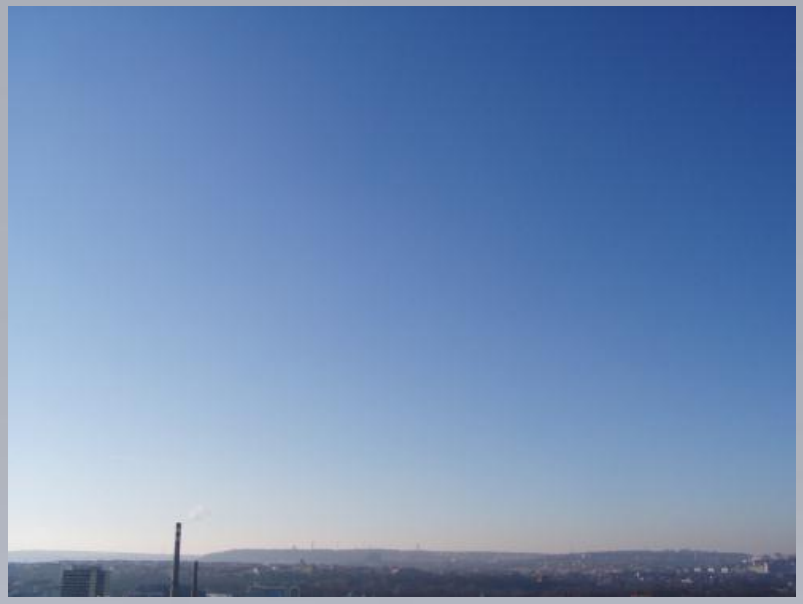
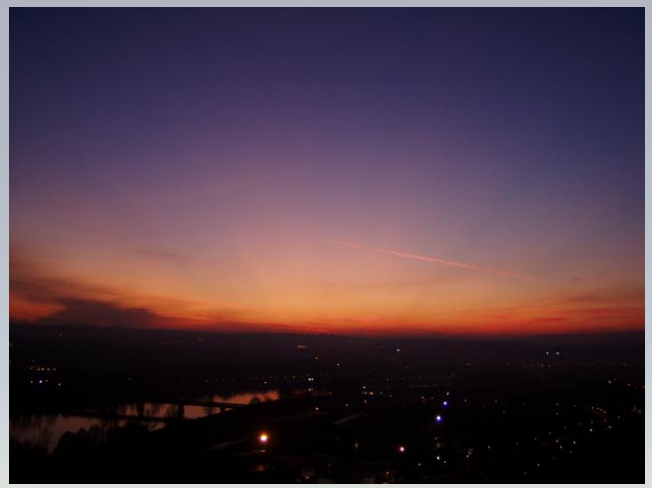
Oskar Elek and Petr Kmoch
Charles University, Prague

# Real-Time Spectral Scattering in Large-Scale Natural Participating Media

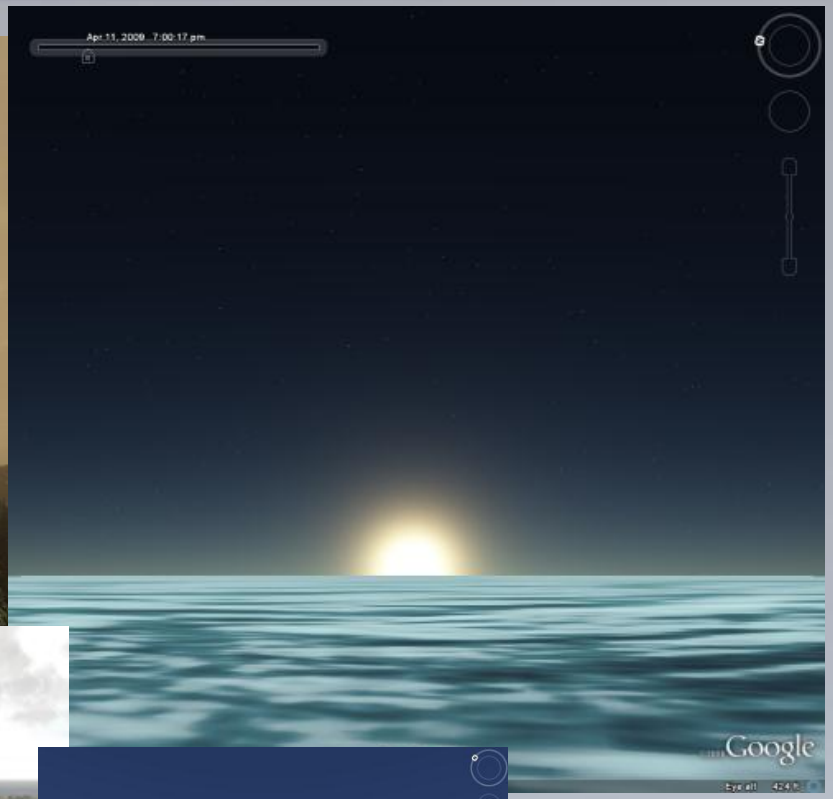
SCCG 2010

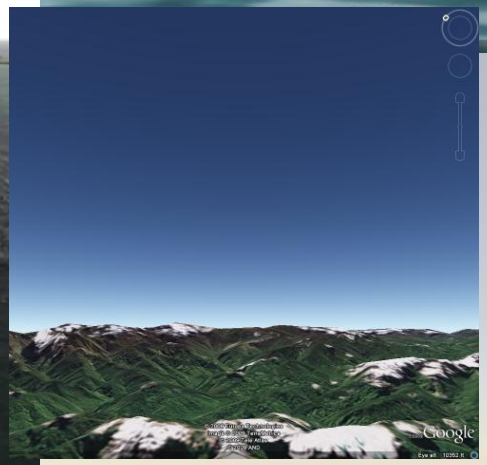
# Motivation





# Motivation



# Outline

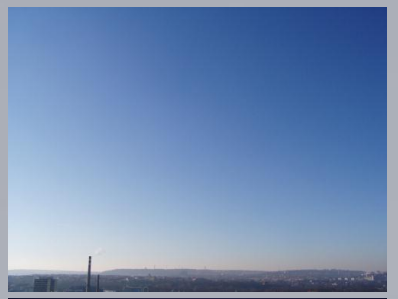
- Introduction
- Related work
- Physical model
- Precomputing scattering
  - Atmosphere
  - Water
  - Spectral precomputation
- Rendering
- Results
- Conclusion
- Demo

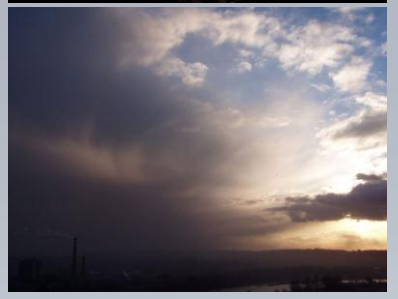
# Outline

- Introduction
- Related work
- Physical model
- Precomputing scattering
  - Atmosphere
  - Water
  - Spectral precomputation
- Rendering
- Results
- Conclusion
- Demo

# Introduction

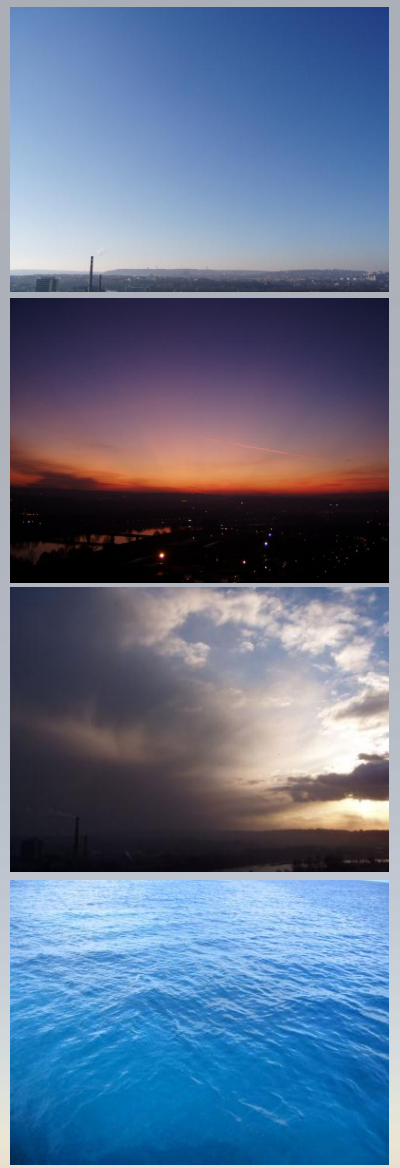
- **Participating media**






# Introduction

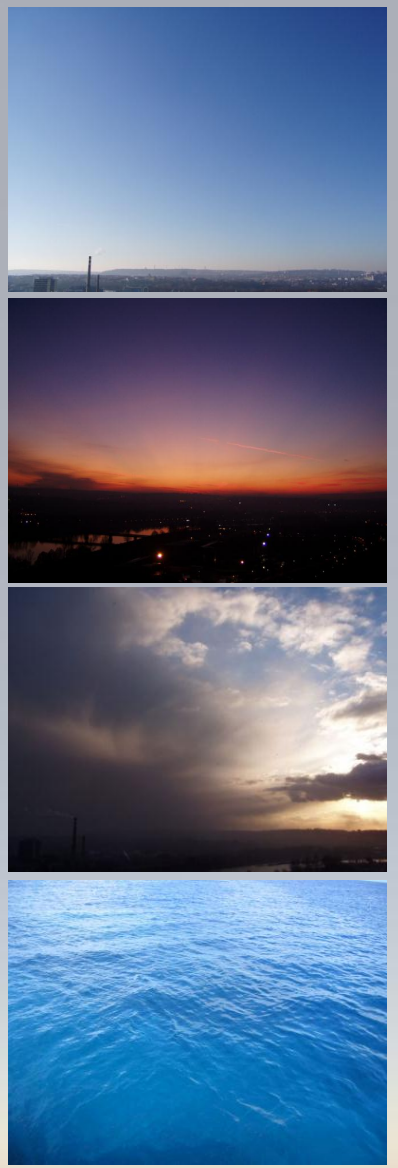
- Participating media
- Light scattering
  - Rayleigh/Mie scattering



# Introduction

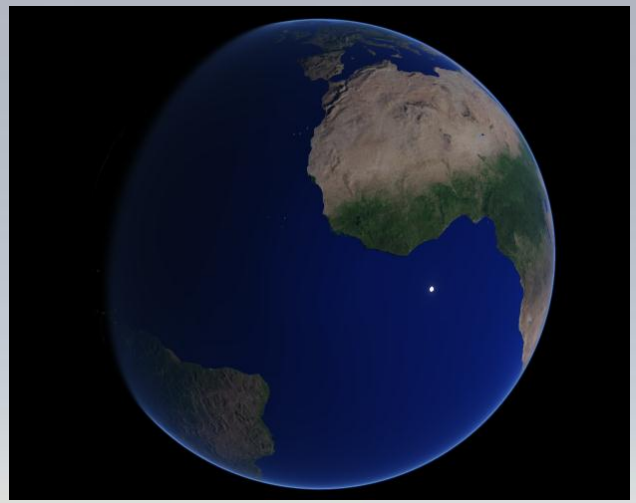
- Participating media
- Light scattering
  - Rayleigh/Mie scattering
  - Multiple scattering

Single scattering | Multiple scattering

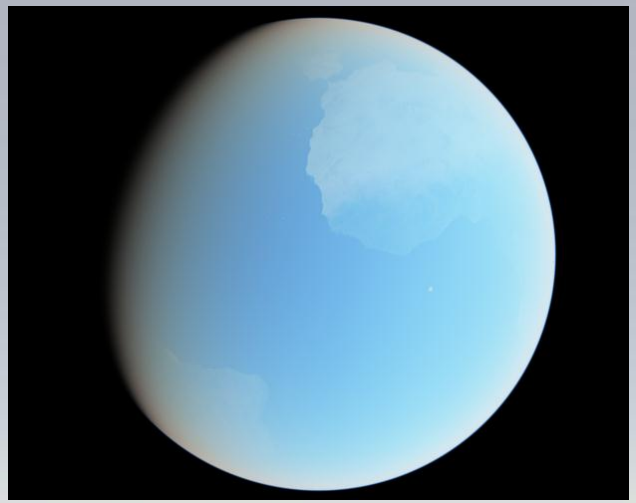


# Introduction

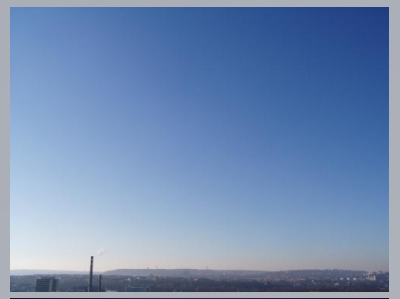
- Participating media
- Light scattering
  - Rayleigh/Mie scattering
  - Multiple scattering
  - Density variation

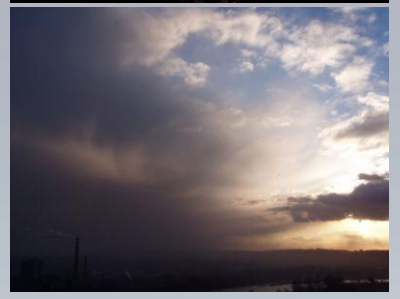


Sparse atmosphere



Dense atmosphere





# Outline

- Introduction
- Related work
- Physical model
- Precomputing scattering
  - Atmosphere
  - Water
  - Spectral precomputation
- Rendering
- Results
- Conclusion
- Demo

# Related Work

- **Physics**
  - **Rayleigh 1871, Mie 1908**

# Related Work

- **Physics**
  - **Rayleigh 1871, Mie 1908**
- **Atmospheric scattering**
  - **Non-RT – Nishita et al. 1993 & 1996, Haber et al. 2005**
  - **RT – Schafhitzel et al. 2007, Bruneton and Neyret 2008**

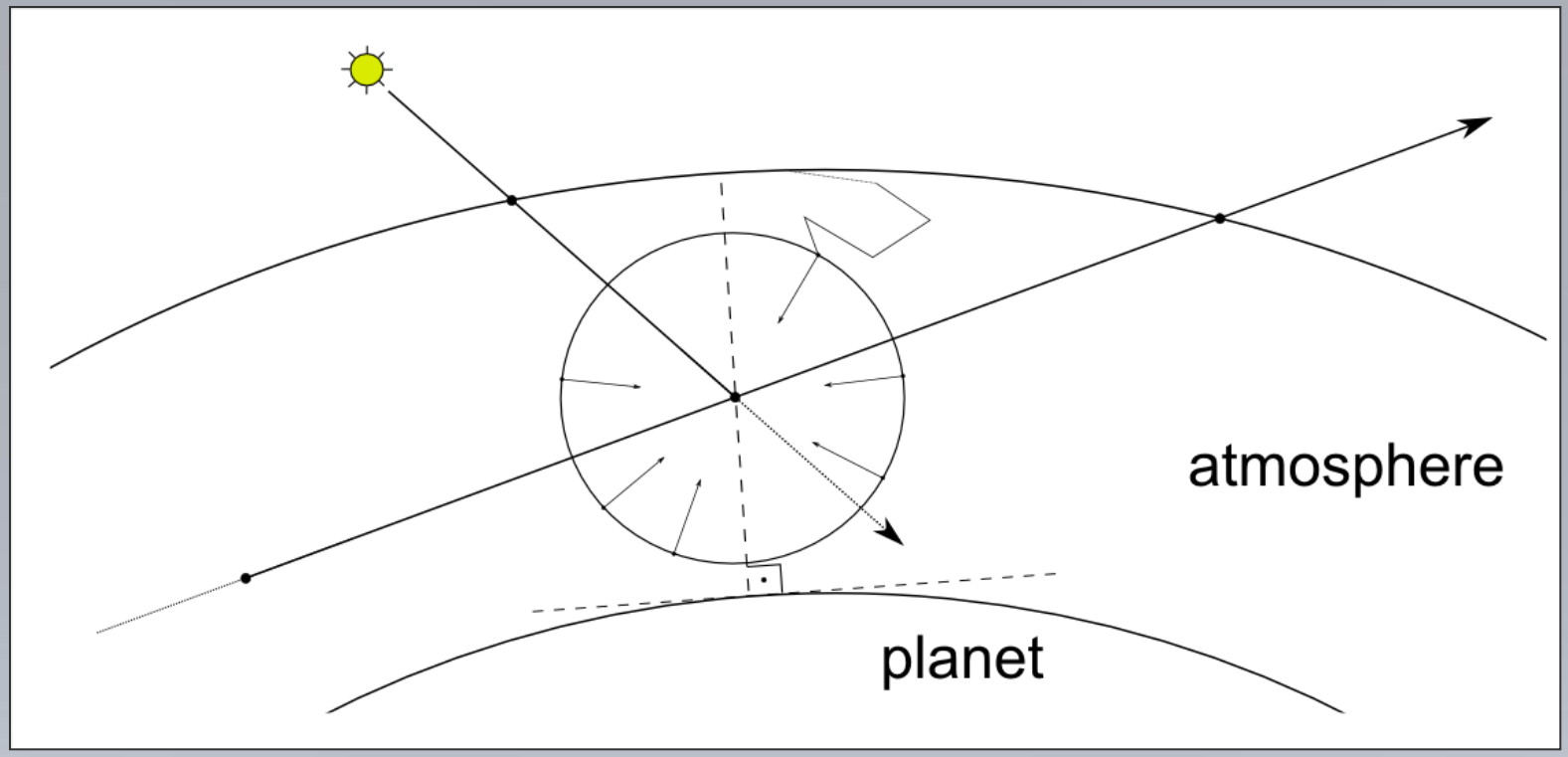
# Related Work

- **Physics**
  - **Rayleigh 1871, Mie 1908**
- **Atmospheric scattering**
  - **Non-RT – Nishita et al. 1993 & 1996, Haber et al. 2005**
  - **RT – Schafhitzel et al. 2007, Bruneton and Neyret 2008**
- **Aquatic scattering**
  - **Nishita et al. 1993, Iwasaki et al. 1996**
  - **Premoze and Ashikhmin 2000**

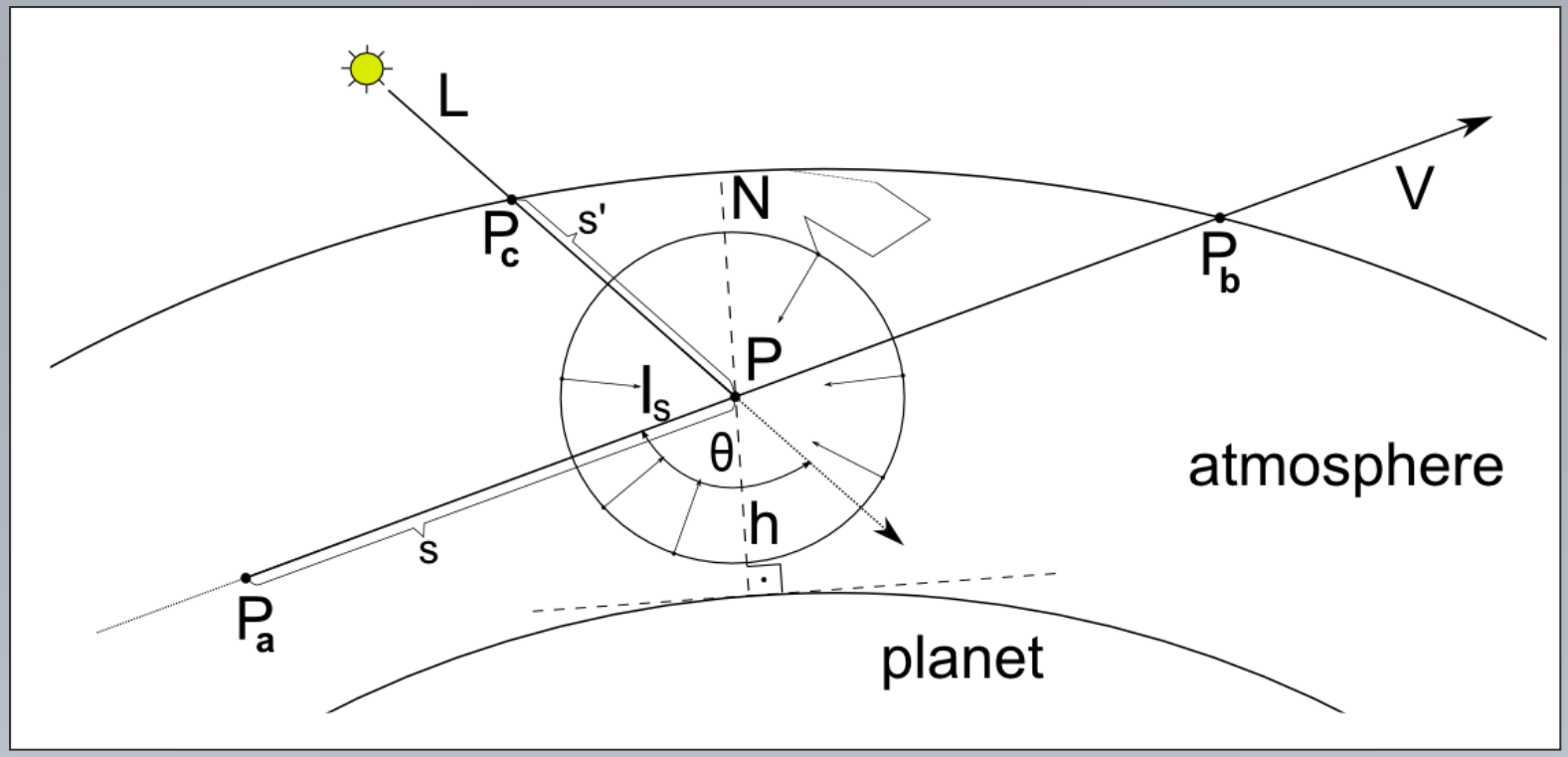
# Outline

- Introduction
- Related work
- Physical model
- Precomputing scattering
  - Atmosphere
  - Water
  - Spectral precomputation
- Rendering
- Results
- Conclusion
- Demo

# Physical Model



# Physical Model



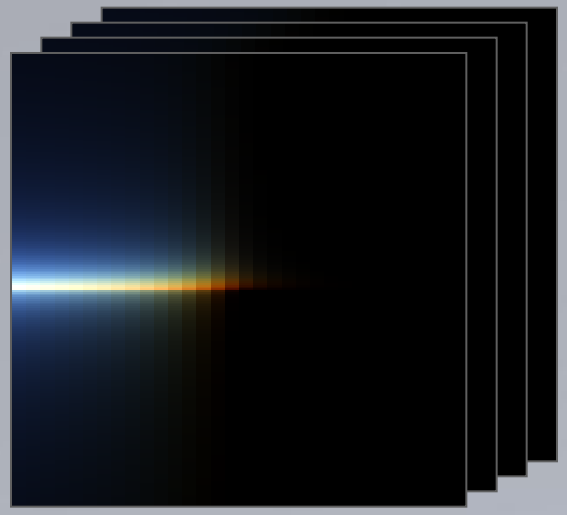

$$I_S(\lambda) = I_I(\lambda) F(\theta) \frac{\beta(\lambda)}{4\pi} \int_{P_a}^{P_b} \rho(h) \exp(-t(PP_c, \lambda) - t(P_a P, \lambda)) ds$$

# Outline

- Introduction
- Related work
- Physical model
- Precomputing scattering
  - Atmosphere
  - Water
  - Spectral precomputation
- Rendering
- Results
- Conclusion
- Demo

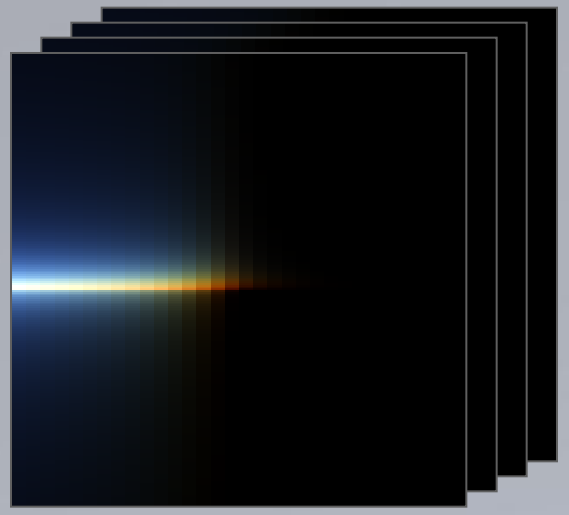
# Precomputing Scattering - Atmosphere

- **Stored in 4D texture for every:**
  - » **Sun zenith angle**
  - » **View zenith angle**
  - » **Sun azimuth**
  - » **Observer altitude**



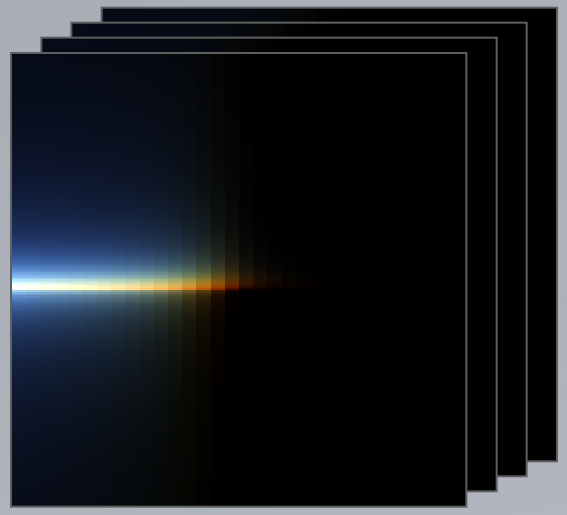
# Precomputing Scattering - Atmosphere

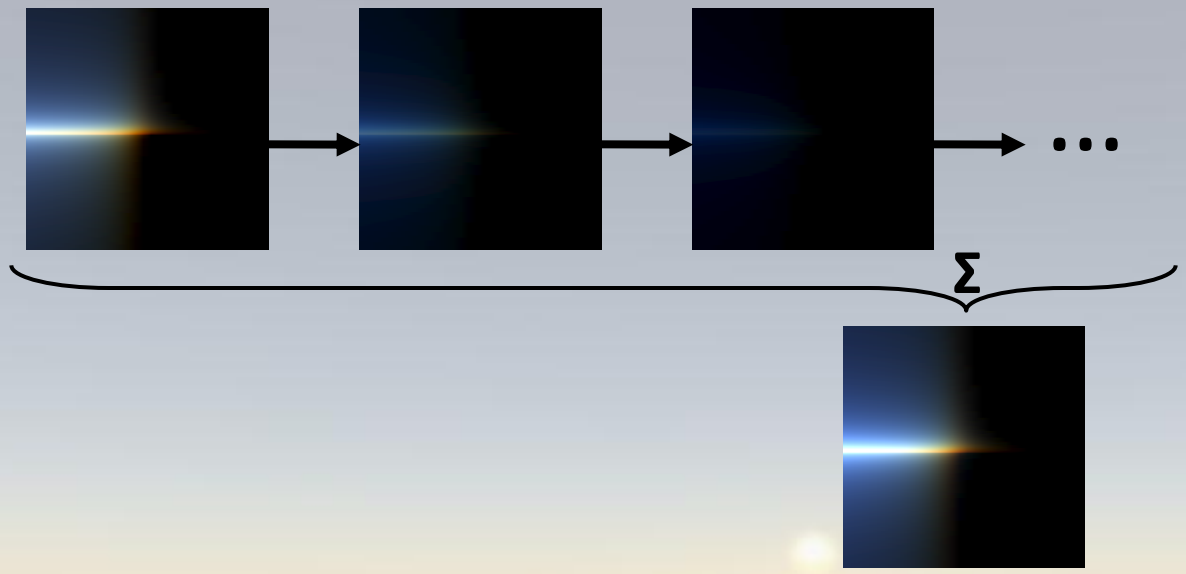
- Stored in 4D texture
- Nonlinear parametrization from Bruneton and Neyret 2008



# Precomputing Scattering - Atmosphere

- Stored in 4D texture
- Nonlinear parametrization from Bruneton and Neyret 2008
- Incremental computation of multiple scattering






Final 4D texture

# Precomputing Scattering - Water

- **Similar to atmospheric scattering**
  - **Physical model**
  - **Precomputation algorithm**

# Precomputing Scattering - Water

- Similar to atmospheric scattering
  - Physical model
  - Precomputation algorithm
- Differences
  - Parametrization
  - Absorption
  - Physical constants
  - Various water depths
  - Atmospheric scattering consideration

# Spectral Precomputation

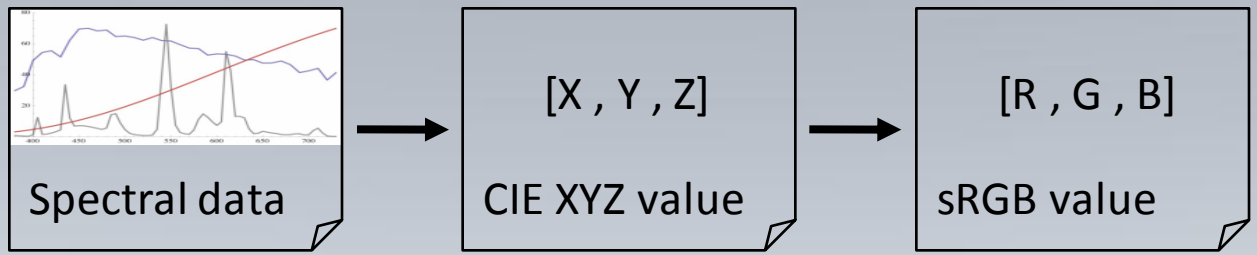
- **Computation in RGB space is neither accurate, nor correct!**

# Spectral Precomputation

- Computation in RGB space is neither accurate, nor correct!
- Entire precomputation now spectral
  - Physical data
  - Tables

# Spectral Precomputation

- **Computation in RGB space is neither accurate, nor correct!**
- **Entire precomputation now spectral**
  - **Physical data**
  - **Tables**
- **Conversion**



# Outline

- Introduction
- Related work
- Physical model
- Precomputing scattering
  - Atmosphere
  - Water
  - Spectral precomputation
- Rendering
- Results
- Conclusion
- Demo

# Rendering

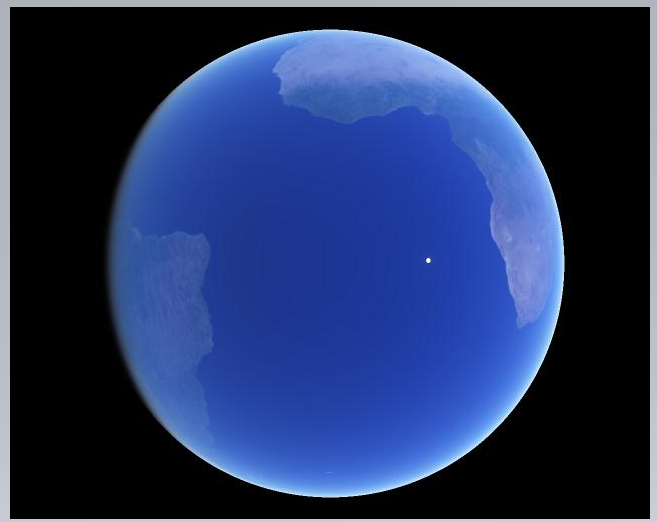
- **GPU – Fragment shader evaluation**

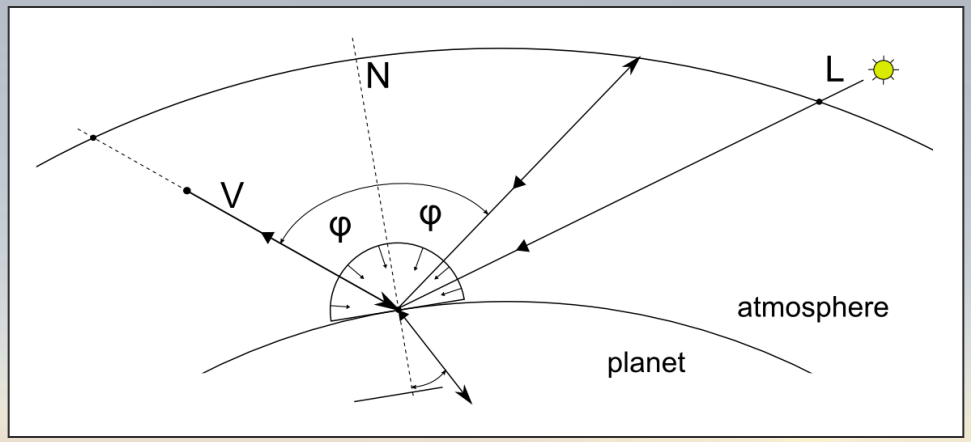
# Rendering

- GPU – Fragment shader evaluation
- Atmosphere
  - Plain sphere
  - Texture lookup (spatial position)

# Rendering

- GPU – Fragment shader evaluation
- Atmosphere
  - Plain sphere
  - Texture lookup (spatial position)
- Planetary surface
  - Atmospheric scattering
  - Surface reflection
  - Water scattering





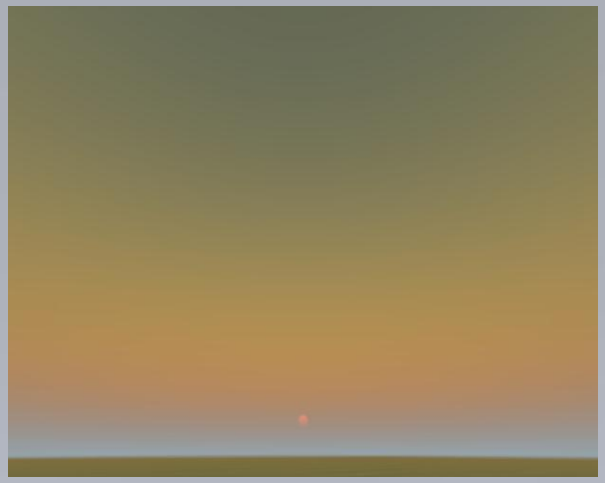
# Outline

- Introduction
- Related work
- Physical model
- Precomputing scattering
  - Atmosphere
  - Water
  - Spectral precomputation
- Rendering
- Results
- Conclusion
- Demo

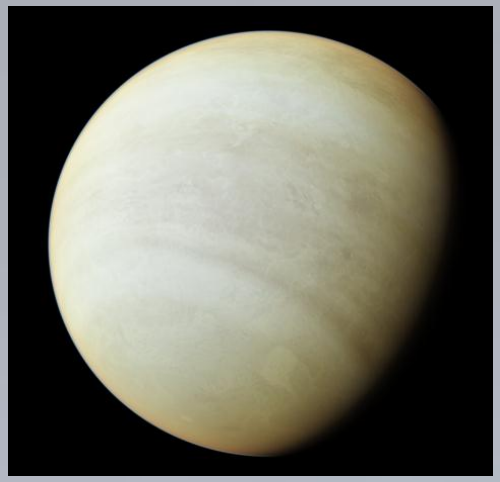
# Results

- **Varying density**

10x sparser



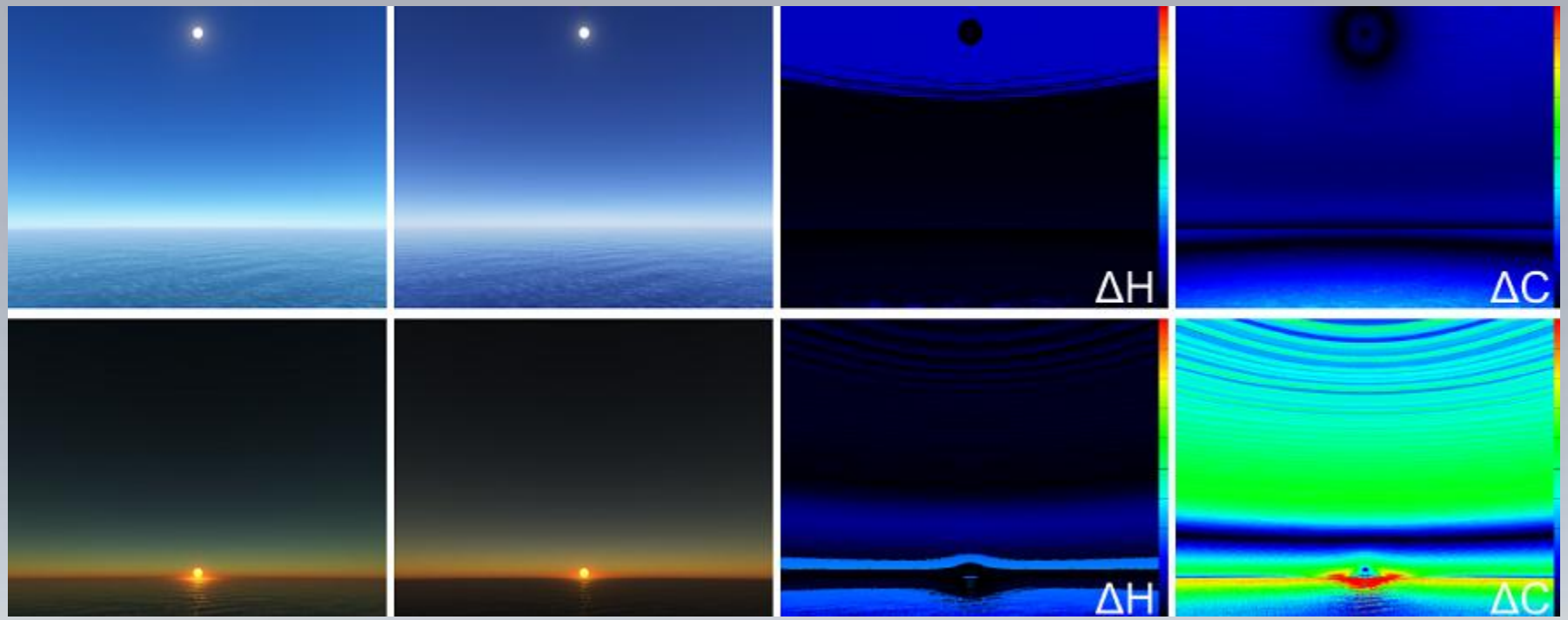
10x denser



Venus

# Results

- Varying density
- **Spectral computation**




RGB images  Spectral images

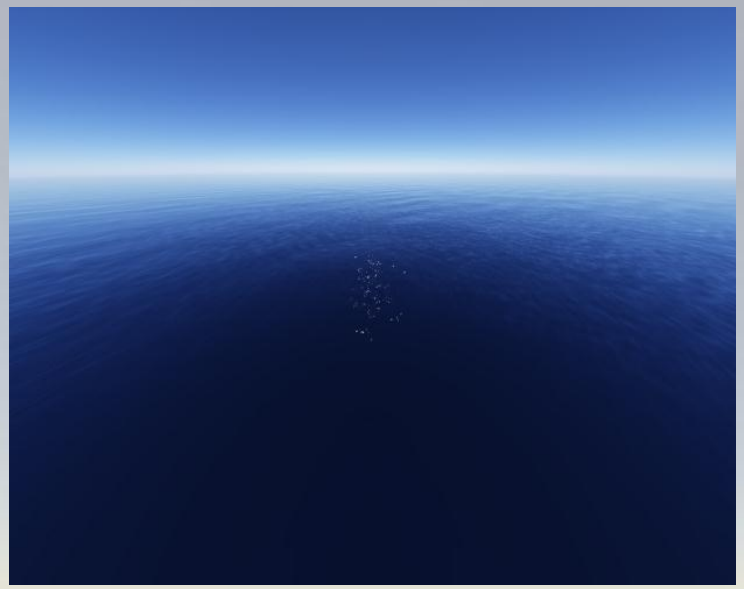
# Results

- Varying density
- Spectral computation
- **Water depth**

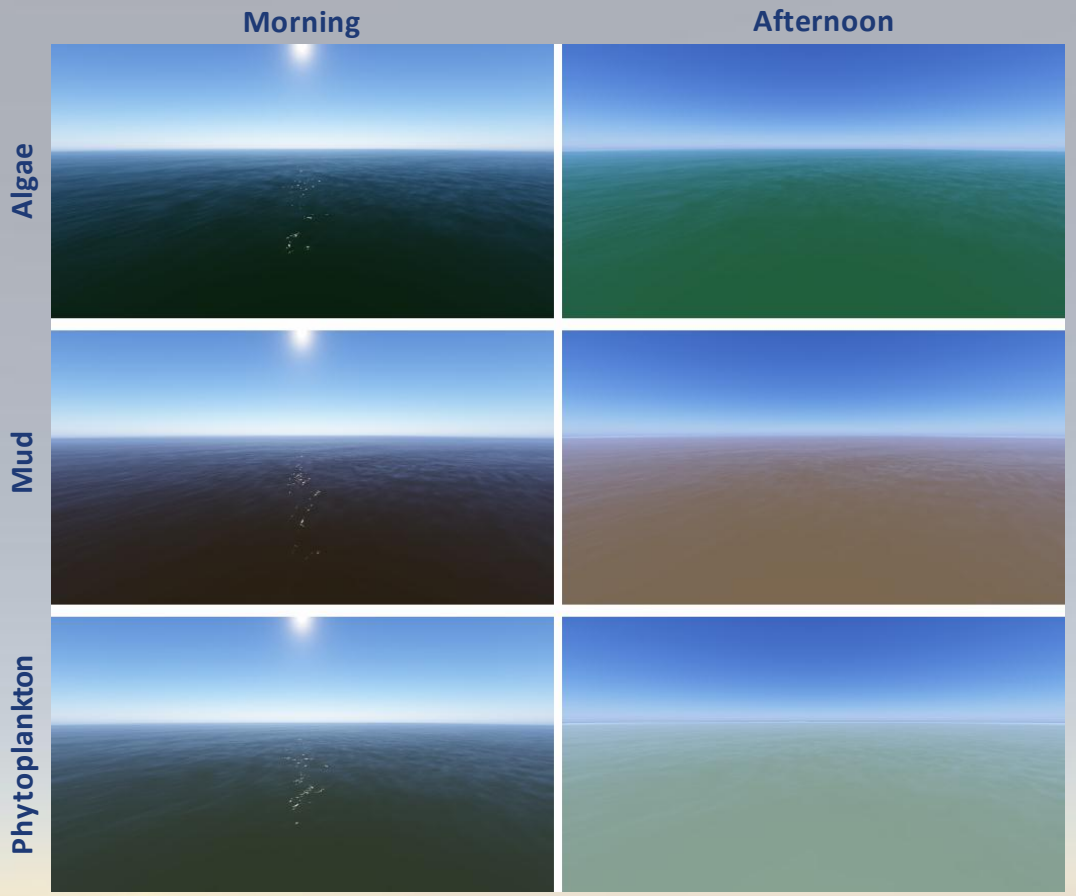
1 meter | 4 meters | 10 meters | 100 meters

# Results

- Varying density
- Spectral computation
- Water depth
- **Water composition**



Pure seawater



# Outline

- Introduction
- Related work
- Physical model
- Precomputing scattering
  - Atmosphere
  - Water
  - Spectral precomputation
- Rendering
- Results
- Conclusion
- Demo

# Conclusion

- **Precomputation**
  - **On CPU or GPU**
  - **Dataset ~10MB**

# Conclusion

- **Precomputation**
  - **On CPU or GPU**
  - **Dataset ~10MB**
- **Rendering**
  - **180 fps (@ 1024x768) and 30 fps (@ 2560x2048) – GeForce 8800GT**

# Conclusion

- **Precomputation**
  - On CPU or GPU
  - Dataset ~10MB
- **Rendering**
  - 180 fps (@ 1024x768) and 30 fps (@ 2560x2048) – GeForce 8800GT
- **Contributions**
  - Formula for arbitrary atmosphere density
  - Water scattering
  - Spectral calculations

# Conclusion

- Precomputation
  - On CPU or GPU
  - Dataset ~10MB
- Rendering
  - 180 fps (@ 1024x768) and 30 fps (@ 2560x2048) – GeForce 8800GT
- Contributions
  - Formula for arbitrary atmosphere density
  - Water scattering
  - Spectral calculations
- Future work
  - Local density variation

# Conclusion

- Precomputation
  - On CPU or GPU
  - Dataset ~10MB
- Rendering
  - 180 fps (@ 1024x768) and 30 fps (@ 2560x2048) – GeForce 8800GT
- Contributions
  - Formula for arbitrary atmosphere density
  - Water scattering
  - Spectral calculations
- Future work
  - Local density variation
- Utilization

# Outline

- Introduction
- Related work
- Physical model
- Precomputing scattering
  - Atmosphere
  - Water
  - Spectral precomputation
- Rendering
- Results
- Conclusion
- Demo

# End

**Thanks!**

**Questions?**