Detection of Energetic Particles by a Network of HF Propagation Paths in Alaska

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Abstract. A network of horizontal propagation paths of HF radiation is proposed to detect ionization paths created by energetic particles near the earth's surface. Coherent phase method is sensitive to sudden changes in ionization in any portion of a long path length.

Recognizing that the flux of magnetic monopoles is low and that a large viewing region is necessary to increase the probability of observation I am proposing an electronic network using commercial cell-phone stations in the entire state of Alaska (Fig.1, 2). The reasons for performing the experiment in Alaska are: the remoteness of the Alaska region means that the level of background noise is significantly lower than that in the lower forty-eight states; the climate in Alaska does not give rise to thunderstorms in most regions, thereby reducing the amount of extraneous ionization which can confuse our detection scheme; most of the infrastructure is already present at the UCLA HIPAS Observatory (Wong, 1999;

www.HIPAS.Alaska.edu), located in the central region of Alaska as a result of our more than twenty years of performing communication experiments on the interaction of electromagnetic waves with the ionosphere (fig 3, 4).

The central idea of our concept consists of sending a coherent HF wave from a vertical antenna located at HIPAS Observatory, which propagates uniformly in all horizontal directions. Receiver sites located at various cellular stations throughout Alaska are used to record this signal in amplitude and phase. These receiver sites (fig 1) all have very accurate timing provided by T-1 lines. The phase stability is one part in 10^9. Therefore very small incremental change in phase can be detected. Receivers are located at distances from 30 km up to 500 km. All data are recorded continuously in a digital mode at the 1 MHz rate and any sudden change in the order of milliseconds or less will ensure that the data will be retained permanently and examined first on a local computer. This procedure avoids the accumulation of an overwhelming amount of uninteresting background data.
Only these pre-screened data are then sent forward in batch formats to a central telescience center using the cell station links. The data from all stations will be examined and correlated. The use of existing cell stations for data gathering and intermittent transfer greatly lowers the cost of this large-scale experiment.

The network can be calibrated by the short burst of ionization generated by a 300-Joule laser (Wuerker, 2001) at the HIPAS Observatory on dust particles. A 2.7 m rotating mirror at HIPAS can be used to focus a laser beam to impact on dust particles at a height of 100 km. The resulting electron population line density of $nl < 10^8$ cm^2 is expected to cause a detectable change in the phase of a propagating HF signal.

The propagation of electromagnetic waves through a medium containing electrons will suffer a change of phase given by the following equation (Wong, 1980):

$$\Delta\phi = \int_0^L \left(k_{\text{vacuum}} - k_{\text{plasma}}\right) dx .$$

Assuming constant n_e through length L, we have:

$$\Delta\phi = \frac{\omega}{c}\left[1 - \left(1 - \frac{\omega_{pe}^2}{\omega^2}\right)^{1/2}\right] L ,$$

where $k_{\text{vacuum}} = \frac{\omega}{c}$, and

$$\omega_{pe} = \left(\frac{4\pi n_e e^2}{m_e}\right)^{1/2} = 5.6\text{x}10^4 n_e^{1/2} \text{(rad/s)}$$

The minimum detectable change in phase is expected to be 0.1 degree, which corresponds to a change in the line density (~n_eL) of 6x10^3 cm^{-2}.

According to the layout of the receiving stations this detection system is expected to cover an area of approximately 500 km in radius. Anytime an energetic particle falls into this area, it will cause ionization detectable by this method. According to the theoretical work by Wick et al (2000) taking the upper flux bound of monopoles as 10^{-16} $cm^{-2}sec^{-1}sr^{-1}$ (Amanda, Baikal and Macro) and considering a region with a radius of 500 km, an upper limit of 5 events/sec is estimated. Even if this were an optimistic estimate our detection system is designed to observe 5 events/year, which can put the flux 10^7 times lower. Wick also estimated that the ionization in the lower atmosphere will give a line density nl ~ 10^5 cm^2 which is well above the sensitivity limit of our detectors.

The line density might be higher if we consider the impact of the monopole on the earth's surface. The material density is higher and gives rise to secondary electron emission and transition radiation. This might result in a large electron shower in the 0-100 km height range we are detecting. We are currently performing computer modeling of such events.

In our proposed experiments the events are discriminated according to the speed of occurrence. Background events cannot in general produce such a large line density within tens of microseconds near the earth's surface.

We have also considered the duration of the electron line density at such low heights. The ionization balance equations for the concentrations N_e of the electrons and N^- of the negative ions take the form (Gurevich, 1978):

$$\frac{dN_e}{dt} = q_i + \nu_{ion} N_e - \nu_a N_e + \nu_d N^- - \alpha N_e (N_e + N^-)$$

$$\frac{dN^-}{dt} = \nu_a N_e - \nu_d N^- - \alpha_i N^- (N_e + N^-)$$

where q_i is the total intensity of the ionization produced by the external source, ν_{ion} is the frequency of the molecule ionization by the fast electrons, ν_a is the frequency of electron attachment to the molecules, and ν_d is the electron detachment frequency. Under the conditions of the lower ionosphere, an important role is played by the attachment of electrons to oxygen molecules in triple collisions $\nu_a \cong k_1 N_{O_2} N_{O_2}$.

According to Phelps (1969), $k_1 = 1.4 \times 10^{-29} \exp(-\frac{600}{T_e}) cm^6 / s$. For the electron detachment frequency, important processes in the ionosphere are photo detachment, detachment in collisions with molecules, and associative detachment:

$$\nu_d = \nu_{ph} + k_6 N'_{O_2} + k_7 N_O + k_8 N_N$$

The rate of change in the electron population is equal to the difference between rates of detachment and attachment.

With $N_e + N^- = N^+$ and ν_a, $\nu_d >> \alpha_I N^+$, we can express the net electron density

$$N_e \cong N^+ \frac{\nu_d}{\nu_a + \nu_d}$$

Depending on the excited states of molecules and the energy released from the interaction between monopoles and atmosphere and ground a rate of change of electron density between 1-100 microseconds is possible.

References

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Acknowledgment

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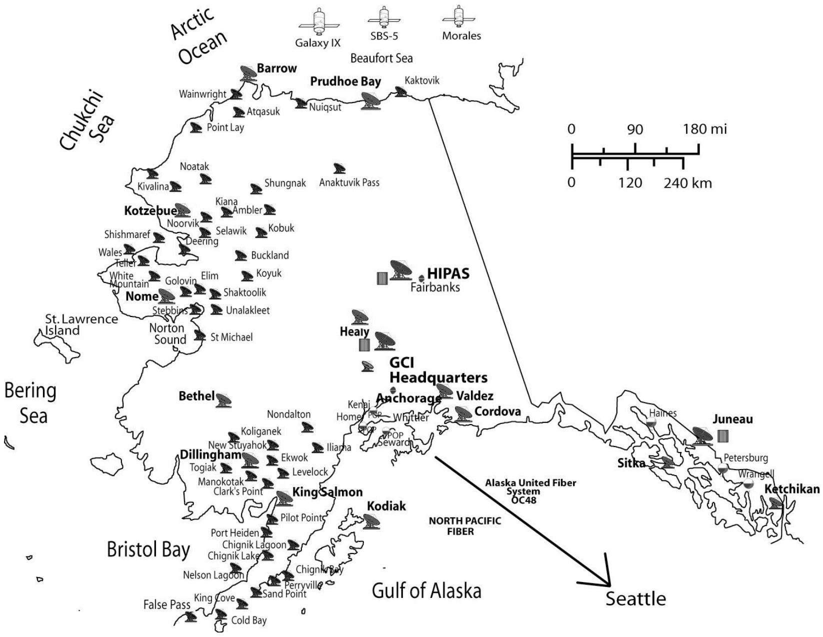

Figure 1: Location of commercial communications receiver sites in Alaska.

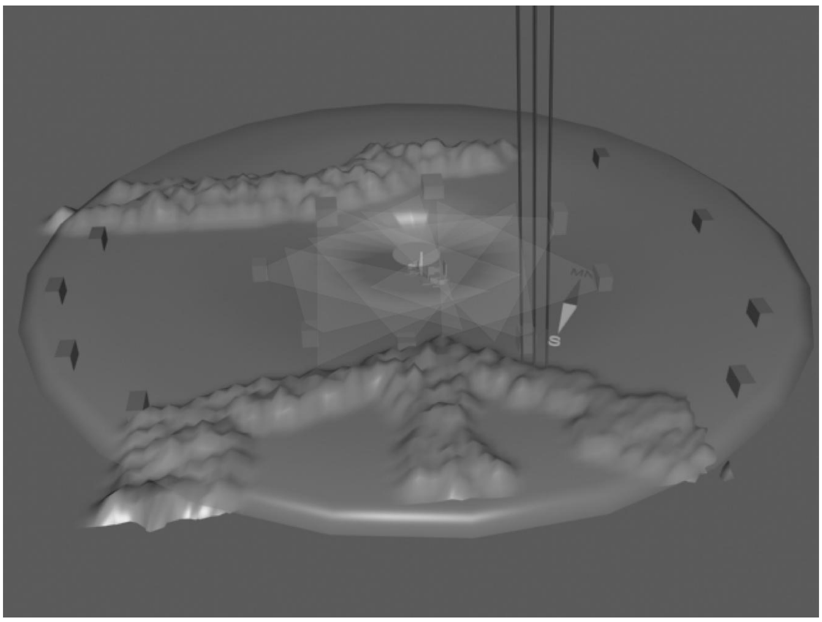

Figure 2: Artist conception of the experimental arrangement. HIPAS is in the center of the array radiating a coherent signal. The radiation pattern of each receiver is shown as an overlapping shade. The earth's magnetic field is represented by vertical magnetic field lines.

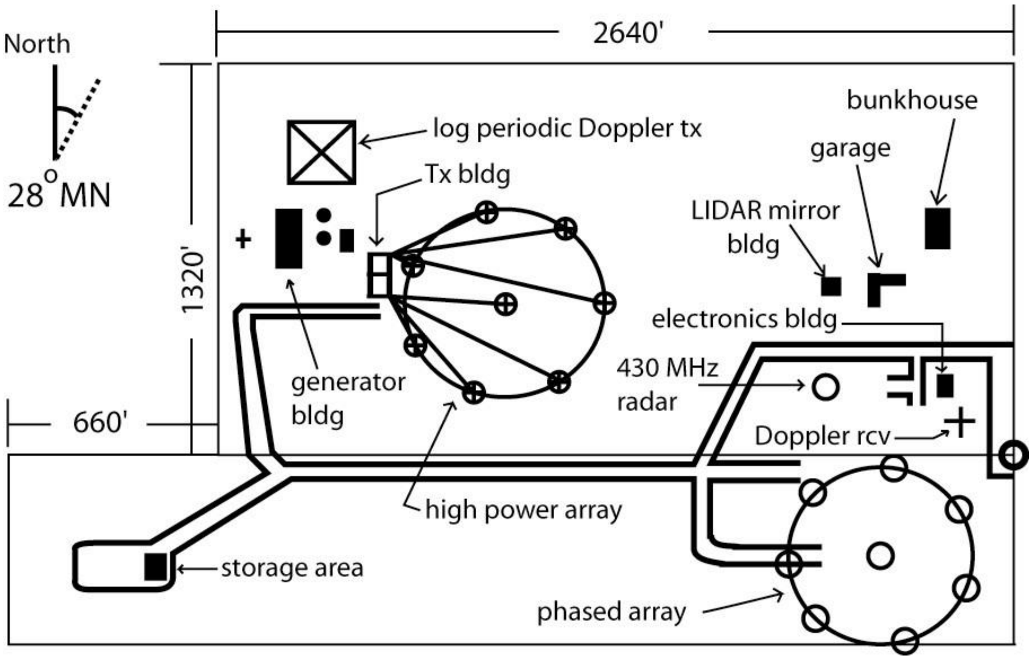

Figure 3: Antenna arrays at the HIPAS Observatory, Fairbanks, Alaska. The frequencies used range from HF to Laser regimes.

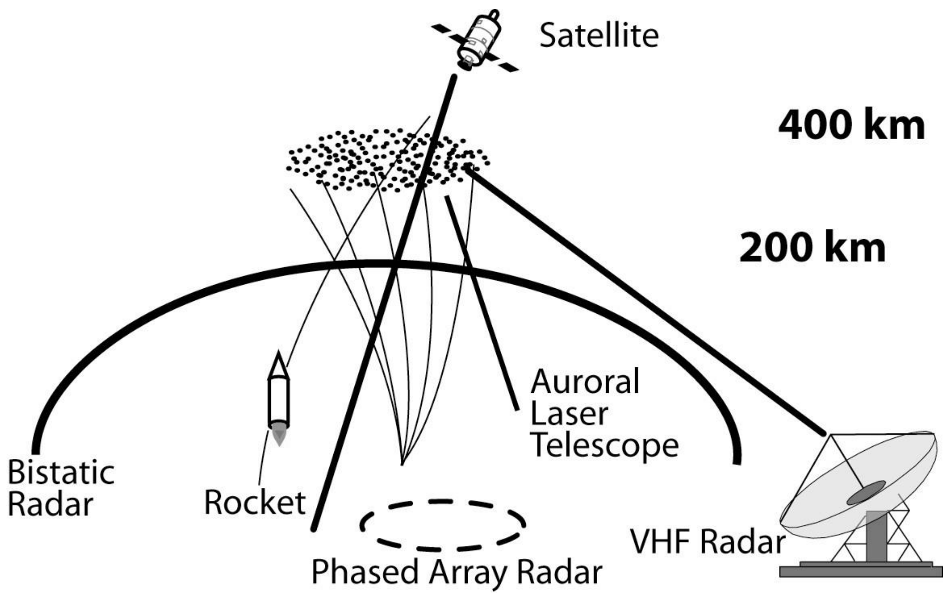

Figure 4 Schematic showing the various diagnostics used in an experiment to investigate the interaction of electromagnetic waves with the ionosphere.

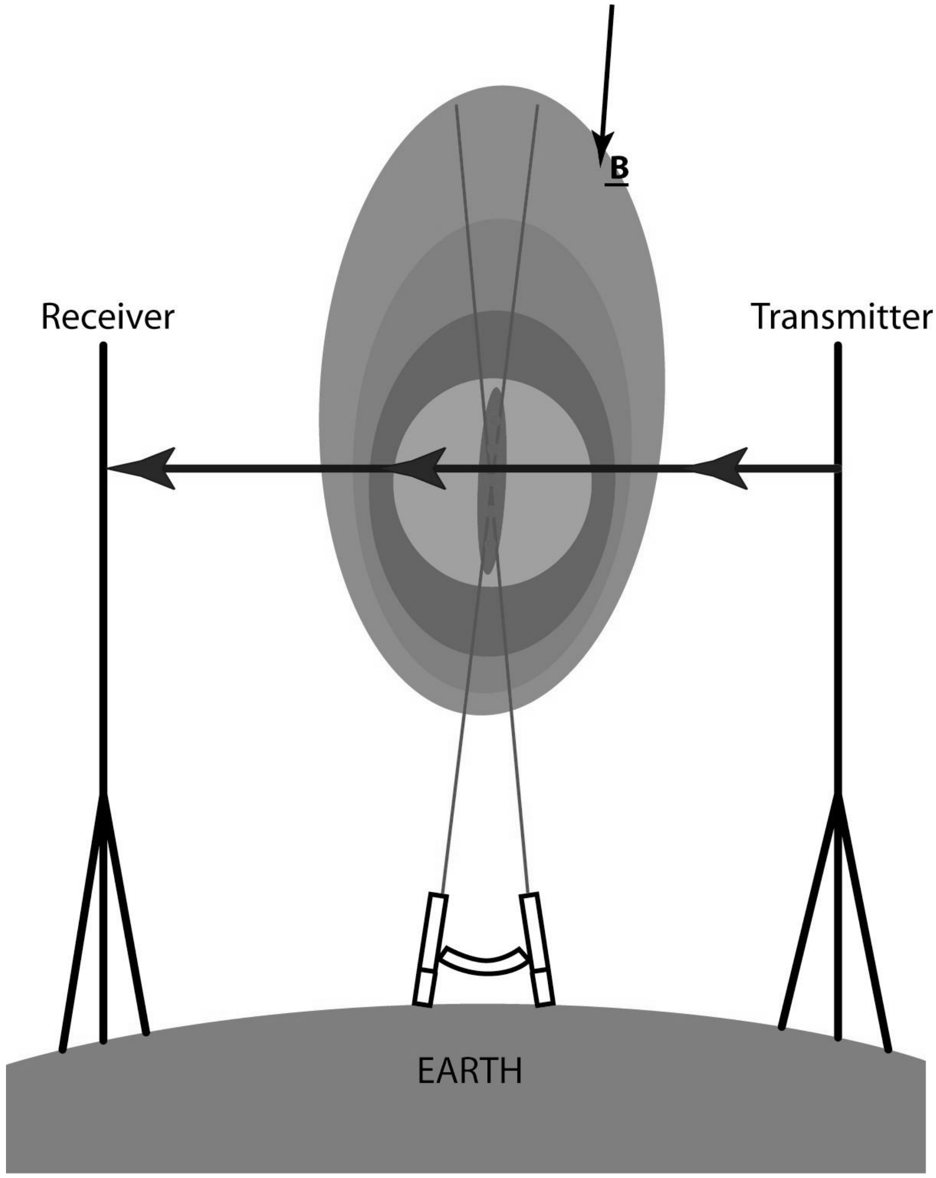

Figure 5 Schematic showing a calibration procedure using a laser to ionize dusts at a height of 100m. The electrons generated will cause phase shift in the coherent signal detected by the receiver.