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Sea-thru: A Method for Removing Water From Underwater Images

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Sea-thru

A physics-based computer vision method
for
color reconstruction of underwater images

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Sea-thru: CVPR 2019

Sea-thru: A Method For Removing Water From Underwater Images

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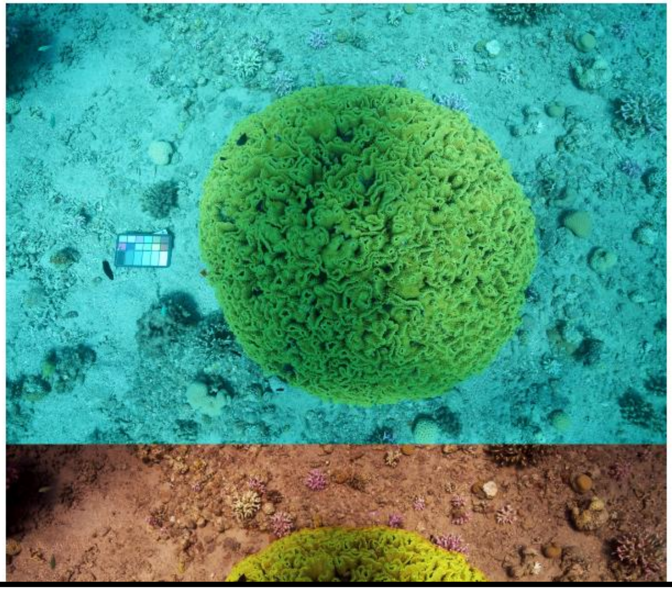
Abstract

Robust recovery of lost colors in underwater images remains a challenging problem. We recently showed that this was partly due to the prevalent use of an atmospheric image formation model for underwater images and proposed a physically accurate model. The revised model showed: 1) the attenuation coefficient of the signal is not uniform across the scene but depends on object range and reflectance, 2) the coefficient governing the increase in backscatter with distance differs from the signal attenuation coefficient. Here, we present the first method that recovers color with our revised model, using RGBD images. The Sea-thru *method estimates backscatter using the dark pixels and their known range information. Then, it uses*



Sea-thru: CVPR 2019 + CVPR 2018

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A Revised Underwater Image Formation Model

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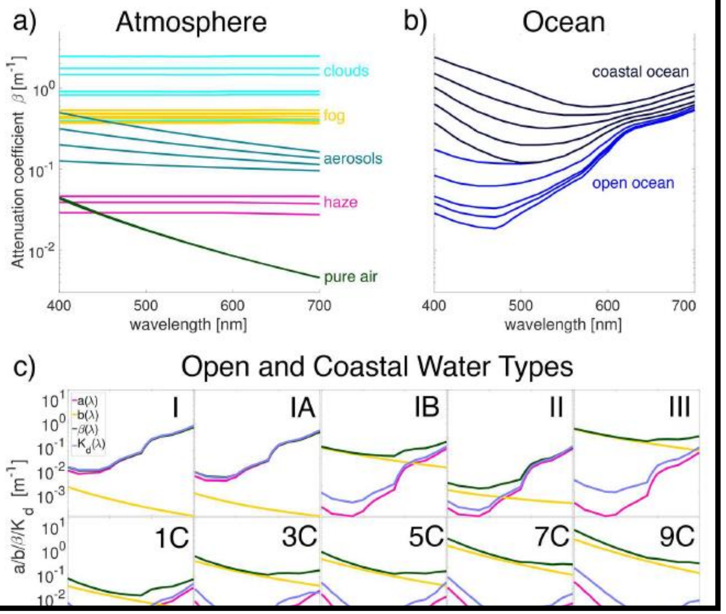
Abstract

The current underwater image formation model descends from atmospheric dehazing equations where attenuation is a weak function of wavelength. We recently showed that this model introduces significant errors and dependencies in the estimation of the direct transmission signal because underwater, light attenuates in a wavelength-dependent manner. Here, we show that the backscattered signal derived from the current model also suffers from dependencies that were previously unaccounted for. In doing so, we use oceanographic measurements to derive the physically valid space of backscatter, and further show that the wideband coefficients that govern backscatter are different than those that govern direct transmission, even though the current model treats them to be the same. We propose a re-



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Light Attenuation in Air vs Water

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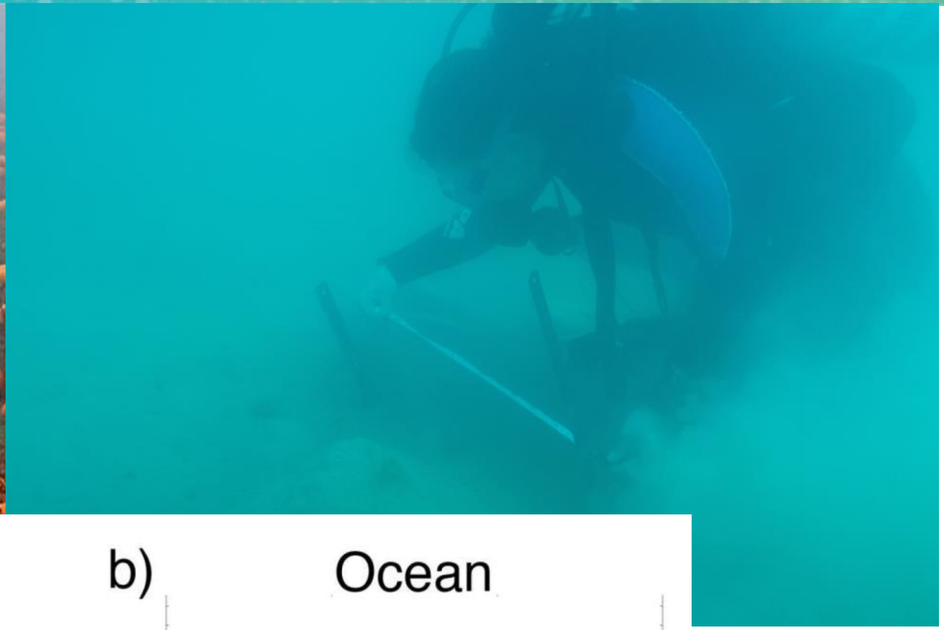

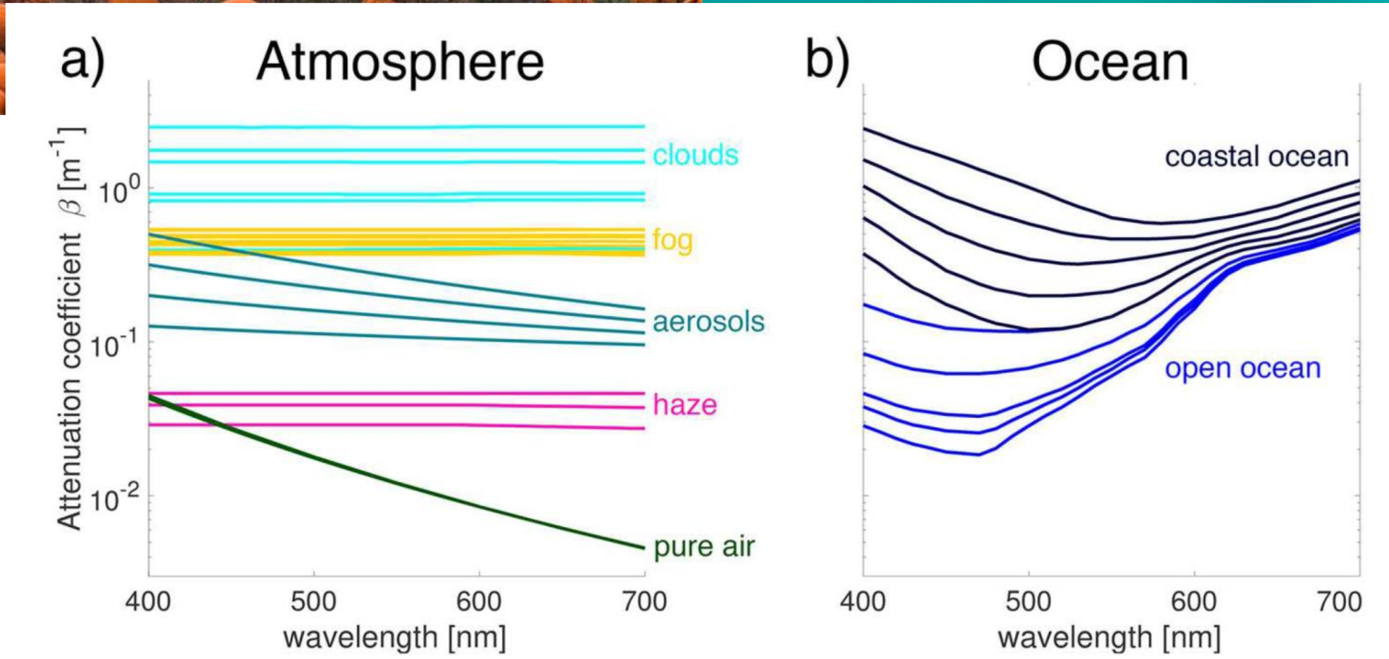

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Sea-thru: CVPR 2019 + CVPR 2018 + CVPR 2017

What Is the Space of Attenuation Coefficients in Underwater Computer Vision?

Derya Akkaynak[1,2], Tali Treibitz[1], Tom Shlesinger[3], Raz Tamir[2,3], Yossi Loya[3], and David Iluz[4]

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Abstract

Underwater image reconstruction methods require the knowledge of wideband attenuation coefficients per color channel. Current estimation methods for these coefficients require specialized hardware or multiple images, and none of them leverage the multitude of existing ocean optical measurements as priors. Here, we aim to constrain the set of physically-feasible wideband attenuation coefficients in the ocean by utilizing water attenuation measured world-wide by oceanographers. We calculate the space of valid wideband effective attenuation coefficients *in the 3D RGB domain and find that a bound manifold in 3-space sufficiently represents the variation from the clearest to murkiest waters. We validate our model using* in situ *experiments in two different optical water bodies, the Red Sea and the Mediterranean. Moreover, we show that contradictory to*

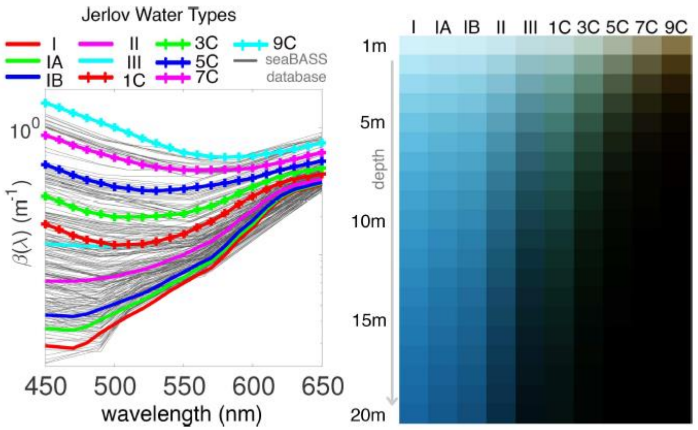
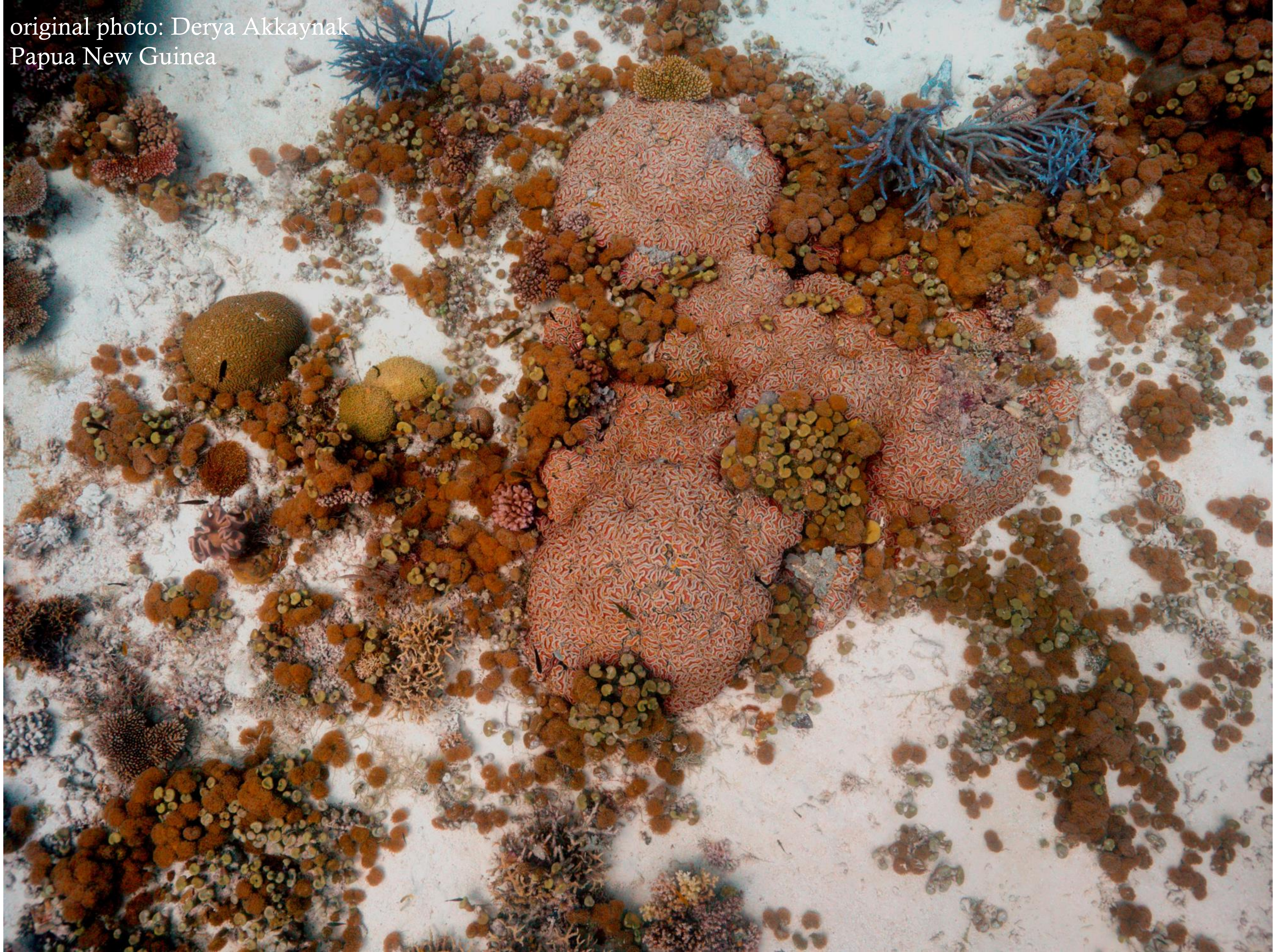
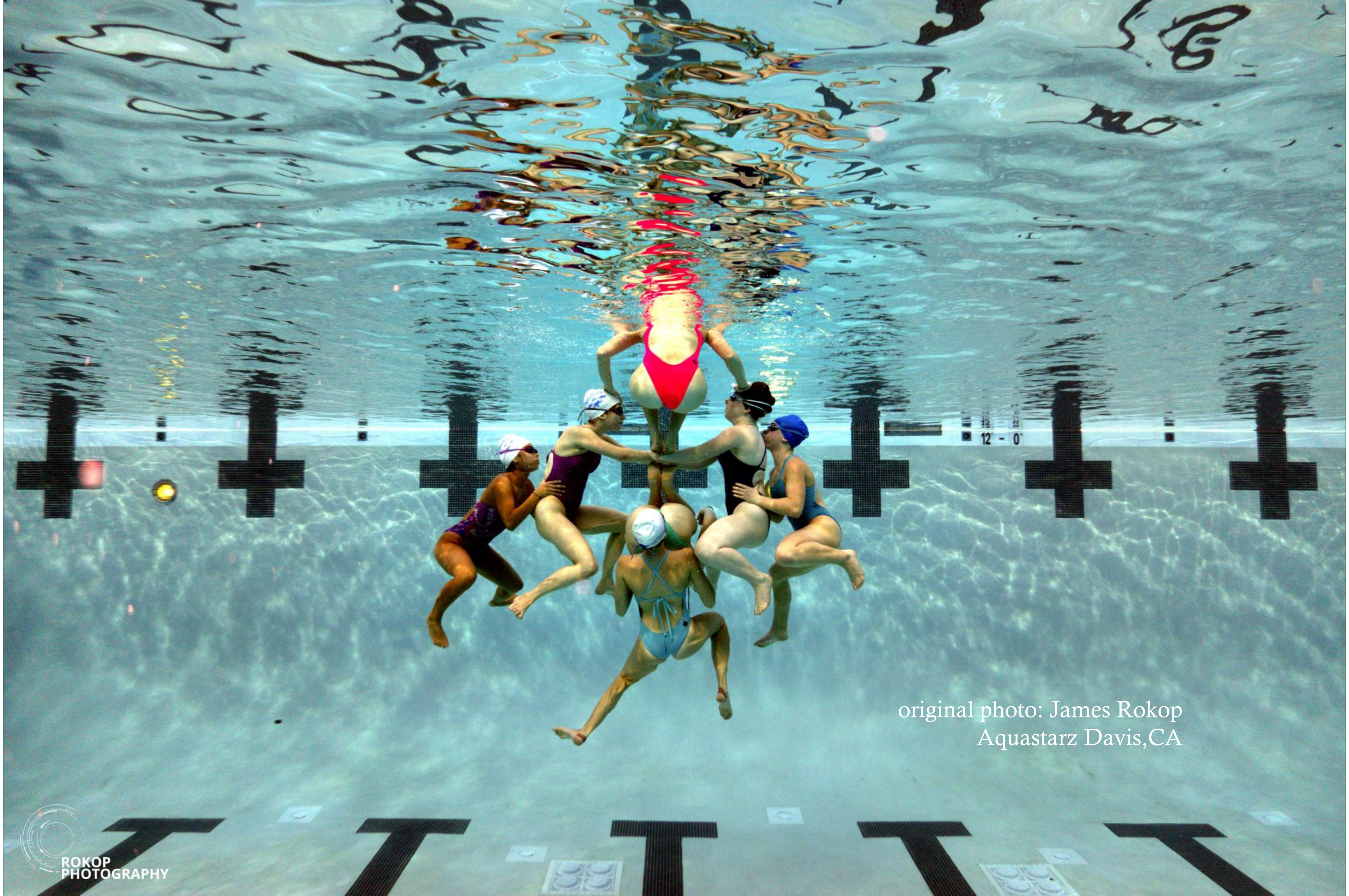


Figure 1. **Water types**. [Left] Based on the attenuation coefficient $\beta(\lambda)$ measurements from a global expedition between 1947-48 [25], 10 optical classes have come to be known as *Jerlov Water Types* [24]. Types I-III are oceanic waters that range from


original photo: Matan Yuval
Eilat, Israel

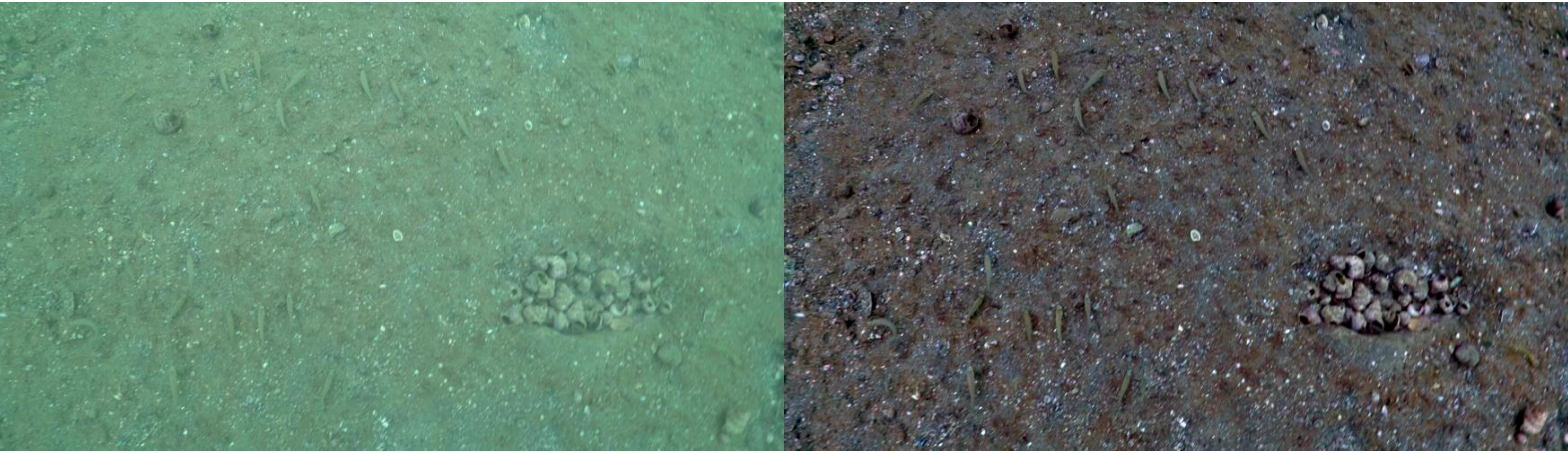

original photo: Derya Akkaynak
Papua New Guinea



original photo: James Rokop
Aquastarz Davis,CA


original photo: Alex Shure
Gloucester, MA USA

Sea-thru works for video too!



https://youtu.be/oSrBMX8e6yo

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Why does Sea-thru work?

- It has range as input (RGB-D method)
  - Does NOT need a color chart (more later)
  - Does NOT need knowledge of optical water type
  - Does NOT require forward-facing imaging
- First method to use the Akkaynak-Treibitz image formation model **("revised" model)**
  - Derived for the ocean, physically accurate
  - Rigorously tested & validated underwater
  - Different coefficients for attenuation and backscatter
  - Attenuation coefficient NOT a constant per scene

Image Formation

$$I_c = D_c + B_c + \cancel{F_c}$$

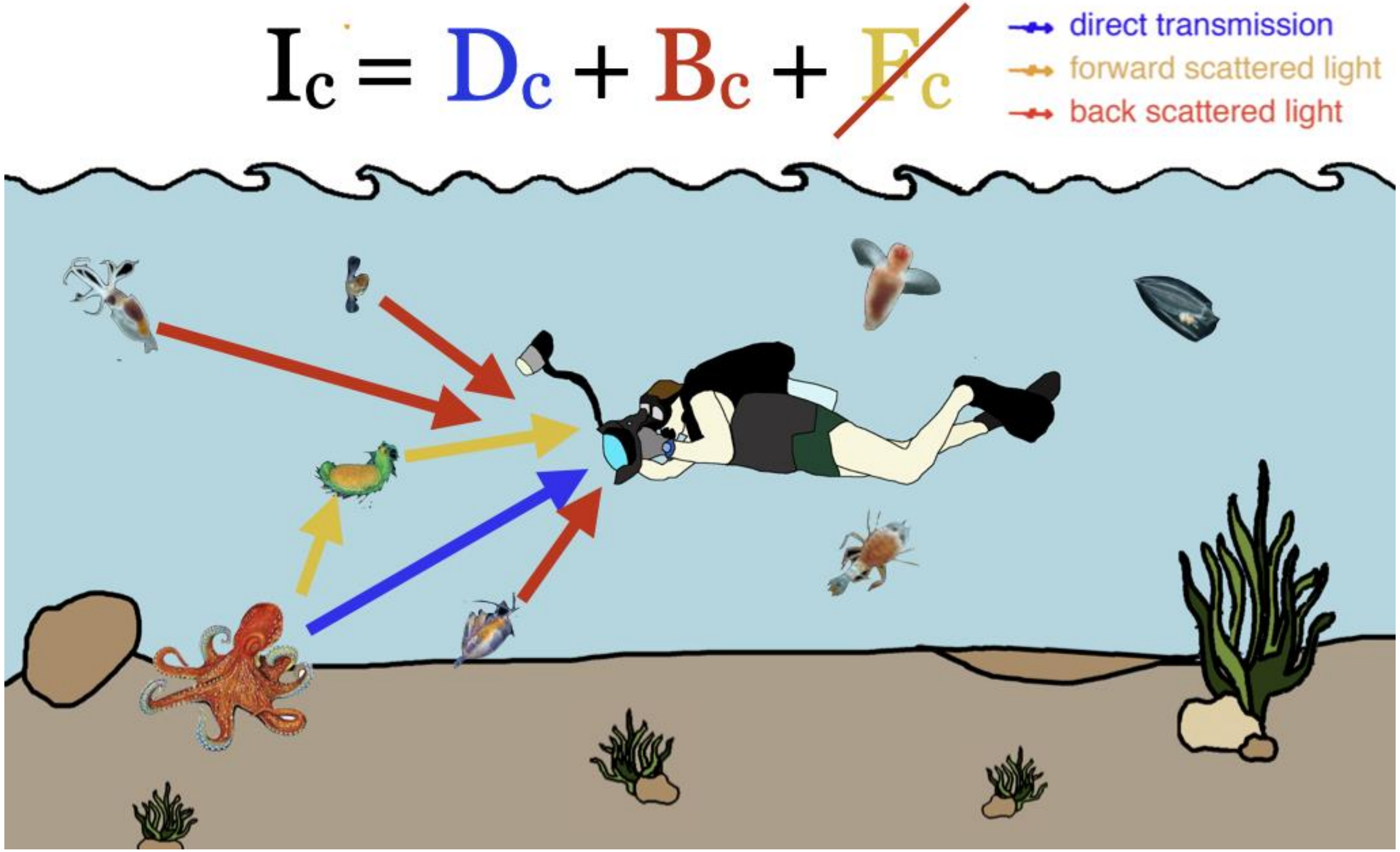

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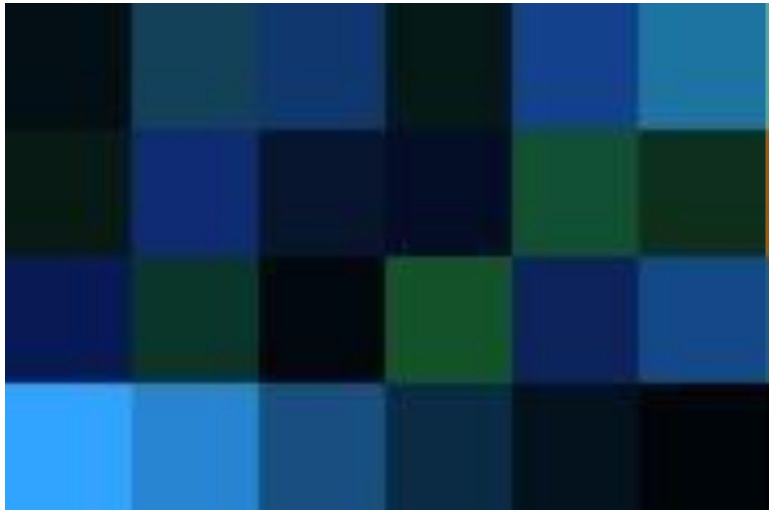
Image Formation

=



+

$$I_c = D_c + B_c$$

image = direct signal + backscatter

OLD (ATMOSPHERIC) Image Formation Model

$$I_c = J_c \cdot e^{-\beta_c z} + B_c^{\infty} \cdot (1 - e^{-\beta_c z})$$

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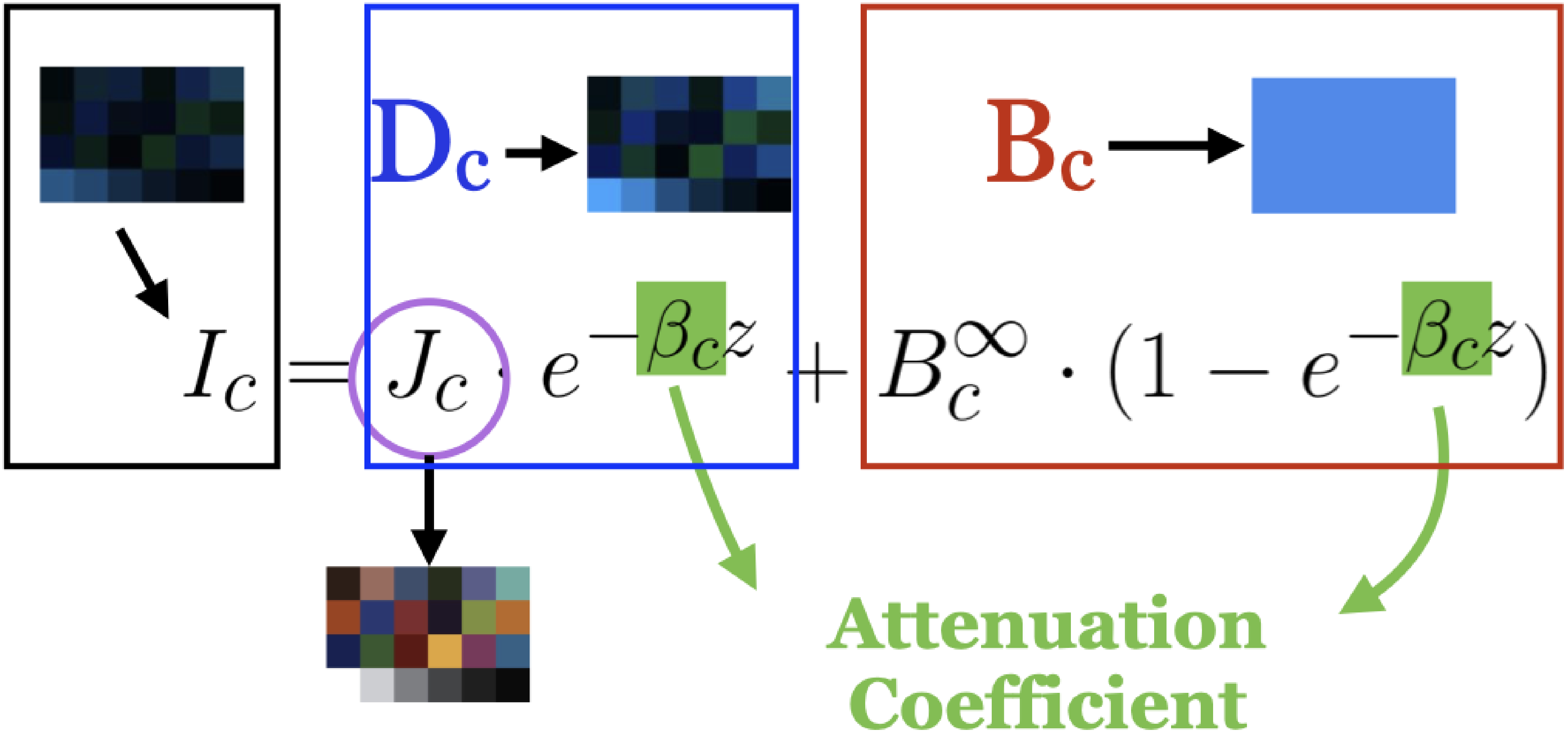
OLD (ATMOSPHERIC) Image Formation Model



Akkaynak-Treibitz Image Formation Model

Old Model

Attenuation Coefficient

$$I_c = J_c \cdot e^{-\beta_c z} + B_c^\infty \cdot (1 - e^{-\beta_c z})$$

Revised Model

Attenuation Coefficient

Backscatter Coefficient

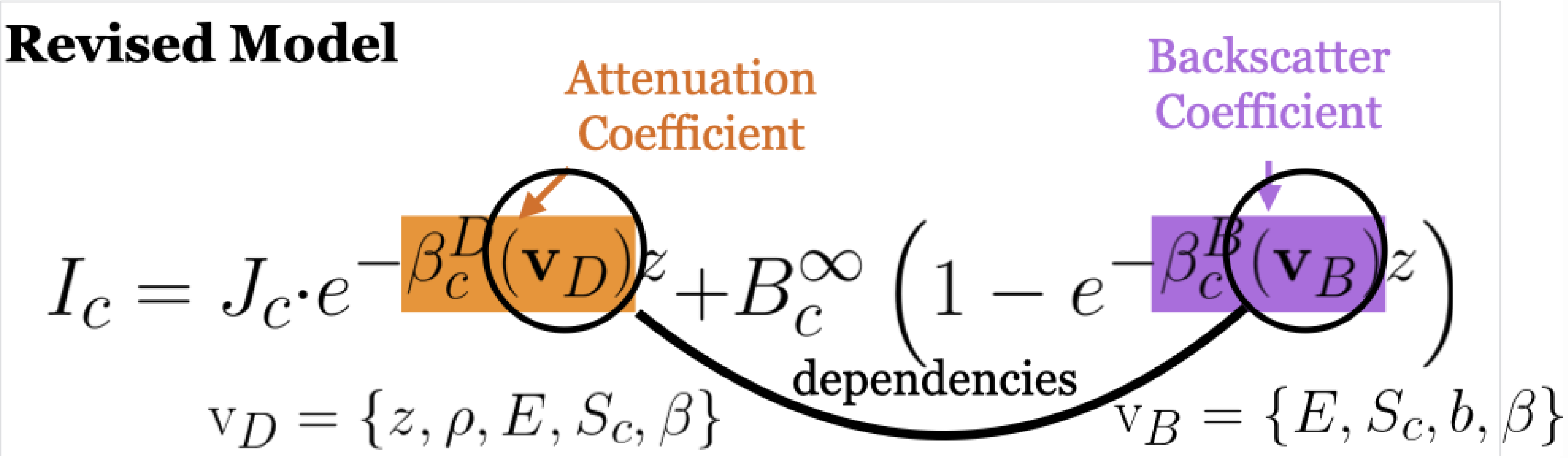
$$I_c = J_c \cdot e^{-\beta_c^D(\mathbf{v}_D) z} + B_c^\infty \left(1 - e^{-\beta_c^B(\mathbf{v}_B) z}\right)$$

dependencies

$\mathrm{v}_D = \{z, \rho, E, S_c, \beta\}$

$\mathrm{v}_B = \{E, S_c, b, \beta\}$

Akkaynak-Treibitz Image Formation Model



range
reflectance
ambient light
camera sensor
physical scattering
physical attenuation
imaging angle

Not just for water!

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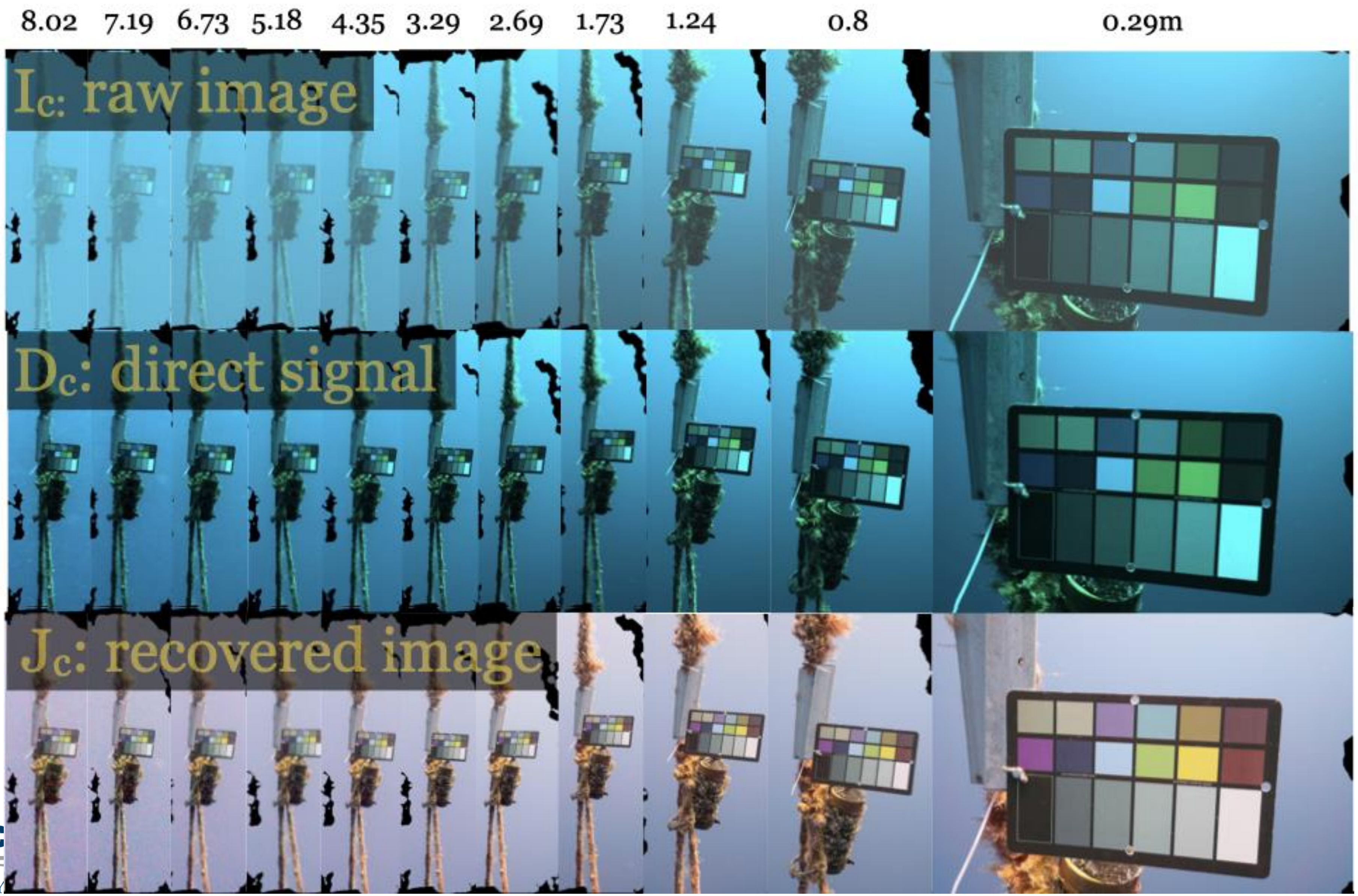
Not just for water!

A calibrated experiment



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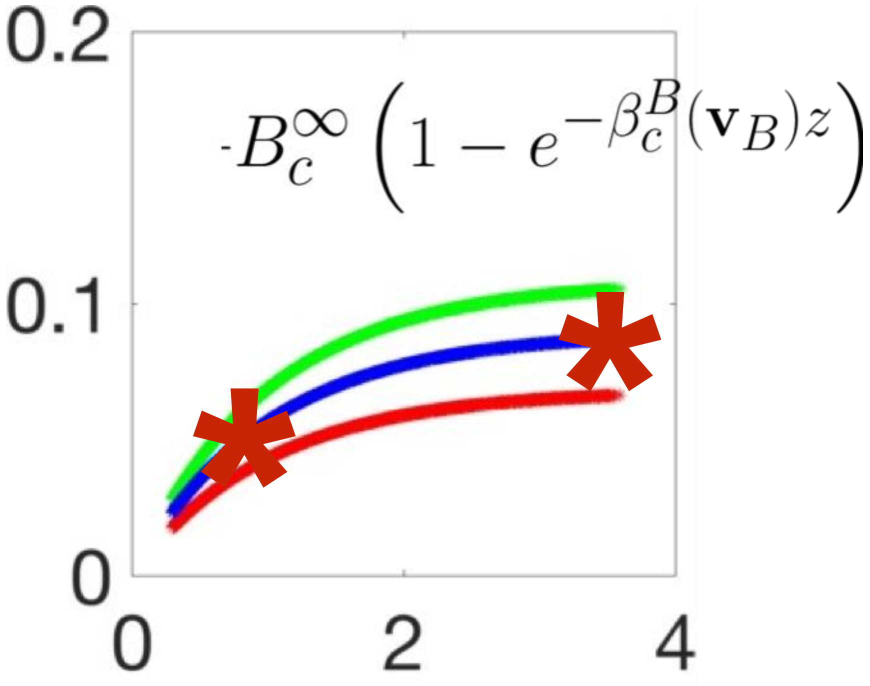
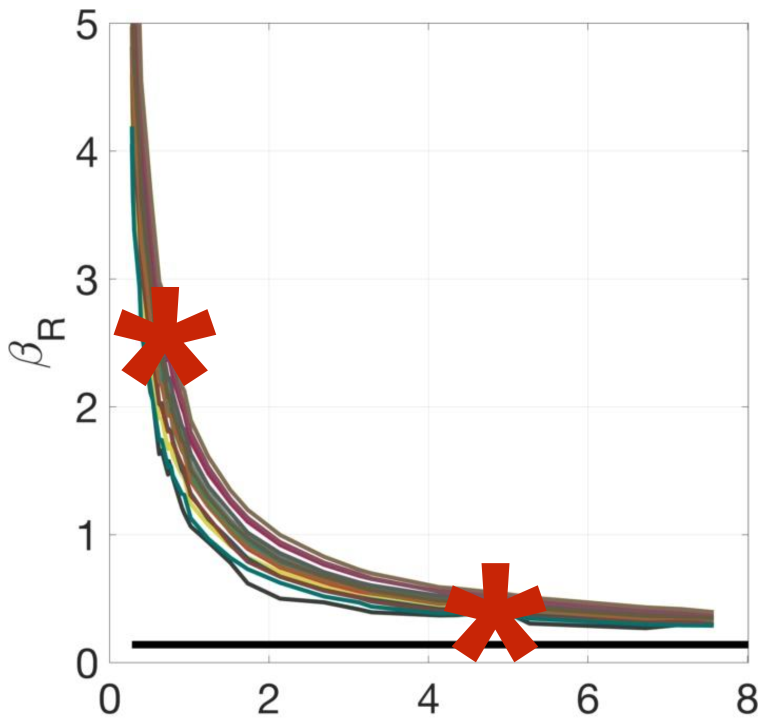
Why one color chart is not enough

Backscatter is a function of range (z)



range z(m)

Attenuation coefficient is a function of range (z)



range z(m)

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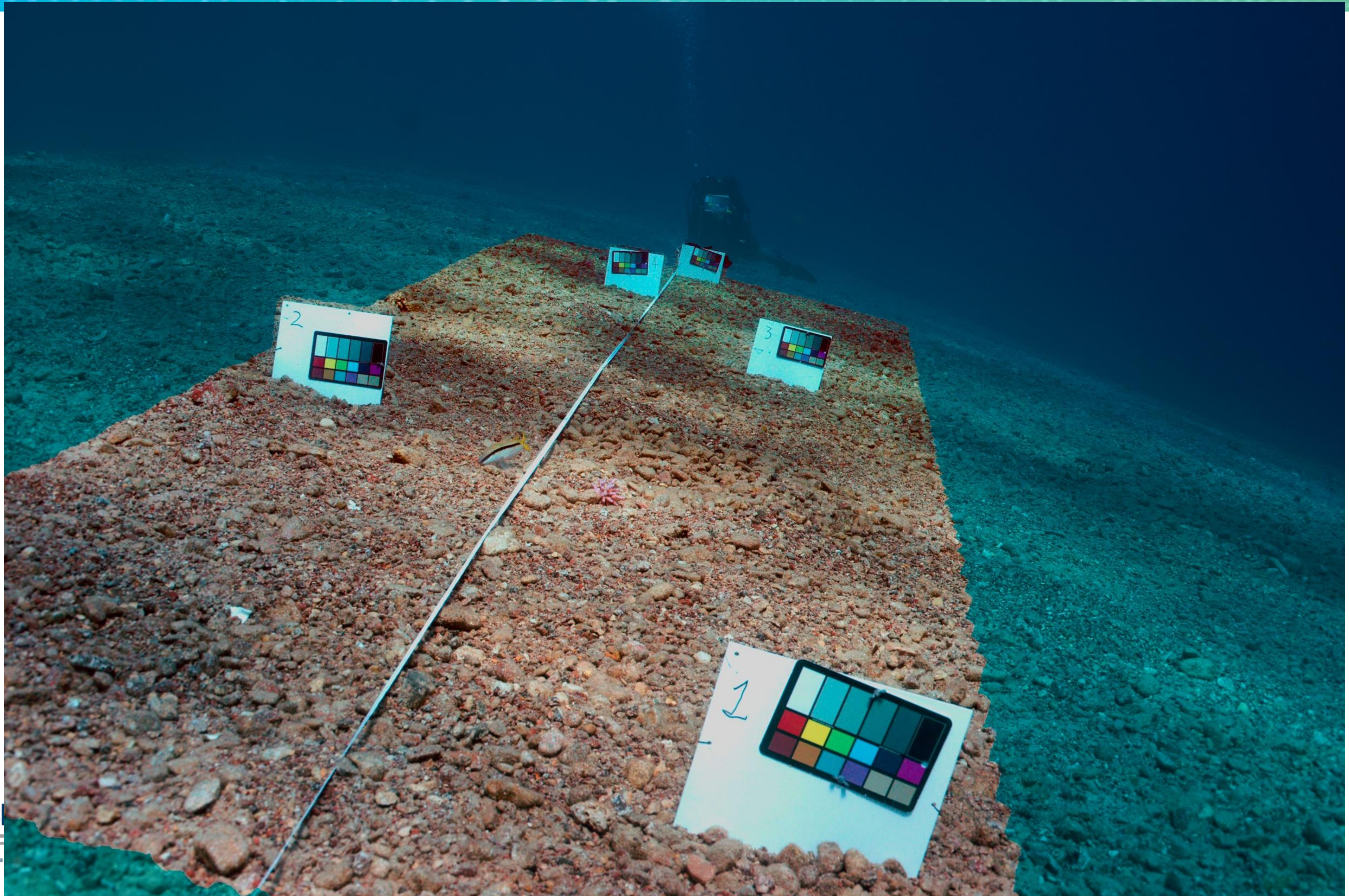
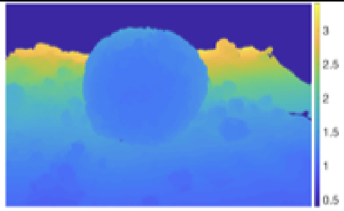
But we rarely have color charts in the scene!



Sea-thru in a nutshell

Uses the revised equation	$I_c = J_c \cdot e^{-\beta_c^D(\mathbf{v}_D)z} + B_c^\infty \left(1 - e^{-\beta_c^B(\mathbf{v}_B)z}\right)$
Requires RGBD images	 
Estimates B_c from darkest 1% of pixels	$I_c = \cancel{D_c} + B_c$ ($D_c \rightarrow 0$)
Estimates $\beta_c^D(z)$ from local illuminant map E_c	$D_c = J_c\, e^{-\beta_c D(z) z}$ ($e^{-\beta_c D(z) z} \rightarrow E_c$)

Photofinishes: camera linear RGB —>
human non-linear RGB

Thank you!

Derya's website

deryaakkaynak.com/sea-thru

Tali's website

http://csms.haifa.ac.il/profiles/tTreibitz/

Papers & data

http://csms.haifa.ac.il/profiles/tTreibitz/datasets/sea_thru/index.html

3D models

https://sketchfab.com/Marine_Imaging_Lab