Practical session: Rendering digitized objects

PRIME

Midterm meeting, December 2021

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Paper providing digital scenes aligned with photos

- We can test these scenes in different renderers to see how well different shaders can represent the appearance of these objects.

https://eco3d.compute.dtu.dk/pages/appearance

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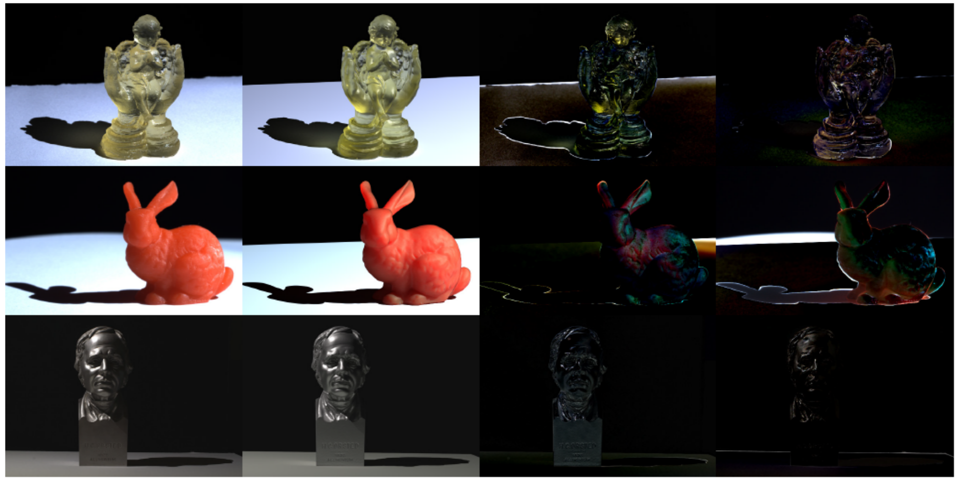

photograph (x) rendering (y) $2\max(y-x,0)$ $2\max(x-y,0)$

Fig. 1. Pixel-by-pixel comparison of renderings with a photograph enables a detailed investigation of the virtues and deficiencies of an appearance model. Our practical alignment technique is here used for testing different models: rough transparent (top), rough translucent (middle), and metallic (bottom). The signed difference images to the right have been scaled by a factor of 2.

Check for updates

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applied optics

Alignment of rendered images with photographs for testing appearance models

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We propose a method for direct comparison of rendered images with a corresponding photograph in order to analyze the optical properties of physical objects and test the appropriateness of appearance models. To this end, we provide a practical method for aligning a known object and a point-like light source with the configuration observed in a photograph. Our method is based on projective transformation of object edges and silhouette matching in the image plane. To improve the similarity between rendered and photographed objects, we introduce models for spatially varying roughness and a model where the distribution of light transmitted by a rough surface influences direction-dependent subsurface scattering. Our goal is to support development toward progressive refinement of appearance models through quantitative validation.

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1. INTRODUCTION

Photorealistic rendering has many applications: product appearance prediction, digital prototyping, inverse rendering to acquire optical properties, 3D soft proofing, etc. In most of these applications, it is important to validate the photorealism

for light source estimation [10,11]. However, as we estimate the object pose, we may as well use the pose for light source estimation. Moreover, if we use the cast shadow for estimating the light position, we can use it to improve the estimate of the object pose as well.

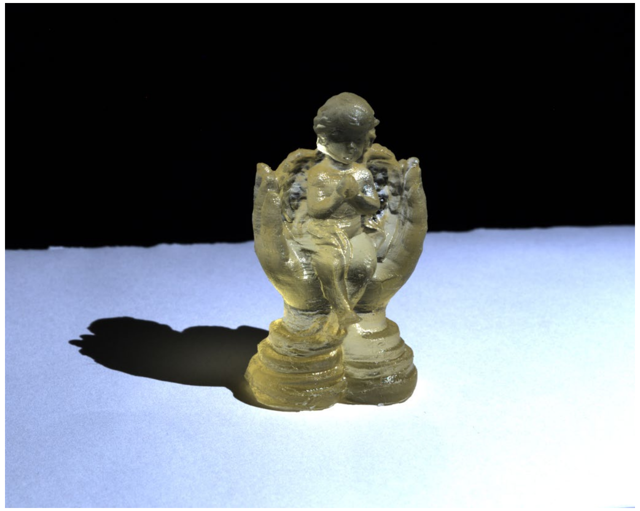
HC Ørsted bust (aluminium, 3D scanned)


Reference photograph

- Bust geometry: hc_orsted.obj (no transformation)
- Table geometry: hco_ground.obj (rotated 90 degrees around X)
- Point light position: [-0.15290257842979774, 0.0010295320183712445, 0.827301670159169]
- Point light intensity: 0.28 W/sr (multiply by 4π to get power)
- Background ambient light: 0.001137 W/(sr m^2)
- Camera position: [0.28255452843554596, -1.4590566335764603, 0.1582019811009315З]
- Camera matrix inverted ($\boldsymbol{K}^{-1}$):
  [9.179619514177686e-05, 0.0, -0.2318790936563762;
  0.0, 9.15419203472016e-05, -0.1878689402381888l;
  0.0, 0.0, 1.0]
- Camera rotation matrix ($\boldsymbol{R}$):
  [0.9999265930643305, 0.0019213613603717853, 0.011963145626623345;
  0.012015137318730981, -0.029819251871890606, -0.9994830907489195;
  -0.001563636138289551, 0.999553460595442, -0.02984014835257065]
- Camera resolution in photo: 4928x3264 (in reference image: 1232x816)

Cupped angel figurine
(transparent photopolymer, 3D print of 3D scan)

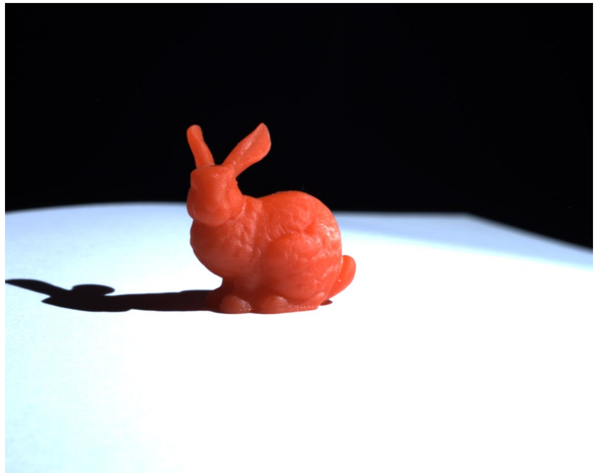
- Bust geometry: cupped_angel.obj (no transformation)
- Table geometry: angel_ground.obj (rotated 90 degrees around X)
- Point light position: [0.20854106219638083, -0.08139660855818596, 0.252323361468482]
- Point light intensity: 0.72 W/sr (multiply by 4π to get power)
- Background ambient light: 0.003922 W/(sr m^2)
- Camera position: [-0.05167859563134386, -0.3561413717418296, 0.18034507441318026]
- Camera matrix inverted ($\boldsymbol{K}^{-1}$):
  [8.218682193244396e-05, 0.0, -0.12377012589190535;
  0.0, 8.218682193244396e-05, -0.08779393983401078;
  0.0, 0.0, 1.0]
- Camera rotation matrix ($\boldsymbol{R}$):
  [0.9537464434892957, -0.2982955615814877, 0.03724888551761668;
  -0.06963864670446258, -0.3397778871228487, -0.9379240088128162;
  0.2924349165484359, 0.8919477256897501, -0.34483485064620684]
- Camera resolution in photo: 2736x2192 (in reference 1026x822)



Reference photograph

Printed bunny
(translucent photopolymer, 3D print of 3D scan)

- Bust geometry: bunny04.obj (no transformation)
- Table geometry: bunny04_ground.obj (rotated 90 degrees around X)
- Point light position: [9.343711424663437, -5.051846268311006, 11.491433391899964]
- Point light intensity: 1800 W/sr (multiply by 4π to get power)
- Background ambient light: 0.003875 W/(sr m^2)
- Camera position: [-7.13180226739496, -22.1455586142838, 4.7383204218931496]
- Camera matrix inverted ($\boldsymbol{K}^{-1}$):
  [0.00021403041584432212, 0.0, -0.1096905881202151;
  0.0, 0.00021403041584432212, -0.08785948570409423;
  0.0, 0.0, 1.0]
- Camera rotation matrix ($\boldsymbol{R}$):
  [0.9489066004753113, -0.31471002101898193, 0.023106893524527555;
  -0.03442377597093582, -0.17602573335170746, -0.983783602714538 6;
  0.3136739134788513, 0.9327232241630554, -0.17786549031734467]
- Camera resolution in photo: 1024x820 (and in reference)



Reference photograph

Vision to graphics camera conversion

- If the ray generation is modifiable, we use the camera matrices directly (as described in the paper).
- For a camera in a rendering system, we
  - convert the rotation matrix $\boldsymbol{R}$ to Euler angles [Slabaugh 1999, e.g.],
  - convert the camera calibration matrix $\boldsymbol{K}$ to camera focal length, sensor width, and shift of principal point, and
  - set the render resolution to have the same aspect ratio as the photograph.

5. RENDERING [Hannemose et al. 2020]

We implemented a progressive unidirectional path tracer using OptiX [69]. To include subsurface scattering, we sample a new set of surface positions for each progressive update. For each update and within each pixel, the ray tracer generates a random position $\mathbf{x}_p$ in pixel coordinates. With the rotation of the camera relative to the object $\mathbf{R}$ and the camera intrinsic matrix $\mathbf{K}$, we get the direction of the corresponding ray using

$$\vec{\omega} = (\mathbf{KR})^{-1}\mathbf{S}\mathbf{x}_p = \mathbf{R}^T\mathbf{K}^{-1}\mathbf{S}\mathbf{x}_p. \qquad (12)$$

Since the intrinsic matrix $\mathbf{K}$ is locked to the resolution of the camera $(W_c \times H_c)$, which is usually very high, we use the scaling matrix $\mathbf{S} = \mathrm{diag}(W_r/W_c,\ H_r/H_c,\ 1)$ to enable rendering in a different resolution $(W_r \times H_r)$.

Hannemose et al. 2020: See slide 2.

Slabaugh, G. Computing Euler angles from a rotation matrix. Technical report. August 1999.

Rotation matrix to Euler ZYX angles

- Rotation matrices

$$\boldsymbol{R}_x(\psi) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\psi & -\sin\psi \\ 0 & \sin\psi & \cos\psi \end{bmatrix}, \ \boldsymbol{R}_y(\theta) = \begin{bmatrix} \cos\theta & 0 & \sin\theta \\ 0 & 1 & 0 \\ -\sin\theta & 0 & \cos\theta \end{bmatrix}, \ \boldsymbol{R}_z(\phi) = \begin{bmatrix} \cos\phi & -\sin\phi & 0 \\ \sin\phi & \cos\phi & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

- Combined

$$\boldsymbol{R} = \boldsymbol{R}_z(\phi)\,\boldsymbol{R}_y(\theta)\,\boldsymbol{R}_x(\psi) = \begin{bmatrix} \cos\theta\cos\phi & \sin\psi\sin\theta\cos\phi - \cos\psi\sin\phi & \cos\psi\sin\theta\cos\phi + \sin\psi\sin\phi \\ \cos\theta\sin\phi & \sin\psi\sin\theta\sin\phi + \cos\psi\cos\phi & \cos\psi\sin\theta\sin\phi + \sin\psi\cos\phi \\ -\sin\theta & \sin\psi\cos\theta & \cos\psi\cos\theta \end{bmatrix} = \begin{bmatrix} R_{11} & R_{12} & R_{13} \\ R_{21} & R_{22} & R_{23} \\ R_{31} & R_{32} & R_{33} \end{bmatrix}$$

- Solution option for the three angles

$$(\psi_1, \theta_1, \phi_1) = \left(\operatorname{atan2}\left(\frac{R_{32}}{\cos\theta_1}, \frac{R_{33}}{\cos\theta_1}\right), -\operatorname{asin} R_{31}, \operatorname{atan2}\left(\frac{R_{21}}{\cos\theta_1}, \frac{R_{11}}{\cos\theta_1}\right)\right)$$

- Another solution$(\psi_2, \theta_2, \phi_2)$ is with $\theta_2 = \pi - \theta_1$

- If $|R_{31}| - 1 < \varepsilon$, we can use $(\psi_1, \theta_1, \phi_1) = \left(\operatorname{atan2}(sR_{12}, sR_{13}), s\frac{\pi}{2}, 0\right)$ with $s = -\operatorname{sgn}(R_{31})$.

- Since the up-direction of the real camera is often flipped, we may need to use $\pi - \psi_1$.

Decomposing the camera calibration matrix

- Suppose the resolution of a given photograph is $W \times H$.
- The camera calibration matrix:

$$\boldsymbol{K} = \begin{bmatrix} \alpha_x & \gamma & c_x \\ 0 & \alpha_y & c_y \\ 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} K_{11} & K_{12} & K_{13} \\ 0 & K_{22} & K_{23} \\ 0 & 0 & 1 \end{bmatrix}.$$

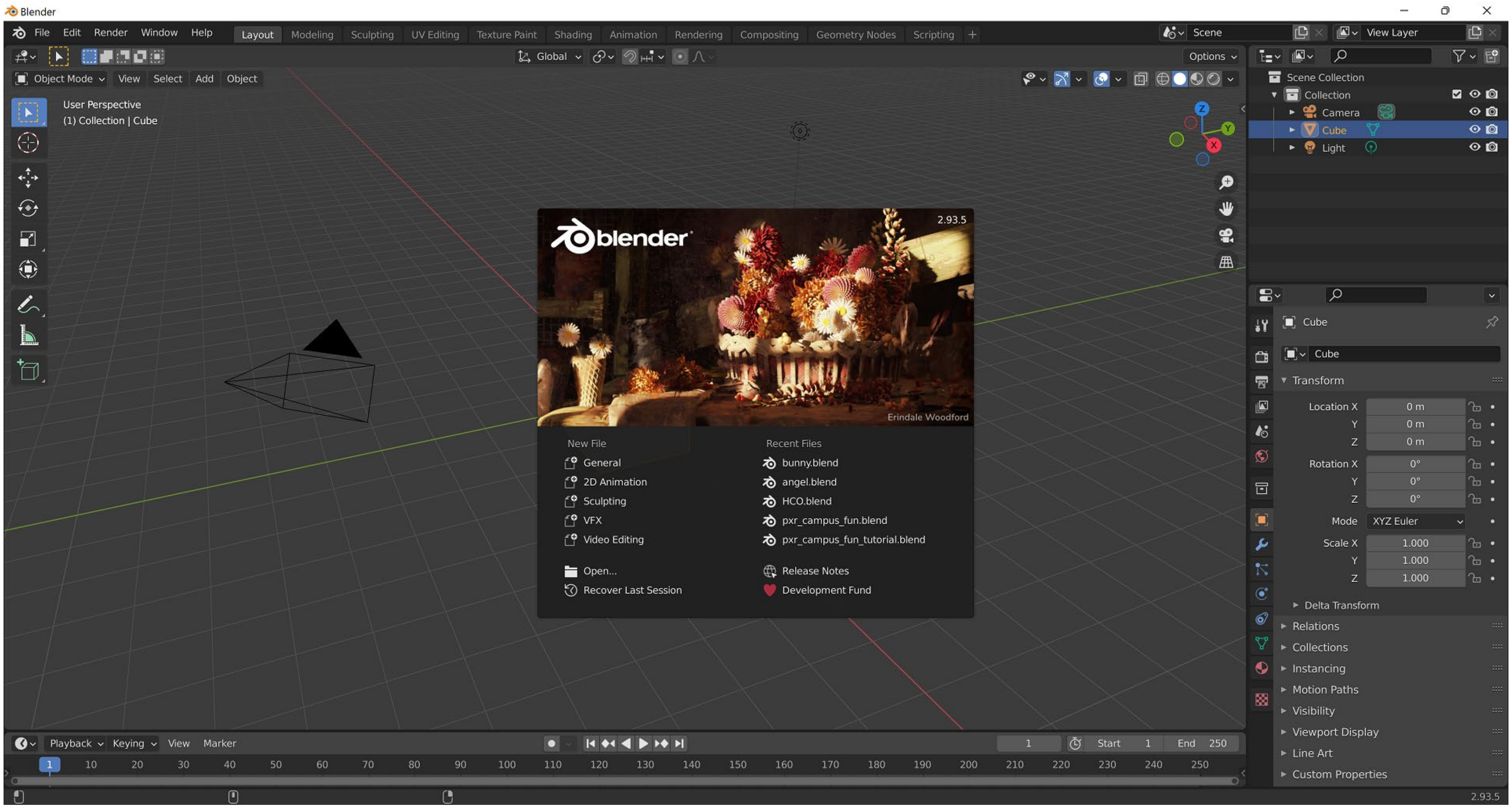
- If f is the focal length of the camera in mm, while m_x^{-1} and m_y^{-1} are the width and the height of a pixel in mm, we have $(\alpha_x, \alpha_y) = (m_x, m_y)f$ and the principal point in pixels is (c_x, c_y).
- This means that the focal length f and shift of principal point (s_x, s_y) of a corresponding virtual pinhole camera are

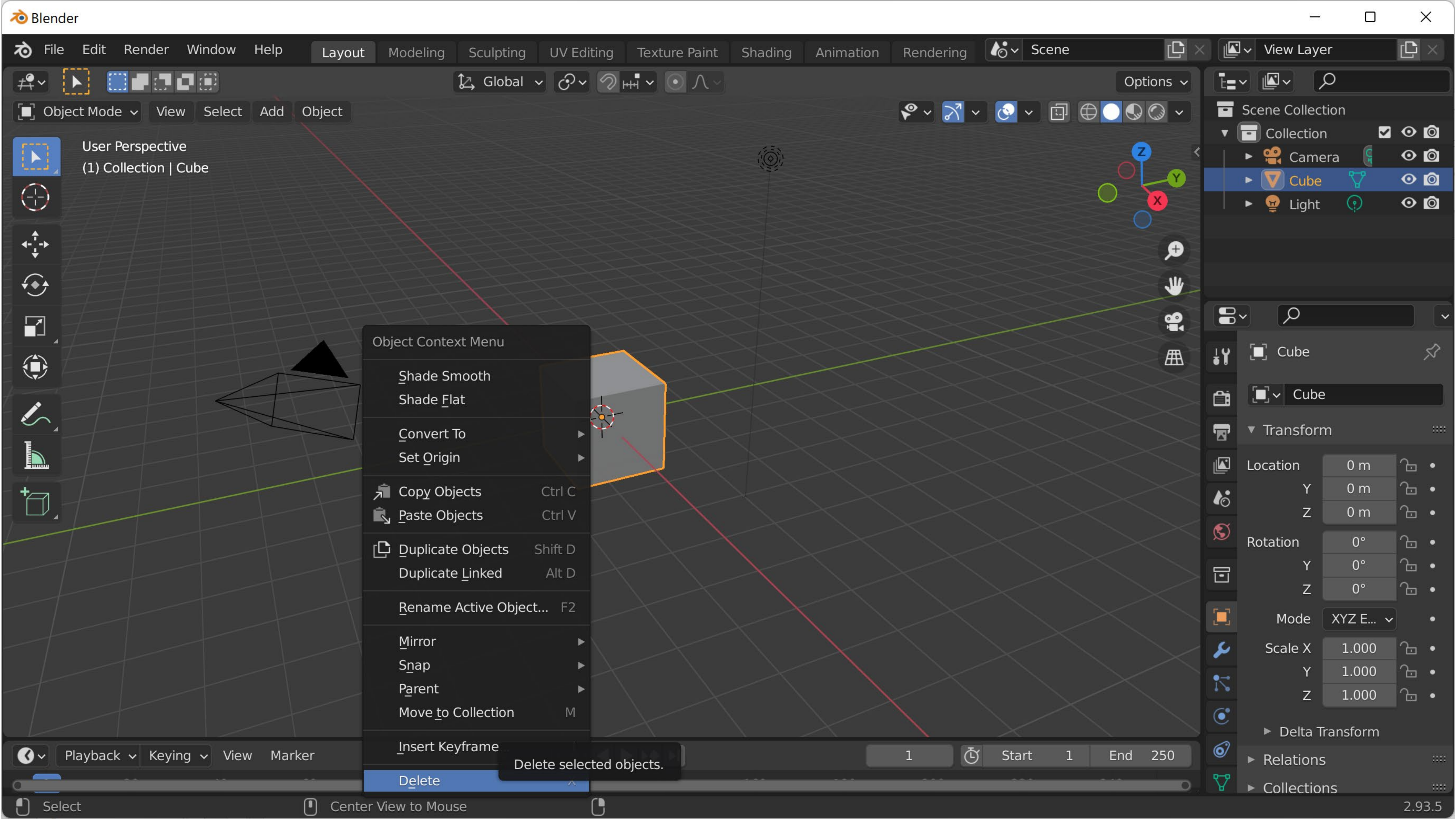
$$f = \frac{h}{H} K_{22}, \qquad (s_x, s_y) = \frac{1}{H}\left(\frac{W}{2} - K_{13}, K_{23} - \frac{H}{2}\right).$$

- In a graphics camera, the height of the image in the image plane is usually $h = 1$. We can in this way specify the camera vertically.
- If we want to specify the camera horizontally instead, we can use

$$w = \frac{c_x\, m_x^{-1}}{c_y\, m_y^{-1}} = \frac{K_{22}K_{13}}{K_{11}K_{23}}, \qquad f = \frac{w}{W} K_{11}, \qquad (s_x, s_y) = \frac{1}{W}\left(\frac{W}{2} - K_{13}, K_{23} - \frac{H}{2}\right)$$

Blender with Cycles as a case study

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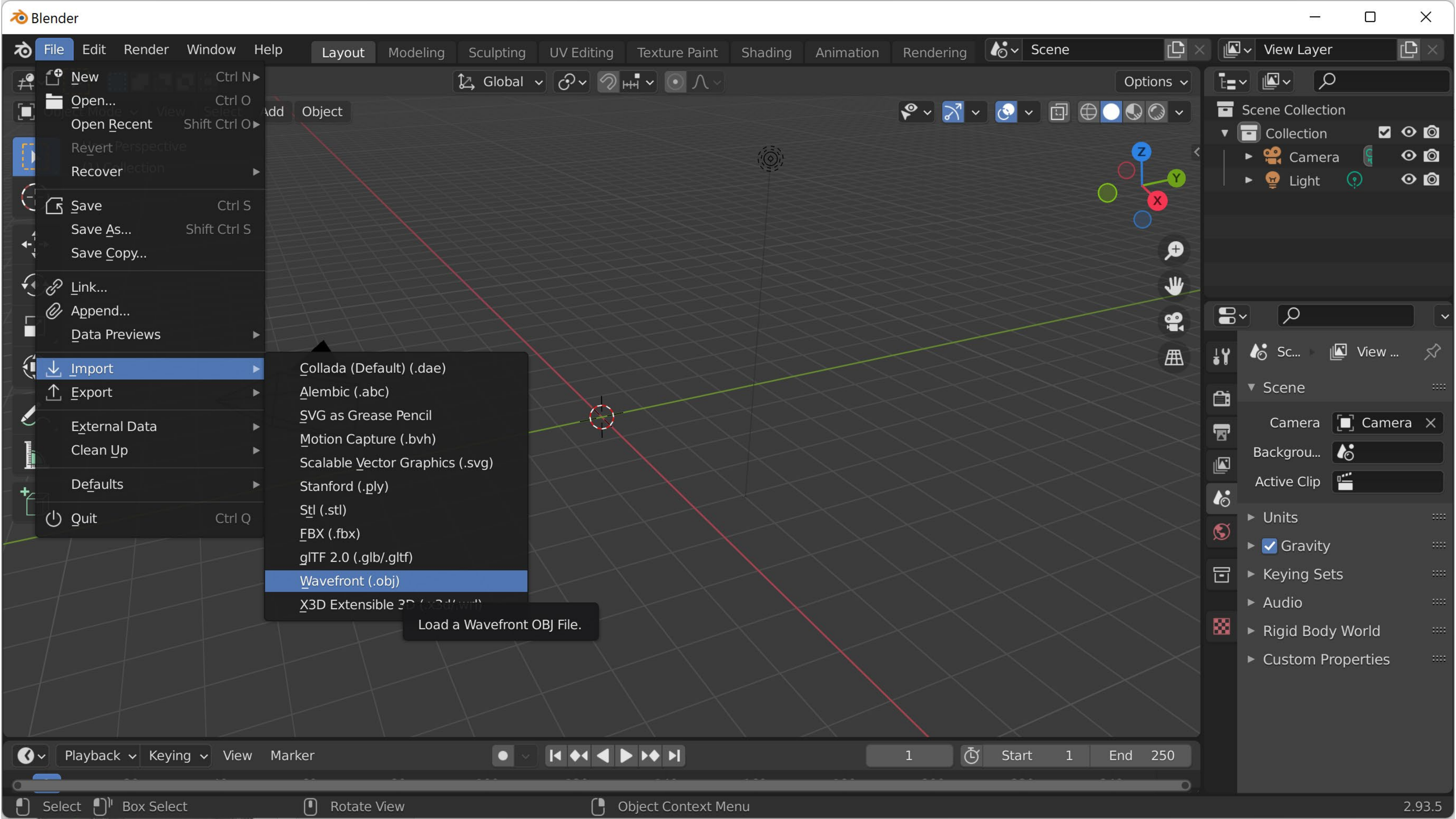

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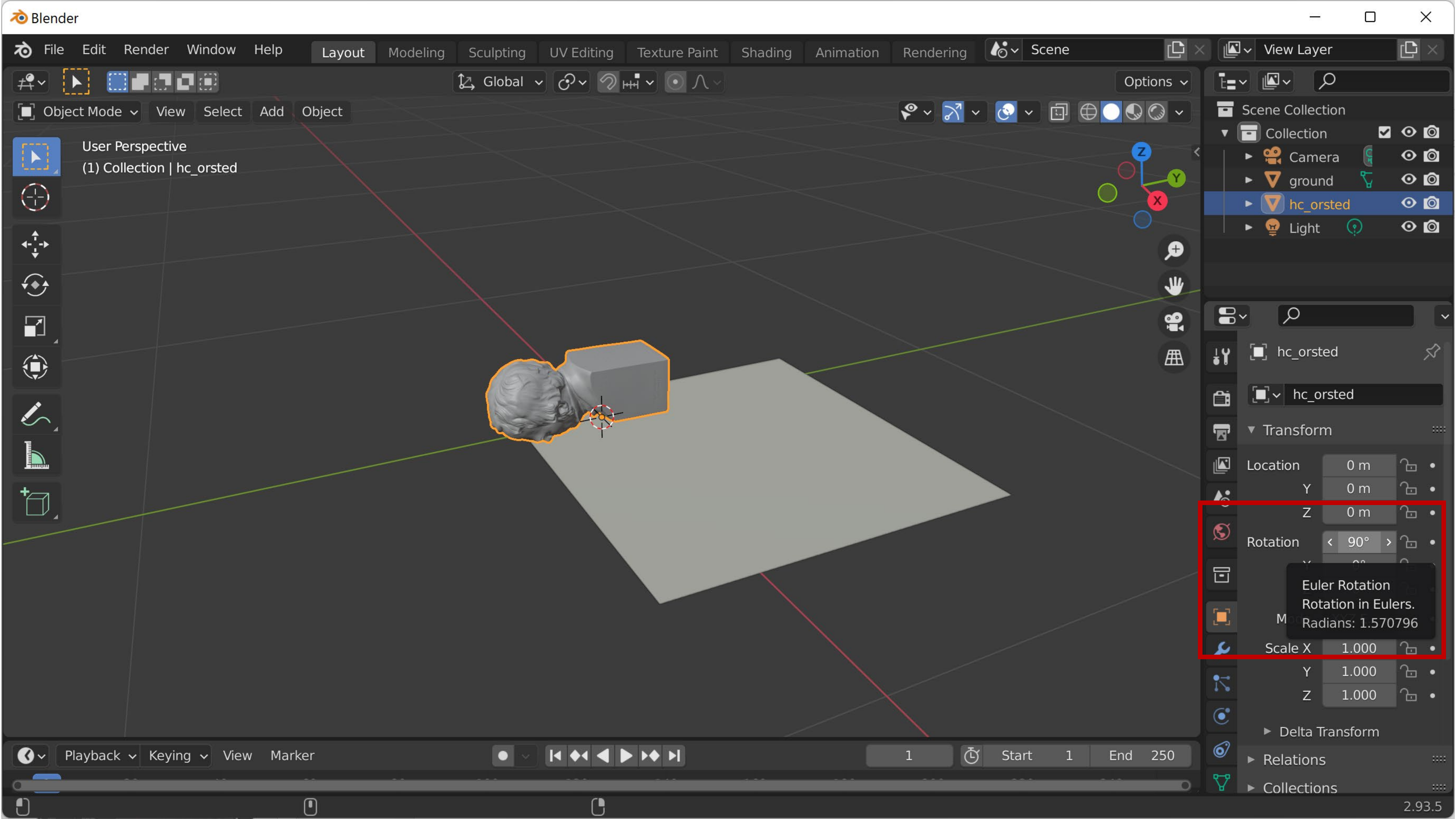
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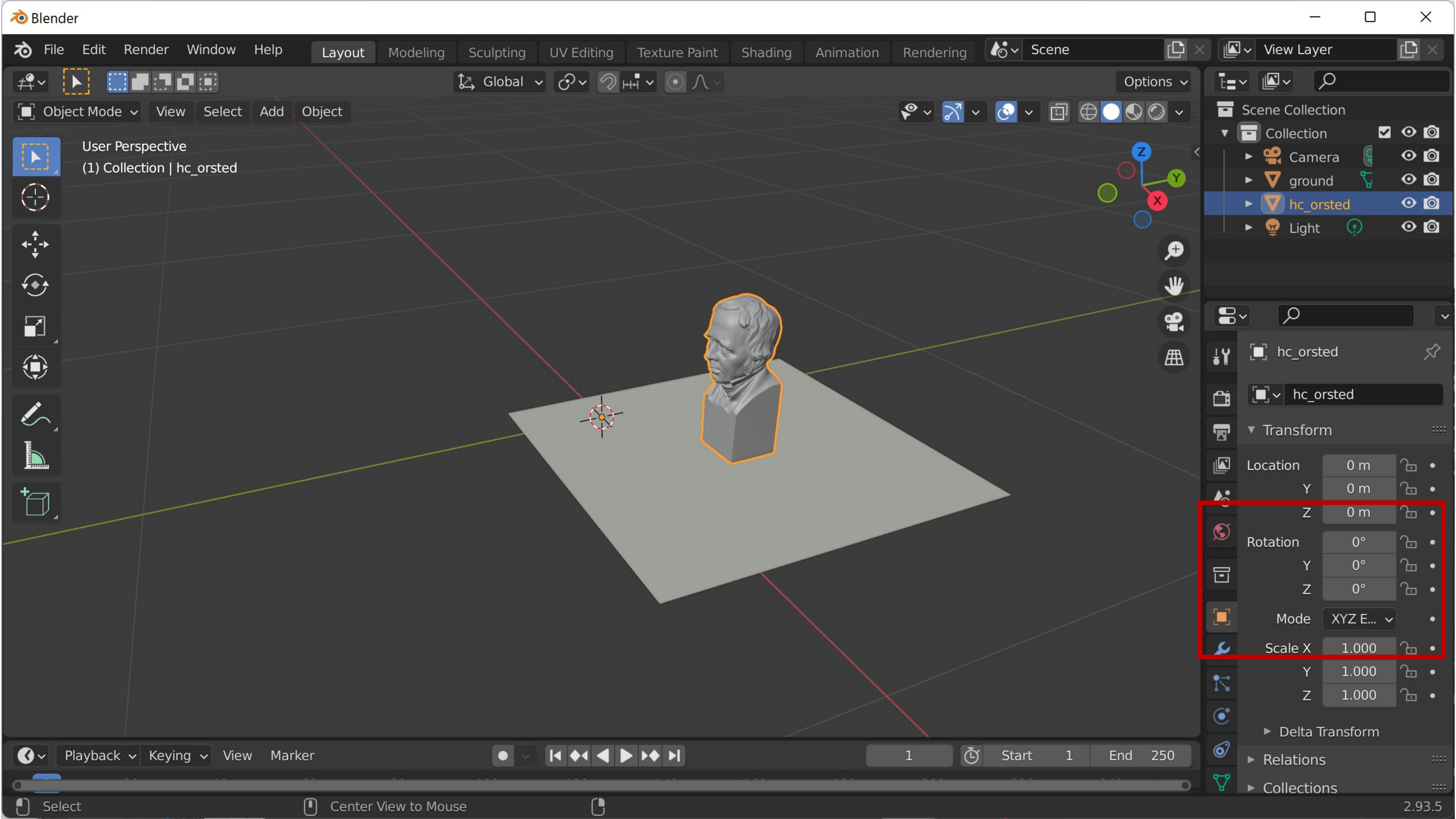
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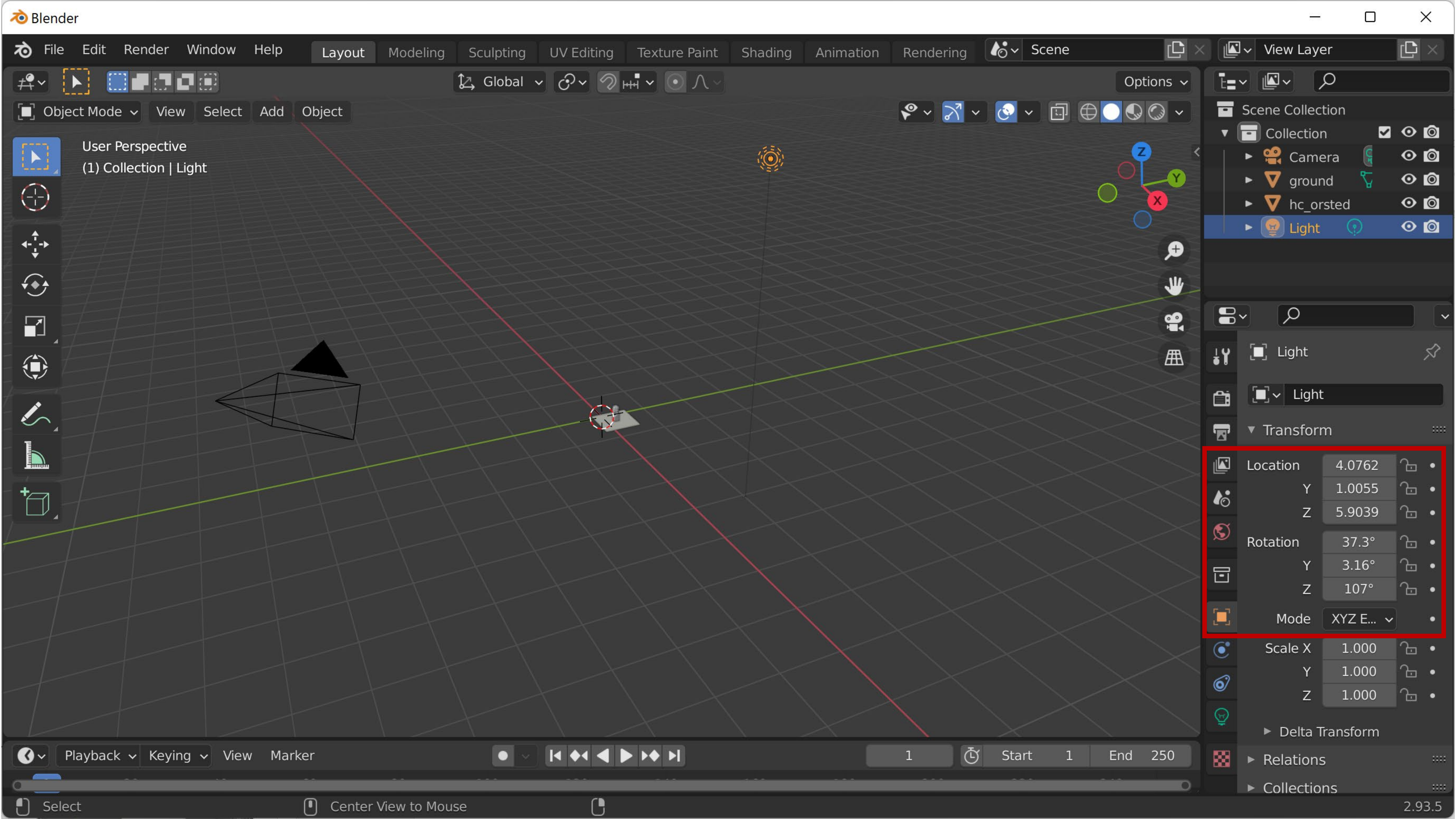

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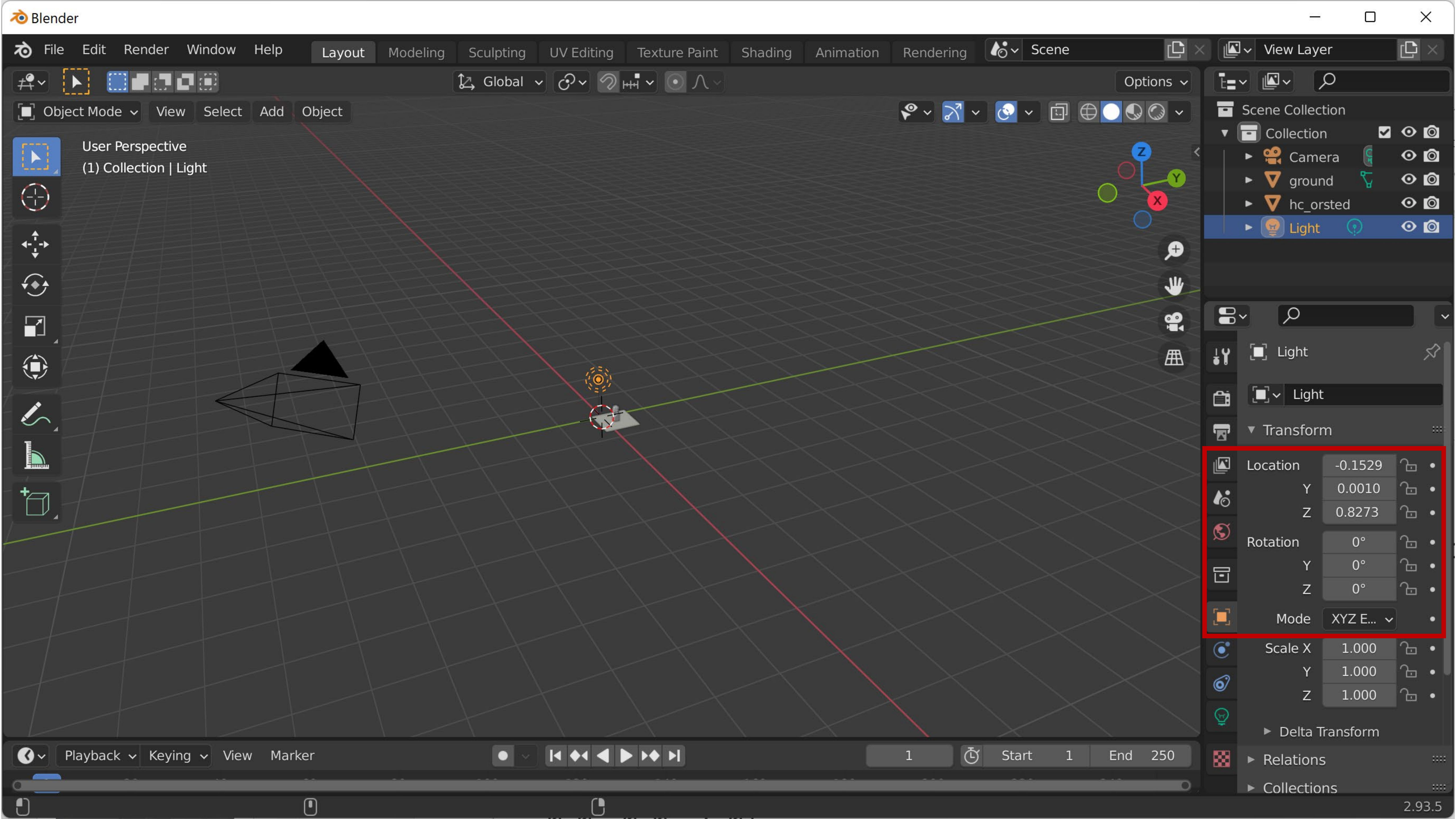
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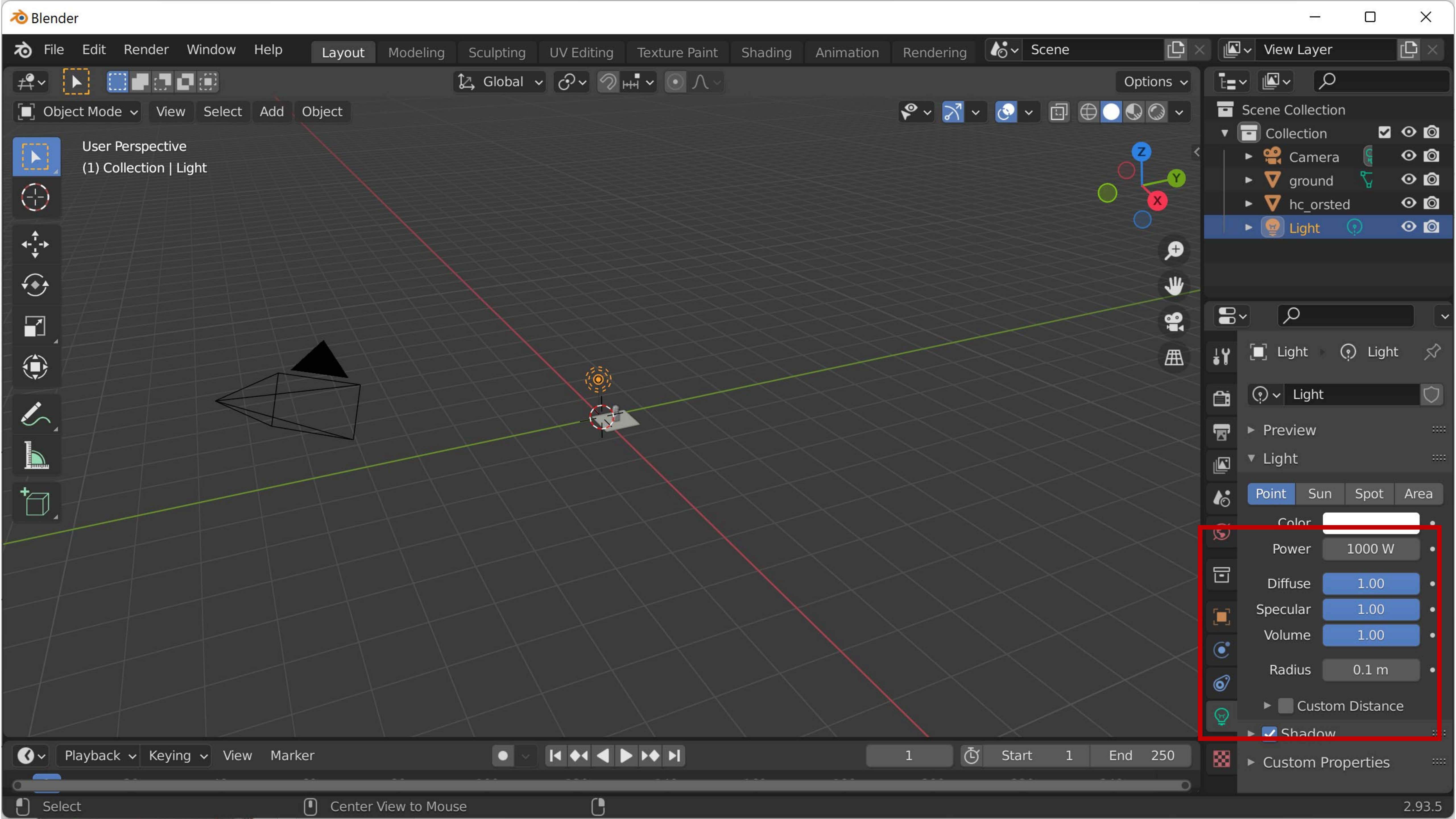
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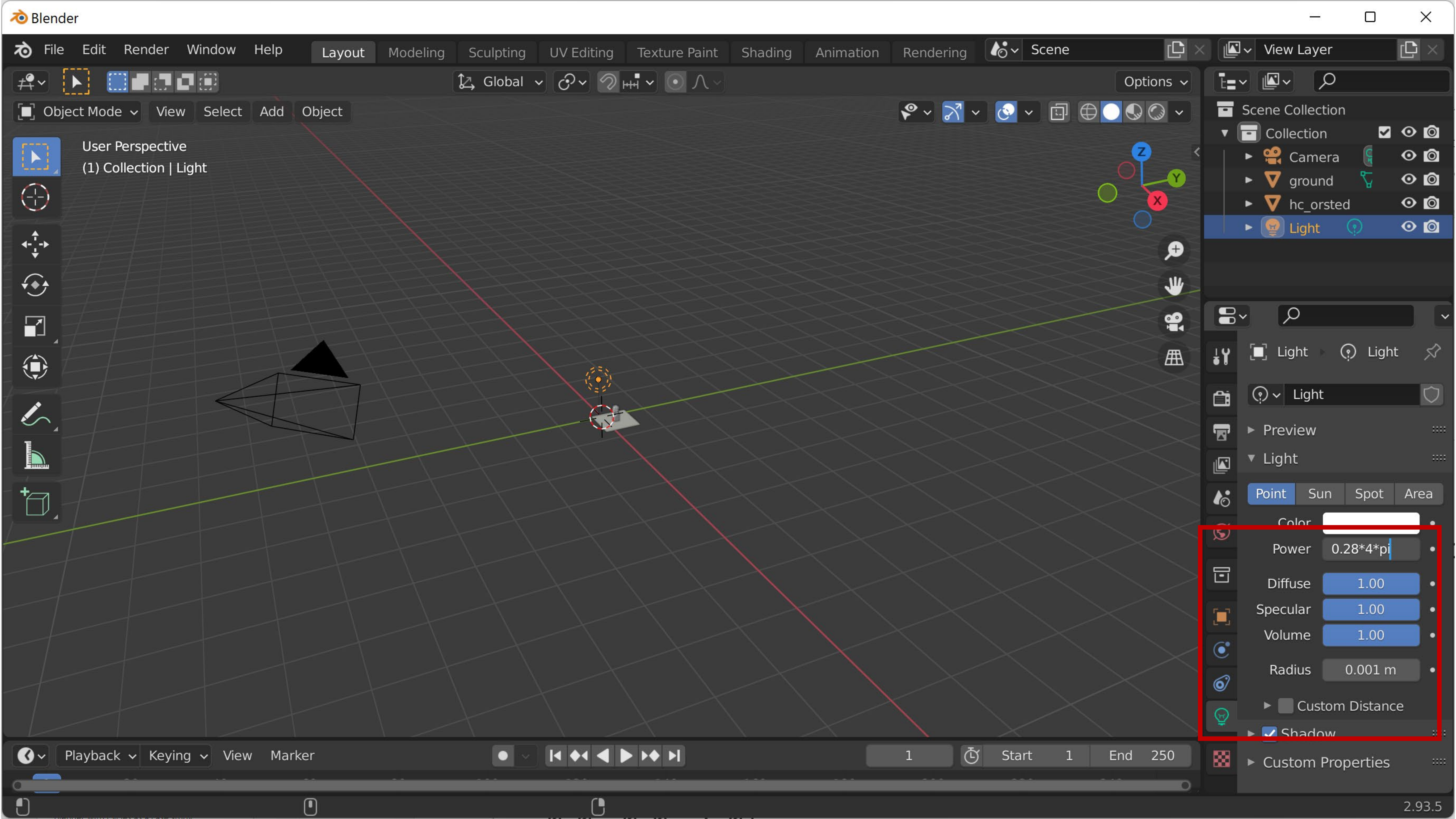
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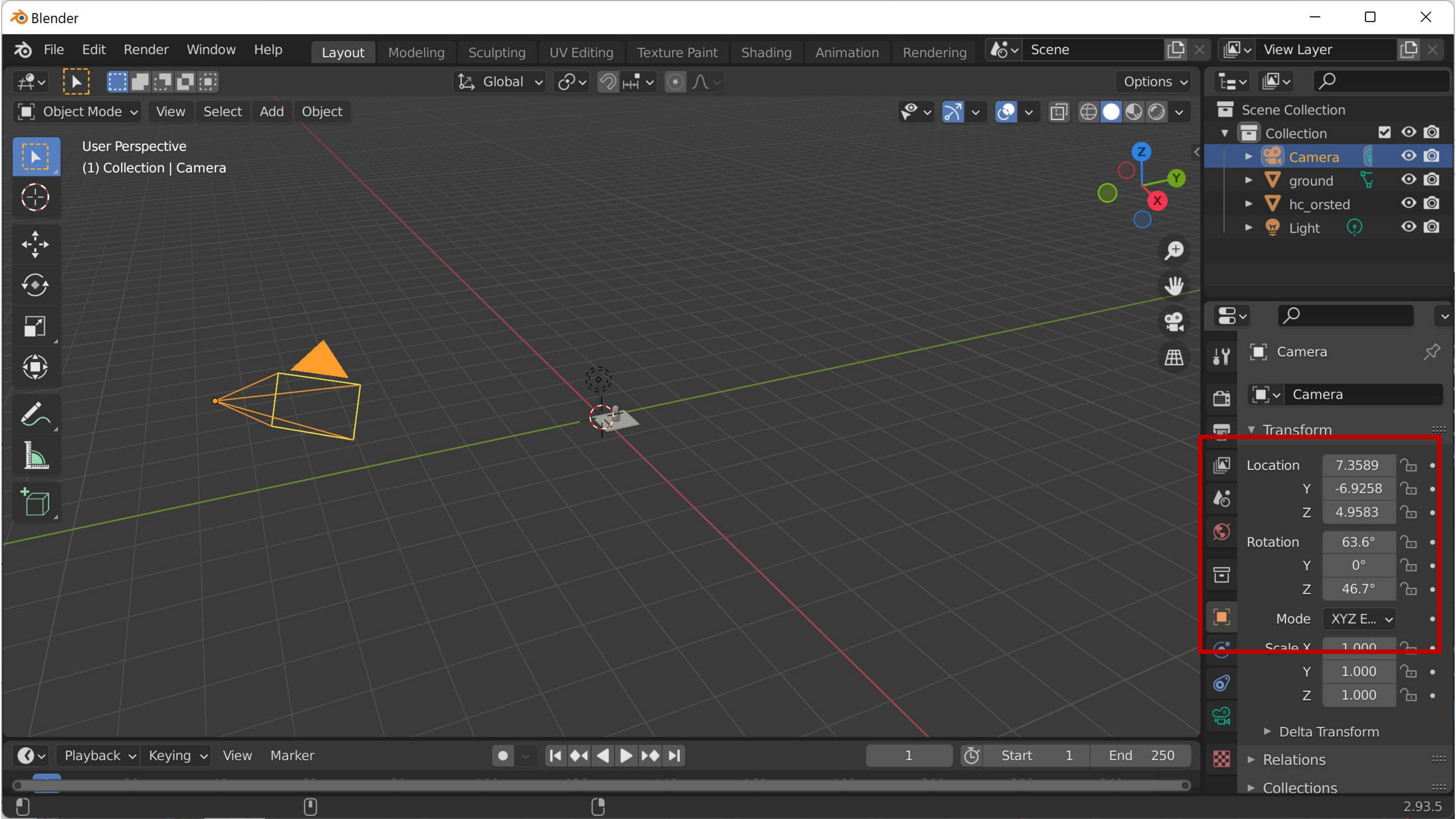

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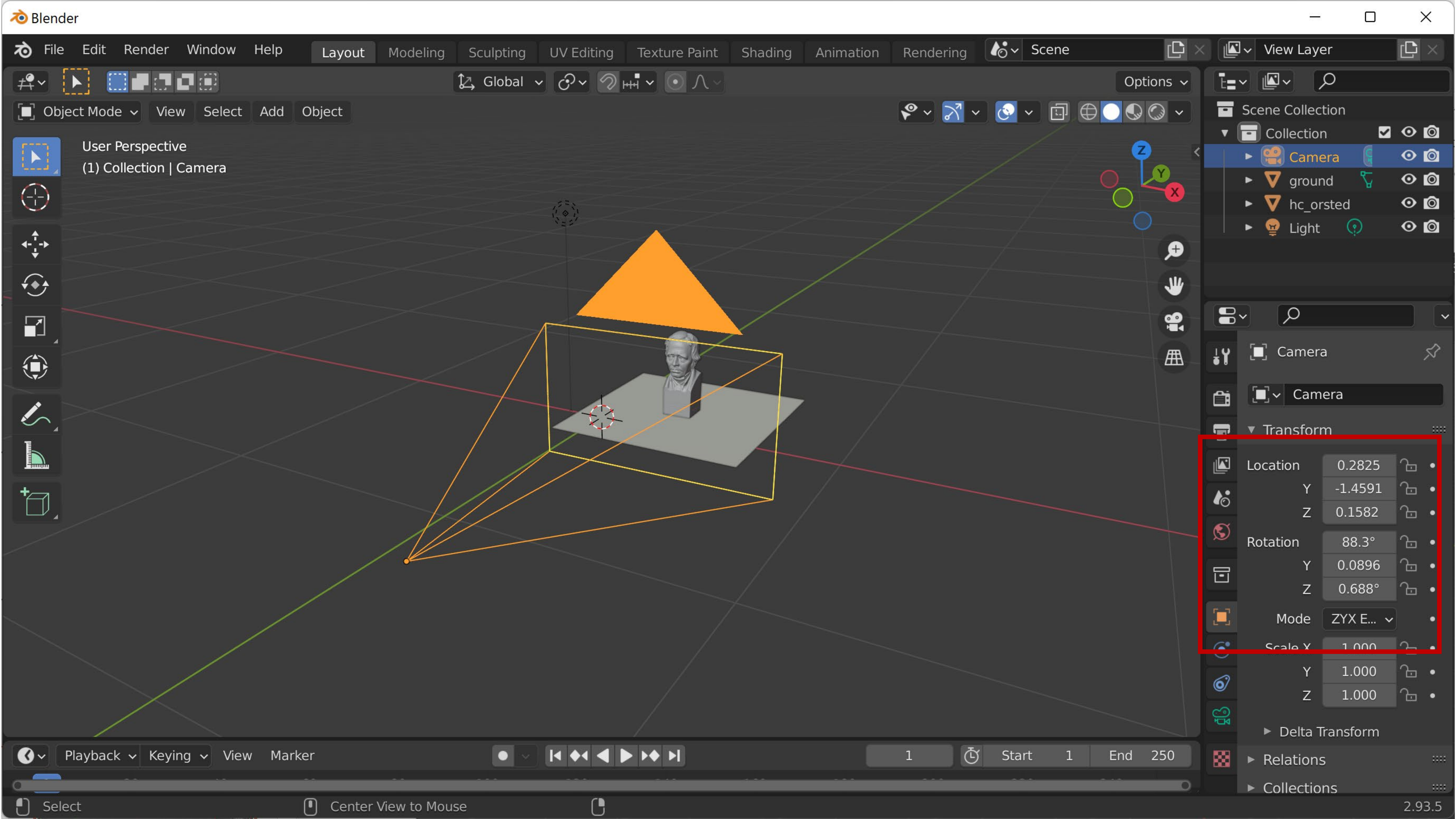
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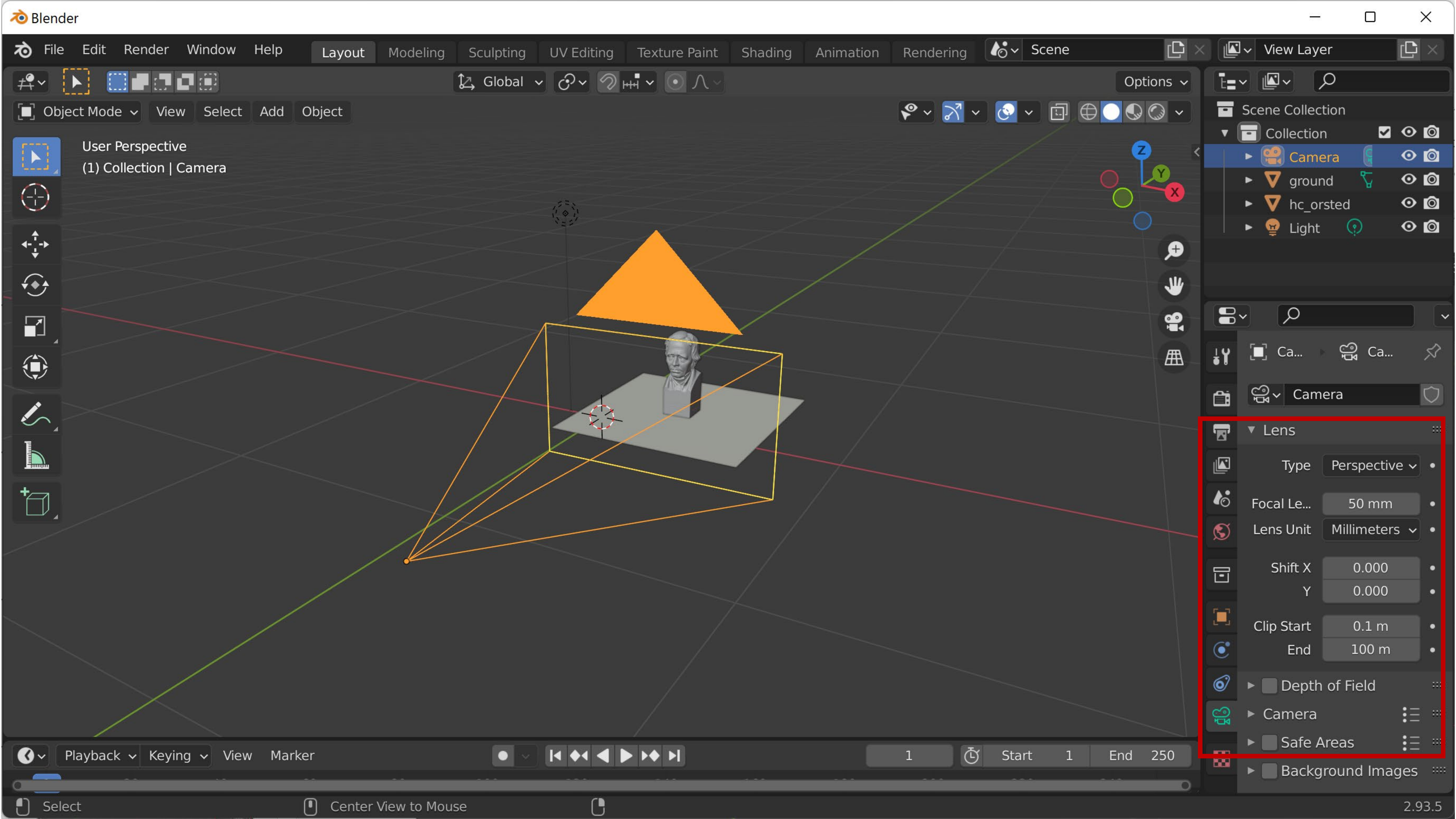
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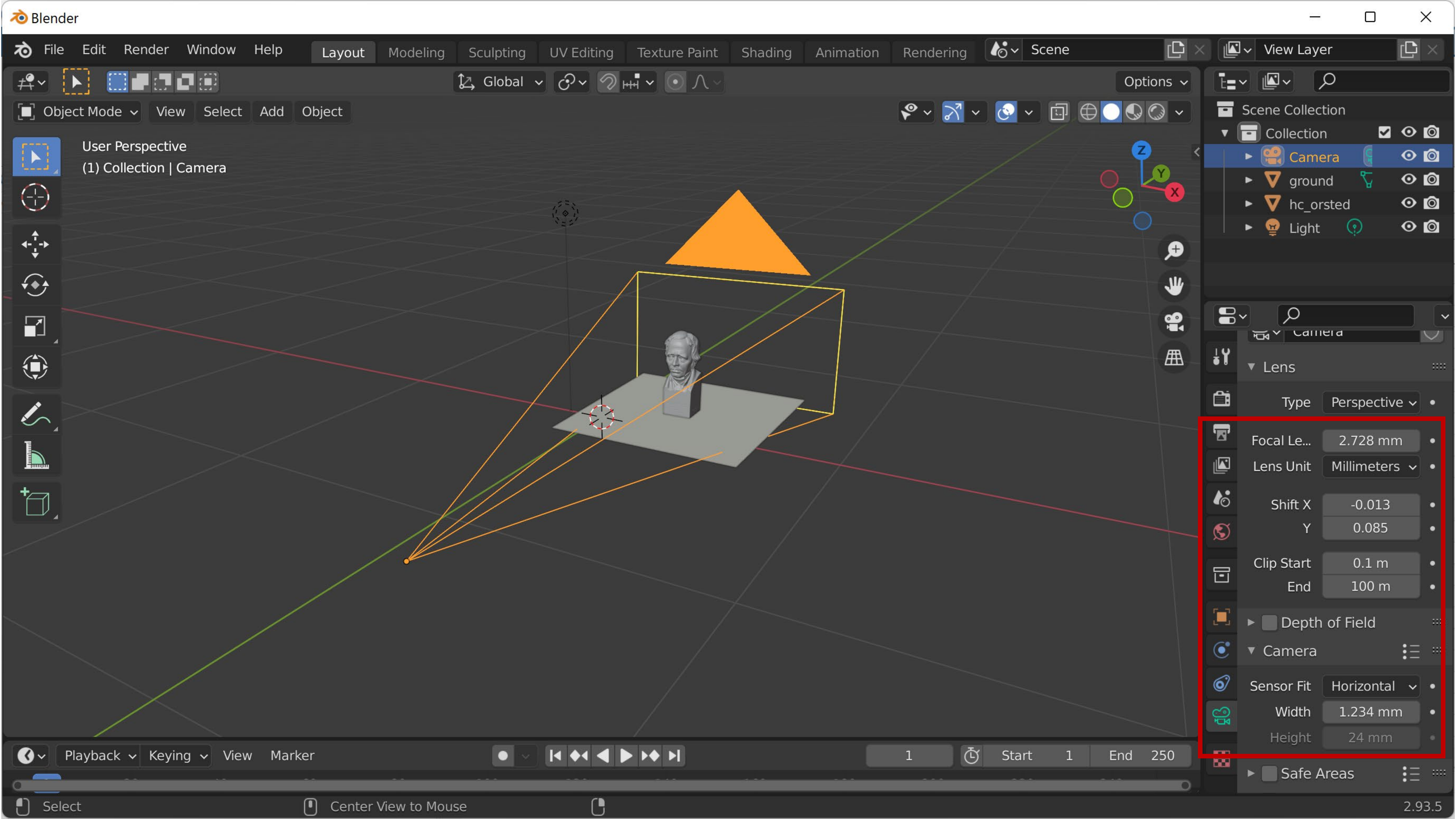
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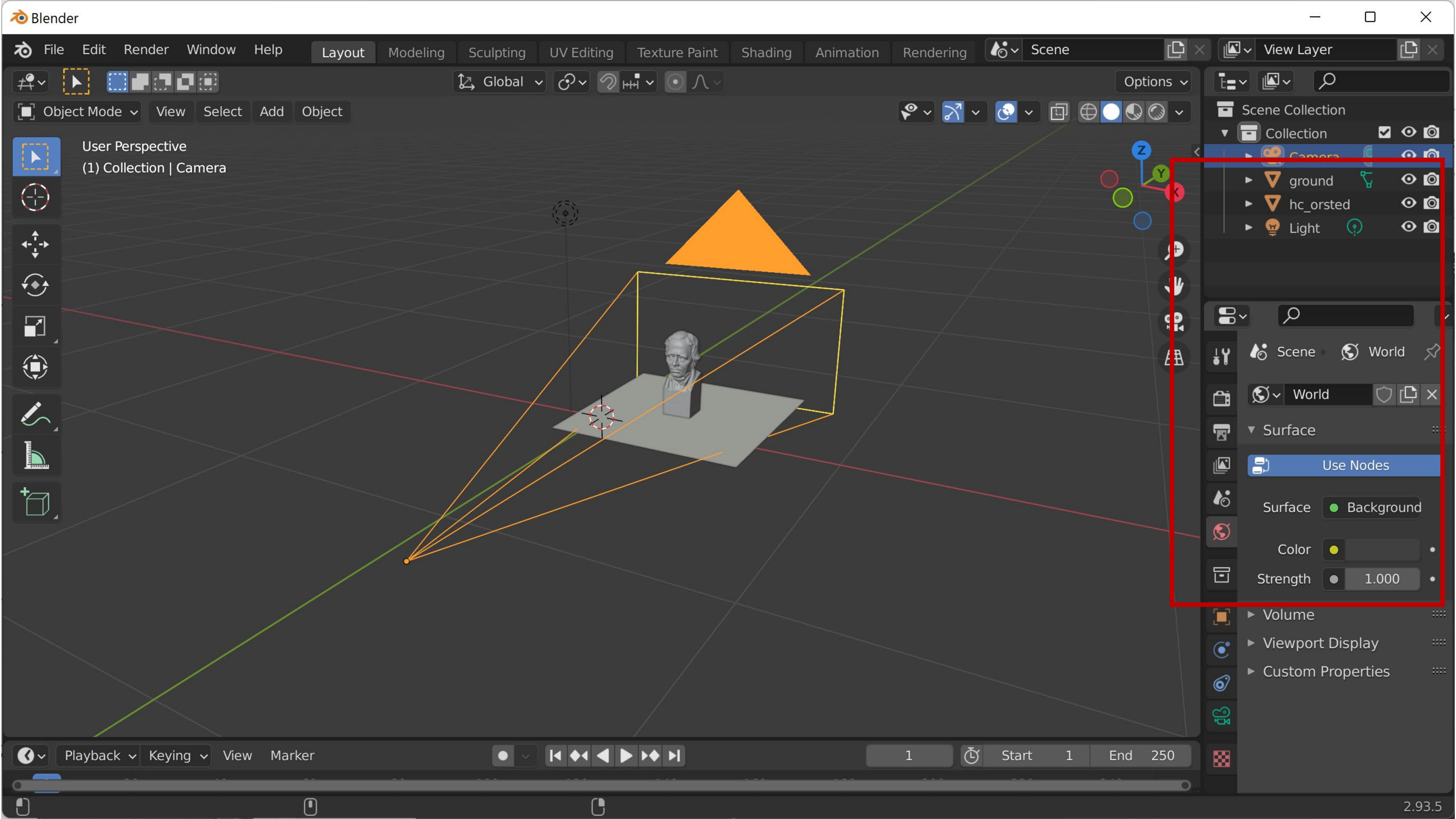
Blender
File
Edit
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Window
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Modeling
Sculpting
UV Editing
Texture Paint
Shading
Animation
Rendering
Scene
View Layer
Global
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Object
User Perspective
(1) Collection | Camera
Scene Collection
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Camera
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hc_orsted
Light
Scene
World
World
Surface
Use Nodes
Surface
Background
Color
Strength
1.000
Volume
Viewport Display
Custom Properties
Playback
Keying
View
Marker
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1
End
250
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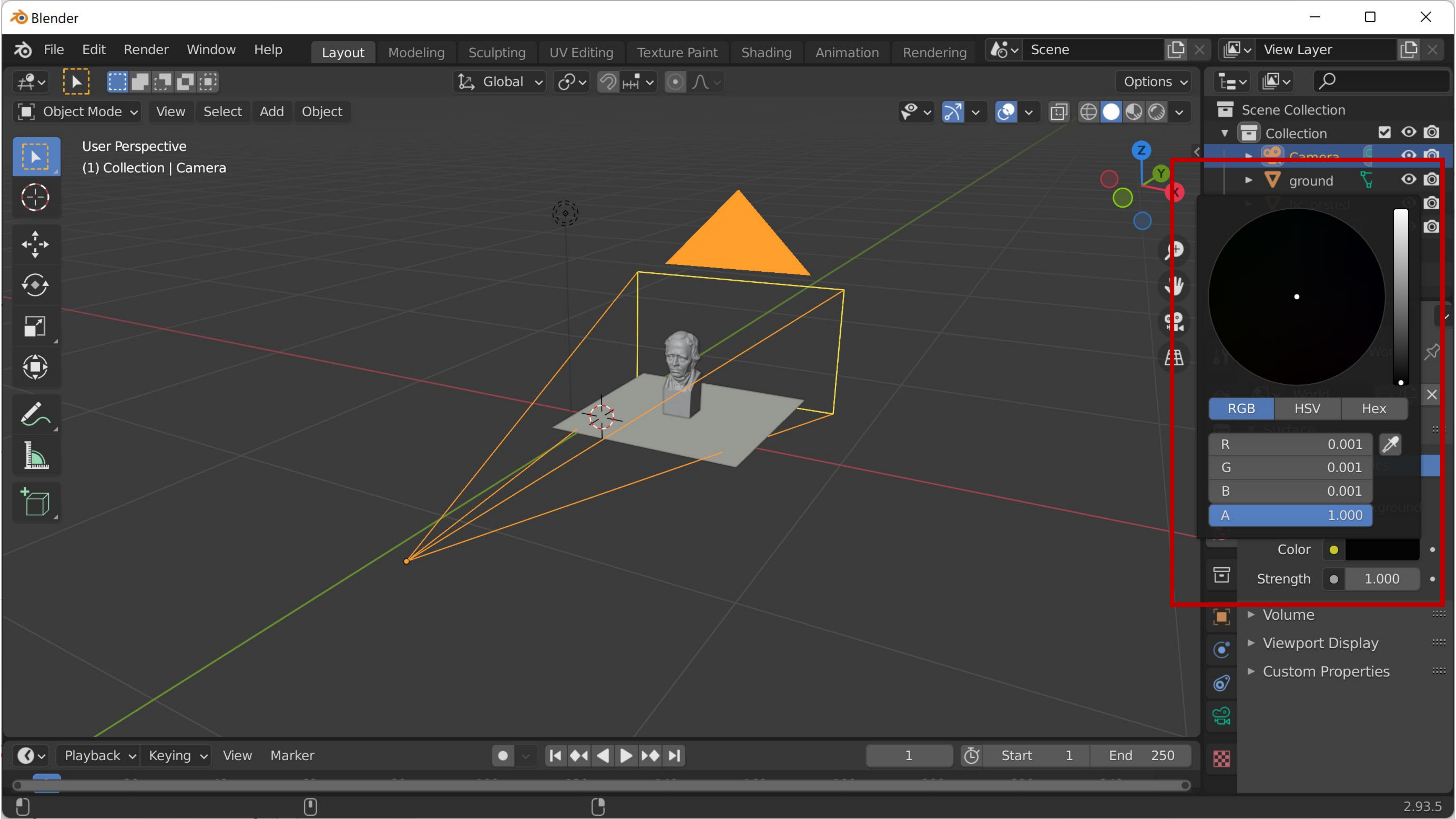
Blender
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Layout Modeling Sculpting UV Editing Texture Paint Shading Animation Rendering
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Object Mode View Select Add Object
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G 0.001
B 0.001
A 1.000
Color
Strength 1.000
Volume
Viewport Display
Custom Properties
Playback Keying View Marker
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End 250
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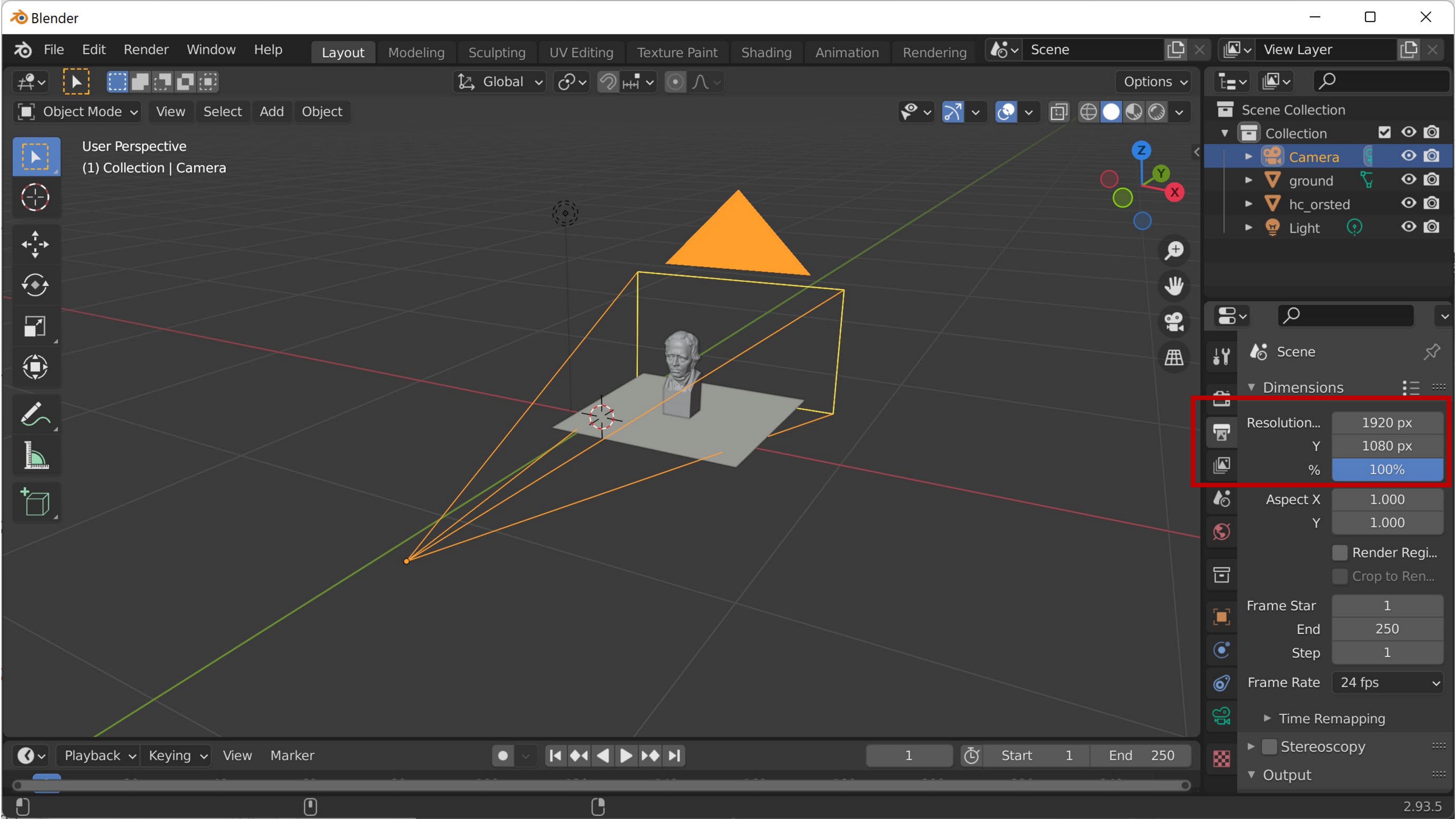
Blender
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Collection
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hc_orsted
Light
Scene
Dimensions
Resolution...
1920 px
Y
1080 px
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100%
Aspect X
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1.000
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Crop to Ren...
Frame Star
1
End
250
Step
1
Frame Rate
24 fps
Time Remapping
Stereoscopy
Output
Playback
Keying
View
Marker
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Start
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End
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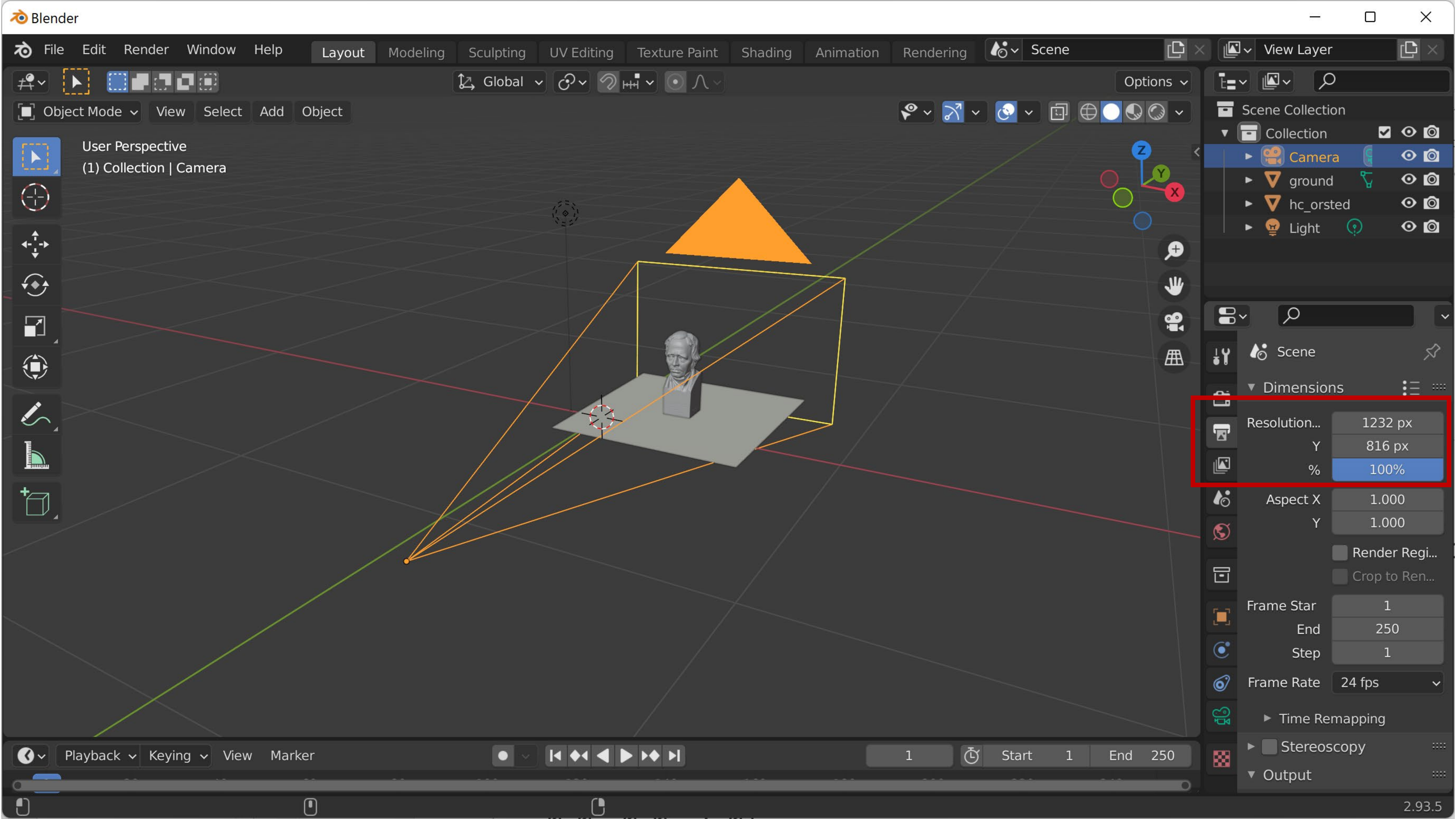
2.93.5



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Y
816 px
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100%
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Crop to Ren...
Frame Star
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Stereoscopy
Output
Playback
Keying
View
Marker
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End
250
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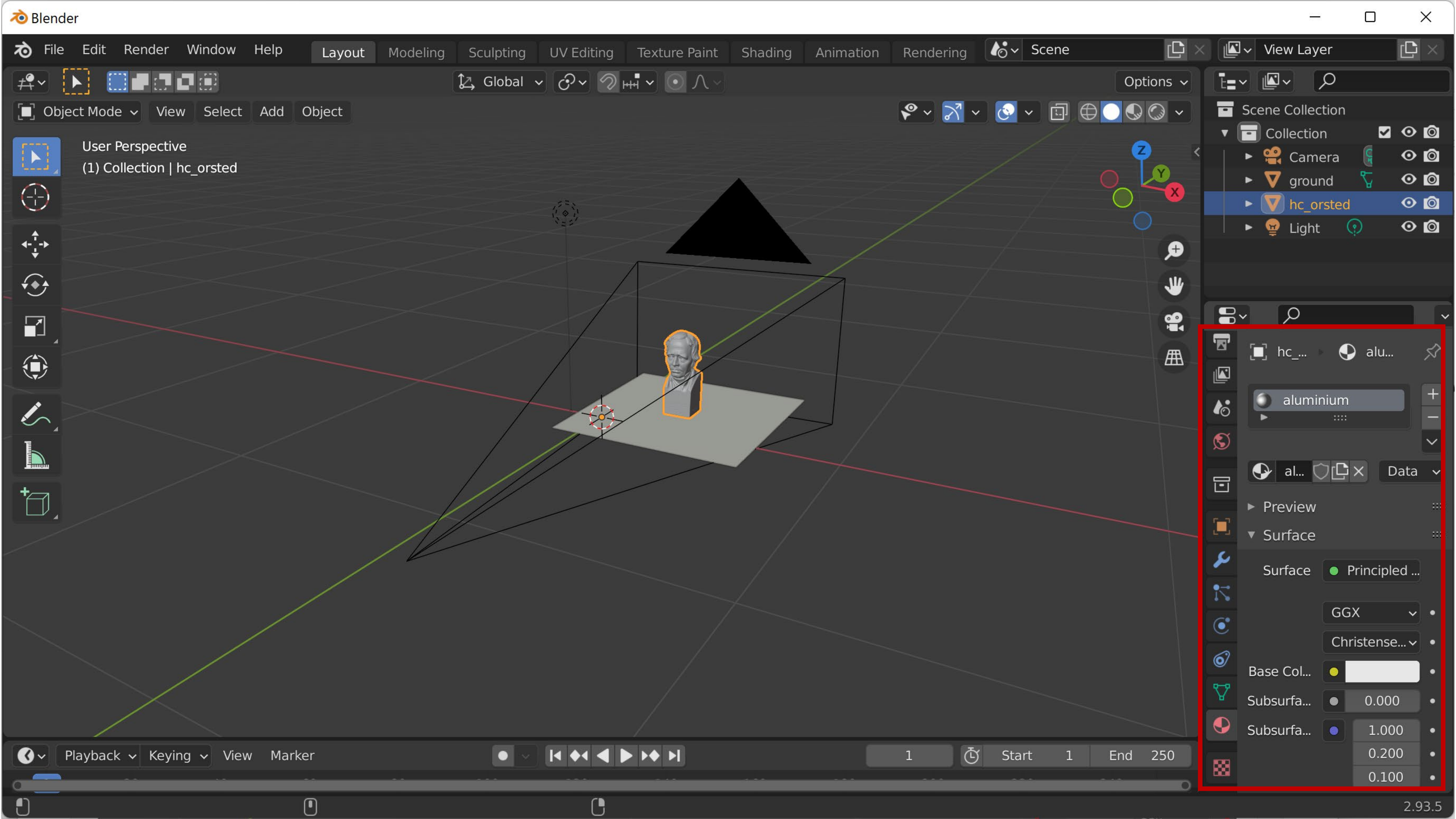
Blender
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Christense...
Base Col...
Subsurfa...
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Subsurfa...
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Playback
Keying
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Marker
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End
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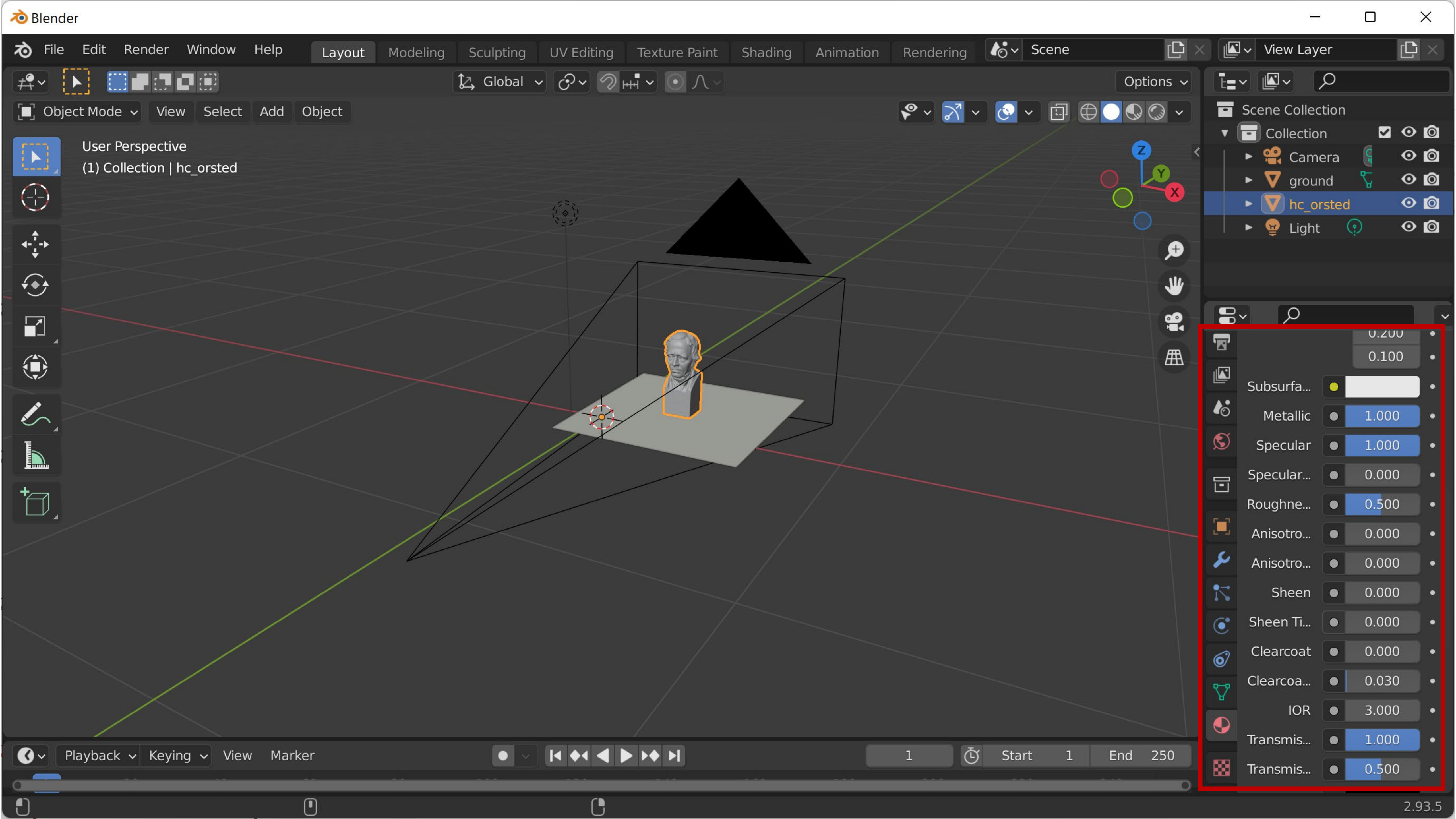
2.93.5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hc_orsted
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Metallic 1.000
Specular 1.000
Specular... 0.000
Roughne... 0.500
Anisotro... 0.000
Anisotro... 0.000
Sheen 0.000
Sheen Ti... 0.000
Clearcoat 0.000
Clearcoa... 0.030
IOR 3.000
Transmis... 1.000
Transmis... 0.500
Playback
Keying
View
Marker
1
Start 1
End 250
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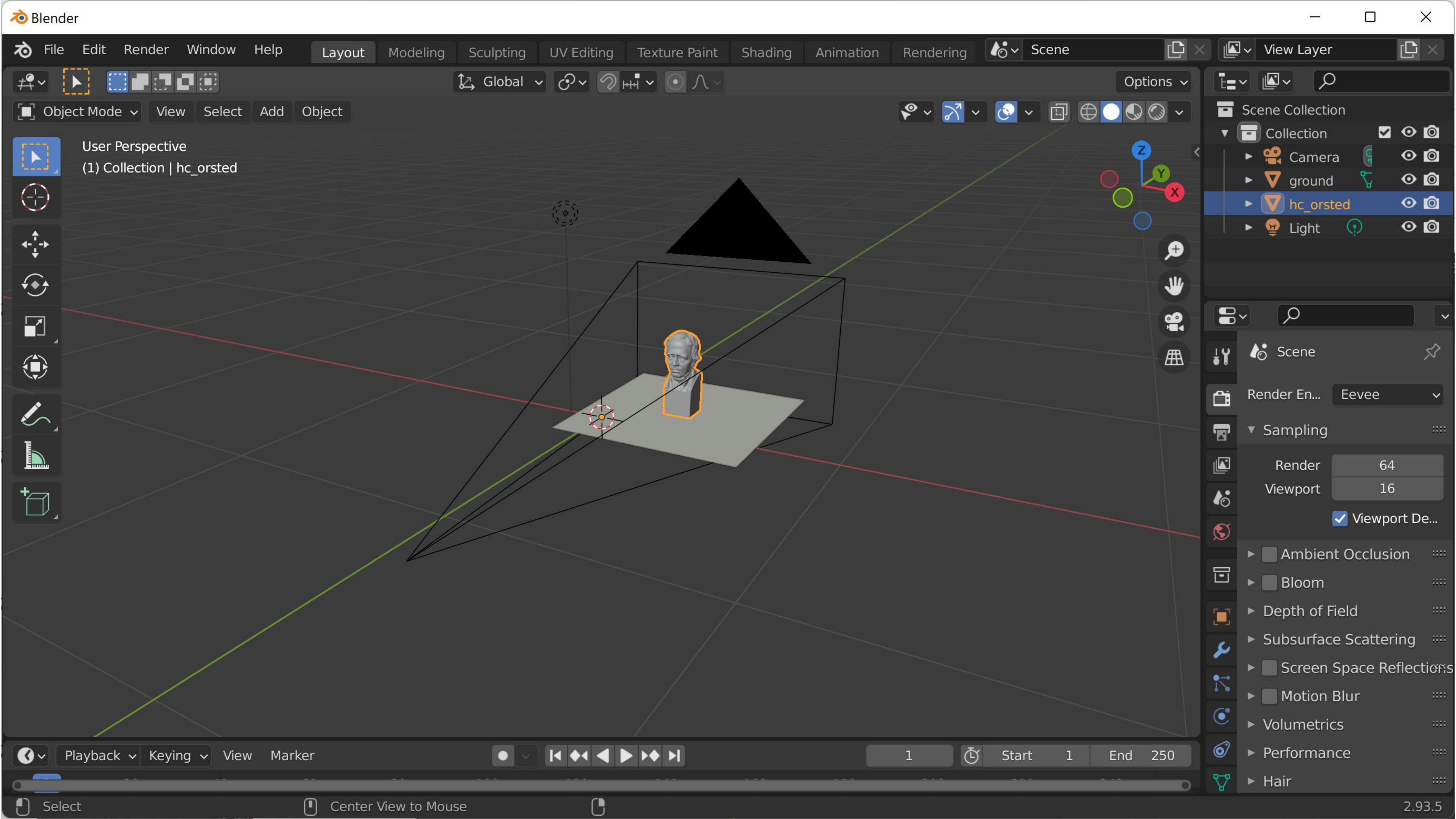
Blender
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Sculpting
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Texture Paint
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View Layer
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User Perspective
(1) Collection | hc_orsted
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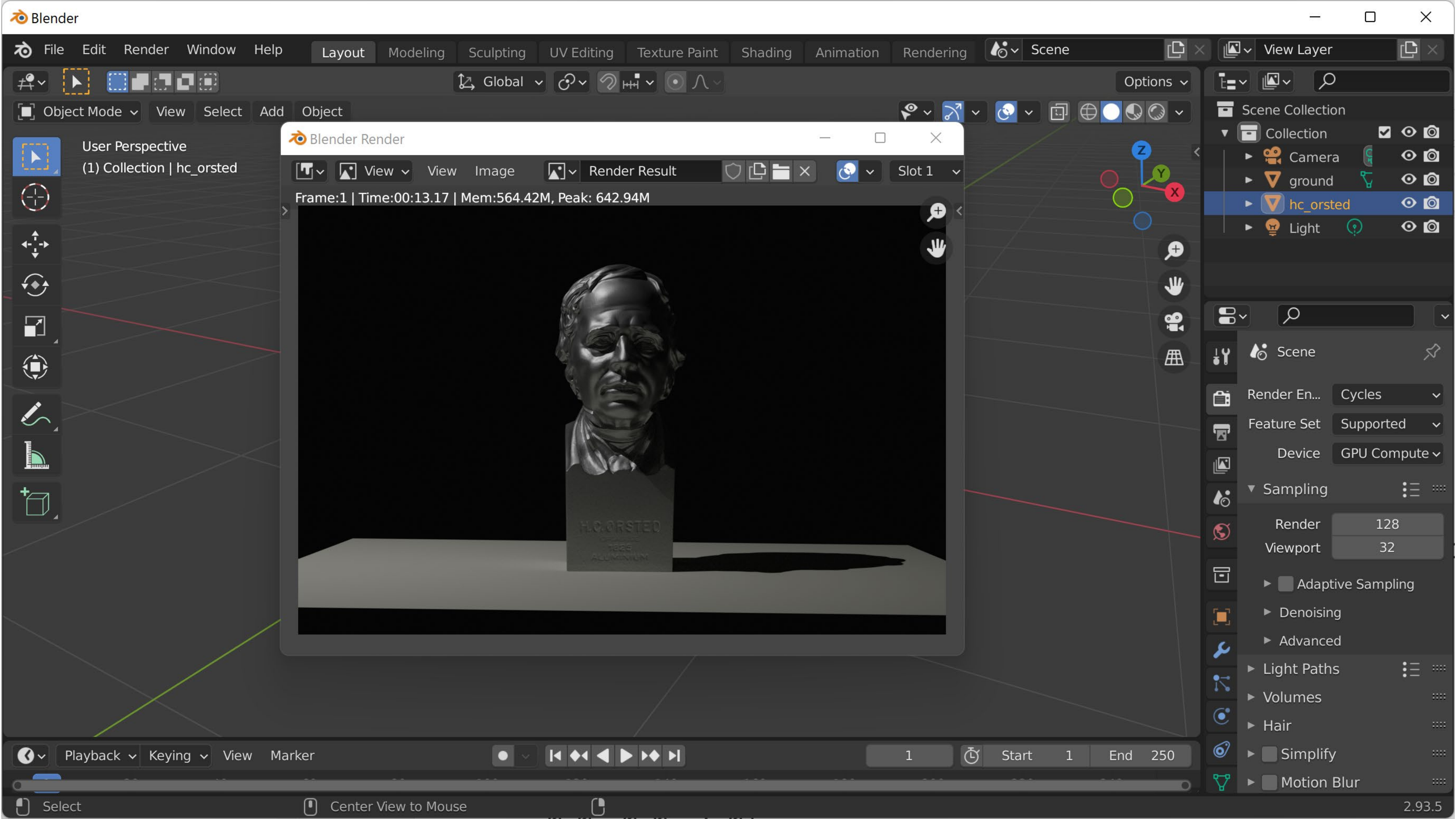
hc_orsted
Light
Scene
Render En...
Eevee
Sampling
Render
64
Viewport
16
Viewport De...
Ambient Occlusion
Bloom
Depth of Field
Subsurface Scattering
Screen Space Reflections
Motion Blur
Volumetrics
Performance
Hair
Playback
Keying
View
Marker
1
Start
1
End
250
Select
Center View to Mouse
2.93.5



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View Layer
Global
Options
Object Mode
View
Select
Add
Object
User Perspective
(1) Collection | hc_orsted
Blender Render
View
View
Image
Render Result
Slot 1
Frame:1 | Time:00:13.17 | Mem:564.42M, Peak: 642.94M
Scene Collection
Collection
Camera
ground
hc_orsted
Light
Scene
Render En...
Cycles
Feature Set
Supported
Device
GPU Compute
Sampling
Render
128
Viewport
32
Adaptive Sampling
Denoising
Advanced
Light Paths
Volumes
Hair
Simplify
Motion Blur
Playback
Keying
View
Marker
1
Start
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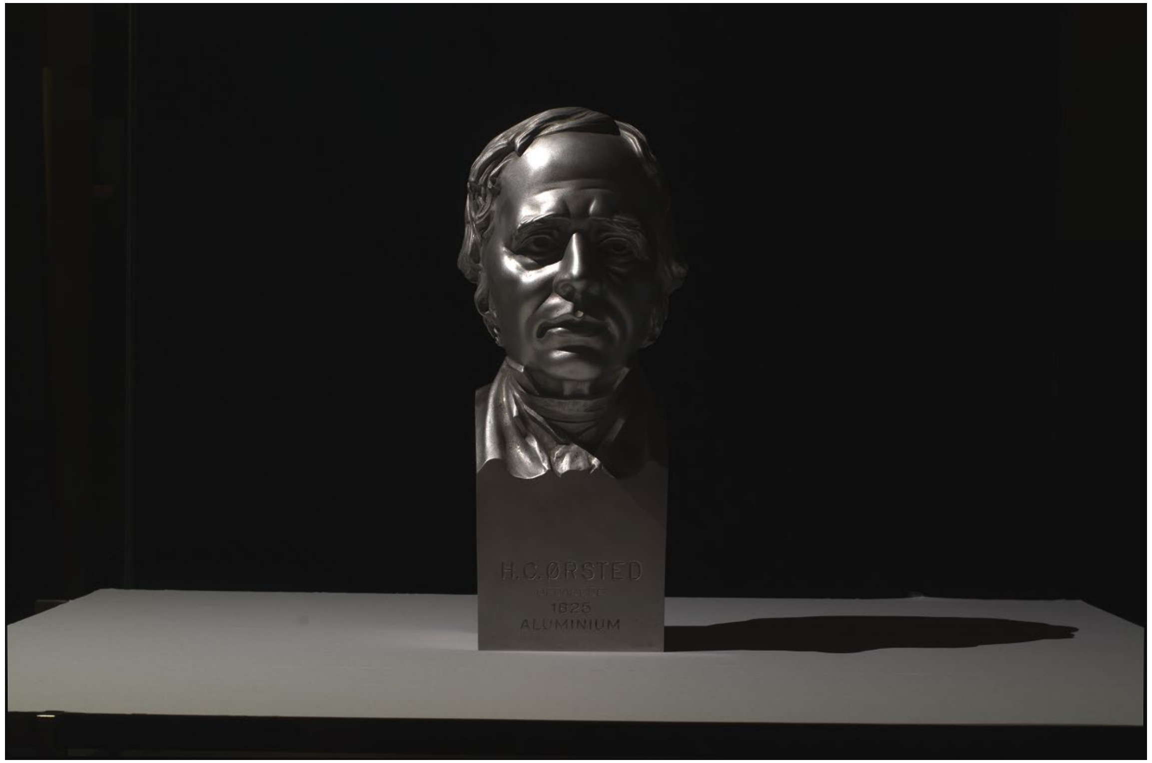
End
250
Select
Center View to Mouse
2.93.5


H.C.ØRSTED
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ALUMINIUM