Simulation of the detectability of different surface properties with bistatic radar observations

J. Krumme (1), **T. P. Andert** (2), R. Weller (1), G. González Peytaví (2), G. Zachmann (1), D. Scholl (2), A. Schulz (2)

(1) Institute for Computer Graphics and Virtual Reality, University of Bremen, Bremen, Germany
(2) Institute of Space Technology and Space Applications, Universität der Bundeswehr München, Neubiberg, Germany

73rd International Astronautical Congress (IAC) Paris, France, 18-22 September 2022

Gefördert durch:
Bundesministerium für Wirtschaft und Klimaschutz
aufgrund eines Beschlusses des Deutschen Bundestages

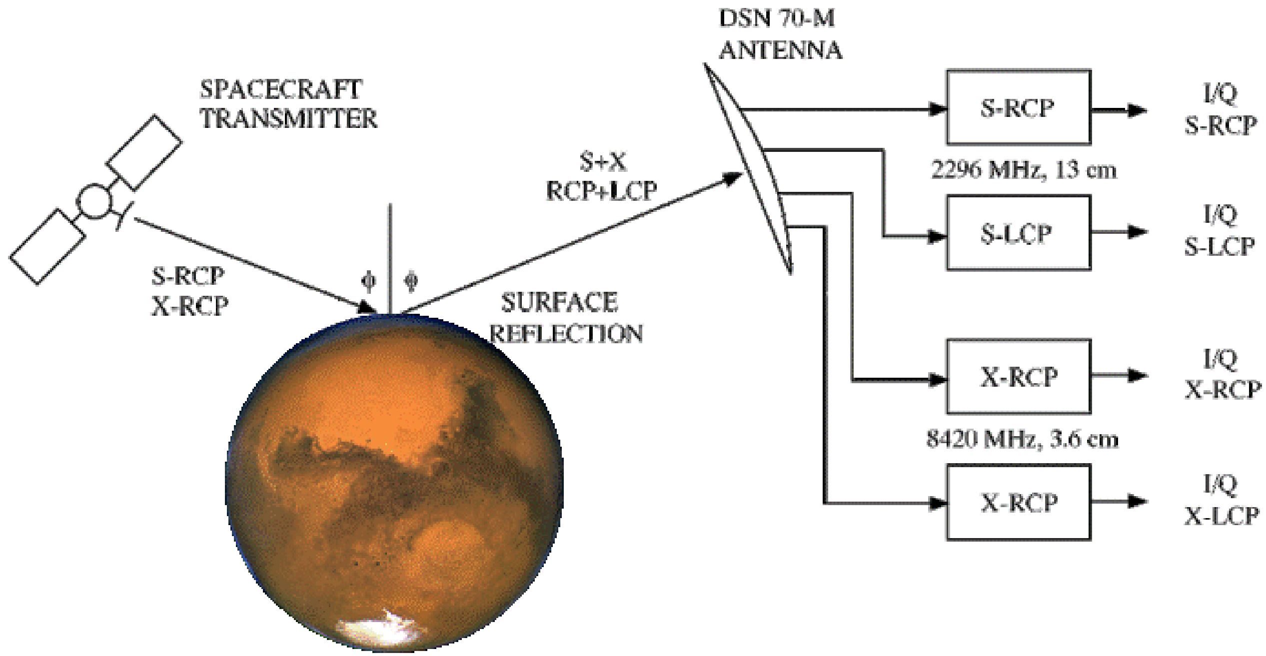
Content

- Bistatic Radar
- Shooting and Bouncing Rays (SBR) method
- Results
- Summary

Gefördert durch:
Bundesministerium für Wirtschaft und Klimaschutz
aufgrund eines Beschlusses des Deutschen Bundestages

Bistatic Radar

Bistatic Radar



Simpson, 1993

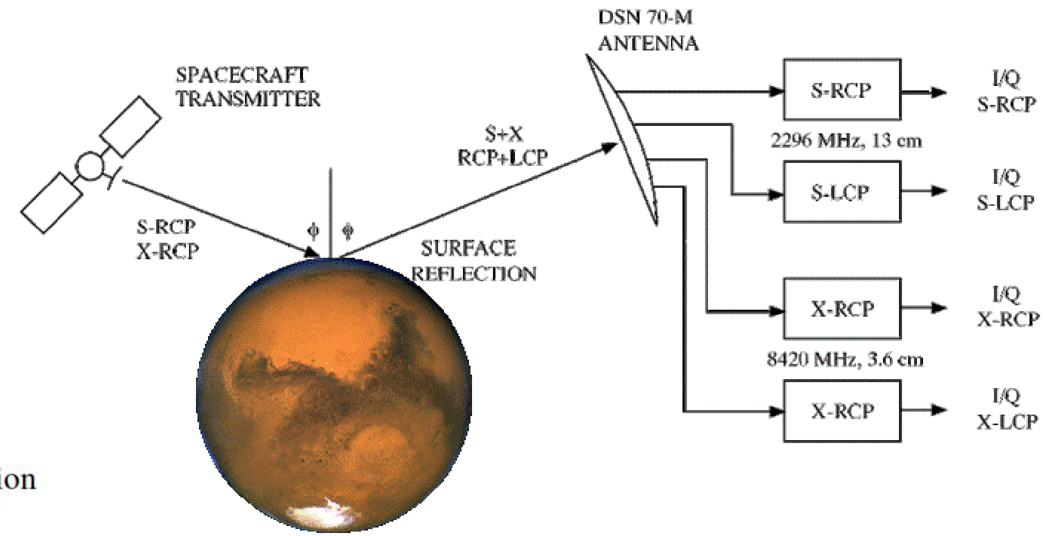
- Transmitter, receiver and reflection point on surface constitute one plane
- Monostatic case if incident angle $\phi = 0°$
- Specular point is defined when incident angle ϕ_i and reflection angel ϕ_r are equal

Bistatic Radar

The radar equation gives the incremental echo power from a small surface element :

$$dP_R = \frac{P_T G_T}{4\pi R_T^2} \sigma \frac{A_R}{4\pi R_R^2} dS$$

- P_T is the transmitted power,
- G_T is the transmitting antenna gain in the direction of the surface element,
- R_T is the distance from the transmitter to the surface element,
- A_R is the effective area of the receiving antenna aperture (which may, like G_T, be directional),
- R_R is the distance from the surface element to the receiver,
- and $\sigma(\phi, \varepsilon)$ the specific radar cross section (RCS).



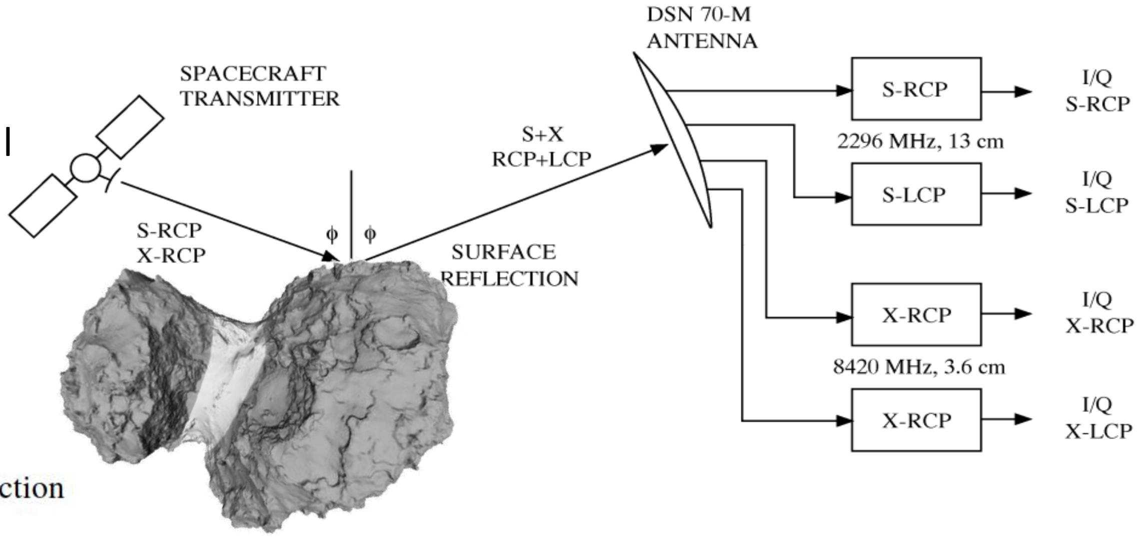
Simpson, 1993

Bistatic Radar

The radar equation gives the incremental echo power from a small surface element :

$$dP_R = \frac{P_T G_T}{4\pi R_T^2} \sigma \frac{A_R}{4\pi R_R^2} dS$$

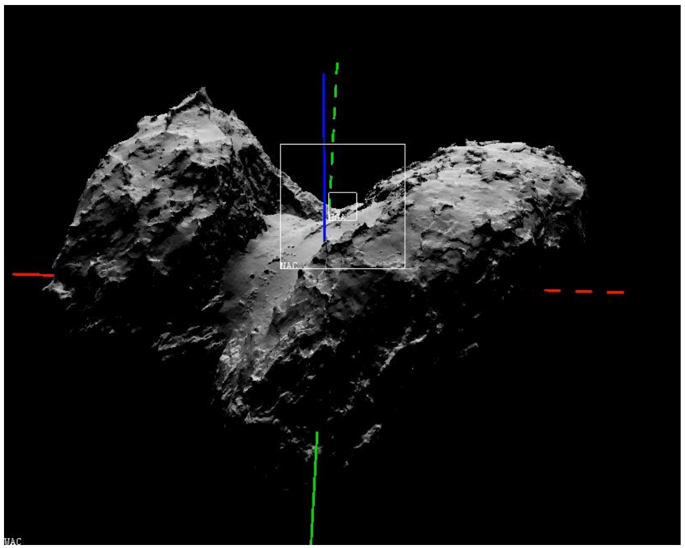
- P_T is the transmitted power,
- G_T is the transmitting antenna gain in the direction of the surface element,
- R_T is the distance from the transmitter to the surface element,
- A_R is the effective area of the receiving antenna aperture (which may, like G_T, be directional),
- R_R is the distance from the surface element to the receiver,
- and $\sigma(\phi, \varepsilon)$ the specific radar cross section (RCS).

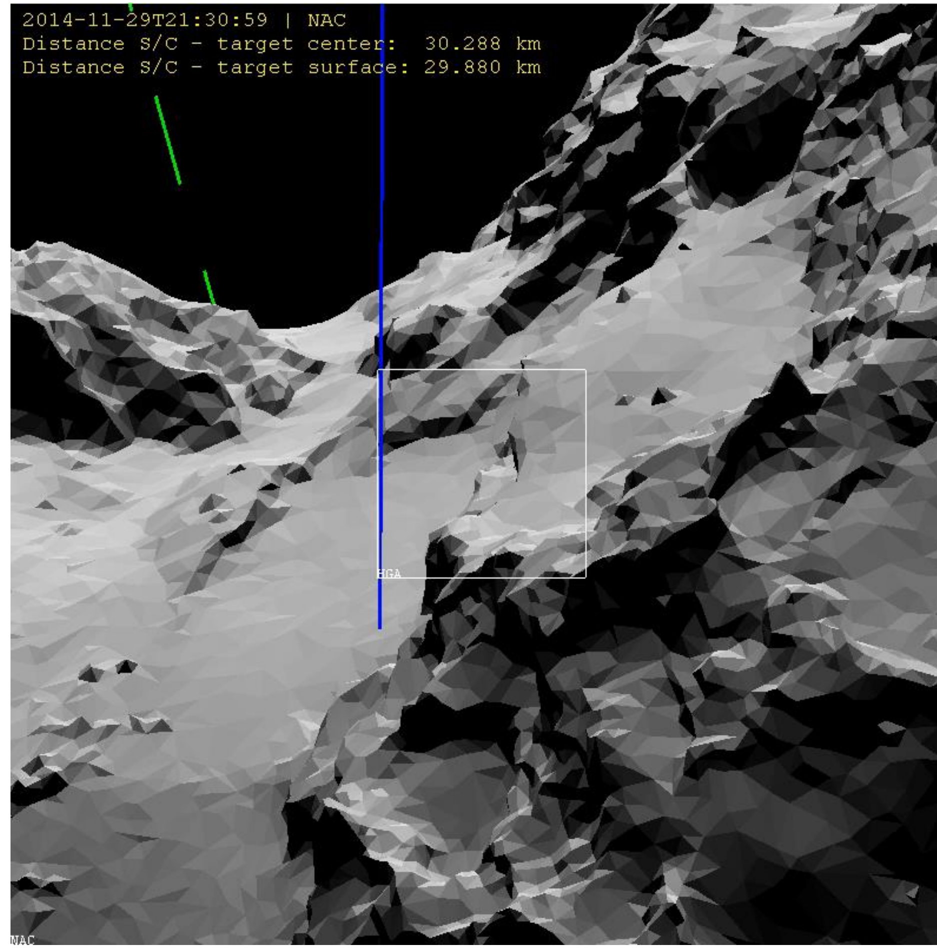


Simpson, 1993

der Bundeswehr
Universität München
Universität Bremen
DLR
Gefördert durch:
Bundesministerium für Wirtschaft und Klimaschutz
aufgrund eines Beschlusses des Deutschen Bundestages

BSR measurement with Rosetta





Universität der Bundeswehr München
Universität Bremen
DLR

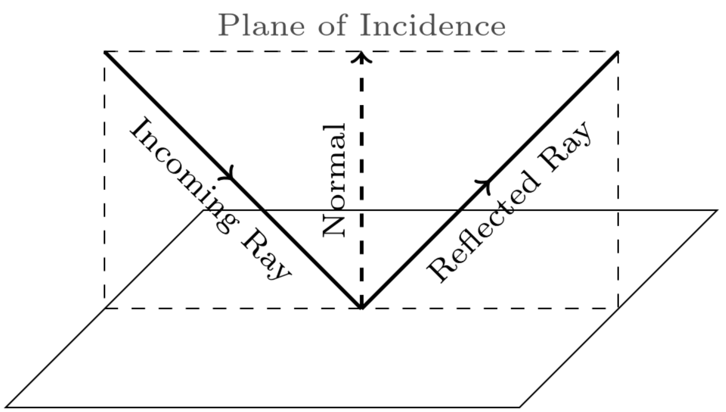
Gefördert durch:
Bundesministerium für Wirtschaft und Klimaschutz
aufgrund eines Beschlusses des Deutschen Bundestages

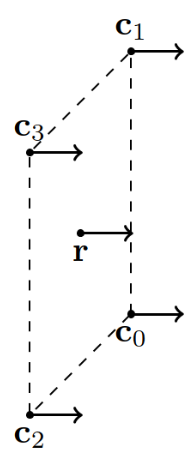
Shooting and Bouncing Rays (SBR) method

Gefördert durch:
Bundesministerium für Wirtschaft und Klimaschutz
aufgrund eines Beschlusses des Deutschen Bundestages

Shooting and Bouncing Rays (SBR) method

- EM wave is assumed to be planar near the target
- SBR method represents an incident plane wave by a dense grid of rays
- Plane wave is expressed by a grid of rectangular ray tubes
- SBR method is divided into
  - Ray tracing
  - Amplitude tracking
  - Physical optics



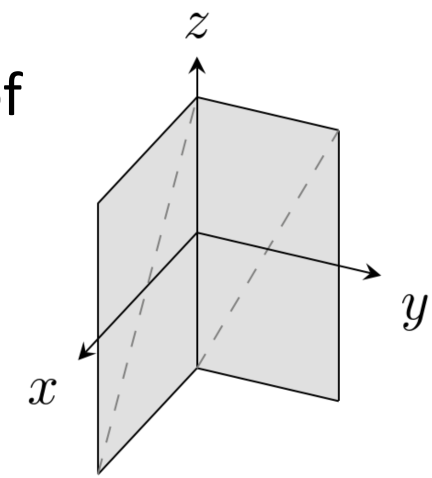


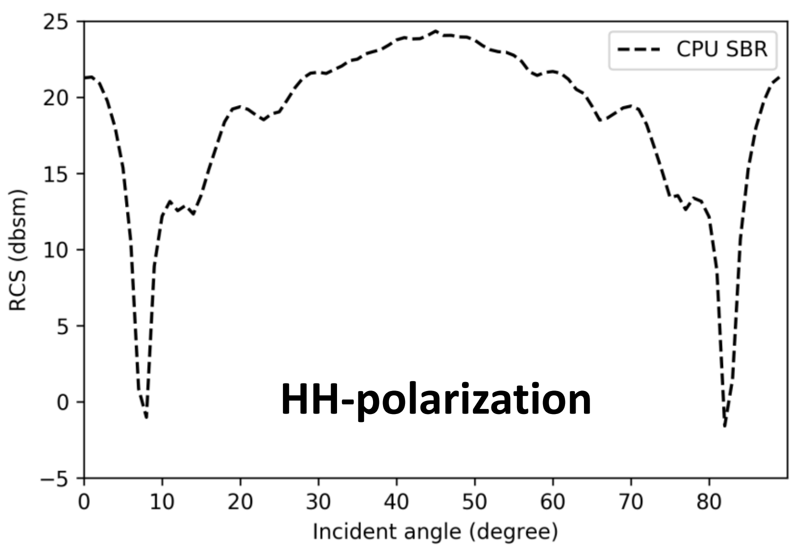
Ling et al., 1989, Baldauf et al., 1991

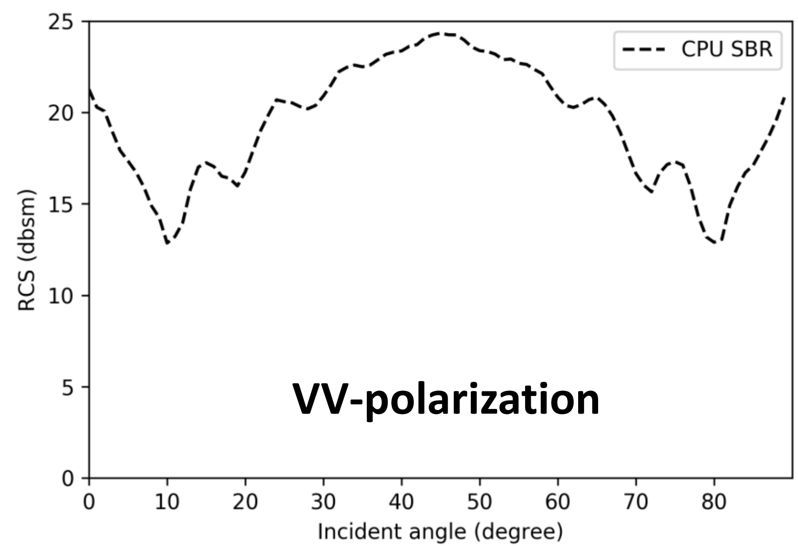
SBR method validation

The SBR implementation is validated with a set of different objects (perfect electrical conductor) :

- sphere,
- Cylinder,
- dihedral corner reflector





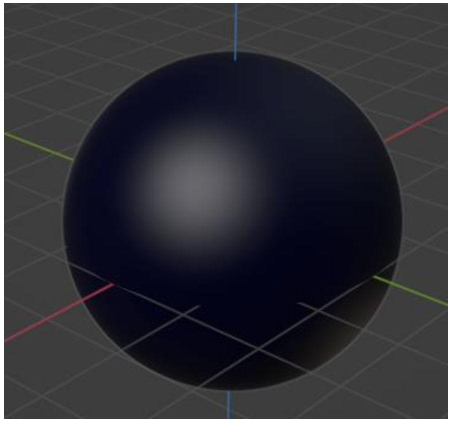


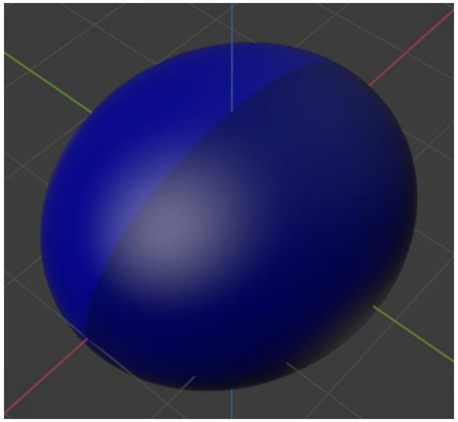
Universität der Bundeswehr München
Universität Bremen
DLR
Gefördert durch:
Bundesministerium für Wirtschaft und Klimaschutz
aufgrund eines Beschlusses des Deutschen Bundestages

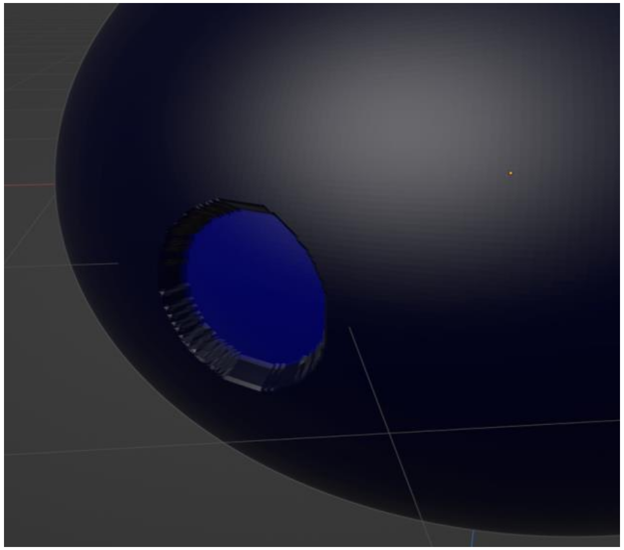
Results

Simulation Setup

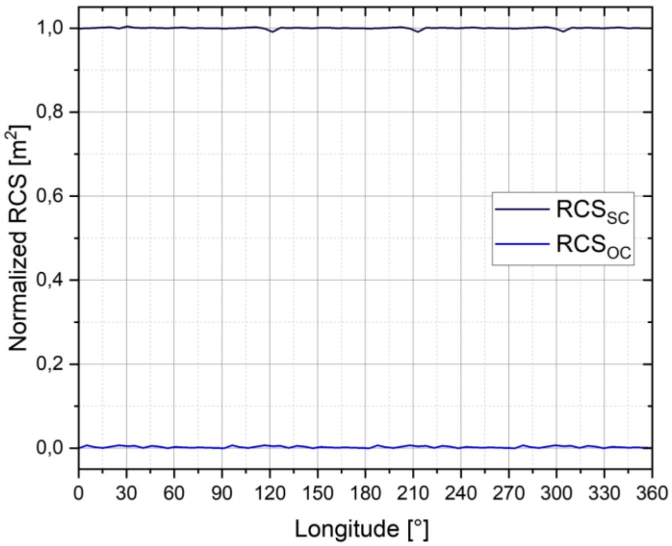
- Transmitter and receiver orbiting small body at a distance of about 1 km distance
- Monostatic and bistatic configurations
- Sphere, Ellipsoid, and Ellipsoid with a single crater as the central body
- Varying dielectric constants

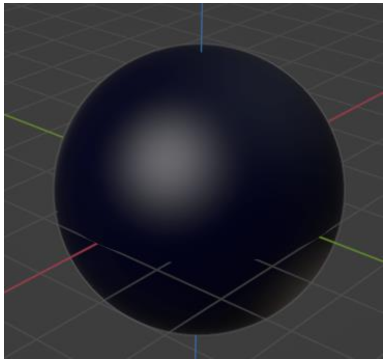




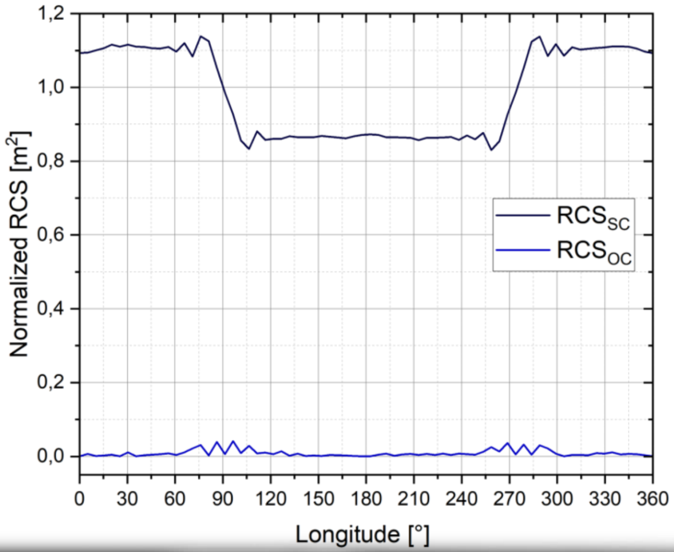


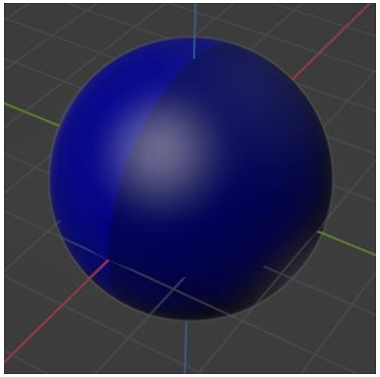
Sphere Monostatic Case





- Sphere with uniform ε = 3
- Radius of 50 m

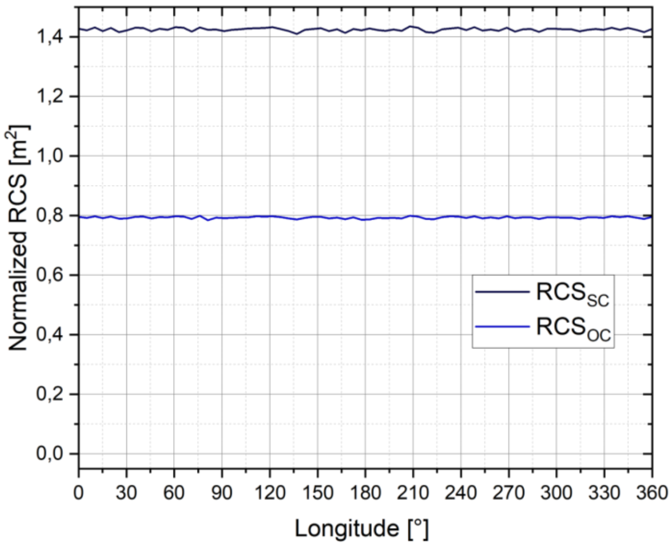




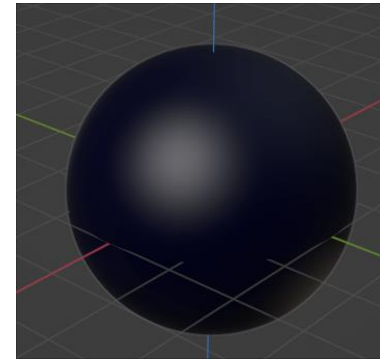
- Sphere with $\varepsilon_1 = 2$ and $\varepsilon_2 = 4$
- Radius of 50 m

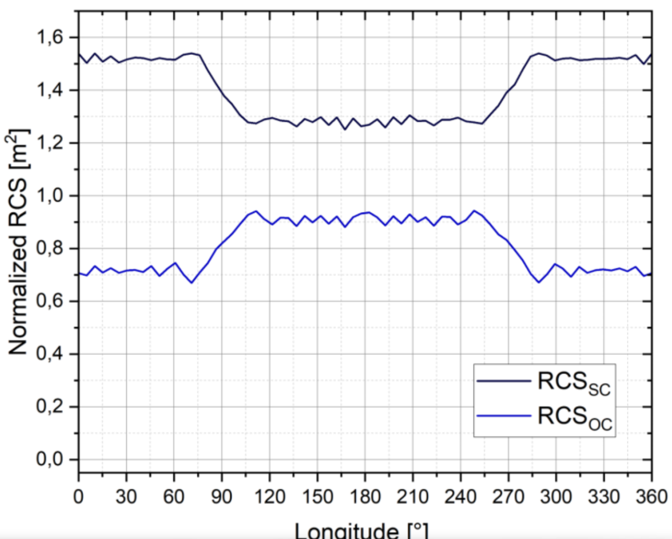
Universität der Bundeswehr München
Universität Bremen
DLR
Gefördert durch:
Bundesministerium für Wirtschaft und Klimaschutz
aufgrund eines Beschlusses des Deutschen Bundestages

Sphere Bistatic Case

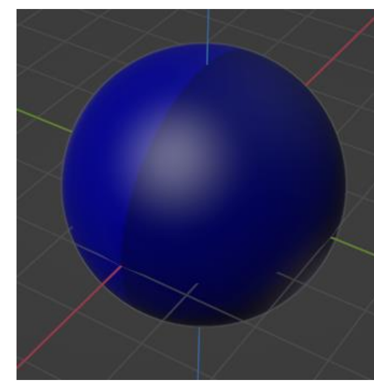


- Sphere with uniform $\varepsilon = 3$
- Radius of 50 m
- Incident angle $\phi = 65°$

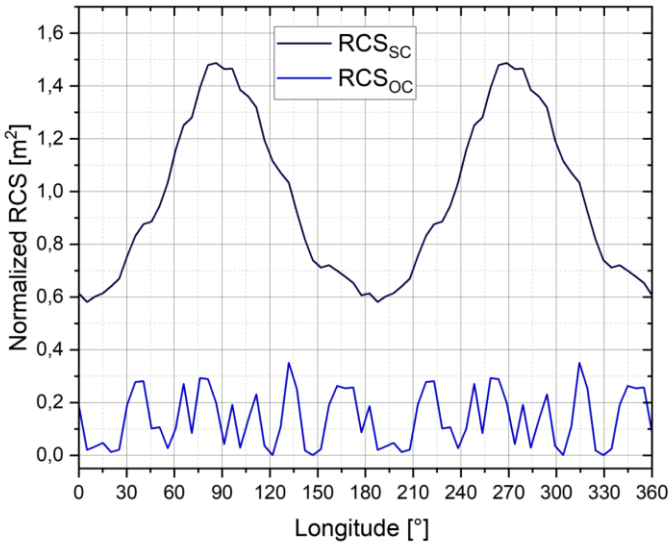


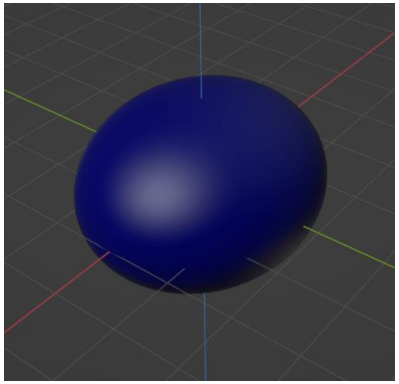


- Sphere with $\varepsilon_1 = 2$ and $\varepsilon_2 = 4$
- Radius of 50 m
- Incident angle $\phi = 65°$

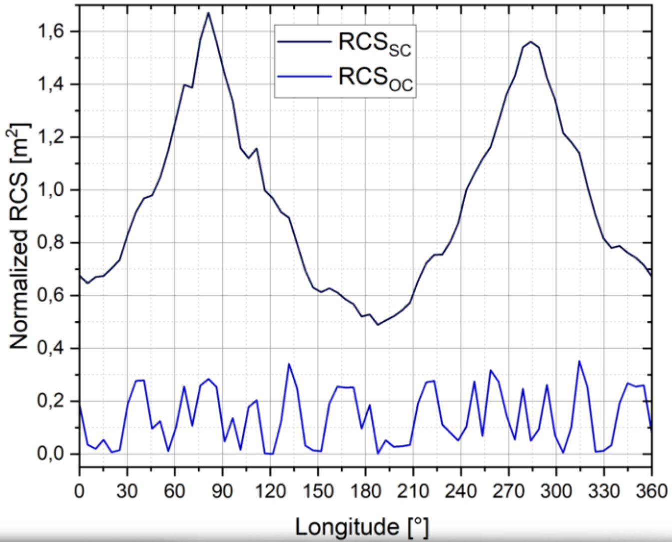


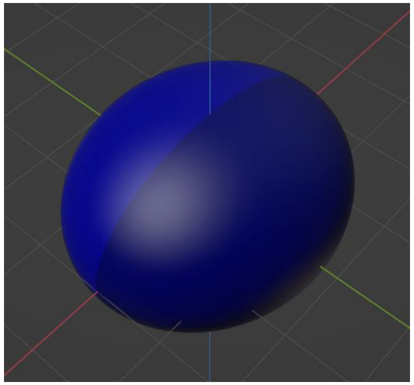
Ellipsoid Monostatic Case





- Ellipsoid with uniform ε = 3
- Dimensions 50 × 44 × 35 m

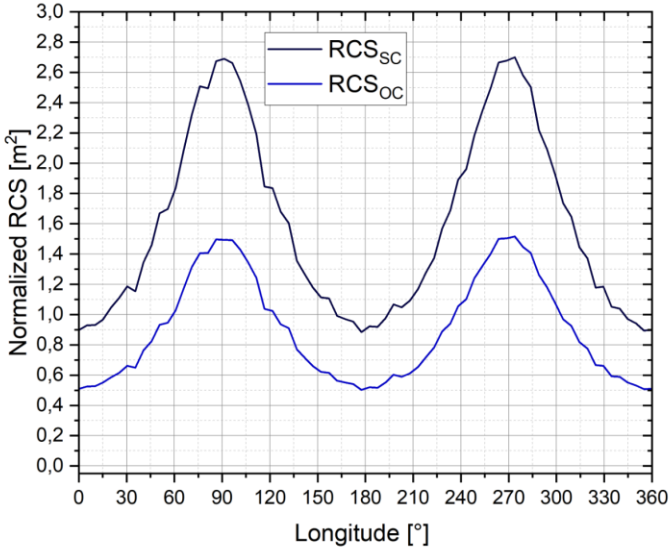




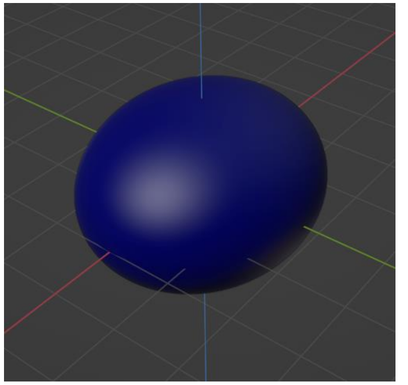
- Ellipsoid with $\varepsilon_1 = 2$ and $\varepsilon_2 = 4$
- Dimensions 50 × 44 × 35 m

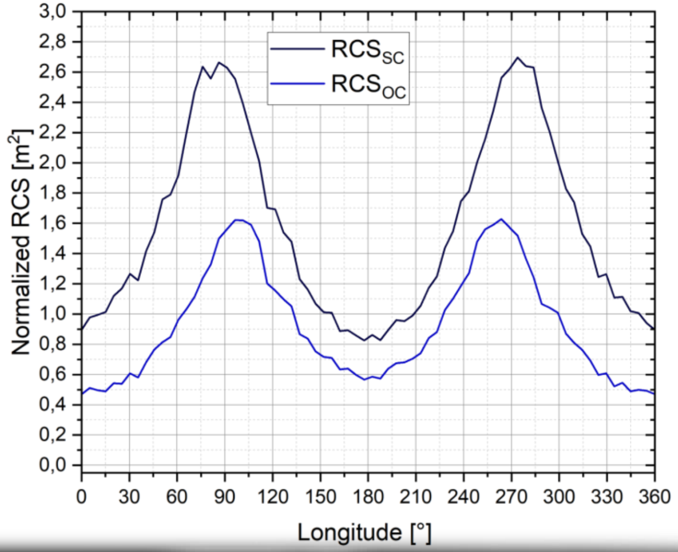
Universität der Bundeswehr München
Universität Bremen
DLR
Gefördert durch:
Bundesministerium für Wirtschaft und Klimaschutz
aufgrund eines Beschlusses des Deutschen Bundestages

Ellipsoid Bistatic Case

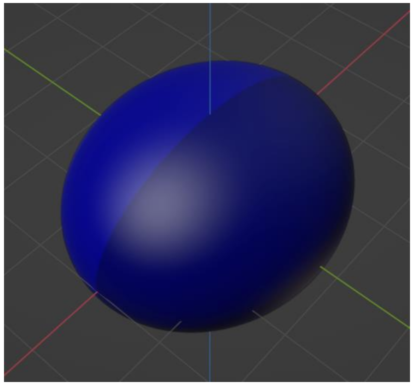


- Ellipsoid with uniform $\varepsilon = 3$
- Dimensions 50 × 44 × 35 m
- Incident angle $\phi = 65°$

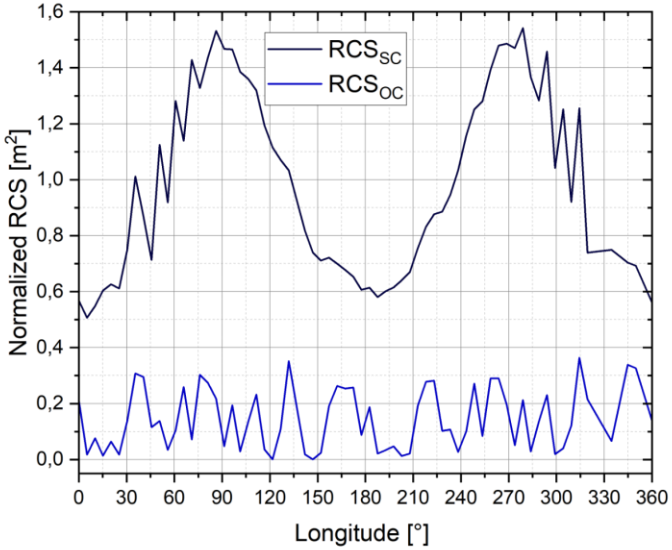


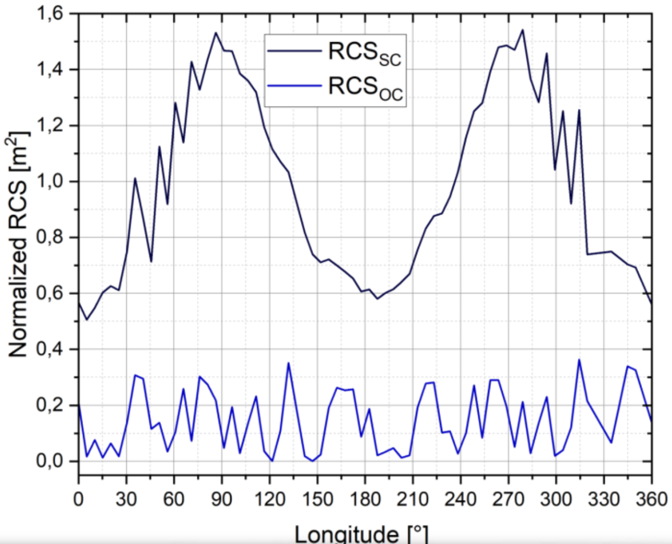


- Ellipsoid with $\varepsilon_1 = 2$ and $\varepsilon_2 = 4$
- Dimensions 50 × 44 × 35 m
- Incident angle $\phi = 65°$

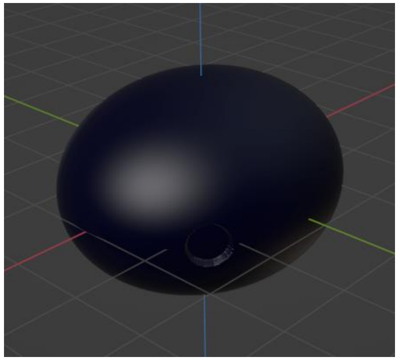


Ellipsoid with Crater Monostatic Case

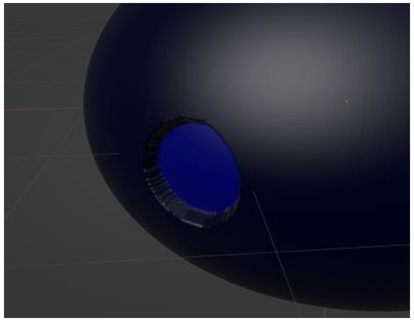




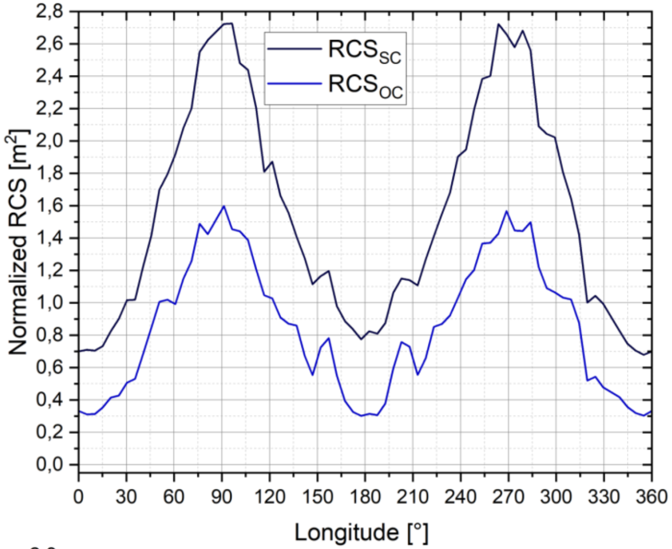
- Ellipsoid with uniform ε = 3
- Dimensions 50 × 44 × 35 m
- Crater at 45° longitude with diameter of 12.5 m and a depth of 22.5 m

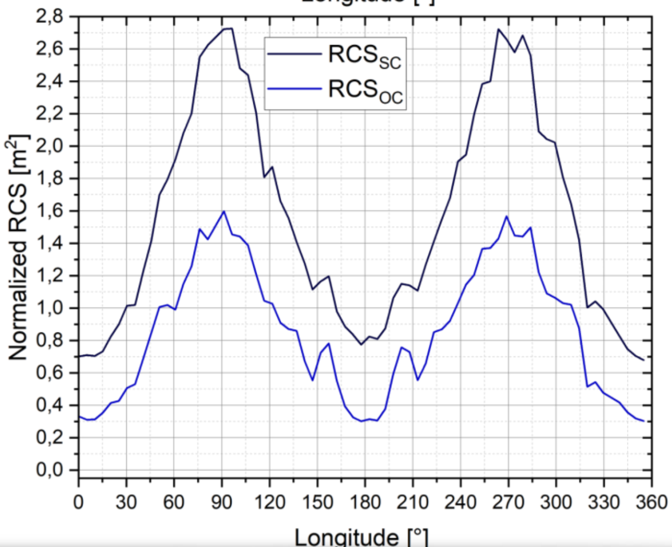


- ε = 3 outside crater
- ε = 3.2 inside crater

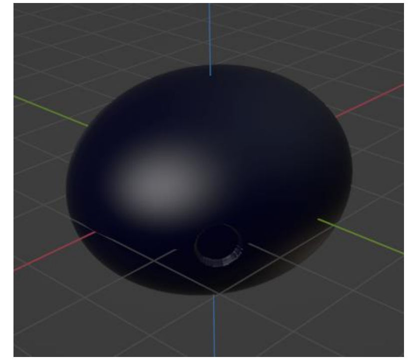


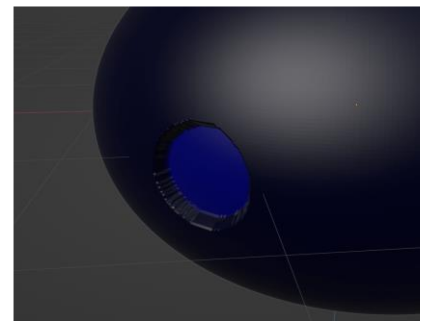
Ellipsoid with Crater Bistatic Case





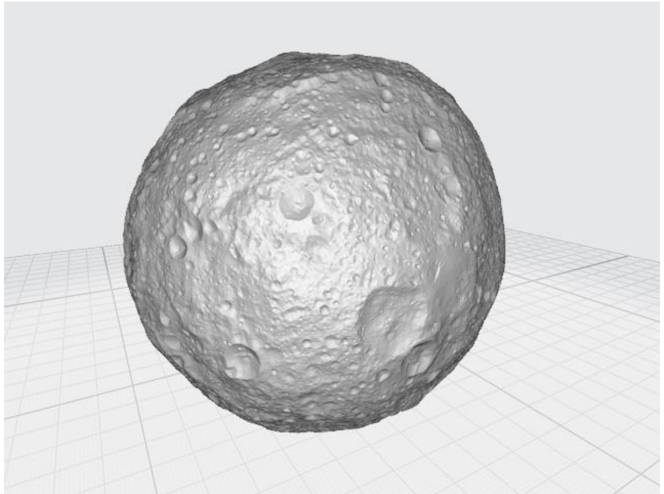
- Ellipsoid with uniform $\varepsilon = 3$
- Dimensions 50 × 44 × 35 m
- Crater at 45° longitude with diameter of 12.5 m and a depth of 22.5 m
- Incident angle $\phi = 65°$
- $\varepsilon = 3$ outside crater
- $\varepsilon = 3.2$ inside crater



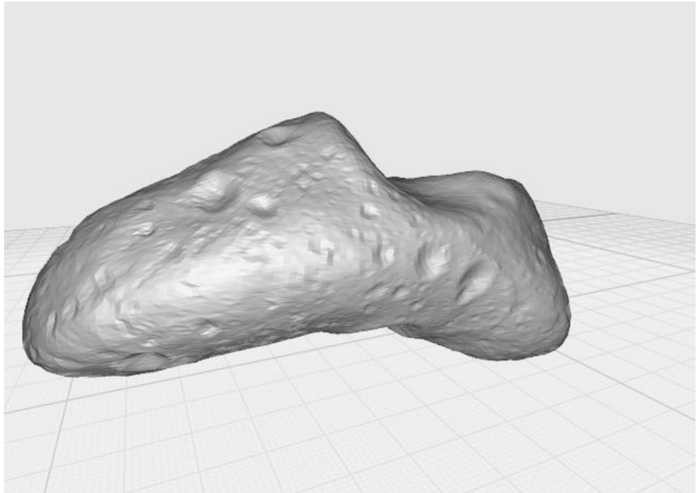


Universität der Bundeswehr München
Universität Bremen
DLR
Gefördert durch:
Bundesministerium für Wirtschaft und Klimaschutz
aufgrund eines Beschlusses des Deutschen Bundestages

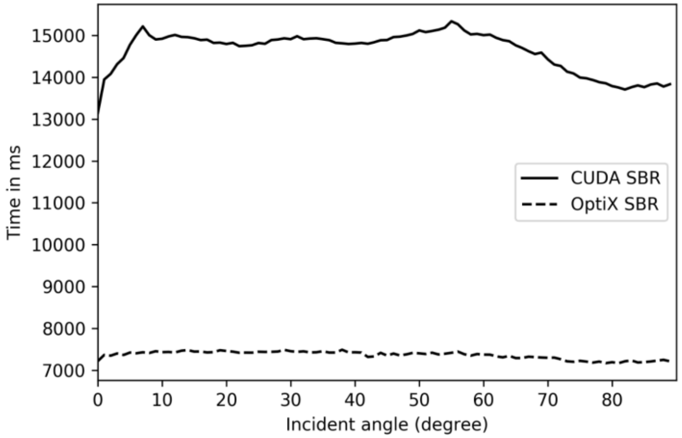
Performance

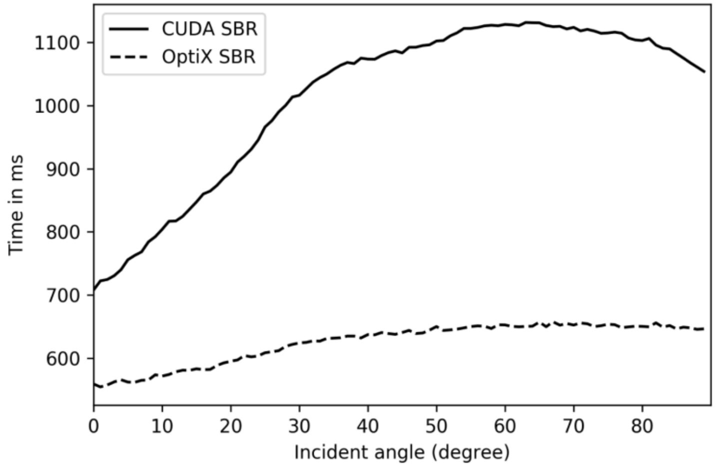


Vesta



Eros





Shape models from https://3d-asteroids.space/asteroids/

der Bundeswehr
Universität München
Universität Bremen
DLR
Gefördert durch:
Bundesministerium für Wirtschaft und Klimaschutz
aufgrund eines Beschlusses des Deutschen Bundestages

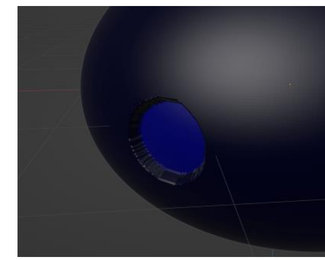
Summary

Gefördert durch:
Bundesministerium für Wirtschaft und Klimaschutz
aufgrund eines Beschlusses des Deutschen Bundestages

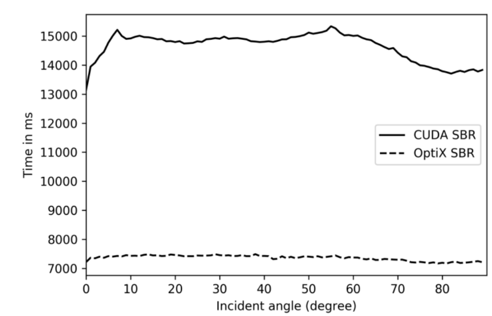
Summary

Summary

- Shooting and Bouncing Rays (SBR) method implemented
- Successful verification with perfect conducting objects in monostatic mode
- First simulations in bistatic mode with different objects
  - Sphere
  - Ellipsoid
  - Ellipsoid with crater



- High-performance OptiX implementation tested which outperforms CUDA implementation



Way Forward

- Examine numerical noise
- Further testing of OptiX implementation

der Bundeswehr
Universität München
Universität Bremen
DLR
Gefördert durch:
Bundesministerium für Wirtschaft und Klimaschutz
aufgrund eines Beschlusses des Deutschen Bundestages

Thank you

The work on the part of the University of Bremen presented in this paper was partially funded by DLR under grant 50NA1916. The work by Bundeswehr University was carried out in the frame of project KaNaRiA-NaKoRa, financed by the German Ministry of Economy and Energy and administered by the German Aerospace Center, Space Administration (DLR, Deutsches Zentrum für Luft- und Raumfahrt, FKZ 50NA1915).

Gefördert durch:
Bundesministerium für Wirtschaft und Klimaschutz
aufgrund eines Beschlusses des Deutschen Bundestages