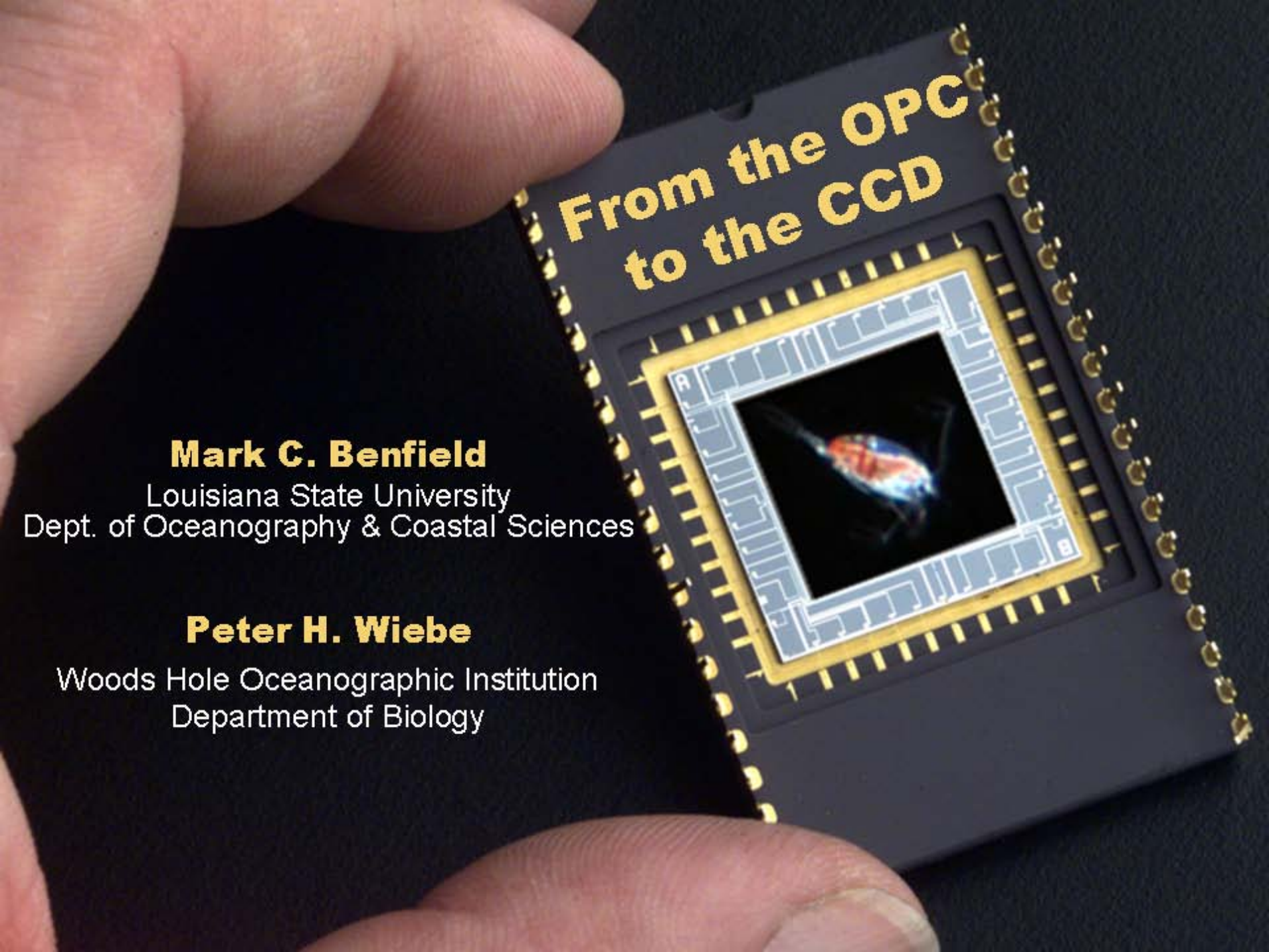
From the OPC to the CCD



Mark C. Benfield
Louisiana State University
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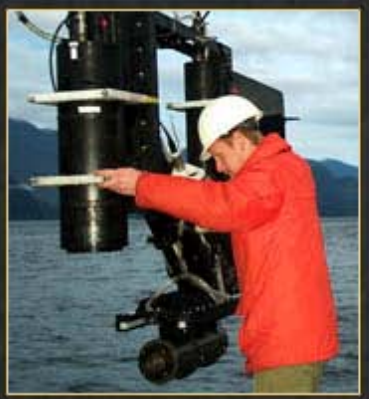
Peter H. Wiebe
Woods Hole Oceanographic Institution
Department of Biology

Introduction

Victor Hensen
(1835 – 1924)

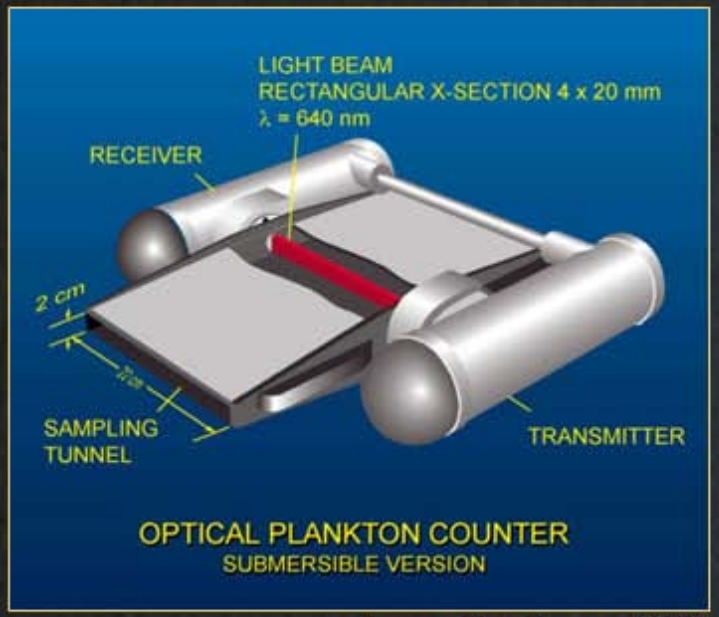
Fundamental Questions

- What are the numbers and kinds of things in the sea at any given time and place?
- How does this material vary from season to season and year to year?
- We are still attempting to answer these same questions



Optical Plankton Counter

- *In-situ* electronic particle counting system developed in 1980s
- Commercially-available in 1990 and in widespread use (~120 units)
- Allowed investigation of plankton and particles on fine horizontal and vertical scales
- Taxonomically ambiguous but when combined with nets, provided a means of inferring composition of patches



▲ Image: Alex Herman (BIO)

Outline

- Imaging systems predate the emergence of the OPC
- At the same time that the OPC was becoming widely employed, analog video and digital still camera technologies saw rapid development
- Recognition that the information content of an instrument like the OPC could be increased if there was more taxonomic information associated with the particle counts
- Examine the historical development of plankton imaging systems
- Summarize the systems that are currently operational or in advanced development
- Speculate on what the future may hold for plankton imaging systems

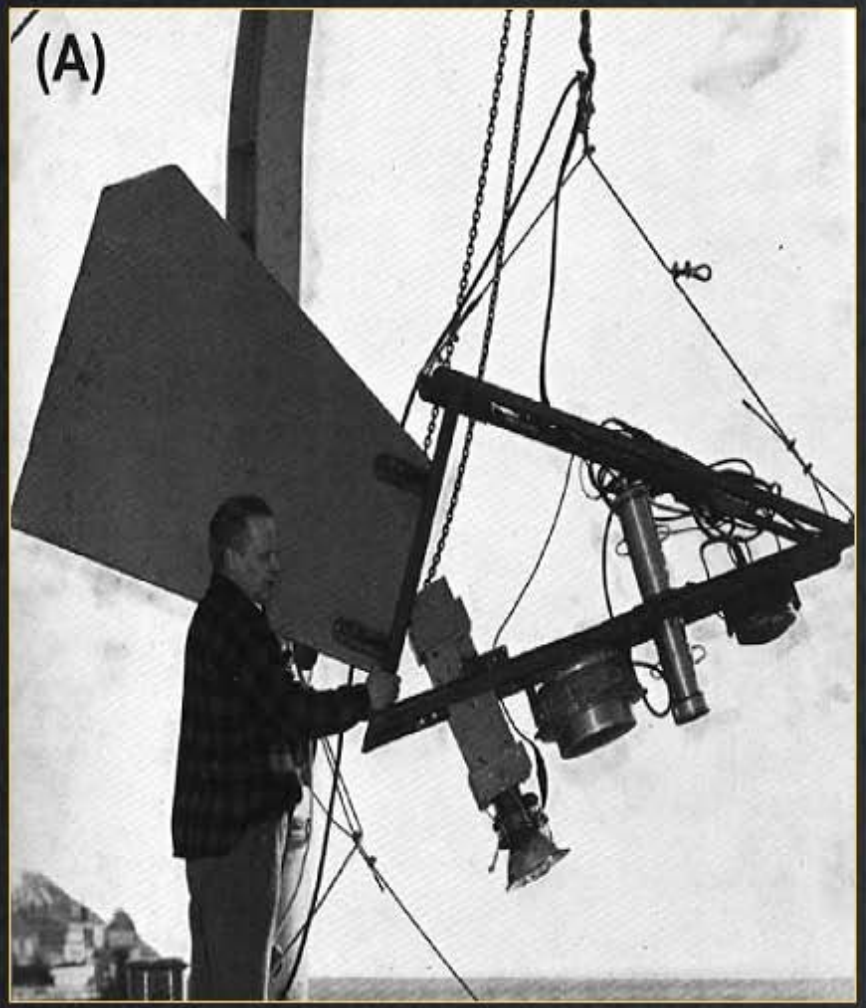
1950 – 1959: *In Situ* Still Photography

- Some of the earliest work on direct imaging of plankton conducted in 1950s in Japan, Europe and North America
  - Nishizawa et al. (1954): still photographs of live zooplankton from within a diving chamber using a collection box outside an undersea observation chamber

Images: Nishizawa et al. (1954)

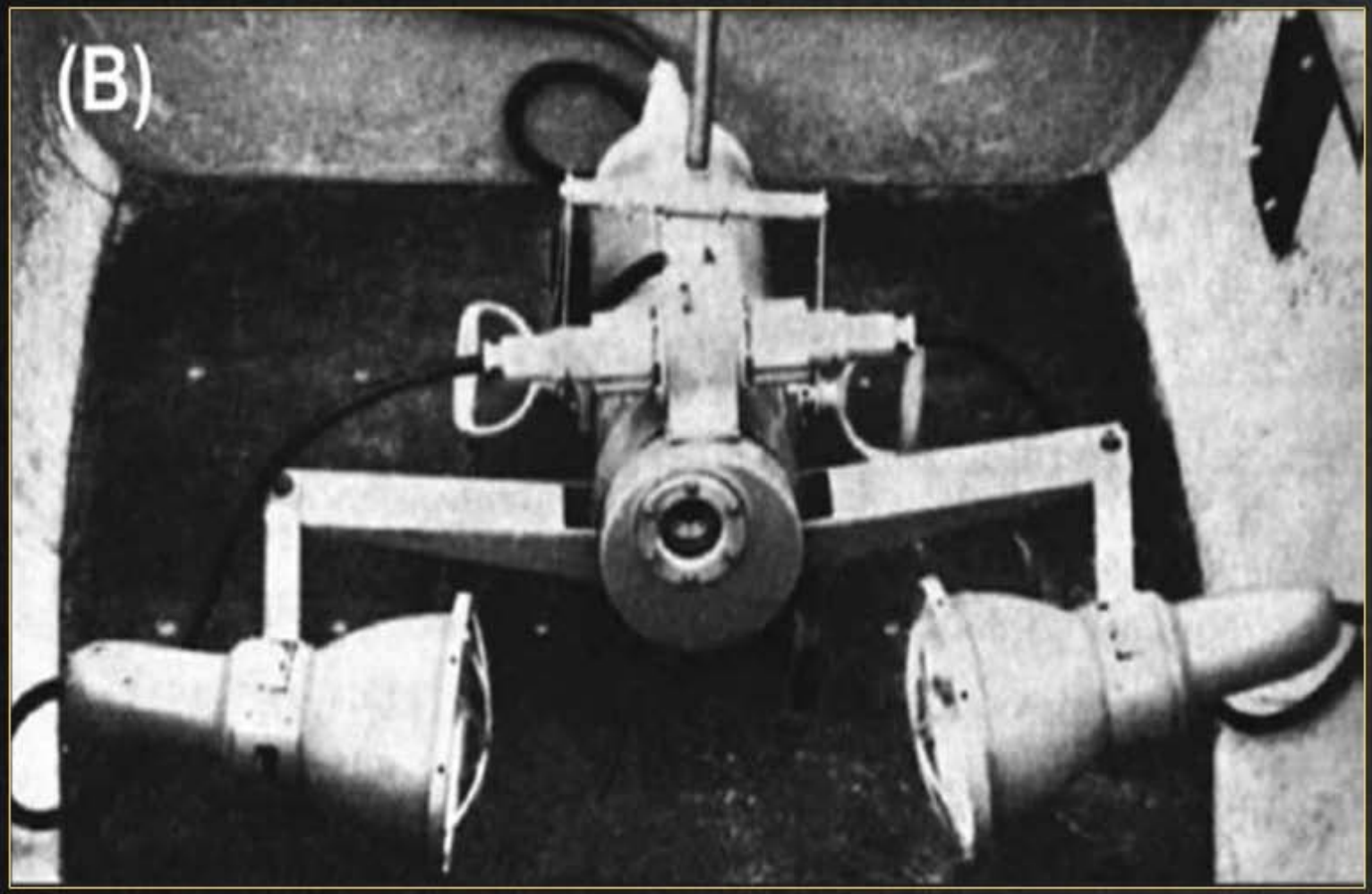
1950 – 1959: 35mm camera system

- Edgerton and Hoadley (1955) developed a 35 mm repeating-flash, shutterless deep-sea camera
- Formed the basis of a photographic profiling system to investigate the composition of the deep-scattering layer
- They were successful in collecting images of larger zooplankton such as salps and micronekton that appeared to be associated with strong acoustic returns



1960 – 1969: Underwater TV

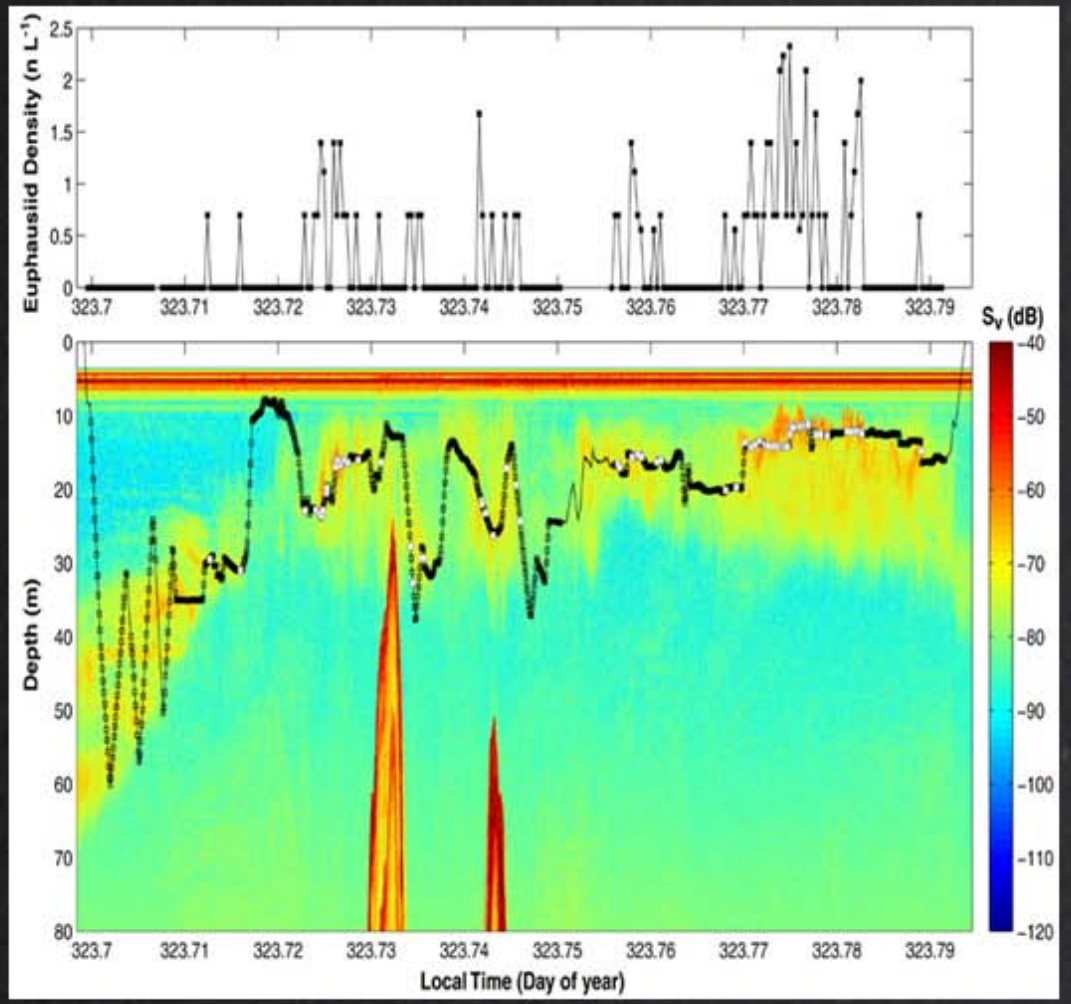
- Schröder (1961) deployed an underwater TV system in the Bodensee (Lake Constance) of Germany to ground-truth the zooplankton composition of sound scattering layers



32 Years Later

Euphausiid abundance from ZOOVIS

Echogram with trajectory of ZOOVIS



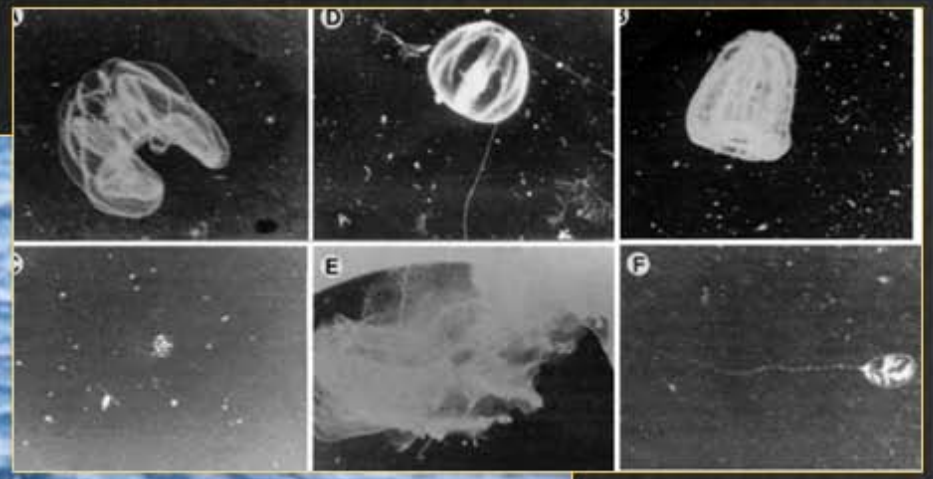
1970 – 1979: Silhouette Photography

- Ortner et al. (1979) described silhouette photographic technique for processing zooplankton samples

Ortner et al. (1979)

Today: ZOOSCAN

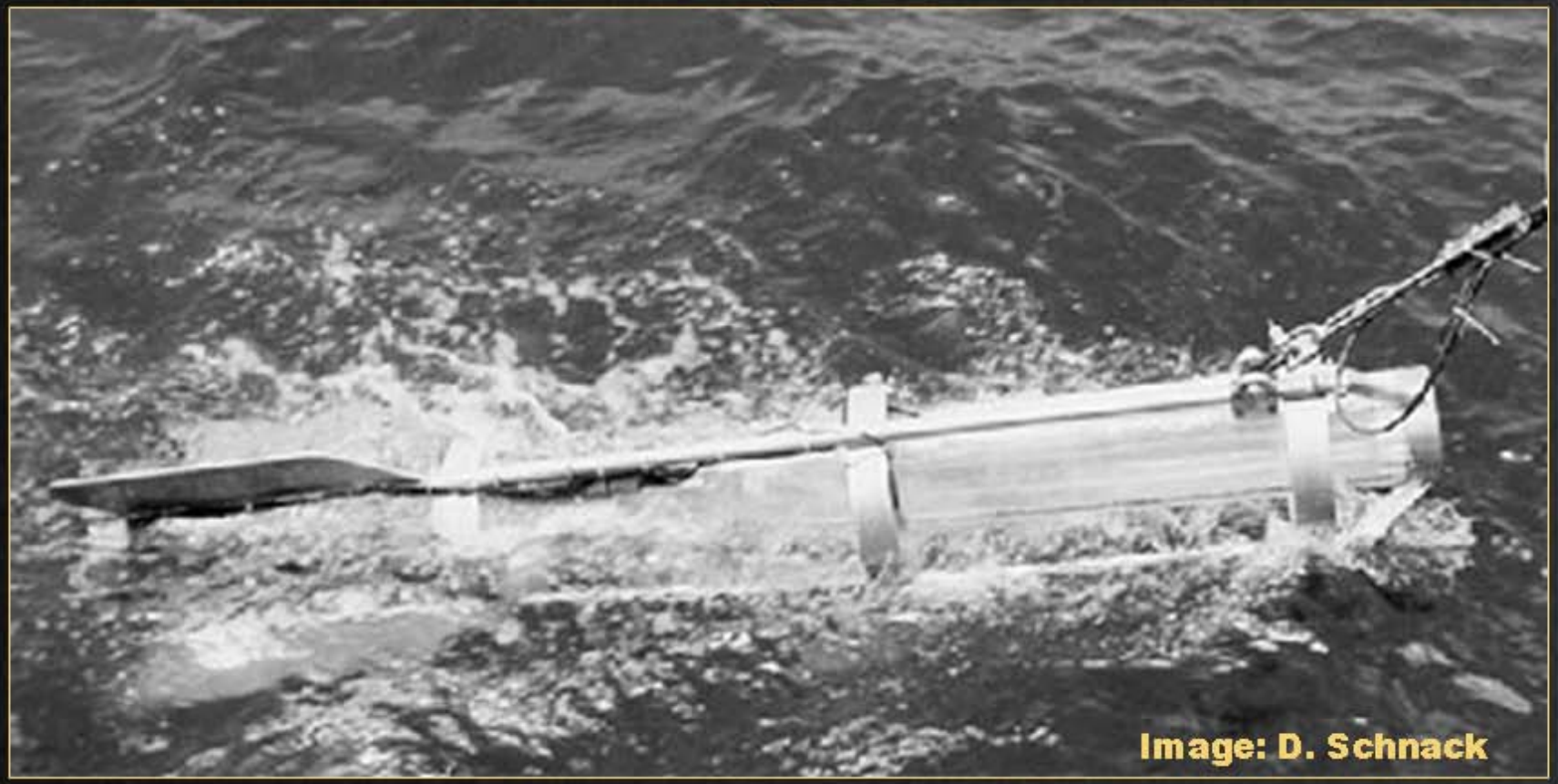
1970 – 1979: Camera – Net System

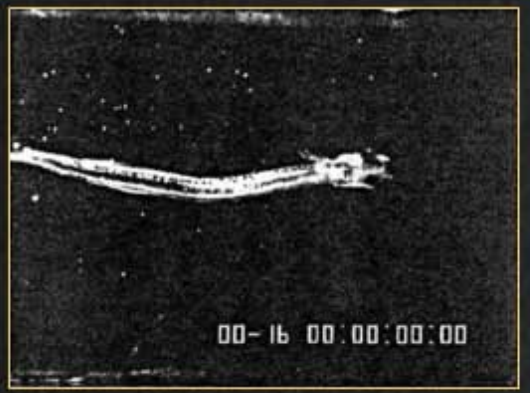


Olney & Houde (1993)

Image: S. Cummings, NOAA

1980 – 1989: Ichthyoplankton Recorder

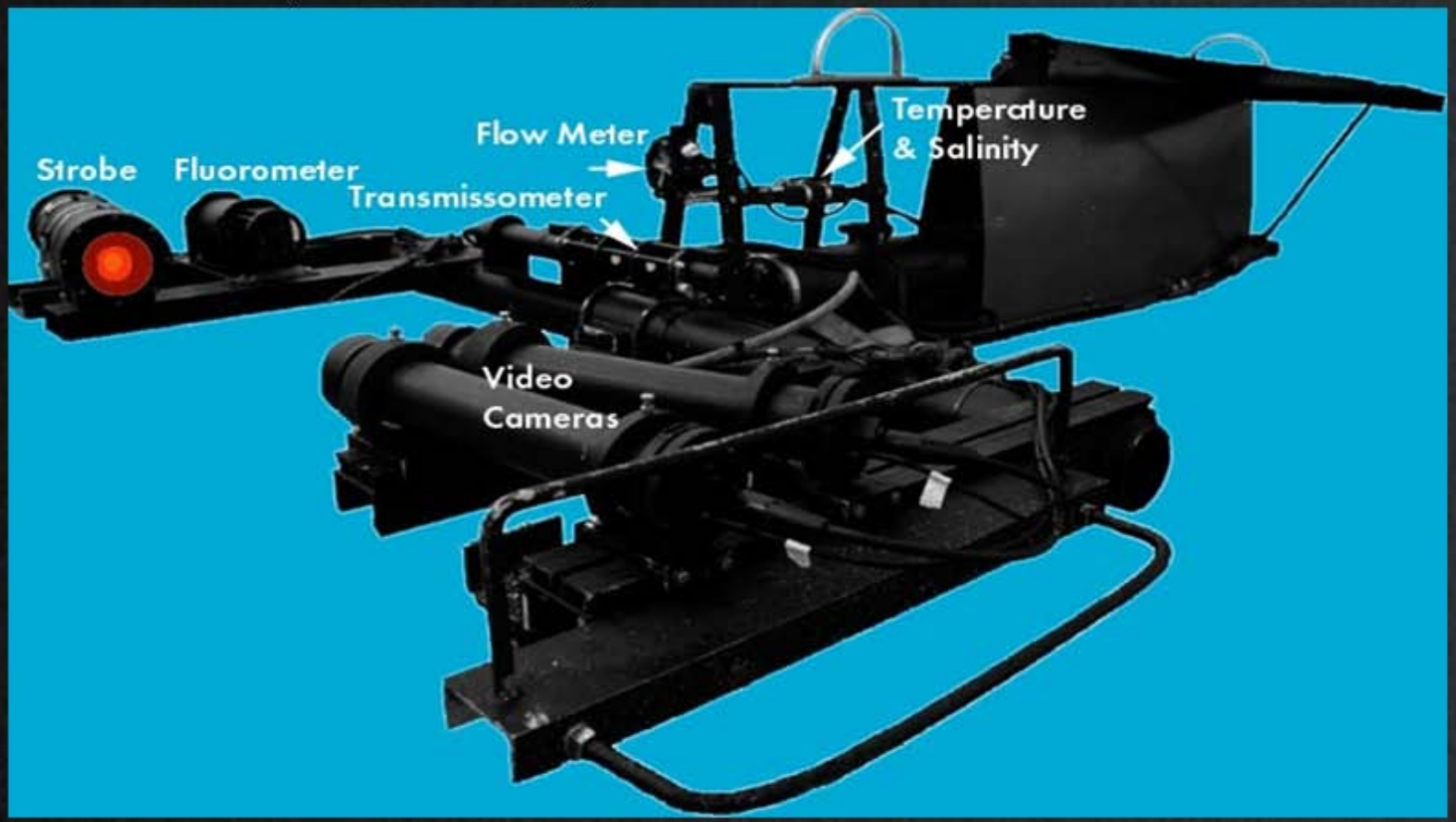




◄ Images: Froese et al. (1990)

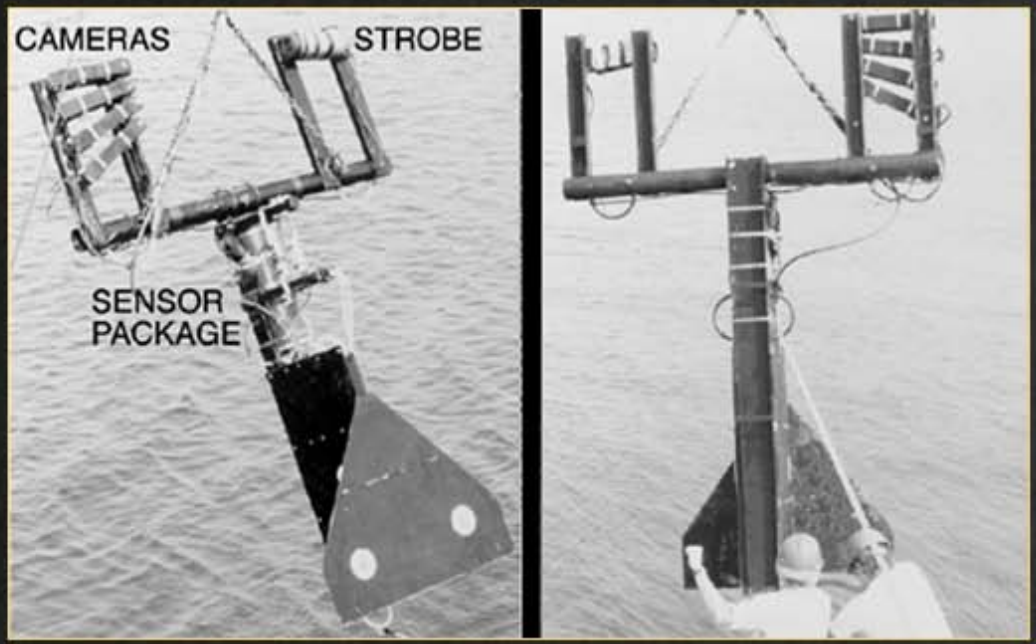
1990 – 1999: Video Plankton Recorder

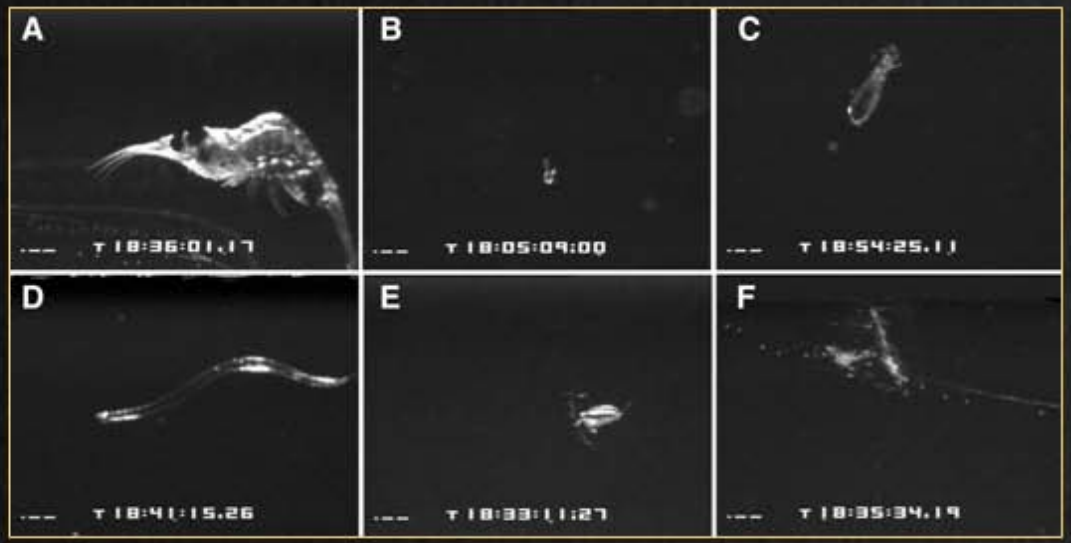
- Video Plankton Recorder (VPR) developed by Davis, Gallager et al. in early 1990s
- Multiple video cameras with different magnifications aimed at concentrically located image volumes



Analog VPR ...

- Dark-field illumination
- Analog video cameras (NTSC)
- Cable to surface for recording on BetaCAM or S-VHS tape
- Manual extraction and ID





1990 – 1999: In Situ Video Profiler

- Several systems based on original VPR were developed

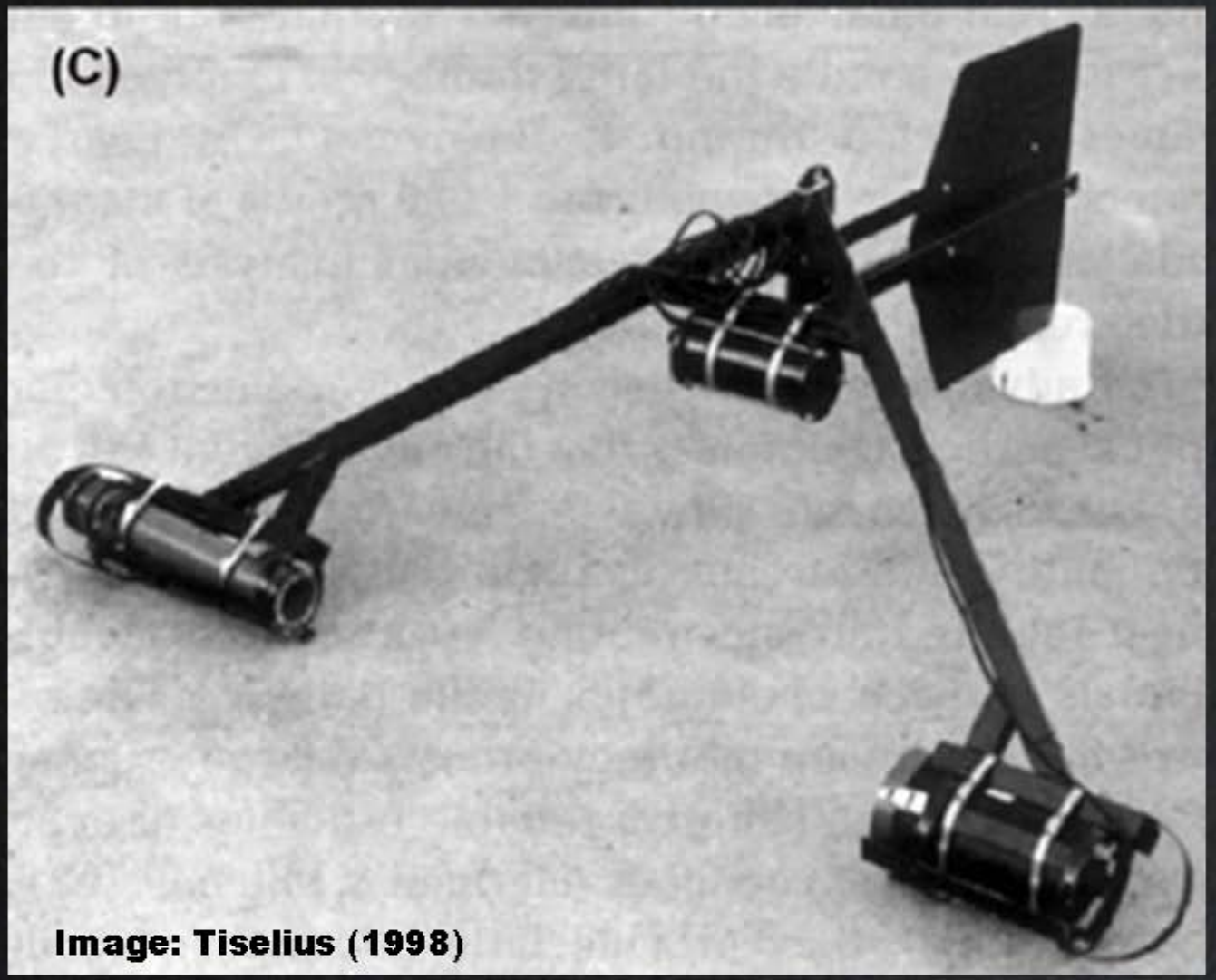


Image: Tiselius (1998)

1990 – 1999: Underwater Video Profiler

- Profiling systems designed to enumerate marine snow led to plankton profiling systems
- Underwater Video Profiler (UVP) employs structures light and two hi-8 video cameras to enumerate plankton and particles (Gorsky et al.)

Image: M. Picheral

Images: G. Gorsky

1990 – 1999: SIPPER

- SIPPER: Shadowed Image Particle Profiling and Evaluation Recorder
- Digital linescan camera system: 4096 pixel array imaging 23K lines per second

Image: T. Sutton

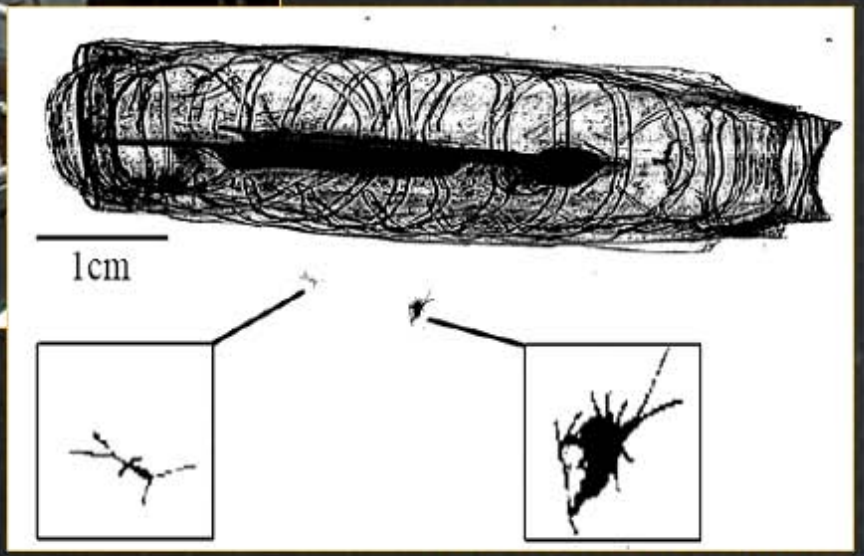
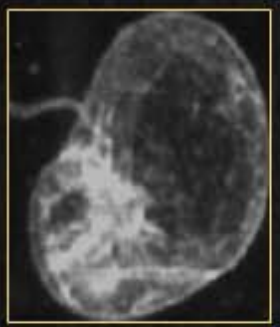


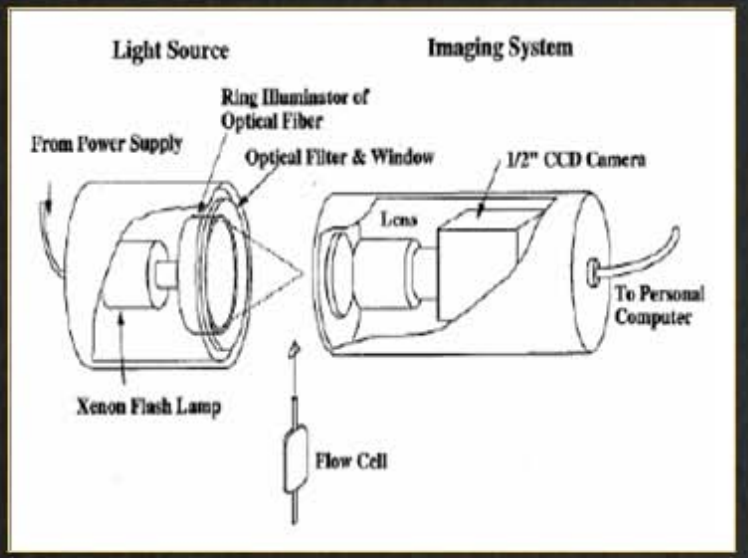
Image: A. Remsen

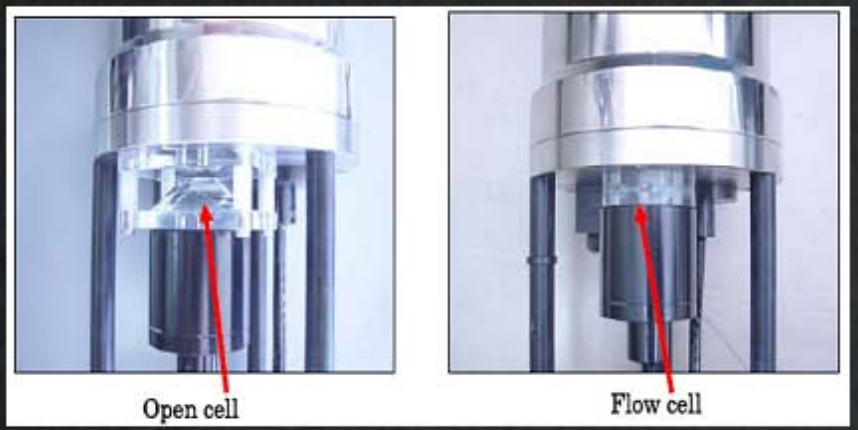
1990 – 1999: Underwater Video Microscope

- Akiba and Kakui (Japanese Electrotechnical Laboratory) developed an underwater microscope
- Sony 0.3 MP analog video camera with a flow cell







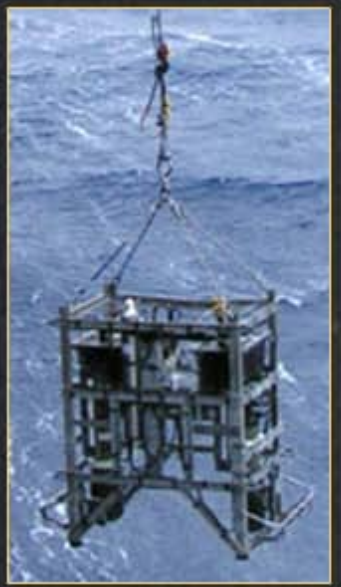
Images: Alec Electronics

The Present (2000 – Today)



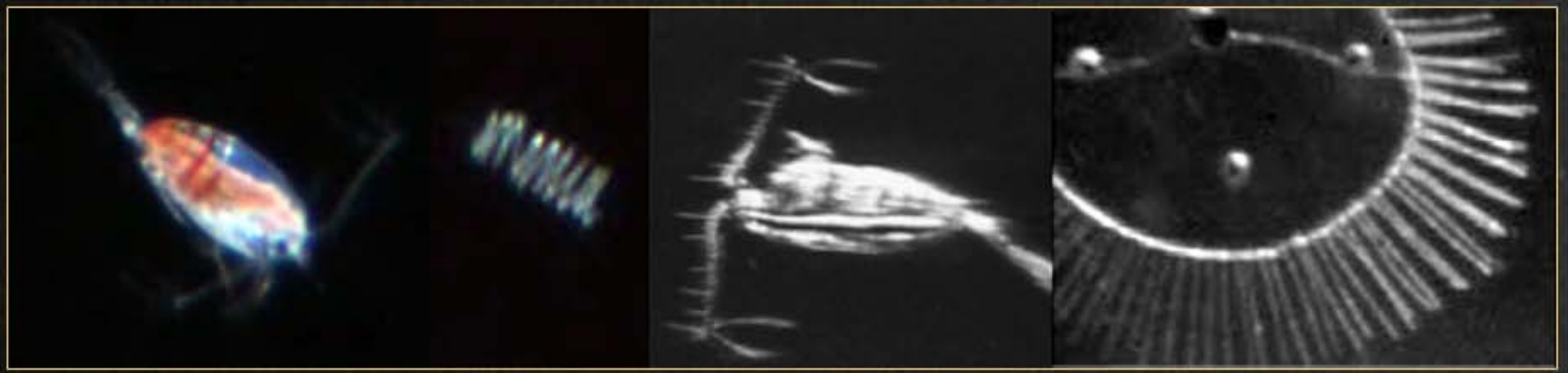




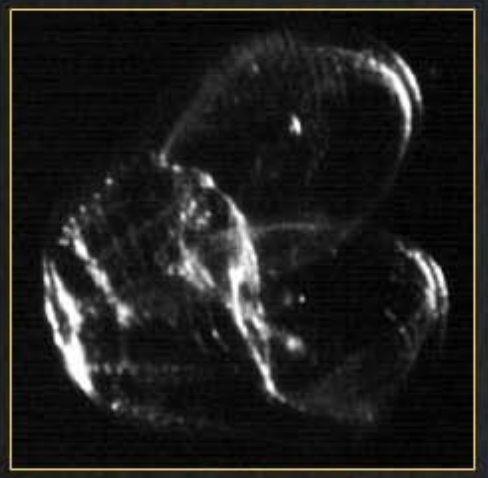



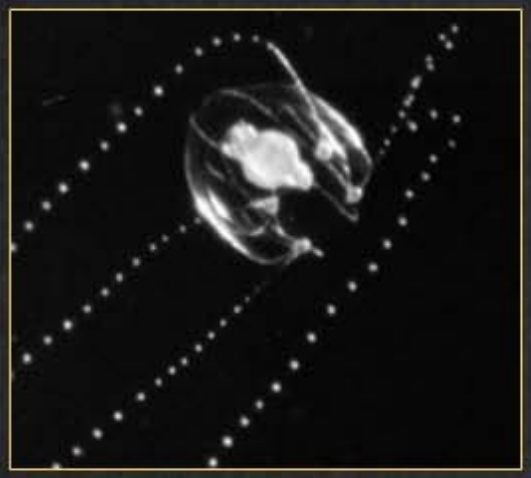
Towed Systems: VPR

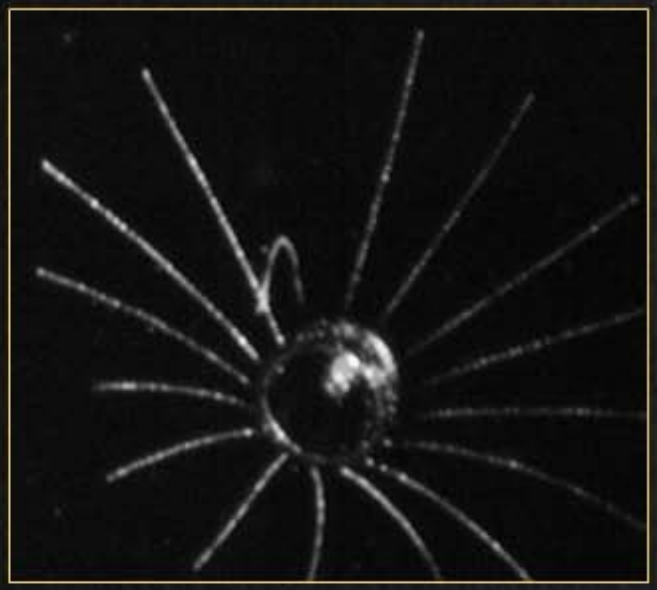
- Towed VPR II in operation: USA, Germany, Japan, Norway



Towed Systems: VPR II





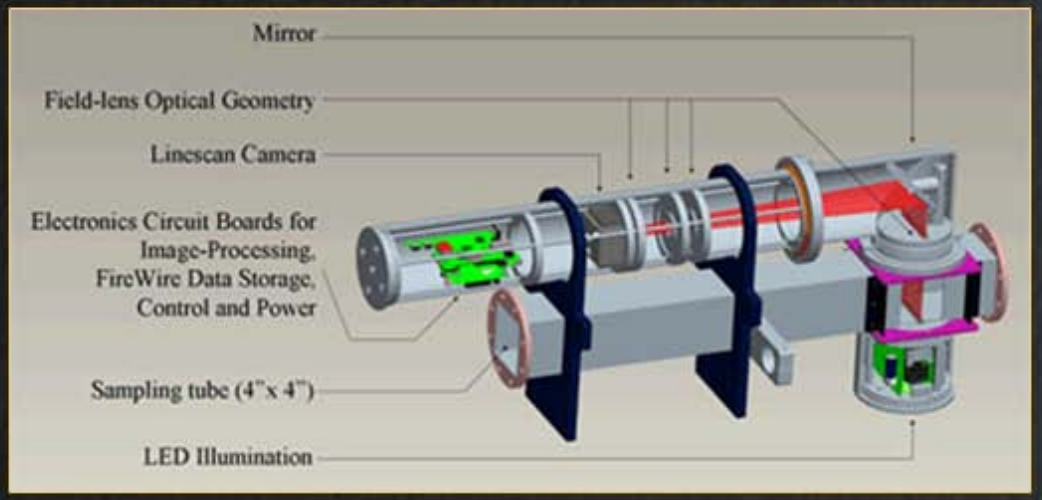


Organism Images: A. Sell

Towed Systems: SIPPER III

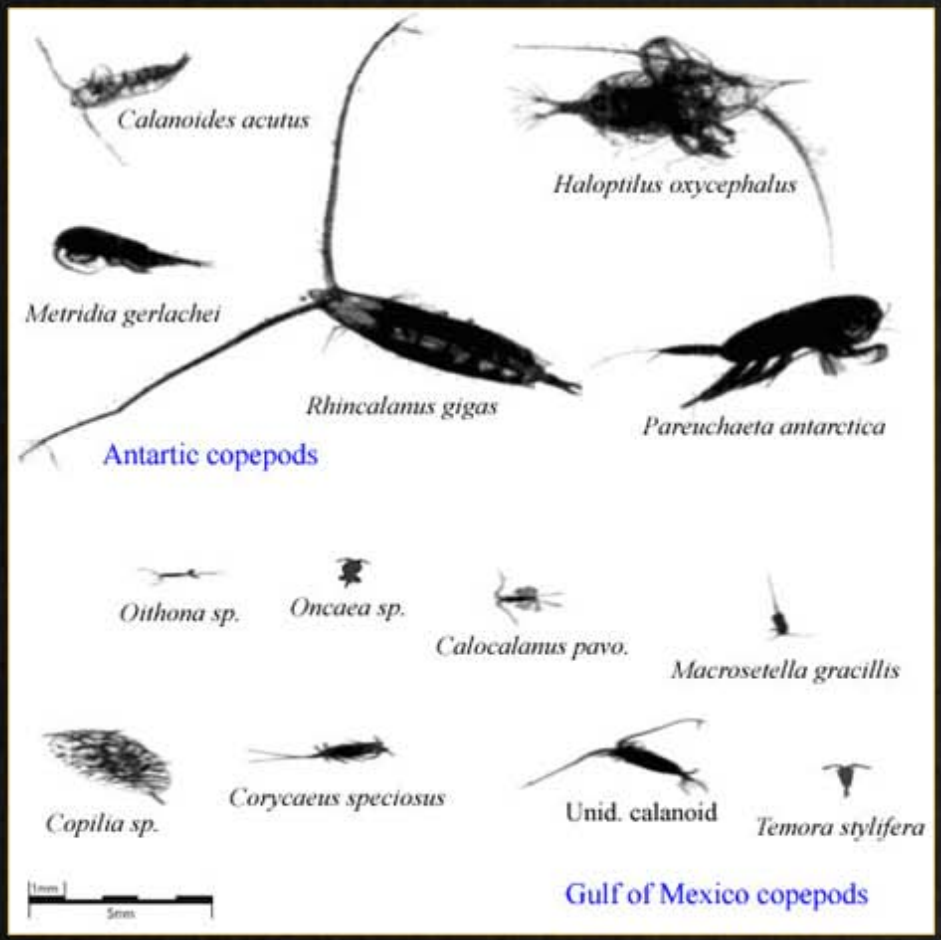
- Linescan camera 4096 pixels @ 36K lines per sec

Image: A. Remsen



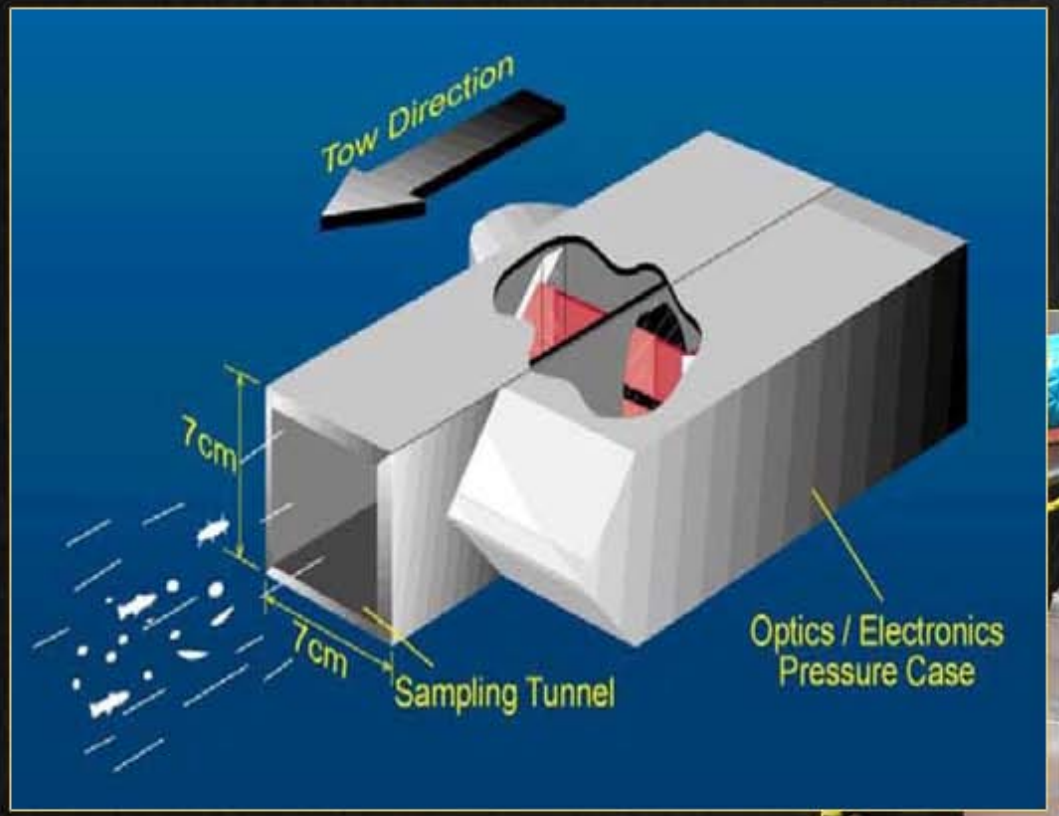
Images: USF-COT

SIPPER …



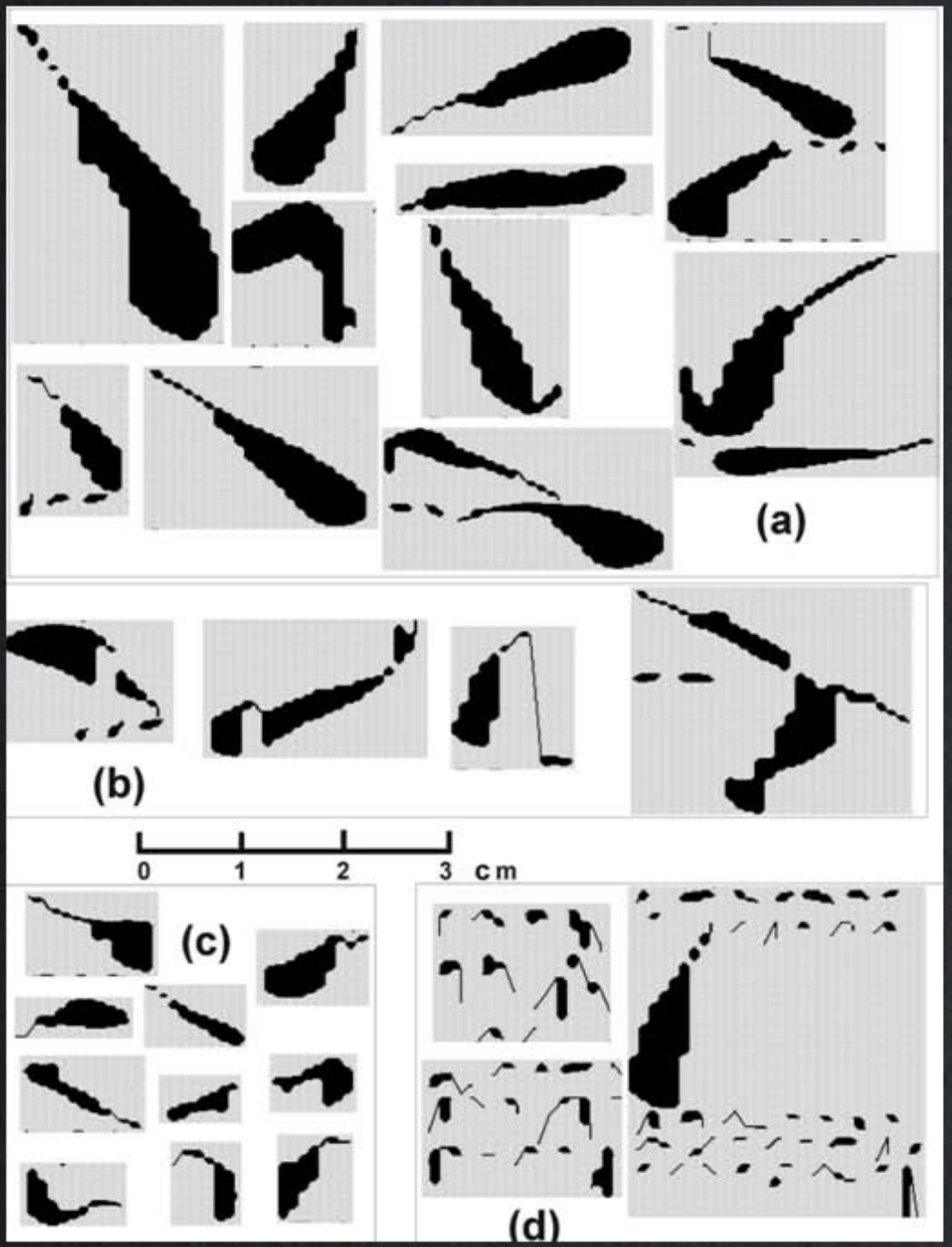
Images: A. Remsen

Towed Systems: LOPC



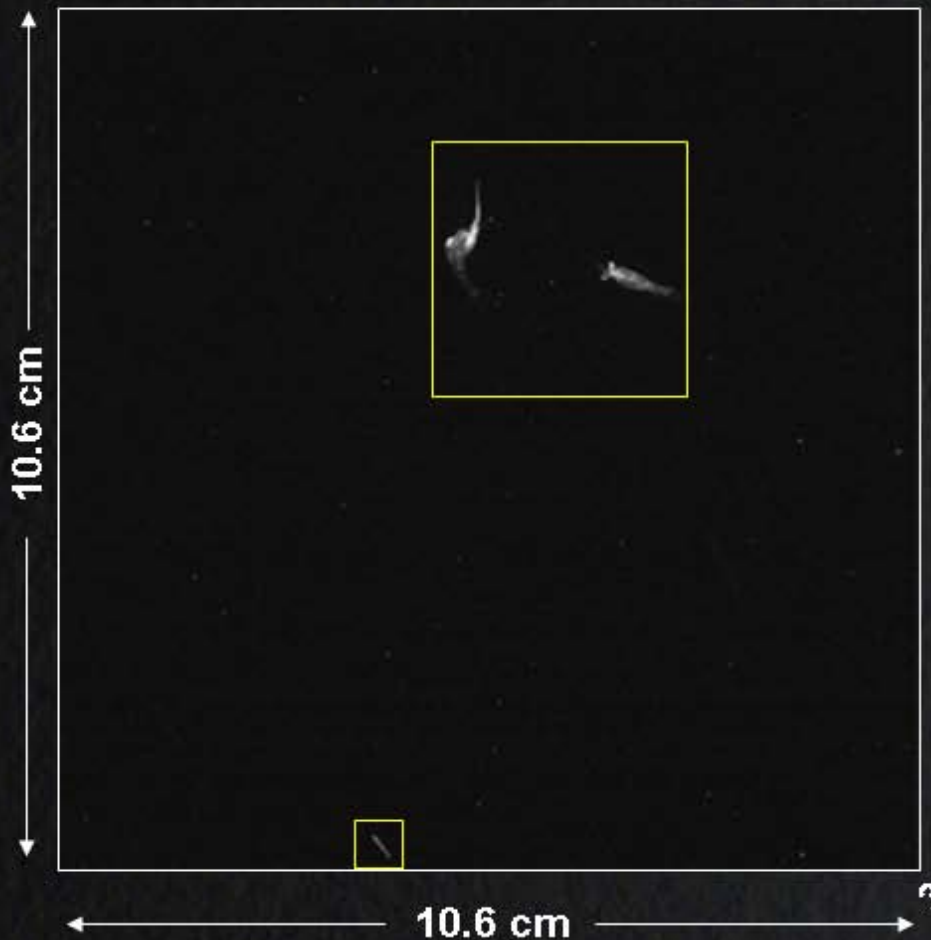
Images: A. Herman

Laser OPC ...



Towed Systems: ZOOVIS

ZOOVIS Images



ZOOVIS Images

3407 ml

Profiling Instruments: UVP4

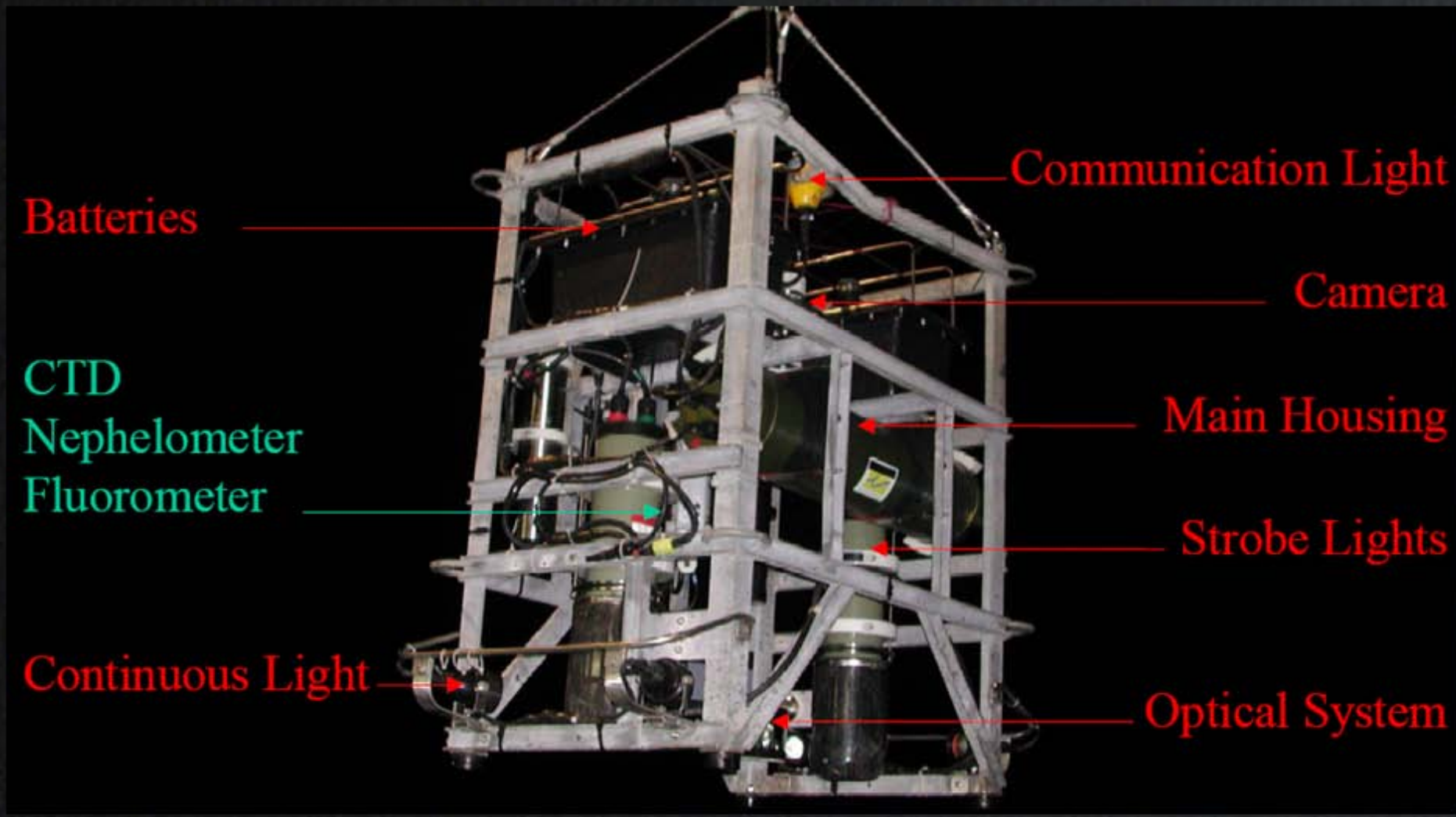
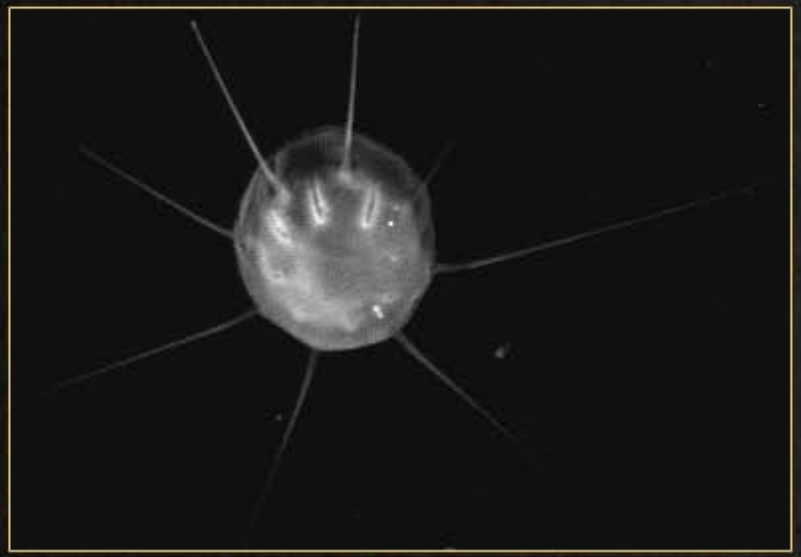
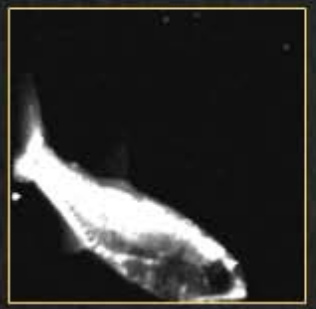


Image: G. Gorsky

Profiling Instruments: UVP

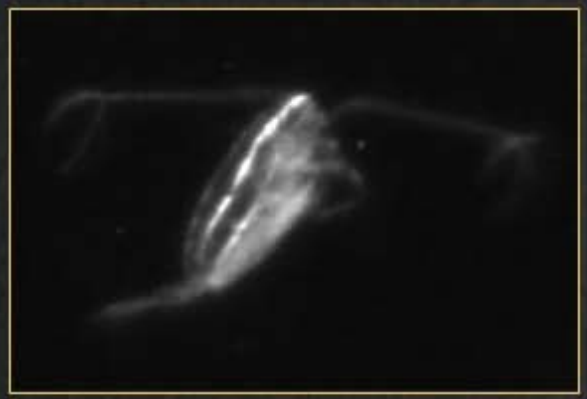




Images: G. Gorsky

Profiling Instruments: VPR I & VPRII

Profiling Instruments: VPRII



Images: M. Baumgartner

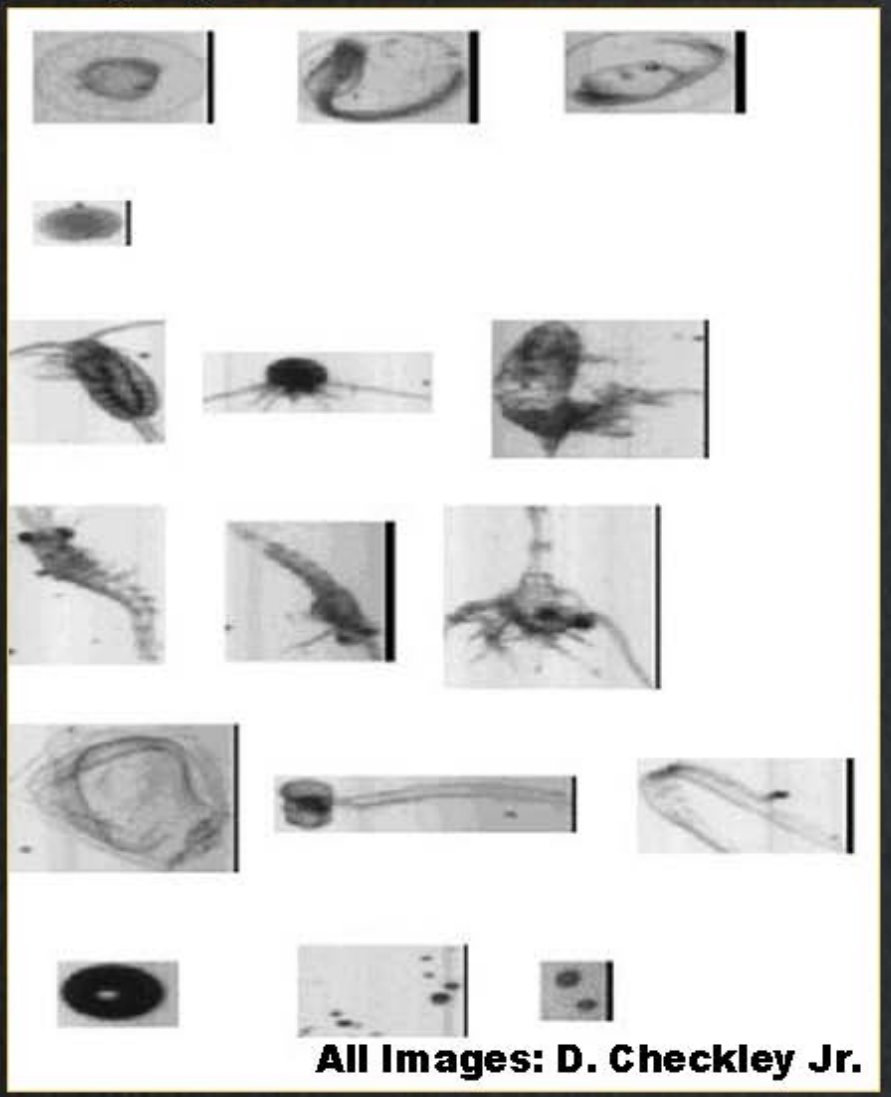
Profiling Instruments: ZOOVIS-SC

Image: M. Sutor

Profiling Instruments: ZOOVIS-SC ...

Shipboard/Lab-Based Systems

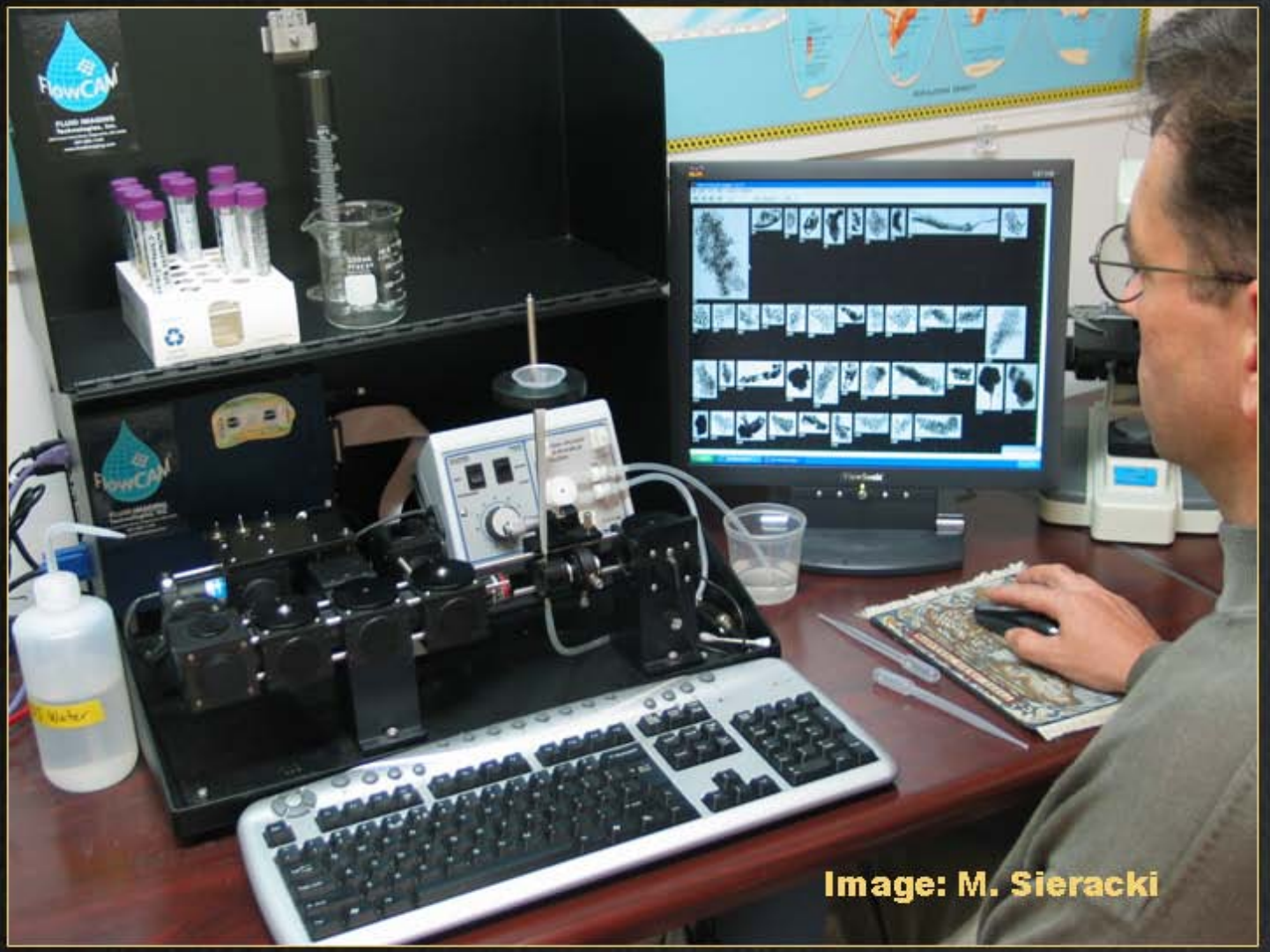
- REFLICS: Real-time Flow Imaging & Classification System



All Images: D. Checkley Jr.

Shipboard/Lab-Based Systems

- FlowCAM



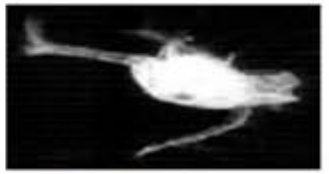
Shipboard/Lab-Based Systems

- FlowCAM

Moored Systems: HAB Buoy

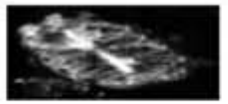
Copepoda: *Calanus finmarchicus V*

Copepoda: *Oithona*

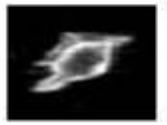


Euphausiid: Calyptopis

Salp: Thaliacea

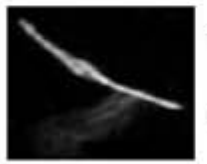


Dinoflagellate: *Ceratium trichoceros*

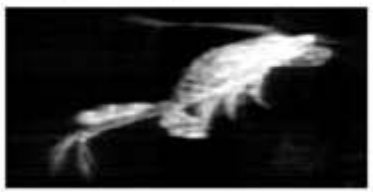


Dinoflagellate: *Dinophysis caudata*

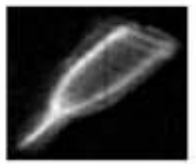
Copepoda: Nauplius



Dinoflagellate: *Ceratium fusus*



Copepoda: *Oithona sp. V1*



Tintinnid: *Cymatocylis*

Cladocera: *Penilia avirostris*

Image: P. Culverhouse

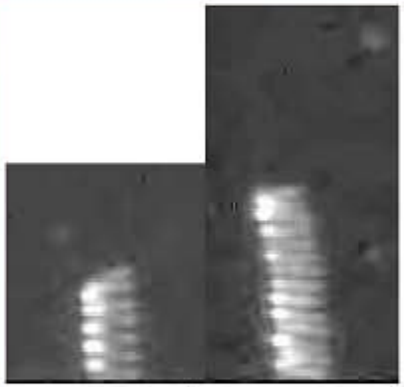
Autonomous Systems

SOLOPC

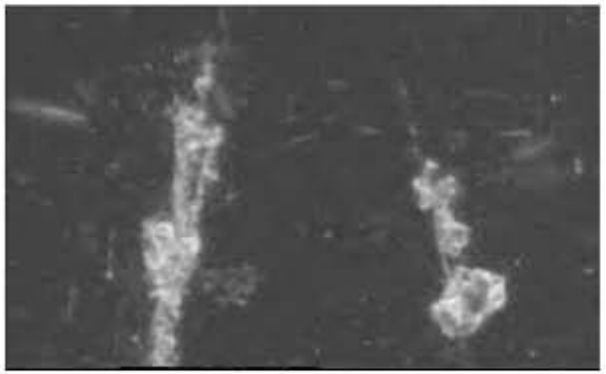
Autonomous Systems: VPR

Image: WHOI

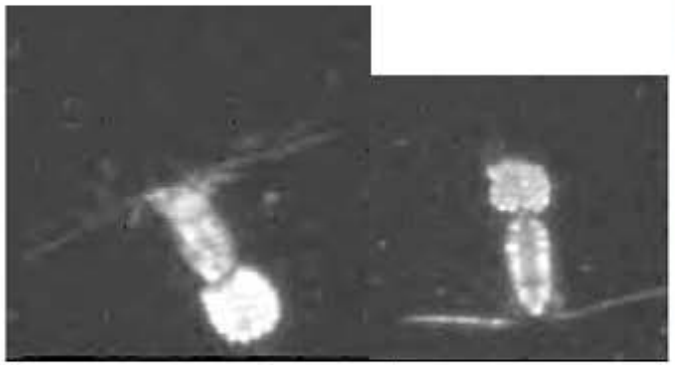
Image: C. Davis



Diatoms
(*Chaetoceros debilis*)



Marine Snow



Copepods
(*Pseudocalanus* w/ eggs)

Autonomous Systems: VPR II

PICASSO AUV

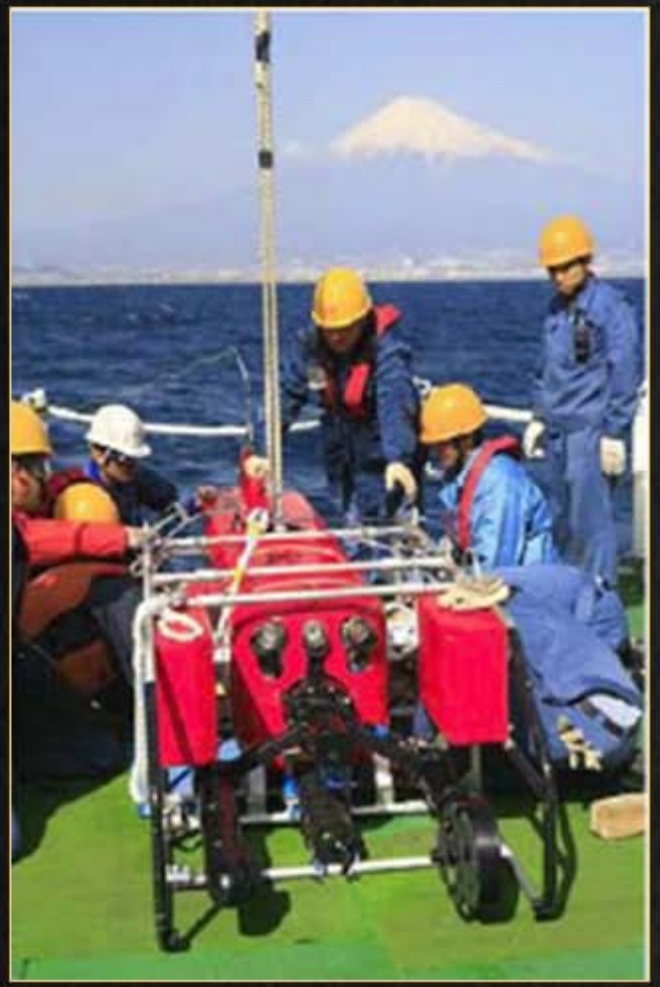
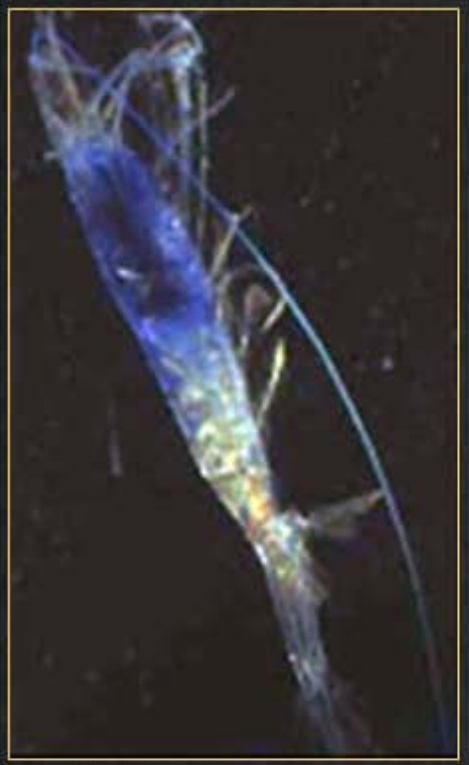
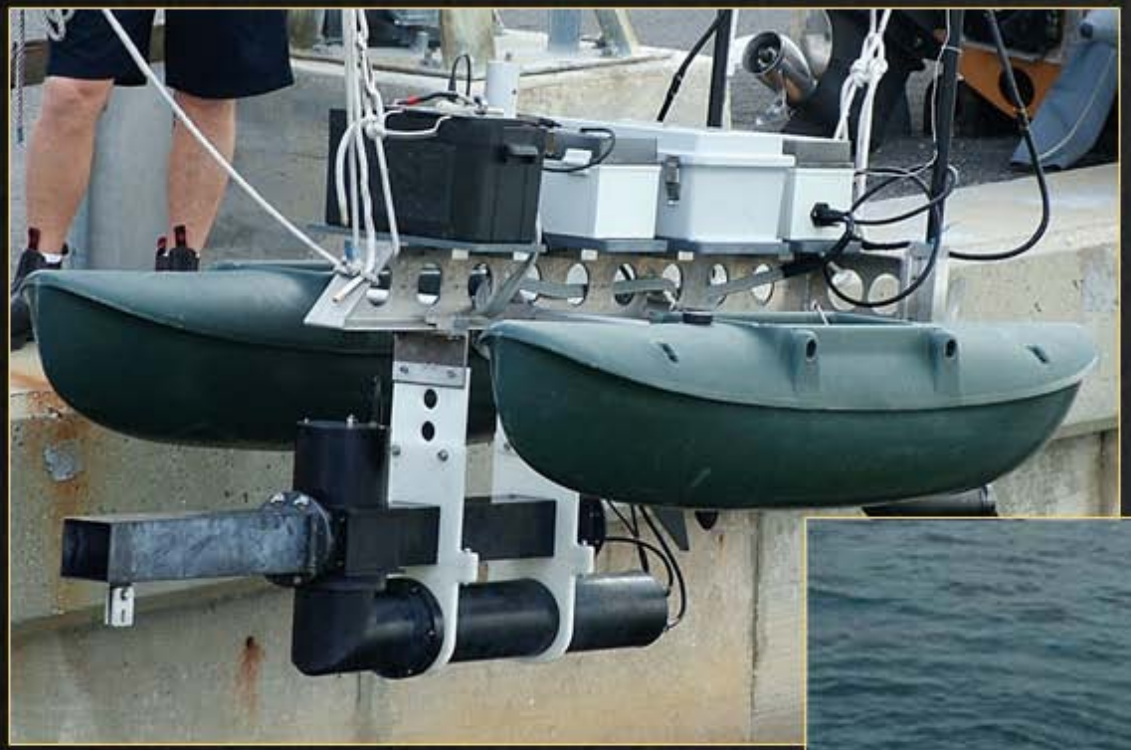


Image: R. Minemizu



Images: JAMSTEC

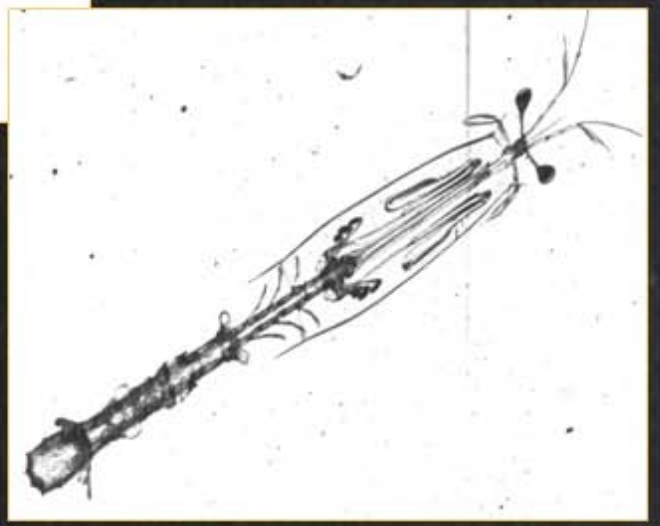
Autonomous Vehicles: SIPPER



Images: Univ. South Florida

ISIIS

In Situ Ichthyoplankton Imaging System



Images: R. Cowen
& C. Guigand

LAPIS

Large-Area Plankton Imaging System

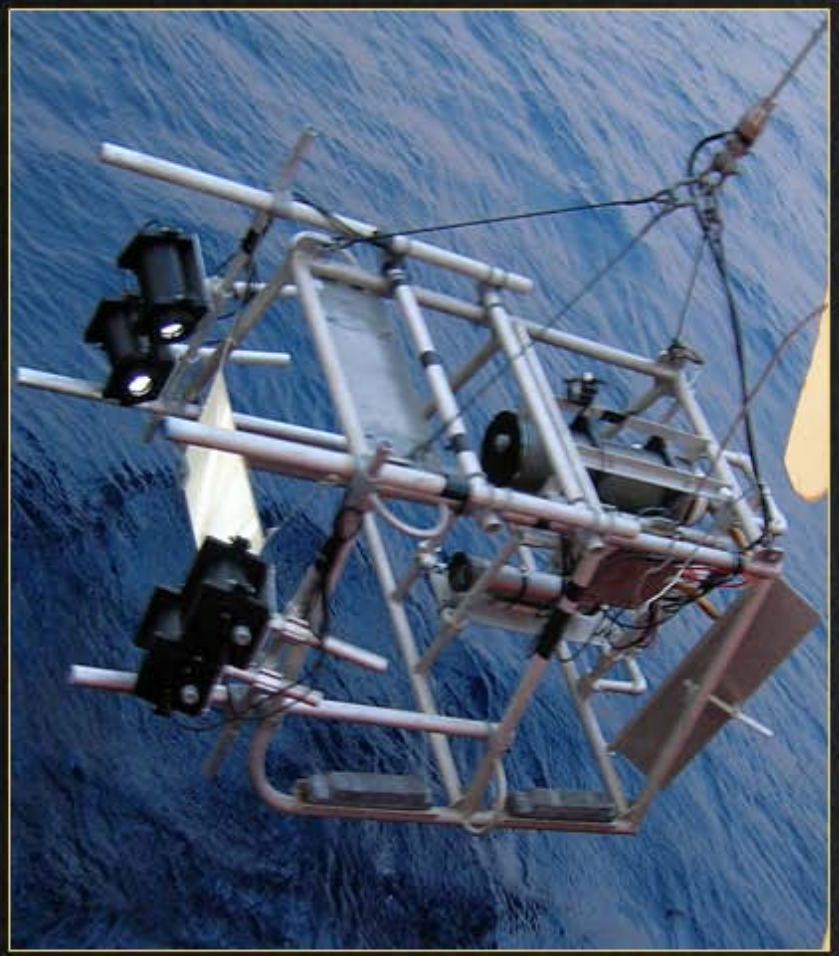
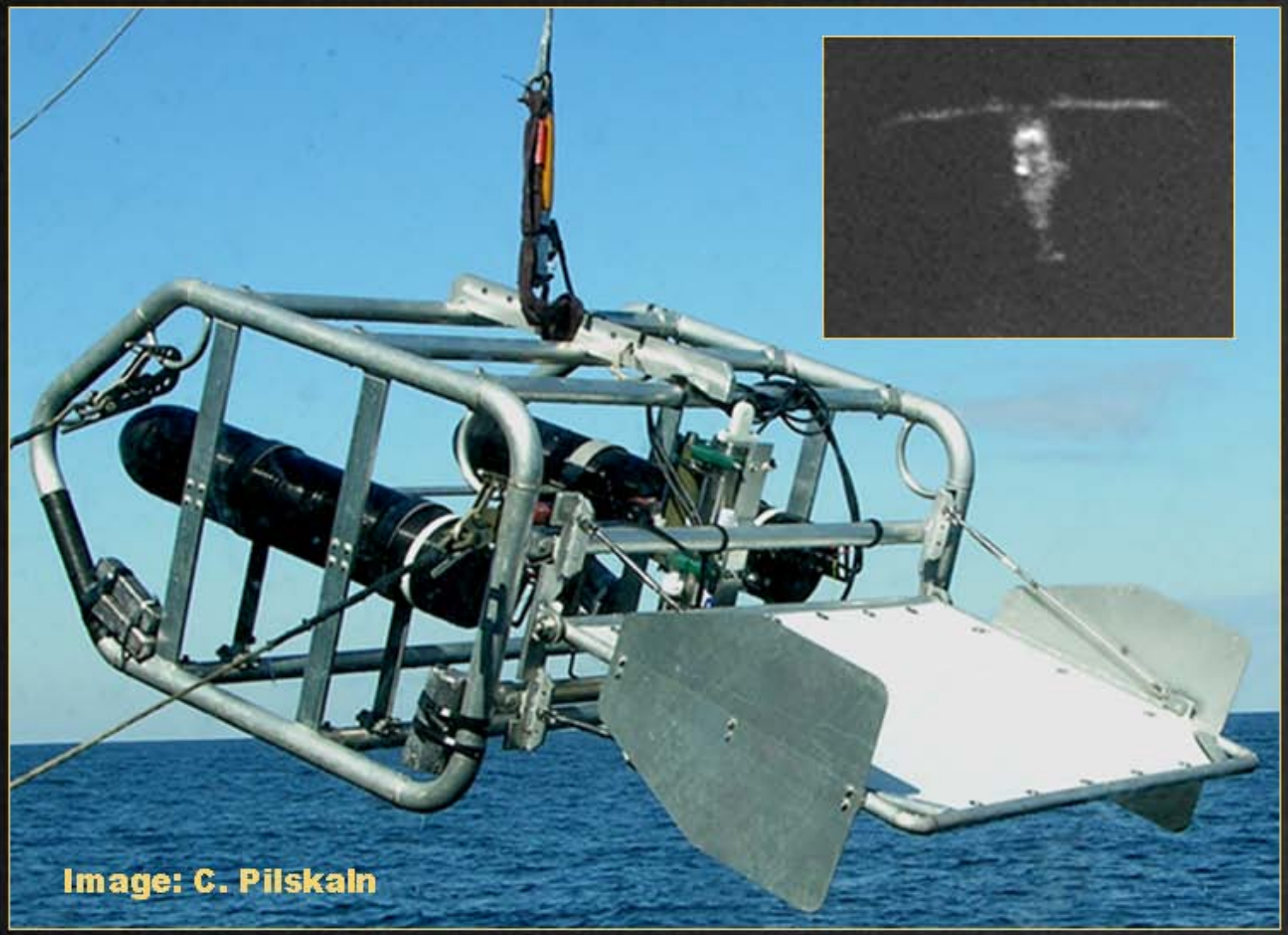


Image: E. Horgan

Image: L. Madin

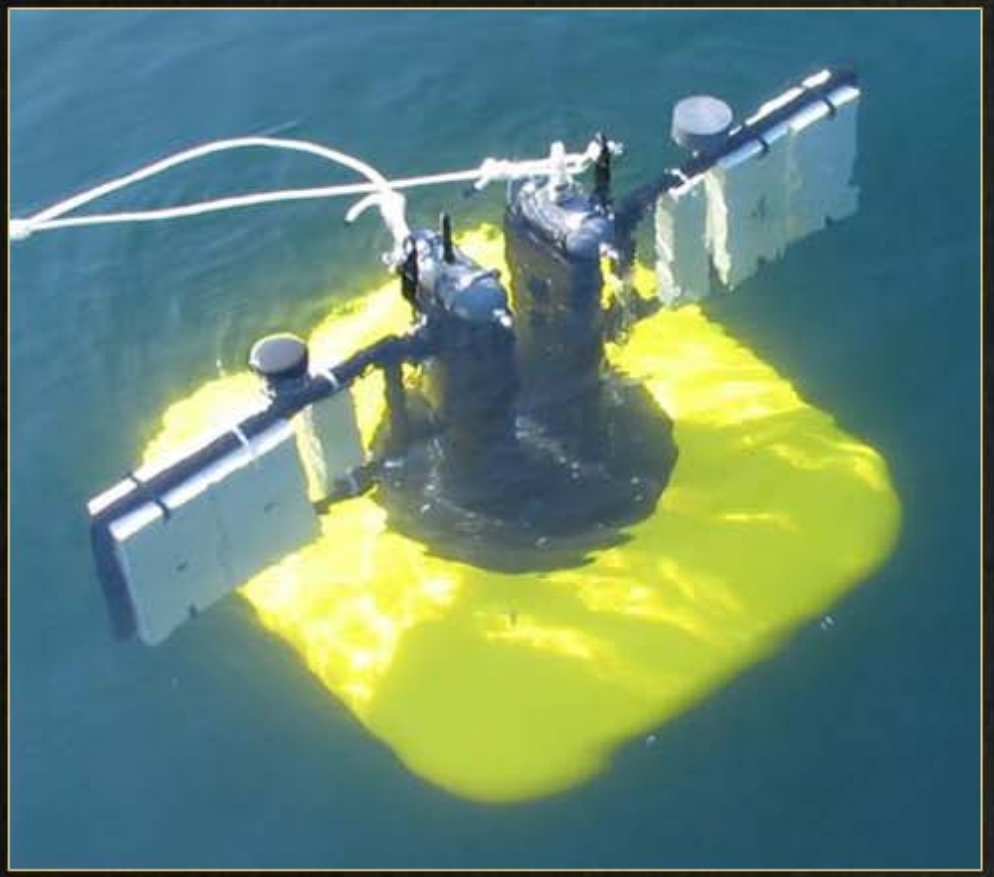
DiVA

Digital Video Acquisition System



Holographic Systems

- Submersible Holographic Drifter



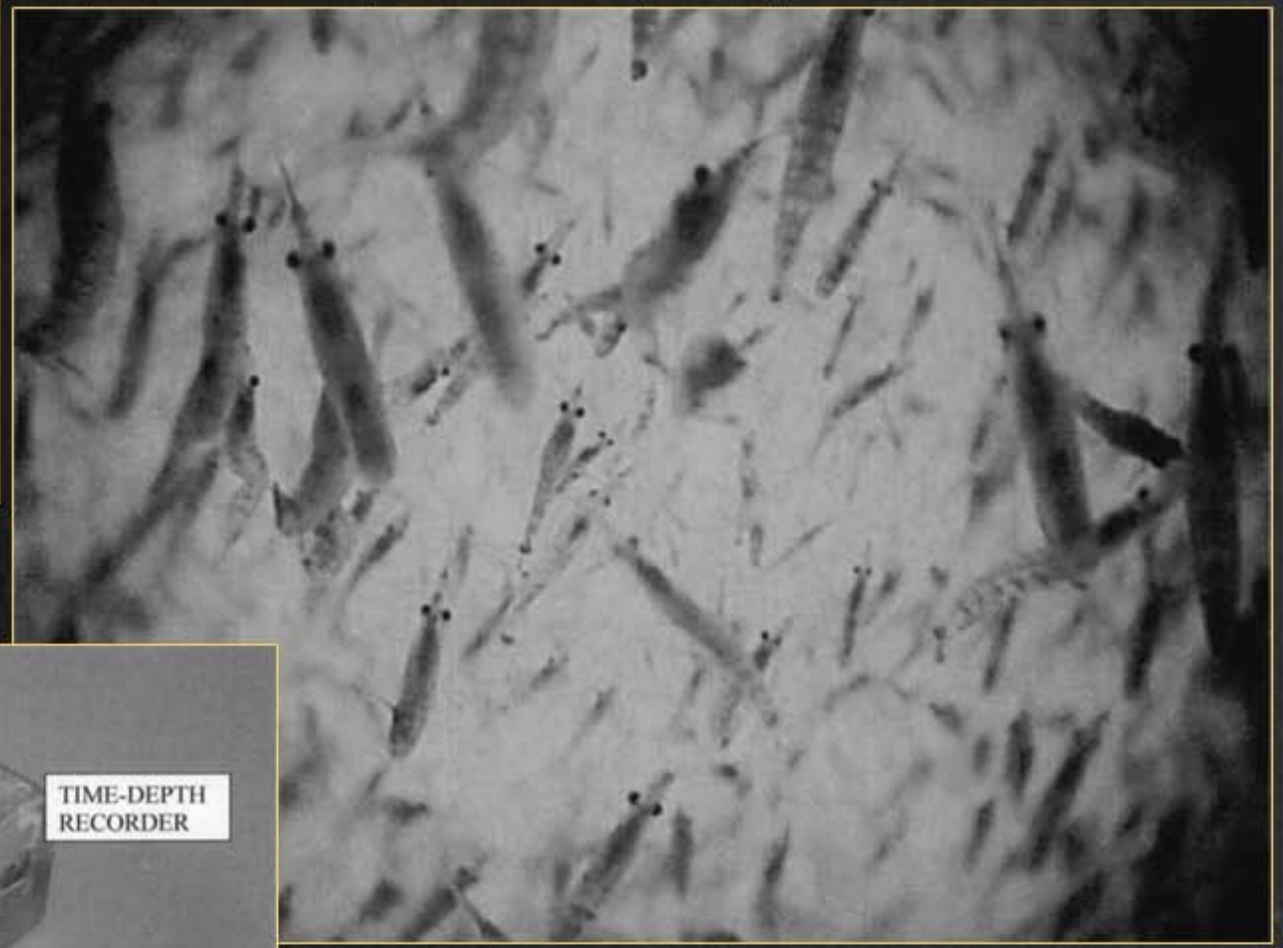
Images: E. Malkiel

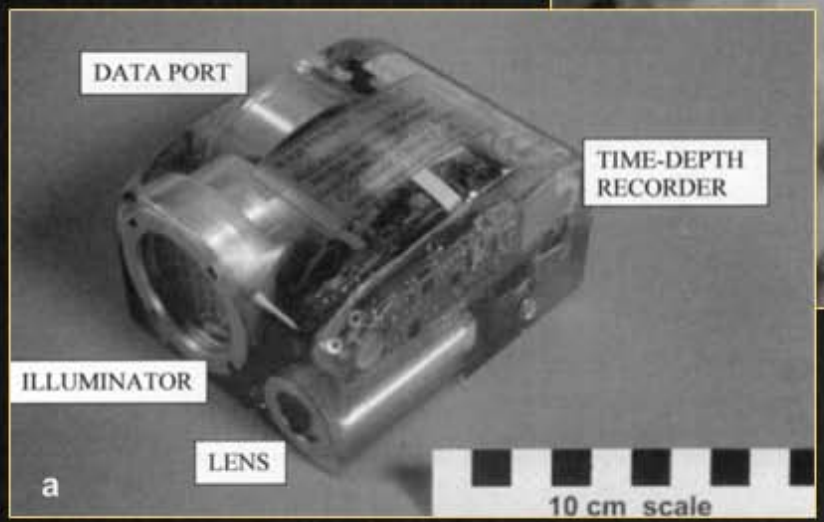
Submersible Holographic Drifter

Image: Pfitsch et al. 2006

Other Platforms

Euphausia superba **imaged by camera on fur seal**





Images: Hooker et al. 2002

Moore's Law

- The number of transistors in a chip doubles every 2 years
- Processing Power

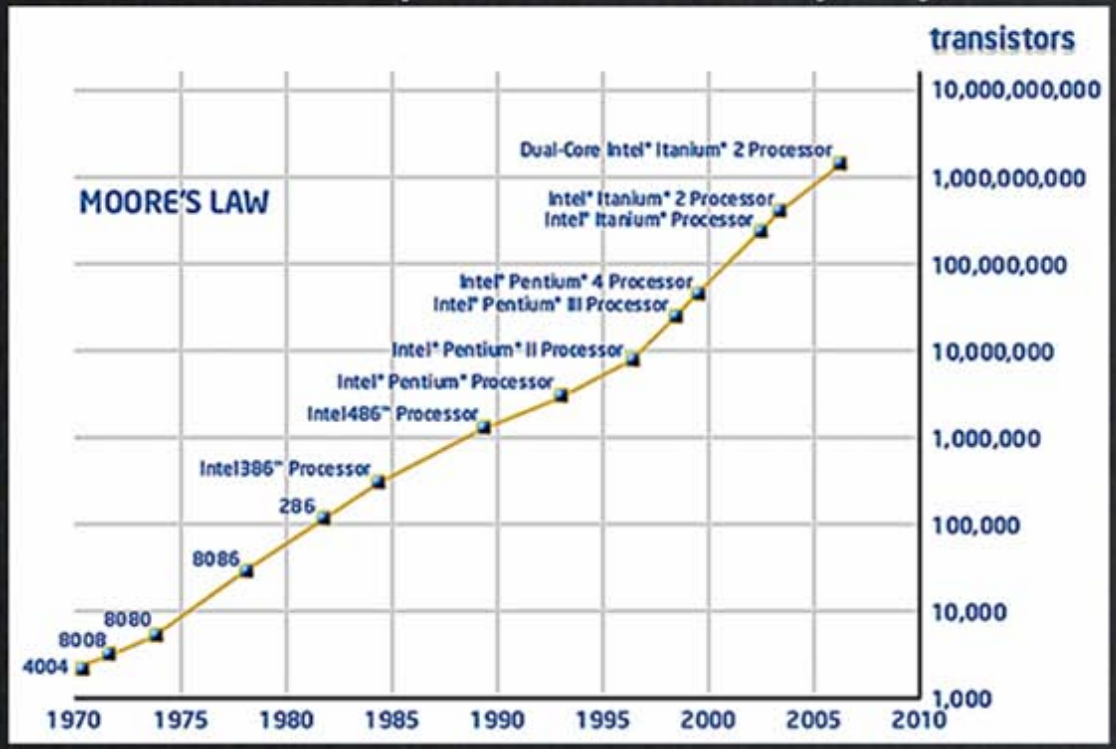
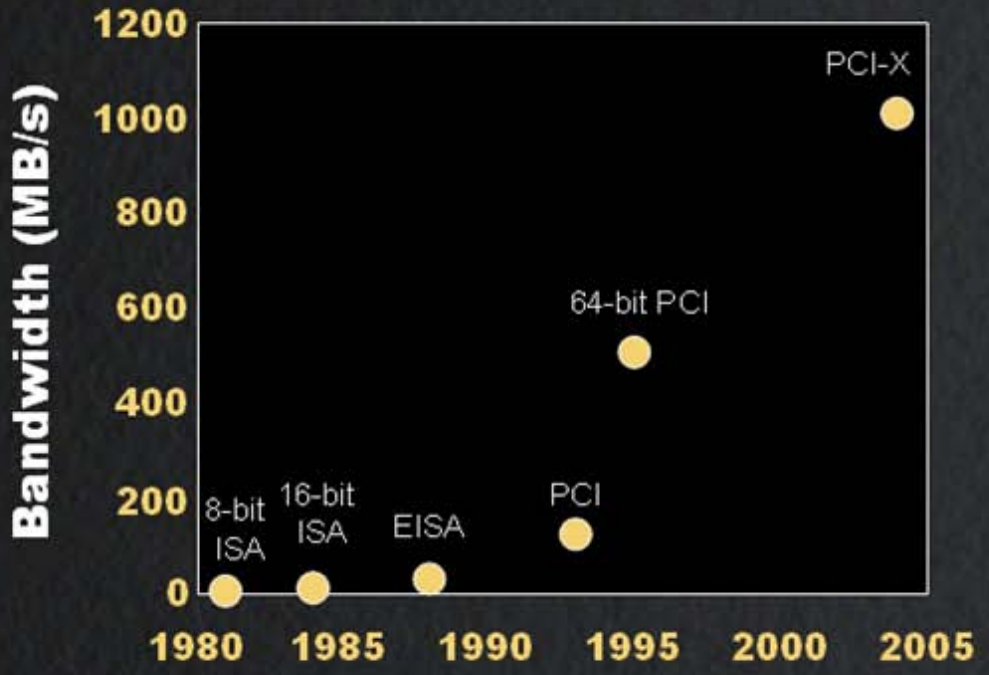


Image: Intel

Moore's Law

- The number of transistors in a chip doubles every 2 years

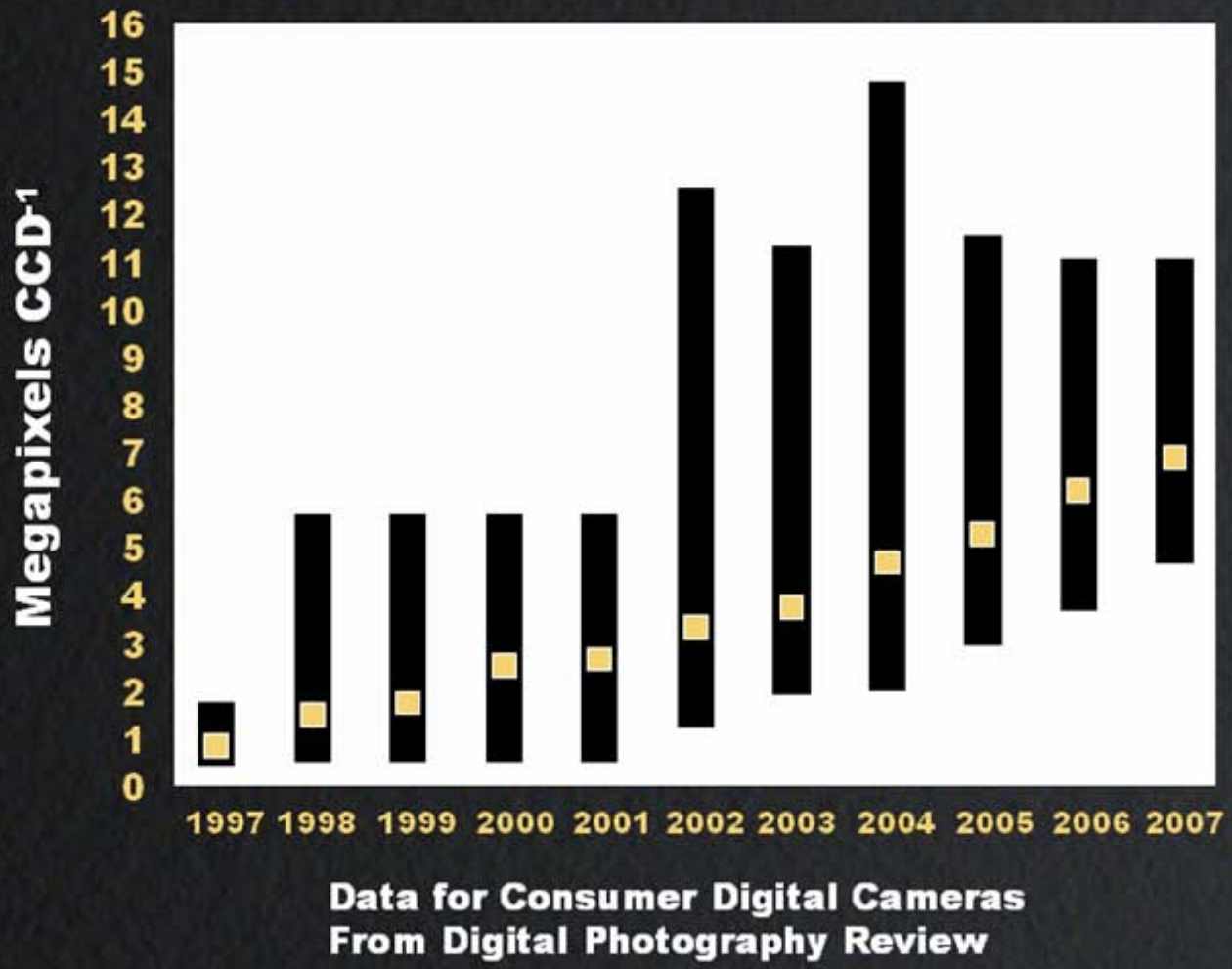
- Processing Power
- Bandwidth



Moore's Law

- The number of transistors in a chip doubles every 2 years

- Processing Power
- Bandwidth
- Image Resolution



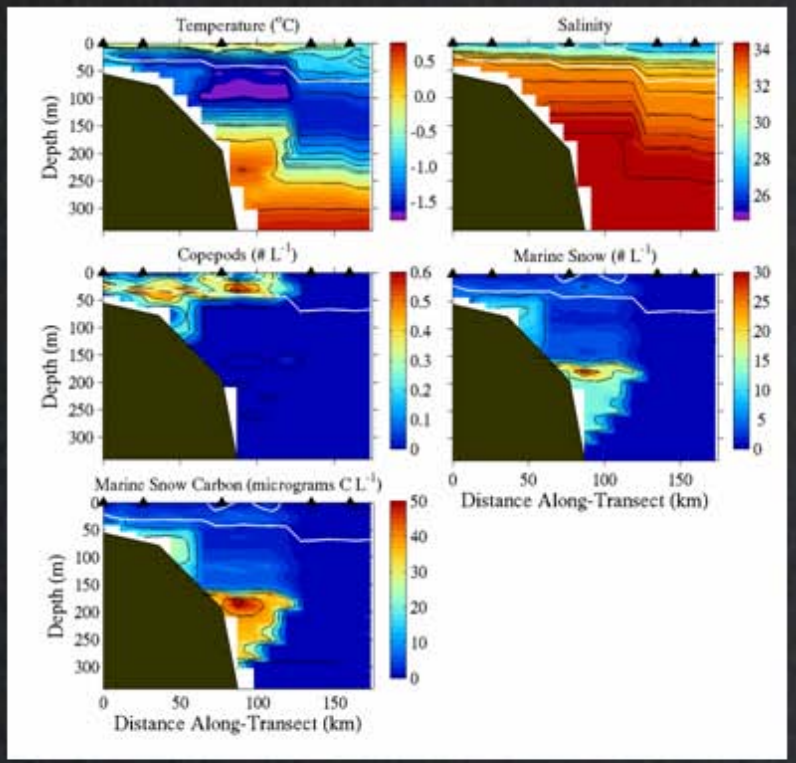
Moore's Law

- The number of transistors in a chip doubles every 2 years

- Processing Power
- Bandwidth
- Image Resolution
- Camera Size
- Power Consumption
- Cost

Hardware will not be limiting

SOFTWARE



Acknowledgements

- Developers of all the imaging systems presented
- PICES and the Symposium Organizing Committee
- SCOR
- Louisiana State University and the Woods Hole Oceanographic Institution

VPR II

VPR on MOCNESS

Image: R. Lough/E. Broughton

There is insufficient time to describe all of the systems, past and present, that have been used to image plankton. To the developers of those systems not presented here, we apologise, and salute your ingenuity.


A THIN LAYER IMAGED BY ZOOVIS-SC IN MONTEREY BAY, 2006