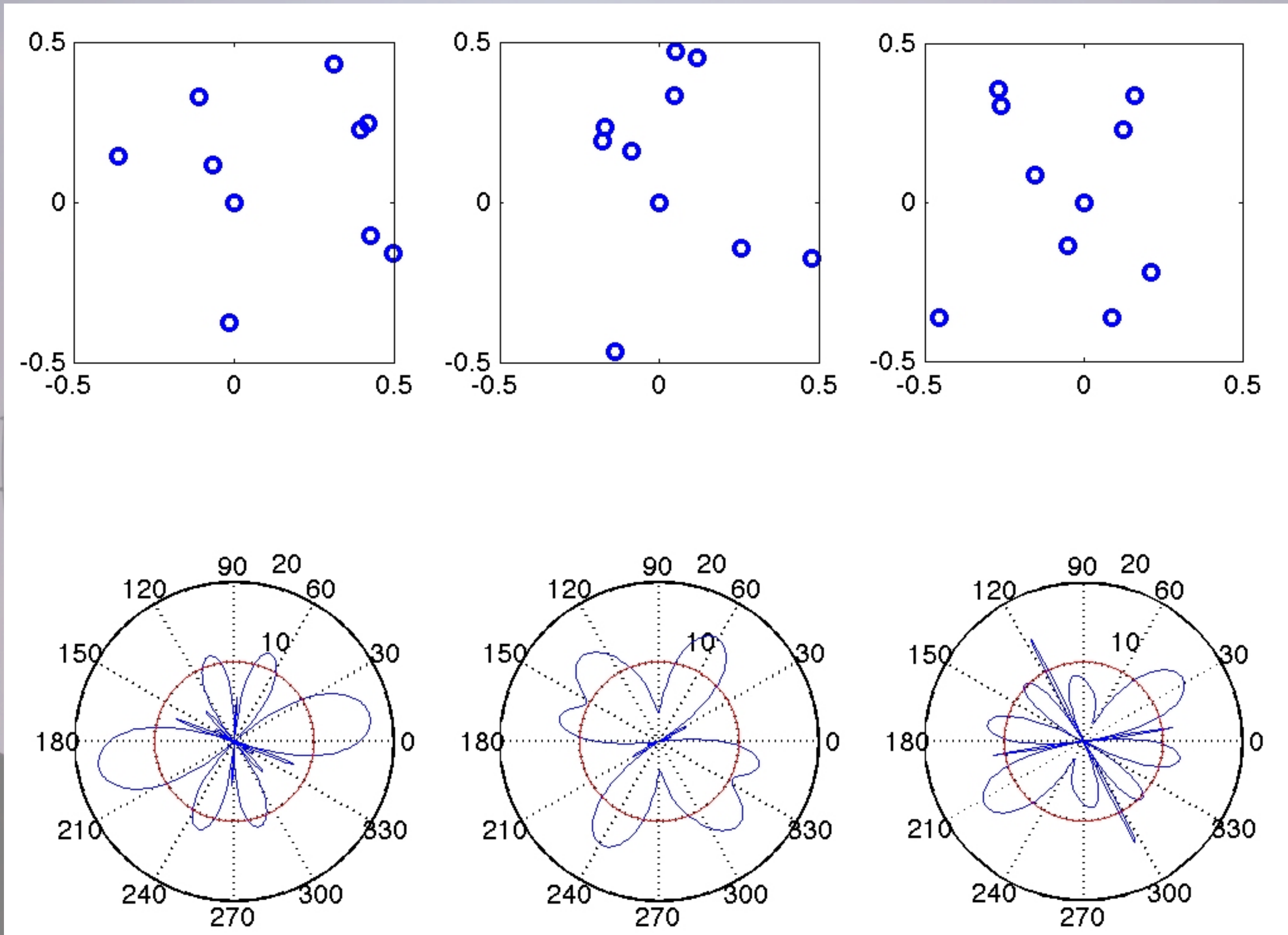
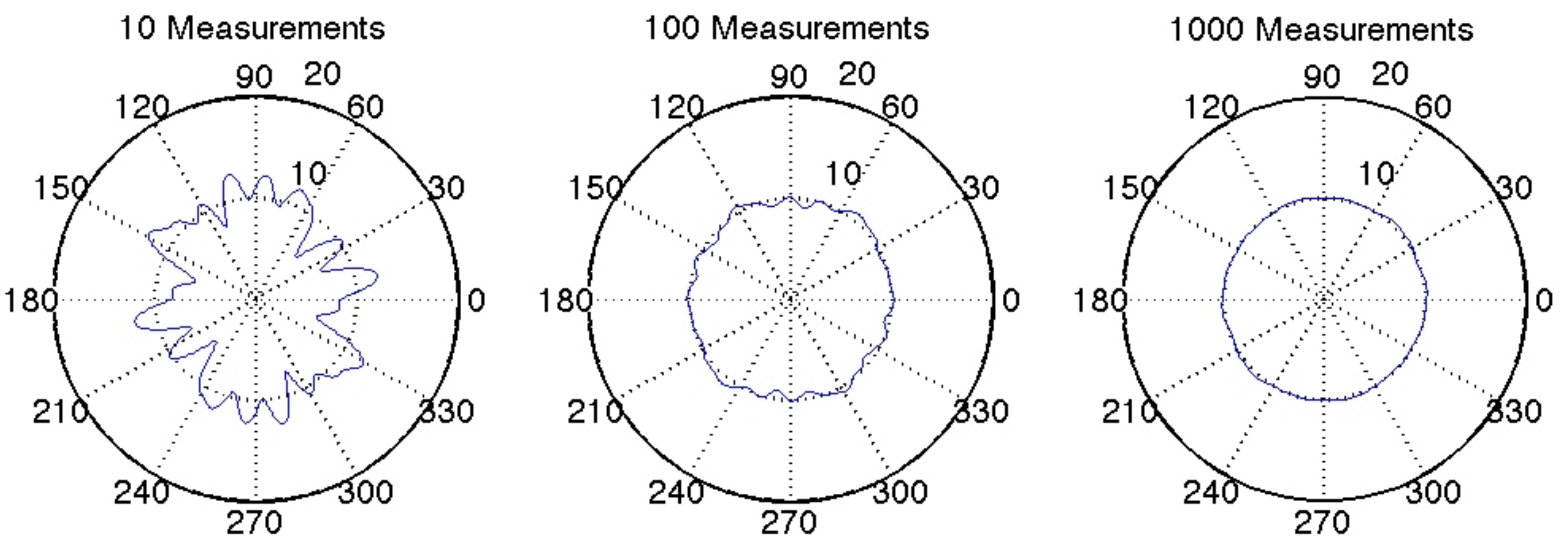
A day in the life of an ISR signal

Photo-Op Alert provided by
Eagle-Eye McCready

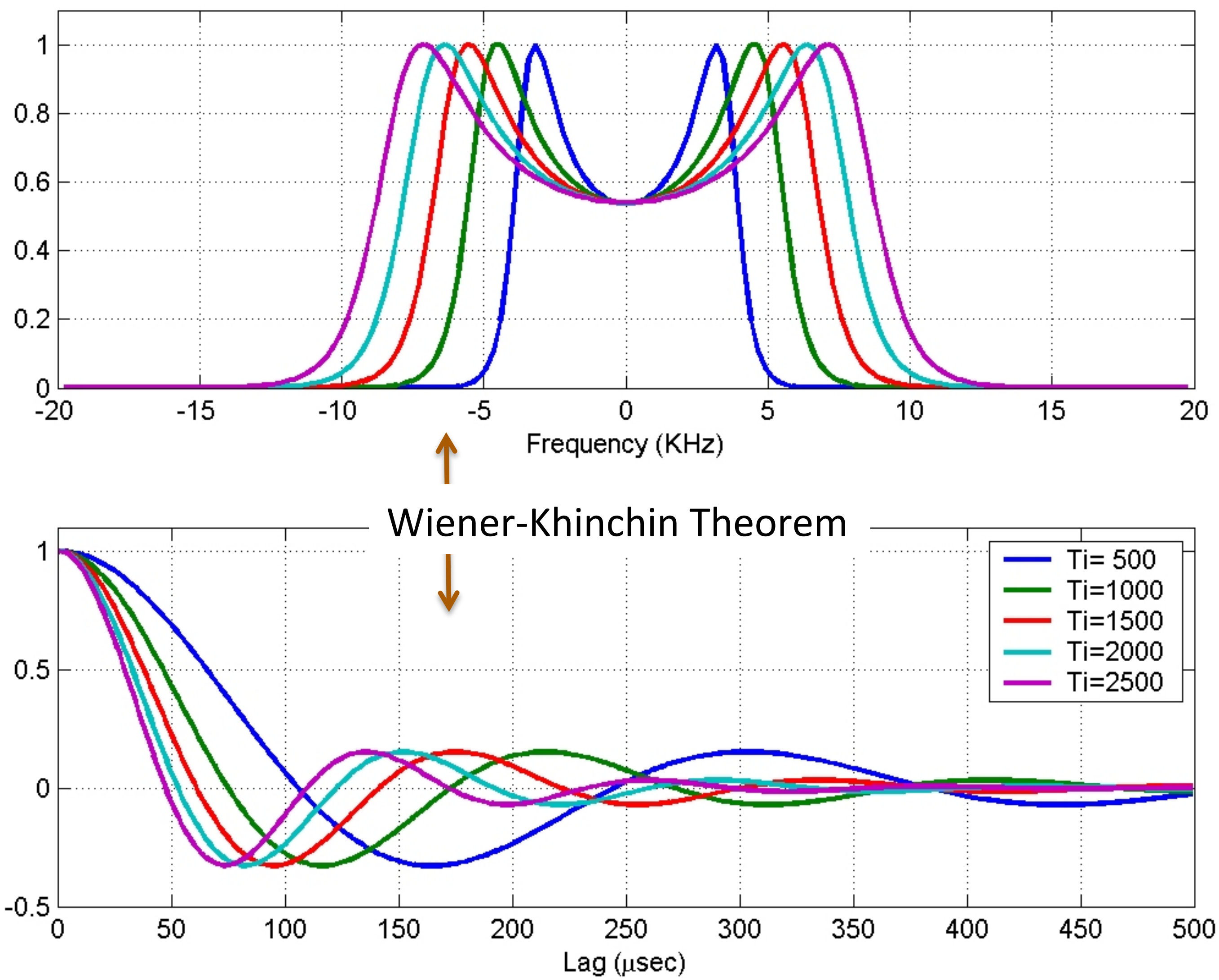
‘Incoherent’ electron positions



Incoherent Integration

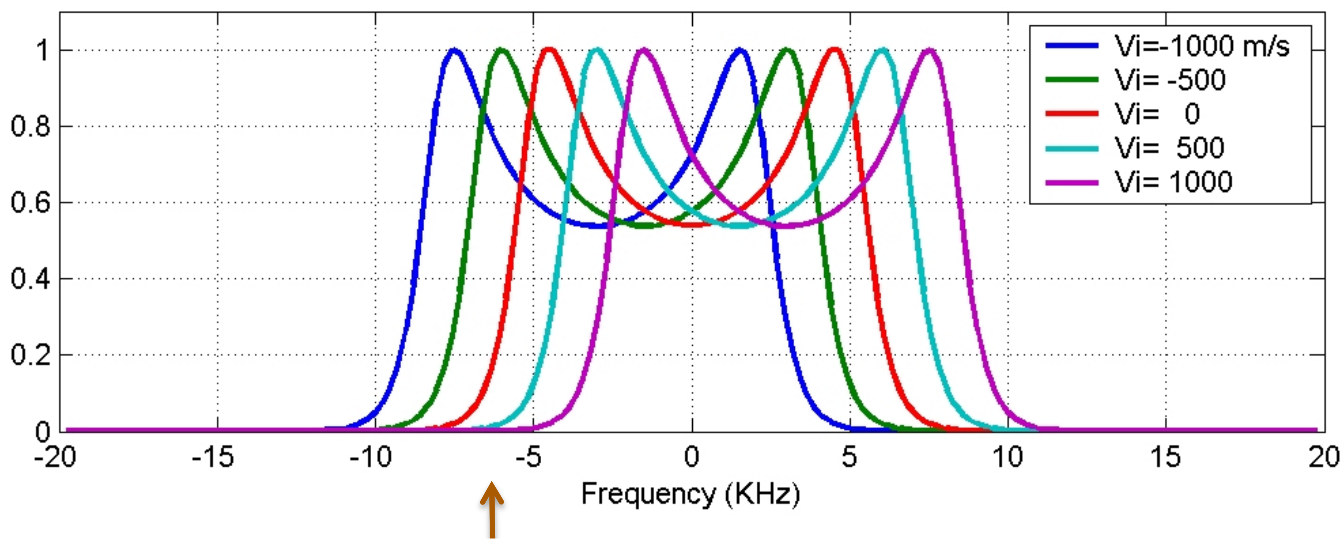


Watching the electrons reconfigure themselves gives us a peek at, e.g., Ion Temperature



<u>Parameters</u>
Freq: 449 MHz
Ne: 10^{12} m^{-3}
Te: 2*Ti
Comp: 100% O^+
ν_{in}: 10^{-6} KHz

By watching the electrons move in bulk (chasing the ions around), we can 'see' Ion Velocity



Parameters
Freq: 449 MHz
Ne: 10^{12} m^{-3}
Ti: 1000 K
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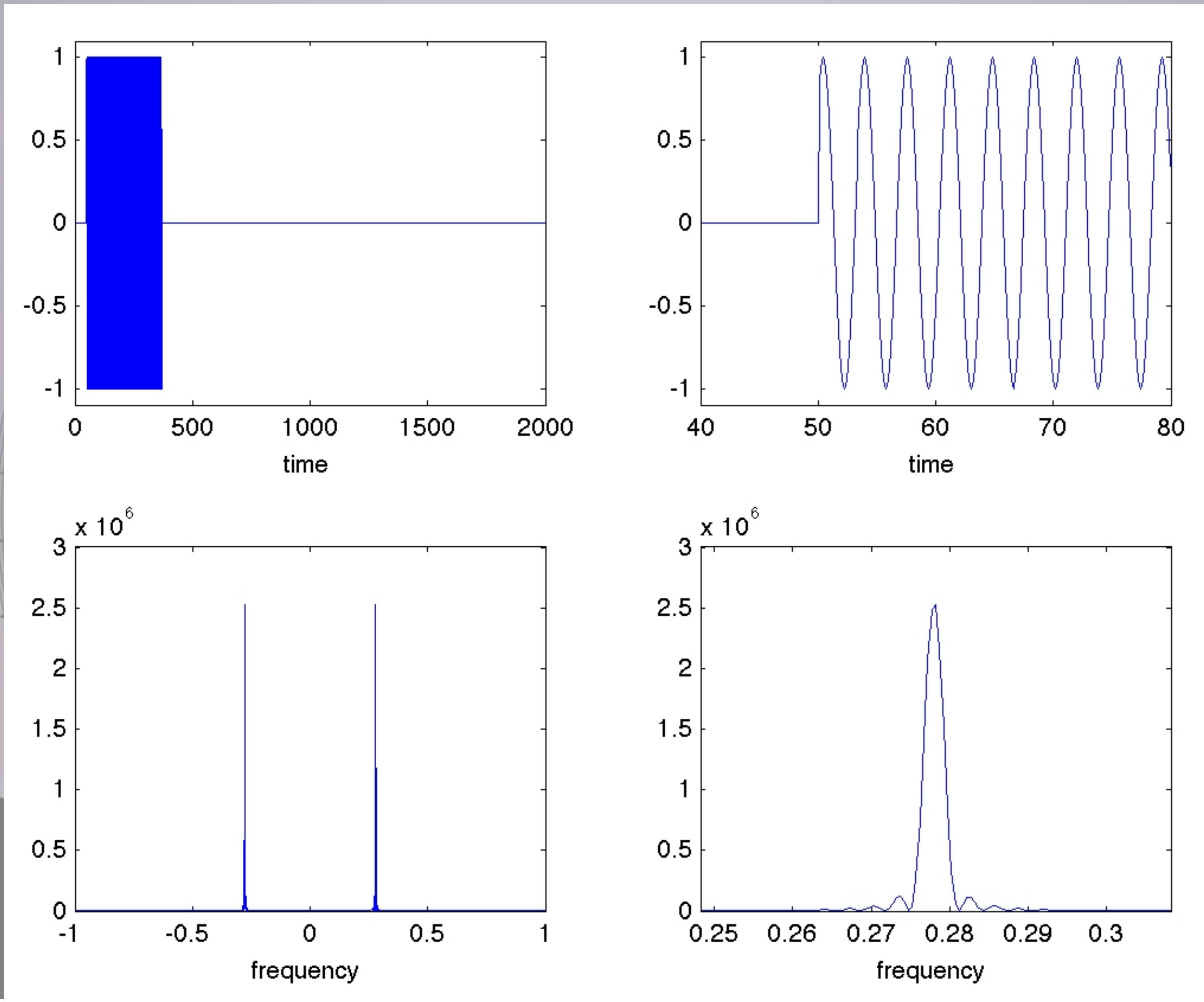
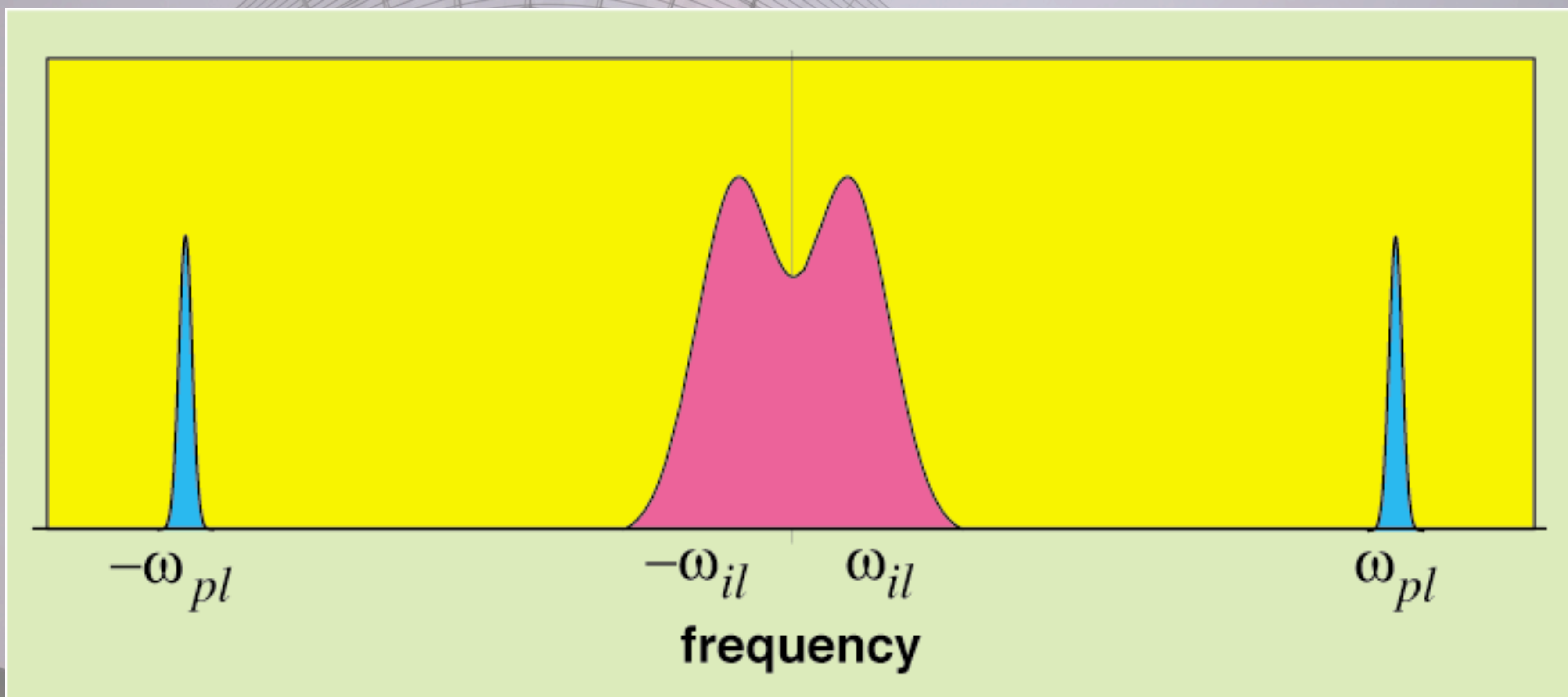
Imaginary parts of a measurement?
What the heck is an imaginary measurement?
How do radars measure imaginary things?
Do imaginary radars measure real things?
Time for a quick refresher…

Transmitted Waveforms



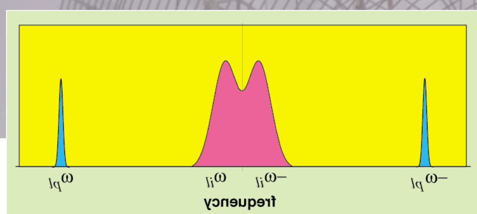
Received signal?

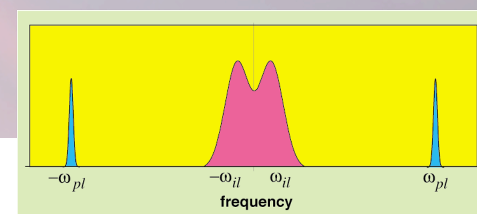


Received signal?

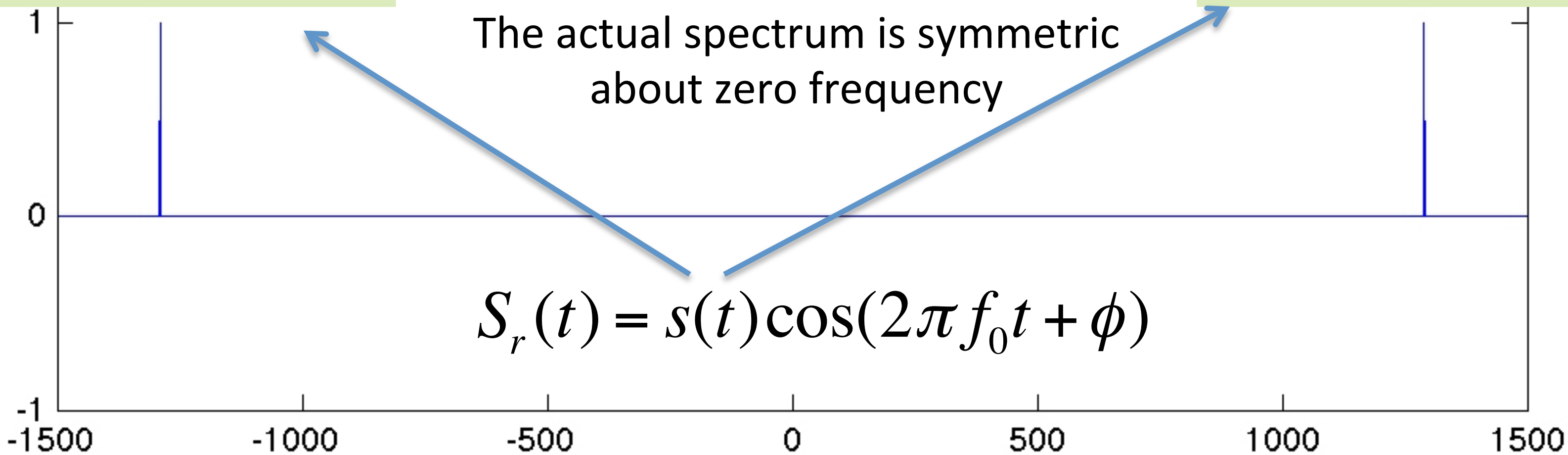
Expected value (statistically speaking) of the Power Spectral Density of the received signal!

The individual sides are **not** symmetric about their center frequencies!





The actual spectrum is symmetric about zero frequency



$$S_r(t) = s(t)\cos(2\pi f_0 t + \phi)$$

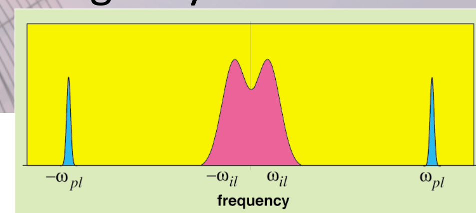
Received signal?

So, can we just sample the received signal and pick this out in software? I can mix and filter, after all!

Well, we need to sample pretty fast to do it this way (the Nyquist frequency would be GHz at Sondrestrom).

Instead, we normally mix it down to an intermediate frequency and sample that. Then the final mixing to baseband (real and imaginary) is done digitally.

$$S_r(t) = s(t)\cos(2\pi f_0 t + \phi)$$



$$S_r(t)\cos(2\pi f_1 t) = s(t)\frac{1}{2}\left[\cos(2\pi(f_0 - f_1)t + \phi) + \cos(2\pi(f_0 + f_1)t + \phi)\right]$$

Intermediate frequency

The signal represented here must be complex because it will not, in general, be symmetric.

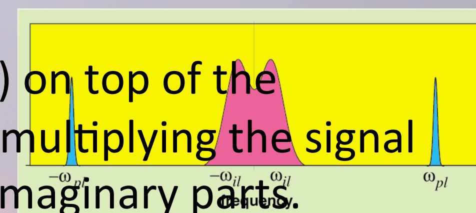
Received signal?

Given that the signal we are interested in must be complex, how do we get such a measurement? What does that mean?

We look at shifting the signal all the way down to center it on the interesting bit. This means mixing with the carrier frequency.

This has to be done in a way that maintains both the cosine (in-phase, real) and sine (quadrature, imaginary) components.

We also have to keep from shifting the positive-frequency part of s(t) on top of the negative frequency part of s(t). This, it turns out, can be handled by multiplying the signal by both cosine and sine and treating the resulting signal as real and imaginary parts.

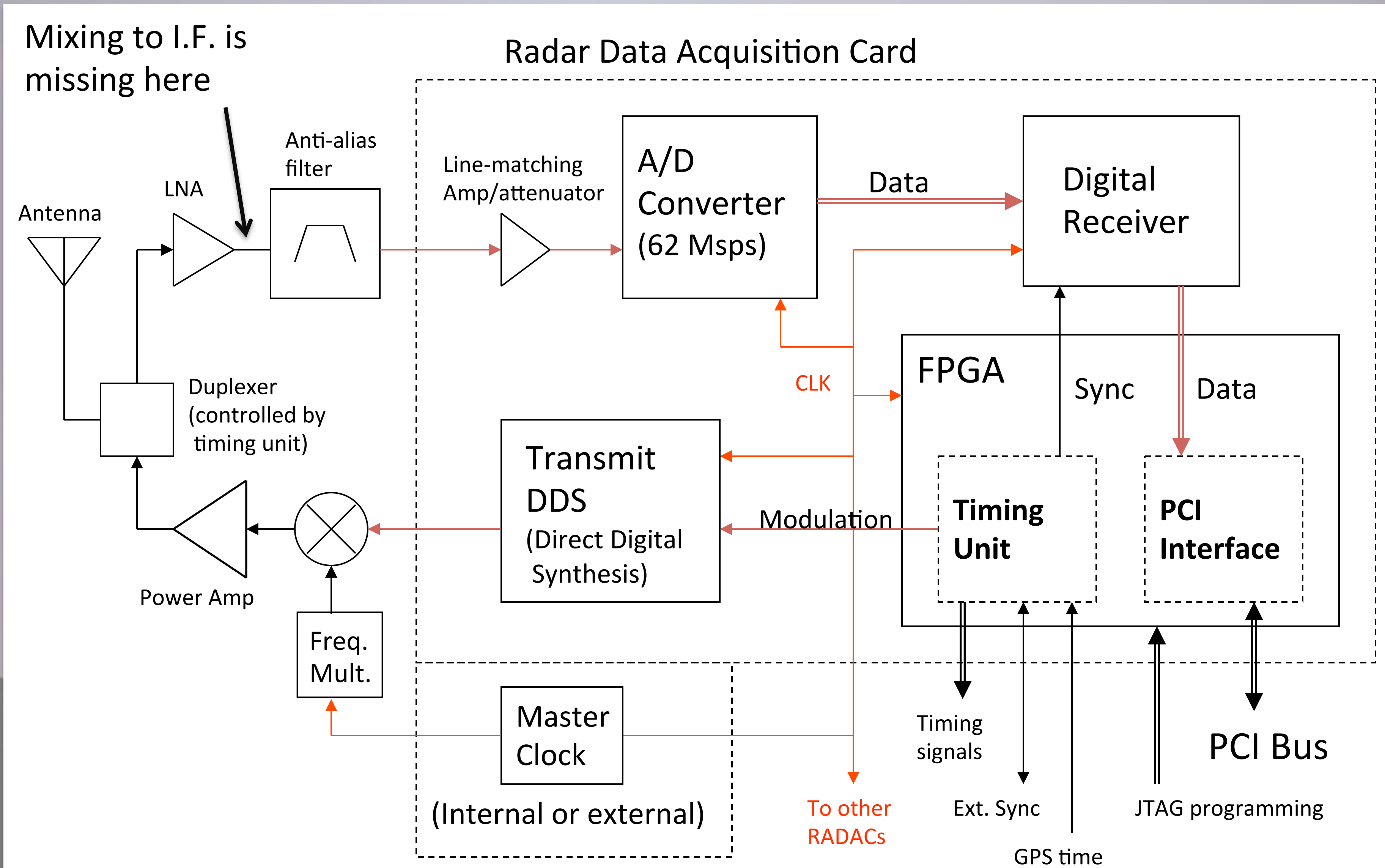


$$S_r(t) = s(t)\cos(2\pi f_0 t + \phi)$$

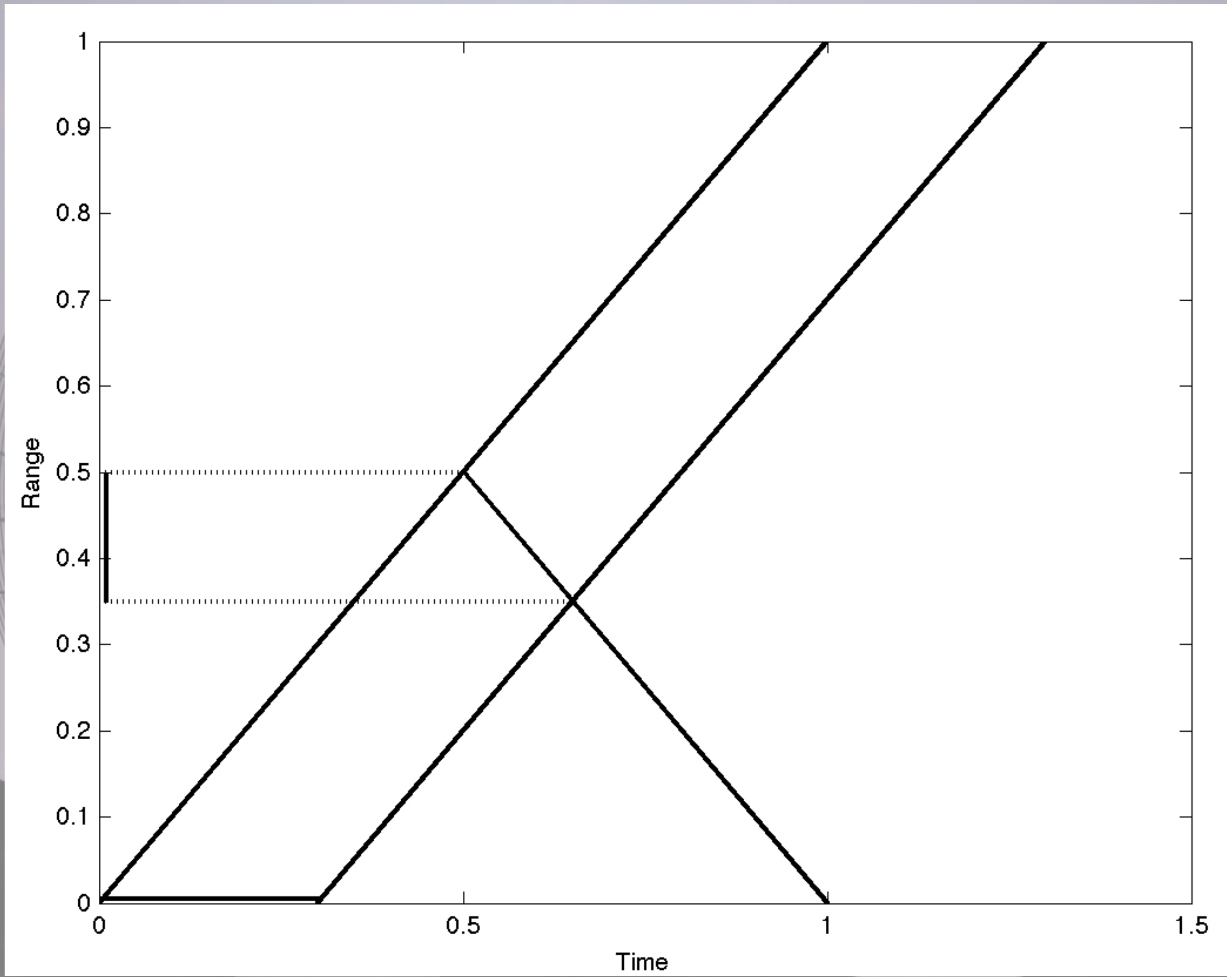
Real $$I = S_r(t)\cos(2\pi f_1 t) = s(t)\frac{1}{2}\left[\cos(\phi) + \cos(2\pi(f_0 + f_1)t + \phi)\right]$$

Imag $$Q = S_r(t)\sin(2\pi f_1 t) = s(t)\frac{1}{2}\left[-\sin(\phi) + \sin(2\pi(f_0 + f_1)t + \phi)\right]$$

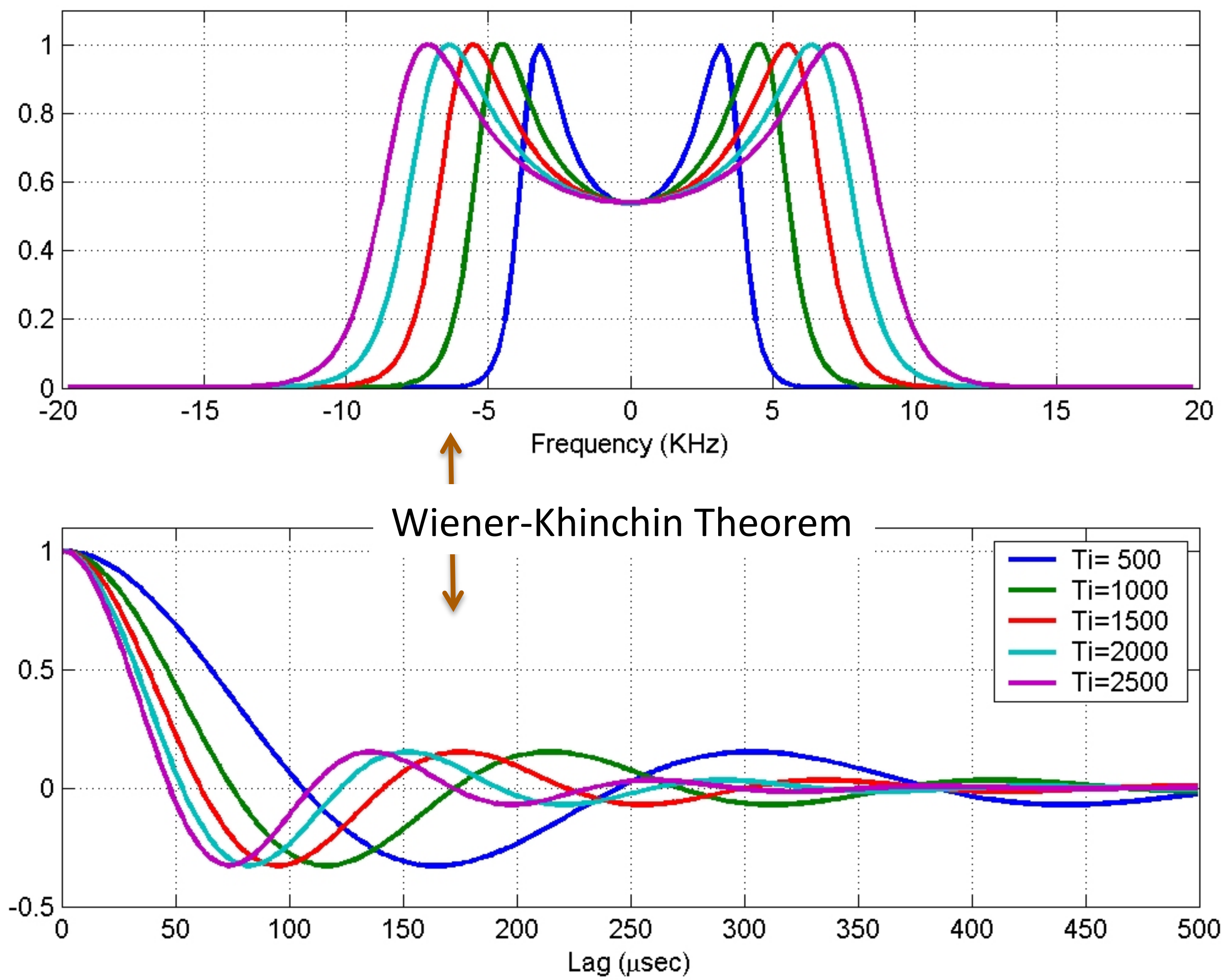
RADAC BLOCK DIAGRAM



What does the ADC see?



But we want power spectral densities



Parameters
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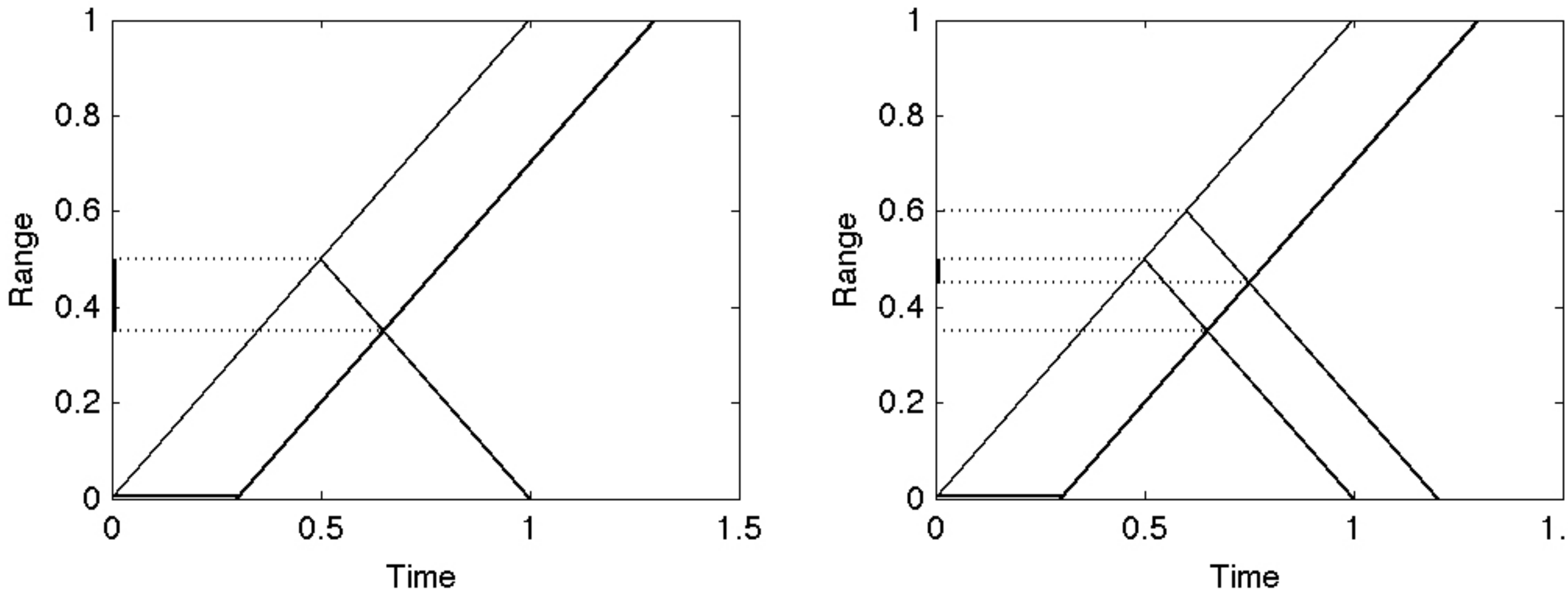
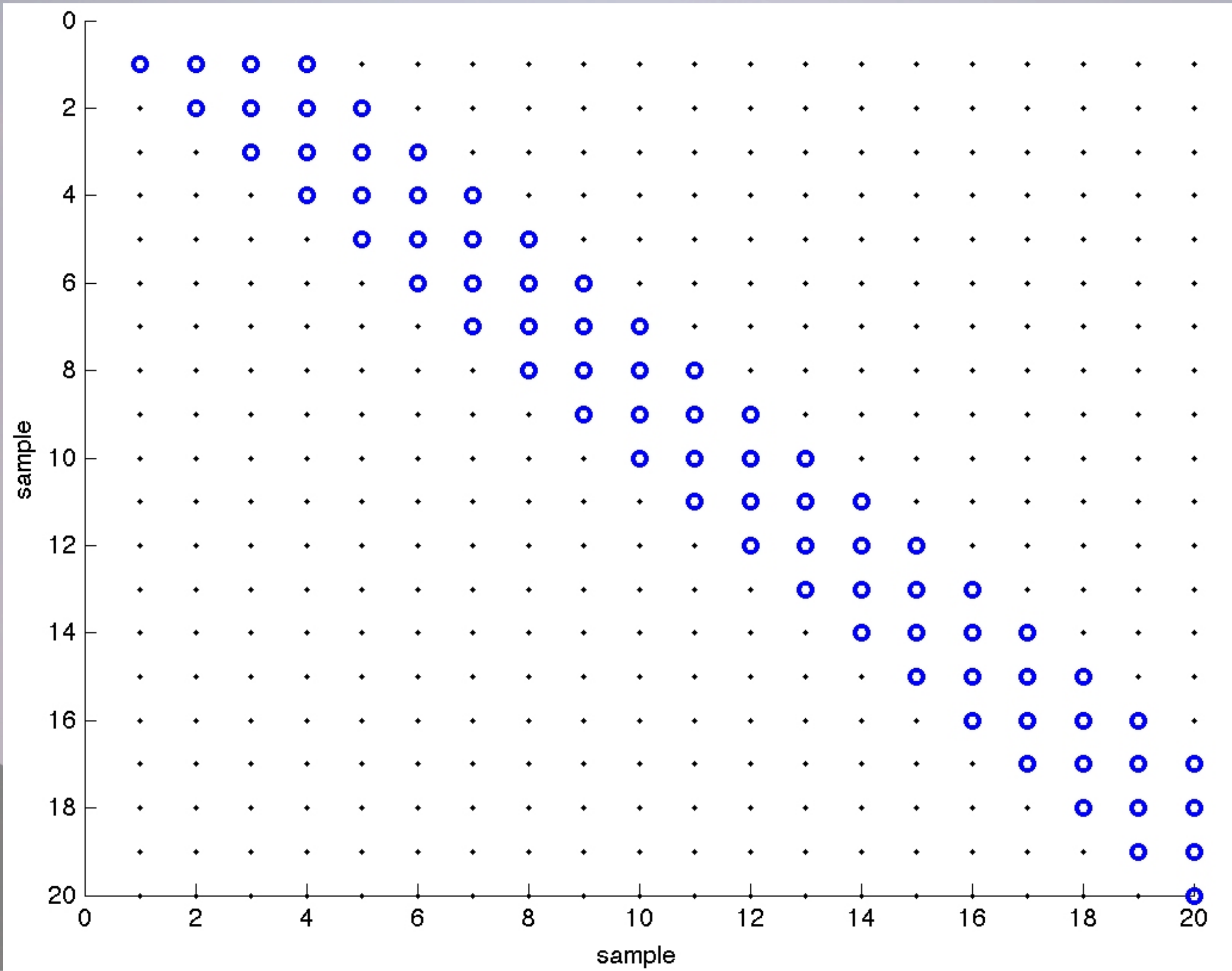
ν_{in}: 10^{-6} KHz

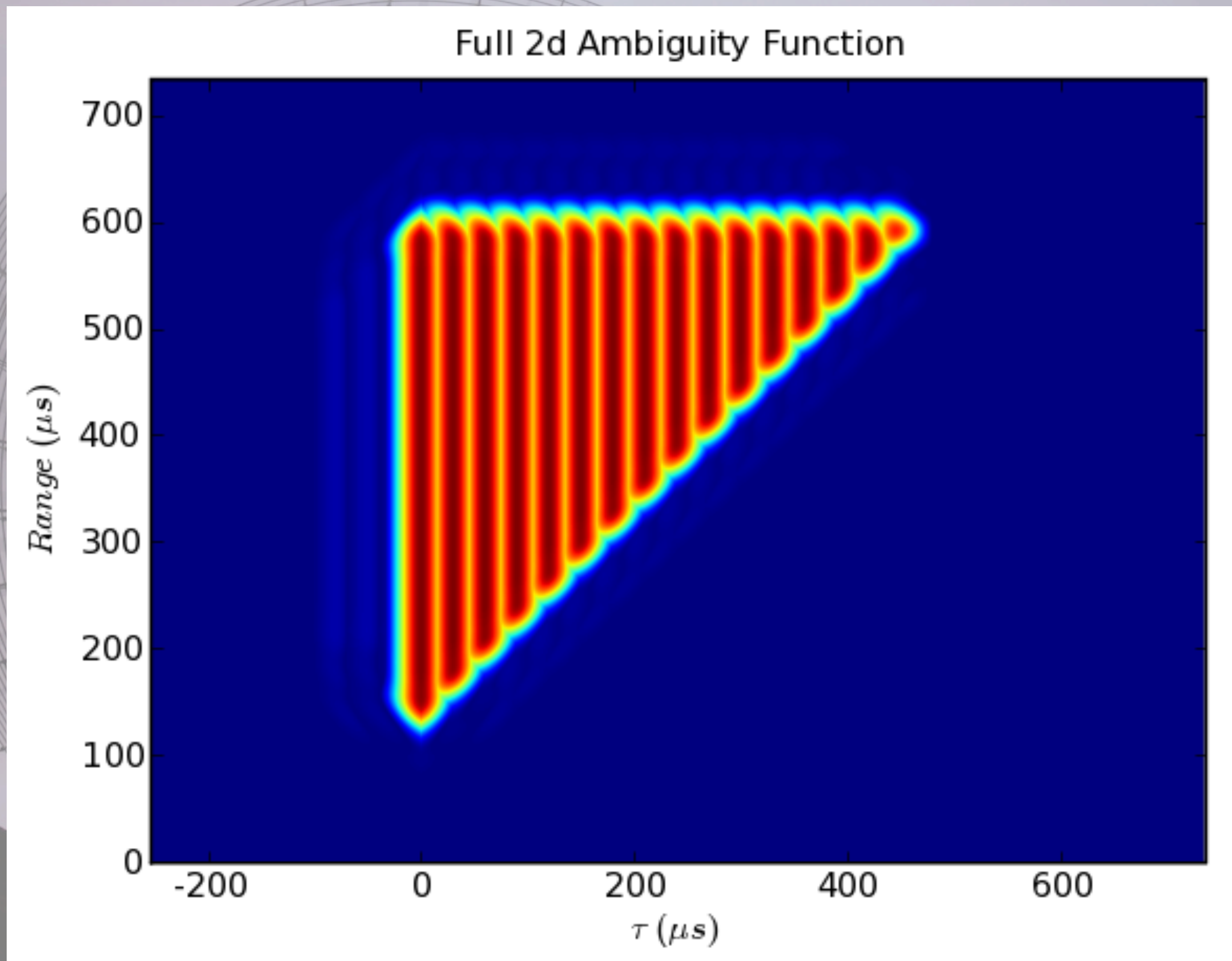
Measuring ACFs



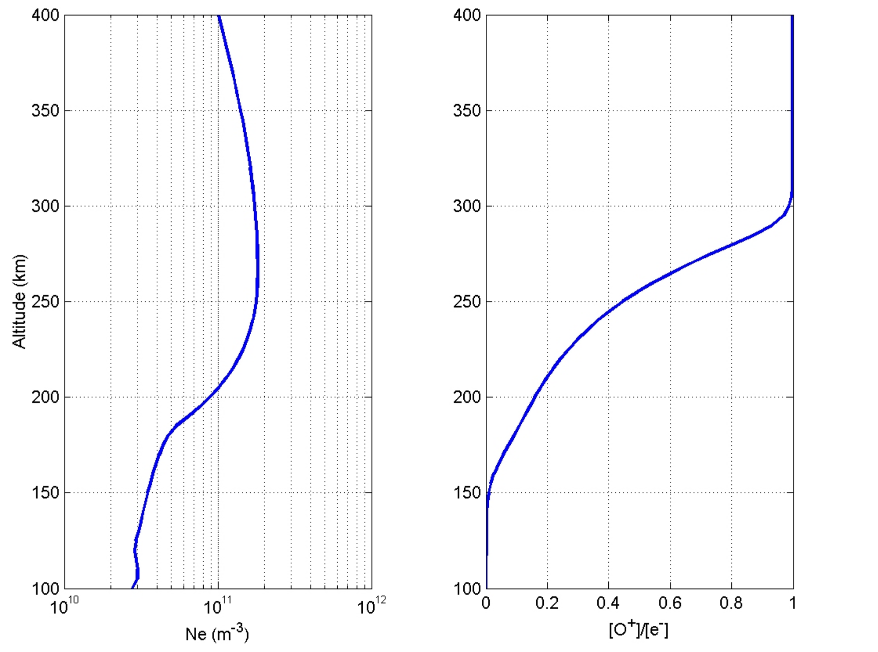
Lag Profile Matrix

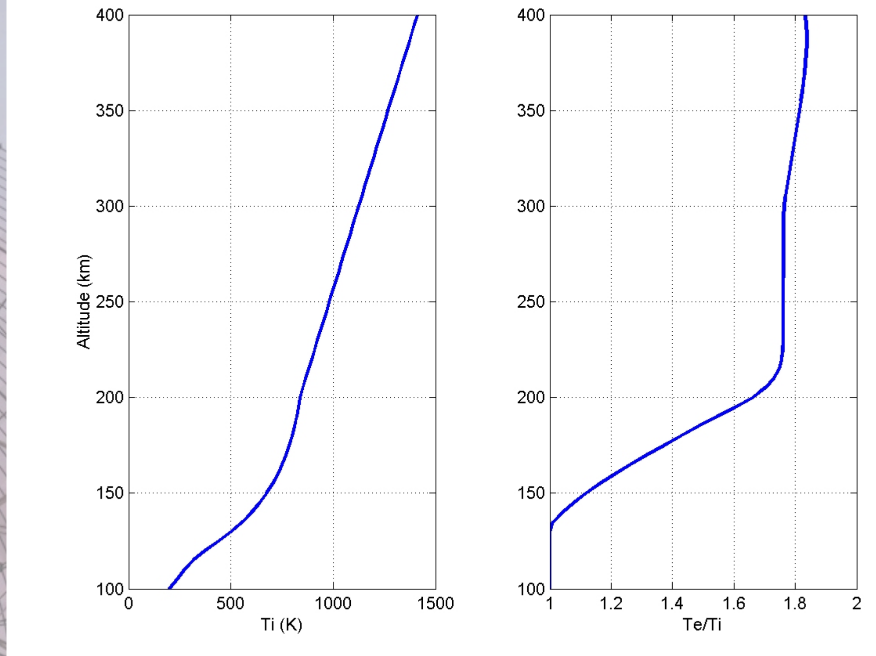


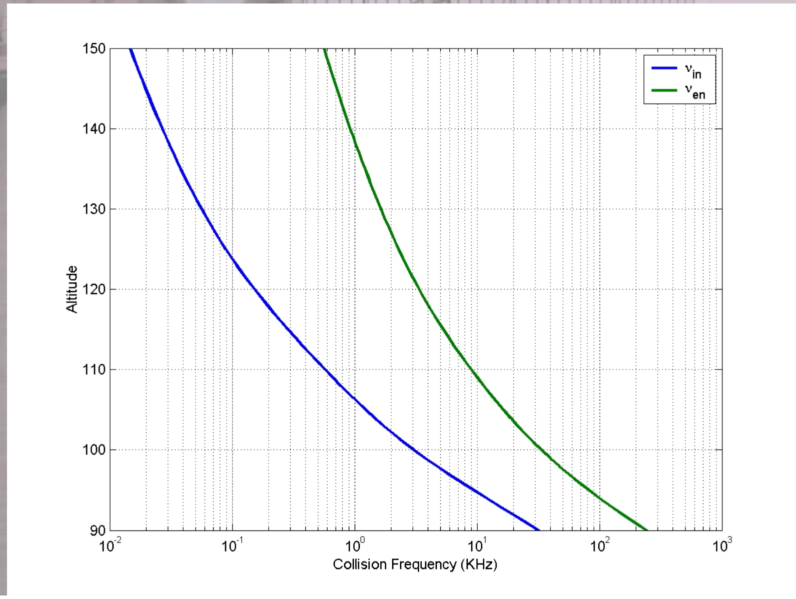
Ambiguity Function
(smearing in range and lag)



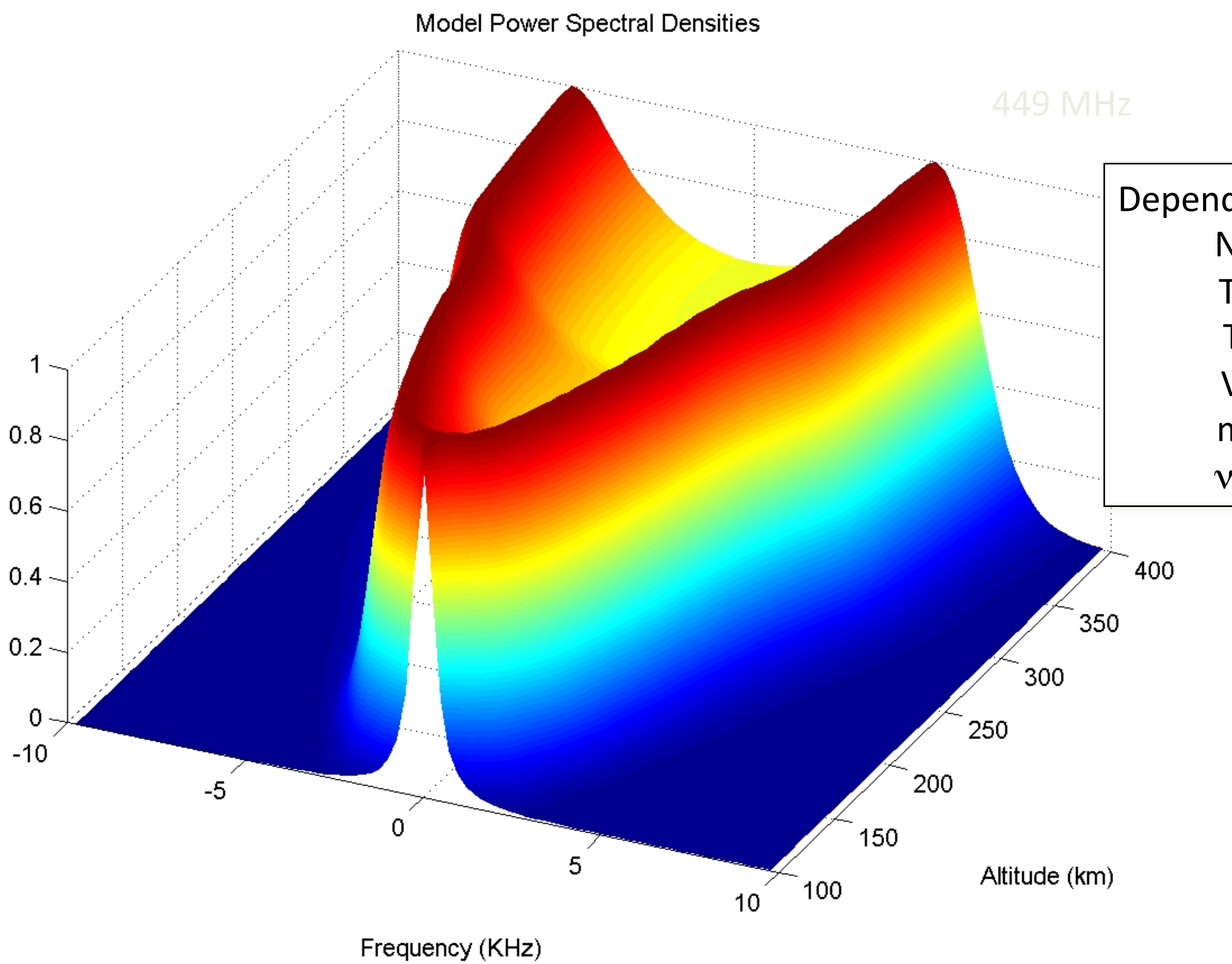
Model Plasma Parameters







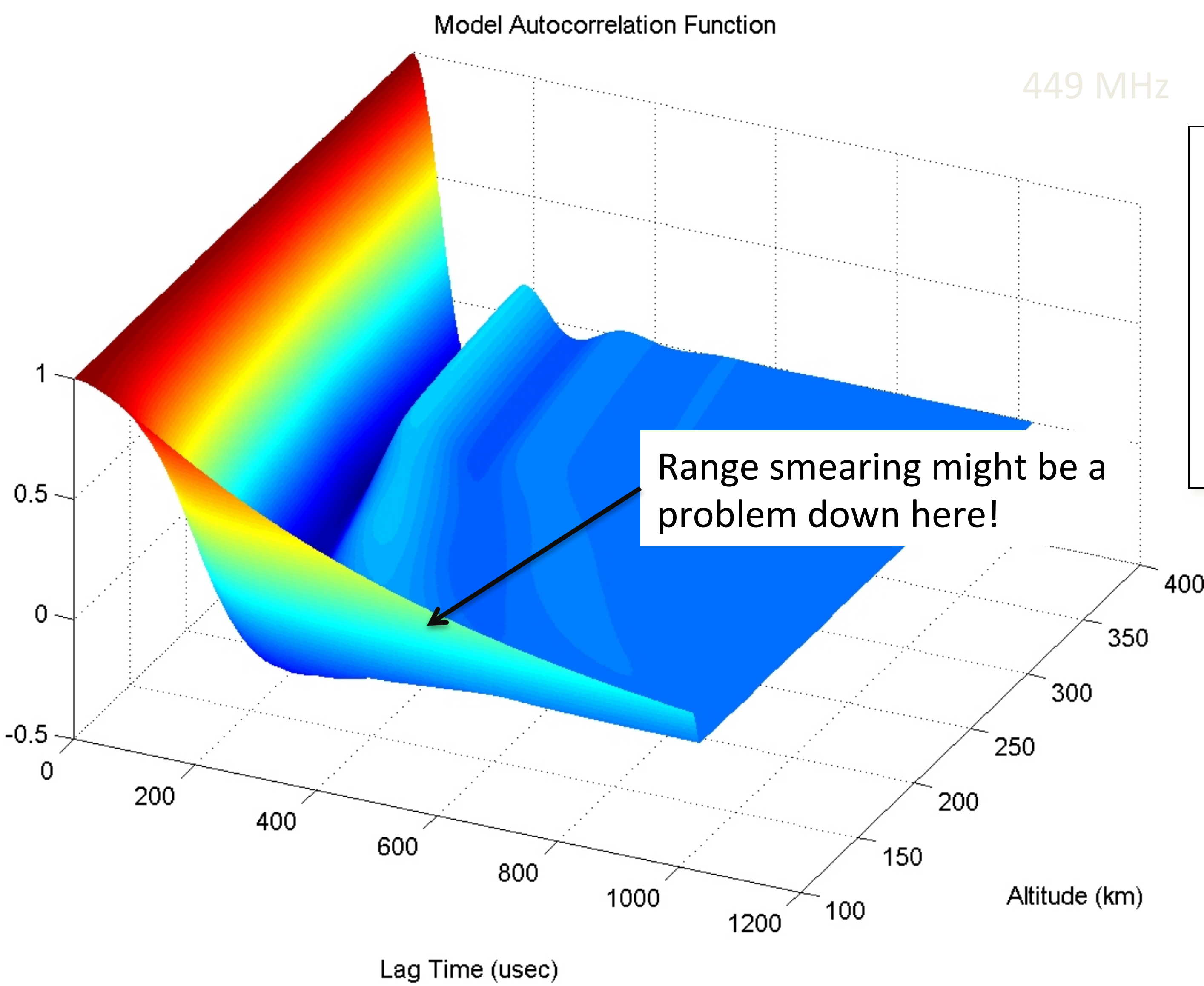
Incoherent Scatter Power Spectra



Dependencies:

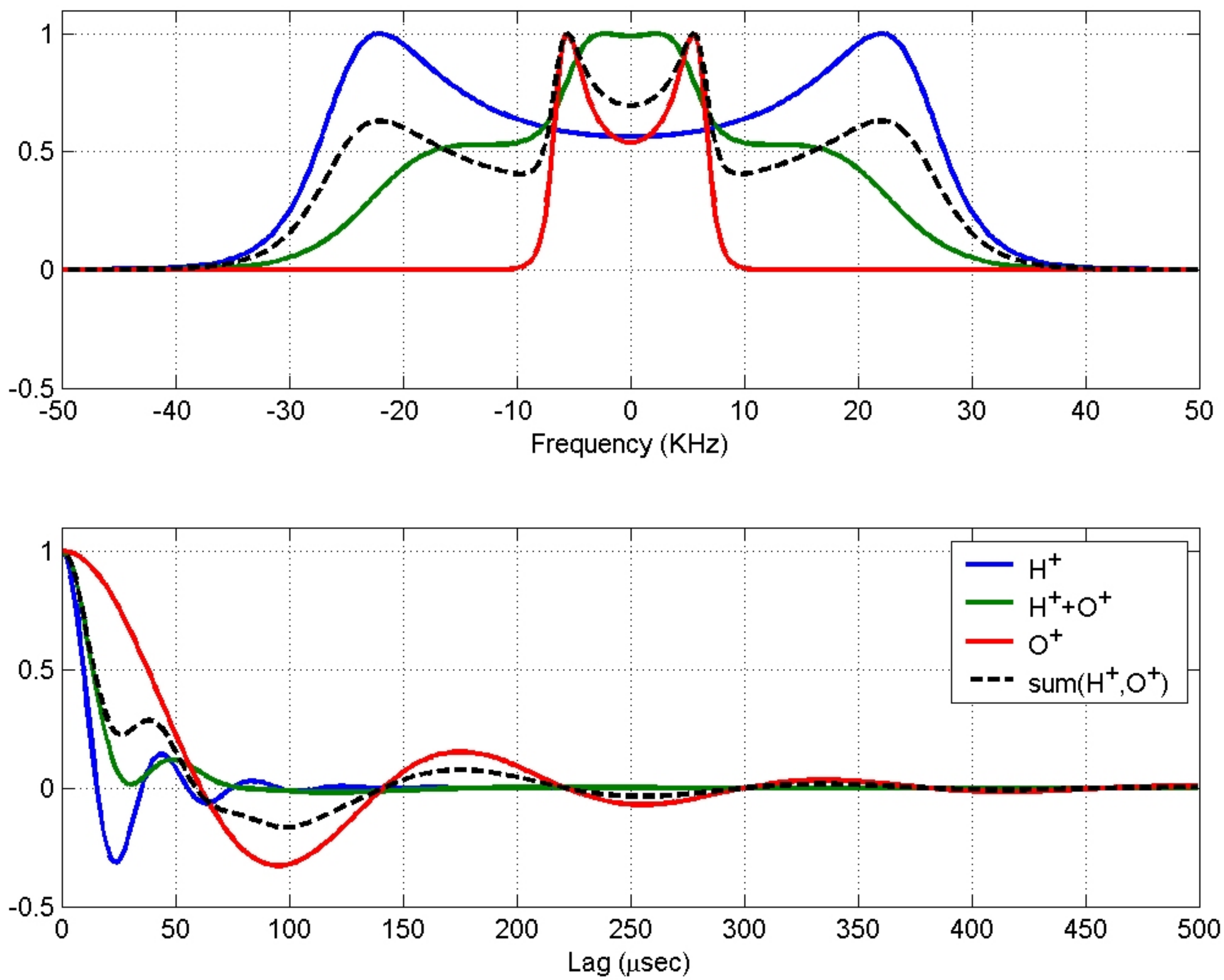
- N_e
- T_e
- T_i
- V_i
- m_i
- ν_{in}

Incoherent Scatter Autocorrelation Functions



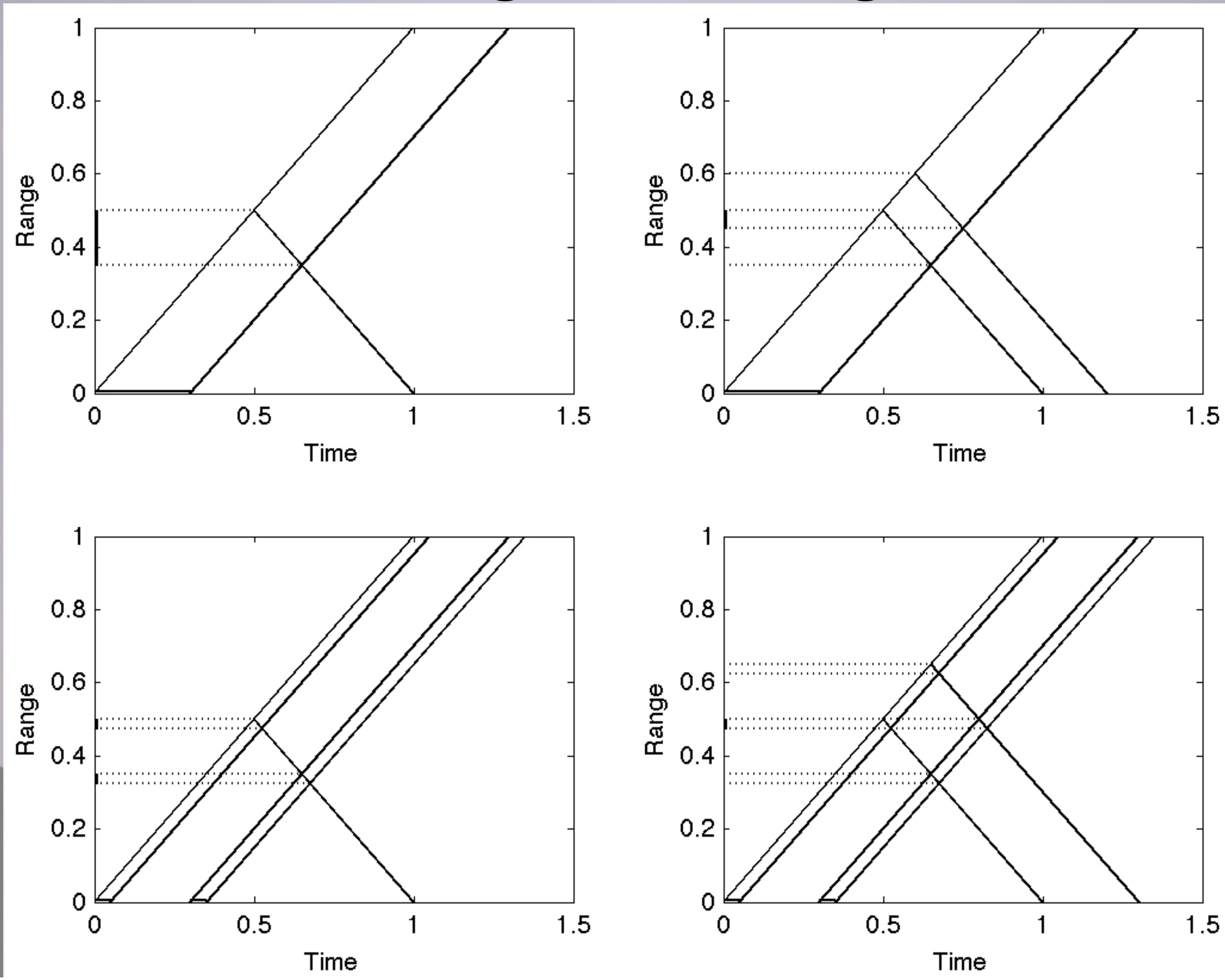
Dependencies:
N_e
T_e
T_i
V_i
m_i
ν_{in}

An aside: Ion Composition (O^+ vs. H^+)

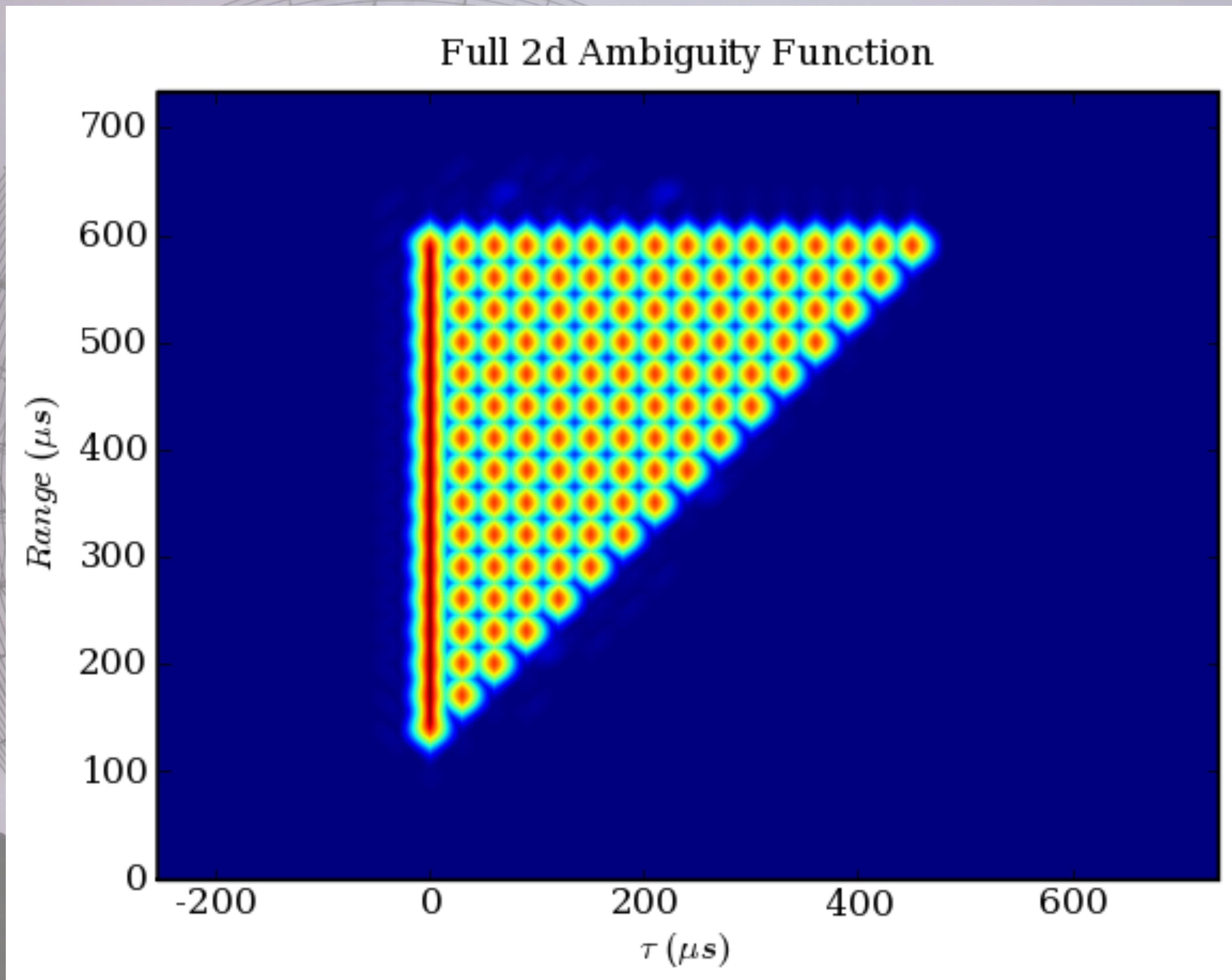


<u>Parameters</u>
Freq: 449 MHz
Ne: 10^{12} m^{-3}
Ti: 1500 K
Te: 3000 K
ν_{in}: 10^{-6} KHz

Range Smearing



Ambiguity Function Alternating Code (smearing in range and lag)



Another aside: Debye Length effects

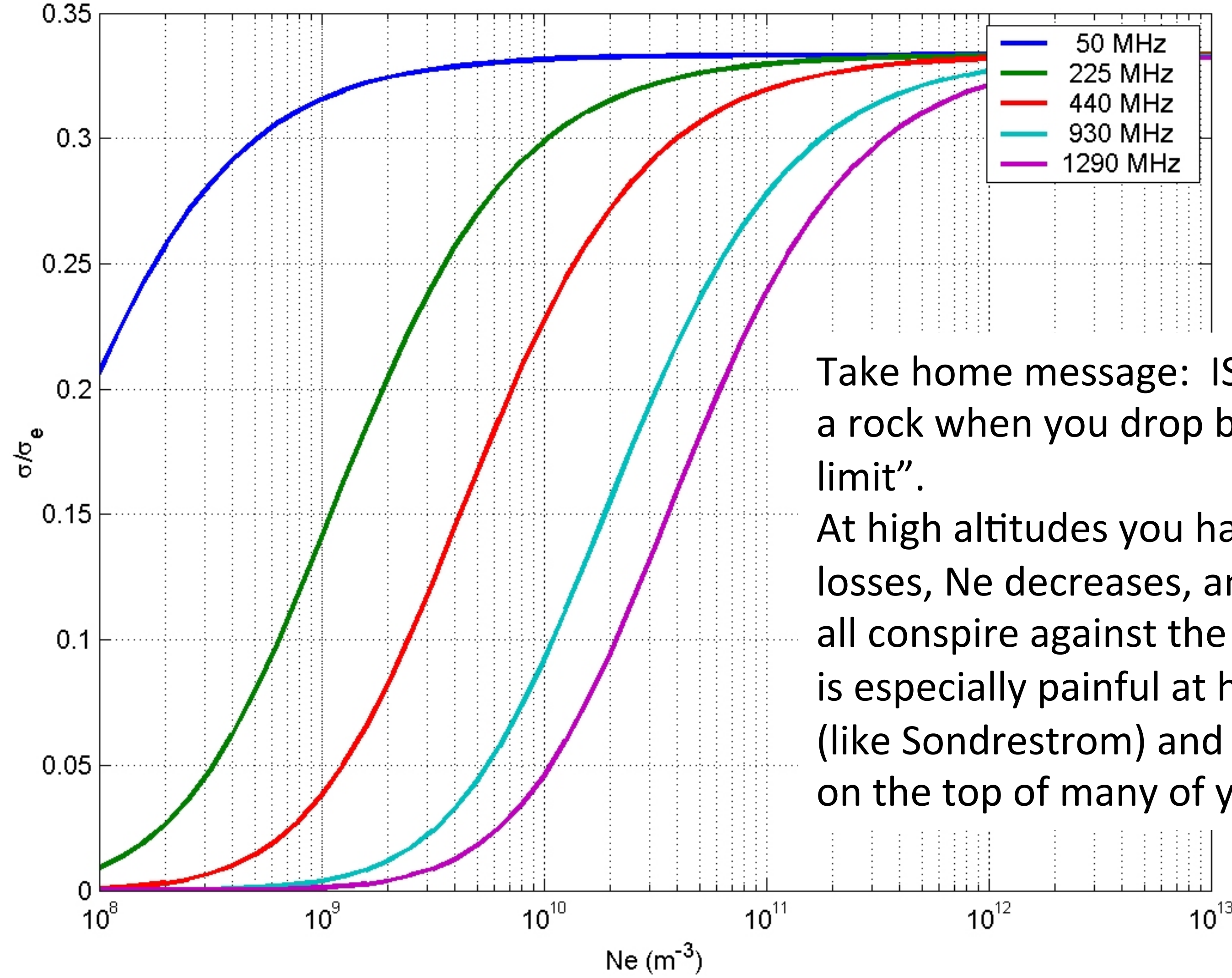
The total per-electron cross-section also a function of plasma temperatures. In particular, the cross-section can be approximated by the following for T_r less than about 4.

$$\sigma_{tot} = \sigma_e \left[\frac{1}{\left(1+(k\lambda_D)^2\right)\left(1+(k\lambda_D)^2+T_r\right)} + \frac{(k\lambda_D)^2}{1+(k\lambda_D)^2} \right]$$

$$\lambda_D = \left(\frac{\varepsilon_0 k_B T_e}{n_e q_e^2} \right) \qquad k = \frac{4\pi}{\lambda_{TX}}$$

This means that ion and electron temperatures must be available to accurately estimate electron density. It also means that the impact of the Debye length is felt at low electron densities and at different densities for different radars (different values of k).

Debye Length effects



__Parameters__
Ti: 1000 K
Te: 2000 K

Take home message: ISR sensitivity drops like a rock when you drop below a "Debye length limit".

At high altitudes you have problems of R^2 losses, Ne decreases, and Te increases which all conspire against the top-side scientist. This is especially painful at higher frequency radars (like Sondrestrom) and explains the hard limit on the top of many of your plots.

The Bottom Line

- ISR signals are noisy. They are noisy regardless of how good your system is. Lots of pulses are needed to beat that noise into submission. But, as Thomas pointed out, don't abuse your data!
- Spectral measurements are typically done via autocorrelation function measurements (lag profiles). This allows you to more easily understand the impacts of range smearing in a pulse.
- Range smearing exists! It isn't always the enemy – it helps your signal statistics, after all. On the other hand, it can confuse things if the amount of smearing covers up the physics you are interested in.
- One implication of this is that you must understand some of the meta-information that follows your data through Madrigal. These instrumental effects cannot necessarily be seen in the data alone!
- When you go to interpret plots of Ne, Te, Ti, and Vi you really should care how it was measured!