Passive Radar Imaging of Meteor Trails

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Outline

- Project Overview
- Concepts
- Tasks and Results
- Conclusion
- Future Work

Project Overview

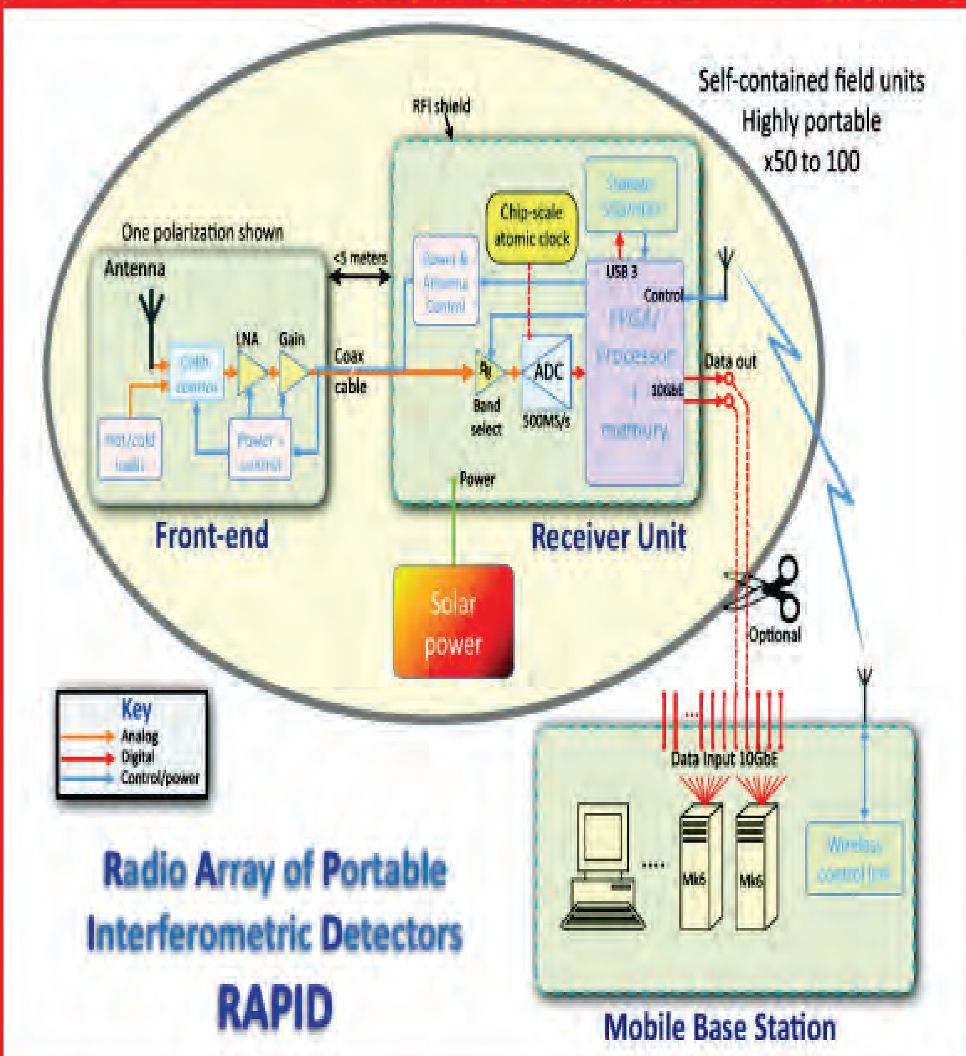
- Study and apply interferometric passive radar techniques to the observation of meteor trails
- Implement software to support the needed mathematical analysis techniques
- Collect experimental data
- Analyze the collected data

Meteor trails

- Small pieces of matter intersect the earth’s orbit
- Visible emissions
- Radio signatures
  - The plasma trail produces a ‘ radar echo ‘
  - Relatively easy to detect
- Imaging can provide details of trail structure and evolution

RAPID

Radio Array of Portable Interferometric Detectors



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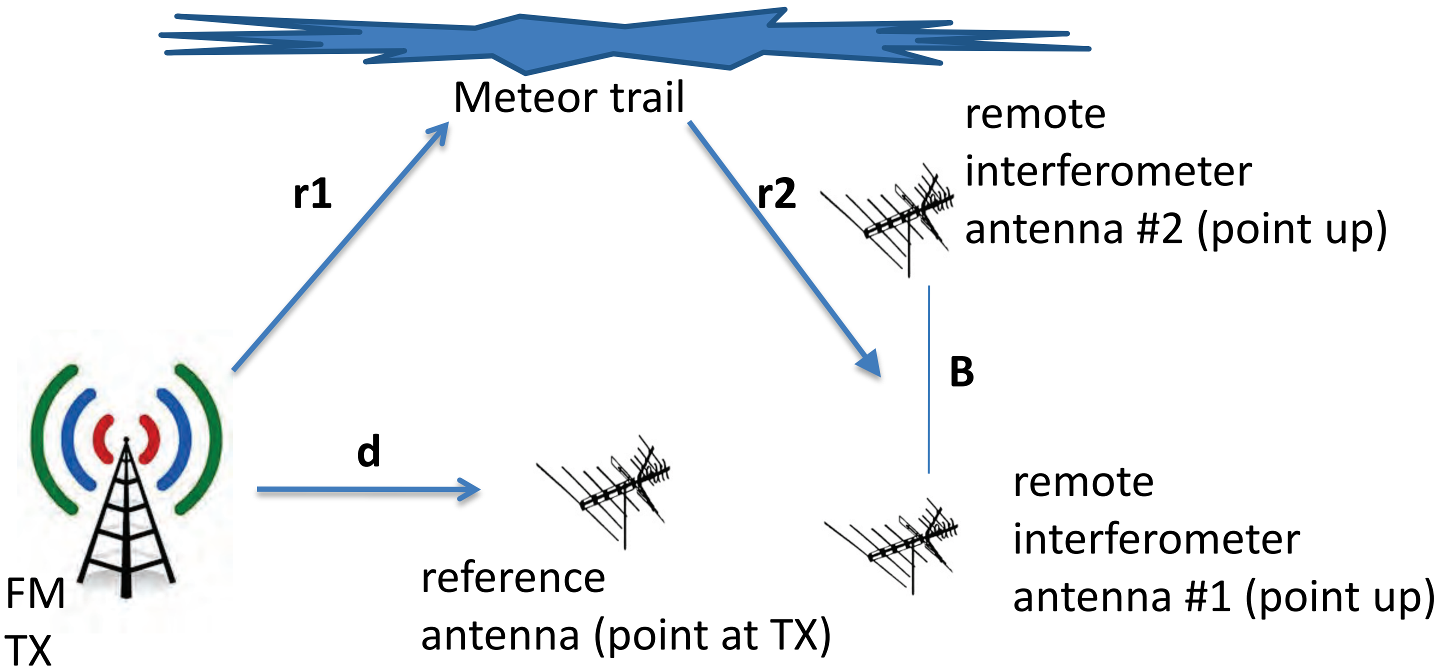
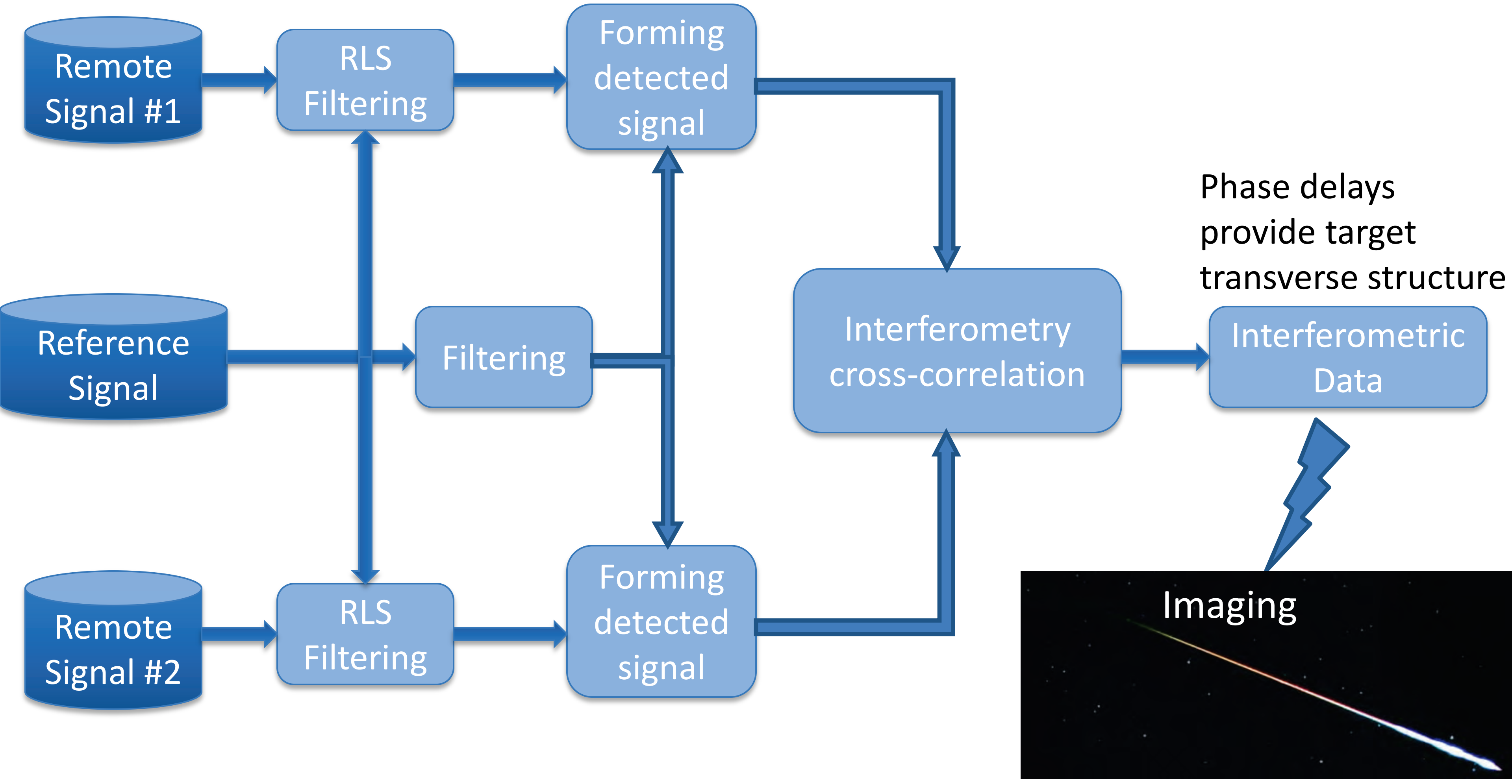
Multi-static Passive Radar



- A transmitter of opportunity illuminates the meteor trail (FM radio)
- The transmitter signal is received by all the antennas at a single site
- The scattered signal is received by the interferometer antennas
- High dynamic range is required to enable detection of weak scatterers
    - Adaptive filtering must be used to remove the transmitter signal
- Matched filtering is used to detect the meteor trail's range and doppler shift

Interferometric Passive Radar Signal Processing

how the project pieces fit together



Adaptive Filtering

- Least-square algorithm:

  -The solution for the least-squares problem can be computed in recursive form resulting:

  -RLS (Recursive Least-square)

  -LRLS (Lattice-base Recursive Least-square)

- RLS algorithms are known to have fast convergence

  - excellent performance when working in time-varying environments

- LRLS algorithms are fast implementations of the RLS problem
- The Goal:

  - Remove the transmitter signal from the remote antenna signals. -> Dynamic Range!

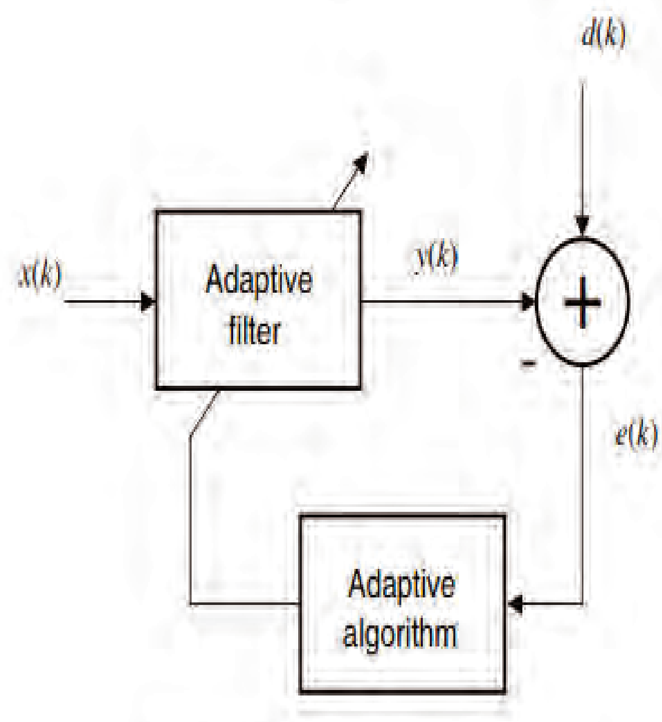
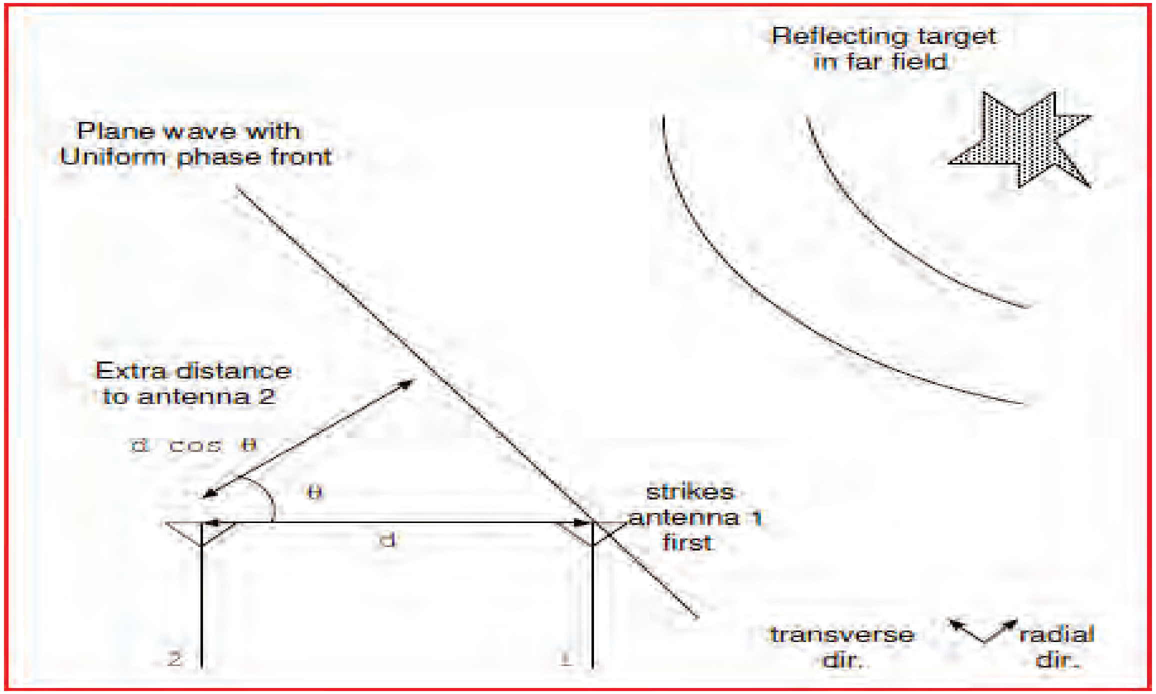


Figure 1.1 General adaptive-filter configuration.

Interferometry and Correlation



- Interferometry
  - Estimation of transverse structure of target
    - Phase difference between signal on two antennas
- Correlation is the way we can measure the phase delay between the two signals
- Enable passive radar interferometry
  - Requires a modified correlator
    - Part of my project was to generalize our passive radar code to handle an interferometric cross correlation.

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Implementing RLS /LRLSFilter: Translating Matlab code to Python

- Translating Adaptive RLS and Lattice-Based RLS Algorithms from Matlab to Python

Matlab LRLS_pos Algorithm

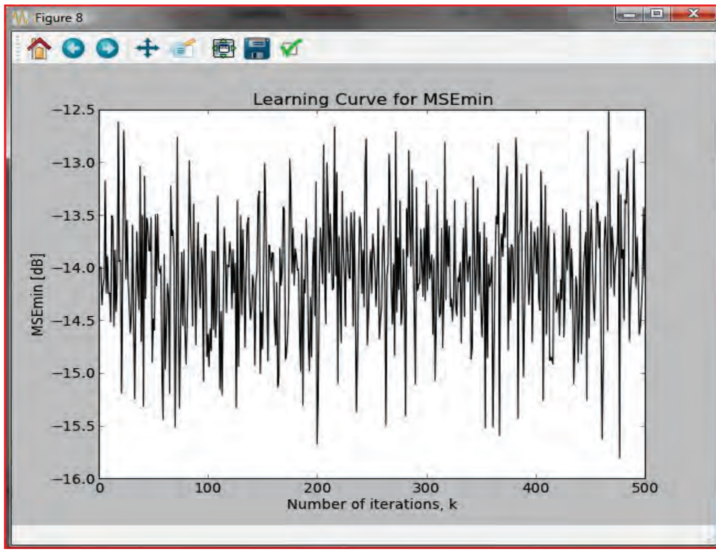
```matlab
%   Definitions:
ensemble    = 1;                        % number of realizations within the ensemble
K           = 5;                        % number of iterations
H           = [0.32+0.21*1j,-0.3+0.7*1j,0.5-0.8*1j,0.2+0.5*1j].';
Wo          = real(H);                  % unknown system
sigma_n2    = 0.04;                     % noise power
lambda      = 0.97;                     % forgetting factor
N           = 4;                        % number of coefficients of the adaptive filter
epsilon     = 1e-2;                     % small positive constant


%   Initializing & Allocating memory:
ladder  = zeros(N  ,K,ensemble);   % ladder coefficients of the algorithm
kappa   = zeros(N  ,K,ensemble);   % reflection coefficients of the lattice algorithm
e       = zeros(N+1,K,ensemble);   % error matrix - a posteriori errors
MSE     = zeros(K,ensemble);       % MSE for each realization
MSEmin  = zeros(K,ensemble);       % MSE_min for each realization
```

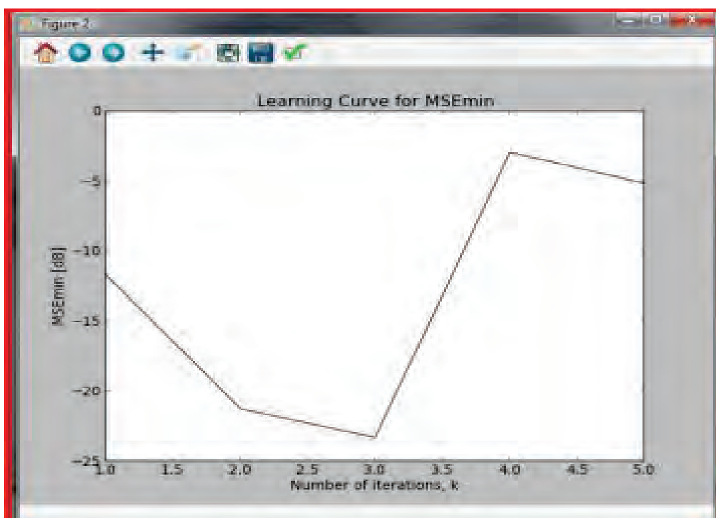
Python LRLS_pos Algorithm

```python
#%   Definitions:
ensemble    = 100                       #% number of realizations within the ensemble
K           = 500                       #% number of iterations
H           = numpy.array([0.32+0.21*1j,-0.3+0.7*1j,0.5-0.8*1j,0.2+0.5*1j]).T
Wo          = H                         #% unknown system
sigma_n2    = 0.04                      #% noise power
N           = 4                         #% number of coefficients of the adaptive filter
delta       = 0.2                       #% small positive constant (used to initialize the
                                        #% estimate of the inverse of the autocorrelation
                                        #% matrix)
llambda     = 0.97                      #% forgetting factor


#%   Initializing & Allocating memory:
W= numpy.zeros((ensemble,N,(K+1)), numpy.complex) #% coefficient vector for each iteration and realization
MSE     = numpy.zeros((K,ensemble))     #% MSE for each realization
MSEPost = numpy.zeros((K,ensemble))     #% MSE a posteriori for each realization
MSEmin  = numpy.zeros((K,ensemble))     #% MSE_min for each realization
a=numpy.genfromtxt('B.dat')
b=numpy.genfromtxt('C.dat')
y=numpy.genfromtxt('Bn.dat')
f=numpy.genfromtxt('Cn.dat')
```

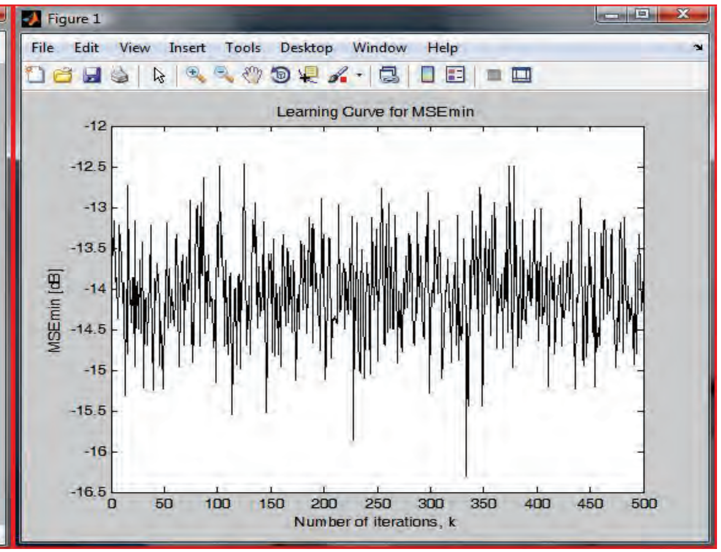
RLS Filter Implementation Results

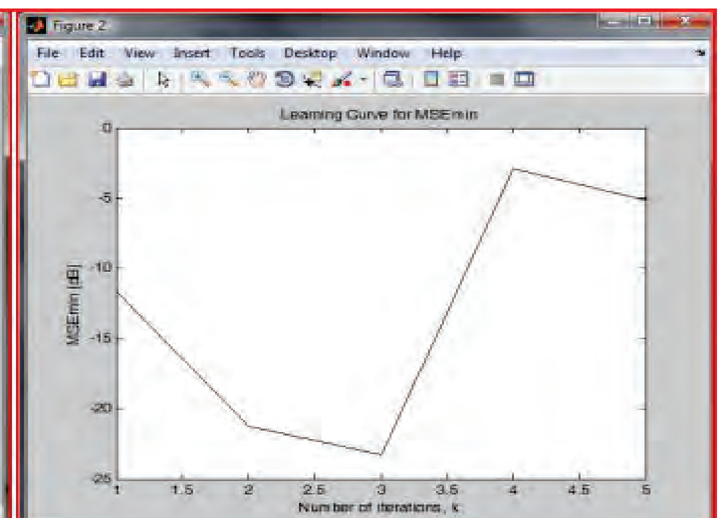
Python Results





Matlab results





RAPID antennas assembly PARTY! Working Party!

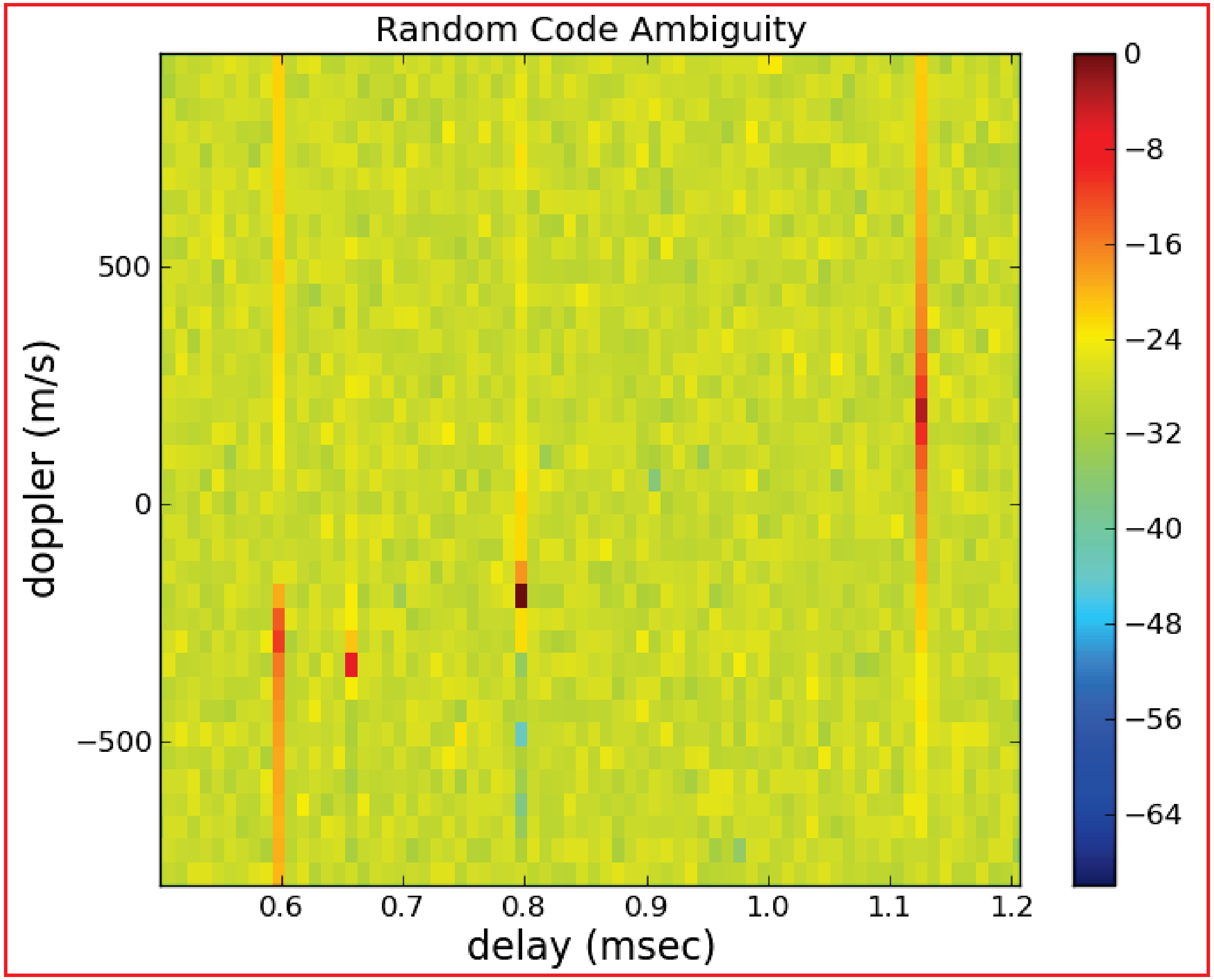
Implementing interferometric Cross-Correlation

- Modified Correlator and Noise-Ambiguity code to:
  - Create artificial interferometric targets
  - Interferometric Cross-Correlation
    - Combine reference signal with two remote antennas
    - Cross correlate remote antennas
    - Estimate coherence and cross phase

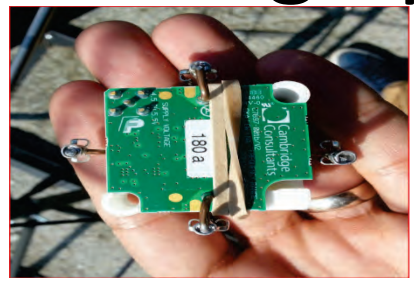
Part of the Noise-Ambiguity code: Puts different targets in detected remote signal

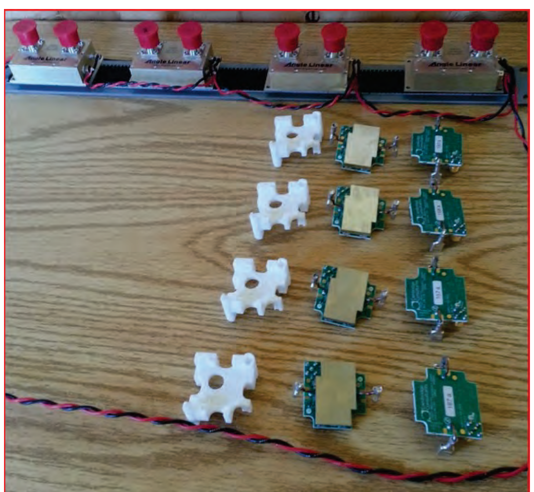
```
def targets(refrence_signal,scatter_amplitude,target_velocity_mps,target_range_km):

    y=refrence_signal*0.0
    for i in range(len(target_velocity_mps)):
        shift_delay=2000*target_range_km[i]/light_velocity
        shift_delay=int(shift_delay*signal_bandwidth)
        print 'shift_delay',shift_delay
        lamb_da=light_velocity / center_frequency
        doppler_frequency=-2*target_velocity_mps[i]/lamb_da
        z = refrence_signal * 0.0
        z[shift_delay:] = refrence_signal[:len(refrence_signal)-shift_delay]
        z= scatter_amplitude[i]*z*numpy.exp(-1j*2*numpy.pi*doppler_frequency*numpy.arange(len(z))/si
        y_buffer = refrence_signal+ z
        y=y+y_buffer
    return y
```

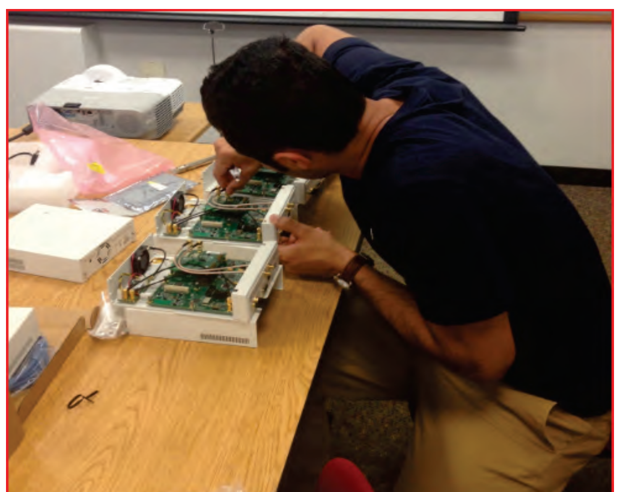
Correlation Results on Simulated Targets

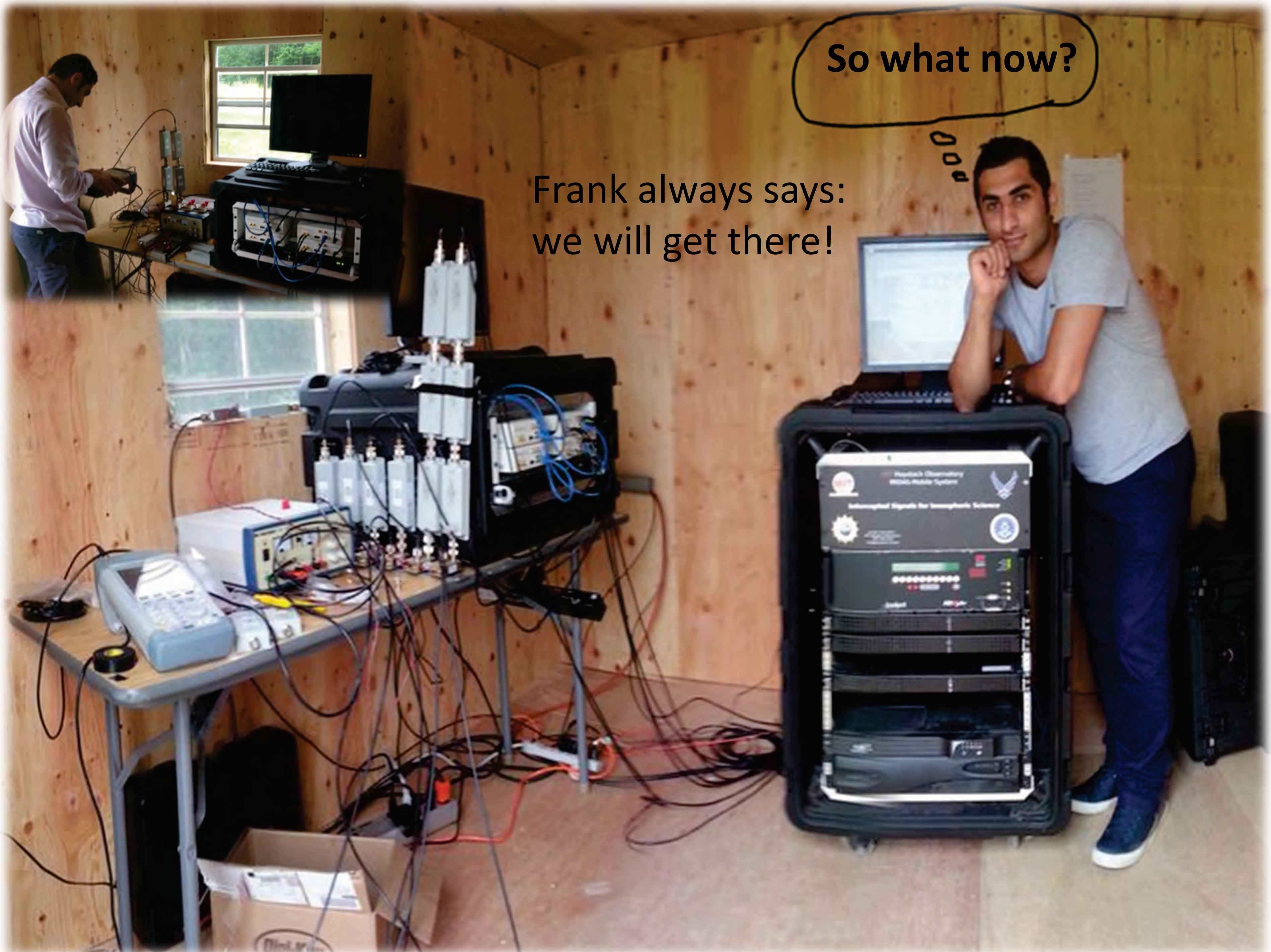


More Field Work:
Installing and setting up the system



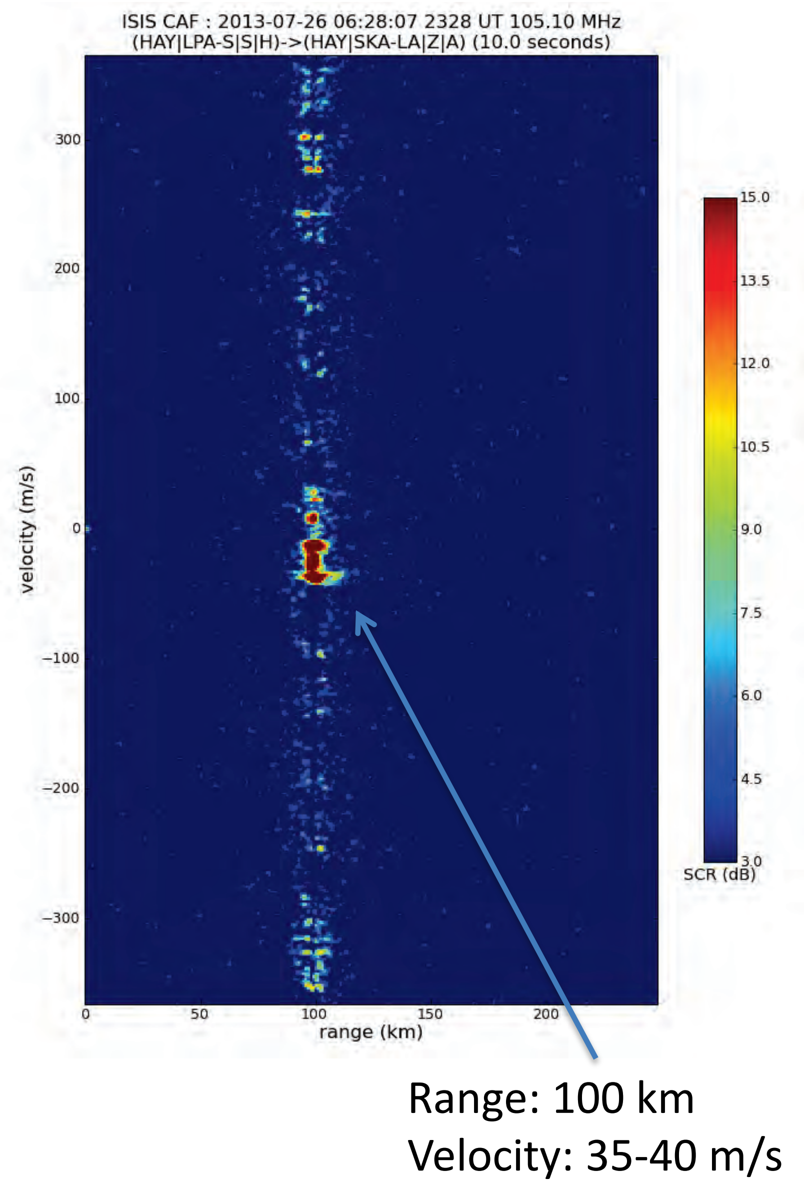





So what now?
Frank always says:
we will get there!

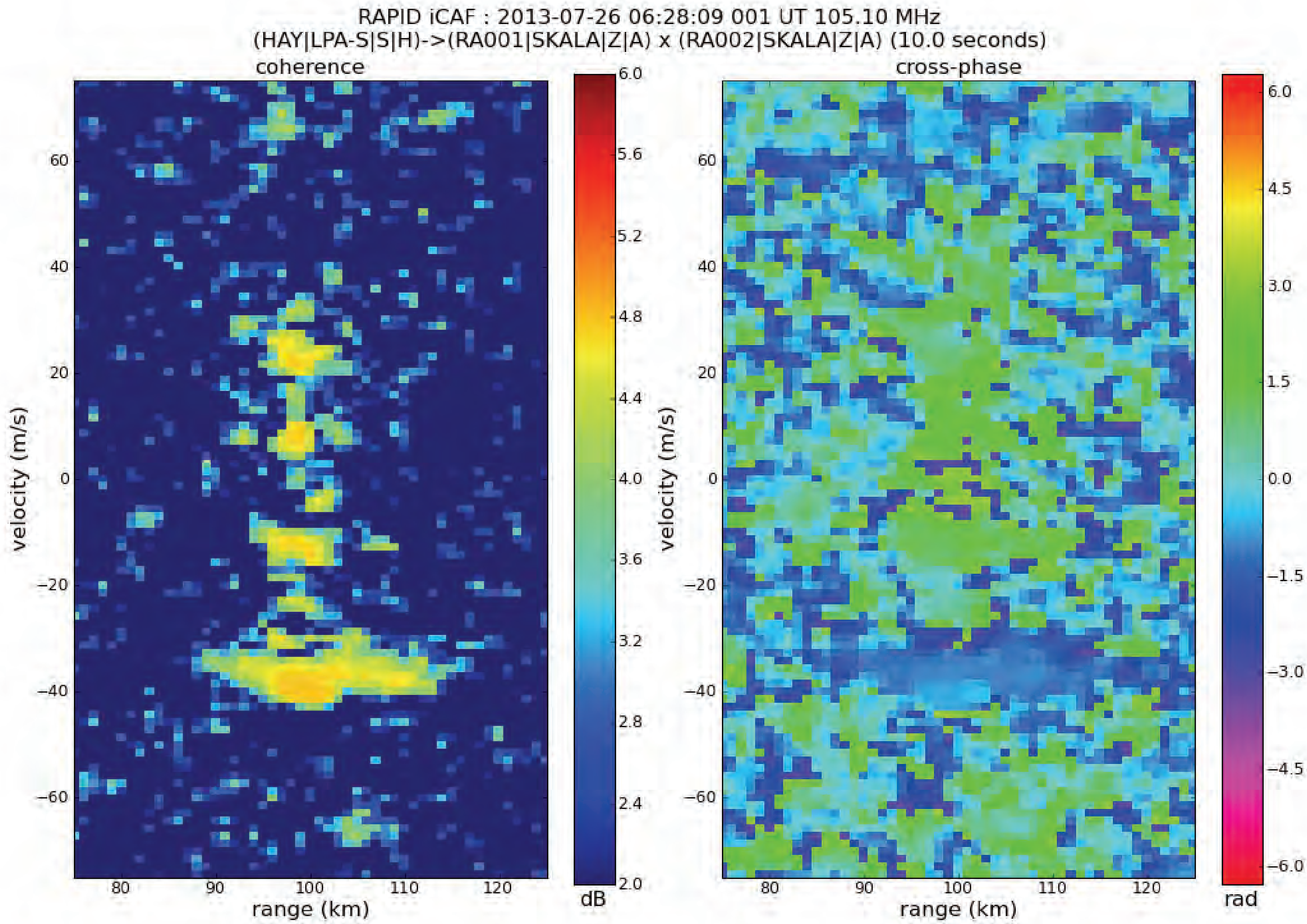
Meteor Data Collection and Results

- Data collections:
  - Two antennas 18λ apart (north-south)
  - Frequency 105.1 MHz
  - Frequency 92.3 MHz
  - For good RFI rejection:
    - Two FM filters on the reference signal
    - Three FM filters on the each remote signal
- Processing the data to test the system
- Now perform interferometry using two antennas…



λ is wavelength
λ = 2.8544 m for 105.1 MHz
18 λ = 51.379 m

Two antenna passive radar interferometry



Conclusions

- LRLS Algorithms now available in Python
- RAPID Antennas successfully detected
  FM band, passive scatter from meteors
- Interferometric passive radar cross correlator (leading to imaging soon…)
- Sometimes Answers become Questions themselves

Future Work

- Setting up a geometries with more antennas and dual polarizations (up to 16 antennas!)
- Implement imaging inversion
- Additional work :
  - Incorporate Lattice RLS filtering
  - Parallelize and optimize correlation
- Science!

Acknowledgements

- First of all, I wanted to thank MIT Haystack Observatory and the people involved in the REU Program
- Special thanks to my really, really good mentors Frank Lind, Philip Erickson, Bob Schaefer for their help and guidance
- Bill Rideout , even though he wasn’t one of my mentor he helped a lot
- K.T. Paul for her gentle reminders to keep us on track otherwise I would have forgot every thing!
- Larisa for taking us to ice cream shop at the Denver's airport
- Chester for taking me to RUN!
- Every body else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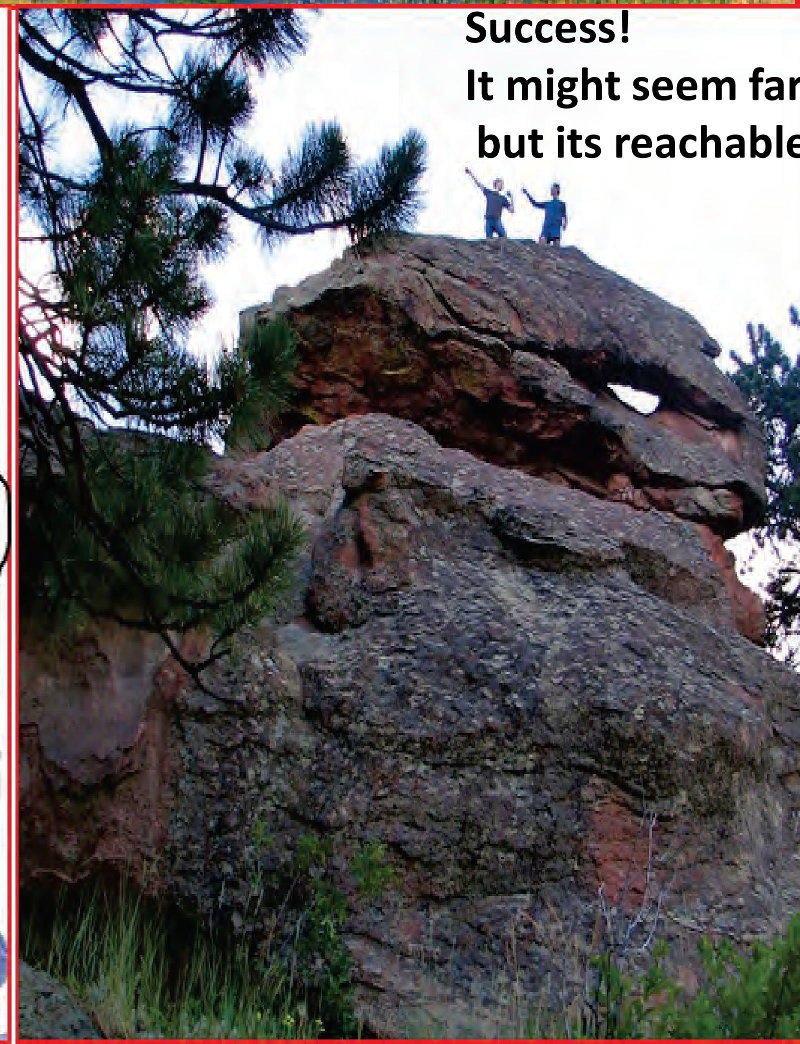
Taken by :
Bill Rideout
hehe
he is crazy
What is the best way to get up there ?
seriously!


Success!
It might seem fa
but its reachabl

References

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