The short introduction to Incoherent Scatter (IS) Theory

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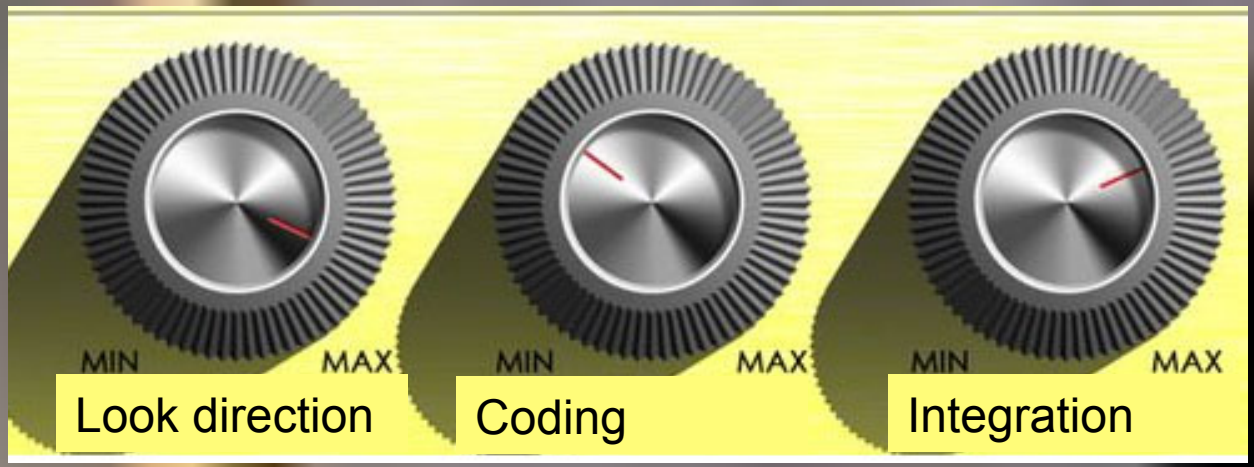
MIN
MAX
VOLUME
MIN
MAX
TREBLE
MIN
MAX
BASS


MIN
MAX
Look direction
MIN
MAX
Coding
MIN
MAX
integration


MIN
MAX
Look direction
MIN
MAX
Coding
MIN
MAX
Integration

Incoherent?...

- **Dictionary: The property of being coherent**
- **Antonym: Incoherent**

- **Incoherent=Random, viz. Incoherent scatter is the process by which radiowaves are randomly scattered by electrons in the ionosphere**

- **Media: Incoherent=Incomprehensible**

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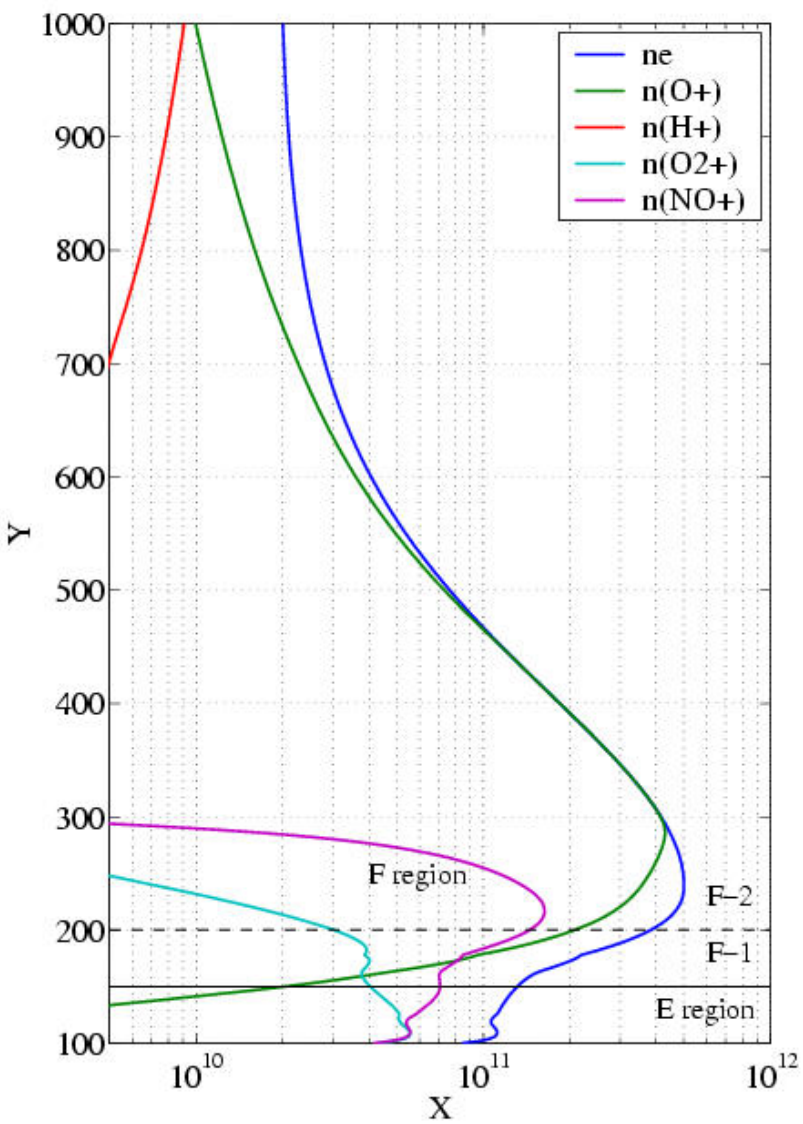
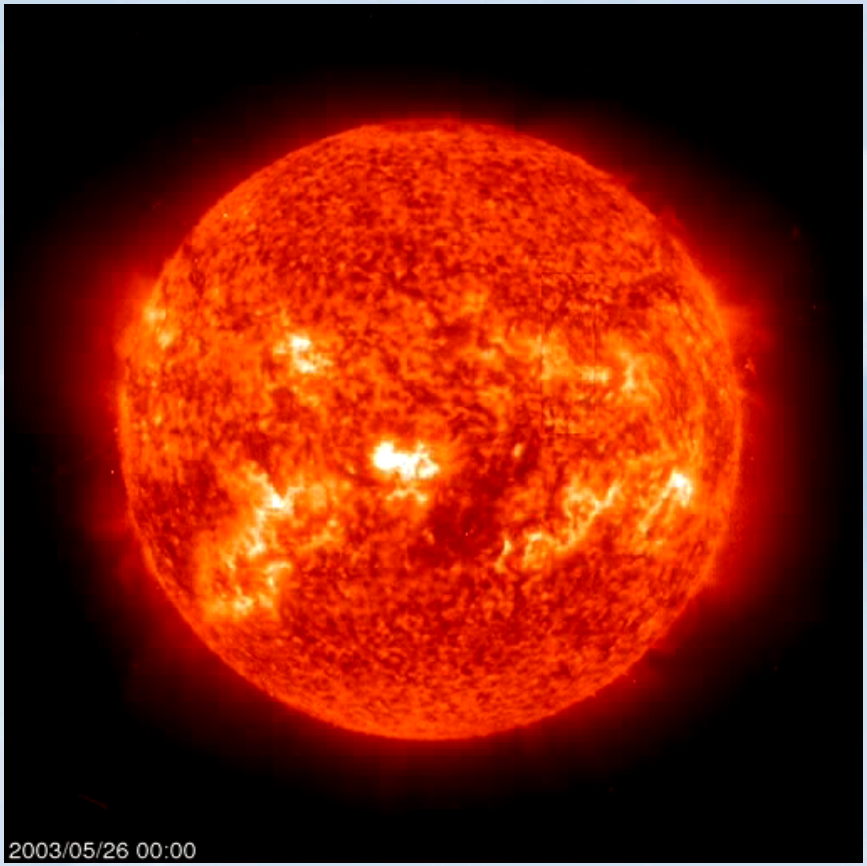
- **Media: Incoherent=Incomprehensible**

Incoherent scatter is neither incoherent nor incomprehensible

First: We need an Ionsophere…

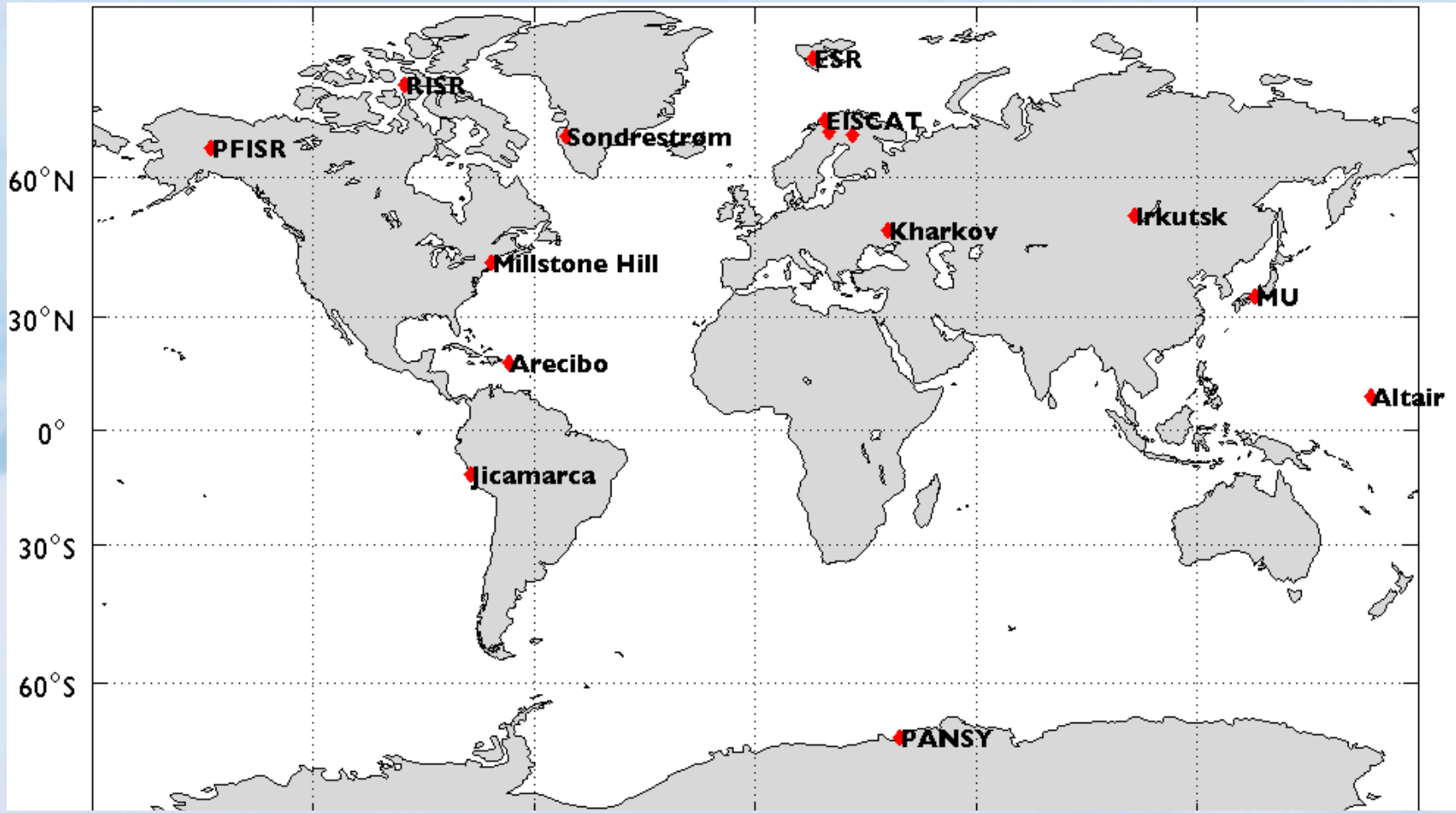
The Earths Ionosphere





Now we have an ionosphere - let's add the Incoherent Scatter Radar (ISR) to probe it!

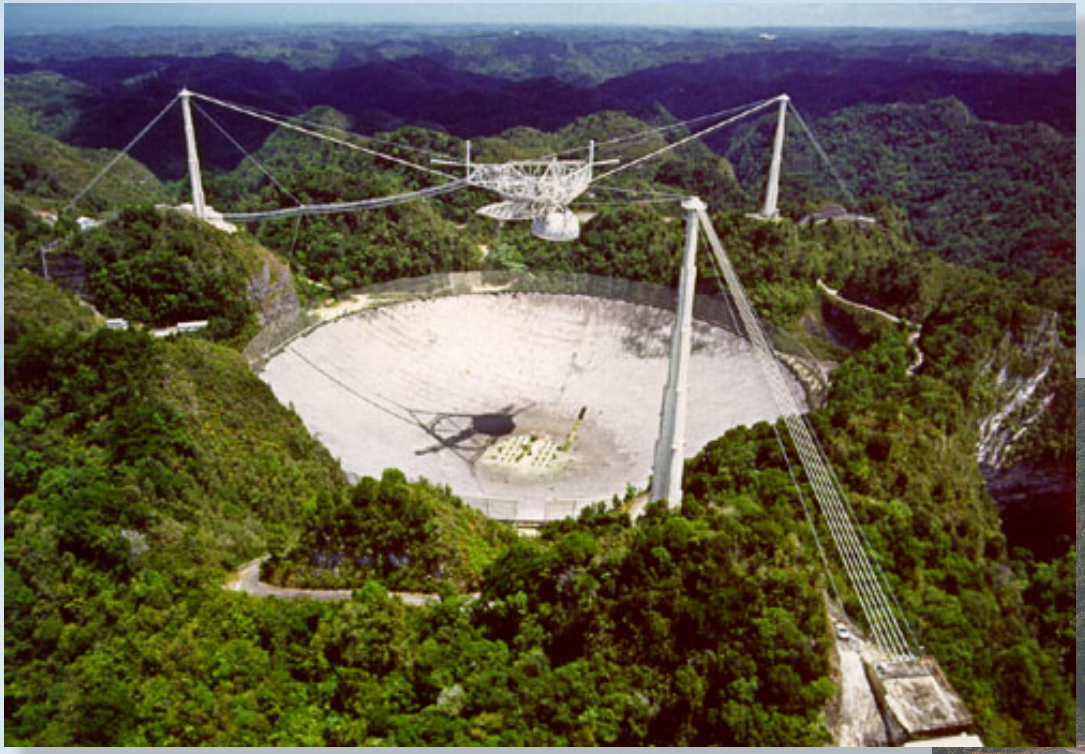
Incoherent Scatter Radars of the World

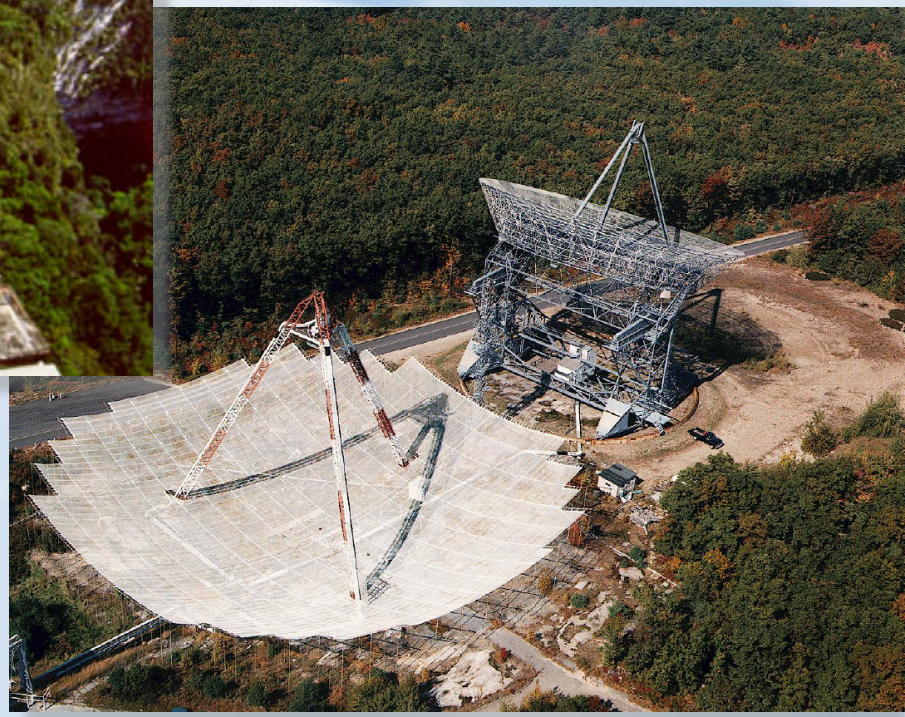


High latitude Incoherent Scatter Radars….

PFISR (Poker Flat Incoherent Scatter Radar) and RISR-N (Resolute Bay Incoherent Scatter Radar North) two AMISRs currently at high latitudes.

Mid-Latitude Incoherent Scatter Radars



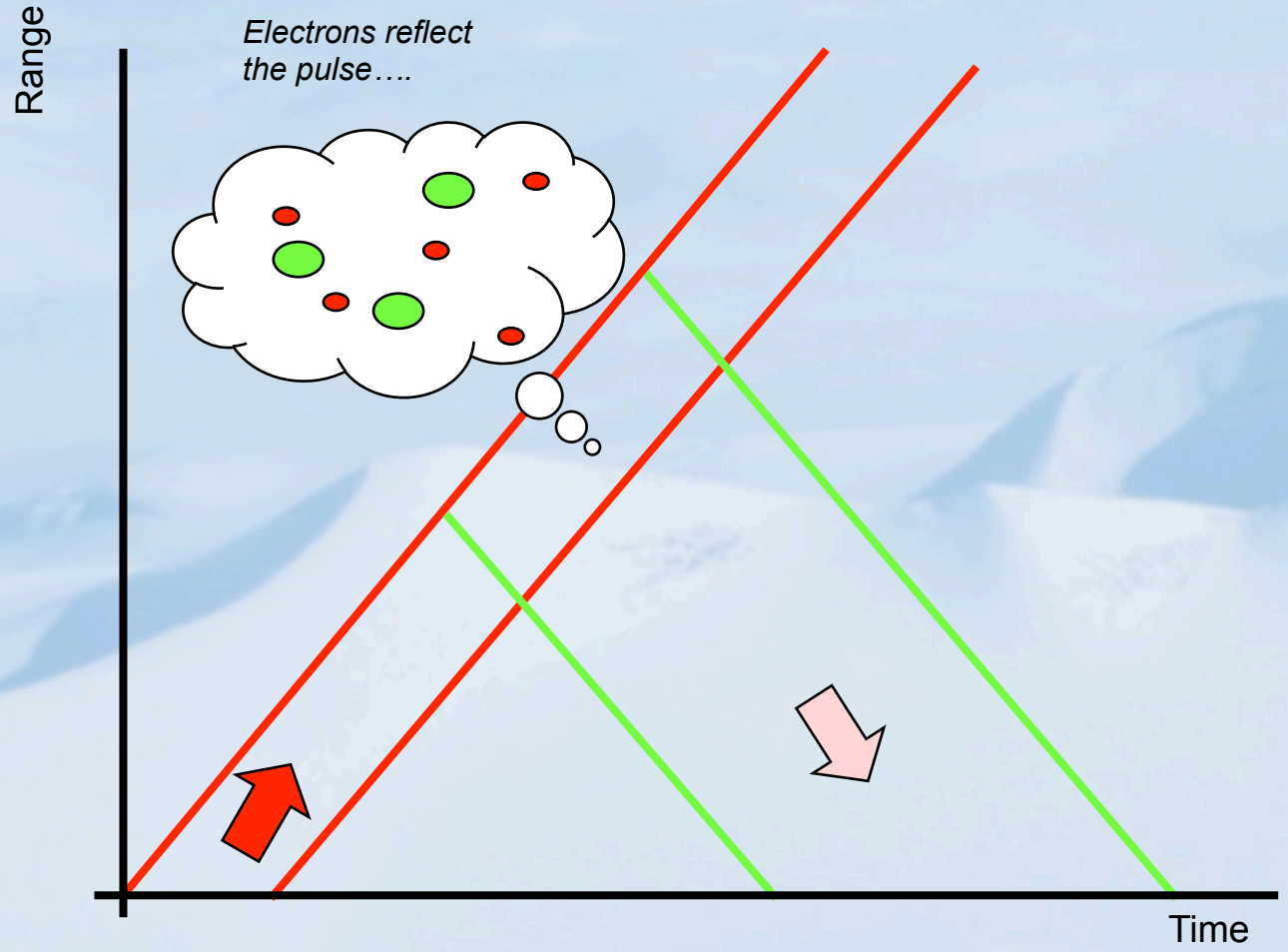


Low-Latitude Incoherent Scatter Radars

Questions you might have now:

- Why are incoherent scatter radars (ISRs) so big? Is it a status-thing?
- Why is it called *incoherent* scattering?
- What do the ISR returns look like and why?
- What can ISRs measure?
- Can we get through this before lunch?

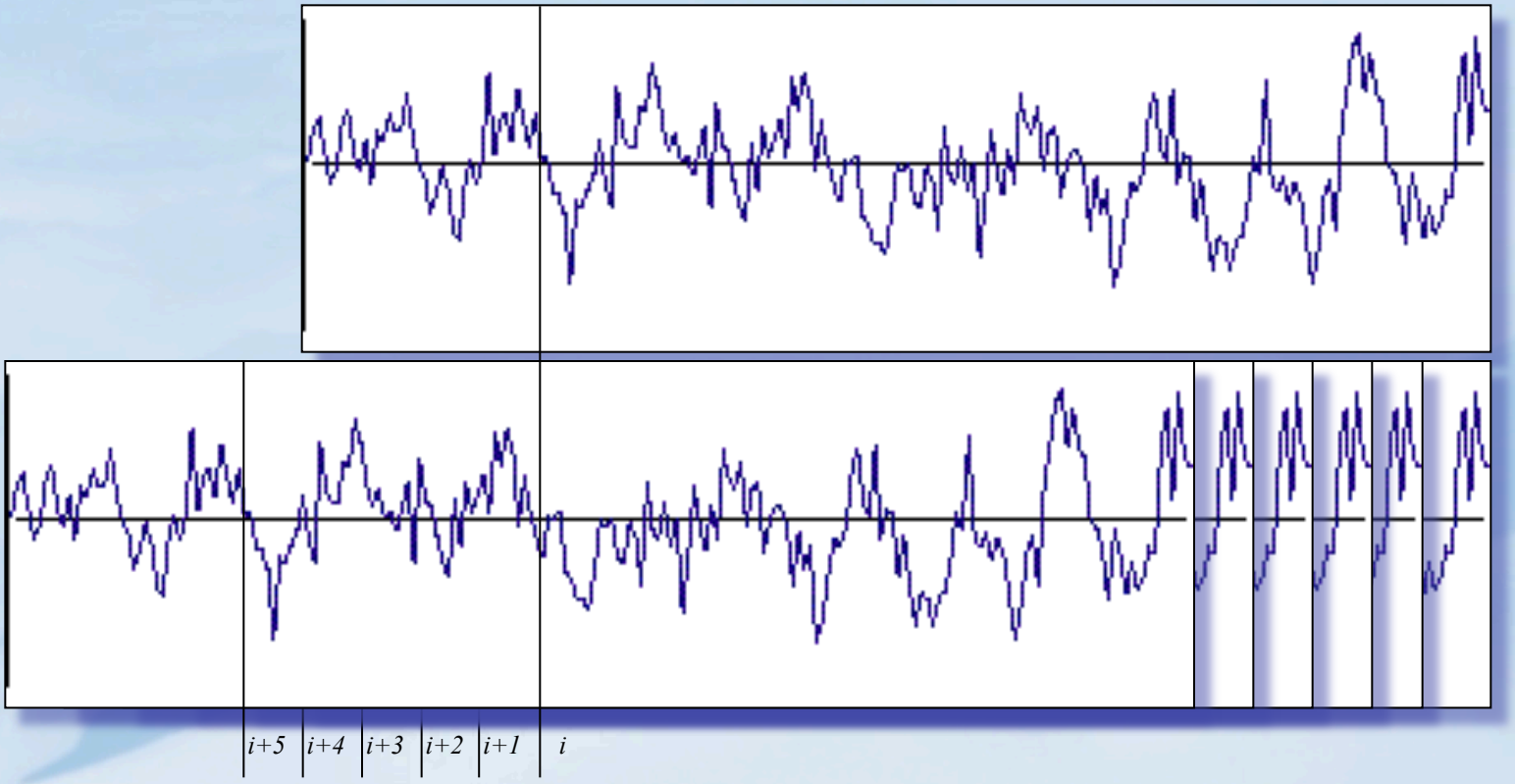
How ISRs work...

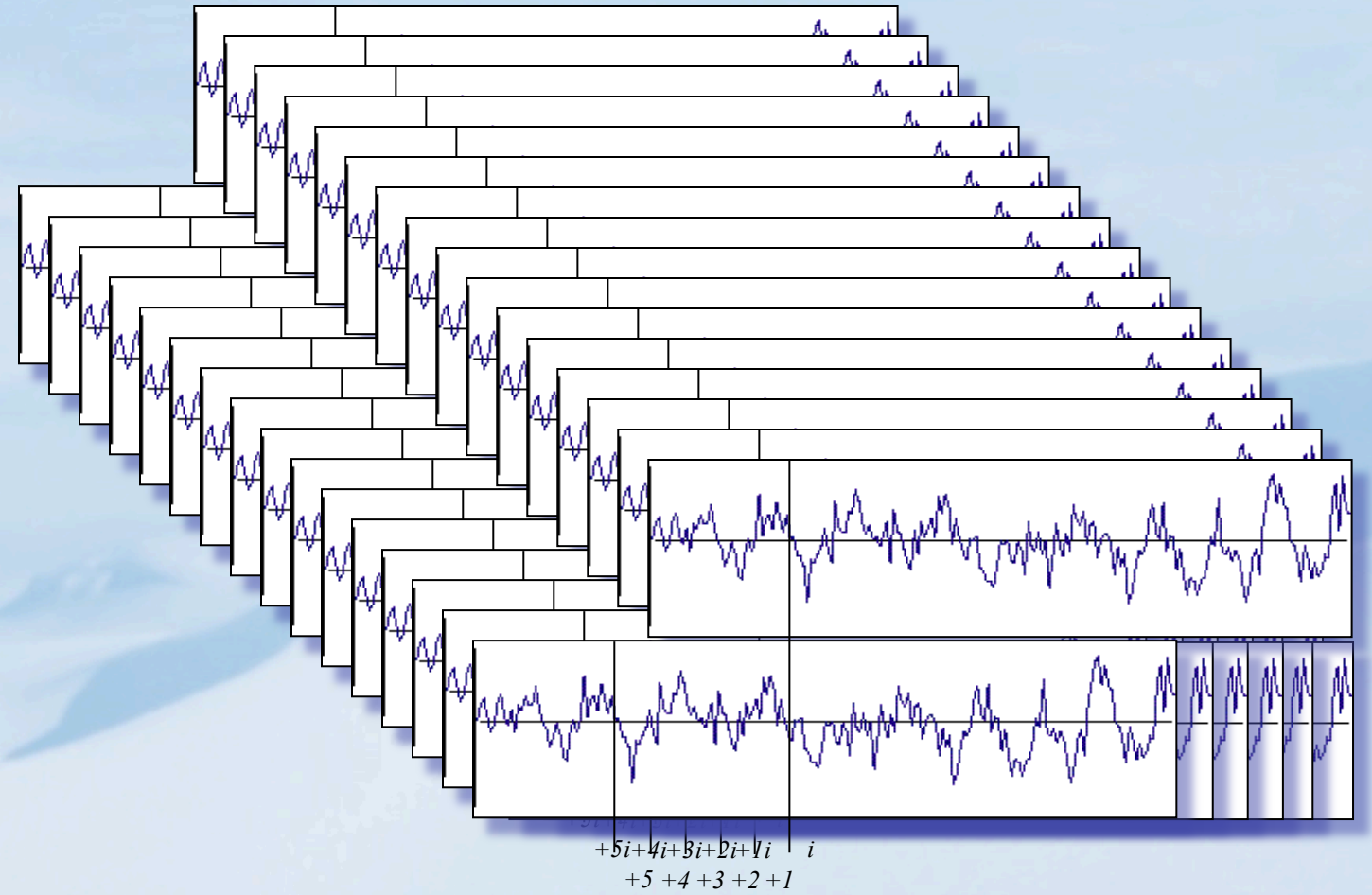


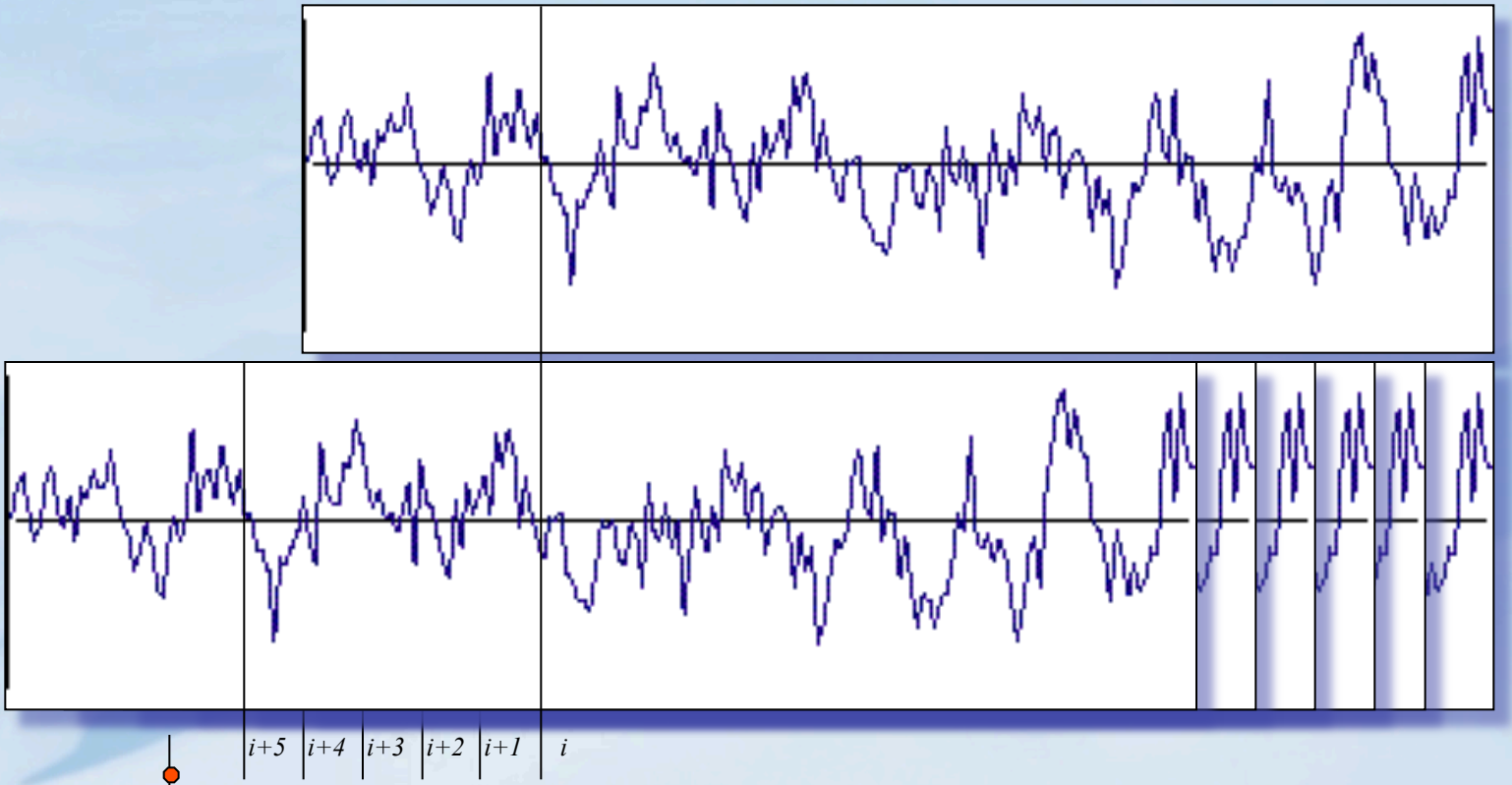
High power pulse

Very sensitive receiver

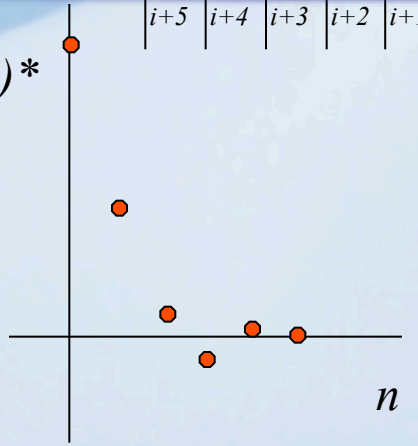
Only ~0.00000000000000001% of the transmitted power is returned!


i+5
i+4
i+3
i+2
i+1
i

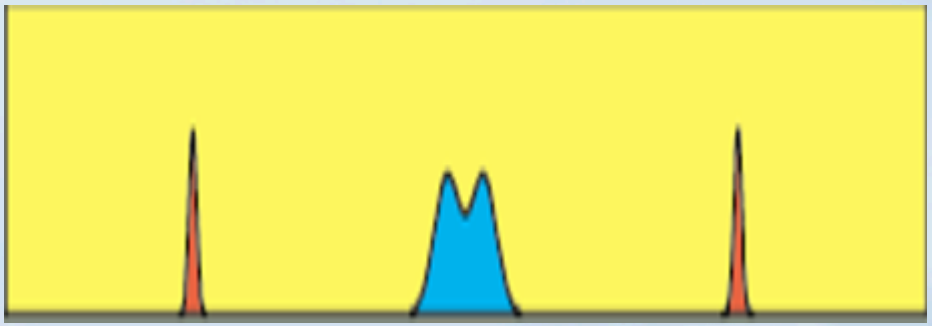

+5i+4i+3i+2i+1i i
+5 +4 +3 +2 +1

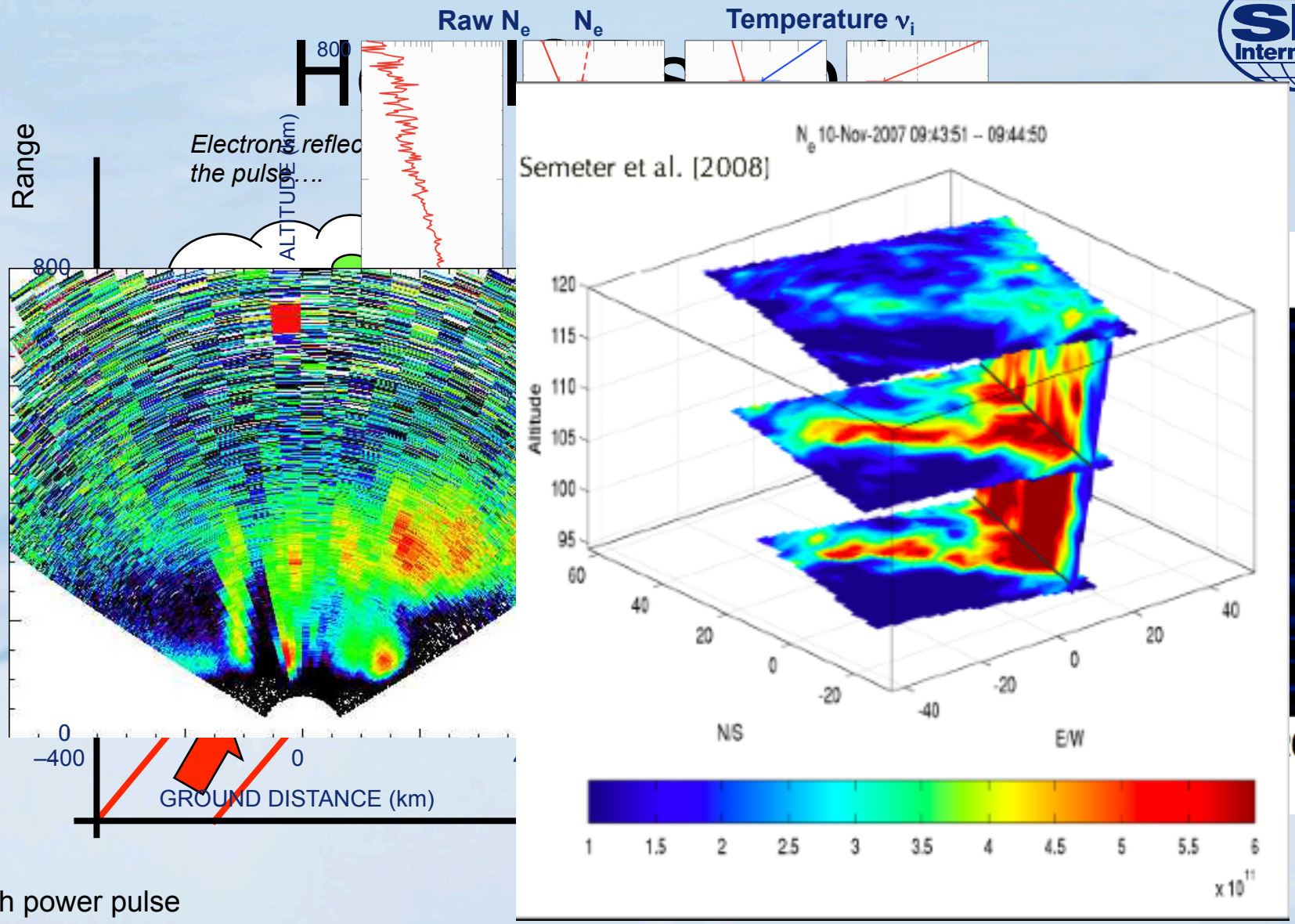


$\Sigma\, i.(i+n)^*$



Fourier Transform





High power pulse

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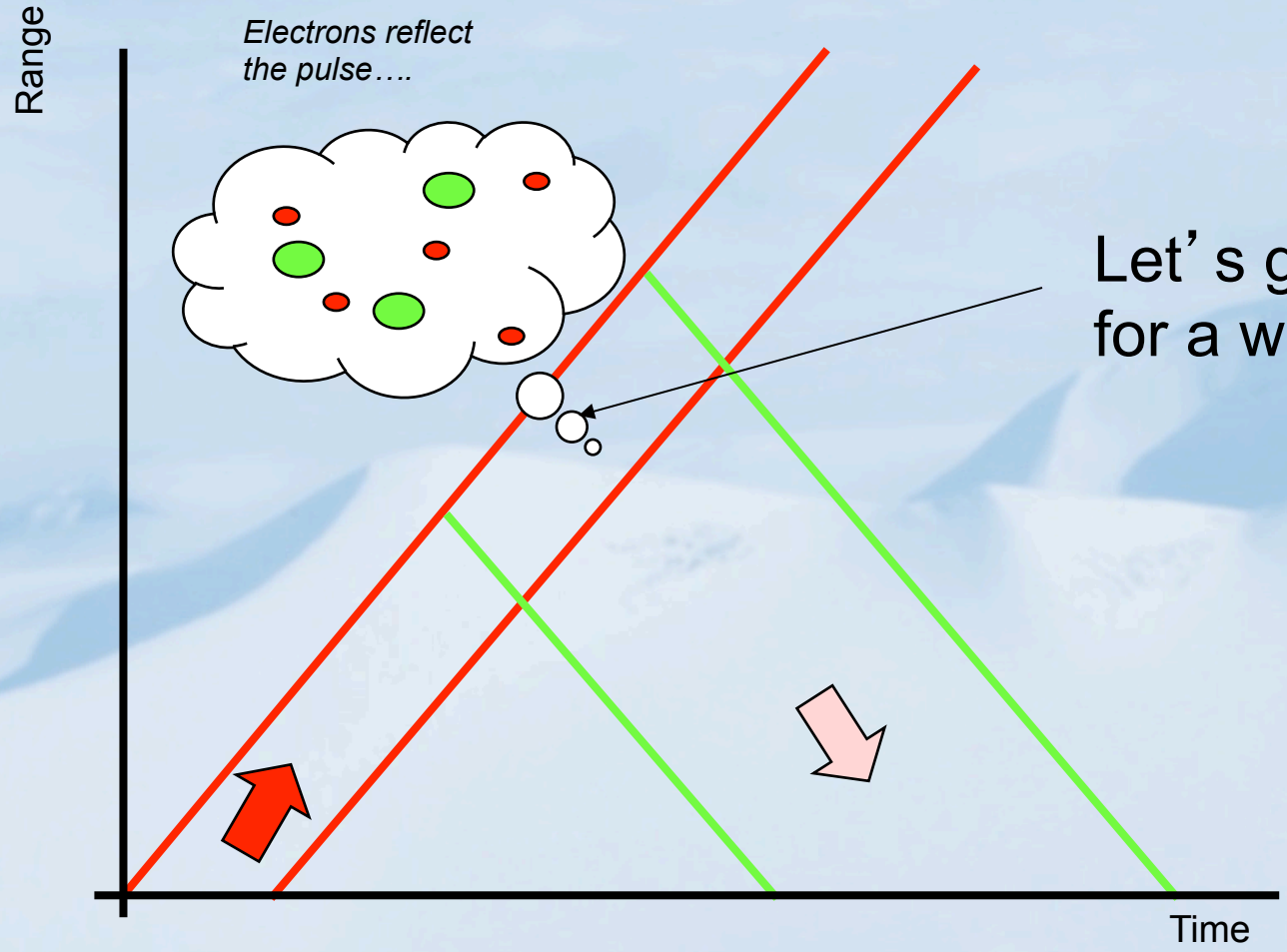
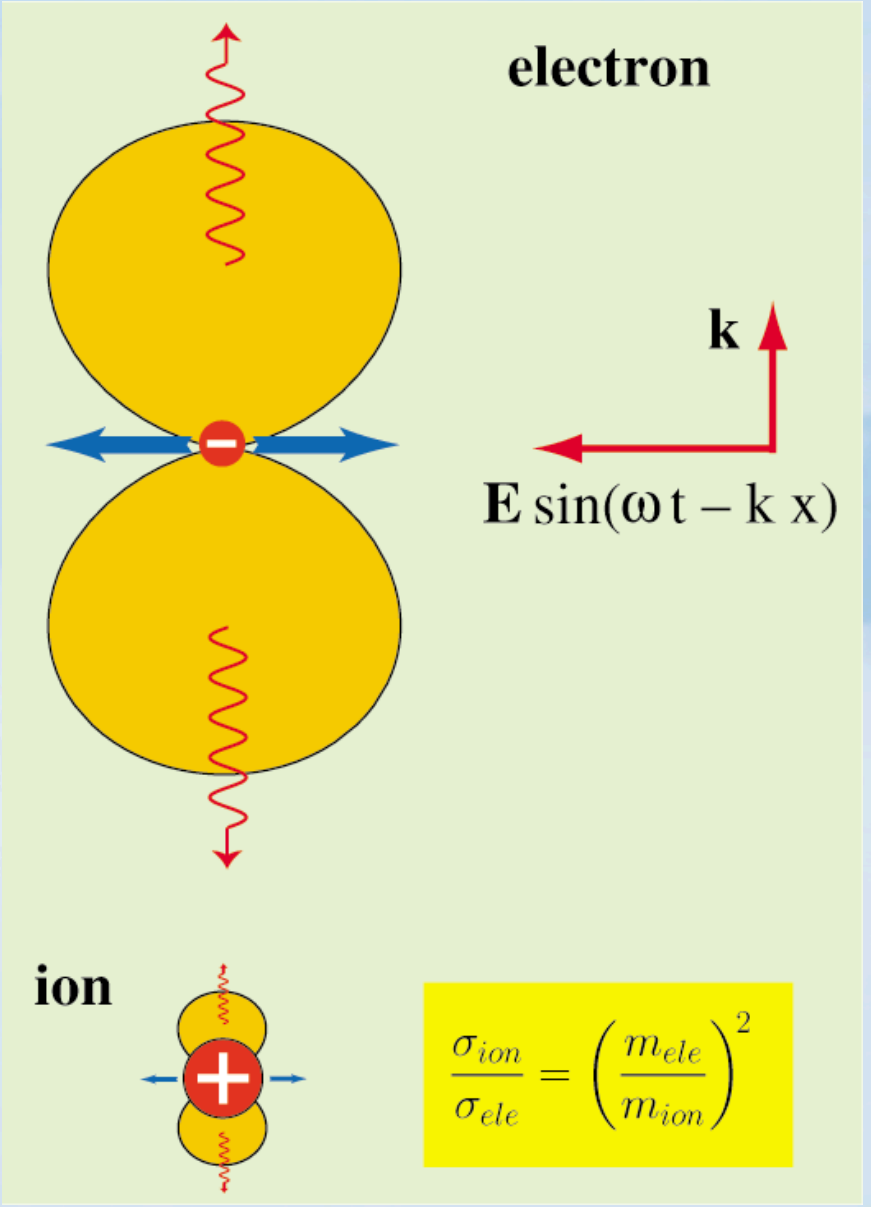
How ISRs work...



Let's go back here for a while…

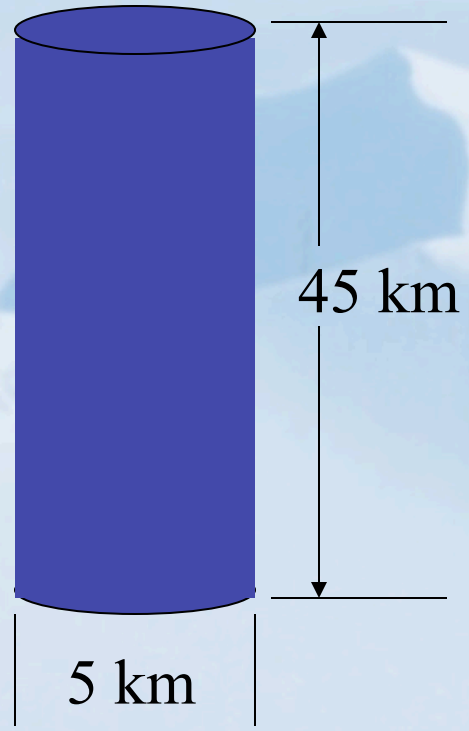
High power pulse

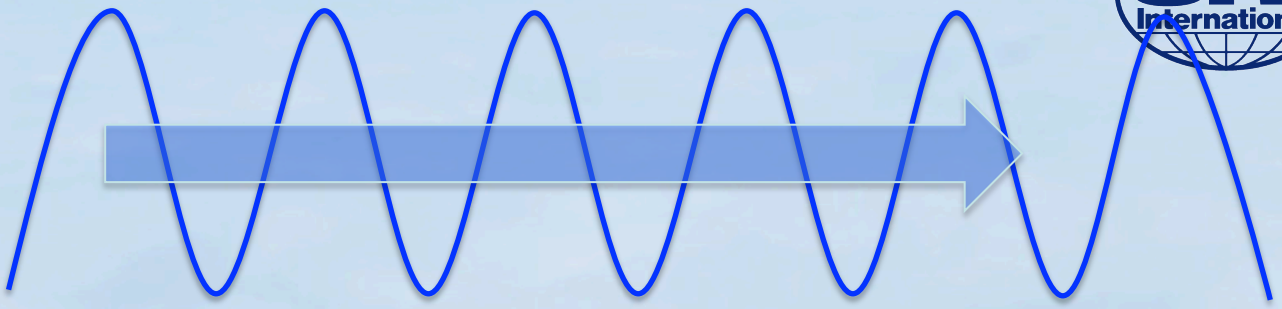
Very sensitive receiver

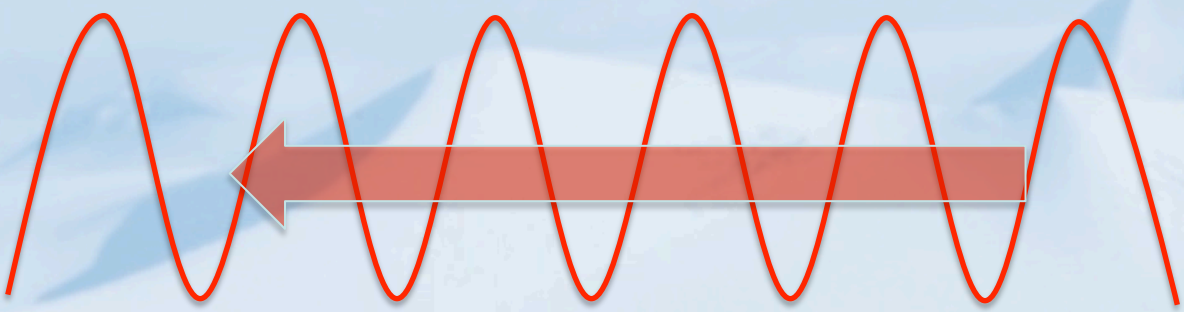

electron
k
E sin(ω t – k x)
ion
$\frac{\sigma_{ion}}{\sigma_{ele}} = \left(\frac{m_{ele}}{m_{ion}}\right)^2$

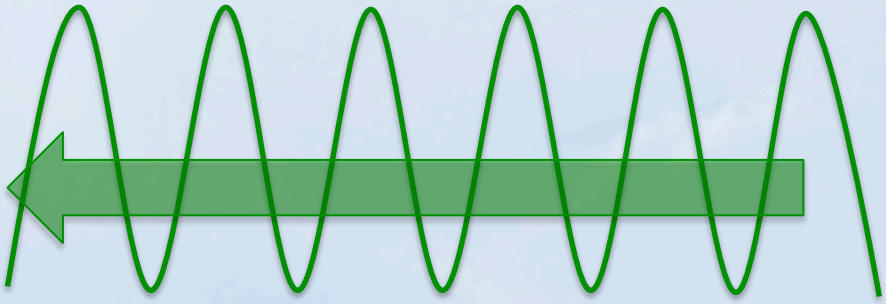
Total Cross-Section Estimate

Consider an antenna with a 1-degree beam measuring the ionospheric plasma at 300 km range and using a 300 microsecond pulse.
If the electron density is 10^{12} m^{-3}, the total number of electrons scattering into a given measurement is ~$8.8x10^{23}$. This yields a total cross-section of 88 mm^2 – we need a big radar!

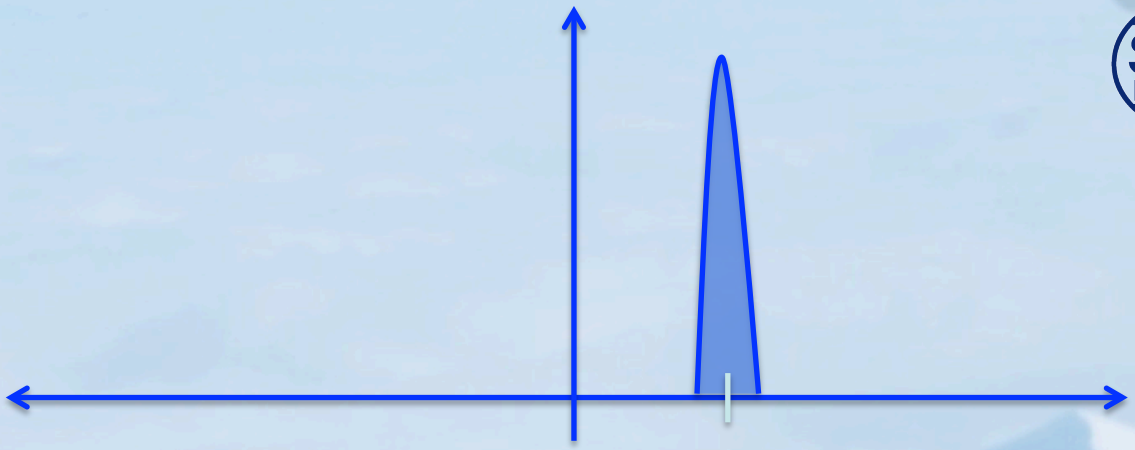


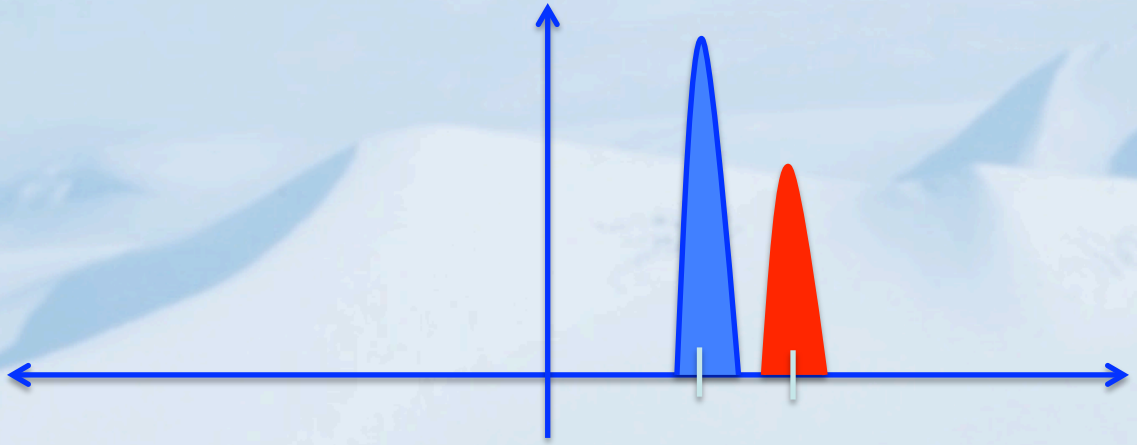


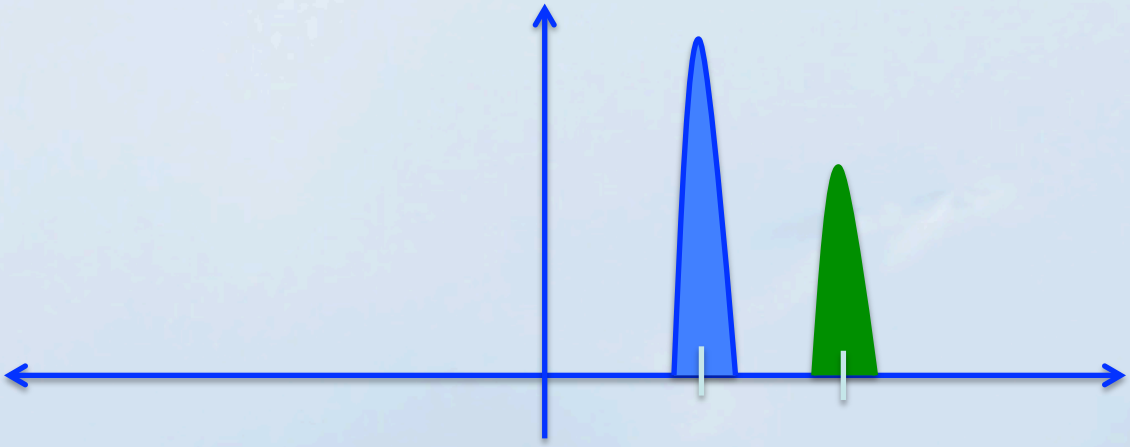




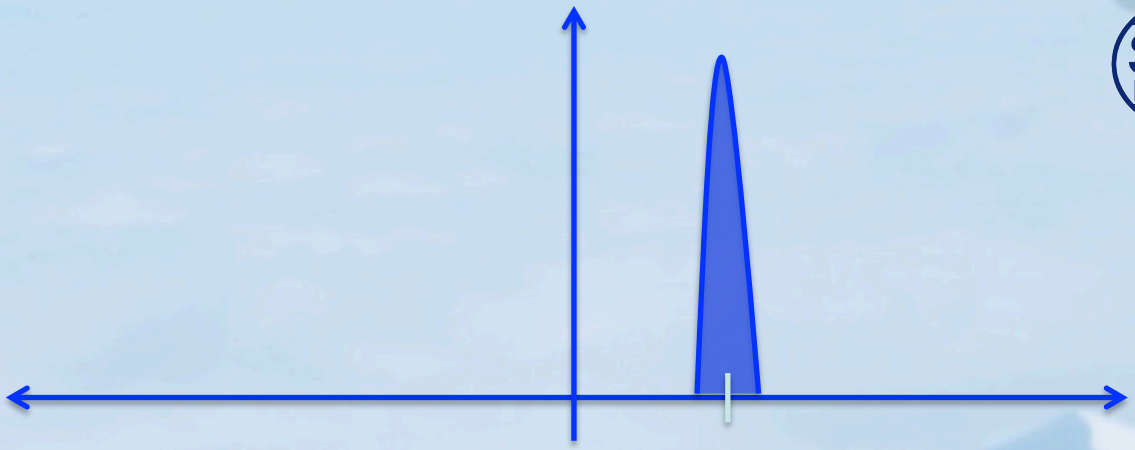

19
ADIUS

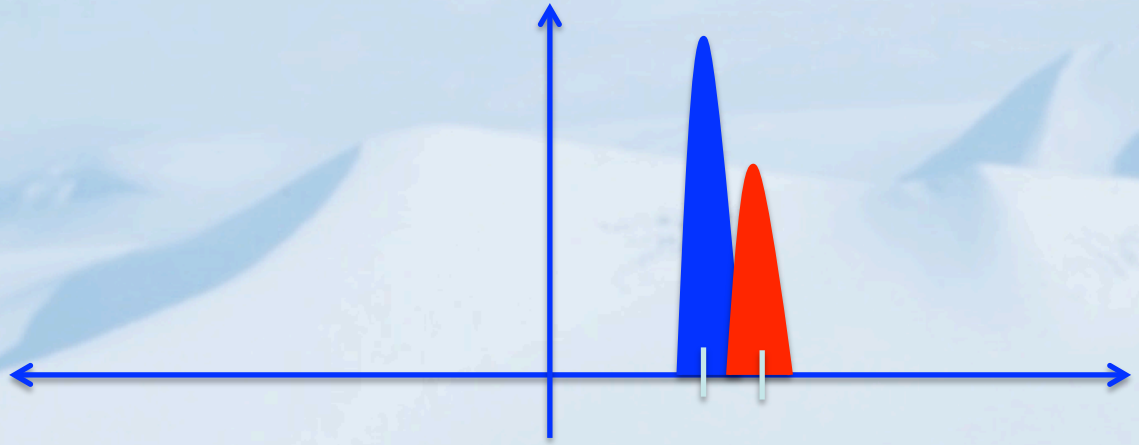


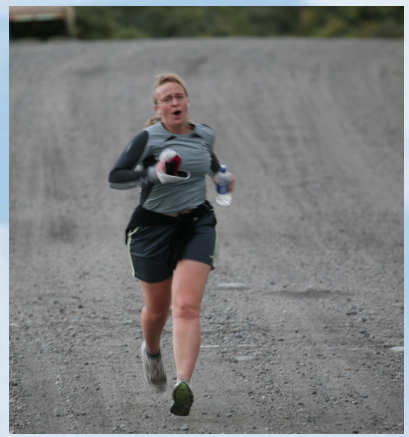


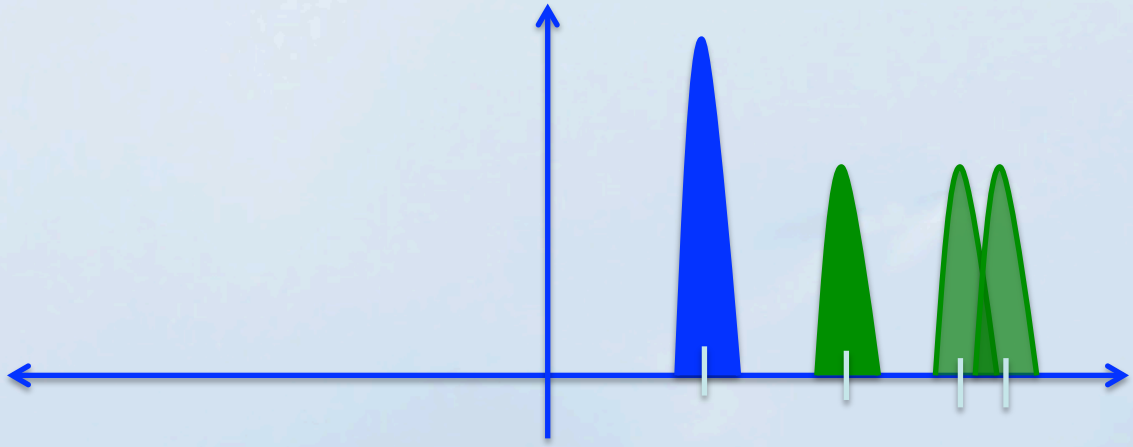


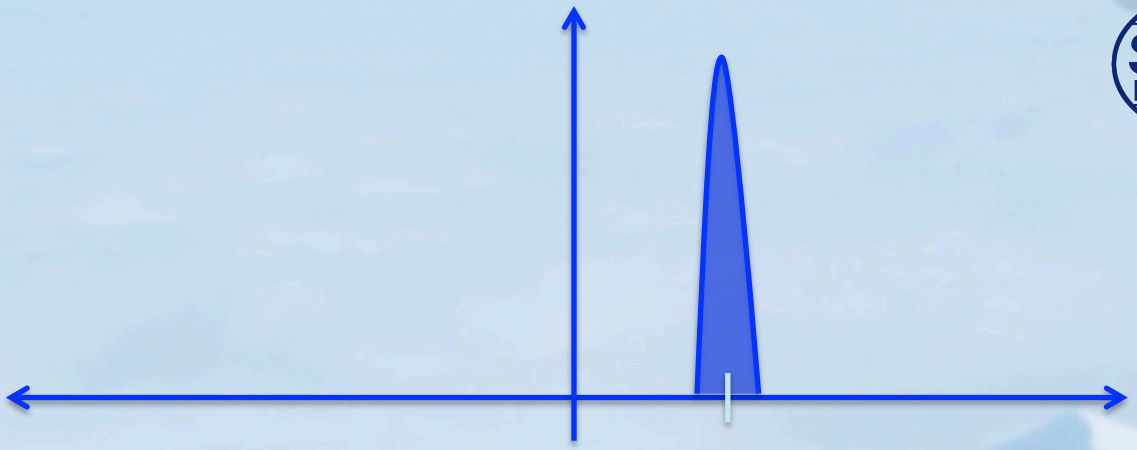

19
ADIUS



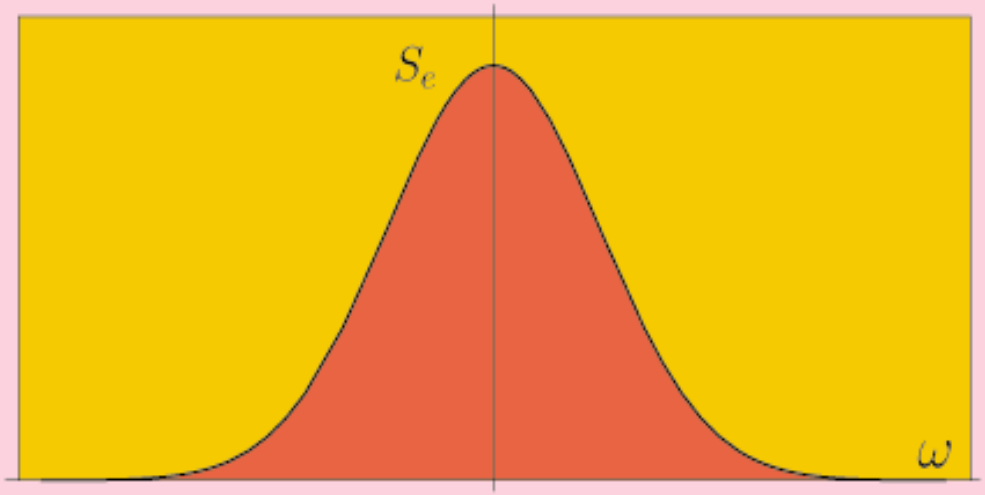




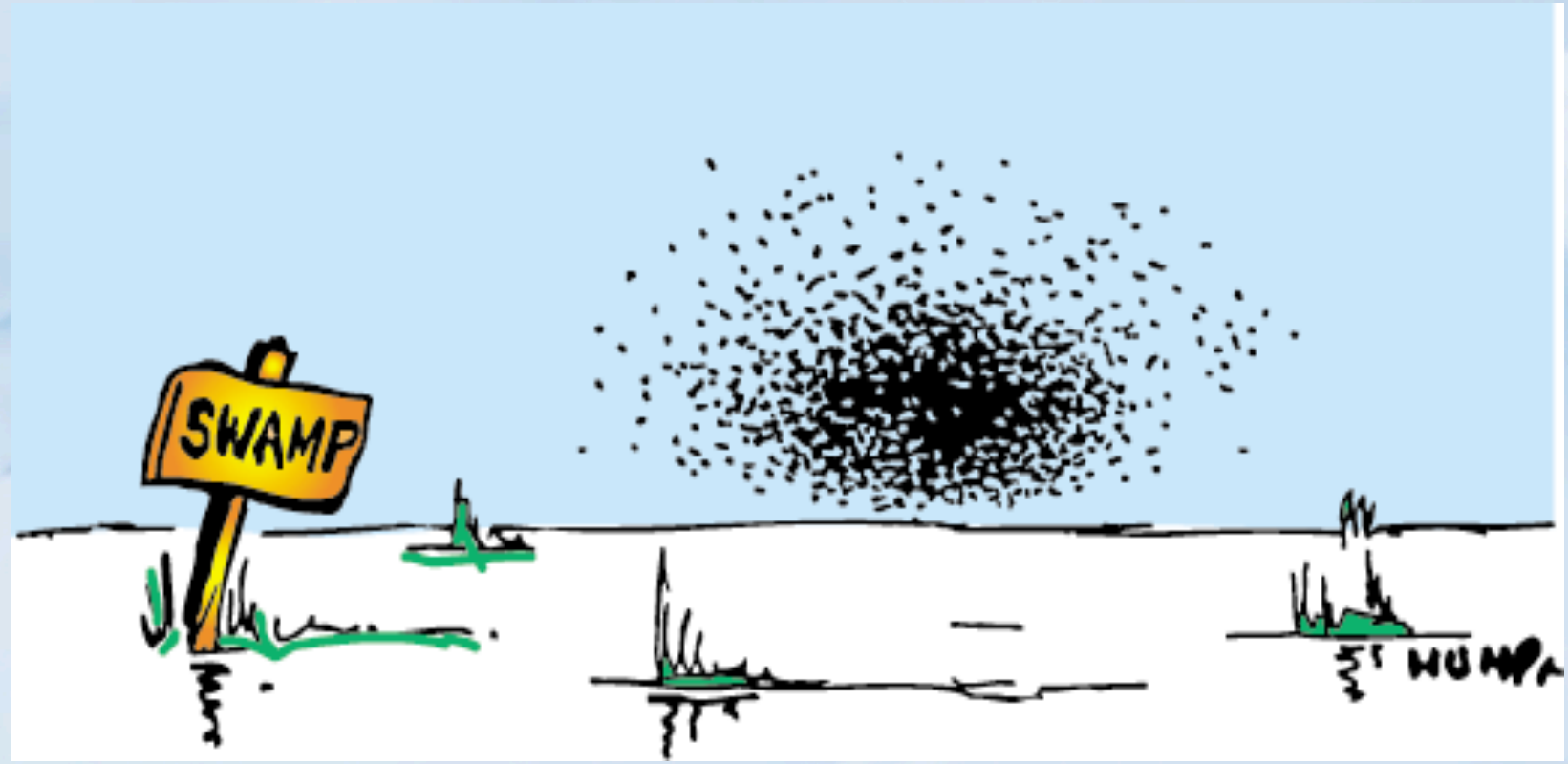




$$S_e(\mathbf{k},\omega) = N_e \int d\mathbf{v}\, f_e(\mathbf{v})\delta(\omega - \mathbf{k}\cdot\mathbf{v})$$



Incoherent scattering - the short story



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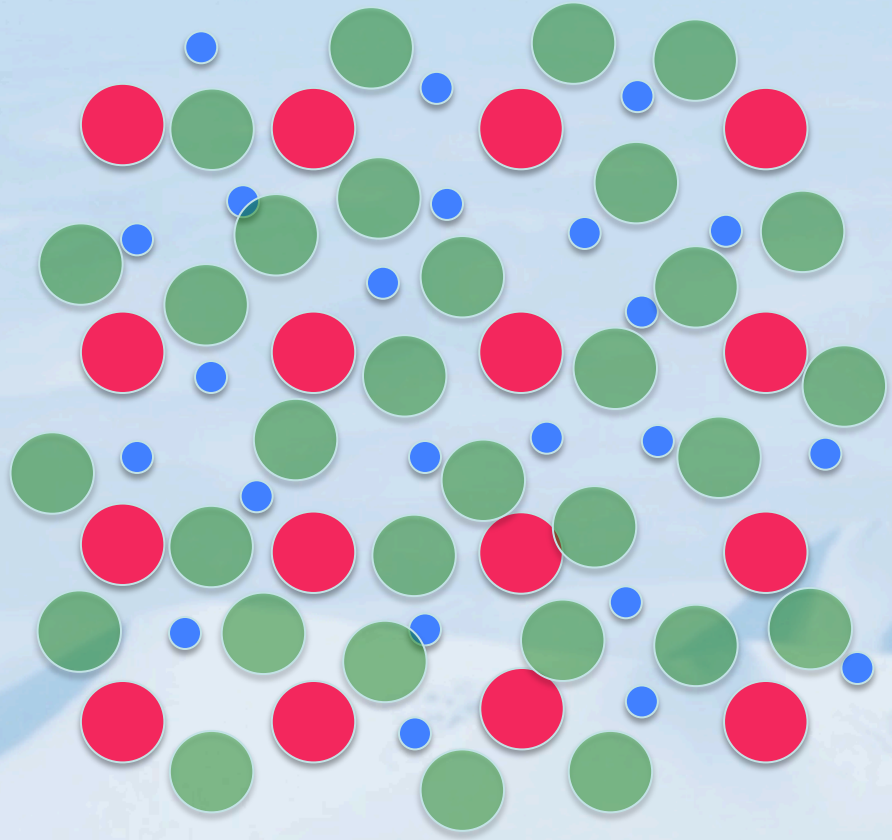
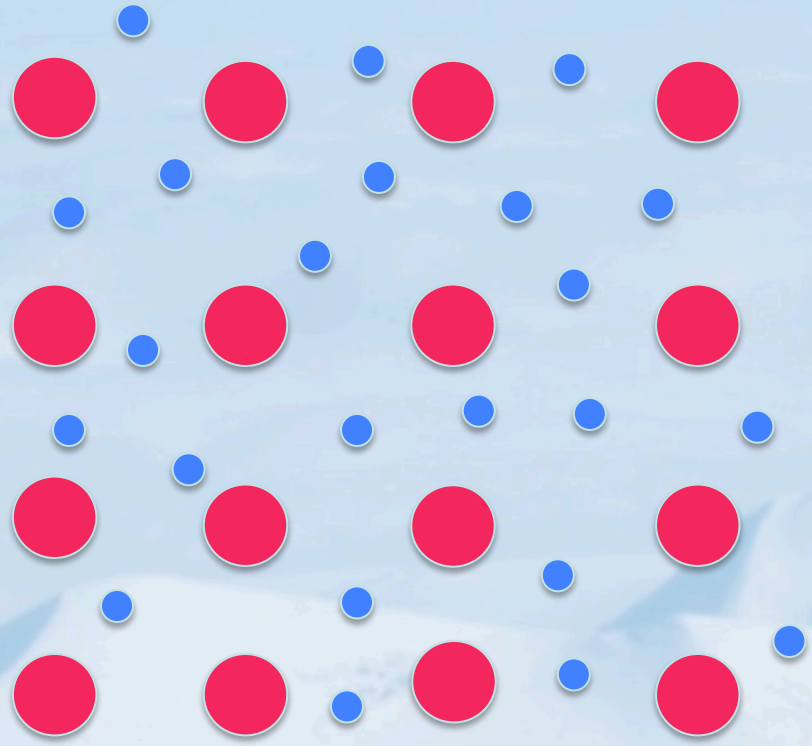
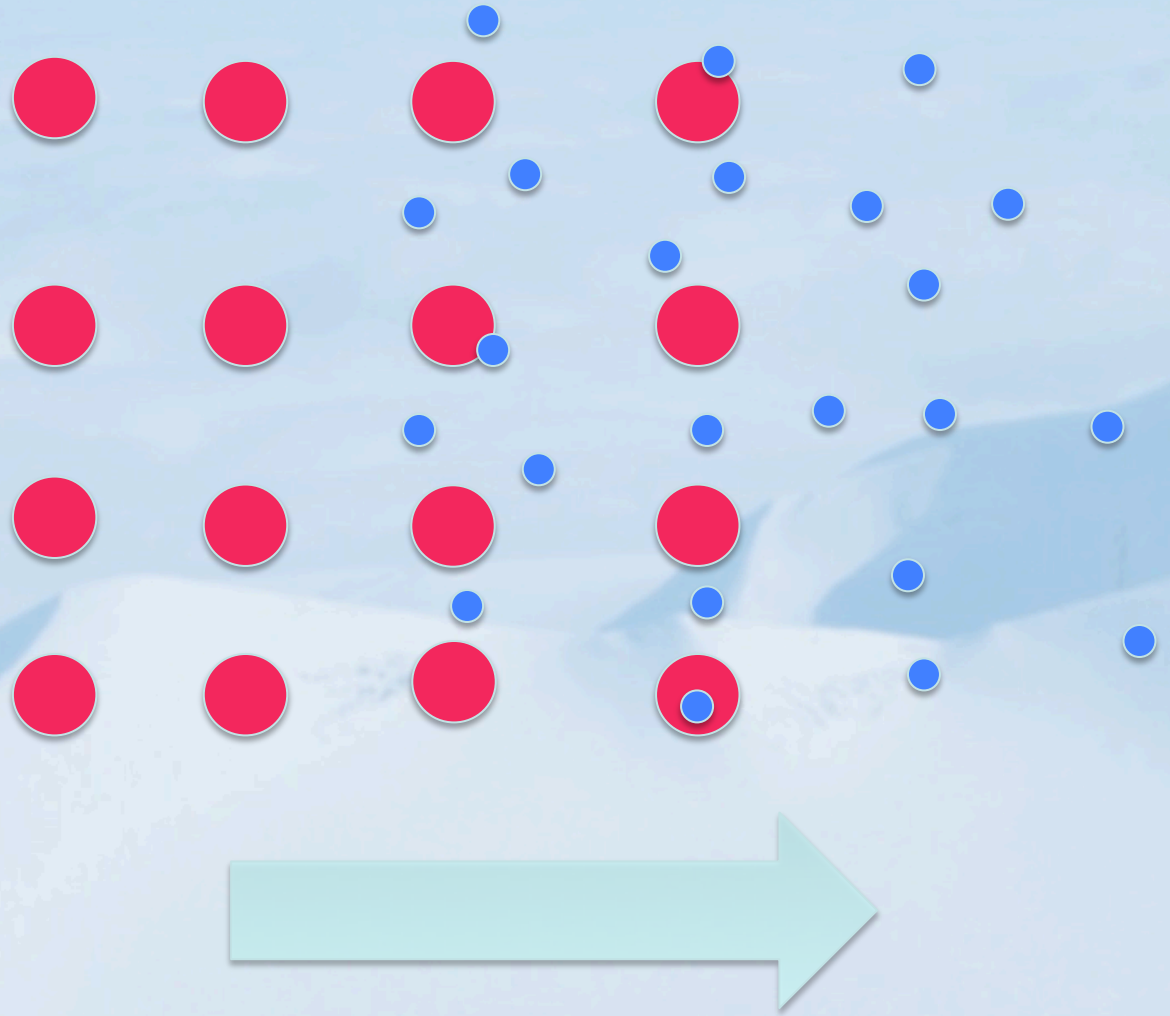
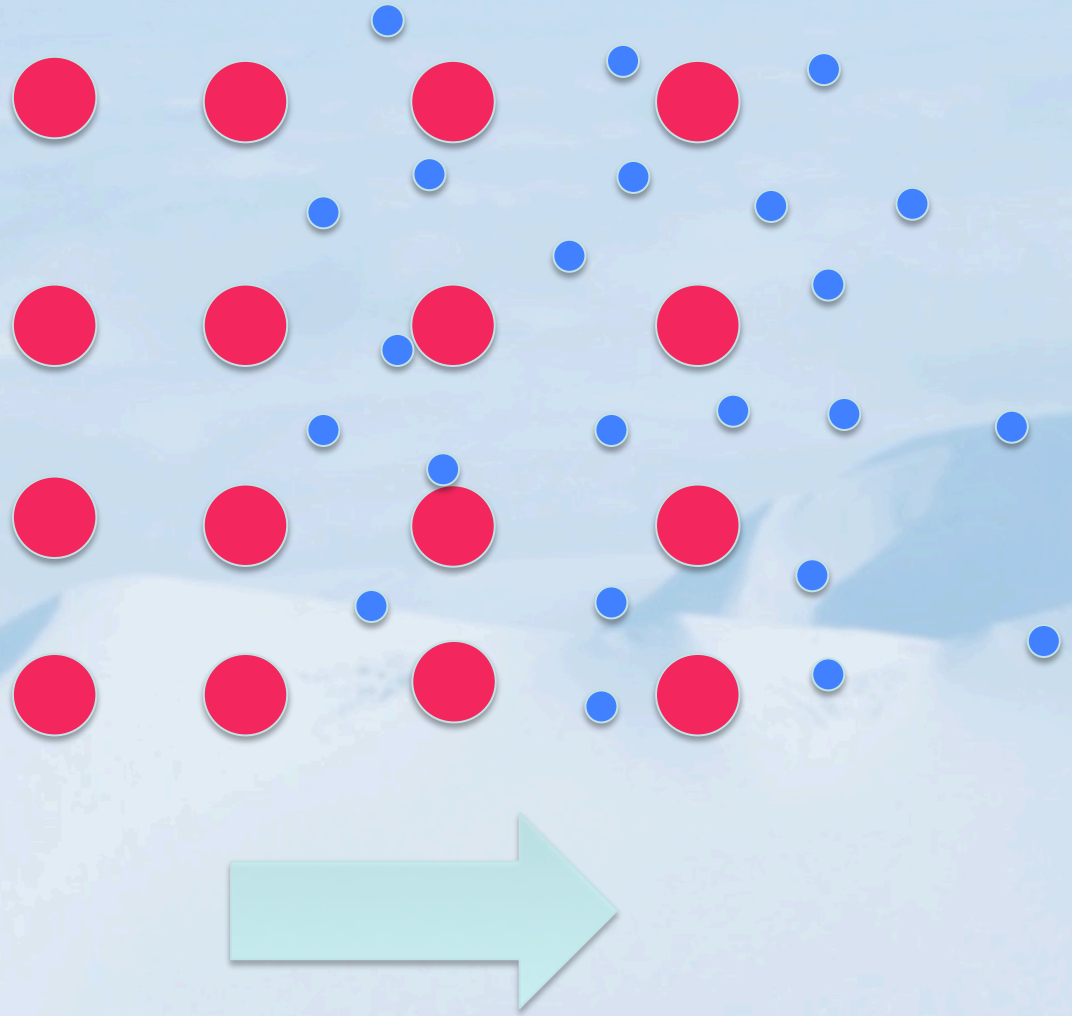
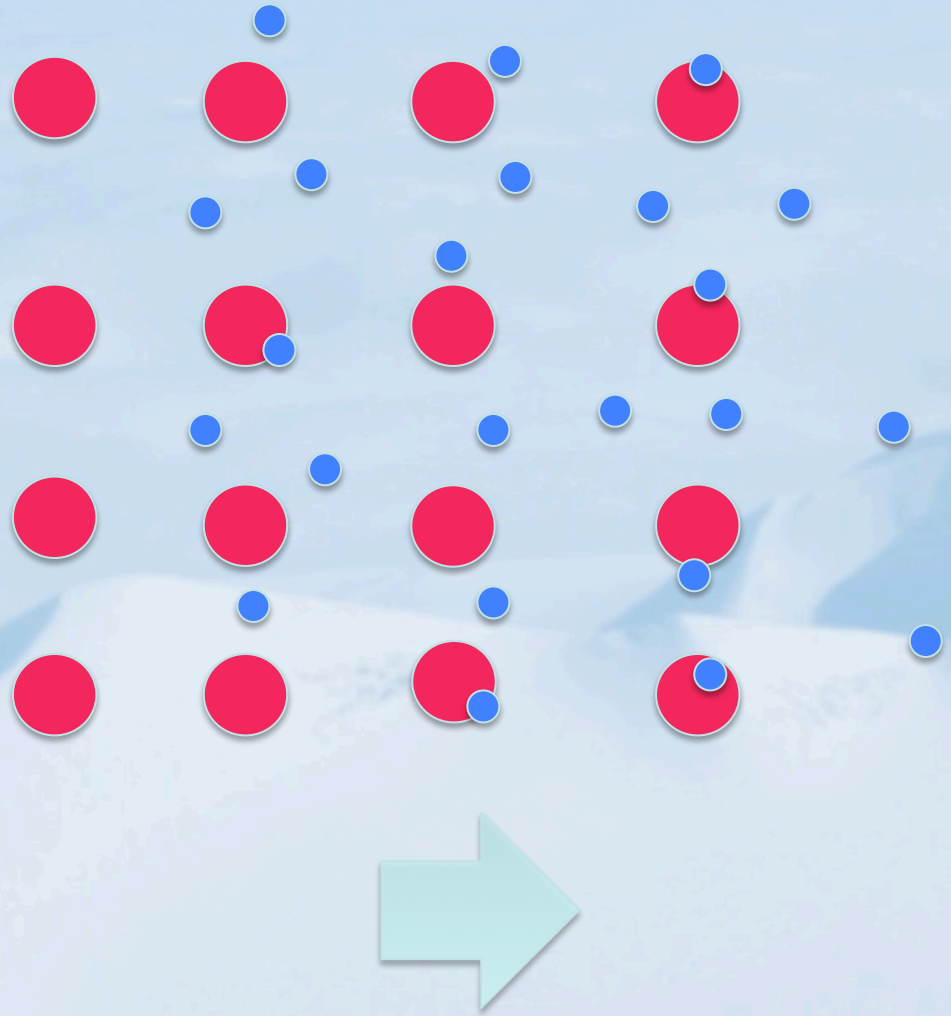
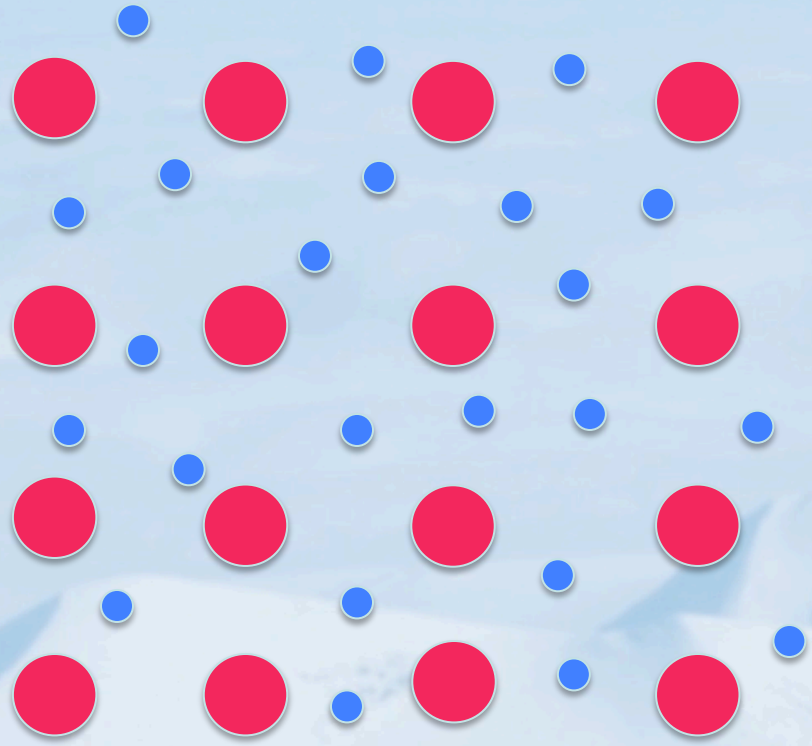


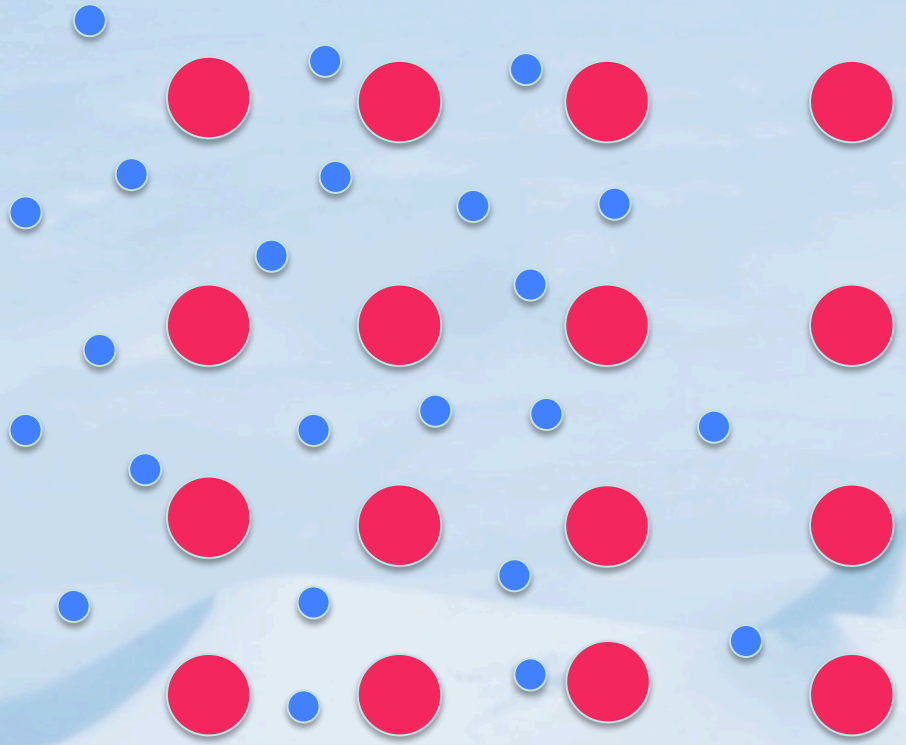


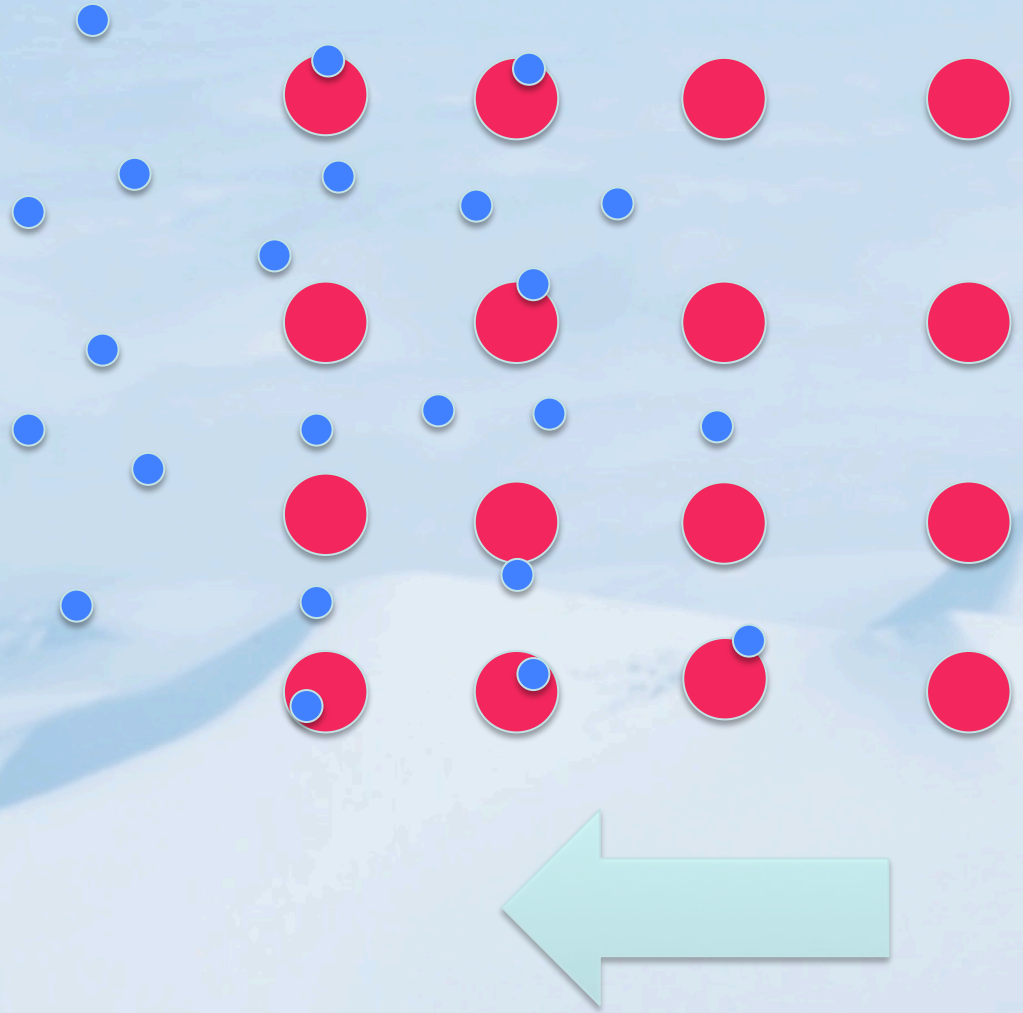


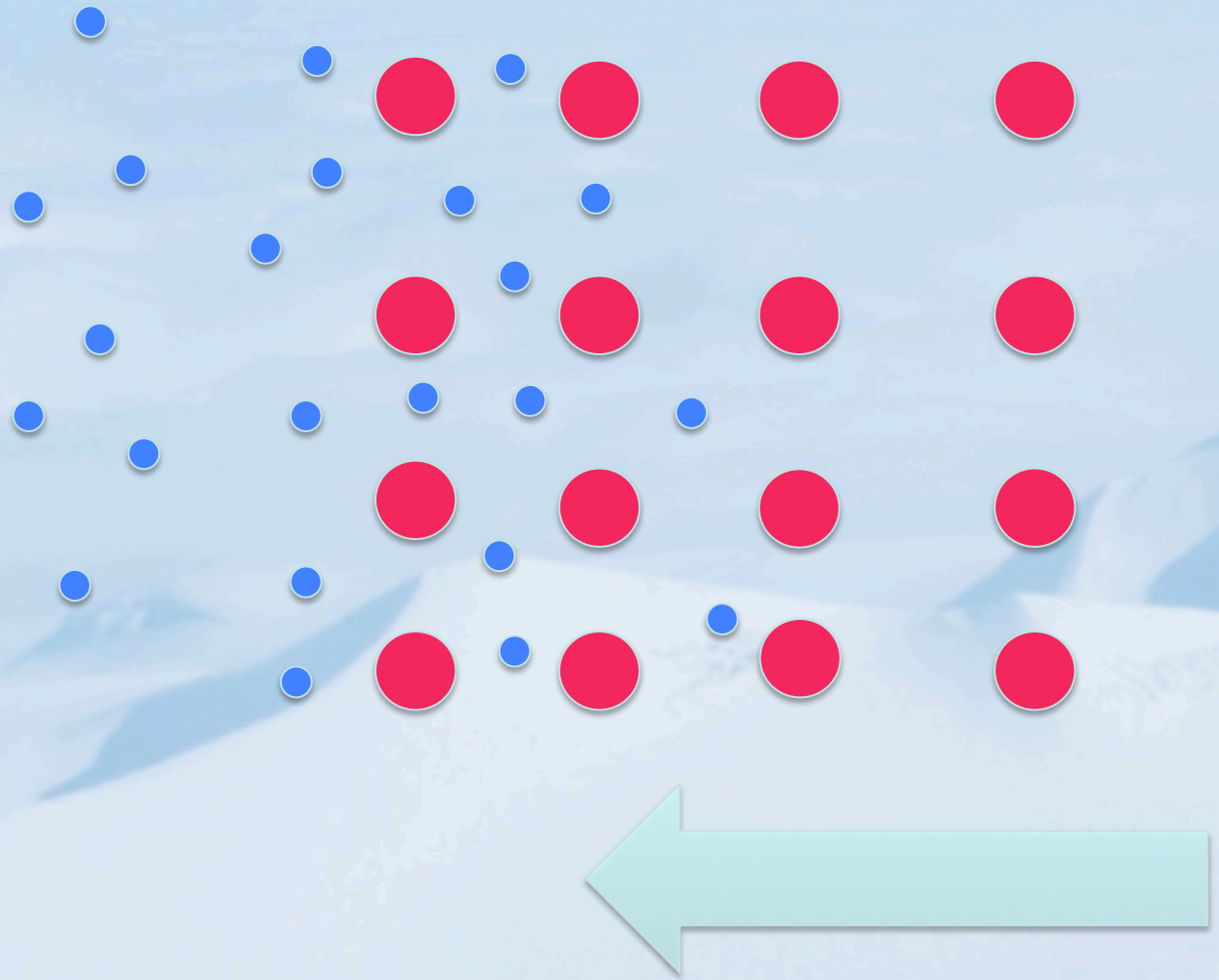


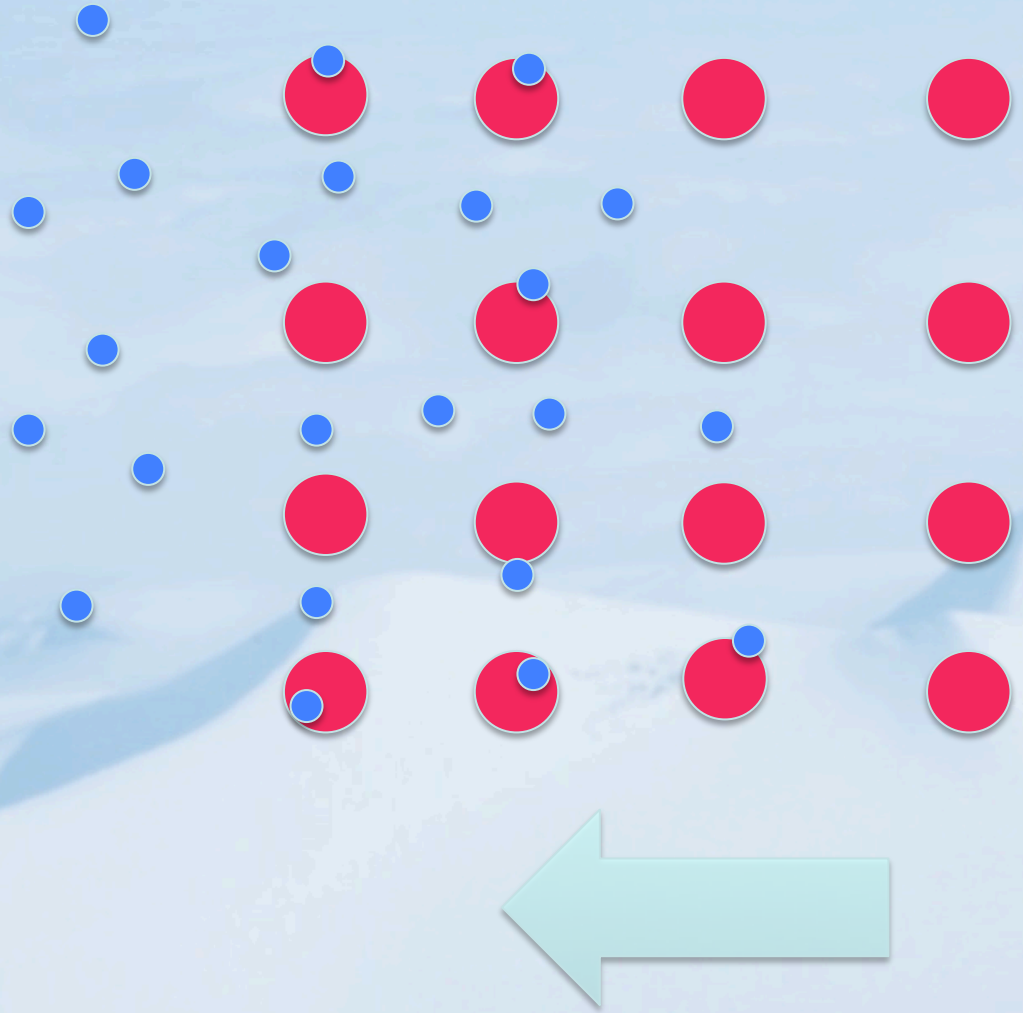


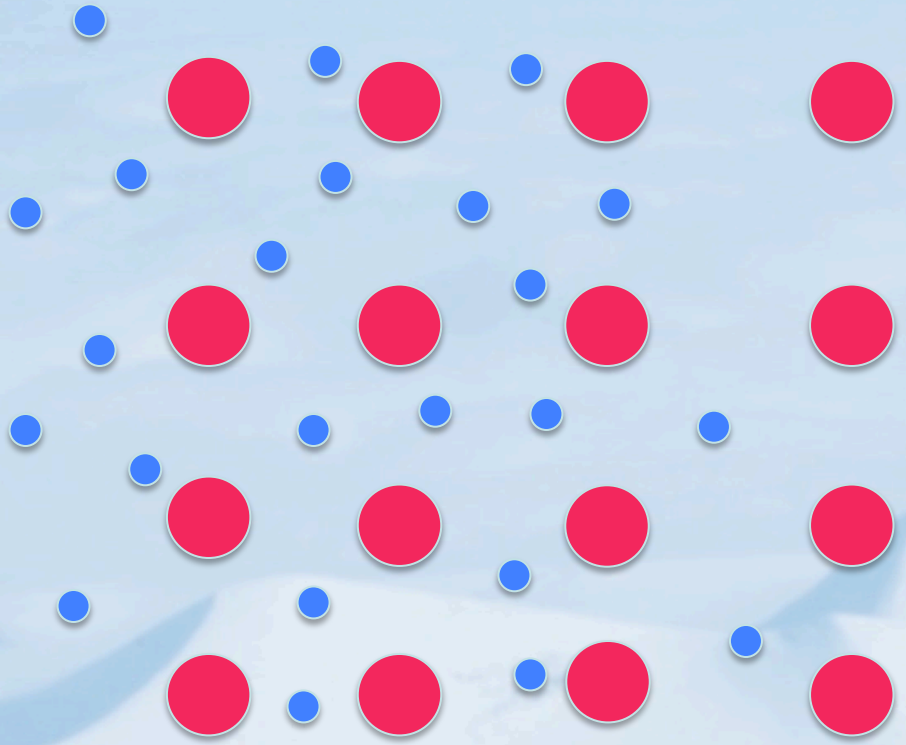


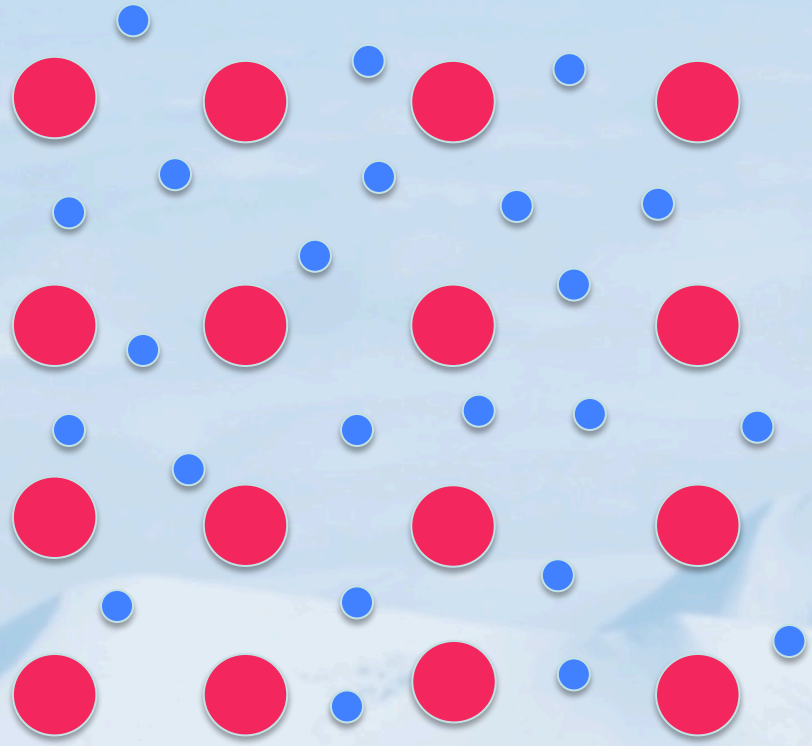


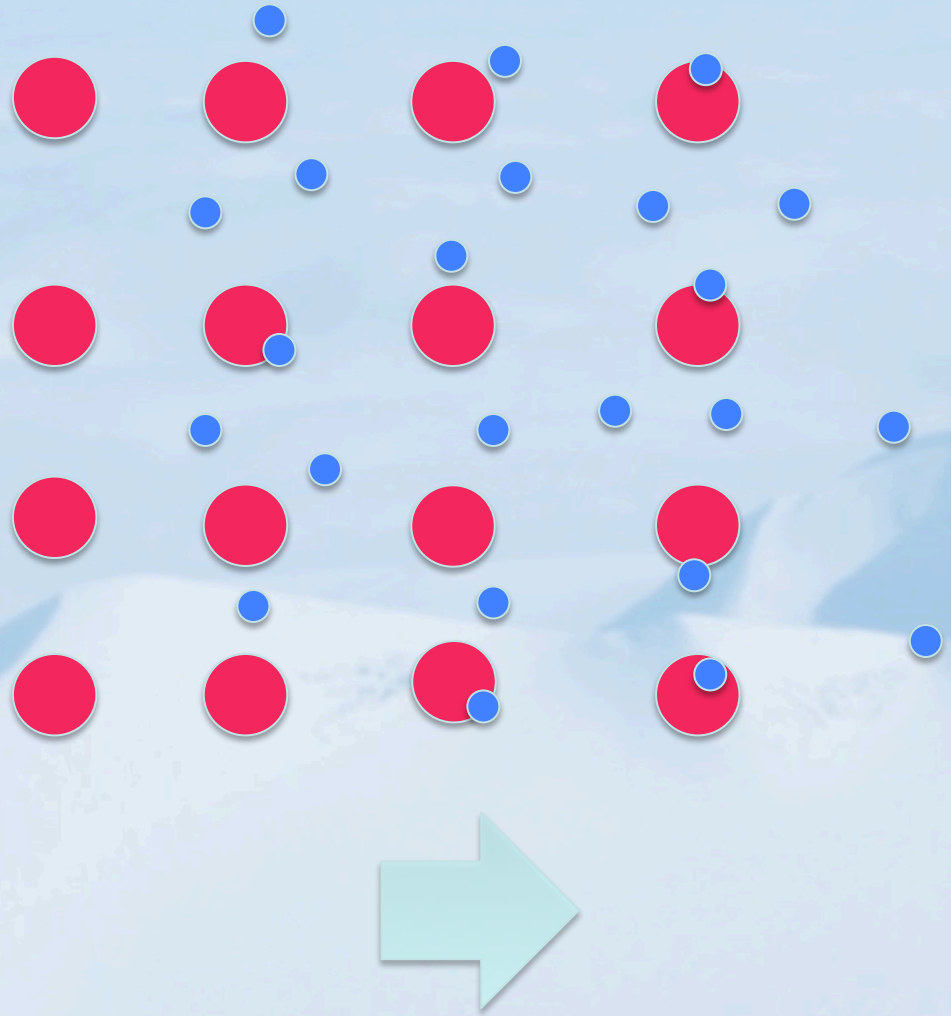


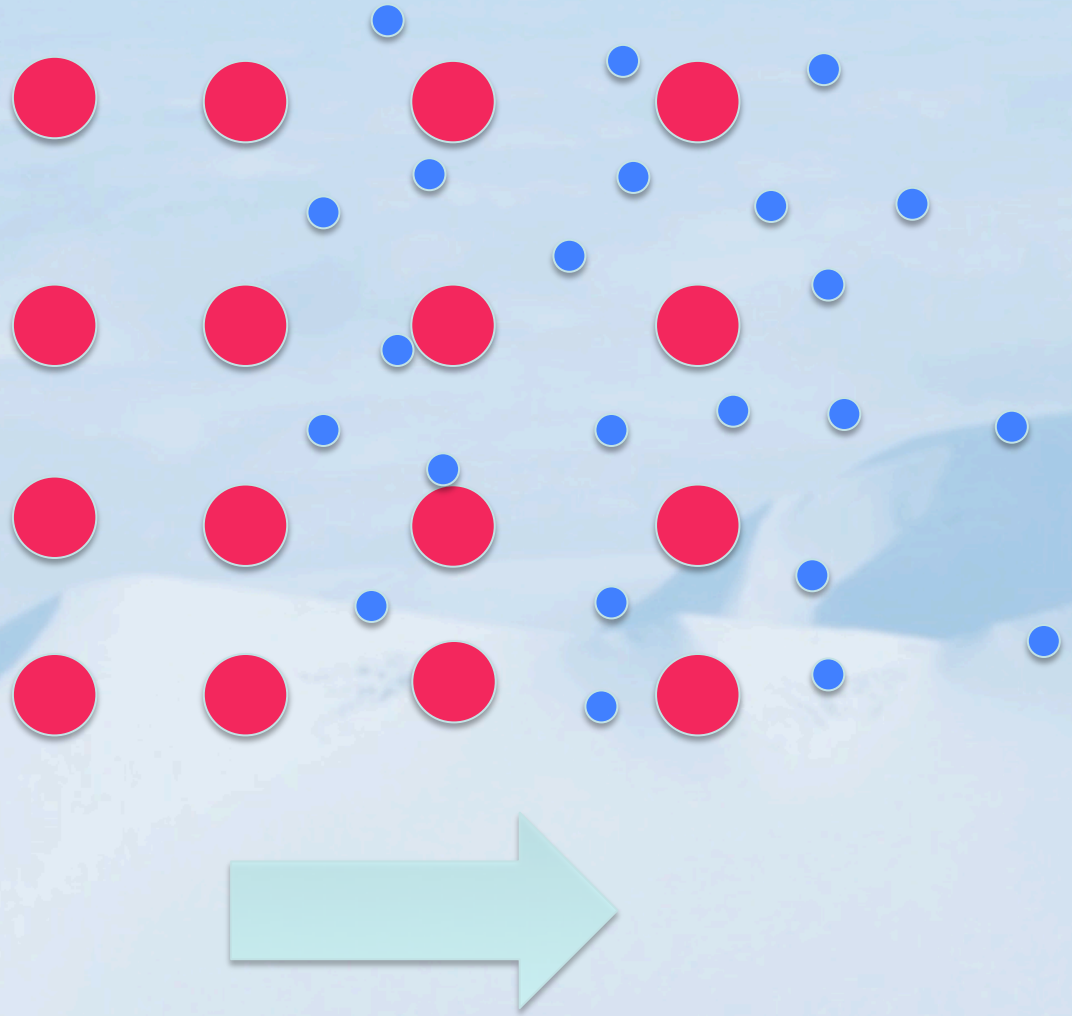


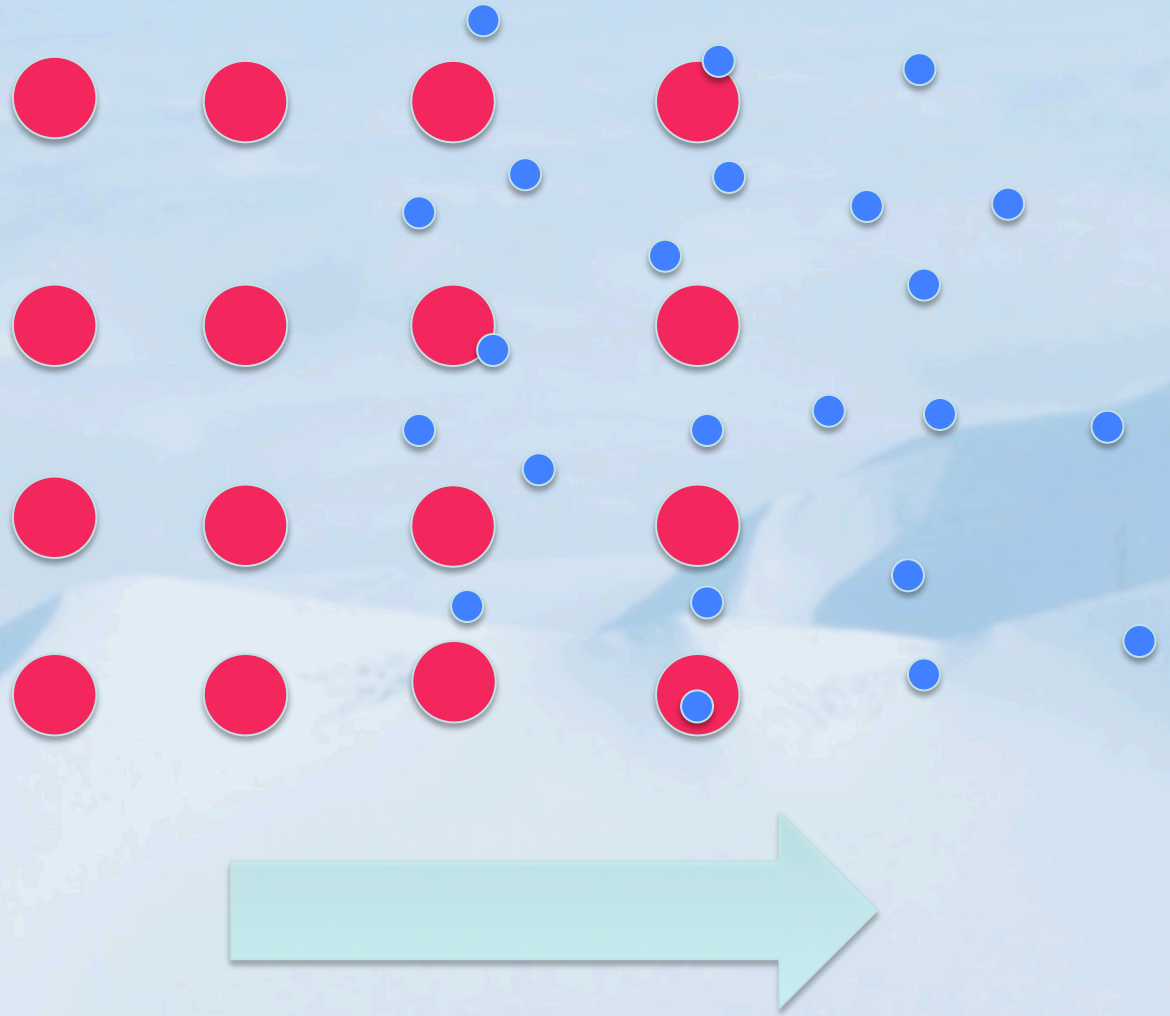




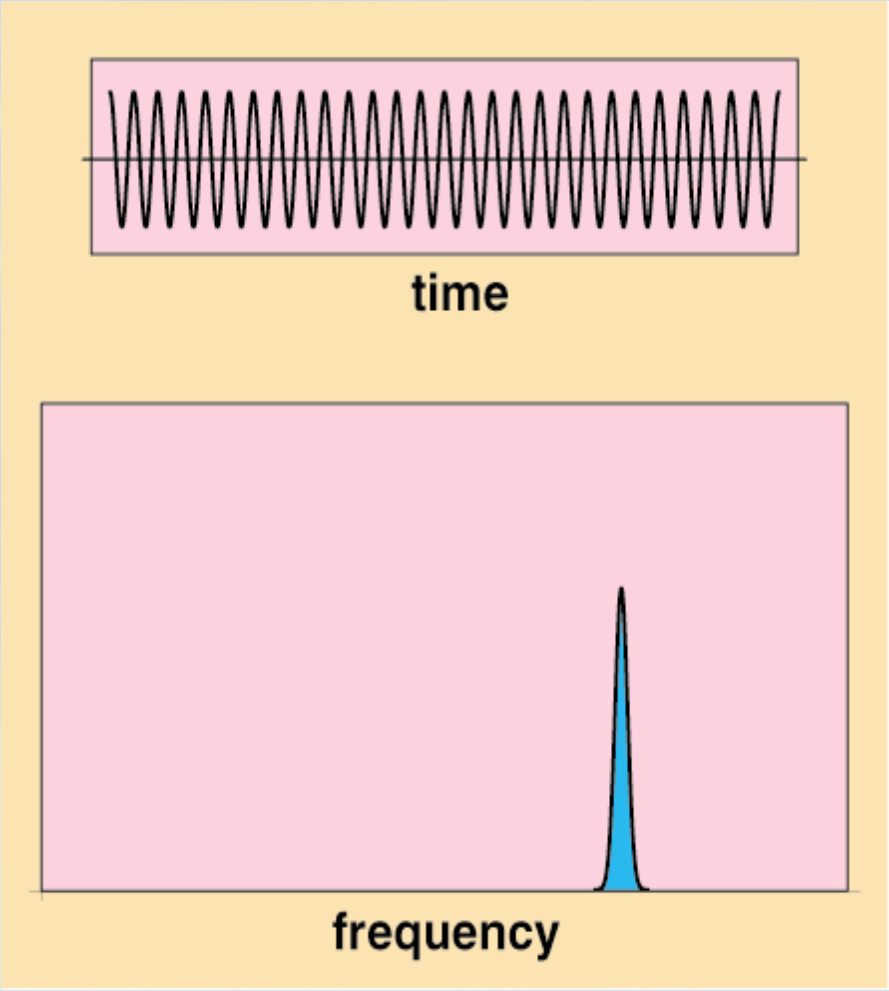


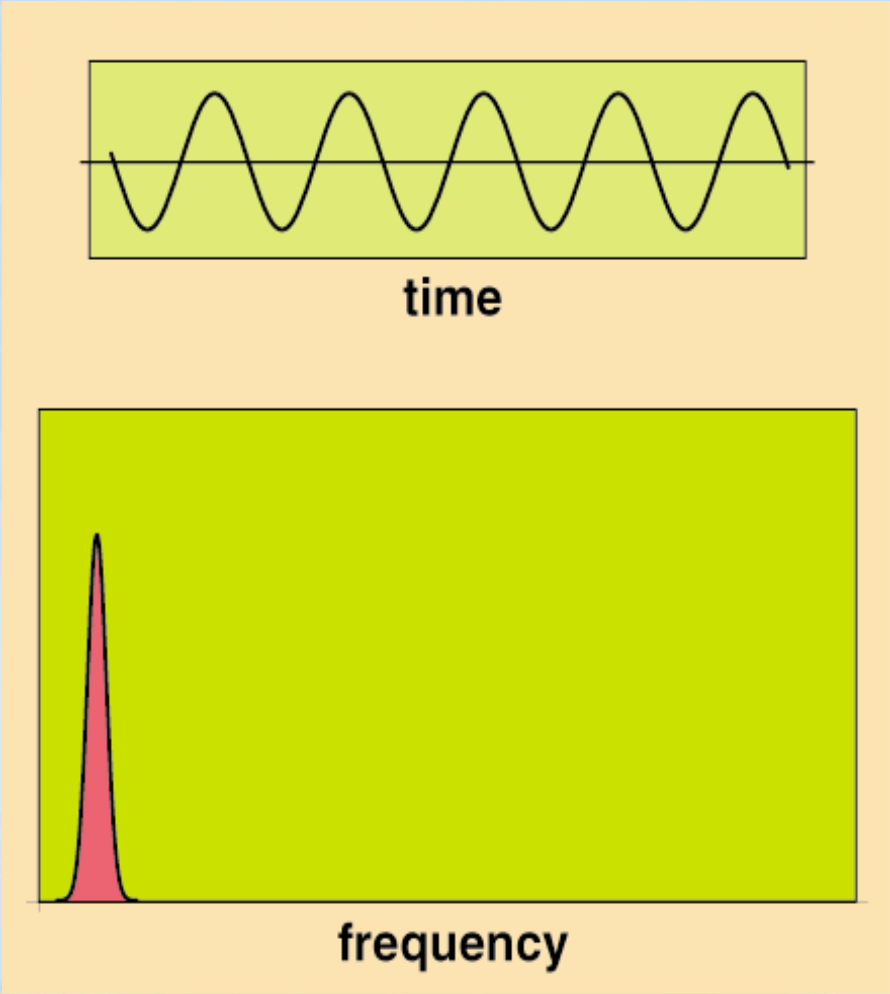


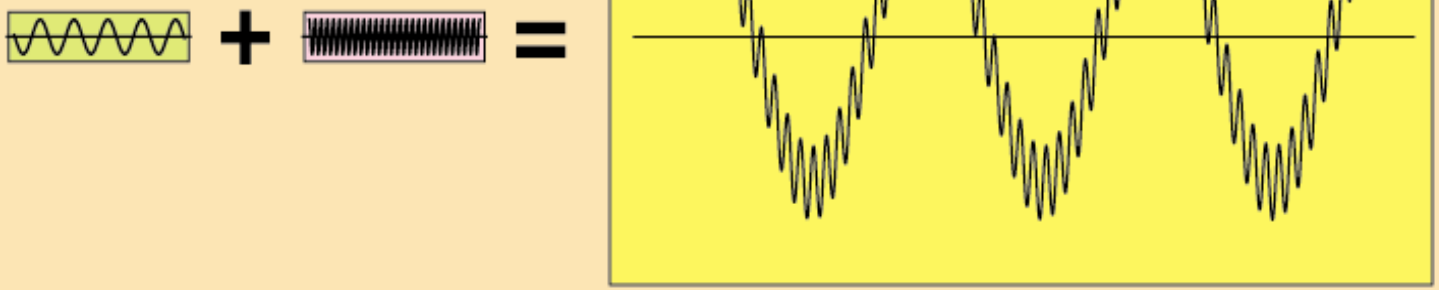




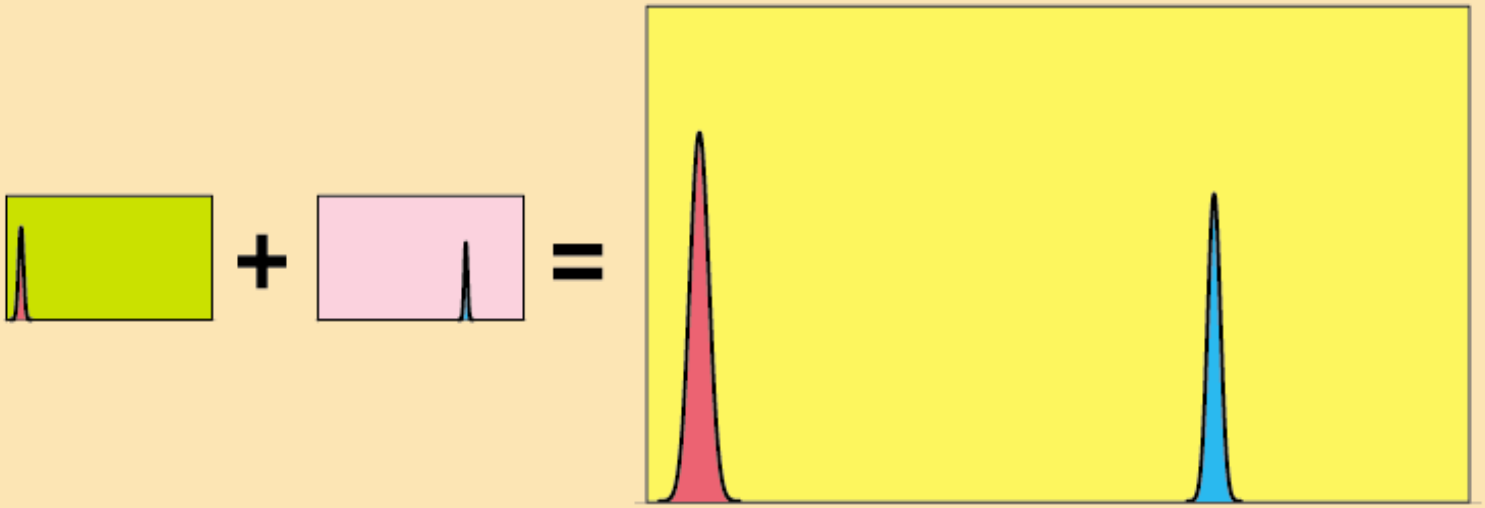
Incoherent scattering - the short story


time
frequency


time
frequency

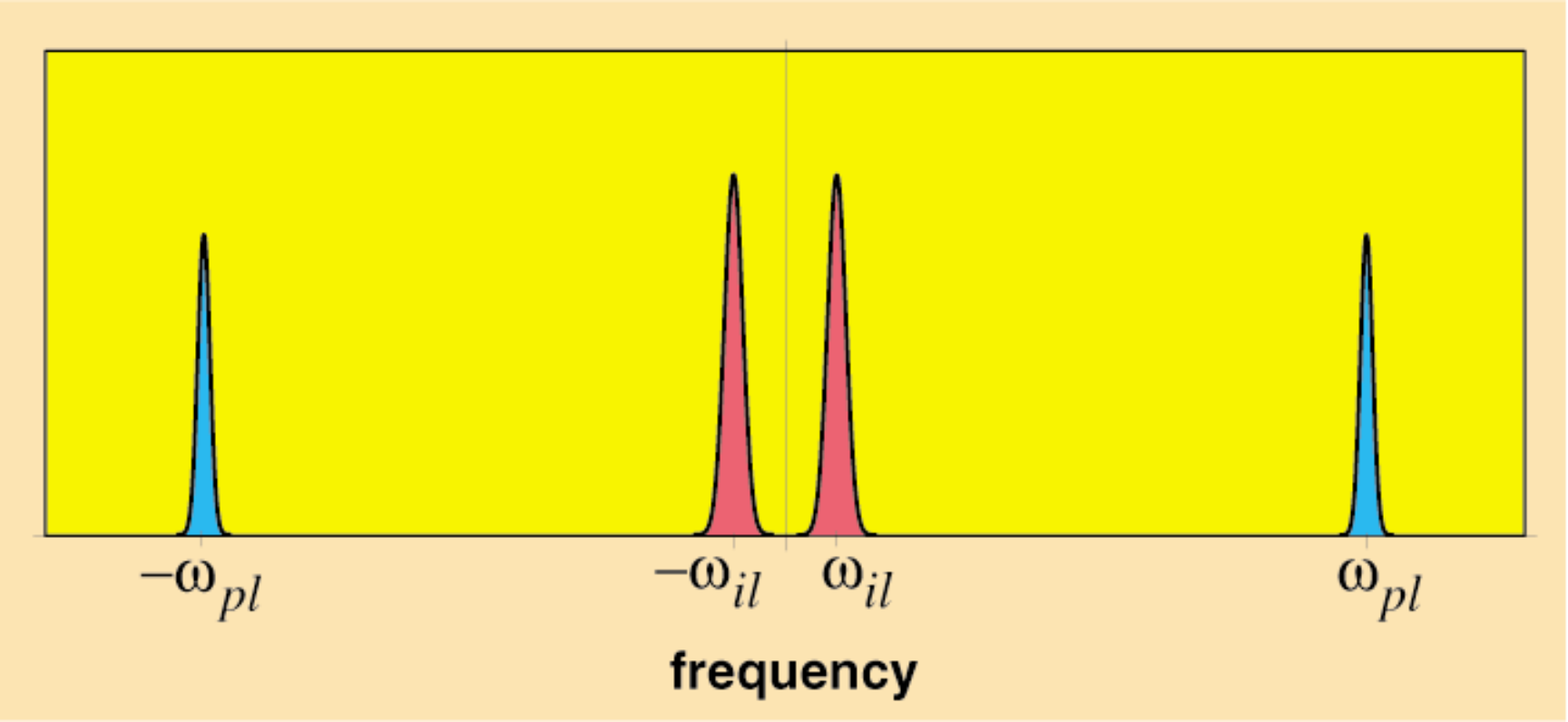


time

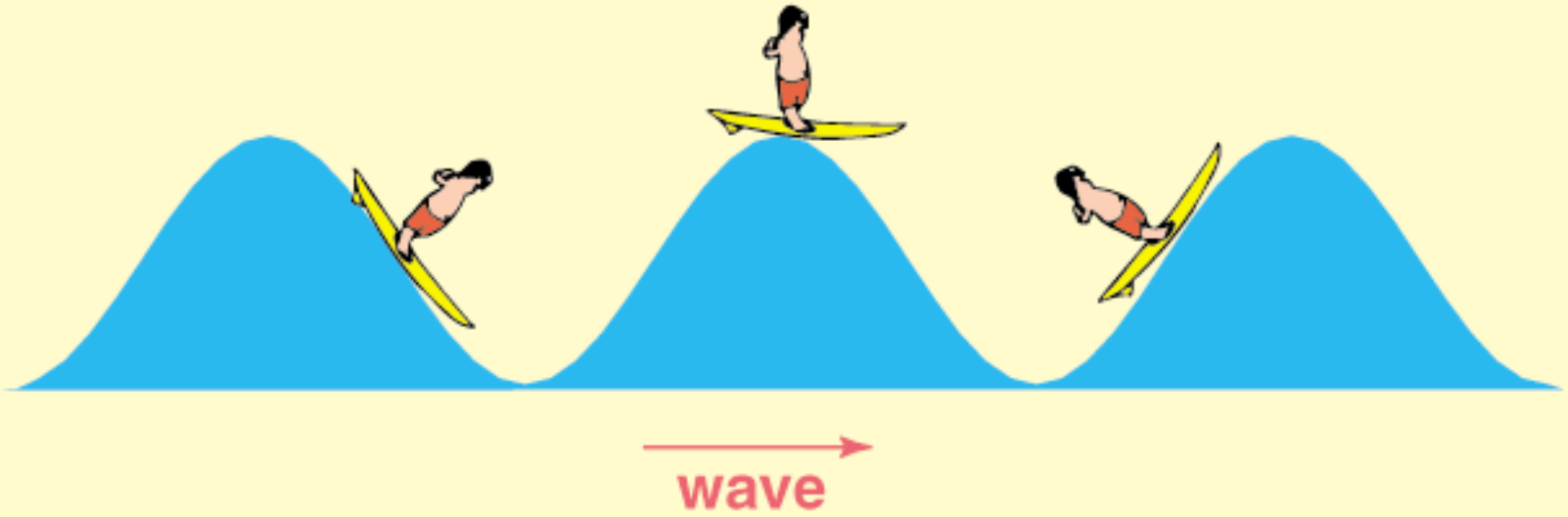


frequency

Plasma Wave Approach (cont'd)



Landau wave-particle interactions



particle gains energy

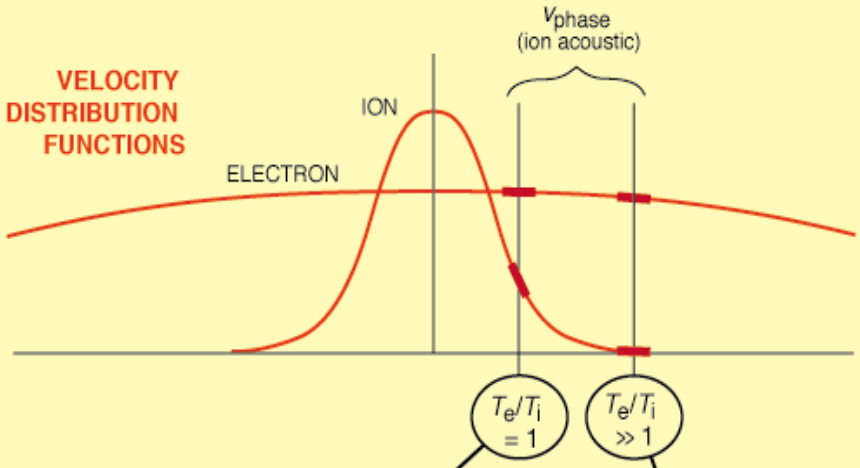
wave gains energy

THE EFFECT OF LANDAU DAMPING ON THE INCOHERENT SCATTER ION LINE SPECTRUM

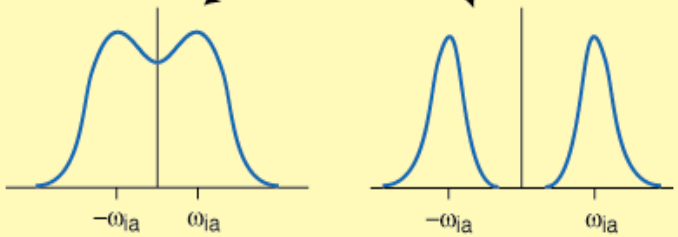
ION-ACOUSTIC DISPERSION EQUATION

$$\omega_{ia} = k\, v_{phase} = k\left(\frac{T_e + 3T_i}{m_i}\right)^{1/2}$$

VELOCITY DISTRIBUTION FUNCTIONS

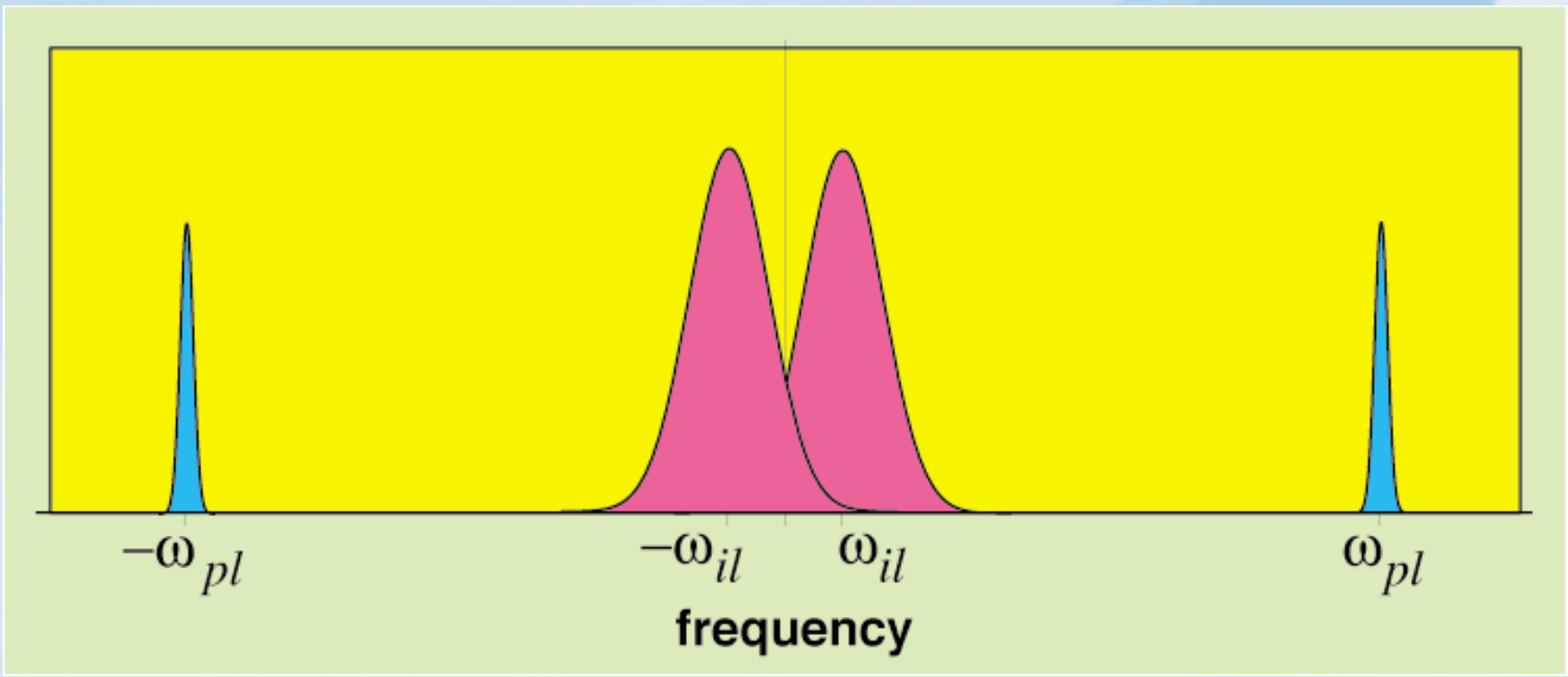


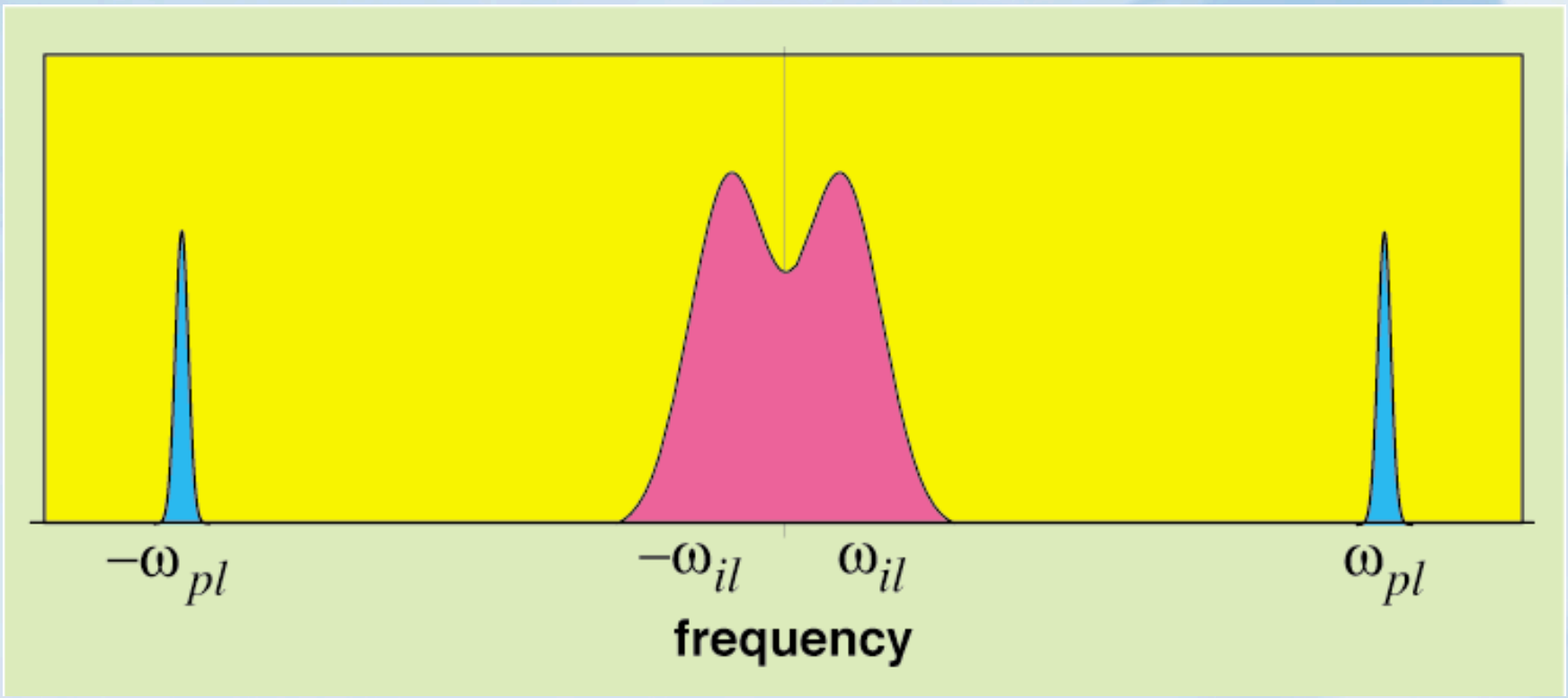
INCOHERENT SCATTER ION LINE SPECTRA



$T_e/T_i = 1$
STRONG LANDAU DAMPING

$T_e/T_i \gg 1$
WEAK LANDAU DAMPING


$-\omega_{pl}$
$-\omega_{il}$
ω_{il}
ω_{pl}
frequency


$-\omega_{pl}$
$-\omega_{il}$
ω_{il}
ω_{pl}
frequency

Incoherent Scattering Spectrum

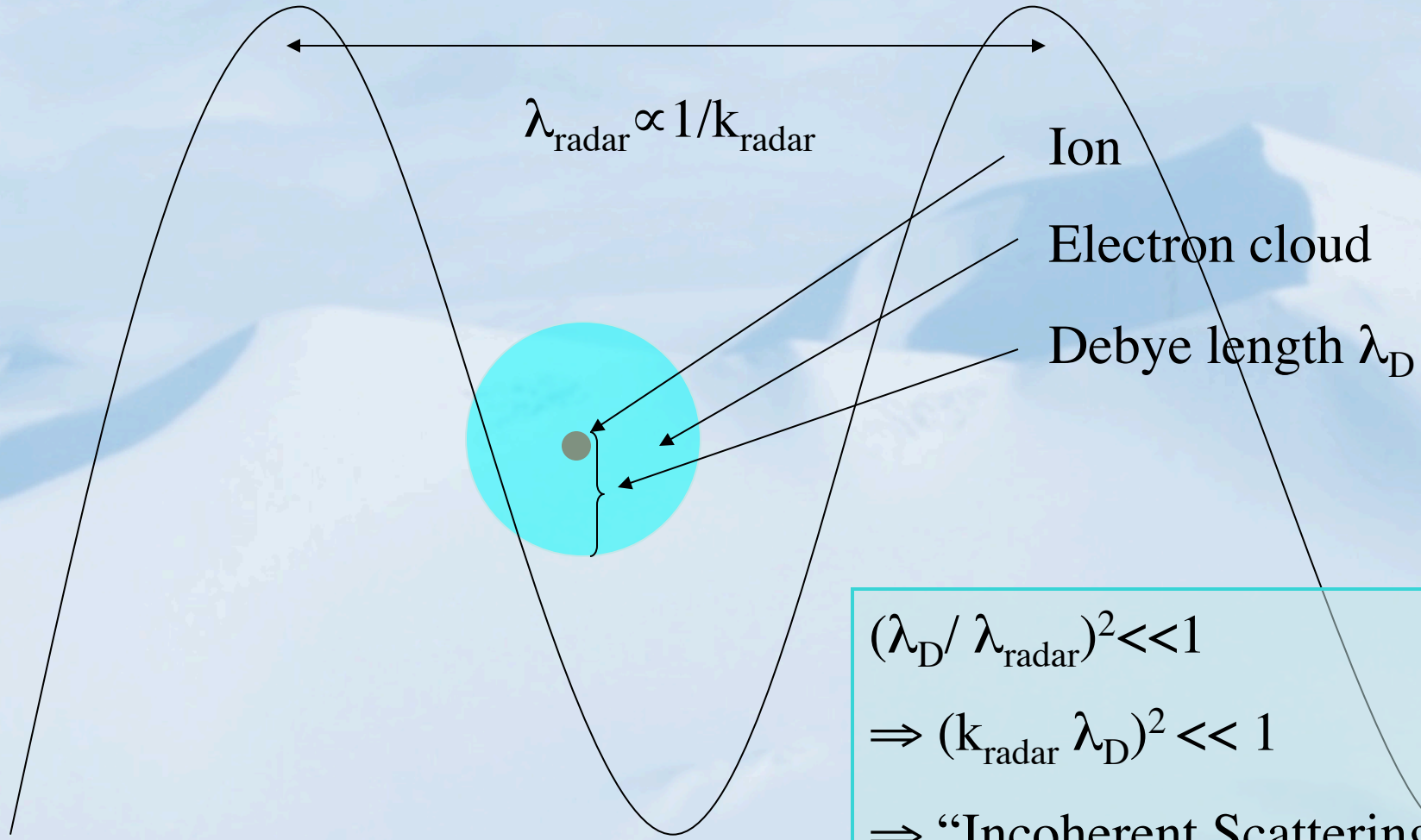
$$S_e(\mathbf{k},\omega) = N_e \left| 1 - \frac{\chi_e(\mathbf{k},\omega)}{\epsilon(\mathbf{k},\omega)} \right|^2 \int d\mathbf{v} f_e(\mathbf{v}) \delta(\omega - \mathbf{k}\cdot\mathbf{v}) + N_i \left| \frac{\chi_e(\mathbf{k},\omega)}{\epsilon(\mathbf{k},\omega)} \right|^2 \int d\mathbf{v} f_i(\mathbf{v}) \delta(\omega - \mathbf{k}\cdot\mathbf{v})$$

Plasma line

Ion line

electric susceptibility	$\chi_{e,i}(\mathbf{k},\omega)$
dielectric constant function	$\epsilon(\mathbf{k},\omega)$
velocity distribution function	$f_{e,i}(\mathbf{v})$

Debye length dependence



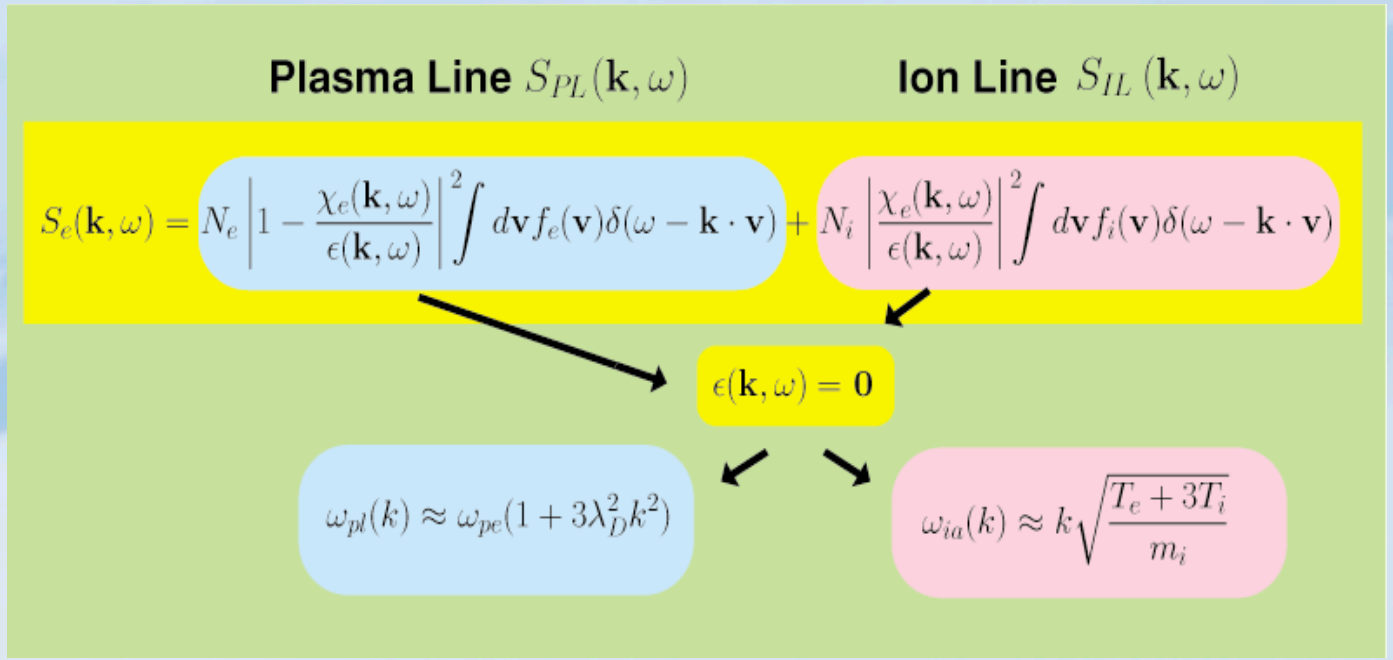
$(\lambda_D / \lambda_{radar})^2 << 1$

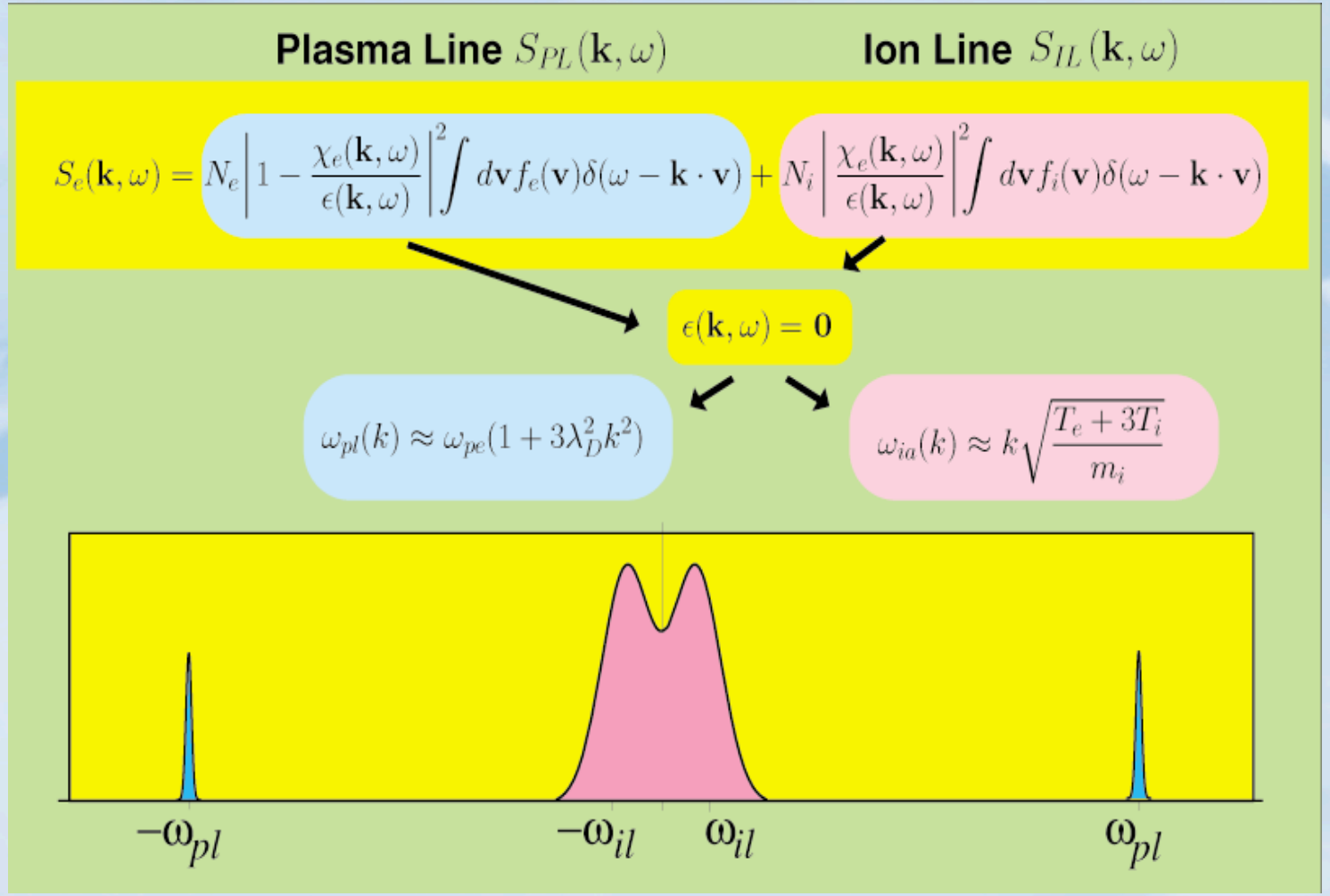
$\Rightarrow (k_{radar}\ \lambda_D)^2 << 1$

$\Rightarrow$ "Incoherent Scattering"

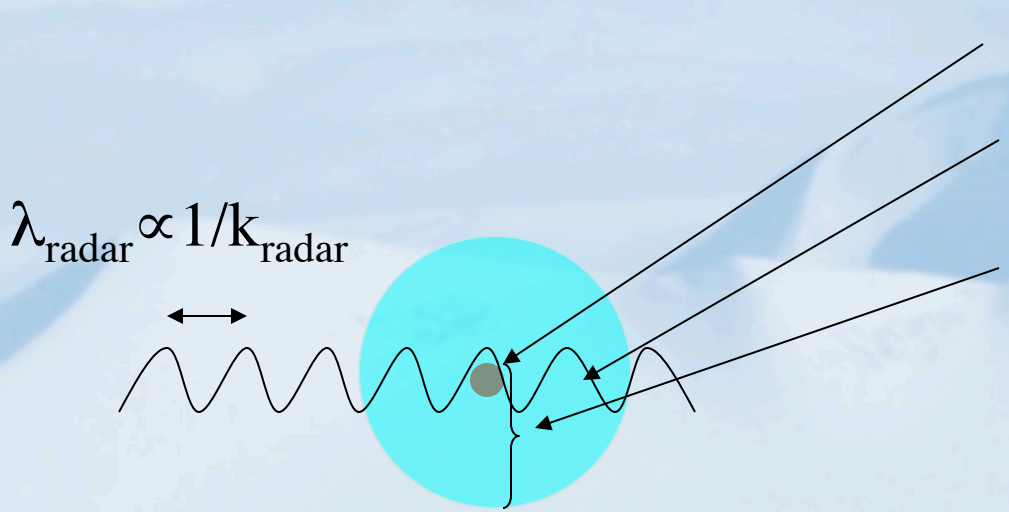
Plasma Line $S_{PL}(\mathbf{k},\omega)$ **Ion Line** $S_{IL}(\mathbf{k},\omega)$

$$S_e(\mathbf{k},\omega) = N_e \left|1 - \frac{\chi_e(\mathbf{k},\omega)}{\epsilon(\mathbf{k},\omega)}\right|^2 \int d\mathbf{v} f_e(\mathbf{v}) \delta(\omega - \mathbf{k}\cdot\mathbf{v}) + N_i \left|\frac{\chi_e(\mathbf{k},\omega)}{\epsilon(\mathbf{k},\omega)}\right|^2 \int d\mathbf{v} f_i(\mathbf{v}) \delta(\omega - \mathbf{k}\cdot\mathbf{v})$$


Plasma Line $S_{PL}(\mathbf{k},\omega)$
Ion Line $S_{IL}(\mathbf{k},\omega)$
$S_e(\mathbf{k},\omega) = N_e \left|1 - \frac{\chi_e(\mathbf{k},\omega)}{\epsilon(\mathbf{k},\omega)}\right|^2 \int d\mathbf{v} f_e(\mathbf{v})\delta(\omega - \mathbf{k}\cdot\mathbf{v}) + N_i \left|\frac{\chi_e(\mathbf{k},\omega)}{\epsilon(\mathbf{k},\omega)}\right|^2 \int d\mathbf{v} f_i(\mathbf{v})\delta(\omega - \mathbf{k}\cdot\mathbf{v})$
$\epsilon(\mathbf{k},\omega) = 0$
$\omega_{pl}(k) \approx \omega_{pe}(1 + 3\lambda_D^2 k^2)$
$\omega_{ia}(k) \approx k\sqrt{\frac{T_e + 3T_i}{m_i}}$


Plasma Line $S_{PL}(\mathbf{k},\omega)$
Ion Line $S_{IL}(\mathbf{k},\omega)$
$S_e(\mathbf{k},\omega) = N_e \left| 1 - \frac{\chi_e(\mathbf{k},\omega)}{\epsilon(\mathbf{k},\omega)} \right|^2 \int d\mathbf{v} f_e(\mathbf{v}) \delta(\omega - \mathbf{k}\cdot\mathbf{v}) + N_i \left| \frac{\chi_e(\mathbf{k},\omega)}{\epsilon(\mathbf{k},\omega)} \right|^2 \int d\mathbf{v} f_i(\mathbf{v}) \delta(\omega - \mathbf{k}\cdot\mathbf{v})$
$\epsilon(\mathbf{k},\omega) = 0$
$\omega_{pl}(k) \approx \omega_{pe}(1 + 3\lambda_D^2 k^2)$
$\omega_{ia}(k) \approx k\sqrt{\frac{T_e + 3T_i}{m_i}}$
$-\omega_{pl}$
$-\omega_{il}$
ω_{il}
ω_{pl}

Debye length dependence



$(\lambda_D / \lambda_{radar})^2 > 1$

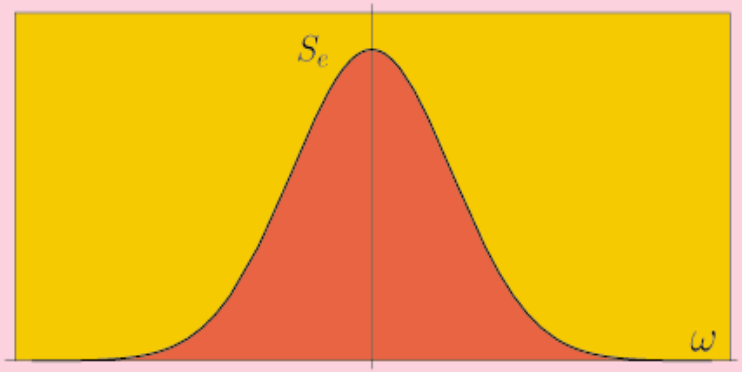
$\Rightarrow (k_{radar}\ \lambda_D)^2 > 1$

$\Rightarrow$ No collective interactions

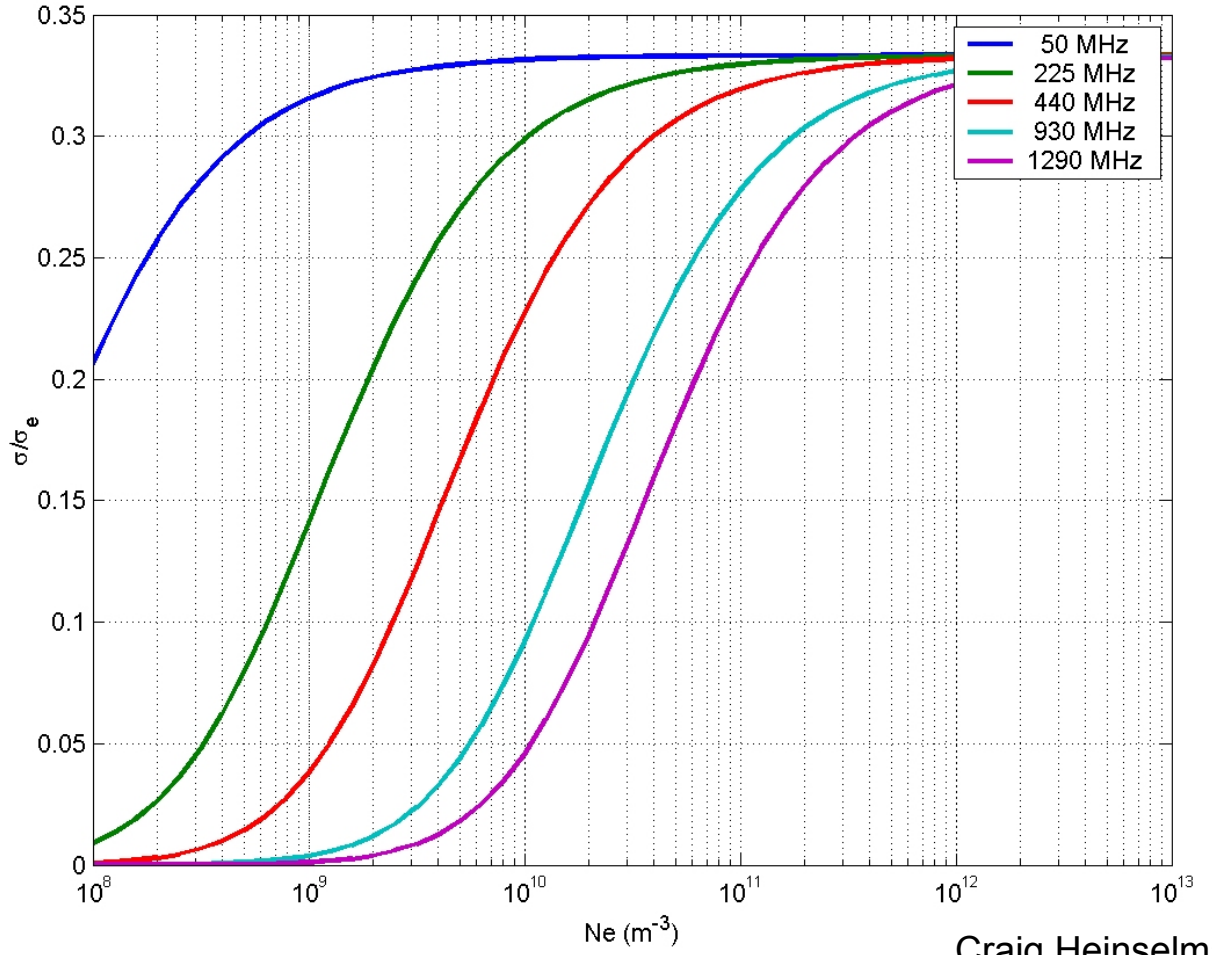
no collective interactions

$$S_e(\mathbf{k},\omega) = N_e \left|1 - \frac{\chi_e(\mathbf{k},\omega)}{\epsilon(\mathbf{k},\omega)}\right|^2 \int d\mathbf{v} f_e(\mathbf{v})\delta(\omega - \mathbf{k}\cdot\mathbf{v}) + N_i \left|\frac{\chi_e(\mathbf{k},\omega)}{\epsilon(\mathbf{k},\omega)}\right|^2 \int d\mathbf{v} f_i(\mathbf{v})\delta(\omega - \mathbf{k}\cdot\mathbf{v})$$

$$S_e(\mathbf{k},\omega) = N_e \int d\mathbf{v} f_e(\mathbf{v})\delta(\omega - \mathbf{k}\cdot\mathbf{v})$$



Debye Length Dependencies



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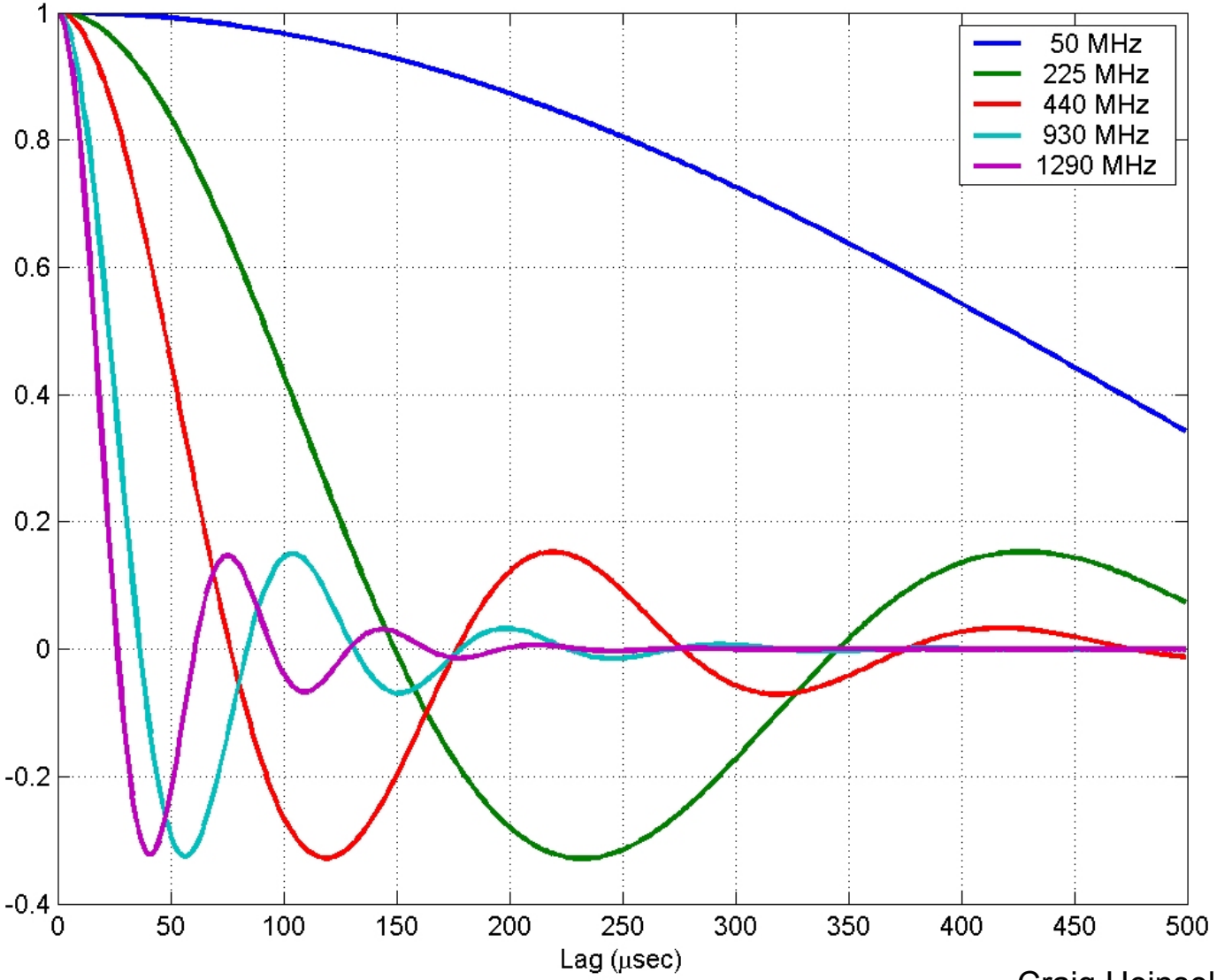
Parameters
Ti: 1000 K
Te: 2000 K



Parameters
Ne: 10^{12} m^{-3}
Ti: 1000 K
Te: 2000 K
Comp: 100% O^+
ν_{in}: 10^{-6} KHz

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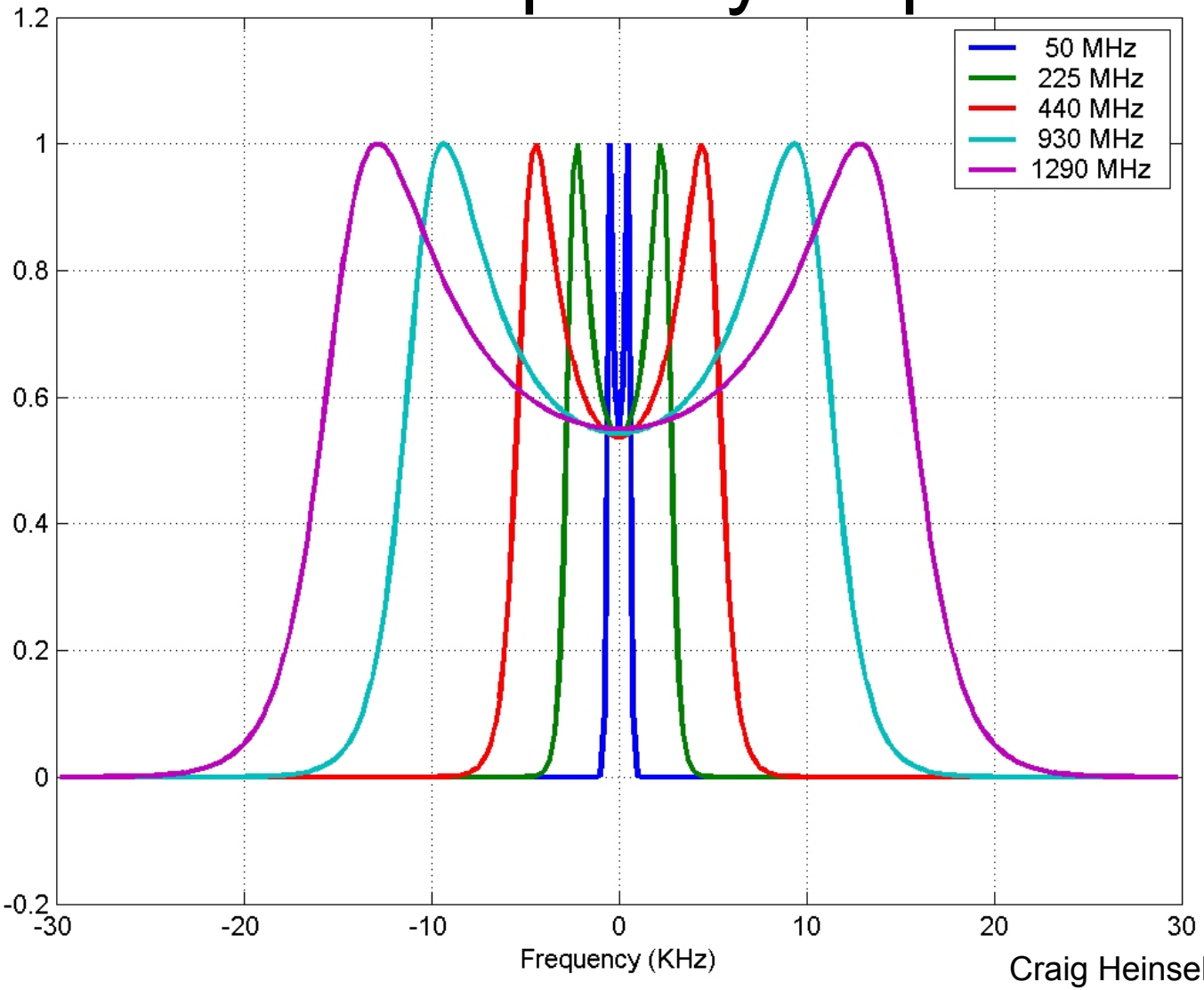
Radar Frequency Dependencies



Parameters

Ne: 10^{12} m^{-3}

Ti: 1000 K

Te: 2000 K

Comp: 100% O^+

ν_{in}: 10^{-6} KHz

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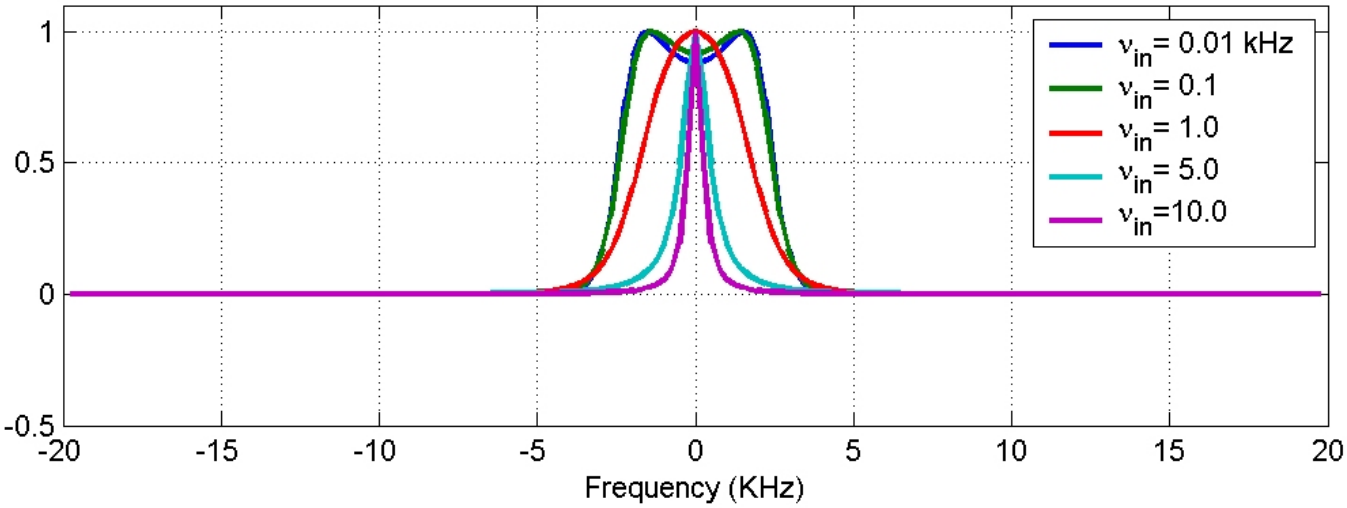
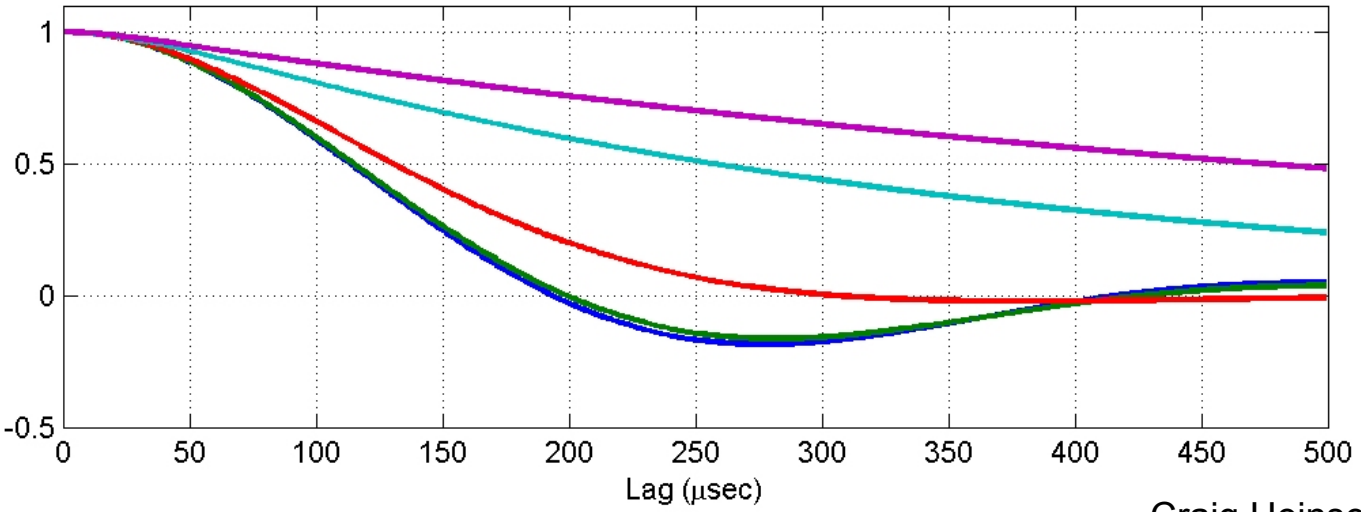
With the frequency of the radar chosen (which is a one time thing!), how does the spectra depend on geophysical parameters?

Ion-Neutral Collision Frequency





Parameters
Freq: 449 MHz
Ne: 10^{12} m^{-3}
Ti: 500 K
Te: 500 K
Comp: 100% NO^+

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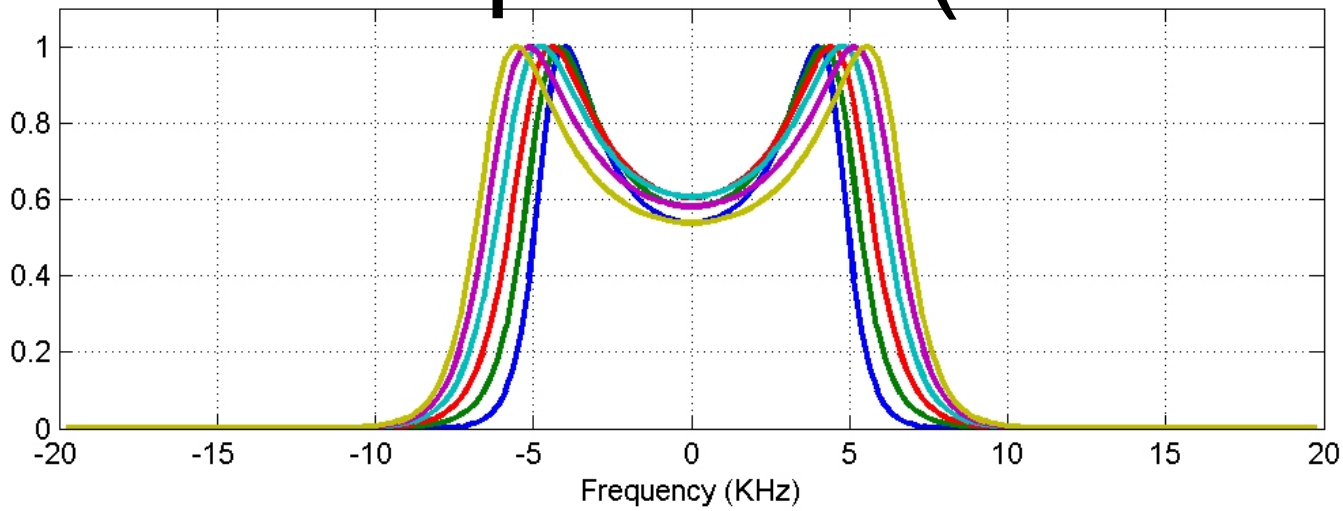
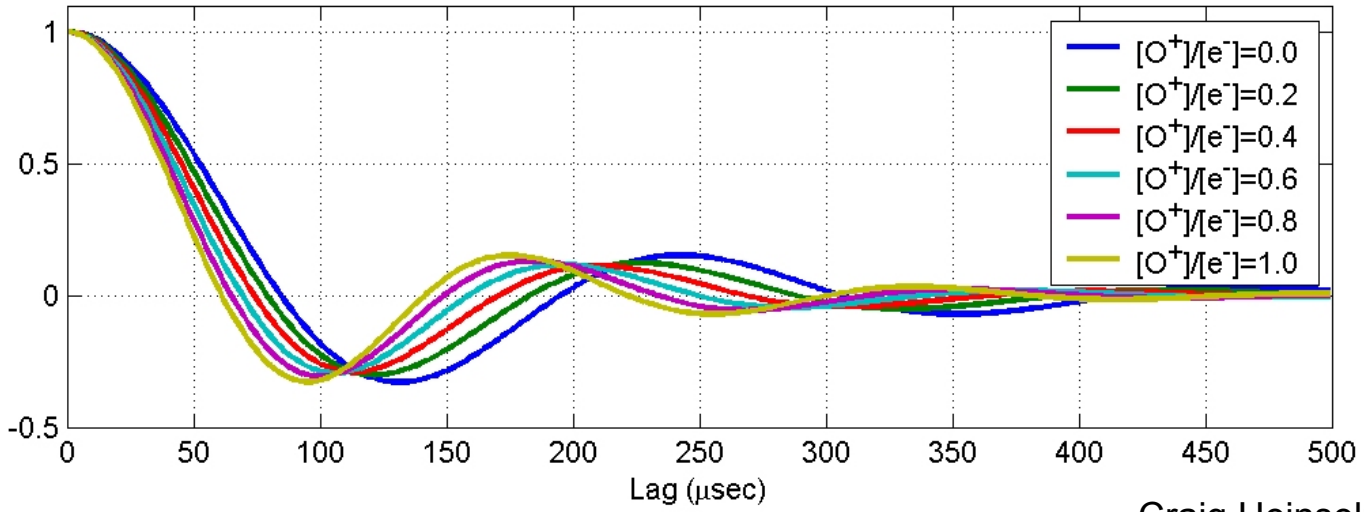
Ion Composition (O^+ vs. NO^+)



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



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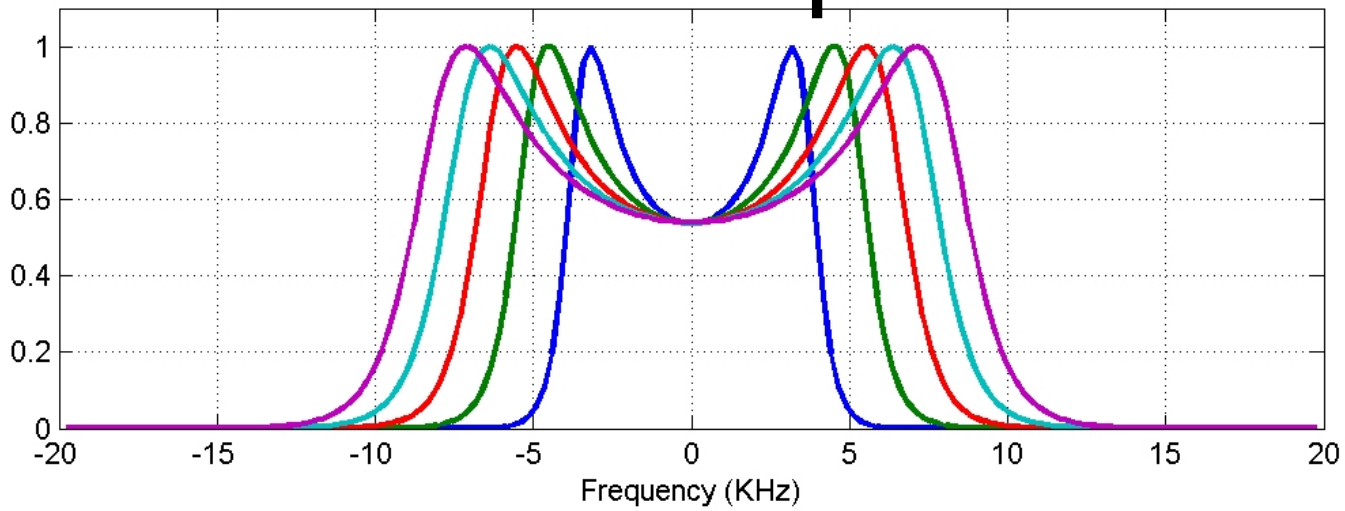
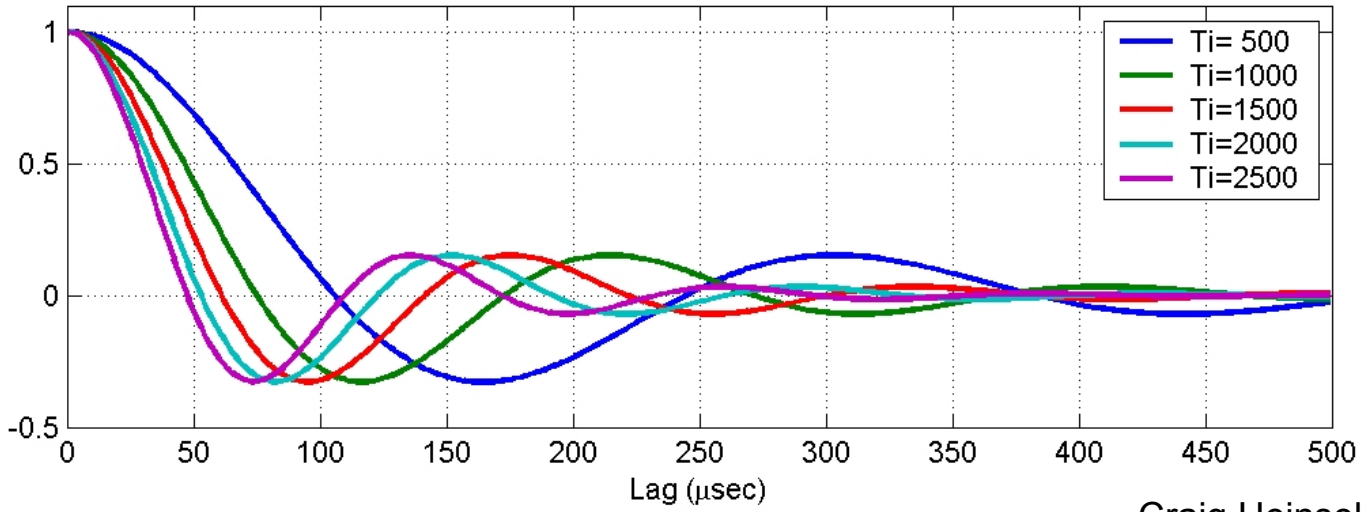
Ion Temperature





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

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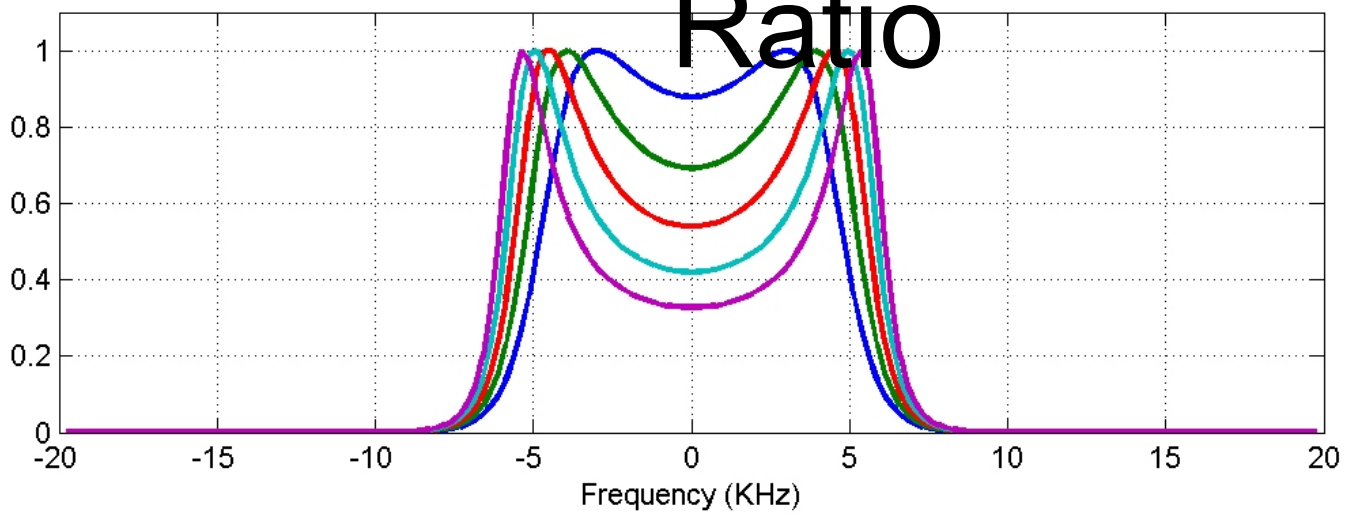
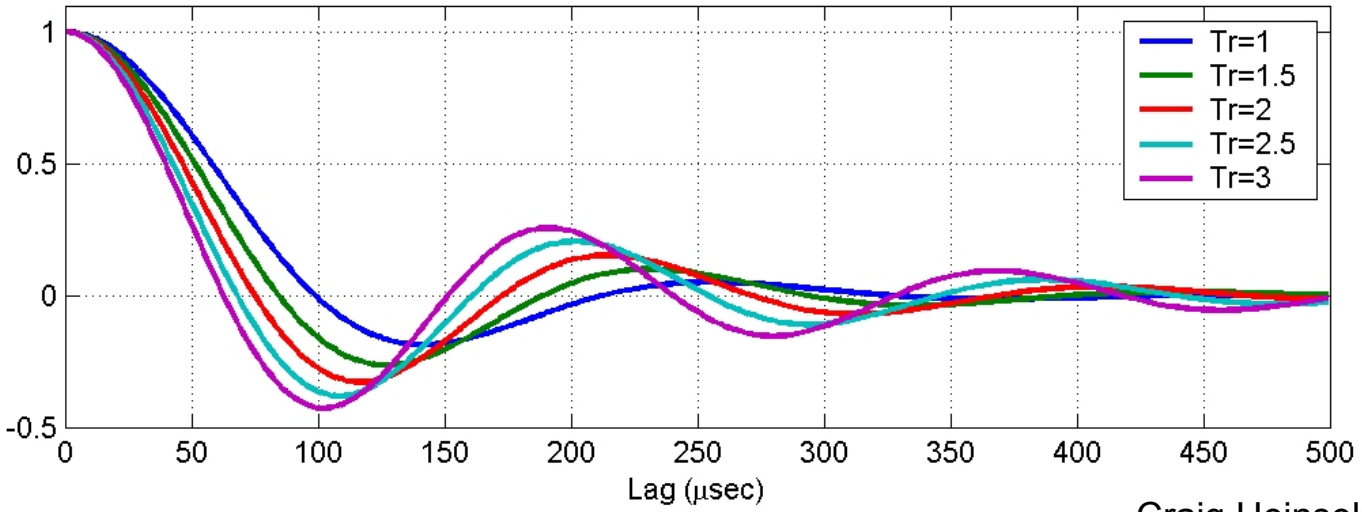
Electron/Ion Temperature Ratio



Parameters
Freq: 449 MHz
Ne: 10^{12} m^{-3}
Ti: 1000 K
Comp: 100% O^{+}
ν_{in}: 10^{-6} KHz



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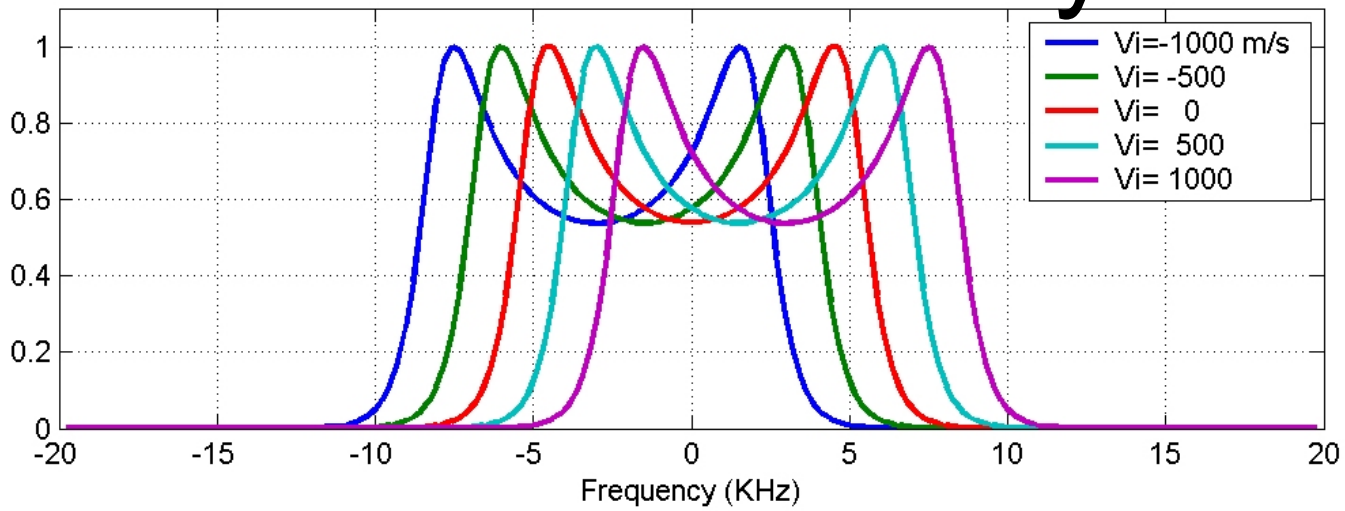
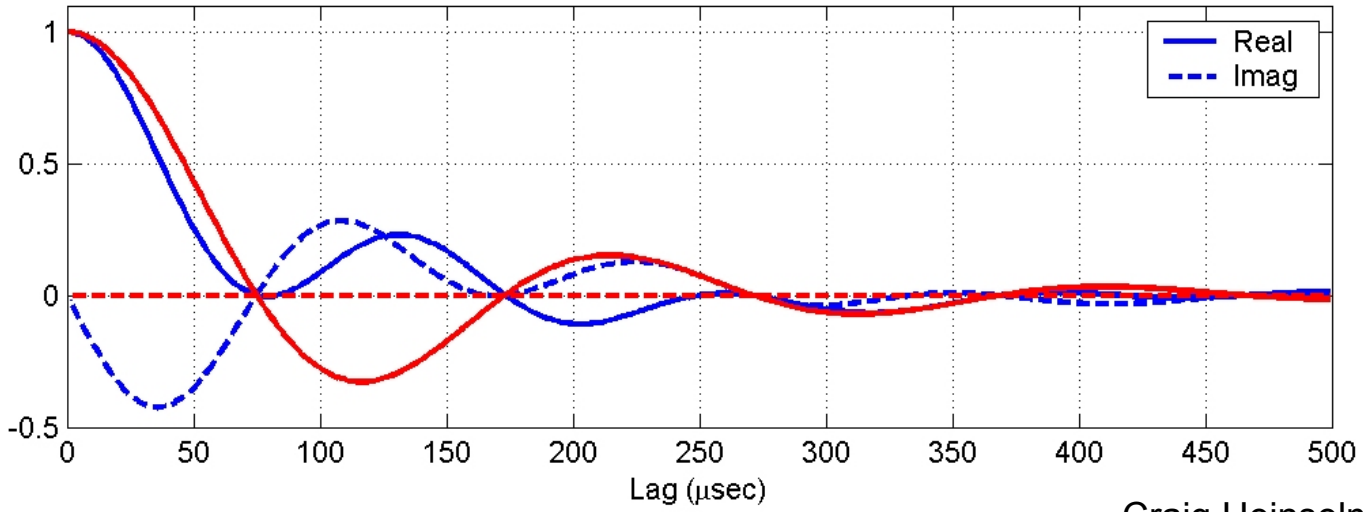
Ion Velocity





Parameters
Freq: 449 MHz
Ne: 10^{12} m^{-3}
Ti: 1000 K
Te: 2000 K
Comp: 100% O^+
ν_{in}: 10^{-6} KHz

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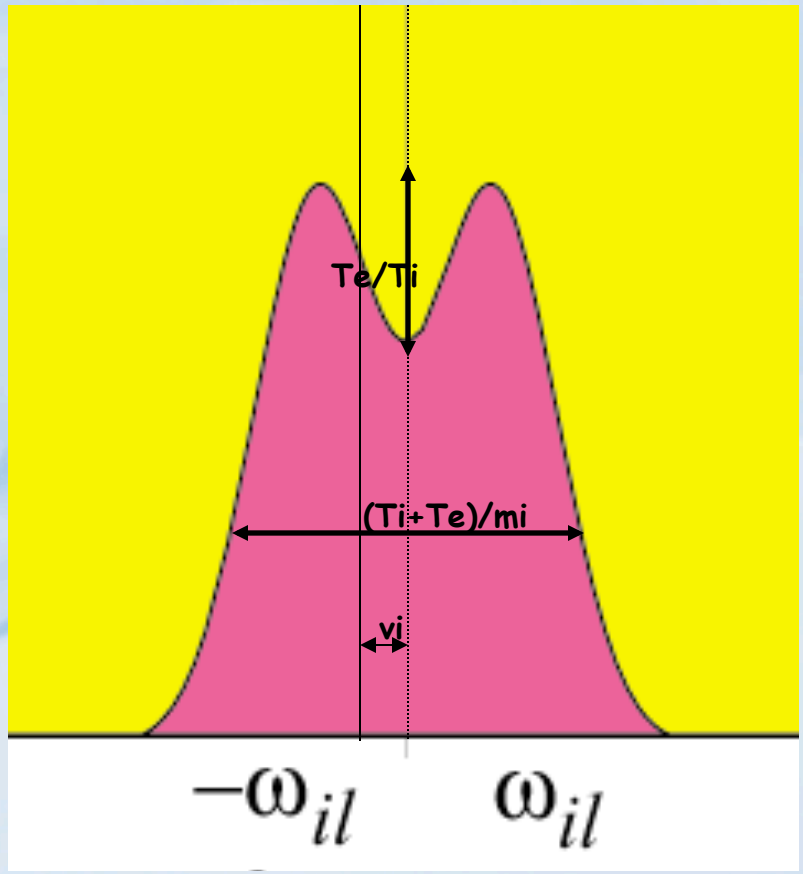
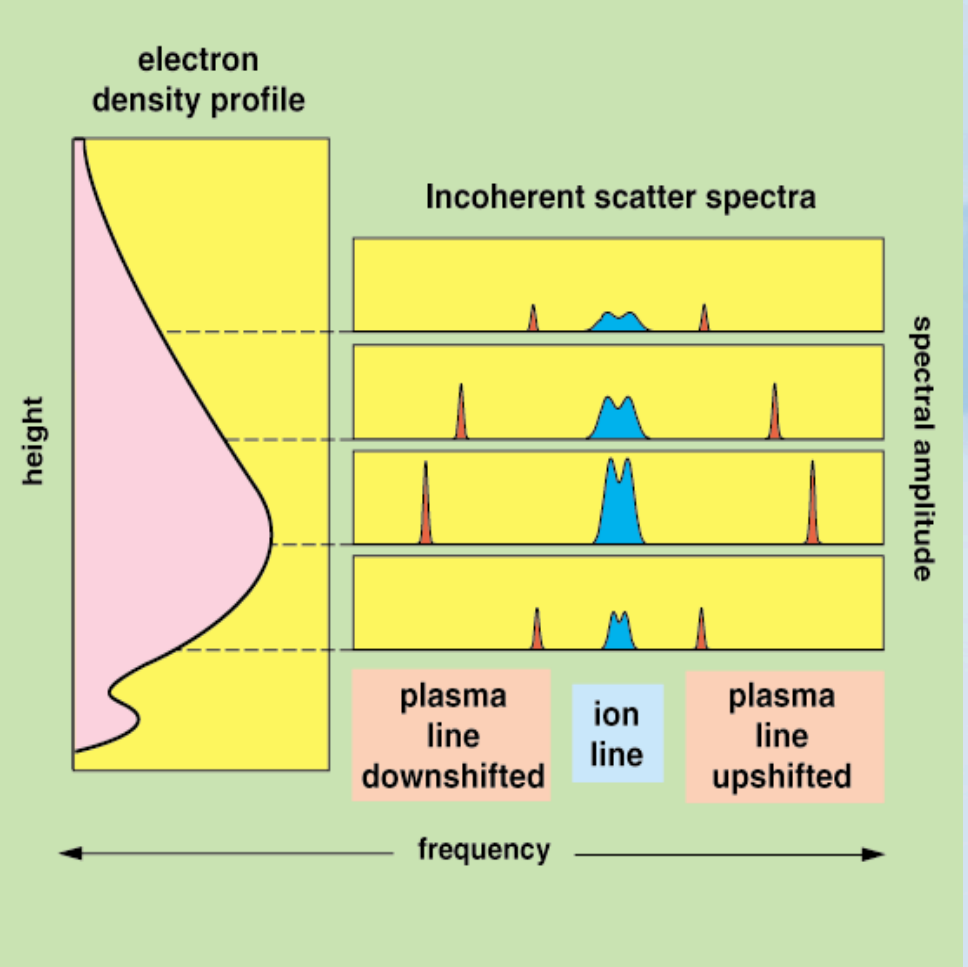
…or to sum up…

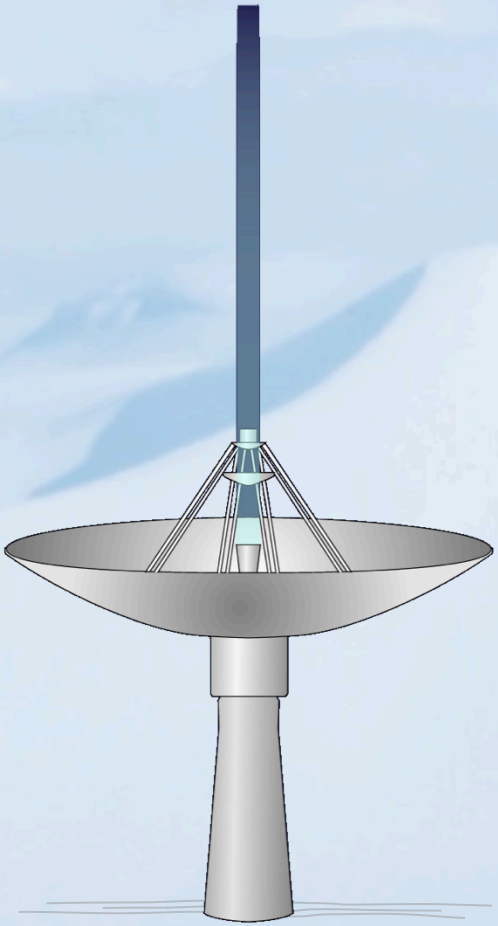


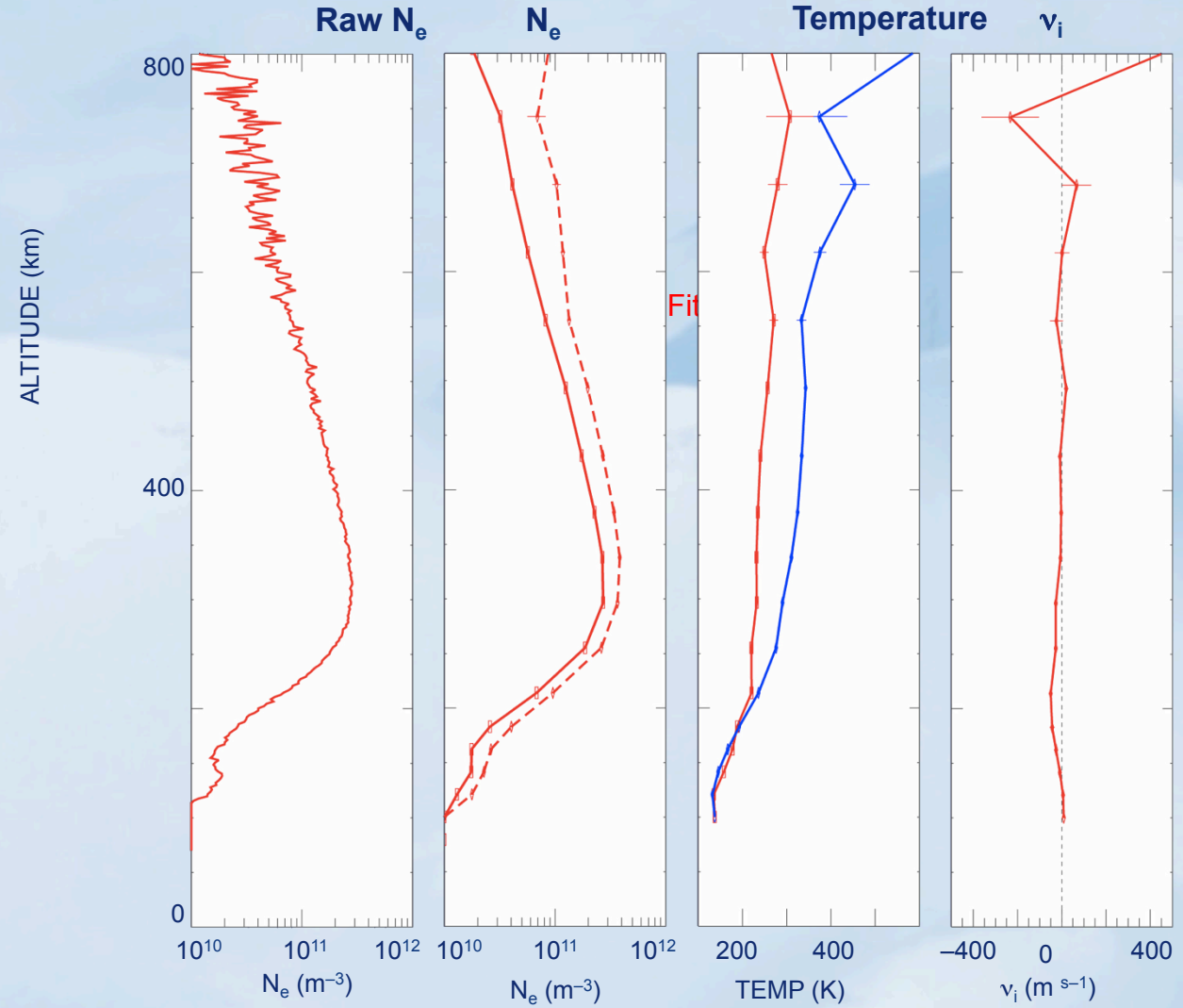
- Ion (and electron) temperature (Ti and Te) to ion mass (mi) ratio from the width of the spectra
- Electron to ion temperature ratio (Te/Ti) from "peak_to_valley" ratio
- Electron (= ion) density from total area (corrected for temperatures)
- Ion velocity (vi) from the Doppler shift

Spectral space as a function of altitude



Plasma Parameter Profile





EISCAT Scientific Association

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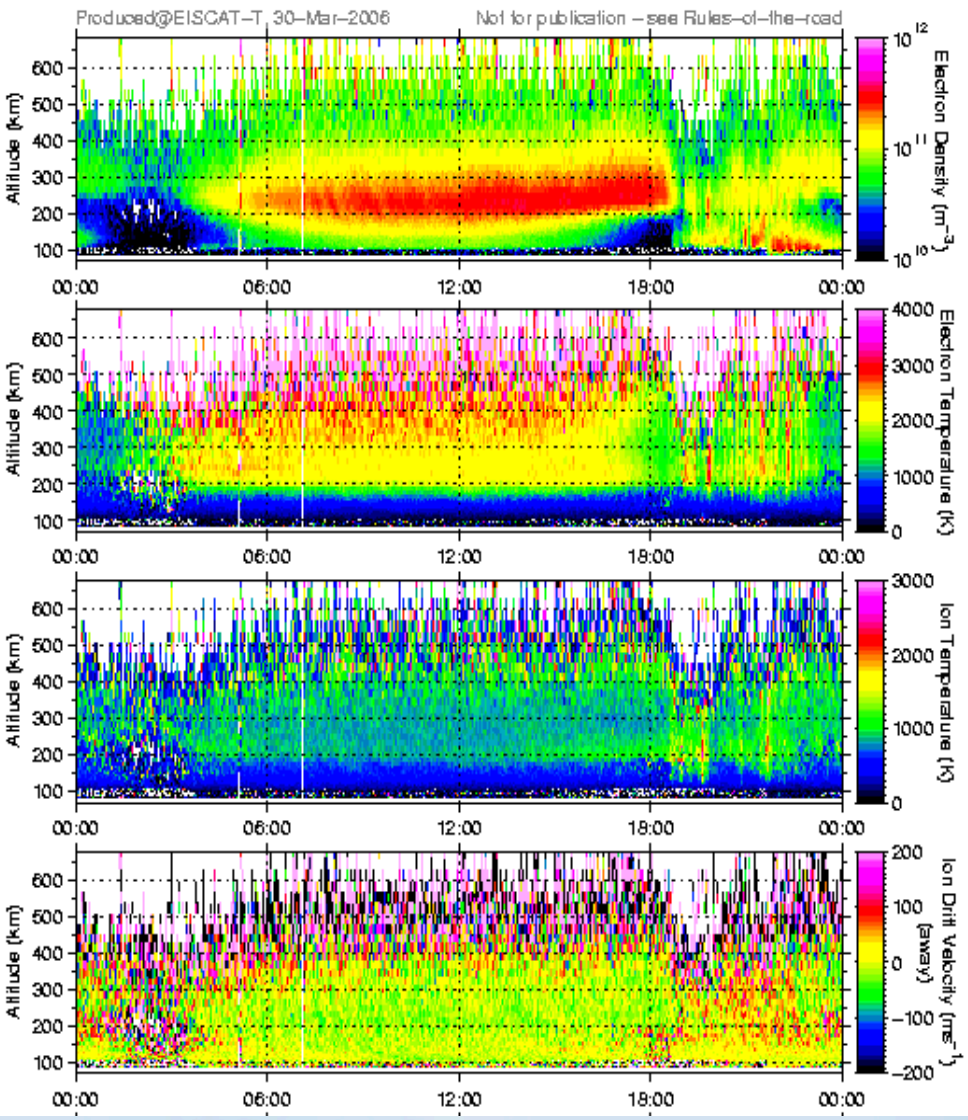
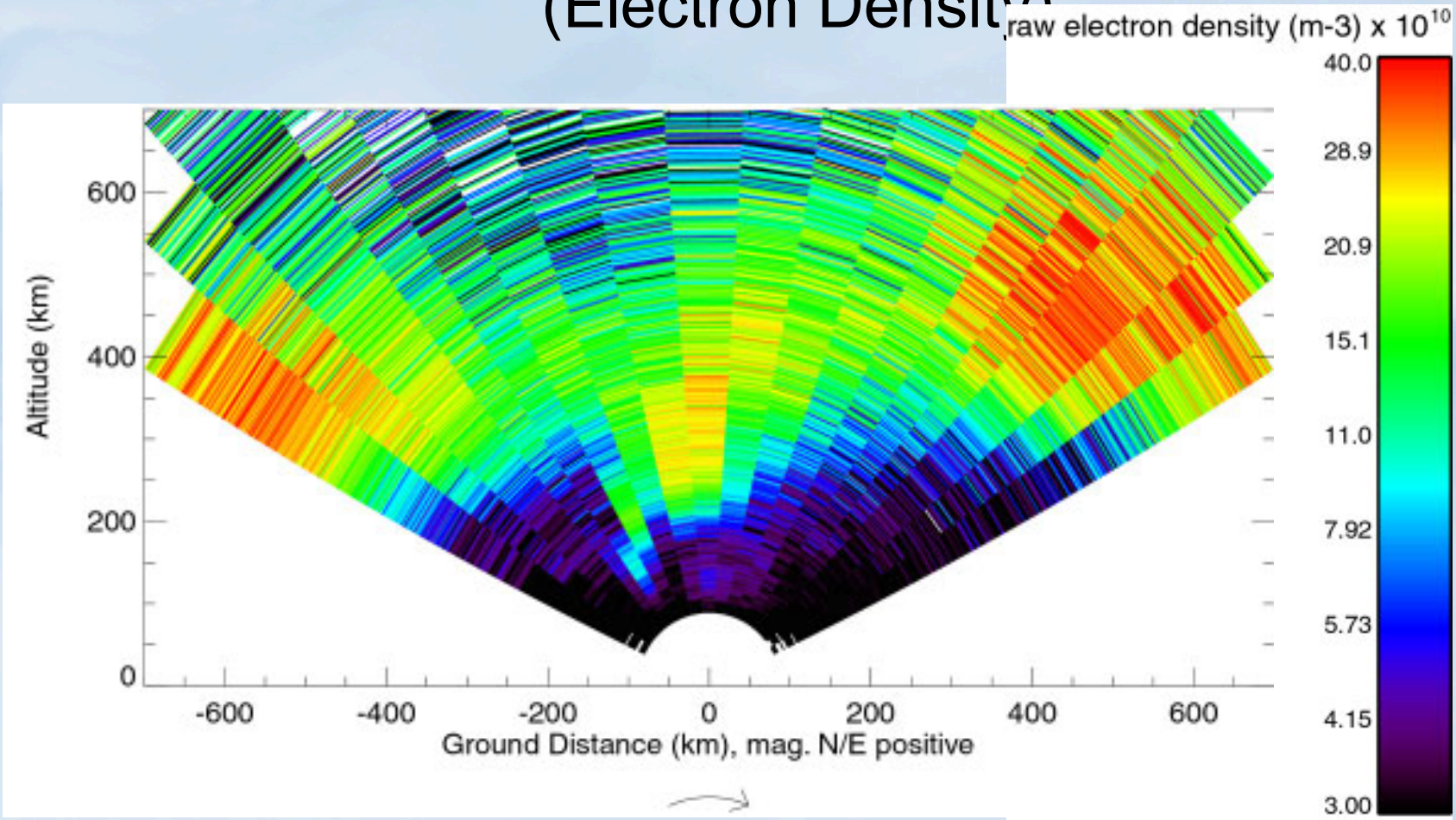
CP, uhf, tau2pl, 29 March 2006

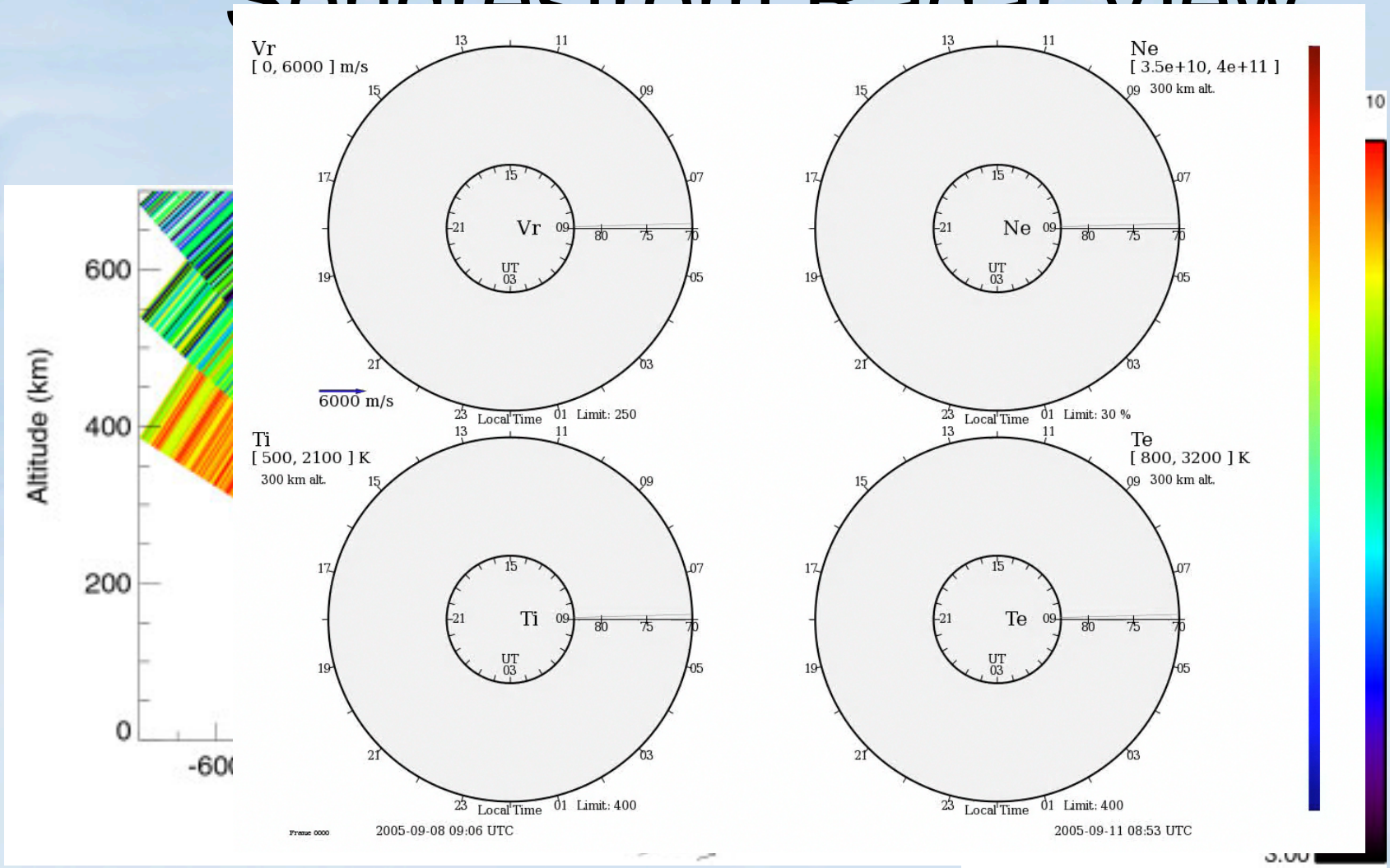


Sondrestrom Radar View

(Electron Density)



Sondrestrom Radar View



And this is the level data we will work on in the MADRIGAL session…