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DEGLI STUDI
DI PADOVA

***Machine Learning Algorithms for Efficient Data
Analysis of Solar System Bodies***

Joel Beccarelli - 39th Cycle

Supervisors: Dr. Maurizio Pajola
Dr. Alice Lucchetti
Professor Giampiero Naletto

Admission 2nd PhD Year - 16/10/2023



Objective



Objective

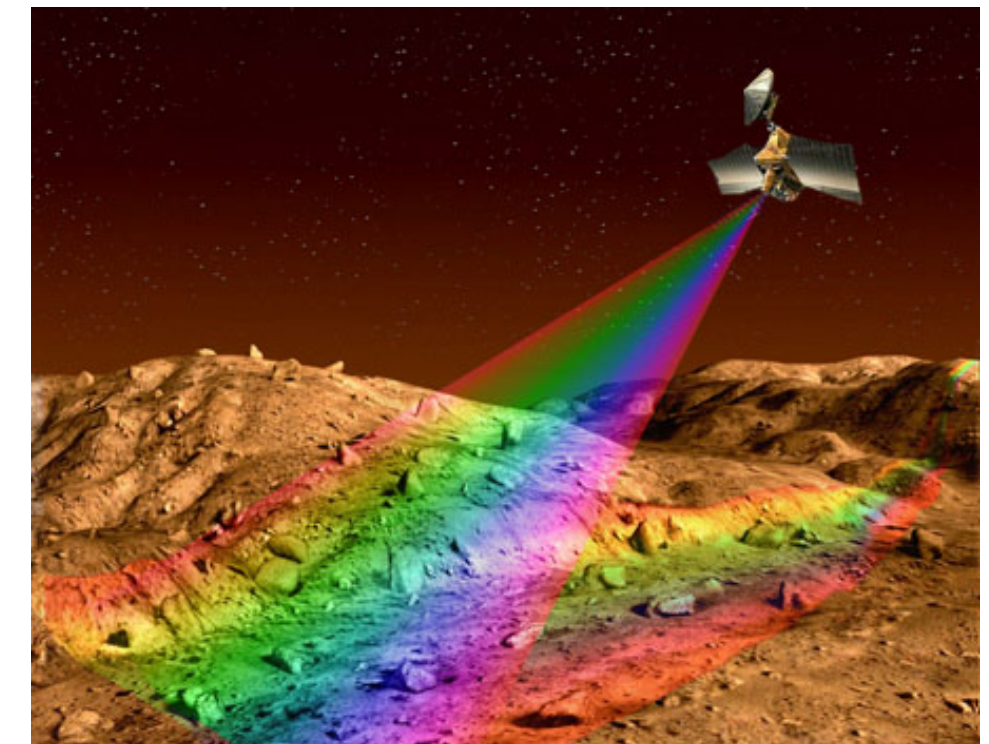


Determine the spectral behavior of SS bodies surfaces including machine learning algorithms promoting the digitalization of the PA

How?



Processing remote sensing data from space missions and develop/use ML algorithms

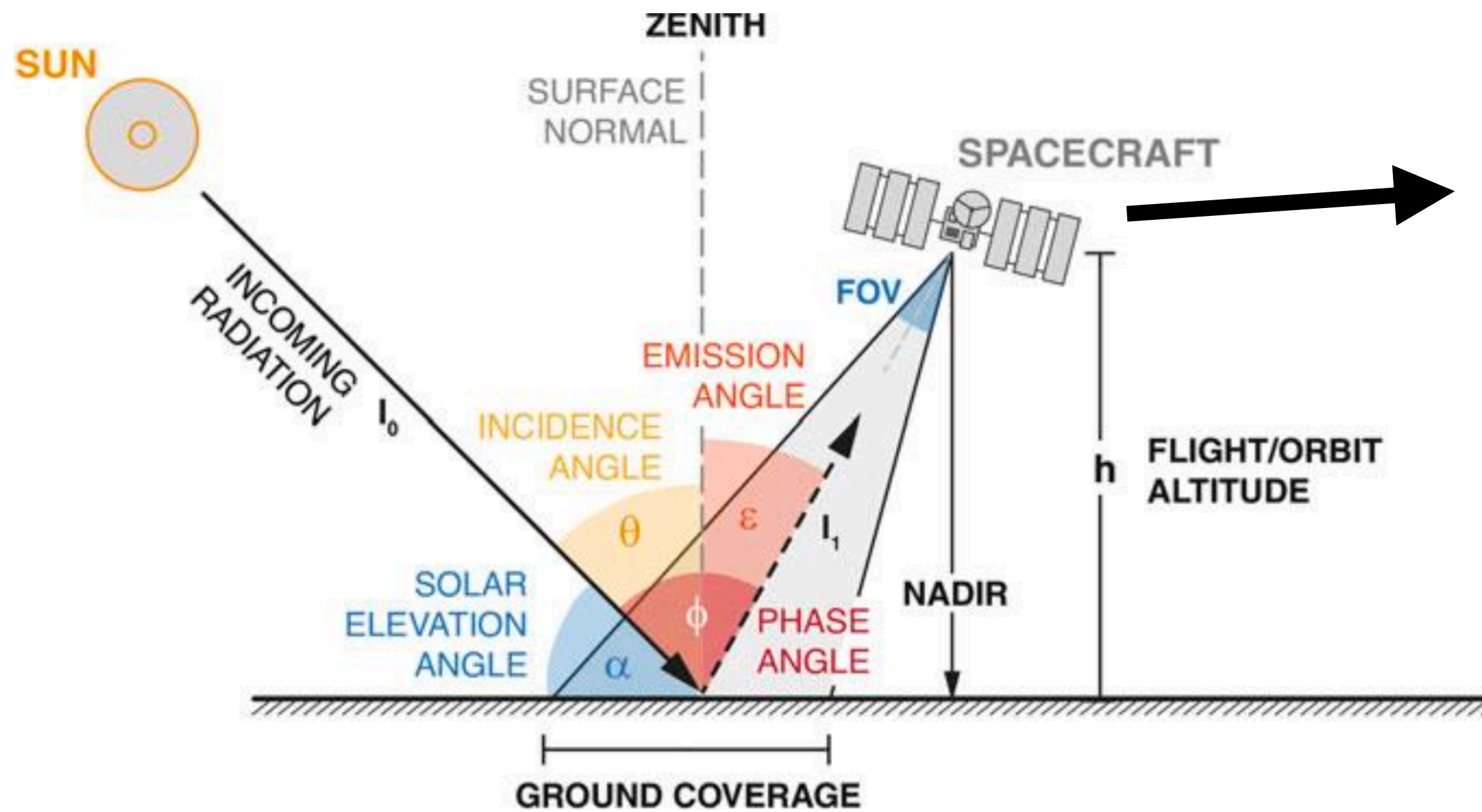


Case Study

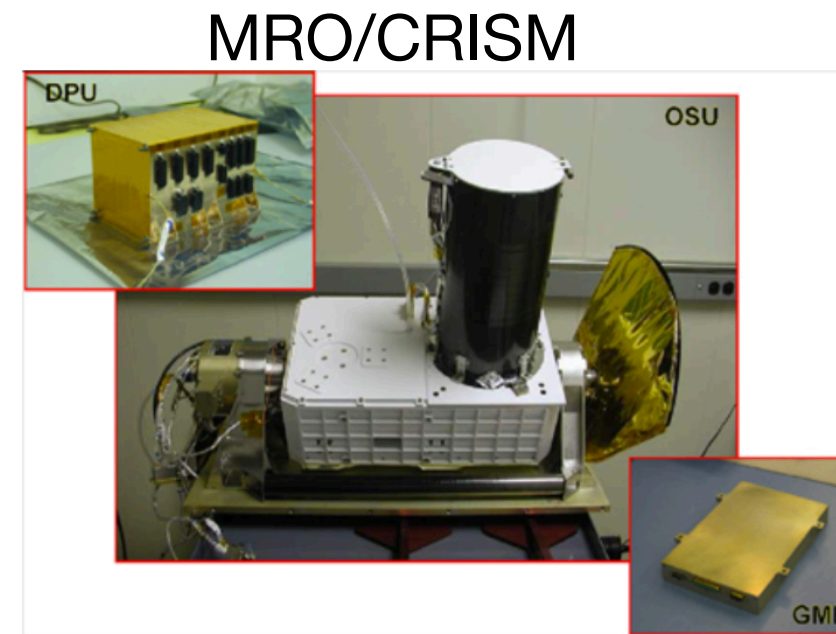


SS bodies, Martian moons, asteroids and comets, icy satellites

Remote Sensing Data

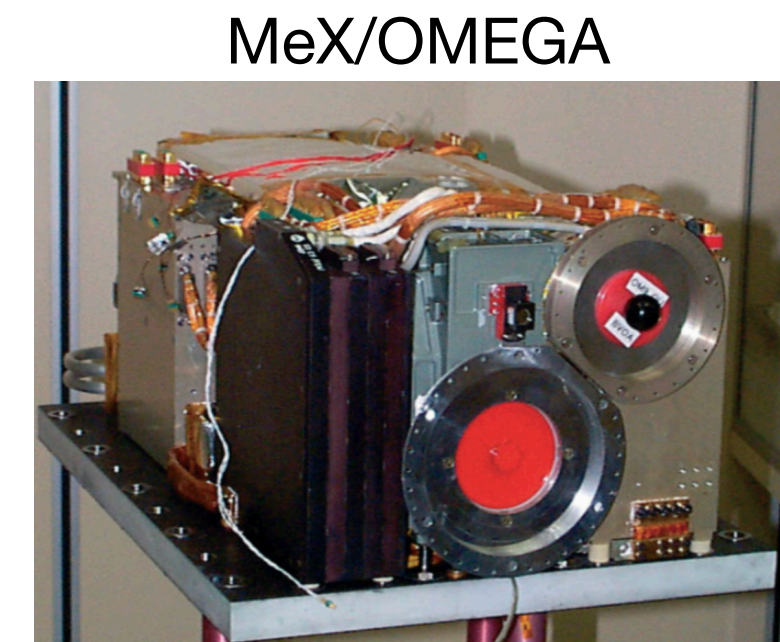


Van Gasselt et al. 2018



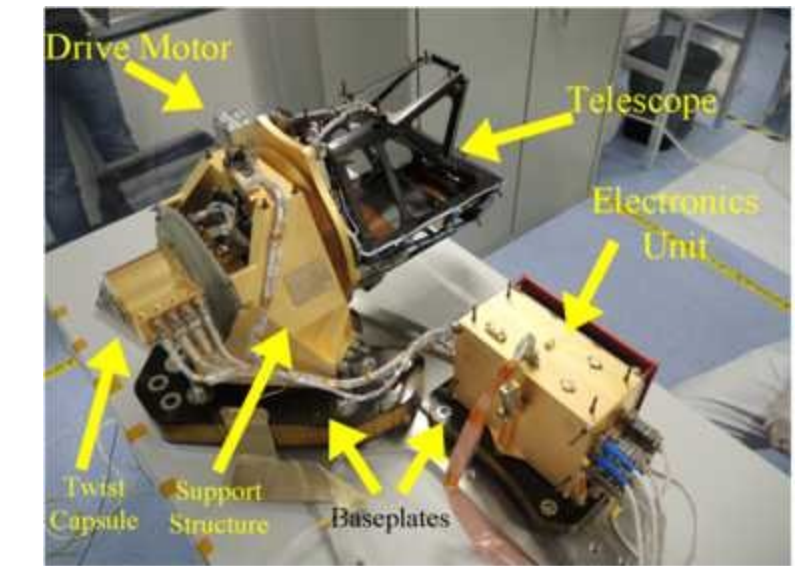
MRO/CRISM

Murchie et al. 2002



MeX/OMEGA

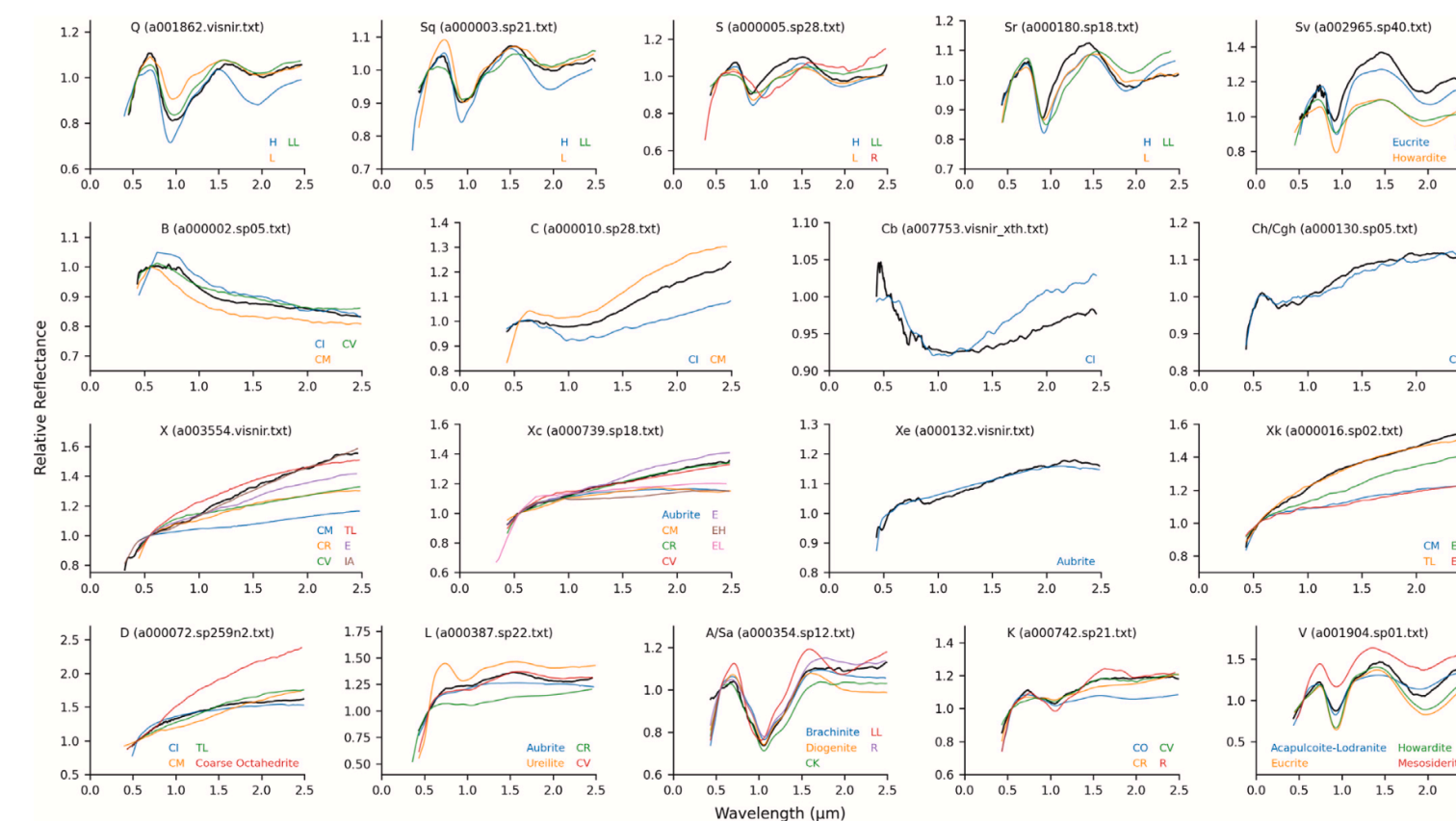
Bibring et al. 2004



TGO/CaSSIS

Thomas et al. 2017

Spectrum!!



De Meo et al. 2022



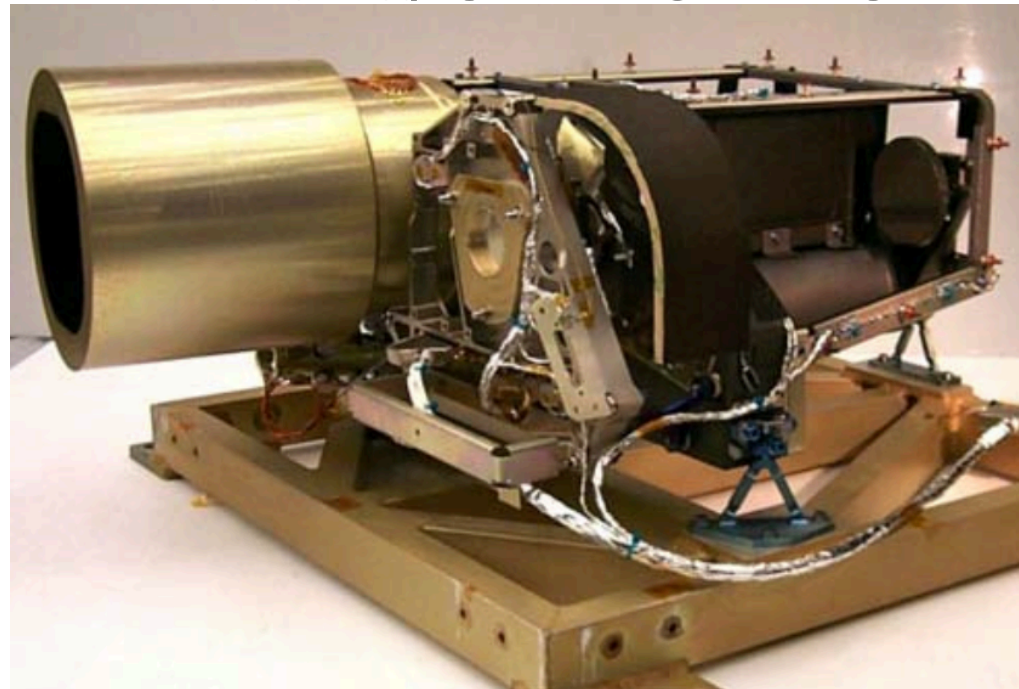
- *Machine learning general knowledge*
- *Solar System Exploration general knowledge*
- *Code for image alignment*
- *Code for photometric correction*
- *Preliminary applications of ML algorithm (k-means) to space missions data*
- *Thermal Continuum Removal and Thermal Modeling general knowledge*



The Rosetta Mission



Rosetta/ORIRIS-NAC



Rosetta/ORIRIS-WAC



Filter Wheel



Keller et al. 2007

(21) Lutetia

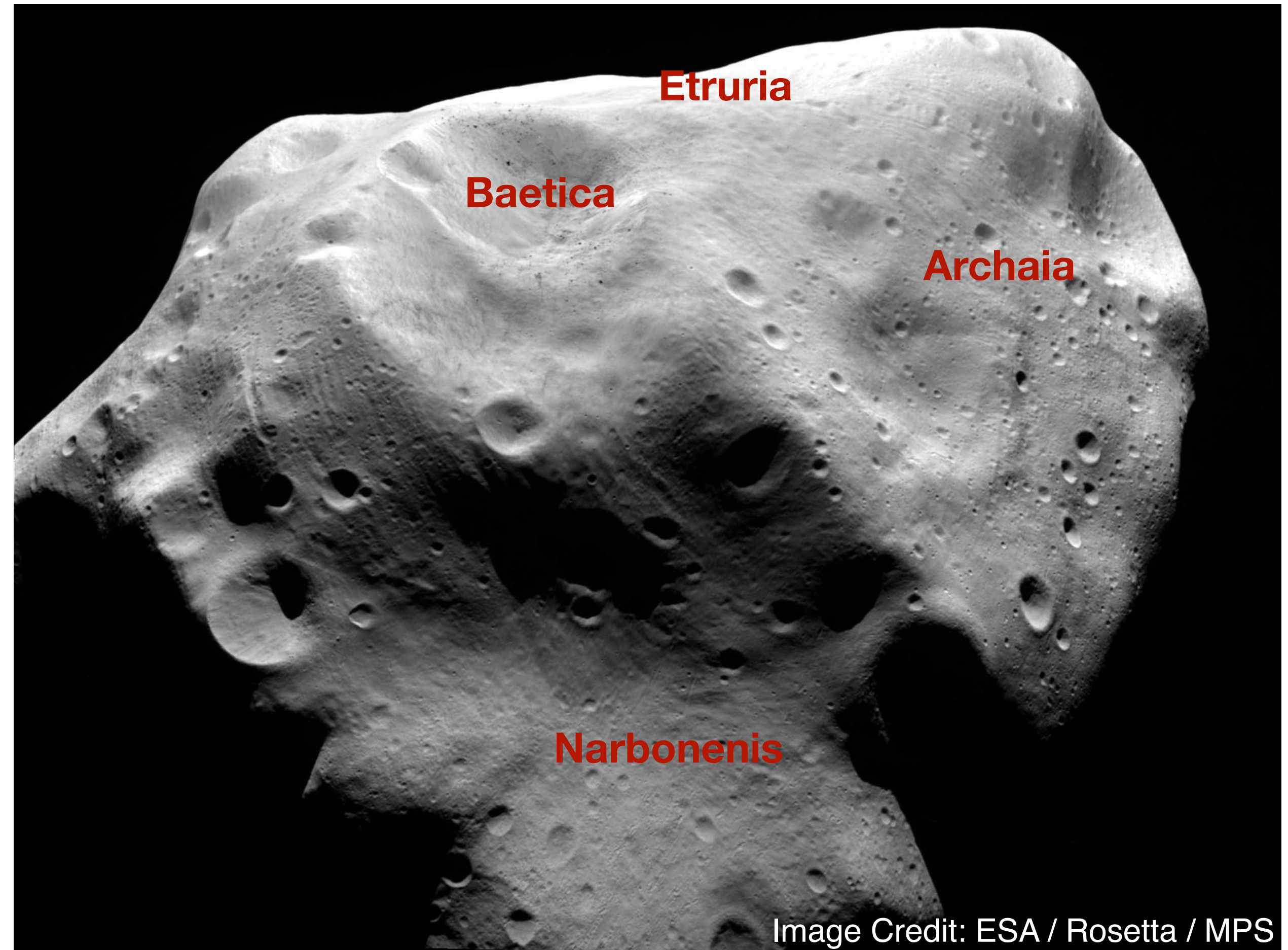


Image Credit: ESA / Rosetta / MPS



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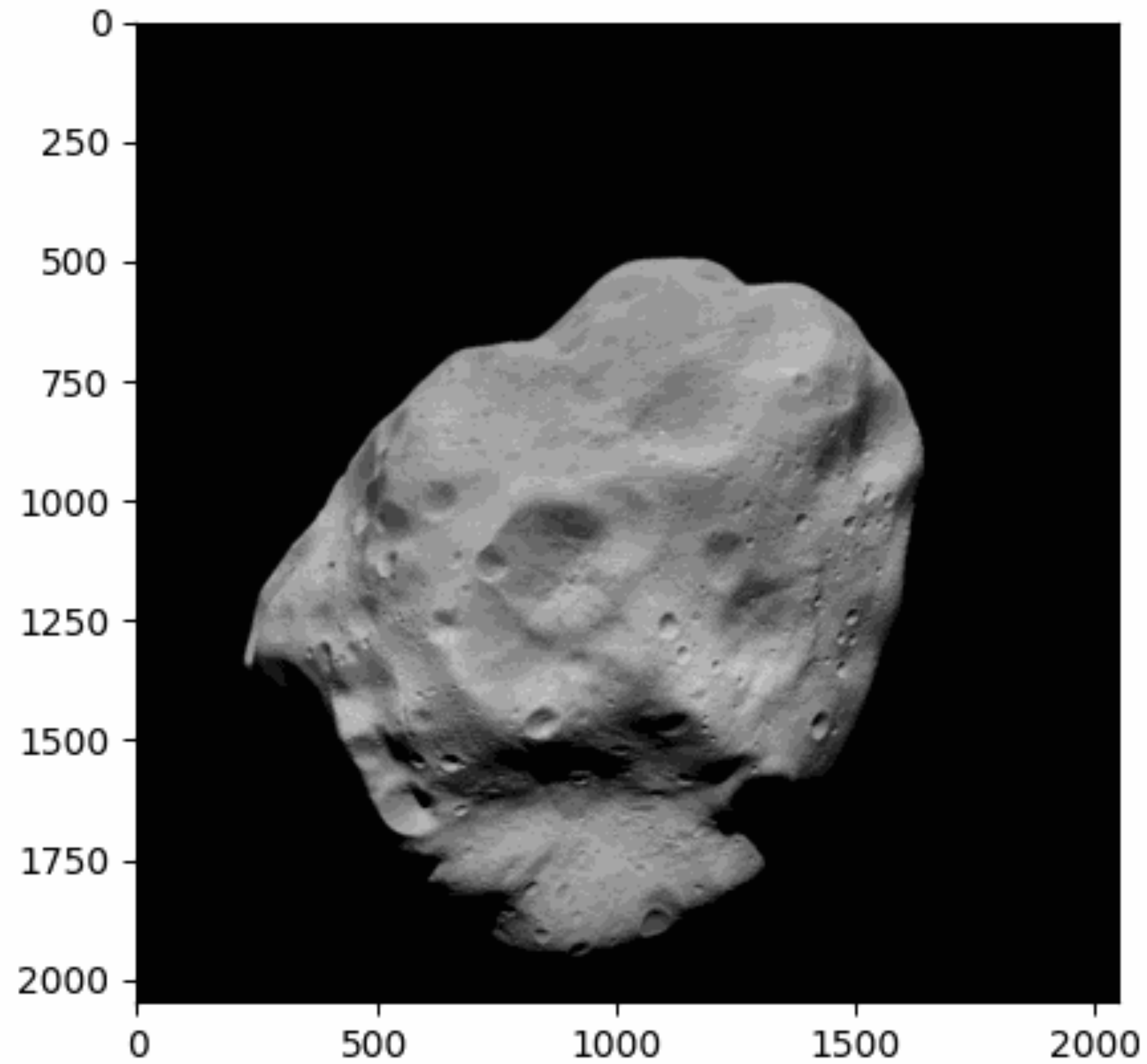
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Image Alignment



NAC



WAC

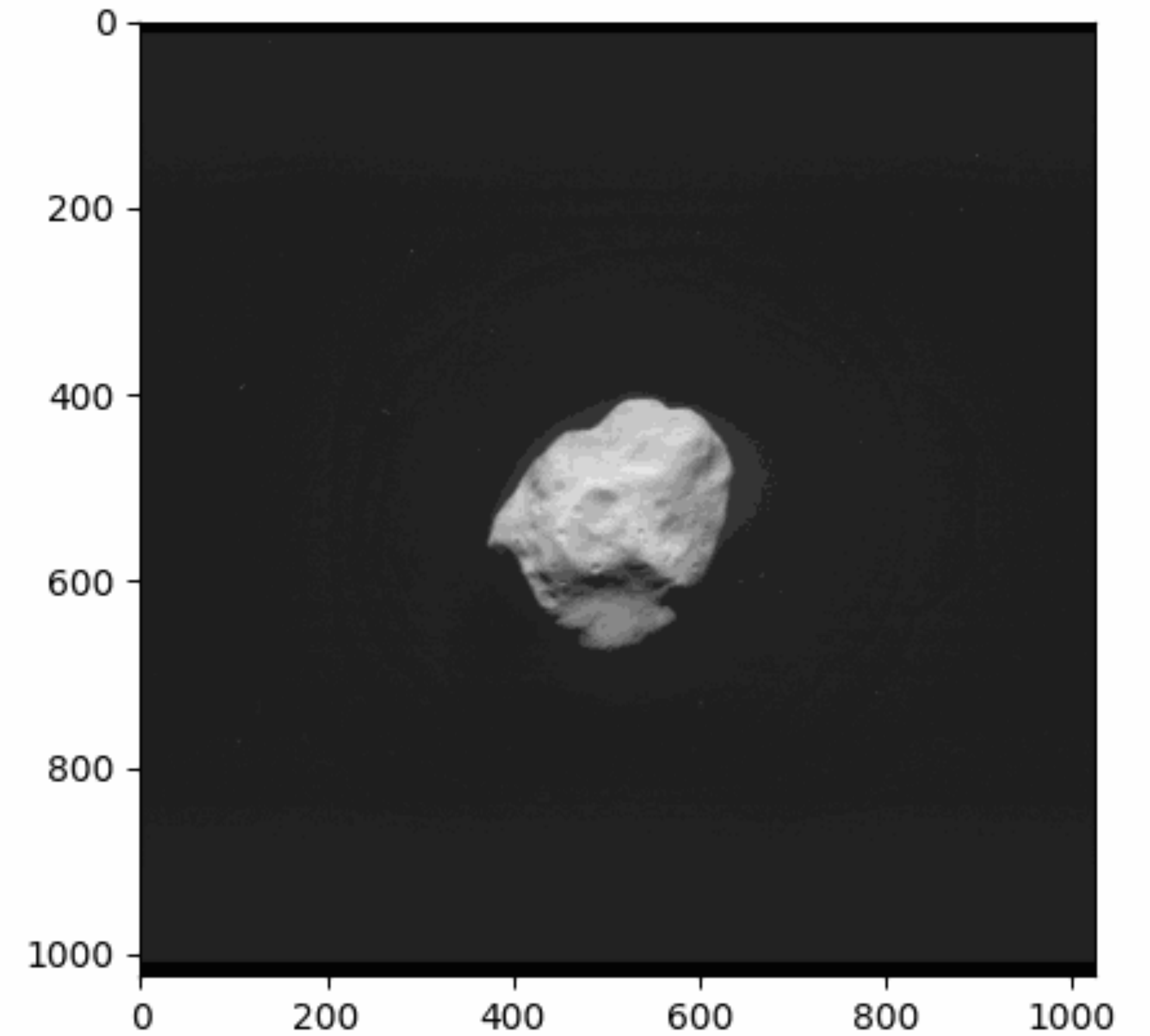
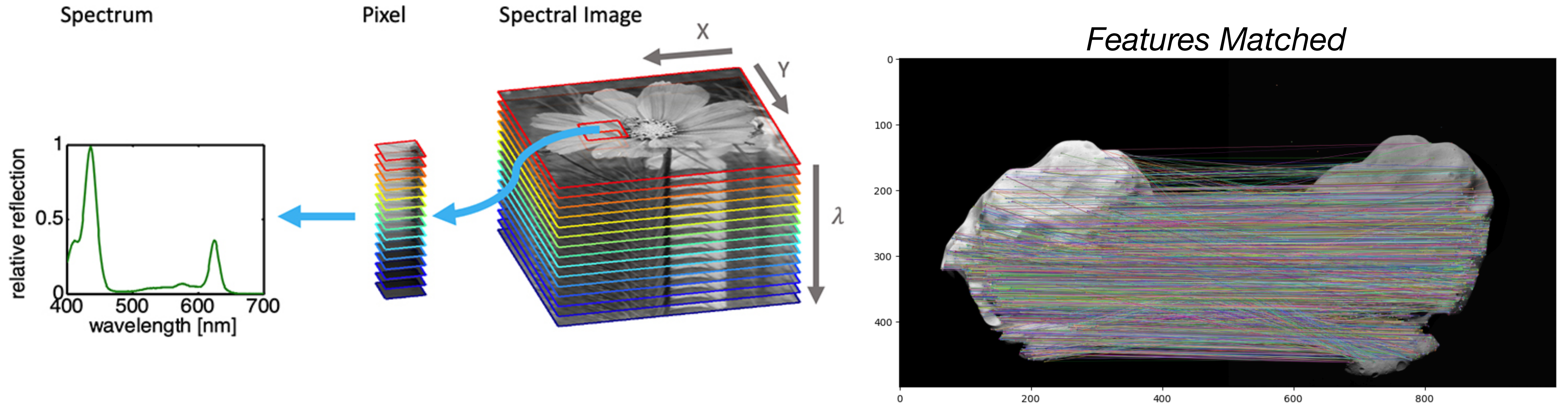


Image Alignment



Features matching based algorithm



ORB *Rough alignment*

Transformation based algorithm



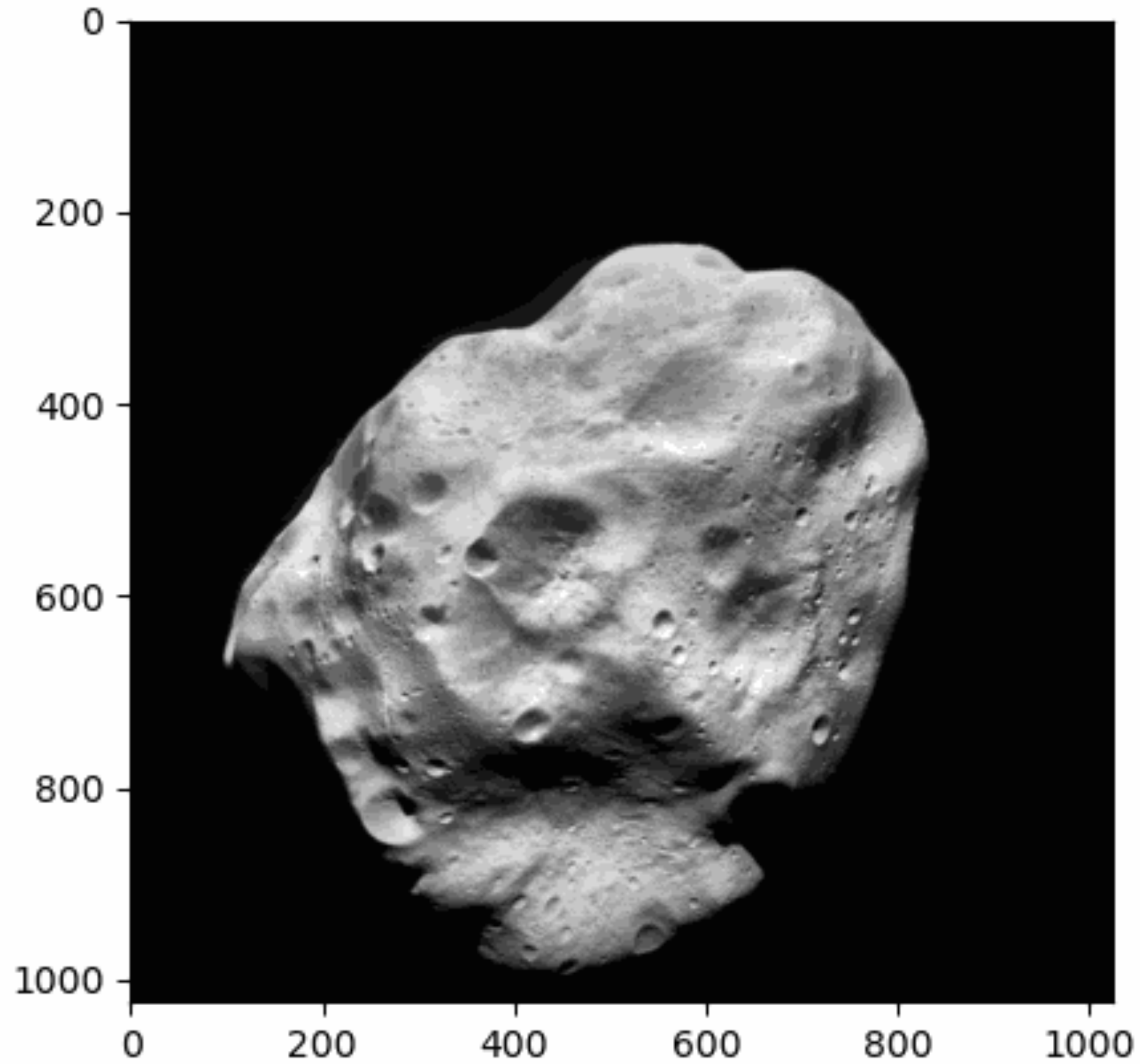
Elastix *Refinement*



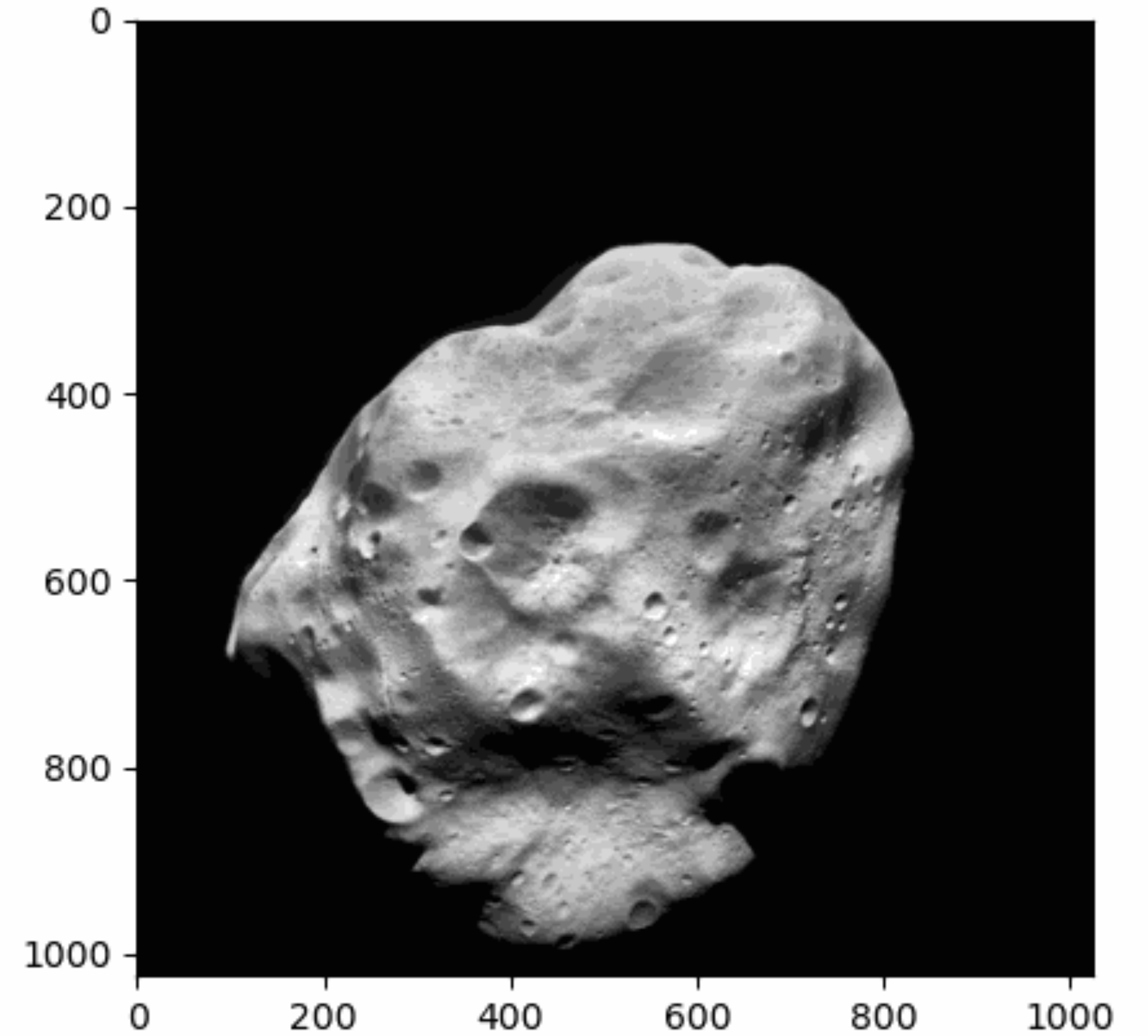
Image Alignment



ORB



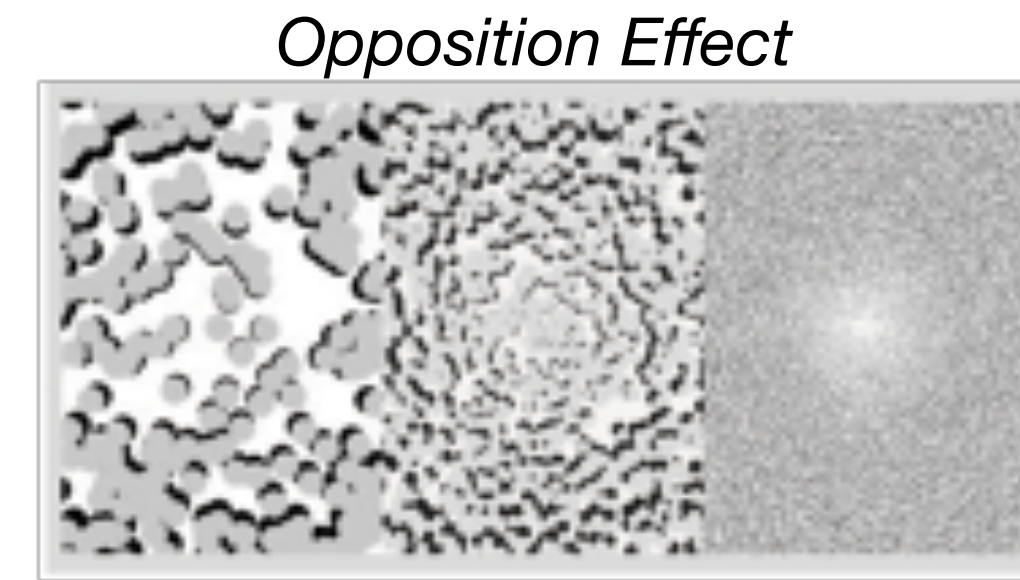
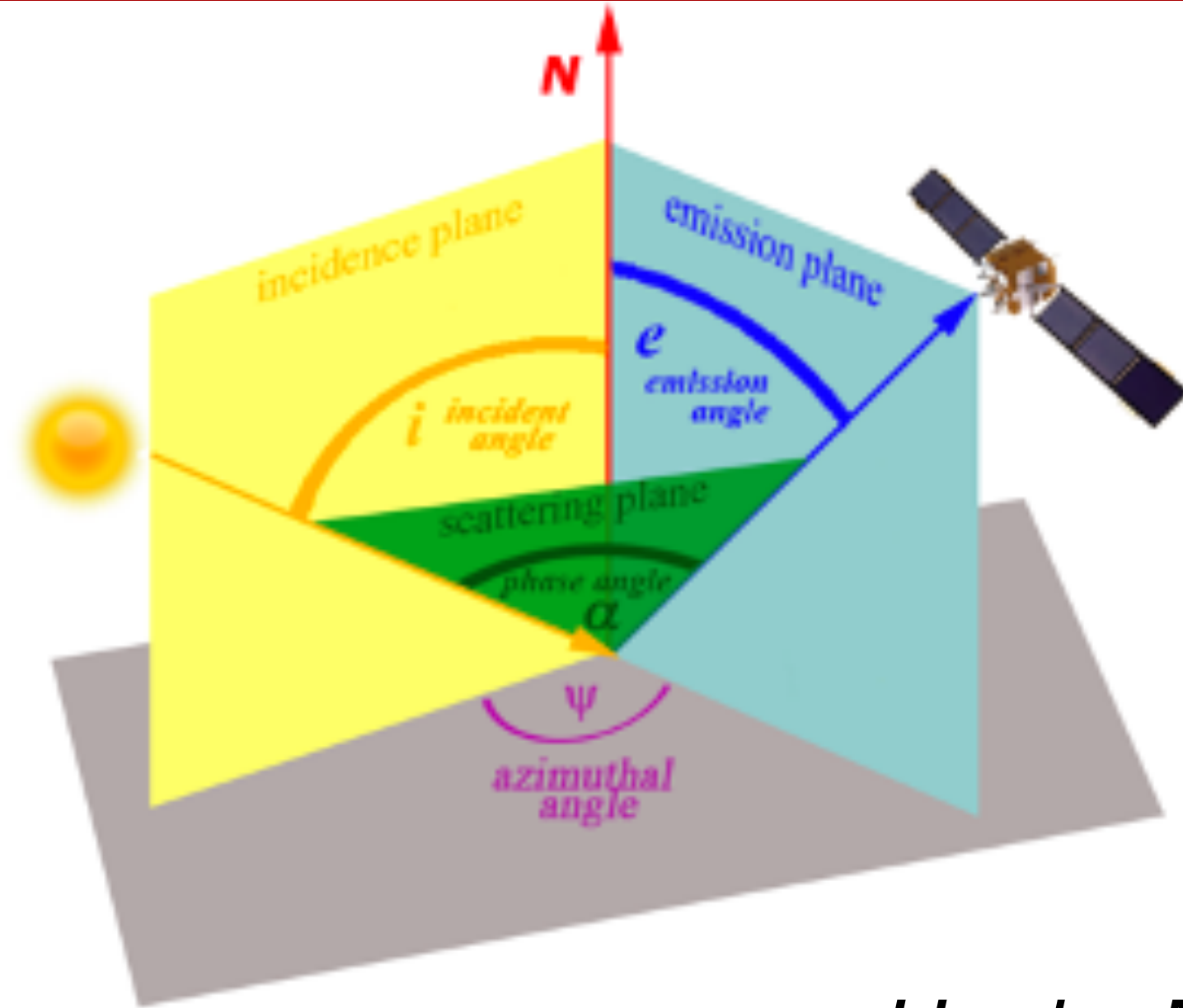
Elastix





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Photometric Correction



Hapke Model $r_R(i, e, g) = \frac{w}{4\pi} \frac{\mu_{0e}}{\mu_e + \mu_{0e}} \cdot \{ [1 + B(g)]p(g) + H(\mu_{0e})H(\mu_e) \} \cdot S(i, e, g)$

Labels for the Hapke Model equation:

- Simple Scattering Albedo: w
- Phase Function: $p(g)$
- Multiscattering Process: $H(\mu_{0e})H(\mu_e)$
- Roughness Correction: $S(i, e, g)$

Lommel Seeliger Disk Function $D(i, e) = \frac{2\cos(i)}{\cos(i) + \cos(e)}$



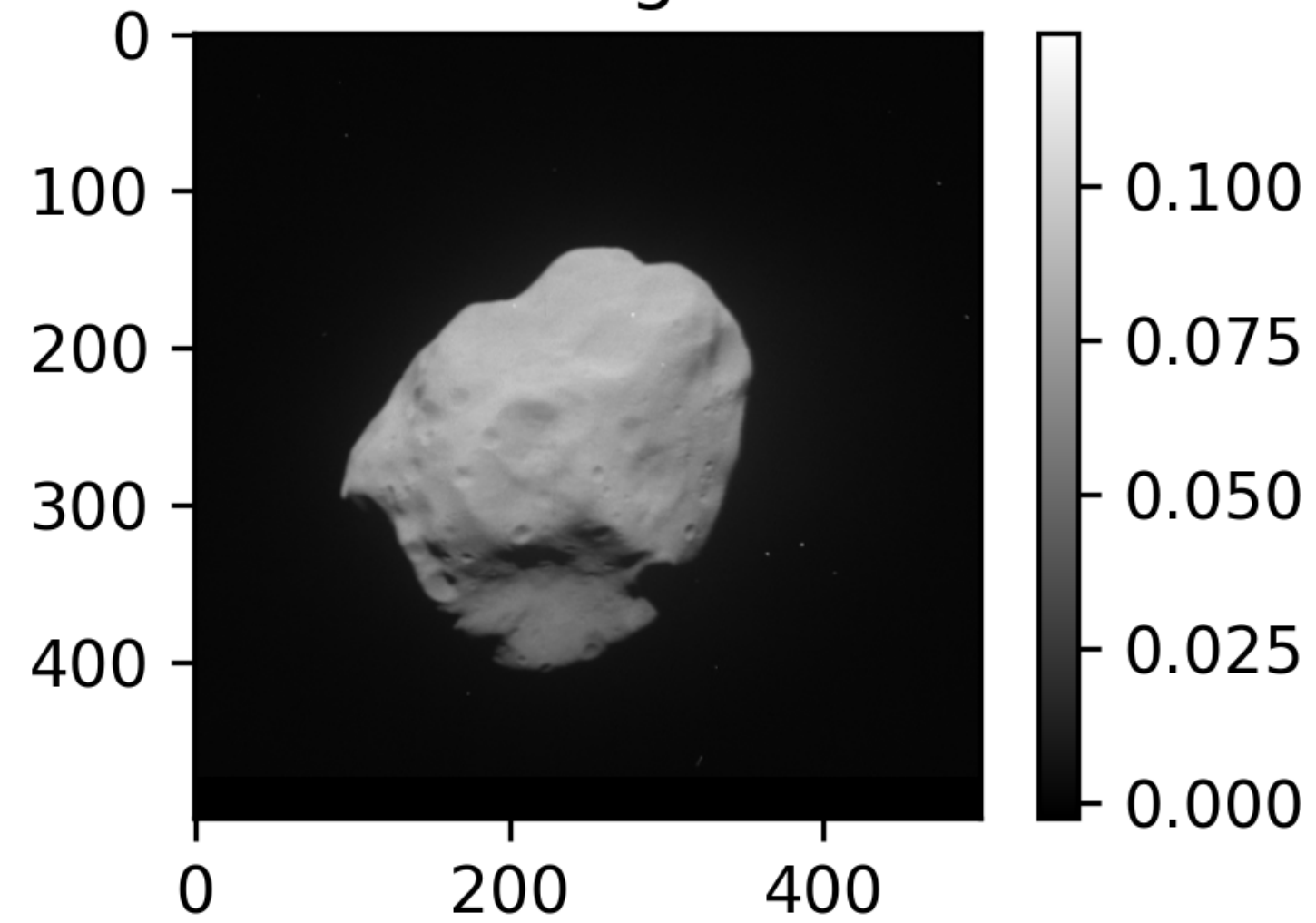
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Photometric Correction

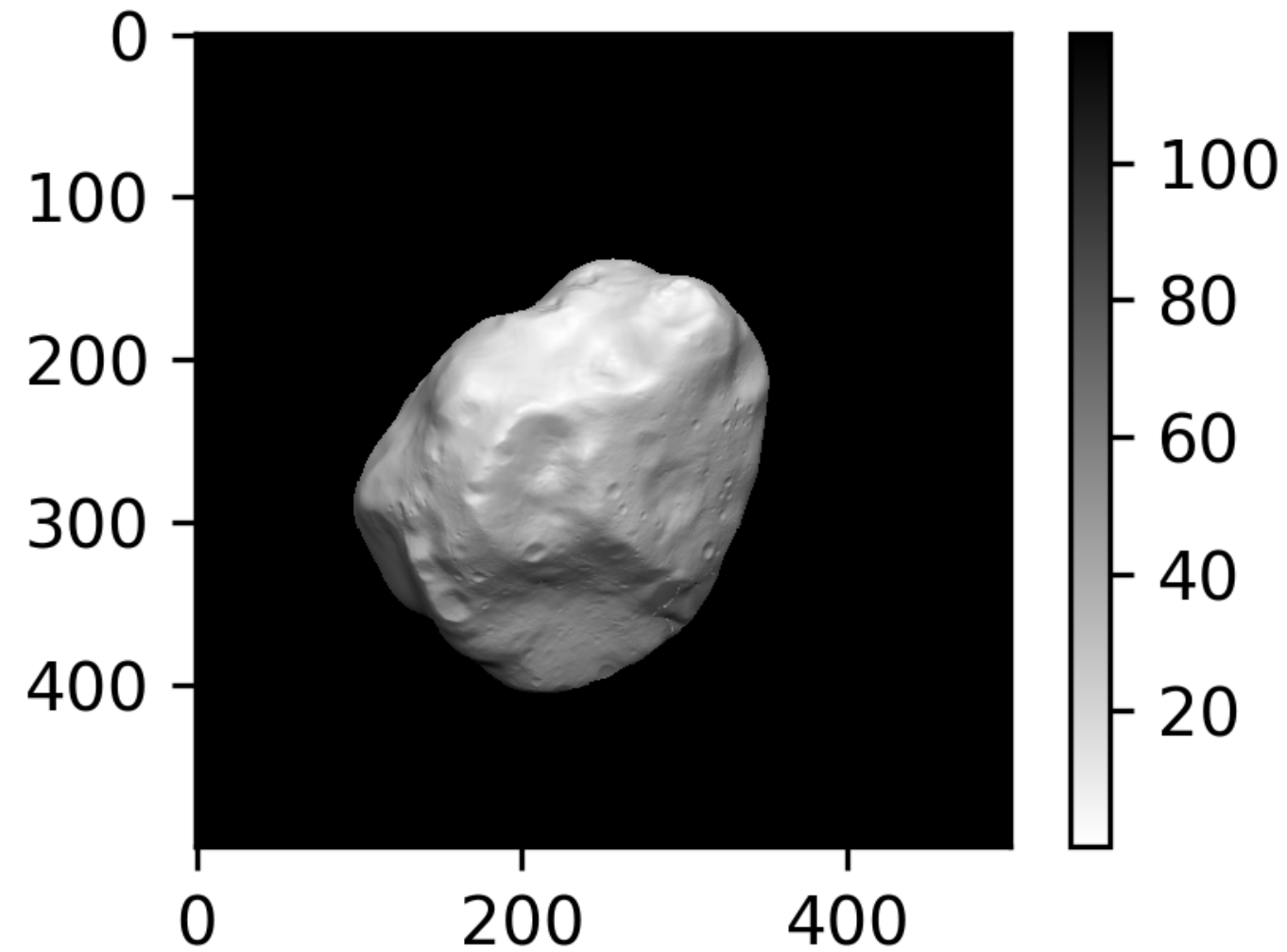


Spice Kernels

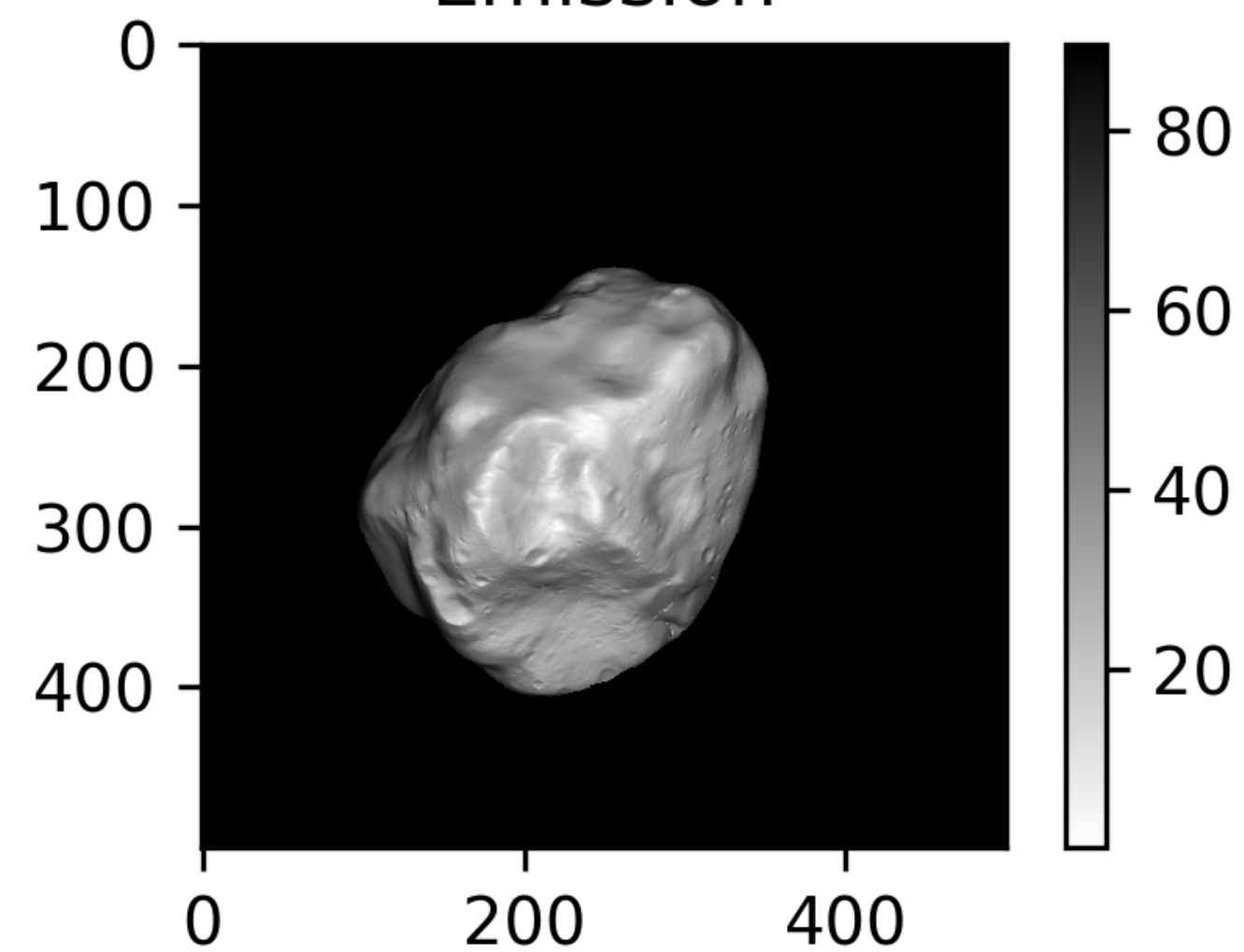
WAC Image F31



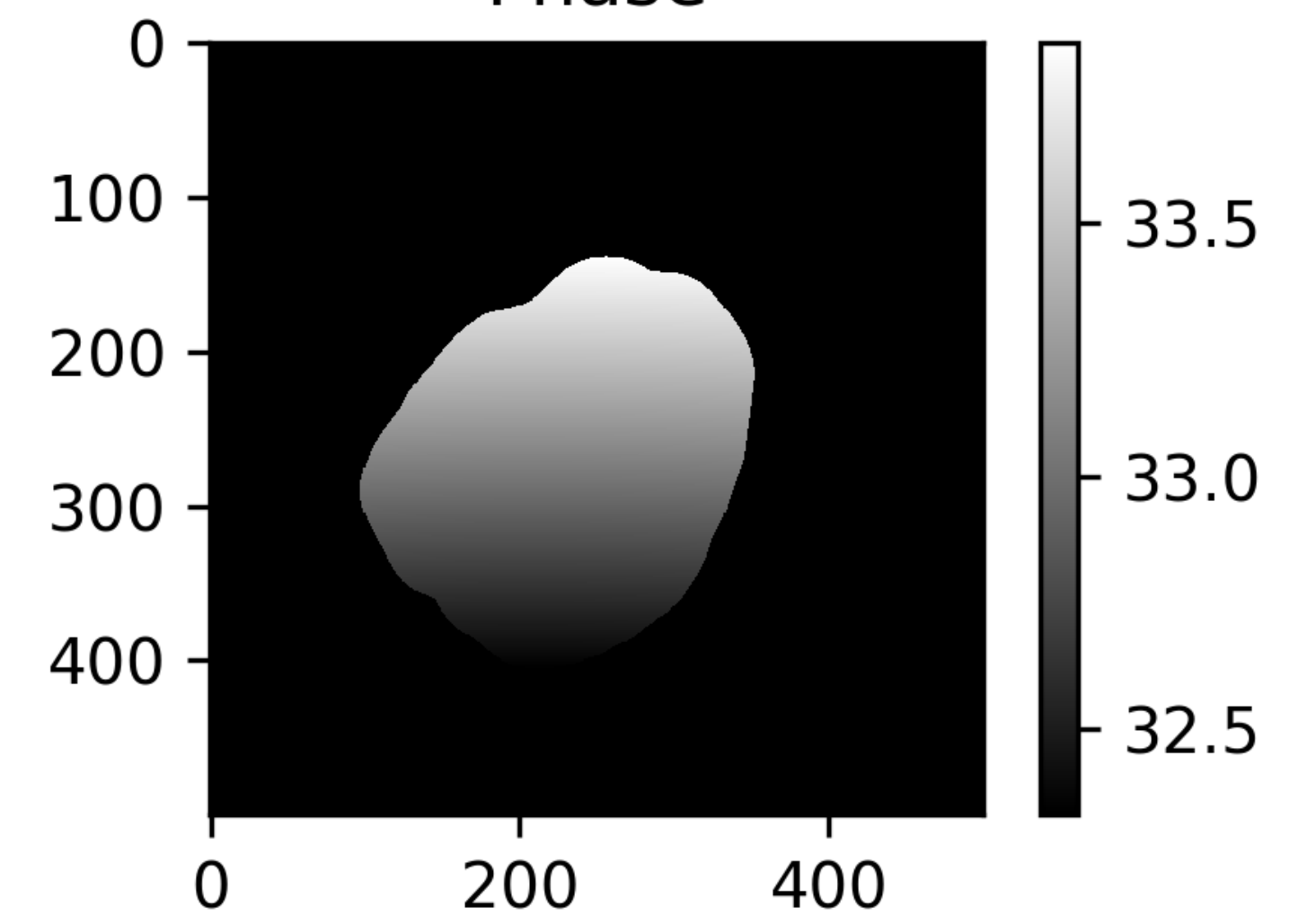
Incidence



Emission

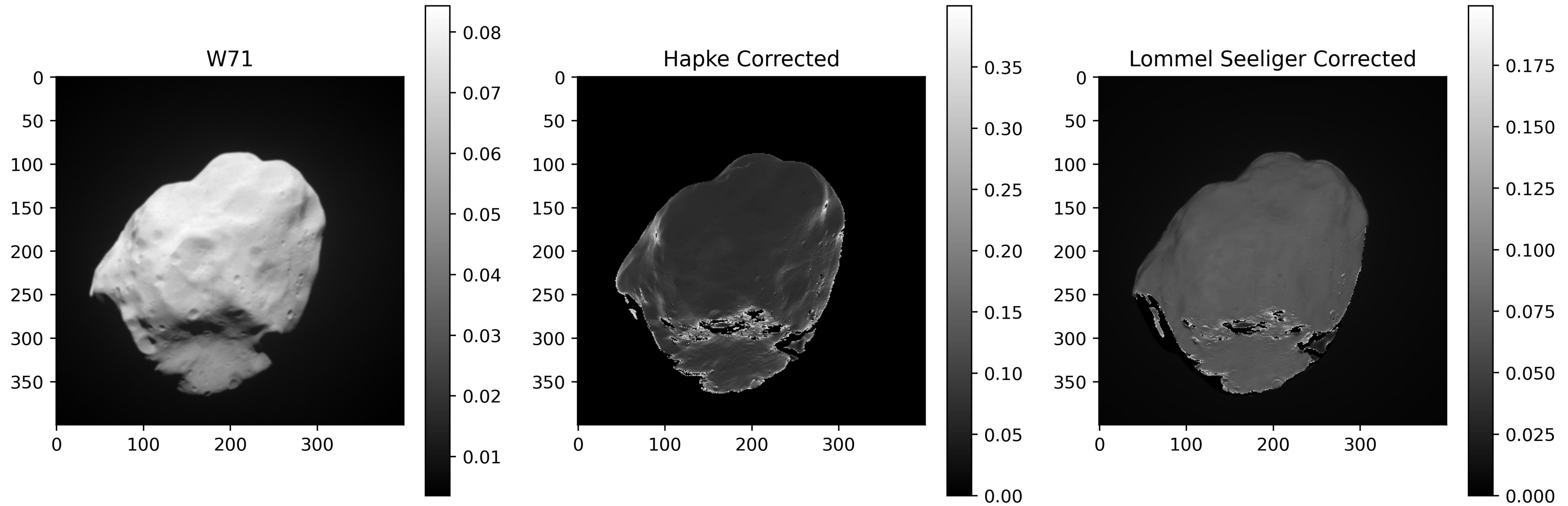


Phase



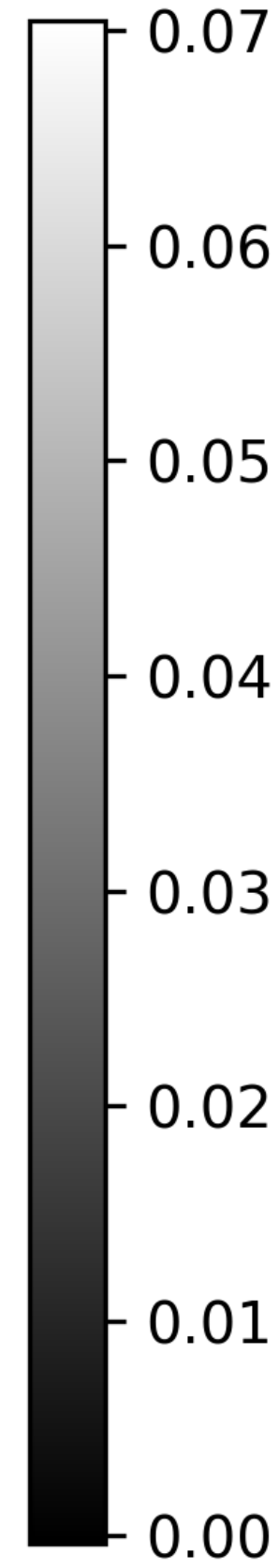
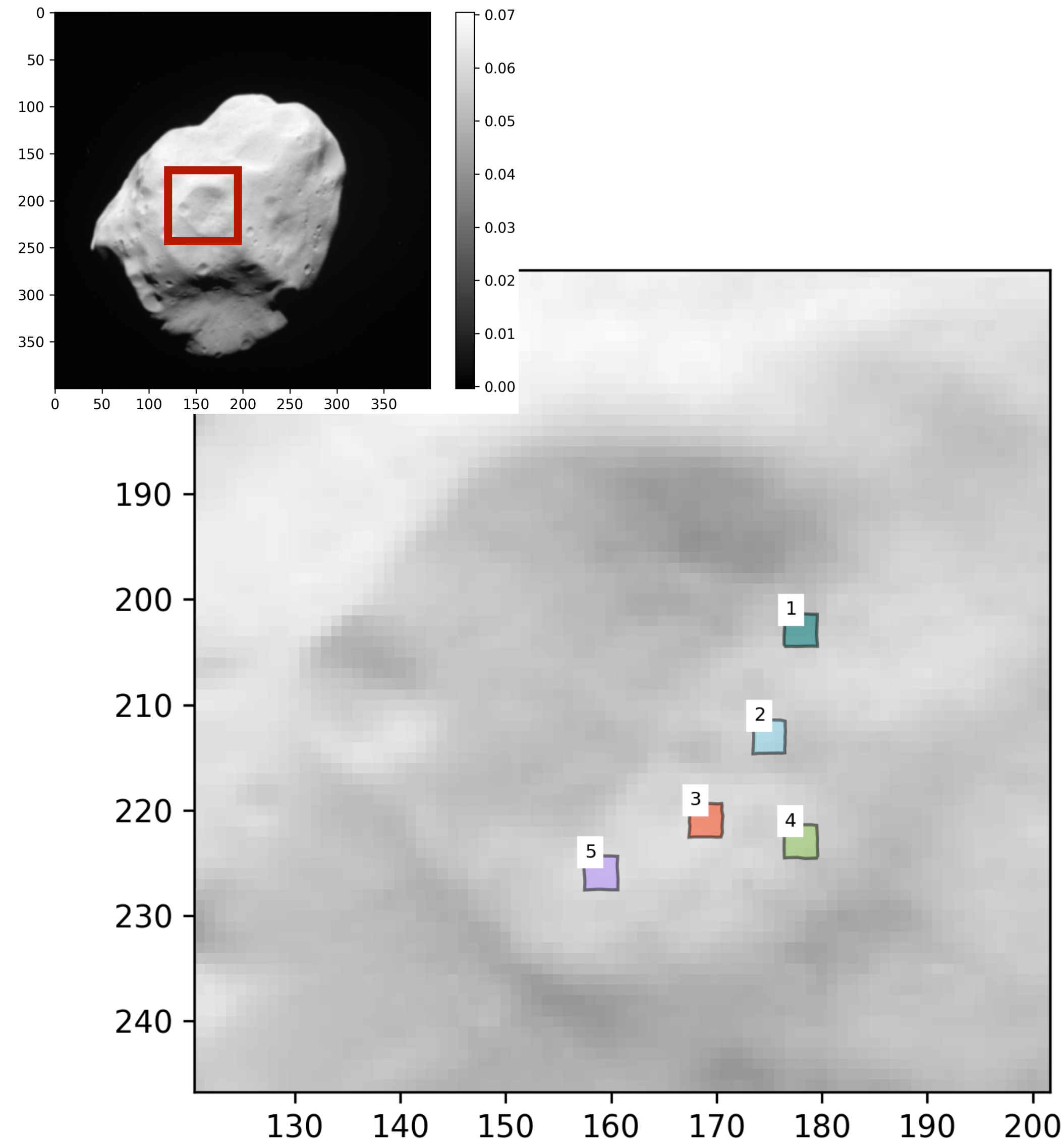


Photometric Correction

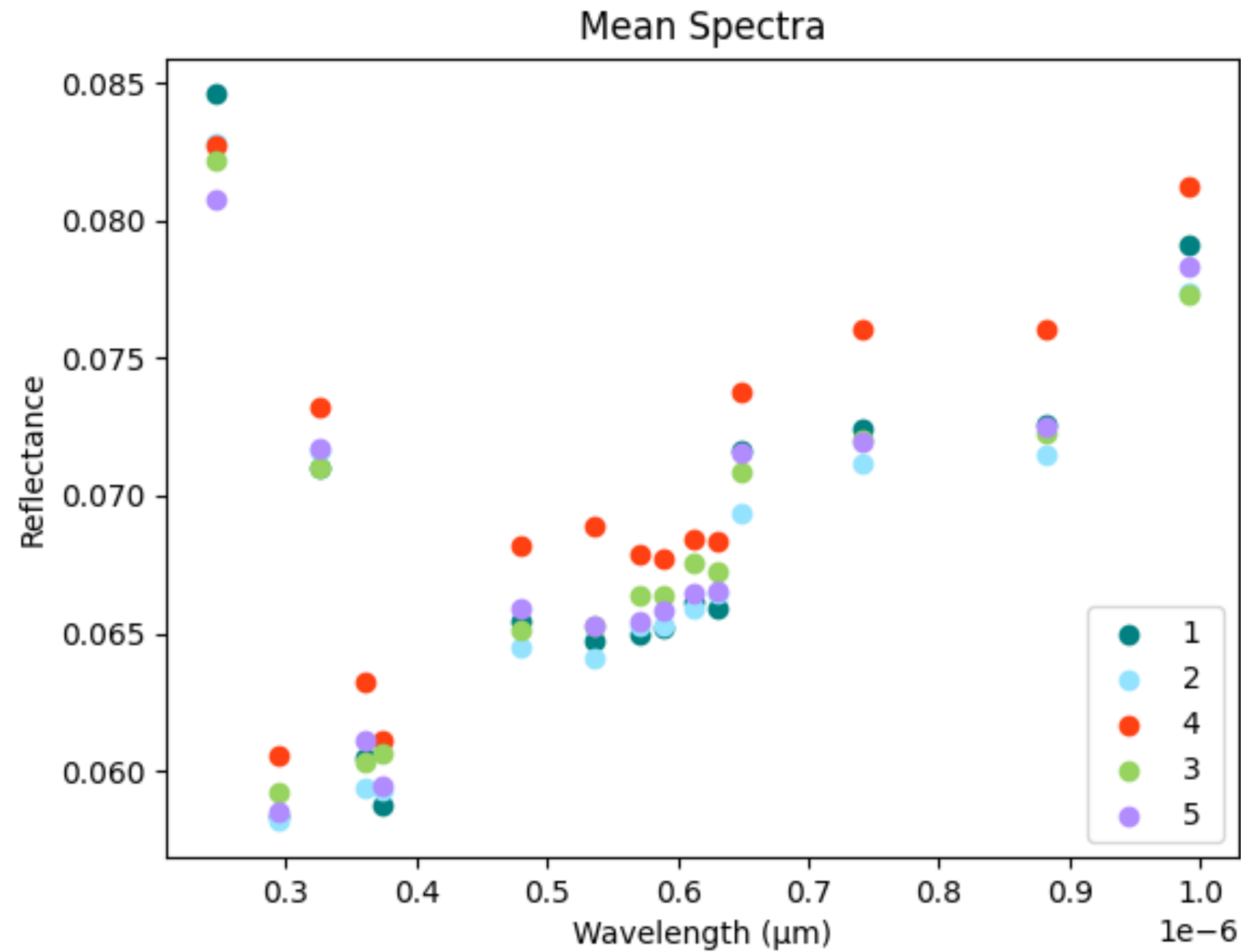




Mean Spectra



15





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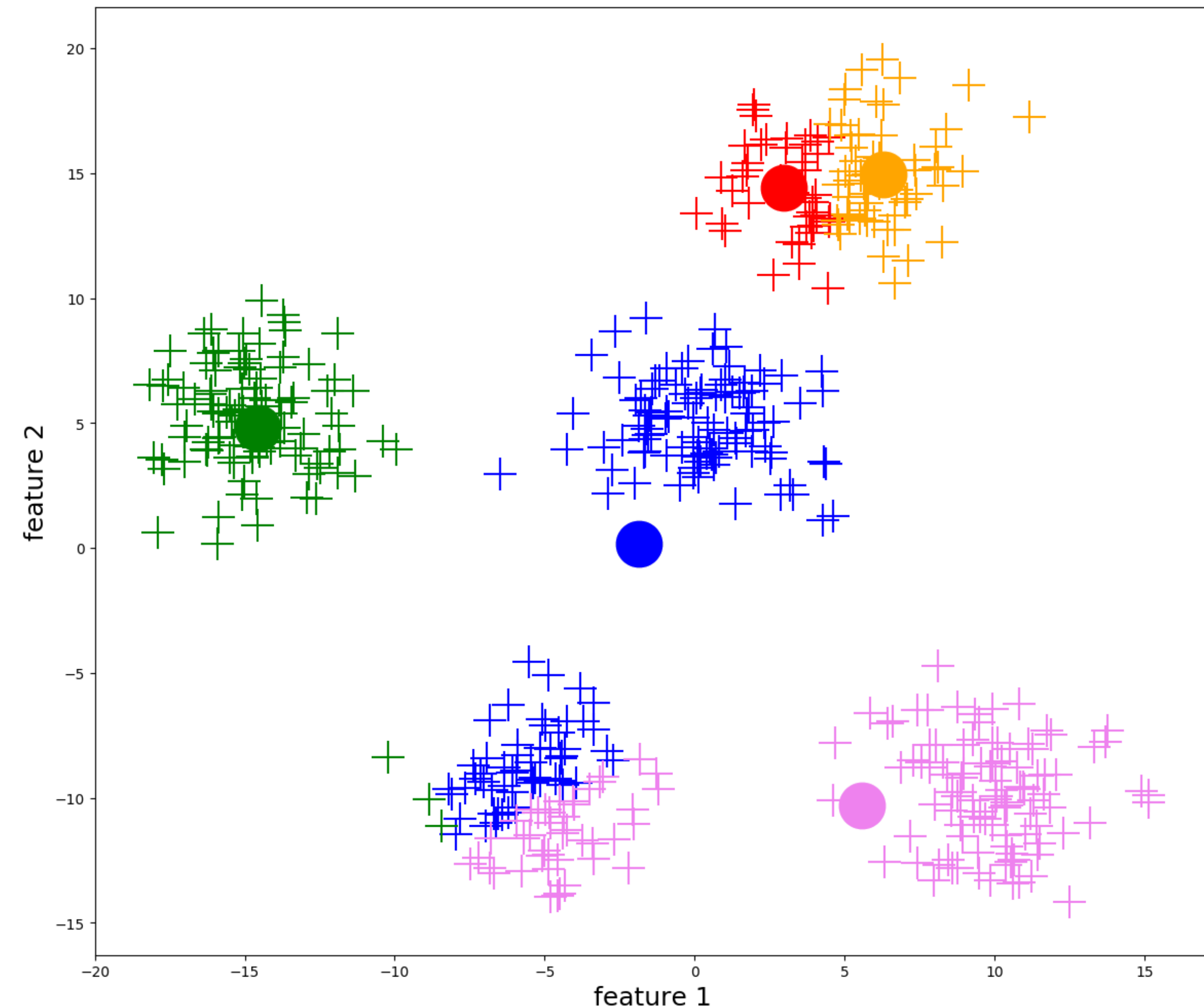


Unsupervised classification - Machine Learning Algorithm

K-Means

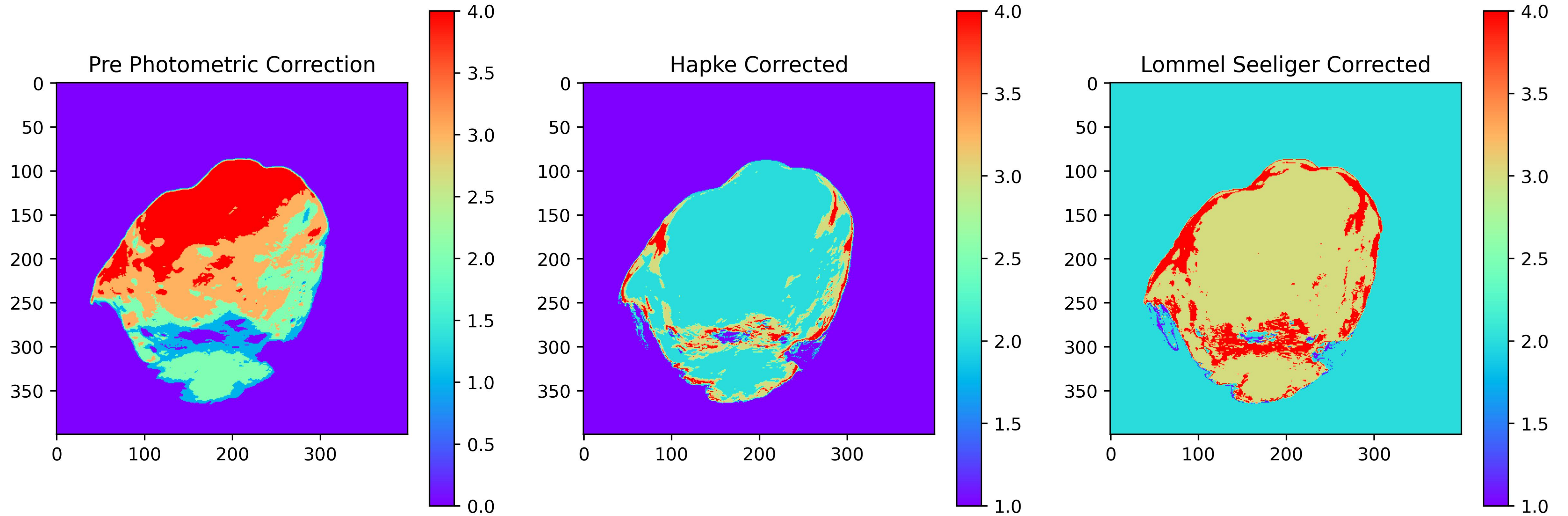
Parameters:

- *Number of cluster* → *Arbitrary*
→ *Calinsky-Harabasz Criterion*
- *Distance* → *Euclidean*
→ *Centroid*
→ *...*
- *Max number of iteration*



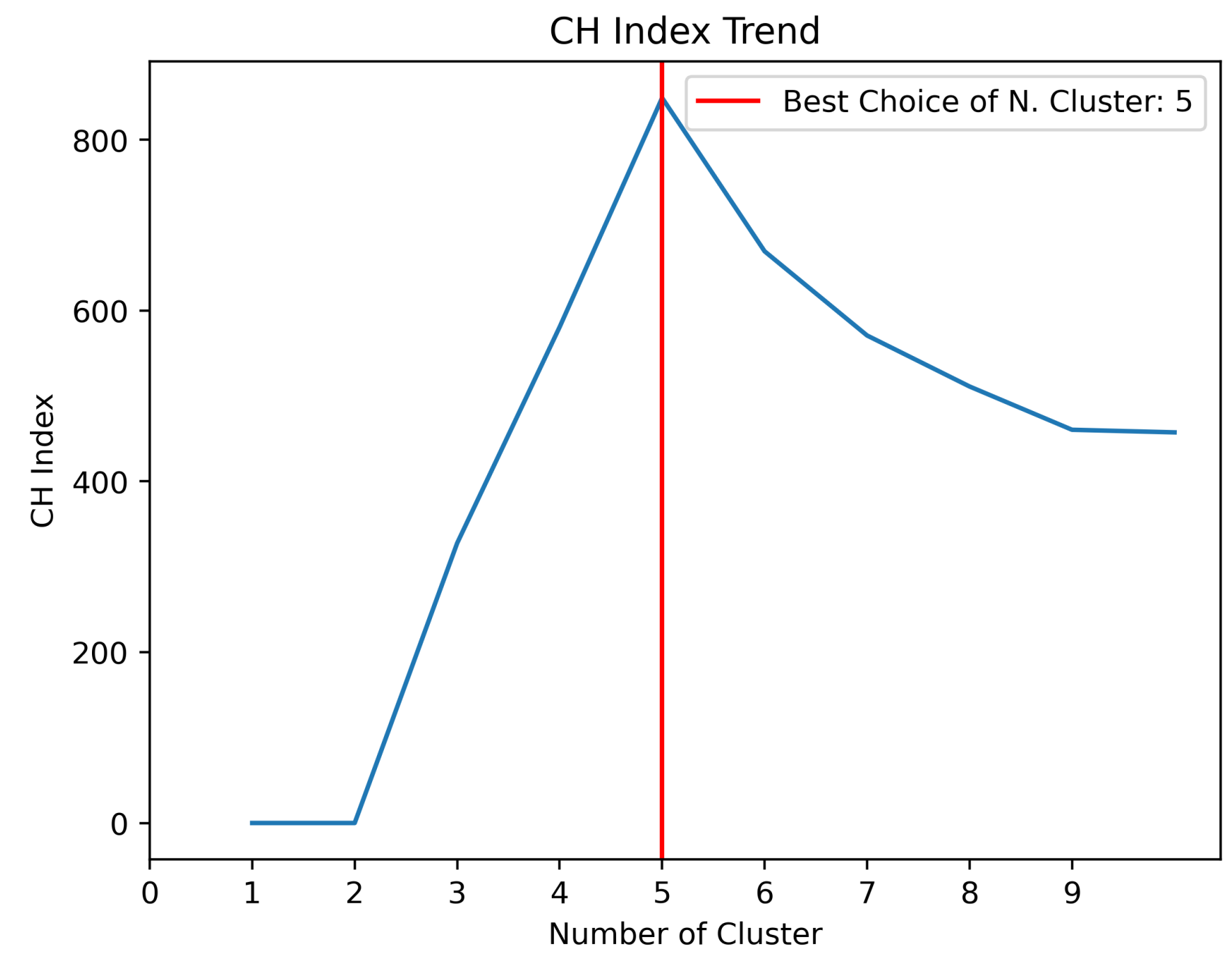
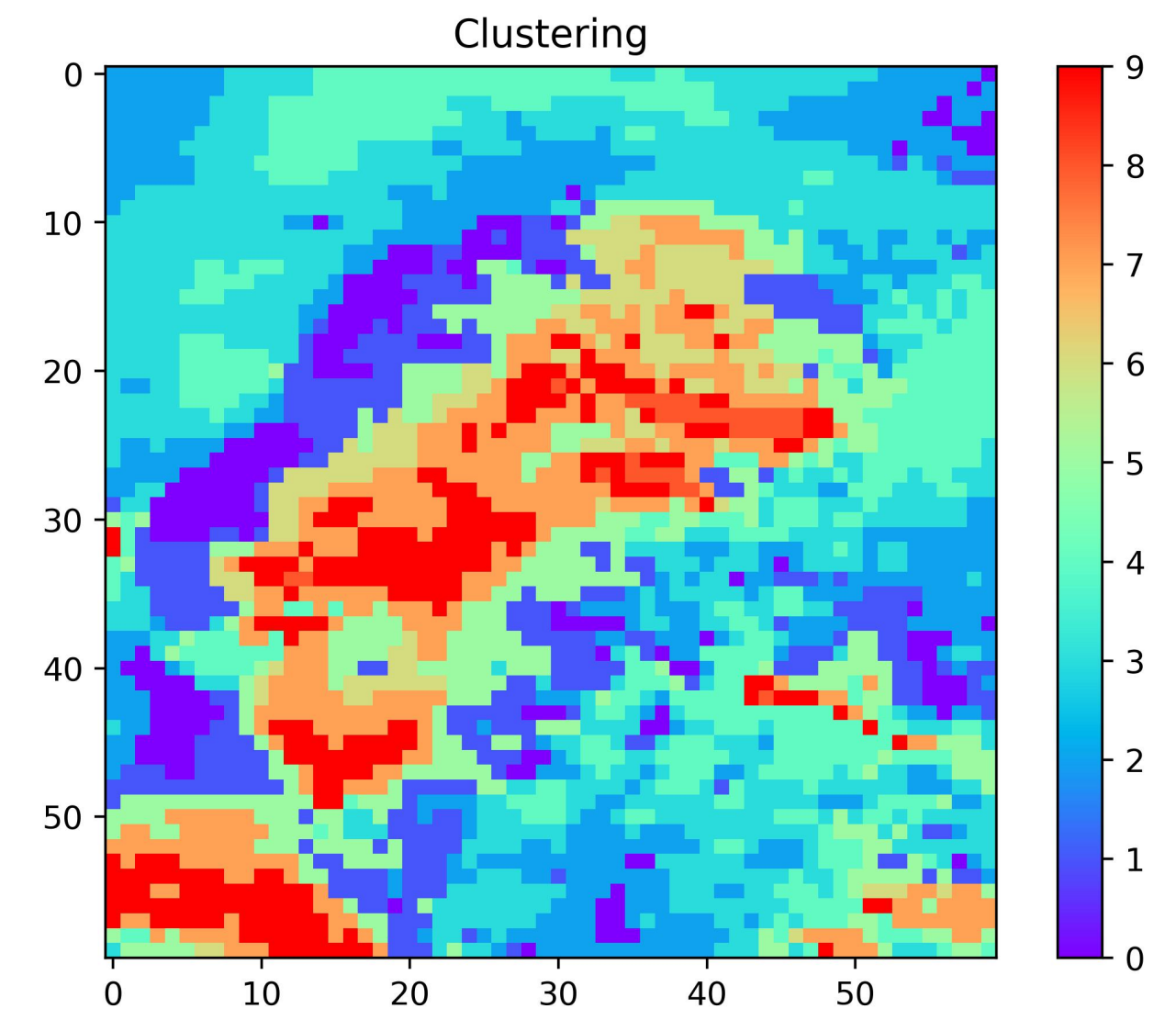
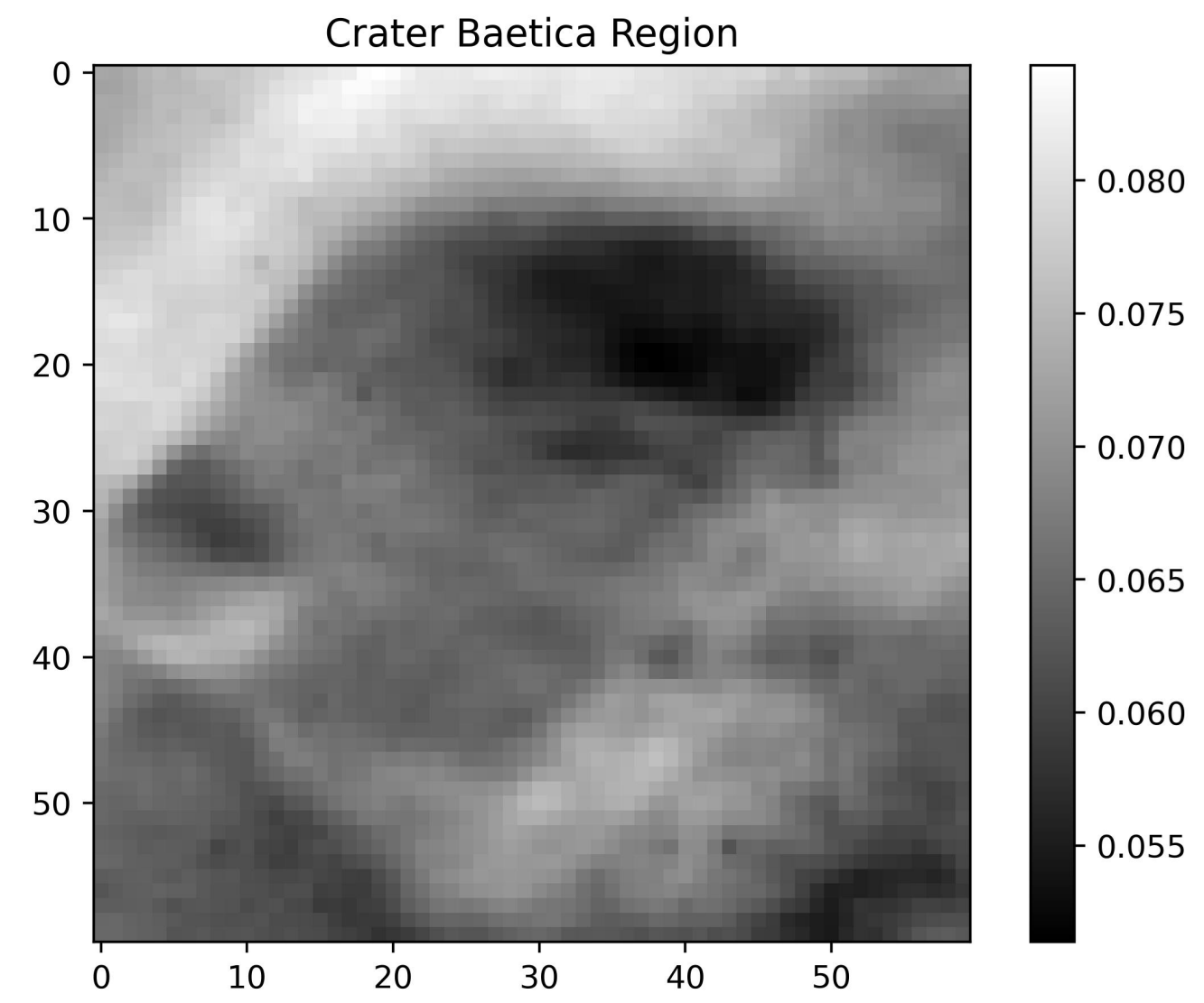
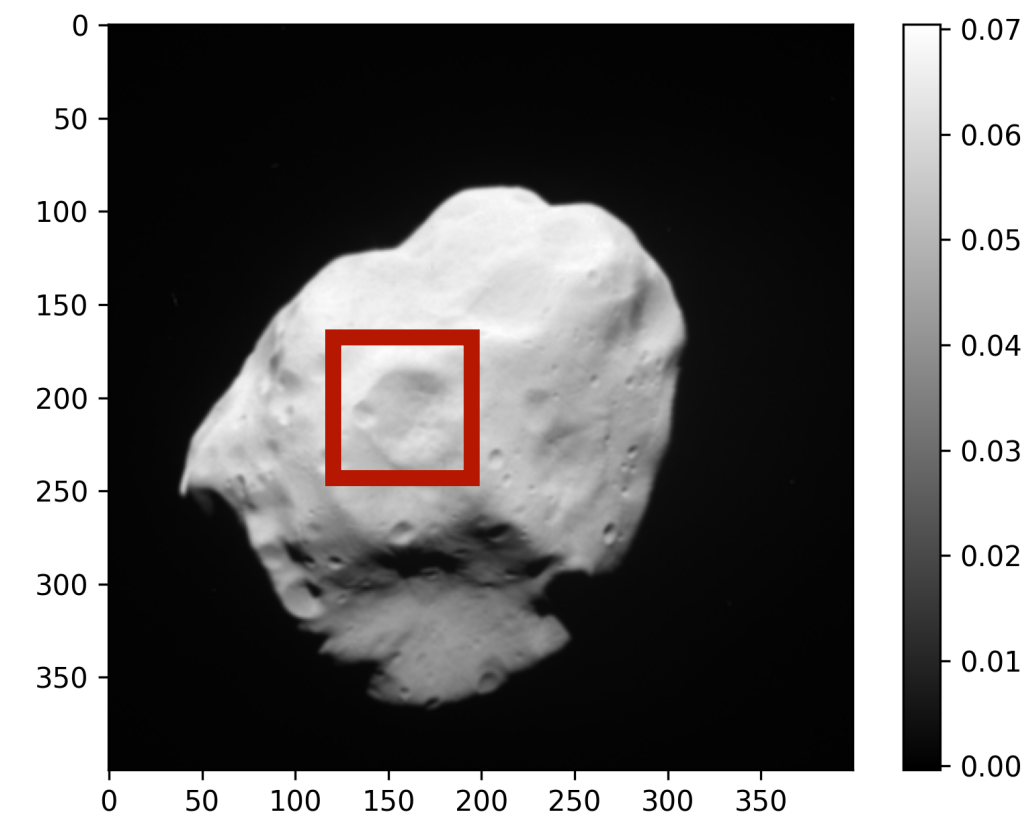


Photometric Correction

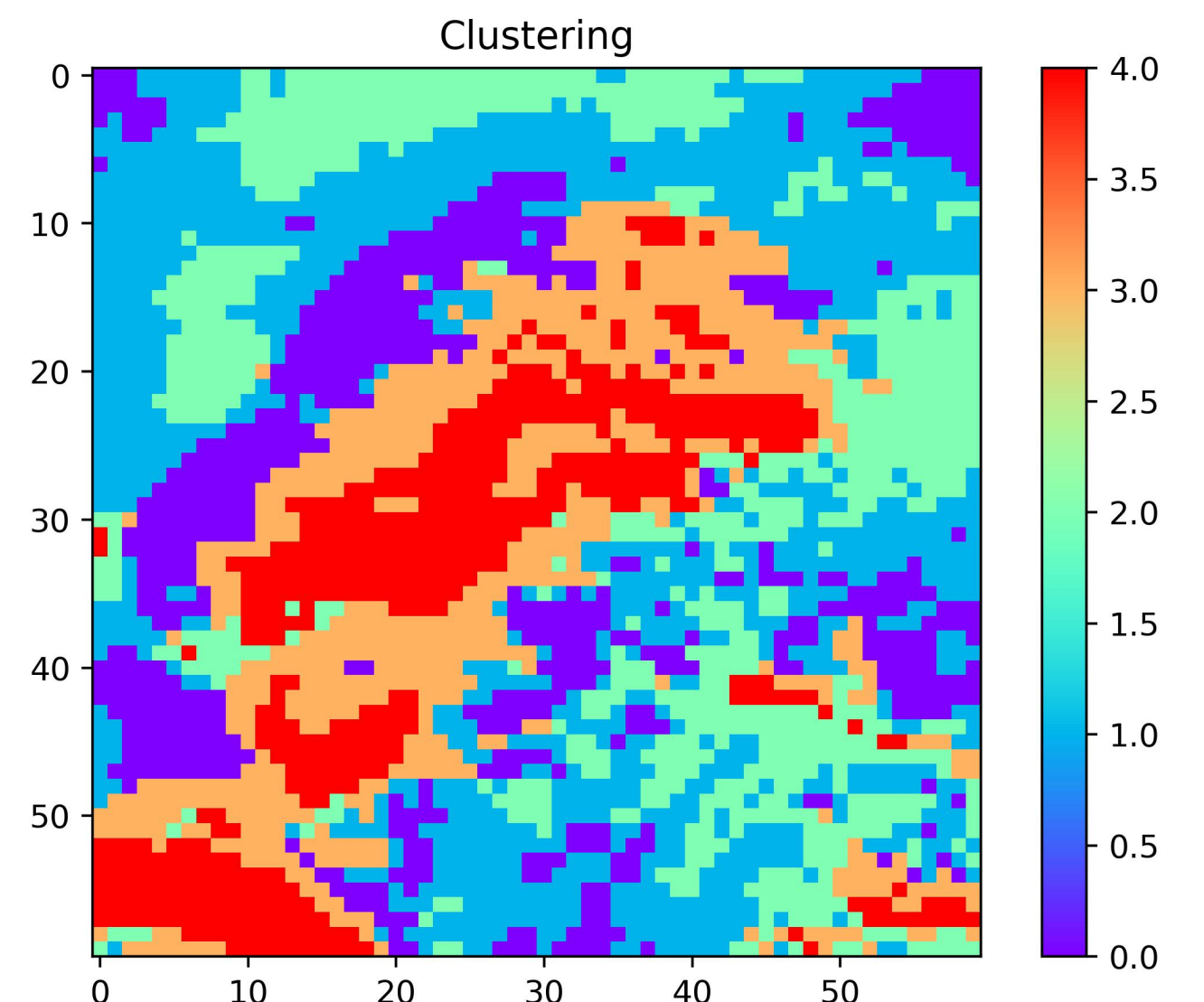




Clustering Analysis



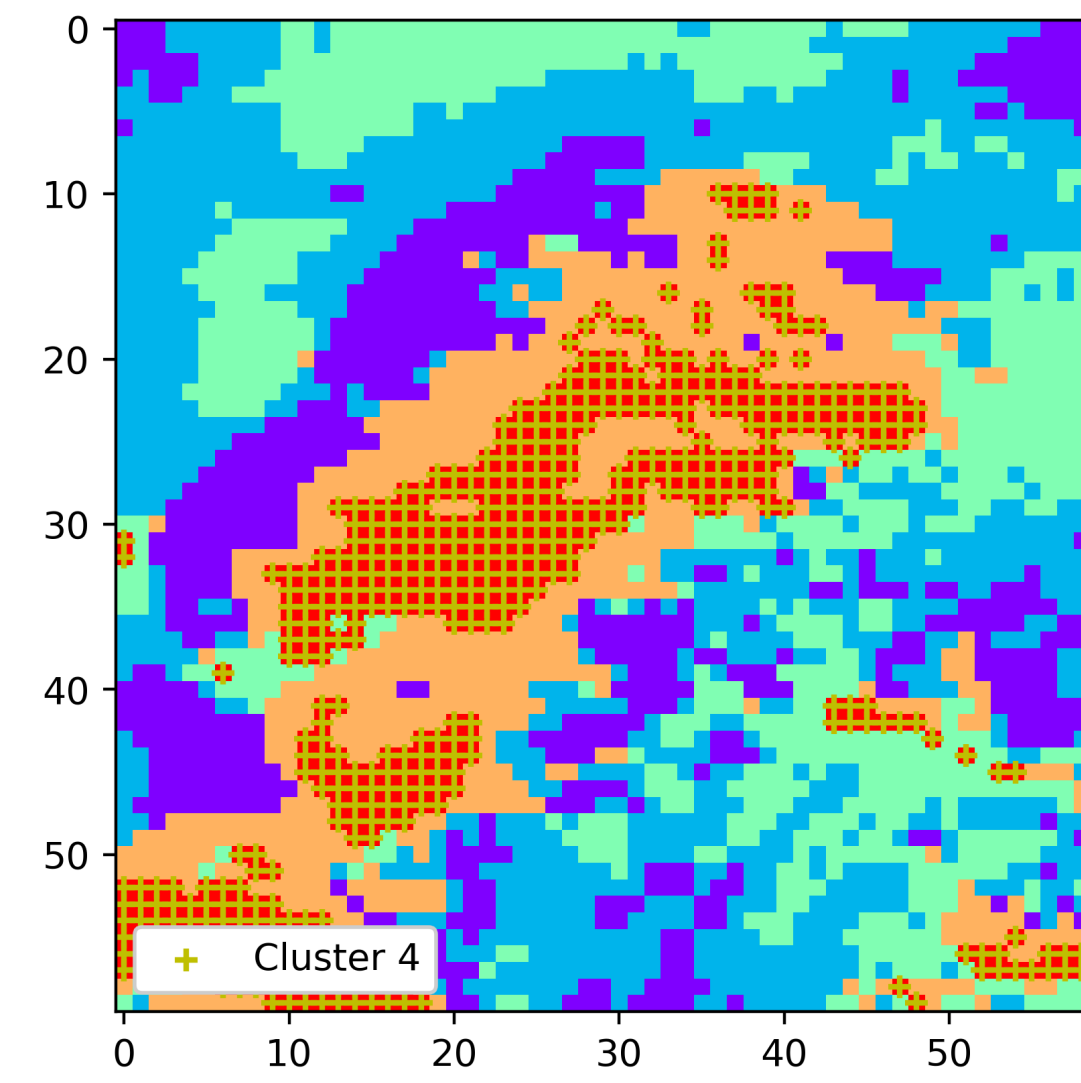
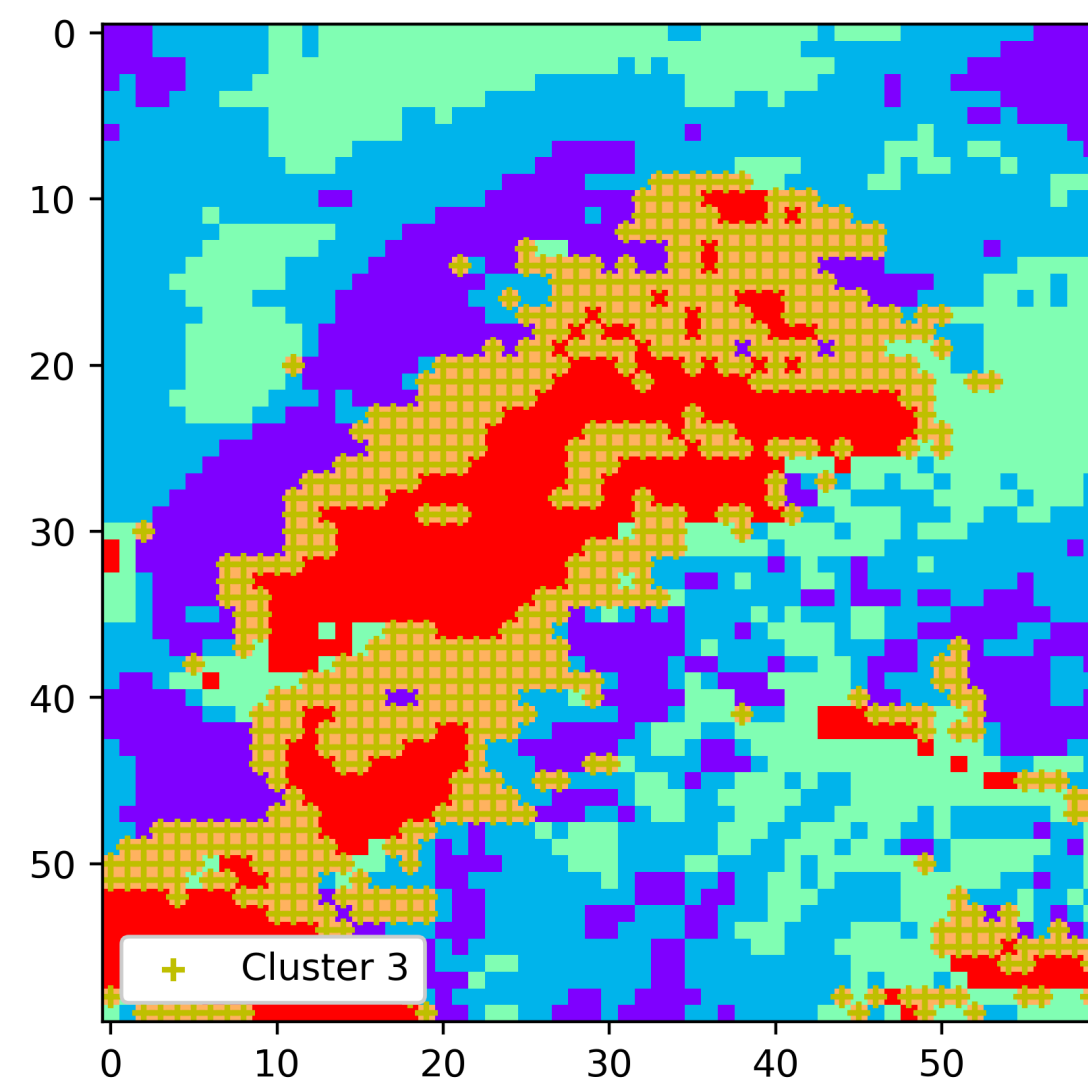
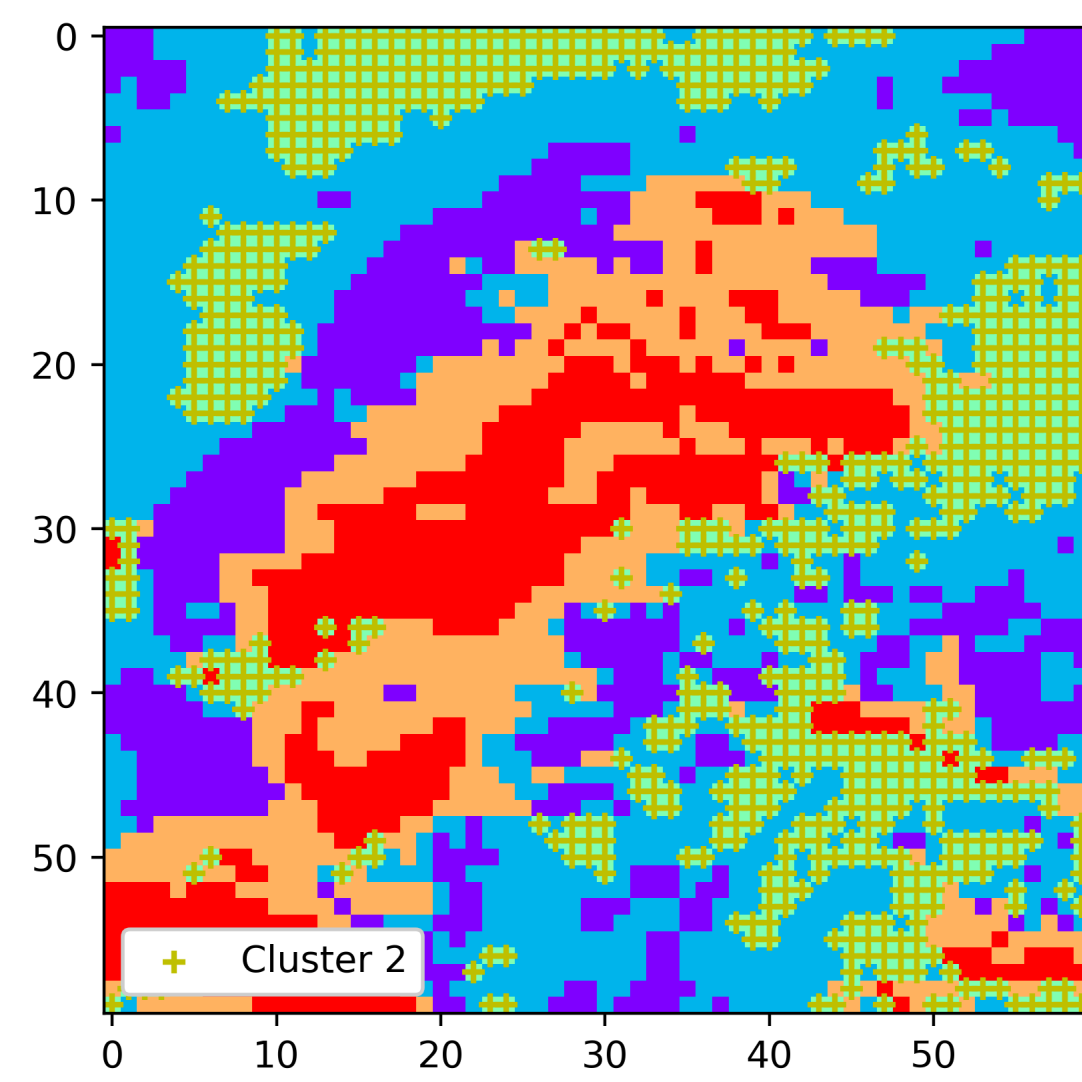
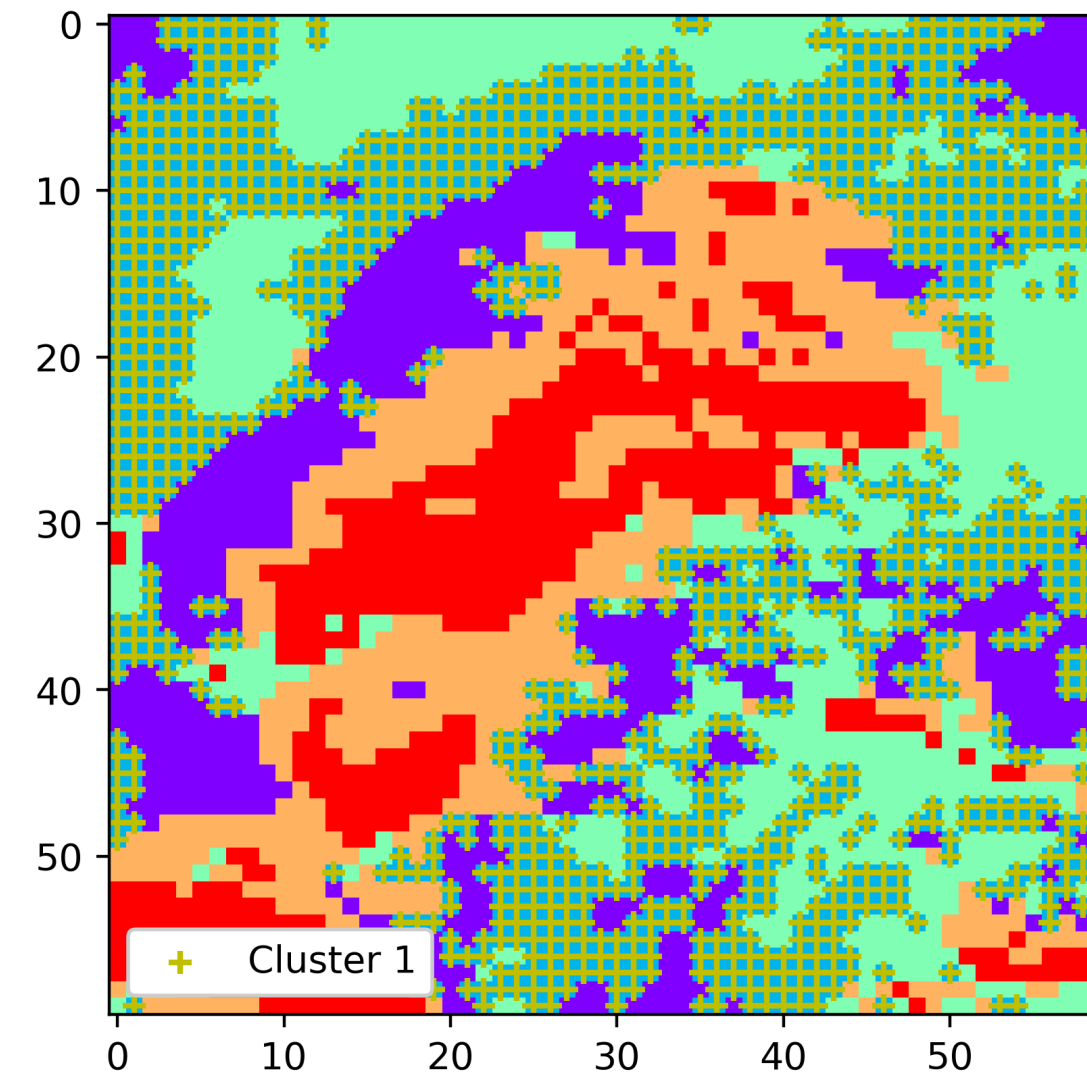
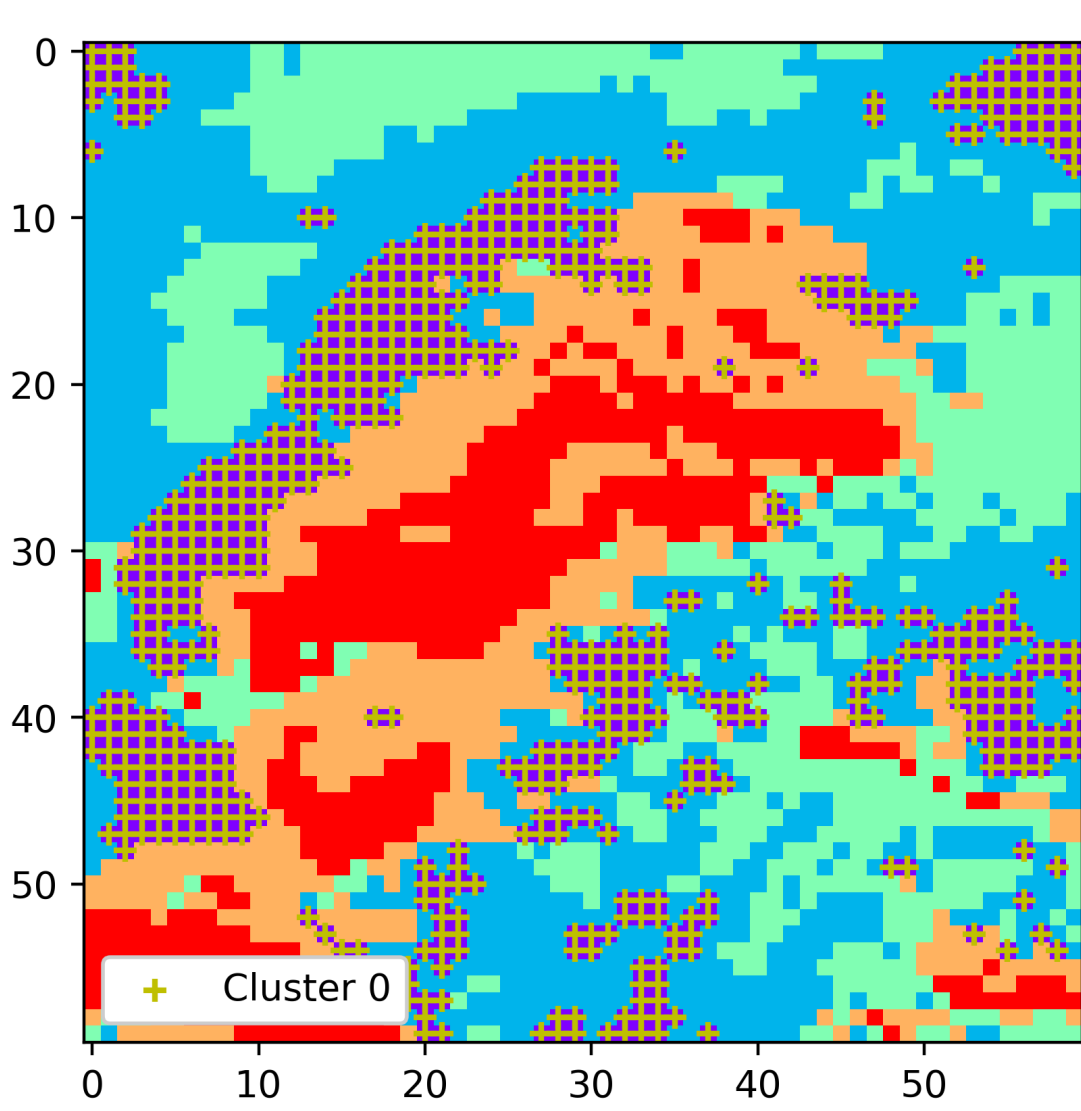
19



↓
10 clusters
k-means

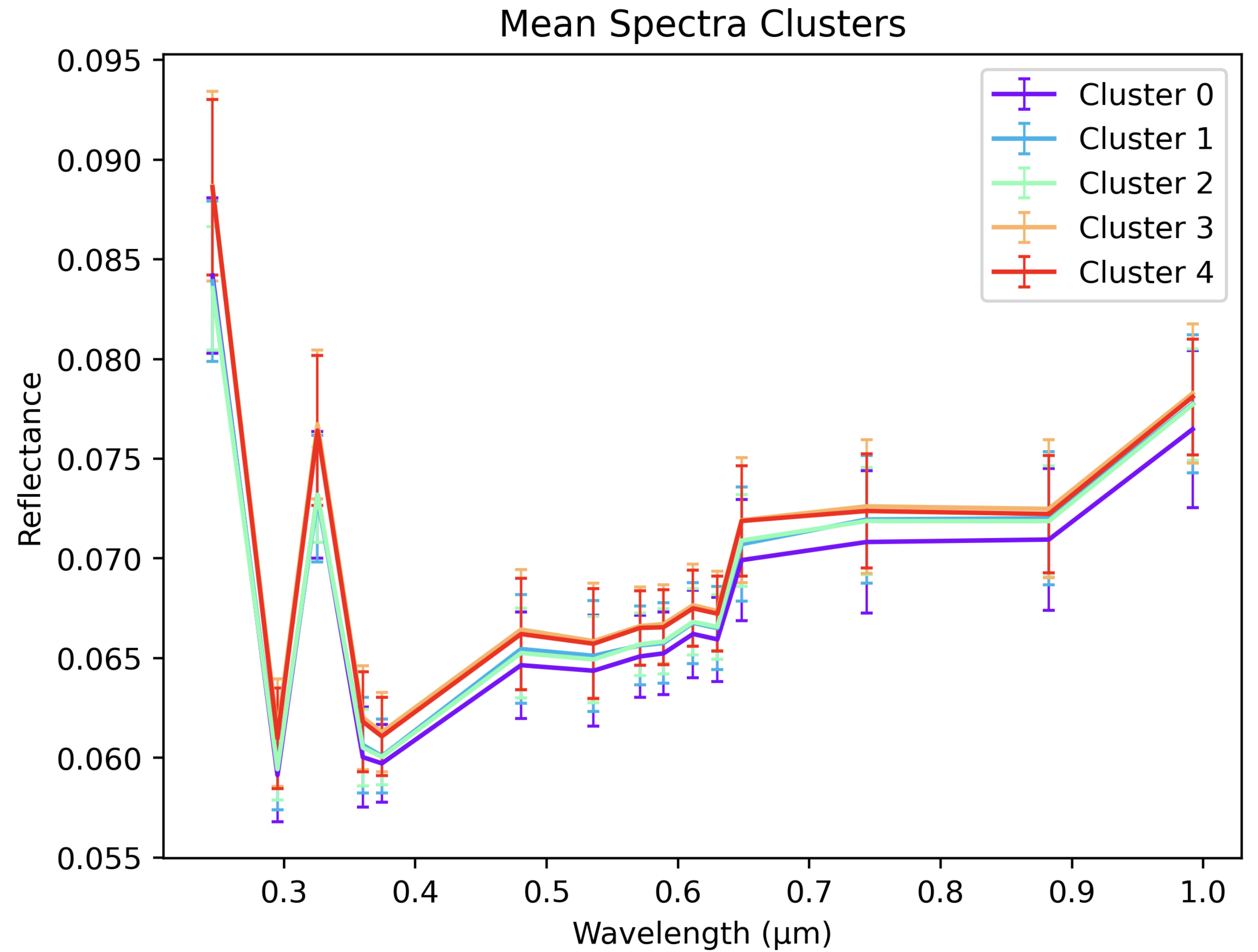
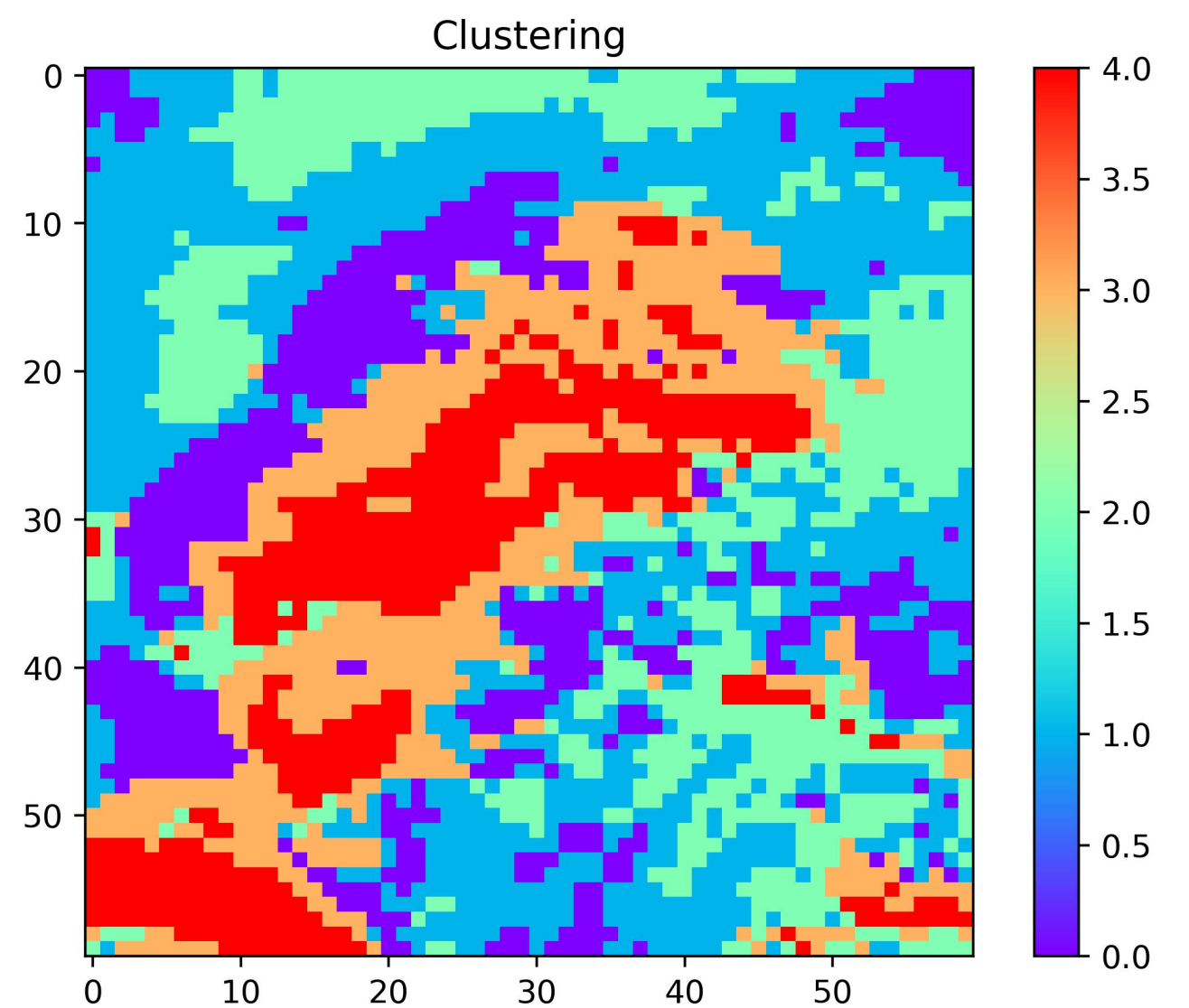
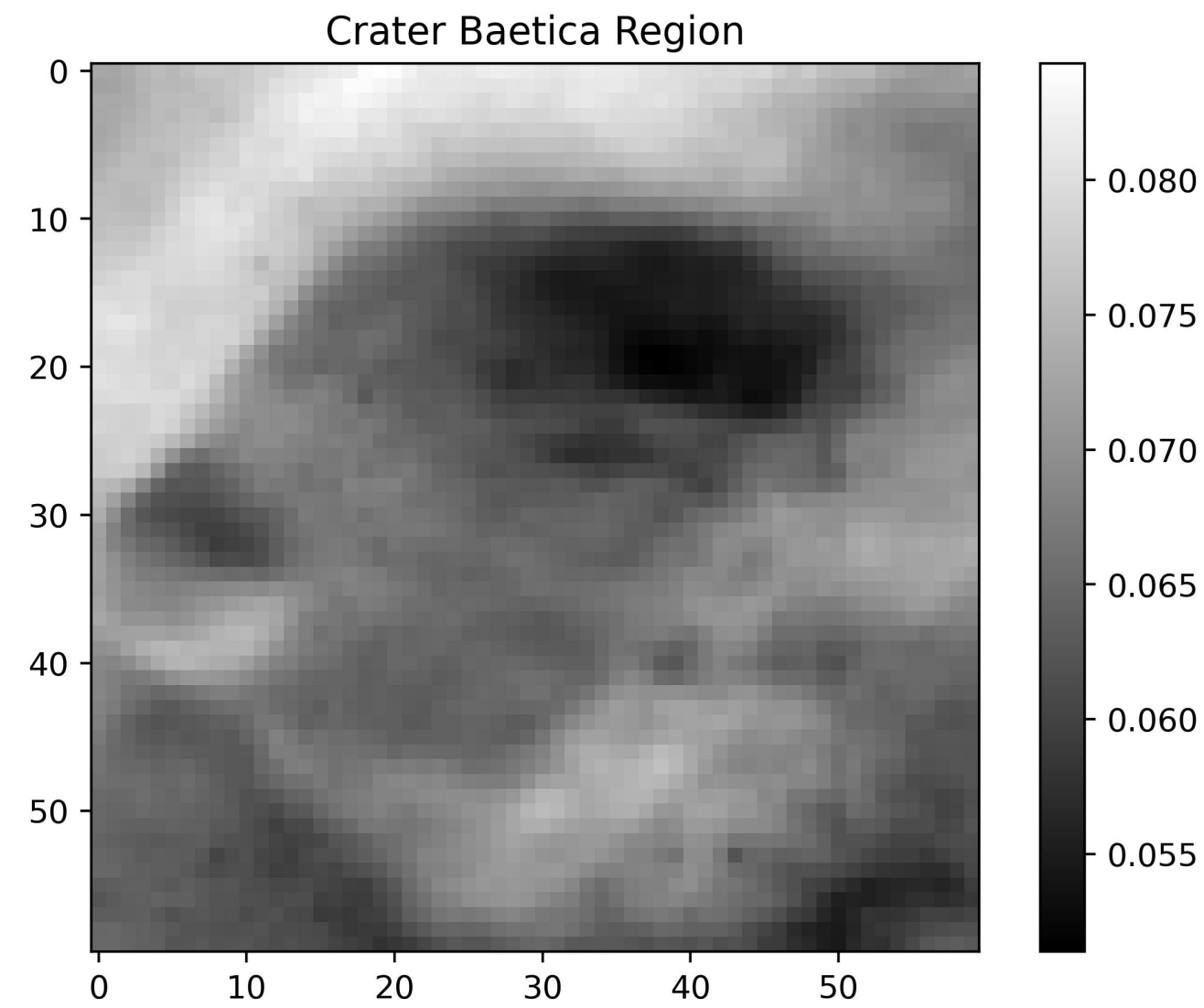


Clustering Analysis





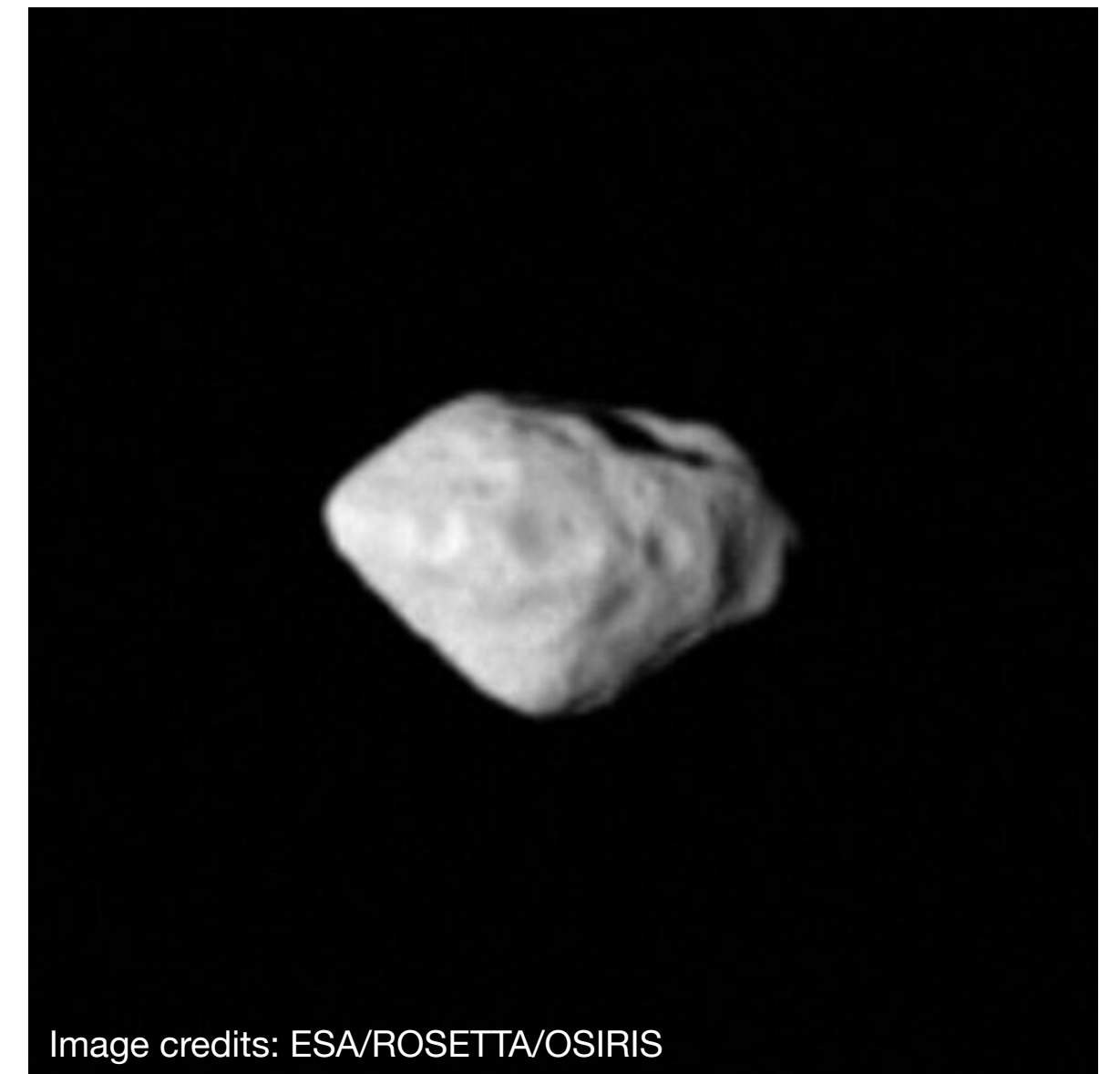
Clustering Analysis



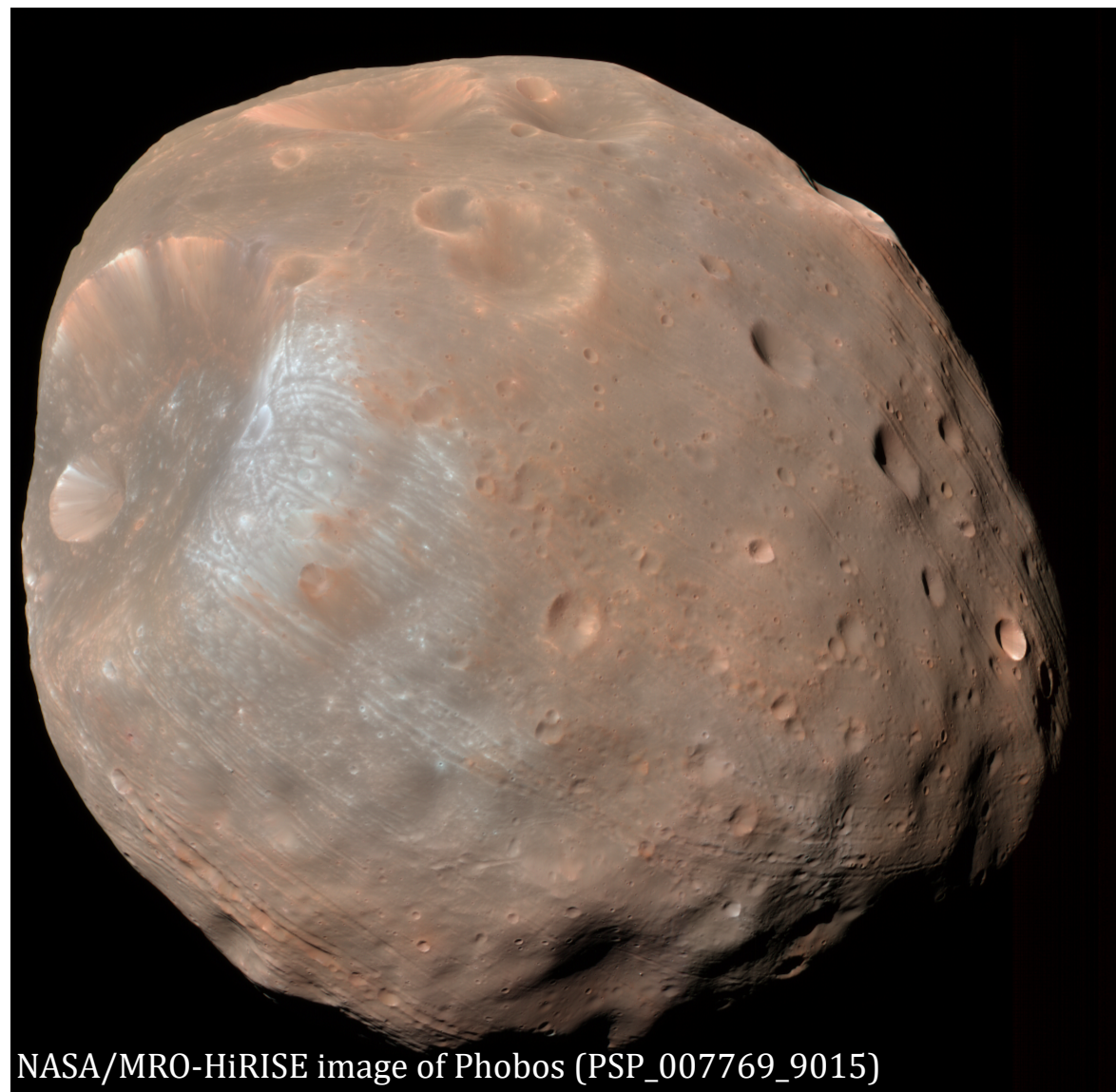
Future Work

- Complete the spectral and clustering analysis of (21) Lutetia → Paper
- Application of acquired knowledge to (2867) Šteins → Paper

2867 Šteins



Phobos



- Thermal correction of MeX/OMEGA Phobos data → Paper
- Application of the clustering analysis to the MeX/OMEGA data of Phobos → Paper



Future Work



- *Search for other metrics to compute the proper number of clusters for the k-means*
- *Implementation of an algorithm to automatize the comparison of extracted spectra with spectral libraries (e.g. RELAB), also using ML procedures*

Thanks for the attention!



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Back-up Slides



In [30]: %matplotlib notebook

```
coordinates, spectra, stdv, color_roi, spectra_norm, num_pix = roi_maker(cube_s_Elastix[:,:,:], \
                                cube_s_Elastix[:,:,:1], \
                                rgb_data=cube_s_Elastix[:,:,:[3,3,3]])
```

```
#cube_uncorr_Elastix_W  
#cube_LS_elastix
```

Figure 1

