recon_PUP_FF_SOFC_hires3_S2

February 7, 2019

1 Overview

This notebook provides detailed steps for the reconstruction (including data reduction and morphology reconstruction) of proejct PUP_FF_SOFC_hires3_S2, which was taken place back in 2015.

> NOTE:
> * Currently, only the first layer (out of seven valid layers) is analyzed. * The choice of the first layer is based on the fact that it contains the tip, the poristy of which has significant impact on the FC performance.

1.1 Prepation

Import modules and define user define functions.

In [1]:
```
# -- import modules
import tomopy
import gc
import numpy   as np
import scipy   as sp
import numexpr as ne

import matplotlib.pyplot as plt

from tqdm import tnrange, tqdm_notebook
from tqdm import trange

from dxchange.reader   import read_aps_1id_metafile
from dxchange.reader   import read_tiff_stack
from dxchange.writer   import write_aps_1id_report
from dxchange.writer   import write_tiff_stack
from dxchange.writer   import write_vtr

from tomopy.prep.alignment import find_slits_corners_aps_1id
from tomopy.prep.alignment import detector_drift_adjust_aps_1id
from tomopy.prep.alignment import remove_slits_aps_1id
from tomopy.prep.normalize import minus_log
from tomopy.misc.npmath    import discrete_cdf
from tomopy.misc.npmath    import gauss1d
```

```
from scipy.signal   import medfilt
from scipy.signal   import medfilt2d
# from scipy.signal   import convolve
from scipy.optimize import curve_fit

from scipy.ndimage import gaussian_filter
from scipy.ndimage import shift
from scipy.ndimage import convolve

from scipy.special import erf, erfc

# --
import ipywidgets as widgets
from ipywidgets import interact, interactive, fixed, interact_manual, IntProgress
from IPython.display import display

# --
from matplotlib import animation, rc
from IPython.display import HTML, Image
```

```
/home/chenz3/.pyenv/versions/anaconda3-5.2.0/lib/python3.6/site-packages/skimage/transform/_wa
  warn("The default mode, 'constant', will be changed to 'reflect' in "
```

```
In [2]: # -- svd function
        def svd_enhance(img, eigen_cut=20):
            U, S, V = np.linalg.svd(img, full_matrices=True)
            eigen_cut = min(eigen_cut, U.shape[1], V.shape[0])
            return np.dot(U[:,:eigen_cut]*S[:eigen_cut], V[:eigen_cut,:])
```

```
In [3]: # -- quick lambda function
        val_atPercent = lambda ar, p: np.sort(ar.flatten())[int(np.prod(ar.shape)*p)]
        wgt_histequal = lambda ar: (np.sort(ar.flatten()).searchsorted(ar) + 1)/np.prod(ar.shap
        wgts_binned   = lambda wgts, bins: np.int64(np.floor(wgts * bins)).astype(wgts.dtype) /
```

1.2 Metadata processing

Process/Parse the metadata (auto-generated during scan) to extract

- beam status (various stability)
- frame quality
- connectivity bewteen rotation angle (ω) and the image sequence number
- group layers into dataframes

```
In [4]: # ----- CONFIG BLOCK ----- #
        # -- change the following based on the sample
        metaf1        = "PUP_FF_SOFC_hires3_S2_TomoStillScan.dat"
        sampleImgName = "PUP_FF_SOFC_hires3_S2/PUP_FF_SOFC_hires3_S2_000008.tif"
```

```
write_base    = "PUP_FF_SOFC_hires3_S2_results/PUP_FF_SOFC_hires3_S2"
reportfn      = "PUP_FF_SOFC_hires3_S2_report/scanSummary.pdf"

# -- reconstruction config
recon_config = {'algorithm': 'gridrec',
                'filter'   : 'hann',
               }

# -- build data frame and generate report
df_layers = write_aps_1id_report(read_aps_1id_metafile(metaf1), reportfn)

layerIDs = df_layers['layerID'].unique()

print(f"Unique layers are: {layerIDs}")
```

```
Unique layers are: [ 6  7  8  9 10 11 12]
```

manual select the first layer, which contains the tip

In [5]:
```
layerID = 6

df_layern = df_layers[df_layers['layerID'] == layerID]

df_layern.describe()
```

Out[5]:

	num	nSeq	exp	fOmega	Omega	\
count	3631.000000	3631.000000	3.631000e+03	3631.000000	3631.000000	
mean	1786.165244	1816.000000	1.500000e-01	-1.487194	-1.487225	
std	1048.041119	1048.323741	1.015994e-14	104.810435	104.810434	
min	1.000000	1.000000	1.500000e-01	-180.000000	-180.000000	
25%	878.500000	908.500000	1.500000e-01	-92.250000	-92.250050	
50%	1786.000000	1816.000000	1.500000e-01	-1.500000	-1.500080	
75%	2693.500000	2723.500000	1.500000e-01	89.250000	89.249900	
max	3601.000000	3631.000000	1.500000e-01	180.000000	180.000000	

	ICint	IC-E1	IC-E2	IC-E3	IC-E4	\
count	3.631000e+03	3631.000000	3631.000000	3631.000000	3631.000000	
mean	6.500000e-01	76380.527403	78185.773891	73212.141283	321.169375	
std	4.441504e-14	4045.376572	4142.571960	3879.211524	15.836482	
min	6.500000e-01	0.000000	0.000000	419.000000	284.000000	
25%	6.500000e-01	76262.000000	78056.000000	72992.000000	309.000000	
50%	6.500000e-01	76515.000000	78320.000000	73298.000000	320.000000	
75%	6.500000e-01	76965.000000	78796.000000	73905.000000	334.000000	
max	6.500000e-01	78201.000000	81453.000000	75524.000000	363.000000	

	...	bpEds	LN2temp	SRcurrent	encoderX	seqNum	\
count	...	3631.000000	3631.000000	3631.000000	3631.0	3631.000000	
mean	...	-13.517194	84.220476	102.049297	0.0	1815.026990	

```
std     ...      1.058316     0.003734     0.174000       0.0  1048.324049
min     ...    -13.574900    84.211000   101.639000       0.0     1.000000
25%     ...    -13.573100    84.218000   101.927000       0.0   907.500000
50%     ...    -13.572800    84.221000   102.052000       0.0  1815.000000
75%     ...    -13.572400    84.223000   102.170000       0.0  2722.500000
max     ...      7.125490    84.230000   102.508000       0.0  3631.000000

       layerID          TBS          VBS          BLS          BLT
count   3631.0  3631.000000  3622.000000  3631.000000  3631.000000
mean       6.0     0.987991          inf     2.105510     0.006412
std        0.0     0.052350          NaN     0.110042     0.039903
min        6.0     0.005654     0.949812     0.000000     0.004191
25%        6.0     0.985021     0.976874     2.107535     0.004288
50%        6.0     0.989150     0.977052     2.112055     0.004315
75%        6.0     0.997342     0.977191     2.114556     0.004344
max        6.0     1.019190          inf     2.147057     0.768496

[8 rows x 23 columns]
```

In [9]:
```
# rotation related quantity (useful for reconstruction)
thetas = np.radians(df_layern.loc[df_layern['type']=='still', 'Omega'].values)
dn = int(np.pi/(thetas[1] - thetas[0]))  # assuming eaqual spacing along omega
```

1.3 Data reduction

The raw data is way to large for regular computer server to handle, therefore data reduction is necessary before further analysis.

first, generate necessary folders for subsequent analysis

In [8]:
```
%%bash

mkdir -p PUP_FF_SOFC_hires3_S2_report
mkdir -p PUP_FF_SOFC_hires3_S2_results
mkdir -p PUP_FF_SOFC_hires3_S2_runtime
```

second, background normalization using collected dark and white field images

In [9]:
```
print(f"Reading in tiff images")
flat_pre = read_tiff_stack(sampleImgName, df_layern.loc[df_layern['type'] == 'pre_white
flat_pst = read_tiff_stack(sampleImgName, df_layern.loc[df_layern['type'] == 'post_whi
dark_pst = read_tiff_stack(sampleImgName, df_layern.loc[df_layern['type'] == 'post_dar
print(f"=> quick summary of background images for layer_{layerID}:")
print(f"\tPre-flat  image:{flat_pre.shape} as {flat_pre.dtype}")
print(f"\tPost-flat image:{flat_pst.shape} as {flat_pst.dtype}")
print(f"\tPost-dark image:{dark_pst.shape} as {dark_pst.dtype}")
```

```
Reading in tiff images
=> quick summary of background images for layer_6:
        Pre-flat  image:(10, 2048, 2048) as uint16
```

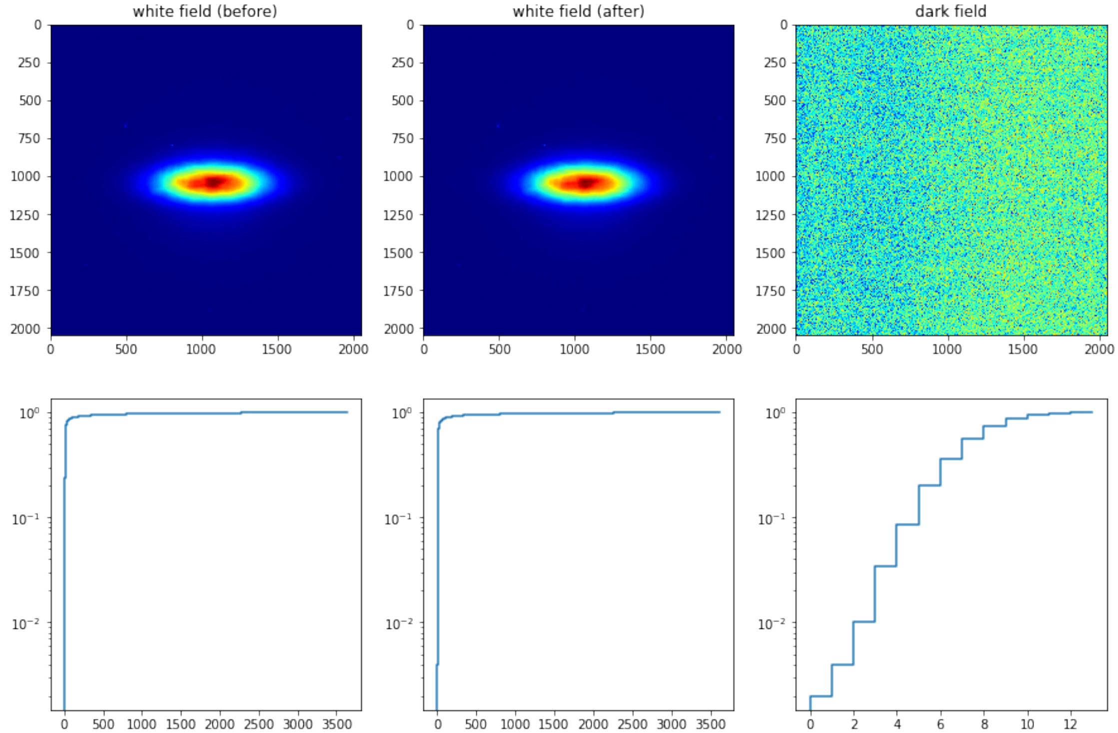
```
Post-flat image:(10, 2048, 2048) as uint16
Post-dark image:(10, 2048, 2048) as uint16
```

In [10]:
```python
# interactively view the flat field image
# 10 dark, 10 white_pre, 10_white_post

def viz_flat(n):
    fig, axes = plt.subplots(2, 3, figsize=(15, 10),)

    axes[0,0].imshow(flat_pre[n,:,:], 'jet')
    axes[0,0].set_title("white field (before)")
    xx,yy = discrete_cdf(flat_pre[n,:,:].flatten(), steps=500)
    axes[1,0].plot(xx,yy)
    axes[1,0].set_yscale('log')

    axes[0,1].imshow(flat_pst[n,:,:], 'jet')
    axes[0,1].set_title("white field (after)")
    xx,yy = discrete_cdf(flat_pst[n,:,:].flatten(), steps=500)
    axes[1,1].plot(xx,yy)
    axes[1,1].set_yscale('log')

    axes[0,2].imshow(dark_pst[n,:,:], 'jet')
    axes[0,2].set_title("dark field")
    xx,yy = discrete_cdf(dark_pst[n,:,:].flatten(), steps=500)
    axes[1,2].plot(xx,yy)
    axes[1,2].set_yscale('log')

# -- use the template
interactive_plot = interactive(viz_flat, n=(0, flat_pre.shape[0]-1))  # still field

output = interactive_plot.children[-1]
interactive_plot
```

```
interactive(children=(IntSlider(value=4, description='n', max=9), Output()), _dom_classes=('wic
```

Static view (for non-interacitve notebook mode)

In [11]:
```python
viz_flat(4)
```



now, it is time to read in the raw projections

NOTE: careful with the memory usage (about **30.0G** per layer).

```
In [12]: projs = read_tiff_stack(sampleImgName, df_layern.loc[df_layern['type'] == 'still',  'r
         print(f"=> quick summary of projection images for layer_{layerID}:")
         print(f"\tprojections image:{projs.shape} as {projs.dtype}")
```

```
=> quick summary of projection images for layer_6:
        projections image:(3601, 2048, 2048) as uint16
```

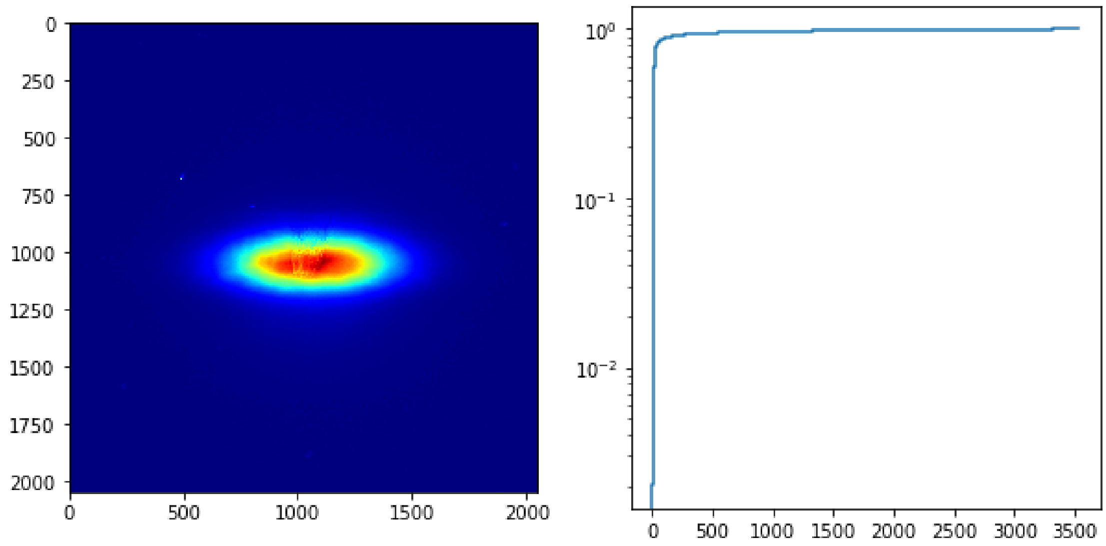
```
In [13]: # Interactive view of the projection images

         def viz_proj(n):

             fig, axes = plt.subplots(1, 2, figsize=(10, 5))

             axes[0].imshow(projs[n,:,:], 'jet')

             xx,yy = discrete_cdf(projs[n,:,:].flatten(), steps=500)
             axes[1].plot(xx,yy)
             axes[1].set_yscale('log')

         # -- use the template
```

```
interactive_plot = interactive(viz_proj, n=(0, projs.shape[0]-1))  # still field

output = interactive_plot.children[-1]
interactive_plot
```

```
interactive(children=(IntSlider(value=1800, description='n', max=3600), Output()), _dom_classes
```

static view of proejctio images (for non-interactive notebook session)

```
In [14]: viz_proj(1800)
```



since the majority of the image is empty, it is better to isolate the region with sample to reduce total data size.

After several interactive visual inspections, the following cropping limit is selected for this layer.

- Layer_6: `img[750:1150, 800:1300]`

1.3.1 Crop down images

```
In [16]: # get the background
         bg_white = np.median(flat_pre, axis=0).astype(float)
         bg_dark  = np.median(dark_pst, axis=0).astype(float)

In [17]: bg_white = bg_white[750:1150, 800:1300]
         bg_dark  = bg_dark[ 750:1150, 800:1300]
         projs    = projs[:, 750:1150, 800:1300]
```

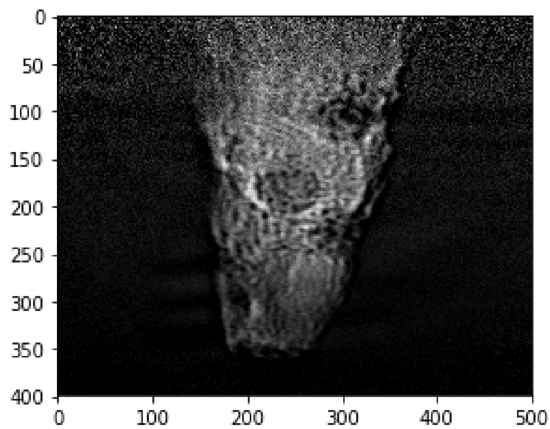
In [20]:
```
# remove the background using both white field and dark field

projs_clean = np.zeros(projs.shape)

for n in tqdm_notebook(range(projs.shape[0])):
    img = np.copy(projs[n,:,:]).astype(float)
    img = np.where(img-bg_dark>0, img-bg_dark, 0)
    bg  = np.where(bg_white-bg_dark>0, bg_white-bg_dark, 1)
    img = img/bg
    img = -np.log(np.where(img>0, img, 1))
    projs_clean[n,:,:] = np.where(img>0, img, 0)
```

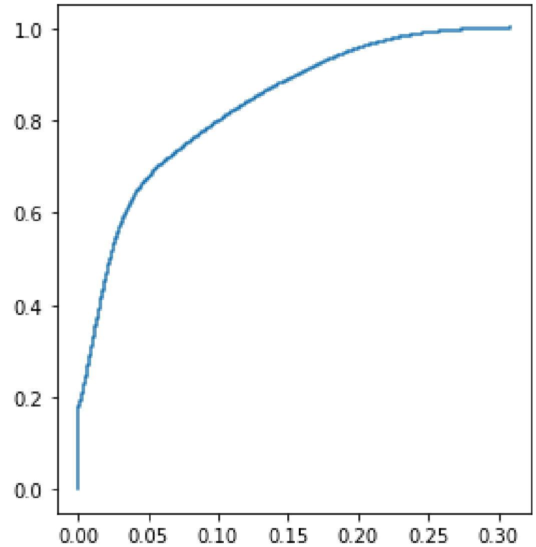
```
HBox(children=(IntProgress(value=0, max=3601), HTML(value='')))
```

In [21]:
```
# Interactive view of the projection images

def viz_proj(n):

    fig, axes = plt.subplots(1, 2, figsize=(10, 5))

    axes[0].imshow(projs_clean[n,:,:], 'gray')

    xx,yy = discrete_cdf(projs_clean[n,:,:].flatten(), steps=500)
    axes[1].plot(xx,yy)

# -- use the template
interactive_plot = interactive(viz_proj, n=(0, projs.shape[0]-1))  # still field

output = interactive_plot.children[-1]
interactive_plot
```

```
interactive(children=(IntSlider(value=1800, description='n', max=3600), Output()), _dom_classes
```

In [22]:
```
# static view
viz_proj(1800)
```





save the reduced projections and **restart kernel (manual)**

```
In [23]: np.save('PUP_FF_SOFC_hires3_S2_runtime/layer6_projs_reduced', projs_clean)
```

1.4 Tomography reconstruction

With the reduced data set, it is now possible to perform the reconstruction.

1.4.1 Counter sample jittering

Due to the experiment setup, significant sample jittering (particularly horizontal one) is present in the data set. This poses a huge issue to the tomography reconstruction process which requires a common rotation axis for all image. Consequelty, a phase correlation based correction process, termed "iterative pair-wise adjustment", is used here to counter the **horizontal** sample jittering by forcing the rotation axis of all iamge to the center of the image.

> Note: Although visible vertical sample jittering is also observed, there is currently no reliable way to counter its impact due to lack of common reference feature.

```
In [7]: # load the reduced data set

        projs = np.load('PUP_FF_SOFC_hires3_S2_runtime/layer6_projs_reduced.npy')

        for n in tqdm_notebook(range(projs.shape[0])):
            projs[n,:,:] /= projs[n,:,:].max()

        print(projs.shape)
```

```
HBox(children=(IntProgress(value=0, max=3601), HTML(value='')))
```

```
(3601, 400, 500)
```

```
In [10]: # -- center the data using iterative pairwise adjustment
         n_iters     = 10
         rot_centers = []

         for i in tqdm_notebook(range(n_iters), desc='iter'):
             # adjust the images
             for n_img in tqdm_notebook(range(int(dn)), desc='adjust'):
                 # locate the pair-wise center through PC
                 _cnt = tomopy.find_center_pc(projs[n_img,:,:],
                                              projs[n_img+dn,:,:],
                                              rotc_guess=projs.shape[2]/2,
                                             )
                 # adjust the pair images
                 # NOTE:
                 #   make sure have order=1 to force using linear interpolation to avoid negat
                 val_shift = np.array([0, projs.shape[2]/2 - _cnt])
                 projs[n_img,:,:]    = shift(projs[n_img,:,:],    val_shift, mode='constant', c
                 projs[n_img+dn,:,:] = shift(projs[n_img+dn,:,:], val_shift, mode='constant', c

             # calculate the average rotation center
             tmp = []
             for n_img in tqdm_notebook(range(int(dn)), desc='calcAvg'):
                 tmp.append(tomopy.find_center_pc(projs[n_img,:,:],
                                                  projs[n_img+dn,:,:],
                                                  rotc_guess=projs.shape[2]/2,
                                                 )
                           )
             # get the average rotation center
             _cnt = np.average(tmp)
             # if the average rotation center has been adjusted to middle, stop
             if abs(_cnt - projs.shape[2]/2)<0.1:
                 break
```

```
HBox(children=(IntProgress(value=0, description='iter', max=10, style=ProgressStyle(descriptio
```

```
HBox(children=(IntProgress(value=0, description='adjust', max=1800, style=ProgressStyle(descri
```

```
HBox(children=(IntProgress(value=0, description='calcAvg', max=1800, style=ProgressStyle(descr
```

During the analysis, it was noiticed that there are three corrupted frames, which will add necessary noise to the reconstruction results. Therefore, the pairs containing corrupted frames are excluded from the reconstruction process.

```
In [11]: # -- gather the horizontal jitter profile (rotation center distribution)
         dict_rotcnts = {}

         thetas = np.radians(df_layern.loc[df_layern['type']=='still', 'Omega'].values)
         dn = int(np.pi/(thetas[1] - thetas[0]))  # assuming eaqual spacing along omega

         rot_centers = []
         for n_img in tqdm_notebook(range(0, int(dn))):
             rot_centers.append(tomopy.find_center_pc(projs[n_img,   :,:], projs[n_img+dn,:,:]

         dict_rotcnts['iterPairWiseAdjust'] = rot_centers + rot_centers

         # -- find the good/bad frames
         rot_cnts = np.array(dict_rotcnts['iterPairWiseAdjust'])

         idx_goodimg = np.where(abs(rot_cnts -250)< 1)[0]
         idx_badimg  = np.where(abs(rot_cnts -250)>=1)[0]

         projs_good  = projs[idx_goodimg,:,:]
         thetas_good = thetas[idx_goodimg]
         rot_cnt = np.average(rot_cnts[idx_goodimg])

         print(projs_good.shape, thetas_good.shape, rot_cnt, np.average(rot_cnts))
```

```
HBox(children=(IntProgress(value=0, max=1800), HTML(value='')))


(3594, 400, 500) (3594,) 249.99763494713412 249.98625
```

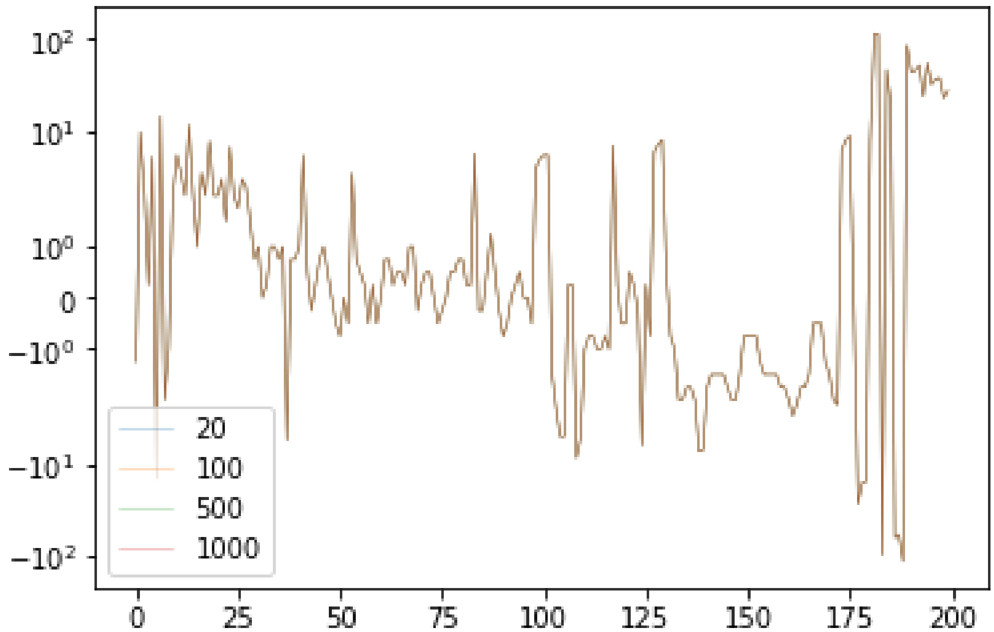
1.4.2 counter rotation axis tilt

Prelimenary analysis (see below) indicate that the rotation axis is tilted, which is most likely caused by the mis-alignment between FF detector and the sample rotation stage. In theory, the most accurate correction would be in-plane rotation to bring the 180^o-pair into a leveled position. However, due to lack of reference points, the exact rotation cannot be deterministically located. Therefore, an finite steps apprixmation is used where different rotation center is used for thin slice of data (two sinograms at a time).

```
In [12]: # testing for single pair

         nimgs = [20, 100, 500, 1000]
         for nimg in nimgs:
             cnts = []
             for nrow in range(0, projs.shape[1], 2):
                 cnts.append(tomopy.find_center_pc(projs[n_img,   nrow:nrow+2,:],
                                                   projs[n_img+dn,nrow:nrow+2,:],
                                                   rotc_guess=projs.shape[2]/2,
                                                  ) - 250
```

```
                     )
    plt.plot(cnts, label=f"{nimg}", linewidth=0.5, alpha=0.5)

plt.yscale('symlog')
plt.legend()
```

Out[12]: <matplotlib.legend.Legend at 0x7f4718c83940>



In [13]:
```
# use slab of 16 pixels
# [32, 16, 8, 4, 2,]

size_slab = 2
recon     = np.zeros((projs.shape[1], projs.shape[2], projs.shape[2]))
rotcnts   = []

for nrow in tqdm_notebook(range(0, projs.shape[1], size_slab), desc='slab'):
    # locate the rotation center
    _projs  = projs[:,nrow:nrow+size_slab,:]
    _rotcnt = []
    for nimg in tqdm_notebook(range(dn), desc=f'r{nrow}_omega'):
        _rotcnt.append(tomopy.find_center_pc(_projs[nimg,   :,:],
                                             _projs[nimg+dn,:,:],
                                             rotc_guess=projs.shape[2]/2,
                                            ),
                      )
    _rotcnt = np.array(_rotcnt + _rotcnt)  # 180 -> 360
```

```python
        # perform the reconstruction
        recon[nrow:nrow+size_slab,:,:] = tomopy.recon(projs_good[:,nrow:nrow+size_slab,:]
                                                      thetas_good,
                                                      center=np.average(_rotcnt[idx_goodi
                                                      algorithm='gridrec', filter_name='ha
                                                     )
        rotcnts.append(np.average(_rotcnt[idx_goodimg]))

    # removal phase artifacts
    recon = tomopy.circ_mask(recon, axis=0, ratio=0.6)

    phase_recon = tomopy.retrieve_phase(recon,
                                        pixel_size=2e-5,   # 200 nm pixel size on the det
                                        dist=10,          # the notes said 36m !?
                                        energy=50,         # 45-50 keV, according to exis
                                        )

    # output to disk
    for n in tqdm_notebook(range(recon.shape[0])):

        img  = np.copy(recon[n,:,:])
        pha  = np.absolute(np.copy(phase_recon[n,:,:]))
        pha /= pha.max()

        img -= img.min()
        img /= img.max()

        msk  = gaussian_filter(pha, sigma=20)

        recon[n,:,:] = img*msk*255

    # -- write to disk
    write_tiff_stack(recon,
                     overwrite=True,
                     fname=write_base,
                     start=0,
                    )
```

```
HBox(children=(IntProgress(value=0, description='slab', max=200, style=ProgressStyle(descripti

HBox(children=(IntProgress(value=0, description='r0_omega', max=1800, style=ProgressStyle(desc

HBox(children=(IntProgress(value=0, description='r2_omega', max=1800, style=ProgressStyle(desc

HBox(children=(IntProgress(value=0, description='r4_omega', max=1800, style=ProgressStyle(desc
```

```
HBox(children=(IntProgress(value=0, description='r6_omega', max=1800, style=ProgressStyle(desci

HBox(children=(IntProgress(value=0, description='r8_omega', max=1800, style=ProgressStyle(desci

HBox(children=(IntProgress(value=0, description='r10_omega', max=1800, style=ProgressStyle(desc

HBox(children=(IntProgress(value=0, description='r12_omega', max=1800, style=ProgressStyle(desc

HBox(children=(IntProgress(value=0, description='r14_omega', max=1800, style=ProgressStyle(desc

HBox(children=(IntProgress(value=0, description='r16_omega', max=1800, style=ProgressStyle(desc

HBox(children=(IntProgress(value=0, description='r18_omega', max=1800, style=ProgressStyle(desc

HBox(children=(IntProgress(value=0, description='r20_omega', max=1800, style=ProgressStyle(desc

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In [14]:
```
# quick sanity check
def peekrecon(n):
    fig, axes = plt.subplots(1, 2, figsize=(20,10))

    img = np.copy(recon[n,:,:])

    axes[0].imshow(img, 'gray')

    # plot the discrete rotation center
    axes[1].plot(rotcnts)
```

```
    # -- use the template
    interactive_plot = interactive(peekrecon, n=(0, recon.shape[0]-1))  # still field

    output = interactive_plot.children[-1]
    interactive_plot
```

```
interactive(children=(IntSlider(value=199, description='n', max=399), Output()), _dom_classes=
```

```
In [15]: # static view
         peekrecon(199)
```