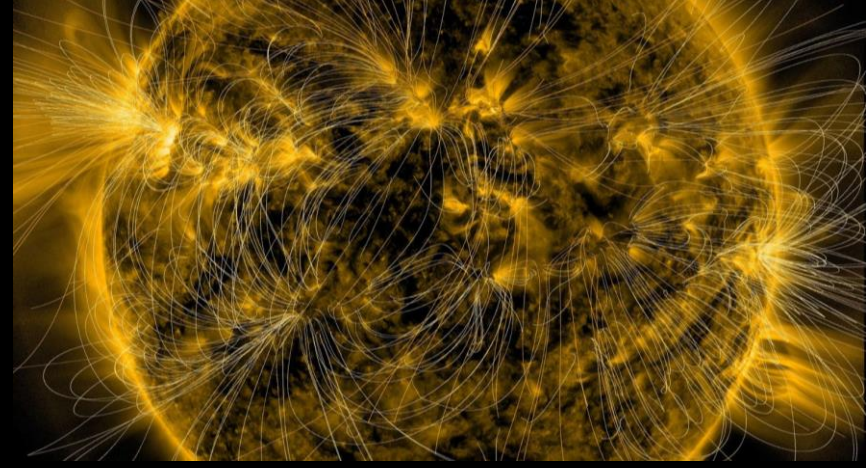
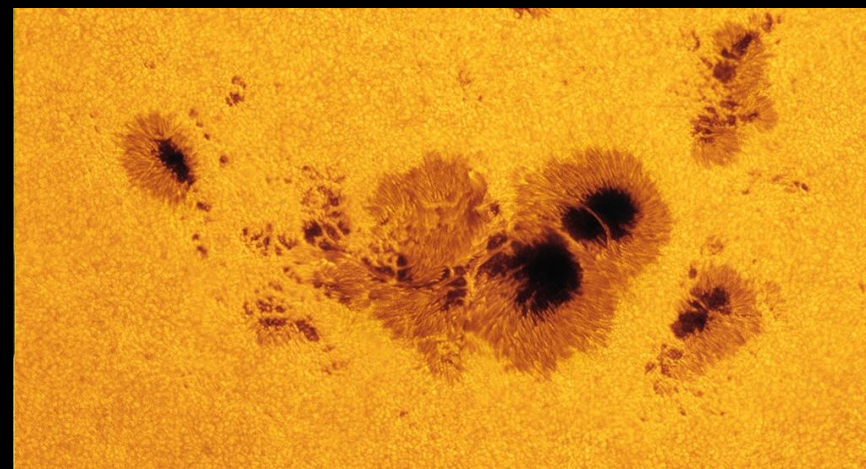
Zdeněk Hrazdíra

NUMERICAL ANALYSIS OF PHOTOSPHERIC PLASMA FLOWS

RESEARCHED TOPICS

- Plasma flows – differential rotation
- Magnetic fields – solar prominences
- Solar corona – coronal loops
- Sunspots



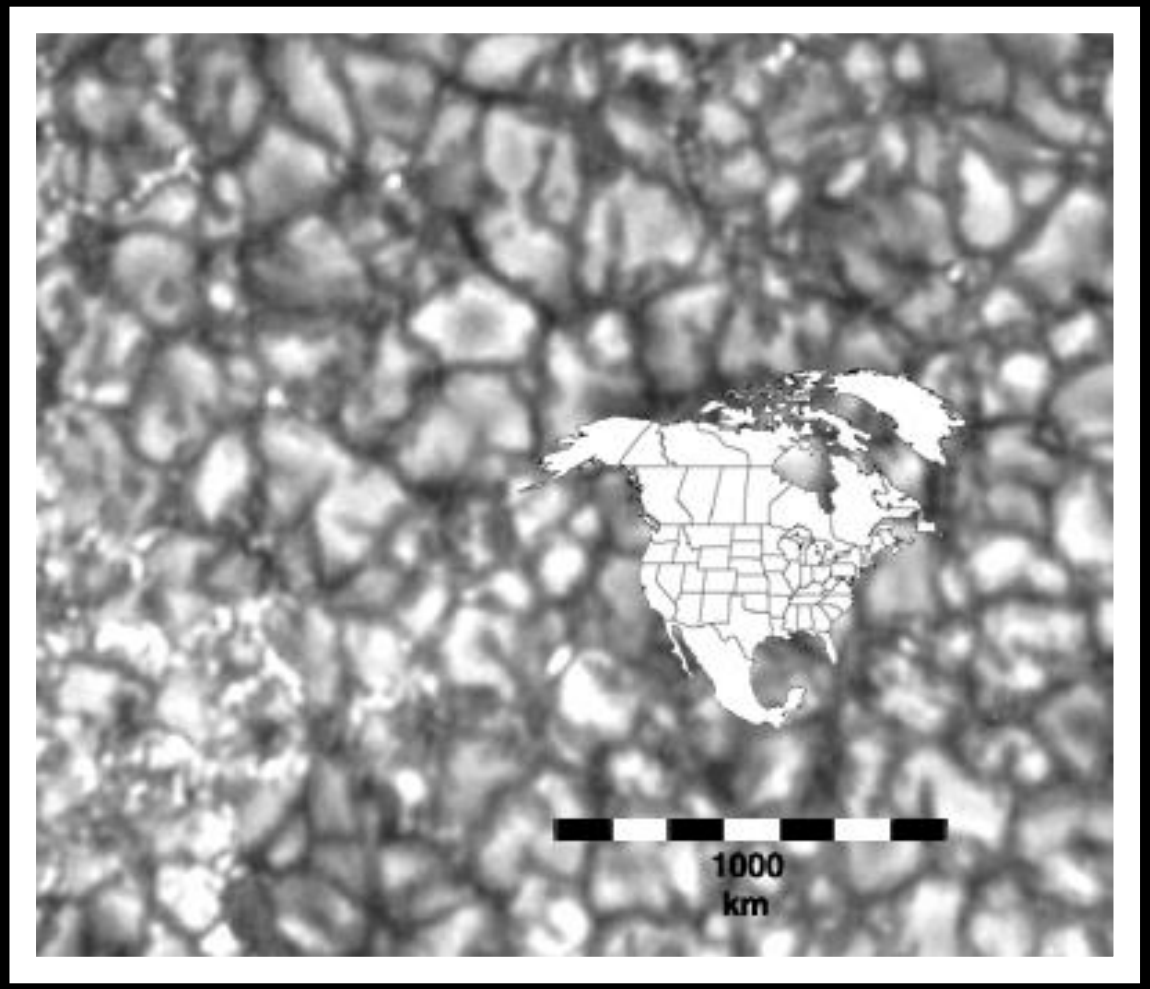


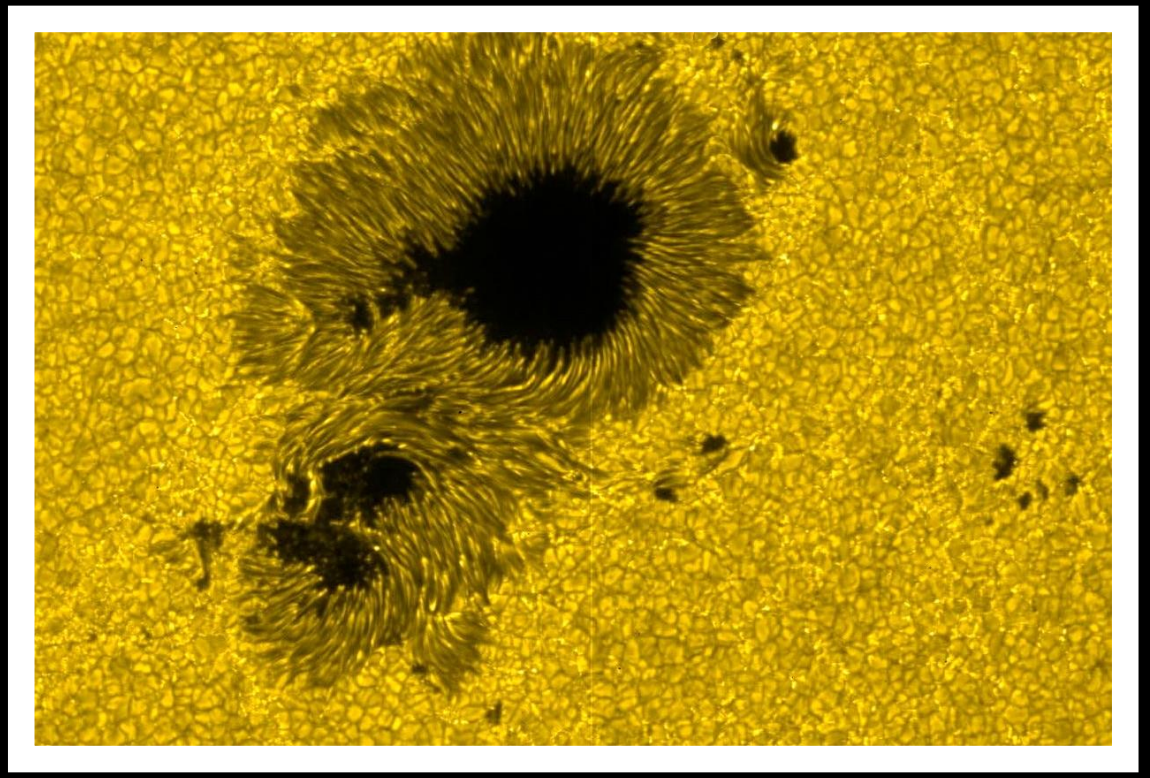
DATA SOURCE

- NASA SDO – Solar Dynamics Observatory
- HMI & AIA instruments – many different wavelengths (93Å – WL)
- 4096x4096 resolution
- 16bit
- Each image around 32Mb
- My work requires thousands of such images
- Efficient low-level data handling in C++
- Currently multi-threaded CPU algorithm
- GPU implementation with CUDA kernels being developed in C

DATA (IMAGE) PROCESSING

- Measuring difference between consecutive images
- Result is shift in pixels, needs to be converted into physical units
- Standard approach - cross-correlation
- More accurate approach – phase-correlation
- Very small ROIs needed – flow accuracy
- Images taken only 45s apart (smallest time difference possible, SDO rate)
- Small time difference needed due to noise and granulation (convection)
- Resulting shift is very small, around 0.2 px
- Need for robust subpixel alignment method, working with small, noisy images

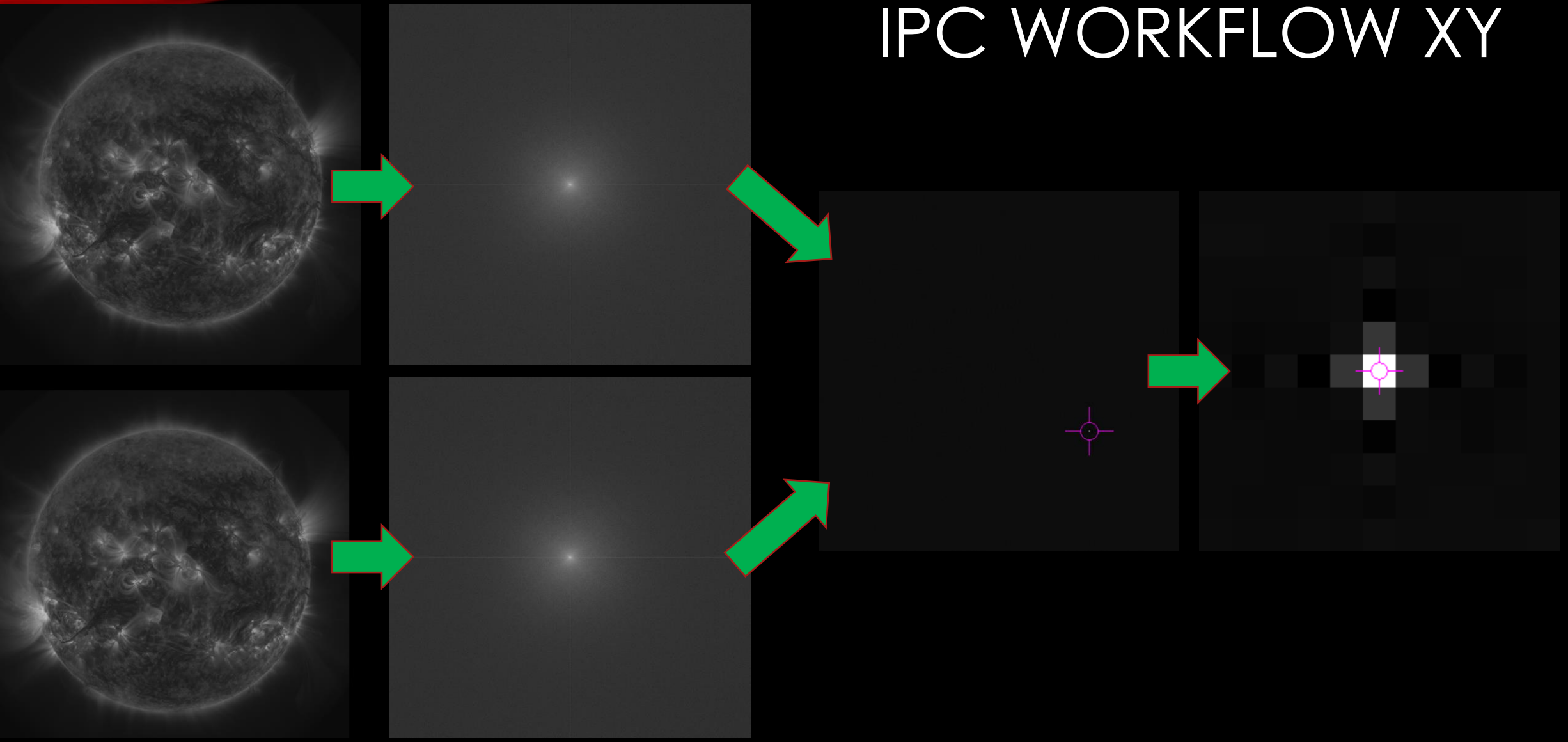

1000
km

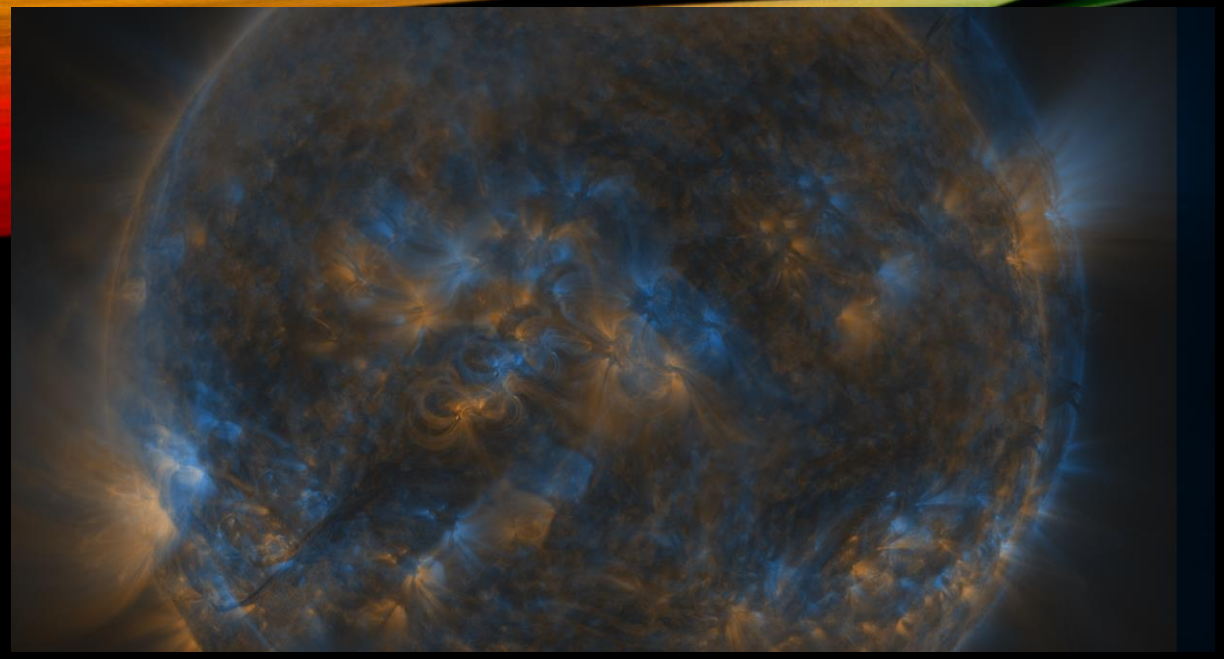


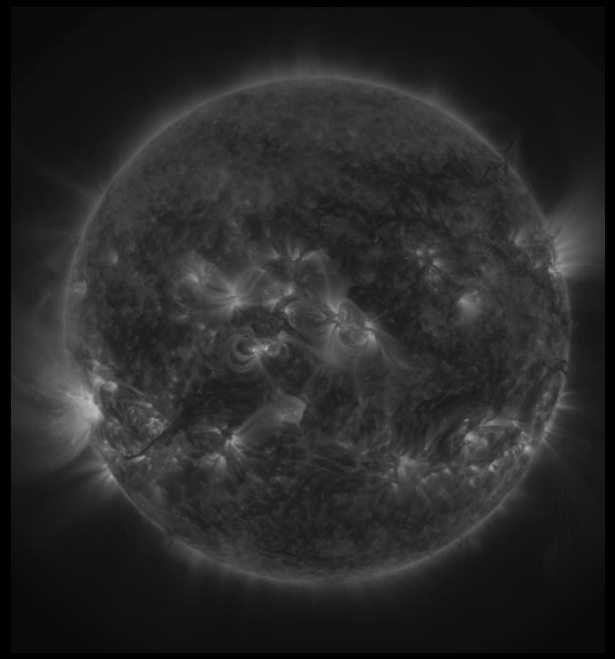
ITERATIVE PHASE CORRELATION

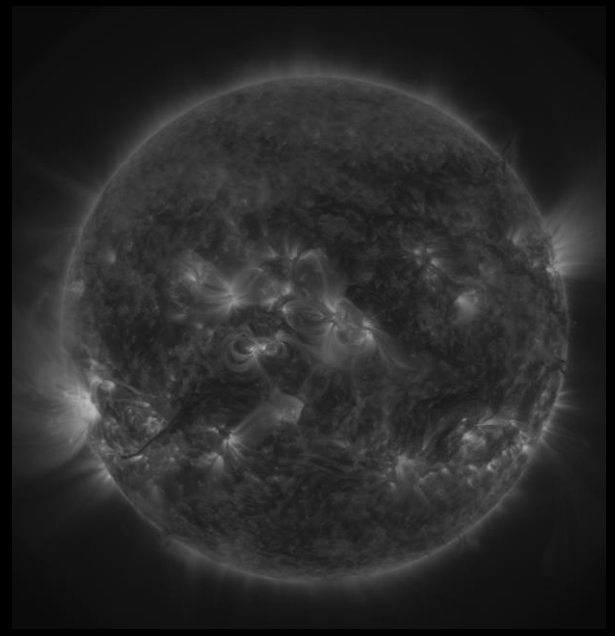
- Algorithm able to determine 4parameters – shift in X/Y, rotation and scale
- Efficiently computed with FFTs
- Standard method pixel accuracy around 0.5px
- Standard method subpixel accuracy (centroid) around 0.3px, still insufficient
- Significant improvement – iterative centroid refinement, upsampling

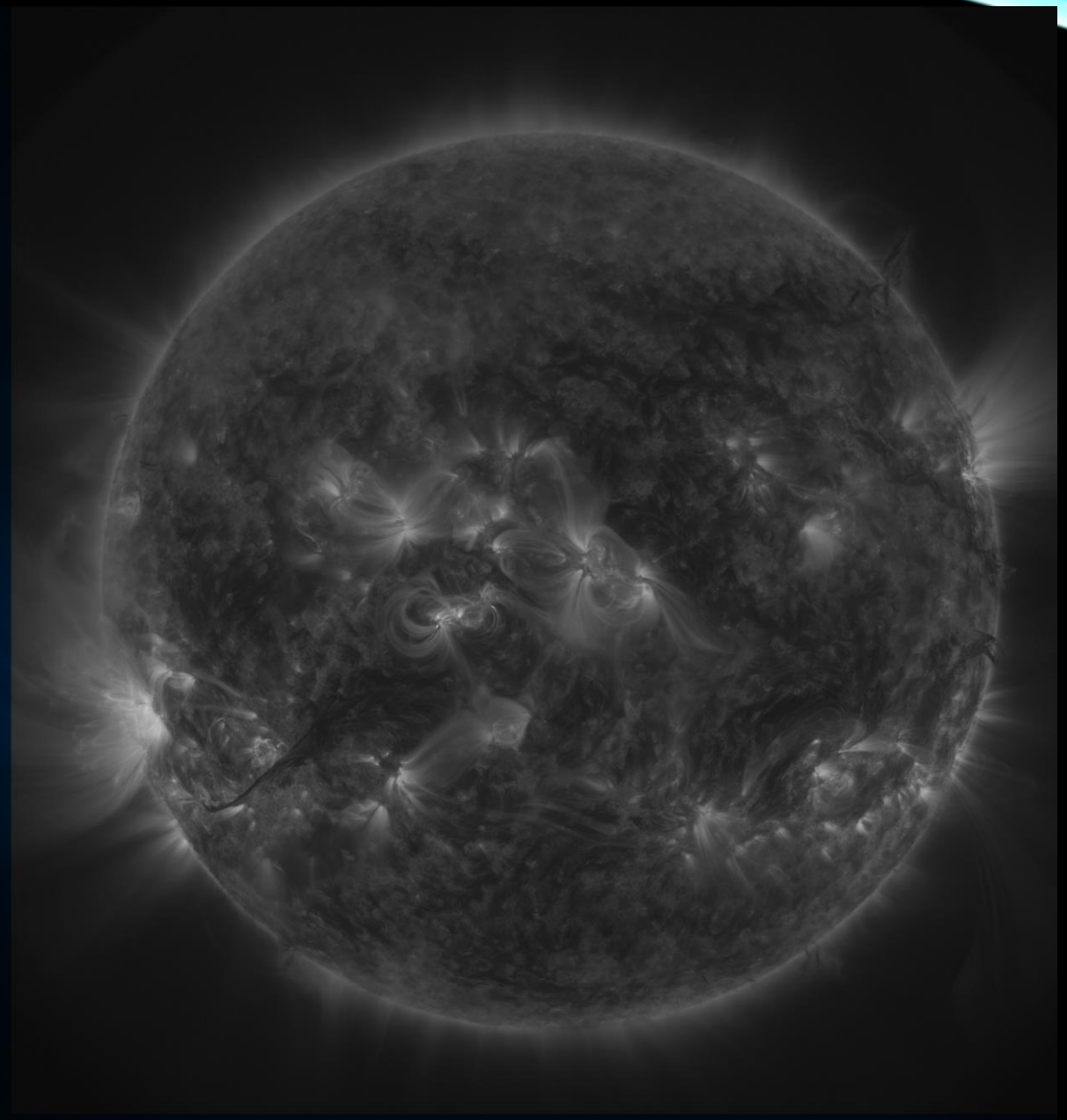
IPC WORKFLOW XY









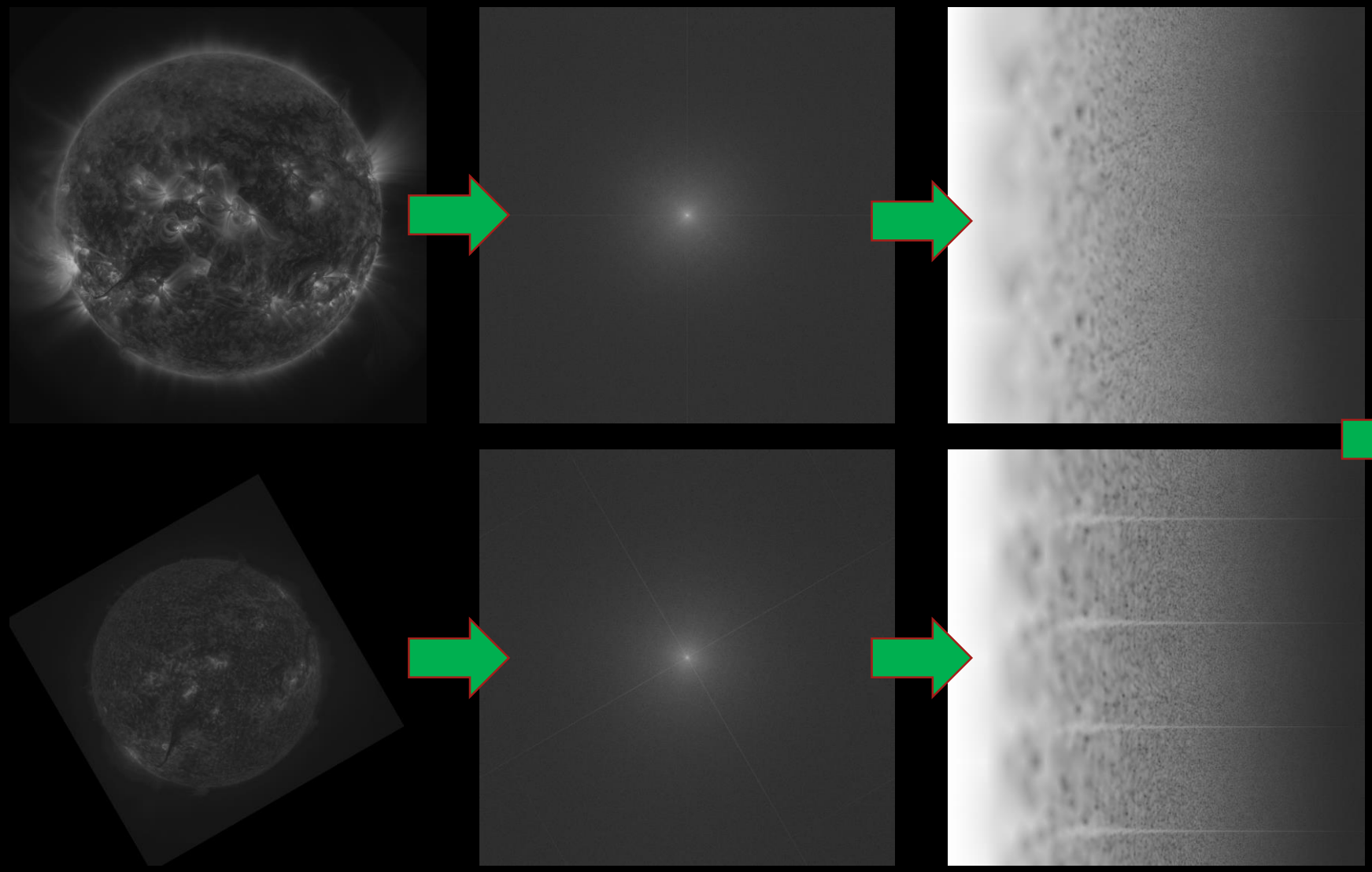


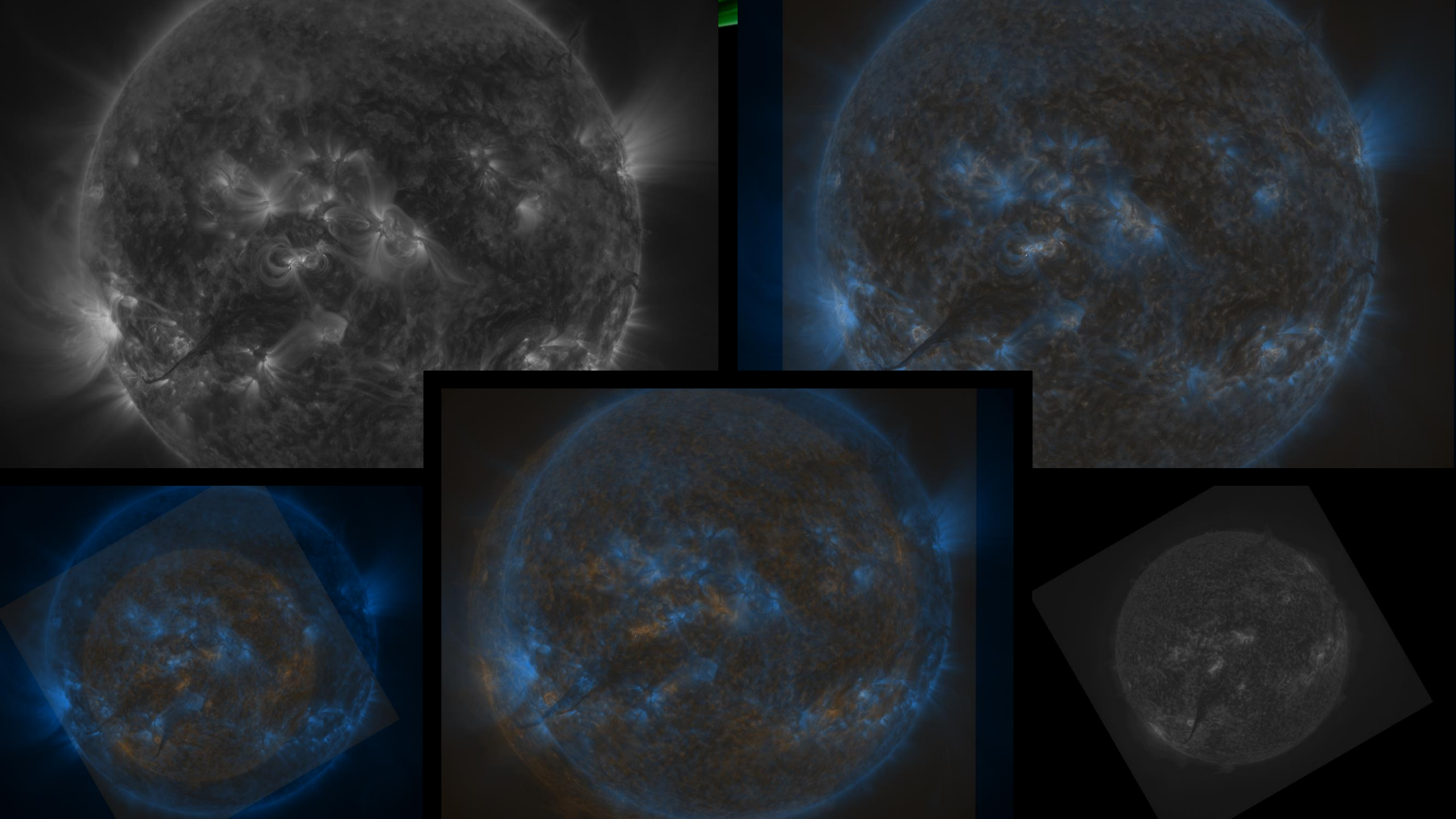
IPC WORKFLOW RS-XY

X/Y → log(S)/R

X/Y → log(S)/R

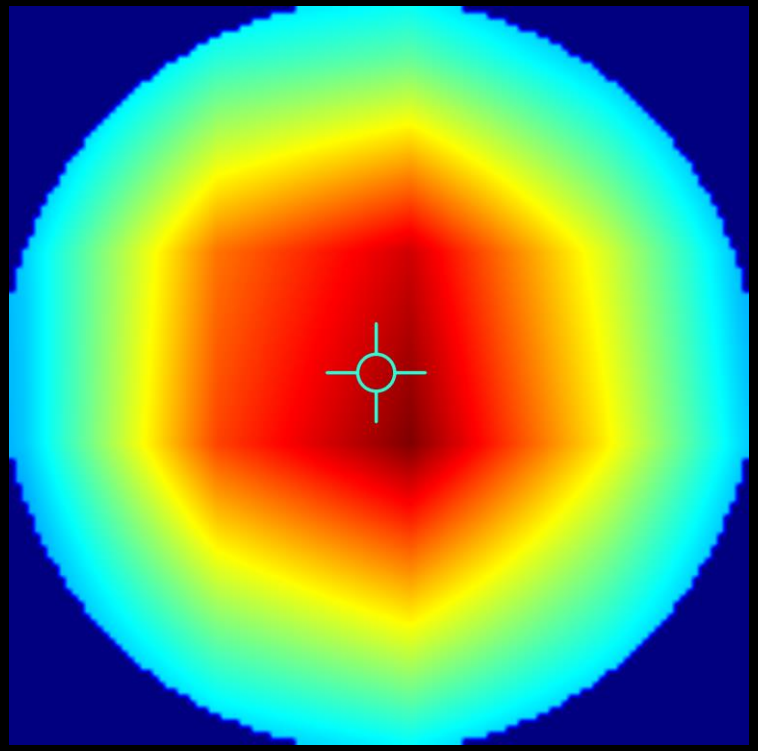
IPC WORKFLOW RS-XY

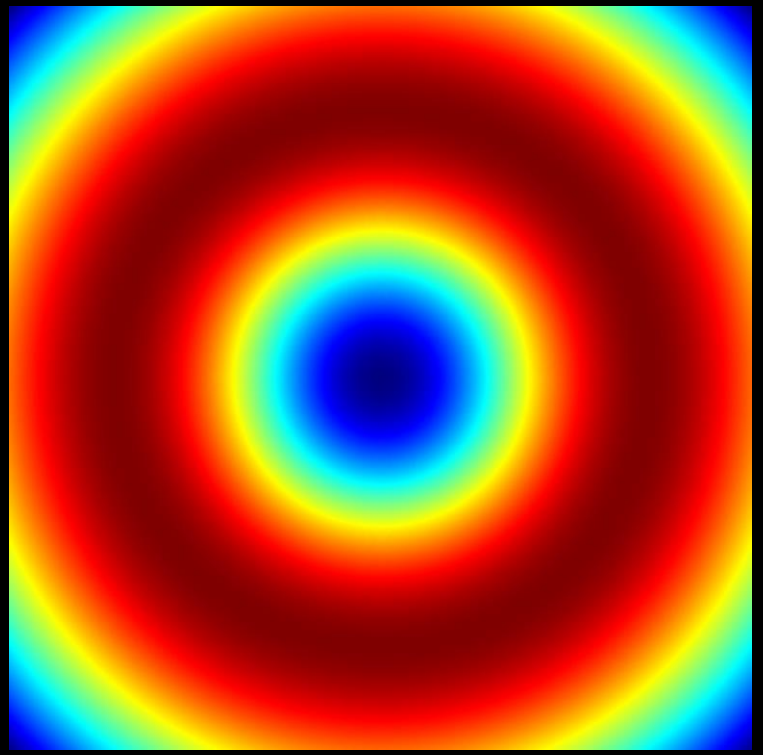


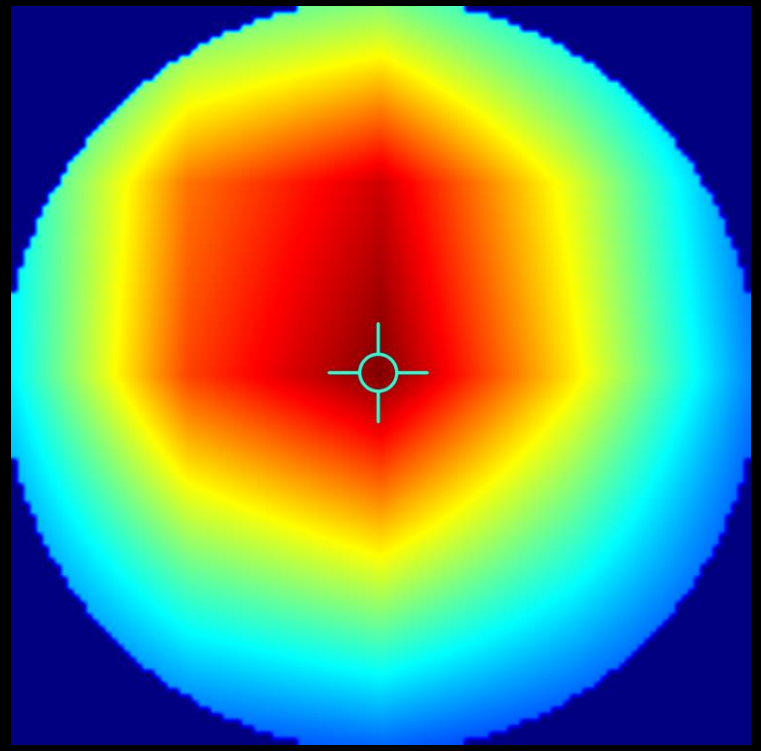


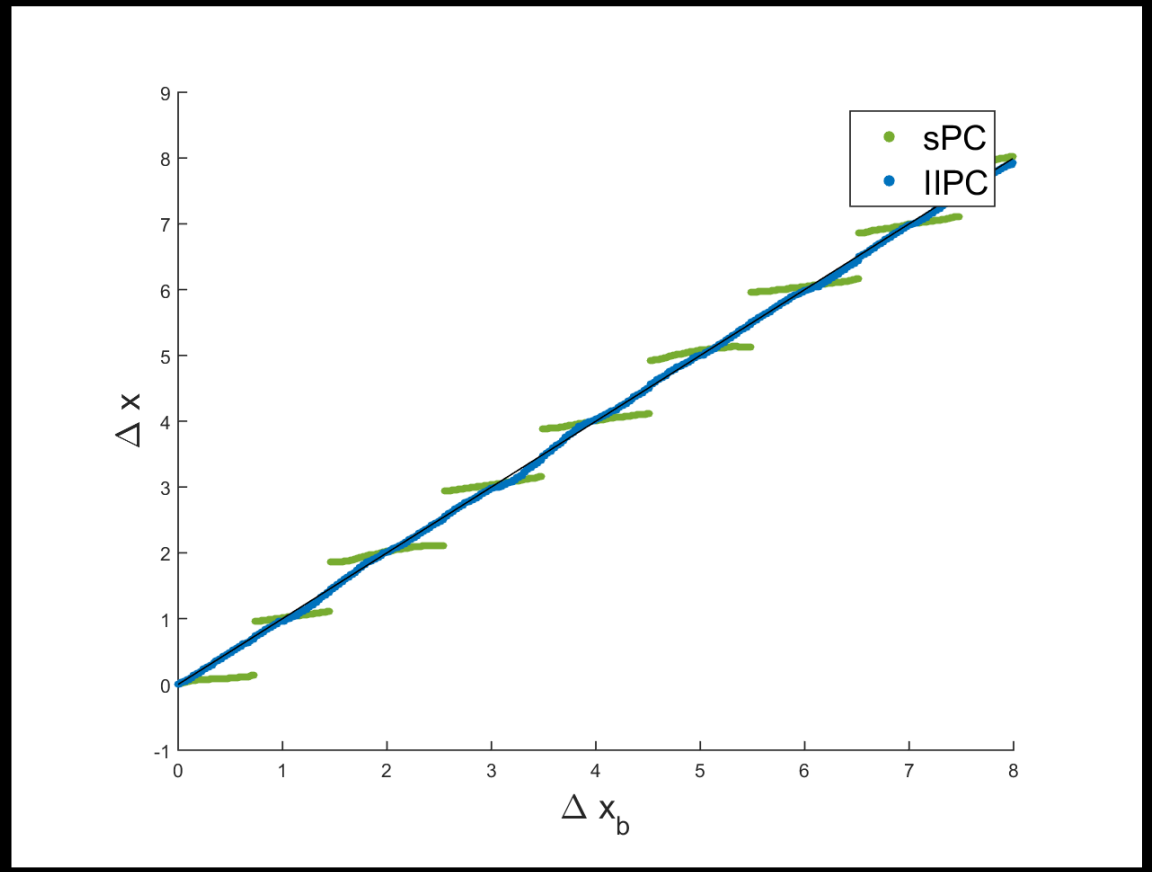
ITERATIVE REFINEMENT

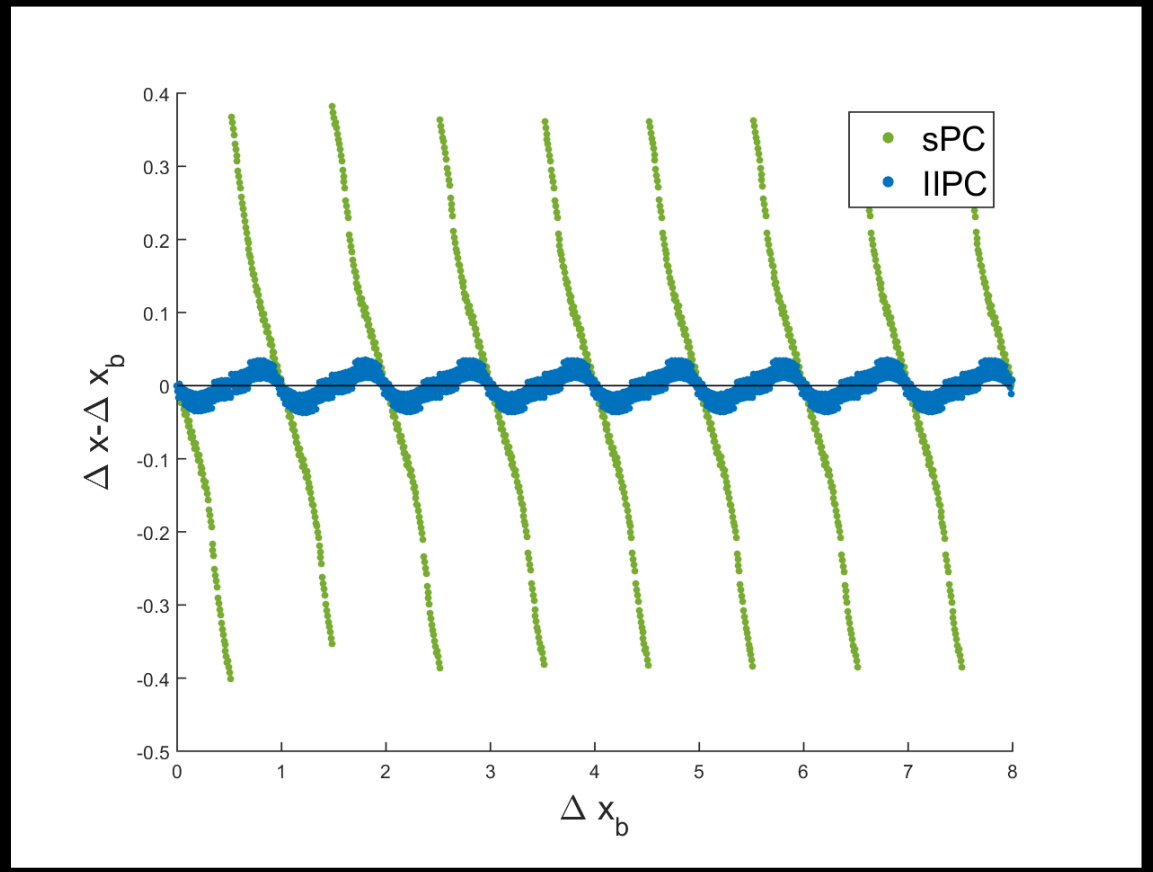
- Phase correlation surface upsampled (bilinear, bicubic, Lanczos)
- Peak location calculated and moved iteratively, according to centroid
- Windowing
- Band-pass filtering
- Band-pass filter optimal parameters and FFT window settings obtained by mathematical optimization
- Objective function – registration error (artificial shifts)
- Objective function non-convex
- Chosen optimizer – *Differential Evolution*

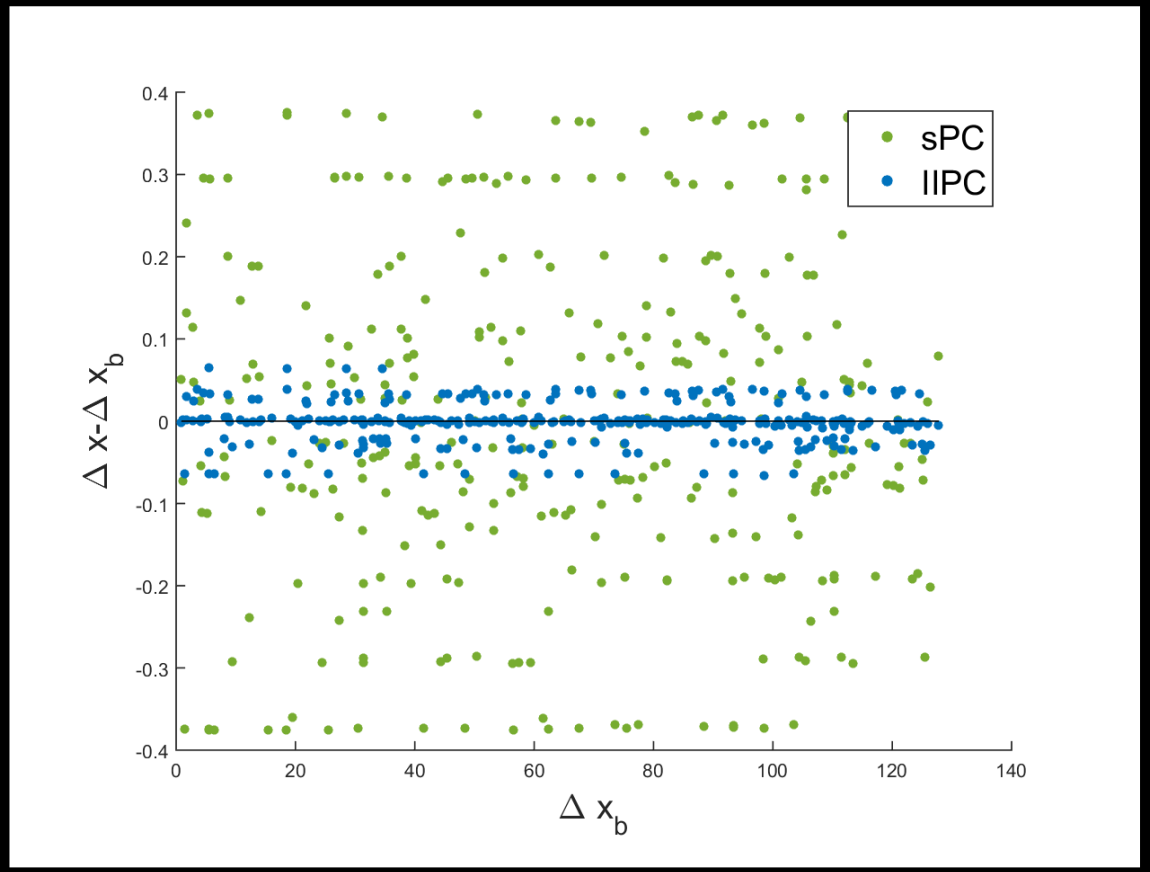


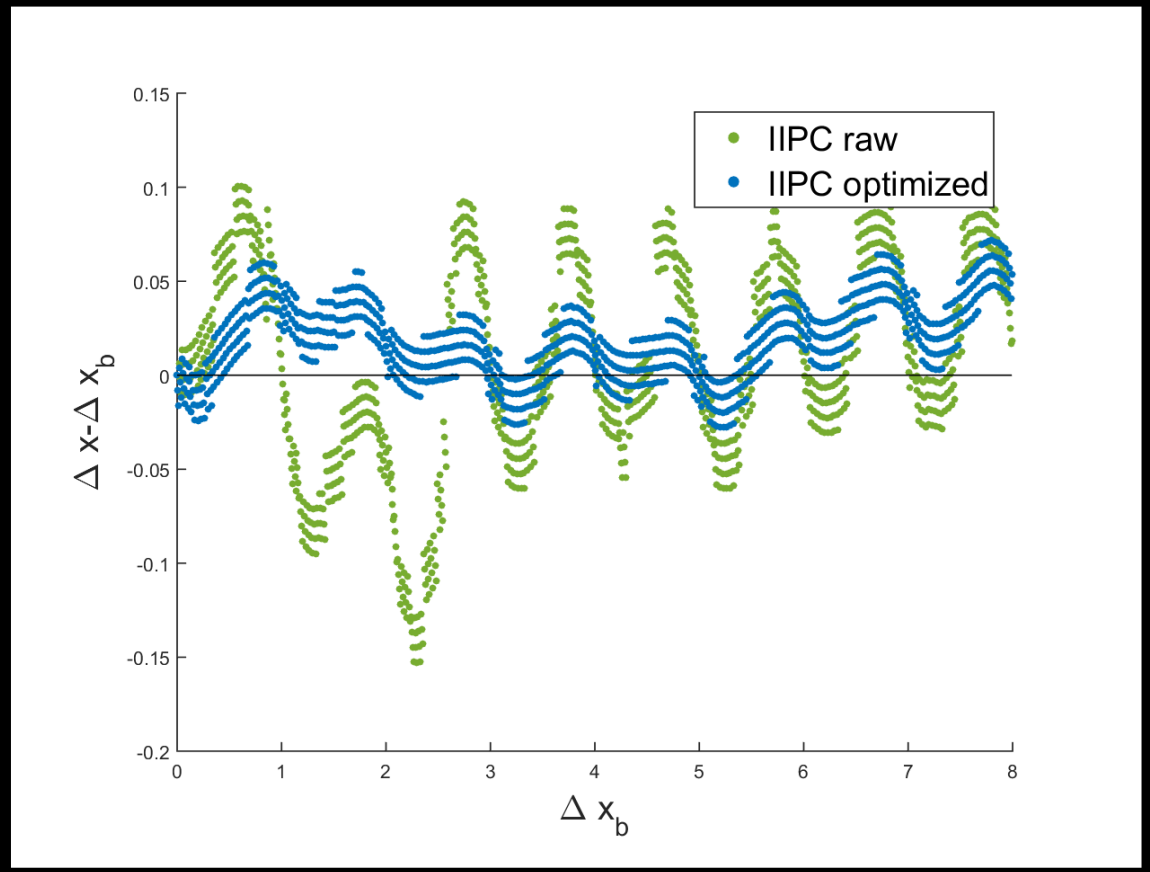





sPC
IIPC
Δ x
Δ x_b
9
8
7
6
5
4
3
2
1
0
-1
0
1
2
3
4
5
6
7
8

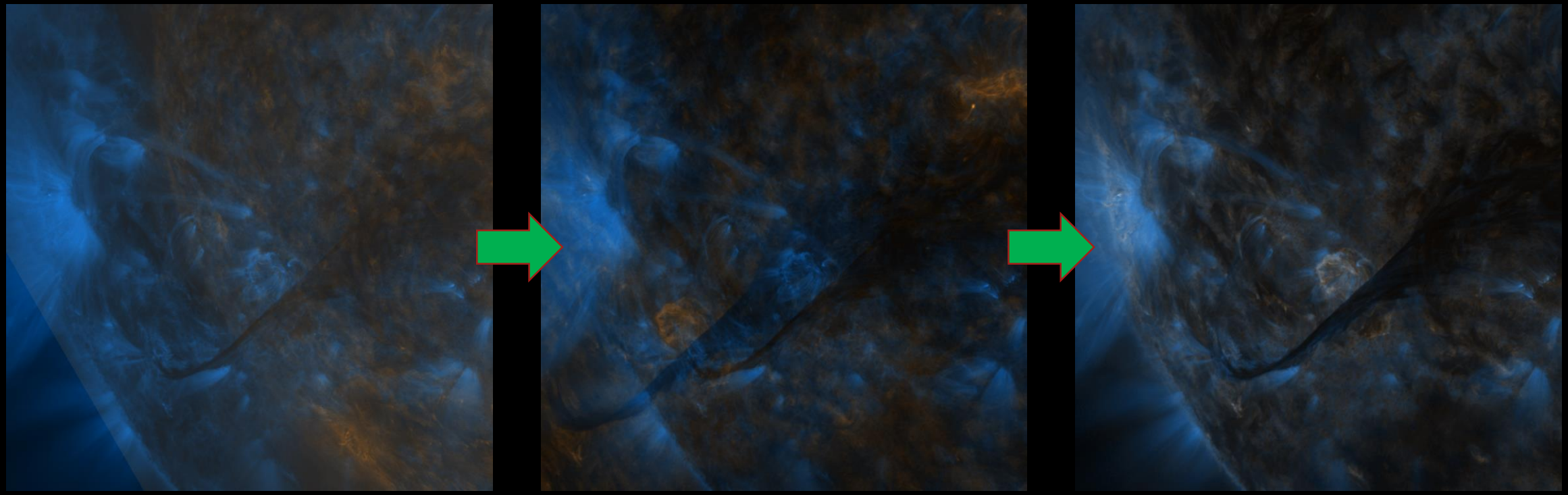

sPC
IIPC
Δ x-Δ x_b
Δ x_b
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
0
1
2
3
4
5
6
7
8


sPC
IIPC
Δ x-Δ x_b
Δ x_b
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
0
20
40
60
80
100
120
140


IIPC raw
IIPC optimized
Δ x-Δ x_b
Δ x_b
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
0
1
2
3
4
5
6
7
8

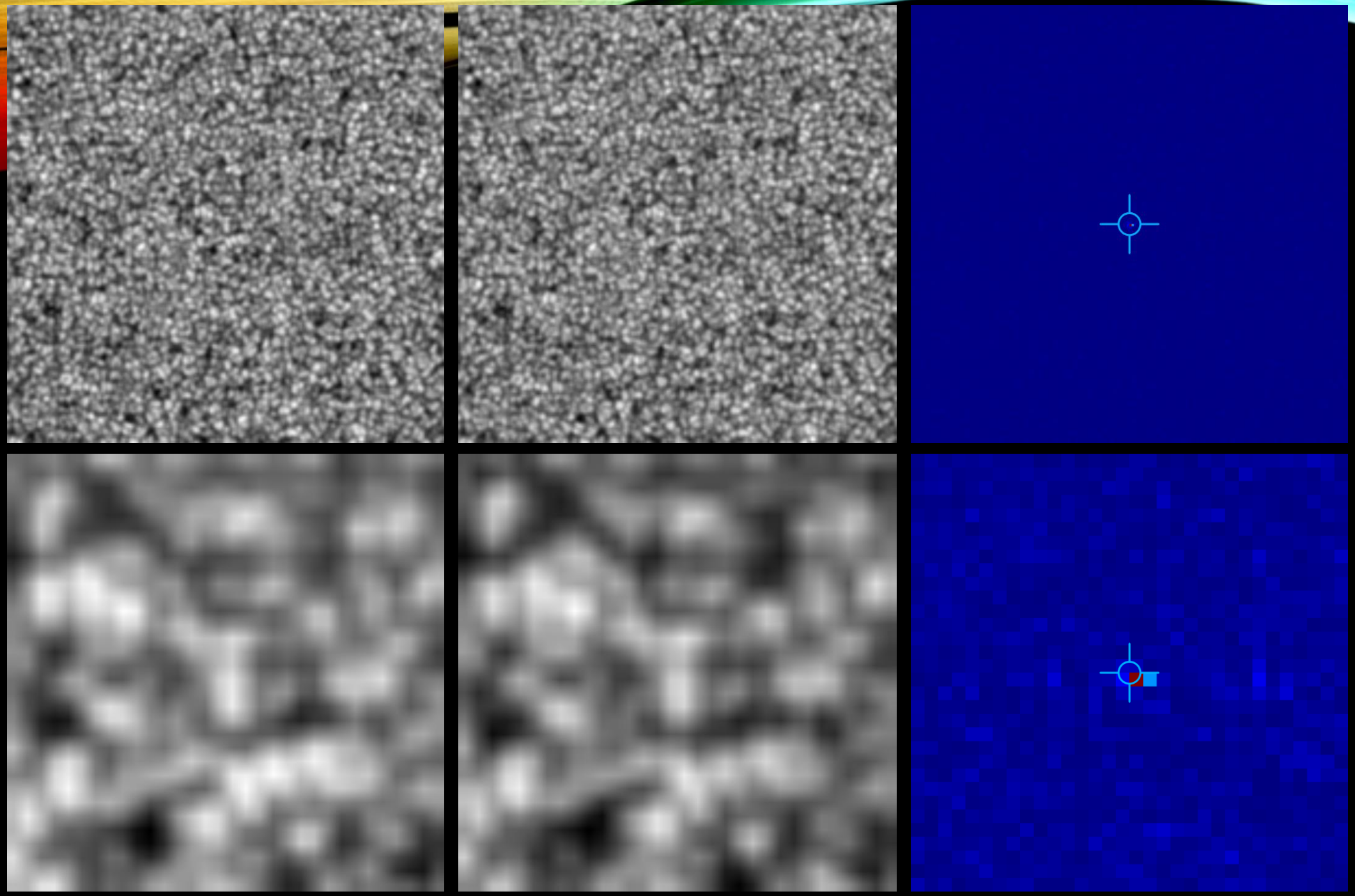
APPLICATIONS – IMAGE ALIGNMENT

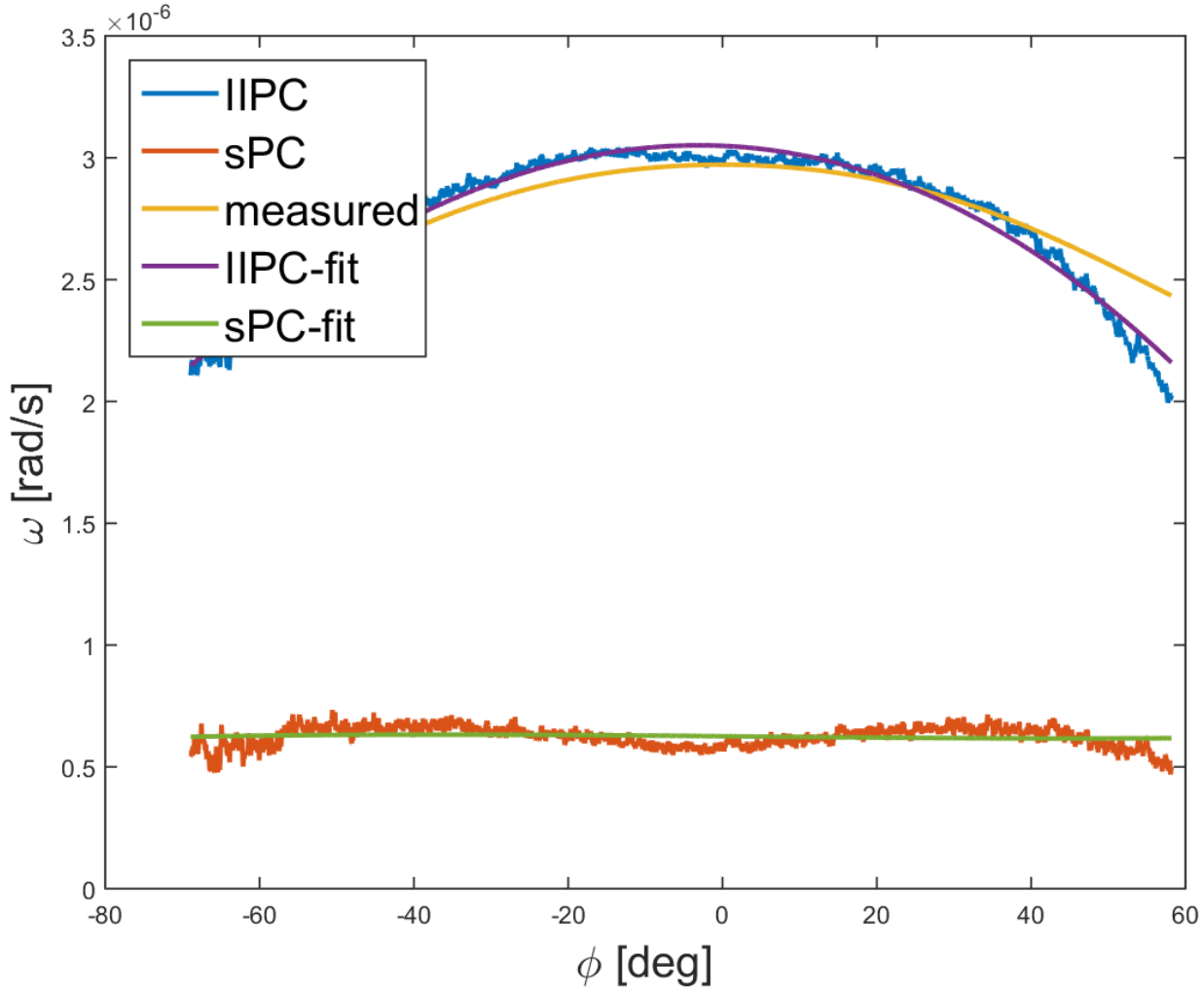
- Alignment of images with different wavelengths
- Robust to noise
- Robust to large misalignments



APPLICATIONS – DIFFERENTIAL ROTATION MEASUREMENT

- Solar rotation dependent on latitude
- Differential rotation curve only measured with LCT (local feature tracking)
- LCT – sparse method, requires large features (e.g. sunspots)
- IPC with small ROIs – dense method, works with virtually featureless images
- Comparison with LCT-based extrapolated differential rotation curve




×10^-6
3.5
3
2.5
2
1.5
1
0.5
0
IIPC
sPC
measured
IIPC-fit
sPC-fit
ω [rad/s]
-80
-60
-40
-20
0
20
40
60
ϕ [deg]

APPLICATIONS – PHOTOSPHERIC PLASMA FLOW NEAR SUNSPOTS

- Source data – Autumn 2014 – one of the biggest sunspots to date
- SDO HMI WL
- Plasma flow significantly different (more interesting) in the neighborhood of sunspots
- Computation of plasma flow velocities relative to the resulting IPC differential rotation curve