Mode Conversion of Radar Waves in Meteoric Plasmas

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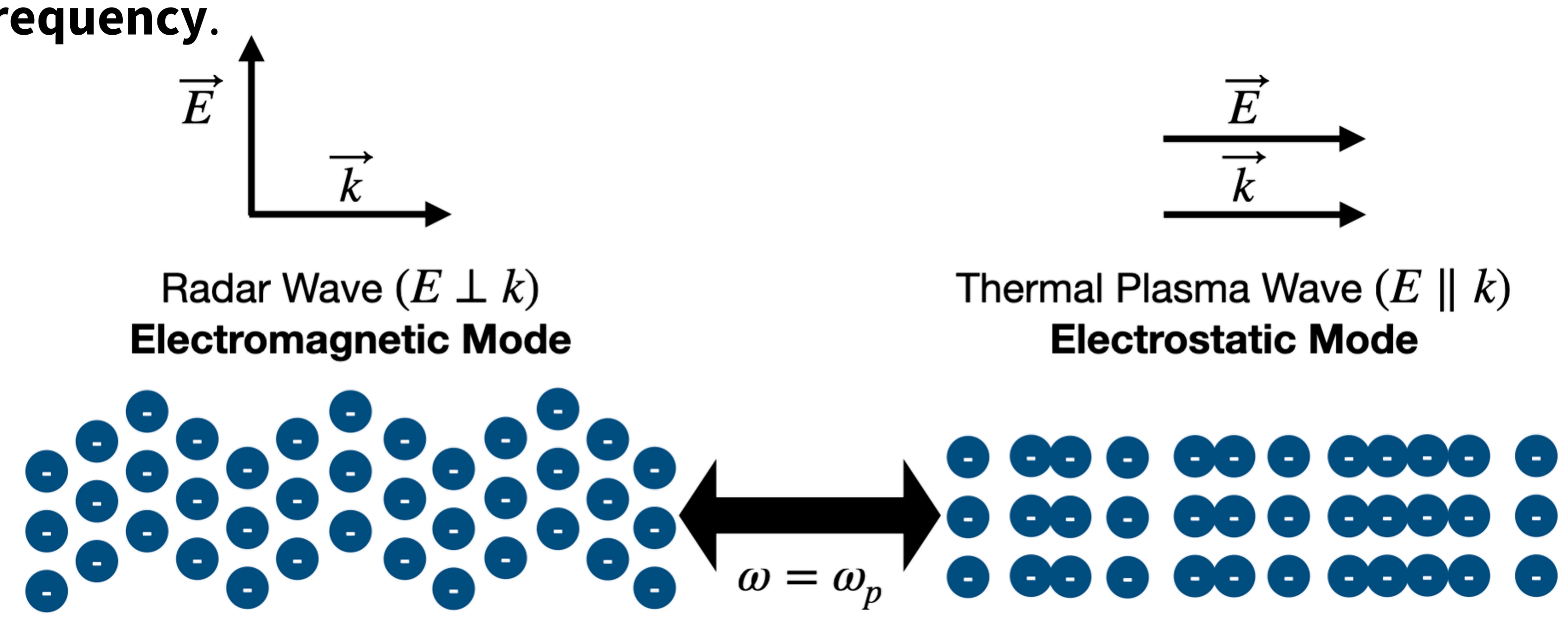
Abstract

Billions of meteoroids enter our atmosphere daily, many of which are detected with ground-based radar. Radar data contains information on meteoroid velocity, mass, density, and orbital elements. Typically, radar pulses reflect off plasmas when the natural frequency of the plasma exceeds that of the pulse. If the plasma is **not of uniform density** the incoming radar pulse can be absorbed and converted into an electrostatic wave mode supported by the plasma in a phenomena called **mode conversion**. Theory has predicted how an incoming vertically polarized electromagnetic wave of oblique incidence angle is absorbed by a 1D parabolic density gradient. Should there be evidence of mode conversion in radar returns, the orientation of the meteor could be reliably determined from first principles for meteors observed at lower altitudes (80-90 km) with radars operating at VHF (30-300 MHz). The objective of this study is to determine the influence of mode conversion by. **contrasting radar returns obtained from uniform plasmas with those from gradient plasmas**

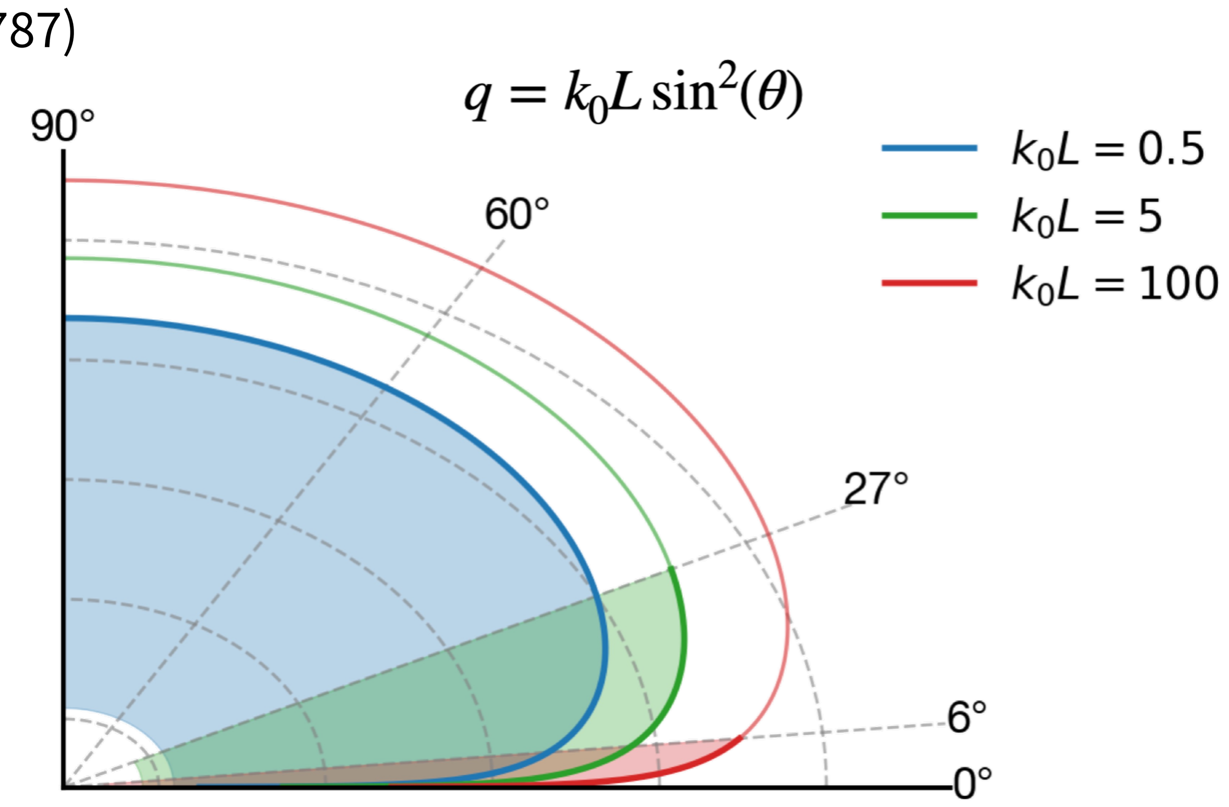
Mode Conversion Theory

Plasmas support two wave modes on time scales relevant to radar waves. Mode conversion can occur between the two types of waves when the radar pulse electric field is aligned both with the electromagnetic mode and electrostatic mode **at the plasma frequency**.



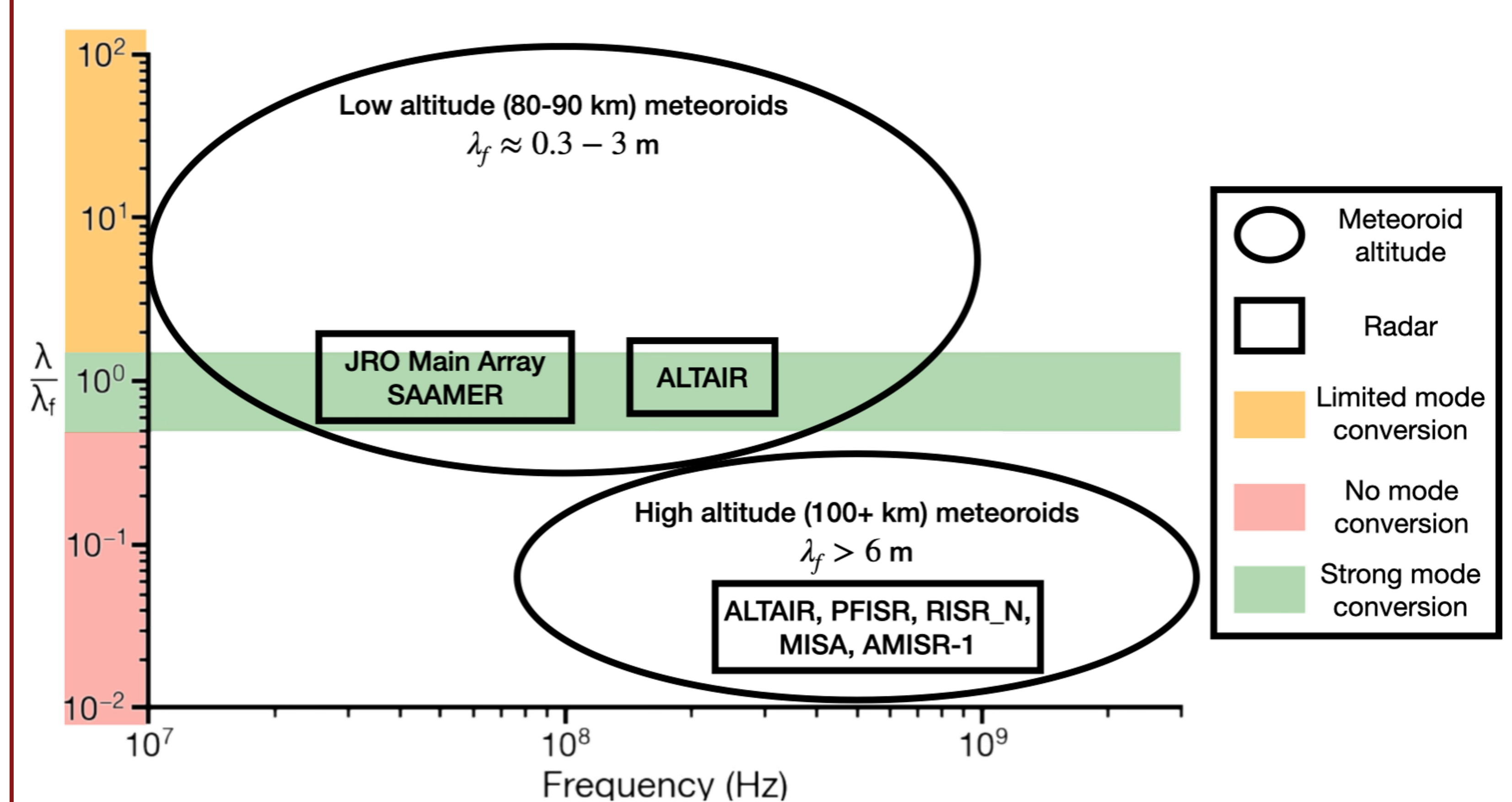
For vertically polarized radar pulses, mode conversion is observed when $0 < q < 1$ which limits the effect to certain oblique incident angles (D. E. Hinkel-Lipsker, B. D. Fried, G. J. Morales, Phys. Fluids B., 4, 1772-1787)

$$q = k_0 L \sin^2(\theta)$$

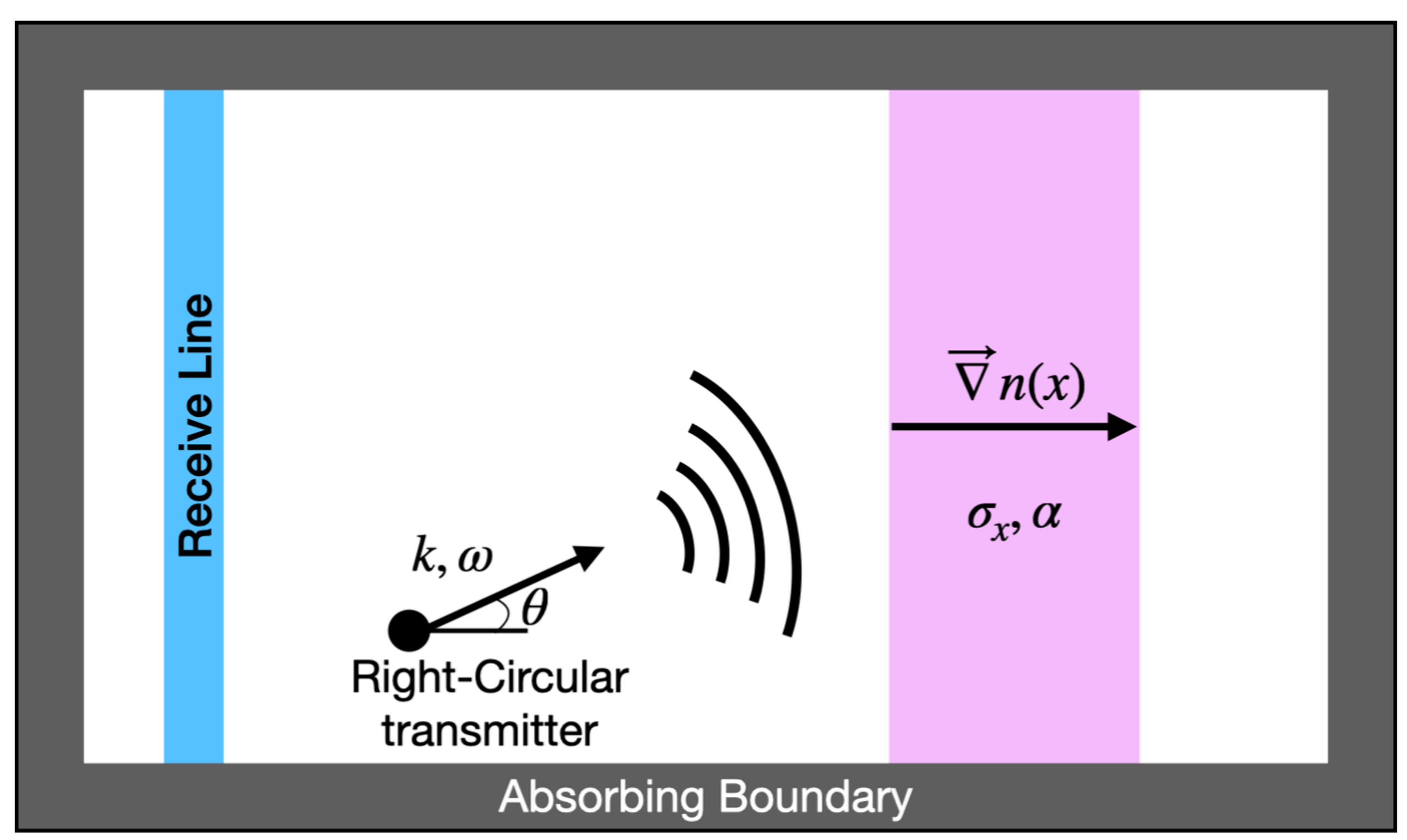


Motivation

The length scale of meteoric plasmas is comparable to the mean free length at the observed altitude. **Low altitude meteoroids (80-90km)** across most operating frequencies and **radars operating at VHF (30-300MHz)** across most typical observed altitudes should experience some mode conversion.



Simulation Domain and Parameters



We launch a pulse at a uniform plasma to generate a baseline signal that has undergone no mode conversion and compare it to the 1D gradient case subject to the following parameters

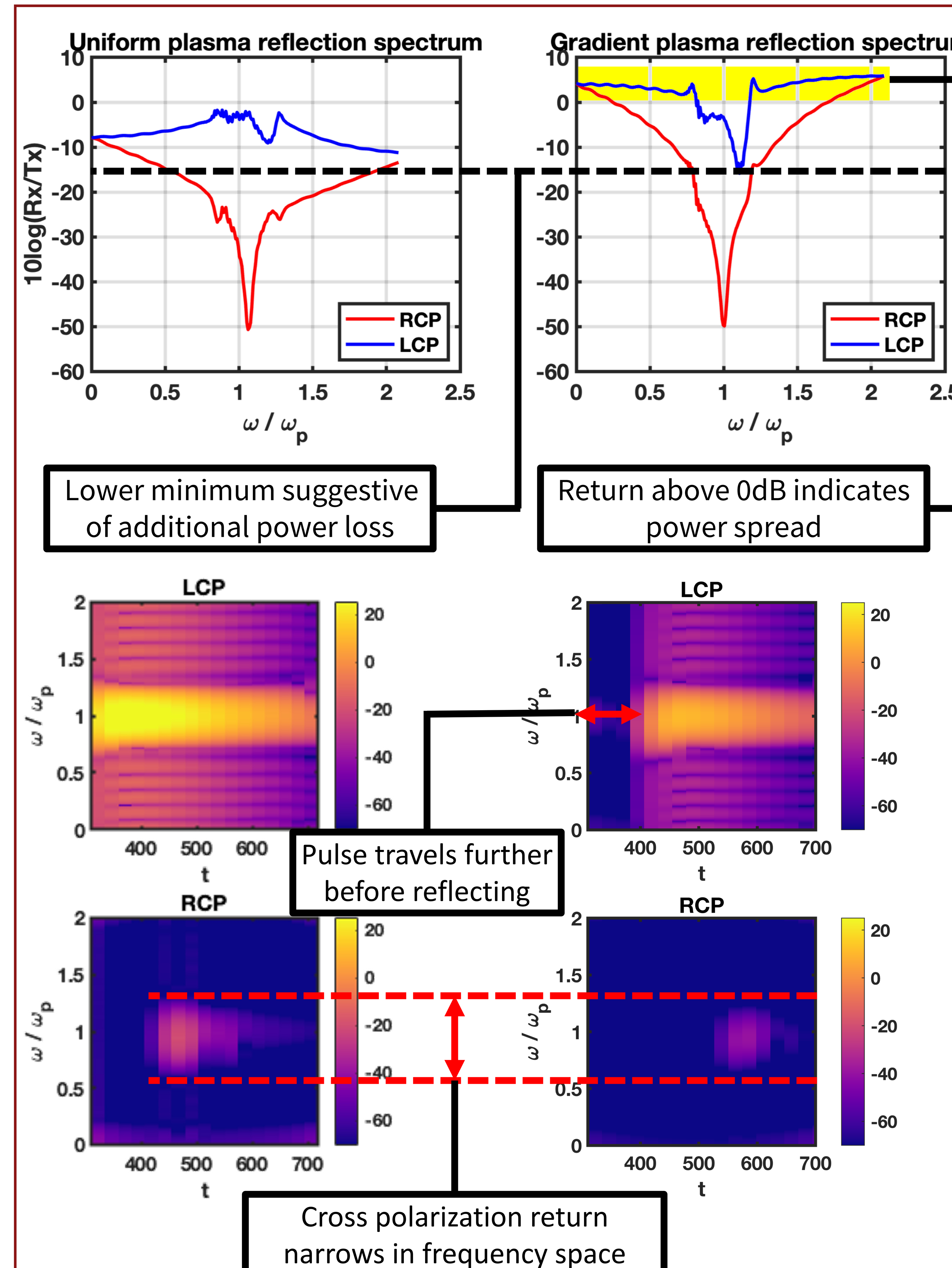
Radar Pulse ($\boldsymbol{k}, \boldsymbol{\omega}, \boldsymbol{\theta}$)

- k – pulse wavenumber, controls wavelength
- ω – pulse frequency, always equal to ω_p to study returns and mode conversion
- θ – incident angle with respect to the gradient, set to 10° for both cases

Plasma ($\boldsymbol{\sigma_x}, \boldsymbol{\alpha}$)

- σ_x – Gaussian standard deviation, controls plasma length scale
- α – Ratio of plasma thermal velocity to the speed of light

Generated Returns



Conclusions and Next Steps

Plasma gradients alter returns in a predictable way. Compared to uniform plasmas, there is a time delay associated with the gradient. Additionally, **the pulse narrows in frequency space** for the **cross-polarization channel** though it is yet to be proven whether this is an artifact of mode conversion. To move forward, the study's current method of estimating return signals, while revealing qualitative features, need to be implemented in a way that **more accurately represents the radar cross section (RCS)** to make statements about radar. Additionally, meteoroid plasmas are **2D gradients** so the dimensionality should reflect that in future simulations.

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