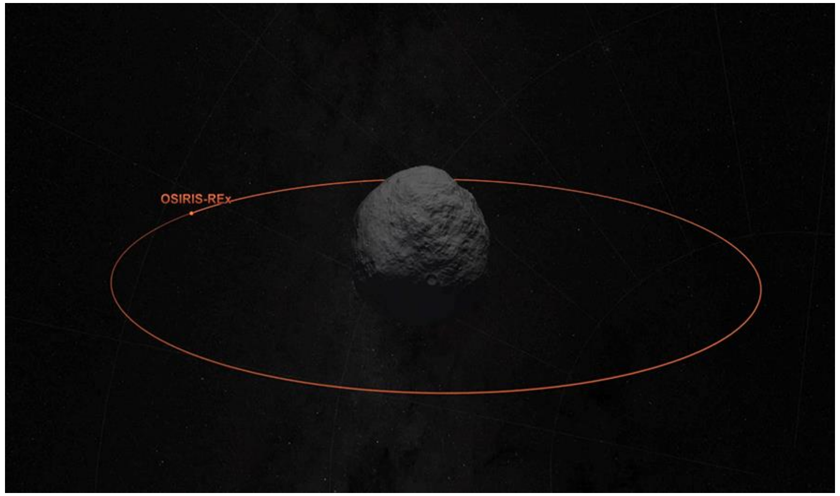
Procedural 3D Asteroid Surface Detail Synthesis

Xi Zhi Li, Rene Weller, Gabriel Zachmann
University of Bremen, Germany
cgvr.informatik.uni-bremen.de

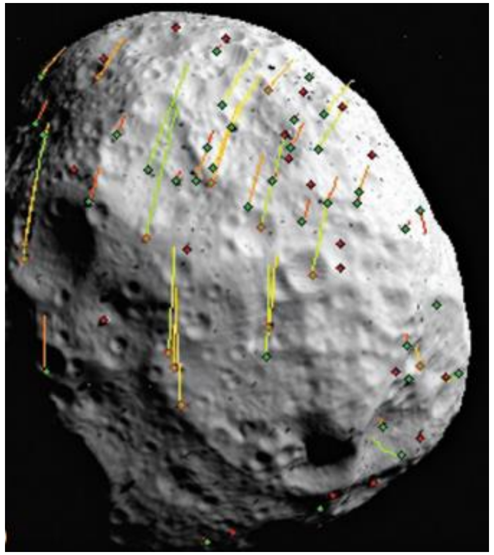
EGEV 2020, May 25-29, Sweden

Motivation

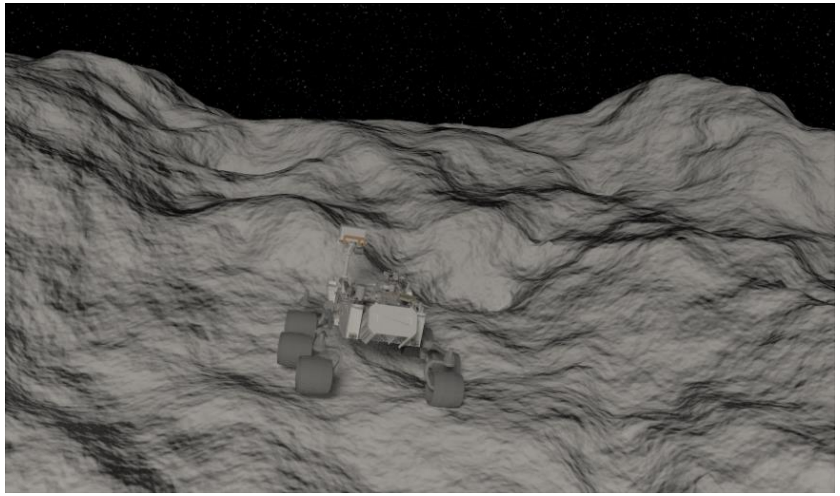
- Space mission simulation
  - Virtual testbed
    - Terrain-based navigation
    - Optic-based tracking & landing
  - Physical mock-ups testing
    - 3D Printing

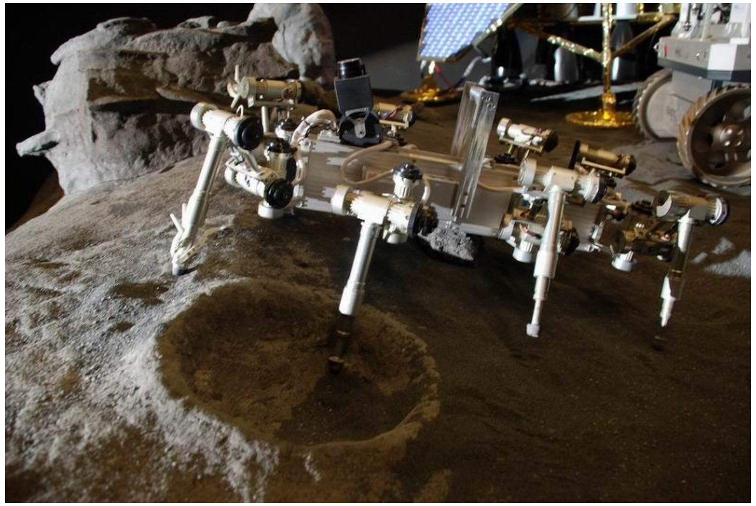


[NASA 2019]



[Martin 2014]





DFKI GmbH

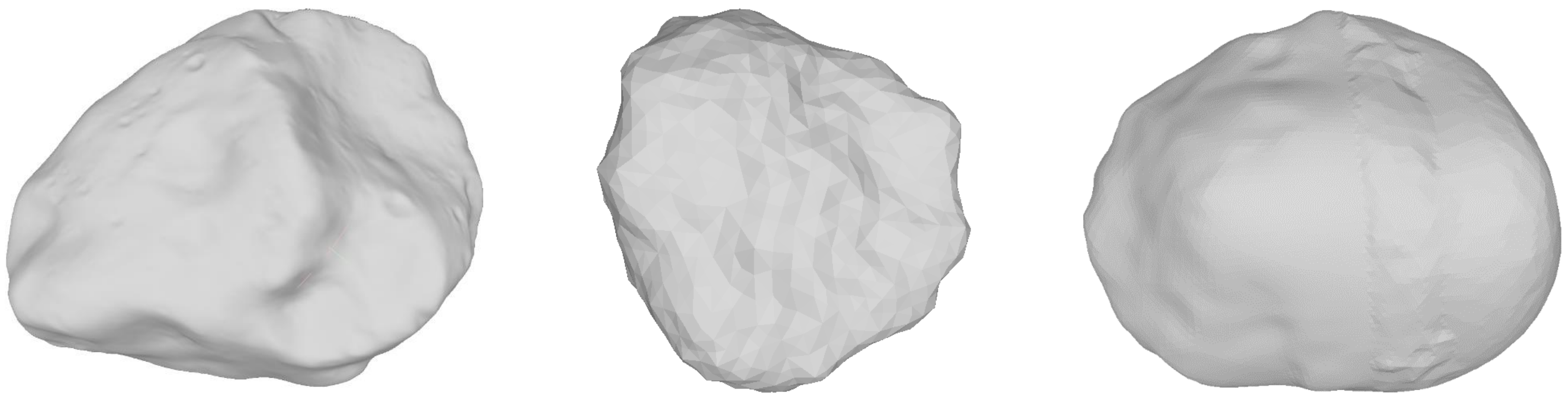
Motivation

- Movies or Video Games
  - Diverse global shapes
  - Diverse surface details

Space Sci-Fi Movies “Iron Sky”

Game “No Man’s Sky”

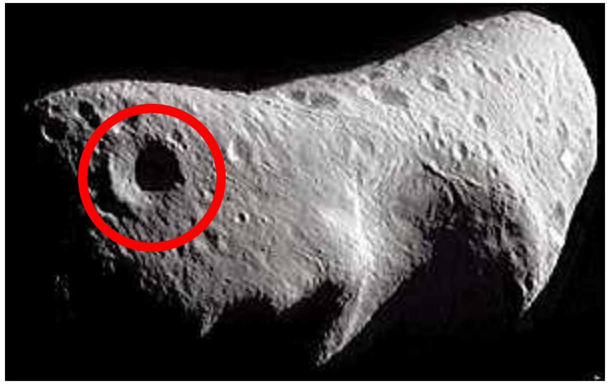
Challenge



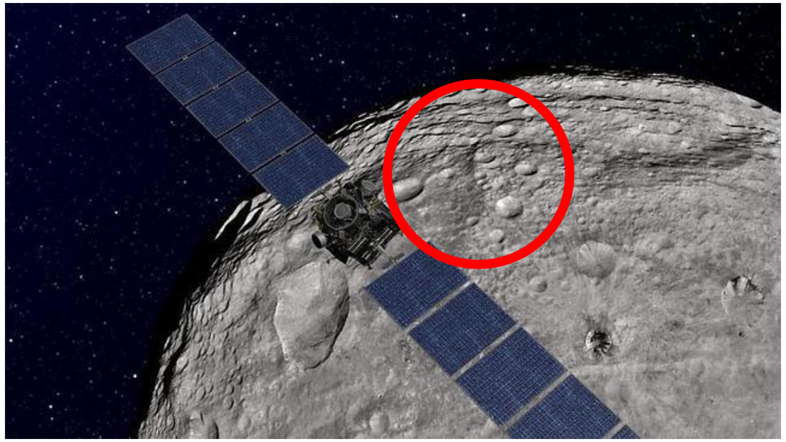
Low-poly models (Data From 3D Asteroid Catalog)

- Realistic (lightcurve inversion, bi-static radar / telescope measurement)

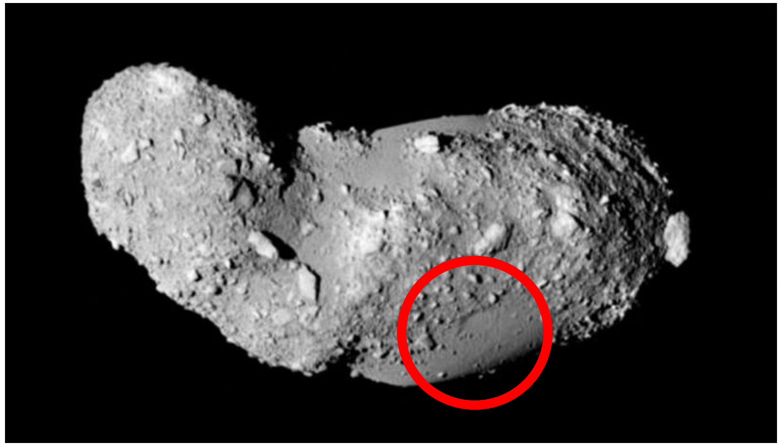
Challenge



Near Shoemaker probe landing on 433 Eros



Dawn Vesta

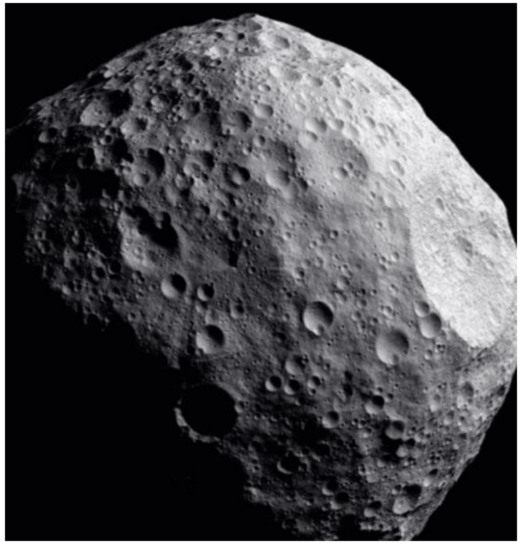


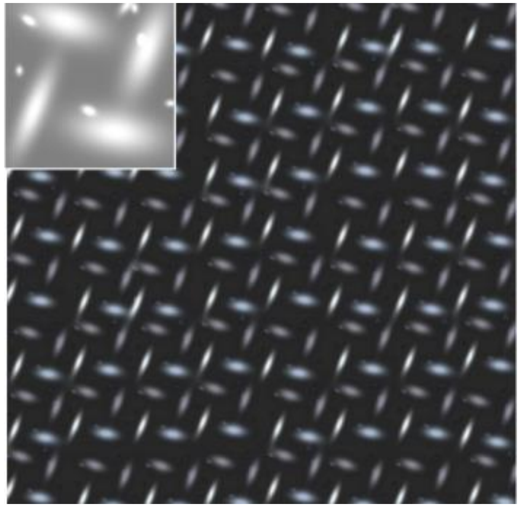
Itokawa

- Realistic (lightcurve inversion, bi-static radar / telescope measurement)
- Diversity
  - Diverse terrain primitives
    - Spatial heterogeneity
- High-resolution model

Previous Work

- Asteroid modeling [Martin 2014]
  - Subdivision surface
  - Integrating real crater height value into subdivision surface
- Texture synthesis by Locally Controlled Spot Noise(LCSN) [Pavie 2016]
  - Kernel shape transfer to texture





Approach

- Evaluate implicit surface $F(p)$ for each grid point p

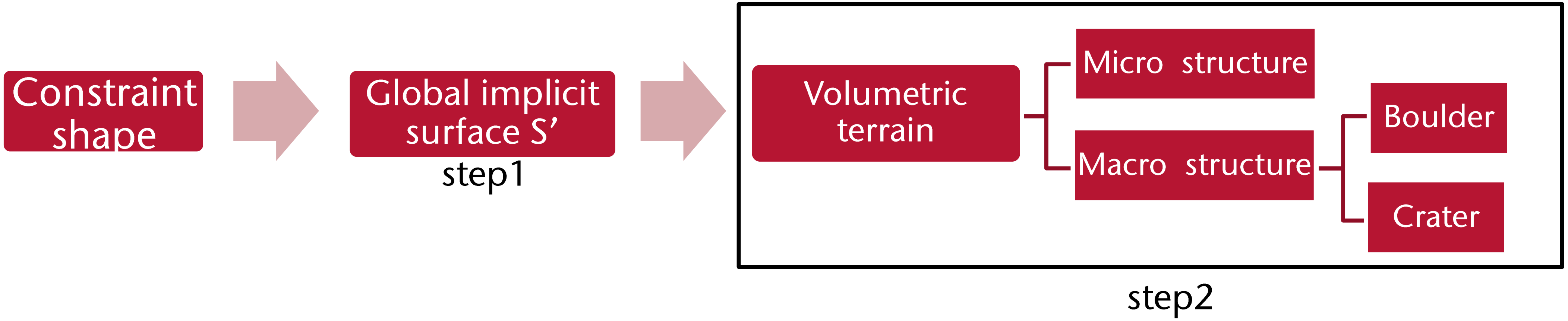
$$S = \{p \in \mathbb{R}^3 \mid F(p) = T\}$$

  - T is the isovalue of the implicit surface

- Pipeline
  - Step1: Metaball representation the global shape of asteroid $M(p)$ [Li 2018]

$$S' = \{p \in \mathbb{R}^3 \mid M(p) = T_0\}$$

  - Step2: Noise model represent the volumetric terrain on the global shape of asteroid $N(p)$

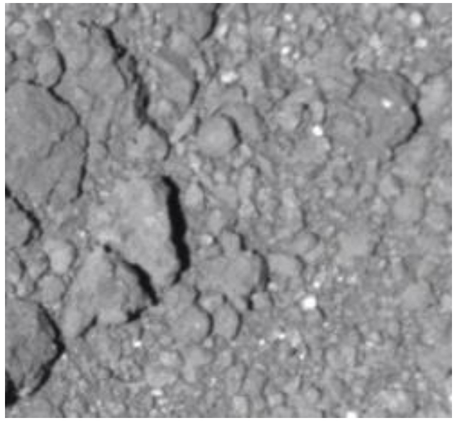


Our contribution

- 3D asteroid model $F(p)$

$$F(p) = Smooth\_global\_shape(p) + surface\_details(p)$$

  - Arbitrary resolution (compute for each point p in 3D space)
  - A new noise model to generate diverse surfaces details on smooth global shape
    - Macro structures
      - Rocks , Craters



JAXA Hayabusa2

NASA

Our contribution

- 3D asteroid model $F(p)$

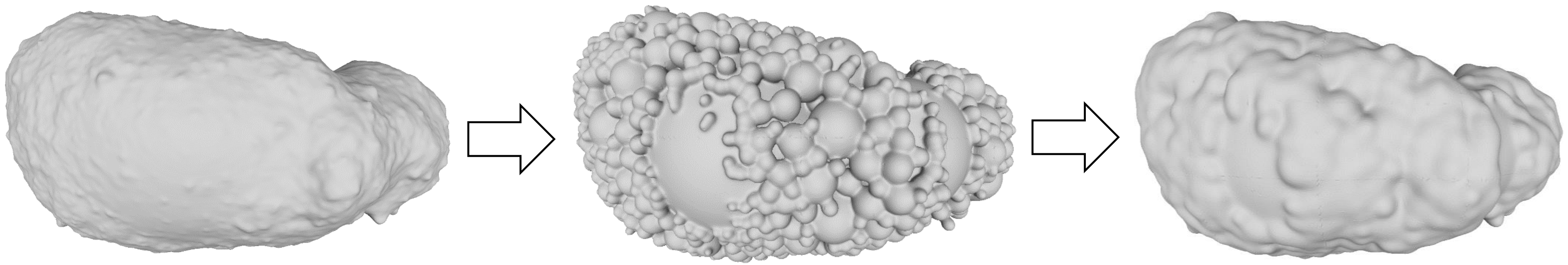
$$F(p) = Smooth\_global\_shape(p) + surface\_details(p)$$

  - Arbitrary resolution (compute for each point p in 3D space)
  - A new noise model to generate diverse surfaces details on smooth global shape
    - Macro structures
      - Rocks , Craters
    - Micro structures
  - Semi-automatic asteroid modeling
    - Intuitive manipulation

NASA

Recap Step 1: Metaball Global Shape Modelling

- Prototype surface (low-poly mesh)
- Metaballs define the isosurface (implicit surface S' with isovalue T_0) to approximate the prototype surface
  - Poly-disverse sphere packing(Sphere Packing [Weller 2010])
    - Micro-Gravity of irregular asteroid [Srinivas 2017]
  - Potential field
  - PSO (Particale Swarm Optimization [Samal 2007])
    - The histogram based comparision algorithm [Li 2017]

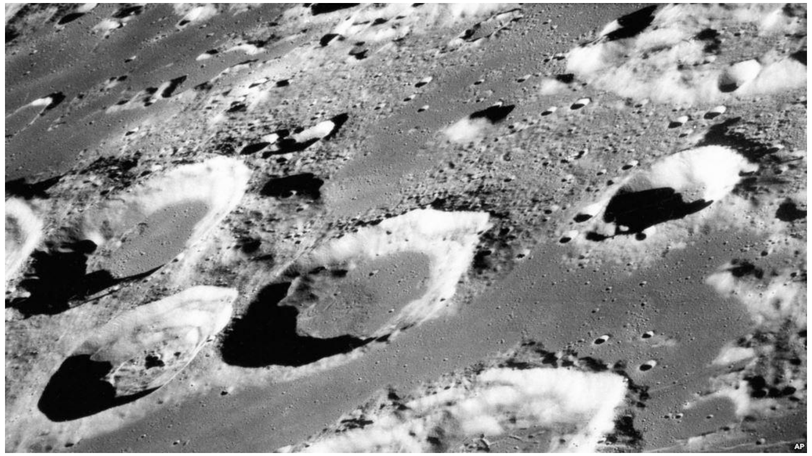


Constraint shape → Metaball shape → optimized smooth global shape

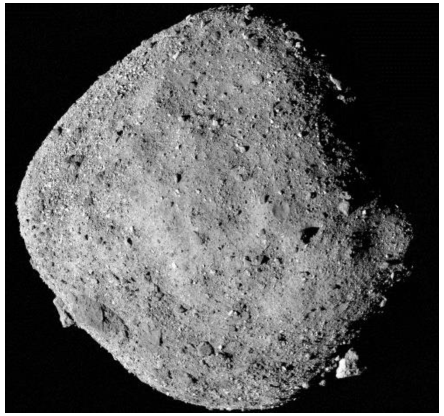
Step2: Noise Model Represent Volumetric Terrain

- Impact cratering: the dominant geological process, most asteroids having heavily cratered surfaces
  - Type1 crater: normal crater
    - impact on the bedrock
    - Bowl-shape interiors
  - Type2 crater: volcanic-shape crater
    - impact on the dust surface
    - Volcanic-shape interiors
- Boulders
  - Local clustering distribution
- Surface details

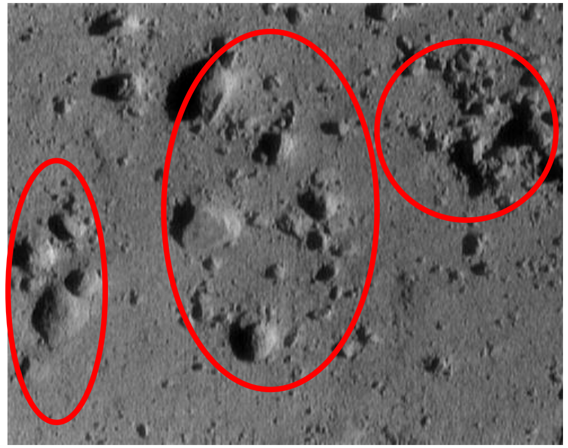
Lutetia: Type1 Crater



Lunar: Type2 Crater



Bennu

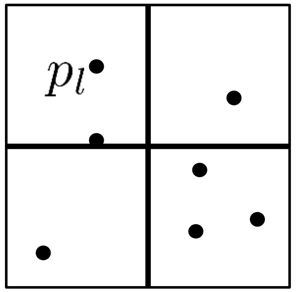


NASA

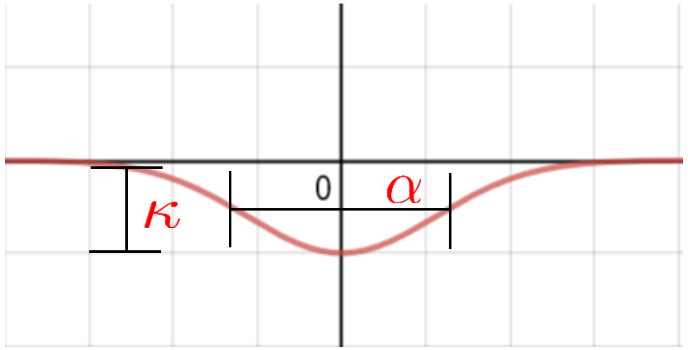
Step2: Macro Structure - LCSN

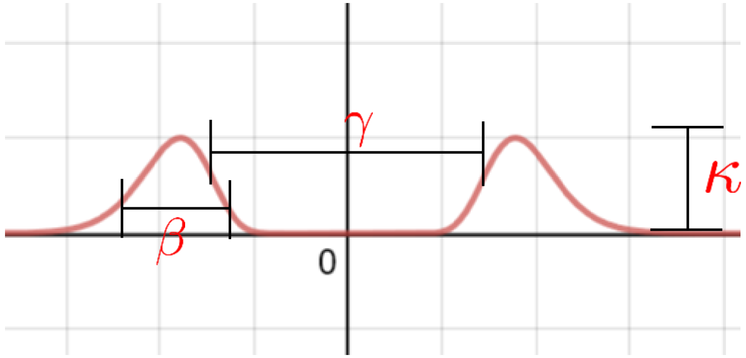
- LCSN

$$spot\_noise(p) = \sum_{l=1}^{L} w_l(k_1(p - p_l) + k_2(p - p_l))$$



  - Kernel shape (in flatland)
    - k1 $k_1(p) = -\kappa e^{-\alpha p^T p}$
    - k2 $k_2(p) = \kappa e^{-\beta(\log(\gamma p^T p))^2}$

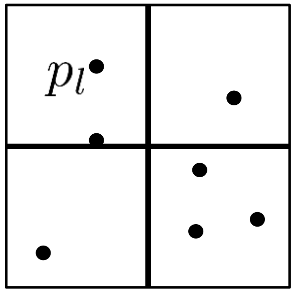




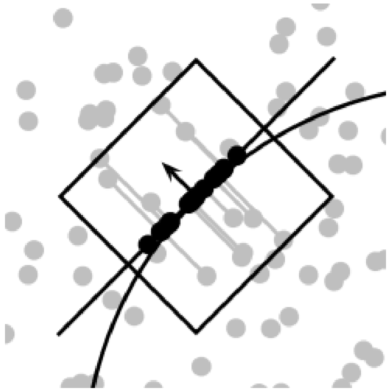
Step2: Macro Structure - LCSN

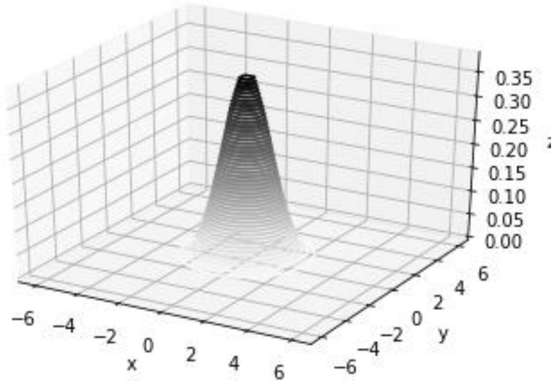
- LCSN

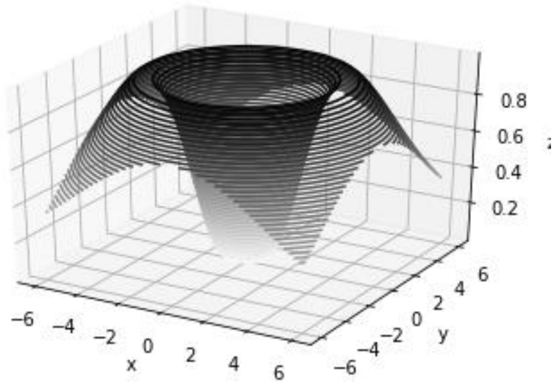
$$spot\_noise(p) = \sum_{l=1}^{L} w_l(k_1(p - p_l) + k_2(p - p_l))$$



  - Kernel shape (in flatland)
    - k1 $k_1(p) = -\kappa e^{-\alpha p^T p}$
    - k2 $k_2(p) = \kappa e^{-\beta(\log(\gamma p^T p))^2}$
  - Kernel shape (in 3D)
  - Projection
  - Result



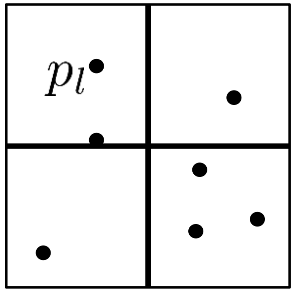




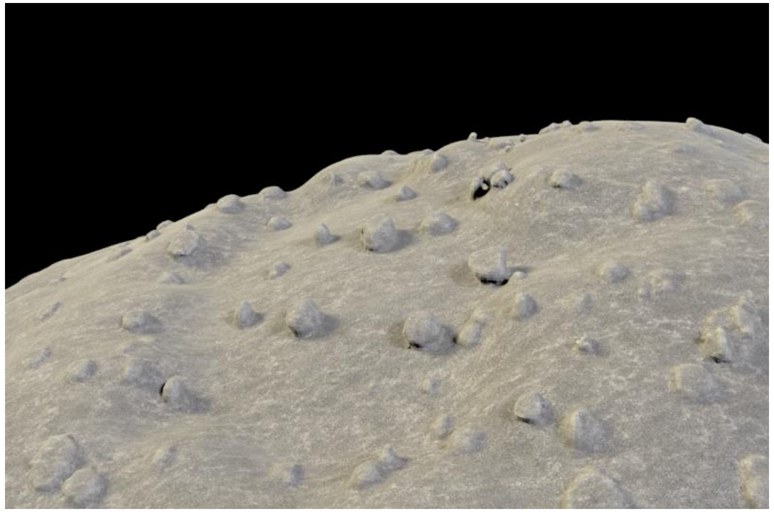
Step2: Macro Structure - LCSN

- LCSN

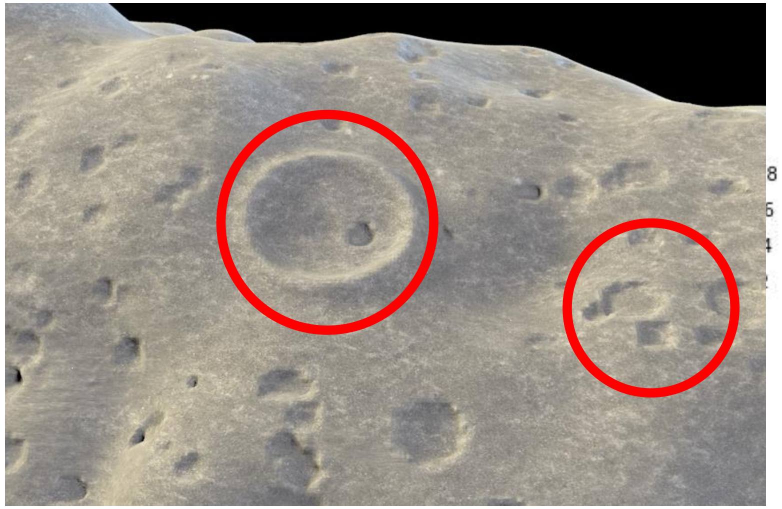
$$spot\_noise(p) = \sum_{l=1}^{L} w_l(k_1(p - p_l) + k_2(p - p_l))$$



  - Kernel shape (in flatland)
    - k1 $k_1(p) = -\kappa e^{-\alpha p^T p}$
    - k2 $k_2(p) = \kappa e^{-\beta(\log(\gamma p^T p))^2}$
  - Kernel shape (in 3D)
  - Projection
  - Result



Boulders



Two types of crater

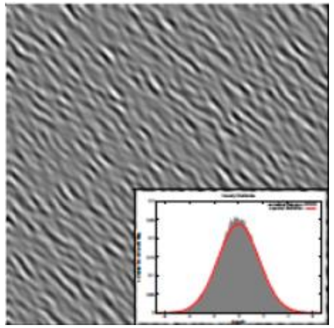
Step2: Micro Structure – Recap GNBE

- Gabor noise & Gabor kernel [Lagae 2009]

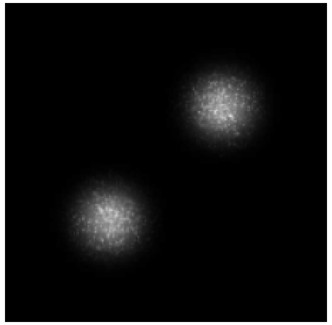
$$Gabor\_noise = \sum_i w_i g(x - x_i, y - y_i)$$

$$g(x, y) = Ke^{-\pi a^2 (x^2 + y^2)} \cos\left[2\pi F_0 (x cos w_0 + y sin w_0)\right]$$

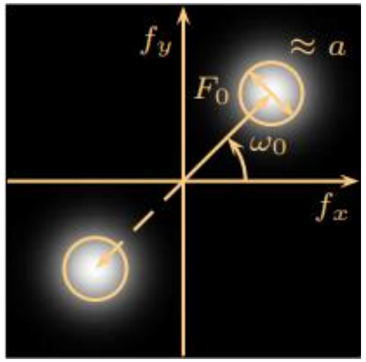
- GNBE
  - Robust Parameter Estimation



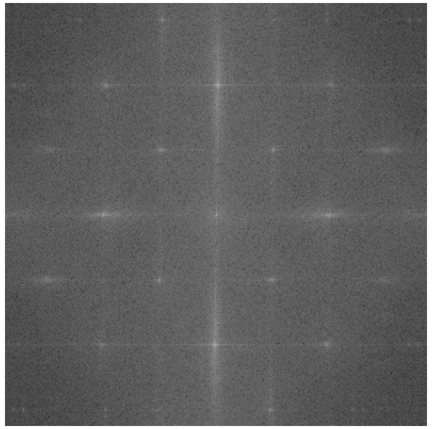
Spatial

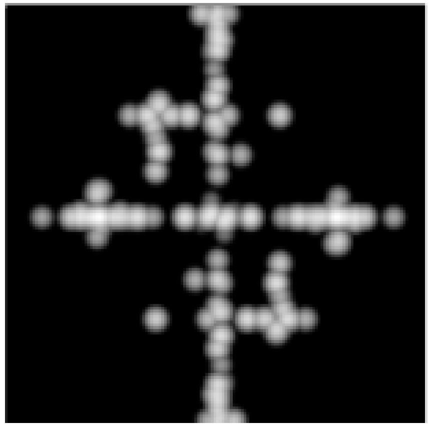


Power spectrum



Gabor kernel Power spectrum





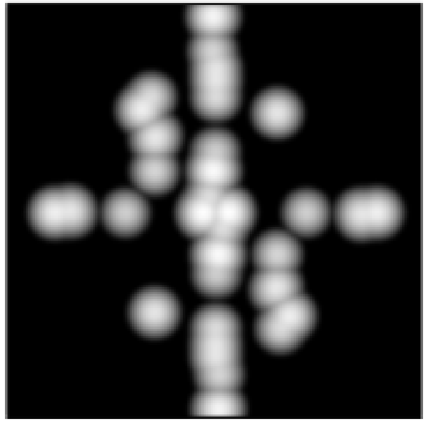
Step2: Micro Structure - GNBE

- Our GNBE

$$\sum_{q=1}^{Q} gabor\_noise_q(p) = \sum_{q=1}^{Q} \sum_{b}^{B} \frac{1}{\sqrt{\lambda_b}} \sum_i \frac{1}{\sqrt{P_{b,i}}} g(p - p_i)$$

  - b sparseness

Power spectrum



b = 5

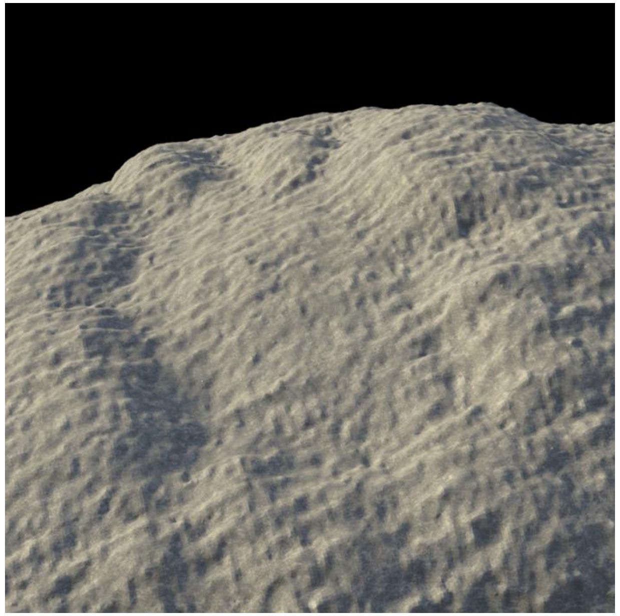
b = 7

Step2: Micro Structure - GNBE

- Our GNBE

$$\sum_{q=1}^{Q} gabor\_noise_q(p) = \sum_{q=1}^{Q} \sum_{b}^{B} \frac{1}{\sqrt{\lambda_b}} \sum_i \frac{1}{\sqrt{P_{b,i}}} g(p - p_i)$$

  - b sparseness
  - Pixel position p ⟶ 3D space point
    - Gray value into height value

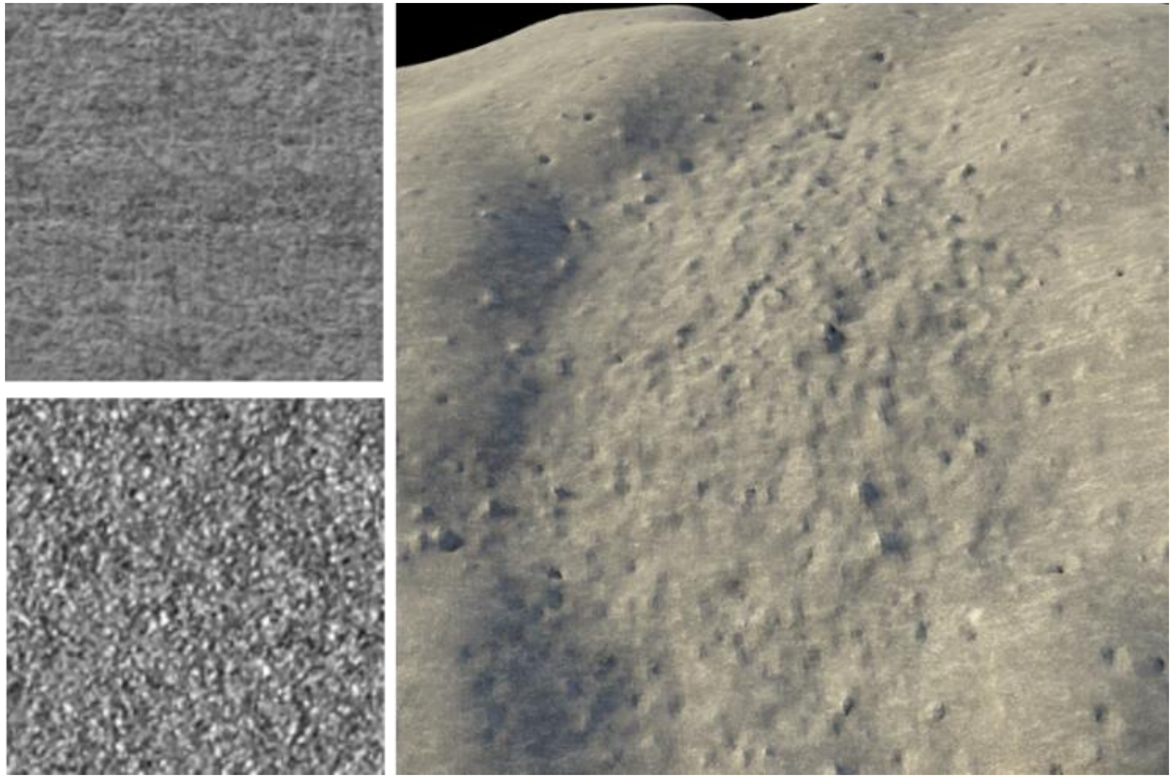


Step2: Micro Structure - GNBE

- Our GNBE

$$\sum_{q=1}^{Q} gabor\_noise_q(p) = \sum_{q=1}^{Q} \sum_{b}^{B} \frac{1}{\sqrt{\lambda_b}} \sum_i \frac{1}{\sqrt{P_{b,i}}} g(p - p_i)$$

  - b sparseness
  - Pixel position p ⟶ 3D space point
    - Gray value into height value
  - Q layers



Step2: Modelling Spatial Heterogeneity

- Noise model $n_i(p)$

$$n_i(p) = \sum_{j=1}^{J} spot\_noise_j(p) + \sum_{k=1}^{K} gabor\_noise_k(p)$$

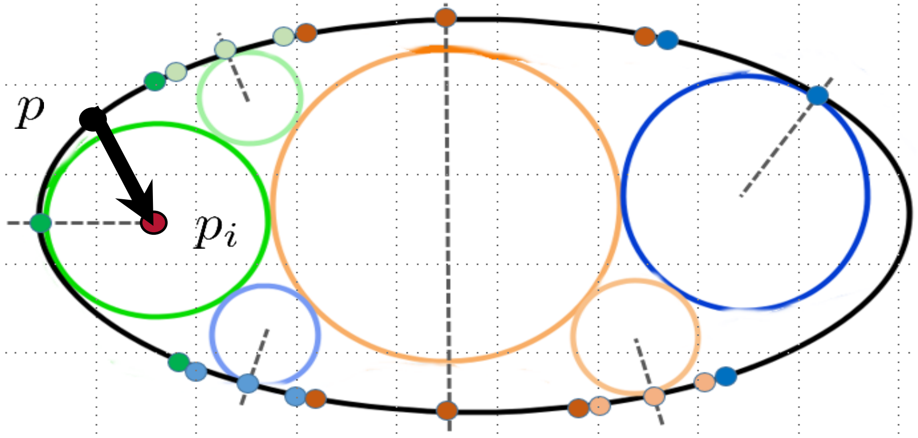
  - Each point p overlapping several layers of terrain primitives

- Spatial heterogeneity
  - Weight the noise model
    - Inverse distance weight

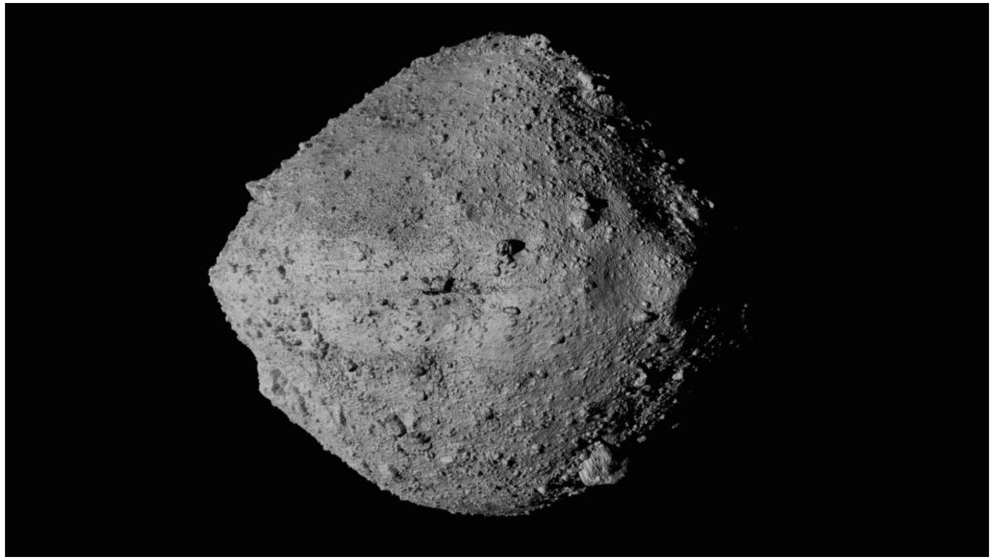
$$dist(p_i - p) = atan(\frac{1}{p_i - p})$$

- Volumetric Terrain $N(p)$

$$N(p) = \sum_{i=1}^{I} dist(p_i - p) n_i(p)$$



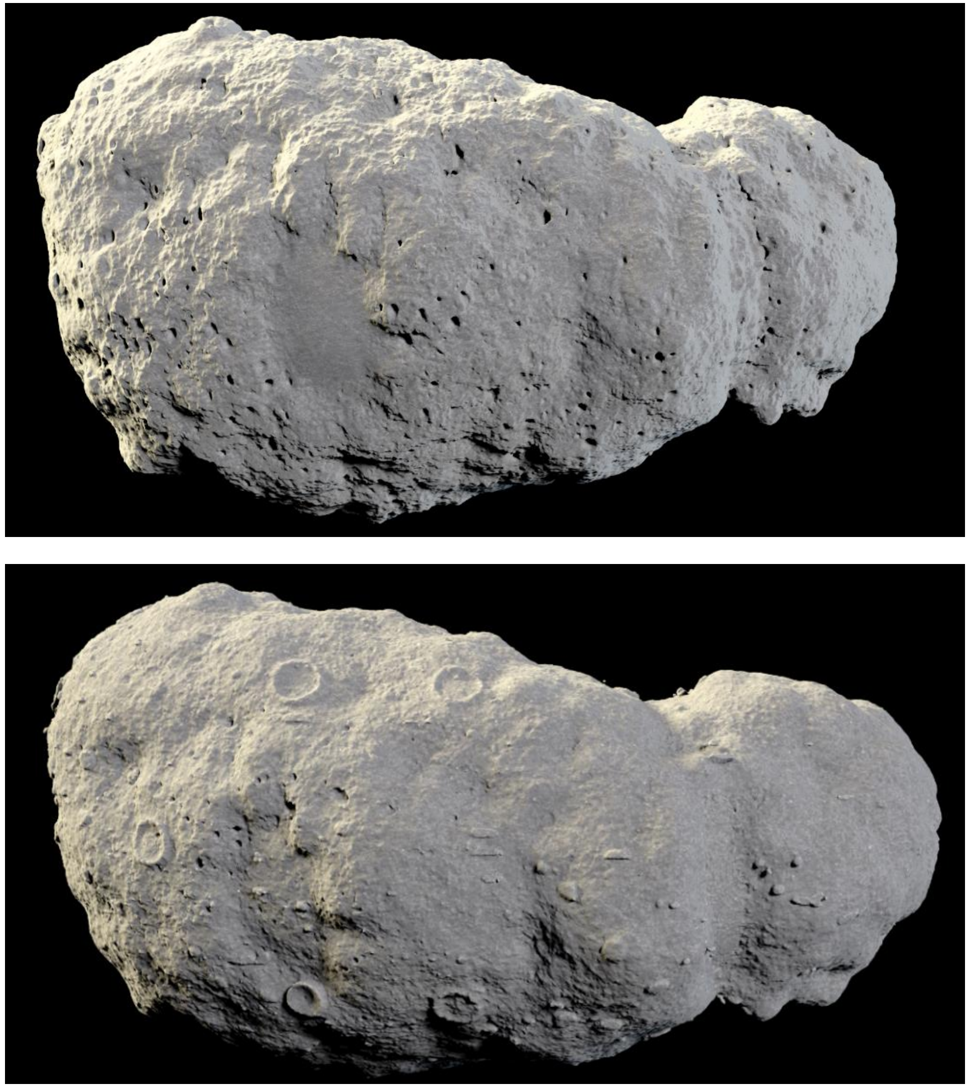
Result



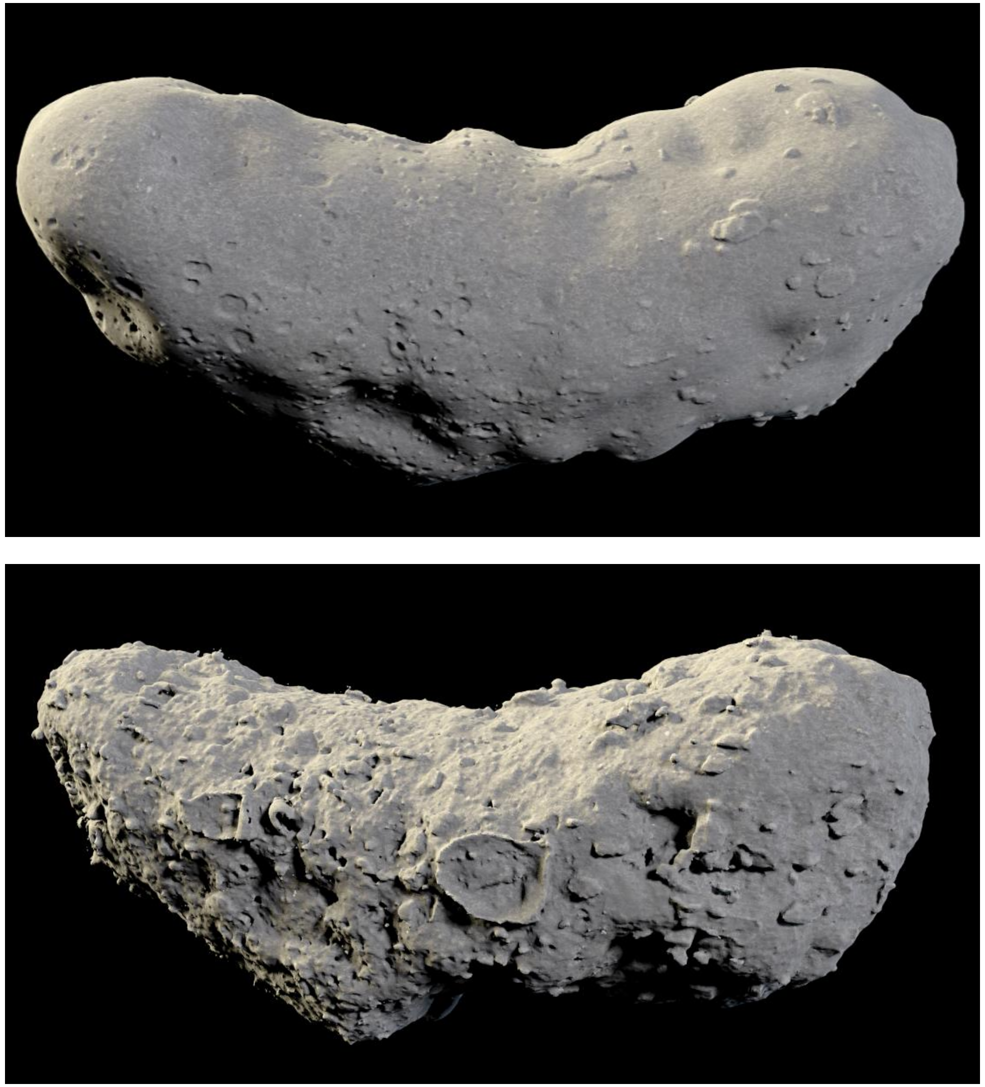
“Bennu” Real 3D Model [NASA 2020]

Synthesized Bennu look-alike

Synthesized Result



Itokawa



Eros

Conclusion & Future work

- Major contributions:
  - Improve the traditional 2D procedural texture into 3D implicit terrain
  - A new noise model to generate Macro & Micro terrain structures
  - Fully implicit representation
    - Each point compute in parallel
- Limitations:
  - Macro structures synthesized by a group of specially designed equations
- Future work
  - More naturalness & More scene
    - Integrated with physically-based noise such as flow noise and curl noise
  - Faster
    - Accelerate the computation of gabor noise [Tavernier 2019]

Thank you