Spacecraft Environmental Interactions and the JEO Mission

Introduction

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"An Ounce of Prevention Is Worth a Kilogram of Cure"

BACKGROUND

The effects of the jovian space environment pose a particularly severe risk to the survival of spacecraft. The spacecraft engineer must understand and take these effects into account in building reliable, survivable, and affordable spacecraft. Too much protections, however, means unnecessary expense while too little will potentially lead to early mission loss. The ability to balance cost and risk necessitates an understanding of how the environment impacts the spacecraft and is a critical factor in its design. This course is intended to address both the space environment and its effects with the intent of providing practical means for mitigating or at least limiting the worst aspects of spacecraft environment interactions for jovian missions.

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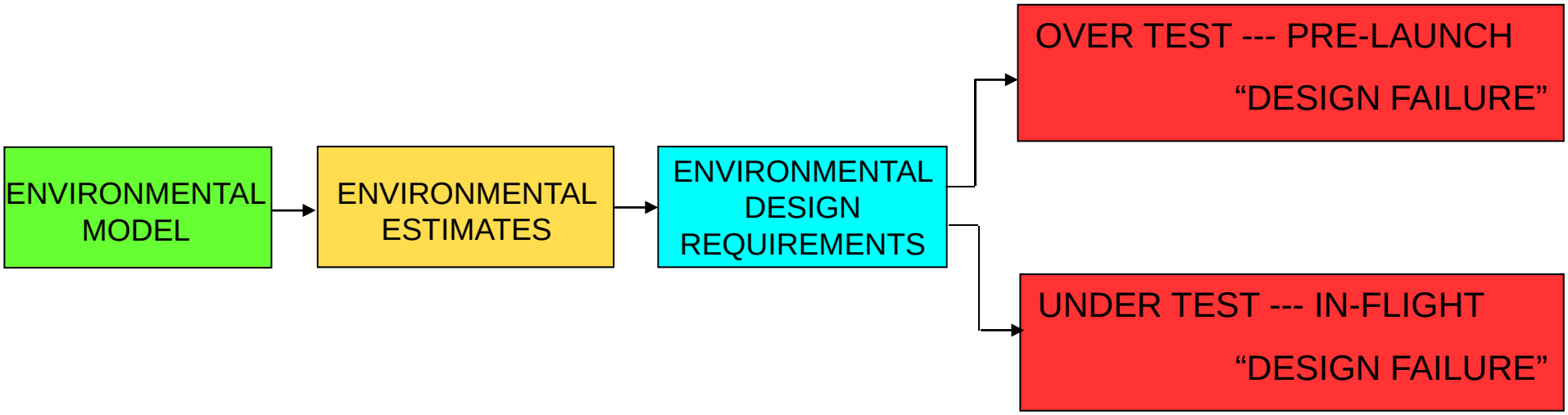
Impact Of Space Environment and Testing On Spacecraft Failures



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Things That Can Go Bump in the Night ...

THE BUMPS:

- MECHANICAL, THERMAL, OPTICAL
- RADIATION
- SURFACE CHARGING
- INTERNAL CHARGING
- CONTAMINATION
- METEOROIDS AND DEBRIS

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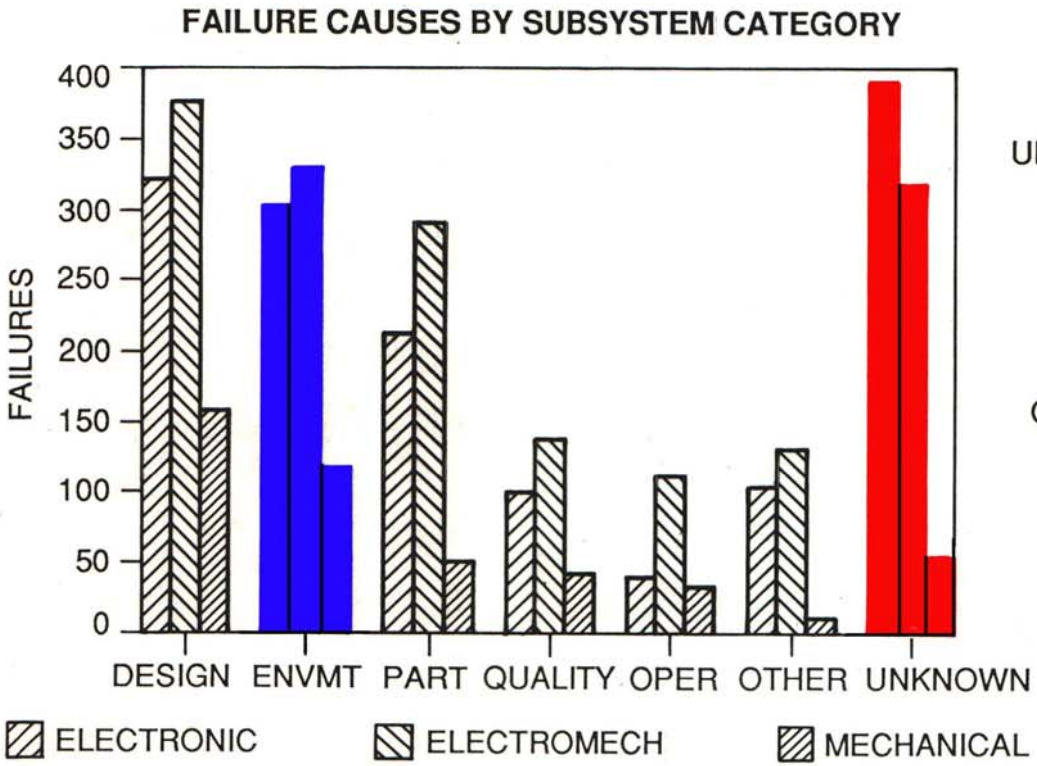
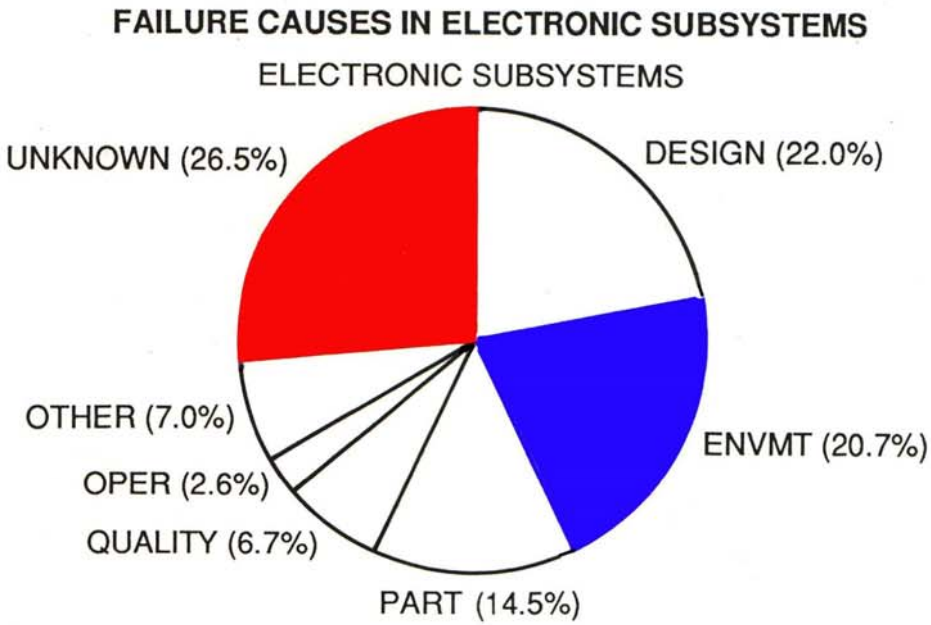
Subsystem In-flight Failure Causes (Hecht, 1985)





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Impact of the Space Environment on Space Systems[+]

Distribution by Anomaly Diagnosis

Diagnosis	Number of Forms
ESD - Internal Charging	74
ESD - Surface Charging	59
ESD - Uncategorized	28
Surface Charging	1
Total ESD & Charging	**162**
SEU - Cosmic Ray	15
SEU - Solar Particle Event	9
SEU - South Atlantic Anomaly	20
SEU - Uncategorized	41
Total SEU	**85**
Solar Array - Solar Proton Event	9
Total Radiation Dose	3
Materials Damage	3
South Atlantic Anomaly	1
Total Radiation Damage	**16**
Micrometeorid/Debris Impact	10
Solar Proton Event - Uncategorized	9
Magnetic Field Variability	5
Plasma Effects	4
Atomic Oxygen Erosion	1
Atmospheric Drag	1
Sunlight	1
IR background	1
Ionospheric Scintillation	1
Energetic Electrons	1
Other	2
Total Miscellaneous	**36**

[+]Koons, H.C., J. E. Mazur, R. S. Selesnick, J. B. Blake, J. F. Fennell, J. L. Roeder, and P. C. Anderson, "The Impact of the Space Environment on Space Systems", presented at Charging Conference, Nov 1998.

Missions Lost/Terminated Due to Space Environment

Vehicle	Date	Diagnosis
DSCS II (9431)	Feb 73	Surface ESD
GOES 4	Nov 82	Surface ESD
DSP Flight 7	Jan 83	Surface ESD
Feng Yun 1	Jun 88	ESD
MARECS A	Mar 91	Surface ESD
MSTI	Jan 93	Single Event Effect
Hipparcos*	Aug 93	Total Radiation Dose
Olympus	Aug 93	Micrometeoroid Impact
SEDS 2*	Mar 94	Micrometeoroid Impact
MSTI 2	Mar 94	Micrometeoroid Impact
IRON 9906	1997	Single Event Effect
INSAT 2D	Oct 97	Surface ESD

*Mission had been completed prior to termination

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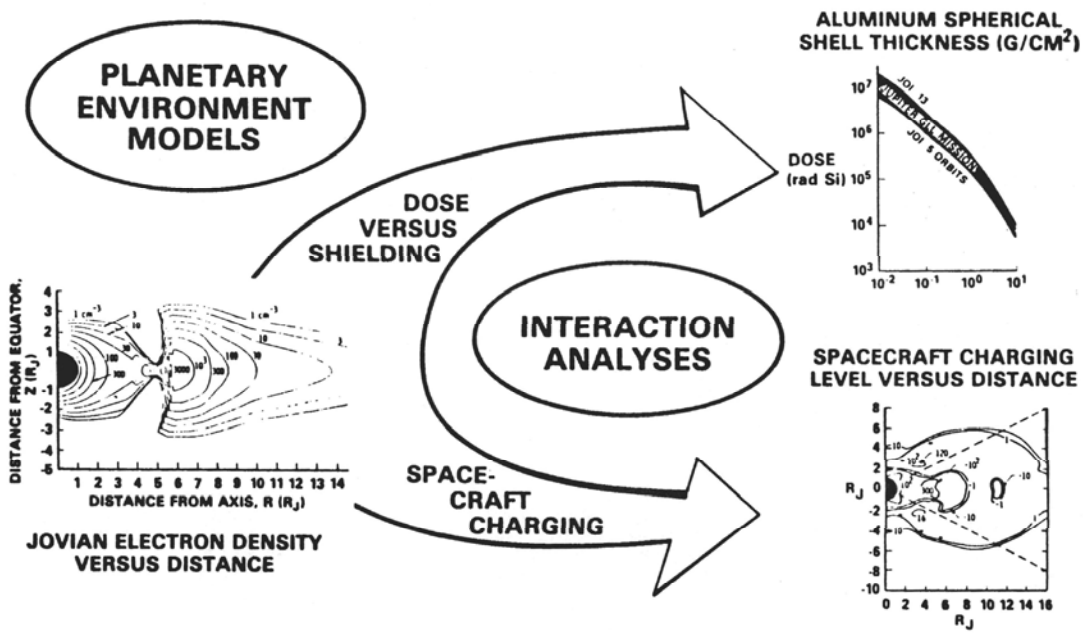
Environmental Requirements Procedural Flow

- THE FIRST STEP IS TO DEFINE THE ENVIRONMENT(S) THAT THE SPACECRAFT CAN BE EXPECTED TO ENCOUNTER.
- STEP TWO IS TO ANALYZE POTENTIAL ENVIRONMENTAL INTERACTIONS THAT COULD BE OF CONCERN
- THE THIRD STEP IS TO CARRY OUT APPROPRIATE STEPS TO MITIGATE THE ADVERSE INTERACTIONS
- THE SPACECRAFT DESIGN IS EVALUATED THROUGH TESTING TO VERIFY THAT IT CAN FUNCTION UNDER THE PRESCRIBED RANGE OF ENVIRONMENTAL CONDITIONS
- IN-FLIGHT DATA FROM THE ACTUAL SPACECRAFT IS ANALYZED TO DETERMINE HOW WELL THE DESIGN METHODS WORKED
- FINALLY, THE INFORMATION LEARNED FROM THE FLIGHT IS USED TO UPDATE AND DEVELOP BETTER MODELS FOR FUTURE DESIGNERS



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Integrated Approach to Mission Design

KEY ENVIRONMENTS VERSUS INTERACTIONS

ENVIRONMENTS \ INTERACTIONS	TOTAL IONIZING DOSE	SINGLE EVENT UPSETS	LATCH-UP	SURFACE CHARGING	INTERNAL CHARGING	PLASMA WAKE/SHEATH	POWER LOSS	VxB	SURFACE DAMAGE	CONTAMINATION	GLOW	PARTICLE IMPACTS	TORQUES	THERMAL
NEUTRAL ATMOSPHERE									**X**	x	**X**		**X**	x
E,B FIELDS				x		x	x	**X**					**X**	
EM FIELDS						x								**X**
SOLAR WIND PLASMA				x									**X**	
IONOSPHERE PLASMA				x		**X**	**X**	x						
AURORA PLASMA				**X**										
TRAPPED RADIATION	**X**	**X**	x		**X**		**X**							
GALACTIC COSMIC RAYS		**X**	x											
SOLAR PROTON EVENTS	**X**	**X**	**X**				x							
METEOROIDS							x					**X**	**X**	
DEBRIS							x					**X**	**X**	

*Legend: **X** = Major Effect x = Observable Effectx = Minor Effect

(Note: assessment very dependent on spacecraft design)

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Integrated Approach to Mission Design

DESIGN OPTIONS VERSUS INTERACTIONS

INTERACTIONS

DESIGN OPTIONS	TOTAL IONIZING DOSE	SINGLE EVENT UPSETS	LATCH-UP	SURFACE CHARGING	INTERNAL CHARGING	PLASMA WAKE/SHEATH	POWER LOSS	VxB	SURFACE DAMAGE	CONTAMINATION	GLOW	PARTICLE IMPACTS	TORQUES	THERMAL
SHIELDING	**X**	**X**	x	**X**	**X**		**X**			**X**		**X**		**X**
POSITIONING	**X**	x	x	**X**	x	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
MATERIAL PROPERTIES				**X**	**X**	x	**X**		**X**	**X**			**X**	**X**
EDAC SOFTWARE	x	**X**	**X**	x	x									
REDUNDANCY	x	**X**	**X**									x		
CIRCUIT DESIGN	**X**	**X**	**X**	**X**	**X**	x	**X**	x						x
MARGIN/HARDNESS	**X**	**X**	**X**	x	x				x			**X**		**X**
GROUNDING				**X**	**X**			**X**		x				
TRAJECTORY	**X**	x	x	**X**	**X**	x	x	**X**	**X**		**X**	**X**	**X**	x
OPERATIONAL PROCEDURES	x	x	x	x	x					x	**X**		**X**	
CONSTRUCTIONS METHODS				**X**	**X**	x	x		x	**X**	x			

*Legend: **X** = Major Effect x = Observable Effectx = Minor Effect

(Note: Assessment very dependent on spacecraft design)

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Integrated Approach to Mission Design

DESIGN OPTIONS VERSUS MISSION DESIGN FACTORS

DESIGN OPTIONS	FACTORS: COST	WEIGHT	POWER	COMPLEXITY	RELIABILITY	AVAILABILITY	USABILITY	SPECIAL ISSUES
SHIELDING	**X**	**X**	x	**X**	x		**X**	**X**
POSITIONING	x	x	x	**X**	x	x	**X**	**X**
MATERIAL PROPERTIES	**X**	x		**X**	x		x	**X**
EDAC SOFTWARE	**X**			**X**	**X**	x	**X**	
REDUNDANCY	**X**	**X**		**X**	**X**	x	x	
CIRCUIT DESIGN	x	x	**X**	**X**	x	**X**	x	**X**
MARGIN/HARDNESS	**X**		x	x	**X**	**X**	**X**	x
GROUNDING	x		x	x	x			**X**
TRAJECTORY	**X**		x	x	x	x		**X**
OPERATIONAL PROCEDURES	x		x	x	x	**X**	x	x
CONSTRUCTION METHODS	x	x	x	x	x			**X**

*Legend: **X** = Major Effect x = Observable Effectx = Minor Effect

(Note: Assessment very dependent on spacecraft design)

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Radiation Definitions

FUNDAMENTAL UNITS OF ENERGY:

- ERG: (CGS SYSTEM) 1 ERG = 1 G-CM^{2}-S^{-2}
- JOULE: (MKS SYSTEM) 1 J = 1 KG-M^{2}-S^{-2}
- ELECTRON VOLT (EV) 1 EV = 1.602 x 10^{-12} ERG = 1.602 x 10^{-19} J

FUNDAMENTAL UNITS OF ENERGY ABSORPTION (DOSAGE):

- RADS*: (CGS SYSTEM) 1 RAD (SI) =100 ERG/G (SI)
- GRAY.: (MKS SYSTEM) 1 GY (GRAY) = 1 JOULE/KG
  1 GY = 100 RAD = 10^{4} ERG/G

FUNDAMENTAL UNIT OF INTENSITY OR FLUX:

- FLUX: NUMBER PER UNIT TIME OF ENERGY E PER UNIT ENERGY INTERVAL dE IN SOLID ANGLE ($d\Omega = \cos\theta\, d\theta\, d\phi$) IN DIRECTION θ, ϕ INCIDENT ON UNIT SURFACE AREA (dA) PERPENDICULAR TO DIRECTION OF OBSERVATION.

- PROTONS OR ELECTRONS: PARTICLES-CM^{-2}-S^{-1}-SR^{-1}-KEV^{-1}
- HEAVY IONS: PARTICLES-M^{-2}-S^{-1}-SR^{-1}-MEV^{-1}-μ^{-1}
  (μ ="NUCLEON")

RAD: "RADIATION ABSORBED DOSE"

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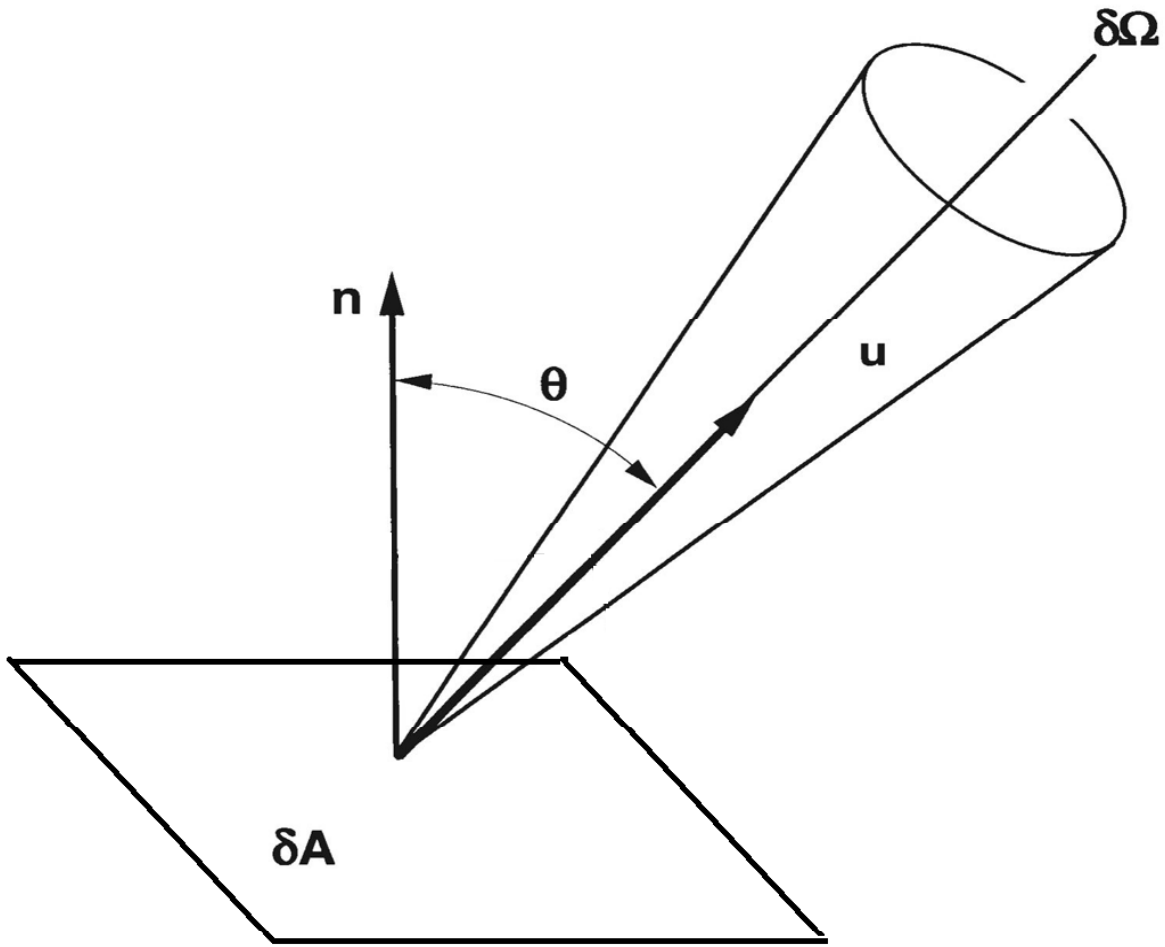
Definition of Angular Coordinates Relative to a Surface



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Key Plasma Parameters

THE MAXWELL-BOLTZMANN PLASMA DISTRIBUTION FUNCTION

$$F(v) = n\left(\frac{m}{2\pi KT}\right)^{3/2} e^{\left(\frac{-mv^2}{2KT}\right)}$$

MOMENTS OF THE PLASMA DISTRIBUTION FUNCTION

NUMBER DENSITY: $$\langle ND \rangle = 4\pi \int_o^\infty \left(v^0\right) F v^2 dv = n$$

NUMBER FLUX: $$\langle NF \rangle = \int_o^\infty \left(v^1\right) F v^2 dv = \left(\frac{n}{2\pi}\right)\left(\frac{2KT}{\pi m}\right)^{1/2}$$

ENERGY DENSITY: $$\langle ED \rangle = \frac{4\pi m}{2} \int_o^\infty \left(v^2\right) F v^2 dv = \frac{3}{2} nKT$$

ENERGY FLUX: $$\langle EF \rangle = \frac{m}{2} \int_o^\infty \left(v^3\right) F v^2 dv = \left(\frac{nm}{2}\right)\left(\frac{2KT}{\pi m}\right)^{3/2}$$

DEFINITIONS OF PLASMA "TEMPERATURE"

$$KT(AVG) = \frac{2}{3}\frac{\langle ED \rangle}{\langle ND \rangle} \qquad KT(RMS) = \frac{1}{2}\frac{\langle EF \rangle}{\langle NF \rangle}$$

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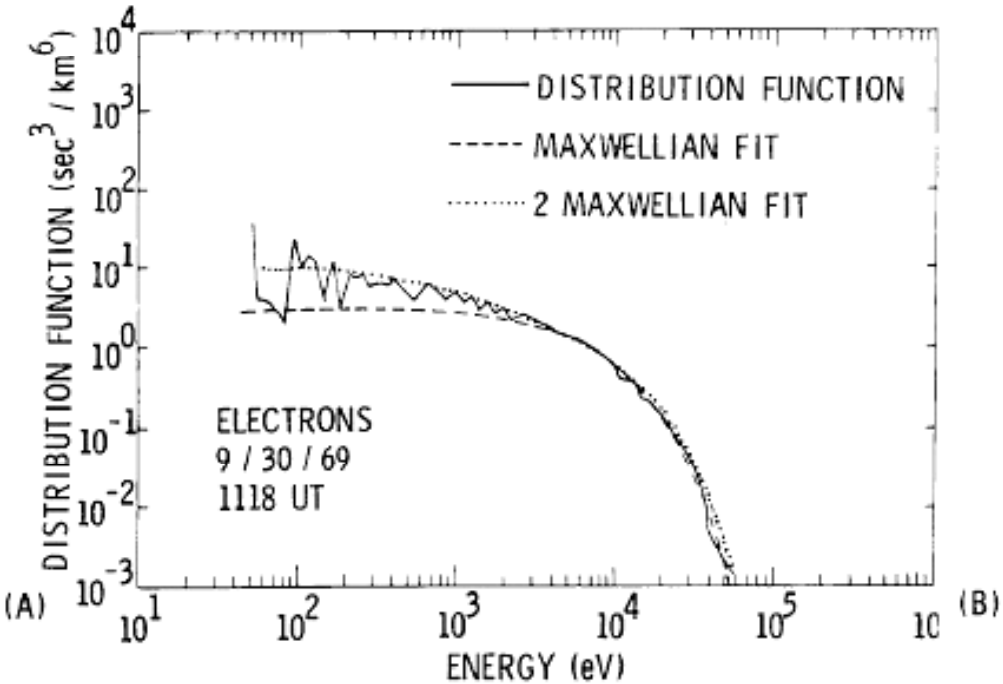
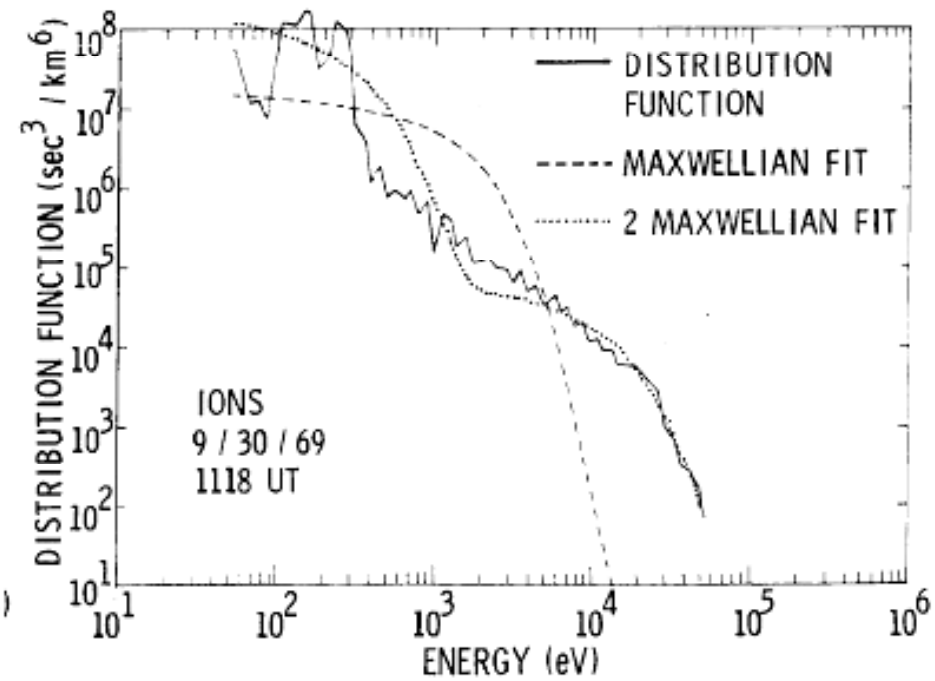
Electron And Proton Plasma Distribution Functions





ELECTRON DISTRIBUTION **PROTON DISTRIBUTION**

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