Modeling comet coma photometry in ESA Comet Interceptor

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OUTLINE

What are comets?

- Small Solar System objects composed of ice and dust
  - Coma and tails caused by Sun's radiation
  - Very eccentric, oval like, orbits
  - Formed in the outer Solar System

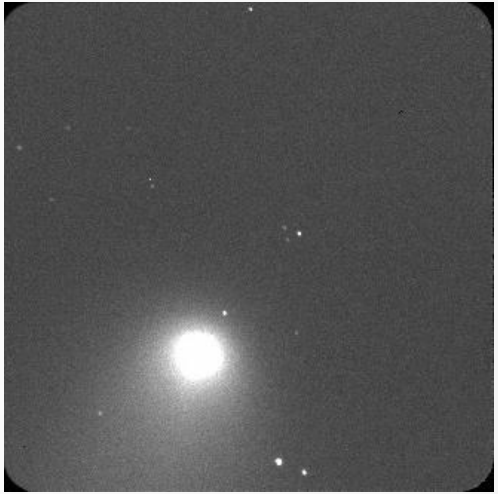

Fig 1: Image of comet C2023/A3 taken with Nordic Optical Telescope

Why study comets?

- Comets are relics from the formation of the Solar System
- Comets are less affected by space weathering than asteroids
- Challenges in studying comets
  - Most of the time very far away
  - Faint and dark objects

Fig 2: Comet C/2020 F3 (NEOWISE)

ESA Comet Interceptor

European space agency (ESA) mission aimed to explore a long-period comet entering the inner Solar System for the first time

- First ESA fast track mission
- Studies the comet's surface, shape, coma composition etc.
- Planned to launch 2029

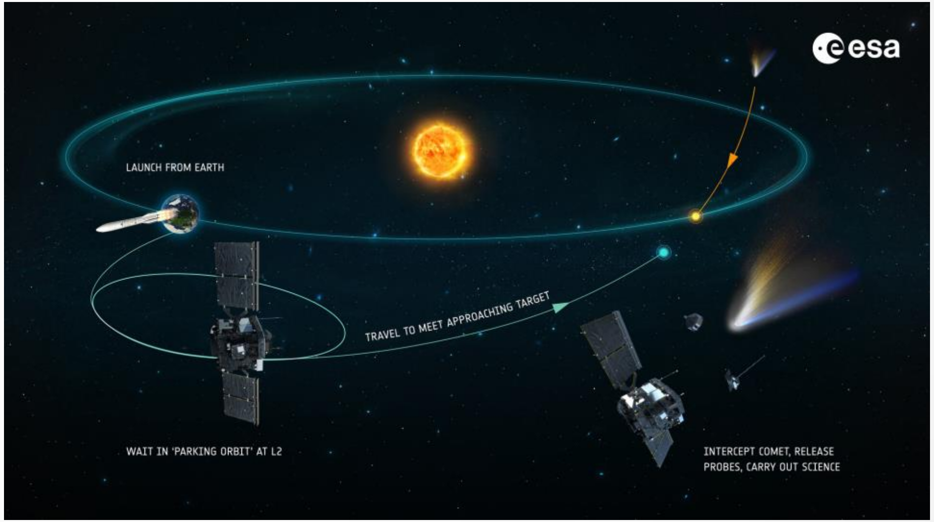

Fig 3: Comet Interceptor path to comet

Asteroid Image Simulator (AIS)

- Simulates imaging instrument operations for Solar System missions
  - Utilizes Blender combined with python-programming
  - Can simulate images from given flight paths of a spacecraft
  - Helps in missions planning

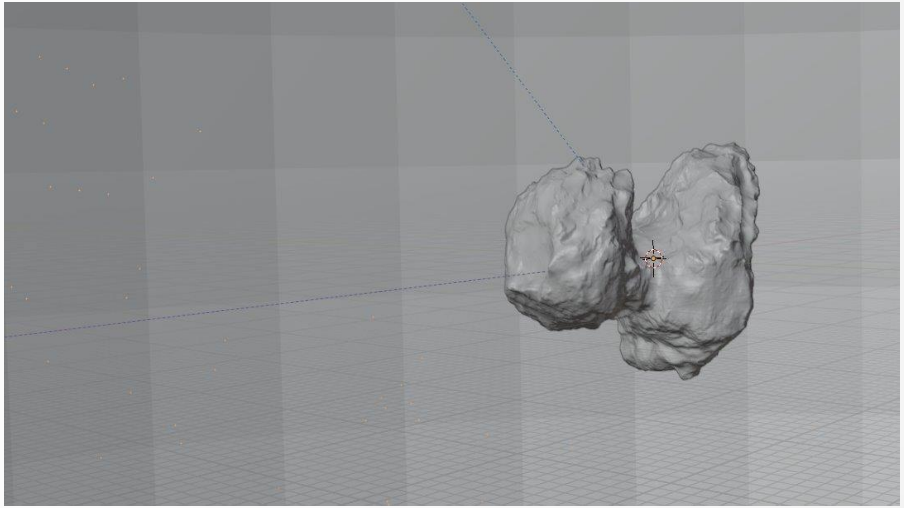

Fig 4: Comet 67/C-G in AIS

Scattering phase functions

- Phase function describes the angular distribution of scattered light
- Rayleigh scattering
  - Scattering by particles much smaller than the wavelength
  - Symmetrical phase function

$$P(\alpha) = \frac{3}{4}\left(1 + \cos^2\alpha\right)$$

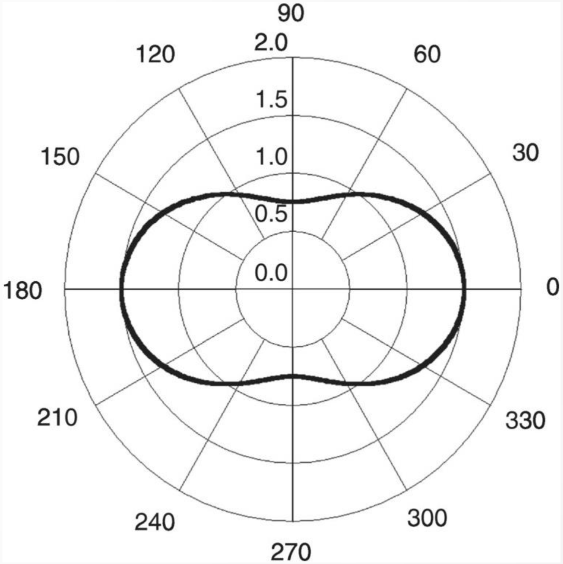

Fig 5: Rayleigh angular distribution

Scattering phase functions

- Henyey-Greenstein phase function
  - Only possibility in the model
  - Approximates light scattering from small particles, such as interstellar dust
  - Asymmetrical phase function

$$P(\theta) = \frac{1 - \xi^2}{\left(1 - 2\xi\cos\theta + \xi^2\right)^{3/2}}$$

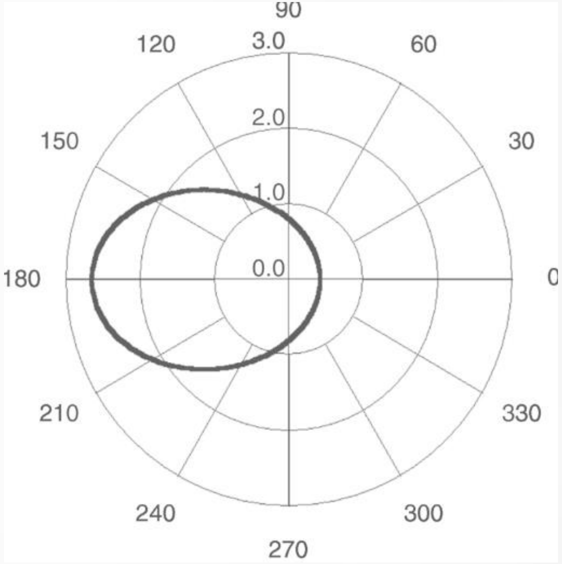

Fig 6: Henyey-Greenstein angular distribution

Comet gas/dust environment

- Crucial information for mission planning
- Engineering gas coma model (EGCM)
  - An analytical model of gas environment of comets
  - Tested if could be applied to dust -> can be
- Engineering dust coma model (EDCM)
  - A numeral spatial distribution model of a dusty-gas coma

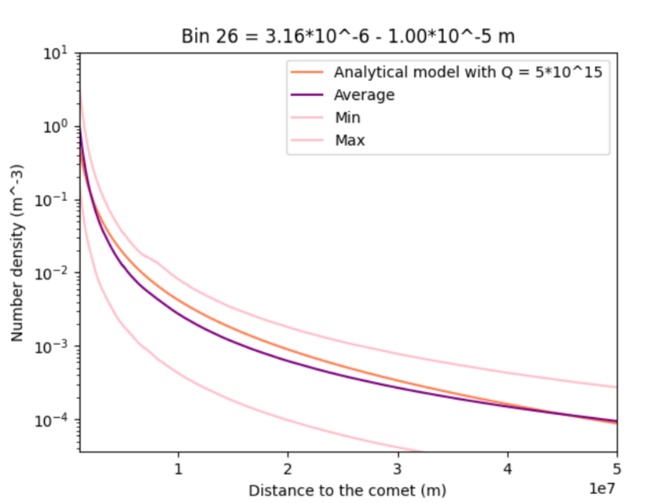

Fig 7: EDCM data compared with EGCM analytical expression

Modeling with Blender

- How is the simulation done?
  - Used shader volumetrics to simulate material inside a spherical volume
  - Blender has a 'volume scatter' node, but it can only model Henyey-Greenstein phase functions

    -> Mix 2 'volume scatter' nodes to get approximation of Rayleigh phase function

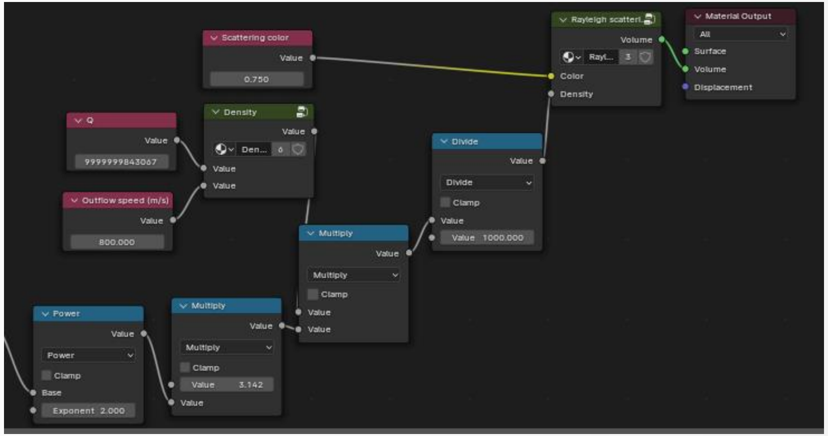

Fig 8: Example of a Blender shader node tree

Coma renders

Fig 9: With coma

Fig 10: Without coma

Photometry analysis

- Importing renders into a separate python program
    - Extract pixel color values from images
    - Calculate different metrics of brightness
    - Plot and export values into an output file

Fig 11: Animation of 67-CG simulated with AIS

Results

- Work in progress
- Coma brightness in different scenarios
- Pixel values as of now
  - Average brightness comparable to physical values

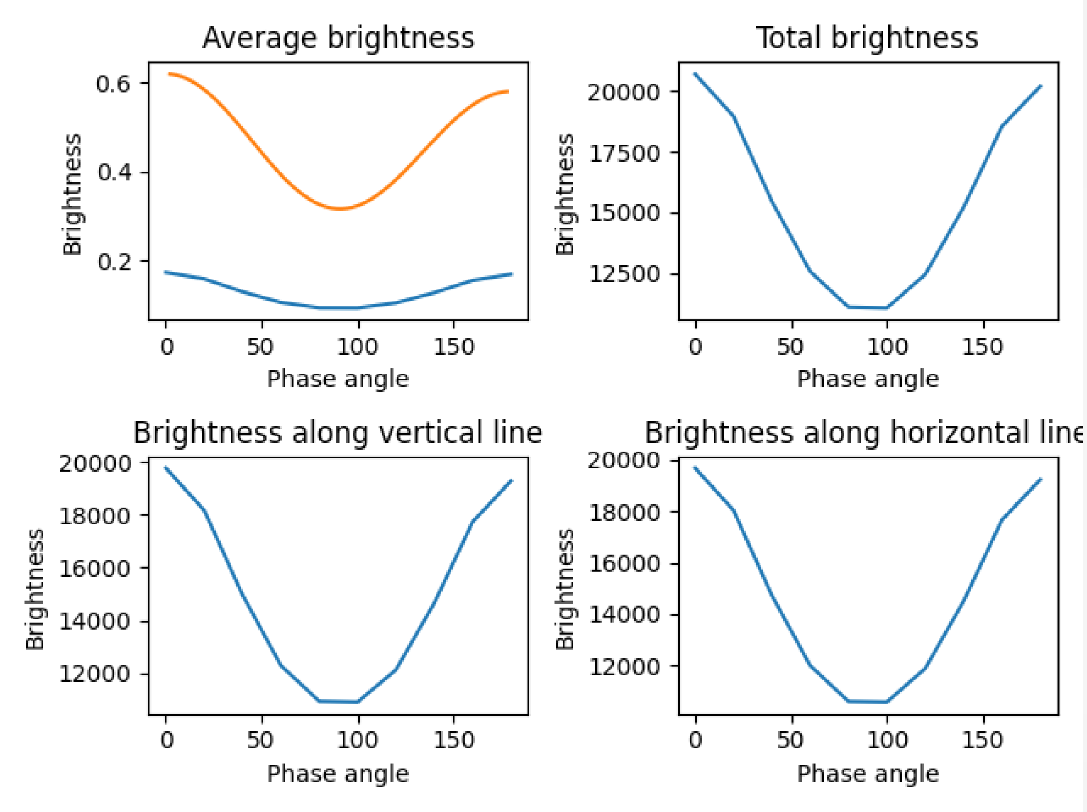

Fig 11: Preliminary results for brightness from model, blue line = model results

The Radiative Transfer Coherent Backscattering (RT-CB)

- Electromagnetic scattering program for discrete sparse random media
- Numerically solves scattering properties of a given system as a function of angle
  - Much faster than exact computing methods

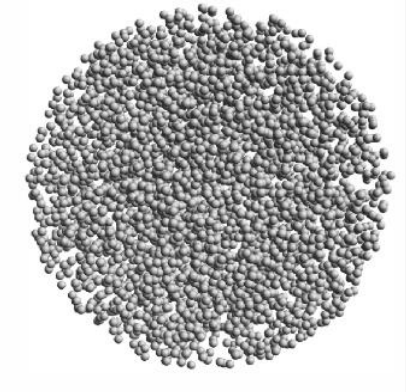

Fig 12: RT-CB random media sphere

Model validation

- RT-CB parameters:
  - Spherical volume with Rayleigh scatterers inside
  - Other parameters from coma model in Blender
- The model gives results that acceptably close to that of RT-CB
  - Difference likely caused by different phase functions

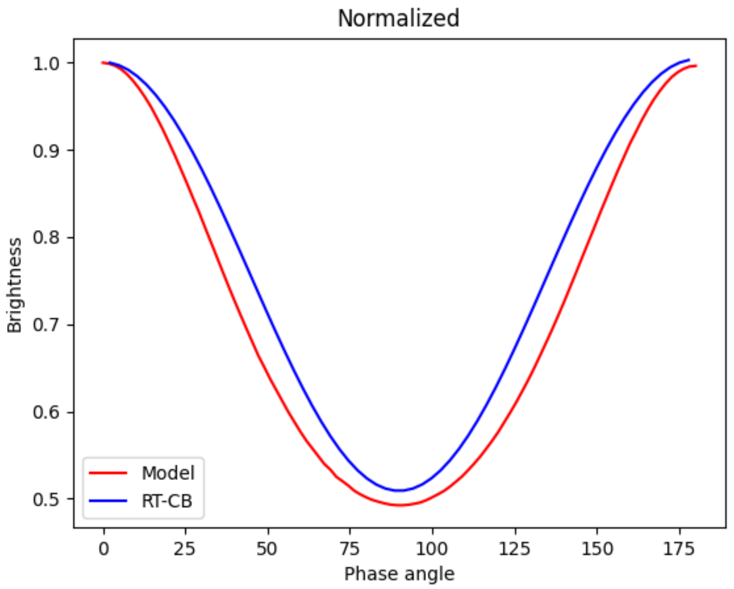

Fig 13: Normalized model photometry compared to RT-CB solution

What next?

- Without normalization a difference of π between model and RT-CB, why?
- Modeling asymmetrical phase functions
- Can the model be improved to give better results?

Conclusions

- Comets give us an insight into how the Solar System was formed
- Comet Interceptor aims to study a previously unknown comet
- AIS can be used to model what an imaging instrument onboard a spacecraft would see when flying by a comet
- The model agrees with RT-CB results with an acceptable accuracy

Questions?

Thank you for listening

References

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Image references

- Comet Interceptor logo: https://www.cosmos.esa.int/web/comet-interceptor
- Fig 3: https://www.esa.int/Science_Exploration/Space_Science/Comet_Interceptor
- Fig 2: https://apod.nasa.gov/apod/ap200722.html
- Fig 12: Vaisanen, Timo, et al. “Validation of Radiative Transfer and Coherent Backscattering for Discrete Random Media.” *2016 URSI International Symposium on Electromagnetic Theory (EMTS)*, IEEE, 2016, pp. 396–99
- Fig 5&6: Shepard, Michael K. *Introduction to Planetary Photometry / Michael K.* Cambridge University Press, 2017.