Cirrus cloud radiative closure experiment using the ATMOSFER 2024 Kiruna FIRMOS-B Far-Infrared Observations

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What is a cirrus cloud radiative closure experiment?

The cirrus cloud radiative closure experiment consists of:

- Measuring the atmospheric nadir spectrum in presence of cirrus clouds.
- Measuring the atmospheric state (profiles of T, H_2O, O_3 and cirrus cloud properties).
- Using the measured atmospheric state as input to simulate the cloudy spectrum.
- Comparison between the cloudy measured and simulated spectra.

This exercise is useful to:

- Improving the spectra simulations in cloudy conditions.
- Detecting problems in the measured spectra.
- Studying the dependence of the spectrum as a function of ice crystal shapes. Particularly useful to understand if a particle shape retrieval is possible.

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Presentation overview

- Description of ATMOSFER 2024 campaign, useful for the radiative closure experiment.
  - FIRMOS-B instrument for measuring atmospheric spectra.
  - Measurement of in-situ cloud properties by NIXE instrument.

- Cirrus cloud radiative closure experiment:
  - In-situ data measured during ATMOSFER 2024 used as input to simulate a cloudy FIRMOS-B spectrum.
  - Strategy for simulating the cloudy FIRMOS-B spectrum.
  - Comparison between cloudy simulated spectrum and the one measured by FIRMOS-B.

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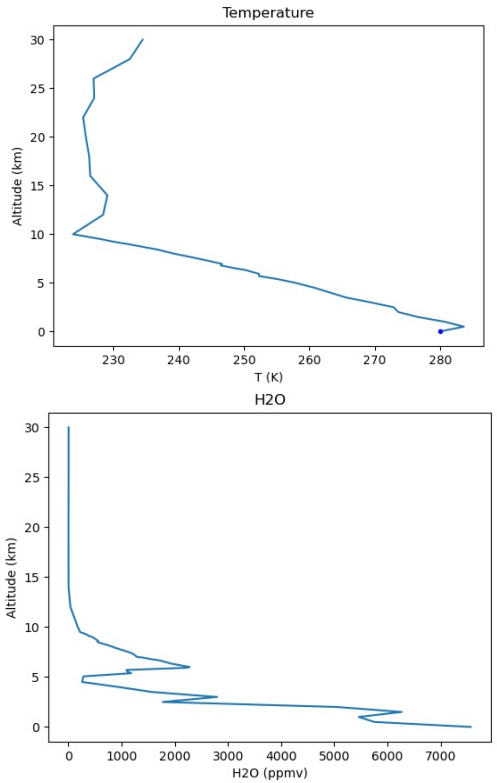
ATMOSFER 2024 Kiruna campaign

FIRMOS-B

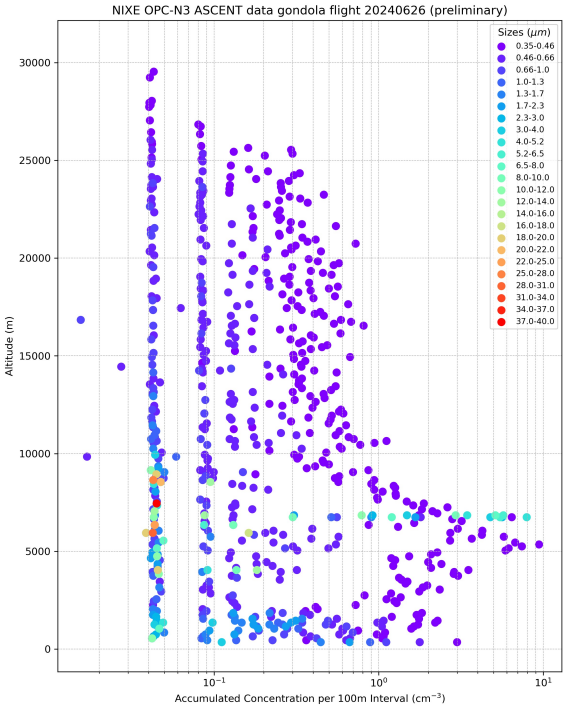
FIRMOS-B was installed as payload of the gondola to perform nadir-spectra measurements from a stratospheric flight.

T, H_2O and O_3 profiles



Three different radiosounds (Pico-light, CFH-Julich, NOAA-FPH) were launched, close in time with the gondola, to measure T, H_2O and O_3 vertical profiles.

NIXE cirrus clouds in-situ measurements



In-situ cloud measurements are performed by the NIXE instrument, installed on the gondola, close to FIRMOS-B.

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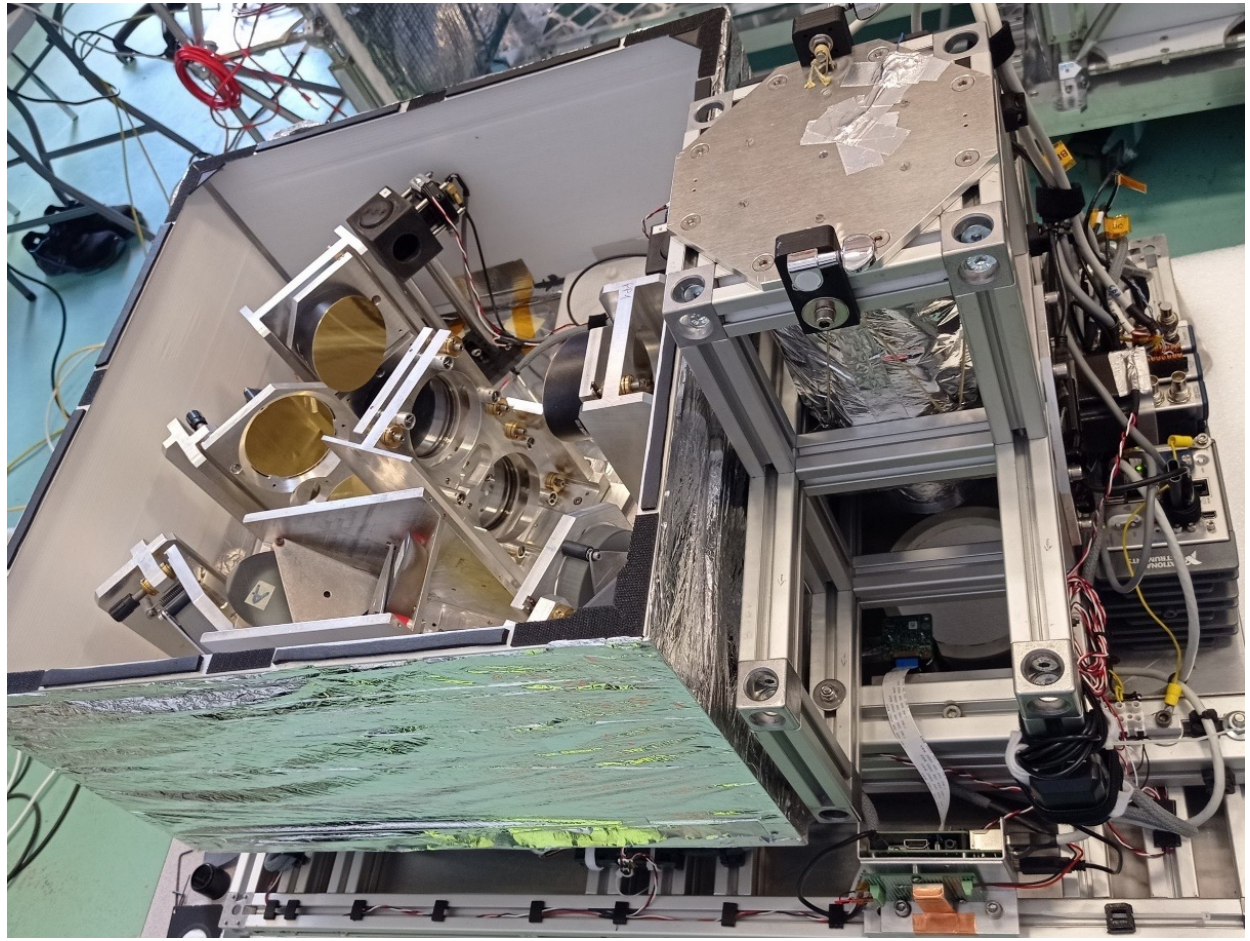
FIRMOS-B

Far-Infrared Radiation Mobile Observation System (- Balloon)



- Fourier Transform Spectrometer
- Spectral coverage = 100-1000 cm^{-1},
- Resolution = 0.3 cm^{-1} double-sided
- Integration time = 3.5 min (average 4 measurements)
- NESR in the range 0.6-2.5 $mW/(m^2\ sr\ cm^{-1})$
- Absolute calibration error < 0.3 K
- Payload: size 85x95x50 cm, 80 kg weight, 60 W avg power

FIRMOS-B can measure both zenith-sky spectra from the ground and nadir-spectra from balloon. **Balloon nadir-spectra are useful to mimic the future satellite measurements acquired by FORUM.**

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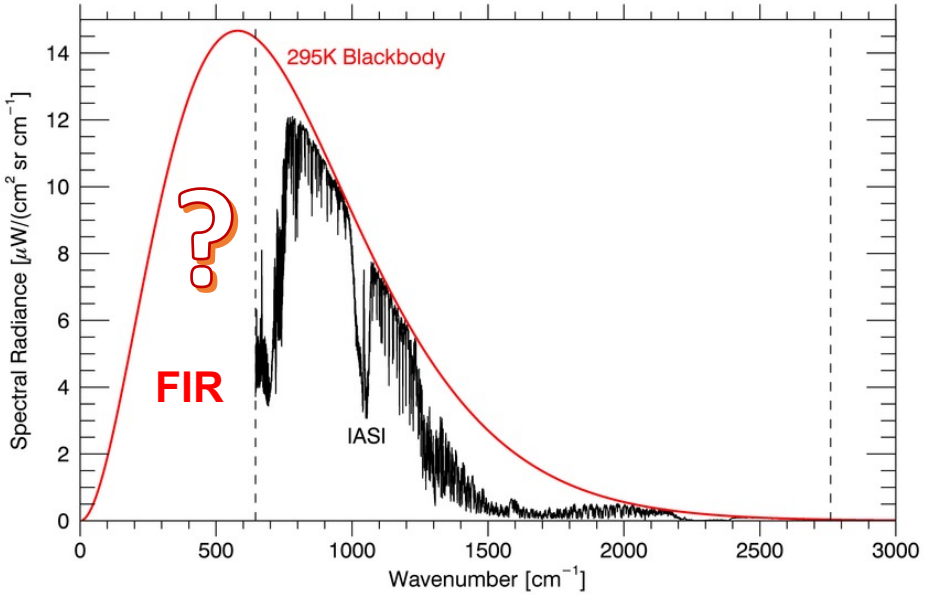
FORUM

FORUM -> Far-infrared Outgoing Radiation Understanding and Monitoring

9th ESA Earth Explorer Mission

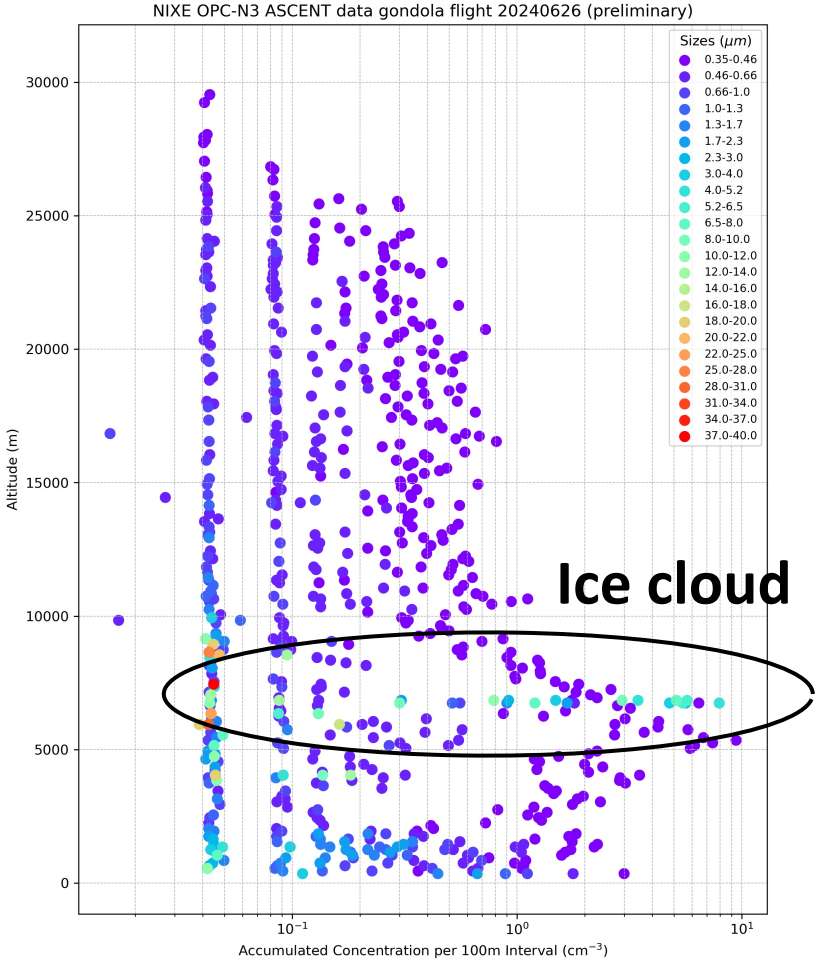


FORUM will measure the satellite FIR radiation (spectrally resolved) emitted by the Earth for the first time.

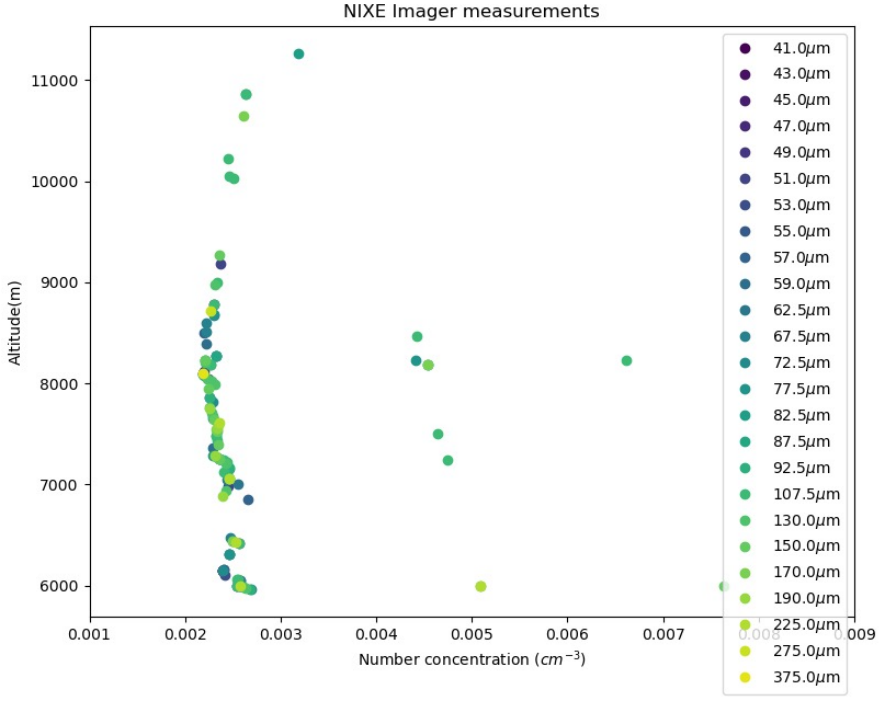
- No FIR observations below 400 cm^{-1}. FORUM will fill this gap.
- Allow to measure the whole Earth emitted spectrum to better estimate the global energy budget.
- The FIR is sensitive to the UTLS water vapor and cirrus clouds.

In-situ cloud measurement

NIXE-OPC. Concentration profile for each size bin, with diameter smaller than 40 μm.



NIXE-Imager. Information of particles with size bigger than 40 μm (concentration, area equivalent diameter and shape).



Picture of a hollow column

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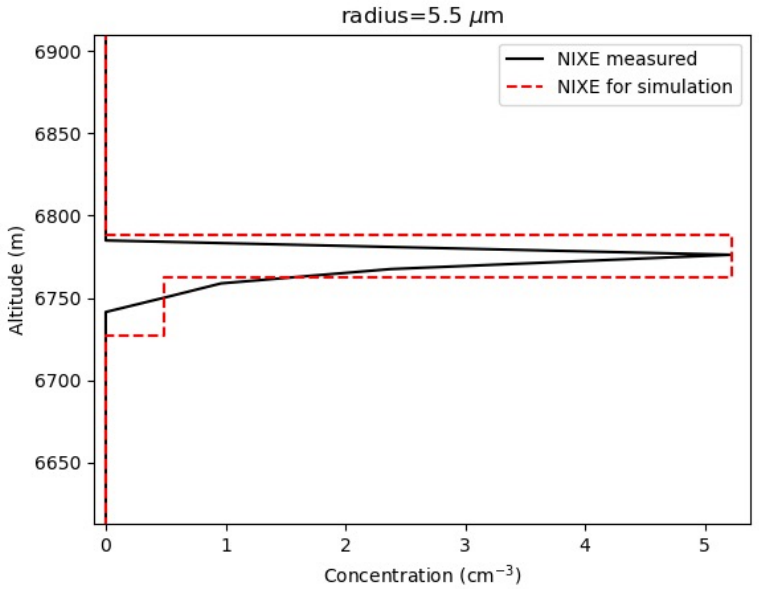
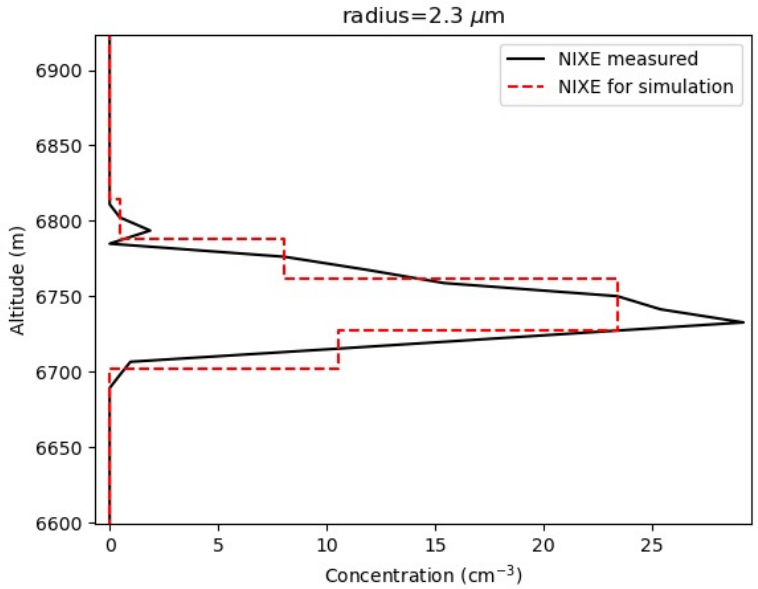
Clouds representation for simulation

The cloud profiles are measured with a very high altitude resolution (about 7 m). We cannot use this high resolution for the simulation. We create synthetic cloud profiles with a minimum vertical step of 25 m.





- A total number of **42 cloud profiles**, each relative to a particle dimension with radius from 1 to 187 μm, are used for the simulation using both NIXE-OPC and Imager data.

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Simulation with GBB-nadir code

- GBB-nadir is a line-by-line code capable to simulate the nadir spectra.
- The results shown are obtained with the **scattering properties computed both with the Mie approximation (ice particles treated as spheres) and with properties accounting for ice particle shapes.**
- The used RTM is DISORT.
- Input parameters used:
  - ✓ P, T and O_3 profiles from NOAA-FPH radiosound.
  - ✓ H_2O profile from CFH-Julich radiosound.
  - ✓ CO_2 from IG2 profiles scaled to the year 2024 according to its trend.
  - ✓ Other minor gases from IG2 climatology.
  - ✓ T surf = 280K from ERA5.
  - ✓ Emissivity = constant value of 0.98.
  - ✓ 42 cloud concentration profiles measured by NIXE.
- Spectroscopic database HITRAN2020.

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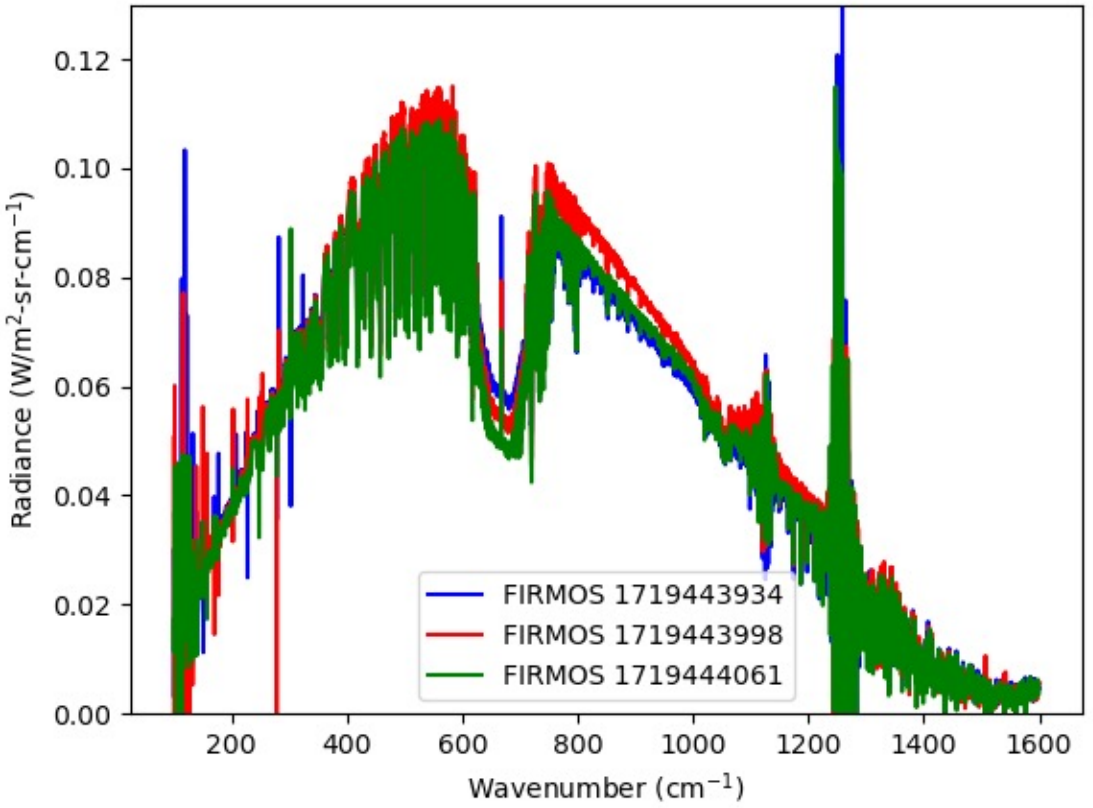
FIRMOS measurements

- In this presentation, we consider the spectrum having the epoch time 1719443934, because is the first spectrum acquired above the clouds.
- Three consecutive spectra are reported to show the variability of the scene.
- The measurement of each spectrum takes 1 minute and after few seconds the following spectrum starts to be acquired.



One challenge of this activity is due to the important variability present in the FIRMOS scenes.

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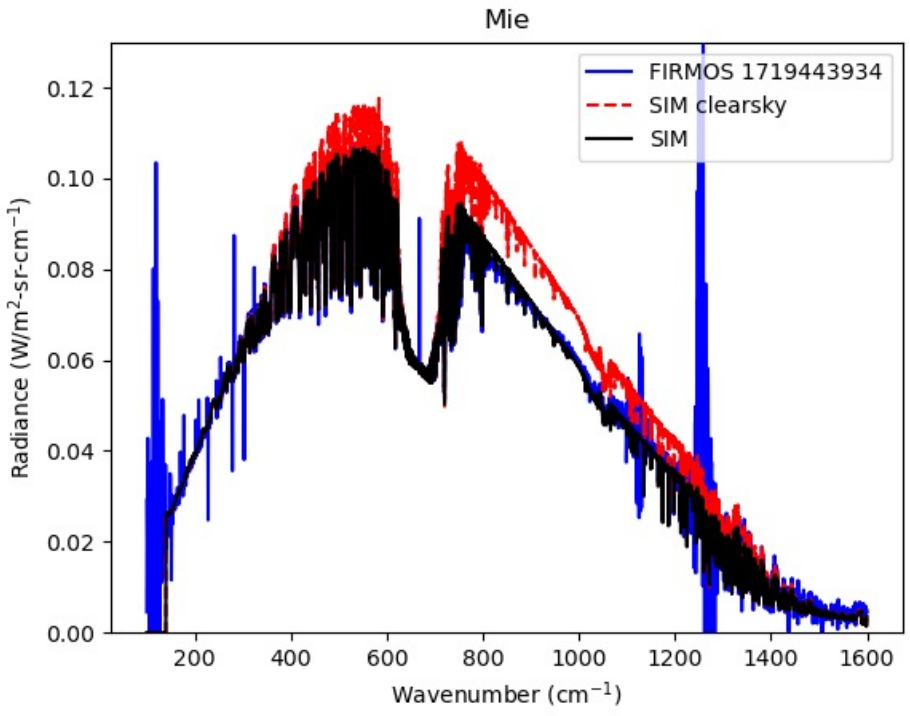
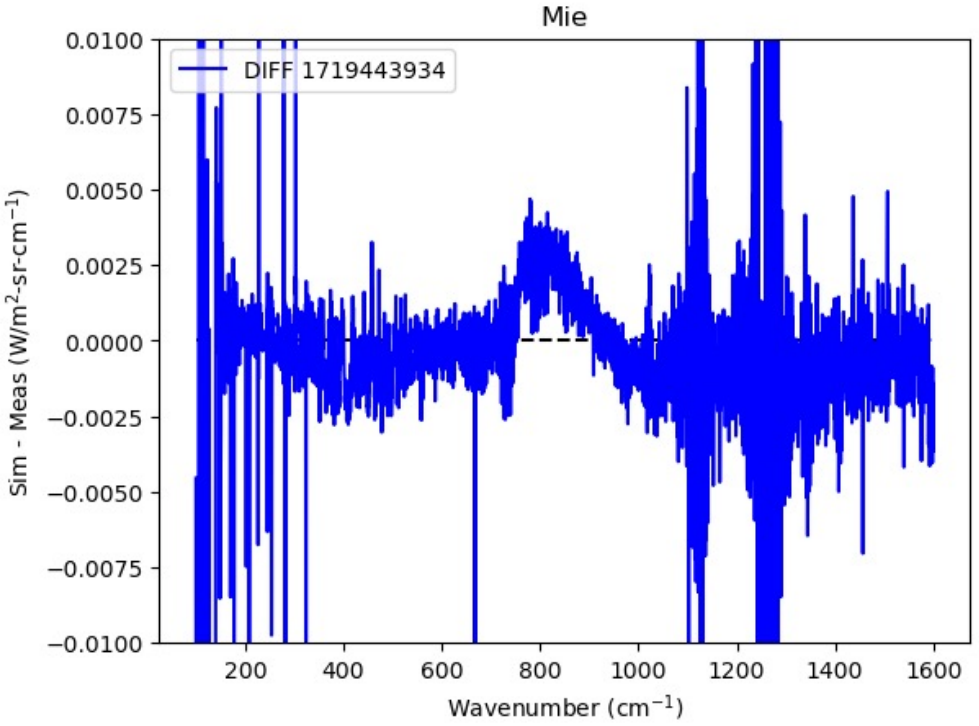
Results with Mie theory





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Using the Mie theory, we cannot reproduce the slope in the atmospheric window.

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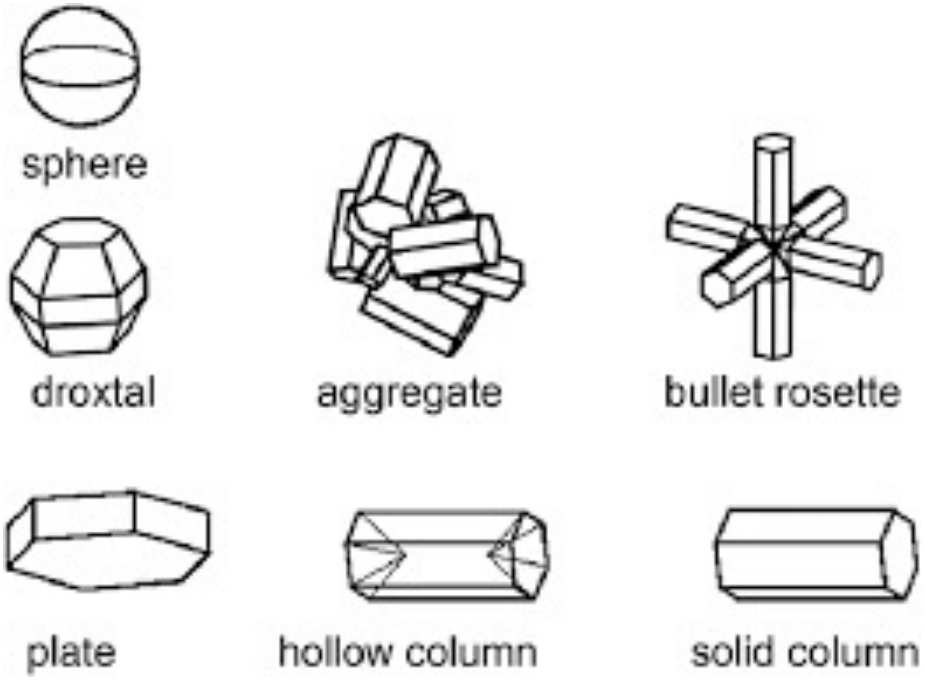
Simulations with properties accounting for the habit

habits:

- Droxtal
- Single column
- Hollow column
- Columns
- Plates
- Hollow bullet rosette
- Single bullet rosette



Tabulated parameters used for simulations (reported as a function of wavenumber and effective radius):

- Extinction efficiency
- Scattering efficiency
- Asymmetry parameter (g)
- Projected area of the crystal

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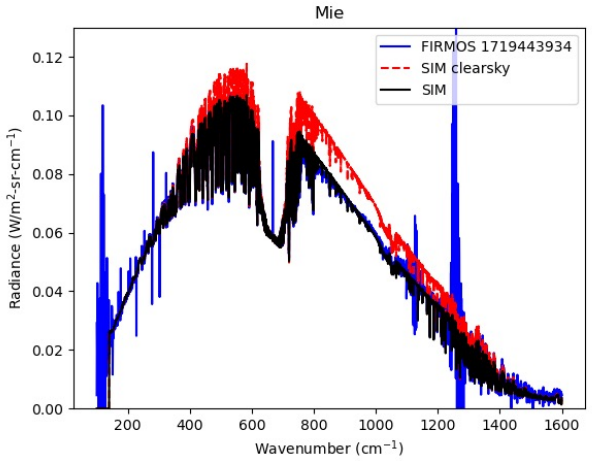
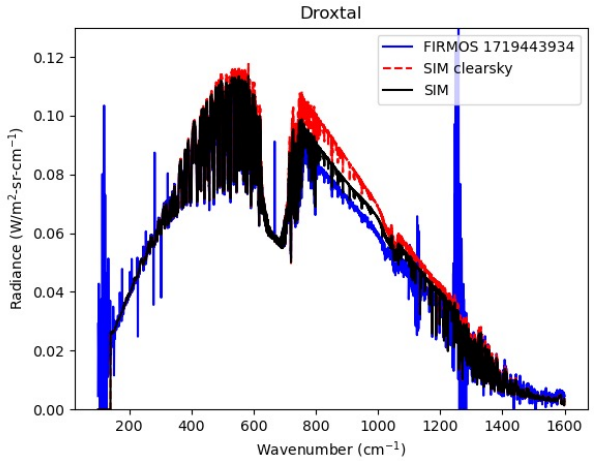
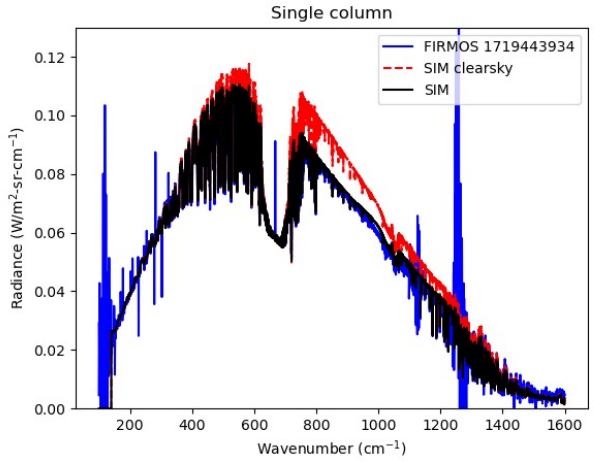
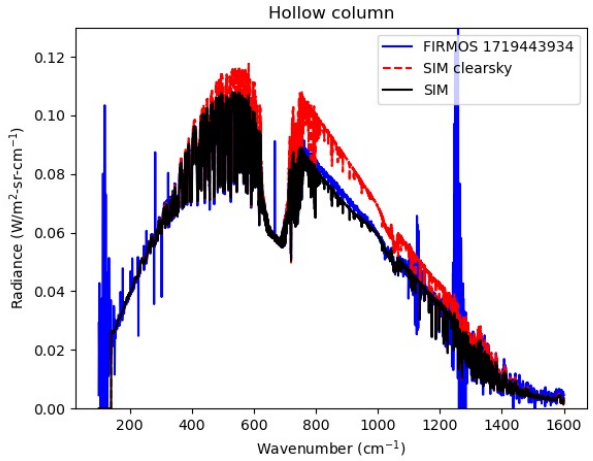
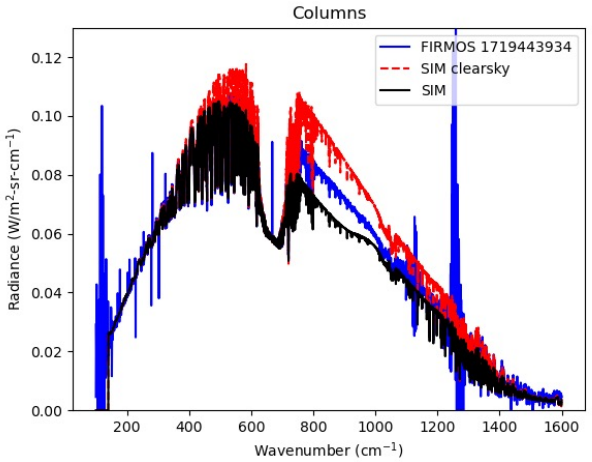
Simulations with properties accounting for the habit

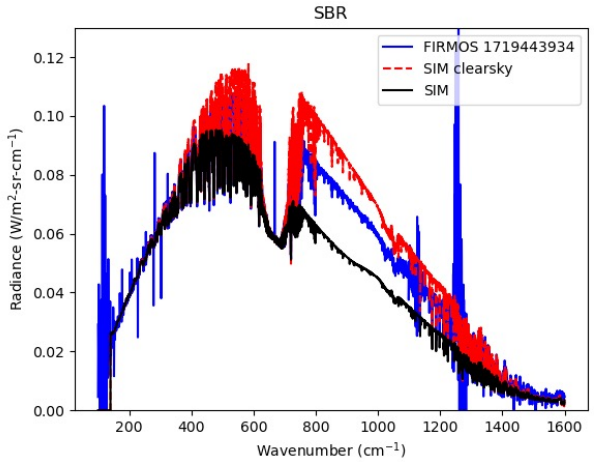


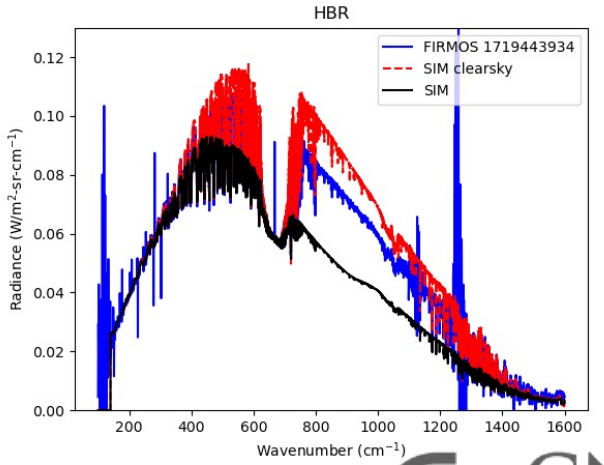


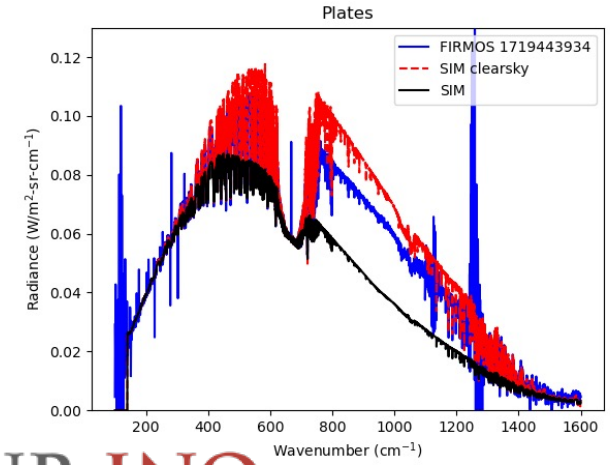




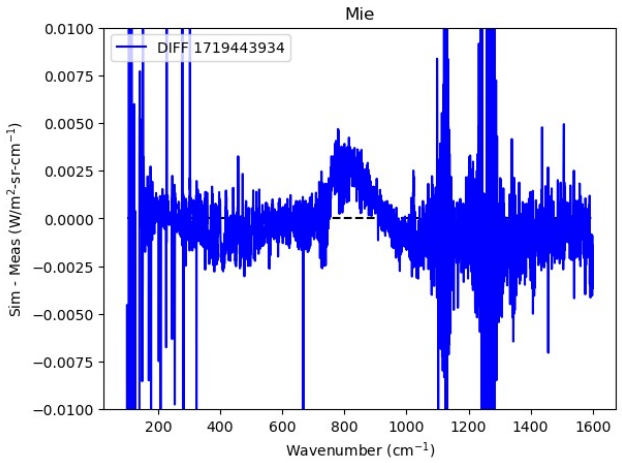


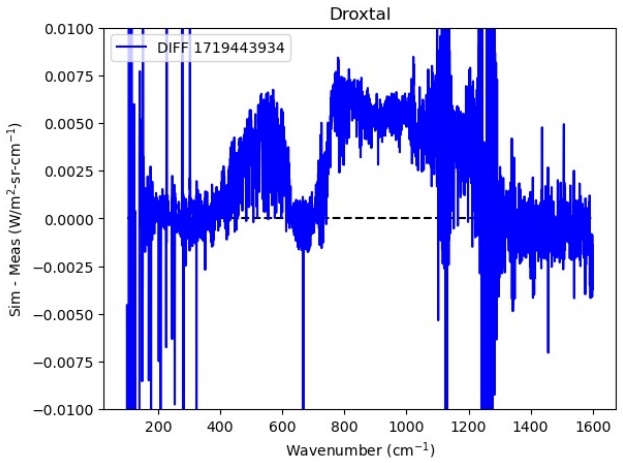


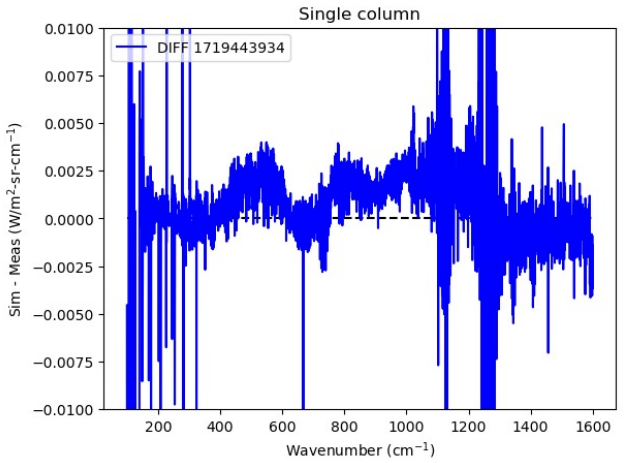


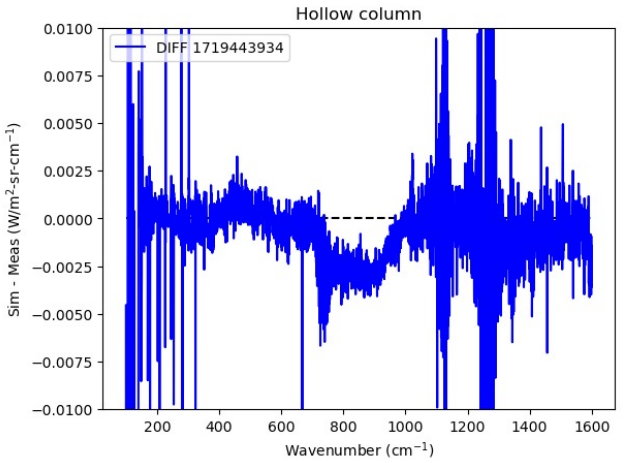


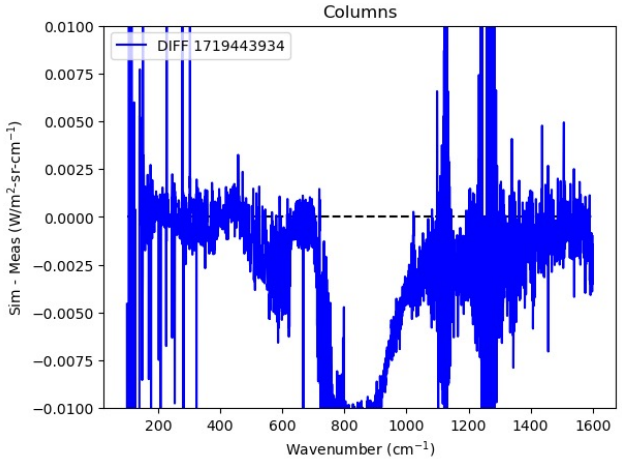
Simulations with properties accounting for the habit

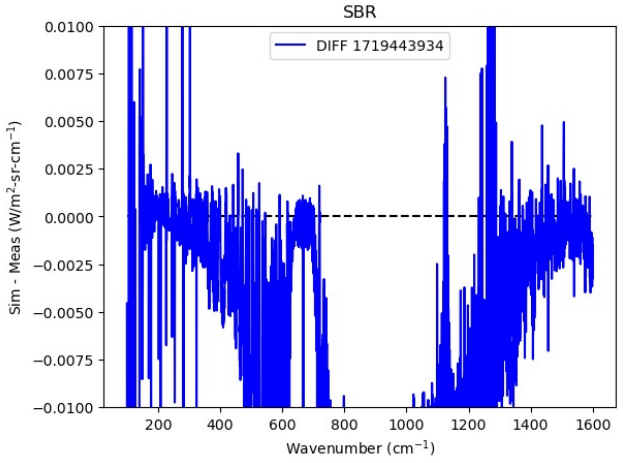


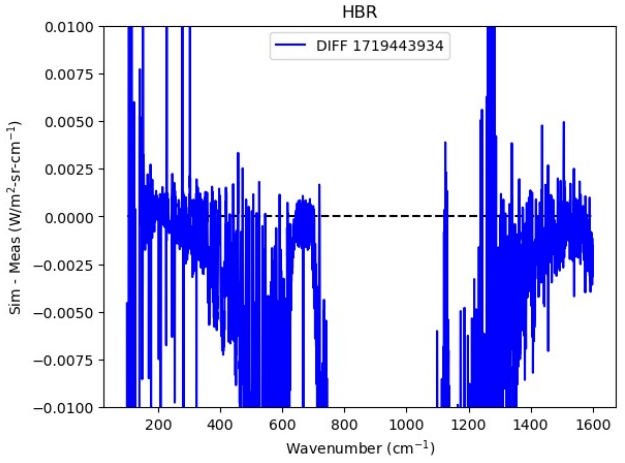


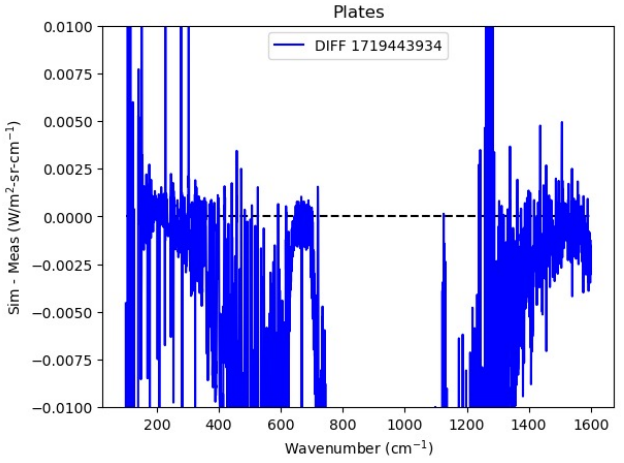




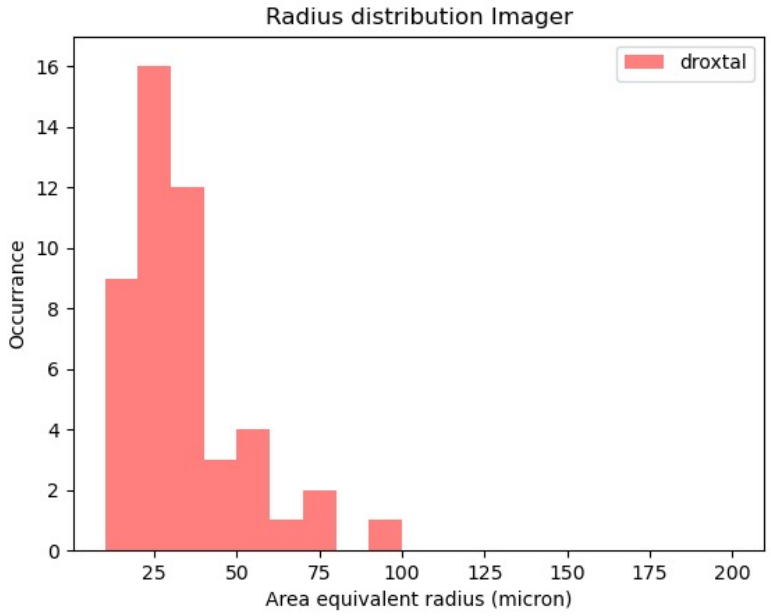


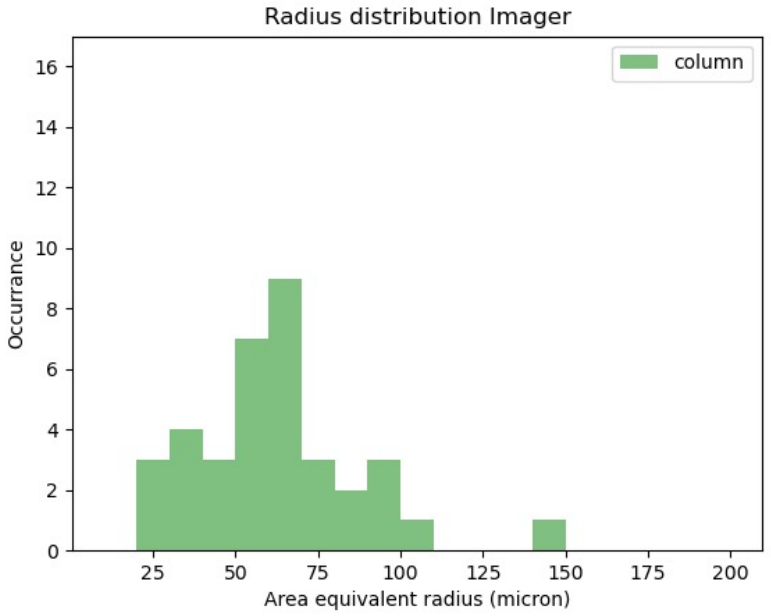


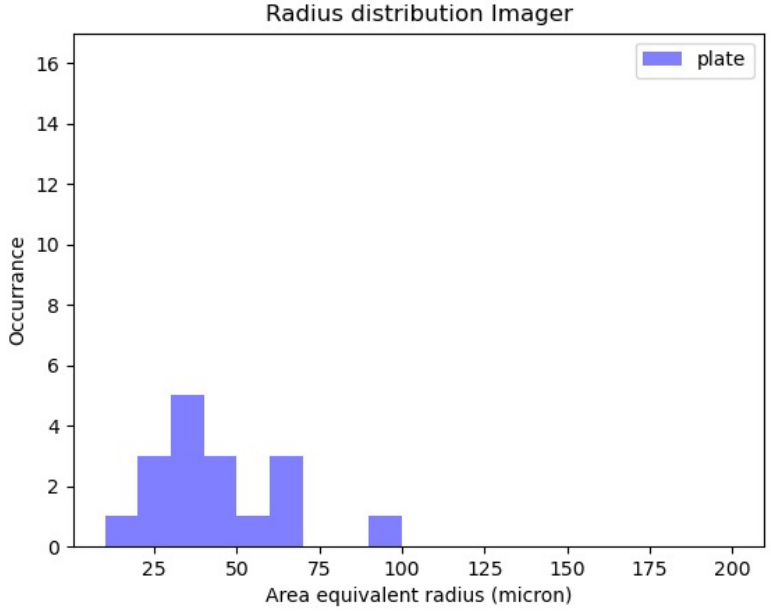


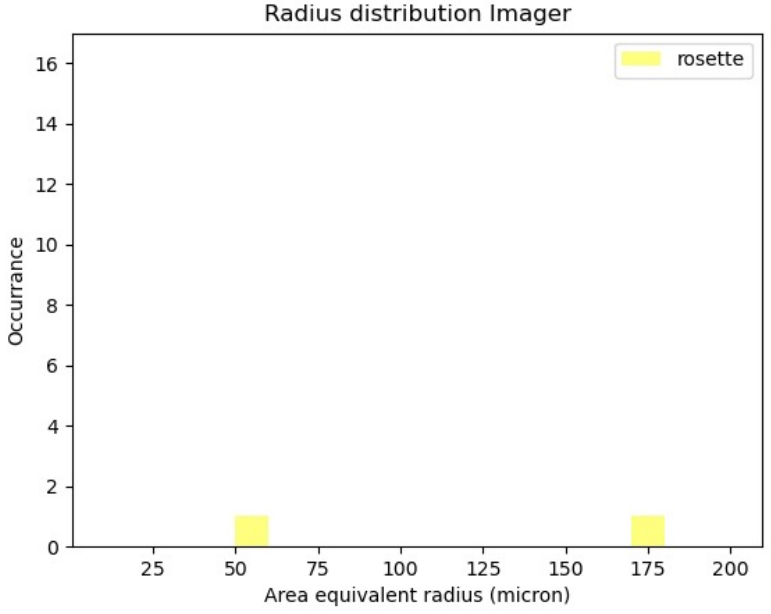


Habits distribution from NIXE-Imager









- Droxtal at small sizes.
- Column at big sizes.
- A few plates are present at small/medium sizes.
- The presence of rosette is negligible.

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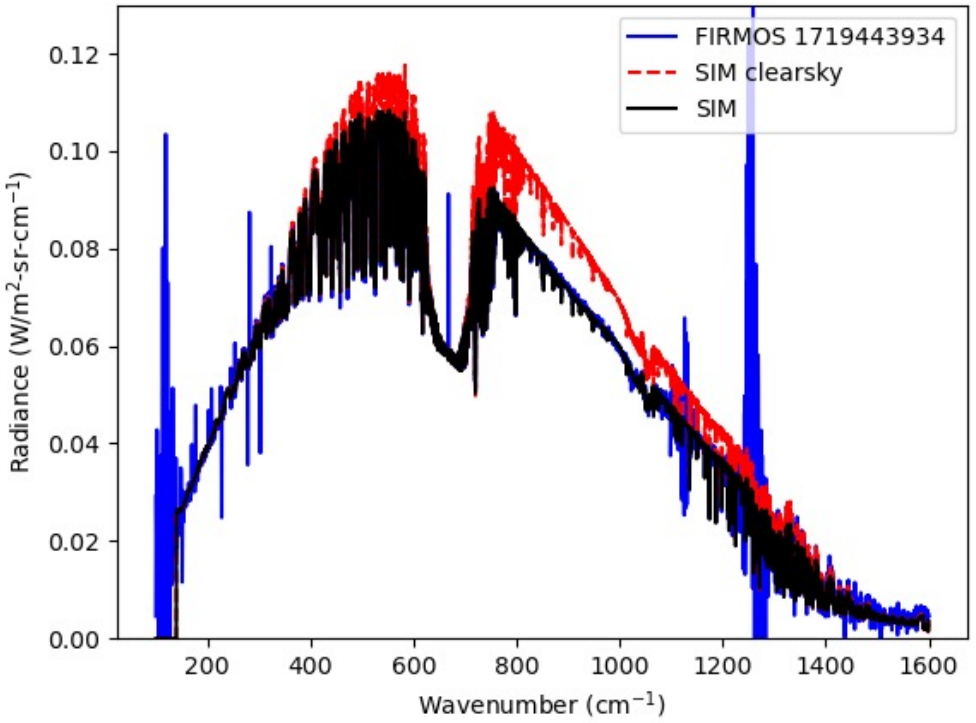
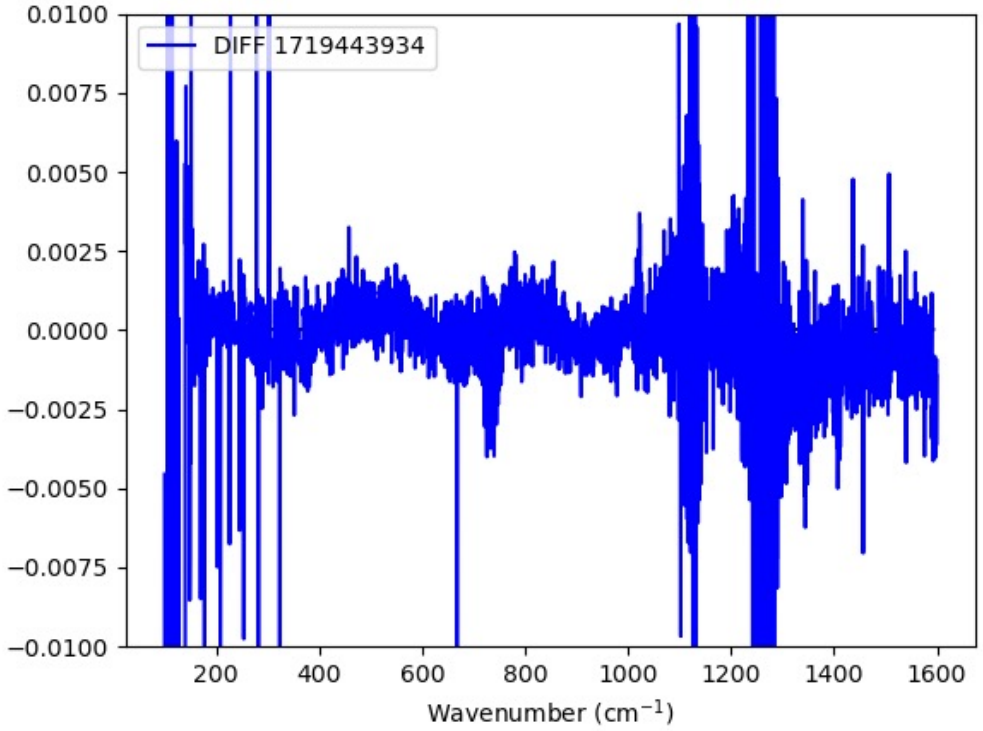
Simulations with mixture of crystal habits

We simulate the spectrum using the tabulated properties, creating a mixture of droxtal, hollow column and plates which takes into account the measured distributions. Particles with size smaller than 40 μm measured by NXE-OPC are assumed droxtal.





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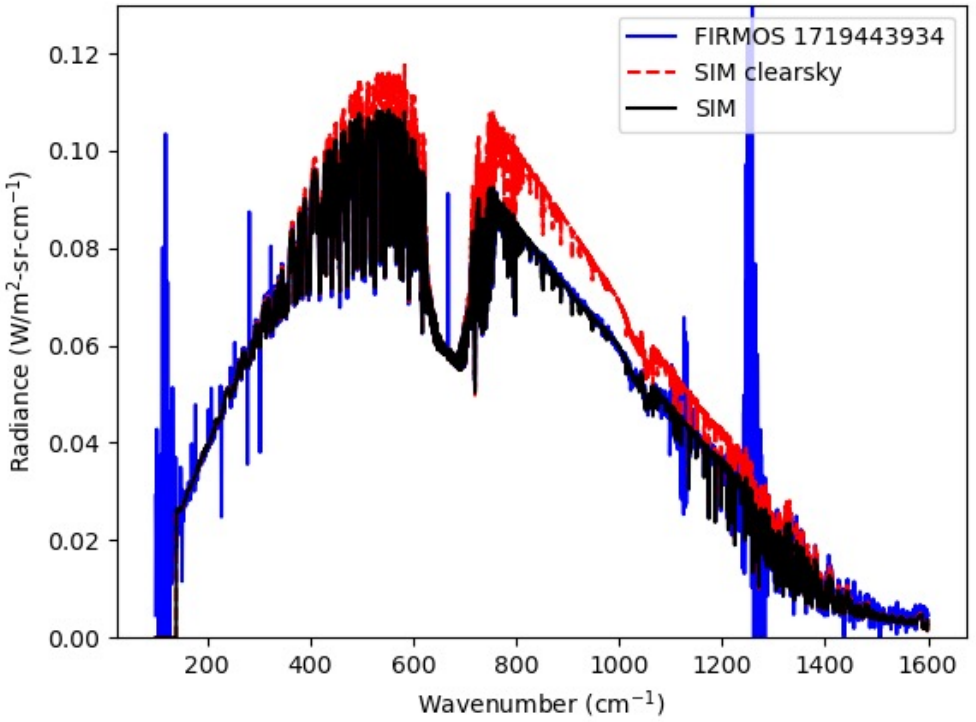

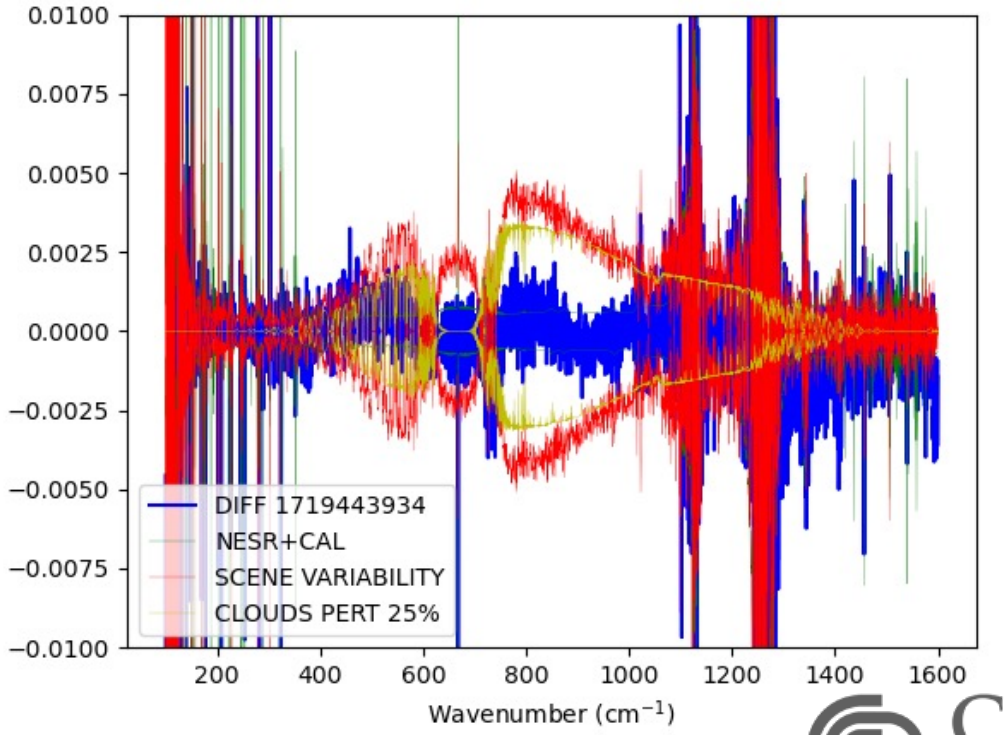

- **NESR+CAL** (green) is the sum in quadrature of NESR and calibration error in the FIRMOS spectrum.
- **SCENE VARIABILITY** represents an estimate of the scene variability. It is the difference between the considered spectrum and the one measured one minute later, divided by 2.
- **CLOUDS PERT 25%** is the error due to the not- perfect cloud representations. We simulated the spectrum perturbing the clouds concentrations of +/- 25%. 25% is the STD of the percent differences between measured and synthetic clouds.

Conclusions

- The radiative closure using the Mie theory leads to good results apart from the atmospheric window where the behavior is not well reproduced.
- The simulations with scattering properties accounting for crystal shape, for 7 different habits, highlight the importance of taking into account the particle shape.
- The final result, obtained with mixture of droxtal, hollow column and plates as measured by NIXE-Imager, is in agreement within the errors almost everywhere.
- We think that the highest error source in this exercise is due to the scene variability.

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