Physically Based Real-Time Rendering of Atmospheres using Mie Theory

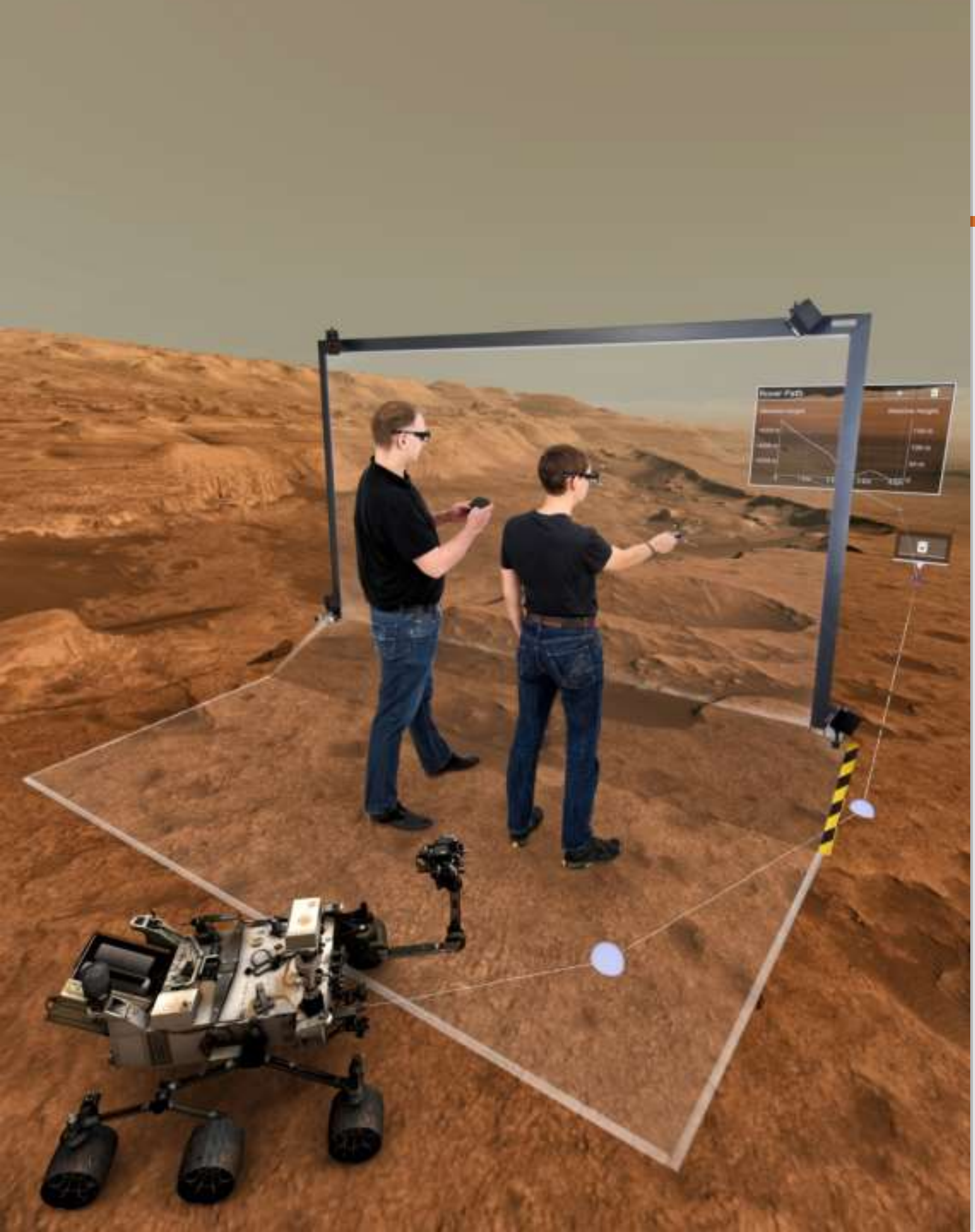
Simon Schneegans[1], Tim Meyran[2], Ingo Ginkel[2], Gabriel Zachmann[1], Andreas Gerndt[1,3]

[1]University of Bremen, Germany [2]Hanover University of Applied Sciences and Arts, Germany [3]German Aerospace Center (DLR)

EUROGRAPHICS CONFERENCE 2024

23.04.2024

The 45th Annual Conference of the European Association for Computer Graphics is organized by CYENS Centre of Excellence in collaboration with the University of Cyprus and the Cyprus University of Technology.



Motivation & Scope

Our Goal:

Real-time rendering of extraterrestial atmospheres based on **physical parameters.**

Possible Applications:

- Interactive space-mission planning
- Public outreach
- Computer games

Universität Bremen

DLR

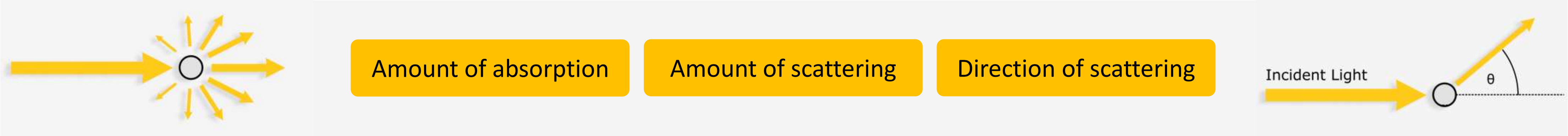
Part I:
Introduction – Atmospheric Light Scattering in CG

Basics of Light Scattering at Atmospheric Particles

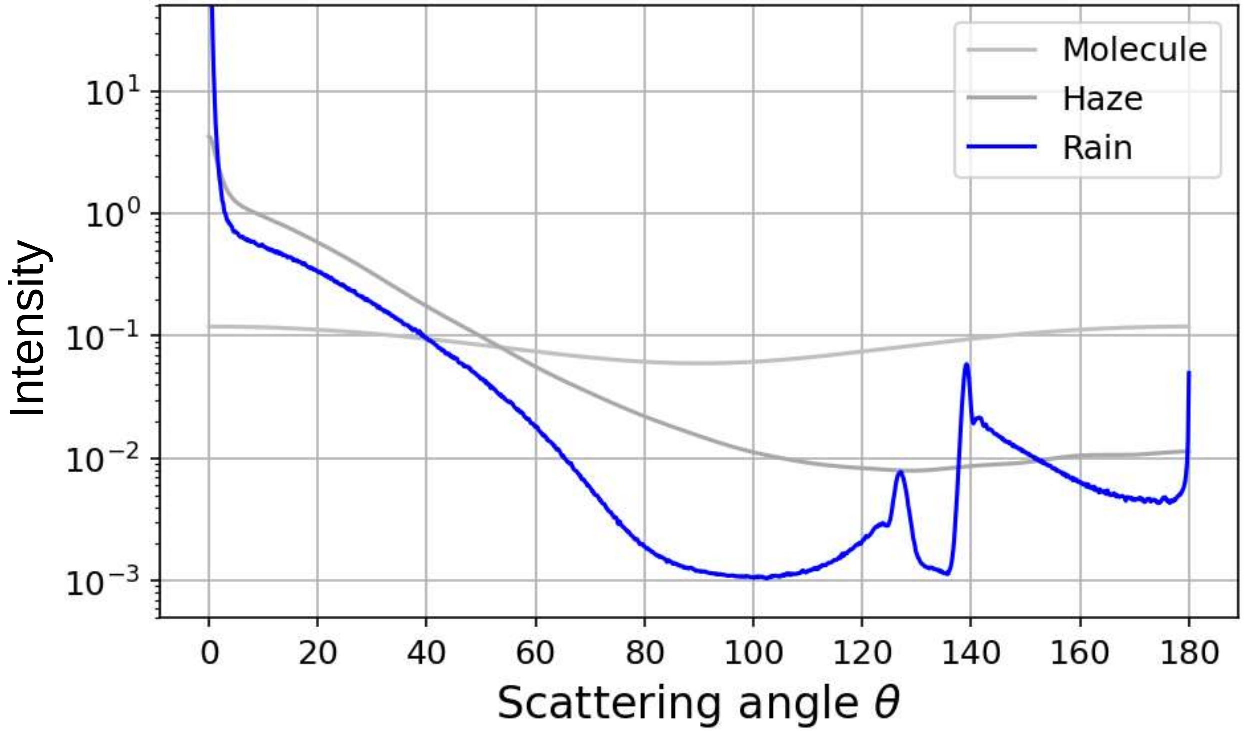
Properties of a scattering event:

Amount of absorption | Amount of scattering | Direction of scattering

Basics of Light Scattering at Atmospheric Particles



- Amount is measured with Extinction Coefficients
- Directional intensity is given by the Phase Function



Earth‘s Atmosphere in CG

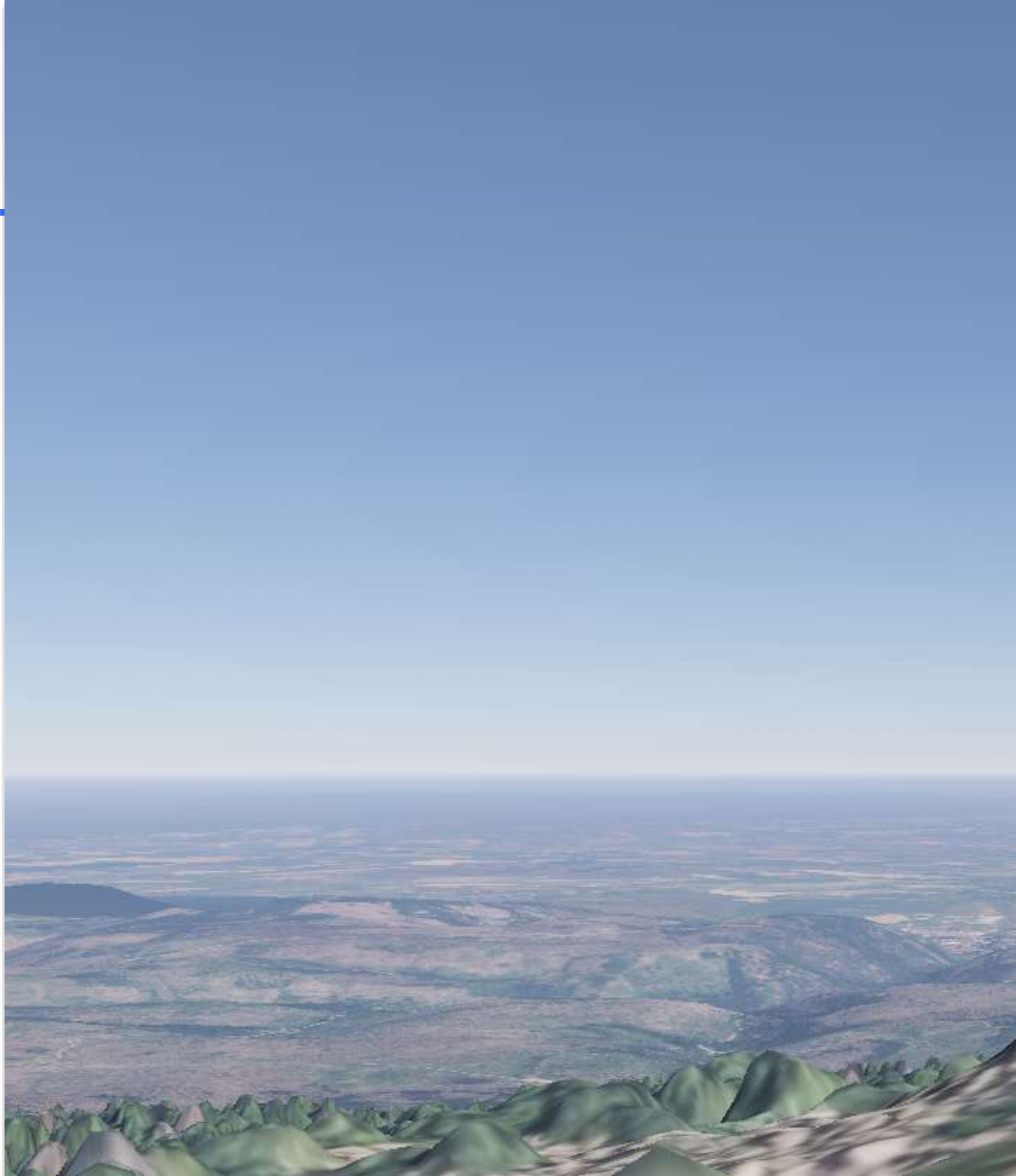
- Atmospheres consists of a wide variety of particle types
- In CG, usually only two components are modelled

Small Particles (Molecules)

➢ Cause **blue sky** and **red sunsets**

Large Particles (Aerosols)

➢ Cause haze and halo around the Sun

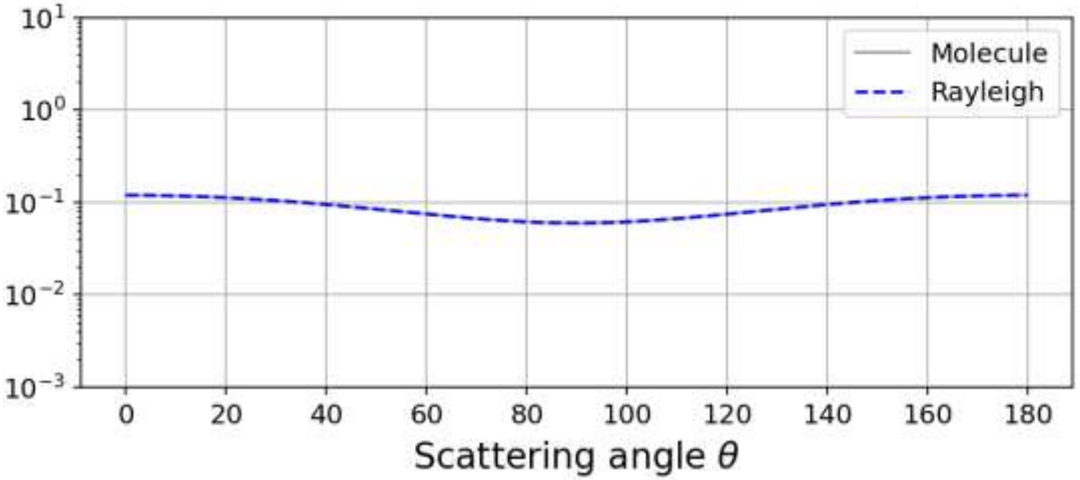


Earth‘s Atmosphere in CG

Small Particles (Molecules)

Rayleigh Theory

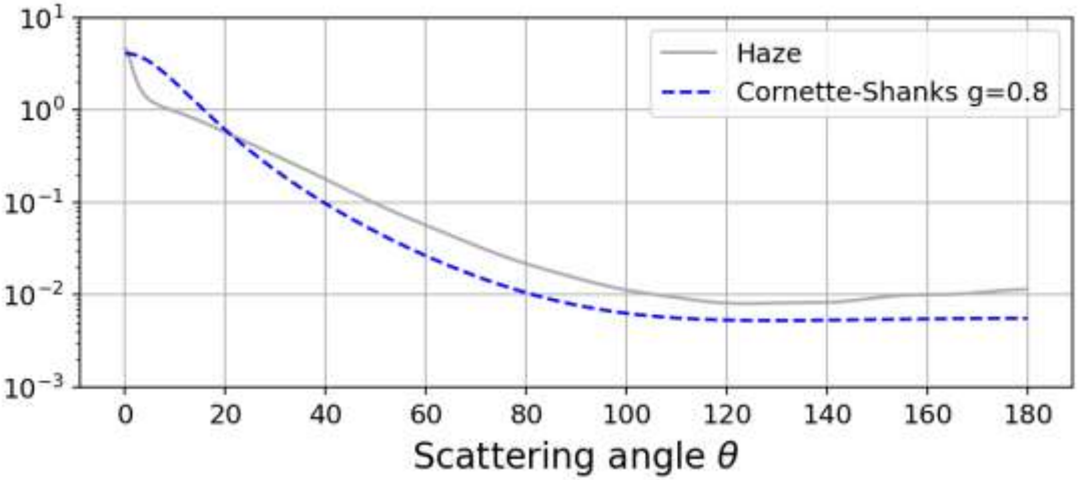
$$P(\theta) = \frac{3}{16\pi}(1 + cos^2\theta)$$

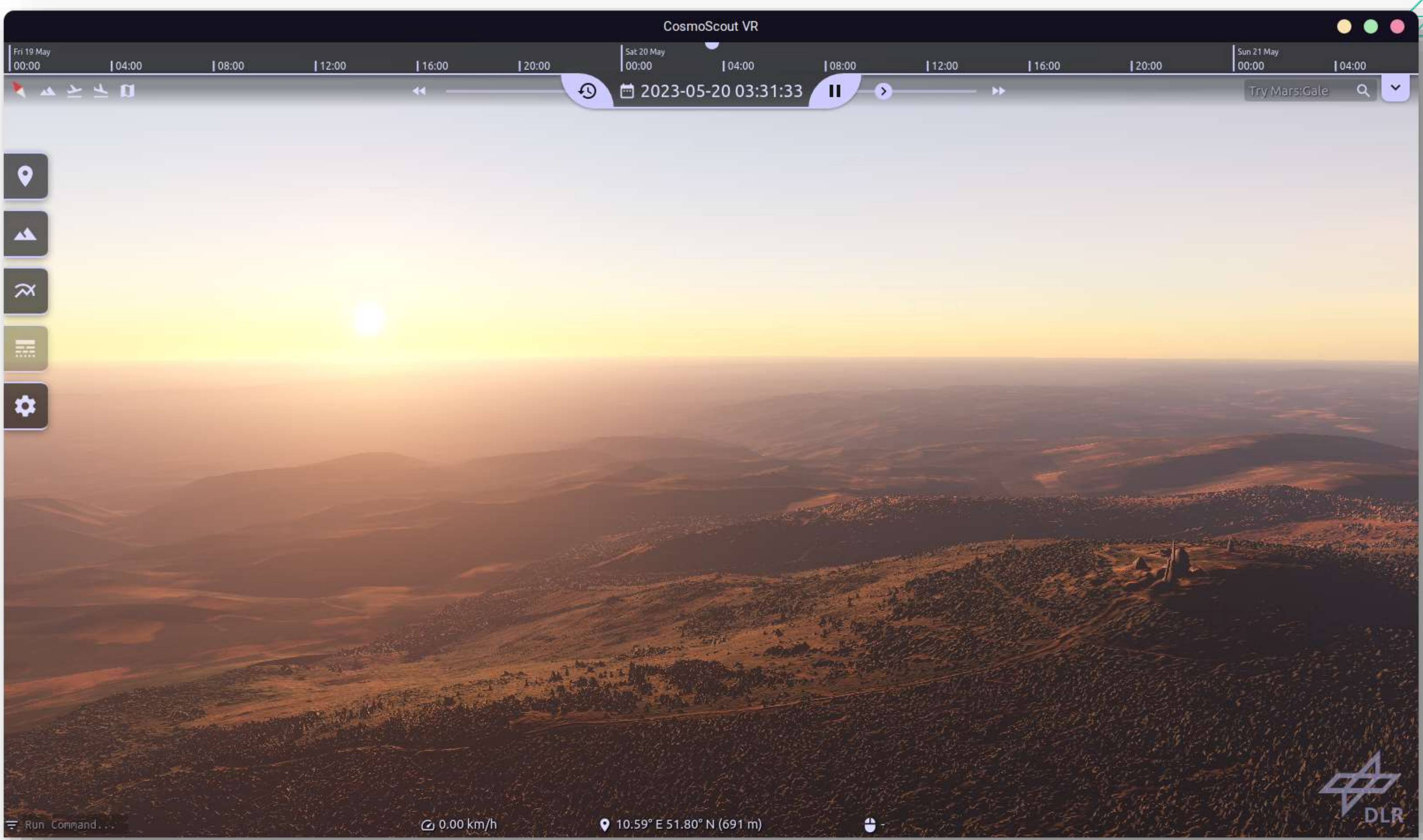


Large Particles (Aerosols)

Parametric phase functions

$$P(\theta, g) = \frac{2}{3}\frac{1-g^2}{2+g^2}\frac{1+cos^2\theta}{1+g^2-2g\,cos\theta}$$



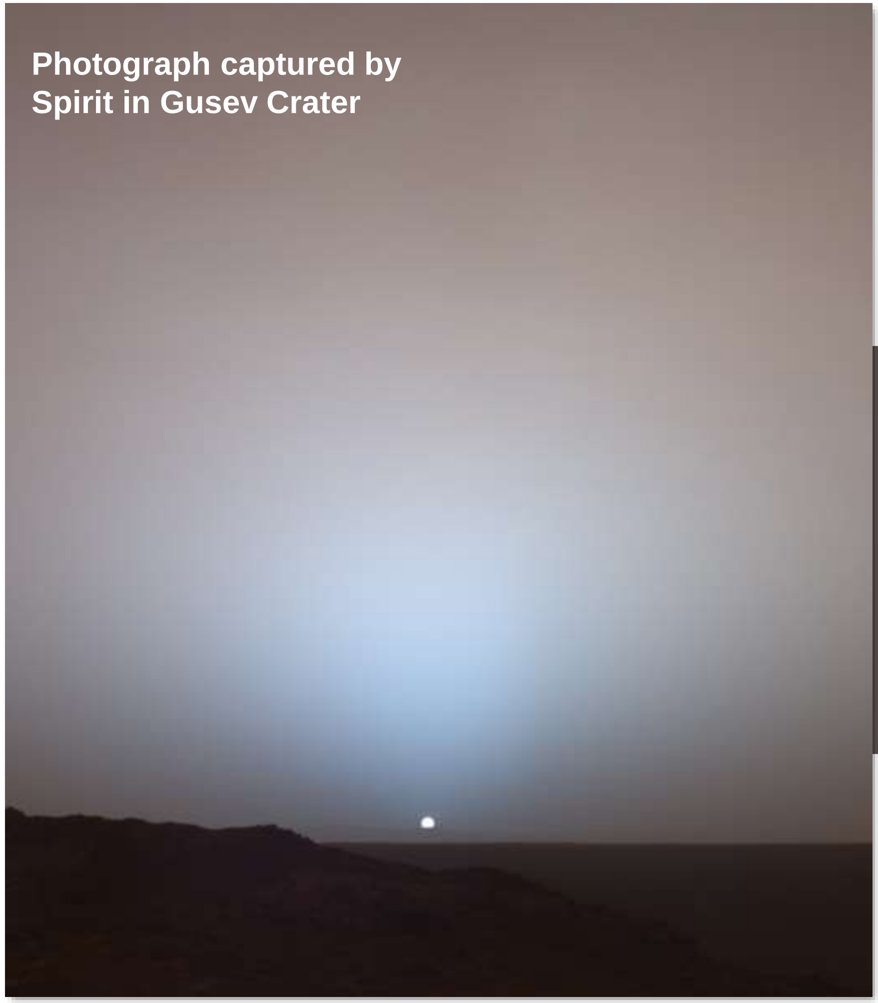


Universität Bremen

DLR

Part II:
Related Work – Challenges of the Martian Atmosphere

Challenges of the Martian Atmosphere



- Thinner & dominated by dust
- Contains hematite which absorbs **blue light**
  - ➢ **Red or brown** appearance

However:

- Absorption of blue light reduces destructive interference in forward direction
  - ➢ **Blue glow around the Sun**

- Impossible to model with parametric phase functions used in CG

State-of-the-Art in Rendering of the Martian Atmosphere

Collienne et al. tweak extinction coefficients to match sky colour to photographs [1]

- Plausible colours during daytime
- Blue glow is a feature of the horizon

[1] COLLIENNE P., WOLFF R., GERNDT A., KUHLEN T.: Physically based rendering of the Martian atmosphere. *Workshop der GI-Fachgruppe VR/AR* (2013)

Costa et al. use multiple parametric phase functions for RGB [2]

- Plausible colours during daytime
- Very wide and soft blue glow

[2] COSTA J., BOCK A., EMMART C., HANSEN C., YNNERMAN A., SILVA C.: Interactive visualization of atmospheric effects for celestial bodies. *IEEE Transactions on Visualization and Computer Graphics* (2021)

Part III:
Our Approach – Physically-based Rendering

Out Idea: Let‘s use Mie Theory instead!

- Developed by German scientist Gustav Mie more than 100 years ago [1]
- Computes the electromagnetic field scattered at a spherical particle

- We use Mie Theory for pre-computing:
  - Phase Functions
  - Extinction Coefficients
- Required input data:

Based on physical properties
no fitting to observations required

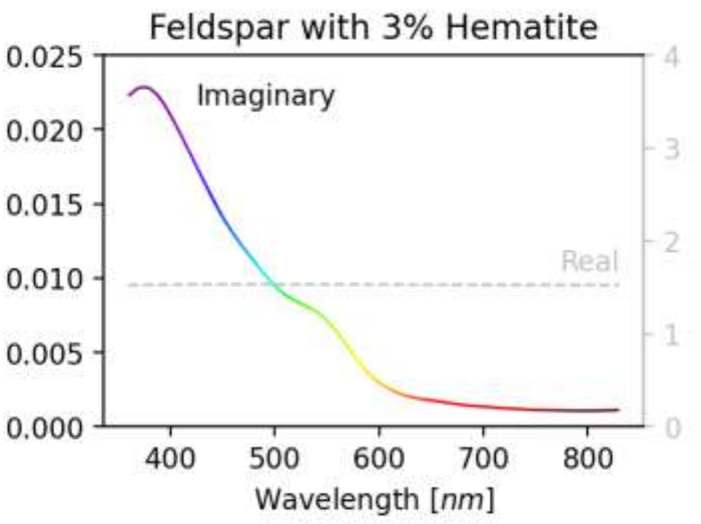
Complex **Refractive Index**
of the atmospheric particles

Particle **Size Distribution**
(e.g. Gaussian)

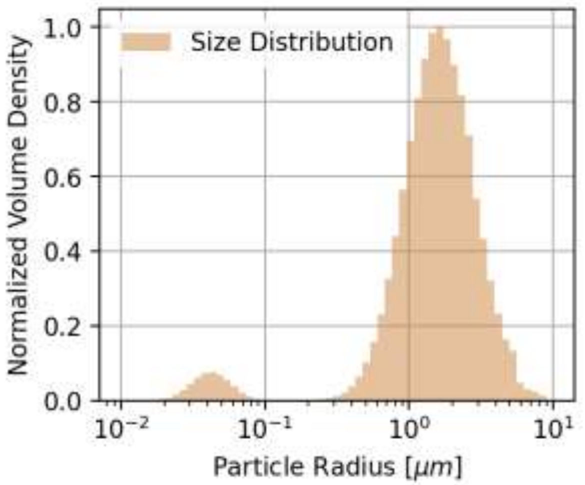
Particle **Density Distribution**
as a function of altitude

[1] MIE G.: Beiträge zur Optik trüber Medien, speziell kolloidaler Metallösungen. **Annalen der Physik** (1908)

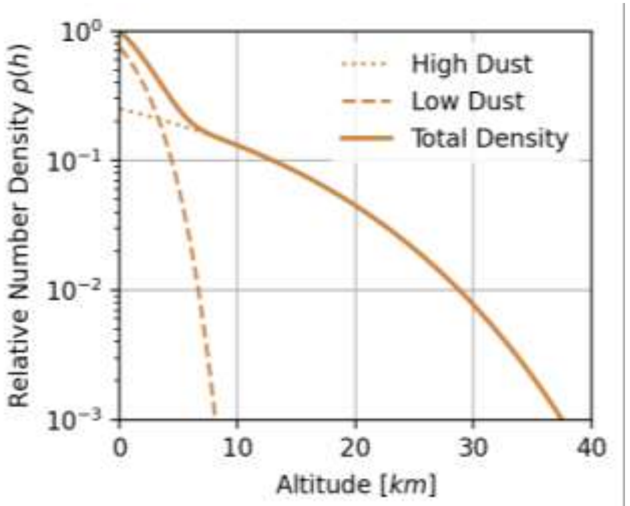
Out Idea: Let‘s use Mie Theory instead!



Complex **Refractive Index**



Particle **Size Distribution**



Particle **Density Distribution**

[1] EHLERS K., CHAKRABARTY R., MOOSMÜLLER H.: Blue moons and Martian sunsets. *Applied Optics* (2014)

[2] FEDOROVA A. A., MONTMESSIN F., RODIN A. V., KORABLEV O. I., MÄÄTTÄNEN A., MALTAGLIATI L., BERTAUX J.-L.: Evidence for a bimodal size distribution for the suspended aerosol particles on Mars. *Icarus* (2014)

[3] SHAPOSHNIKOV D. S., RODIN A. V., MEDVEDEV A. S., FEDOROVA A. A., KURODA T., HARTOGH P.: Modeling the hydrological cycle in the atmosphere of Mars: Influence of a bimodal size distribution of aerosol nucleation particles. *Journal of Geophysical Research: Planets* (2018)

Out Idea: Let‘s use Mie Theory instead!

Particle **Size Distribution**

Particle **Density Distribution**

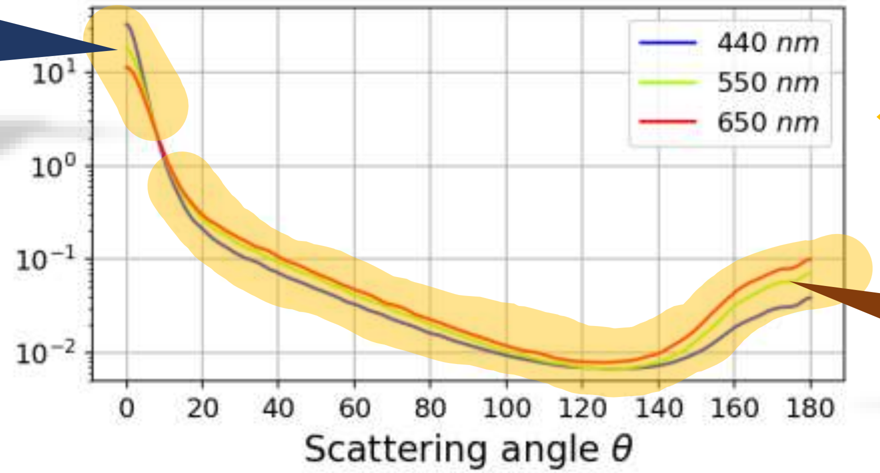
Complex **Refractive Index**

Evaluate Mie Theory
For many scattering angles
For various wavelengths

Tabulated **phase functions** and **extinction coefficients**

In the forward direction, blue light dominates

Phase function of simulated Martian dust with 3% Hematite



For all other directions, red light dominates

These tabulated values can now be used in an existing atmospheric rendering model!

Extending the Model by Eric Bruneton [1]

Particle **Size Distribution**

Particle **Density Distribution**

Complex **Refractive Index**

Evaluate Mie Theory
For many scattering angles
For various wavelengths

Tabulated **phase functions** and **extinction coefficients**

Multiple Scattering Precomputation
According to [1]

2D and 4D lookup textures containing **radiance** and **irradiance** values

Real-Time Rendering
According to [1]

Only a few texture lookups are required per pixel!

[1] BRUNETON E., NEYRET F.: Precomputed atmospheric scattering. *In Computer graphics forum* (2008)

Extending the Model by Eric Bruneton VR

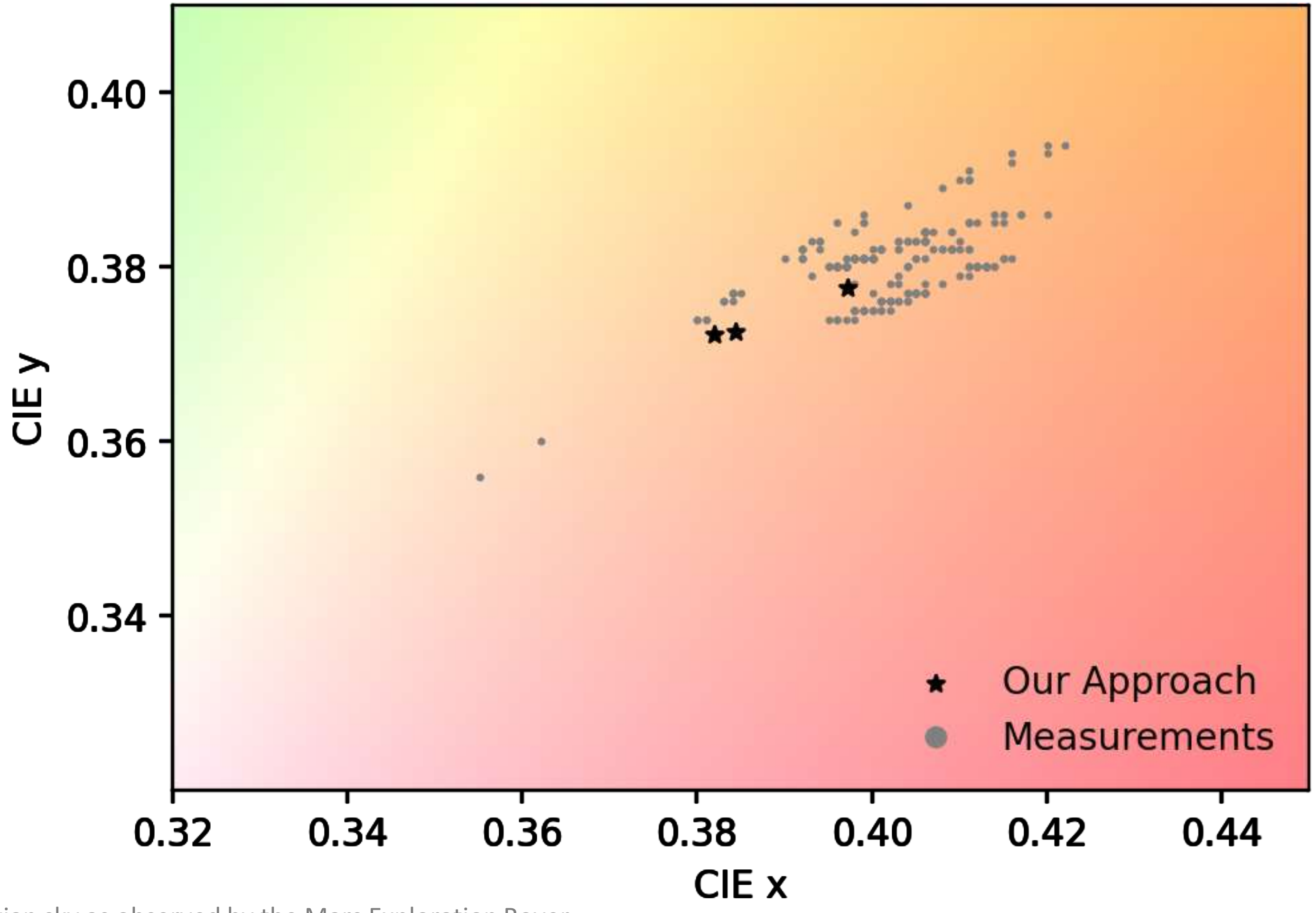
- Implemented in CosmoScout VR
- Evaluated the color and brightness of the Martian sky
- Compared to…
  - ➢ Real-world data
  - ➢ Previous approaches

CosmoScout VR is an open source 3D simulation of our Solar System for visualizing huge scientific datasets

Universität Bremen DLR

Chromaticity Results

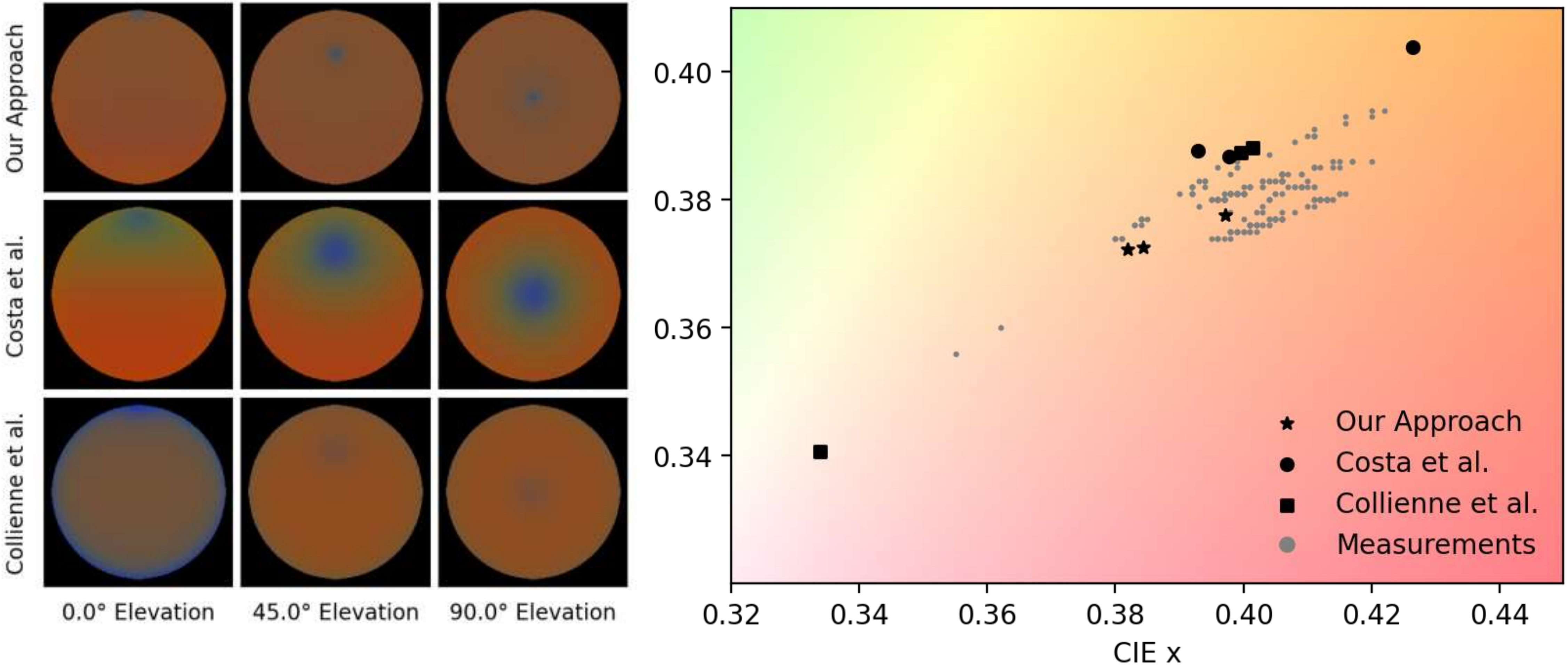
Compared to sky chromaticity measurements by Spirit and Opportunity [1]



[1] BELL J. F., SAVRANSKY D., WOLFF M. J.: Chromaticity of the Martian sky as observed by the Mars Exploration Rover Pancam instruments. *Journal of Geophysical Research: Planets* (2006)

Universität Bremen DLR

Chromaticity Results

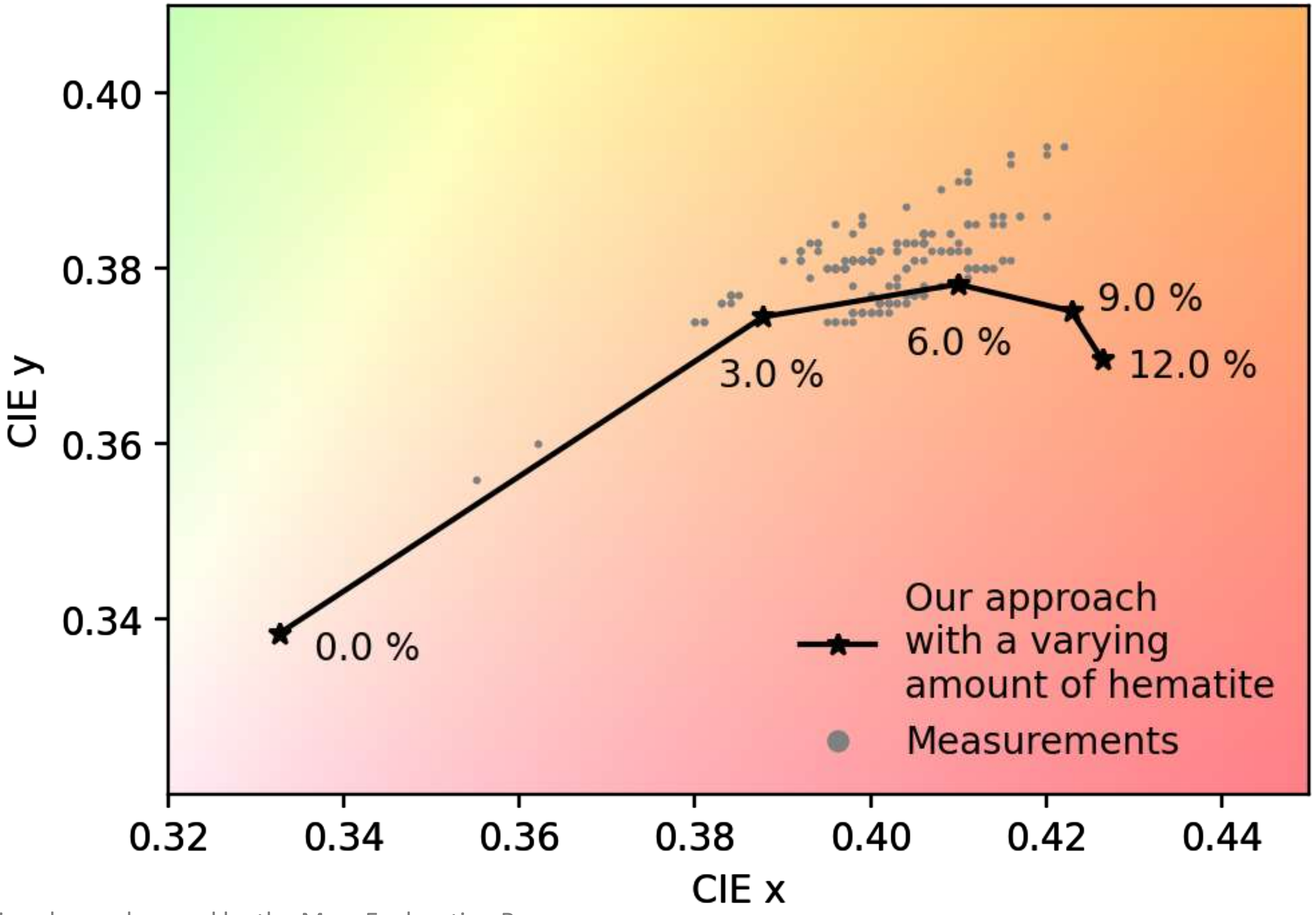


[1] BELL J. F., SAVRANSKY D., WOLFF M. J.: Chromaticity of the Martian sky as observed by the Mars Exploration Rover Pancam instruments. *Journal of Geophysical Research: Planets* (2006)

Chromaticity Results

Compared to sky chromaticity measurements by Spirit and Opportunity [1]

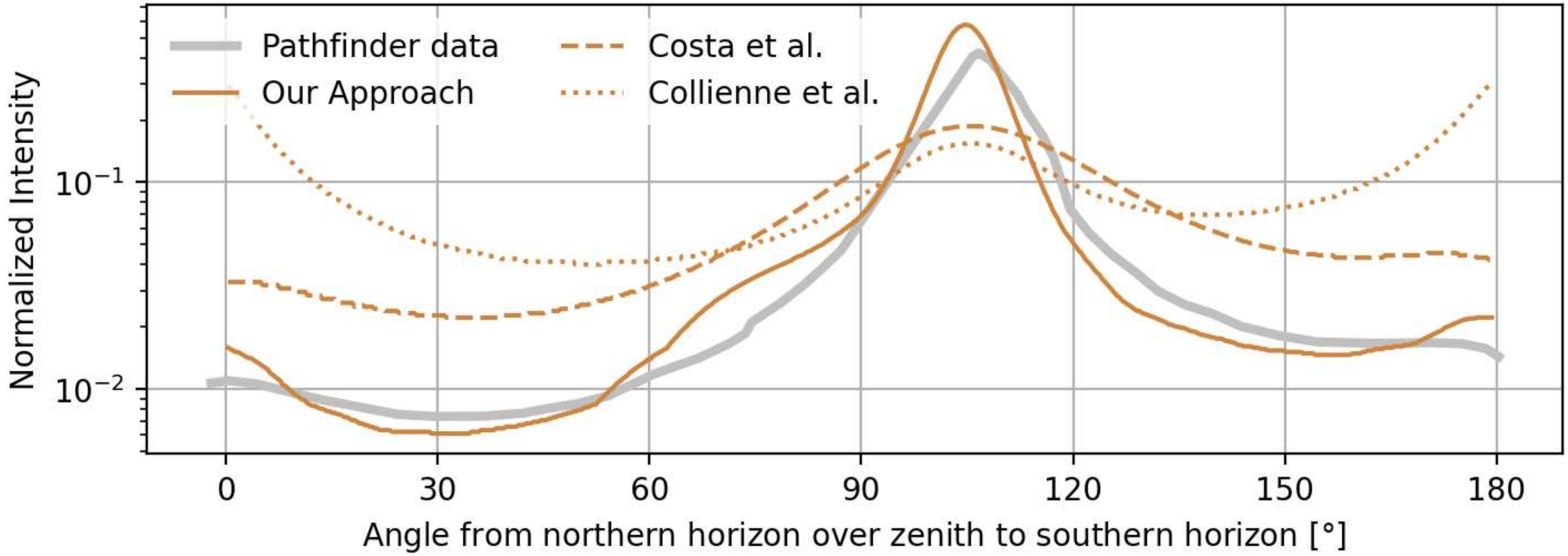
➢ We can explore the impact of hematite!



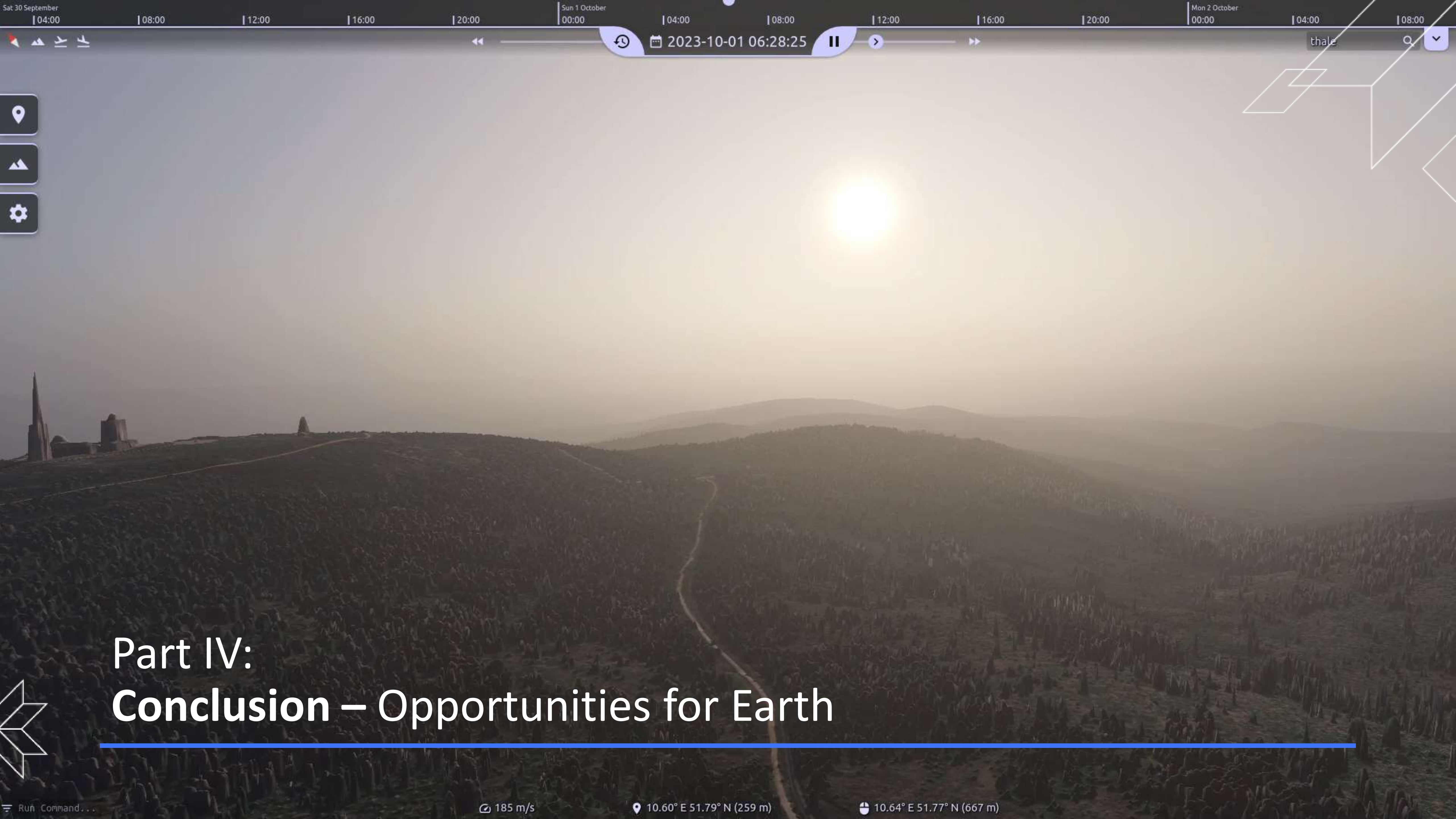
[1] BELL J. F., SAVRANSKY D., WOLFF M. J.: Chromaticity of the Martian sky as observed by the Mars Exploration Rover Pancam instruments. *Journal of Geophysical Research: Planets* (2006)

Brightness Results

Compared to radiance measurements by the Mars Pathfinder [1]



[1] MARKIEWICZ W., SABLOTNY R., KELLER H., THOMAS N., TITOV D., SMITH P.: Optical properties of the Martian aerosols as derived from Imager for Mars Pathfinder midday sky brightness data. *Journal of Geophysical Research: Planets* (1999)

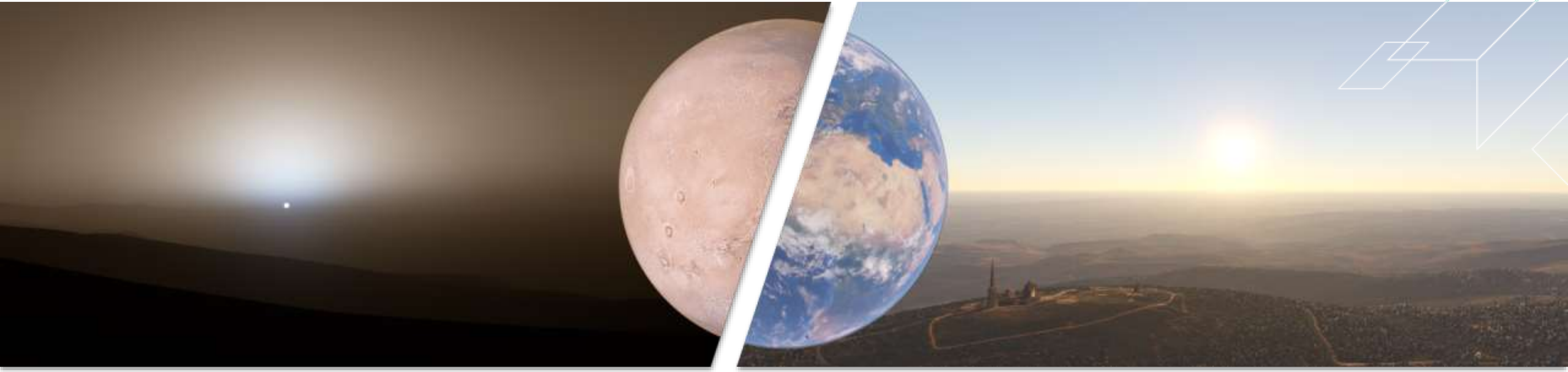


Part IV:
Conclusion – Opportunities for Earth

Opportunities for Earth‘s atmosphere

- Mie Theory can improve the realism of thick haze layers
- Wavelength-dependent phase functions can be used to create rainbows
- Other phenomena?
- We have not yet fully explored the possibilities…

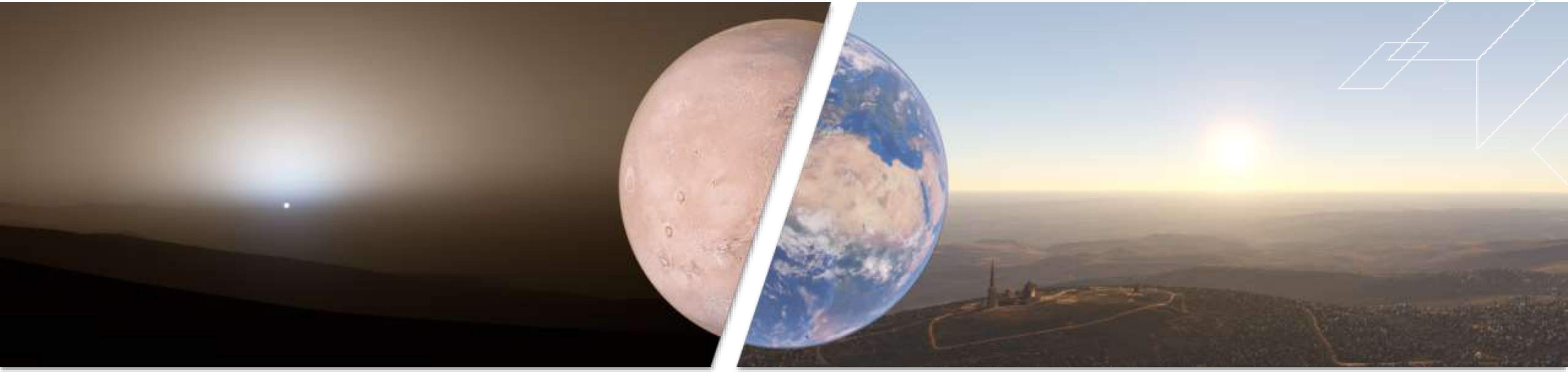
Our proposed approach can be used to simulate a variety of (global) weather phenomena on Earth.



Summary

- Generalized the Bruneton model to use it for extraterrestial atmospheres
- Evaluated for the Martian atmosphere
- Performance is similar to previous methods
- Not limited to the Bruneton Model -> can we use it in the Hillaire Model [1]?

[1] HILLAIRE S.: A scalable and production ready sky and atmosphere rendering technique. *Computer Graphics Forum 39* (2020)



Future Work

- Explore opportunities for Earth
- Other planets or moons such as Venus or Titan
- Effect of refraction
- Simulation of eclipses

Thank you.

More Information:

github.com/cosmoscout/cosmoscout-vr

Contact Information:

simon.schneegans@dlr.de

sschneeg@uni-bremen.de

DLR

Universität
Bremen