VSRT MEMO #029

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To: VSRT Group
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Subject: Detection of the 3_{13}-4_{04} 11 GHz transition of ozone in the mesosphere using VSRT components.

Introduction

While millimeter-wave transitions of ozone at 101.737, 142 and 235.71 GHz are routinely observed in the mesosphere there are no published reports of detections of atmospheric ozone lines below 100 GHz. Measurements in the centimeter-wave band have some scientific advantages. For example, several ground based microwave radiometers of the Network for the Detection of Atmospheric Composition Change (NDACC) routine measurements of the ozone using the line at 110 or 142 GHz but have difficulty distinguishing between the ozone in the stratosphere, where the ozone is concentrated around 40 km, and the variable ozone concentrations in the mesosphere. This is because the thermal Doppler broadening equals the pressure broadening at about 50 km whereas the Doppler broadening at 11 GHz is ten times smaller and equals the pressure broadening at around 75 km.

The ozone is created in mainly the upper stratosphere by the Sun's ultraviolet rays acting on the oxygen molecules to form atomic oxygen which then combines with 0_2 to form 0_3. Ozone is essential as it protects life from excessive ultra violet radiation. The ozone in the mesosphere is destroyed during the day by photolytic action of the Sun whose ultraviolet is unfiltered. At night the ozone forms rapidly again from the reaction of atomic oxygen, with O_2 in collisions involving a 3rd molecule like N_2 in the mesosphere. The details of the diurnal variations have been studied by Wilson and Schwartz (1981) at 101.737 GHz and by Dumitru et al. (2006) at 142.175 GHz. The line at 11.072 GHz has the potential for a more detailed study of the processes which create and destroy ozone.

Line strength and profile

The atmosphere at 11 GHz is almost completely transparent and the line is very weak so that the brightness is given by

$$T(\nu) = I\int_0^{\infty}\left[T_L(h)\,n(h)\,\ell(\nu)\Big/\int_{-\infty}^{+\infty}\ell(\nu)\,d\nu\right]dh$$

where ν = frequency offset from line center (MHz)

I = line intensity (cm^2 MHz)

T_L = atmospheric temperature (K)

$\ell(\nu)$ = line profile

h = height in atmospheric (cm)

n = molecules/cm^3

The thermal doppler width of the Gaussian line profile is

$$\Delta\nu = 2.14\times10^{-2} T^{1/2} \Big/ \left(\lambda M^{1/2}\right) \quad (MHz)$$

where T = temperature (K)

λ = wavelength (cm)

M = mass in atomic units

$\Delta\nu$ = 18 kHz for 0_3 at 260 K

Pressure broadening is about 2 GHz at 1 atmosphere and decreases inversely with pressure and equals the thermal line width 1.0 *Pa* at about 80 km.

For ozone above 80 km the brightness is at the zenith is approximately

$$10^{-6.99}\times10^{-14}\times4\times10^{14}\times260/0.018 = 0.005K$$

for a column density of 4×10^{14} cm^{-2} or an equivalent of about 0.01 Dobson units, atmospheric temperature of 260 K and intensity of $10^{-6.99}$ nm^2 MHz. At 8 degrees elevation the opacity increases by about 4.5 and the brightness is about 0.02 K. Figure 1 shows a plot of the expected line in the day and at night using the mixing ratio data from Dumitru (2006).

Hardware setup

Figure 2 shows a block diagram of the hardware whose major components are:

18" satellite TV dish

LNBF Invacom SNH-031 03dB NF

1300 MHz filter

Mixer

1172 MHz 2nd L.O. (first L.O. at 9.75 GHz)

600 MHz LPF

EDGES mini-spectrometer

Figure 3 shows the antenna and LNBF pointed at 8° elevation.

Results of test observation

A "test" observation was made using the hardware set-up shown in Figure 2.

Figure 4 shows the result of about 30 nights of observation from 0 to 09 UT which is approximately 20 to 05 LT. The ozone line is only about 20 mK out of the approximately 100K system noise for the elevation of 8 degrees. The line center is at 11.07246 GHz ±10 kHz which is equal to the frequency of 11.0724545±0.1 kHz given by Colmont et al. (2005) to within the experimental error. The frequency of 11.072457 GHz ± 5 given by

Pochan et al (1969) is clearly in error by about 180 kHz. At this point I have not fit a spectrum as improvements in the spectrometer are planned and better observations should be possible. Owing to the weakness of the line frequency switching by 500 kHz was used to place the line in both the signal and comparison spectrum.

The spectrum was divided into the upper and lower portions. The difference was taken between the 2 halves and the result divided by 2. Further enhancement of the SNR could be achieved by folding about the line center frequency as was done in the early mm-wave work by Wilson and Schwartz (1981). Fig. 5 shows the spectrum from the daytime [The daytime data could be corrupted to some extent by the X-band radar which is very close to the VSRT.]

Potential for future enhancement

If the 11 GHz line is useful for ozone research the sensitivity could be enhanced by a least an order of magnitude by the following:

1] Improving the spectrometer efficiency. Under windows the VSRT spectrometer only gather data 20% of the time. The remaining time being taken up with data transfer and other latencies. A version written under Linux is at least 50% efficient.

2] Using both polarizations and adding more LNBFs. Since the equipment is not expensive it could be replicated. Twenty dual polarized units would improve the sensitivity by $\sqrt{40}$. It should also be pointed out that 11 GHz radiometer is less subject to weather than the NDACC millimeter-wave radiometers.

Potential for future teaching projects

The set-up to observe the 11 GHz ozone line requires more hardware. With some development it may be possible to replicate the added hardware at modest cost. The ozone observations provide unique data and could form a basis for some publishable research as well as being a data source for training students.

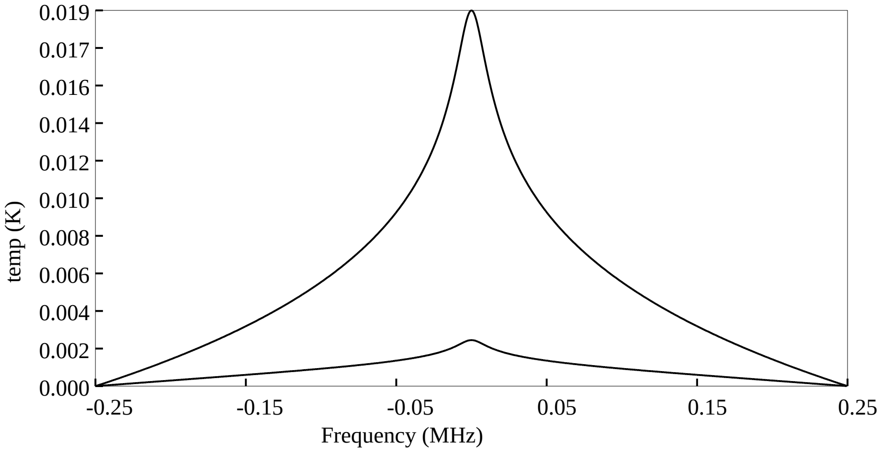

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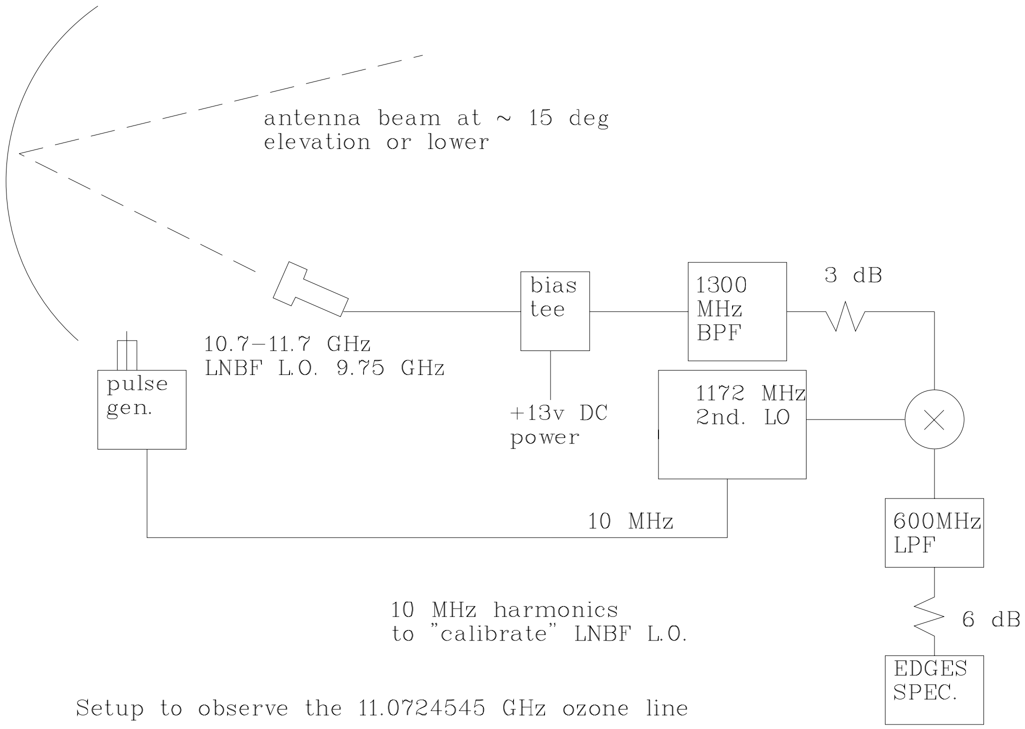
Figure 1. Estimated profile for the 11 GHz ozone at an elevation of 8 degrees. The upper curve is for nighttime and the lower for daytime. A “zero baseline” is taken at ± 0.25 MHz to show the line in a 1 MHz window. The nighttime profile assumes a 1 ppmv about 70km.



Setup to observe the 11.0724545 GHz ozone line

Figure 2 shows a block diagram of the hardware

Figure 3 VSRT antenna and LNBF set-up to observe the 11 GHz ozone line in the Mesosphere.

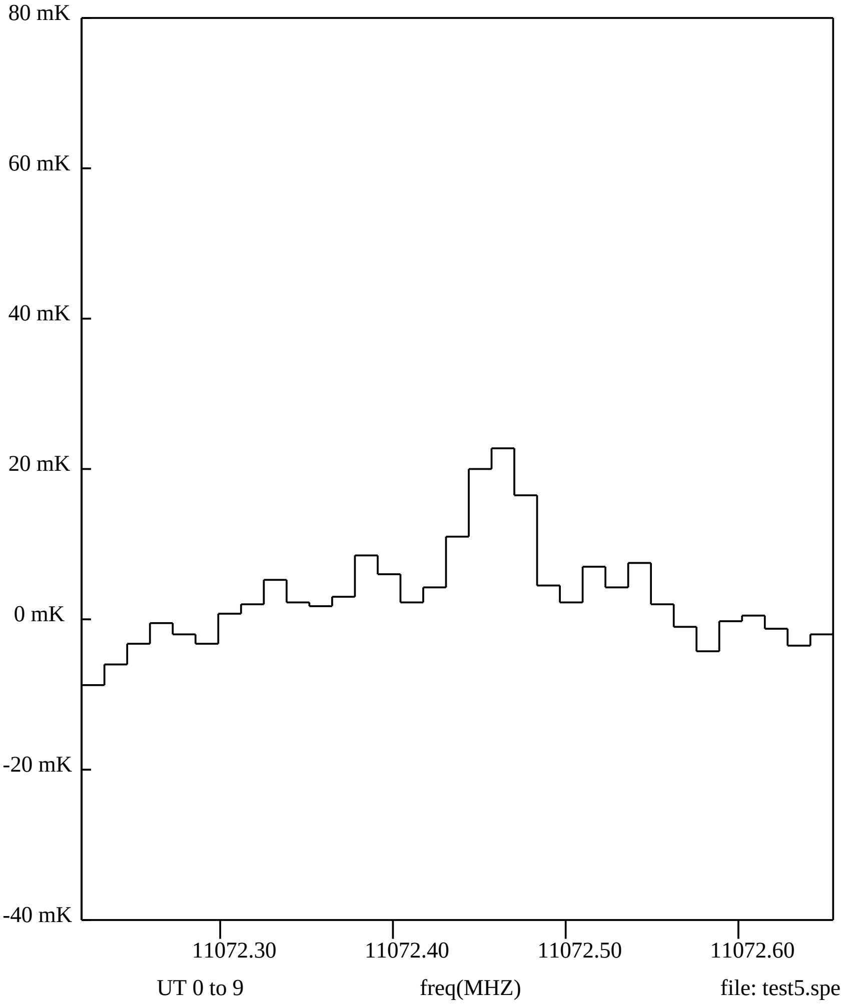


Figure 4. 11 GHz Ozone line observed at Haystack Observatory. The data is nighttime (0 to 9 UT) averaged from 1 through 30 September 2007. ± 1 sigma noise is ± 3 mK. A nighttime ozone concentration above 70 km in excess of 1 ppmv is required to be consistent with this data.

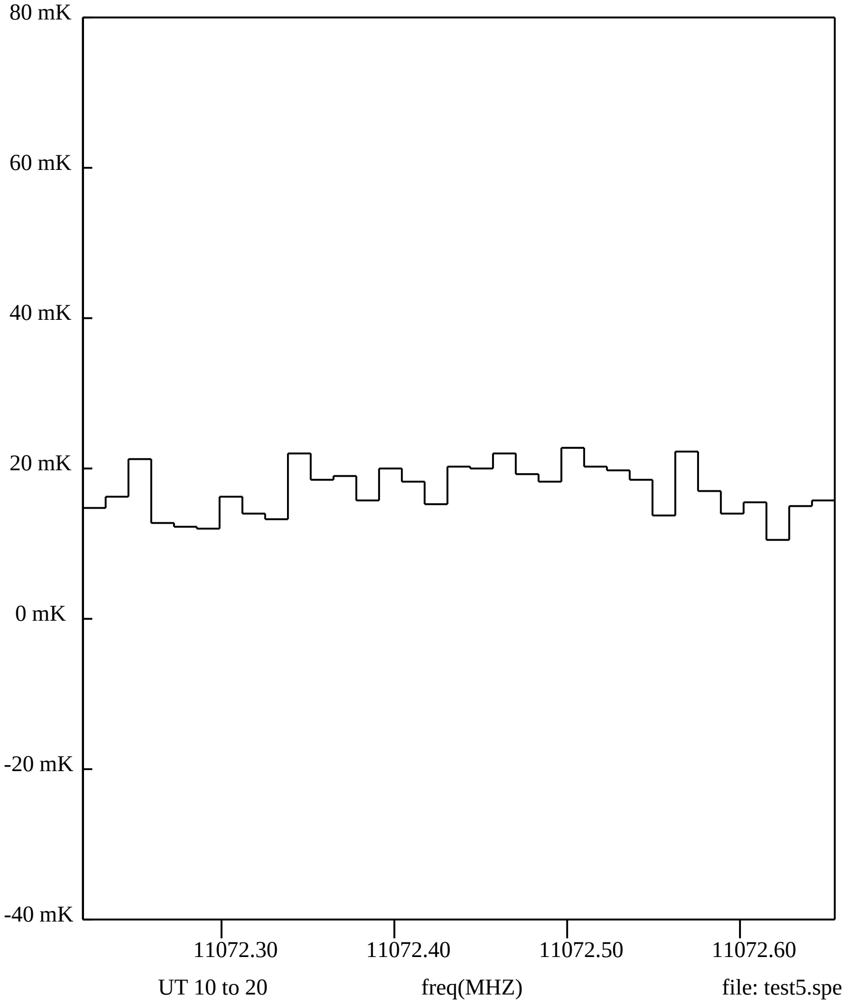


Figure 5. Daytime observations from 10 to 20 UT showing that the line peak at 11072.45 MHz disappears.

References:

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