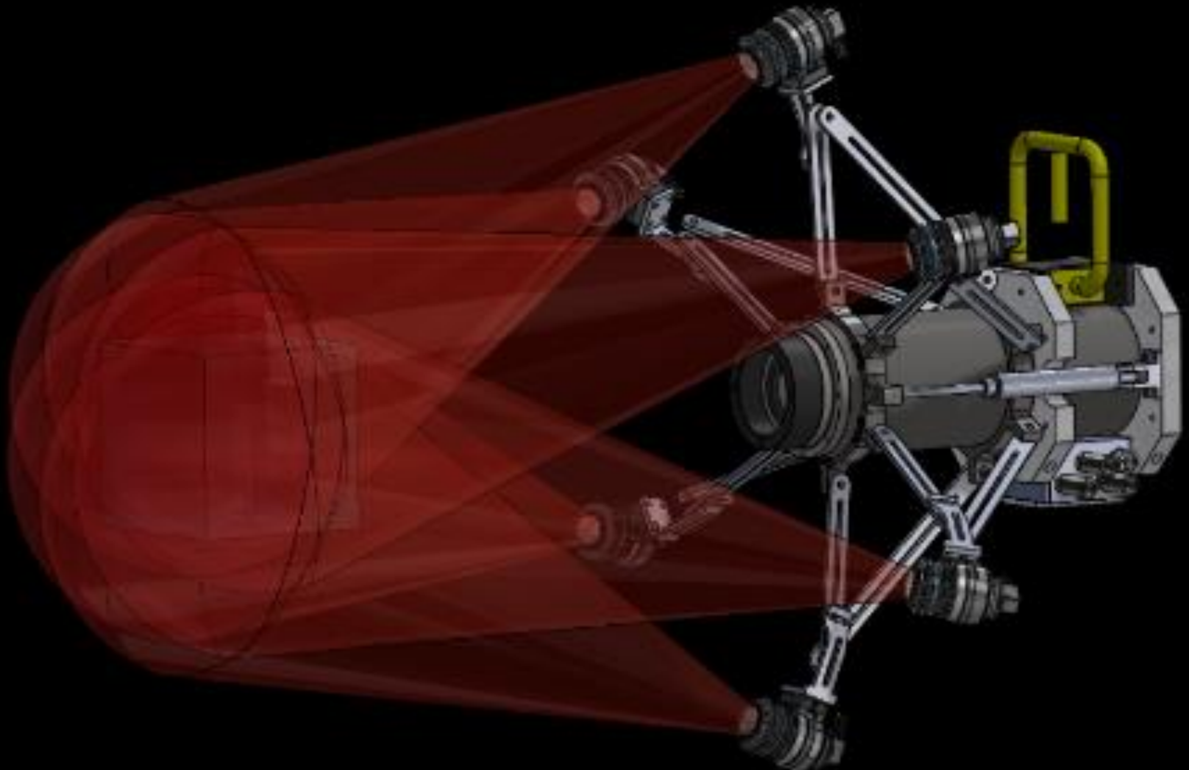
A three-dimensional, high-resolution, in situ particle and flow imaging instrument (EyeRIS)



Paul L. D. Roberts, Kakani Katija, Henry Ruhl, Alana Sherman, Denis Klimov, Jon Erickson, Rich Henthorn

GORDON AND BETTY MOORE FOUNDATION

Monterey Bay Aquarium Research Institute

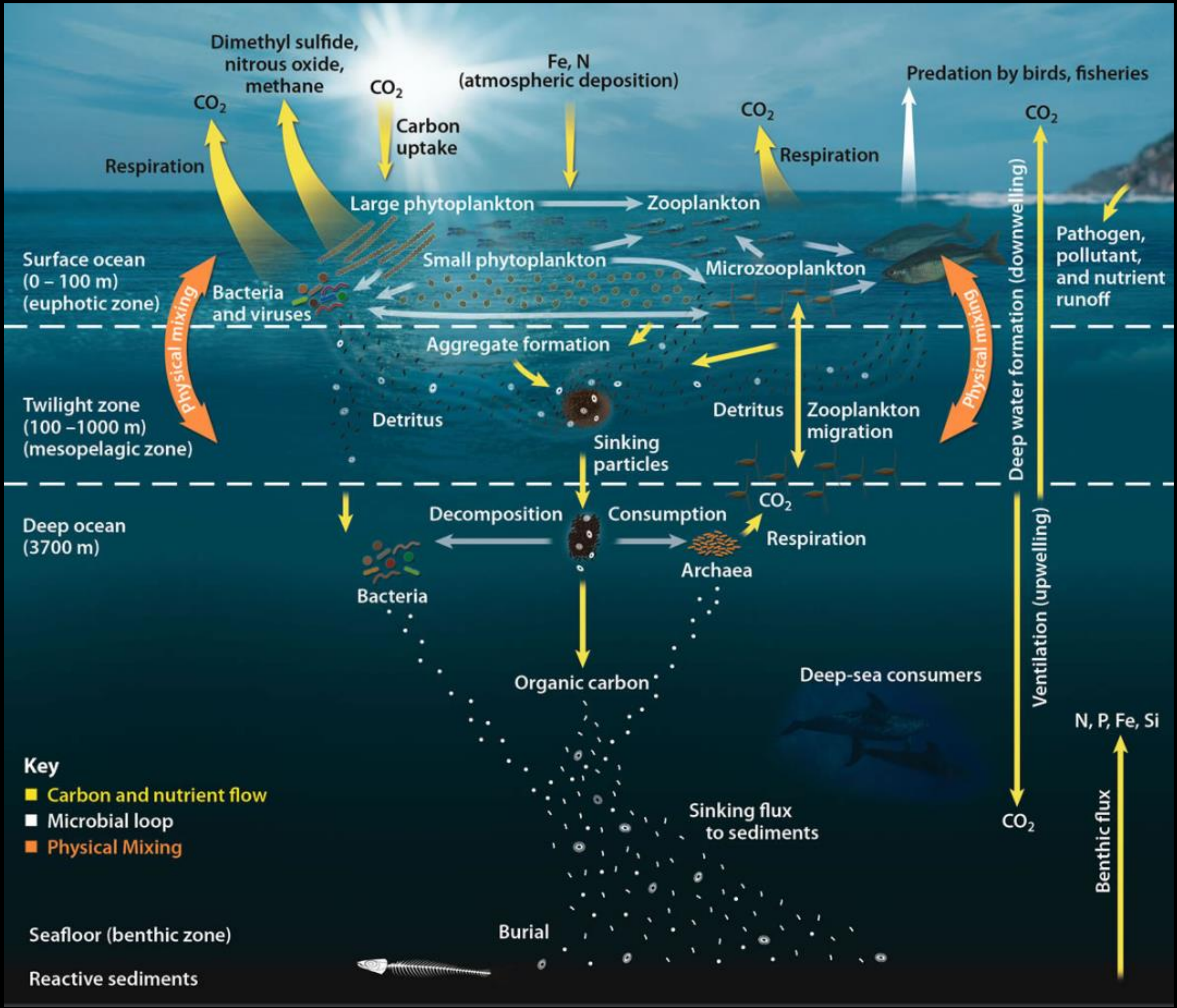
3rd Marine Imaging Workshop
June 25th 2019 – Victoria, BC

Fine-Scale Biophysical Interactions

Scales
- Microns to centimeters
- Days to years

Organisms
- Phytoplankton
- Zooplankton
- Marine Snow

Metrics
- Object size
- 3D distribution
- Fluid flow
- Behavior



The Ocean Carbon Cycle. Image credit: Oak Ridge National Laboratory

Fine-Scale Biophysical Interactions

Scales

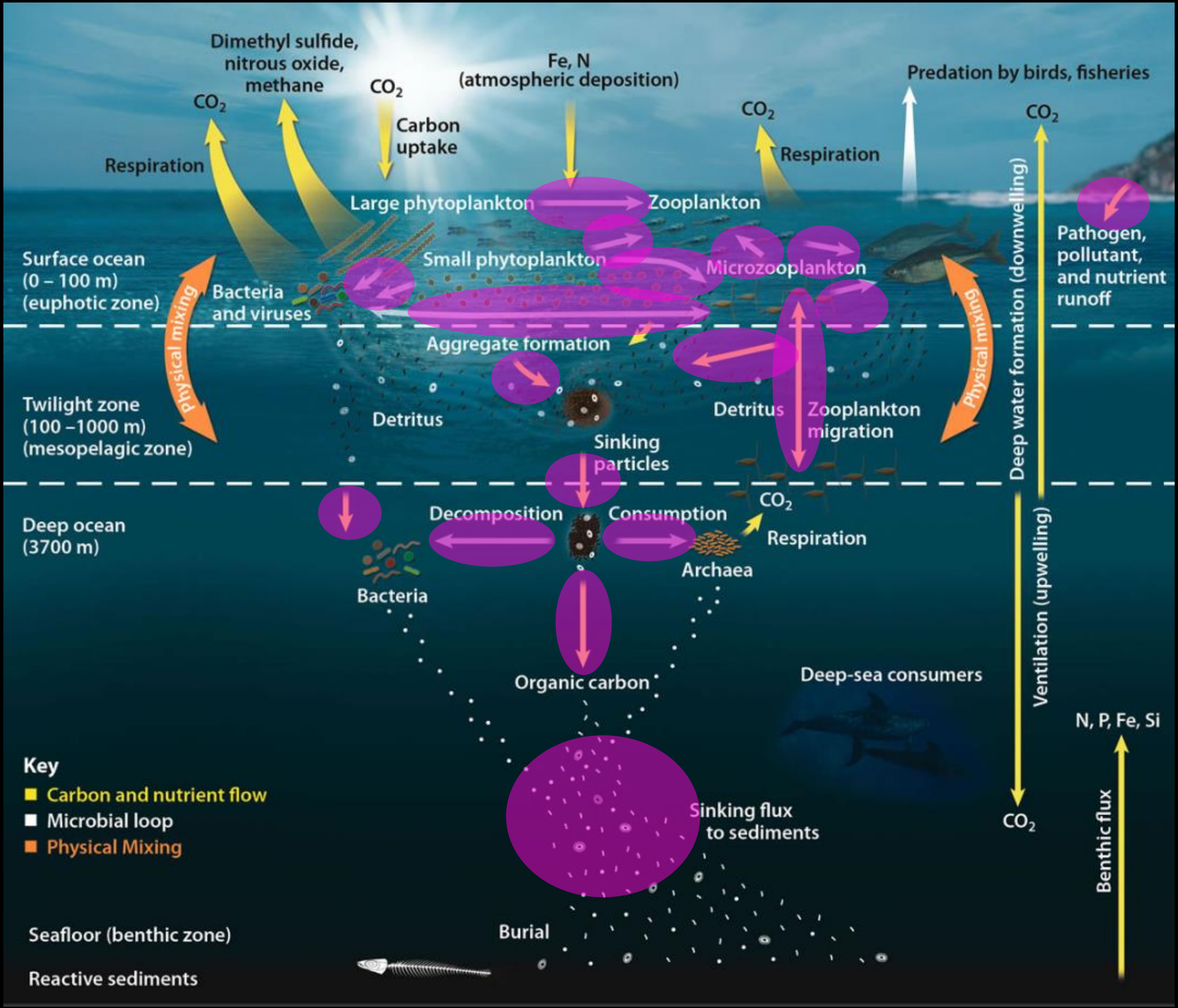
- Microns to centimeters
- Days to years

Organisms

- Phytoplankton
- Zooplankton
- Marine Snow

Metrics

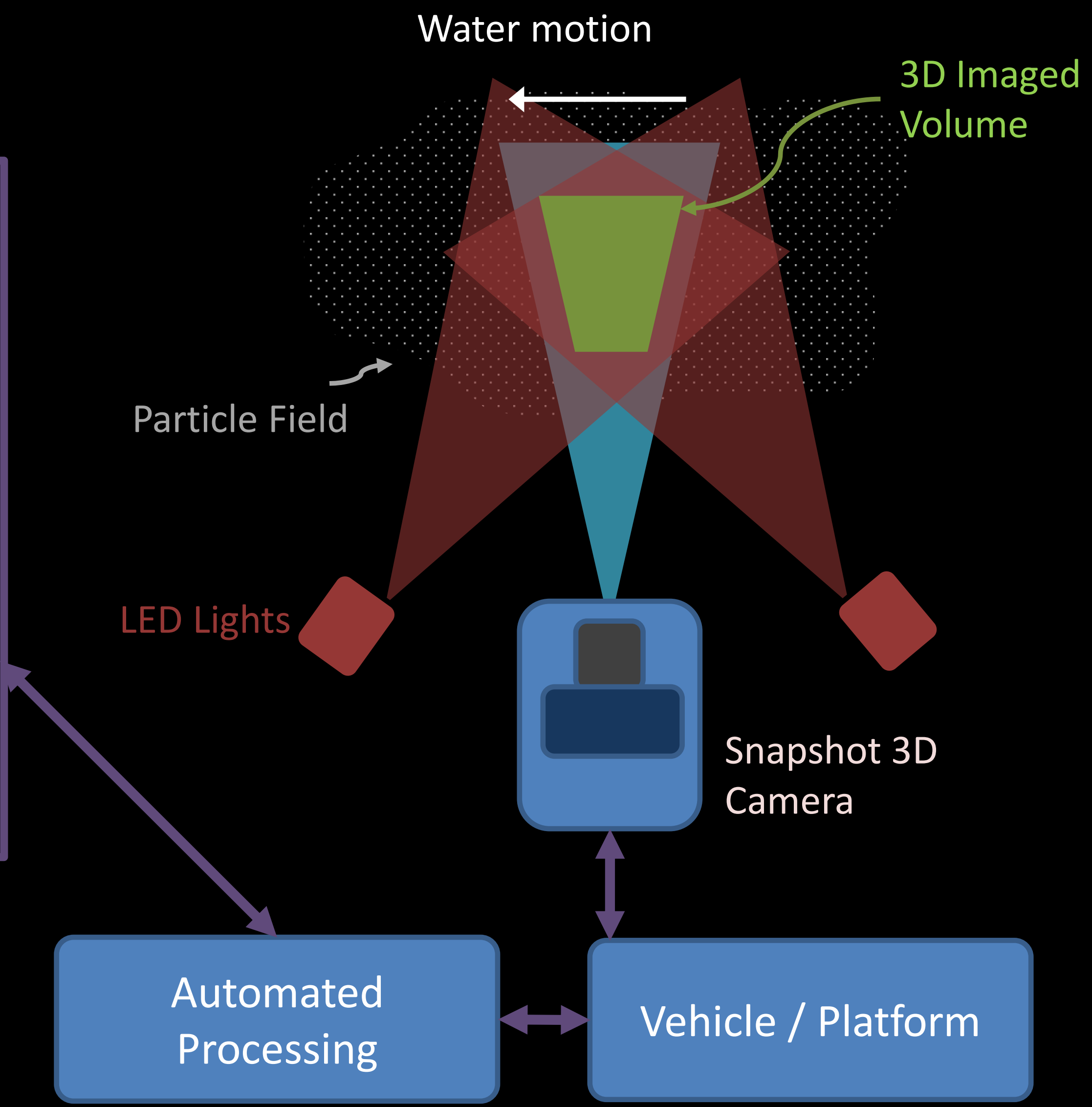
- Object size
- 3D distribution
- Fluid flow
- Behavior



The Ocean Carbon Cycle. Image credit: Oak Ridge National Laboratory

System Concept and Science Objectives

- In situ 3D particle distributions
- In situ 3D velocity fields
- Particle size and concentration



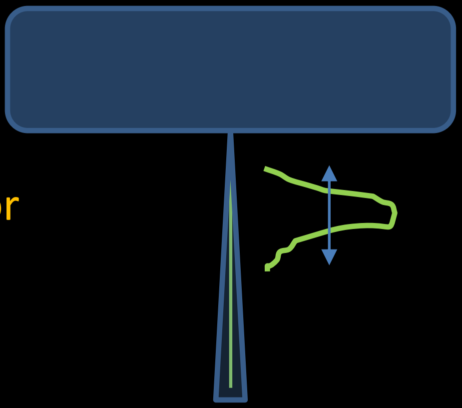
Why 3D?

- Plankton and particles live in a 3D fluid environment
- 2D cameras project this 3D environment and loose important spatial information
- With 3D imagery one can
  - Make more accurate size and flow measurements
  - Reduce ambiguity in imaged volume, nearest neighbor distance, cell concentration
  - Construct a more accurate representation of the particle/fluid-flow environment

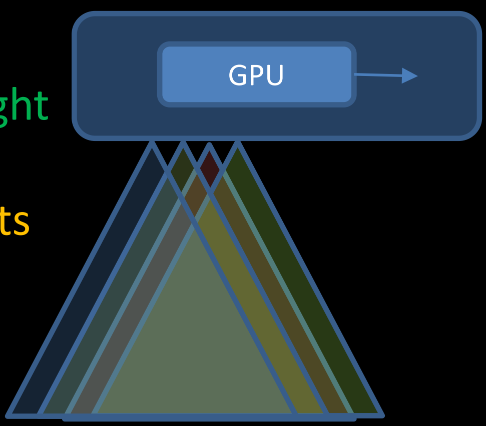
In Situ 3D Imaging Methods

Stereoscopic
- Inexpensive hardware
- Trades light collection for imaged volume

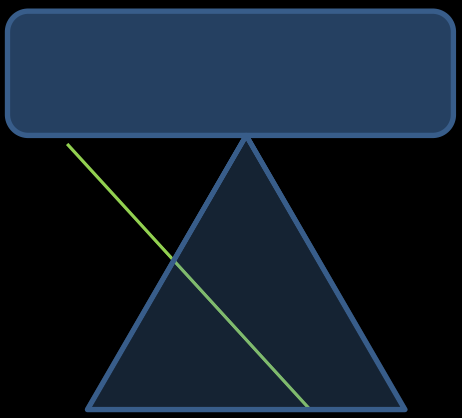
Time of Flight
- Does not require object texture
- Limited resolution for particles



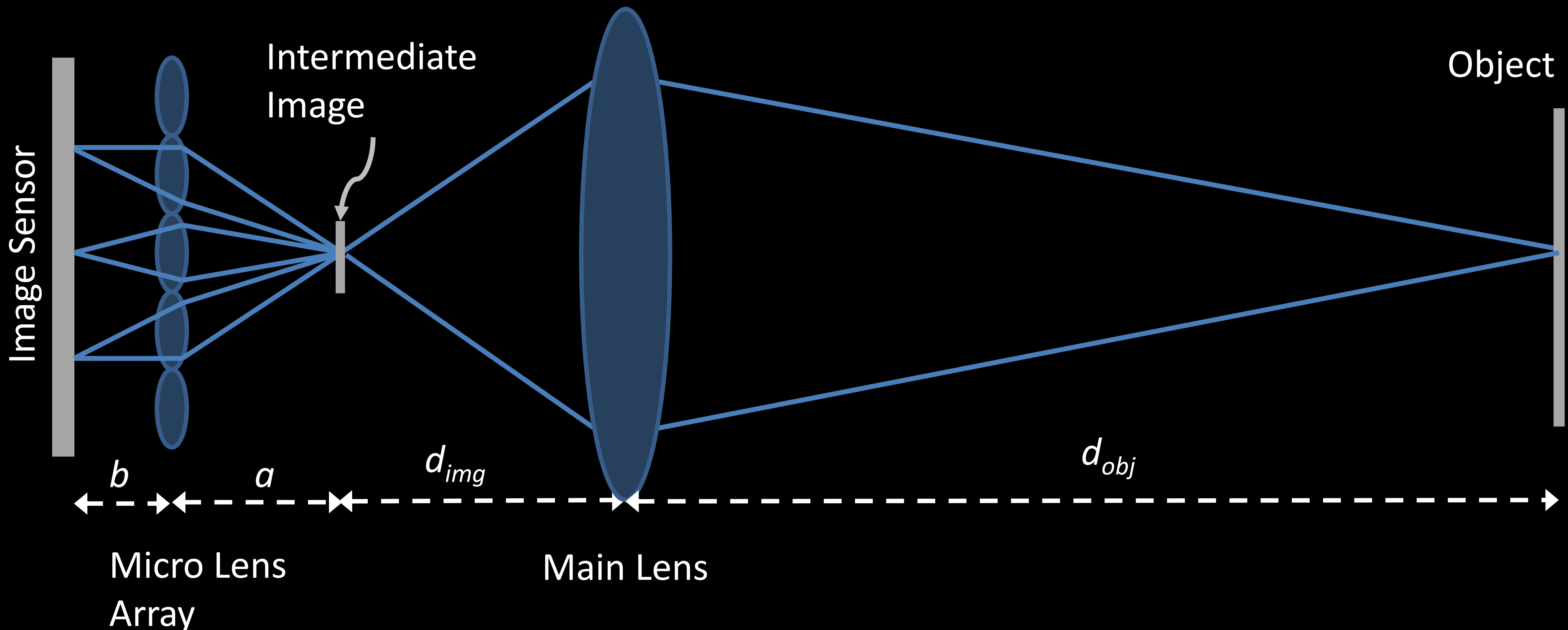
Plenoptic
- Excellent light collection
- Requires lots of pixels



Structured Illumination
- Does not require object texture
- Sensitive to water turbidity



Plenoptic Imaging



- Microlenses act as a miniature camera array
- Image the same point in the intermediate image from multiple perspectives on to the sensor
- ***3D position information for each point on Object***

Advantages of Plenoptic Imaging for Particles

- 3D volume is generally sparse
  - Can recover particle images at the resolution of the sensor
- Point correspondence estimation is simplified (compared to stereo) by point-like image of particle and multiplicity of microlens array geometry
- Can apply additional constraints to localize particles in 3D

Commercial Plenoptic Cameras

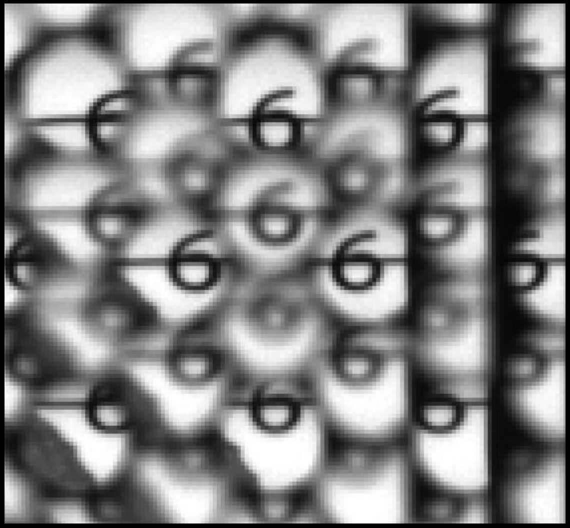
Raytrix R26 Camera
(High-Speed Flow Visualization)

26 MP sensor, 6 MP effective resolution
80 FPS max
CoaXPress CXP-6 Quad interface
Power < 13 W
Requires high-speed bus and desktop-sized
Frame-grabber and GPU

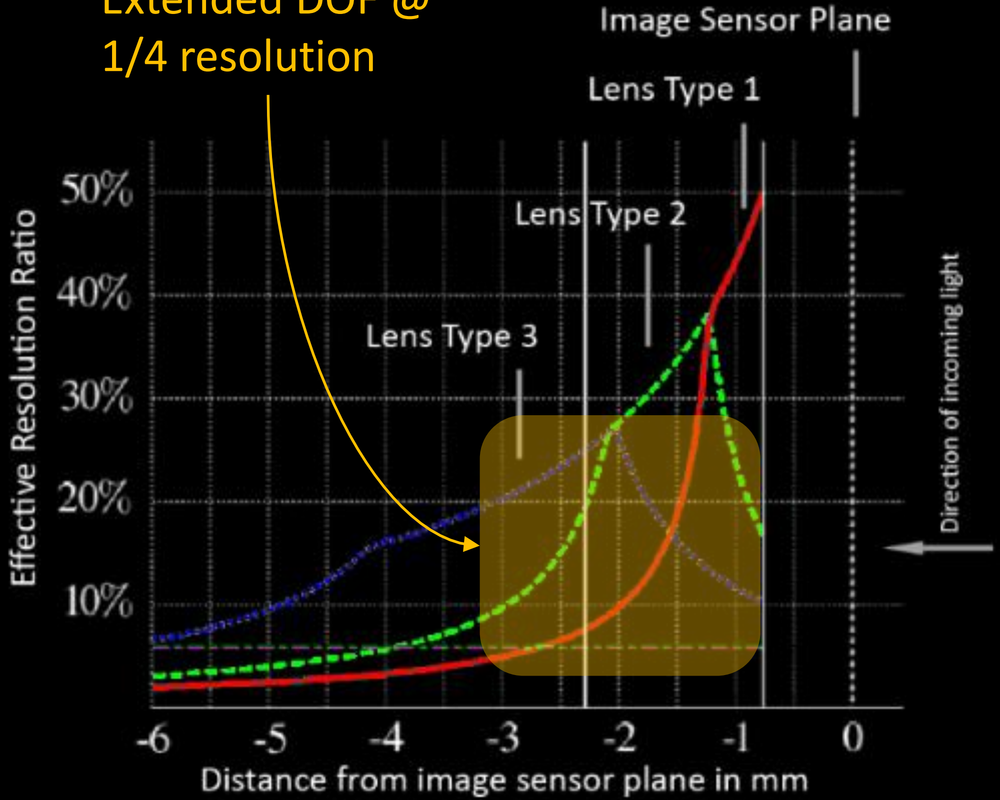
Raytrix R42 Camera
(High-Resolution, Compact, Embedded)

42 MP sensor, 10 MP effective resolution
7 FPS max
USB3 interface
Power < 4 W
Easy to integrate with embedded GPU

Multi-Focus Plenoptic Imaging



Extended DOF @
1/4 resolution



Plentoptic Image Reconstruction

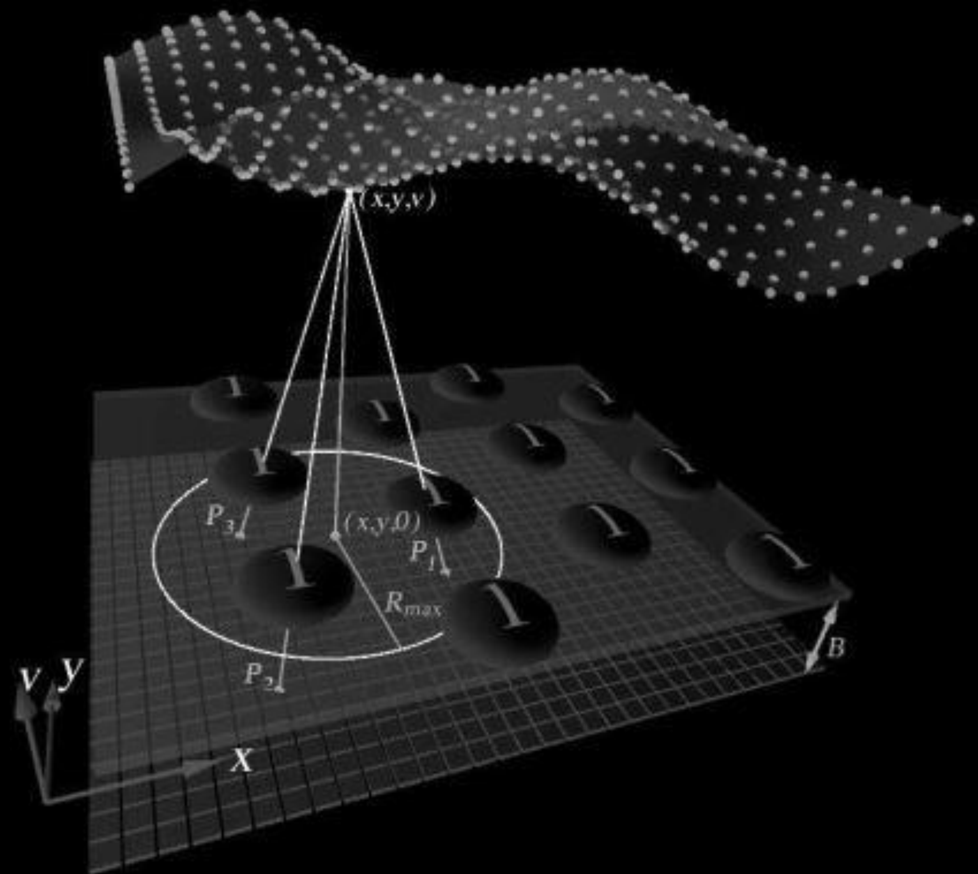
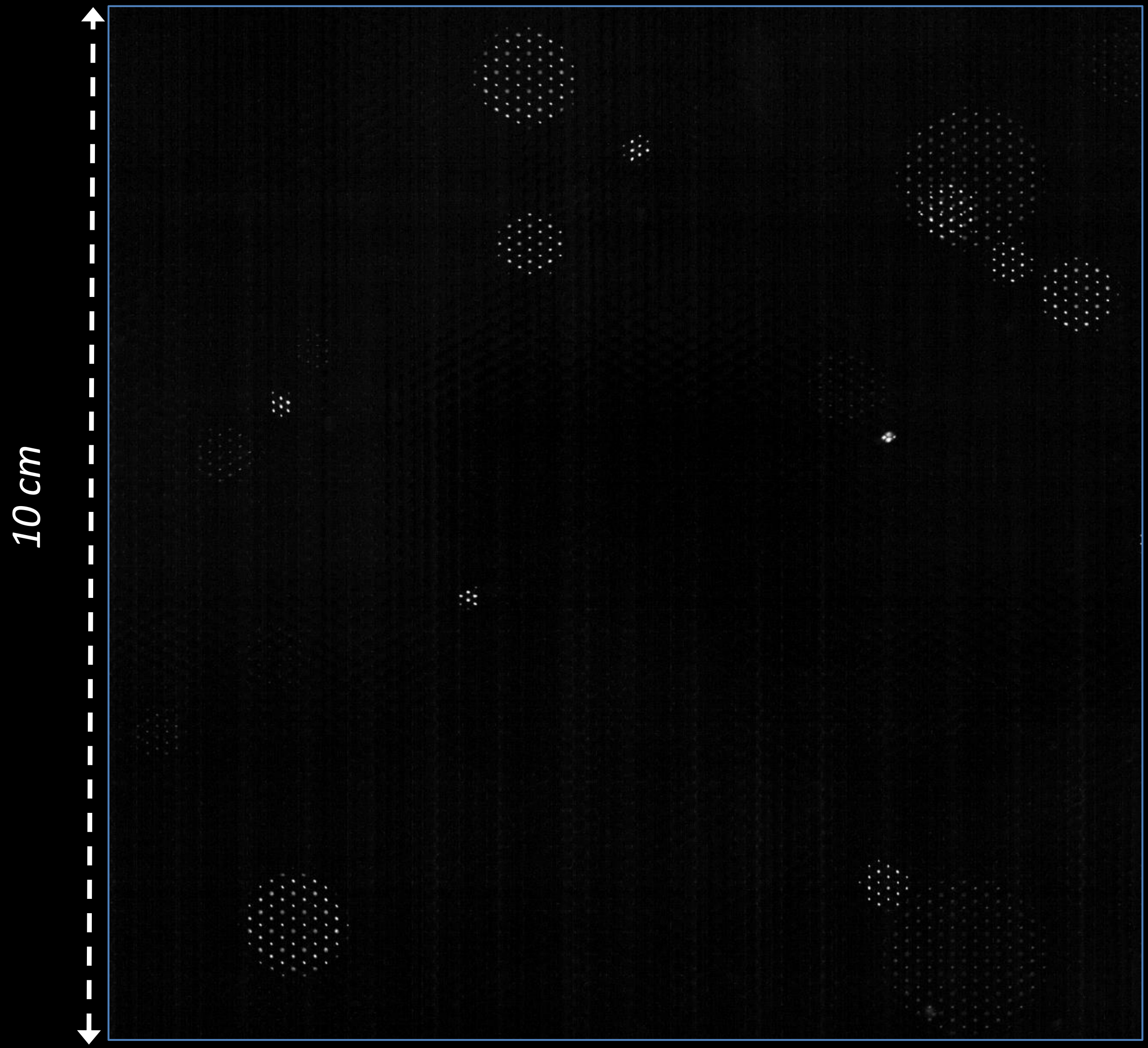


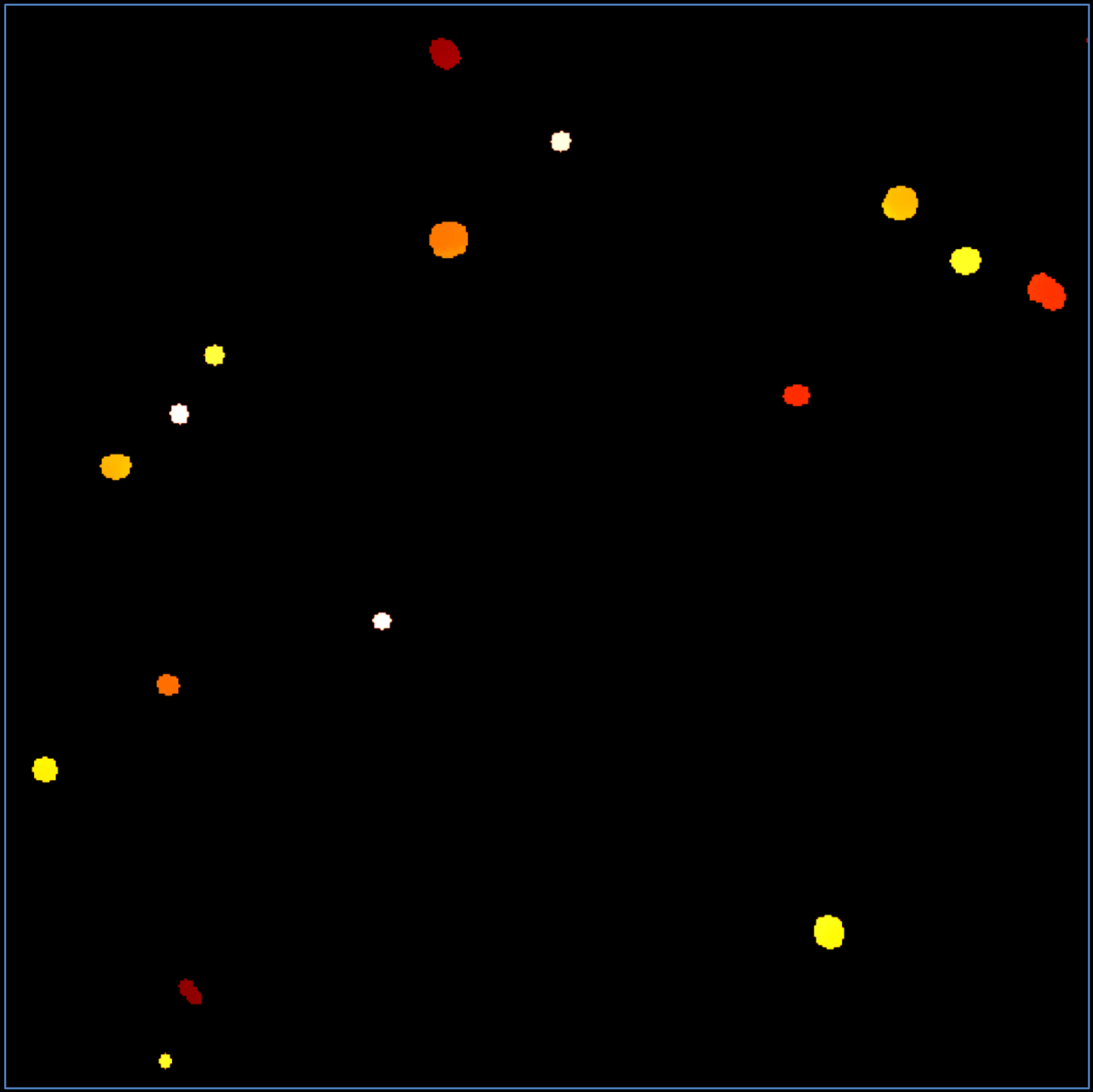
Figure 13. Synthesizing an image from the raw image of a plenoptic camera.

Christian Perwaß and Lennart Wietzke
"Single lens 3D-camera with extended depth-of-field",
Proc. SPIE 8291, Human Vision and Electronic Imaging XVII,

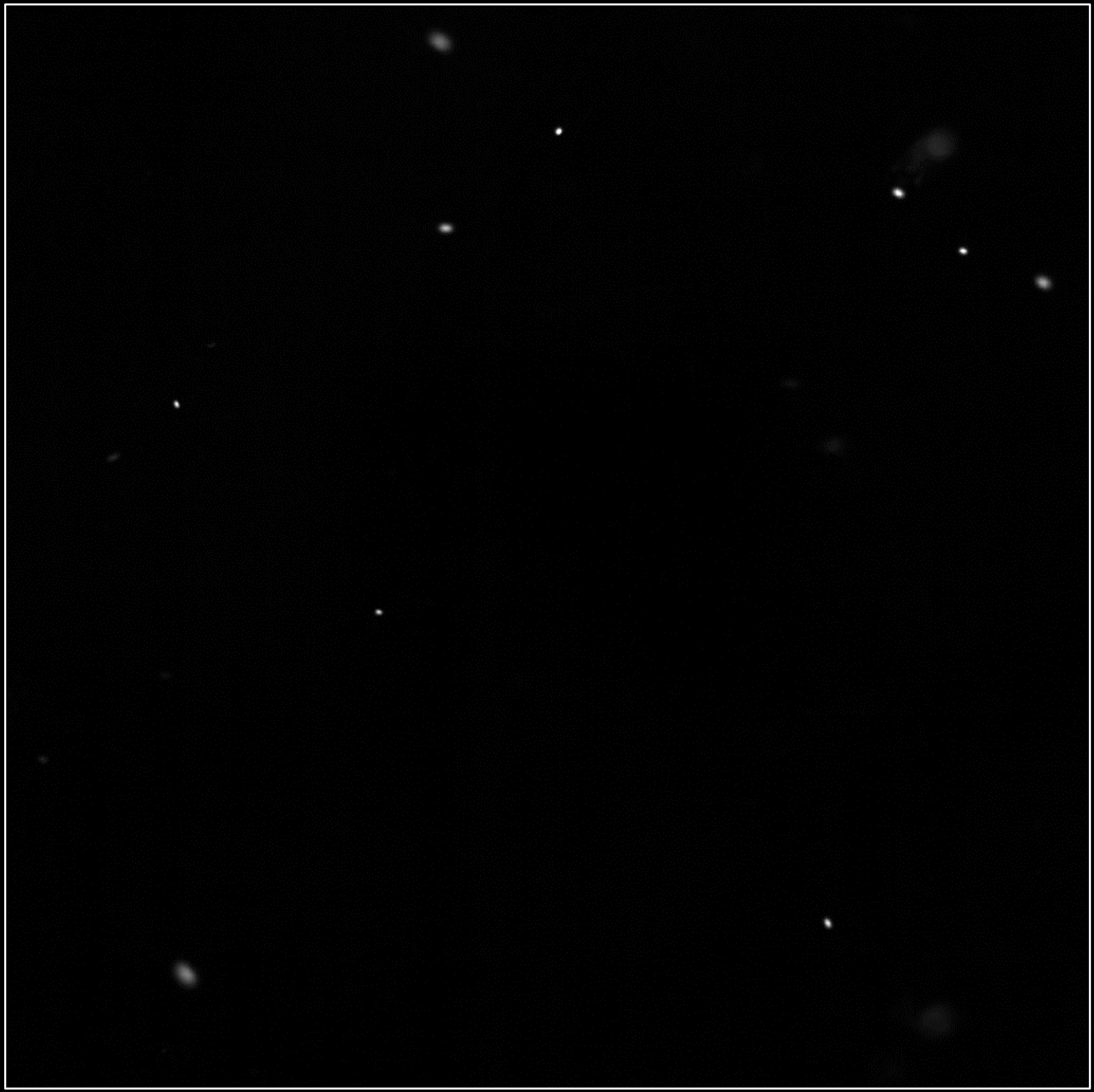
Plenoptic Image Processing: Raw Image



Plenoptic Image Processing: Depth Map



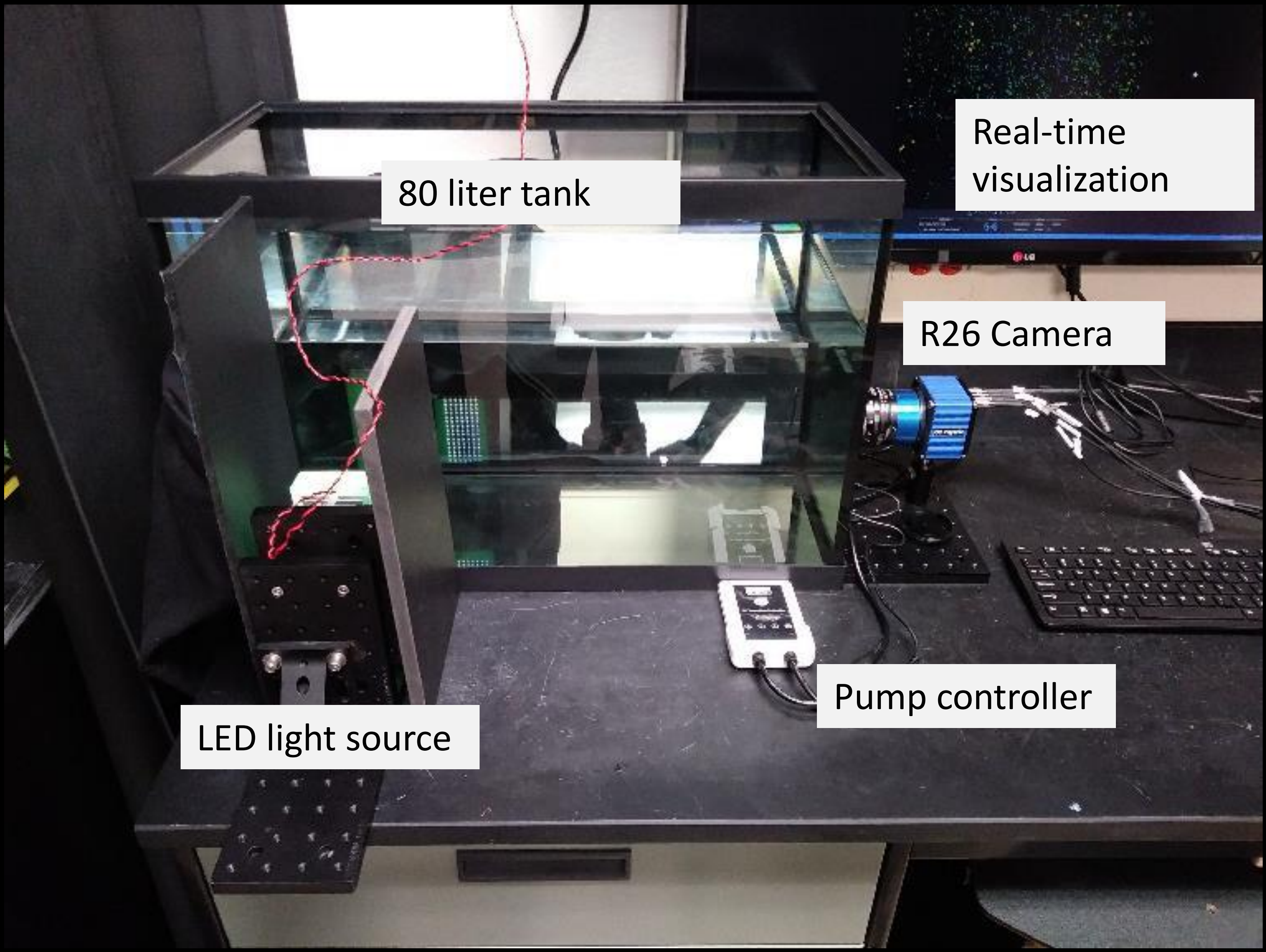
Plenoptic Image Processing: Total Focus



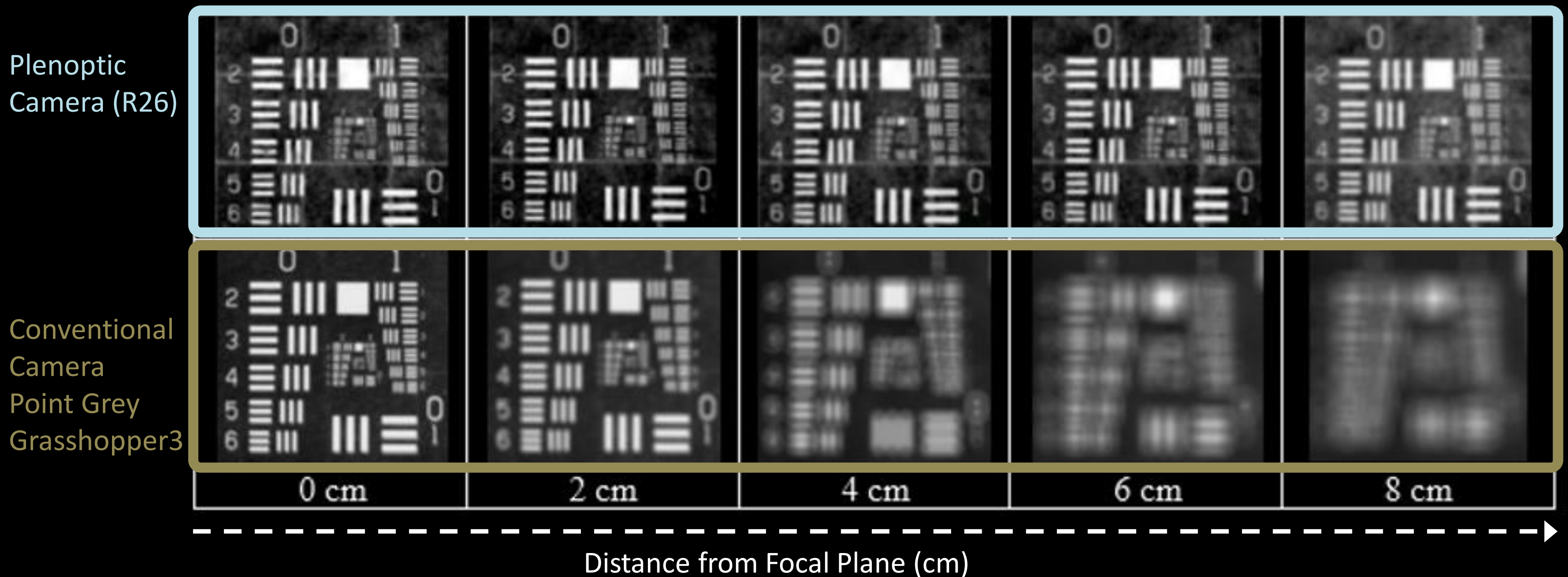
Laboratory Validation

- Image particle fields in a tank
- Perform concentration experiments with several particle sizes
- Compare measured to known concentrations and sizes

Laboratory Test Setup

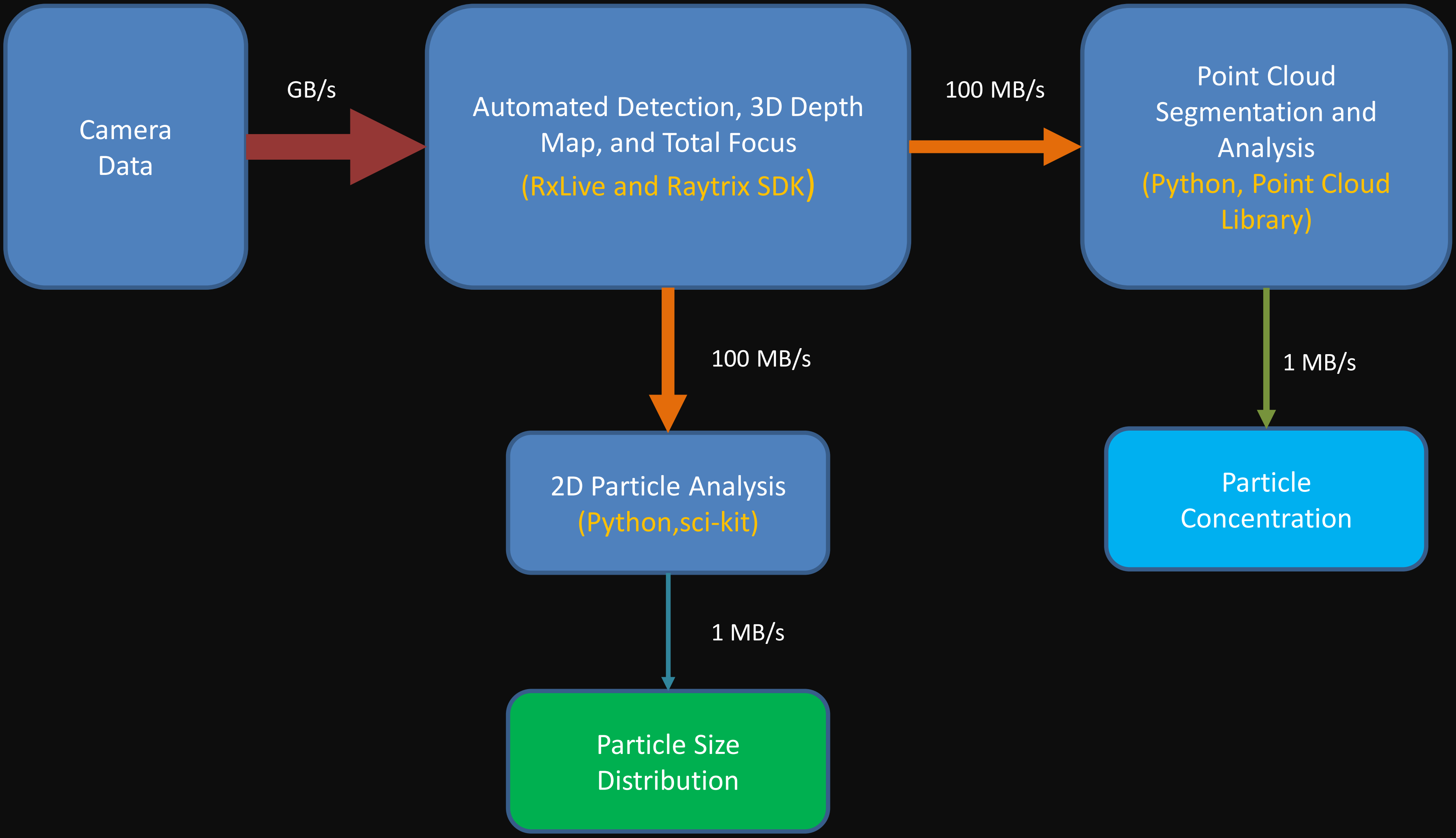


Extended Depth of Field with Good Light Collection

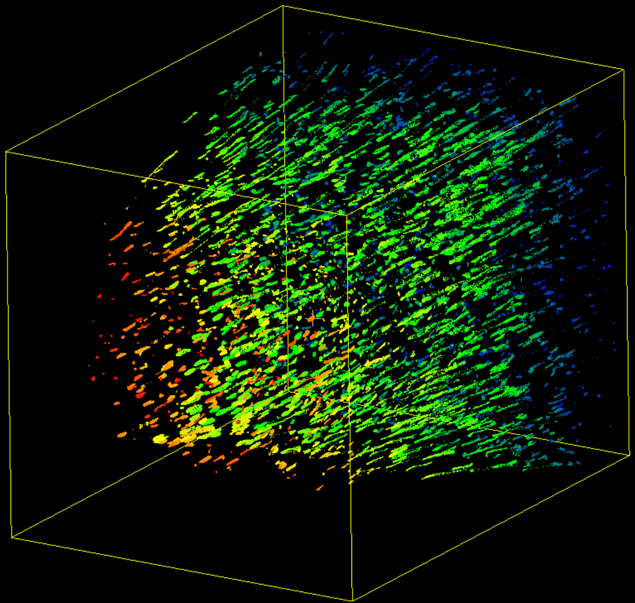


- Image series recorded with identical lens settings, F2.8 aperture, focused from 50 to 40 cm
- Plenoptic camera has half the spatial resolution at focal plane, but more than 4x the DOF at equal light collection efficiency.

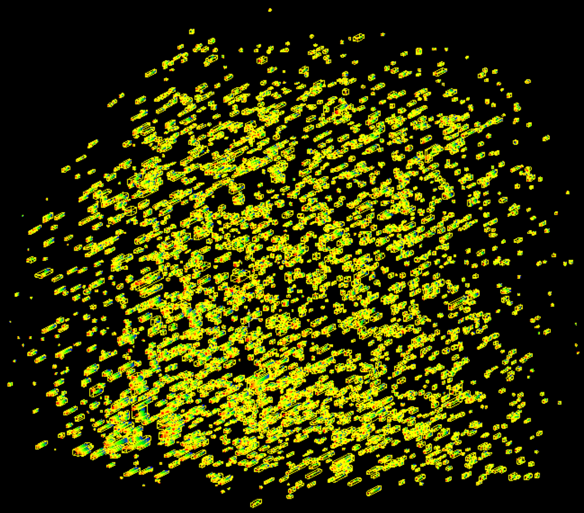
Particle Processing Workflow



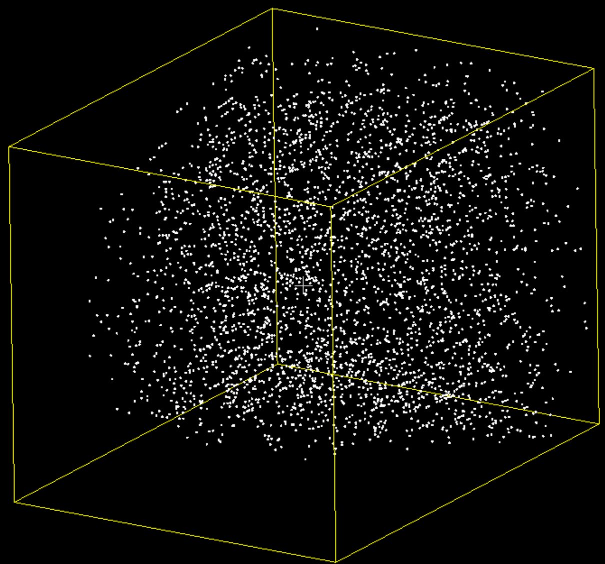
3D Point Cloud and Particle Segmentation



Raw point cloud from RxLive



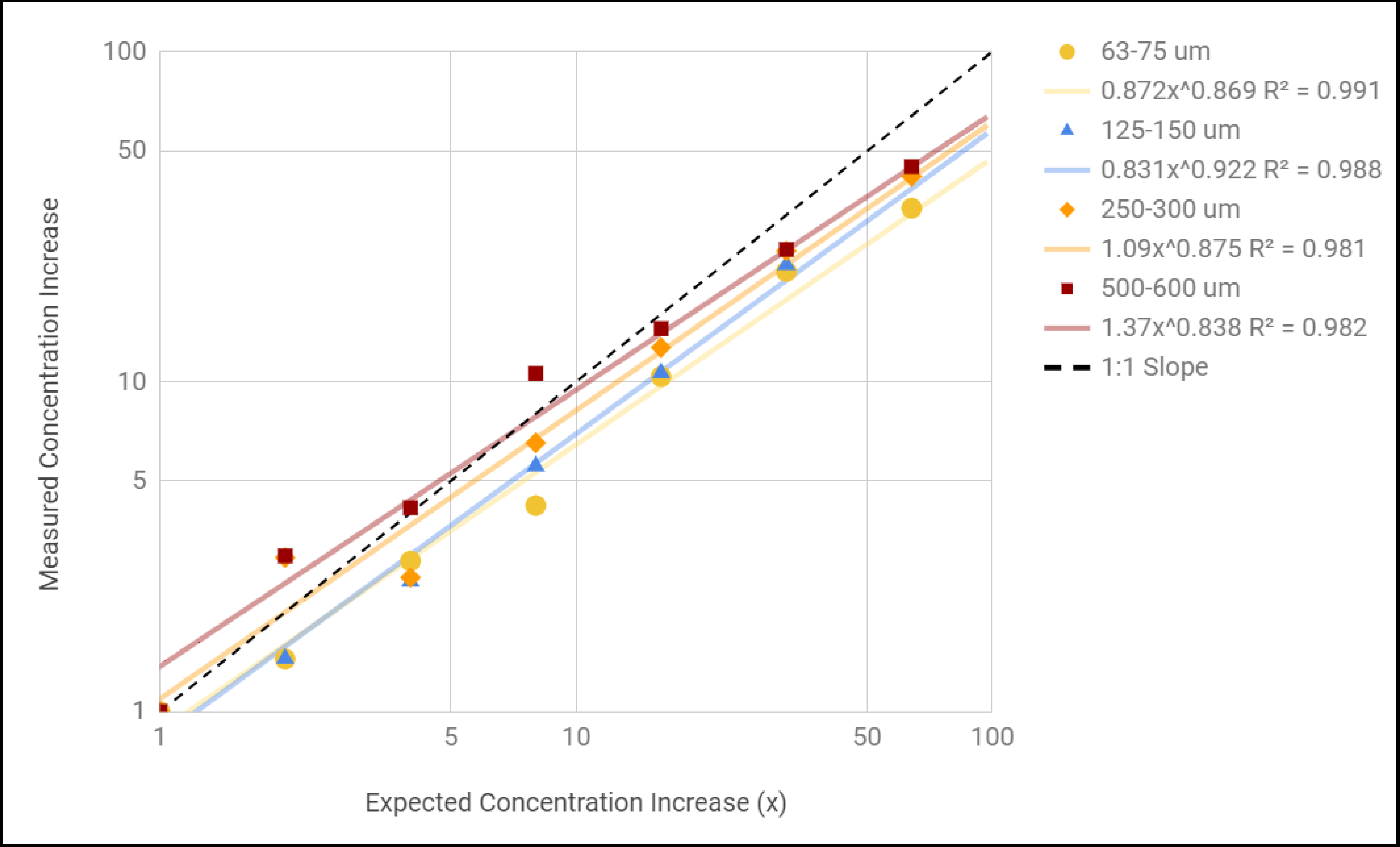
Segmented particles using kdtree clustering



Resulting point cloud

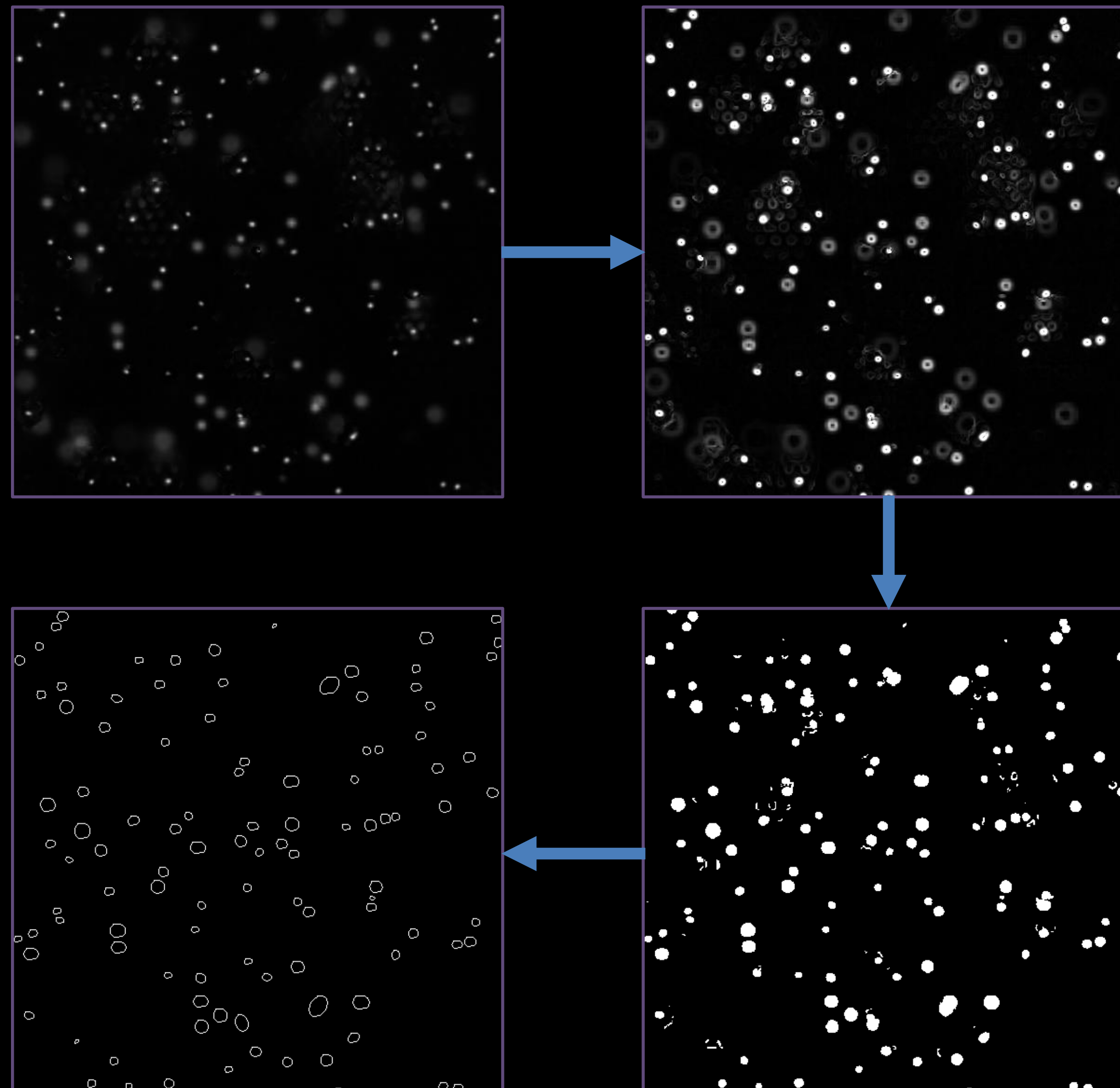
- Segmented cloud can be used to estimate particle concentration, 3D nearest neighbor pdf, etc.
- Segmentation is easily automated

Estimated Particle Concentrations



Particle Size Estimation

- To estimate particle size, use Total Focus image with corrected magnification from depth map
  - Higher resolution than point cloud
  - Use standard imaging processing methods



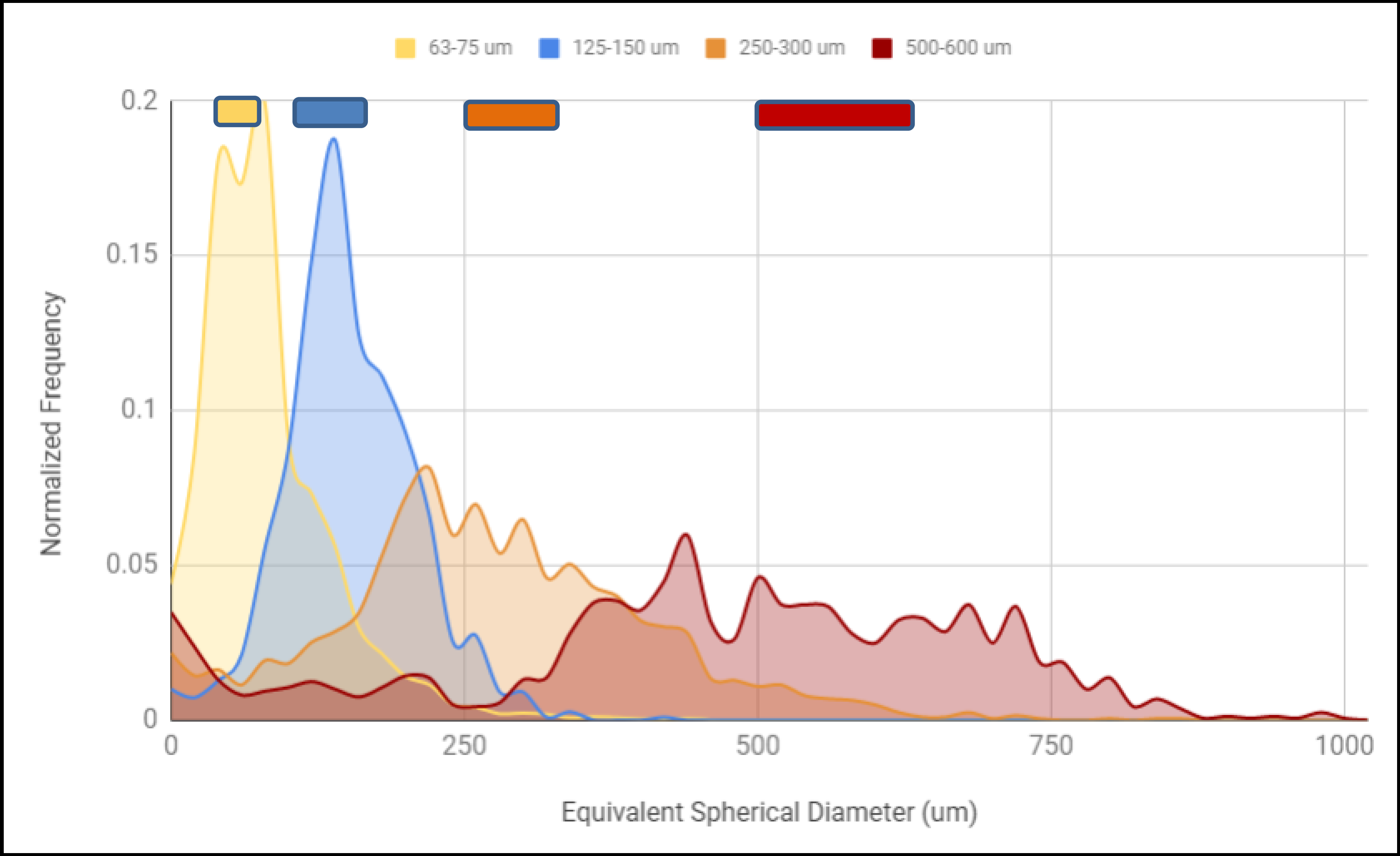
Total Focus Image

Edge Magnitude Image

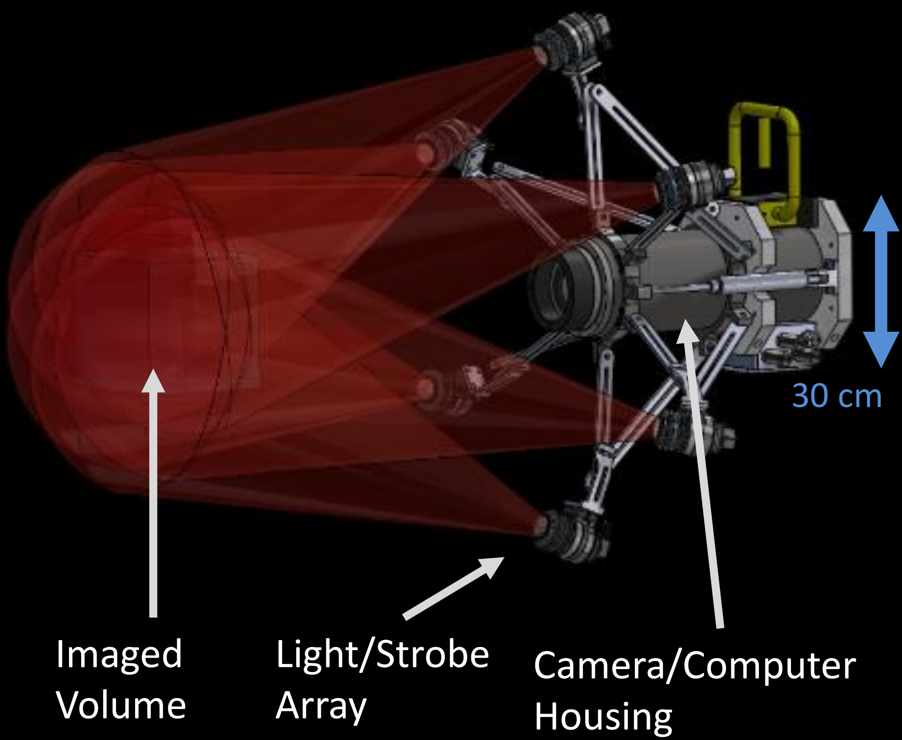
Segmented Image

Detected Particles

Estimated Particle Size

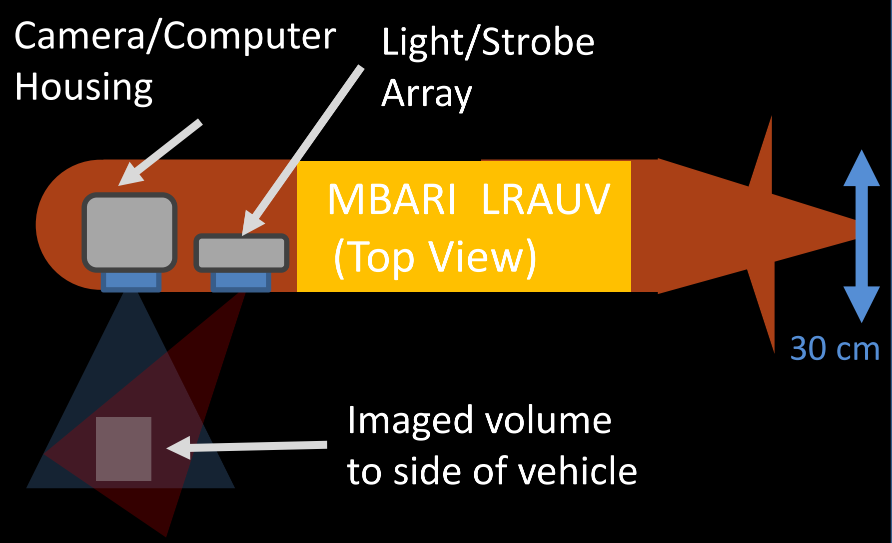


Next Steps: EyeRIS Remote Imaging System



Cabled Instrument Aug 2019

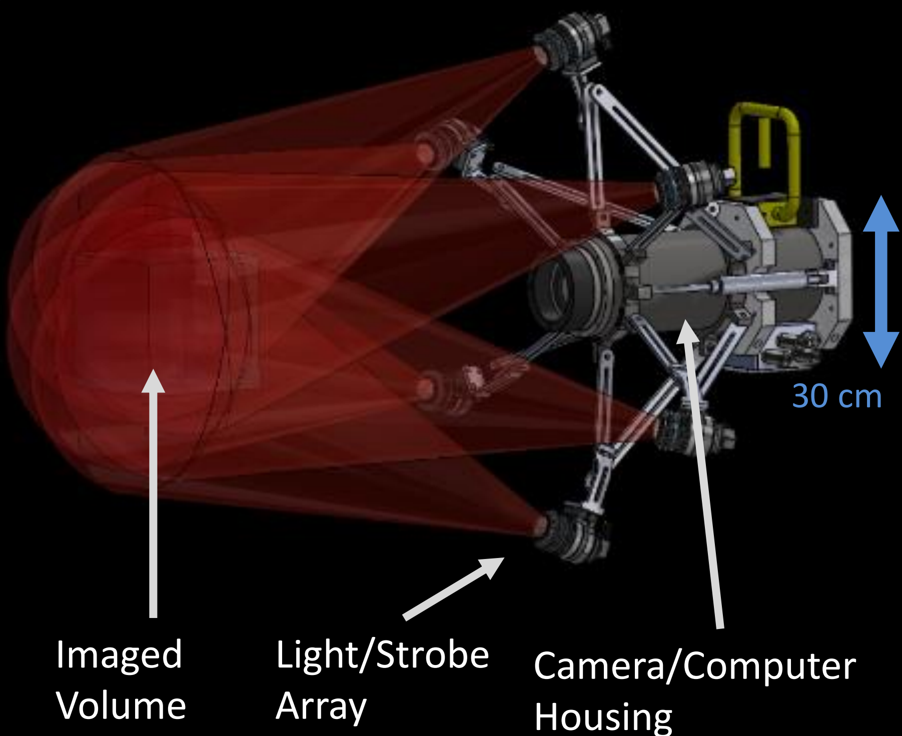
- High-speed (2 GB/s) data to ship
- Real-time visualization of 3D particle fields
- Deployable on ROVs or moorings with power and single mode fiber



Autonomous Instrument Summer 2020

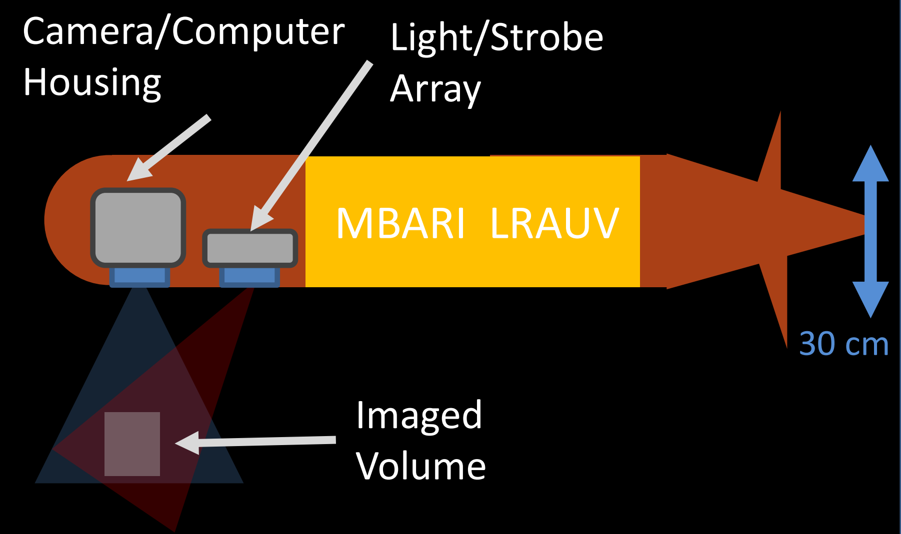
- Low-power, high-resolution plenoptic camera
- Embedded GPU
- Local storage with real-time particle counts

Next Steps: EyeRIS Remote Imaging System



In situ Flow Visualization/Quantification

- Bring 3D capability to in situ flow quantification
- Discern feeding behavior and rates
- Help quantify food web dynamics of plankton, sponges and other fauna



Biological Carbon Pump

- The LRAUV platform can image space and time scales well beyond that possible with ships
- Will visualize BCP dynamics in high resolution over seasonal evolutions
- Including imaging short episodic pulses occurring a few times per year.

Summary

- Presented an approach to in situ 3D particle imaging using a commercial Plenoptic camera
- Demonstrated that this approach can be used to measure particle concentration and size for particles with diameter much smaller than camera Field of View
- Have designed and will soon test a cabled in situ imaging instrument using this technology

MBARI’s Bioinspiration Lab


Kakani Katija


Kevin Barnard


Joost Daniels


Clara Fannjiang

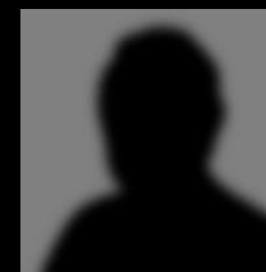

Chad Kecy


Alana Sherman


Denis Klimov


Paul Roberts


Jon Erickson


Sachin Agrawal

GORDON AND BETTY MOORE FOUNDATION

Monterey Bay Aquarium Research Institute

3rd Marine Imaging Workshop
June 25th 2019 – Victoria, BC