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INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
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H4-SMR 393/10

SPRING COLLEGE ON PLASMA PHYSICS

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ALFVENIC TURBULENCE IN BEAM-PLASMA SYSTEMS (III)

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PITCH ANGLE DIFFUSION

Gaffey et al JGR 93, 5470, 1988
Gaffey & Wu JGR in press 1989

The equation for $\partial F/\partial t$ in quasilinear theory can be written as a diffusion equation in the wave frame

$$\frac{\partial F}{\partial t} = \frac{\partial}{\partial \mu}\left[(1-\mu^2) D \frac{\partial F}{\partial \mu}\right] + \epsilon\, S(v,\mu)$$

$$\mu = \cos\alpha \qquad \epsilon = \frac{\partial n_i}{\partial t} \quad (\text{ionisation rate})$$

where
$$D = \frac{\pi q^2}{4 m^2 V_A^2} \int d^3k\, I_k\, \delta(\omega - k v_0 \mu_0 - \Omega_i)$$

Assume $D(\mu) = D(\mu_0)$ to make problem tractable

Put $F(\mu, v, 0) = \frac{n_i}{2\pi v_0^2}\, \delta(v - v_0)\, \delta(\mu - \mu_0)$

PITCH ANGLE DIFFUSION SOLUTIONS

Gaffey & Wu JGR (in press) 1989

$$F(\mu, v, t) = \frac{1}{2\pi v_0^2}\, \delta(v - v_0)\, G(\mu, t)$$

$$G(\mu, t) = n_0 G_0(\mu, t) + \frac{\epsilon}{D} G_1(\mu, t)$$

$$G_0(\mu, t) = \sum_{l=0}^{\infty} (l + \tfrac{1}{2}) P_l(\mu) P_l(\mu_0) \exp[-D l(l+1) t]$$

$$G_1(\mu, t) = \frac{Dt}{2} + \frac{1}{2} \sum_{l=1}^{\infty} \frac{(2l+1)}{(l+1)l} P_l(\mu) P_l(\mu_0) \{1 - \exp[-D l(l+1) t]\}$$

$$D = \frac{\pi}{2} \frac{\Omega_i^2}{B_0^2} \frac{V_A}{V_0} \frac{1}{|\cos\alpha|} P_B(\omega_\kappa)$$

$$\omega_\kappa = \Omega_i + k V_0 \cos\alpha_0$$

$P_B(\omega)$ – power spectral density of magnetic field at ω.

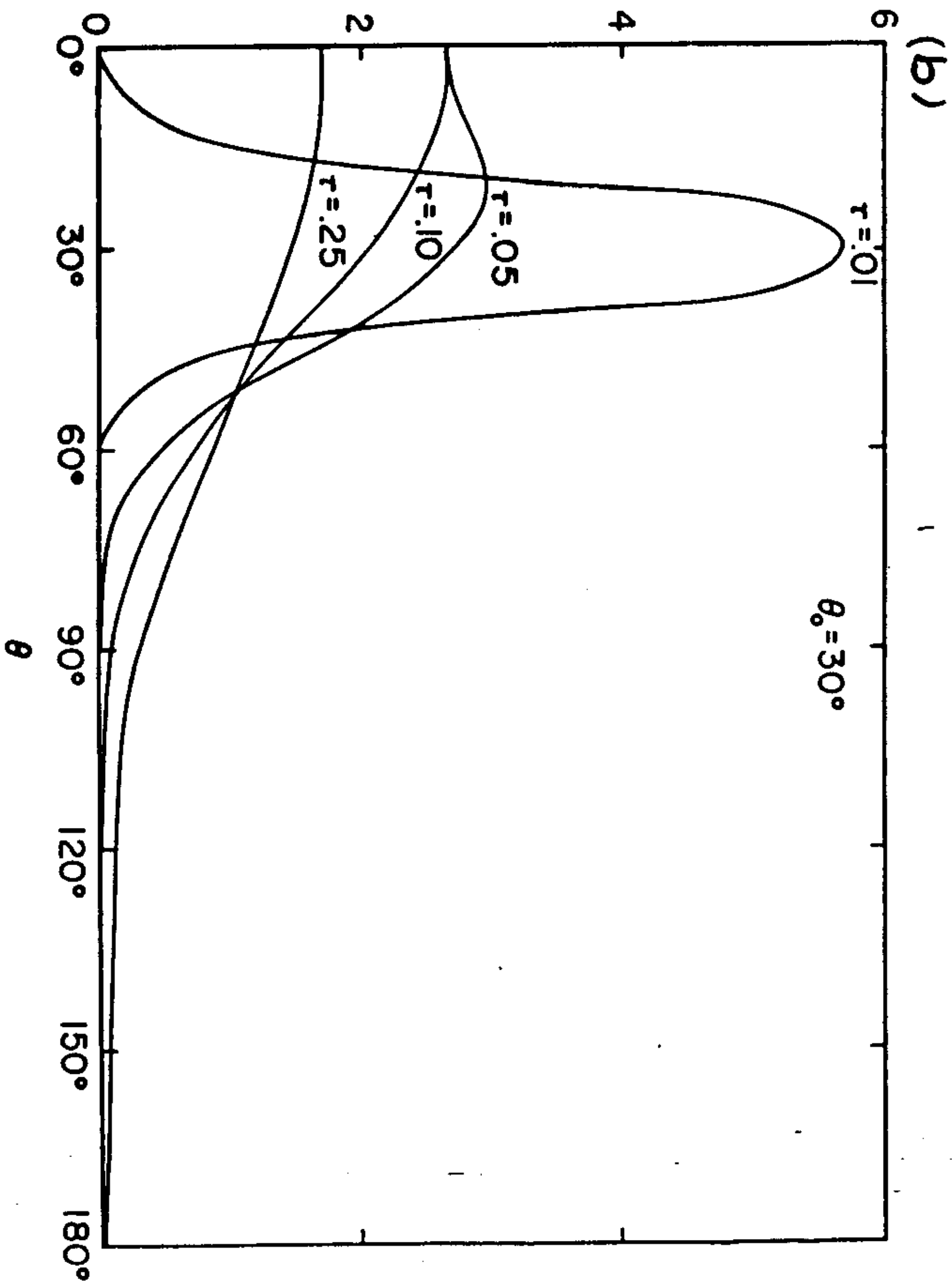


Figure 1b

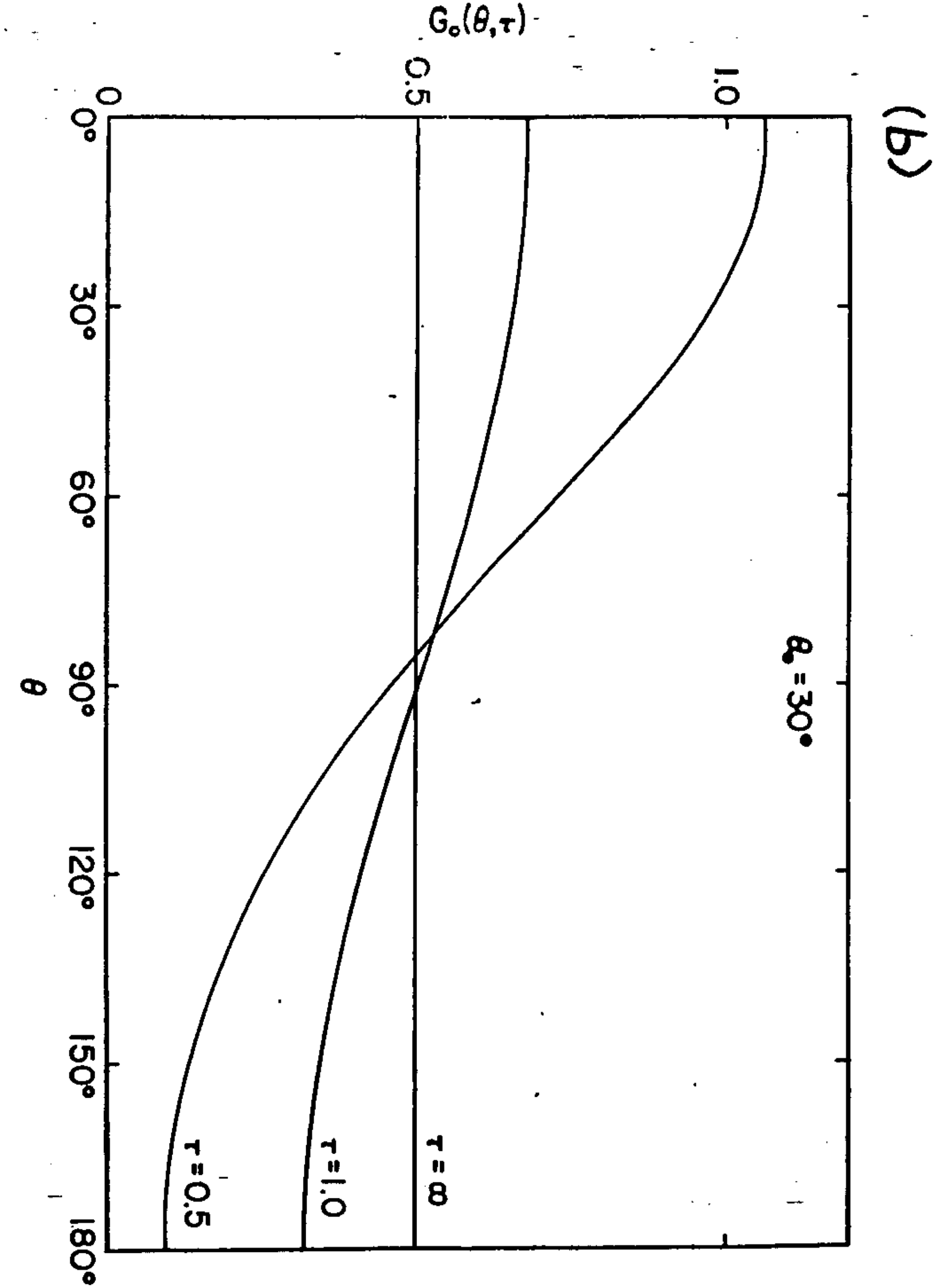


Figure 2b

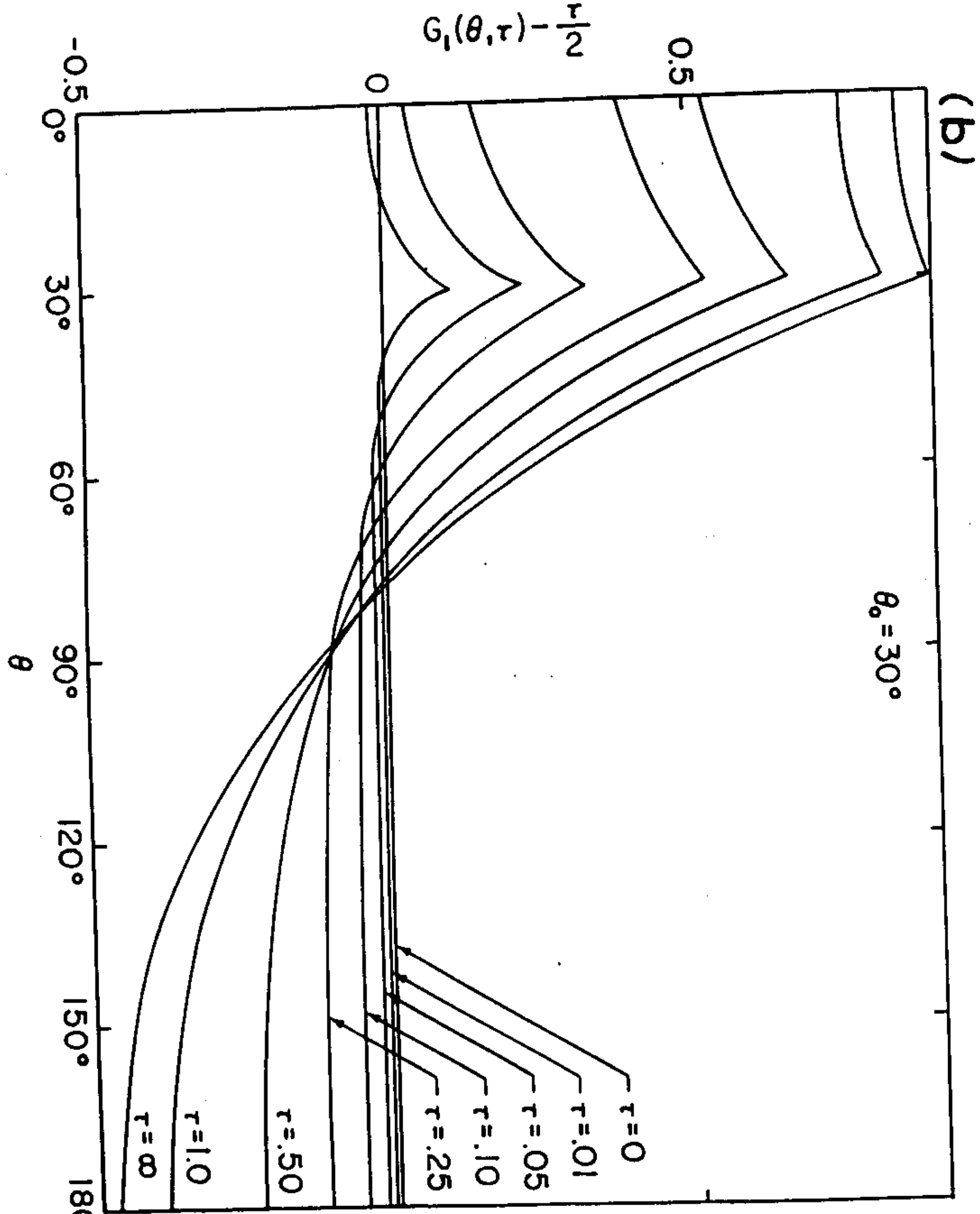
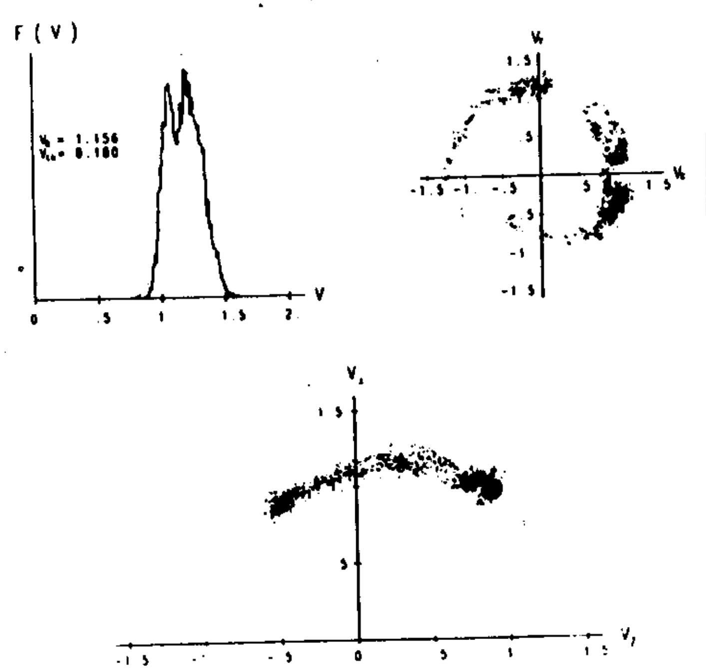


Figure 3b

0.5 gyroperiods

$\Omega_i t = 3.2$



$\frac{\delta B}{B} \sim 1$

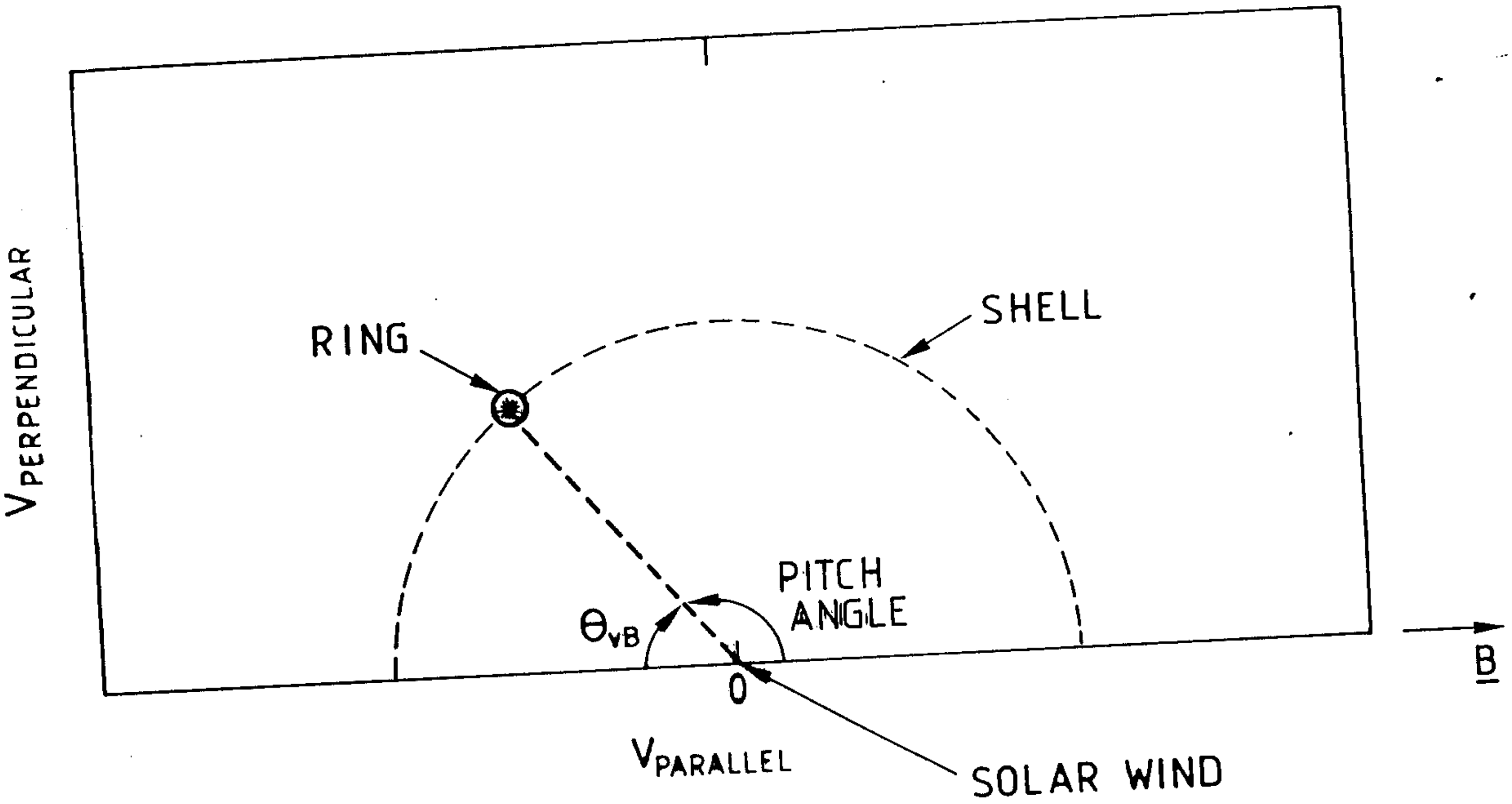


Figure 2 - View of the $v_\perp$-$v_\parallel$ frame centred on the solar wind. Integration is performed in the gyro angle around $\underline{B}$. A ring distribution is marked by the circled star and a shell distribution centred on the solar wind speed is shown by the dashed semicircle. Figures 3-8 are data plots using this format.

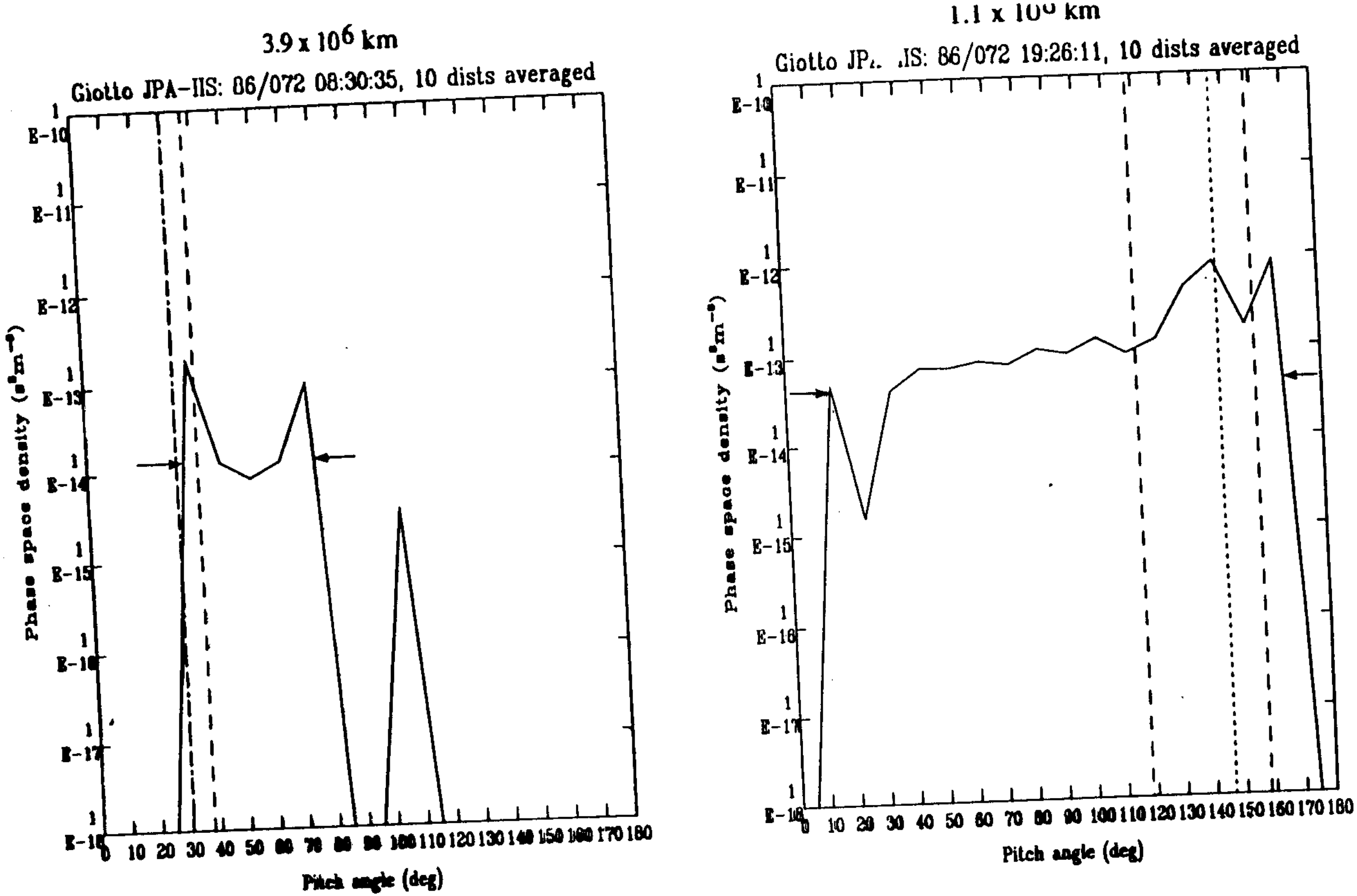


Figure 4 - Water group ion phase space density summed over energy as a function of pitch angle for two distances, (a) 3.9×10^6 km (b) 1.1×10^6 km. The pitch-angle width is defined as the width at 0.1 times the phase space density peak. There is some

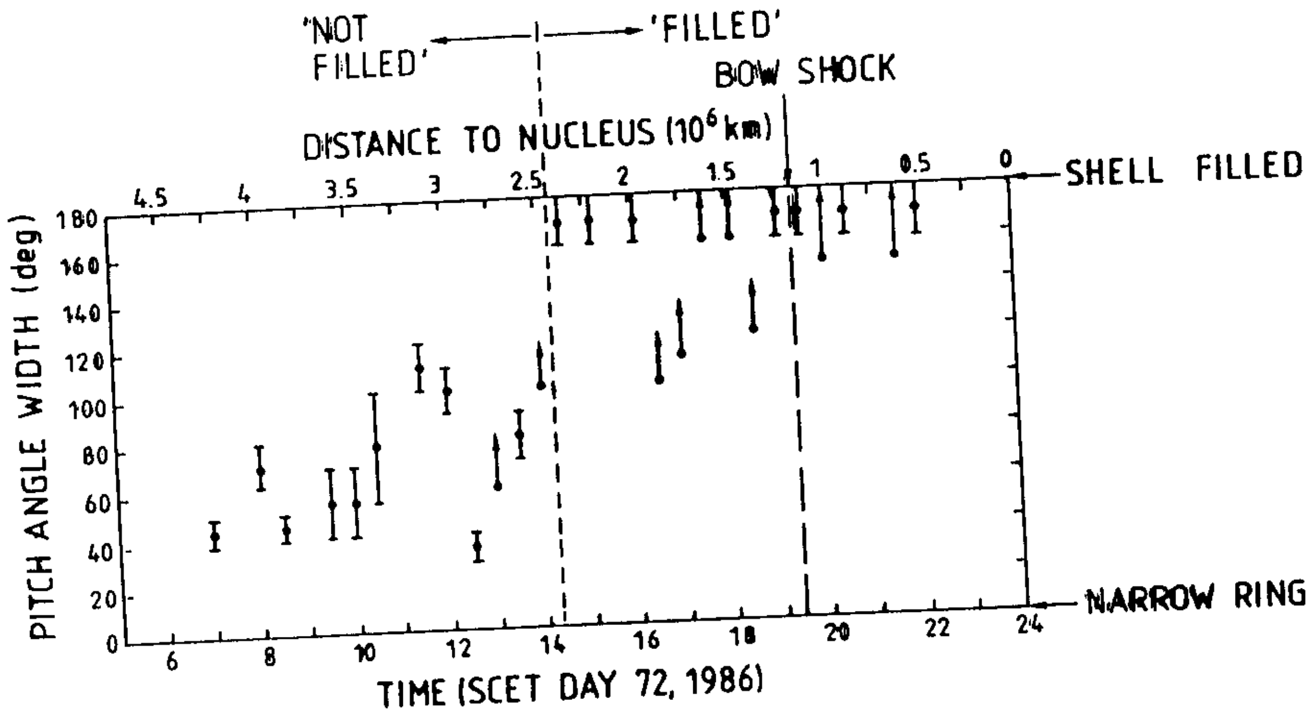
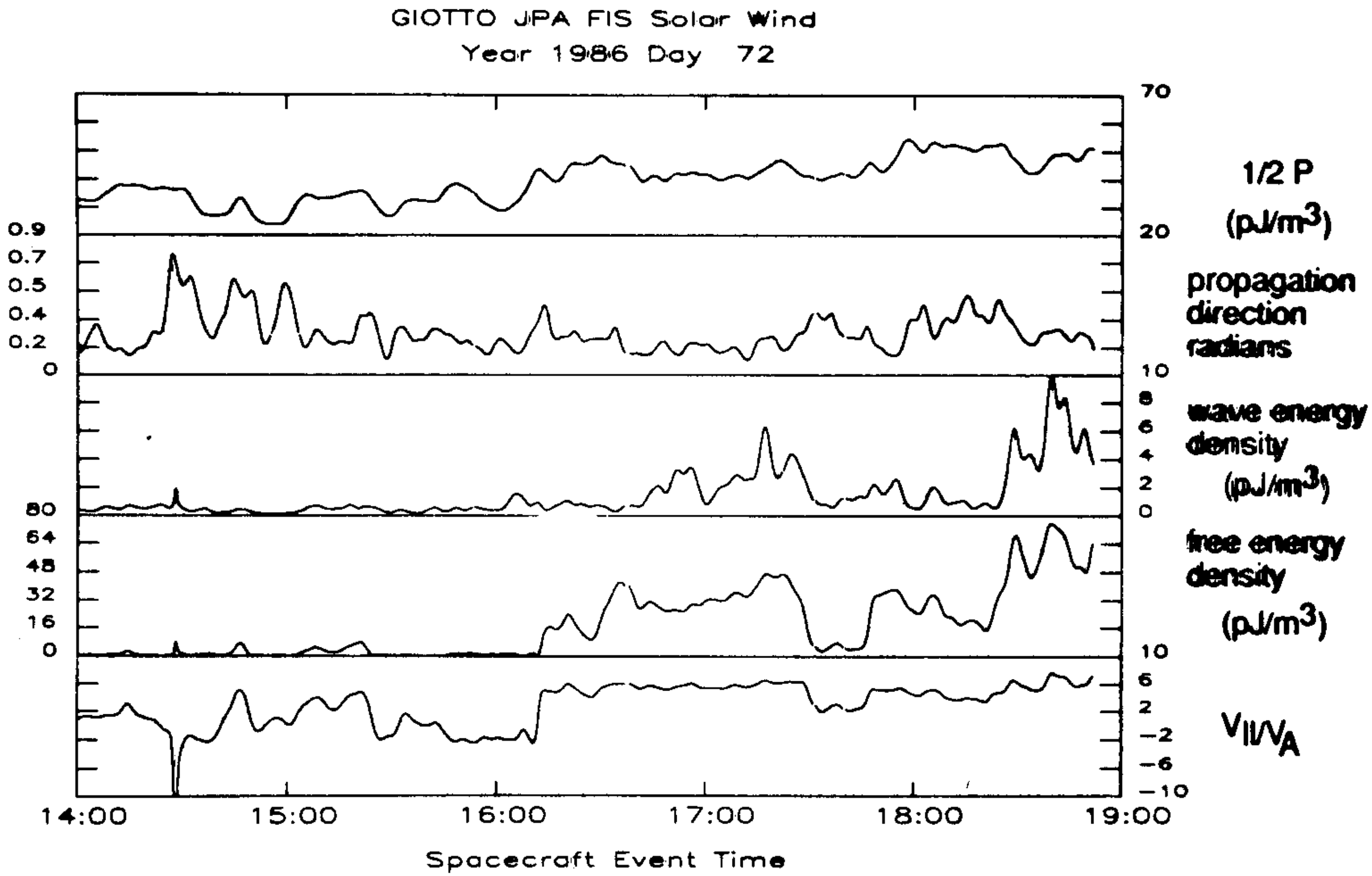


Figure 5 - Evolution of pitch-angle width with distance from the comet. A full shell would appear towards the top of the plot.


GIOTTO JPA FIS Solar Wind
Year 1986 Day 72
1/2 P
(pJ/m3)
propagation direction radians
wave energy density (pJ/m3)
free energy density (pJ/m3)
VII/VA
70
20
10
8
6
4
2
0
10
10
6
2
−2
−6
−10
0.9
0.7
0.5
0.4
0.2
0
80
64
48
32
16
0
14:00
15:00
16:00
17:00
18:00
19:00
Spacecraft Event Time

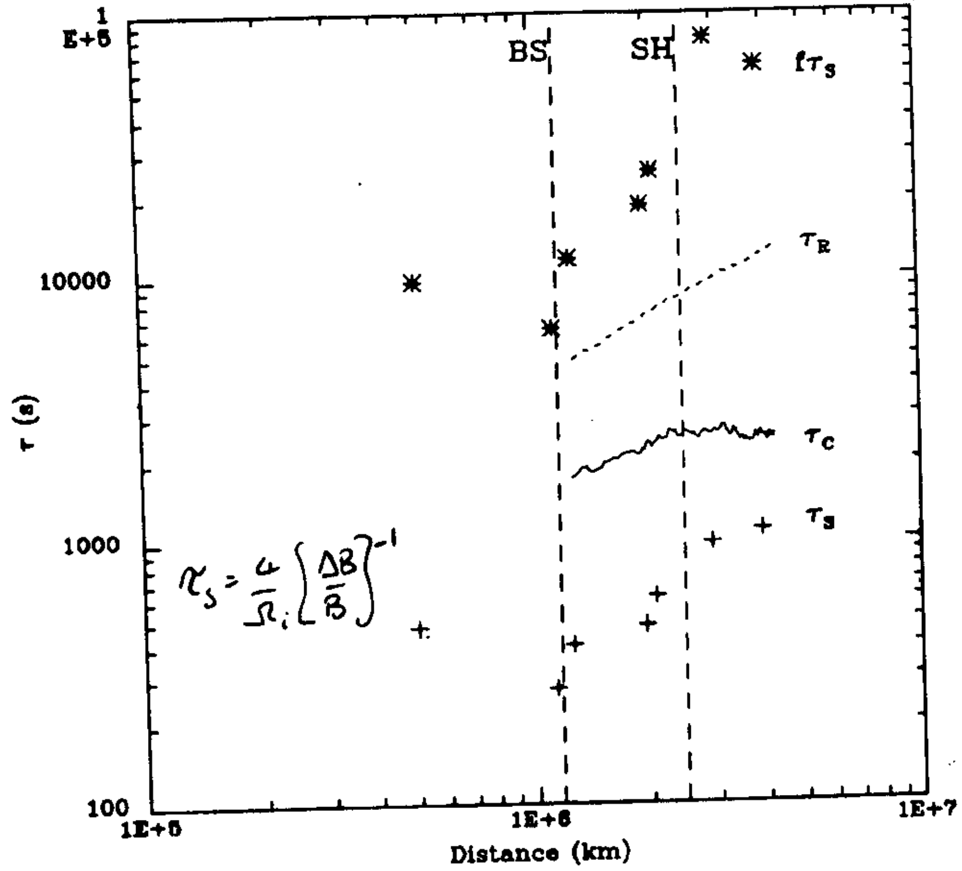


Figure 10 - Pickup times according to Equation 6 (τ_R - pickup region size assuming constant ionization rate [Richardson et al, 1988]), Equation 7 (τ_C - average time ions spend in solar wind flow [this paper]), Equation 3 (τ_S - pitch angle scattering time [Gaffey et al, 1988]), and f (= $(v_s/v_A)^2$) times τ_S ($f\tau_S$ - energy scattering time [Lyons and Williams, 1984]). The vertical lines indicate the maximum distance where the observations show a filled shell (SH) and the position of the bow shock (BS).

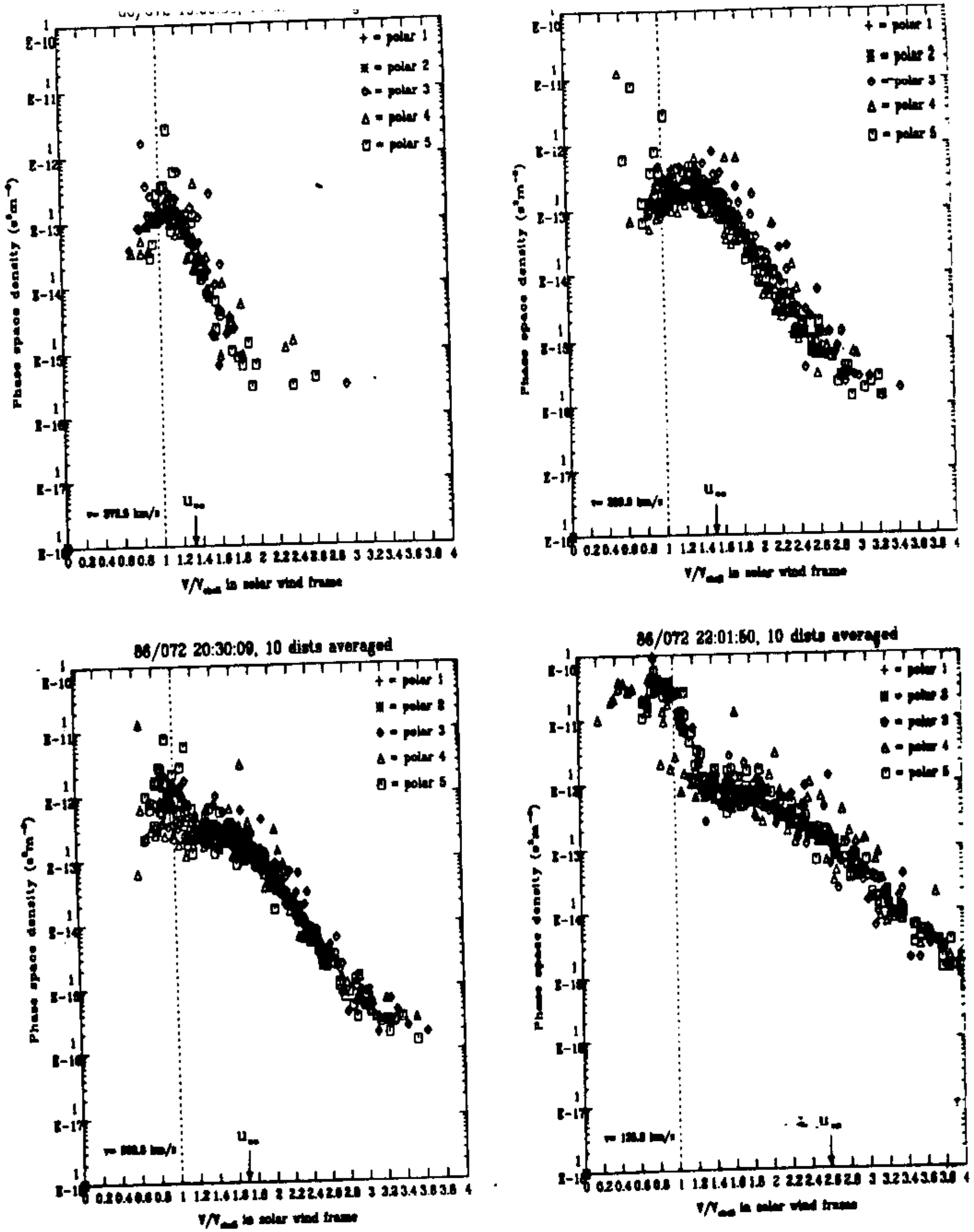
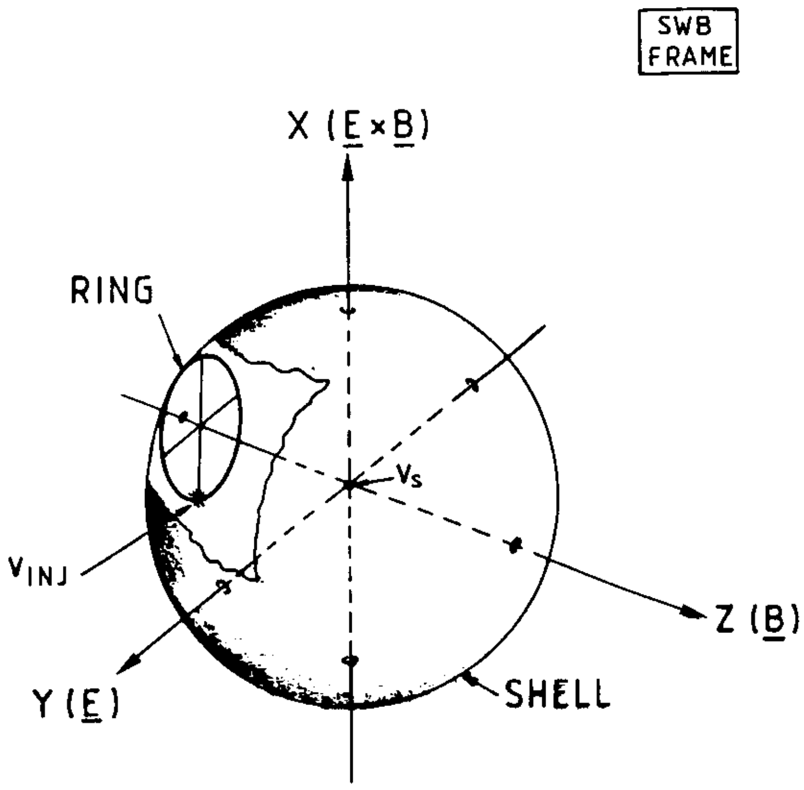


Figure 7 - Phase space density versus velocity normalised to the local solar wind speed, in the solar wind frame. Downstream of the shock a second component, travelling at the upstream solar wind speed (cf Thomsen et al 1987) is visible.



$$V_{INJ\parallel} = \frac{\underline{V} \cdot \underline{B}}{B}$$

$$V_{INJ\perp} = \frac{\underline{E} \times \underline{B}}{B^2}$$

Predicted bulk velocities in SWB Frame

RING distribution $(0,0,V_{INJ\parallel})$

SHELL distribution $(0,0,0)$

SHELL distribution,
centred on $\pm V_a$ along B $(0,0,\pm V_a)$

Figure 2 - The SWB (solar wind field-aligned) frame, showing the ion injection point (v_{inj}, shown by a star), ring and shell distributions, with the coordinates of v_{inj}

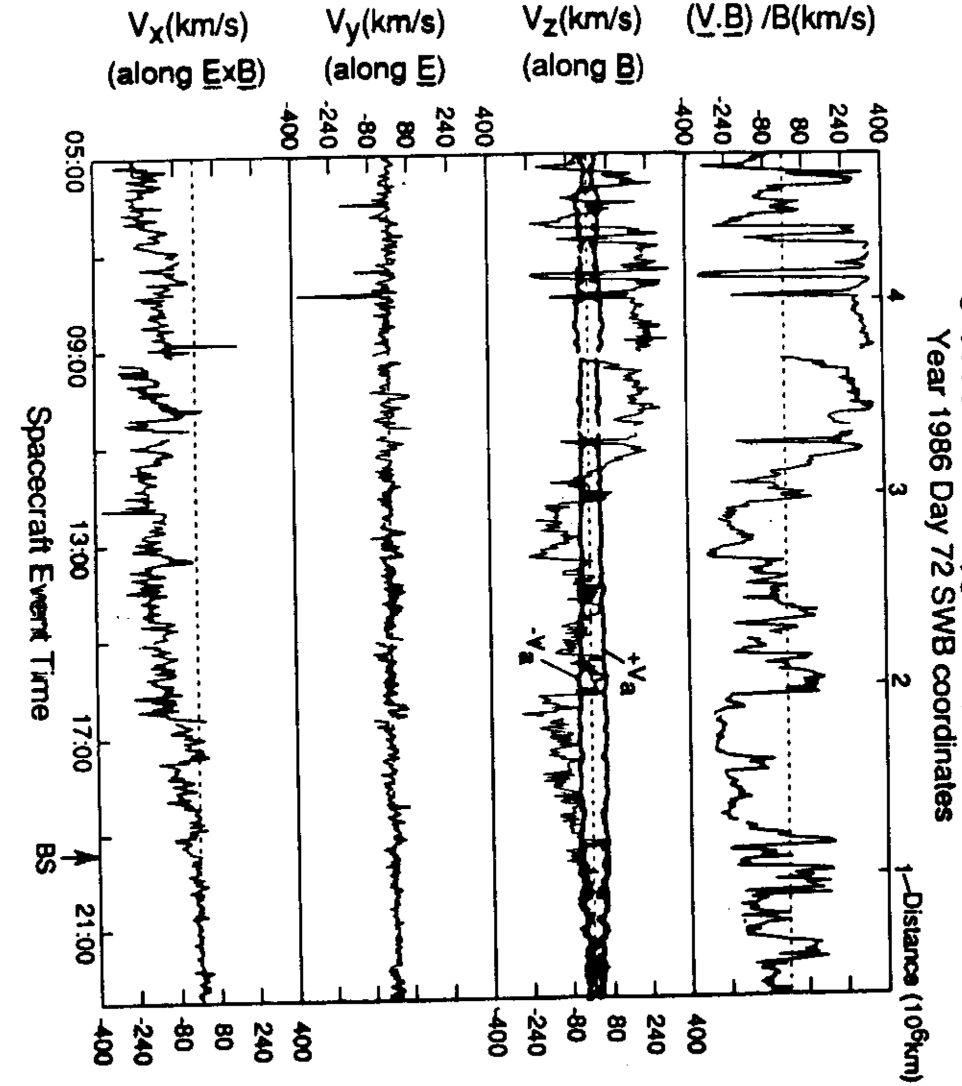


Figure 6 - From the bottom, the first 3 panels show the measured water group velocity components in the SWB frame for the inbound leg. The top panel shows the ring

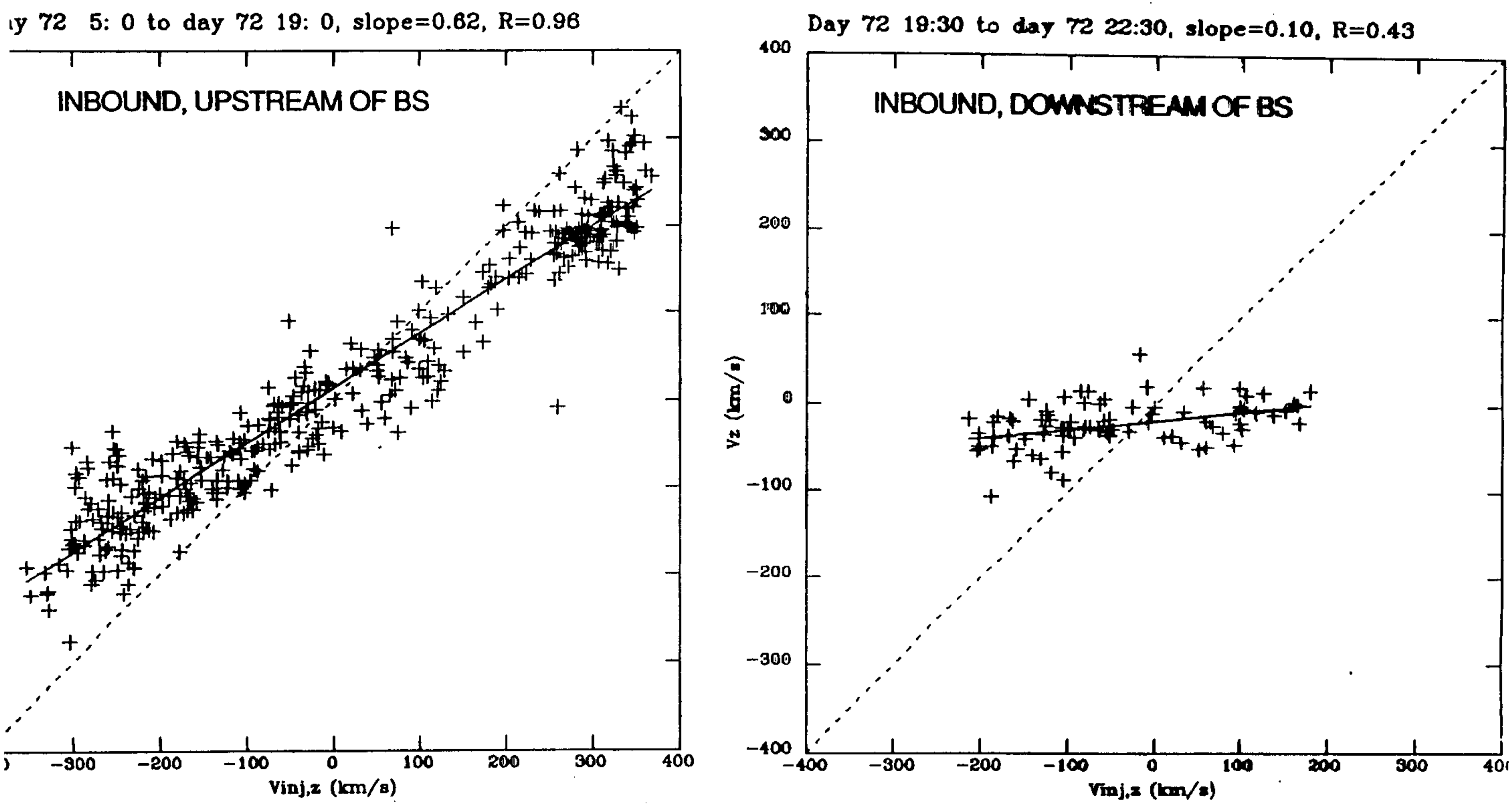


Figure 7 - (a) Scatter plot of the measured v_z component (ordinate) against the ring prediction (abscissa), upstream of the bow shock on the inbound pass. (b) Similar

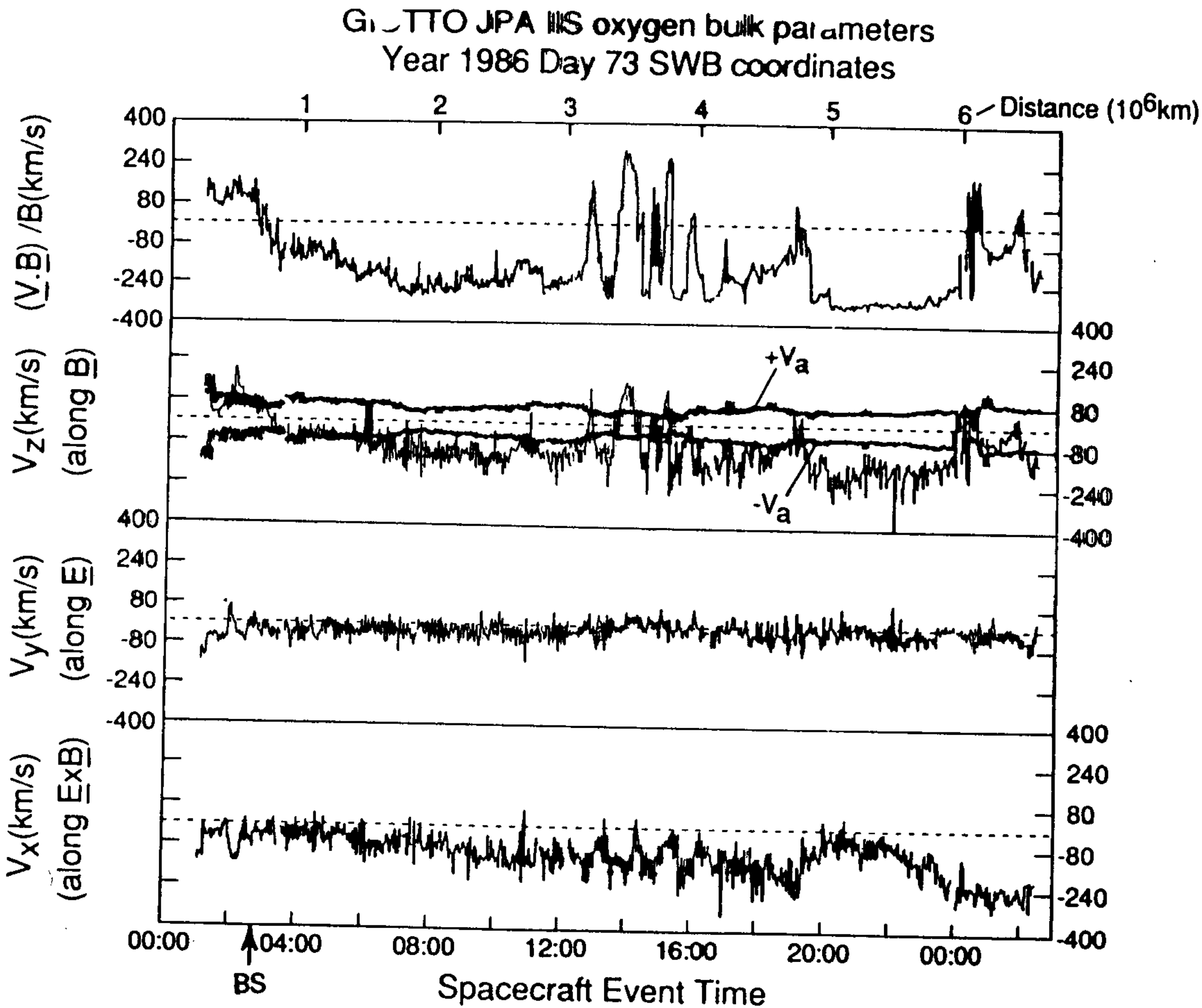


Figure 11 - From the bottom

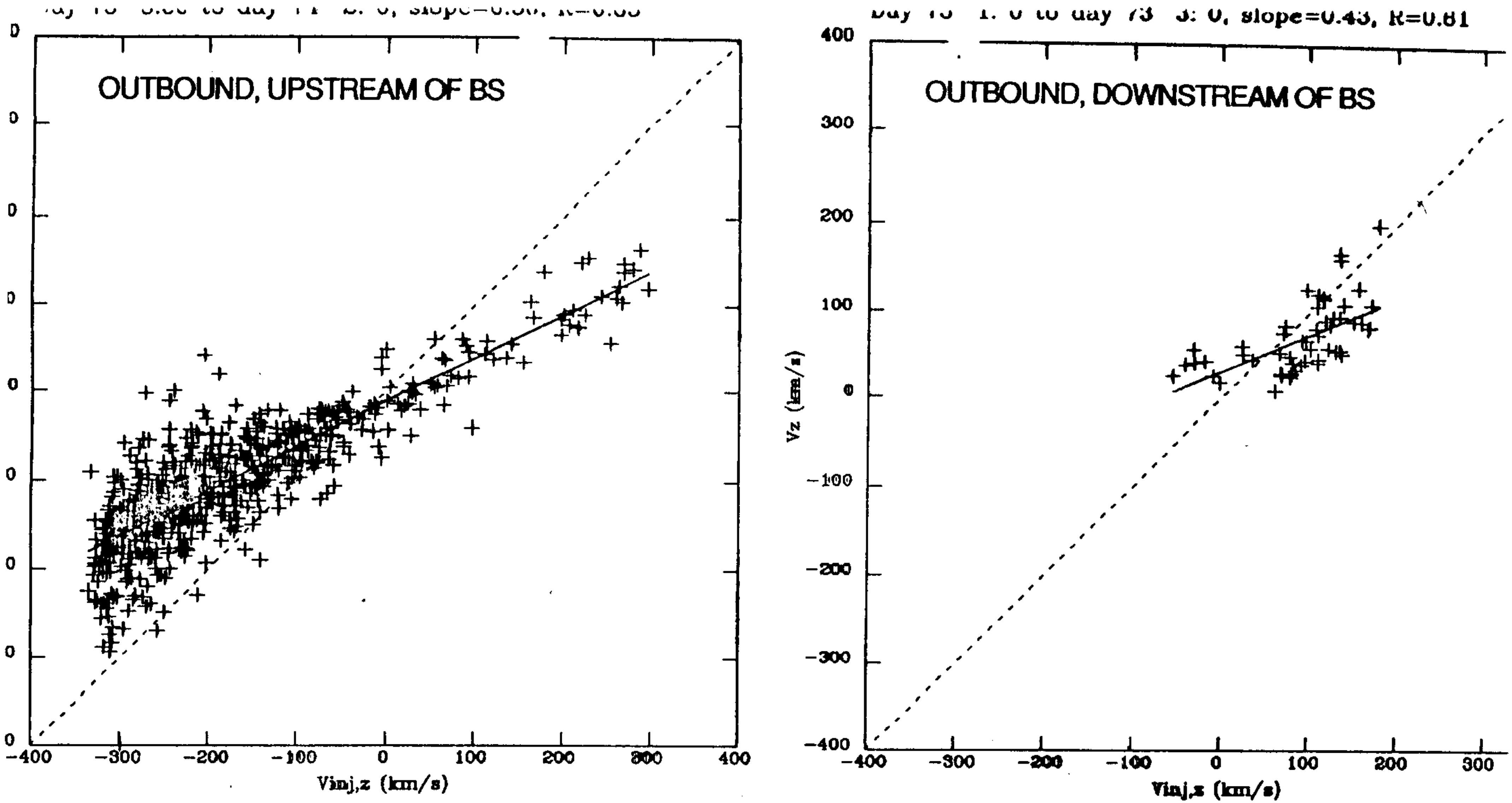


Figure 12 - (a) Scatter plot of the measured v_z component (ordinate) against the ring prediction (abscissa), upstream of the bow shock on the outbound pass. (b) Similar scatter plot for the downstream region.