



# 面向室内场景数字化

如视科技

李臻

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01 背景

02 数据集介绍

03 基于物理的逆渲染--PhyIR

04 真实场景多视图逆渲染--TexIR

# 01 背景

- 现有的室内场景数字化
  - VR全景图+三维模型+RGB贴图



VR全景图



三维模型+贴图

# 01 背景

- 期望可用的虚拟资产
  - 三维模型+多种材质贴图+光照



三维模型+材质贴图



渲染图像

# 01 背景



- 现实与理想的差距在哪？
  - 如何从RGB图像中重建albedo, roughness等材质信息, 光照信息？
  
- 如何实现？
  - 逆渲染

# 01 背景

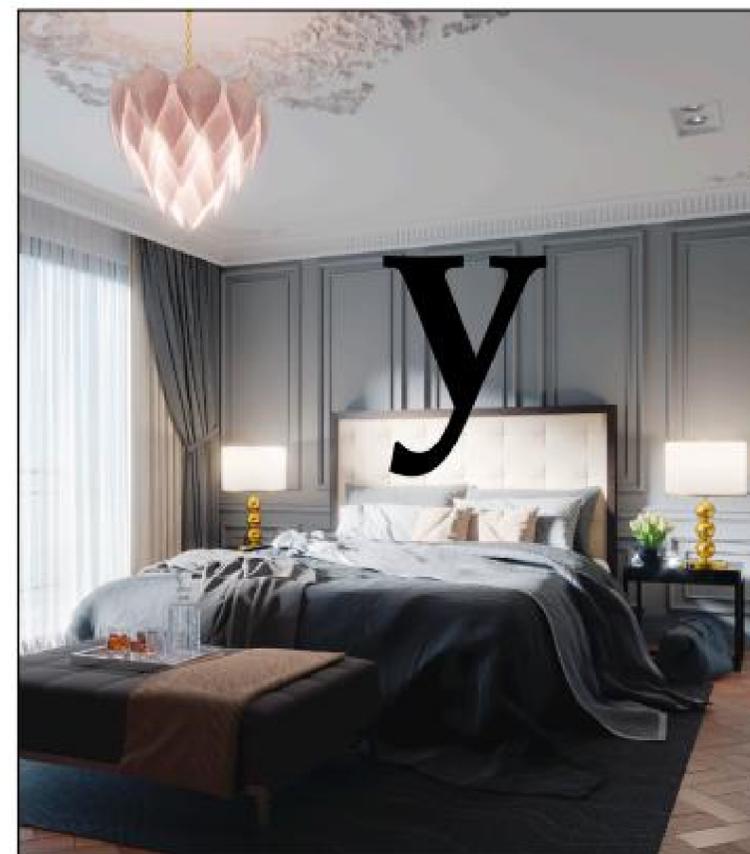
- 逆渲染:



Geometry, materials, emitters, ...

Rendering  
 $y = f(x)$

Inverse rendering  
 $x = f^{-1}(y)?$



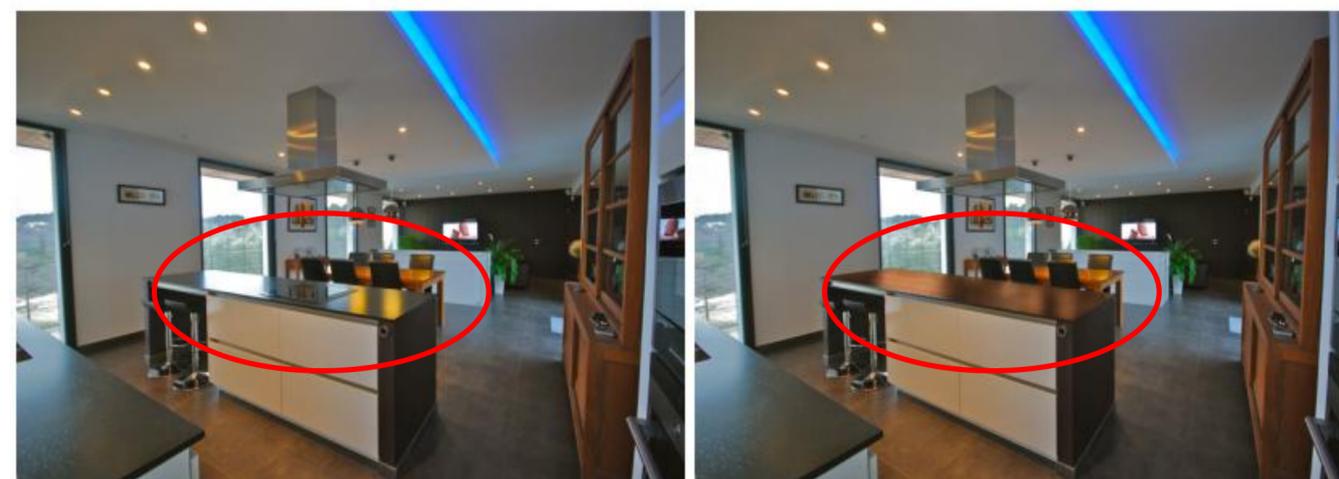
Scene: "bed classic" from jiraniانو

- 应用:

1. 三维重建
2. 位姿优化
3. 光照优化
4. 材质优化

# 01 背景

- 应用示例



Original Image (Real)

Replacing Materials



input

reconstruction

MR

材质替换

视角合成/重打光  
真实重建



Novel view 1

Novel view 2



# 01 背景

- 正向渲染:

渲染方程: 
$$L_0(x, \omega_0) = L_e(x, \omega_0) + \int_{\Omega} f_r(x, w_i, \omega_0) L_i(x, w_i) (n \cdot \omega_i) dw_i$$

$L_0(x, w_0)$  x点从某方向接收的radiance

$L_e(x, w_0)$  x点朝某方向的自发光

$x$  观察点

$w_0$  x点的出射方向

$L_r(x, w_i, w_0)$  反射方程, 用来描述x点光的入射出射分布, 跟材质/几何有关

$L_i(x, w_i)$  x点的入射光

- 逆渲染:

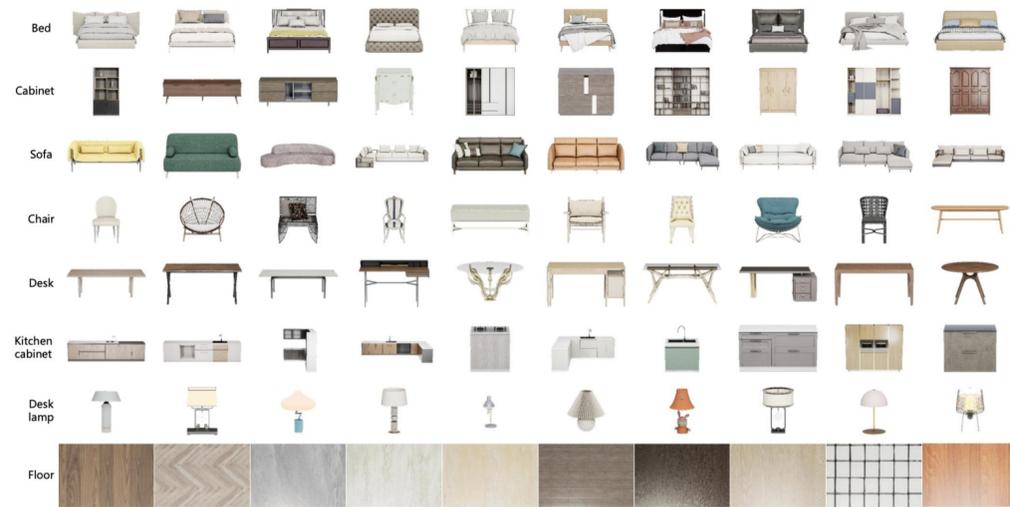
直接求解极其困难, 各种参数互相耦合  $\longrightarrow$  Data-driven

## 02 数据集--FutureHouse



- **真实场景数据集匮乏:**
  - 实际场景的材质/光照等标签极难采集;
- **虚拟场景数据集质量低:**
  - 模型质量, 丰富度, 真实感, 隐私等限制;

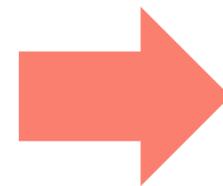
# 02 数据集--FutureHouse



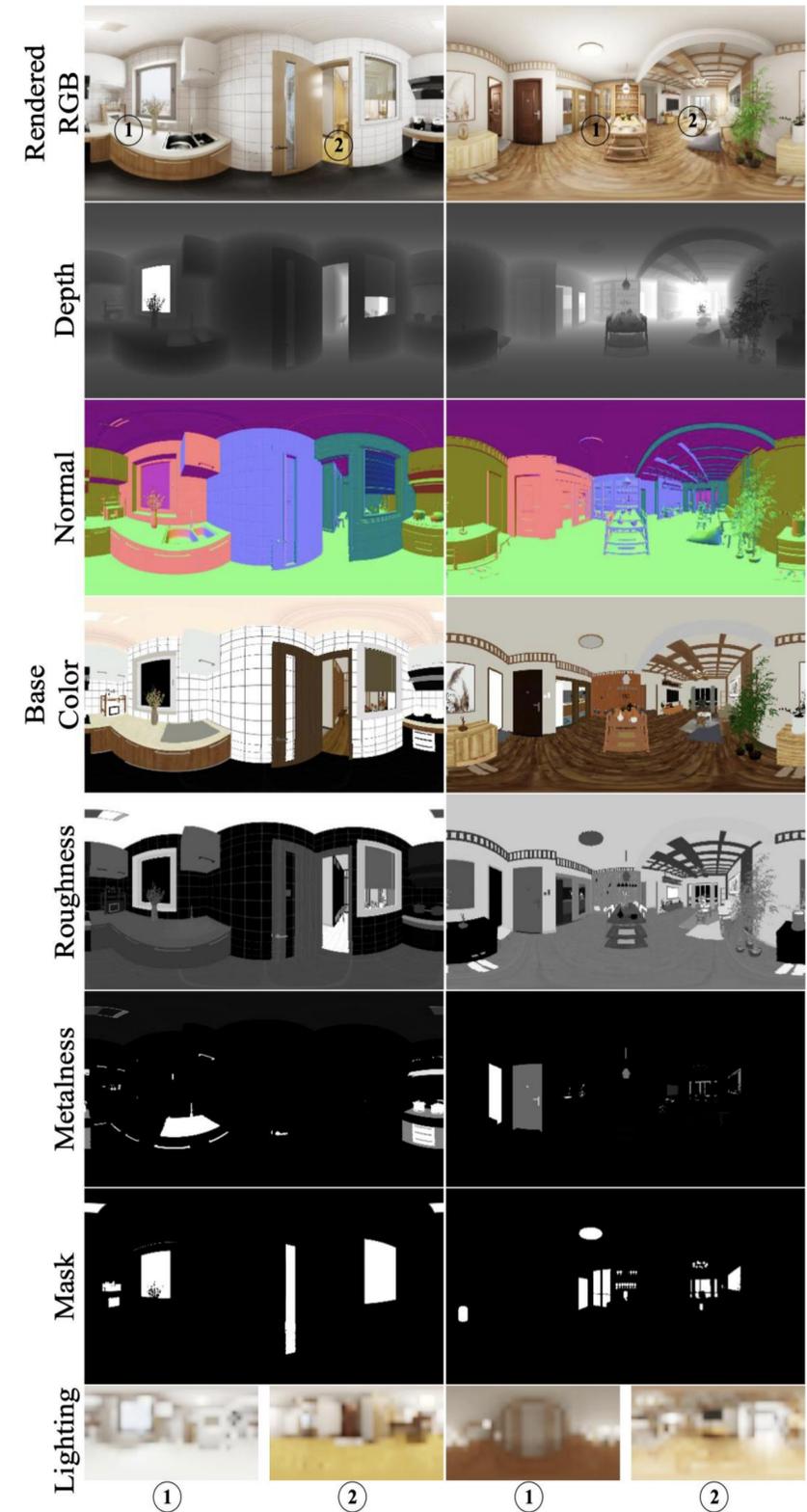
超70,000 高质量物体模型



人工设计的高质量户型图



高质量全局光照渲染



## 02 数据集--FutureHouse



	Layout Type	CAD Model	Geometry Annotation	Material Annotation	Lighting Annotation	Light source Annotation	Panorama
InteriorNet	artist-designed	artist-designed	✓	diffuse	shading	✗	✓
Structure3D	artist-designed	artist-designed	✓	diffuse	shading	✗	✓
OpenRooms	auto-generated	scanned	✓	microfacet	per-pixel HDR envmap	✓	✗
FutureHouse	artist-designed	artist-designed	✓	microfacet	per-pixel HDR envmap	✓	✓

- 在标签丰富度，布局合理性，模型质量，图像质量等方面优于现有数据集

## 03 基于物理的逆渲染--PhyIR<sup>CVPR'22</sup>

• 之前工作--InvIndoor存在的问题:

1. 可微渲染模型不够好



缺失细节的镜面反射



细节丰富的镜面反射

## 03 基于物理的逆渲染--PhyIR<sup>CVPR'22</sup>

- 之前工作--InvIndoor存在的问题:

### 2. 光照表示不合适



闪烁的动态虚拟物体

## 03 基于物理的逆渲染--PhyIR<sup>CVPR'22</sup>

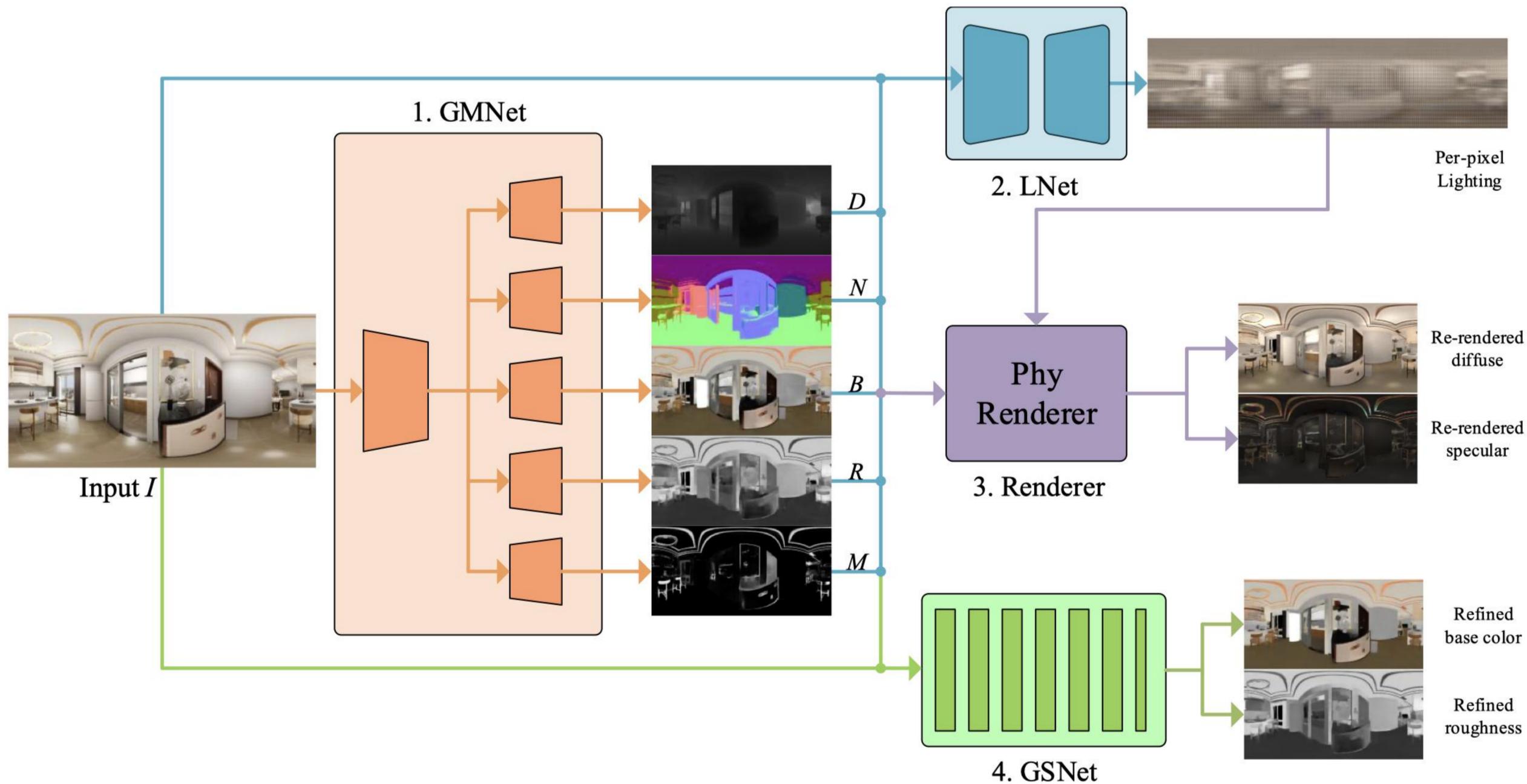


### 贡献/创新点

- **更物理**的模型，可以很好的建模高光，金属，镜子等复杂材质
- 空间**一致变化**的光照模型，光照更细节
- 大型照片真实感**合成数据集**，包含丰富的几何/材质/光照注释

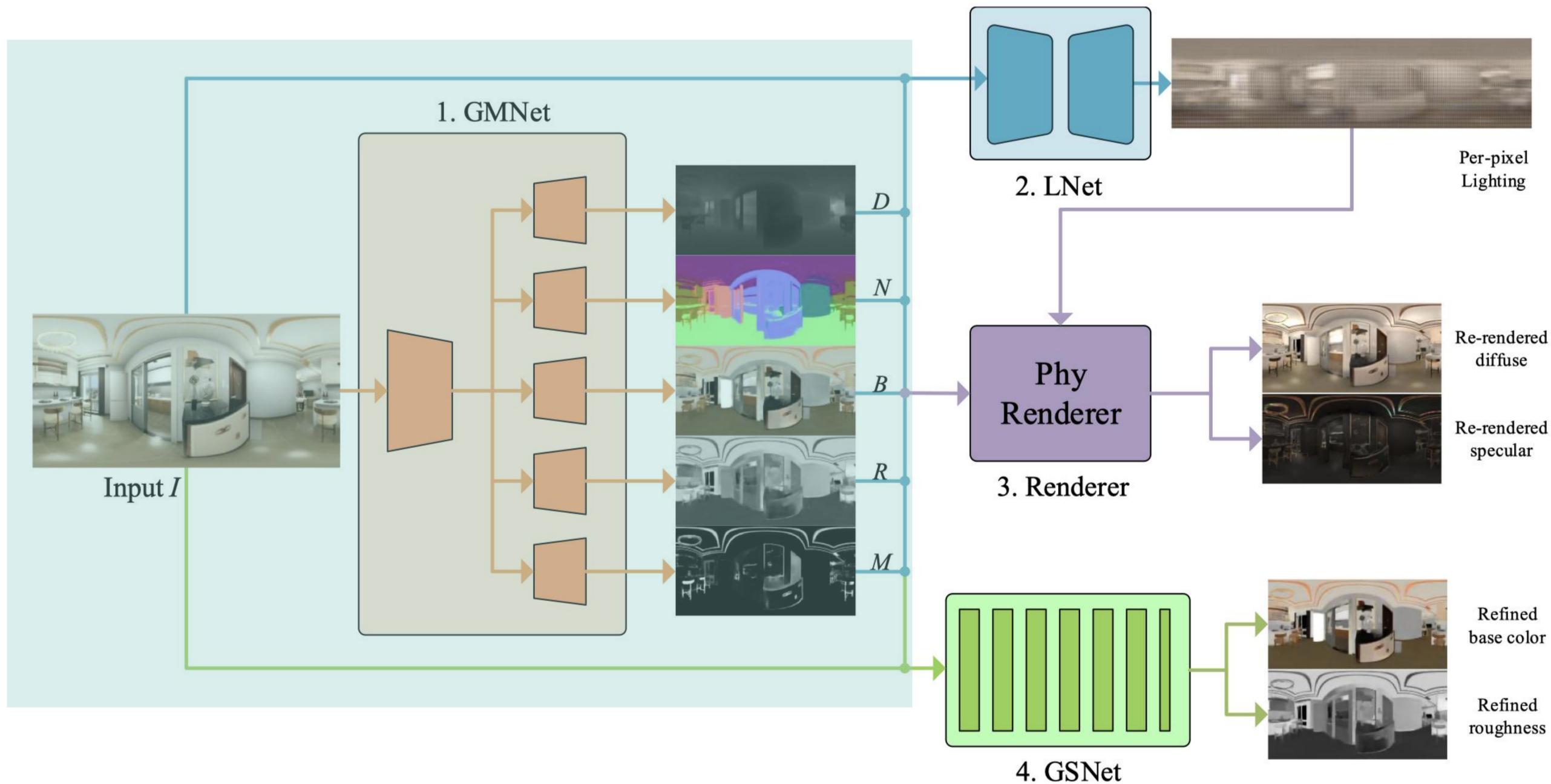
# 03 基于物理的逆渲染--PhyIR<sup>CVPR'22</sup>

- 框架



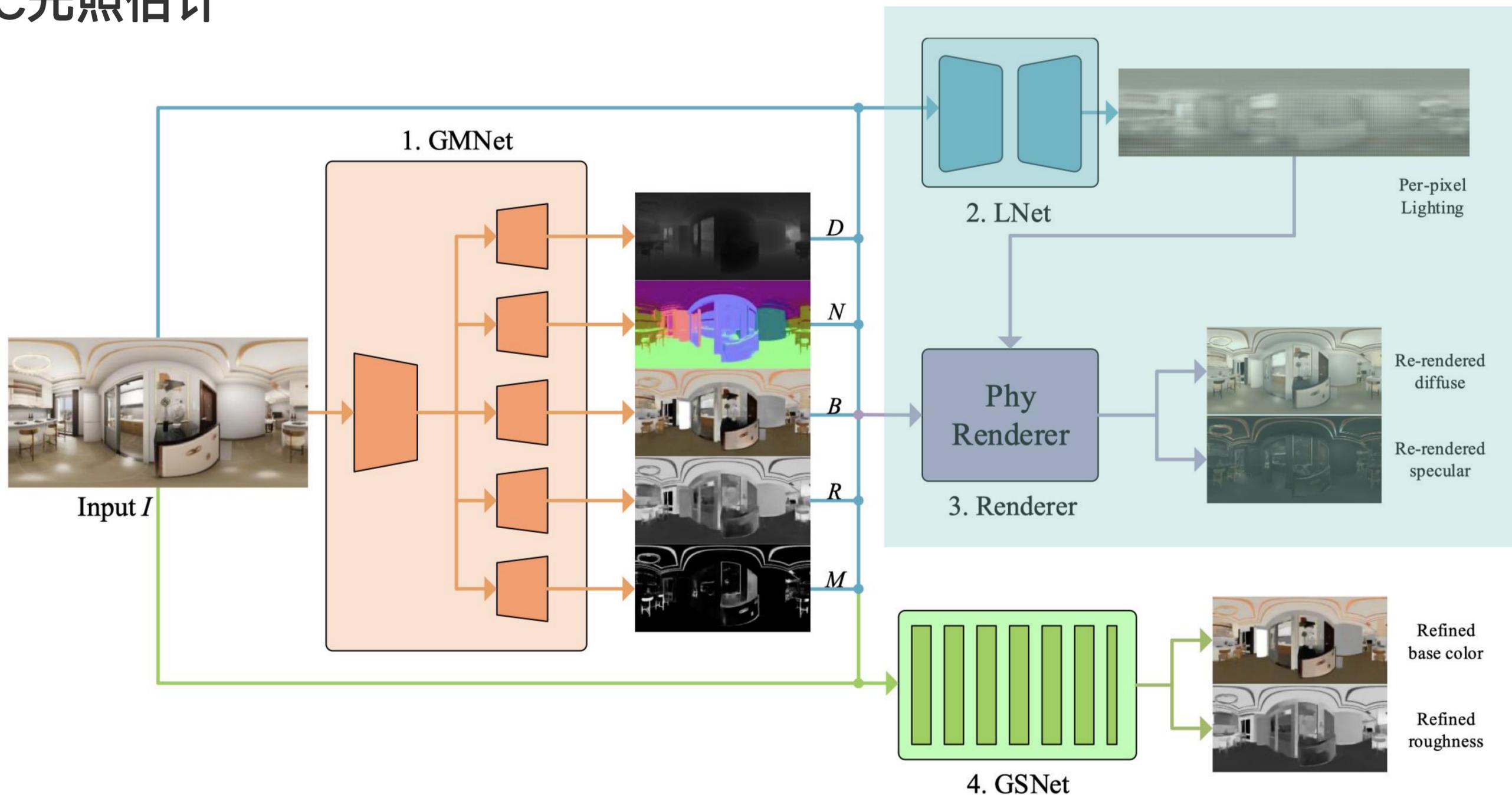
# 03 基于物理的逆渲染--PhyIR<sup>CVPR'22</sup>

- 几何/材质估计



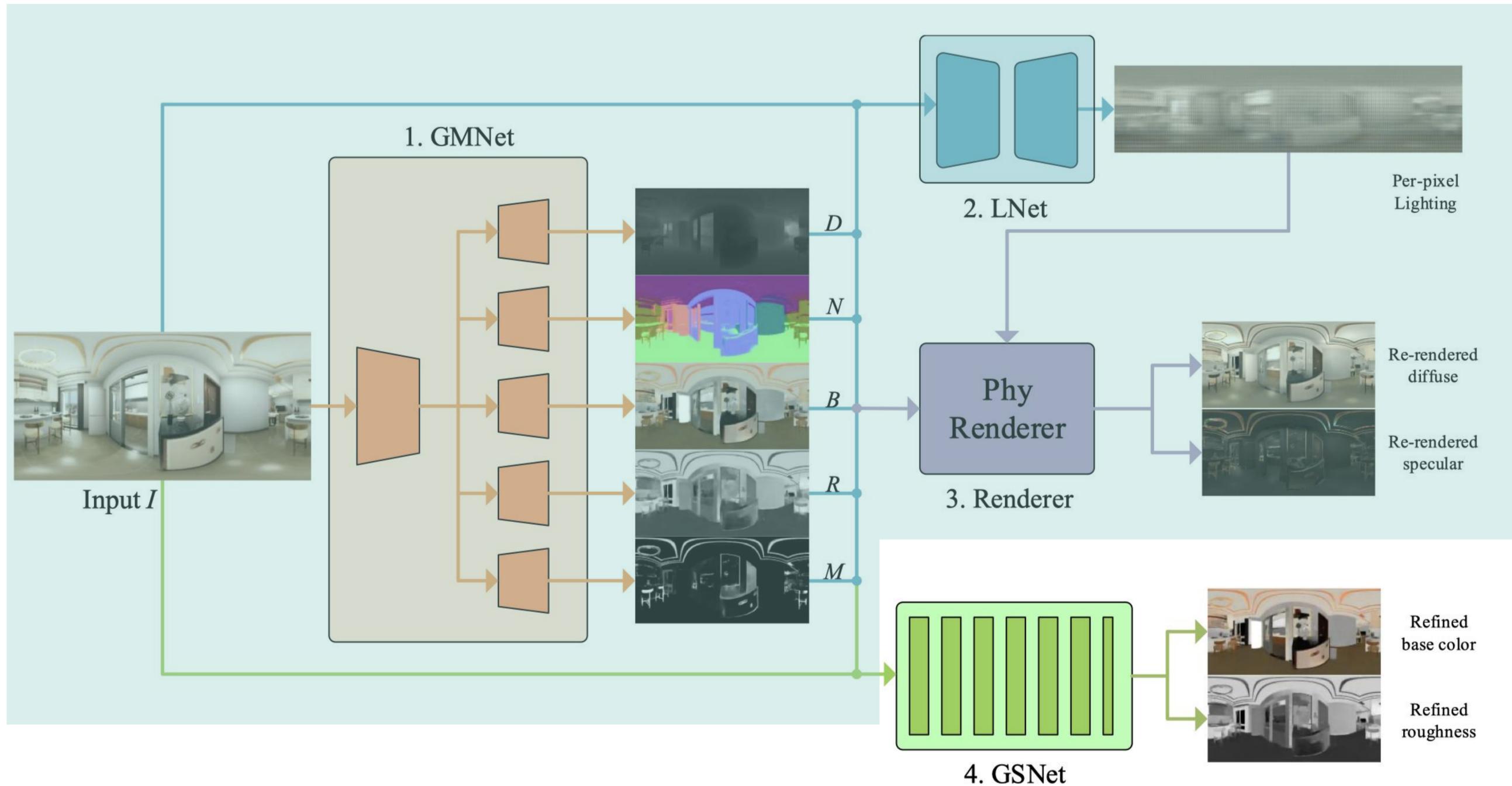
# 03 基于物理的逆渲染--PhyIR<sup>CVPR'22</sup>

- SC光照估计



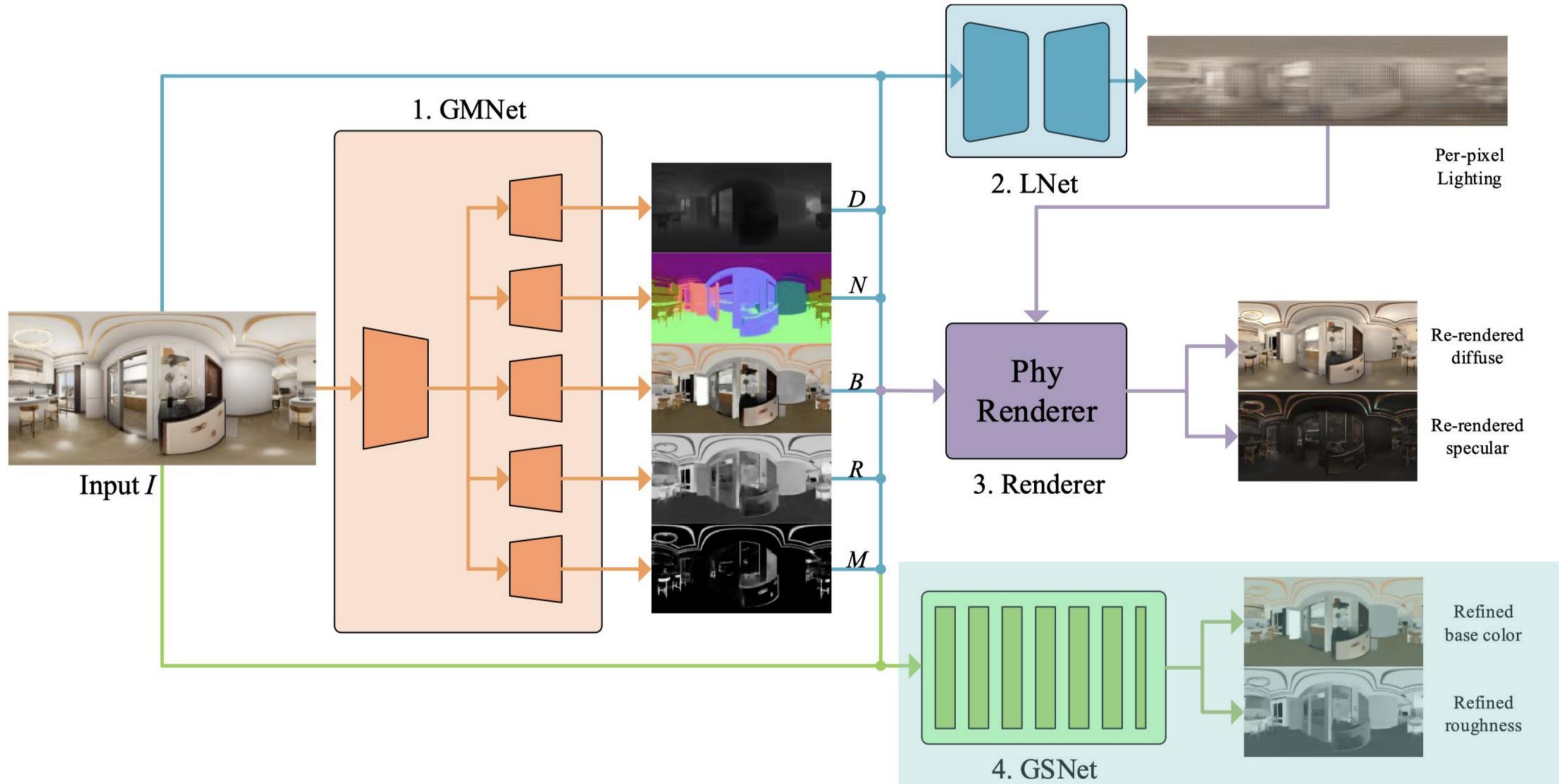
# 03 基于物理的逆渲染--PhyIR<sup>CVPR'22</sup>

- 联合训练



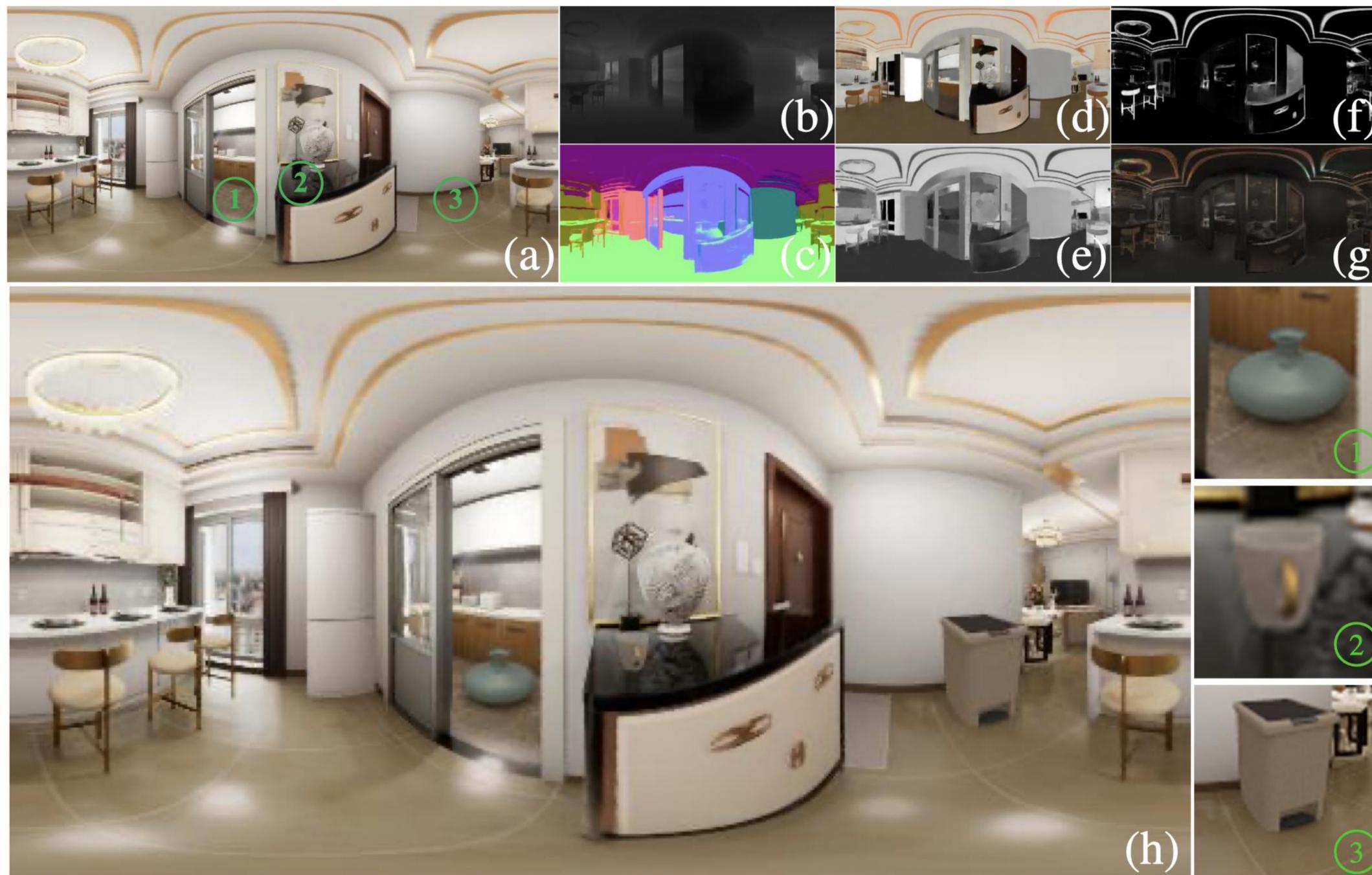
# 03 基于物理的逆渲染--PhyIR<sup>CVPR'22</sup>

- 材质Refine



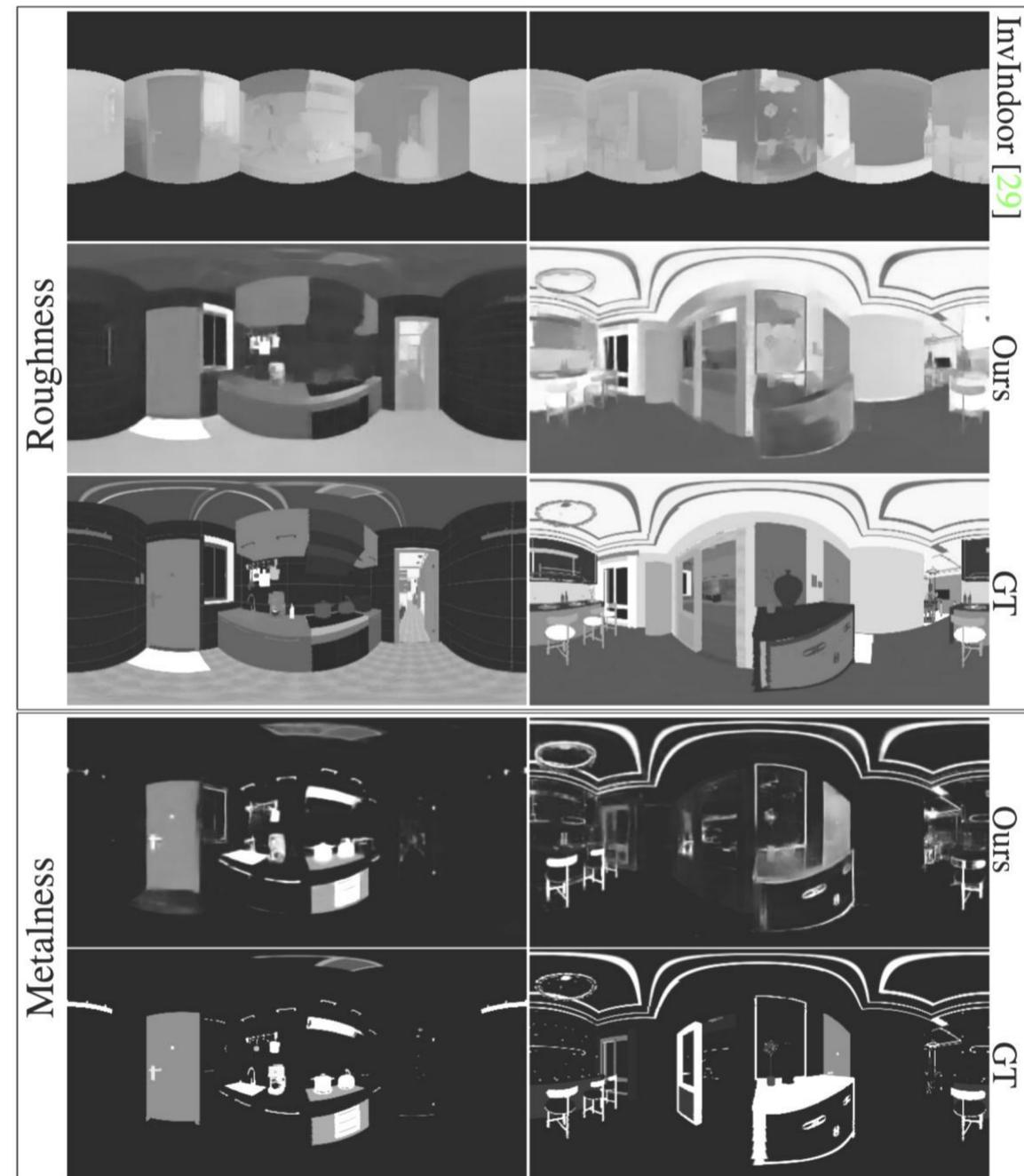
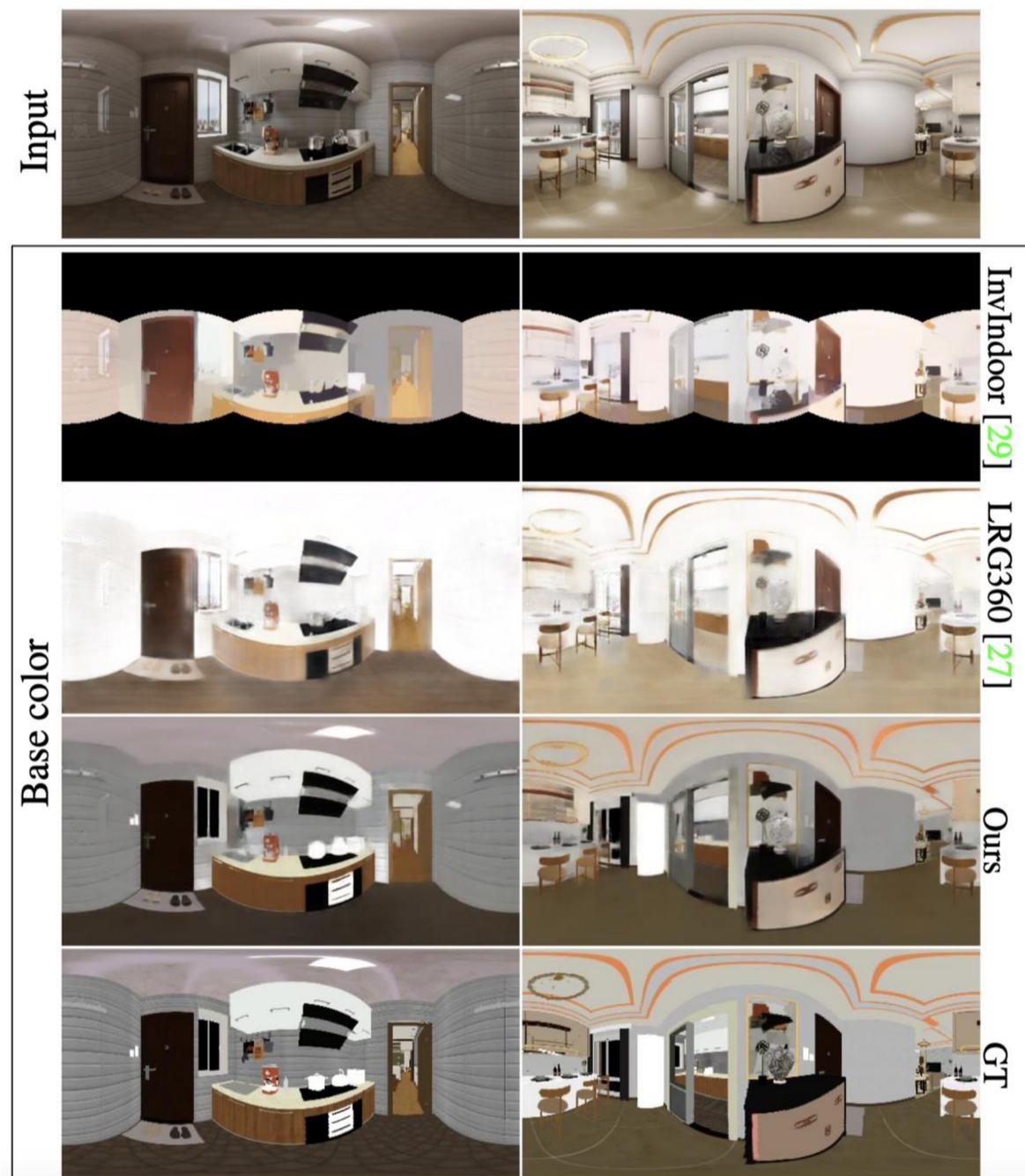
# 03 基于物理的逆渲染--PhyIR<sup>CVPR'22</sup>

- 效果概览



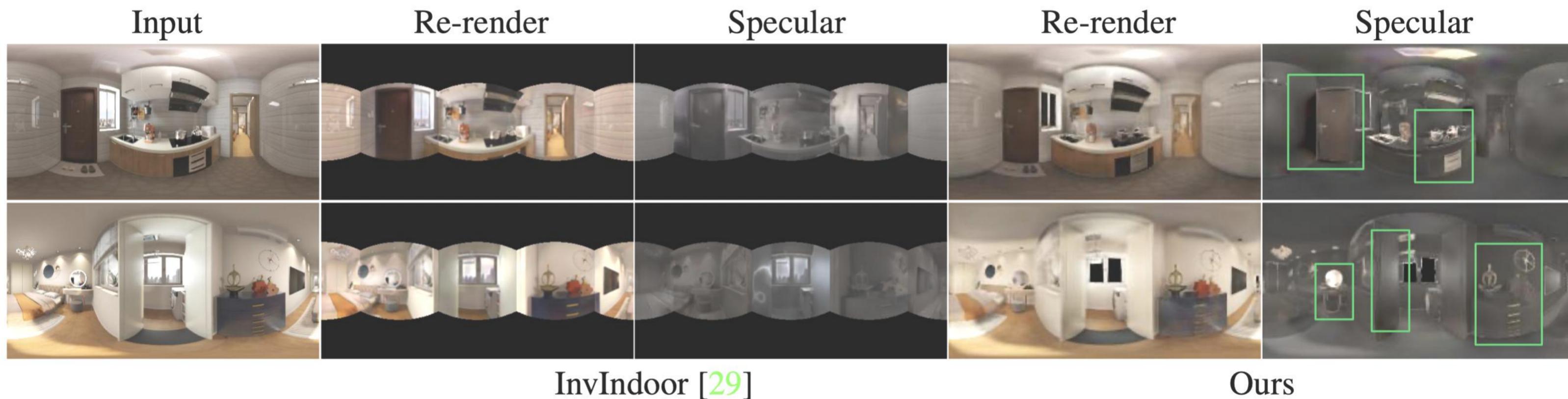
# 03 基于物理的逆渲染--PhyIR<sup>CVPR'22</sup>

- 更好的材质估计结果



# 03 基于物理的逆渲染--PhyIR<sup>CVPR'22</sup>

- 更物理的预测结果



## 03 基于物理的逆渲染--PhyIR<sup>CVPR'22</sup>

- 与SOTA方法对比:

未来家测试数据

	Base color	Normal	roughness	Metallic	Re-render
InvIndoor [29]	0.1093	63.73°	0.0868	N.A.	0.0108
LRG360 [27]	0.0968†	11.40°	N.A.	N.A.	-
Ours	<b>0.0090</b>	<b>10.26°</b>	<b>0.0187</b>	<b>0.0115</b>	<b>0.0059</b>

LRG测试数据

	LRG360 [27]		Ours	
	Coarse	Refine	Coarse	Refine
Albedo	0.234	0.155	0.150	<b>0.146</b>
Normal	16.5°	N.A.	<b>15.1°</b>	15.2°

## 03 基于物理的逆渲染--PhyIR<sup>CVPR'22</sup>

- 结果展示：（动态物体插入）



## 03 基于物理的逆渲染--PhyIR<sup>CVPR'22</sup>



结论:

- **更物理**的模型，可以很好的建模高光，金属，镜子等复杂材质
- 空间**一致变化**的光照模型，光照更细节
- 大型照片真实感**合成数据集**，包含丰富的几何/材质/光照注释

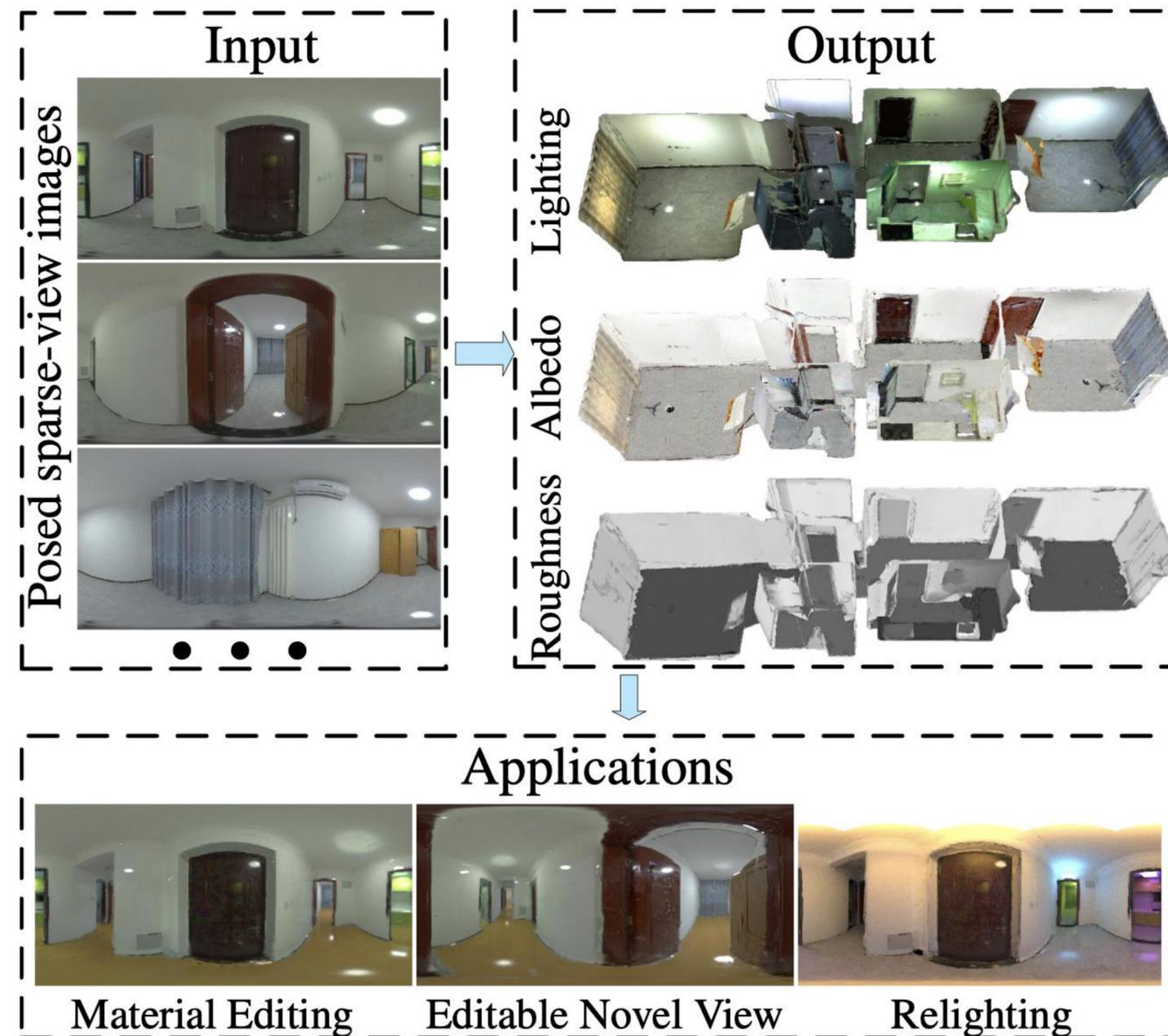
## 04 真实场景多视图逆渲染--TexIR<sup>CVPR'23</sup>



PhyIR的问题：

- 只利用了单视图的线索，精度有限；
- 在真实场景下性能下降；
- 只预测了单视图材质图像，并非期望的模型资产；

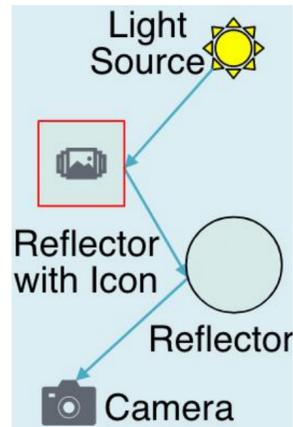
# 04 真实场景多视图逆渲染--TexIR<sup>CVPR'23</sup>



可恢复物理合理的材质贴图

# 04 真实场景多视图逆渲染--TexIR<sup>CVPR'23</sup>

- 更适合室内场景的光照表示;



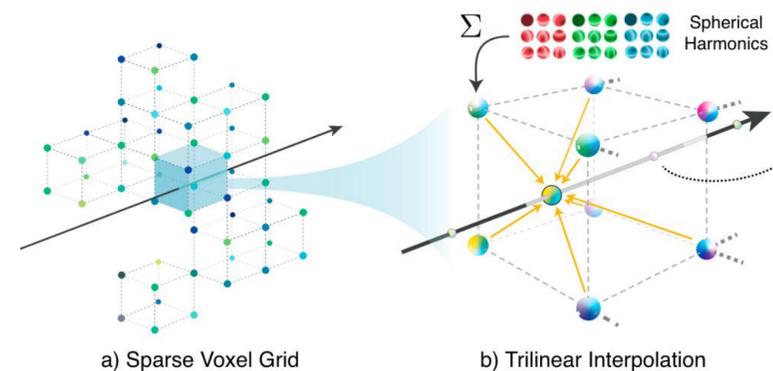
parametric lighting



dense-voxel lighting<sup>2</sup>



per-pixel lighting<sup>1</sup>

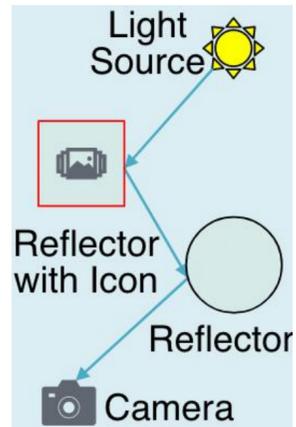


sparse-voxel lighting<sup>3</sup>

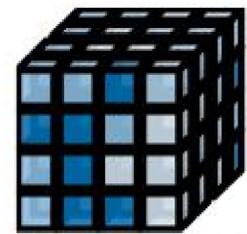
[1]. PhylR: Physics-Based Inverse Rendering for Panoramic Indoor Images. CVPR'2022  
[2]. Learning Indoor Inverse Rendering with 3D Spatially-Varying Lighting. ICCV'2021  
[3]. Plenoxels: Radiance Fields without Neural Networks. CVPR'2022

# 04 真实场景多视图逆渲染--TexIR<sup>CVPR'23</sup>

- 更适合室内场景的光照表示;

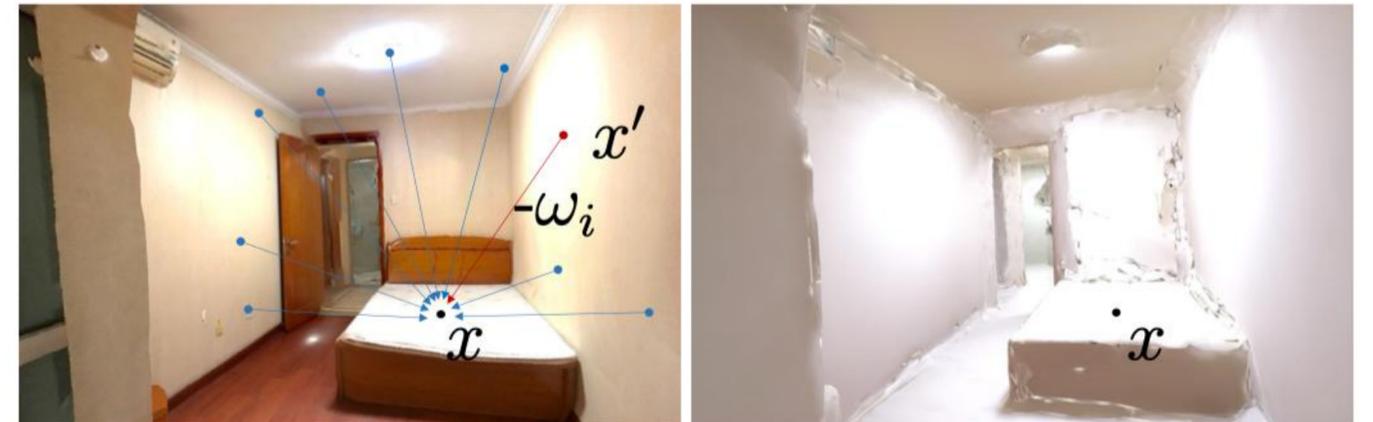


parametric lighting



Lighting  $\hat{L}$

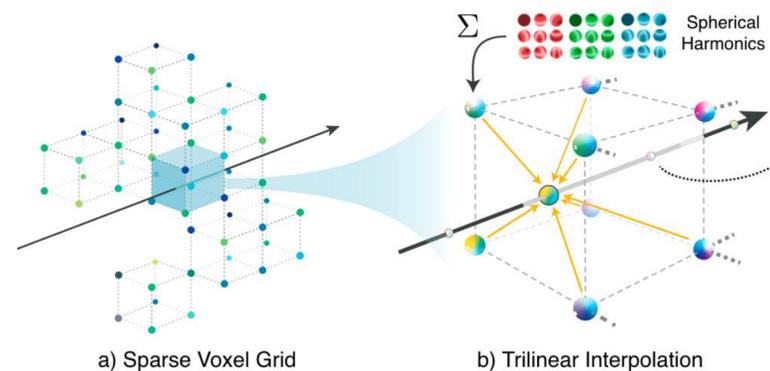
dense-voxel lighting<sup>2</sup>



texture-based lighting  
(left: lighting texture; right: irradiance texture)



per-pixel lighting<sup>1</sup>

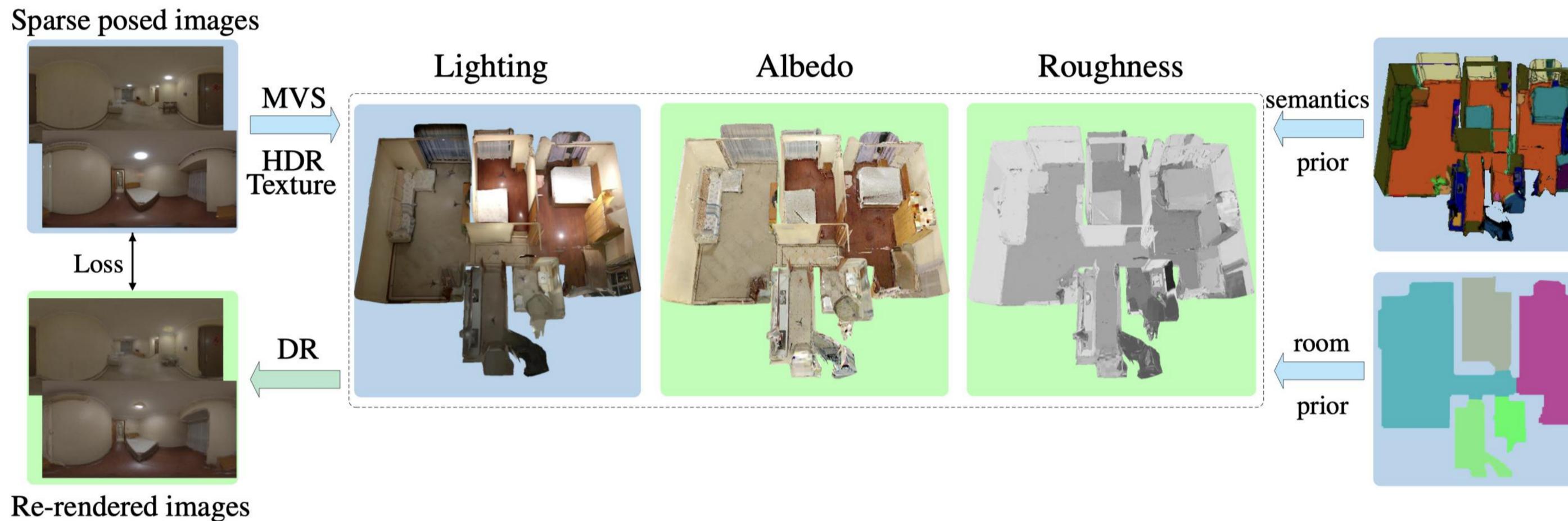


sparse-voxel lighting<sup>3</sup>

[1]. PhylR: Physics-Based Inverse Rendering for Panoramic Indoor Images. CVPR'2022  
[2]. Learning Indoor Inverse Rendering with 3D Spatially-Varying Lighting. ICCV'2021  
[3]. Plenoxels: Radiance Fields without Neural Networks. CVPR'2022

# 04 真实场景多视图逆渲染--TexIR<sup>CVPR'23</sup>

- 引入语义分割，分间等先验；



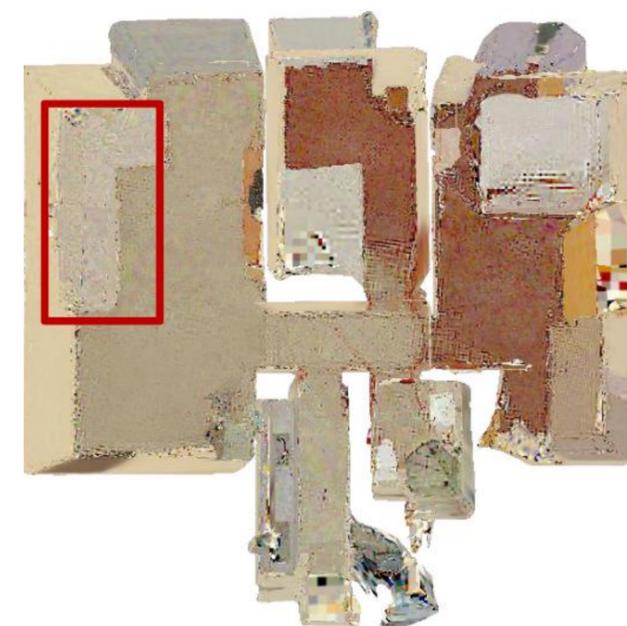
# 04 真实场景多视图逆渲染--TexIR<sup>CVPR'23</sup>

- 三阶段材质估计
  - 阶段1: albedo初始化

$$\mathcal{L}_{albedo} = |I - L_d| + \beta_{ssa} \mathcal{L}_{ss} \quad (5)$$

$$L_d(x, \omega_o) = f_d(x) I r(x) \quad (3)$$

$$\mathcal{L}_{ss} = \sum_c \left| F - \frac{\sum_p F \odot M_{seg}(c)}{\sum_p M_{seg}(c) + \epsilon} \right| \odot M_{seg}(c) \quad (4)$$



# 04 真实场景多视图逆渲染--TexIR<sup>CVPR'23</sup>

- 三阶段材质估计

- 阶段2: roughness估计与传播

$$\mathcal{L}_{roughness} = |I - L_o| + \beta_{sp} \mathcal{L}_{sp} \quad (7)$$

$$\mathcal{L}_{sp} = \sum_c \left| R\text{-quantile}(R \odot M_{vhl}(c), q) \right| \odot (M_{seg}(c) - M_{vhl}(c)) \quad (6)$$

VHL区域

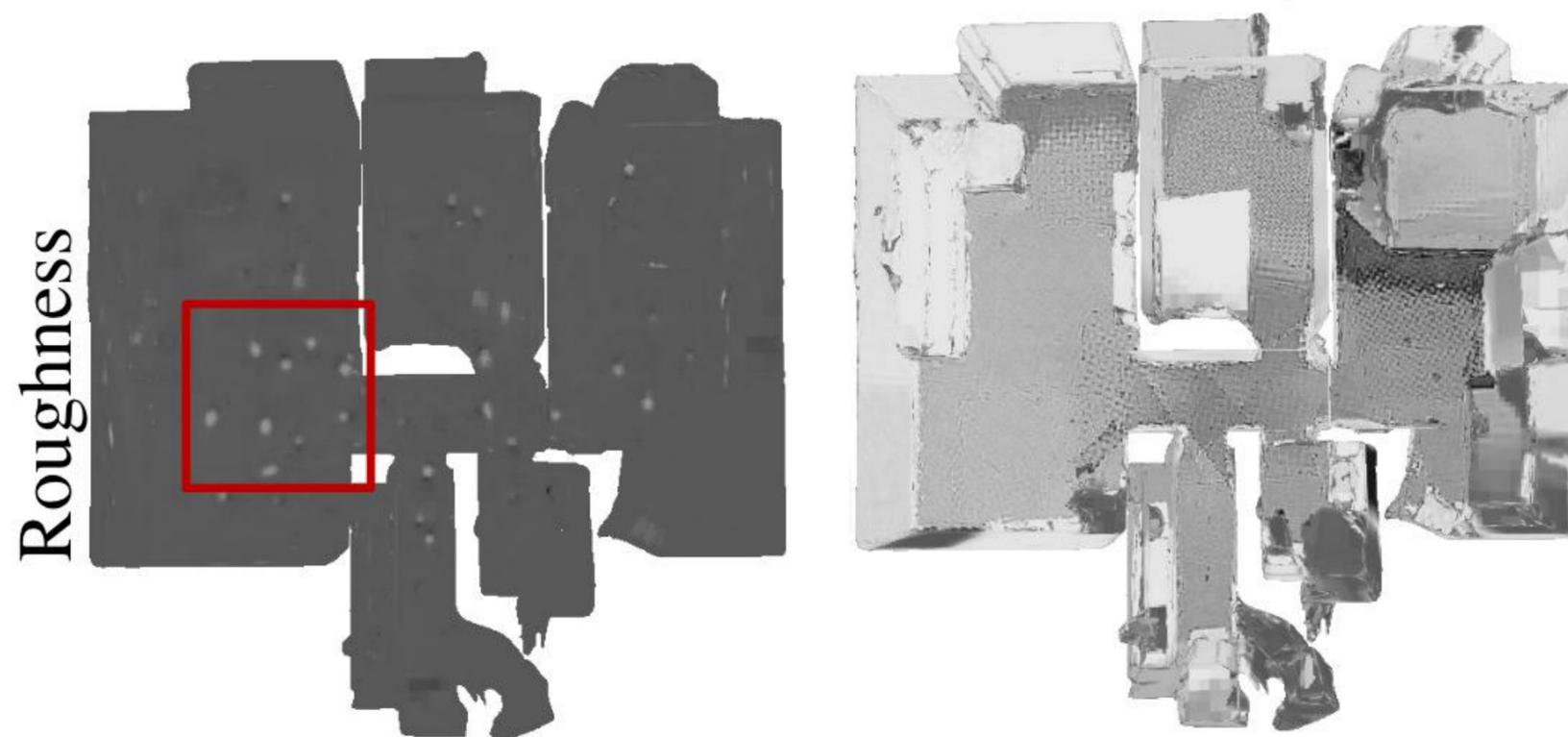


# 04 真实场景多视图逆渲染--TexIR<sup>CVPR'23</sup>

- 三阶段材质估计
  - 阶段2: roughness估计与传播

$$\mathcal{L}_{roughness} = |I - L_o| + \beta_{sp} \mathcal{L}_{sp} \quad (7)$$

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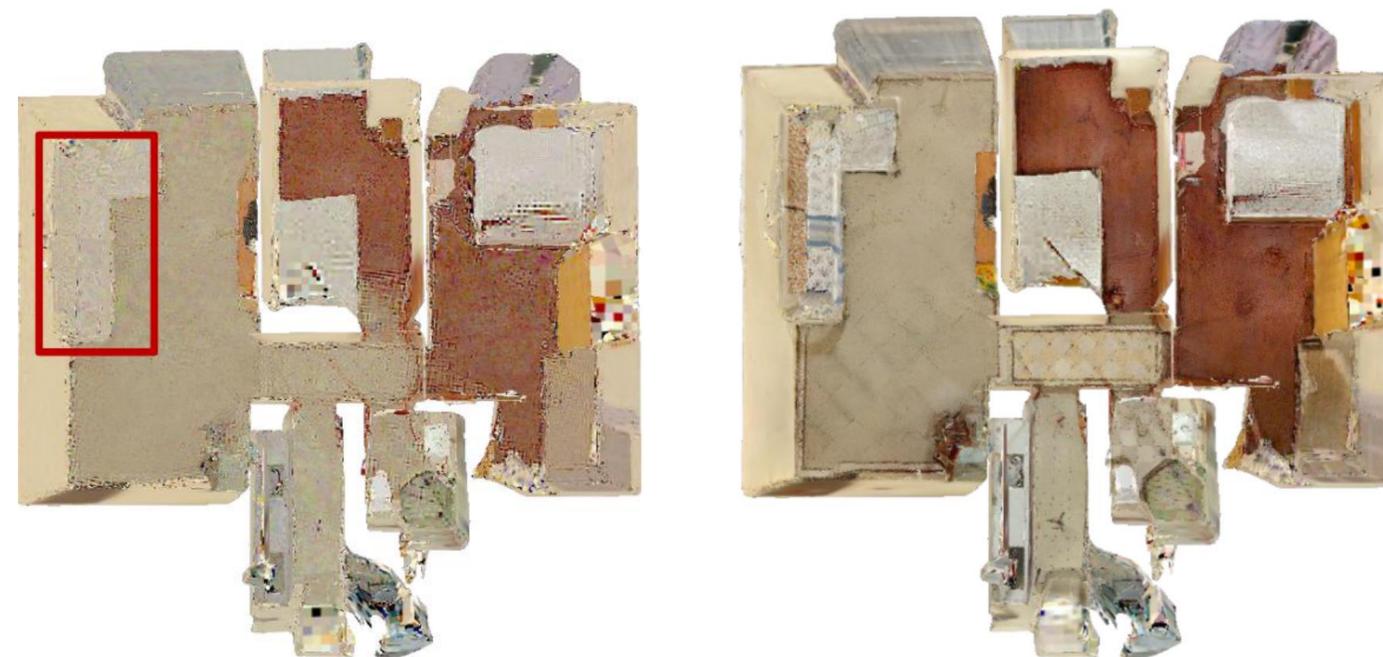


# 04 真实场景多视图逆渲染--TexIR<sup>CVPR'23</sup>

- 三阶段材质估计
  - 阶段3: 材质微调

$$\mathcal{L}_{all} = |I - L_o| + \beta_{ssr}(\mathcal{L}_{ss} + \mathcal{L}_{rs}) \quad (9)$$

$$\mathcal{L}_{rs} = \sum_c \left| R - \frac{\sum_p R \odot M_{room}(c)}{\sum_p M_{room}(c) + \epsilon} \right| \odot M_{room}(c) \quad (8)$$



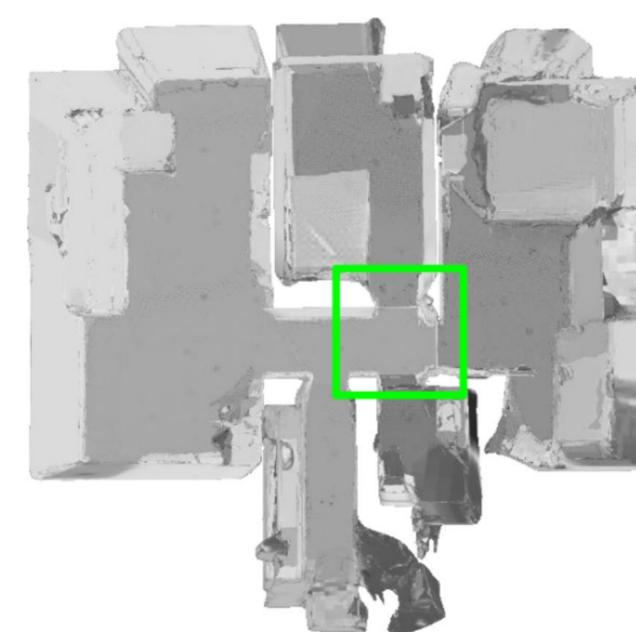
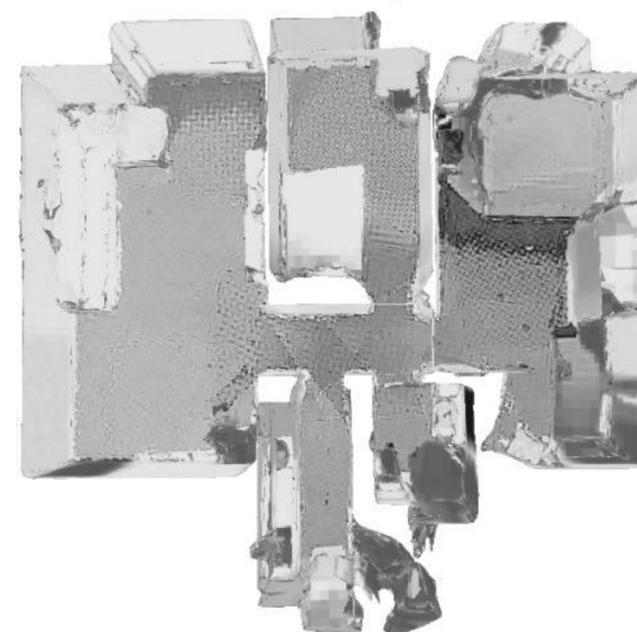
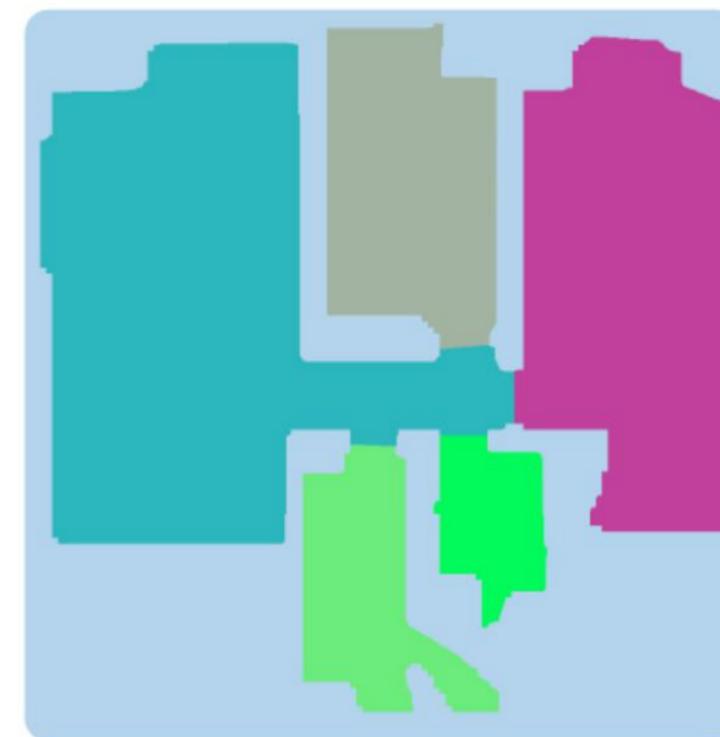
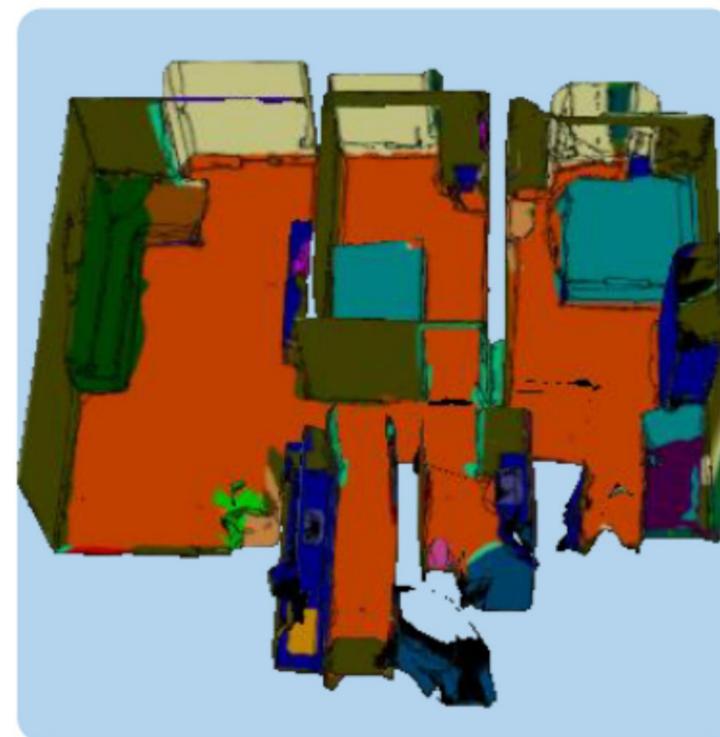
# 04 真实场景多视图逆渲染--TexIR<sup>CVPR'23</sup>



- 三阶段材质估计
  - 阶段3: 材质微调

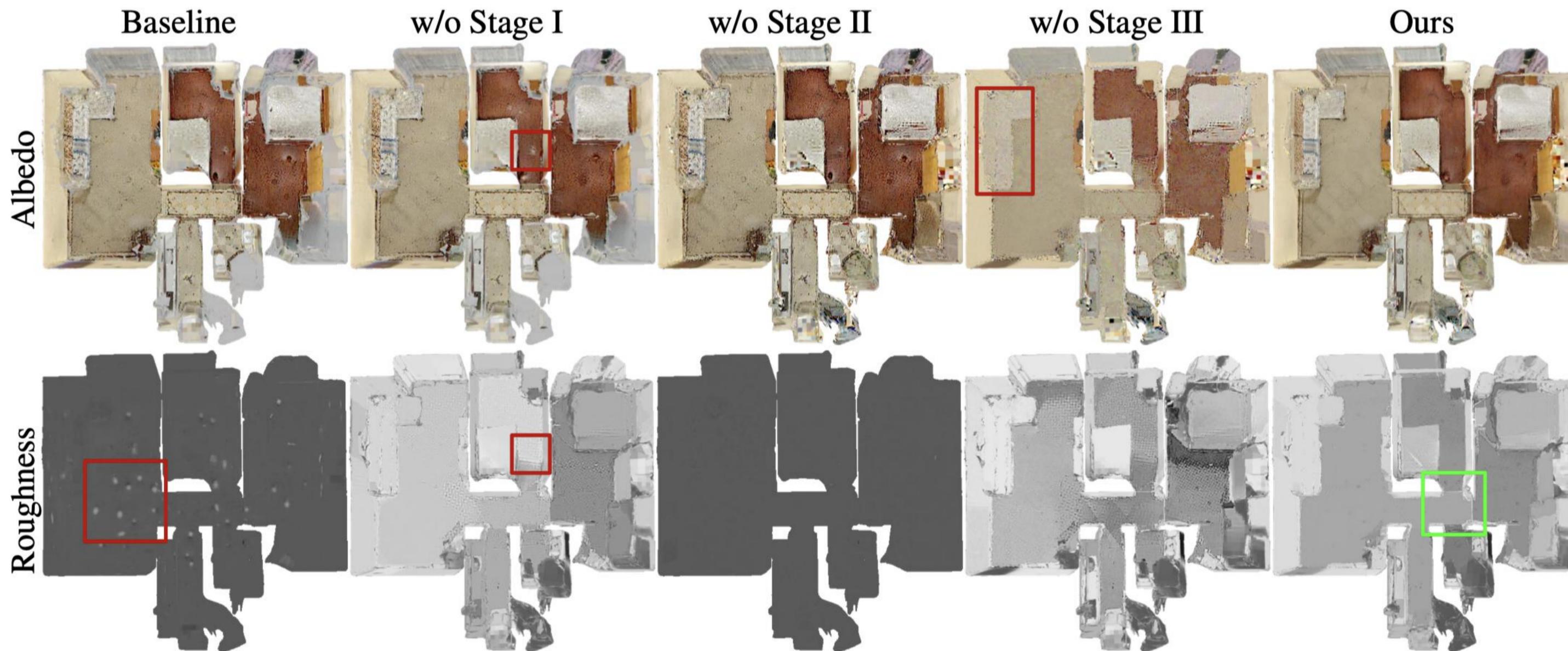
$$\mathcal{L}_{all} = |I - L_o| + \beta_{ssr}(\mathcal{L}_{ss} + \mathcal{L}_{rs}) \quad (9)$$

$$\mathcal{L}_{rs} = \sum_c \left| R - \frac{\sum_p R \odot M_{room}(c)}{\sum_p M_{room}(c) + \epsilon} \right| \odot M_{room}(c) \quad (8)$$



# 04 真实场景多视图逆渲染--TexIR<sup>CVPR'23</sup>

- 三阶段材质估计--消融实验



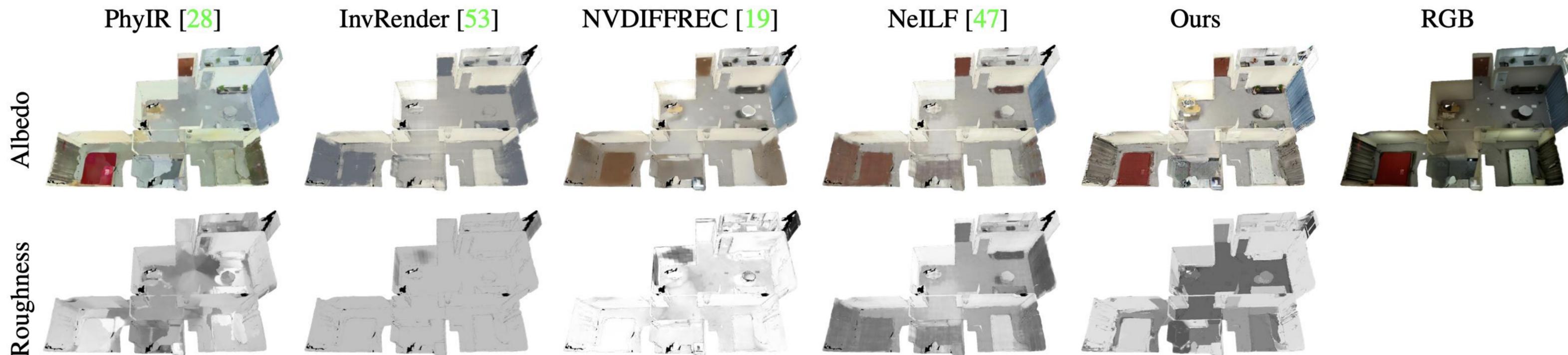
# 04 真实场景多视图逆渲染--TexIR<sup>CVPR'23</sup>



Method	Albedo			Roughness			Novel view synthesis			Re-rendering		
	PSNR↑	SSIM↑	MSE↓	PSNR↑	SSIM↑	MSE↓	PSNR↑	SSIM↑	MSE↓	PSNR↑	SSIM↑	MSE↓
PhyIR [35]	11.9726	0.6880	0.0635	12.5468	0.7671	0.0556	-	-	-	-	-	-
InvRender [65]	16.9760	0.6305	0.0201	9.1806	0.4787	0.1208	22.2771	0.7826	0.0059	24.2851	0.7834	0.0037
NVDIFFREC [41]	<b>21.2551</b>	0.8100	<b>0.0075</b>	7.6269	0.1348	0.1727	23.4959	0.9019	0.0045	29.7279	0.9323	0.0011
NeILF* [58]	14.2137	0.5184	0.0379	11.5778	0.5974	0.0695	22.3765	0.7598	0.0058	25.1092	0.7654	0.0031
NeILF [58]	17.0707	0.6489	0.0196	11.1654	0.7099	0.0765	22.0703	0.7823	0.0062	24.4710	0.7857	0.0036
Ours	20.4169	<b>0.8514</b>	0.0091	<b>20.2132</b>	<b>0.9161</b>	<b>0.0095</b>	<b>25.0462</b>	<b>0.9264</b>	<b>0.0031</b>	<b>34.2669</b>	<b>0.9635</b>	<b>0.0004</b>

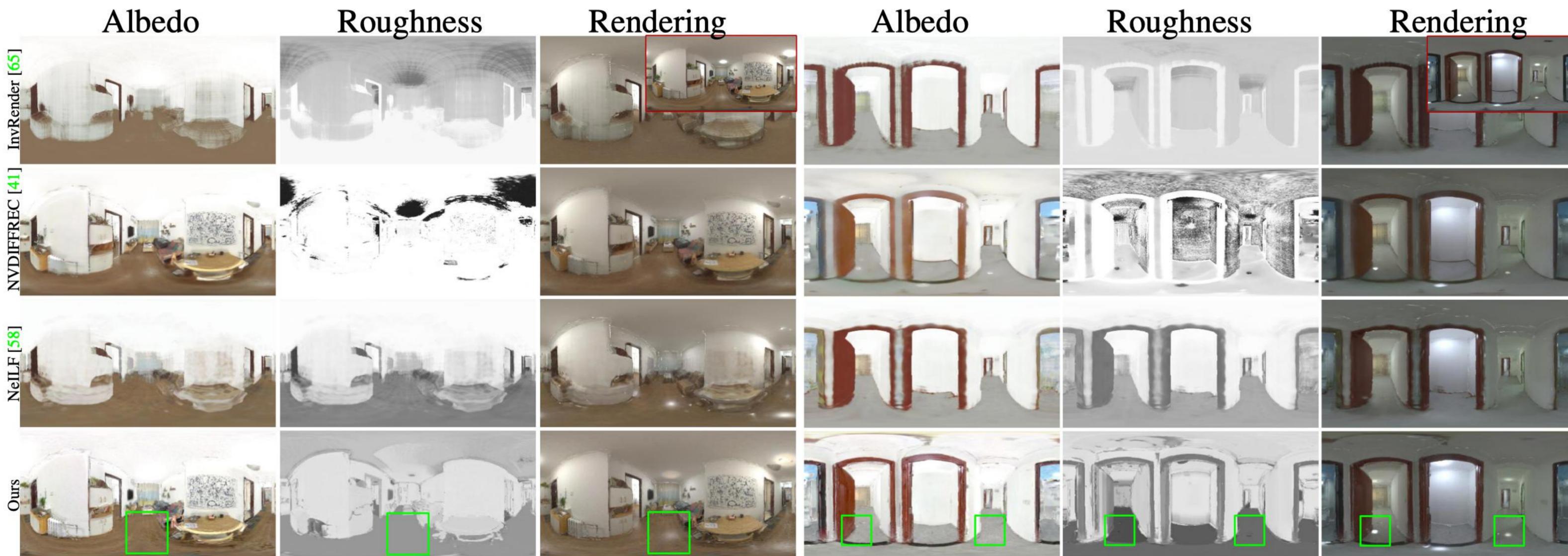
合成数据上定量对比

# 04 真实场景多视图逆渲染--TexIR<sup>CVPR'23</sup>



恢复物理合理的材质贴图

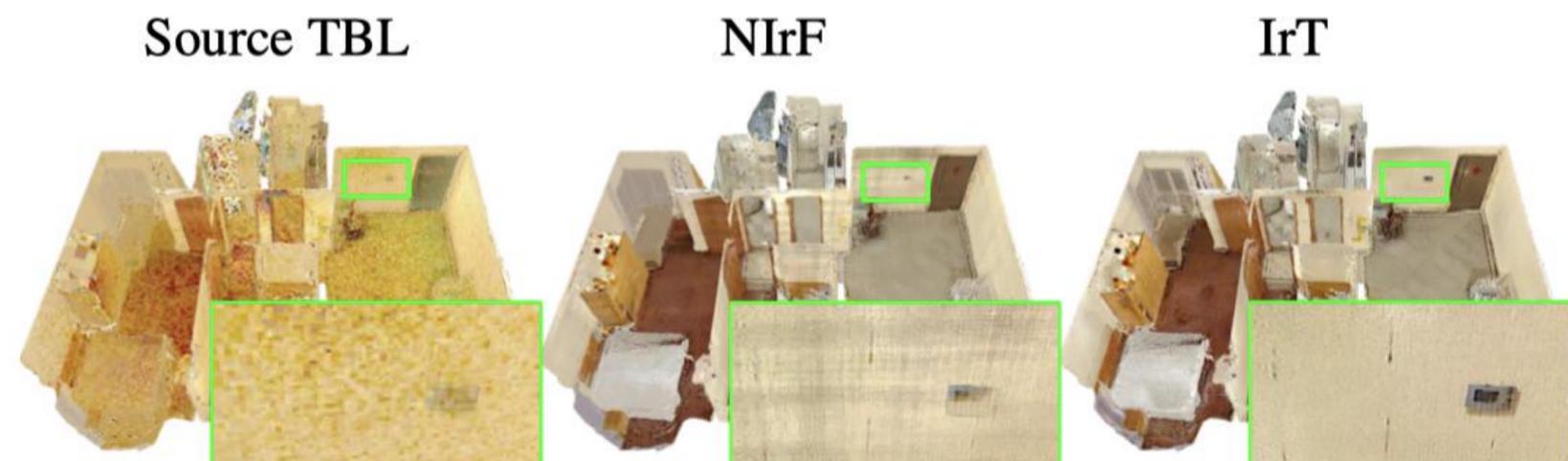
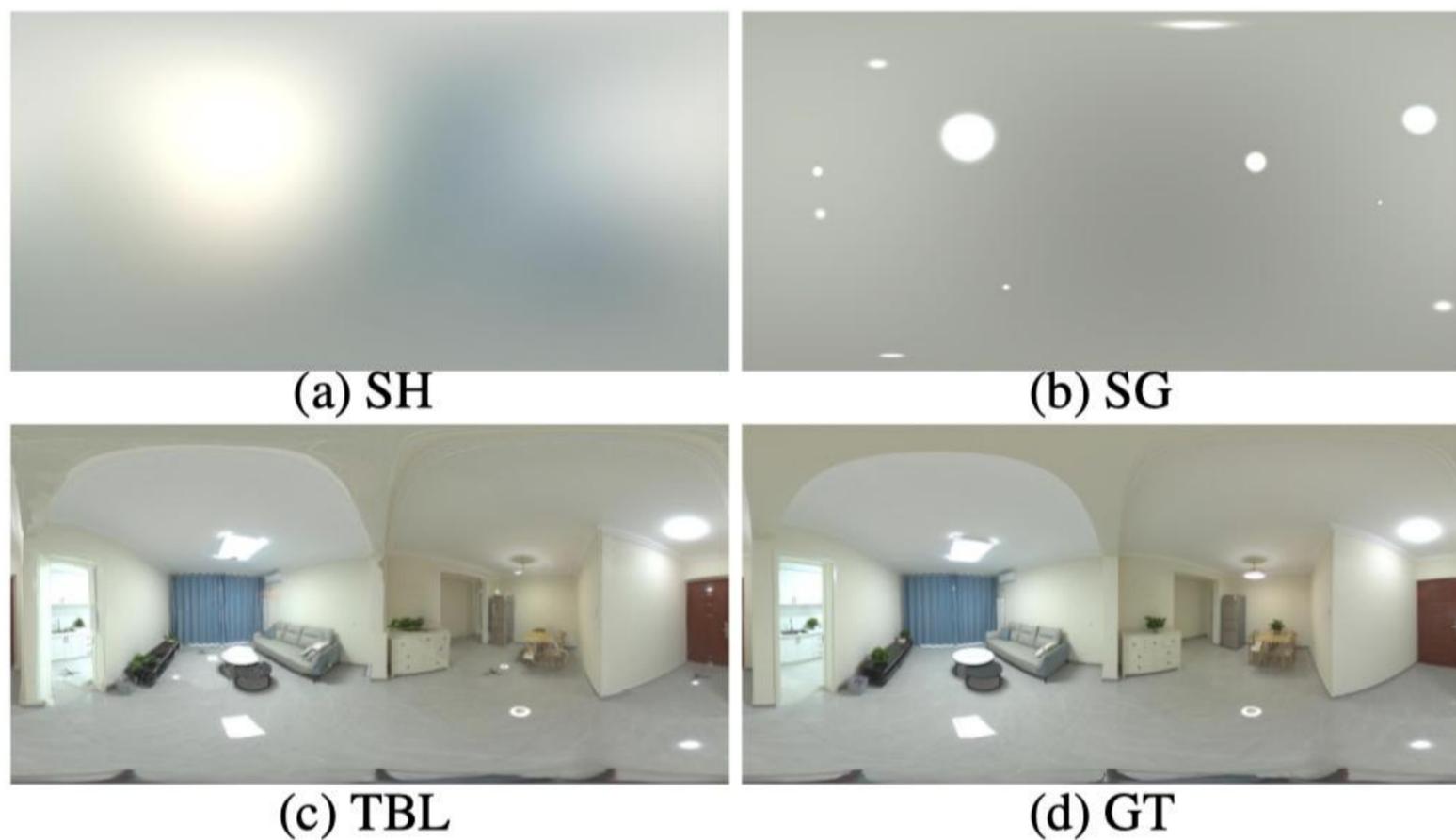
# 04 真实场景多视图逆渲染--TexIR<sup>CVPR'23</sup>



恢复物理合理的材质贴图

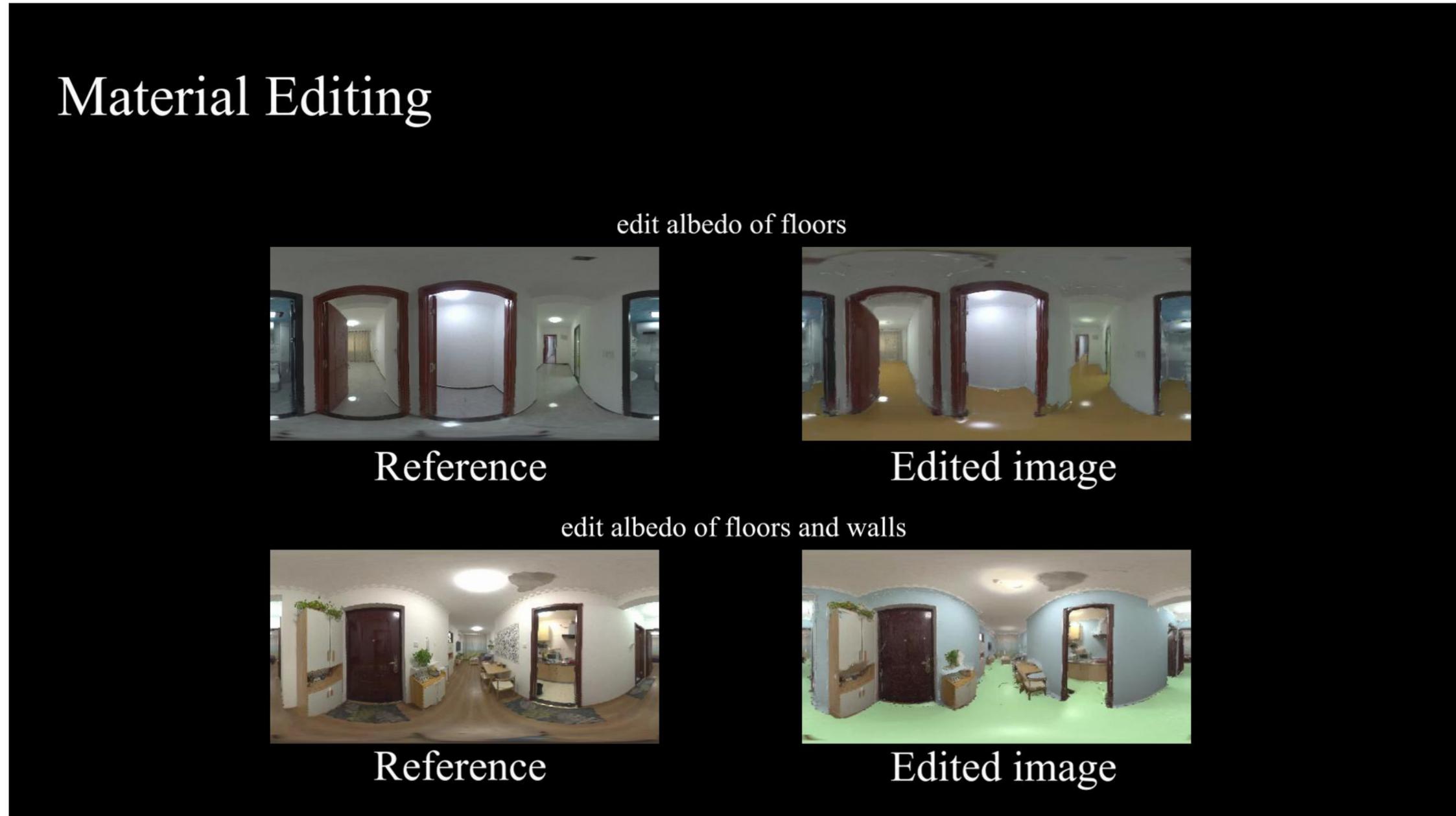
# 04 真实场景多视图逆渲染--TexIR<sup>CVPR'23</sup>

- TBL--消融实验



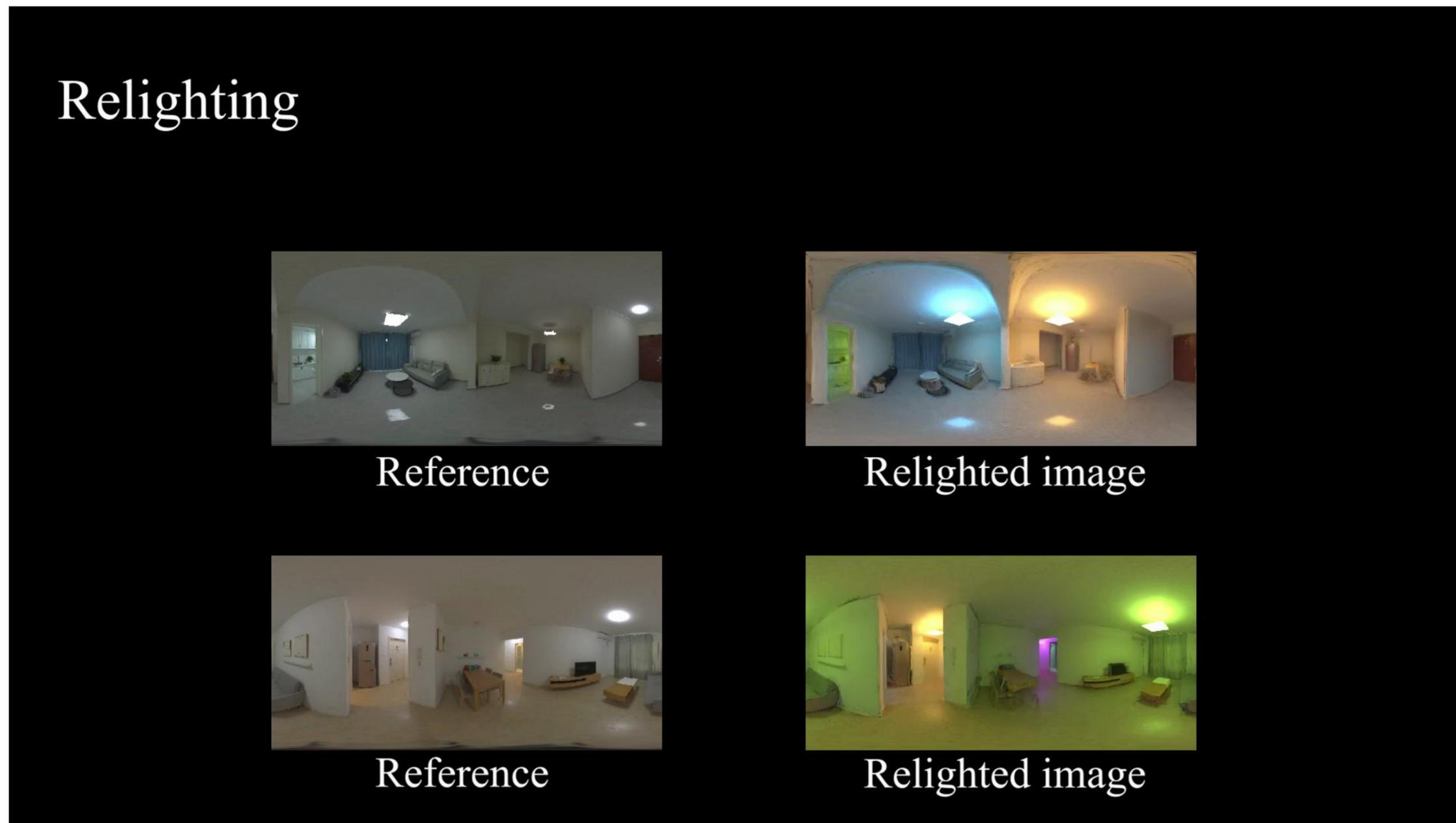
# 04 真实场景多视图逆渲染--TexIR<sup>CVPR'23</sup>

- 应用示例:



# 04 真实场景多视图逆渲染--TexIR<sup>CVPR'23</sup>

- 应用示例:



# 04 真实场景多视图逆渲染--TexIR<sup>CVPR'23</sup>

- 应用示例:

## Editable Novel View Synthesis



edit albedo of walls,  
and roughness of floors



### Edited Novel Views



### Reference

Top View

## 04 真实场景多视图逆渲染--TexIR<sup>CVPR'23</sup>



- 项目主页:

<http://yodlee.top/TexIR/>

- 代码:

[http://github.com/LZleejean/TexIR\\_code](http://github.com/LZleejean/TexIR_code)

