Physically Based Real-Time Rendering of Atmospheres using Mie Theory

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Motivation & Scope

Our Goal:
Real-time rendering of extraterrestrial atmospheres based on **physical parameters**.

Possible Applications:
- Interactive space-mission planning
- Public outreach
- Computer games
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

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

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**However:**

• Absorption of blue light reduces destructive interference in forward direction

➢ **Blue glow around the Sun**

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• 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


Costa et al. use multiple parametric phase functions for RGB [2]
- Plausible colours during daytime
- Very wide and soft blue glow

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:
  - Complex **Refractive Index** of the atmospheric particles
  - Particle **Size Distribution** (e.g. Gaussian)
  - Particle **Density Distribution** as a function of altitude

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Evaluate Mie Theory
- For many scattering angles
- For various wavelengths

Evaluate Mie Theory

- Tabulated phase functions and extinction coefficients

Phase function of simulated Martian dust with 3% Hematite

In the forward direction, blue light dominates

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

Multiple Scattering Precomputation
- According to [1]

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

Real-Time Rendering
- According to [1]

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

Only a few texture lookups are required per pixel!

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
Chromaticity Results

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

Chromaticity Results

➢ We can explore the impact of hematite.

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Brightness Results

Compared to radiance measurements by the Mars Pathfinder [1]

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 extraterrestrial 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]?

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

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