# Hints of what we can expect from satellite Far Infrared spectrally resolved measurements

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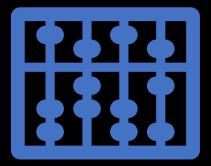
# Outline

Motivation



Our forward/inverse model

Application

Summary

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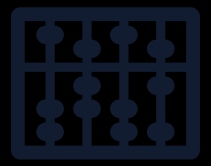

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# Expectation

- **Spectroscopy**
  - The knowledge of  water vapor continuum absorption is still subject to large uncertainties (especially at low temperatures and low pressure)
  - $HNO_3$ line parameters in the FIR
- **Role of clouds: microphysics and optics**
  - Ice refractive index at FIR depends on temperature. Currently this dependency is not accounted for in radiative transfer codes. New reference database are coming out (Reng et al. 2025: https://doi.org/10.1029/2025GL116735 )
  - The 410 $cm^{-1}$ minimum in the imaginary part of the refractive index of ice enhances the role of scattering at FIR. Cirrus **scattering** properties at FIR are strongly dependent on crystal shape.

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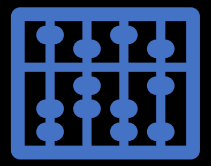

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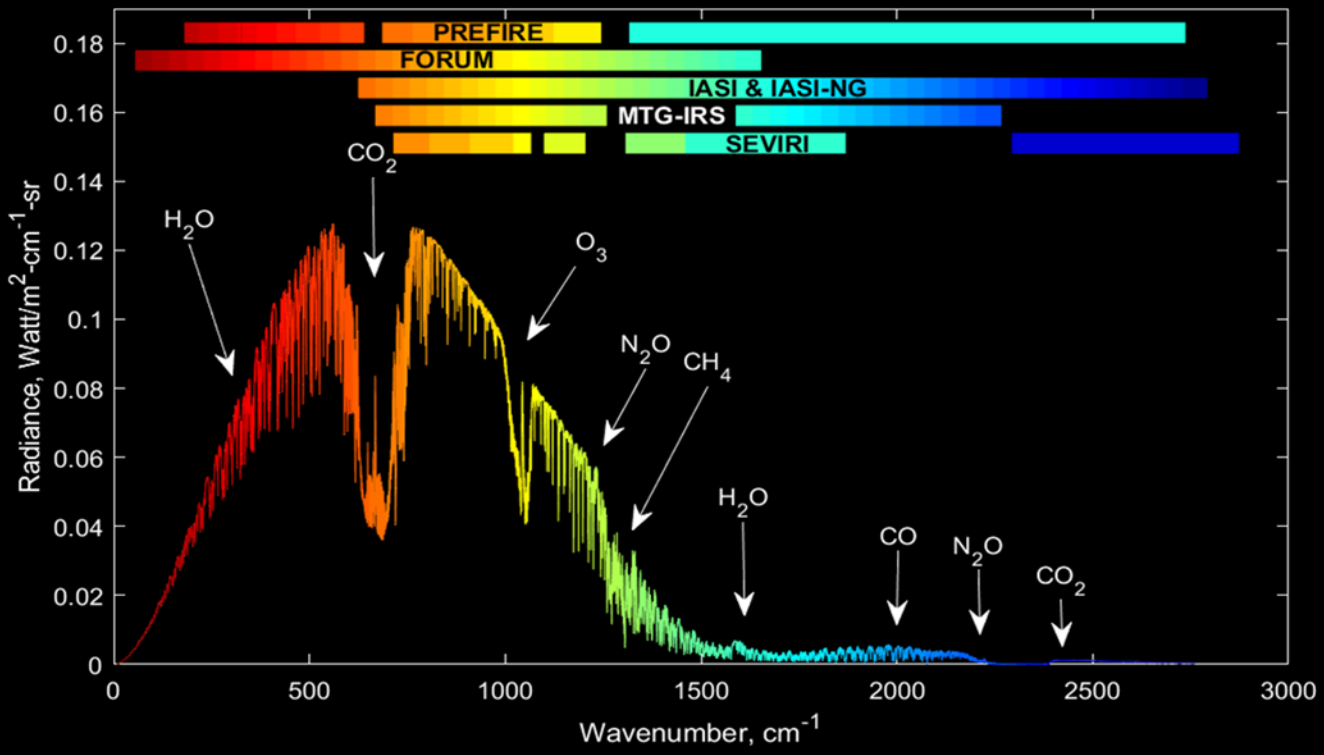
# σ-IASI/F2N, σ-FORUM, simply σ


The RTM developed in the framework of EUMETSAT programs

- Assessment of IASI data for the Atmosphere (1996-2004) grants
  - EUM/CO/96/407/DD, EUM/CO/99/688/DD, EUM/CO/02/1053/PS
- Italian Space Agency ASI programs (2019-Now)
  - FORUM-Scienza Program of Italian Space Agency (Contract No. 2019-20-HH.0, P.I. CNR-INO)
  - FIT-FORUM (contract n. 2023-23-HH.0, CUP F33C23000240005, P.I. DIFA, University of Bologna),
  - MC-FORUM (contract n. 2023-23-HH.0, CUP F93C2300046000, P.I. IBE-CNR)
- Pseudo-monochromatic (0.01 $cm^{-1}$)
- 5-3000 $cm^{-1}$ spectral range
- OD databases (parametrized in T and $\rho$)
- Clouds and aerosols properties (parametrized in $r_{eff}$)
- In presence of scattering layers, the code accounts for a Chou+Tang solution (k-Tang)
- Analytical Derivatives in clear and cloudy condition
- Masiello, G., Serio, C., Liuzzi, G., Venafra, S., Maestri, T., Martinazzo, M., Amato, U., & Grieco, G. (2023). σ-IASI (2.4). Zenodo. https://doi.org/10.5281/zenodo.8152674

# Spectral coverage of σ

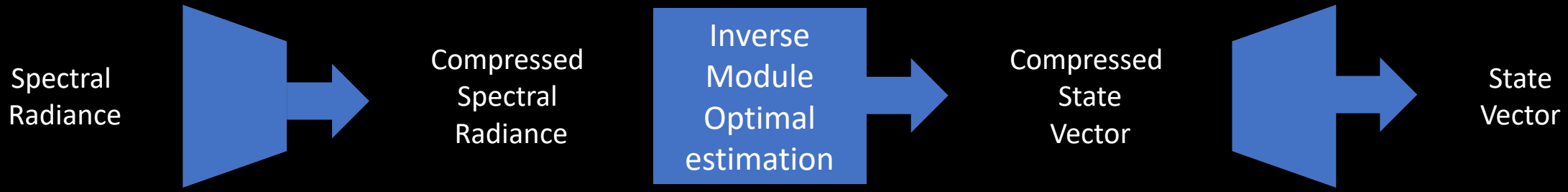


# More details about Radiative Transfer Calculations

- Spectral Range : 5-3000 $cm^{-1}$
- Surface Type: Lambertian or Specular
- Radiance
- Jacobian with respect to the profile of
  - Temperature,
  - $H_2O$, HDO, $CO_2$, $O_3$, $N_2O$, CO, $CH_4$, $SO_2$, $NH_3$, $HNO_3$, OCS, $CF_4$ concentrations
  - Liquid cloud re, and concentrations
  - Ice cloud De, and concentrations
  - Aerosols re, and concentrations
- And Jacobian with respect to
  - Surface Temperature and Emissivity
  - $H_2O$ self and foreign continua coefficients, $CO_2$ foreign continuum coefficients

Masiello et al. JQSRT 2024
https://doi.org/10.1016/j.jqsrt.2023.108814

# Our Retrieval Scheme




It is based on Optimal estimation with a compression of both radiances and State vector

State vectors simultaneously retrieved

$$\mathbf{V} = (T_s, \mathbf{T}, \mathbf{Q}, \mathbf{O}, \mathbf{D}, \mathbf{q_{LWC}}, \mathbf{r_e}, \mathbf{q_{IWC}}, \mathbf{D_e}, \mathbf{q_{CO_2}}, \mathbf{q_{OCS}}, \mathbf{q_{N_2O}}, \mathbf{q_{CO}}, \mathbf{q_{CH_4}}, \mathbf{q_{SO_2}}, \mathbf{q_{HNO_3}}, \mathbf{q_{NH_3}}, \mathbf{q_{CF_4}}, pc_\epsilon)$$

- Surface temperature, (Ts ), Atmospheric profiles of Temperature, Water vapour, Ozone, HDO, $CO_2$, OCS, CO, $N_2O$, $CH_4$, $SO_2$, $HNO_3$, $NH_3$, and $CF_4$, liquid and ice water clouds and related effective dimension;
- PC scores for surface emissivity

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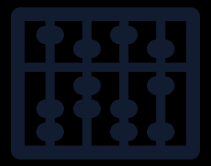

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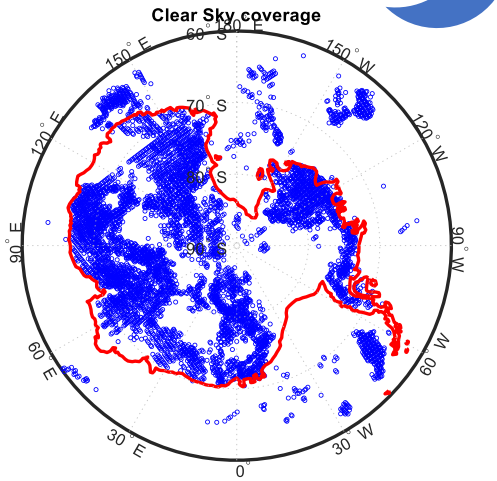
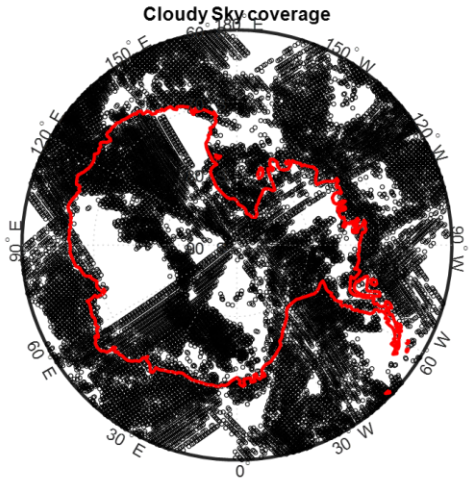
# Overcoming Cloud Interference in Infrared Remote Sensing

- Our model effectively processes **infrared spectra** under **cloudy conditions** just as well as under **clear-sky conditions**.
- This breakthrough allows us to retrieve **geophysical parameters** even **above the clouds**.
- **Key Application: Antarctic Ozone hole**
- This capability is particularly vital for monitoring **Ozone** levels during the **Antarctic winter**, where cloud cover is frequent.
- e.g. 1 day IASI (Infrared Atmospheric Sounding Interferometer) B & C Antarctica overpasses
  - In blue clear sky in black cloudy sky

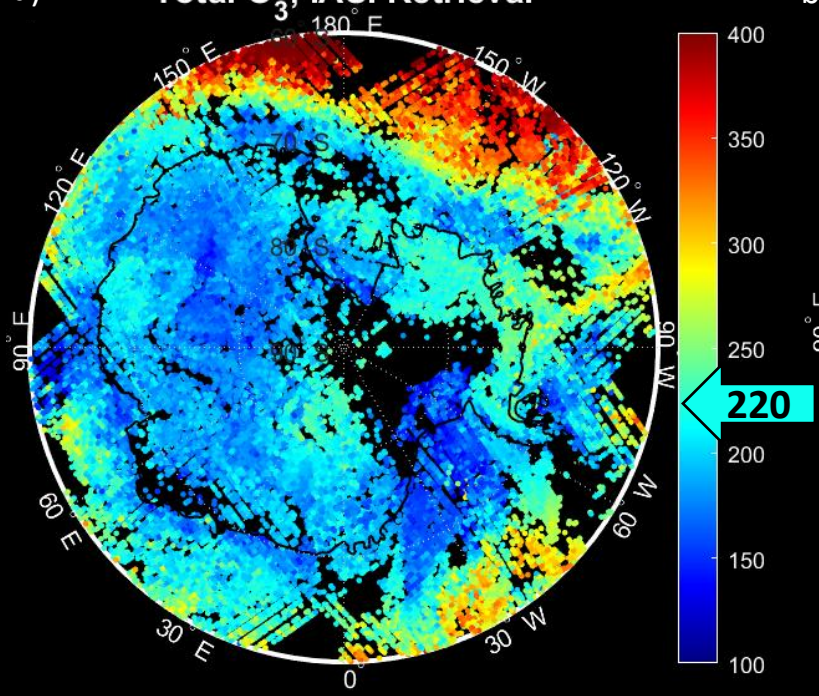


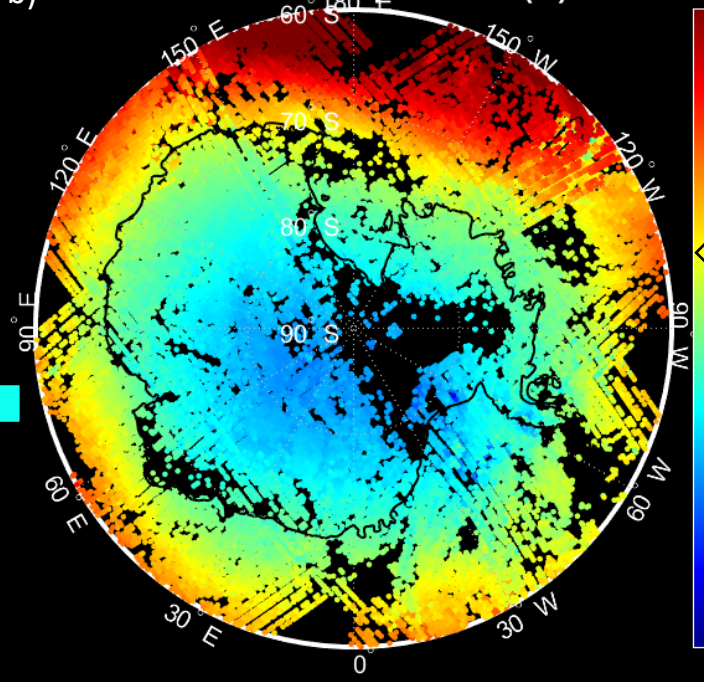
# Probing Polar Stratospheric Chemistry: The Ozone Hole Mechanism

- In the inner continent, the temperature is well below 195 K (b)
- Low amount of $HNO_3$ < 500 pptv in the inner continent (c)
- Ozone hole (<220 DU) boundary follows low T shape (a)
- PSCs formation may lead to the removal of nitric acid from the gas phase.
- The formation of Polar Stratospheric Clouds (PSCs) is the fundamental catalytic mechanism that accelerates ozone destruction.
- Observing the co-evolution of $O_3$ and $HNO_3$ allows us to track the denitrification process.

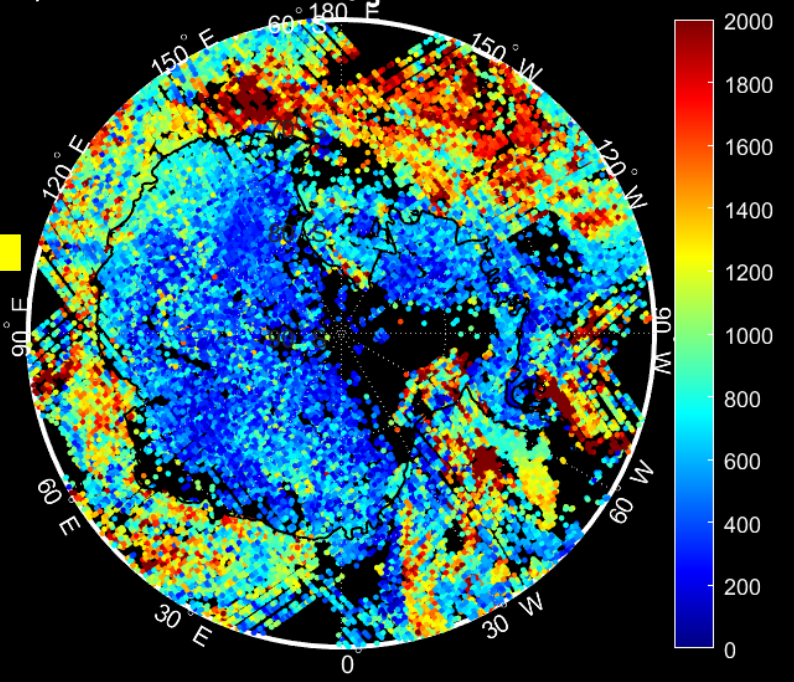
a)




b)



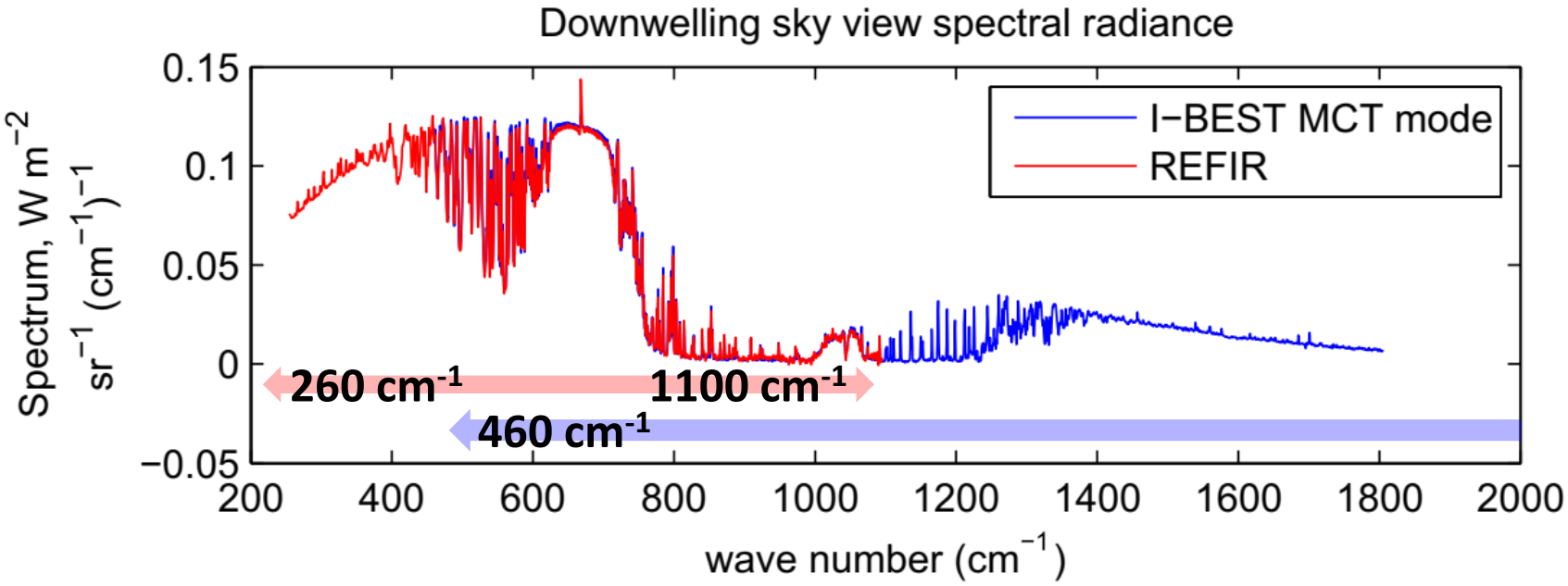

c)




Serio et al. JQSRT 2024
https://doi.org/10.1016/j.jqsrt.2024.109211

# Cobra/ecowar, Alps, March 2007

- FarIR measurements
- REFIR located at Testa Grigia (3500 m asl)
- I-BEST (Bomem MR100) located at Cervinia (1990 m asl)
- Microwave radiometres, Lidar, Radiosonde
- Comparison between MT_CKD H2O foreign continuum and Retrieved coefficients obtained with FarIR ground-based measurements



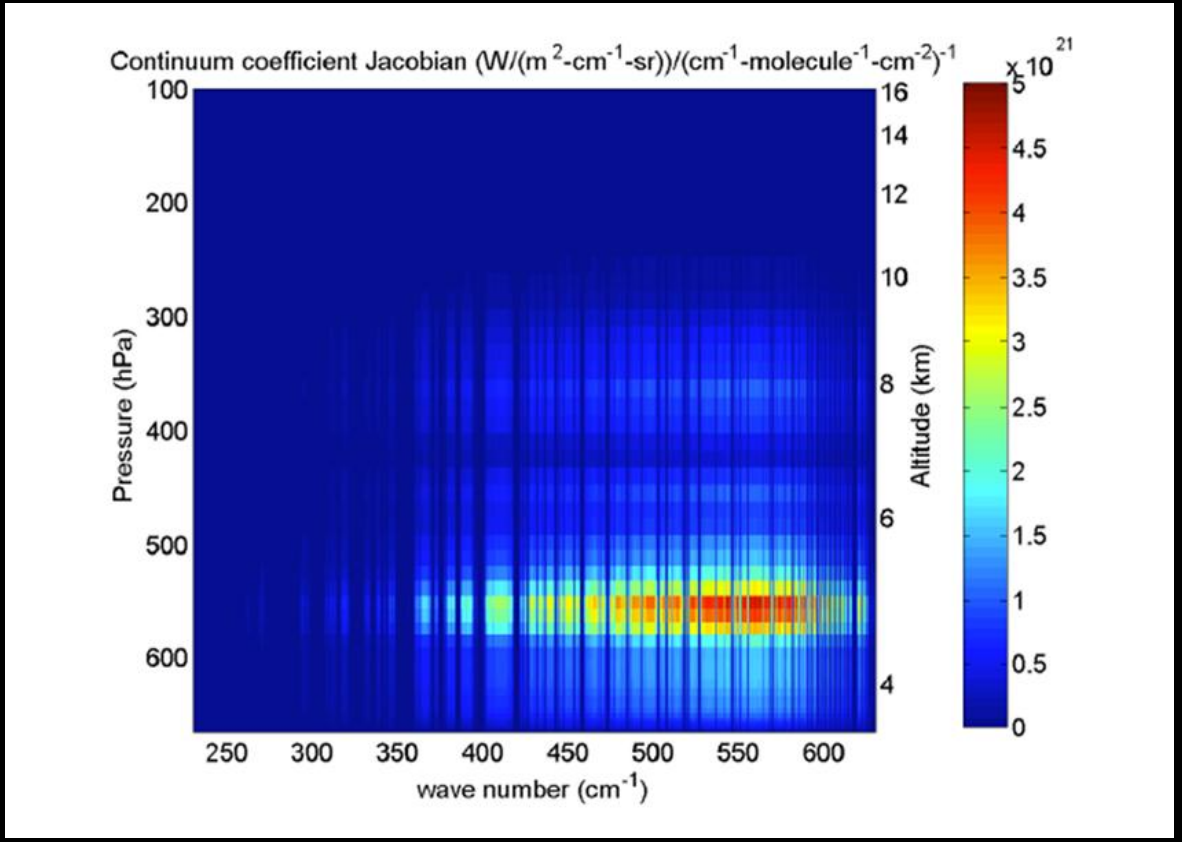
# $H_2O$ Foreign continuum REFIR and I-BEST

- The absorption coefficient of water vapor k @ σ is

$$k = k_{local} + C_f \frac{\rho_f}{\rho_0} + C_s \frac{\rho_s}{\rho_0}$$

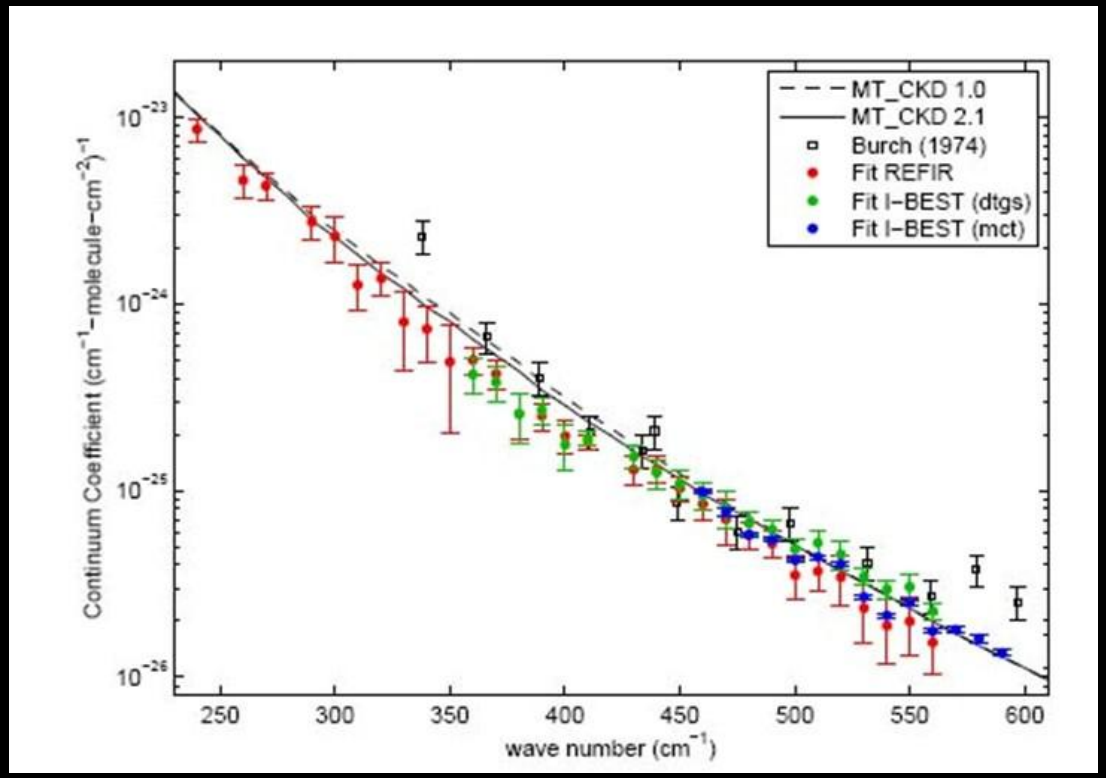
Lines + Foreign + Self

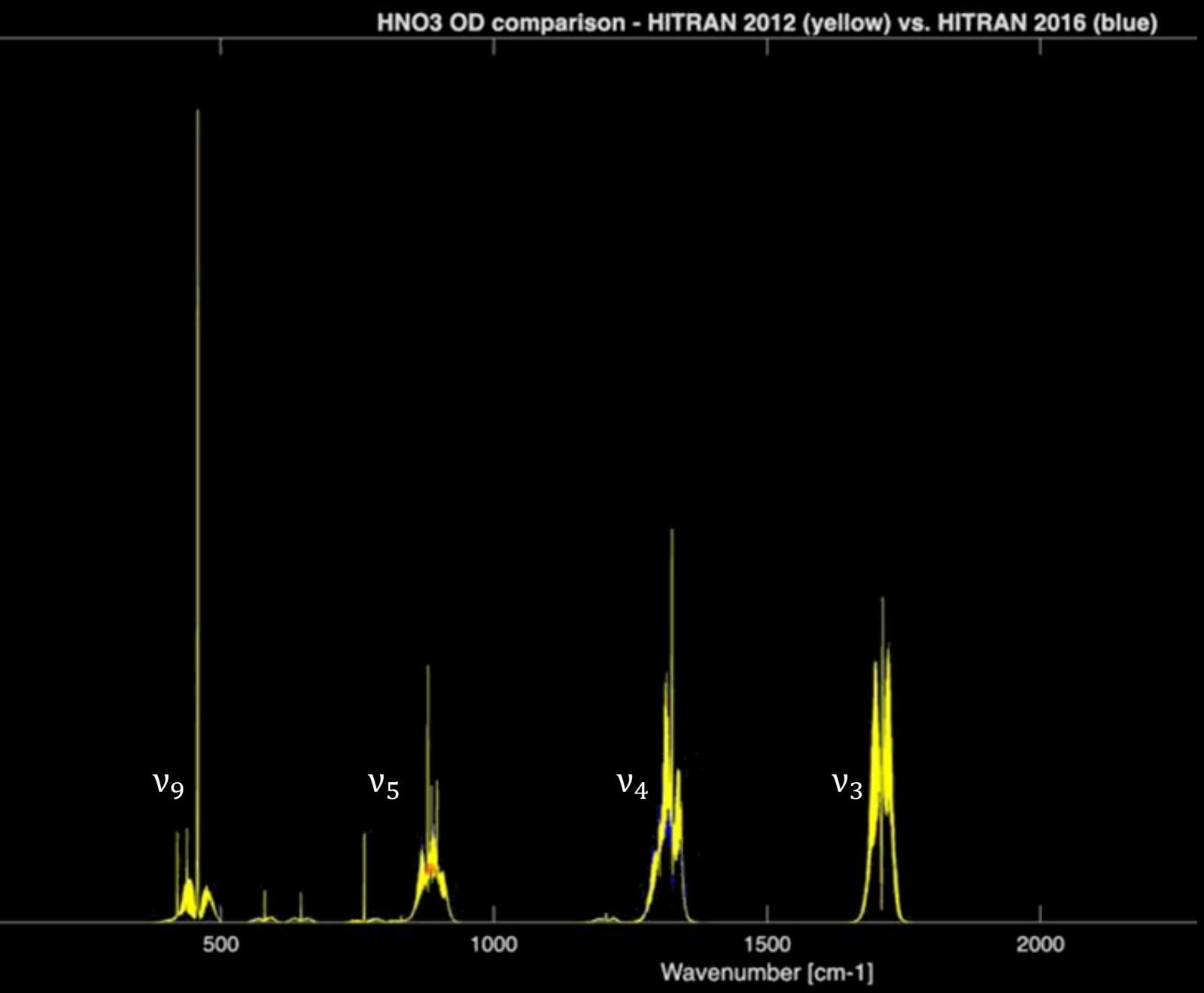
- With fixed line parameters, we retrieved $C_f$ using analytical derivatives of continua.
- Retrieval scheme simultaneously retrieve atmospheric state vector and spectroscopic parameters.
- 20 clear sky spectra were processed (recorded in 2 hours) to derive 20 state vectors and one set of continuum spectral coefficients, ensuring the time-independence of spectroscopic parameters.
- $\mathbf{V}(t) = \left(\mathbf{T}(t), \mathbf{Q}(t), C_f(\sigma)\right)$
- Serio et al Optics express 2008 https://doi.org/10.1364/OE.16.015816



# $H_2O$ lines parameters and Continua

- We found that MT_CKD model  is more absorbent than the measures in FarIR region.
- Following AER (lblrtm) changed H2O lines halfwidth in the FarIR
- Mlawer et al. 2019 (doi: 10.1029/2018JD029508) updated a couple of dozen far-IR water vapor line parameters from their values
- These values form the priority data file for the HITRAN2020 update (Gordon et al. 2021, doi: 10.1016/j.jqsrt.2021.107949 )
- "Our preliminary results show that the foreign continuum we derived in Mlawer et al. (2019) from our Chile campaign were too high (we think the water vapor profiles we used in that study were not that accurate), so our new coefficients will be closer to the values you derived than the coefficients in the current MT_CKD." 2025 E. Mlawer, Private Communication






# Nitric Acid Spectroscopy

- "The far infrared region needs a revision". HITRAN 2008 paper, Rothman et al. 2009 https://doi.org/10.1016/j.jqsrt.2009.02.013
- No change in FIR spectral Range
- $HNO_3$ spectral parameters in the Far Infrared also suffer from a lack of robust validation
- The Opportunity: Simultaneous retrieval schemes, combining Thermal IR and FIR data, will allow for a comprehensive and robust validation of key atmospheric absorbers.

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# Summary and Future Outlook

- **Key Takeaways:**
  - Developed a robust **All-Sky Radiative Transfer Forward/Inverse Model (100–3000 $cm^{-1}$)**
  - Enabled **Enhanced Geophysical Retrieval** ($O_3$, $HNO_3$, PSCs) under cloudy conditions using IASI data.
  - Demonstrated the need for satellite FIR data to **Constrain Spectral Parameters** ($H_2O$ continuum, $HNO_3$ lines).
  - Assessment of Clouds optical and microphysical properties (Tiziano's Talk)
- **ESA's FORUM Mission:**
  - FORUM will provide the first spectrally resolved FIR data from space.
  - Combined with our advanced retrieval approach, it will offer **significant capability** to enhance our understanding of the full vertical structure of the atmosphere and constrain the **Earth's Energy Budget**.

IMPACT FACTOR 4.1

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# Remote Sensing Special Issues

## "Advances in far-to-near Infrared Quantitative Spectroscopy and Remote Sensing, in honor of Professor Carmine Serio"

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Guido Masiello

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Coming Soon!


# Thank you

Guido Masiello

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