

Miocene insect
fossilised in
opaque amber
from Cape York
(Paul Tafforeau,
ESRF, Susan
Hand, UNSW)

An Introduction to X-TRACT for tomographic reconstruction and phase-retrieval

Sherry Mayo, Tim Gureyev & Darren Thompson
CSIRO

Micro-CT and Phase-Contrast

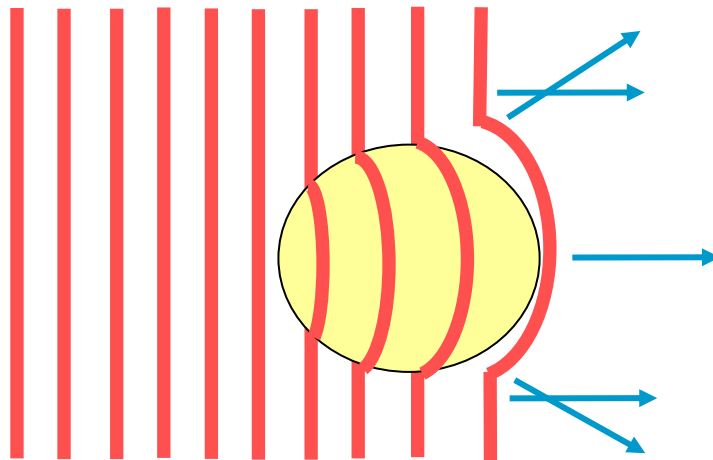
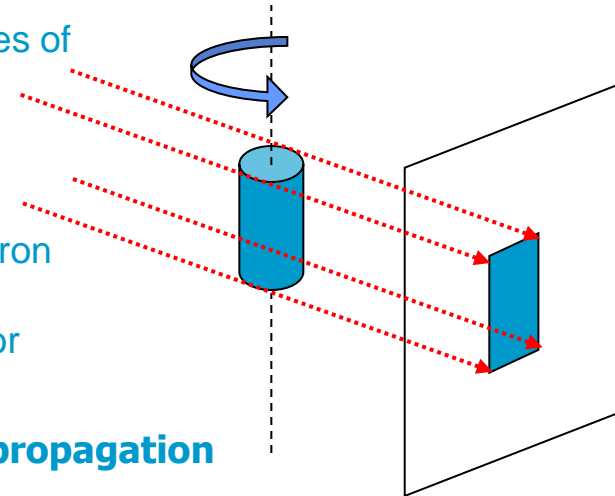
Micro-CT forms a 3D digital reconstruction of an object from a series of x-ray transmission images acquired at different rotation angles.

The 3D digital dataset can then be digitally dissected to examine internal structure without damage to the sample.

Conventional CT uses only absorption contrast but with a synchrotron source we also benefit from phase contrast which arises from **refraction** of x-rays. This can be made visible using propagation or gratings (amongst others).

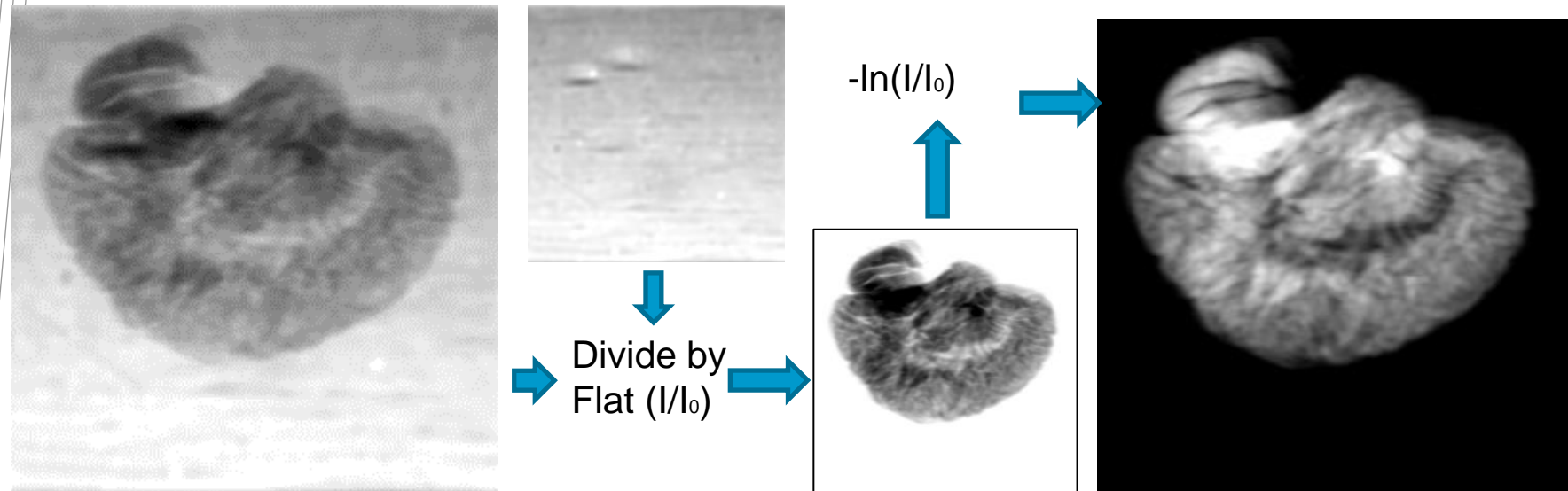
A phase gradient represents a change in direction of propagation

...



... leading to interference.

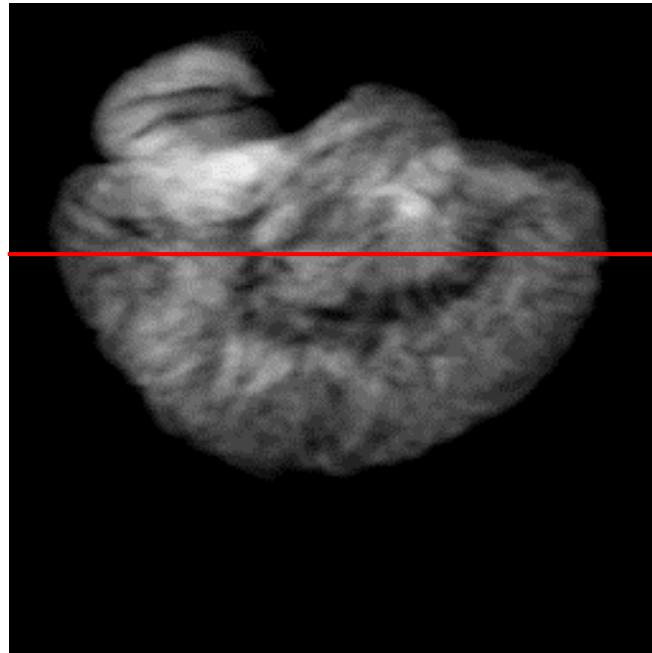
Tomographic reconstruction - using Beers law



$$I = I_0 e^{-\int \mu dt}$$

$$\int \mu dt = -\ln(I/I_0)$$

Tomographic reconstruction – making sinograms



100
pixels

Angle



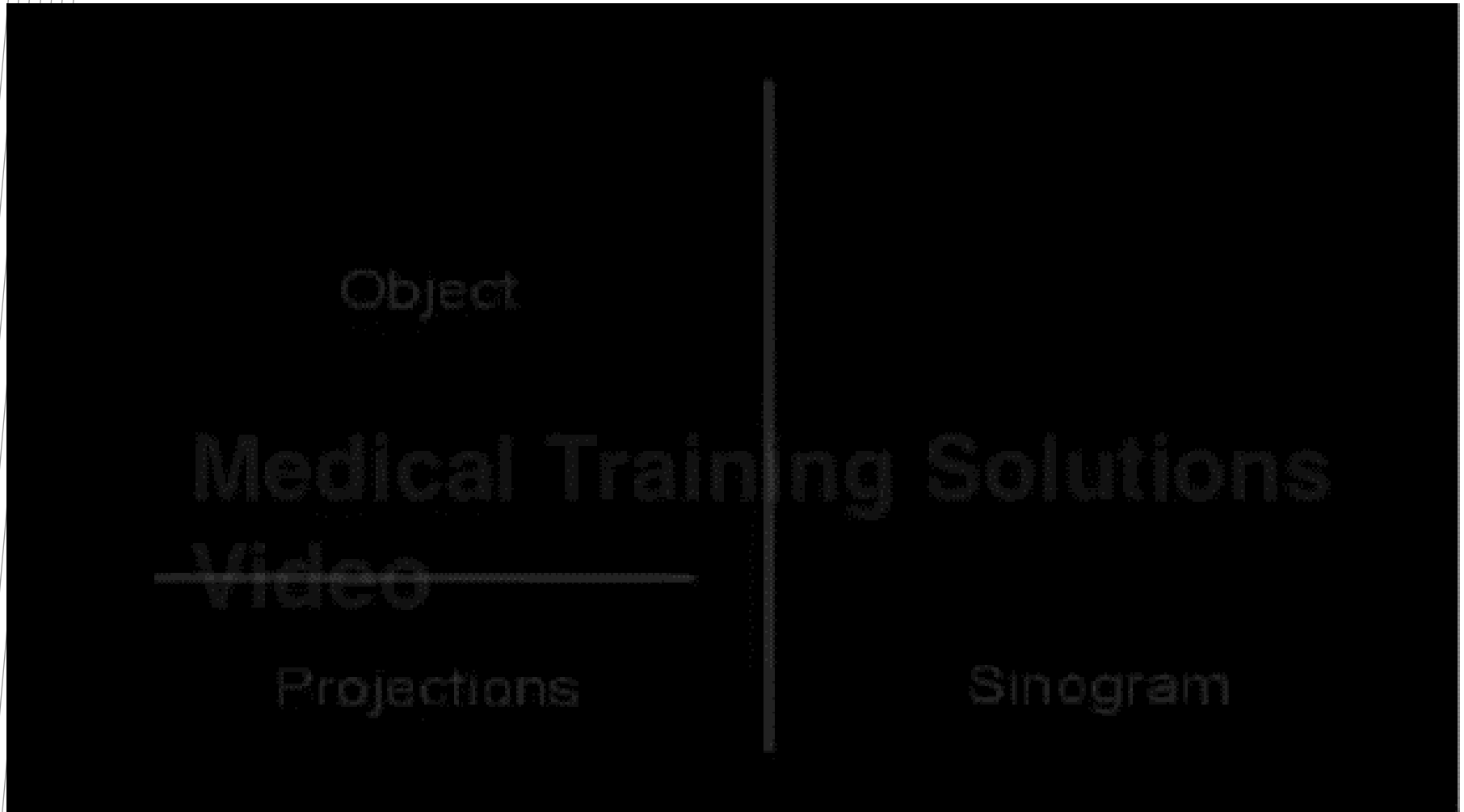
Sino100.tif

Compiled
from 100th
row each
image in
sequence

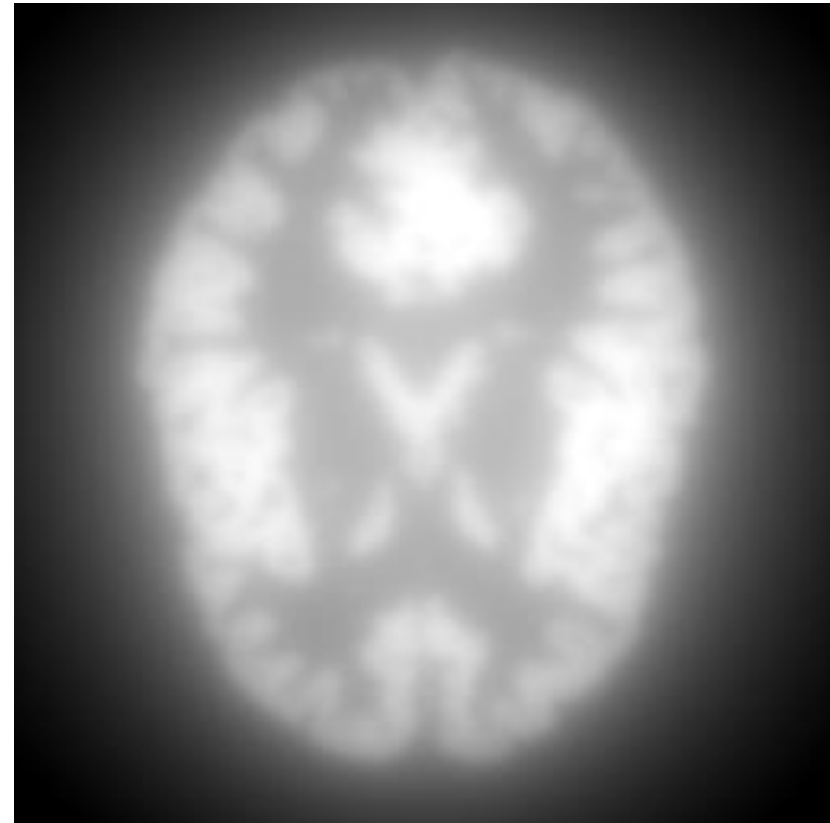
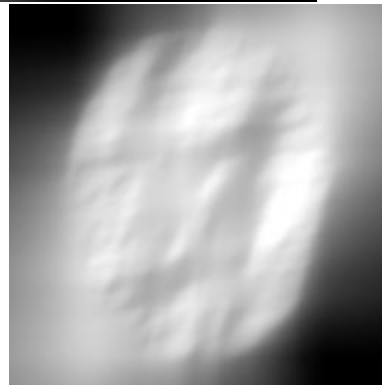
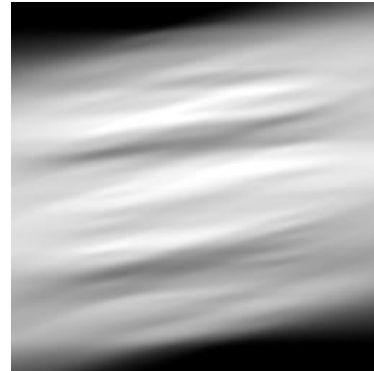
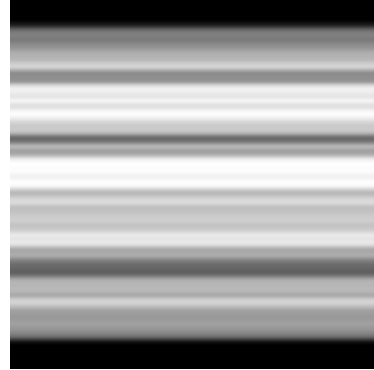
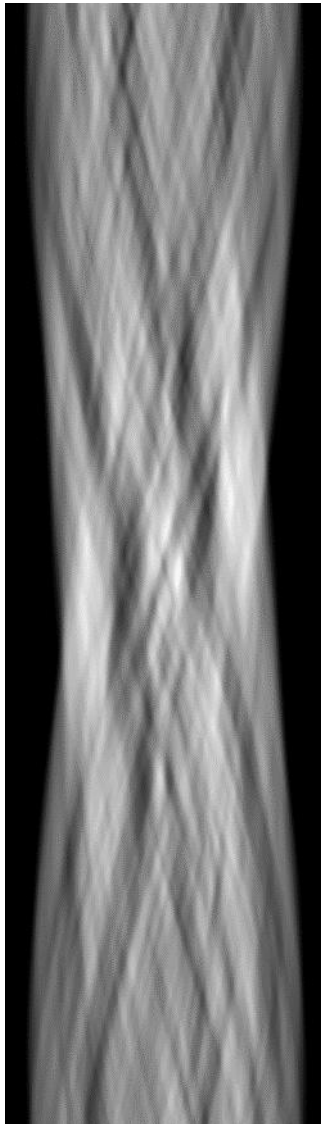
For each row-number in the image a corresponding sinogram is compiled by taking that row from all the images in the sequence.

Each sinogram contains all the information for a given cross section of the object

Quick movie on back projection



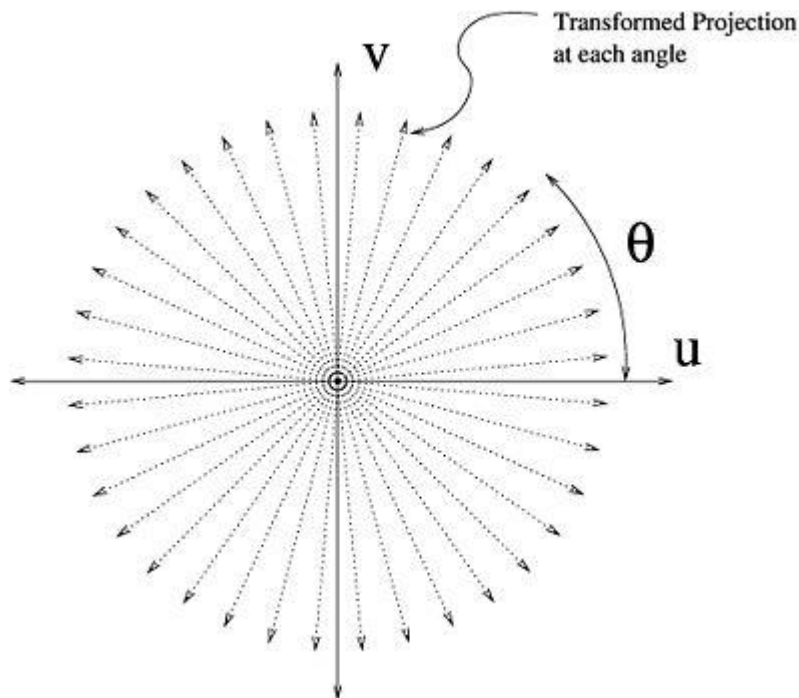
Back-projection – reconstructing a cross-section



Hmm.. Looks
a bit fuzzy

What we're doing in Fourier space...

Fourier transform of cross section



High-pass filtering compensations for the excess information at low spatial frequencies compared to high frequencies.

The simplest ramp filter multiplies Fourier space components in proportion to their spatial frequency.

Voila! Filtered back-projection!

Apply a high-pass ramp* filter to the sinogram first.



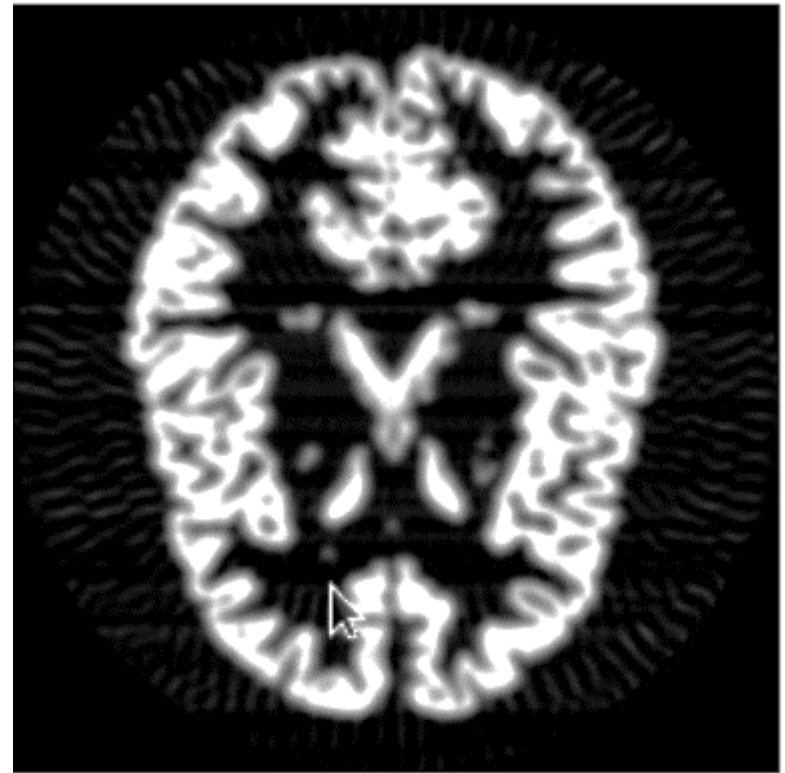
*or Shepp-Logan/
Hann/Cosine/Hamming...
filter



A brief aside about sampling



900 views – rather
oversampled



90 views – somewhat under-
sampled

XLI CT Workflow on ASCI

The screenshot displays the XLI CT Workflow application interface on an ASCI Desktop environment. The application window is titled "XLICTWorkflow" and features several tabs: "Experiment parameters", "Pre-processing raw parameters", "Pre-processing parameters", "CT Reconstruction parameters", and "Console". The "Experiment parameters" tab is active, showing fields for "Input file regular expressions" (Frames: tomo\d+.tif, 901; Darks: dark\d+.tif, 3; Flats: flat\d+.tif, 3), "HDFS File", "Experiment" (Pixel size (um): 1, Energy (keV): 20, Angle step (deg): 0.2), and "Output" (Output sinograms, Files: Directory /data/imbl/workshop/output/testdata_out, Reconstructed slice prefix: recon_, TIFF, Sinogram prefix: sino_, TIFF, Output parameters file: params_ctworkflow.txt, HDFS File, Output to input HDFS, Copy input datasets). A file manager window is open over the application, showing the "X-tract" application. The application status bar at the bottom indicates "Processing failed (9 s)" and "1 nodes available (v1.0.1)".

Australian Synchrotron Computing Infrastructure

Speed up in parallel mode for single machine and CSIRO and MASSIVE clusters

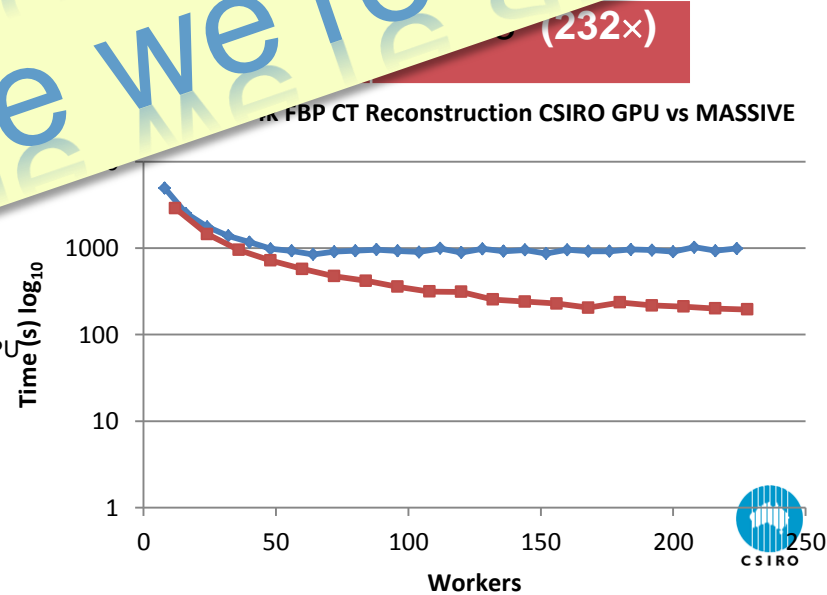
Considerable speed-up even on a single machine using multi-threading and especially GPU

Speedup for parallelised operation on cluster increases with number of nodes initially.

Ultimately it is limited by I/O and network bandwidth, making a big difference.

Volume

Let's open XLI CT Workflow on ASCI (and Fiji while we're at it)



XLICT Workflow – first pane

XLICTWorkflow

Experiment parameters | Pre-processing raw parameters | Pre-processing parameters | CT Reconstruction parameters | Console

Input

☒ Files Directory /data/imbl/workshop/input/Absorption ...

Input file regular expressions

Frames tomo\d+.tif 901 Darks dark\d+.tif 3 Flats flat\d+.tif

☐ HDF5 File ...

Experiment

Pixel size (um) 1 Energy (keV) 20 Angle step (deg) 0.2

Output

☒ Output sinograms

☒ Files Directory /data/imbl/workshop/output/testdata_out ...

Reconstructed slice prefix recon_ TIFF Sinogram prefix sino_ TIFF

Output parameters file params_ctworkflow.txt

☐ HDF5 File ...

☐ Output to input HDF5 ☐ Copy input datasets

Process Cancel

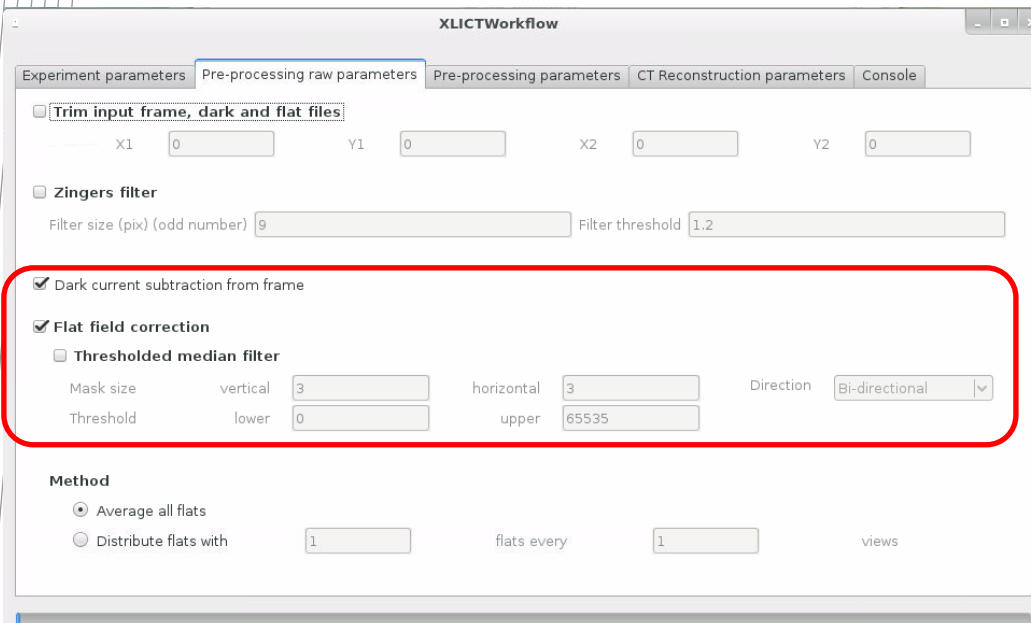
Processing failed (9 s) 1 nodes available (v1.0.1)

In this workflow we can set up basic parameters for the data:

- Input and output directories
- File name patterns (regular expressions)
- Pixel size, energy, angle step
- Output filenames
- Output file type
- Option of saving sinograms

Set your own XLI CT Workflow 'Experiment parameters' tab like this but **remember to substitute your own output directory.**

XLI CT Workflow – 2nd and 3rd panes: preprocessing



XLI CT Workflow

Experiment parameters | **Pre-processing raw parameters** | Pre-processing parameters | CT Reconstruction parameters | Console

☐ Trim input frame, dark and flat files

X1: 0 Y1: 0 X2: 0 Y2: 0

☐ Zingers filter

Filter size (pix) (odd number): 9 Filter threshold: 1.2

☒ Dark current subtraction from frame

☒ Flat field correction

☐ Thresholded median filter

Mask size: vertical: 3 horizontal: 3 Direction: Bi-directional

Threshold: lower: 0 upper: 65535

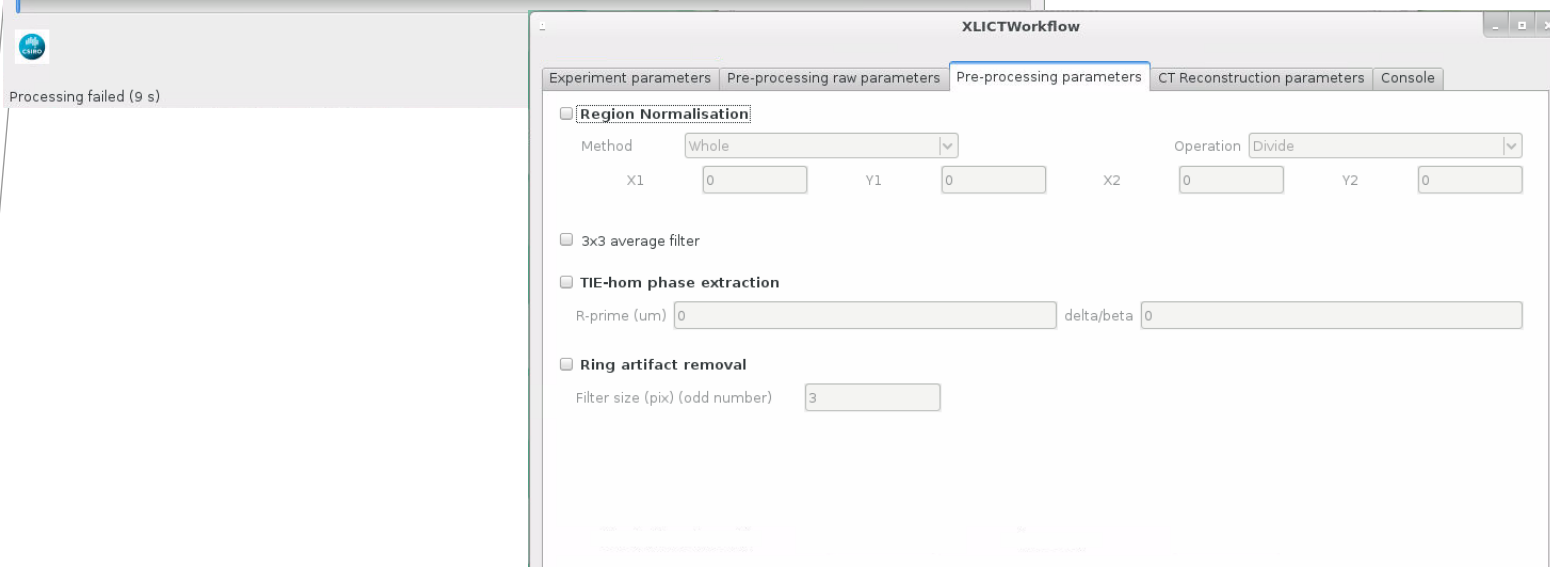
Method

☒ Average all flats

☐ Distribute flats with: 1 flats every: 1 views

The settings in these panes are all about correcting for various imaging artefacts to produce clean normalised sinograms (and if necessary applying phase retrieval)

To start with lets just use the flat-field and dark-current corrections



XLI CT Workflow

Experiment parameters | Pre-processing raw parameters | **Pre-processing parameters** | CT Reconstruction parameters | Console

☐ **Region Normalisation**

Method: Whole Operation: Divide

X1: 0 Y1: 0 X2: 0 Y2: 0

☐ 3x3 average filter

☐ TIE-hom phase extraction

R-prime (um): 0 delta/beta: 0

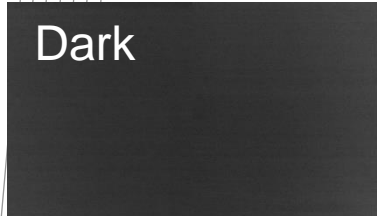
☐ Ring artifact removal

Filter size (pix) (odd number): 3

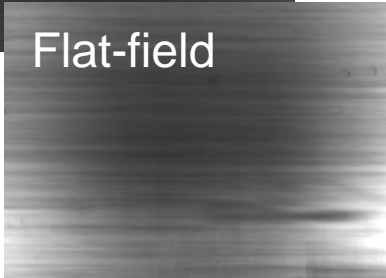
X-TRACT for Tomography

1. Preprocessing – CCD artifact corrections

Dark



Flat-field



Correcting CCD/Illumination artefacts:

- 1) Dark current (the CCD signal with no illumination)

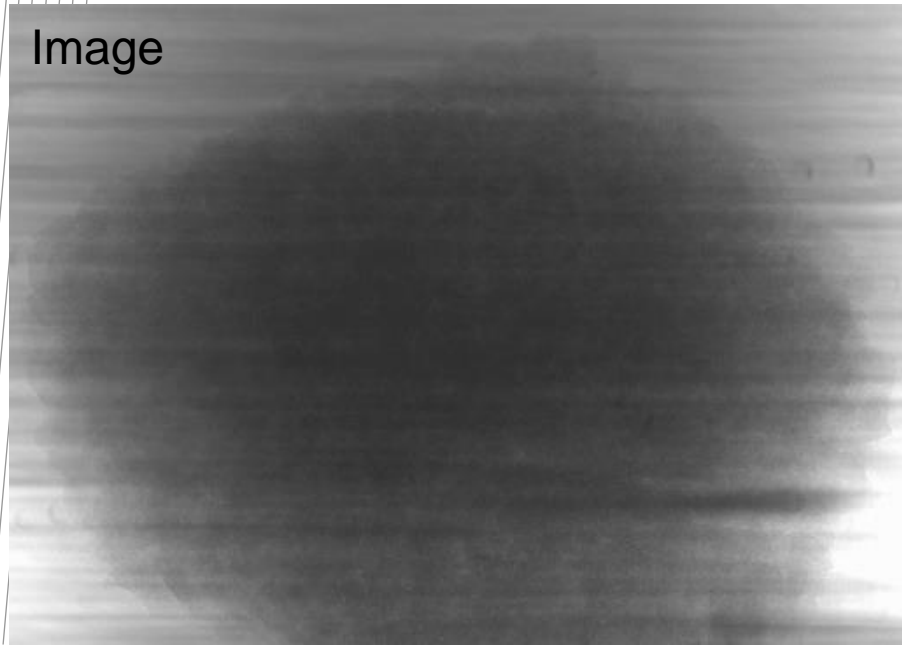
Several dark current files are collected at the beginning/end of a data collection

- 2) Flat-field (The x-ray illumination distribution)

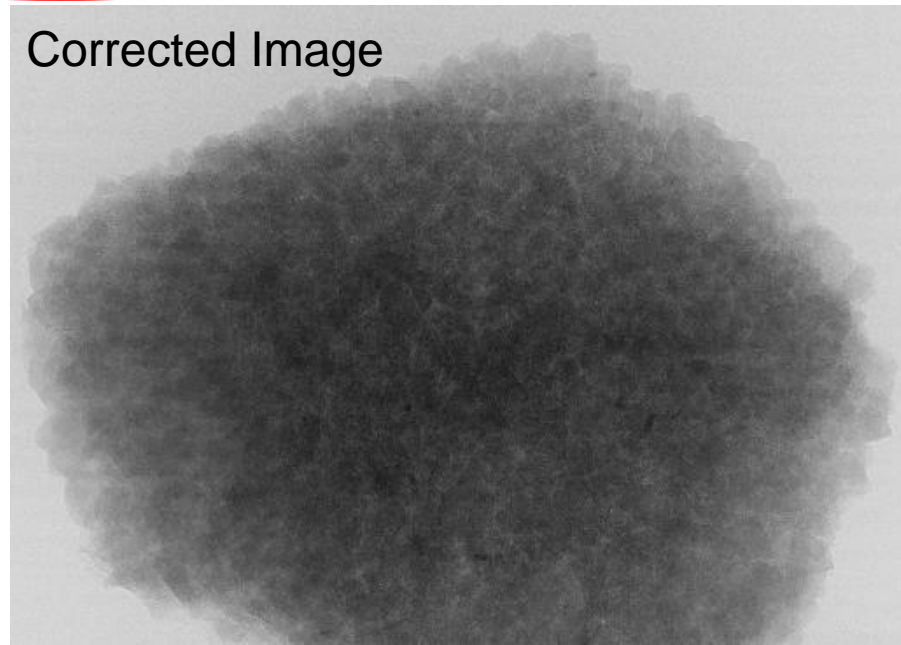
Flat-field files are often collected at regular intervals during data collection

$$\text{Corrected Image} = \frac{\text{Image} - \text{Dark}}{\text{Flat-field} - \text{Dark}}$$

Image



Corrected Image



XLICT Workflow – third pane - reconstruction

XLICTWorkflow

Experiment parameters Pre-processing raw parameters Pre-processing parameters **CT Reconstruction parameters** Console

Reconstruction method: **Gridrec**

Reconstruction range

☐ All

☒ Sub-range First slice z-index: 100 Last slice z-index: 100

☒ Output Mu (cm-1)

Filter: Linear-Ramp

Centre of rotation

☐ Auto (correlation) ☐ Manual 0

☒ Auto (error) ☐ Auto (sinogram) Index: 0

☐ Reconstruction sub-region

X1: 0 Y1: 0 X2: 0 Y2: 0

☐ Rescale reconstructed slices

☒ Auto

☐ Manu Min: 0 Max: 1

Data Type (TIFF & HDF5 Only): 32bit float

Process Cancel

Processing failed (9 s)

1 nodes available (v1.0.1)

Here we can select

- Reconstruction method
- Range of slices to reconstruct
- Output in Mu format
- Centre of rotation method

Set it up as shown and hit process

X-TRACT for Tomography

1. DEMO – Reconstruction (no phase-retrieval)



Ring artefacts and Ring filter (Show original data & sino)

Zinger artefacts (Ring then zinger – zinger at 101,97)

Phase contrast & phase retrieval

Noisy

Noisy phase-contrast

general params: pixel size 10, keV 10, ang 0.2, output Mu (cm-1), DC and FF

Phase retrieval: 100000 (= 10cm) delta/beta = 400

Noisy: (no PR) ringfilt: 51

Zingers: 101 and 97 have rings, filter 9, 1.05 for complete removal (but 1.1 might be more realistic in presence of noise)

Ring: more realistic 2% noise dataset



Thank you

Contact Us

Phone: 1300 363 400 or +61 3 9545 2176

Email: enquiries@csiro.au Web: www.csiro.au