Creating a Framework for Simulated CT Analysis

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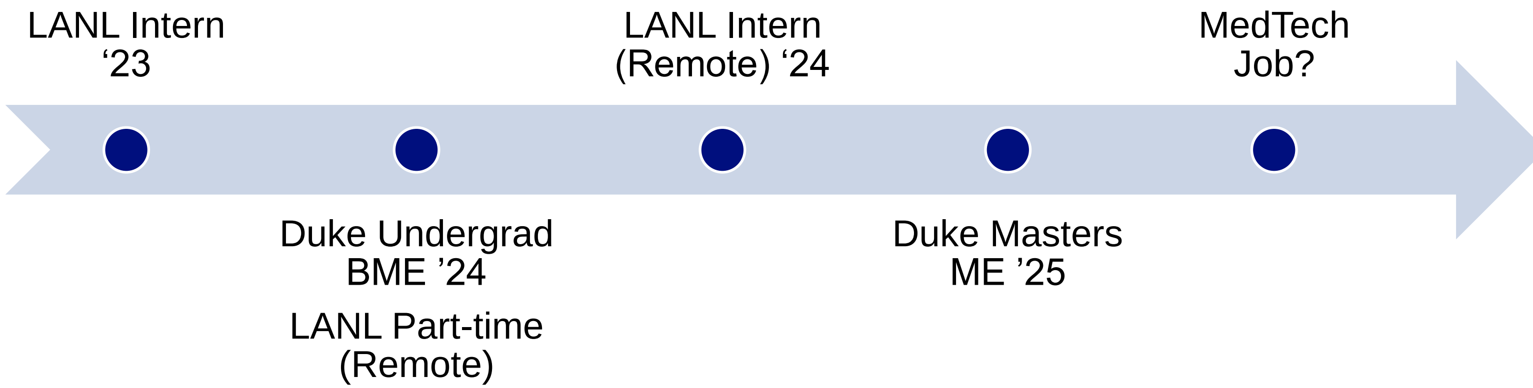
August 26, 2024

LA-UR-24-31153

About Me!



My background:

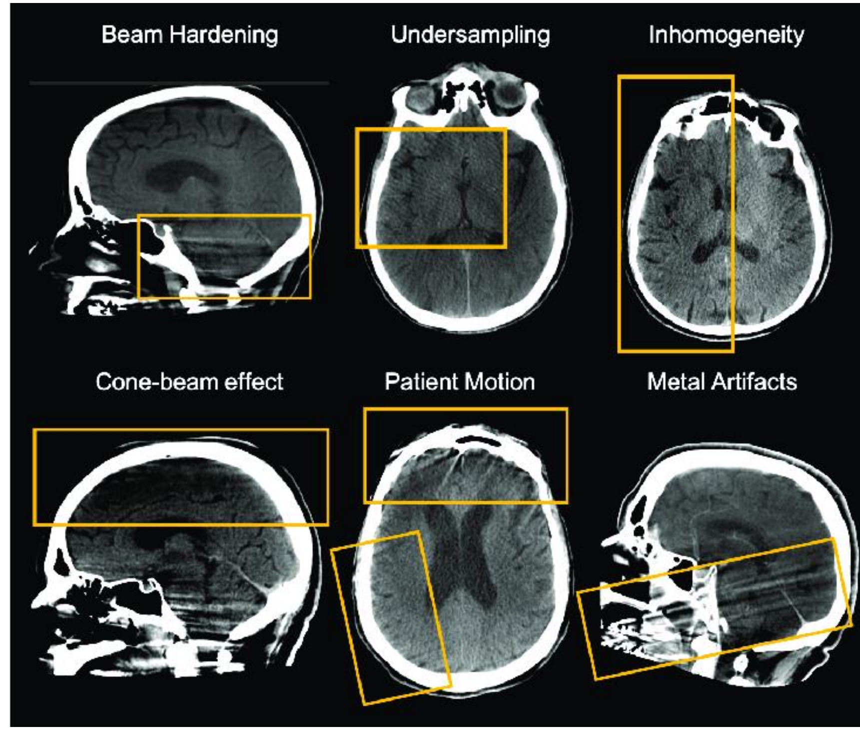
- Medical imaging (CT)
- Medical device design
- Surgical robotics

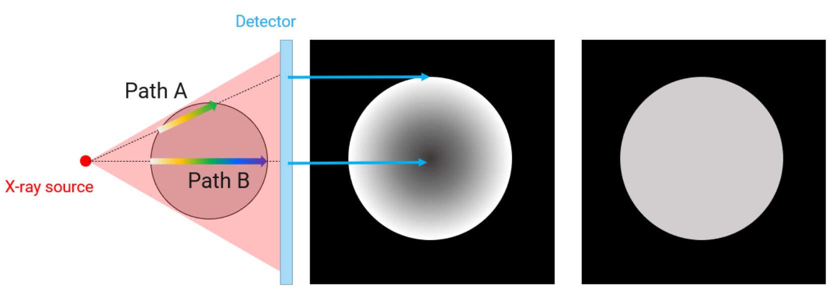
Last summer:

- aRTist CT scans
- Out-of-plane detector tilt

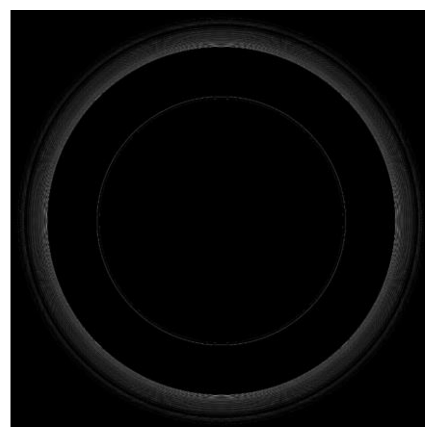
Overview: CT Artifacts

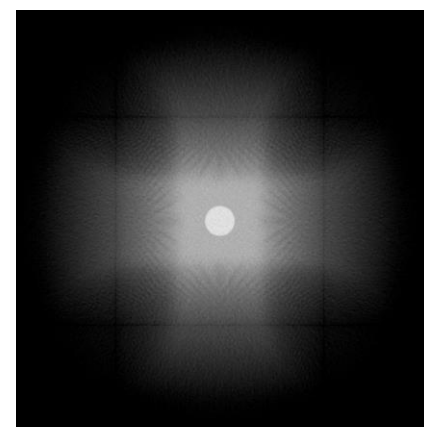
- A few common artifacts





With beam hardening artifacts   Without beam hardening artifacts

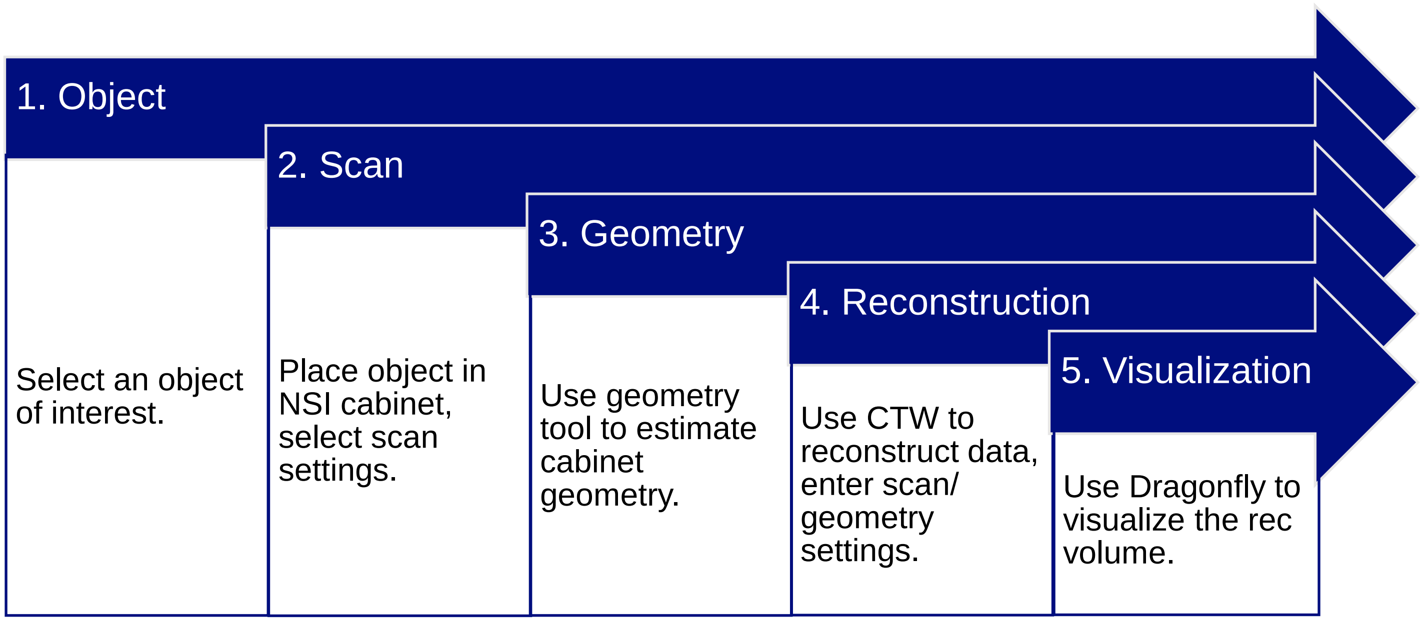




Overview: CT Scanning Process

1. Object
   Select an object of interest.
2. Scan
   Place object in NSI cabinet, select scan settings.
3. Geometry
   Use geometry tool to estimate cabinet geometry.
4. Reconstruction
   Use CTW to reconstruct data, enter scan/ geometry settings.
5. Visualization
   Use Dragonfly to visualize the rec volume.

Overview: CT Scanning Process



- How might we simulate these steps?

Overview: CT Scanning Process

1. Object	2. Scan	3. Geometry	4. Reconstruction	5. Visualization
Select an object of interest.	Place object in NSI cabinet, select scan settings.	Use geometry tool to estimate cabinet geometry.	Use CTW to reconstruct data, enter scan/ geometry settings.	Use Dragonfly to visualize the rec volume.

Phantom (Fins Redux)	aRTist software	Inherently known/variable	Recon	E1695 analyses

Overview: CT Scanning Process

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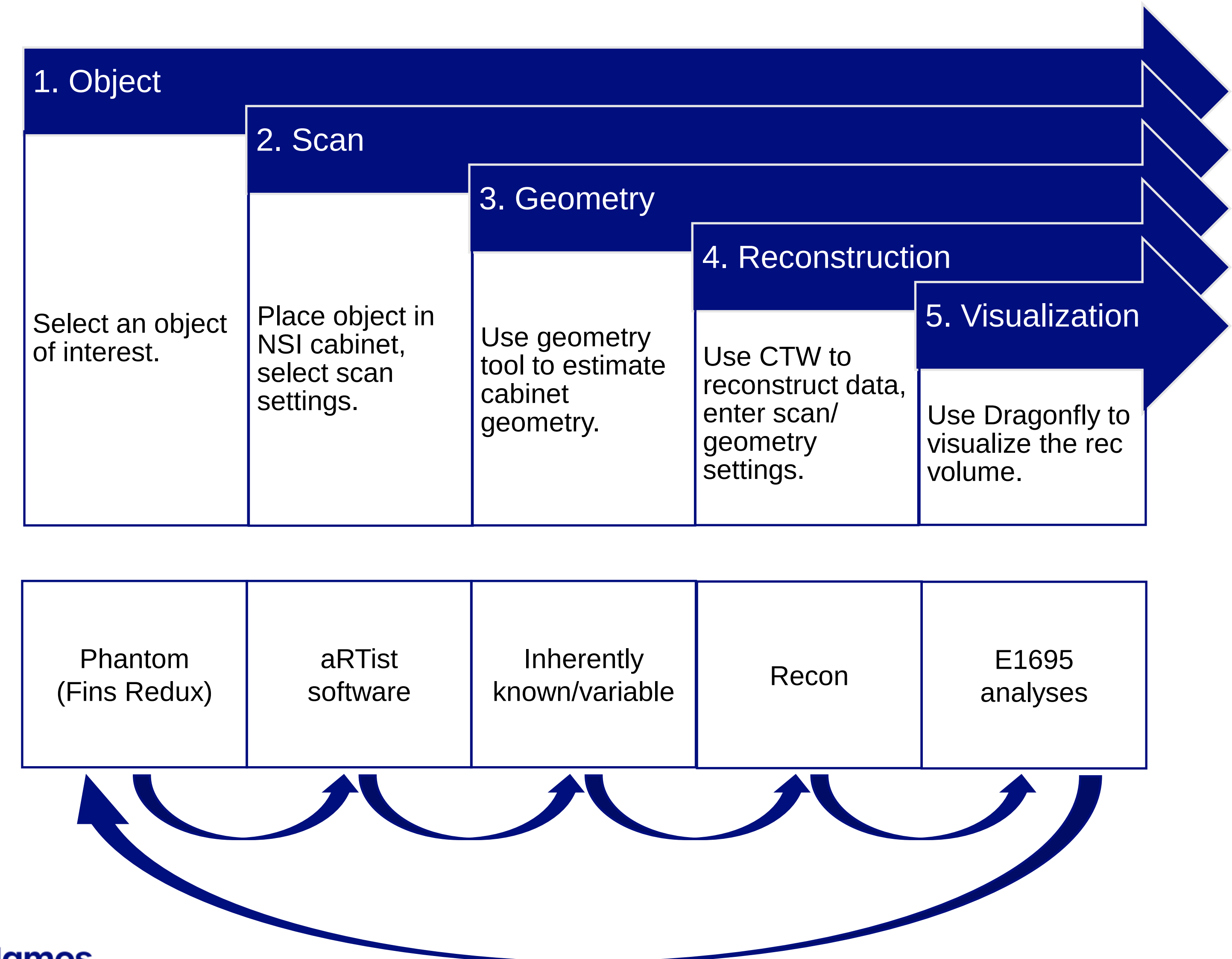
Select an object of interest.	Place object in NSI cabinet, select scan settings.	Use geometry tool to estimate cabinet geometry.	Use CTW to reconstruct data, enter scan/ geometry settings.	Use Dragonfly to visualize the rec volume.

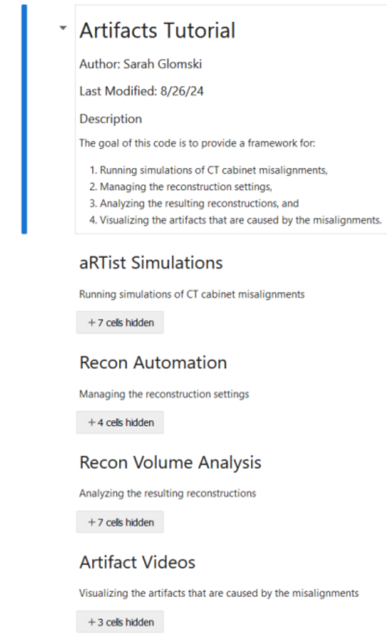
Phantom (Fins Redux)	aRTist software	Inherently known/variable	Recon	E1695 analyses

- How might we integrate/automate these steps?

Overview: CT Scanning Process

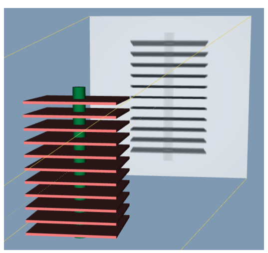


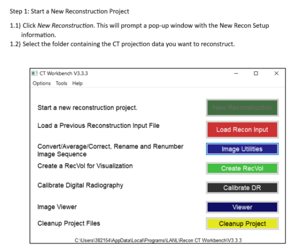
Introducing the Artifacts Tutorial

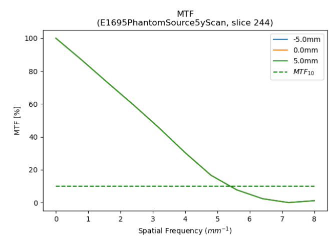


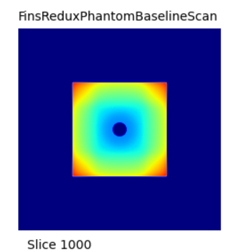
Goals:

1. Run simulations of CT cabinet misalignments,
2. Manage the reconstruction settings,
3. Analyze the resulting reconstructions, and
4. Visualize the artifacts that are caused by the misalignments.









- Smooth interfaces between steps
- Easily repeatable for automation (whole process or subprocesses)

Located in my git repo: https://git.lanl.gov/e-6/members/students/sarahglomski

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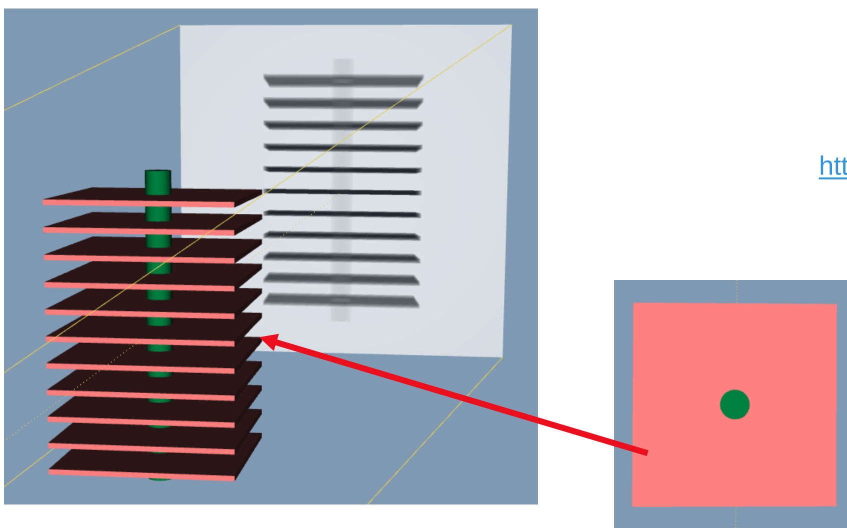
Fins Redux Phantom

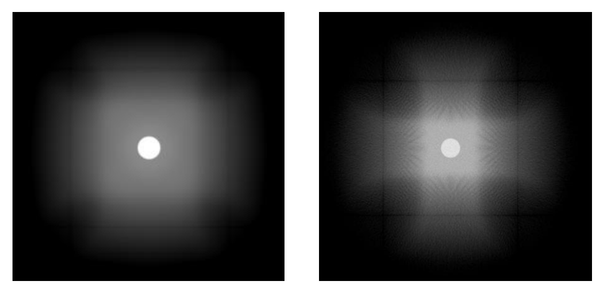
- Used in the Artifacts Tutorial
- Square Al fins around HDPE cylindrical rod
  - Difficult to reconstruct due to harsh lines
  - Emphasizes cone beam artifacts and vertical beam offsets

- Leeds makes a similar MicroCT phantom with cylindrical fins

https://leedstestobjects.com/index.php/phantom/microct-set/



Simulated in aRTist



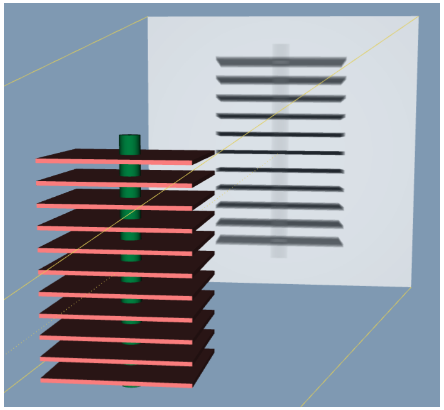
Cone beam artifacts

Accounting for CT Artifacts

- All can be simulated in aRTist, but not all are accounted for in Recon
- Used vertical beam offsets in the Artifacts Tutorial

Examples	Calculated by Geometry Estimation?	Accounted for in Recon?
Beam center offset (vertical, horizontal)	✔	✔
In-plane detector tilt	✔	✘
Out-of-plane detector tilt	✘	✘
Center of rotation shift	✘	✘
Beam hardening (dishing)	✘	✘
Focal spot blur	✘	✘
Metal artifacts	✘	✘
Ring artifacts	✘	✔

Using the Tutorial: Simulating Beam Offsets



- Artistlib: package used to automate the scanning process
  - Setup geometry
  - Beam energy
  - Phantom material
  - Scan parameters
  - Documentation: https://artist.bam.de/files/aRTist-Scripting.pdf
- Output: tiff stack

- Example: Add a vertical beam offset and iterate from -5 mm to +5 mm.

-5 mm　　0 mm　　+5 mm

Recon Overview

- CT Workshop (Recon) runs by continuously updating the ReconInput.txt file
  - Has instructions on which step of the reconstruction process to execute
    - Common File Specs
    - **Calibration of Raw Files Tab**
    - Median filter between calibration and attenuation
    - **Raw file to Attenuation Tab**
    - Filter raw files
    - Raw file Resize
    - Detector Geometry
    - Scan specifications
    - **Sinogram Generation Tab**
    - **Centering Tab**
    - Ring Removal
    - Sinogram filtering and resizing
    - Additional Sino Processing
    - Sinogram Background for 0 padding
    - Region of Interest
    - Half Image Options
    - **General Reconstruction Options**

ReconInput - Notepad

File Edit Format View Help

```
//------------------------ Detector Geometry ------------------------
panel_dist_mm              800.0     // Distance from source to panel, L (L = any consistent length unit, mm in FlashCT)
obj_dist_mm                400.0     // source to object centerline radius
panel_horiz_pix            1200      // number of pix in panel rows, horizontal direction (to calc the horizontal center)
panel_vert_pix             1200      // number of pix in panel column, vertical direction (to calc vert_center)
pixel_horiz_mm             0.125     // horizontal pixel size in panel, L (used for horizontal scaling, panel distances)
pixel_vert_mm              0.125     // vertical pixel size in panel, L (used for vertical scaling, cone angle, vert center)
vert_cen_offset_mm         0.0       // offset of perpendicular from source to center of panel, + = down, L units
horiz_cen_offset_mm        0.0       // horizontal distance in L units from panel center to beam center + = right
crop_horiz_pix             1200      // number of pix in cropped region, horizontal direction
crop_vert_pix              1200      // number of pix in cropped region, vertical direction
offset_horiz_pix           0         // distance from panel left to crop region left, + = right (used for calibration)
offset_vert_pix            0         // vert pixel dist from panel to cropped region, top left corners, + down (vert cent)


//------------------------ Scan specifications ------------------------
// NOTE: 180 + fan angle scans are rebin or Parker weighted for fan angle correction.  180 scans are parallel only
// scan_angle needs to be specified only for opt_scan_angle = 1.  Calculated internally otherwise.

// example for 360 degree scan
opt_scan_angle             0         // 0 = 360 circle, 1 = 180 + fan angle, 2 = 180 stopping 1 short, 3 = 180 with redundant point at 180
rotations                  1885      // Number of rotations (raw files) used to make a sinogram (1 + last raw index)
scan_angle                 0         // angle (deg) of last raw file after rotations -1 intervals.  User input for opt_scan_angle = 1 only

//------------------------ Sinogram Generation Tab ------------------------
opt_sin_create_rec         0         // 0 = do not create sinograms in recon, 1 = create sinograms
sino_create_first          0         // Index of first sinogram file to be created (row index of raw file, min = 0)
sino_create_last           1199      // Index of last sinogram file to be created (row index of raw file, max = numrows-1)
MB_per_sino_block          15000     // Number of MB of memory (MB = 1024 * 1024 bytes) allowed for one block of sinos

//------------------------ Centering Tab ------------------------
opt_center                 4         // 0 = don't center; 1 = 1 pass; 2 = 2 pass; 3 = 2 pass from previous file; 4 = manual
```

Ln 45, Col 4 | 100% | Windows (CRLF) | UTF-8

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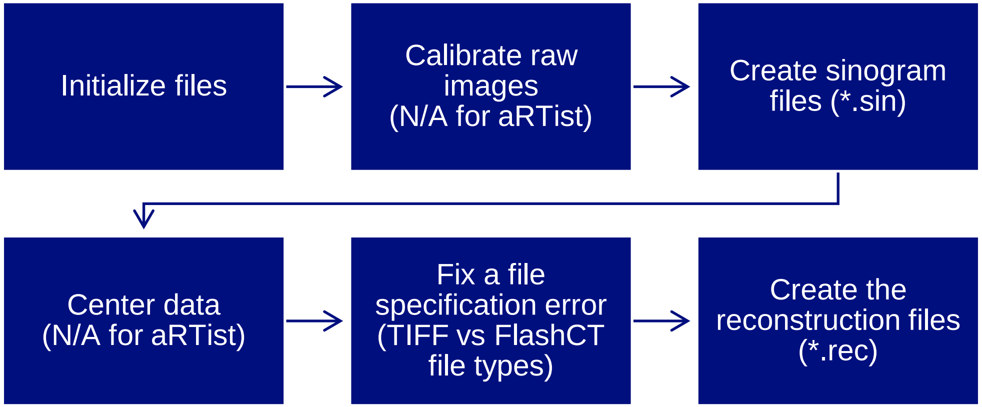
Recon Overview

- Recon steps:

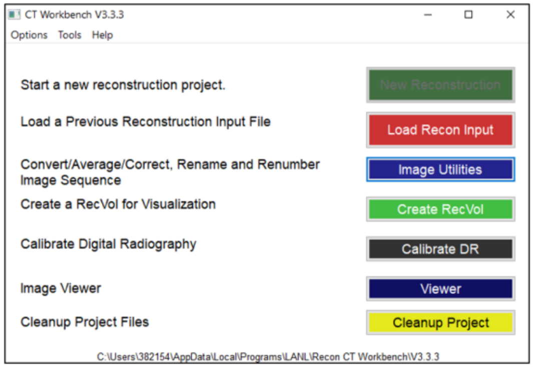


- Tutorial for running aRTist data through CT Workshop: [\\e6vault\Students\2024\aRTistRecon](\\e6vault\Students\2024\aRTistRecon)

Step 1: Start a New Reconstruction Project

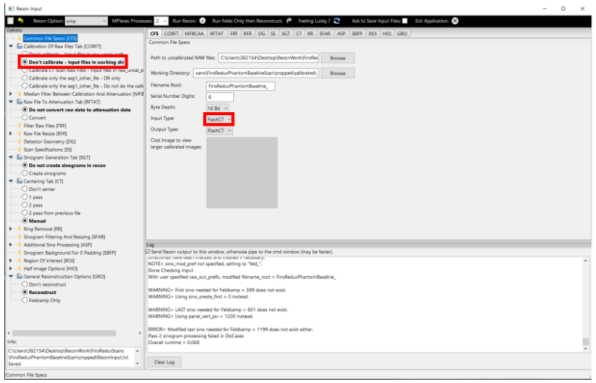
1.1) Click *New Reconstruction*. This will prompt a pop-up window with the New Recon Setup information.

1.2) Select the folder containing the CT projection data you want to reconstruct.



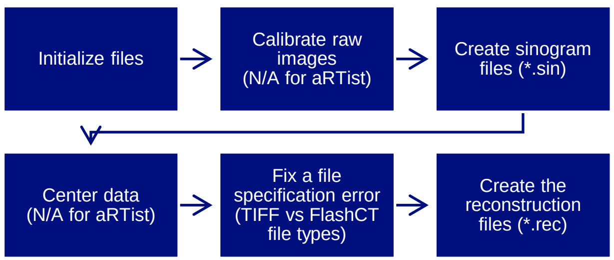
8.7) Change the Input Type to *FlashCT*.

8.8) Click *Don't calibrate – input files in working dir*.

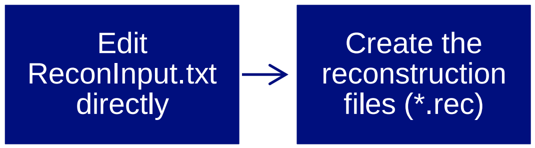


Using the Tutorial: Selecting Recon Settings

- Can either run Recon "from scratch"

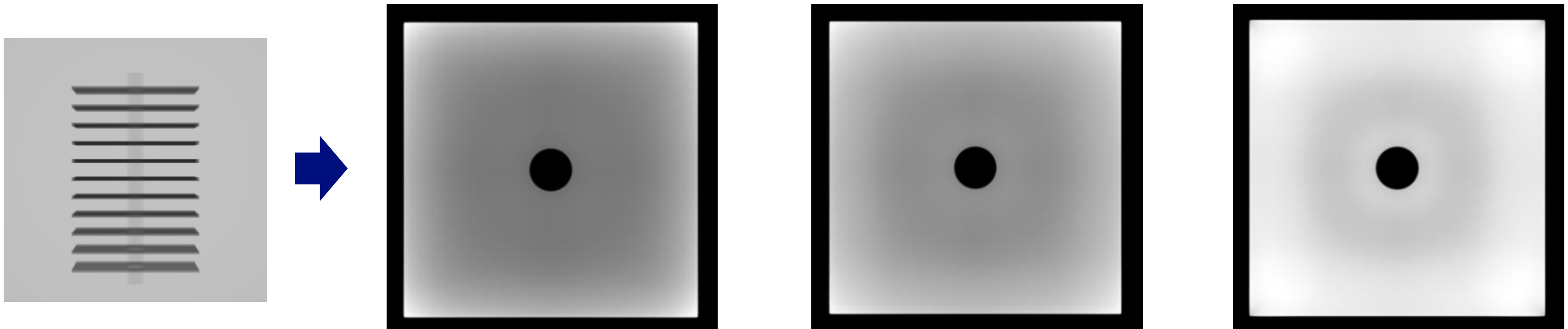


- Or edit the ReconInput.txt file and re-run the final reconstruction step



- Example: Account for a vertical beam offset and iterate from -5 mm to +5 mm.

Actual offset: -5 mm



-5 mm

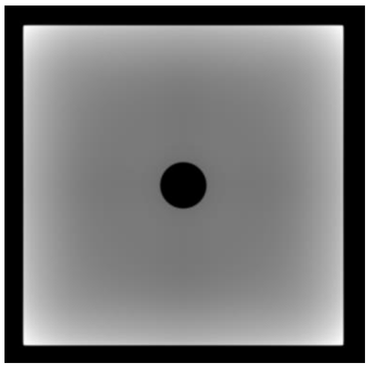
-5 mm | 0 mm | +5 mm

Using the Tutorial: Selecting Recon Settings

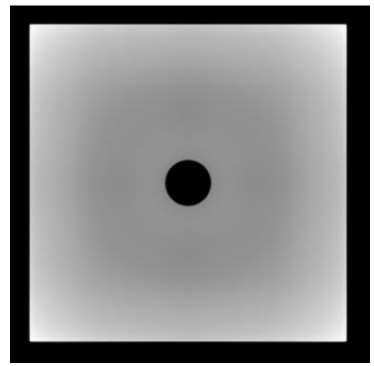
- Can also reconstruct specific slices

Actual offset: -5 mm

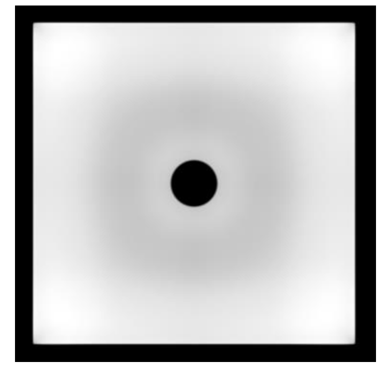
Slice 244 (bottom fin):



-5 mm

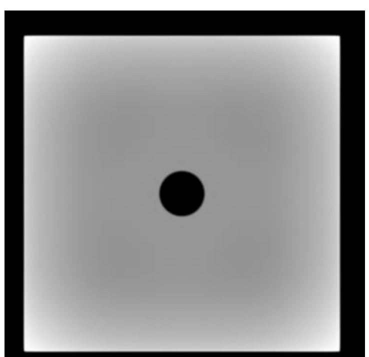


0 mm

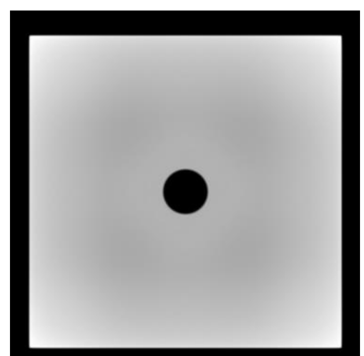


+5 mm

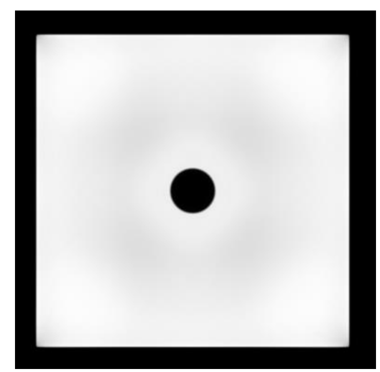
Slice 324 (2nd fin from bottom):



-5 mm



0 mm



+5 mm

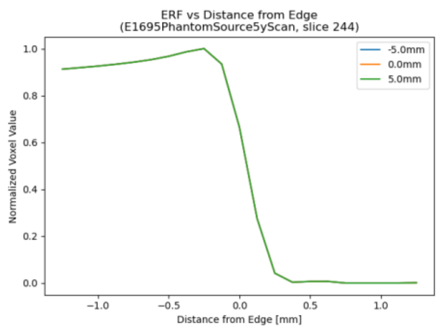
Using the Tutorial: Analyzing Rec Volumes

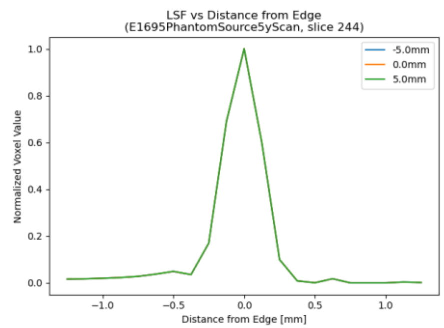
- Packages:
  - Pillow E
  - NDT image toolkit
  - Matplotlib
  - OpenCV

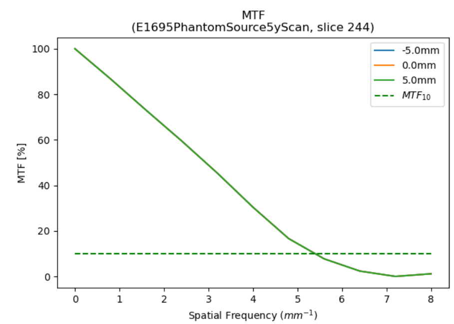
- E1695 analyses:
  - Edge Response Function (ERF)
  - Line Spread Function (LSF)
  - Modulation Transfer Function (MTF)
  - MTF_{10}

ERF | LSF | MTF

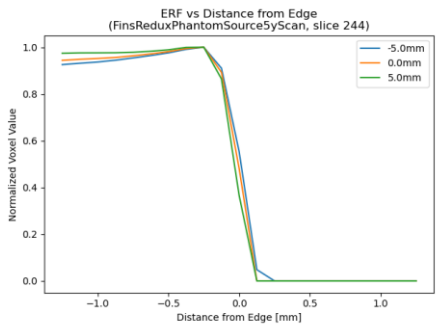
E1695 Phantom:

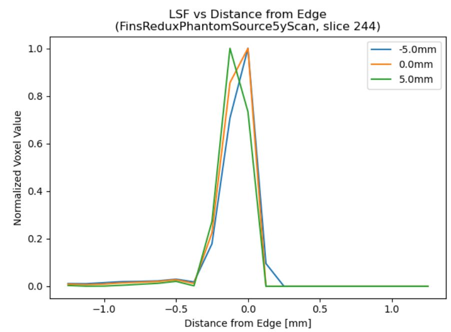


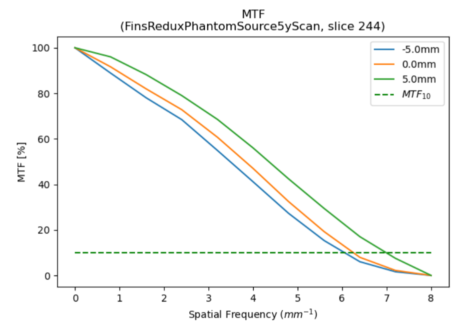




Fins Redux Phantom:





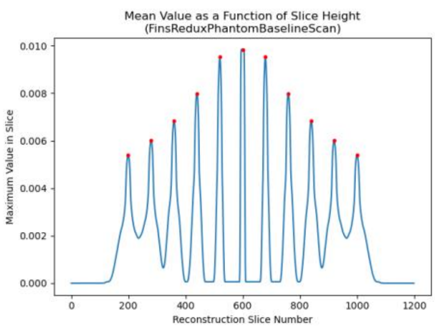


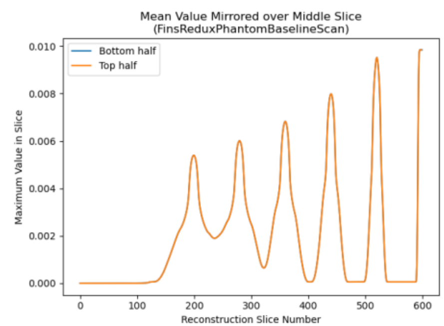
Using the Tutorial: Analyzing Rec Volumes

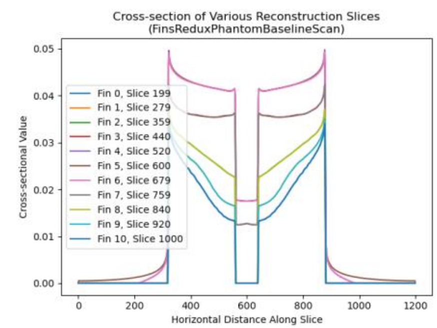
- Compare different scans quantitatively with:
  - Max/mean value plot
  - Mirrored plot
  - Cross section plot
  - Finding fins

Mean Value Plot | Mirrored Plot | Cross Section Plot

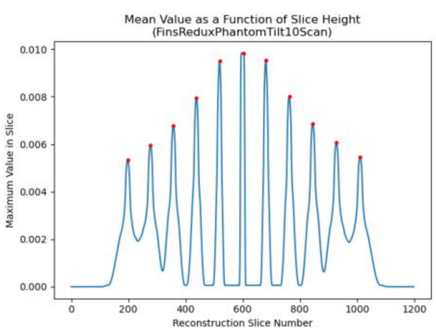
Out-of-plane tilt: 0 deg

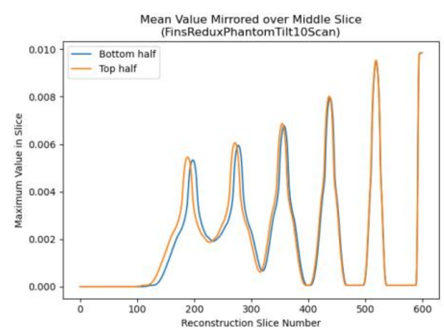


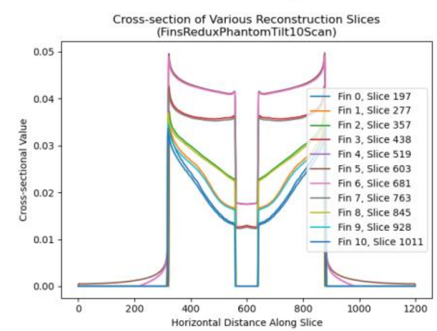




Out-of-plane tilt: 10 deg







Using the Tutorial: Visualizing Artifacts

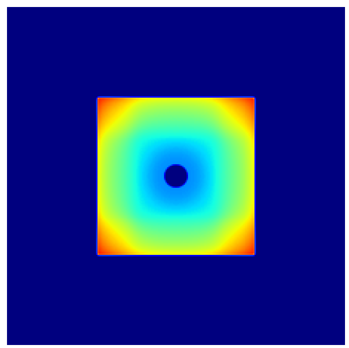
- Find fins on different scans and compare qualitatively with colored images

Slice 1000 (top fin for 0 deg tilt):

Slice 1011 (top fin for 10 deg tilt):

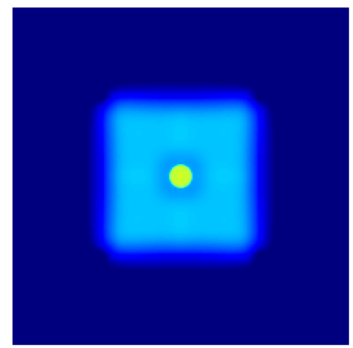
Out-of-plane tilt: 0 deg

FinsReduxPhantomBaselineScan



Slice 1000

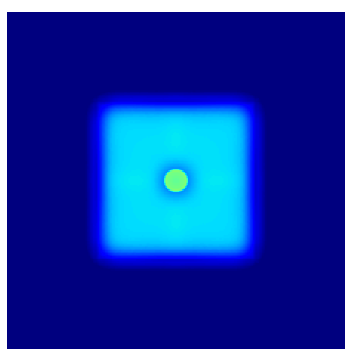
FinsReduxPhantomBaselineScan



Slice 1011

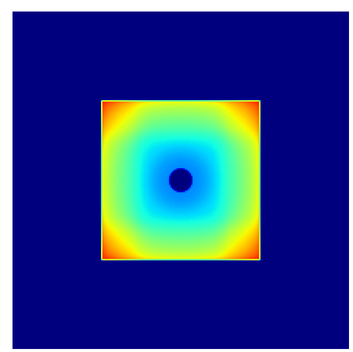
Out-of-plane tilt: 10 deg

FinsReduxPhantomTilt10Scan



Slice 1000

FinsReduxPhantomTilt10Scan



Slice 1011

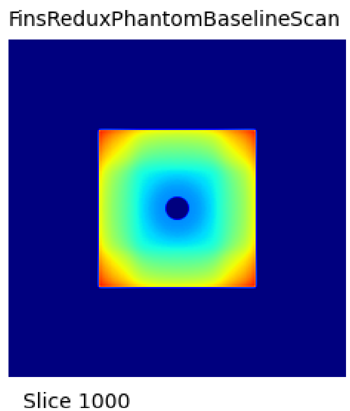
Using the Tutorial: Visualizing Artifacts

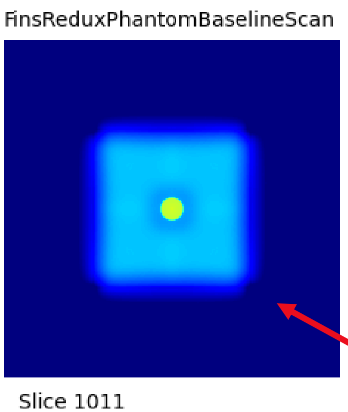
- Find fins on different scans and compare qualitatively with colored images

Slice 1000
(top fin for 0 deg tilt):

Slice 1011
(top fin for 10 deg tilt):

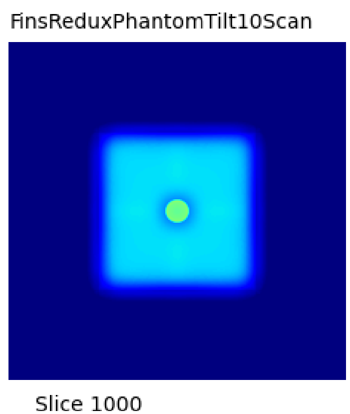
Out-of-plane tilt:
0 deg

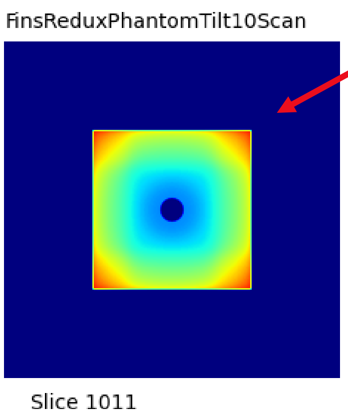




2.3% error

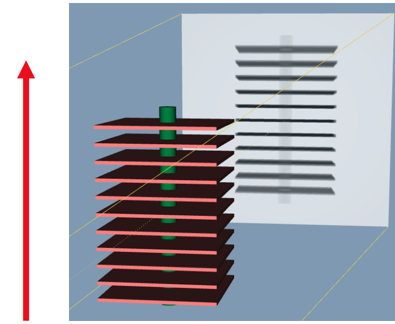
Out-of-plane tilt:
10 deg





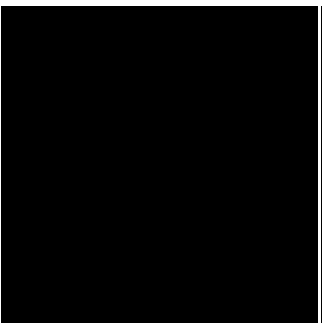
Using the Tutorial: Visualizing Artifacts

- Account for different offsets and compare qualitatively with gifs

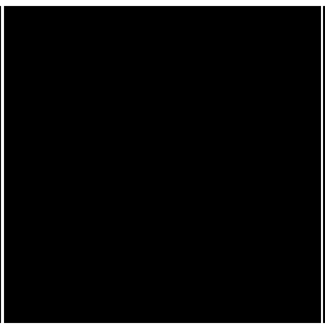


Reconstructions from bottom to top

Actual offset: -5 mm



-5 mm



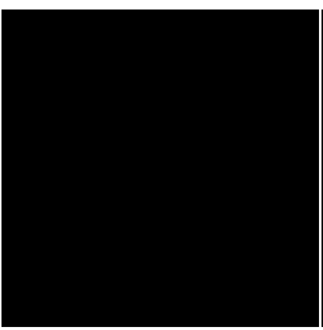
-4 mm

-3 mm

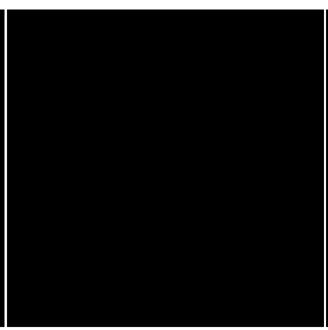
-2 mm

-1 mm

0 mm



+5 mm



+4 mm

+3 mm

+2 mm

+1 mm

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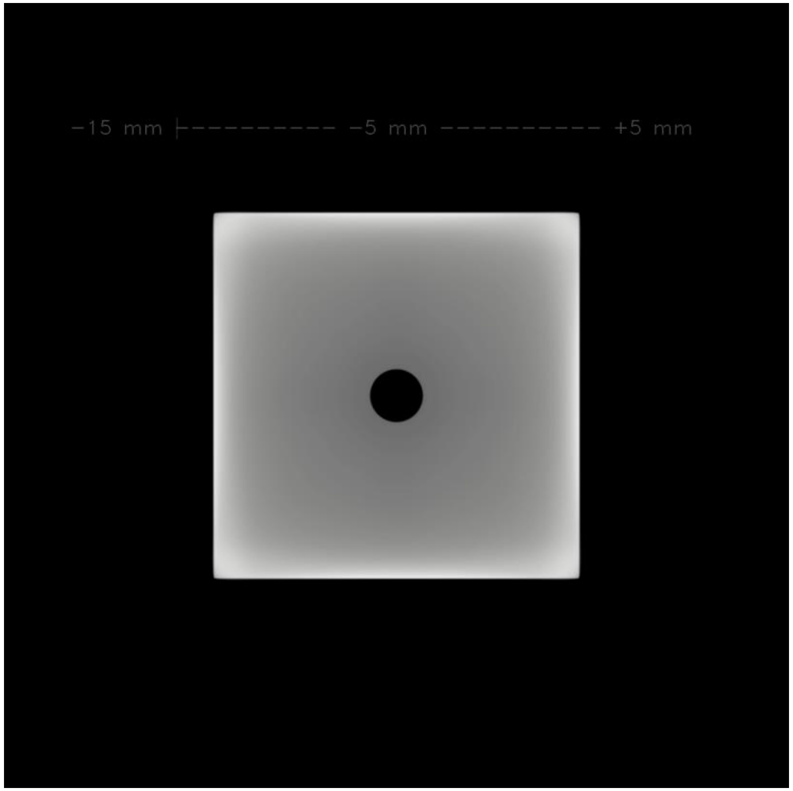
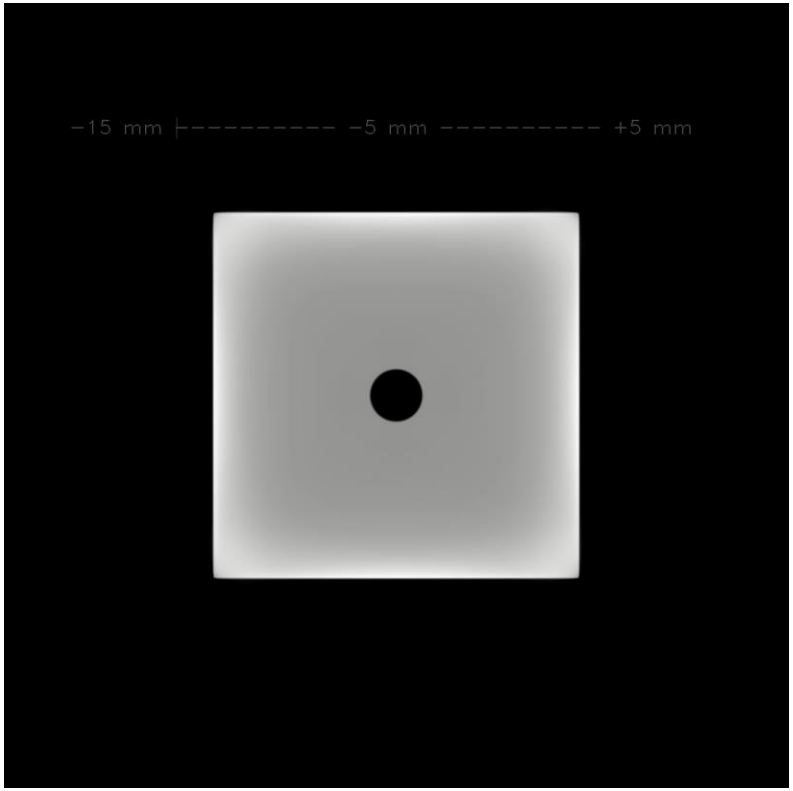
Using the Tutorial: Visualizing Artifacts

- Morph to show same slice with varying levels of artifact intensity



Slice 244
(bottom fin)



Slice 324
(2nd fin from bottom)

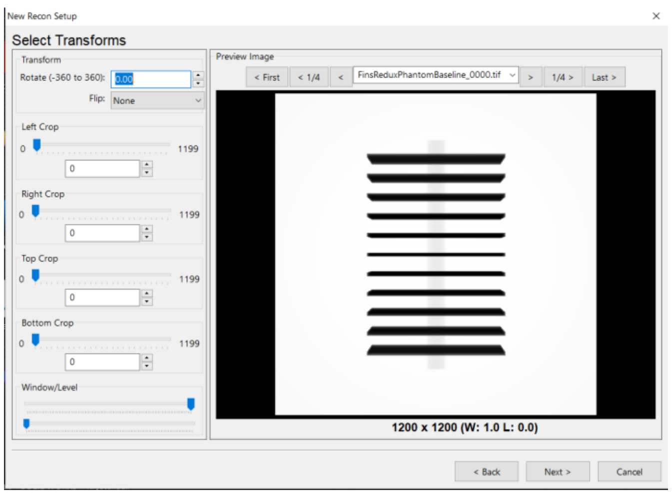
Challenges Faced Along the Way

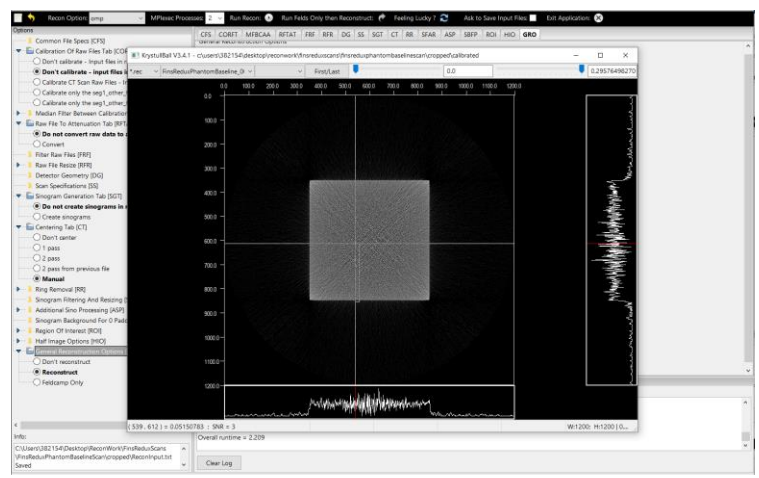
- Roadblocks
  - Updating aRTist version for automation
  - aRTist settings
  - Wi-Fi troubles
  - Broken card reader
  - Covid
  - Love/hate relationship with AskIT
  - Love/hate relationship with remote work
- aRTist quirks – there are many!
  - List of helpful hints so you don't have to struggle like I did
  - In my git repo: https://git.lanl.gov/e-6/members/students/sarahglomski

- We made it! I am very grateful to Matt and Shannon for their support and flexibility throughout this project.

Future Work

- Creating more example artifacts using the existing Artifacts Tutorial
- Further developing the Artifacts Tutorial
  - Turn the Jupyter notebook into an interactive training program
  - Add a GUI with example problems to work through
  - Use examples of both extreme and subtle artifacts
  - Show how combinations of artifacts interact





Thank you! Questions?

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- Git repo: https://git.lanl.gov/e-6/members/students/sarahglomski