ISR Theory 5: ISR Spectral Shapes

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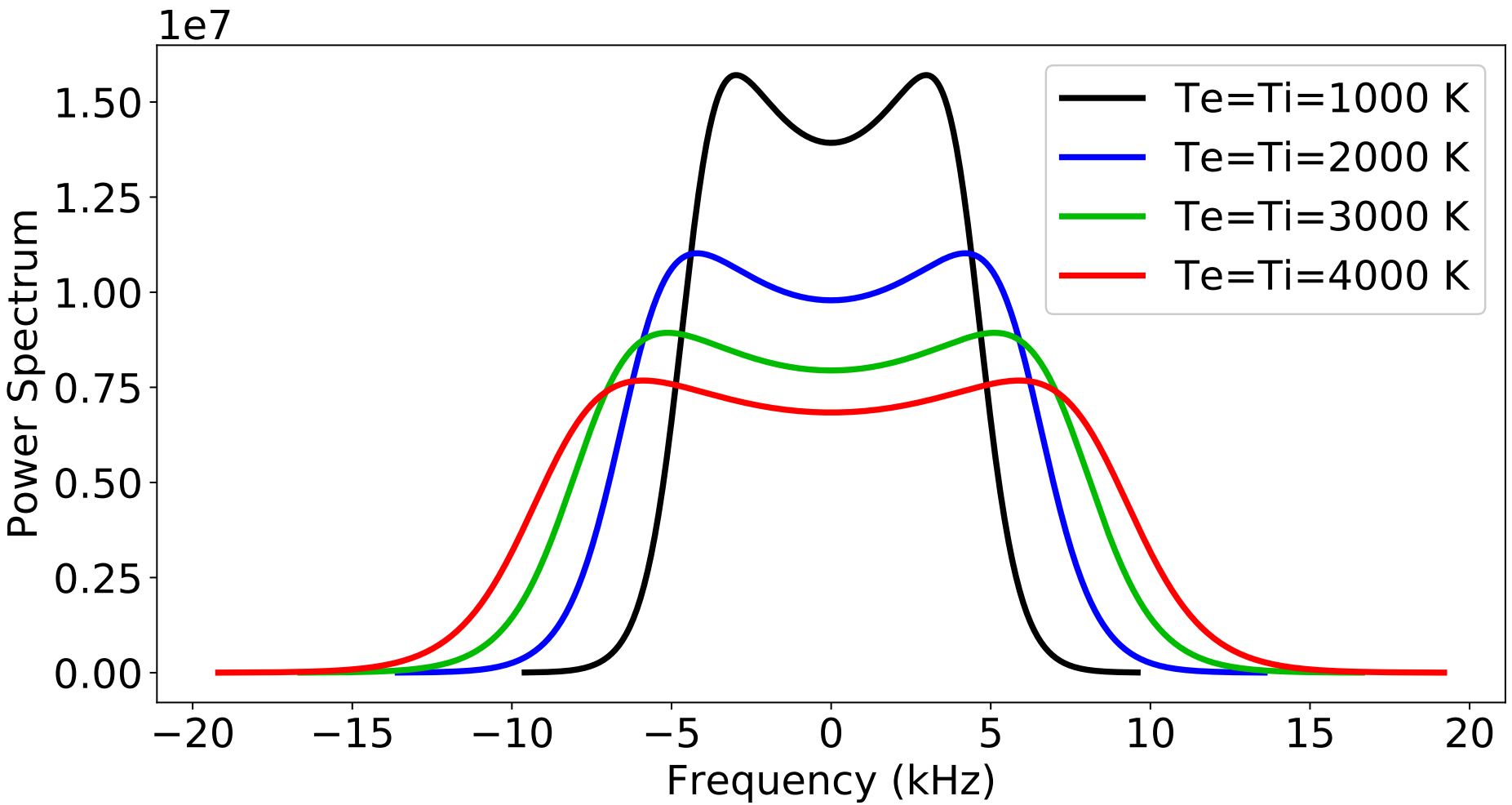
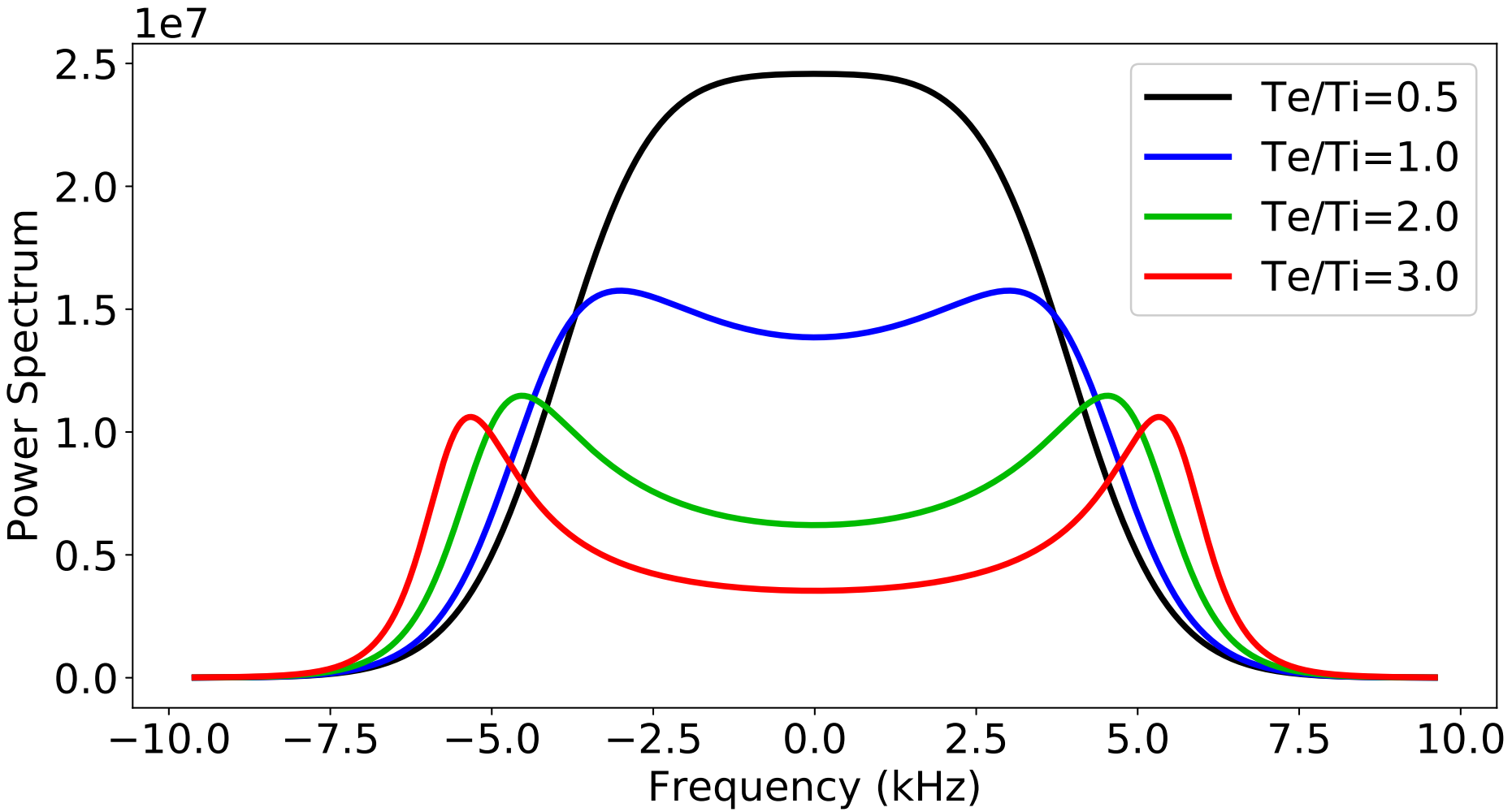
July, 2020

Temperature Effects ($T_e/T_i = 1$)



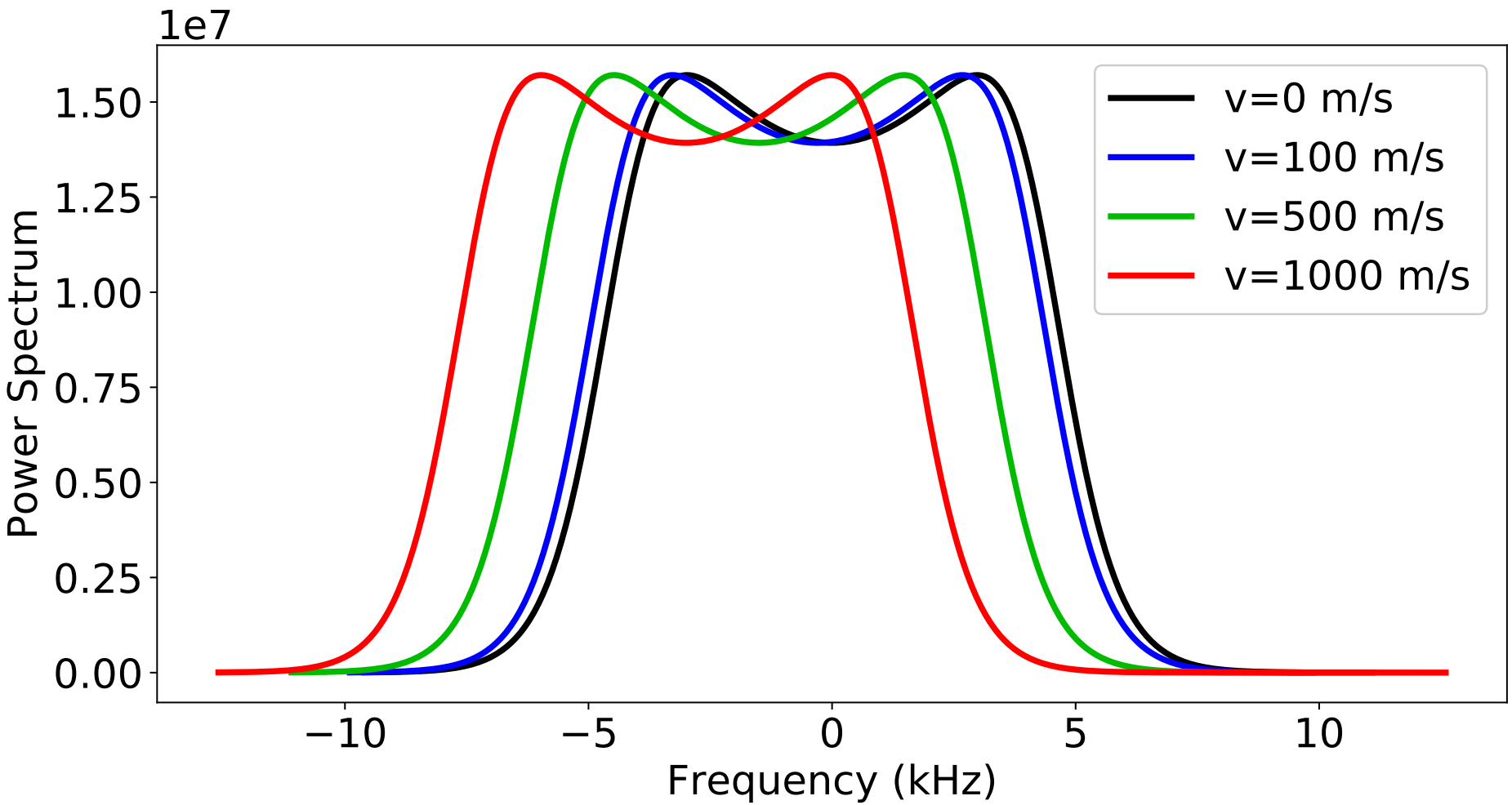
$f = 449.3$ MHz $\quad N_e = 3 \times 10^{11}$ m^{-3} $\quad m_i = 16$ amu

Temperature Ratio Effects



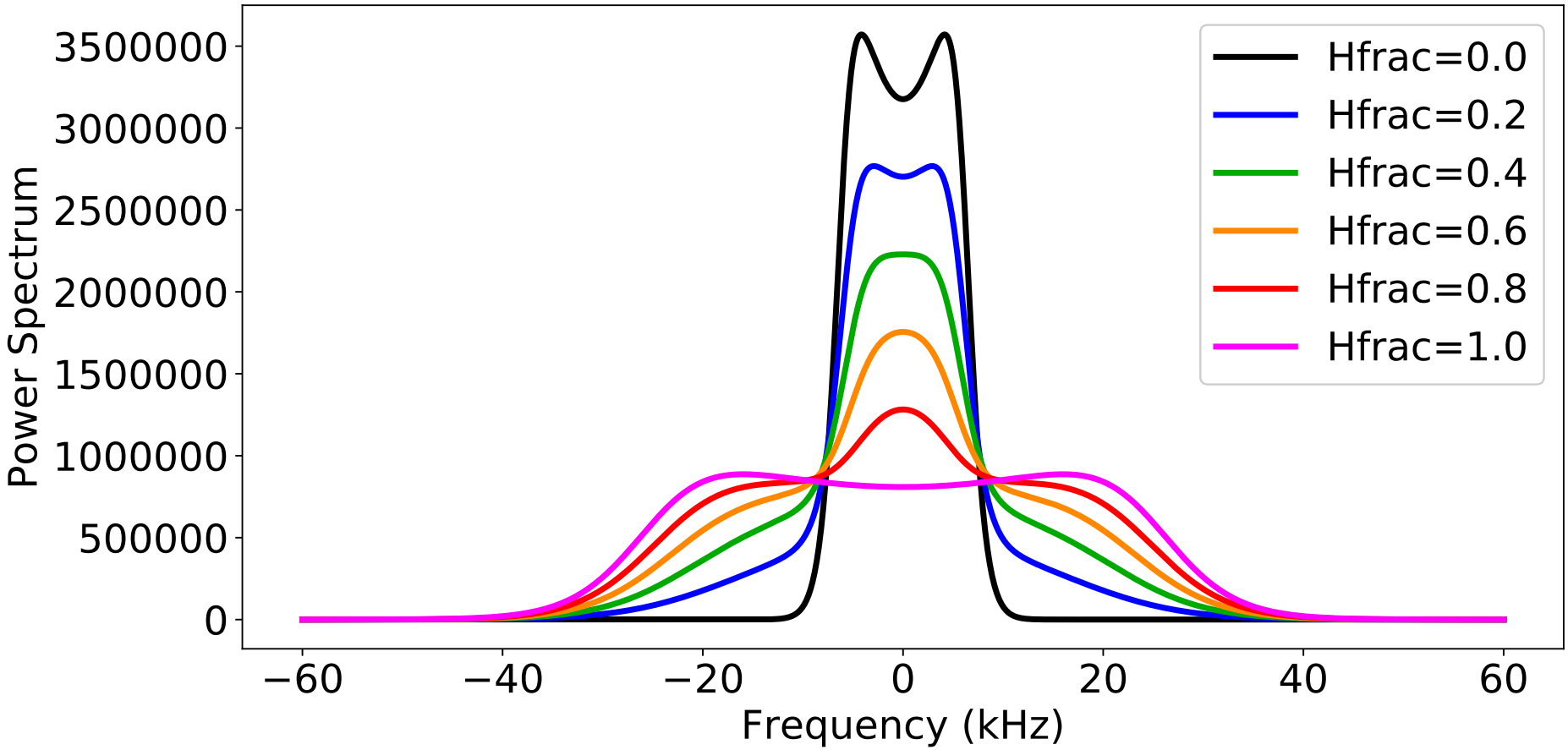
$f = 449.3\ \mathrm{MHz} \quad N_e = 3 \times 10^{11}\ \mathrm{m}^{-3} \quad m_i = 16\ \mathrm{amu} \quad T_i = 1000\ \mathrm{K}$

Ion Velocity Effects



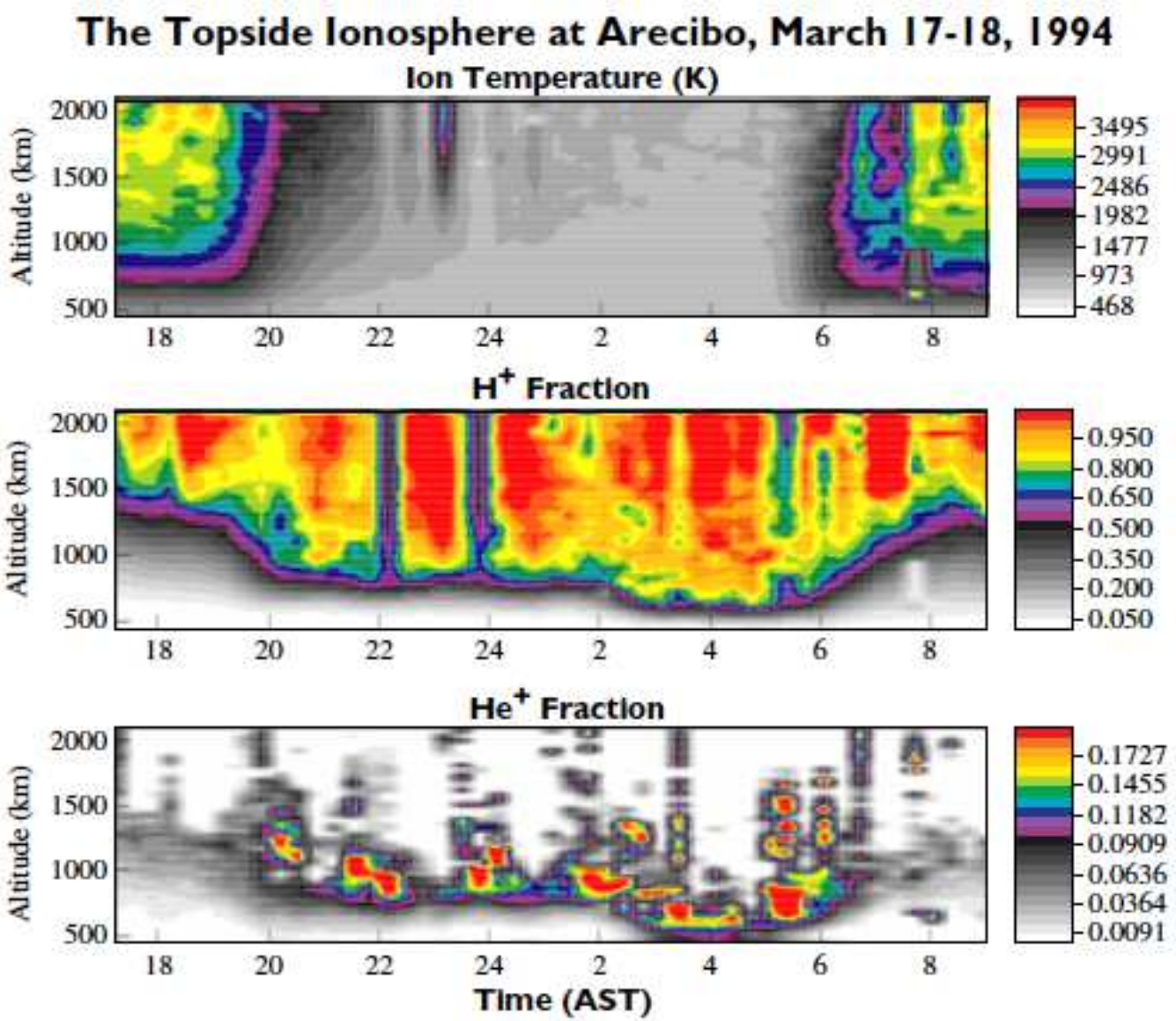
$f = 449.3\ \mathrm{MHz} \quad N_e = 3 \times 10^{11}\ \mathrm{m}^{-3} \quad m_i = 16\ \mathrm{amu} \quad T_e = T_i = 1000\ \mathrm{K}$

Light Ion Composition (O^+ and H^+)



$$f = 449.3 \text{ MHz} \quad N_e = 1 \times 10^{11} \text{ m}^{-3} \quad T_e = T_i = 2000 \text{ K}$$

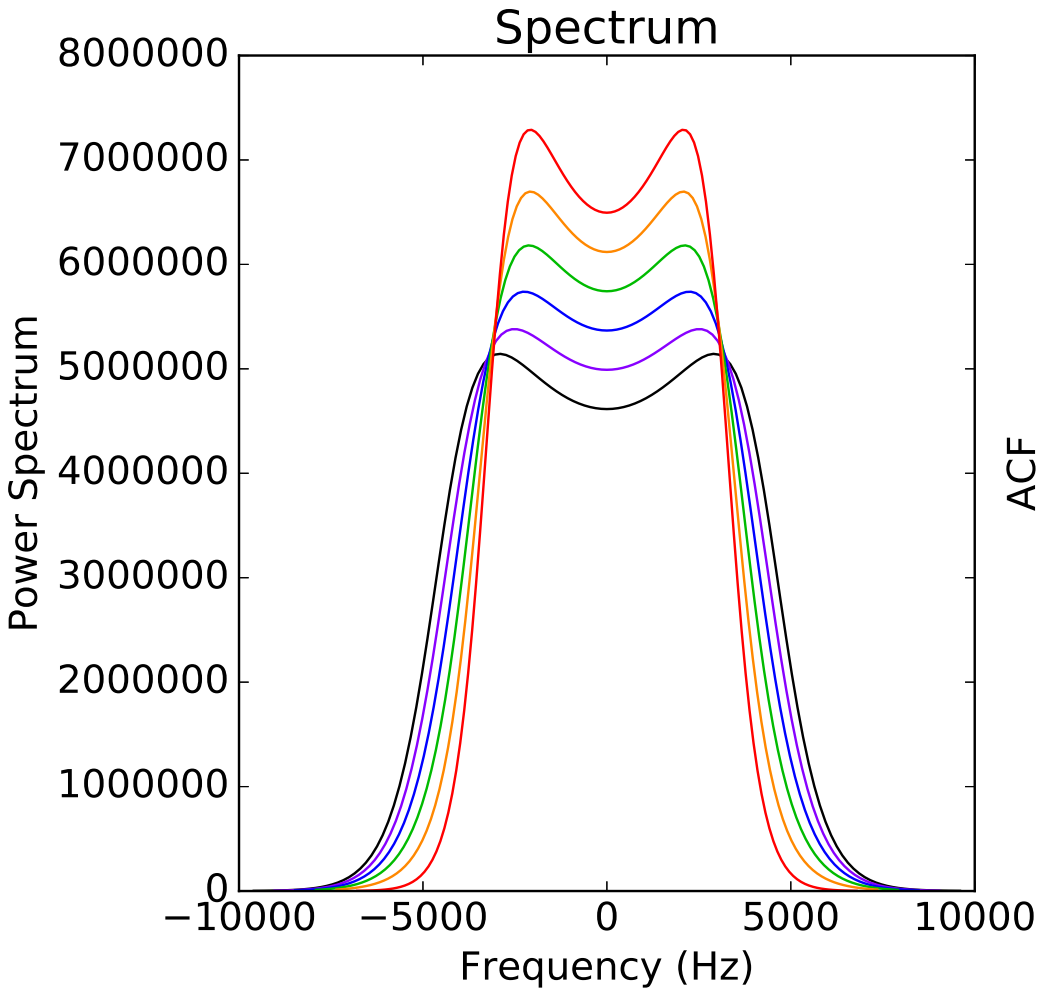
Arecibo Topside Ion Composition

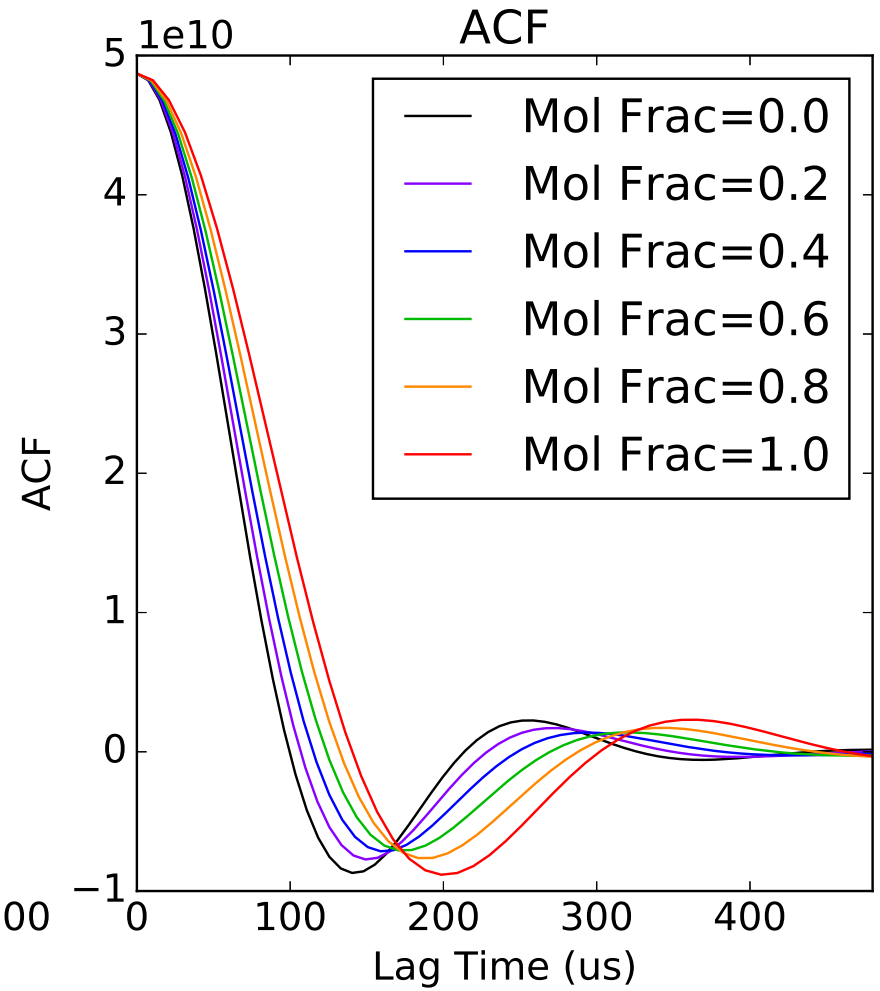


González and Sulzer, 1996

Molecular Ion Composition

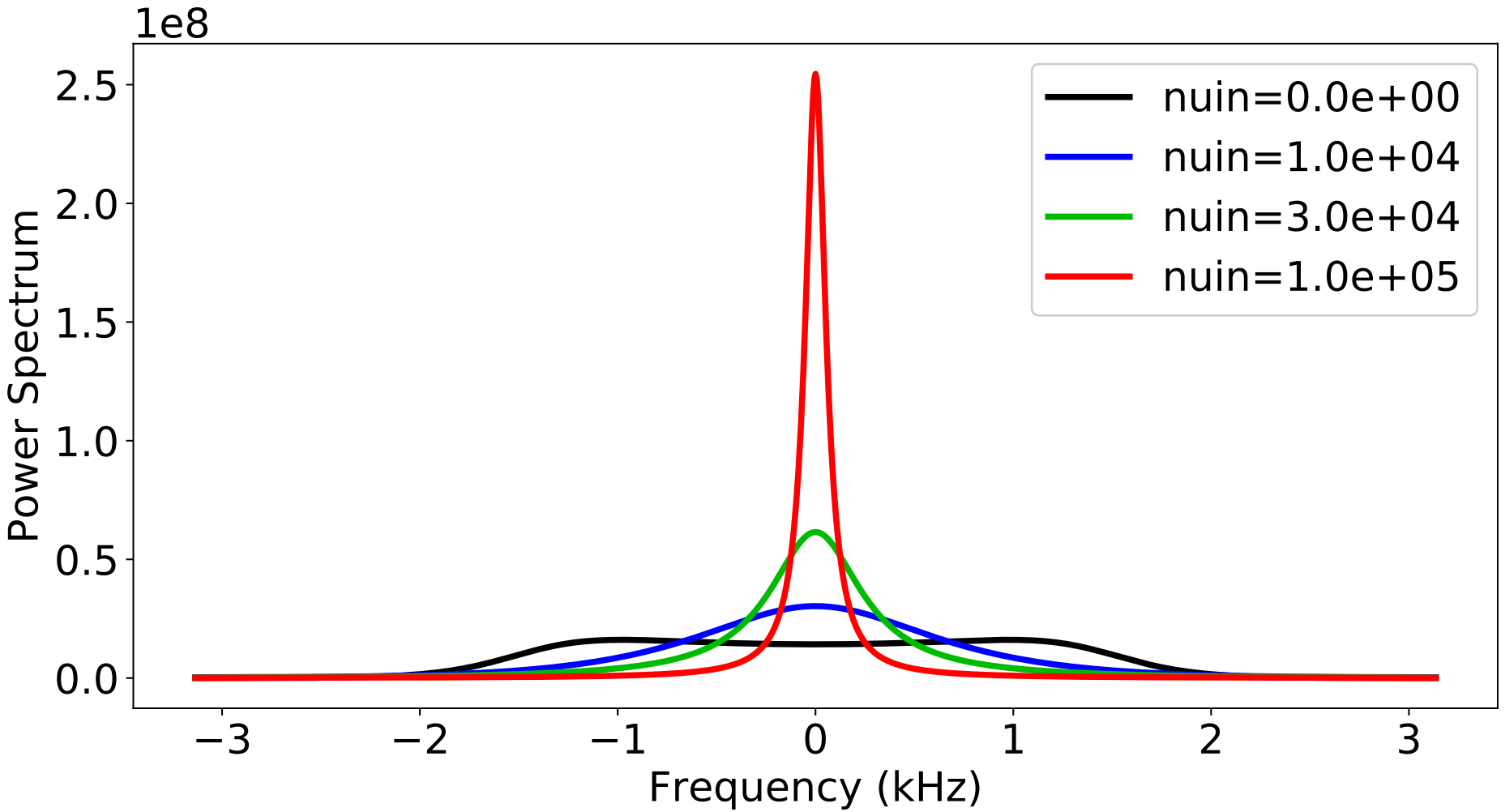
Mixtures of O^+ and O_2^+ using $N_e = 10^{11}$, $T_e = T_i = 1000$ K





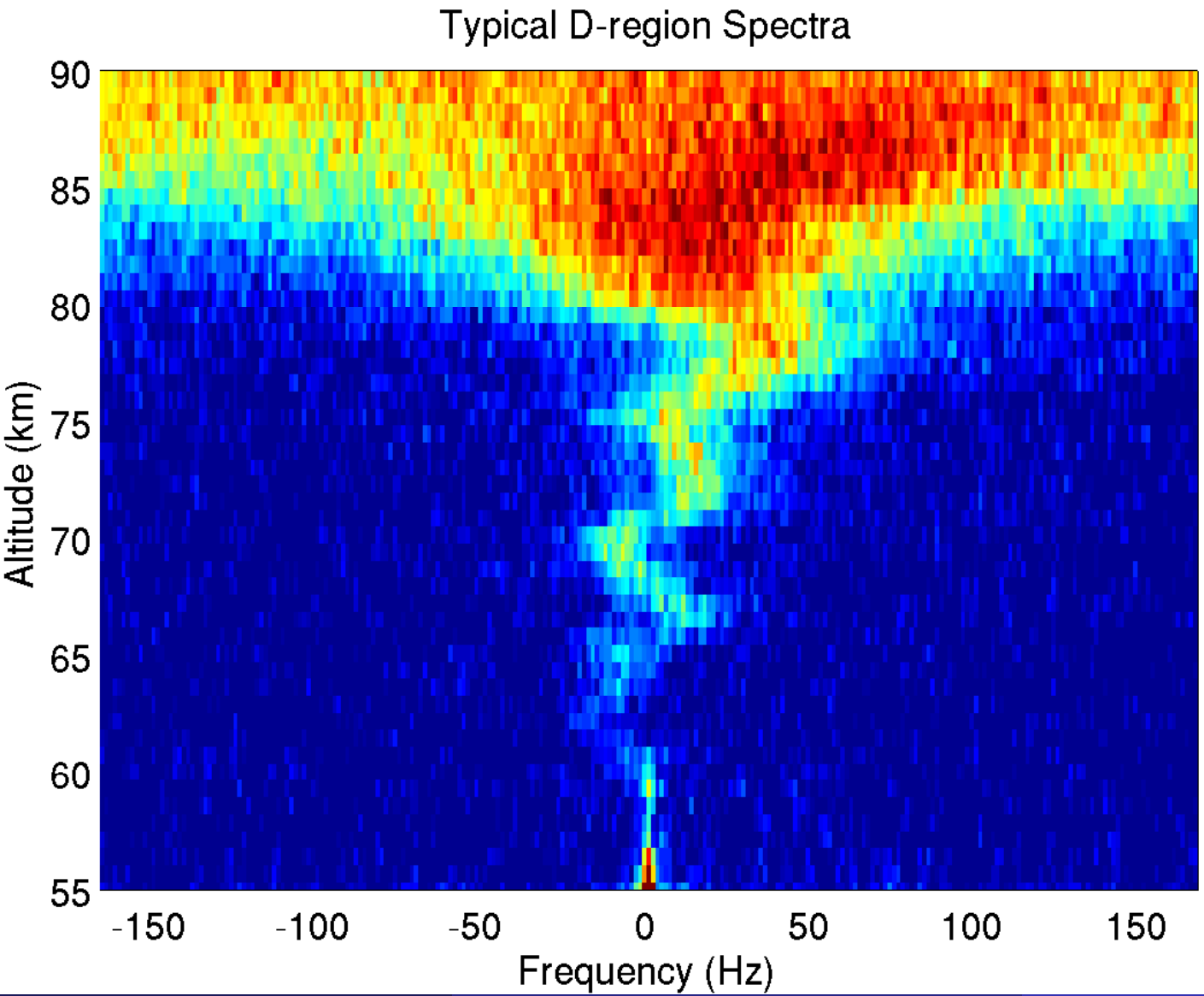
ISR spectrum measures $\sqrt{\frac{T_i}{m_i}}$, ambiguity between T_i and m_i

Ion-Neutral Collisions



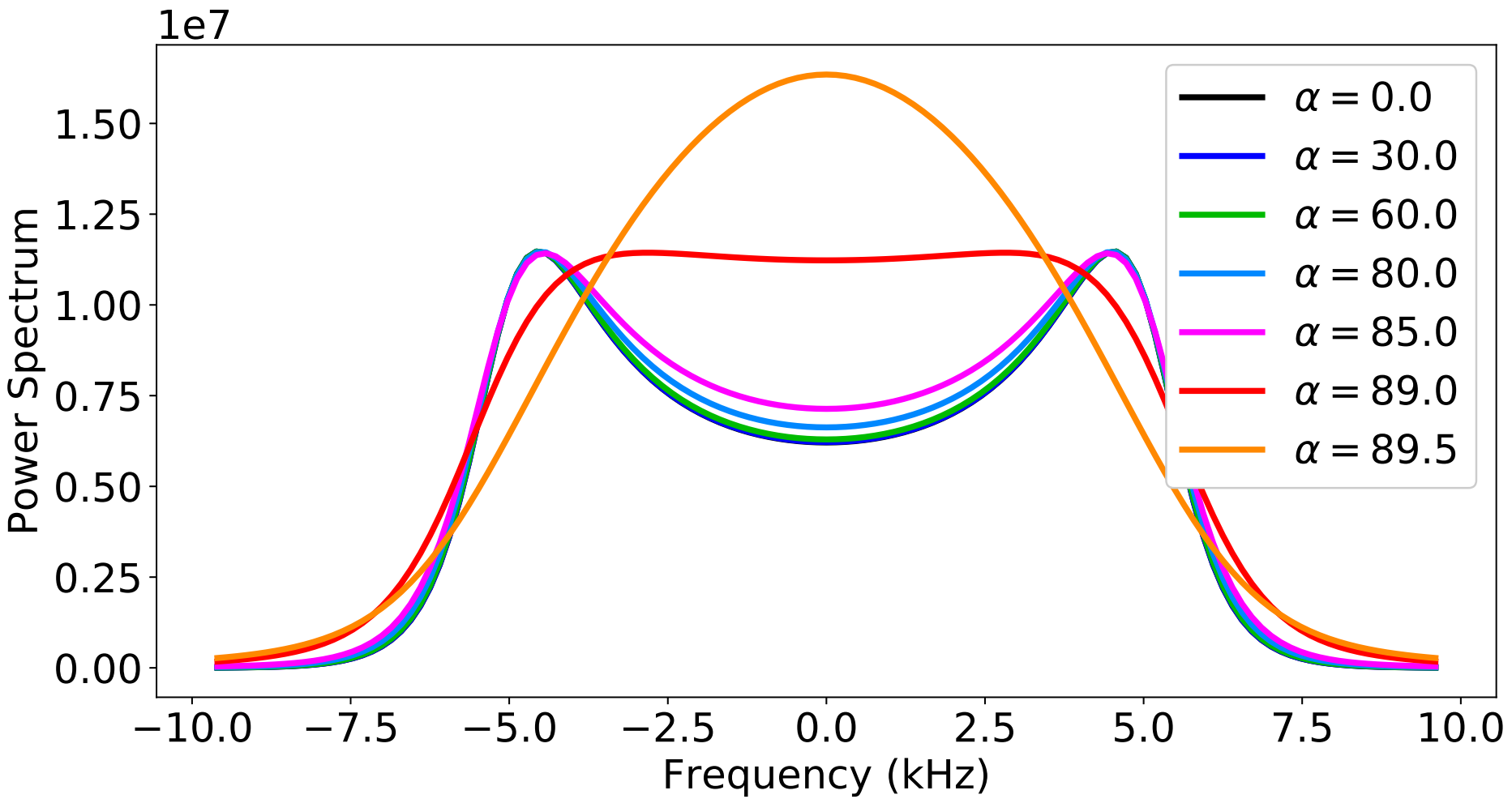
$f = 449.3\ \mathrm{MHz} \quad N_e = 1 \times 10^{11}\ \mathrm{m}^{-3} \quad m_i = 30\ \mathrm{amu} \quad T_e = T_i = 200\ \mathrm{K}$

PFISR D-region Spectra



$$\Delta f = \frac{16\pi k_B T_i}{\lambda_R^2 m_i \nu_{in}}$$

Angle from B

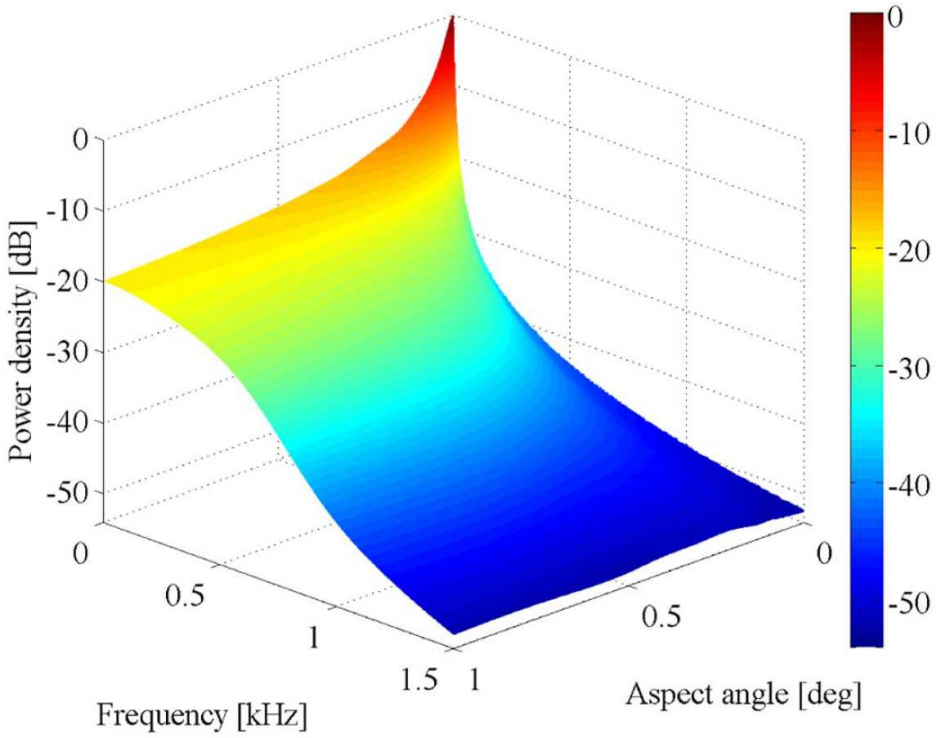


$f = 449.3$ MHz $\quad N_e = 3 \times 10^{11}$ m^{-3} $\quad m_i = 16$ amu

$T_i = 1000$ K $\quad T_e = 1000$ K

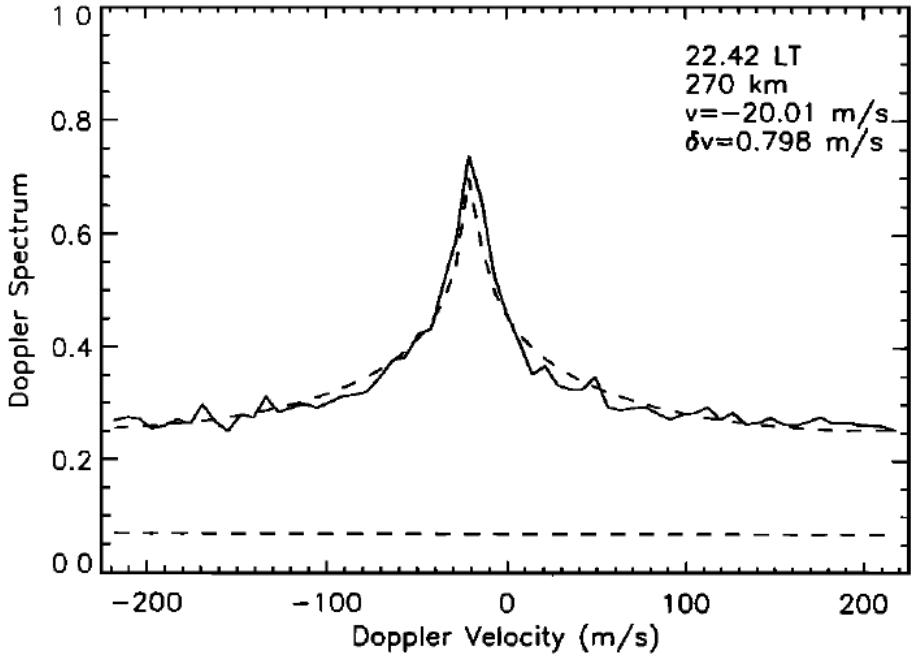
Perpendicular to B

Theoretical Jicamarca Spectra within 1° of Perpendicular



Milla and Kudeki (2011)

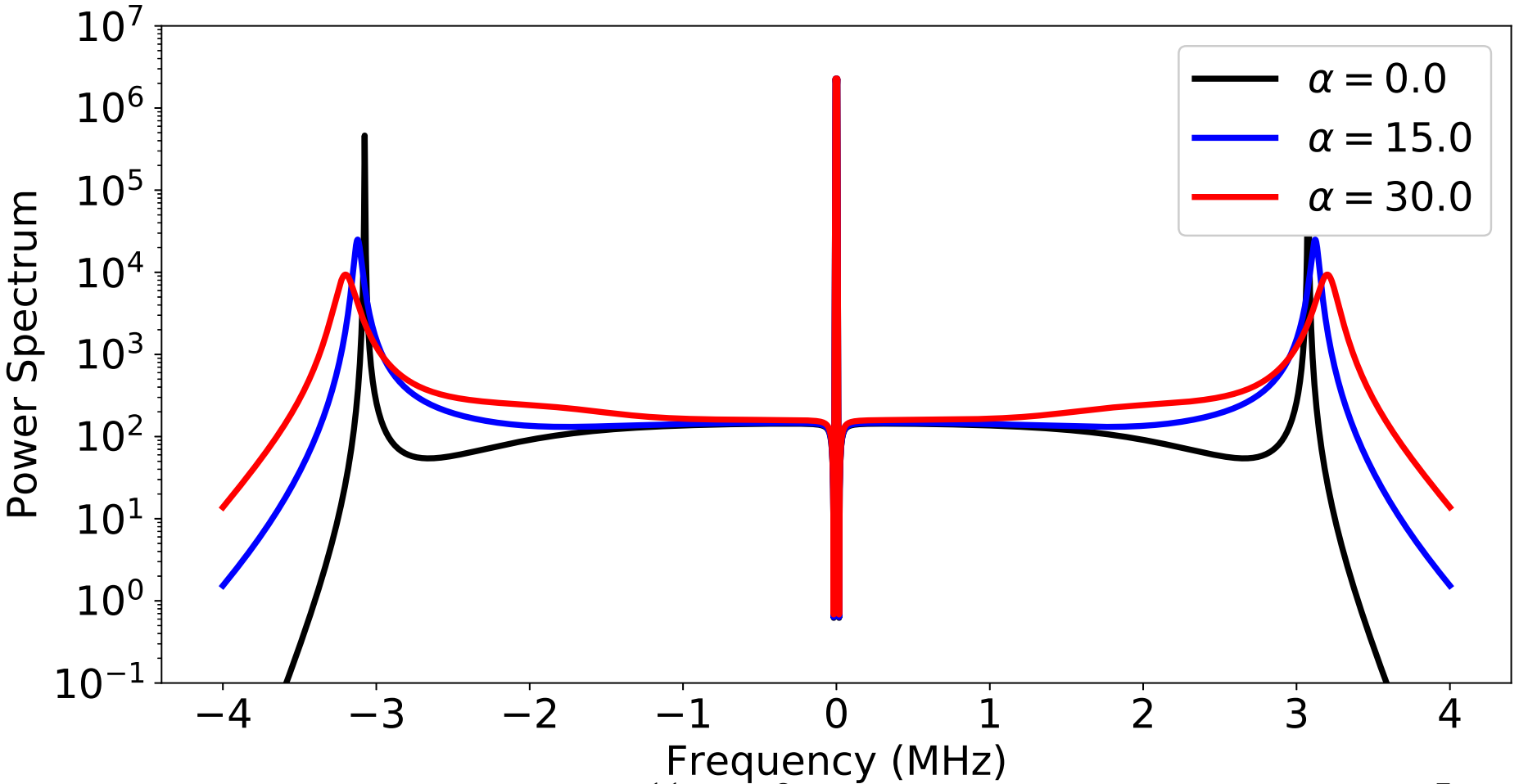
Jicamarca Measured Perpendicular Spectrum



Kudeki et al. (1999)

B-field Effects on Plasma Lines

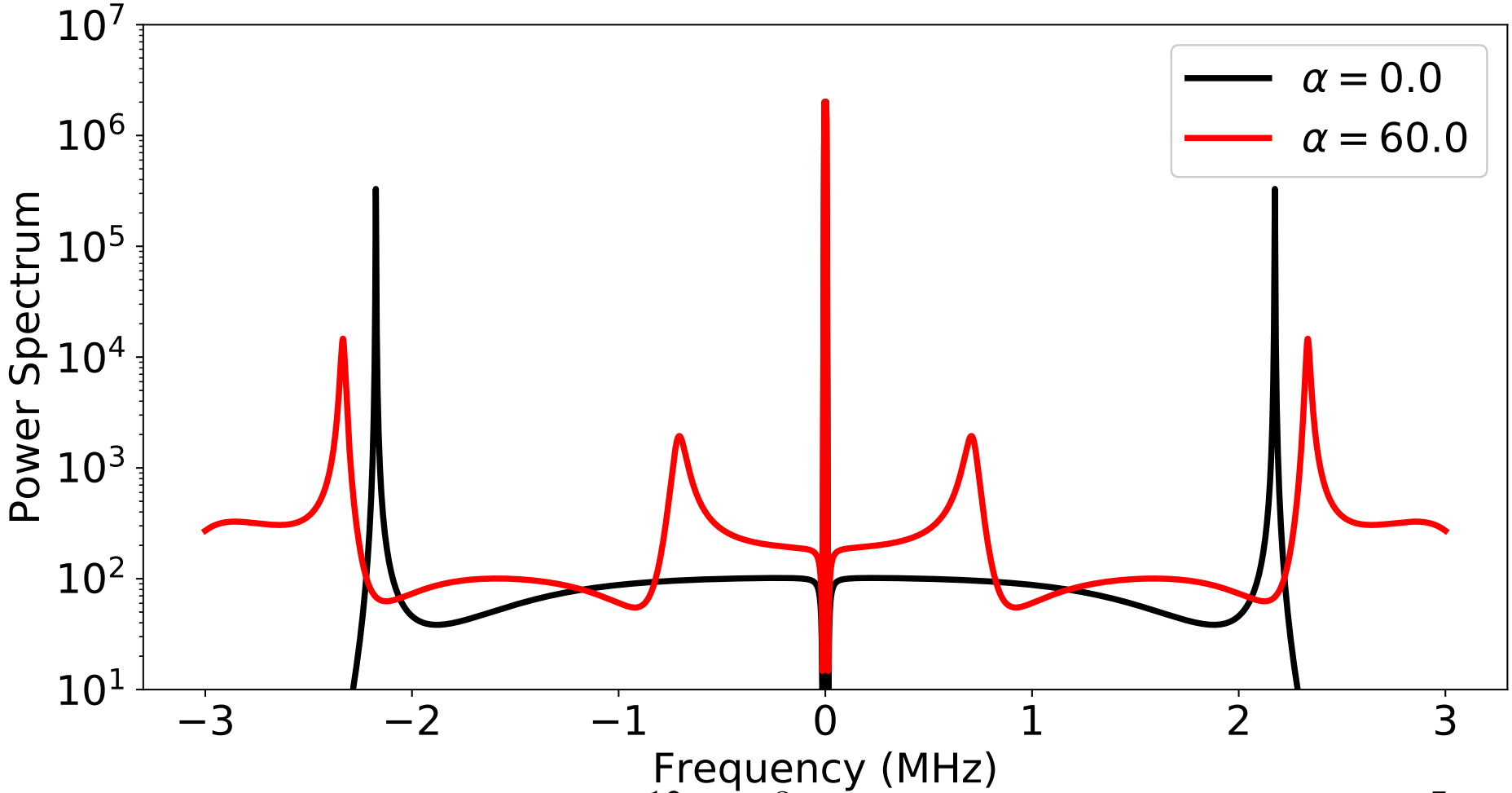
$$\omega^2 = \omega_{pe}^2 + \frac{3}{2}k^2 v_{th}^2 + \Omega_e^2 \sin^2 \alpha$$



$f = 449.3\ \mathrm{MHz} \quad N_e = 1 \times 10^{11}\ \mathrm{m}^{-3} \quad T_e = 3000\ \mathrm{K} \quad B = 5 \times 10^{-5}\ \mathrm{T}$

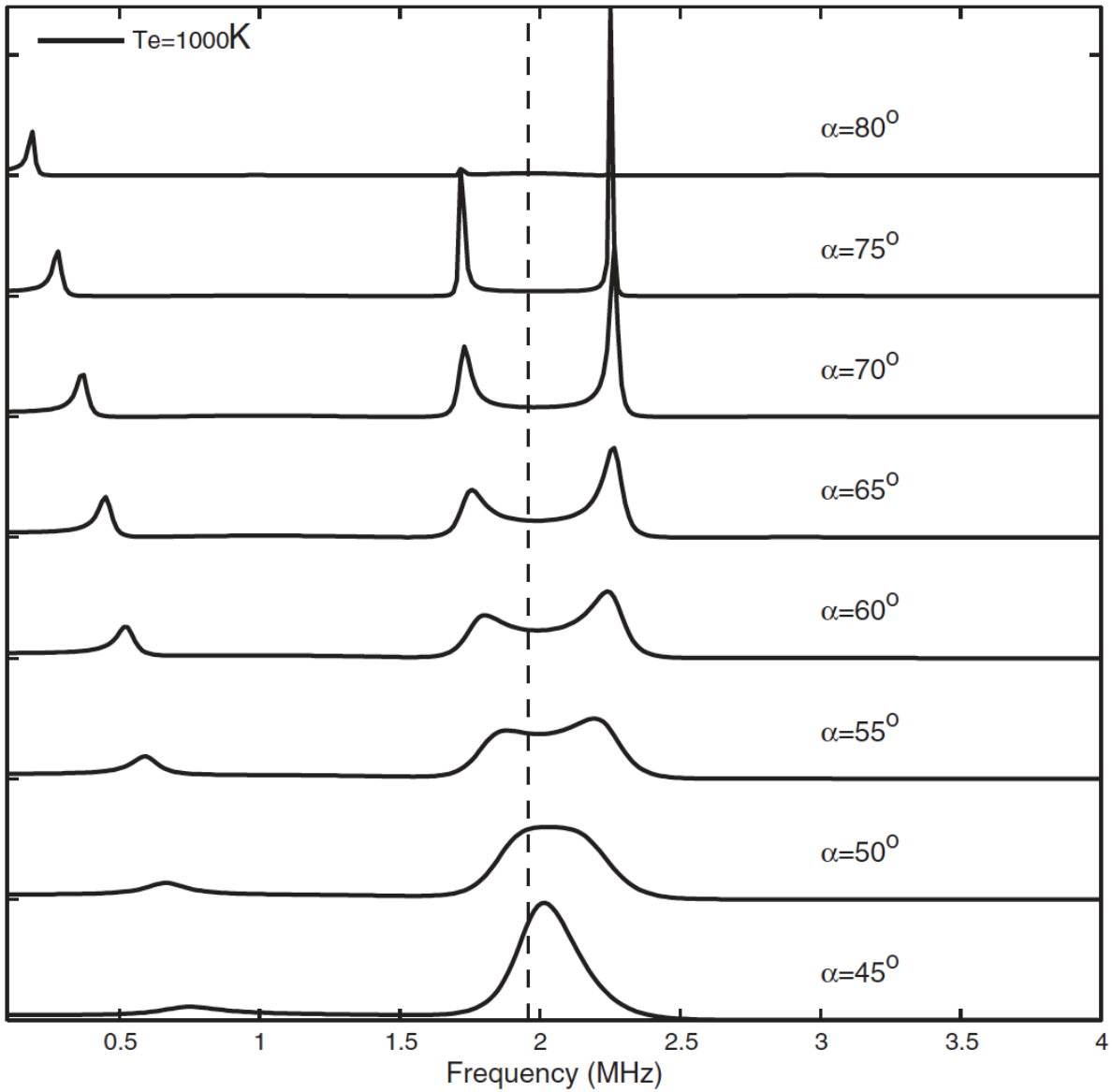
Gyro Lines (Electrostatic Electron Cyclotron Waves)

$$\omega^2 \approx \Omega_e^2 \cos^2\alpha \left(1 + \frac{11}{4}\frac{k^2 v_{th}^2}{\Omega_e^2} - \frac{\Omega_e^2}{\omega_{pe}^2}\right)$$



$f = 449.3$ MHz $\quad N_e = 5 \times 10^{10}$ m^{-3} $\quad T_e = 1500$ K $\quad B = 5 \times 10^{-5}$ T

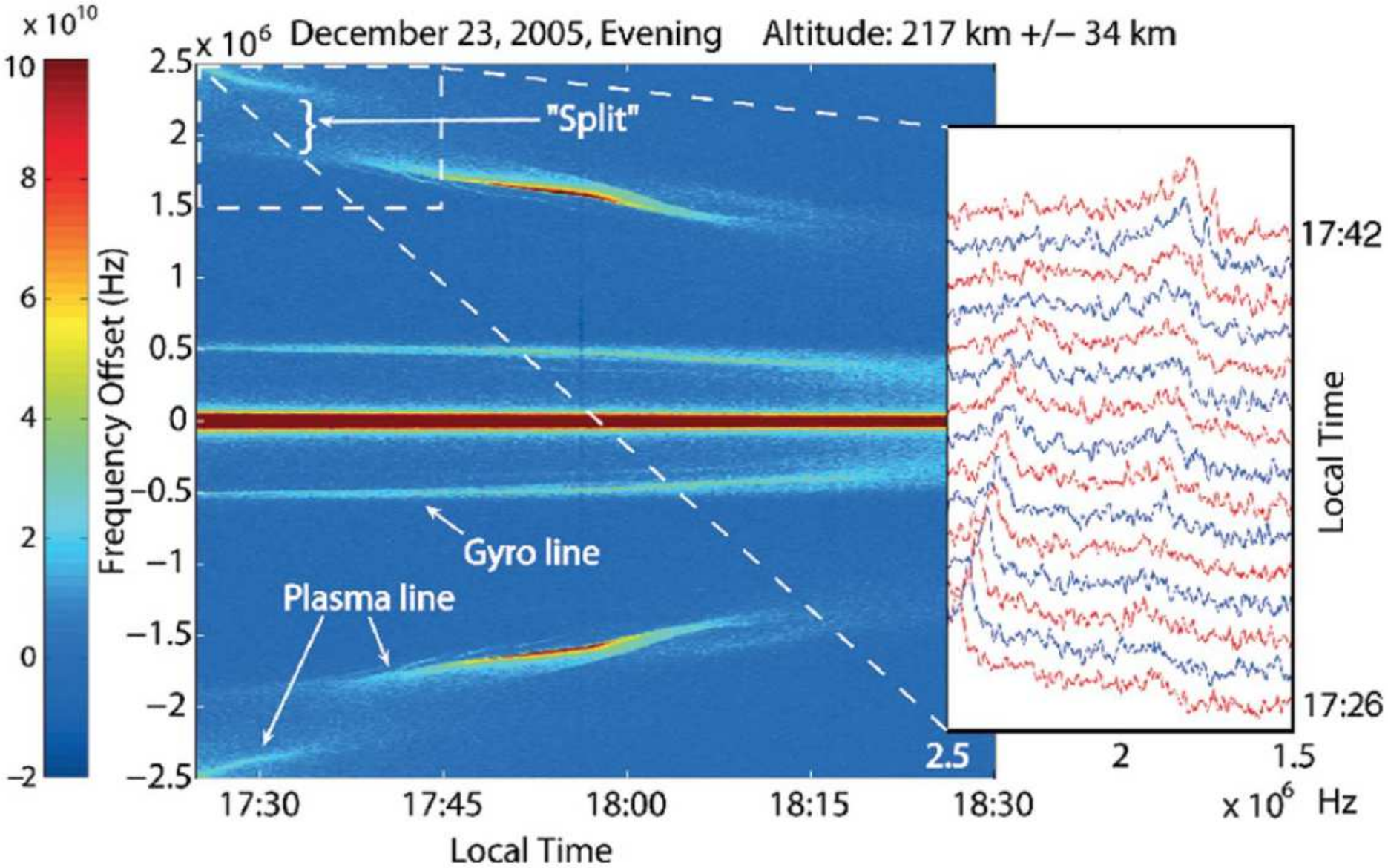
Plasma Line Splitting



- Requires $\omega_{pe} = 2\Omega_e$
- Only happens for certain angles

Bhatt et al. (2008) 10.1103/PhysRevLett.100.045005

Arecibo Observations at Sunset (Bhatt et al. 2008)



Spectral Shapes Summary

- Ion Line shape depends on
  - T_i
  - T_e/T_i
  - v_i
  - ν_{in}
  - Ion composition
  - B-field only important very close to perpendicular
- Electron Line shape depends on
  - ω_{pe} (N_e)
  - B-field effects