INTERNATIONAL ATOMIC ENERGY AGENCY
UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION
INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
I.C.T.P,P.O. BOX 586,34100 TRIESTE,ITALY,CABLE:CENTRATOM TRIESTE

H4-SMR 1012 - 40

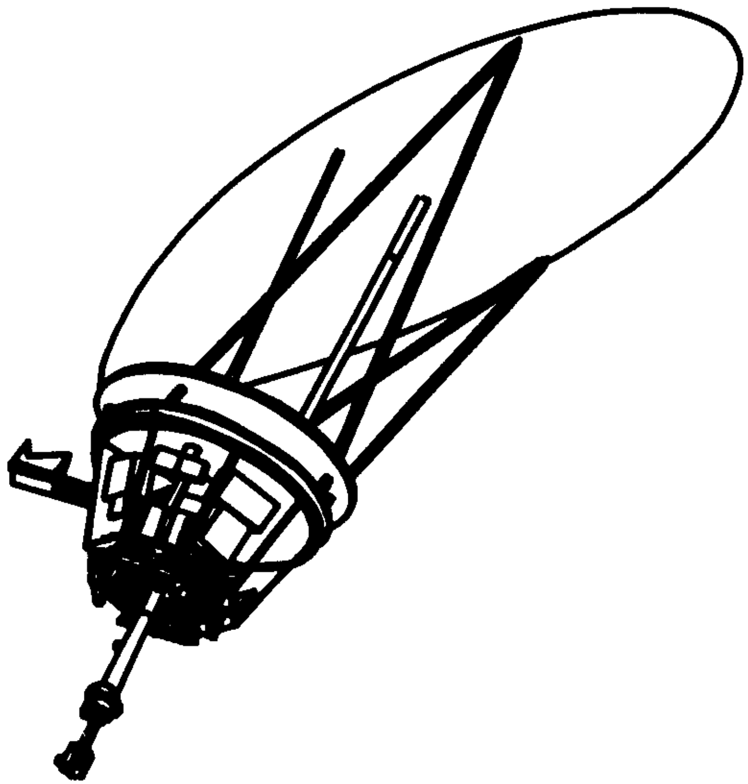
AUTUMN COLLEGE ON PLASMA PHYSICS

13 October - 7 November 1997

SOLAR PROBE CURRENT STATUS

B.T. TSURUTANI

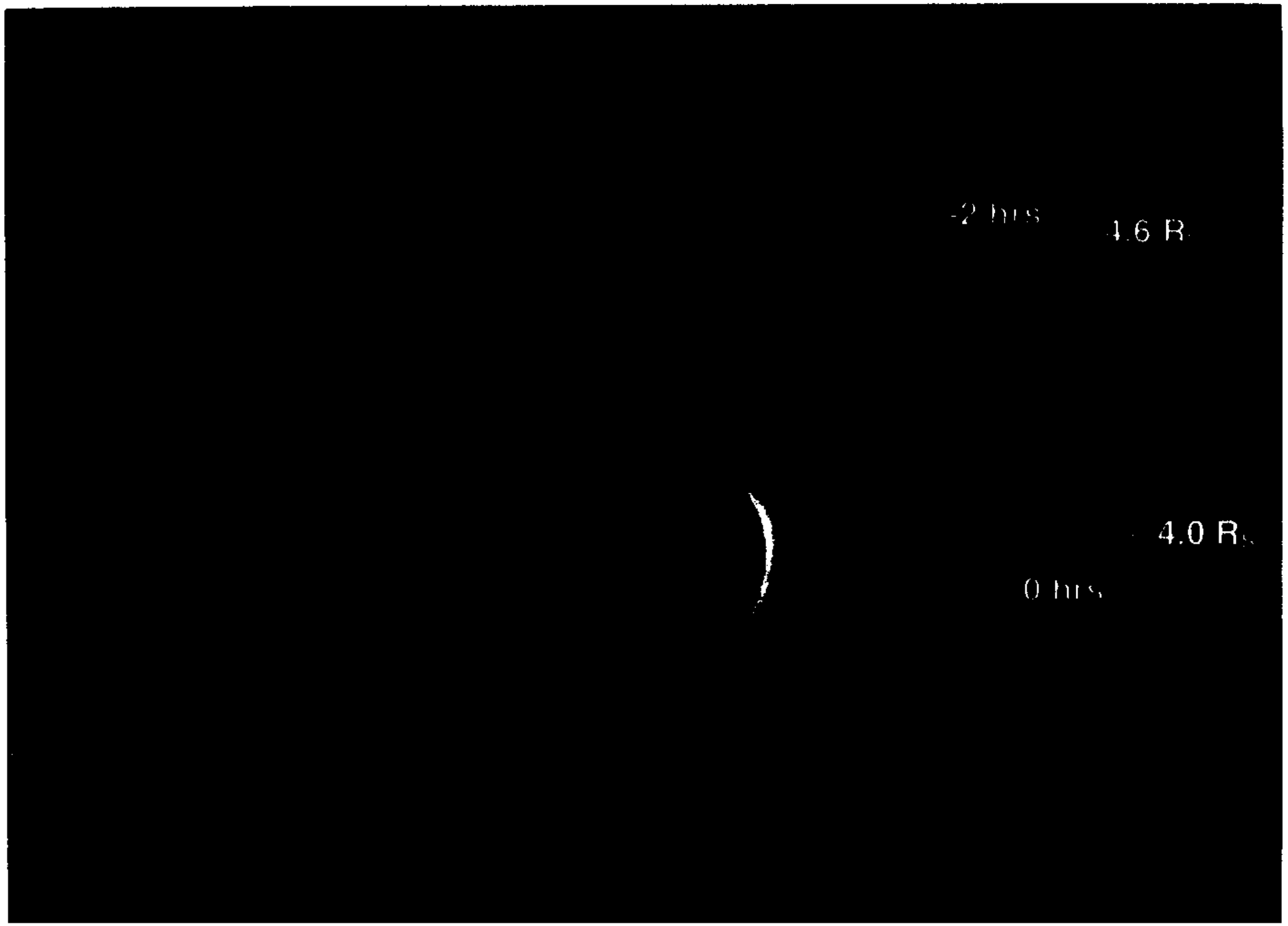
Jet Propulsion Laboratory, California Institute of Technology,
Pasadena, U.S.A.

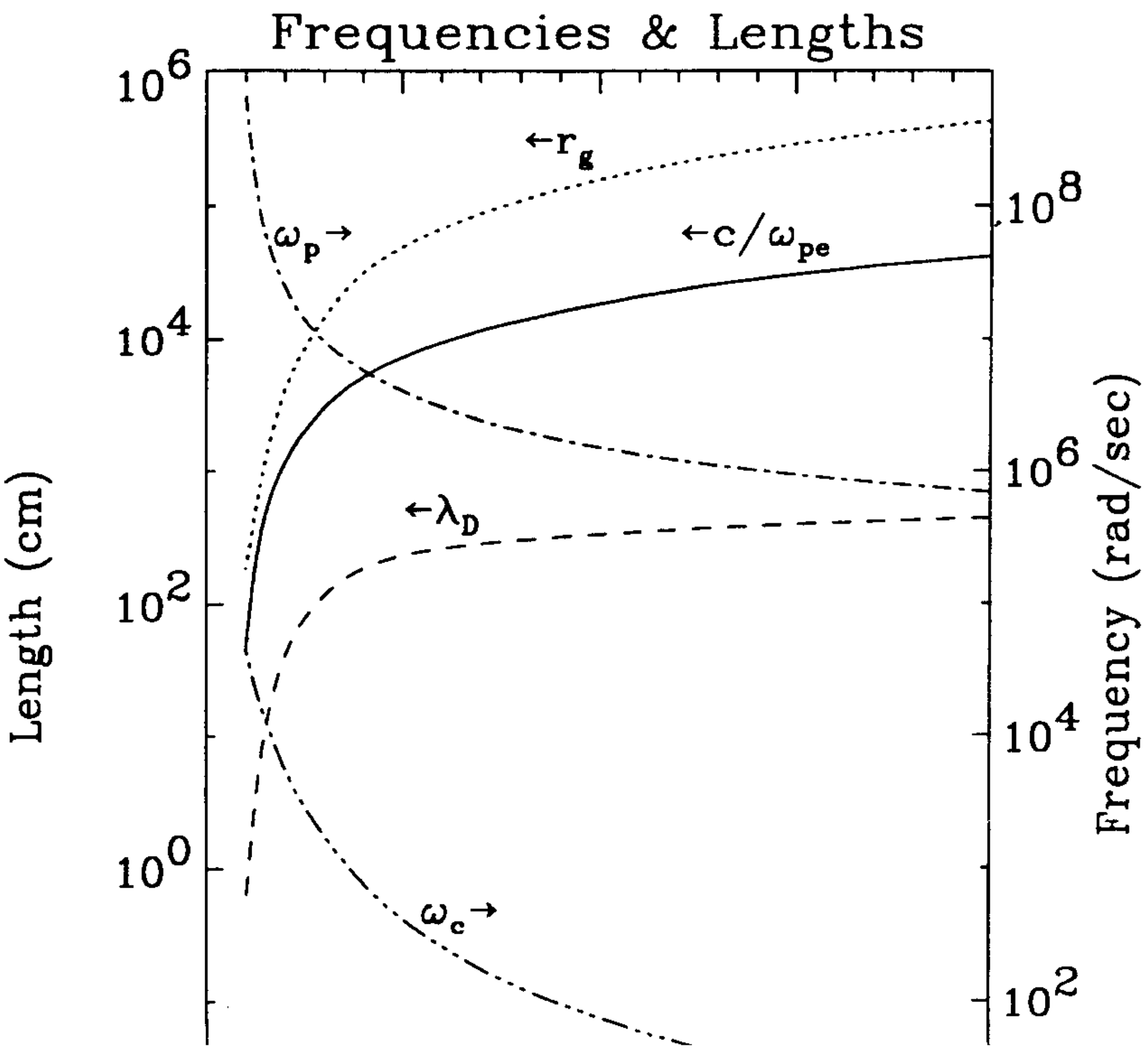


Solar Probe Current Status

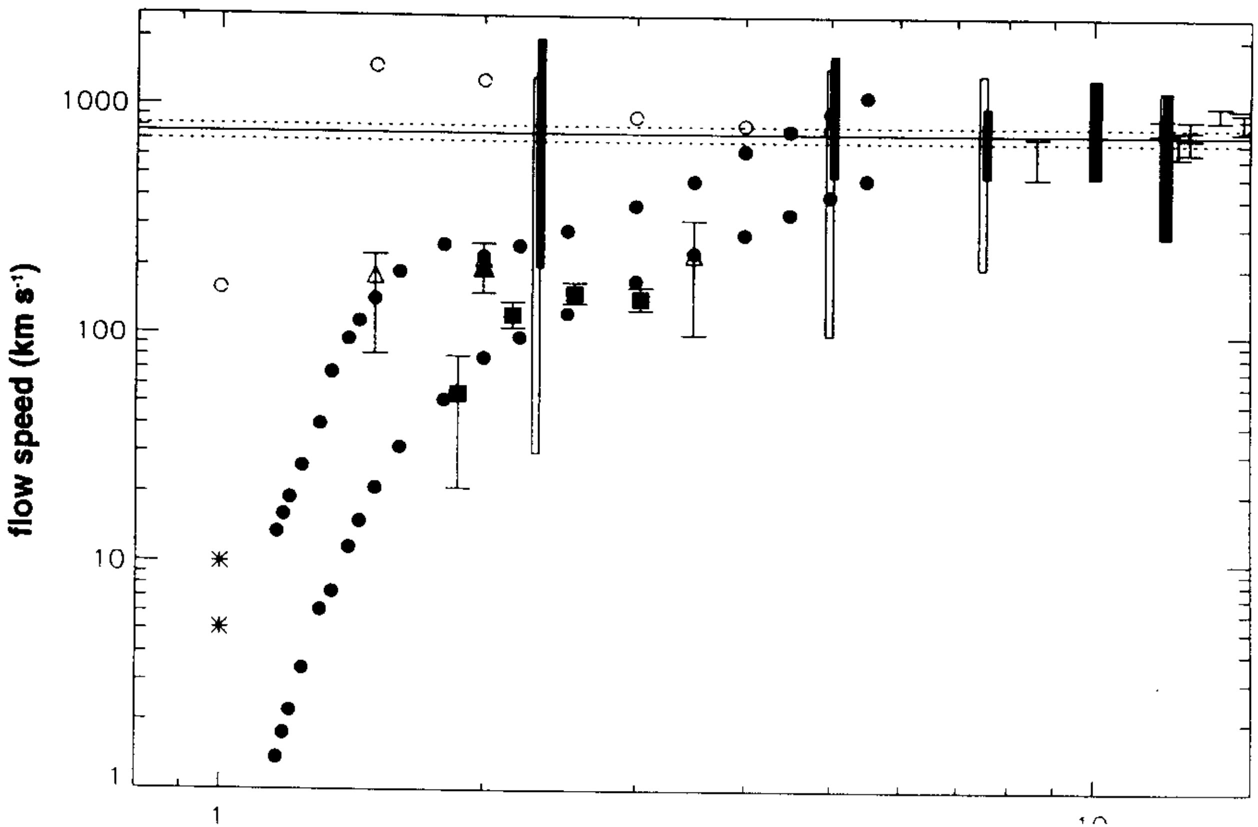
October 1997

Mission to the Sun



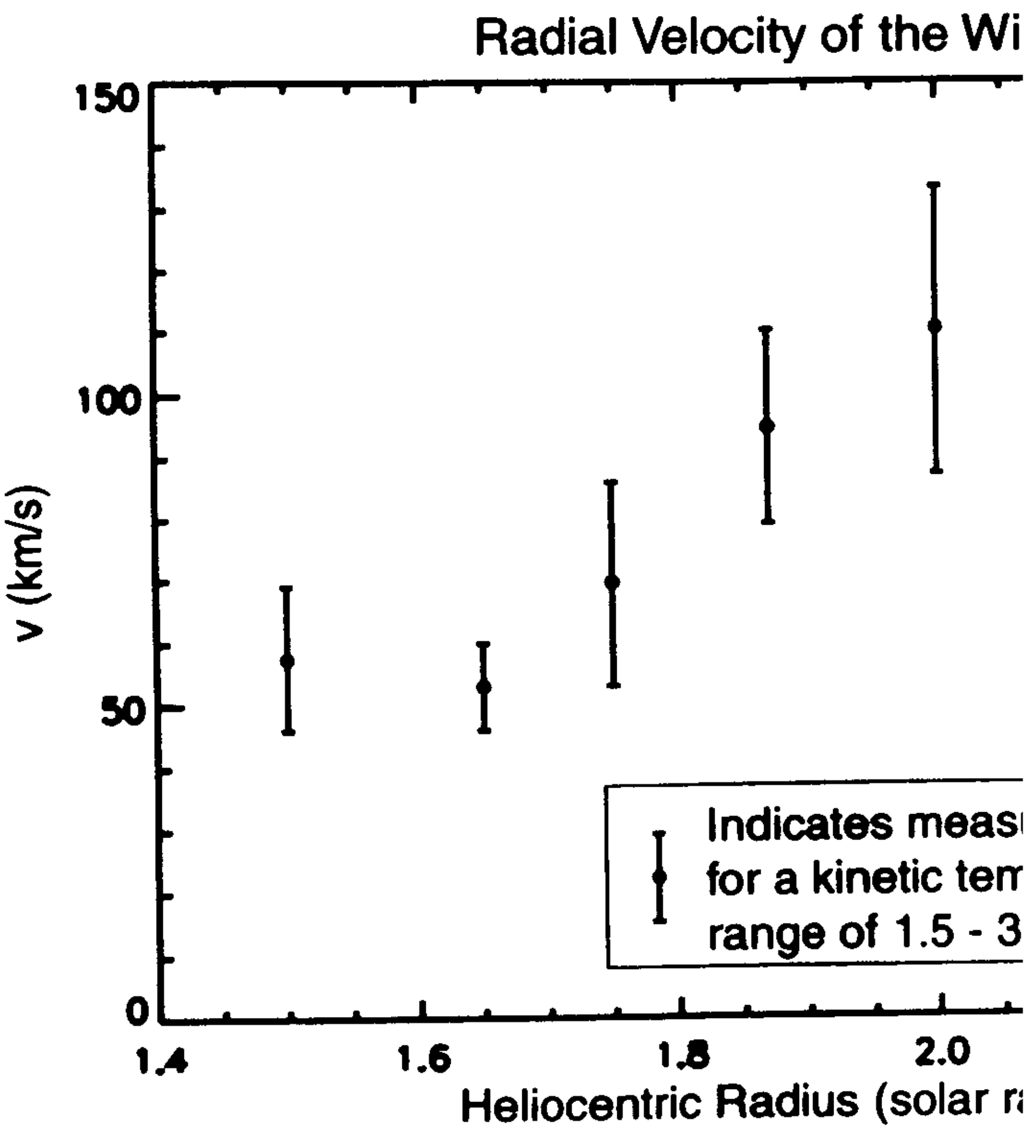


Frequencies & Lengths
Length (cm)
Frequency (rad/sec)
10^6
10^4
10^2
10^0
10^8
10^6
10^4
10^2
$\leftarrow r_g$
$\omega_p \rightarrow$
$\leftarrow c/\omega_{pe}$
$\leftarrow \lambda_D$
$\omega_c \rightarrow$

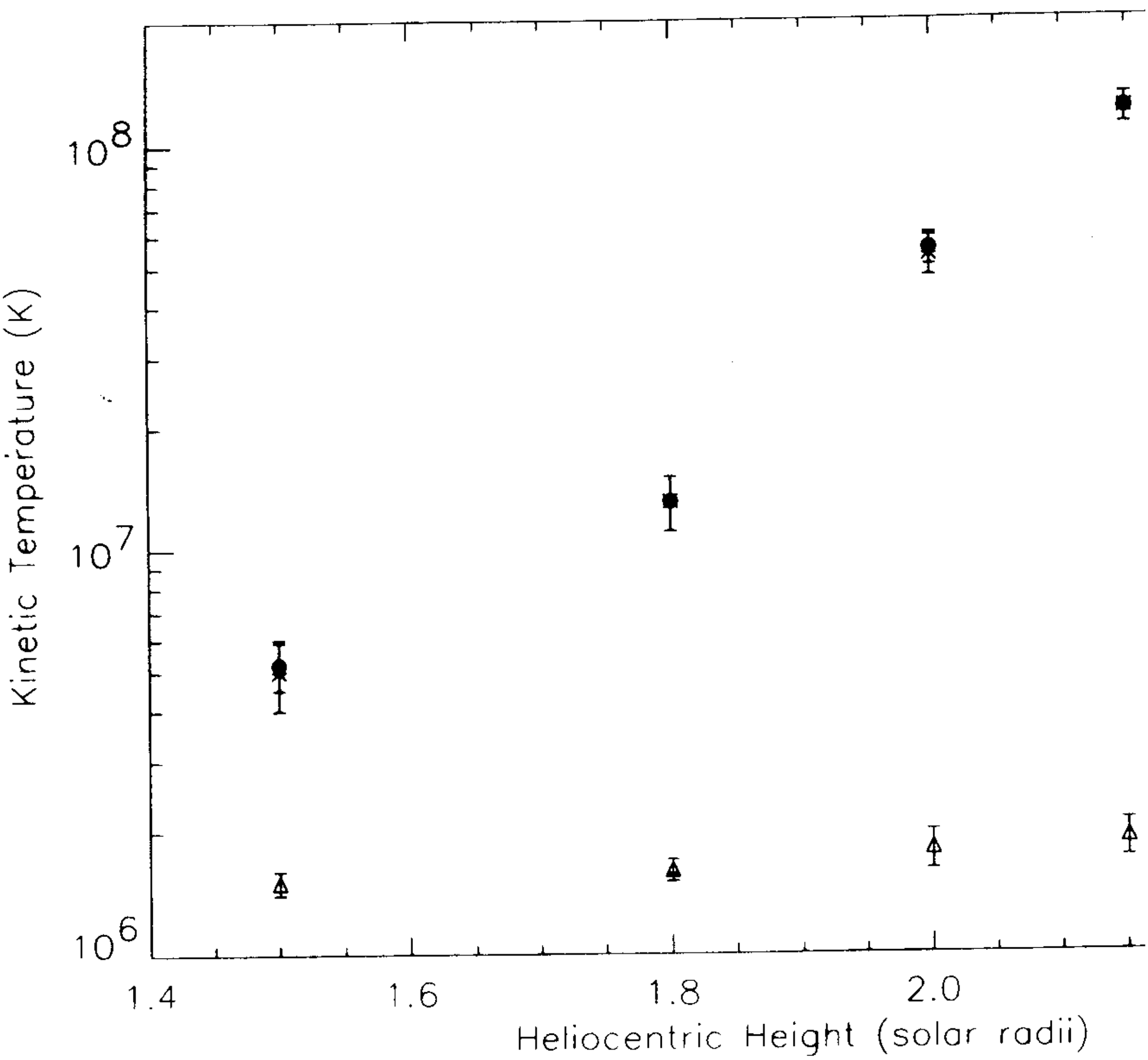


1000
100
10
1
flow speed (km s⁻¹)
1
10

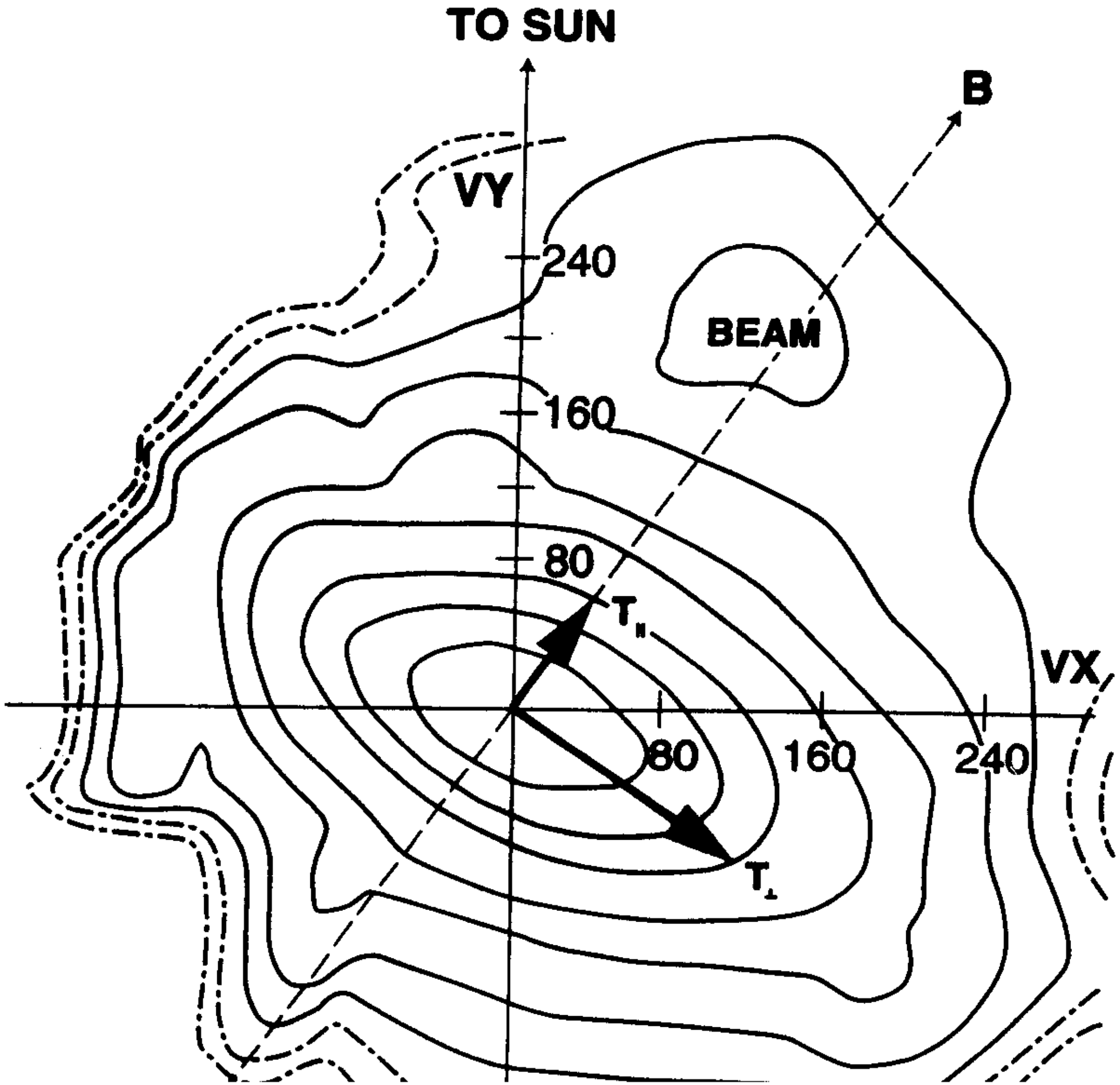
UVCS

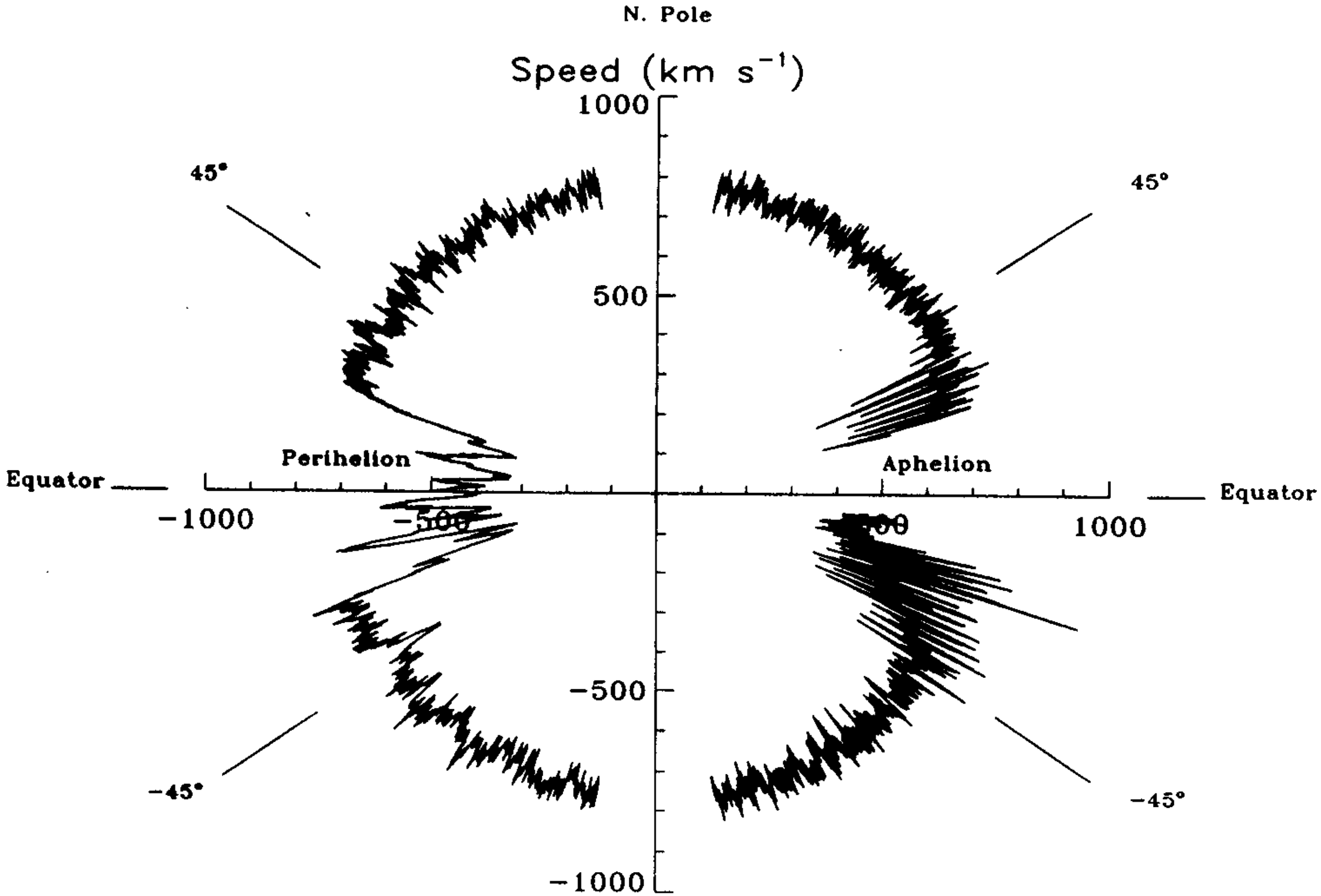


Radial Velocity of the Wi
150
100
50
0
v (km/s)
1.4
1.6
1.8
2.0
Heliocentric Radius (solar ra
Indicates meas
for a kinetic tem
range of 1.5 - 3



Kinetic Temperature (K)
10^8
10^7
10^6
1.4
1.6
1.8
2.0
Heliocentric Height (solar radii)


TO SUN
B
VY
240
160
80
BEAM
T∥
VX
80
160
240
T⊥



N. Pole
Speed (km s⁻¹)
1000
500
-500
-1000
45°
45°
-45°
-45°
Perihelion
Aphelion
Equator
Equator
-1000
-500
500
1000

JPL

PLASMA PARAMETERS

$B \approx 5$ nT

$N \approx 3\text{-}10$ cm^{-3}

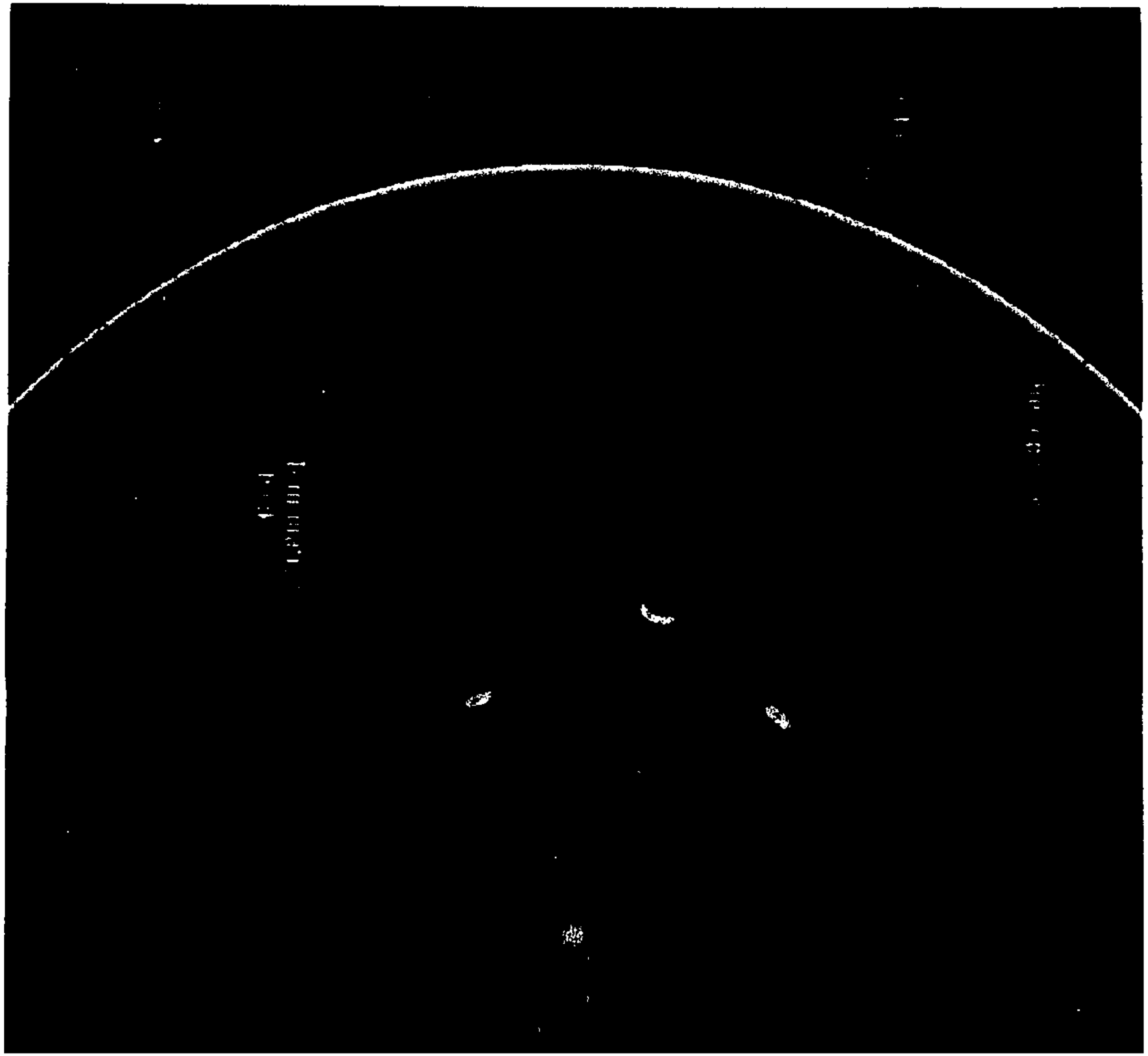
$T_p \approx 8 \times 10^4$ K

$V_{SW} = 400$ km s^{-1}

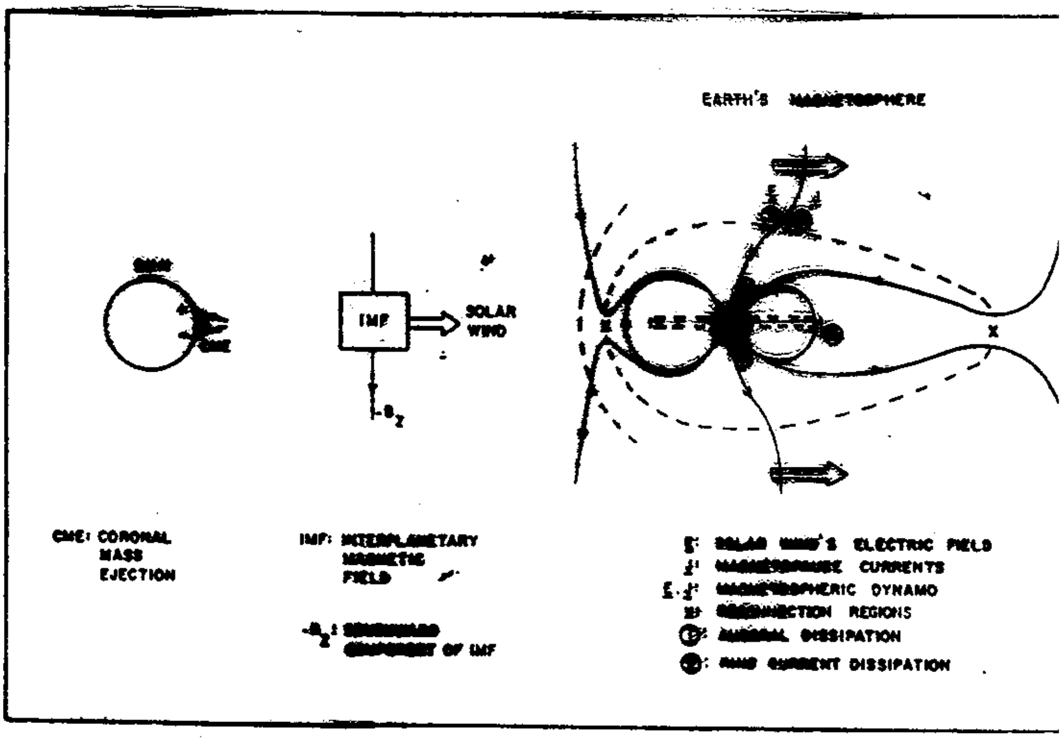
$\beta \approx 1.0$

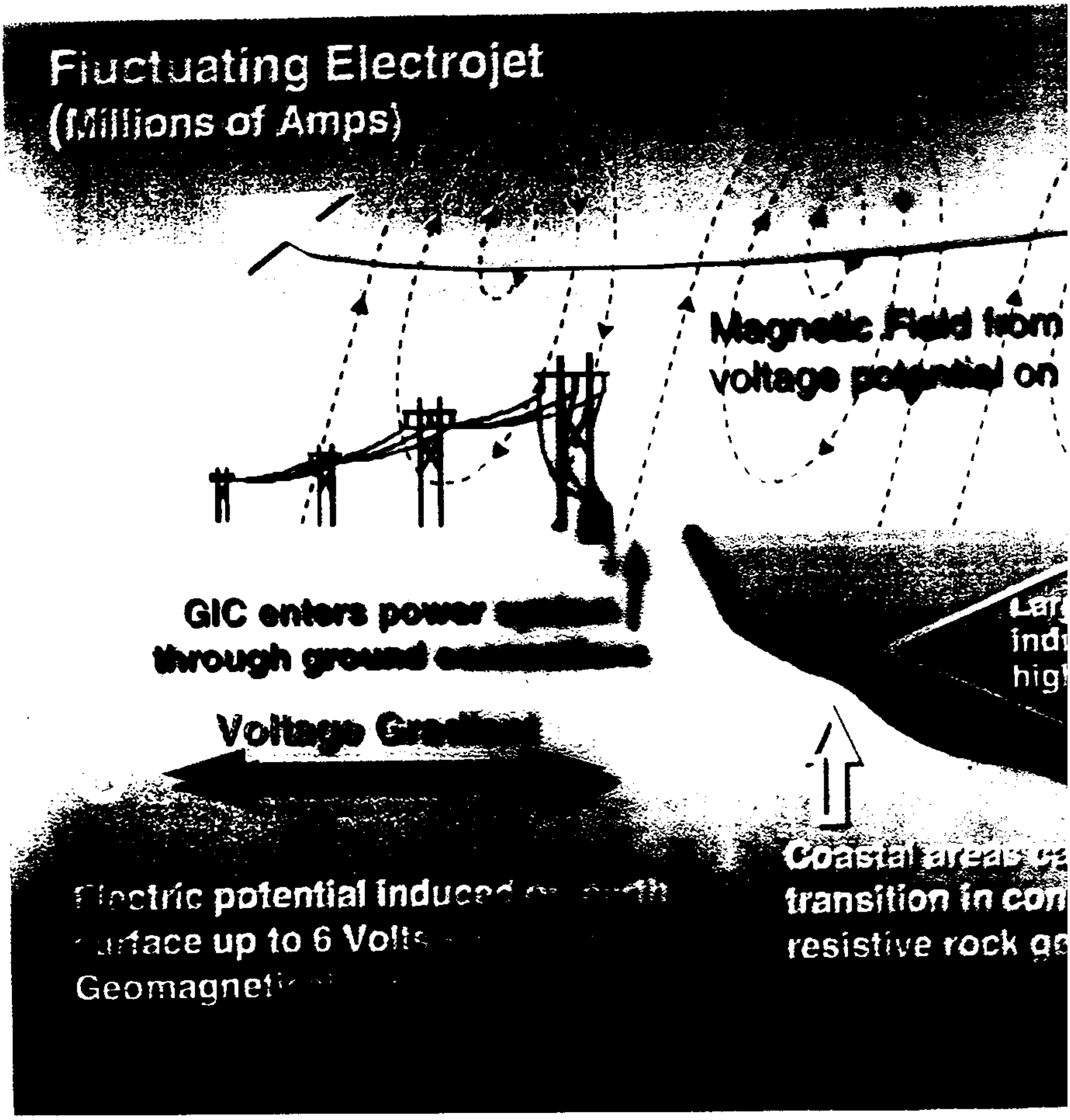
$V_A \approx 45$ km s^{-1}

$V_{MS} \approx 50$ km s^{-1}

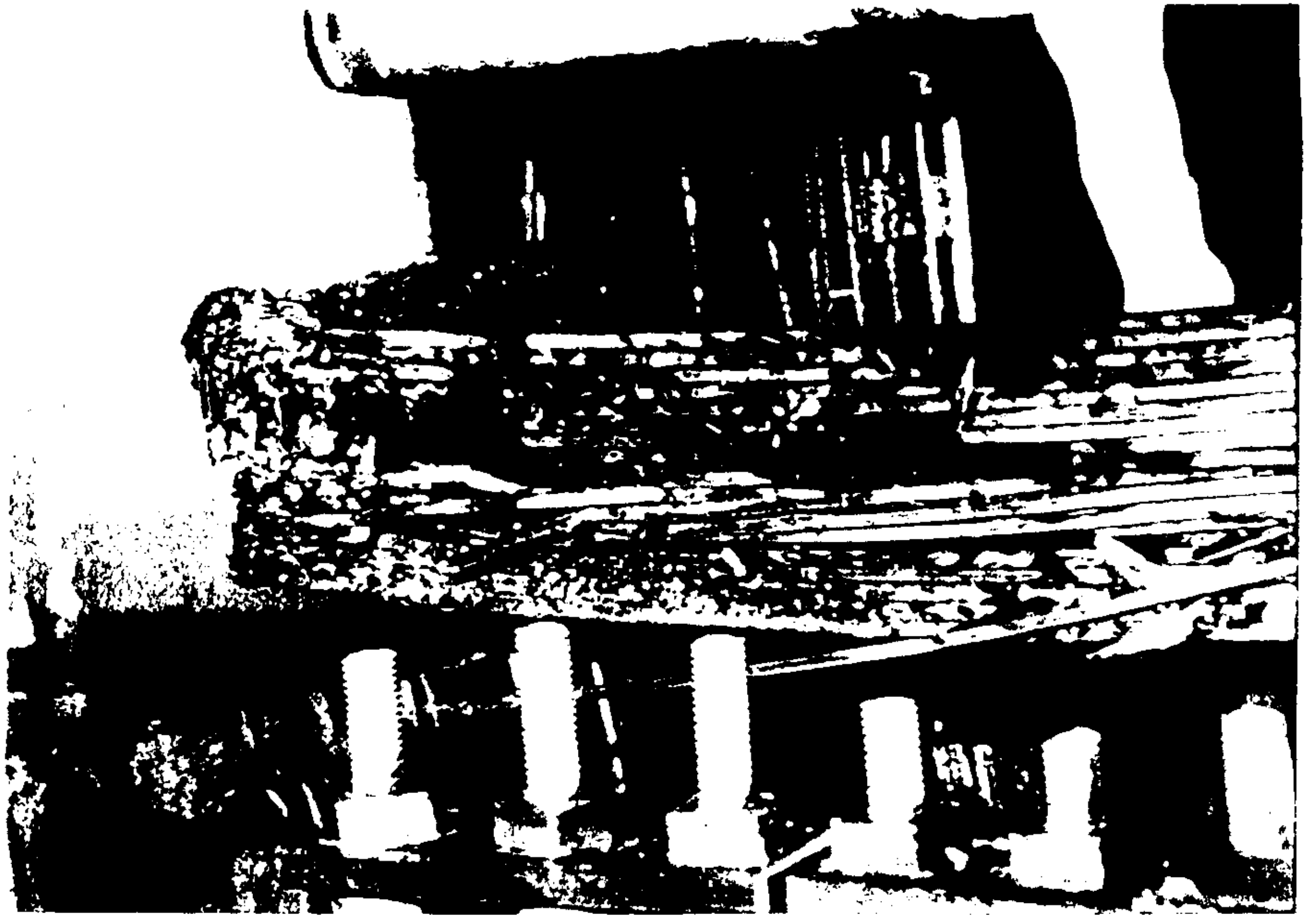


SOLAR - INTERPLANETARY - MAGNETOSPHERE COUPLING





Fluctuating Electrojet
(Millions of Amps)
Magnetic Field from
voltage
on
GIC enters power
through ground
Voltage
Electric potential induced
surface up to 6 Volts
Geomagnet
Coastal areas
transition in co
resistive rock



Solar Probe Science Definition Team

Shadia Habbal
Harvard Smithsonian
Center for Astrophysics
60 Garden Street
Cambridge, Massachusetts 02138
email: habbal@cfassp29.harvard.edu

Thomas E. Moore
NASA Goddard SFC
Code 692, Bldg 2, Room 138
Greenbelt, Maryland 20771
email: t.e.moore@msfc.nasa.gov

Clarence Korendyke
Naval Research Laboratory
Code 7662K
Bldg, 209, Room 256
Washington, D.C. 20375
email: koren@cyclops.nrl.navy.mil

Stewart Moses
TRW Space & Technology Group
One Space Park, MS R1/2144
Redondo Beach, California 90278
email: smoses@amelia.sp.trw.com

Paulett C. Liewer
MS 169-506
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, California 91109
email: pauly@spaceport.jpl.nasa.gov

Robert Rosner
Astronomy & Physics, Fermi Institute
University of Chicago
5640 So. Ellis Avenue
Chicago, Illinois 60637
email: rrosner@oddjob.uchicago.edu

Ralph McNutt
Applied Physics Laboratory
Johns Hopkins Univ , Room 24
Laurel, Maryland 20723-4638
email: ralph_mcnutt@jhuapl.edu

James A. Slavin
Electrodynamics Branch, NASA
Goddard Space Flight Center
Code 696
Greenbelt, Maryland 20771
email: slavin@lepjas.gsfc.nasa.gov

Eberhard Moebius

Alan Title

Solar Probe

Mission Description:

- 1-meter spacecraft, Delta launch, Jupiter gravity assist to close solar-polar trajectory
- 10-day solar flyby over pole to equator, from 100 solar radii to 3 solar radii from the surface
- Remote sensing of the solar corona and surface at the poles, plus in situ plasma measurements

Technology Advancements

- X-2000 and Outer Planets
- Thermal shield and contro at Sun
- Small solar arrays are effi

Science Objectives:

- Understand the source of observing:
  - plasma processes whic fast and slow solar wi
  - true relationship betwe solar wind,
  - dynamics of interior c in the polar regions, a
  - high latitude solar ma how it projects outwa

Measurement strategy:

- Magnetograph, doppler, I characterize the polar ma flows, magnetic structure acceleration mechanism
- In-situ diagnostic measu waves and particles, from acceleration mechanism

Solar Probe Science Evolution

	Science Objectives	Mission Concepts						Instruments						
		82	89	91	94	95*	97	Flds		Particles				
								[redacted]					NPD	[redacted]
1	[redacted]	X	X	X	X	X	[redacted]	[redacted]					X	[redacted]
2	[redacted]	X	X	X	X	X	[redacted]							
3	[redacted]	X	X	X	X	X	[redacted]	[redacted]		[redacted]				X
[redacted]	[redacted]	X	X			X	[redacted]							
5	[redacted]	X				X	[redacted]							
6	Solar Flare Composition	X	X	X	X							(X)		
7	Dust Evolution	X		X										
8	Nuclear Interactions	X												
9	Solar Quadrupole Moment	X												
10	Gravity Waves (Cruise)	X												
11	Relativity Theory	X												
	Payload Mass (kg)	142	134	90	17	8	16							
	Payload Power (W)	95	101	100	14	11	16							
	Number of Science Objectives	11	5	6	5	5	5							
	Number of Instruments/Sensors	16	6	8	6	7	8							

Solar Probe Evolution

82: Original Starprobe concept
89: Remove half the science
91: Add Dust & X-ray
94: Reduce mass, delete Dust & X-ray
95: Reduce mass, add imaging
97: Integrated adv technology sensor suite

* Minimum Solar Mission (95): Limited spacecraft performance severely reduces science data return

Potential Solar Probe Instruments/Sensors

MAG: Triaxial Fluxgate Magnetometer
PWS: Plasma Wave Sensor
PPD: Proton Plasma Detector
IEP: Ion/Electron Plasma Detector
NPD: Neutral Particle Detector
EPD: Energetic Particle Detector
HRC: High-resolution Coronagraph
EUV: EUV Imager

VMG: Visib
XRI: X-ray I
EUV: EUV I
CLA: Coron
DD: Dust D
SND: Solar
DFS: Drag
MC: Maser

New Solar Probe Mission Greatly
Improves Science Return Over MSM

- Planning for Outer Planets/Solar Probe Line rather than Discovery Class (Minimum Science)

- X-2000 spacecraft enables more mass for science payload

- NASA Solar Probe NRA sensor/integrated instrument funding advances high-technology, small, lightweight and low power instrument

  - Solar Probe Science Definition Team selects NRA sensors/integrated instrument as strawman payload

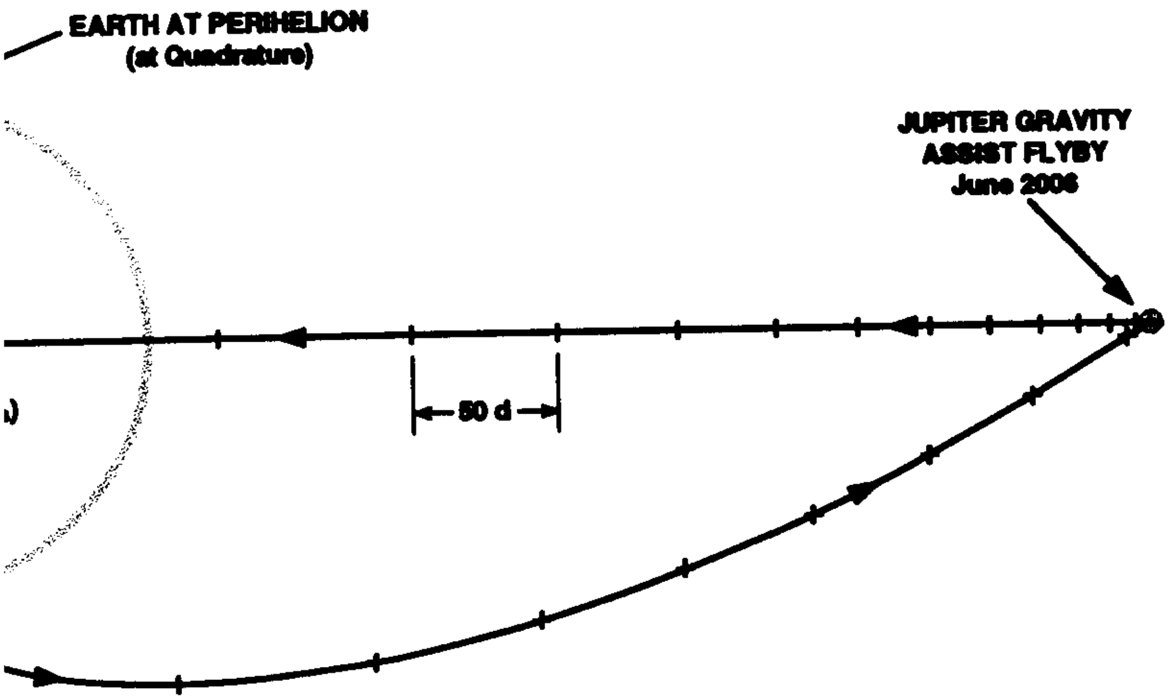
  - Integrated plasma, plasma wave, magnetometer time-synchronized measurements at 10^{-2} s

- NASA PIDDP funding helps develop new type of plasma sensor

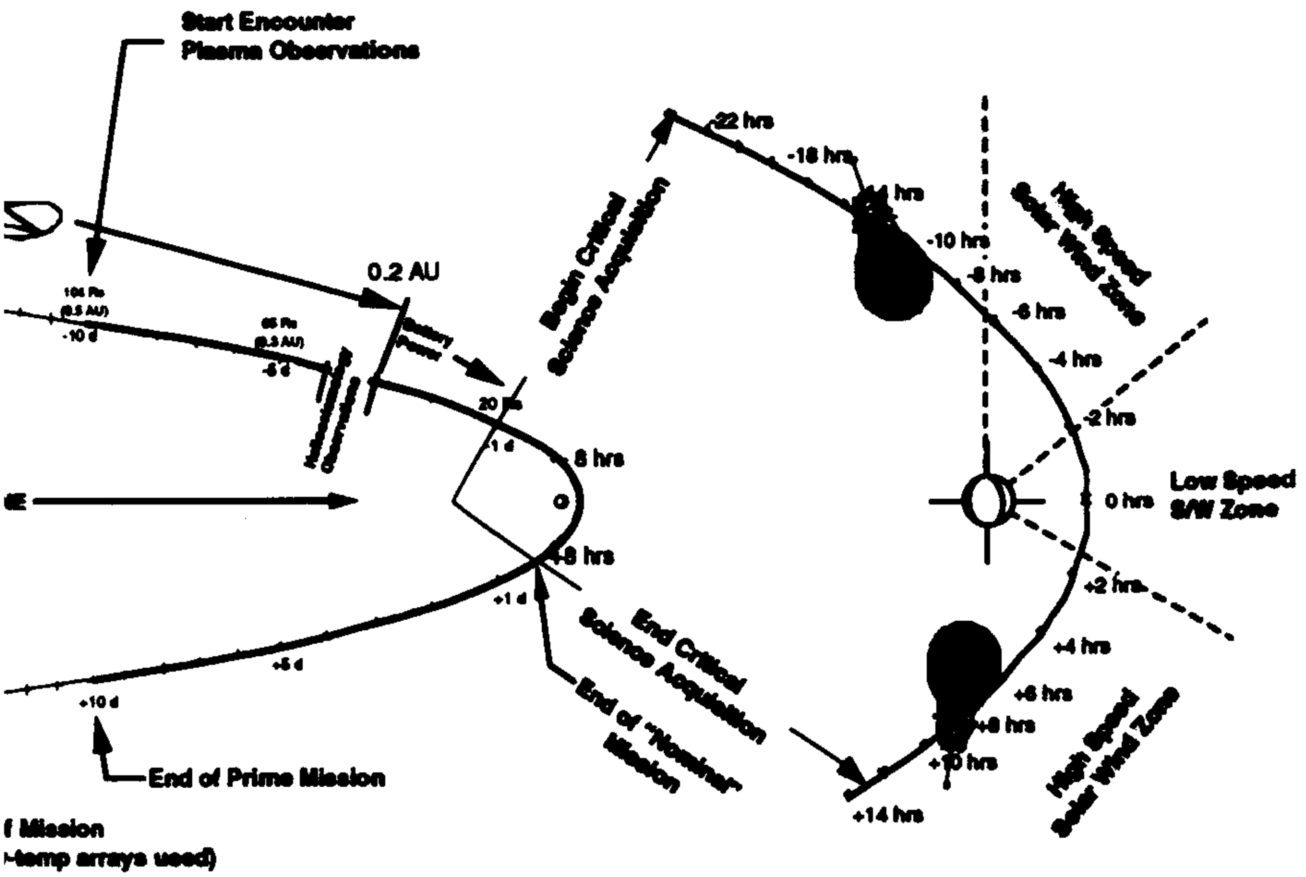
  - Miniaturized delta-doped APS high-time resolution plasma sensor capable of 3-d plasma distribution functions in $\sim 10^{-2}$ s (whereas current technology is ~10 s)

  - At Solar Probe perihelion, the proton cyclotron frequency is ~300 Hz. Need ion distribution function on time scales comparable to f_c to understand wave-particle interaction processes leading to coronal heating.

Solar Probe 2004
Interplanetary Trajectory



ᴾrobe Near Perihelion Activities
(View from Earth)



Solar Probe Innovations

rihelion Telecommunications

aximize X-band Telemetry Rate in Scintillation Environment at Perihelion

R Conjunction Results

formance of Telemetry System and Receiver Better than Expected

Analyzed in the Time Domain (for the First Time)

cintillations ± < 5 dB Most of the Time

Can Maintain Lock on Telemetry Subcarrier

nplitude Scintillations ± > 10 dB Intermittently

for Duration of Event ($\Delta t \sim 1$ sec) Plus Three Data Frames to Relock

ptions

st be Captured (i.e., Cover the ± 10 dB Spikes)

Rate ~ **5 kb/s**, No Drop Outs

nptions

rmittent Drop Outs (every 1 to 5 minutes)

Telemetry Rate ~ **50 kb/s**

nes Duration (0.24 sec) Lost in Order to Relock + Δt : 0.24 sec + Δt

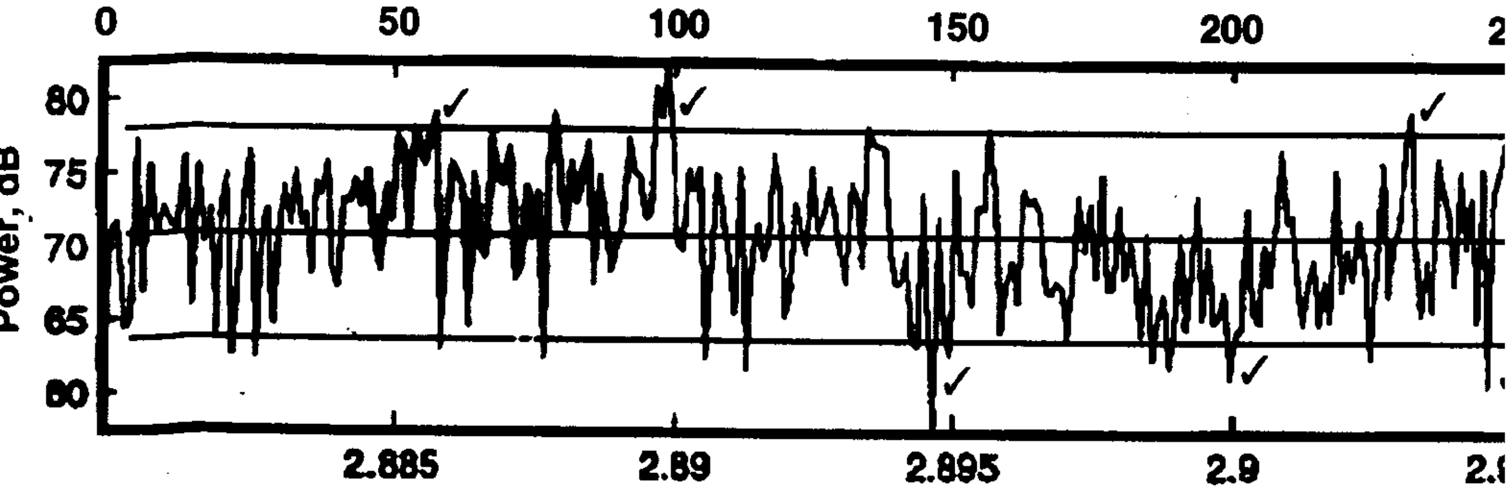
s Than 2% of the Data Because of the Scintillation Drop Outs

Near Perihelion Increased by Almost an Order of Magnitude

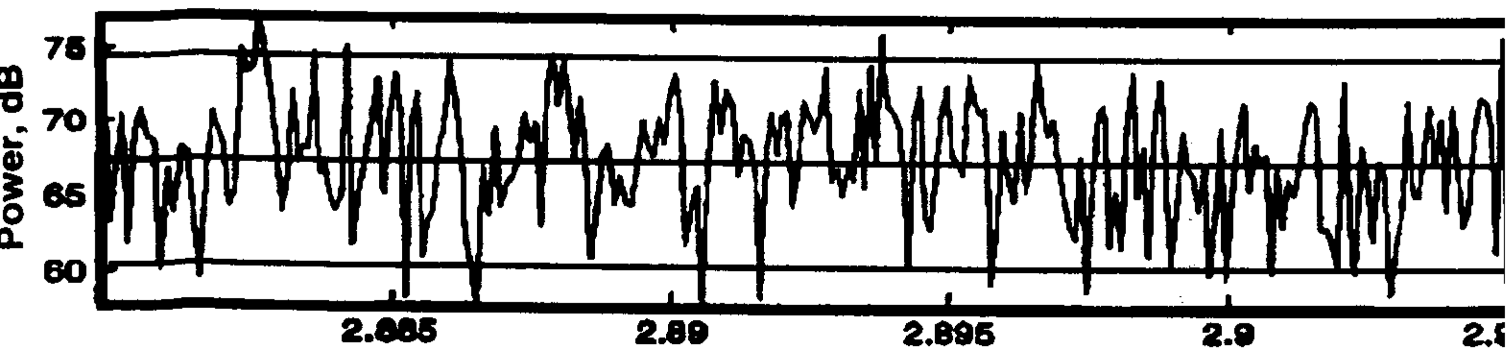
NEAR Conjunction Data

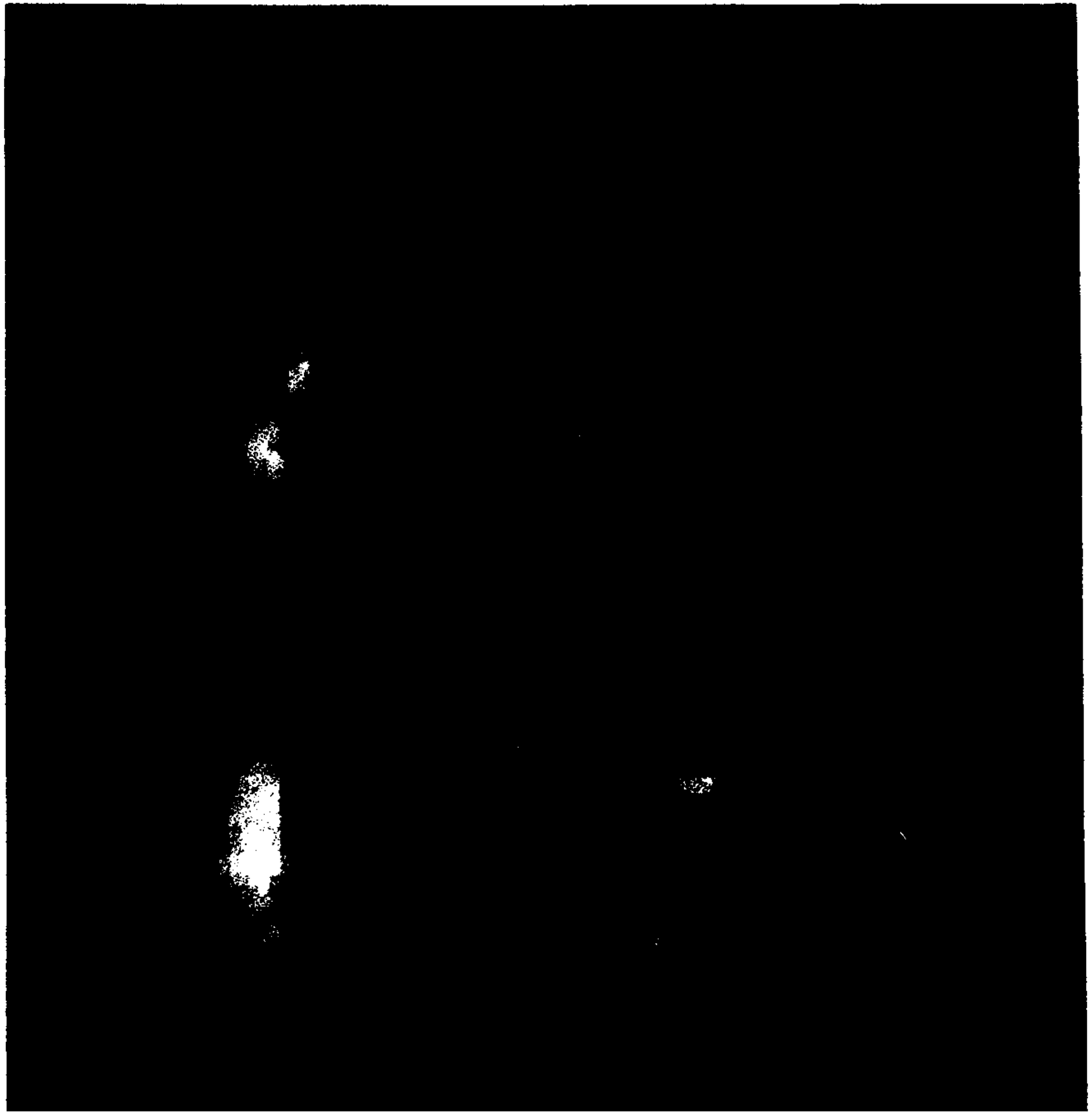
DAY 52 Overlap Tracking Interval Between Stations 45 and 65

DSS 45 (08:00)



DSS 65 (08:00)





Ulysses Results: New Questions

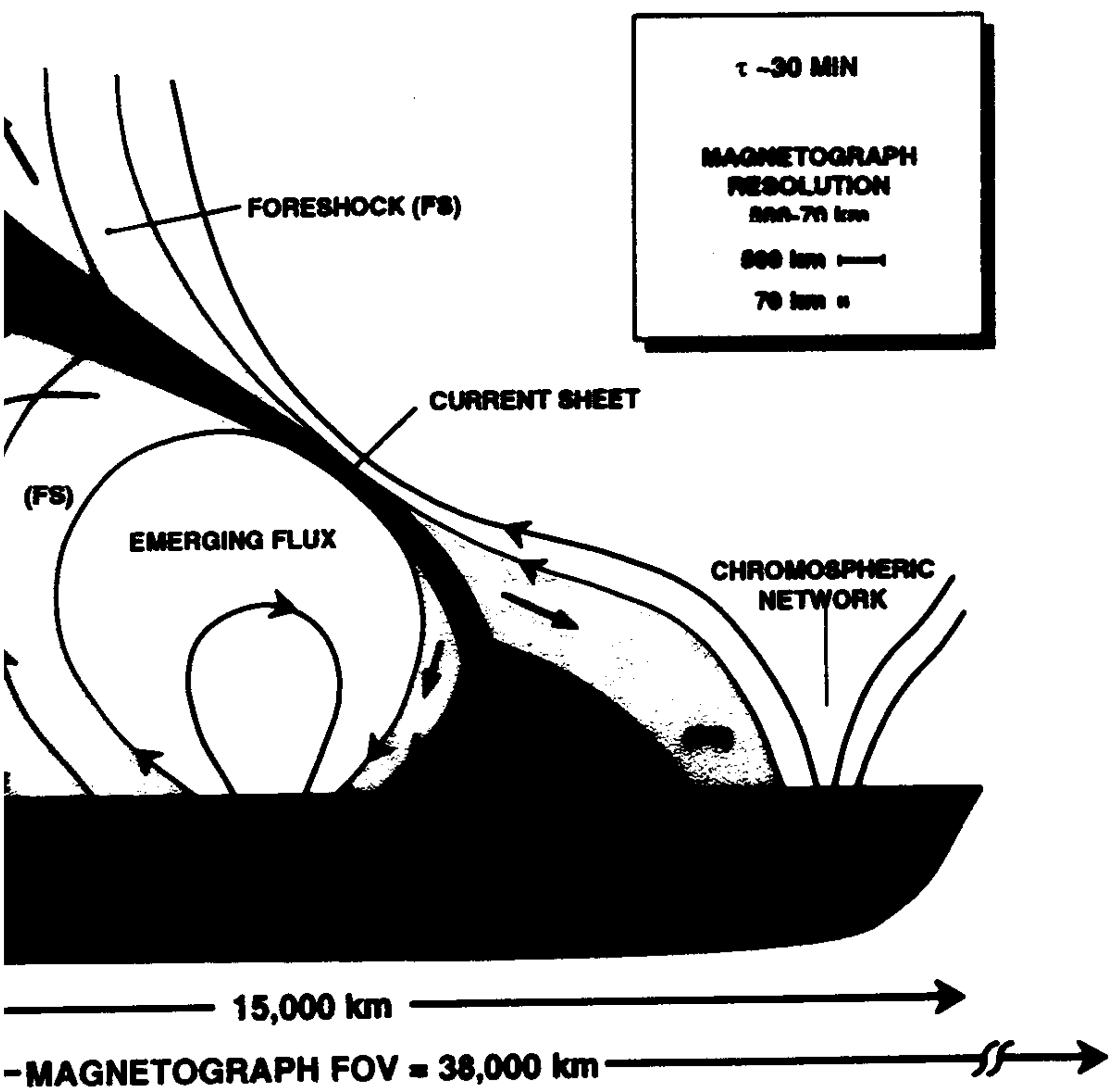
r Plumes/High Speed Solar Wind

; are located throughout polar coronal holes,
enhancements of up to 30% relative to
gions, extend from the photosphere to at
re stable for at least several days, and are
'ith intense monopolar fields at the

lese structures and how are they
d?

theoretical model that can explain the small
with radial distance.

nental question of the acceleration
n of the high-speed solar wind still remains,
ghtly revised: does it come from plume or
regions?

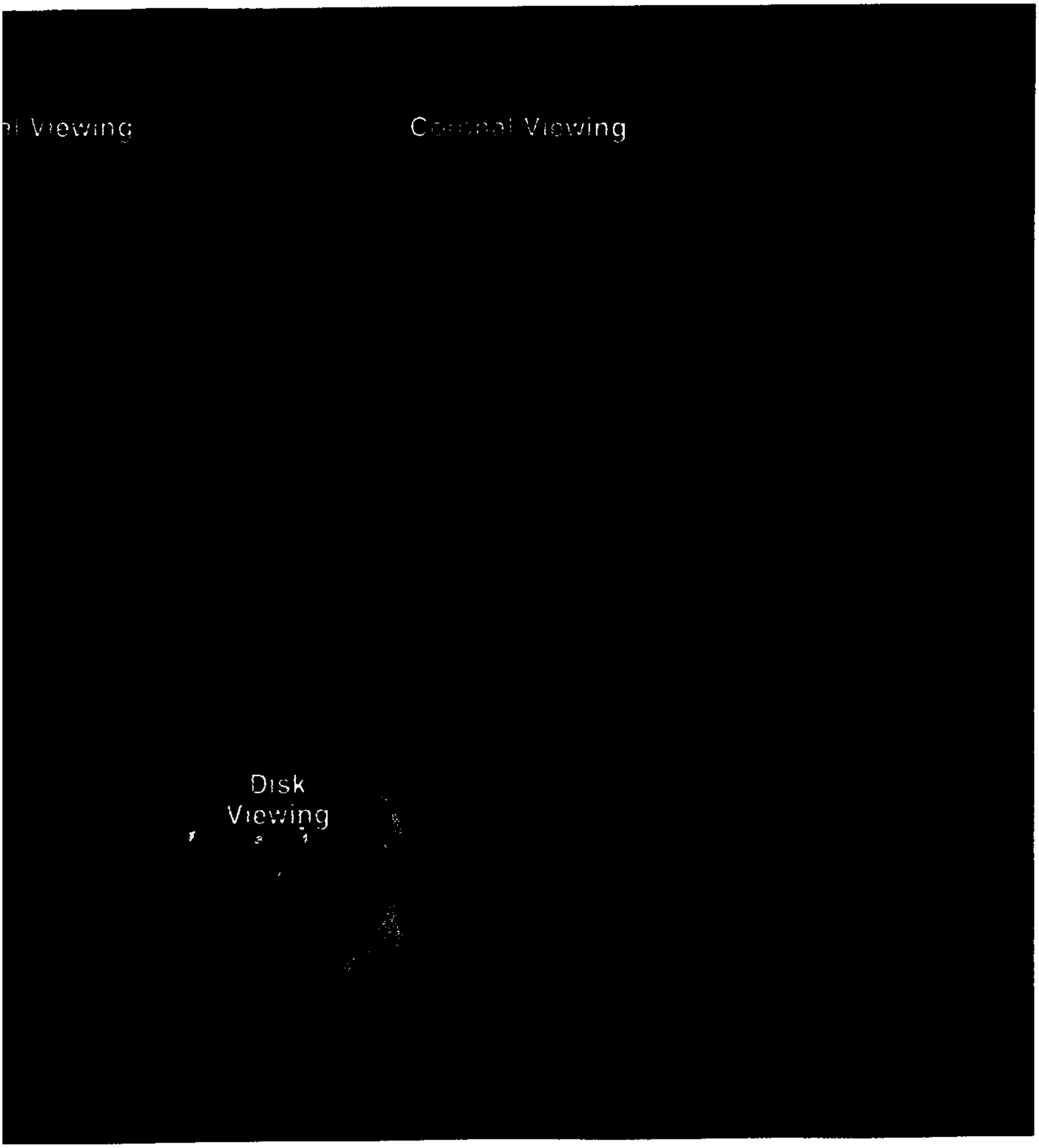

τ ~30 MIN
MAGNETOGRAPH
RESOLUTION
70 km
FORESHOCK (FS)
CURRENT SHEET
(FS)
EMERGING FLUX
CHROMOSPHERIC
NETWORK
15,000 km
MAGNETOGRAPH FOV = 38,000 km

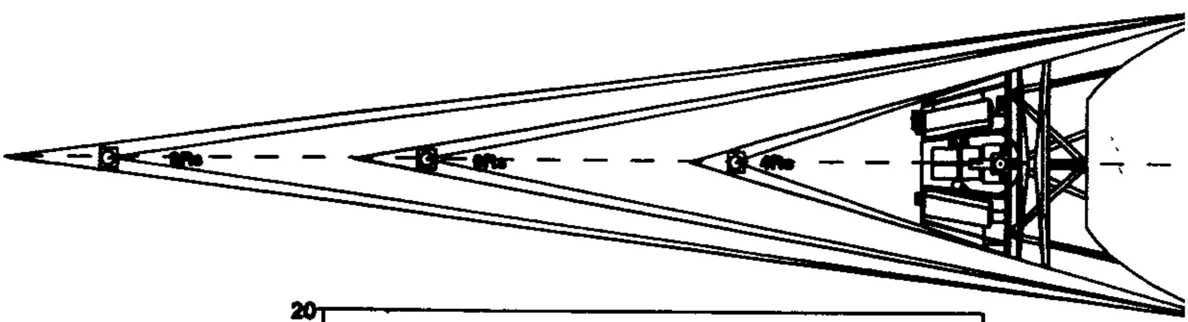
In Situ Plasma and Field Measurements

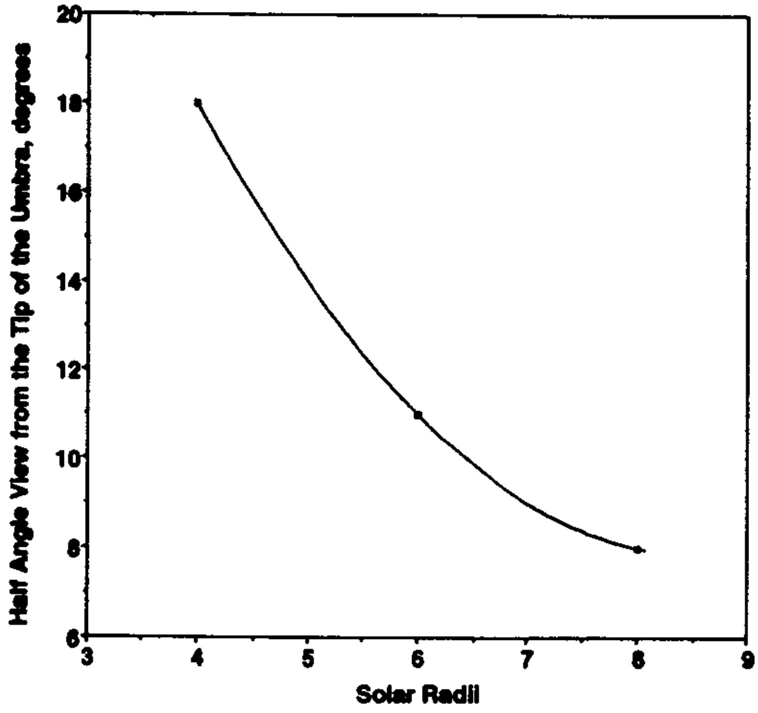
- High time resolution, synchronized plasma and field (plasma, plasma wave, magnetometer) measurements to study solar wind heating and acceleration.

  - Will resolve plume/interplume structures (with coronagraph context viewing) to 1.5 km resolution and will determine where high-latitude solar wind acceleration is taking place

  - Will resolve magnetic and plasma structures to 3.0 km in the helmet streamer belt. Perihelion occurs at a distance below the sonic point.

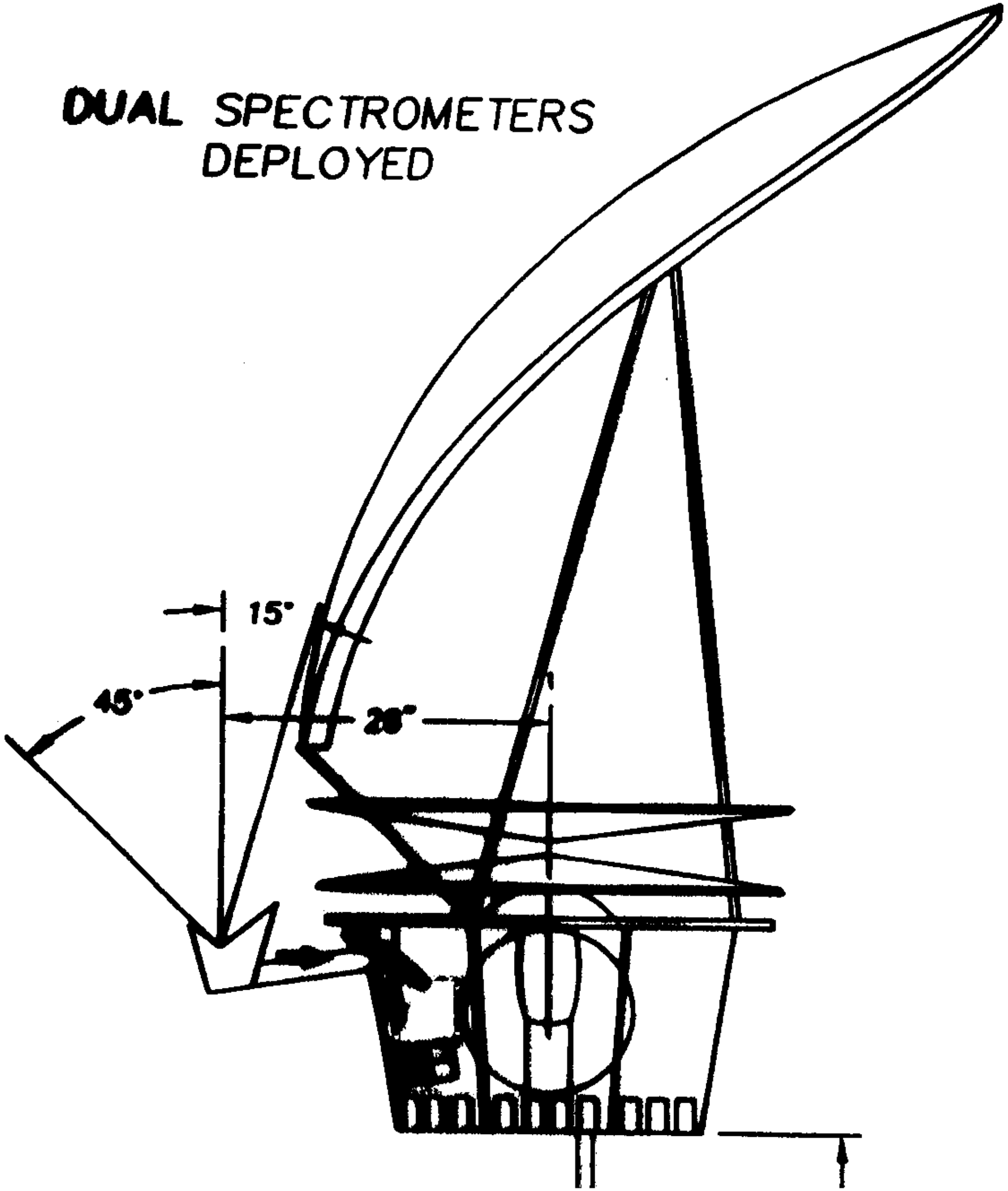

Viewing
Viewing
Disk Viewing



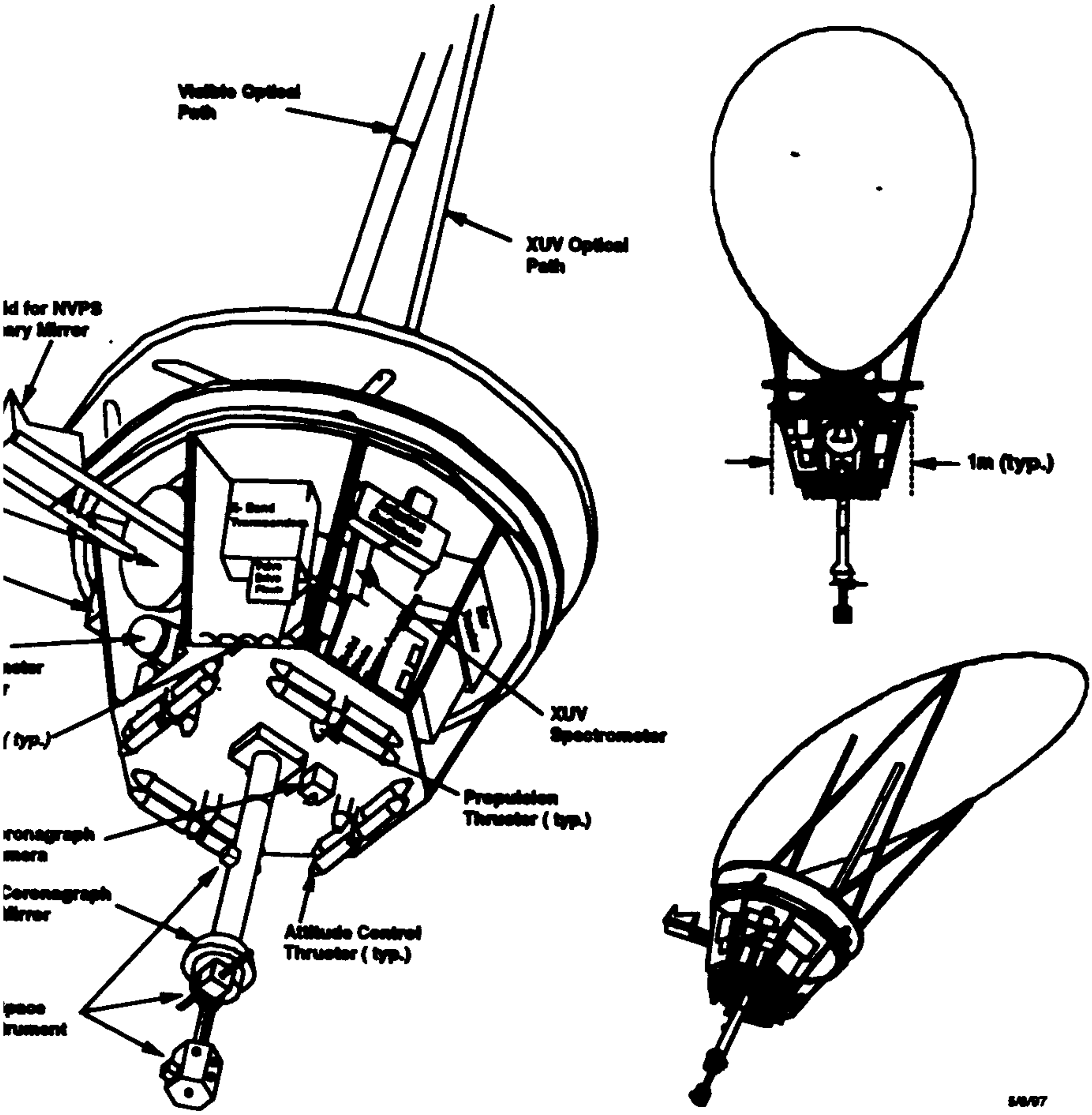


Half Angle View from the Tip of the Umbra, degrees
Solar Radii
6
8
10
12
14
16
18
20
3
4
5
6
7
8
9

DUAL SPECTROMETERS DEPLOYED



OBE BASELINE CONFIGURATION



Slow Speed Solar Wind

- The slow wind has a constant accelerat at least 30 R_s. (New SOHO result)
  - What mechanism can explain such o
  - Are the heating and acceleration mec different than for high speed stream

Helioseismology/Circumpolar

- Although SOHO helioseismology mea the polar regions are limited, circumpol are found within 15 degrees of the pole. extend to only 20,000 km below the vi There is some indication that a polar v to the bottom of the convection zone.

eismology from Solar Probe

of the ecliptic it is difficult to obtain
s above 60° latitude, and brightness
: 75° latitude. Nonetheless, very low noise
ı the MDI instrument on SOHO provide
ımpolar jets and significant decreases in
ies at the poles. All of this is tainted by
he pole.

lelioseismology observations from Solar
inbound polar pass will greatly improve our
internal dynamics of the Sun at high

Solar Probe Innovations

rmal Protection - Primary Thermal Shield

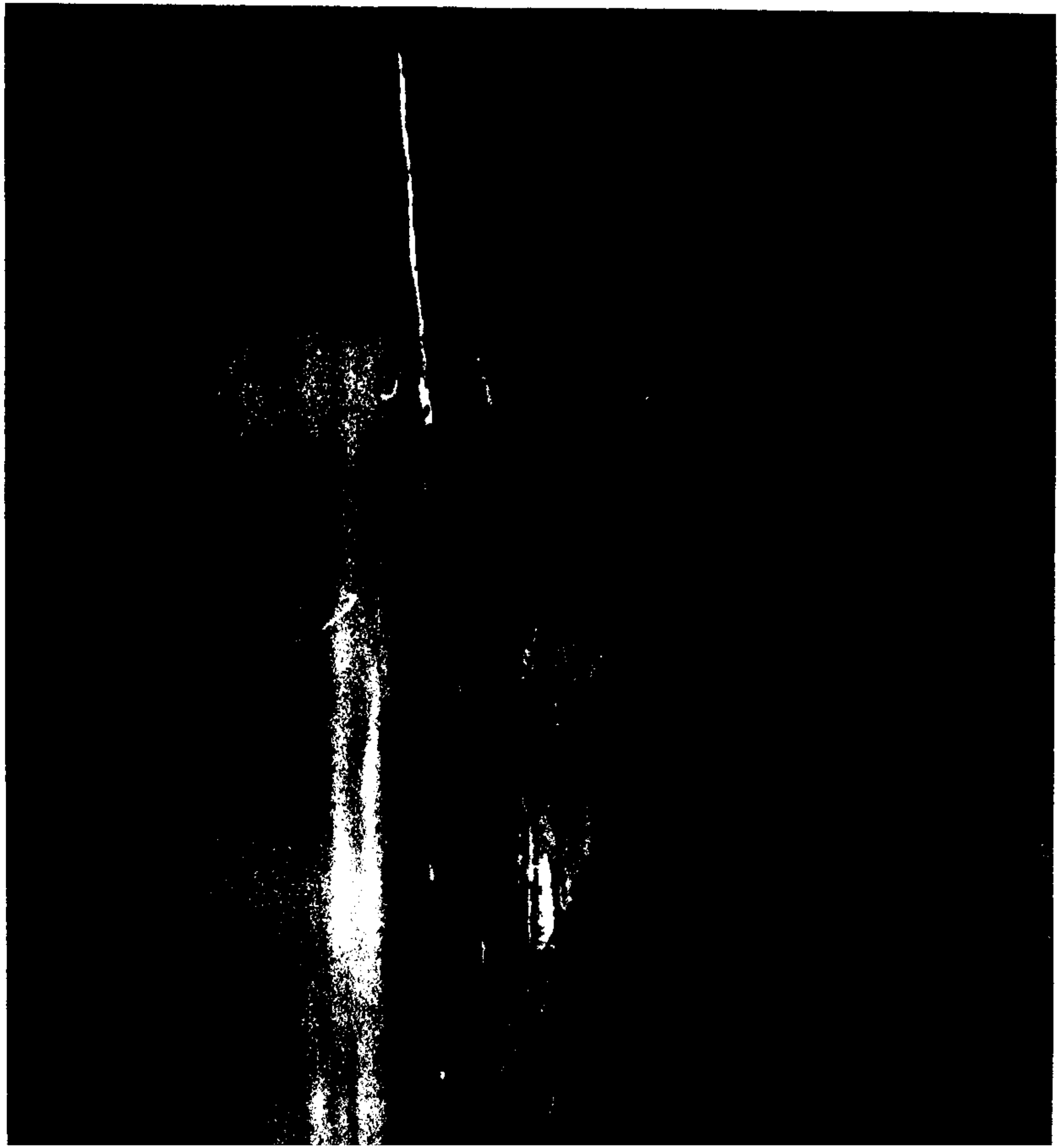
ɔnceptual Design: Evolution of Parabolic Shield

ınd Ceramics Rejected over Carbon-Carbon Composite Materials
Savings, Structural Stability

ɔperties of Carbon-Carbon: Screening Test Program in 1996
ation of Carbon-Carbon Fabrication Recipes for Optical Properties
al Vapor Infiltration (CVI) as Final Carbon Densification Step
Emissivity (α/ε) Ratio Reduced from 1.1 to 0.7 with CVI
erature Reduced from ~ 2400K to ~ 2100K (with $\alpha/\varepsilon = 0.7$)

es of Carbon-Carbon
ation Lowest Mass Loss of Candidate Recipes

Mass Loss Reduced from about 1 mg/sec to less than 0.01 mg/sec



C_3 Heat Shield Mass Loss Rate

of 2.5 mg/s would lead to a spacecraft
0V.

ed/General Atomic tests indicate the
vill be substantially less.

2.1×10^{-3} mg/s	C_1
0.6×10^{-3} mg/s	C_2
0.7×10^{-3} mg/s	C_3
3.4×10^{-3} mg/s	$C_1 + C_2 + C_3$

ience Performance Requirements

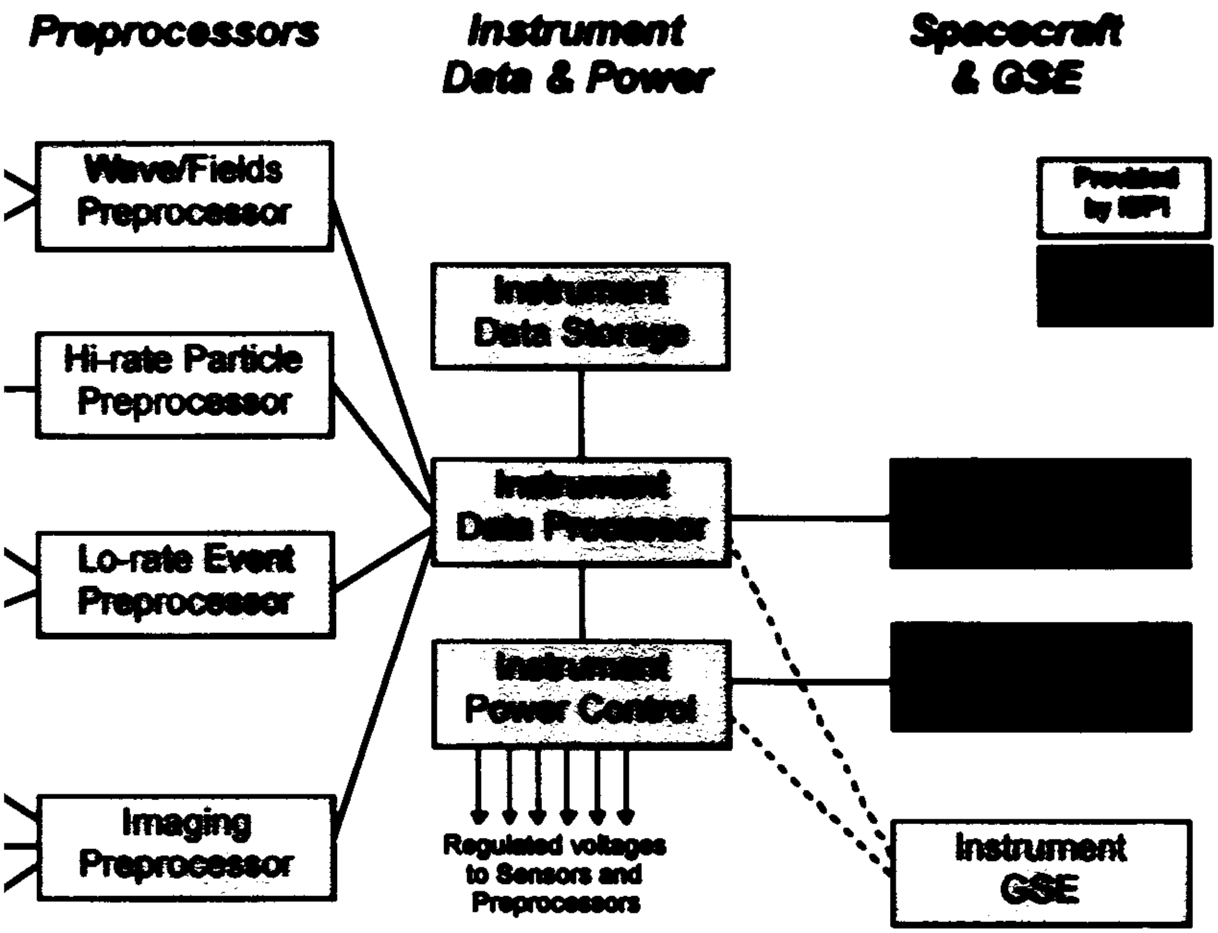
Range	Sensitivity	Sample Rate
) ± 65,000 nT) ± 64 nT	(1) ± 0.5 nT (2) ± 0.05 nT	10 ms Res-Perih: 3 km
Hz - 150kHz $^{-5}$ - 10 V/m (E) $^{-9}$ - 10^{-3} nT^2/Hz (B)	20 log channels 5% (4/decade)	1 ms (wave cap) 1 sec (spectral)
eV - 50keV (p+), for ns up to 16 AMU	10 eV	1-10 ms Res-Perih: 0.3 - 3 km
eV - 30keV eV – 8 keV (nadir)	7% ΔE/E	8 sec Res-Perih: 2400 km
keV - 1MeV (e-) keV - 20MeV (p+/He+)	10^5 events/s (max)	1 sec
.0 - 3000 nm)V: TBD	30-500 km/pixel	1 image/sec (max)
.02 nm (Zeeman line))V: TBD	1-3000 Gauss 30-500 km/pixel	1 image/sec (max)
5 - 6.0 R_s FOV	TBD	1 image/sec (max)

ated Solar Probe Strawman Payload
Mass/Power/Data Rates

imate

Element	Mass (kg)	Power (W)	Data (kbps)
tometers (2)	0.3	0.4	1.2
ensors	0.5	0.4	9.6
3)	0.8	1.5	20.0
sma (2)	3.1	3.4	20.0
es (2)	0.4	0.5	4.0
	2.0	0.8	30.0
graph/X-ray	1.8	1.5	30.0
Coronagraph	2.4	2.0	2.0
sor	2.0	6.0	0.5
ersion/Distribution	0.5	2.0	0.0
Total	**13.8**	**18.5**	**117.3**

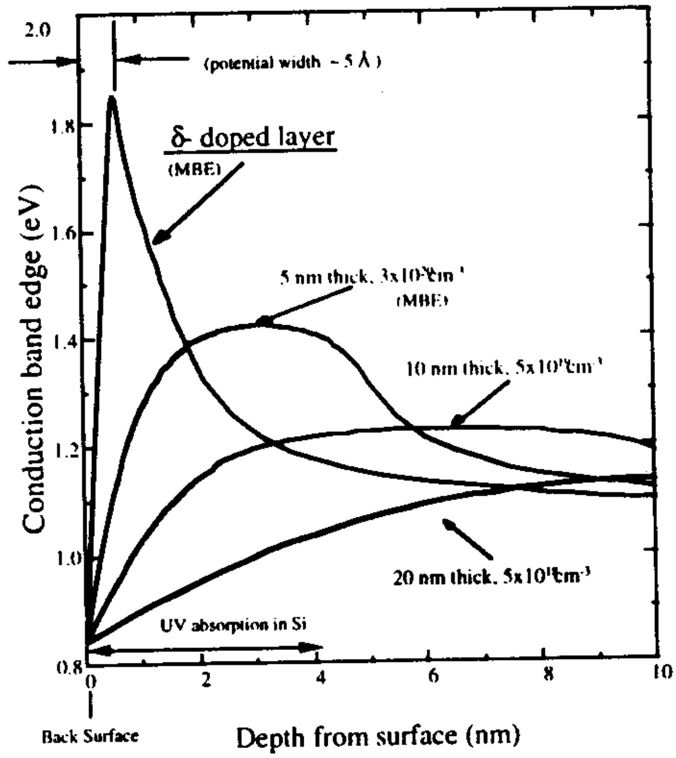
Solar Probe Instrument Architecture



Delta-doping Technology

ɔed device structure

Backside Potential Well Modifications With B Doping



grown on silicon detectors using molecular beam epitaxy (MBE). This delta-doped silicon
ɔposited in a single atomic layer, approximately 5-10Å below the surface.

ns at right show that the delta-doping process reduces the backside potential width to only 5
ɔlectrons generated by UV photons.

ɅIiniature Plasma Particle Detector

Particle Detector

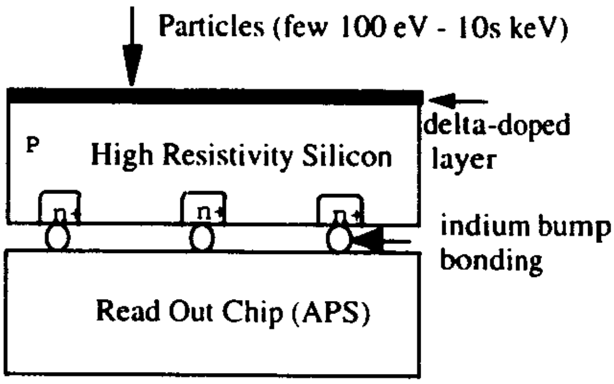
:CD technology

Integrated Space Physics
Solar Probe Mission

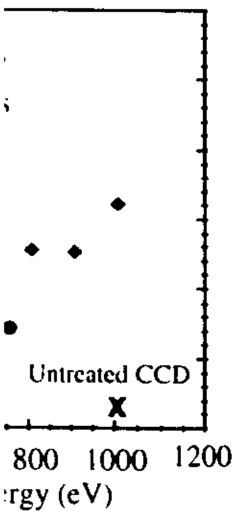
ıtribution functions at speeds
of the art (<1msec frame rate)

ıents on the same time scale as
instruments for the first time

Hybrid Advanced Detector
Combining APS and Delta-doping Technology

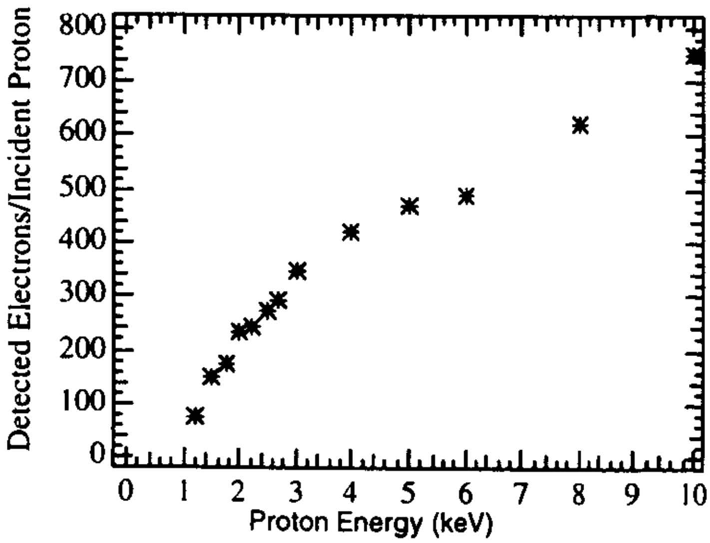


ʳ-energy Electron Detection

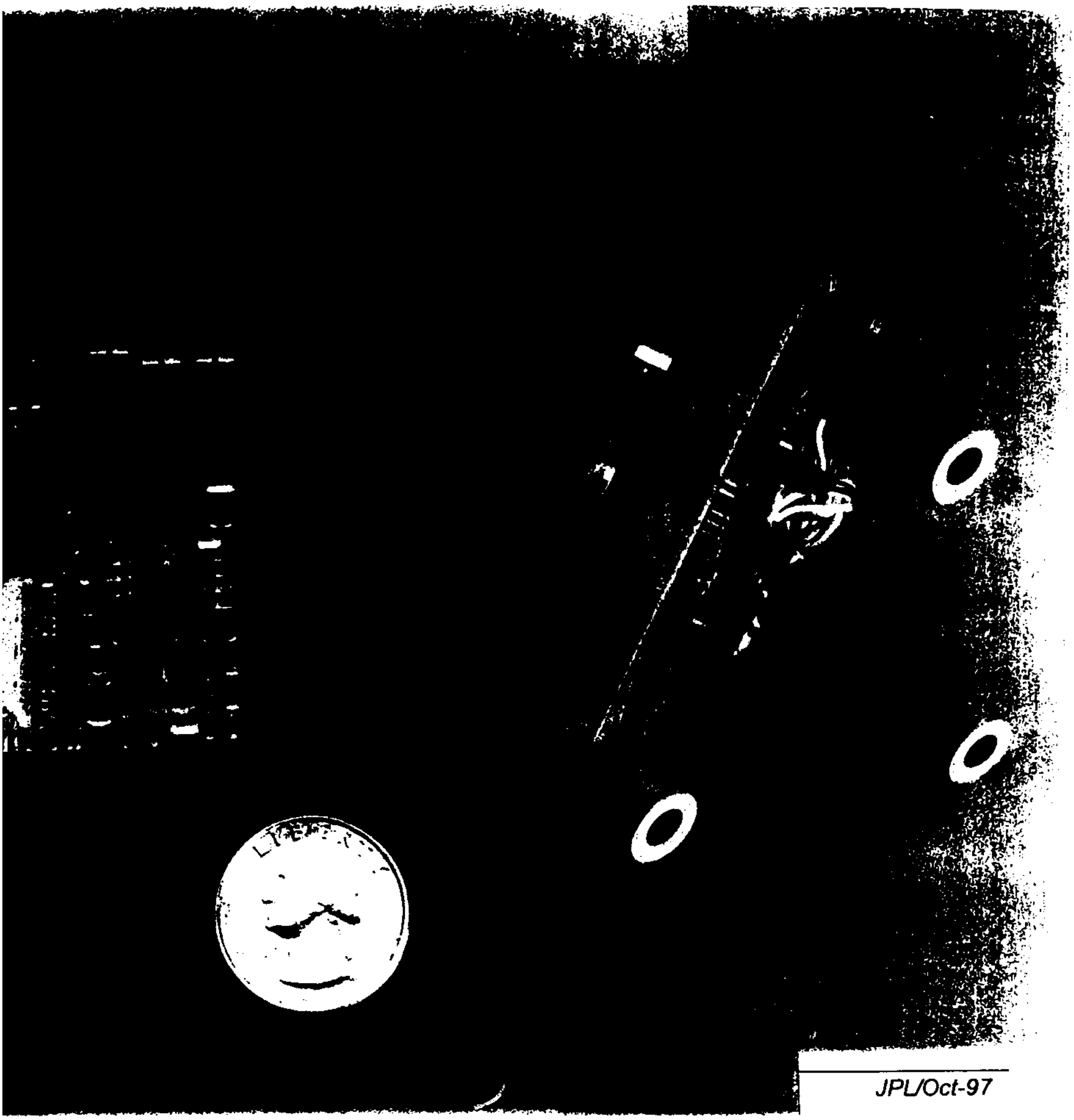


ncreasing incident energy
ved with untreated CCD
ıreshold observed to date for electrons

Delta-doping Technology for Low-energy Proton Detection



- Delta-doped CCD was used to detect protons
- Response of CCD increases with increasing energy
- Conventional detectors have a 10 keV detection threshold



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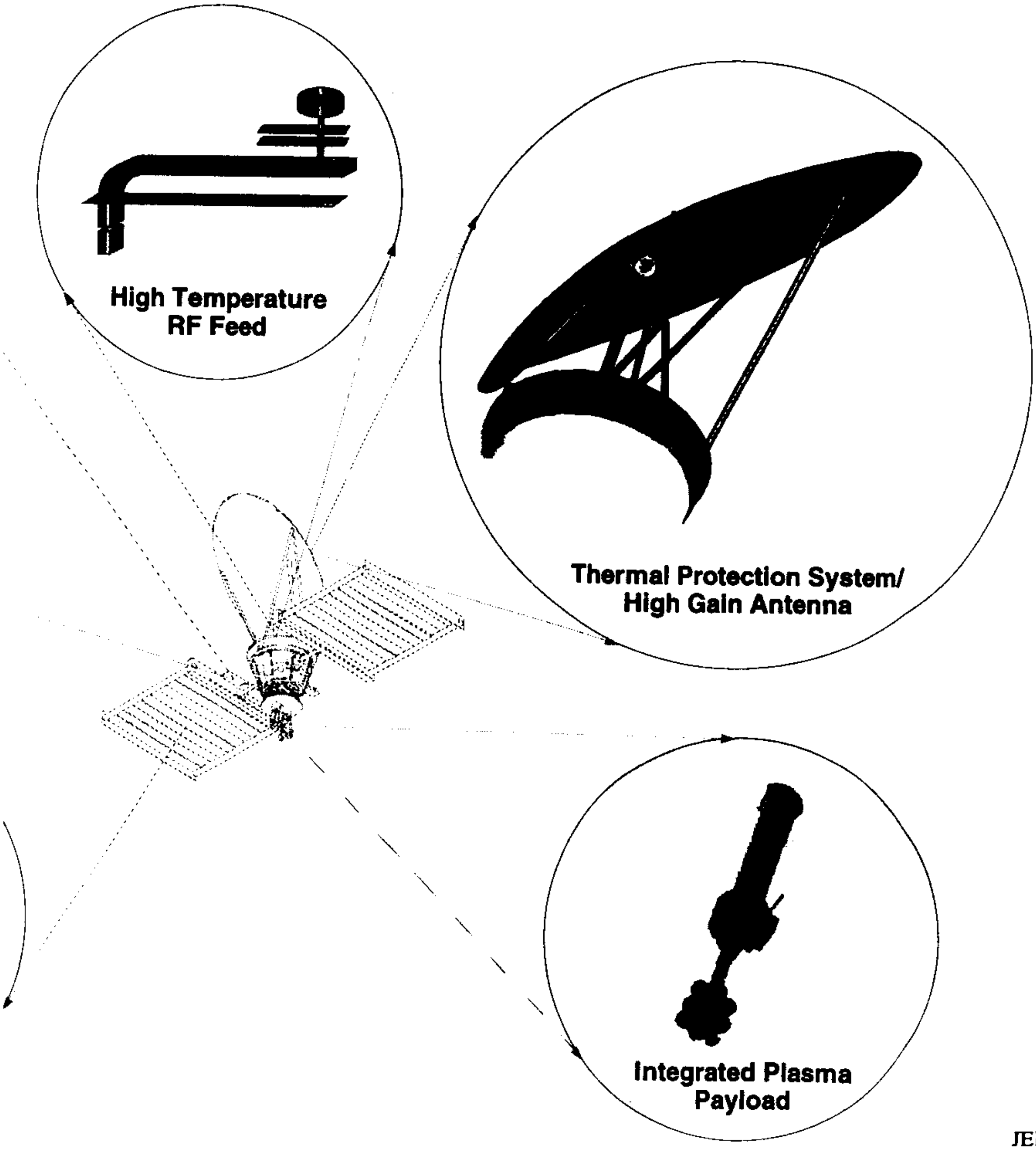
Solar Probe Innovative Technologies



›be Conclusions and Recommendations

; a Joint Partner in the Outer Planets/Solar Probe Program
m this Partnership Include the X-2000 Avionics Development

ıce That the Technology Development Plan is Viable
ın Submitted to NASA Headquarters - 9/16/97

Exploration has Assumed the First OP/SP Program Launch
r Express or Europa Orbiter in 2002

ΛS Recommendation for **SOLAR PROBE 2004** Launch
;ion Unique Technology Development Funding in FY1998