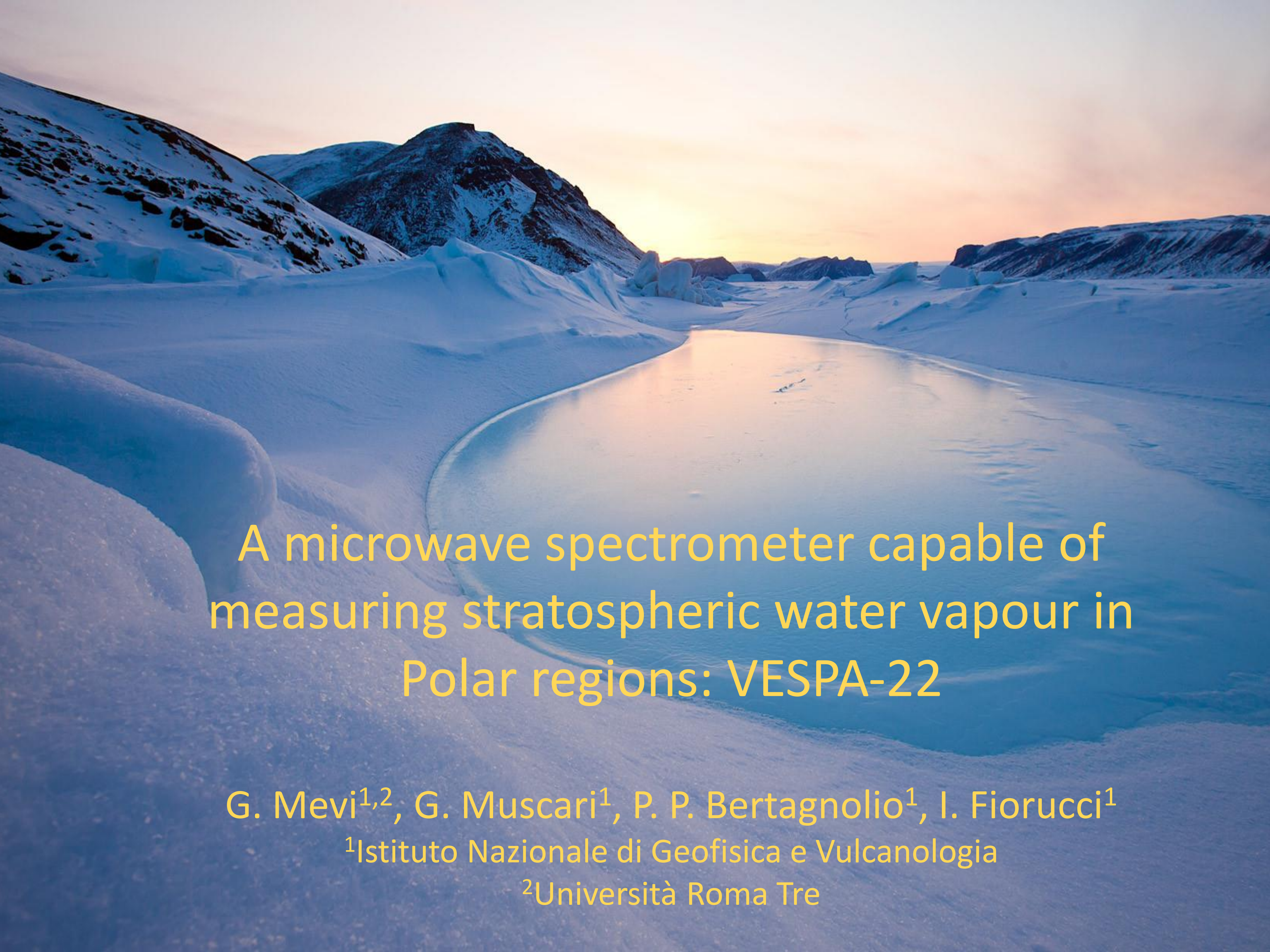


A microwave spectrometer capable of measuring stratospheric water vapour in Polar regions: VESPA-22

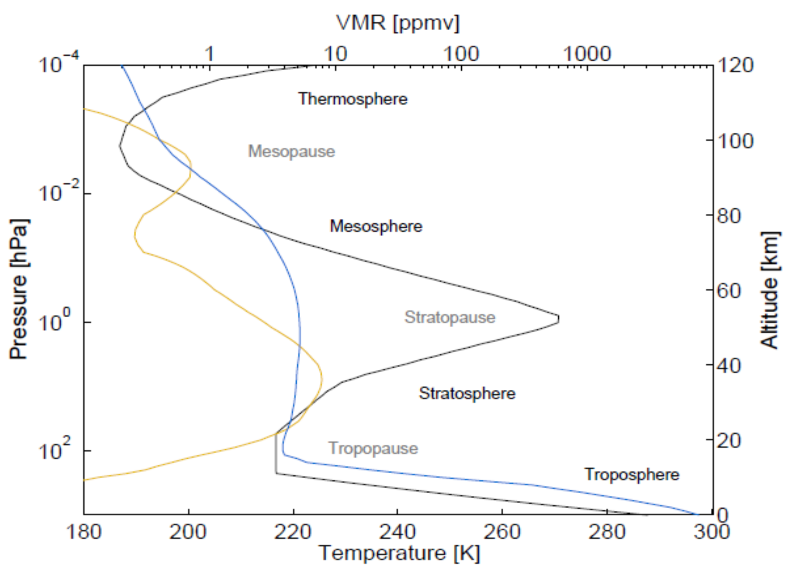
G. Mevi[1,2], G. Muscari[1], P. P. Bertagnolio[1], I. Fiorucci[1]
[1]Istituto Nazionale di Geofisica e Vulcanologia
[2]Università Roma Tre

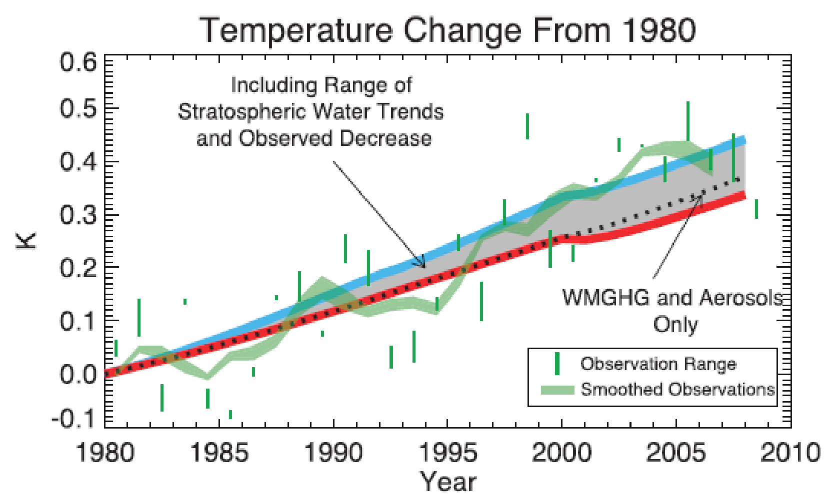
The importance of polar stratospheric water vapour

• Stratospheric water vapour regulates cloud formation in the upper troposphere and is involved in the surface temperature increasing measured in the last decades. (Solomon et al., 2010)

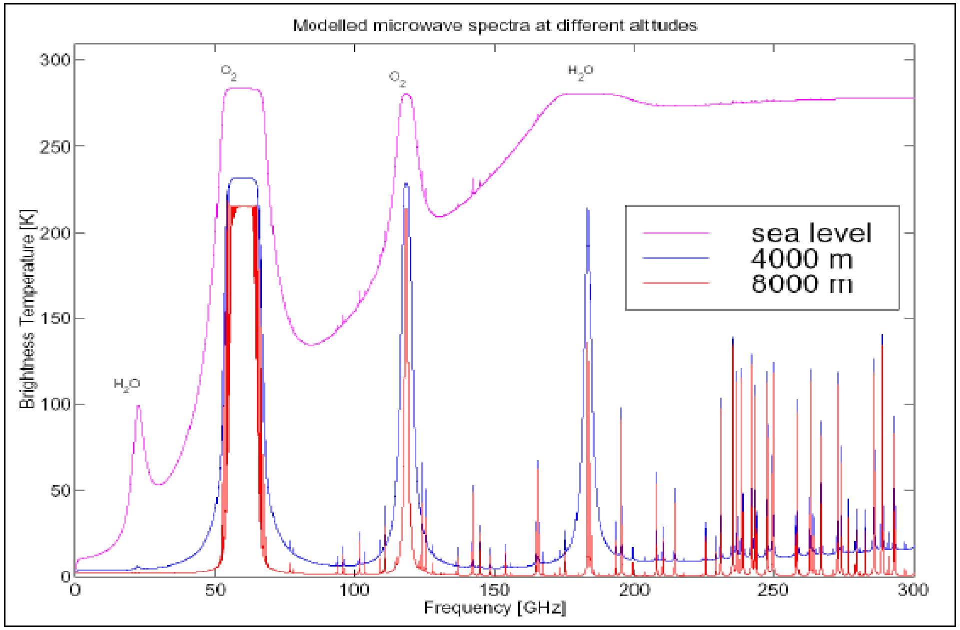
• It can be used as a tracer to study the air mass dynamics and the exchanges between troposphere and stratosphere (Holton et al., 1995).

• It has an important role in the seasonal ozone loss observed in the polar stratosphere.





An indirect measurement: the microwave spectroscopy

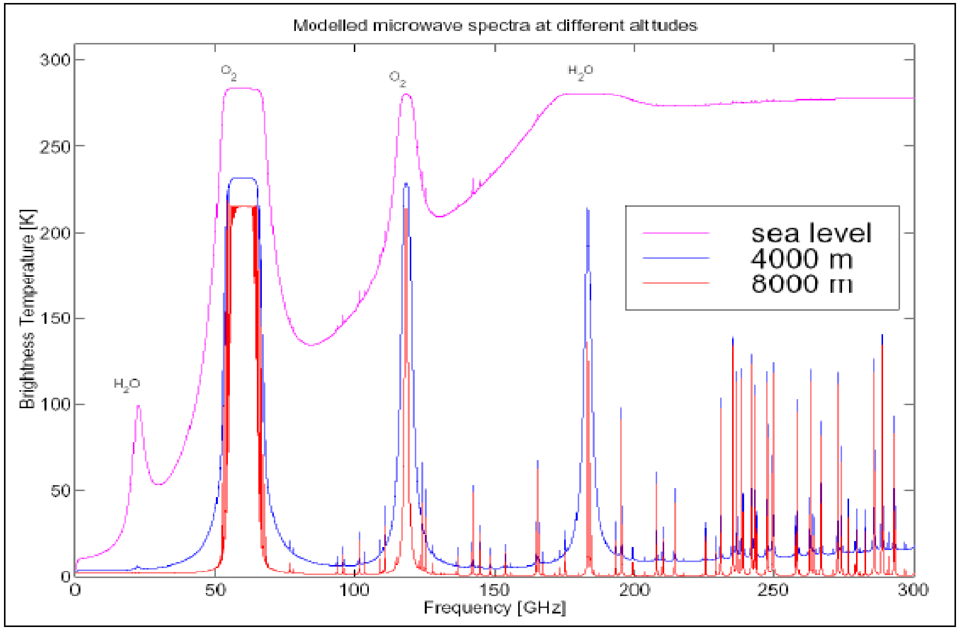


We can obtain information about the vertical concentration profile of the water vapour by measuring its thermal emission.

Benefits:

- The transition is between well populated states at typical stratospheric temperature
- We can take measurements during both day and night
- We can neglect the scattering due to aerosol and atmospheric molecules
- We can use low cost components to assembly the instrument

An indirect measure: the microwave spectroscopy



We can obtain information about the vertical concentration profile of the water vapour by measuring its thermal emission.

Disadvantages:

- We need at least 6 hours of integration of our signal to grant a significant signal to noise ratio
- We need an observation site characterized by a dry troposphere to minimize the signal absorption.

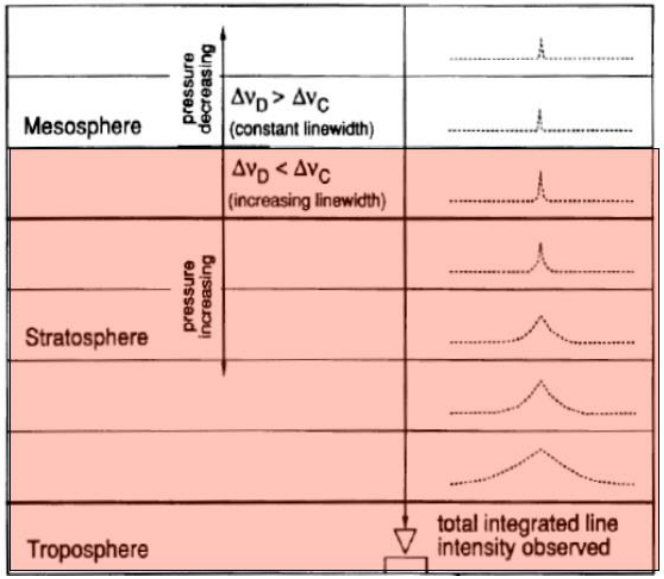
Key physical principles behind the measurement

Radiative transfer

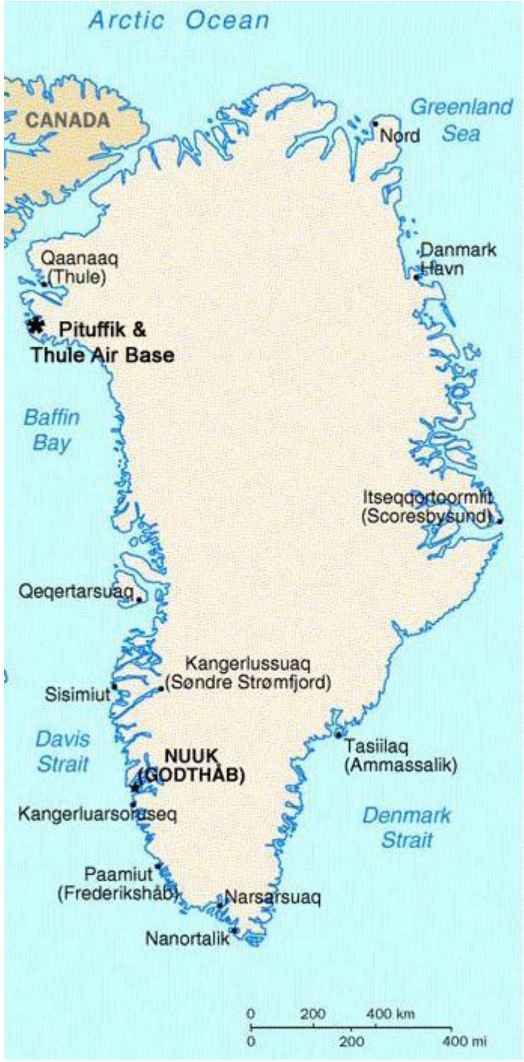
$$I_\nu\left(s_0\right) = I_\nu\left(s_{toa}\right) e^{-\tau\left(s_{toa}\right)} + \int\limits_{s_0}^{s_{toa}} B_\nu\left(T\left(s\right)\right) e^{-\tau(s)} \alpha_\nu\left(s\right) ds$$

Pressure broadening

$$\Delta\nu_L = wP\left(z\right)\left(\frac{T_0}{T\left(z\right)}\right)^x$$

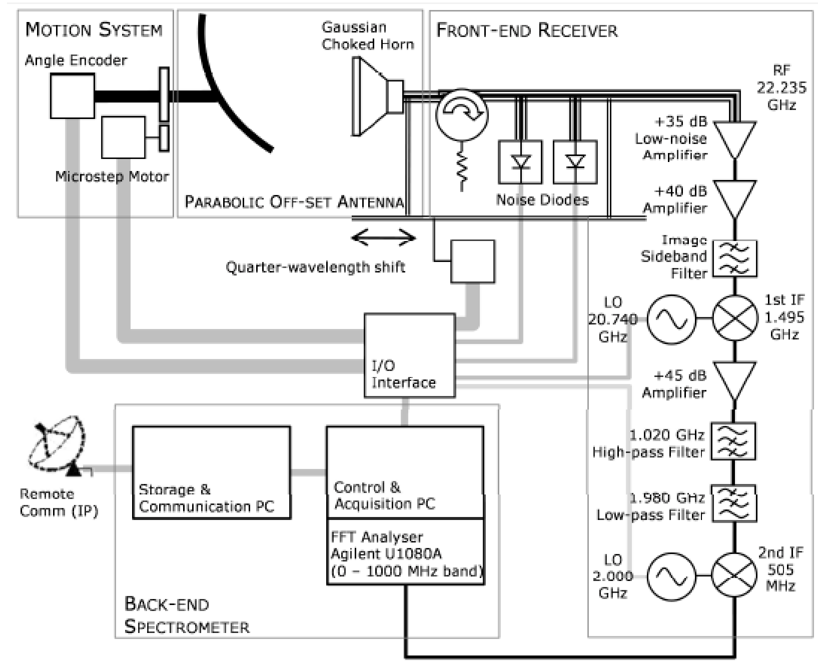


The spectrometer VESPA-22



Central frequency: 22.23 GHz
Bandwidth: 500 MHz
Frequency resolution: 31 kHz (16384 channels)
No need for cryogenic cooling
Theoretically we can retrieve H_2O vertical profile from 30 to 90 km of altitude

The spectrometer VESPA-22



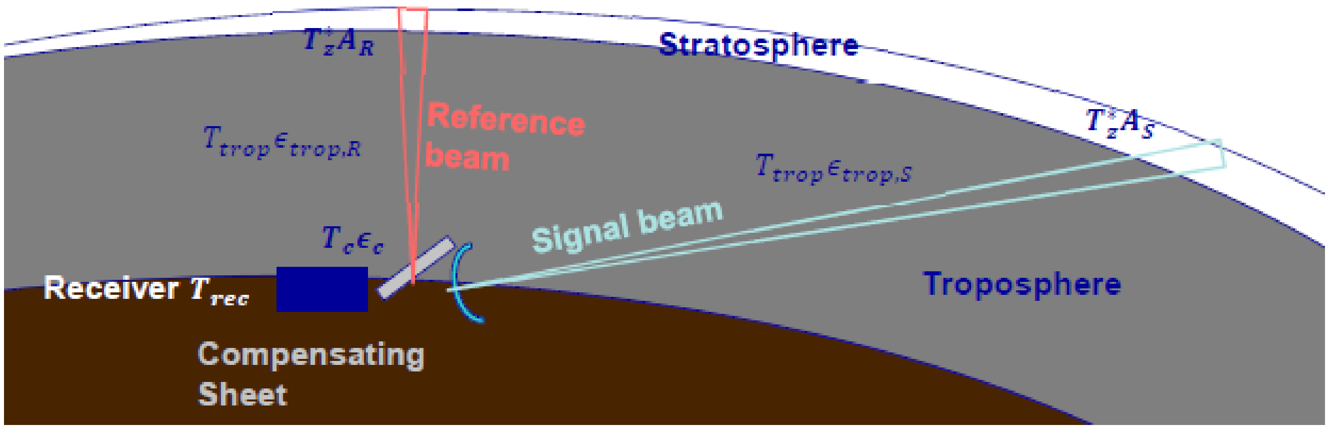
The signal is channelled to the front end electronics by a parabolic mirror

The mirror can rotate to receive radiation from different angles.

The front end is composed by low noise amplifiers, a noise diode to calibrate the signal and two mixers to shift the signal to lower frequencies.

The back end spectrometer converts the signal from the time to the frequency domain.

How to get the stratospheric signal: the balanced beams technique



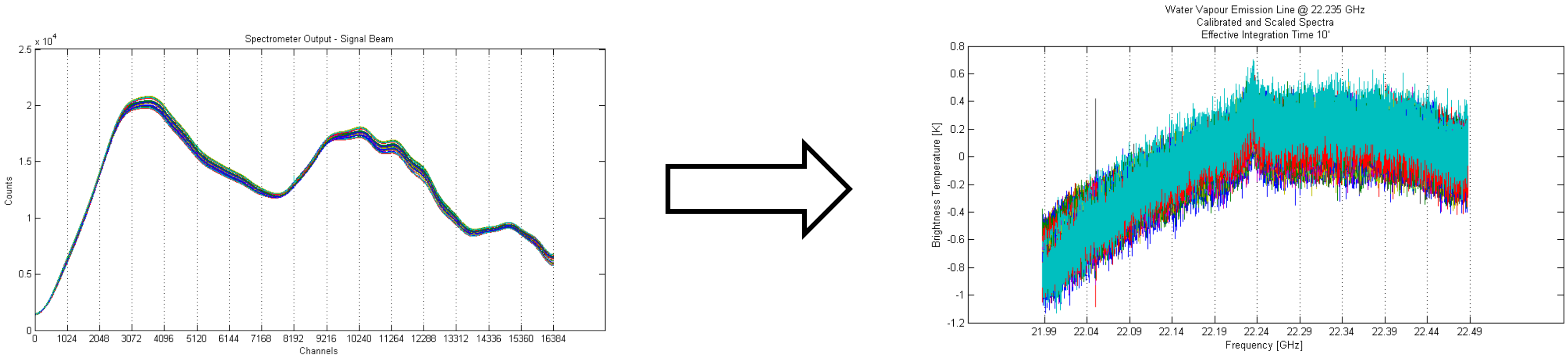
$$T_z(\nu) \simeq \frac{T_S(\nu) - T_R(\nu)}{\mu_s e^{-\mu_S \tau_z} - \mu_r e^{-\mu_r \tau_z - \tau_d}} = SF\left(T_S(\nu) - T_R(\nu)\right)$$

$$SF = \frac{1}{\mu_s e^{-\mu_s \tau_z} - \mu_r e^{-\mu_r \tau_z - \tau_d}}$$

The signal of our interest is very small compared to the tropospheric background signal.

In order to observe the stratospheric emission we compare the emission from two different beams at different zenital angles and rescale our measurement by a scaling factor.

How to get the stratospheric signal: the balanced beams technique



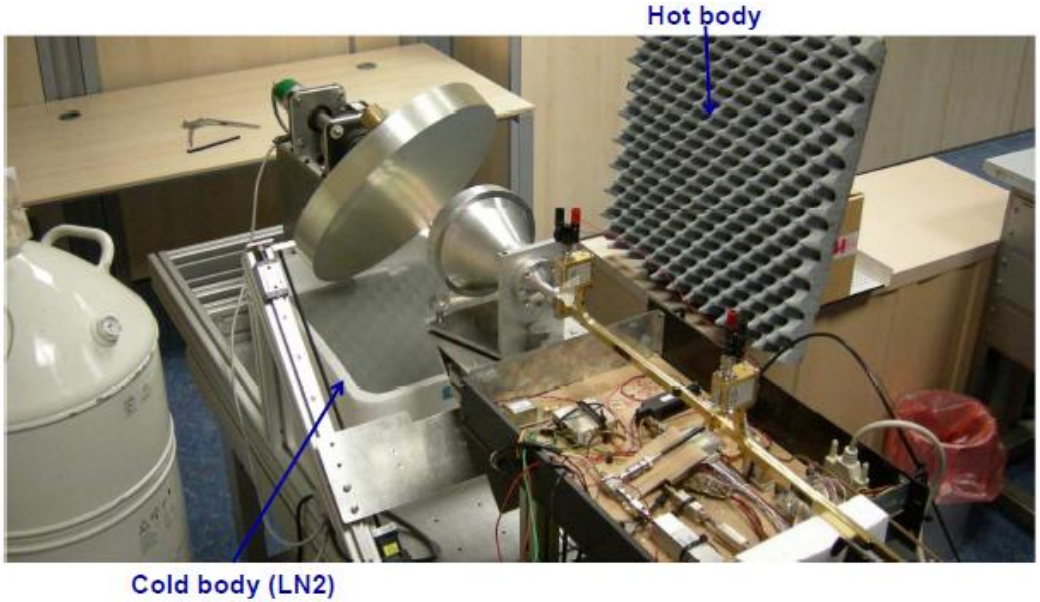
- By using this technique we remove gain nonlinearities from the spectrum
- **Tropospheric opacity** can change during the measurement. In order to average several hours of data we need a **Scaling Factor** to normalize the measured spectra
- In order to perform this technique we assume a horizontally homogeneous sky

Signal calibration

$$V_s = \alpha\left(T_s + T_{rec}\right)$$

$$V_{s+ND} = \alpha\left(T_{rec} + T_S + T_{ND}\right)$$

$$\alpha = \frac{V_{S+ND} - V_S}{T_{ND}}$$



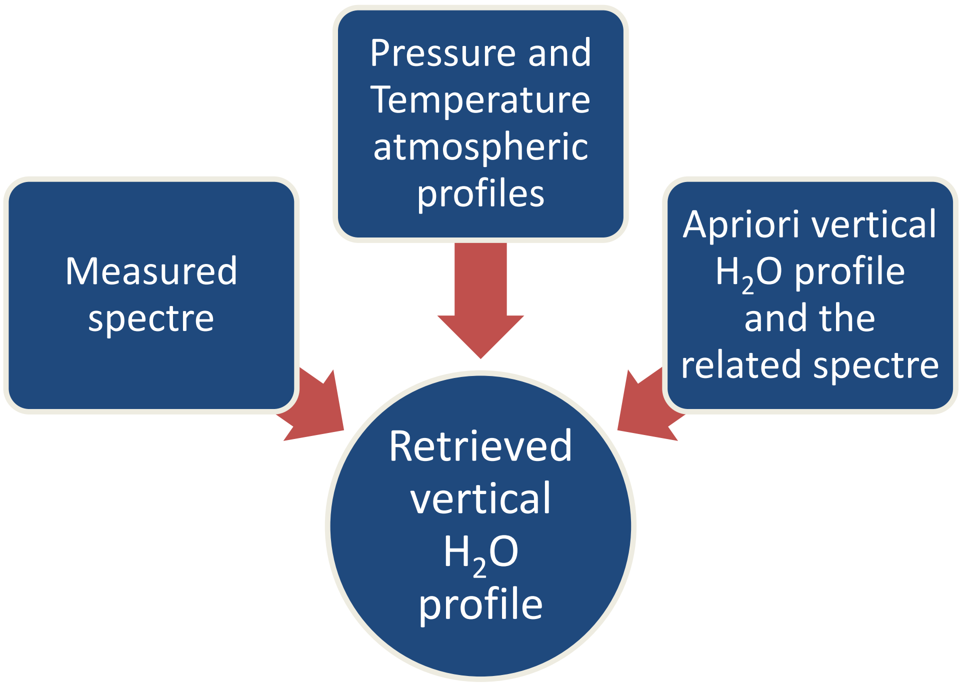
$$T_S(\nu) - T_R(\nu) = \frac{1}{\alpha}\left(V_S(\nu) - V_R(\nu)\right)$$

To calibrate the observed spectra we use the known emission of noise diodes.

We calibrate the noise diodes by observing the emission from two black body sources at known different temperatures (~77 K and ~300 K).

From the measured spectrum to the concentration vertical profile

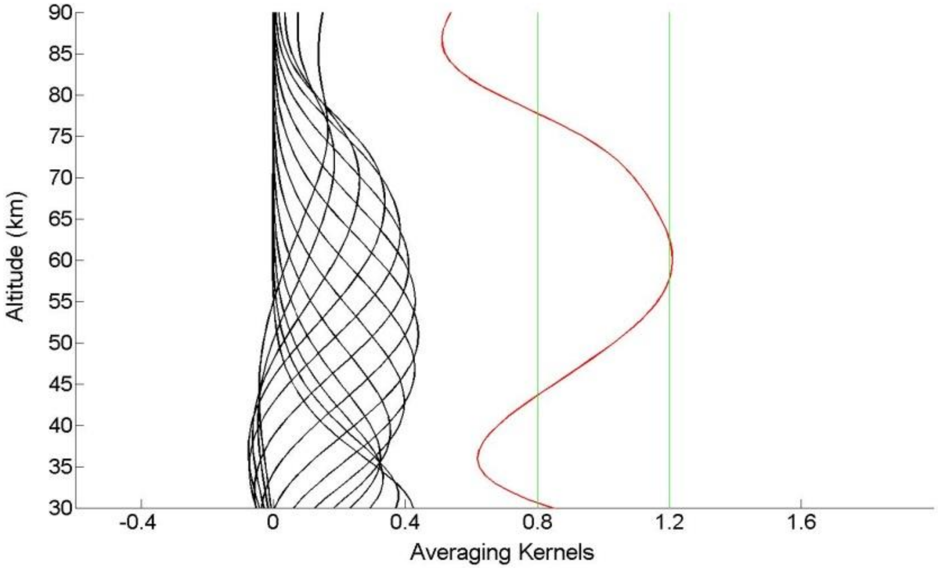
- Water vapour vertical profiles can be obtained from our measurements by using the indirect problem theory
- We employ an optimal estimation algorithm to retrieve the profile that has the largest probability of generating the observed spectrum, given the local climatology



The optimal estimation algorithm

$$\hat{\mathbf{x}} = \left(\mathbf{K}^{\mathbf{T}}\mathbf{S}_{\epsilon}^{-1}\mathbf{K} + \mathbf{S}_{\mathbf{a}}^{-1}\right)^{-1}\left(\mathbf{K}^{\mathbf{T}}\mathbf{S}_{\epsilon}^{-1}\mathbf{y} + \mathbf{S}_{\mathbf{a}}^{-1}\mathbf{x}_{\mathbf{a}}\right)$$

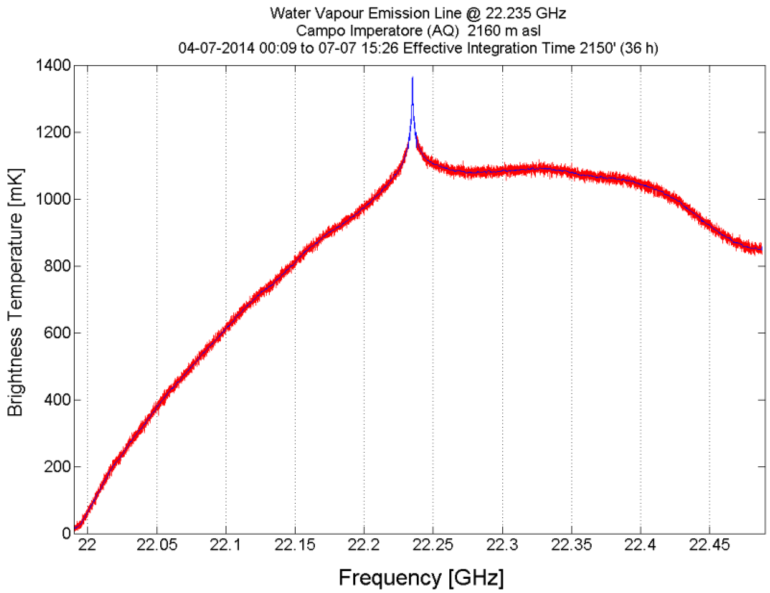
$$\hat{\mathbf{x}} = \mathbf{A}\left(\mathbf{x} - \mathbf{x}_{\mathbf{a}}\right)$$

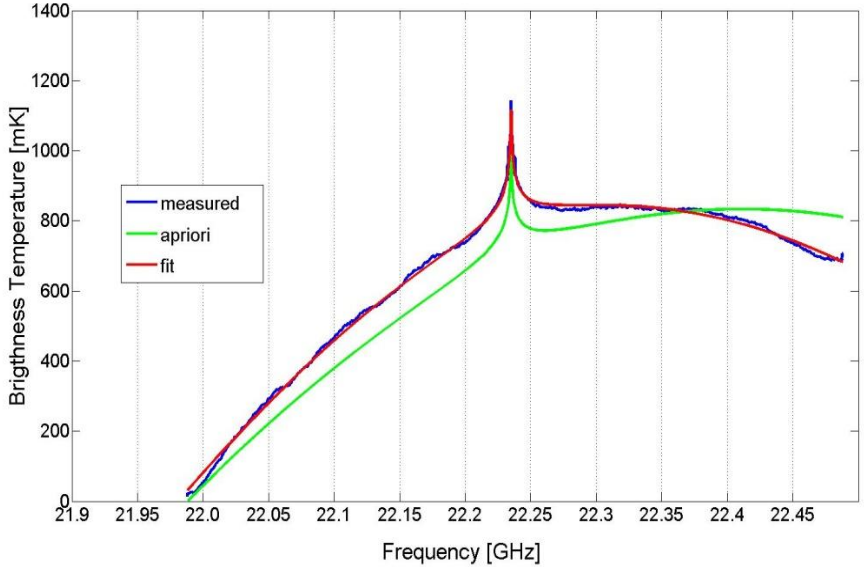


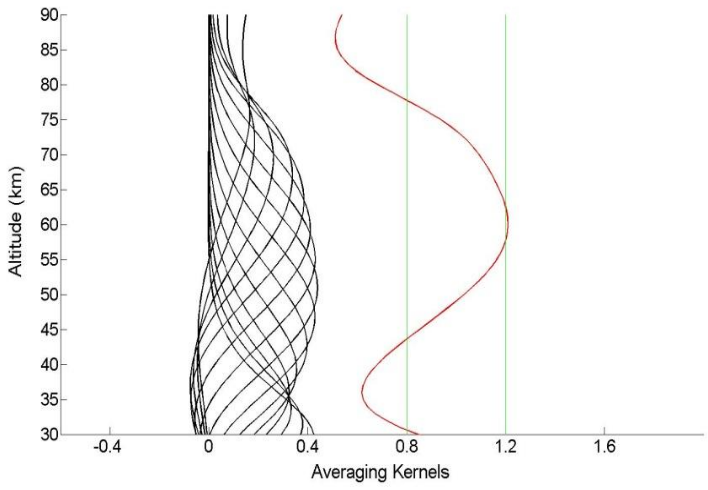
- We modify our apriori profile using the spectral information
- The Optimal Estimation can be seen as a weighted average of the apriori information given by local climatology and the new information gathered with the measurement
- The matrix A can be used as an estimate of the vertical resolution and sensibility interval of retrieved profiles

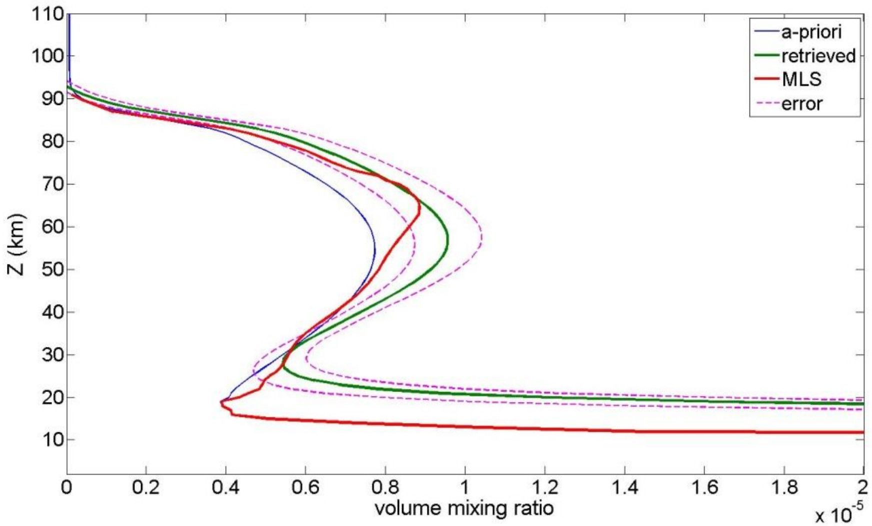
A test measurement campaign at Campo Imperatore (AQ)

A test measurement campaign at Campo Imperatore (AQ)









Conclusions and things to do…

- Vespa-22 is capable of retrieving vertical stratospheric water vapour profiles from 30 to 90 km altitude, but signal artifacts can reduce this range.

- It can operate automatically, with low level technical assistance and with a temporal resolution of 2-4 measures/day, depending on weather conditions

- We are working on the instrumental setup to minimize signal artifacts

- The retrieval algorithm must be improved to reduce the dependency of the 15-30 km altitude interval to the water vapour concentration in the troposphere. This can be done using auxiliary measurements as apriori profile

- The collected measurements will be studied to better understand the radiative and dynamical processes that characterize the polar atmosphere.


Thank you for the attention!