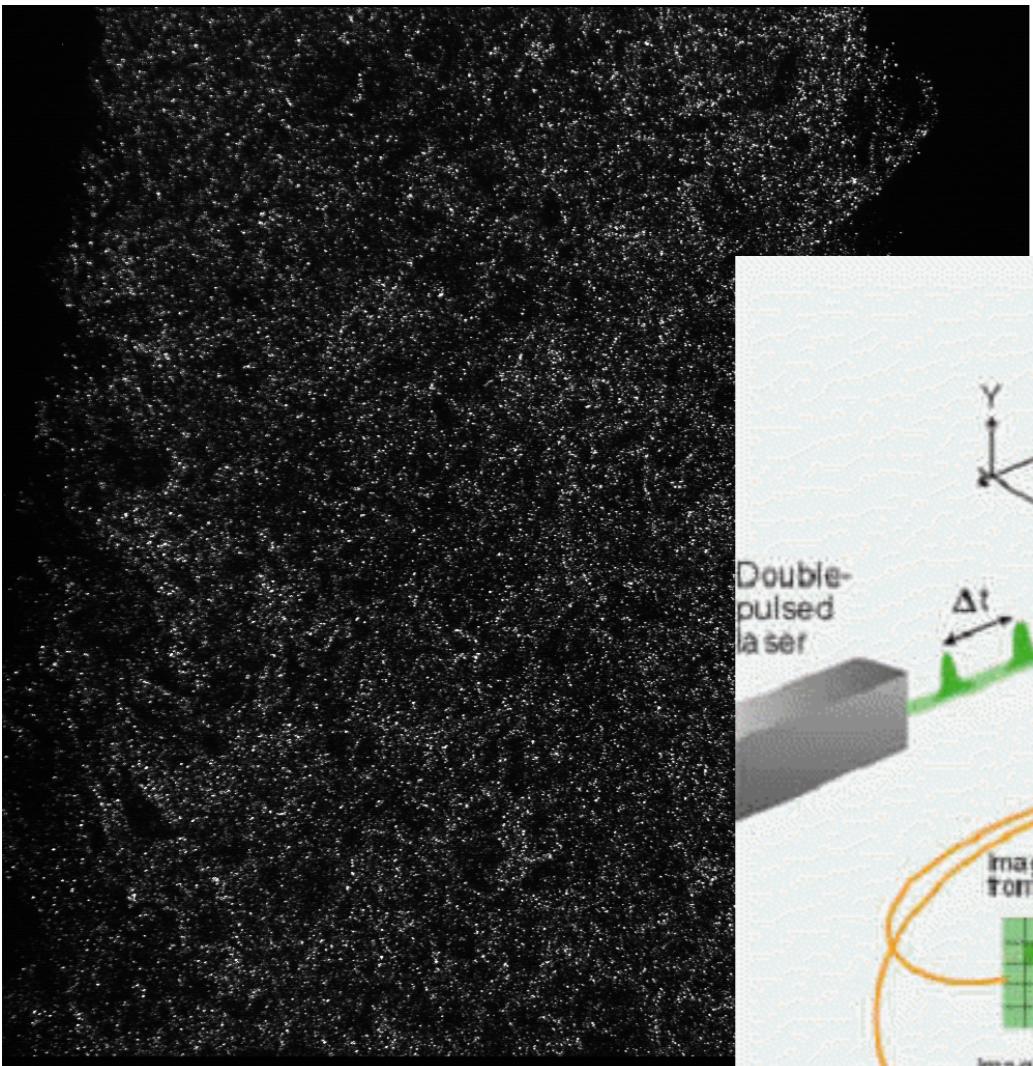


# Adaptive Particle Image Velocimetry (PIV)

Robin Deits

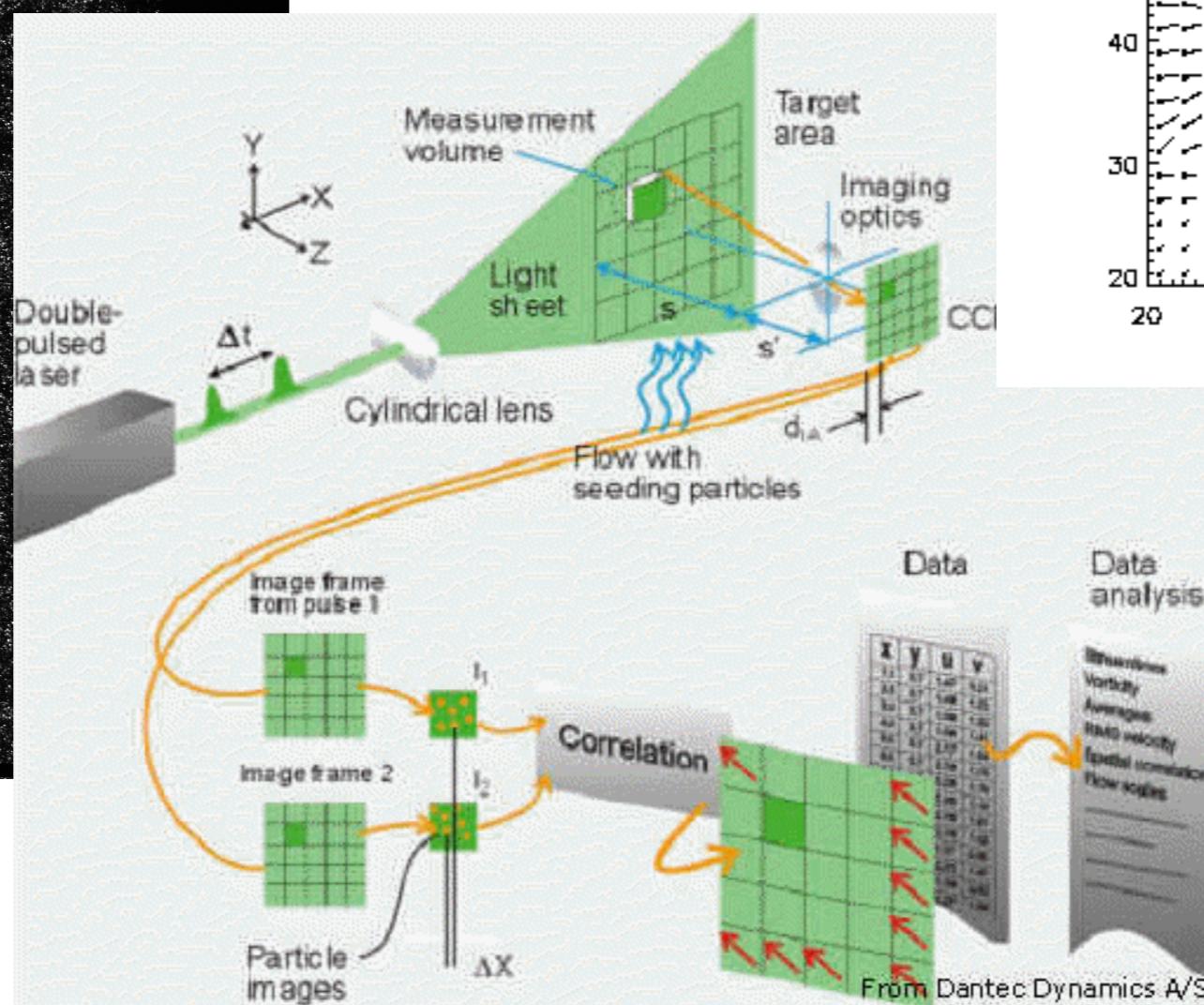
# Particle Image Velocimetry

[http://efdl.cims.nyu.edu/laboratory/lab\\_numerical/educate/codes/PIV/simple\\_flow/expt\\_001\\_a.bmp](http://efdl.cims.nyu.edu/laboratory/lab_numerical/educate/codes/PIV/simple_flow/expt_001_a.bmp)



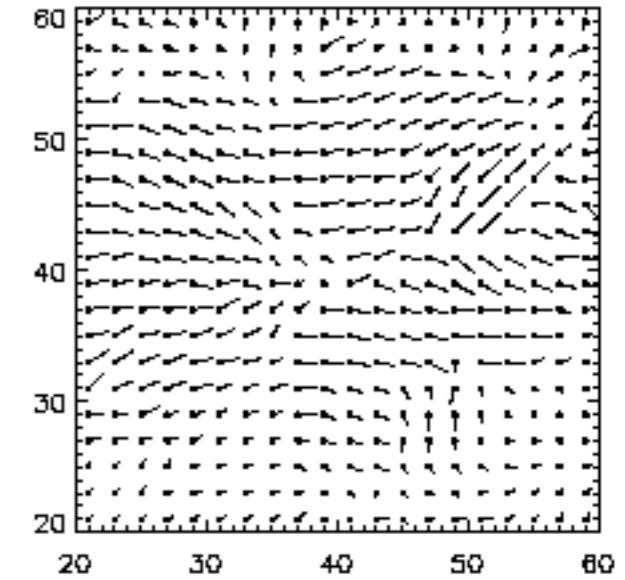
Seed particles

<http://www.coe.neu.edu/Research/rcl/projects/PIV/piv.gif>



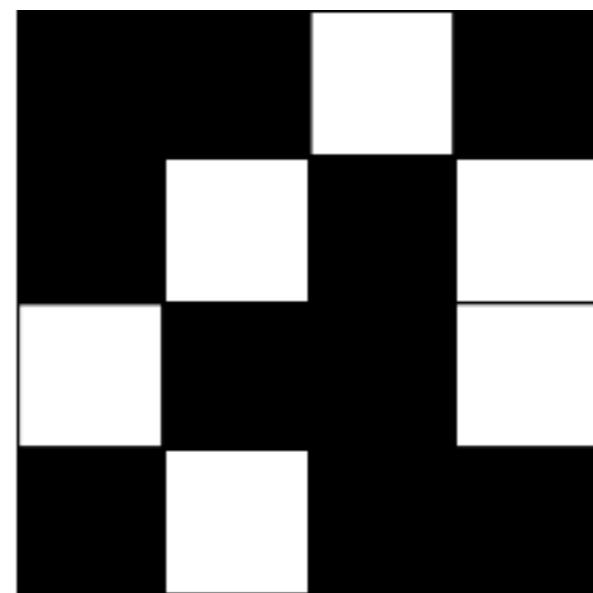
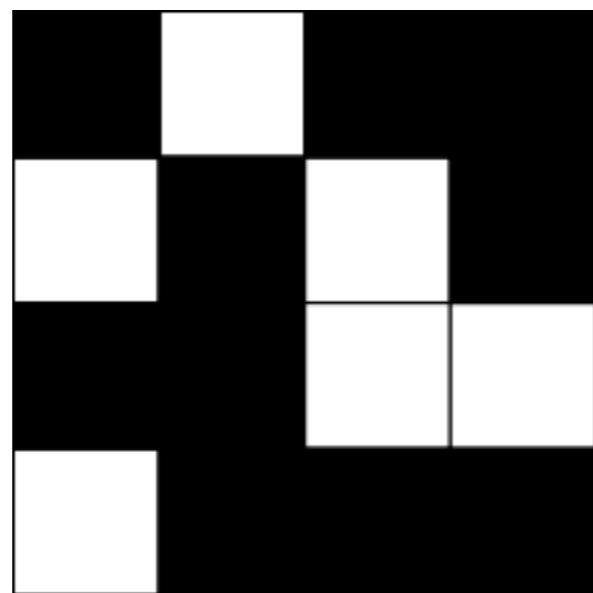
Cross-correlation

<http://www.physics.emory.edu/~weeks/idl/pics/piv02.gif>

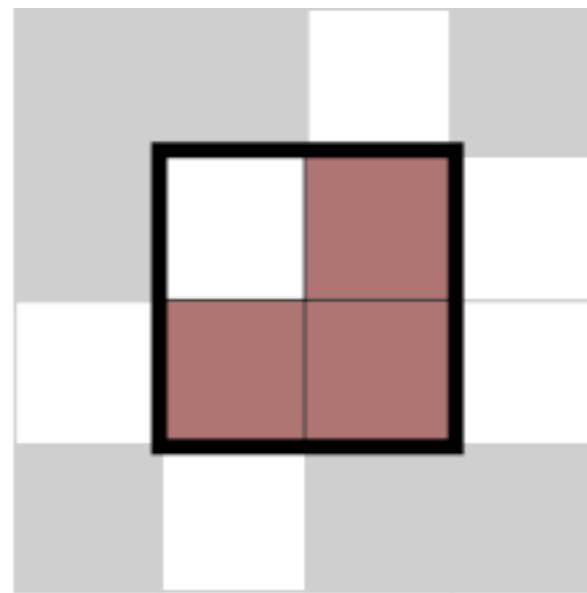
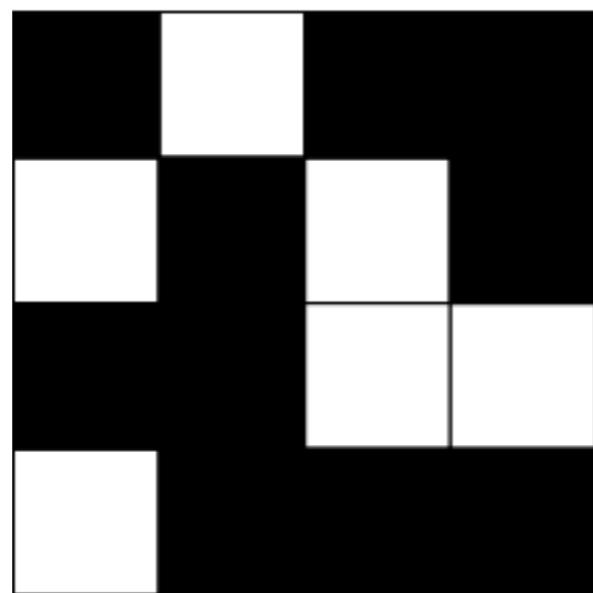


Flow vector field

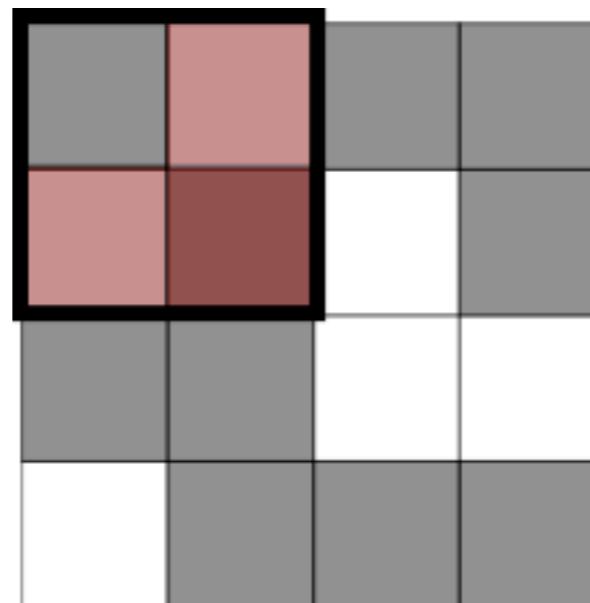
# Cross-Correlation



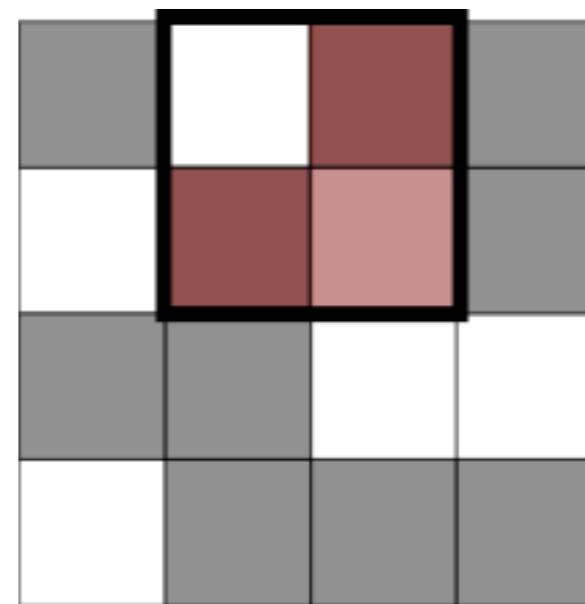
# Cross-Correlation



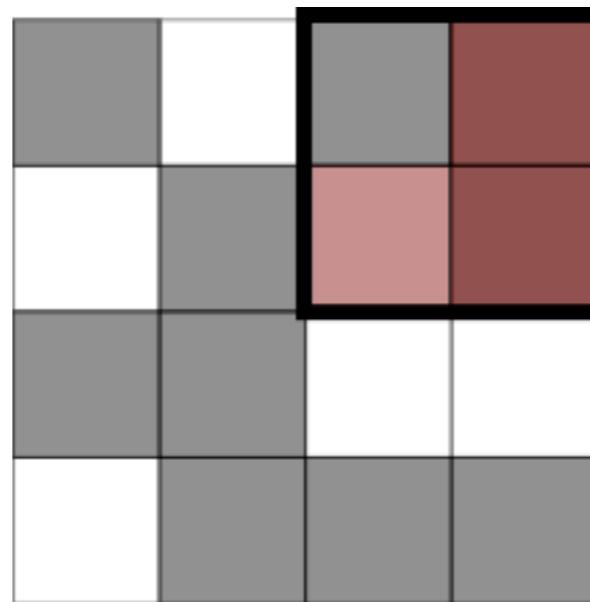
# Cross-Correlation



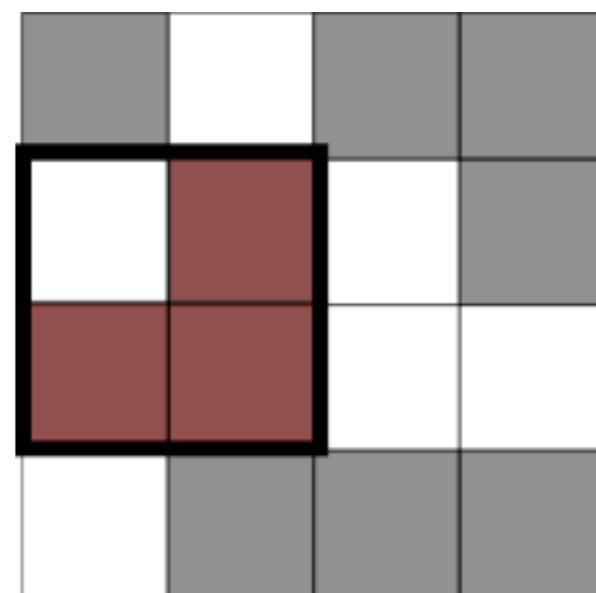
# Cross-Correlation



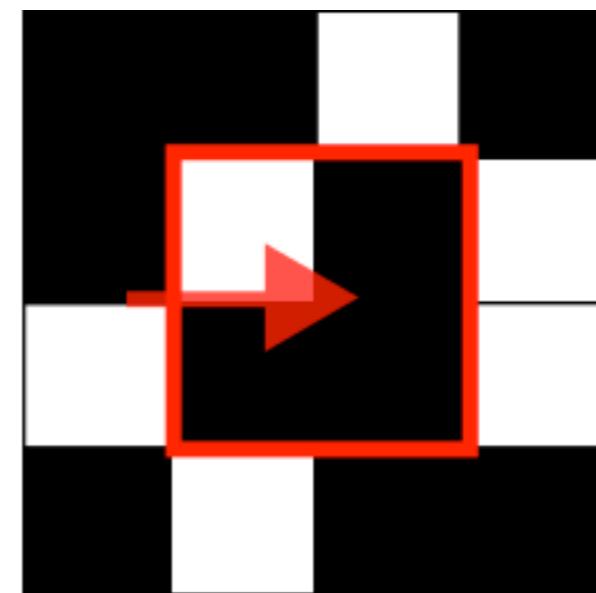
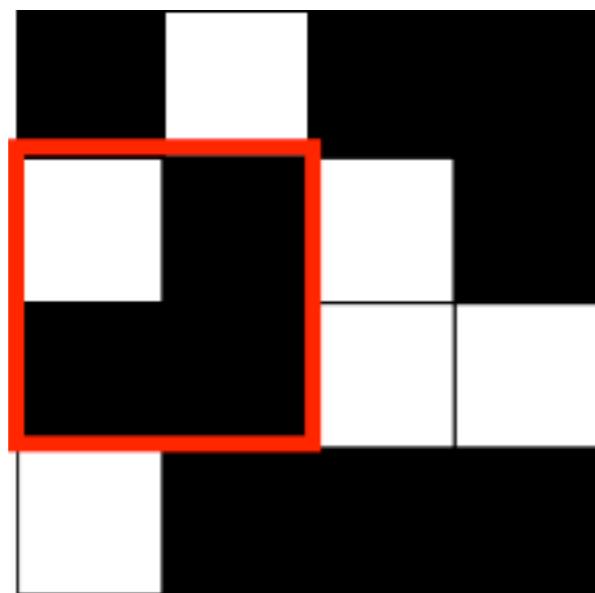
# Cross-Correlation



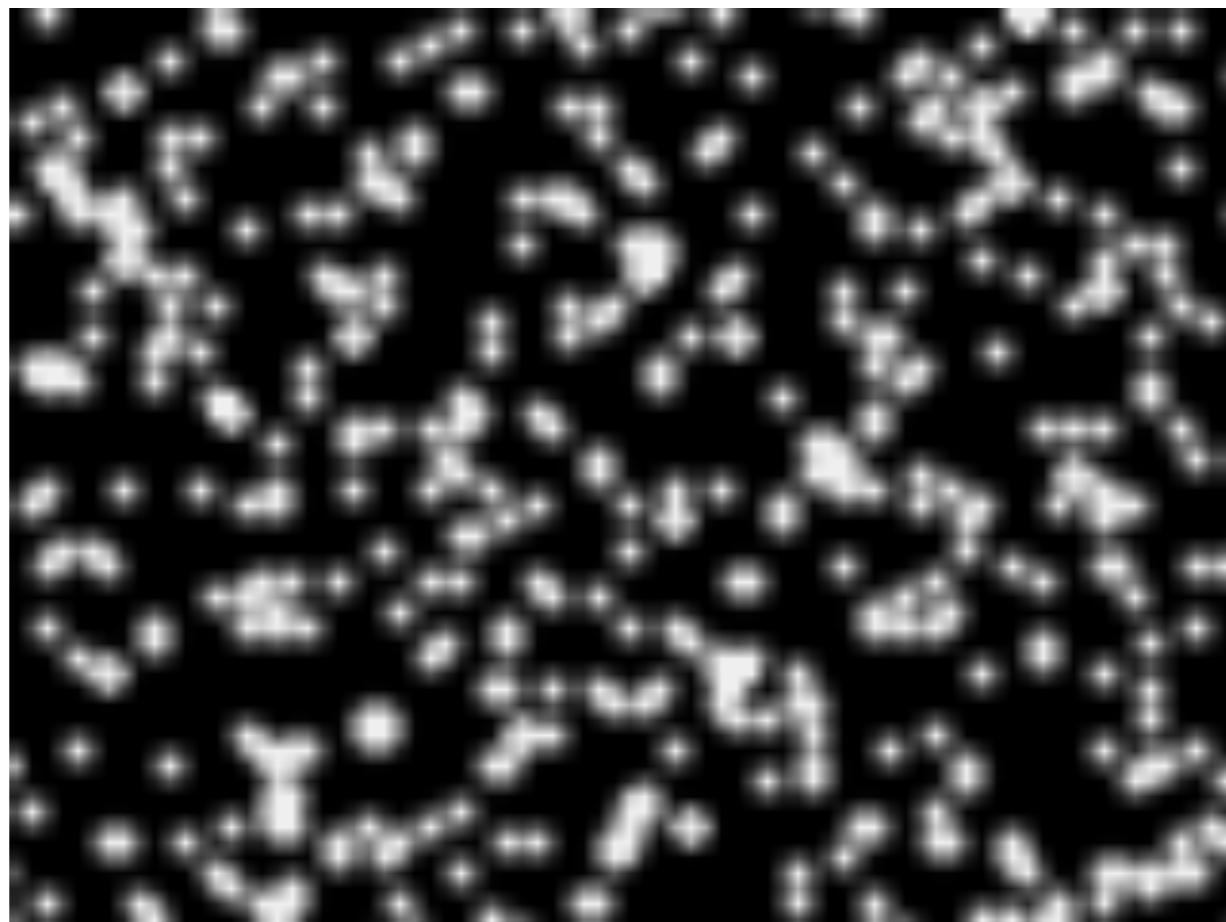
# Cross-Correlation



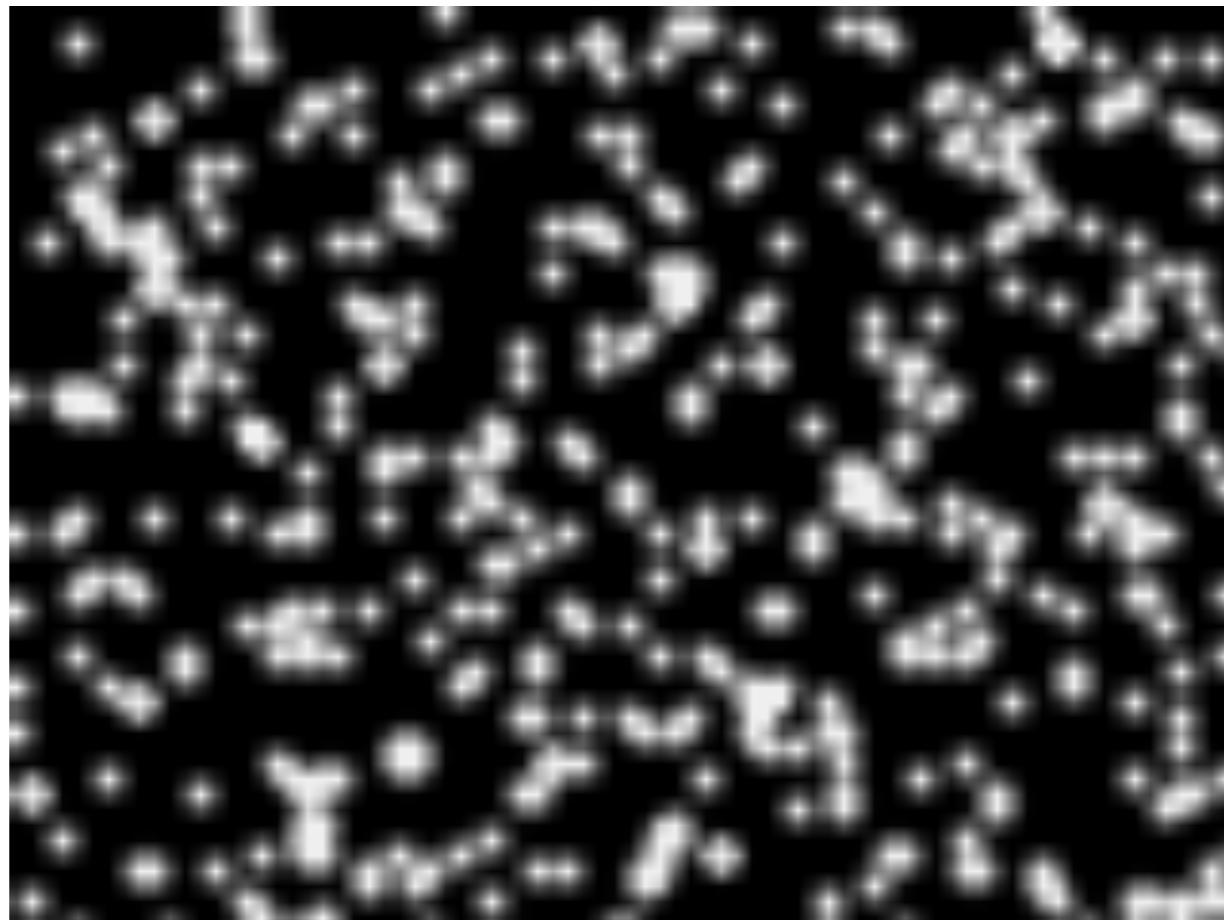
# Cross-Correlation



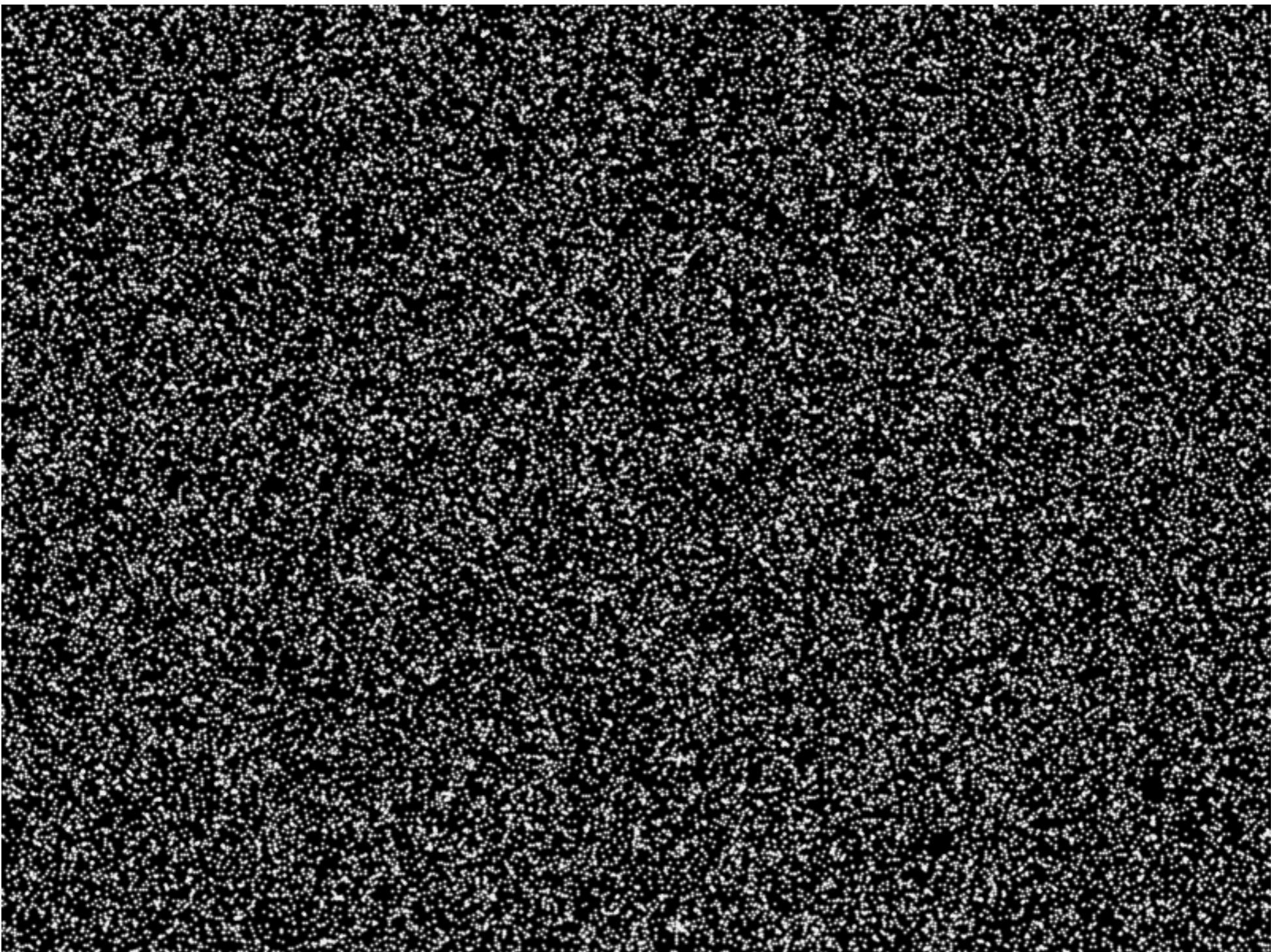
# PIV Example



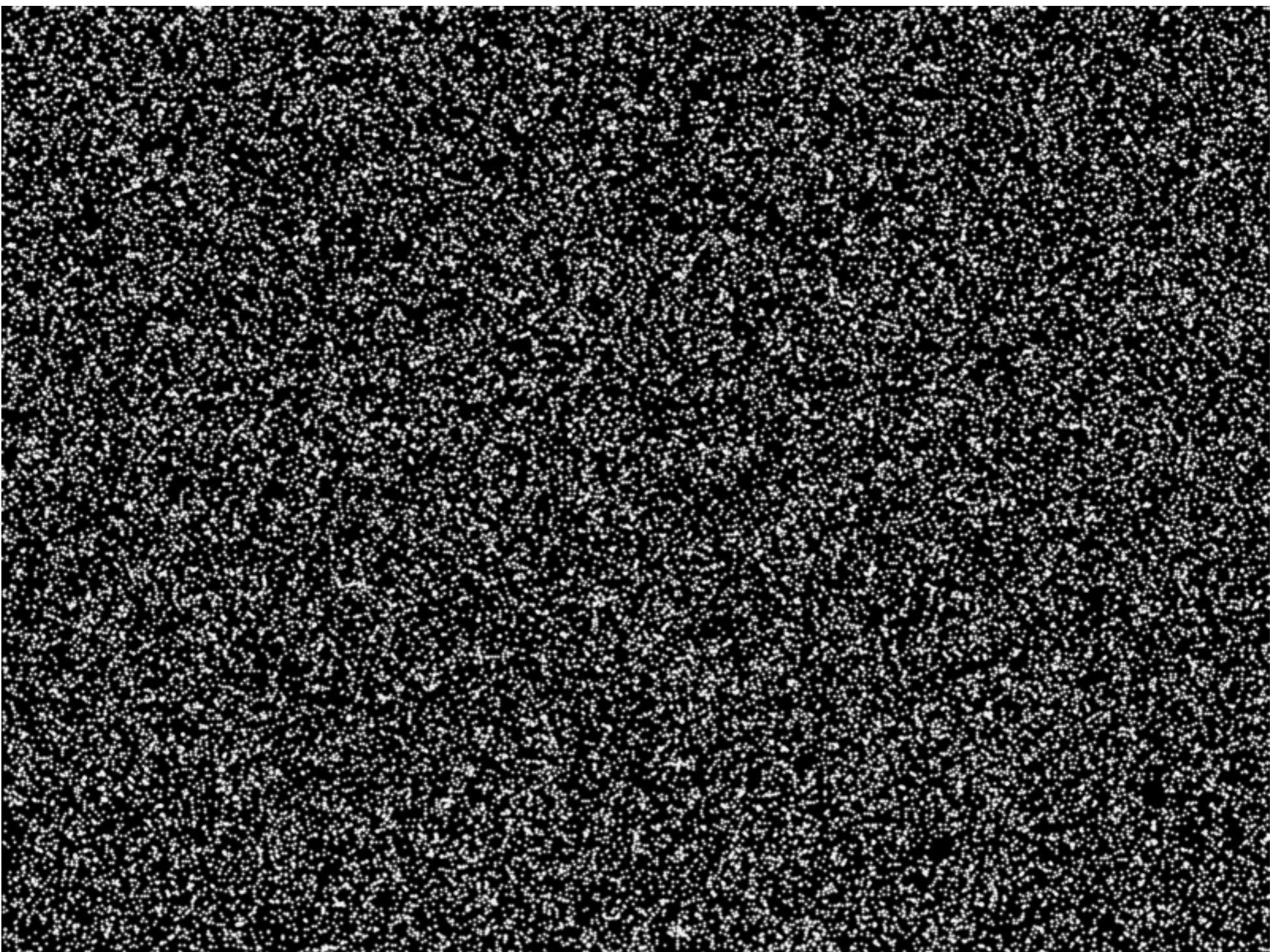
# PIV Example



# PIV Example



# PIV Example



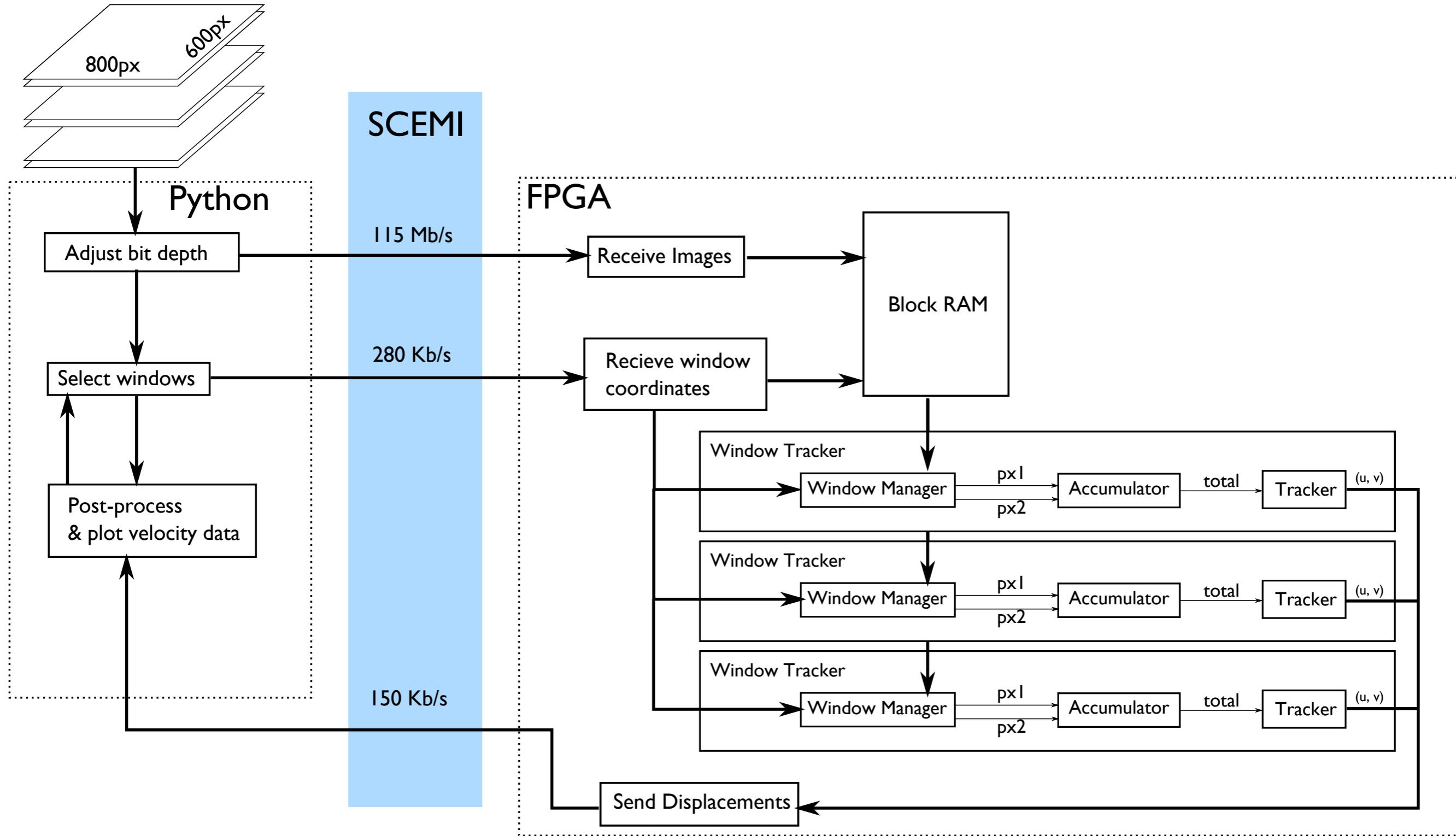
# Computational Requirements

- Cross-correlation window of 32x32 px
- 9x9 cross-correlation matrix (max. displacement of  $\pm 4$  px)
- 15 image pairs per second
- 800x600 px images, 1680 windows per image (every 8 px)
- $32 * 32 * 9 * 9 * 15 * 1680 \approx 2 \text{ billion}$   
**multiplications per second**

# Adaptive PIV

- Standard PIV:
  - Interrogation windows spaced evenly across image
- Adaptive PIV:
  - Use seed particle density and *previous* velocity estimate to control interrogation window size and placement
  - More information in busier regions

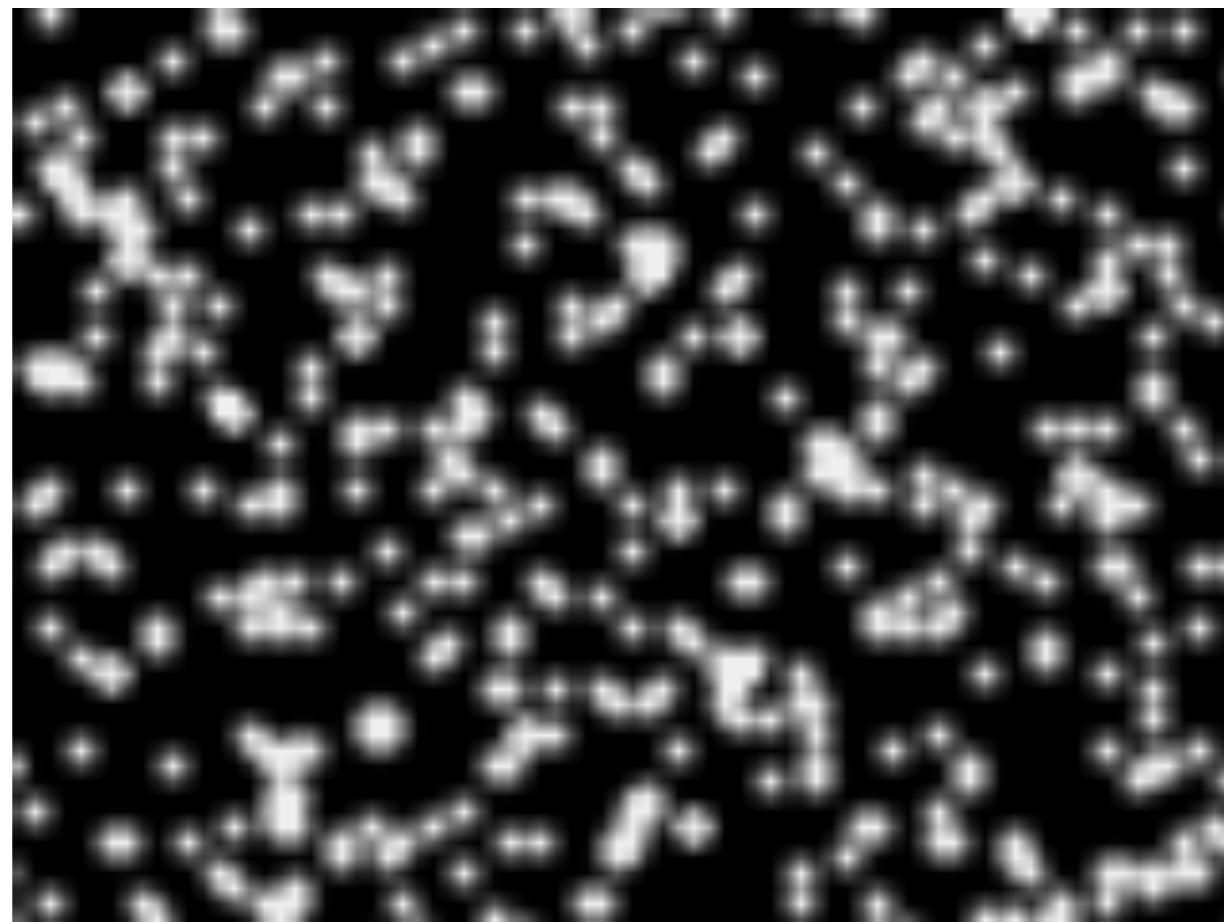
# PIV on FPGA



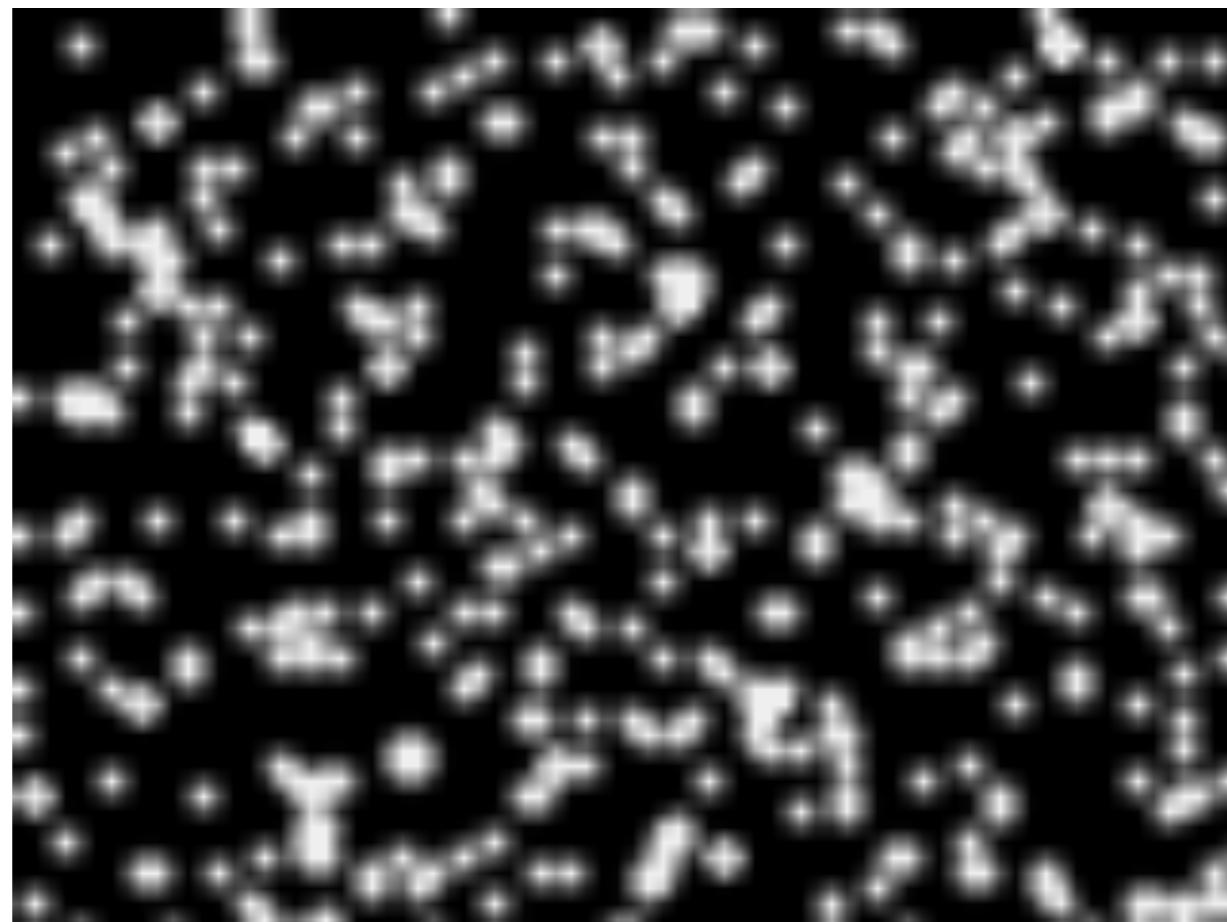
# Design Goals

- Many windows evaluated in parallel
- Flexibility for different PIV implementations
- Real-time image throughput

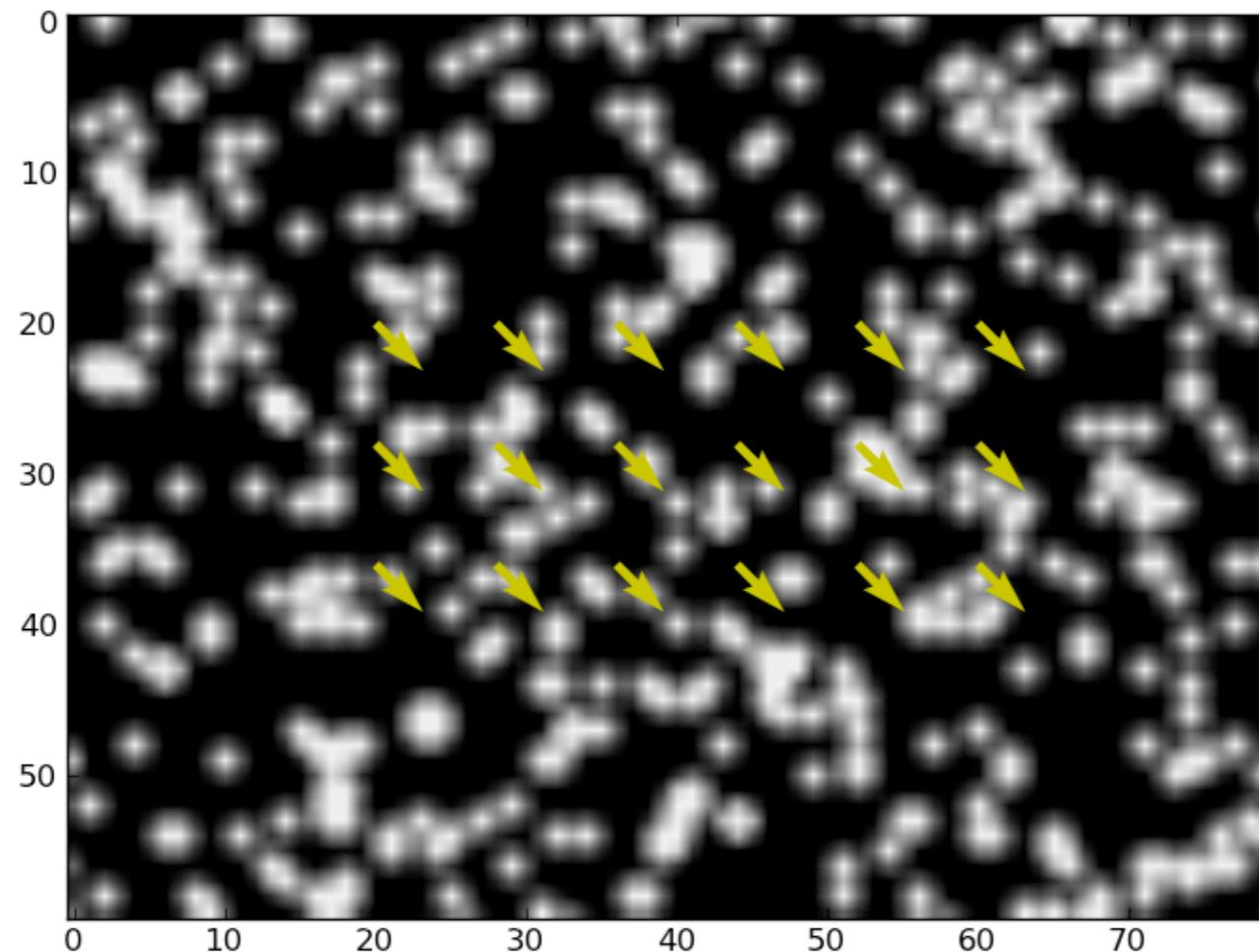
# Results: Small Images



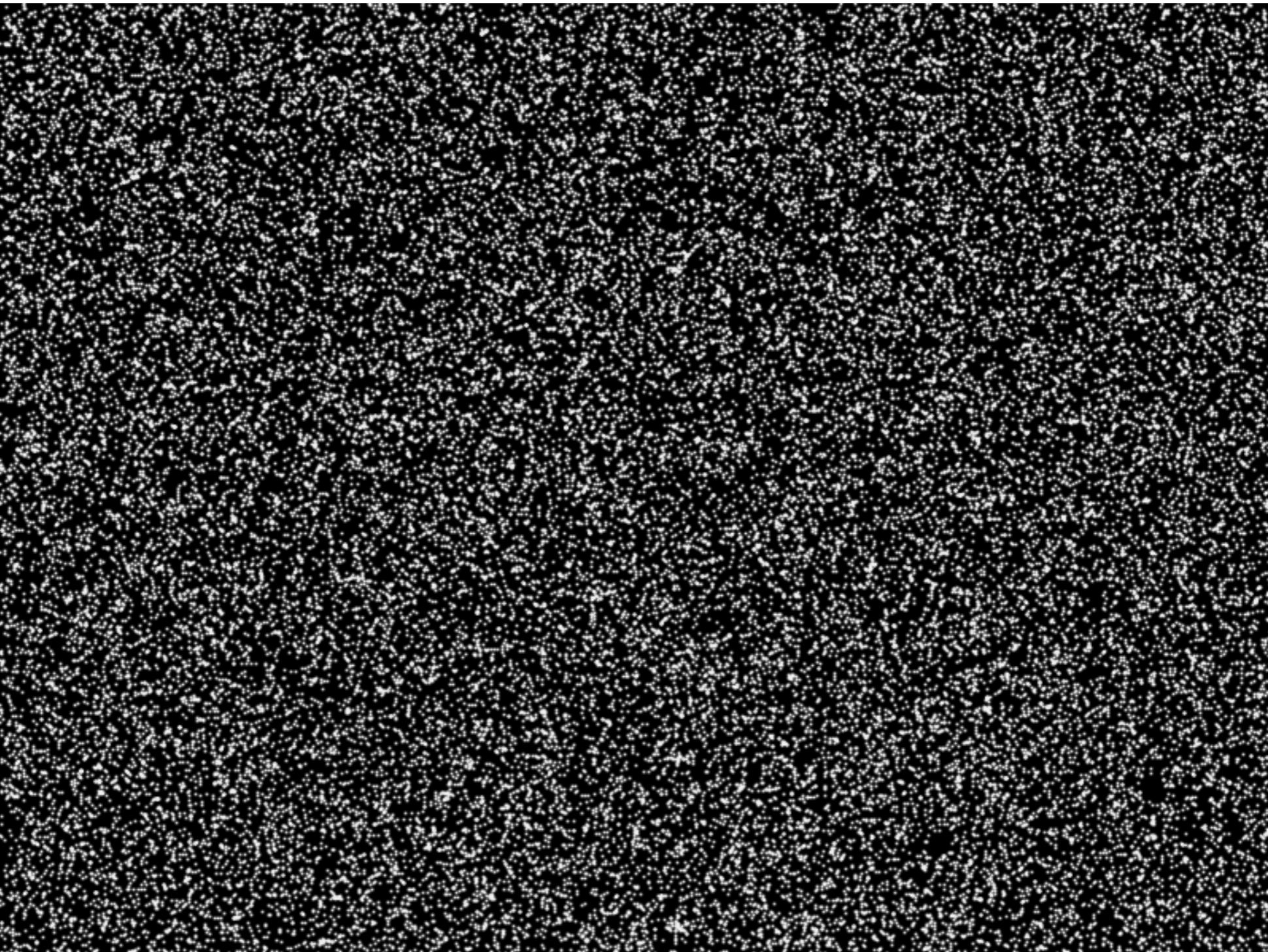
# Results: Small Images



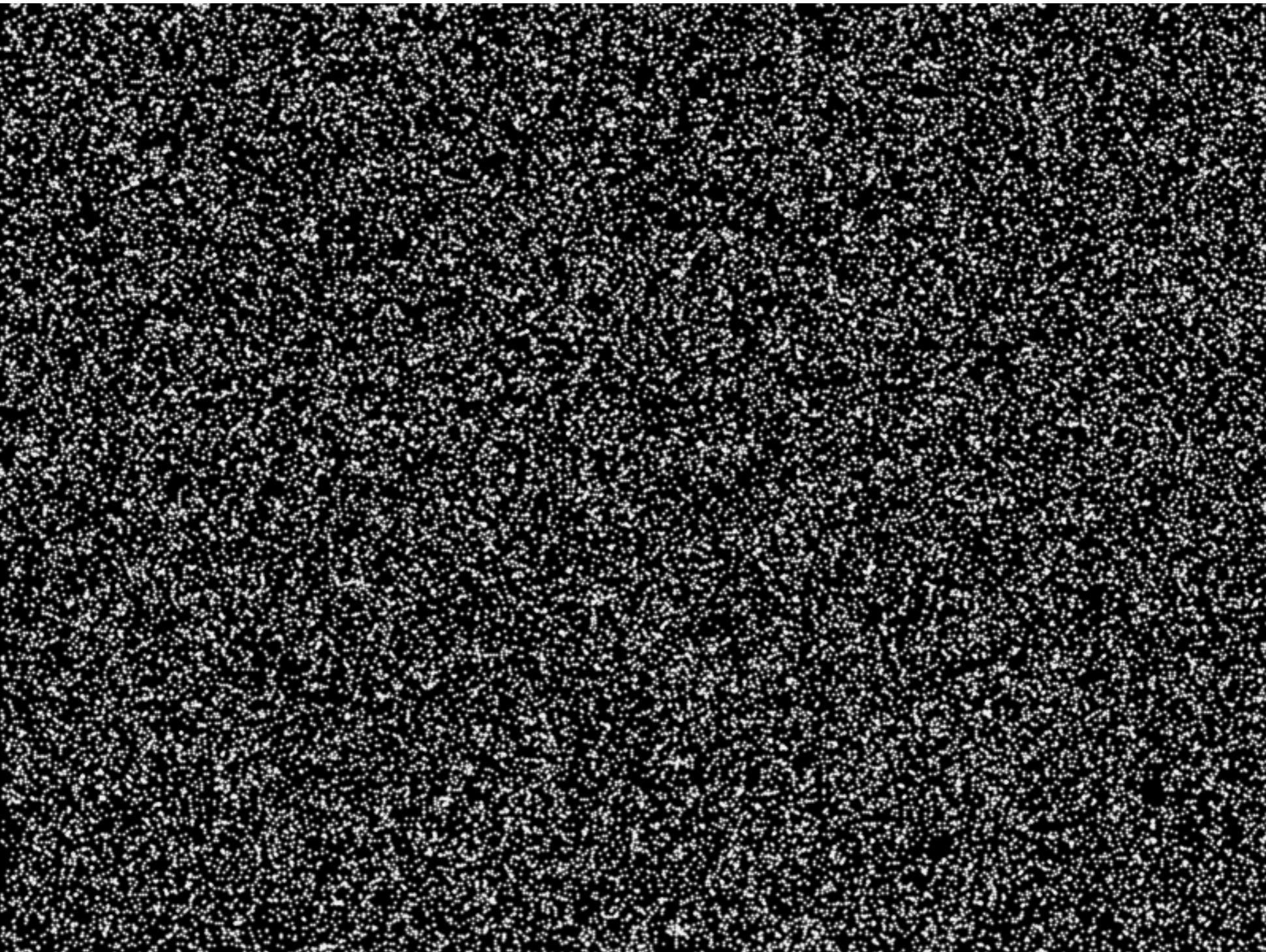
# Results: Small Images



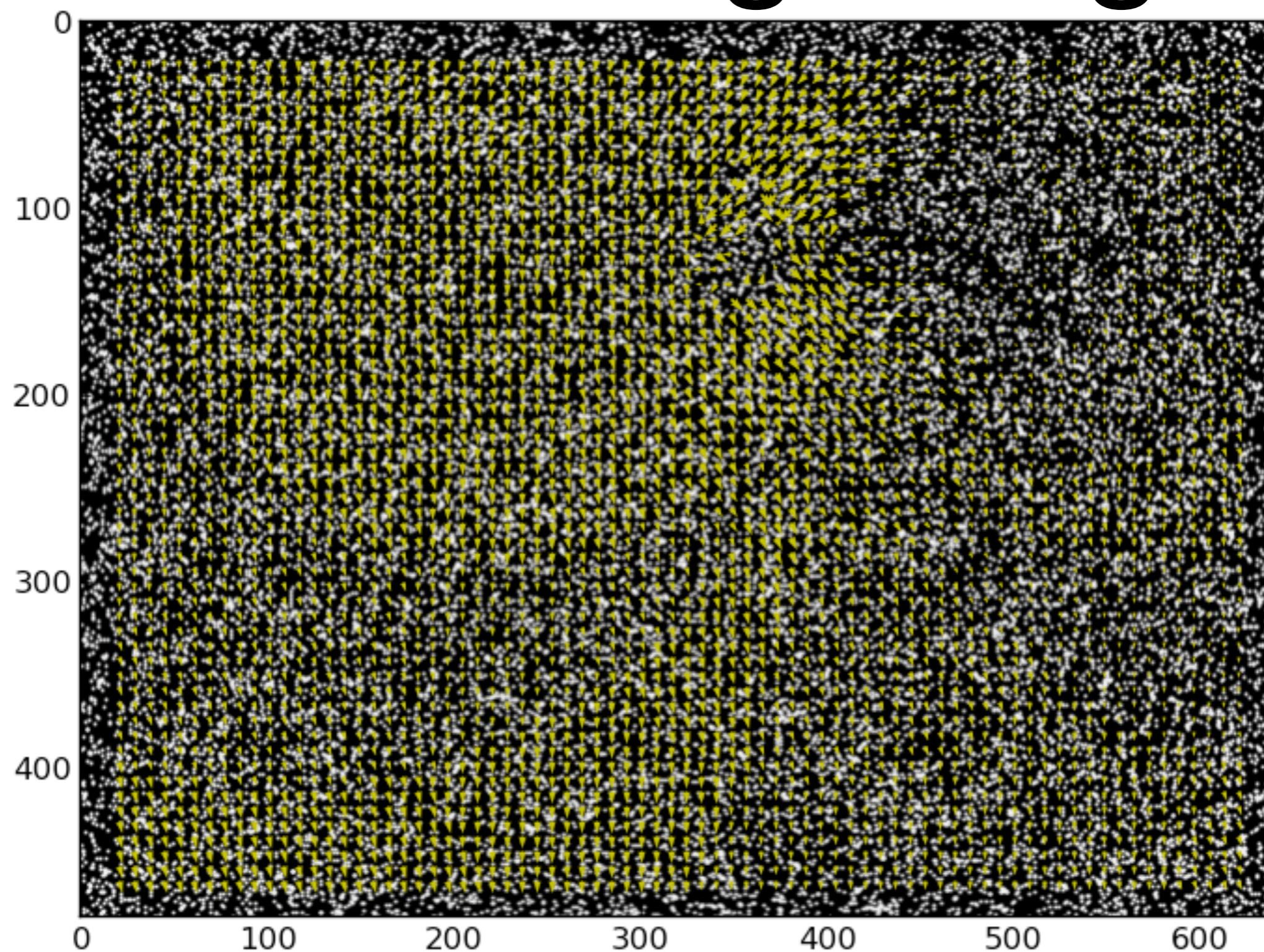
# Results: Large Images



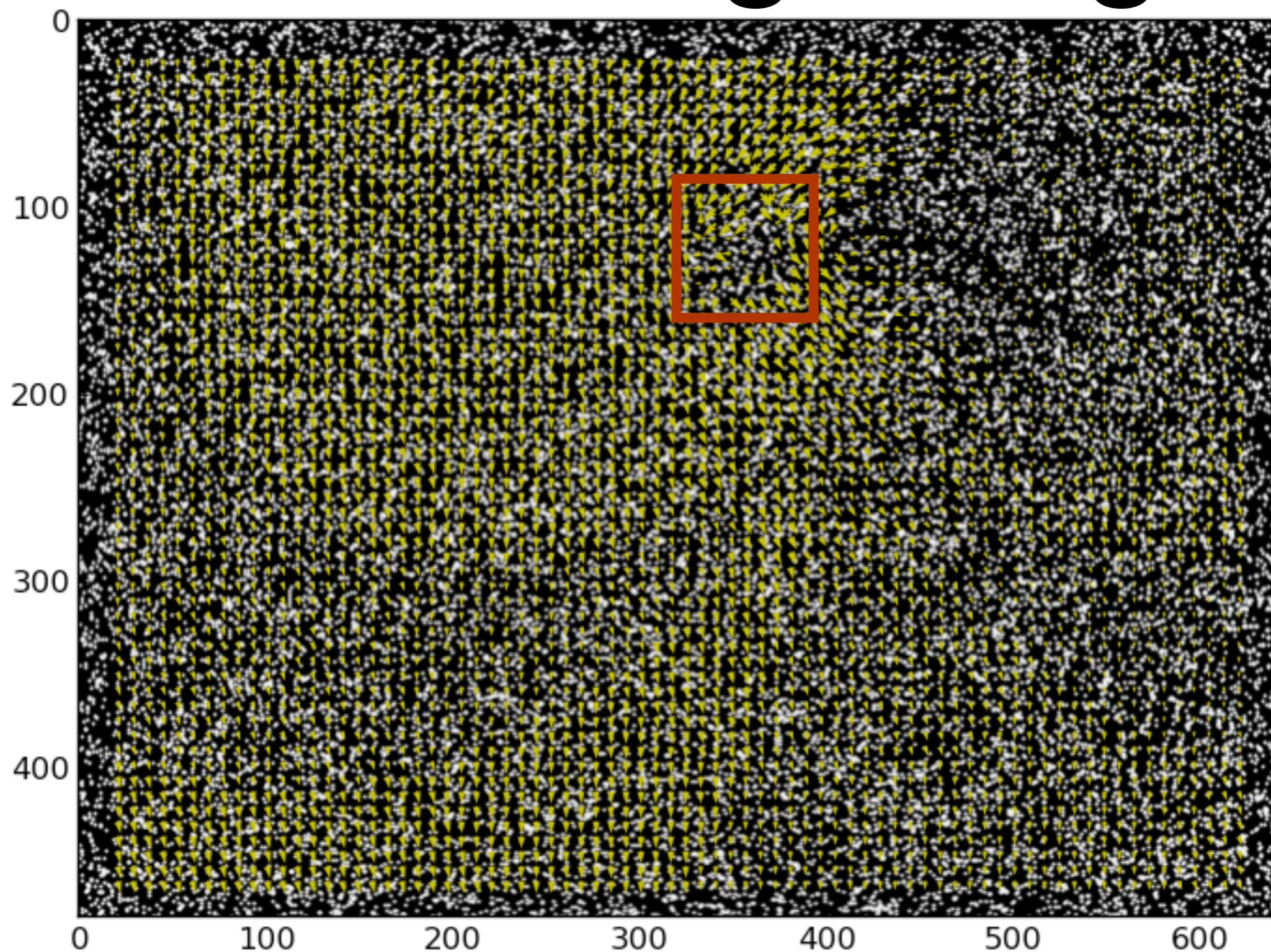
# Results: Large Images



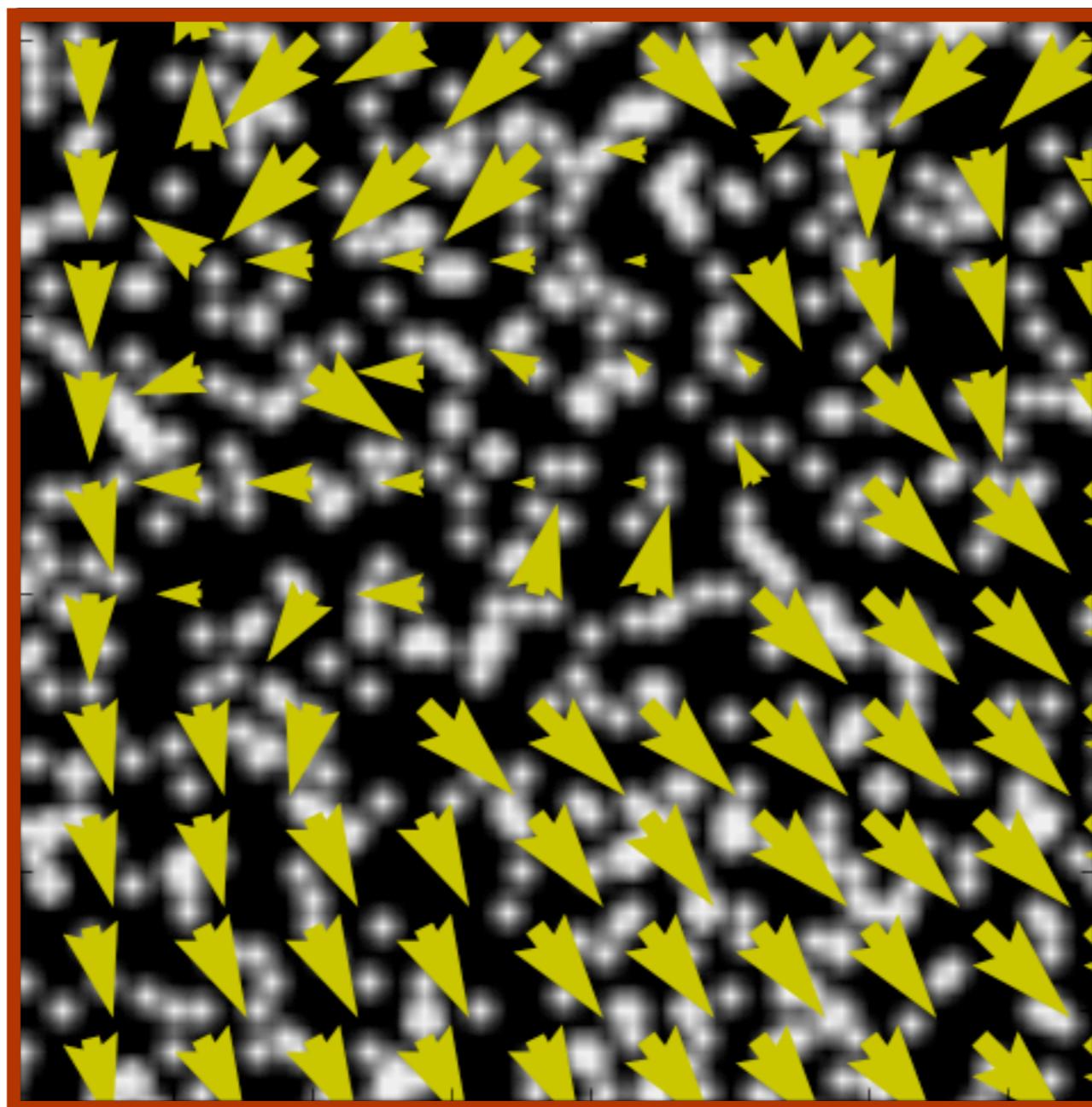
# Results: Large Images



# Results: Large Images

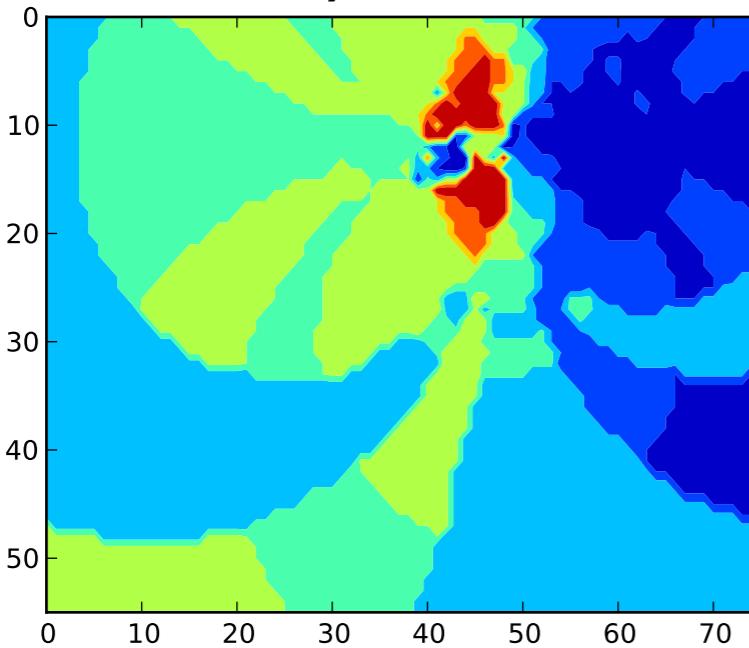


# Results: Large Images

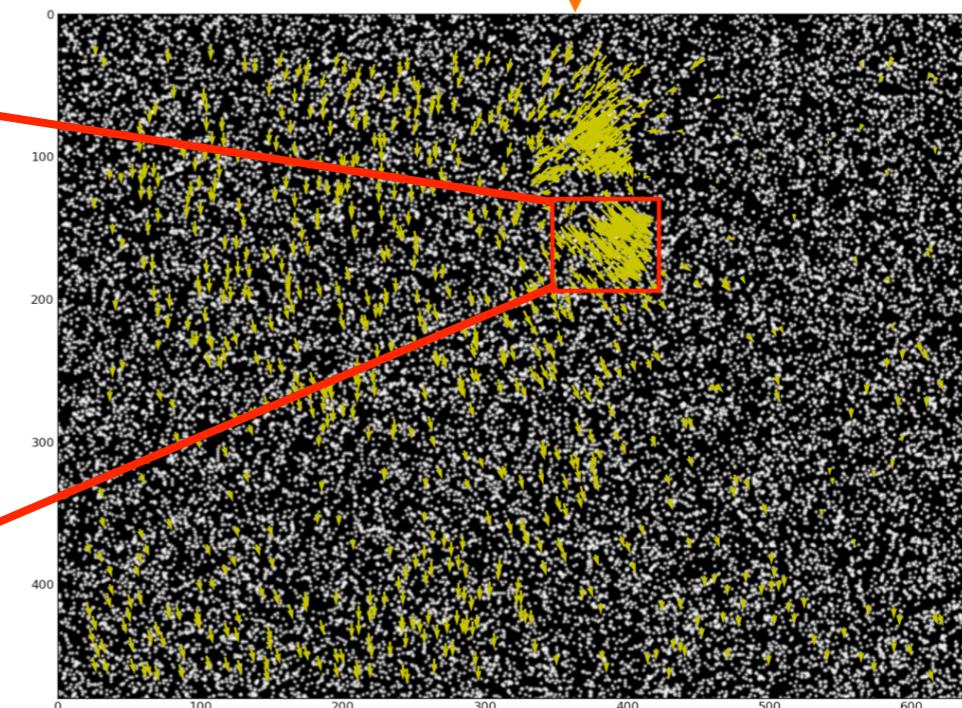
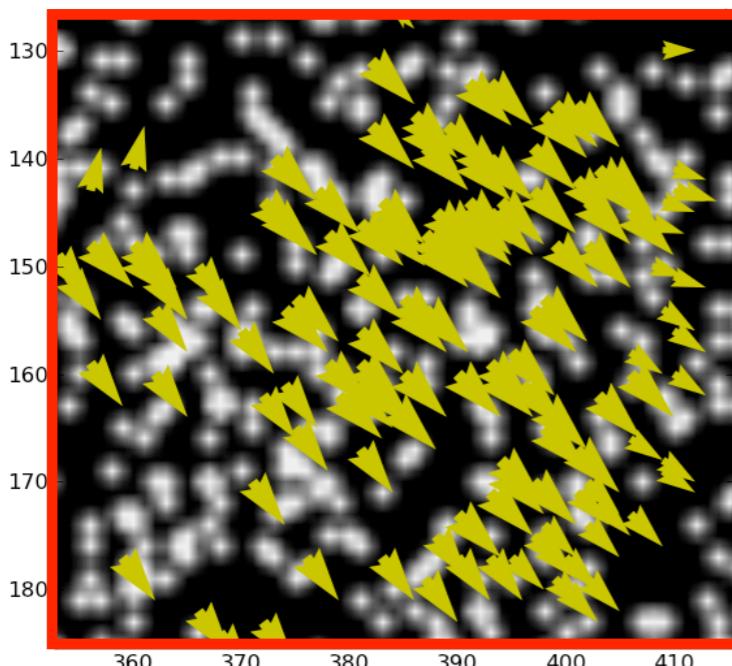
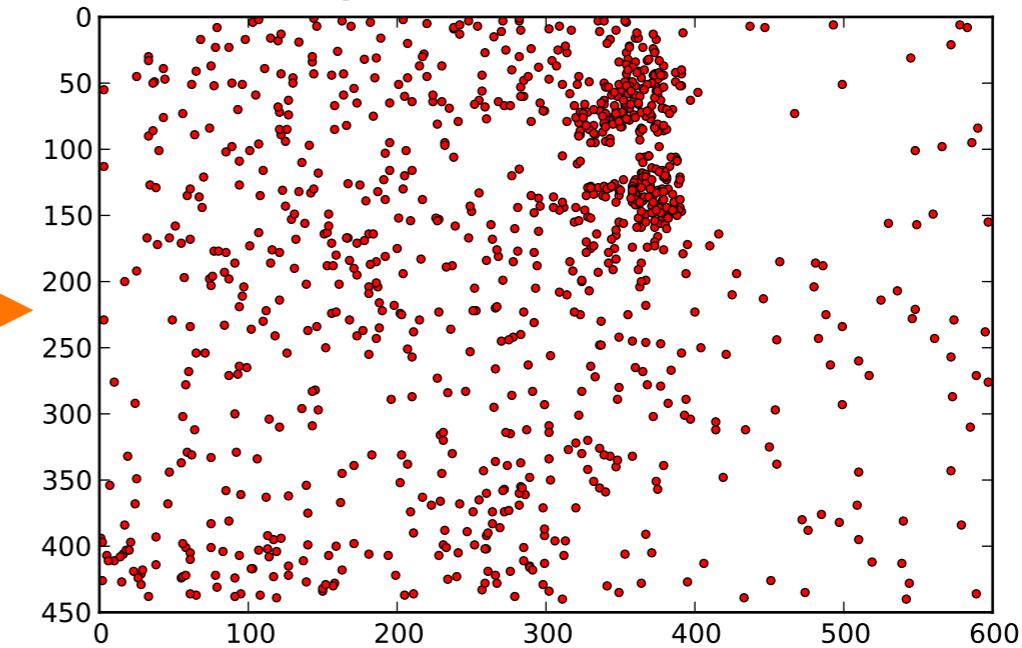


# Adaptive Sampling

Velocity Distribution



Sampled Window Locations



# Results: Performance

- 800x600 px images result in synthesis problems, 640x480 px more successful
- With 2 parallel tracking modules:
  - 18,000 32x32 px window displacements computed in 15 seconds
    - 100 million multiplications per second
    - Exactly as planned
  - Doesn't scale past two parallel modules yet

# Future Improvements

- Better RAM management to allow more parallel trackers
- Variable window size for adaptive PIV