THE SCIENCE OF MARINE MICROPLASTICS:

What are the issues, and how can an oceanographic perspective advance our understanding?

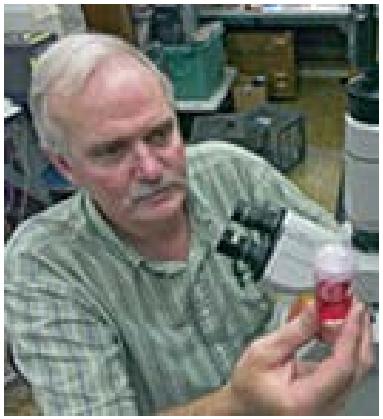
2017-18 WHOI Phase I Catalyst Project

Agenda

- Short presentations by microplastics Catalyst Team
  Brief questions after each talk
- 15 minute break
- Group Discussion
  Critical challenges for the research of microplastics

Why WHOI?

Principal Investigator



Scott M. Gallager, Bio

Co-Principal Investigators

Christopher M. Reddy, MC&G

Carol Anne Clayson, PO

Mark E. Hahn, Bio

Jake Gebbie, PO

Anna P. Michel, AOPE

Hauke Kite-Powell, MPC

Amy Apprill, MC&G


What’s wrong with this picture?

Edward Carpenter, SJ Anderson, GR Harvey, HP Miklas, BB Peck

Woods Hole Oceanographic Institution

Polystyrene Spherules in Coastal Waters

Science 178(4062), 749-750 1972

Edward Carpenter and KL Smith

Woods Hole Oceanographic Institution

Plastics on the Sargasso Sea Surface

Science 175(4027):1240-1 · 1972

The first papers on microplastics came from WHOI

SCIENTIFIC REPORTS

OPEN

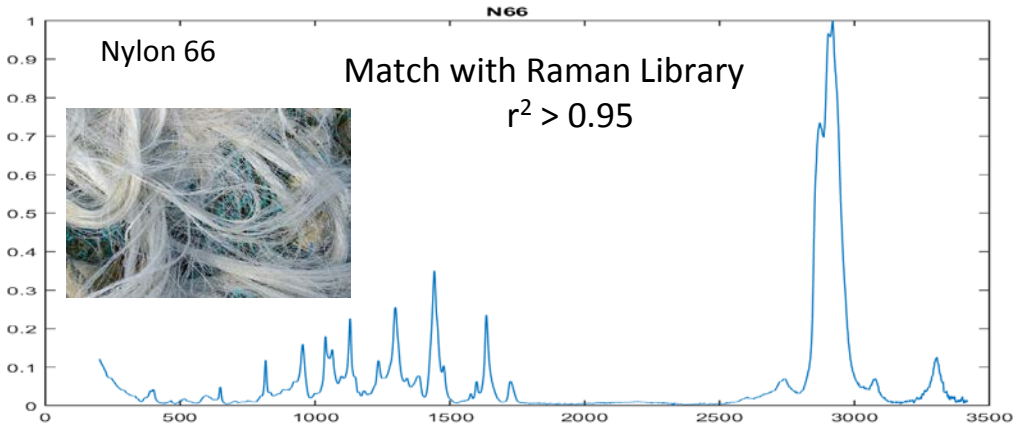
d: 17 October 2017
d: 5 March 2018
d online: 22 March 2018

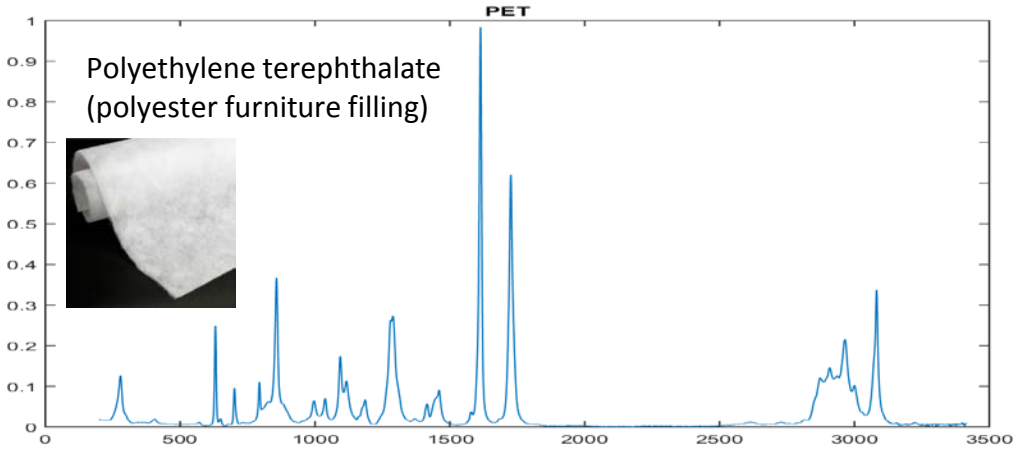
Evidence that the Great Pacific Garbage Patch is rapidly accumulating plastic

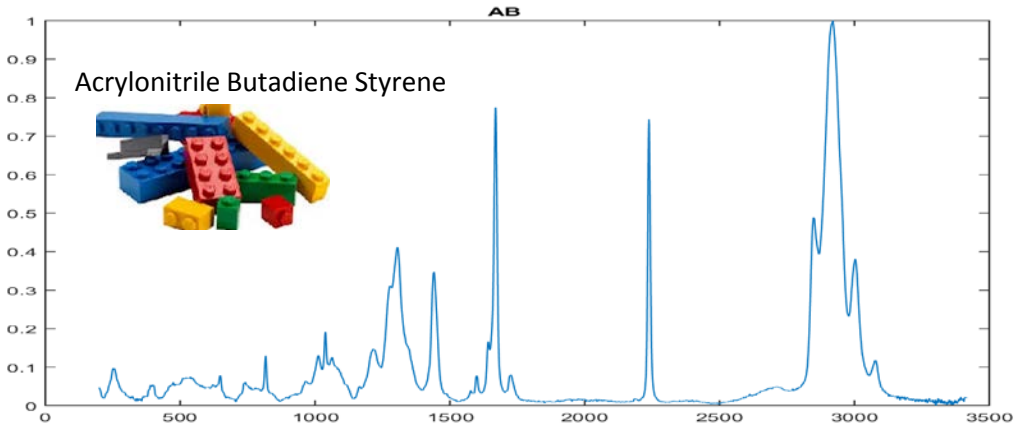
L. Lebreton[1,2], B. Slat[1], F. Ferrari[1], B. Sainte-Rose[1], J. Aitken[3], R. Marthouse[3], S. Hajbane[1], S. Cunsolo[1,4], A. Schwarz[1], A. Levivier[1], K. Noble[1,5], P. Debeljak[1,6], H. Maral[1,7], R. Schoeneich-Argent[1,8], R. Brambini[1,9] & J. Reisser[1]

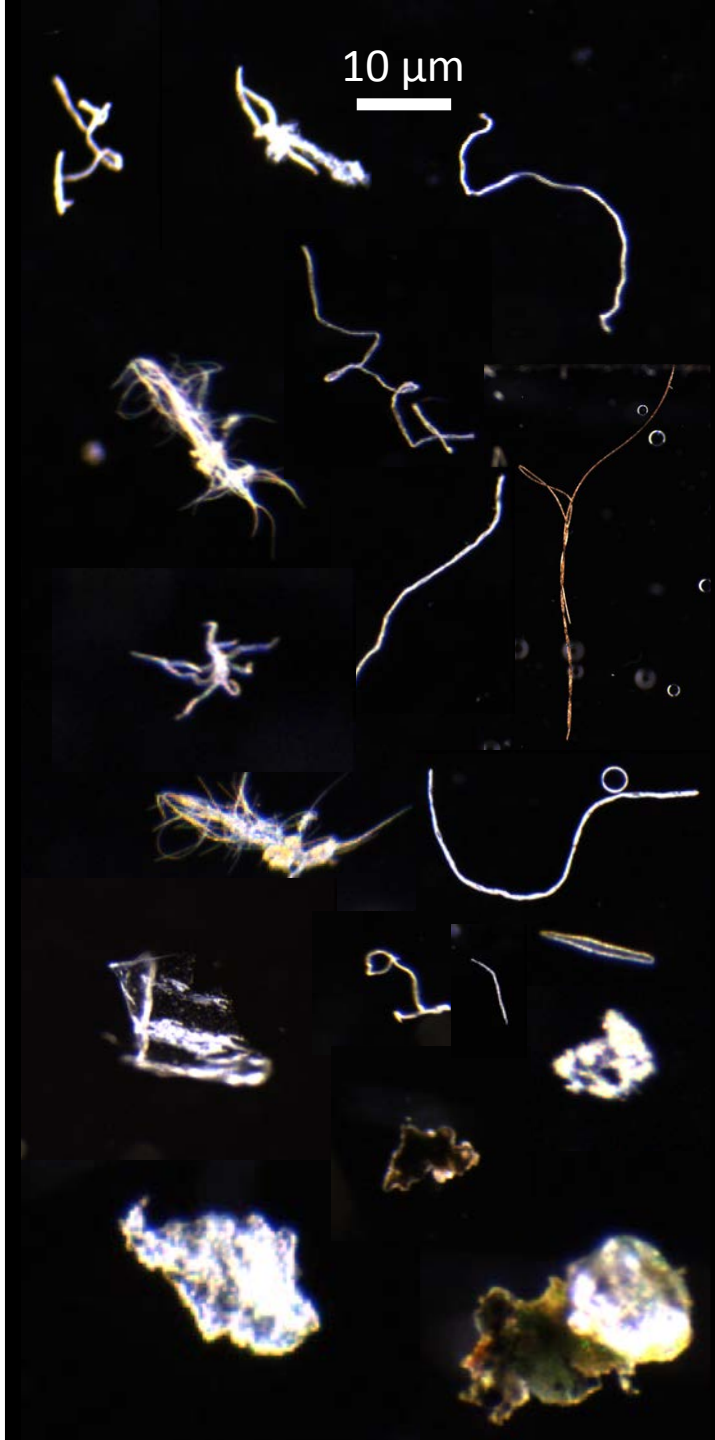
Ocean plastic can persist in sea surface waters, eventually accumulating in remote areas of the world's oceans. Here we characterise and quantify a major ocean plastic accumulation zone formed in subtropical waters between California and Hawaii: The Great Pacific Garbage Patch (GPGP). Our model, calibrated with data from multi-vessel and aircraft surveys, predicted at least 79 (45–129) thousand tonnes of ocean plastic are floating inside an area of 1.6 million km²; a figure four to sixteen times higher than previously reported. We explain this difference through the use of more robust methods to quantify larger debris. Over three-quarters of the GPGP mass was carried by debris larger than 5 cm and

What are microplastics?


N66
Nylon 66
Match with Raman Library
$r^2 > 0.95$


PET
Polyethylene terephthalate
(polyester furniture filling)

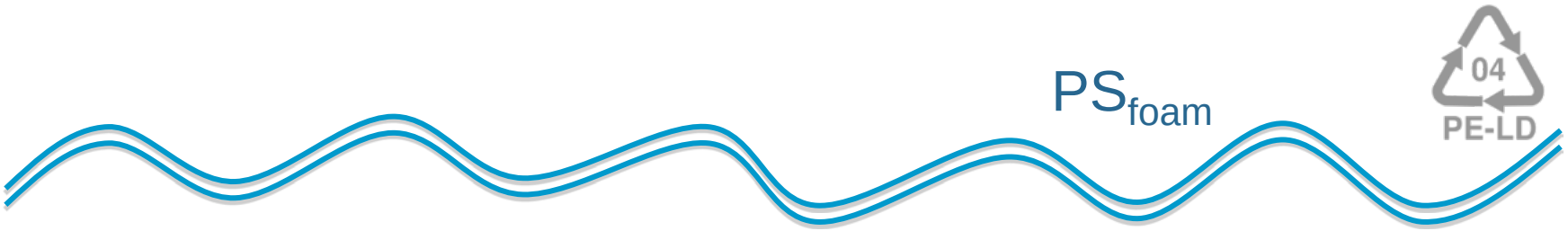

AB
Acrylonitrile Butadiene Styrene


10 µm

Types of plastics and their density

Floats

- Polypropylene (PP): straws, marine line, plastic caps and lids
- High Density Polyethylene (HDPE): milk jugs, trash bags, detergent bottles
- Low Density Polyethylene (LDPE)L grocery/produce bags, food packaging



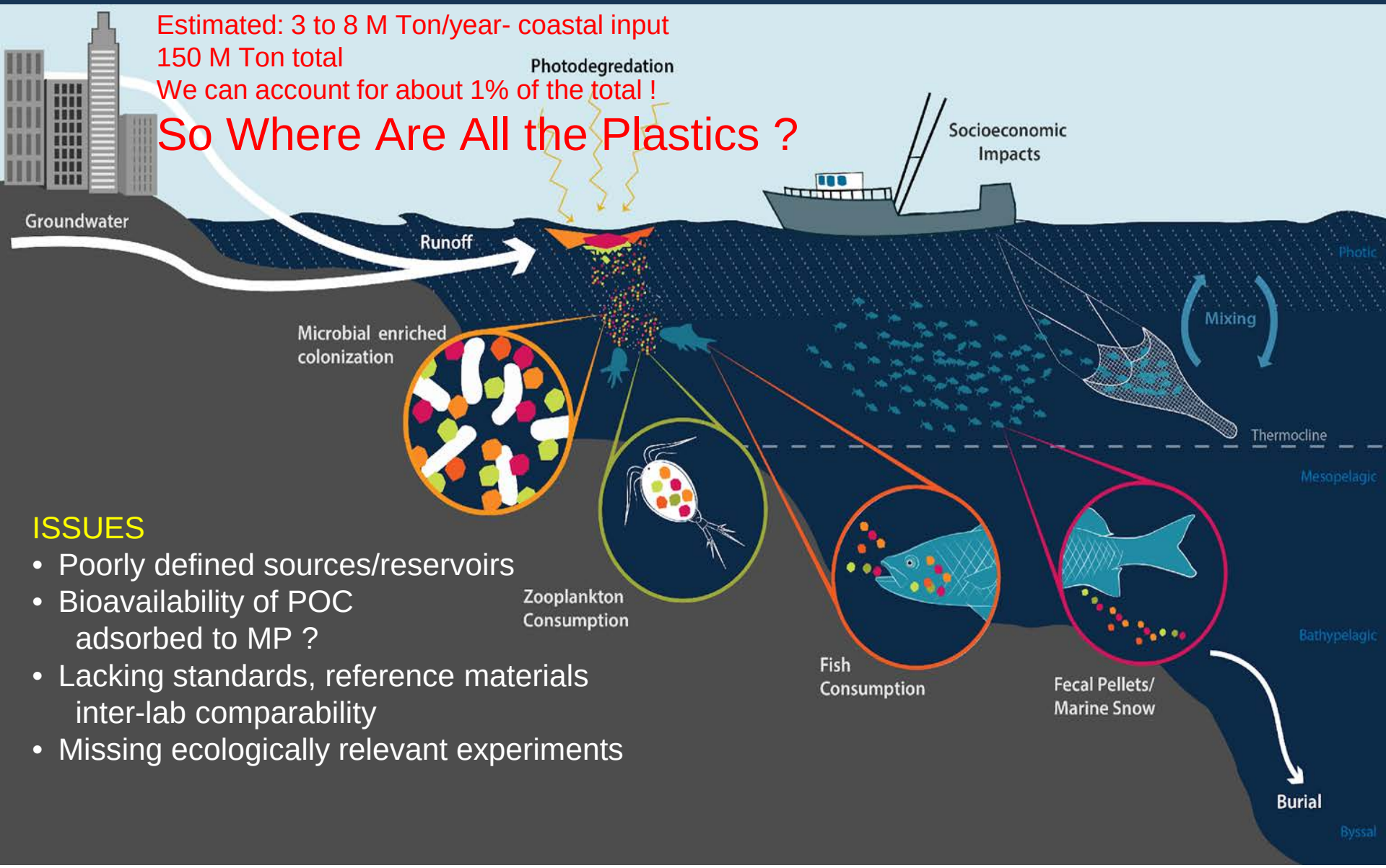
Sinks

- Polystyrene (PS): disposable cutlery, CD cases
- Polyvinyl chloride (PVC): cooking oil bottles, packaging around meat
- Polyethylene Terephthalate (PET): drink/water bottles, mouthwash bottles

Microplastics are an oceanographic problem

Estimated: 3 to 8 M Ton/year- coastal input
150 M Ton total
We can account for about 1% of the total !

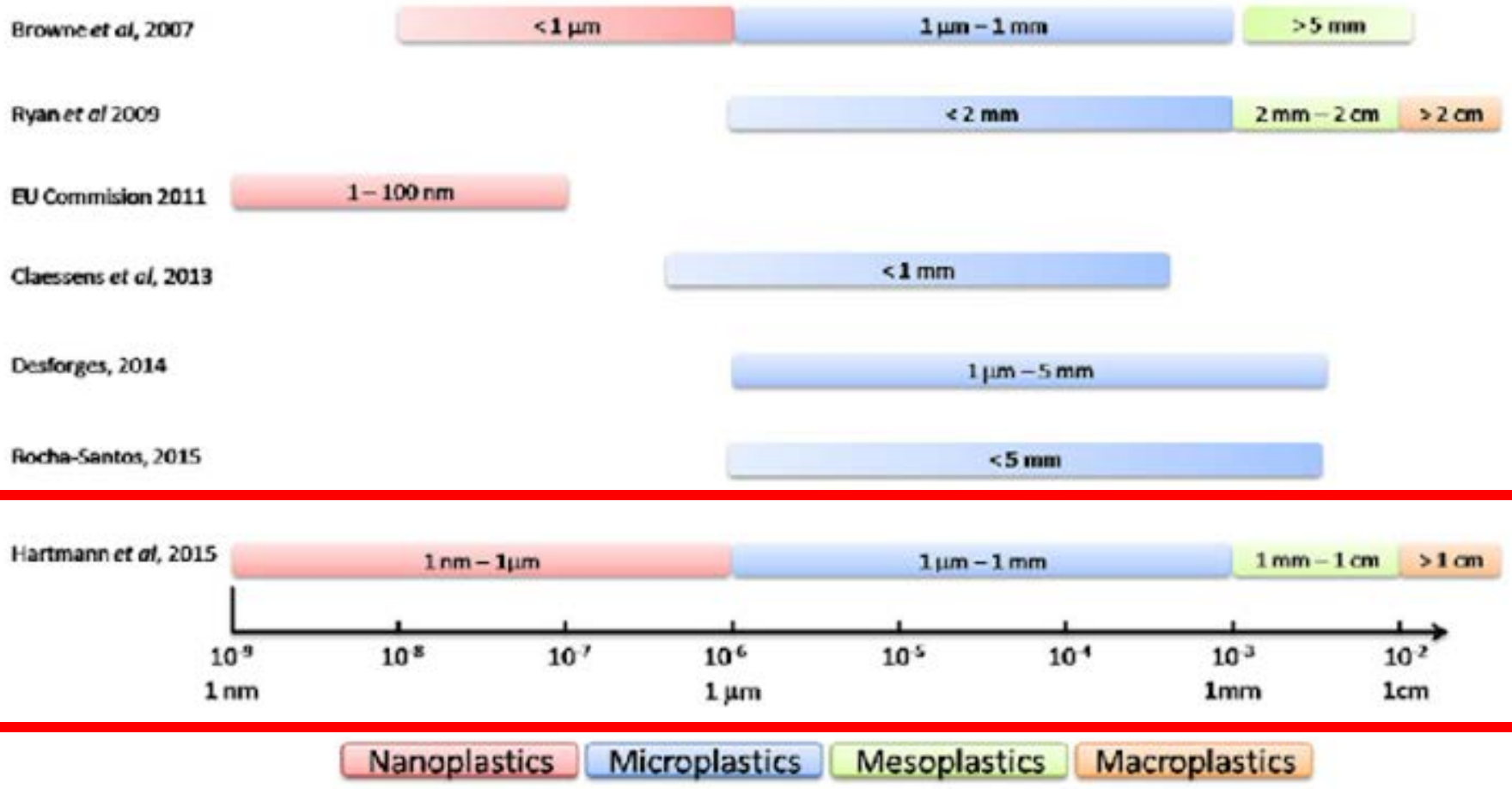
So Where Are All the Plastics ?



ISSUES

- Poorly defined sources/reservoirs
- Bioavailability of POC adsorbed to MP ?
- Lacking standards, reference materials inter-lab comparability
- Missing ecologically relevant experiments

How many ways can you define MP size?



What do we know about MPs?

- Estimated: 3 to 8 M Ton/year- coastal input
- 150 M Ton total
- Can account for about 1% from surface sampling
- MPs are in the food chain now-
  ciliates, copepods, larvaceans, salps, benthic suspension feeders (scallop), lobsters, fish, squid, humans
- Consequences: no nutritional value, physical blockages, inflammation, vector for pathogens, transport of invasive species
- Degradation decreases molecular weight and mechanical integrity
  modulated by photo- and thermal-oxidation, hydrolysis and biodegradation mediated by microbial activity
- Their presence has been reported worldwide, from polar regions to the equator, from intertidal zone to abyssal sediments

What do we know about MPs (con't):

- MPs contain additives-
  polybrominated diphenyl ethers (heat resistance, endocrine-disrupting),
  triclosan (microbial resistance),
  nonylphenol (oxidative resistance),
  phthalates (emollients soften plastics),

- Polyvinyl chloride, polyethylene, polypropylene, polystyrene have a high sorption capacity for:
  DDTs,
  polycyclic aromatic hydrocarbons (PAHs),
  hexachlorocyclohexanes,
  chlorinated benzenes
  Polychlorinated biphenyls (PCBs)

- MPs should not be considered as biologically inert materials
  - cellular pathways adversely affected after their ingestion by marine organisms

What we don't know about MPs?

- Little about temporal and spatial accumulation of MPs along the coasts, mid-water column, and below 1000m. e.g., Are MPs sinking to an equi-density point, e.g., pycnocline or the many density steps known in the mesopelagic zone?

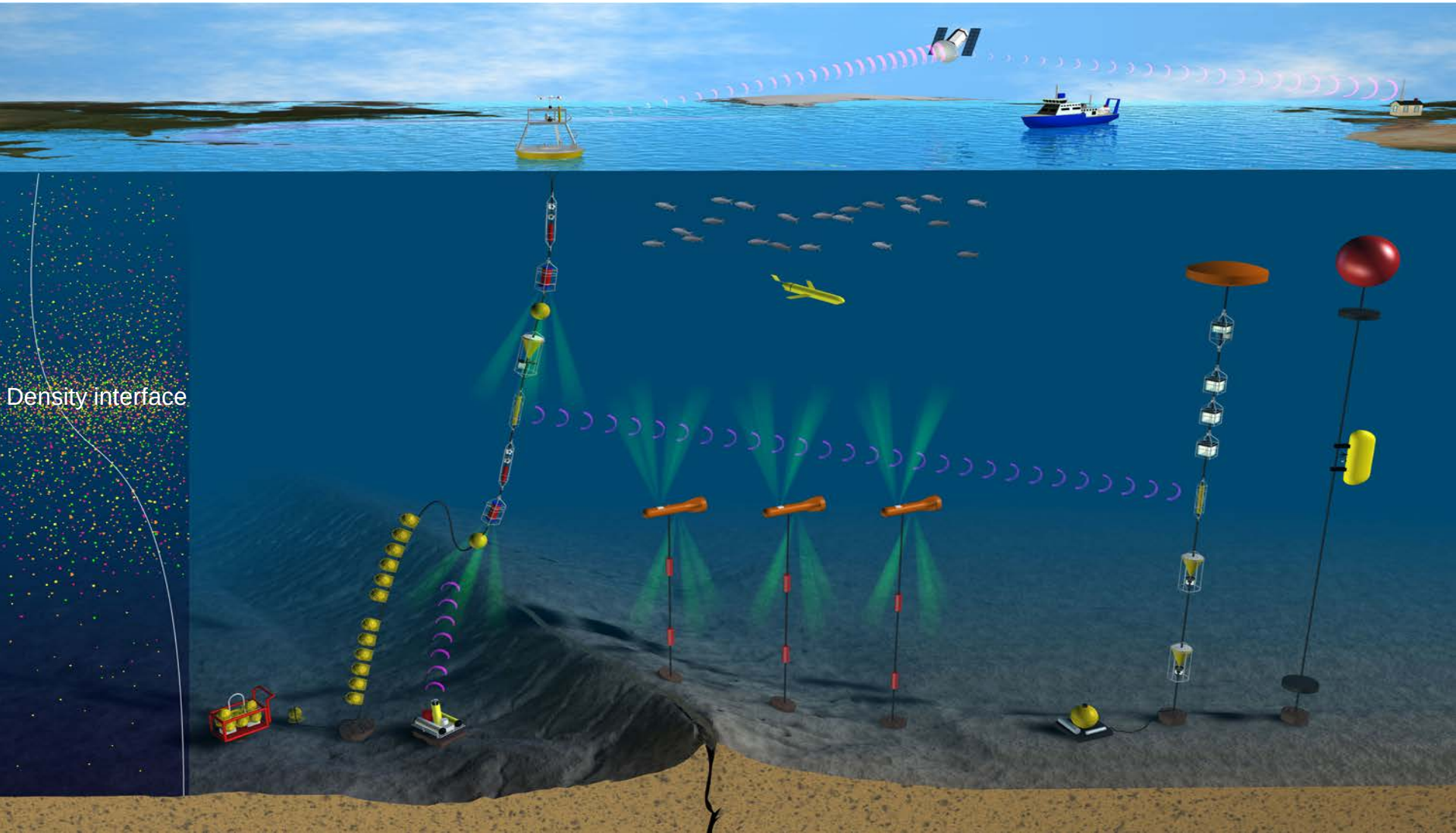
- Nothing about nanoplastics- important since these are known to be translocated across membranes

- Little about the mechanisms involved in the biodegradation, though some microbial strains capable of biodegrading plastics are reported. Further studies may help to manufacture biodegradable plastics and other materials.

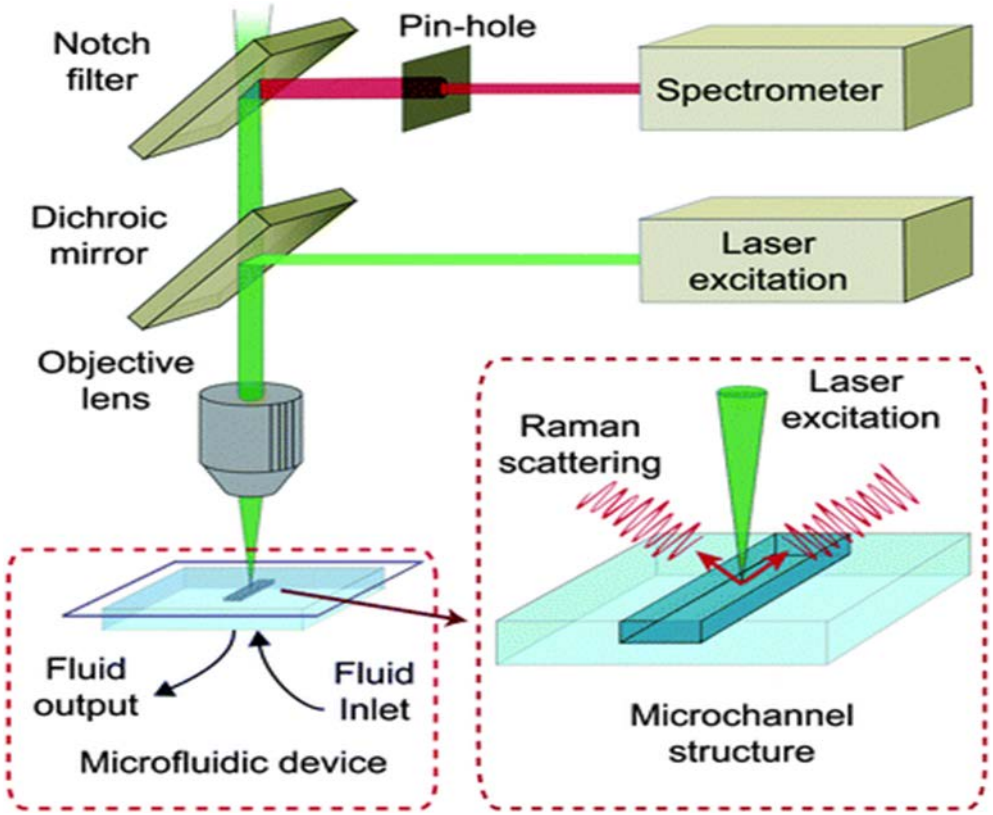
- Little about mechanisms and factors of adsorption or desorption of POPs and metals among plastic types in the marine environment or in organisms- e.g., vectors for biomagnification,

Five Major Questions

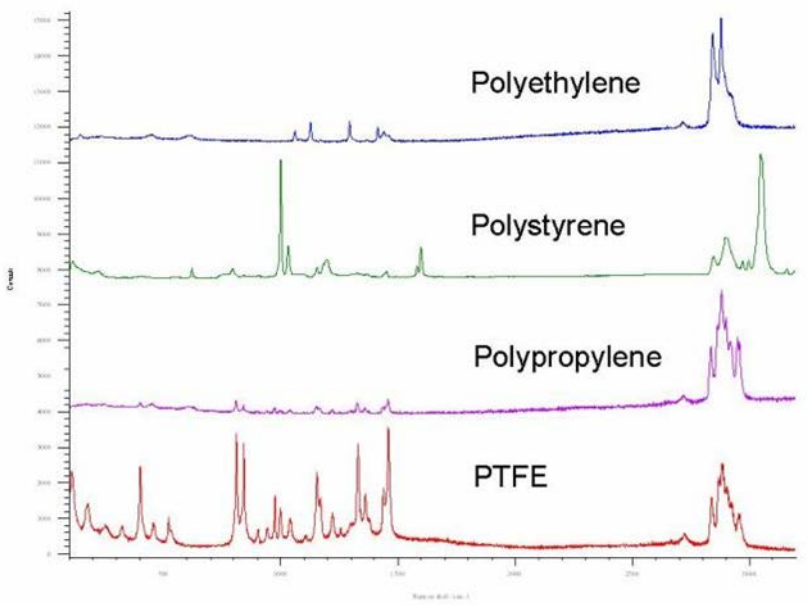
1) Can we develop a mass budget for MPs in the world ocean. We need new technology!



Sensor Development: Novel Application of Raman Spectroscopy to Detect, Classify and Quantify Plastics in the Ocean



The Raman signal can be a very precise finger print for a given plastic compound.



Time-Resolved Flow-Through Imaging Raman Spectrometer

Top View

Dark field illumination array

in

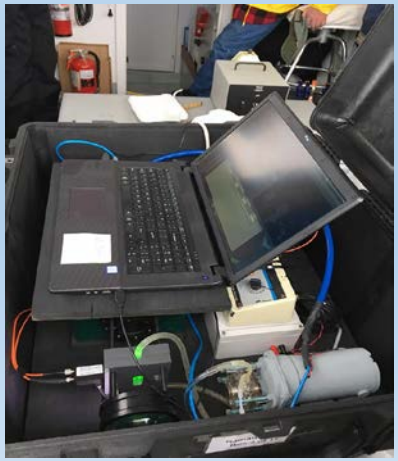
Flow cell

out

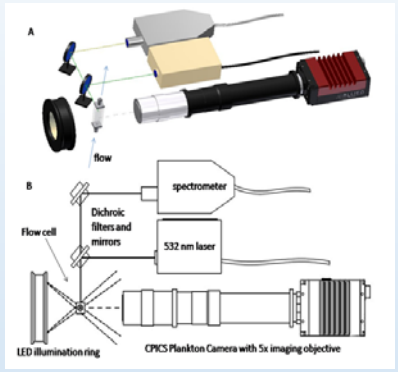
Focused particle stream

Telecentric lens

Color CCD camera



Side View



Piezo electric acoustic focusing element

in

out

20x LD objective

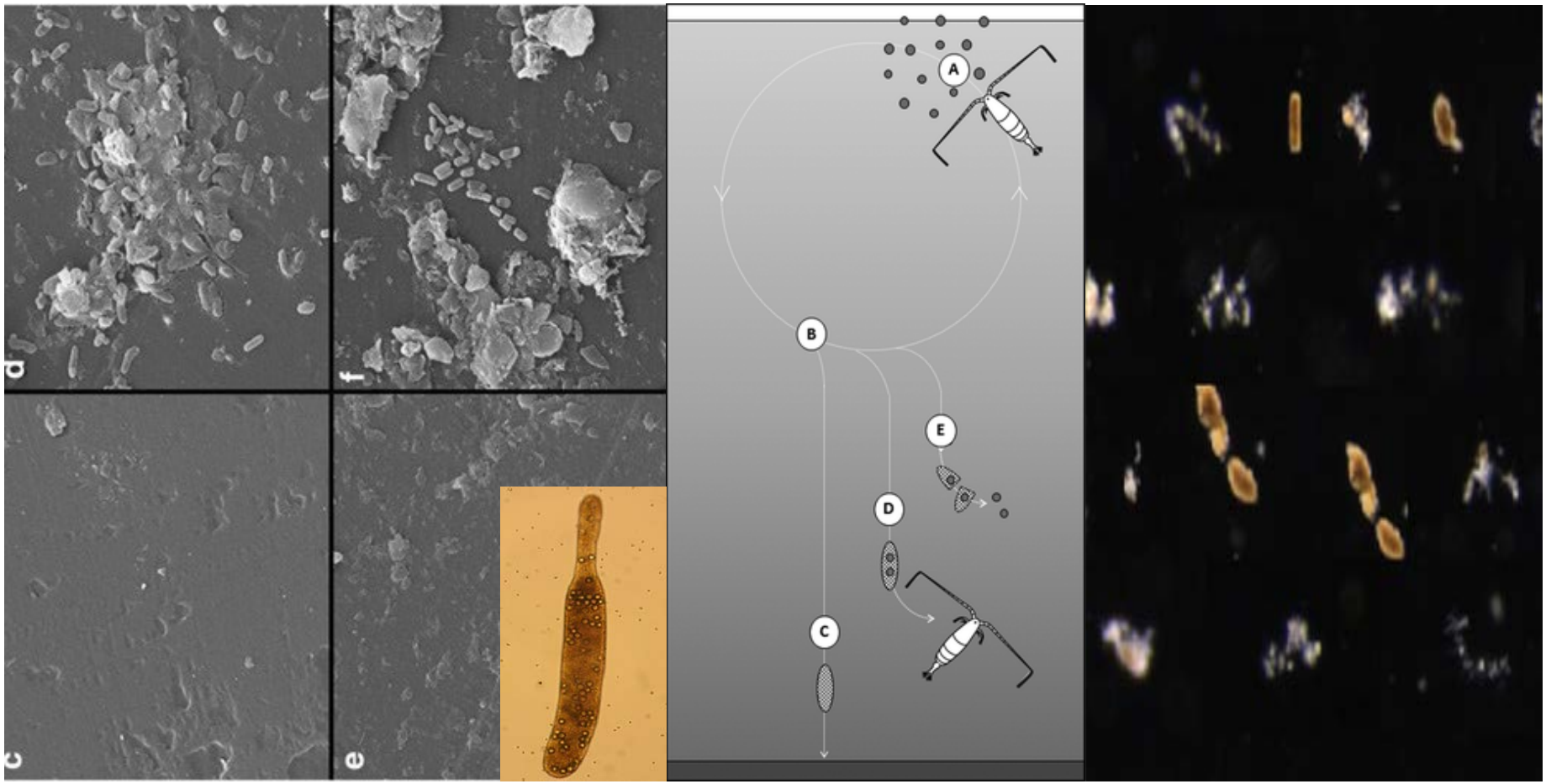
Single Photon Avalanche Detector (SPAD) Spectrometer

Nanosecond Laser 25 kHz 532 nm

Trigger generator/delay

Five Major Questions

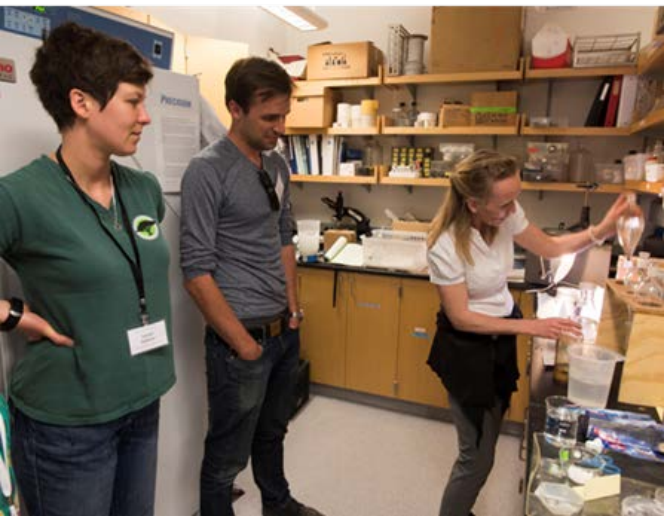
2) How does microbial activity affect the physical and chemical properties of MPs?



Five Major Questions

3) Can we establish standards for inter-laboratory calibration on a global scale?

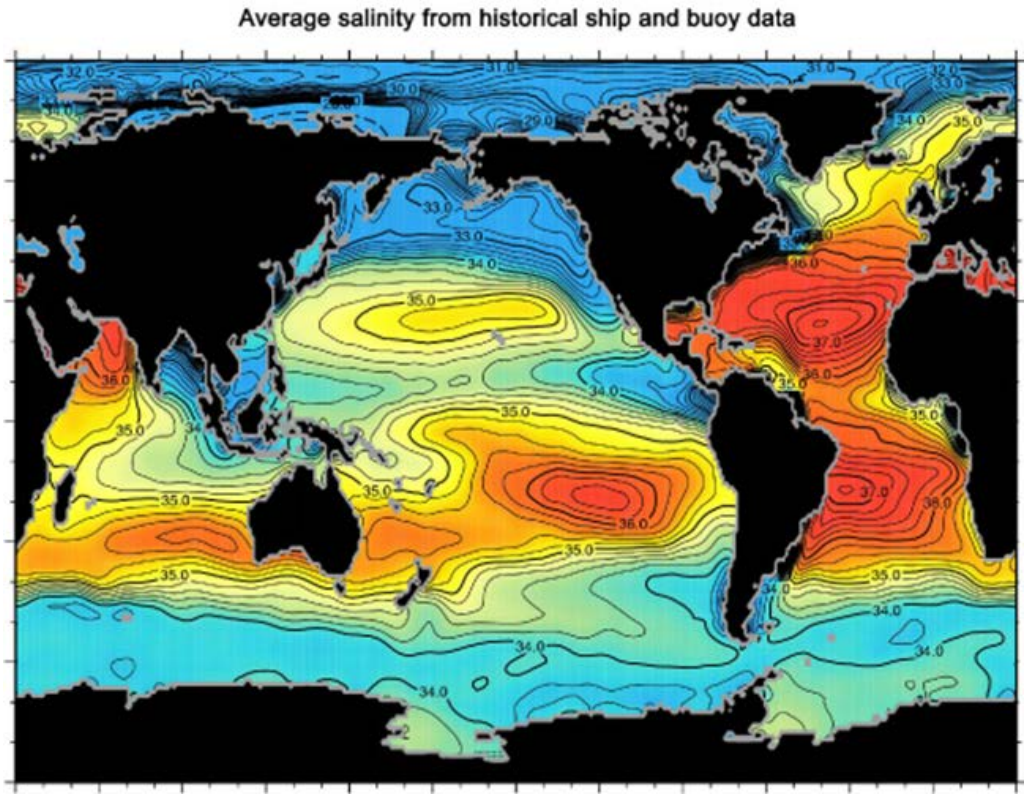
e.g., units of measure, instrumentation for classification of polymers, reporting standards or particle size and shape..



Ocean Outlook course on microplastics, May 2018

Five Major Questions

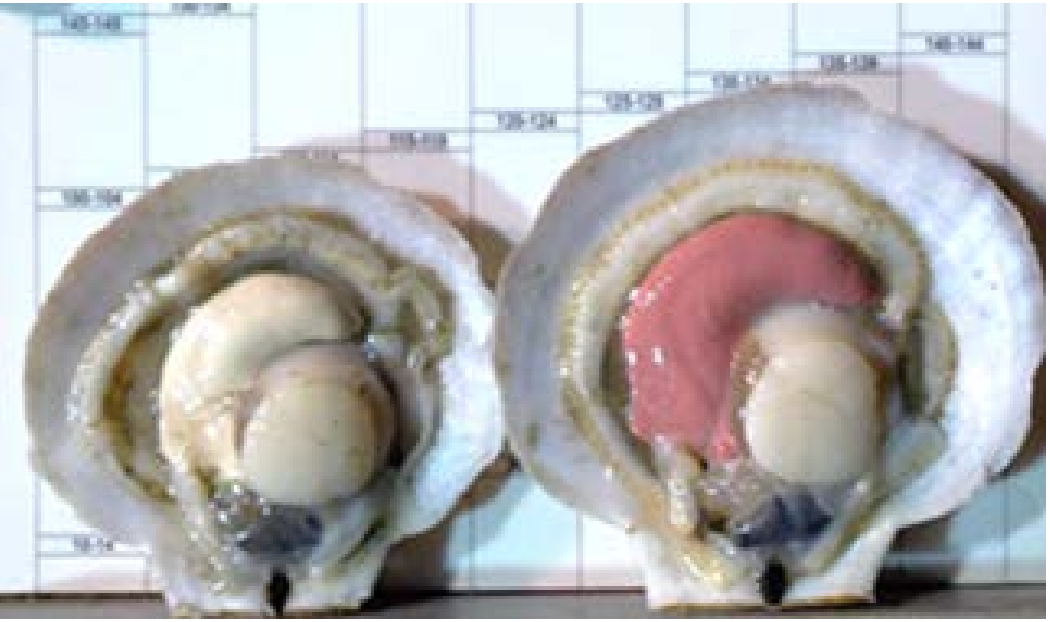
4) What kinds of numerical models do we need to develop and evaluate to predict MP concentration, distribution, and transport?

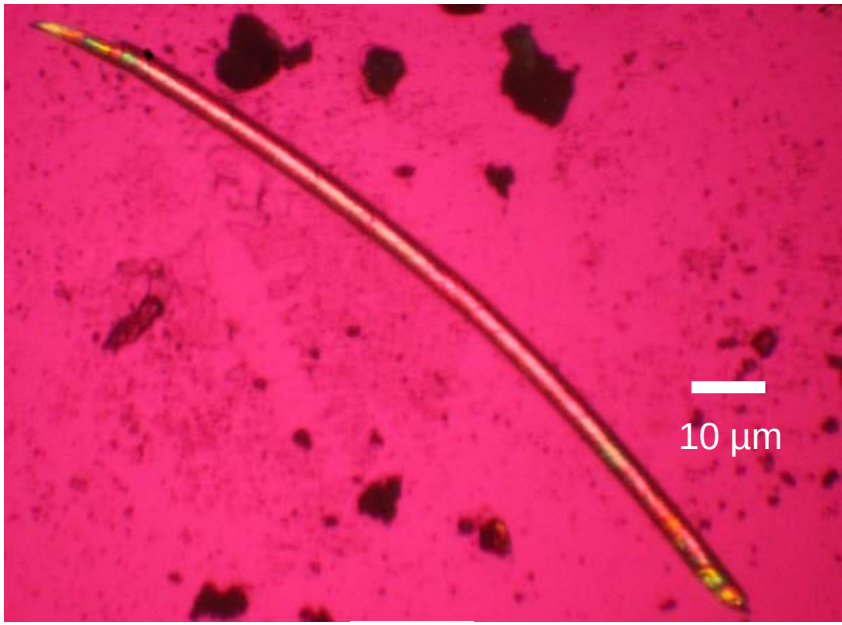


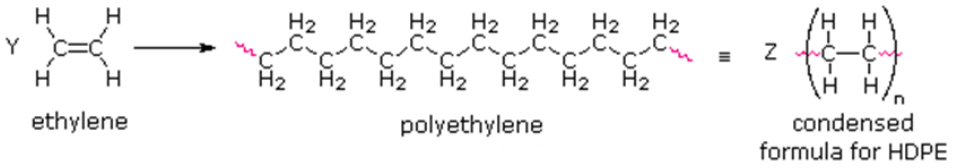
Local scale vertical processes to basin scale distributions.

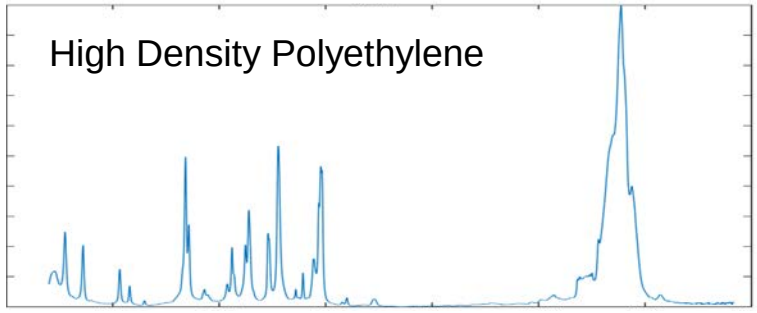
Five Major Questions

5) What is the ecological impact of MPs on marine organisms, ecosystems, and human health?



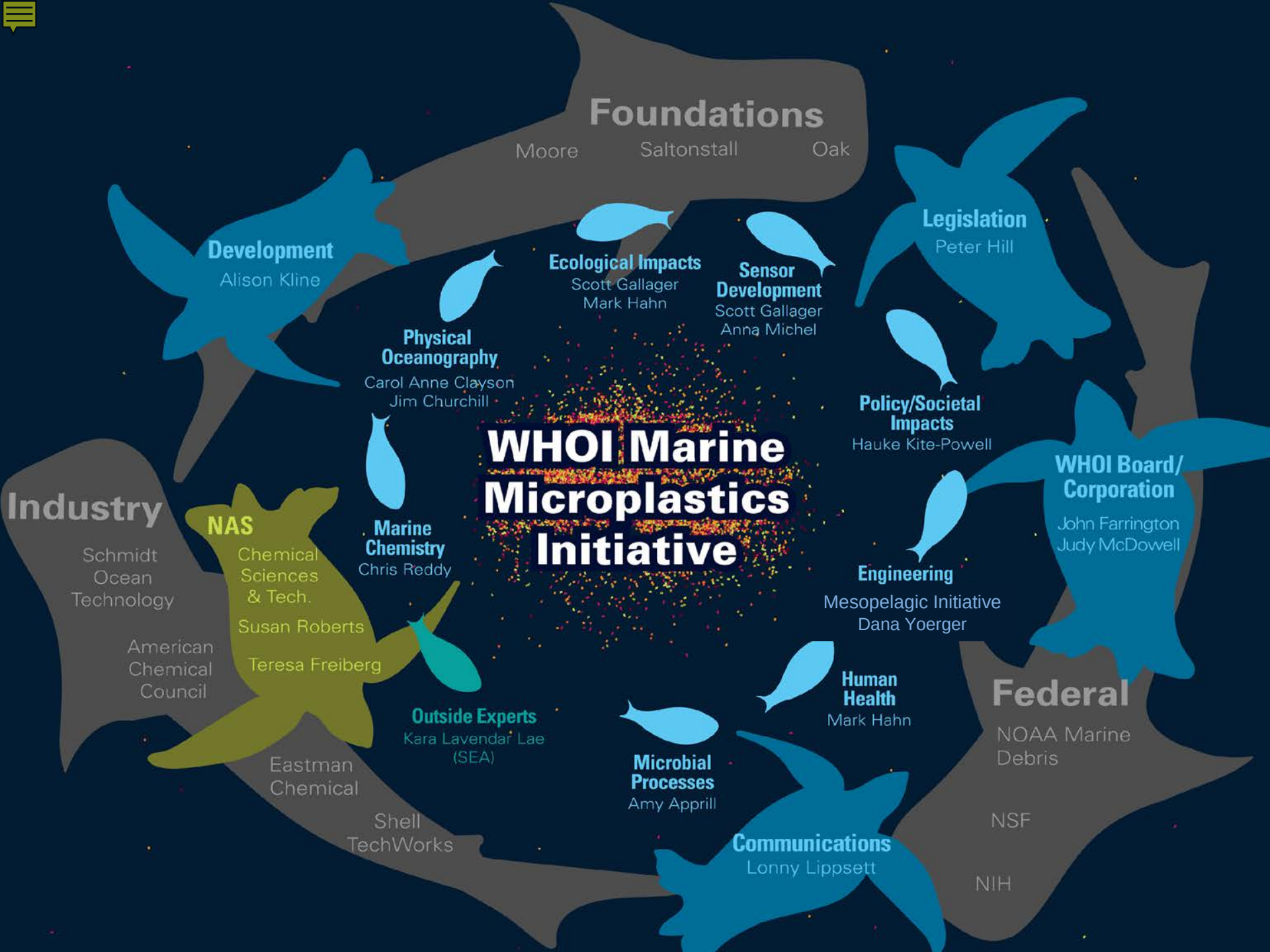






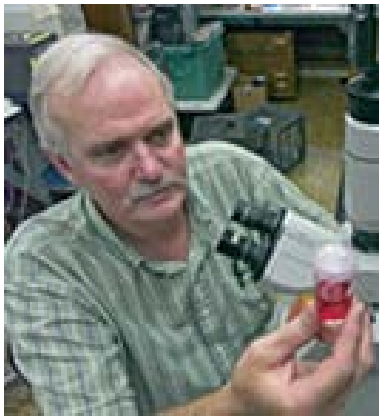
What do we plan to do with our first $30 million?

1. Conduct international workshop to entrain the world.
2. Identify key technology needs (start with ships of opportunity?).
3. Partner with existing global MP research initiatives, develop exchange programs.
4. Design numerical models of vertical transport, local processes, and basin-scale and global distribution.
5. Initiate studies on:
    a. Microbial impacts on MP density and water column distribution
    b. Ecological impacts (esp. suspension feeders)
    c. Human and socioeconomic impacts via seafood


Foundations
Moore
Saltonstall
Oak
Development
Alison Kline
Ecological Impacts
Scott Gallager
Mark Hahn
Sensor Development
Scott Gallager
Anna Michel
Legislation
Peter Hill
Physical Oceanography
Carol Anne Clayson
Jim Churchill
Policy/Societal Impacts
Hauke Kite-Powell
WHOI Marine Microplastics Initiative
WHOI Board/ Corporation
John Farrington
Judy McDowell
Industry
Schmidt Ocean Technology
American Chemical Council
NAS
Chemical Sciences & Tech.
Susan Roberts
Teresa Freiberg
Marine Chemistry
Chris Reddy
Engineering
Mesopelagic Initiative
Dana Yoerger
Human Health
Mark Hahn
Federal
NOAA Marine Debris
NSF
NIH
Outside Experts
Kara Lavendar Lae
(SEA)
Microbial Processes
Amy Apprill
Eastman Chemical
Shell TechWorks
Communications
Lonny Lippsett

Why WHOI?

Principal Investigator



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Anna P. Michel, AOPE

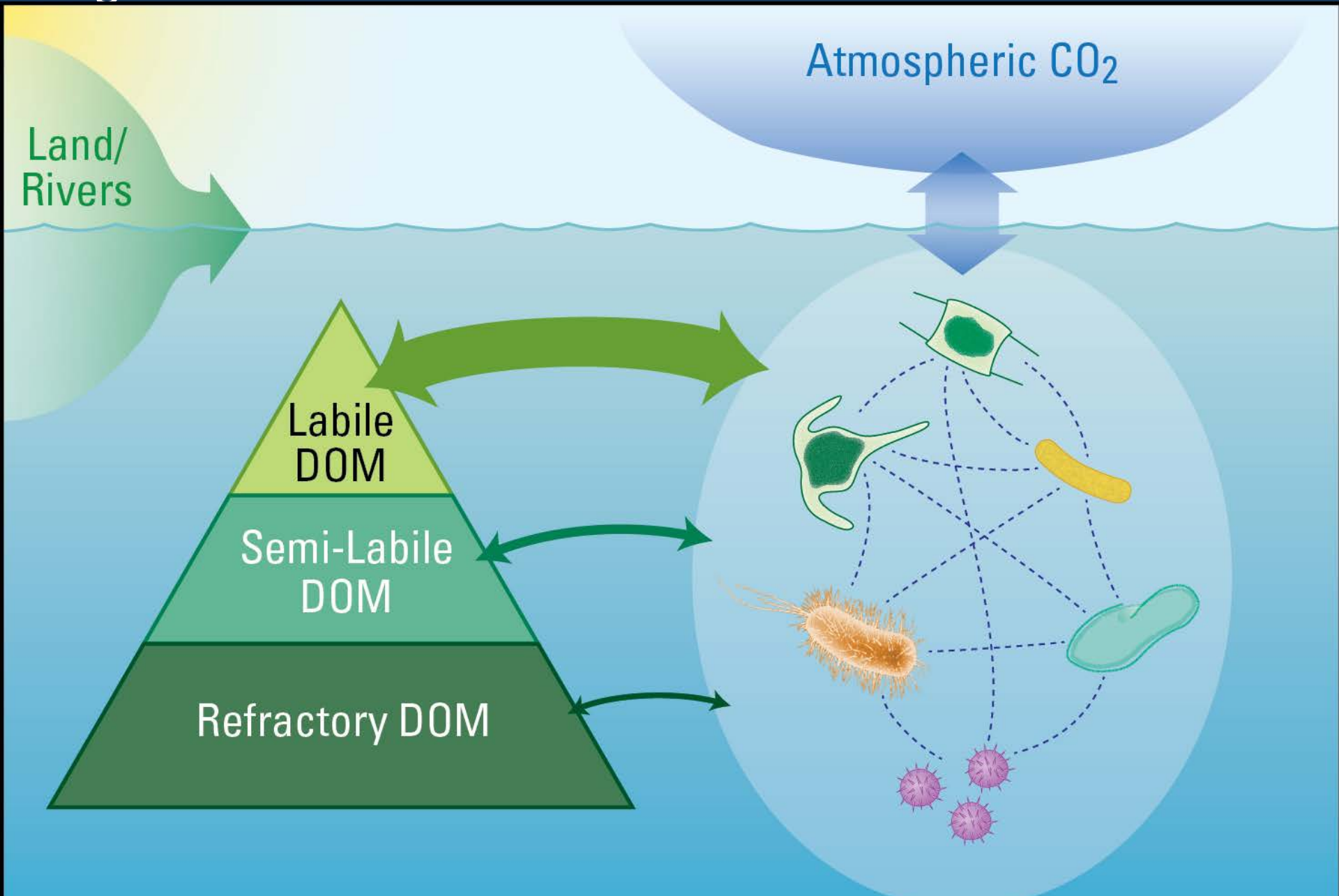
Hauke Kite-Powell, MPC

Amy Apprill, MC&G

LETS TREAT PLASTIC LIKE ANOTHER FRACTION OF THE GLOBAL CARBON CYCLE

Chris Reddy
Dept. Marine Chem. And Geochem.

Plastics are just another term in the carbon continuum and budget



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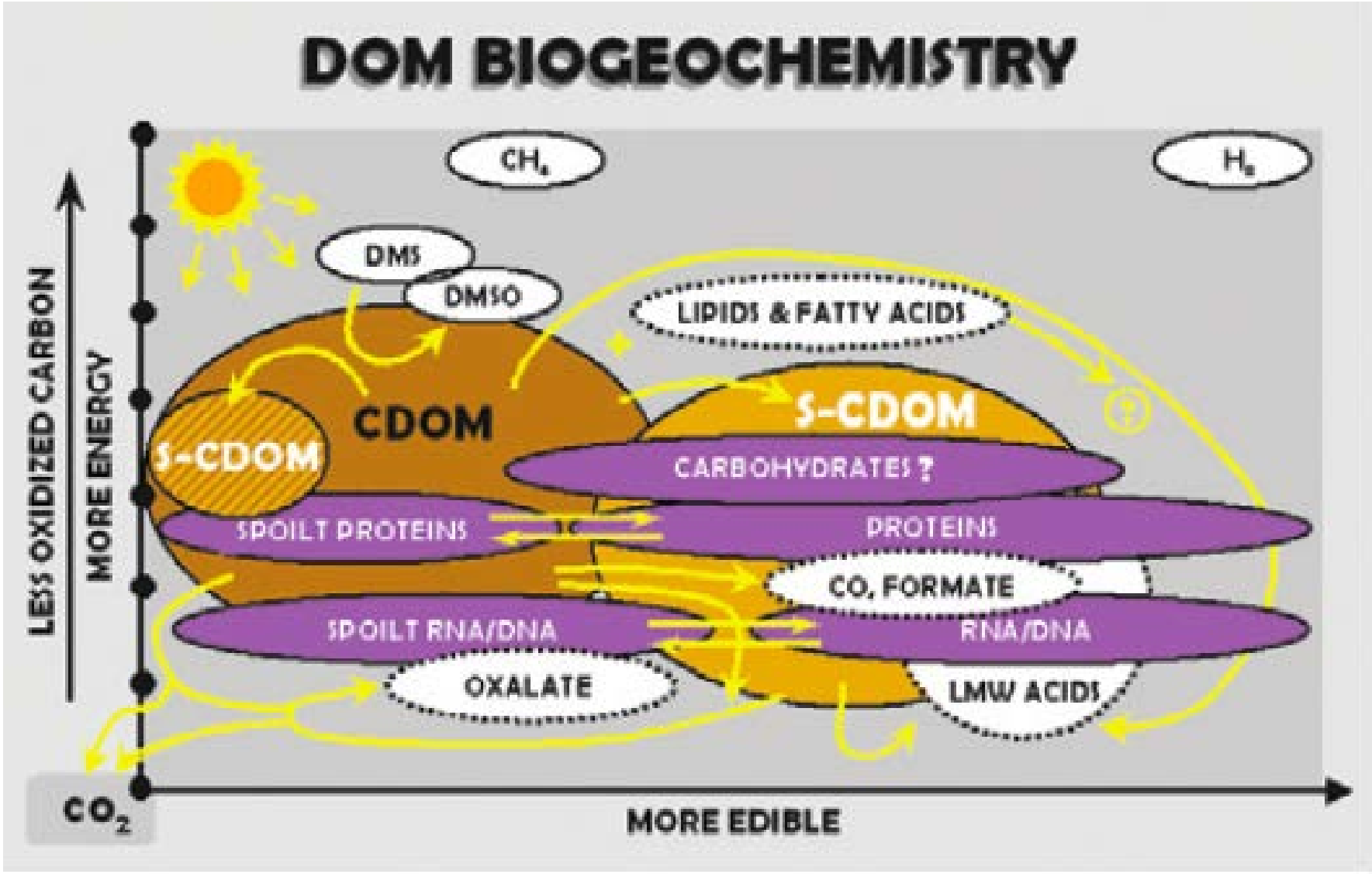
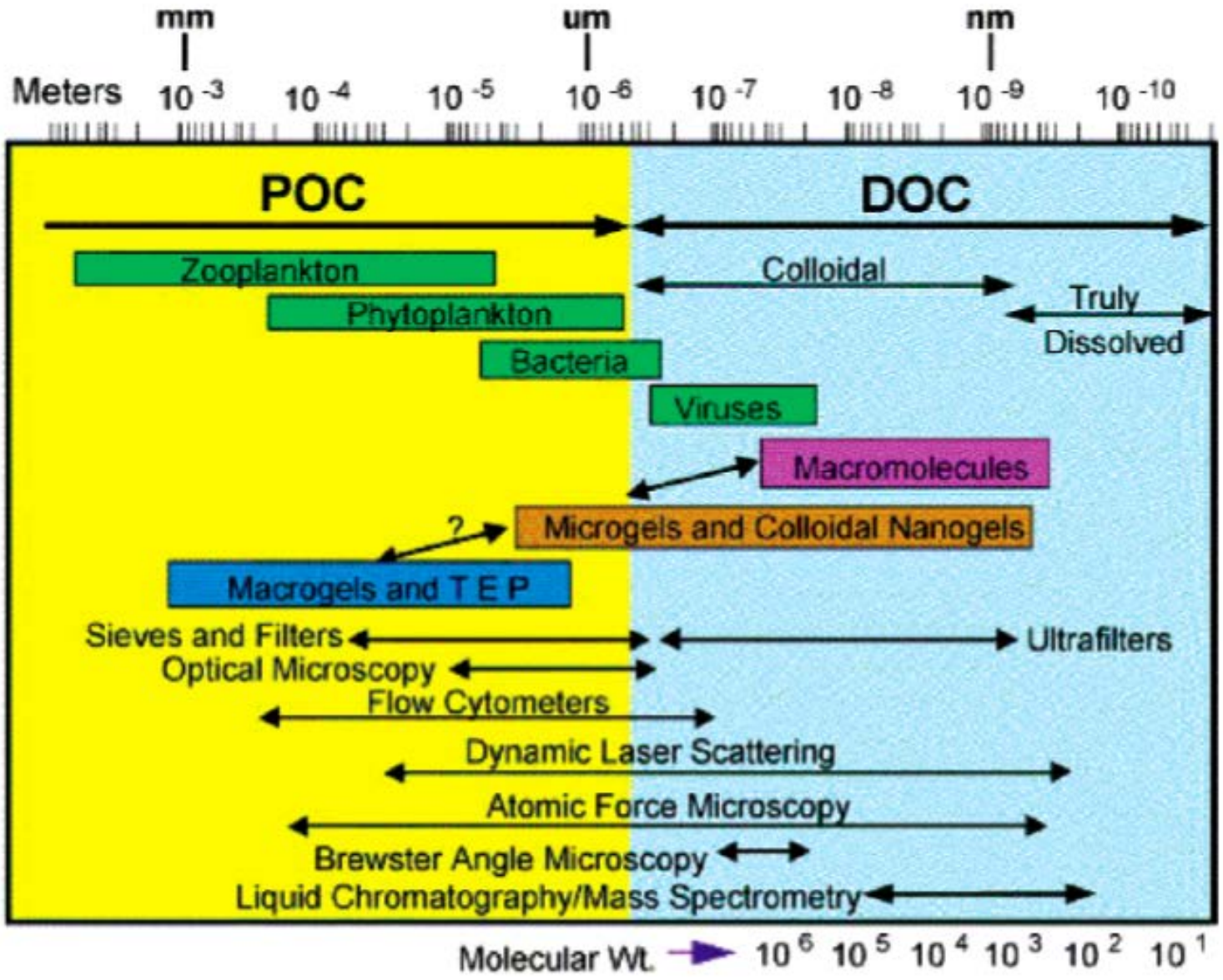
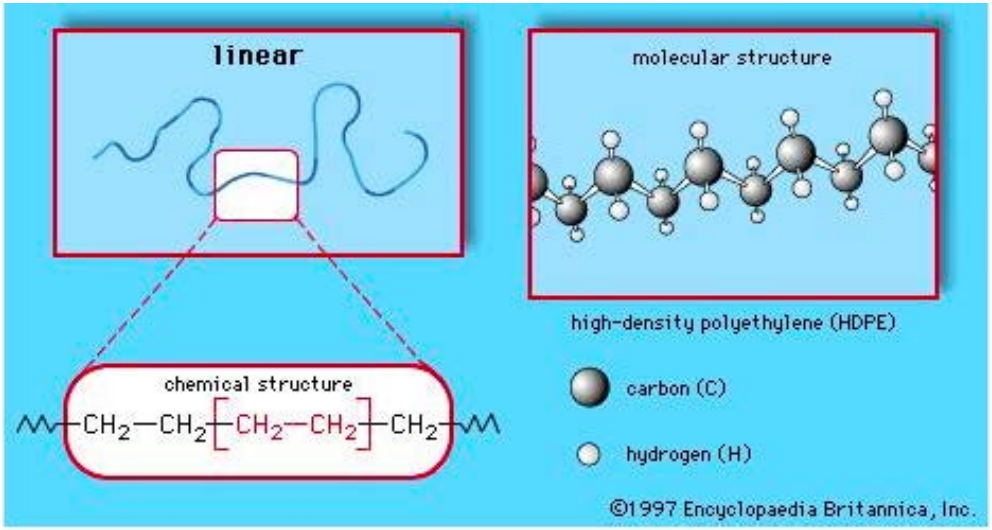


Plastics are just another term in the carbon continuum and budget

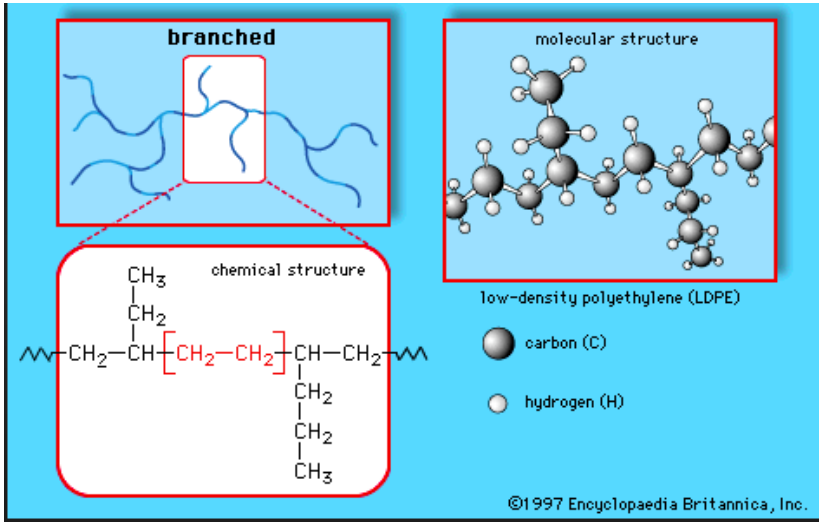


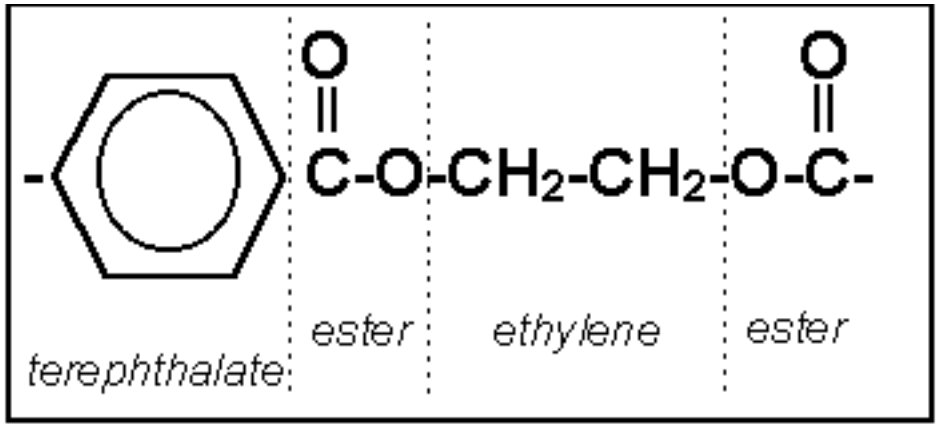
Plastics have different structures.

High density polyethylene



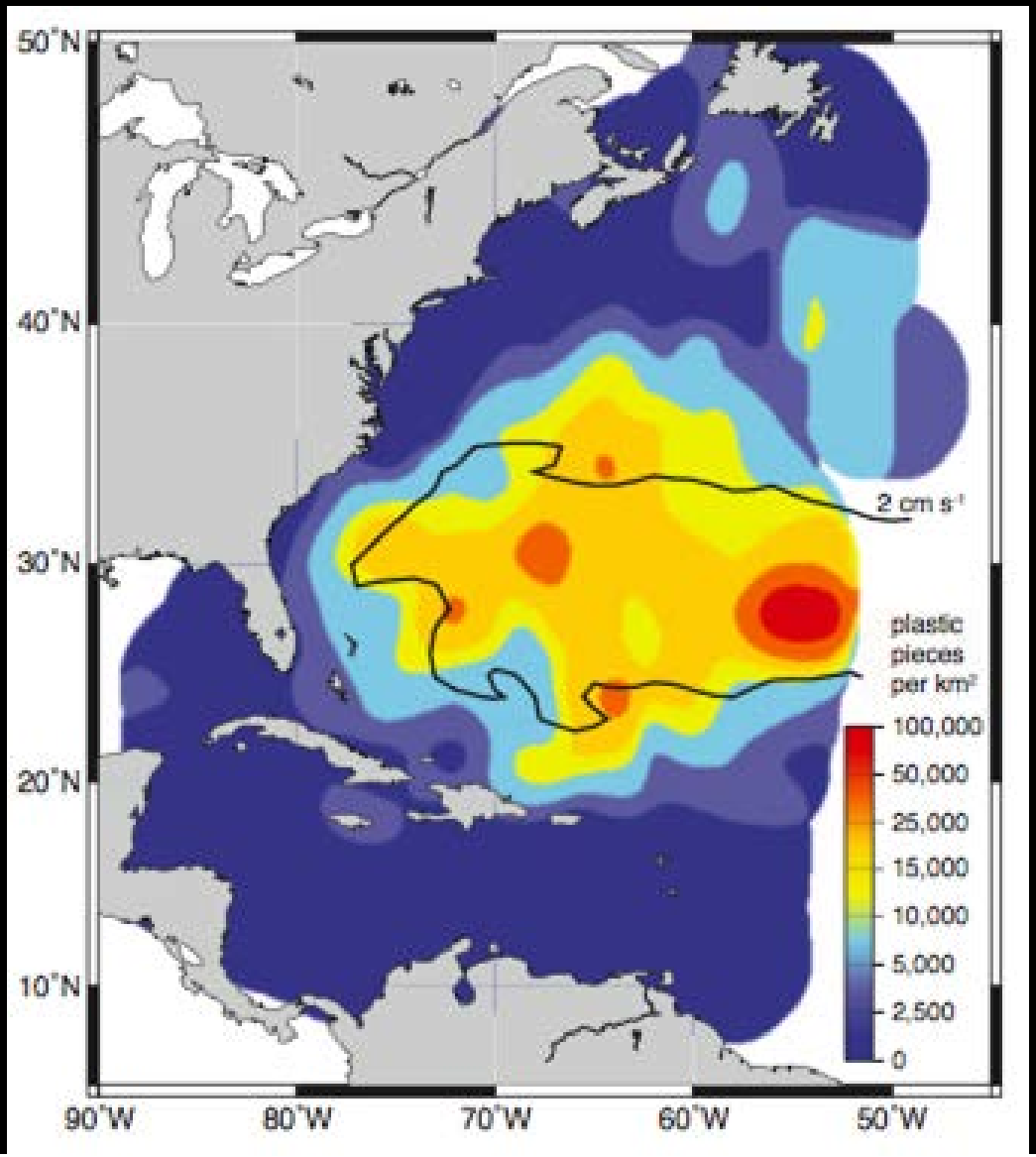
Low density polyethylene

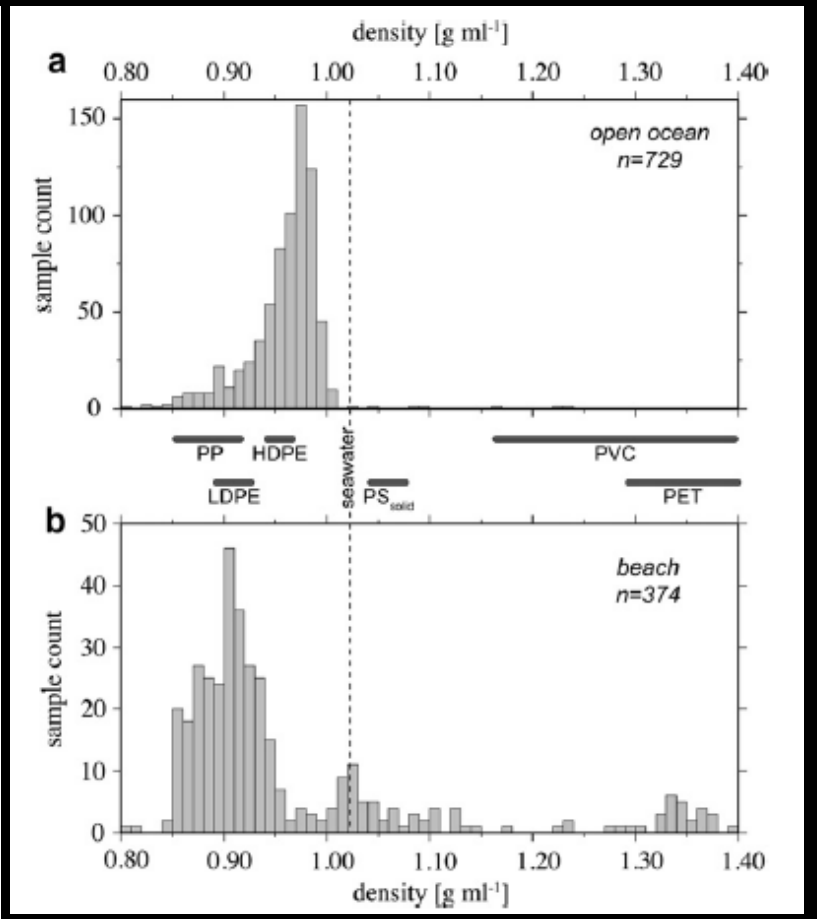




Polyethylene terephthalate

Where is PETE?



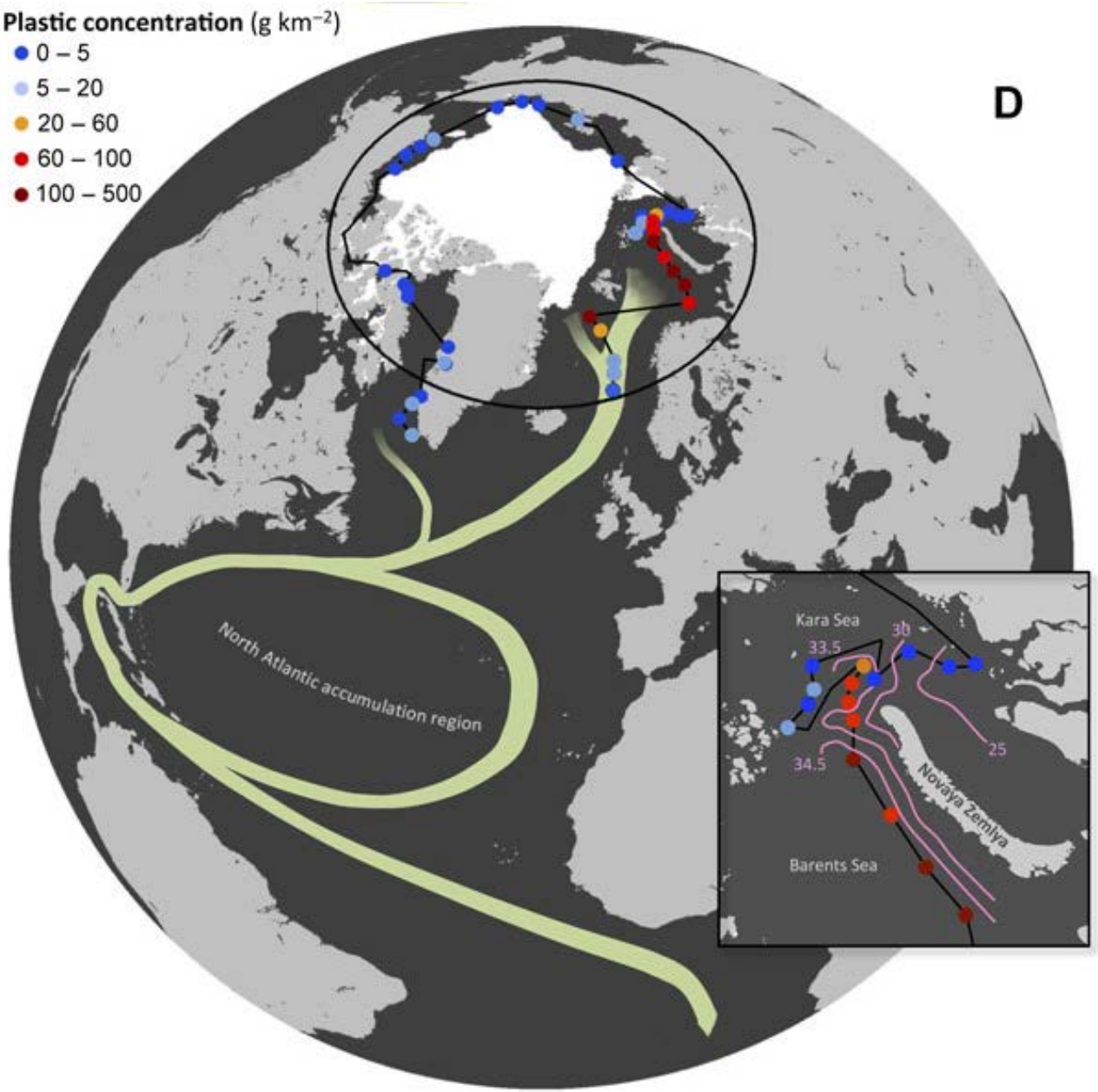


CAN MICROPLASTICS CONSTRAIN OCEAN MIXING AND CIRCULATION?

Jake Gebbie
Associate Scientist, Physical Oceanography

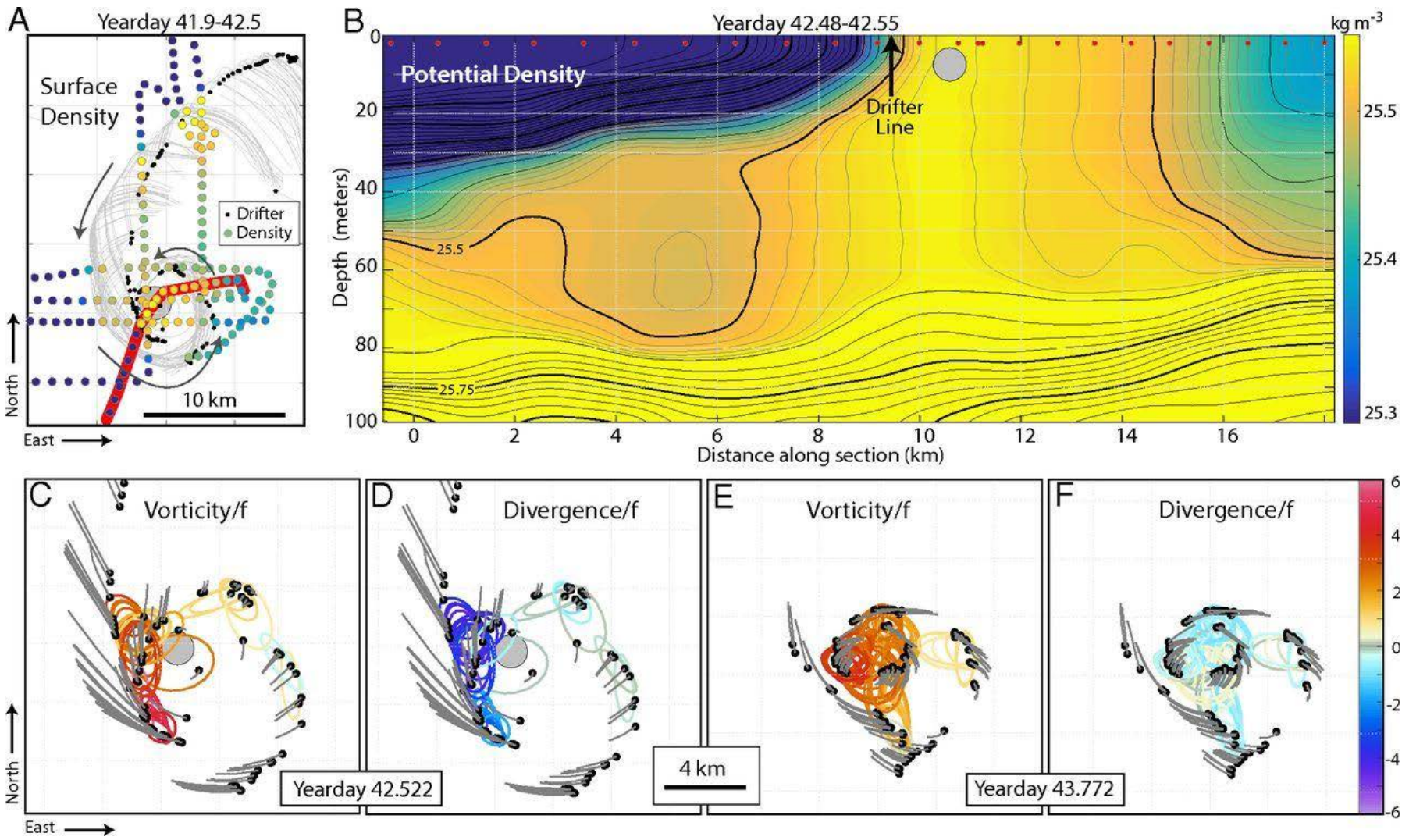
Woods Hole Oceanographic Institution

Microplastics: Ocean stirring and mixing at all lengthscales



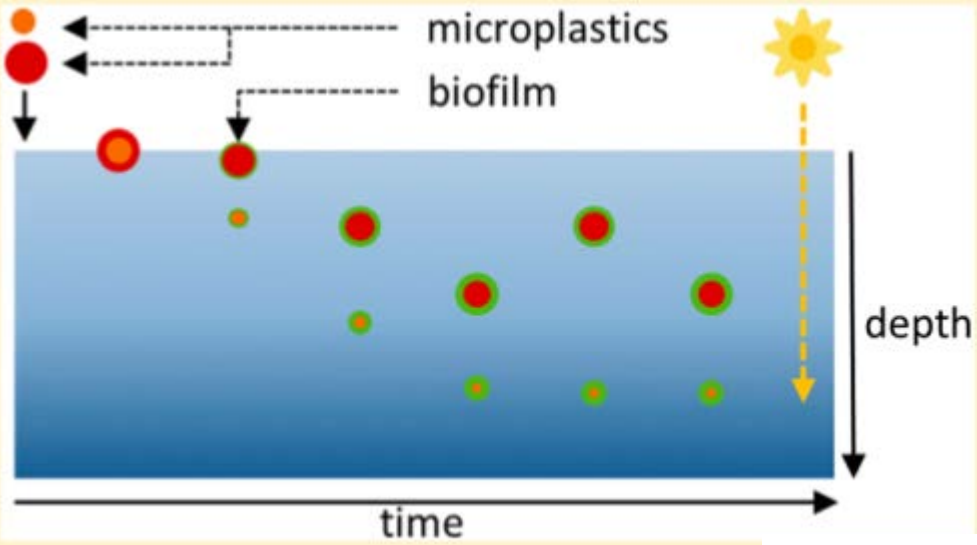
Cozar et al. 2017
Science Advances

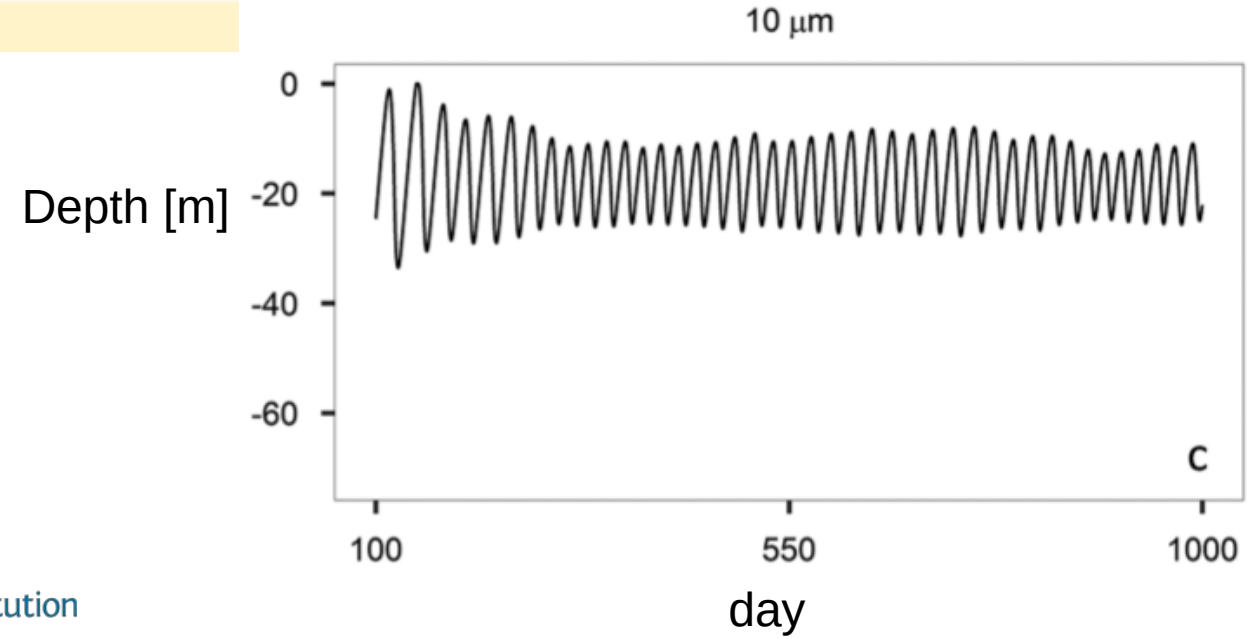
Microplastics: Submesoscale stirring and mixing



Eric A. D'Asaro et al. PNAS doi:10.1073/pnas.1718453115

Microplastics: Novel water column constraints





Kooi et al., 2017, *Env. Sci. Tech.*

Microplastics: constraining ocean mixing and circulation

- Using microplastics as a tracer has not really been done
  - If we can identify distribution, rates of breakdown, possible source locations, can we back out advection and mixing across multiple scales?
  - Same processes that concentrate plankton – so can extend into pure biological aspects also
- Source regions often rivers/coasts: so microplastics connects rivers to open oceans
- Will require multiple scales of modeling, from microscale to mesoscale to basin scale

NEED FOR ADVANCED TECHNOLOGY

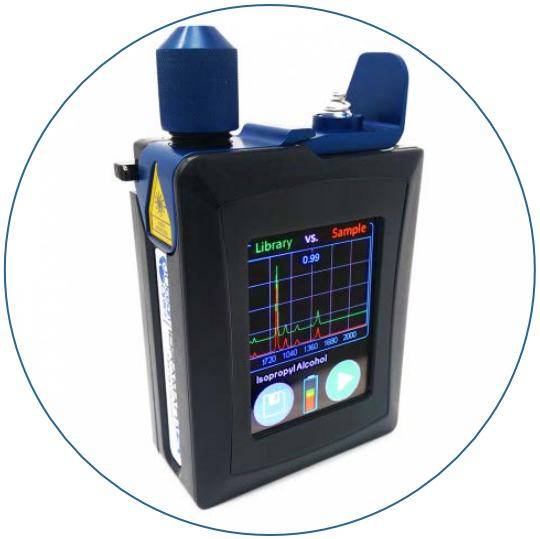
Anna Michel
Associate Scientist, Applied Ocean Physics & Engineering

Woods Hole Oceanographic Institution

Need for Advanced Technology

- Currently we “hand pick” for microplastics
- Can we develop sensors to rapidly identify plastics?
  - Ship flow through systems
  - Submersible systems
  - Sediment analysis
- Challenges:
  - Large water volume
  - Colored plastics
  - Proprietary additives

Advanced Optical Sensing Systems



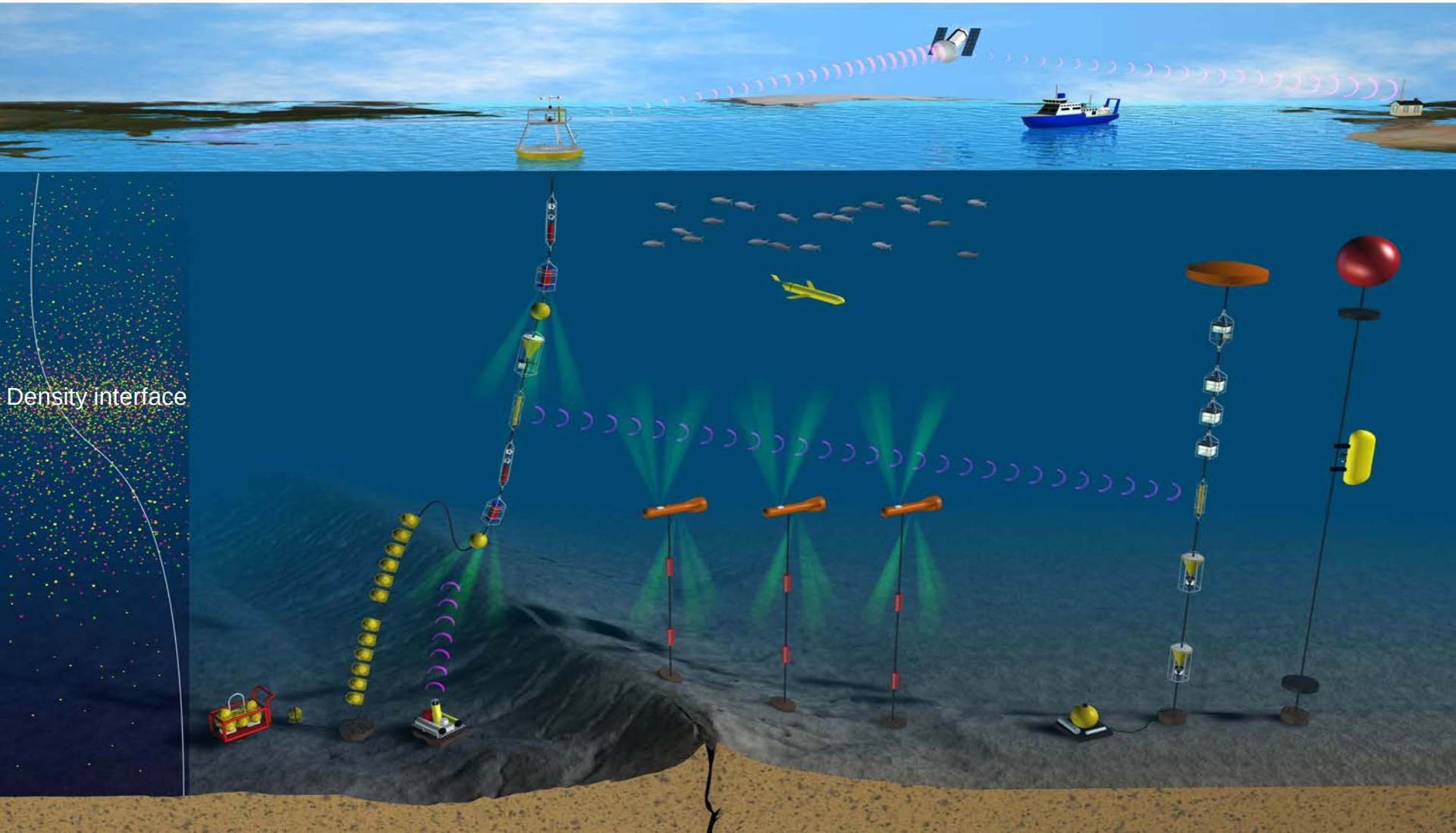
Raman Spectroscopy

Laser Induced Breakdown Spectroscopy

Infrared Sensing (FTIR, NIR, MIR)

???

We need to sample large volumes of water over extended periods of time



APPRILL LAB - MICROPLASTICS

Shavonna Bent

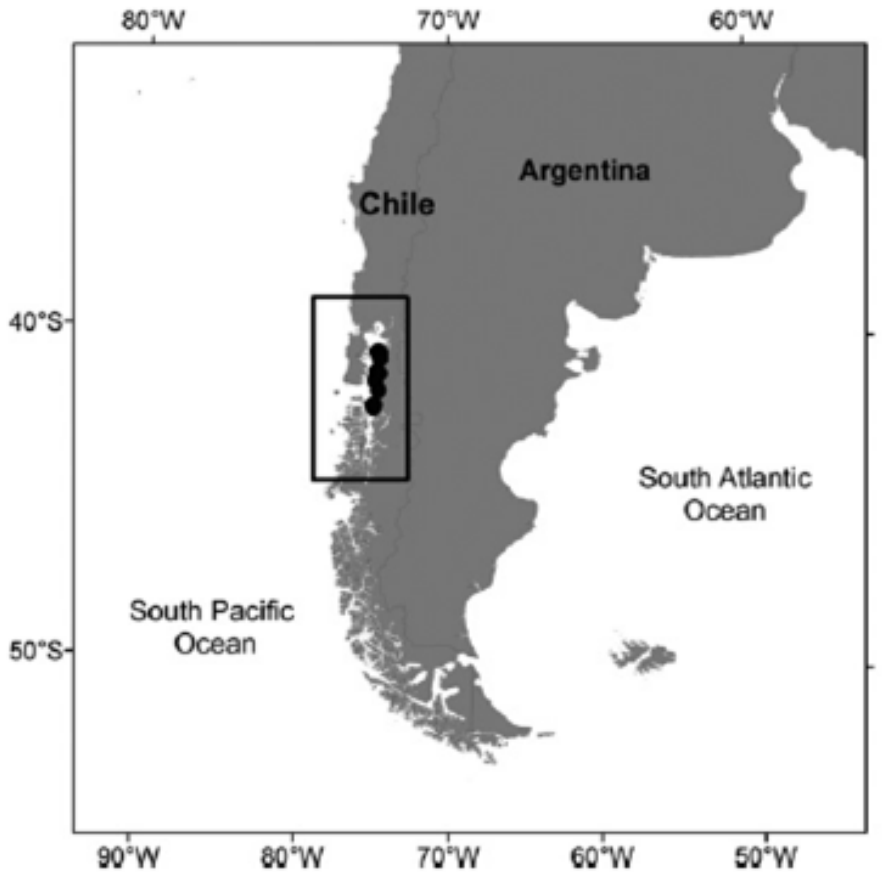
WHOI Guest Student

Microbes and microplastics

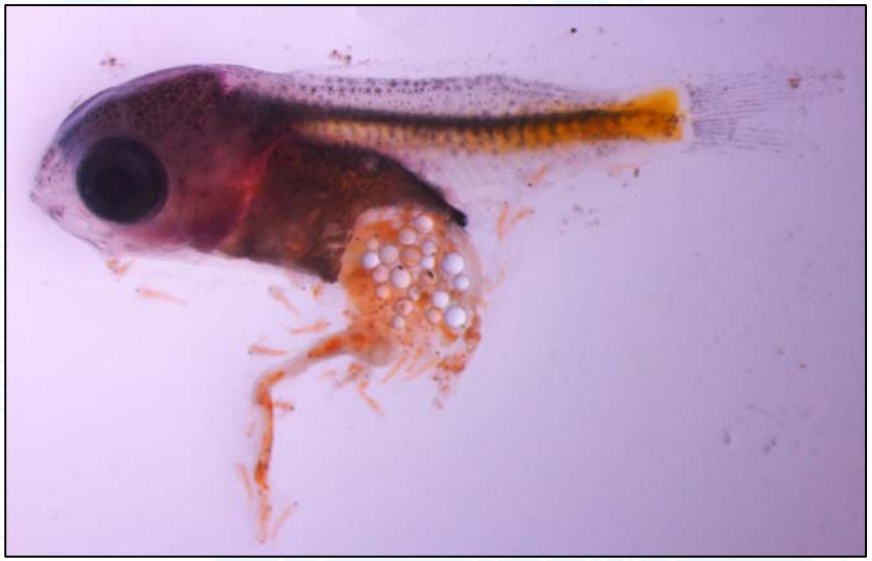
- Currently no microplastics research in Apprill lab
- Lab examines microbiomes of sensitive animals and ecosystems of the ocean (coral reefs, large whales)
- Strong emphasis on field campaigns and experiments
- Can leverage current tools and analysis to examine microbial community growth, succession and degradation of microplastics:
  - Who's there
  - What are they doing (functional genes)
  - How are communities organized (imaging)
  - Transfer of cells from plastics to animal hosts

Microbes and microplastics

- Interest in field microplastics project in Gulf of Corcovado, Patagonia, Chile
- Important ecosystem - largest southern feeding grounds for blue whales
- Significant plastic debris from aquaculture
- Connection with locals



FUNDACIÓN MERI



ECOLOGICAL AND HUMAN HEALTH IMPACTS OF MICROPLASTICS

Mark Hahn
Biology Dept. and Woods Hole Center for Oceans & Human Health

Are Microplastics a Health Risk?

Lancet Planetary Health

Editorial

Microplastics and human health—an urgent problem

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Microplastics come from many sources: synthetic clothing fibres, dust from tyres, road paints, and the breakdown of larger items. Orb Media's recent investigation has brought the issue of microplastics in the environment into sharp focus. The analysis of tap water samples from around the world found that a high proportion of drinking water is contaminated with microscopic fragments of plastic (83% of samples collected worldwide, but up to 94% in the USA). Microplastic contamination seems more widespread than we perhaps knew, and they are regularly being ingested by people worldwide. Most concerning is how little is known about the effects of microplastic consumption on human health.

are in place in parts of the USA and Europe. However, progress on this front has been slow and piecemeal.

To speed up progress on reducing plastic waste, manufacturers of plastic could be forced to take

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Stressor Exposures Determine Risk: So, Why Do Fellow Scientists Continue To Focus on Superficial Microplastics Risk?

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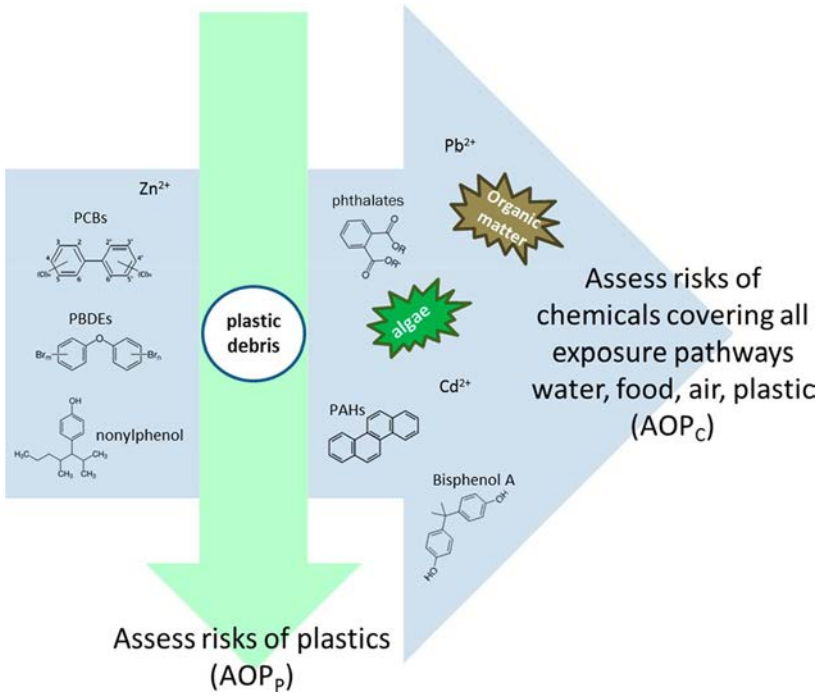
SCIENTIFIC OPINION NON-PEER REVIEWED

each with their own strengths and limitations, but no one is sufficient. High numbers of false positive and false negatives have been identified, depending on the methods used, which makes it impossible to compare microplastic studies that may be overestimating or under-estimating exposures.[2,11,12] Nevertheless, the great majority of studies are stating the highest concentrations typically found are in the range of less than 1 to 10s of particles per meter squared (i.e., 1000 L).[2,3,7,8,13,14] These concentrations are several orders of magnitude lower than virtually all laboratory studies and organisms feeding on this sized range will find orders of magnitude more plankton available for ingesting. Also, many of the studies measure concentrations based on mass (e.g., mg/L) or surface area (number/km^2), and these units add large uncertainty to actual organism exposures to these diverse particles.[3]

Woods Hole Oceanographic Ins

Multiple Potential Impacts of consumed MPs



Koelmans et al. (2017) *ES&T*

- Obstruction
- Tissue reaction (inflammation, ox stress)
- Leaching of additives (phthalates, BPA)
- Leaching of contaminants (PCBs, PBDEs, PAHs)
- Vector for pathogens (*Vibrio* spp.)
- Effect on gut microbiome

Microplastics Risk Assessment

Aquatic animal model systems (BO, COHH)

MP distribution and fate (PO and CO)

Hazard Assessment

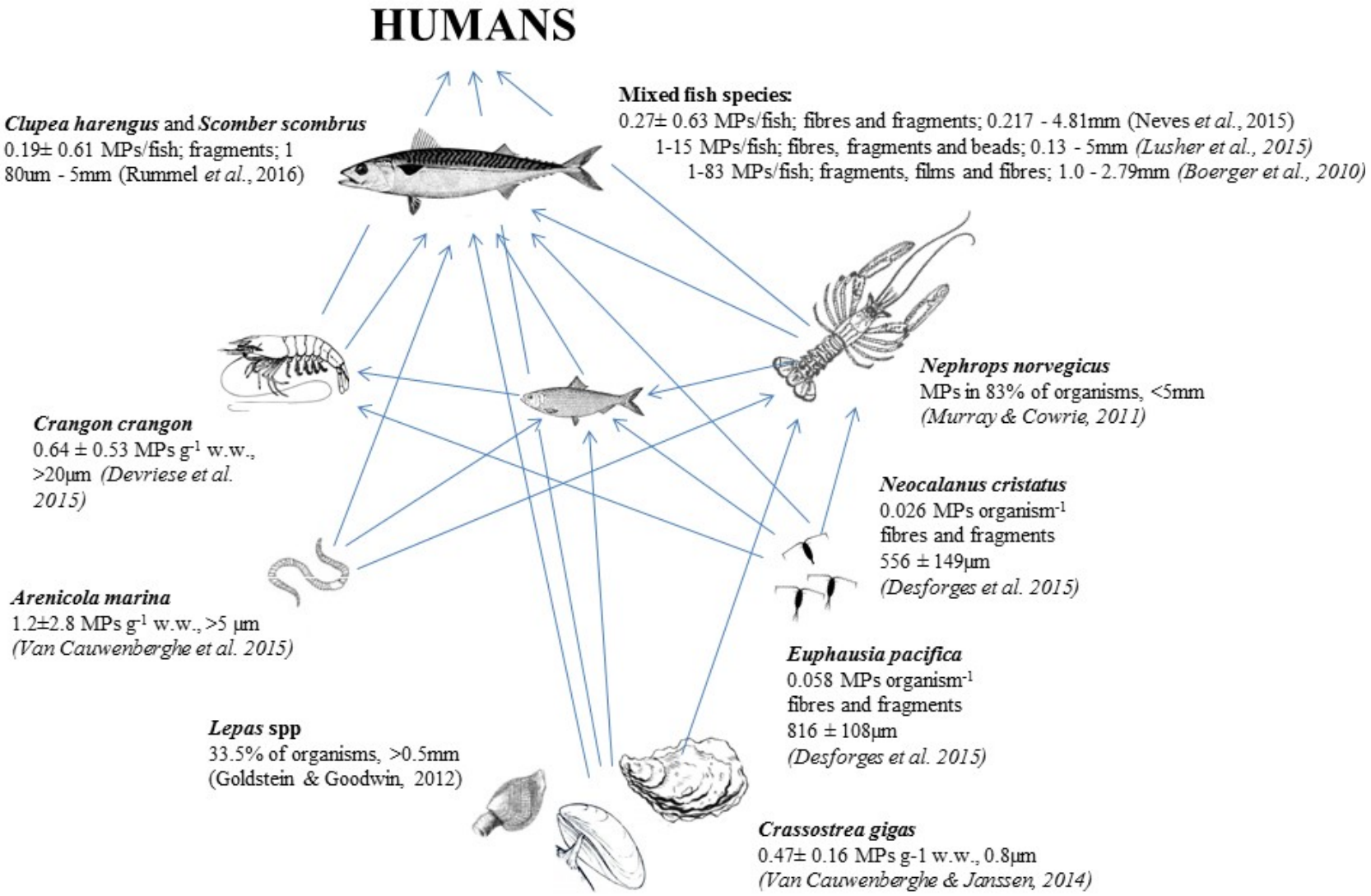
- Effects
- Mechanisms
- Dose-response relationships

Exposure Assessment

- Sources & Routes
- Amounts
- Types & Sizes

Human Health Risk Assessment
Ecological Risk Assessment

Human Exposure through Marine Food Webs



Soucre: Carbery et al. 2018

MPs and Human Health:
What we know…What we don't know

We know:

- Microplastics occur in seafood (fish, shellfish)
- Microplastics can carry toxic chemicals (contaminants, additives)
- Microplastic-adsorbed chemicals can be transferred to animals

We don't know:

- Are consumed microplastics taken up by humans?
- Relative contribution of seafood vs other MP exposures?
- Fate of consumed MPs in humans?
- Adverse effects in humans from consuming microplastics?
- Bioavailability of MP-adsorbed contaminants to humans?
- Relative contribution of MP vs other sources of toxic chemicals?
- Influence of size, shape, polymer, etc. on all of the above

Policy Questions

Hauke Kite-Powell

Marine Micro-Plastics Policy Questions

- Risks/costs associated with human health effects
- Role in carbon cycling in the ocean
  - Implications for C uptake and climate
- Cost-effective ways to reduce MP risks
  - Point source inputs (wastewater) of MPs
  - Non-point plastic waste input

Human Health Risk from Marine Micro-Plastics

MPs bio-accumulate in the marine food chain, and can be ingested by humans via seafood

- Higher risk of ingestion via seafood such as shellfish, where the gut is consumed

Potential human health risks include:

- Exposure to plastics additives such as Bisphenol A (BPA), a synthetic estrogen, leaching from microparticles
- Exposure to other environmental pollutants sorbed to the surface of microparticles
- Physical effects of large quantities of microparticles in the human gut or other organs

Research synergies with ongoing work on health effects from plastic food packaging and nano-medicine

What's Next?

- Questions?
- 15 minute break
- Slides from the audience
- Discussion on how we can influence the field of MP research in oceanography.

Critical Challenges

1. Policy makers want to reduce flux of plastics to ocean
   but
2. Identification of polymers and their additives is difficult for large volumes of water

   Raman, FTIR, Pyrolysis GCMS
   What is acceptable cut off accuracy? 75-90%

3. Establish Raman and FTIR libraries

4. Can not identify origin (yet)

5. Impact of weathering on spectra, density, sorption

6. Nanoplastics- no information but possibly most important

7. Standardize methods for sampling, extraction, quantification

Critical Challenges, con't

- Develop new instrumentation and outline the use of autonomous vehicles needed to sample, process, and classify MPs in high volume,
- Design lab experiments to understand degradation by physical processes, UV, microbial colonization, and its impact on marine snow formation,
- Design field observational surveys at key locations to build a mass budget of MPs in the ocean,
- Develop a robust set of standards for improved inter-laboratory collaboration on a global level,
- Develop a suite of numerical models to provide predictive indices of transport and fate of MPs, and
- Assess the impacts of MPs on the health of humans and marine ecosystems through both laboratory and field experimentation, epigenetics, and molecular ecology.