The Physics of Space Plasmas

The Space Age
and
Tools of the Trade

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12 September 2012
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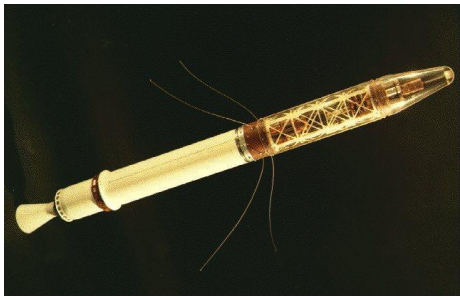
The Space Age

Open Skies and SPUTNIK:

- The 1950s were a critical period in the "cold war"
- 1953 Nikita Khrushchev and Dwight Eisenhower came to power at nearly the same time
- 1955 Eisenhower proposed "Open Skies" ➔Khrushchev rejects: correlation of forces
- 1957 Soviet scientists boast that they will put a satellite in orbit during IGY
- 1956 --1957 Eisenhower rejects von Braun's request to beat the Soviets into space
- 1957 Launch of SPUTNIK
- 1958 NASA stand up as civilian space agency
- 1960 Gary Powers/U2 incident.
- 1963 Nuclear Test Ban Treaty
- 1972 ABM treaty and non-interference with national means of verification

The NASA Explorer Series



1: Explorer 1: January 31, 1958
Energetic particle studies, discovered Van Allen radiation belt
2: Explorer 2: March 5, 1958
Failed to achieve orbit
3: Explorer 3 (Gamma 1): March 26, 1958
Energetic particle studies
4: Explorer 4: July 26, 1958
nuclear test studies
5: Explorer 5: August 24, 1958
Failed to achieve orbit
6: Explorer 6 (S-2 (Able 3)): August 7, 1959
Magnetosphere research
7: Explorer 7 (S 1A): October 13, 1959
Energetic particle studies
8: Explorer 8 (S 30): November 3, 1960
Measured atmospheric composition of the ionosphere
9: Explorer 9 (S 56A): February 16, 1961
Atmospheric density measurements
10: Explorer 10: March 25, 1961
Investigated magnetic field between the Earth and Moon

The NASA Explorer Series

11: Explorer 11 (S 15): April 27, 1961
Gamma ray astronomy
12: EPE-A (S 3, Energetic Particle Explorer-A): August 16, 1961
Energetic particle research
13: S 55A: August 25, 1961
Micrometeoroid research
14: EPE-B (Energetic Particle Explorer-B): October 2, 1962
Energetic particle research
15: EPE-C (Energetic Particle Explorer-C): October 27, 1962
Energetic particle research
16: S-55B: December 16, 1962
Micrometeoroid research
17: AE-A (Atmosphere Explorer-A): April 3, 1963
Atmospheric research
18: IMP-A (IMP 1, Interplanetary Monitoring Platform-A): November 27, 1963
Magnetospheric research
19: AD-A (Atmospheric Density-A): December 19, 1963
Atmospheric density measurements
20: IE-A (S 48, TOPSI, Ionosphere Explorer-A): August 25, 1964
Micrometeor research

The NASA Explorer Series

21: IMP-B (IMP 2, Interplanetary Monitoring Platform-B): October 4, 1964
Magnetospheric research
22: BE-B (S 66, Beacon Explorer-B): October 10, 1964
Ionospheric and geodetic research
23: S 55C (Explorer 23): November 6, 1964
24: AD-B (Atmospheric Density-B): November 21, 1964
Atmospheric density measurements
25: Injun 4 (IE-B, Ionosphere Explorer-B): November 21, 1964
Ionospheric research (magnetically stabilized s/c)
26: EPE-D (Energetic Particle Explorer-D): December 21, 1964
High energy particle observations
27: BE-C (Beacon Explorer-C): April 29, 1965
Magnetospheric research
28: IMP-C (IMP 3, Interplanetary Monitoring Platform-C): May 29, 1965
Magnetospheric research
29: GEOS 1 (GEOS-A): November 6, 1965
Geodetic earth monitoring
30: SOLRAD 8 (SE-A): November 19, 1965
Solar radiation monitoring

The NASA Explorer Series

31: DME A: November 29, 1965
Ionospheric research
32: AE-B (Atmosphere Explorer-B): May 25, 1966
Atmospheric research
33: IMP-D, Interplanetary Monitoring Platform-D): July 1, 1966
Magnetospheric research
34: IMP-F (IMP 4, Interplanetary Monitoring Platform-F): May 24, 1967
Magnetospheric research
35: IMP-E (Interplanetary Monitoring Platform-E): July 19, 1967
Magnetospheric research
36: GEOS 2 (GEOS-B): January 11, 1968
Geodetic earth monitoring
37: Solrad 9 (SE B): March 5, 1968
Solar radiation monitoring (Cover for covert ELINT mission)
38: RAE-A (RAE 1, Radio Astronomy Explorer-A): July 4, 1968
Radio astronomy
39: AD-C (Atmospheric Density-C): August 8, 1968
Atmospheric density measurements
40: Injun 5 (Injun C, IE-C, Ionosphere Explorer-C) August 8, 1968
Magnetospheric Research ➔ Inverted V auroral stuctures

The NASA Explorer Series

41: IMP-G (IMP 5, Interplanetary Monitoring Platform-G): June 21, 1969
Magnetospheric research

42: Small Astronomy Satellite-A (SAS 1): December 12, 1970
X-Ray Astronomy

43: IMP-H (IMP 6, Interplanetary Monitoring Platform-H): March 13, 1971

44: Magnetospheric 44: Solrad 10 (SE-C, SOLRAD-C): July 8, 1971
Solar radiation monitoring

45: SSS-A (S-Cubed A): November 15, 1971
Magnetospheric research ➔ plasmapause shape, ring current nose structure

46: Meteoroid Technology Satellite (MTS, METEC): August 13, 1972
Micrometeor research

47: IMP-I (IMP 7, Interplanetary Monitoring Platform-I): September 23, 1972
Magnetospheric research

48: SAS-B (Small Astronomy Satellite-B, SAS 2): November 15, 1972
X-Ray Astronomy

49: RAE-B (RAE 2, Radio Astronomy Explorer-B): June 10, 1973
Radio astronomy

50: IMP J (IMP 8, Interplanetary Monitoring Platform-J): October 26, 1973
Magnetospheric research ➔ Only solar wind / IMF source for decades

The NASA Explorer Series

52: Hawkeye 1, Injun 6 (IE-D, Ionosphere Explorer-D): June 3, 1974
Magnetospheric research

53: SAS-C (Small Astronomy Satellite-C, SAS 3): May 7, 1975
X-Ray Astronomy

51: AE-C (Atmosphere Explorer-C): December 16, 1973
Atmospheric research

54. AE-D (Atmosphere Explorer-D): October 6, 1975
Atmospheric research

55: AE-E (Atmosphere Explorer-E): November 20, 1975
Atmospheric research

57: IUE: January 26, 1978
Ultraviolet astronomy

58: HCMM (AEM-A,, Heat Capacity Mapping Mission): April 26, 1978
Thermal mapping of Earth

56: ISEE 1 & 2 (International Sun-Earth Explorer-A & B): October 22, 1977
Magnetospheric research

59: ISEE 3 (International Sun-Earth Explorer-C, ICE): August 12, 1978
Magnetospheric research First satellite at L_1

The NASA Explorer Series

60: SAGE, Stratospheric Aerosol and Gas Experiment): February 18, 1979
Stratospheric aerosol and ozone data
61 MAGSAT: October 30, 1979
Mapped the near surface magnetic field of the Earth

62: DE 1 (DE-A, Dynamics Explorer-A): August 3, 1981
Magnetospheric research
63: DE 2 (DE-B, Dynamics Explorer-B): August 3, 1981
Magnetospheric research

64: SME (Solar Mesosphere Explorer): October 6, 1981
Atmospheric research
65: AMTPE/CCE (Active Magnetospheric Particle Tracer Explorers/Charge Composition Explorer): August 16, 1984
Magnetospheric research
66: COBE: November 18, 1989
Microwave background astronomy
67: EUVE: June 7, 1992
Ultraviolet astronomy
68: SAMPEX: July 3, 1992
Magnetospheric research

The NASA Explorer Series

69: RXTE: December 30, 1995
X-ray astronomy
70: FAST: August 21, 1996
High altitude auroral phenomena
71: ACE: August 25, 1997
Solar/interplanetary/interstellar particle research from L1 orbit
72: SNOE: February 26, 1998
Atmospheric research
73: TRACE: April 2, 1998
Solar observatory run by U. of Deleware
74: SWAS: December 6, 1998
Submillimeter astronomy
75: WIRE: March 5, 1999
Infrared astronomy, primary mission failed due to loss of coolant
76: TERRIERS: May 18, 1999 (Boston University)
Atmospheric research, satellite failed shortly after achieving orbit
77: FUSE: June 23, 1999
Ultraviolet astronomy

The NASA Explorer Series

78: IMAGE March 25, 2000
Magnetospheric research
79: HETE-2: October 9, 2000
UV, X-Ray, and gamma ray astronomy
80: WMAP: June 30, 2001
Microwave astronomy
81: RHESSI: February 5, 2002
X-ray and gamma ray solar flare imaging
82: CHIPSat: January 13, 2003
Ultraviolet spectroscopy and astronomy
83: GALEX: April 28, 2003
Ultraviolet astronomy
84: SWIFT: November 20, 2004
Gamma ray astronomy

The NASA Explorer Series

85: THEMIS A: February 17, 2007
Magnetospheric research
86: THEMIS B (ARTEMIS P1): February 17, 2007
Magnetospheric research
87: THEMIS C (ARTEMIS P2): February 17, 2007
Magnetospheric research
88: THEMIS D: February 17, 2007
Magnetospheric research
89: THEMIS E: February 17, 2007
Magnetospheric research

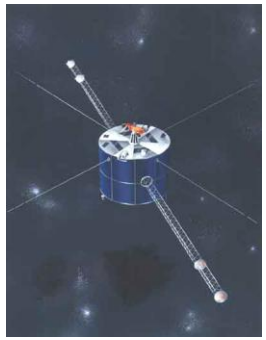
David Stern's
"Profile Mission"

90: AIM: April 25, 2007
Noctilucent cloud observation
91: IBEX: October 19, 2008
Mapping the boundary between the Solar System and interstellar space.
92: WISE: December 14, 2009
Infrared astronomy
93 NuSTAR: June 13, 2012
High-energy X-ray astronomy

Other NASA Missions

- Voyager 1: September 5, 1967: Interplanetary & heliospheric exploration
- Voyager 2: October 20, 1967: Interplanetary & heliospheric exploration

- Mariner 2: August 27, 1962: Venus flyby
- Mariner 4: November 28, 1964: Mars flyby
- Mariner 5: June 14, 1967: Venus probe
- Mariner 6: February 24, 1967: Mars probe
- Mariner 7: March 21, 1967: Mars probe
- Mariner 9: November 30, 1971: Mars orbiter

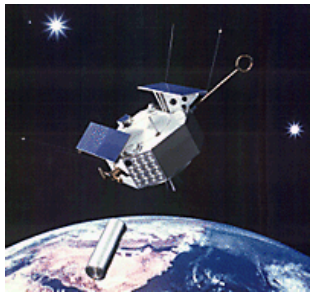


Geotail

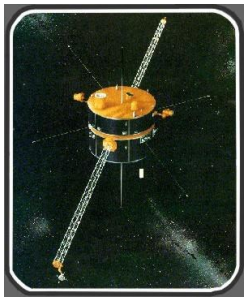
- Apollo 14: February 5, 1971: CPLEE and SIDE
- Apollo 15: August 1, 1971: SIDE
- Apollo 16: April 21, 1972: SIDE ==> Rice University

ISTP Project

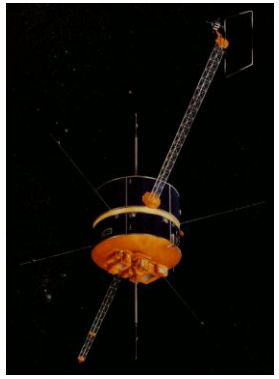
- CRRES: (USAF) July 25, 1991
- Geotail: July 24, 1992 (ISAS)
- Wind: November 1, 1994
- Polar: February24, 1996



CRRES



Wind



Polar

DoD Space Missions

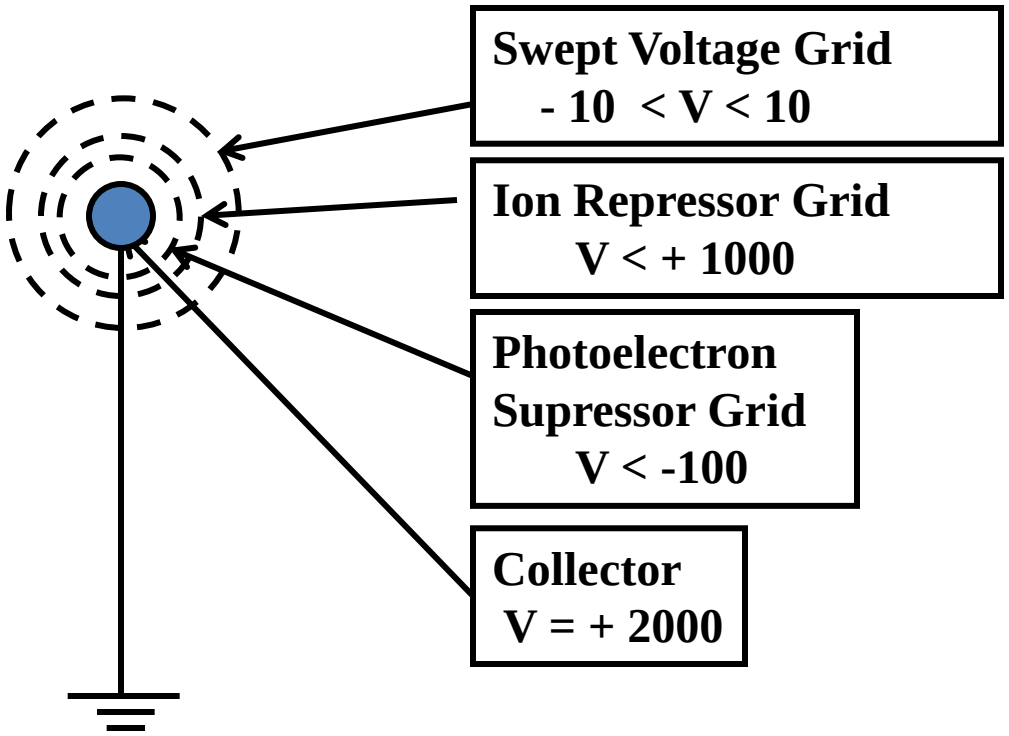
DoD Satellites:

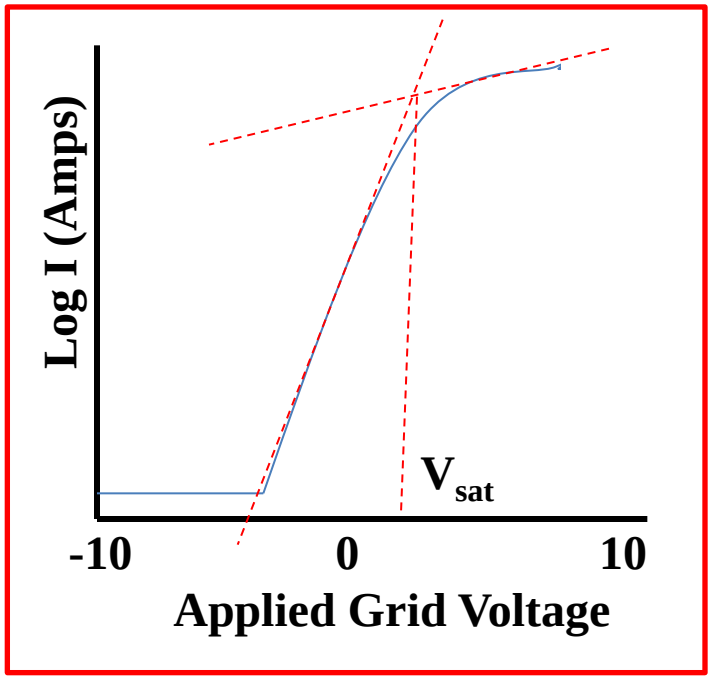
- **TRIAD: September 3 1972; ➔Systematics of Birkeland currents**
- **VELA: 1963 – 1984: Monitors for Nuclear Test Ban treaty**
- **S3-2: December 1975: Ionospheric plasma, electric and magnetic fields**
- **S3-3: July 1976: Energetic particles and electric fields at high altitudes**
- **LANL: Monitor outer radiation belt and test band treaty compliance**
- **SCATHA: January 30, 1979 spacecraft charging at high altitudes**
- **CRRES: July 25, 1990: Microelectronic vulnerability in radiation environments**

AFRL participated in Tethered Satellite Program to specify charging levels of the Shuttle during STS 1 and STS 1R in 1992 and 1996.

Space Plasma & Field Sensors

Spherical Langmuir Probe
Ionospheric Electrons





$$I(V) = \pi r_g^2 \beta n q c e^{-\frac{qV}{kT}}$$

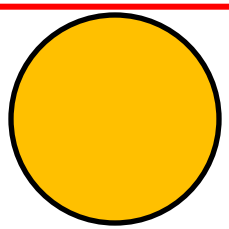
$$c = \sqrt{8kT / \pi m_e}$$

$$T = -\frac{q}{k}\frac{d\ln(-I)}{dV}$$

Mott-Smith, H. M., and I. Langmuir, The theory of collectors in gaseous discharges, *Phys. Rev.*, *28*, 727, 1926.

Space Plasma & Field Sensors

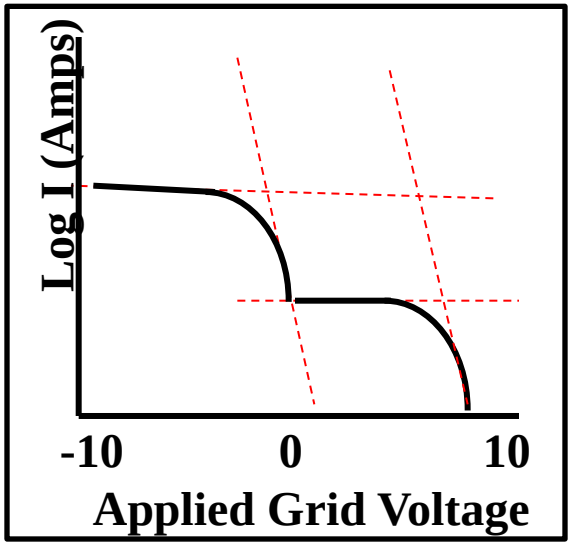
Planar Langmuir Probe
Ionospheric Ions



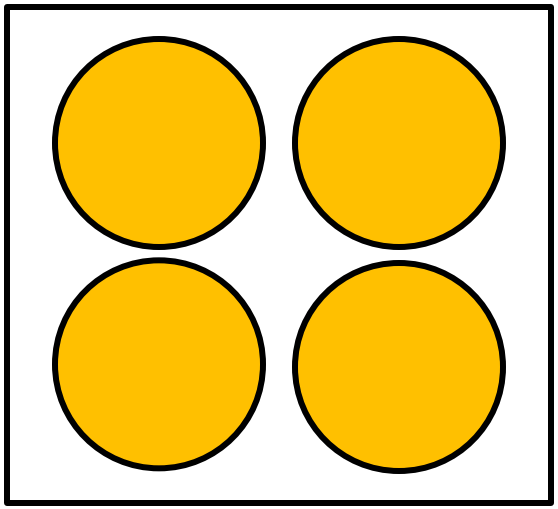
Swept Voltage Grid
- 10 < V < 10

Photoelectron
Supressor Grid
V < -100

Collector
V = + 100



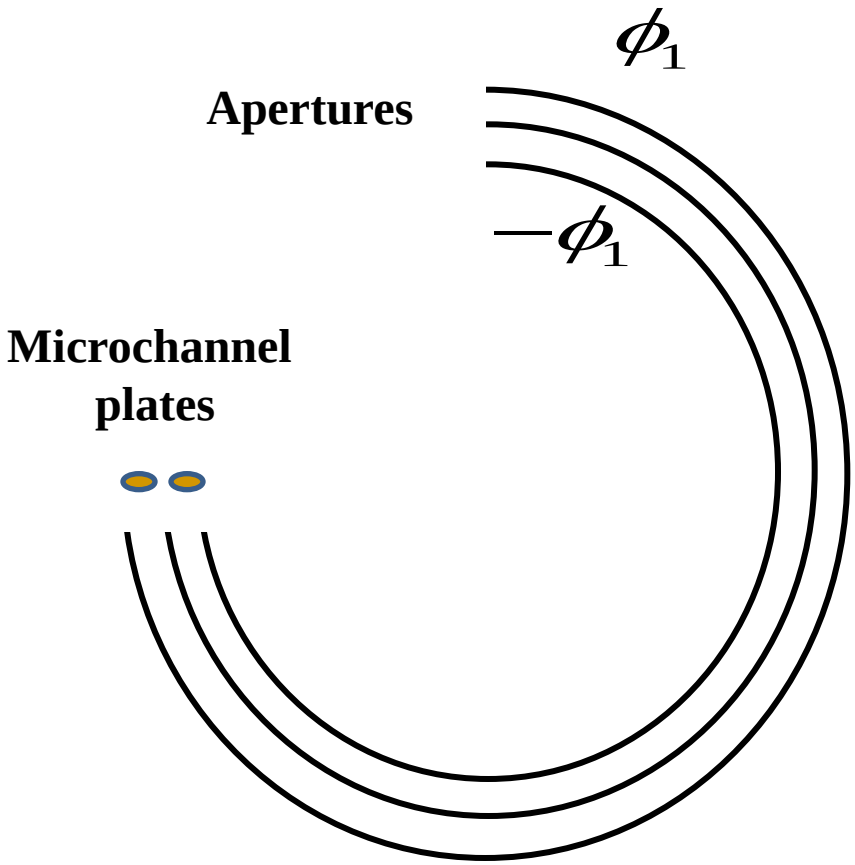
T_i, N_{light}, N_{heavy} Vs, ϕ_{Sat}



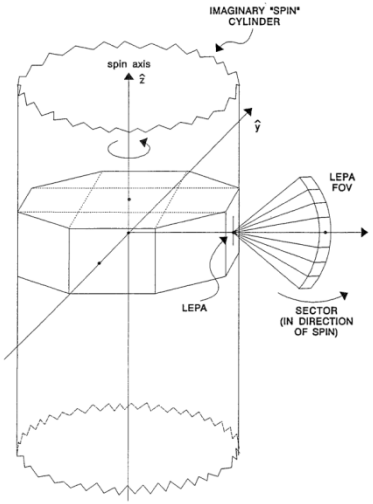
Ion Drift Meter
V_H, V_V

Space Plasma & Field Sensors

Electrostatic Analyzers
Ions & Electrons
30 eV ≤ E ≤ 30 keV



Flown on CRRES, STS 1, 1R and DMSP

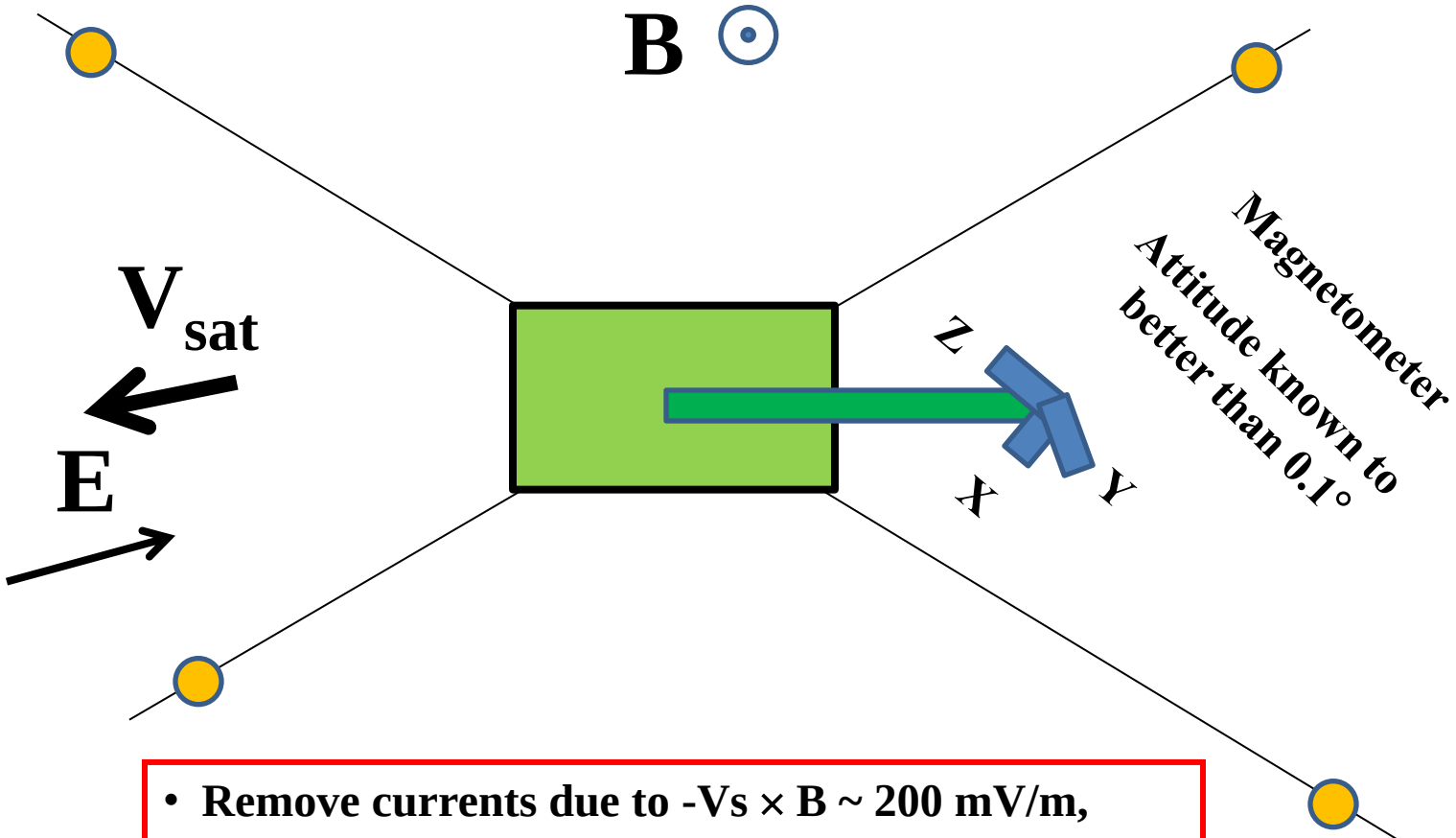


$$j_N(E_i,\Omega) = \frac{Counts_i}{GF \cdot \Delta t \cdot \Delta E} = \frac{Counts_i}{GF \cdot \Delta t \cdot \alpha E_i}$$

$$j_E(E_i,\Omega) = \frac{Counts_i \cdot E_i}{GF \cdot \Delta t \cdot \Delta E} = \frac{Counts}{GF \cdot \Delta t \cdot \alpha}$$

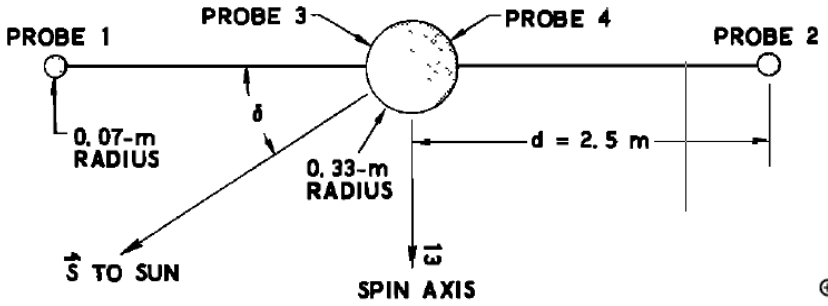
$$\alpha = \Delta E / E_i$$

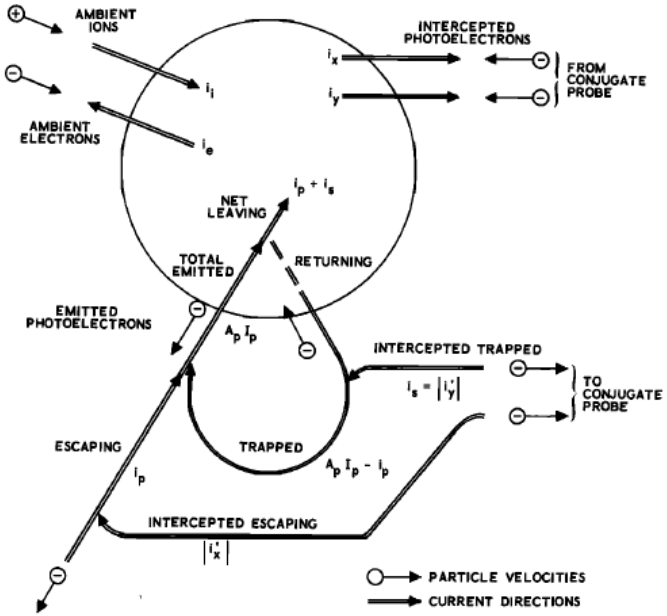
Electric and Magnetic Field Measurements



- Remove currents due to -Vs × B ~ 200 mV/m, photoelectron current, & different work functions
- Voltage drop across ballast resistors
- Difference amplifiers remove vehicle potential

Space Plasma & Field Sensors





Cauffman and Maynard, *JGR, 79*, 2427 – 2438, 1974.