Ultra Low Frequency Wave effects on the Square Kilometre Array

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Introduction:

The proposed Square Kilometre Array (SKA) will be the worlds largest Radio Telescope with a maximum baseline of over 5500 km, 50-100 times the sensitivity and 10,000 times the survey speed of current generation telescopes. Possible sites are located in Australia and South Africa. The Australian option has a central core site at Boolardy Station, Western Australia.

The frequency range will be from 70MHz – 3GHz+, reaching deep into the bands used for radio, wireless, mobile, TV, aircraft, and other transmissions, so the site needs to be as radio quiet as possible.

The array points of the SKA, along with the complex correlation algorithms allow the telescope to perform Very Long Baseline Interferometry. This requires information about the phasing of signals from each antenna.

There are a number of natural phenomena that perturb the ionosphere plasma. This poster focusses on Ultra Low Frequency (ULF) waves which are generated through the interaction of the solar wind with the Earth's magnetosphere. These perturbations alter the ionosphere total electron content (TEC) through the ***advection*** and ***divergence*** mechanisms described by Poole and Sutcliffe (1987):

$$\Delta TEC = -Advection - Divergence = -\left(-\int_0^s -v_z \frac{dN_e}{dz} ds\right) - \left(\int_0^s N_e \nabla \cdot \bar{v}\right)$$

The refractive index can be calculated from the Appleton Hartree equation:

$$n^2 = 1 - \frac{X}{1 - jZ - \left(\frac{Y_T^2}{2(1-X-jZ)}\right) \pm \left(\frac{Y_T^4}{4(1-X-jZ)^2} + Y_L^2\right)^{1/2}}$$

In this poster, we estimate typical phase shifts experienced by radio astronomy signals, due to TEC perturbations induced by ULF waves.

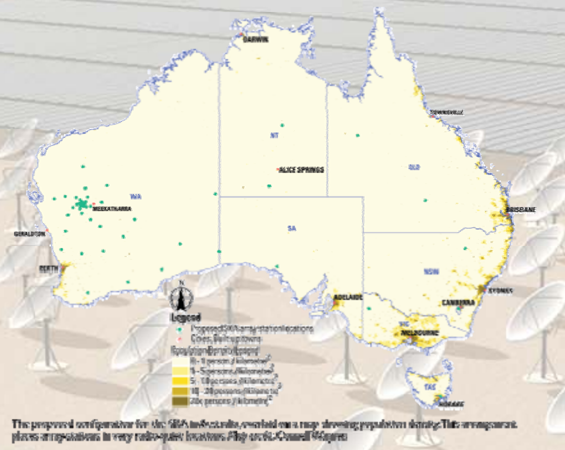

Figure 1: A proposed setup for the SKA in a Logarithmic 5-arm spiral to maximise spectral coverage

ULF Waves in the Ionosphere:

The SuperDARN radars routinely show ULF wave induced perturbations in the ionosphere plasma. Figure 2 shows a typical example from the TIGER-Bruny radar in Tasmania.

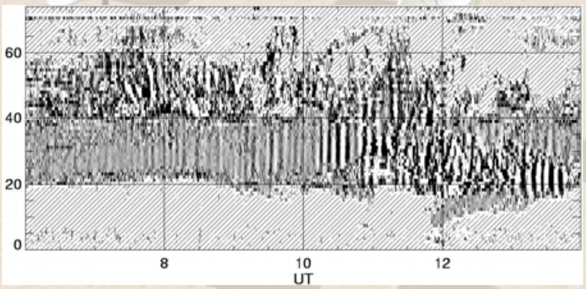

Figure 2: Doppler oscillations produced by ULF wave activity in the ionosphere as seen by the TIGER-Bruny SuperDARN radar. The data were from beam 14 for 06-14 UT, 21 February, 2000. Range-time cells with no data have diagonal shading. A detailed expalantion of these data are provided by Ponomarenko et al., 2003.

ULF Data

Data from the Learmonth magnetometer were analysed for typical ULF wave amplitude, frequencies and wave mode. The average power over 5 mHz bands over 3 months (each season) were calculated. Evidence for an enhanced amplitude, field line resonance was found at 65mHz.

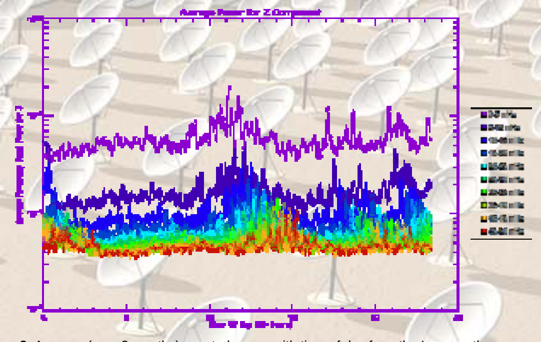

Figure 3: Average (over 3 months) spectral power with time of day from the Learmonth Magnetometer data separated into various frequency bands. Note the Frequency shifted with time peaks. The cause of this behaviour is unknown.

TEC Variations and the SKA

The ULF amplitudes at the ground were mapped back into the ionosphere using the model of *Sciffer et al., 2005*. The advection and divergence terms were calculated to give the changes in TEC. Using the Appleton-Hartree equation, the phase delay of 70 MHz signals were obtained as a function of the ULF wave spatial scale size, as shown in Figure 4.

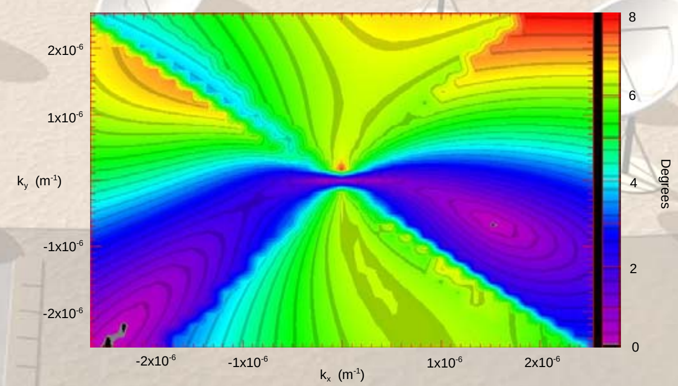

Figure 4: Phase delays (in Degrees) for a 70MHz signal affected by a 65mHz ULF wave with 5 nT (horizontal component perturbation) at the ground.

References

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R.T. Schilizzi *et al*, "Draft Specifications for the Square Kilometre Array", 2007 (Available online at: http://www.skatelescope.org/PDF/Draft_specifications_10Sep07.pdf , Last Accessed 2/2/2008)

T.H. Stix, "Waves in Plasmas", American Institute of Physics, 1992

Notes on the SKA Poster

1. Planetary and Space Science ran a special issue in 2004 on the SKA and associated technology (such as LOFAR). See, for example, Kassim et al., "The low-frequency array (LOFAR): Opening a new window on the Universe, Planet. Space Sci., 52, 1343, 2004.

2. T. L. Gaussiran et al., "LOFAR as an ionospheric probe", Planet. Space Sci., 52, 1375, 2004 highlights the importance of expertise in near-Earth space science for radio astronomy. These research areas should work together rather than compete for resources.

3. The poster provides some Results for a range of ULF wave spatial properties. ULF wave research has advanced greatly since the 1950s by near-Earth Space (Solar-Terrestrial) Physicists. Studies from South Africa (Sutcliffe and Poole), Japan (Yoshikawa and Itonaga))and Australia (Sciffer and Waters) have provided more detailed insights into the interaction between ULF wave energy and the ionosphere. It has been possible to experimentally verify the theoretical models using SuperDARN and Doppler sounder data.

4. We know the ULF wave parameters that alter the ionosphere electron distribution:

ULF wave mode mix (fast or shear Alfven modes)

Geomagnetic field dip angle (Sciffer and Waters)

ULF wave frequency (Inductive or 'back emf' effect described by Yoshikawa and Itonaga)

Spatial scale size of the ULF disturbances

Ionosphere conductivities

ULF waves are ubiquitous in the magnetosphere and ionosphere. The poster provides some insights as a function of ULF wave spatial scale size. Further studies would examine the other parameters listed above.

5. Disturbed conditions would give ULF magnetic perturbation amplitudes greater than the 5 nT ground magnitude chosen in the poster. This ground magnetic perturbation amplitude scales with the radio signal phase differences plotted in Figure 4. Larger phase differences mean greater complexity for the radio telescope interferometer correlator.

6. ULF waves occupy a band of frequencies (mHz to Hz). Each sub-band (Pc1-5 etc.) has various propagation and generation mechanisms that are the subject of current research. Therefore, ULF wave disturbances are certainly not limited to a single frequency as chosen for the poster. A given ULF time series contains multiple spatial scale sizes and enhanced frequencies. Since the 1990s we can routinely identify FLRs (enhanced shear Alfven modes). Research on the properties of the fast mode and how they mix with the shear Alfven mode continues. For example, Figure 3 shows a time shift in ULF wave power as a function of frequency, up to 2 hours for the 45-50 mHz band. This is season dependent.

7. These ULF wave properties also vary with latitude, becoming less sinusoidal and larger in amplitude at higher latitudes. There is a remarkable difference between the time series of ULF waves recorded by magnetometers located at L=1.8 (Newcastle) compared with L=2.0 (Canberra) or L=2.8 (Tasmania). For example, multi shear Alfven FLR harmonics are often seen in the data from Tasmania. A telescope that spans a wide range of latitudes (over Australia) would need to consider these differences.

8. In addition to ULF waves, larger TEC variations occur due to gravity waves, TIDs and other ionosphere disturbances that propagate from the high latitude regions.