Particle Image velocimetry (PIV) is currently the most widely used tool for investigating fluid flows. In PIV, image-processing algorithms estimate flow velocity by measuring the displacements of flow-tracer particles suspended in a fluid. The fundamental operation in PIV is the Fourier-based cross-correlation (CC), which yields the displacement relating two similar (but shifted) flow tracer image patterns. Recently, PIV is finding use in applications where the images contain excessive noise levels and depart from the fundamental conventions of the method, e.g. in microscopy, x-ray, ultrasound, etc., thus increasing errors and even, often times, causing the measurement to fail completely. Despite such shortcomings, little attention has been paid to fundamentally understanding and improving measurements at the level of the CC, which uses the same framework since its adoption by the PIV community, over 25 years ago.

In this talk I will show you a different way to look at, and interpret the Fourier-based cross-correlation. We will depart from the traditional spatially resolved CC and we will explore the structure of the CC in the Fourier phase space. From this new vantage point the signal reveals itself amidst the noise. Using this insight, we developed a model of PIV cross correlations that explains the fundamental sources that drive the measurement error and we show how the shapes of the tracer particles and the distributions of their displacements affect the correlation signal to noise ratio (SNR). We then develop an algorithm that automatically generates a dynamic Fourier-based weighting filter, and demonstrate its improved accuracy and robustness.

Finally, we apply the above framework in two applications where traditional PIV fails. First, measuring the motion of 3-4nm diffusion dominated nanoparticles with laser scanning confocal microscopy, and second to measure blood flows in the beating hearts of grasshoppers using x-ray PIV. For the former, we are able to extend the applicability and accuracy of PIV to probe flow in nanoscales. In the latter, we discovered a flow process that is contrary to the current prevailing understanding of the insect heart as a producer of directional flows.