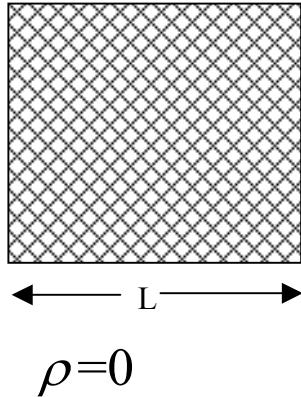
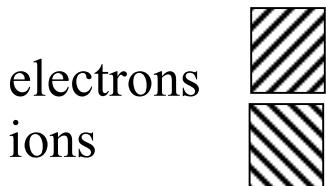
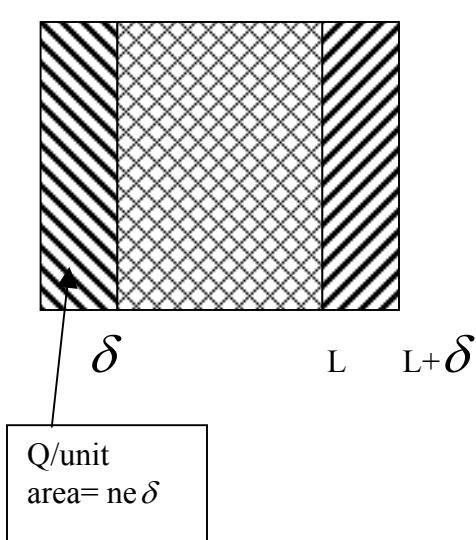


# Plasma Response Time

Slab Model  
Assumes electrons and ions are cold



Now shift the electrons a small distance  $\delta$



Force/unit area on these displaced electrons is

$$\text{Lorentz Force on whole slab} = E * \frac{\text{Charge}}{\text{Area}} = -neL \frac{ne\delta}{\epsilon_0} = \frac{n^2 e^2 \delta L}{\epsilon_0}$$

Now

$$\vec{F} = m\vec{a} \Rightarrow \frac{\text{Force}}{\text{Area}} = \text{Lorentz} = \frac{m}{\text{Area}} * \text{acceleration} = nm_e L \frac{d^2 x}{dt^2}$$

mass/area of slab

28

$$n m_e L \frac{d^2 x}{dt^2} + \frac{n e^2 L x}{\epsilon_0} = 0$$

has the form  $\ddot{x} + \frac{n e^2}{m_e \epsilon_0} x = 0$

simple harmonic oscillator with frequency

$$\omega_e = \left( \frac{n e^2}{m_e \epsilon_0} \right)^{1/2}$$

electron  
Plasma frequency

$$\omega_e \equiv \omega_{pe}$$

See problems for examples.

$$\omega_e \equiv \omega_{pe}$$

electron plasma  
frequency

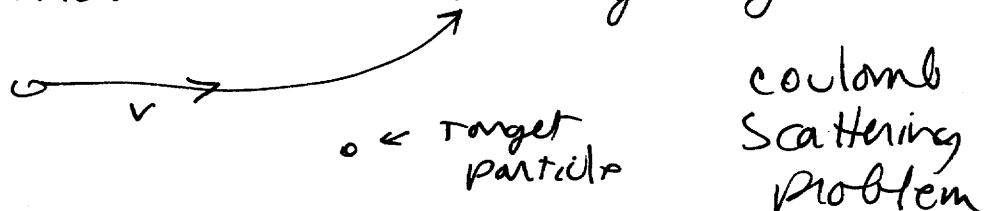
Need one more thing - information about background, or otherwise targets for collisions.

we want  $\gamma$  (collision frequency)  $\ll \omega_e$

$$\gamma = \frac{\text{collisions}}{\text{sec}}$$

$\Rightarrow$  complicated to derive.

we want to know how often Coulomb collisions occur with large angle reflections



## Coulomb scattering

Depends on density of targets,  
momentum considerations etc.

Good Reference Nicholson (1983) p. 9-14

$$V = \frac{2ne^4(\ln N_D)}{\epsilon_0 m_e^2 v_0^3} \quad (\text{take as } d \text{ given})$$

$$\text{Find } \frac{V}{\omega_p} = \frac{2n_0 e^4 \ln N_D}{\epsilon_0 m_e^2 v_0^3} \left( \frac{\epsilon_0 m_e}{n e^2} \right)^{1/2}$$

$\sqrt{\frac{kT}{m}} = \text{average velocity}$

$$\approx \frac{2 \ln N_D}{n_0 v_0^3} \quad \boxed{\approx \frac{1}{N_D} \approx \frac{V}{\omega_p}}$$

neglect  $\ln N_D$  w.r.t  $N_D$ , neglect factors of order unity

This is a very approximate expression  
but gives an idea about limit at  
which  $V$  can be tolerated in a  
plasma before <sup>long range</sup> EM interactions  
become less important than nearest  
neighbors.

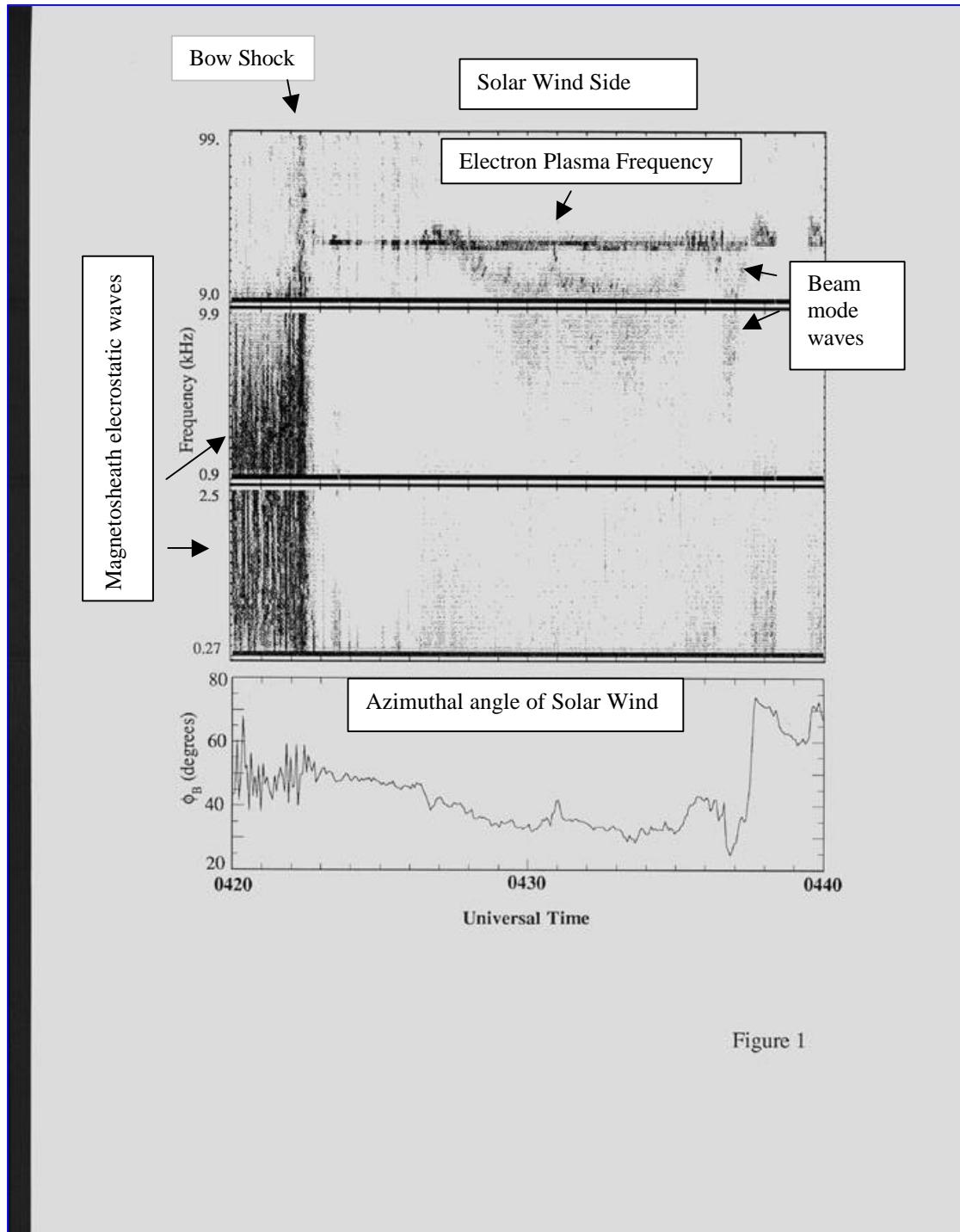


Figure 1

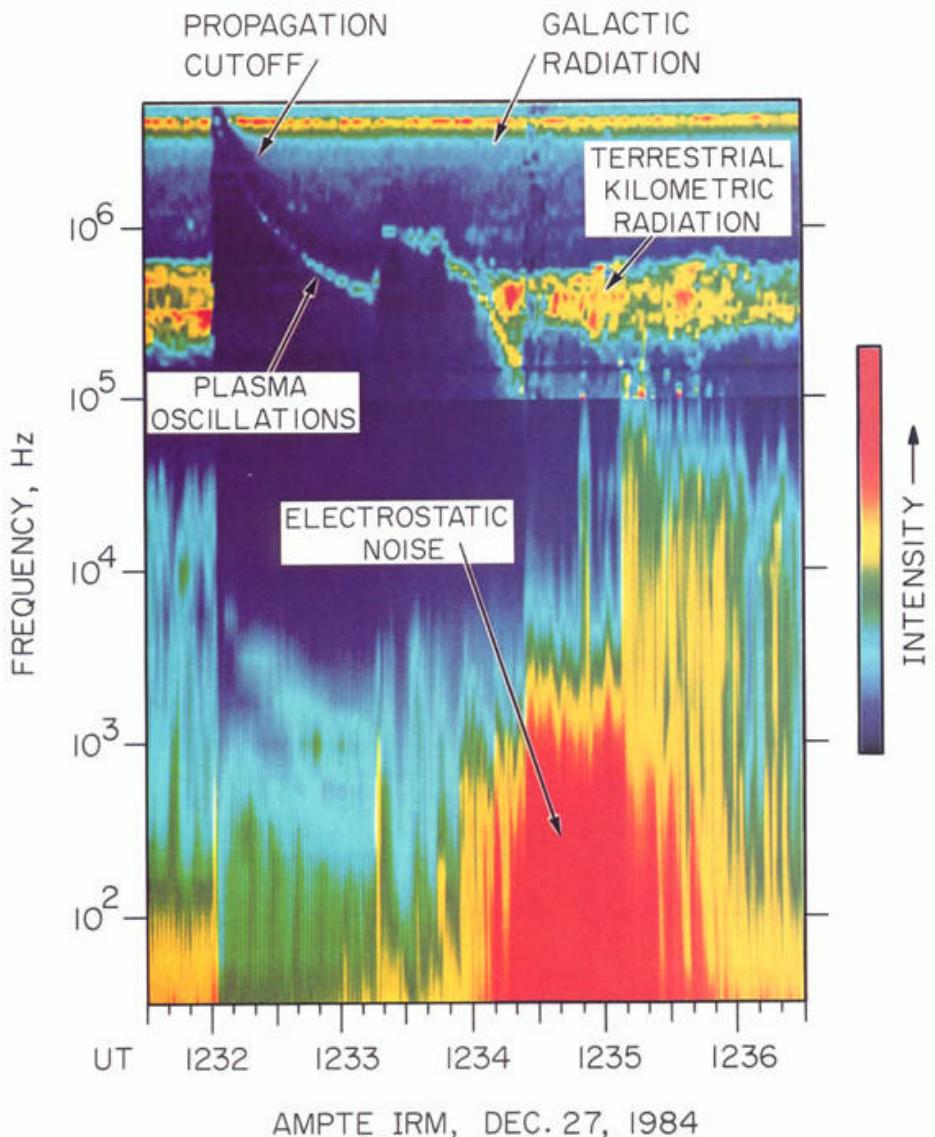


Plate 1. A frequency-time spectrogram from the high-frequency sweep-frequency receiver. The intensity scale is adjusted as a function of frequency so that the dynamic range extends from the instrument noise level (blue) to the saturation level (red). The dense plasma cloud formed by the explosion at 1232:00 blocked the galactic and terrestrial radio noise and produced depressed noise intensities for about 2 min as the cloud expanded over the spacecraft. The electron number density  $N_e$  can be determined from the electron plasma oscillation line, which is at the local electron plasma frequency  $f_{pe}$  =  $9000 (N_e)^{1/2}$  Hz, where  $N_e$  is in  $\text{cm}^{-3}$ .

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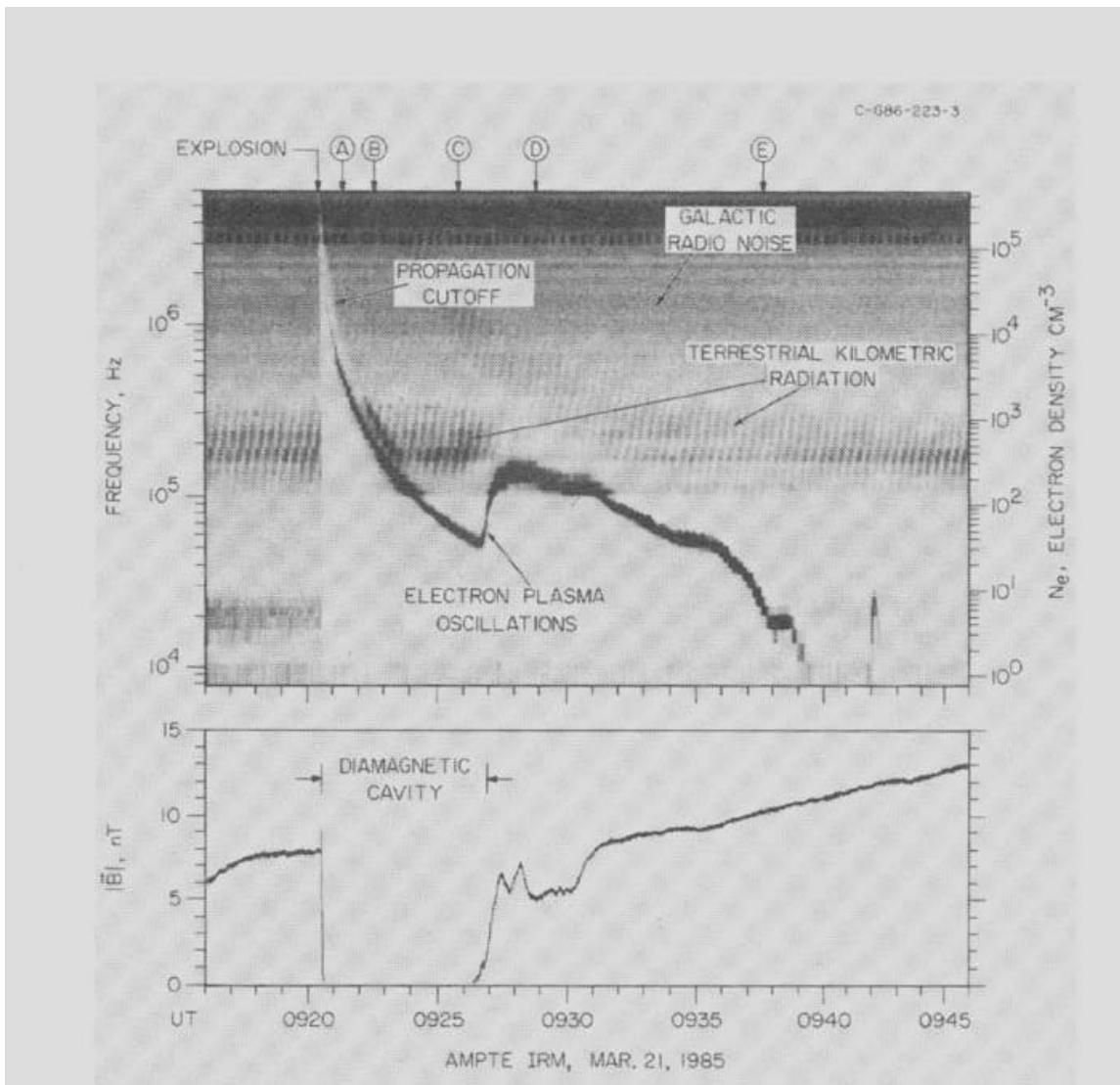


Fig. 1. A frequency-time spectrogram of the plasma wave electric fields observed during the magnetotail barium release on March 21, 1985. The ion cloud formed by the explosion blocked the galactic and terrestrial radio noise and produced the depressed noise levels evident after 0920:34. The electron plasma oscillations give the local electron density, as indicated by the scale on the right-hand side of the plot.

forget time evolution of f

(4)

## More on Distribution Function

Since we were discussing it as an introductory item (for more full discussion in last  $\frac{1}{2}$  of course), here are a few more concepts related to the distribution function

$f(\bar{r}, \bar{v}, t)$  defined in 6-dim + time  
actually we start with

$$F(\bar{x}_1, \bar{x}_2, \bar{x}_3, \dots, \bar{x}_N, \bar{v}_1, \bar{v}_2, \dots, \bar{v}_N, t)$$

for a plasma with  $N$  particles

6N+1 dimensions

$N$  can be huge ( $10^{10}$ )  
say

The 1-particle distribution function reduces 6N dimensions to 6-dim.

integrate  $F$  over all coordinates and velocities except 1 type of particle - call it  $\alpha$ . Then multiply by the # of particles of type  $\alpha$ .

1-body distribution

$$\bar{n}_\alpha f_\alpha^{(1)}(\bar{x}, \bar{v}, t) = N_\alpha \int F(\bar{x}_1, \bar{x}_2, \dots, \bar{x}_N, \bar{v}_1, \bar{v}_2, \dots, \bar{v}_N, t) d\bar{x}_2 \dots d$$

$$\text{where } \bar{n}_\alpha = \frac{N_\alpha}{V}$$

$\nearrow$   
skip  $d\bar{x}_1, d\bar{v}_1$

in thermal equilibrium  $f$  is a Maxwellian

5

Liouville's Theorem says  $\frac{dF}{dt} = 0$

$$\frac{dF}{dt} = 0 = \frac{\partial}{\partial t} F + \sum_i \frac{\partial}{\partial x_i} F \cdot \bar{v}_i + \frac{\partial F}{\partial v_i} \cdot \bar{a} = 0$$

Similarly for  $f$

$$\frac{\partial f}{\partial t} + \bar{v} \cdot \frac{\partial f}{\partial x} + \frac{\partial f}{\partial v} \cdot \bar{a} = 0$$

but  $\bar{x}$  is independent of  $\bar{v}$  statistically

$$\frac{\partial f}{\partial t} + \bar{v} \cdot \frac{\partial f}{\partial x} + \bar{a} \cdot \frac{\partial f}{\partial v} = 0 \quad \begin{matrix} \text{Boltzmann} \\ \text{Equation} \end{matrix}$$

$\uparrow$   
Force  
mass

---

How to measure  $f$ ?

count particles w/ certain energy,  
velocity and position

$$\begin{aligned} J &= \text{Differential Flux} \\ &= p^2 f \end{aligned}$$

$\uparrow$   
momentum<sup>2</sup> & Energy  
(may be mass  
missing)  
See erata??