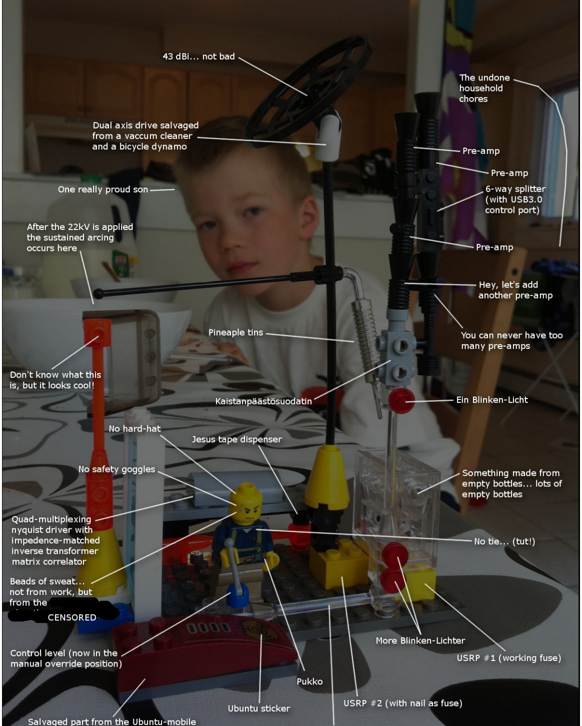


43 dBi... not bad
The undone household chores
Dual axis drive salvaged from a vaccum cleaner and a bicycle dynamo
Pre-amp
Pre-amp
6-way splitter (with USB3.0 control port)
One really proud son
After the 22kV is applied the sustained arcing occurs here
Pre-amp
Hey, let's add another pre-amp
You can never have too many pre-amps
Pineaple tins
Don't know what this is, but it looks cool!
Kaistanpäästösuodatin
Ein Blinken-Licht
No hard-hat
Jesus tape dispenser
No safety goggles
Something made from empty bottles... lots of empty bottles
Quad-multiplexing nyquist driver with impedence-matched inverse transformer matrix correlator
No tie... (tut!)
Beads of sweat... not from work, but from the [redacted] CENSORED
More Blinken-Lichter
USRP #1 (working fuse)
Control level (now in the manual override position)
Pukko
Ubuntu sticker
USRP #2 (with nail as fuse)
Salvaged part from the Ubuntu-mobile

ISR Spectrum – and some other less often mentioned things you can do with high power large aperture radars

Juha Vierinen

MIT Haystack Observatory

July 24, 2015

Full ISR spectrum

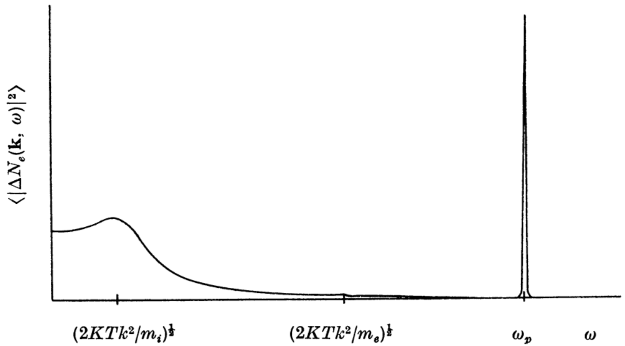


FIGURE 2. Diagrammatic sketch (not to scale) of the spectrum of the thermal density fluctuations of the electrons in a collision-less plasma over the whole range of frequencies.

From Dougherty and Farley (1960). Enhancement explained by Yngvesson and Perkins (1968).

Plasma line

Plasma resonance frequency f_r is to first order a function of plasma frequency f_p, wave number k, electron temperature T_e, electron mass m_e, electron gyrofrequency f_c and magnetic field aspect angle α:

$$f_r^2 = f_p^2 + \frac{3k^2}{4\pi^2}\frac{k_b T_e}{m_e} + f_c^2 \sin^2\alpha \tag{1}$$

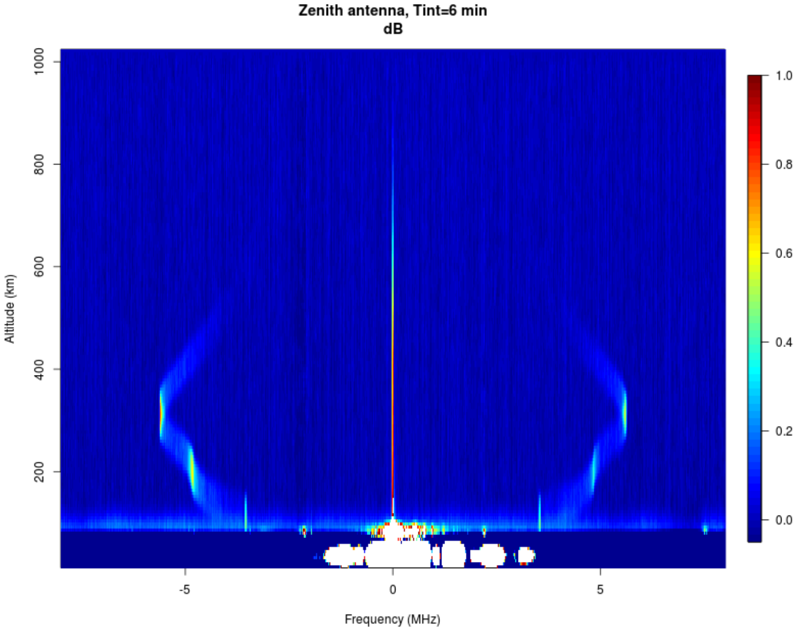
Plasma line power:

$$T_p(v_\phi) = T \frac{f_m(v_\phi) + f_p(v_\phi) + \chi}{f_m(v_\phi) - KT \frac{d}{dE_\phi} f_p(v_\phi) + \chi} \tag{2}$$

(Yngvesson and Perkins, 1968)

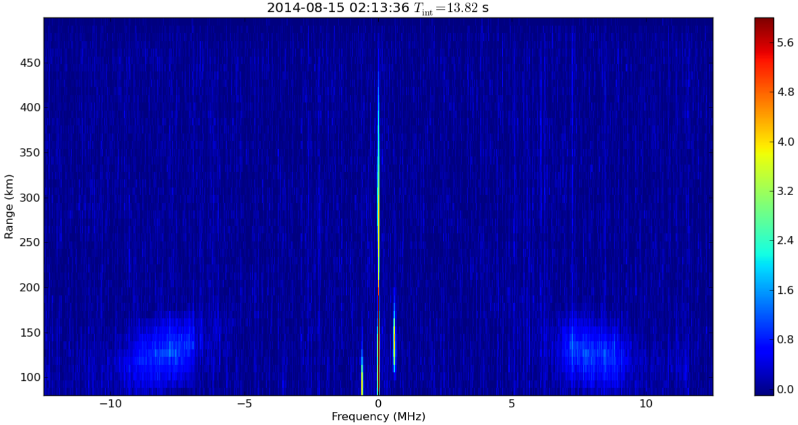
Haystack plasma lines

Haystack plasma lines



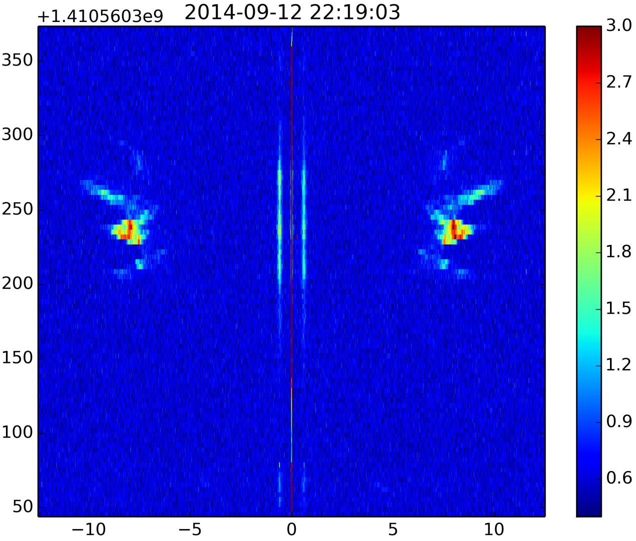
Haystack plasma lines

Sondestrom auroral enhancement of plasma lines



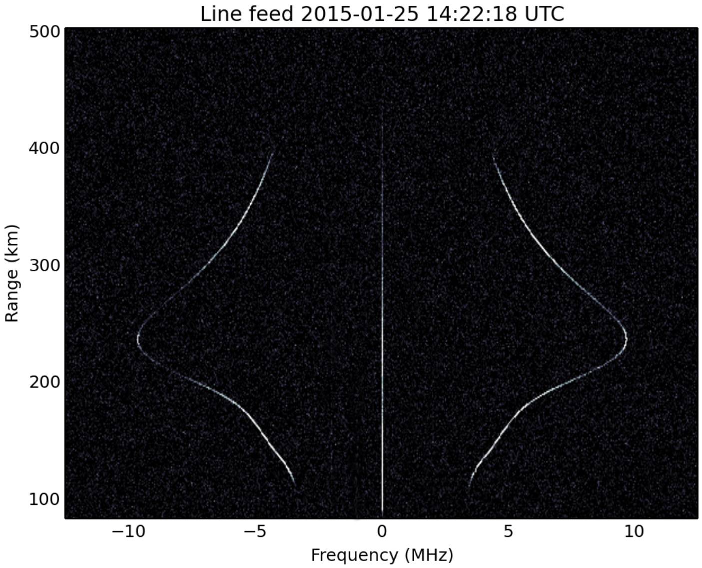
(Valladares 1988; Heinselman and Vickrey 1992; Showen 1995)

Sondestrom plasma lines

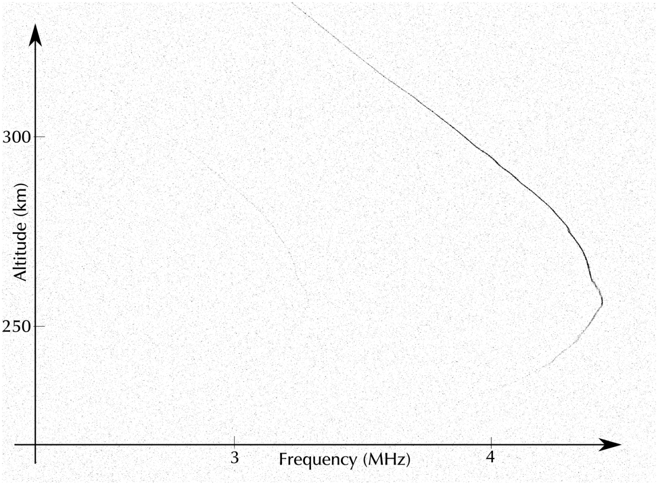


Arecibo plasma lines

Arecibo plasma lines

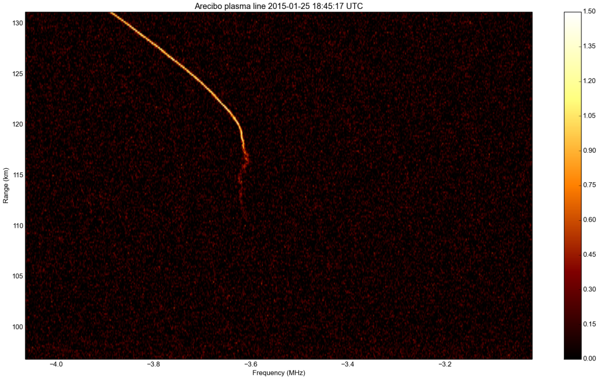


Arecibo plasma lines

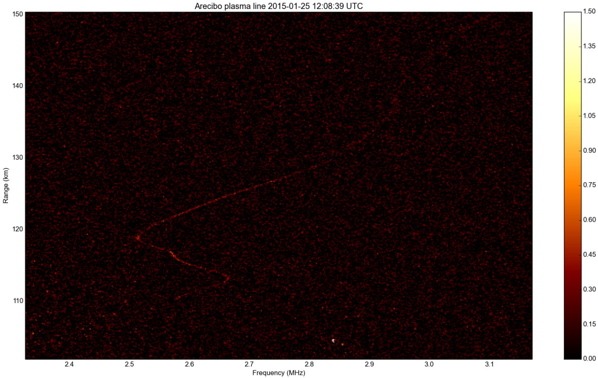


150 meter range resolution, 1 kHz frequency resolution, 20 second time resolution.

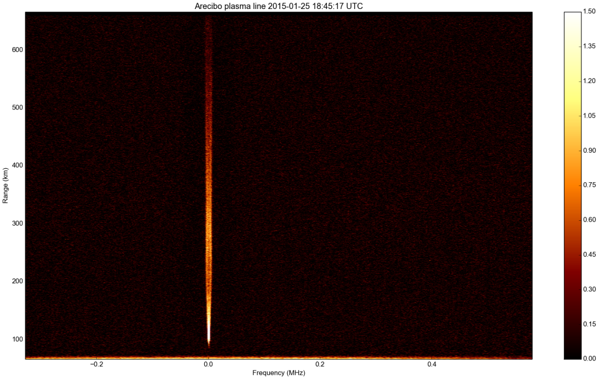
Arecibo plasma line, turbopause



E-region waves

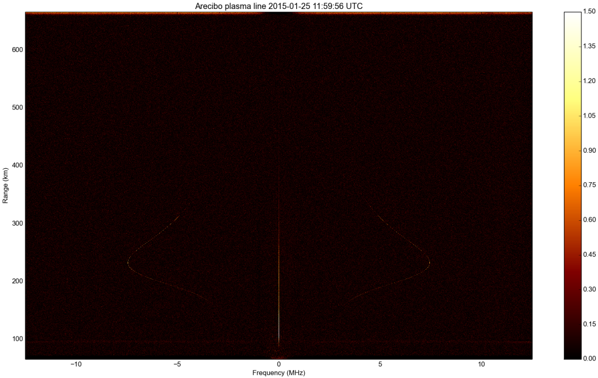


Ion line

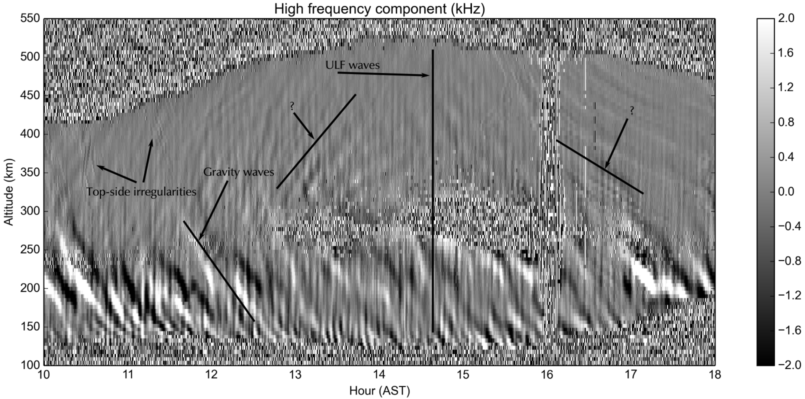


Arecibo plasma line 2015-01-25 18:45:17 UTC
Range (km)
600
500
400
300
200
100
−0.2
0.0
0.2
0.4
Frequency (MHz)
1.50
1.35
1.20
1.05
0.90
0.75
0.60
0.45
0.30
0.15
0.00

Full ISR spectrum

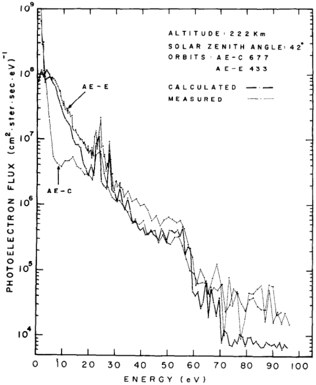


Ionospheric waves



(Ganguly and Behnke 1982; Sulzer 1986; Djuth 1997; Dyrud et.al., 2008)

Plasma line power



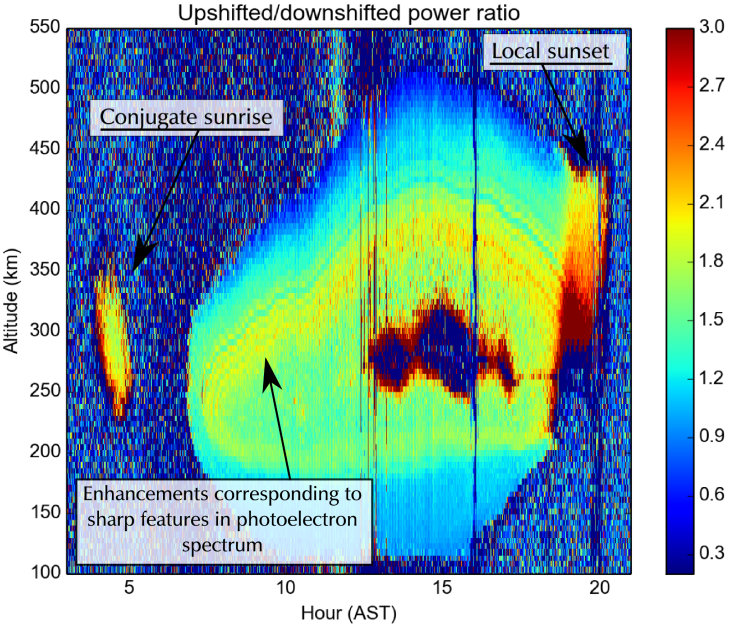
(Hernandez et.al., 1983)

$$T_p(v_\phi) = T \frac{f_m(v_\phi) + f_p(v_\phi) + \chi}{f_m(v_\phi) - KT \frac{d}{dE_\phi} f_p(v_\phi) + \chi} \tag{3}$$

(Yngvesson and Perkins, 1968)

Conjugate flow of photoelectrons

Upshifted/downshifted power ratio



T_e and v_e from plasma lines

Plasma resonance frequency f_r is to first order a function of plasma frequency f_p, wave number k, electron temperature T_e, electron mass m_e, electron gyrofrequency f_c and magnetic field aspect angle α:

$$f_r^2 = f_p^2 + \frac{3k^2}{4\pi^2}\frac{k_b T_e}{m_e} + f_c^2 \sin^2\alpha \qquad (4)$$

Up and down shifted wavenumbers:

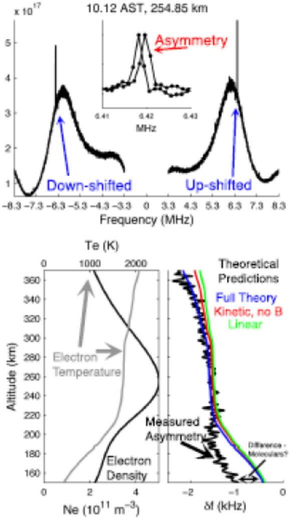
$$k_\pm = \frac{2\pi}{c}[f_0 + (f_0 \pm f_f)] \qquad (5)$$

Because of slightly different wave numbers:

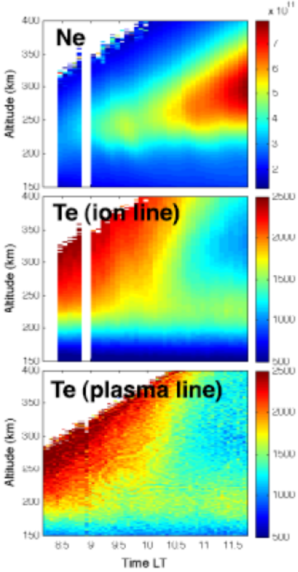
$$\delta f = f_{r-} - f_{r+} \approx \frac{f_0}{c}\left(4v_e - \frac{12k_b T_e}{cm_e}\right) \qquad (6)$$

High Resolution Plasma Line and Asymmetry

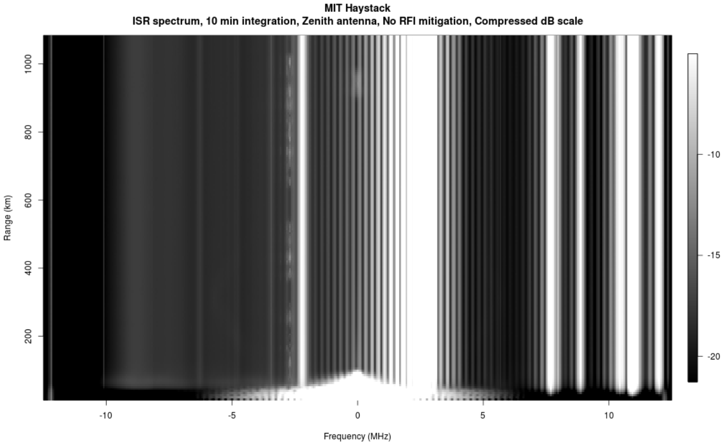
Using the asymmetry of the up- and down-shifted plasma lines, we can obtain an independent, high resolution measurement of T_e



Nicolls et al., GRL, 2006



Radio frequency interference (RFI)

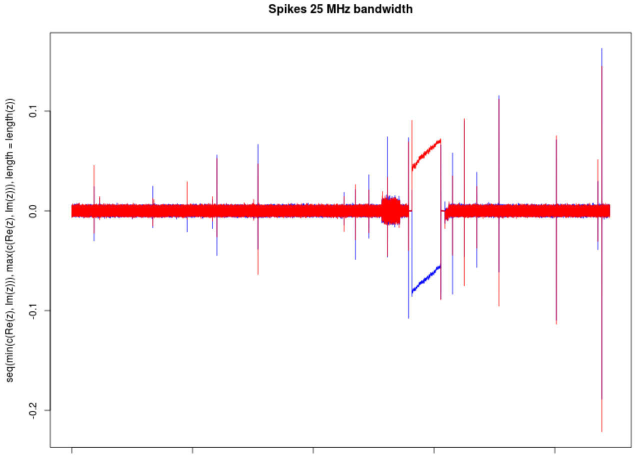


RFI mitigation, outlier detection (1/2)

Estimate the variance of raw voltage samples using median.

$$\hat{\sigma_z}^2 = \left(\frac{9}{7}\right)^3 \mathrm{median}(|z_t|^2) \quad (7)$$

Use threshold to detect outliers (eg., spikes in data).



RFI mitigation, sample variance estimation (2/2)

Range, time, and frequency dependent estimation of variance from measurements.

$$S'_{r,t',\omega} = \frac{1}{N-1}\sum_{t=0}^{N} S_{r,t+t'N,\omega} \tag{8}$$

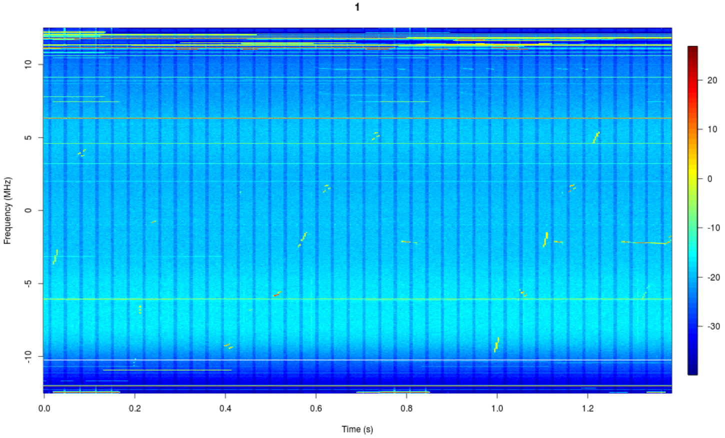
Intermediate range, time and frequency dependent sample variance estimate:

$$\hat{\sigma}^2_{r,t',\omega} = \frac{1}{N-1}\sum_{t=0}^{N} |S_{r,t+t'N,\omega}|^2 \tag{9}$$

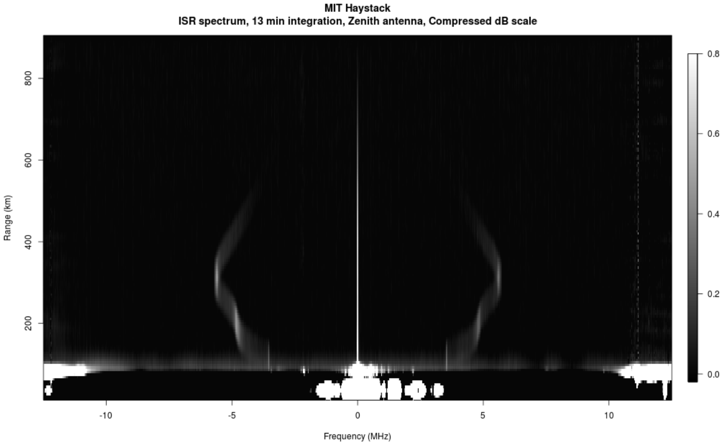
Now we can average the spectra at the output resolution using variance weighted averaging:

$$S''_{r,t'',\omega} = \frac{1}{\sum_{t'=0}^{M} \hat{\sigma}^{-2}_{r,t',\omega}}\sum_{t'=0}^{M} \frac{1}{\hat{\sigma}^2_{r,t',\omega}} S'_{r,t'+t''M,\omega} \tag{10}$$

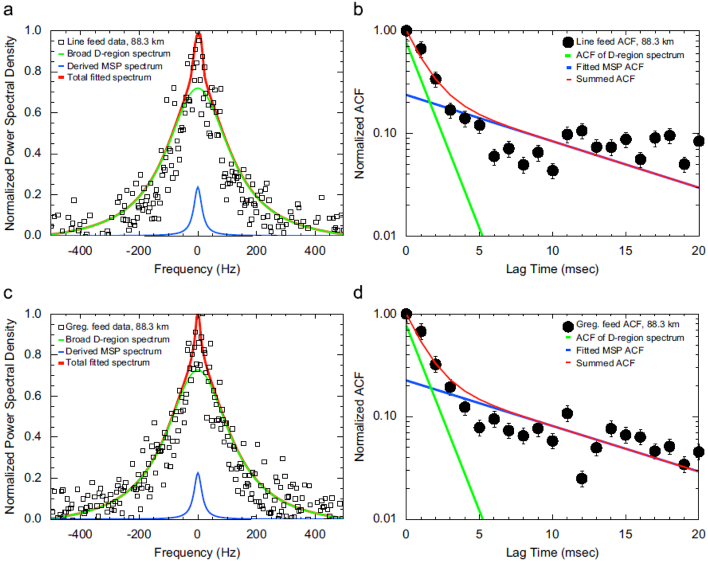
RFI


1
Frequency (MHz)
10
5
0
-5
-10
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Time (s)
20
10
0
-10
-20
-30

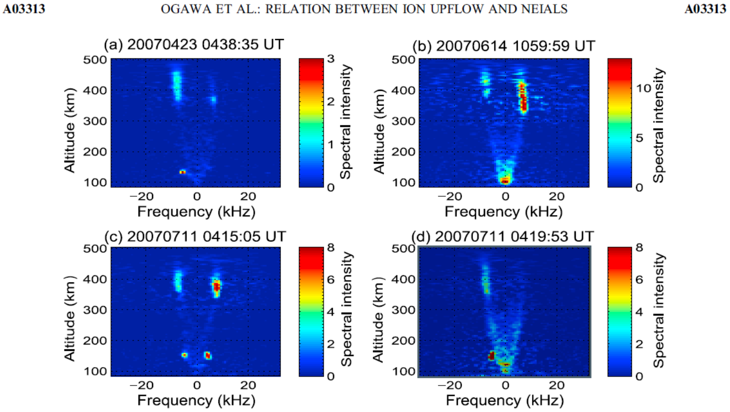
RFI


MIT Haystack
ISR spectrum, 13 min integration, Zenith antenna, Compressed dB scale
Range (km)
800
600
400
200
-10
-5
0
5
10
Frequency (MHz)
0.8
0.6
0.4
0.2
0.0

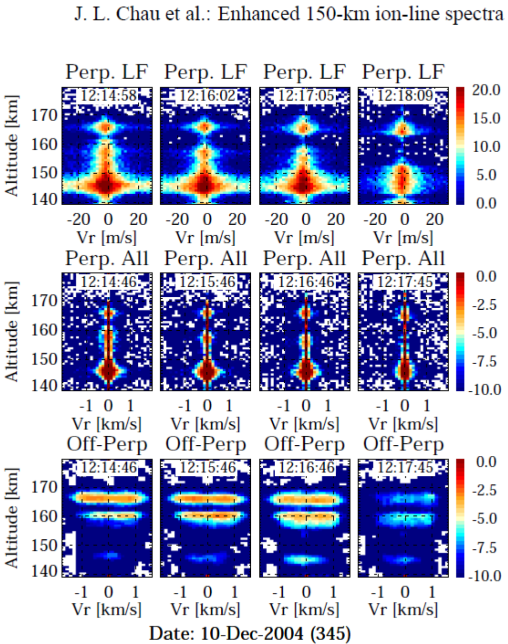
D-region, collisional dusty plasma, massive ions, smoke particles (Fentzke et al., 2009)



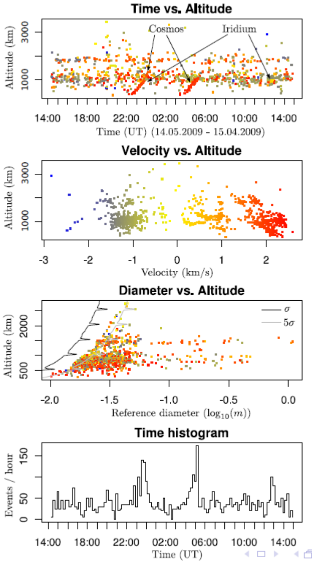
Naturally enhanced ion-acoustic lines (Ogawa et al 2011)



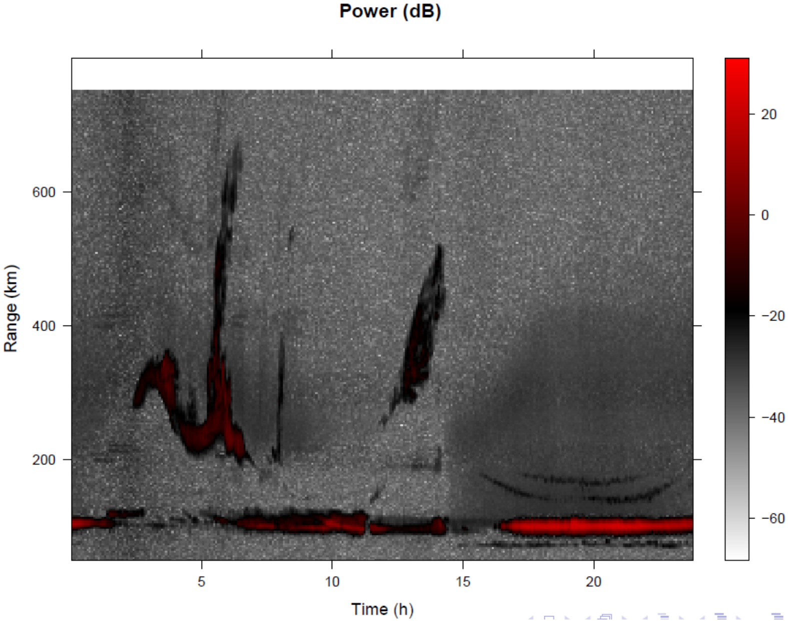
150 km echoes (Chau et al 200?)



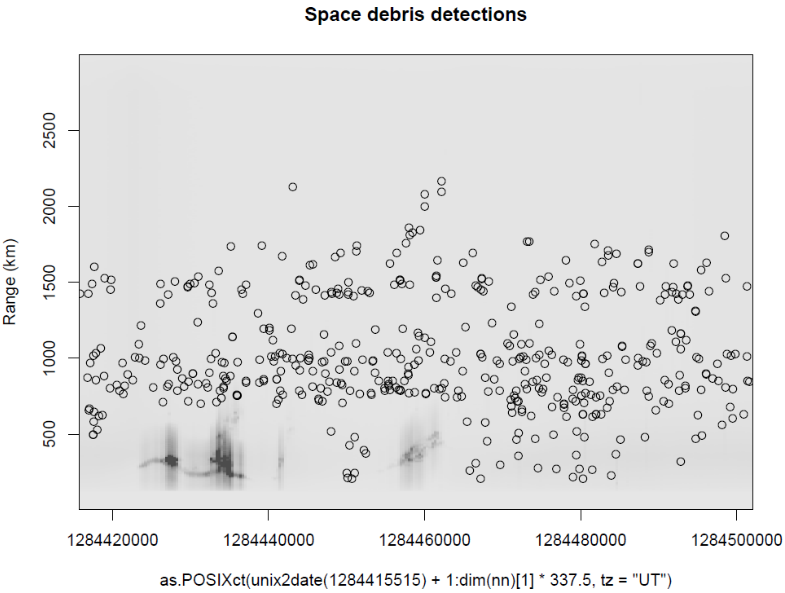
Space debris: EISCAT Iridium-Cosmos collision



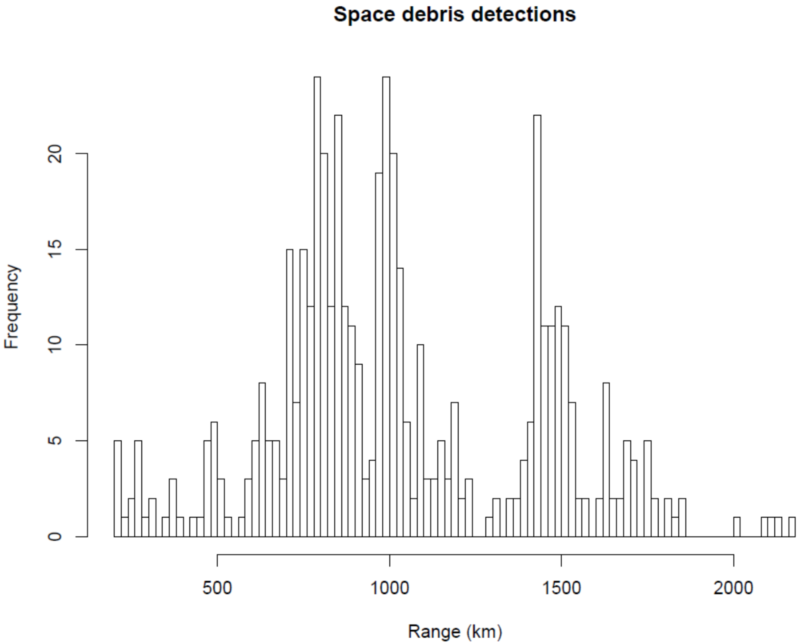
Space debris: Jicamarca



Space debris: Jicamarca



Space debris: Jicamarca



Meteors, meteor head echo

1802 *J. Kero et al.*

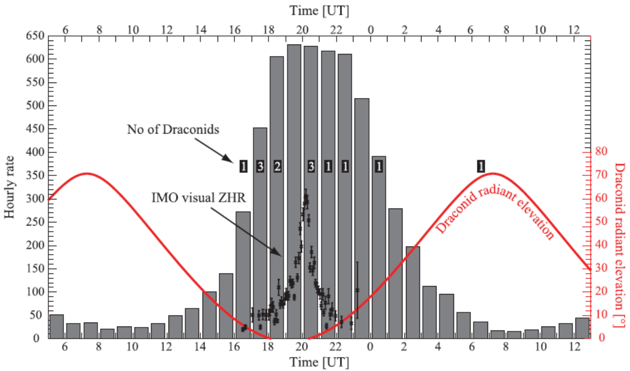
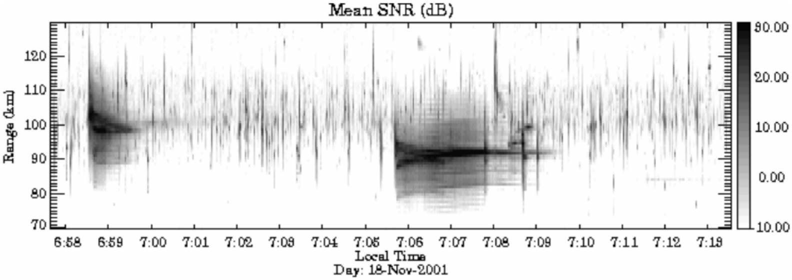
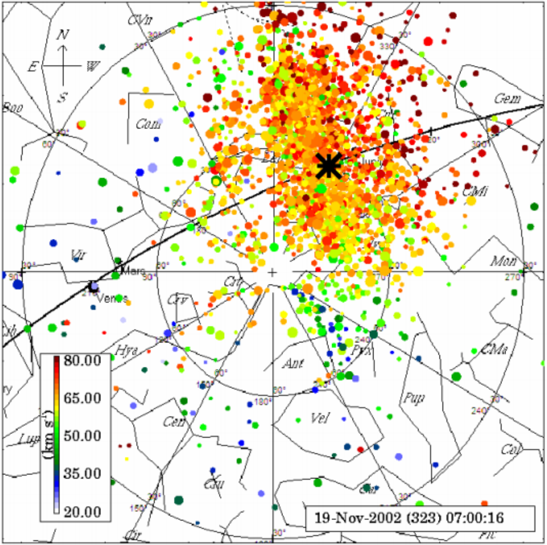


Figure 2. Histogram of the hourly meteor detection rate and the number of observed Draconids during the MU radar observation from 2011 October 8 05:00 UT to October 9 13:00 UT. The elevation of the Draconid radiant (red) peaks at ∼70° around 7 UT. The error bars show the ZHR calculated by G. Barentsen from 2164 visually observed Draconids collected by the IMO.

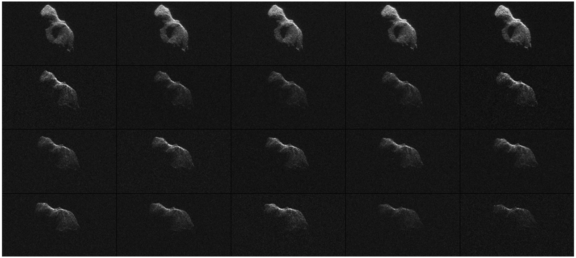
Meteors, meteor head echo



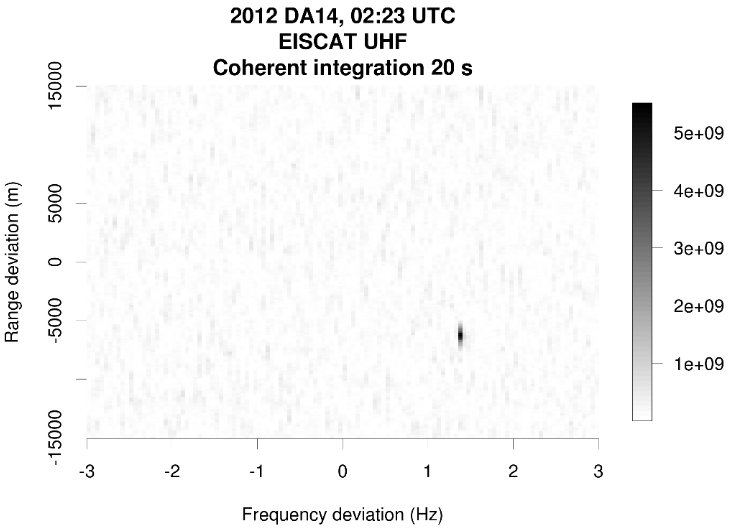
Meteors, meteor head echo



Asteroids



Asteroids


2012 DA14, 02:23 UTC
EISCAT UHF
Coherent integration 20 s
Range deviation (m)
15000
5000
0
-5000
-15000
Frequency deviation (Hz)
-3
-2
-1
0
1
2
3
5e+09
4e+09
3e+09
2e+09
1e+09

Moon 930 MHz