



European  
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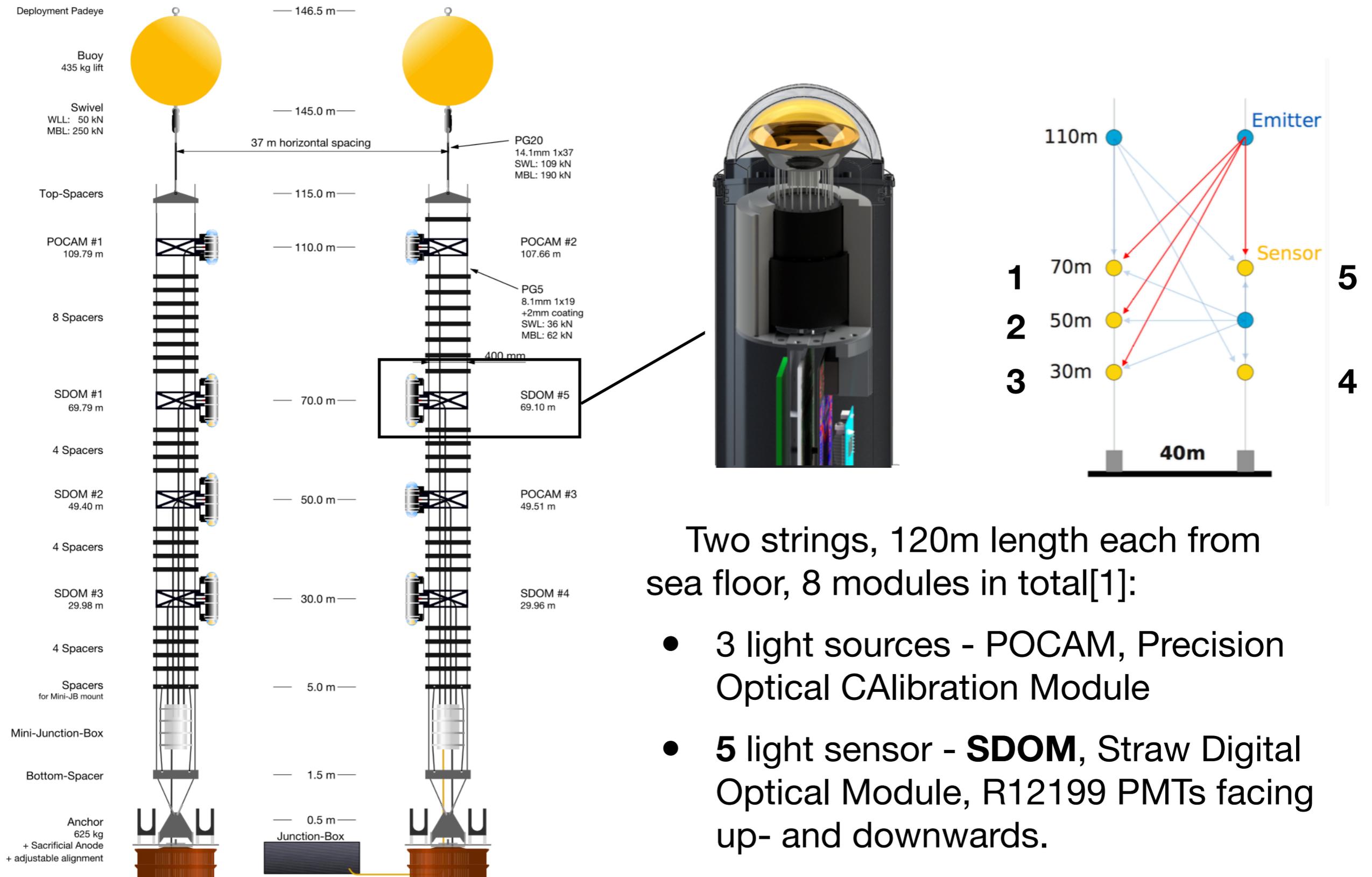
# Four-years baseline characterization for the Pacific Ocean Neutrino Experiment (P-ONE) in the Cascadia Basin

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for the P-ONE Collaboration

# Overview

- Motivation: STRAW/STRAWb as pathfinders of P-ONE
- Properties of bioluminescence events:
  - Time & Spatial **distribution**
  - Water current triggering
  - **Spectral** analysis and **species** identification
  - Reduction of PMTs rates accounting to **biofouling**
- Conclusion: pathfinders give essential inputs for P-ONE event simulation

# Instruments - STRAW



Two strings, 120m length each from sea floor, 8 modules in total[1]:

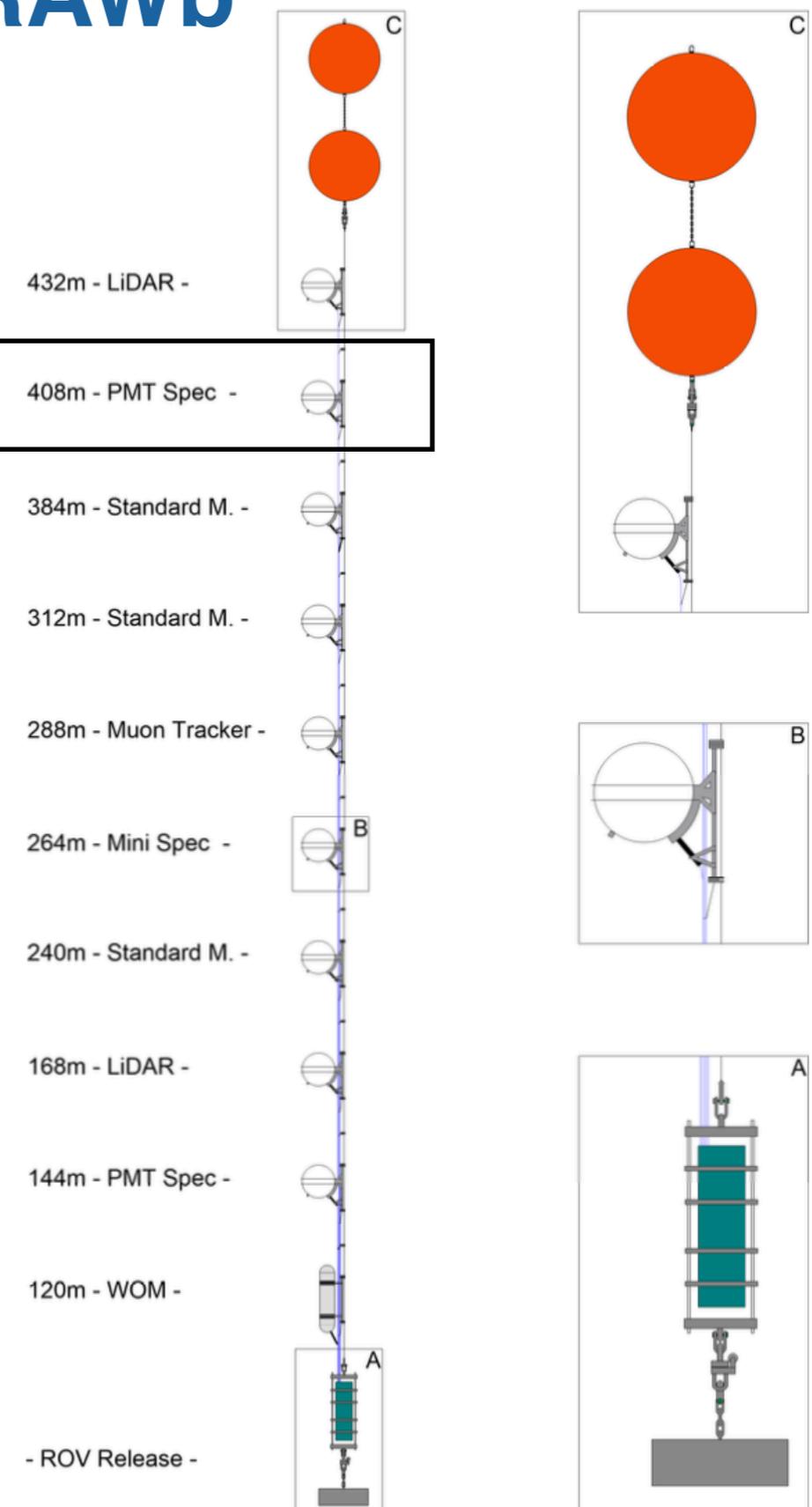
- 3 light sources - POCAM, Precision Optical CALibration Module
- 5 light sensor - **SDOM**, Straw Digital Optical Module, R12199 PMTs facing up- and downwards.

# Instruments - STRAWb

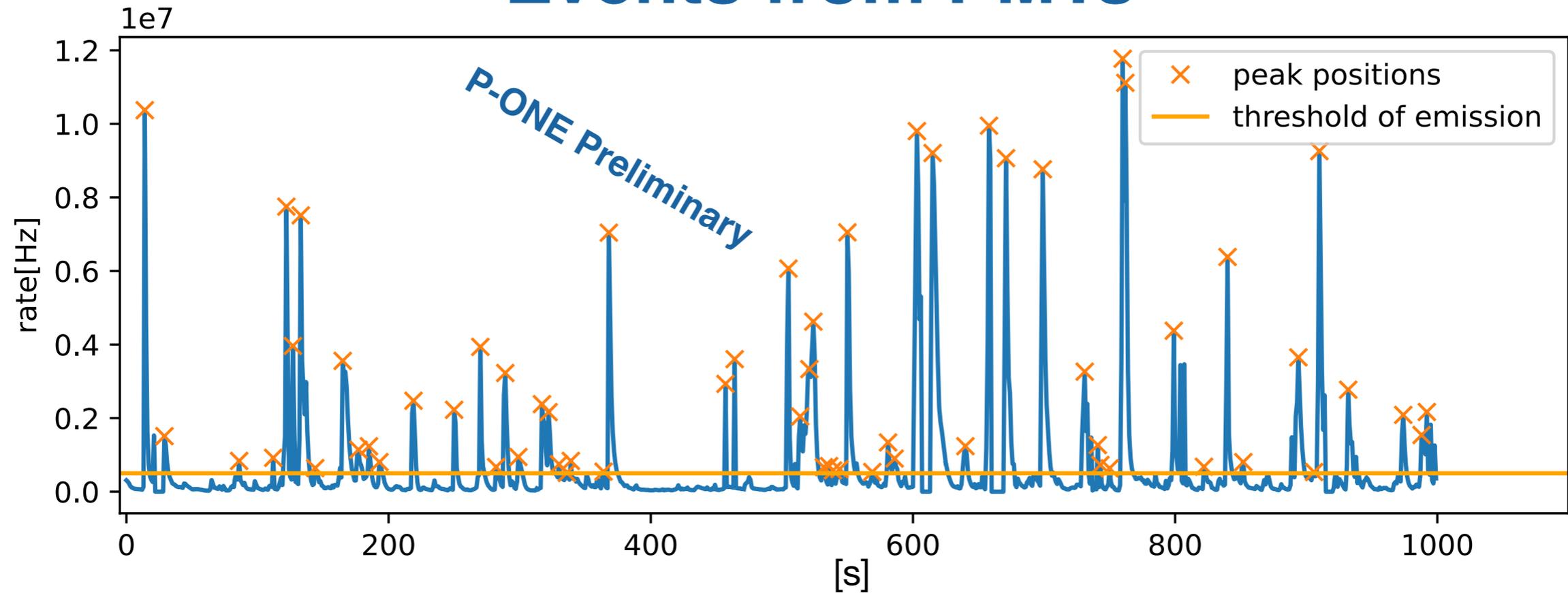


## Two PMT-Spectrometers:

- **12 PMTs + filters** with central wavelengths (CWL) in the range 350-575nm to measure the integrated/monochromatic spectrum.
- **Camera:** extract bioluminescence events by image recognition. Color filter make image sensitive for a single R/G/B color.



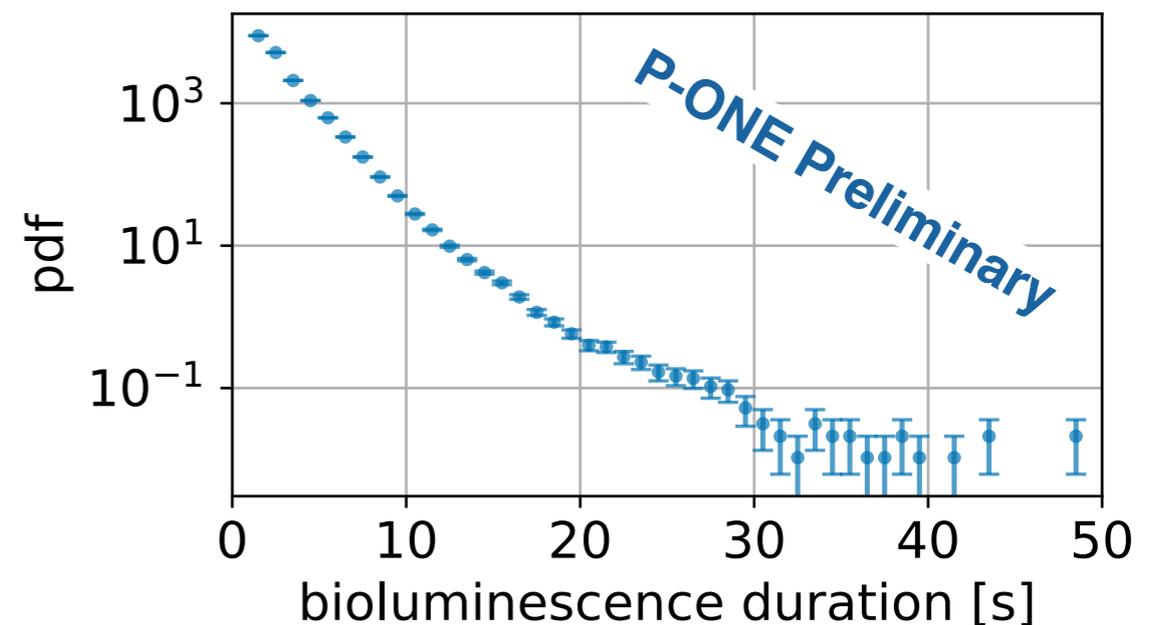
# Events from PMTs



Baseline PDF has gaussian distribution with  $\mu$ ,  $\sigma$ (fit parameters). Use  $R = \mu + 2\sigma$  as threshold of emission.

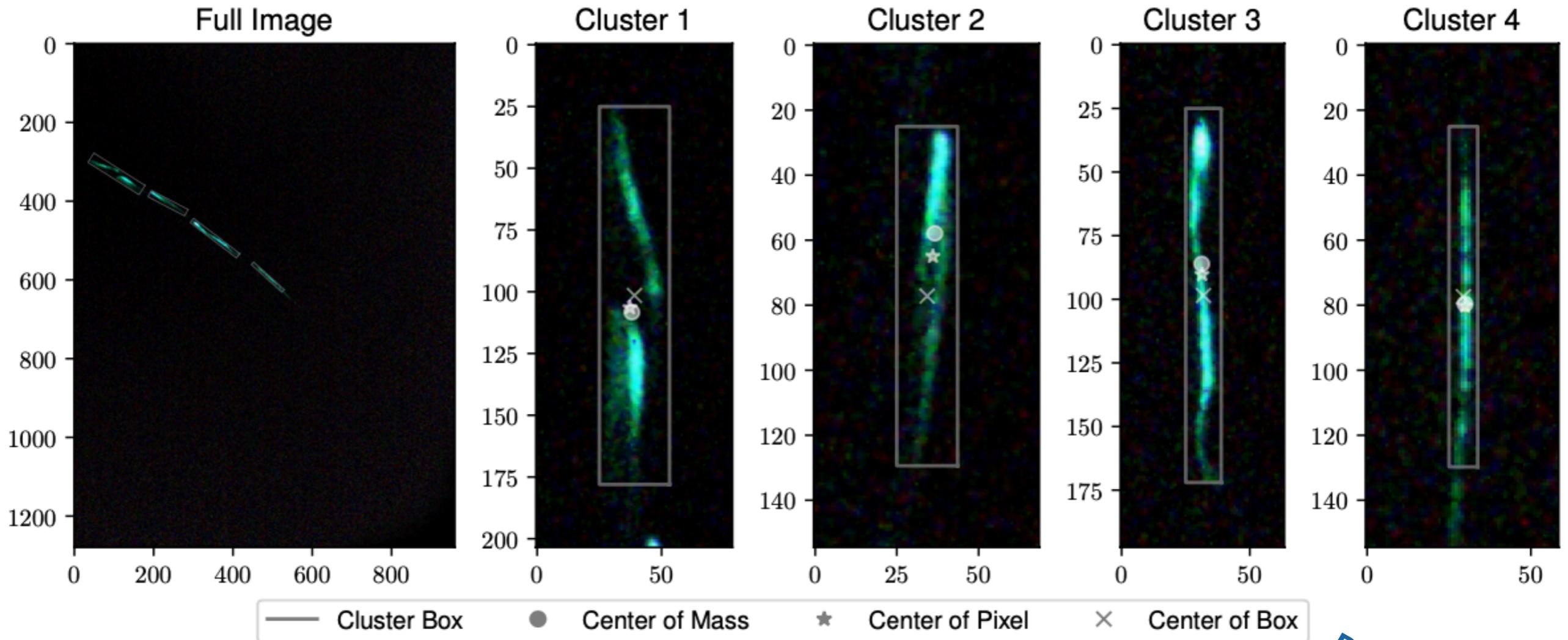
- PDF(Probability of peak height/ pulse duration) of extracted events shows:

Emission has very high frequency ( $\sim$ MHz). Duration mostly has seconds-scale



# Events from Camera

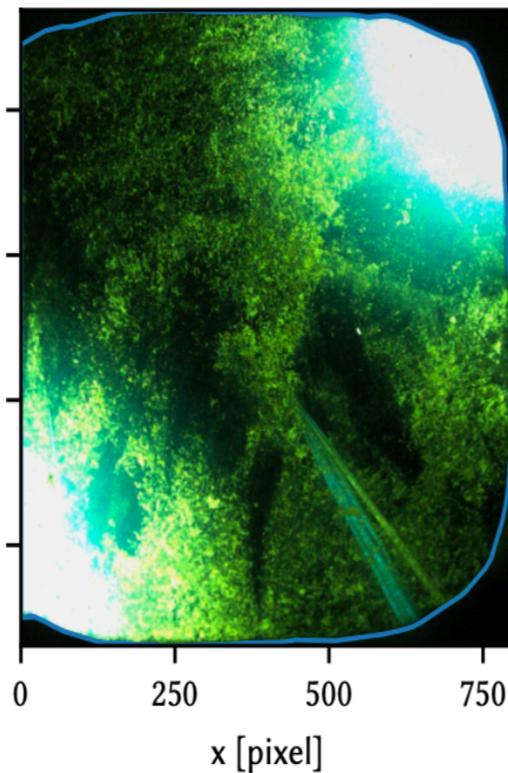
Cluster detection + DNN detect the objects on the image



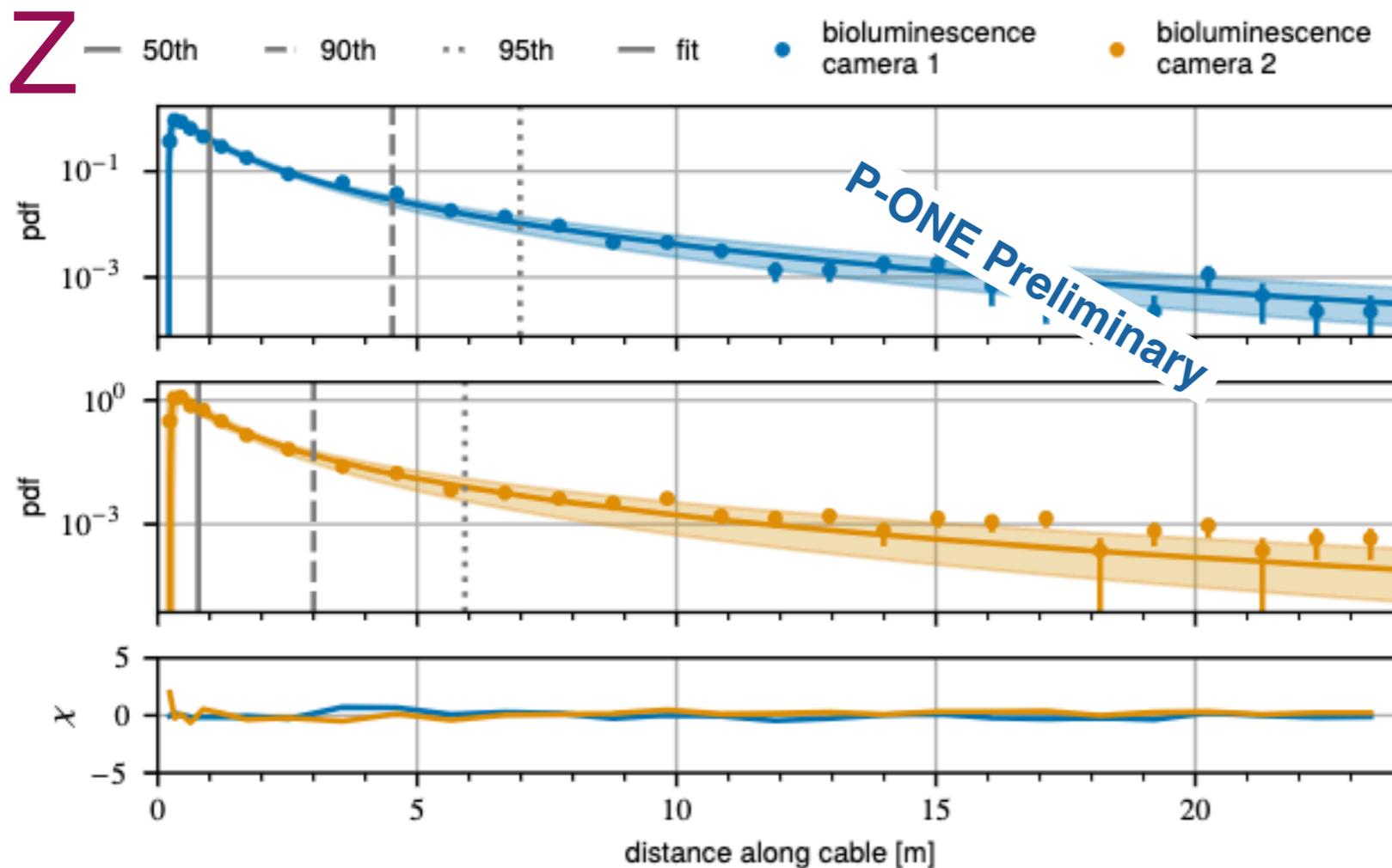
- provides: position, track length, RGB color, and emission shape.

P-ONE Preliminary

# Spatial Distribution

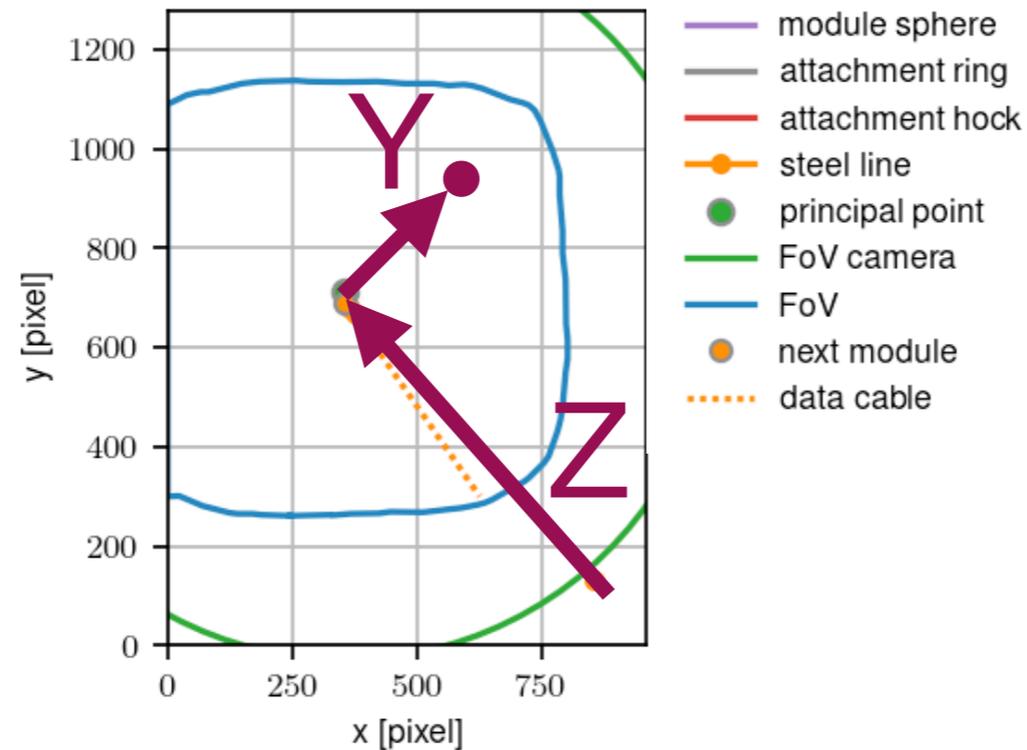


- The optics are known
- Given 2D Position relative to cable

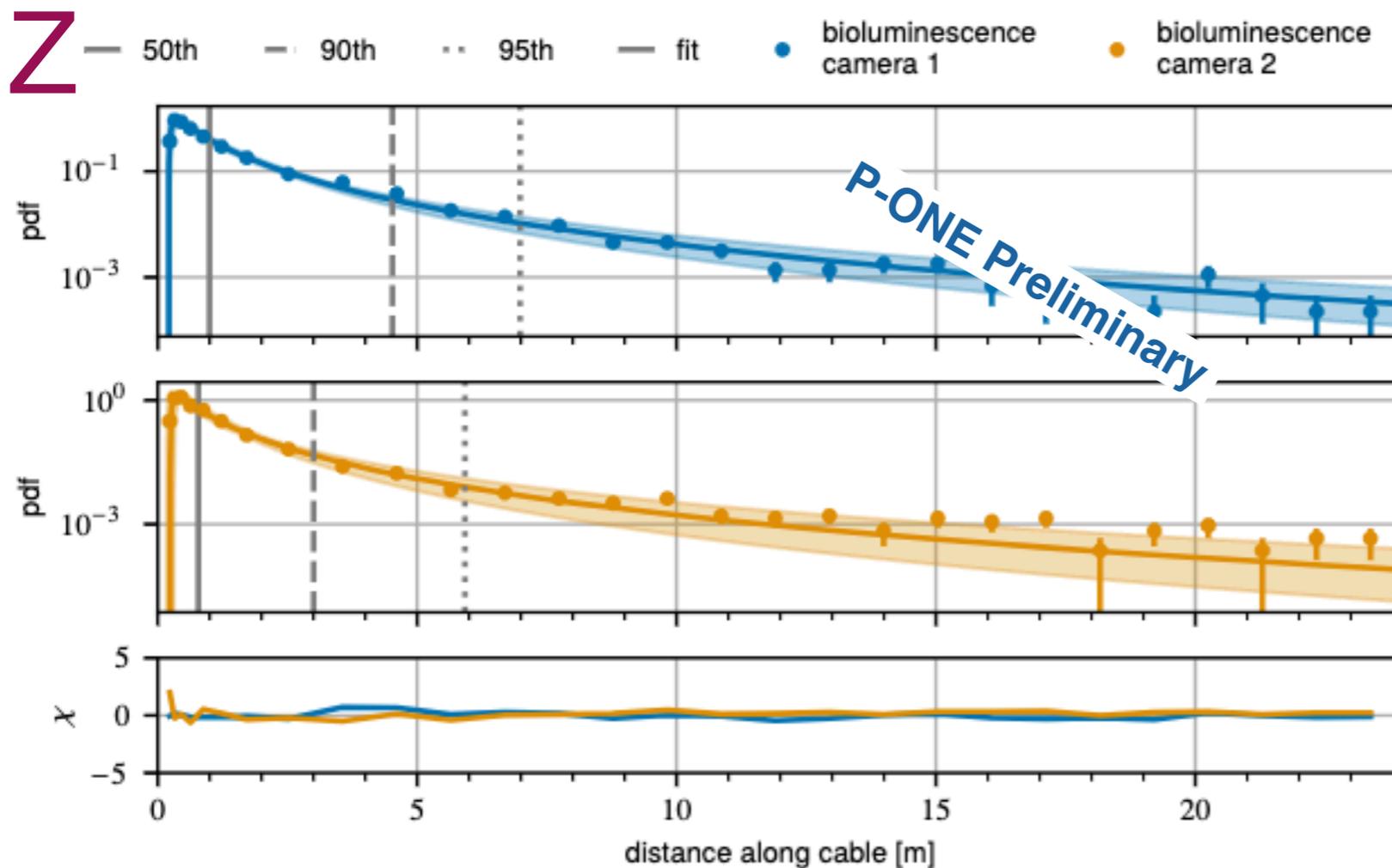


- the camera detects bioluminescence up to ~5m from the camera
- most events are within ~1m around the line

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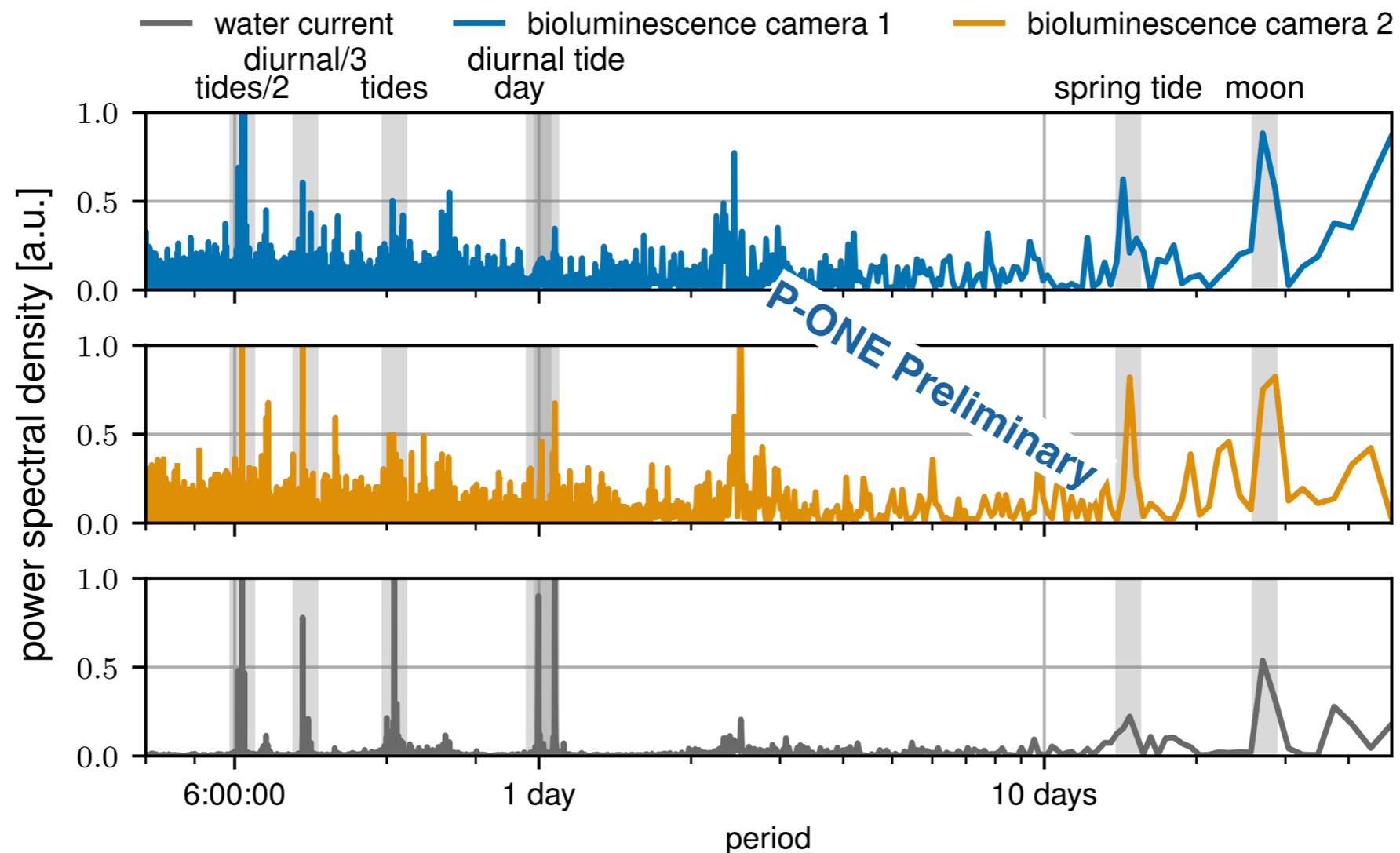


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# Time Distribution

Use FFT(Fast Fourier Transformation) convert frequency data into time domain and plot its **PSD**(Power Spectrum Density) vs period.

- **Same** periods show up in the both bioluminescence and water current
- Could explain the most significant periods: one day 24h ; tides 12:5h; moon 27.3 days...



# Water Current Triggering

- Bioluminescence is mainly triggered by **contact** or **shear** forces induced by objects.
- The emission probability is proportional to the shear forces  $p_{\text{shear}}(\vec{u}) \sim \alpha \nabla \vec{u}$
- Rate of emissions:

$$R = R_{\text{contact}} + R_{\text{shear}}$$

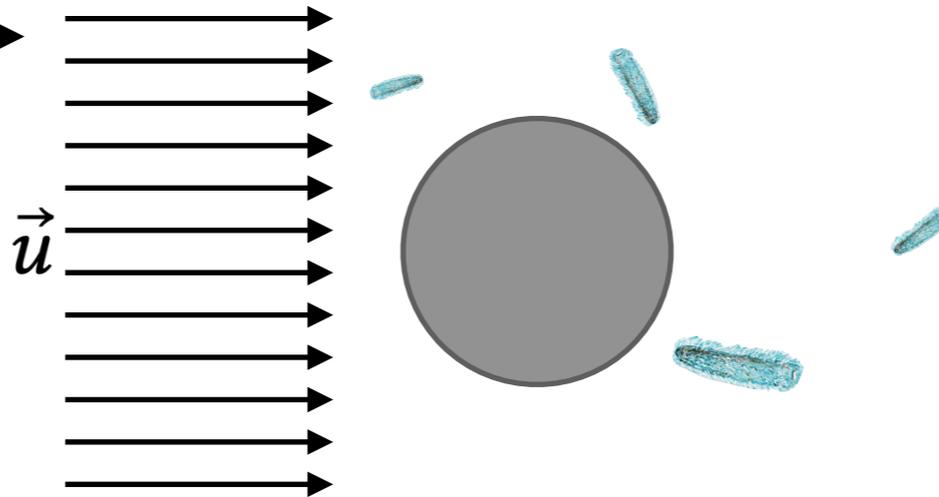
## Rate shear

(derived by divergence theorem):

$$R_{\text{shear}} = c_{\text{bio}} \alpha A_{\perp}^* (\vec{u}) |\vec{u}|$$

## Rate contact

$$R_{\text{contact}} = c_{\text{bio}} A_{\perp} p_{\text{contact}} |\vec{u}|$$



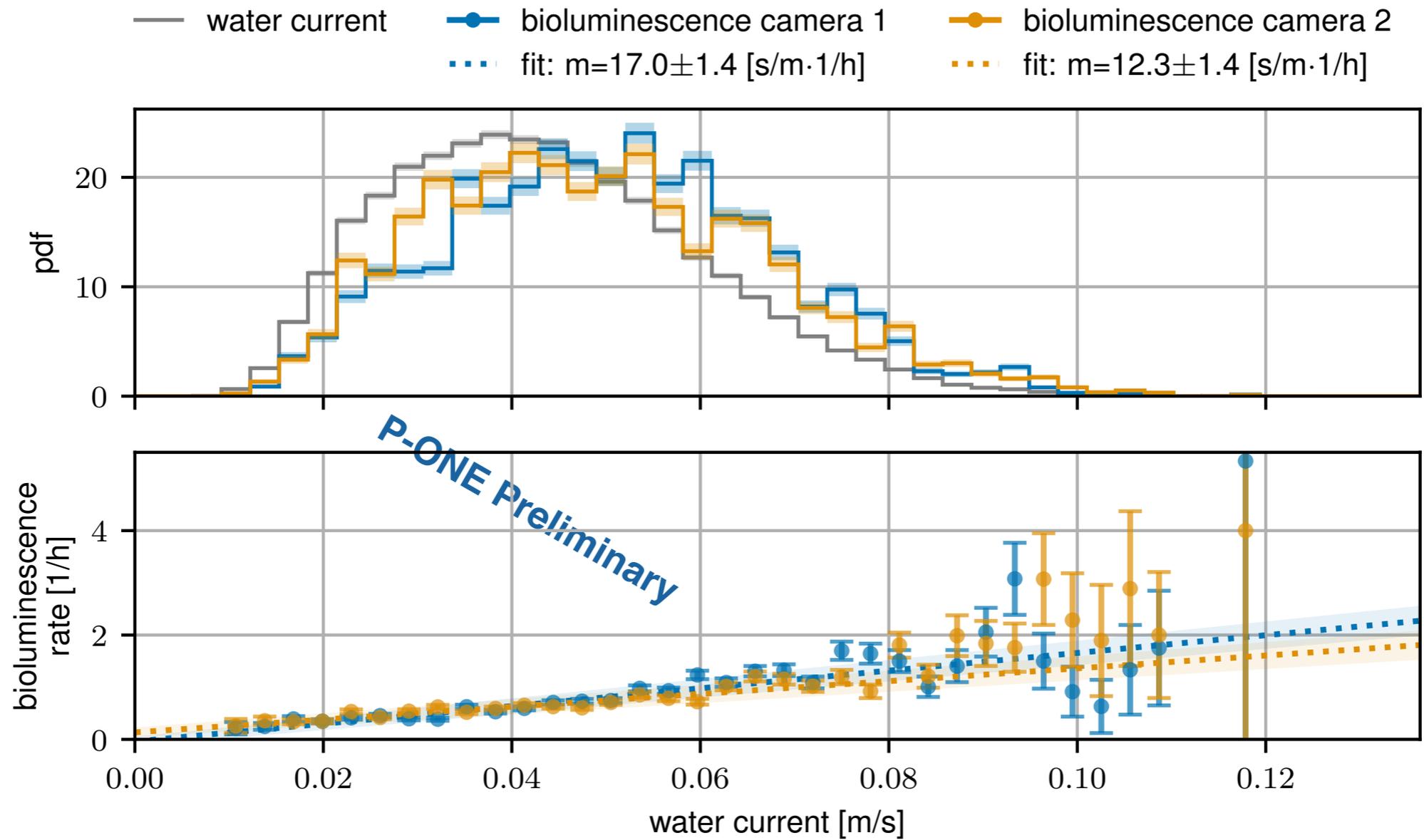
emission rate  $R = c_{\text{bio}} A_{\perp} p_{\text{contact}} |\vec{u}| + c_{\text{bio}} \alpha A_{\perp}^* |\vec{u}|$

$$= c_{\text{bio}} \left( A_{\perp} p_{\text{contact}} + \alpha A_{\perp}^* \right) |\vec{u}|$$

**m**

water current speed

# Water Current Triggering - STRAWb

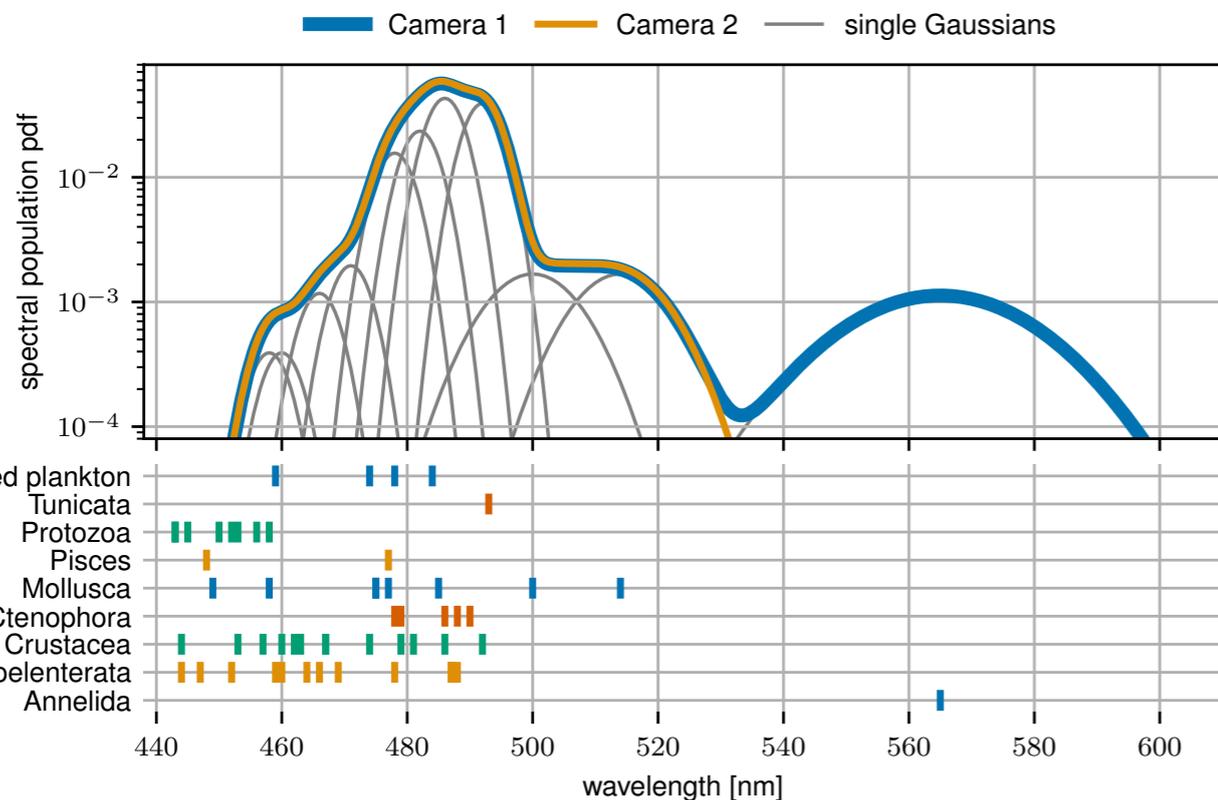


	$m$ [s/(m h)]	$R_0$ [1/s]	$y^*$ [m]	$z^*$ [m]	$A_{\perp}^*$ [1/m <sup>2</sup> ]	$c_{\text{bio}}$ [1/m <sup>3</sup> ]
Camera 1	$17.0\pm 1.4$	$0.0\pm 0.1$	0.154	0.982	0.151	$0.031\pm 0.003$
Camera 2	$12.3\pm 1.4$	$0.1\pm 0.1$	0.124	0.794	0.096	$0.035\pm 0.004$

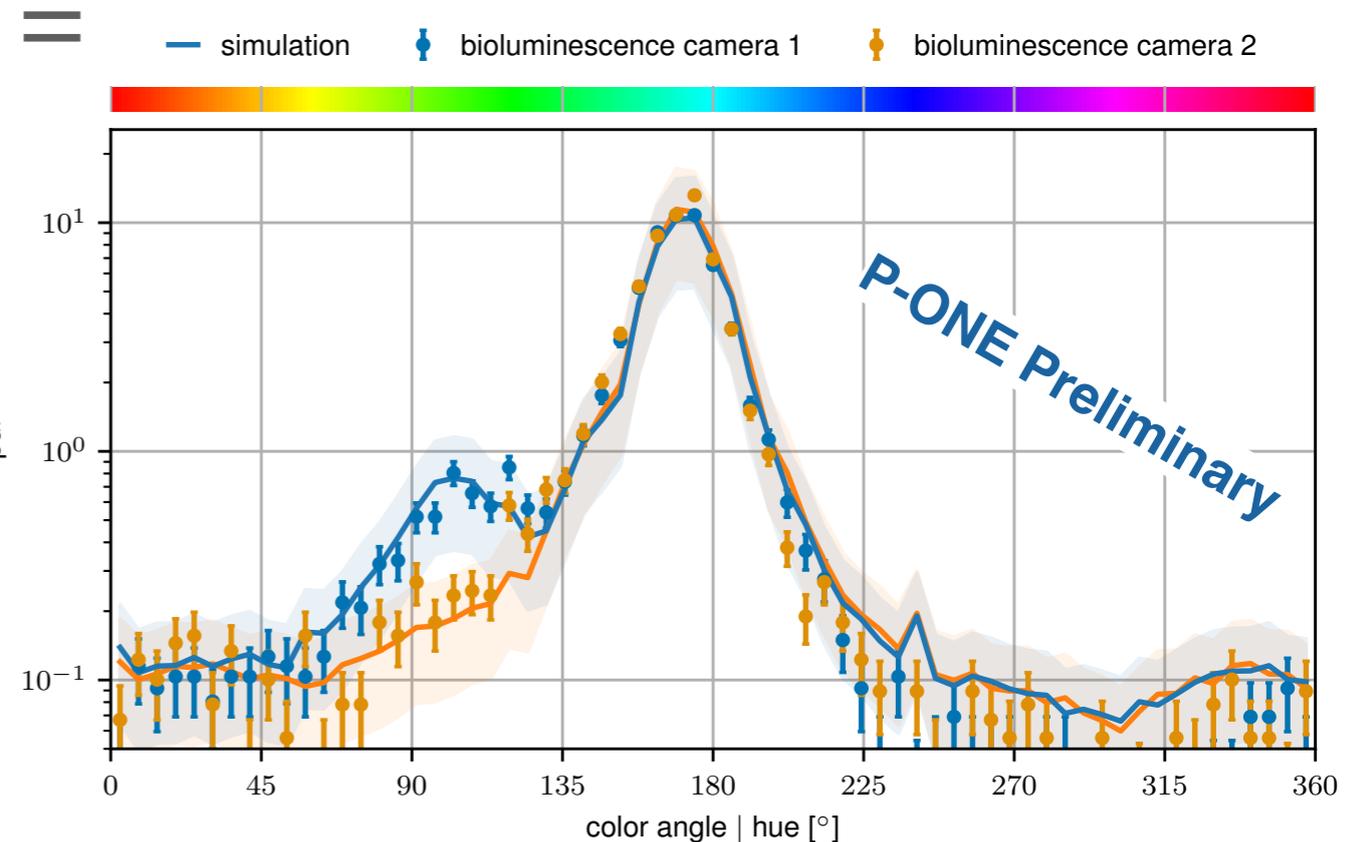
# Spectral Analysis

- To convert RGB to a hue angle
- Bioluminescence catalog of organisms with their spectrum(CWL& FWHM)  
Matching the simulation data with camera measurement by varying **species population**
- The found population agree with catalog and STRAWb PMTs measurement

Camera response +  
spectral catalog of bioluminescence

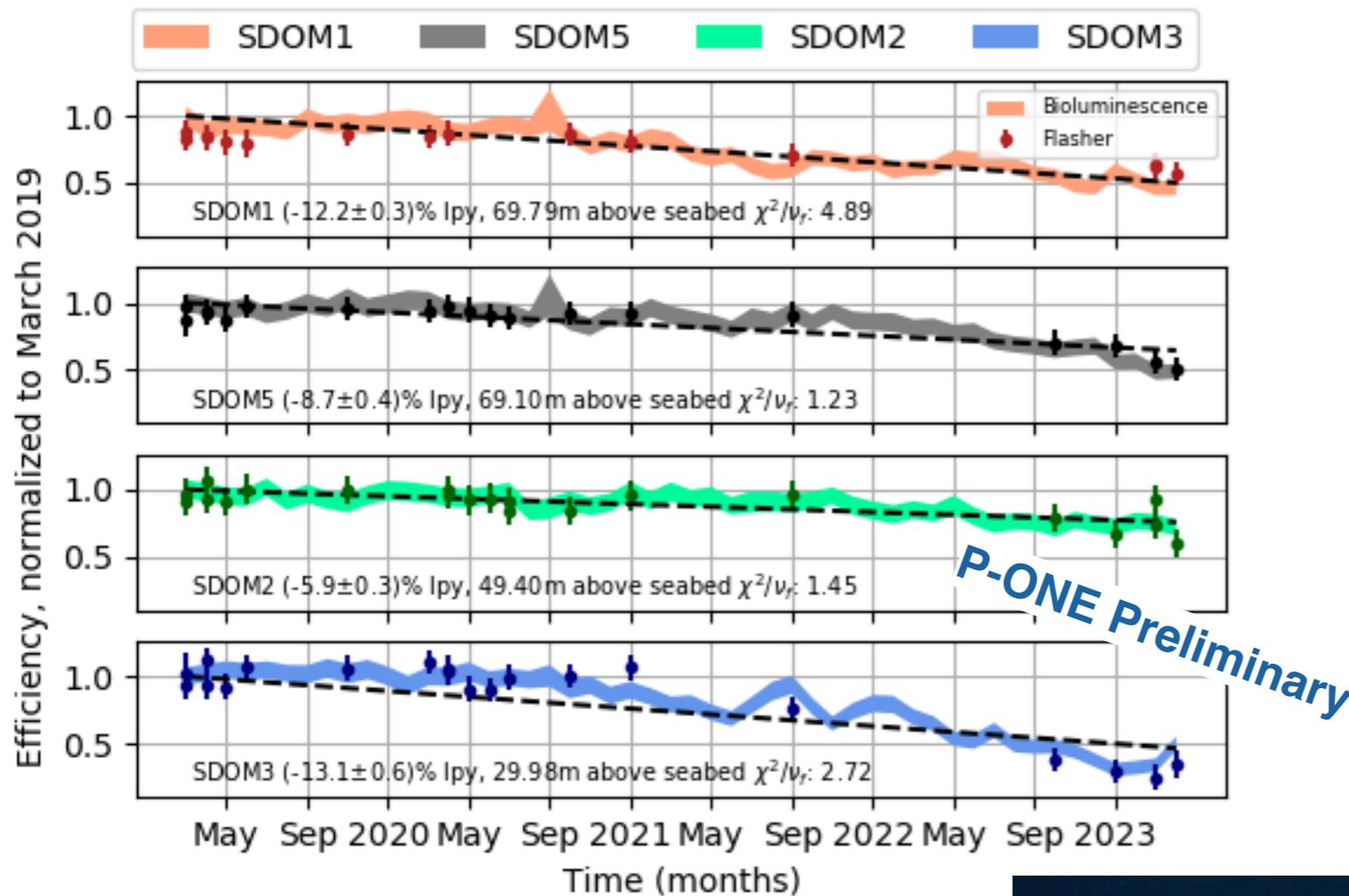


detected and simulated hue distribution



- M. I. Latz, T. M. Frank, and J. F. Case. "Spectral composition of bioluminescence of epipelagic organisms from the Sargasso Sea". Marine Biology 3 (June 1988).

# Biofouling

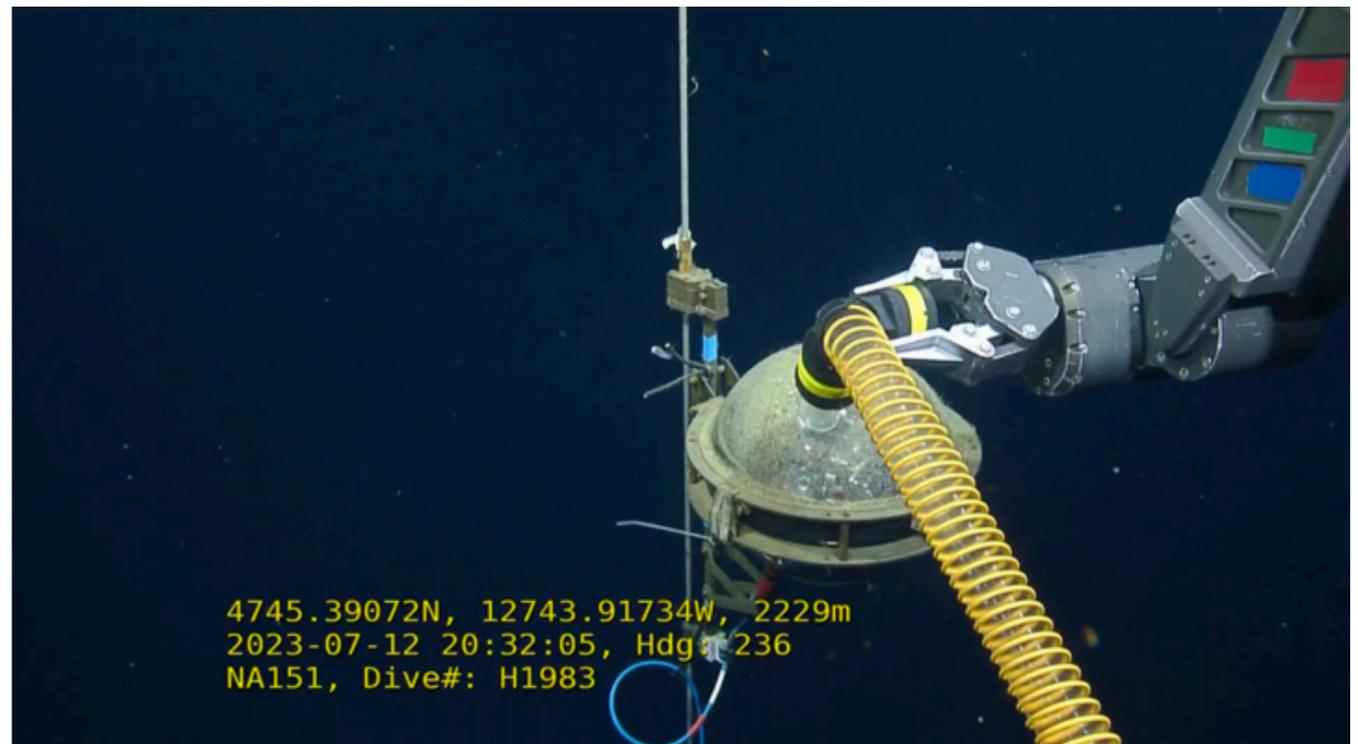


## Two independent measurements:

1. from STRAW's continuous data taking mode (thick band), with the width of the band indicating  $\pm 1\sigma$  confidence interval.
2. using the POCAM flashers. The fraction of detected flashes were measured (points).

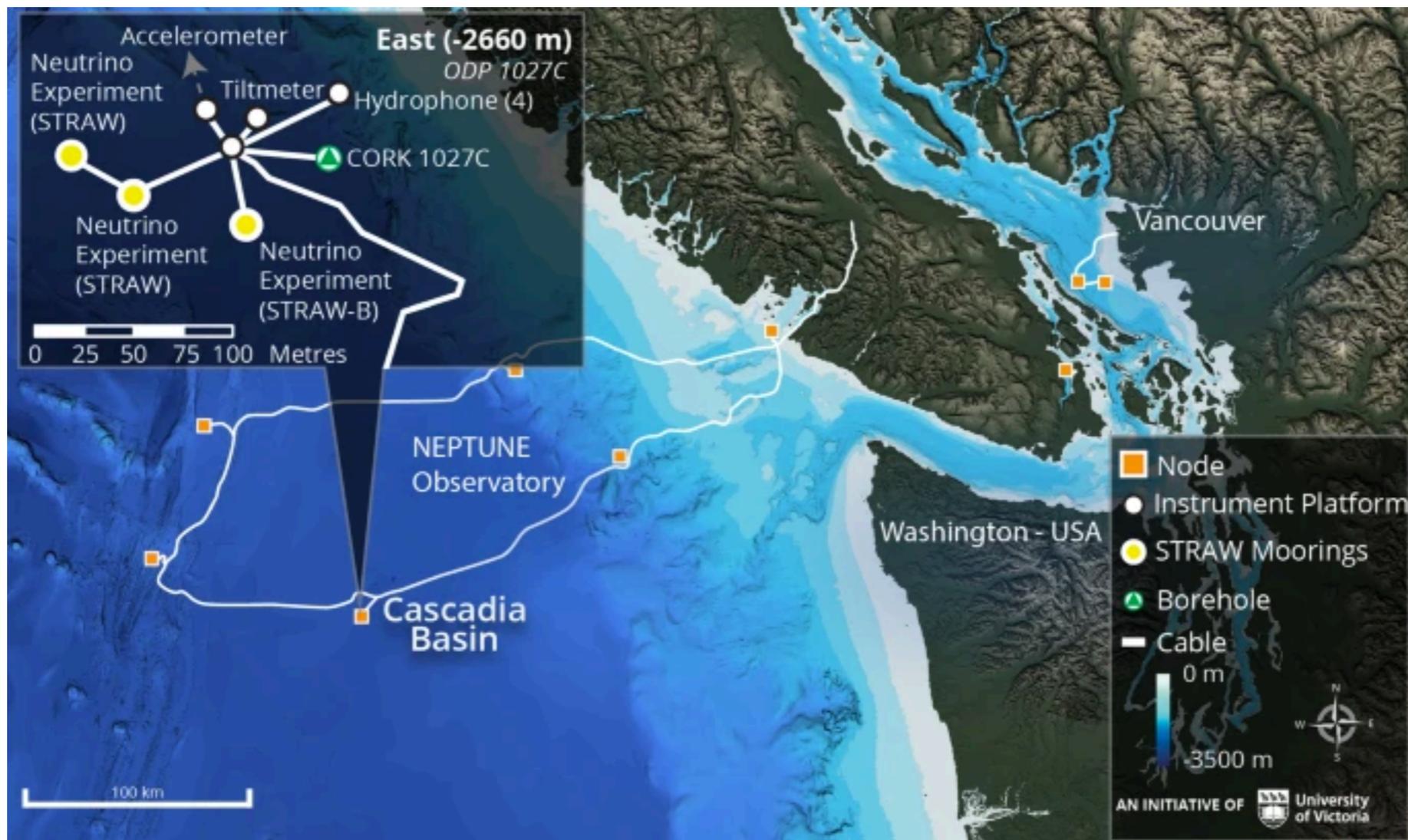
linear fit **slopes** indicated **percentage loss** per year.

Recall the position of each sDOM, the **deepest** sDOM3(blue) lost most efficiency.



# Data collected by STRAW & STRAWb

	STRAW	STRAWb
Read-out frequency	33Hz	1kHz
Height from see floor	30-110m	120-430m
Data period after commissioning	4 years	2 years
Software to process data	No	strawb python package

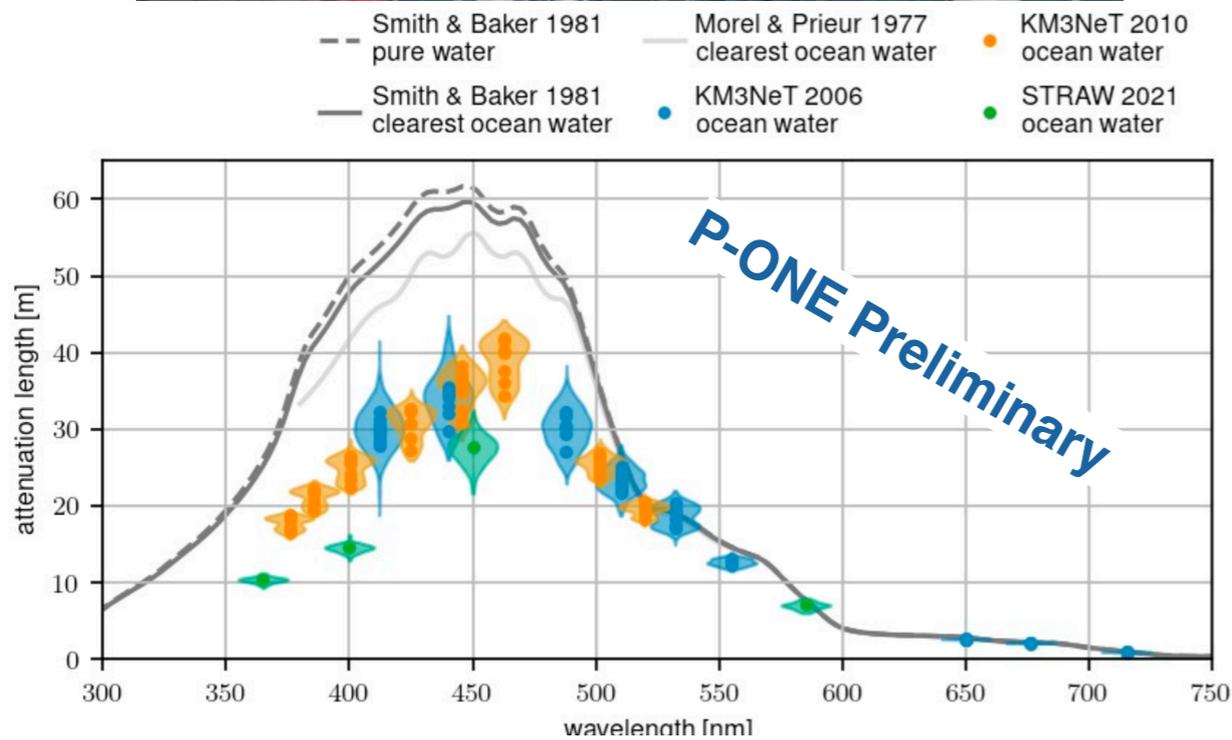


# Input for Future P-ONE

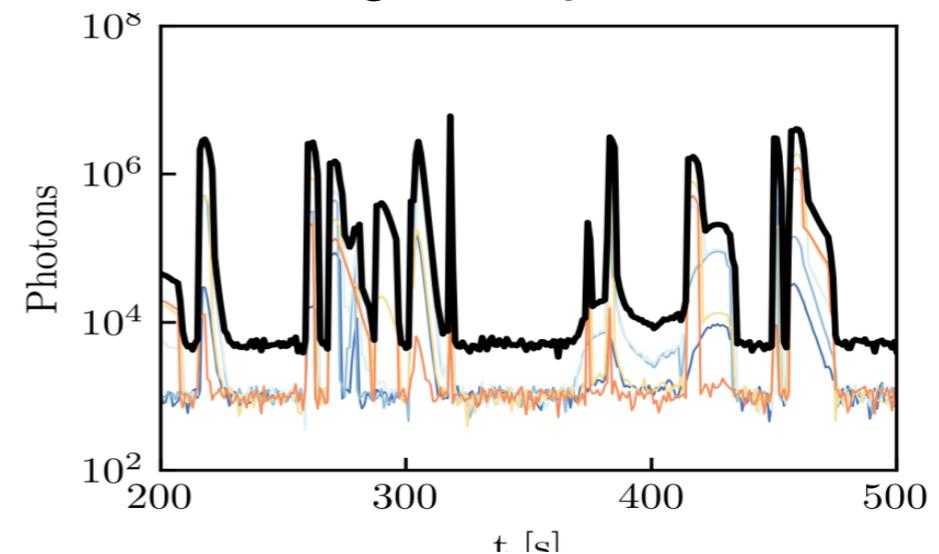
Experience of Deployment



Better design of optical module



Optical and Dynamical properties of deep sea water



A python package to simulate the bioluminescence in the deep sea:  
**[arXiv:2103.03816](https://arxiv.org/abs/2103.03816) Bioluminescence modelling for deep sea experiments**

# Conclusion and Outlook

STRAW and STRAWb successfully operated through planned service time and has collected data with good quality. They are essential input knowledge for P-ONE simulation.

We learn properties of bioluminescence:

- Events properties: MHz and seconds long pulse.
- Location: most emission happens near the cable/module and triggered by water current.
- Spectral shape and population of bioluminescence (& photographs for large organisms)
- Sedimentation/Bio-fouling accumulation speed: depth dependence. New design of P-ONE optical model, more investigation.

More details in **ICRC2023 PoS: Pathfinders of the Pacific Ocean Neutrino Experiment**

**Thanks for your attention !**

# Backup

# Consistency Check

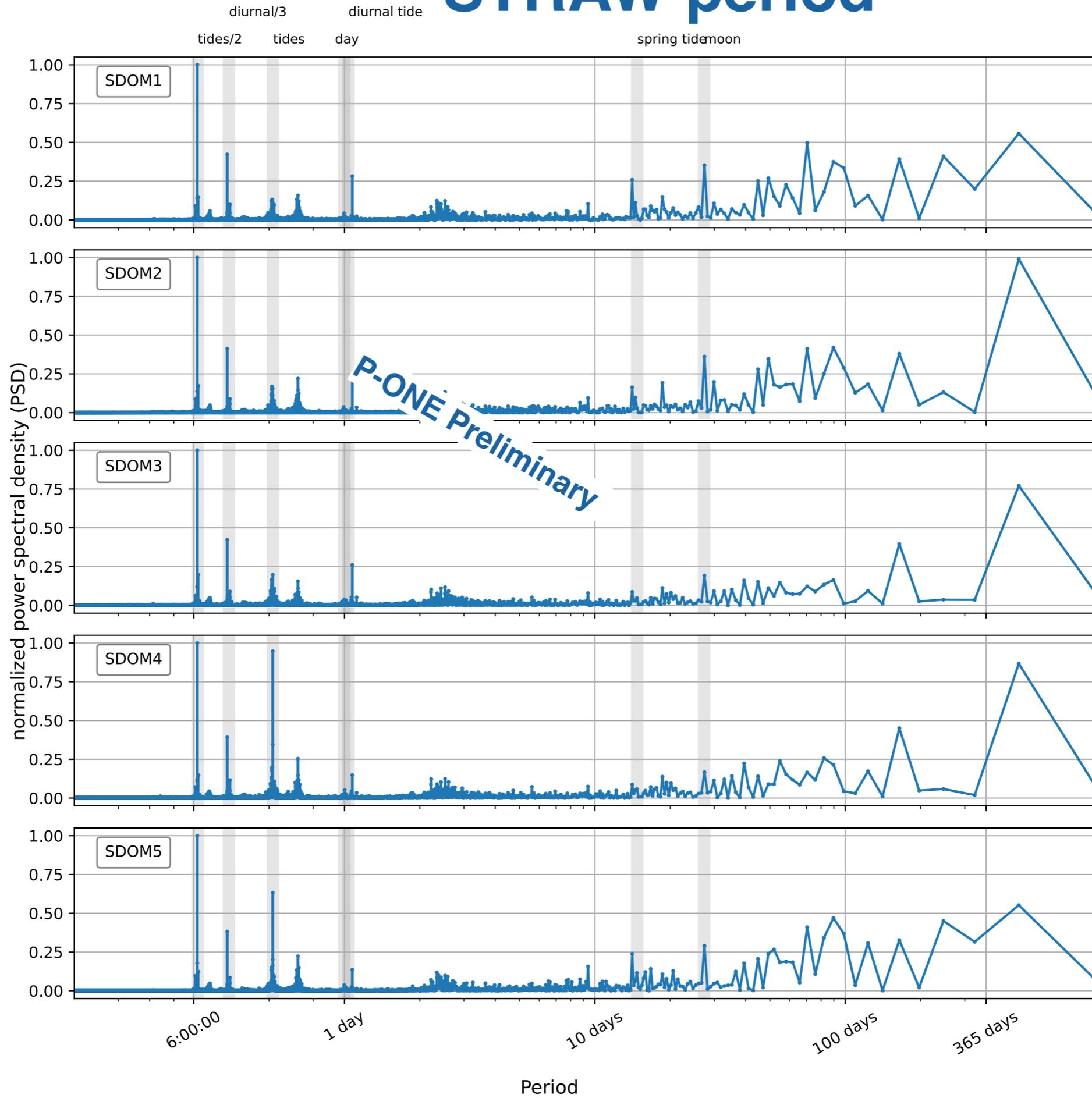
Most analyses were done both with STRAW and STRAWb data. The results from two experiments show consistence.

The analysis also consists with KM3NeT attenuation (Anassontzis et al. “Water transparency measurements in the deep Ionian Sea”. In: Astroparticle Physics 34.4 (2010))

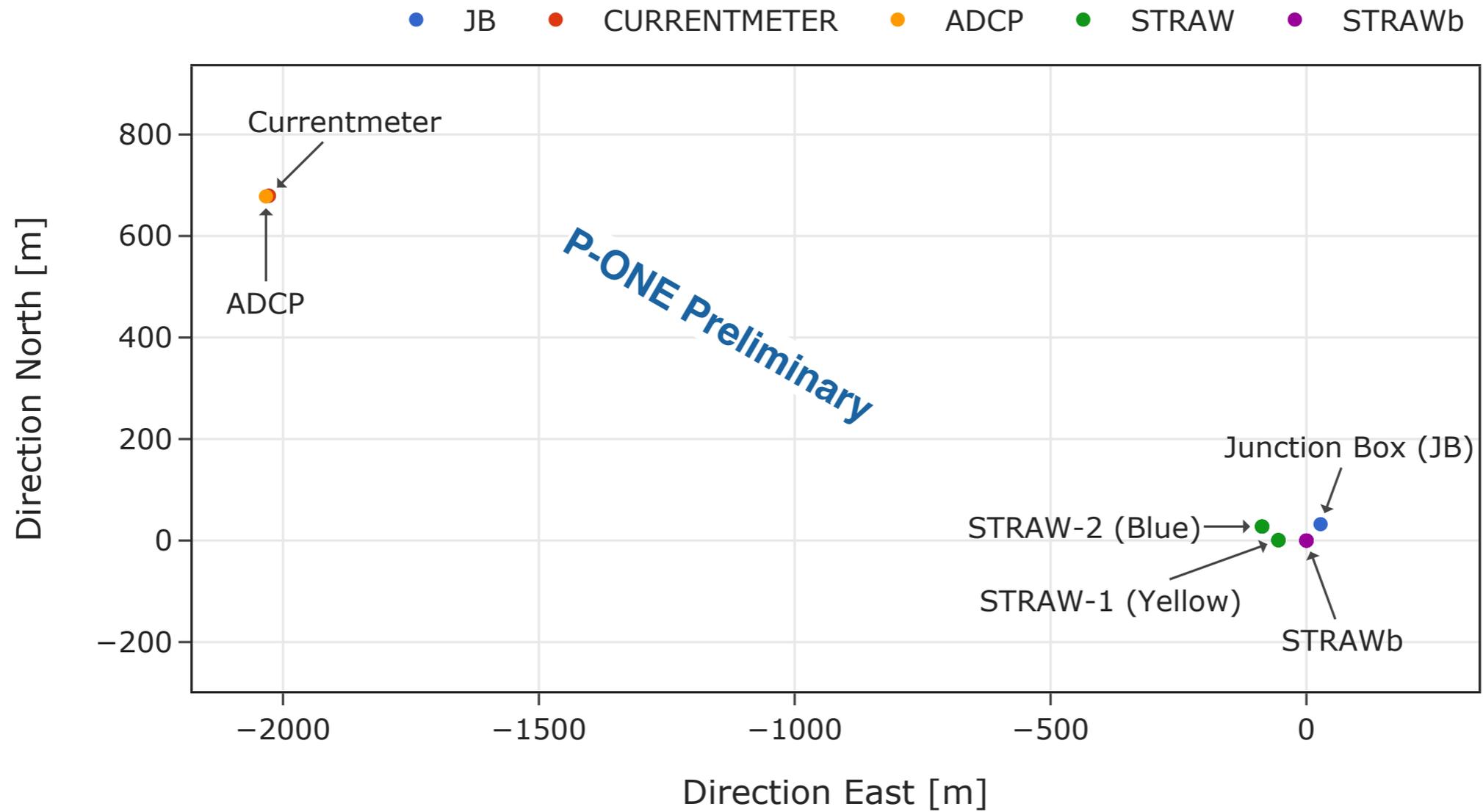
and ANTARES bioluminescence concentration (G. Priede et al. “The potential influence of bioluminescence from marine animals on a deep-sea underwater neutrino telescope array in the Mediterranean Sea”. In: Deep Sea Research Part I: Oceanographic Research Papers 55.11 (2008))

**Results.**

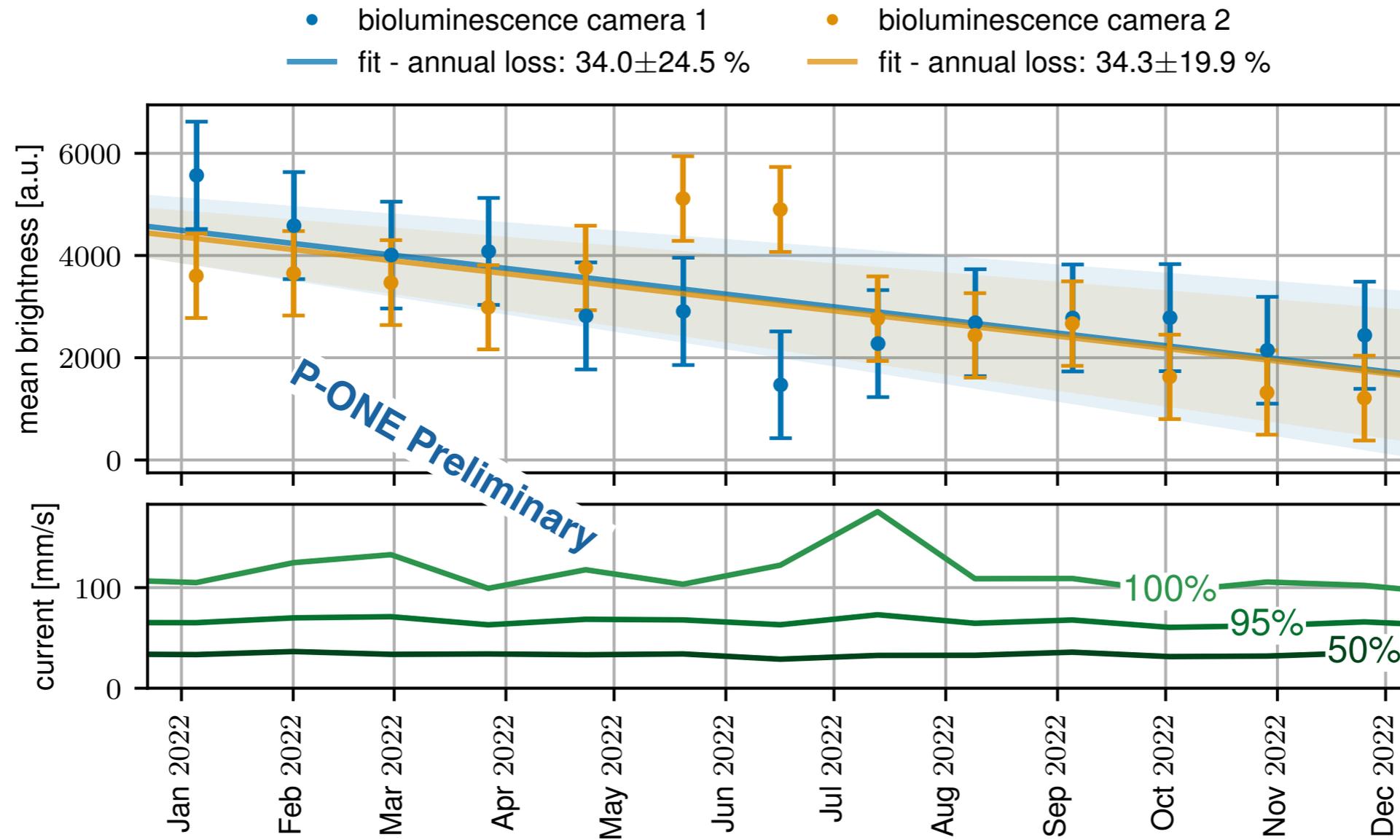
# STRAW period



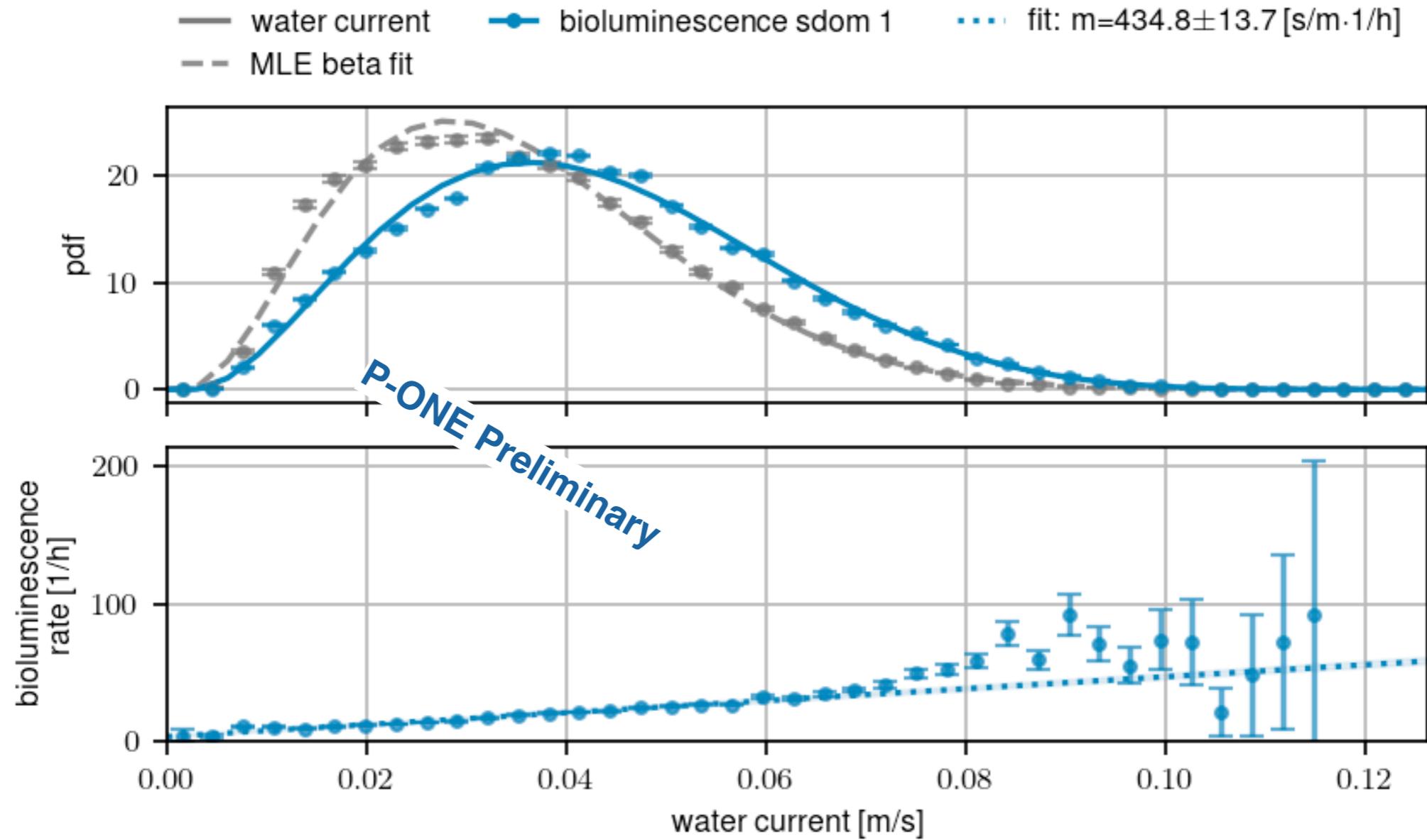
# Current meter - STRAW/b distance



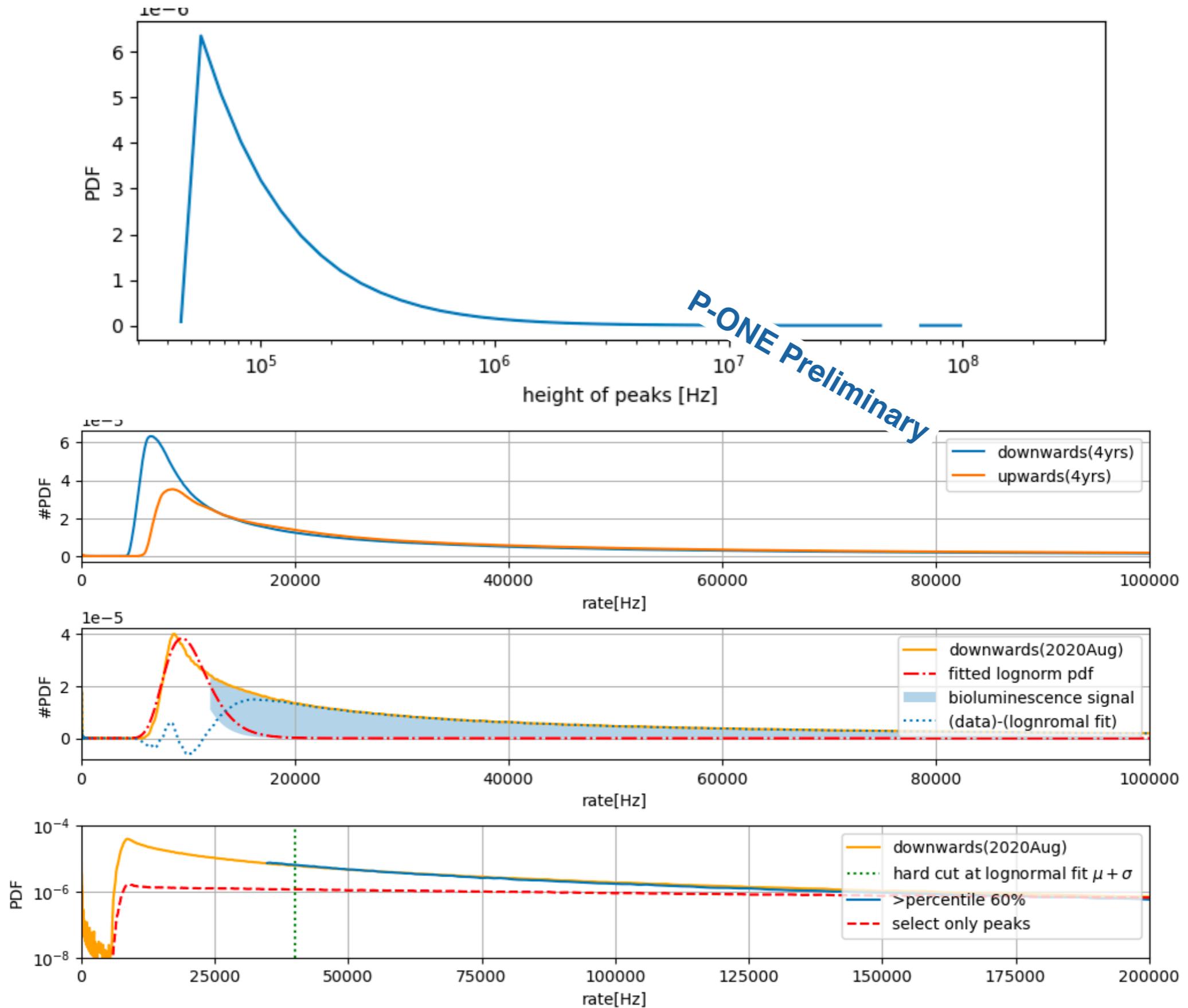
# Biofouling linear fit - STRAWb



# Water Current Triggering -STRAW



# STRAW - Emission Distribution



# Picture of species hue

P-ONE Preliminary

