Review of Columnar Density Changes with Differential Doppler

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Doppler Shift

- Signals at different frequencies follow different paths through the corona through Snell's Law
- This causes a red shift in the frequency of the carrier

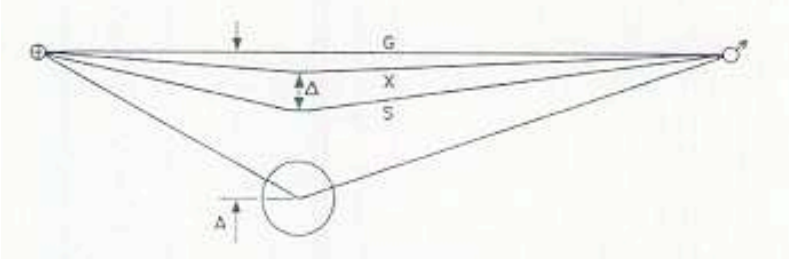


Figure 1.26: *Schematic of the effect of the radial distribution of electron density affecting the index of refraction on EM waves propagating from a spacecraft* $\odot$ *to the Earth* $\oplus$*. Between the spacecraft and the Earth, the visual line of sight (G) is deflected towards the Sun by the coronal plasma depending on frequency* $(X(8GHz) > S(2GHz))$*.* Δ *is the distance separating the deflected S- and X-band waves (Tyler* et al.*, 1977).*

Doppler Equation

- The frequency shift is proportional to the change in density along the line of sight

$$\frac{\Delta f_p}{f} = \frac{d}{dt} \int_{LOS} \frac{n}{c} ds$$

- which gives

$$\Delta f_p = \frac{-e^2}{8\pi^2 f c \epsilon_o m_e} \Delta I$$

Bertotti and Giampieri, 1998

Relative Doppler to Density

- In the case of Cassini with a 2-way link

$$\Delta f_x = \Delta f_{nd} + \Delta f_{pu} + \frac{\Delta f_{pd}}{\alpha_x^2}$$
$$\Delta f_{ka} = \Delta f_{nd} + \Delta f_{pu} + \frac{\Delta f_{pd}}{\alpha_{ka}^2}$$

- where f_{nd} is from the relative motions of the Earth and SC, f_p is the plasma contribution on the uplink and downlink, and alpha is the ratio of f_{pd}/f_{pu}

Relative Doppler to Density

- Therefore the correspondence between Doppler shifting and density is

$$\frac{-e^2}{8\pi^2 c\epsilon_o m_e}\Delta I$$ =(Δfx-Δfka)/(fx-fka)

- The change in columnar density with time is

$$I(t) - I_o = \sum_t \Delta I(t)\Delta t$$

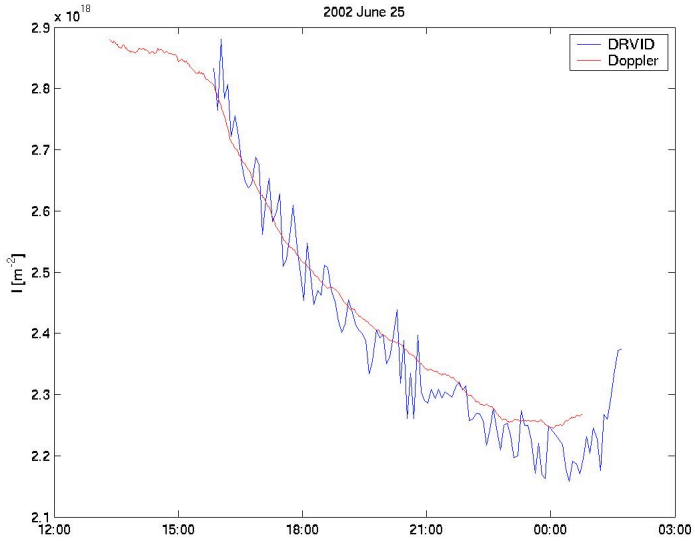


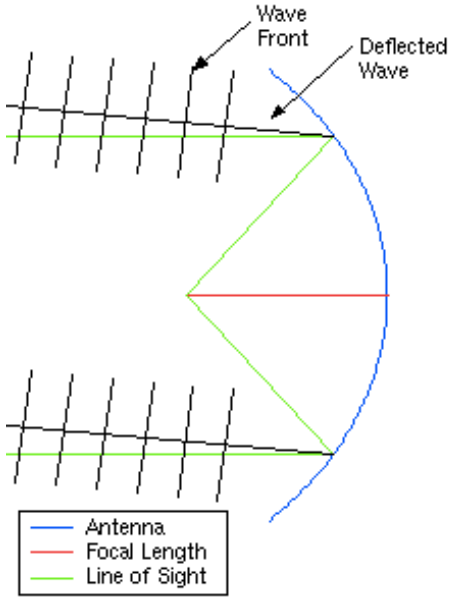
Figure 1.25: *Comparison between the columnar electron density from ranging (blue) and Doppler (red) over the 12 hour period of observation on 2002 June 25. The initial columnar electron density is unknown in the Doppler measurement and was set to* $2.88 \times 10^{18}\ m^{-2}$. *The variability in electron density was due to the integration of electron density through the solar corona following a coronal mass ejection on the 24th.*

Technical Application

- In the case of
  - a source with a unique spectrum in frequency space
  - an observing system capable of observing at two different frequencies
- The red shift of the spectrum in two frequencies can be used to measure the columnar electron density

Angular Offset Alternative

- The increase in the length of the ray path is proportional to the angular offset of the ray from the visual line of sight
- Stelzried found that this offset at 2.3 GHz is ~1X10^{-4} deg for a line of sight with a solar offset of 3Rs
- Potentially useful in strong scattering regimes?



Questions

- Can either of these techniques be done?
- What are the technical challenges involved?