Radio-Based Detection of Ultra-High Energy Cosmic Rays with the Telescope Array Radar (TARA) Observatory Remote Stations

Photon 2015 Steven Prohira University of Kansas

UHECR and Extensive Air Showers



Primary interaction in upper atmosphere results in cascade of charged particles

Cascade may be detected at surface (Auger, TA) or through florescence (Fly's Eye, TA)

Why another method?

FLUX of ~10¹⁹ eV events approximately 1/km²/century!

Not enough time-need more area-need a cost-effective solution.





TARA

Telescope Array RAdar exploits the ionization properties of the EAS to cover more area with less apparatus than 'traditional' detectors.

WF2XHR Dense enough shower core will re-radiate RF at sounding frequency if resonant with frequency of plasma in dense shower core:



Lang Flight

Function of number of electrons-at critical density, shower will be resonant to our frequency, 54.1 MHz.



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Telescope Array Locations General Reference Map

2.003

Bi-Static Radar





Transmitter









Detection Scheme





Chirps



Field-captured calibration chirp. Courtesy S. Kunwar Our bi-static approach minimizes Doppler shift, allowing for detection at VHF.

As subtended angle tx-->shower core-->rx increases, Doppler shift decreases.

Result is an approximately linear downgoing chirp

This chirp is differentiated from the CW carrier and background through system hardware/firmware





Meteors-a Lab for cosmic rays







TARA Remote Stations



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TARA Remote Stations

Fully autonomous UHECR detectors



Station structure







Antenna



Log Periodic Dipole Antenna gives broadband response to broadband chirps with roughly flat response.







Station structure







Filtration



Removal of carrier=no amp saturation.

Crystal notch filter.





Amplify-Galaxy check



RMS voltage of forced trigger data fit to the bore-sight track of the galactic center-excellent agreement=galactic floor visible





Station structure







De-Chirp

We take the input signal and mix it with a delayed copy of itself, using the Heterodyne method:

$$sin(\theta)sin(\phi) = \frac{1}{2}cos(\theta - \phi) + \frac{1}{2}cos(\theta + \phi)$$
 Neglect-out of band

For a linear chirp,

$$\theta = \omega t - \frac{k}{2}t^2$$
 $\phi = \omega(t+\tau) - \frac{k}{2}(t+\tau)^2$

Where k is the chirp rate, and τ is the amount of delay. Solving gives a monotone at frequency

$$f_m = k\tau$$

As illustrated on the next slide.







Chirp (blue) mixed with a delayed copy of itself (green) and the resultant monotone (red).











Detect



Trigger logic ensures that no two adjacent bands may trigger simultaneously-rejection of time transients like lightning





Brains

Nexsys 3 Spartan-6 FPGA .

-200 MS/s ADC for data channels into FPGA with in-house custom firmware

-Trigger logic

-4 channels with different bandpass filters -logic rejects broadband time transients

Raspberry Pi

-Data is transferred to Single Board Computer (SBC)
-Ethernet link allows for total control of threshold parameters and station control
-low power consumption





Station structure







Chirp Calibration Unit (CCU)



CCU



Field Captured Calibration Signal

Fires once a second for ten seconds Every hour, to keep an eye on Backgrounds and trigger performance





Upgrades-June 2015

-Improved station timing accuracy

-Firmware update-more control



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Timing

Timing:

-2 stations with 65 meter baseline

-GPS unit provides 100 pps output with ~10 ns resolution -each FPGA runs local 200 MHz clock - drives counter with ~5 ns resolution -counter is reset every 10ms

-triggered event reads counter value for precision timing=angular resolution.





Firmware

Spartan-6 firmware has several parameters:

-Trigger board

-4 channels each varying in width-offsets provide more stable triggering capabilities

-Threshold

-total trigger threshold may be set based on current ambient noise level (in the works)

-Time-Over-Threshold

-TOT width and thresh allows for greater reject of short time transients





Current Status

-Currently taking data-hope for an uninterrupted capture from now until September

-Station Upgrade happening right now! Implementation of new firmware revision.



