MAMBO: MARS ATMOSPHERE MICROWAVE BRIGHTNESS EXPLORER

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MAMBO Science Objectives

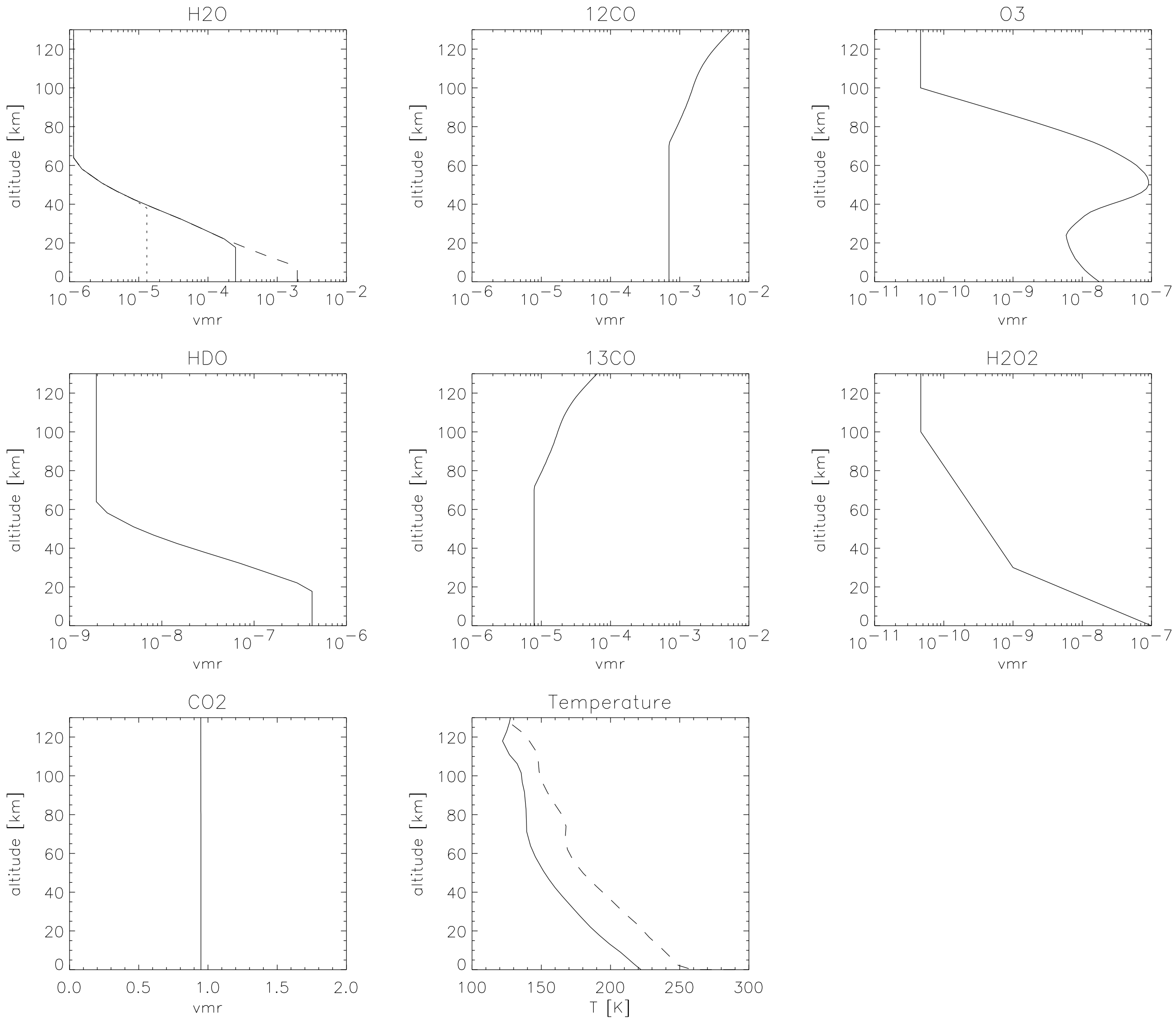
→ Understanding the present and past of planet MARS:

1. **Characterizing the general circulation:**
   4-d fields of temperature and winds (0-120 km).

2. **Characterizing the water cycle:**
   4-d fields of water vapor during all seasons (H_2O, HDO: 0-60 km).

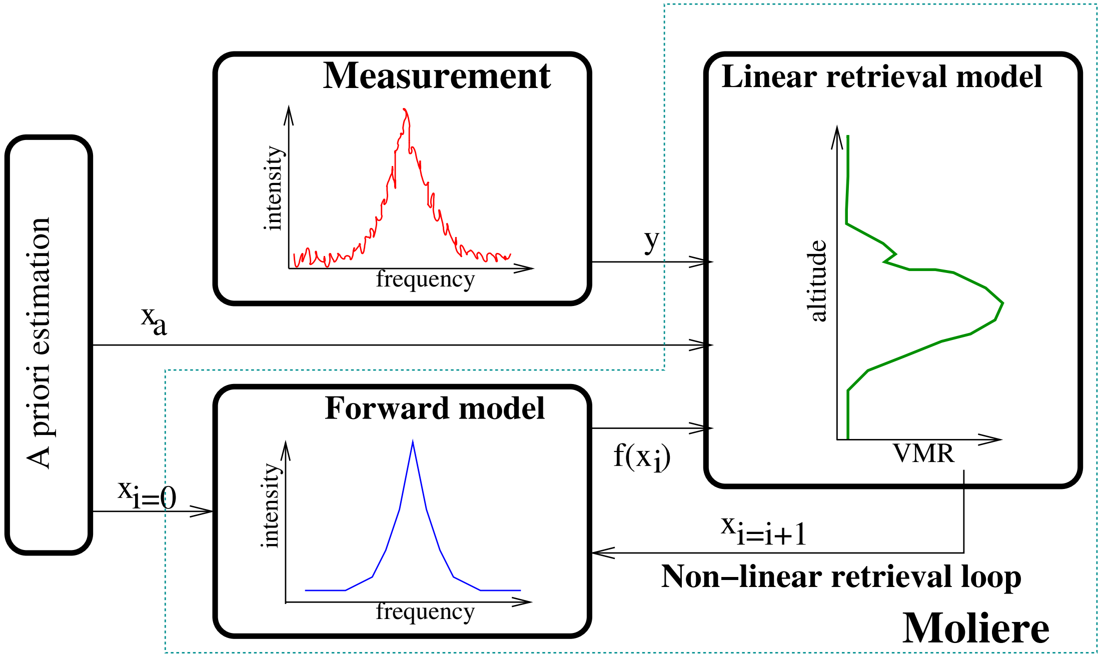
3. **Characterisation of the photochemical state of the martian atmosphere:**
   4-d fields of key minor species (CO, C-13-O, H_2O_2, O_3).

4. **Surface science:**
   Mapping of polarised surface emissions.


H2O
12CO
O3
HDO
13CO
H2O2
CO2
Temperature
altitude [km]
vmr
T [K]

MOLIERE - v 5

- General, modular 1-d forward- and retrieval code for the mm- and sub-mm range.



Modules:

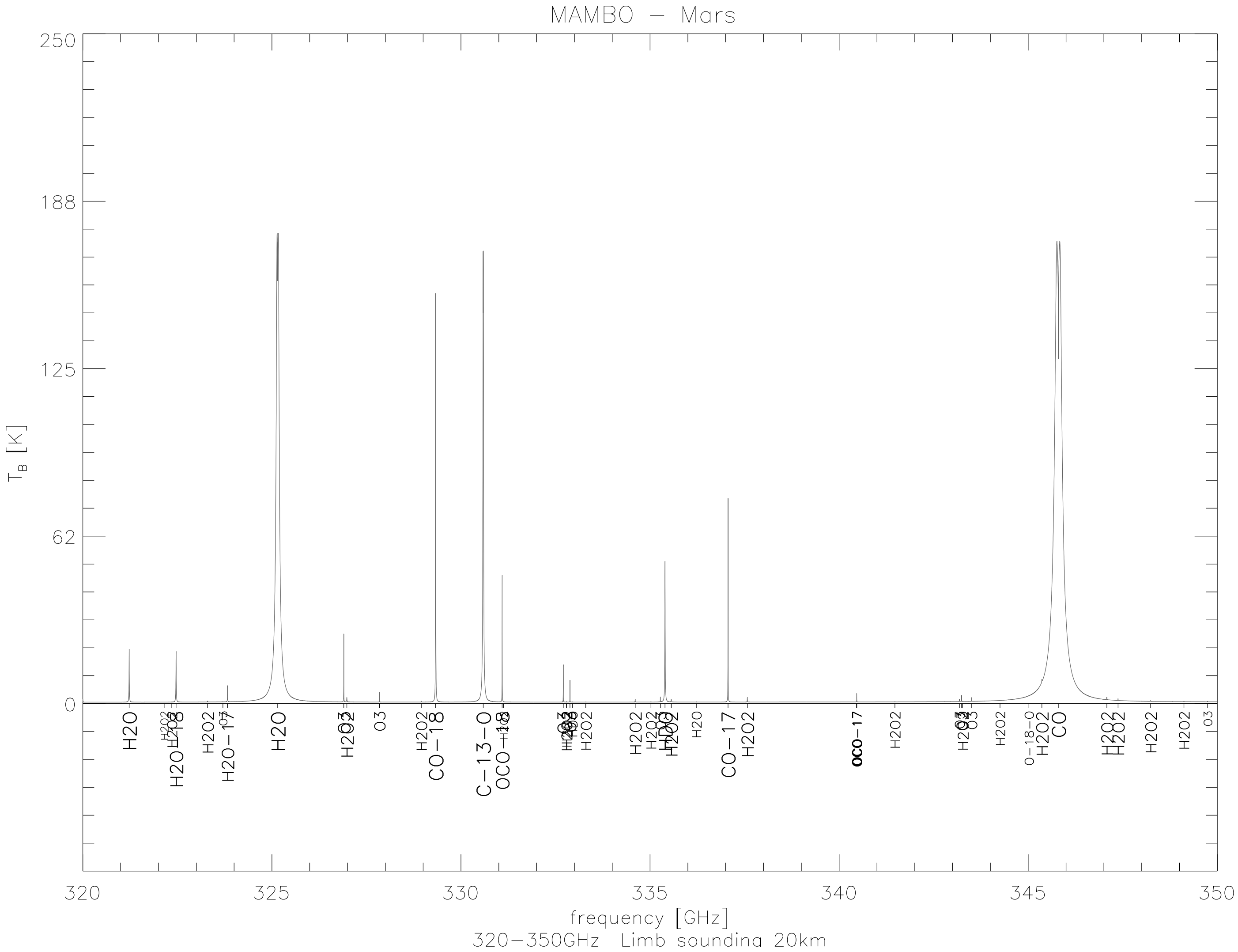
1. **ABS.** Spectroscopic model:
   line-by-line, continua.
2. **RT.** Radiative transfer:
   limb, nadir, up-looking geometry.
   Differential weighting functions.
3. **INST.** Sensor model:
   antenna, sideband, spectrometer.
4. **OEM.** Linear inversion model:
   Optimal Estimation Method.
5. **NLIN.** Non-linear retrievals:
   Levenberg-Marquardt iteration scheme.

MOLIERE-5 on Mars

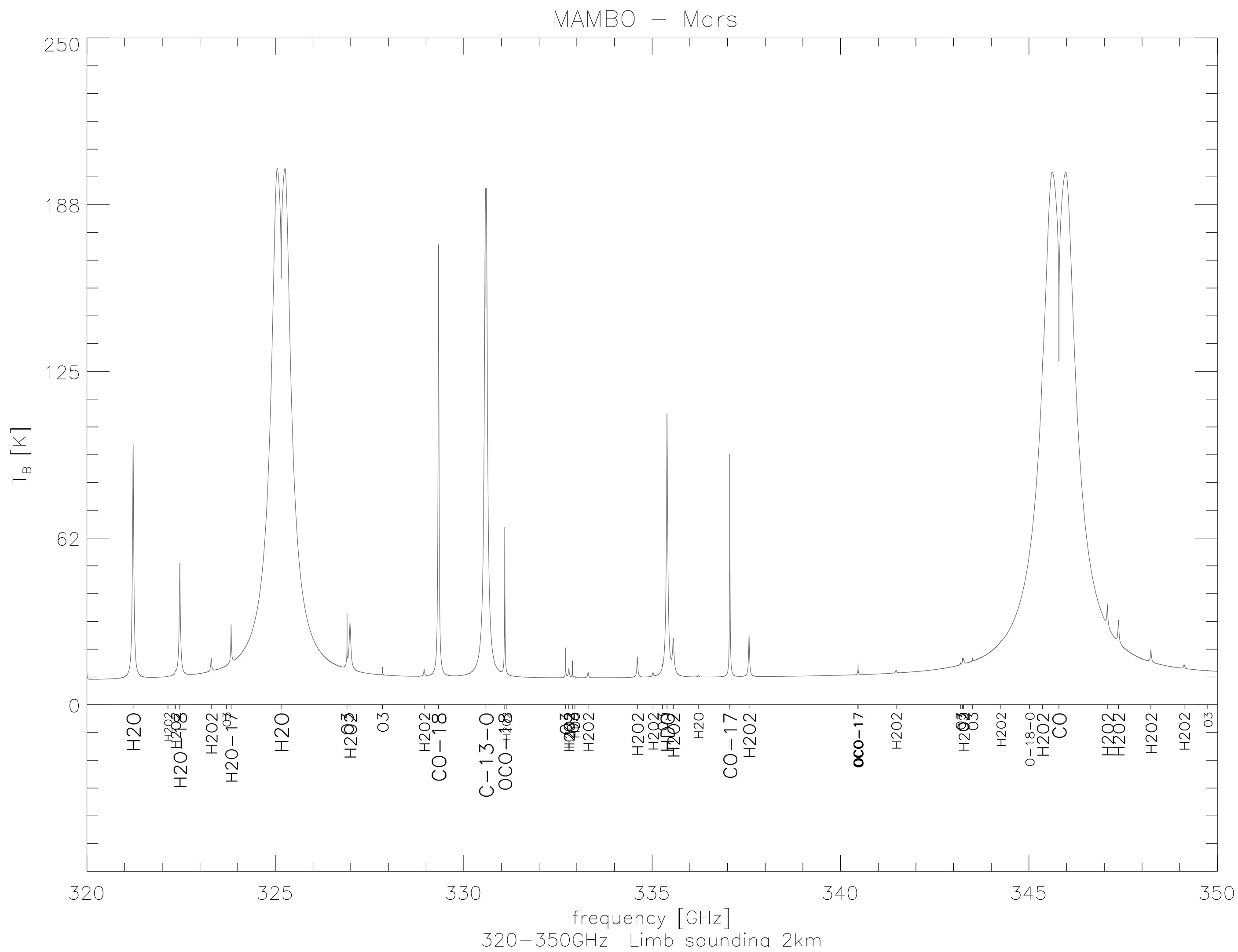
→ **Adaptation of MOLIERE-5 forward model:**

- **MARS radius?** 3397 km.
- **Refraction?** Ground pressure ∼7 hPa.
- **Continuum?** CO_2 atmosphere (95 %).
- **Isotopic ratios?**
  D/H ratio in water vapor ∼5.5 times that on Earth [Owen et al., 1988] (IR spectroscopy).
- **Spectroscopy?**
  Linebroadening parameters in CO_2 atmosphere (∼1.65 times that on Earth).
- **LTE?**
- **Surface emissivity?** Limb measurements affected at low tangent heights.

MAMBO
h_t = 20 km

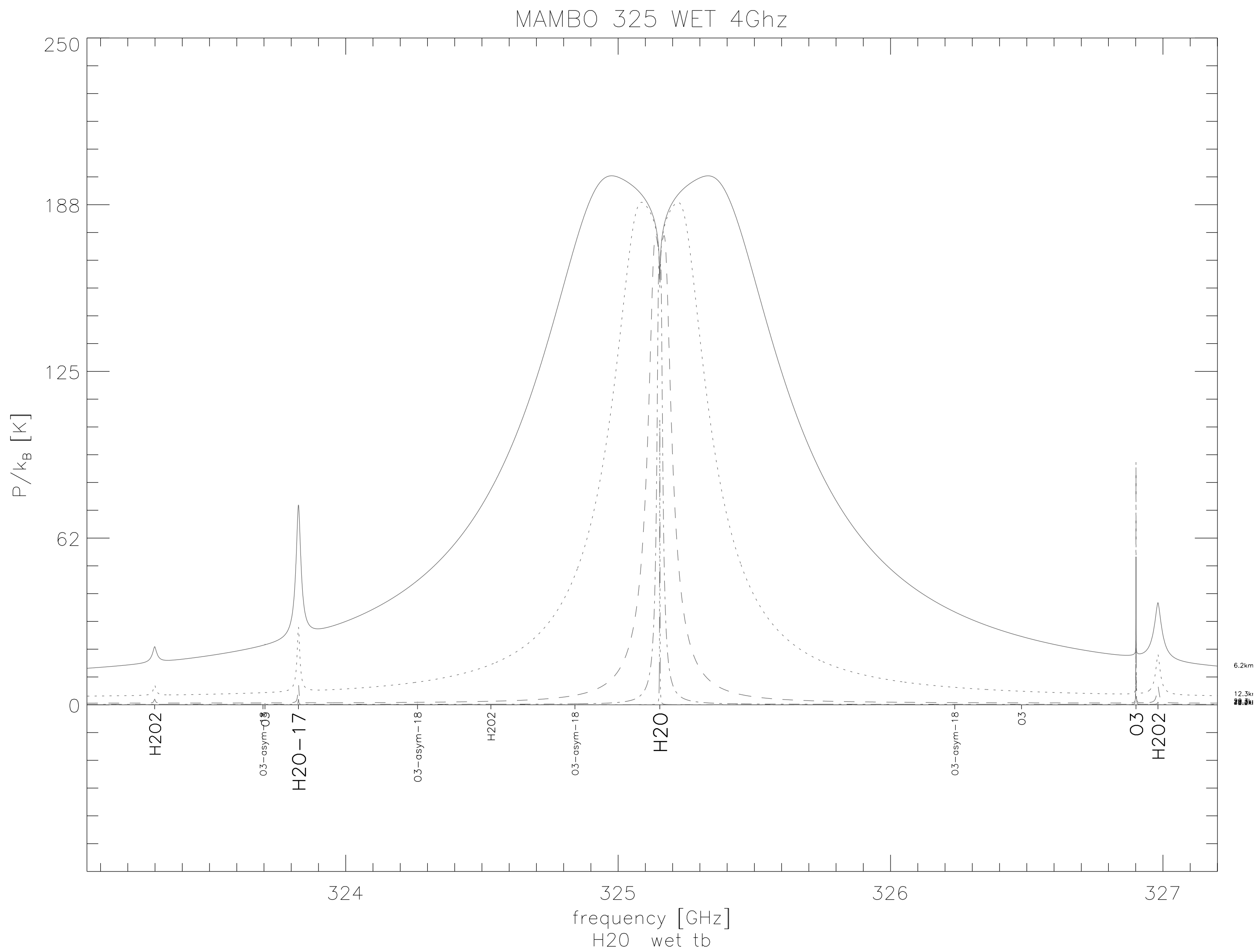


MAMBO
h_t = 2 km

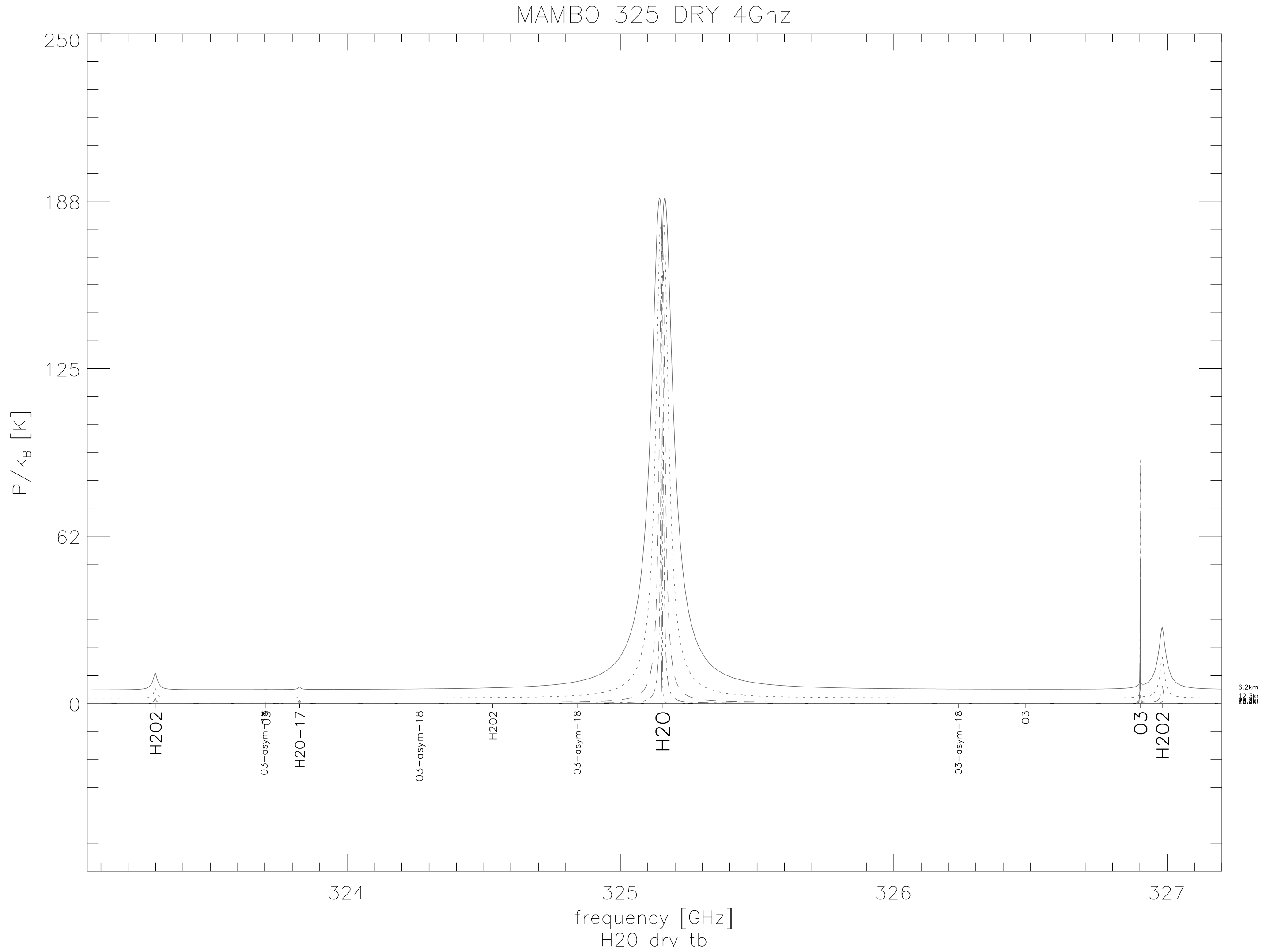


OBSERVATOIRE
ASTRONOMIQUE
DE BORDEAUX

H_2O @ 325.2 GHz
WET



H_2O @ 325.2 GHz
DRY



Retrieval

- **Optimal Estimation**

  → Linear least squares method, allowing “a priori” knowledge to be taken into account.

  → Atmospheric parameters $\hat{\mathbf{x}}$ estimated by minimizing

  $$Z(\mathbf{x}) = [\mathbf{y} - \mathbf{F}(\hat{\mathbf{x}}, \mathbf{b})]^t\ \mathbf{S}_y^{-1}\ [\mathbf{y} - \mathbf{F}(\hat{\mathbf{x}}, \mathbf{b})] + [\hat{\mathbf{x}} - \mathbf{x}_0]^t\ \mathbf{S}_{x_0}^{-1}\ [\hat{\mathbf{x}} - \mathbf{x}_0]$$

  $\mathbf{y}$: Spectral measurement

  $\mathbf{F}(\hat{\mathbf{x}}, \mathbf{b})$: Forward model

  $\mathbf{b}$: Model parameters (spectroscopy, instrument)

  $\mathbf{x}_0$: “A priori” vector

  → Weights: Measurement and “a priori” covariance matrices $\mathbf{S}_y$ and $\mathbf{S}_{x_0}$.

  → Diagnostics: Error covariances, averaging kernels.

- **Levenberg-Marquardt method**

  → Non-linear problems

Non-linear retrieval

- **Linearisation of forward model:**

$$\mathbf{F}(\mathbf{x}, b) \approx \mathbf{F}(\mathbf{x}_{ref}, \mathbf{b}) + \left(\frac{\partial \mathbf{F}}{\partial \mathbf{x}}\right)_{\mathbf{x}_{ref}} (\mathbf{x} - \mathbf{x}_{ref})$$

$\mathbf{F}(\mathbf{x}, \mathbf{b})$: Forward model

$\mathbf{b}$: Model parameters (spectroscopy, instrument)

$\mathbf{x}, \mathbf{x}_{ref}$: Parameter and reference vector

$\Rightarrow$ Optically thin lines:
Linearisation correct for any $\mathbf{x}_{ref}$

$\Rightarrow$ Optically thick lines:
Linearisation correct only in the neighbourhood of $\mathbf{x}_{ref}$

$\rightarrow$ **Solutions:**

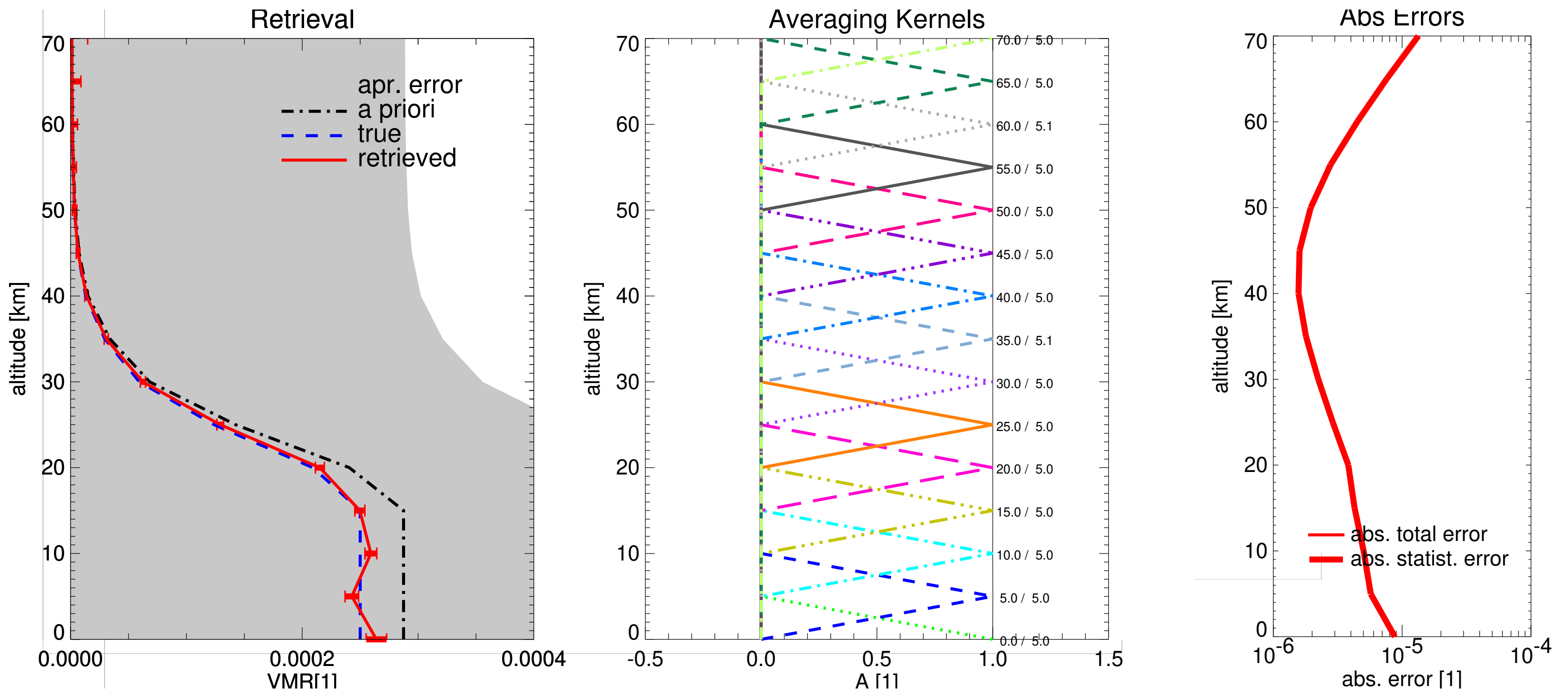
1. Removal of optically thick channels ($\tau > \tau_{limit}$)
2. OEM with Levenberg-Marquardt iteration scheme:

$$\mathbf{x}_{i+1} = \mathbf{x}_0 + (\mathbf{S}_0^{-1} + \mathbf{K}_i^T \mathbf{S}_y^{-1} \mathbf{K}_i + \gamma \mathbf{I})^{-1}$$
$$(\mathbf{K}_i^T \mathbf{S}_y^{-1}([\mathbf{y} - \mathbf{F}(\mathbf{x}_i, \mathbf{b})] + \mathbf{K}_i[\mathbf{x}_i - \mathbf{x}_0]) + \gamma[\mathbf{x}_i - \mathbf{x}_0])$$

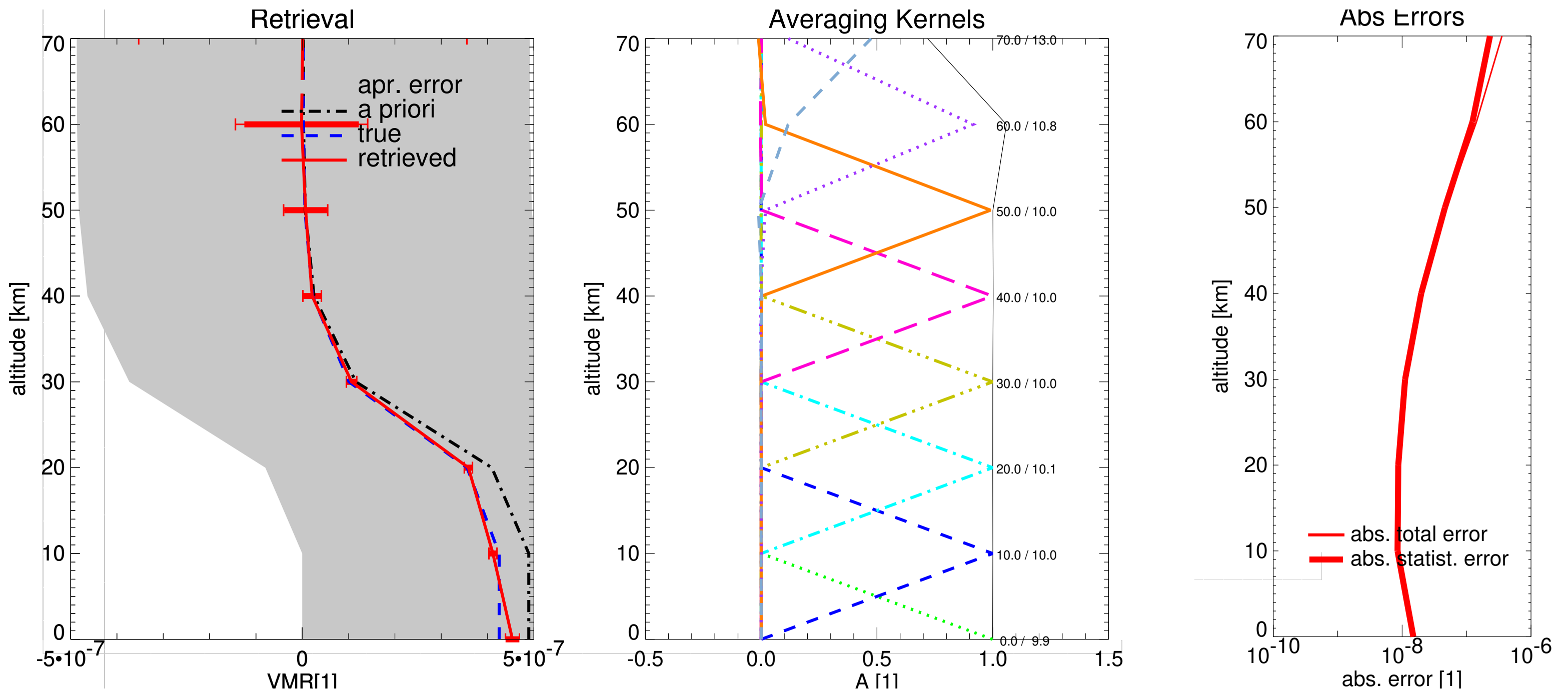
$\mathbf{S}_0, \mathbf{S}_y$: “a priori” and measurement covariance matrix

$\mathbf{K} = \left(\frac{\partial \mathbf{F}}{\partial \mathbf{x}}\right)_{\mathbf{x}_i}$: weighting function matrix

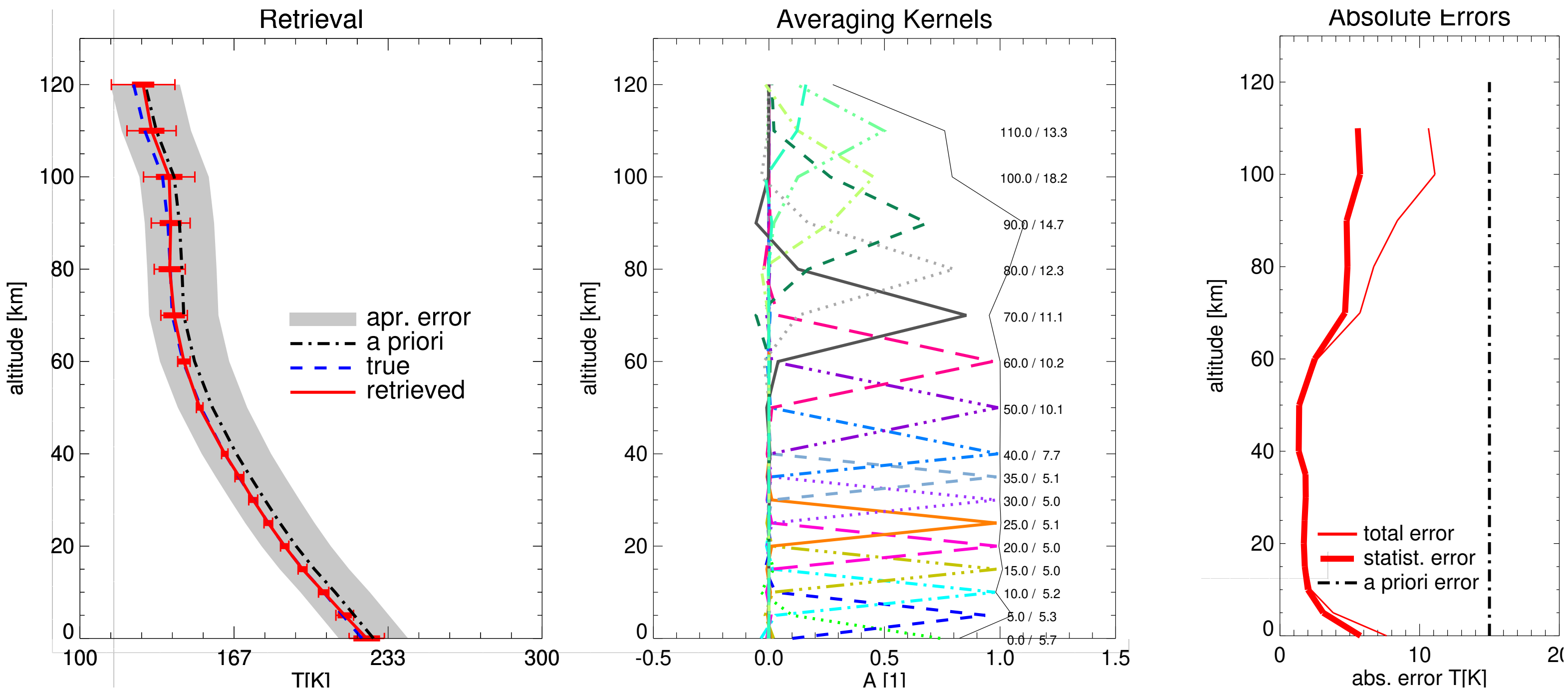
MAMBO: H_2O @ 325.2 GHz



MAMBO: HDO @ 335.4 GHz



MAMBO: Temperature (C-12-O @ 345.8 GHz / C-13-O @ 330.6 GHz)



Conclusions