# Introduction to the Ionosphere (part 4)

2020 ISR Summer School

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# Radio measurements of the upper atmosphere

- Propagation and Reflection Experiments:
  - Consider ionospheric plasma as a continuum
  - Ray-bending and reflection governed by variable index of refraction
- Incoherent Scatter Radar:
  - Consider ionospheric plasma as a collection of electron point targets
  - Assume plasma is stable and near thermodynamic equilibrium
  - Use statistical mechanics to describe scatter
- Coherent Scatter Radar:
  - Consider ionospheric plasma as a heterogenous, structured medium
  - Scatter from turbulence, plasma irregularities, etc.

# Incoherent scatter radar

Radar Cross Section of One Electron:

$$\sigma_e = 4\pi r_e^2 \approx 10^{-28} \text{ m}^2$$

Suppose $N_e = 10^{11} \text{ m}^{-3}$ and $V = 1 \text{ km}^3$:

$$\sigma = 10^{11} \times 10^9 \times 10^{-28} = 10^{-8} \text{ m}^2$$

Power received by a 430 MHz, 300 m radar with 1 MW of power and 60% efficiency from a 100 $\mu$m $\times$ 100 $\mu$m target at 300 km:

$$P_r = P_t \frac{G}{4\pi R^2} \sigma \frac{A_{eff}}{4\pi R^2} \approx 4 \times 10^{-15} \text{W}$$
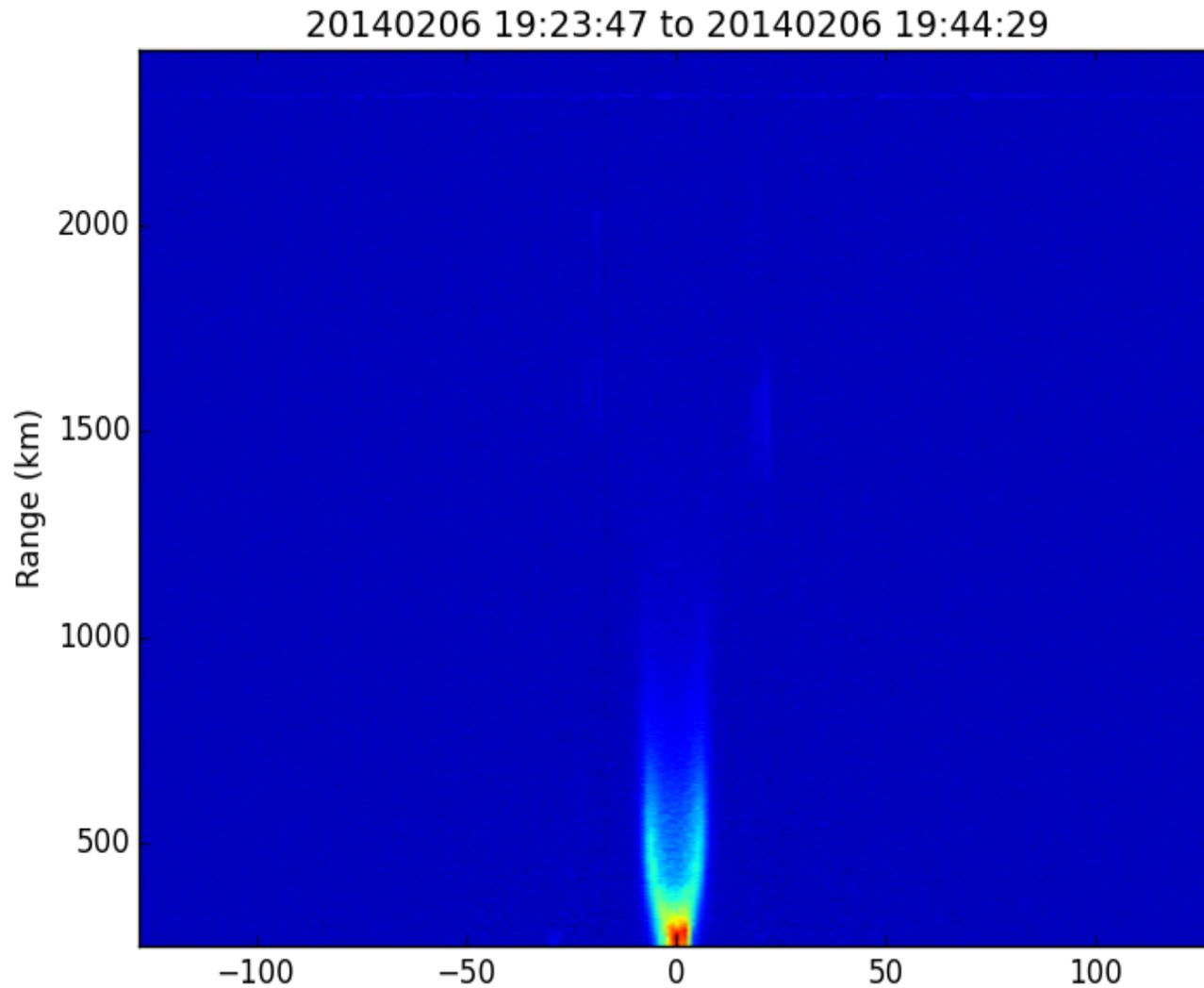
Noise Power for a 200 K receiver with a 500 kHz bandwidth:

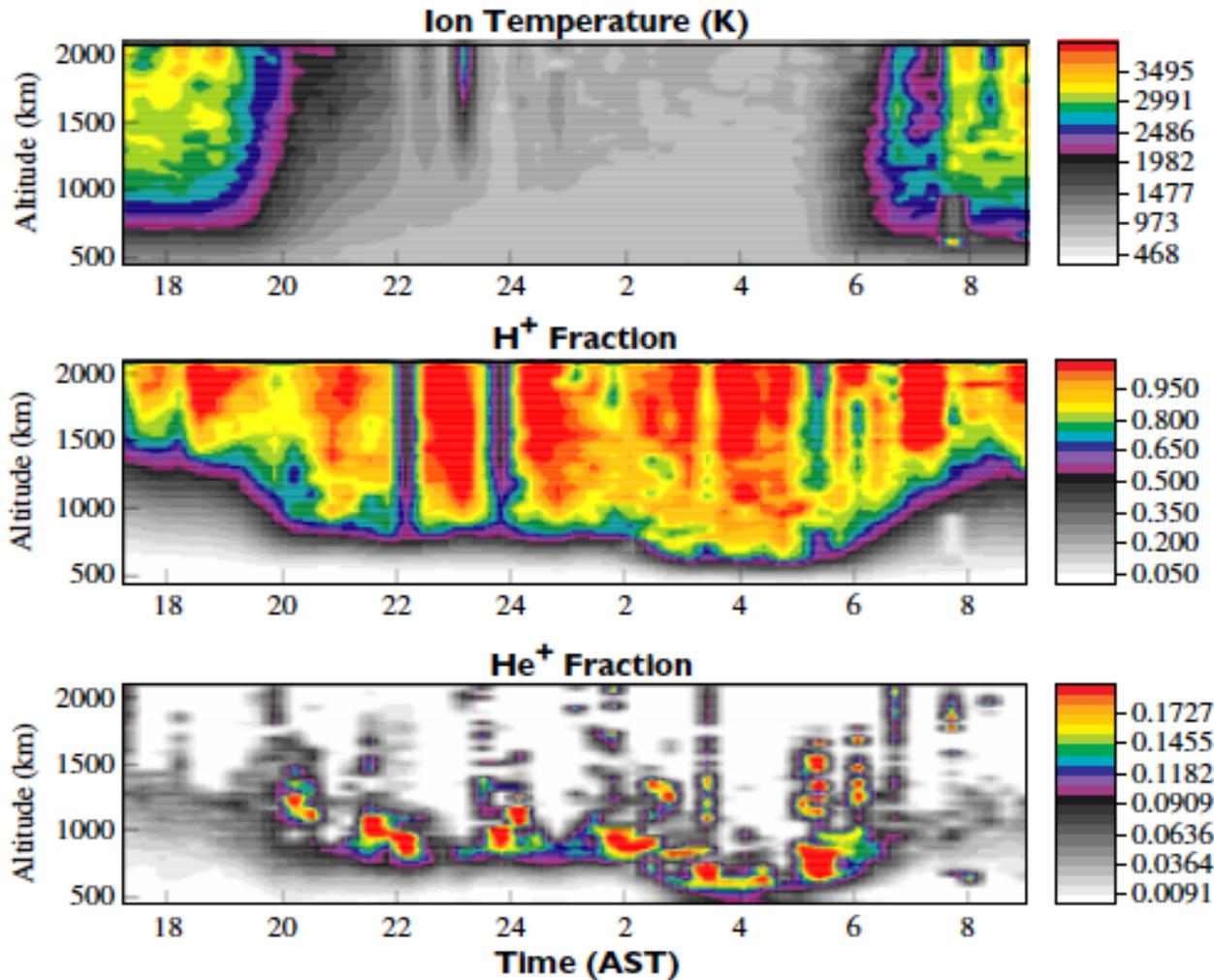$$N = k_B T_{sys} B = 1.4 \times 10^{-15} \text{W}$$

# Incoherent Scatter Radar

# Incoherent Scatter Radar



20140206 19:23:47 to 20140206 19:44:29

# Incoherent Scatter Radar



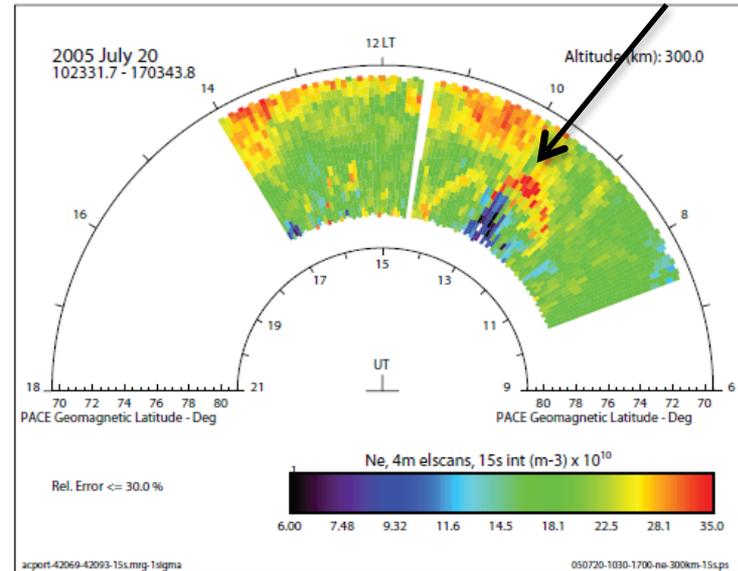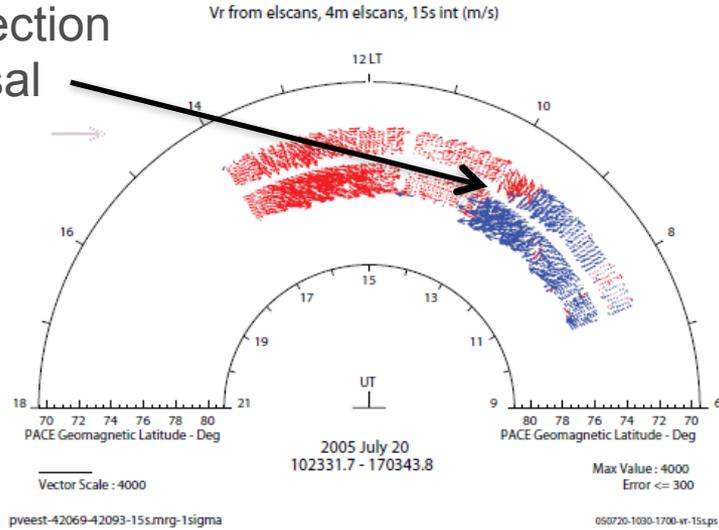The Topside Ionosphere at Arecibo, March 17-18, 1994

# Sondrestrom

**Influx of particles and Joule heating (due to current flow)**
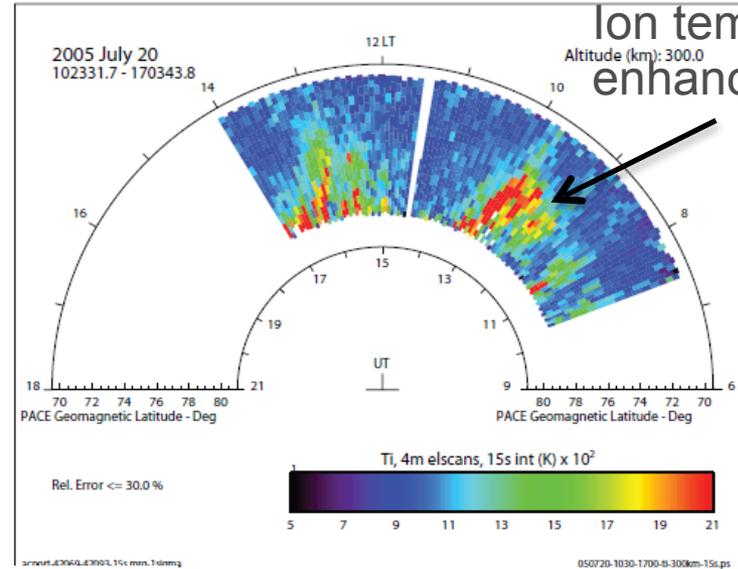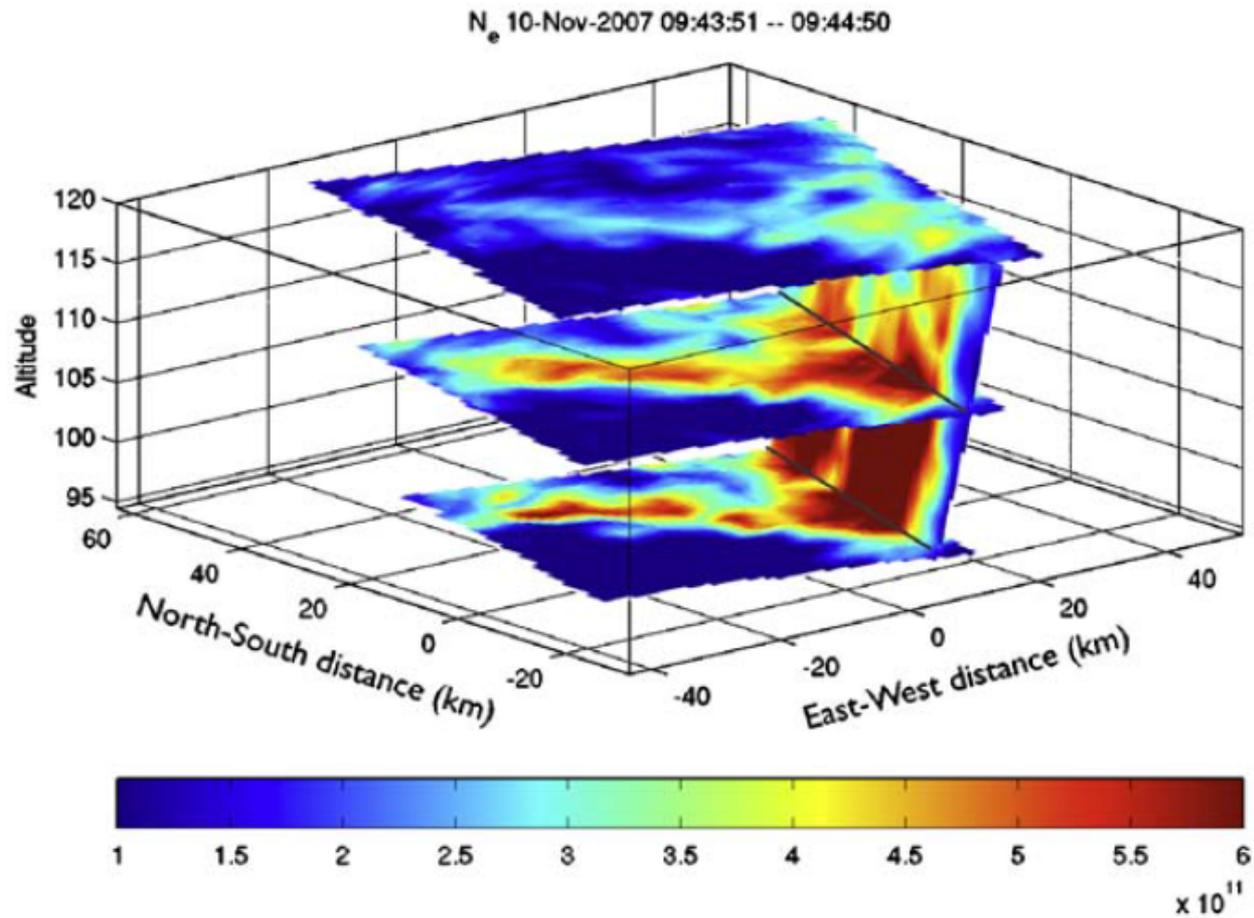
**Electron density enhancement**

**Convection reversal**



Vr from elscans, 4m elscans, 15s int (m/s)

2005 July 20
102331.7 - 170343.8

Vector Scale : 4000

Max Value : 4000
Error <= 300



2005 July 20
102331.7 - 170343.8

Altitude (km): 300.0

Rel. Error <= 30.0 %

Ne, 4m elscans, 15s int (m-3) x $10^{10}$

6.00   7.48   9.32   11.6   14.5   18.1   22.5   28.1   35.0

**Ion temperature enhancement**



2005 July 20
102331.7 - 170343.8

Altitude (km): 300.0

Rel. Error <= 30.0 %

Te, 4m elscans, 15s int (K) x $10^2$

14.0   16.5   19.0   21.5   24.0   26.5   29.0   31.5   34.0

**Electron temperature enhancement**



2005 July 20
102331.7 - 170343.8

Altitude (km): 300.0

Rel. Error <= 30.0 %

Ti, 4m elscans, 15s int (K) x $10^2$

5   7   9   11   13   15   17   19   21

# Incoherent Scatter Radar



N$_e$ 10-Nov-2007 09:43:51 -- 09:44:50
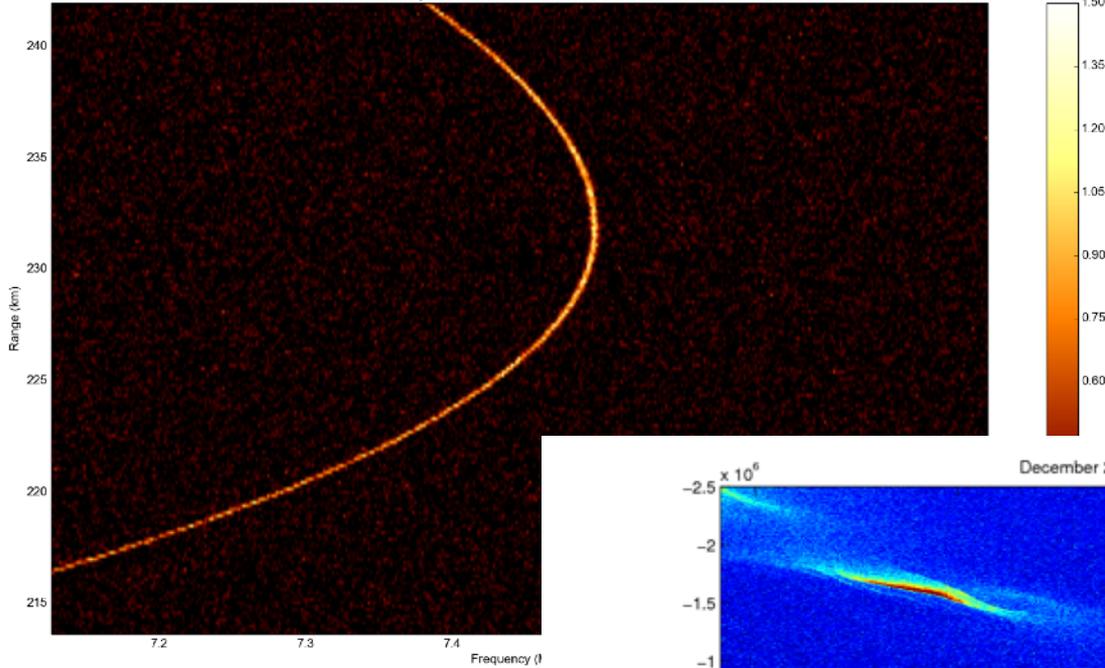
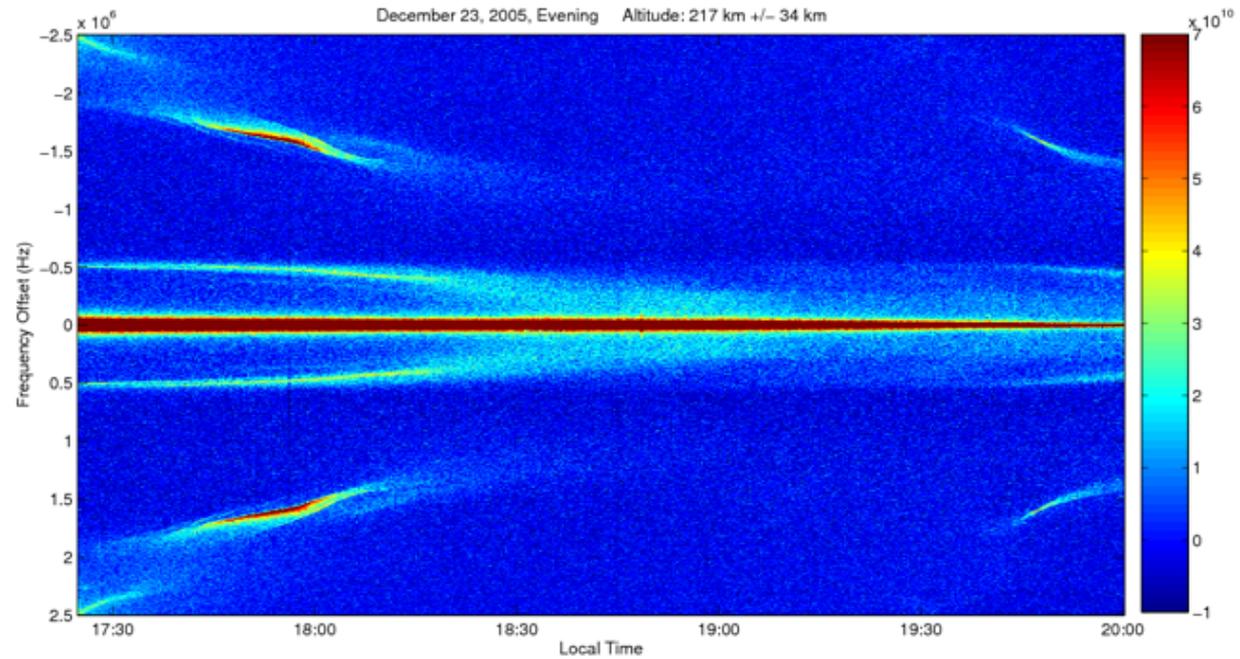# Incoherent Scatter Radar



Typical D-region Spectra

# Incoherent Scatter Radar



Arecibo plasma line 2015-01-25 12:02:17 UTC

December 23, 2005, Evening    Altitude: 217 km +/- 34 km

Juha Vierinen
Asti Bhatt

# Literature

- Brekke, A.: Physics of the Upper Atmosphere, John Wiley & Sons, 1997.
- Hunsucker, R. D. and J.K. Hargreaves, The High-Latitude Ionosphere and its Effects on Radio Propagation, Cambridge University Press, 2003
- Kelley, M. C.: The Earth's Ionosphere, Academic Press, 1989
- H. Risbeth and O. K. Garriot: Introduction to Ionospheric Physics, Academic Press, 1969
- Hargreaves, J. K., The solar-terrestrial environment, Cambridge University Press, 1992.