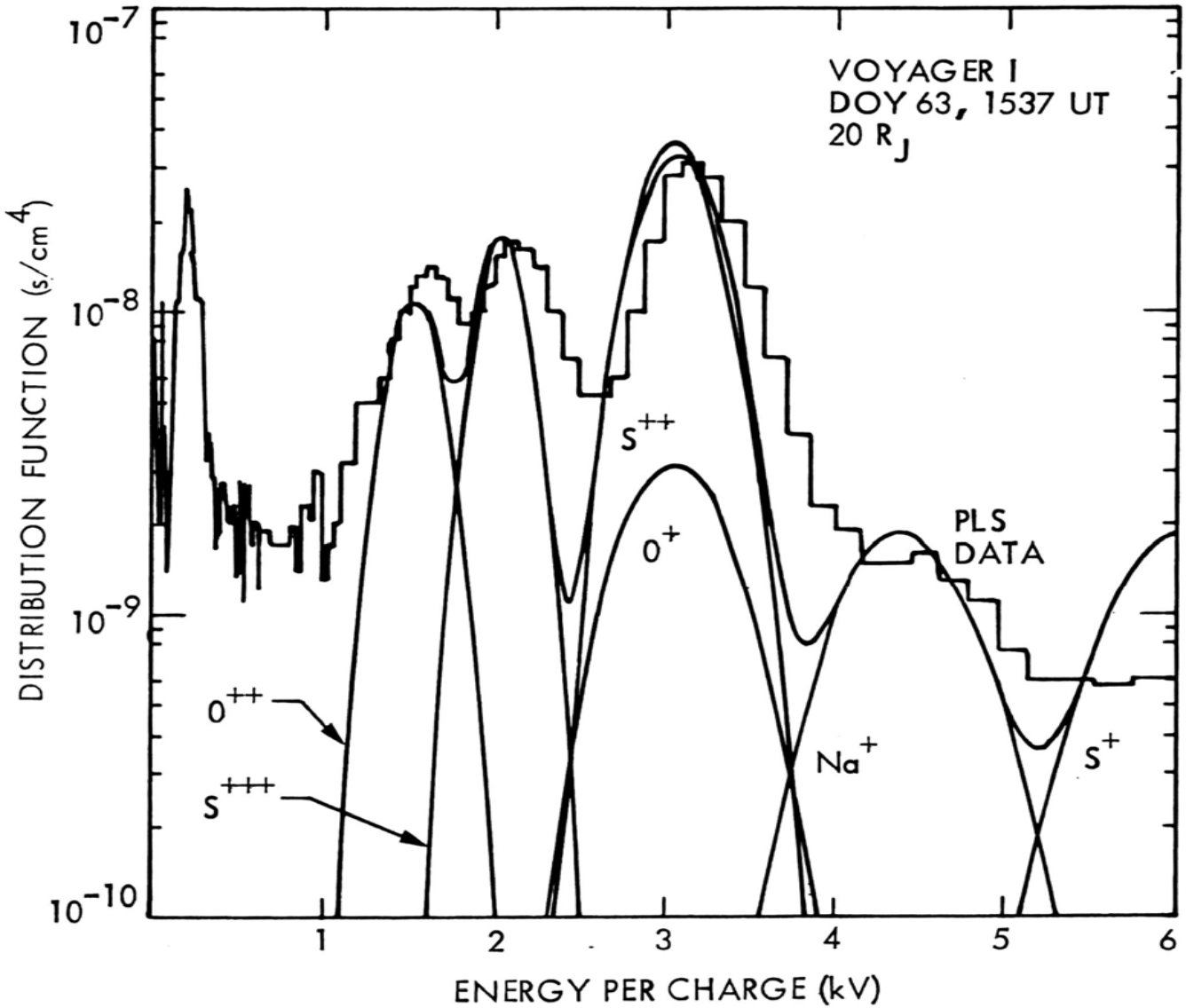
Jovian Plasma Distribution



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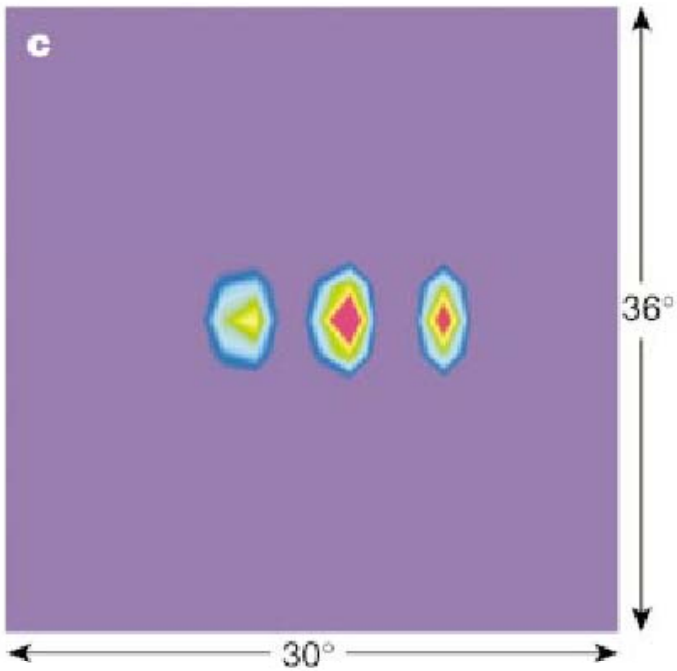
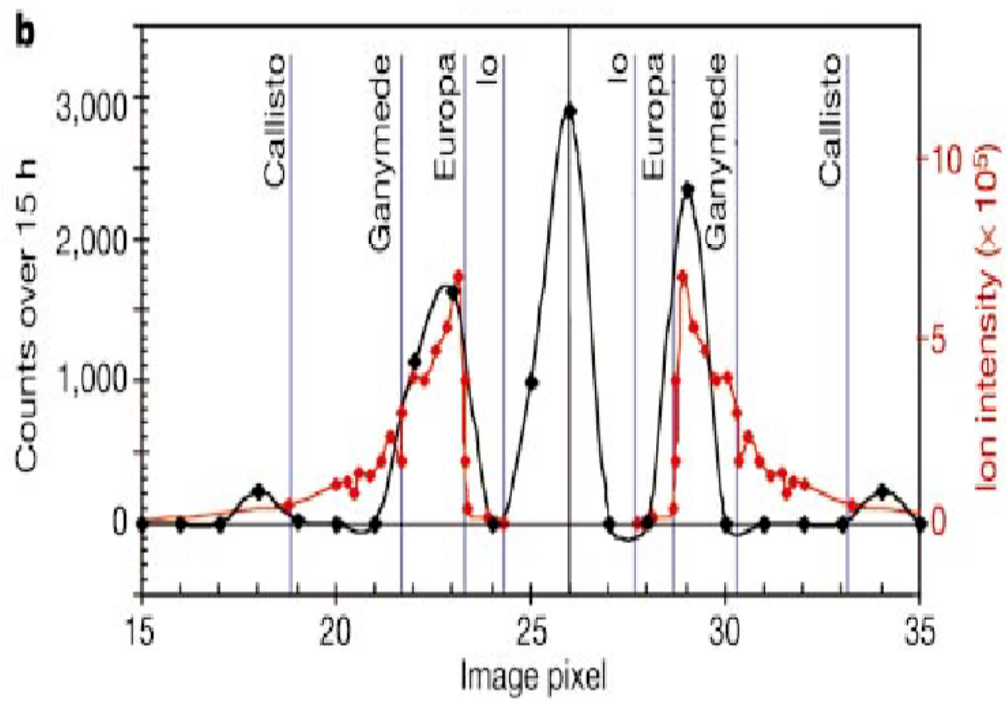
Europa Oxygen Torus



Cassini energetic neutral atom (ENA) image of Jupiter's magnetosphere. 15-hr image at ~140 Rj. ENAs are hydrogen atoms between 3,000-4,000 km s^{-1} (50–80 keV) with fraction of O or S atoms at same speed. Red represents ~1,450 counts. Middle feature centered on Jupiter, outermost just beyond orbit Europa at ~9.5 Rj.

1-D ENA profiles. Vertical lines mark distances of Callisto, Ganymede, Europa, Io (26, 15, ,9.5, 5.9 Rj). Intensities ($cm^{-2}s^{-1}sr^{-1}$) of 50-80 keV energy-integrated protons from Galileo EPD. Energy-integrated O and S ions are factor ~8 lower than proton intensities.



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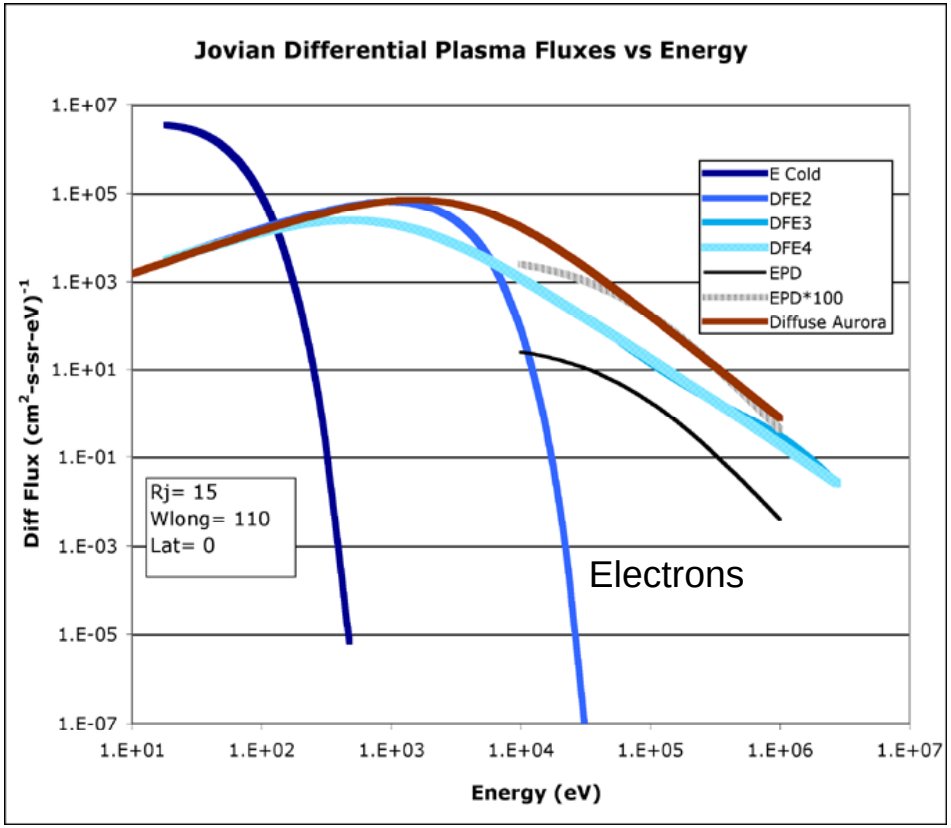
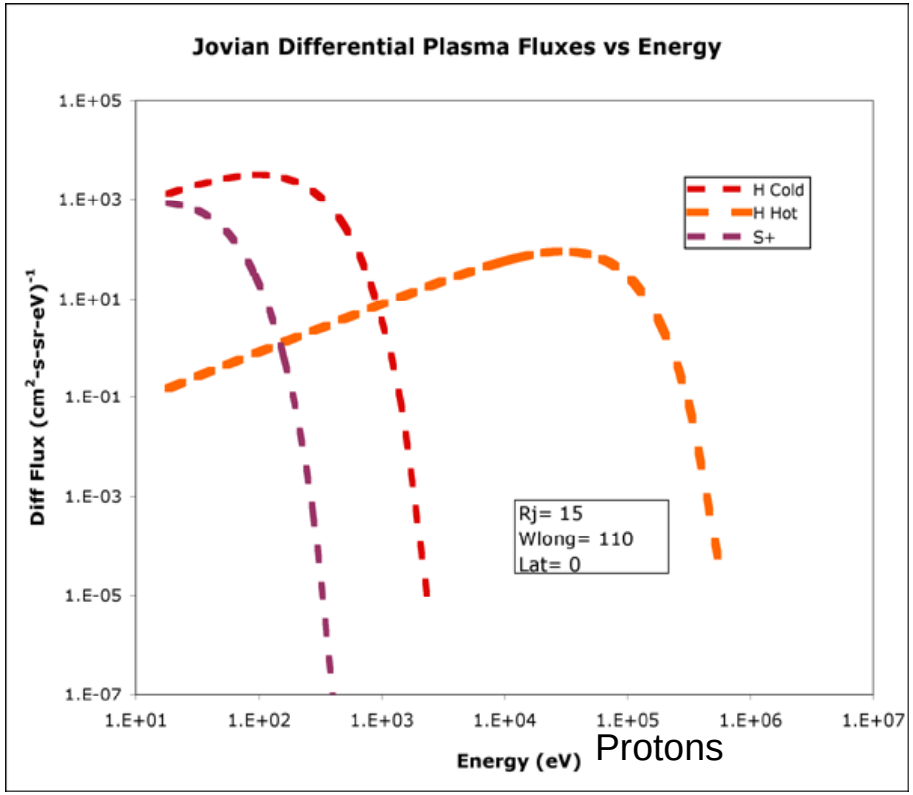
The Ambient Environment at Jupiter



Representative Differential Spectra at 15.0 Rj--0°



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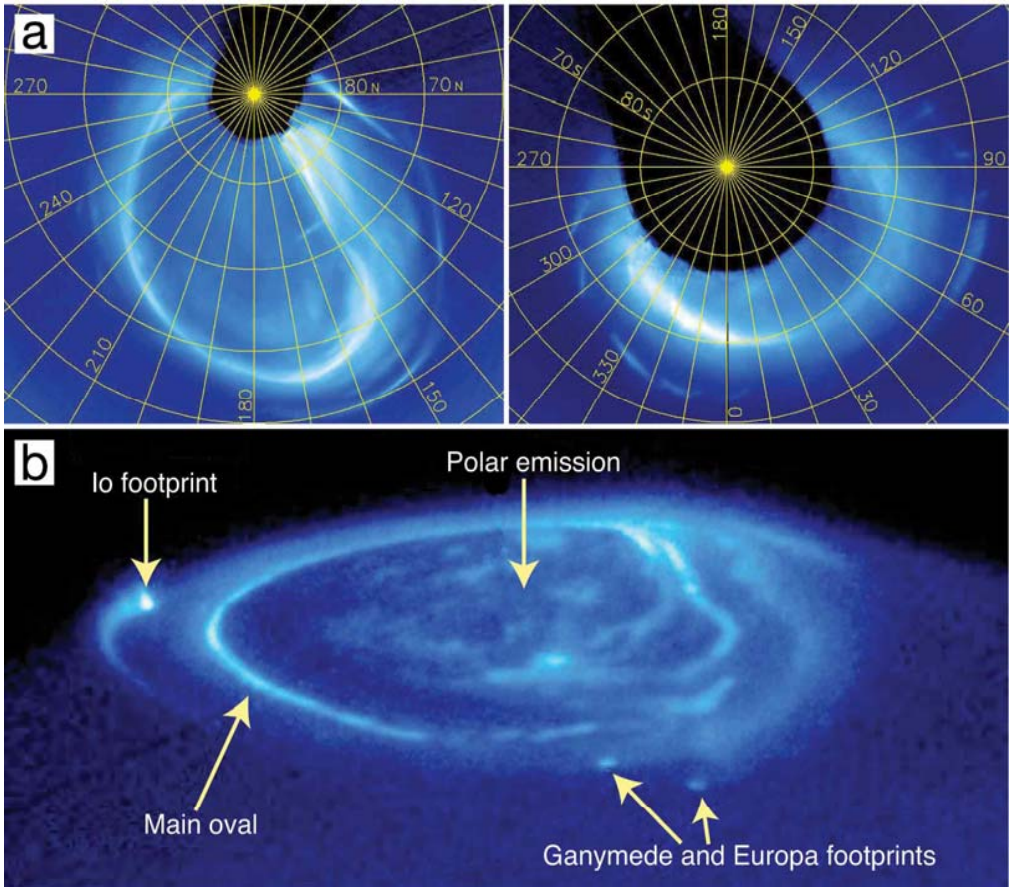
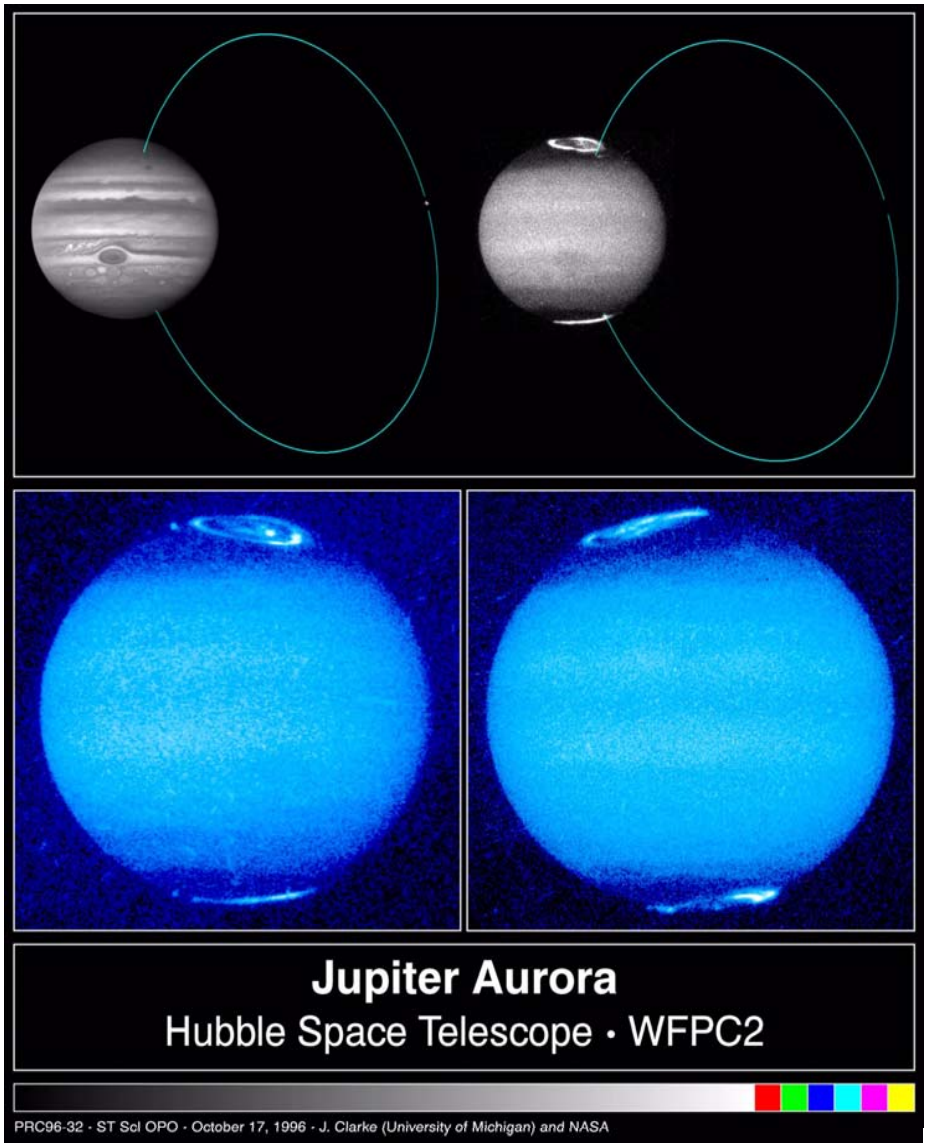
Jovian Aurora





HST UV images of the Jovian aurora. (a) Polar projections of the main auroral ovals, left is for the North Pole, right is for the South Pole. (b) Image of the northern aurora, showing main features: Main oval and polar emissions as well as footprints from three of the Galilean moons.[10]

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Galactic Cosmic Rays

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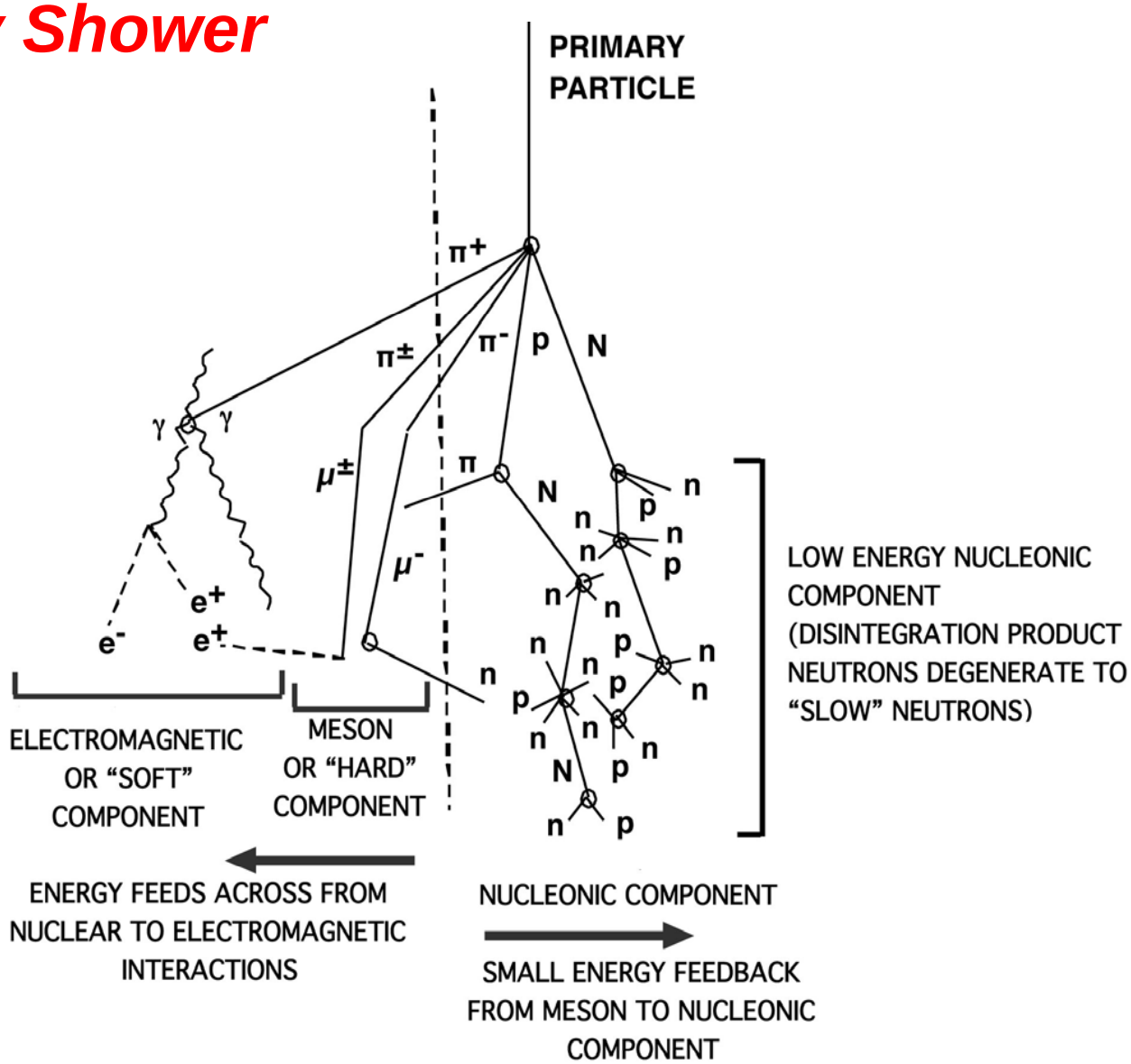
Cosmic Ray Shower



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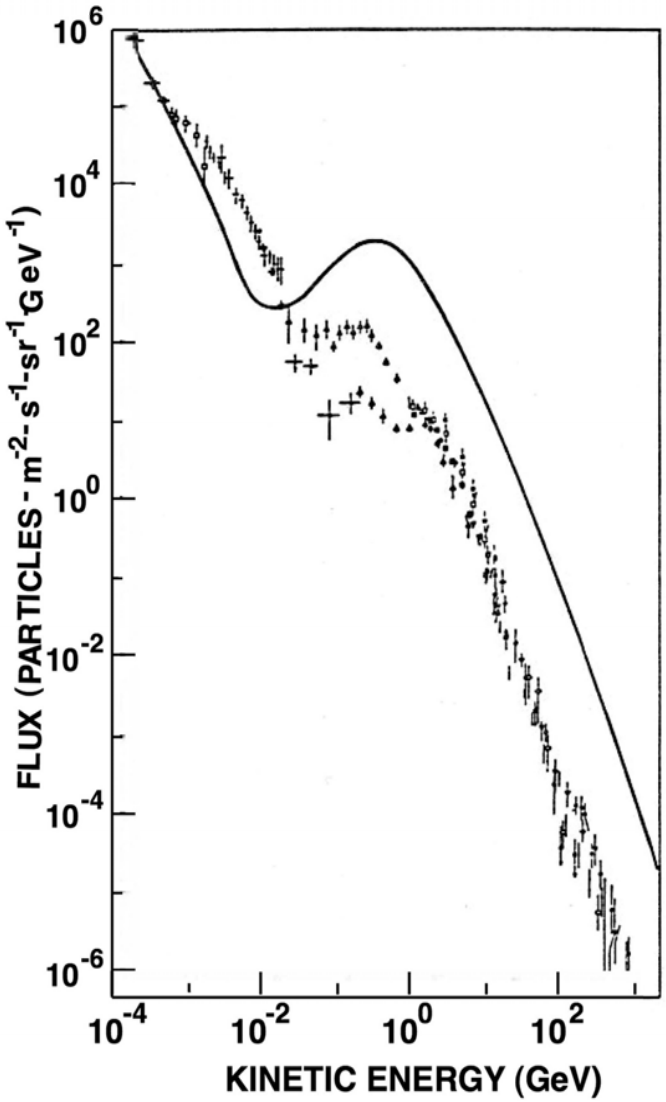
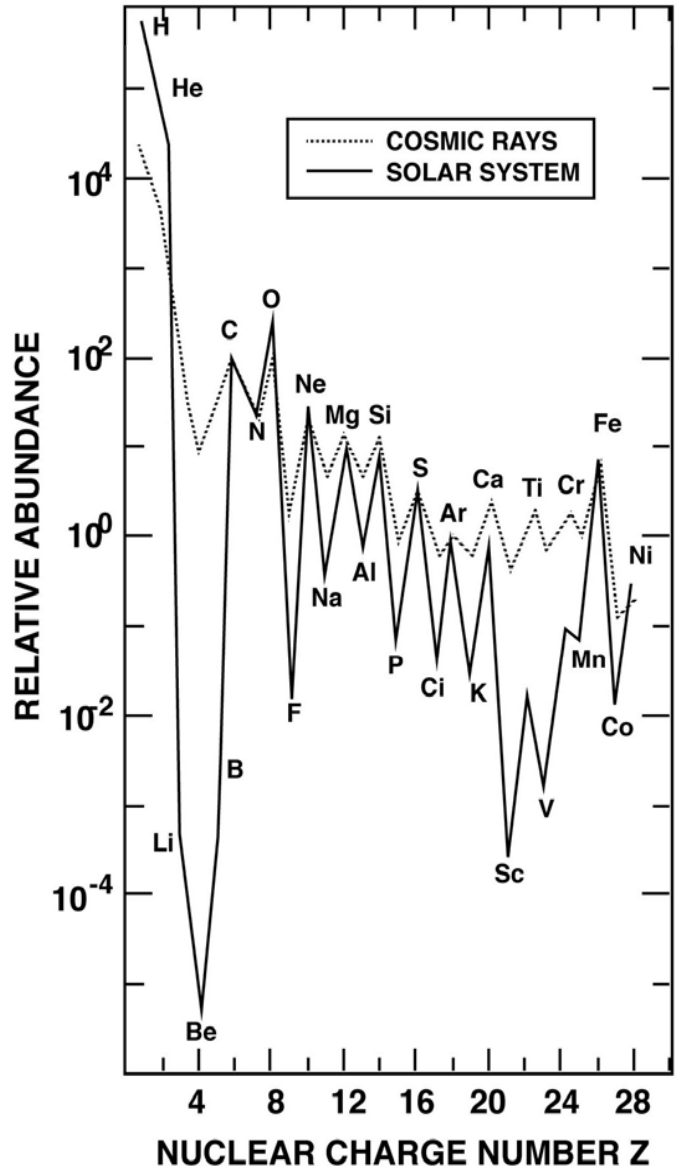
COSMIC RAY PROTONS (–) AND ELECTRONS (•)



COSMIC RAY COMPOSITION



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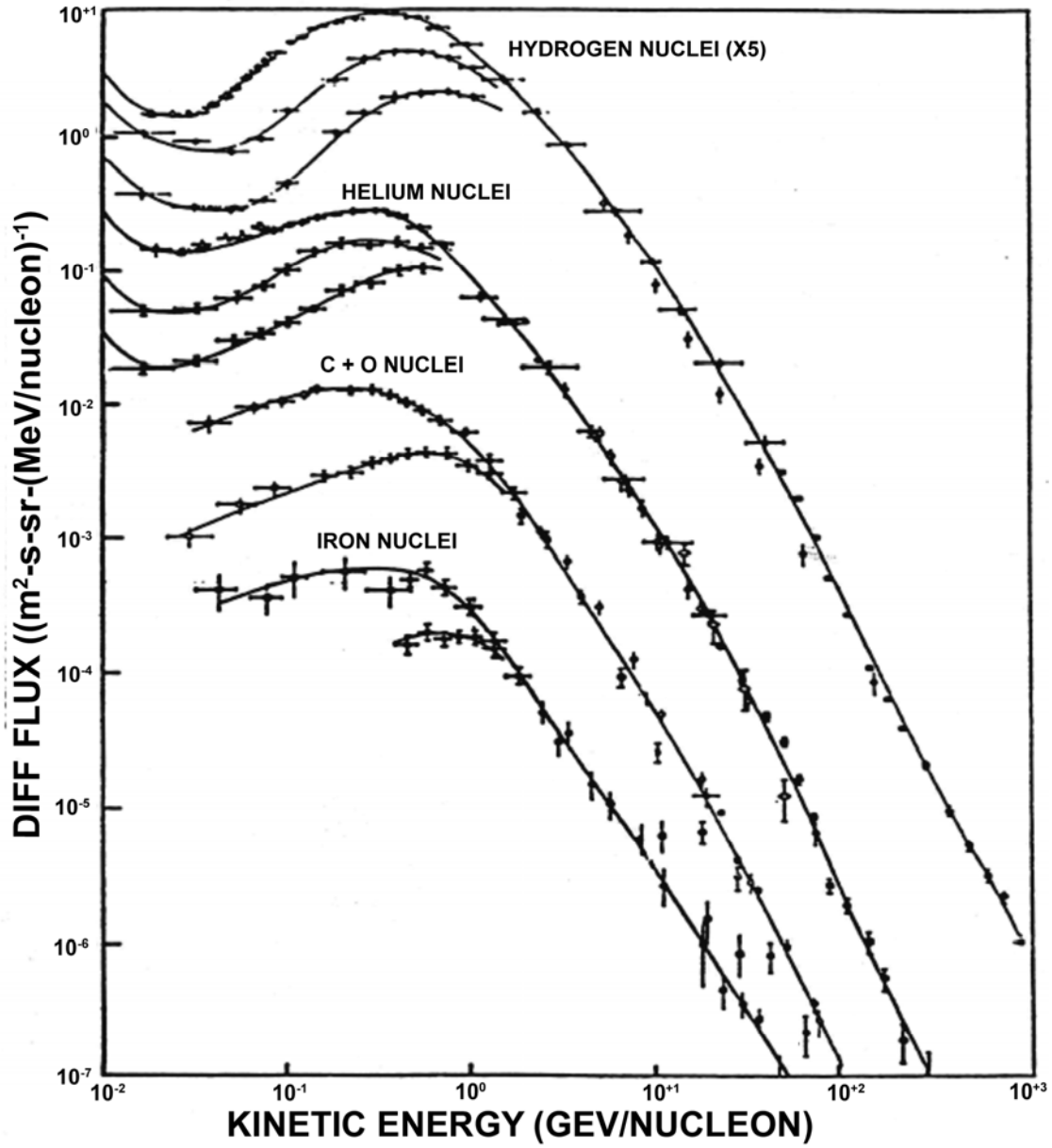
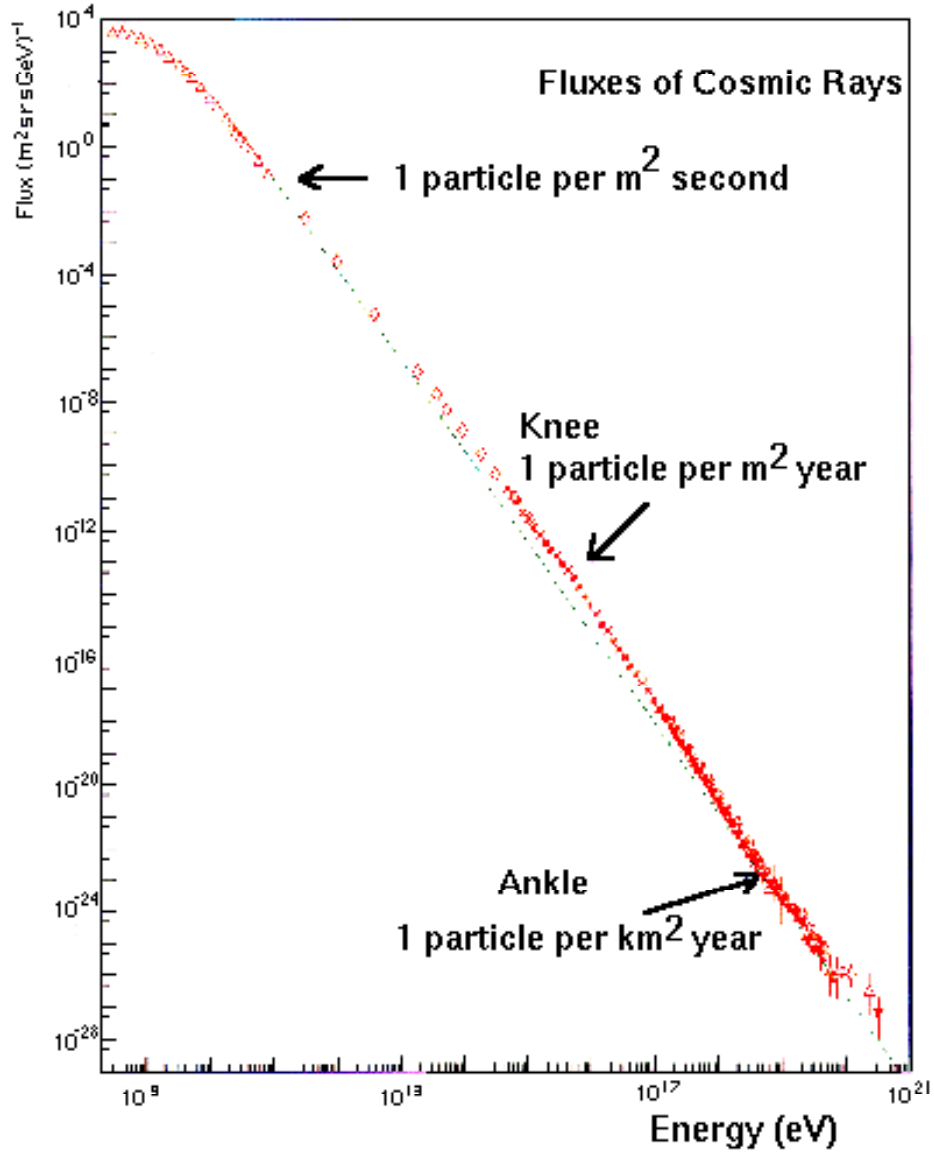
Cosmic Ray Nuclear Species Spectra at 1 AU





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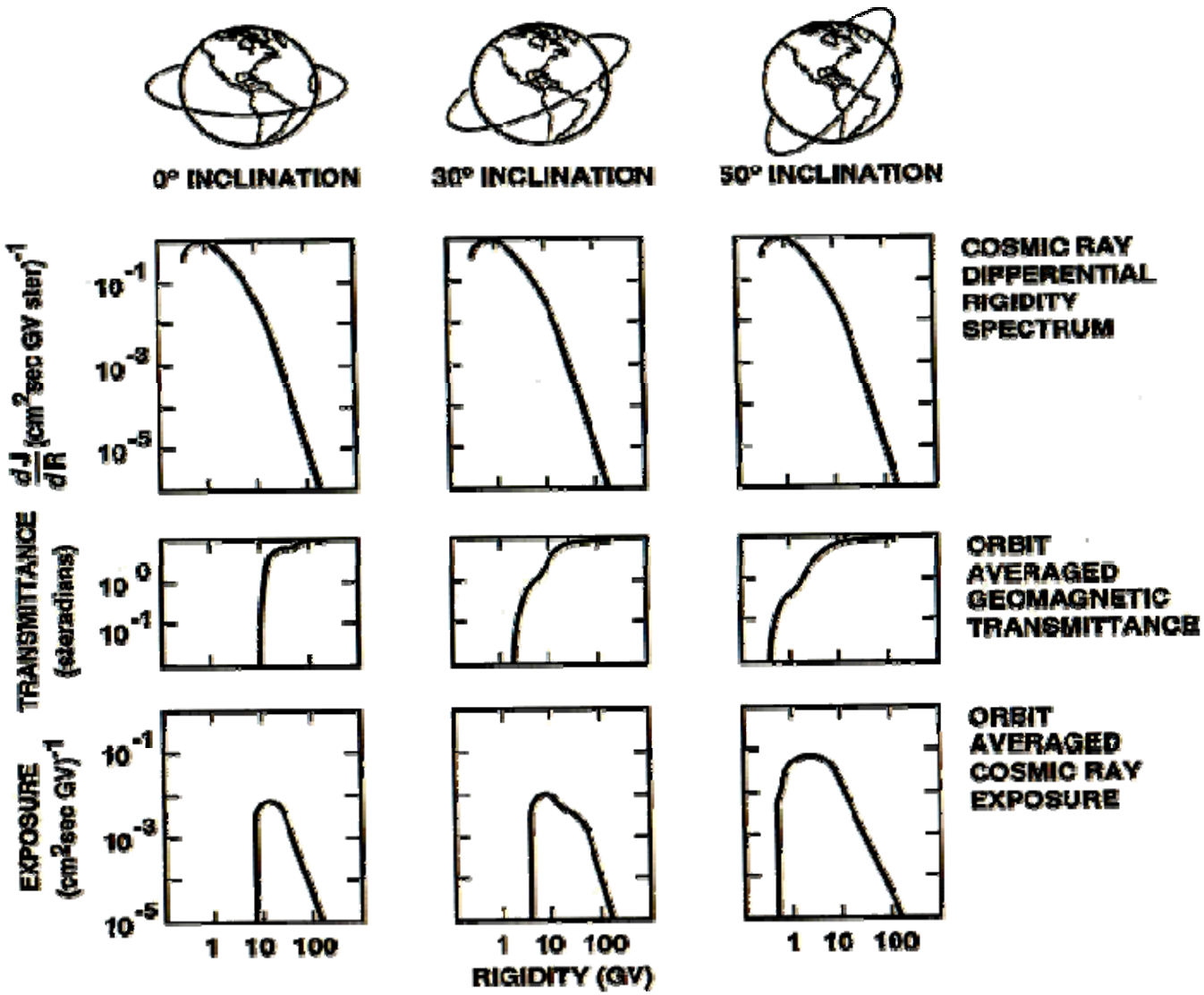
Effects of a Magnetic Field on GCR Transmission



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