High-Performance Graphics HPG
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FAST PLANETARY SHADOWS USING FOURIER-COMPRESSED HORIZON MAPS

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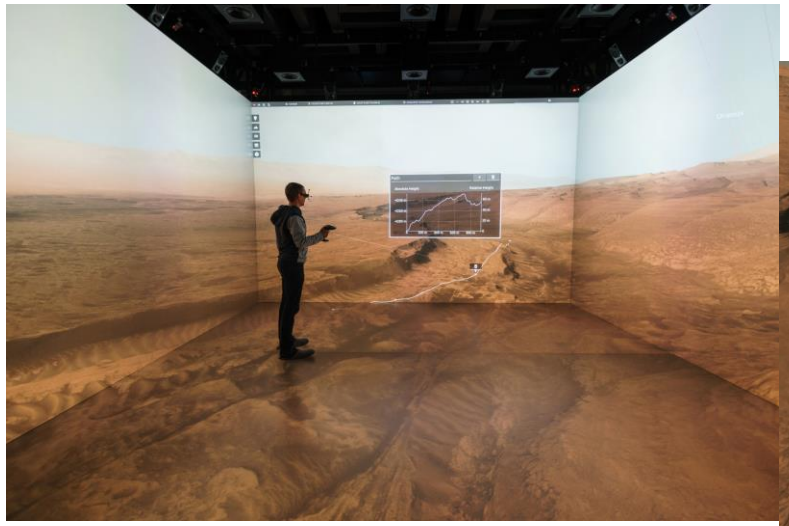
Scope

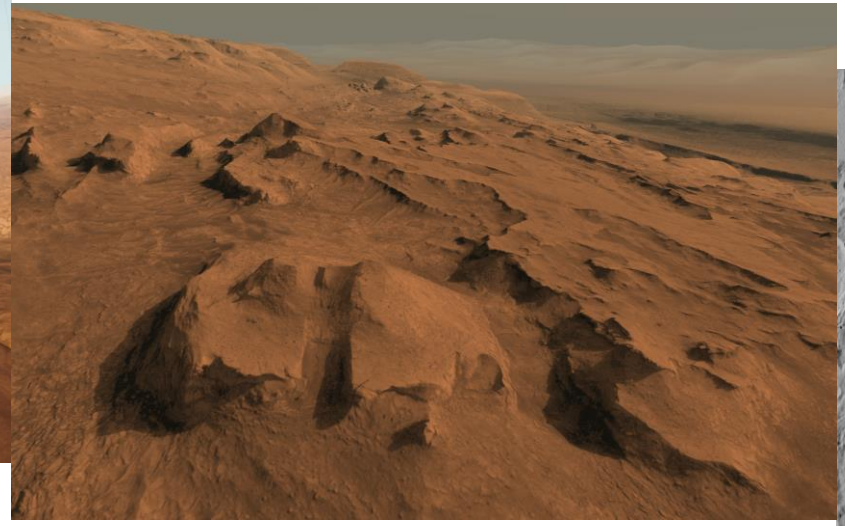
Fast Shadows

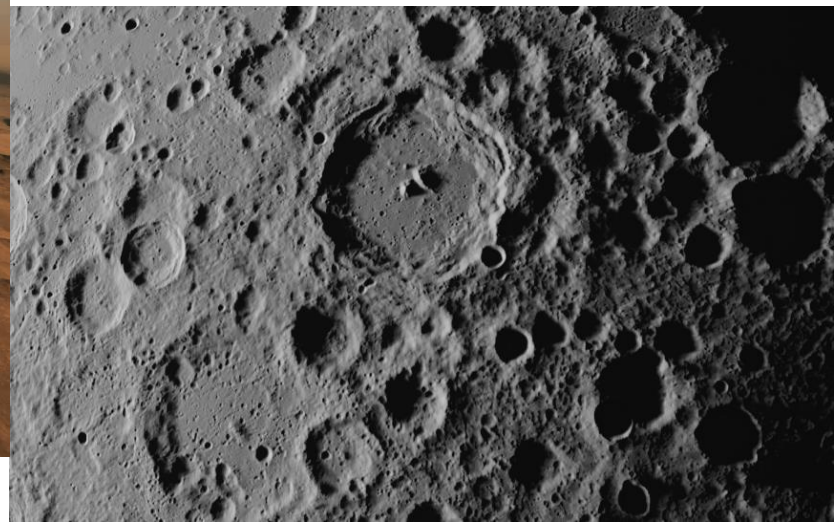
- Real time capable
- Support virtual reality systems

Planetary (Soft) Shadows

- Self shadowing for large scale, planetary terrains
- Requiring out of core storage

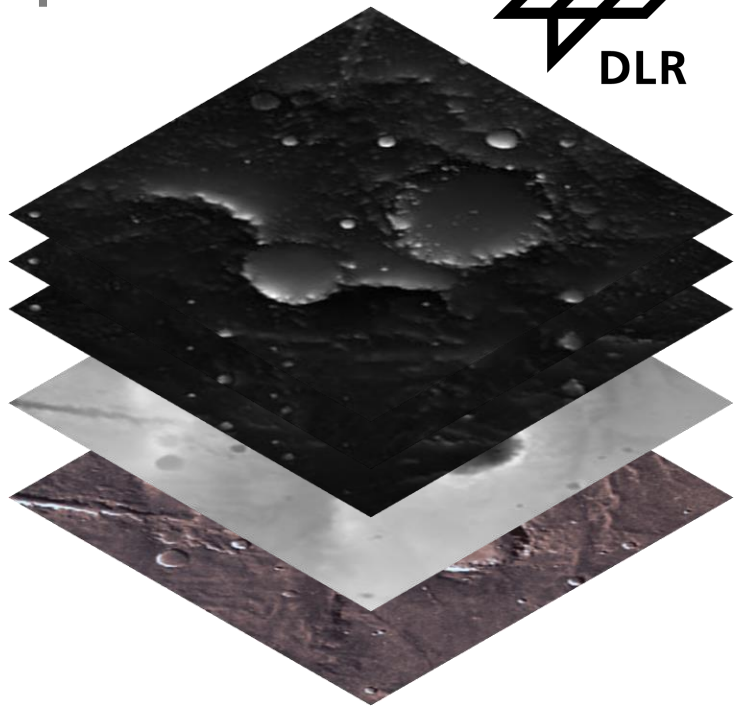






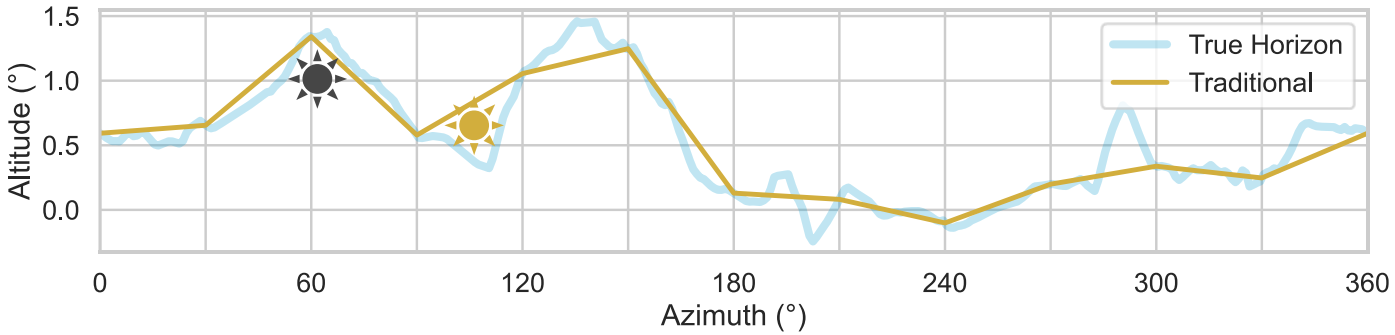
Fast Planetary Shadows using Fourier-Compressed **Horizon Maps**

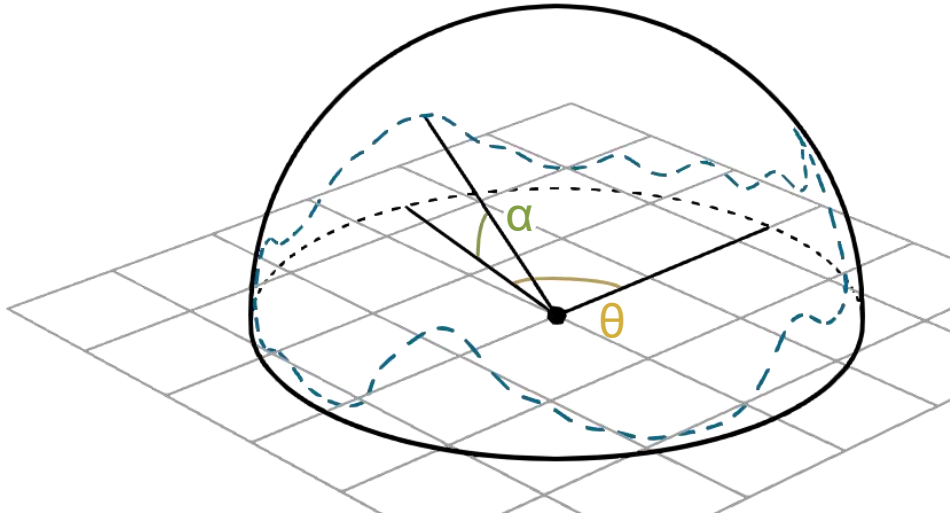
Traditional Horizon Mapping [1]



Core Idea

- Let *Horizon* = Border between sky and ground as viewed from a given point
- Terrains represented by 2D-heightmaps can have neither overhangs nor caves
  → Horizon forms continuous and periodic function in polar coordinates
- Compare altitude α_s of light source to altitude α_h of horizon to determine lighting
- Resolution reduced to 8/12 samples at fixed azimuths for storage
- Horizon function is modeled as linear interpolation between 8 support points at fixed azimuths
- Per pixel horizon is stored in additional texture layer: *Horizon Map*

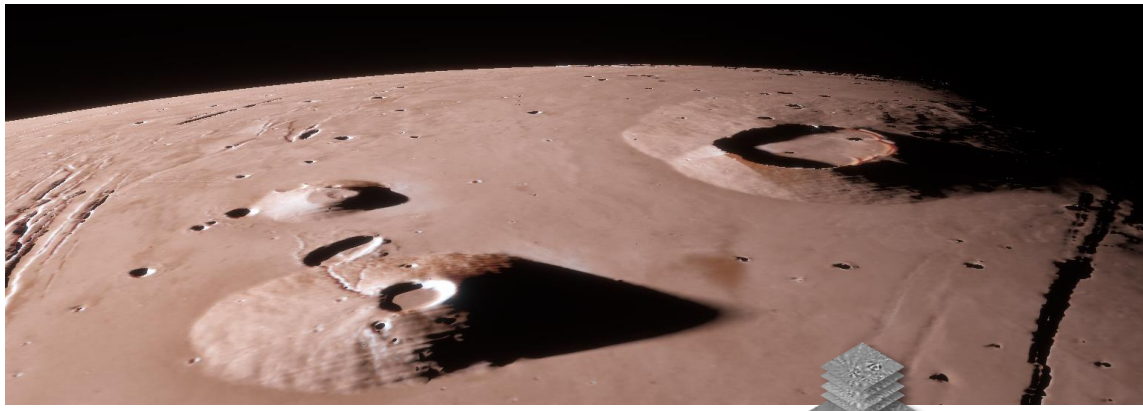


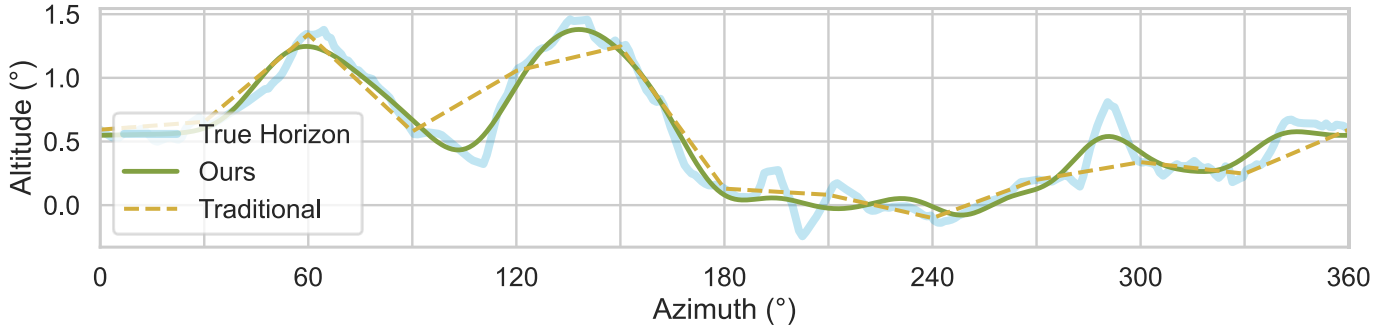


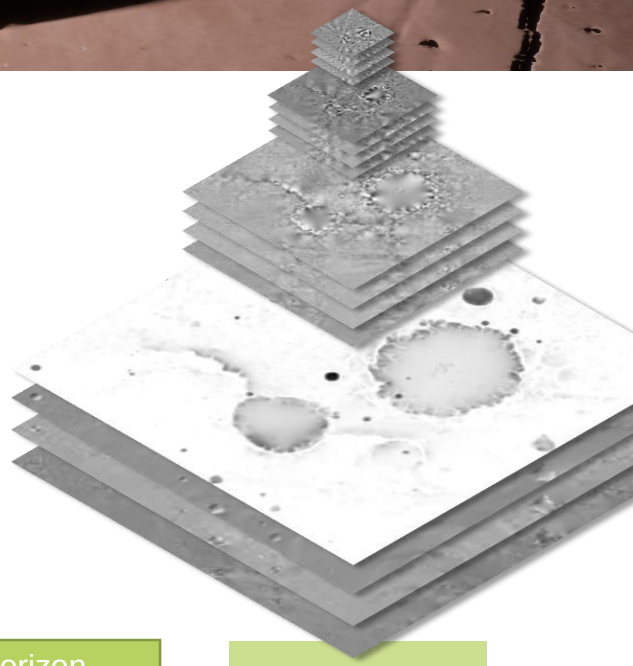
[1] N. L. Max: Horizon mapping: shadows for bump-mapped surfaces. The Visual Computer 4, 2 (Mar. 1988)

Our Method

- Represent horizons as Truncated Fourier series
  - Stored in a single multi-resolution texture file
- Trades high frequency features for more consistent shadows
- Across all azimuths, results in higher average accuracy than traditional horizon mapping



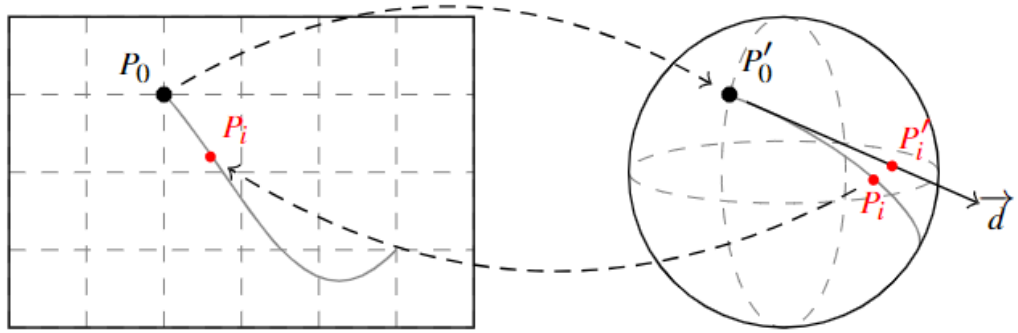




Preprocessing

Horizon Calculation

- First, compute horizon map from given terrain heightmap
- For each pixel, trace geodesic lines across terrain in 360 azimuthal directions
- For our proof-of-concept, a brute-force approach was viable
- For highly detailed terrain models, more efficient algorithms [2] should be used



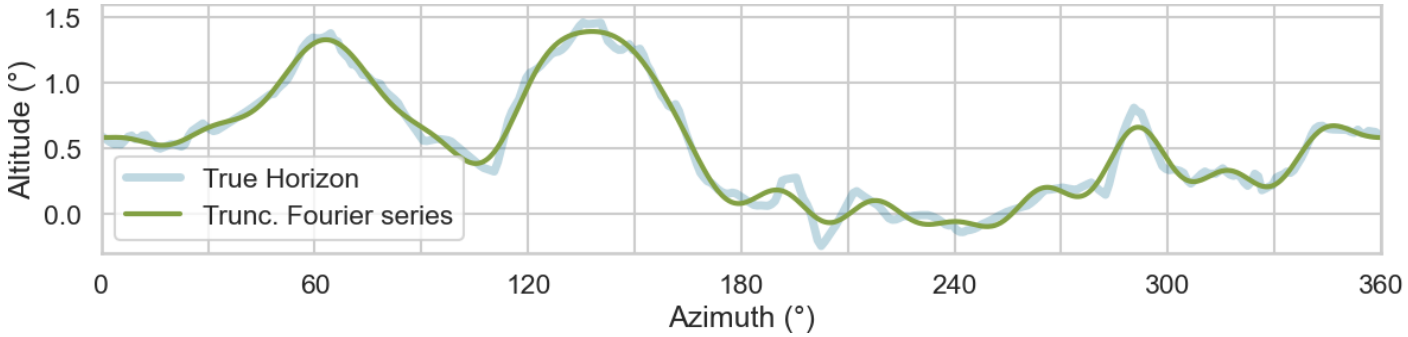
[2] A. Stewart: Fast horizon computation at all points of a terrain with visibility and shading applications. IEEE Transactions on Visualization and Computer Graphics 4, 1 (Jan 1998)

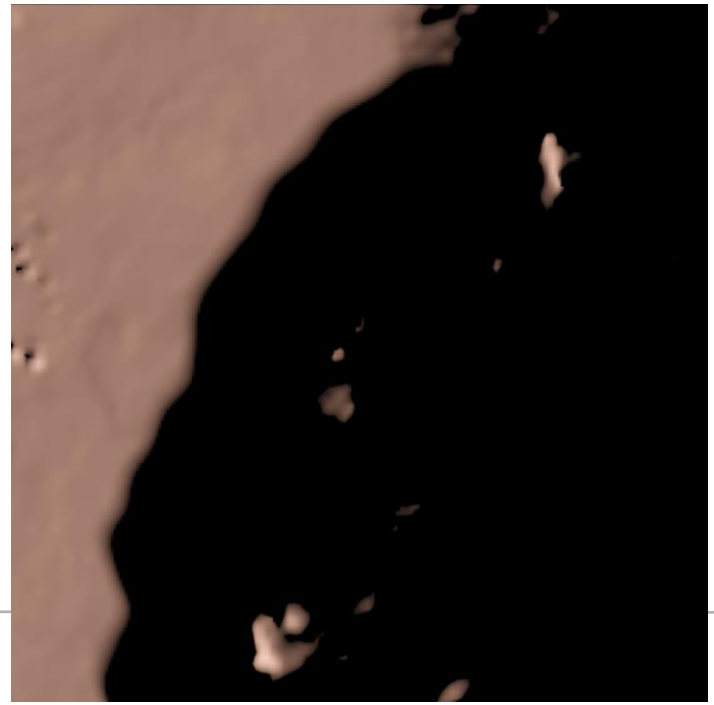
High Res. Horizon Calculation → Discrete Fourier Transform → Truncate Fourier Series → Reduce Bit Depth → Multi-Resolution Pyramid → Horizon Altitude Reconstruction → Compute Solar Visibility

Preprocessing

Truncated Fourier Series

- Apply a discrete Fourier Transform to each individual high res. Horizon
  - Lossless, e.g. 360 real horizon samples → 181 complex Fourier coefficients
- Truncate Fourier series to 16 complex coefficients
- Shadows lose high frequency details but stay spatially consistent





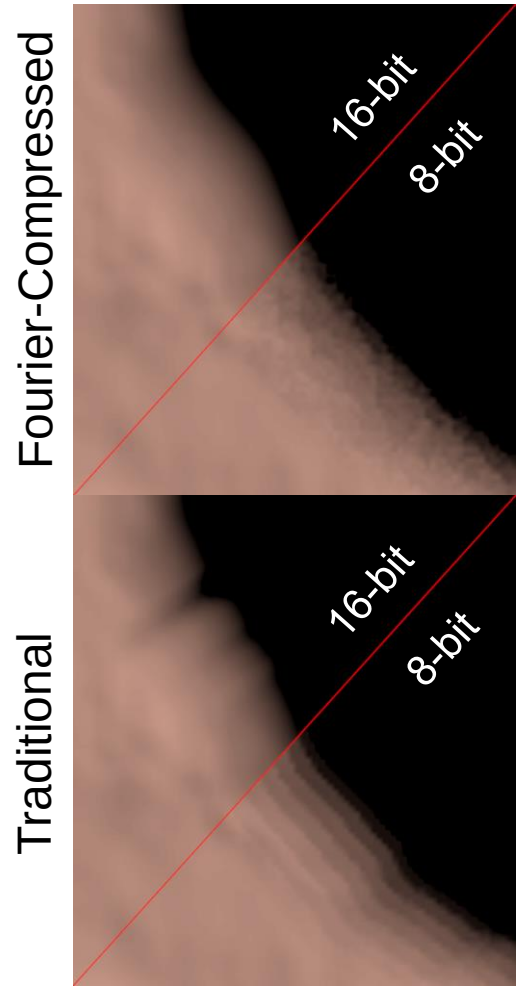
High Res. Horizon Calculation → Discrete Fourier Transform → Truncate Fourier Series → Reduce Bit Depth → Multi-Resolution Pyramid

Preprocessing

Reduce Bit Depth

- 32 bit → 16 bit: No noticeable changes
- 16 bit → 8 bit: Significant artifacts for both horizon models

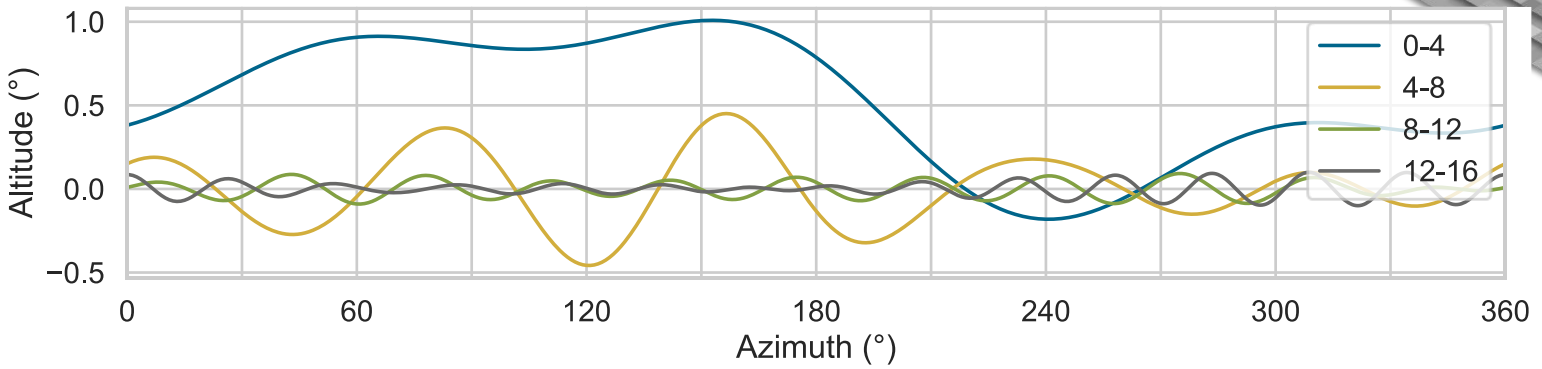
- We use 16 bit floating point scalars (32 bit per complex number)

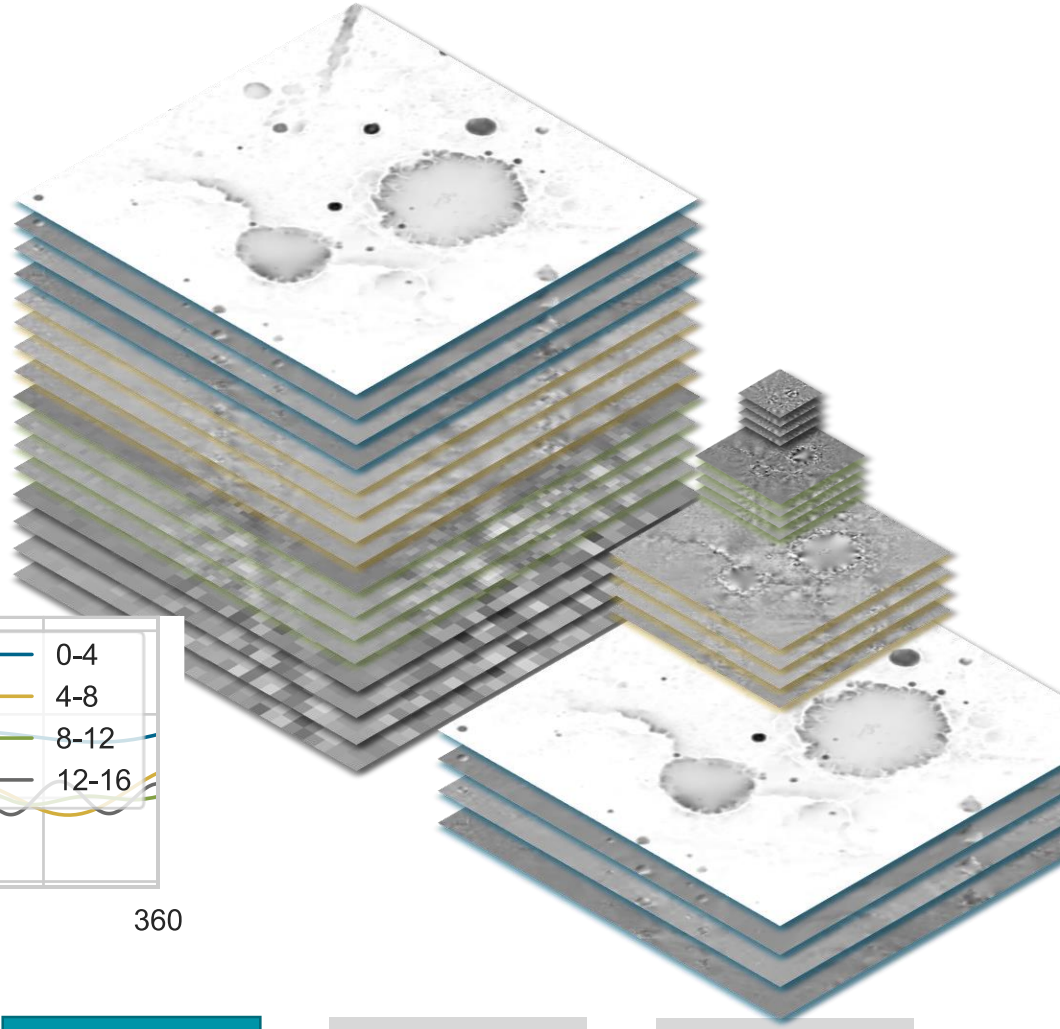


Preprocessing

Multi-Resolution Pyramid

- Key step to achieve accurate results at low memory
- Decrease spatial (u-v) resolution of some coefficients
- 4 lowest frequency coefficients at full resolution
- 4 highest frequency coefficients at eigth resolution





High Res. Horizon Calculation → Discrete Fourier Transform → Truncate Fourier Series → Reduce Bit Depth → **Multi-Resolution Pyramid** → Horizon Altitude Reconstruction → Compute Solar Visibility

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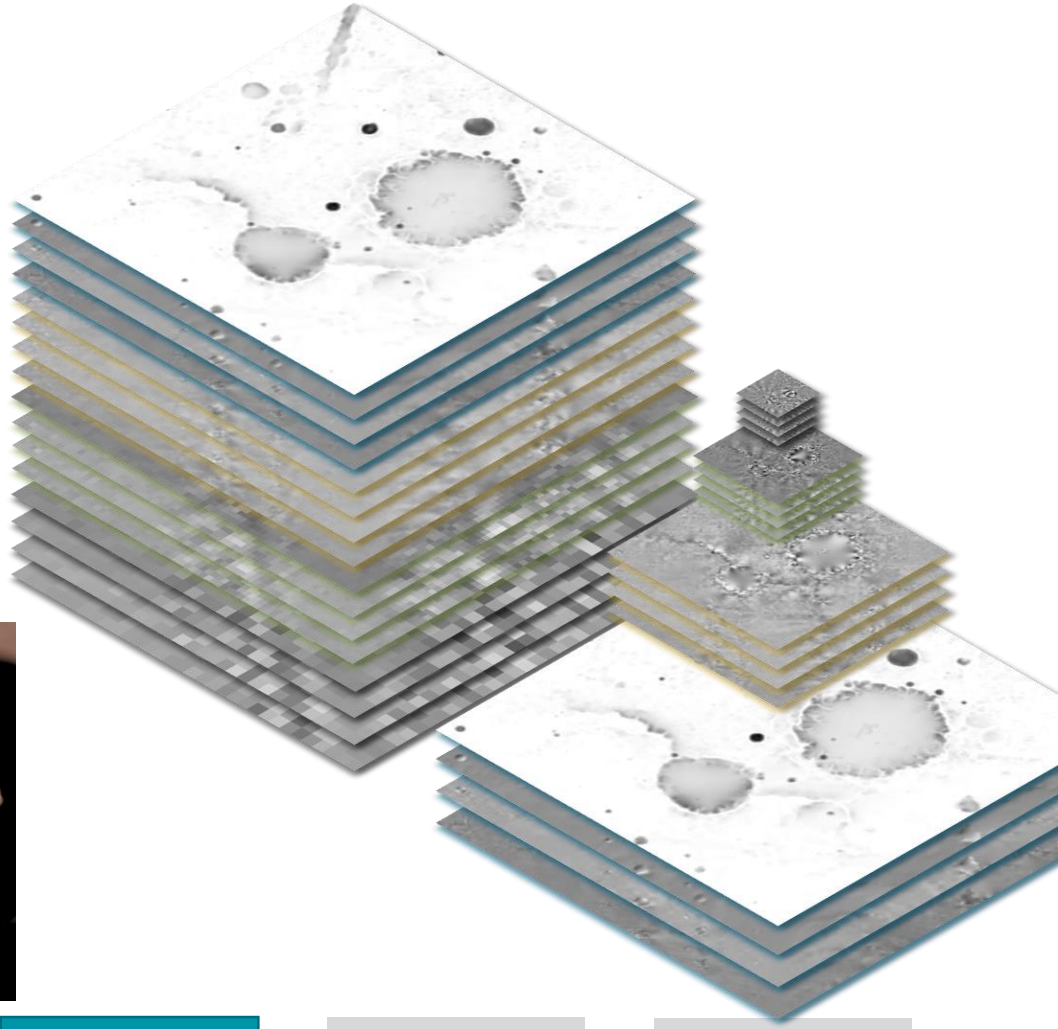
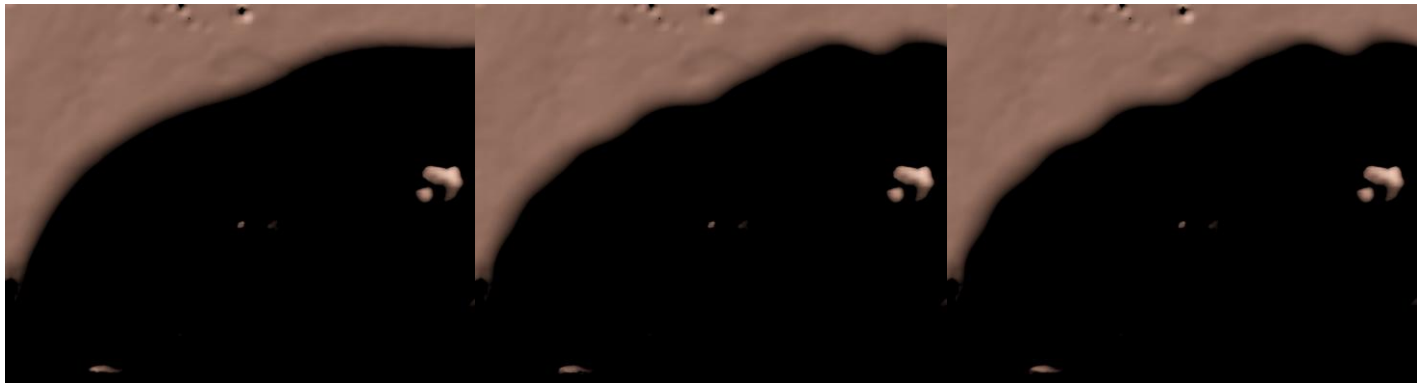


6 Coeffs., Full res. | 16 Coeffs., Multi res. | 16 Coeffs., Full res.



High Res. Horizon Calculation → Discrete Fourier Transform → Truncate Fourier Series → Reduce Bit Depth → **Multi-Resolution Pyramid** → Horizon Altitude Reconstruction → Compute Solar Visibility

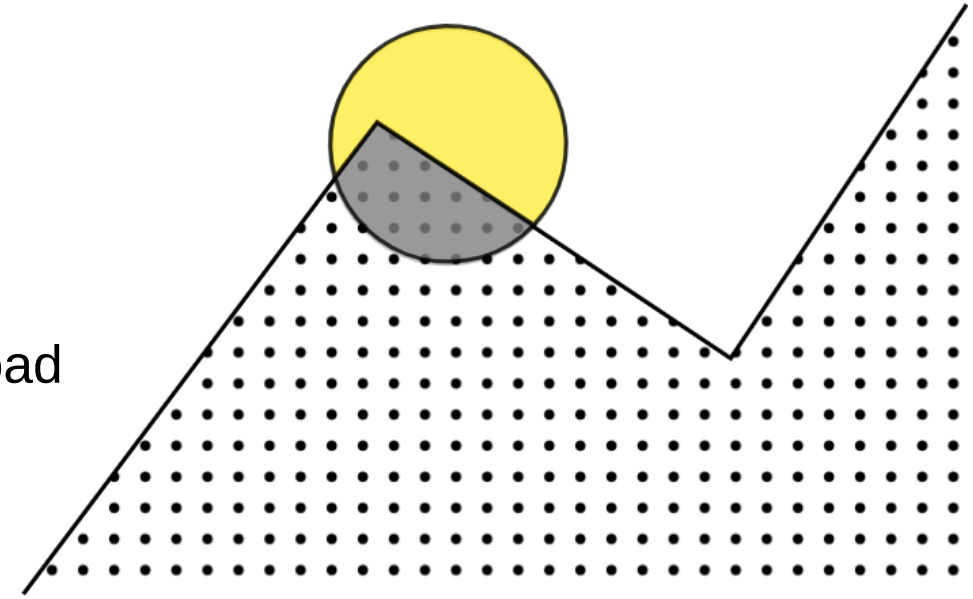
Runtime

Soft Shadows

- Attenuation of light depends on intersection area between light source and horizon
- Horizon altitude around solar azimuth has to be reconstructed
  - Sum up all basis functions for each azimuth

$$\alpha_h = \sum_{k=0}^{N-1} \left(X_k^r \cdot \cos\left(k\theta_s\right) - X_k^i \cdot \sin\left(k\theta_s\right)\right)$$

- Approximate intersection to reduce computational load

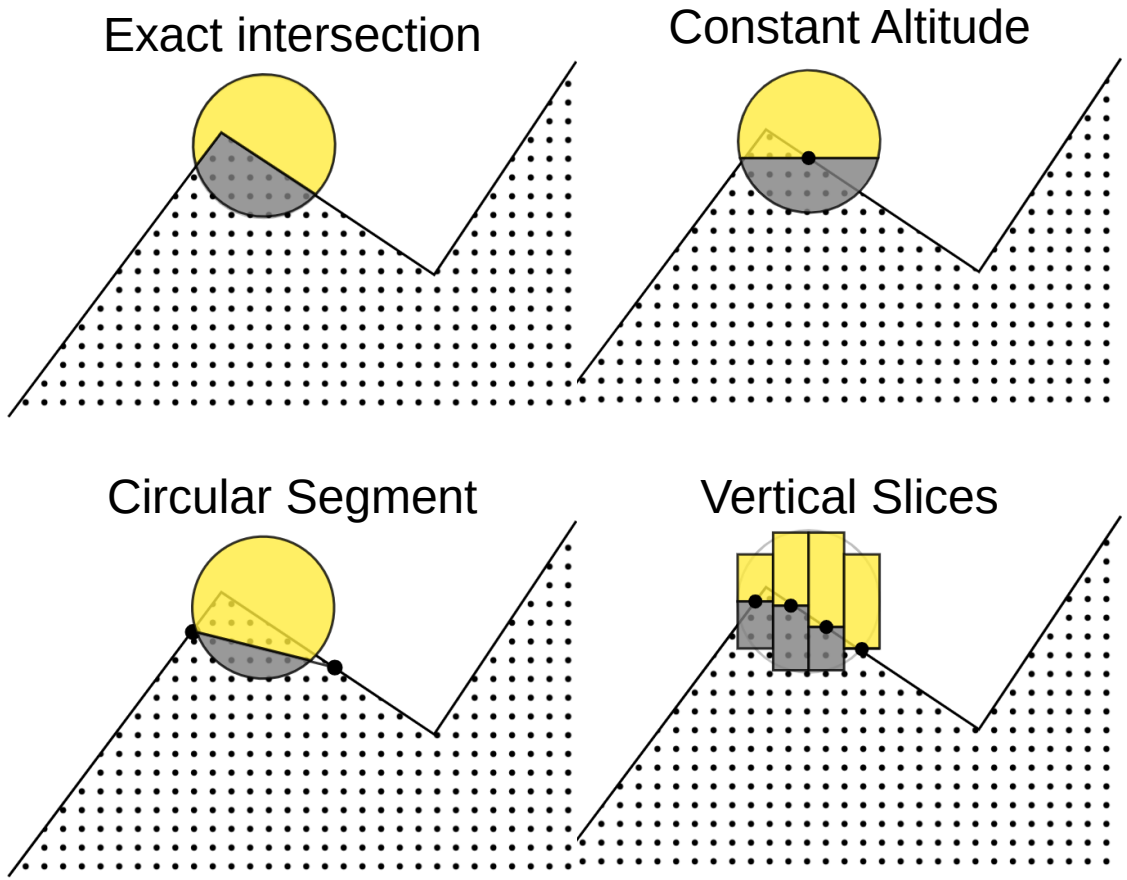


High Res. Horizon Calculation → Discrete Fourier Transform → Truncate Fourier Series → Reduce Bit Depth → Multi-Resolution Pyramid → **Horizon Altitude Reconstruction** → Compute Solar Visibility

Runtime

Intersection Approximations

- **Constant Altitude:** As used by Max [1]. Assume horizon has constant altitude across solar disk
- **Circular Segment:** Assume constant slope between θ_s +- r_s
- **Vertical Slices:** Numerically approximate integral of intersection
- *Constant Altitude* has proven to produce good results at low computational cost



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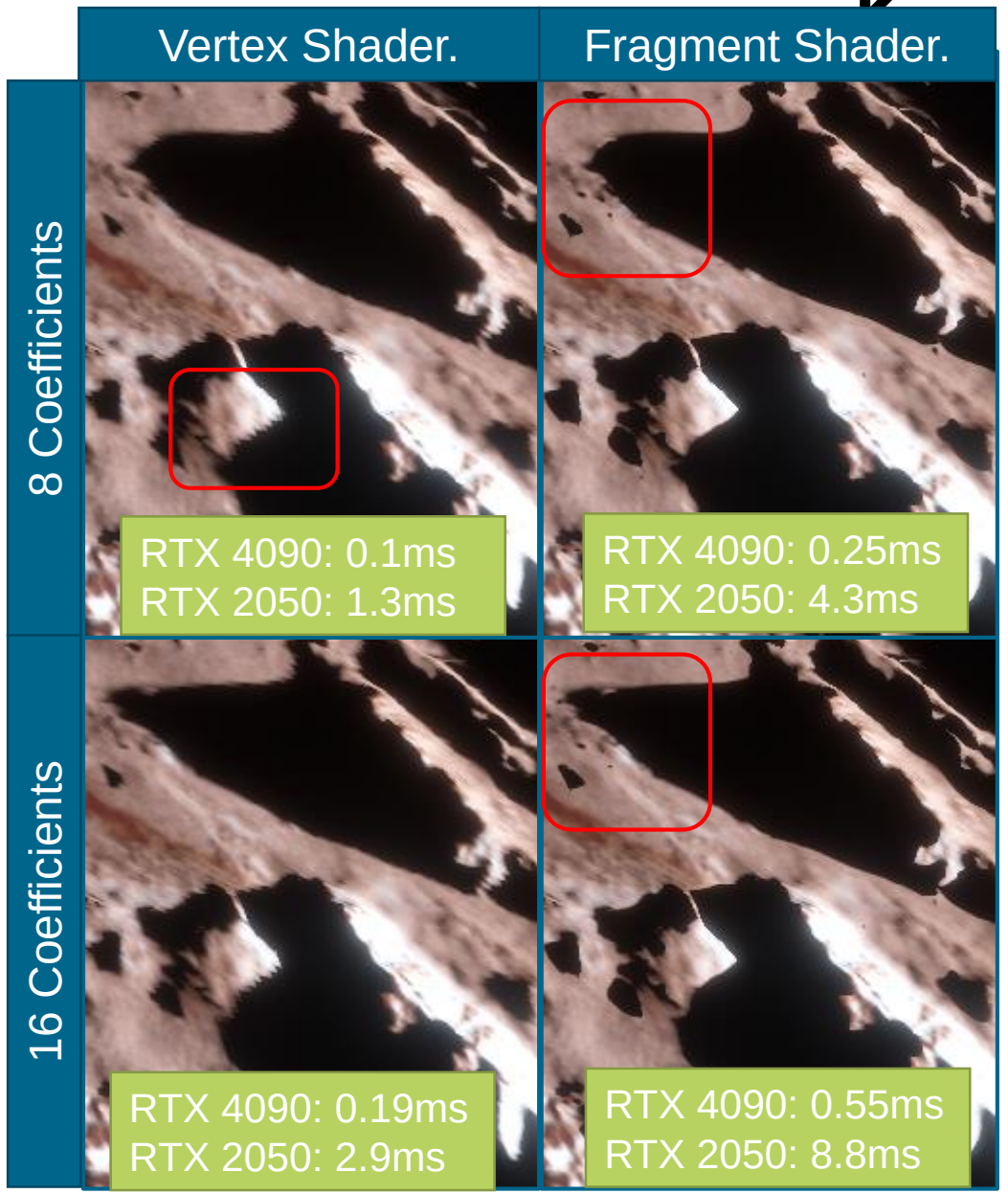
Evaluation

Performance

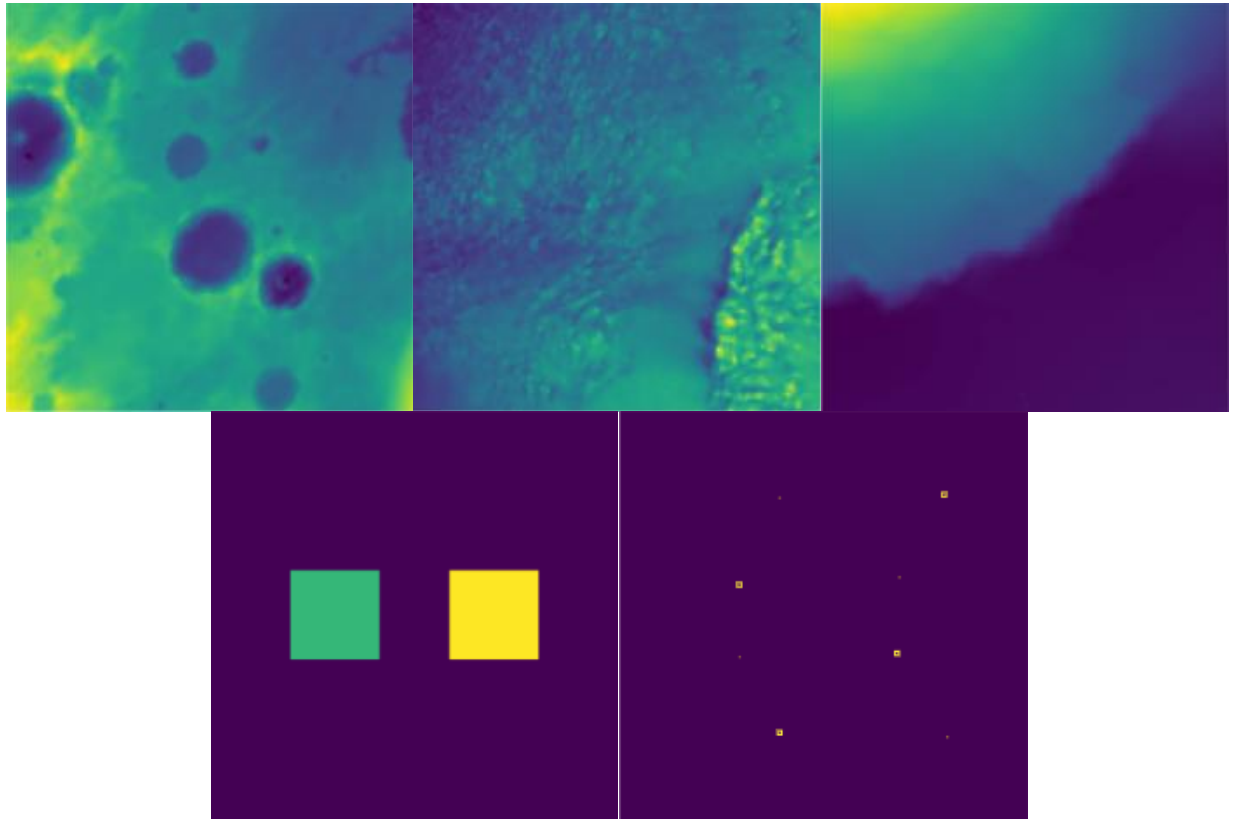
- Implemented in CosmoScout VR for benchmarks
  - https://cosmoscout.github.io/
- Rendered scene at 1920x1080
- Two test systems:
  - Entry-level notebook (RTX 2050)
  - High-end desktop (RTX 4090)
- Vary number of coefficients and shader stage for quality-performance tradeoff
- Displayed numbers are overhead compared to non-shadowed terrain rendering



Evaluation

Visual Quality

- Computed shadows for 5 test scenes
- **Ground truth:** Traditional at 360 samples
- **Reference:** Traditional at 12 samples
- **Our method:** Evaluated at 8/16 coefficients
- Hard shadows, no diffuse lighting



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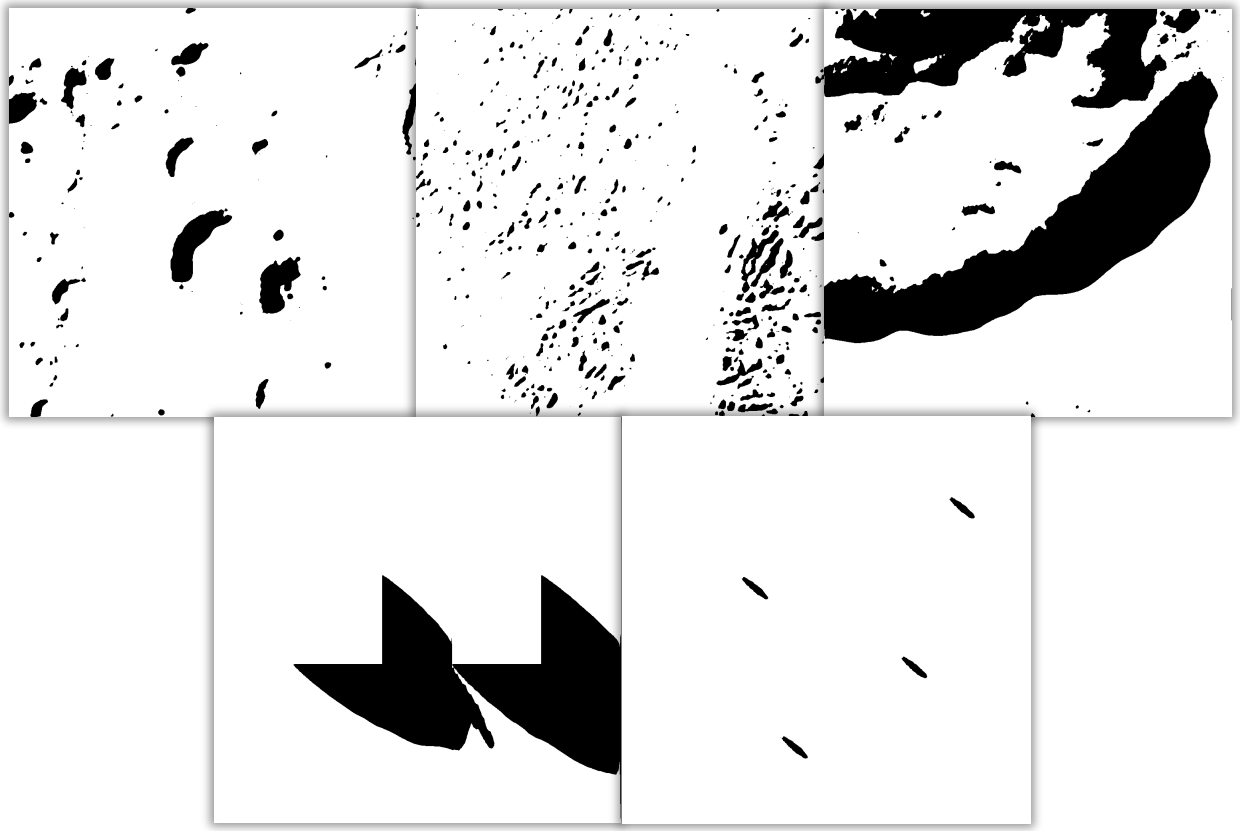
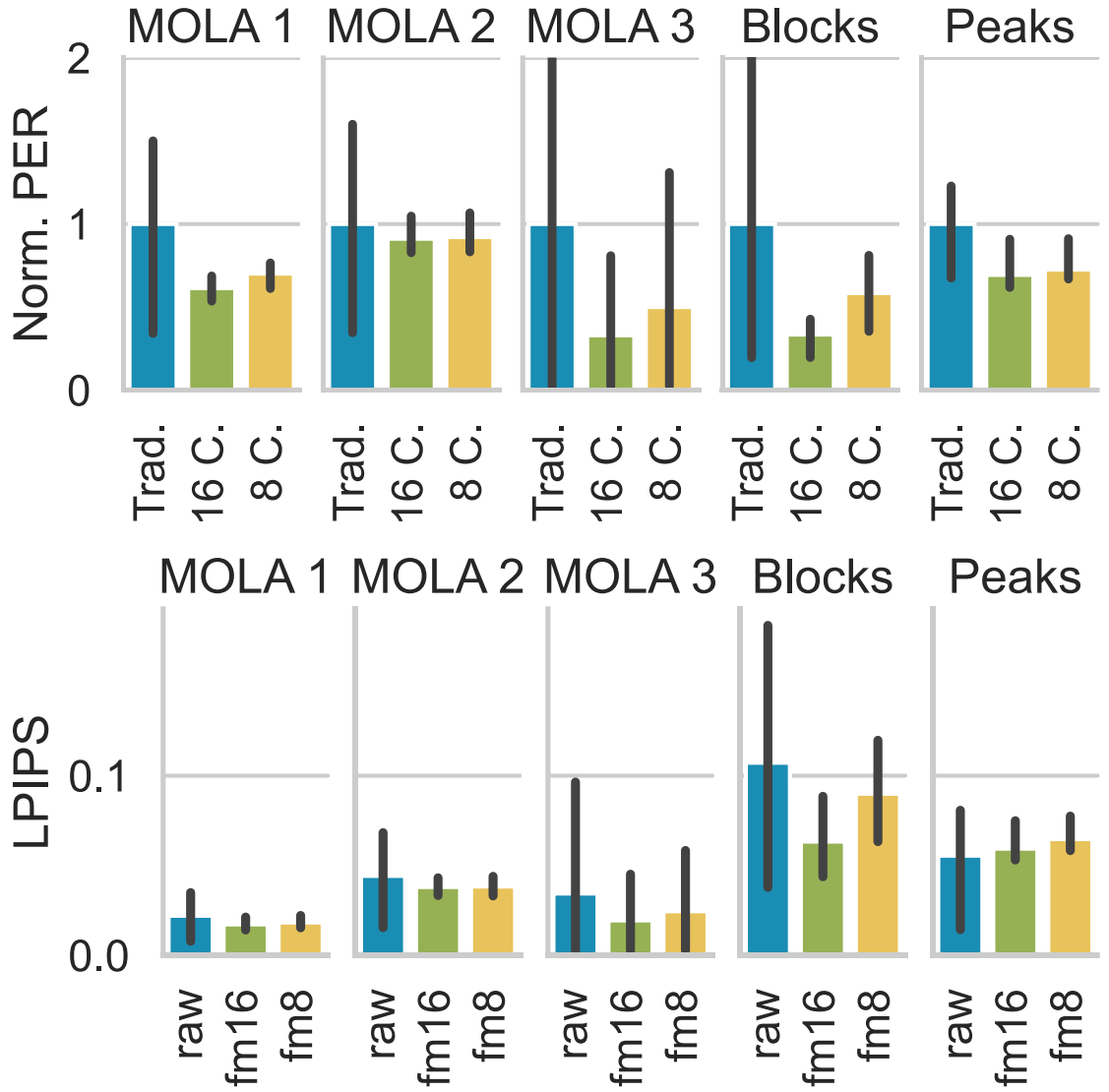


Evaluation

Visual Quality

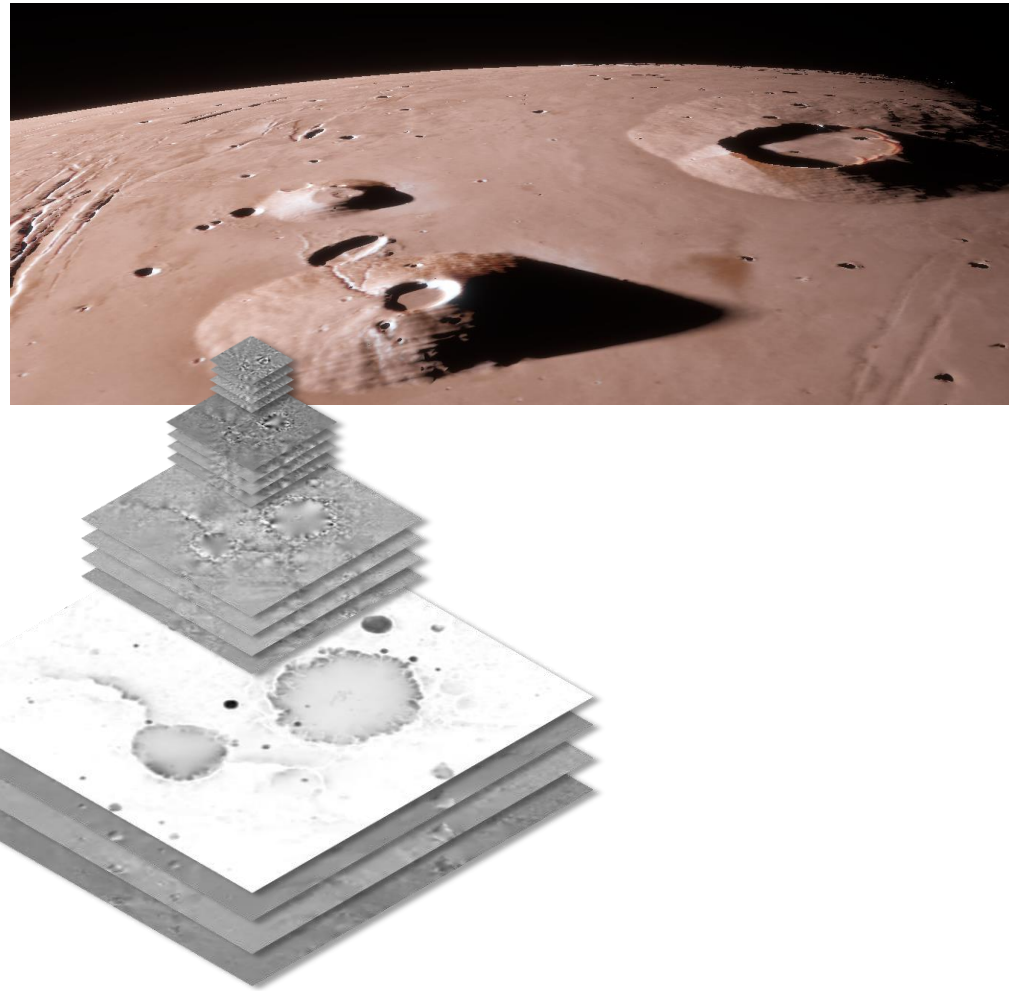
- Pairwise comparison on **SSIM**, **LPIPS**, **PER** (pixel error rate)
- These metrics differ heavily between scenes
- In general our method achieves better average scores (except Peaks & LPIPS)
- Our method performs more consistently



Conclusion & Future Work

- We presented Fourier-Compressed Horizon Maps, an extension of the horizon mapping algorithm
- By representing local horizon functions as truncated Fourier series and storing their coefficients in a multi resolution pyramid we can produce more consistent and accurate shadows
- Implementation as part of CosmoScout VR demonstrates adequate performance

- Still, we want to explore other compact horizon representations, e.g. neural horizon maps



See supplementary material for demo video

THANK YOU FOR YOUR ATTENTION

Imprint

Topic:	**Fast Planetary Shadows using Fourier-Compressed Horizon Maps**
Date:	2025-06-24 (YYYY-MM-DD)
Author:	Jonathan Fritsch
Institute:	Institute of Software Technology
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