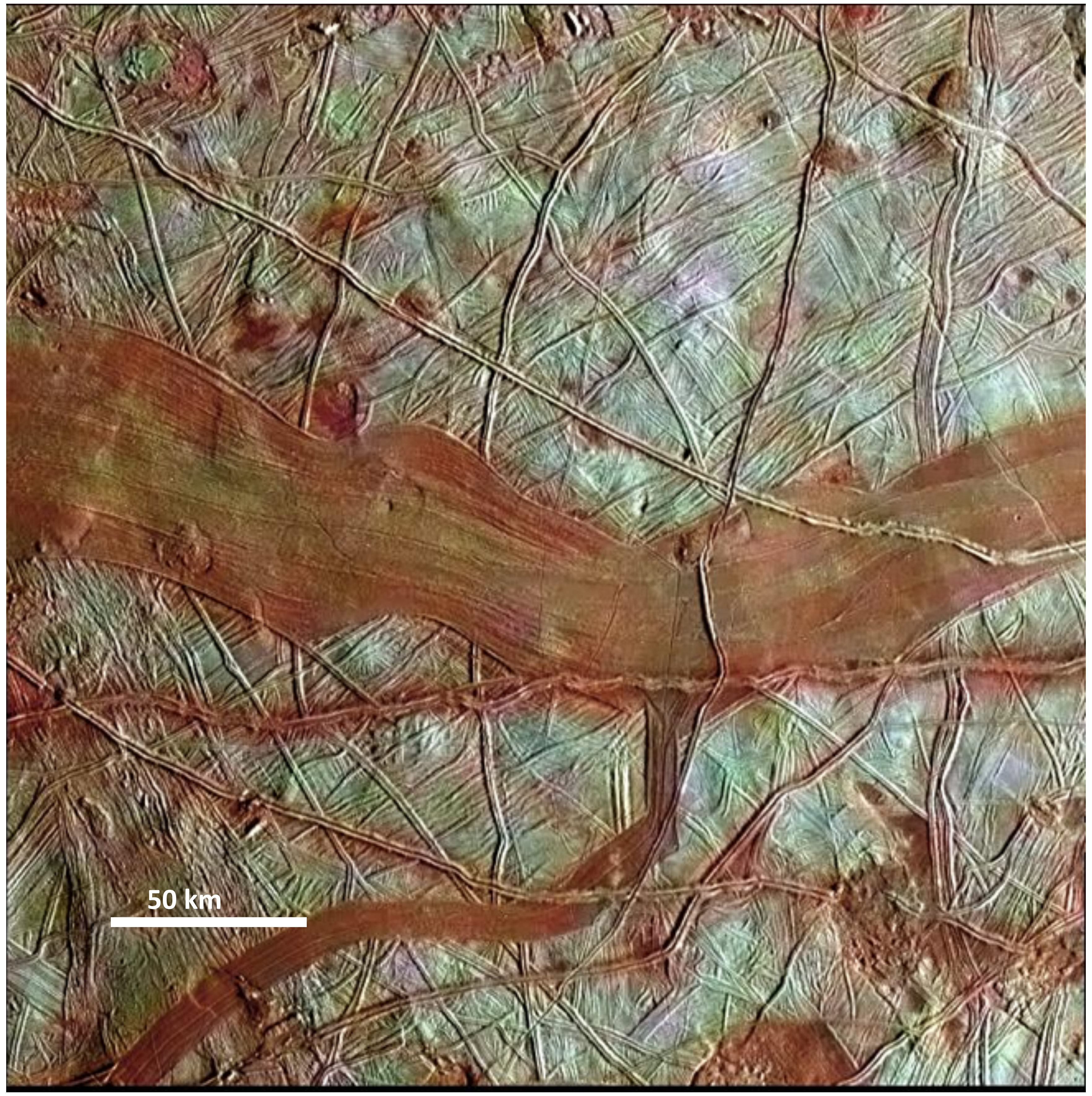
Microphysics of Europa’s surface using Galileo/NIMS data

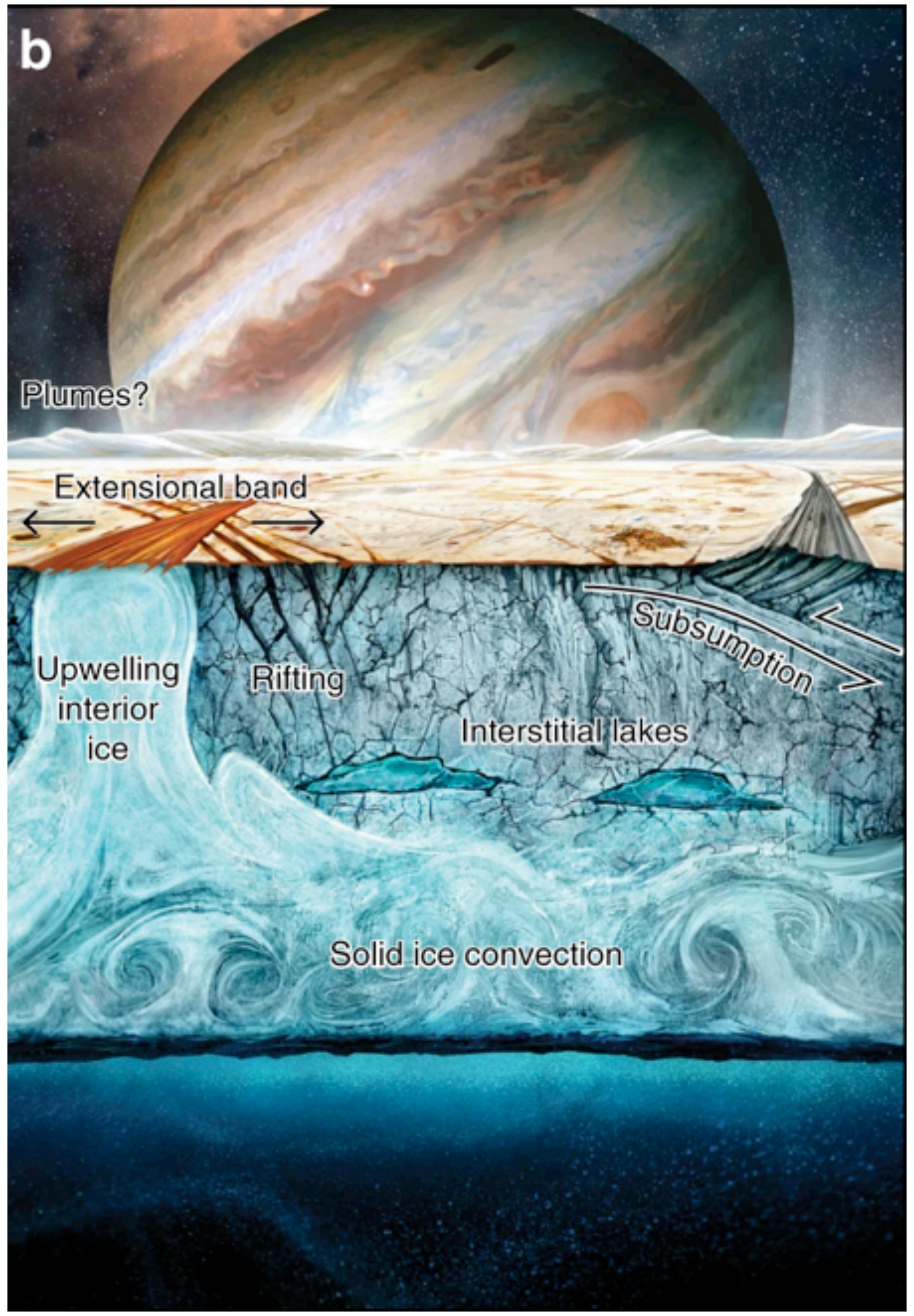
Guillaume Cruz-Mermy, F. Schmidt, F. Andrieu, I. Belgacem, T. Cornet

Surface morphology

Dilatation bands



Credit: NASA/JPL-Caltech/SETI Institute



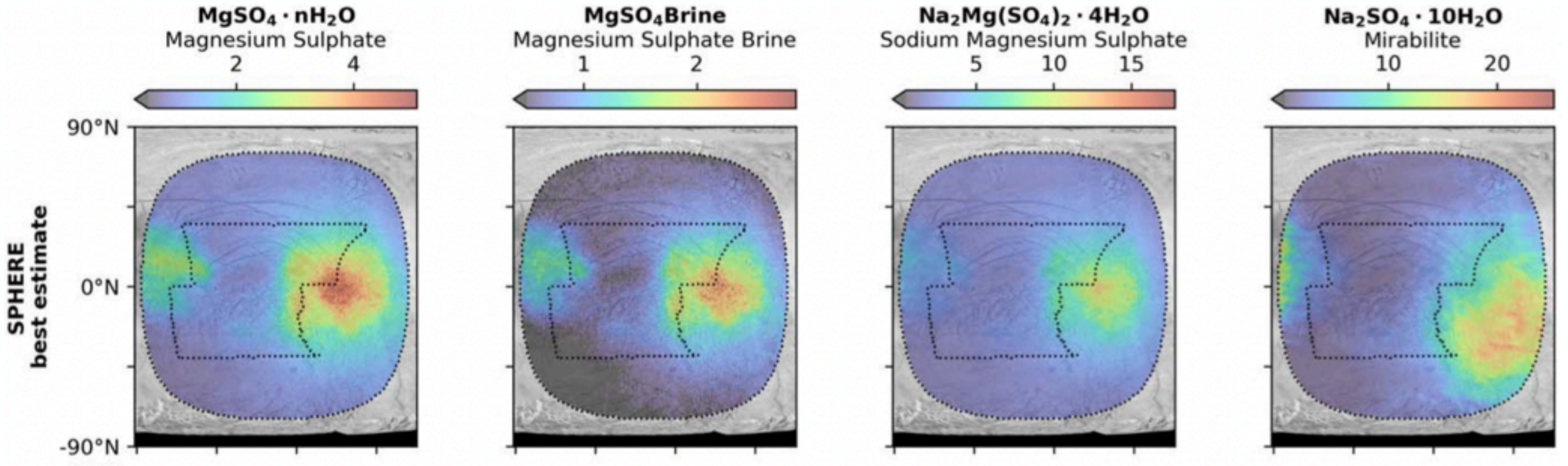
Howell & Pappalardo, 2020

- Hemispherical dichotomy (Leading Vs Trailing)
- Ridges, Linea, Bands, Craters ….
- Various spatial extension
- Endogenic Vs Exogenic
- Surface : key witness

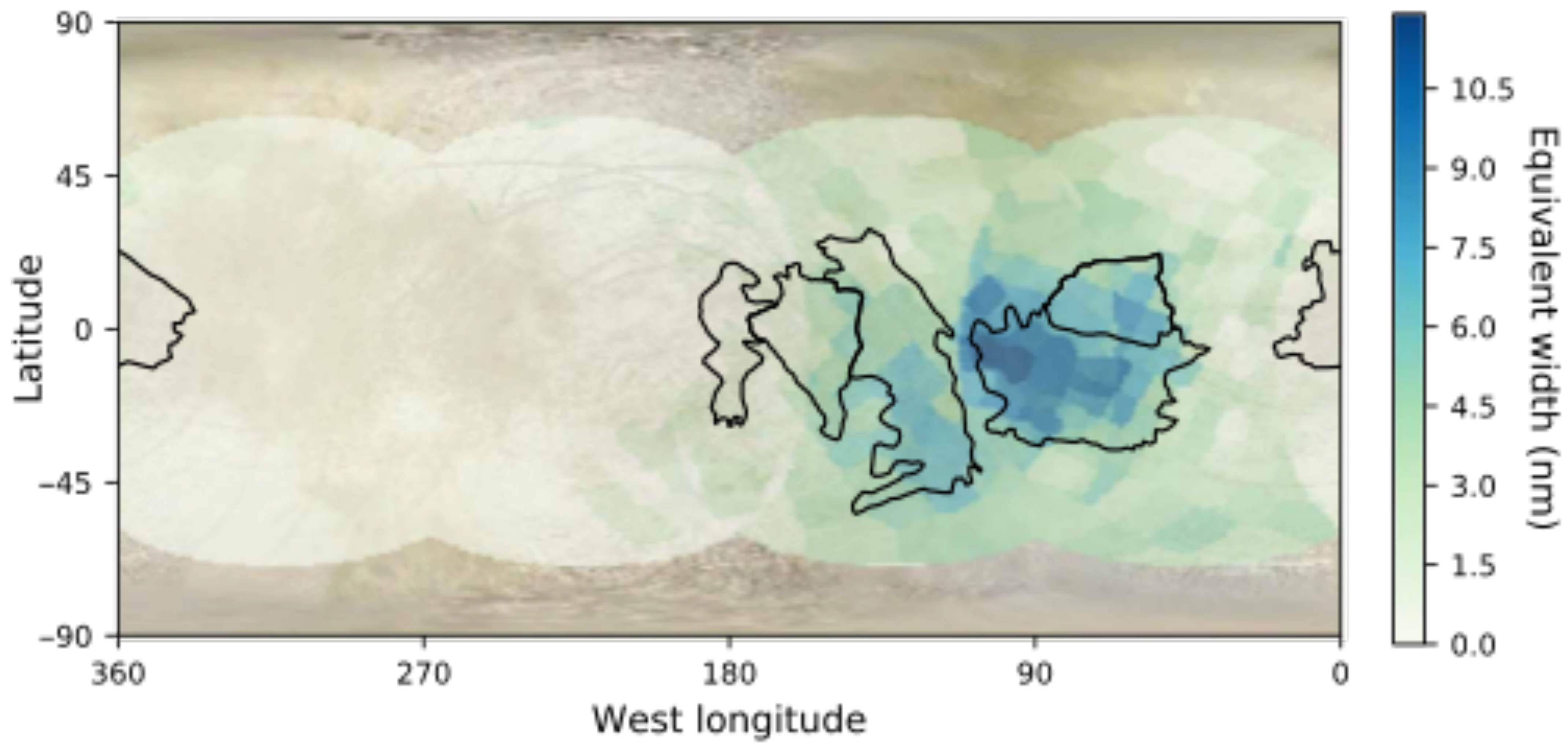
Surface composition

UV-VIS-NIR Spectroscopy

- Water ice (crystalline/amorphous)
  - Kuiper et al. (1957), Calvin et al. (1995)
- Sulfuric Acid Octahydrate (SAO)
  - Carlson et al. (1999, 2005), Mishra et al. (2021)
- Hydrated sulfates
  - McCord et al. (1998), Dalton et al. (2007, 2012), Ligier et al. (2016), King et al. (2022)
- Chlorinates
  - Brown et al. (2013), Hanley et al. (2014), Ligier et al. (2016), Trumbo et al. (2020)
- Oxidants
  - Carlson et al. (1999), Hand et al. (2006), Trumbo et al. (2019)



Hydrated sulfates distribution, from King et al. (2022)



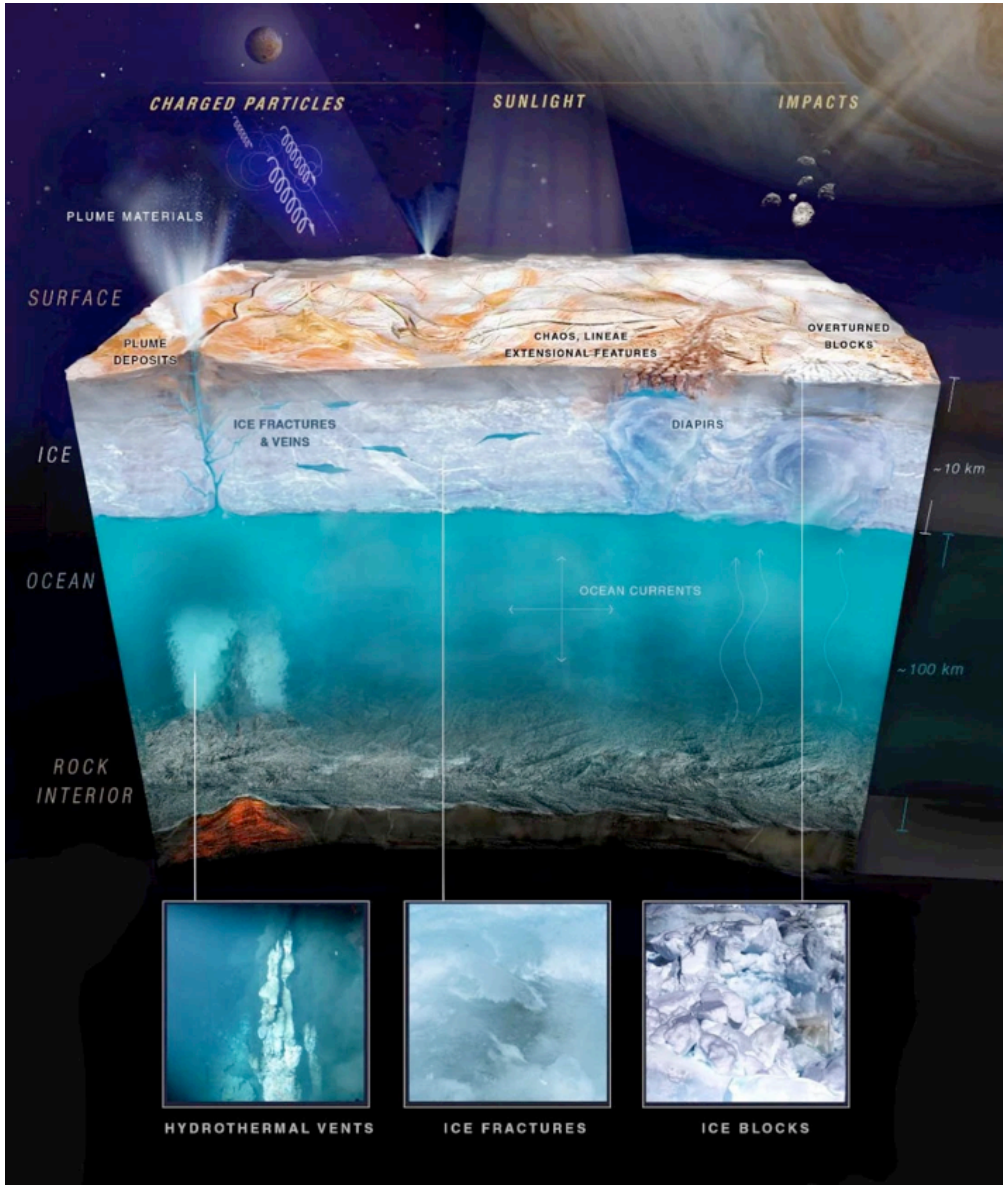
NaCl distribution, from Trumbo et al. (2020)

Why studying the surface ?

- **Previous studies:**
  - Linear mixture model / Hapke model
  - Spectral comparison
  - Low spatial resolution observations

- **Objectives:**
  - Use accurate radiative transfer & bayesian approach
  - Use Galileo/NIMS high spatial resolution images
  - Differentiate between endogenous and exogenous processes

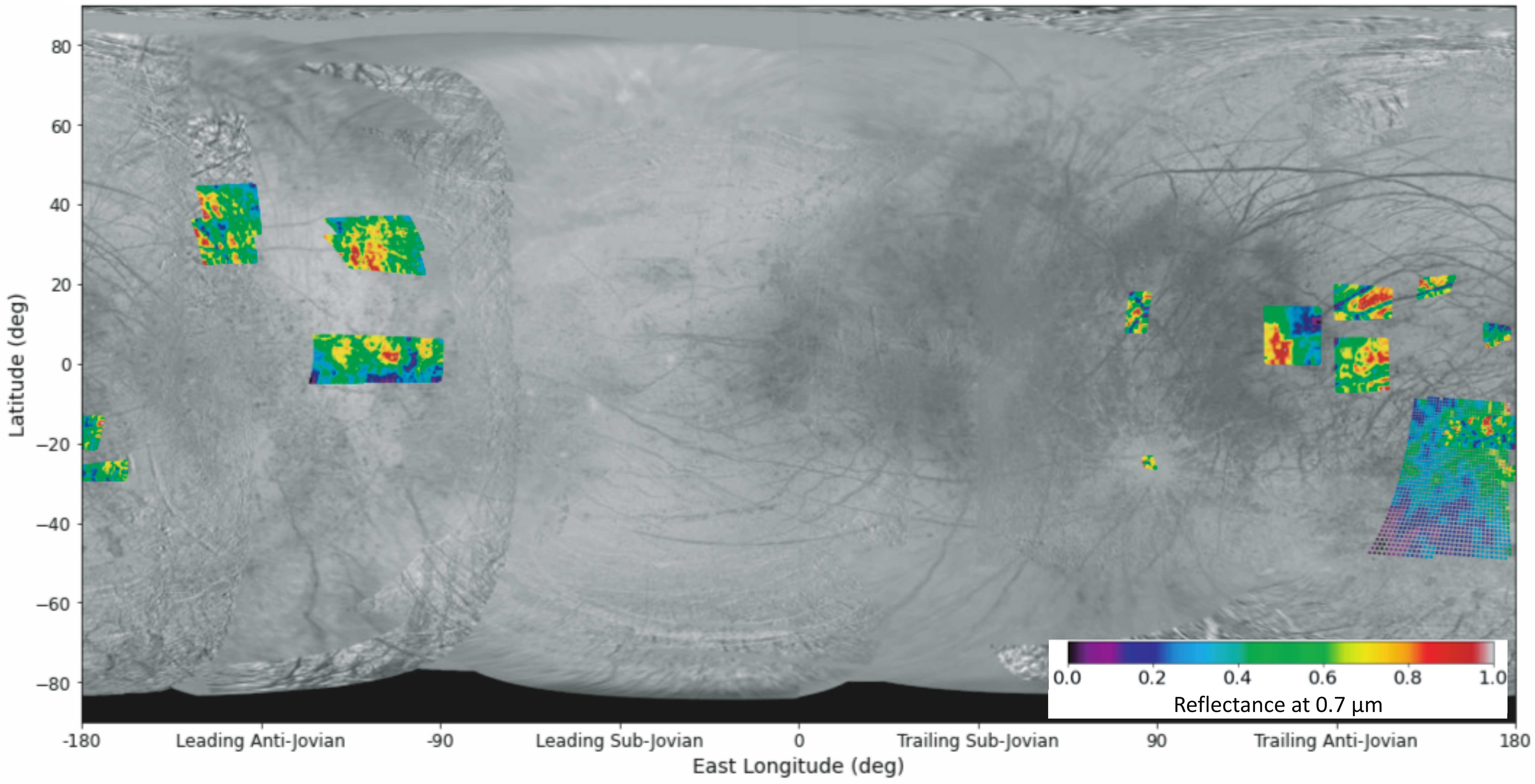
→ **What is the true surface composition ?**
What is the ice microphysics ?



Galileo/NIMS hyperspectral data

- NIR wavelengths:
  0.7 - 5.2 µm
- Spectral resolution:
  0.125 - 0.250 µm
- Spatial resolution up to **2.5 km/pixel** (flyby)

All observation with spatial resolution < 10 km/pixel



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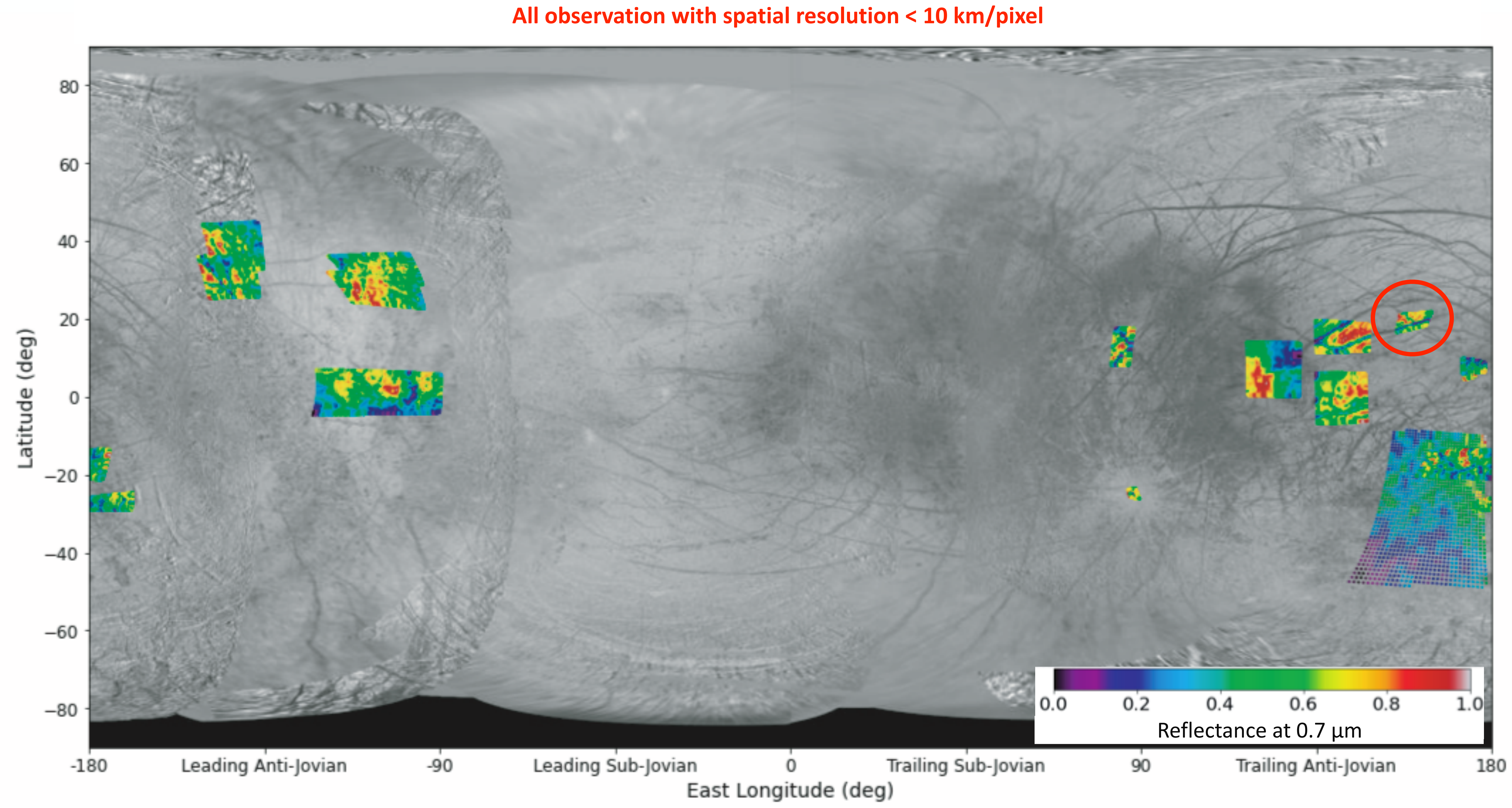
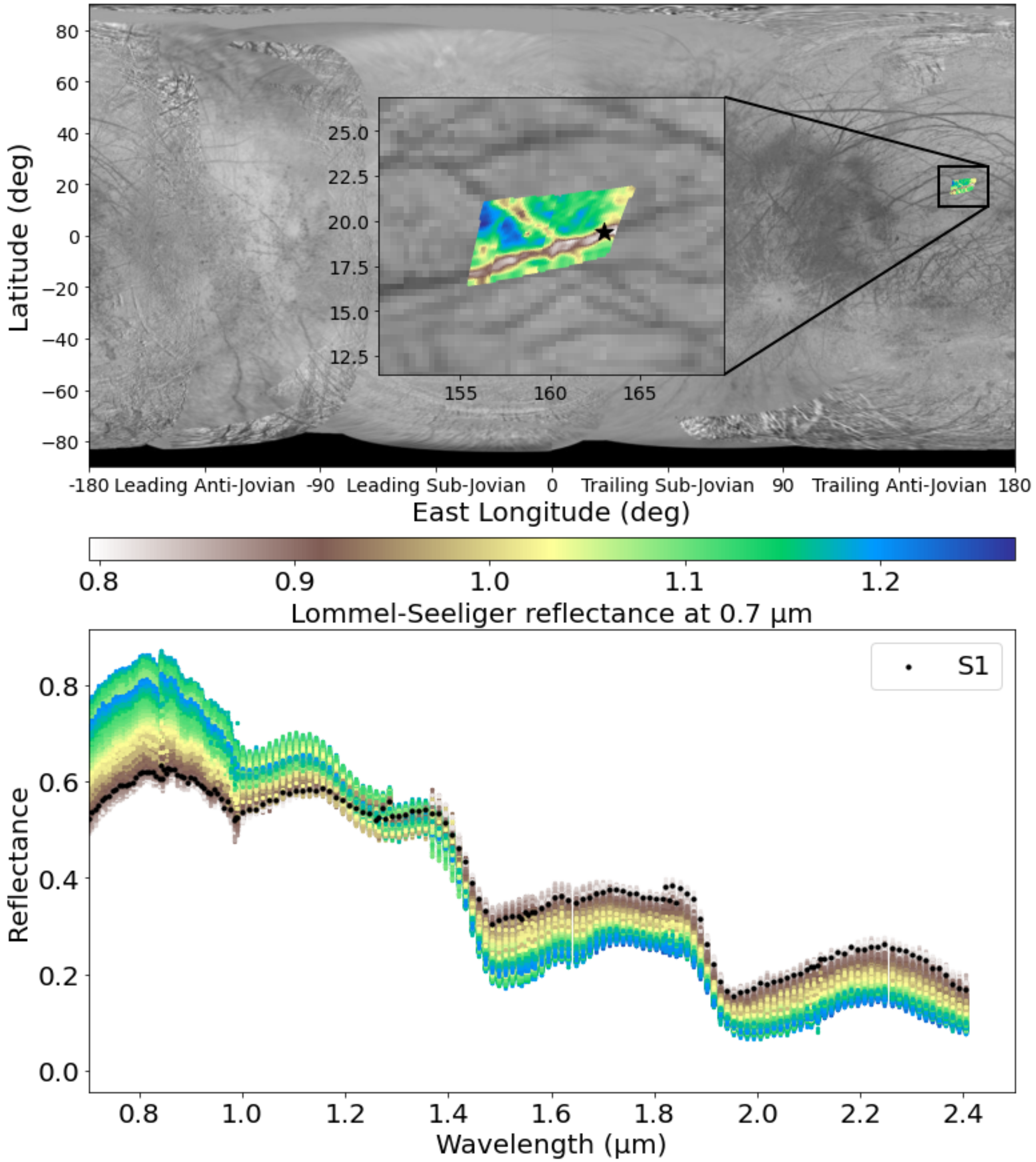
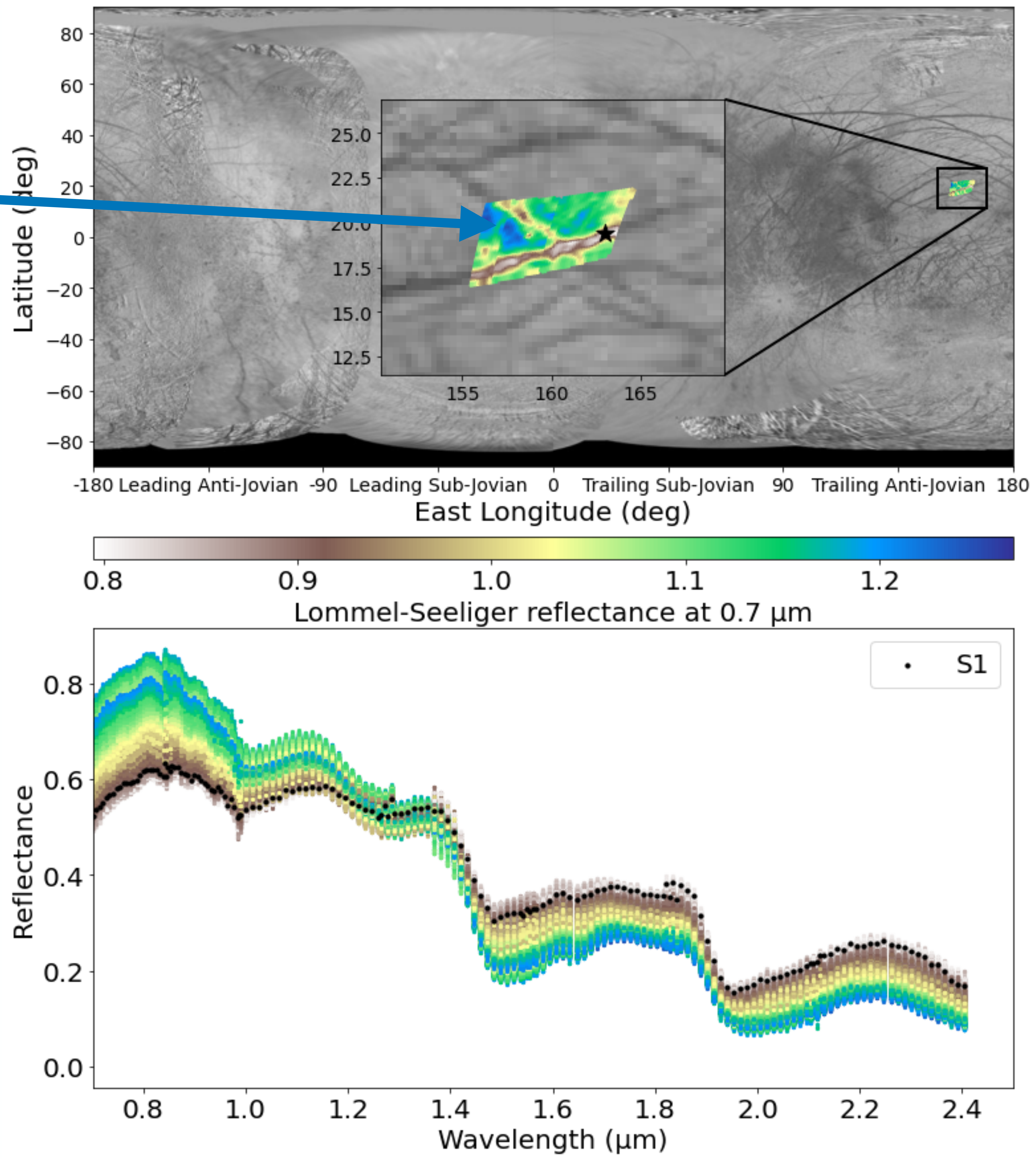


Test case: Harmonia Linea



Test case: Harmonia Linea

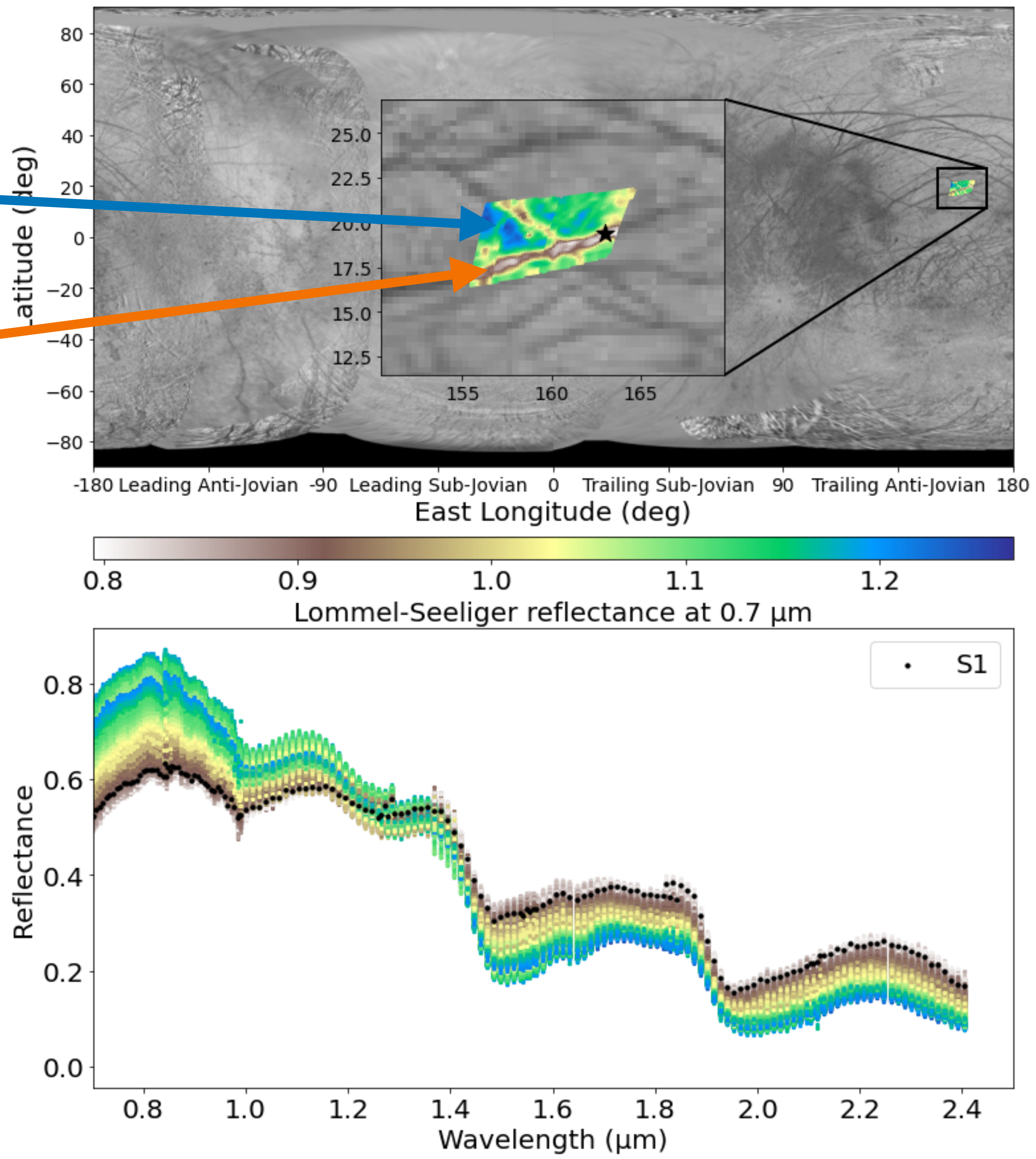
Bright plains



Test case: Harmonia Linea

Bright plains

Dark lineaments



Test case: Harmonia Linea

Bright plains

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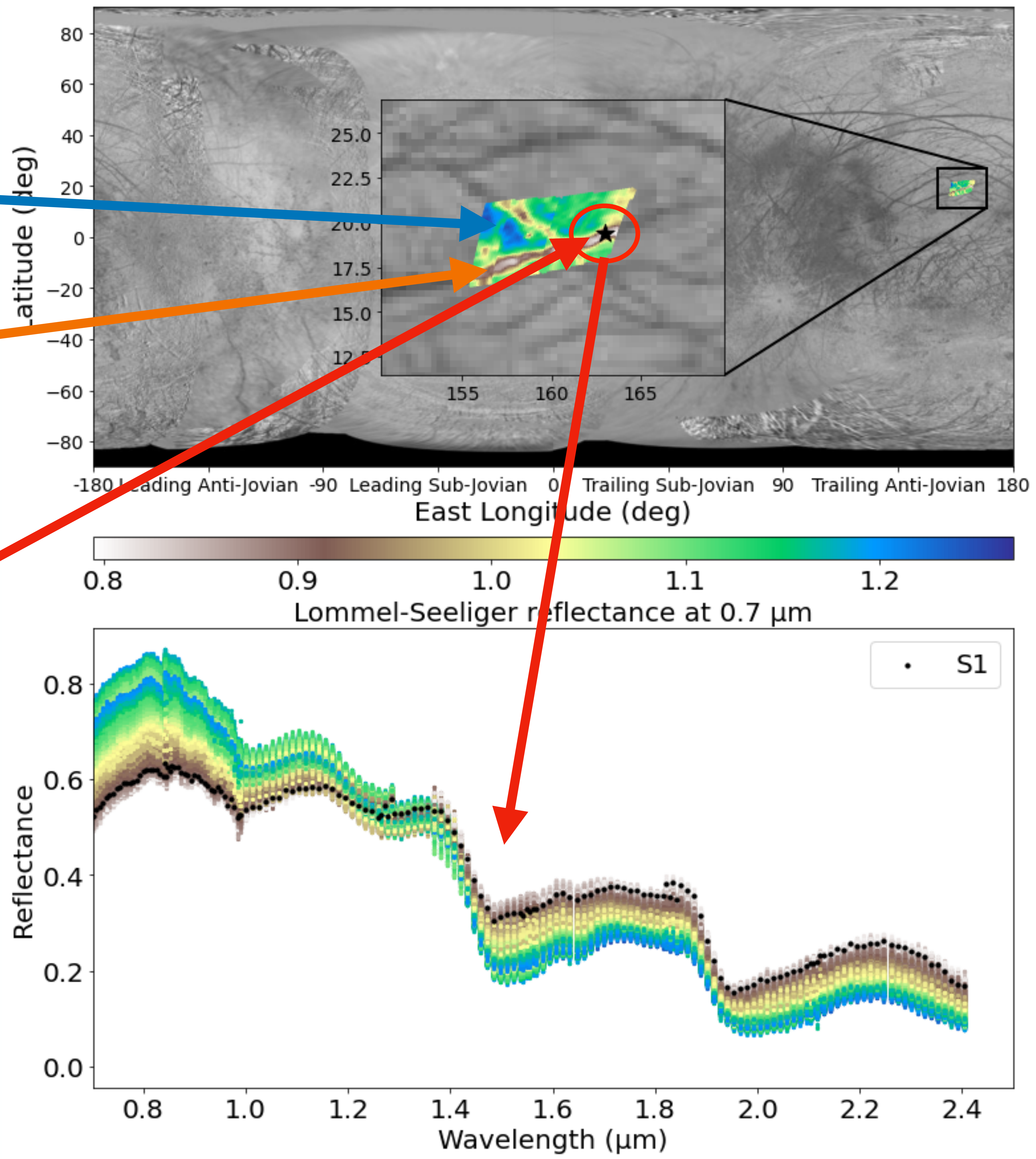
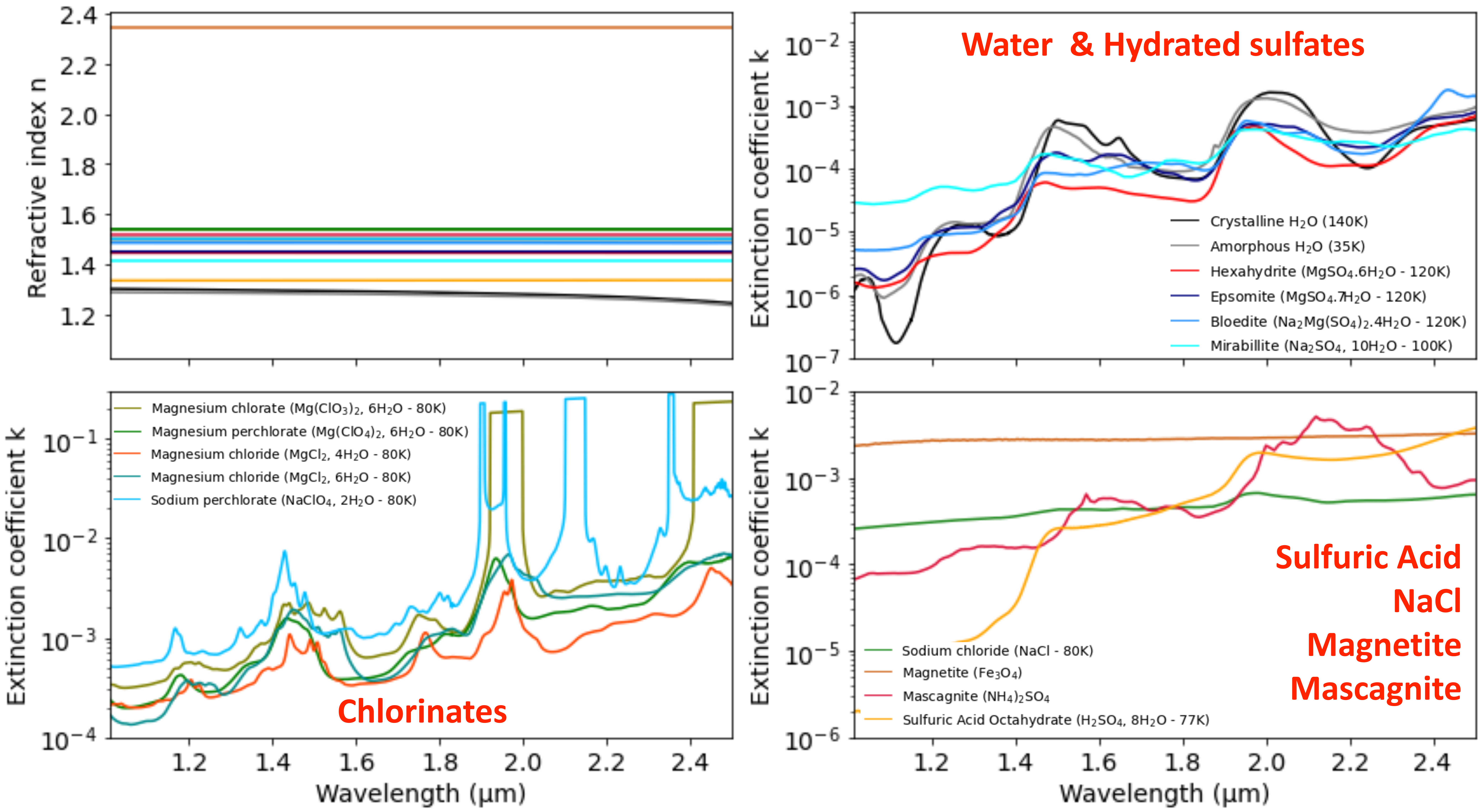
Reference spectrum

- Good spectral res.
- Distorted absorption bands
- Hard to fit !



Compound selection



Compound selection

- K out of 15 potential endmembers

Crystalline H_2O (140K)	Magnesium chloride ($MgCl_2$, $4H_2O$ - 80K)
Amorphous H_2O (35K)	Magnesium chloride ($MgCl_2$, $6H_2O$ - 80K)
Hexahydrite ($MgSO_4.6H_2O$ - 120K)	Sodium perchlorate ($NaClO_4$, $2H_2O$ - 80K)
Epsomite ($MgSO_4.7H_2O$ - 120K)	Sodium chloride (NaCl - 80K)
Bloedite ($Na_2Mg(SO_4)_2.4H_2O$ - 120K)	Magnetite (Fe_3O_4)
Mirabillite (Na_2SO_4, $10H_2O$ - 100K)	Mascagnite $(NH_4)_2SO_4$
Magnesium chlorate ($Mg(ClO_3)_2$, $6H_2O$ - 80K)	Sulfuric Acid Octahydrate (H_2SO_4, $8H_2O$ - 77K)
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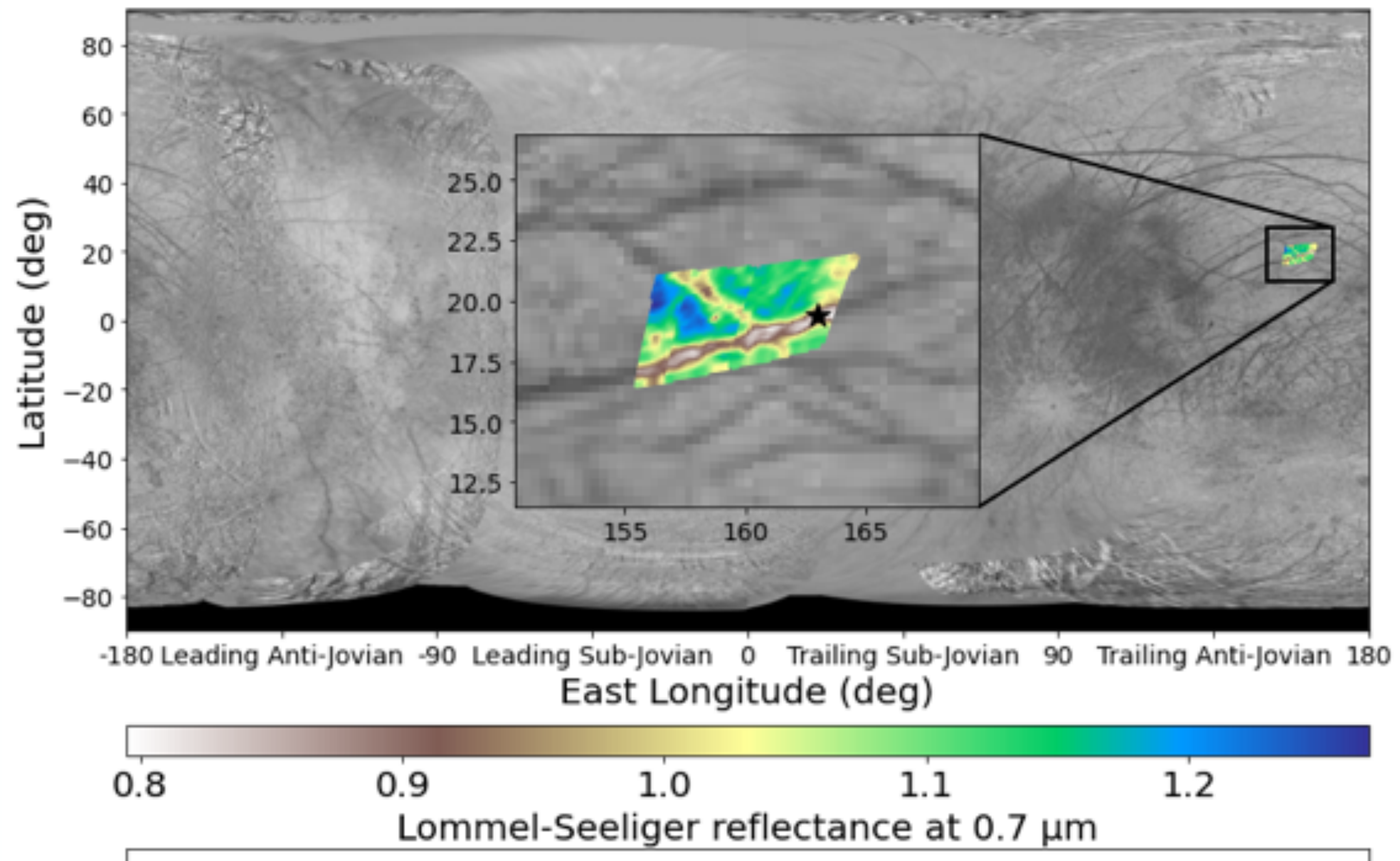
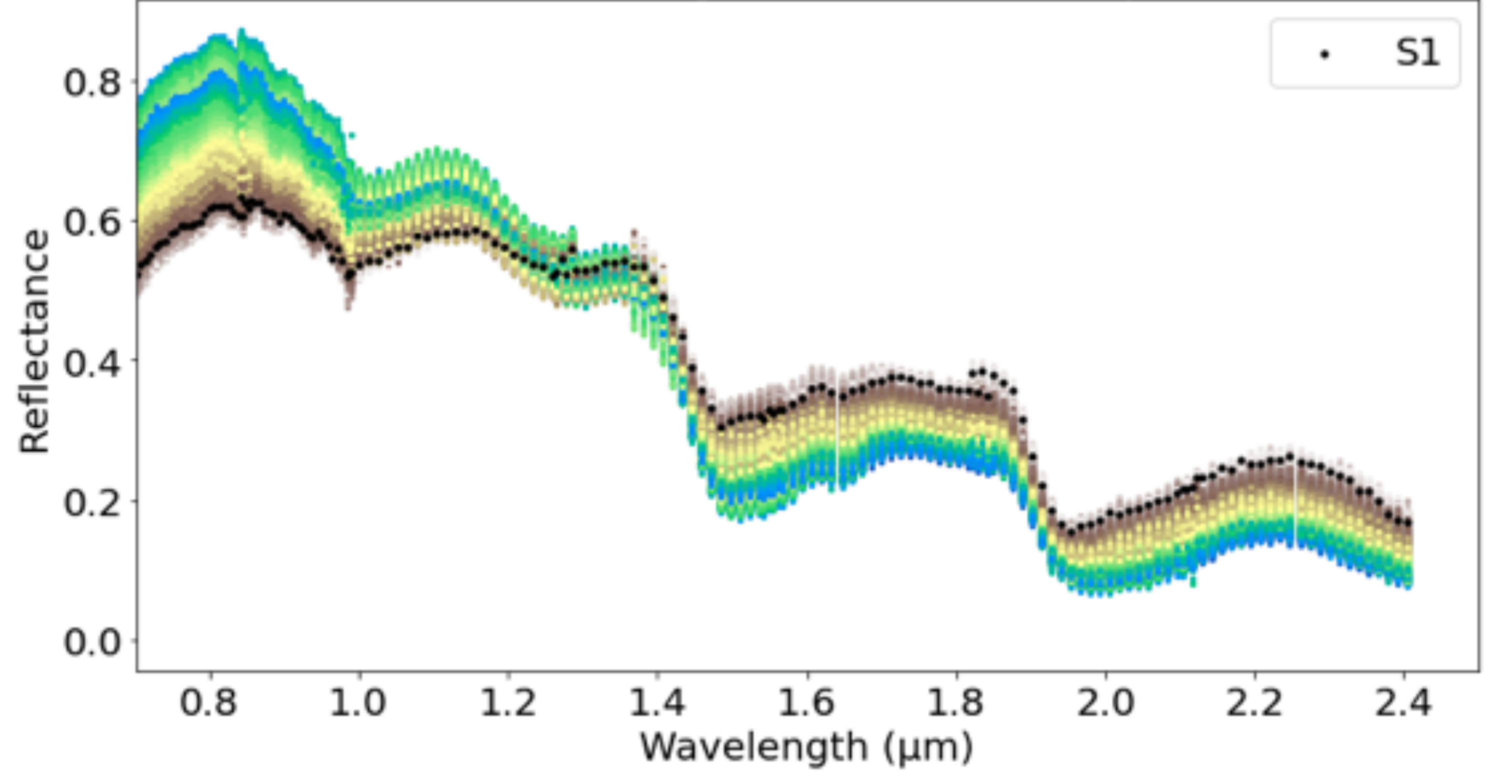
- Radiative transfer: Hapke et al. (1993, 2012)
  - Volume abundance, Grain size, Surface roughness
- Bayesian MCMC
  - DEMCz algorithm (Python mc3): Cubillos et al. (2016)





$$\binom{n}{k} = \frac{n!}{k!\times(n-k)!}$$

→ 455, 1365 and 3003 combinations

k = 3, 4 and 5

Which compounds to use ? Test all combinations !

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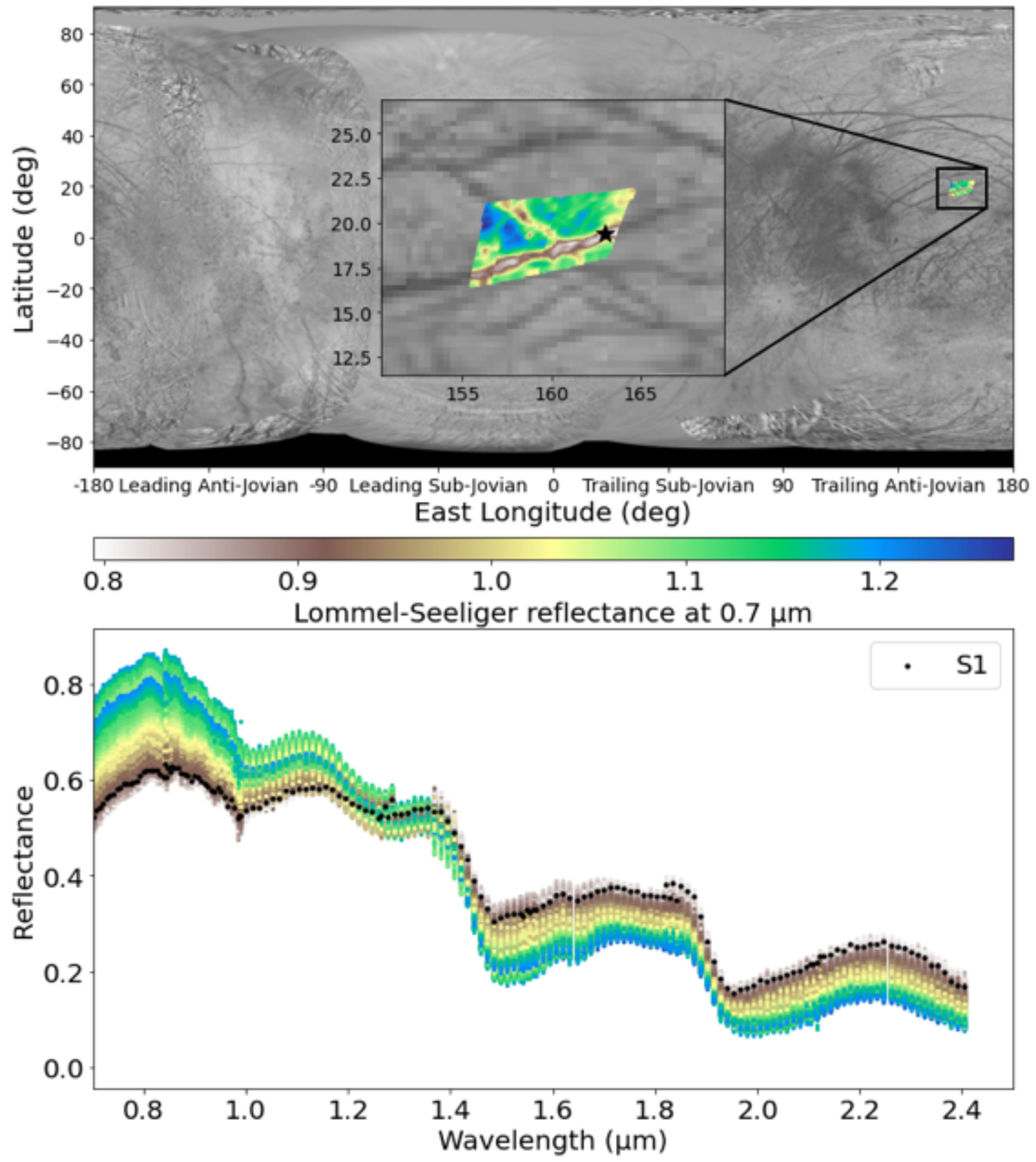

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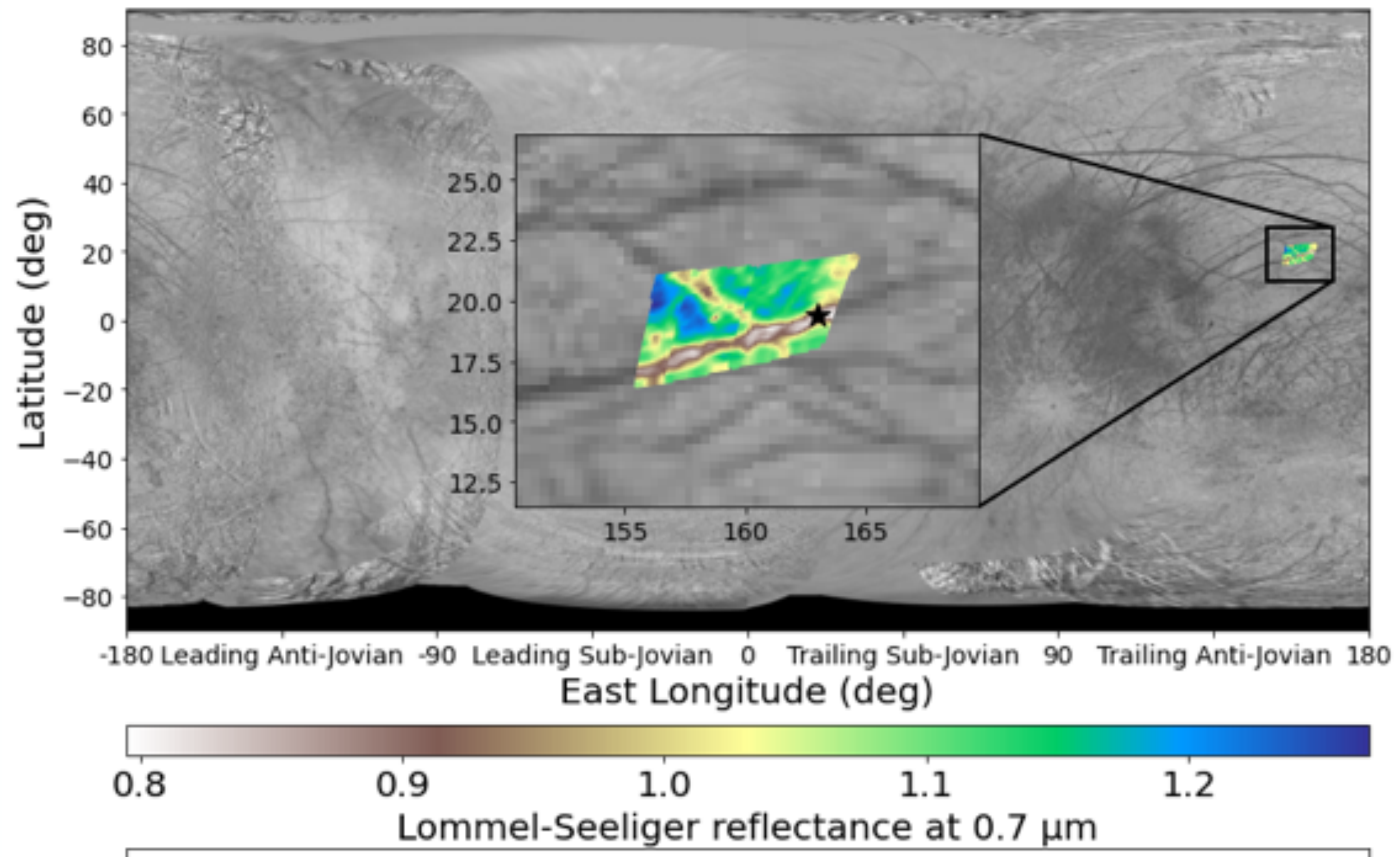

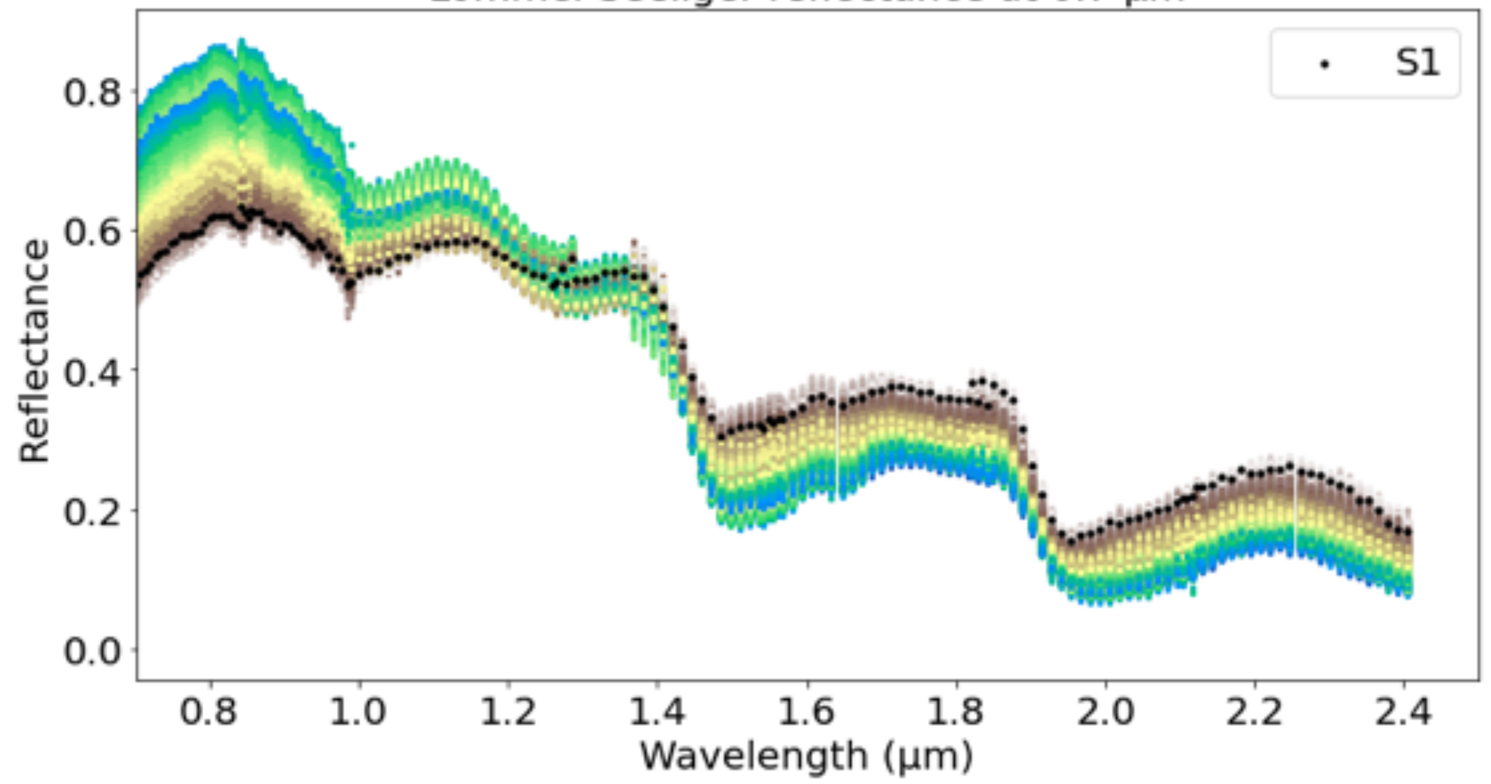

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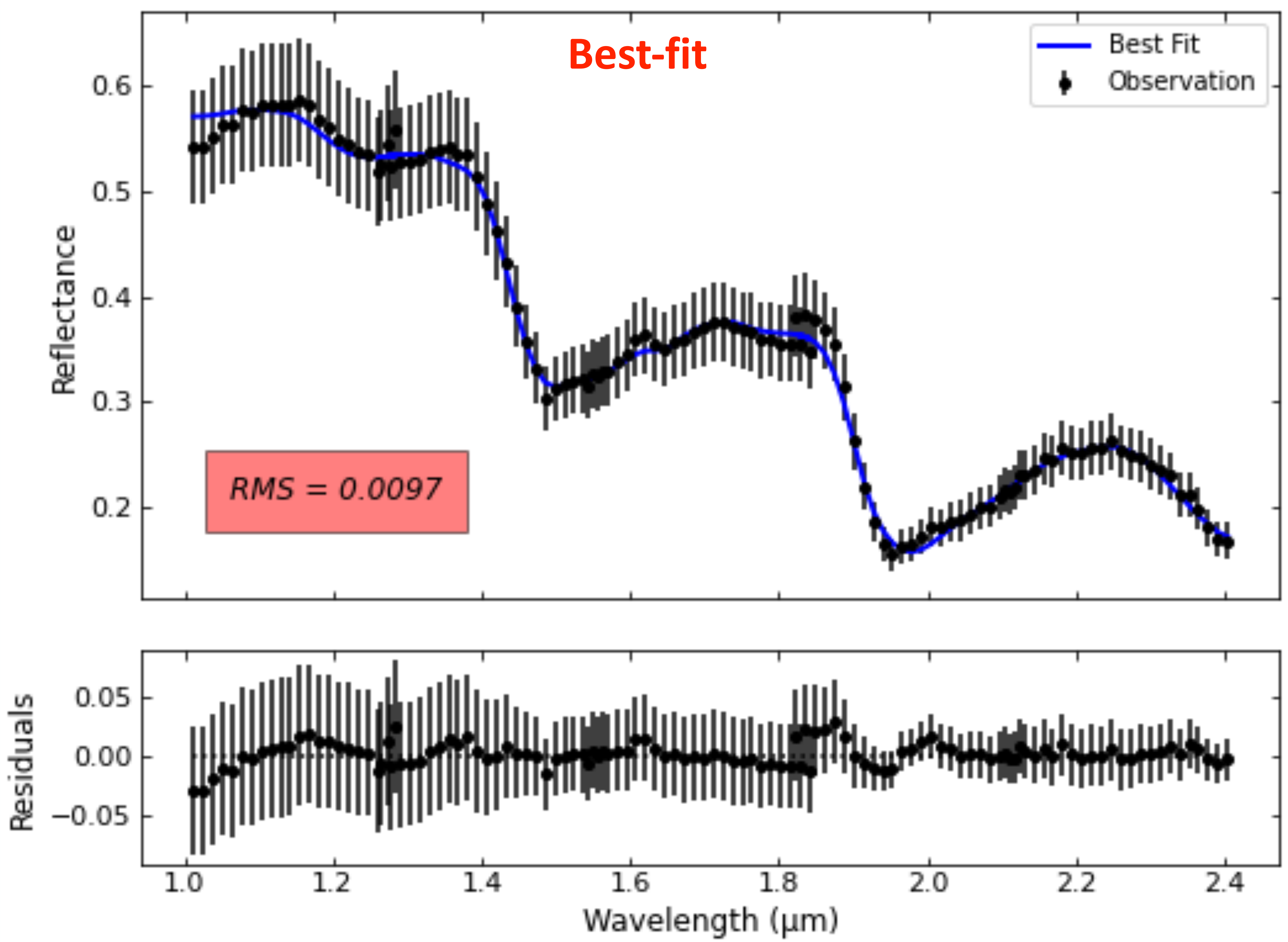
Typical fit



H_2O
$MgSO_4.6H_2O$
$H_2SO_4.8H_2O$
$MgCl_2.4H_2O$
$NaSO_4.10H_2O$

- Data uncertainty:
  10% (Carlson et al., 1992)

All best-fit

- 2 scenarios:
  - SNR of 5 (20% uncertainties)
  - SNR of 50 (2% uncertainties)

All best-fit

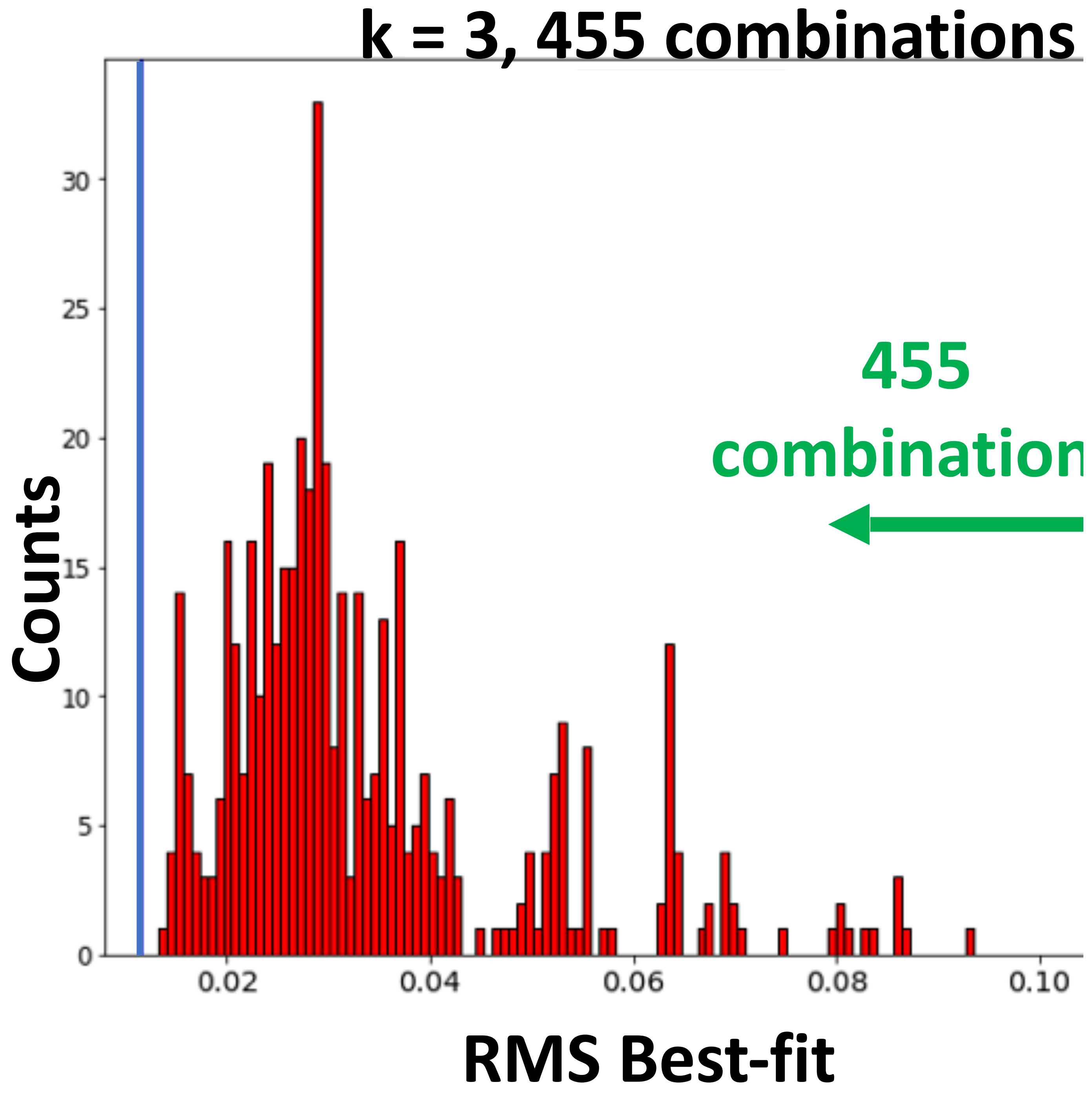
- 20% uncertainties: **All acceptable**

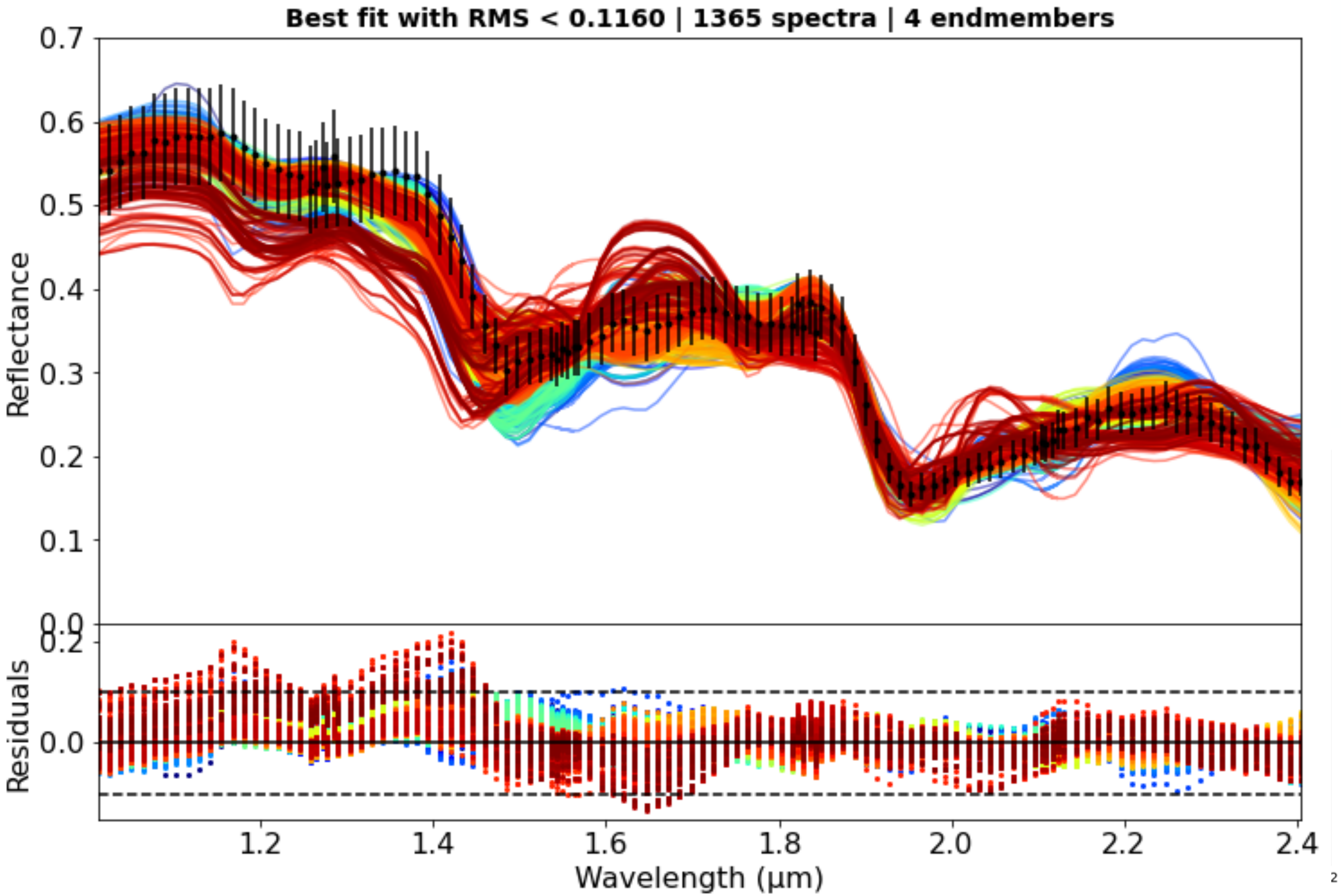
All best-fit

- 20% uncertainties: **All acceptable**

All best-fit

- 20% uncertainties:



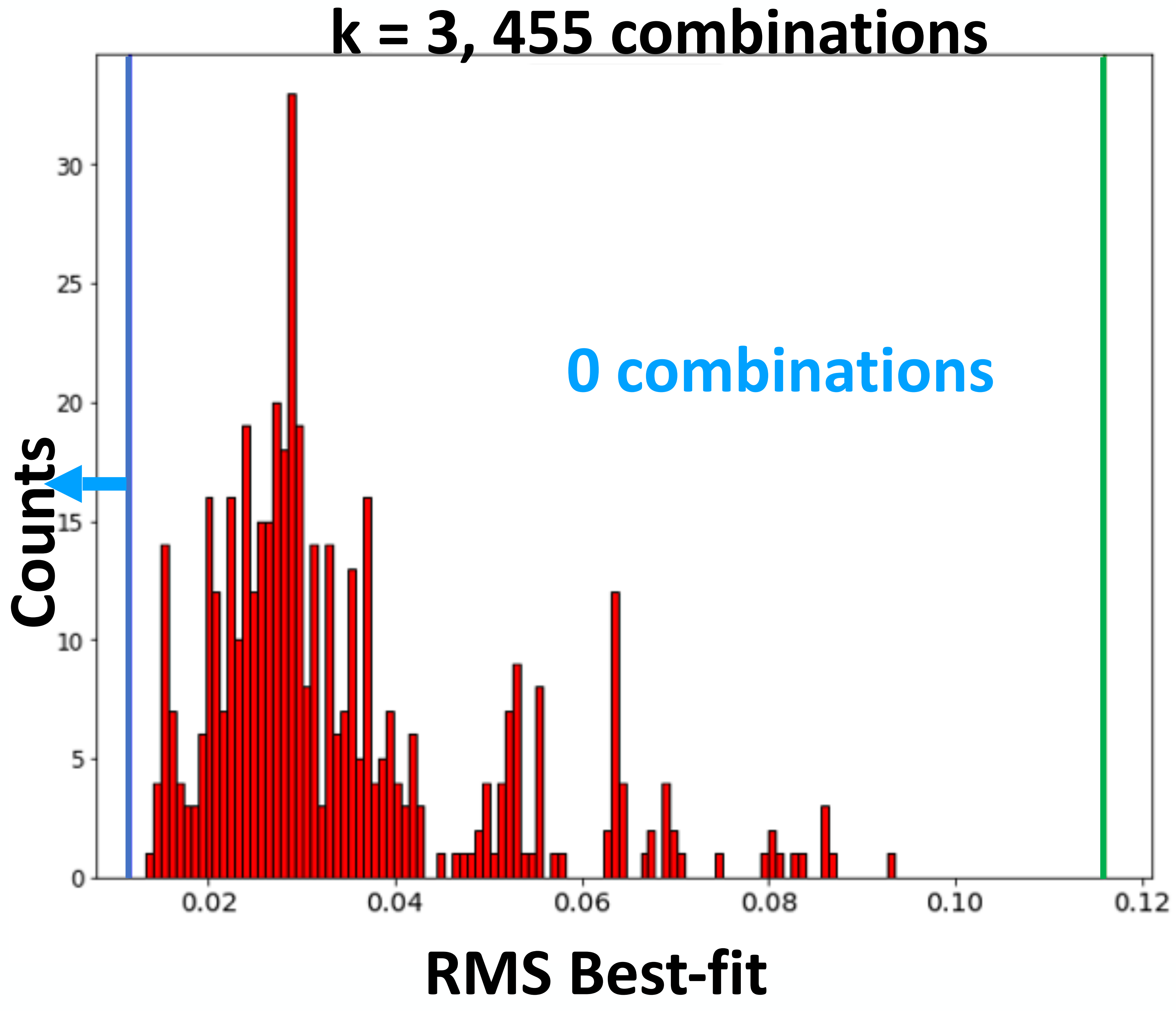


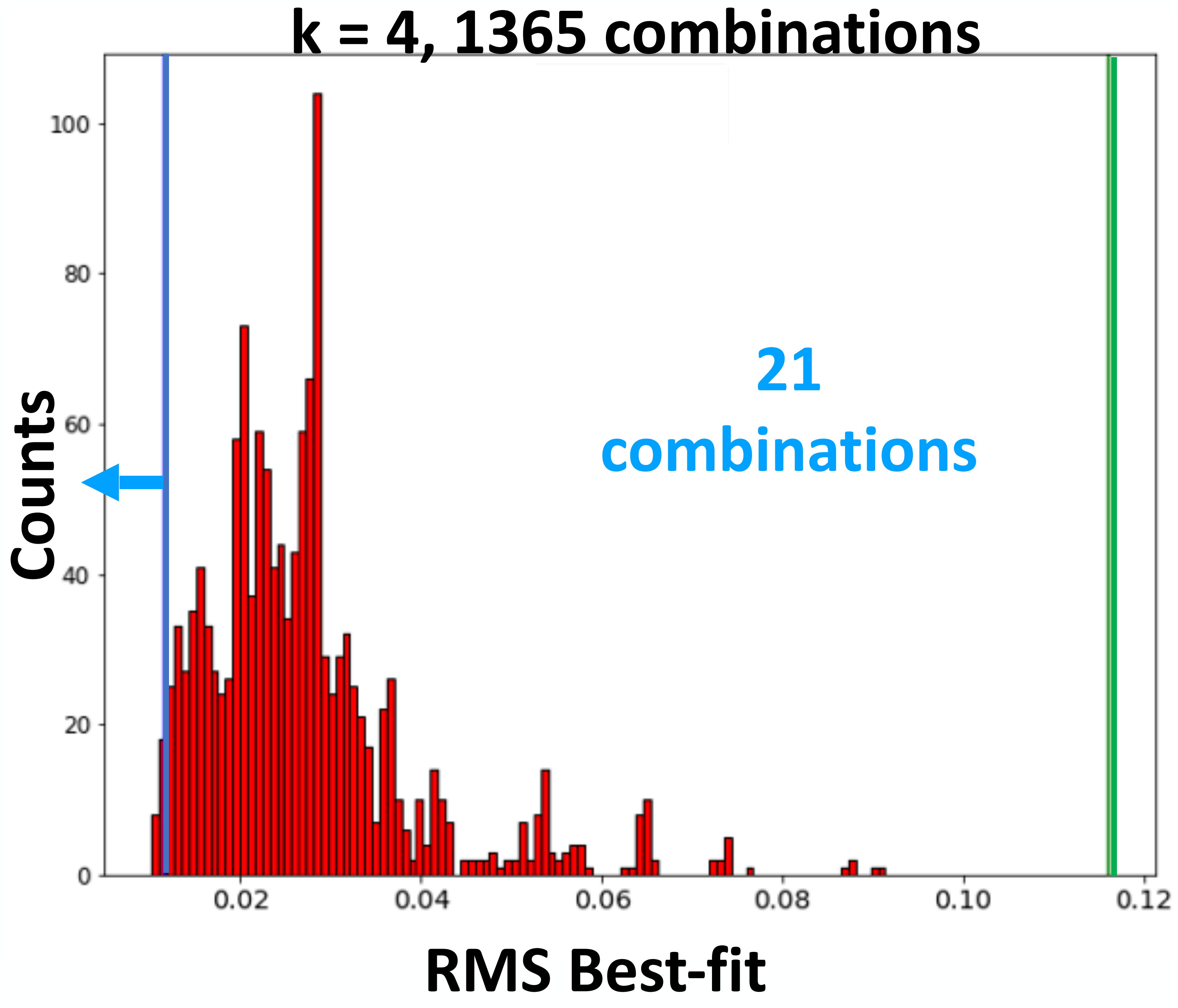
RMS Best-fit

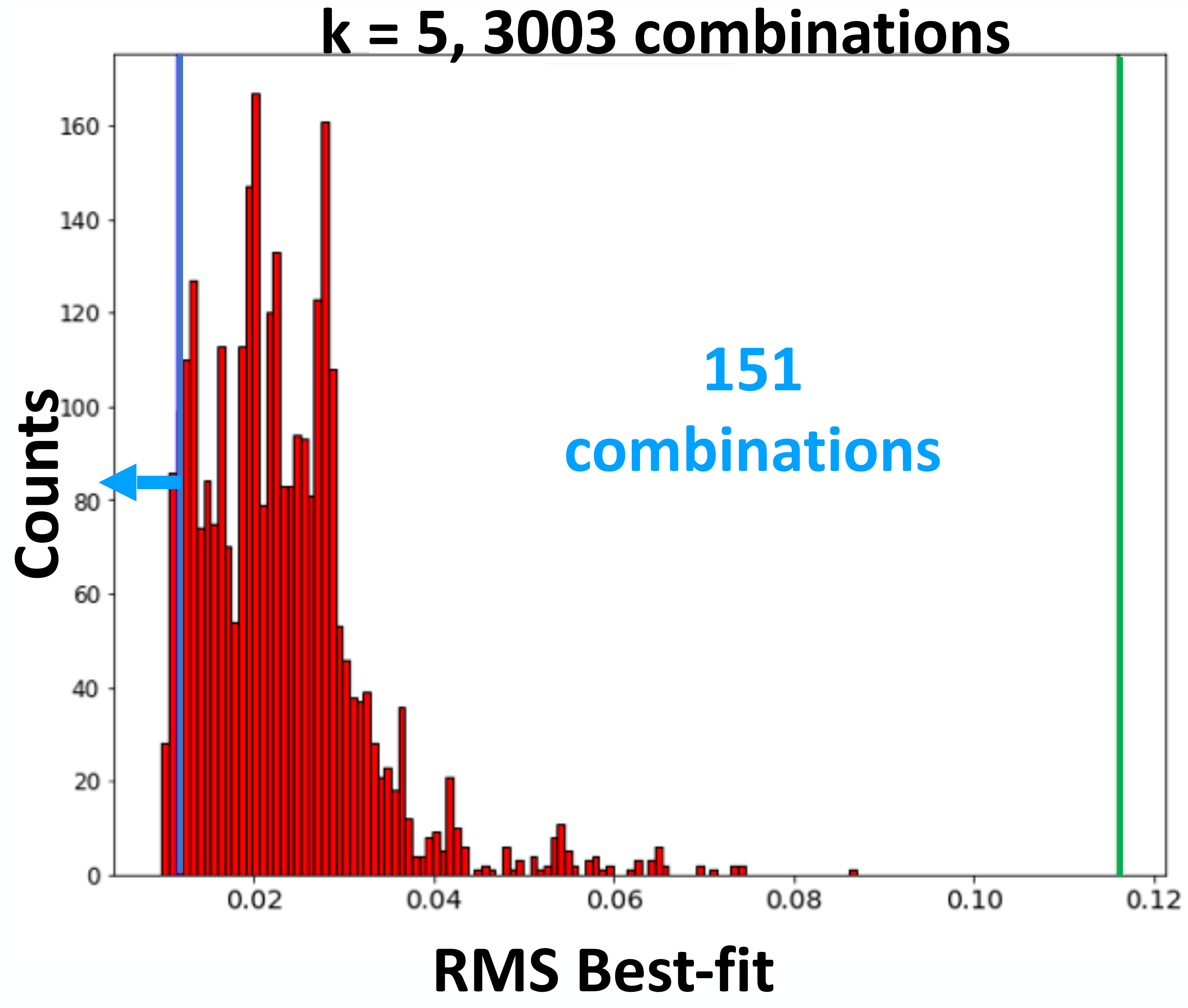
RMS Best-fit

All best-fit

- 2% uncertainties: **few acceptable !**







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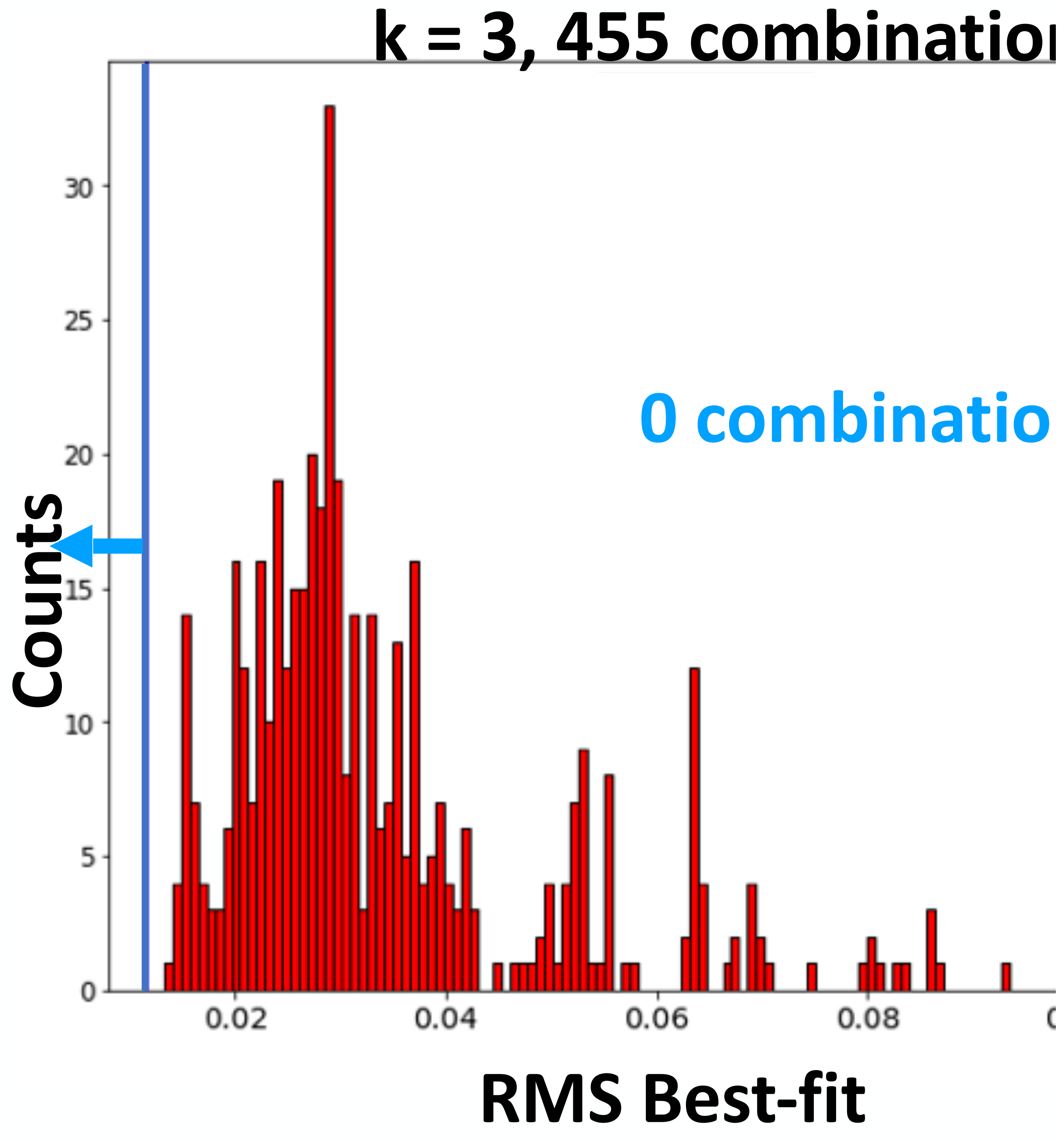
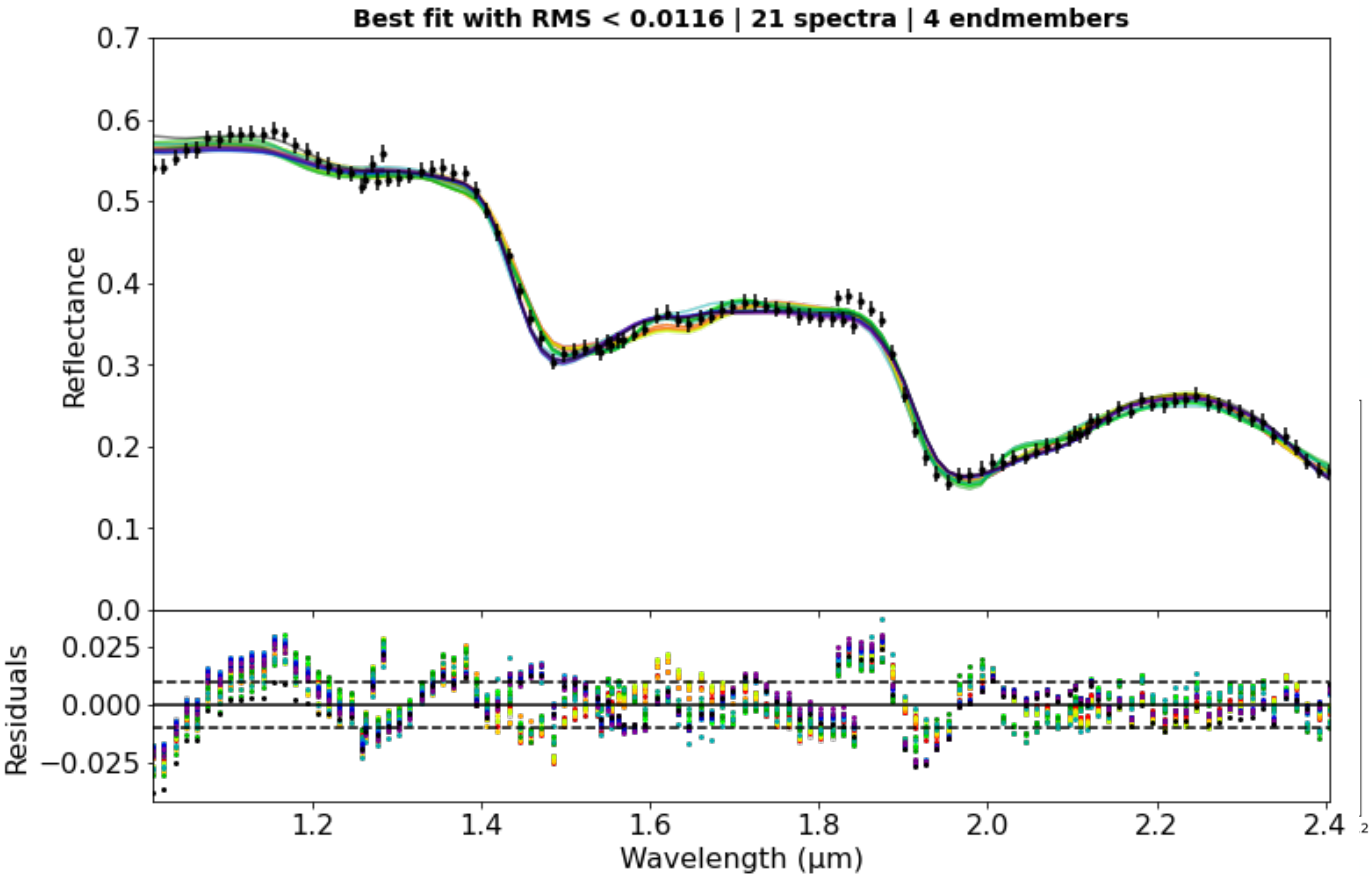
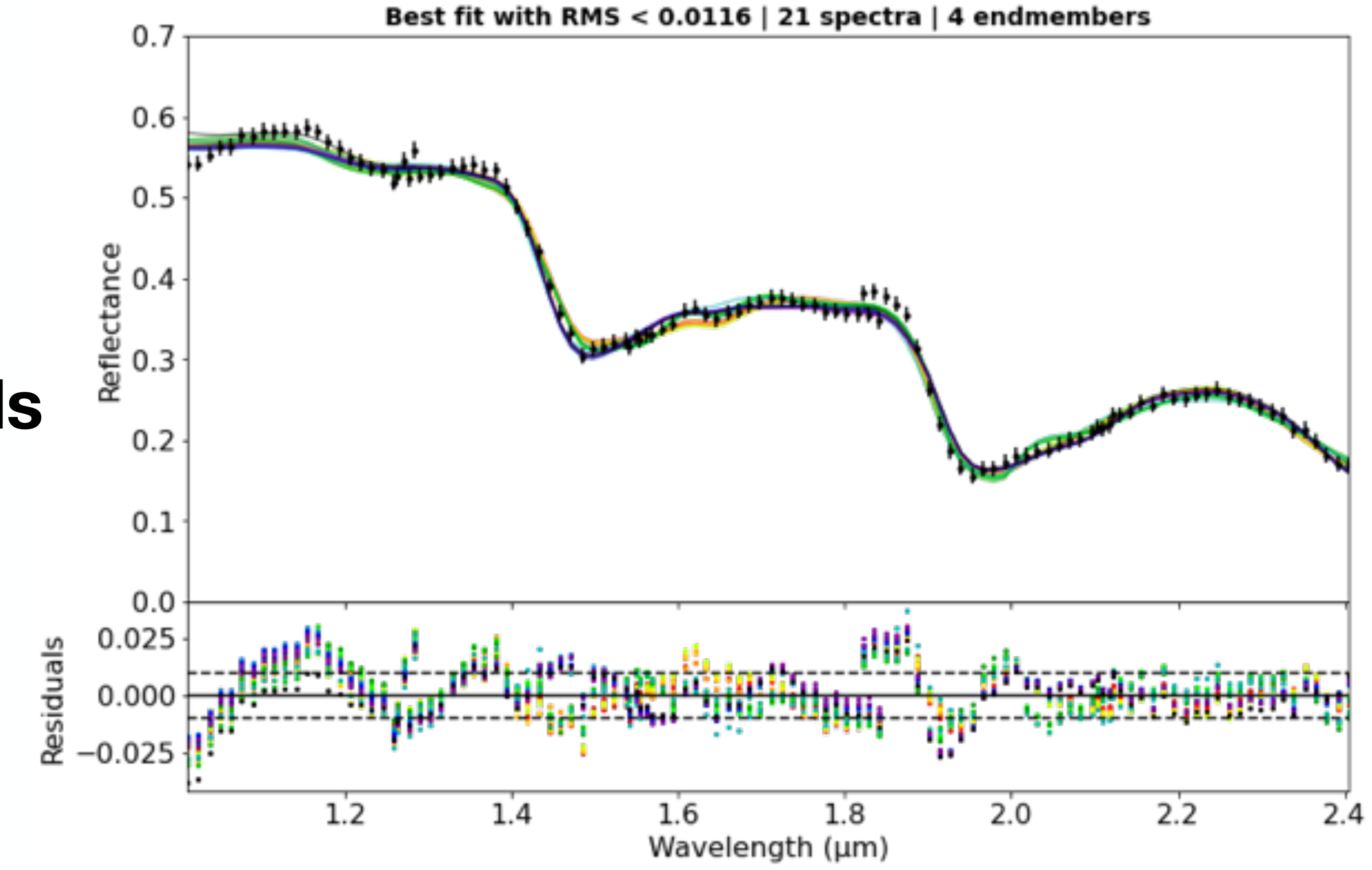
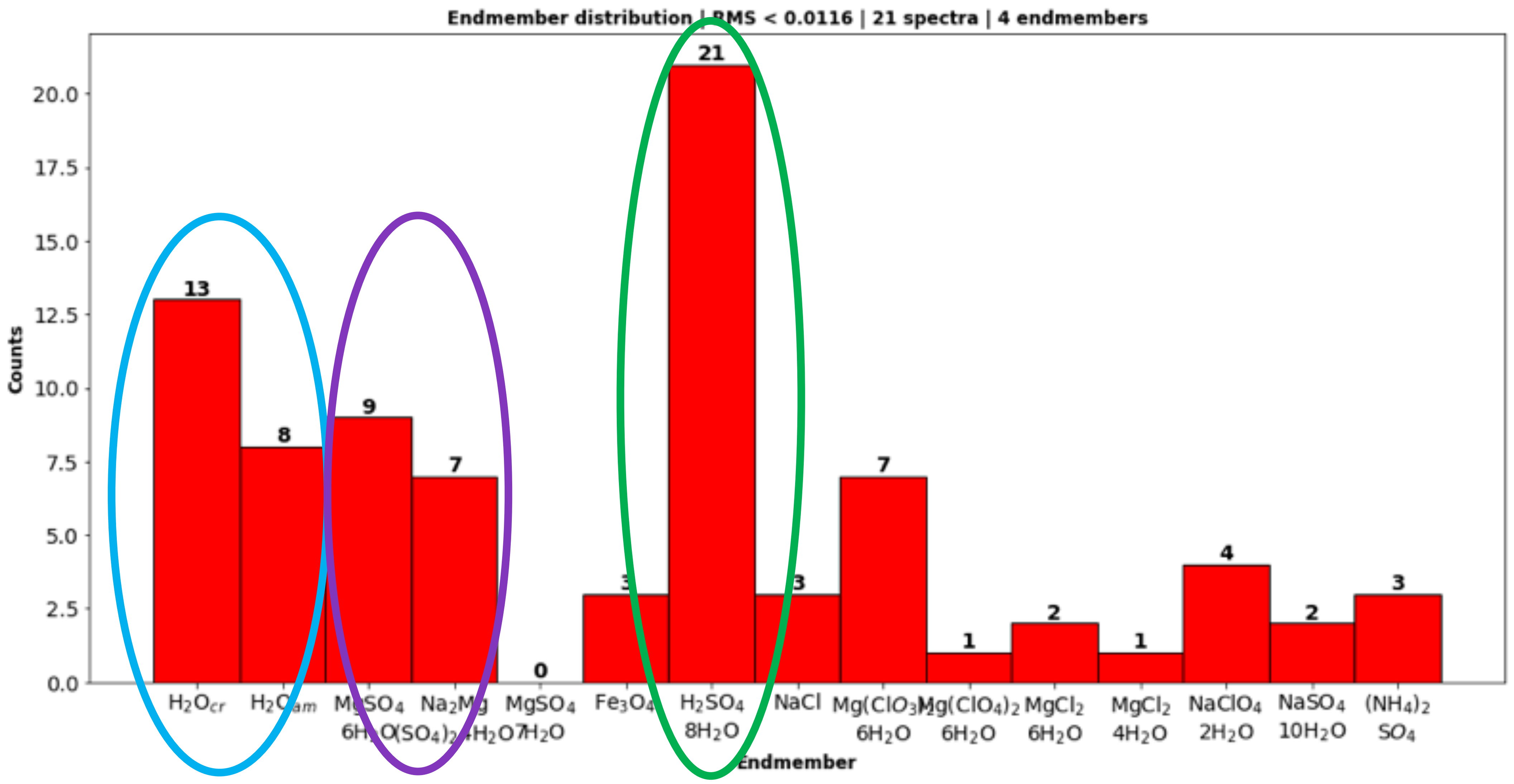




2% uncertainties scenario

4 Compounds

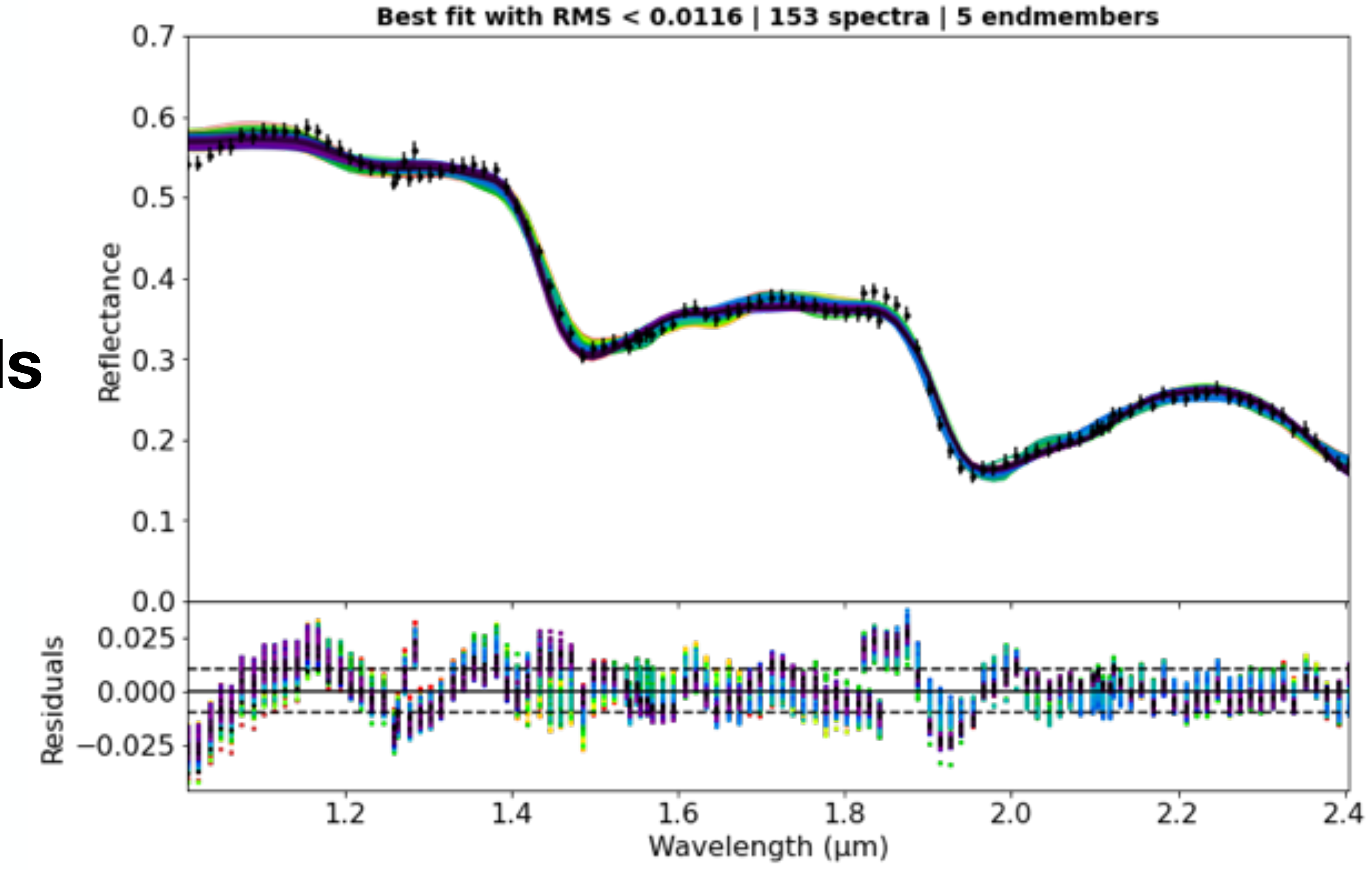


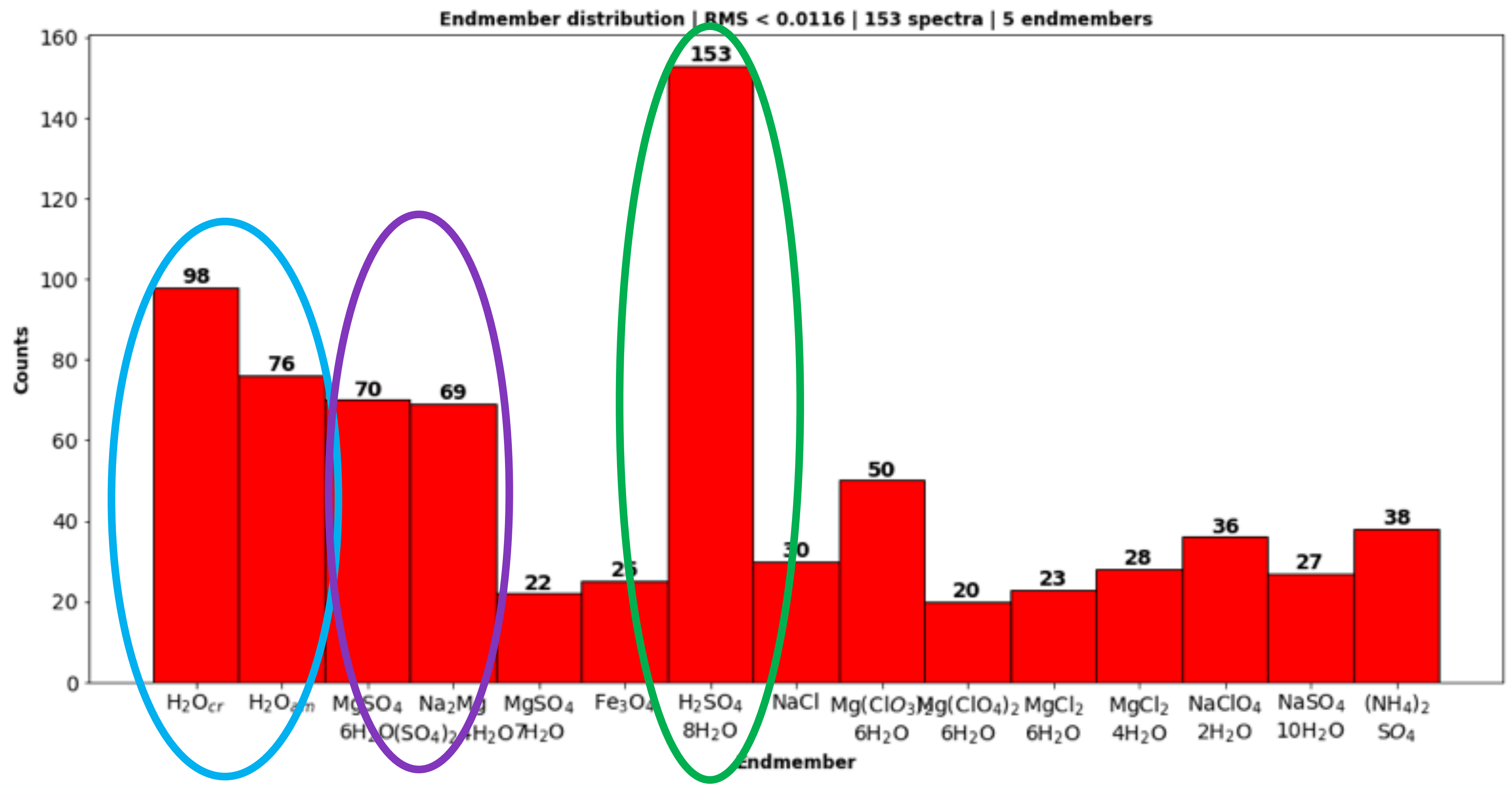


Sulfuric Acid Octahydrate

Water Ice

5 Compounds





Hexahydrite
Bloedite

Selection criteria

- RMS comparison → Goodness of fit per end member
- Spectral improvement factor → Spectral contribution per endmember
- Endmembers distribution → Statistics on all acceptable fits
- Numerical abundance → Representation of the medium

Criteria	H_2SO_4 $8H_2O$	H_2O (cr)	$MgSO_4$ $.6H_2O$	$Na_2Mg(SO_4)_2$ $.4H_2O$	H_2O (am)	$MgSO_4$ $7H_2O$	$(NH_4)_2$ SO_4	Na_2SO_4 $10H_2O$	$Mg(ClO_3)_2$ $6H_2O$	$Mg(ClO_4)_2$ $6H_2O$	$MgCl_2$ $6H_2O$	NaCl	$MgCl_2$ $4H_2O$	$NaClO_4$ $2H_2O$	Fe_3O_4
RMS (SNR 5)	1	1	0.5	0.5	0.5	0.5	0.5	0	0	0	0	0	0	0	0
Improvement factor (SNR 5)	1	1	1	1	1	1	1	0.5	0	0	0	0	0	0	0
Distribution (SNR 50)	1	0.5	0.5	0.5	0.5	0	0	0	0.5	0	0	0	0	0	0
Numerical Abundances (SNR 50)	1	0	0.5	0.5	0	0.5	0	0.5	0.5	0.5	0.5	0.5	0	0	0
Average	1	0.625	0.625	0.625	0.5	0.5	0.375	0.25	0.25	0.125	0.125	0.125	0	0	0

Conclusion: surface composition

- Very good spectral fit to NIMS data without artificial compounds and/or high porosity
- Water ice & Sulfuric Acid Octahydrate: **Mandatory**
- Hydrated Sulfates & Chlorinates: **Indistinguishable** but **required**
- Magnetite, Magnesium Chloride, Sodium perchlorate: **not necessary** or **absent**

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Research Paper

Selection of chemical species for Europa's surface using Galileo/NIMS

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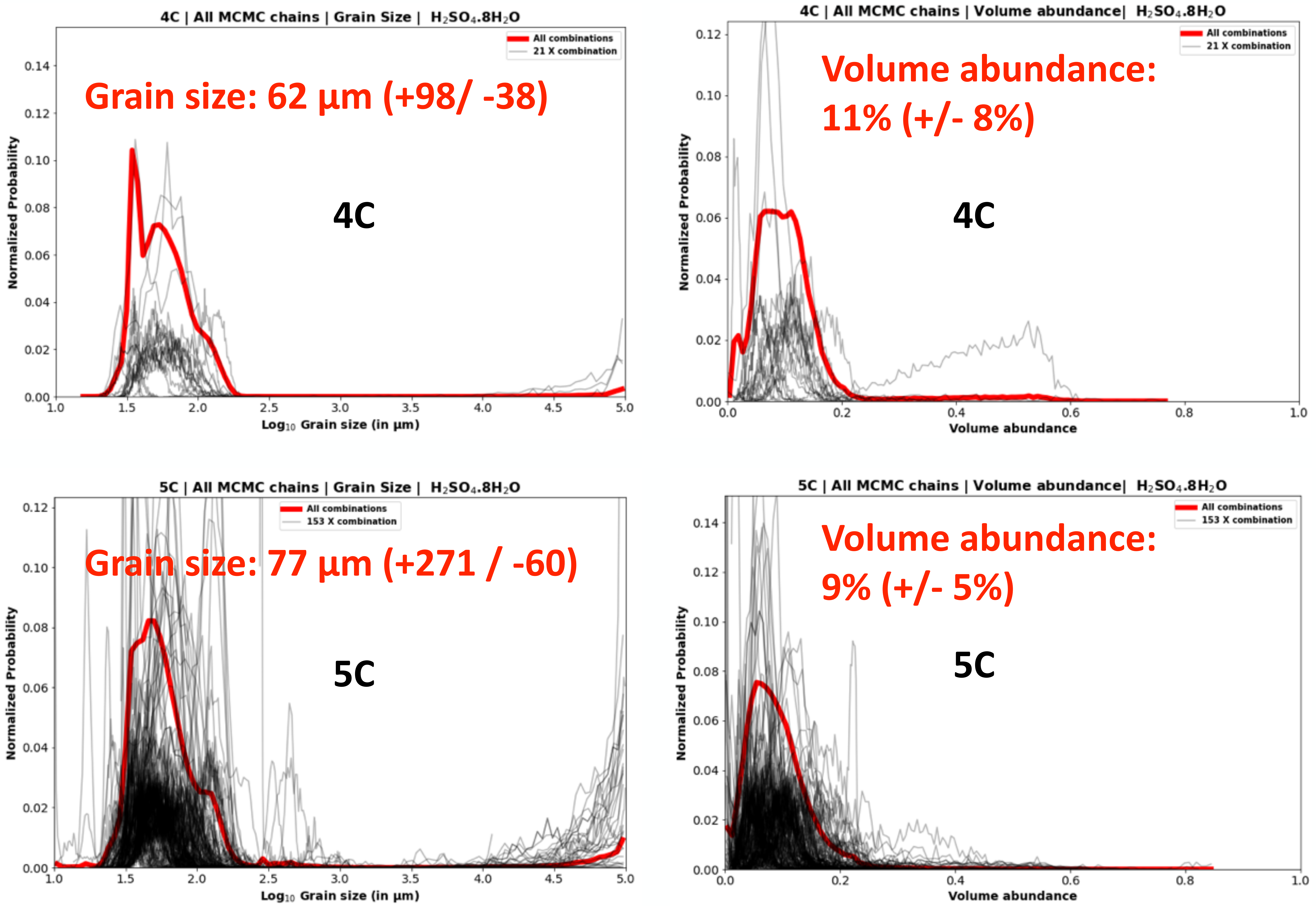
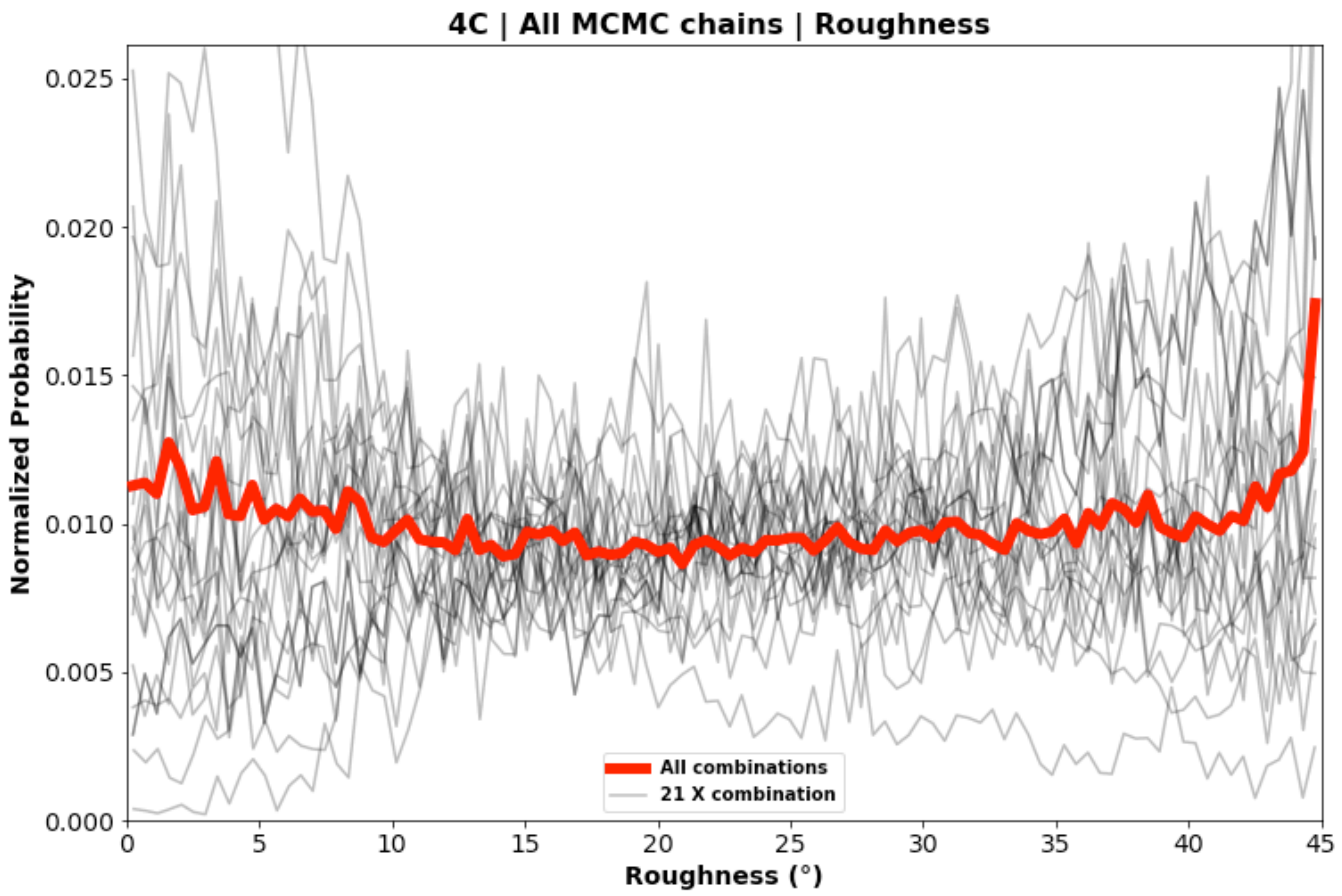
Microphysics: grain size & abundance

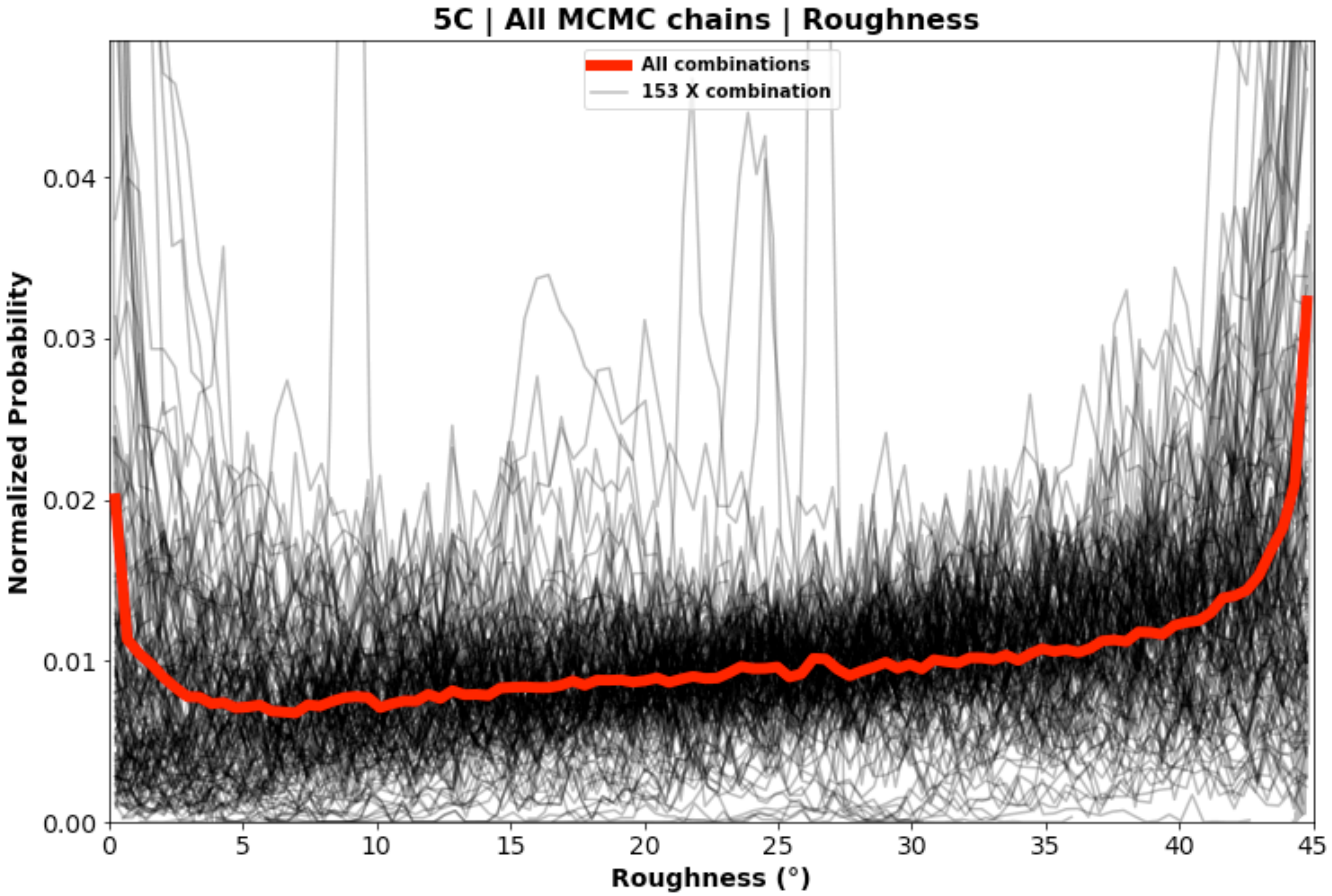
- All 21 and 153 acceptable combinations
- MCMC modeling with 2% uncertainties
- Probability Density Function



Cruz-Mermy et al. (2023) *In prep*

Microphysics: surface roughness





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