ROYAL ACADEMY OF ENGINEERING

Engineering Alloys

DEPARTMENT OF MATERIALS

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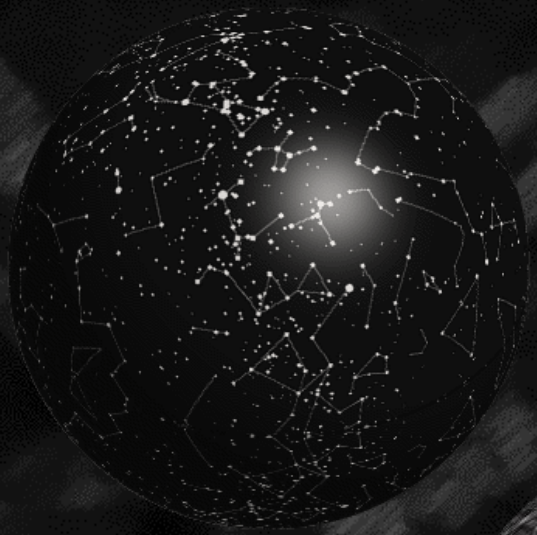

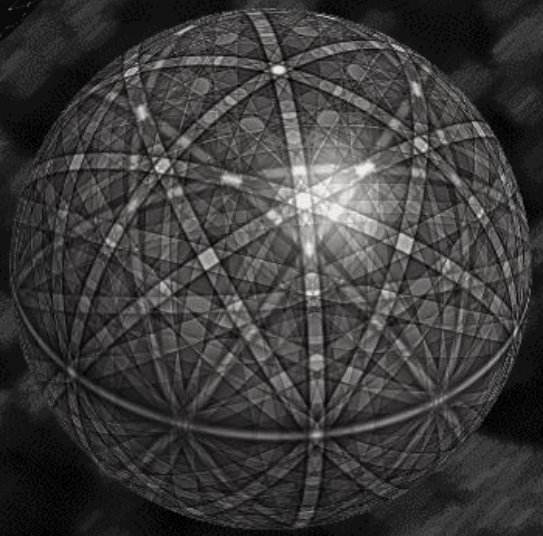

AstroEBSD: EXPLORING NEW SPACE IN PATTERN INDEXING WITH METHODS LAUNCHED FROM AN ASTRONOMICAL APPROACH

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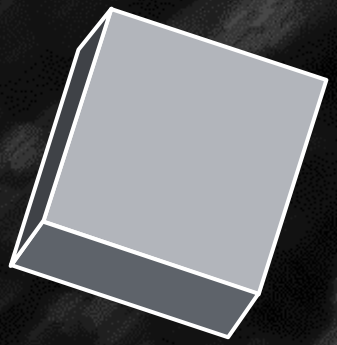
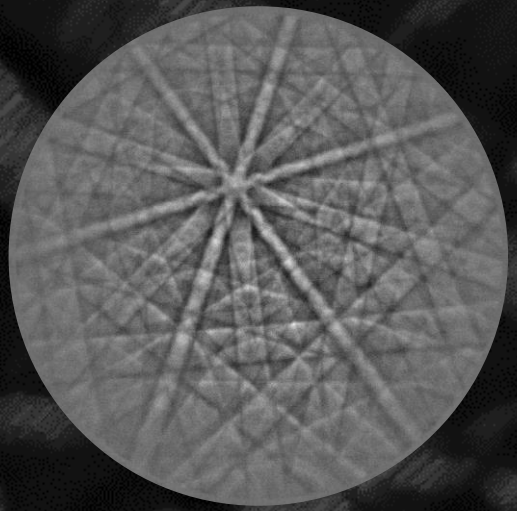
Figure from Wilkinson and Britton {2012} Materials Today

‘Hough’ based analysis

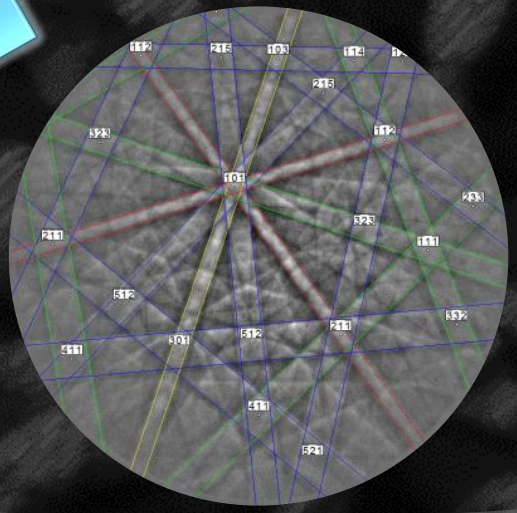
Crystal orientation



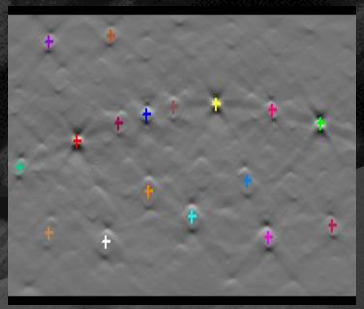
Raw copper pattern with background correction



Indexed pattern



Hough transform, with peaks identified



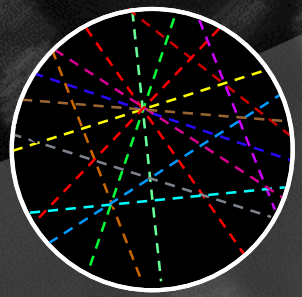


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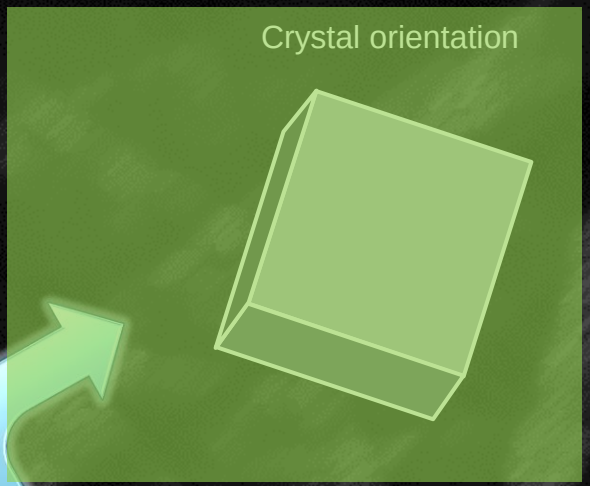
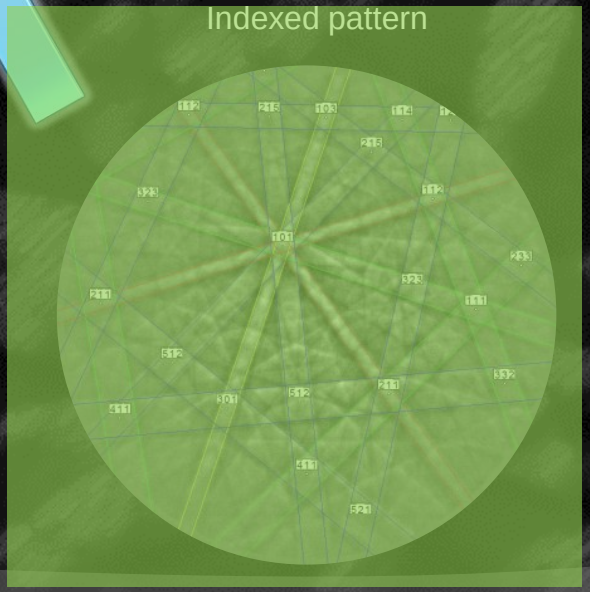
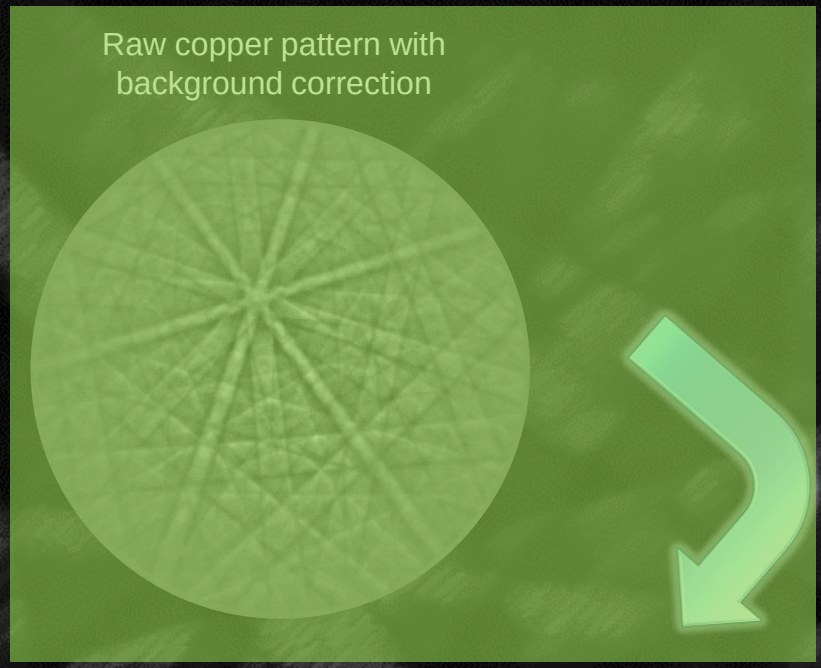
Figure from Wilkinson and Britton {2012} Materials Today

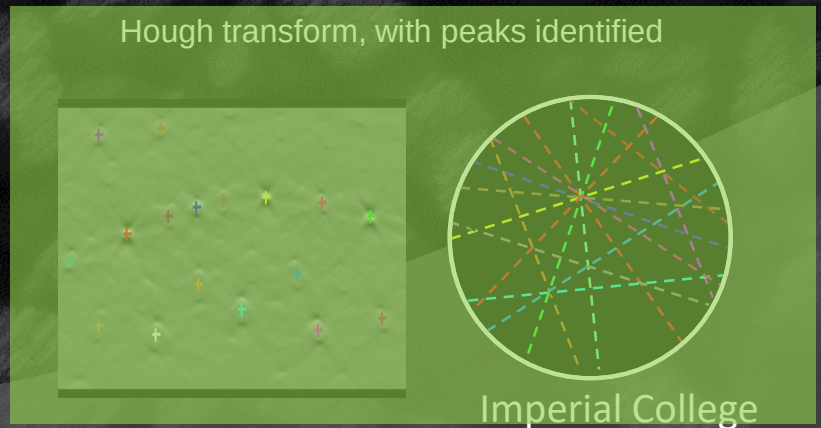
‘Hough’ based analysis





Can we go boldly?





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Indexing

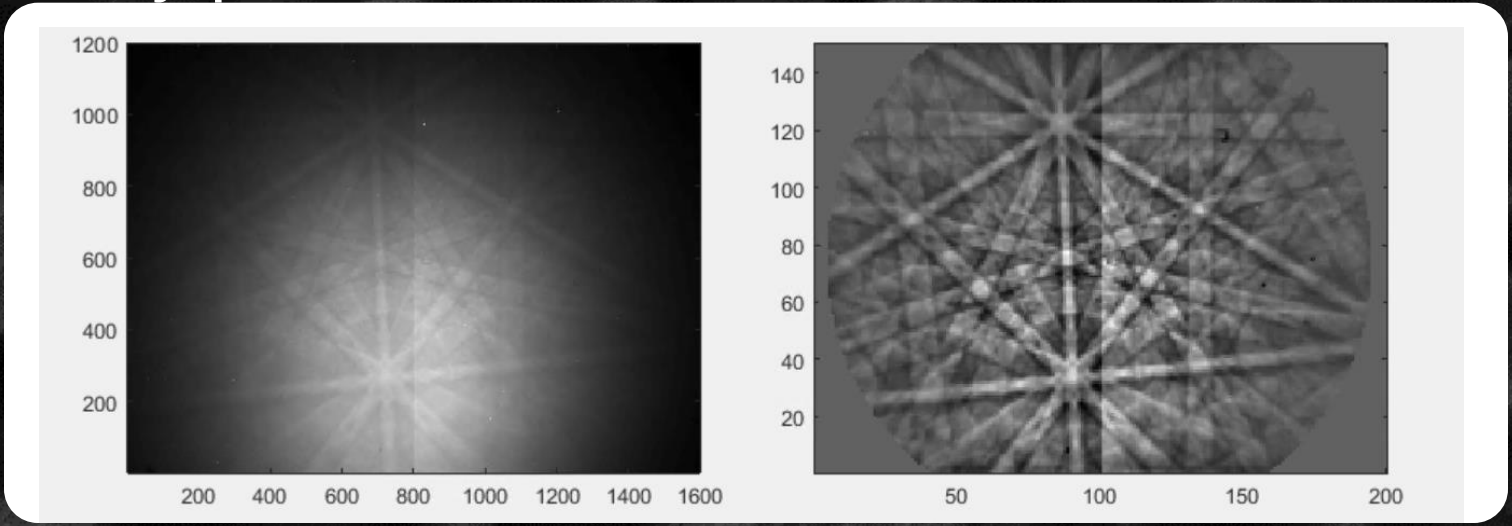
- Utilise conventional Hough/Radon approach
  - Quick & established
- Can utilise to develop confidence in orientations & pattern centres determined
- Enables independent EBSD analysis

AstroEBSD

- Matlab based – on GitHub:
  - http://astroebsd.expmicromech.com
- Based upon indexing star positions
  - Angles between stars = independent of satellite location
- Careful consideration of coordinate system, crystal symmetry
- Works on HDF5 format data sets {using BCF converter}

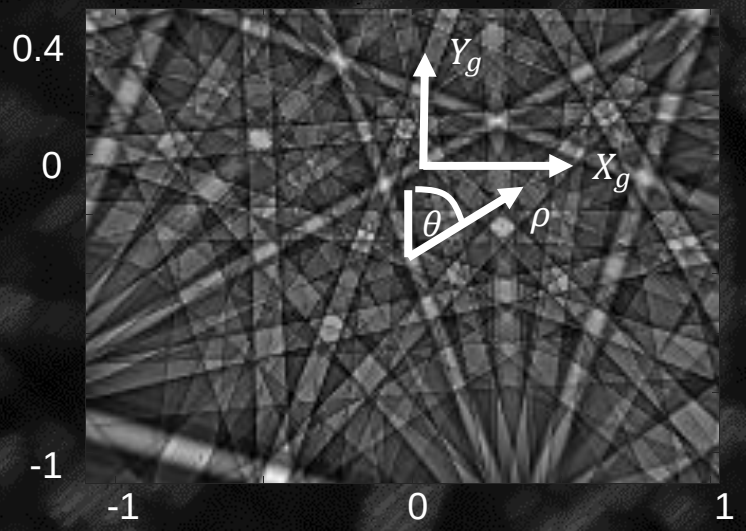
1. Background Correction

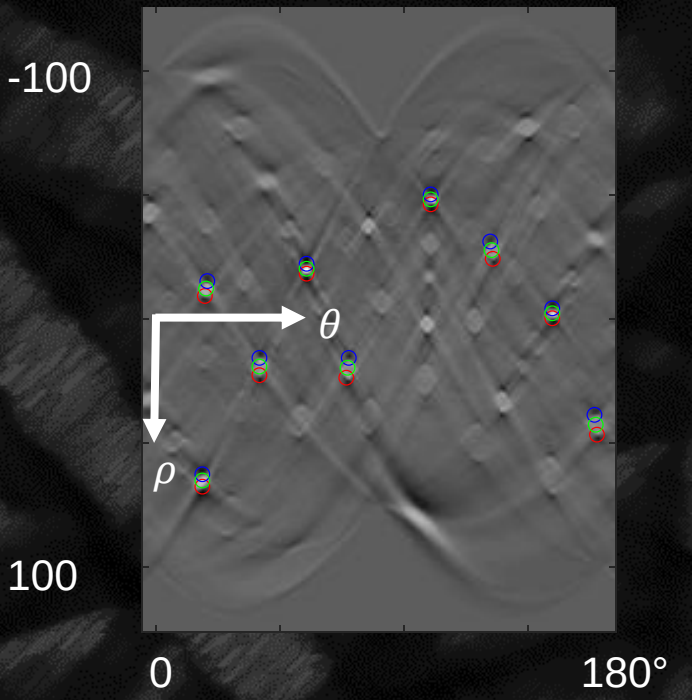
- Aim to generate radon transform of EBSD for easy peak identification



- Resize + Gauss flatten (low frequency filter) + crop
- Toolkit can perform also perform static & hot pixel corrections

2. Radon transform

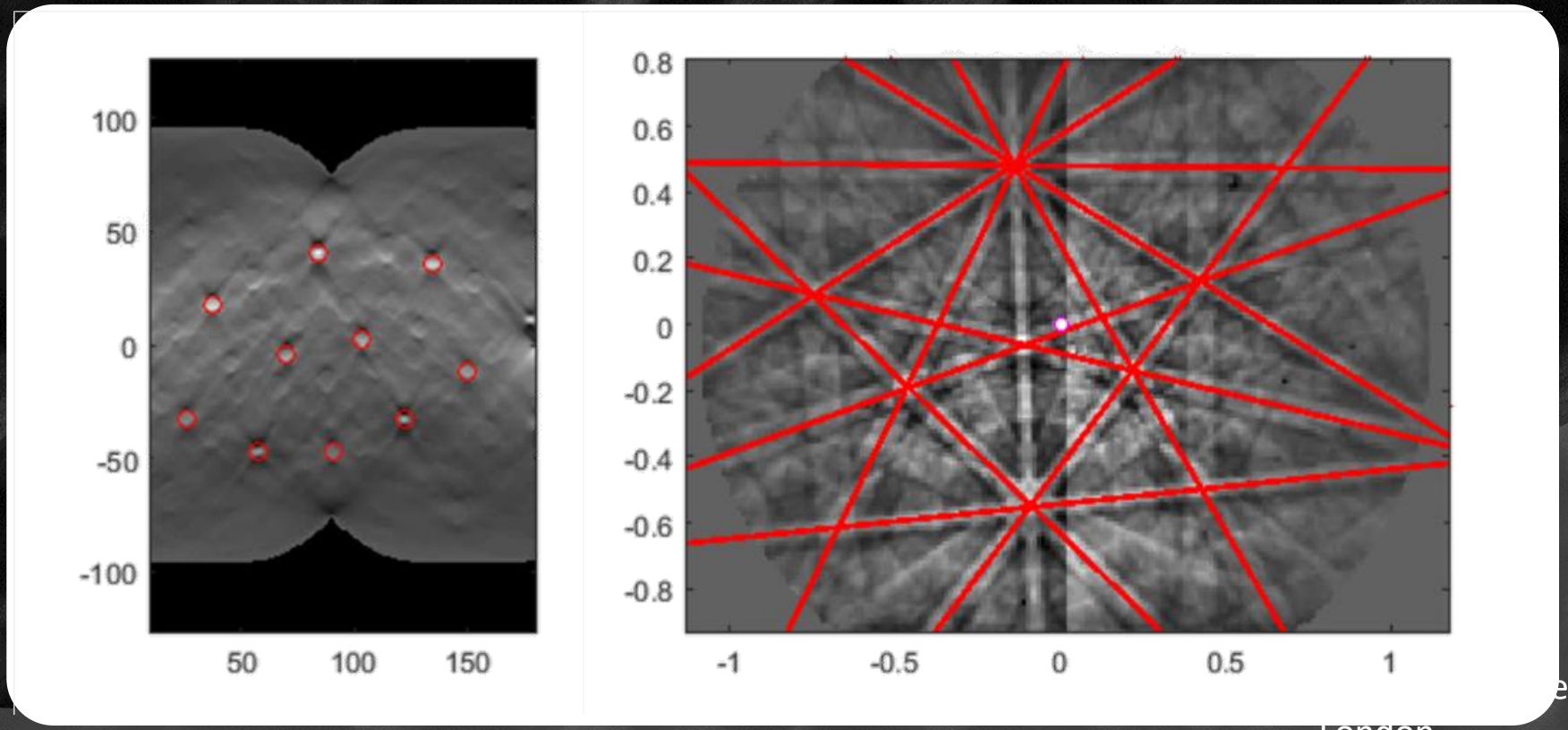




- Perform radon transform in matlab
  - ρ = from resize
  - θ = fixed step size used
- Care with coordinate systems

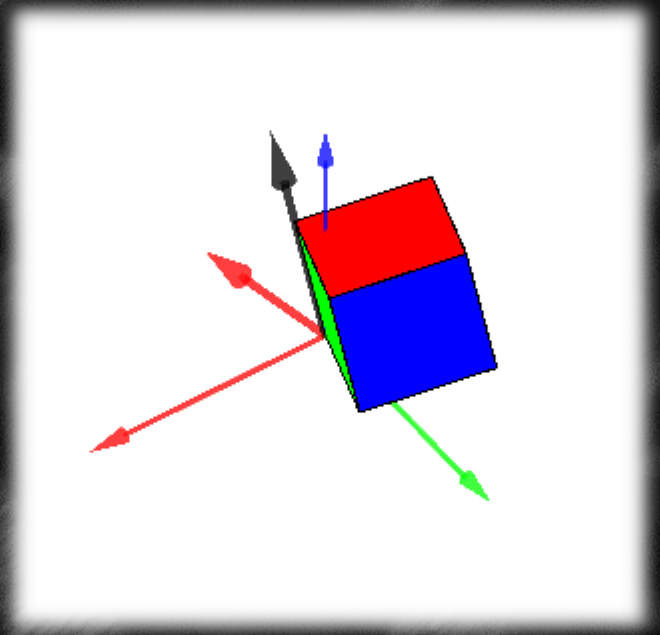
3. Peak ID

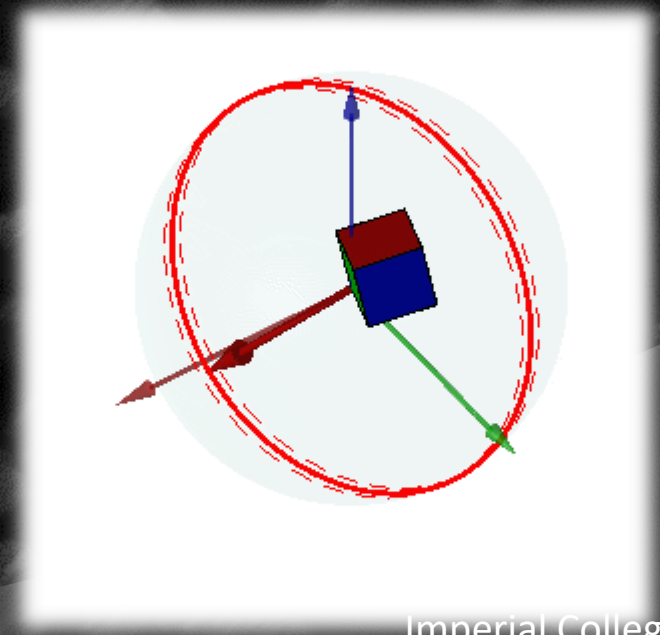
- Find edges {in ρ} → find centres
- Plot centres & back transform

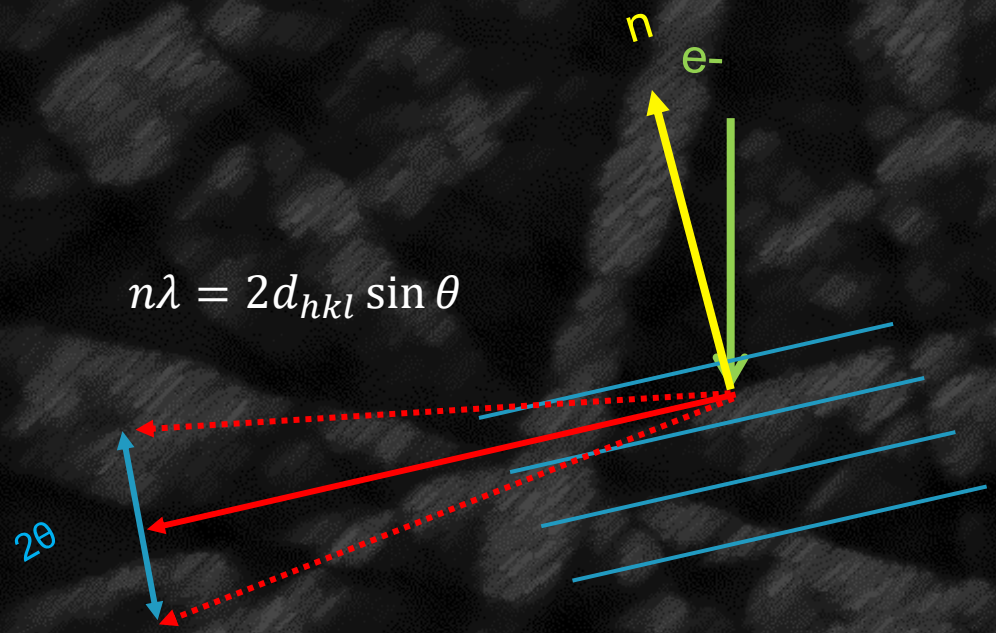


4. Indexing

- Each band has a characteristic plane normal







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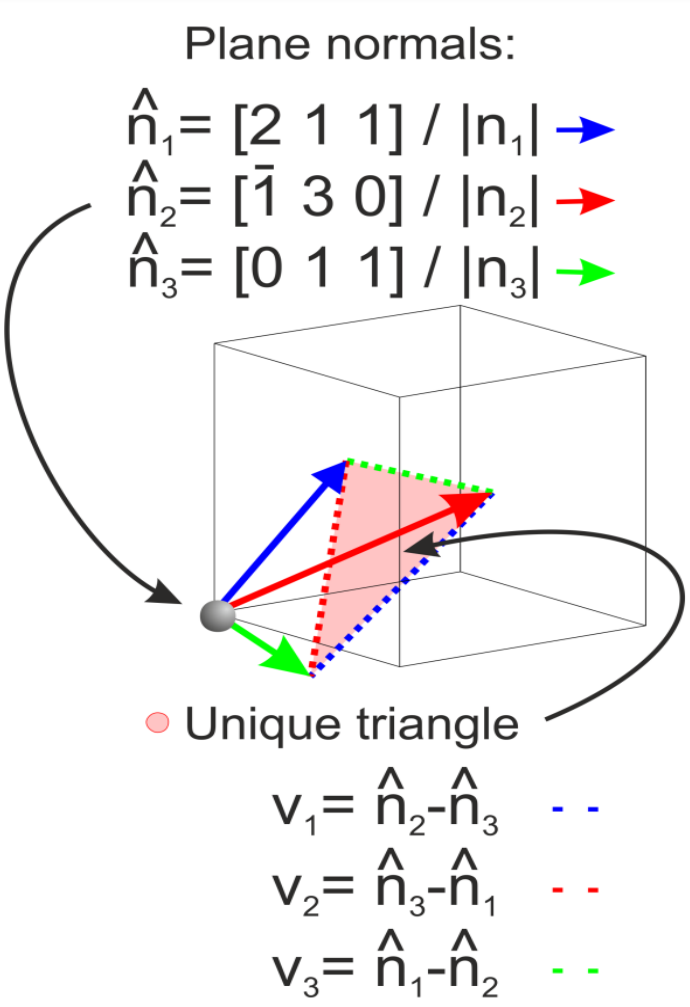
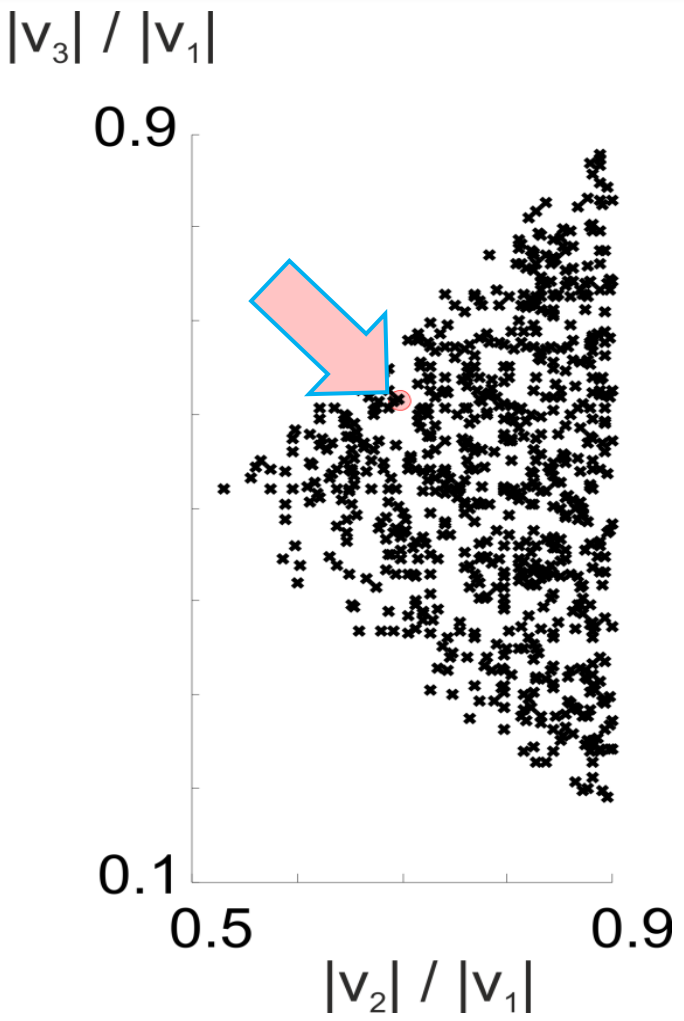
4. Indexing

- Each plane on the screen linked to a normal vector
- Each normal = 1 ‘star’ in sky
- Calculate ‘characteristic triangles’ for star-based indexing

4. Indexing





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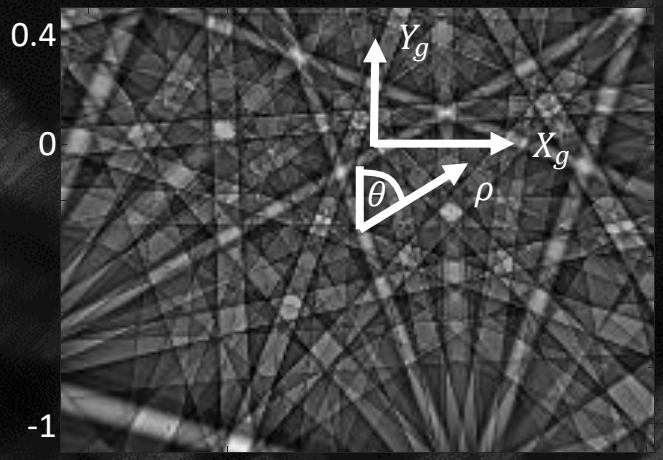
4. Indexing

- Symmetry in crystals complicated

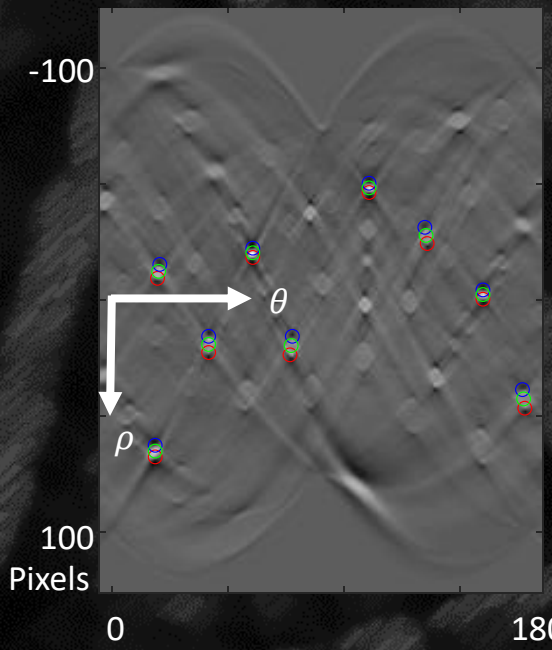
- Solve through:
  - ID plane family options {triangle search}
  - For each triangle → test potential fitting of indexing for whole pattern
  - Ascribe ‘best’ fitting index set
  - Flexible for ‘bad’ bands
    - Absent in LUT, incorrect

4. Indexing

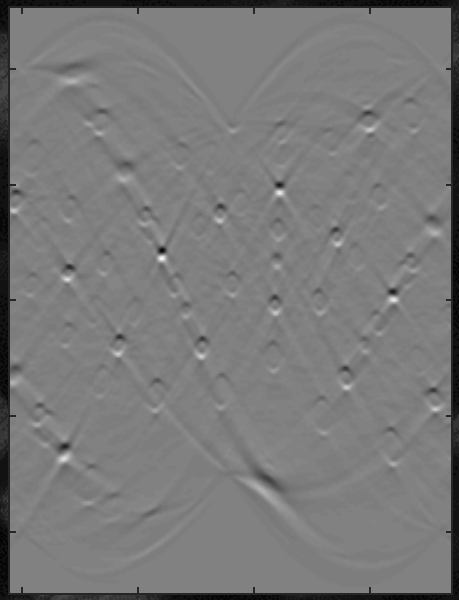
{a} Input Pattern & Coordinate Systems



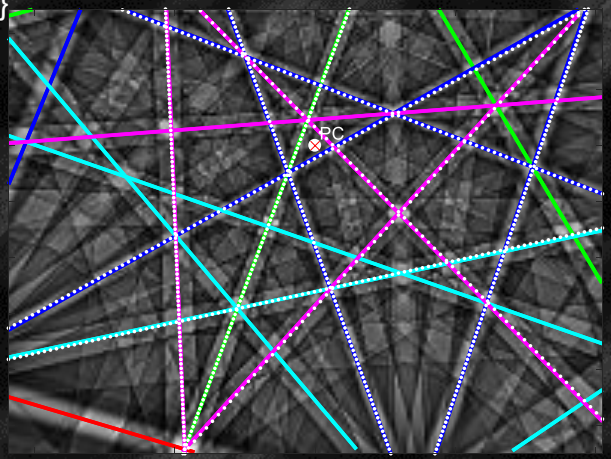
{b} Radon Transform, with Peaks



{c} Radon + ρ Edge Convolution

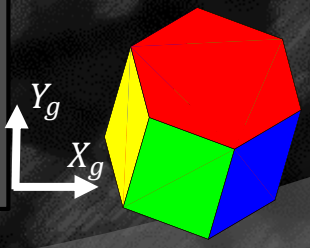


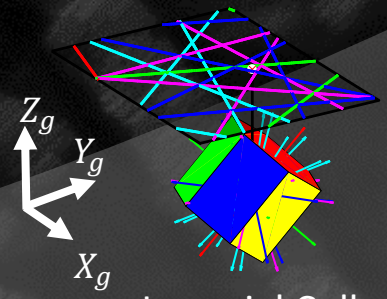
{d}



Detected
$\{0001\}$
$\{1\bar{2}10\}$
$\{10\bar{1}1\}$
$\{\bar{1}103\}$
$\{\bar{1}2\bar{1}2\}$

{e} Crystal Orientation: $(\phi_1, \Phi, \phi_2) = \{-16°, 140°, 36°\}$ [in detector frame]





Indexed Pattern & Band Overlay. $(PC_x, PC_y, DD) = \{0.52, 0.31, 0.63\}$

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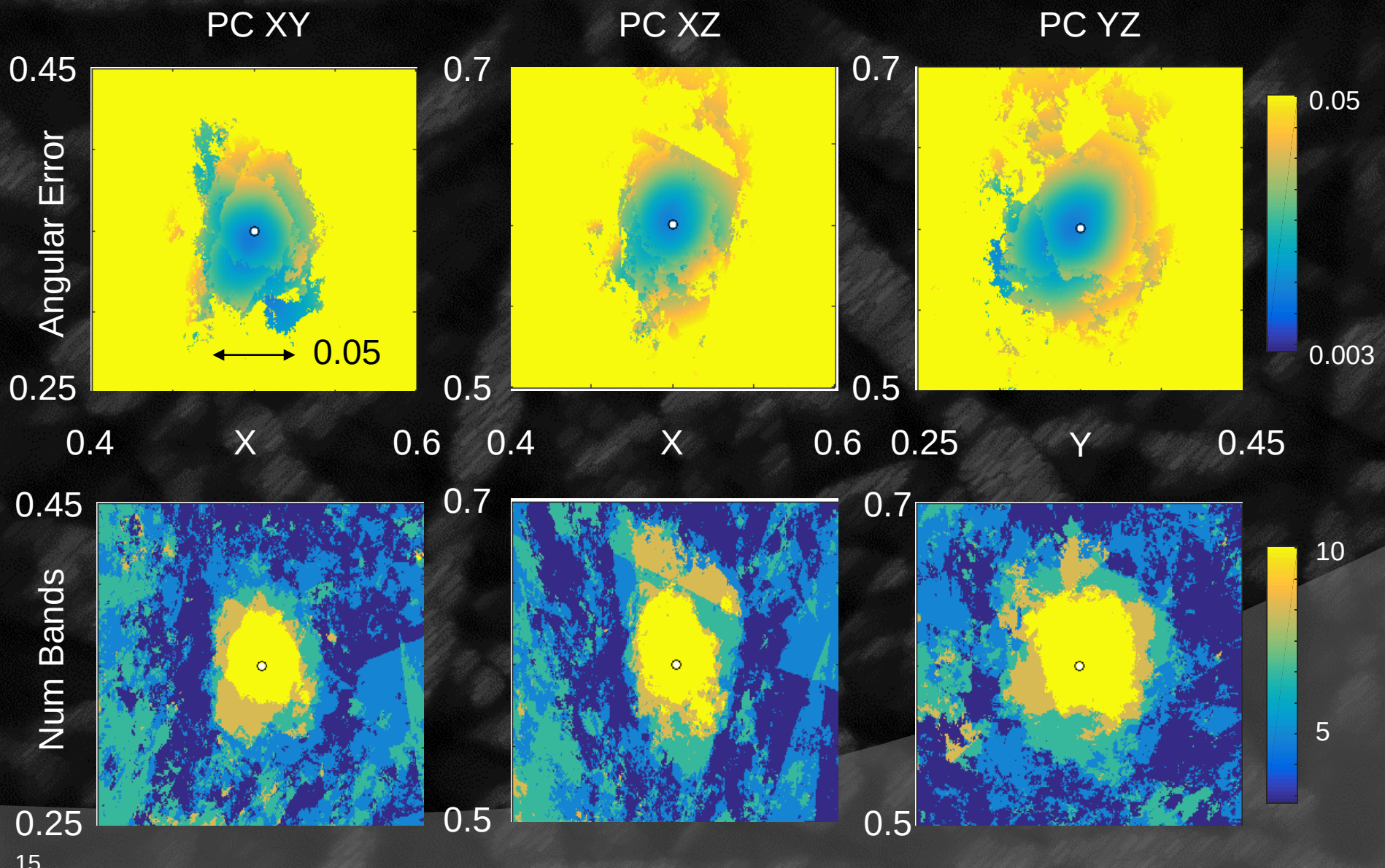
5. Pattern Centre

- Geometry of pattern centre important
- Changes apparent interplanar angles
- Can search & index, reducing angular deviation of determined bands vs LUT bands

PC=[0.5,0.3,0.6]

5. Pattern Centre



5. Pattern Centre Search

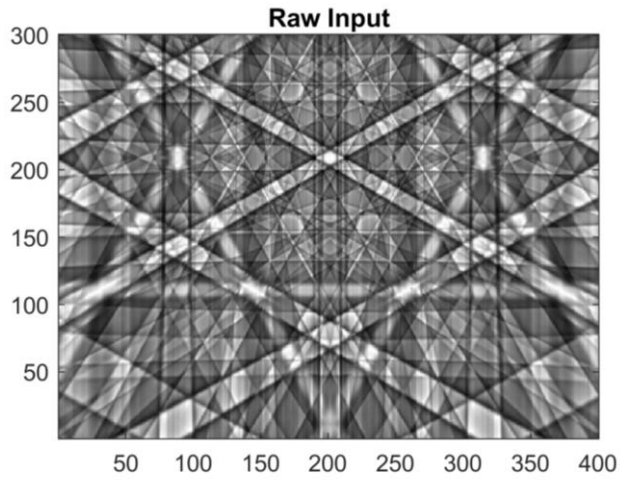
- Use a genetic algorithm
  - Enables searching of a rough space
  - Optimise number of bands {more} & Angular Error {lower}

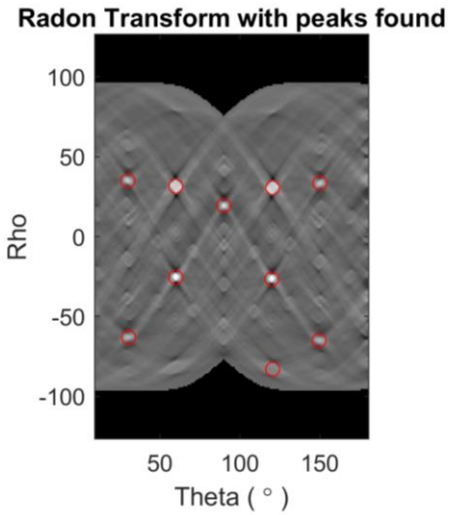
Generation	f-count	Best f(x)	Mean f(x)	Stall Generations
1	60	0.05085	0.6399	0
2	90	0.05085	0.5659	1
3	120	0.05085	0.4692	2
4	150	0.04516	0.3769	0
5	180	0.04516	0.3275	1
6	210	0.04516	0.2737	2
7	240	0.04516	0.4158	3
8	270	0.04516	0.5197	4
9	300	0.0324	0.4521	0
10	330	0.01071	0.4112	0
11	360	0.01071	0.4263	1
12	390	0.01071	0.421	2
13	420	0.01071	0.3841	3
14	450	0.004858	0.3169	0
15	480	0.004858	0.2458	1

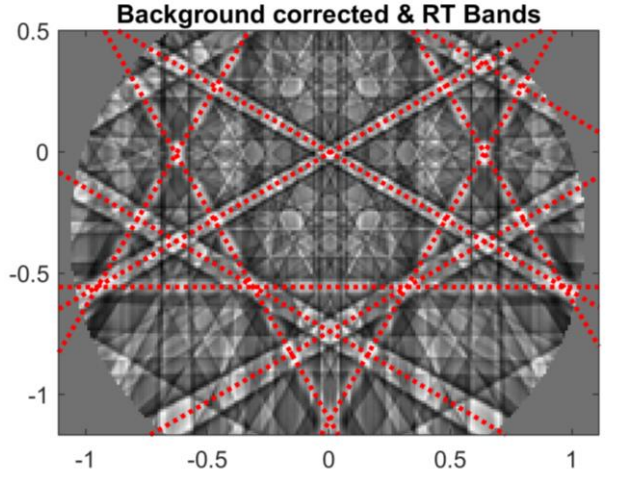
Optimization terminated: maximum number of generations exceeded.

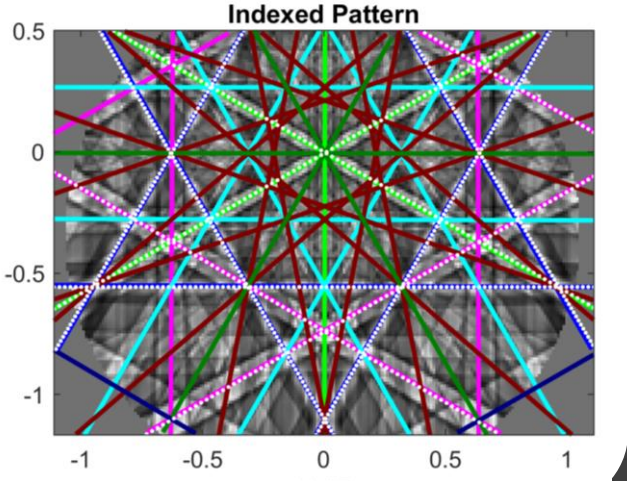
6. Accuracy

- α-Ti
  - [400 x 300]
- Reflector list:
  - {0,0,1}; {1,-2,0}; {1,0,1}; {-1,1,3}; {-1,2,2}; {0,-2,1}; {-3,1,1}; {1,0,0}; {1,-2,4};
- Radon & Band ID
  - $\theta_{step} = 1°$
  - $\rho = 150$
  - 10 peaks

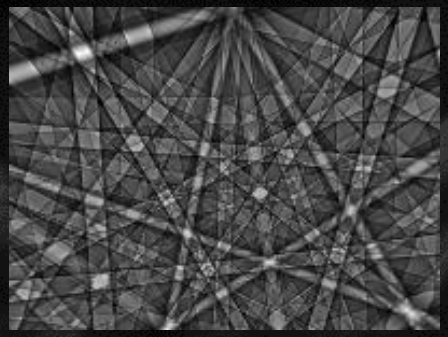




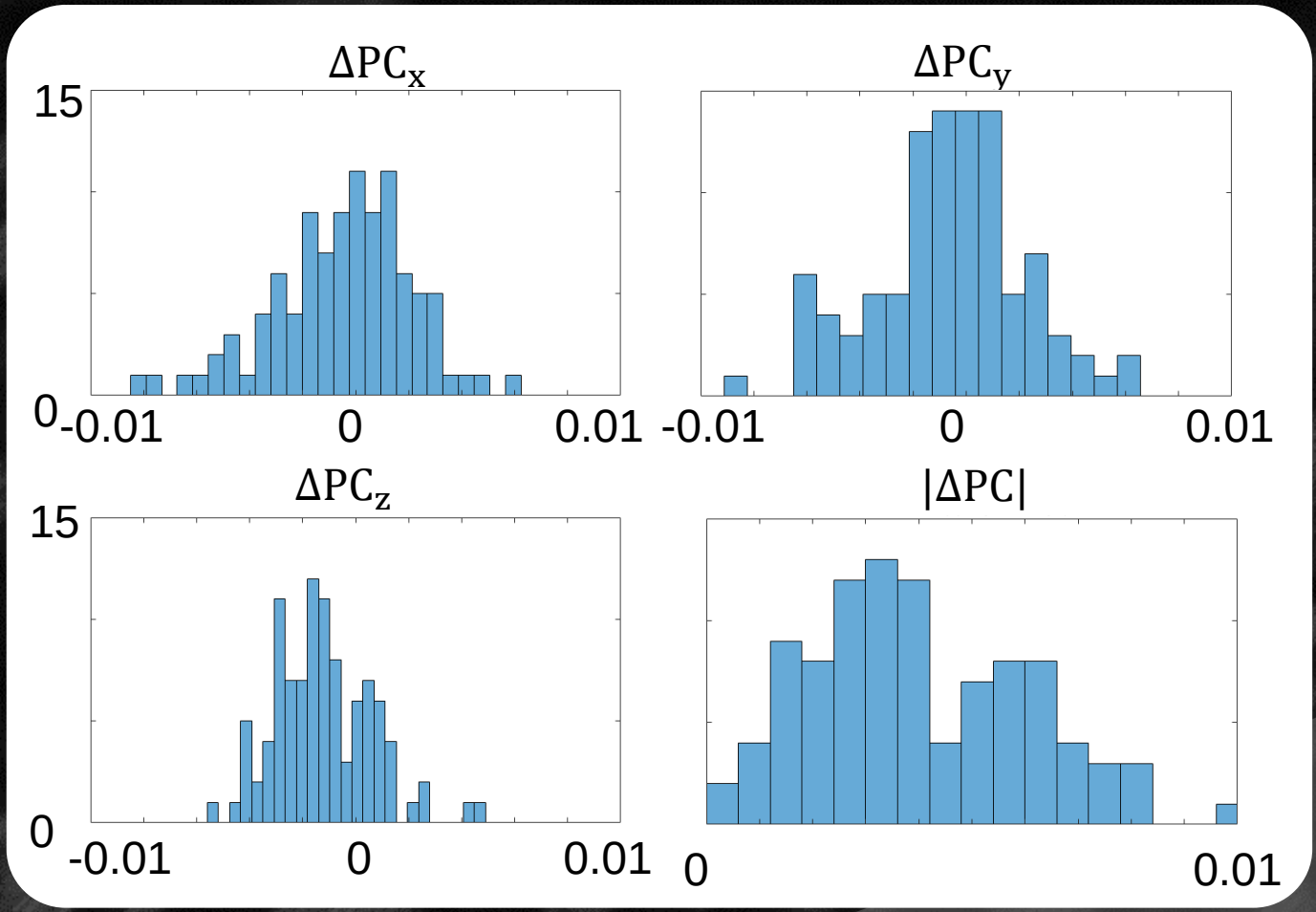




6. Accuracy - PC



- Random orientation & pattern centre
- Find orientation AND pattern centre



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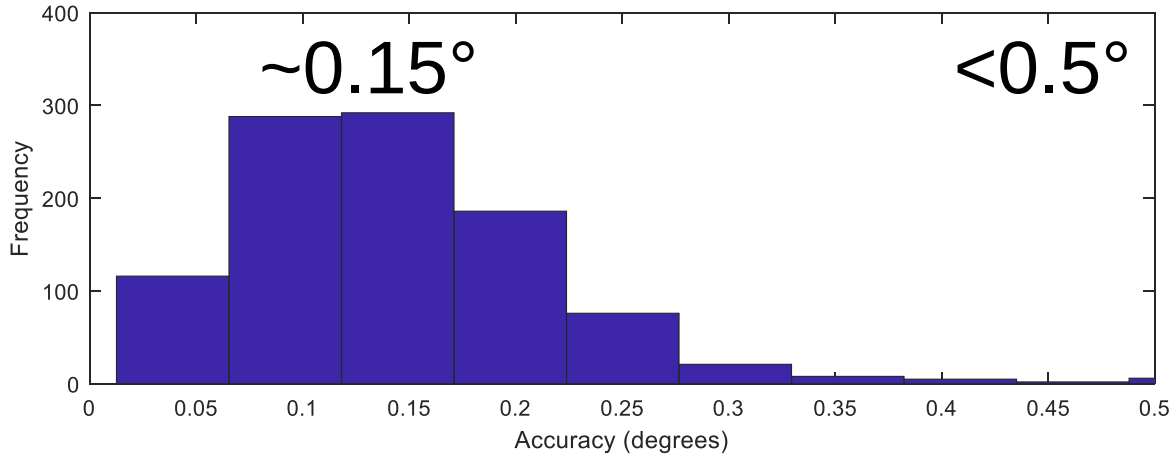
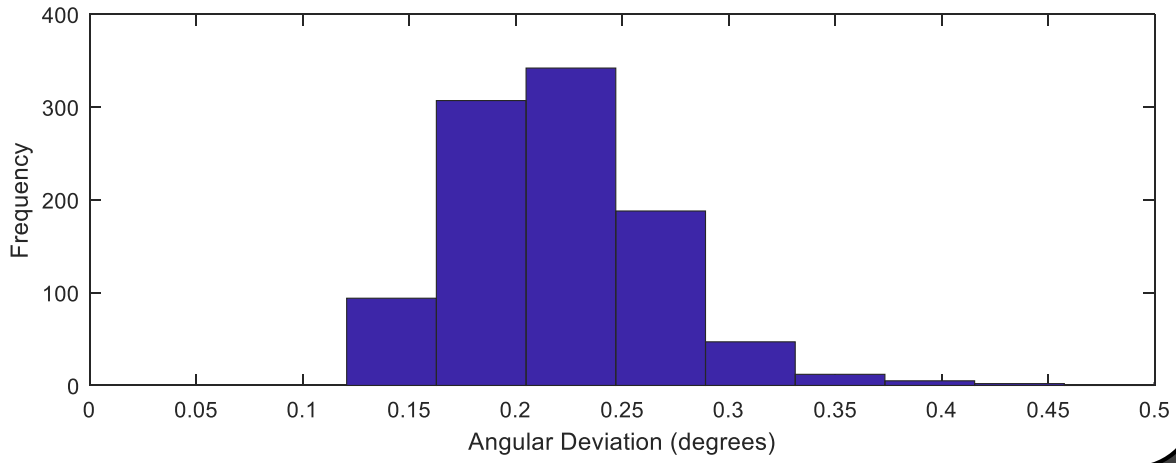
6. Accuracy - Orientation

- Accuracy <0.5°
  - Improve with >Radon + Peak ID
  - PC Exact
- Reasonable regularisation error
  - i.e. angular deviation





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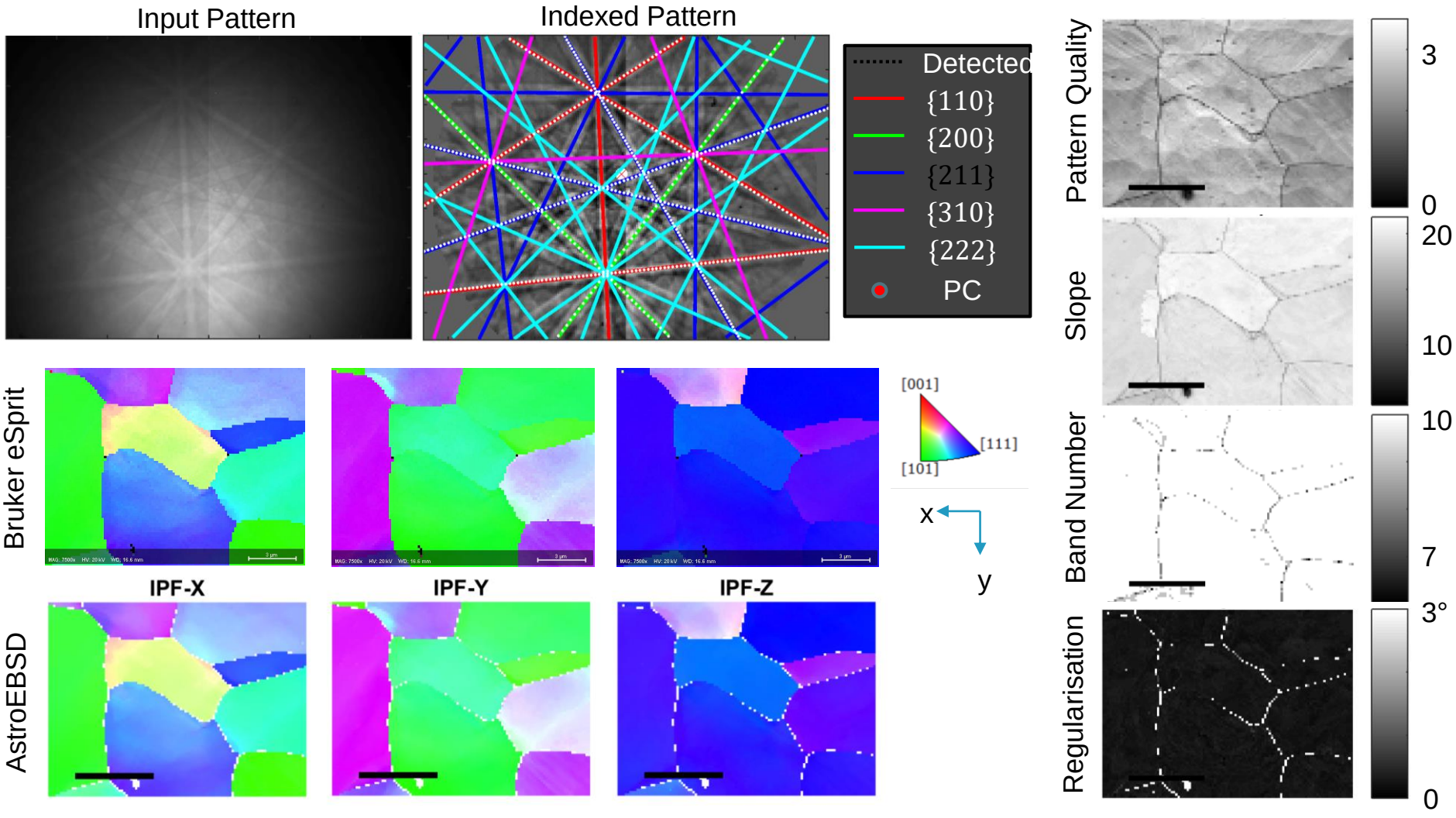
7. Demonstration - Fe



Summary

- AstroEBSD Indexing Tool Created
  - Open Source – see
- Solves symmetry + band ID
  - HCP, FCC, BCC tested
- Pattern centre measurement
- Consistent coordinate systems
- Can test new ideas…