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AUTUMN COLLEGE ON PLASMA PHYSICS

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Spiral Angle

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Spiral Angle

Electric field in Inertial space
$= E$

In the moving solar wind frame

$$E' = E + V \times B$$

$E' = 0$ because it cannot have a component parallel to B ($\sigma \to \infty$) and there can be no drift of the plasma in this frame by definition.

$\therefore \quad E + V \times B = 0$

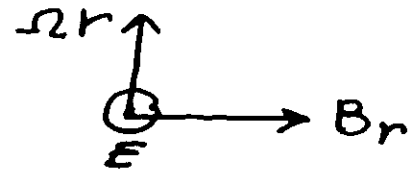
$V \times B = 0$ only if $E = 0$.

then $V \parallel B$.

However, because the corona is rotating, there is an

$$E = -\Omega r B_r \hat{e}_\theta$$

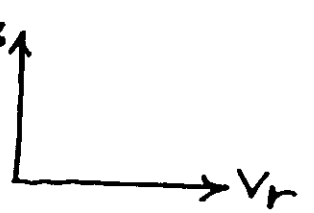
(northward)



Since $V \times B = -V_r B_\phi \hat{a}_\theta$

and

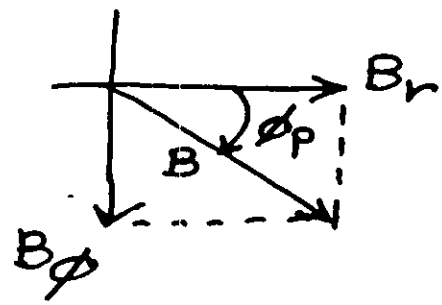
$$-\Omega r B_r - V_r B_\phi = 0$$



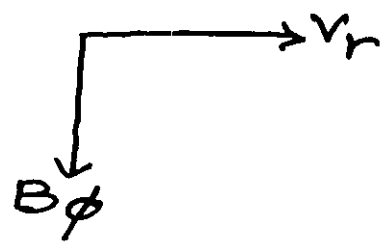
$$\therefore B_\phi = -\frac{\Omega r B_r}{V_r}$$

If $B_r > 0$ as assumed

$B_\phi < 0$



So $V_r \times B_\phi$ is southward



and

Compensates northward E in the solar wind frame.

In the inertial frame, there is an Electric field given by $E = -\Omega r B_r \hat{e}_\theta$

or by $-V \times B = V_r B_\phi \hat{e}_\theta$.

then $V_r B_\phi = -\Omega r B_r$

or $B_\phi = -\frac{\Omega r}{V_r} B_r$

as above.

the solutions in the two frames are consistent.

$\mathcal{E}$ fields can be avoided by operating in a reference frame in which the electric field vanishes.

In this case, that is a frame corotating with the sun.

No drift of plasma implies $E' = 0$.

The $E = -\Omega r B_r$ can be eliminated in a frame rotating so that

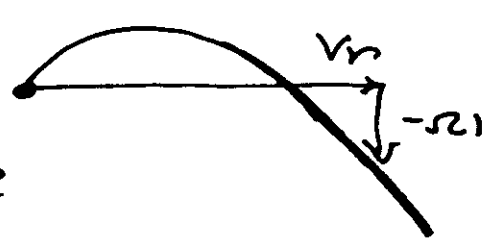
$$(v_\phi - \Omega r) B_r \doteq 0$$

or $v_\phi = \Omega r$.

Then $v \times B = 0$ or $v \parallel B$.

The stream lines have

$$\frac{r\,d\phi}{dr} = \frac{-\Omega r}{v_r}.$$



The field lines have

$$\frac{r\,d\phi}{dr} = \frac{B_\phi}{B_r} = -\frac{\Omega r}{v_r}$$

in both the corotating and inertial frames

$$\therefore \quad \frac{B_\phi}{B_r} = \tan\phi_p = -\frac{\Omega r}{v_r}.$$

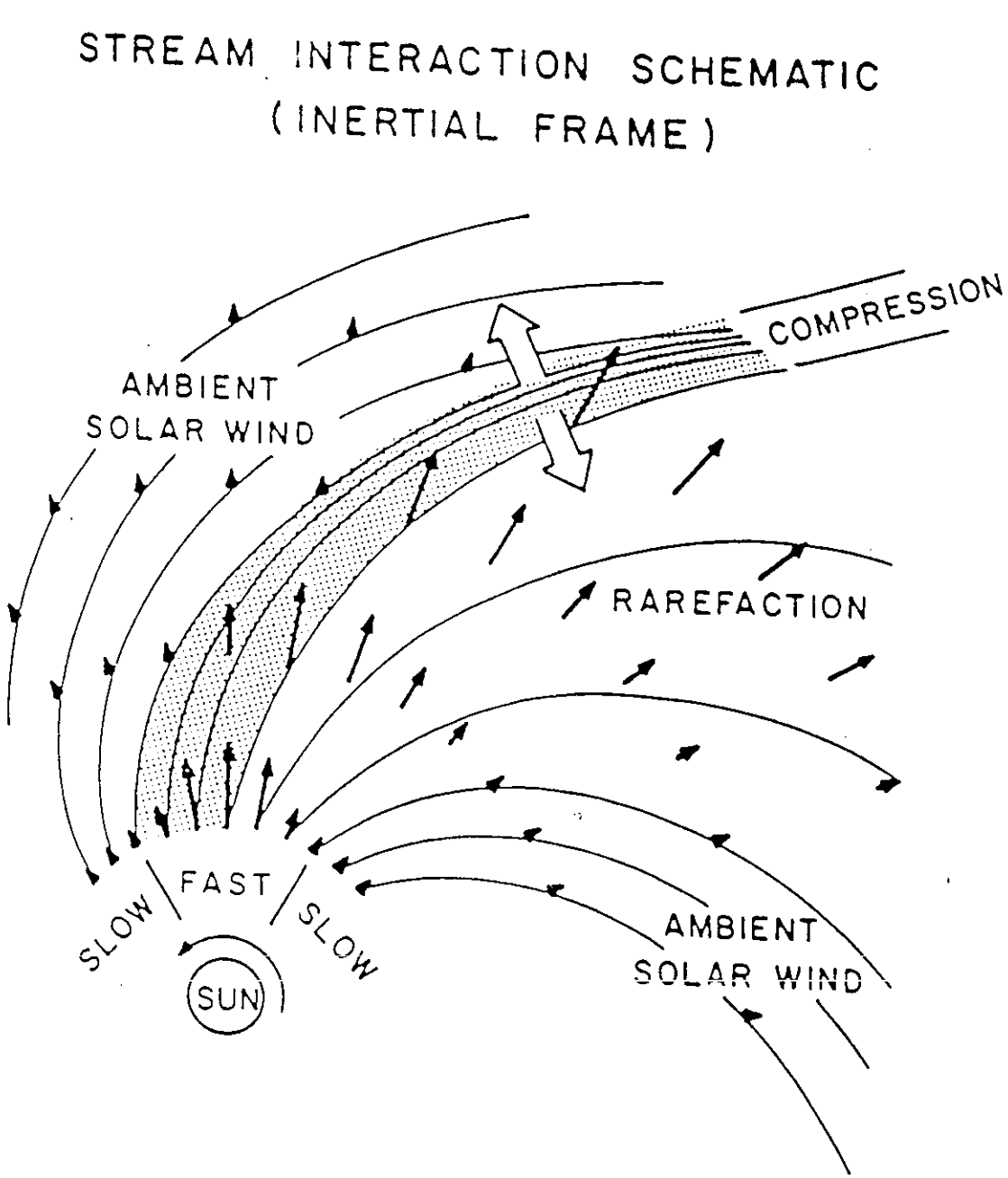
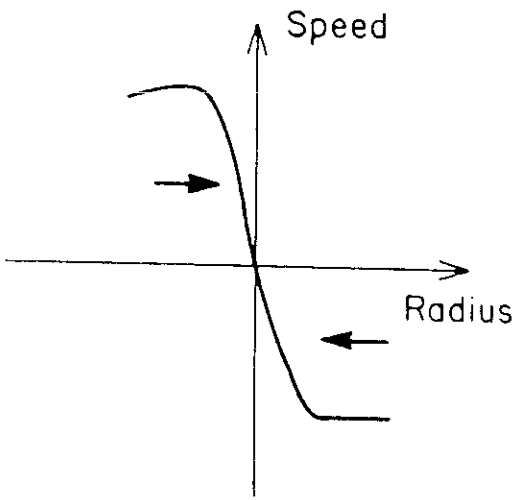
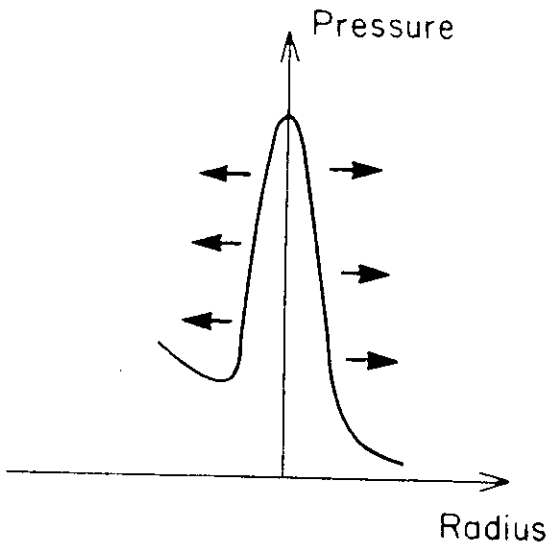


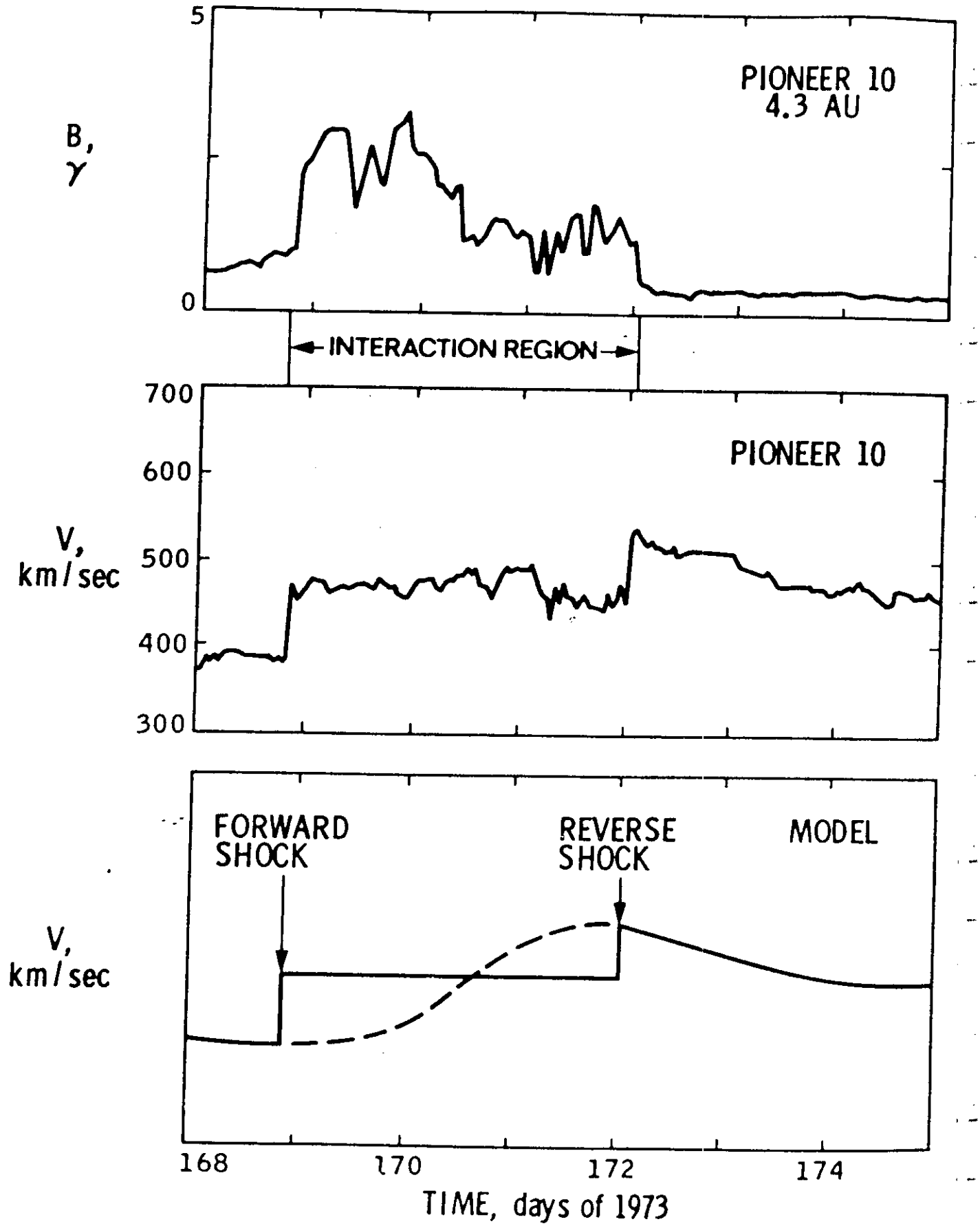
Figure 4. Solar wind structures associated with slow and fast streams corotating with the sun.

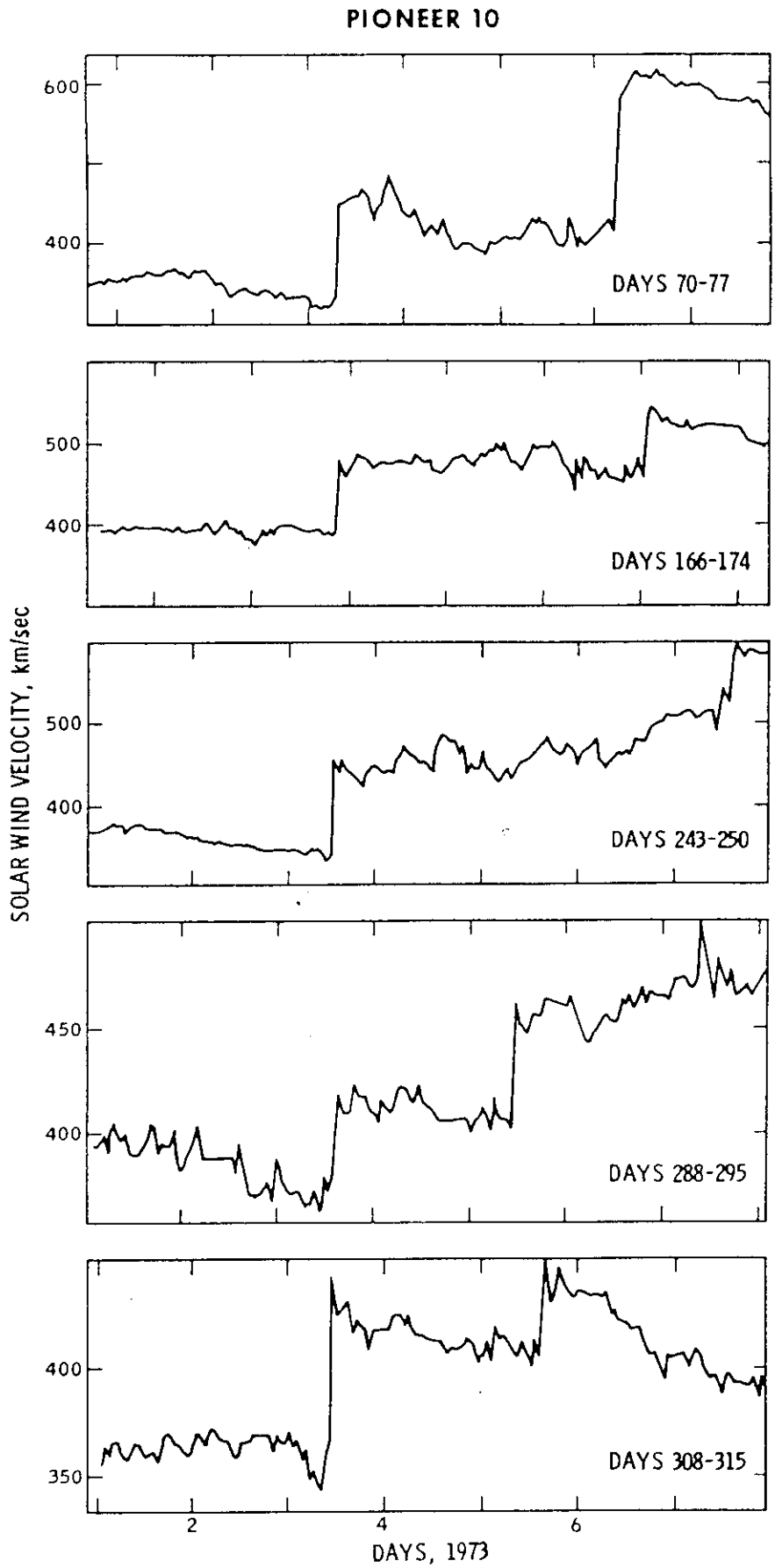


Flow is converging on this fluid parcel from both front and back.

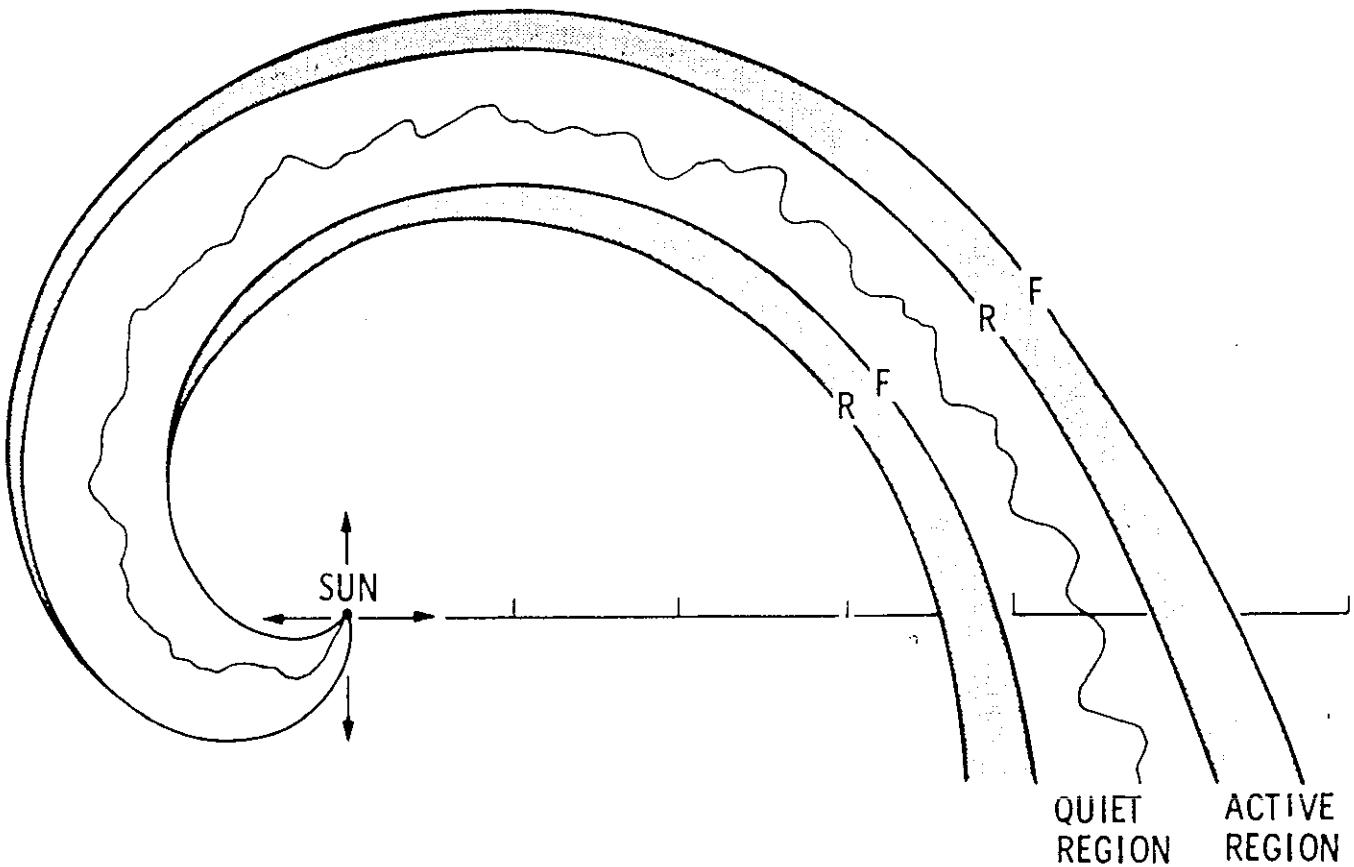


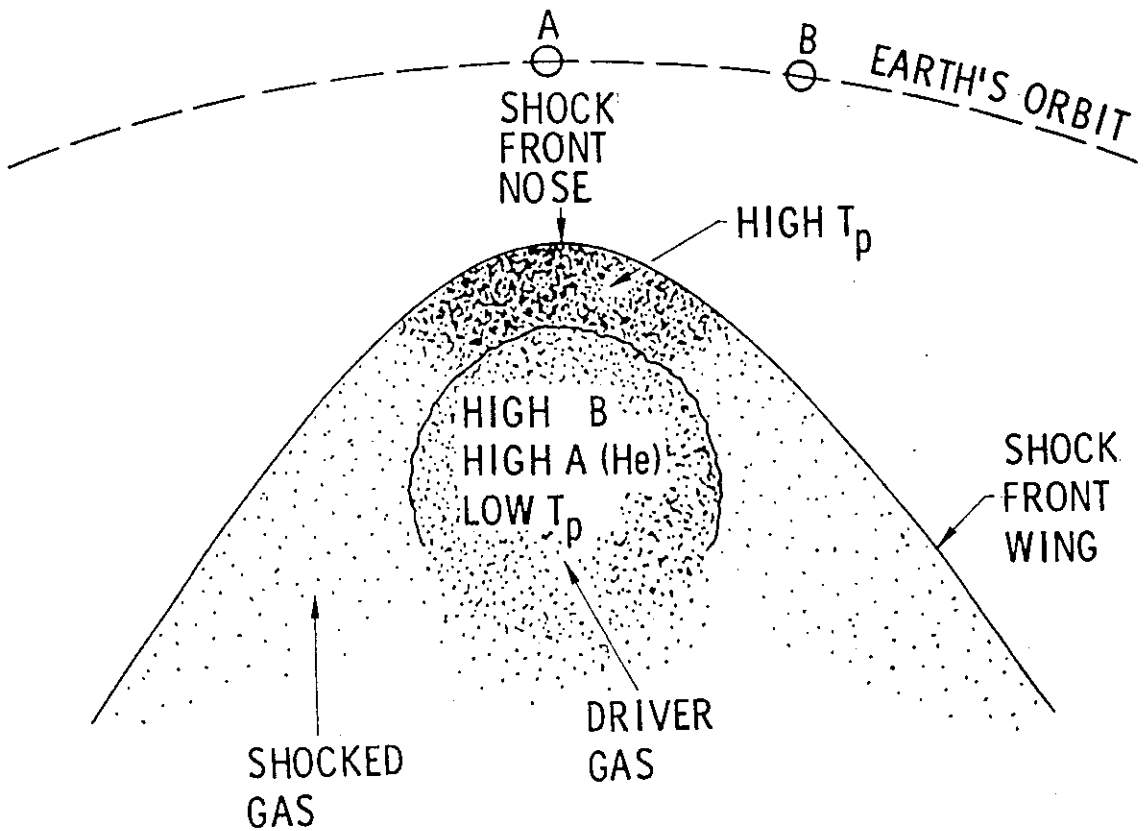
Pressure forces act to counter this convergence, reduce speeds to zero (in this frame).

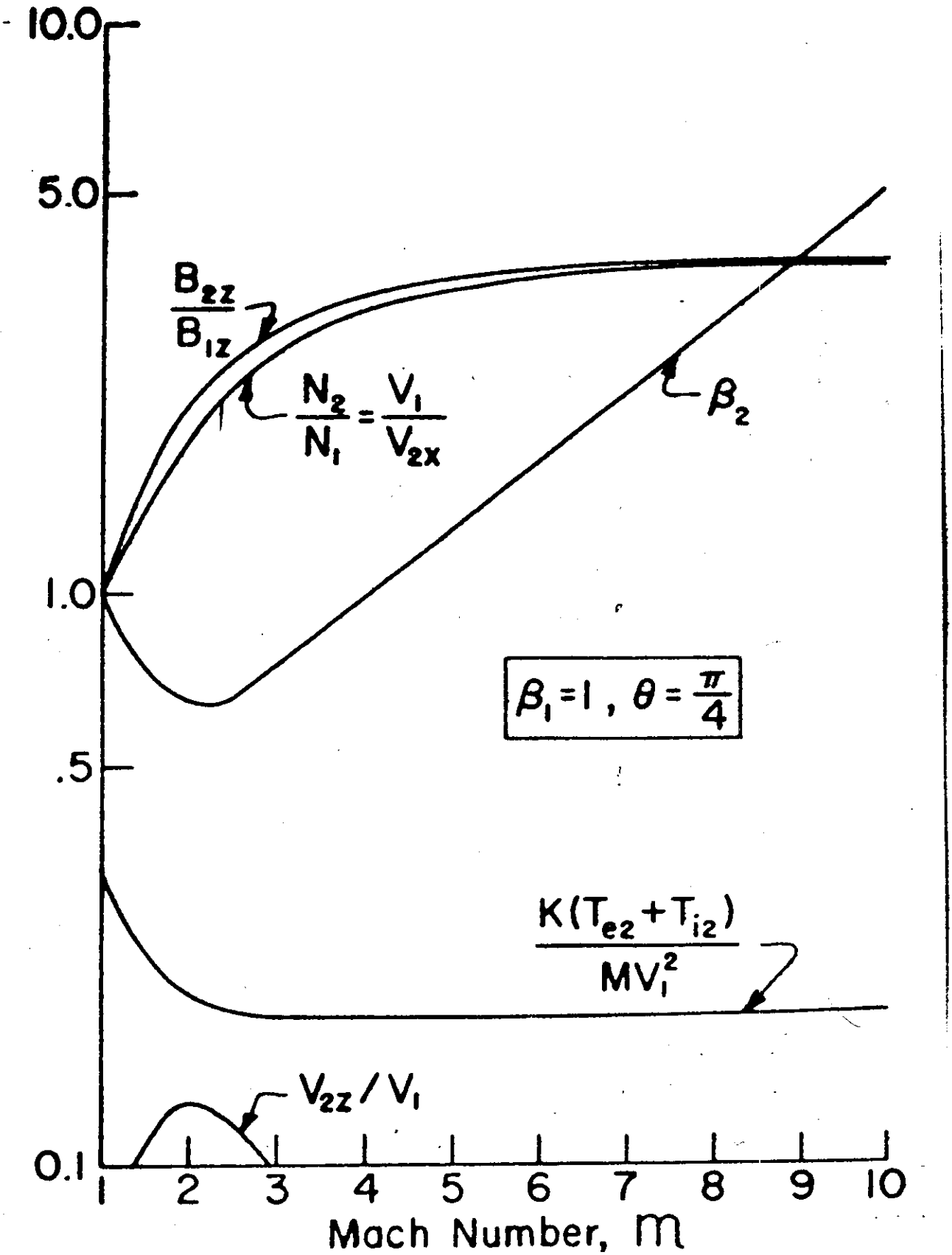

5
0
B,
γ
PIONEER 10
4.3 AU
INTERACTION REGION
700
600
500
400
300
V,
km/sec
PIONEER 10
FORWARD
SHOCK
REVERSE
SHOCK
MODEL
V,
km/sec
168
170
172
174
TIME, days of 1973


PIONEER 10
600
400
DAYS 70-77
500
400
DAYS 166-174
SOLAR WIND VELOCITY, km/sec
500
400
DAYS 243-250
450
400
DAYS 288-295
400
350
DAYS 308-315
2
4
6
DAYS, 1973

COROTATING INTERPLANETARY REGIONS




A
B
EARTH'S ORBIT
SHOCK
FRONT
NOSE
HIGH T_p
HIGH B
HIGH A (He)
LOW T_p
SHOCK
FRONT
WING
SHOCKED
GAS
DRIVER
GAS


10.0
5.0
1.0
.5
0.1
$\frac{B_{2z}}{B_{1z}}$
$\frac{N_2}{N_1} = \frac{V_1}{V_{2x}}$
β_2
$\beta_1 = 1$, $\theta = \frac{\pi}{4}$
$\frac{K(T_{e2} + T_{i2})}{MV_1^2}$
V_{2z} / V_1
2
3
4
5
6
7
8
9
10
Mach Number, M

SHOCK SPEED
SOLAR WIND FRAME

- CONSERVATION OF MASS

$$V_S = \left(\frac{\rho_2}{\rho_2 - \rho_1}\right) \Delta\vec{V} \cdot \hat{n}$$

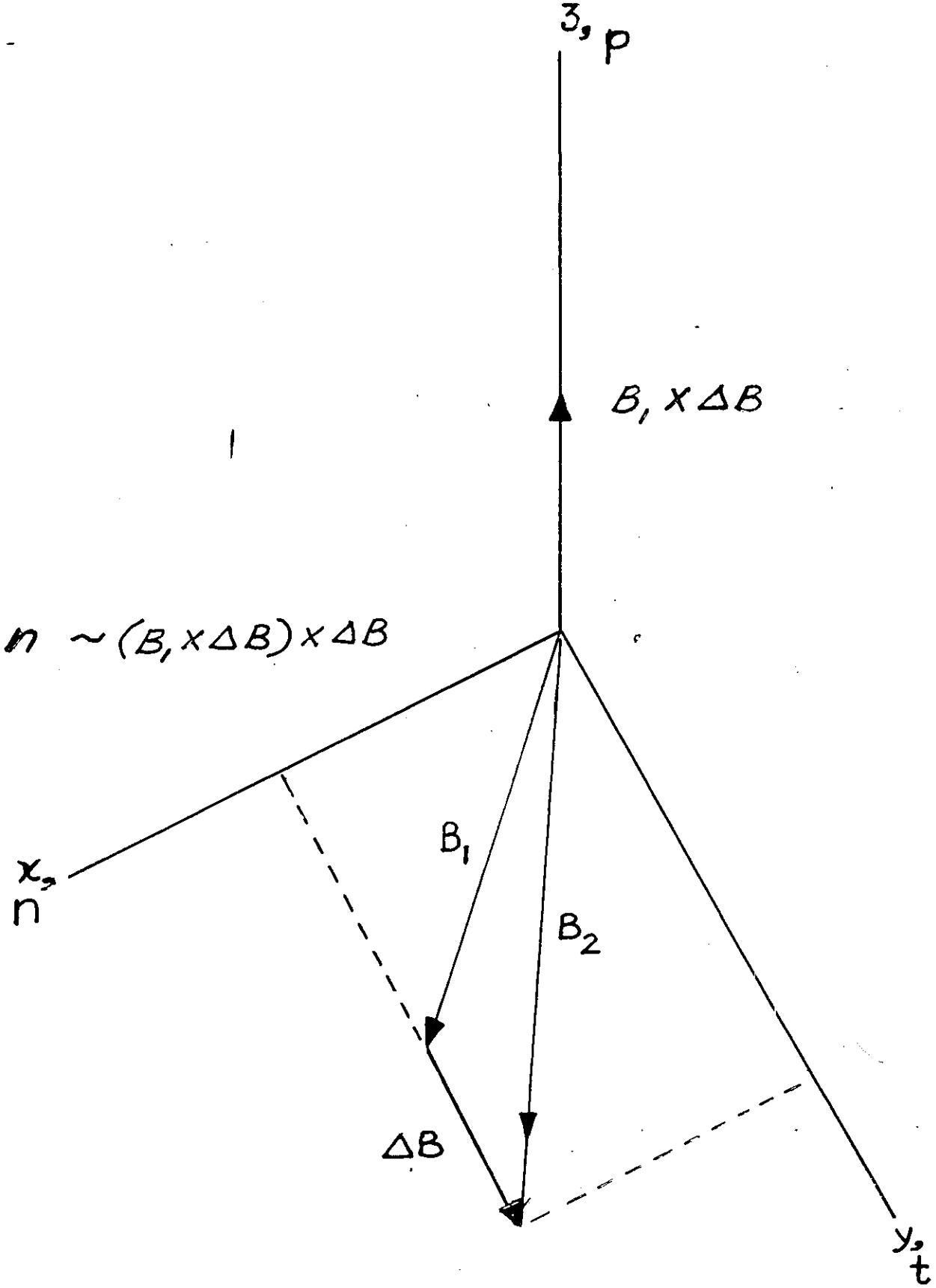
- CONSERVATION OF ELECTRIC FIELD

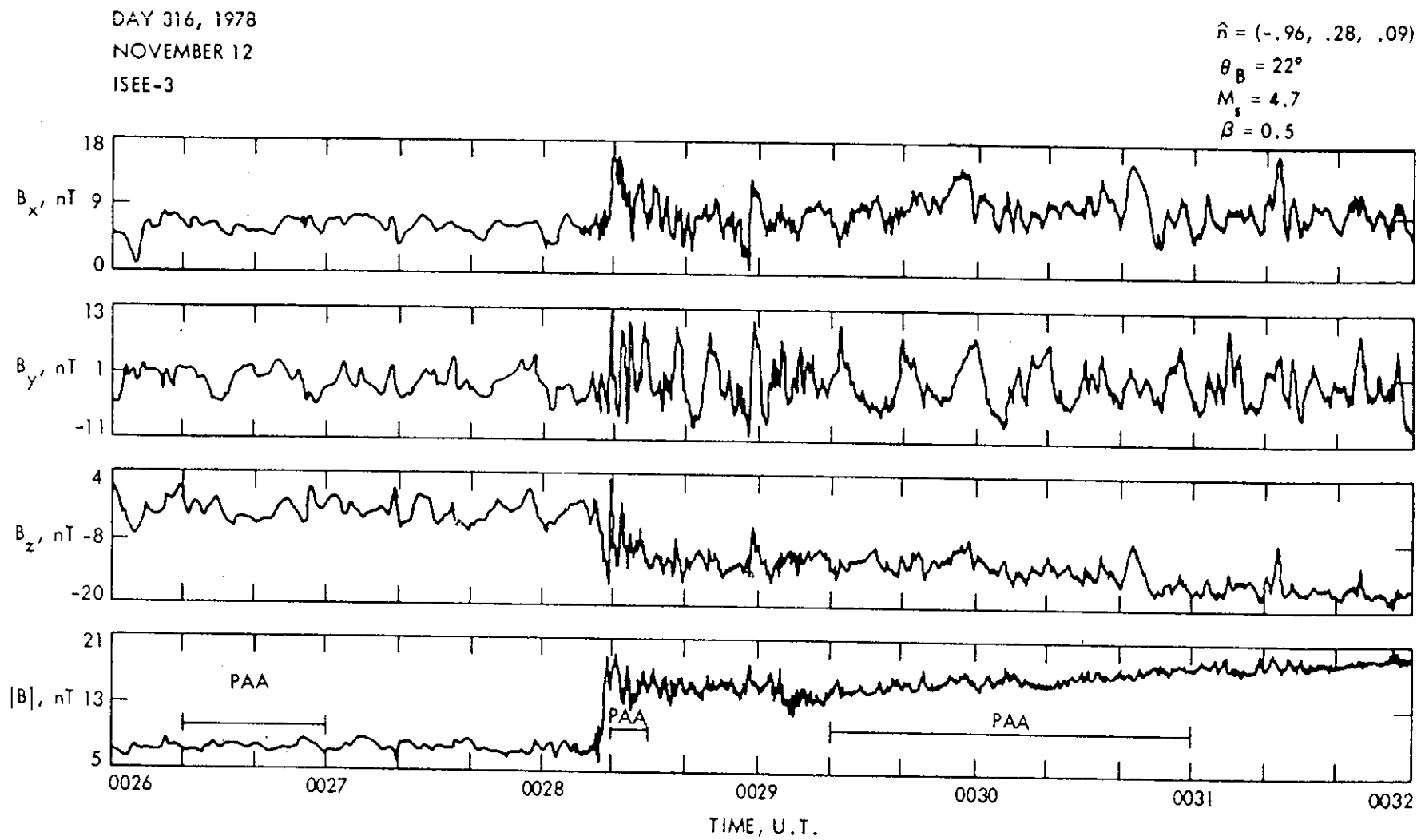
$$V_S = \frac{\left|\Delta\vec{V} \times \vec{B}_2\right|}{\left|\vec{B}_2 - \vec{B}_1\right|}$$

ADVANTAGES: NO RELIANCE ON $\hat{n}$

RAPID SAMPLING OF $\vec{B}$

Coplanarity




DAY 316, 1978
NOVEMBER 12
ISEE-3
$\hat{n}$ = (-.96, .28, .09)
θ_B = 22°
M_s = 4.7
β = 0.5
18
B_x, nT 9
0
13
B_y, nT 1
-11
4
B_z, nT -8
-20
21
|B|, nT 13
5
PAA
PAA
PAA
0026
0027
0028
0029
0030
0031
0032
TIME, U.T.

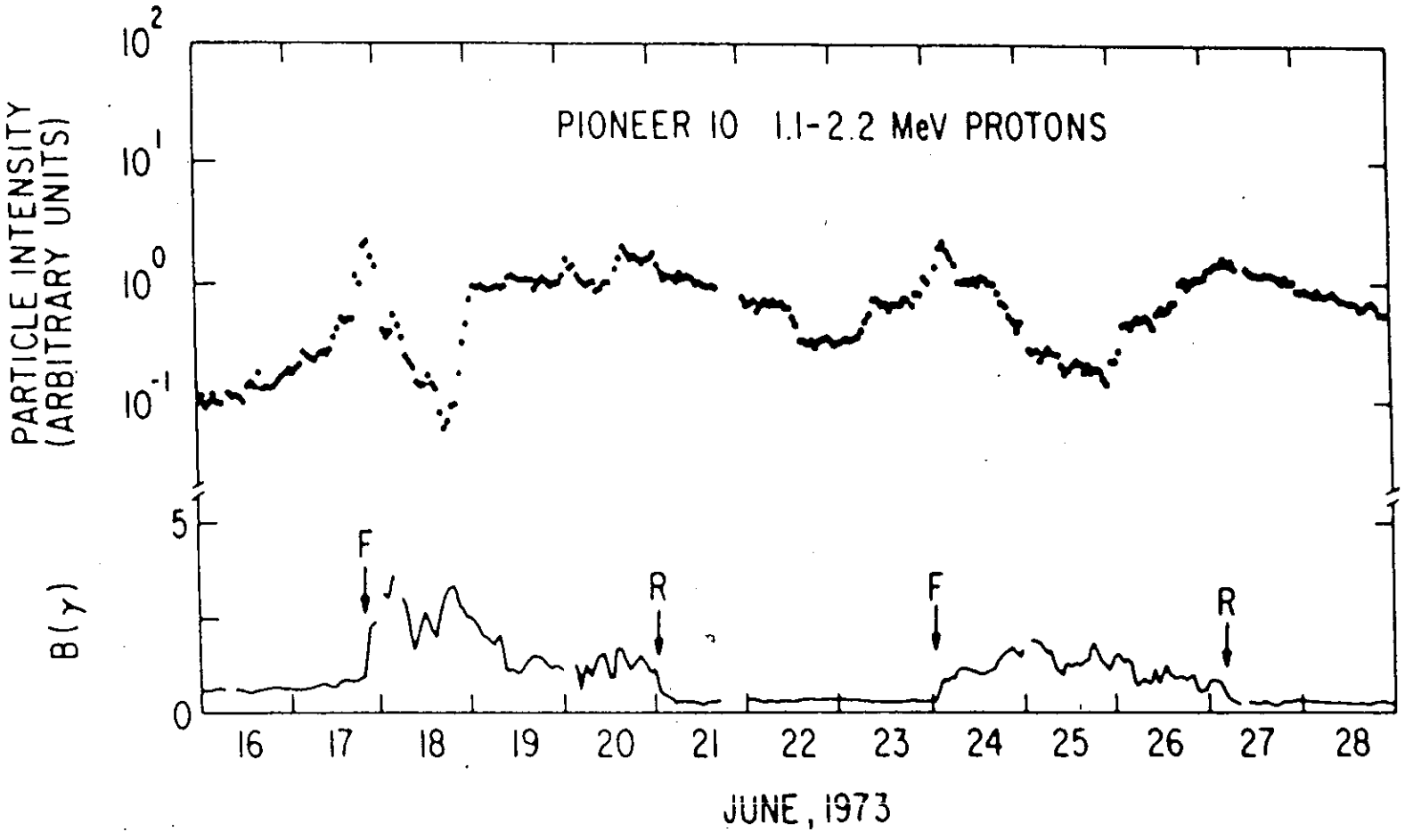
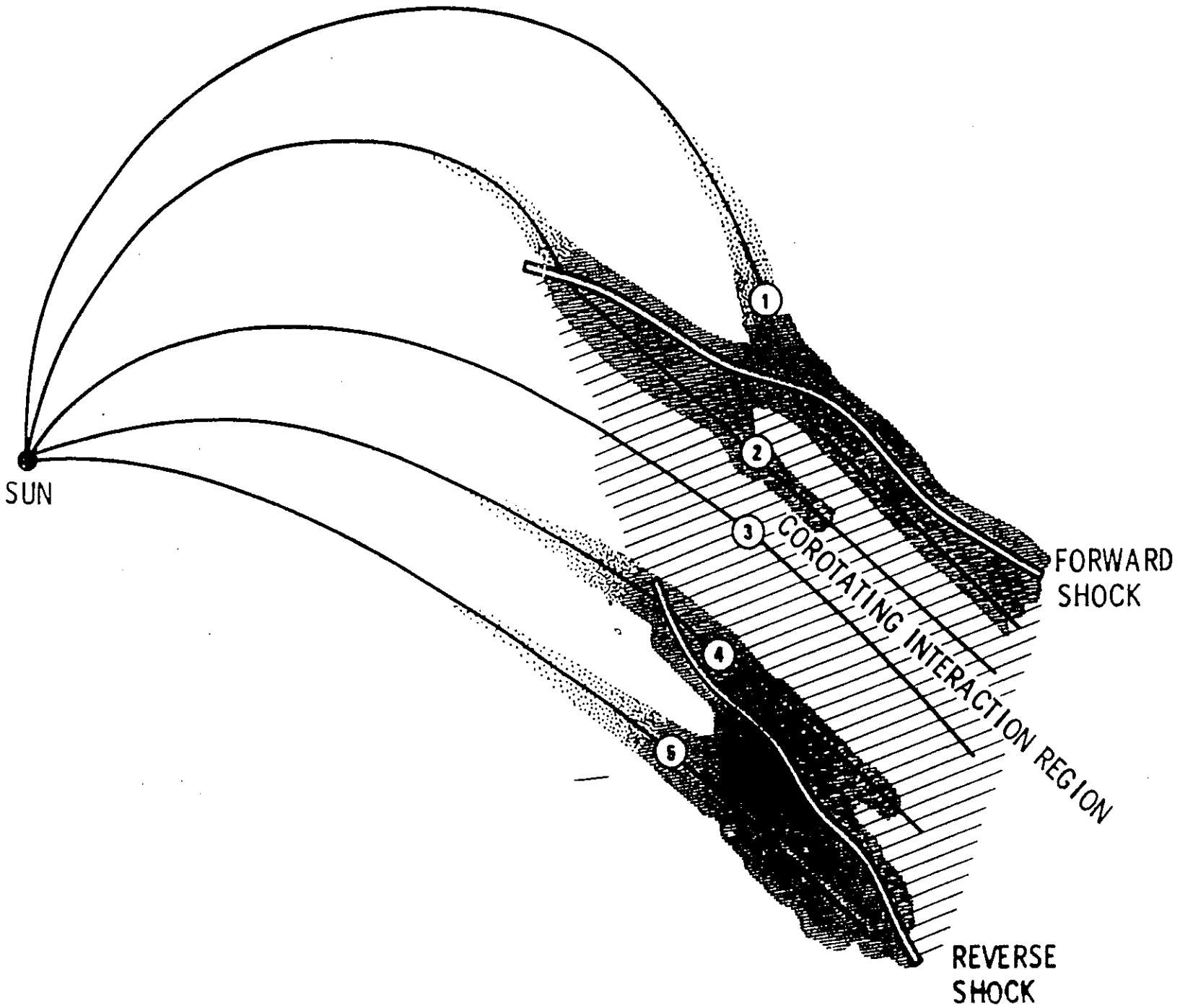


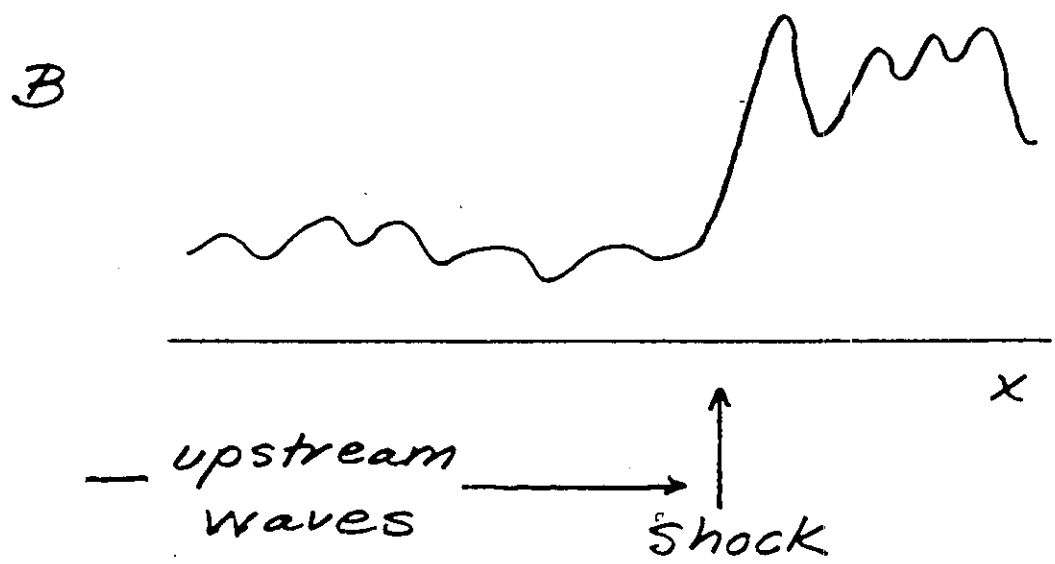
Figure 5. Interplanetary Particles accelerated at Forward and Reverse Shocks accompanying Corotating Interaction Regions.


SUN
1
2
3
4
6
COROTATING INTERACTION REGION
FORWARD SHOCK
REVERSE SHOCK

~ Acceleration of particles

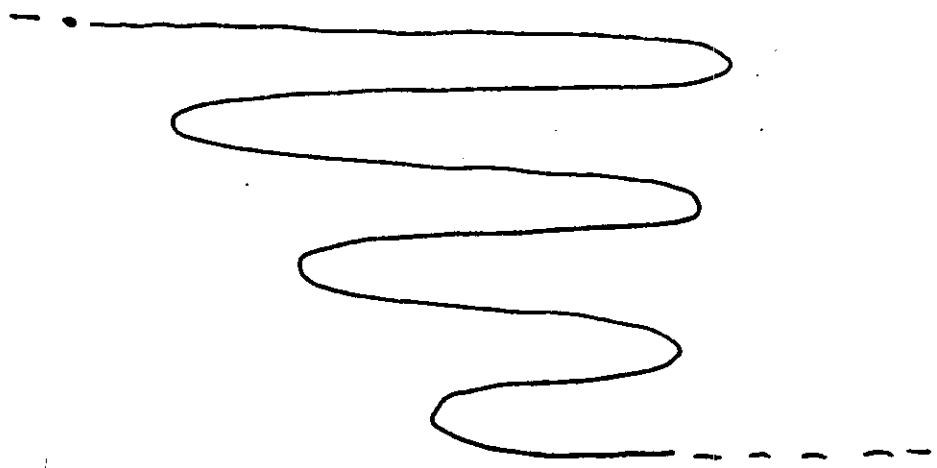
- Fermi Mechanism

- Involves waves and shocks



- particles trapped between Shock and approaching waves

- particle motion



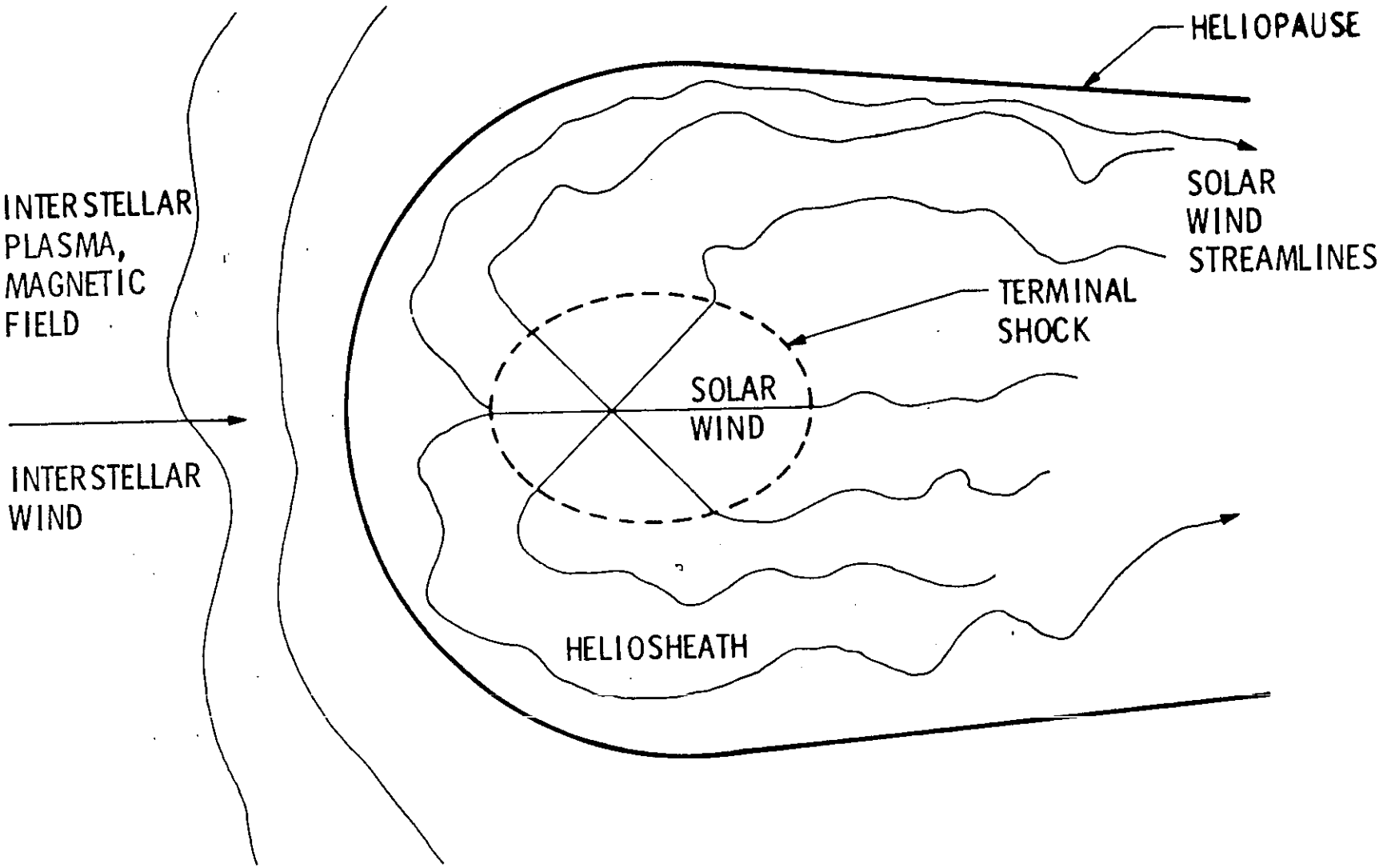
INTERSTELLAR CONSTITUENTS ORIGINATING OUTSIDE THE HELIOSPHERE

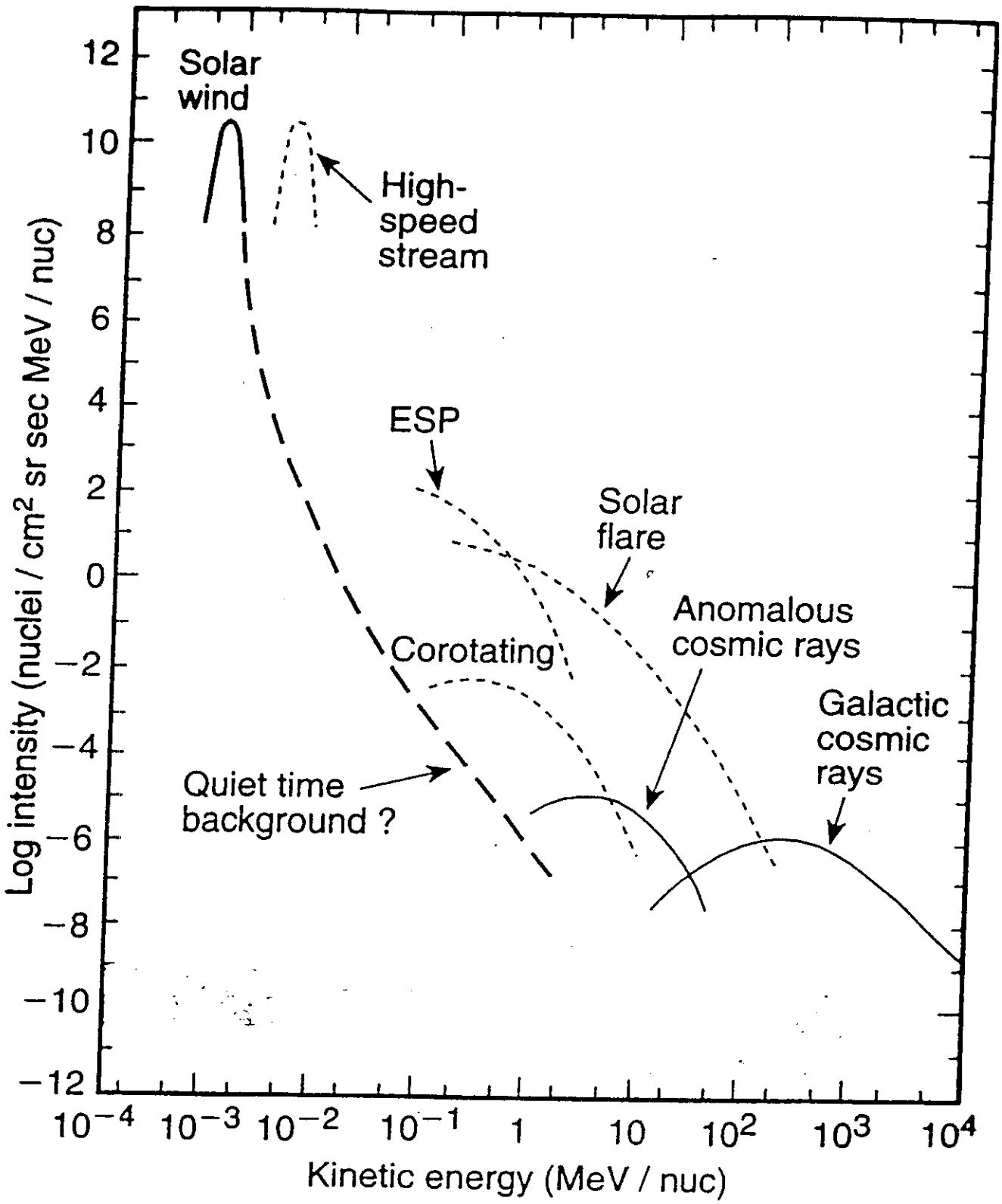
- Magnetic field
- Plasma
  - ions and electrons
- Neutral particles*
- Galactic cosmic rays*
- Dust*
- Gamma rays*
- Gravitational radiation?*

* Can penetrate into the heliosphere

ULYSSES

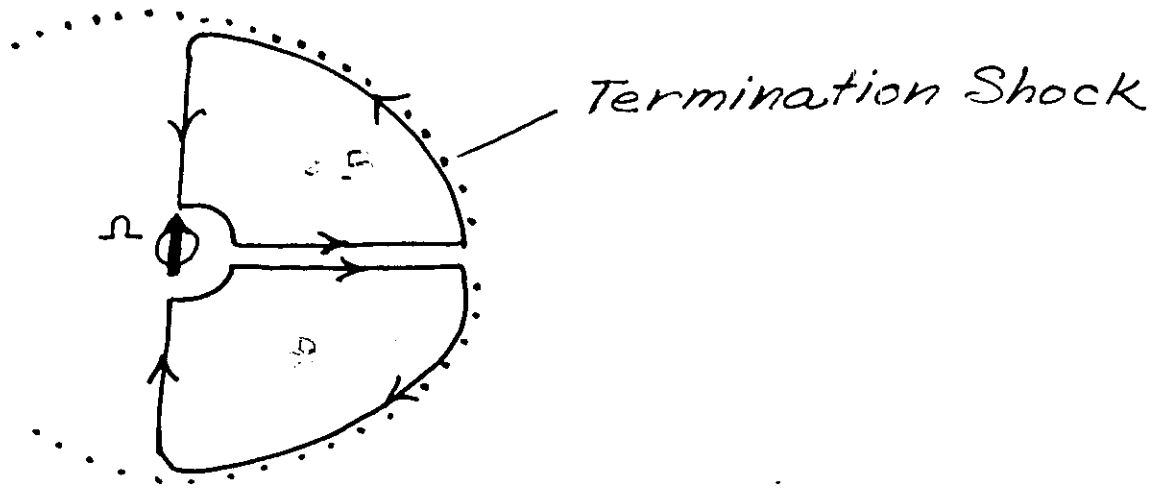
THE HELIOSPHERE





Spectra of energetic ^{16}O nuclei from various particle populations. (Other nuclear species tend to have similar spectra.) Solid curve = steady-state components; light dashed curve = transient phenomena; heavy dashed curve = postulated quiet-time flux of supra-thermal solar particles.

Drift of Anomalous Cosmic Rays



. shock drift acceleration

$$V = \int_{\pi/2}^{0} E_\theta \, r \, d\theta$$

$$E_\theta = -\vec{v} \times \vec{B} = -v_r B_\phi$$

$$B_\phi = -\frac{\Omega r \sin\theta}{v_r} B_r$$

$$E_\theta = -\Omega r_0 \sin\theta \, B_{r_0} (r_0/r)$$

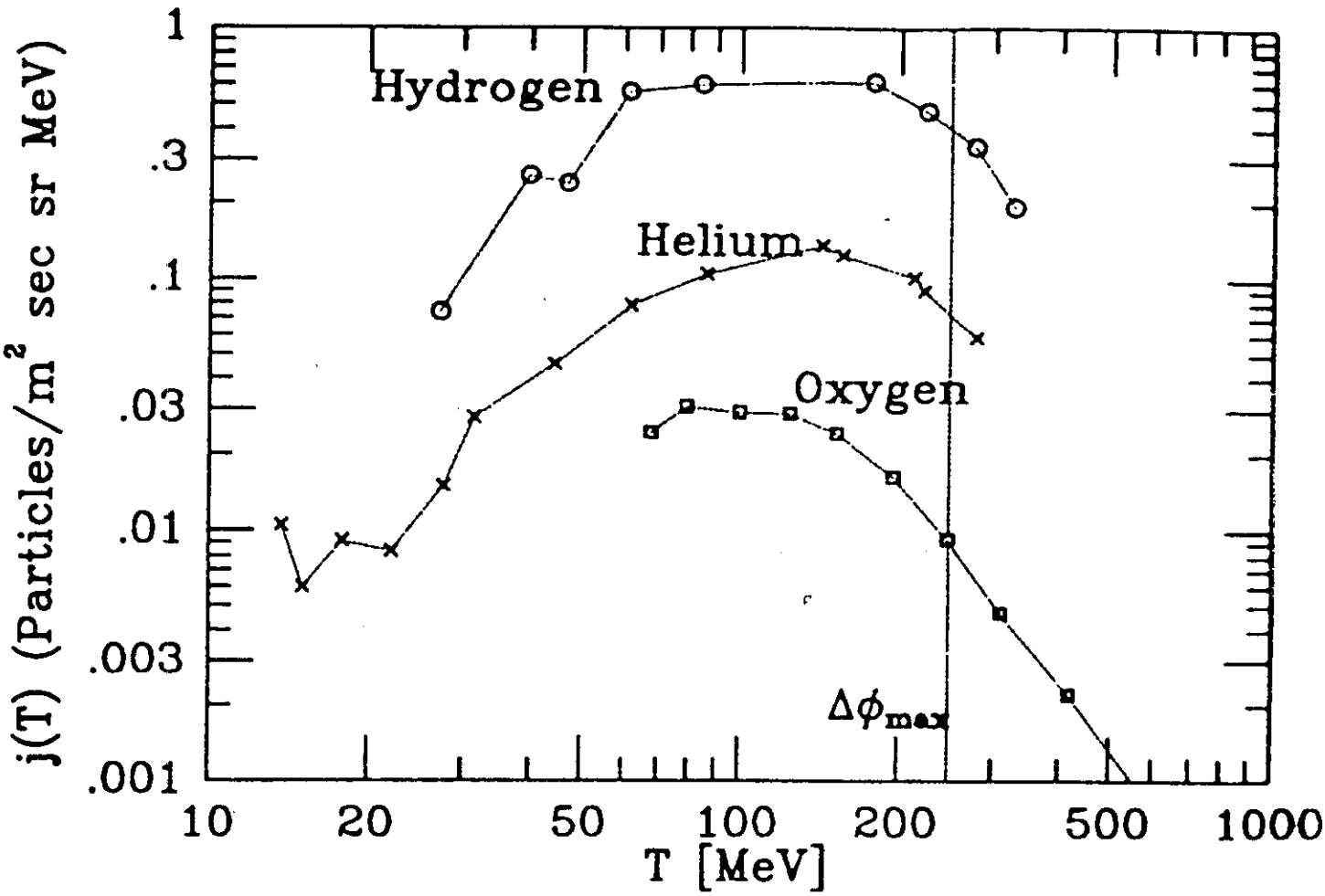
$(r_0 = 1\ AU)$

$$V = -\Omega r_0 B_{r_0} r_0 \int_{\frac{\pi}{2}}^{0} \sin\theta \, d\theta$$

$$= \Omega r_0 B_{r_0} r_0$$

$$\cong \left(400 \frac{km}{s}\right)\left(3 \times 10^{-9} T\right)\left(1.5 \times 10^{8} km\right)$$

$\therefore V = 2 \times 10^{8}$ volts


Hydrogen
Helium
Oxygen
$\Delta\phi_{max}$
j(T) (Particles/m^2 sec sr MeV)
T [MeV]
1
.3
.1
.03
.01
.003
.001
10
20
50
100
200
500
1000