Using blur to affect perceived distance and size

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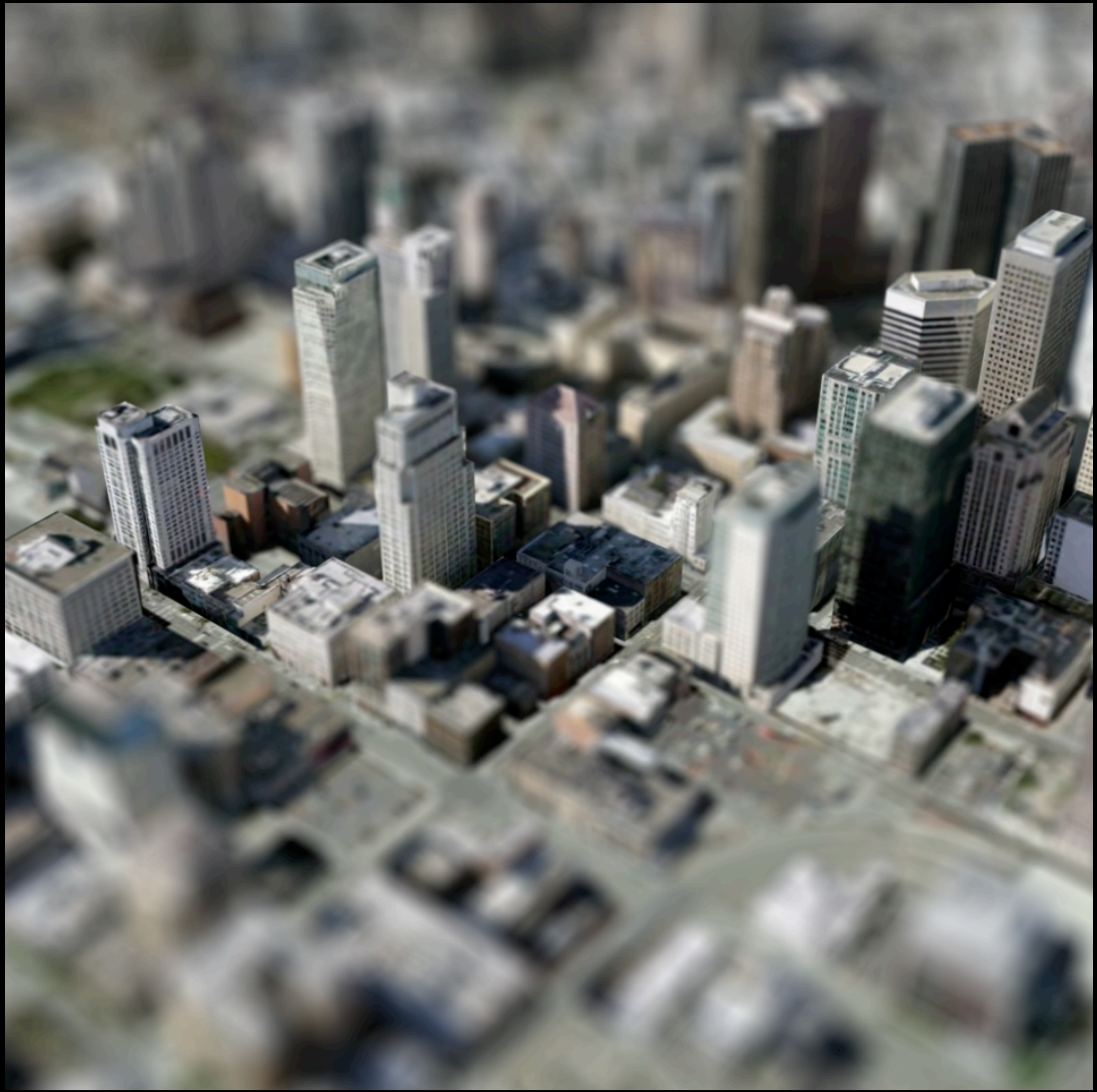

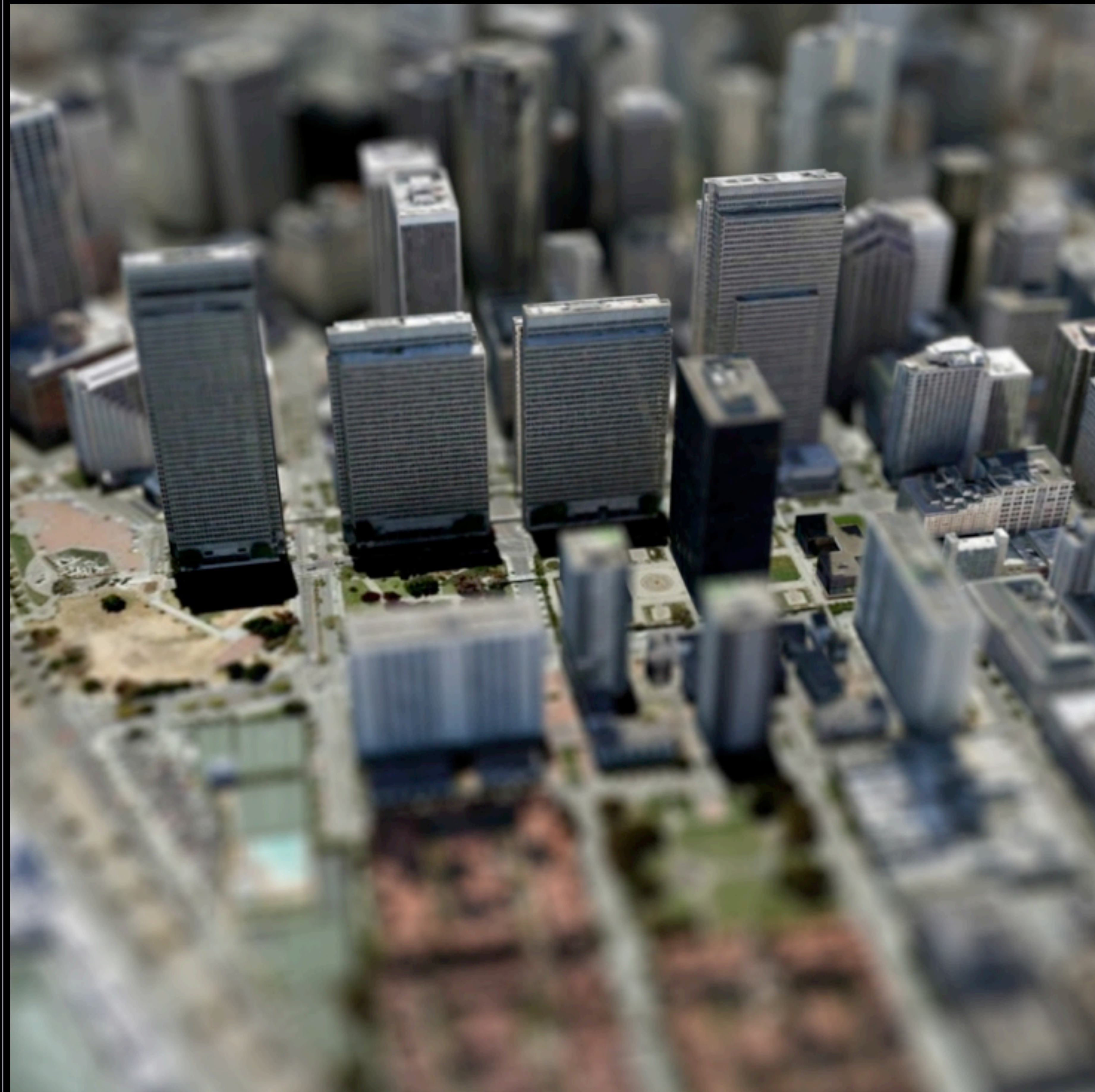

Blur in cinema

- Minimize blur
- Result: Scale models appear life-sized

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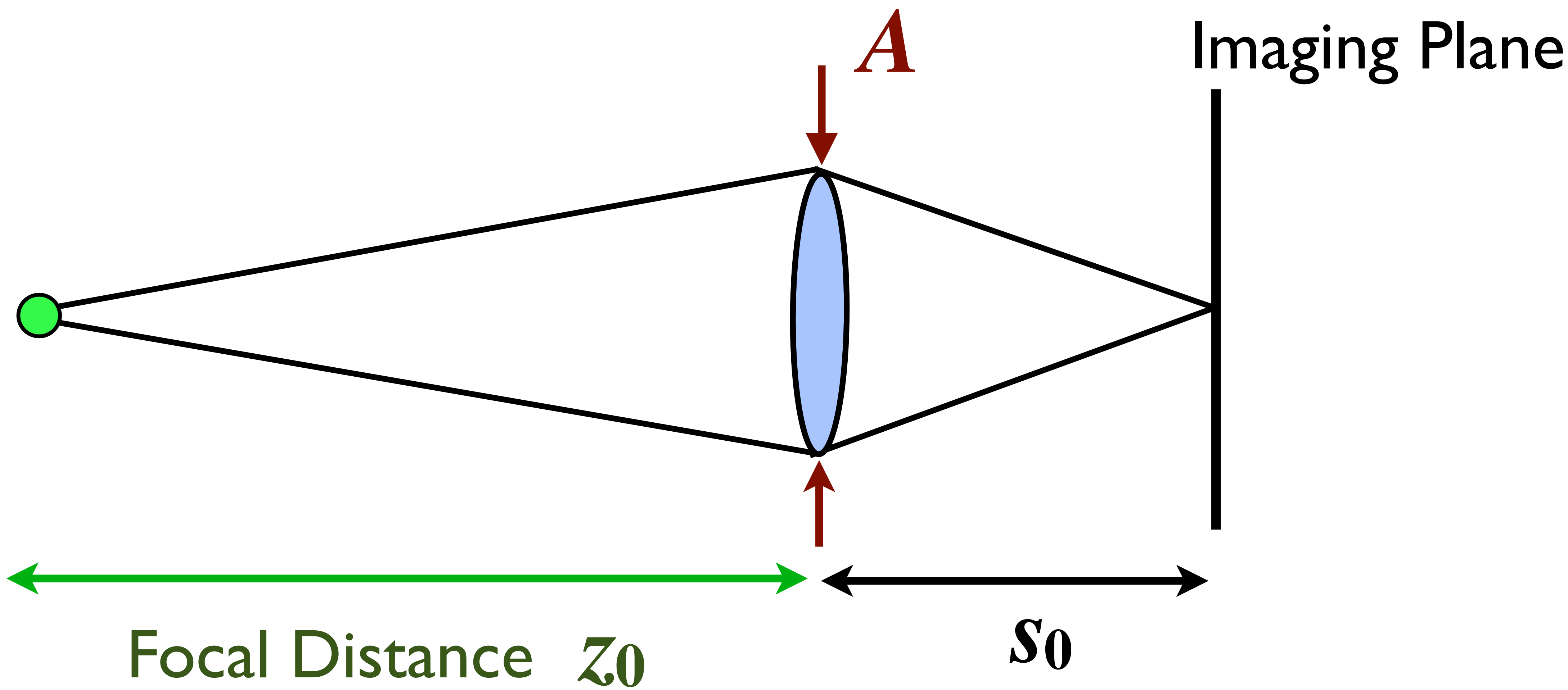
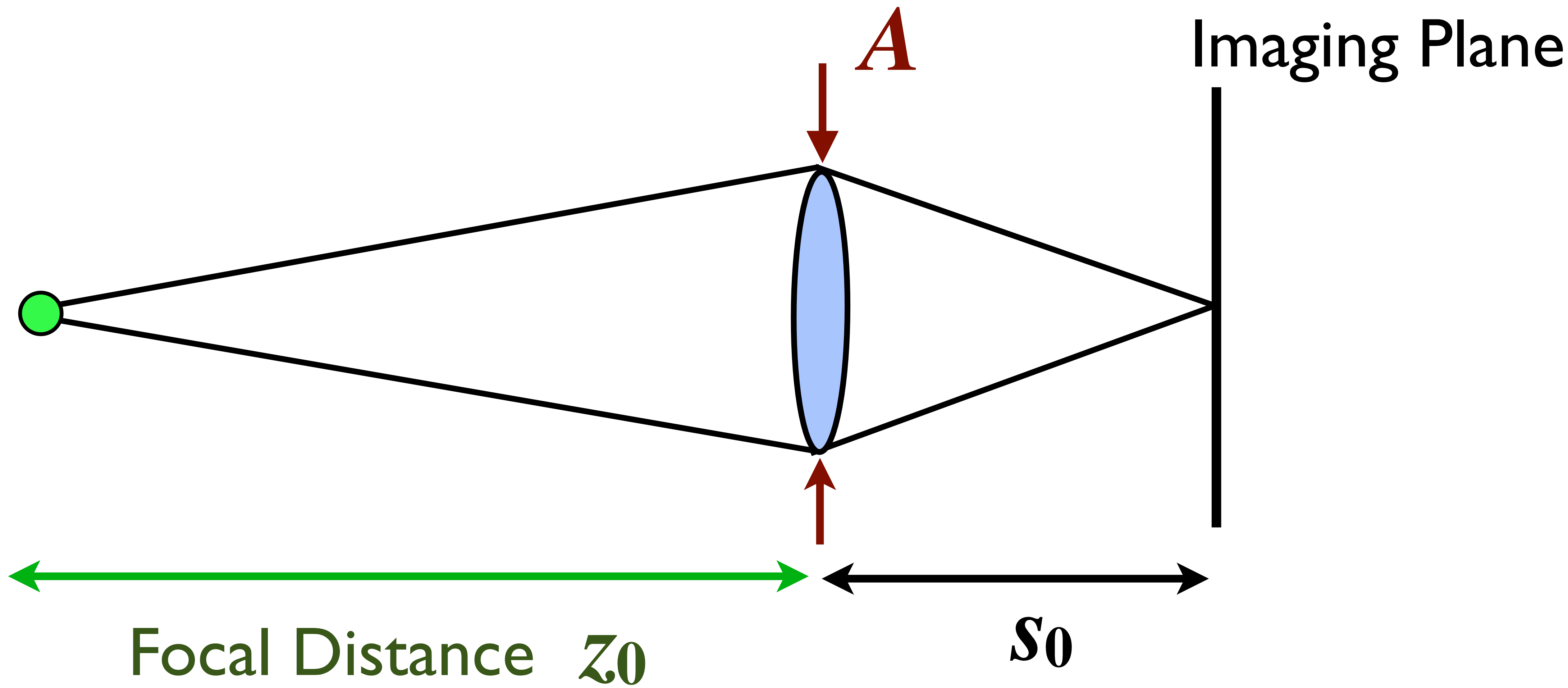
Goals

1. Review optics of blur
2. Determine how blur acts as a distance (and size) cue
3. Develop tips and rules for changing blur

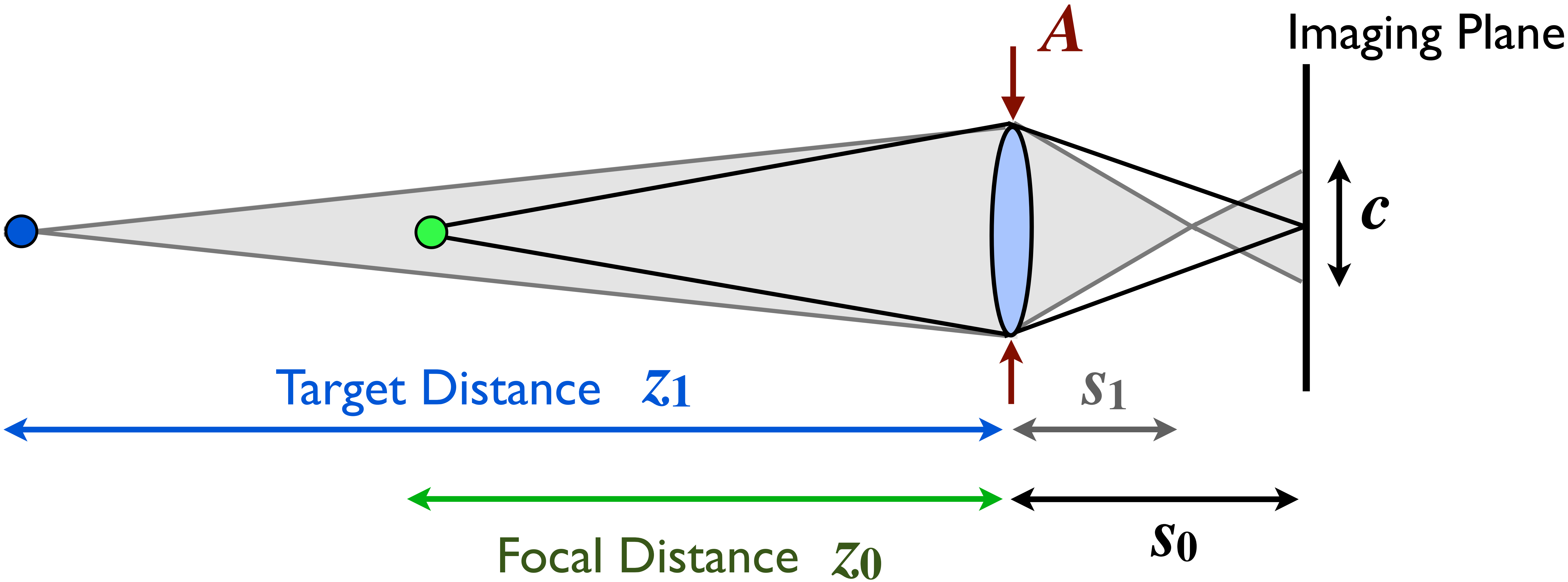
Optics of blur



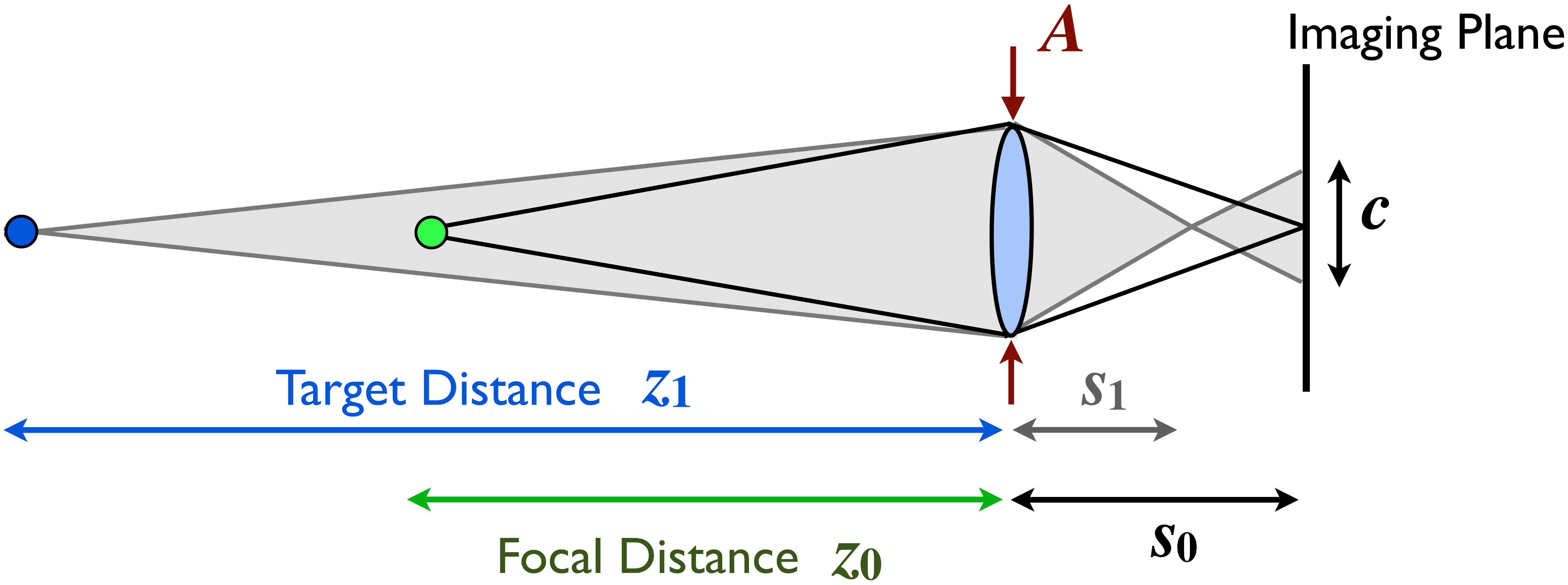
Optics of blur



Optics of blur



Optics of blur



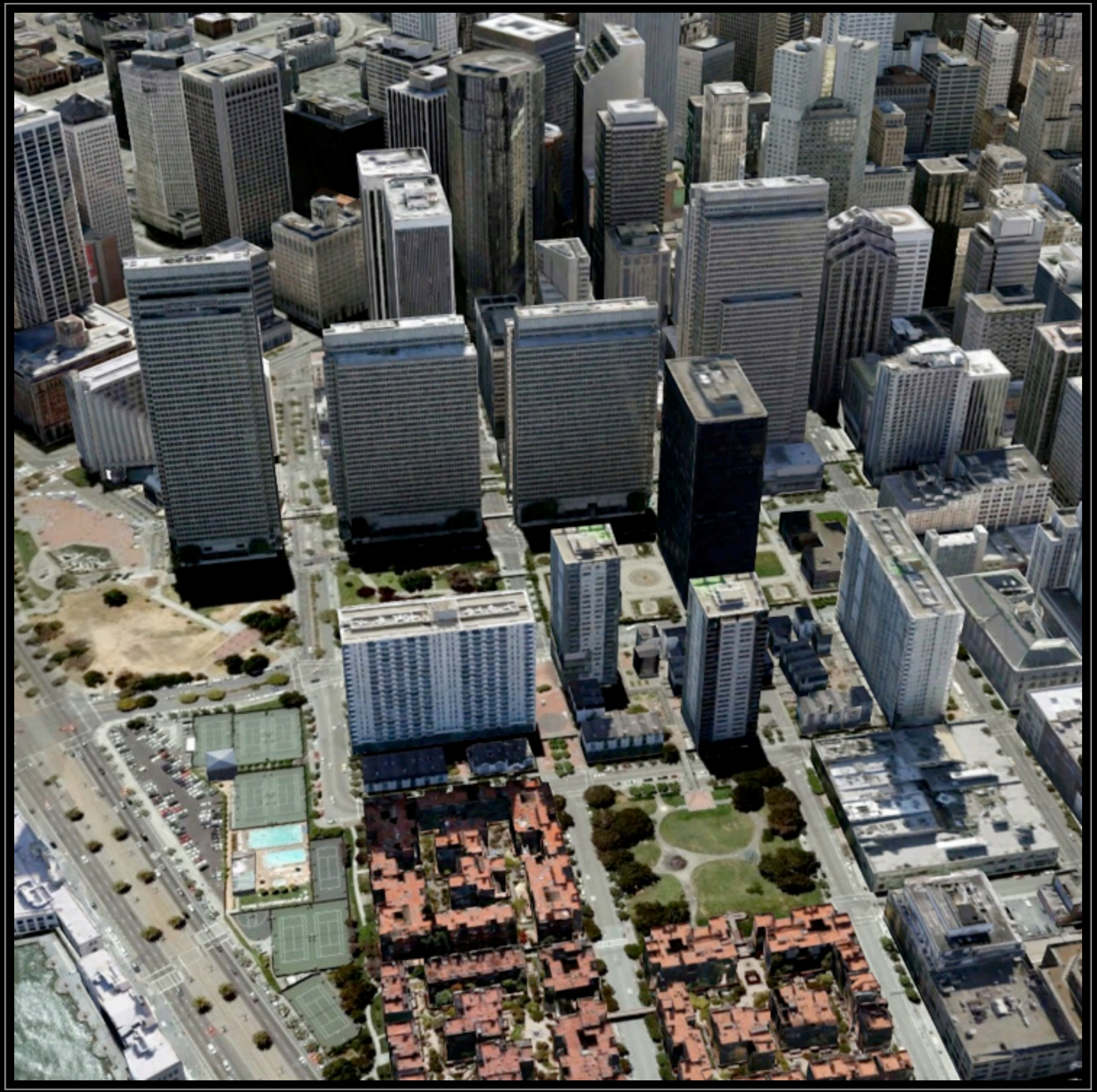
$$c = A\left(\frac{s_0}{z_0}\right)\left|1 - \frac{z_0}{z_1}\right|$$

Blur in cinema, revisited

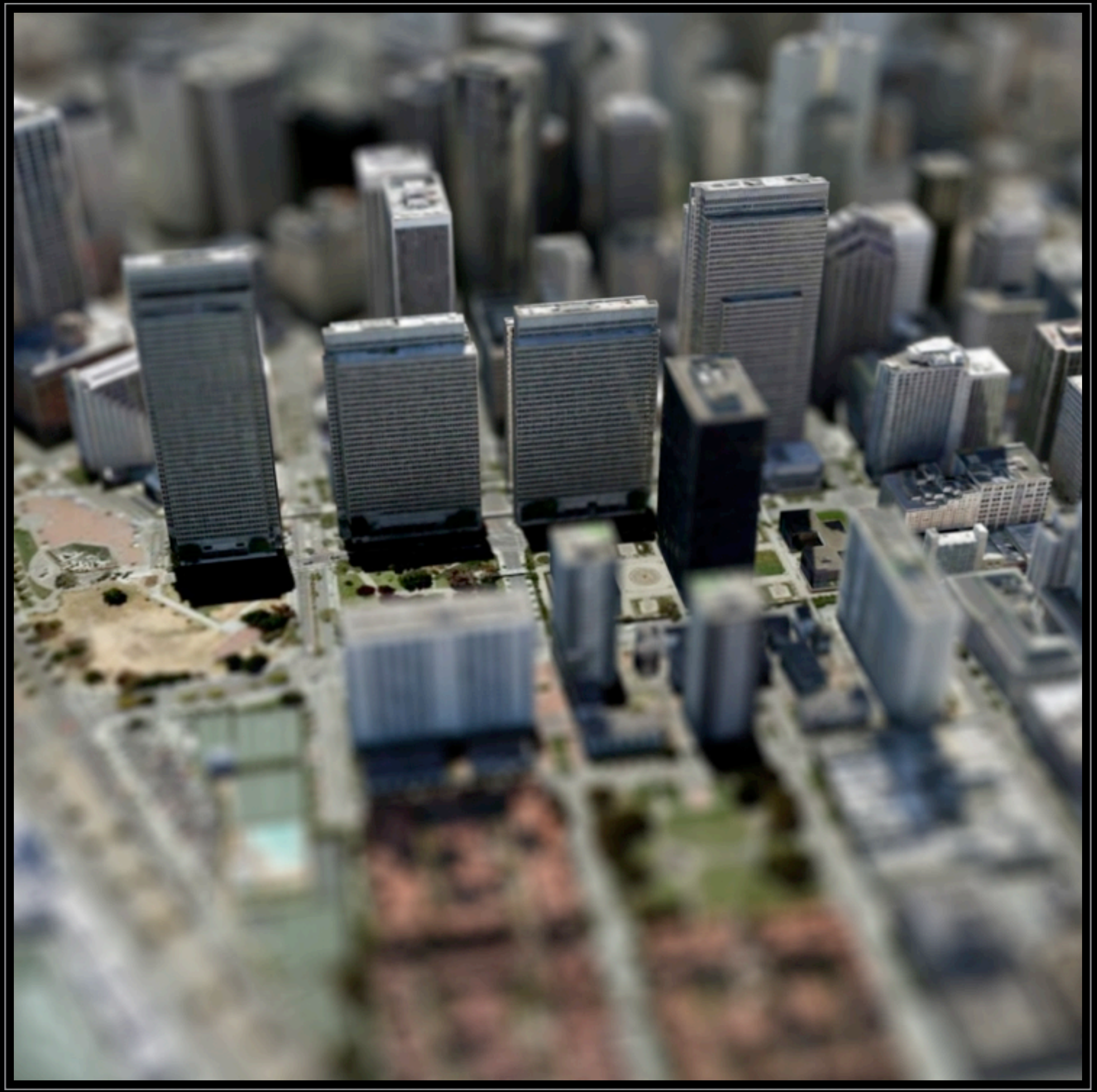
- Minimize blur (small aperture, long exposure)
- Result: Scale models appear life-sized

Images copyright Lucasfilm Ltd.

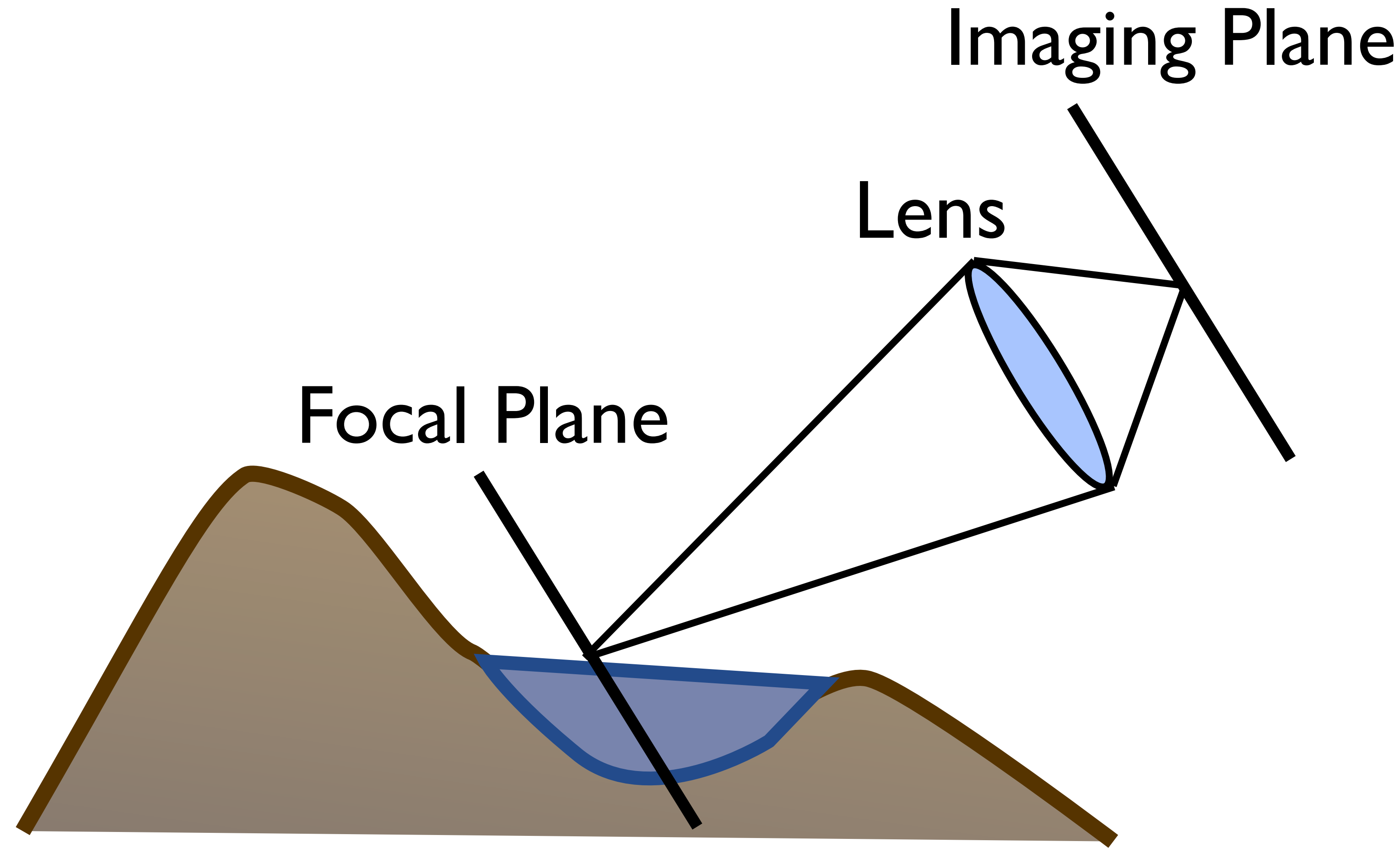
A = 4.5mm



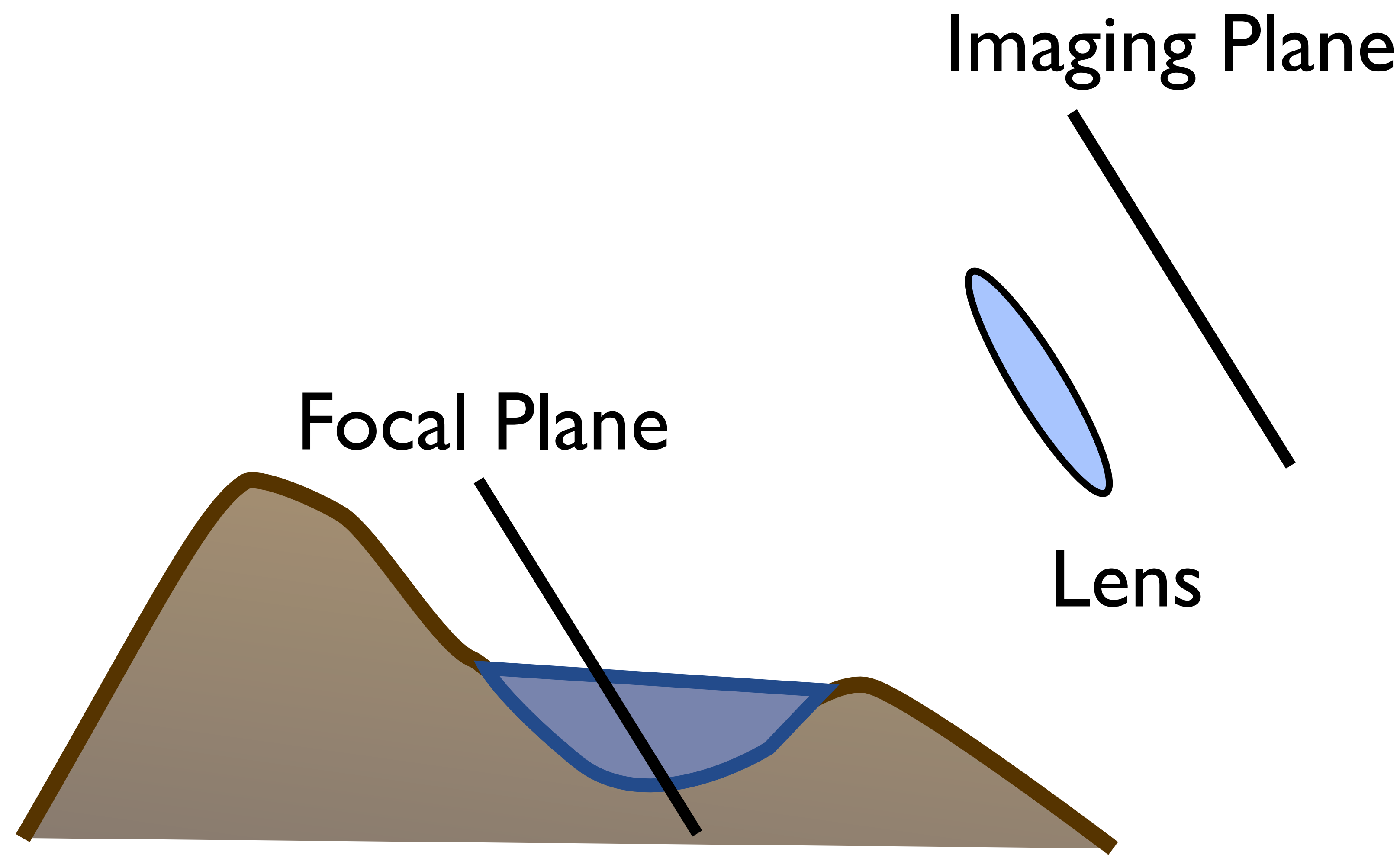
A = 60m



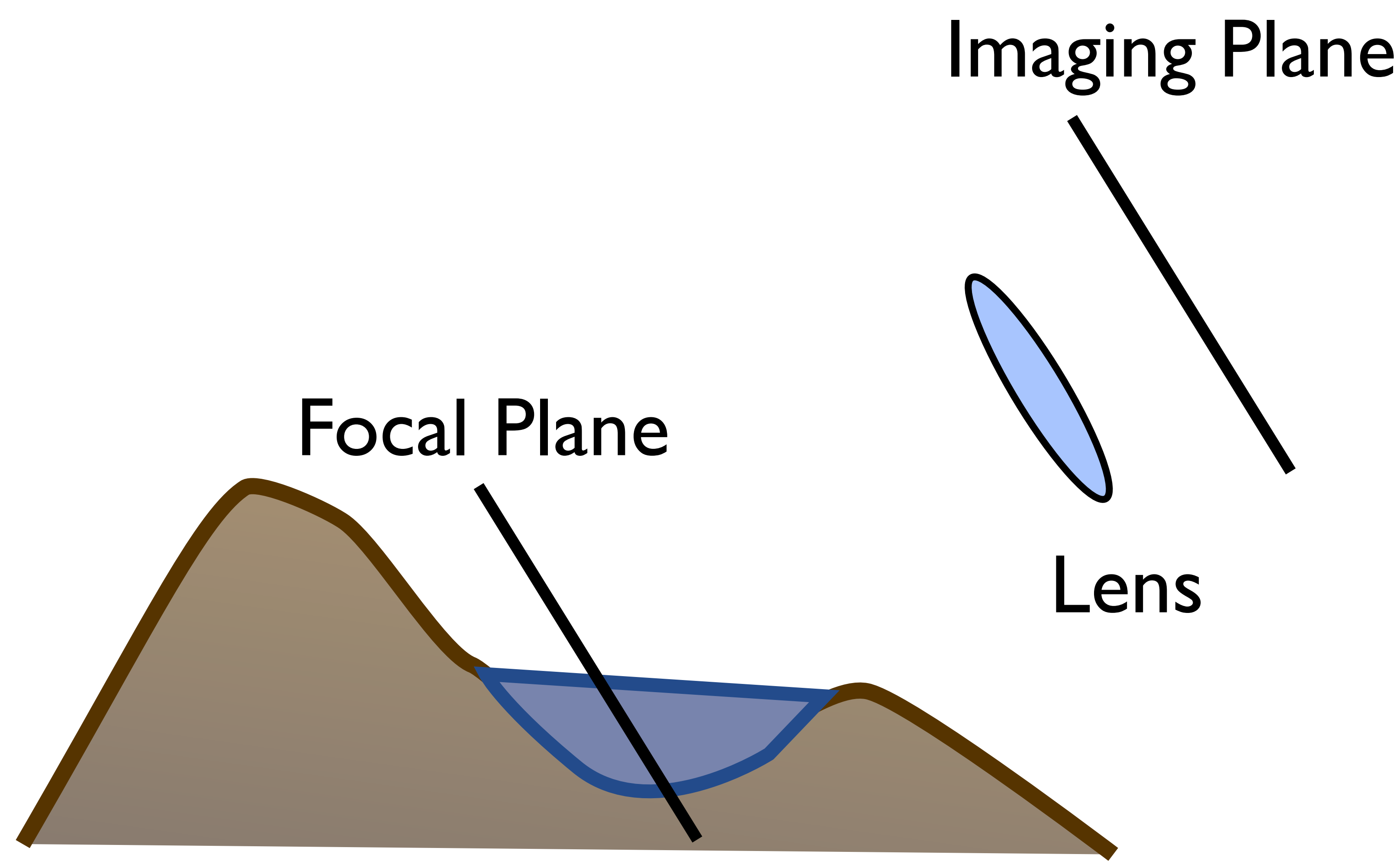
“Fake blur” (tilt-and-shift lens)



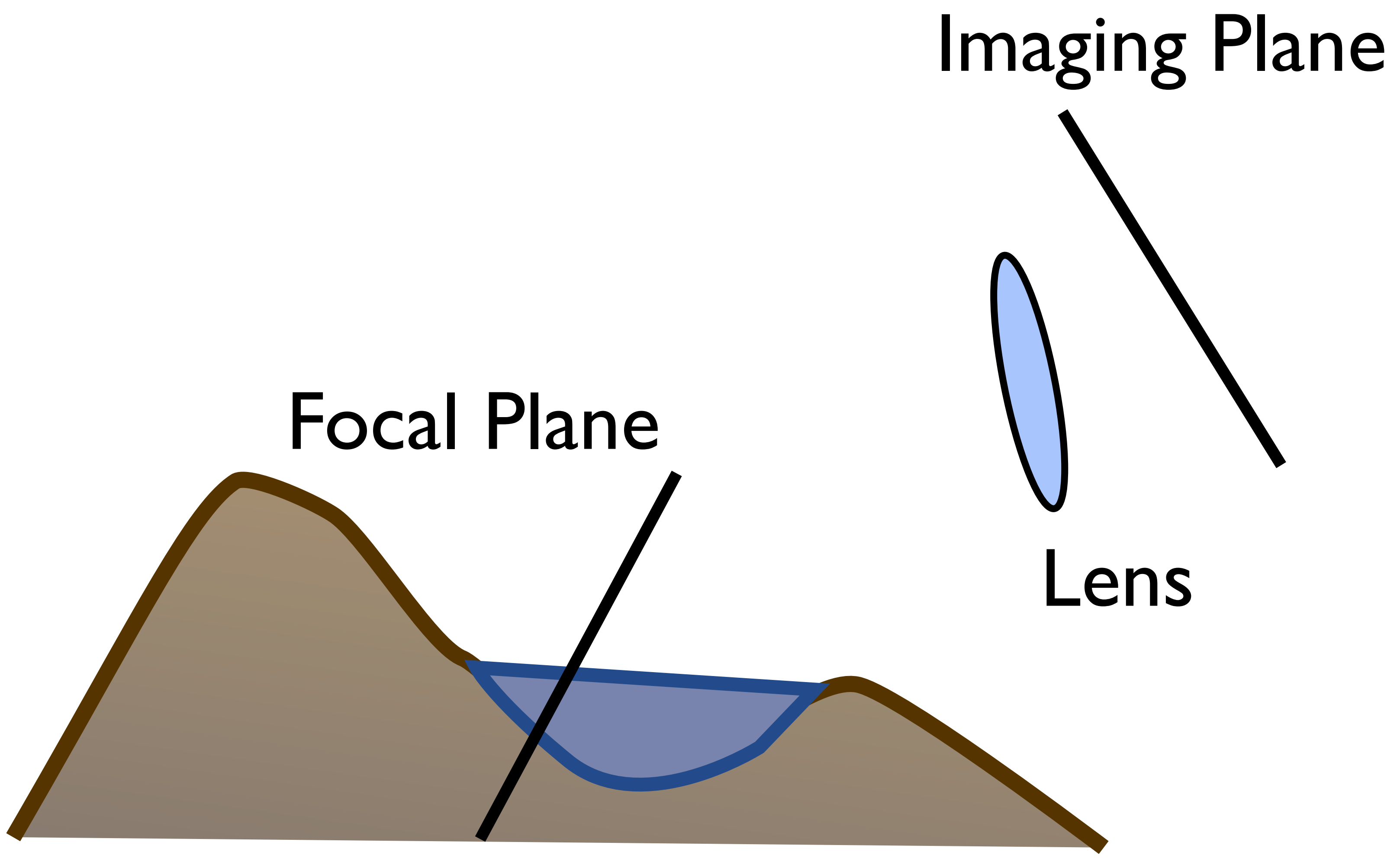
"Fake blur" (tilt-and-shift lens)



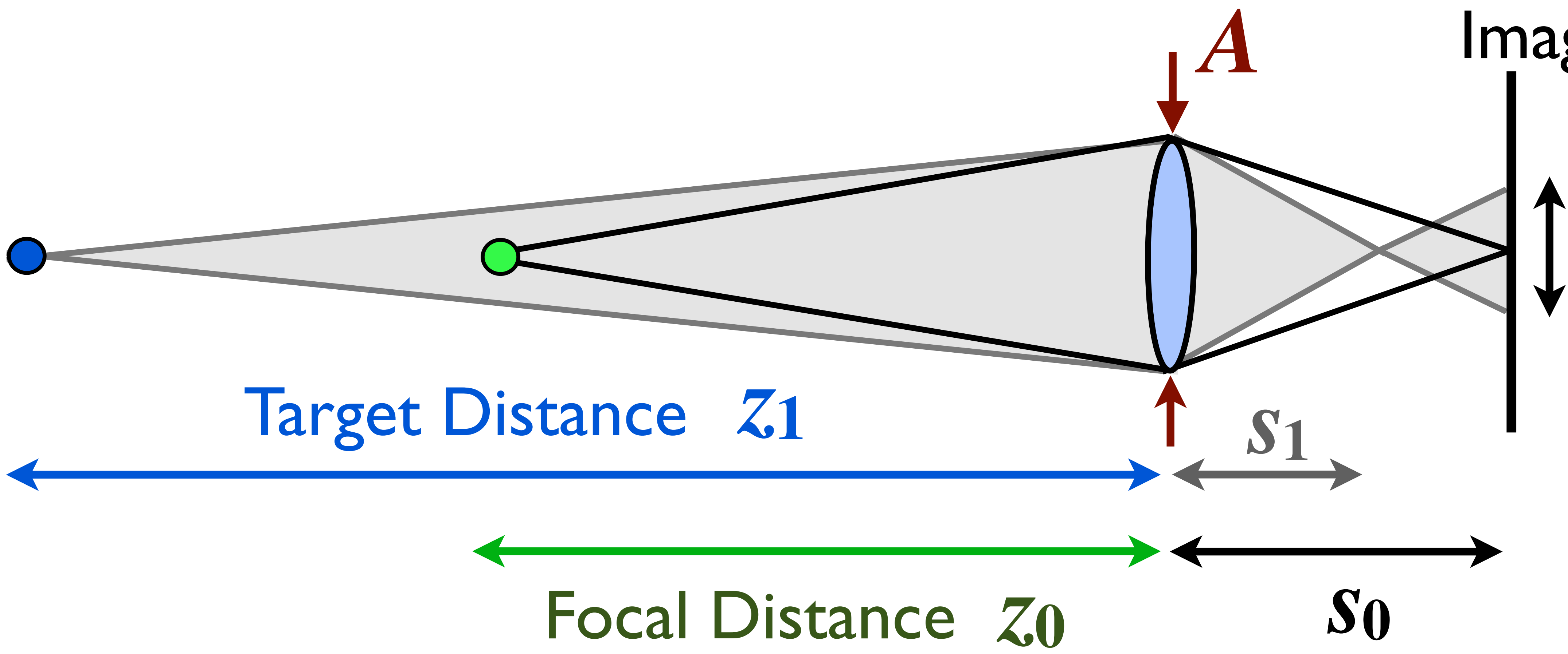
“Fake blur” (tilt-and-shift lens)



"Fake blur" (tilt-and-shift lens)

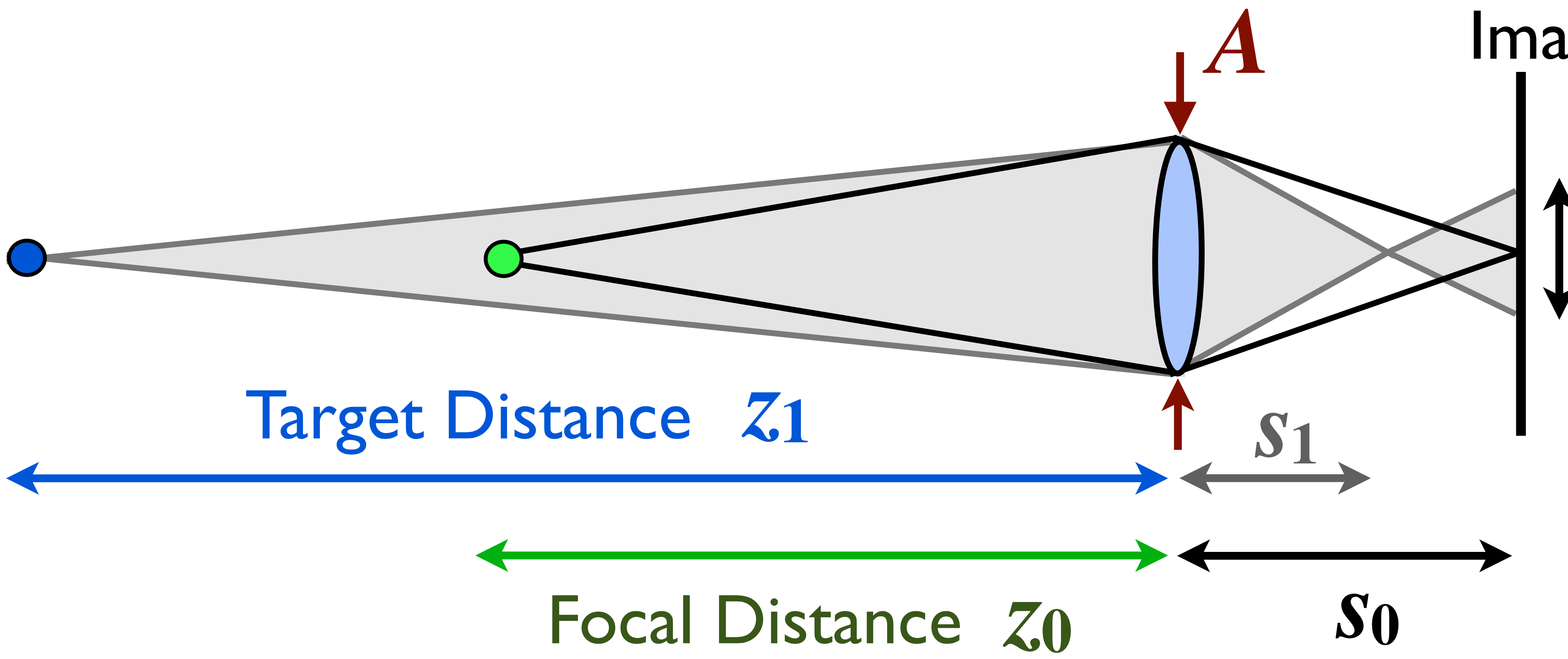


Information from blur



$$c = A\left(\frac{s_0}{z_0}\right)\left|1 - \frac{z_0}{z_1}\right|$$

Information from blur



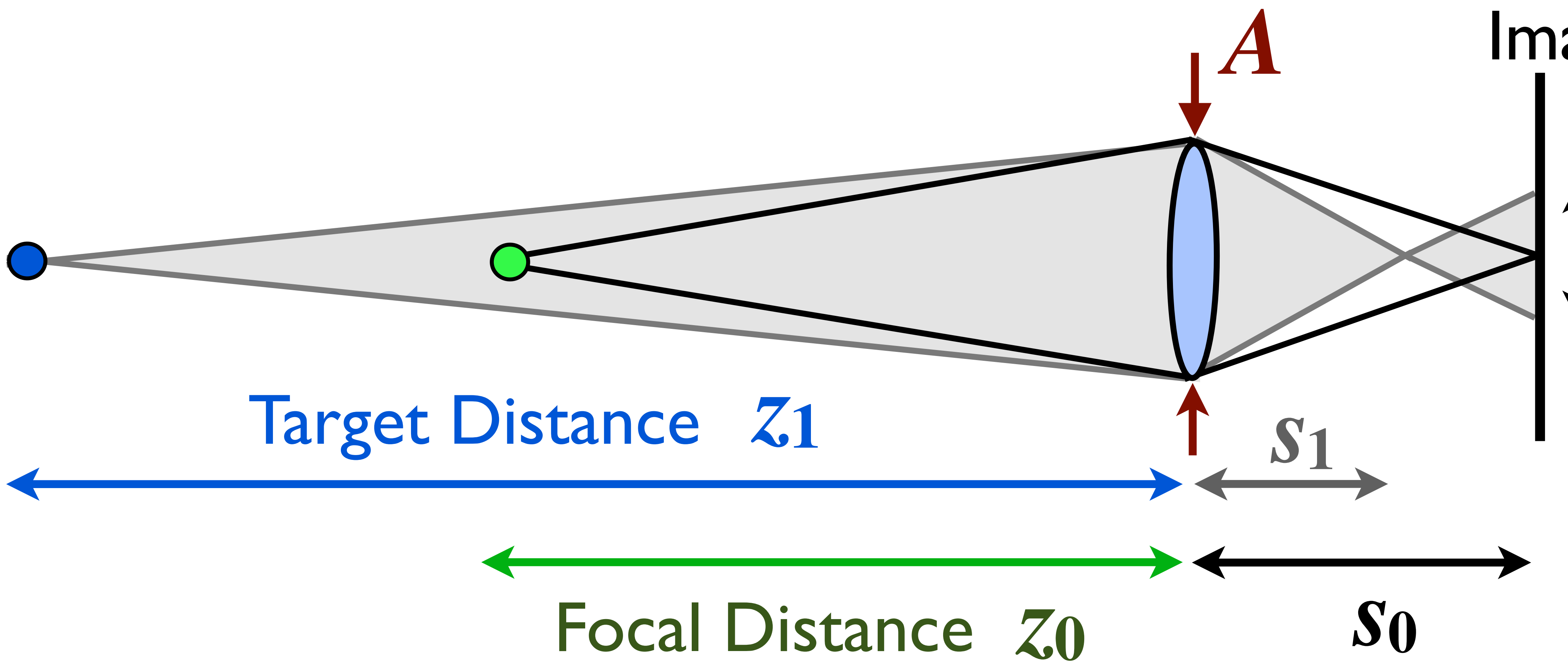
$$c = A\left(\frac{s_0}{z_0}\right)\left|1 - \frac{z_0}{z_1}\right|$$

Typical values for human eye:

A = Pupil size (~4.6mm)

s_0 = Eye length (~17mm)

Information from blur



$$c = A\left(\frac{s_0}{z_0}\right)\left|1 - \frac{z_0}{z_1}\right|$$

Typical values for human eye:

A = Pupil size (~4.6mm)

s_0 = Eye length (~17mm)

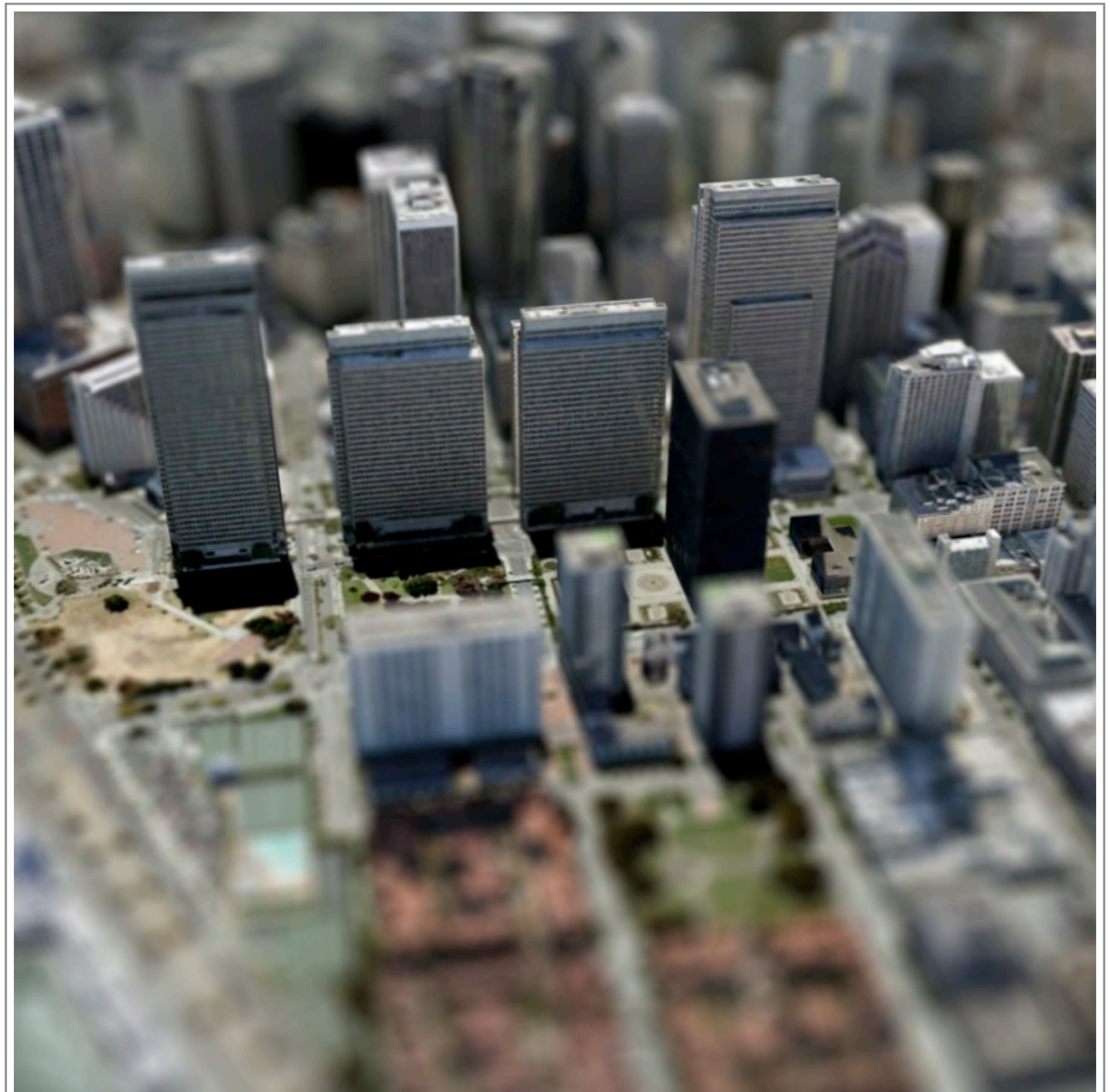
Important terms:

Blur magnitude: c

Focal (absolute) distance: z_0

Relative distance: z_1/z_0

Information from blur

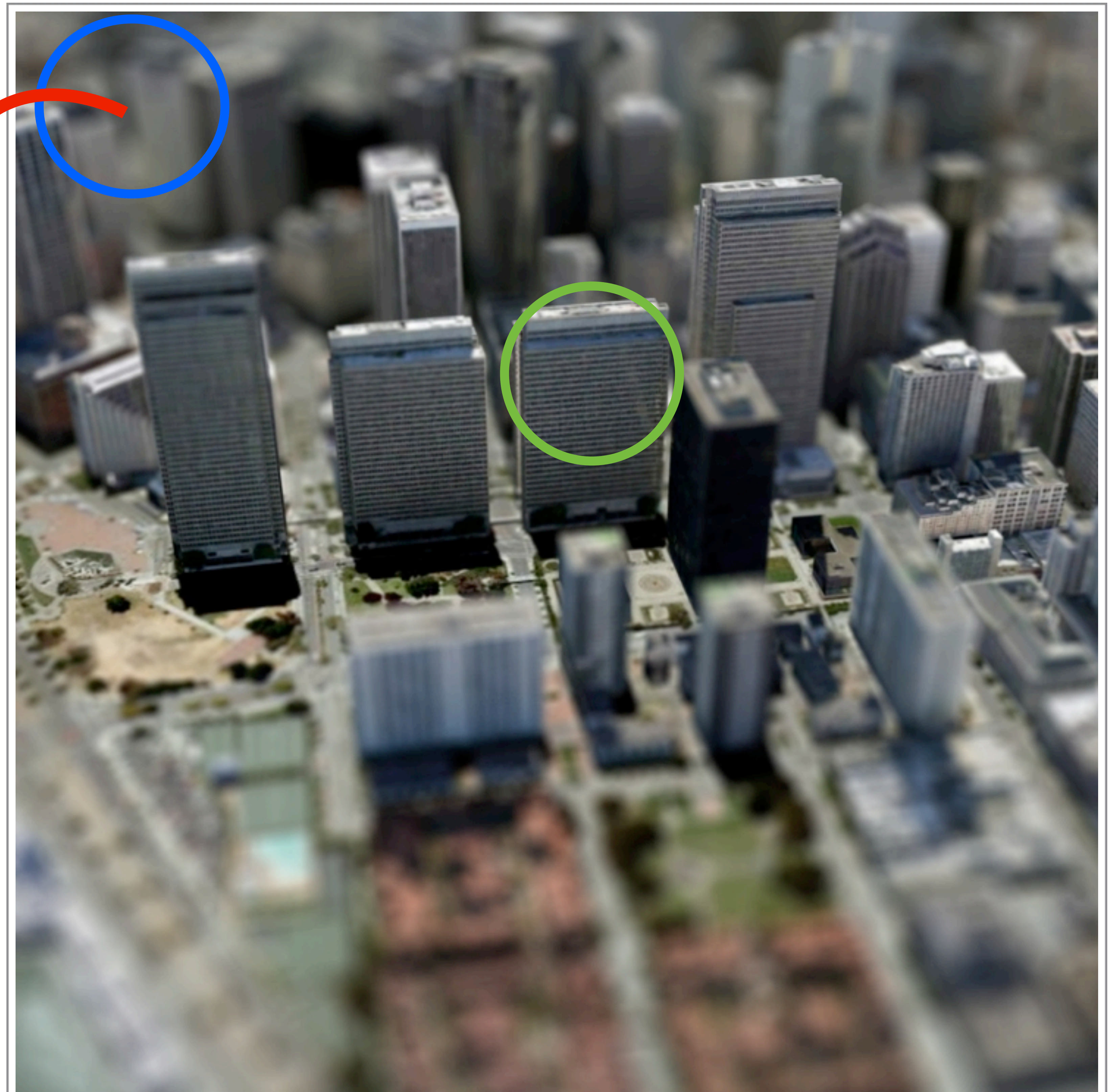


Information from blur

c

$$c = A\left(\frac{s_0}{z_0}\right)\left|1 - \frac{z_0}{z_1}\right|$$

Information from blur



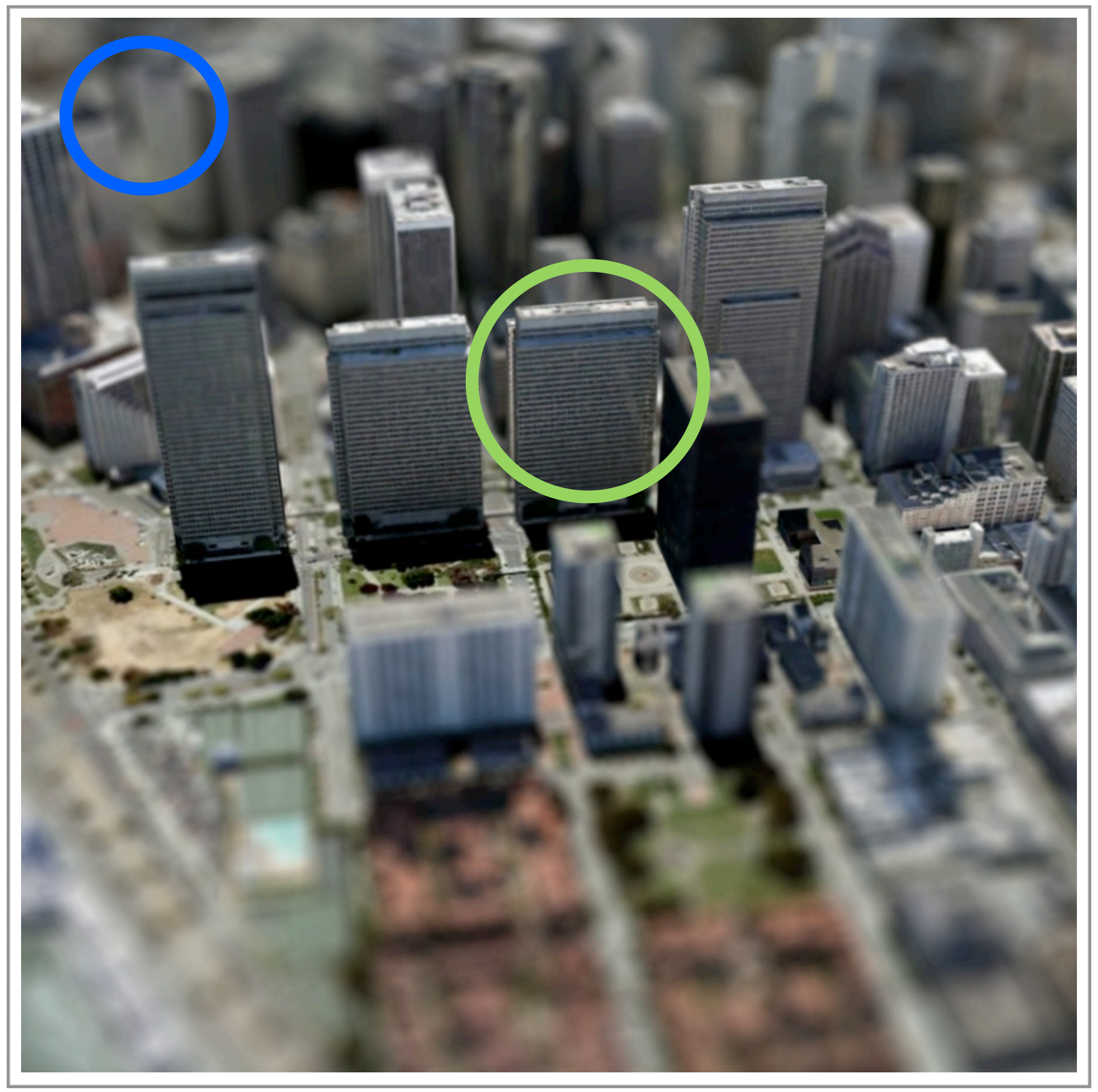
c

$$c = A\left(\frac{s_0}{z_0}\right)\left|1 - \frac{z_0}{z_1}\right|$$

$$z_0 = A\left(\frac{s_0}{c}\right)\left|1 - \frac{z_0}{z_1}\right|$$

Information from blur

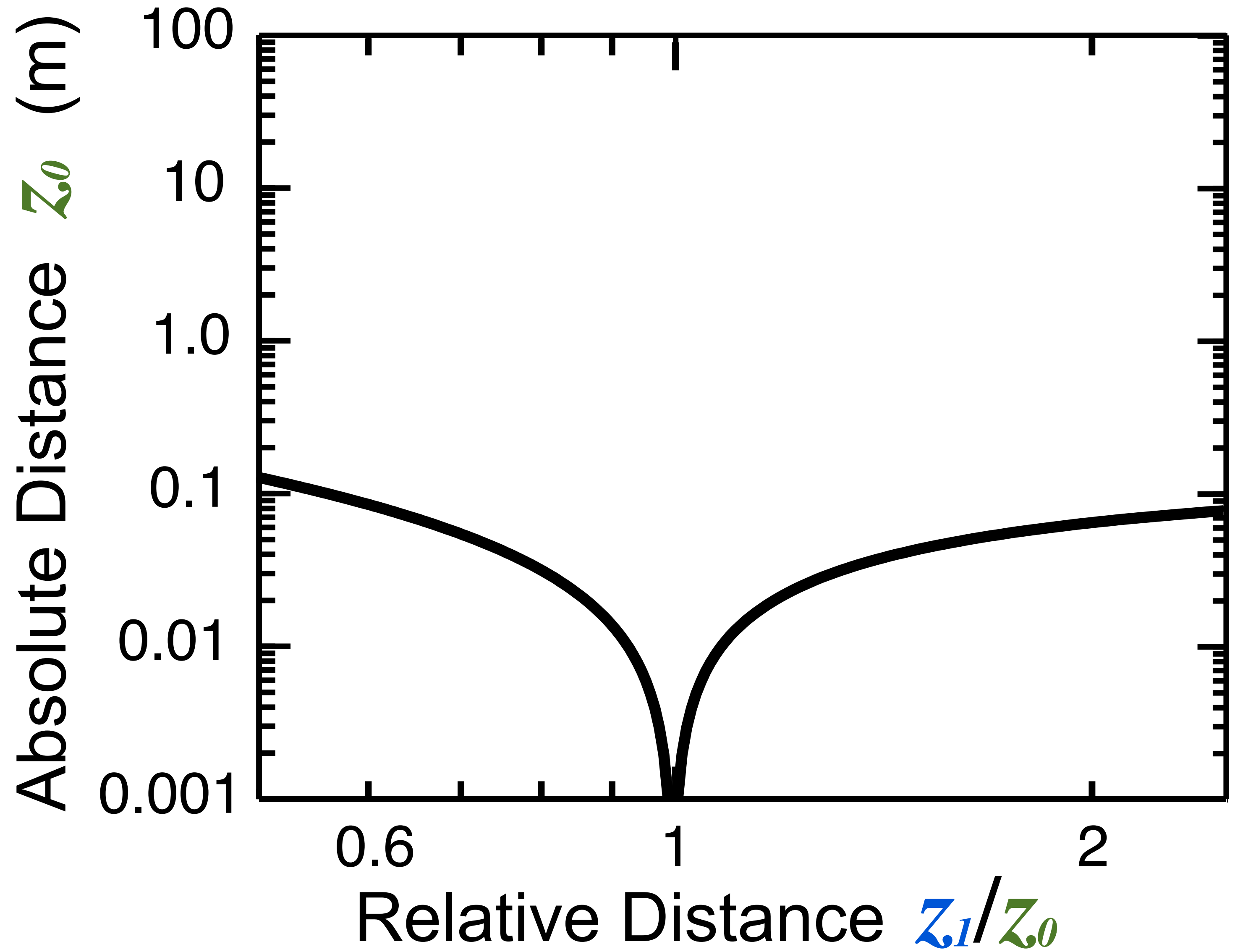
- Blur alone cannot reveal absolute distance



4.6mm 17mm

$$z_0 = A\left(\frac{s_0}{c}\right)\left|1-\frac{z_0}{z_1}\right|$$

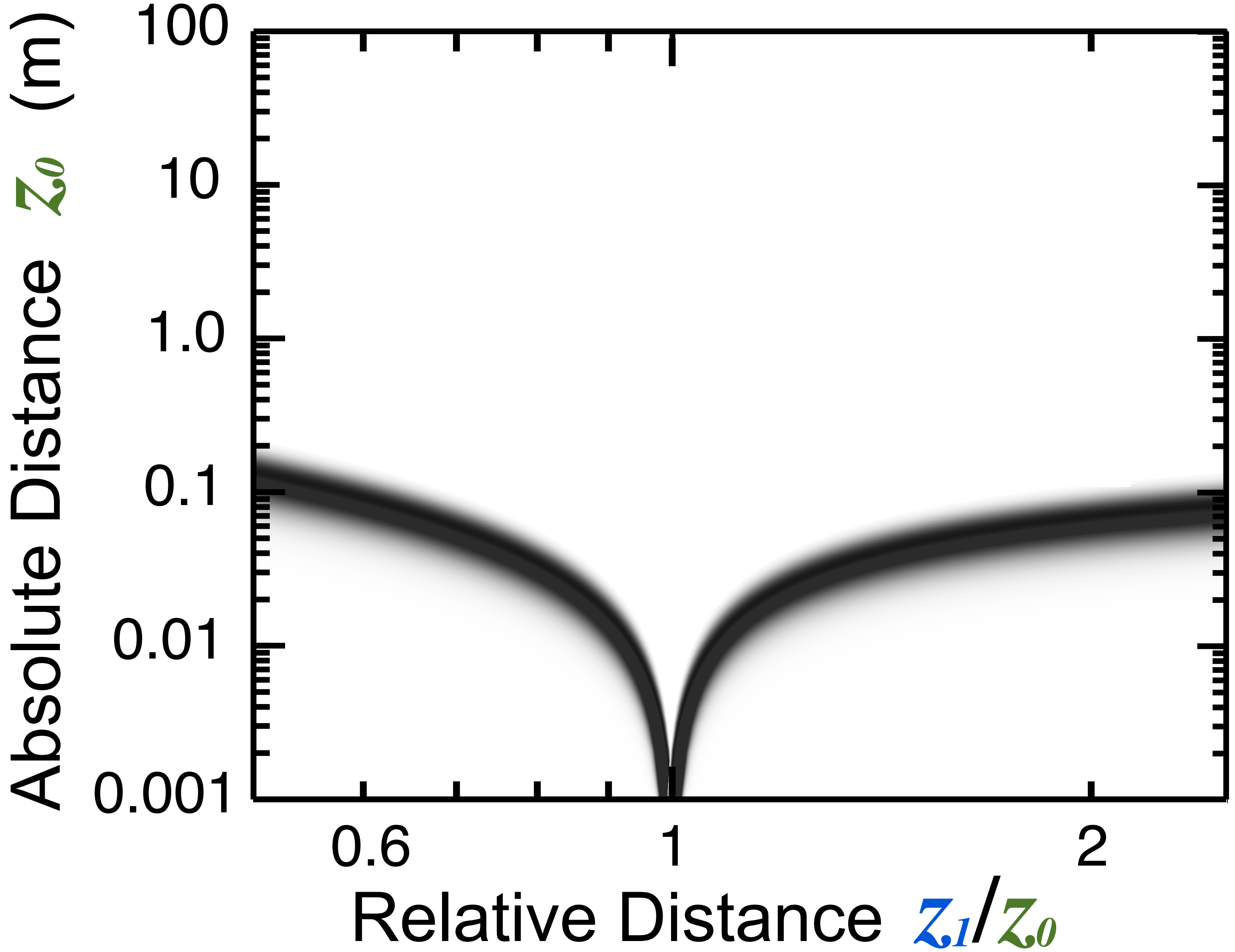
0.60mm



Information from blur

- Blur alone cannot reveal absolute distance

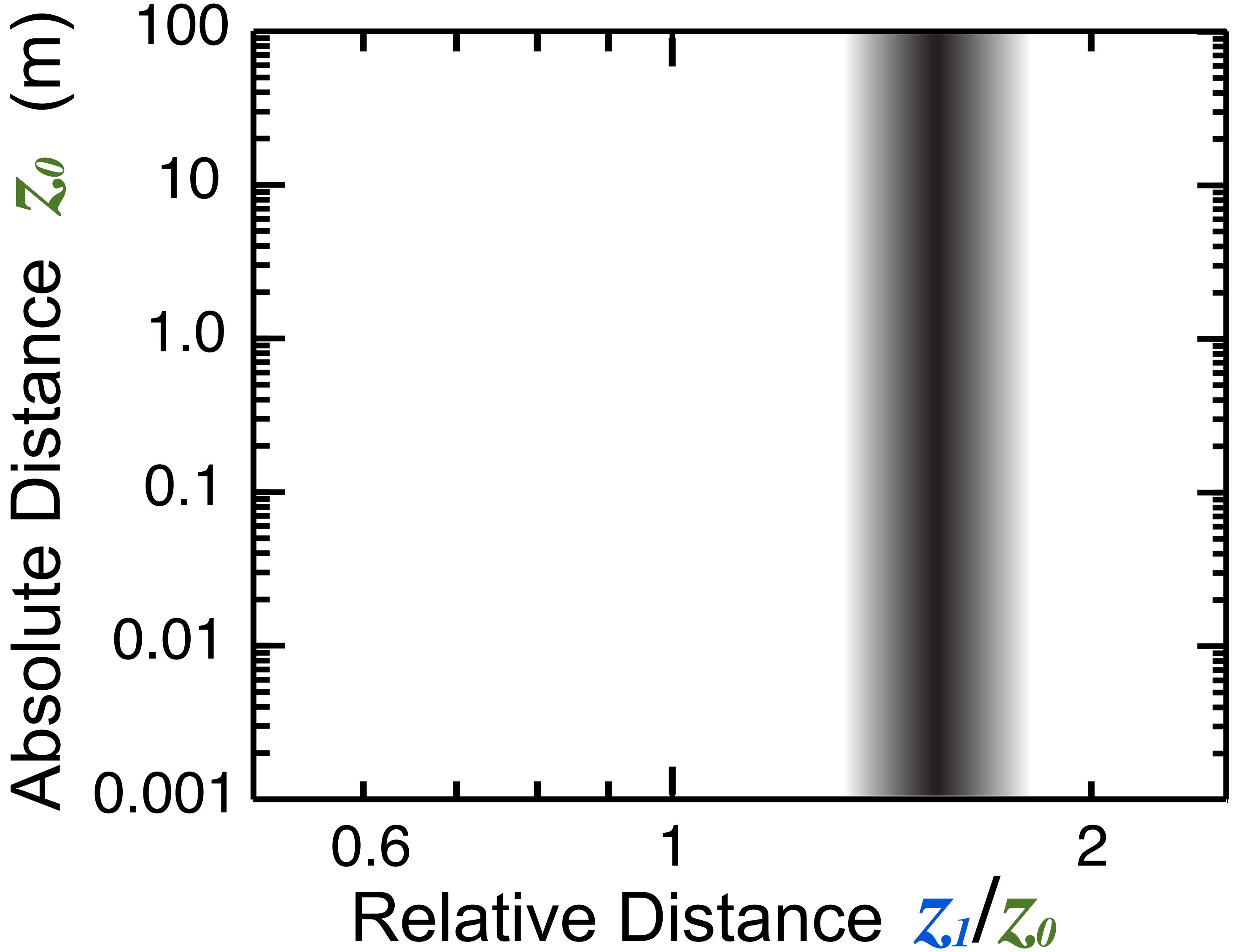
$$z_0 = \underbrace{A}_{4.6 \pm 1.0\text{mm}} \left(\frac{\overbrace{s_0}^{17\text{mm}}}{\underbrace{c}_{0.60\text{mm}}} \right) \left| 1 - \frac{z_0}{z_1} \right|$$



Other information

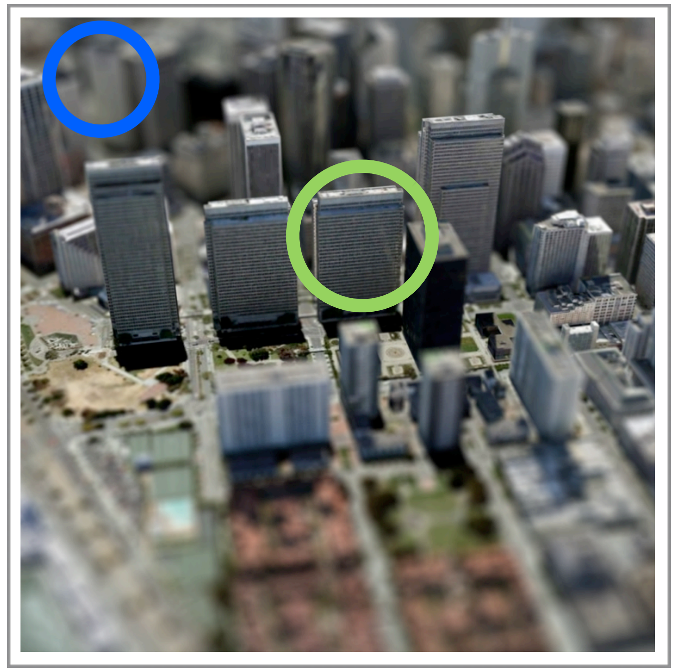
- Perspective information can reveal z_1/z_0

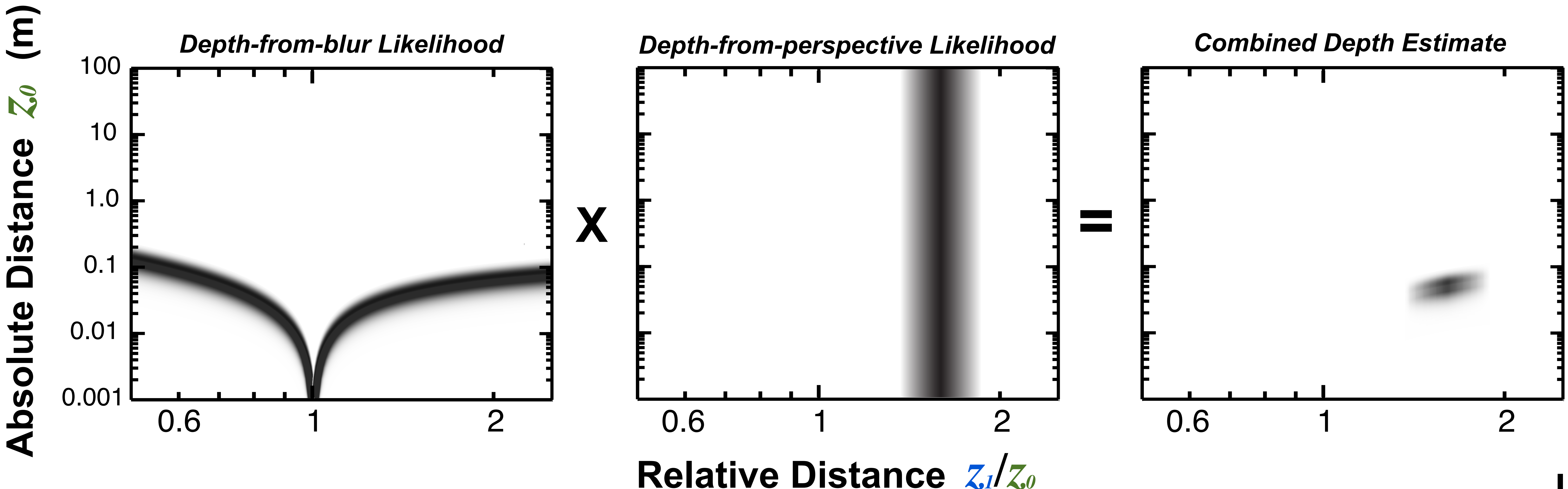
$$z_0 = A\left(\frac{s_0}{c}\right)\left|1 - \frac{z_0}{z_1}\right|$$



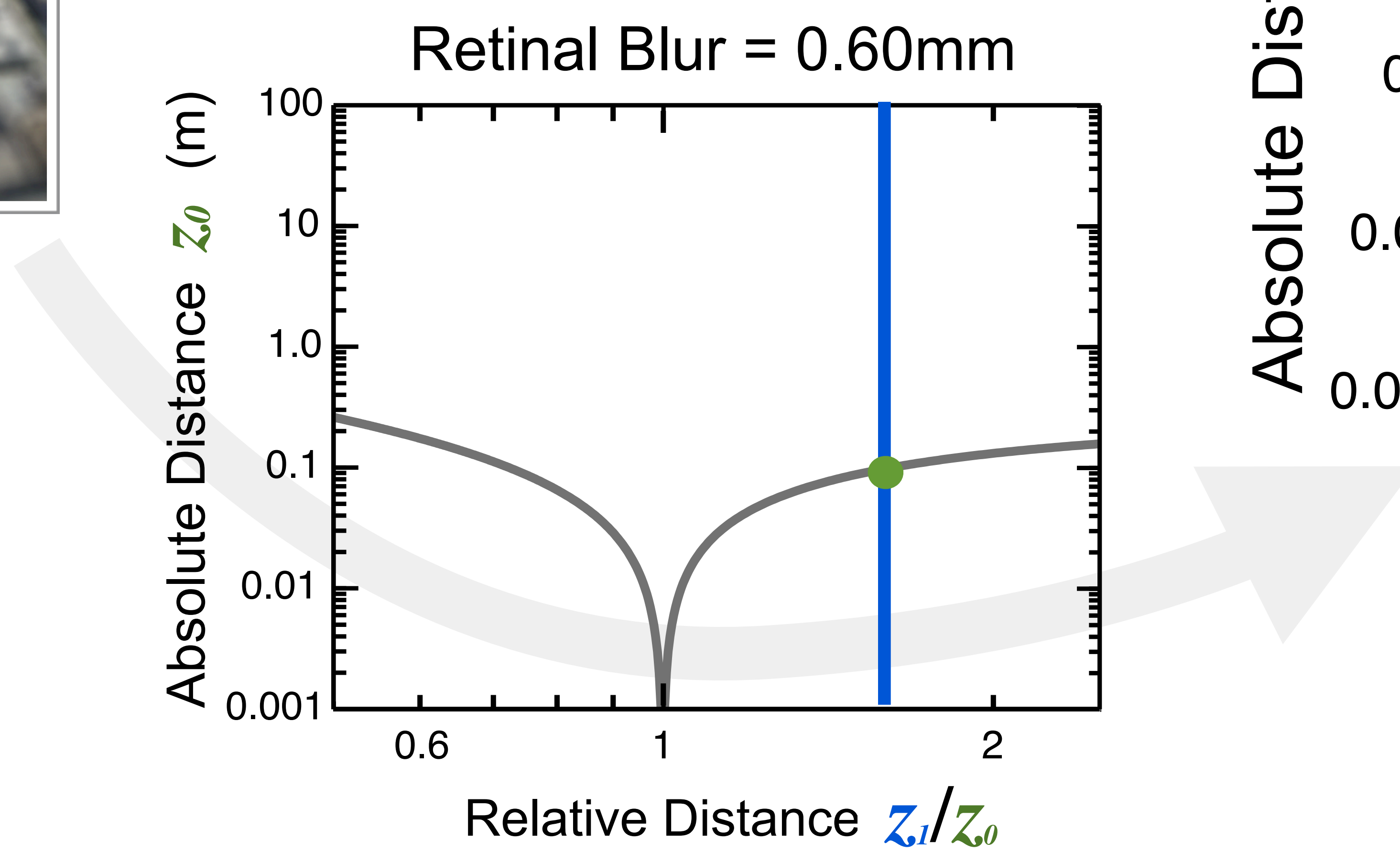
Model

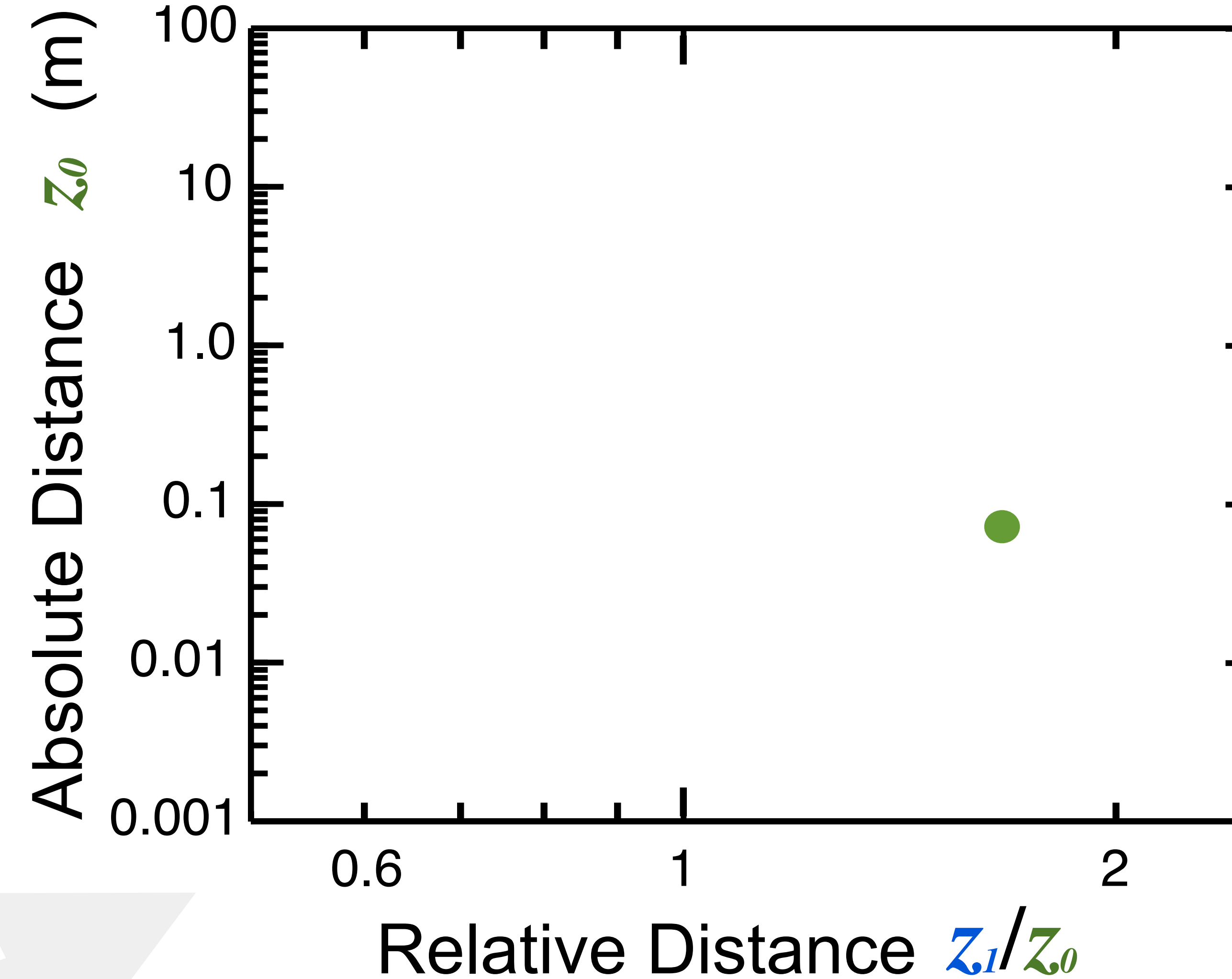
- Combined with relative depth information, blur can act as a cue to absolute distance
- Bayesian approach:



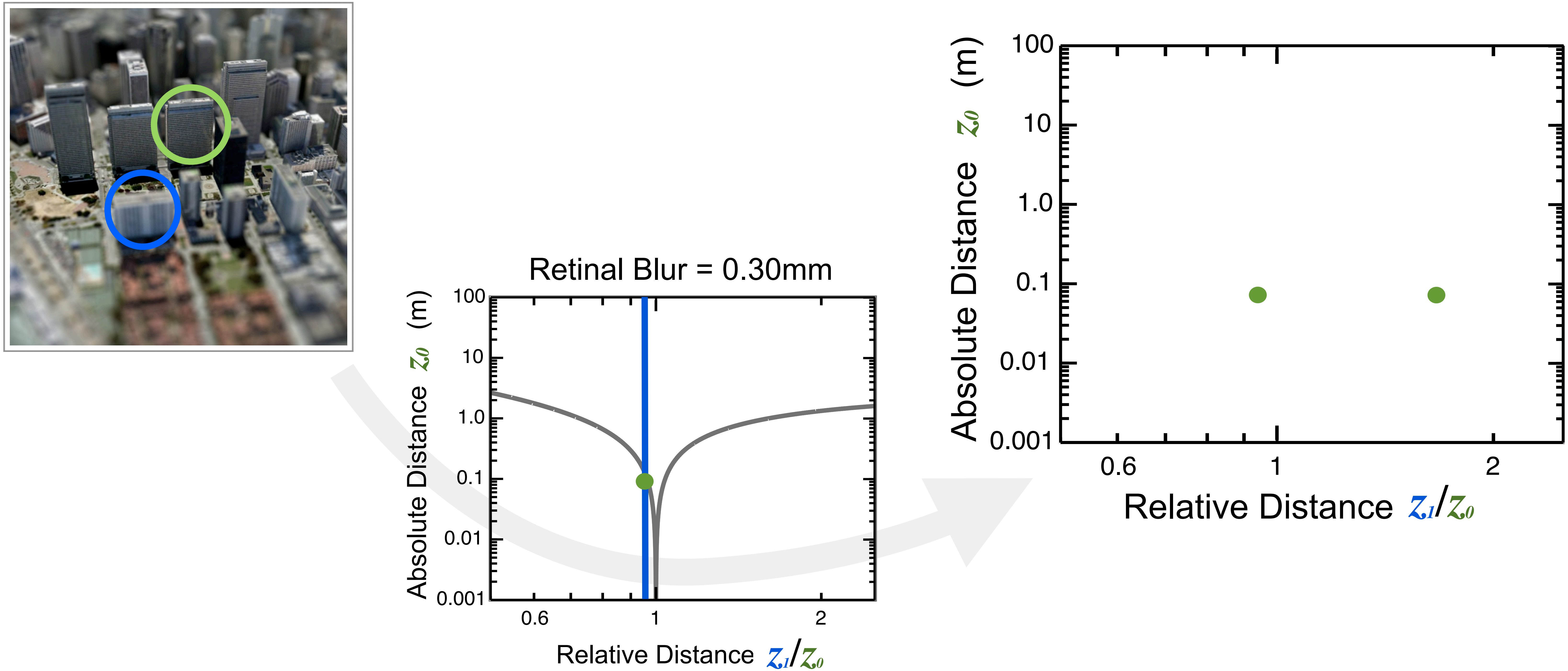


Recovering absolute distance

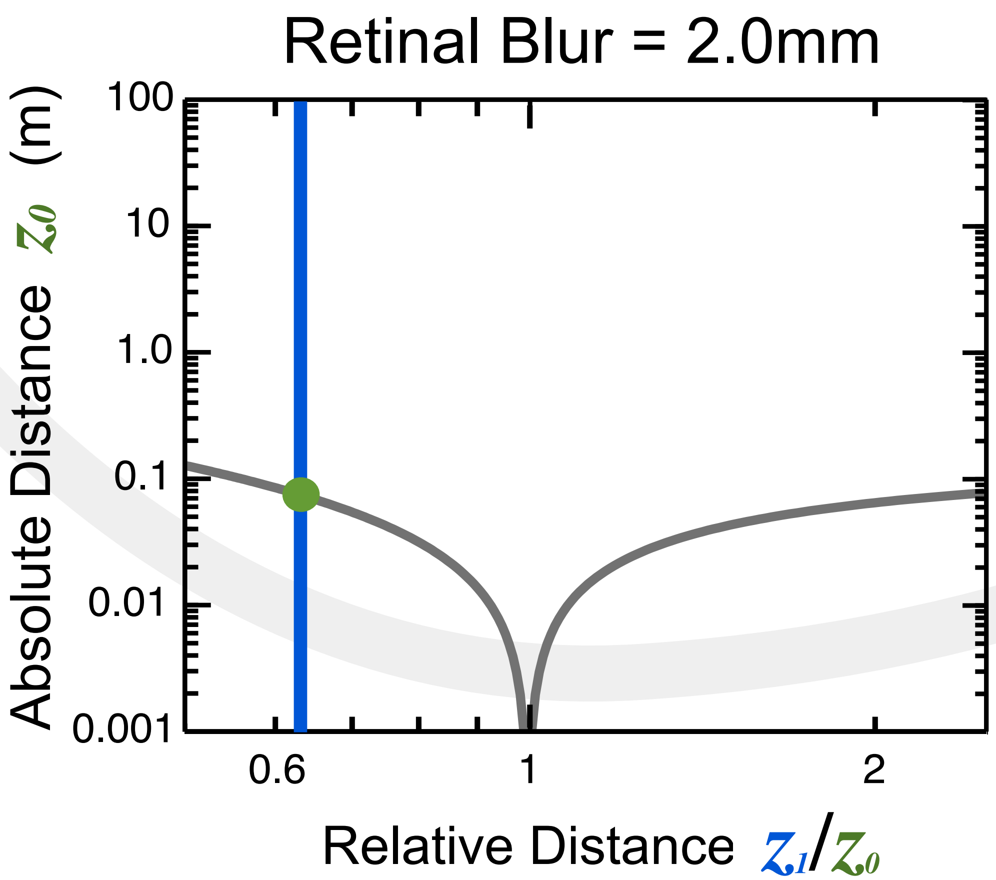


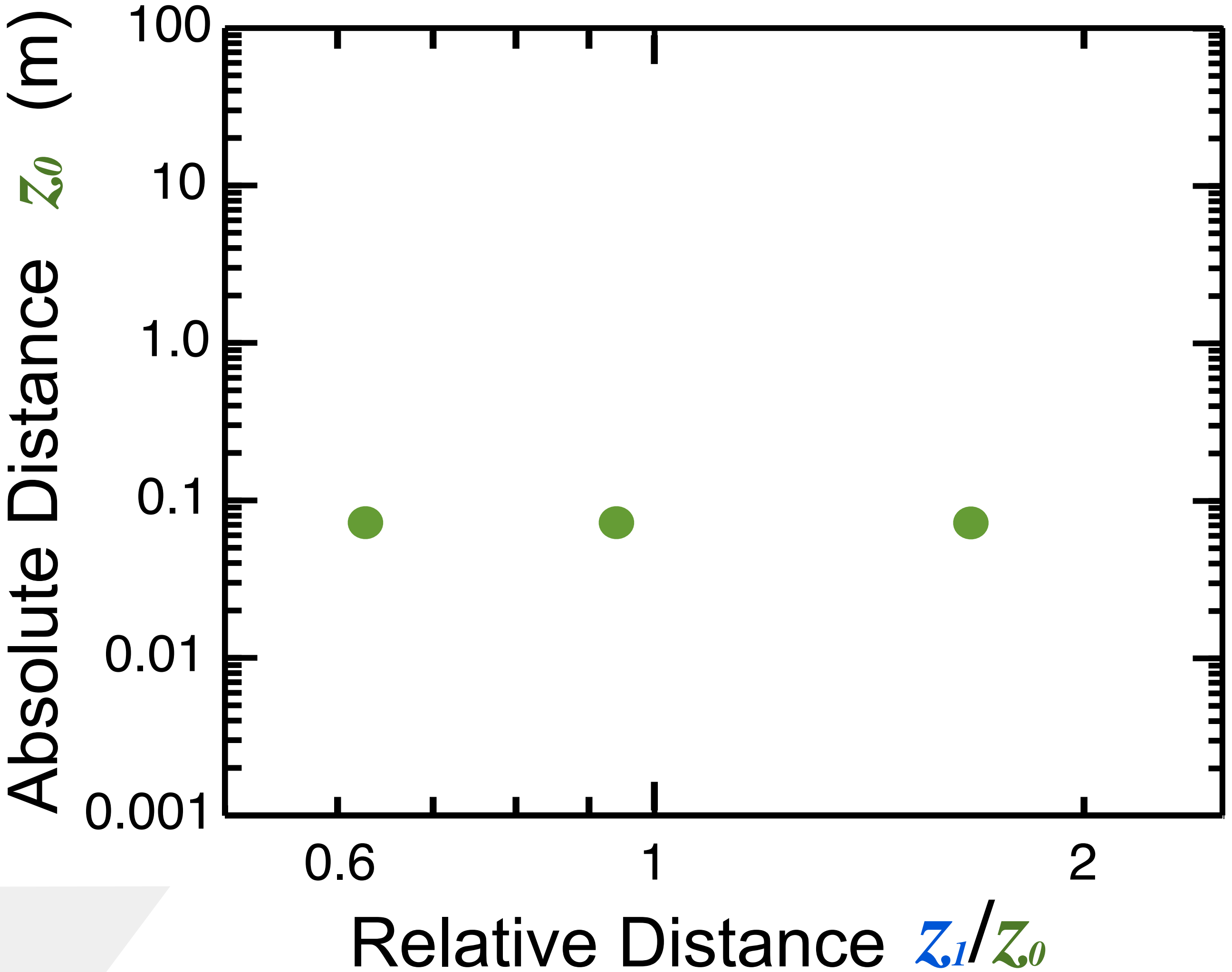


Recovering absolute distance

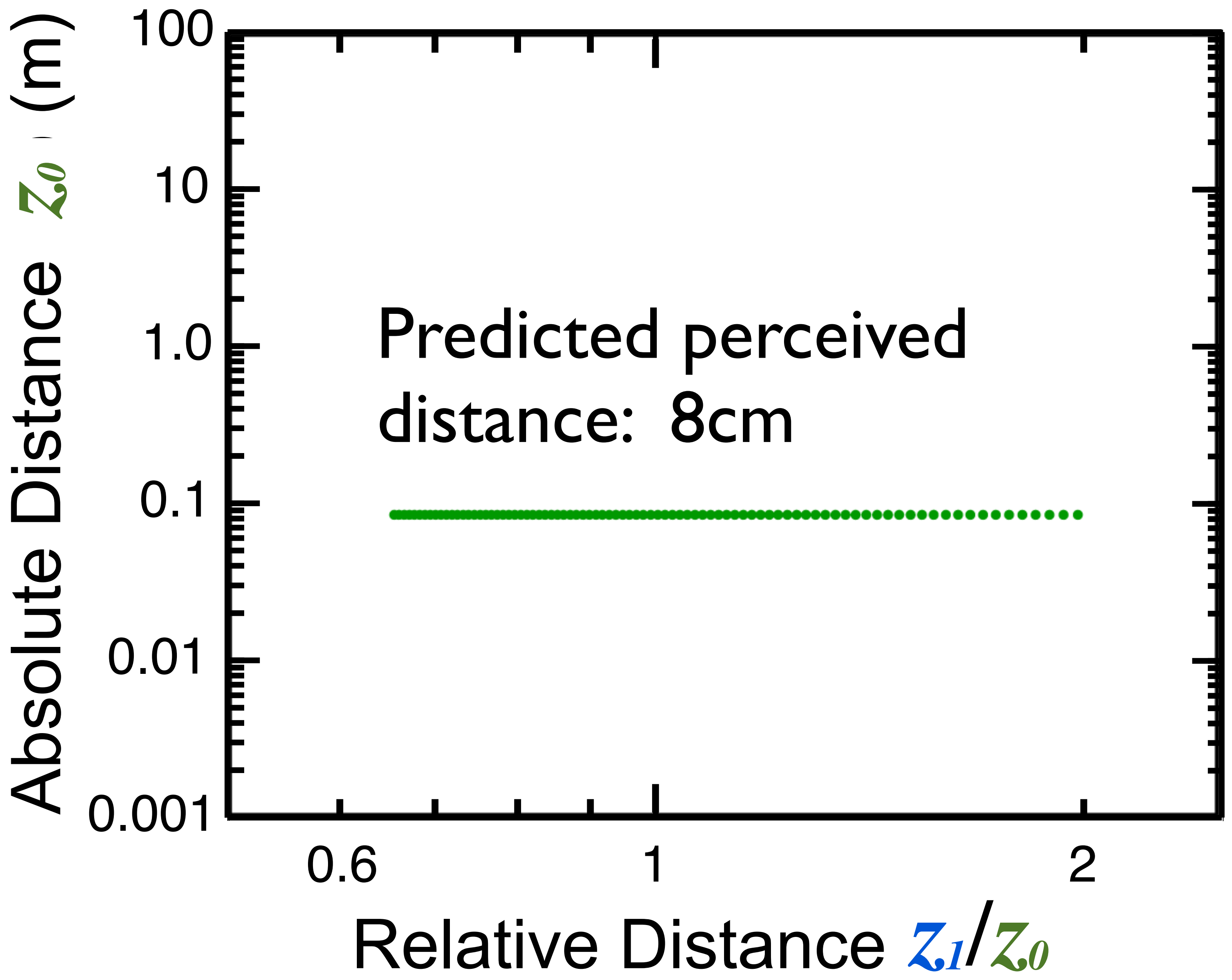


Recovering absolute distance

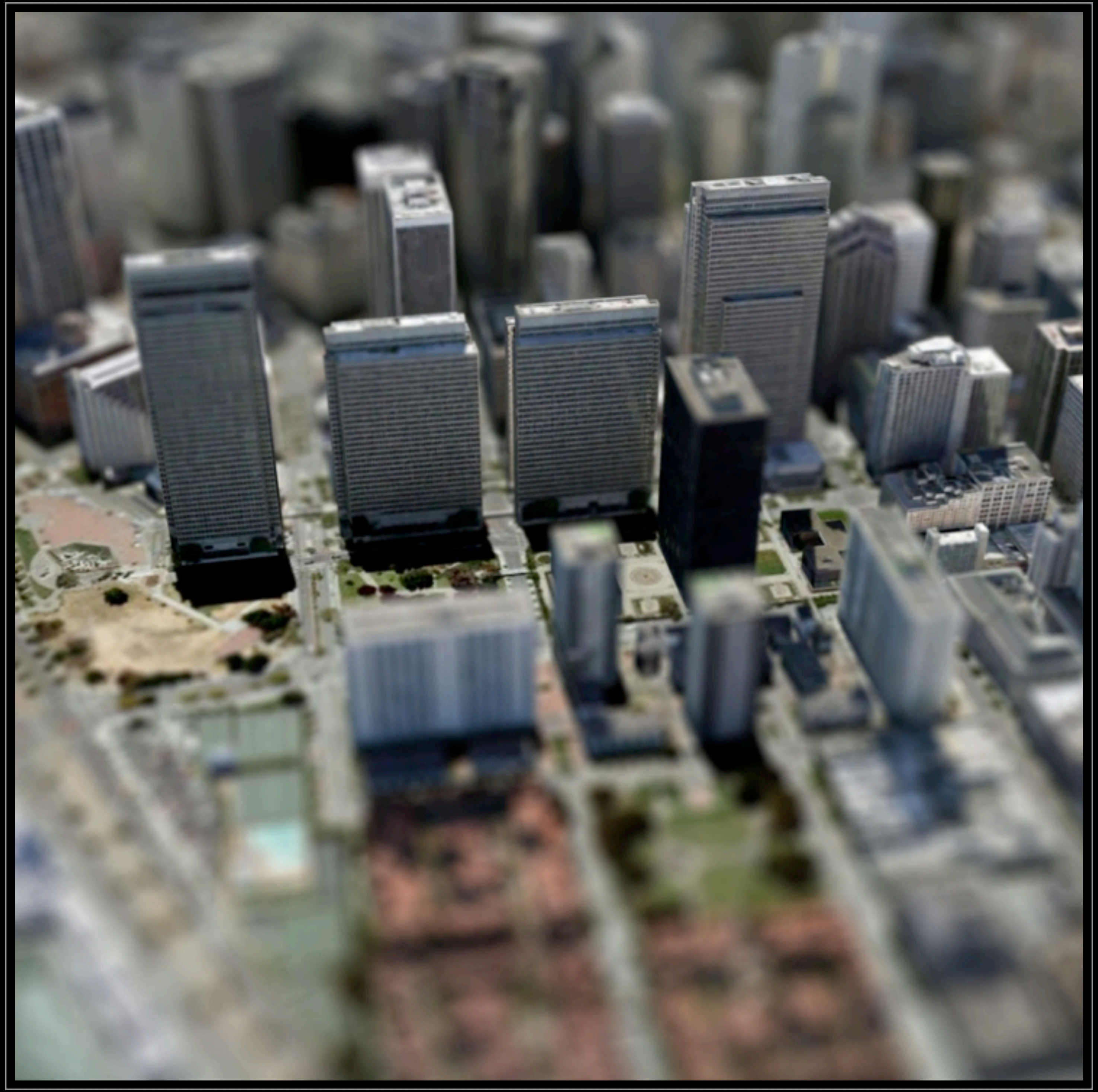




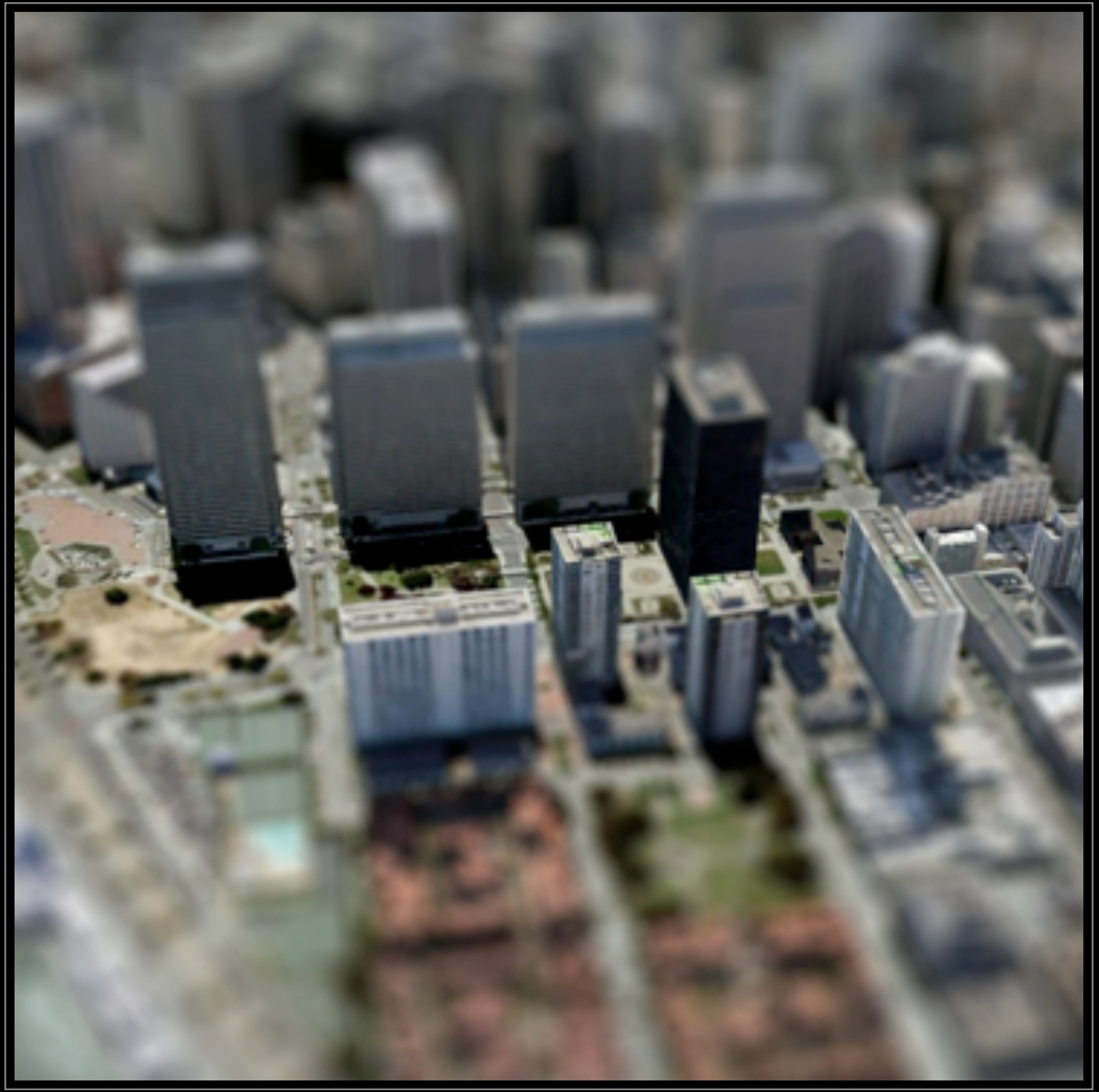
Recovering absolute distance



Approximating blur

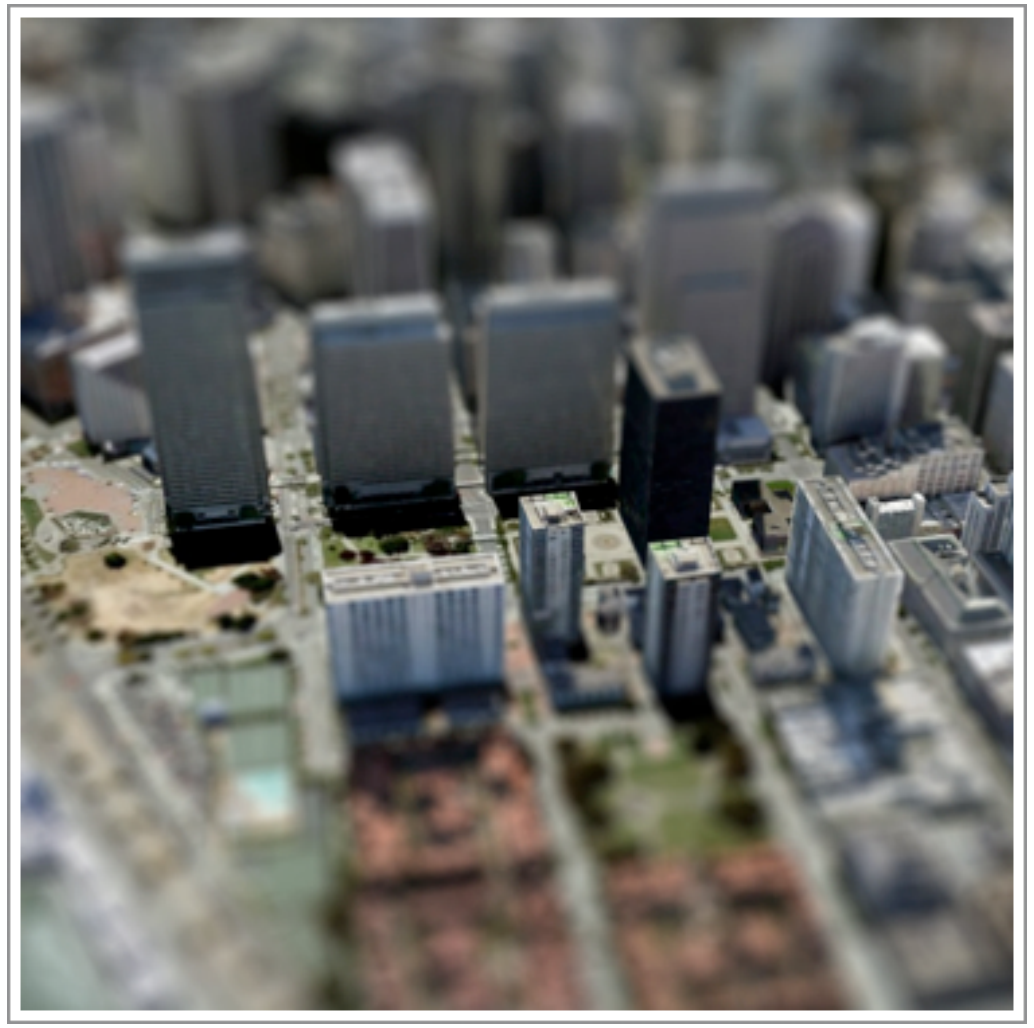


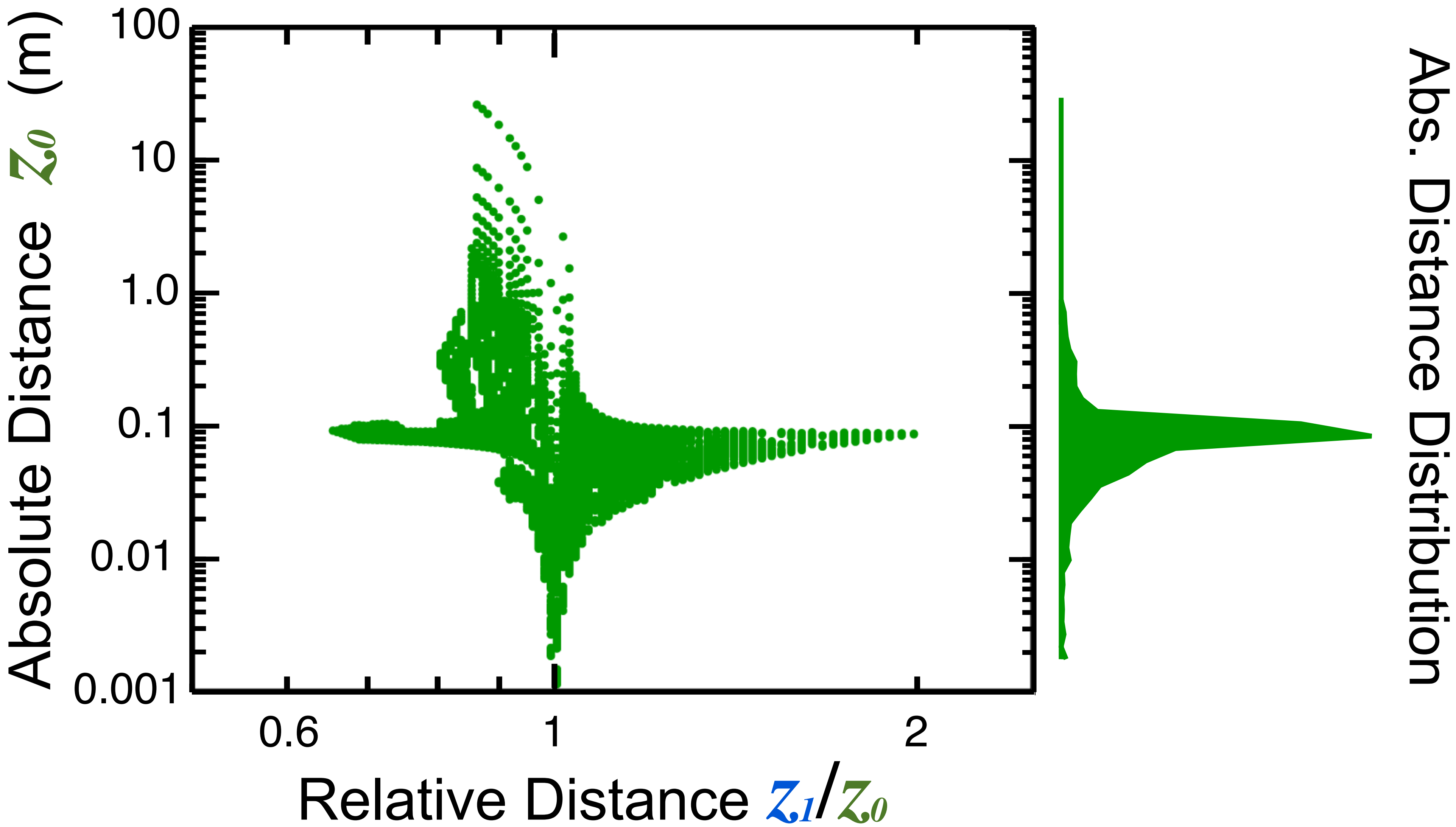
Consistent blur



Aligned blur gradient

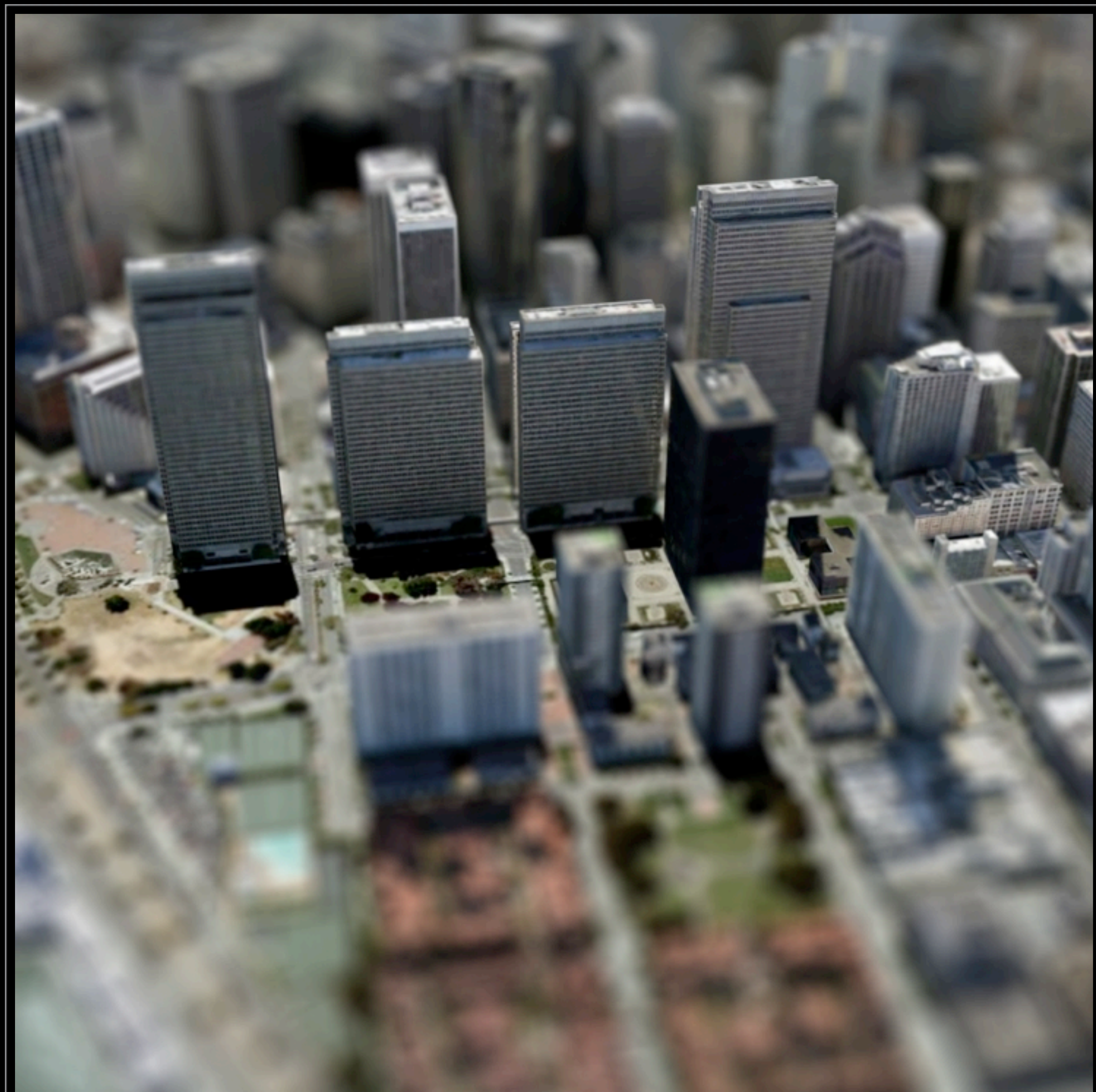
Aligned blur gradient



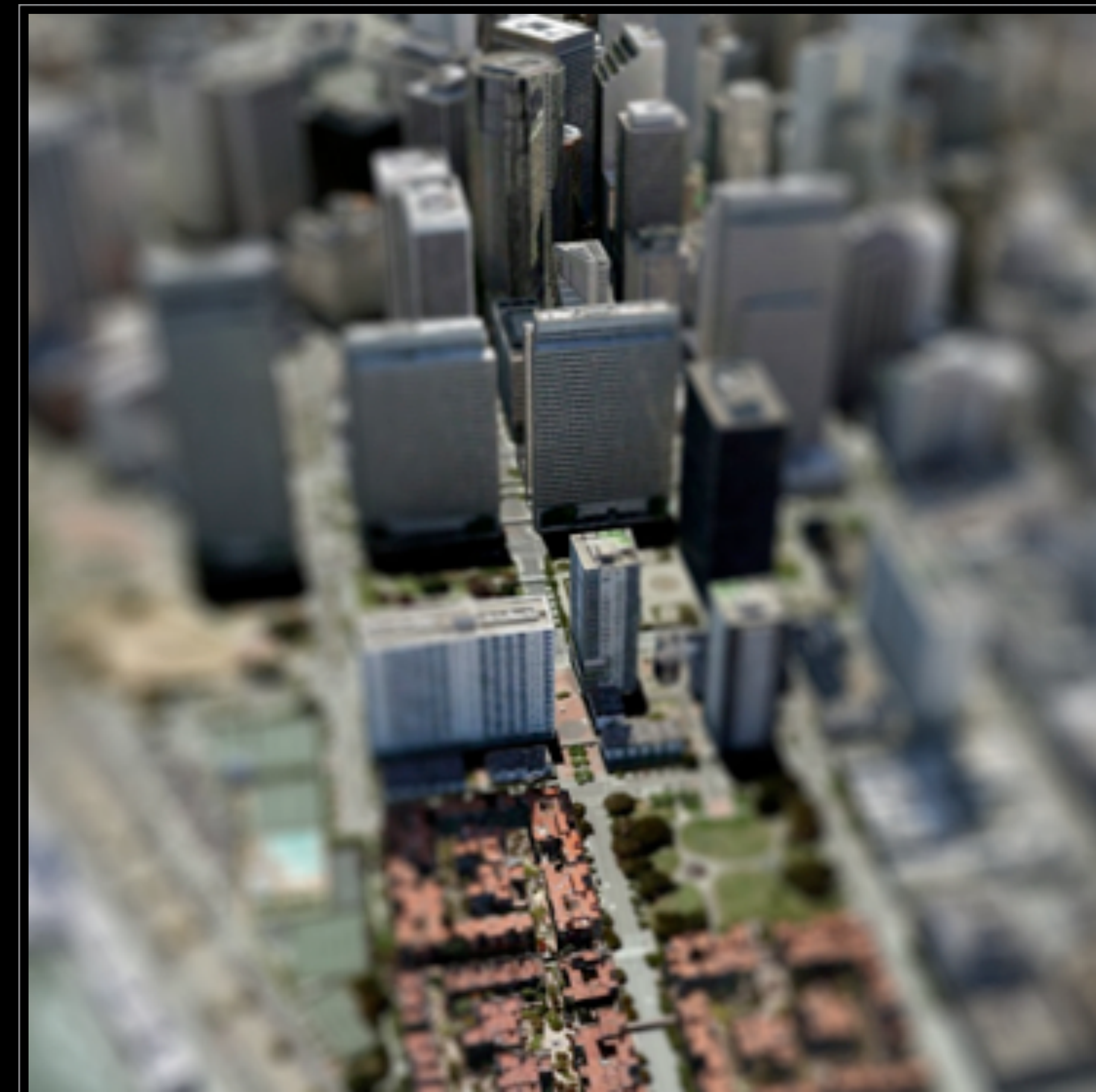


- Predicted perceived distance: ~8cm
  - Expect weaker influence of blur due to variance

Approximating blur (very badly)

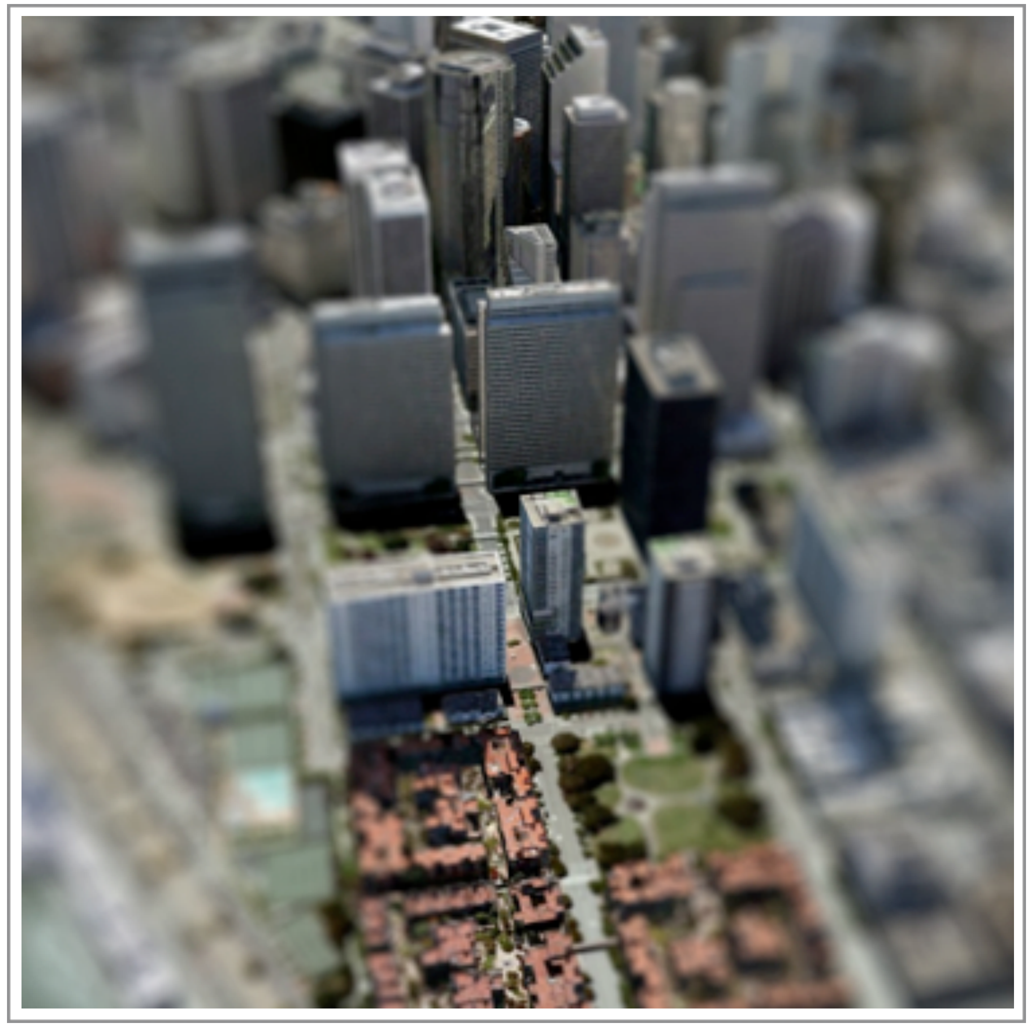


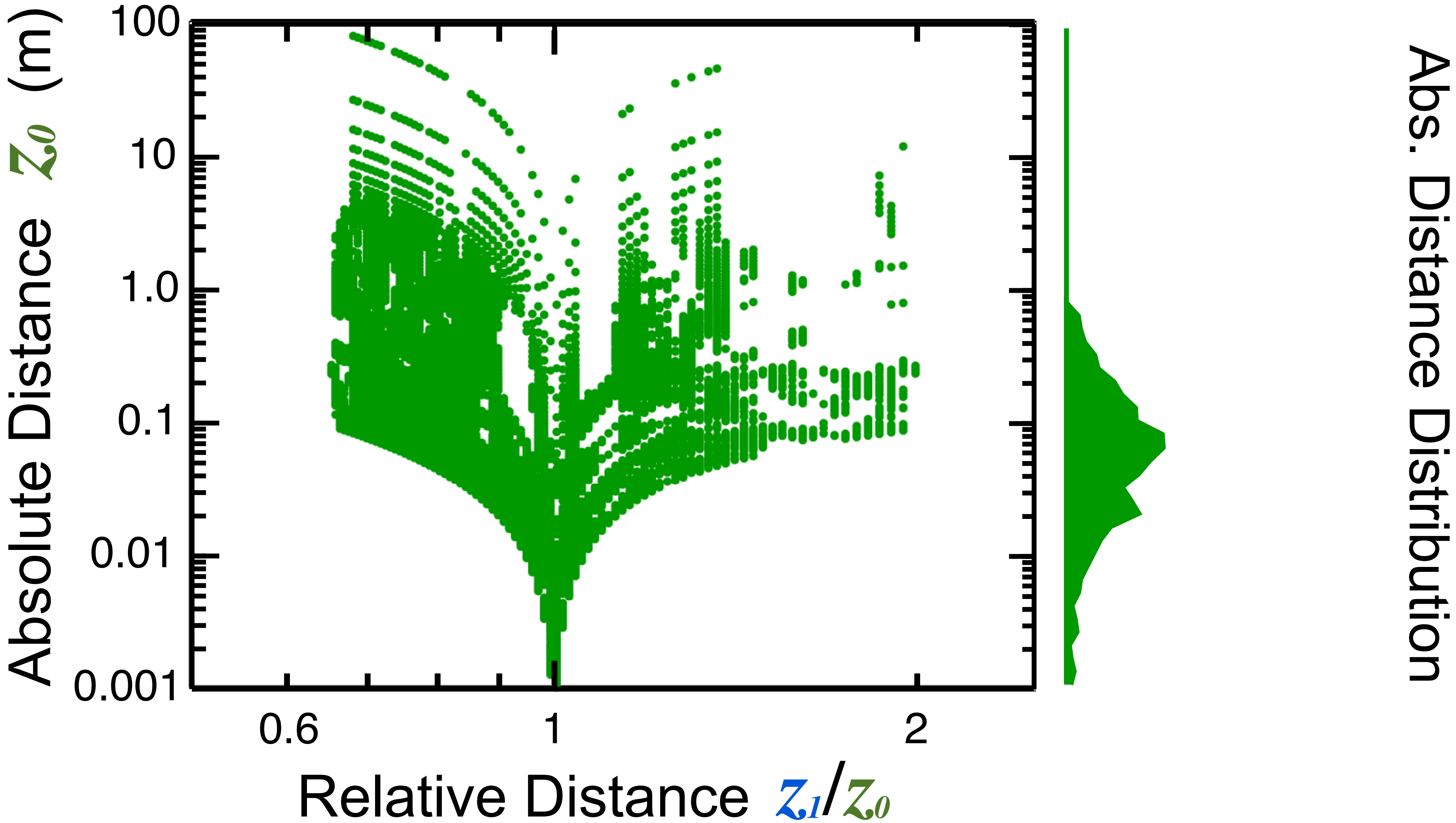
Consistent blur



Unaligned blur gradient

Unaligned blur gradient

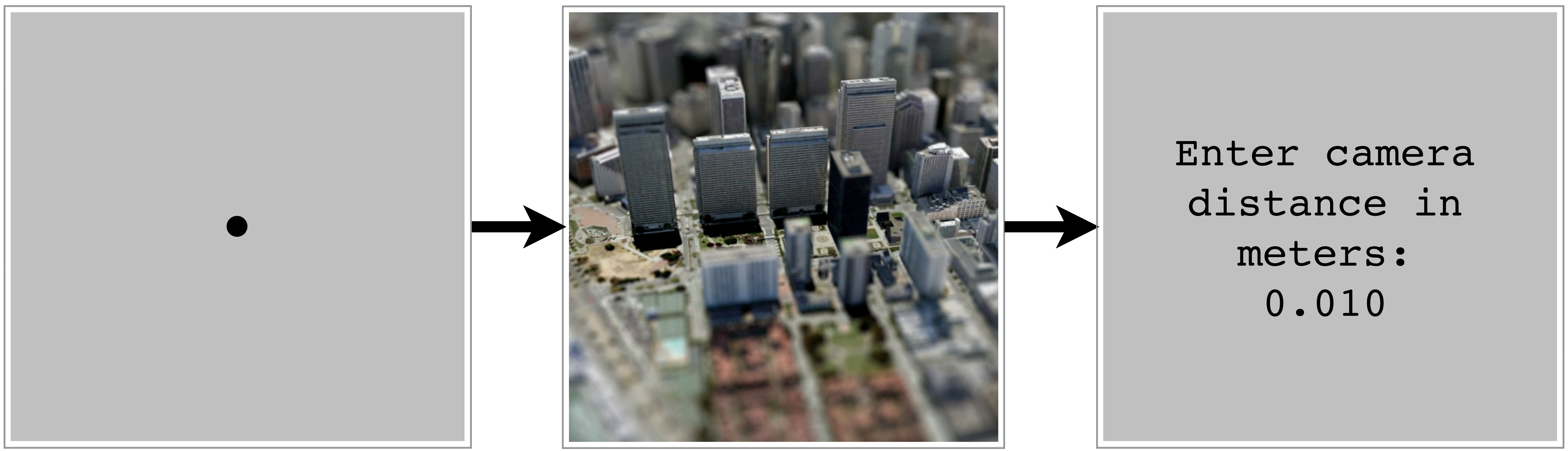




- Predicted perceived distance: ambiguous
  - Expect weakest miniaturization effect, if any

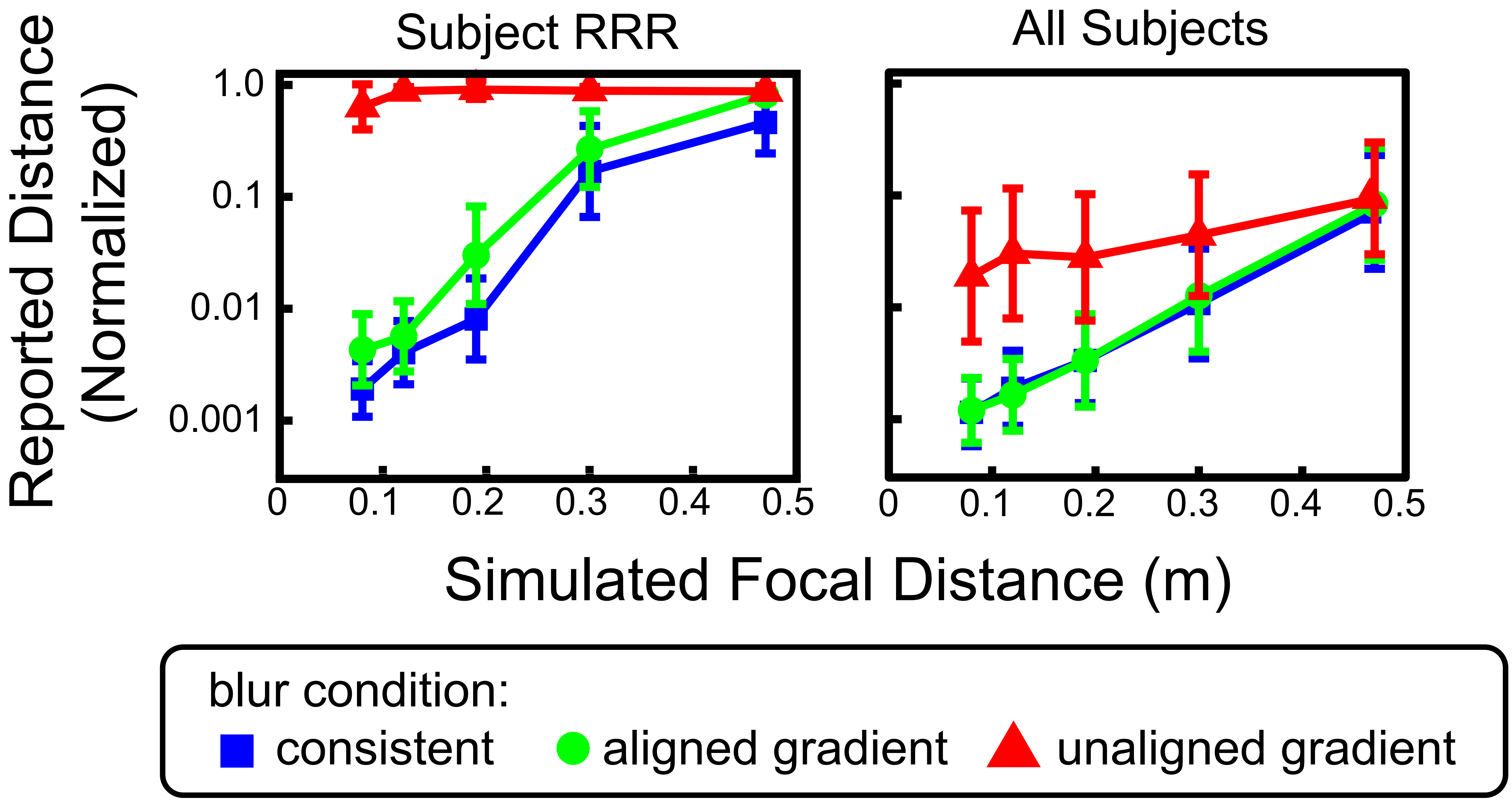
Experiment

- 7 sample scenes from GoogleEarth
- Each scene rendered sharply and with consistent, aligned gradient, and unaligned gradient blur
- 5 blur magnitudes

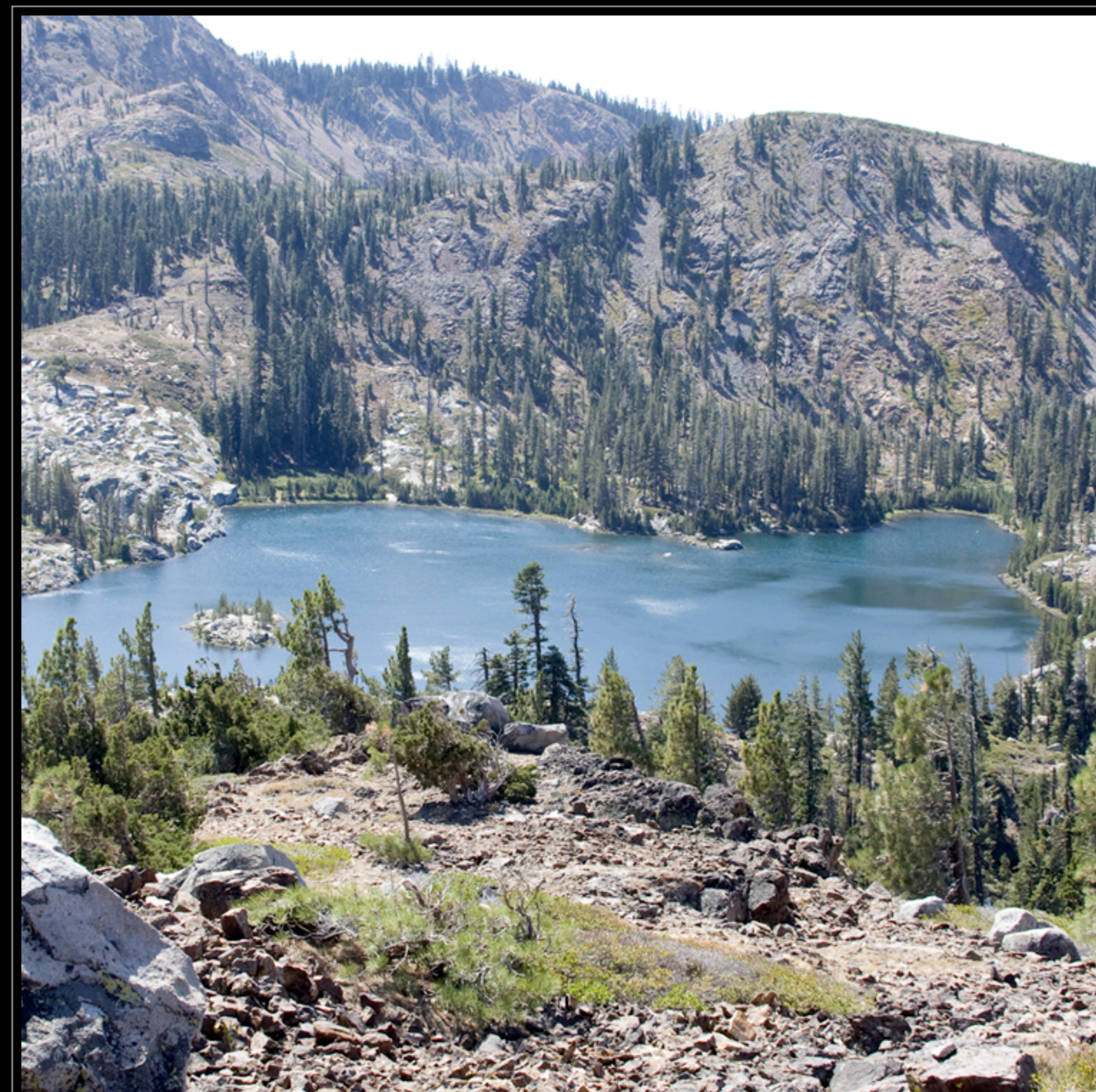


Fixation point (0.5s) Stimulus (3s) Response

Results

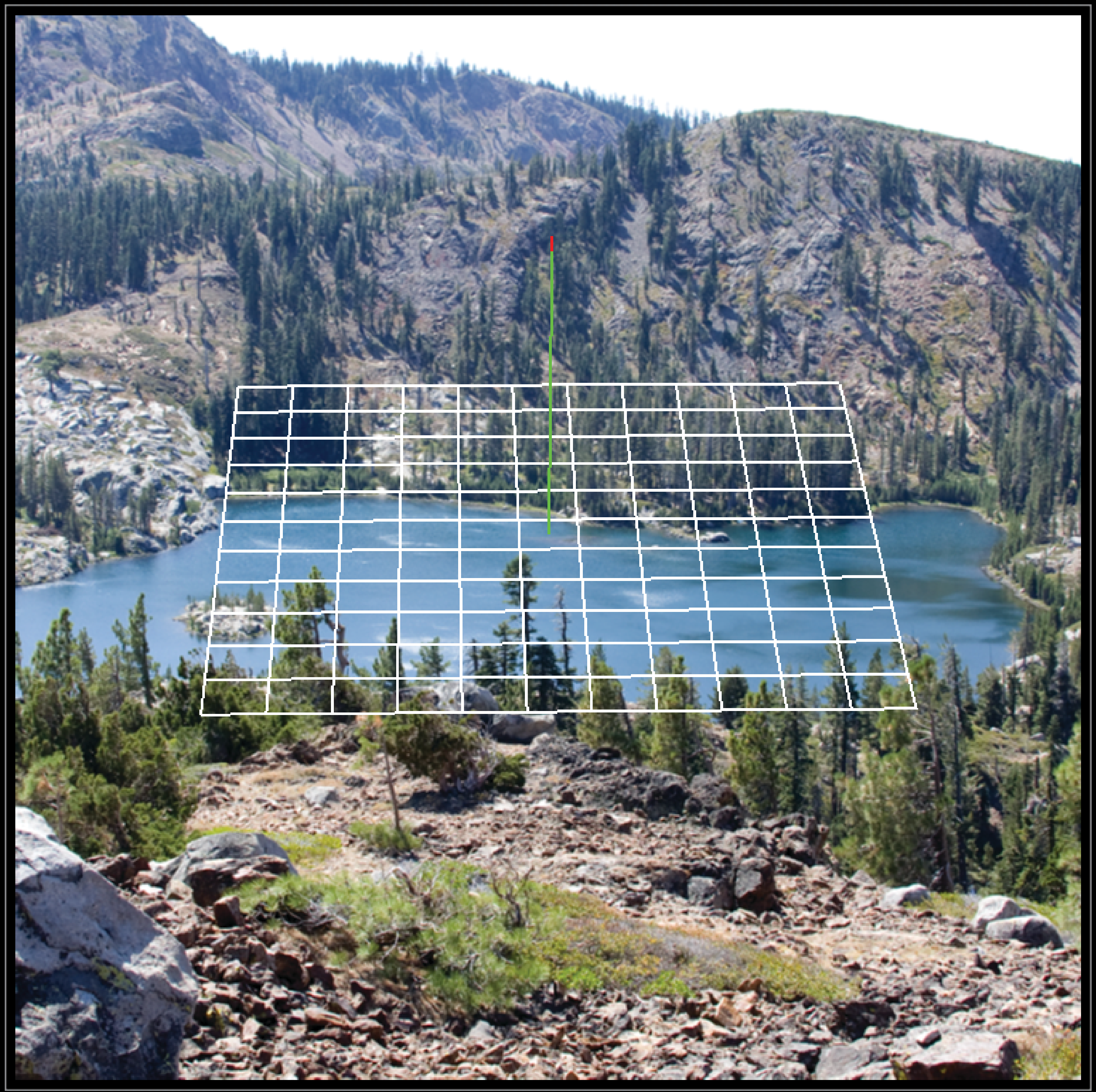

Subject RRR
All Subjects
Reported Distance (Normalized)
1.0
0.1
0.01
0.001
0
0.1
0.2
0.3
0.4
0.5
Simulated Focal Distance (m)
blur condition:
consistent
aligned gradient
unaligned gradient

Semi-automated Algorithm

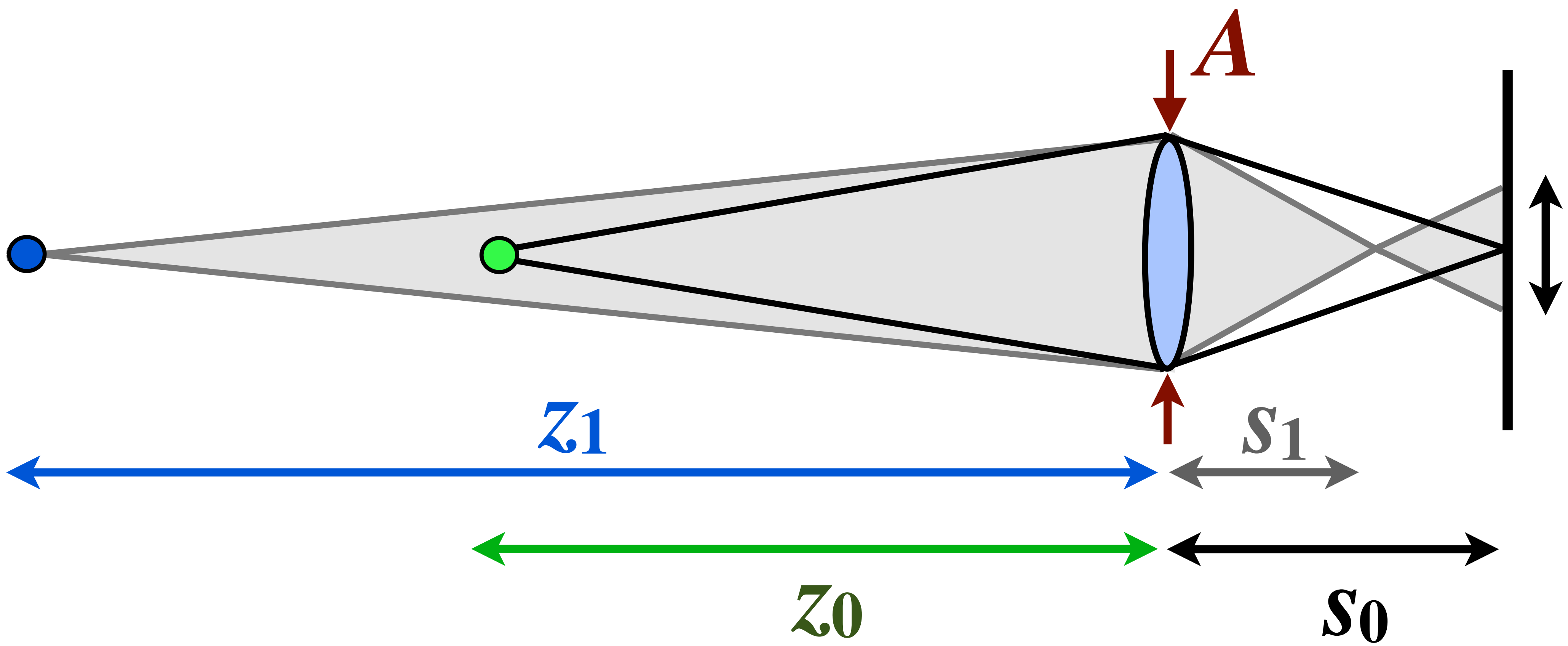


Semi-automated Algorithm

Semi-automated Algorithm

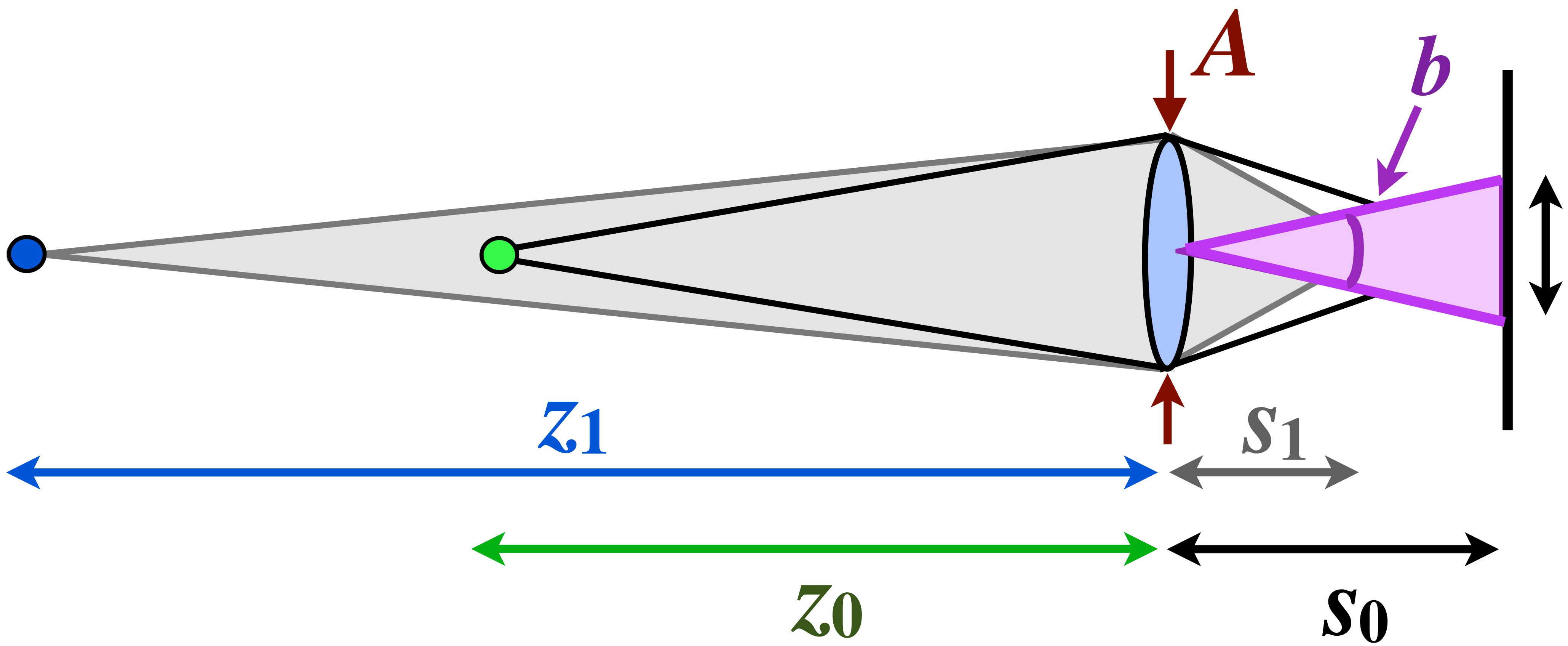


Choosing A for desired depth of field



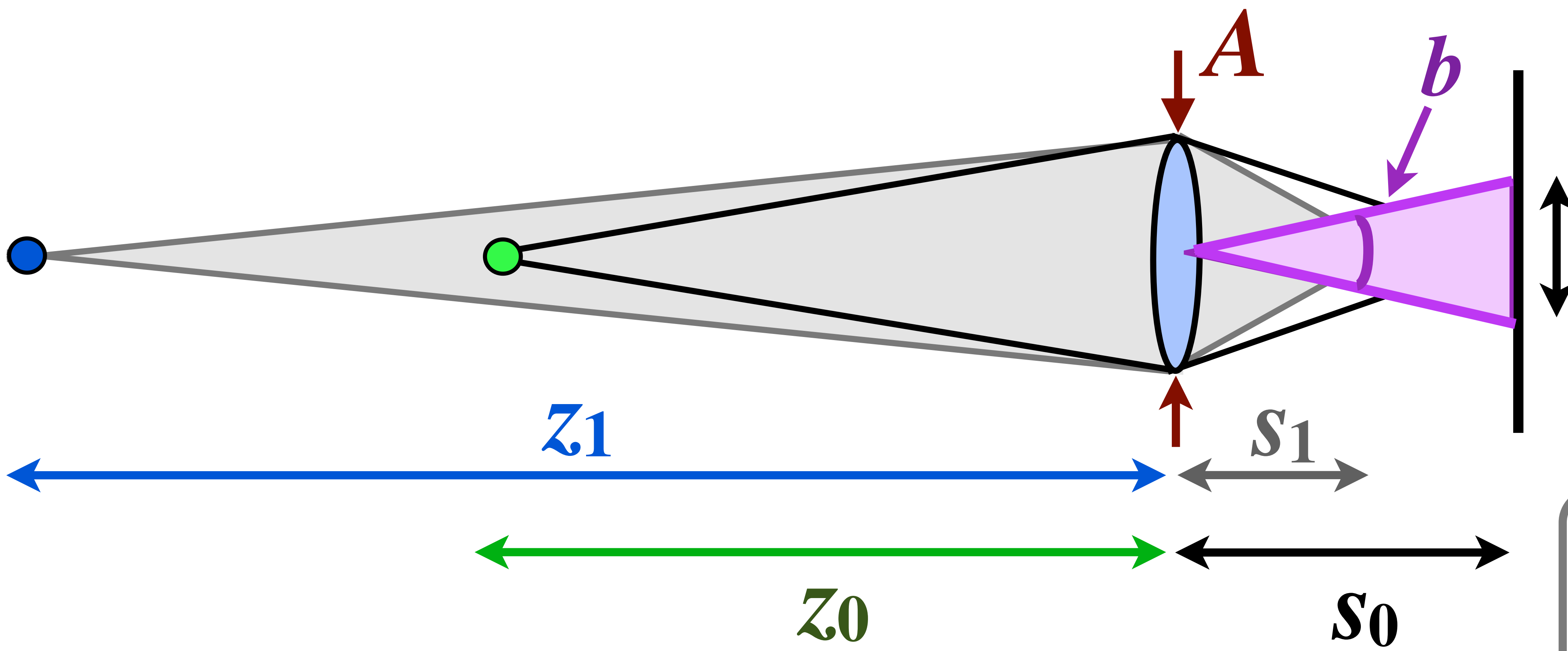
$$c = A\left(\frac{s_0}{z_0}\right)\left|1 - \frac{z_0}{z_1}\right|$$

Choosing A for desired depth of field



$$c = A\left(\frac{s_0}{z_0}\right)\left|1 - \frac{z_0}{z_1}\right|$$

Choosing A for desired depth of field

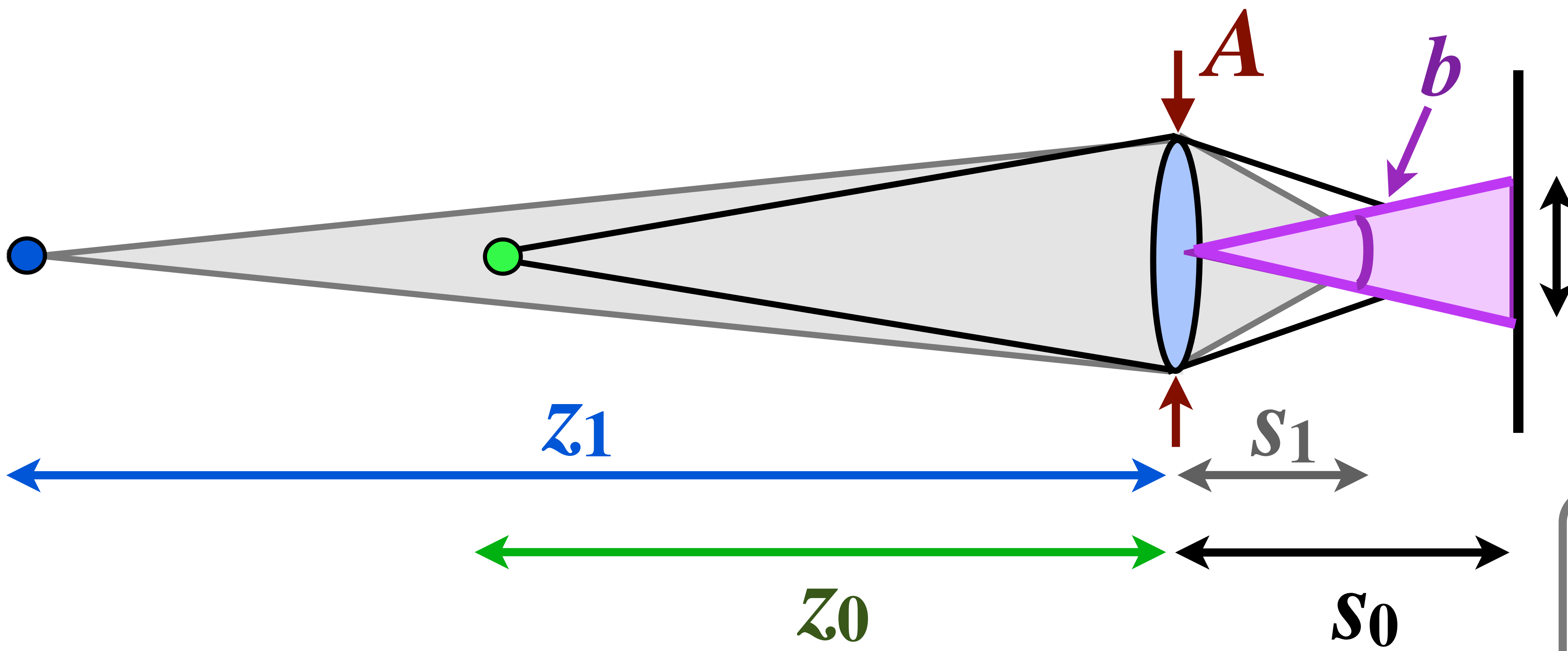


$$c = A\left(\frac{s_0}{z_0}\right)\left|1 - \frac{z_0}{z_1}\right|$$

Blur in angular units:

$$b = 2\arctan\left(\frac{c}{2s_0}\right) \approx \frac{c}{s_0}$$

Choosing A for desired depth of field



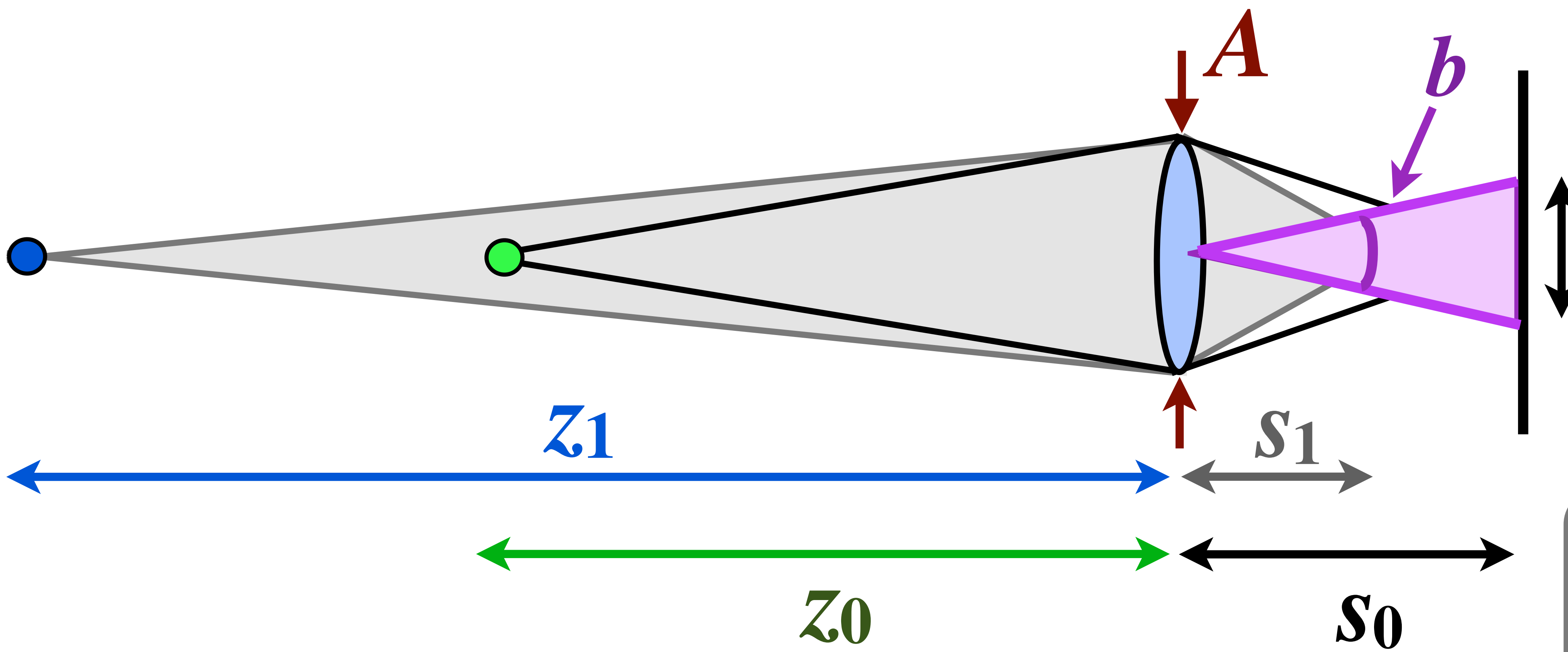
$$c = A\left(\frac{s_0}{z_0}\right)\left|1 - \frac{z_0}{z_1}\right|$$

Blur in angular units:

$$b = 2\arctan\left(\frac{c}{2s_0}\right) \approx \frac{c}{s_0}$$

$$b = \left(\frac{A}{z_0}\right)\left|1 - \frac{z_0}{z_1}\right|$$

Choosing A for desired depth of field



$$c = A\left(\frac{s_0}{z_0}\right)\left|1 - \frac{z_0}{z_1}\right|$$

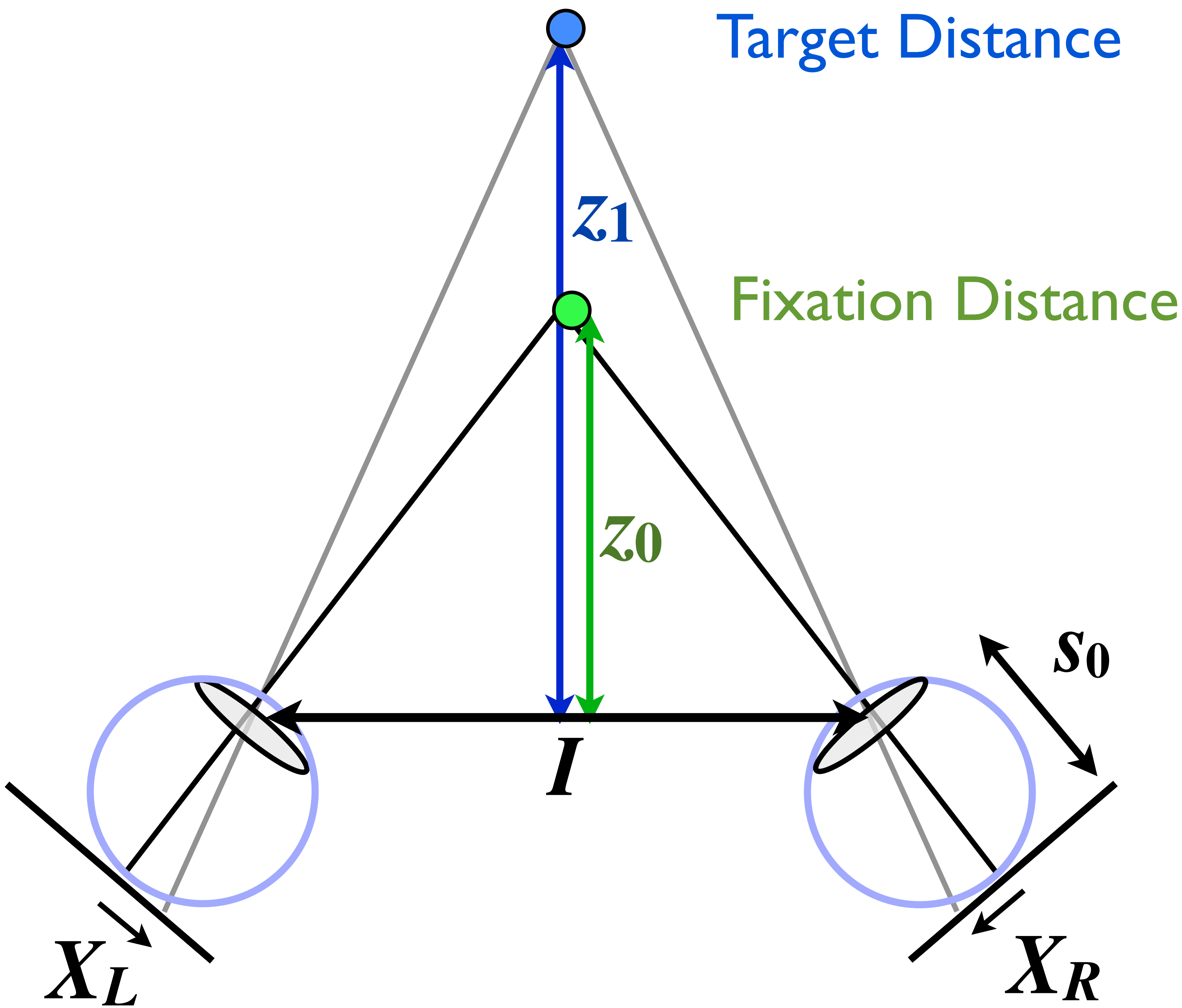
Blur in angular units:

$$b = 2\arctan\left(\frac{c}{2s_0}\right) \approx \frac{c}{s_0}$$

$$b = \left(\frac{A}{z_0}\right)\left|1 - \frac{z_0}{z_1}\right|$$

- Blur depends on scene structure only
- For natural blur, set camera aperture to pupil size (~4.5mm)

Connecting cues: Blur and disparity



Disparity of target relative to fixation:

$$\delta = X_L - X_R$$
$$= I\left(\frac{s_0}{z_0}\right)\left(1 - \frac{z_0}{z_1}\right)$$

Connecting cues: Blur and disparity

Disparity of target relative to fixation:

$$\delta = I\left(\frac{s_0}{z_0}\right)\underline{\left(1-\frac{z_0}{z_1}\right)}$$

Diameter of blur circle:

$$c = A\left(\frac{s_0}{z_0}\right)\underline{\left|1-\frac{z_0}{z_1}\right|}$$

Connecting cues: Blur and disparity

Disparity of target relative to fixation:

$$\delta = I\left(\frac{s_0}{z_0}\right)\underline{\left(1-\frac{z_0}{z_1}\right)}$$

Diameter of blur circle:

$$c = A\left(\frac{s_0}{z_0}\right)\underline{\left|1-\frac{z_0}{z_1}\right|}$$

$$\boxed{c = (A/I)|\delta|}$$

- **In natural viewing, blur is proportional to disparity**

Connecting cues: Blur and disparity

Disparity of target relative to fixation:

$$\delta = I\left(\frac{s_0}{z_0}\right)\underline{\left(1-\frac{z_0}{z_1}\right)}$$

Diameter of blur circle:

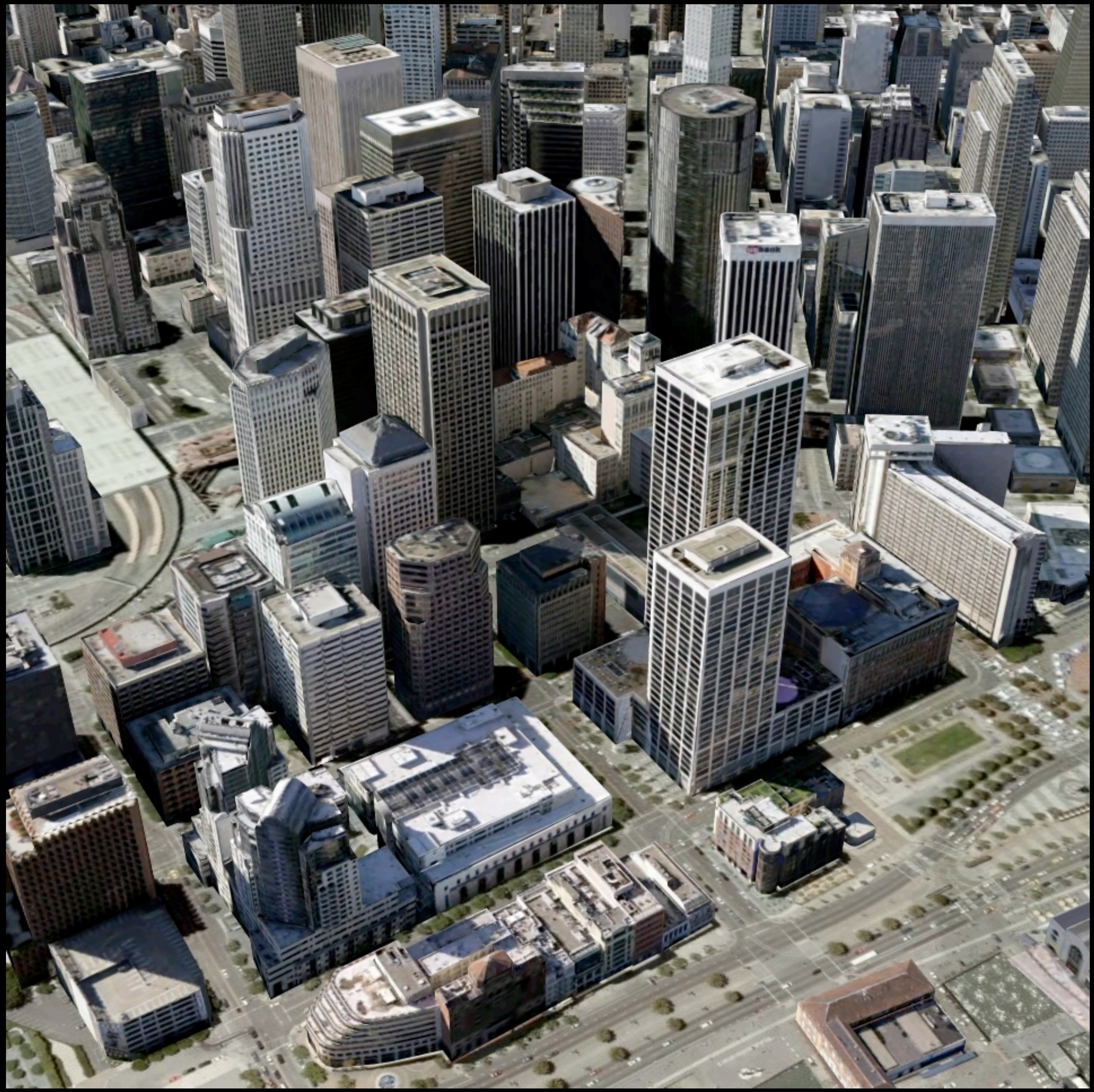
$$c = A\left(\frac{s_0}{z_0}\right)\underline{\left|1-\frac{z_0}{z_1}\right|}$$

$$\boxed{c = (A/I)|\delta|} \rightarrow \boxed{c \approx \frac{|\delta|}{12}}$$

- **In natural viewing, blur is proportional to disparity**
- Practical application: Natural stereo content should be generated with camera apertures ~1/12 the camera baseline

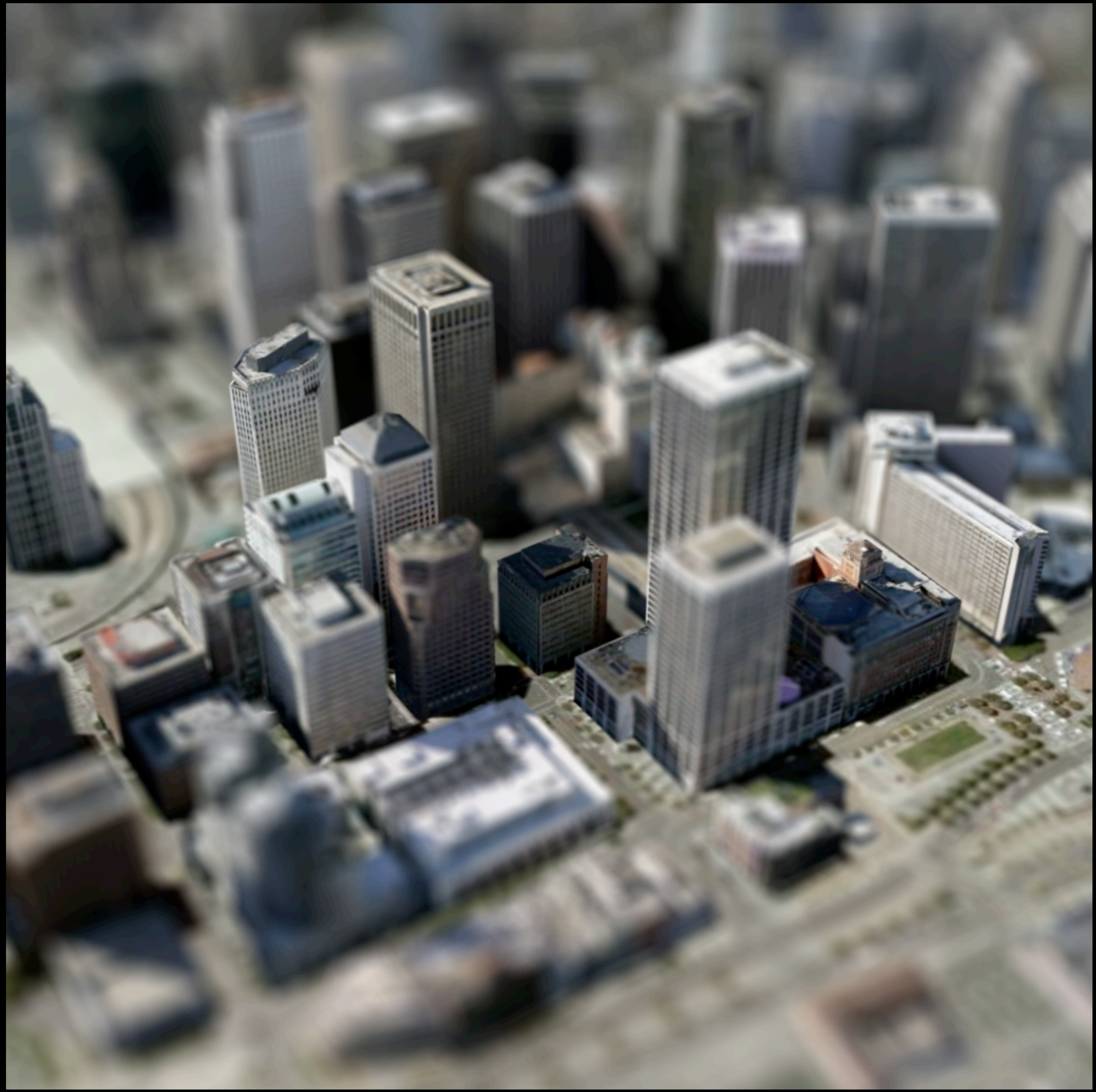
Discussion

- Blur is deeply connected to distance
- Also closely related to other distance cues
- Modeling and understanding the relationship between blur and other depth information helps us understand how to make blur appear natural



Discussion

- Once we know how to make blur look natural, we can intentionally modify to create perceptual effects
  - Tilt-shift, model photography were gross modifications
- Blur-based effects in stereo photography deserve attention



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- NSF Graduate Research Fellowship
- NDSEG Graduate Research Fellowship
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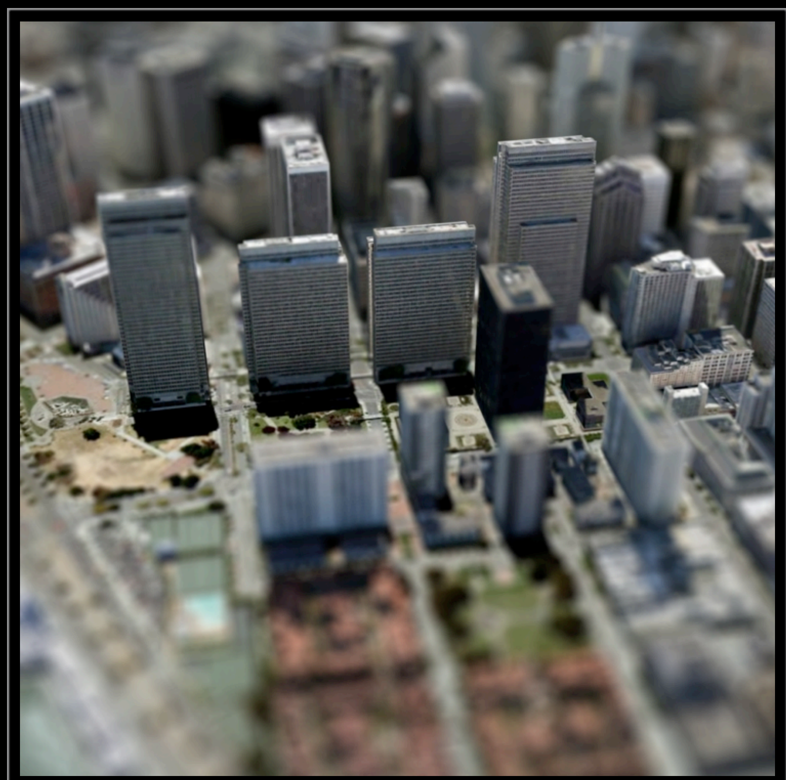
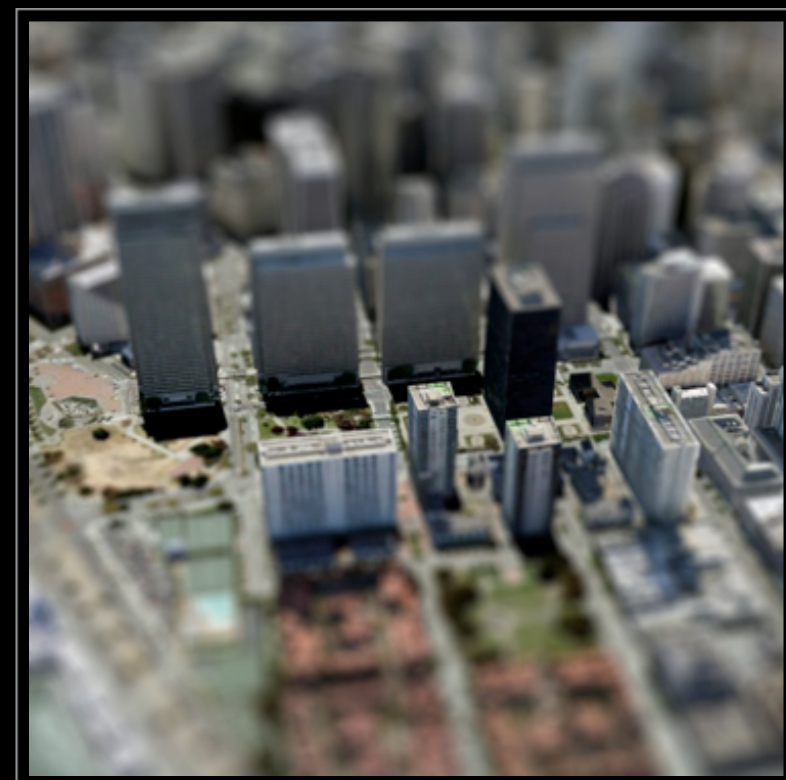
- NSF BCS-0117701

Tilt-shift effect

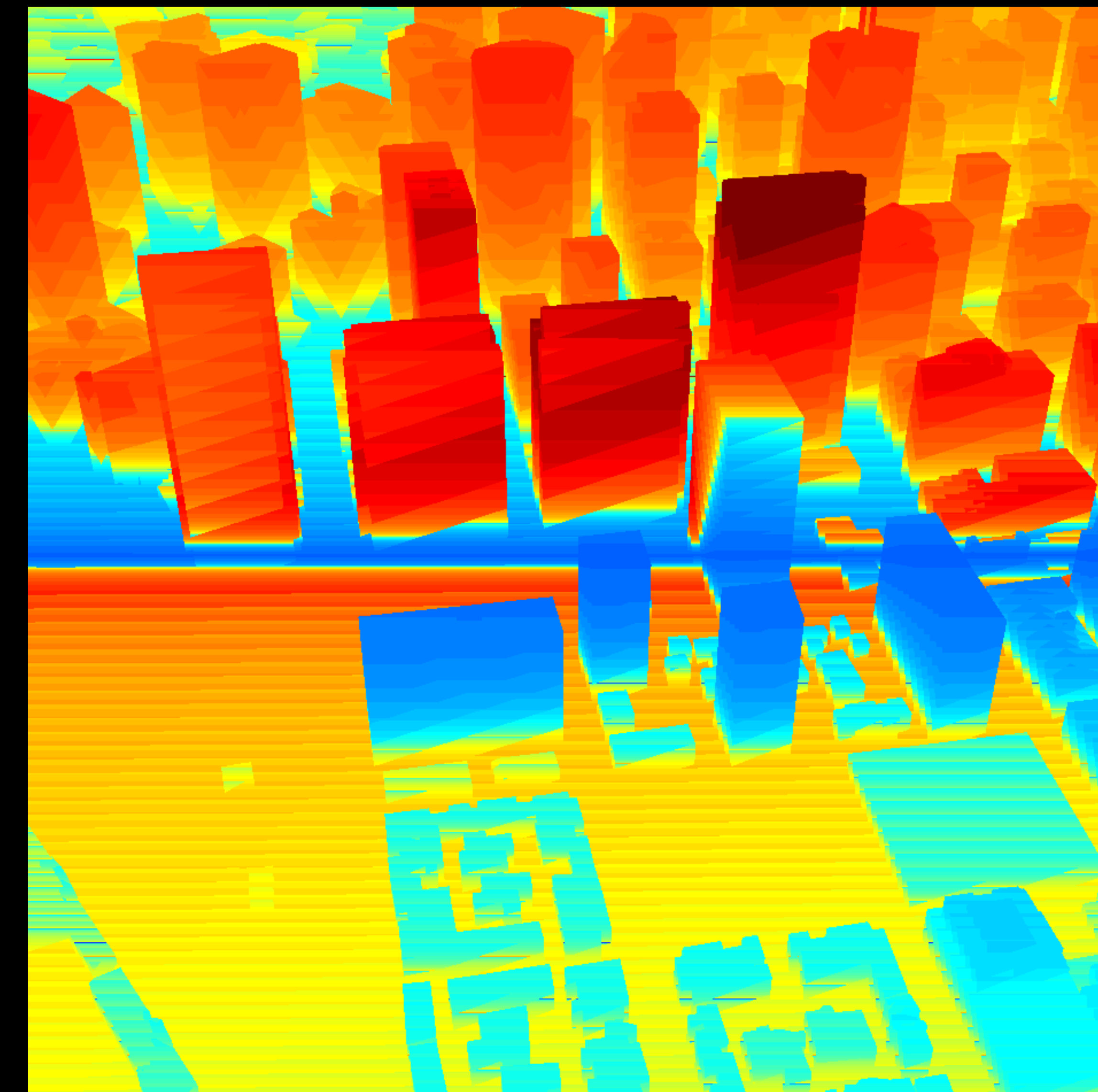
Approximating blur



Consistent blur



Aligned
blur gradient



% Difference
(blur-circle diameter):