# SC-OmniGS: Self-Calibrating Omnidirectional Gaussian Splatting

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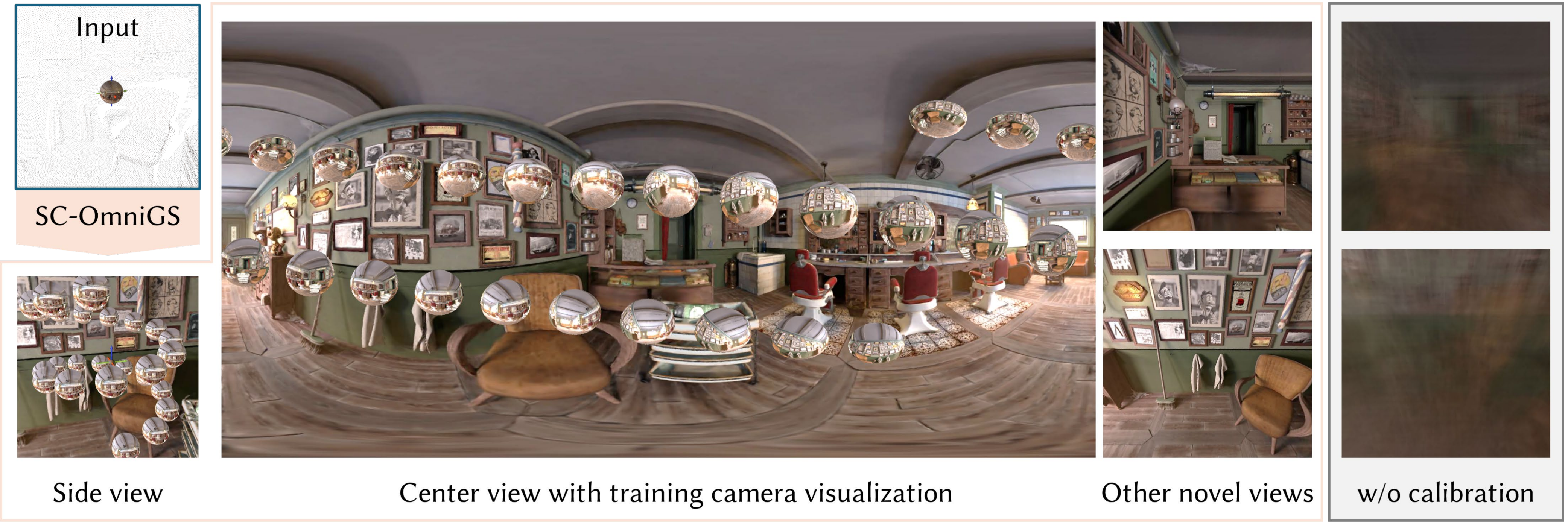
* Equal Contribution

Homepage : https://www.chenyingshu.com/sc-omnigs/



# Motivation

***Robust omnidirectional radiance field reconstruction*** is challenging due to:

1. Non-ideal camera model


Sparse and wide-baseline 360° image dataset [1]

Image distortion

[1] H. Huang et al. 360Roam: Real-Time Indoor Roaming Using Geometry-Aware 360° Radiance Fields, SIGGRAPH Asia 2022 Technical Coms.

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2. Reliance on camera estimation,
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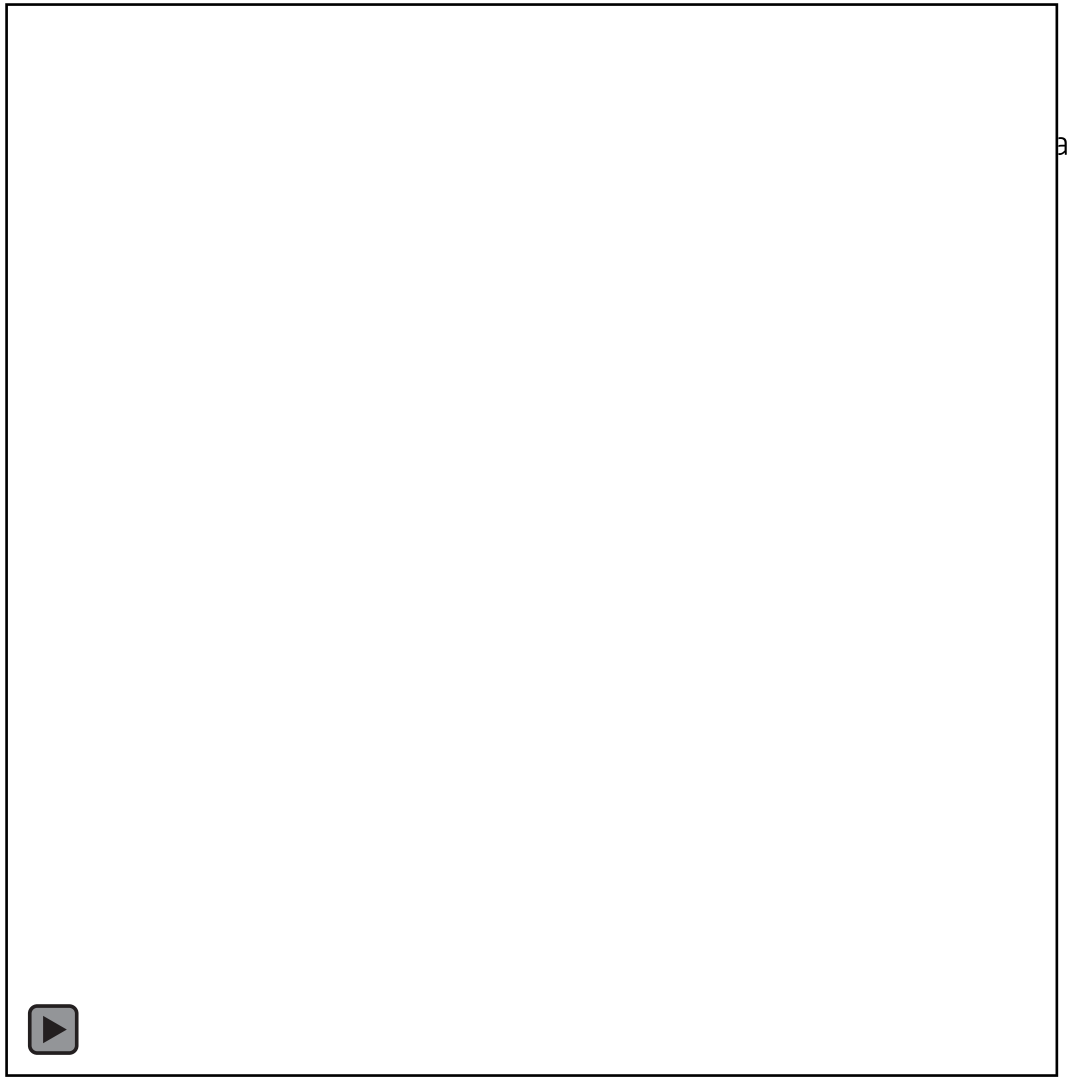

CamP [2] adds join camera optimization to NeRF training

[2] Park, Keunhong, et al. "CamP: Camera preconditioning for neural radiance fields." TOG 2023.

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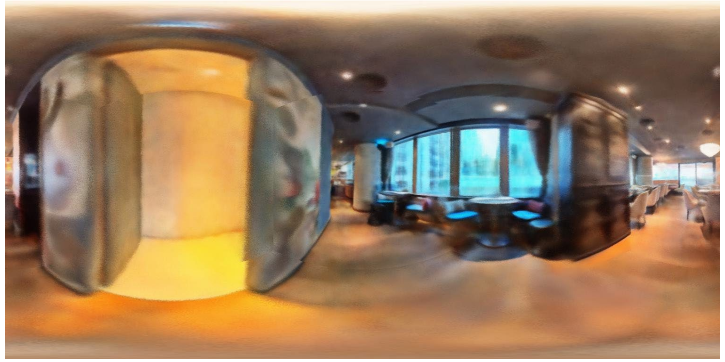
equirectangular to cube map

6 perspective images

SC-OmniGS (Ours)



Naïve solution: cube map + calibration [3]

[3] Chen, Yue, et al. "Local-to-global registration for bundle-adjusting neural radiance fields." CVPR 2023.

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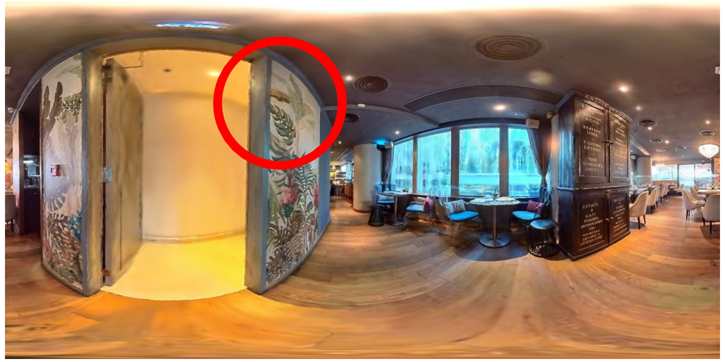

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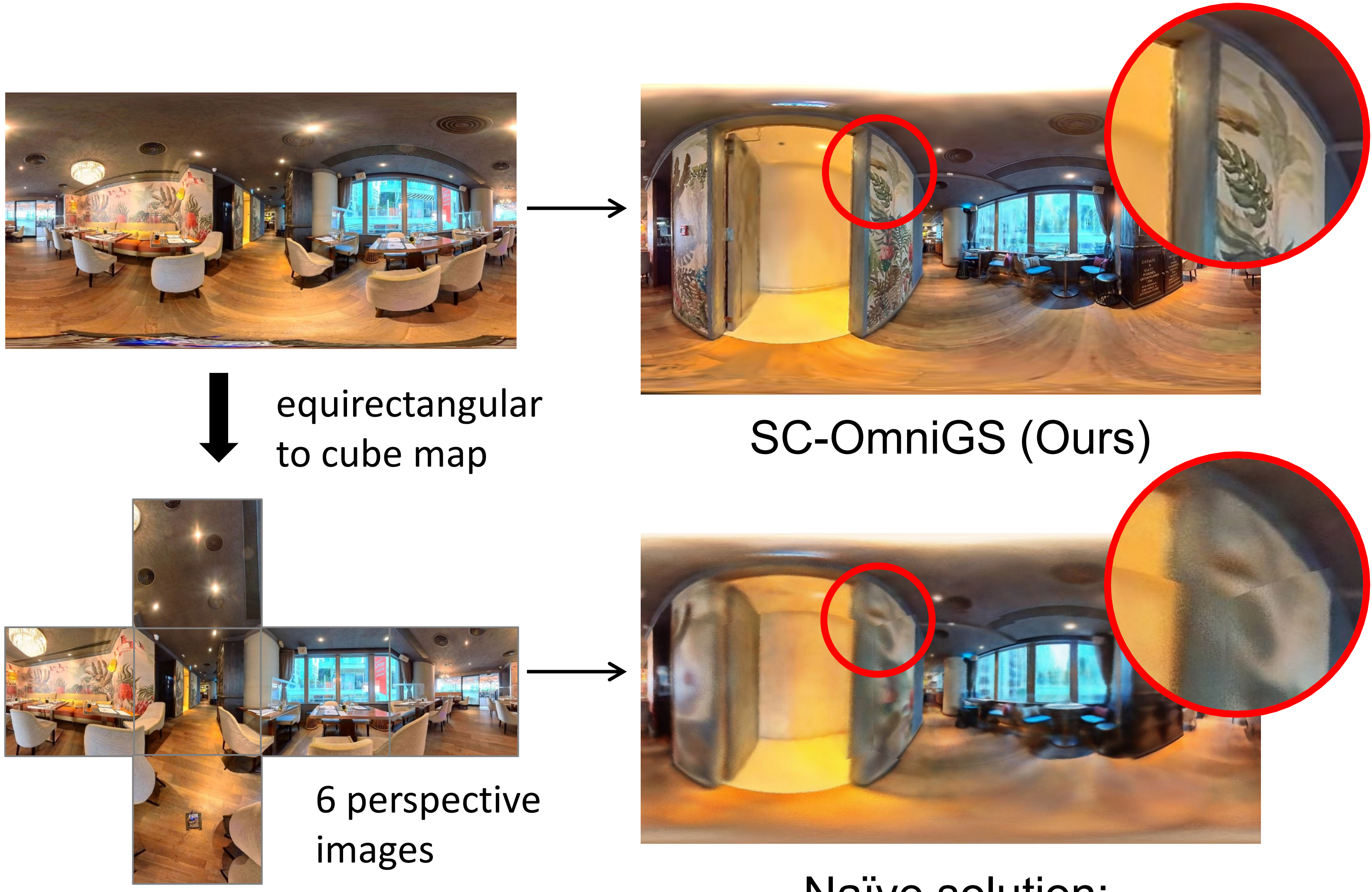


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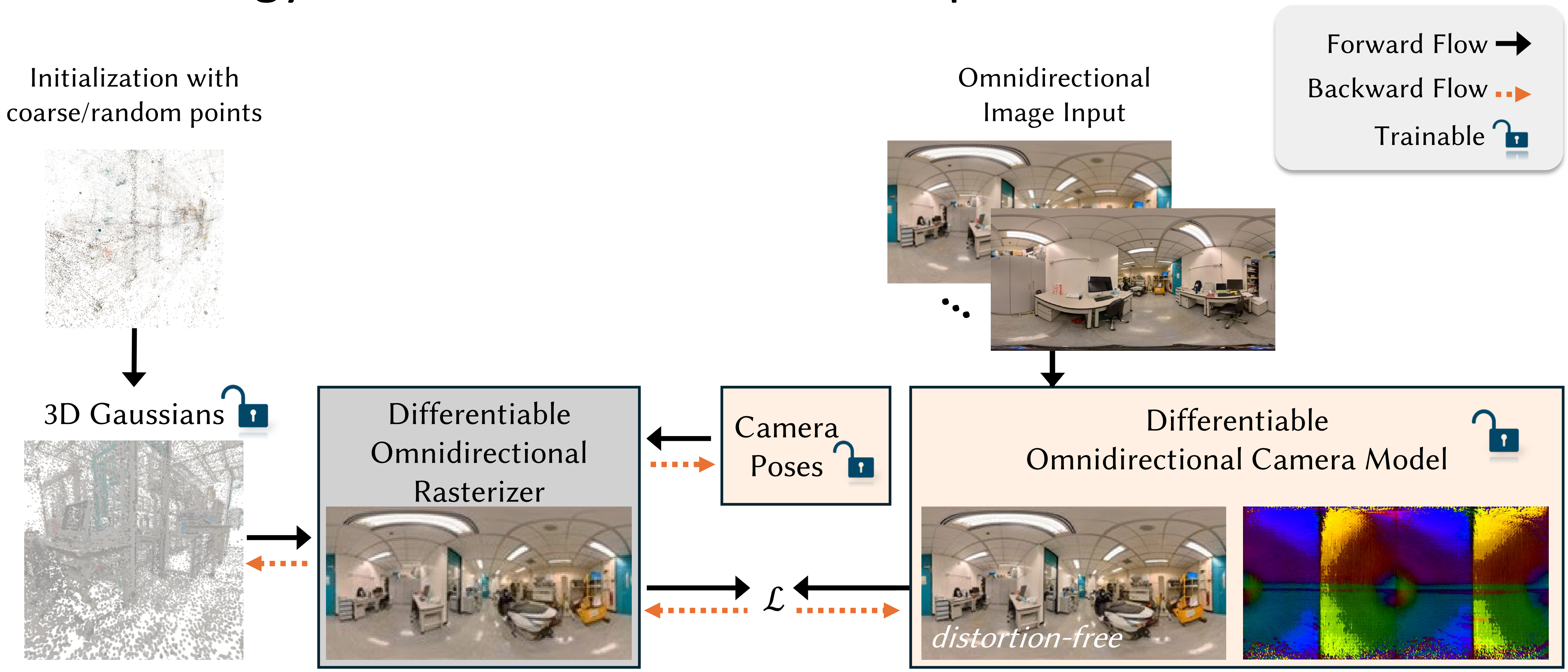
# Methodology: Overview of SC-OmniGS Optimization Flow




H. Huang* and Yingshu Chen*, L. Li, H. Cheng, T. Braud, Y. Zhao, S.-K. Yeung, "SC-Omnigs: Self-Calibrating Omnidirectional Gaussian Splatting". 2024.

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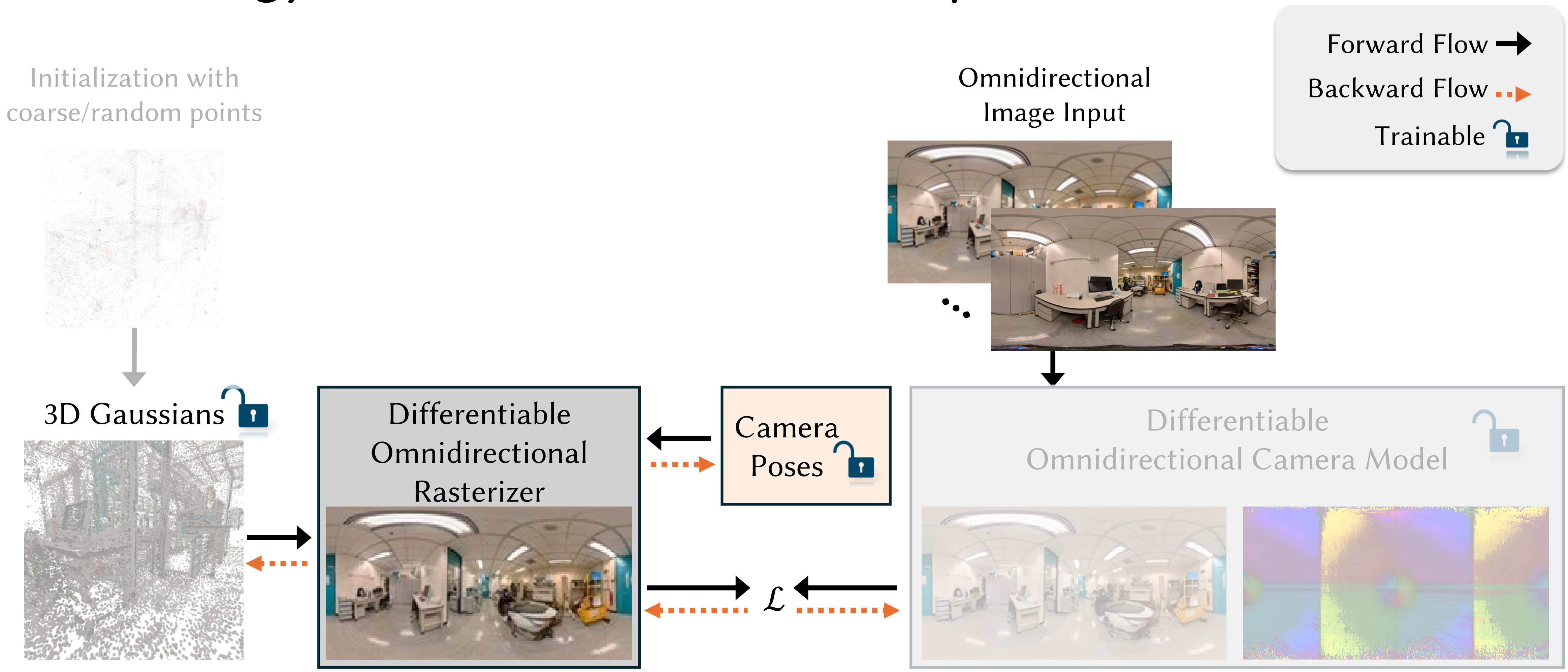


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# Methodology: Gradients of Omnidirectional Camera Pose

## Omnidirectional Gaussian Splatting (OmniGS)[4]

- Equirectangular projection $\phi^{o}$:

$$\mathbf{u} = \phi^{\mathbf{o}}(\mathbf{x}) = \begin{bmatrix} f_x^o \cdot arctan2(x, z) + c_x^o \\ f_y^o \cdot arcsin(y/d) + c_y^o \end{bmatrix} = \begin{bmatrix} \frac{W}{2\pi} \cdot arctan2(x, z) + \frac{W}{2} \\ \frac{H}{\pi} \cdot arcsin(y/d) + \frac{H}{2} \end{bmatrix}$$

- Rendered color of pixel $\mathbf{u}$ in an omnidirectional image:

$$\mathbf{C}^o(\mathbf{u}) = \sum_{i \in \mathcal{N}} c_i \alpha_i^o \prod_{j=1}^{i-1} (1 - \alpha_j^o), \quad \alpha_j^o = \sigma_j \cdot \mathbf{r}_{2D}^o(\mathbf{u})$$

derivation

## Gradients of camera pose $\mathbf{T}$:

Part 1: $$\frac{\partial c}{\partial \mathbf{T}'} = \frac{\partial c}{\partial dir} \cdot \frac{\partial dir}{\partial \mathbf{T}'} = \frac{\partial c}{\partial dir} \cdot \left[ \frac{\partial dir}{\partial \mathbf{R}} \cdot \frac{\partial \mathbf{R}}{\partial \mathbf{q}} \quad \frac{\partial dir}{\partial \mathbf{t}} \right]$$

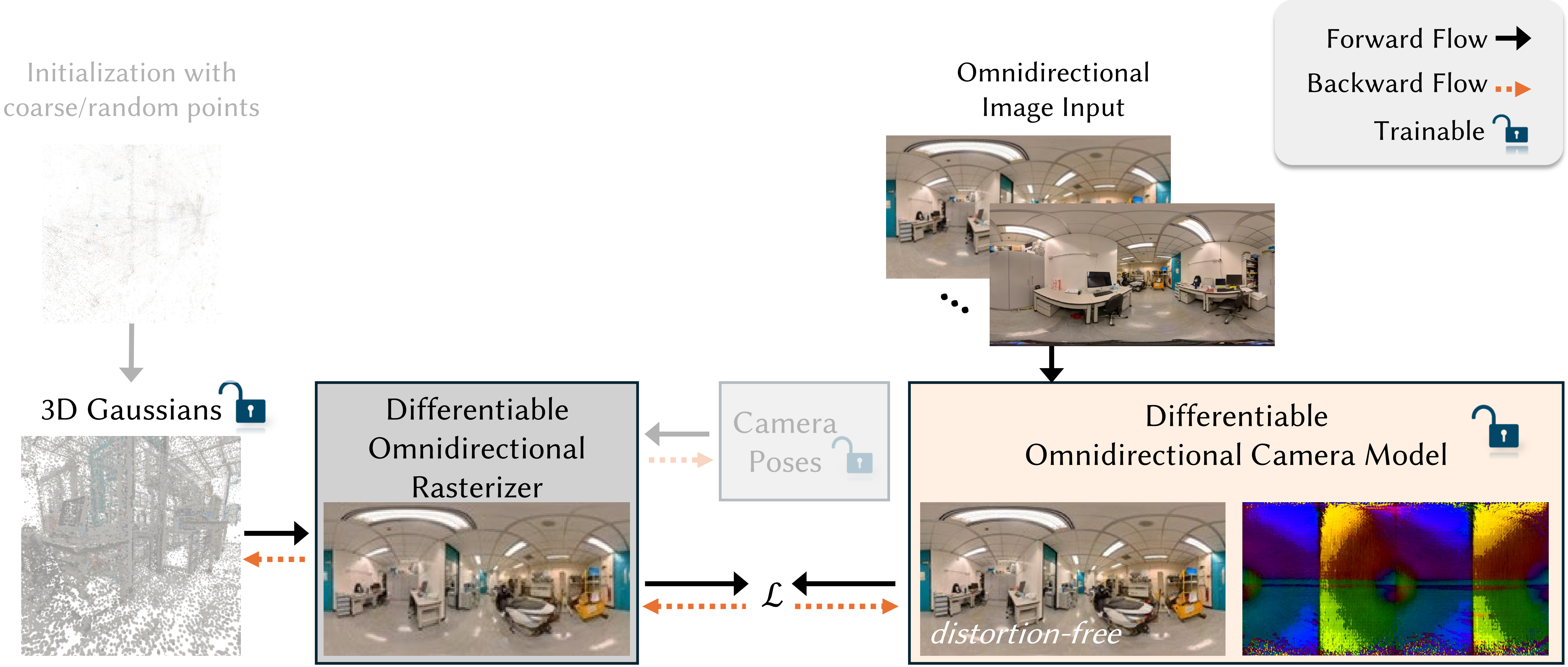
Part 2: $$\frac{\partial \mathbf{r}_{2D}^o}{\partial \mathbf{T}'} = \left[ \frac{\partial \mathbf{r}_{2D}^o}{\partial \mathbf{u}_i} \cdot \frac{\partial \mathbf{u}_i}{\partial \mathbf{T}'} \quad \frac{\partial \mathbf{r}_{2D}^o}{\partial \mathbf{J}_i^o} \cdot \frac{\partial \mathbf{J}_i^o}{\partial \mathbf{T}'} \quad \frac{\partial \mathbf{r}_{2D}^o}{\partial \mathbf{R}} \cdot \frac{\partial \mathbf{R}}{\partial \mathbf{T}'} \right] = \left[ \frac{\partial \mathbf{r}_{2D}^o}{\partial \mathbf{u}_i} \cdot \frac{\partial \mathbf{u}_i}{\partial \boldsymbol{x}_i}, \quad \frac{\partial \mathbf{r}_{2D}^o}{\partial \mathbf{J}_i^o} \cdot \frac{\partial \mathbf{J}_i^o}{\partial \boldsymbol{x}_i} \right] \cdot \left[ \frac{\partial \boldsymbol{x}_i}{\partial \mathbf{R}} \cdot \frac{\partial \mathbf{R}}{\partial \mathbf{q}}, \quad \frac{\partial \boldsymbol{x}_i}{\partial \mathbf{t}} \right] + \frac{\partial \mathbf{r}_{2D}^o}{\partial \mathbf{R}} \cdot \frac{\partial \mathbf{R}}{\partial \mathbf{q}}$$

Center View


Side View


[4] L. Li, et al. "OmniGS: Omnidirectional Gaussian Splatting for Fast Radiance Field Reconstruction using Omnidirectional Images." 2024.

# Methodology: Overview of SC-OmniGS Optimization Flow

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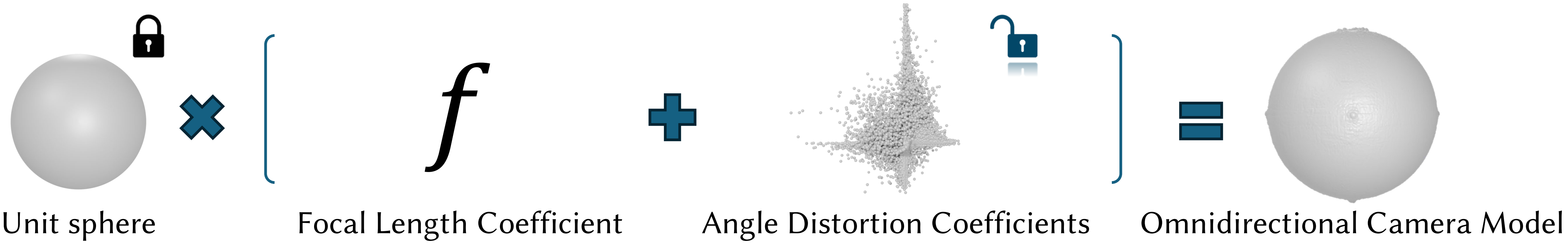
# Methodology: Differentiable Omnidirectional Camera Model

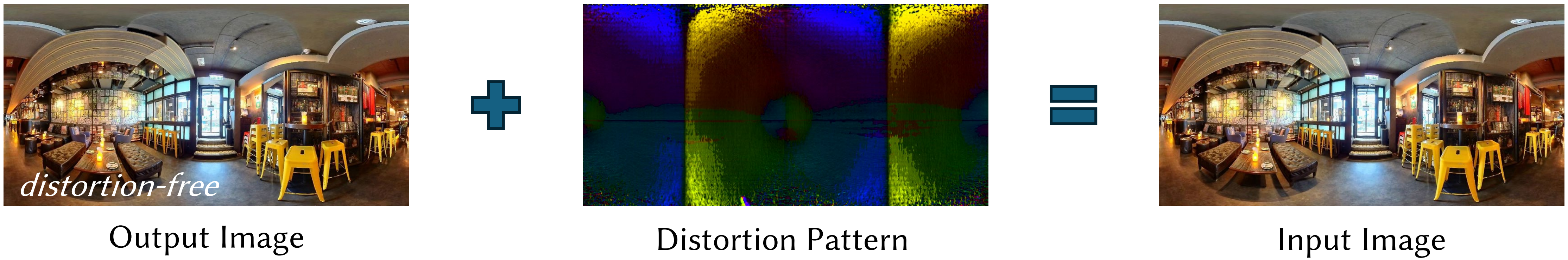
- The **generic** omnidirectional camera model $\Theta$ is defined as:

$$\Theta := S \cdot f_t + S \odot D.$$

$S \in \mathbb{R}^{H\times W\times 3}$ is a spherical grid; angle distortion coefficients $D \in \mathbb{R}^{H\times W\times 3}$ are initialized to zeros; for simplicity, we fix focal length coefficient $f_t$ to 1.

Frozen
Trainable



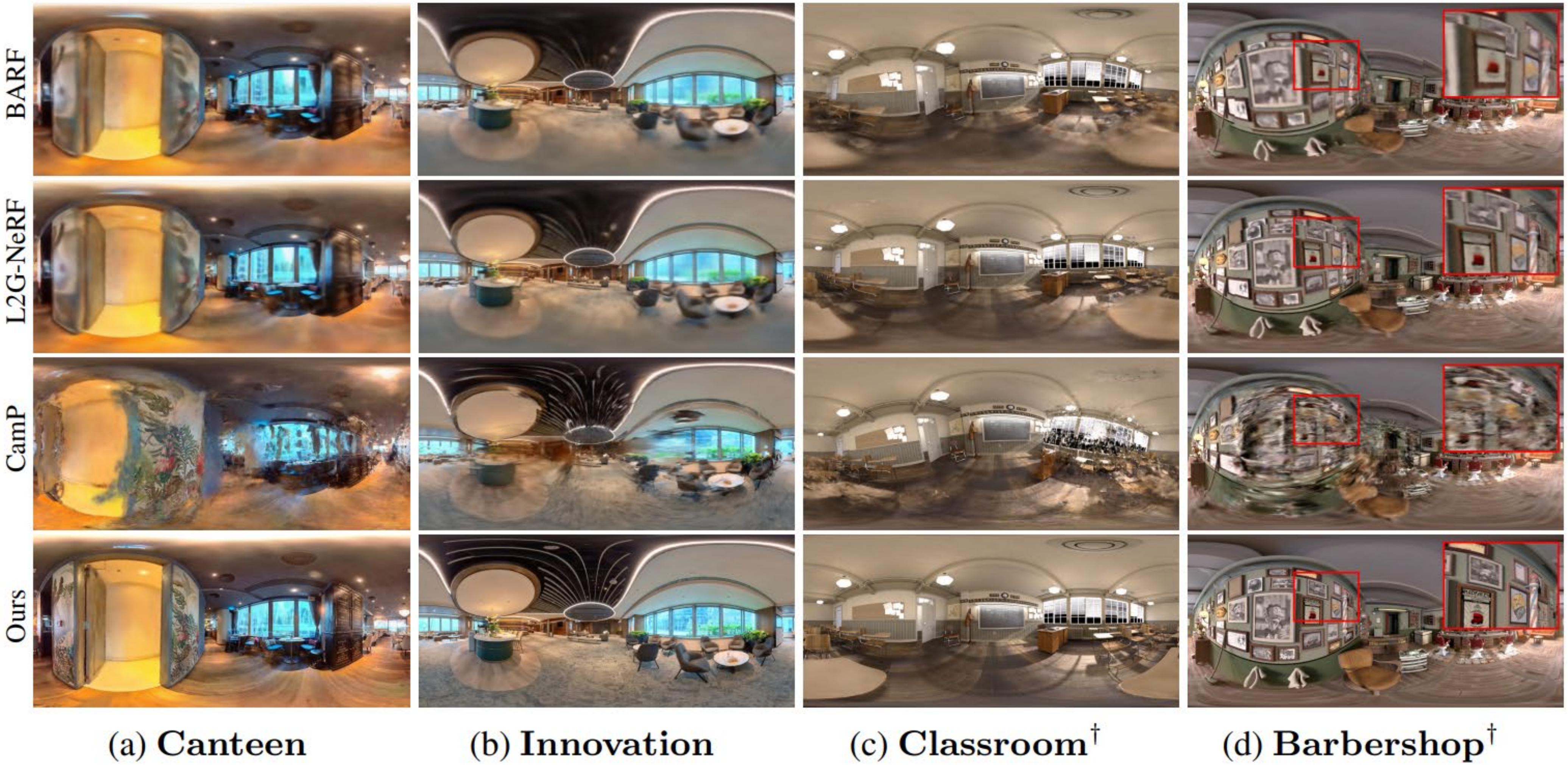



# Result Comparisons

**Quantitative comparisons** on real-world dataset 360Roam. "Perturb" indicates perturbed camera poses as inputs, "train" and "test" indicate training and test views, respectively. We mark the best two results with **first** and second .

| | On 360Roam | Perturb | train PSNR↑ | train SSIM↑ | train LPIPS↓ | test PSNR↑ | test SSIM↑ | test LPIPS↓ | Input images |
|---|---|---|---|---|---|---|---|---|---|
| Non-calibration methods | 3D-GS [20] | × | 23.943 | 0.744 | 0.223 | 20.791 | 0.684 | 0.261 | Perspective images |
| Non-calibration methods | OmniGS [22] | × | 28.517 | 0.861 | **0.137** | 24.212 | 0.768 | **0.176** | 360-degree images |
| Non-calibration methods | OmniGS [22] | ✓ | 22.111 | 0.705 | 0.334 | 15.619 | 0.455 | 0.489 | 360-degree images |
| Calibration methods | BARF [23] | ✓ | 21.699 | 0.594 | 0.465 | 20.200 | 0.572 | 0.481 | Perspective images |
| Calibration methods | L2G-NeRF [8] | ✓ | 21.797 | 0.598 | 0.460 | 20.507 | 0.576 | 0.473 | Perspective images |
| Calibration methods | CamP [28] | ✓ | 24.592 | 0.735 | 0.264 | 14.253 | 0.438 | 0.573 | Perspective images |
| Calibration methods | SC-OmniGS (Ours) | ✓ | **29.232** | **0.872** | 0.147 | **24.910** | **0.790** | 0.188 | 360-degree images |

# Result Comparisons




**Qualitative comparisons** of 360-degree novel views among calibration methods. Our results outperform in both rendering quality and camera accuracy. † indicates training from scratch without camera priors.

# Ablation Study

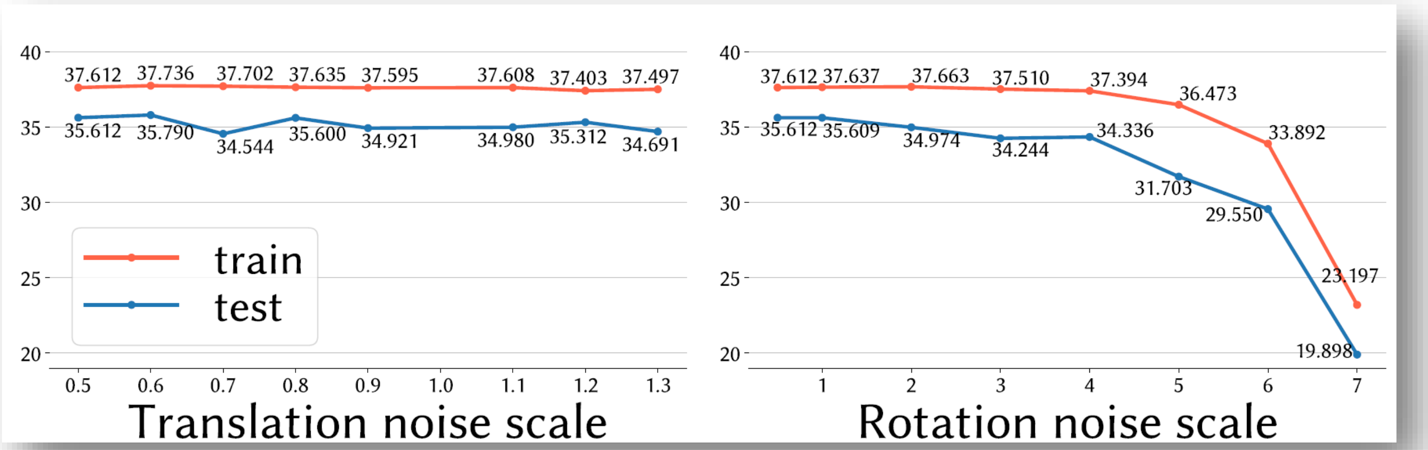
**Ablation study** on real scene **Center** of 360Roam, in terms of the optimization of camera model, camera pose, or both. “Perturb” indicates perturbed camera poses, “train” and “test” indicate training and test views, respectively. We mark the best two results with **first** and second .

| Calibration | w/o Perturb | | | | | | w/ Perturb | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | train | | | test | | | train | | | test | | |
| | PSNR ↑ | SSIM ↑ | LPIPS ↓ | PSNR ↑ | SSIM ↑ | LPIPS ↓ | PSNR ↑ | SSIM ↑ | LPIPS ↓ | PSNR ↑ | SSIM ↑ | LPIPS ↓ |
| none | 28.728 | 0.848 | 0.170 | 24.264 | 0.763 | 0.213 | 22.740 | 0.717 | 0.372 | 15.597 | 0.510 | 0.553 |
| +camera model | **30.230** | **0.877** | **0.153** | 25.123 | 0.795 | **0.195** | 22.743 | 0.730 | 0.408 | 15.702 | 0.543 | 0.568 |
| +pose | 28.334 | 0.837 | 0.191 | 24.906 | 0.781 | 0.224 | 28.130 | 0.834 | 0.198 | 24.739 | 0.777 | 0.233 |
| +camera model+pose | 30.035 | 0.872 | 0.169 | **25.802** | **0.813** | 0.203 | **29.706** | **0.867** | **0.177** | **25.304** | **0.799** | **0.220** |

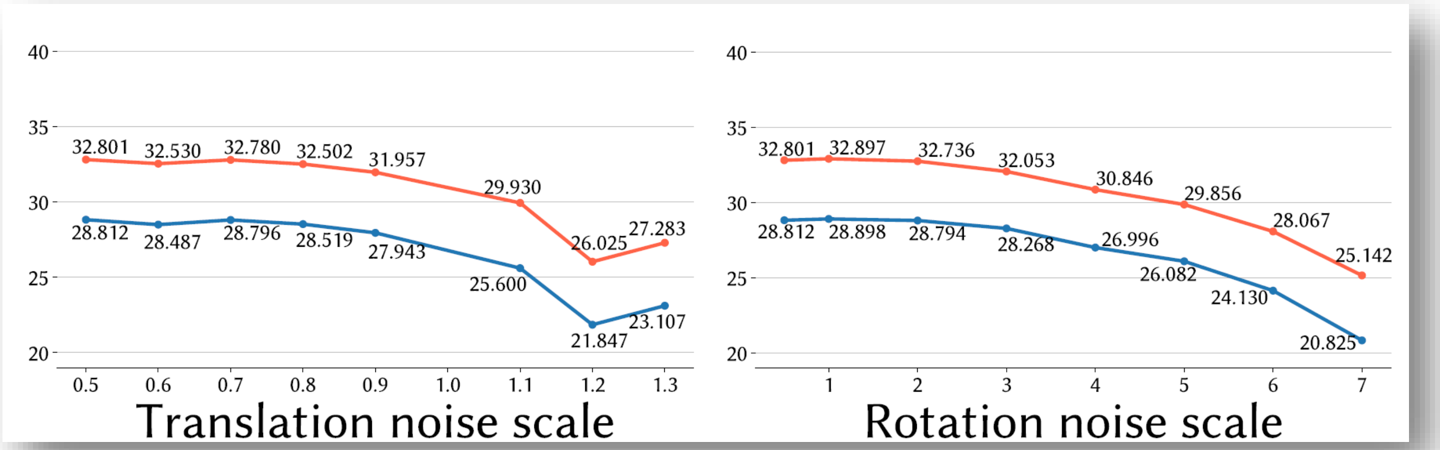
360-degree real-scene data:

Imperfect camera model exhibits distortion

(a) Synthetic scene

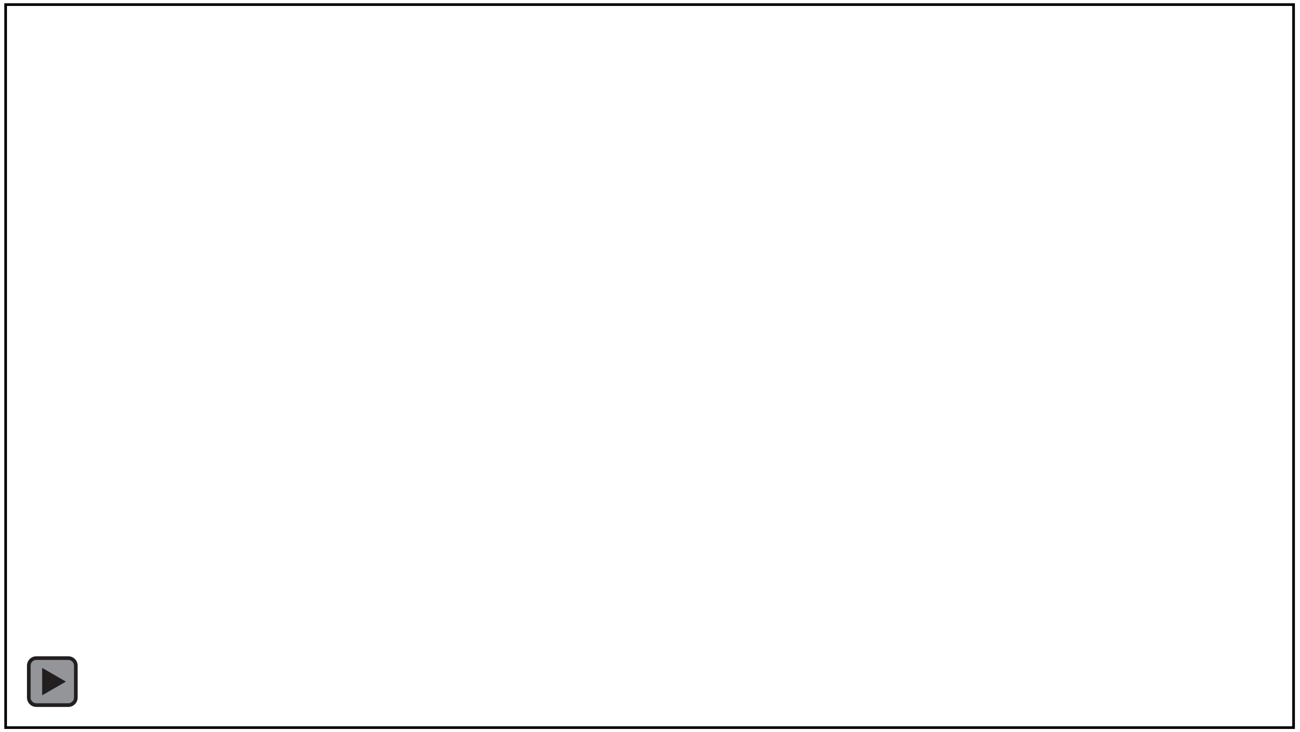



(b) Real world scene

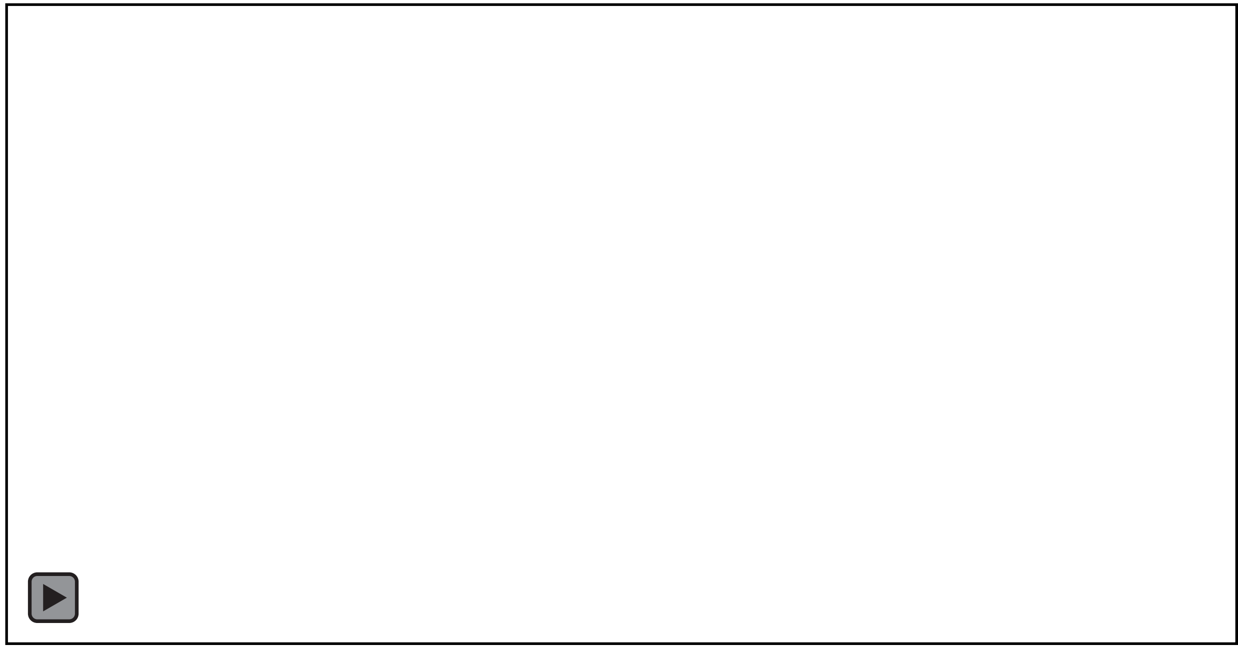



Robustness with different level camera perturbations (PSNR↑).

# Ablation Study – real-time rendering comparisons



Perspective novel views



Omnidirectional novel views

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# Thank You