Livermore Tomography Tools (LTT) Software Package

Kyle Champley
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Other Contributors: Steve Glenn, Brad Funsten, Jerel Smith, Jeff Kallman, Bill Brown, Isaac Seetho, Steve Azevedo, Maurice Aufderheide, Harry Martz, George Overturf

Lawrence Livermore National Laboratory

Nondestructive Characterization Institute

Livermore Explosives Detection Program (LEDP)

LLNL-PRES-707793

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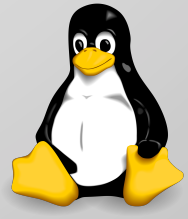
What is LTT?

Cross-platform (Windows, Mac, Linux) collection of Computed Tomography (CT) algorithms written entirely in C/C++

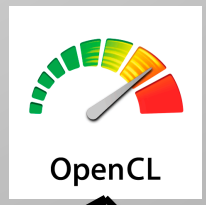
Capable of processing CT data from raw detector counts to reconstructed images and beyond

Supports most conventional scanner geometries (parallel beam, fan beam, cone beam) and irregular sampling/ geometries (e.g. modern fixed-gantry systems)



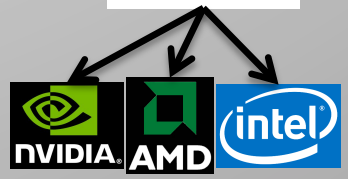
Algorithms are designed to provide quantitatively-accurate results (with specified units) in a timely manner

Includes many state-of-the-art and novel algorithms, including iterative reconstruction, physics-based scatter, beam hardening, and detector blur correction



LTT is multi-threaded (OpenMP) and utilizes GPU processing (OpenCL)

Data sets that are too large to fit into memory are processed in smaller chunks



Efficiently process data from any CT system on any computer with exceptional accuracy

User Interface

LTT script

```
1  # Set data file names and location
2  archdir = /tomography/          # path to location of data
3  dataType = raw uncalib          # specify that data is raw
4  sfile = raw_0.tif               # one of the raw radiograph files
5
6  # Set the scanner geometry
7  geometry = parallel             # parallel beam geometry
8  ncols = 2048                    # number of detector columns
9  nrows = 2048                    # number of detector rows
10 centerCol = (ncols-1)/2         # center detector column
11 pixelWidth = 0.00127            # detector pixel width (mm)
12 pixelHeight = pixelWidth        # detector pixel height (mm)
13 nangles = 720                   # number of projections
14 arange = 180                    # angular range of projections (degrees)
15
16 # Set the reconstruction volume
17 setDefaults
18
19 # Processing Queue
20 makeAttenRadsALS                # convert from raw to attenuation radiographs
21 outlierCorrection               # remove outliers
22 ringRemoval                     # correct projection data to prevent ring artifacts
23 findCenter                      # automatically determine center detector column
24 FBP                            # reconstruct with Filtered Backprojection
25 imageRingRemoval                # image-space ring removal
26 display {z=(0,rzelements-1)}    # display reconstructed volume
```

Executing Algorithms and Setting Parameters

script file (can call scripts within other scripts)

interactive command line

submit commands through TCP/IP connection

Designed to be easy to use

built-in help/ manual pages

parameters/ variables can be set with mathematical expressions

don't need to specify any/ all algorithm parameters because all algorithm parameters have default values

Data and Image Visualization

two-way communication with ImageJ for data/ image visualization

http://imagej.nih.gov/ij/

Example Script

```
# Set data file names and location
archdir = /tomography/                  # path to location of data
dataType = raw_uncalib                  # specify that data is raw
sfile = raw_0.tif                       # one of the raw radiograph files

# Set the scanner geometry
geometry = parallel                     # parallel beam geometry
ncols = 2048                            # number of detector columns
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centerCol = (ncols-1)/2                 # center detector column
pixelWidth = 0.00127                    # detector pixel width (mm)
pixelHeight = pixelWidth                # detector pixel height (mm)
nangles = 720                           # number of projections
arange = 180                            # angular range of projections (degrees)

# Set the reconstruction volume samples
setDefaults

# Processing Queue
makeAttenRadsALS                        # convert from raw to attenuation radiographs
outlierCorrection                       # remove outliers
ringRemoval                             # correct projection data to prevent ring artifacts
findCenter                              # automatically determine center detector column
FBP                                     # reconstruct with Filtered Backprojection
imageRingRemoval                        # image-space ring removal
display {z=(0,rzelements-1)}            # display reconstructed volume
```
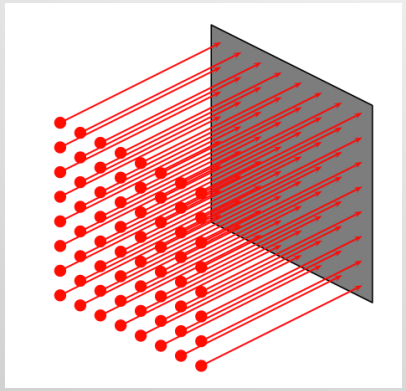
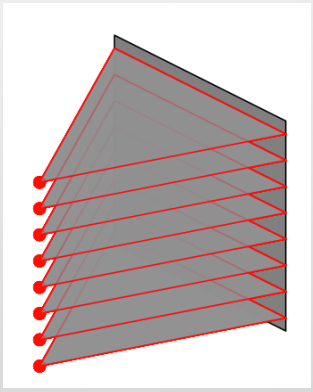

Scanner Geometries Supported

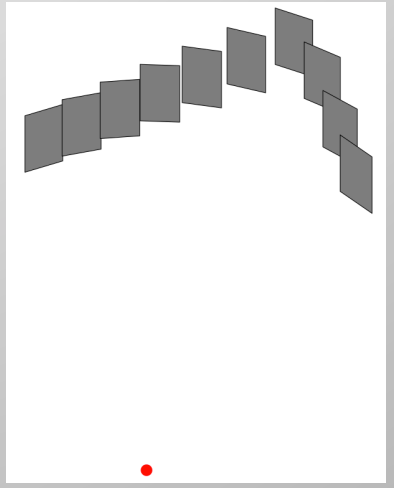
Parallel Beam



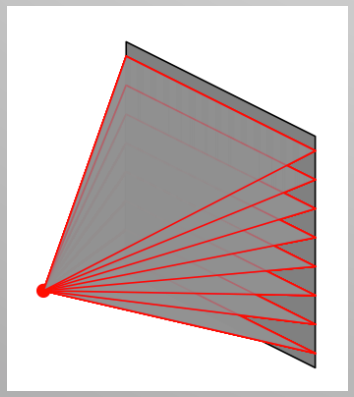
Fan Beam



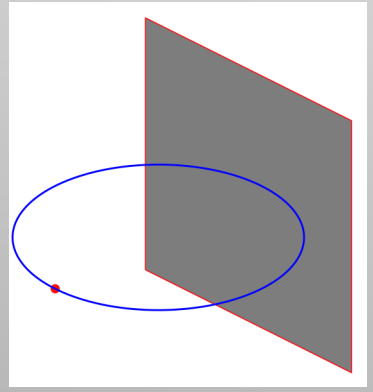
Custom Geometry Capability



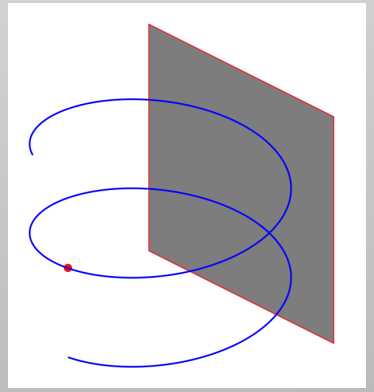
Cone Beam



Axial Source Path



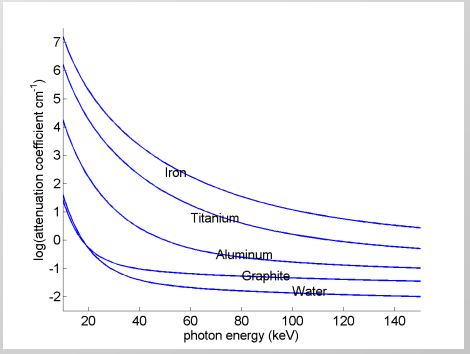
Helical Source Path



Simulation and Modeling

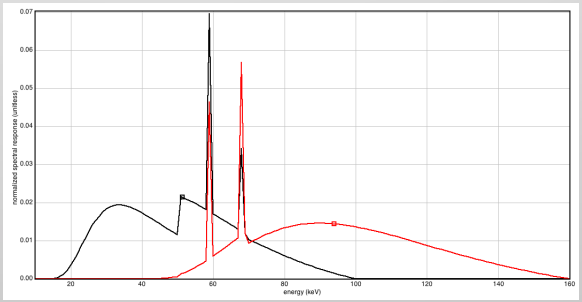
Energy Dependent Cross Section Tables

- x-ray photoelectric absorption, incoherent scatter, coherent scatter, pair production, triplet production cross section tables (EPDL-97) for energies from 1 keV to 10 MeV of elements 1 to 100
- model cross section of any materials that can be described by a chemical formula (or by mixture of materials and mass fractions)



X-ray Tube Spectral Distributions

- tungsten, molybdenum, gold, or copper x-ray targets
- variable take-off angle
- can specify x-ray filters
- can specify detector response model



CT Data Simulation

- utilizes analytic ray-tracing techniques (energy-dependent Beer-Lambert law)
- phantoms composed of collection of geometric objects

Preprocessing Algorithms (1 or 3)

Algorithm Name	Description
badPixelCorrection	correct bad detector pixels
gainCorrection	detector pixel gain correction and flat fielding
outlierCorrection	detects and corrects outlier detector pixels
lowSignalCorrection	corrects pixels with low signal (low SNR)
detectorDeblur	corrects for energy-dependent detector blur
downSample	down sample projection data
cropProjections	crop projection data
interpolateMissingViews	Interpolates missing projection files
makeTransmission	converts data to transmission space
makeAttenRads	converts data to attenuation space
makeSinos	converts data to sinogram space
makeAttenRadsALS	converts ALS data to attenuation space
orientDetector	correct detector for rotational misalignments

Preprocessing Algorithms (2 of 3)

Algorithm Name	Description
inpaintForeground	inpaints a specified region of the projections
zFilter	filtering along detector columns
transmissionShift	corrects for scatter by subtracting a constant value in transmission space
slitScatterCorrection	corrects for scatter on systems with slit collimators
scatterCorrection	physics-based scatter correction
ringRemoval	removes ring artifacts; can be applied to projection data or reconstructed volume
polynomialBHC	polynomial beam hardening correction
empiricalBHC	empirical beam hardening correction
iterativeBHC	physics-based iterative beam hardening correction
balanceDetector	corrects for detector readout imbalance

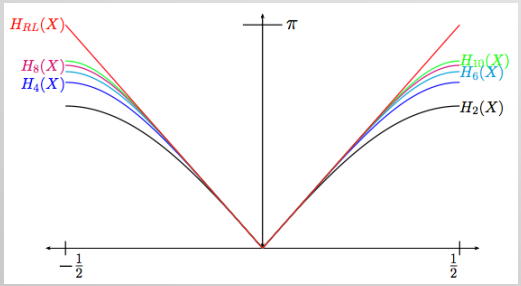
Preprocessing Algorithms (3 of 3)

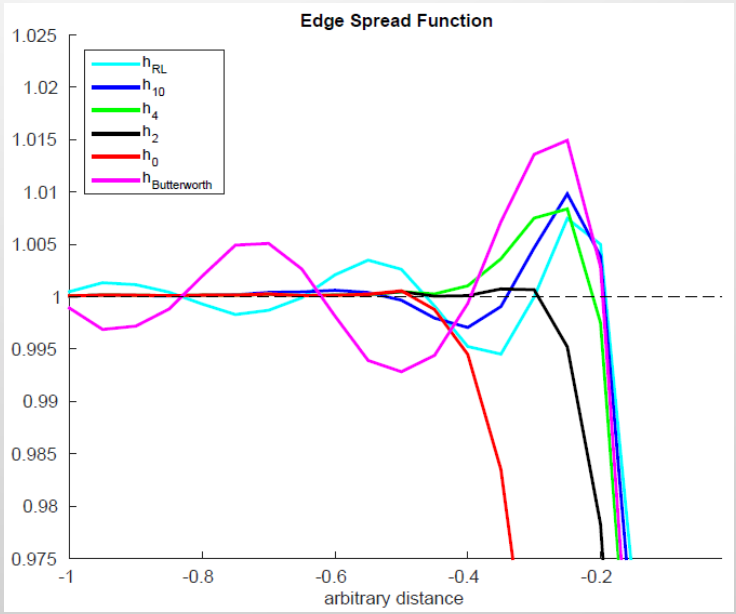
Algorithm Name	Description
dualEnergyDecomposition	removes beam hardening artifacts and enables transformation of basis from a pair of registered projections at different spectra
tripleEnergyDecomposition	removes beam hardening artifacts and enables transformation of basis from a triplet of registered projections at different spectra
ROIprep	prepares projection data so that one may perform region of interest iterative reconstruction
findCenter	automatically estimates pxcenter by minimizing the sum of the squares of differences of conjugate rays
parameterSweep	sweeps through a specified range of values of pxcenter and/ or pxmidoff, performing a single-slice reconstruction for each value, and printing sharpness and entropy metrics to help determine correct values
projectionSegmentation	segments projection data (to determine bad data)

Analytic Reconstruction Algorithms

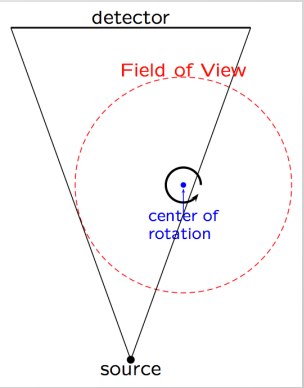
Algorithms

- Filtered Backprojection (FBP)
- Derivative Backprojection (DBP)
- Lambda (Local) Tomography

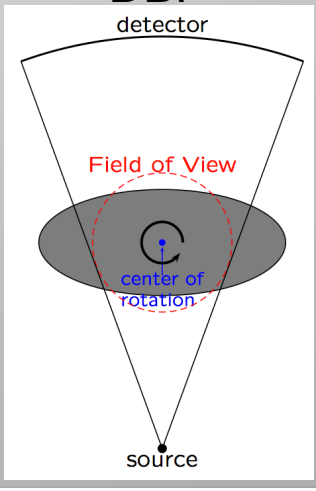




offset detector FBP



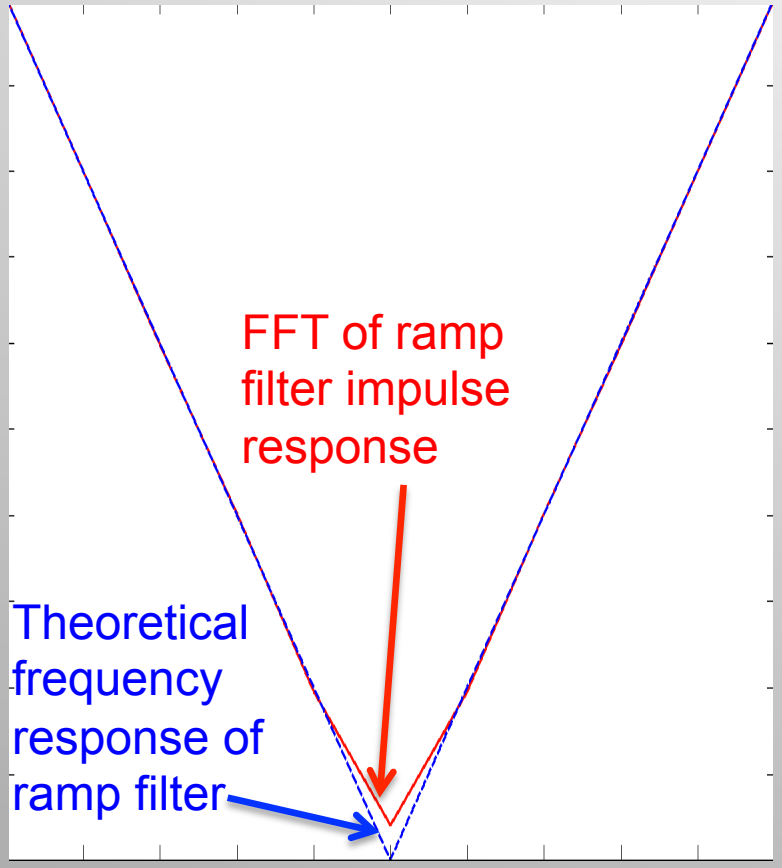
DBP

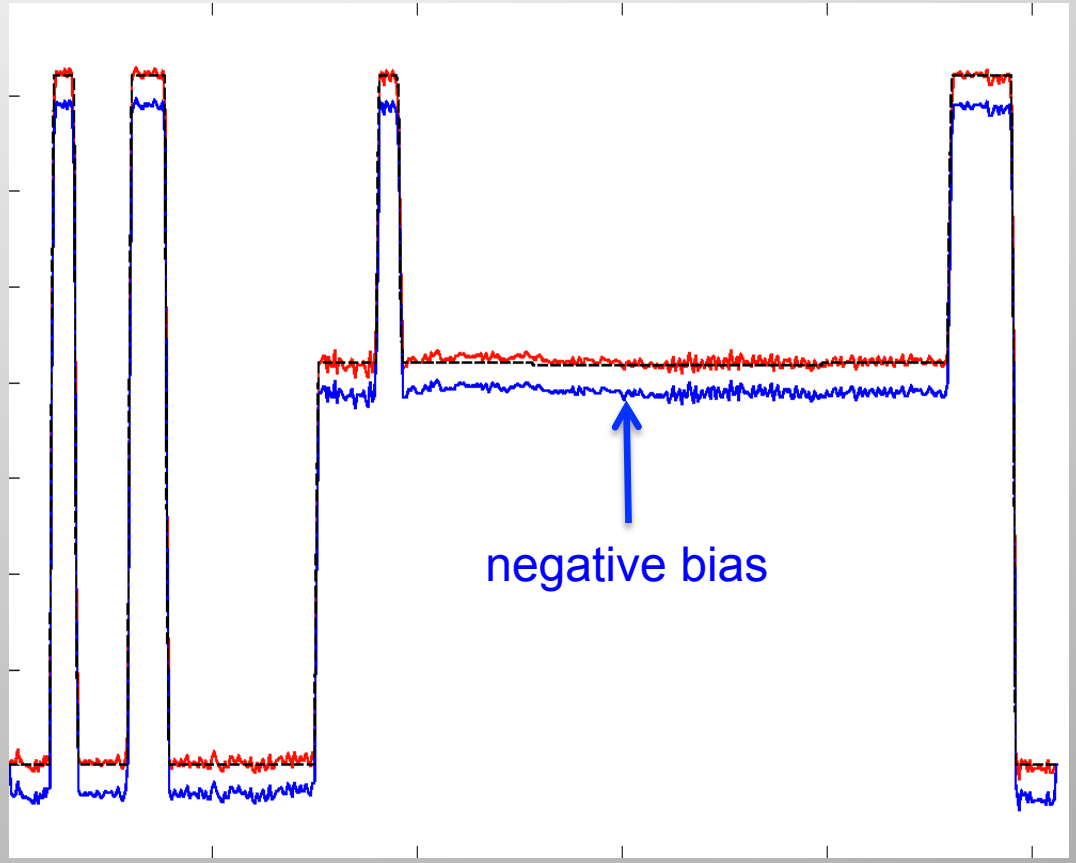


Features

- 2D/ 3D parallel beam, 2D/ 3D fan beam, cone beam with axial or helical source trajectory
- short scan/ full scan/ multiple revolutions
- can specify ramp filter by its FWHM
- offset detector (offset center of rotation) reconstruction algorithm

Defining the ramp filter in the frequency domain causes a negative bias- all ramp filters in LTT defined in spatial domain





Iterative Reconstruction Algorithms

Algorithms

Ordered Subsets Simultaneous Algebraic Reconstruction Technique (OS-SART)

Regularized Weighted Least Squares (RWLS; can also use a Huber-like loss function)

Adaptive Steepest Descent- Projection onto Convex Sets (ASD-POCS)

Prior Image Constrained Compressed Sensing (PICCS)

Other proprietary algorithms

FBP

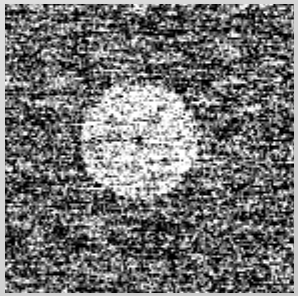


Image Priors and Constraints

non-negativity

L^2 or Huber-like loss function on magnitude of gradient (Tikhonov or TV)

image sparsity

sparsity of difference from a prior image

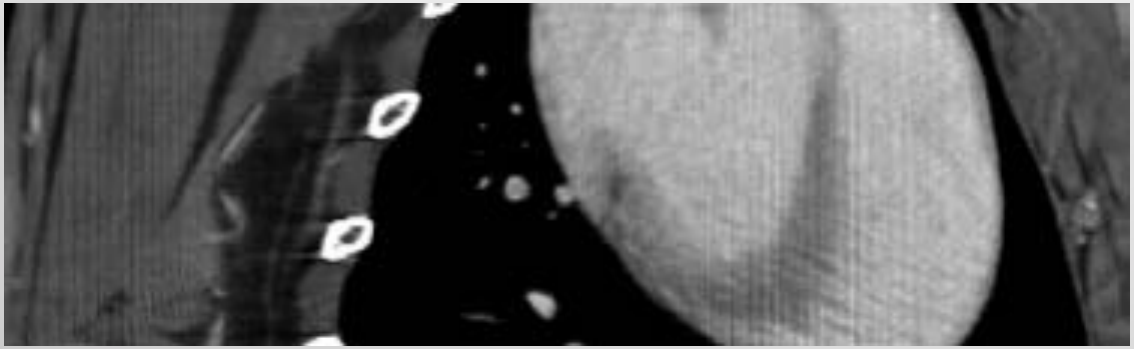
sparsity of gradient of the difference of a prior image

RWLS

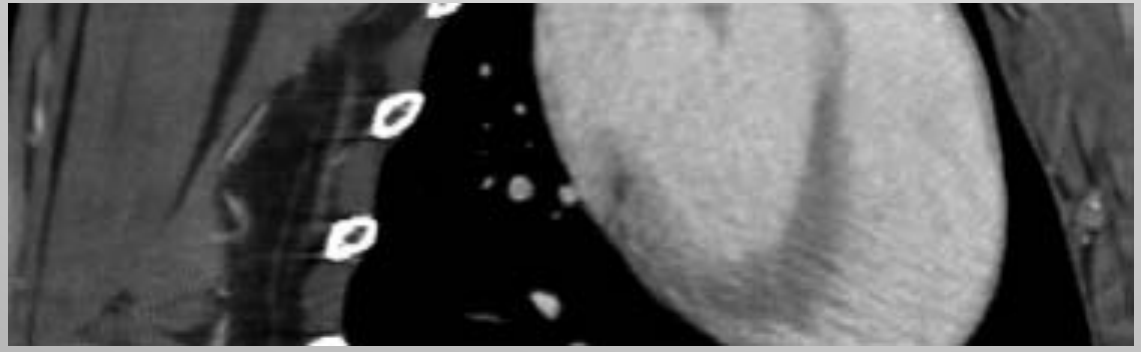
can specify certain data points as “bad” and these data points will be ignored by iterative algorithm

Projector Model Matters- LTT uses Matched Separable Footprint Model

Iterative reconstruction using ray-driven (point detector) projector

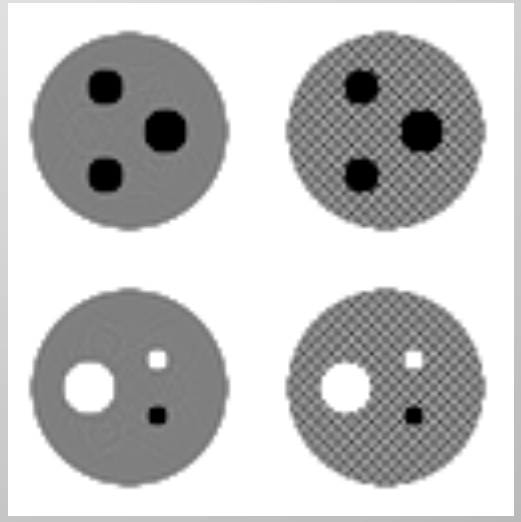


Iterative reconstruction using distance-driven (finite detector) projector



Long, Fessler, Balter, TMI, 2010
De Man and Basu, PMB, 2004

Matched Unmatched



Postprocessing

Image Denoising

- Tikhonov or Total Variation (TV) image regularization
- (thresholded) median filter/ outlier removal
- image-space ring removal

Volume Reformatting

- output into XY, XZ, or YZ slices
- elliptical shell extraction
- rotational slices

Segmentation

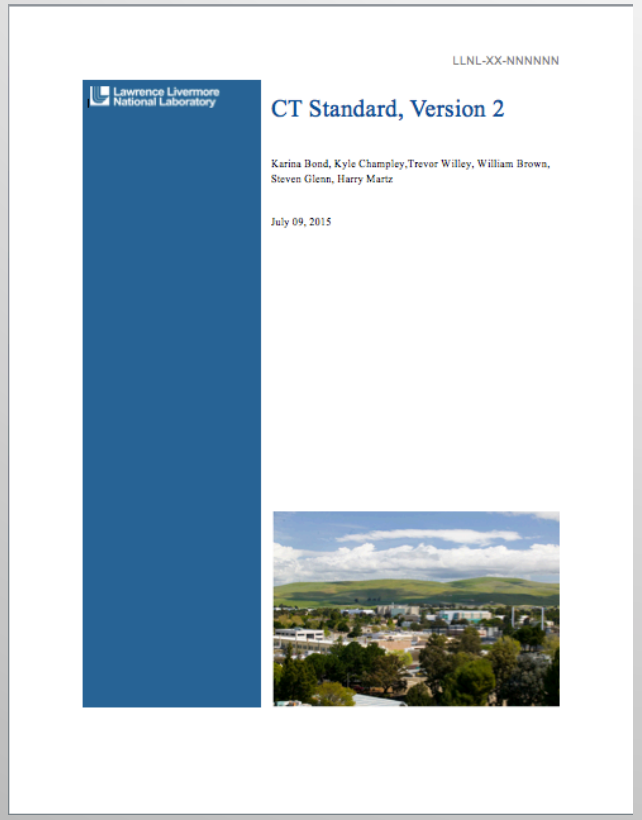
- active contours (level set method) + mathematical morphology

Transformations of Image Reconstruction Space

- attenuation coefficient (mm^{-1} or cm^{-1})
- Compton/ photoelectric coefficients
- effective atomic number
- electron density (electrons * mol / mm^3 or electrons * mol / cm^3)
- mass density (g/mm^3 or g/cm^3)

Documentation

CT Standards Guide


LLNL-XX-NNNNNN

Lawrence Livermore National Laboratory

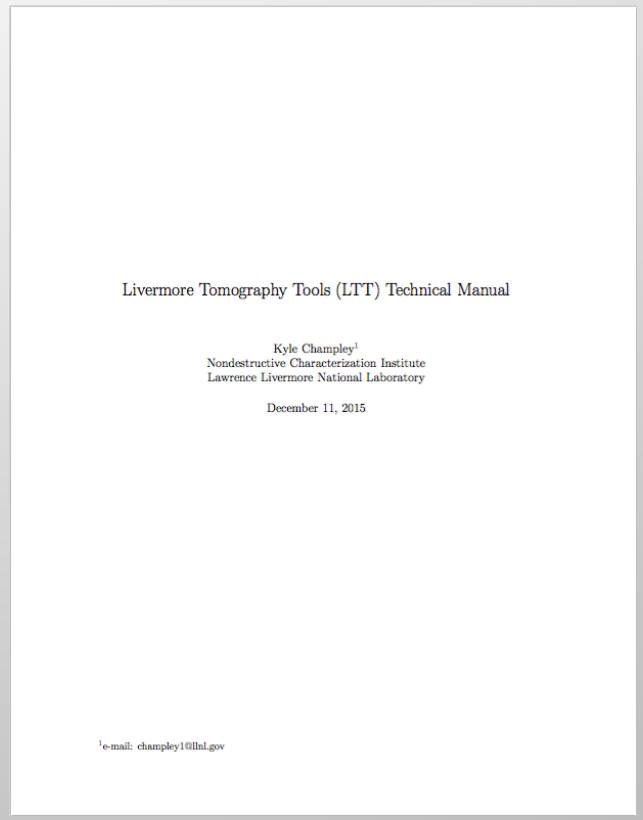
CT Standard, Version 2

Karina Bond, Kyle Champley, Trevor Willey, William Brown, Steven Glenn, Harry Martz

July 09, 2015

Describes all parameters, settings, file formats, etc

Technical Manual and User's Guide


Livermore Tomography Tools (LTT) Technical Manual

Kyle Champley[1]
Nondestructive Characterization Institute
Lawrence Livermore National Laboratory

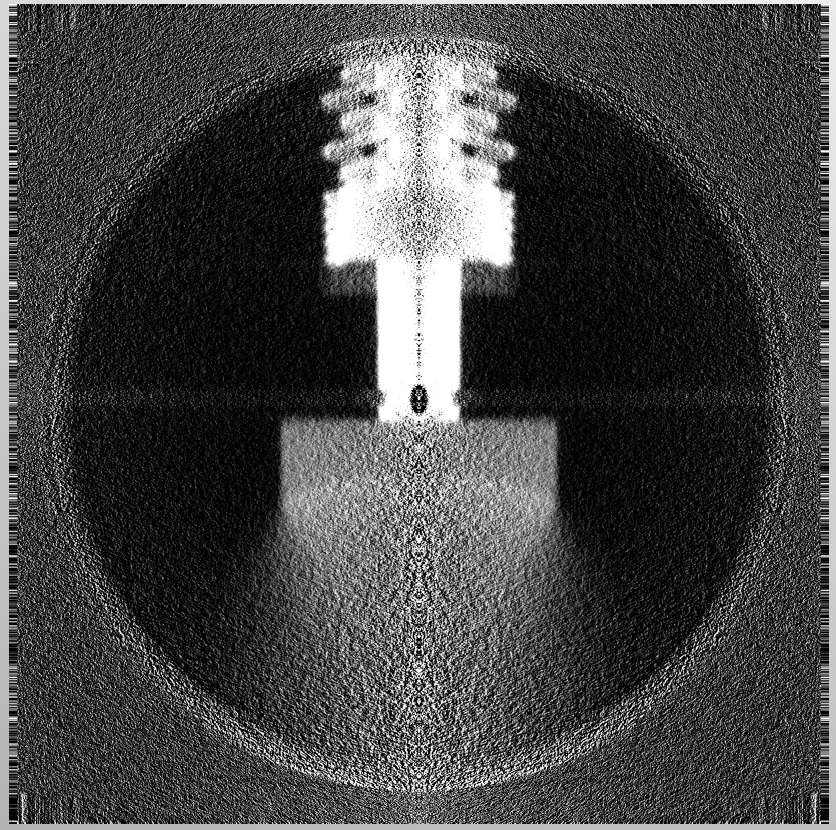
December 11, 2015

[1]e-mail: champley1@llnl.gov

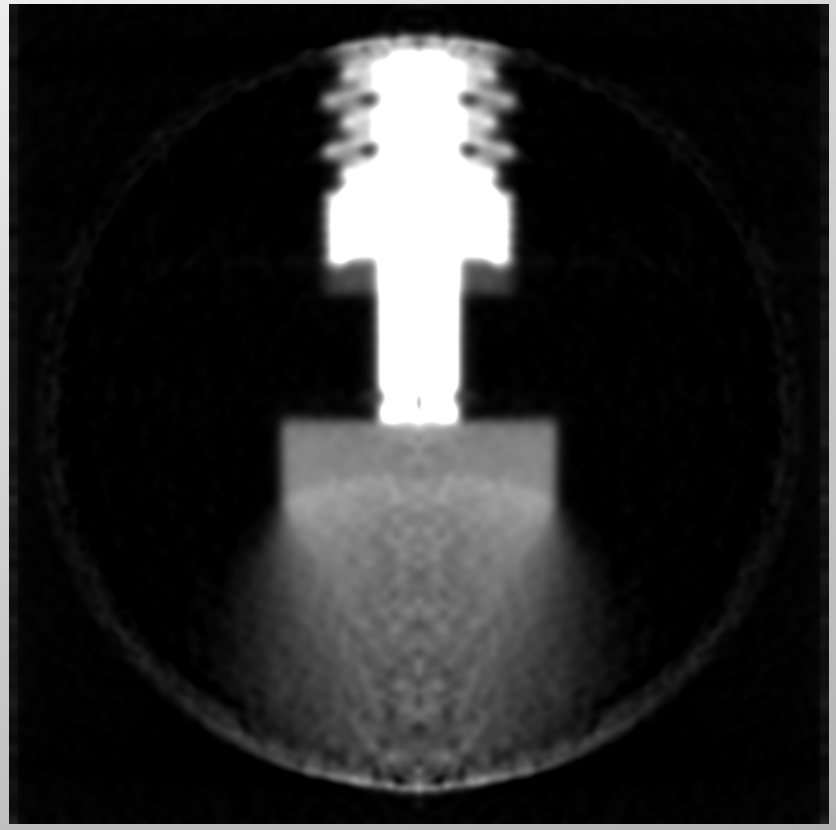
Technical details and how to run all algorithms in LTT (over 160 pages)

Abel Inversions (single radiograph) of explosive ignition

Standard Abel Reconstruction



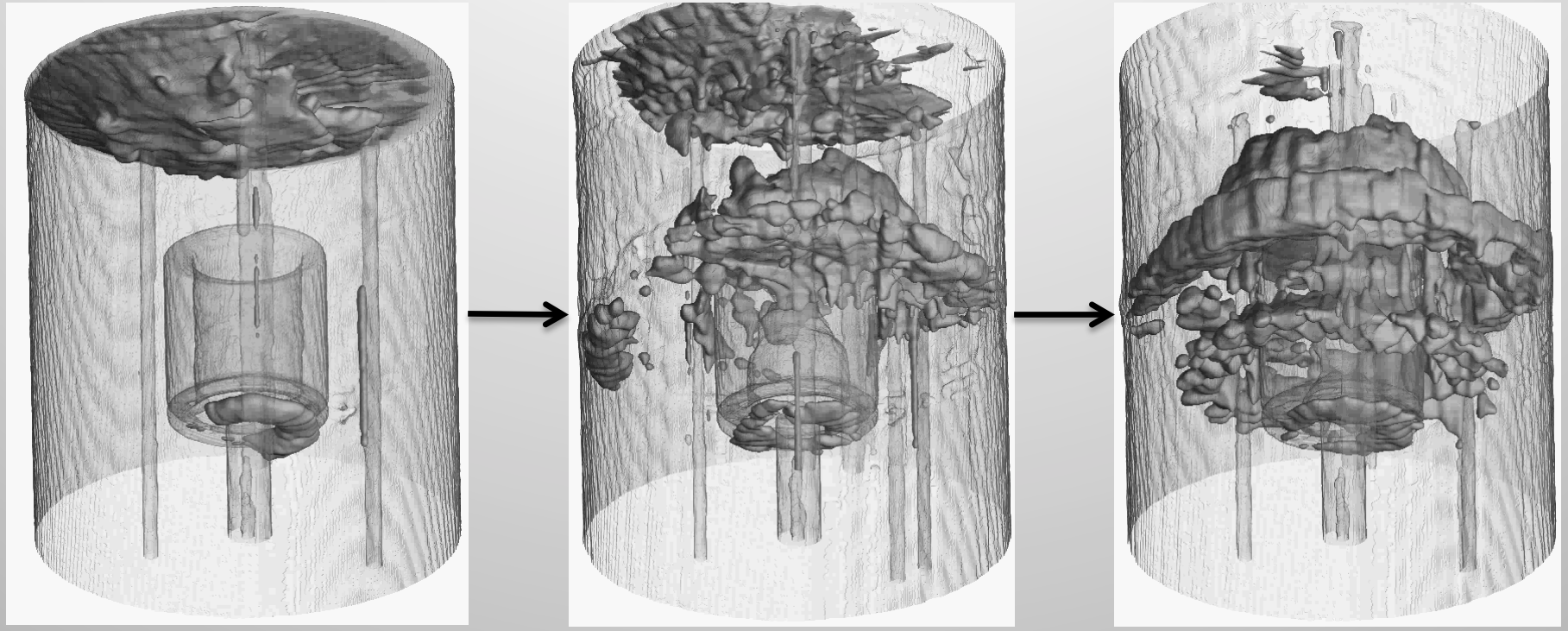
Modified Abel Reconstruction with adaptive noise suppression



data acquired at ALS by: Michael Bagge-Hansen, Lisa Lauderbach, Mike Nielsen, Ralph Hodgin, and Trevor Willey

SNR 11 times higher

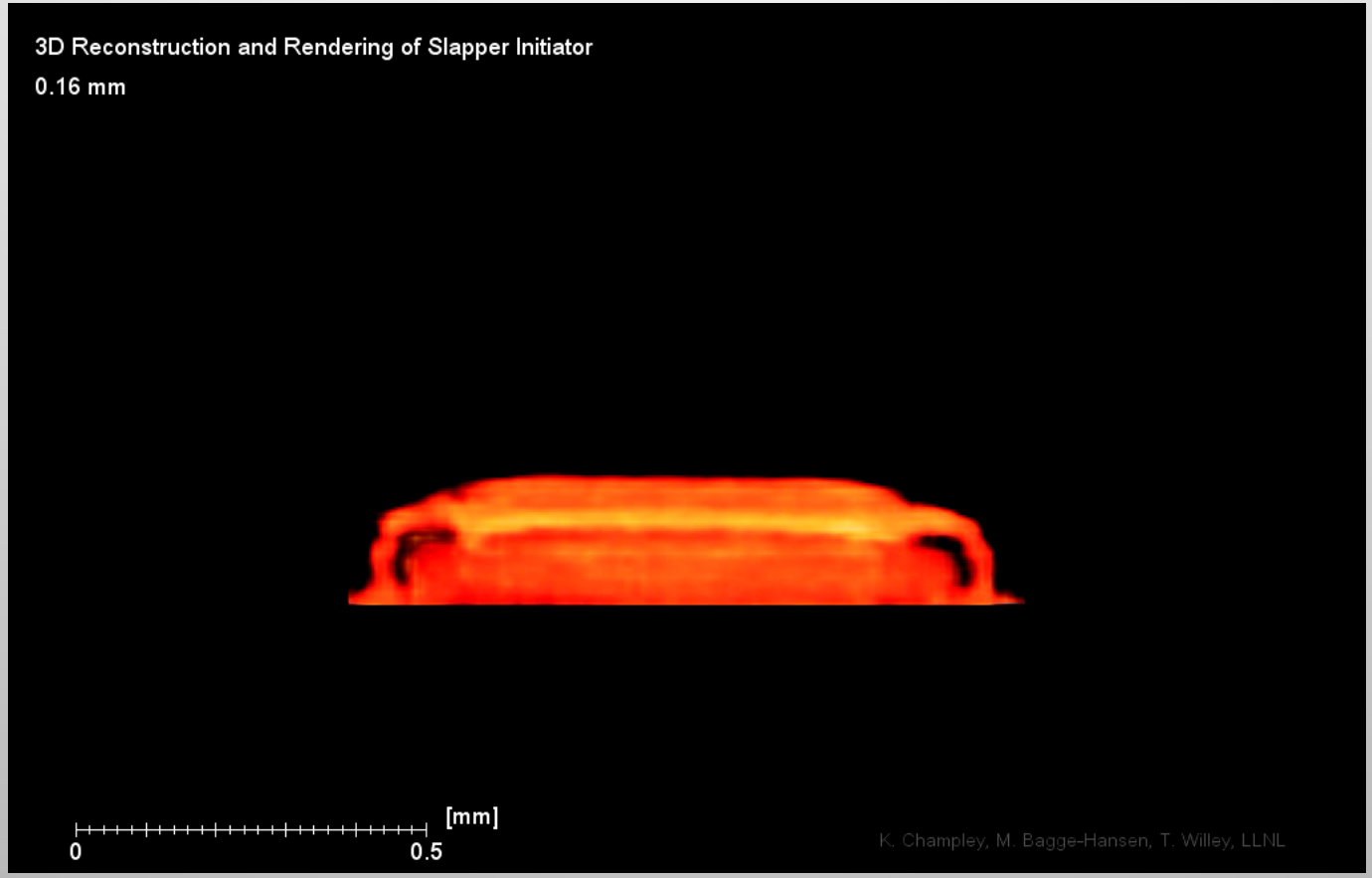
Dynamic CT of heating a sample (13 views per rotation/ 29 rotations)



data acquired by: Brian Fix, Cary Pincus, and Joe Tringe
3D rendering by: Jefferson Cuadra and Jerel Smith

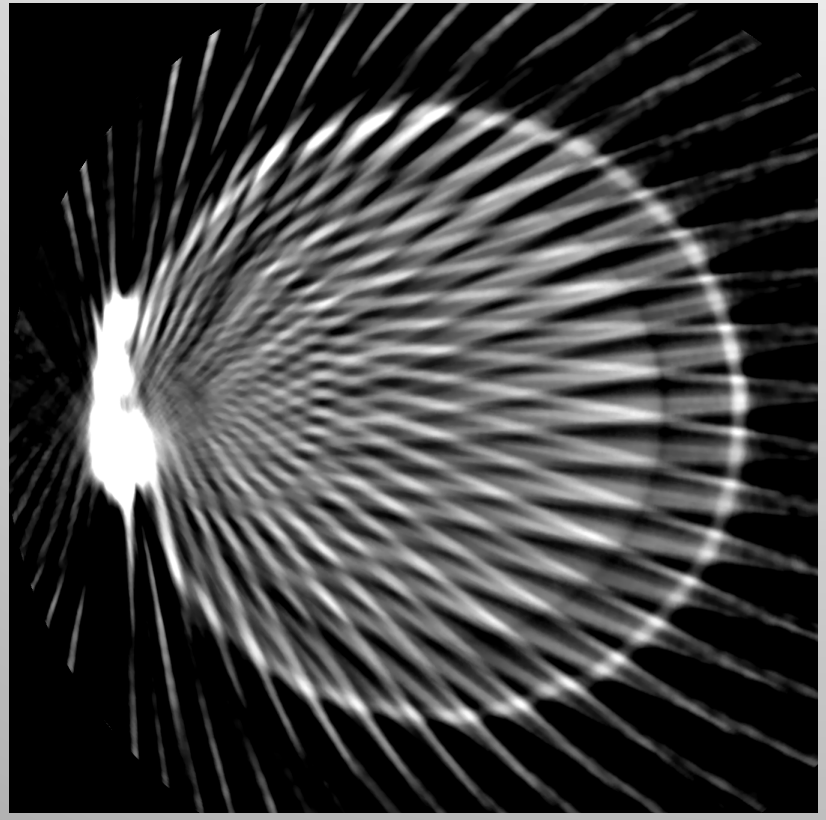
7-View Reconstruction of In-Flight (2.5 km/sec) Slapper Initiator

Willey, Champley, Hodgin, Lauderbach, Bagge-Hansen, May, Sanchez, Jensen, Iverson, van Buuren

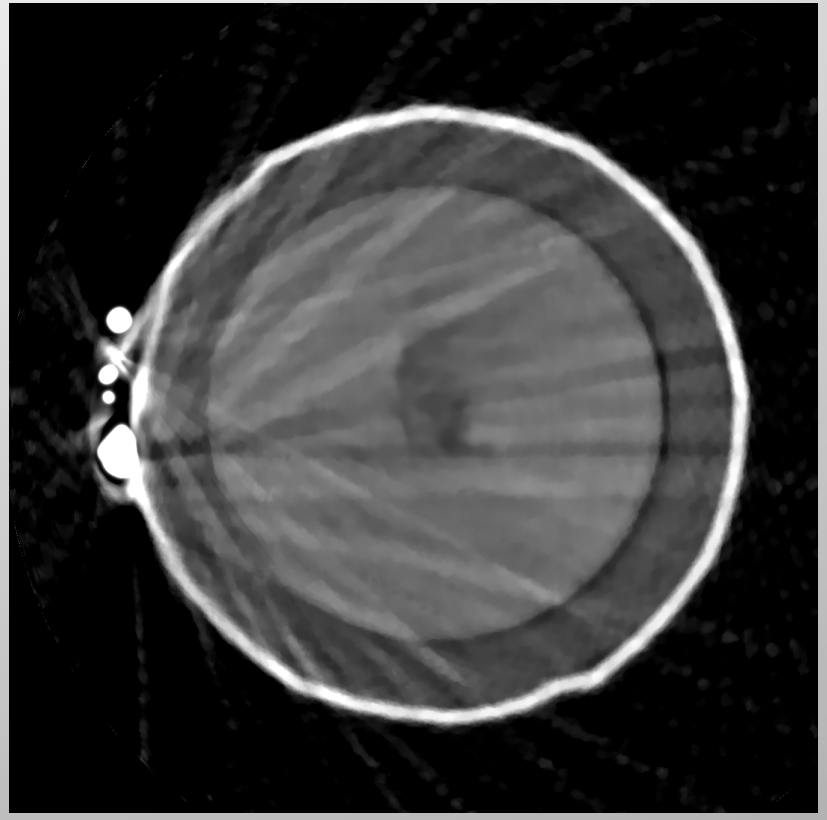


Reconstruction of industrial object with 40 views

State of the Art Method

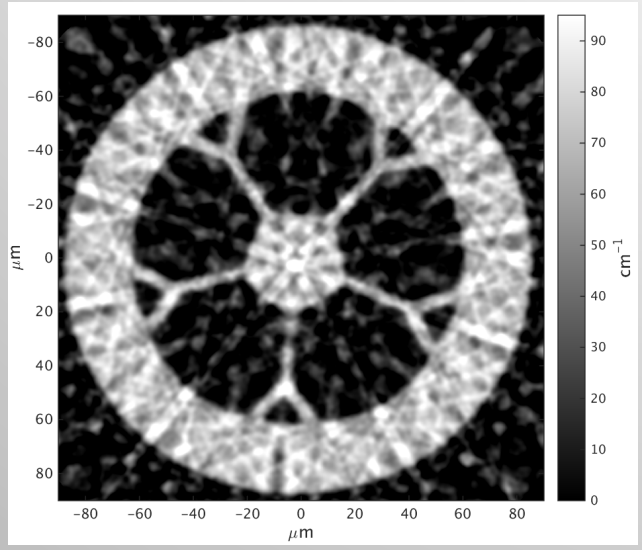


LTT

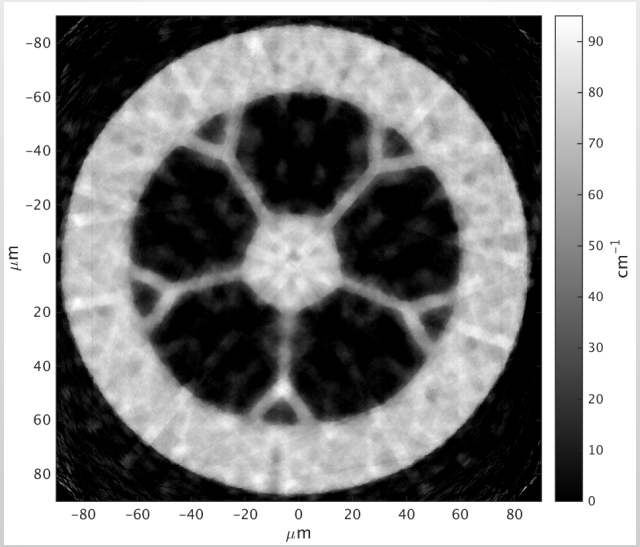


180 µm Diameter Glass Fiber Reconstruction with 19 views

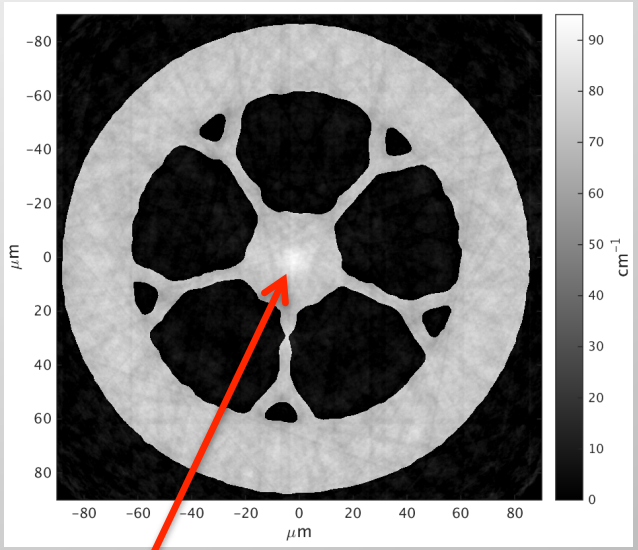
Filtered Backprojection (FBP)



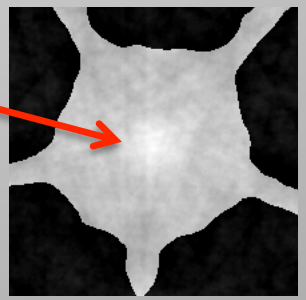
State of the Art Method



LTT

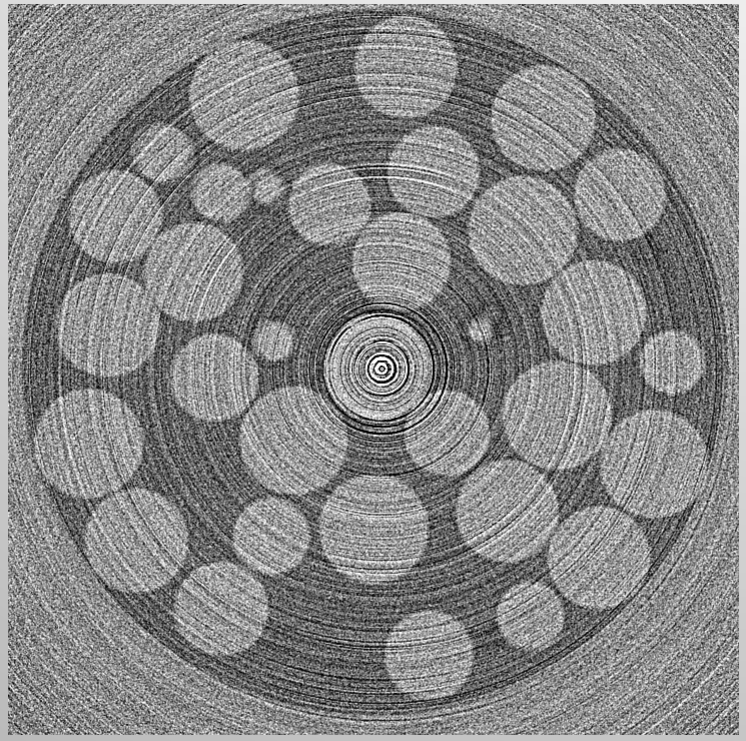


the germanium-doped core is only visible with the LTT algorithm

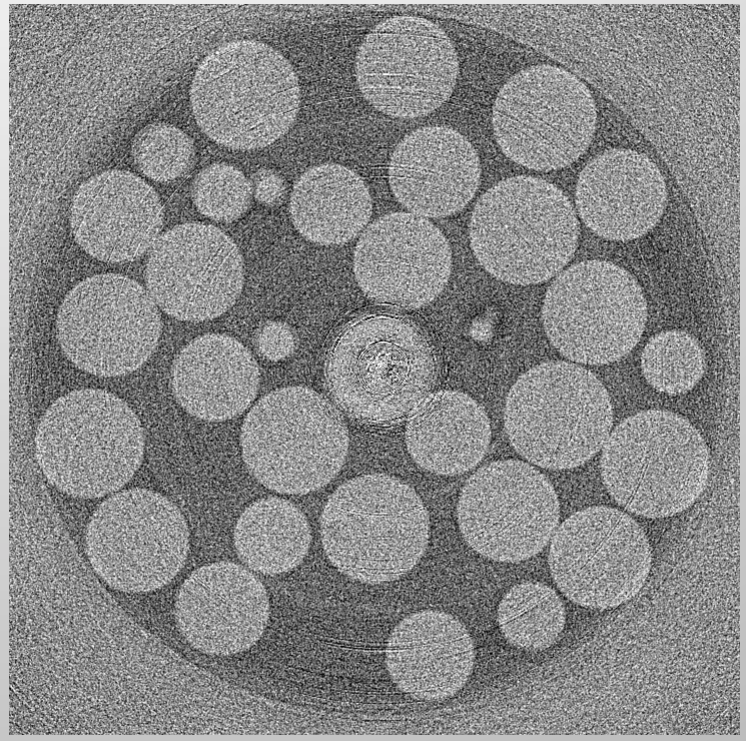


Ring Removal

Without Ring Removal



With Ring Removal



data acquired at ALS by Minta Akin
Prell et al., PMB, 2009

Work In Progress

- Multi-GPU Support
- Cross-platform GUI
- Advanced Algorithms
  - sparse/ few view CT
  - dynamic CT
  - multi-spectral CT
  - phase contrast reconstruction

Questions?

to obtain a copy of LTT contact:

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