Solar Astronomy at DSES

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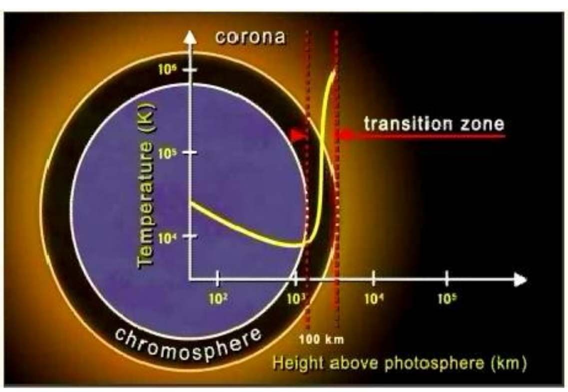
Plasma Motion Detection at Radio Frequencies

A phenomenon of interest is the increasing temperature from the solar photosphere to the solar corona. I've been thinking about testable hypotheses for how to measure the different altitudes (via a temperature scale) of the transition zone (between photosphere and corona) of the sun. I think if we choose the appropriate frequencies, one close to the surface, say 11.7 GHz and one above the 2km breakpoint, say 12.2 GHz we might test for a couple of possible phenomena: (1) At Extremely Low Frequencies (ELF), are we seeing a Doppler shifting in the phase of plasma motions, and (2) in a polarized recording of data, can we measure electromagnetic waves in both electric and magnetic components. The temperatures that are being measured at 11.7 GHz are approximately 15,000 Kelvin and the temperature at 12.2 GHz is approximately 17,000 Kelvin. The plasma motions between these two temperatures, should be a measure of the thermal Doppler motion in the solar plasma as phase differences between the two frequencies.

Introduction:

The temperatures resulting from the emission of microwaves at the two frequencies noted above occur at different altitudes in the transition zone separated by a few hundred kilometers. However, depending on the opacity of the Sun's transition zone we're looking at variations of the transition zone's plasma motions between the two frequencies, which may change depending upon solar activity such as flares.



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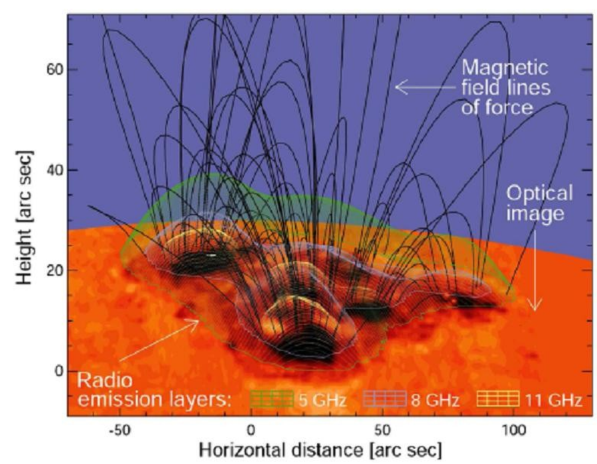

Radio Emissions from Solar Active Regions

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A radio receiver capable of detecting ELF (sonic) thermal plasma motion requires the ability to output in frequency buckets that are separated by a two Hertz. In addition, the output of the Local Oscillator (LO) must be low enough to not contribute significantly to the desired result. This allows the analysis to discriminate between the ELF components of the received signal from those of the solar drift scans. Currently, Paul Oxley's (2007) solar radio uses an Invacom QPH-031 dual polarities, dual frequency LNB that is available from the Receive Only Satellite market.

Table 1: Receiver stability requirements for measuring ELF waveforms on Sun.

Long Term Frequency Stability	**+/- 100 ppm Max**
Short Term Frequency Stability	**10 Hz/Second**
Power Output	**+13 dBM**
Tones (All sources)	**-18 dBc**

Illustration 1: A 90 centimeter offset dish with Invacom QPH-031 dual polarity dual frequency LNB.

Methods:

Currently, Paul Oxley's (2007) solar radio uses an Invacom QPH-031 dual polarities, dual frequency LNB that is available from the Receive Only Satellite market. The four LNB outputs are at L Band Intermediate Frequency (IF) (950 MHz to 1450 MHz). The two linearly polarized inputs are in the frequency band 11.7 GHz to 12.2 GHz. The circular polarity inputs are in the band 12.2 GHz to 12.7 GHz. The IF is down converted to base band and sampled by a 20 MHz A/D converter using the National Instruments PCI5102 board. The two frequencies are phased locked (PLL) down to 2 Hertz, which is the ELF of interest. Table 1 lists the receiver stability requirements for measuring ELF waveforms on the Sun. Illustration 1 shows the Invacom QPH-031 dual polarity dual frequency LNB to the right of the opened chassis view of Paul Oxley's receiver. Illustration 2 shows the Invacom QPH-031 dual polarity dual frequency LNB on a 90 cm offset dish.

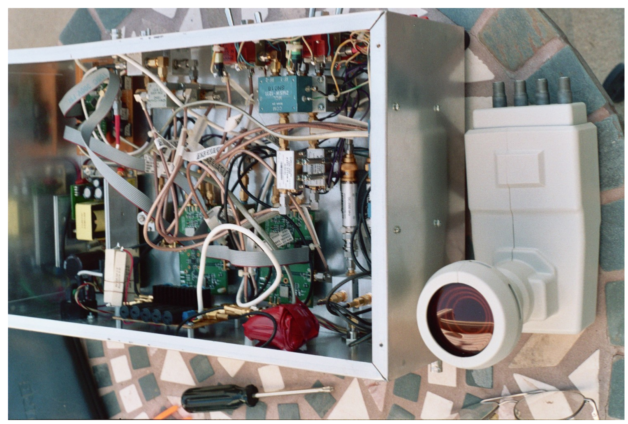

Illustration 2: Invacom QPH-031 dual polarity dual frequency LNB (right) and Paul Oxley's receiver (left).

Before solar observation can be made, the receiving system is characterized. The antenna was pointed to a group of trees so the receiver was subjected to "ambient" noise calibrated as a 300 K background. The data collected are in a time series, which is an ordered sequence of observations (Riggs, 2007). In the resulting captured data, the sequence is through time, and we make the assumption that each consecutive observation is separated by the same time interval.

Results:

For every daily Sun Scan there is a 2 second snapshot taken at the peak of the sun scan. These data from all 4 channels are captured as Angle, Imaginary, Real and Magnitude values. Then a FFT run does a quadrature cross correlation at 2 Hertz bins. When all values are positive together there maybe a good chance we are detecting plasma motion in the transition region at Extremely Low Frequencies.

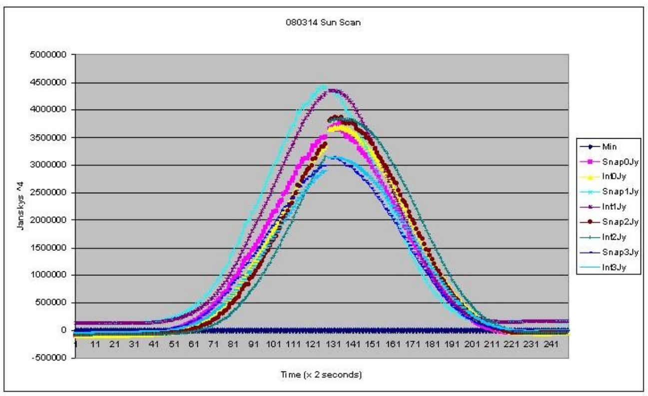

Illustration 6: Channels 0 - 3 during a Sun Scan. There is pause near the peak where a 2 second snapshot of data was taken for the Quad Cross Correlation routines to examine possible ELF motions.

```
ptr0 = ch0fftptr;
     ptr1 = ch1fftptr;
     ptr2 = ch2fftptr;
     ptr3 = ch3fftptr;
     crossptr = fftcode->compalloc(ch0FFTsamps);
          ELF_FFTEditCntl->Insert("QUAD CROSS
DATA\nFREQ,REAL,IMAG,MAG,ANGLE\n");
          i = 0;
          for(ptr=crossptr; ptr!=NULL; ptr = ptr->next) {
                   if(i > ch0FFTsamps/2) break; // Printout
lower half +1
       if(ptr0 == NULL || ptr1 == NULL || ptr2 == NULL || ptr3
== NULL) break;
       // Create Products
       ptr->freq = ptr0->freq;
       ptr->mag = sqrt(sqrt(ptr0->mag) * sqrt(ptr1->mag) *
          sqrt(ptr2->mag) * sqrt(ptr3->mag));
       ptr->angle = (ptr0->angle + ptr1->angle + ptr2->angle +
          ptr3->angle) / 4;
       ptr->real = ptr->mag * cos(ptr->angle);
       ptr->imag = ptr->mag * sin(ptr->angle);

                   sprintf(buf,"%.1f,%g,%g,%g,%g\n",
          ptr->freq ,
          ptr->real * meanJy / bw // Restore Jy Val
      ,ptr->imag * meanJy / bw
      , ptr->mag * meanJy / bw
      ,ptr->angle );
    ELF_FFTEditCntl->Insert(buf);
    i++;
    ptr0 = ptr0->next;
    ptr1 = ptr1->next;
    ptr2 = ptr2->next;
    ptr3 = ptr3->next;}
  ELF_FFTEditCntl->Insert("END QUAD CROSS DATA\n");
```

Illustration 7: This is the result of a Quad Cross Correlation starting at 0 Hertz to 100 Hertz (in 2 second bins). When Real, Imaginary, and Magnitude values are positive there may be a significant correlation between the two frequencies and a possible indication of plasma motion and electron precipitation at these extremely low frequencies. In this case at bin 25 (50 Hertz) and bin 37 (74Hertz).

Discussion:

In the tradition of George Gamow, who wrote a book called: *The Birth & Death of the SUN*, 1952, which has caused me to work up a computer model, because I think there is a passage in the middle of his book, although written 55 years ago, which might well translate into a description of the transition region this whole project is trying to study.

This transition zone might be the product of two phenomena, which Gamow describes on page 92-93:

> "… particles of a hot gas do not all move with exactly the same velocity, but show a rather broad velocity dispersion known as the Maxwell distribution. It is true, of course that the number of particles possessing anomalously large energies is comparatively small; but we must not forget that the effectiveness of collision rapidly increases with the increasing energy of impact. Thus, although few, these high-energy particles can be of great importance for the total disintegration balance. In Figure 1 the curve A represents the familiar Maxwellian energy-distribution of thermal motion, giving the relative number of the particles of gas possessing different values of energy (E). The curve B, on the other hand gives us the disintegration ability (penetrativity of nuclear barriers) of particles corresponding to these energies. Finally, A x B, the product of these two curves, represents the total disintegration effect (number of particles times their relative effectiveness). We see at once that the maximum effect corresponds to a certain intermediate energy value for which the number of particles is not yet too small and their penetrativity of barriers is already sufficiently high. "

Gamow's description can be used to fit the transition region, and with Paul Oxley's radio we may be looking at two microwave temperatures in the transition region: the 11.7 GHz is somewhere around 15,000 K and the 12.2 GHz is about 17,000 K (Rose, 1998). It is important to calculate what Gamow is describing by creating a distribution which is the product of A; Planck's blackbody radiation curve, and B; the increase in x-ray and gamma ray flux density created at the photosphere. Using the Inverse Compton Effect (ICE) in place of Gamow's energy (E), we can characterize the electron precipitation in the transition region where, '… A x B, the product of these two curves, represents the total disintegration effect (number of particle times their relative effectiveness)' in penetrating this region and transferring high temperatures up into the corona.

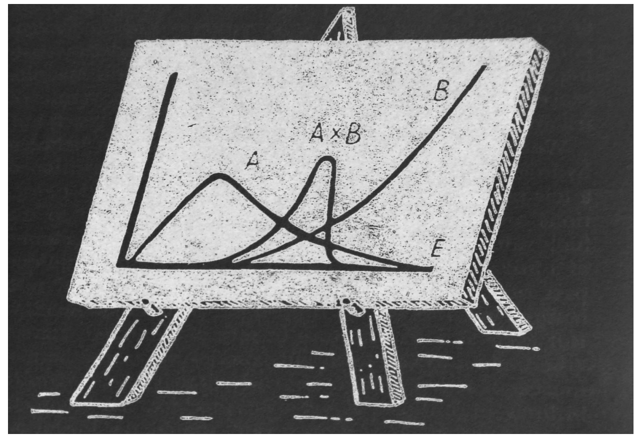

Illustration 8: The above graph, and equations below, represent the maximum radiative pressure (A X B) for the thermal energy (A) of the photosphere required to penetrate the transition region at the start of the Sun's corona (B), and possibly represent the transition zone being measured by the two microwave frequencies 11.7 GHz and 12.2 GHz.

```
Temperature of transition zone of Ch0,
K ~ 15000
Temperature of transition zone of Ch2,
K ~ 17000
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T= 15000., IONT= 17000., Iterations= 20, x-div= .10, P value= .50

TZ=km	ICE	A=(hv) Frequency	B=g-ray Flux Density	AXB
2100	.574549E+01	.108254E+10	.376824E+12	.000000E+00
2110	.517898E+01	.125703E+10	.333788E+12	.184229E-40
2120	.387884E+01	.190817E+10	.238610E+12	.642654E-25
2130	.205284E+01	.474130E+10	.115927E+12	.160268E-03
2140	**.132719E+01**	**.954335E+10**	**.637136E+11**	**.341926E+05**
2150	.274384E+01	.429538E+10	.104637E+12	.467137E-11
2160	.627436E+01	.116095E+10	.333034E+12	.000000E+00
2171	.107968E+02	.524063E+09	.669651E+12	.000000E+00
2181	.166835E+02	.285991E+09	.114539E+13	.000000E+00
2191	.244185E+02	.172360E+09	.180422E+13	.000000E+00
2201	.346586E+02	.110198E+09	.270905E+13	.000000E+00
2211	.482313E+02	.732590E+08	.394257E+13	.000000E+00
2221	.661153E+02	.501309E+08	.560608E+13	.000000E+00
2231	.893911E+02	.351406E+08	.781529E+13	.000000E+00
2241	.119164E+03	.251820E+08	.106929E+14	.000000E+00
2251	.156466E+03	.184354E+08	.143586E+14	.000000E+00
2261	.202156E+03	.137844E+08	.189180E+14	.000000E+00
2271	.256839E+03	.105240E+08	.244531E+14	.000000E+00
2281	.320819E+03	.819994E+07	.310157E+14	.000000E+00

These are 4 non-linear differential equations to substitute for real experimental values of the constants needed to create the Gamow curves (distributions) as particles increase in radial distance from the photosphere, and attempt to penetrate the transition zone.

The formula used is as follows:

1). for h (substitute for Planck's constant)

h = e((((ln(r)) * pi)-1) cos-1)
h = 1/ (pi*2)*h

2). for mass m (substitute for m)

m = e((((ln(r))/.4)-1) cos-1)
m = 1/m

3). for E2 (substitute for electric charge)

E2 = (e(atan((ln(pi*m))-1)))-1

4). for Boltzmann's k (substitute for k)

k = ((e(atan(e(pi*ln(ln(r))))))**3)-1

5). alpha = (h / mc) (Black Body Curve)

6). Inverse Compton Effect (ICE),
Cumulative (beta dist.)
ICE=1/(3*pi*(h**3*v**3))*(3*sqrt(E2)/(4*pi*m*v))**(kT))

where;

alpha = ((h/m*c)/ICE)
beta = ((ICE*v)*(m*c))
gamma = ((alpha+beta)**(-ICE))*c2

r = radial distance from the photosphere
v = some Very Low Frequency,
T = microwave temperature being recorded in the transition zone
c = constant for light (distance in cm)

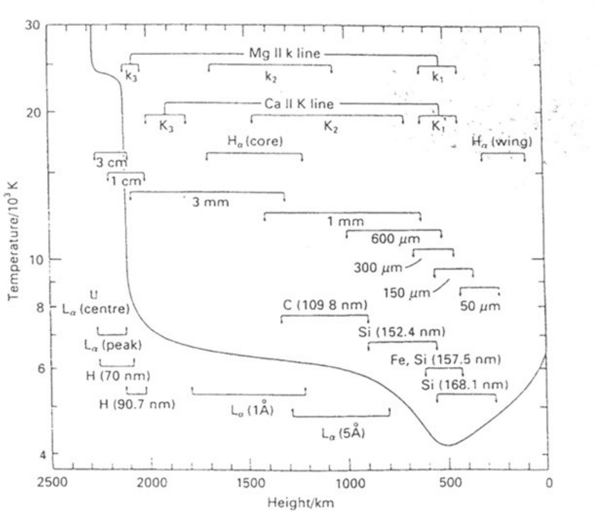

Illustration 9: The above equations and table of output represent the altitudes of the transition region for the temperature region being recorded, i.e., between 11.7 GHz and 12.2 GHz, approximately 2,140 kilometers above the photosphere (red). As there may be differences in altitudes of the transition region during active flares on the Sun, these are only estimates as in this Athay Chart, (1986).

Where the ELF Cross -Correlations recorded by the Solar Radio may indicate how these plasma motions in this region of the sun are transferring thermal energy into the corona, we'll only be able to test these hypotheses by analyzing data from a quite sun through the solar cycle of the upcoming active years, and comparing these data with other data collected on plasma motions between the photosphere and the corona.

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