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Title: Practical Considerations for Analysis By Synthesis, a Real World Example using DARHT Radiography

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Web

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Practical Considerations for Analysis By Synthesis, a Real World Example using DARHT Radiography.

By James L. Carroll

2013

LA-UR-13-xxxx

Abstract

- The mathematical theory of inverse problems has been intensely explored for many years. One common solution to inverse problems involves analysis by synthesis, where a forward model produces a synthetic data set, given model inputs, and optimization is used to find model inputs that minimize the difference between the real data and the synthetic data. Some beautiful mathematical results demonstrate that under ideal situations, this procedure returns the MAP estimate for the parameters of the model. However, many practical considerations exist which makes this procedure much harder to actually use and implement. In this presentation, we will evaluate some of these practical considerations, including: Hypothesis testing over confidence, overfitting systematic errors instead of overfitting noise, optimization uncertainties, and complex measurement system calibration errors. The thrust of this work will be to attempt to qualitatively and quantitatively assess the errors in density reconstructions for the Dual Axis Radiographic Hydrotest Facility (DARHT) and LANL.

What is Hydrodynamic Testing?

- **High Explosives (HE) driven experiments to study nuclear weapon primary implosions.**
  - Radiographs of chosen instants during dynamic conditions.
  - Metals and other materials flow like liquids under high temperatures and pressures produced by HE.

Static Cylinder Set-up

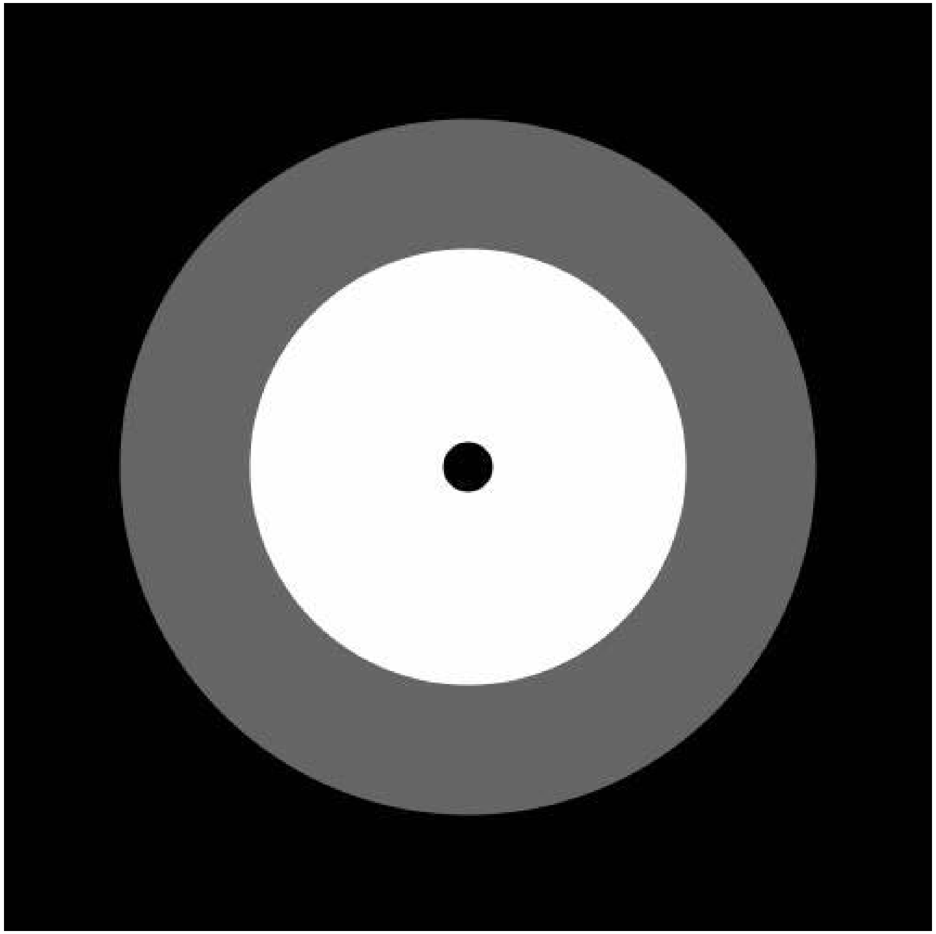
Static Cylinder shot

Static Cylinder Radiograph

DARHT:

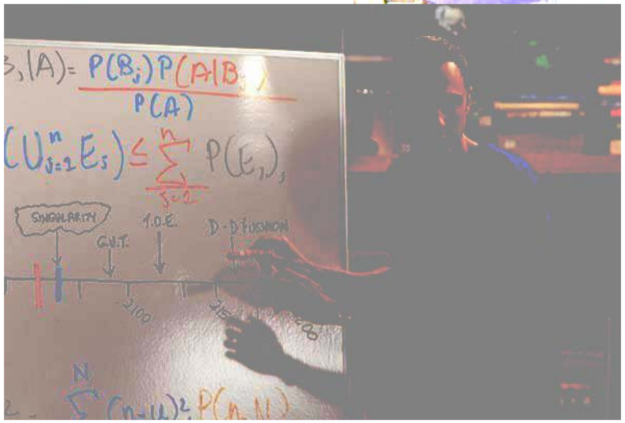
FIED

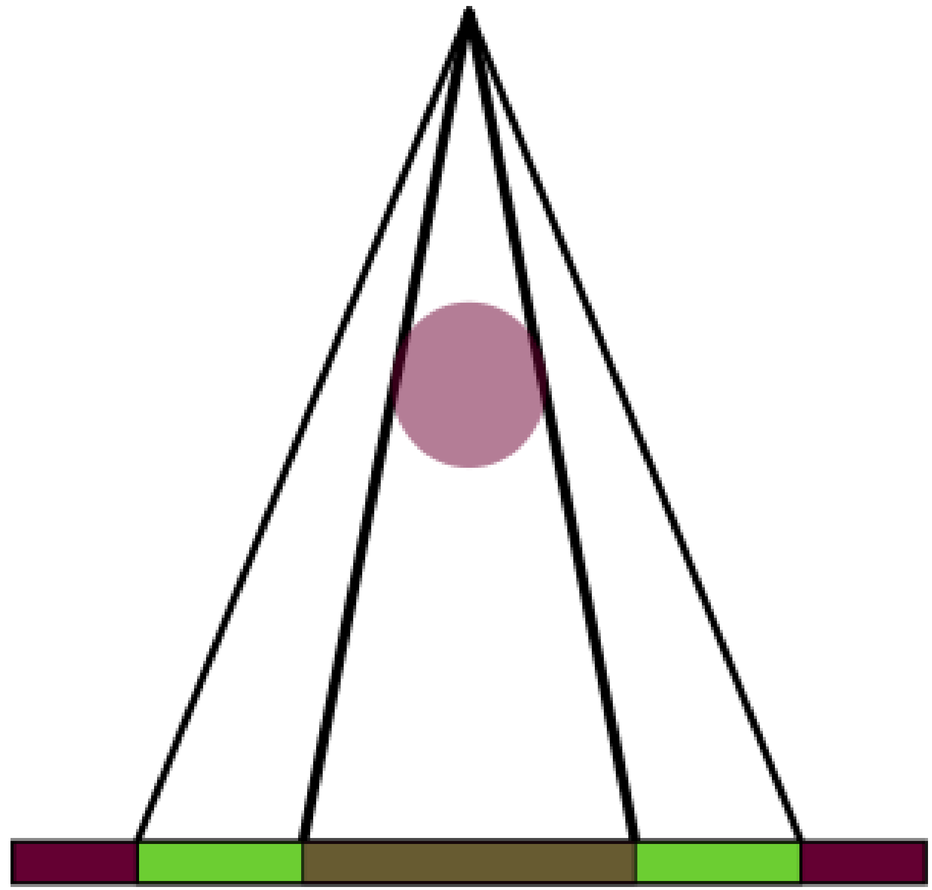
THE FTO



Challenges:

Dose/Dynamic Range

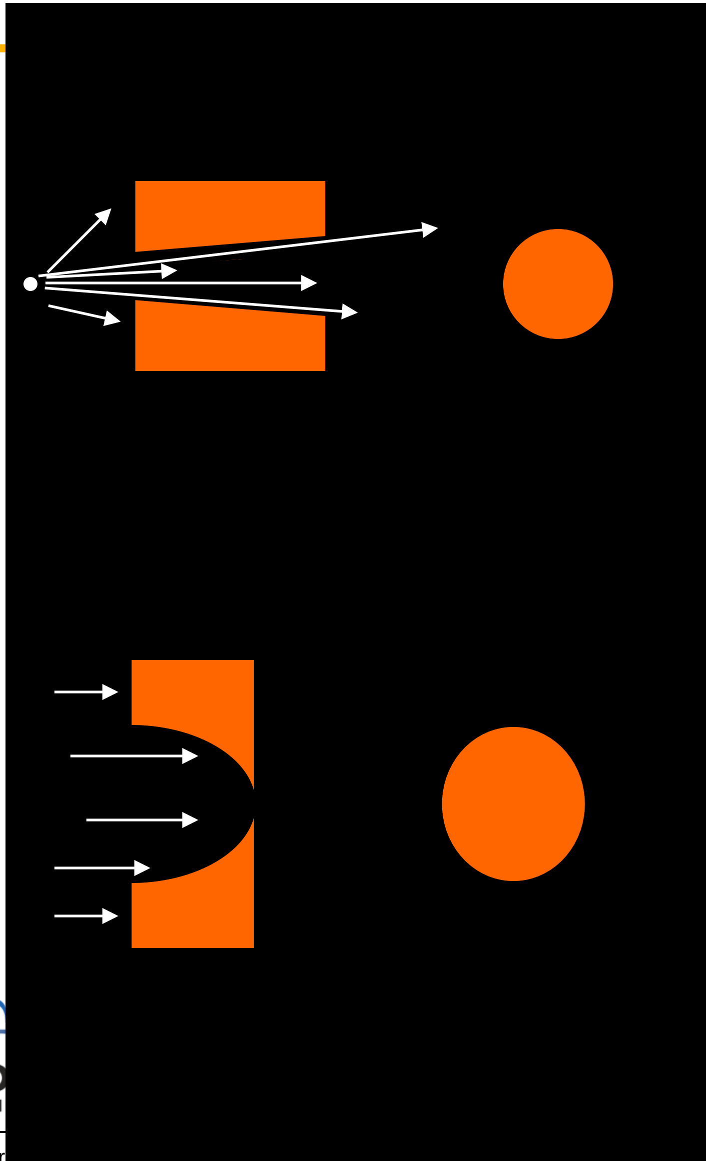




Static Test Objects (e.g. FTO)

- Allow us to calibrate against objects with *known* geometry.
- Comparison of machines (microtron, PHERMEX, DARHT)
- Benchmark radiographic codes (e.g. SYN_IMG, the BIE)
- Benchmark scatter codes (MCNP).
- Develop understanding and train experimentalists.

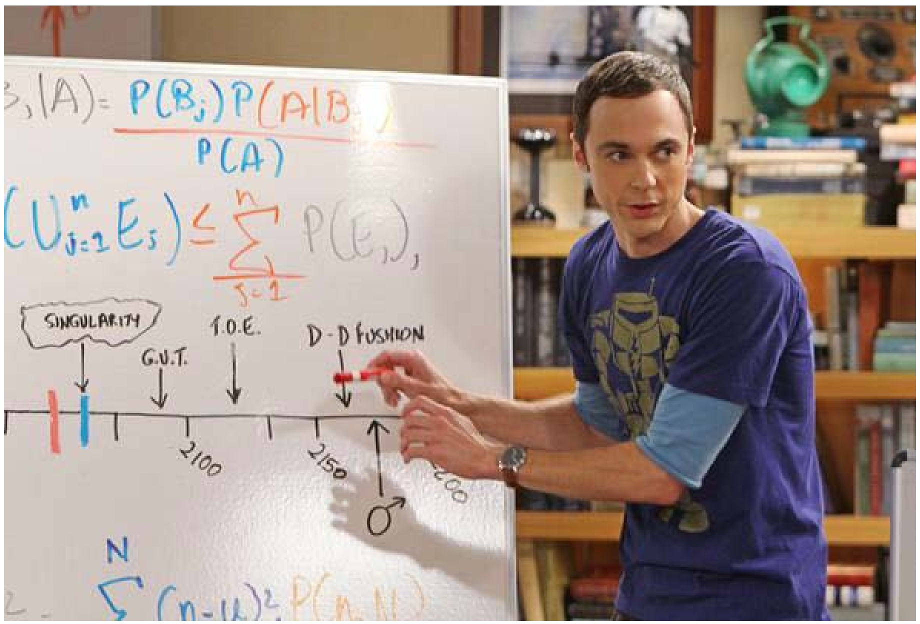
Collimation



- *Rough* collimation controls angular extent and direction of radiation fan.
- Shields from source scatter.
- A *Graded* collimator is an approximate pathlength inverse of object and flattens field for reduced dynamic range and reduced scatter.
- An exact graded collimator would produce an image with *no features*!

Challenges

Dose/Dynamic Range



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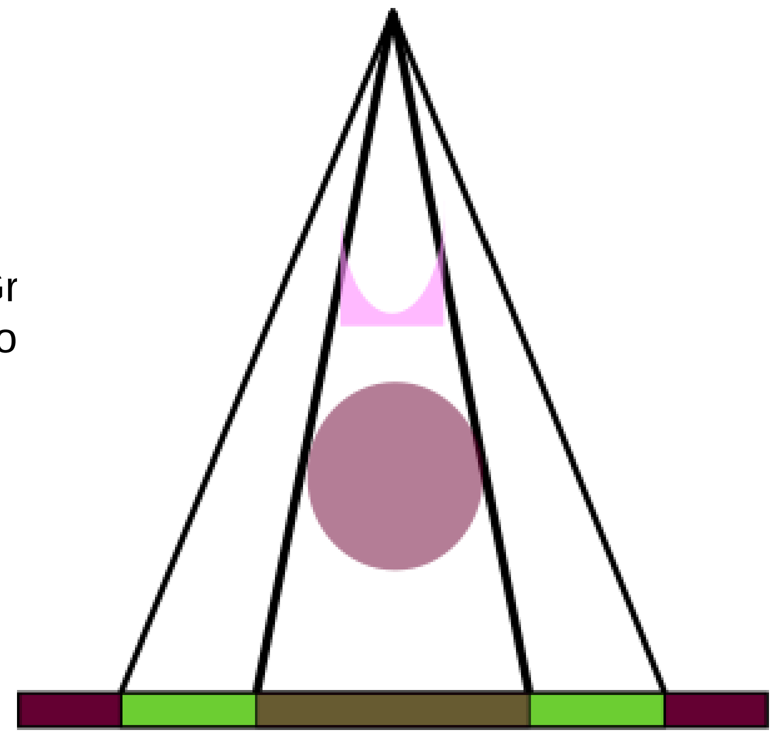
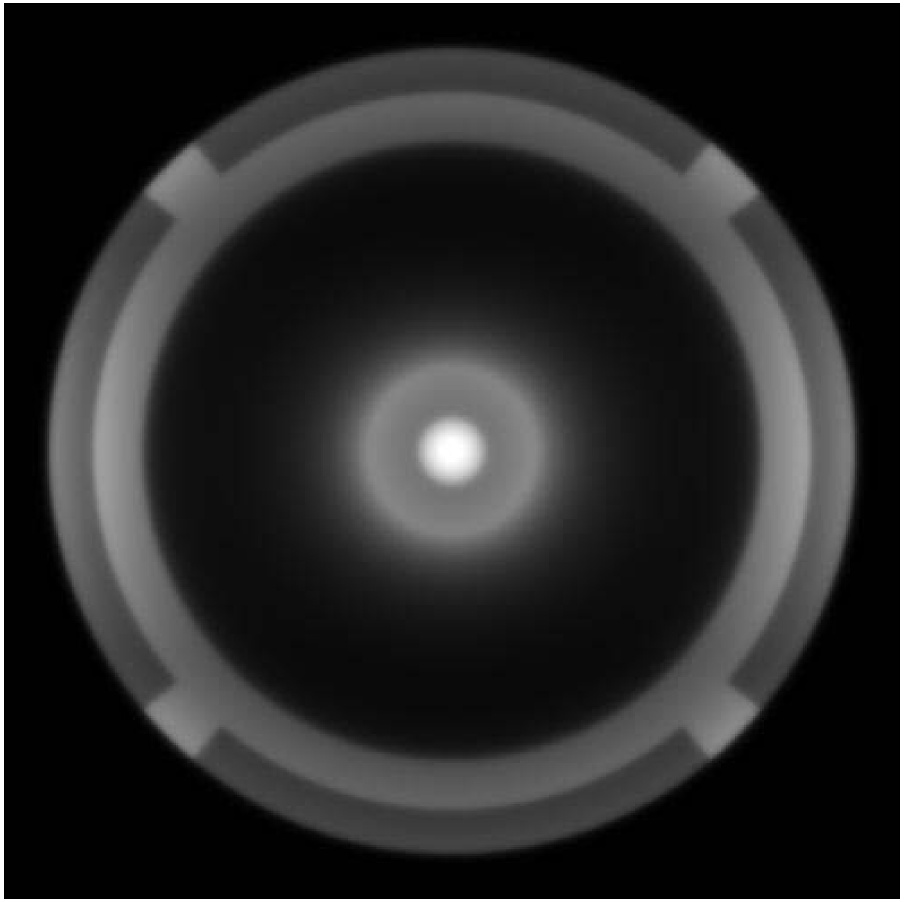
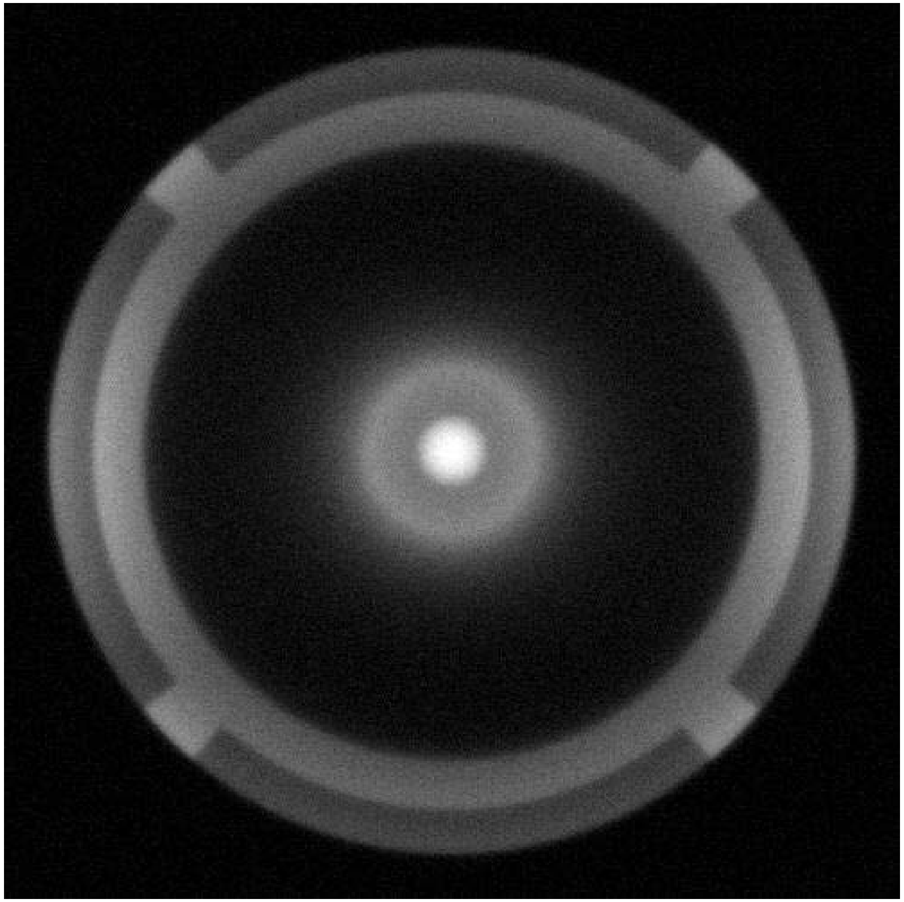


(FTO+Collimator+Fiducial+plates)





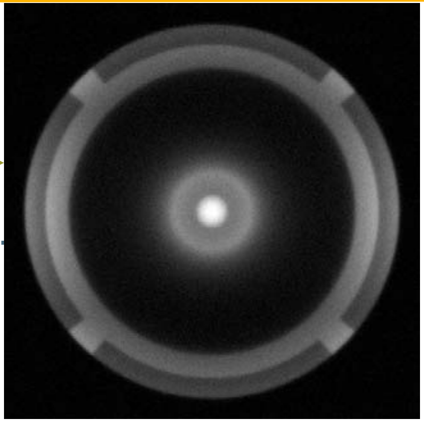
A forward modeling approach is currently used in analysis of (single-time) radiographic data

?

True radiographic physics

Inverse approach (approximate physics)

True density (unknown)



Transmission (experimental)

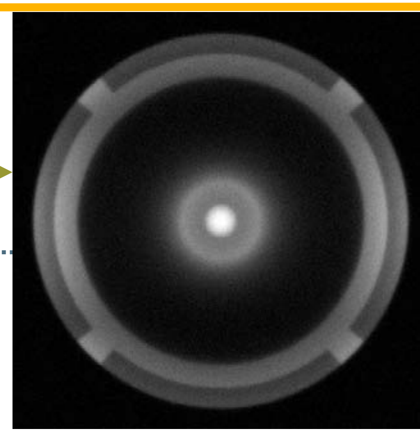
A forward modeling approach is currently used in analysis of (single-time) radiographic data

?

True density (unknown)

True radiographic physics →

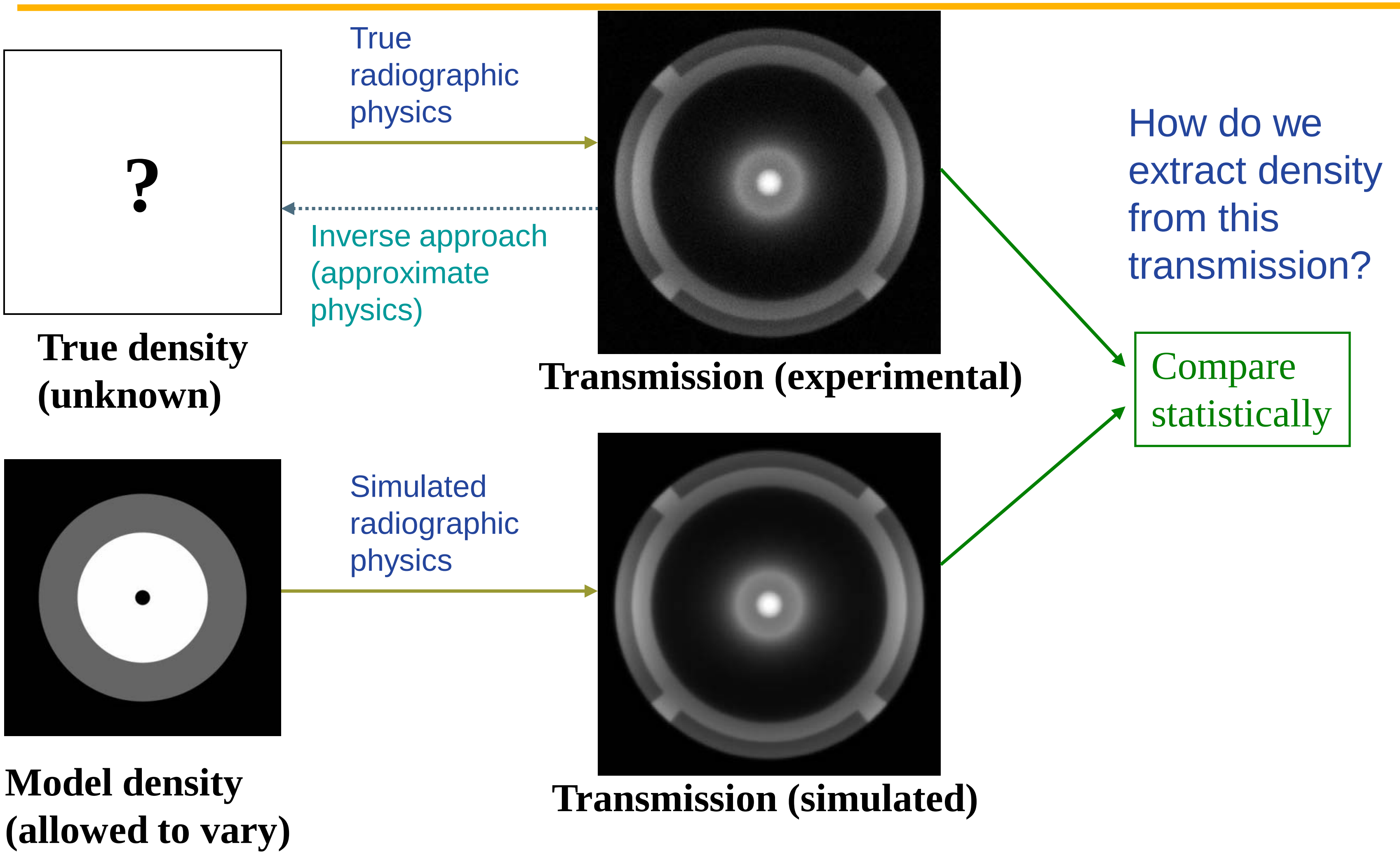
← Inverse approach (approximate physics)



Transmission (experimental)

How do we extract density from this transmission?

A forward modeling approach is currently used in analysis of (single-time) radiographic data



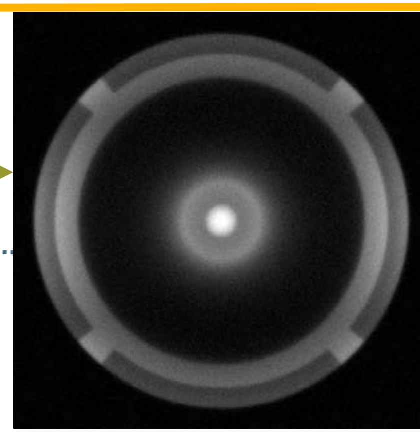
A forward modeling approach is currently used in analysis of (single-time) radiographic data

?

True density (unknown)

True radiographic physics

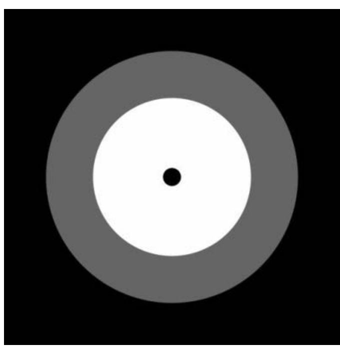
Inverse approach (approximate physics)



Transmission (experimental)

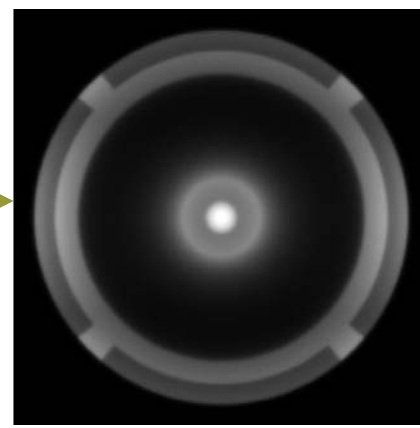
How do we extract density from this transmission?

Compare statistically



Model density (allowed to vary)

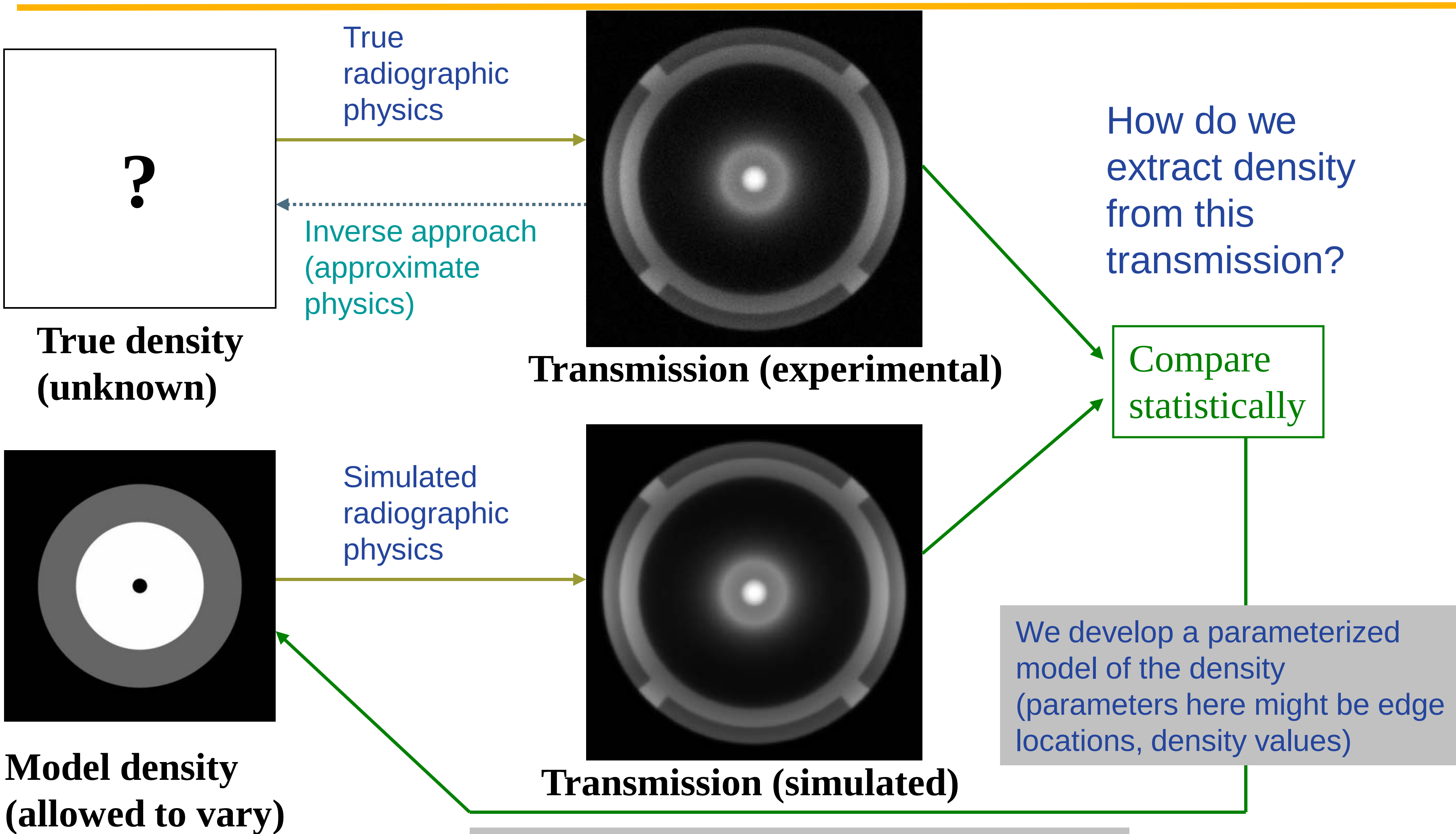
Simulated radiographic physics



Transmission (simulated)

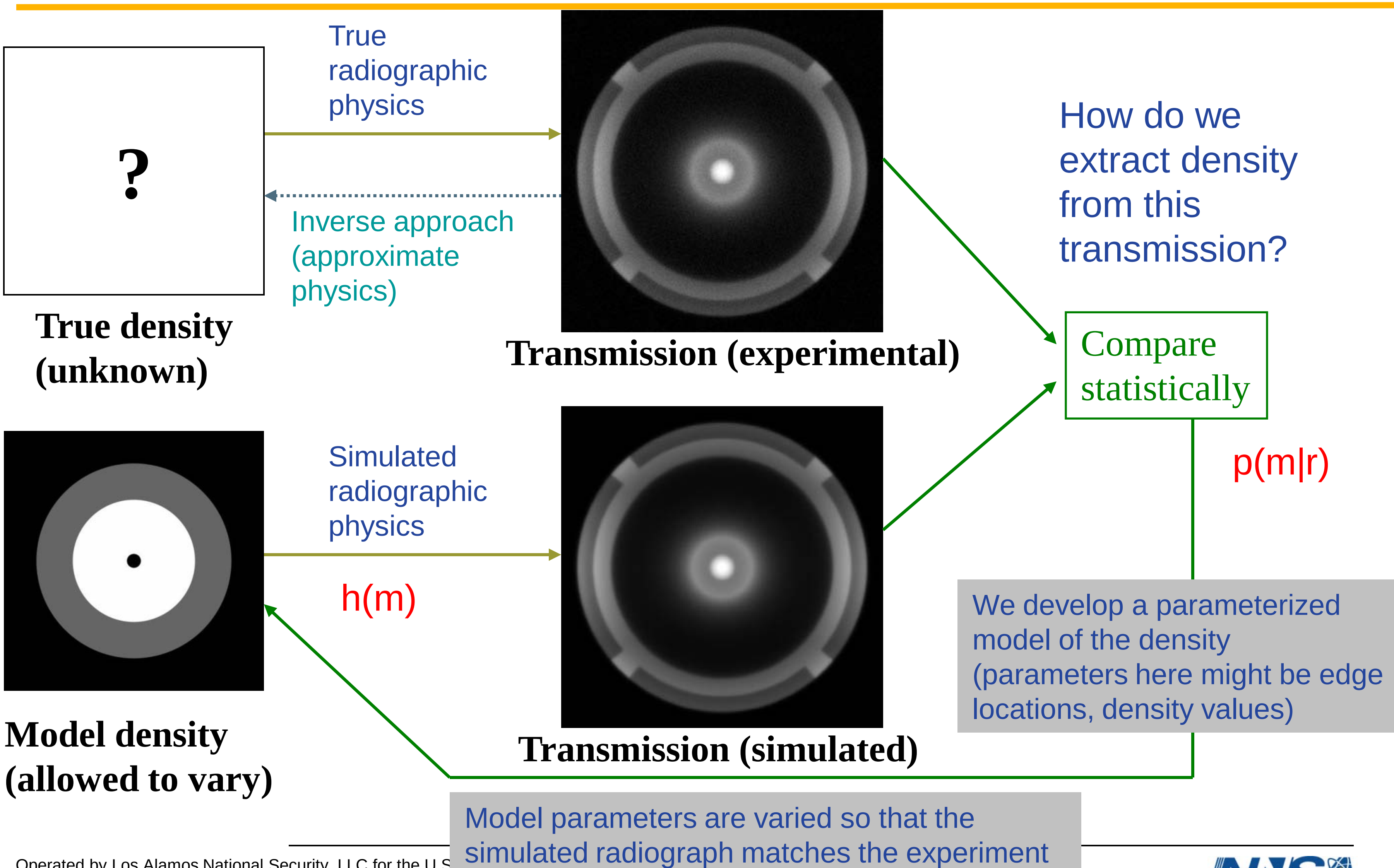
We develop a parameterized model of the density (parameters here might be edge locations, density values)

A forward modeling approach is currently used in analysis of (single-time) radiographic data



Model parameters are varied so that the simulated radiograph matches the experiment

A forward modeling approach is currently used in analysis of (single-time) radiographic data



Bayesian Analysis

$$p(m|r) = \frac{p(r|m)p(m)}{\int p(r|m)p(m)dm}$$

$$p(m|r) \propto p(r|m)p(m)$$

$$-\ln[p(m|r)] \propto -\ln[p(r|m)] - \ln\,[p(m)]$$

Assumptions

$$r = h(m) + n$$

- **Where n is some independent , additive noise.**
- **If n is Gaussian then:**

$$-\ln[p(r|m)] \propto \frac{1}{2\sigma_n^2}|r - h(m)|^2$$

Plug that in:

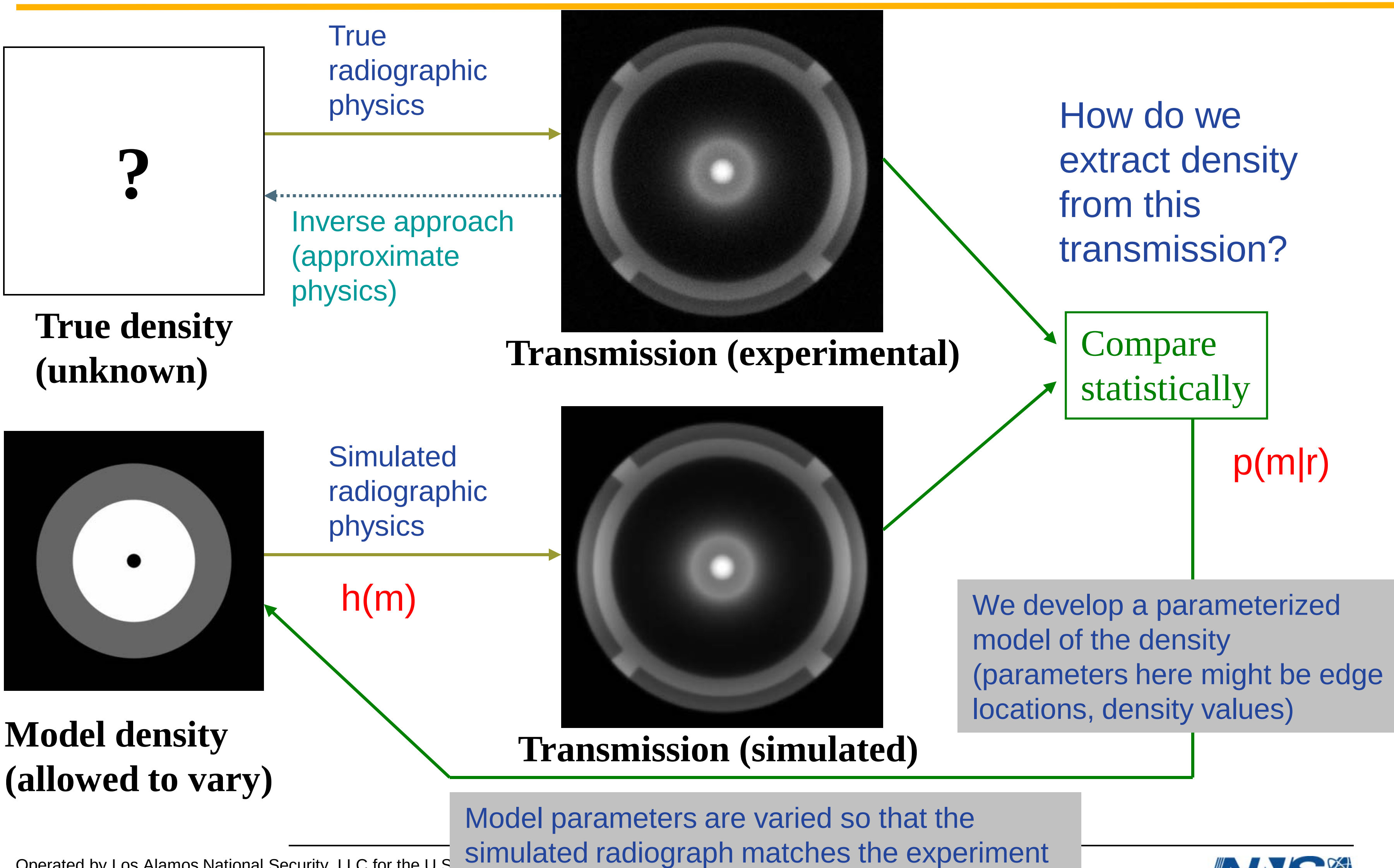
$$-\ln[p(m|r)] \propto -\ln[p(r|m)] - \ln\,[p(m)]$$

$$-\ln[p(m|r)] \propto \frac{1}{2\sigma_n^2}|r - h(m)|^2 - \ln[p(m)]$$

- **If I assume a uniform prior then:**

$$\min_{m} \frac{1}{2\sigma_n^2}|r - h(m)|^2 = \max_{m} p(m|r)$$

A forward modeling approach is currently used in analysis of (single-time) radiographic data



The Solution

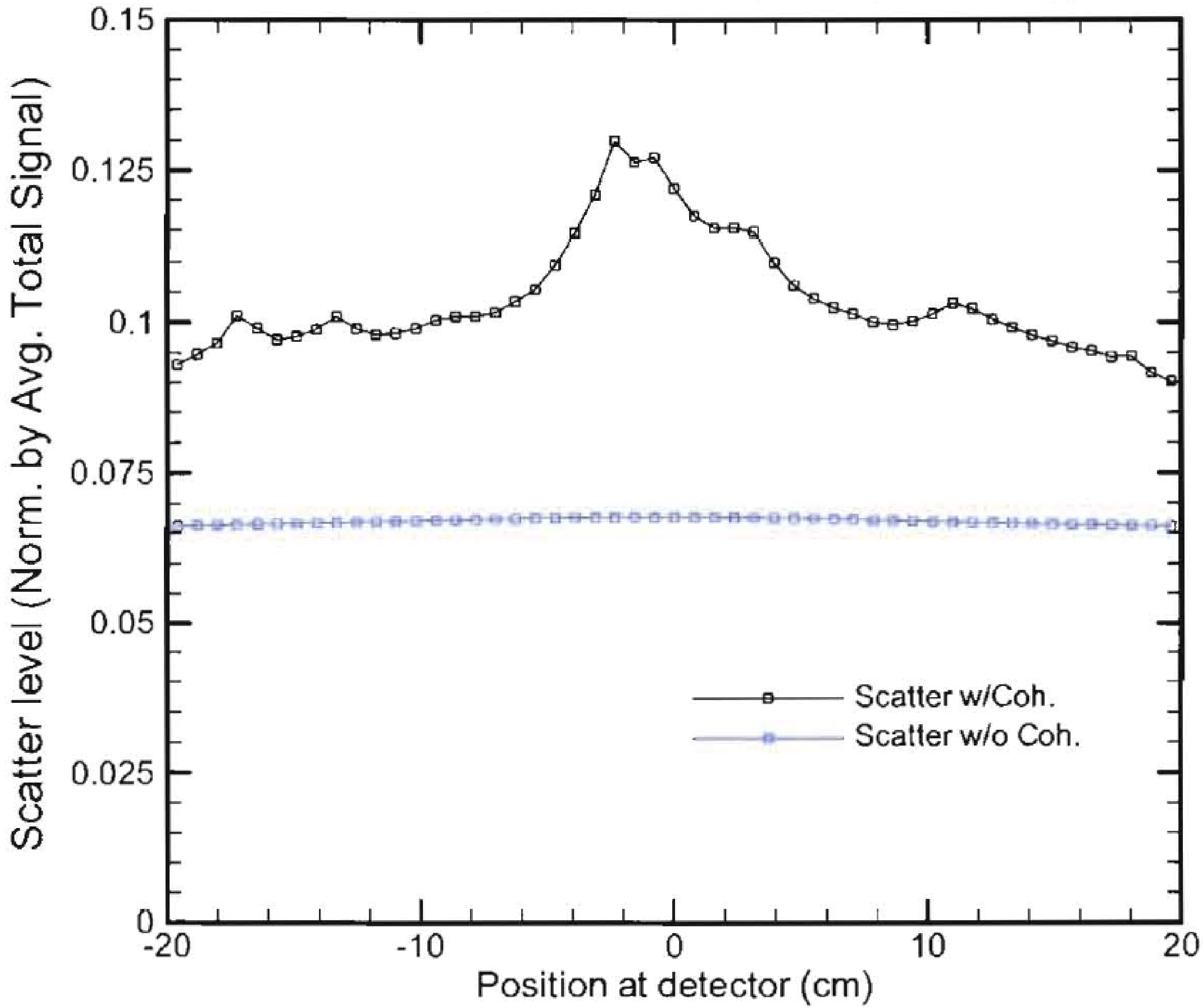
- **Building h(m)**
- **Optimizing parameters m**

Using the Prior

- **Computer vision is notoriously under constrained.**
- **Penalty terms on the function to be optimized can often overcome this problem.**
- **These terms can be seen as ill-posed priors**
  - GGMRF

Dealing with Scatter

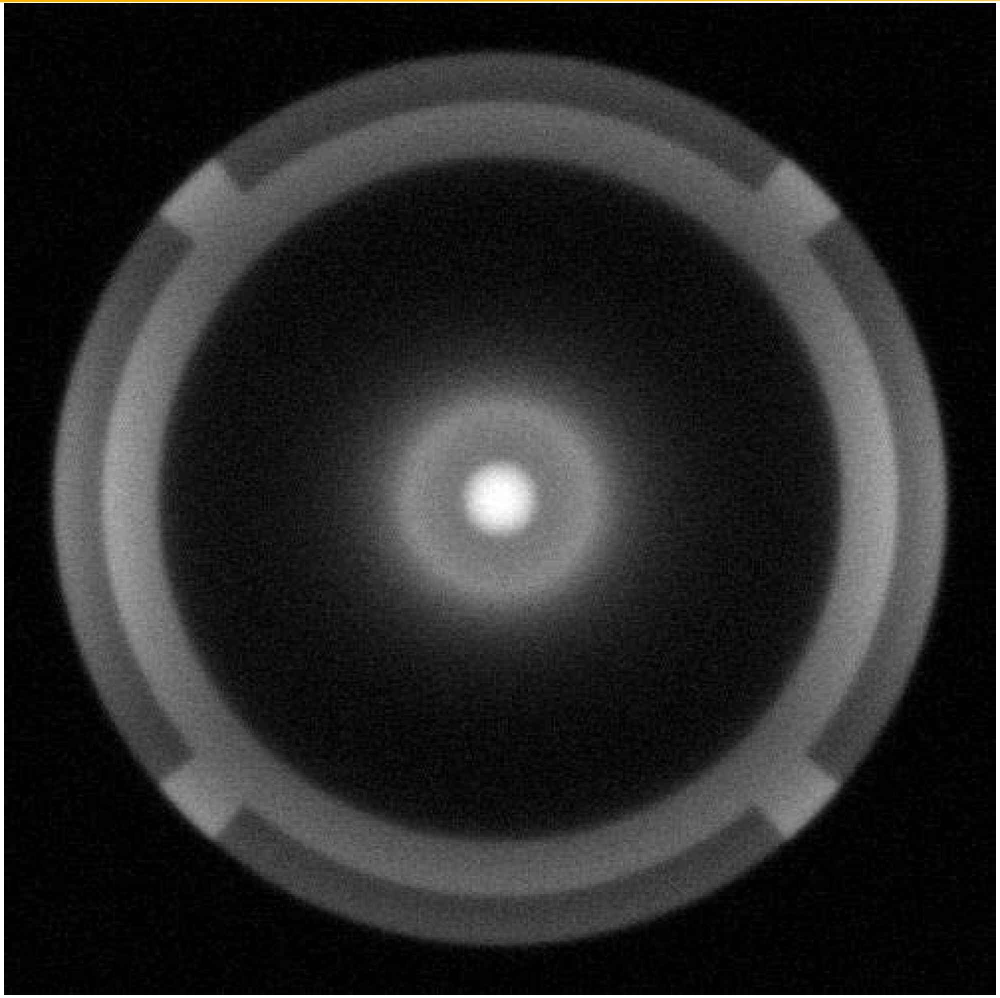
MCNP calculations of scatter fields for fiducial object, with and without coherent scatter (calc. by M. Klasky).



Example, approximating scatter

$$T = Ie^{-\mu\rho L_1} + S$$

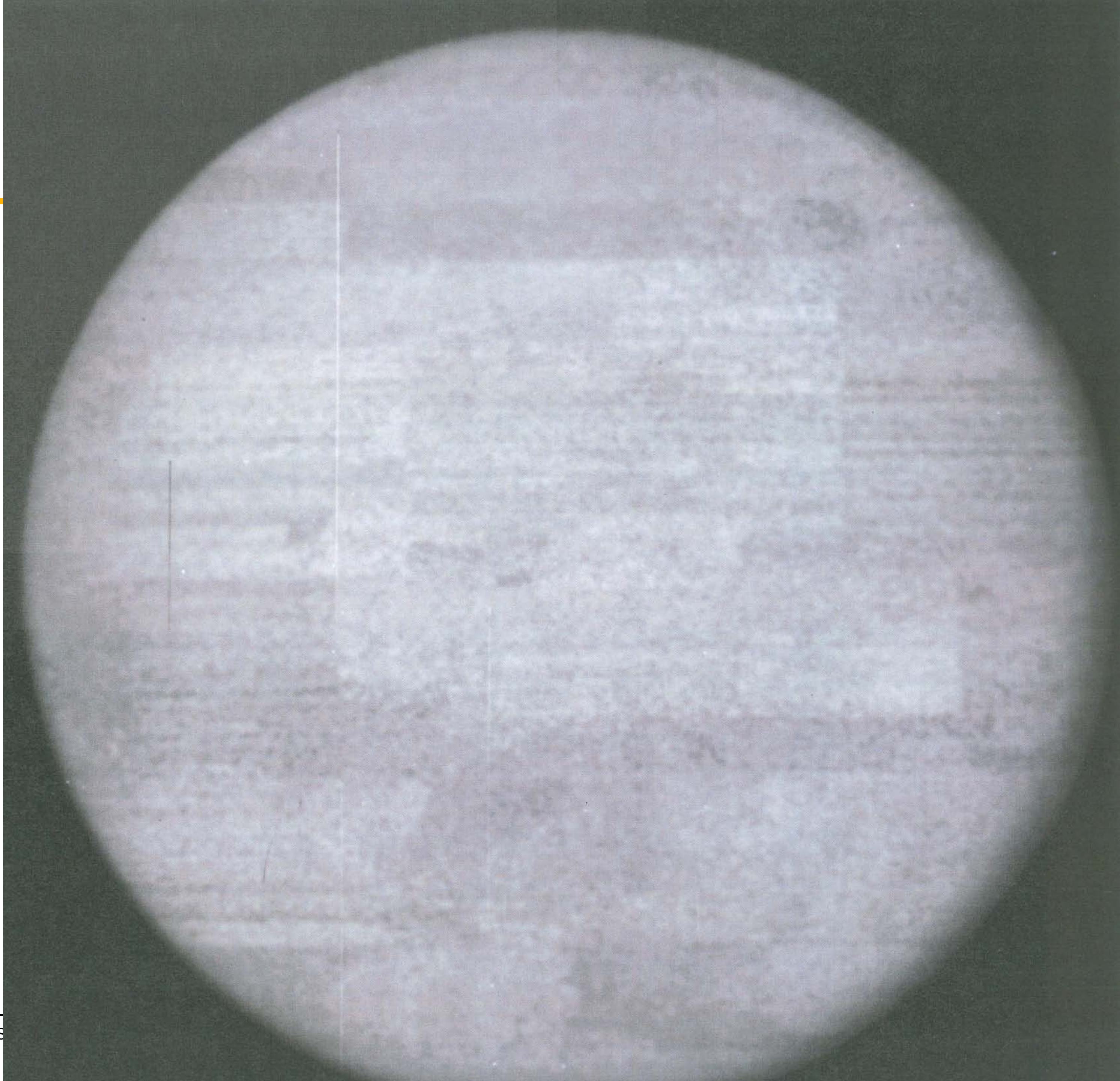
$$T = Ie^{-\mu\rho L_2} + S$$



Beautiful, Yes!

Practical Considerations

- **Axis 2, Time 1 Flat Field**



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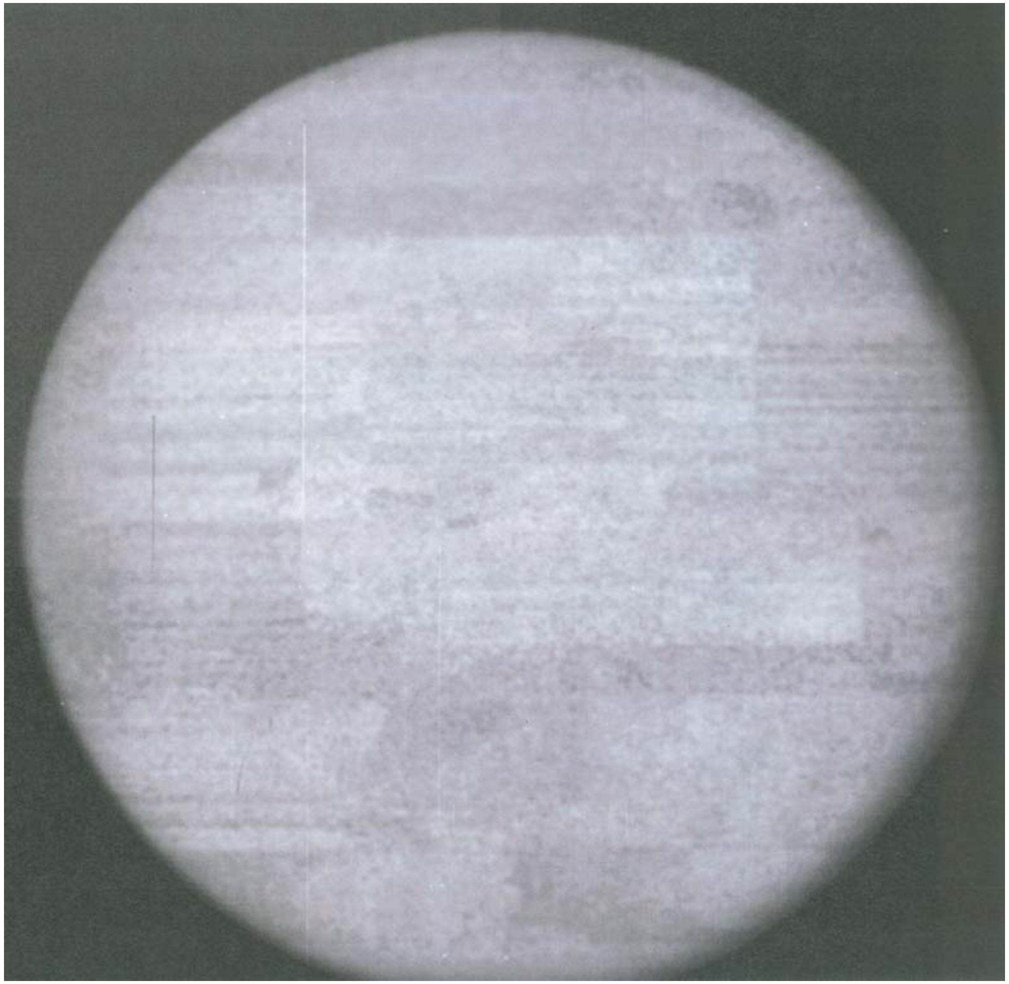
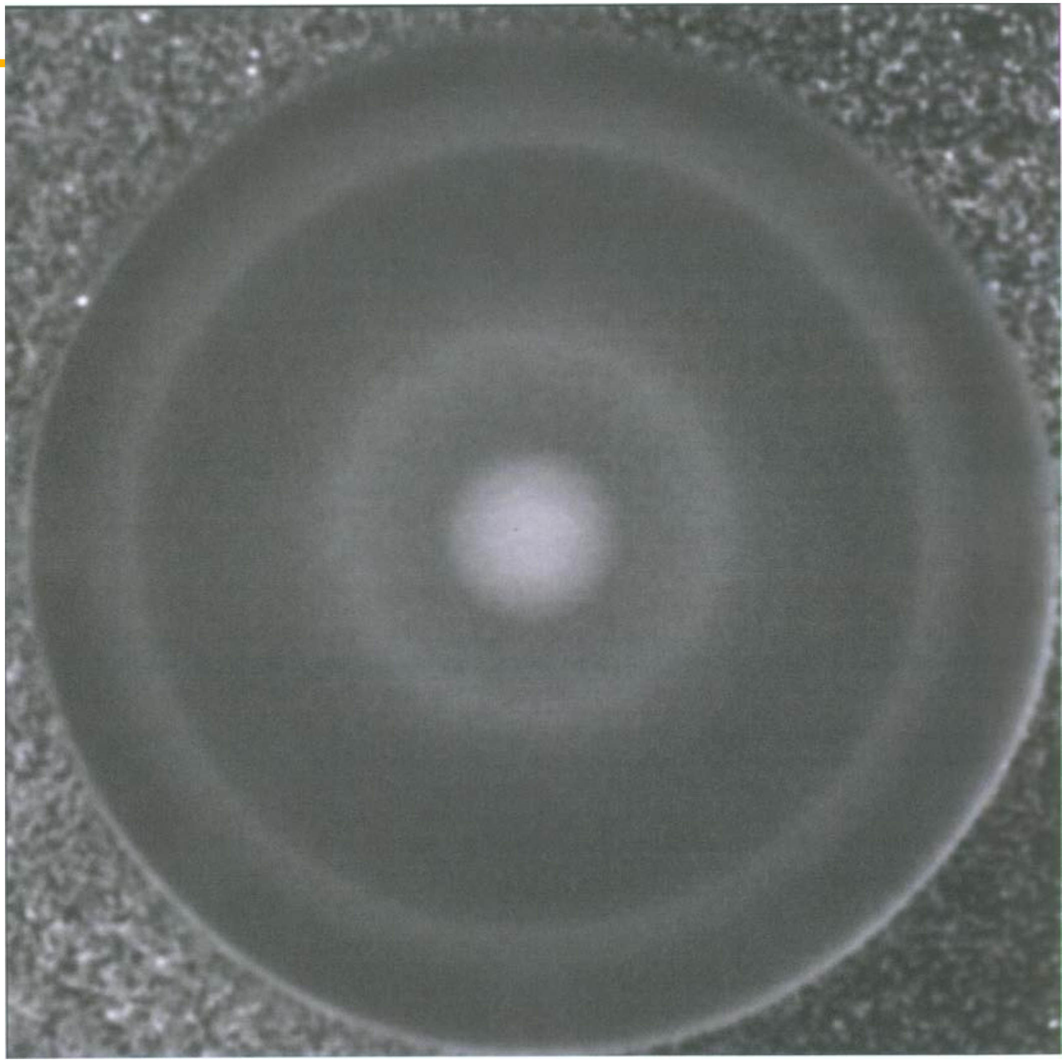
Flatfield Components

- $F = B_p D_r + S_f$



Necessary Assumptions

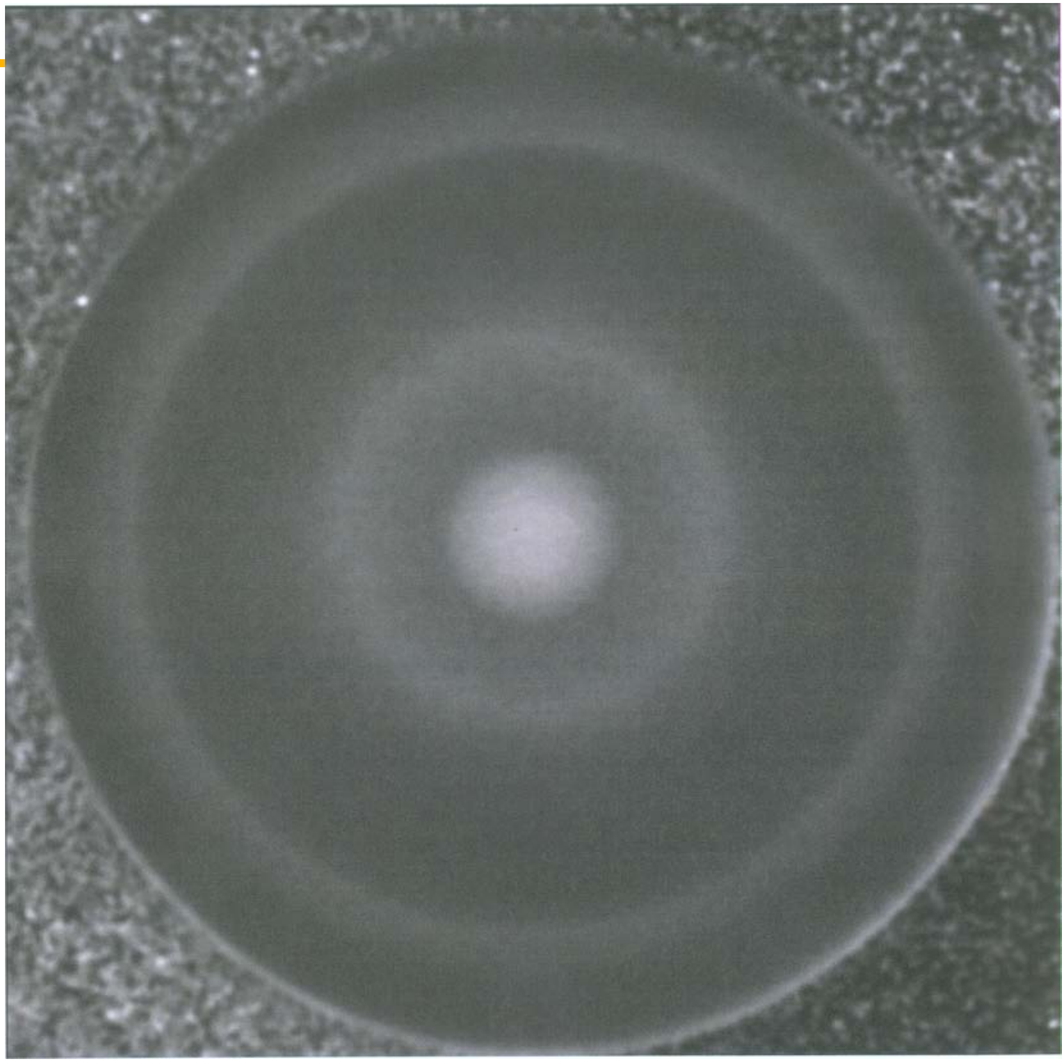
Axis 2 Time 1 FTO



Necessary Assumptions

Axis 2 Time 1 FTO

$$Image = B_p D_r I e^{-\rho l} + D_r S_i$$

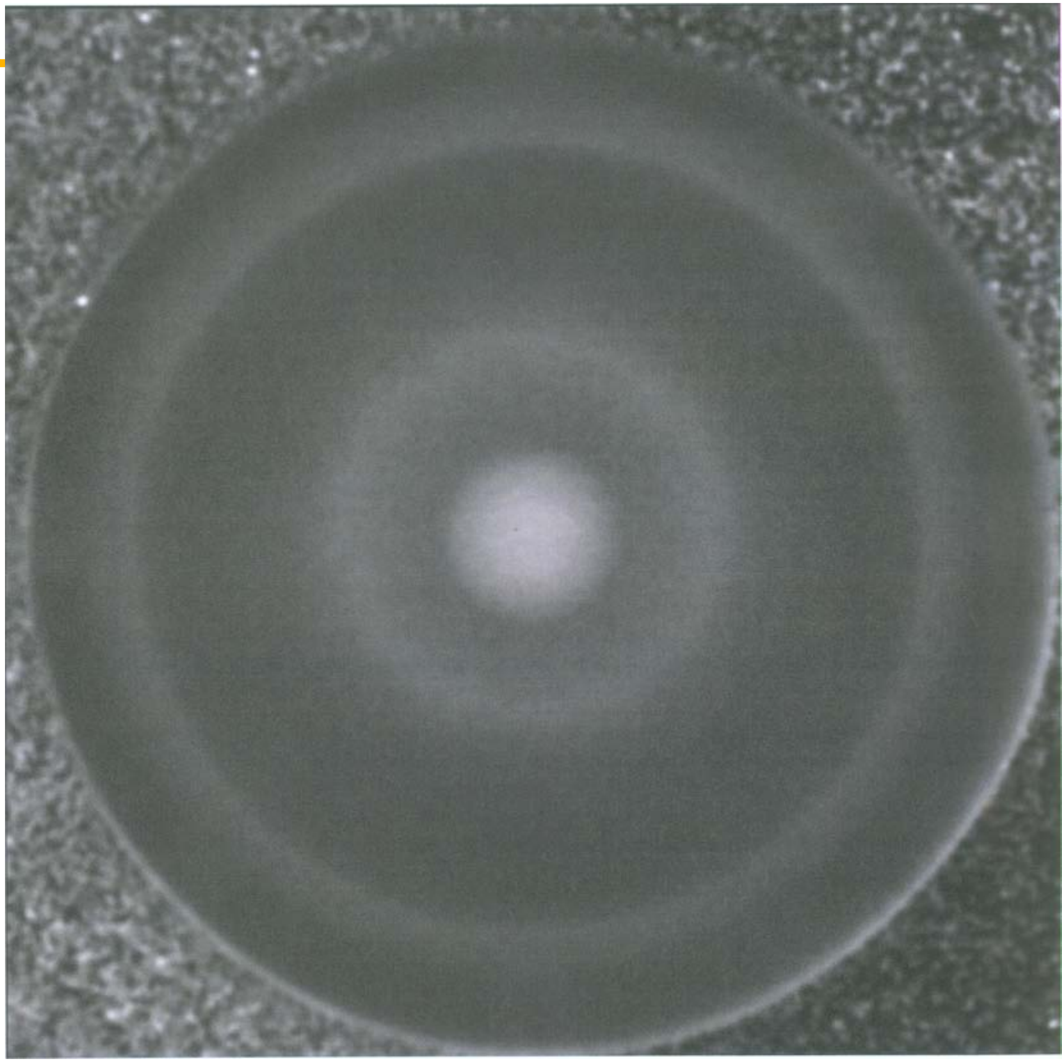


Necessary Assumptions

Axis 2 Time 1 FTO

$$Image = B_p D_r I e^{-\rho l} + D_r S_i$$

$$\frac{Image}{flatfield} = \frac{B_p D_r I e^{-\rho l} + D_r S_i}{B_p D_r + D_r S_f}$$



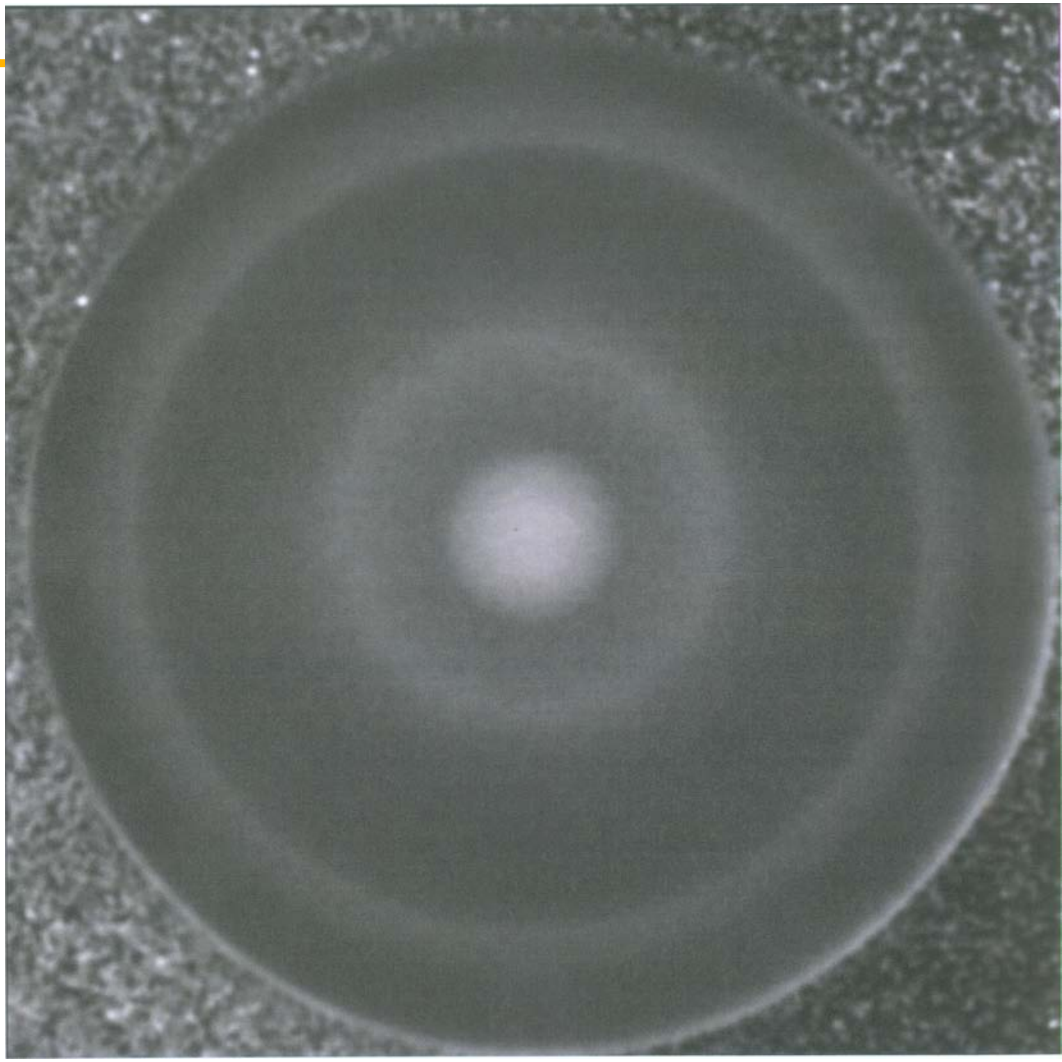
Necessary Assumptions

Axis 2 Time 1 FTO

$$Image = B_p D_r I e^{-\rho l} + D_r S_i$$

$$\frac{Image}{flatfield} = \frac{B_p D_r I e^{-\rho l} + D_r S_i}{B_p D_r + D_r S_f}$$

$$\frac{Image}{flatfield} = \frac{B_p D_r I e^{-\rho l} + D_r S_i}{B_p D_r}$$



Necessary Assumptions

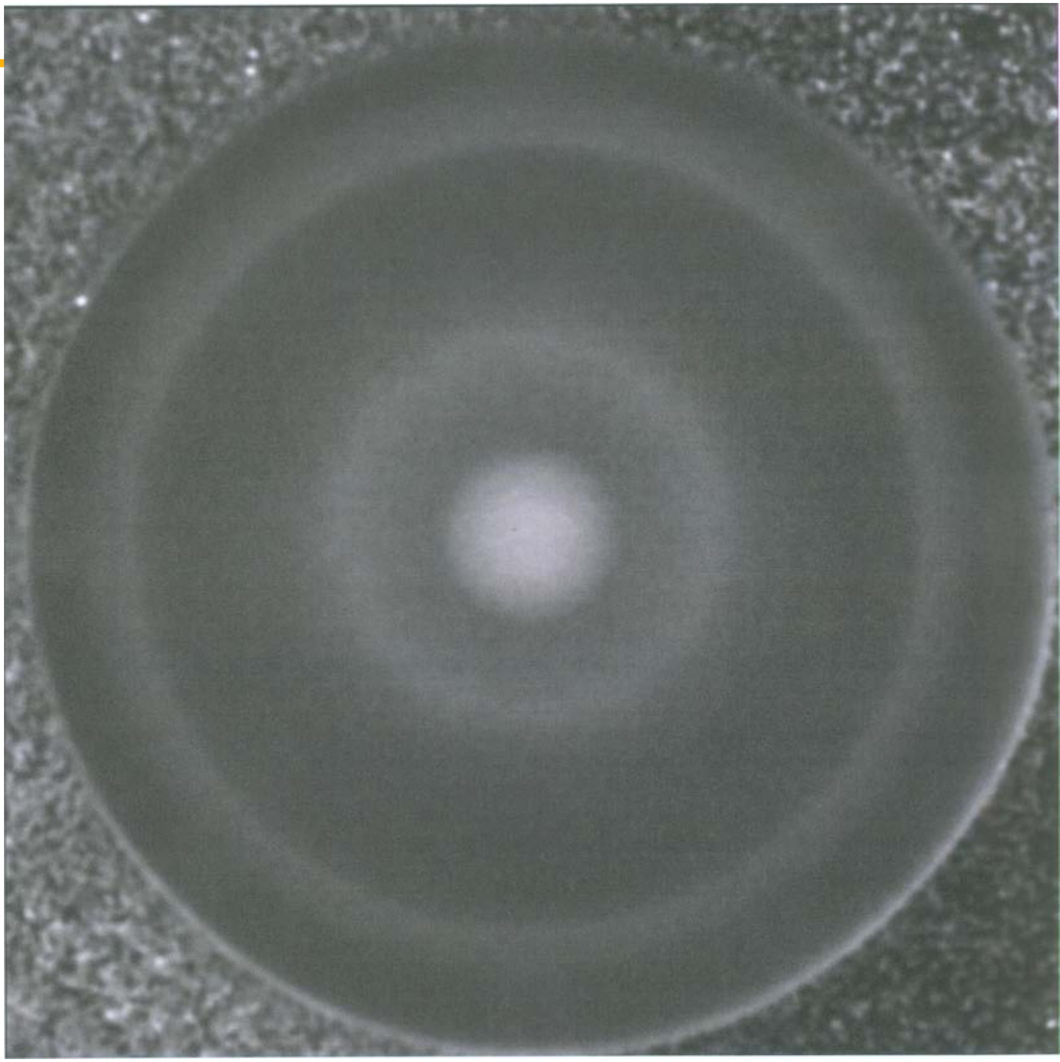
Axis 2 Time 1 FTO

$$Image = B_p D_r I e^{-\rho l} + D_r S_i$$

$$\frac{Image}{flatfield} = \frac{B_p D_r I e^{-\rho l} + D_r S_i}{B_p D_r + D_r S_f}$$

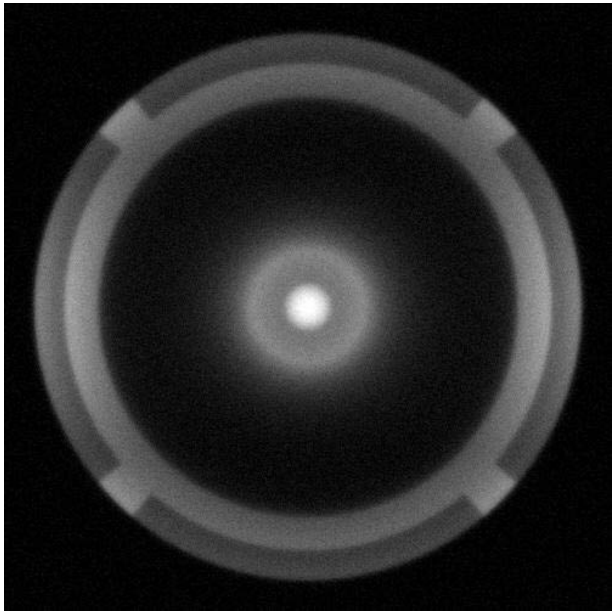
$$\frac{Image}{flatfield} = \frac{B_p D_r I e^{-\rho l} + D_r S_i}{B_p D_r}$$

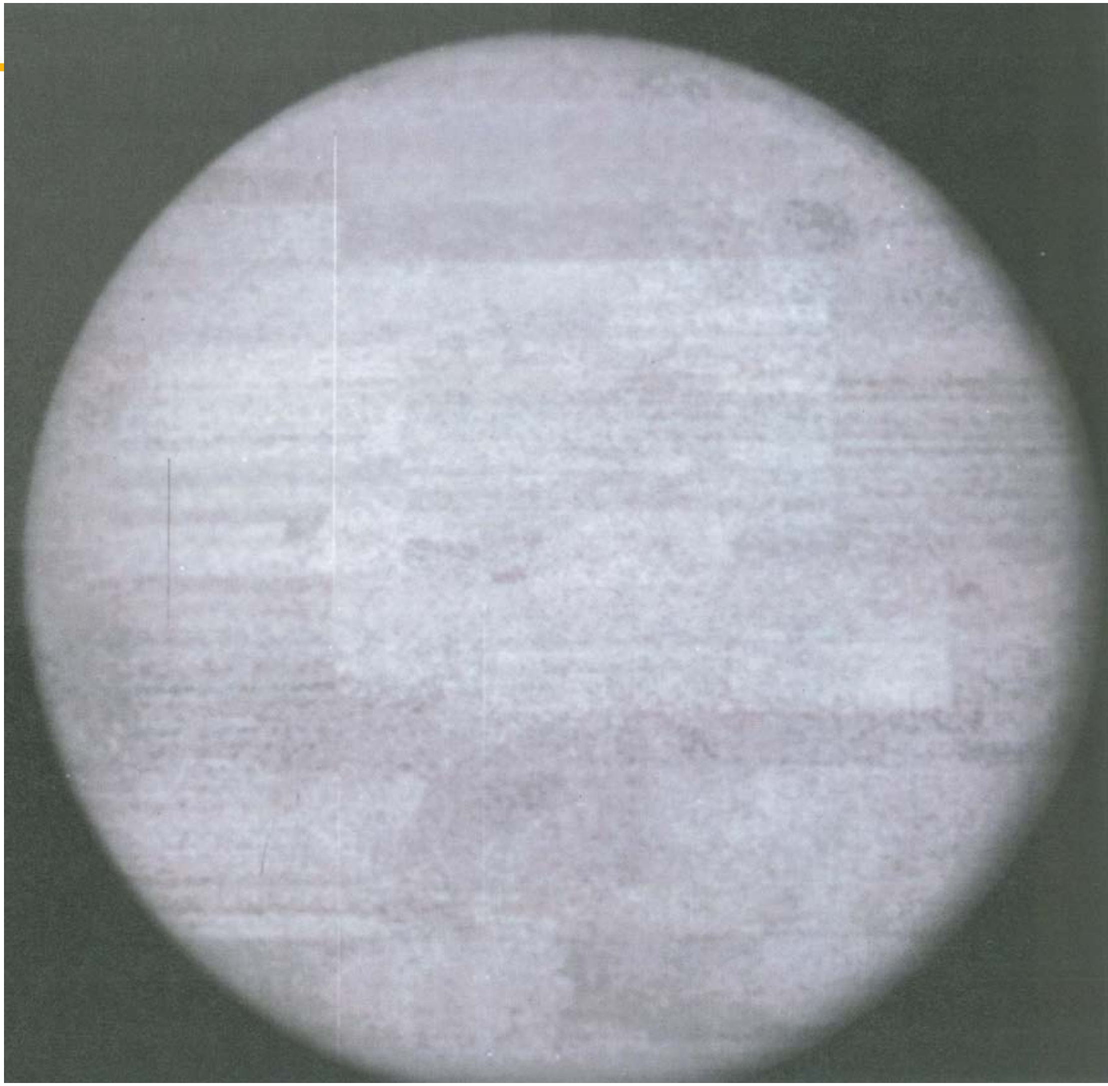
$$\frac{Image}{flatfield} = I e^{-\rho l} + \frac{S_i}{B_p}$$



- **Produce Low Frequency Fit to Flat Field**

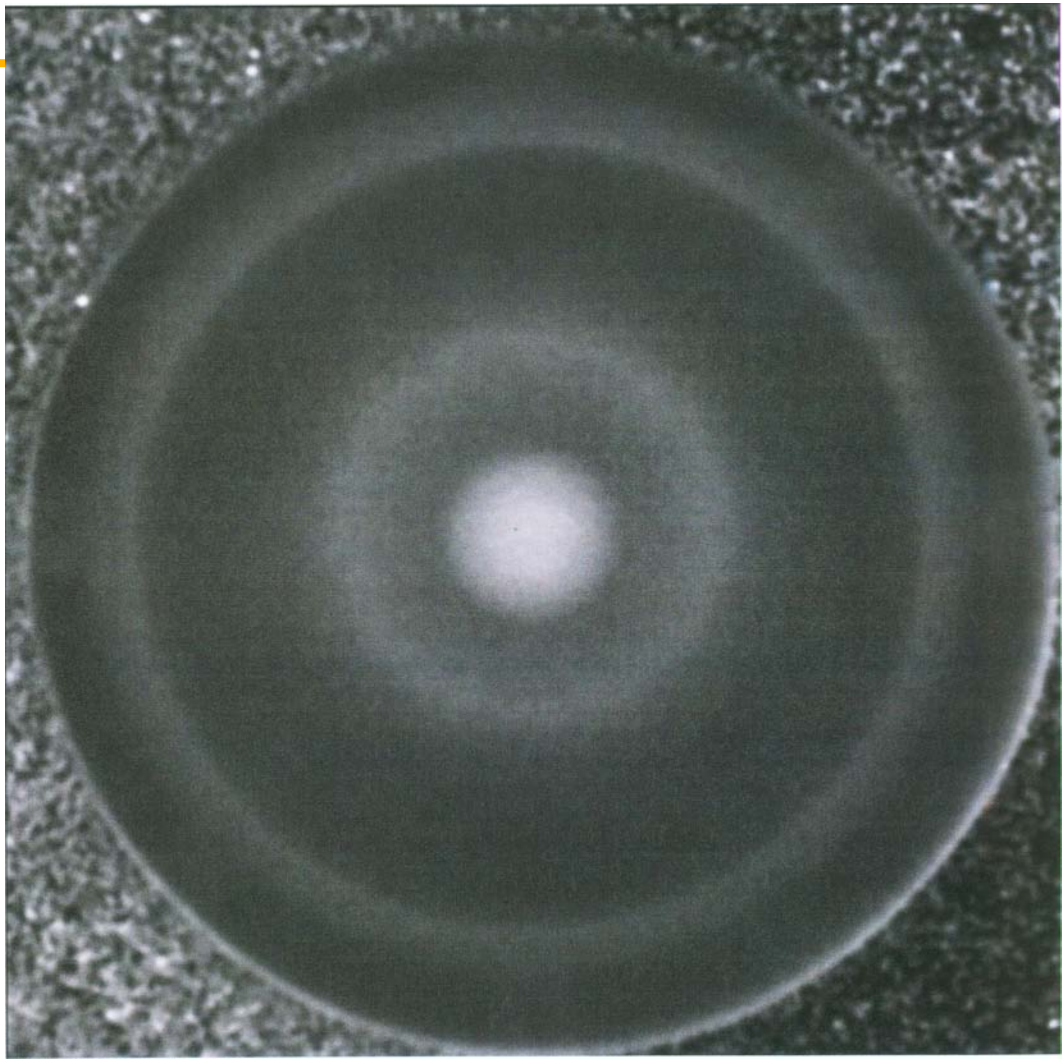
- $$\frac{Image}{flatfield} = Ie^{-\rho l} + \frac{S_i}{B_p}$$





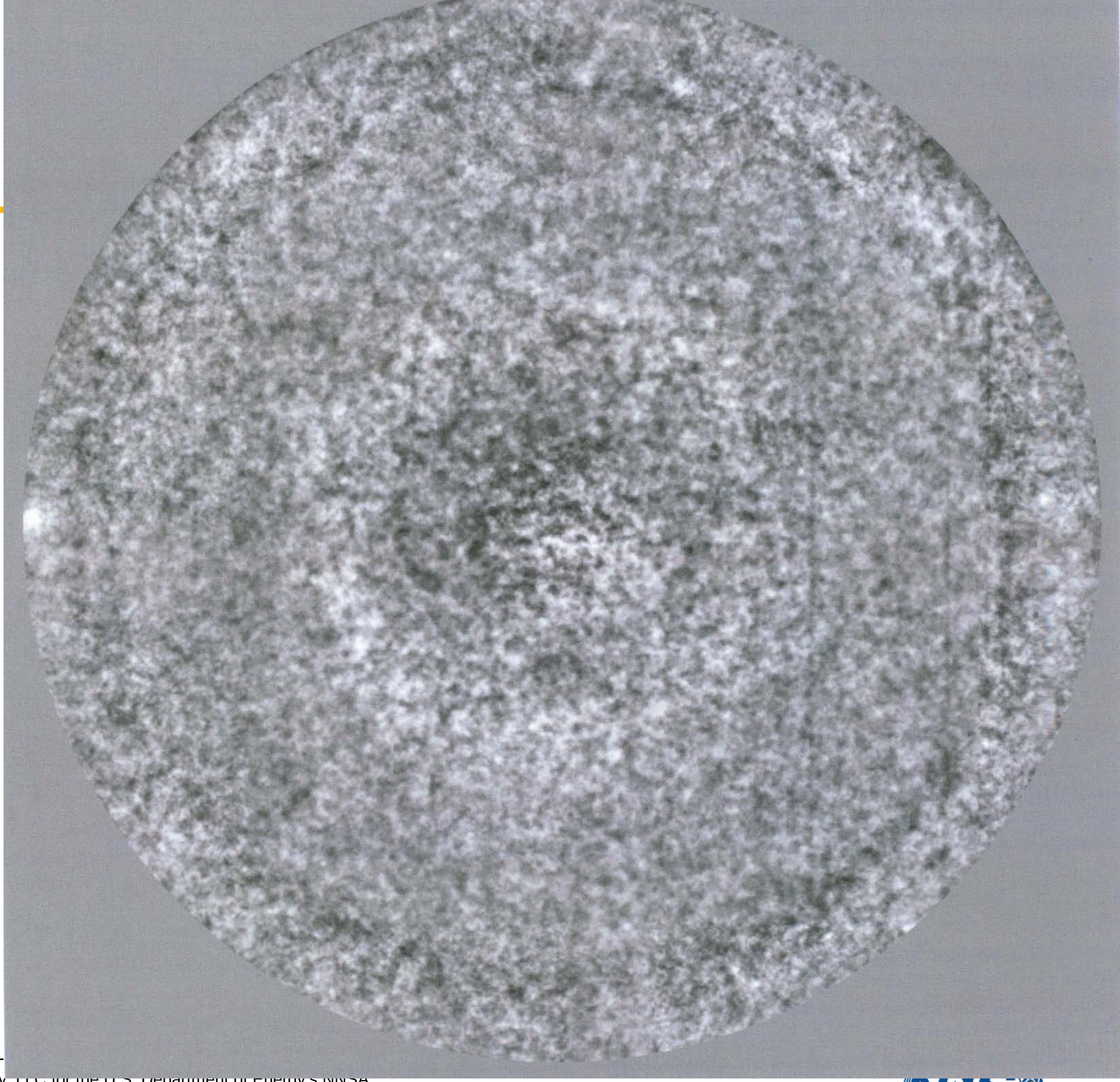
Learning Fields

- Treat entire known chain (FTO+collimator+fiducial plate) as a fiducial
- Examine fields Produced



4df s 4df g FTO Residuals

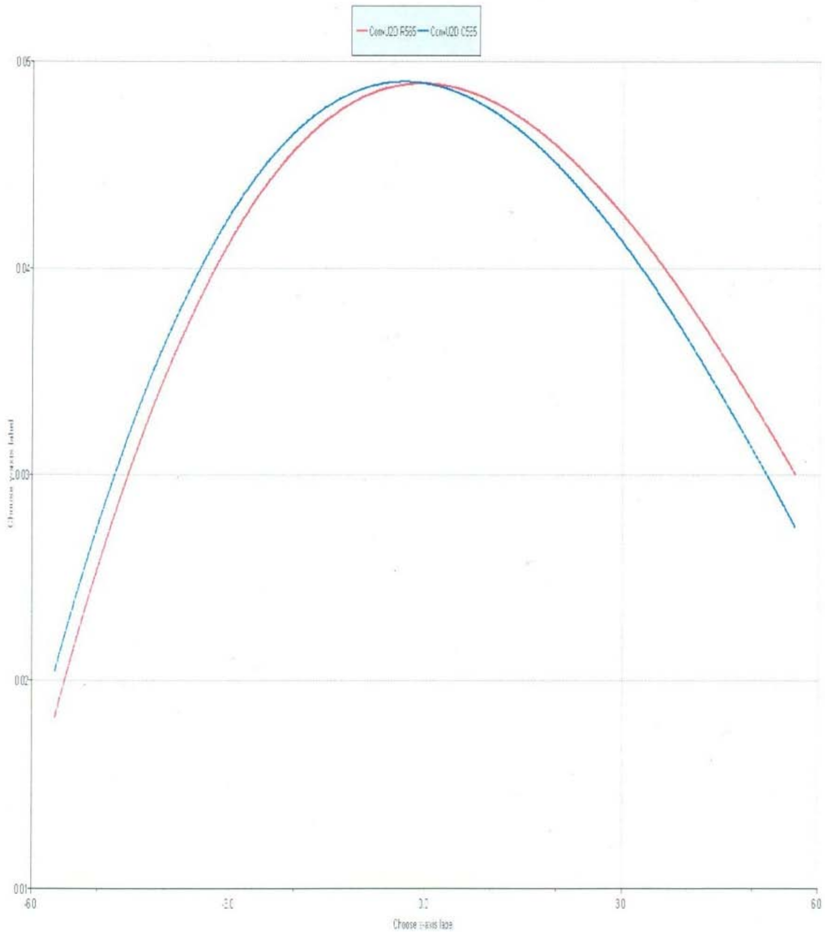
- 5% residuals



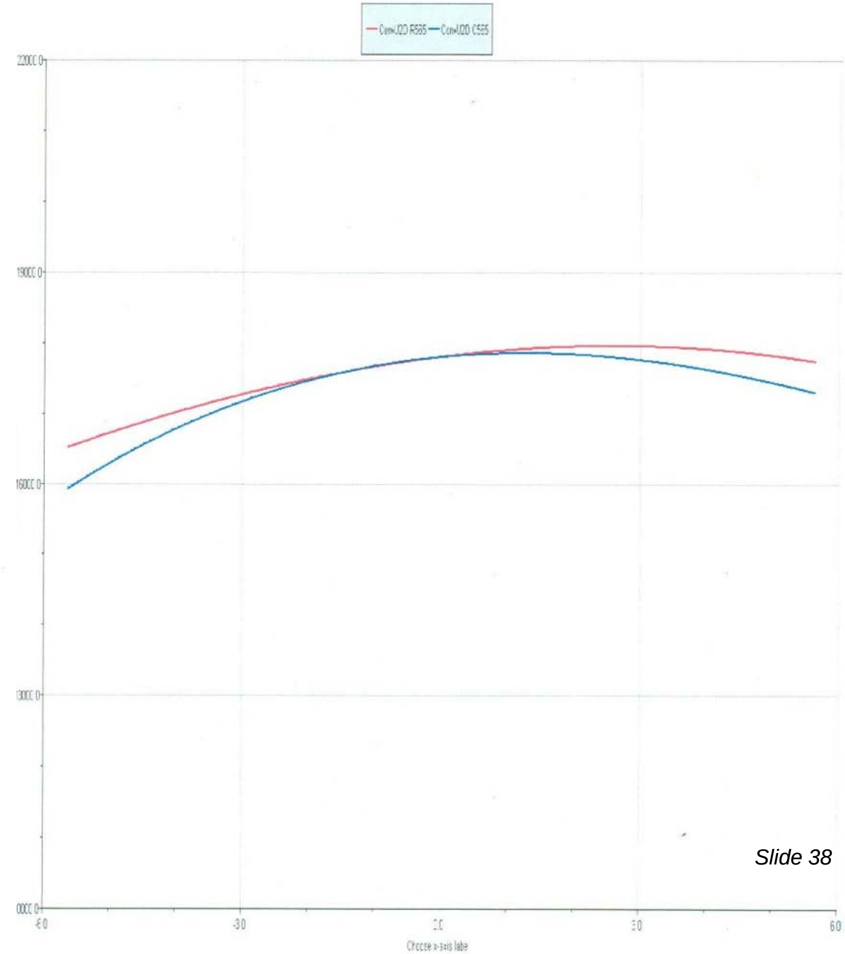
Nov 2012 FTO Data Scatter and Gain Analysis (5 plates)

- **4DF S 4DF G**

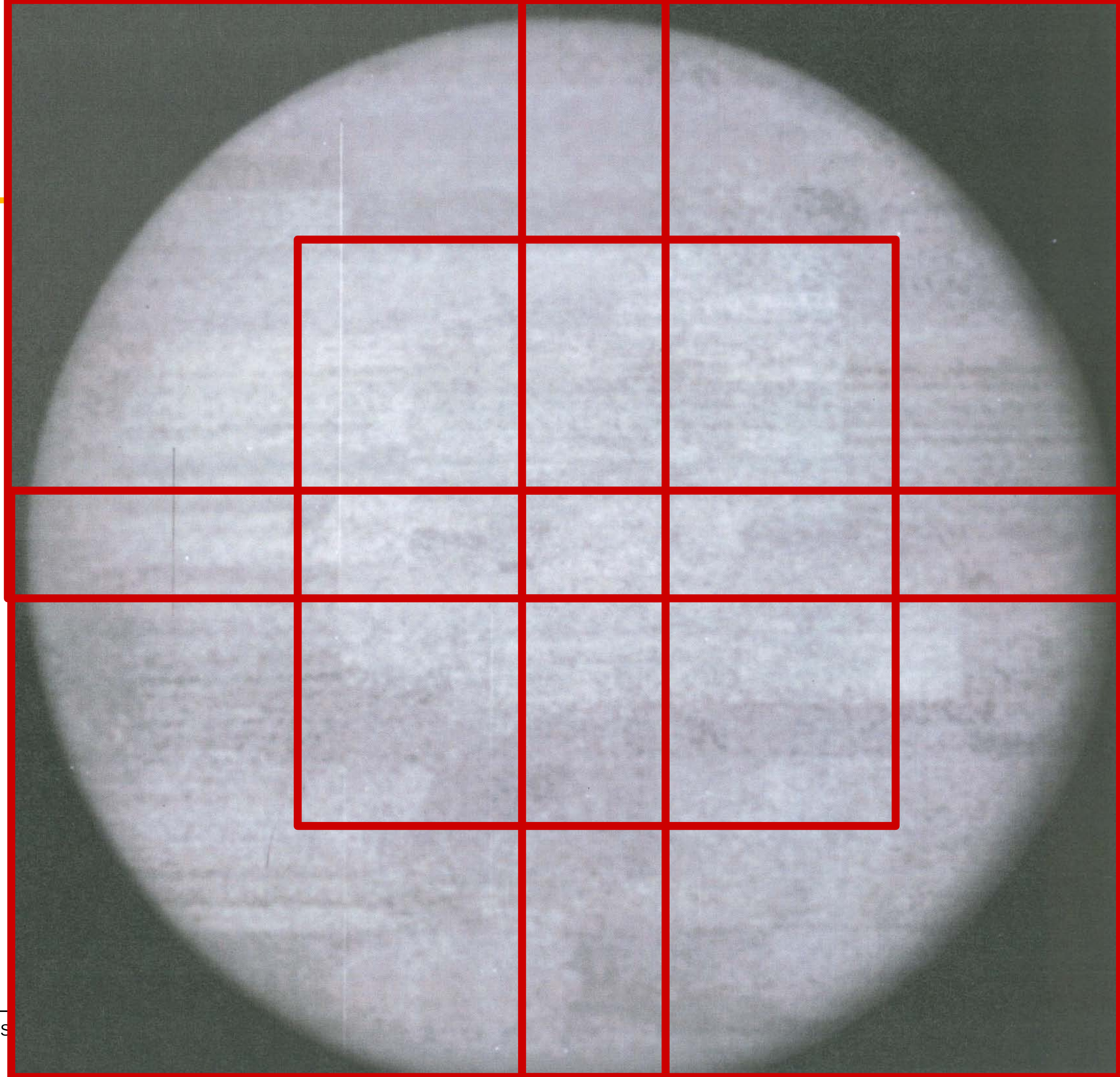
48%



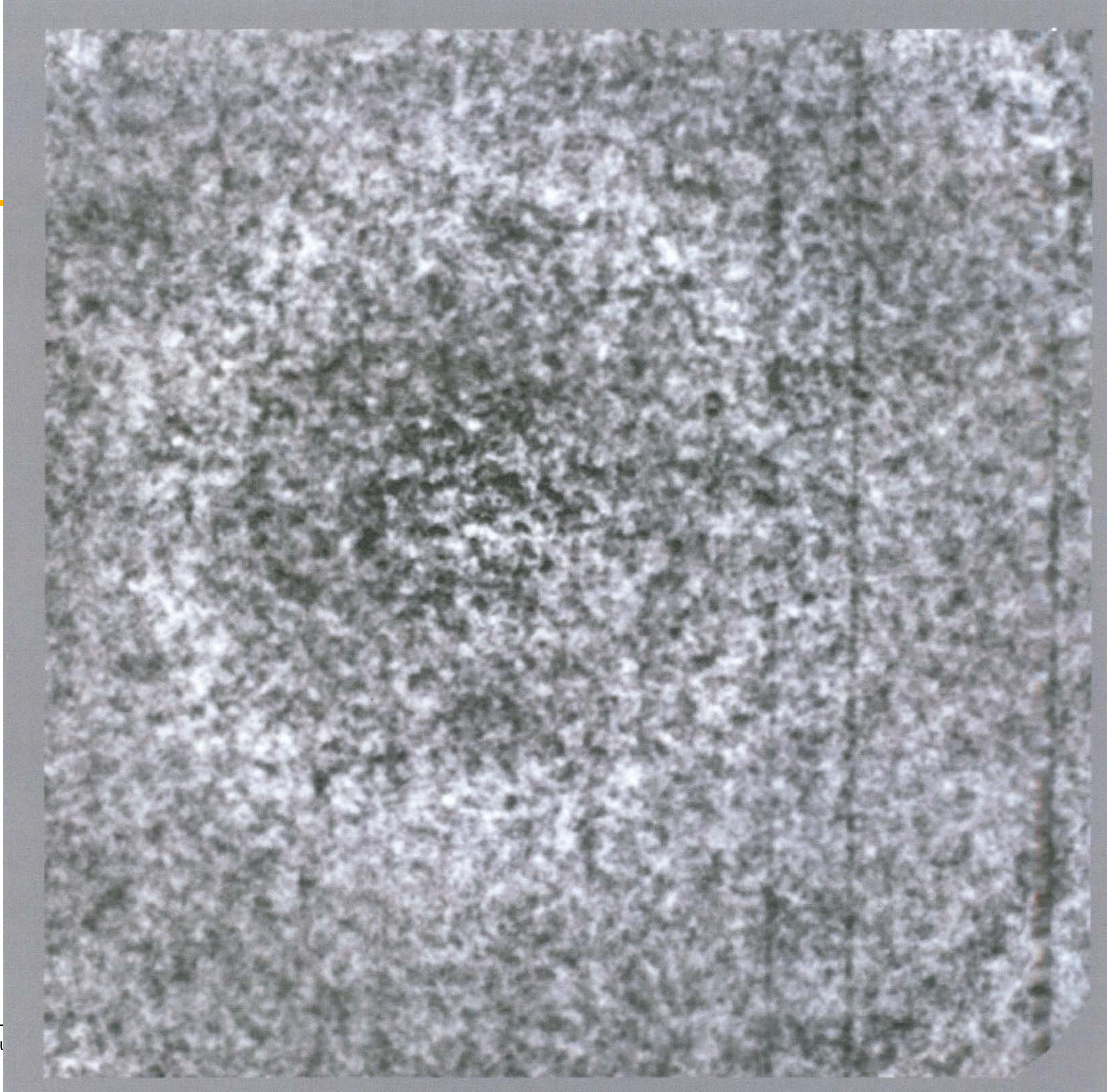
8%



- **Axis 2, Time 1 Flat Field**



Center Camera Only FTO Residuals



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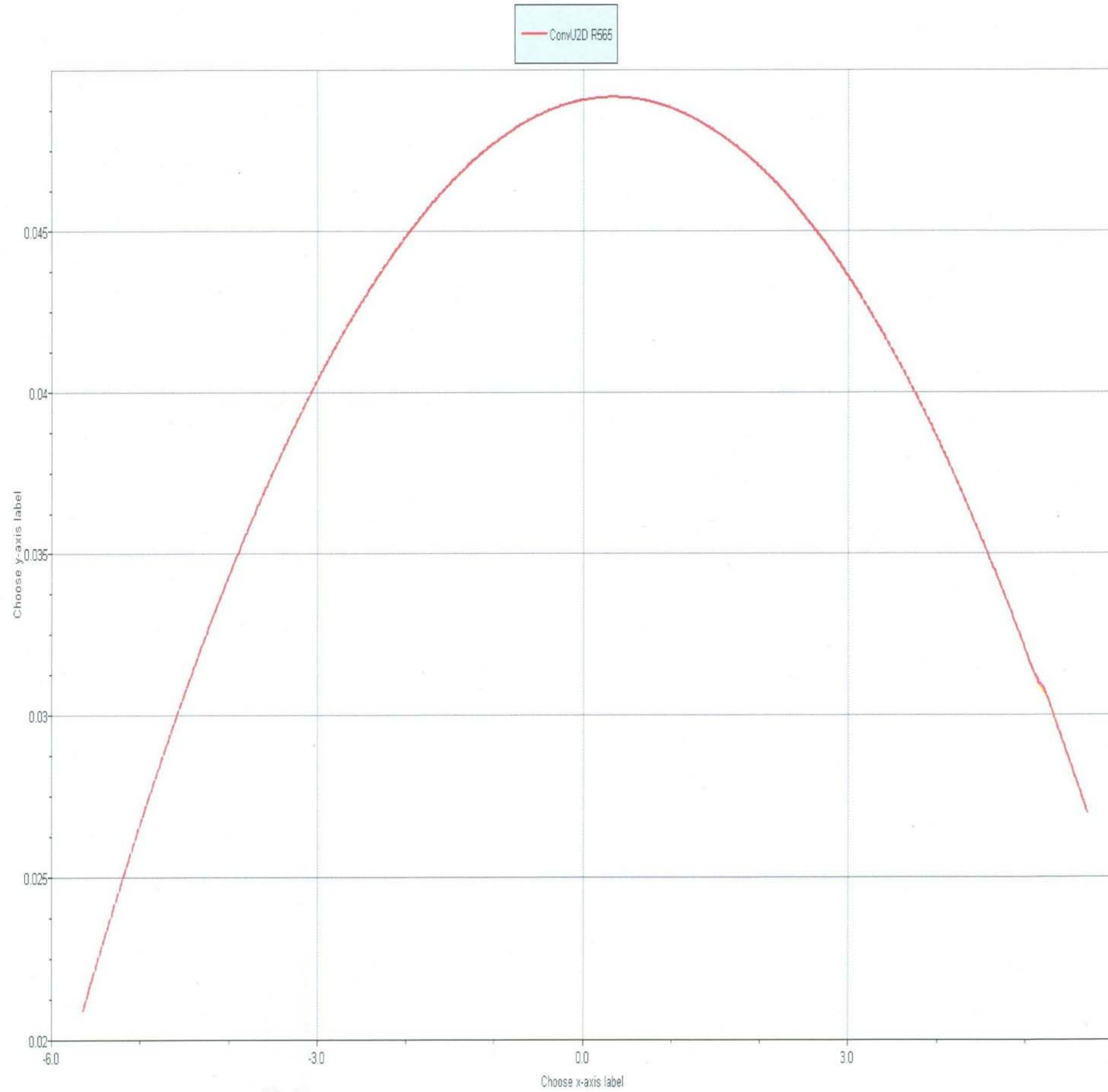
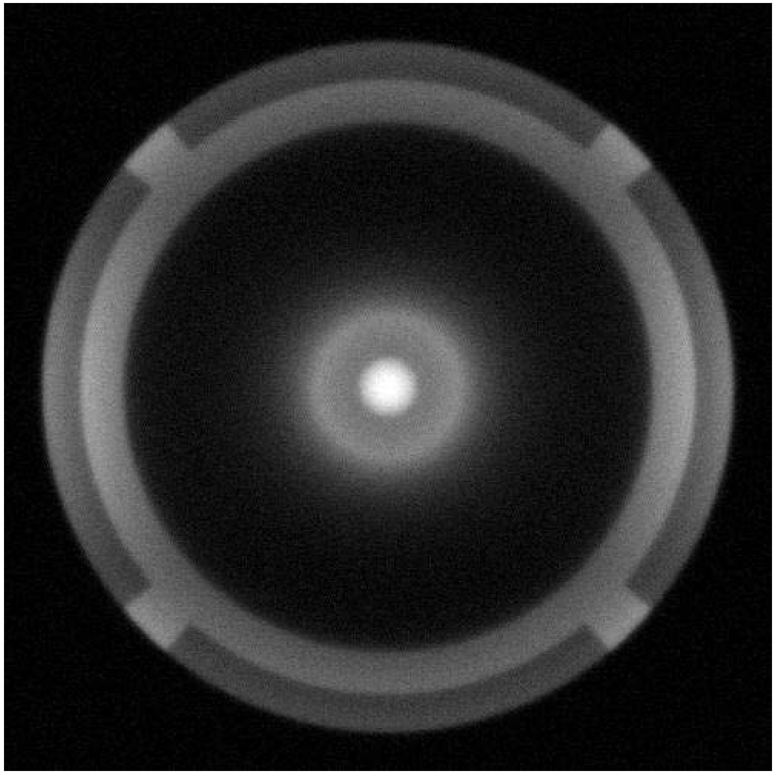
Inferred Scatter, FTO



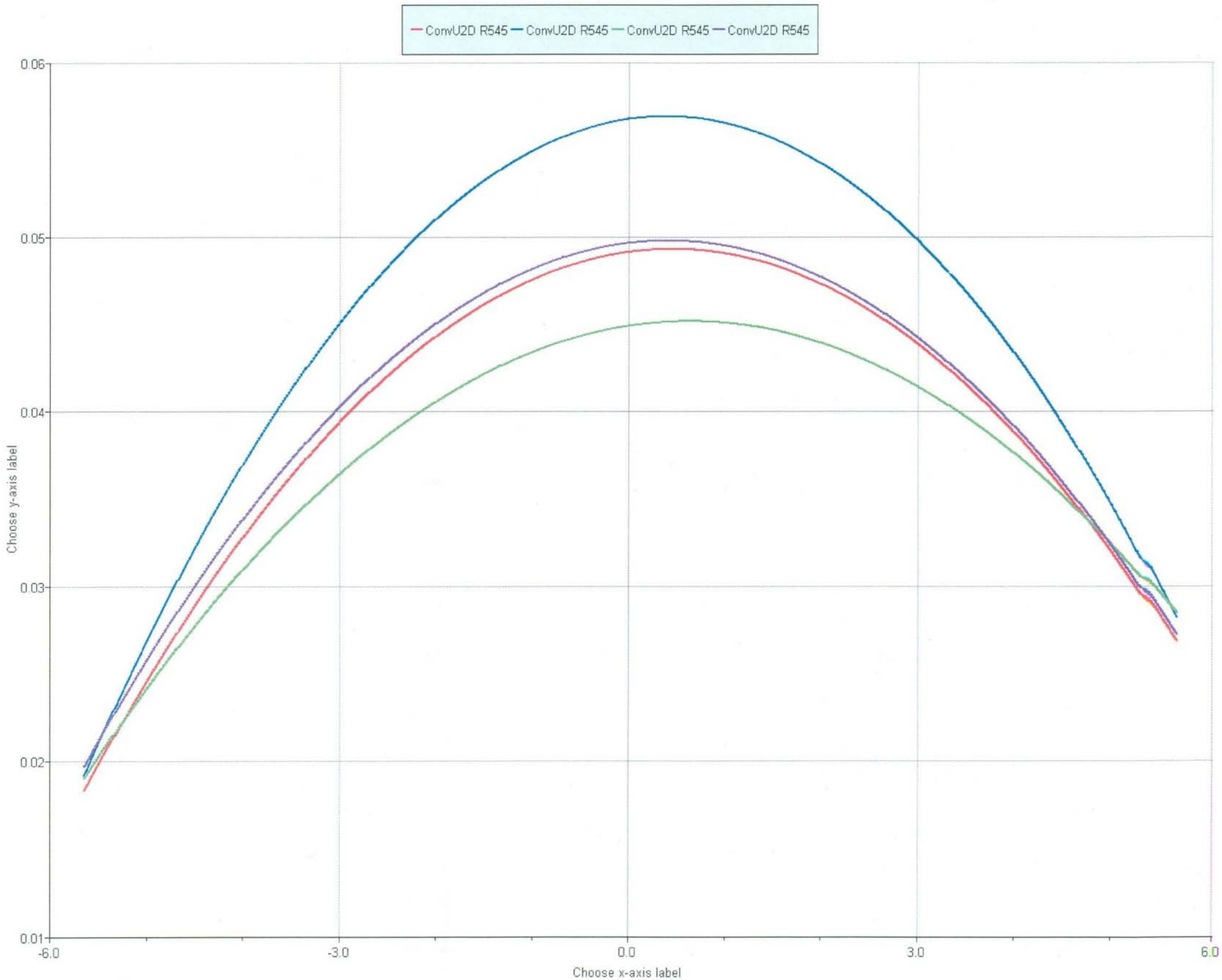
So What?

- **Simulation is broken,**
- **Just learn whatever the field is…**



Width of the Known Ring for FTO

- 5.4-4.5
- 5.4-4.25
- 5.4-3.5
- 5.4-0



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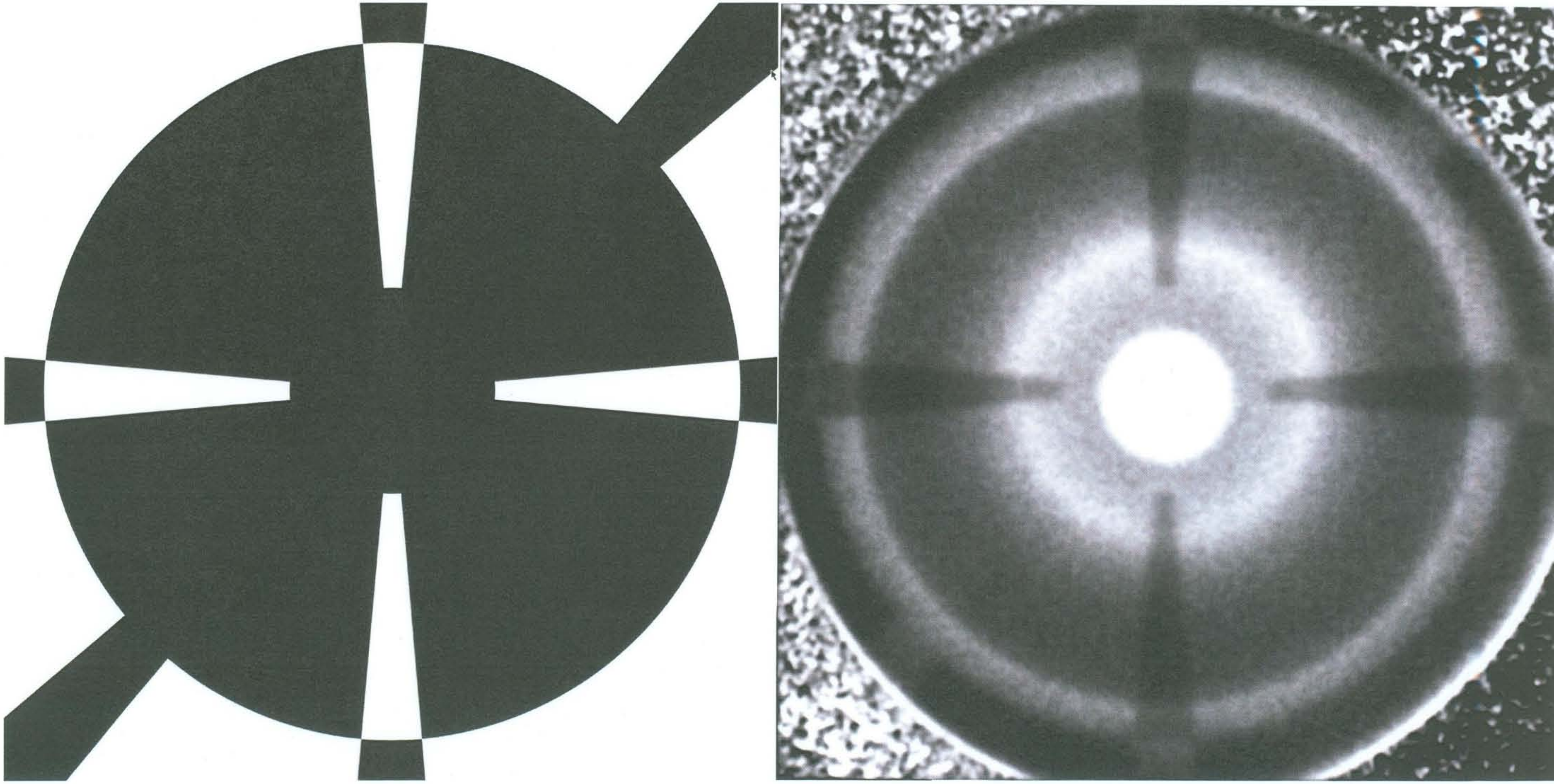
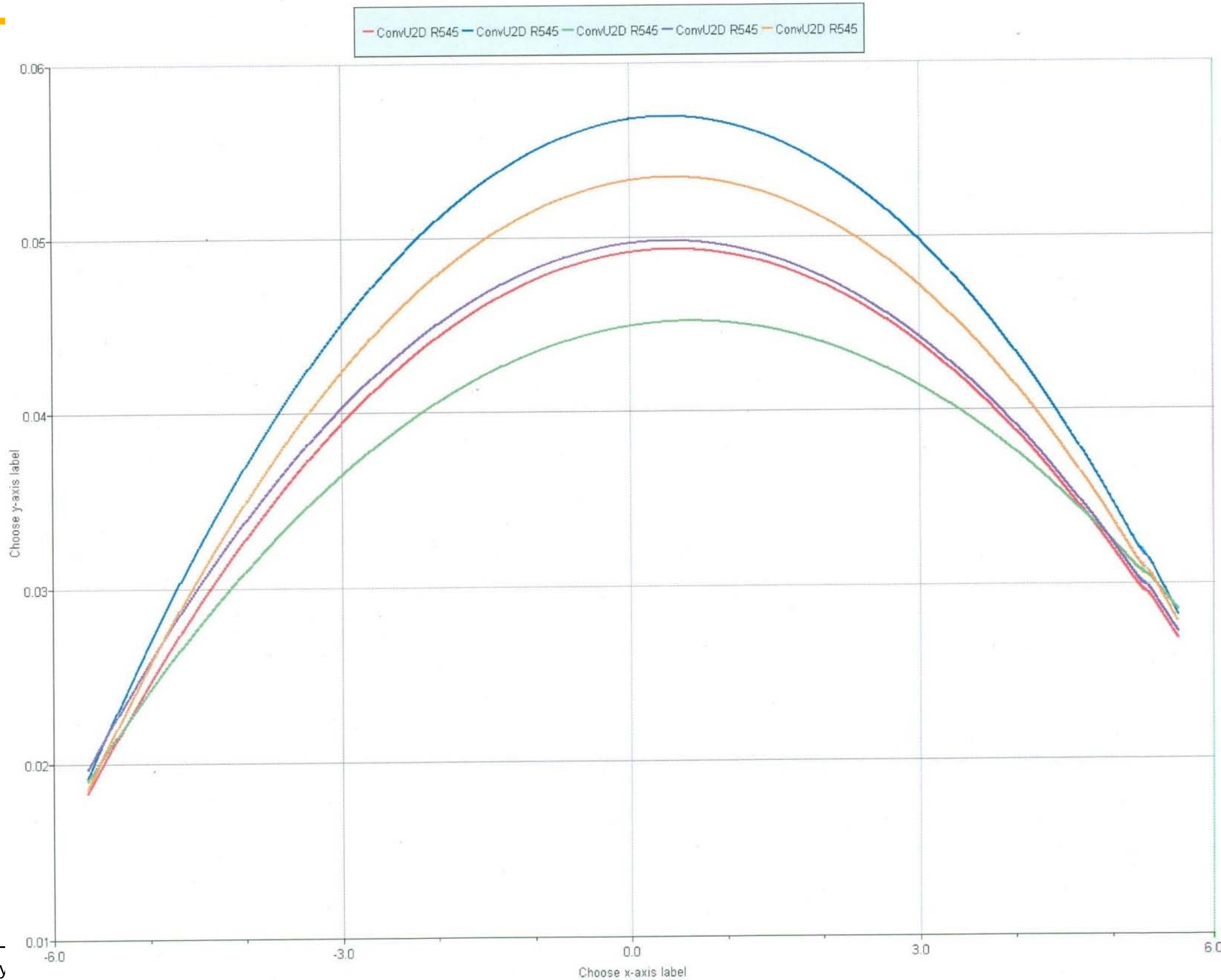
Additional synthetic fiducials in FTO graded collimator, with FTO

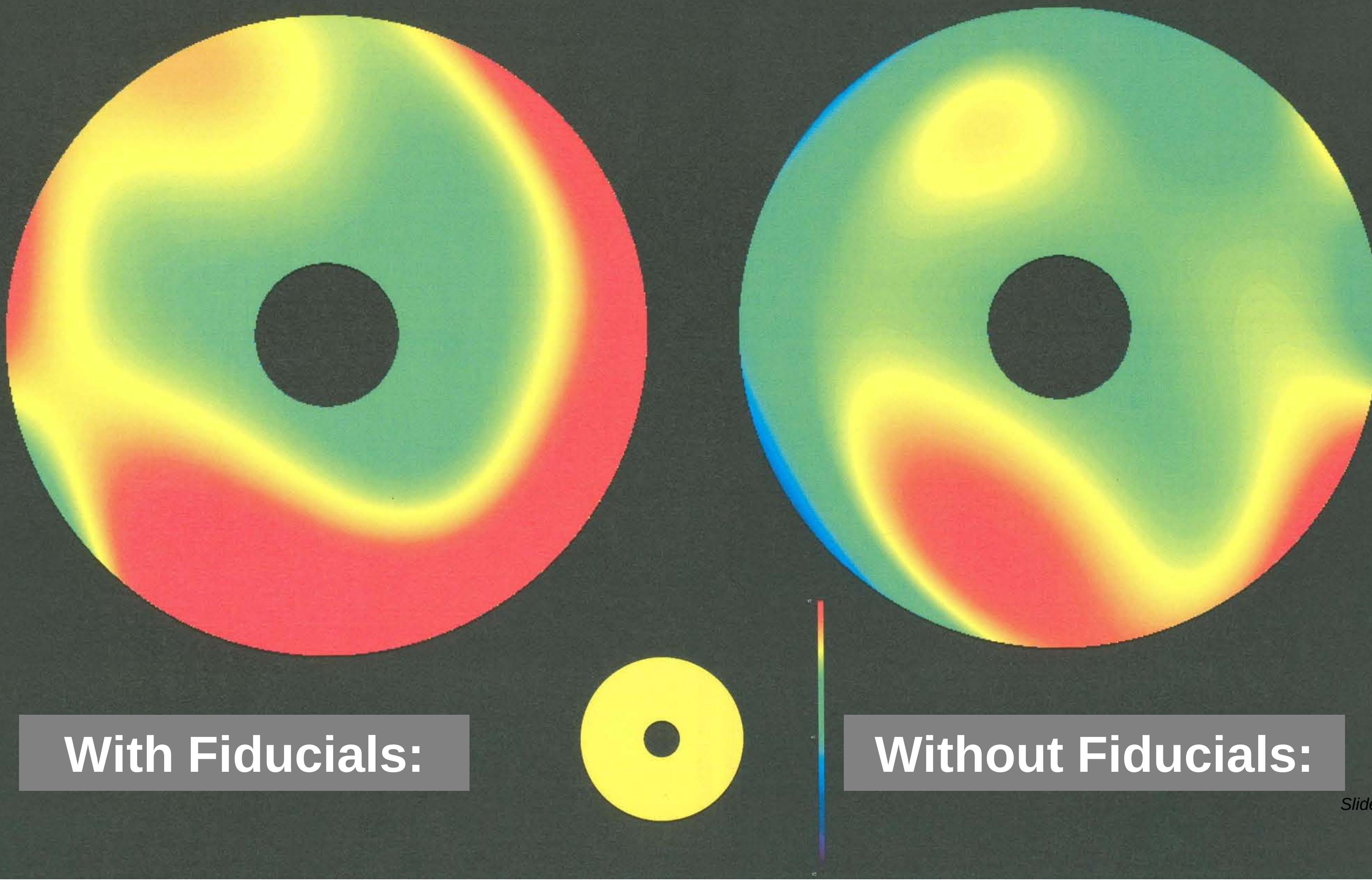


Width of the Known Ring for FTO

- 5.4-4.5
- 5.4-4.25
- 5.4-3.5
- 5.4-0
- Fiducials



Density in the FTO Ta



With Fiducials:

Without Fiducials:

Conclusion

- Scatter is more curved than previously thought
- Curved fields can't be learned accurately in existing thin fiducial ring
- Fiducials inside unknown objects don't perfectly solve the problem
- But they can help

Questions