Lighting Estimation in Outdoor Image Collections

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`http://vision.gel.ulaval.ca/~jflalonde/projects/imageCollectionLight`
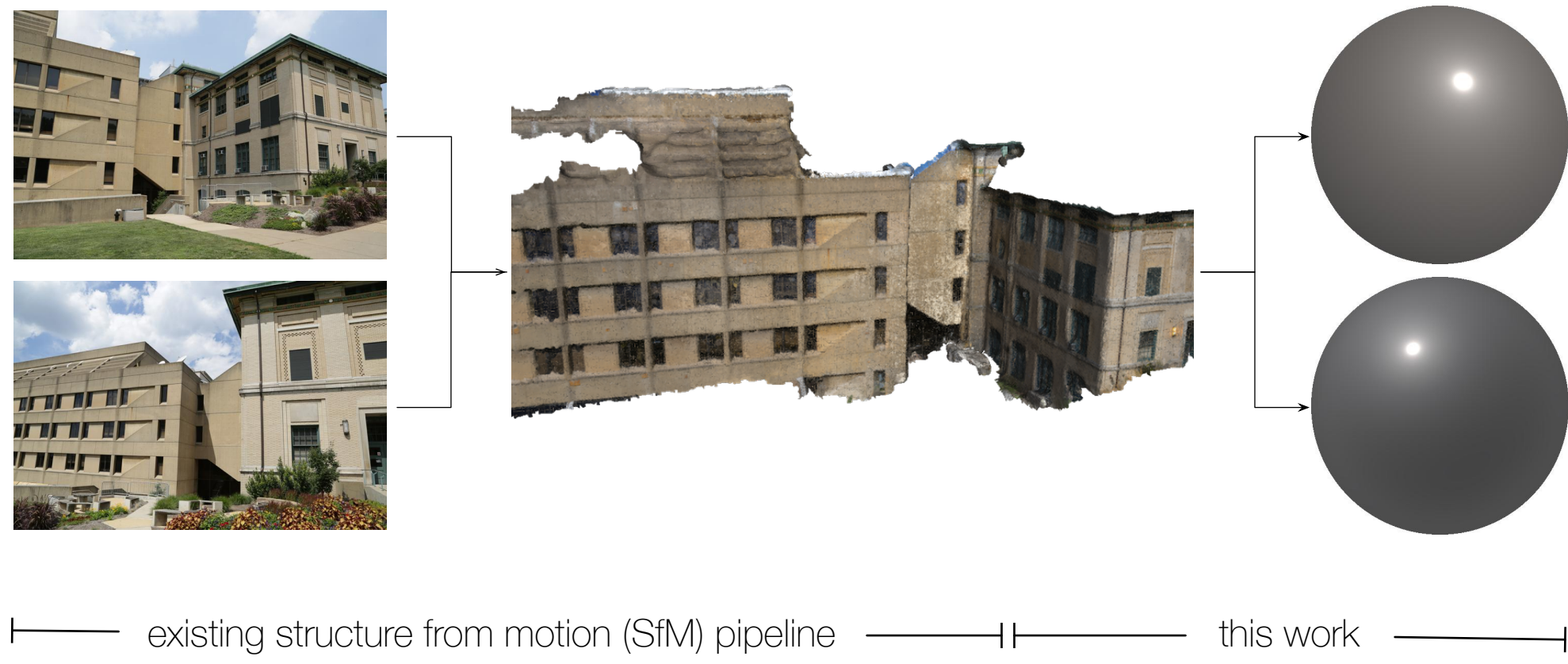
Motivation

Go beyond 3D reconstruction:
estimate physically-plausible **lighting** from outdoor image collections

existing structure from motion (SfM) pipeline — this work

Light and Image Collections Database

22 locations, 1,850 LDR images
350 HDR lighting conditions over **6** months

Example location #1

- 524 images for SfM
- 98 images with illumination conditions

ground-level images

corresponding illumination conditions

SfM reconstruction + poisson mesh

Example location #2

- 465 images for SfM
- 90 images with illumination conditions

ground-level images

corresponding illumination conditions

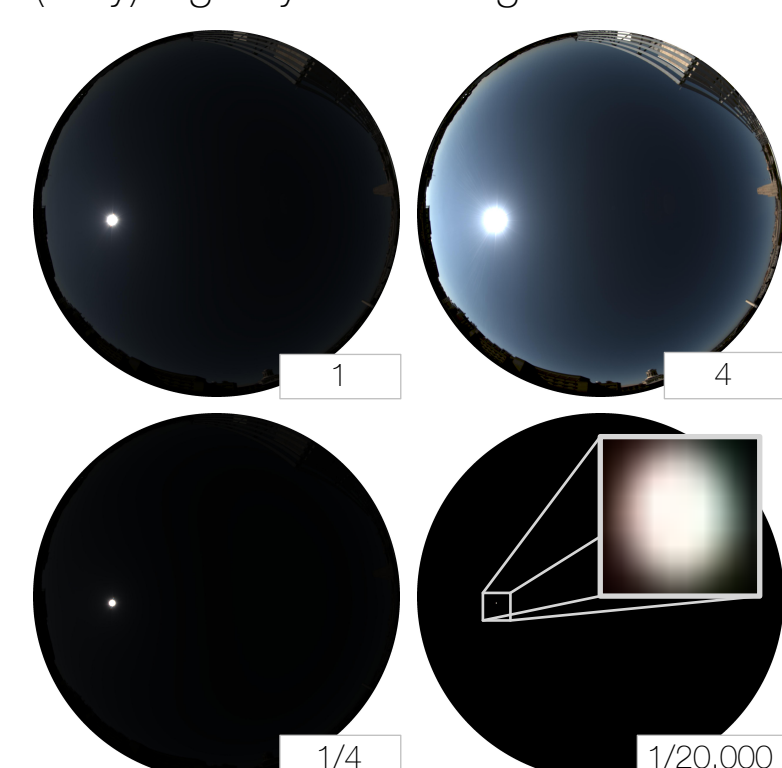SfM reconstruction + poisson mesh

HDR light capture

as in [Stumpfel et al., AFRIGRAPH 2004]

- camera on roof of tall building
- controlled by Raspberry Pi
- 180º fisheye lens
- 7 expositions
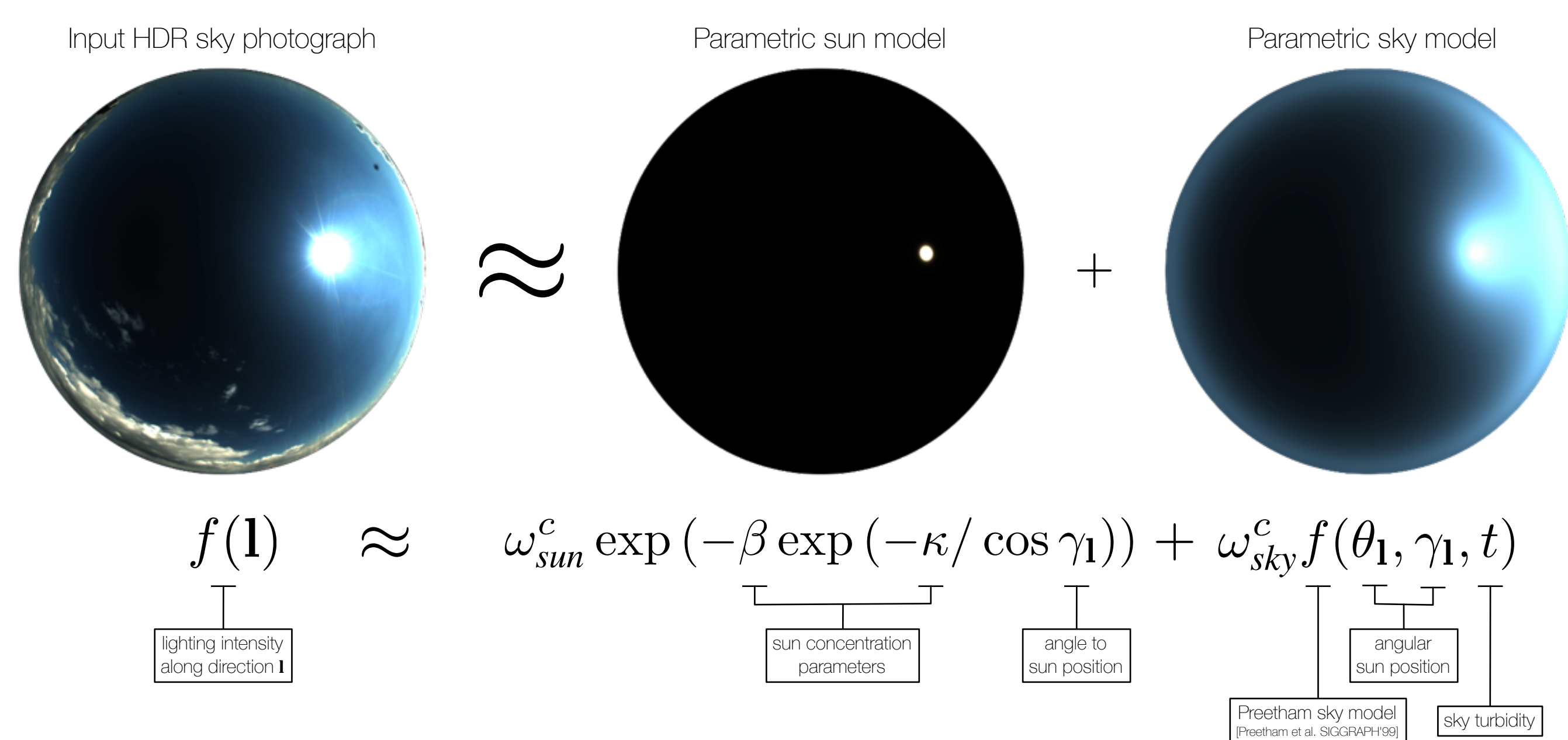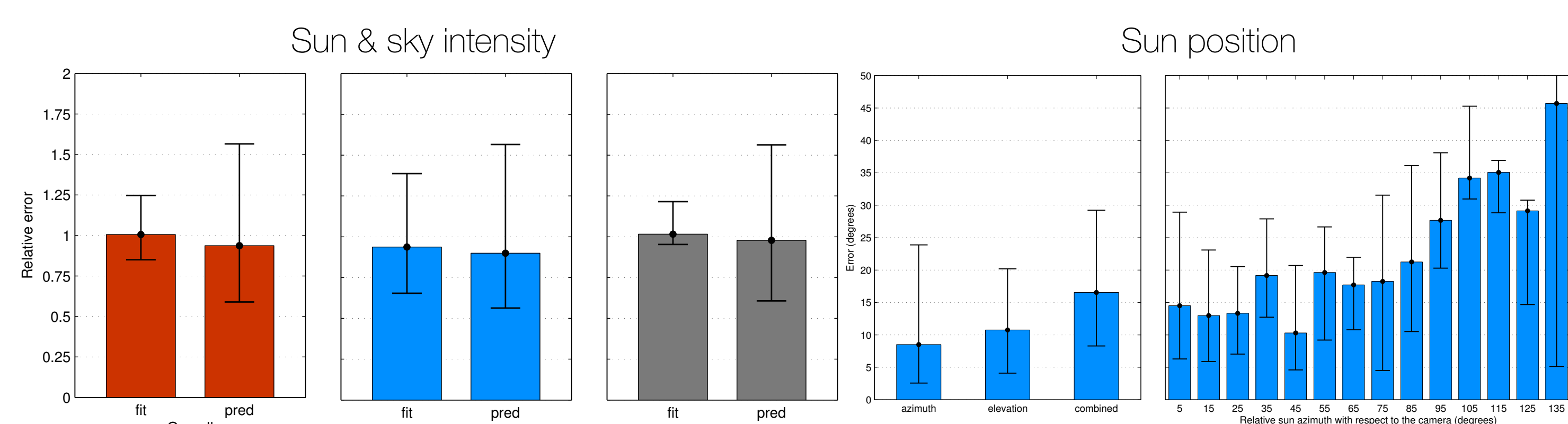- ND 3.0 filter to expose the sun

Capture setup

(Very) high dynamic range
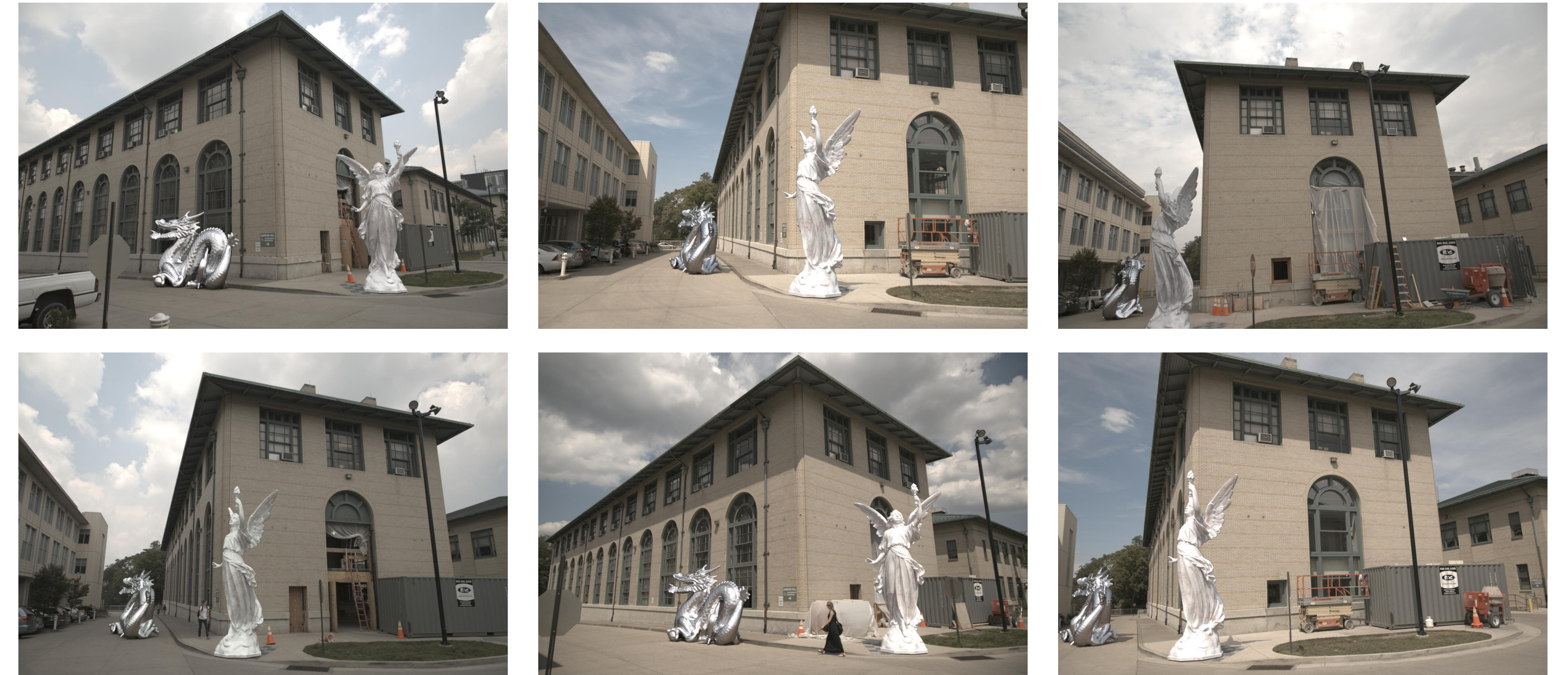
Parametric HDR Outdoor Lighting Model

Models an (RGB) outdoor light probe using 11 parameters

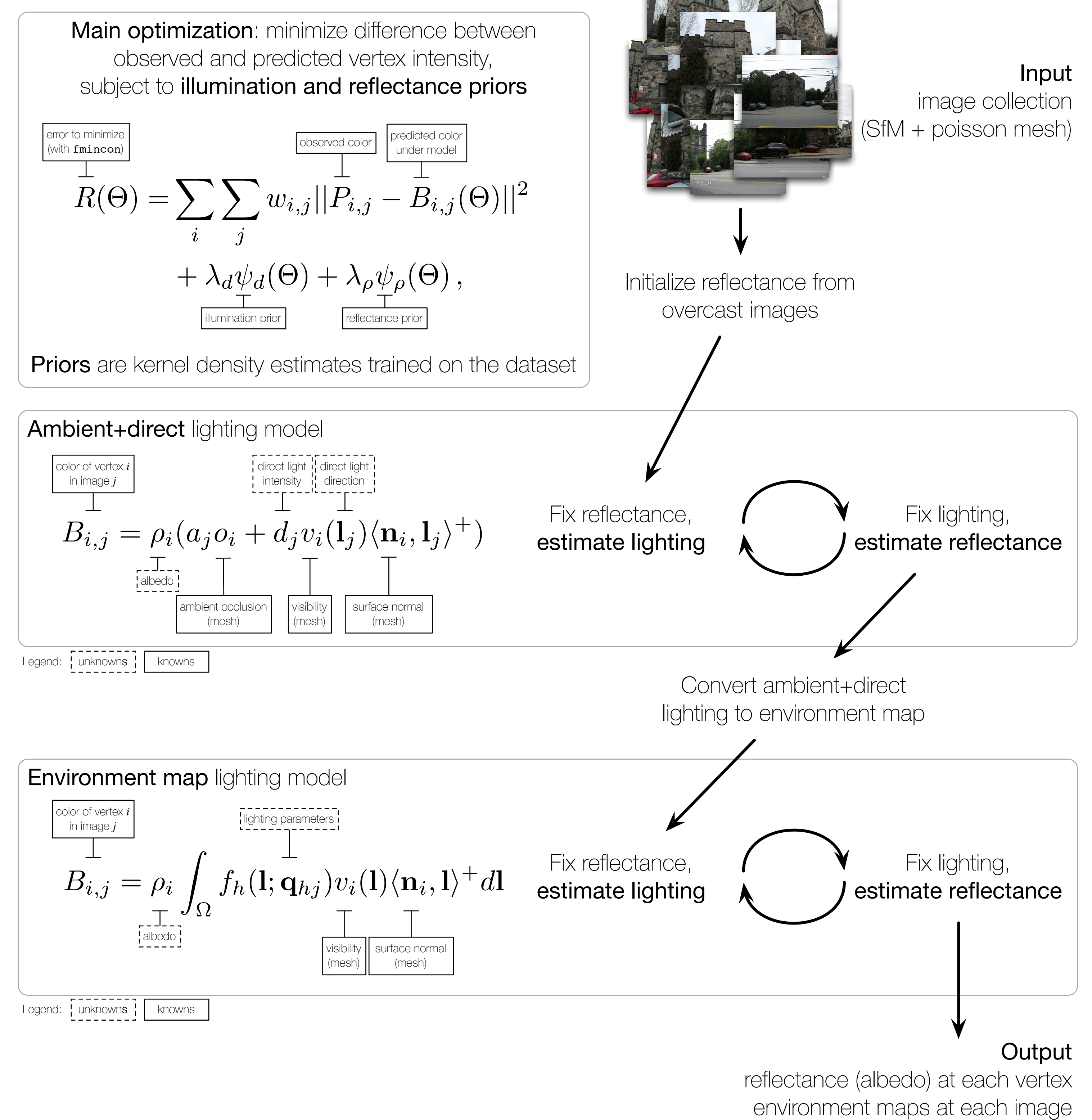Input HDR sky photograph   Parametric sun model   Parametric sky model

$$f(\mathbf{l}) \approx \omega_{sun}^c \exp\left(-\beta \exp\left(-\kappa/\cos\gamma_{\mathbf{l}}\right)\right) + \omega_{sky}^c f(\theta_{\mathbf{l}}, \gamma_{\mathbf{l}}, t)$$

lighting intensity along direction **l** | sun concentration parameters | angle to sun position | angular sun position | Preetham sky model [Preetham et al., SIGGRAPH'99] | sky turbidity

Quantitative Evaluation

Sun & sky intensity   Sun position

Multi-view, Multi-light Relighting

Results tone-mapped for display (with gamma = 2.2)

Approach

Main optimization: minimize difference between observed and predicted vertex intensity, subject to **illumination and reflectance priors**

error to minimize (with **fmincon**) | observed color | predicted color under model

$$R(\Theta) = \sum_i \sum_j w_{i,j} ||P_{i,j} - B_{i,j}(\Theta)||^2 + \lambda_d \psi_d(\Theta) + \lambda_\rho \psi_\rho(\Theta),$$

illumination prior | reflectance prior

Priors are kernel density estimates trained on the dataset

Input
image collection
(SfM + poisson mesh)

Initialize reflectance from overcast images

Ambient+direct lighting model

color of vertex i in image j | direct light intensity | direct light direction

$$B_{i,j} = \rho_i(a_j o_i + d_j v_i(\mathbf{l}_j)\langle \mathbf{n}_i, \mathbf{l}_j \rangle^+)$$

albedo | ambient occlusion (mesh) | visibility (mesh) | surface normal (mesh)

Legend: unknowns | knowns

Fix reflectance, estimate lighting ⟷ Fix lighting, estimate reflectance

Convert ambient+direct lighting to environment map

Environment map lighting model

color of vertex i in image j | lighting parameters

$$B_{i,j} = \rho_i \int_\Omega f_h(\mathbf{l}; \mathbf{q}_{hj}) v_i(\mathbf{l})\langle \mathbf{n}_i, \mathbf{l}\rangle^+ d\mathbf{l}$$

albedo | visibility (mesh) | surface normal (mesh)

Legend: unknowns | knowns

Fix reflectance, estimate lighting ⟷ Fix lighting, estimate reflectance

Output
reflectance (albedo) at each vertex
environment maps at each image

Qualitative Comparison

Input image (LDR)

Ground truth lighting (HDR)

Ground truth model fit (HDR)

Estimated lighting (HDR)