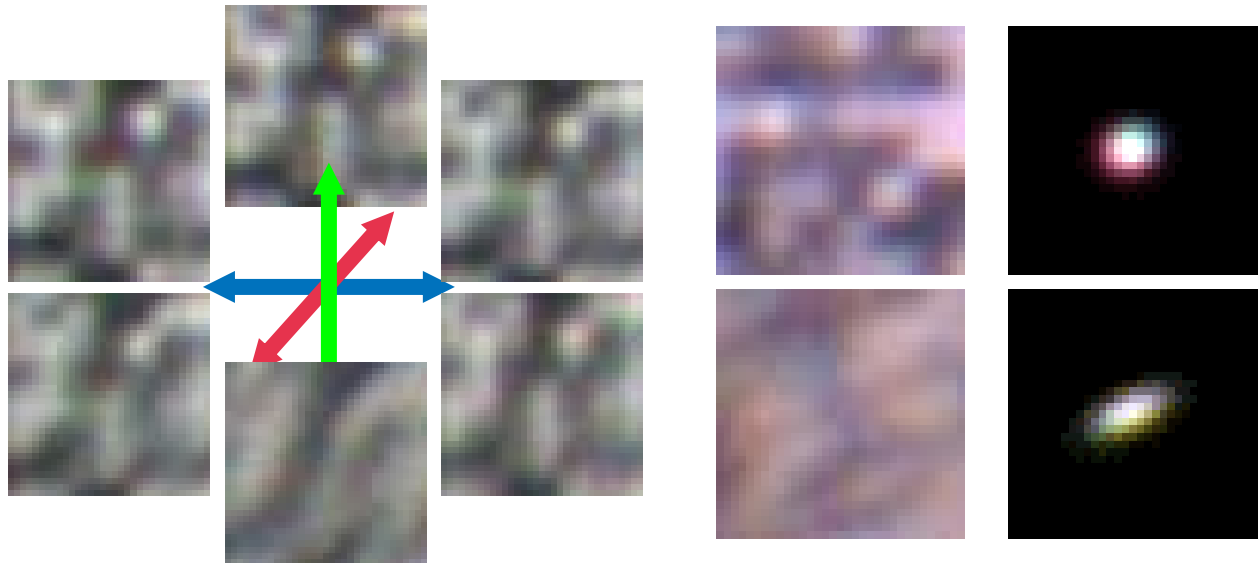


# Gaussian Light Field: Estimation of Viewpoint-Dependent Blur for Optical See-Through Head-Mounted Displays

Yuta Itoh, Toshiyuki Amano, Daisuke Iwai, and Gudrun Klinker  
IEEE ISMAR 2016, Tue. 20th Sep. 2016



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# Blur artifacts in HMDs



# Head-Mounted Displays (HMDs)

## Non Optical See-Through



## Optical See-Through (OST-HMD)



# We want make AR with HMD **real**



# Realism in AR (with OST HMDs)

## Temporal



[Zheng '14]



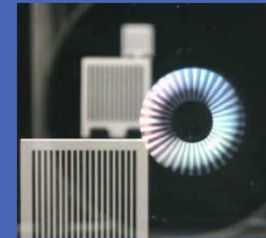
[Lincoln '16]

## Visual

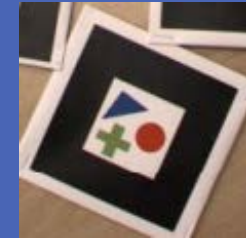


D) Final result

[Kiyokawa '01]

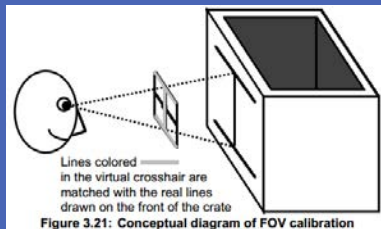


[Liu '08]



[Lee '09]

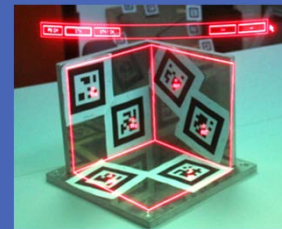
## Spatial



[Azuma '95]



[Tuceryan '00] [Genc '02]



[Grubert '08]

# Realism in AR (with OST HMDs)

## Temporal



[Zheng '14]



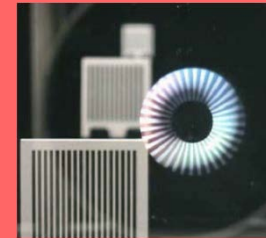
[Lincoln '16]

## Visual



D) Final result

[Kiyokawa '01]

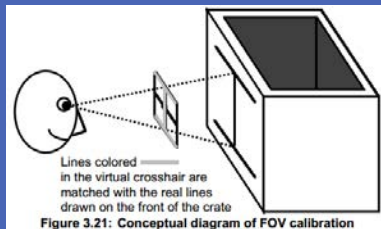


[Liu '08]



[Lee '09]

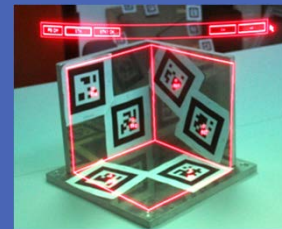
## Spatial



[Azuma '95]



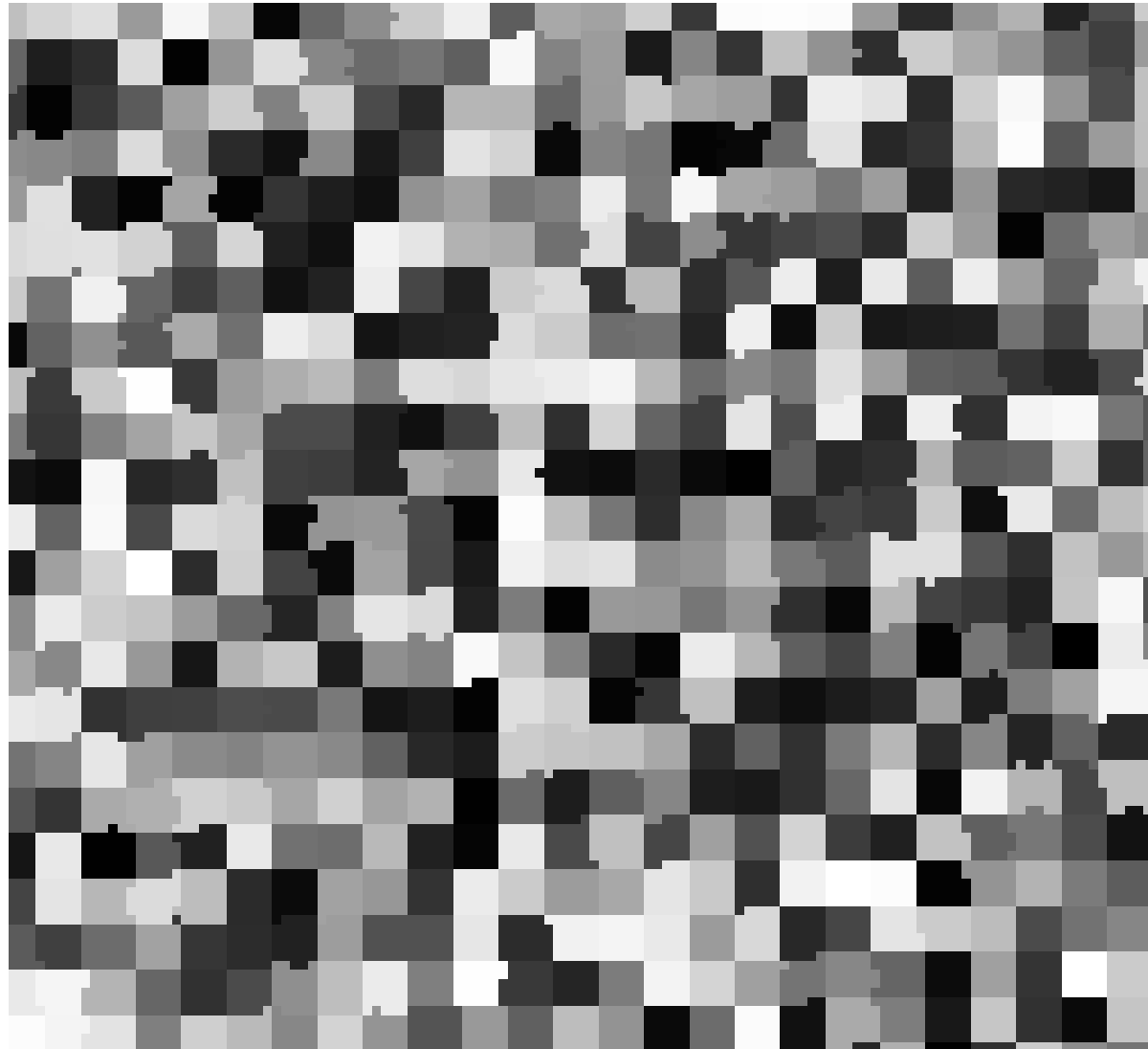
[Tuceryan '00] [Genc '02]



[Grubert '08]

# Image blur in (OST-)HMDs

Ideal Output





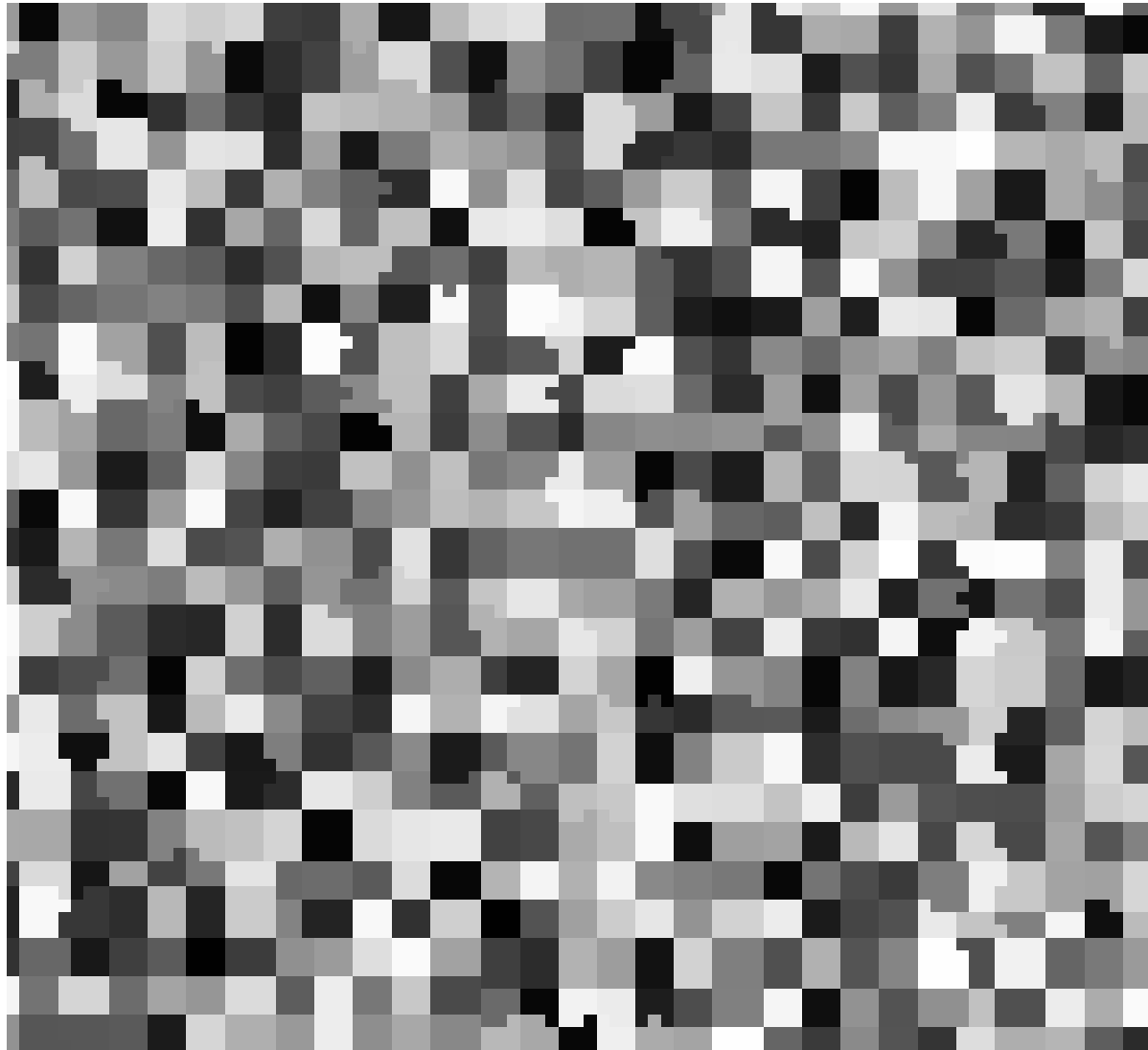
# Image blur in (OST-)HMDs

**Actual observation**



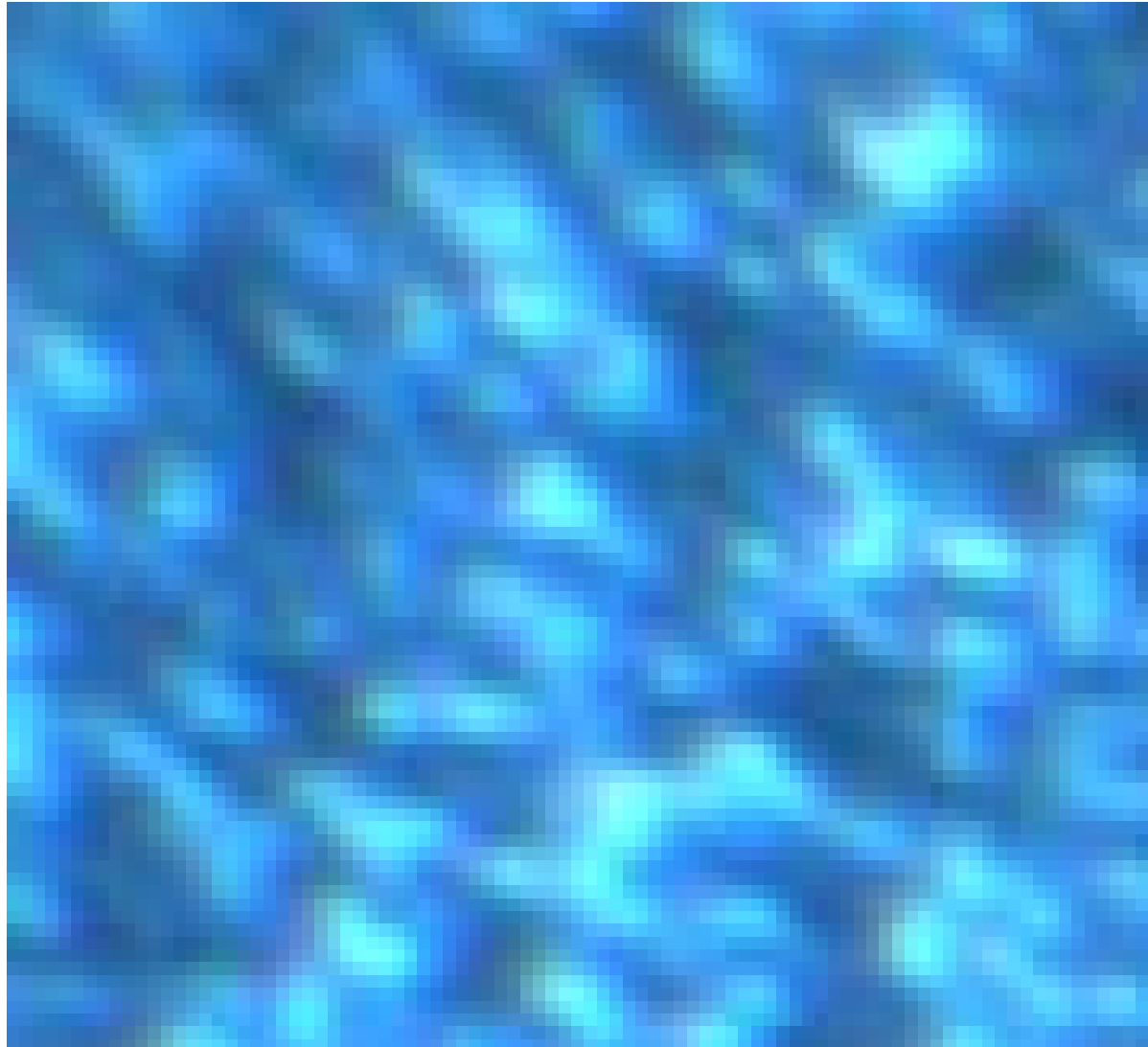
# Image blur in (OST-)HMDs

Ideal Output



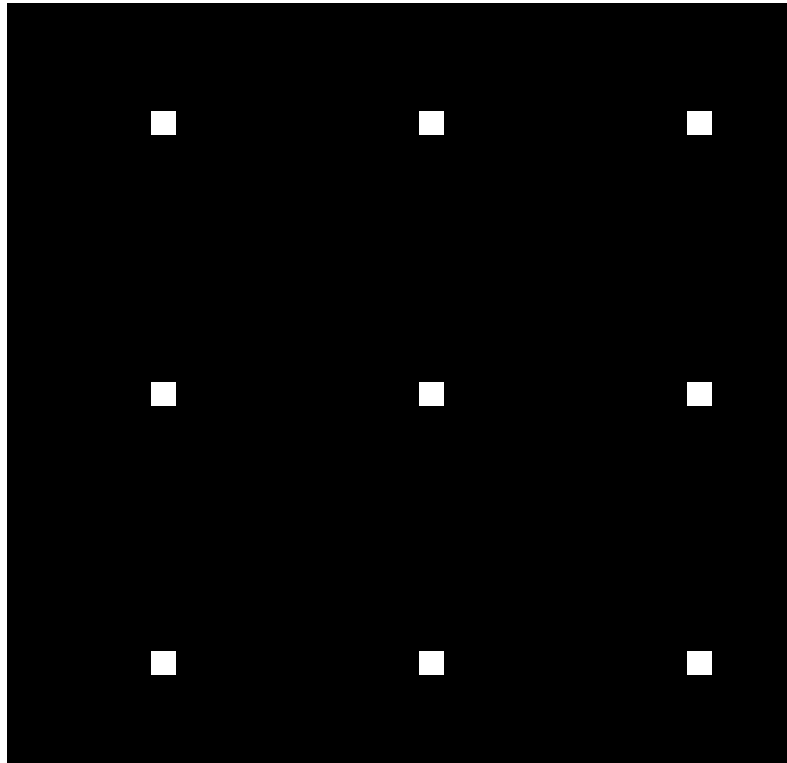
# Image blur in (OST-)HMDs

**Actual observation**



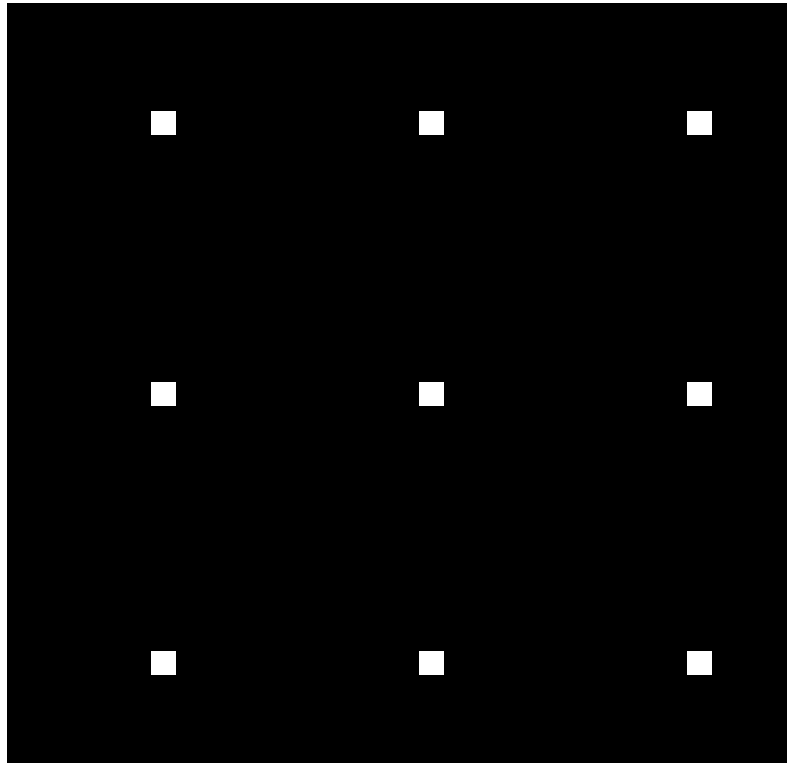
# Image blur $\rightarrow$ Impulse Responses

Impulse responses



# Image blur $\rightarrow$ Impulse Responses

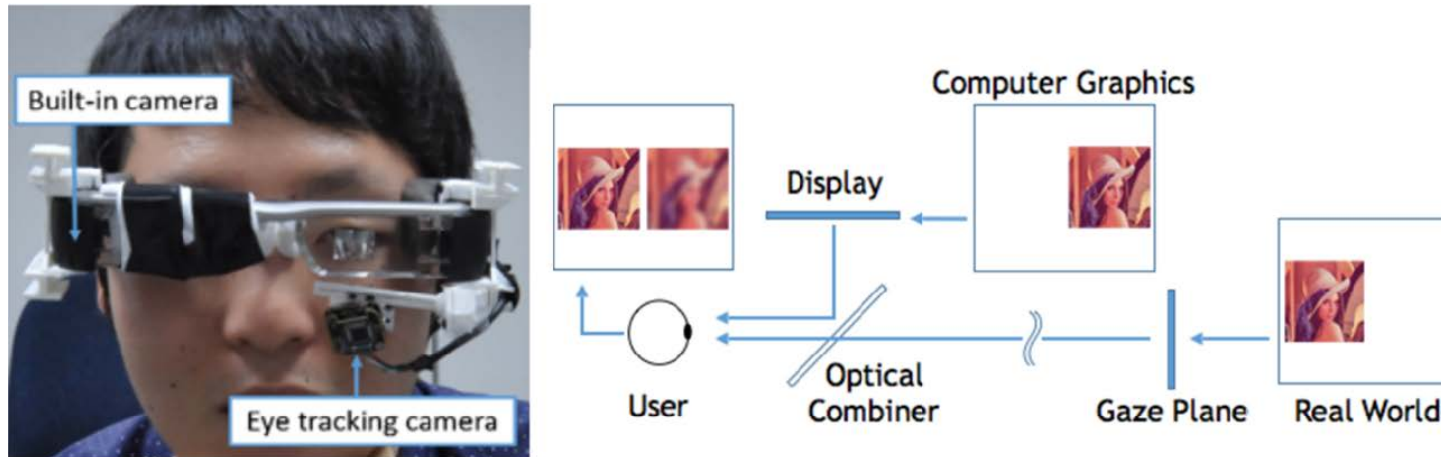
Impulse responses





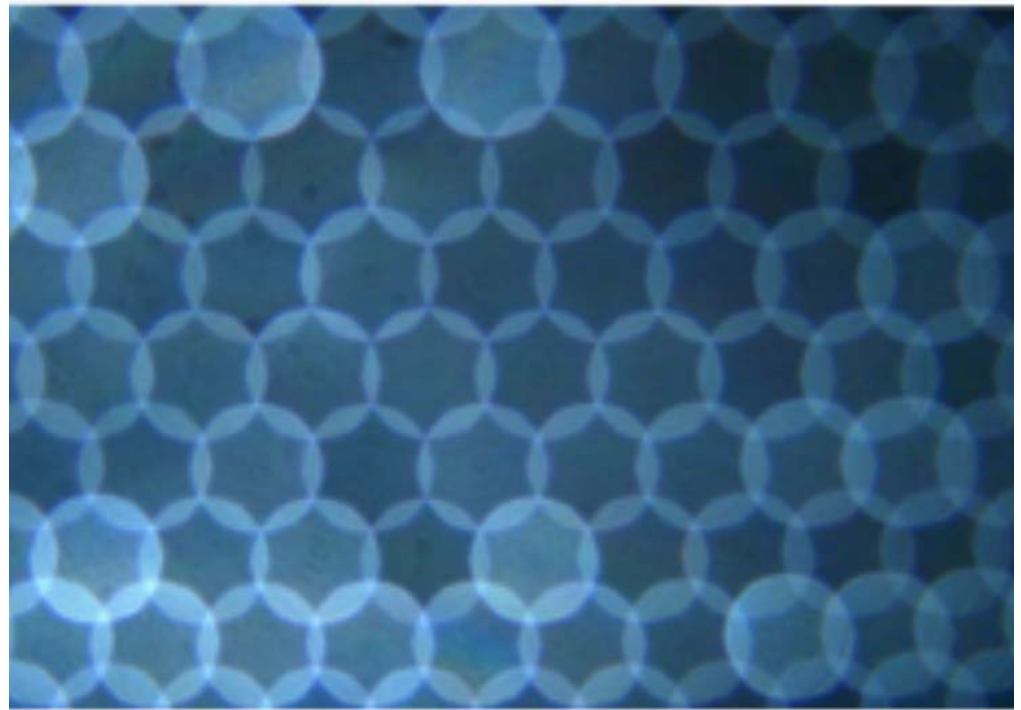
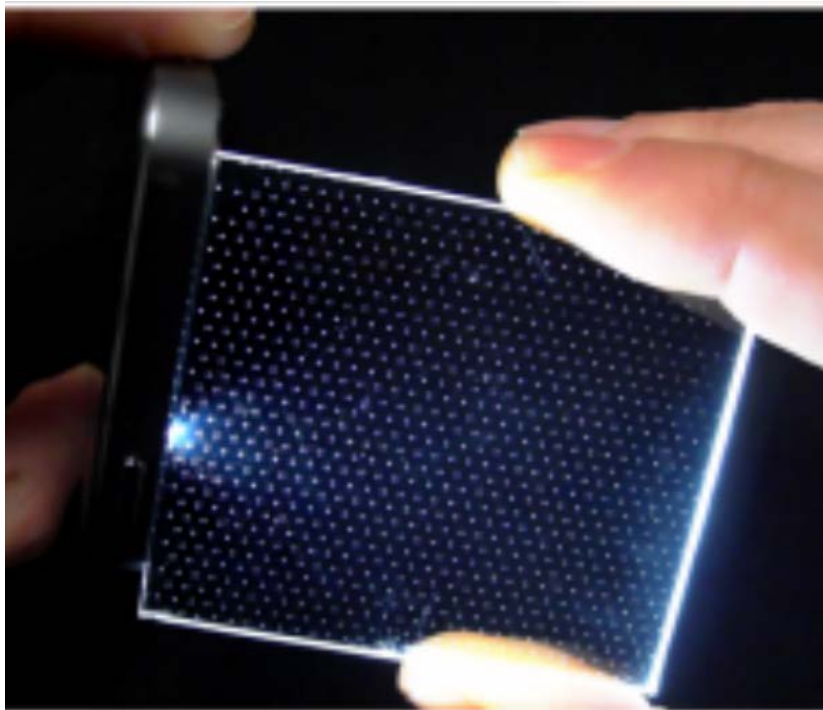
Why do we care  
about **blur**?

# Related Work: SharpView



*SharpView: Improved Clarity of Defocused Content on Optical See-Through Head-Mounted Displays, Oshima et al. 2015*

# Related Work: **Pinlight Displays**



*"Pinlight Displays: Wide Field of View Augmented Reality Eyeglasses using Defocused Point Light Sources" Maimone et al., TOG'14*

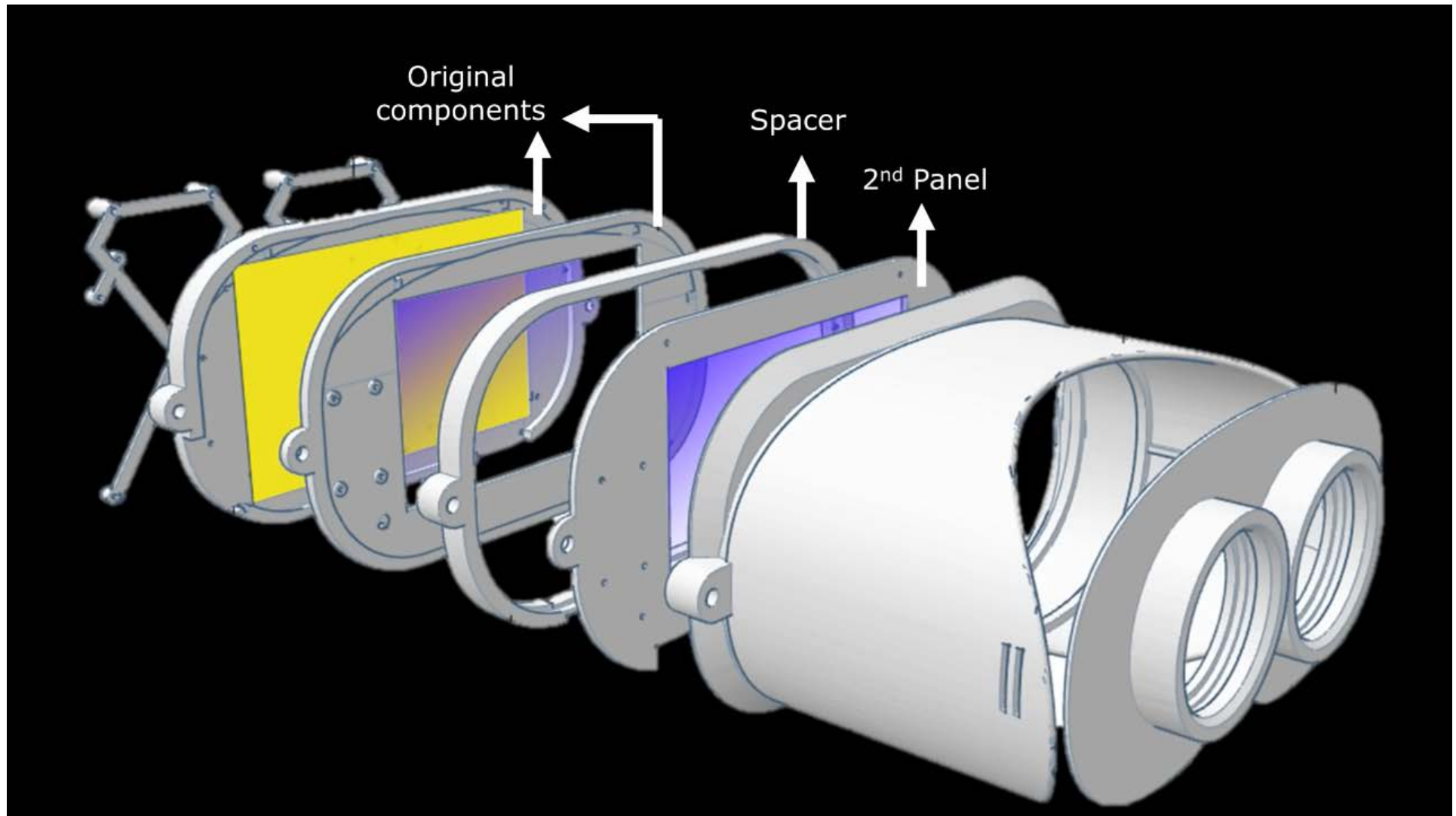


# Related Work: **Pinlight Displays**



*"Pinlight Displays: Wide Field of View Augmented Reality Eyeglasses using Defocused Point Light Sources" Maimone et al., TOG'14*

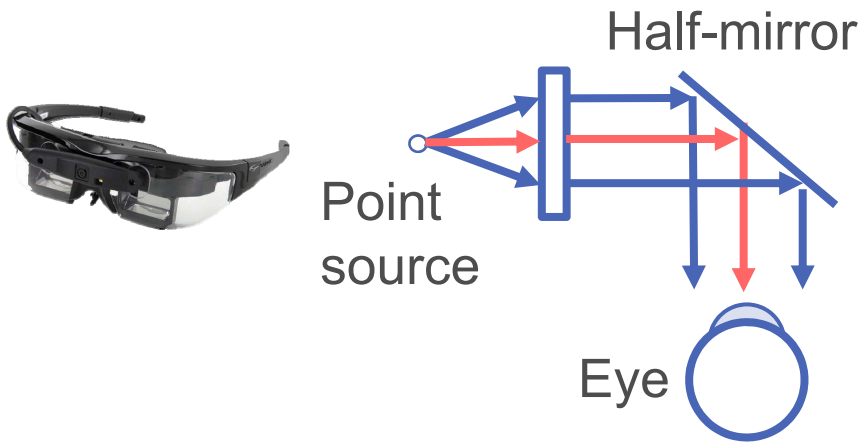
# Related Work: **Light field displays**



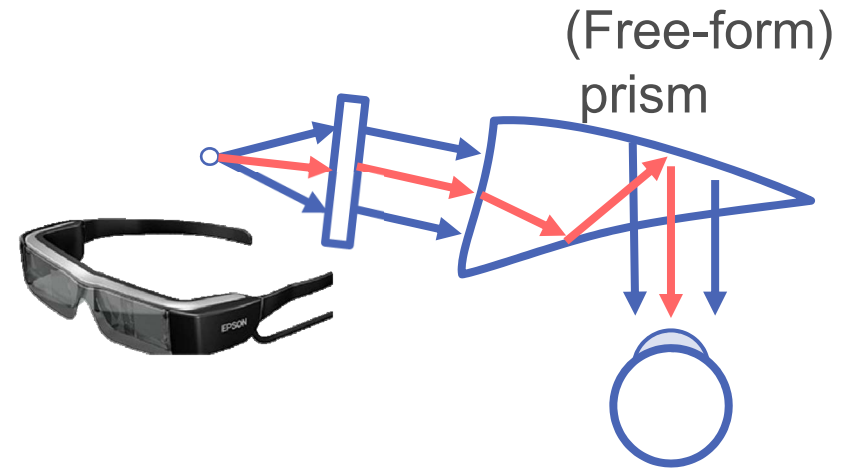
*The Light Field Stereoscope,*  
Huan et al., SIGGRPAH 2015

# Optics Designs of OST-HMDs

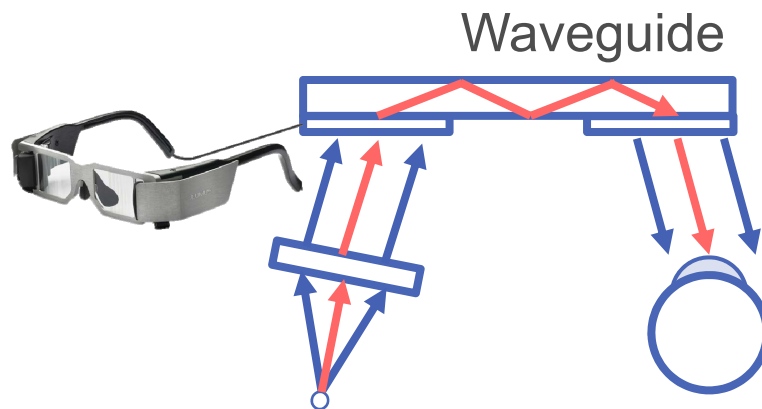
## Half-mirror



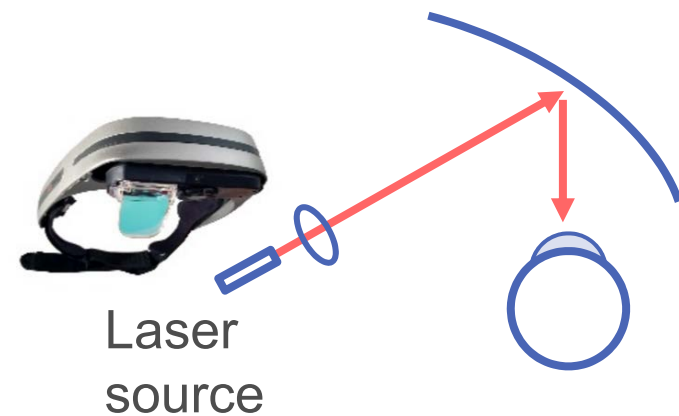
## Prism-based



## Waveguide-based



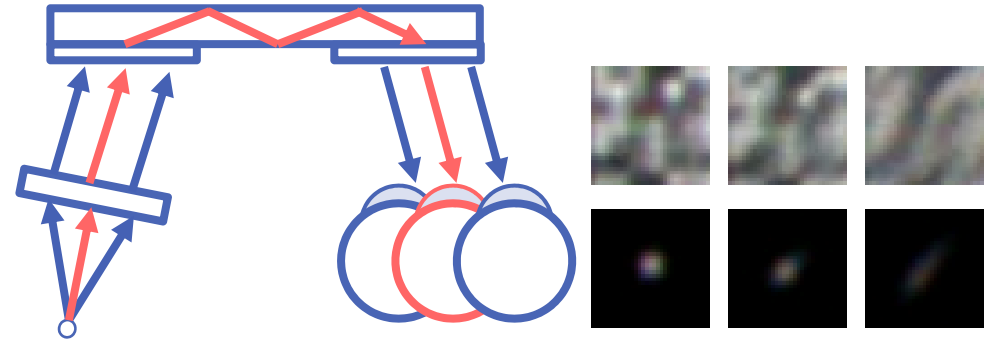
## Retinal Scanning



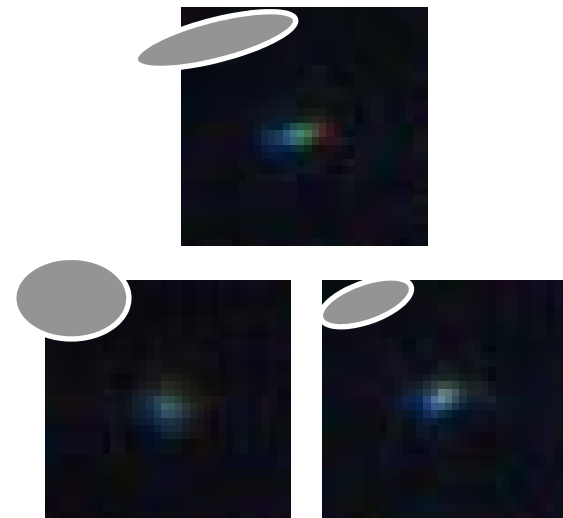
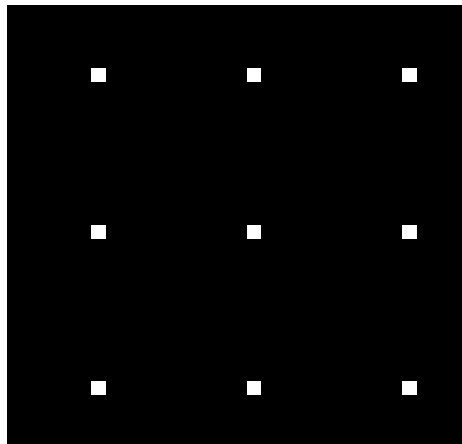
Based on: Hainich and Bimber, *Displays Fundamentals and Applications*, 2011

# Image blur in HMDs

- View-dependent

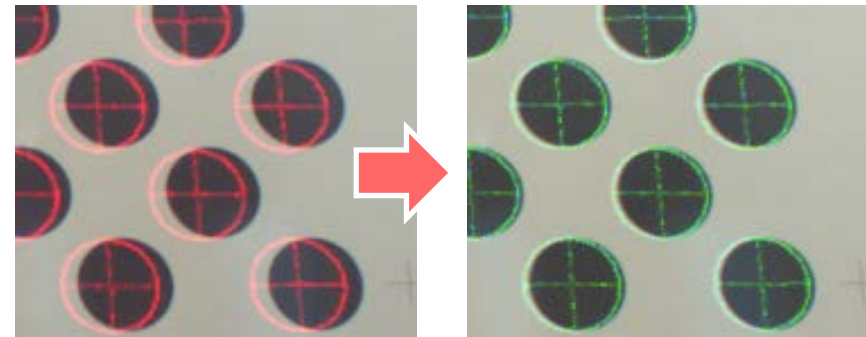


- Non-linear (and RGB-wise)



# Image Undistortion for OST-HMDs

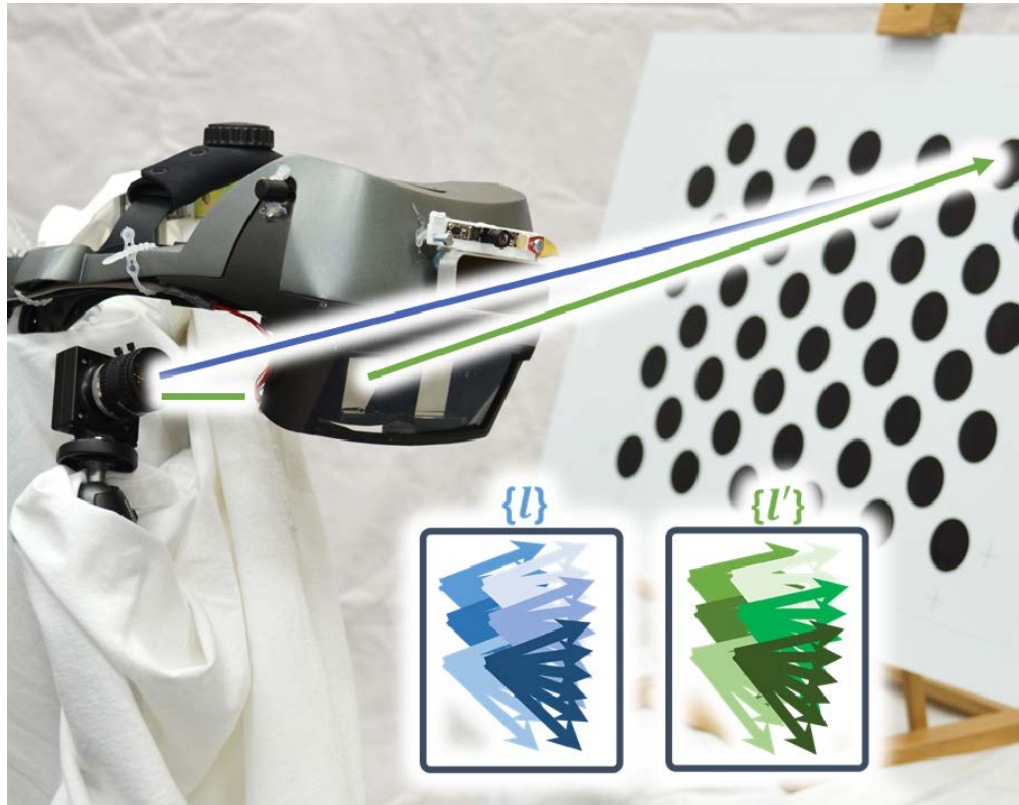
Image Undistortion for OST-HMDs



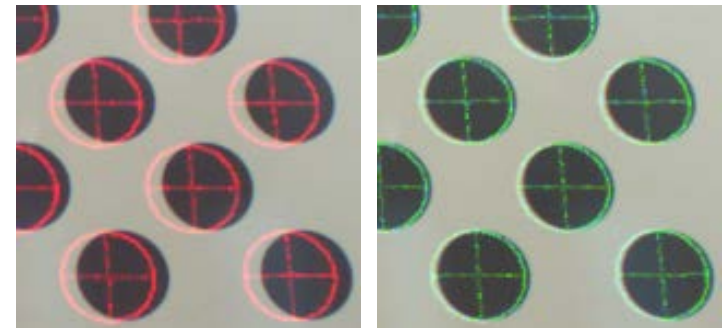
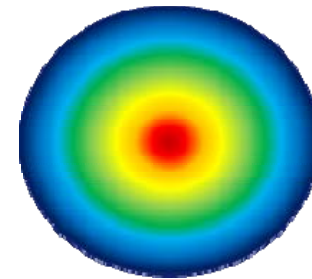
Itoh et al.  
IEEE TVCG '15 (VR '15) & IEEE ISMAR '15

# How to model?

4D **Light Field** model +

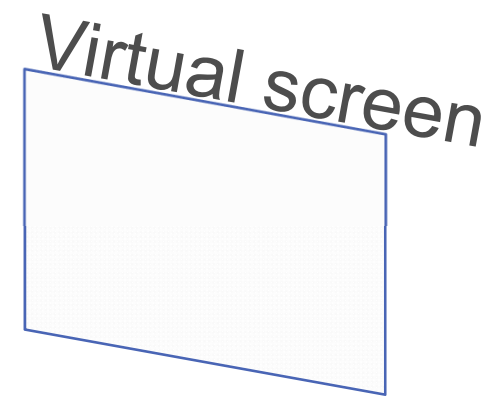


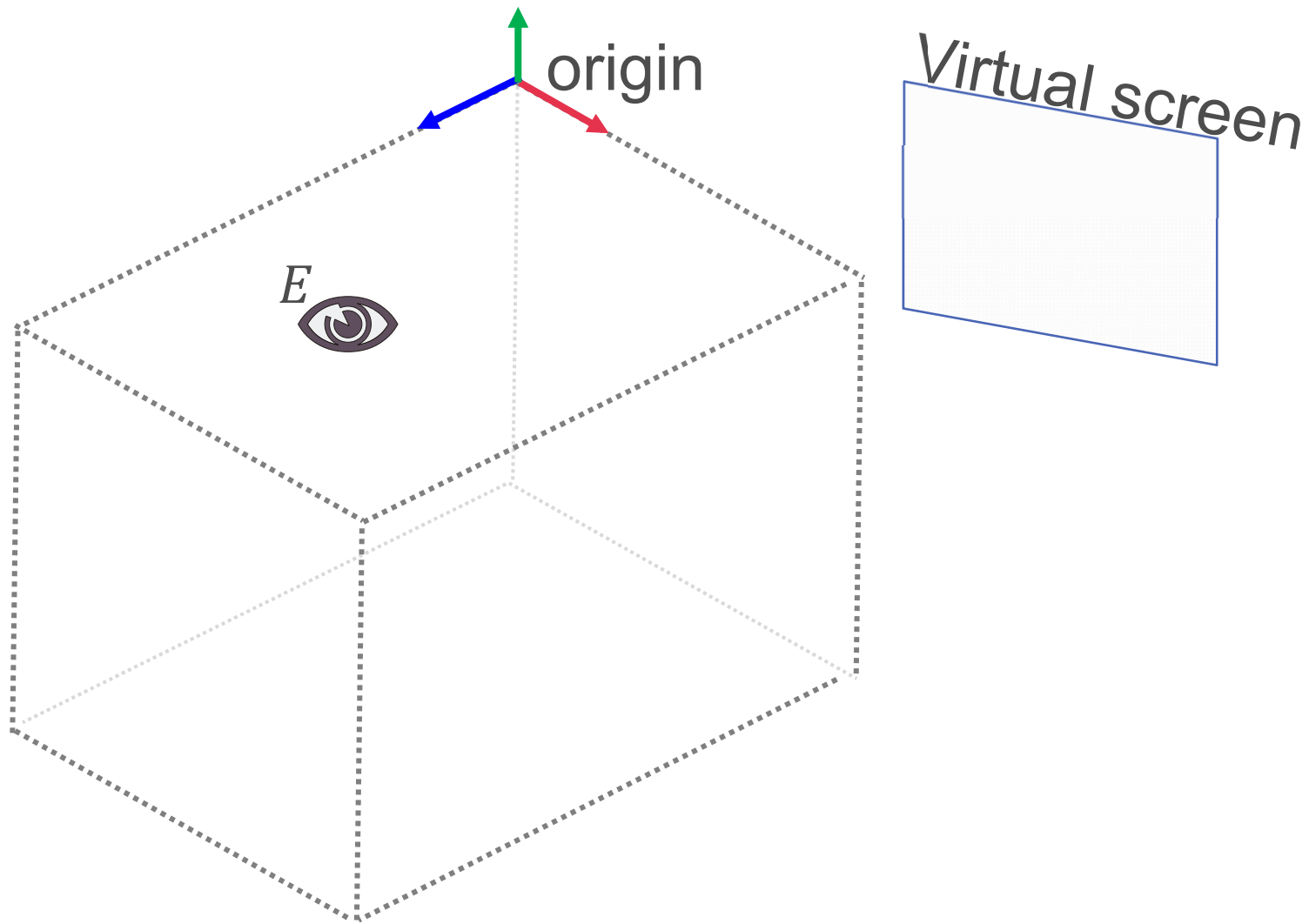
Point Spread  
Function (**PSF**)



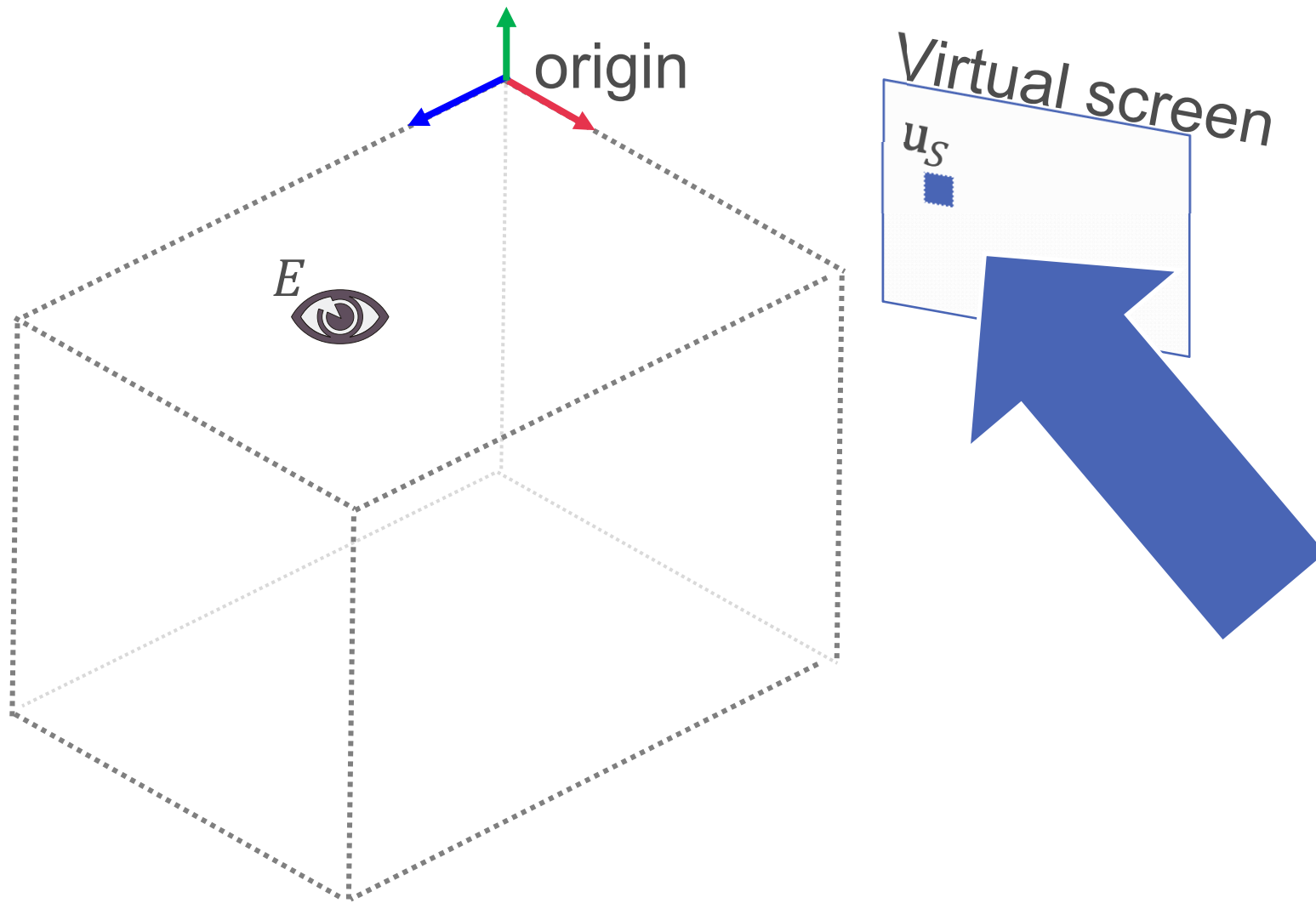
Itoh et al.

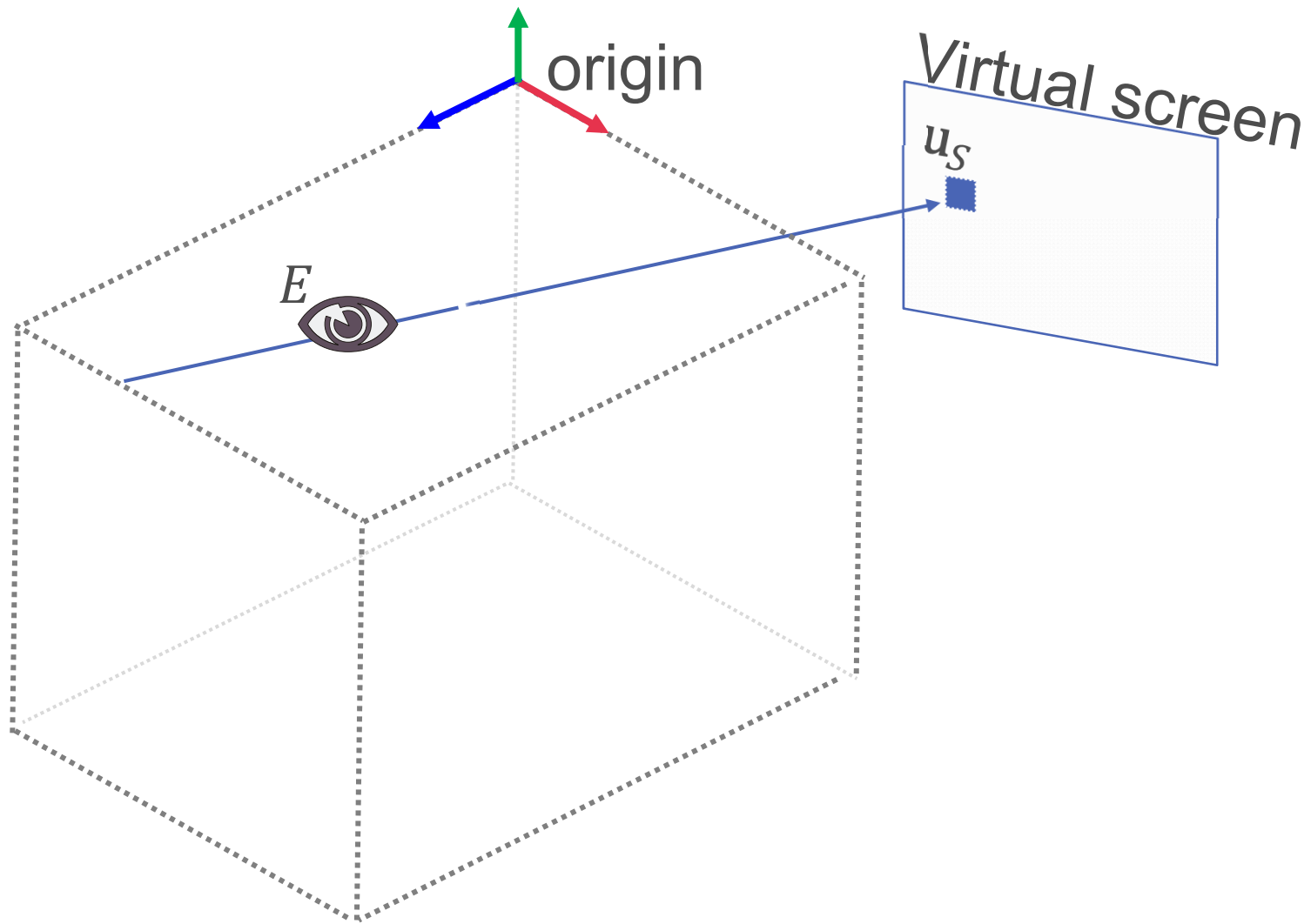
IEEE TVCG '15 (VR '15) & IEEE ISMAR '15

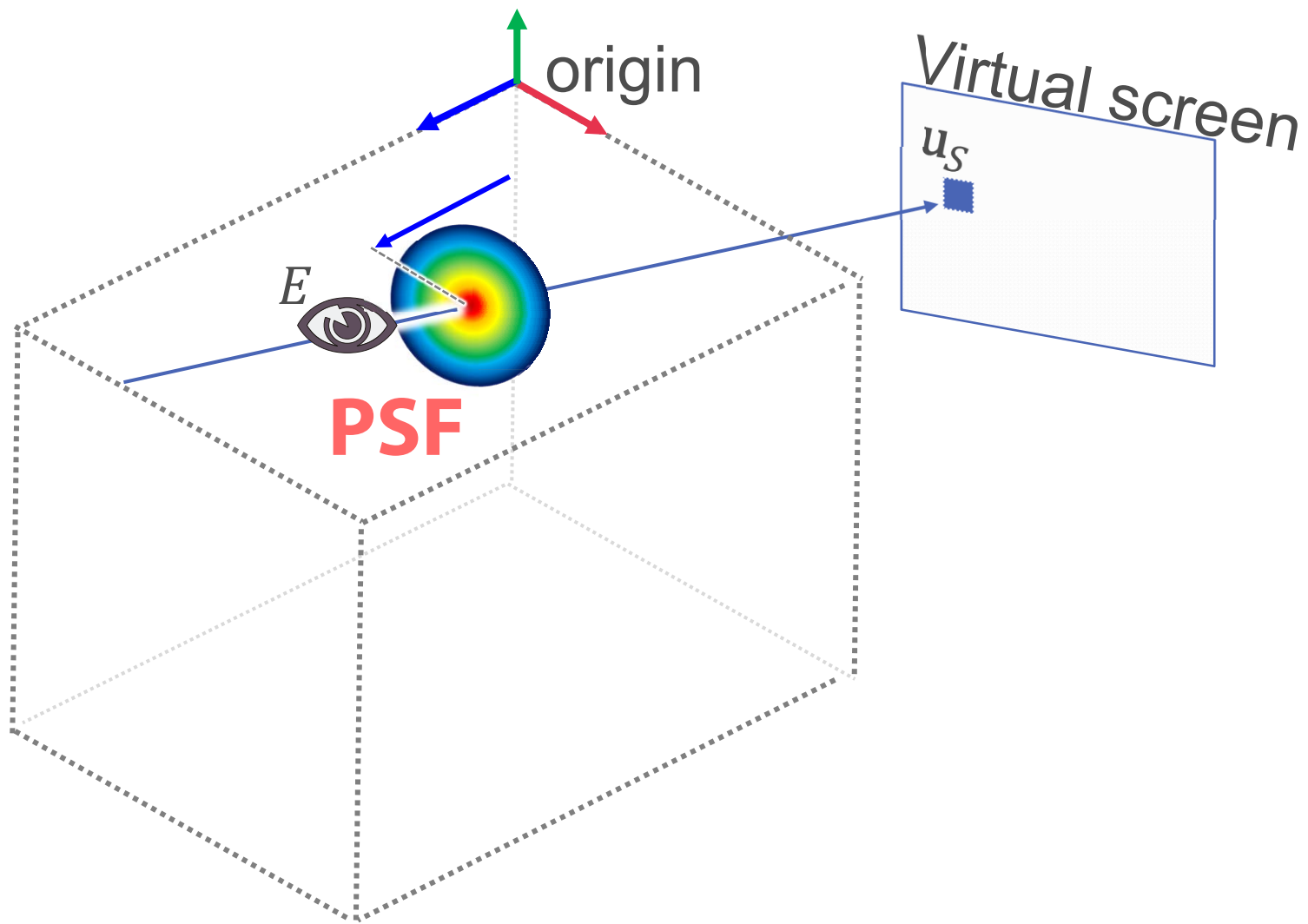


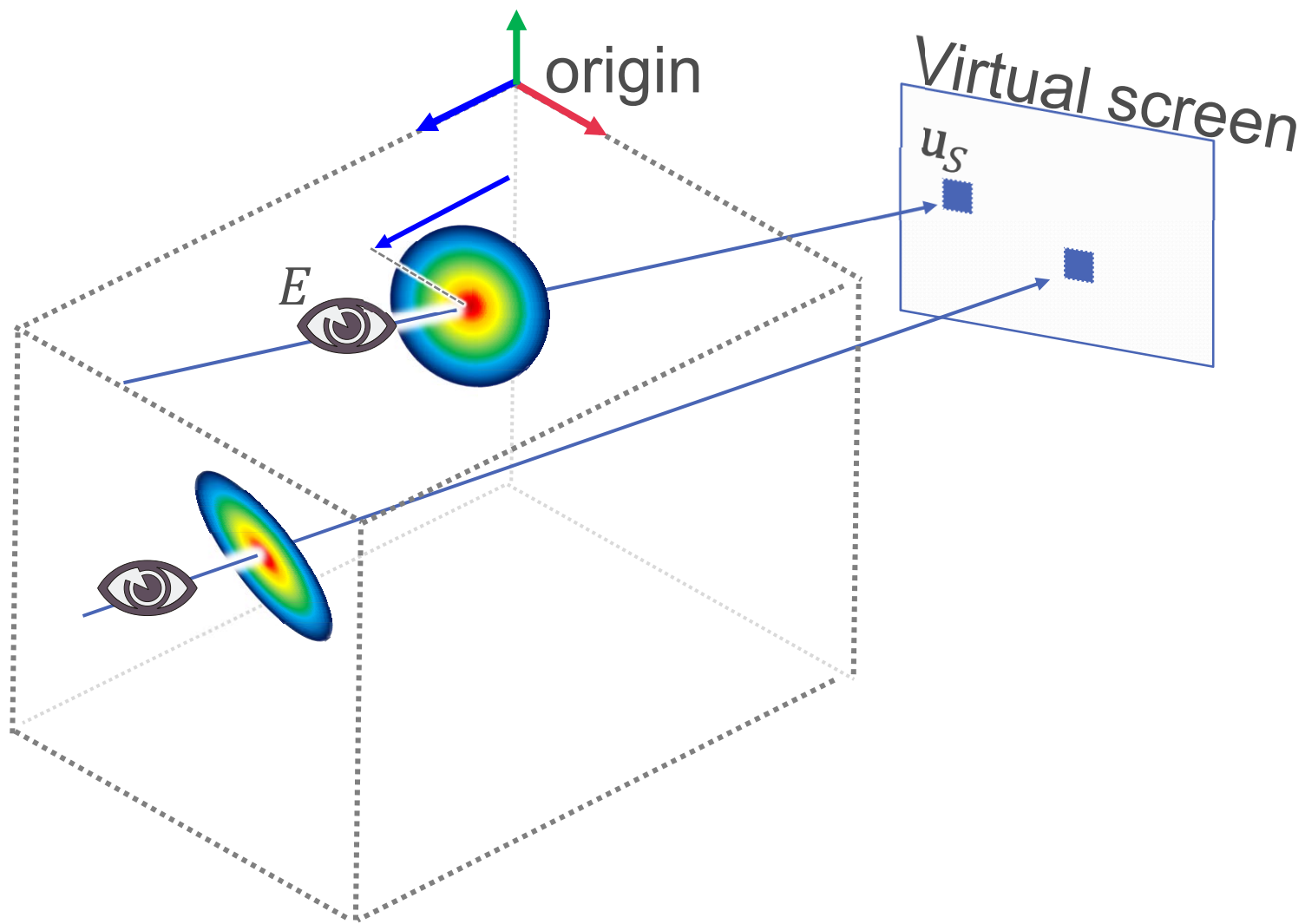


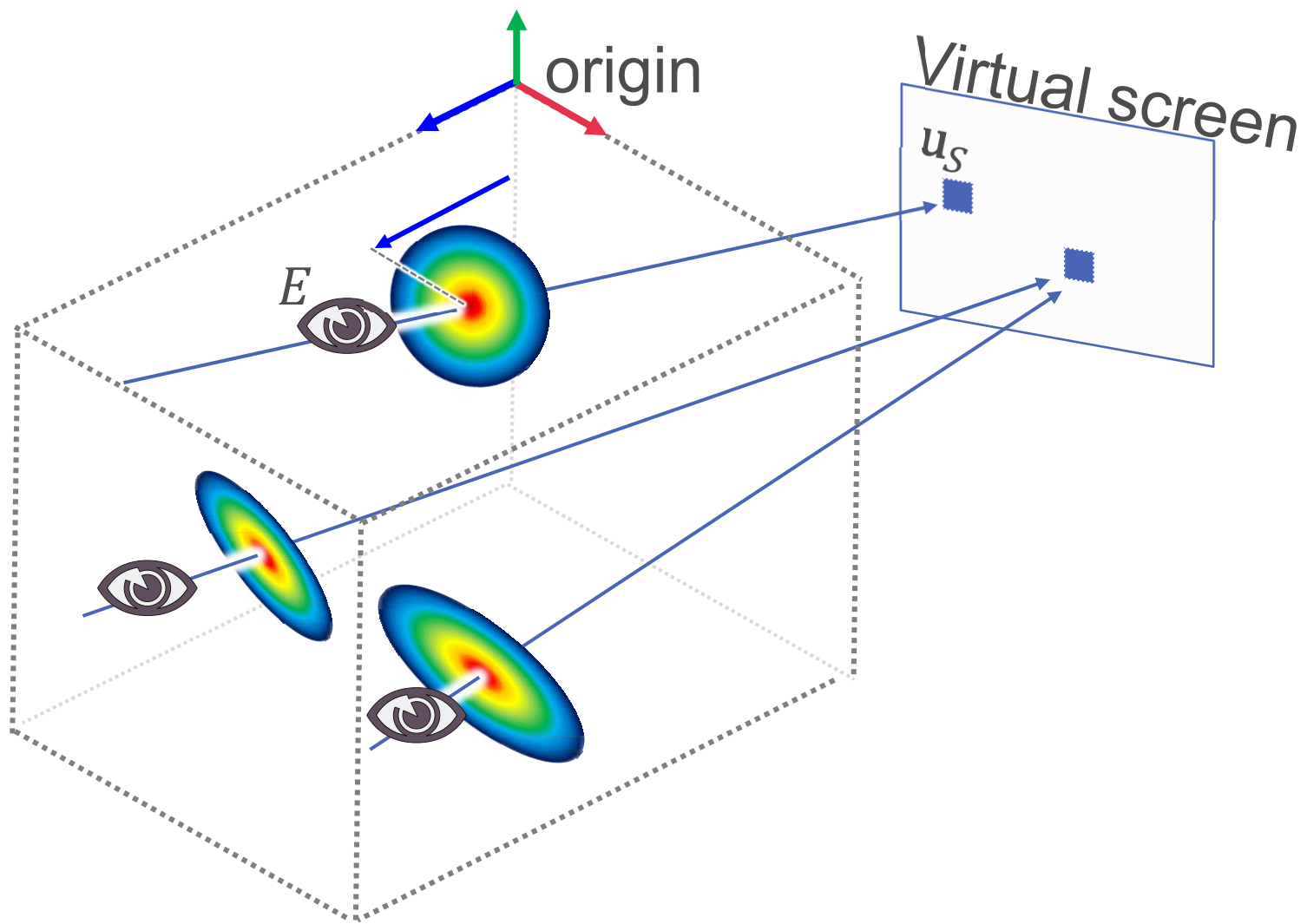


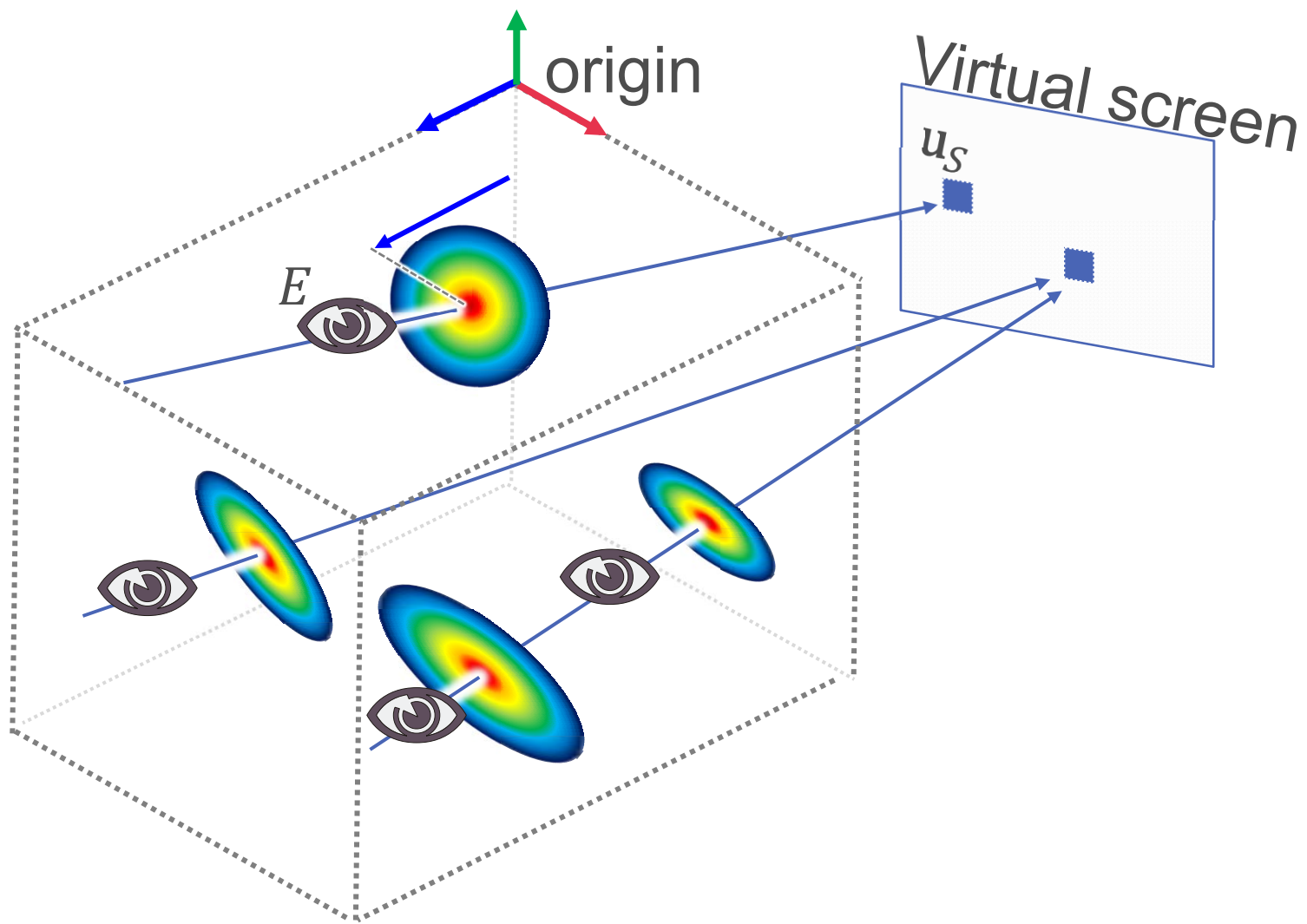


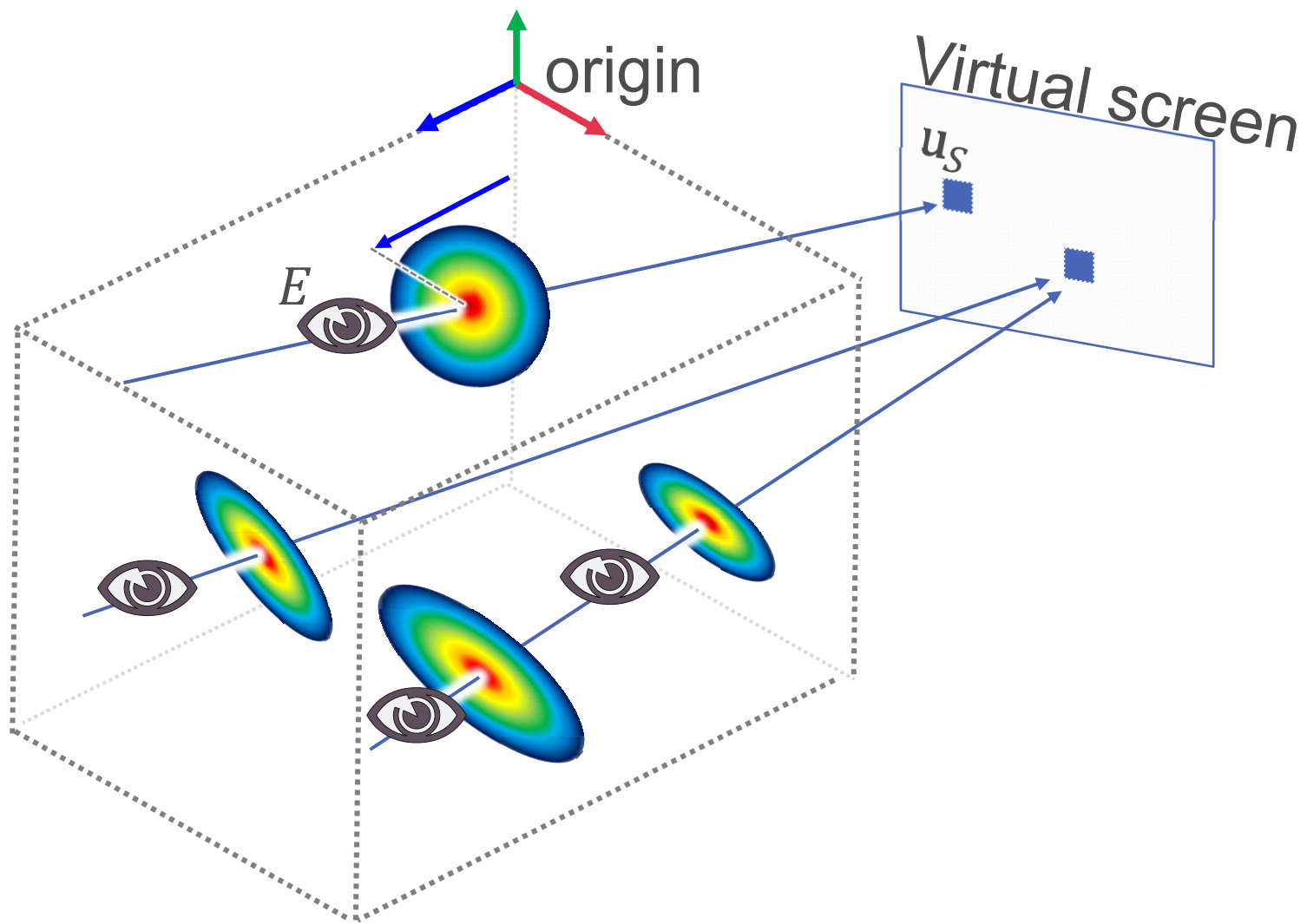


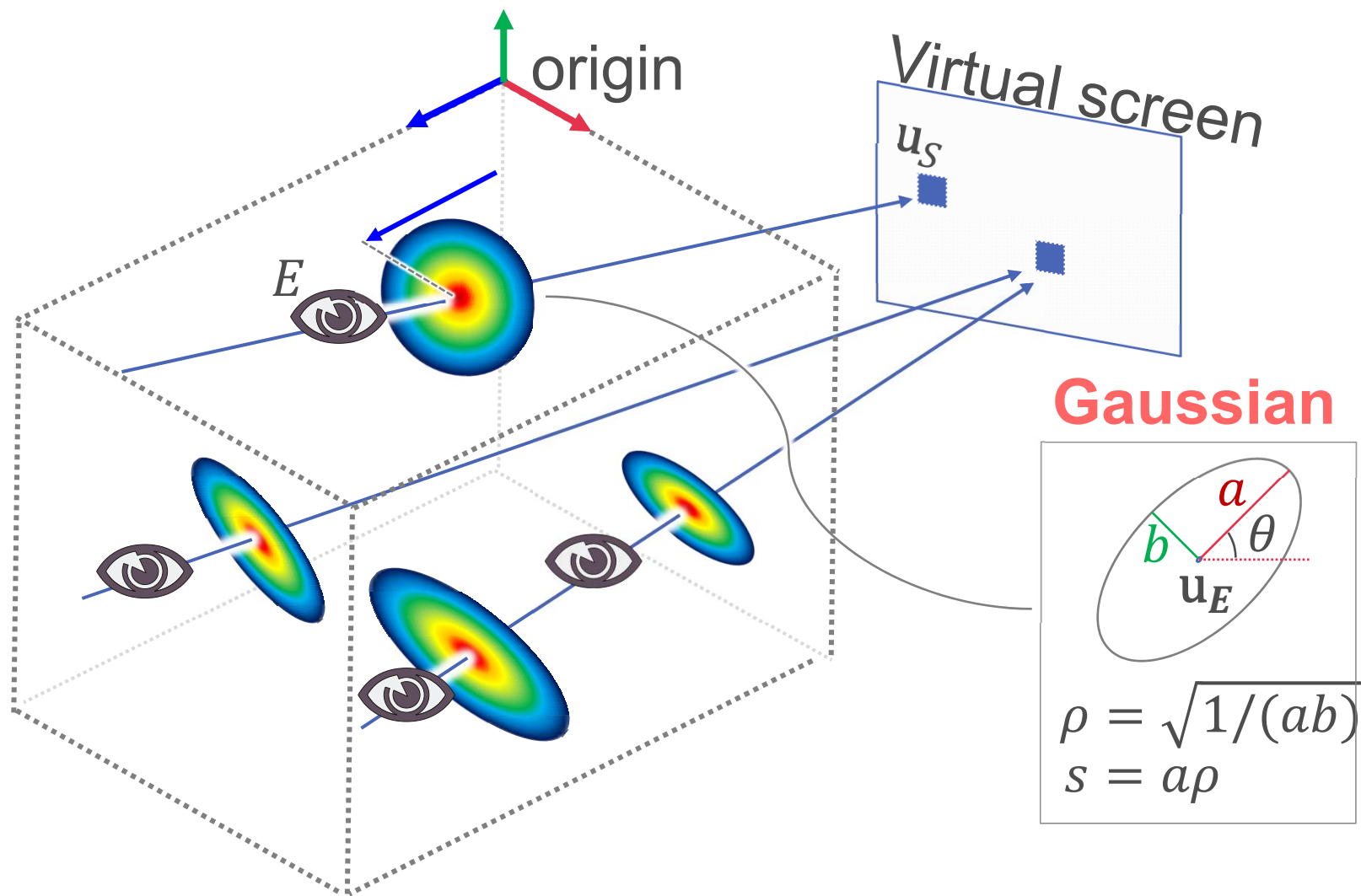










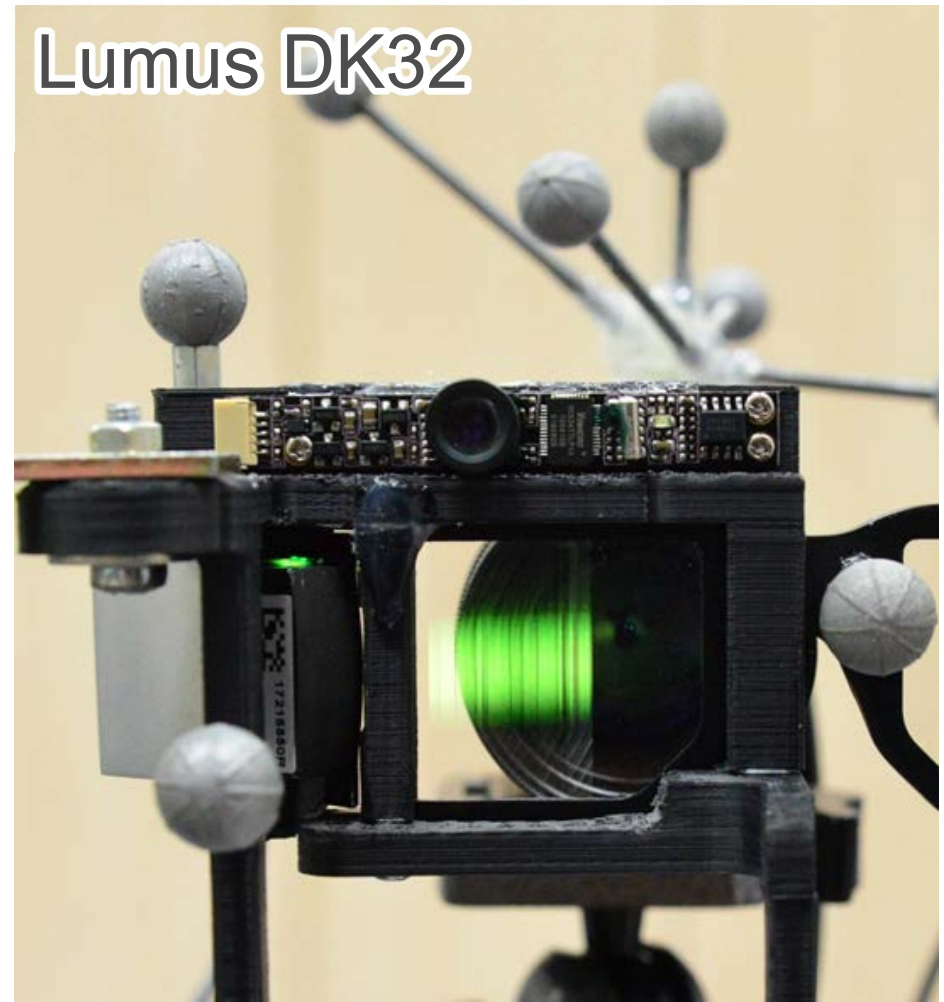




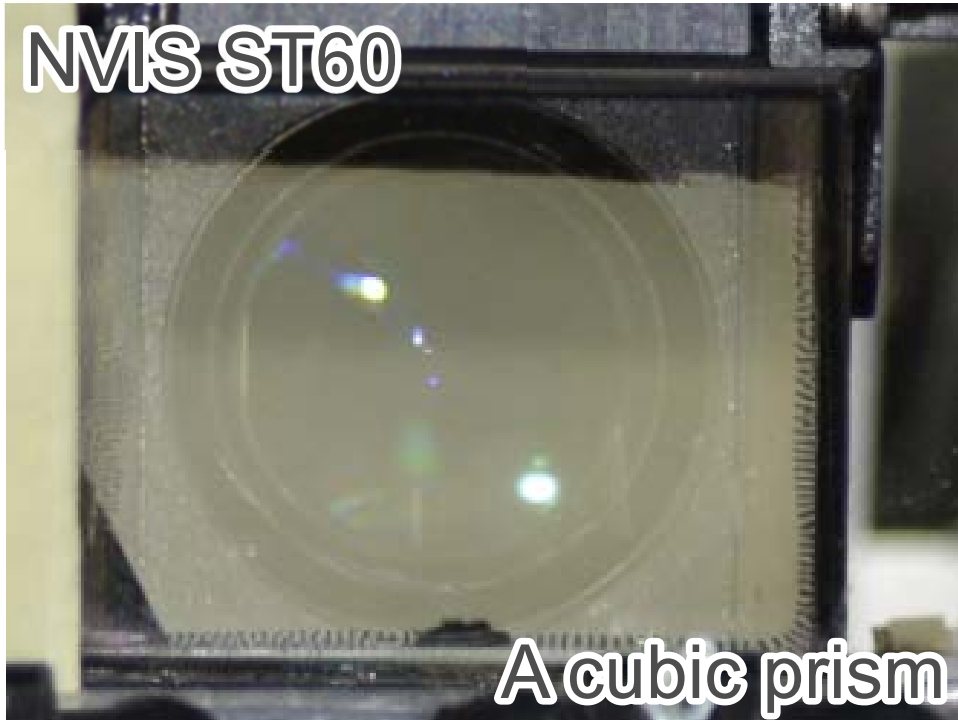
NVIS ST60



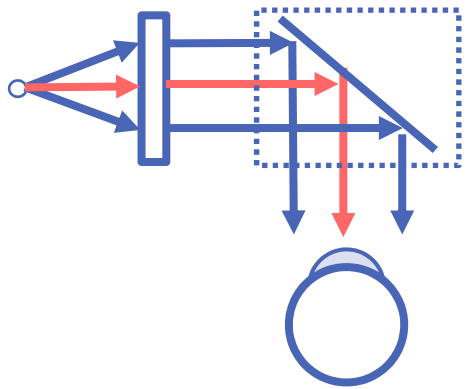
Lumus DK32



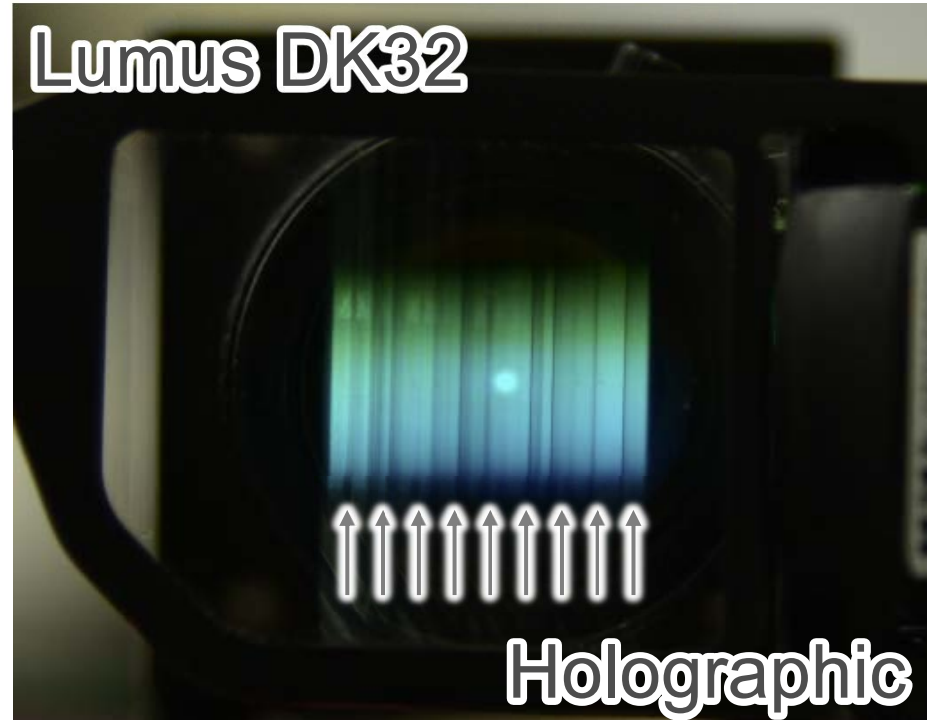
NVIS ST60



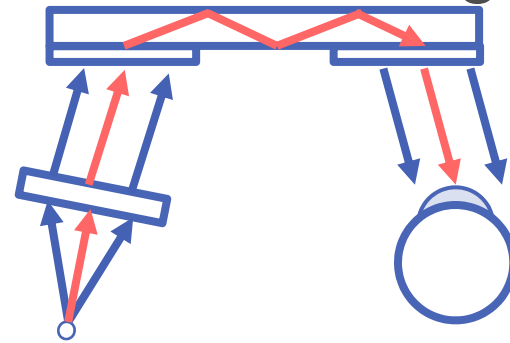
A cubic prism



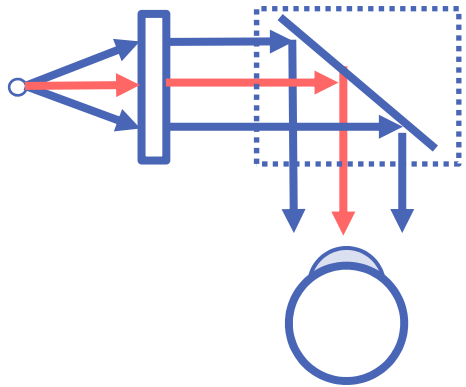
Lumus DK32



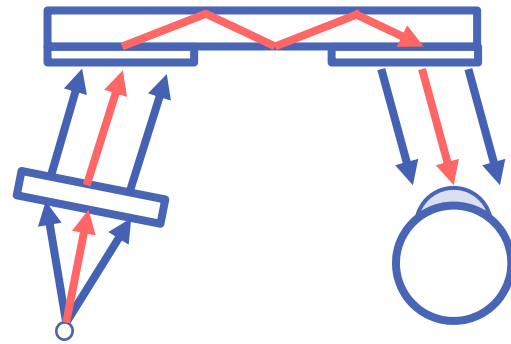
Holographic gratings



NVIS ST60

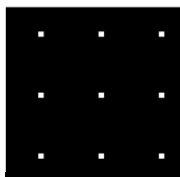


Lumus DK32

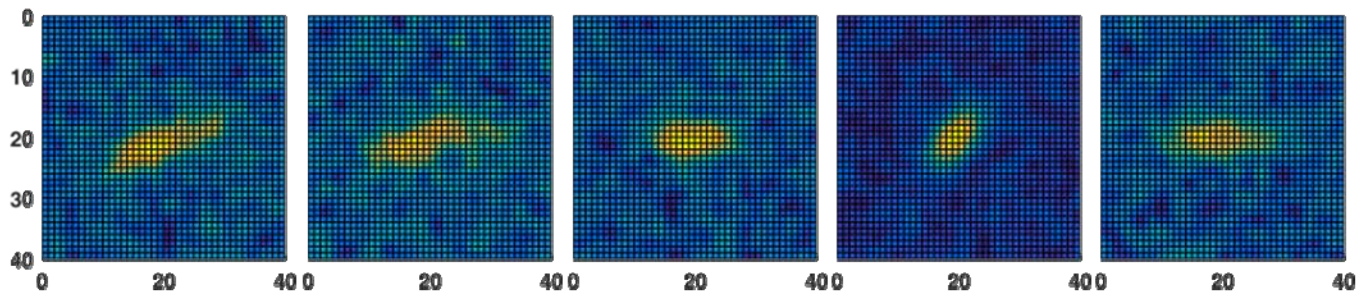


# Data collection

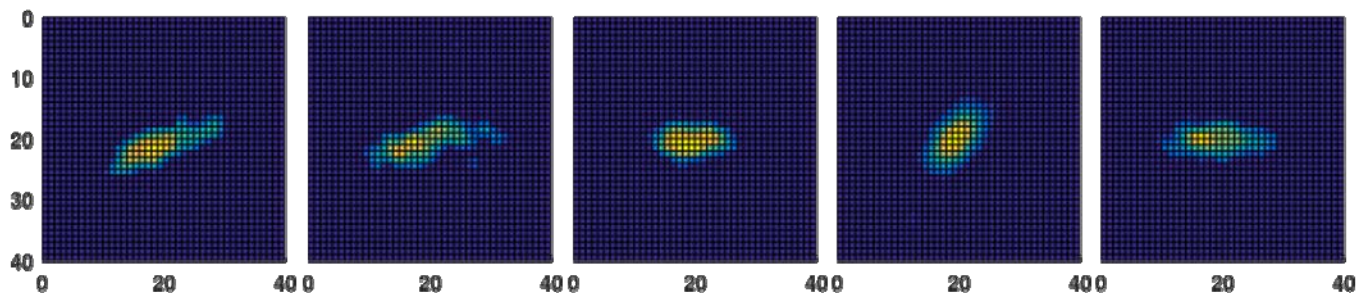
Input



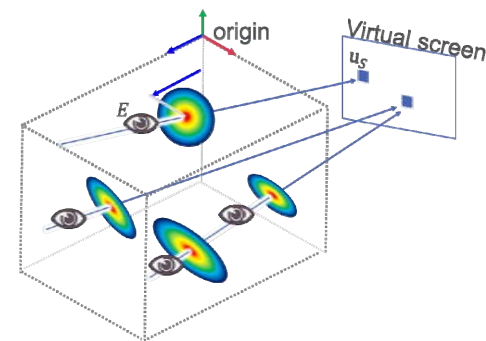
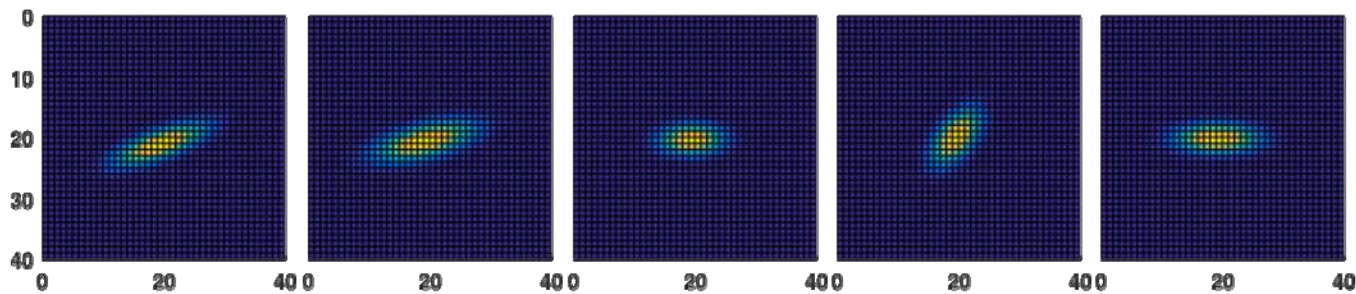
Raw image



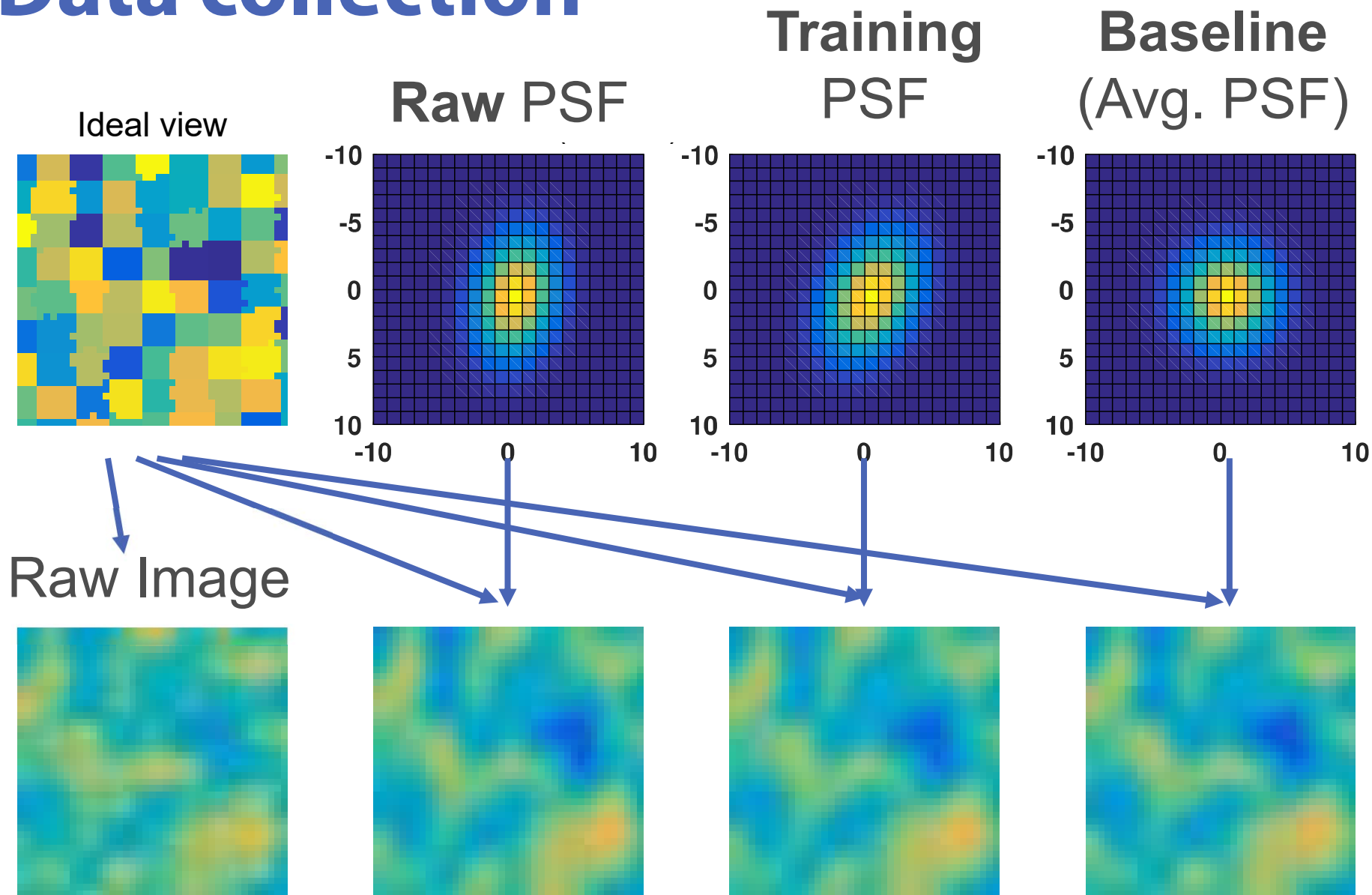
Filtered  
(Raw PSF)



Training  
PSF

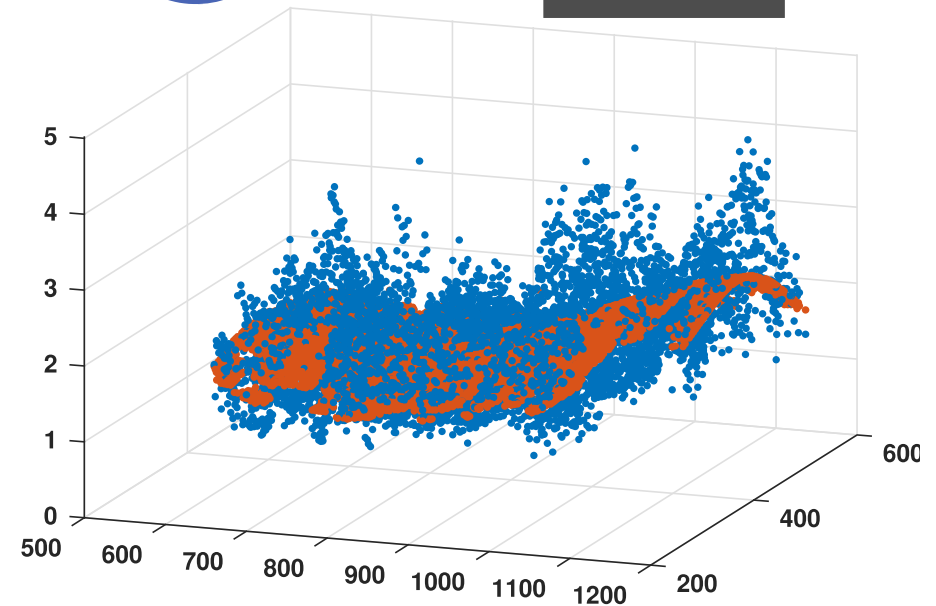
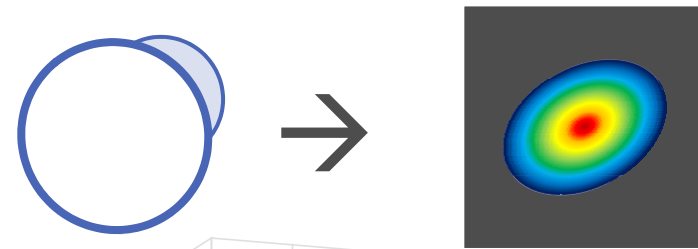
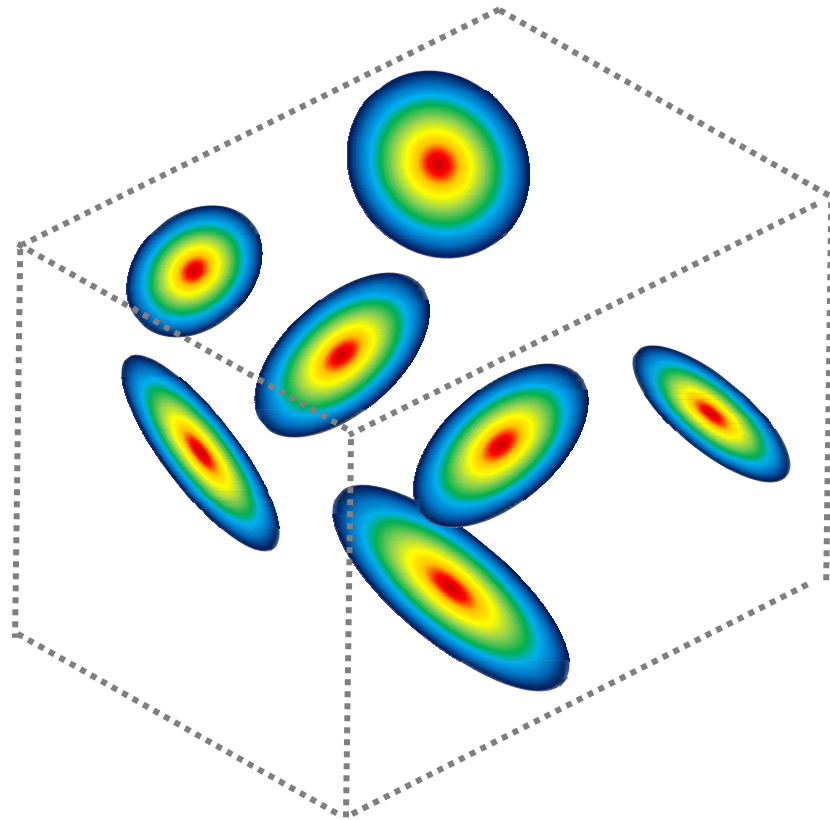


# Data collection

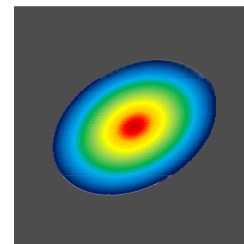
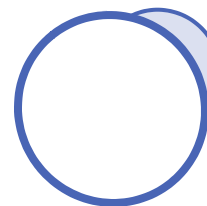
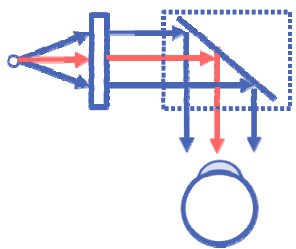


# Learning

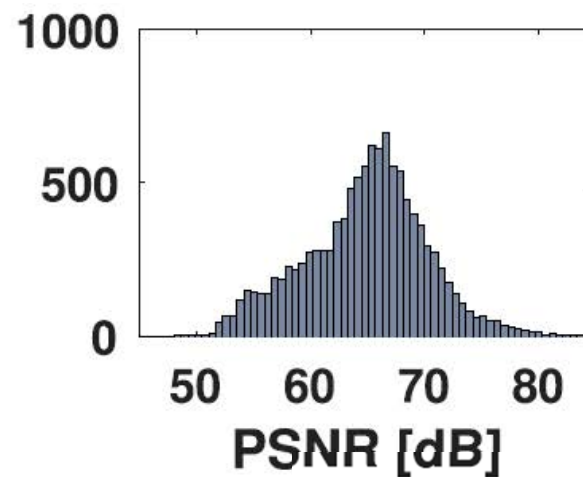
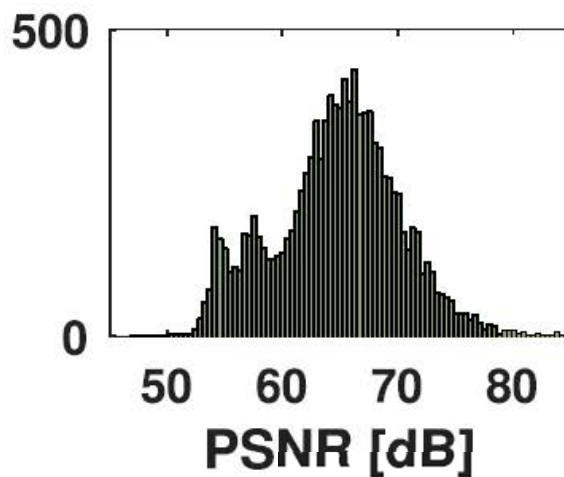
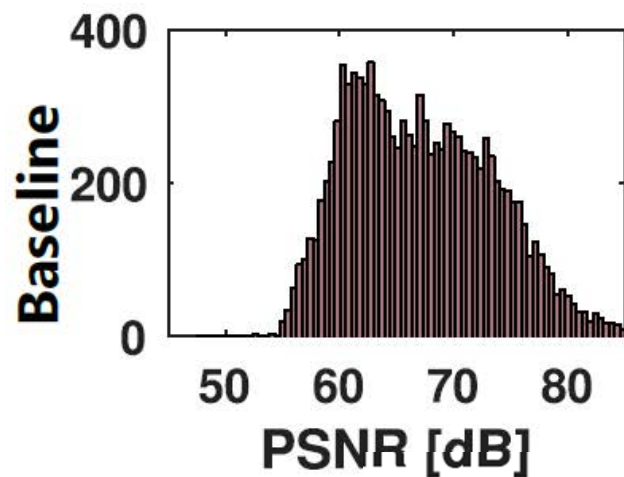
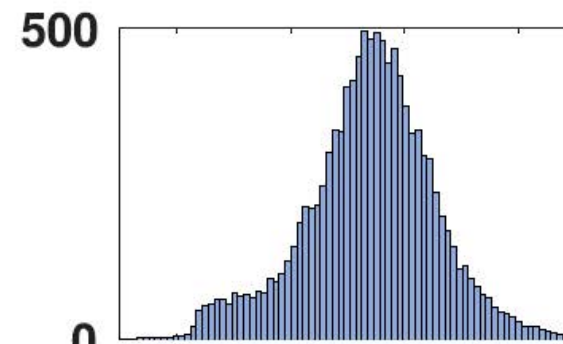
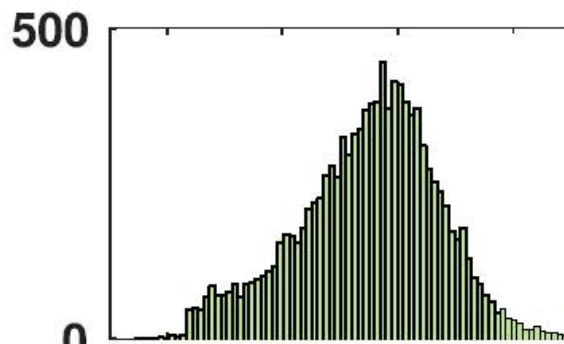
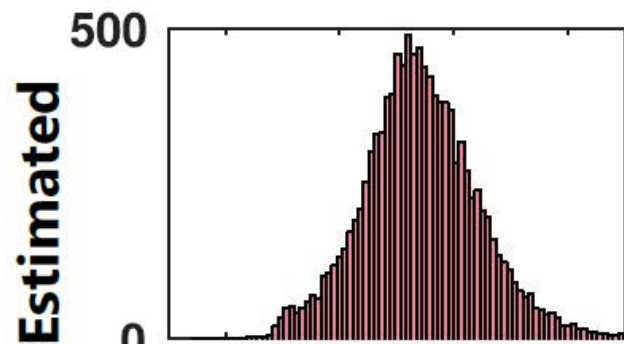
Training data  $\rightarrow$  Regression



# Testing



ST60



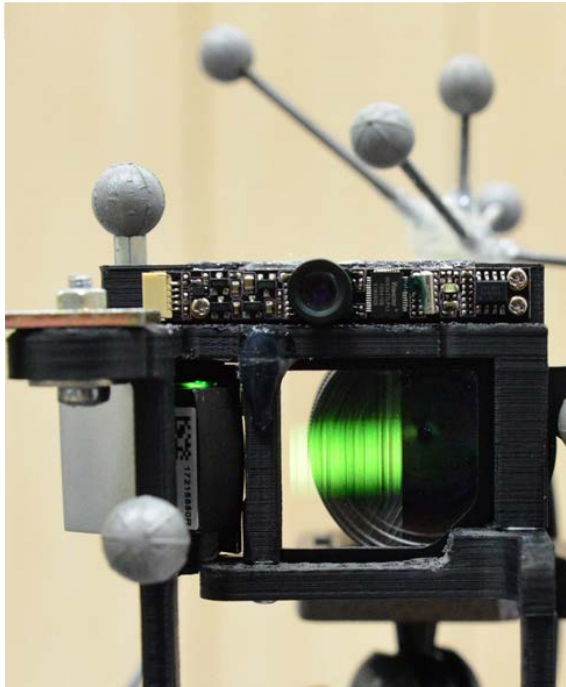
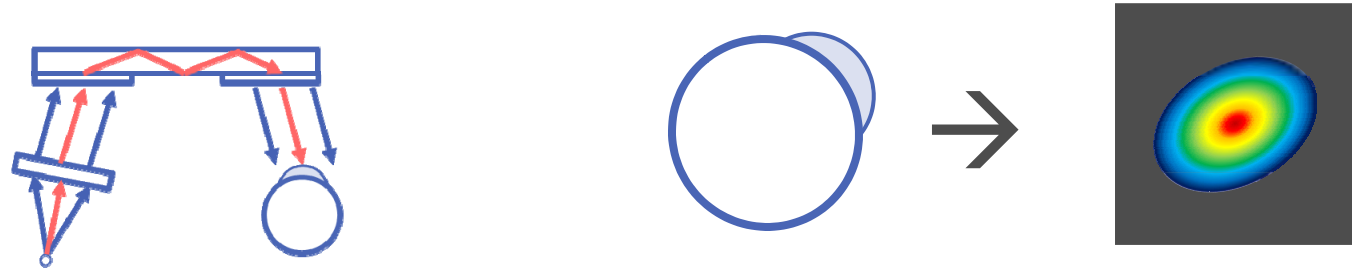
➔ Better

➔ Better

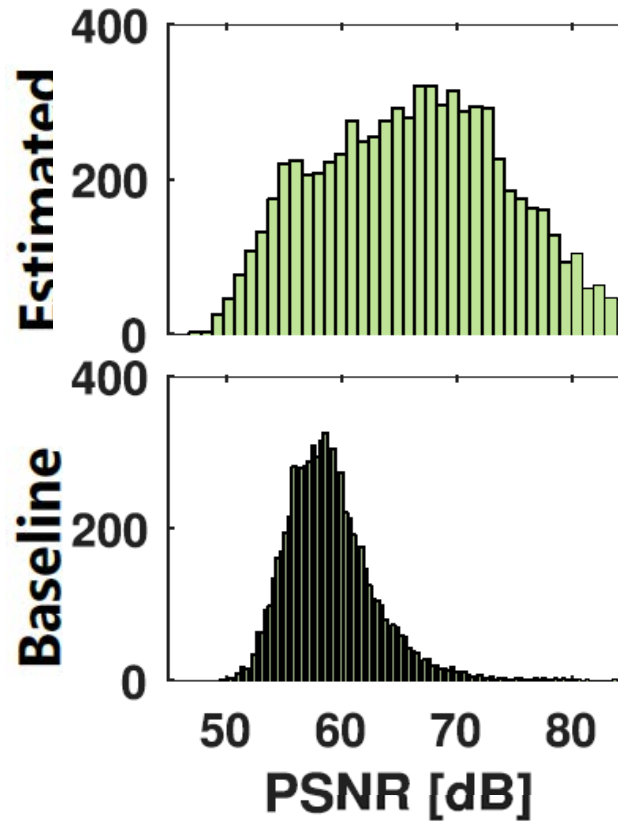
➔ Better

# Testing

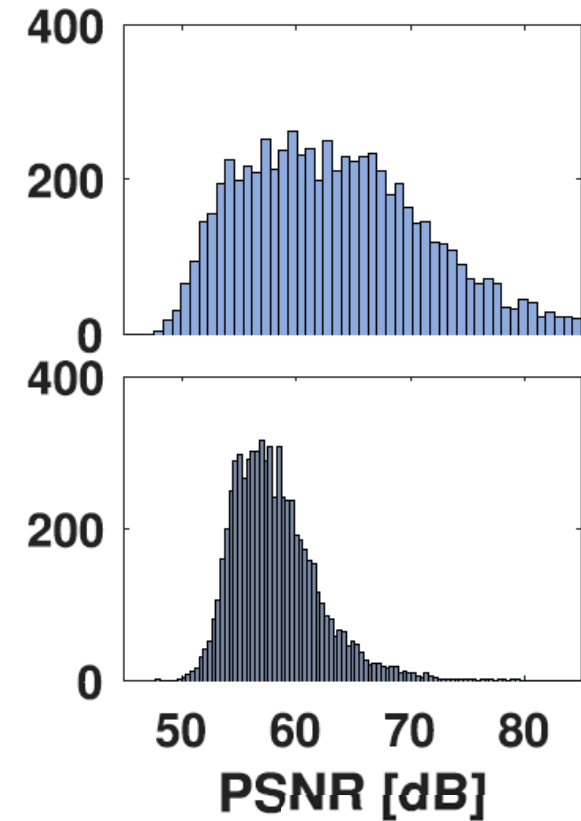
DK32



We failed to get enough # of data for the red channel



➔ Better

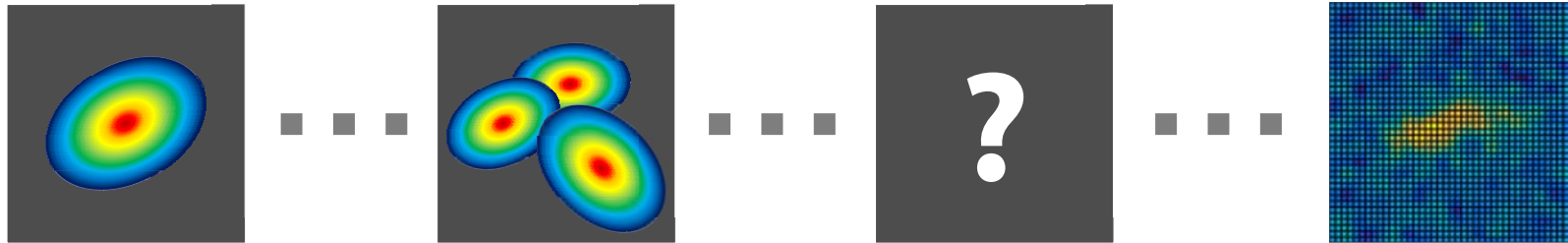


➔ Better

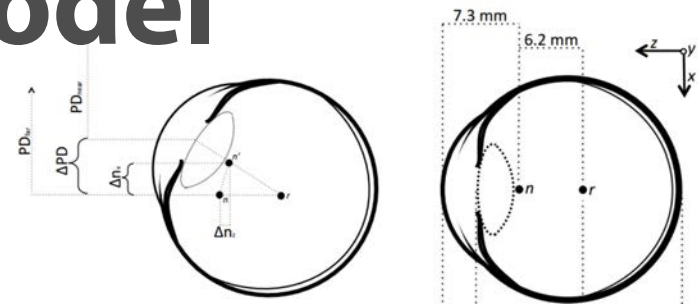
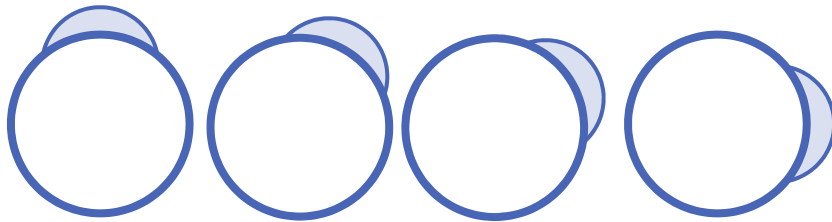


# Future work

- **Best PSF model?**



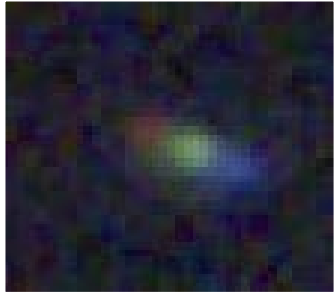
- **Eye orientation+model**



e.g., Jones et al., IEEE 3DUI 2016

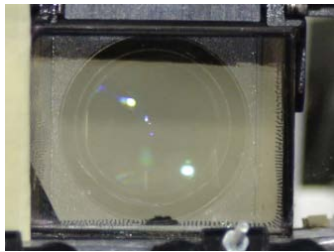
- **Real-time processing**

# Summary



- **Spatio-Visual** Realism in AR

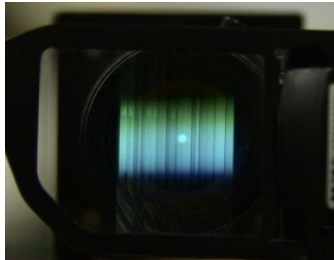
- Image blur in HMDs



- **View-dep. blur** model

- 4D light field

- + Point Spread Functions



- Evaluation on two HMDs

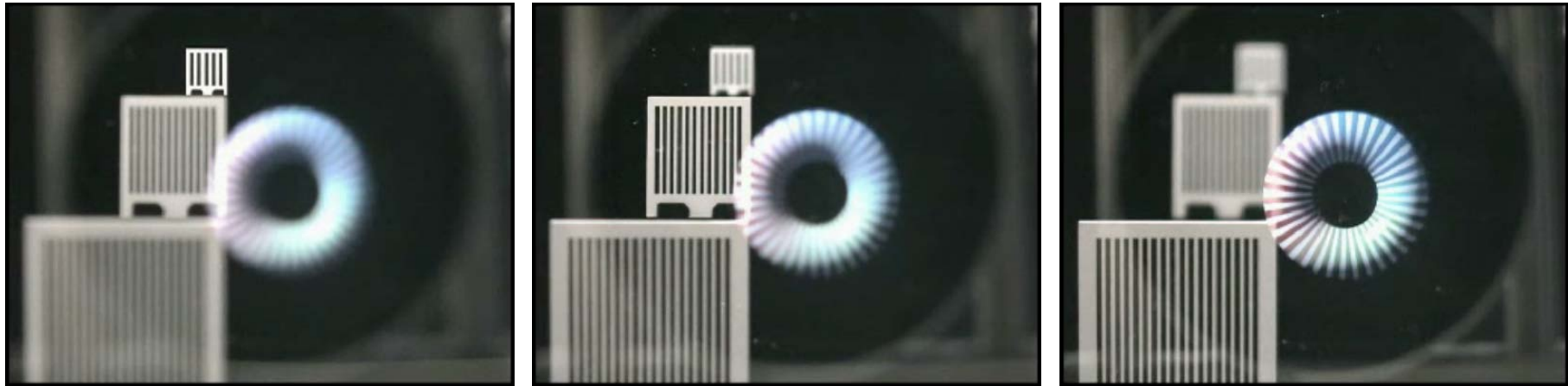
- Cubic prism & Waveguides

Thank you!

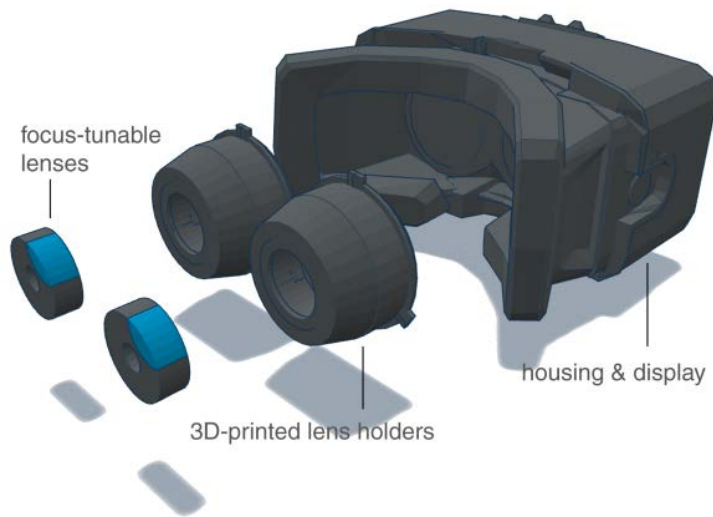


# Appendix

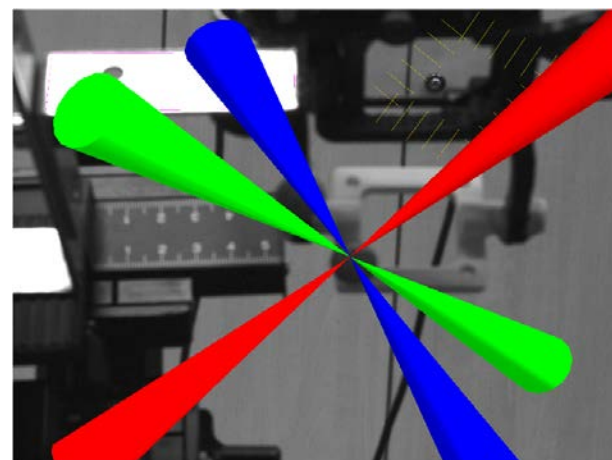
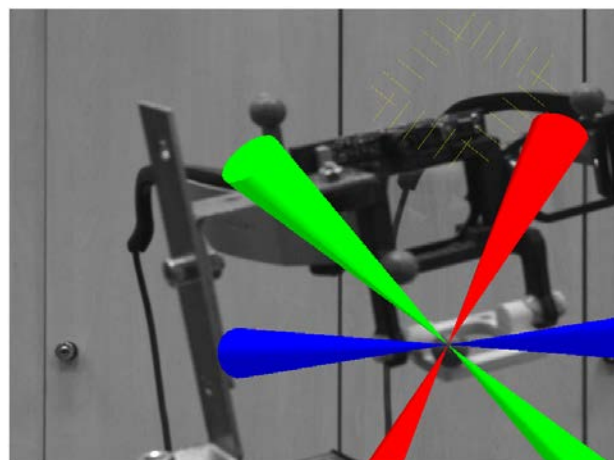
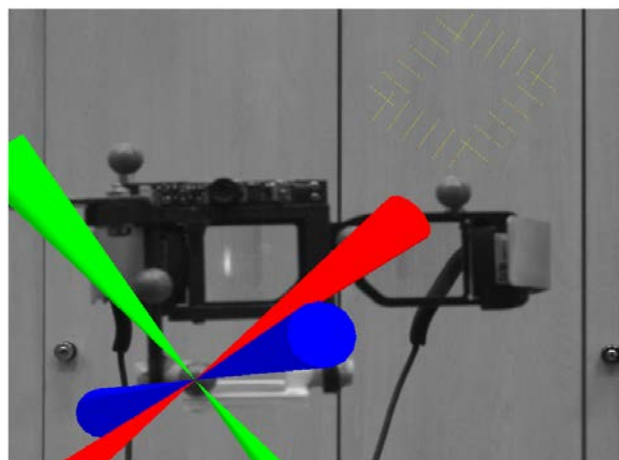
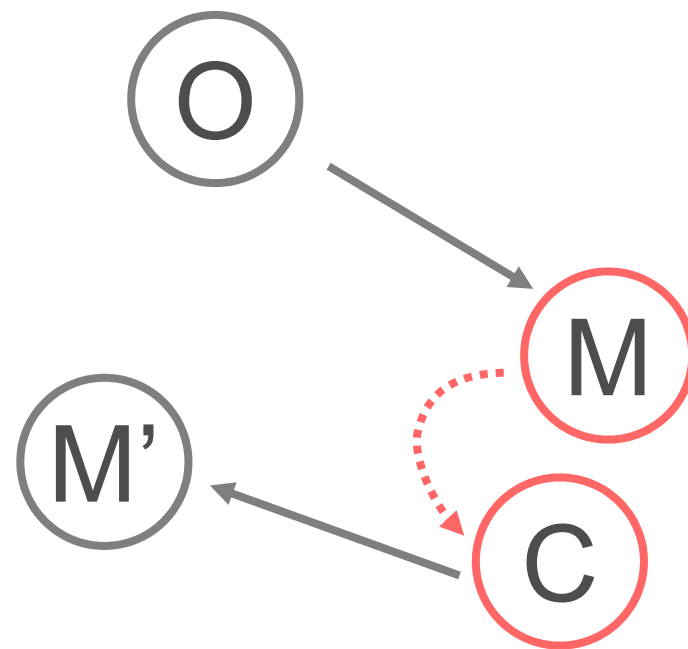
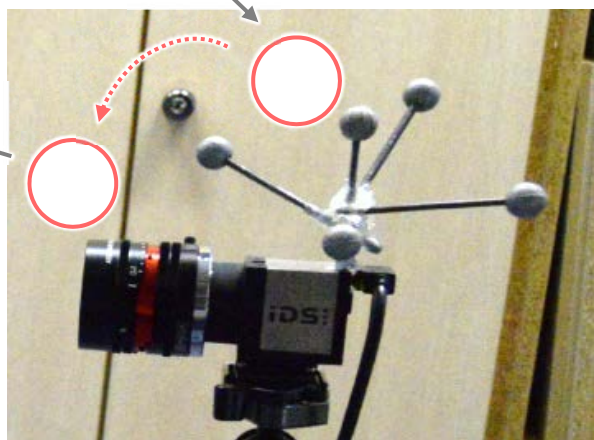
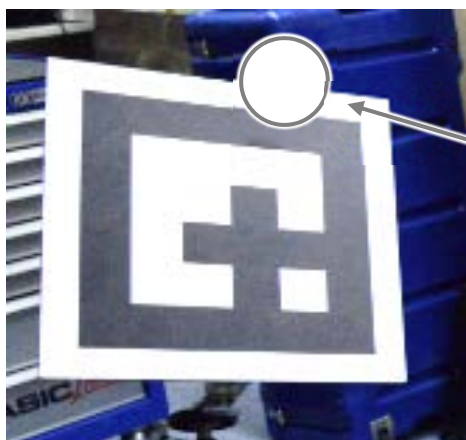
# Related Work: Multi-focus HMDs



Liu et al. 2008

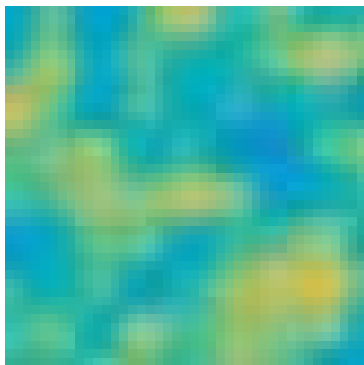


Konrad et al. 2016

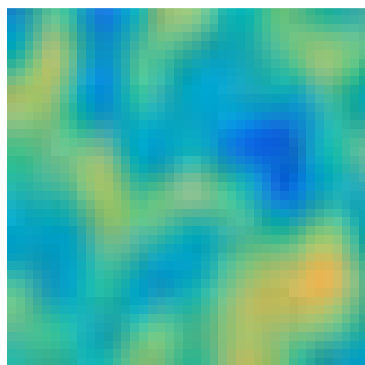


# Testing

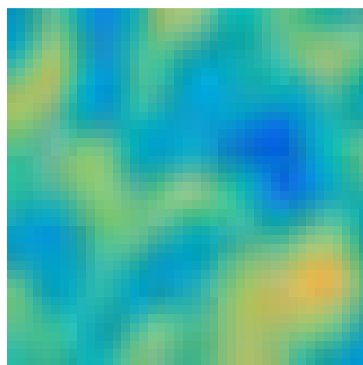
Observed view



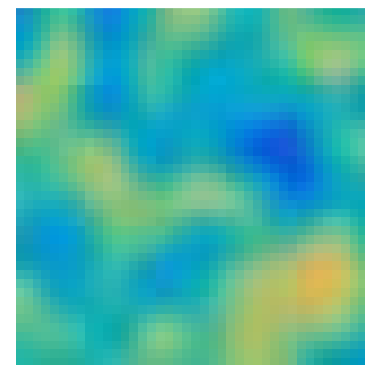
Raw PSF



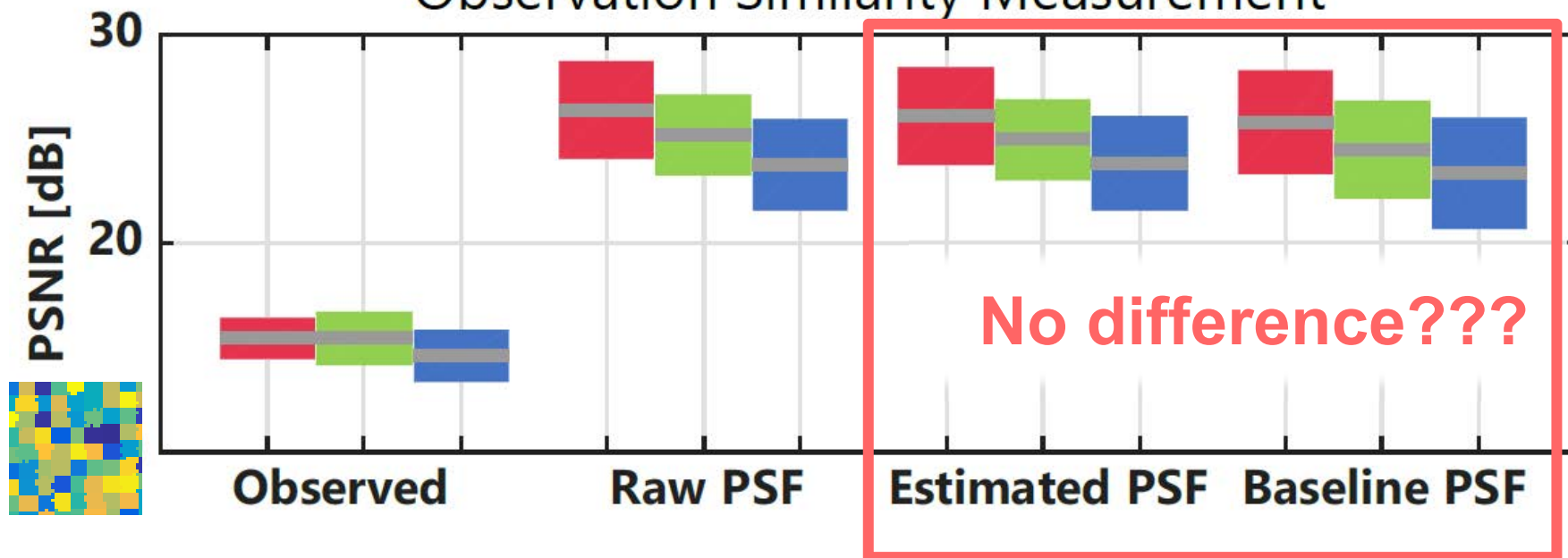
Estimated PSF



Baseline (Avg. PSF)



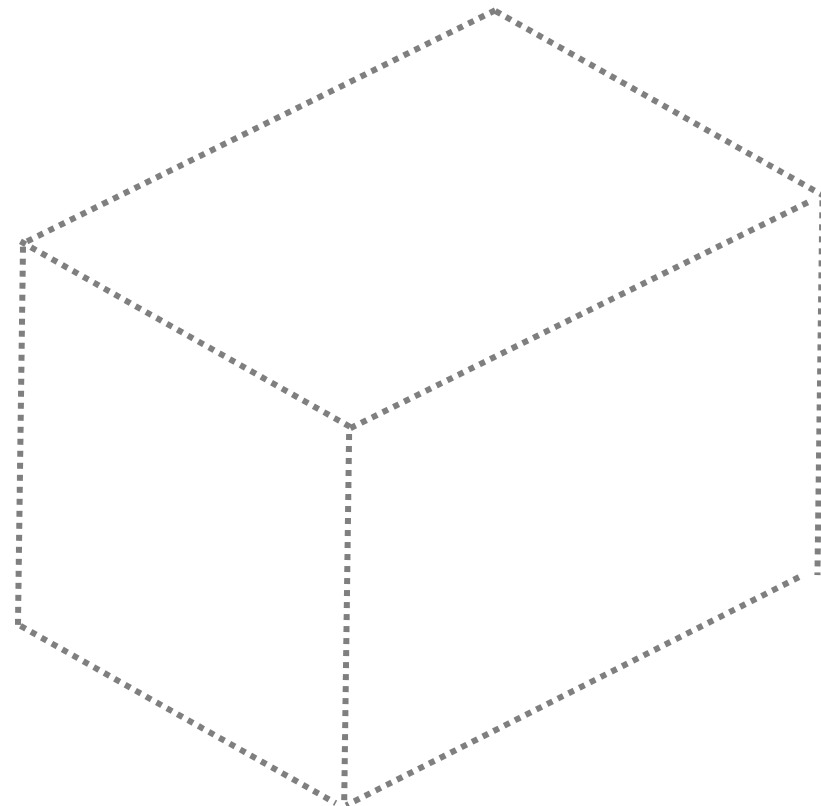
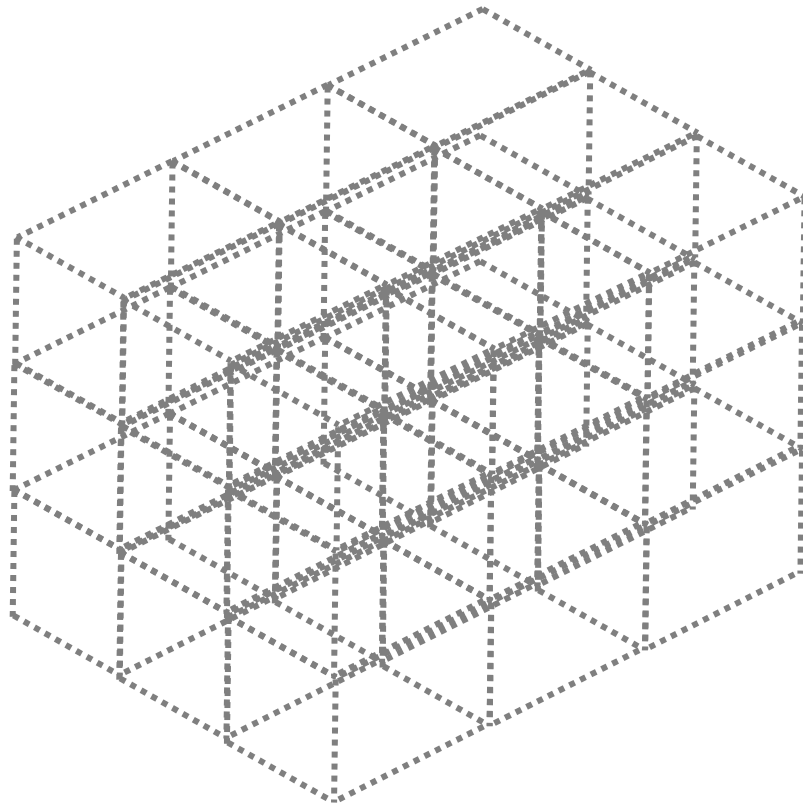
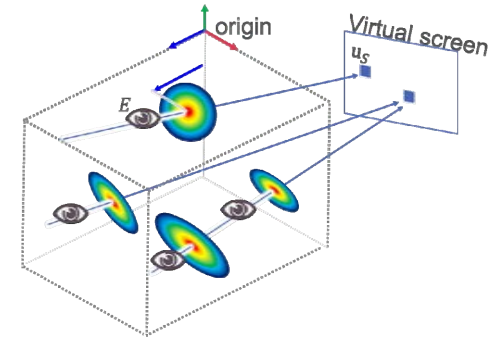
Observation Similarity Measurement

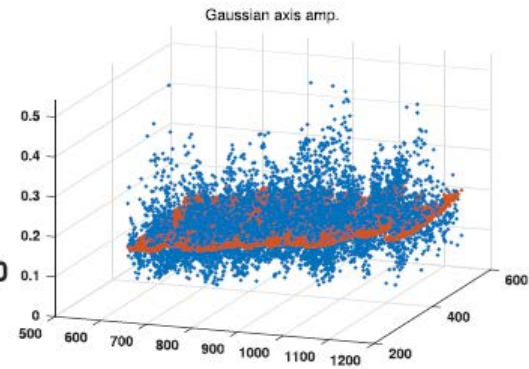
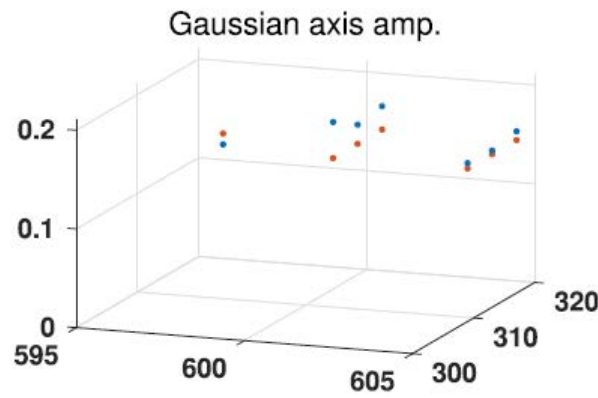
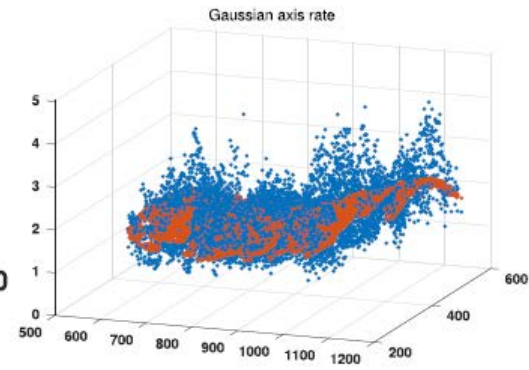
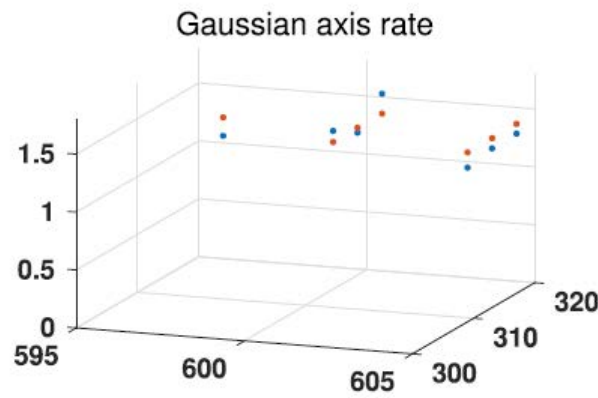
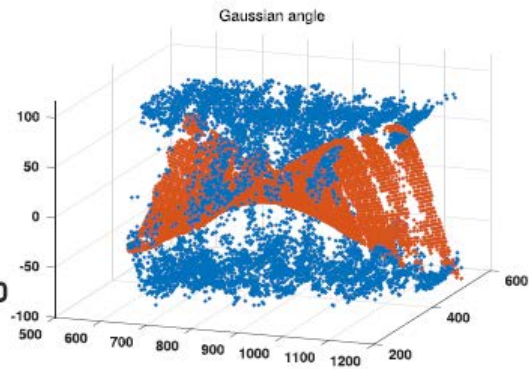
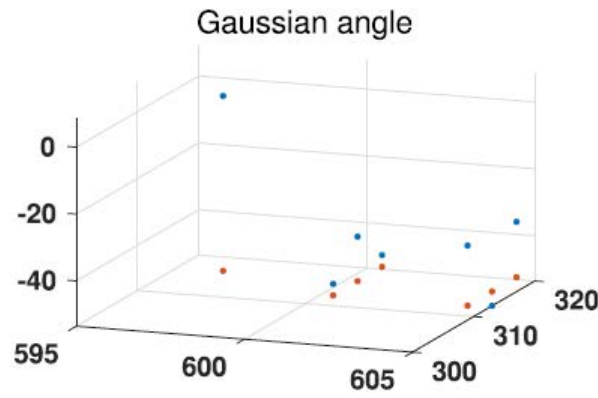






# Local v.s. Global sampling





● Ground-truth points ● Estimated points

- Global: 80,000 points

+ Local: <150 points/grid

