Sparse 2D SAR apertures for 3D SAR

NATO SET265 Salamanca

Dr Dan Andre
Mr George Price
Dr Mark Finnis
Prof David Blacknell

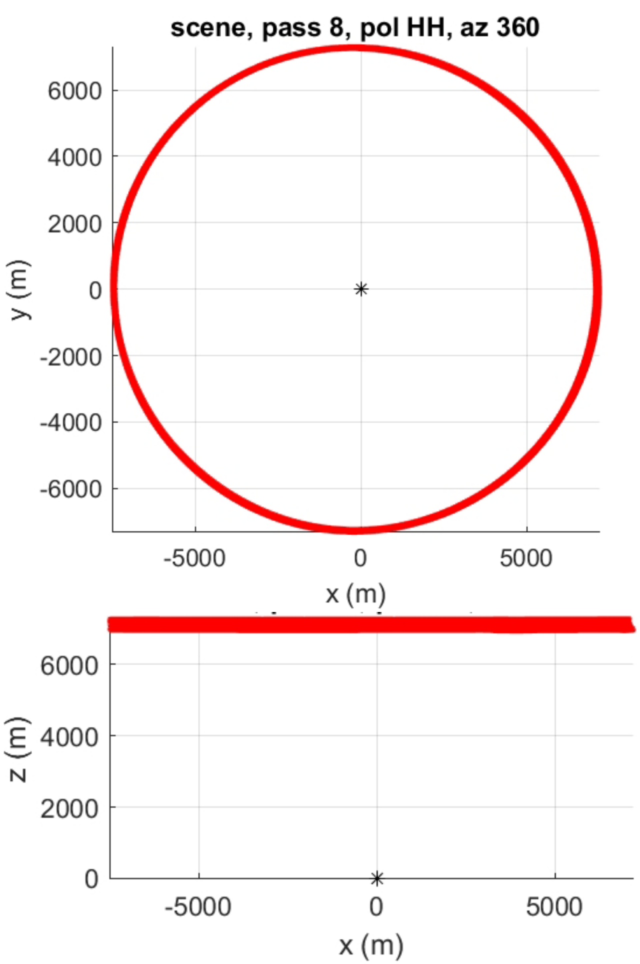
Cranfield GBSAR Laboratory

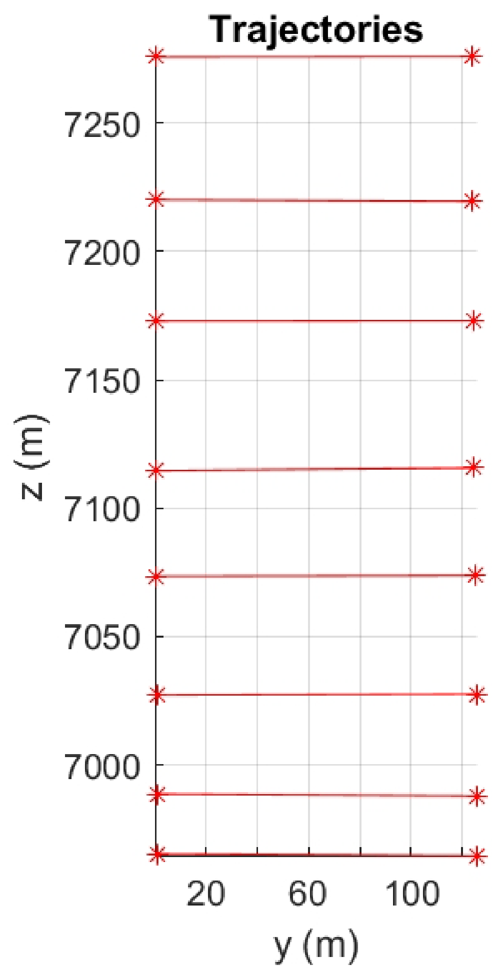
Introduction

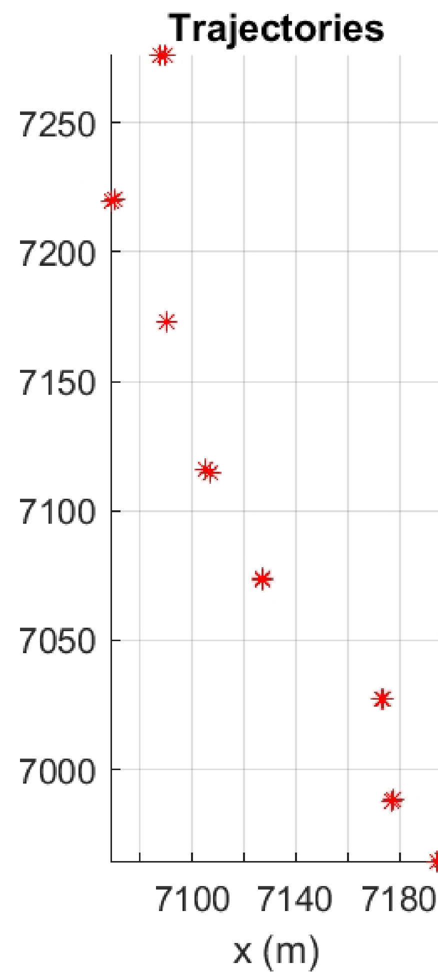
- There is a need to **remotely** determine internal structures of buildings, detecting presence of equipment & human activity
  - Current techniques involve close contact of radar against wall.
- 3D LF SAR would penetrate walls & separate clutter
- Supporting Dstl programme: **Remote Intelligence of Building Interiors**
- Several strands of work ongoing including processing of airborne volumetric LF CSAR: Airbus/Dstl dataset

GOTCHA airborne 3D SAR

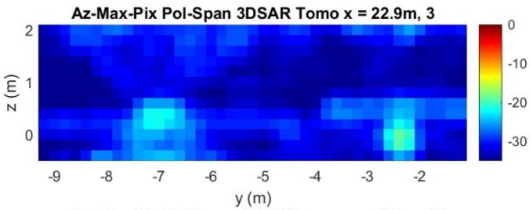
- We are working on MOCO for the Airbus CSAR dat
- In meantime we have been working on X-Band airborne 3DSAR image formation with the GOTCHA urban challenge dataset
  - Eight circular trajectories at different heights

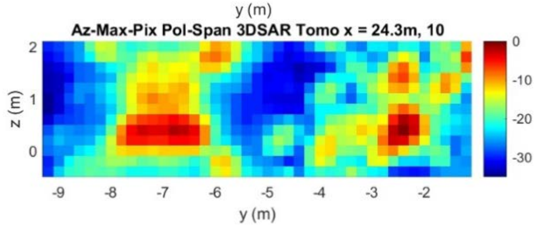


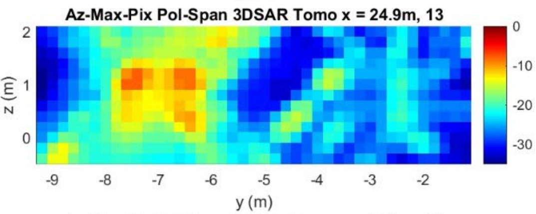


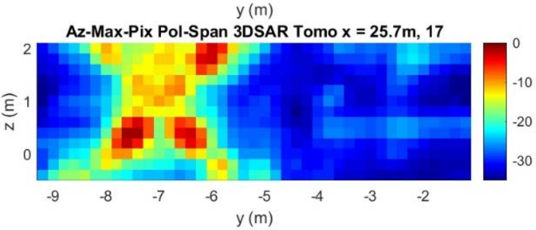


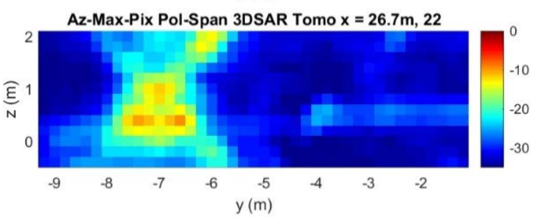
GOTCHA Airborne CSAR
Fork lift truck tomograms

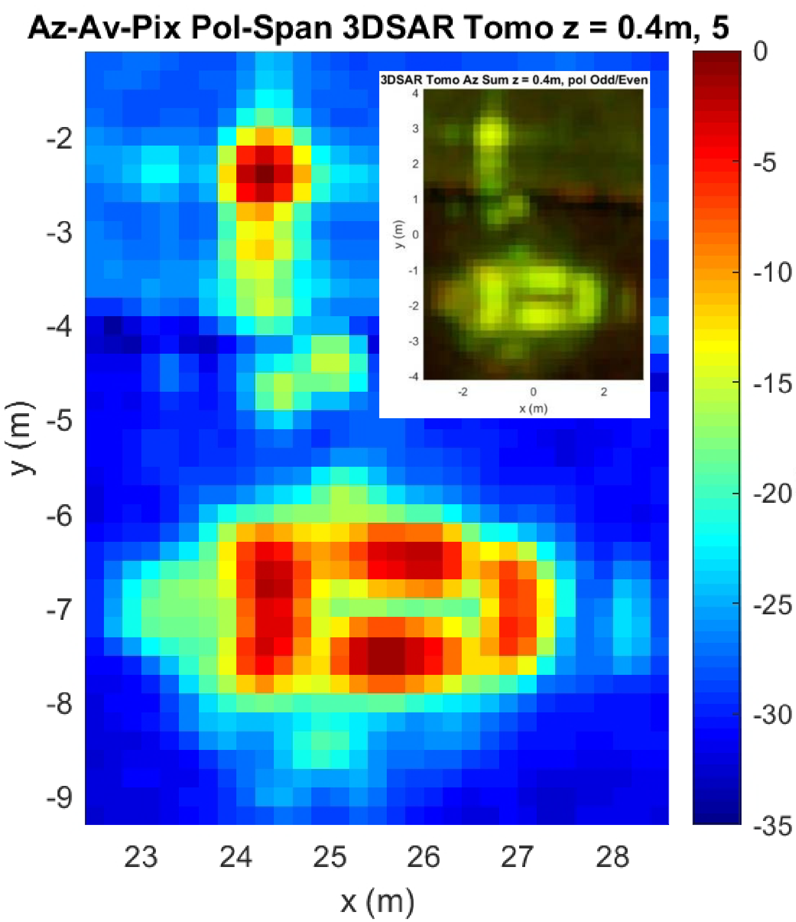


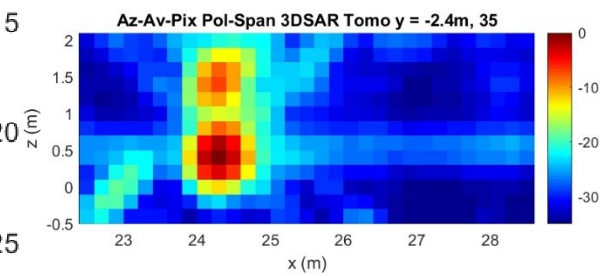


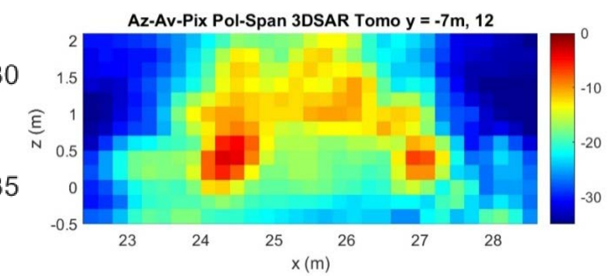








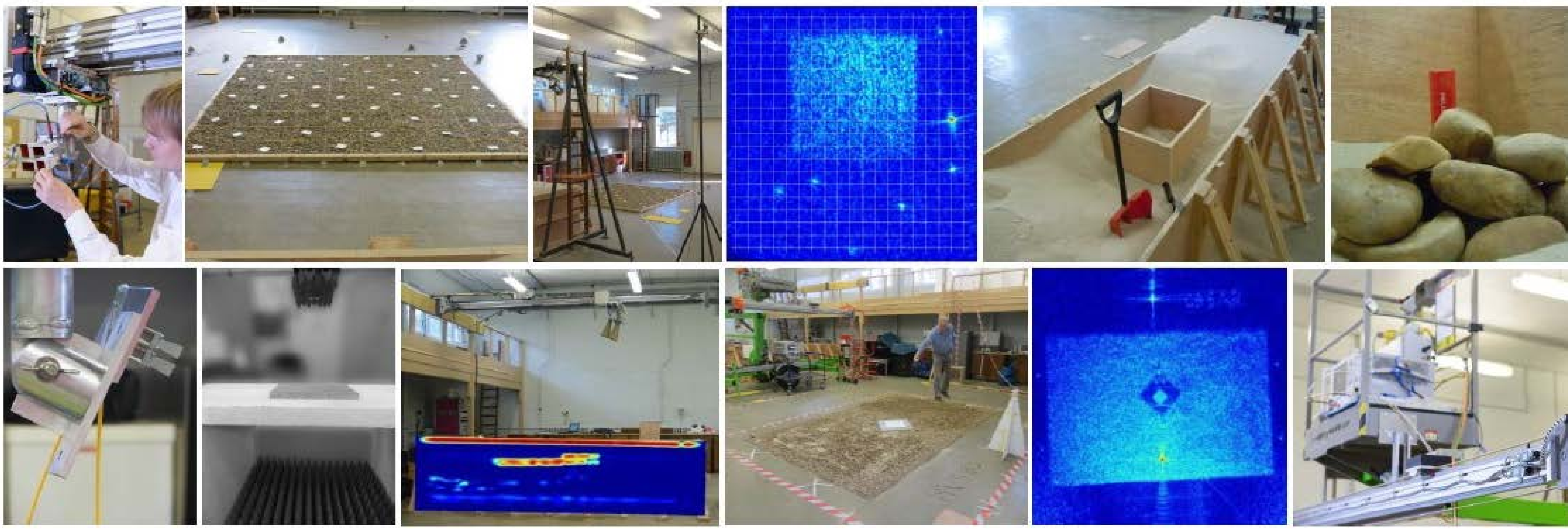




GBSAR System

The Indoor System

The indoor system is housed within a flexible 17m (l) x 9m (w) x 5m (h) laboratory workspace, which provides a highly controlled, precision, repeatable, ‘radar-quiet’ measurement environment. The system is currently figured to operate up to 26.5GHz, but can operate up to 50GHz for bespoke measurements. Radar imagery can be collected in both SAR and Tomographic Profiling modes, as well as reflectivity measurements for the determination of material properties. Numerous bi-static and multi-static configurations are available. Automation allows the system to collect large, continuous image sets for the study of slowly evolving scattering processes without the need for operator presence. The 4m x 1m x 1m sand trough is used in the study of sub-surface imaging phenomena.



SAR, bistatic SAR
500MHz – 40GHz

Polarisation: Full quad

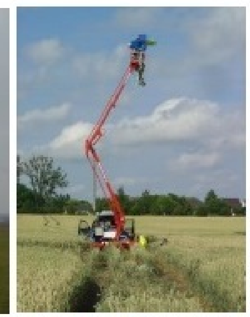
Nominal Accuracies: 1dB, 5°

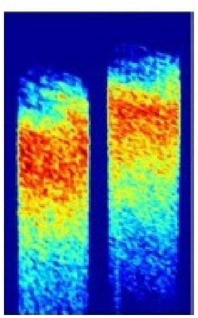
GBSAR System

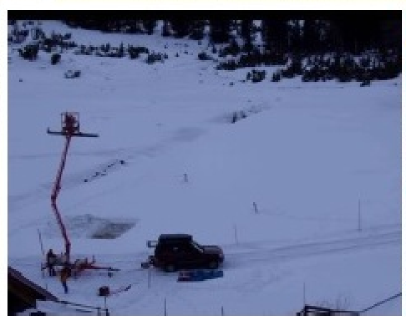
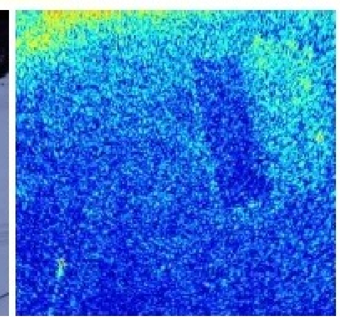
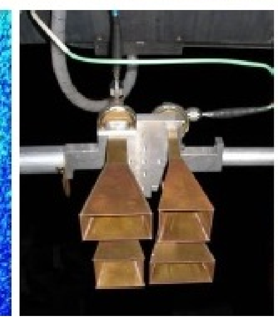
The Outdoor System

The outdoor system is a bespoke, portable outdoor radar imaging system. It consists of a trailer-mounted hoist, which is transported to site by a Land Cruiser 4x4 vehicle. For deployment, the horizontal scanning boom is attached to the basket and lifted to the chosen height. Imagery is collected by scanning the antenna sledge along the boom. The standard imaging modes are SAR and Tomographic Profiing (TP). The radar unit sits in the basket, and the whole system is controlled from a laptop at ground level. The antenna sledge can be offset front-back to provide an interferometric baseline. In addition, bespoke set-ups can collect bi-static imagery.



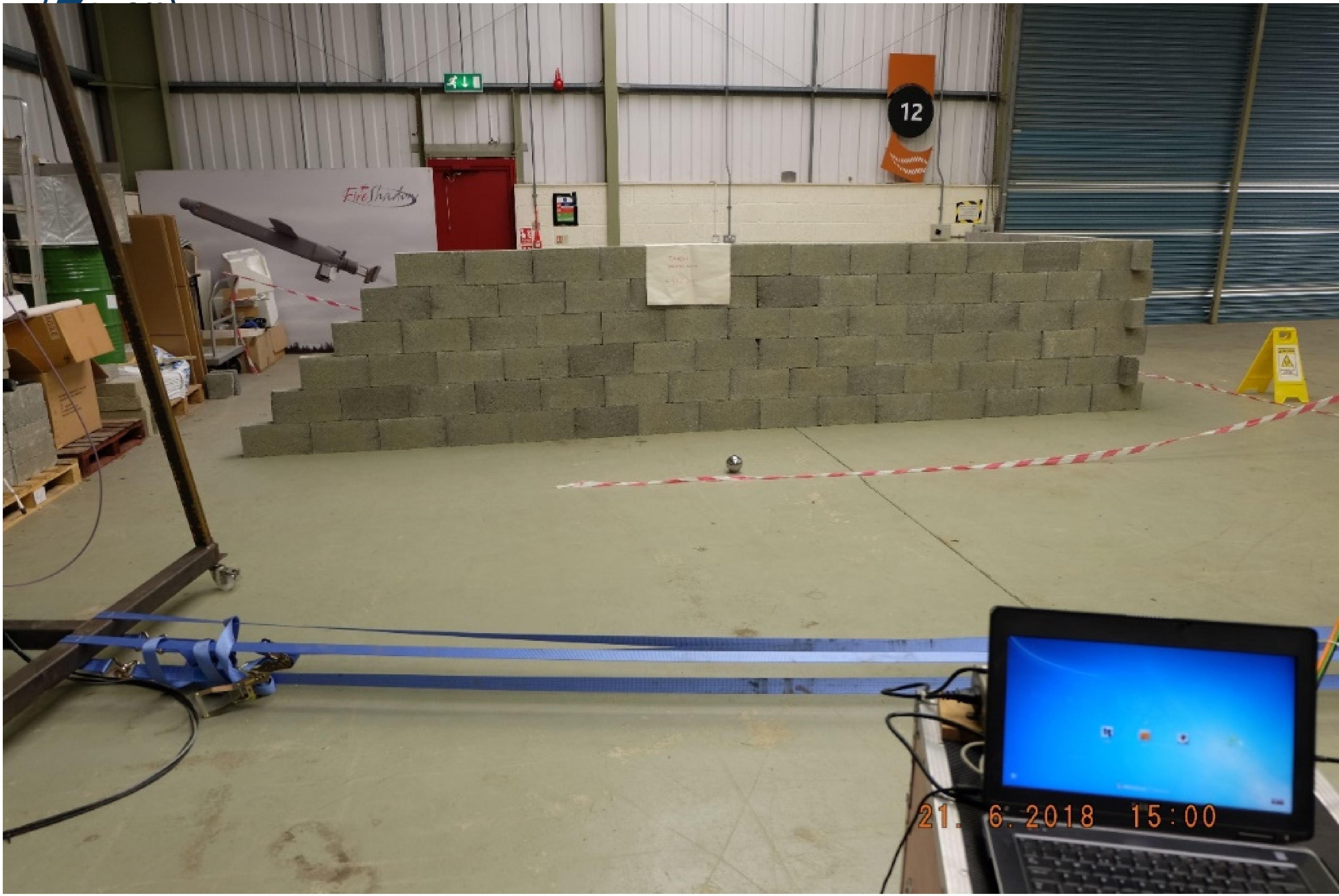




SAR, bistatic SAR   500MHz – 40GHz

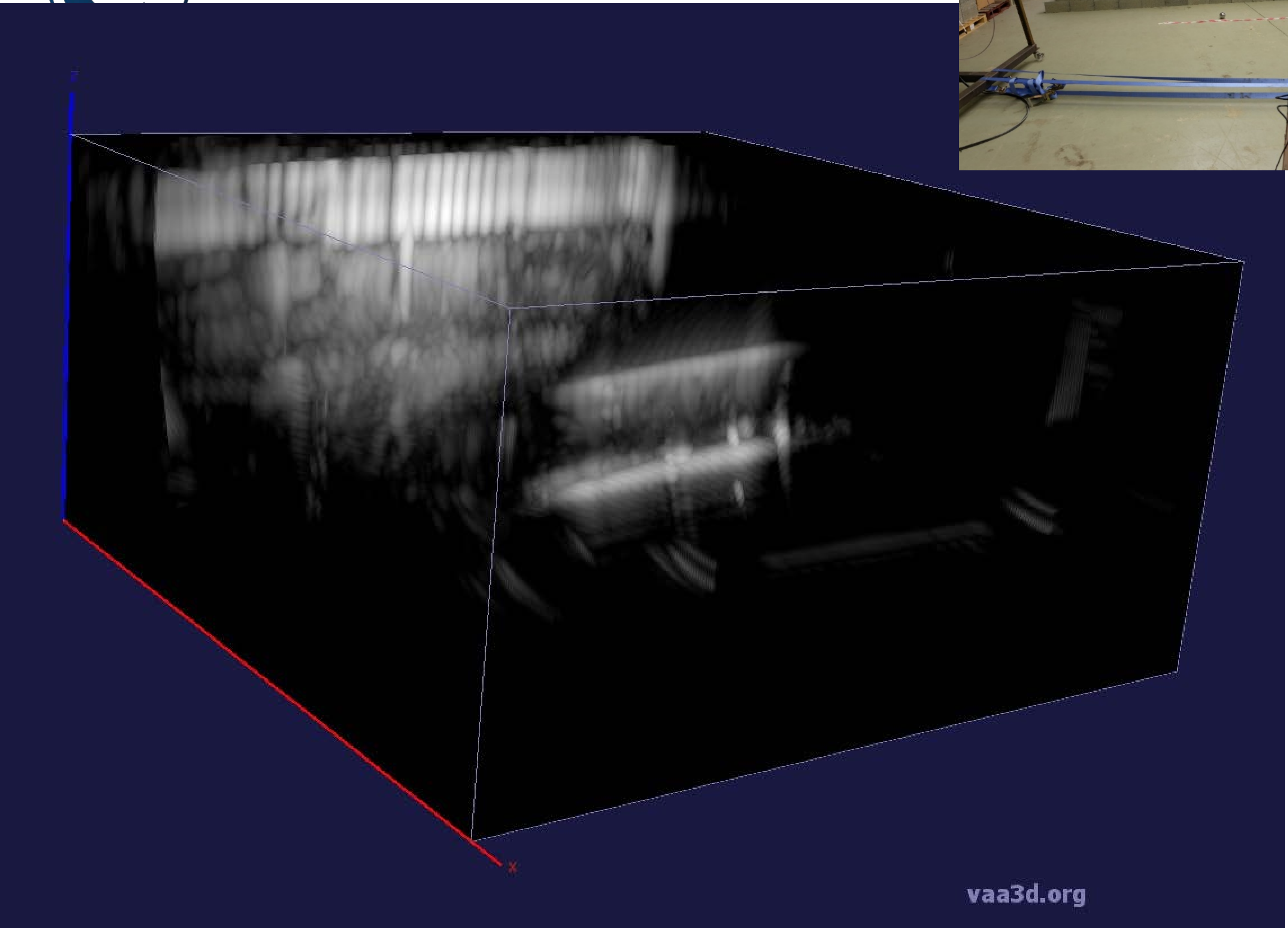
Polarisation: Full quad
Height: 0-10m
Nominal Accuracies: 1dB, 5°

3D SAR of GBSAR Lab

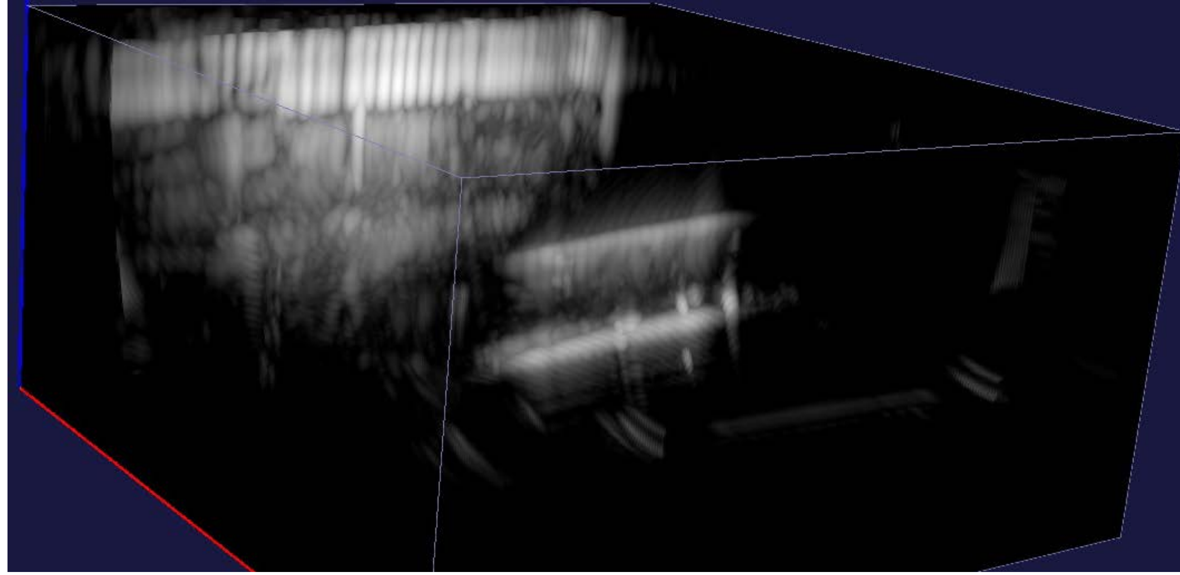


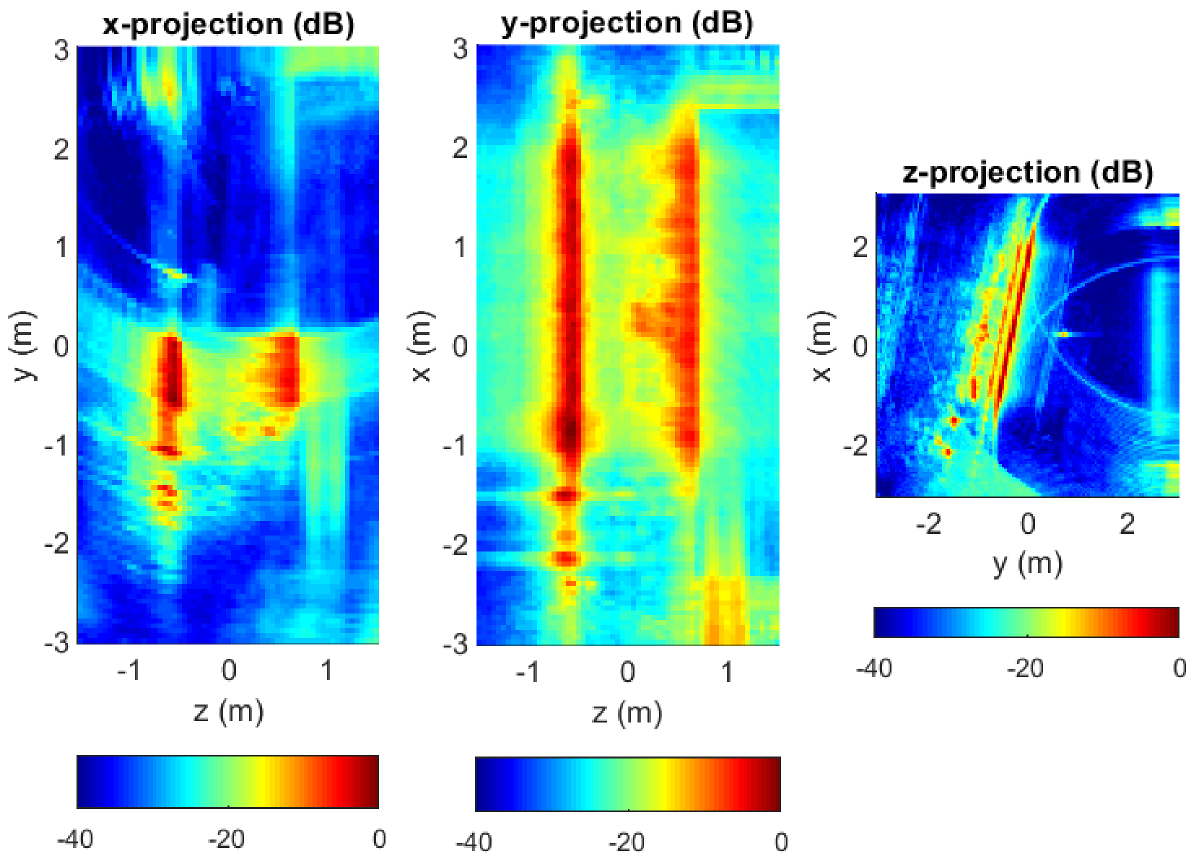
3D SAR of GBSAR Lab

3D LF SAR of GBSAR Lab



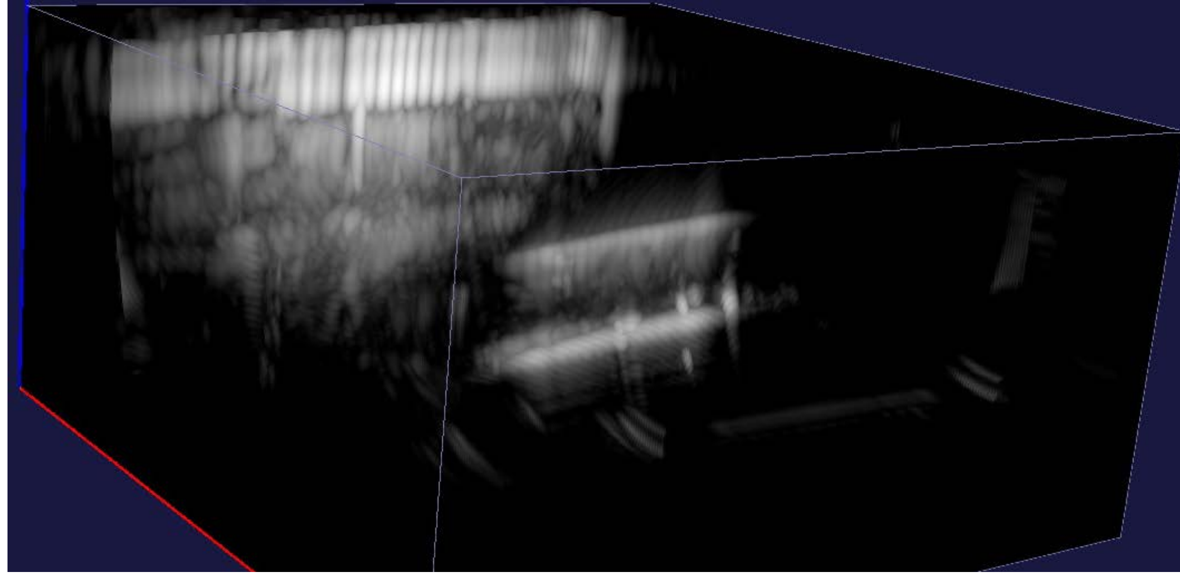
- Projections
  - Barrels, multipath
  - Briefcase
  - Monitor
  - Desk

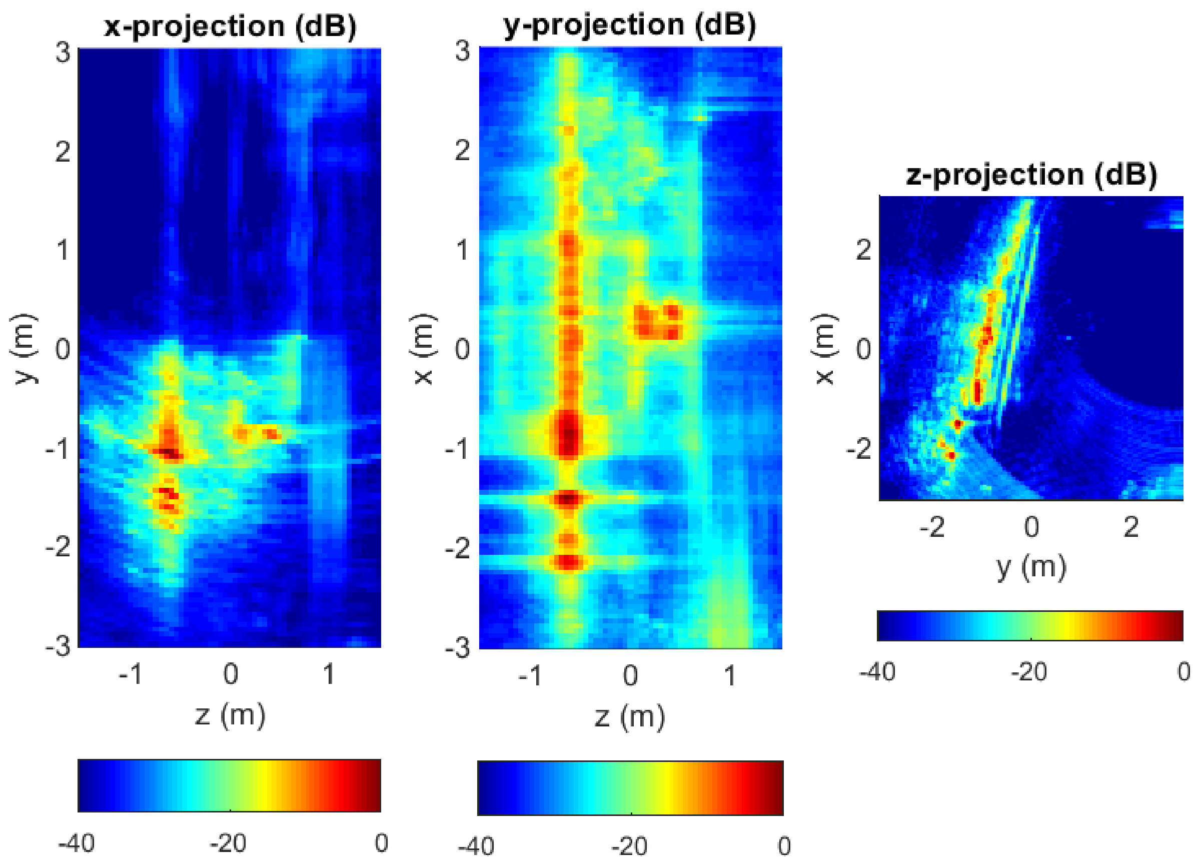




- Projections

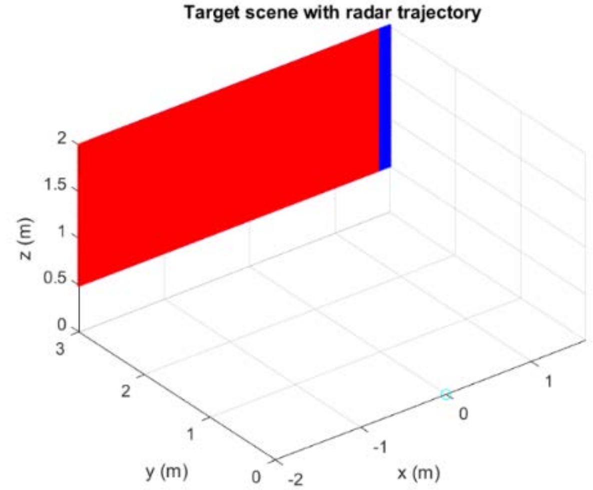
- **Background subtracted**
  - Barrels, multipath
  - Briefcase
  - Monitor
  - Desk

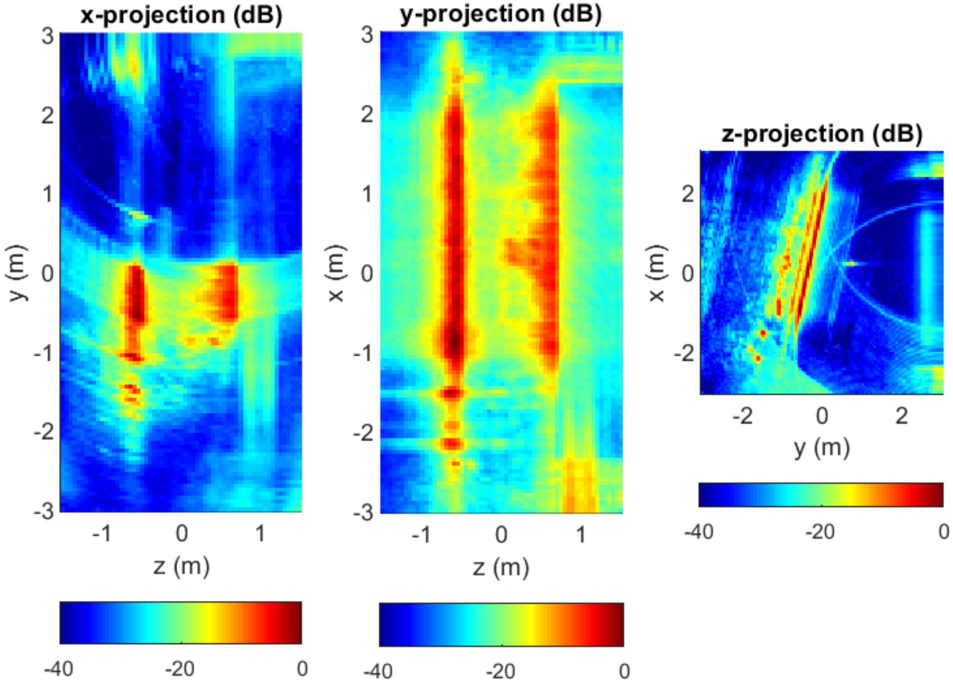


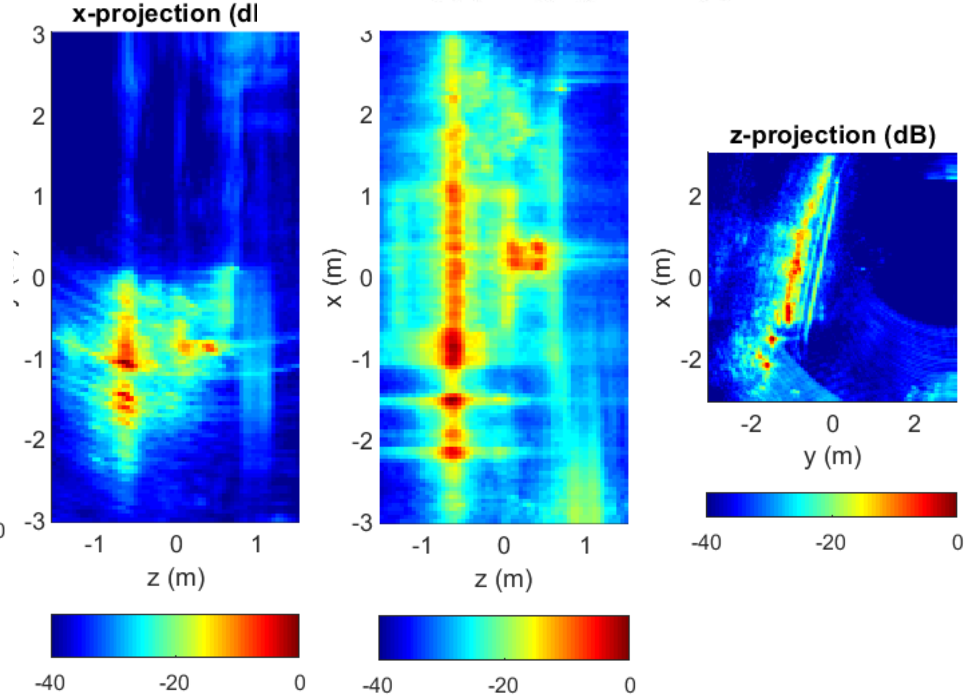


Fully sampled 2D aperture

- 3D LF SAR of GBSAR Lab

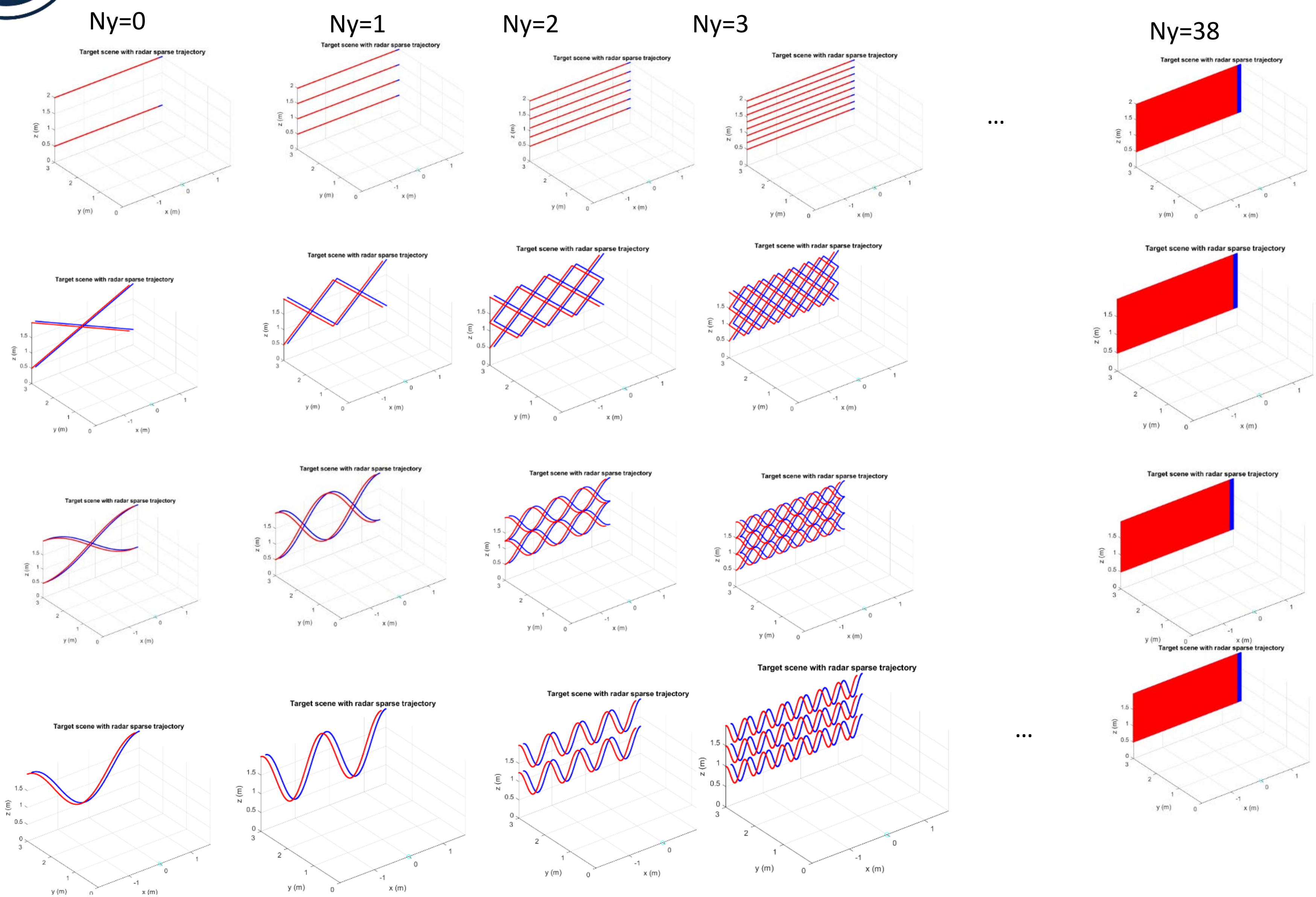




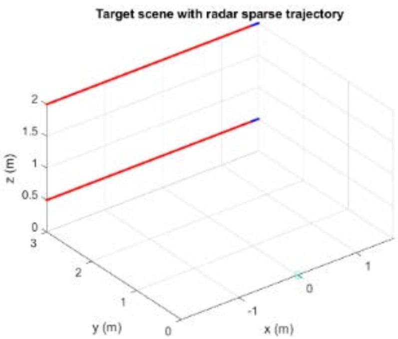


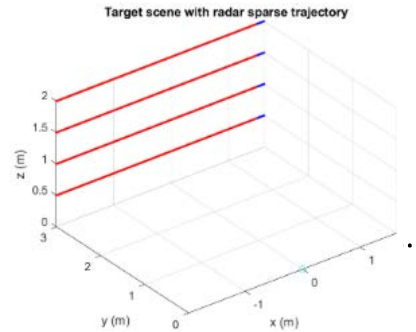
Background subtracted

Classes of sparse sampled trajectories

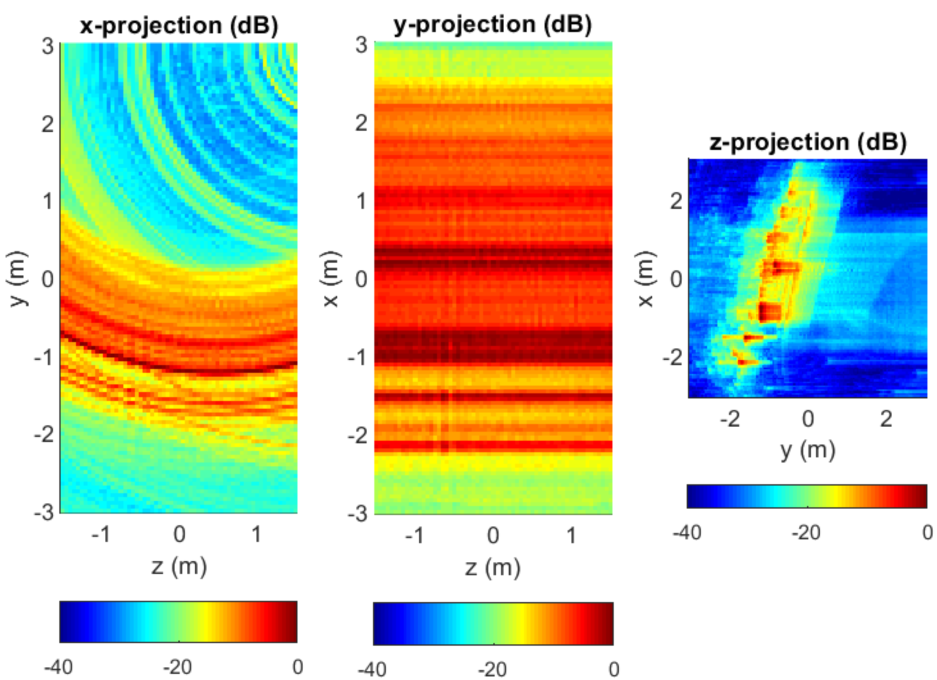


Repeat Linear pass

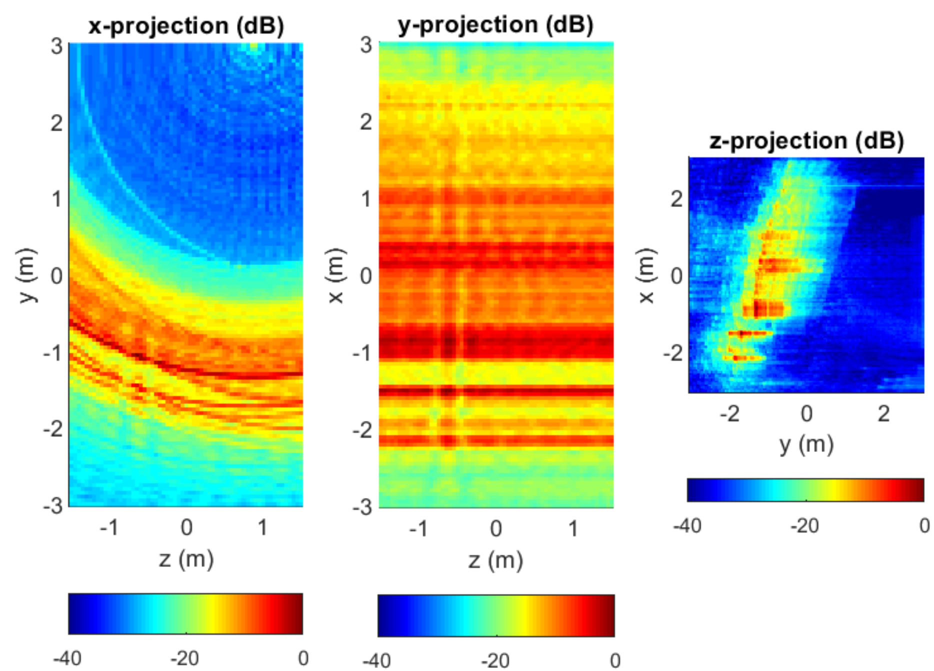




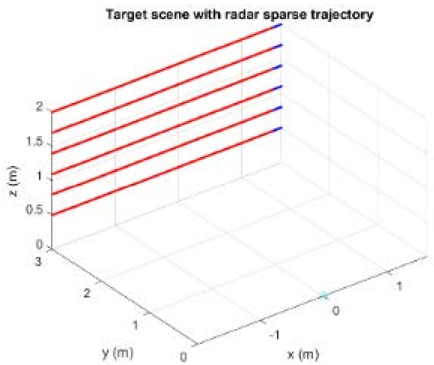
Sparse RL
2 passes, bg-s

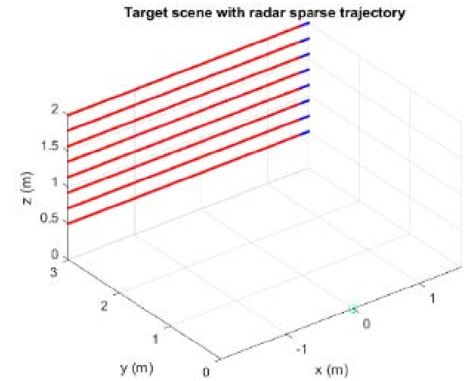


Sparse RL
4 passes, bg-s

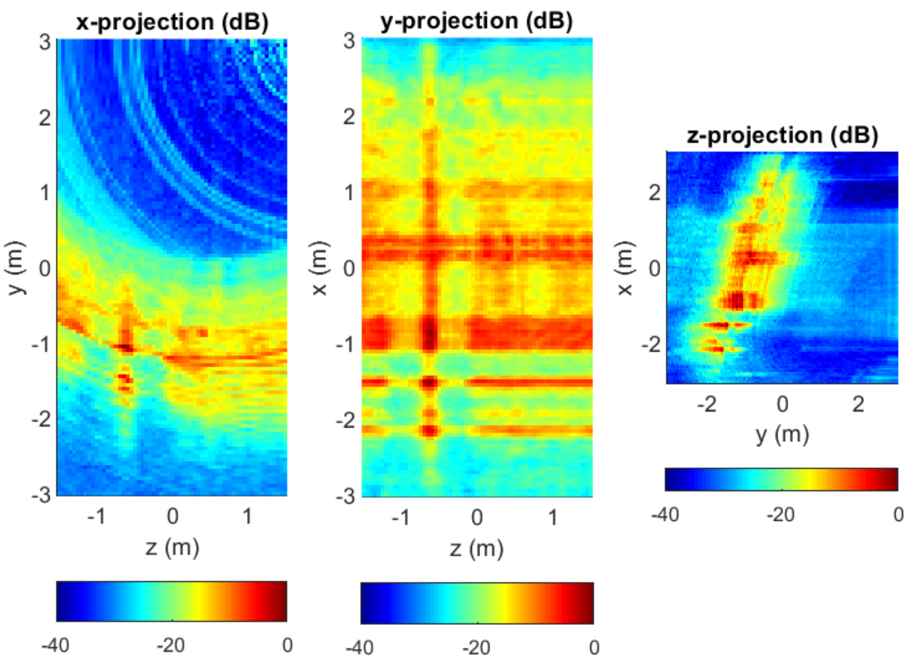


Repeat Linear pass

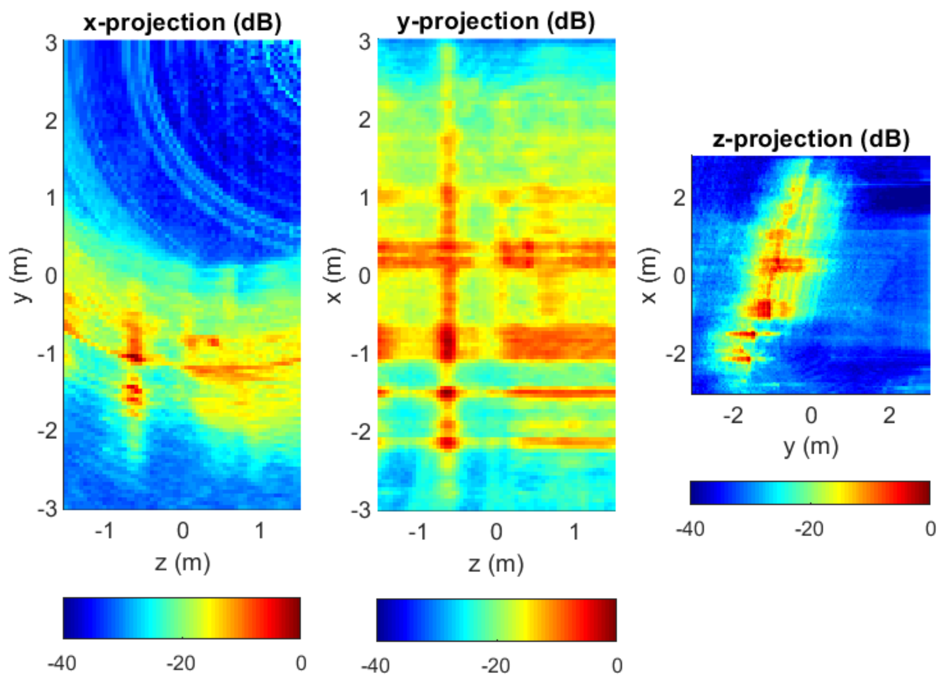




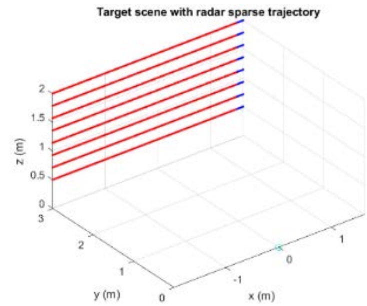
Sparse RL
6 passes, bg-s



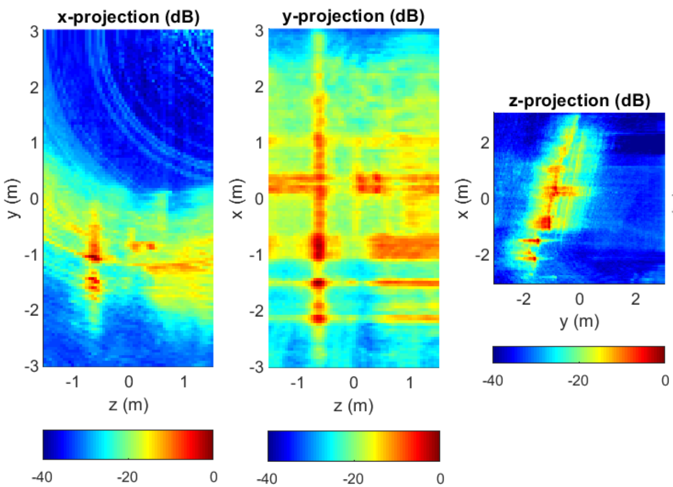
Sparse RL
8 passes, bg-s



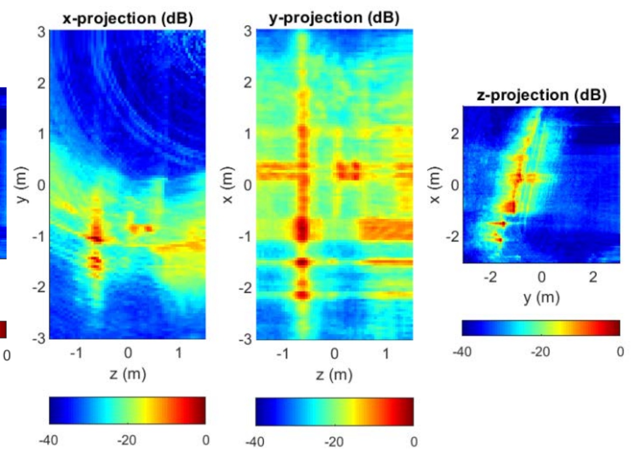
Repeat Linear pass



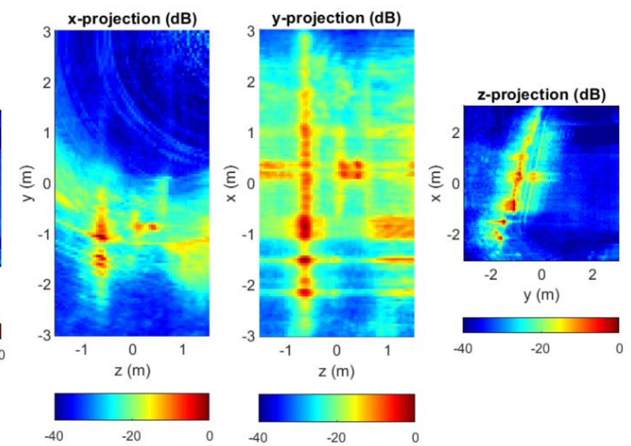
Sparse RL 10 passes bg-s



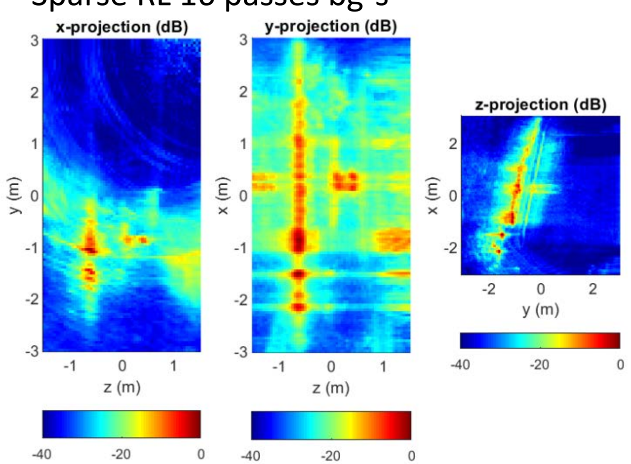
Sparse RL 12 passes bg-s



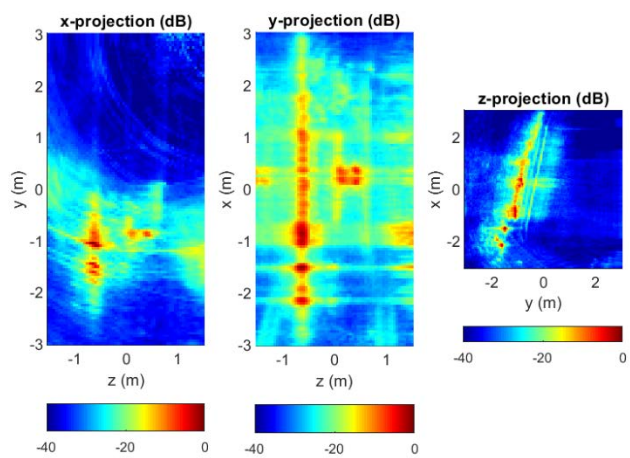
Sparse RL 14 passes bg-s



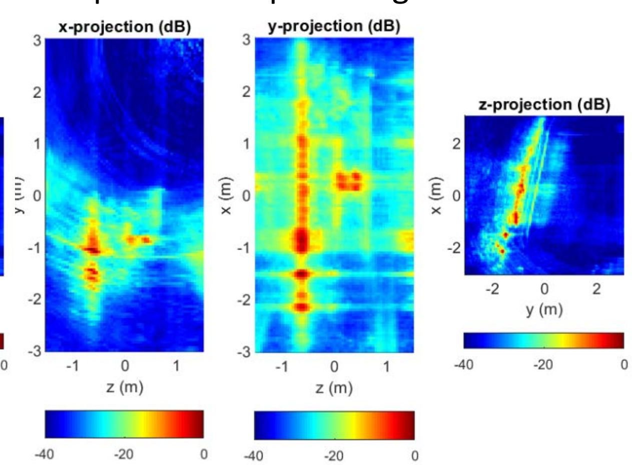
Sparse RL 16 passes bg-s



Sparse RL 18 passes bg-s



Sparse RL 20 passes bg-s



Nyquist Sampling

(1) Vertical Nyquist sampling: $\theta_s f_c = c / (2 L_z)$

(2) Range-angle: $z_d = R \theta_s$

(3) Vertical Aperture division: $z_d = A_z / (N_z - 1)$

Combining: $A_z / (N_z - 1) = R \theta_s = R c / (2 L_z f_c)$

$N_z = 2 A_z f_c / (R c) L_z + 1$

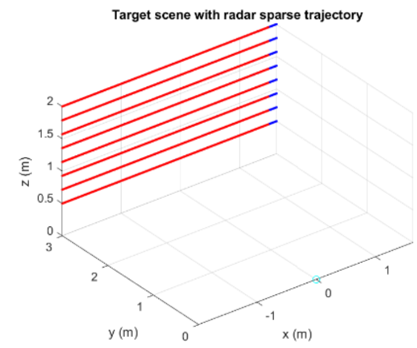
$N_z = B L_z + 1$

Setting: $A_z = 1.5\text{m}, f_c = 3.5\text{GHz}, R = 4\text{m}, c = 0.3\text{Gm/s}$

$B = 2*1.5*3.5/4/0.3 = 8.75$

$\underline{N_z = 8.75 L_z + 1}$

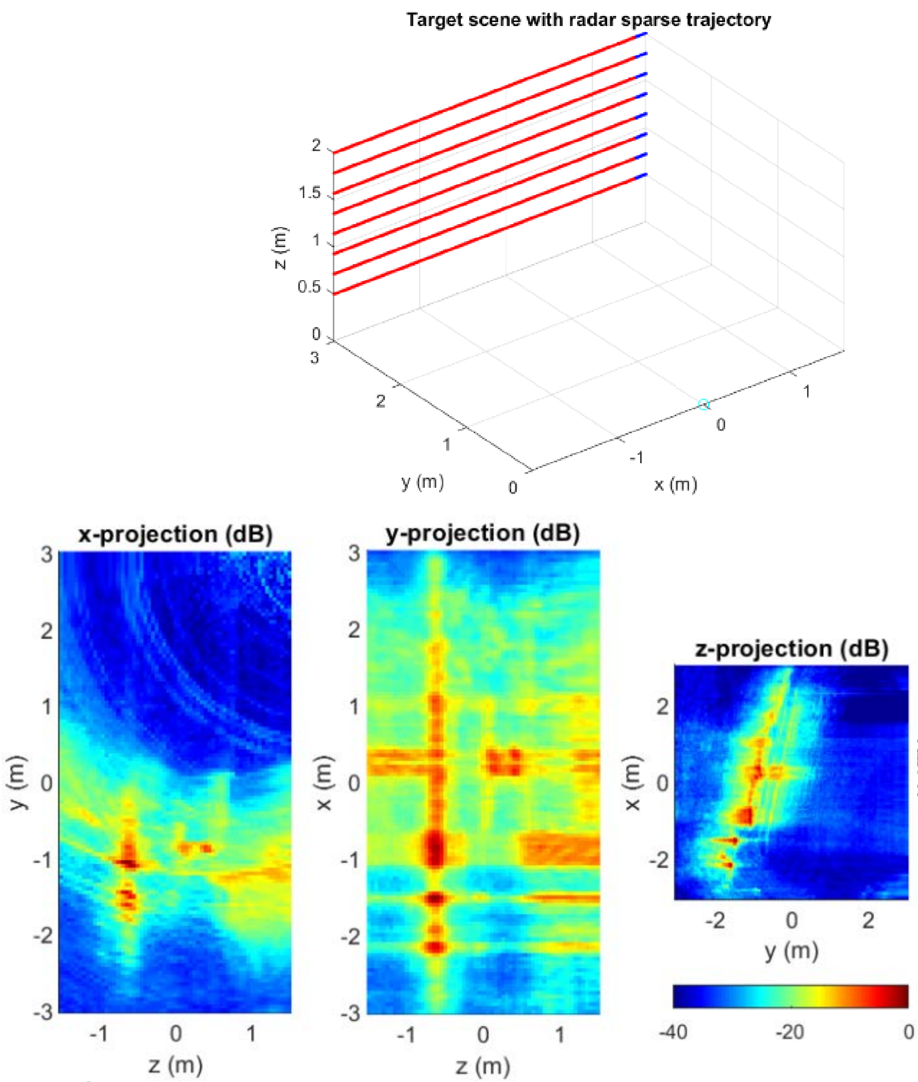
Cell = 5



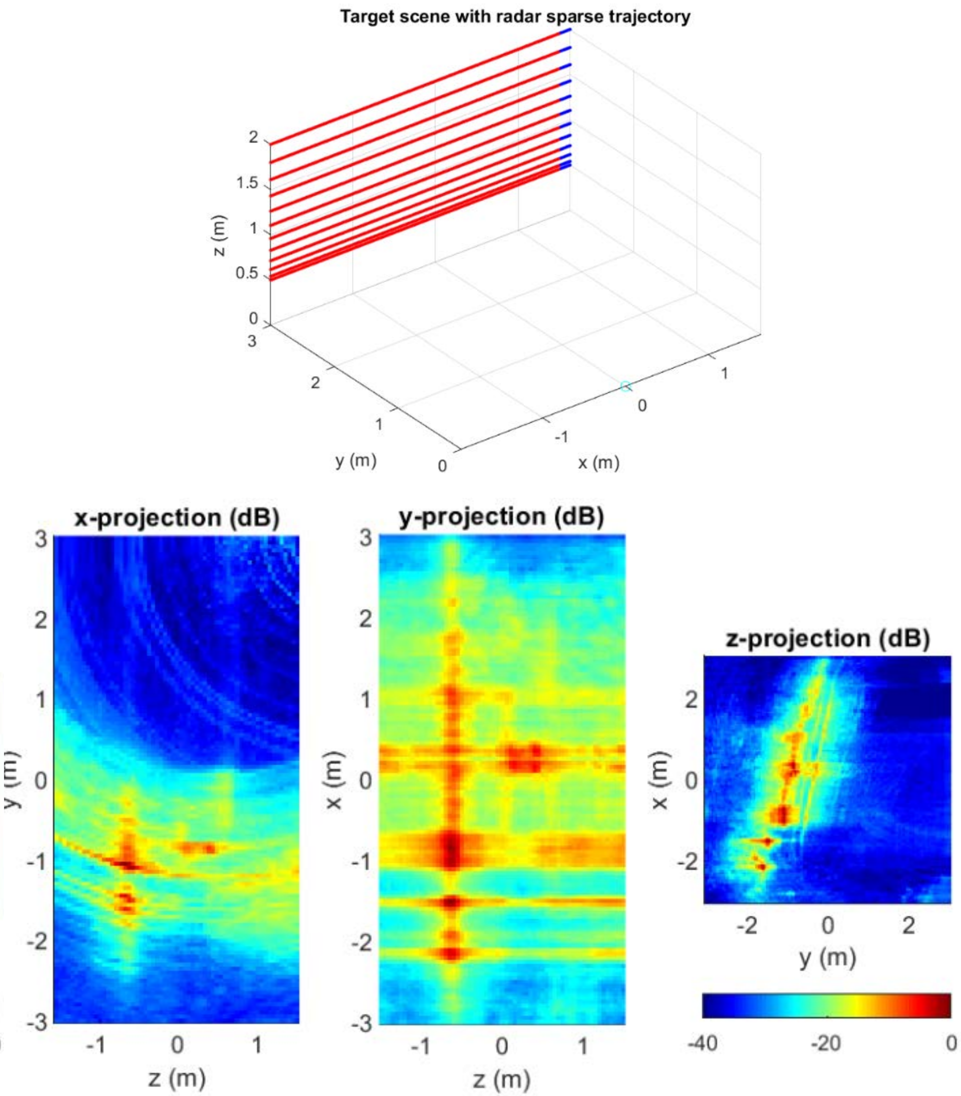
Lz (m)	Nz (frac)	Nz
0.5	5.4	6
1	9.8	10
1.5	14.1	15
2	18.5	19
2.5	22.9	23

Repeat linear pass, nonlinear in height

To attempt to spread aliased energy, try nonlinear spacing in height

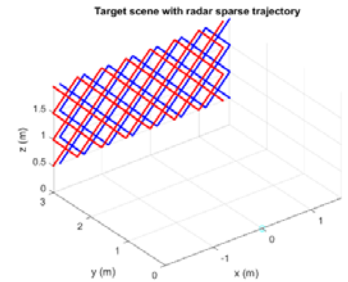


12 passes

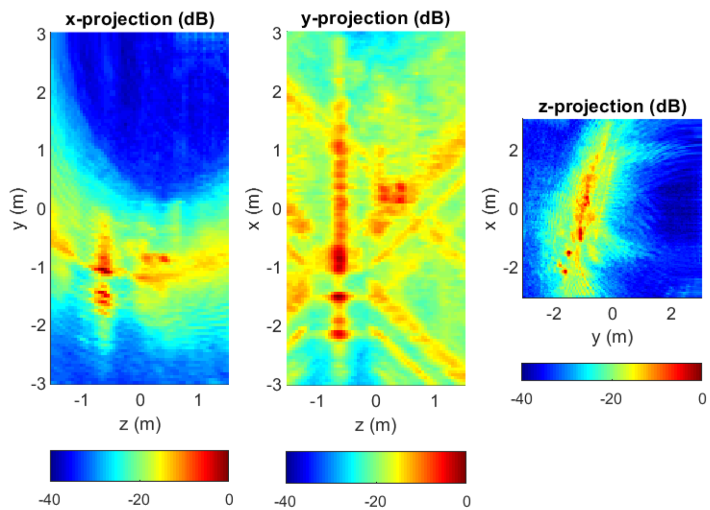


12 passes Nonlinear spacing in height

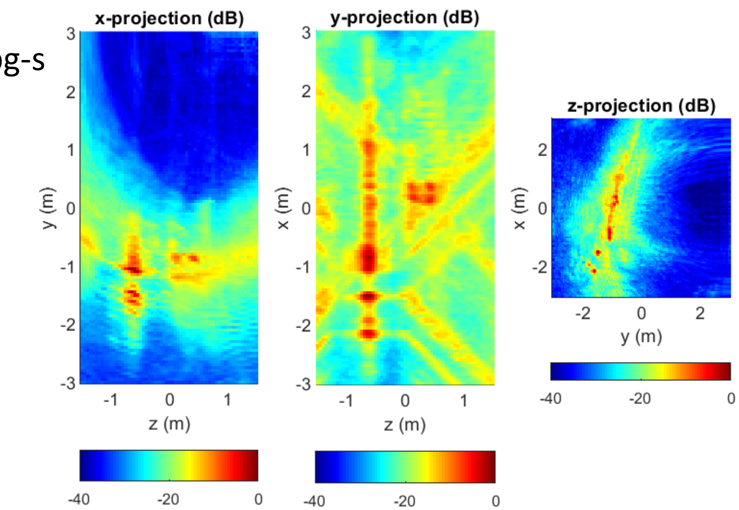
Crossed Linear pass



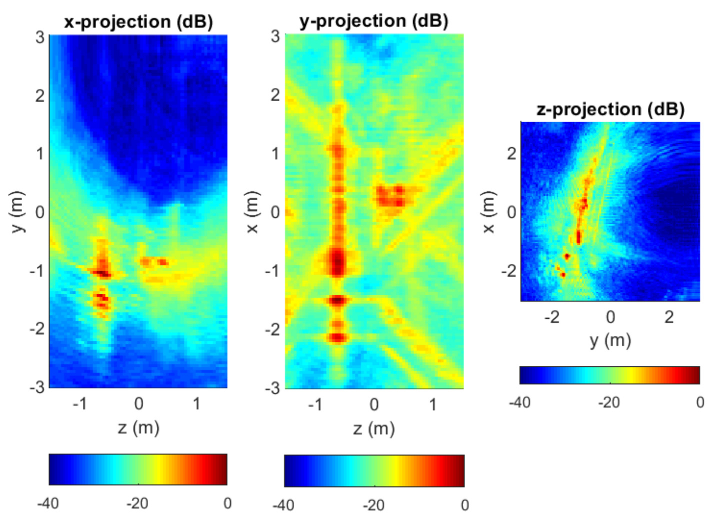
C=1 NY=5 bg-s



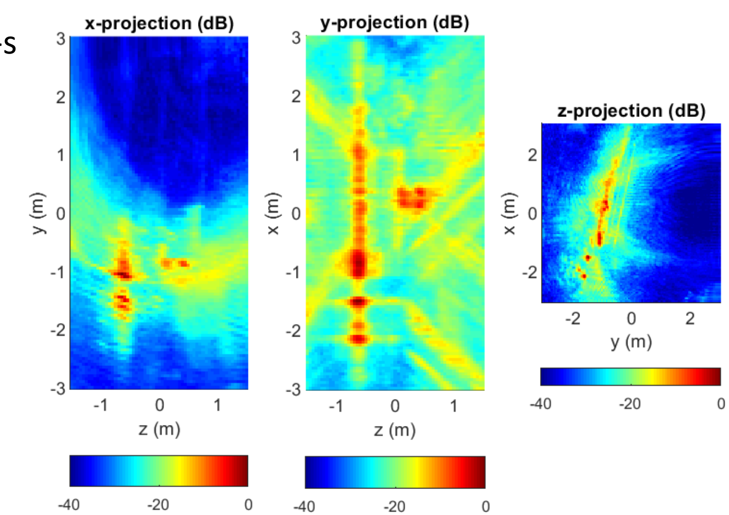
C=1 NY=6 bg-s



C=1 NY=7 bg-s



C=1 NY=8 bg-s



Nyquist Sampling

(1) diagonal Nyquist sampling: $\theta_s f_c = c / (2 L_d)$

(2) Range-angle: $l_d = R \theta_s$

(3) Vertical Aperture division: $l_d = A_d / (N_d - 1)$

Combining: $A_d / (N_d - 1) = R \theta_s = R c / (2 L_d f_c)$

$N_d = 2 A_d f_c / (R c) L_d$

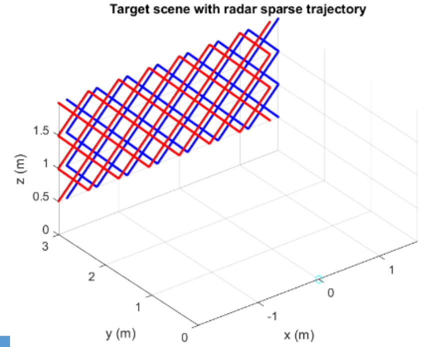
$N_d = B L_z$

Setting: $A_d = 1.5/\sqrt{2}=1.1{=}m$, $f_c = 3.5GHz$, $R = 4m$, $c = 0.3Gm/s$

$B = 2*1.5*3.5/4/0.3 = 6.19$

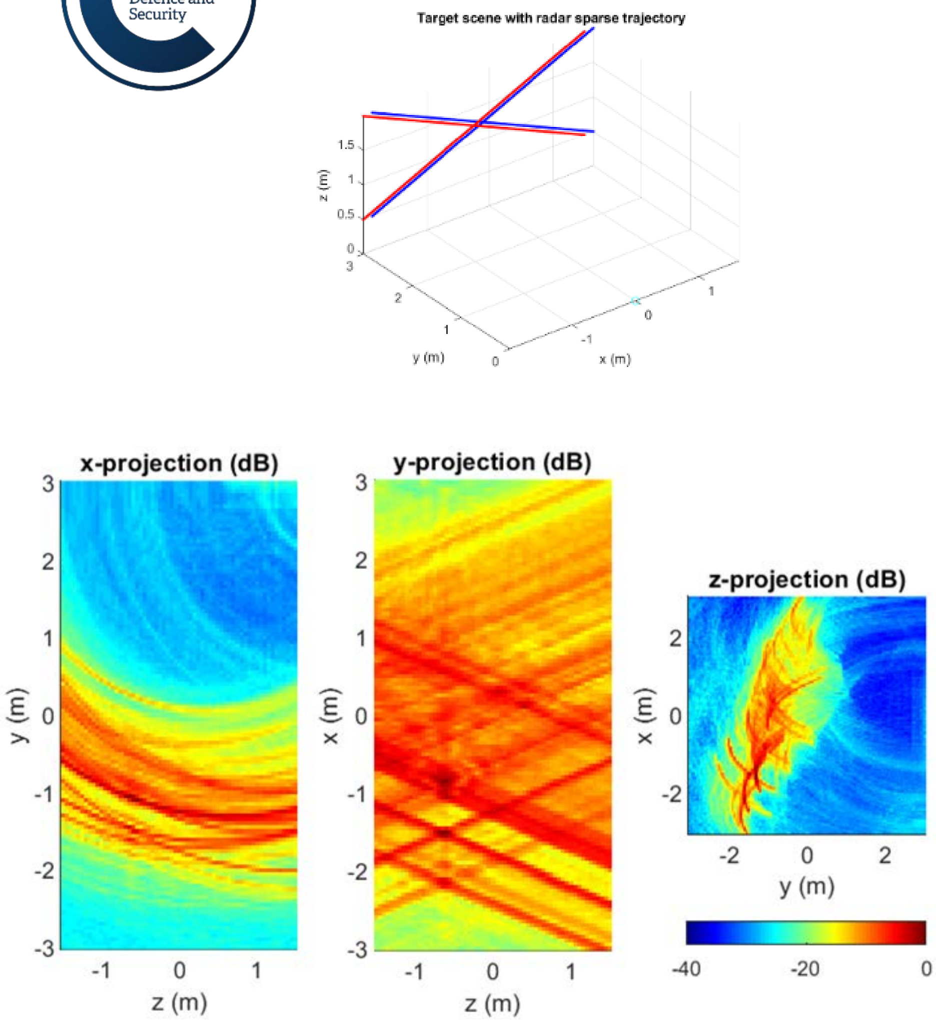
<u>$N_z = 6.19 L_z$</u>

Cell = 1

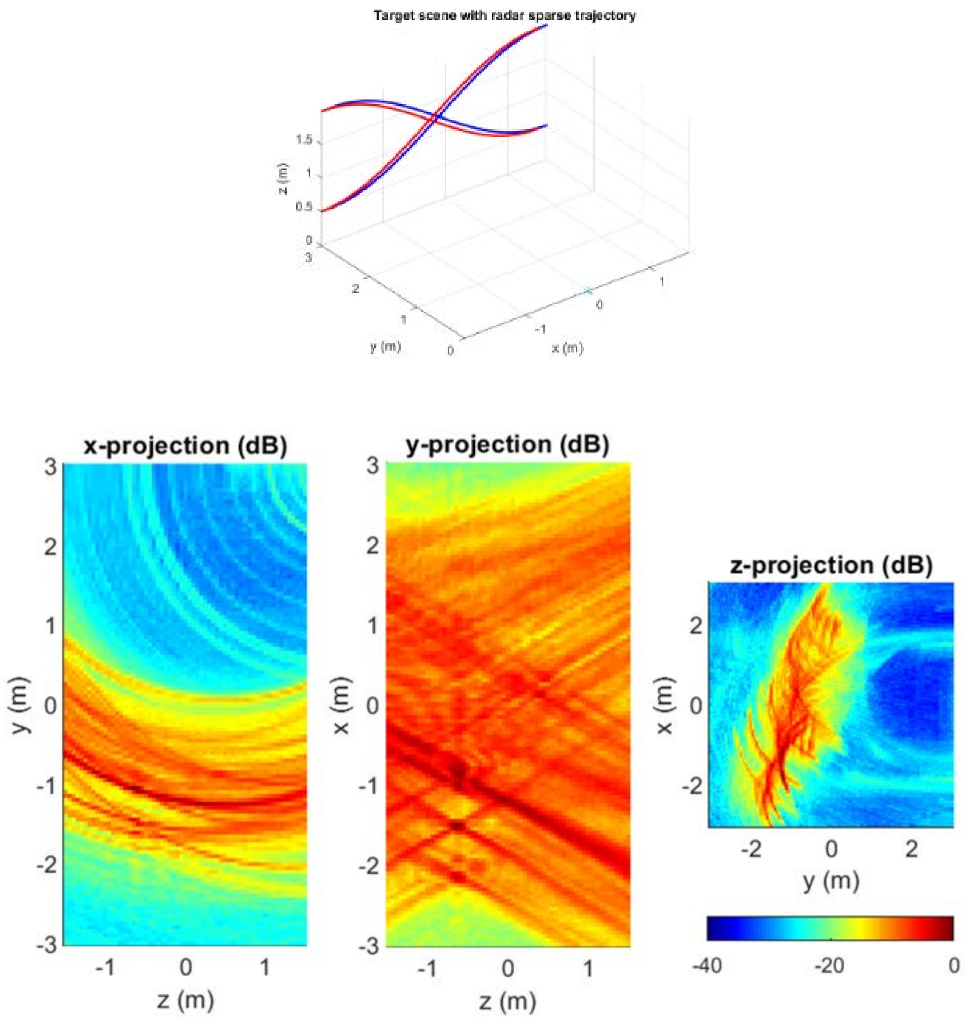


Ld (m)	Nd (frac)	Nd
0.5	3.1	4
1	6.2	7
1.5	9.3	10
2	12.4	13
2.5	15.5	16
3	18.6	19
3.5	21.7	22

Crossed Linear and Sinusoid pass

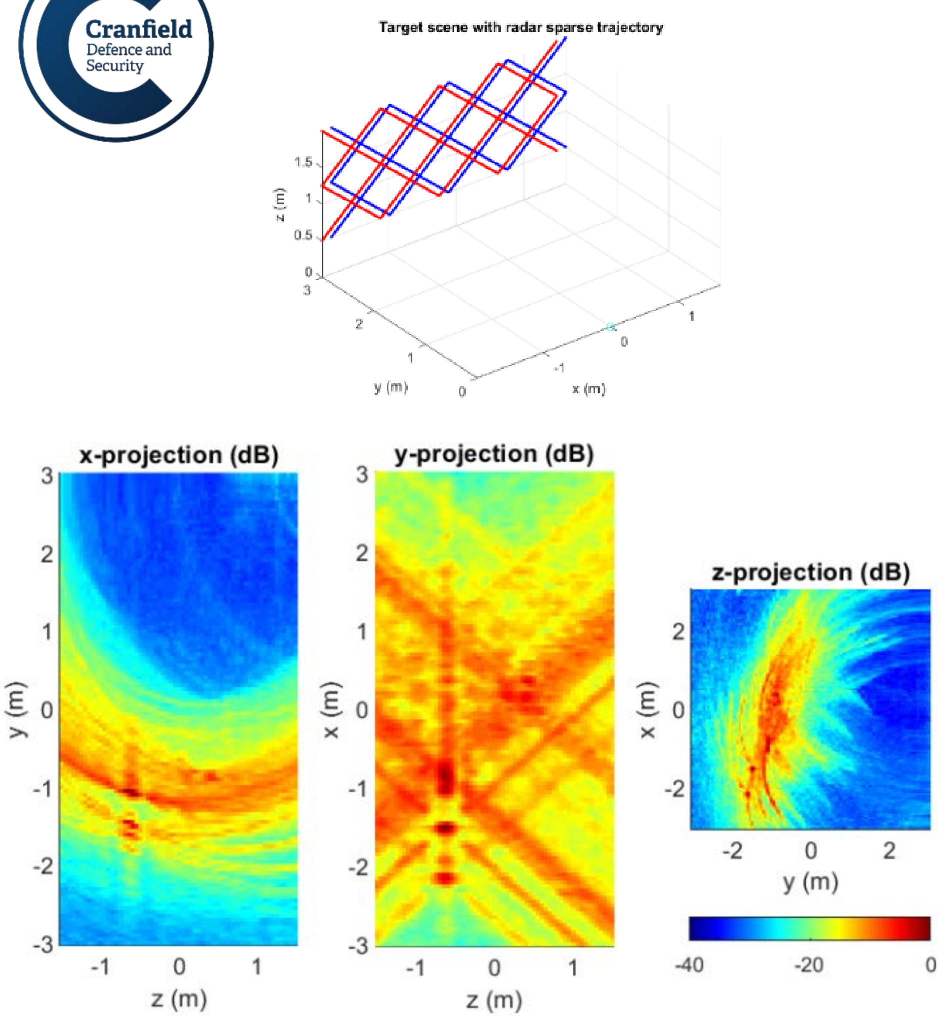


Sparse CL 2 passes

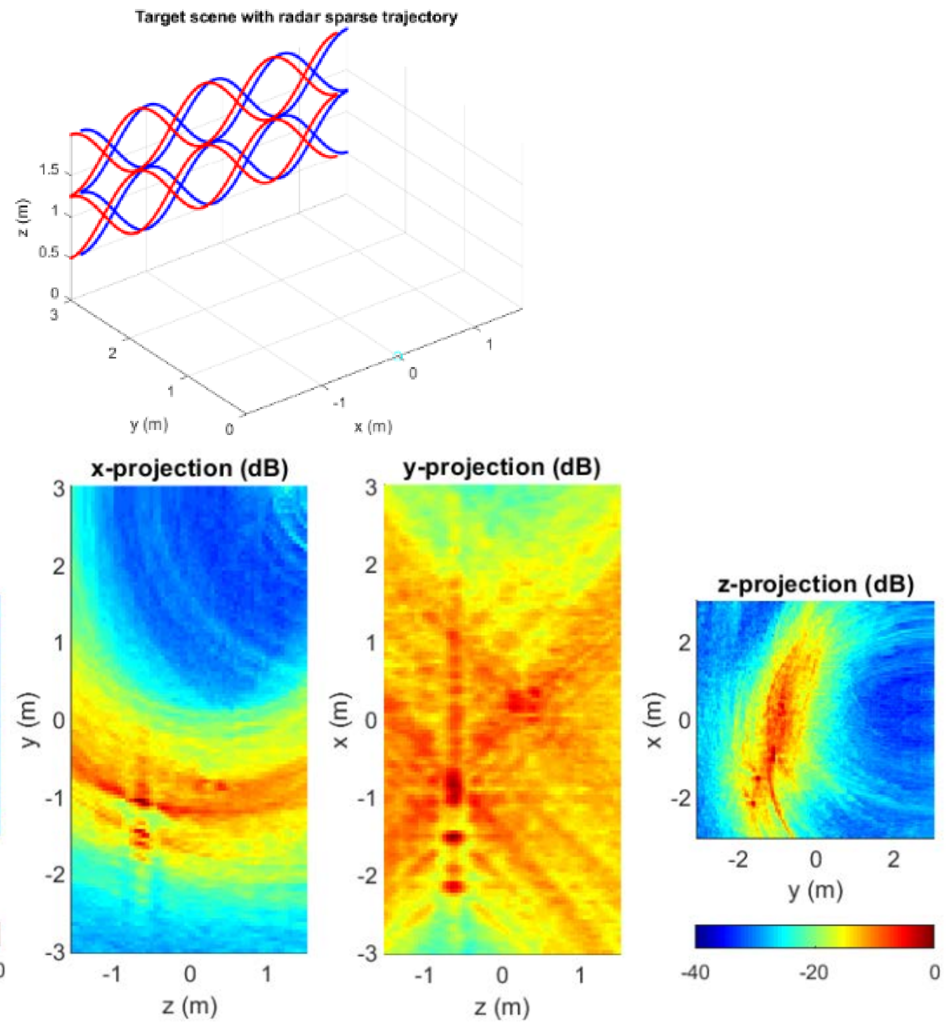


Sparse CS 2 passes

Crossed Linear and Sinusoid pass

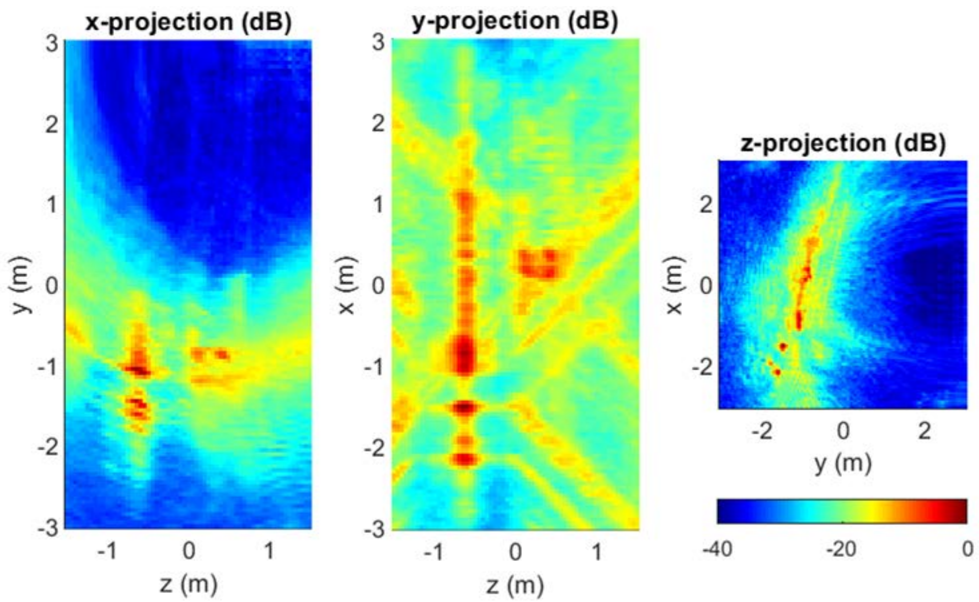


Sparse CL 4 passes 2*4 crosses

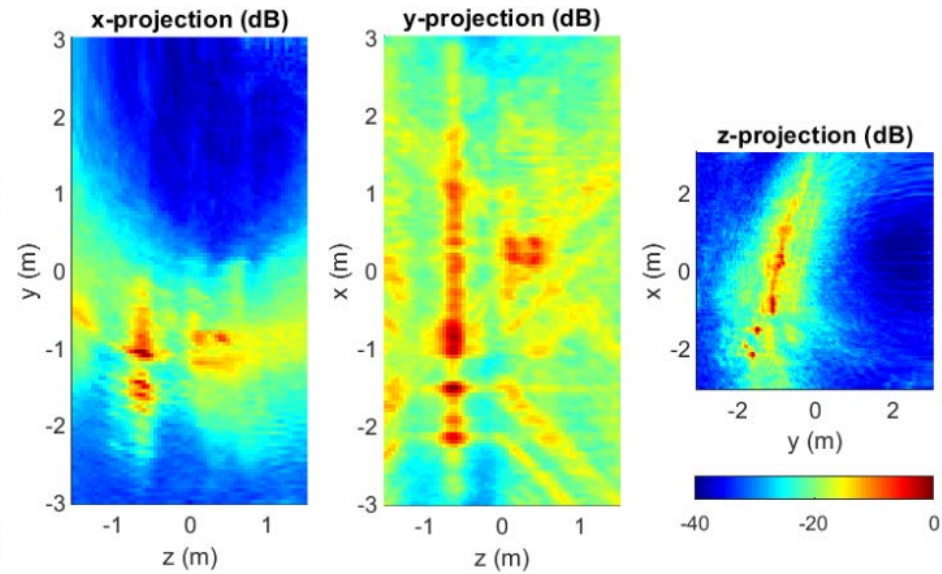


Sparse CS 4 passes 2*4 crosses

Crossed Linear and Sinusoid pass

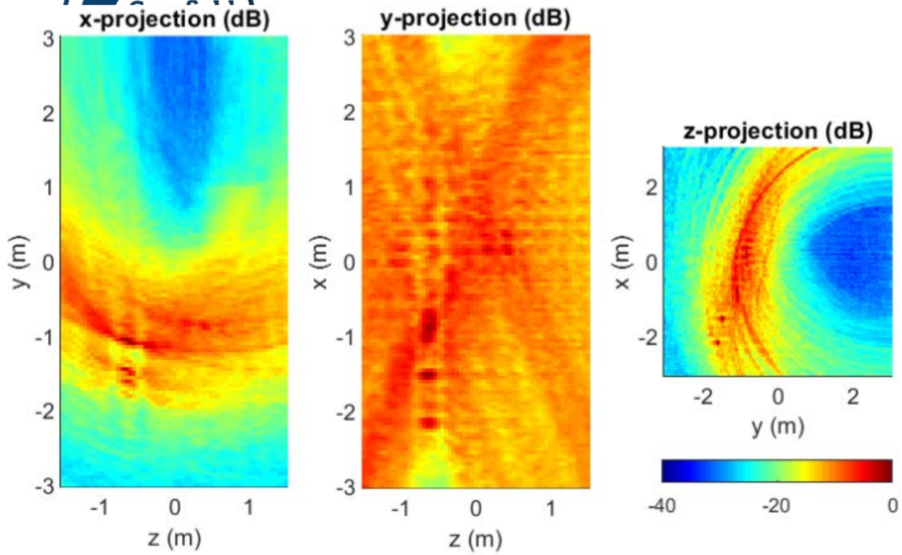


Sparse CL 12 passes 6*14 crosses

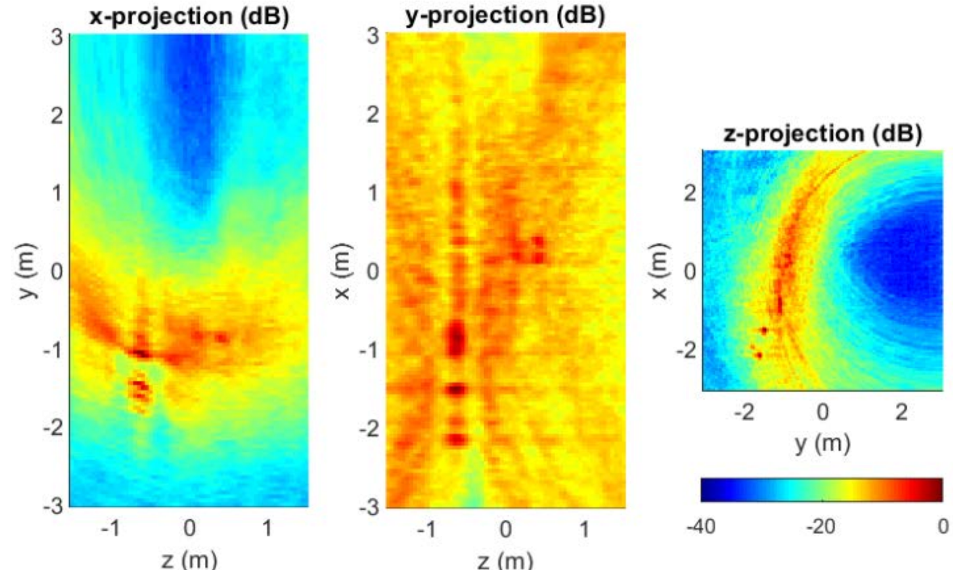


Sparse CS 12 passes 6*14 crosses

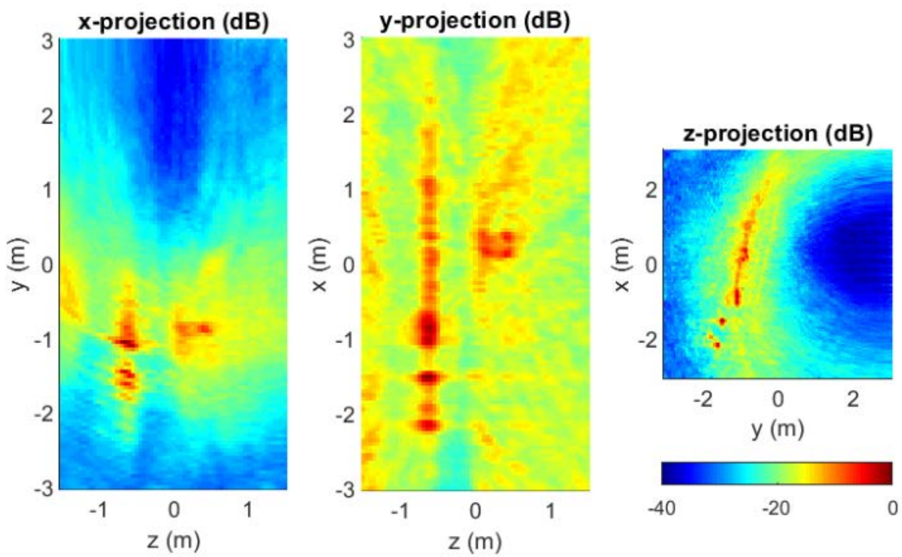
Repeat sinusoid pass



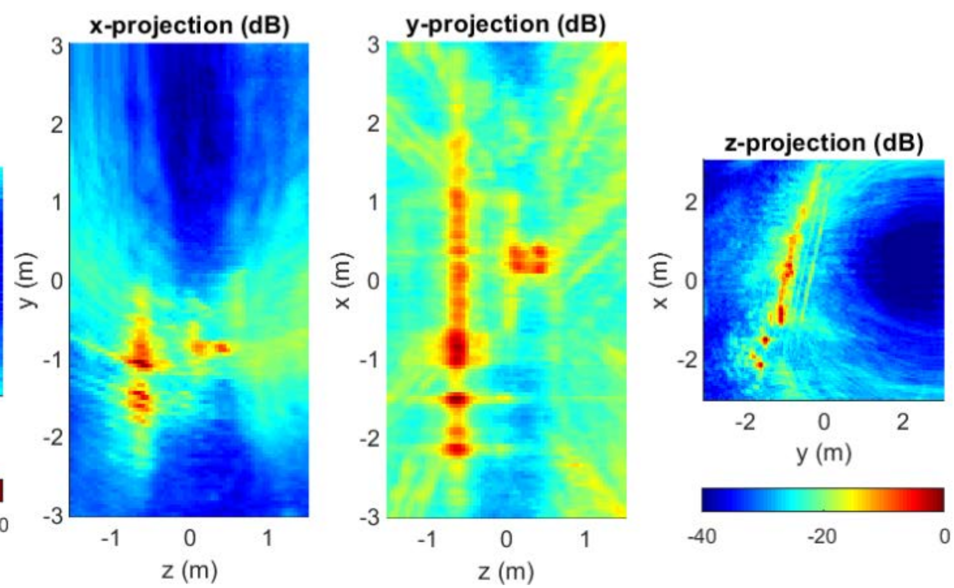
Sparse RS, 2 pass, 4 sinusoids/pass



Sparse RS, 3 pass, 9 sinusoids/pass

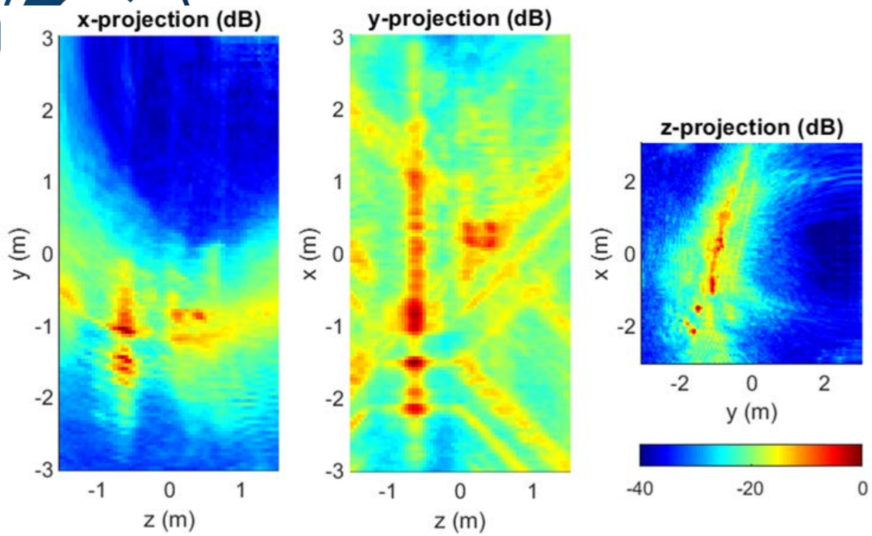


Sparse RS, 6 pass, 14 sinusoids/pass

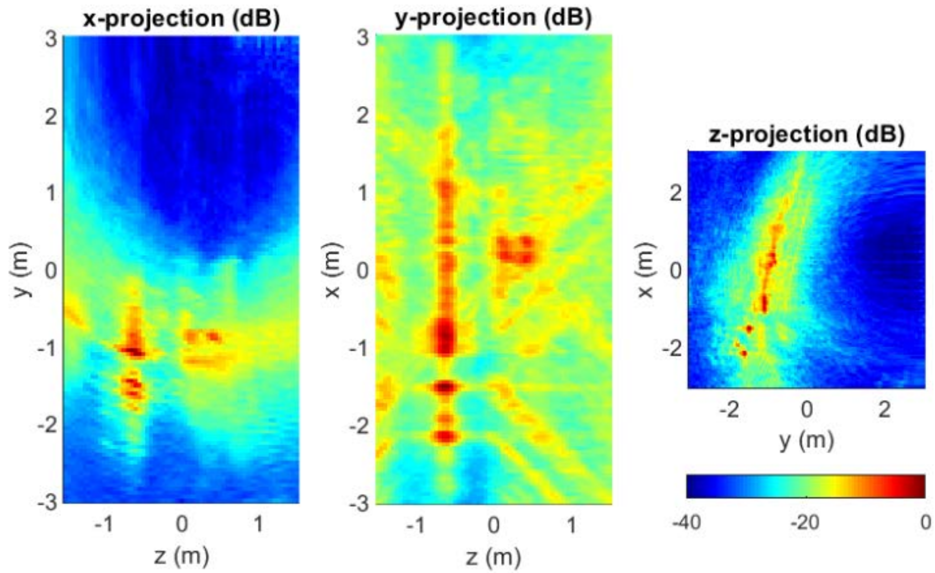


Sparse RS, 12 pass, 28 sinusoids/pass

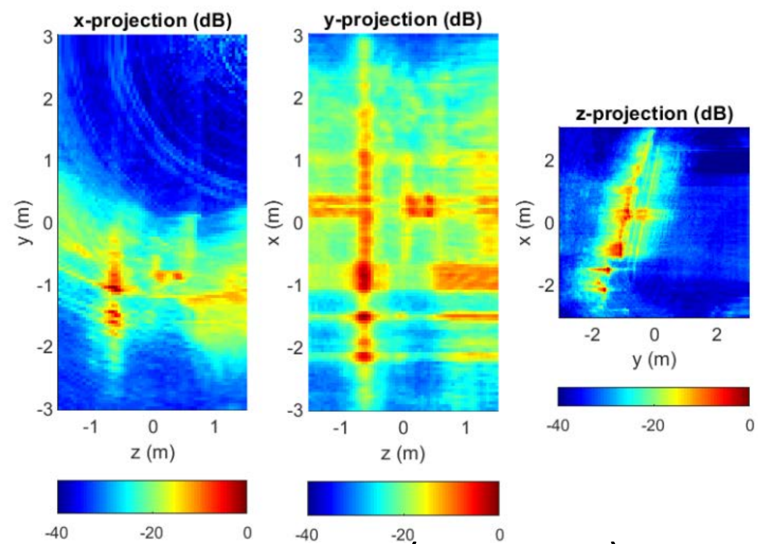
Comparison of 12 pass casses



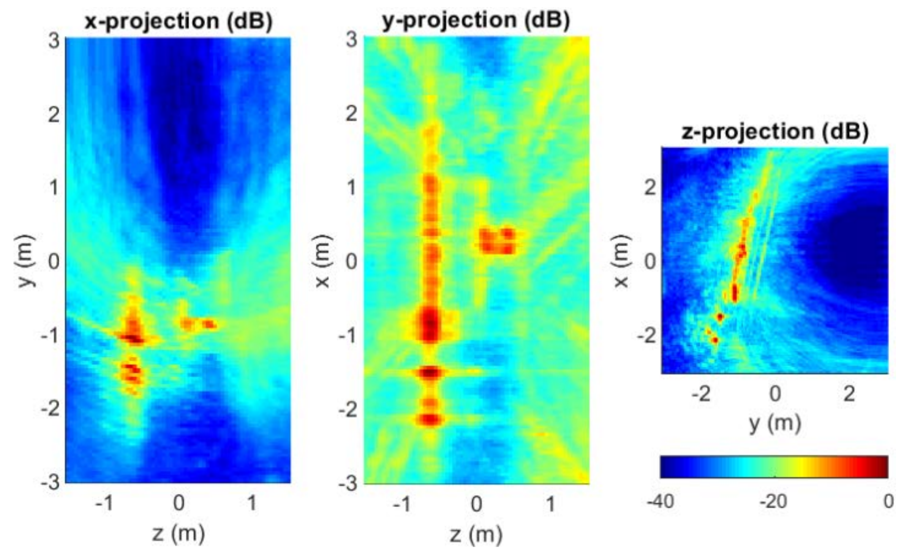
Sparse CL 12 passes 6*14 crosses



Sparse CS 12 passes 6*14 crosses



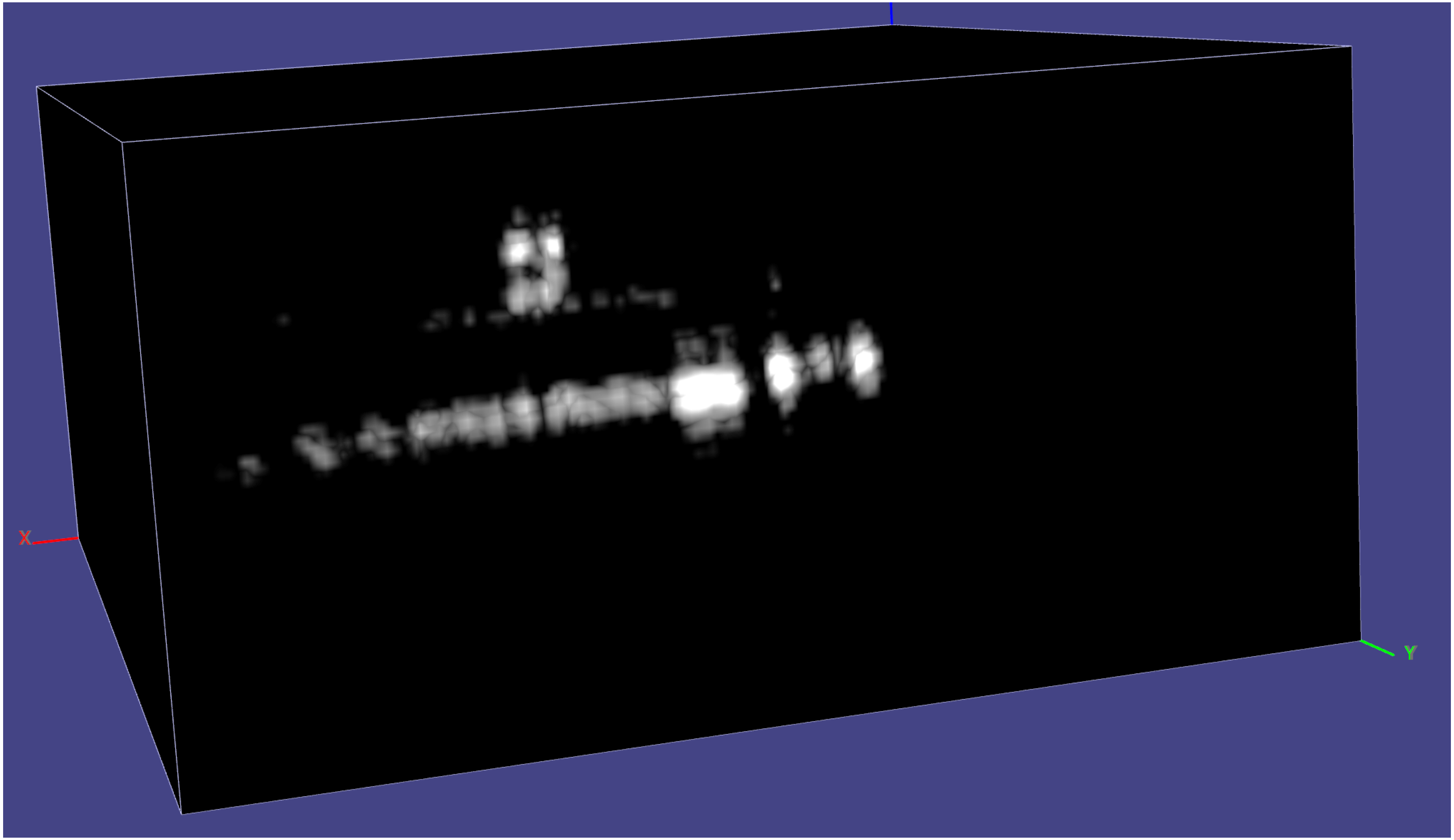
Sparse RL NY=6 (12 passes)



Sparse RS, 12 pass, 28 sinusoids/pass

12 repeat sinusoid pass

12 repeat sinusoids, giving at least **15dB** artefact free dynamic range



Conclusion

- The resolution is mostly set by the overall aperture sizes;
- However aliased energy is dependent on the density of trajectories.
- If the aliased energy is spread out, then the max intensity of the aliased energy is reduced, giving an artefact free dynamic range.
- Crossed linear trajectories lead to spreading out of energy.
    - Curved crosses lead to further spreading out.
- The repeat pass sinusoid path seems to spread aliased energy the most, such that the higher the density of trajectory, the larger the artefact free dynamic range.
- No doubt many other useful sparse trajectories exist, and the key seems to be to spread out aliased energy.

Dr Dan Andre
d.andre@cranfield.ac.uk