EyeRIS Cabled Instrument Preliminary Design Review

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Outline

- Science goals and motivation
- Functional requirements
- Cabled instrument design

Science Goals and Motivation

- Goal 1:
  - Study spatially resolved high-resolution 3D velocity fields in situ
- Goal 2:
  - Image and track 3D deformable surfaces in situ
- Goal 3:
  - Combine 1 and 2 to improve our understanding of critical biophysical processes in the oceans
    - Entrainment of particles by gelatinous plankton
    - Feeding rates of benthic organisms
    - 3D morphology of in situ organisms and its impact on the fluid environment

Functional Requirements (Cabled Instrument)

- EyeRIS shall provide single-camera, single frame, 3D underwater imaging
- EyeRIS shall be remotely controllable
- EyeRIS shall stream live video to a surface vessel
- EyeRIS shall record data on an external high-resolution recorder on a surface vessel
- EyeRIS shall operate to a depth of 4000 meters
- EyeRIS shall be compatible with existing ROV power and communications
- EyeRIS shall be deployable on a manipulator arm of an ROV

Complete Details: 01-EyeRIS-Functional Requirements-1.0.2.pdf

Cabled Instrument Design

- Optical Design
  - Camera selection and validation
  - Lens and viewport selection
  - Underwater imaging geometry: Where to place lights and camera?
  - Optical power budget: How much light is needed?
  - Light selection
- Electrical Design
  - High-level interface to provide real-time visualization on ship
  - Fiber extenders to transfer data from camera
  - Control of lights, camera, and system status
- Mechanical Design
  - External fixtures
  - Internal fixtures
  - Thermal considerations
- Risks and Mitigation
- Safety

Optical Design: 3D Imaging Method

- A deep-sea plenoptic imaging system
  - Single camera, single-frame, 3D sensor
  - High light efficiency compared to traditional camera: better contrast with shorter exposure times and less motion blur
  - Simplified system integration
    - Smaller form factor
    - Fewer connections
    - No synchronization needed between multiple cameras

For more details see: 02-EyeRIS-Comparison-of-3D-imaging-methods.pdf

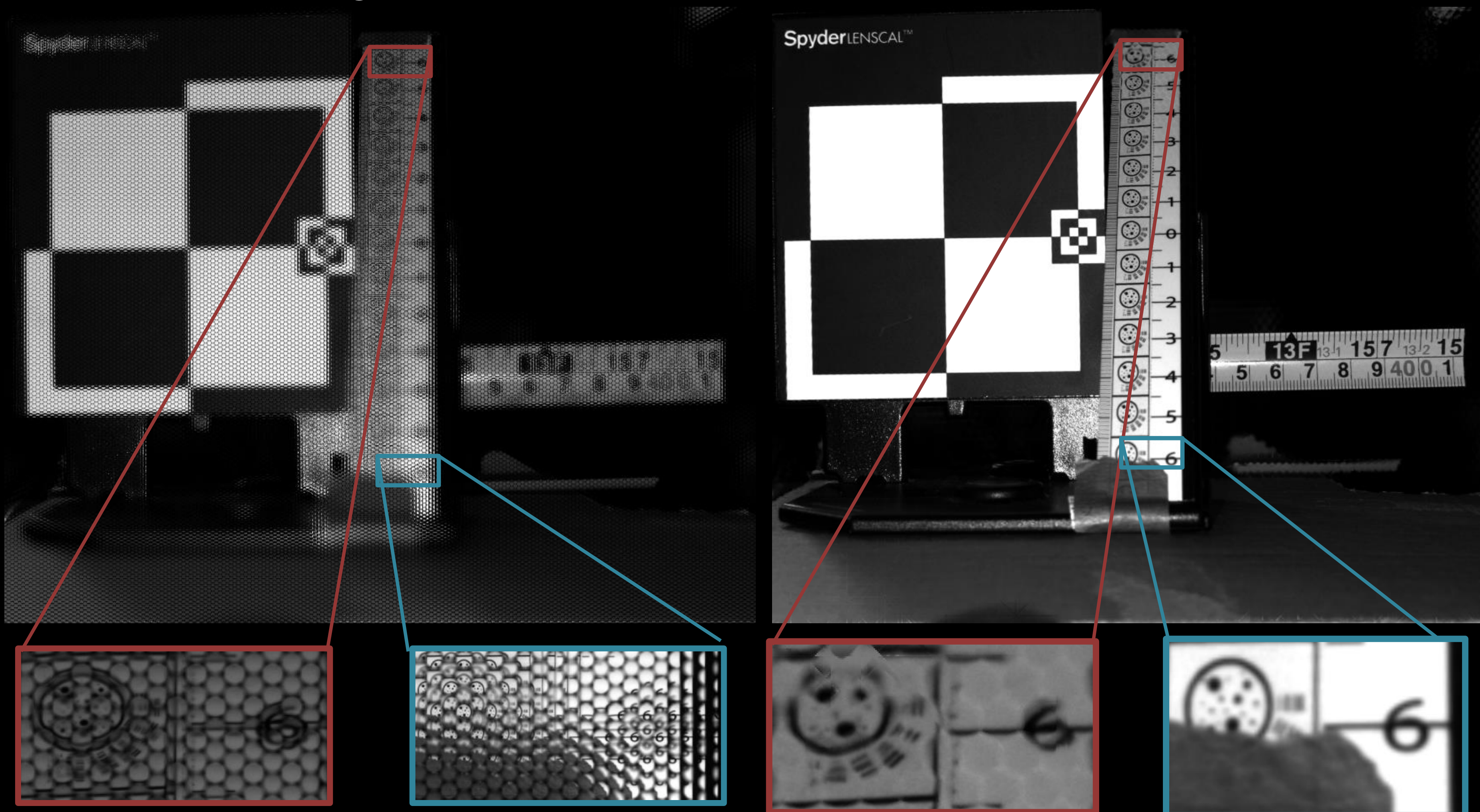
Optical Design: Raytrix R26 Camera

- 25 MP sensor
- 80 fps max rate
- ~ 2 GB/s data rate
- 4-channel CoaXPress-6 interface
- 4.5 um x 4.5 um pixels
- 23 mm x 23 mm sensor
- 12000 electron full well depth
- 41 dB peak SNR

/Datasheets: R26 Camera Specifications.pdf, Sensor: NOIP1SN025KA-D.pdf

Optical Design: Example Raw and Refocused Images

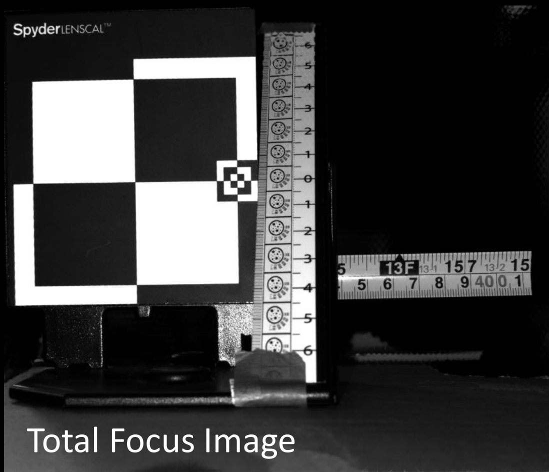
Raw Image from R26 | Total Focus Image from R26



Far | Near | Far | Near

Depth of field target with metric scale on 45 degree ramp, with in/cm ruler in middle position

Optical Design: Example 3D Data



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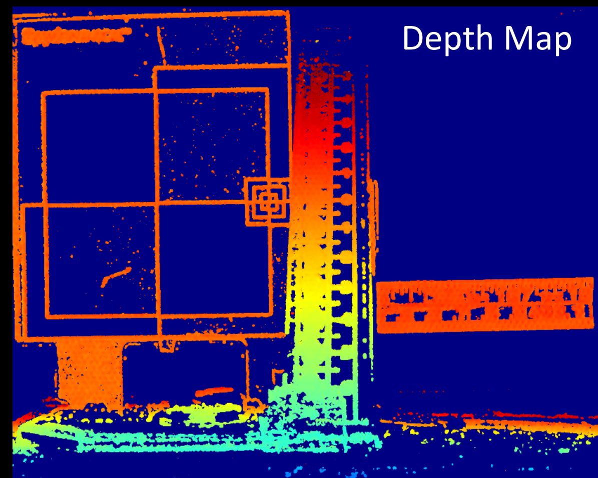
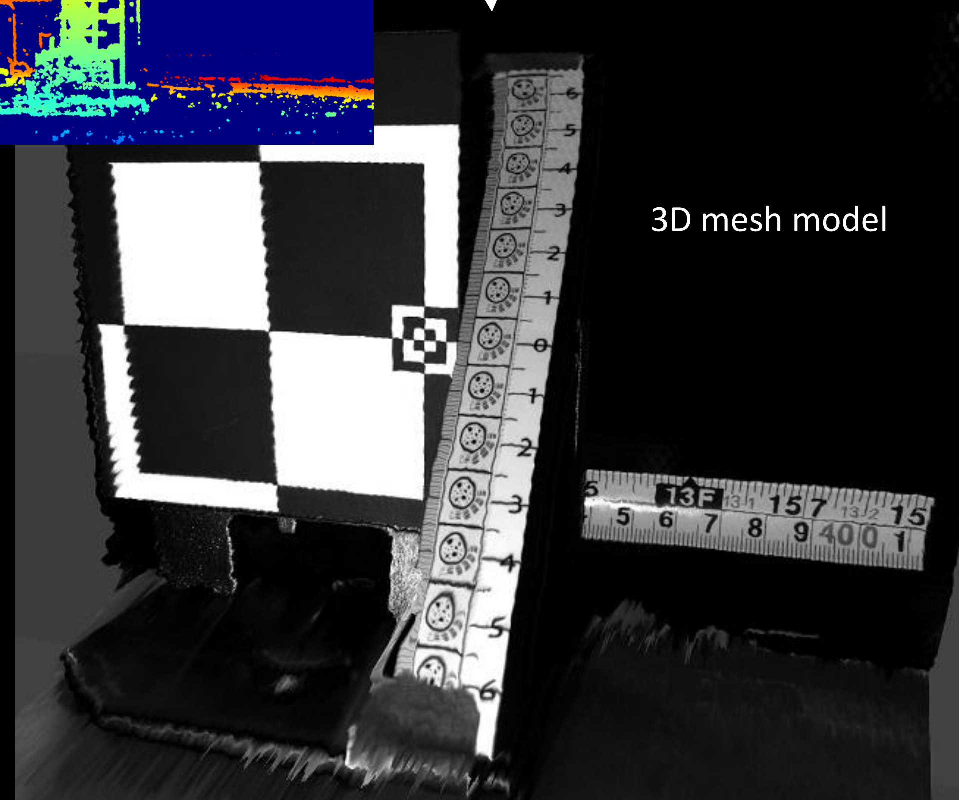


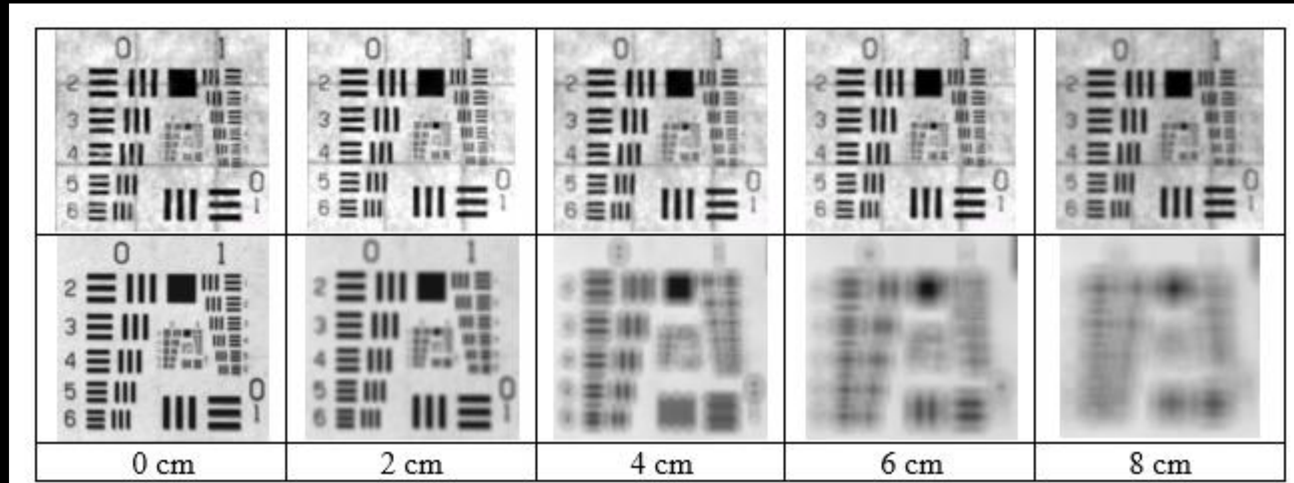


- Color used to code depth in the scene
- Spots with good features are localizable in 3D and shown in depth map
- Depth map is combined with total focus image to yield 3D model.
- Can be done in real-time on Nvidia Titan in lab

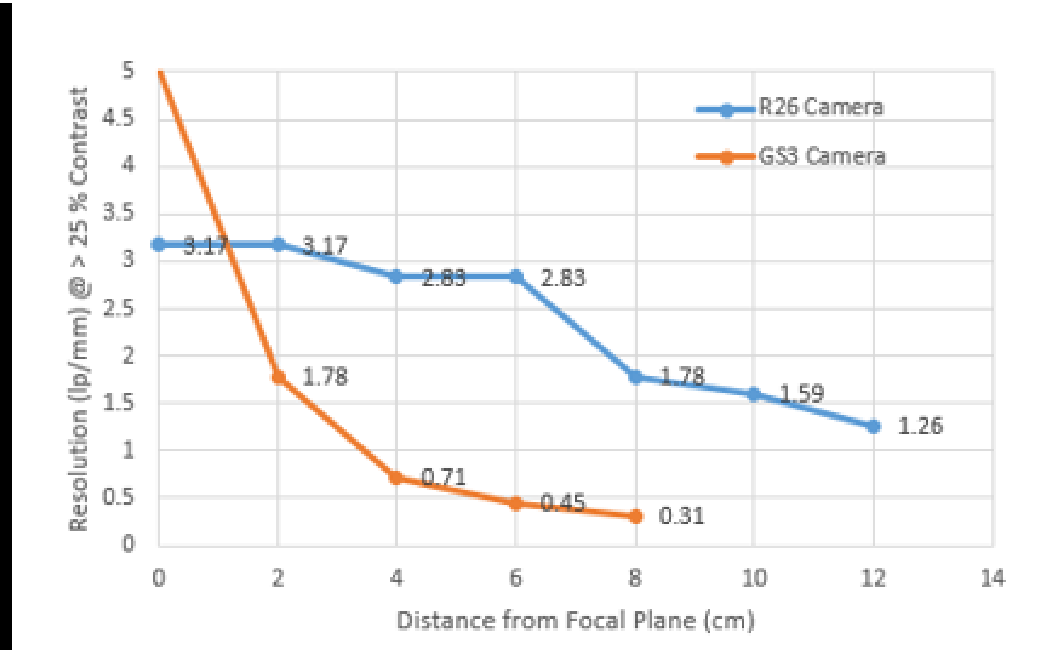
Optical Design: Depth of Field

R26 (Plenoptic)
Camera with F/2.8 lens

GS3 (Conventional)
Camera with F/2.8 lens

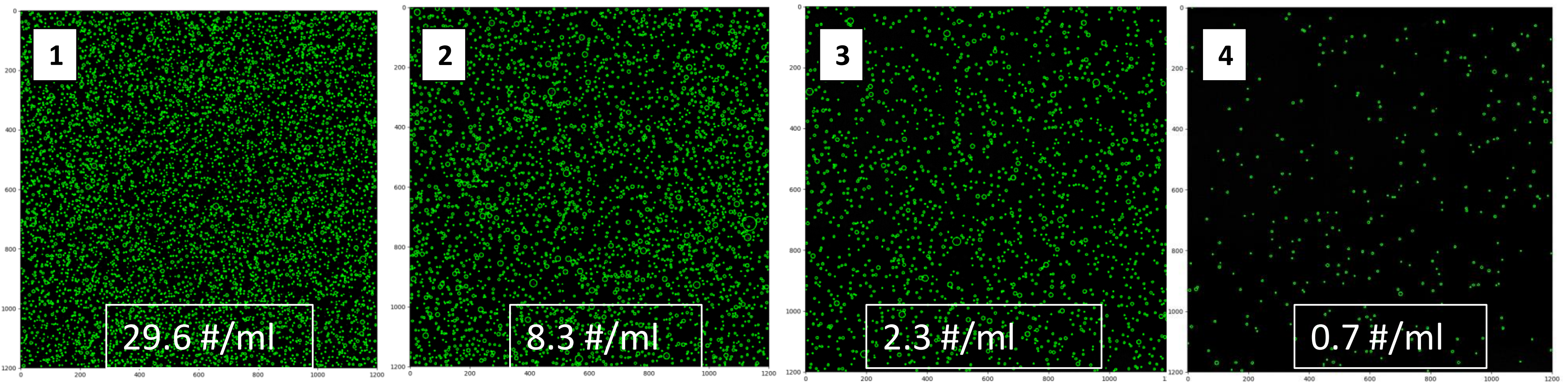


- R26 Camera trades lower resolution at the focal plane for much larger depth of field and higher resolution away from the focal plane

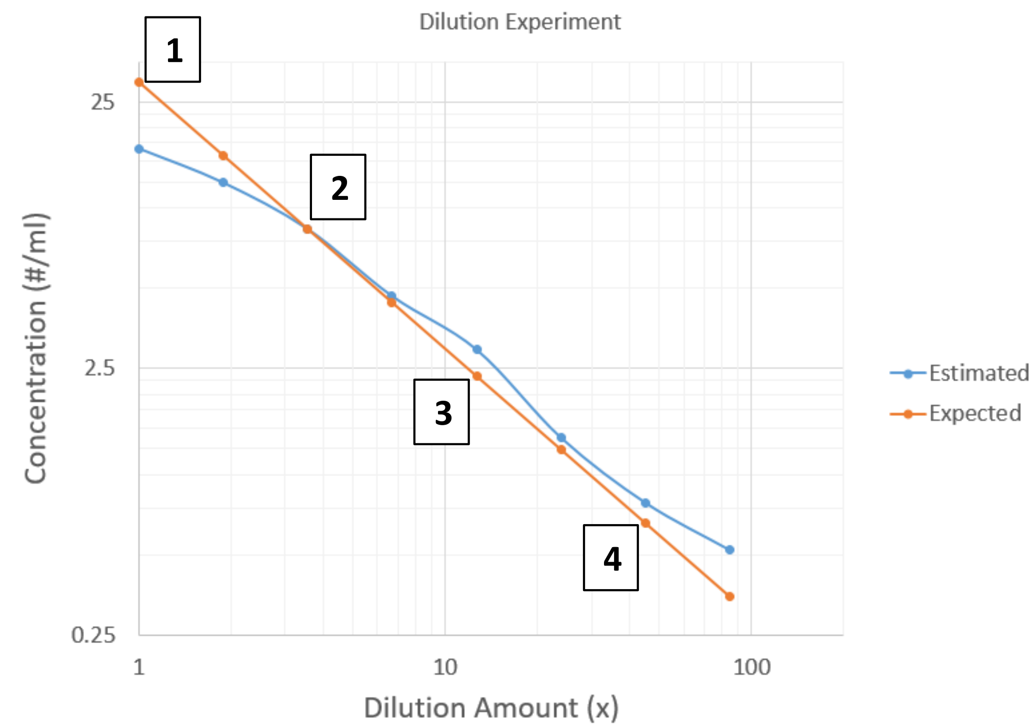


Complete Details in: 03-EyeRIS-7583-Activities-and-Results-March-2019.pdf

Optical Design: Particle Concentration



- Detected particles in sequential dilution steps
- Estimated and expected dilution of particles show good agreement when concentration is not too high



Optical Design: Lens Selection

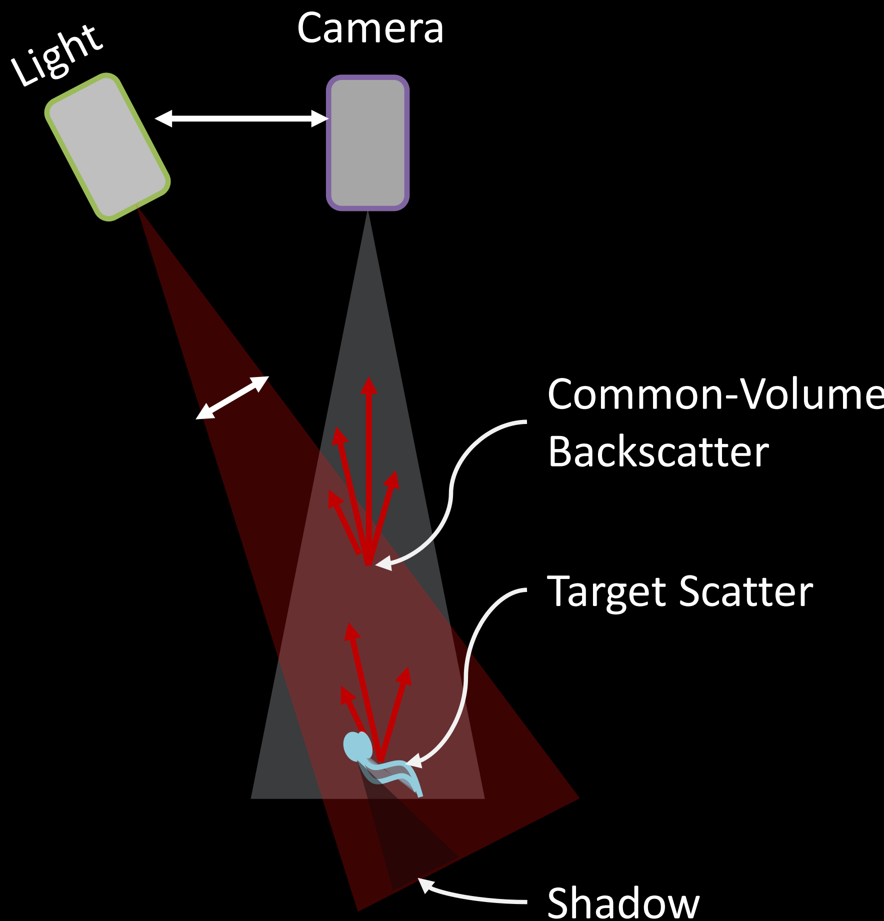
- Lens Selection
  - Key constraint: lens must have F# similar to F/2.4 of R26 microlens array.
  - F/2.4 is rare we use F/2.8 instead with sufficient fill of microlens
  - 50 mm lens provides a 18 deg x 18 deg FOV in water with R26 camera
  - Plan to use Zeiss 50 mm lens to start but can use others as needed
  - Lens 35 mm format (36 mm x 24 mm, conservative for 23 mm x 23 mm sensor)

Optical Design: Port Selection

- Is using a flat port okay?
  - FOV of interest are narrow, less than 10 degree half angle
  - Distortion from flat port is small in this case (Treibtiz et. al CVPR 2008)
- We can leverage the optical design of DeepPIV and use the same port
- This eliminates a potentially expensive step in designing a new optical port

Optical Design: Imaging Geometry

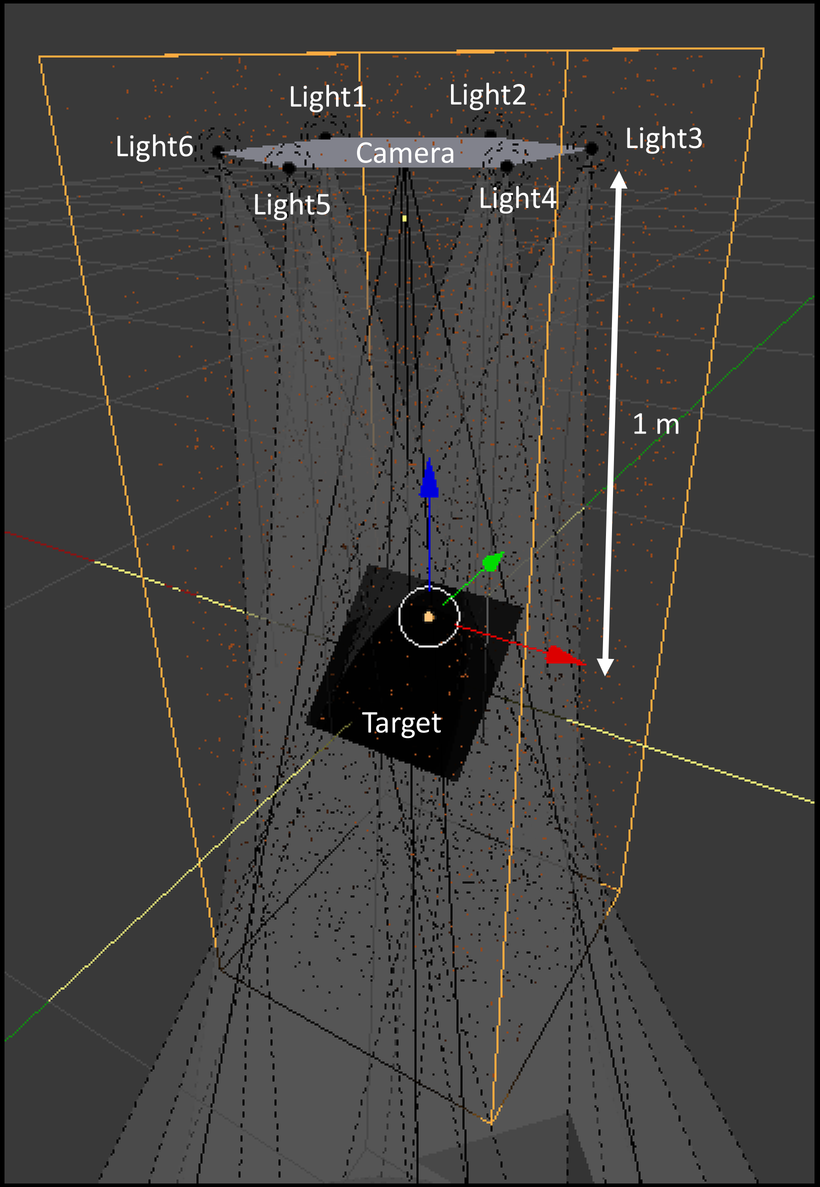
- Where to place lights and camera?
- Camera-light separation
  - Mitigate backscatter
- Spot vs flood
  - Small camera FOV benefits from spot light due to higher power density
  - Narrow spot light reduces backscatter
- Adding more lights
  - Reduces shadows
  - Compared: 1, 2, 3, 6



Complete Details in: 04-EyeRIS-Imaging-Geometry.pdf

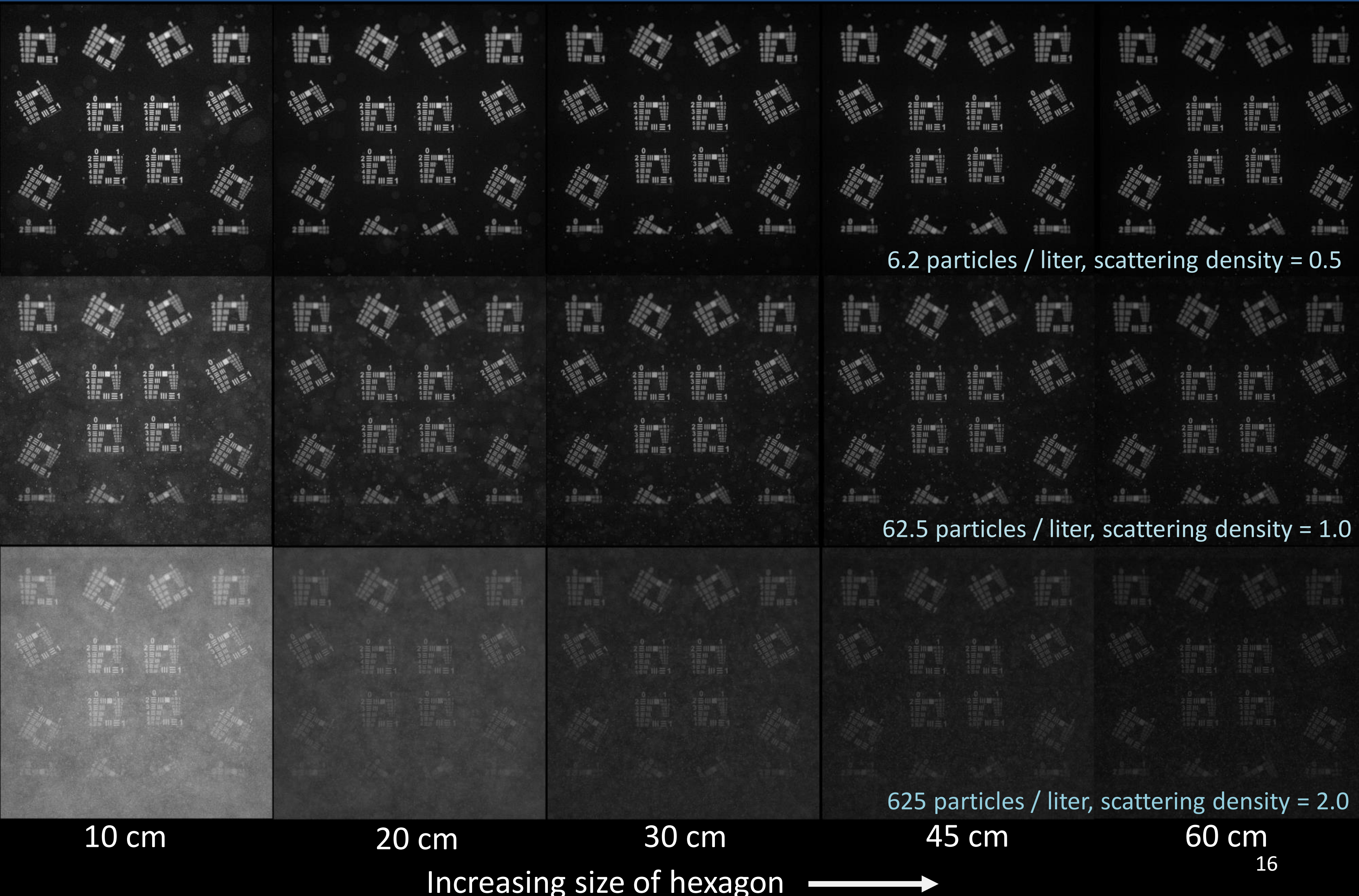
Optical Design: Imaging Geometry Simulation

- Blender simulation
  - Six lights in hexagon
  - One camera at center of hexagon
  - Target at 1 m range
- Vary the size of the hexagon to test different source-receiver separation
- Volume scattering based on Henyey-Greenstein phase function
- Uniformly random distribution of 1 mm particles with varied concentration

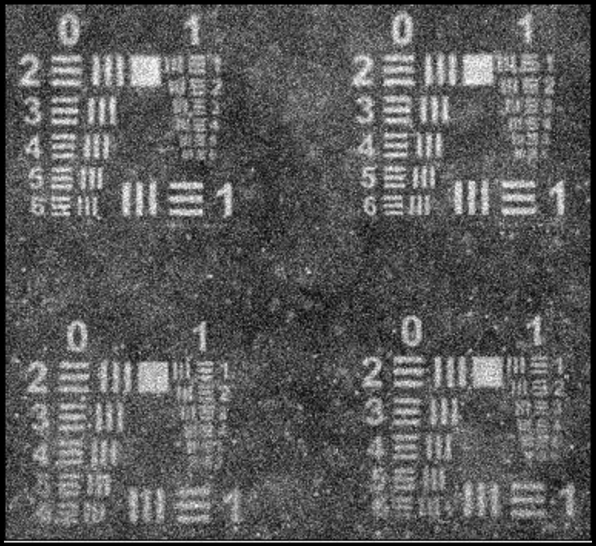


Phase function details:
http://www.oceanopticsbook.info/view/scattering/the_henyeygreenstein_phase_function

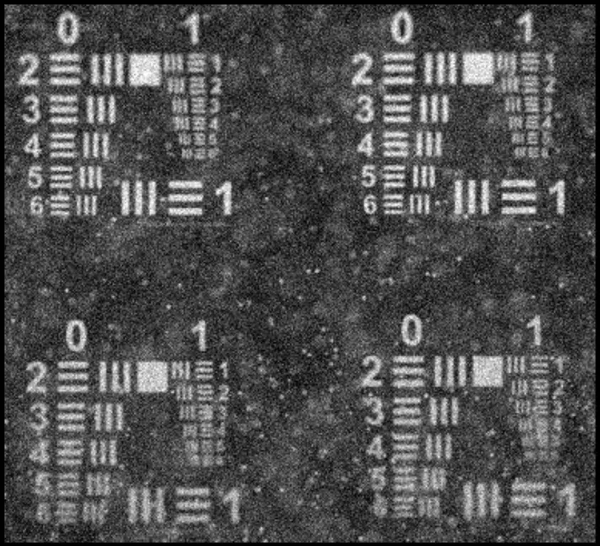
Optical Design: Imaging Geometry Simulation



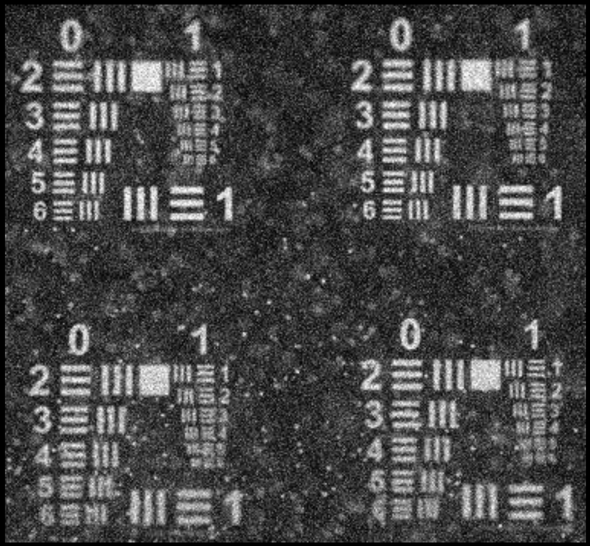
Optical Design: Imaging Geometry Simulation



10 cm



30 cm

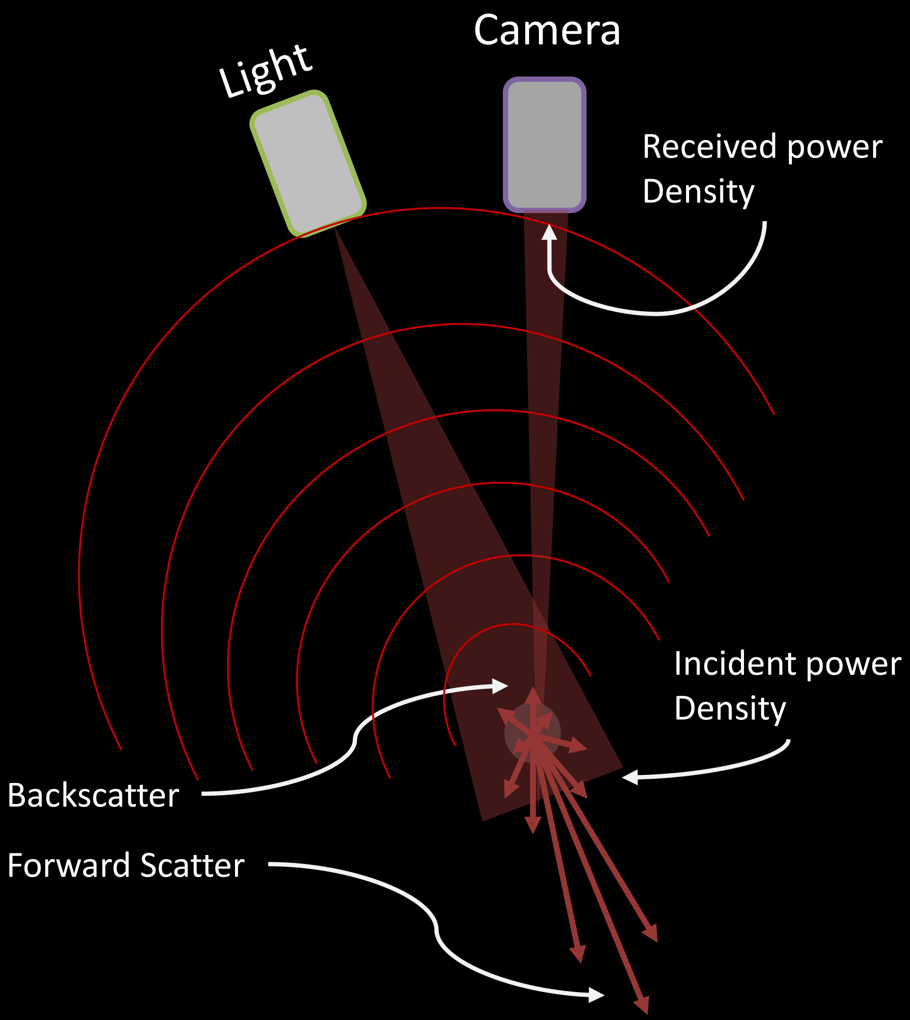


60 cm

- Individual particles have much better contrast at 30, 60 cm compared to 10 cm
- Overall image contrast is significantly higher at 30 or 60 cm compared to 10 cm

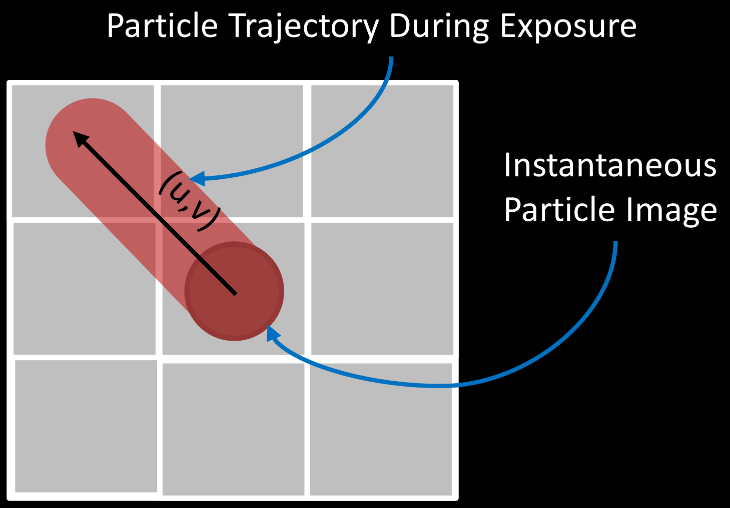
Optical Design: Optical Power Budget

- How much light is needed?
- Received signal calculation
  - 100 um particle
  - Volume scatter
  - Particle motion requires short exposure time
  - SNR ~ sqrt(QE*photons)



Optical Design: Optical Power Budget

- Key design constraints
  - Motion blur: reduces SNR per-pixel
    - SNR ~ 1 /#pixels_moved
  - Minimum particle size: larger particle scatter more light
    - SNR ~ paticle_radius^2
  - Scattering and absorption in water (beam_c): increased IOPs reduce SNR exponentially
    - SNR ~ exp(-2* range * beam_c)



Optical Design: Optical Power Budget

Light Power Output	10	W	This is ther optical power output from a single light source in the array
Total number of lights	6	#	Assume that all lights combine equally to illuminate the imaged volume
Fraction of light in illuminated area	0.5		This is the fraction of the output power that actually illuminates the imaged volume
Illuminated area	625	cm^2	This is the cross-sectional area of the imaged volume that is illuminated
Power Density	0.048	W/cm^2	Total power density of the lights
Total path length in water	2	m	Two-way path length in water
Absorption coeff	0.3	1/m	at 630 nm in seawater
Scattering coeff	1	1/m	one-way scatter vs two way aborption since the on the way to the target the scattered light still hits the target.
Attenuation over total path in water	0.201896518		Fraction of power lost to attenuation in water
Scattering Intensity ratio from MiePlot	1E-11		Fraction of input intensity to backscatered intensity over 150-180 deg for a 100 um sphere of 1.4 refractive index in 1.34 water at 630 nm
Power scattered back towards lens	9.69103E-14	W/cm^2	Watts per solid angle in the backward hemisphere
Focal length of lens	50	mm	
Aperature of lens	2.8	F/#	
Effective area subtended by lens	2.504458429	cm^2	
Power collected by lens	2.42708E-13	W	
Lens efficiency	0.75		
Power Incident on pixel	1.82031E-13	W	
Exposure Time	0.0005	s	Longest exposure at 10 cm/s and 50 um pixel to avoid motion blur
Energy on pixel during exposure	9.10155E-17	J	
Photons per Pixel at 630 nm	288.9379636		From : https://www.pveducation.org/pvcdrom/properties-of-sunlight/energy-of-photon
Sensor Quantum Efficiency	0.5		
Pixel SNR (assuming not dark noise limited)	**12.01952502**		

- With a 10 cm/s velocity, and 50 um pixel, max exposure to blur less than 1 pixel is 500 us
- A set of 6x 10 W (optical output power) lights provide 12 dB SNR for a 100 um particle at 500 us exposure

Model Worksheet: Source-Files/LightBudget.xlsx

Optical Design: Light Selection

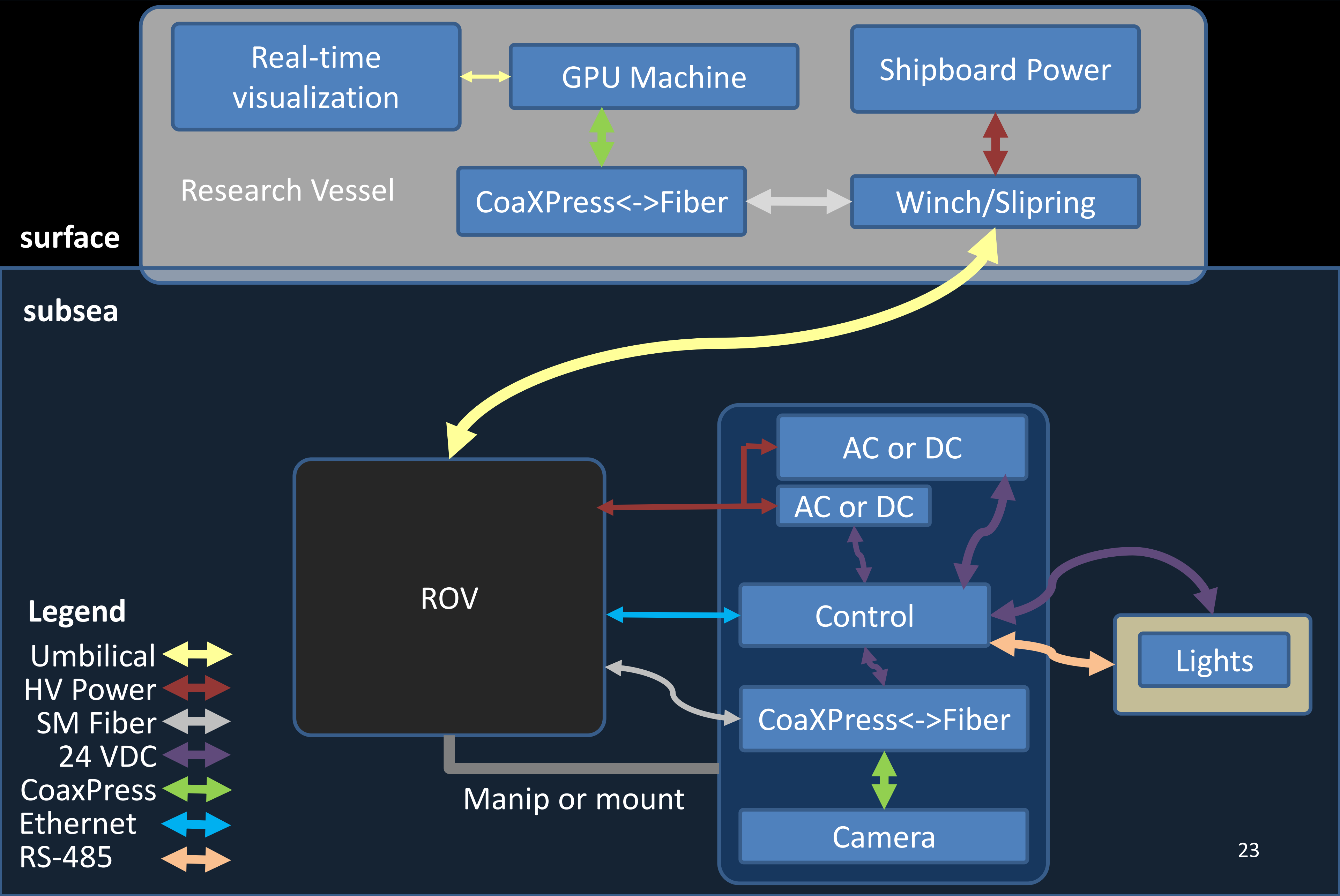
- First version will use DSPL SeaLite
- Easy to integrate and provides RS-485 dimming
- Size: 2.5” OD x 4” long
- Proven on many other MBARI assets
- Can choose color from range of Cree LEDs

/Datasheet: MultirayLEDSeaLite2025_Specifications.pdf

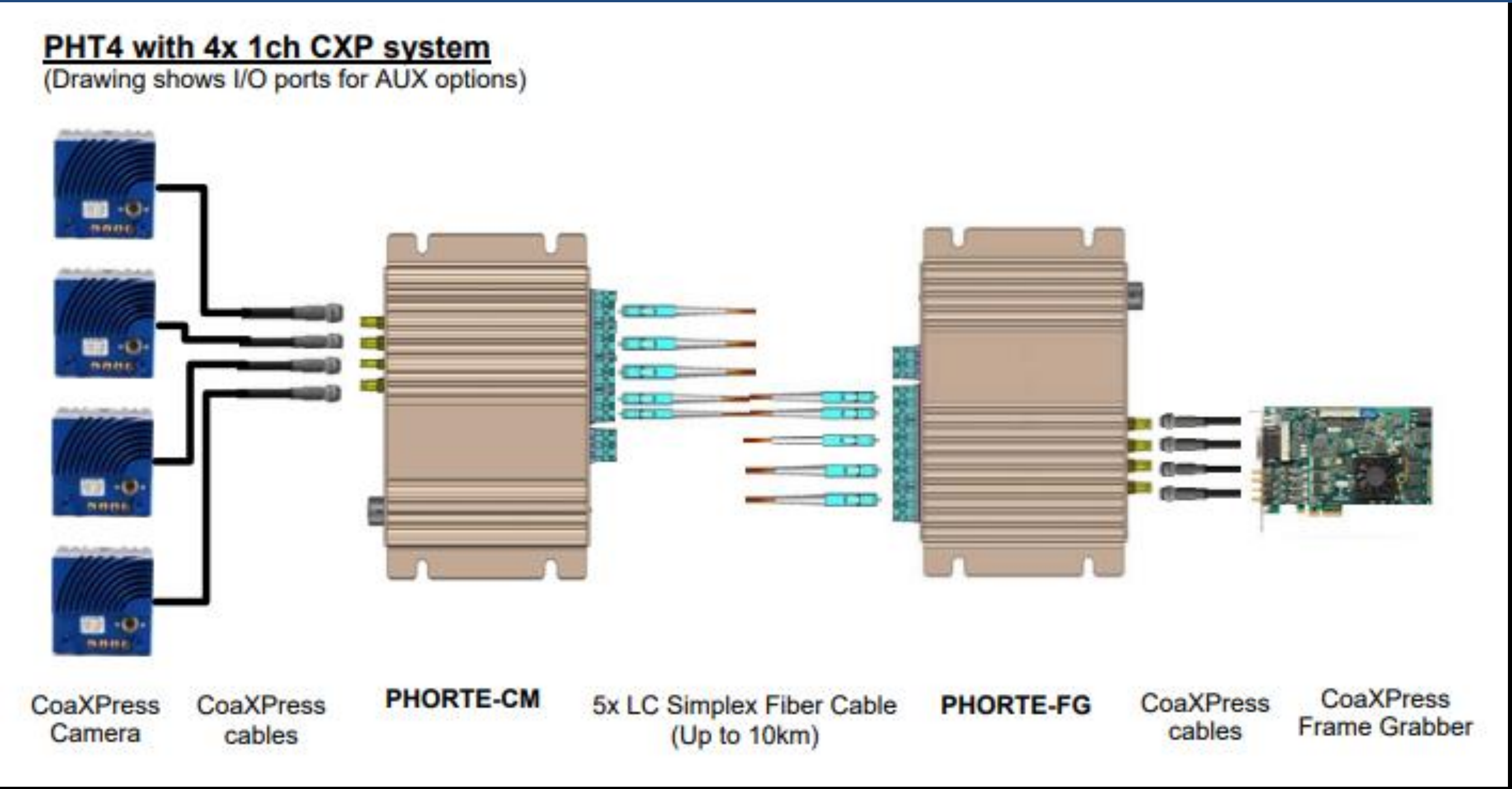
Electrical Design

- Key challenge: high data rate from CoaXPress camera bus to ship
- Approach: CoaXPress to fiber extender with CDWM muxing
- Requires: Minimum of 5 free CDWM wavelengths

Electrical Design: High-Level Block Diagram



Electrical Design: CoaXPress to Fiber Conversion

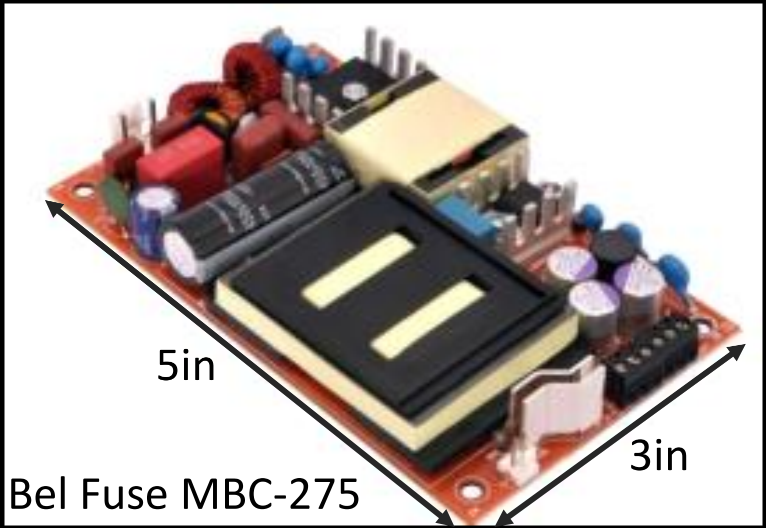


- One of only a few options for CoaxPress to fiber
- Tested with the same frame grabber board we currently use with the camera
- Fits in existing DeepPIV housing

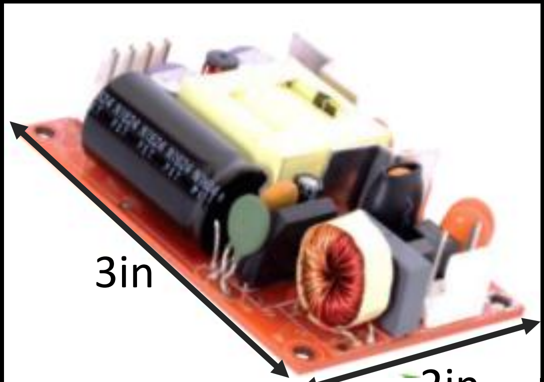
/Datasheet: PHORTE-spec-v3.1-1.pdf

Electrical Design: Power Conversion

- Universal AC and HV DC input
  – 80-264 VAC
  – 390 VDC
- Very low-profile
  – 0.7" tall
- Meets EN/IEC 60601-1
  – 300/100 uA leakage current



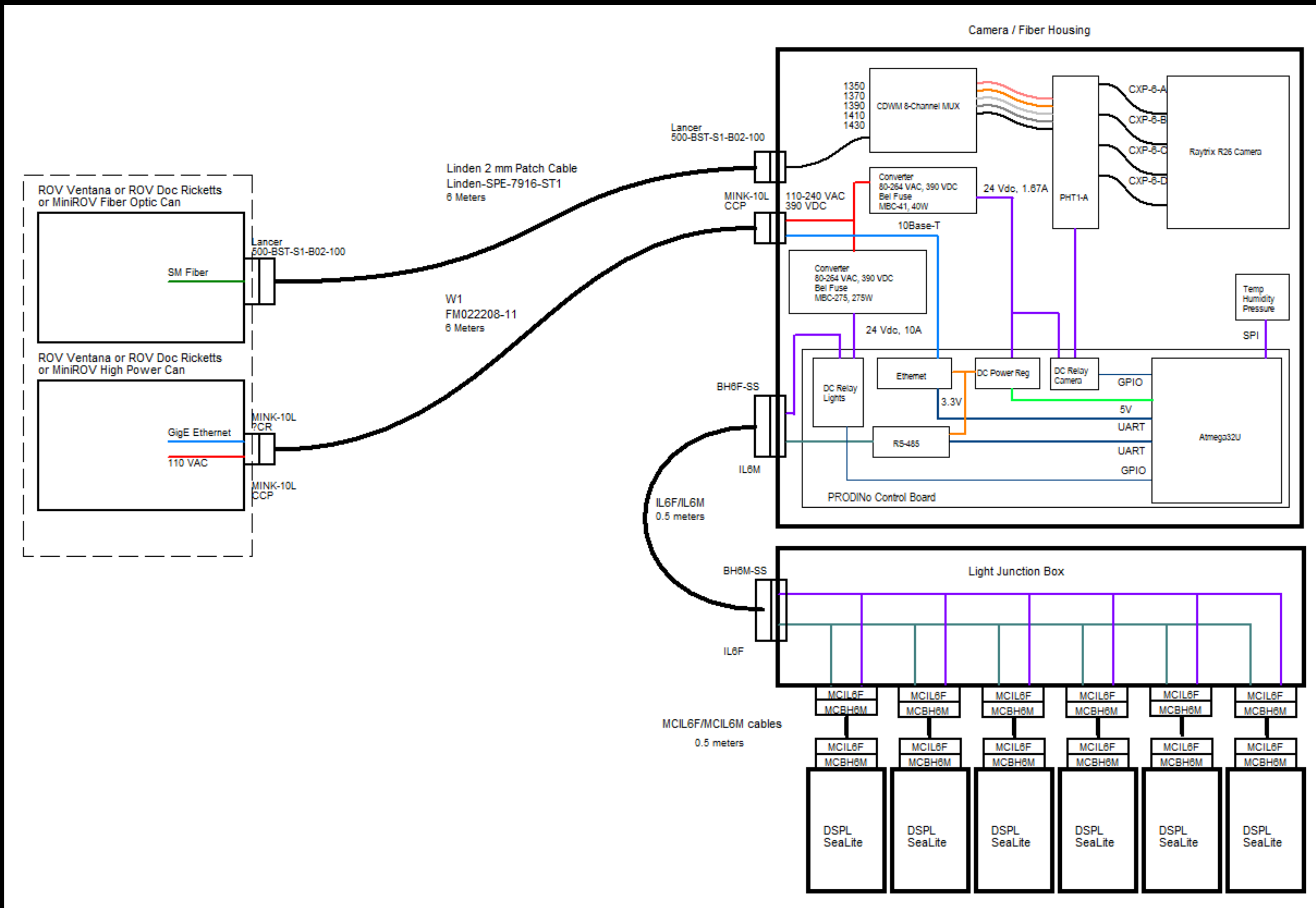
Bel Fuse MBC-275



Bel Fuse MBC-41

/Datasheets: ds-BPS-mbc275-series.pdf and ds-BPS-mbc41-series.pdf

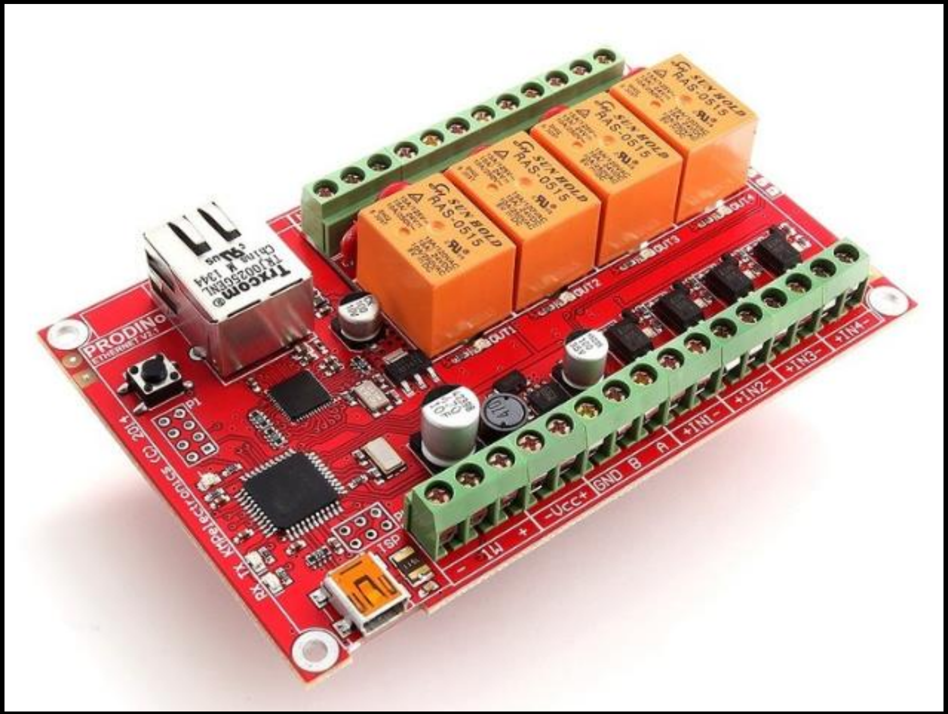
Electrical Design: System Diagram



Details: 06-EyeRIS-System-Diagram.pdf

Electrical Design: Stock Control Board

- Arduino Leonardo Core
- Atmega32U4
- 10Base-T Ethernet
- RS-485
- 15A relays
- SPI interface for temperature sensors
- Isolated digital inputs



/Datasheets: ProDiNo Ethernet V2.pdf and ProDinoEthV2_1_Schematic.pdf

Electrical Design: Power Budget

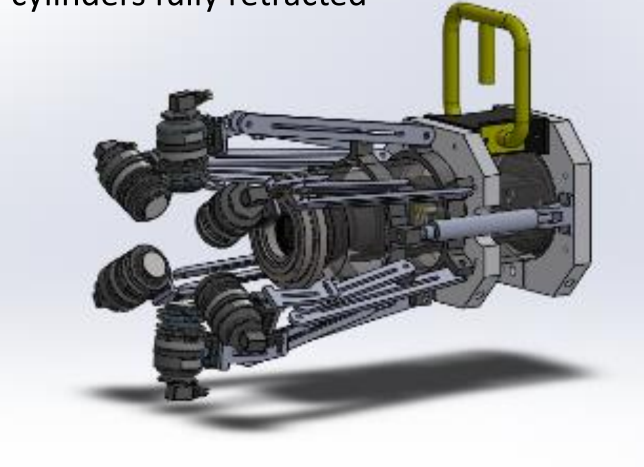
Item	Power Draw	Efficiency	Power Consumption
MBC-41: Camera: 13 W CoaxPress<->Fiber: 7 W PRODINo: < 1 W	21 W	90 %	23.3 W
MBC-275: 6, DSPL lights, 40.5 W ea	243 W	90 %	270 W
		Total	**293.3 W**

Mechanical Design

- Match DeepPIV form factor to the extent possible
  - Proven housing design
  - Know the space of possible deployments and operations well
- Use foldable armature for lights to facilitate large baseline when imaging
  - Allow us to better control the illumination geometry and still fit in DeepPIV form factor
- Package the system into a single housing
  - Reduce the number of housings required to one plus lights

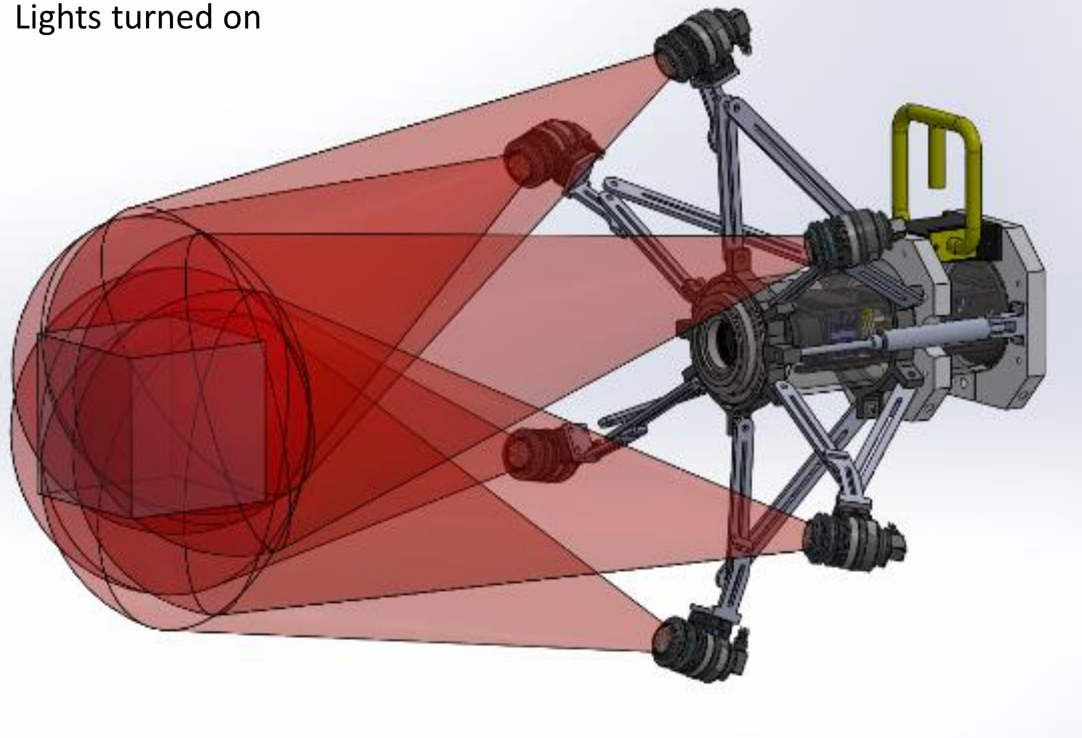
Mechanical Design: External Assembly

Folded light array with hydraulic cylinders fully retracted



Folded OD : 42 cm
Expanded OD : 85 cm
Length: 89 cm
Approx weight in air: 25 kg
Approx weight in water: 15 kg

Expanded light array with hydraulic cylinders fully extended and Lights turned on

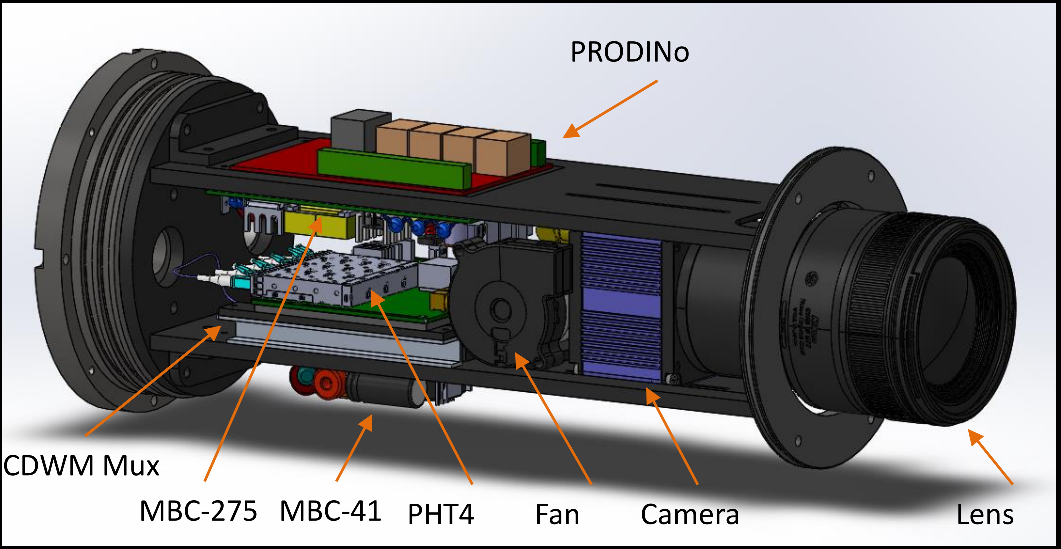


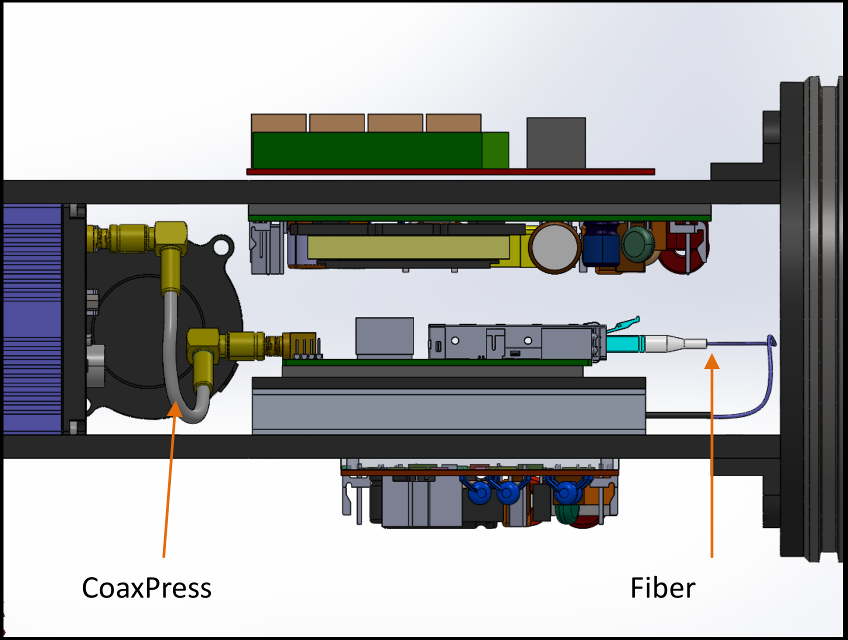
- Hydraulic cylinders used to actuate the array
- Cylinder stroke limits the extended and retracted position

Details in : 07-EyeRIS-Dimensions.pdf

Mechanical Design : Internal Assembly

- Two-plate assembly with camera and lens in between
- Electronics and fiber coms sit behind camera
- Slots for camera mount allow for adjustment to accommodate different lenses
- End of plates mount to rack support with o-ring to pick up tube ID
- Two blower fans bracket the space between camera and electronics and blow in opposite directions

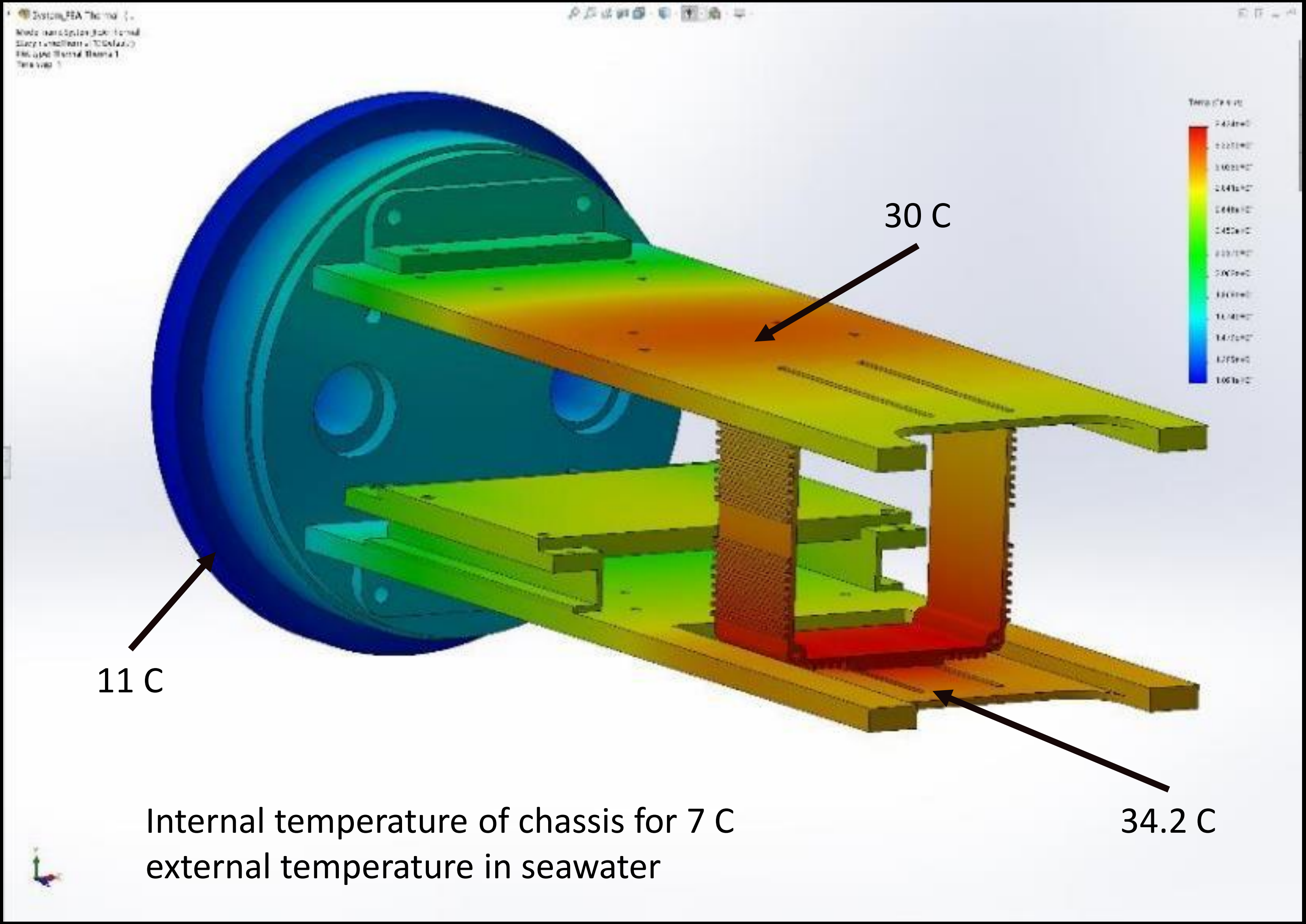




Mechanical Design: Thermal

- Heat generation inside the housing
  - R26 Camera : 13 W
  - Fiber extender: 7 W
  - MBC-275 (lights): 27 W
  - MBC-41 (camera and fiber extender): 3 W
- Total heat in housing: 50 W
- Will use forced air plus conductive coupling to endcap
- Likely will need to run lights at low power on deck

Mechanical Design: Thermal



Details: 08-EyeRIS-Thermal-Calculations.pdf

Risks and Mitigation

- Optical
  - Low contrast in natural particle images or low particle densities
    - Add baffles to lights to limit output at large angles
    - Inject plastic particles with higher contrast
  - Low contrast for featureless 3D structures
    - Add structured illumination
- Electrical
  - CoaXPress to fiber converter does not perform well
    - Work with vendor to test different laser diodes (a few options here)
    - Test an extender made by Kaya instruments
  - Bel Fuse converters don't perform to spec
    - Move the power conversion to a separate housing with larger CUI or Meanwell converters
- Mechanical
  - Folding array is not reliable
    - Revise roller bearings and lengths of the bars in the linkage to improve robustness
    - Reduce size of array

Safety

- High voltage AC or DC input to housings
  - Ground fault detection?
- Moving parts on light array and hydraulics
- Bright output from LEDs

Development Schedule

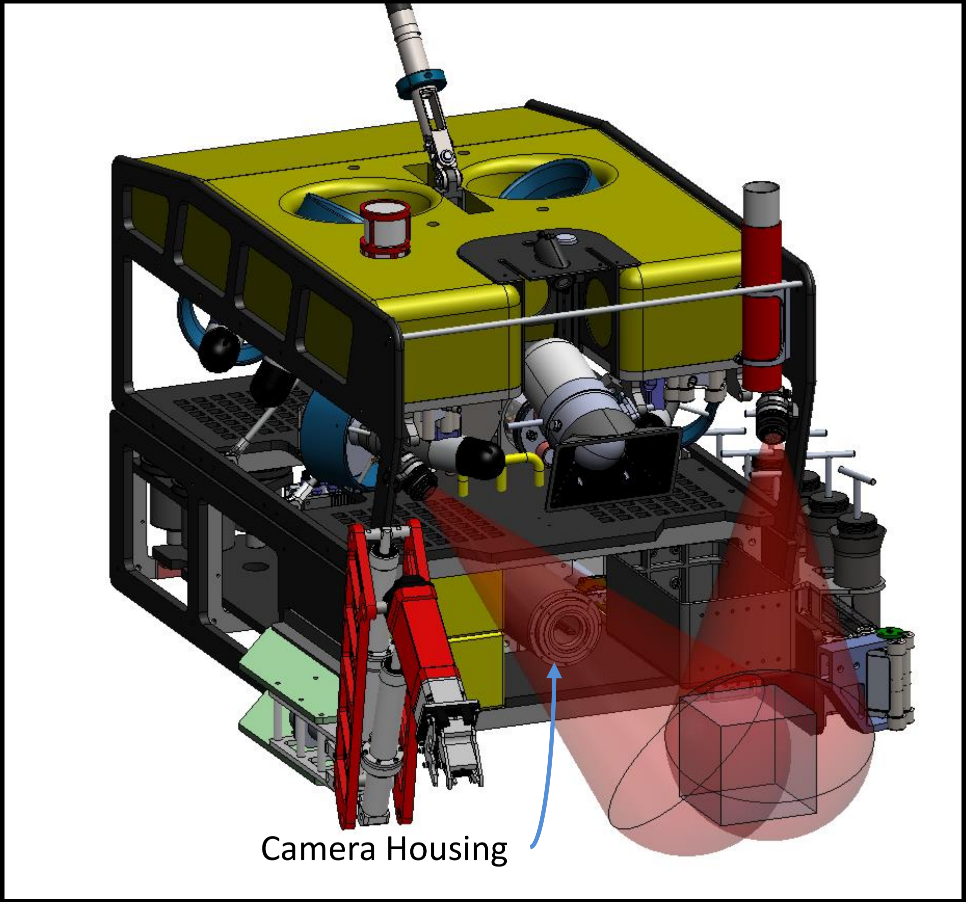
- Phase 1a July 2019:
  - Mount on MiniROV and test in the pool
  - Refine illumination geometry and lens selection
- Phase 1b Aug 2019:
  - Deploy at sea on MiniROV
- Phase 2 Jan 2020:
  - Deploy on Ventana and Ricketts
- Phase 3 Summer 2020:
  - Deploy alongside DeepPIV on Ventana and Ricketts

Mounting on ROVs

- Mini ROV
  - Mount to tool sled in fixed position with room for manip and sampler
- Ventana (tbd)
  - Held by manip, hydraulics used to open and close light array
- Ricketts (tbd)
  - Held by manip, hydraulics used to open and close light array

MiniROV

- Mount lights directly to ROV
- Fit camera between tray and foam in tool sled



Thanks!