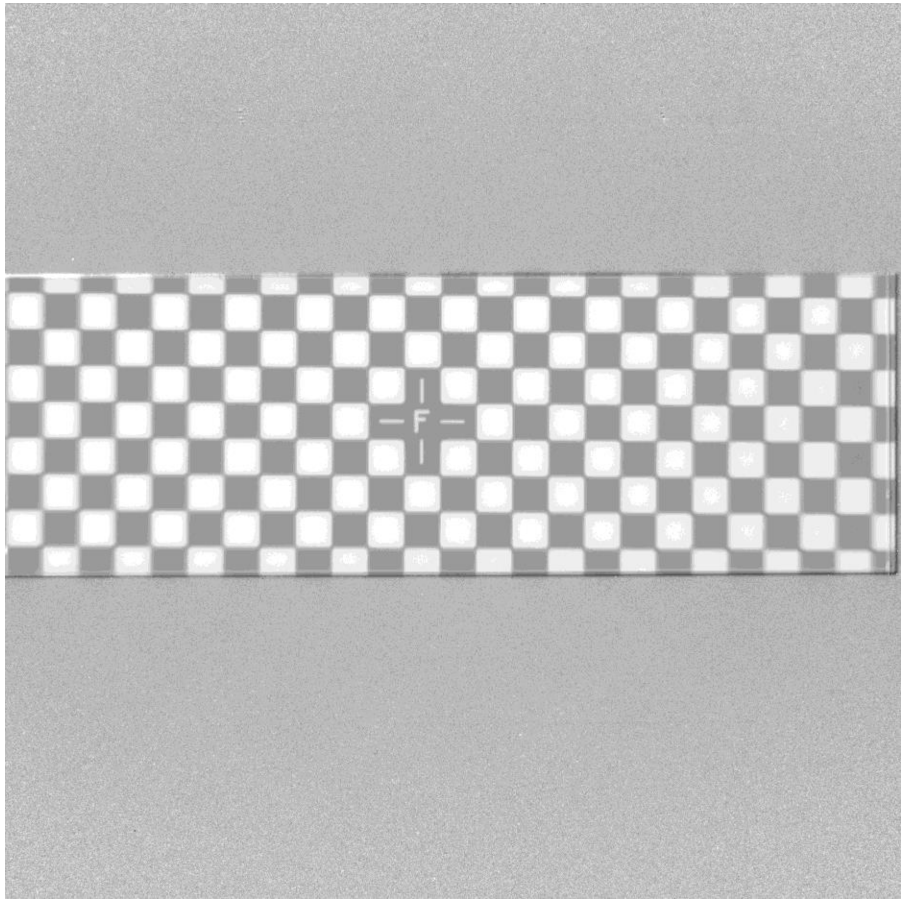
DOE/NV/03624--0671

Advanced Characterization of Spatial Aspects of Image System Blur

Experiments in Spatially Varying Deconvolution



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Jessica Pillow (U of Arizona),
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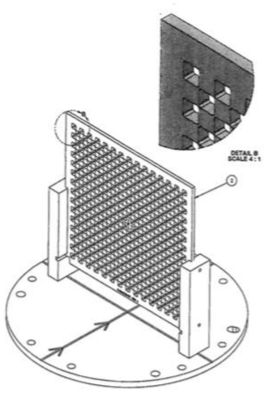
Aaron Luttman (PNNL)



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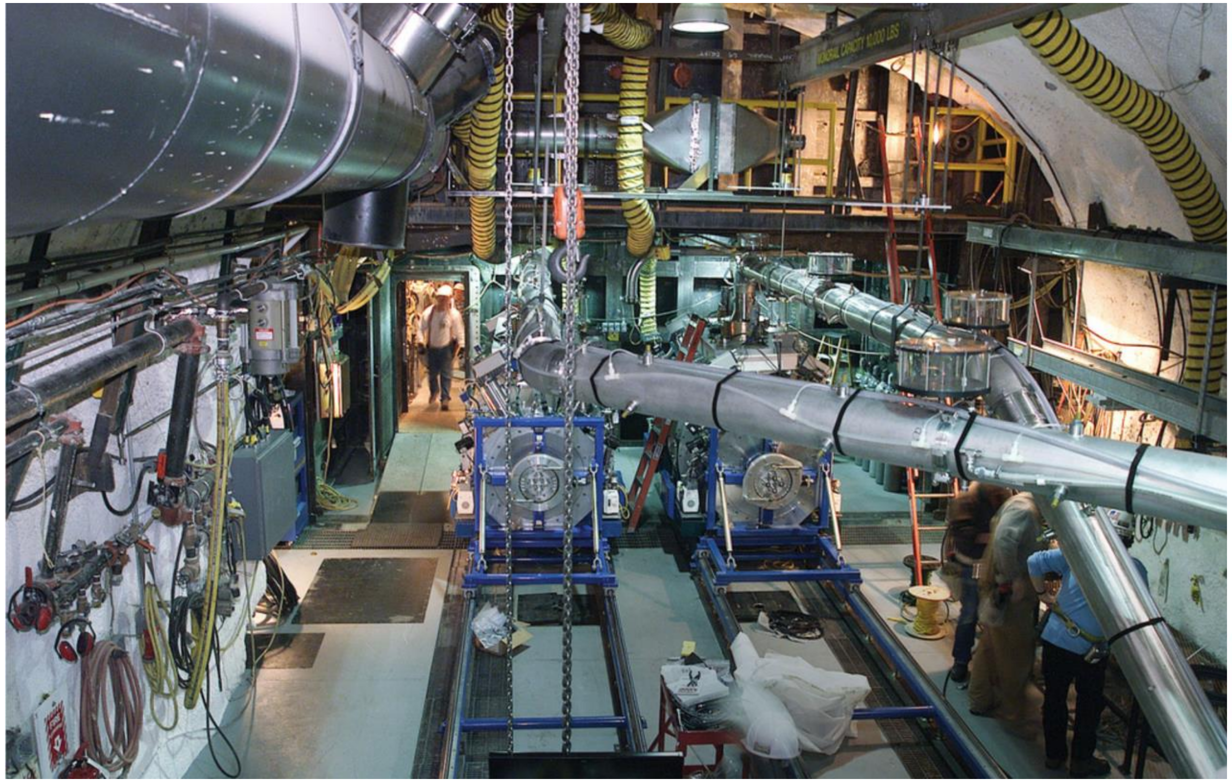
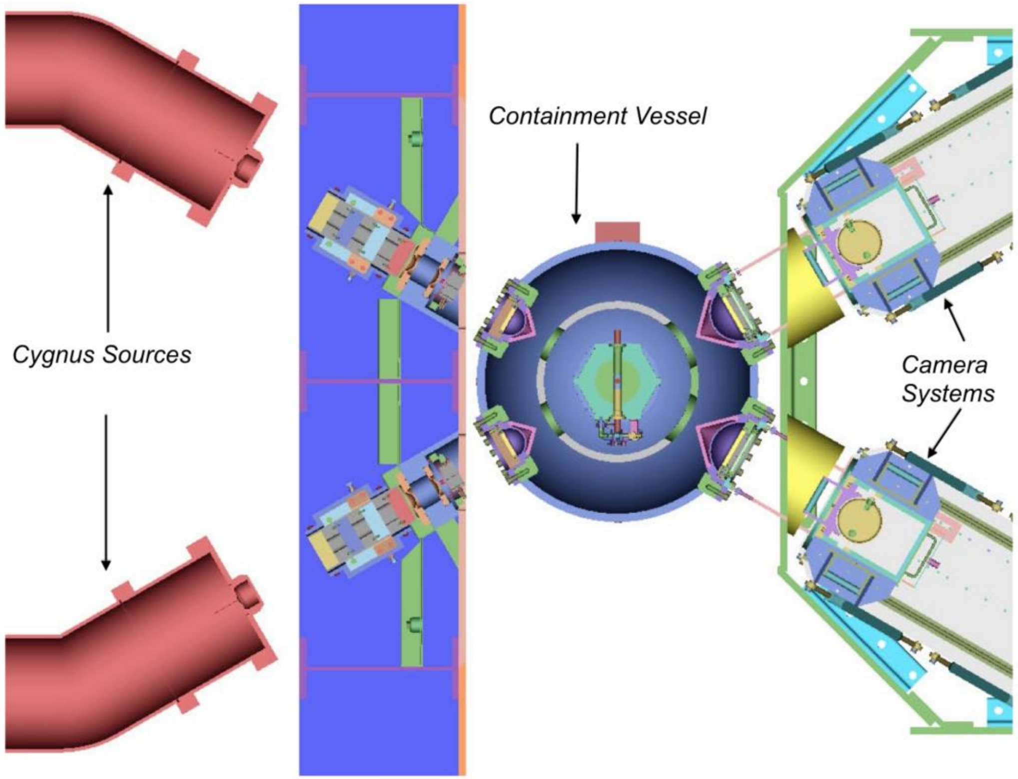
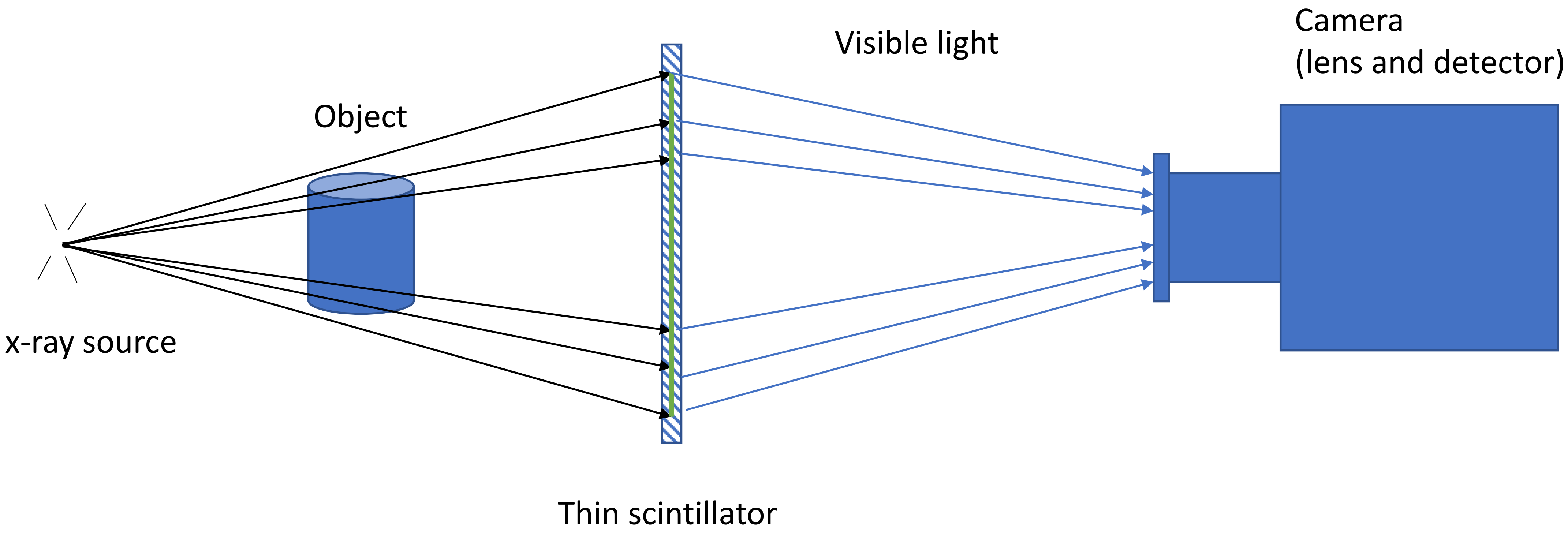
Radiography at the NNSS

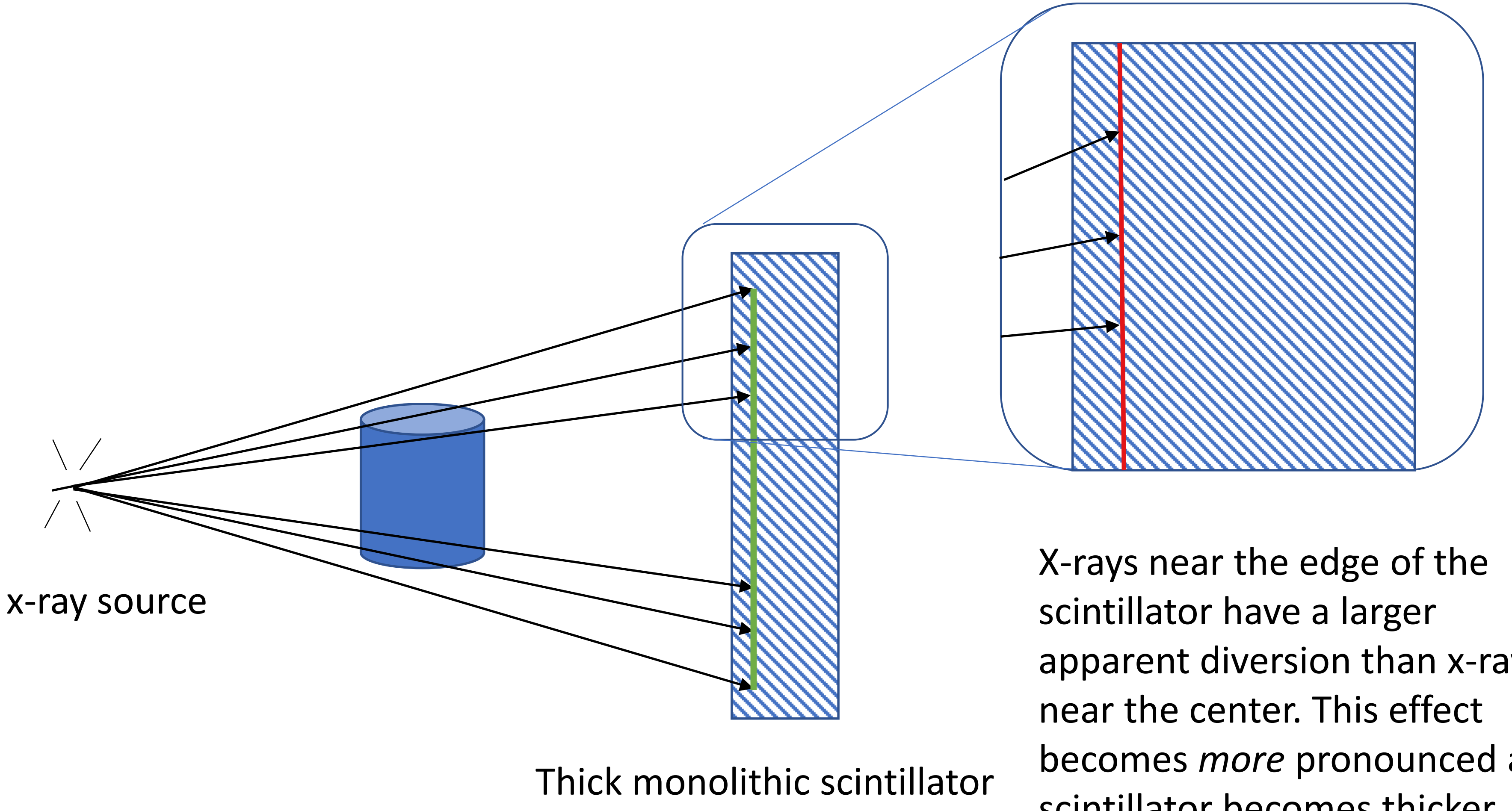




Blur in x-ray imaging



Spatially varying blur in x-ray imaging with thick scintillators and cone beams



X-rays near the edge of the scintillator have a larger apparent diversion than x-rays near the center. This effect becomes *more* pronounced as a scintillator becomes thicker.

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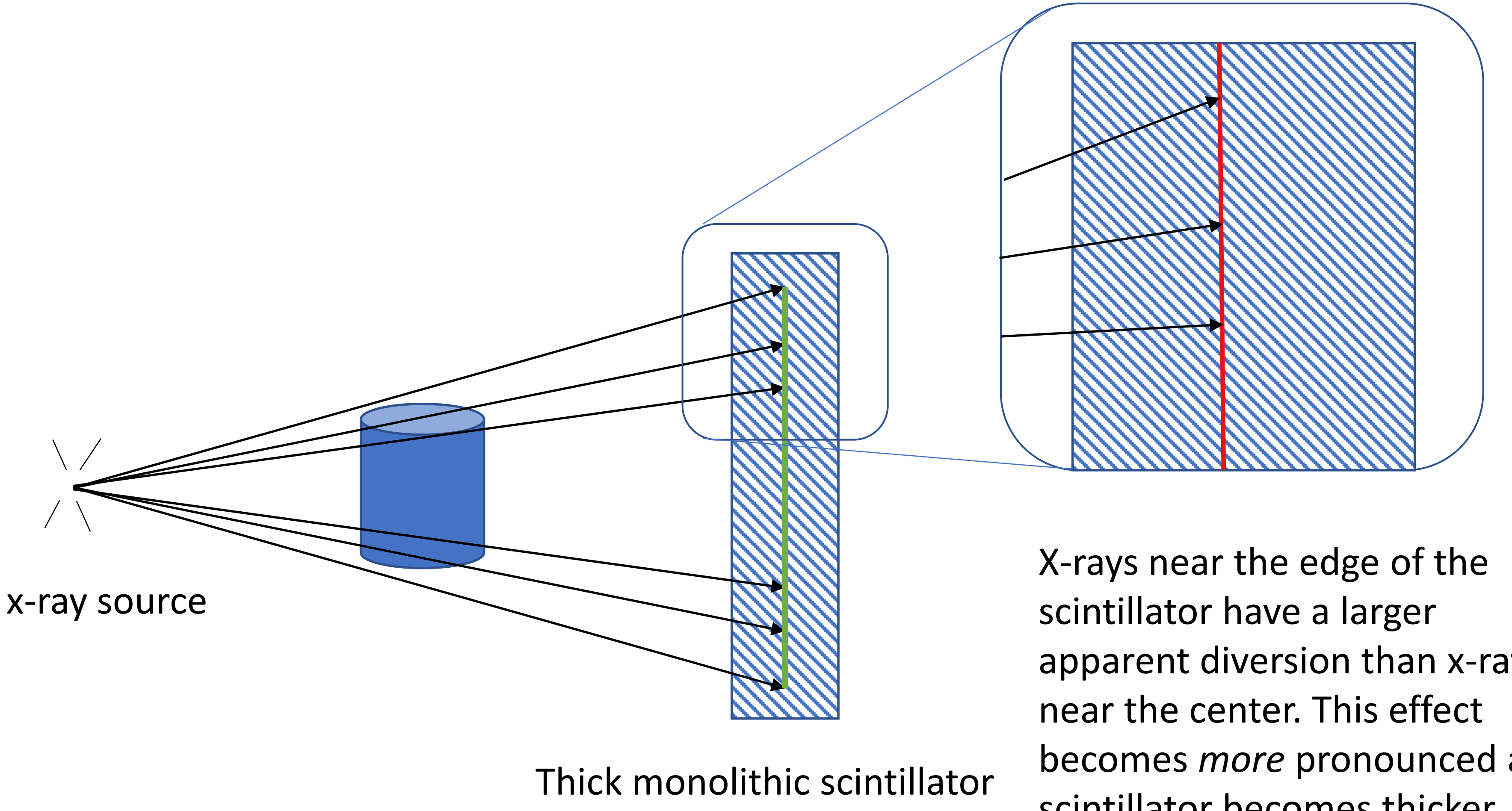

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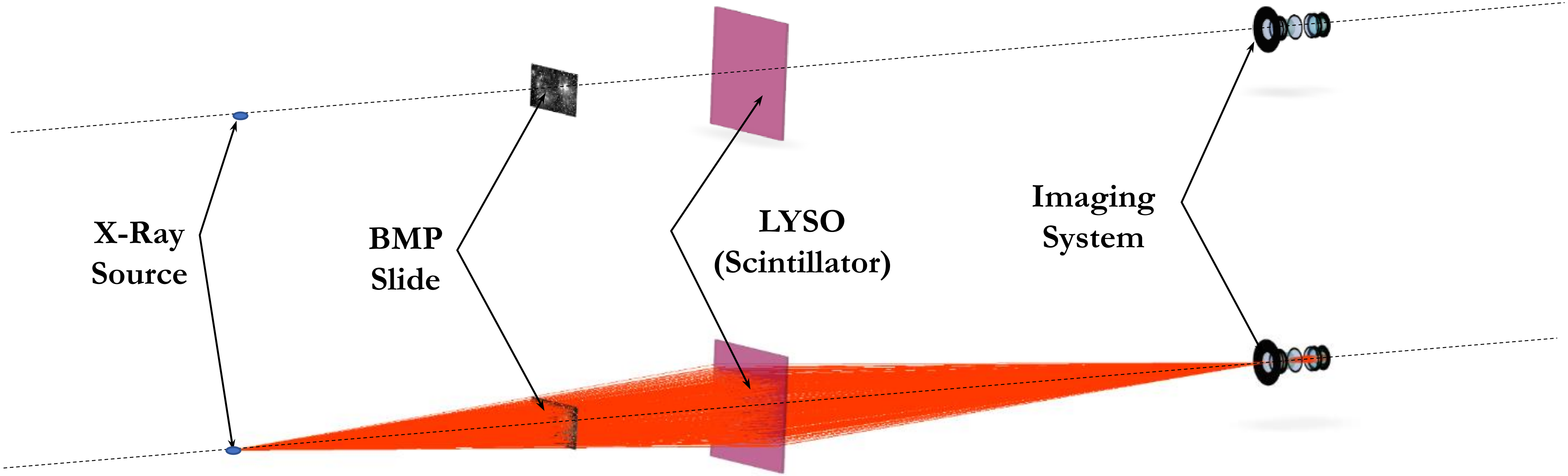
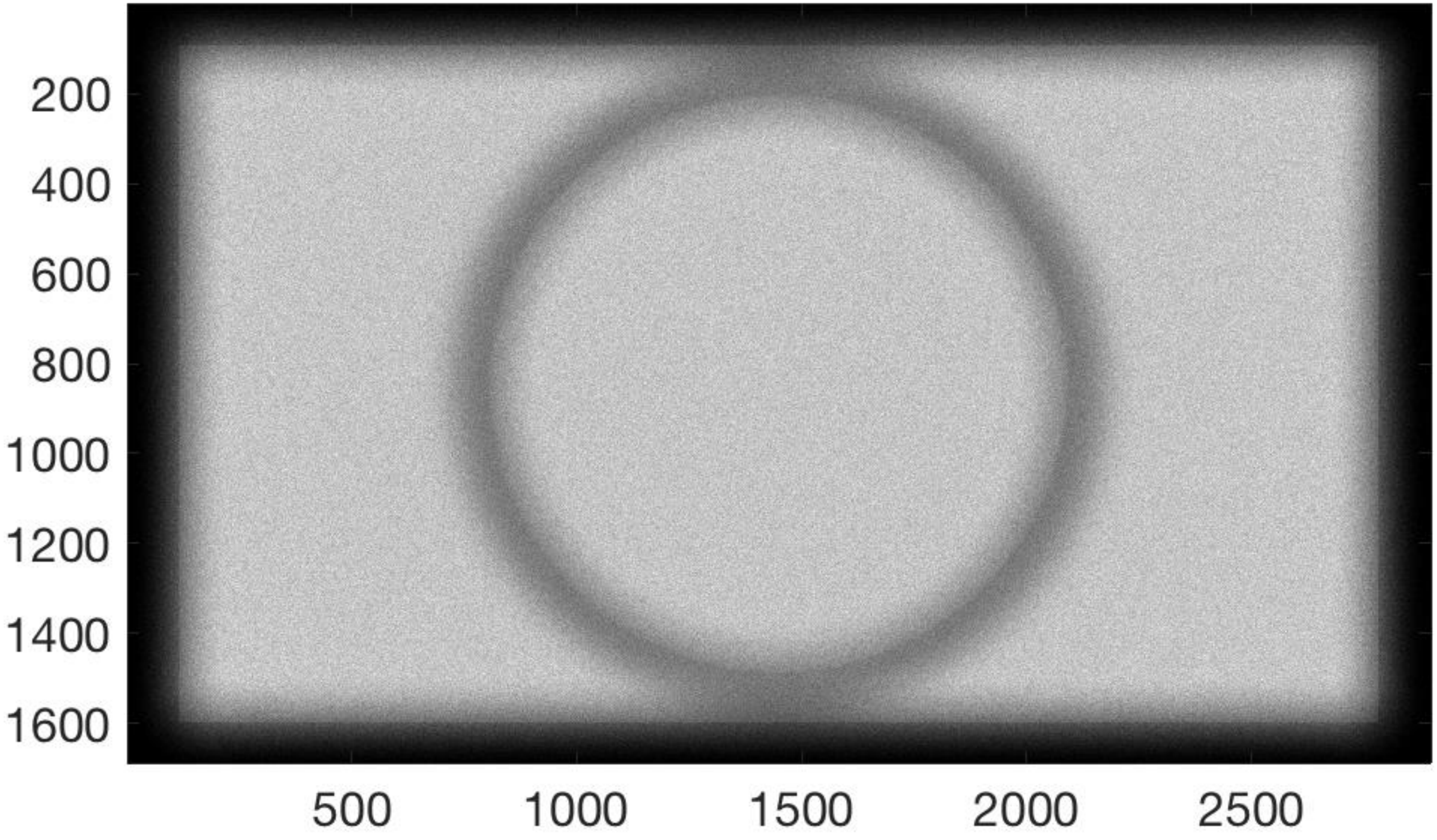
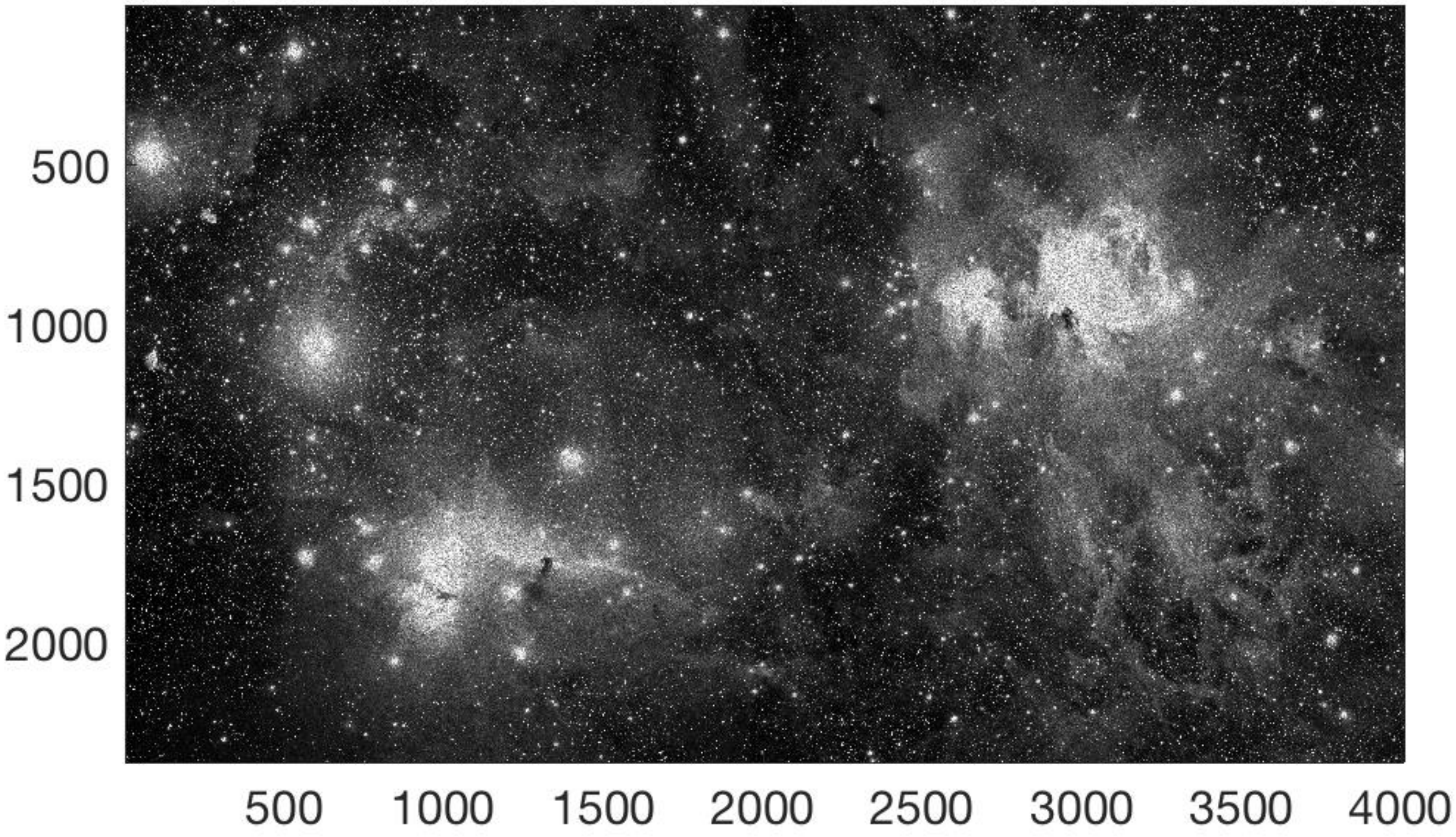
Synthetic data from optical software



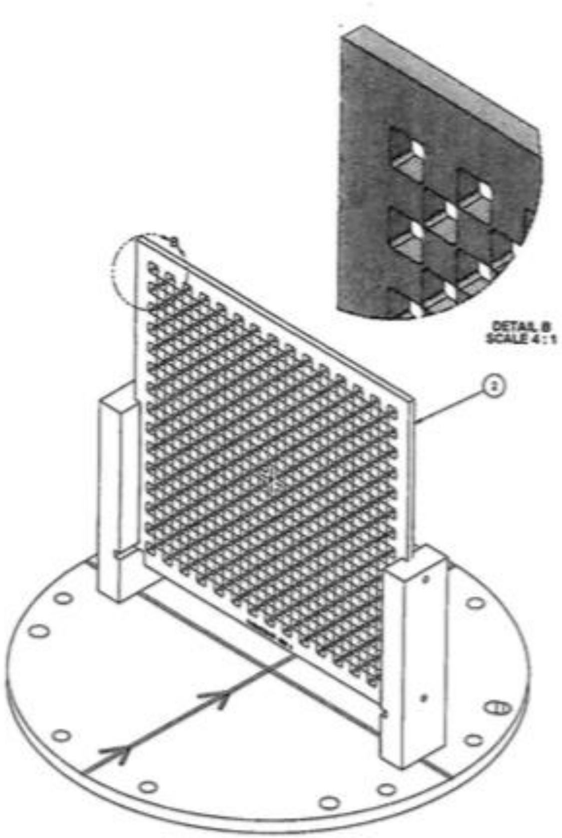
Synthetic data example 1: radially symmetric object

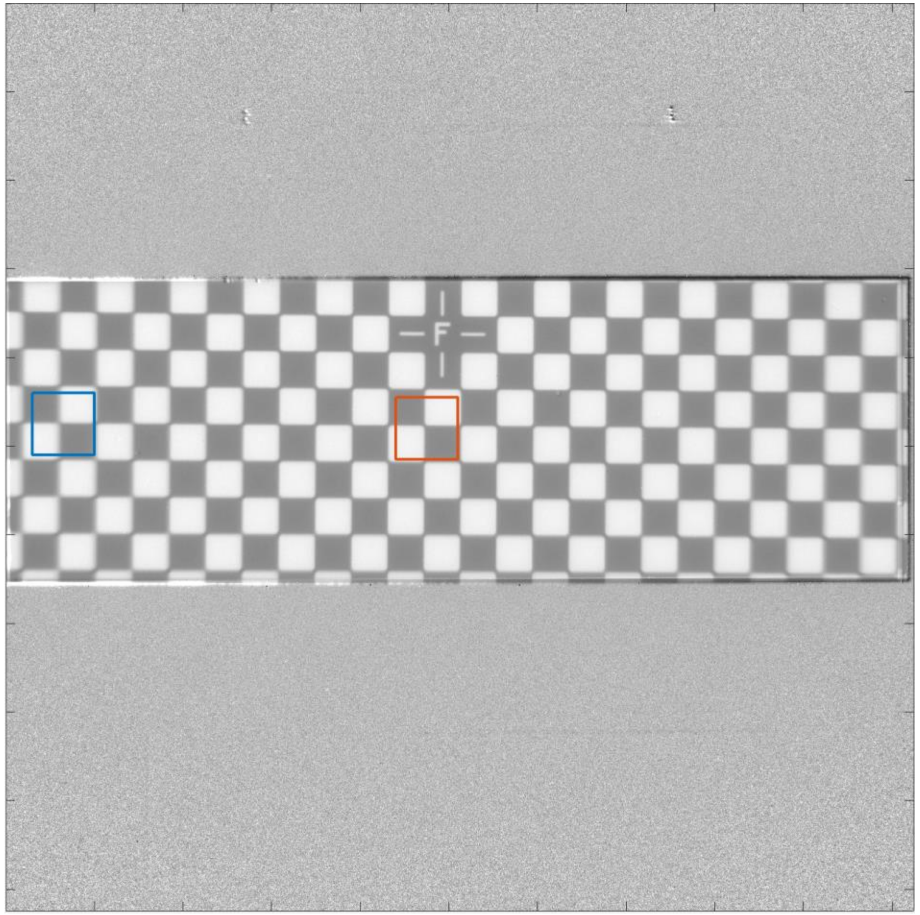


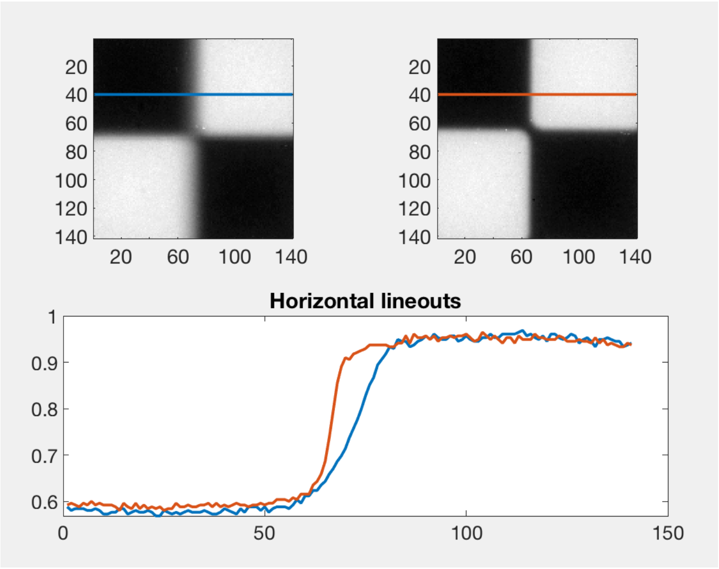
Synthetic data example 2: Orion nebula



Real data: checkerboard object







Standard deconvolution model

- $\boldsymbol{B}$: image data
  - Blurred and noisy
  - $\boldsymbol{b} = vec(\boldsymbol{B})$: column stacked image data
- $\boldsymbol{X}$: image reconstruction
  - Unknown, deblurred
  - $\boldsymbol{x} = vec(\boldsymbol{X})$: column stacked image
- $\boldsymbol{A}$: Blurring matrix
  - Based on a known blurring kernel

$$\boldsymbol{b} = \boldsymbol{A}\boldsymbol{x}$$
$$\boldsymbol{x} = (\boldsymbol{A}^\top \boldsymbol{A} + \gamma \boldsymbol{L})^{-\mathbf{1}} \boldsymbol{A}^\top \boldsymbol{b}$$

- γ: regularization scaling parameter
- $\boldsymbol{L}$: regularization matrix

Standard deconvolution model with UQ

- Likelihood:
  - $\boldsymbol{b}|\boldsymbol{x}, \lambda \sim N(\, \boldsymbol{A}\boldsymbol{x}, \lambda^{-1}\boldsymbol{I})$
  - λ: likelihood precision
- Prior:
  - $\boldsymbol{x}|\delta \sim N(\, \boldsymbol{0}, (\delta \boldsymbol{L})^{-1} \,)$
  - δ: prior precision
- $\boldsymbol{A}$: Blurring matrix
  - Based on a known blurring kernel
- $\boldsymbol{L}$: regularization matrix
- $\boldsymbol{H}_{\boldsymbol{\lambda},\boldsymbol{\delta}} = \lambda \boldsymbol{A}^\top \boldsymbol{A} + \delta \boldsymbol{L}$

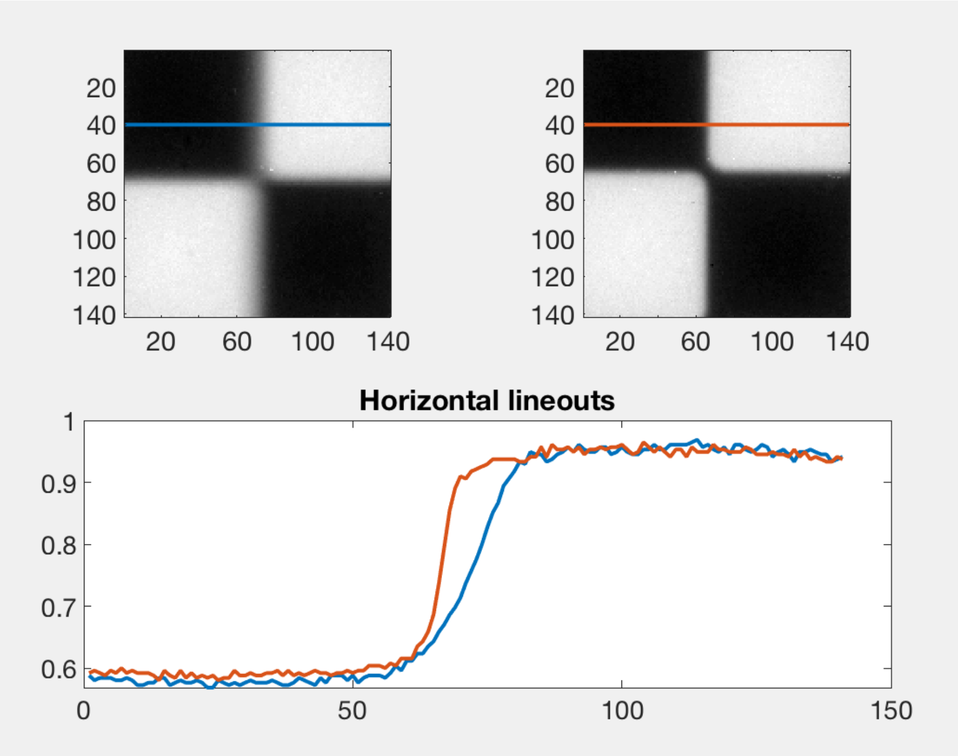
$$\boldsymbol{b} = \boldsymbol{A}\boldsymbol{x} + \boldsymbol{\epsilon}$$

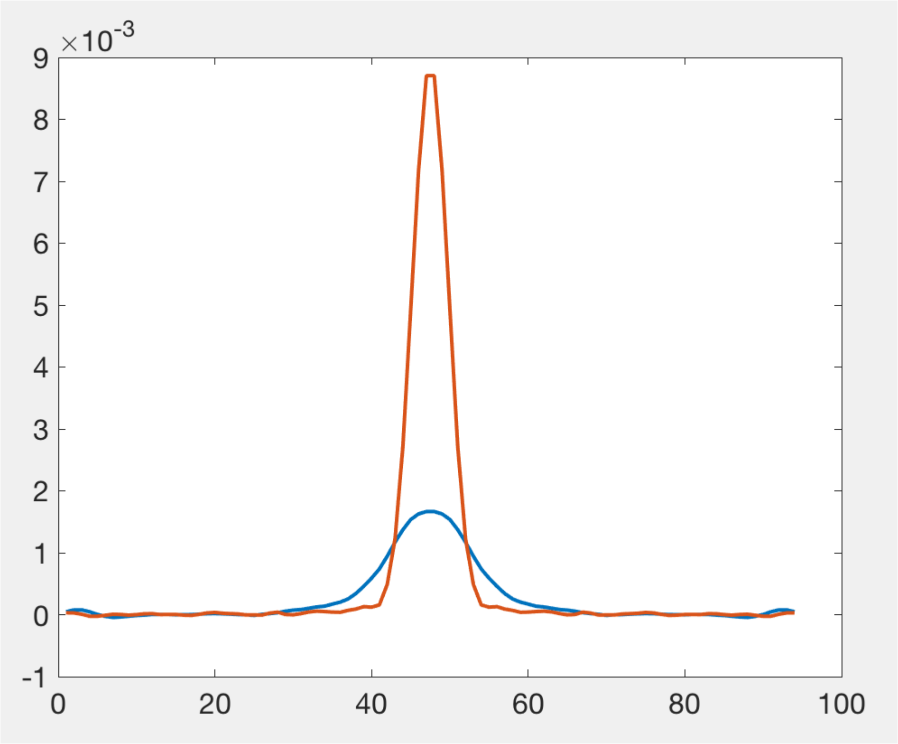
$$\boldsymbol{x}|\boldsymbol{b}, \lambda, \boldsymbol{\delta} \sim \boldsymbol{N}\left(\lambda \boldsymbol{H}_{\lambda,\delta}^{-\boldsymbol{1}}\, \boldsymbol{A}^\top \boldsymbol{b}, \boldsymbol{H}_{\lambda,\delta}^{-\boldsymbol{1}}\right)$$

- Hyperprior parameters:
  - $\lambda \sim \Gamma(\, \alpha_\lambda, \beta_\lambda)$
  - $\delta \sim \Gamma(\, \alpha_\delta, \beta_\delta)$

Problem with the deconvolution approach

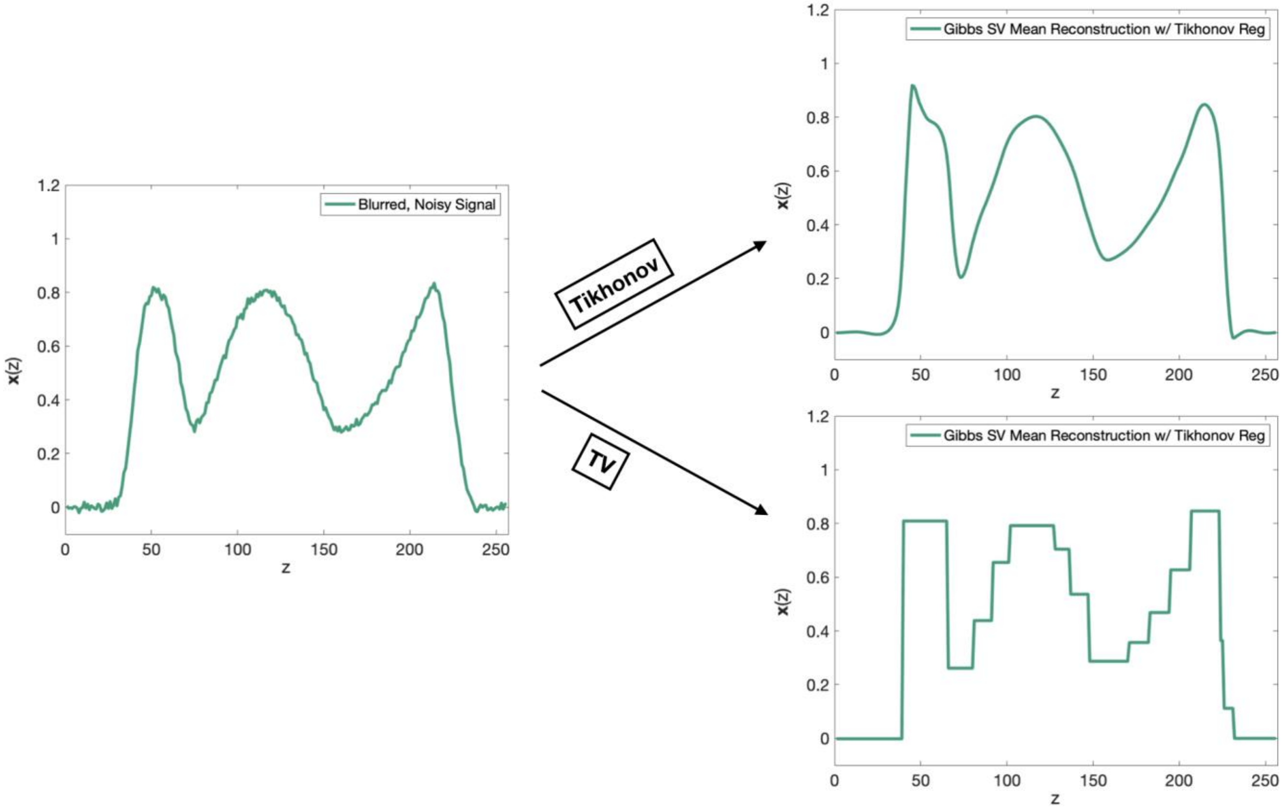
- When blur varies spatially, assuming the same blurring kernel everywhere is incorrect and can result in poor reconstructions





Spatially Varying Parameters and Multi-regularization

- Allow different regularization parameters at different locations in the signal
  - $\boldsymbol{\lambda}, \boldsymbol{\delta}$ are now vectors
- Allow different regularizations depending on the signal



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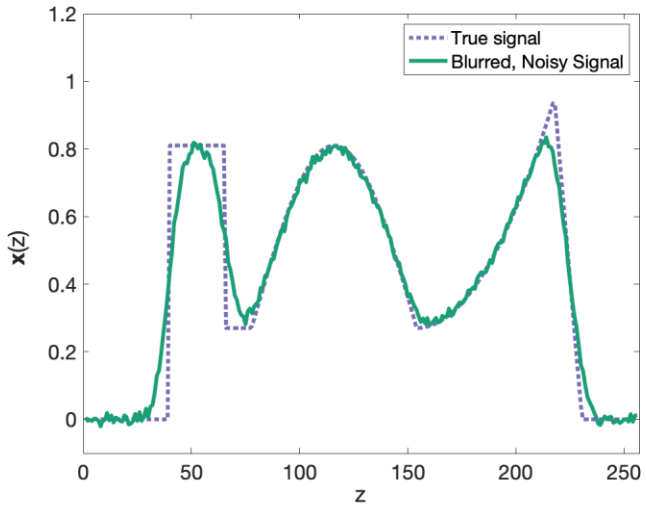
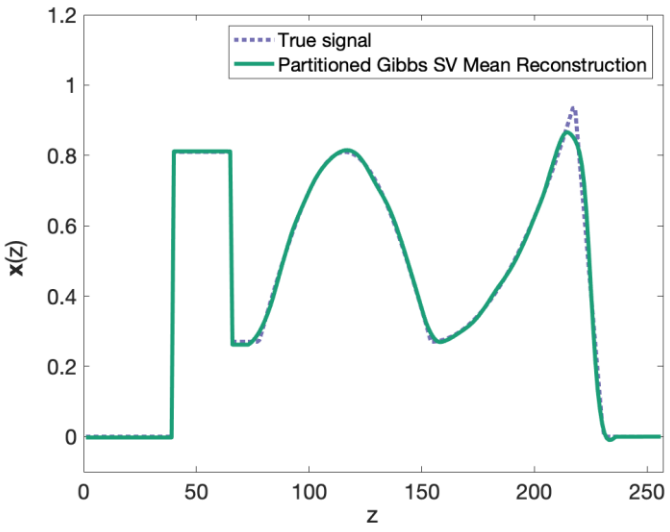
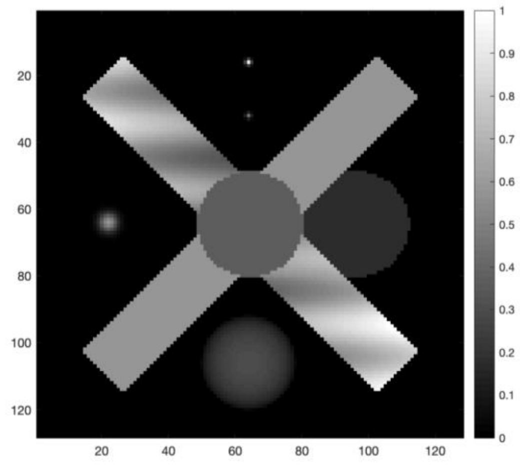




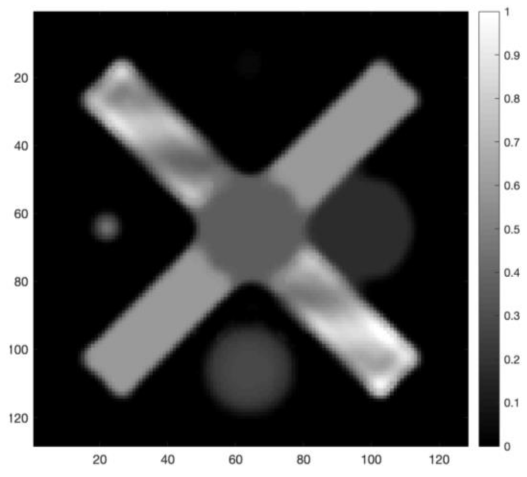
Spatially Varying Parameters and Multi-regularization in 2D

- Need to choose how to partition the image for regularization
- Need methods that will work on large (e.g. 4k x 4k) images

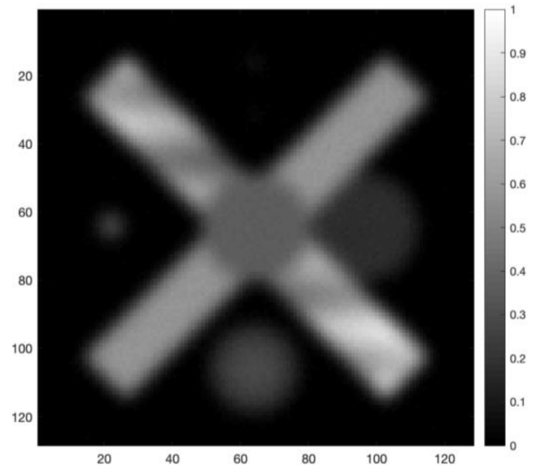
Truth



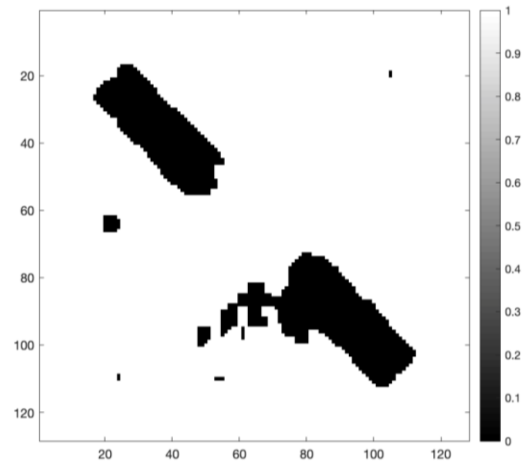
Reconstruction



Blurred



Partition



Possible approaches to spatially varying deblurring

- Piecewise convolution algorithms
- Wavelet based deblur
- Machine Learning