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Mineral Identification And Characterization: An Integrated Approach To Recover Mineralogical Information From Hyperspectral Images

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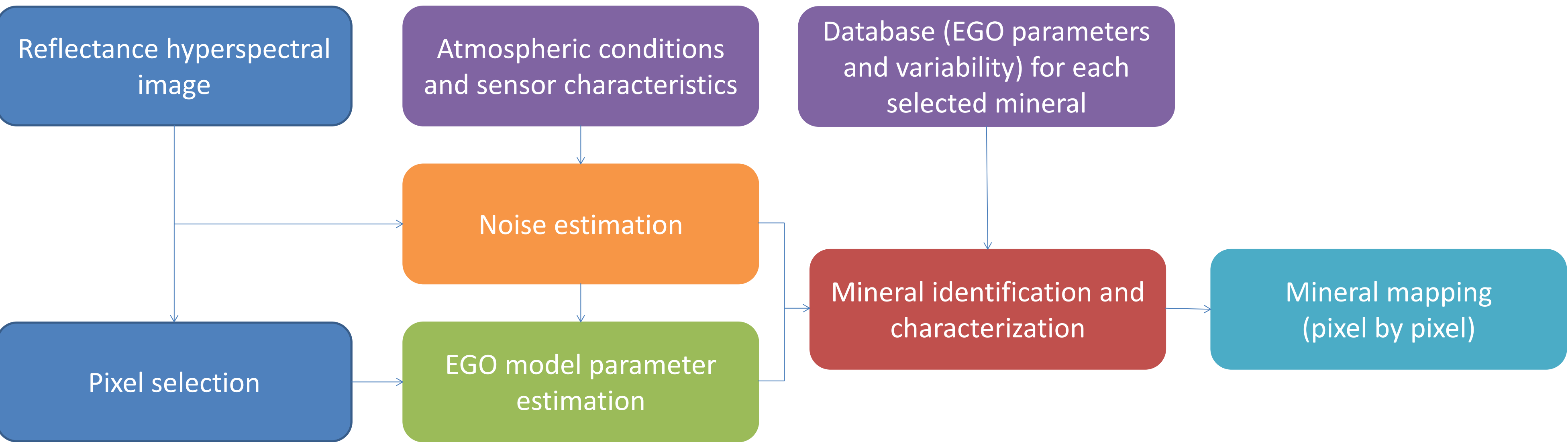


Introduction and objectives

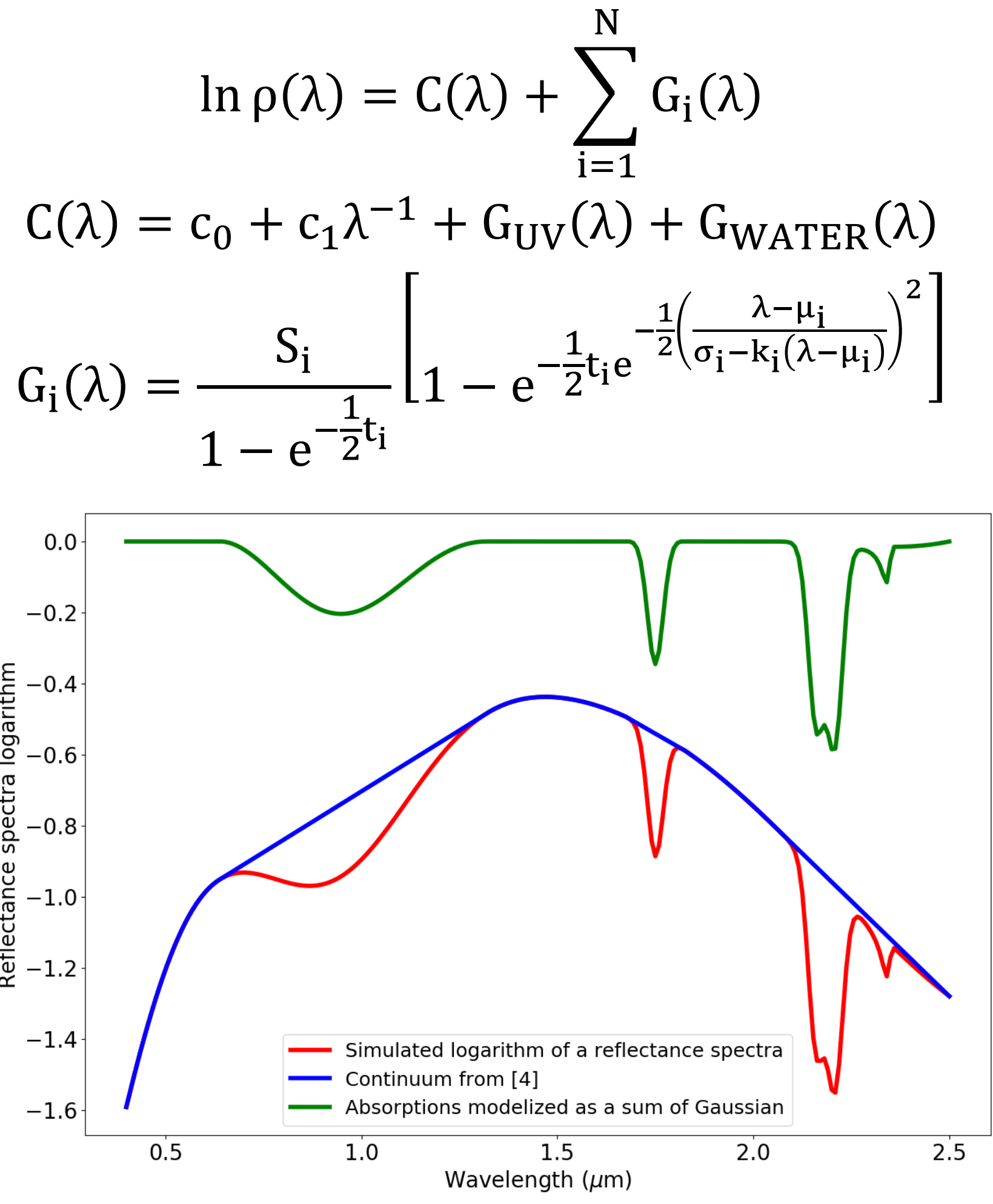
- **Integrated and automatic procedure** for mineral mapping from airborne and spaceborne hyperspectral images
- **Mineral reflectance spectra decomposition** in the **VNIR/SWIR** using EGO model (Exponential Gaussian Optimization)
- **Noise model** evolution for recent spectrometers
- **Identification procedure** from estimated parameters

AGM (Automatized Gaussian Model) procedure [1]

AGM flowchart



EGO model for the VNIR/SWIR [2][3]

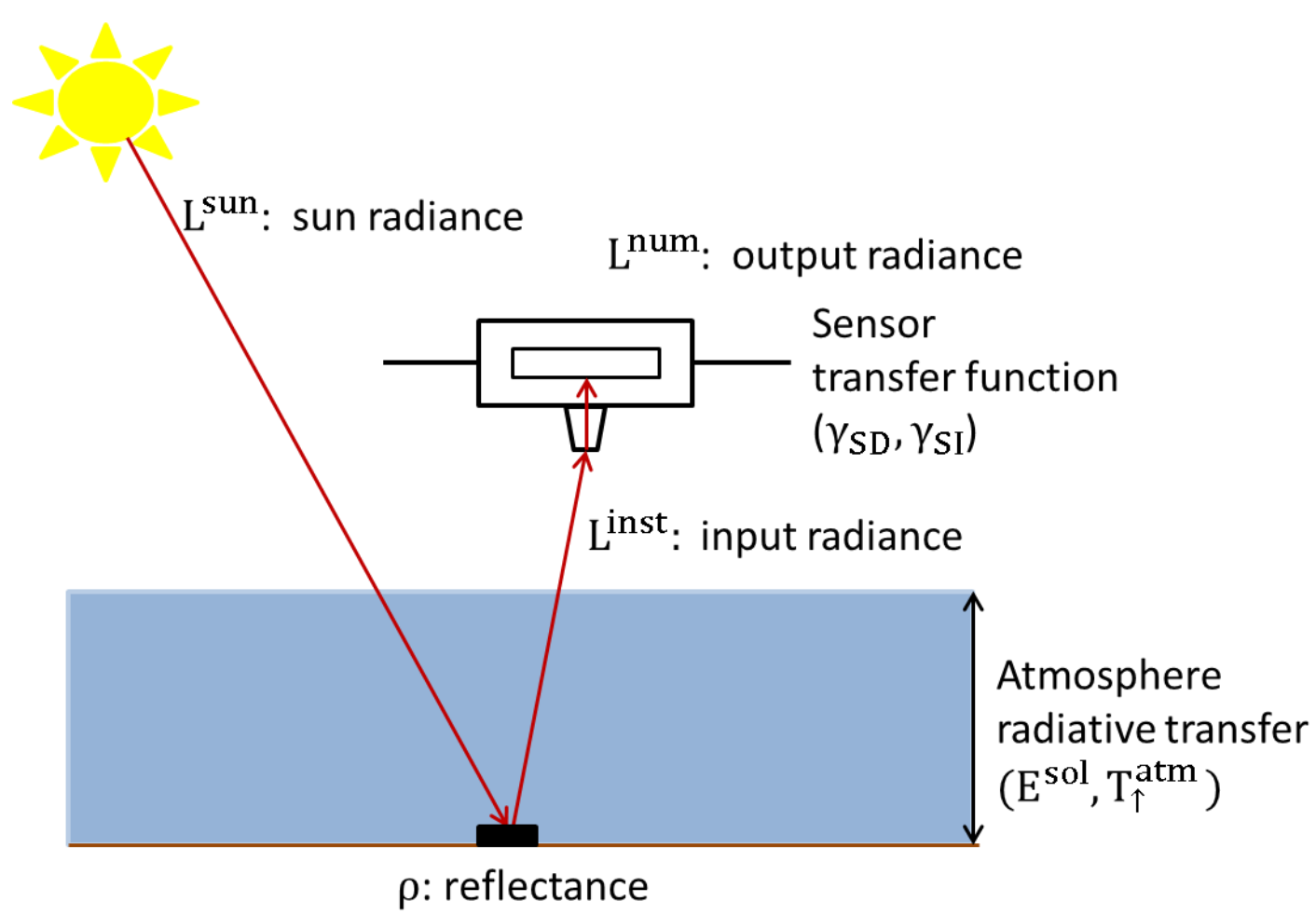


Signal dependent noise model (reflectance)

$$\rho^{\text{obs}}(\lambda_k) \sim \mathcal{N}(\rho(\lambda_k), \sigma_p^2(\lambda_k))$$
$$\sigma_p^2(\lambda_k) = \gamma'_{SD}(\lambda_k) L^{\text{num}}(\lambda_k) + \gamma'_{SI}(\lambda_k)$$

If S^{atm} negligible (radiative transfer VNIR/SWIR)

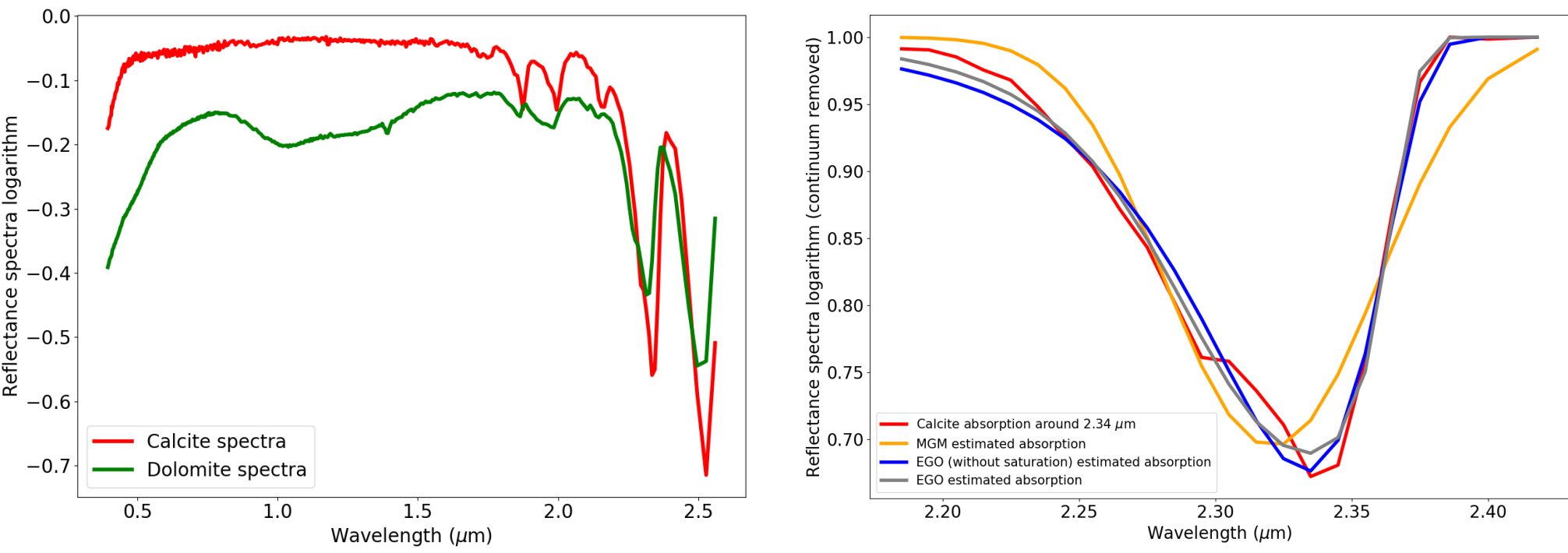
$$\gamma'_{SD}(\lambda_k) = \left[\frac{\pi}{E^{\text{sol}}(\lambda_k) T_{\uparrow}^{\text{atm}}(\lambda_k)} \right]^2 \gamma_{SD}(\lambda_k)$$
$$\gamma'_{SI}(\lambda_k) = \left[\frac{\pi}{E^{\text{sol}}(\lambda_k) T_{\uparrow}^{\text{atm}}(\lambda_k)} \right]^2 \gamma_{SI}(\lambda_k)$$



Results

EGO model validation

- Goals: 1 - EGO and MGM models comparison
2 - Asymmetry and saturation evaluation

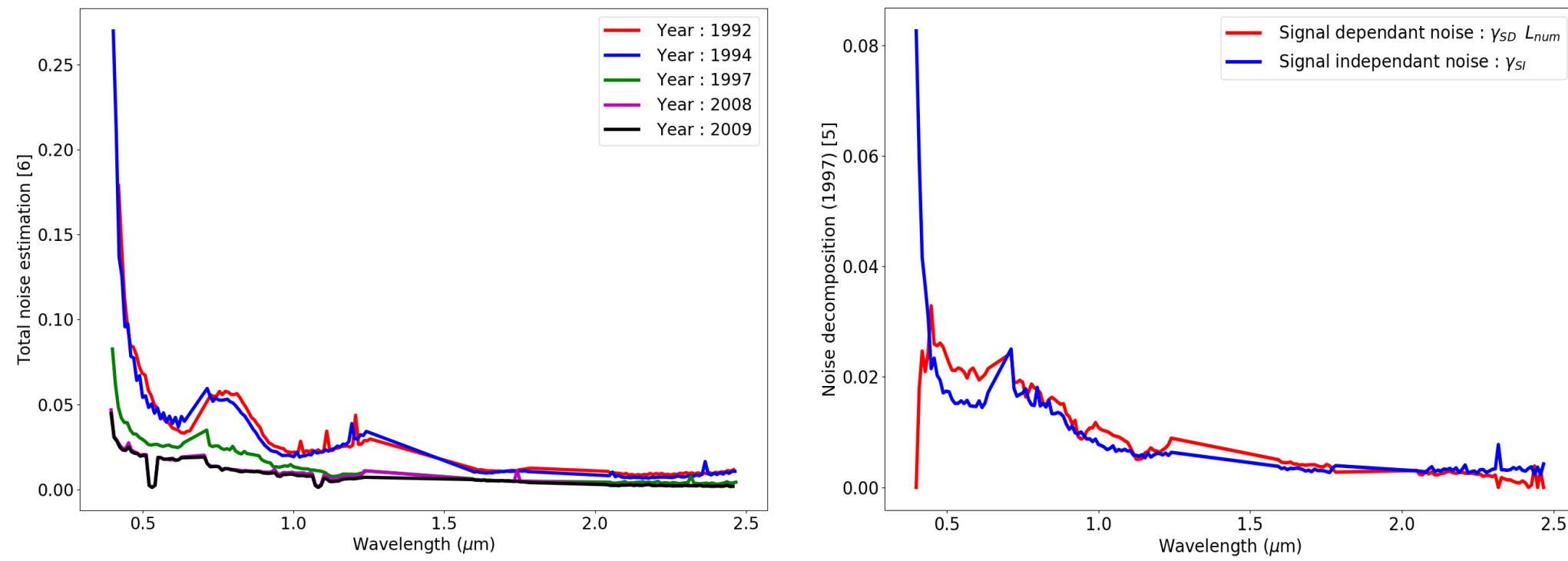


Sample - Method	Calcite – [11]	Calcite – MGM	Calcite – EGO (without saturation)	Calcite – EGO
Center	2.34 (theory) – 2.335 (measure)	2.31661	2.33516	2.33386
Amplitude	-0.32865	-0.324858	-0.426273	-0.431379
Width	0.09	0.0321666	0.0318745	0.0683448
Asymmetry	≈ -0.4	/	0.393188	0.761379
Saturation	/	/	/	-10
Sample - Method	Dolomite – [11]	Dolomite – MGM	Dolomite – EGO (without saturation)	Dolomite – EGO
Center	2.32 (theory) – 2.315 (measure)	2.30195	2.31275	2.31306
Amplitude	-0.32682	-0.259494	-0.287883	-0.254443
Width	0.085	0.041663	0.036179	0.0270031
Asymmetry	≈ -0.45	/	0.278652	0.192566
Saturation	/	/	/	3.70758

- EGO model better fits SWIR absorptions and is sufficient to discriminate calcite from dolomite
- Estimated parameters might loose some meaning (width, saturation, asymmetry)

Noise evolution

Goal: Evaluate the radiance total noise and the signal dependent and independent components over years (AVIRIS – Lunar Lake – 1992 to 2009)



- The AGM total noise and noise components estimation procedure is applied on 5 AVIRIS images
- Total noise evolution: increasing SNR makes mineral identification easier
- For recent spectrometers, noise is not totally independent from signal
- Main noise sources and their impact:
 - Dark current ⇒ independent noise
 - Photon noise ⇒ dependent noise
- Estimation depends on the radiance of the image (high radiance implies high photon noise)

Noise estimation (HYNPE [5])

- 1) Signal and noise separation: HYSIME [6]
- 2) Noise parameter initialization: Methods of Moments
- 3) Noise parameter estimation: Maximum likelihood

EGO model parameter estimation

- 1) Continuum and absorption separation [4]
- 2) Continuum parameters initialization: nonlinear least squares
- 3) Absorptions parameters initialization: continuous wavelet transform [7] + nonlinear least squares
- 4) Joint continuum and absorption parameters estimation: optimal estimation [8] or nonlinear least squares

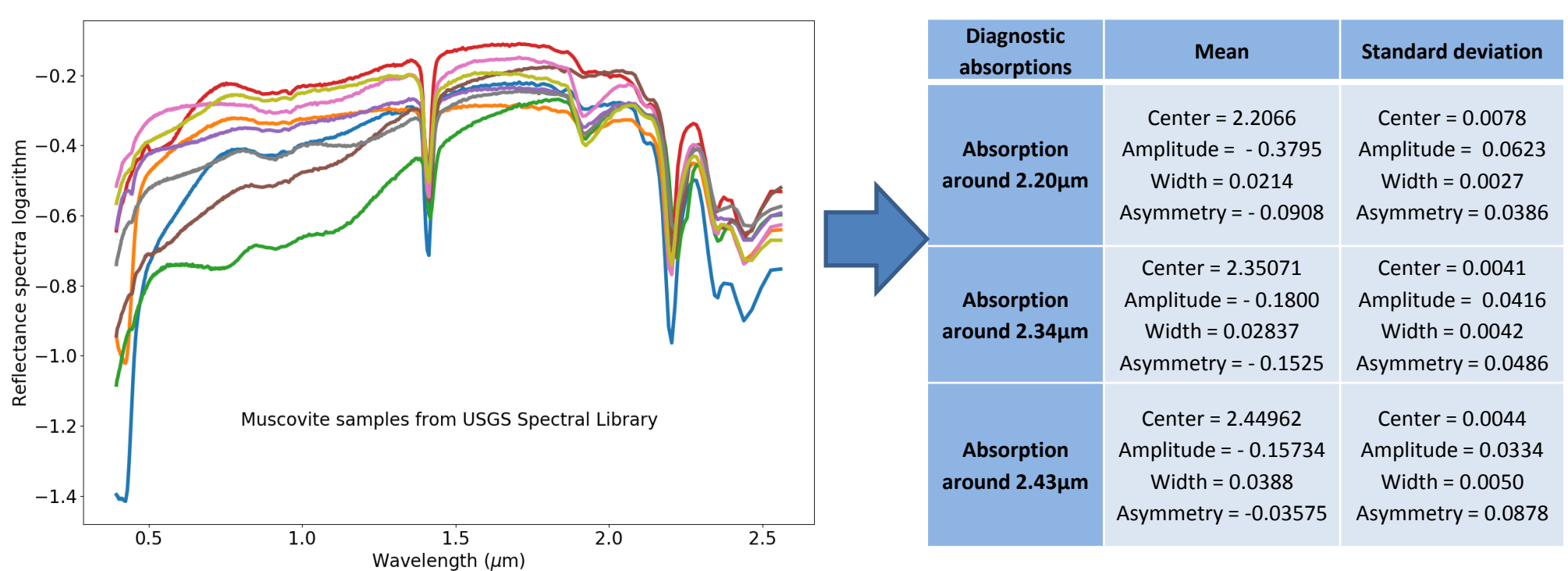
Mineral identification and characterization

- 1) Database of EGO model parameters and their variabilities calculated from a database of specific mineral reflectance spectra
- 2) Compare, using a fuzzy logic system [9] and a set of expert rules, the database and the estimated EGO model parameters
- 3) Identification is mainly based on the positions of the absorptions
- 4) Depending on the identified mineral, several properties (composition, grain size, humidity) can be evaluated

Mineral identification procedure

Goal: Mineral identification from EGO model parameters

Database creation



Diagnostic absorptions	Mean	Standard deviation
Absorption around 2.20μm	Center = 2.2066 Amplitude = -0.3795 Width = 0.0214 Asymmetry = -0.0908	Center = 0.0078 Amplitude = 0.0623 Width = 0.0027 Asymmetry = 0.0386
Absorption around 2.34μm	Center = 2.35071 Amplitude = -0.1800 Width = 0.02837 Asymmetry = -0.1525	Center = 0.0041 Amplitude = 0.0416 Width = 0.0042 Asymmetry = 0.0486
Absorption around 2.43μm	Center = 2.44962 Amplitude = -0.15734 Width = 0.0388 Asymmetry = -0.03575	Center = 0.0044 Amplitude = 0.0334 Width = 0.0050 Asymmetry = 0.0878

Identification procedure [9]

- Each mineral is defined by a set of parameters (P_1, \dots, P_M) and an expert rule to ensure the meaning of the identification
- Identify the mineral by comparing database parameters to the estimated ones (A_1, \dots, A_M) under the following constraints:
$$P_i \neq P_j \neq P_M \text{ where } i \in (P_1, \dots, P_M)$$
$$P_i \in G(m_i, \sigma_i)$$
- The output gives an identification probability for each mineral (several minerals can have non negative probability)

Future works

1. Validate EGO model for several minerals having different absorption shapes
2. Improve the automatic EGO model parameter estimation
3. Take into account new noise model for completeness
4. Create database and associated expert rules
 - Adapt the procedure for mineral mixture
 - Develop expert rules for mineral characterization

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