Experiment Guide (Sondrestrom)

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Experiment Design and Analysis Exercise

- We have timeslots 1.5 hours long available for each group at the Sondrestrom Radar.

Each group that wants to use Sondrestrom should :

- Discuss and decide on a science topic you want to study within the limitations of experiment design for the school.
- Decide what mode and antenna positions to run to accomplish your science goals.
- Write a request for radar time and send it to Anja and Craig.
- Get the request approved by one of the advisors.
- Run your experiment tonight…

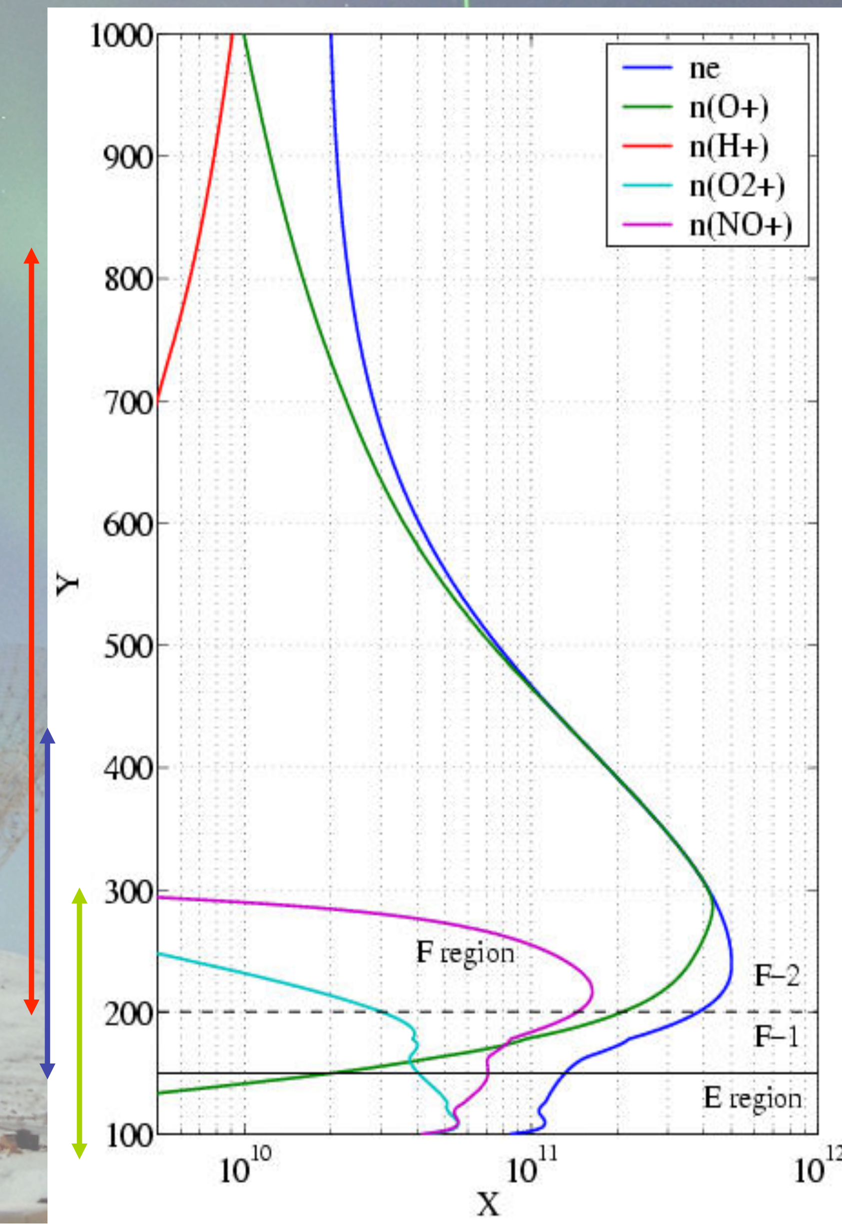
Experiment specifics:

Three different pulse schemes are available for use with Sondrestrom (for the school):

Long Pulses - LP-(320μs) resulting in ~50 km resolution data between ~100-700 km

Alternating Codes - AC - (16 baud 20μs - 32 pulses) resulting in 3 km resolution between ~90-200 km

Barker Codes - BC - (13 baud 4μs) resulting in 0.6 km resolution between ~90-150 km



ISR Signal Strength

Differential received power

$$dP_r = \frac{P_T L \lambda^2 G_{TX}(\theta,\phi) G_{RX}(\theta',\phi') n_e(\theta,\phi,r)\sigma}{(4\pi)^3 r^4} dV$$

Assuming a narrow antenna beam and sufficiently short pulse

$$dV = \left(\frac{c\tau_P}{2}\right) r d\theta \cdot r \sin\theta \cdot d\phi$$

$$P_r(r) \approx \frac{P_T L \lambda^2 c\tau_P n_e(r)\sigma}{2(4\pi)^2 r^2} \frac{1}{4\pi} \iint G^2(\theta,\phi) \sin\theta \cdot d\theta \cdot d\phi$$

Defining the mean squared gain (backscatter gain) as

$$G_{BS} = \frac{1}{4\pi} \iint G^2(\theta,\phi) \sin\theta \cdot d\theta \cdot d\phi$$

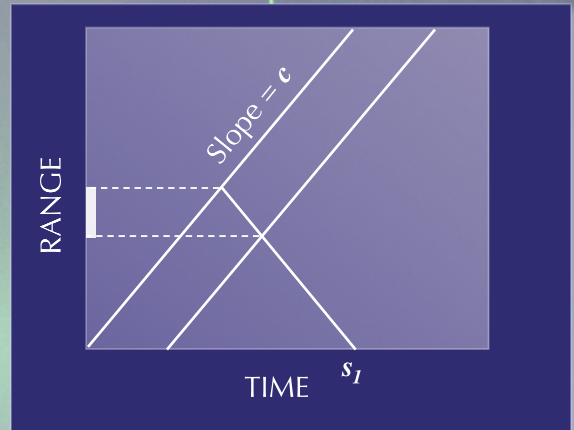
and from Hagen and Baumgartner (1996)

$$G_{BS} \approx C_{BS} \frac{4\pi A_{eff}}{\lambda^2}$$

$$P_r(r) \approx \frac{P_T L c\tau_P C_{BS} A_{eff} n_e(r)\sigma}{2(4\pi) r^2}$$

$$P_r(r) \approx \frac{P_T L c\tau_P C_{BS} A_{eff}}{8\pi r^2} \frac{n_e(r)\sigma_e}{\left(1 + k^2\lambda_D^2\right)\left(1 + k^2\lambda_D^2 + T_r\right)}$$

$$P_n = k_B T_{sys} BW$$



- P_T = transmitter peak power
- L = transmit feed line losses
- c = speed of light
- τ_P = transmit pulse duration
- C_{BS} = backscatter gain constant
- A_{eff} = antenna effective aperture
- n_e = electron number density
- σ_e = electron radar cross-section
- $k = {}^{2\pi}/_{\lambda}$ = radar wave number
- λ_D = plasma debye length
- T_r = electron to ion temperature ratio
- k_B = Boltzmann constant
- T_{sys} = system noise temperature
- BW = receiver bandwidth

v5A

Ambiguity Functions

- Based on the principle of a 'matched filter'
  - Output of the matched filter maximizes the attainable SNR when both signal and white noise are applied to the input
  - Impulse response is the complex conjugate of the time reversed version of the signal

$$h(t) = s^*(t_M - t)$$

$$H(f) = S^*(f)\exp(-j2\pi f t_M)$$

where

$h(t)$ is the impulse response of the matched filter

$s(t)$ is the signal to be detected

t_M is the measurement time

t, f are time and frequency

Ambiguity Functions

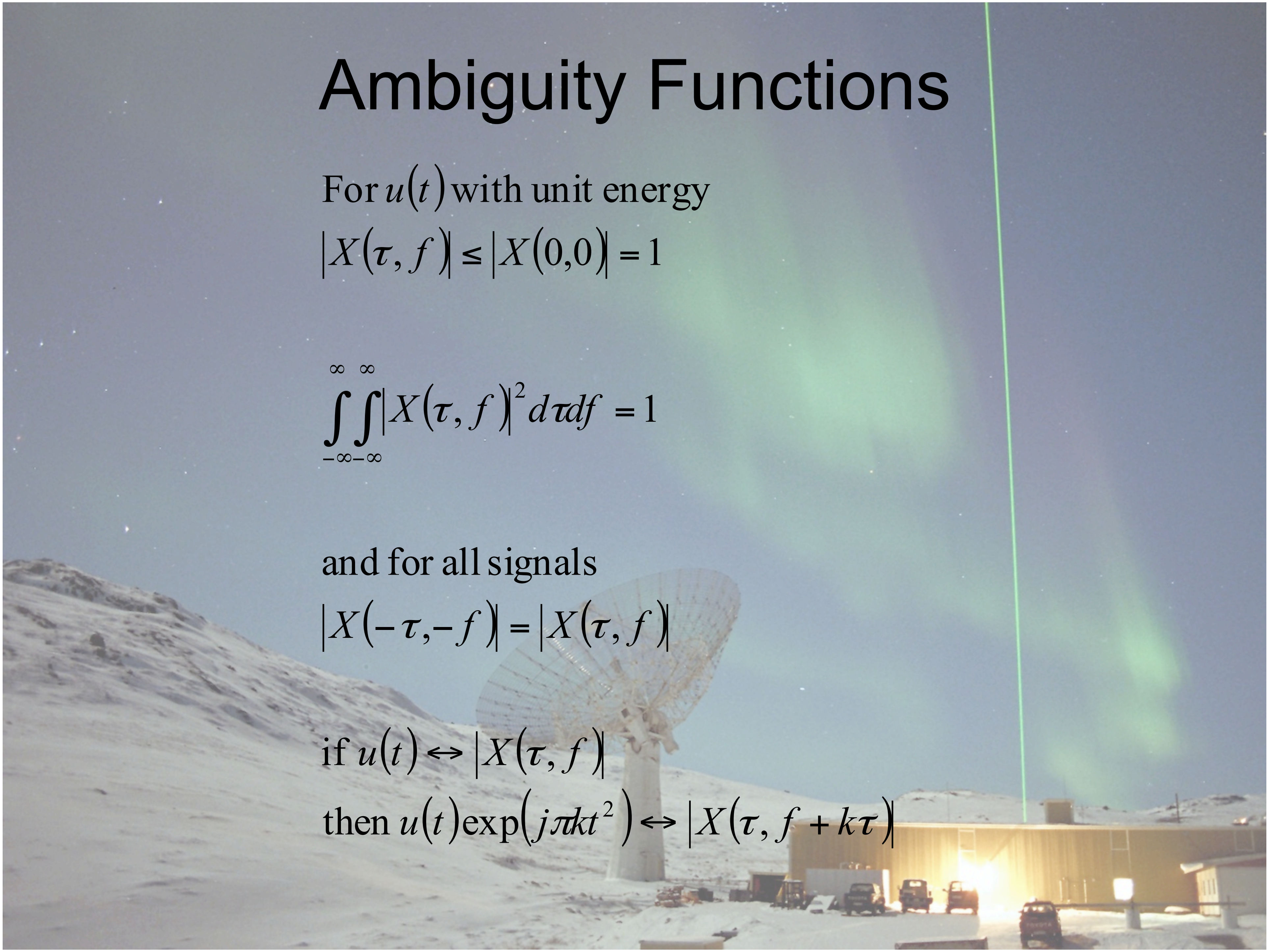
- The ambiguity function is defined as the absolute value of the envelope of the output of a matched filter when the input to the filter is a Doppler shifted version of the original signal

$$\left|X(\tau, f)\right| = \left|\int_{-\infty}^{\infty} u(t)u^*(t-\tau)\exp(j2\pi ft)dt\right|$$

$u(t)$ is the complex envelope of the signal

τ is the additional delay

f is the frequency shift (Doppler)



Ambiguity Functions

For $u(t)$ with unit energy

$$|X(\tau, f)| \le |X(0,0)| = 1$$

$$\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} |X(\tau, f)|^2 \, d\tau \, df = 1$$

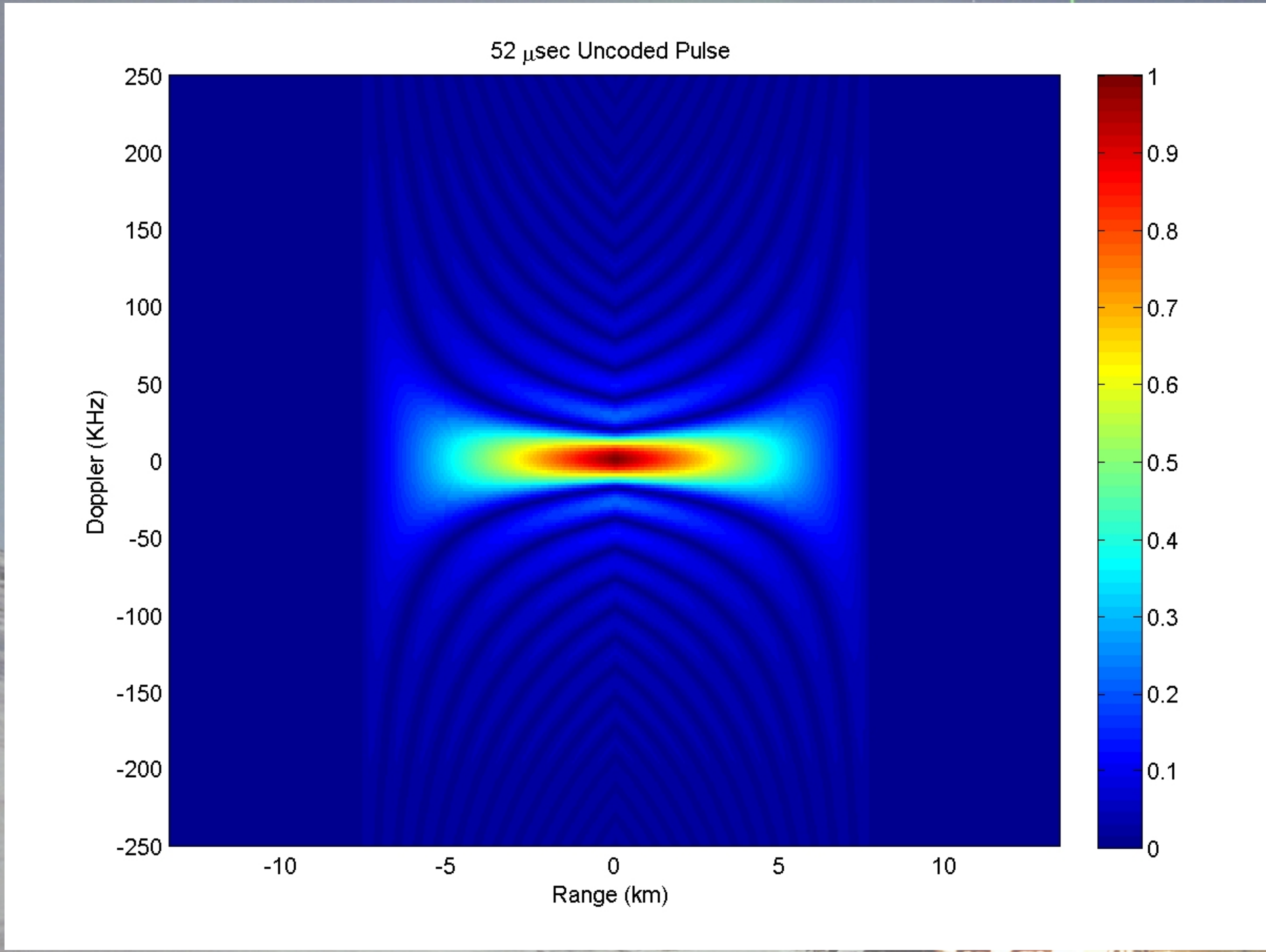
and for all signals

$$|X(-\tau, -f)| = |X(\tau, f)|$$

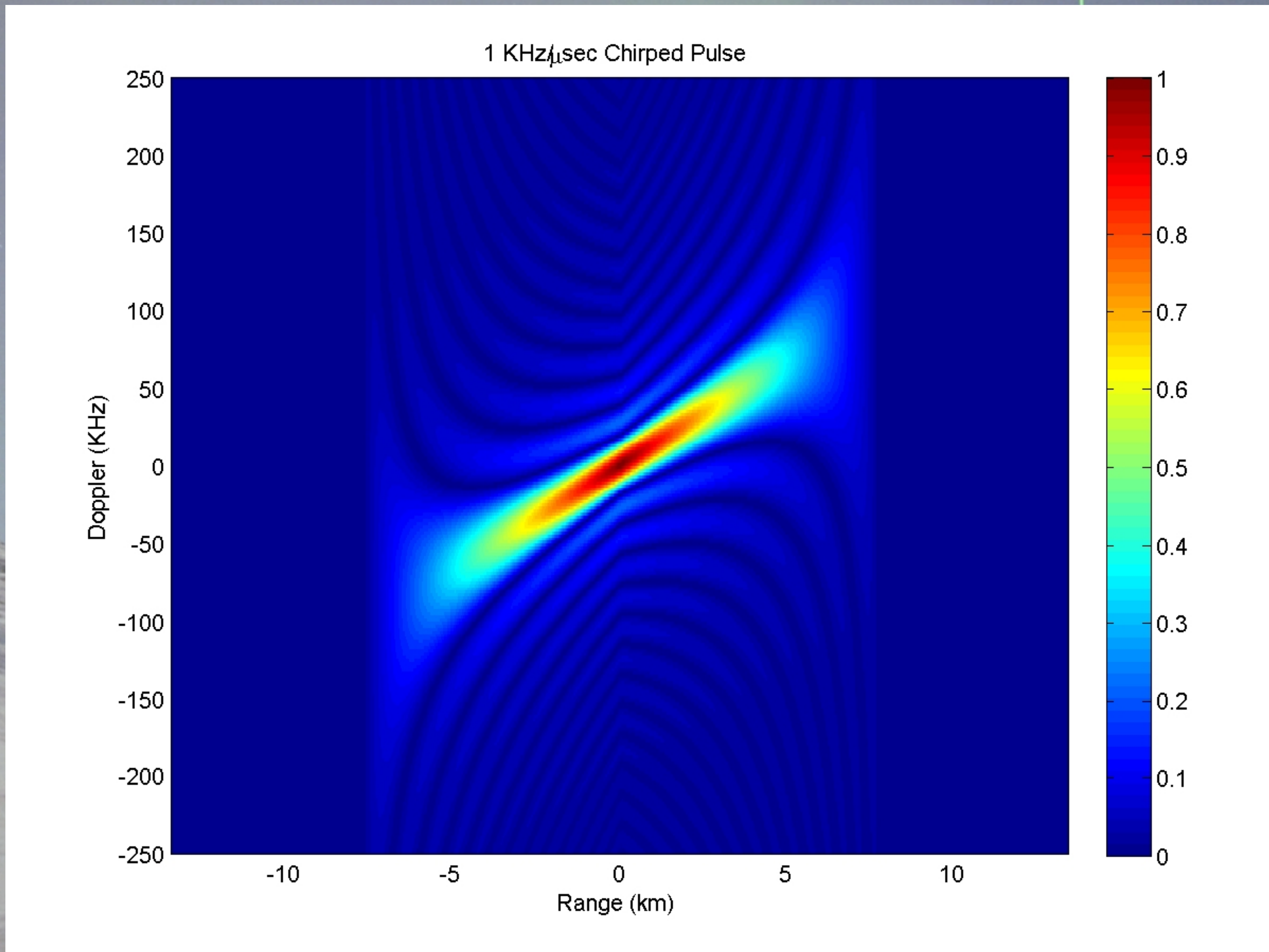
if $u(t) \leftrightarrow |X(\tau, f)|$

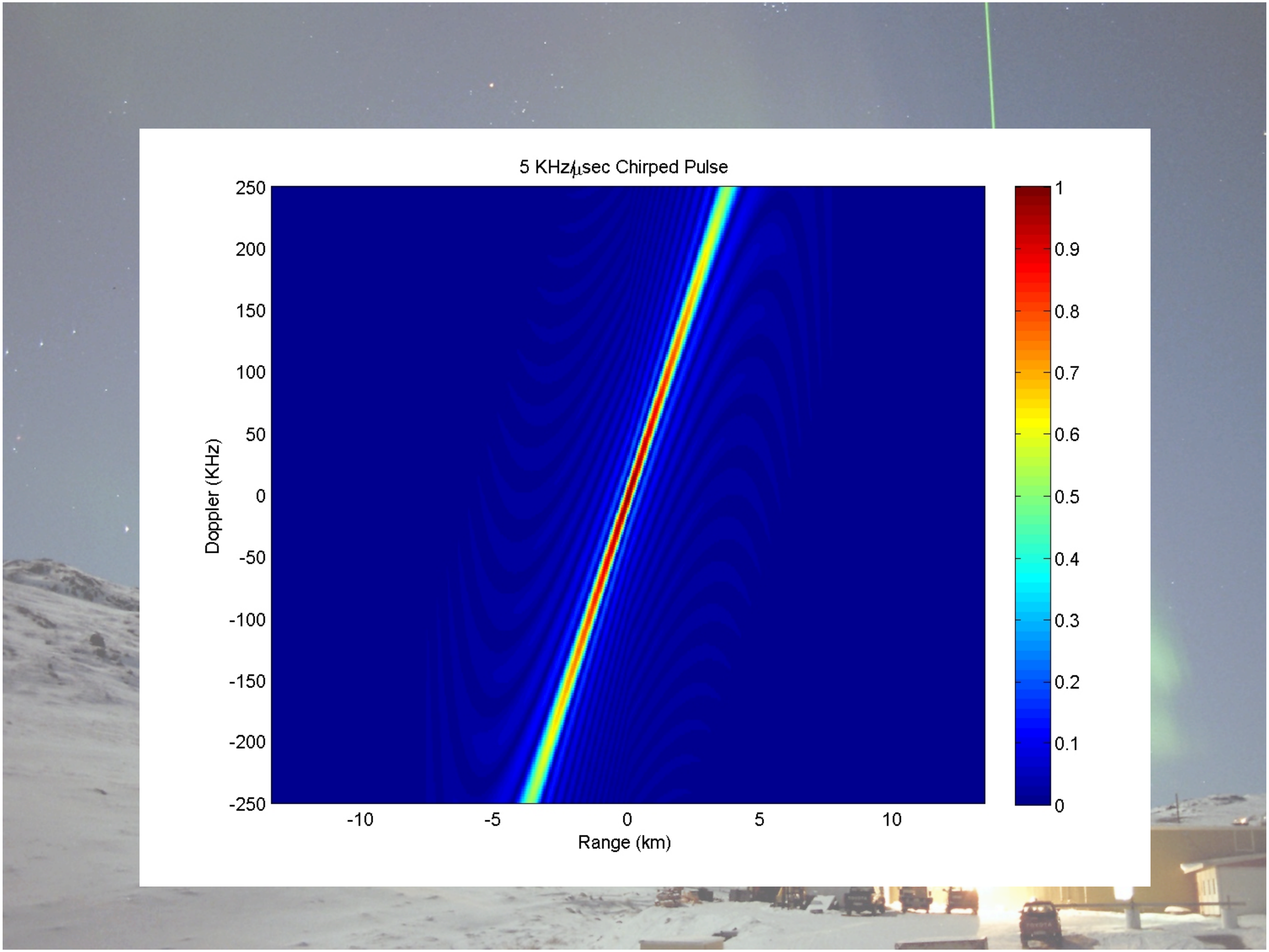
then $u(t)\exp\left(j\pi k t^2\right) \leftrightarrow |X(\tau, f + k\tau)|$

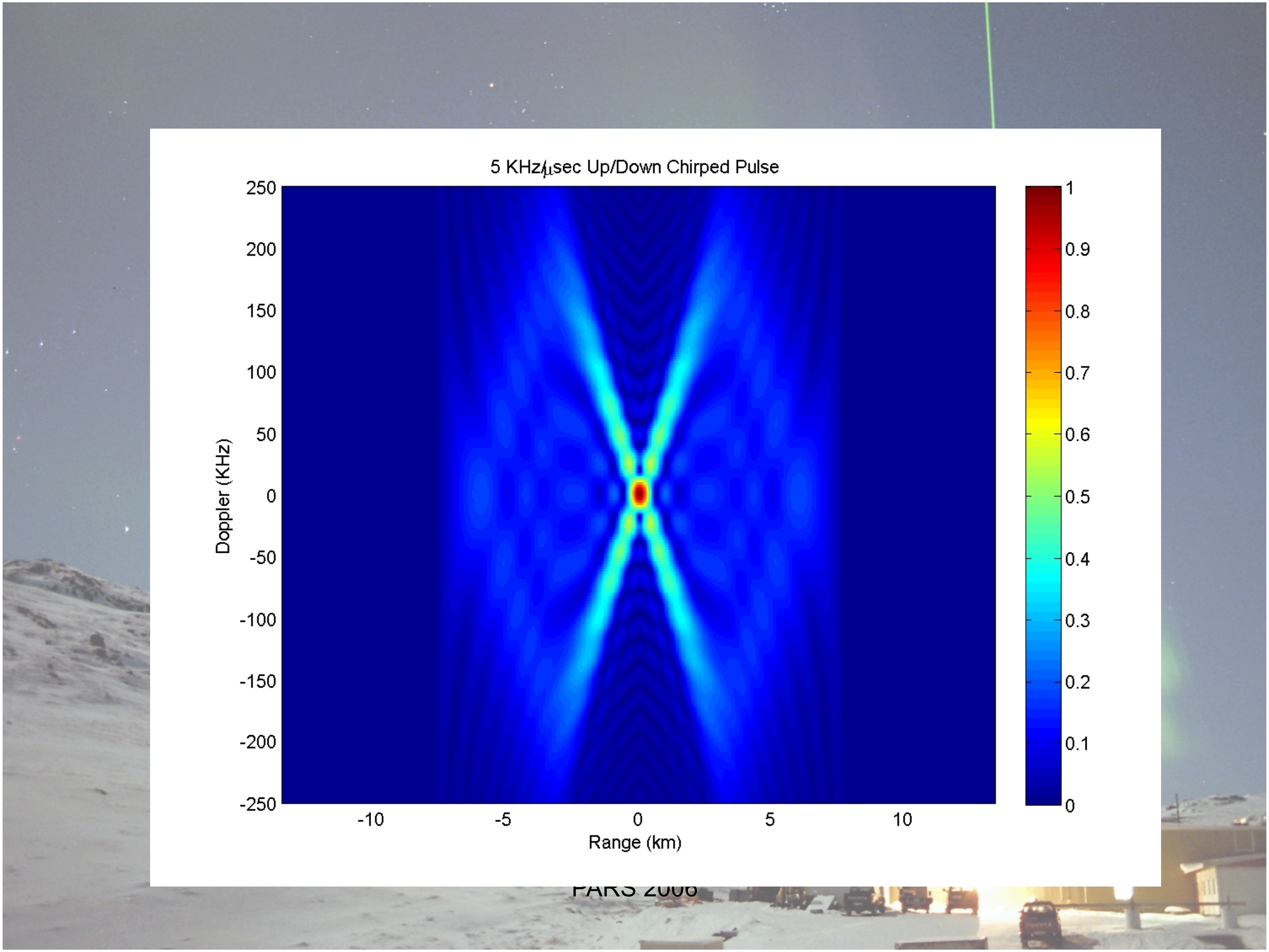
Ambiguity Function

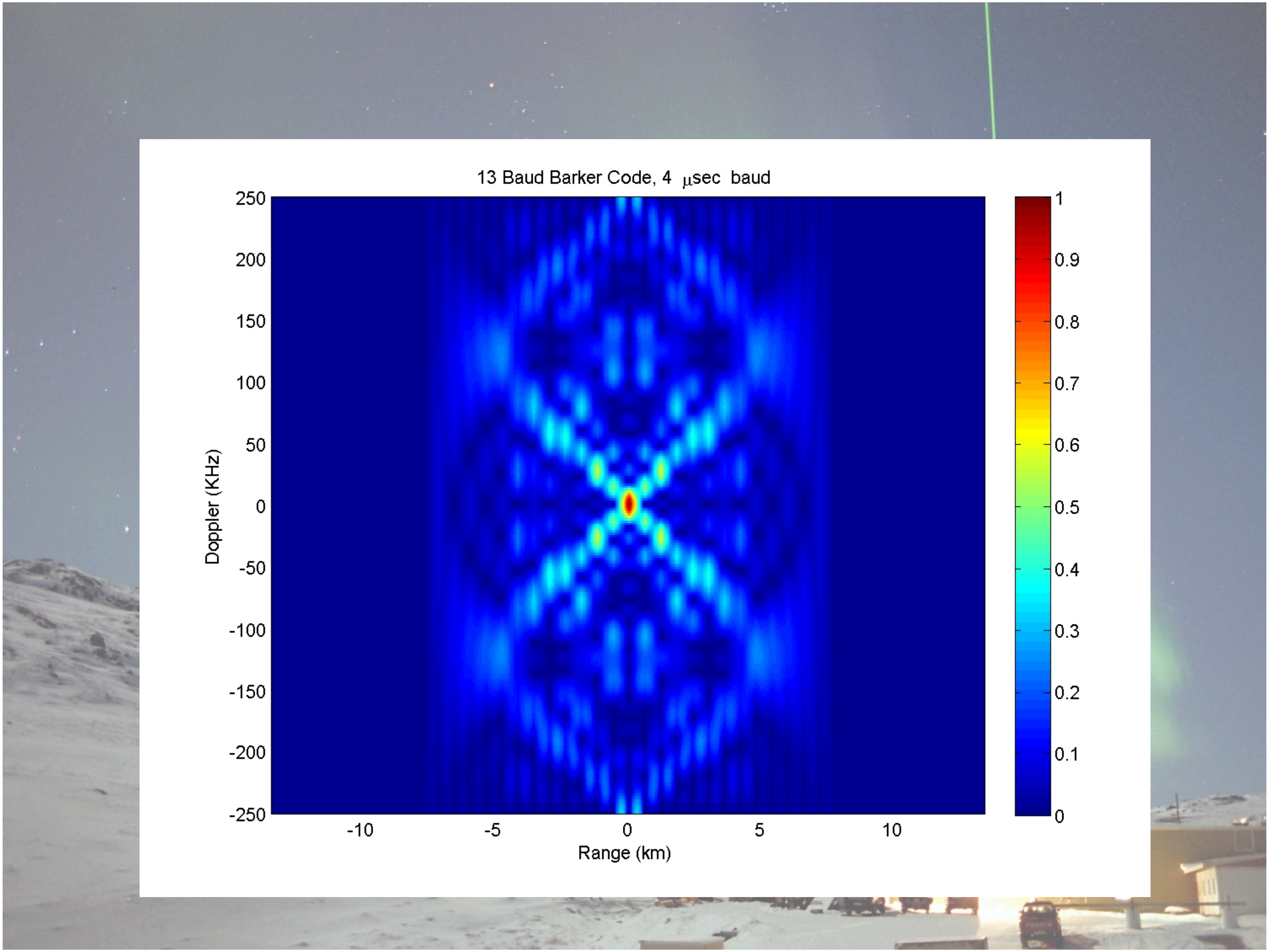


Ambiguity Function




5 KHz/μsec Chirped Pulse
Doppler (KHz)
250
200
150
100
50
0
-50
-100
-150
-200
-250
Range (km)
-10
-5
0
5
10
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0


5 KHz/μsec Up/Down Chirped Pulse
Doppler (KHz)
250
200
150
100
50
0
-50
-100
-150
-200
-250
-10
-5
0
5
10
Range (km)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

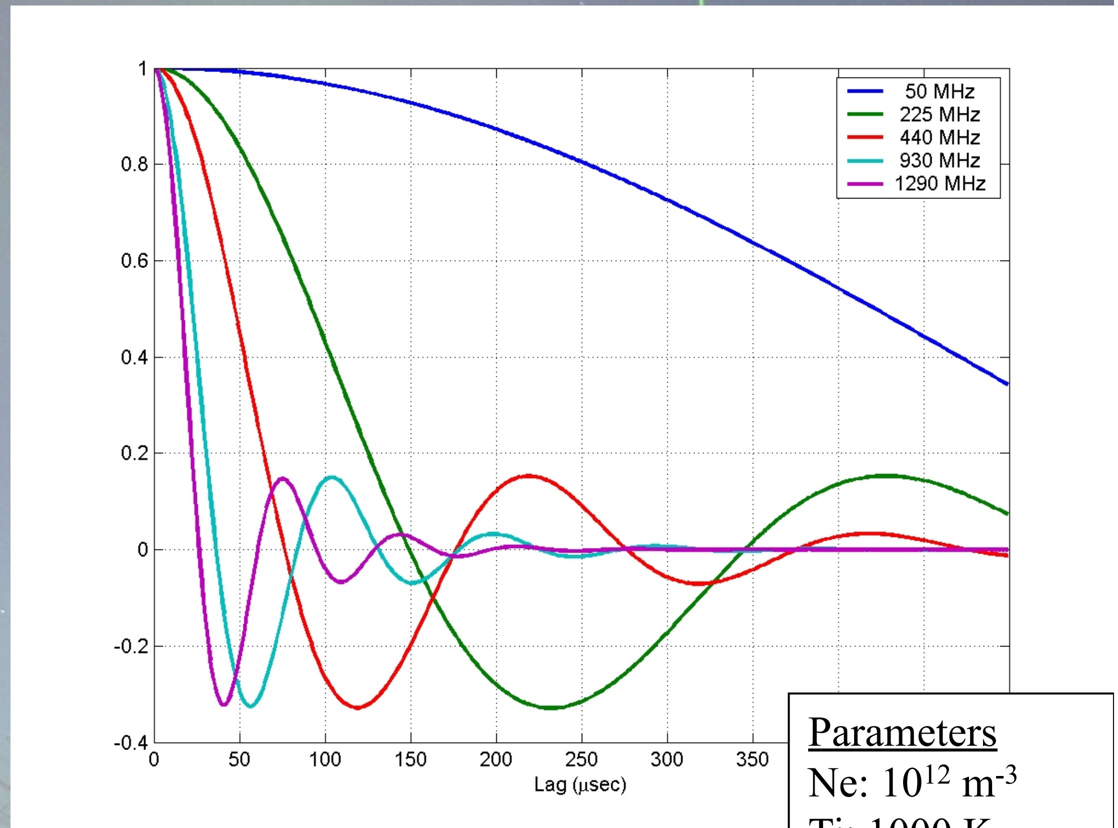

13 Baud Barker Code, 4 μsec baud
Doppler (KHz)
250
200
150
100
50
0
-50
-100
-150
-200
-250
-10
-5
0
5
10
Range (km)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

Incoherent Scattering

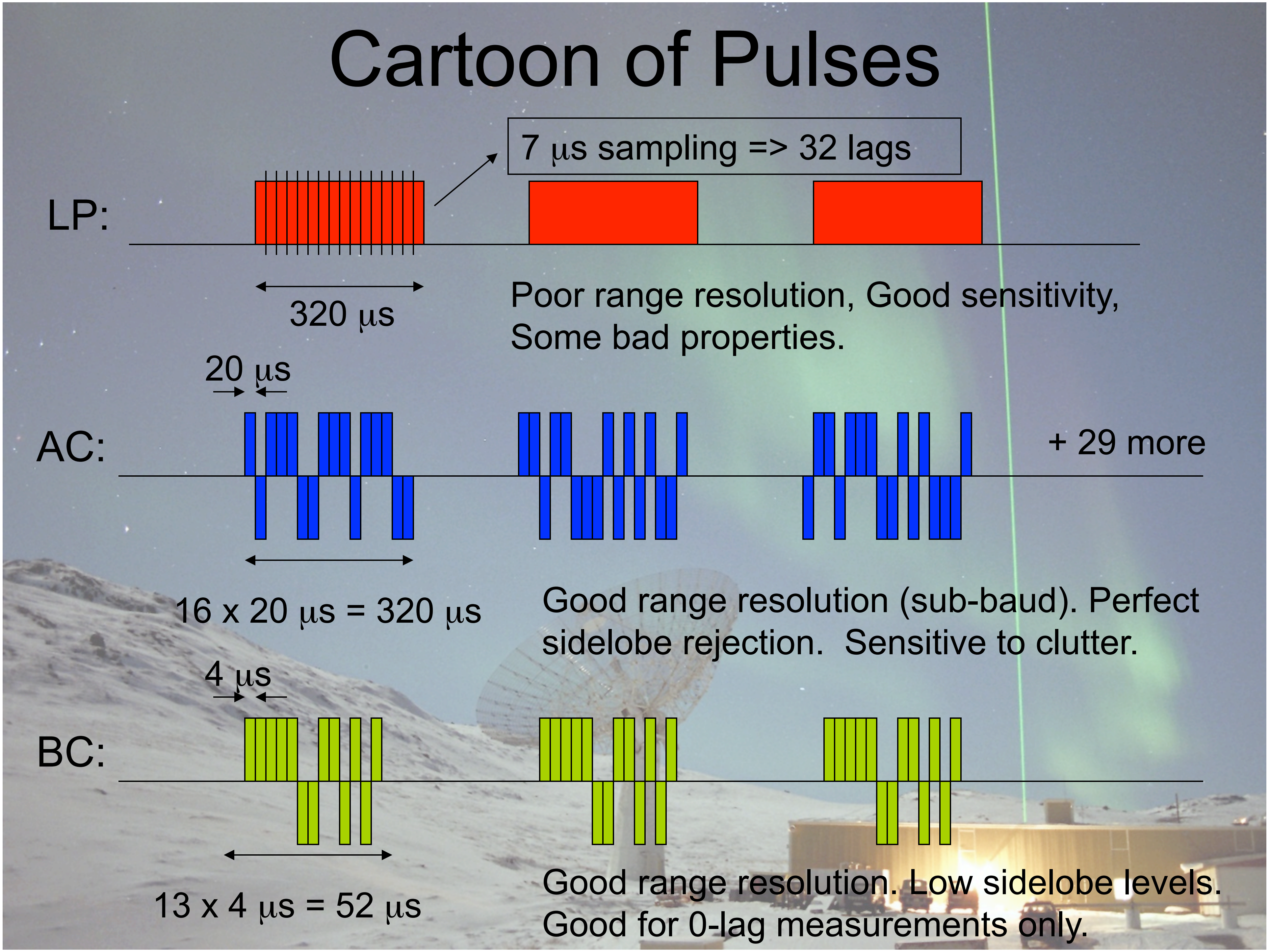
- This would all be great, *if* we were looking at coherent targets!
- The fact that we have a finite correlation time means that we cannot simply employ a filter matched to the expected waveform because we do not, in general, know what that (non-deterministic) waveform will look like.
- All is not lost on this front (in fact, much is gained!).
- There are a number of techniques available for improving range resolution of an autocorrelation function measurement without overly degrading the Doppler resolution.

Can we use phase coding?

- Yes, but we must be careful!
- Barker codes, for instance, can be used if the total code length is sufficiently short (less than the correlation time of the medium – Gray and Farley, 1973). This only gives us power (0-lag) information!
- Other classes of modulation are also available that, when incoherently averaged, provide good range resolution at the expense (usually) of increased bandwidth and processing complexity
  - Alternating Codes (Lehtinen and Haggstrom, 1987)
  - Coded Long Pulse (Sulzer, 1986)
  - Compressed Alternating Codes
  - Multipulse (not used much for ISR any more because of the superior performance of other techniques)
  - A good, slightly dated reference for many of these techniques is (Sulzer, 1989)
- Finally, at Arecibo they often have too much SNR and use phase coding to obtain more estimates of the acf.

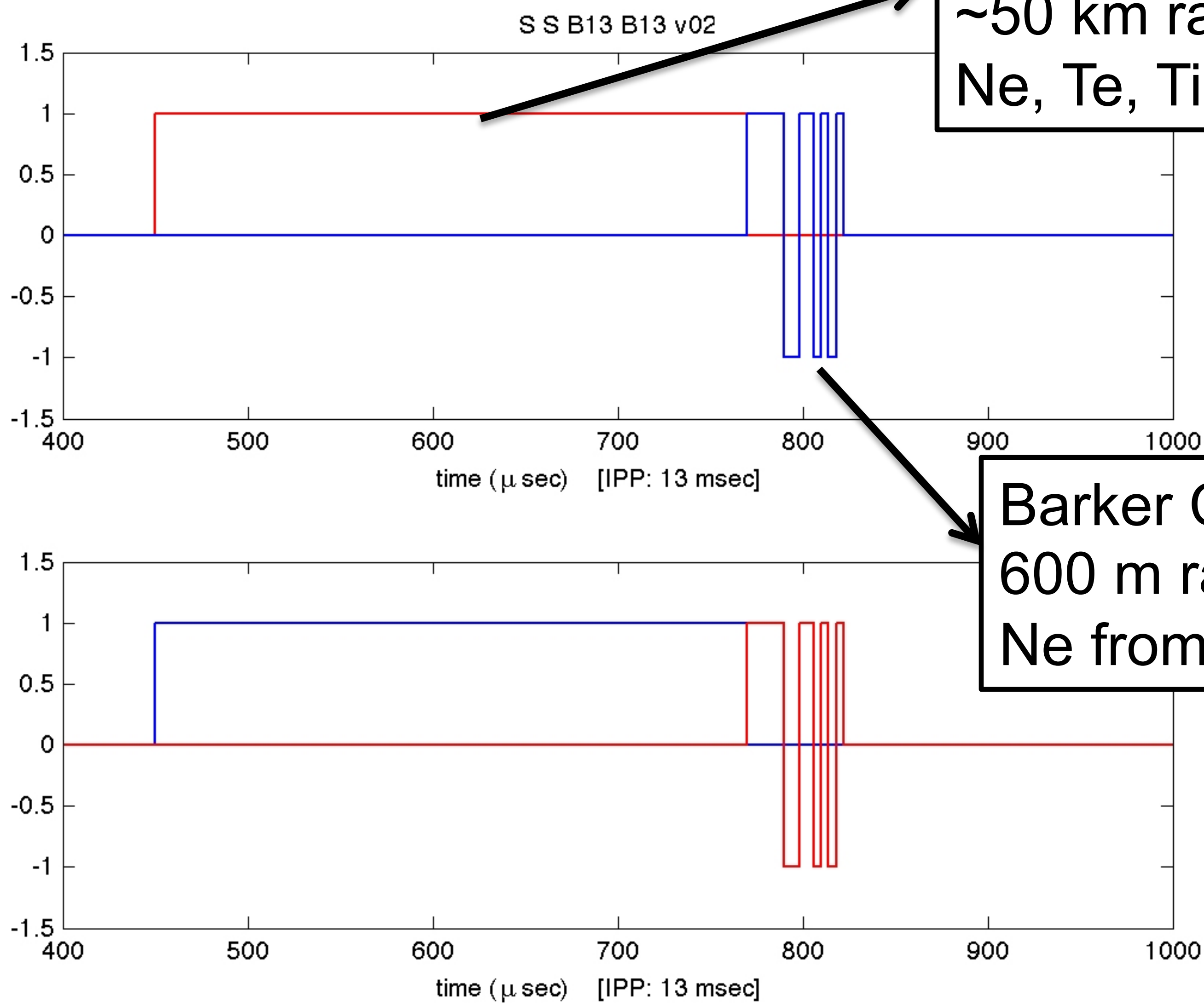


<u>Parameters</u>
Ne: 10^{12} m^{-3}
Ti: 1000 K
Te: 2000 K
Comp: 100% O^+
ν_{in}: 10^{-6} KHz



Cartoon of Pulses
7 μs sampling => 32 lags
LP:
320 μs
Poor range resolution, Good sensitivity,
Some bad properties.
20 μs
AC:
+ 29 more
16 x 20 μs = 320 μs
Good range resolution (sub-baud). Perfect
sidelobe rejection. Sensitive to clutter.
4 μs
BC:
13 x 4 μs = 52 μs
Good range resolution. Low sidelobe levels.
Good for 0-lag measurements only.

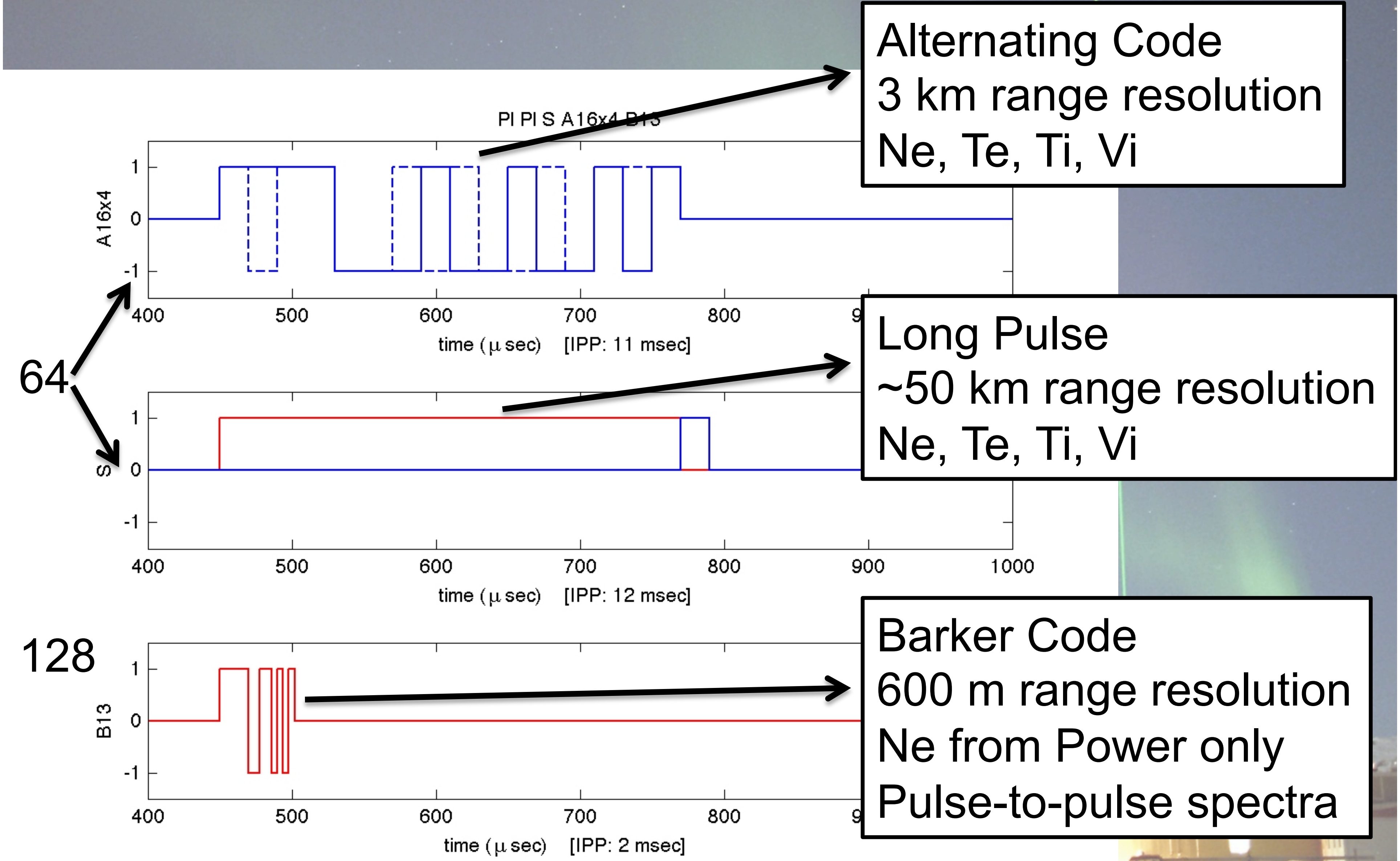
Actual Pulses (Option 1)



Long Pulse
~50 km range resolution
Ne, Te, Ti, Vi

Barker Code
600 m range resolution
Ne from Power only

Actual Pulses (Option 2)



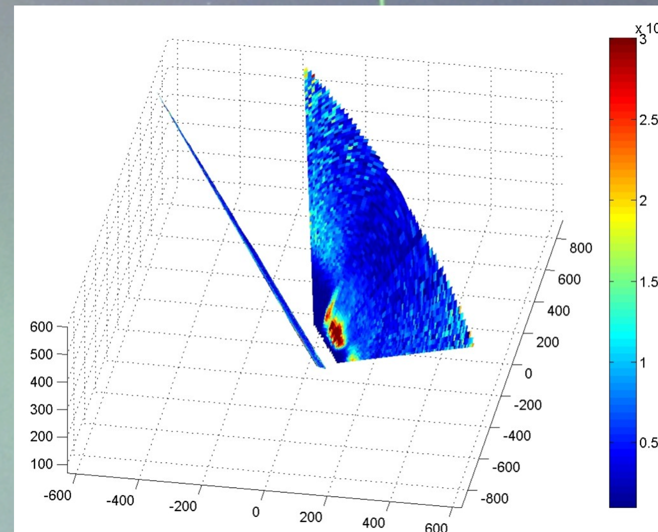
Sondrestrom Antenna Control

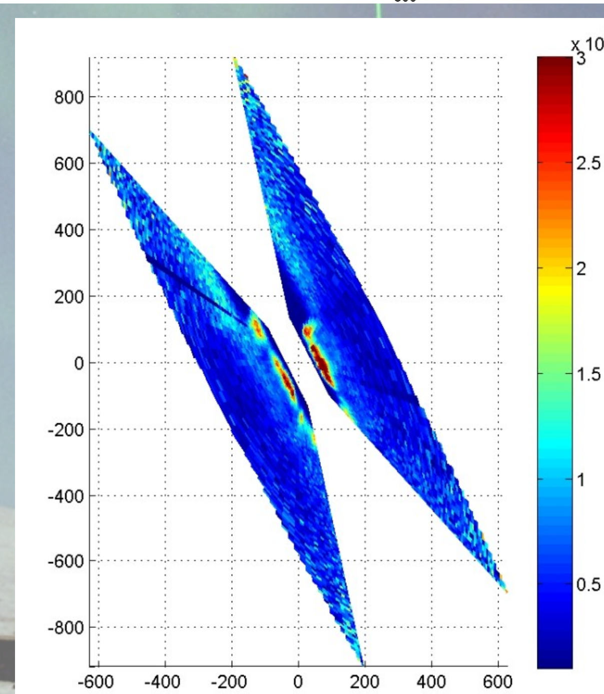
- You need to specify a sequence of events for the antenna and the duration for each event.
- These events can consist of dwells (for which there is no antenna motion during data collection) and/or scans (the antenna moves while data are collected).
- For each dwell you must specify the Az/El combination and the duration.
- For each scan you must specify the two end points, the type of scan, and the duration.
- Scan types are:
  – Azimuth (constant angular rate, no elevation motion)
  – Elevation (constant angular fate, no azimuth motion)
  – Constant rate composite
  – Variable rate elevation (constant ground track)
  – Variable rate composite (constant ground track)

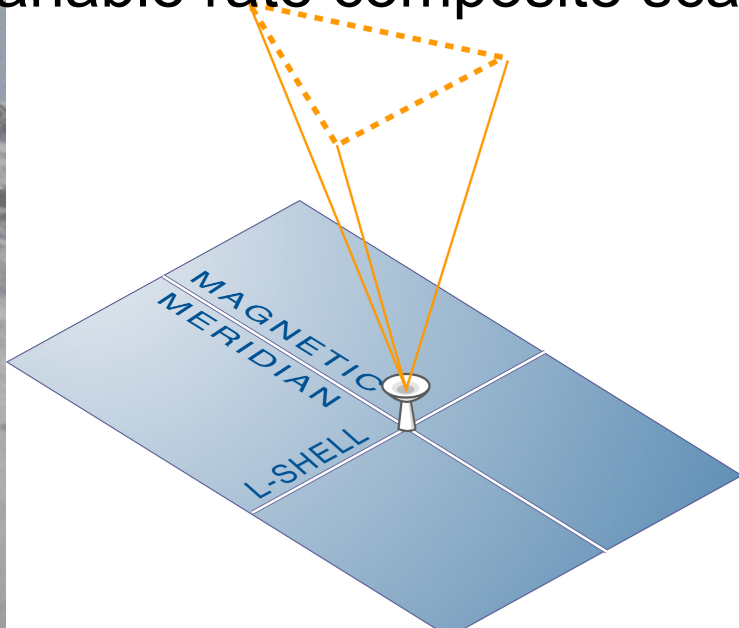
Sondrestrom Antenna Control

• Local measurements of electrodynamics and plasma parameters are well supported by a series of dwells

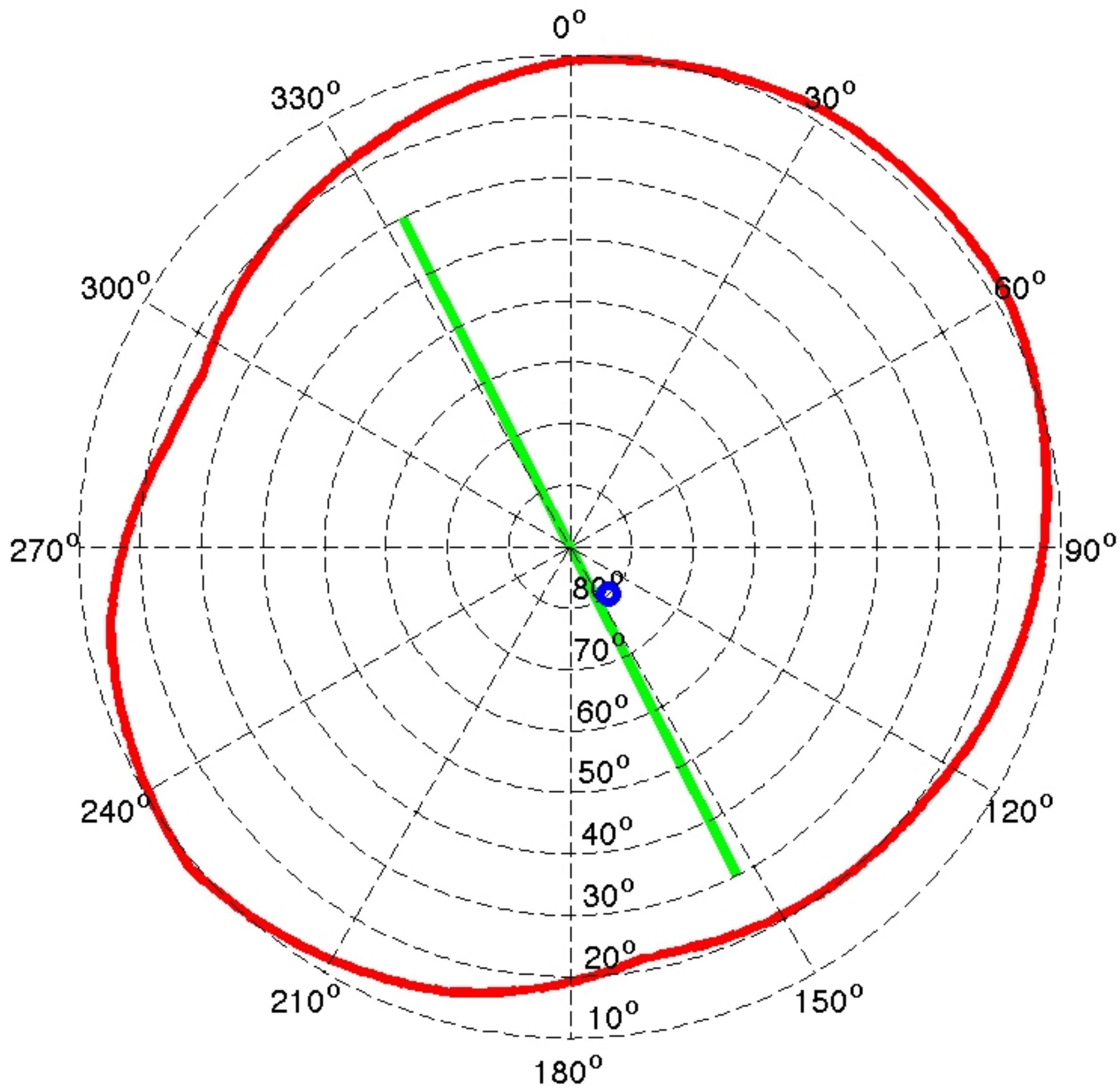
• Latitudinal coverage of electrodynamics and plasma parameters can be derived from variable rate composite scans





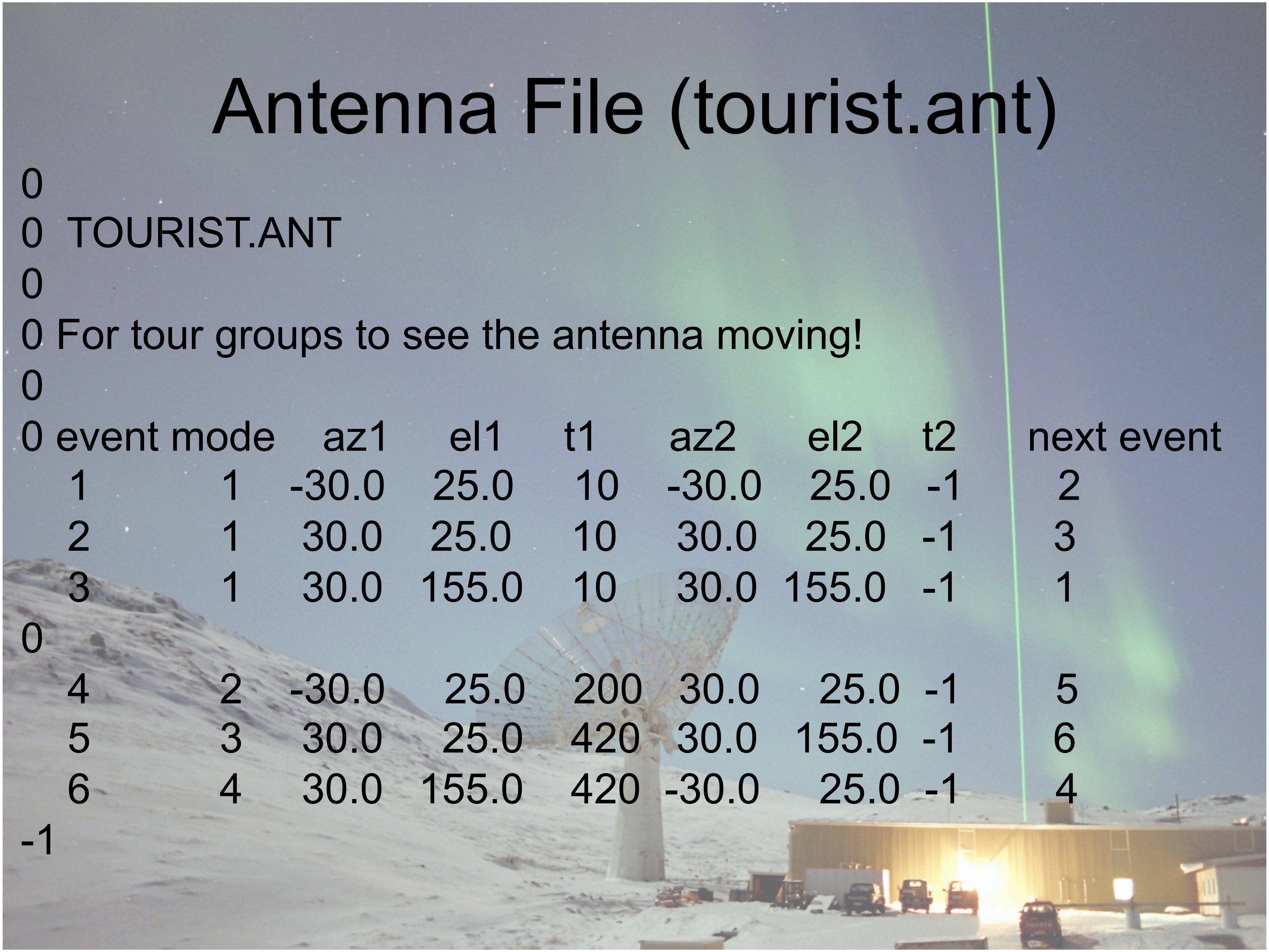


Sondrestrom Antenna Control

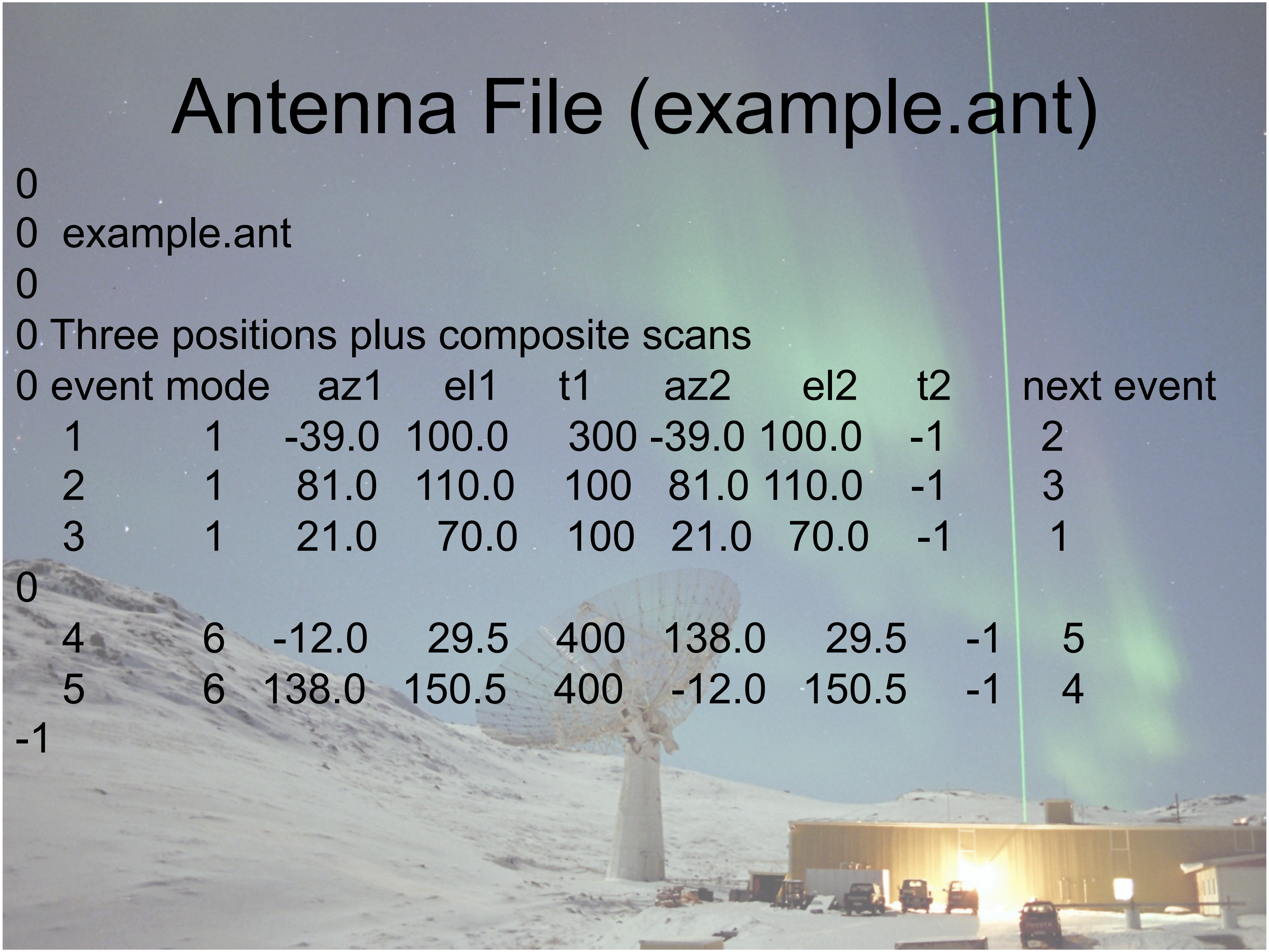


Local magnetic field
Az 141°
El 80°
Magnetic Meridian
Az 153°

Antenna File (tourist.ant)



```
0
0  TOURIST.ANT
0
0 For tour groups to see the antenna moving!
0
0 event mode    az1     el1     t1      az2     el2    t2     next event
   1         1   -30.0   25.0     10    -30.0   25.0   -1        2
   2         1    30.0   25.0     10     30.0   25.0   -1        3
   3         1    30.0  155.0     10     30.0  155.0   -1        1
0
   4         2   -30.0    25.0   200   30.0    25.0  -1        5
   5         3    30.0    25.0   420   30.0   155.0  -1        6
   6         4    30.0   155.0   420  -30.0    25.0  -1        4
-1
```



Antenna File (example.ant)

```
0
0  example.ant
0
0 Three positions plus composite scans
0 event mode    az1     el1     t1      az2      el2    t2      next event
   1       1    -39.0  100.0    300 -39.0 100.0    -1        2
   2       1     81.0   110.0   100   81.0 110.0    -1        3
   3       1     21.0     70.0   100   21.0   70.0    -1        1
0
   4       6   -12.0     29.5   400   138.0     29.5    -1     5
   5       6  138.0   150.5   400    -12.0   150.5    -1     4
-1
```

What can/should you “design” today?

- Decide on a scientific or experimental goal
  - **What do you want to investigate? How will you accomplish this?**
- Design an experiment that is consistent with the goals
- Choose a pulse scheme (Option 1 or 2)
- Choose your antenna positions

The most important thing for you is identify an interesting science case AND find the experiment setup most suitable to study it!

You will have both the real-time and any processed datasets to achieve these goals.

You need to justify your use of pulse schemes and your choice of beam positions!

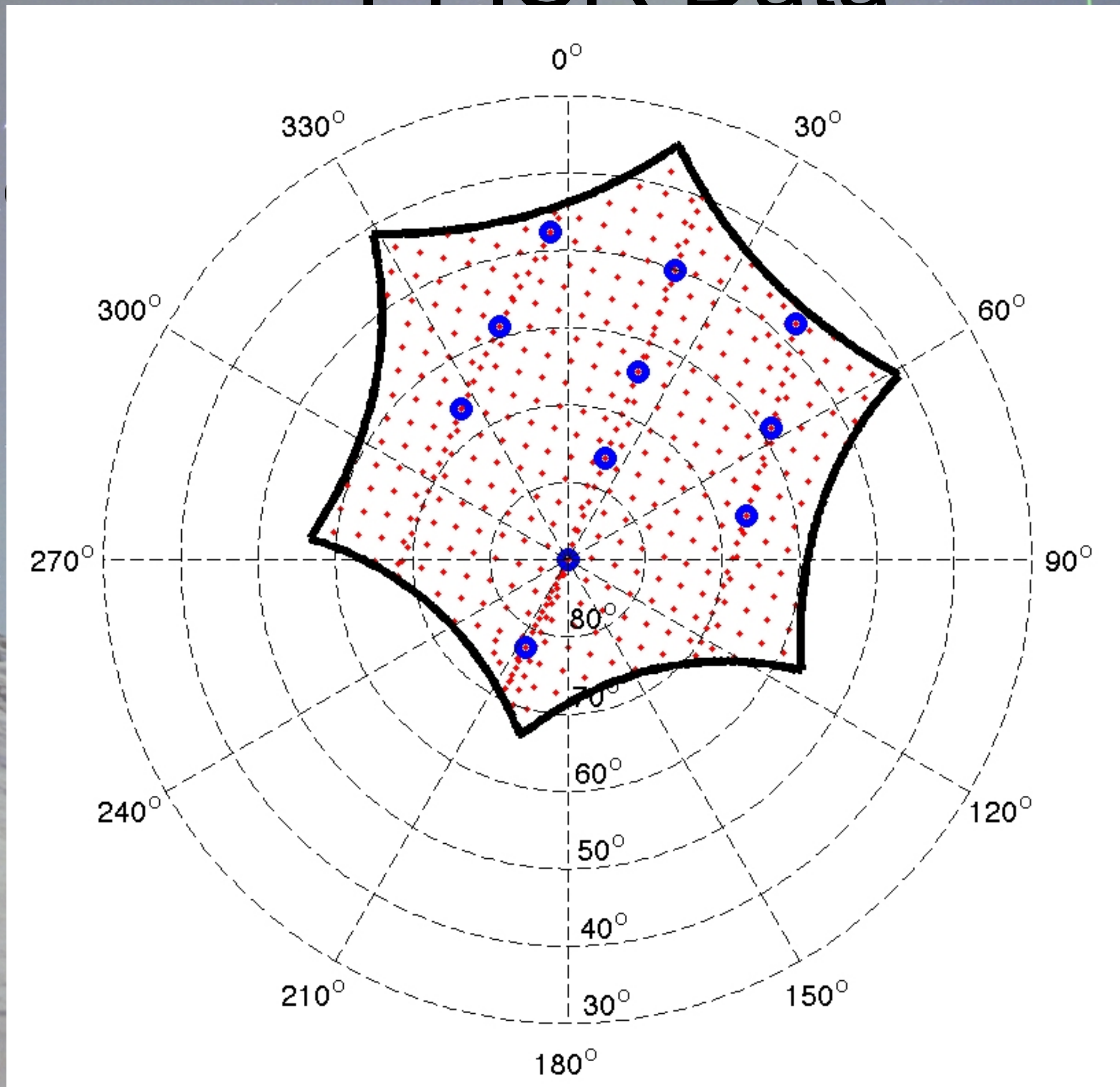
PFISR Data

• the

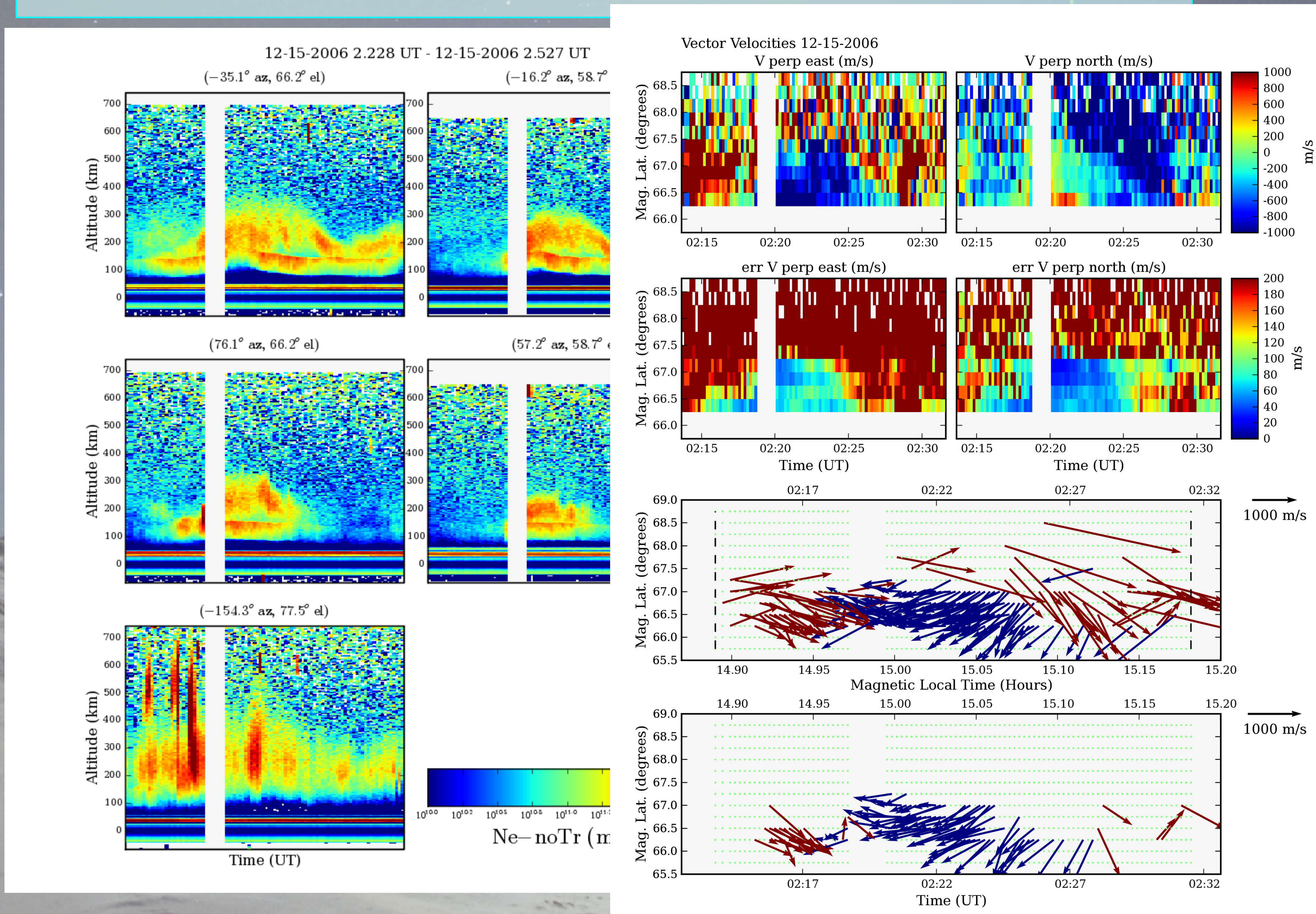
(

baud

to-



Standard Parameters and resolved velocities



Remember:

- The request for Sondrestrom radar time should contain:
  - Science goals
  - Mode option
  - Antenna Positions
  - Desired Data Product (density, temperature, velocity etc)
  - Submit to:

Anja.stromme@sri.com
Craig.heinselman@sri.com