# Reflectance and Natural Illumination from a Single Image

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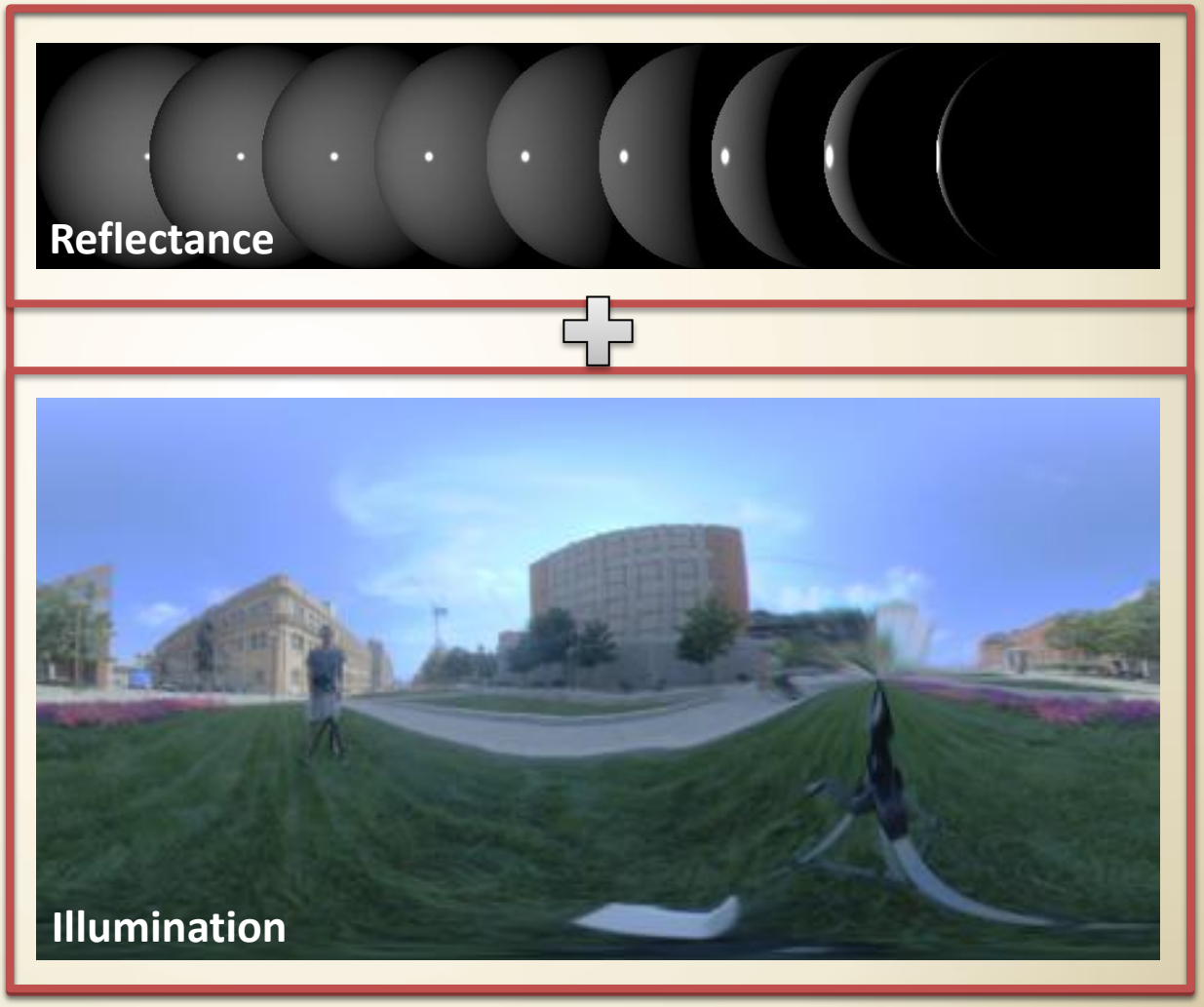
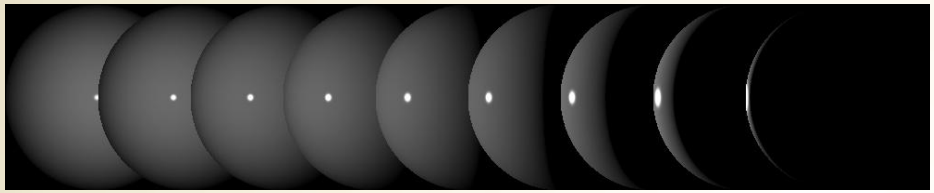
# Reflectance and Illumination Estimation



# Past Work on Reflectance and Illumination Recovery

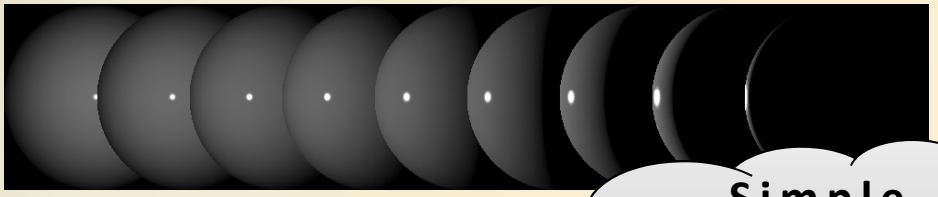


**Reflectance Only**
[Klinker et al. '88]
[Kay and Caelli '94]
[Lu and Little '95]
[Sato et al. '97]
[Boivin and Gagalowicz '01]
[Romeiro et al. '08]
[Romeiro and Zickler '10]
[Chandraker and Ramamoorthi '11]
[Lombardi and Nishino '12]
[Oxholm and Nishino '12]

**Joint Recovery**
[Land and McCann '71]
[Barrow and Tenenbaum '78]
[Sinha and Adelson '93]
[Tappen et al. '02]
[Ramamoorthi and Hanrahan '04]
[Hara et al. '05, '08]
[Sunkavalli et al. '08]
[Hara and Nishino '09, '11]

**Illumination Only**
[Sato et al. '03]
[Stumpfel et al. '04]
[Finlayson et al. '04]
[Kim and Hong '05]
[Basri et al. '07]
[Lalonde et al. '09, '11]
[Mei et al. '11]

# Past Work on Reflectance and Illumination Recovery



**Simple Reflectance Model**

**Simple Illumination Conditions**

**Many input images**

**Joint Recovery**

[Land and M...]
[B...]
[Sunkavalli et al. '08]
[Hara and ...]

**Reflectance Only**

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[Lalonde et al. '09, '11]
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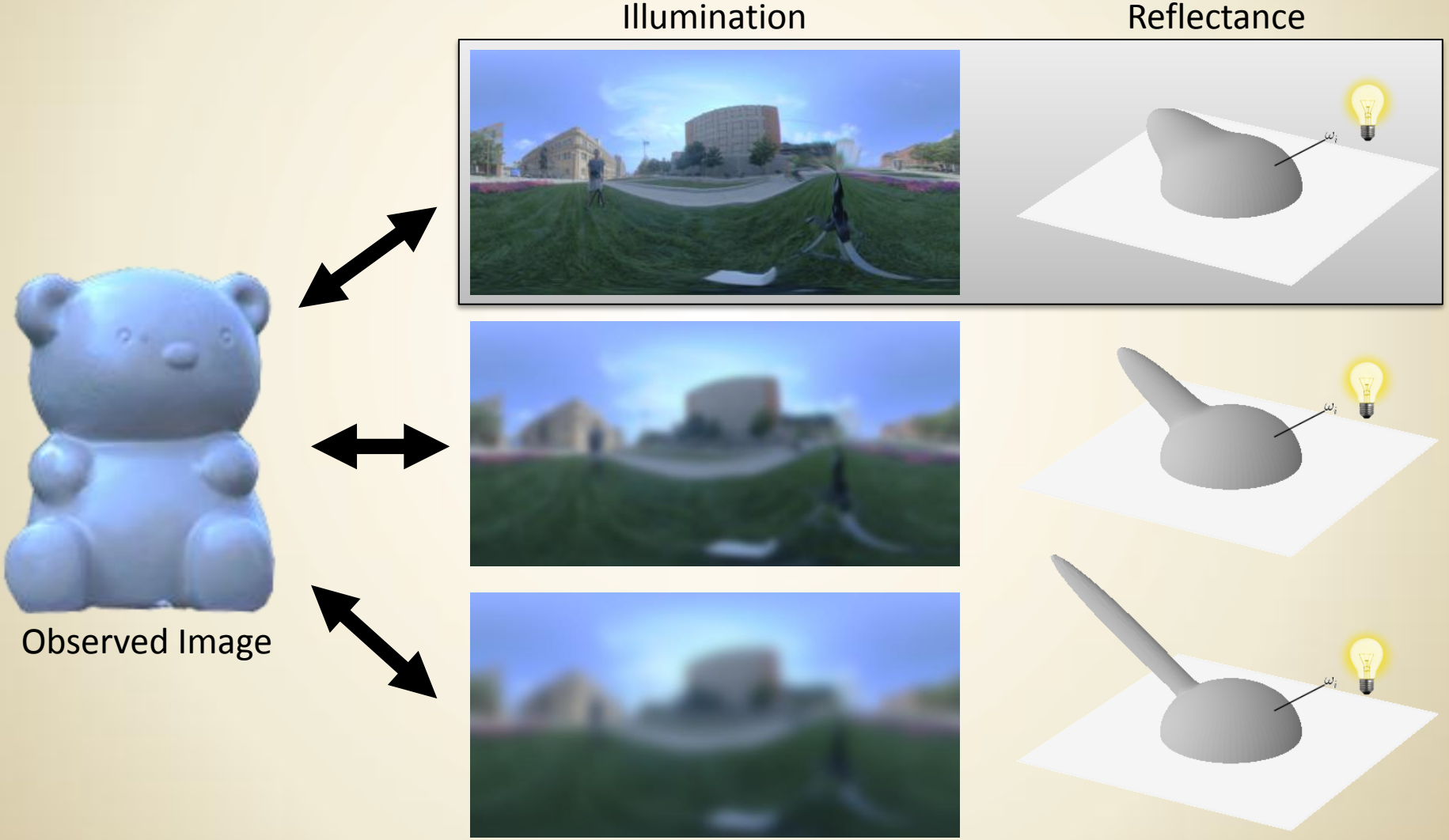
# Frequency Ambiguity

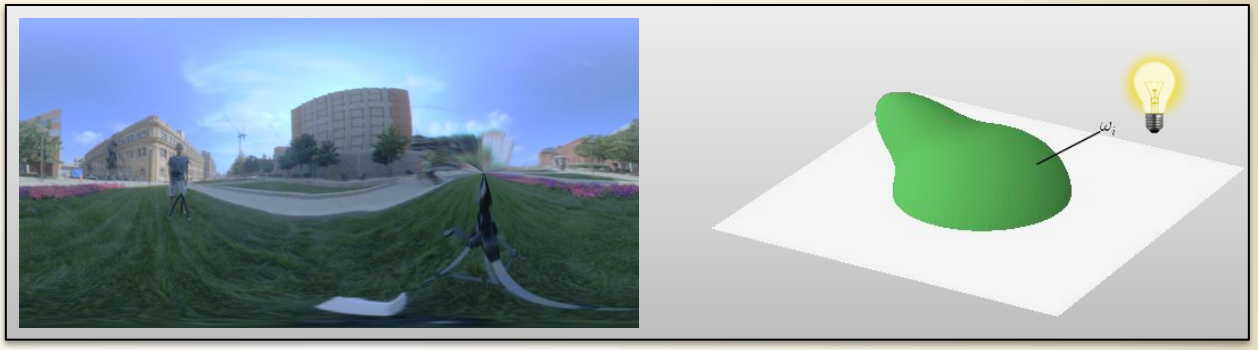


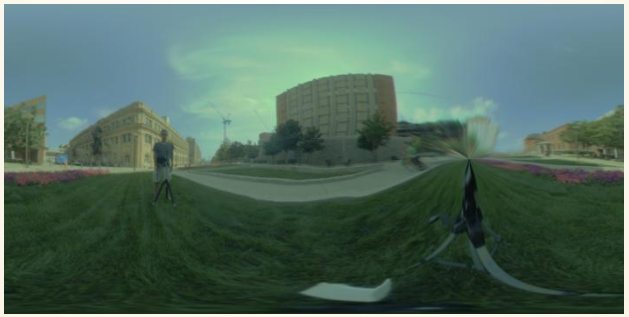
# Color Ambiguity

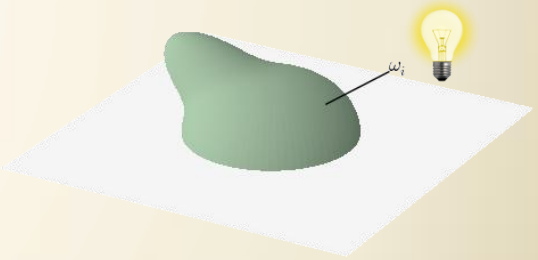
Observed Image

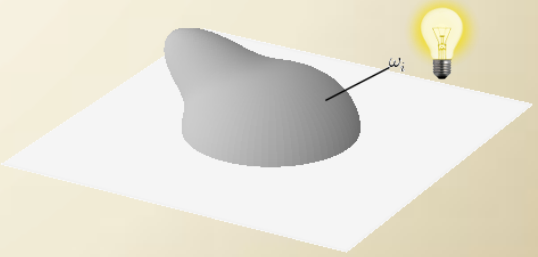
Illumination

Reflectance









# Constraining Reflectance and Illumination

$$p(R, L|I) \propto p(I|R, L)p(R)p(L)$$

Input Image

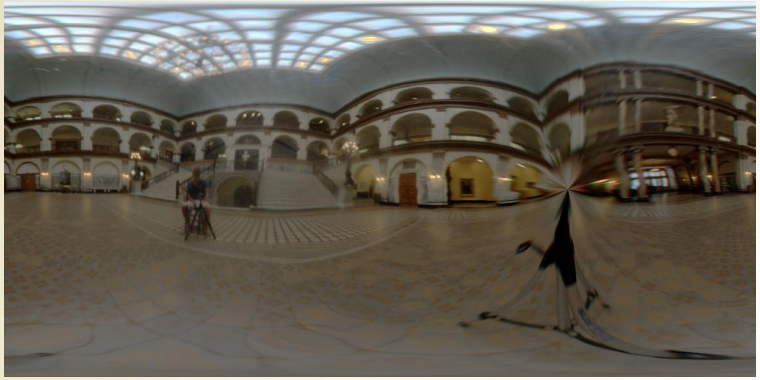
Likelihood

Reflectance Prior

Illumination Prior

$$p(I|R, L) = \prod_{\mathbf{x}} \mathcal{N}(I_{\mathbf{x}}|E_{\mathbf{x}}(R, L), \sigma^2)$$

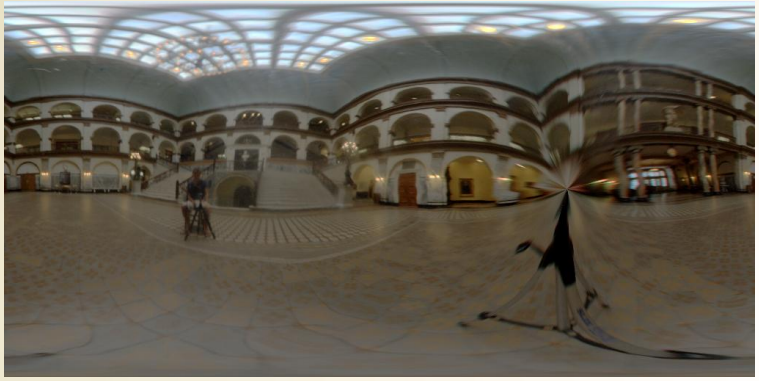
# Constraining Illumination: Natural Image Statistics



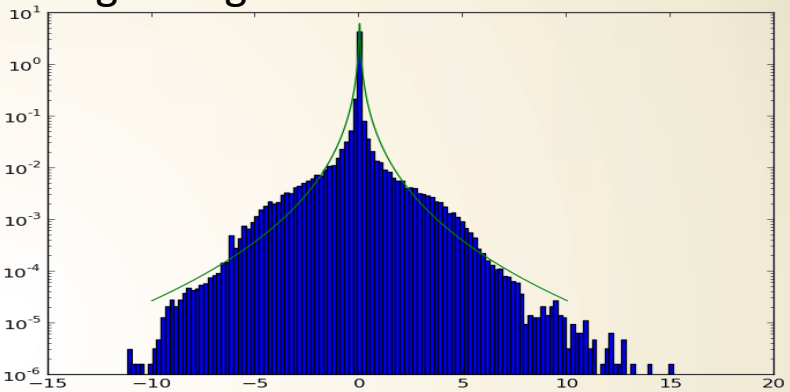
We can leverage natural image statistics!

# Constraining Illumination: Natural Image Statistics

$\mathbf{L}$



Log histogram of the derivatives of $\mathbf{L}$

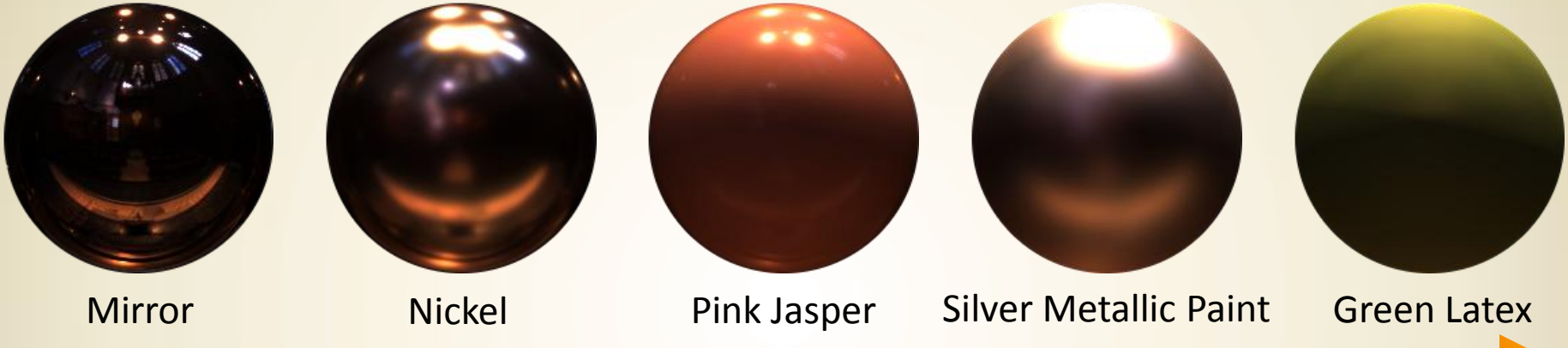



$$p_s(\mathbf{L}) \propto \prod_i \exp\left[ -\left|\frac{\partial}{\partial x}\mathbf{L}_i\right|^{\alpha} - \left|\frac{\partial}{\partial y}\mathbf{L}_i\right|^{\alpha} \right]$$

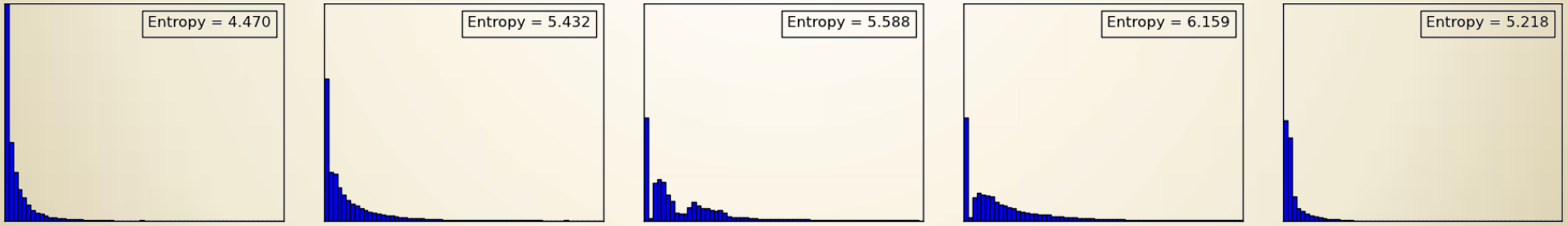
x derivative

y derivative

# Constraining Illumination: Entropy Increase Due to Reflectance




**Blur Increases**




**Entropy Increases**

# Enforcing a Low-Entropy Illumination Estimate

- A prior that encourages low entropy

$$-\ln p_e(\mathbf{L}) = H(\mathbf{L})$$

Entropy

- Continuous entropy

$$H(\mathbf{L}) = -\int p(x) \log p(x) dx$$

Image intensity density

- Kernel density estimation (Gaussian kernel)

$$p(x) = \frac{1}{N} \sum_{i=1}^{N} \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left[-\frac{(x - \mathbf{L}_i)^2}{2\sigma^2}\right]$$

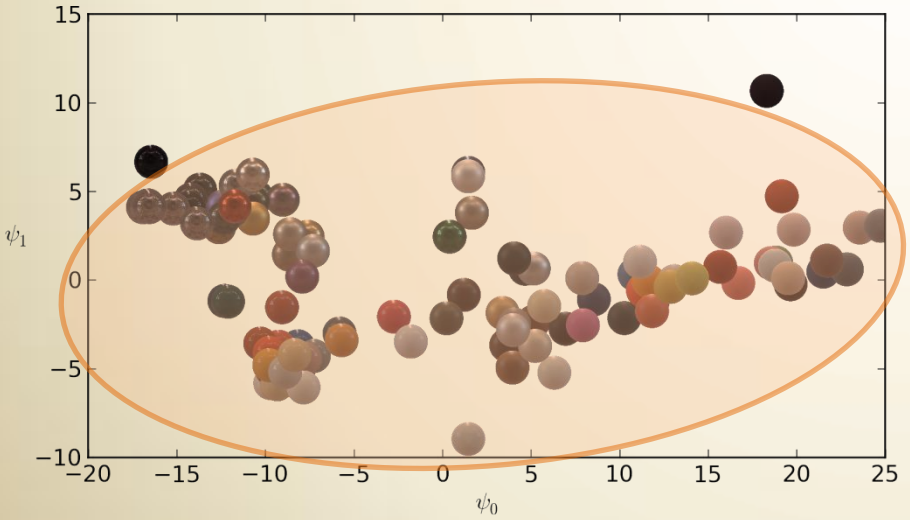
Gaussian kernel

# Constraining Reflectance: A Statistical Approach

- Directional Statistics BRDF [Nishino '09][Nishino and Lombardi '11]

$$f_\lambda(\omega_i, \omega_o) = \sum_j \exp\left[\kappa^{(j,\lambda)}(\theta_d)\cos^{\gamma^{(j,\lambda)}(\theta_d)}(\theta_h)\right] - 1$$

reflectance lobes magnitude acuity

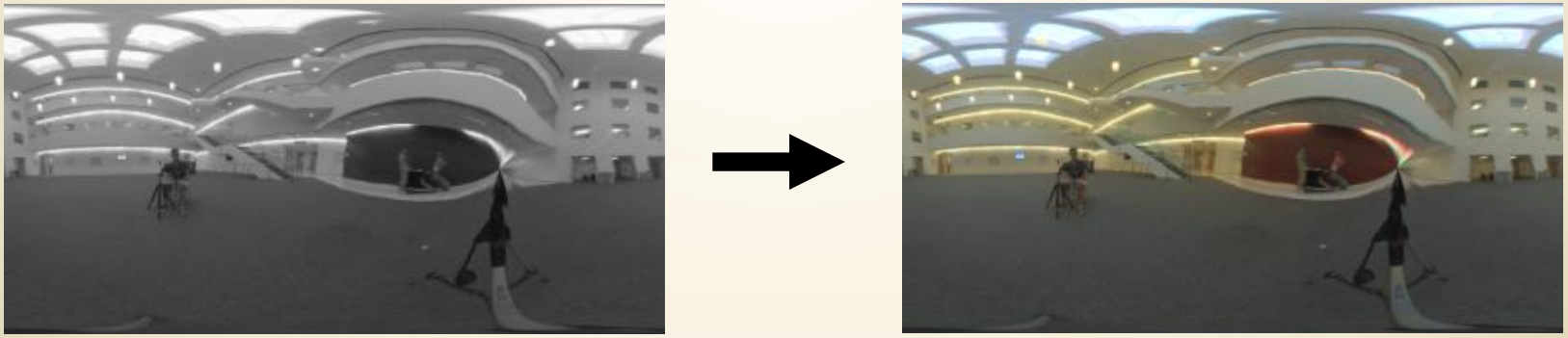



- Simple but powerful prior

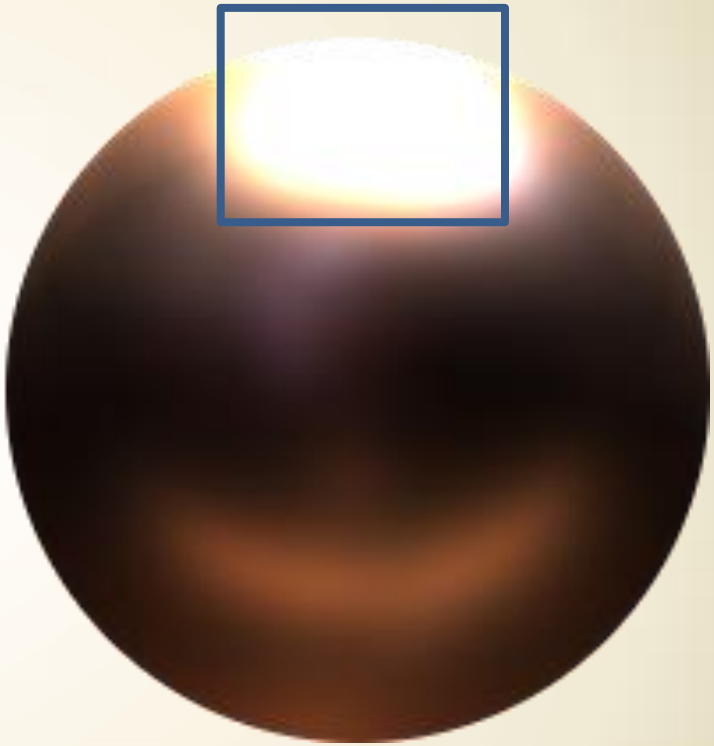
$$p(\mathbf{R}) \sim \mathcal{N}(0, \Sigma_R)$$

# Color Ambiguity

- Perform estimation two times:
  - First constraining illumination to be greyscale
  - Next allowing illumination to be full color

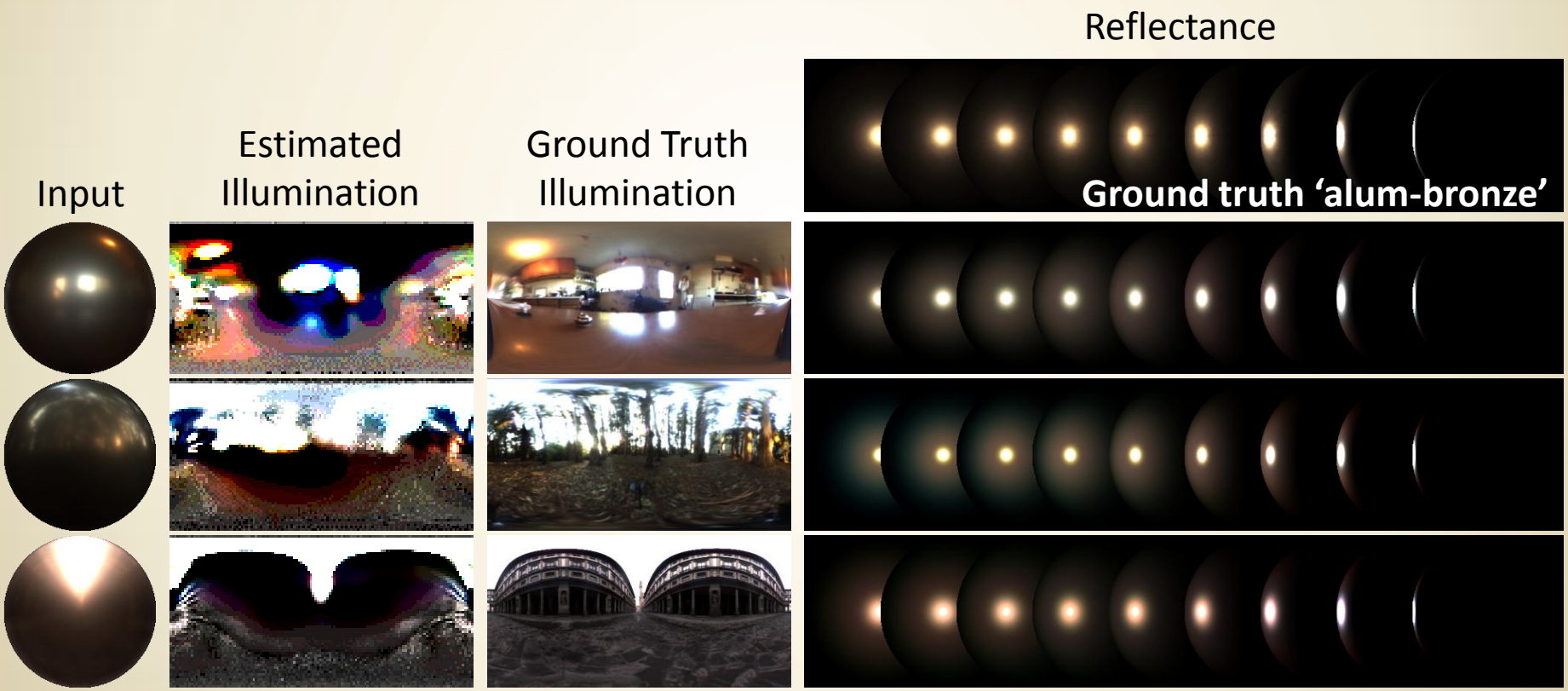


# How many lights are there?

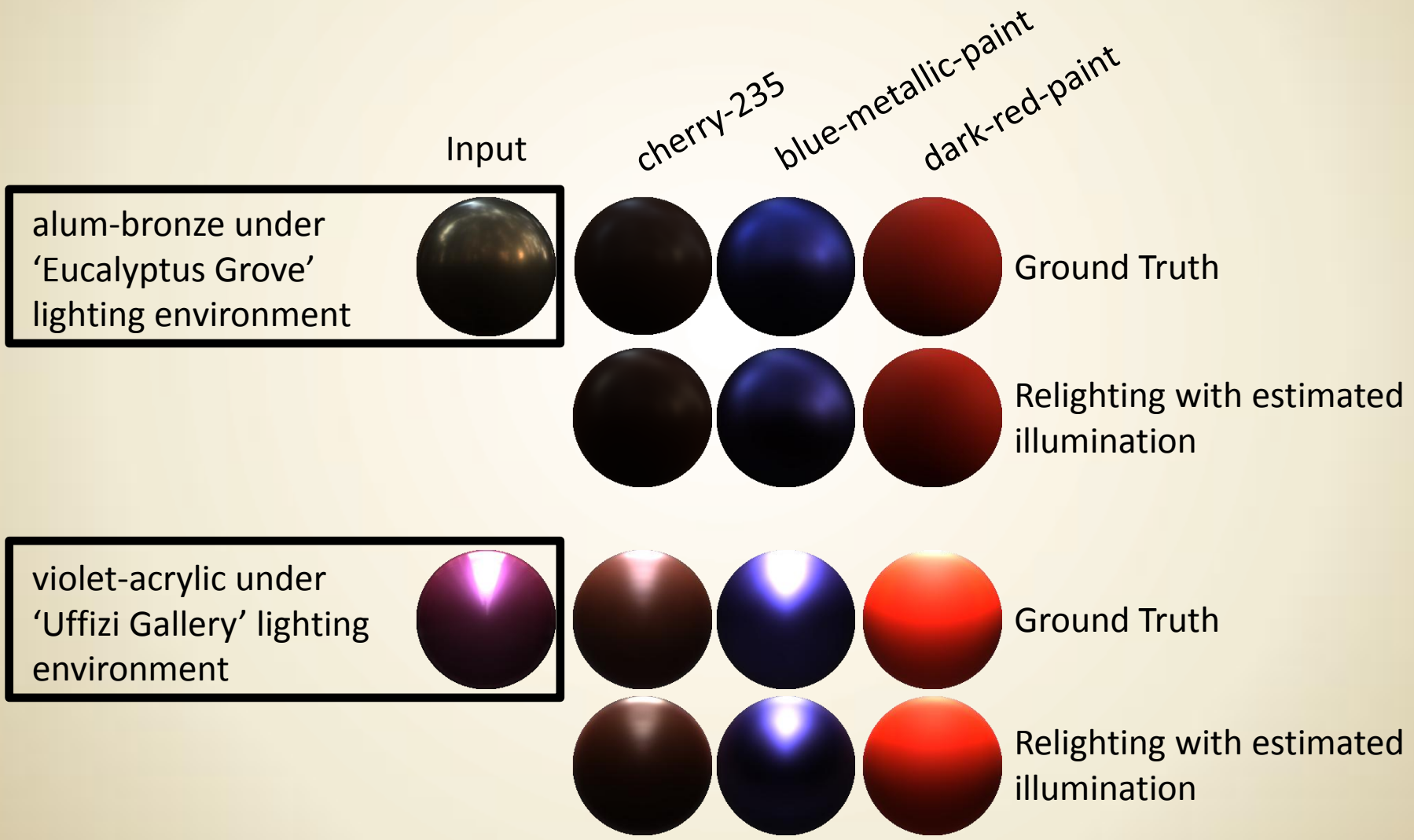


We can’t know

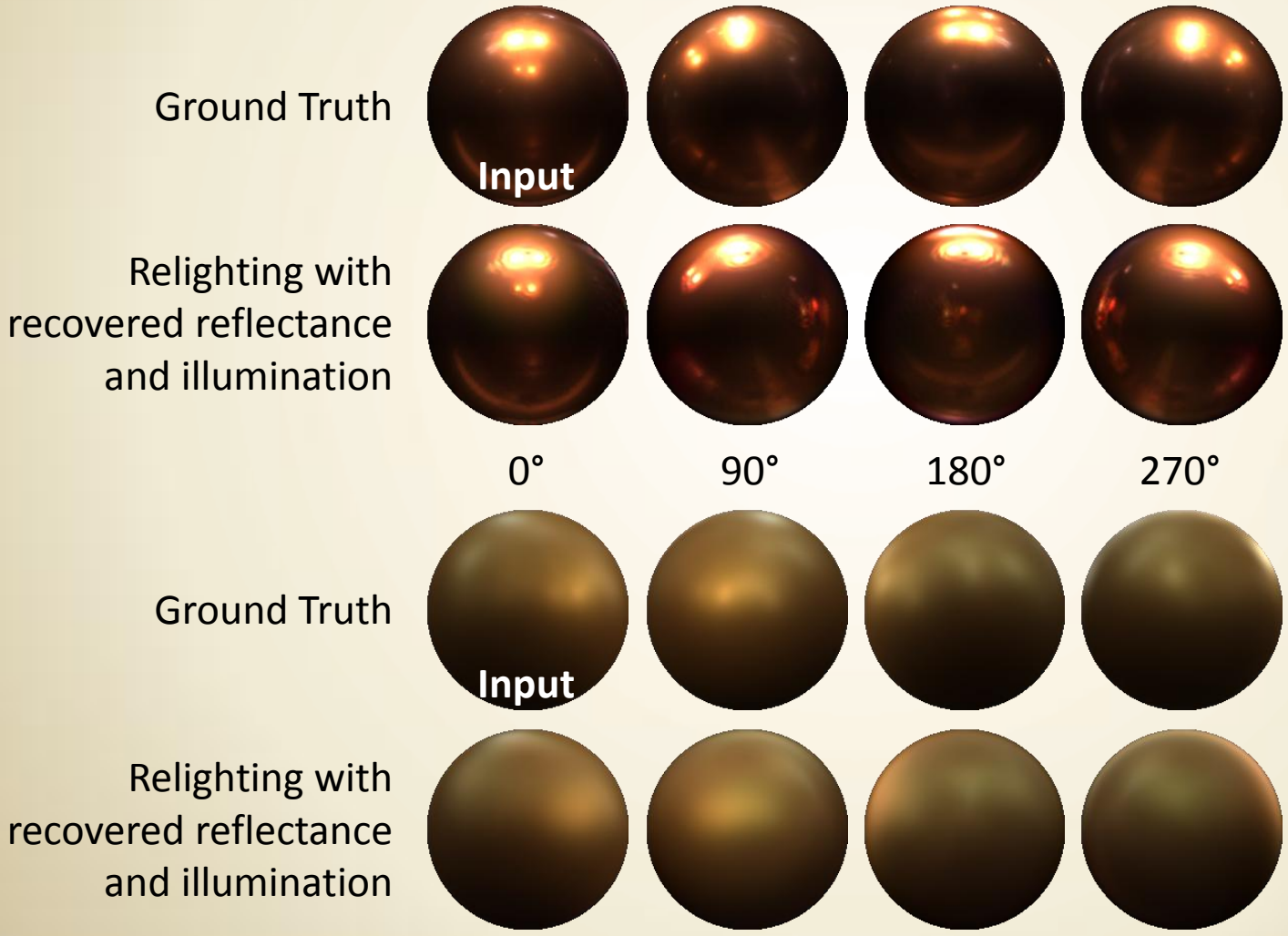
# Results: Synthetic



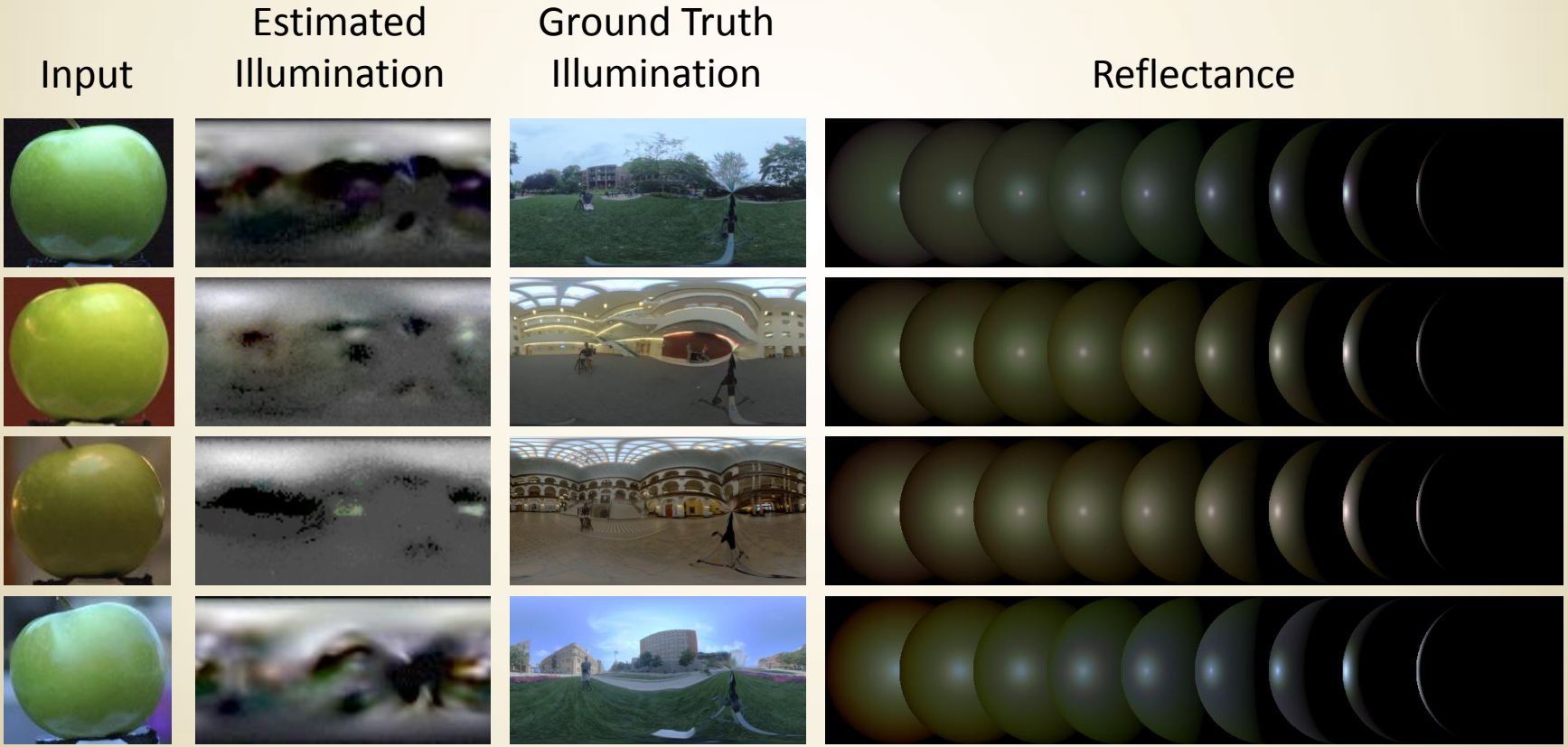
# Predicting the Appearance of Materials with Recovered Illumination



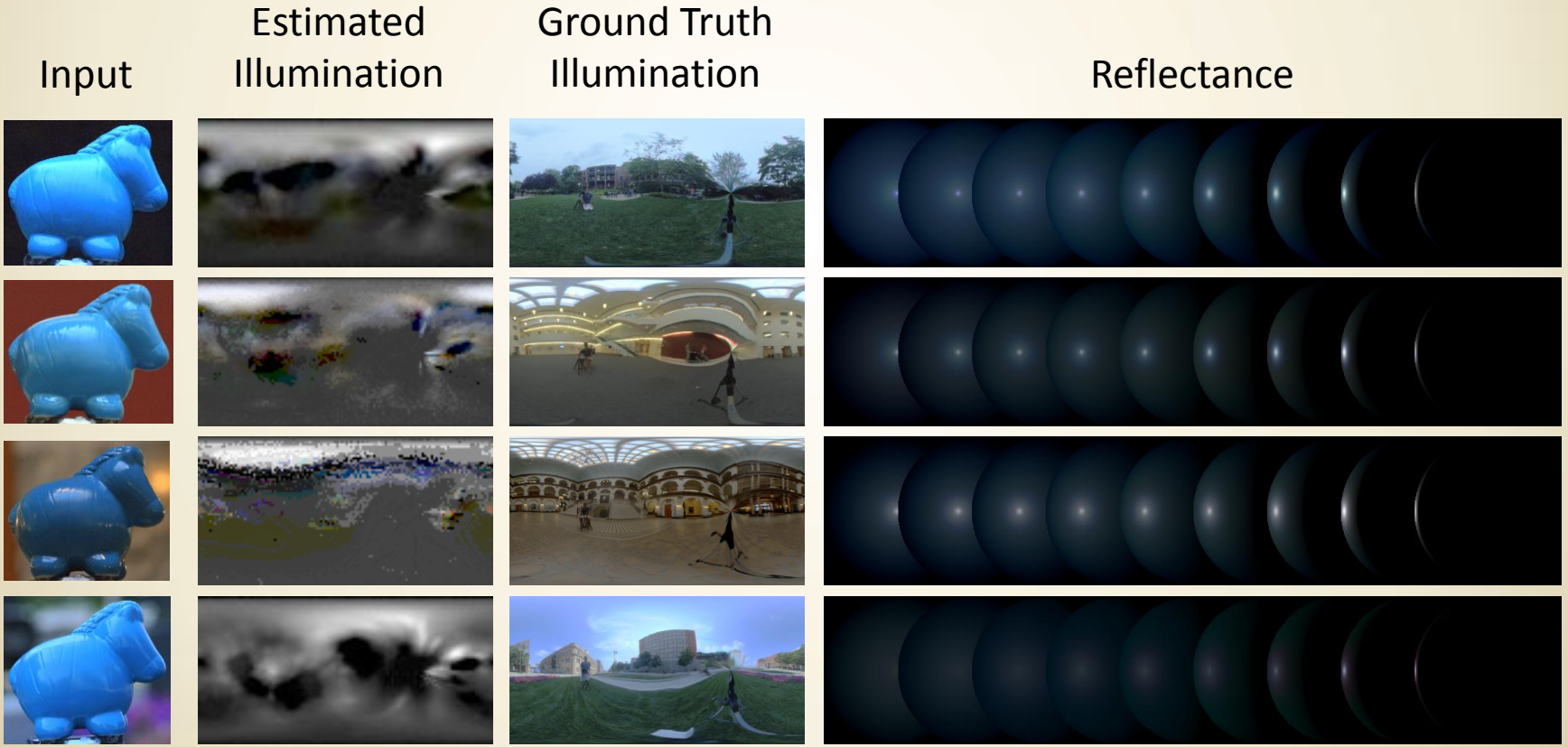
# Predicting Object Appearance from Different Views



# Results:
# Real-world

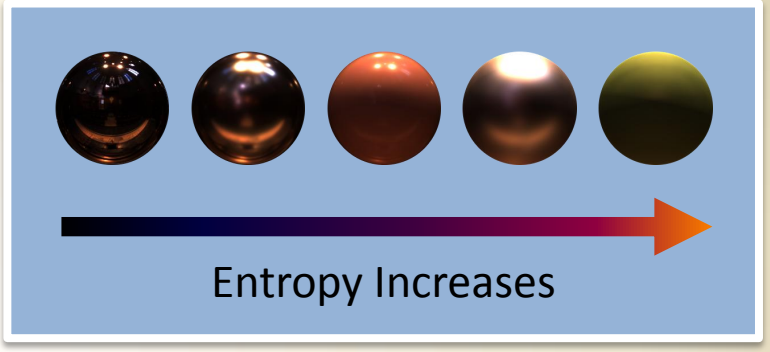


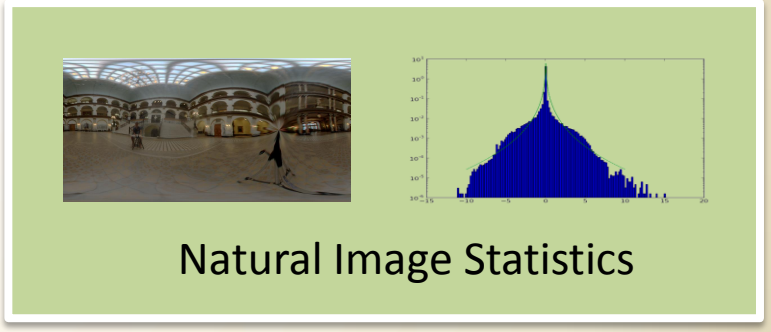
# Results:
# Real-world

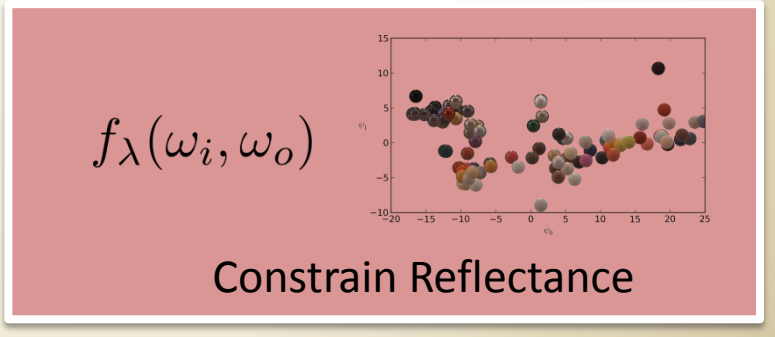


# Successful Estimation through the Right Priors

- Joint recovery requires tight constraints on reflectance and illumination
  - Novel entropy prior
  - Natural image statistic prior
  - DSBRDF reflectance prior
- Despite the inherit limits, we recover important illumination features to allow object appearance prediction



# Source Code

available soon!

cs.drexel.edu/~sal64

# Data

available soon!

cs.drexel.edu/~kon/natgeom

Data set includes 6 objects in 5 natural illumination environments with calibrated ground-truth geometry