AuSRoS

Australian School of Robotic Systems

THE UNIVERSITY OF SYDNEY

Australian Centre for Field Robotics

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Postdoctoral Investigator

&

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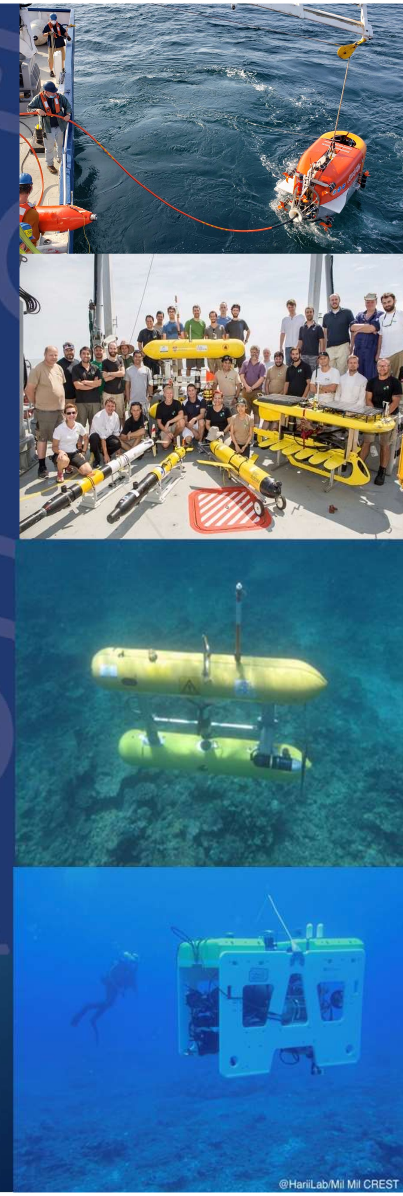
Senior Technical Officer

MARINE ROBOTICS SYSTEMS



We Depend on The Ocean

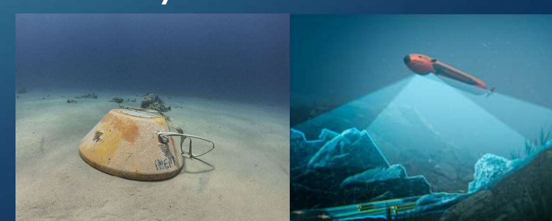
- Contains majority of world's biomass
- > 80% of world's diverse plant and animal species
- Global consumption of aquatic sourced food is increasing 3% per year
- Increasing offshore industry and resource harvesting

Global Food Production

Offshore Industries

Pharmacology & Medicine

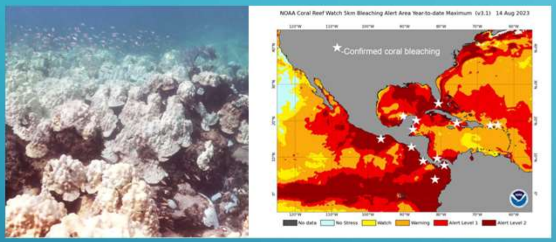
Military & Defense



The Ocean Depends on Us

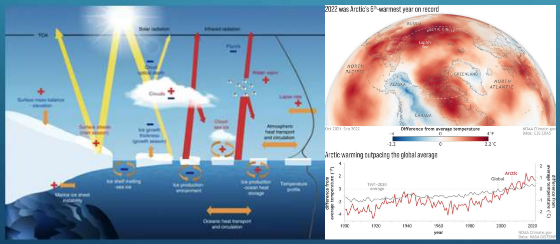
- High CO_2 levels lead to ocean warming and acidification, toxic to corals
- Global shipping is a likely catalyst for disease and invasive species spread
- Polar ice dynamics tightly coupled with ocean circulation and global climate

Warming & Acidification

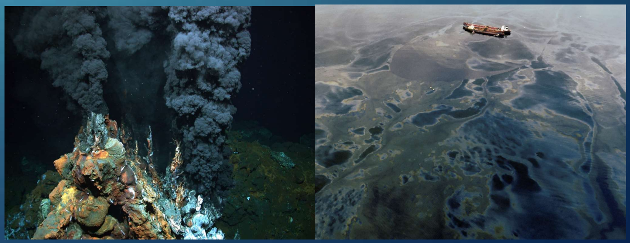


Disease & Invasive Species Spread

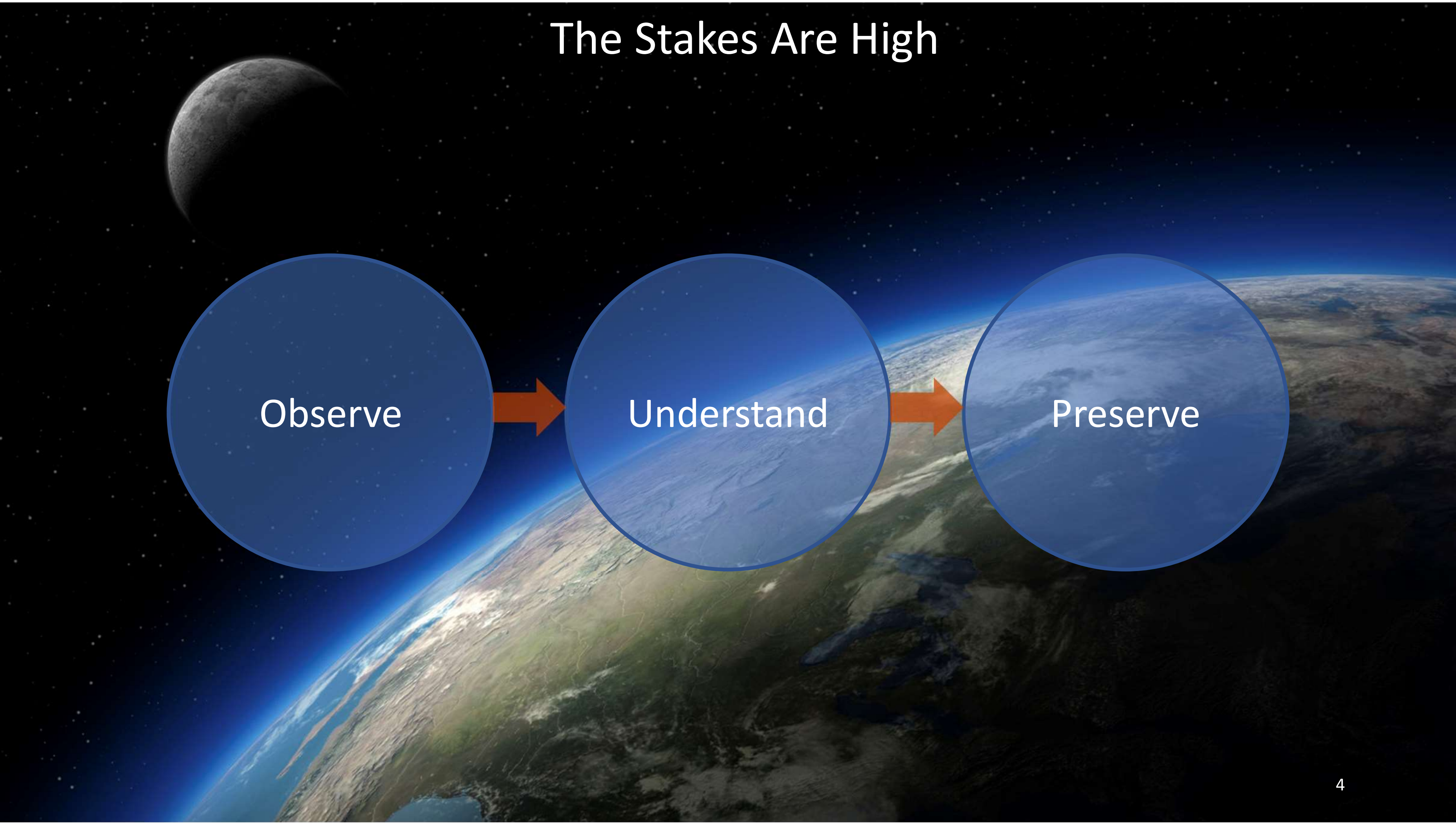
Melting Polar Ice

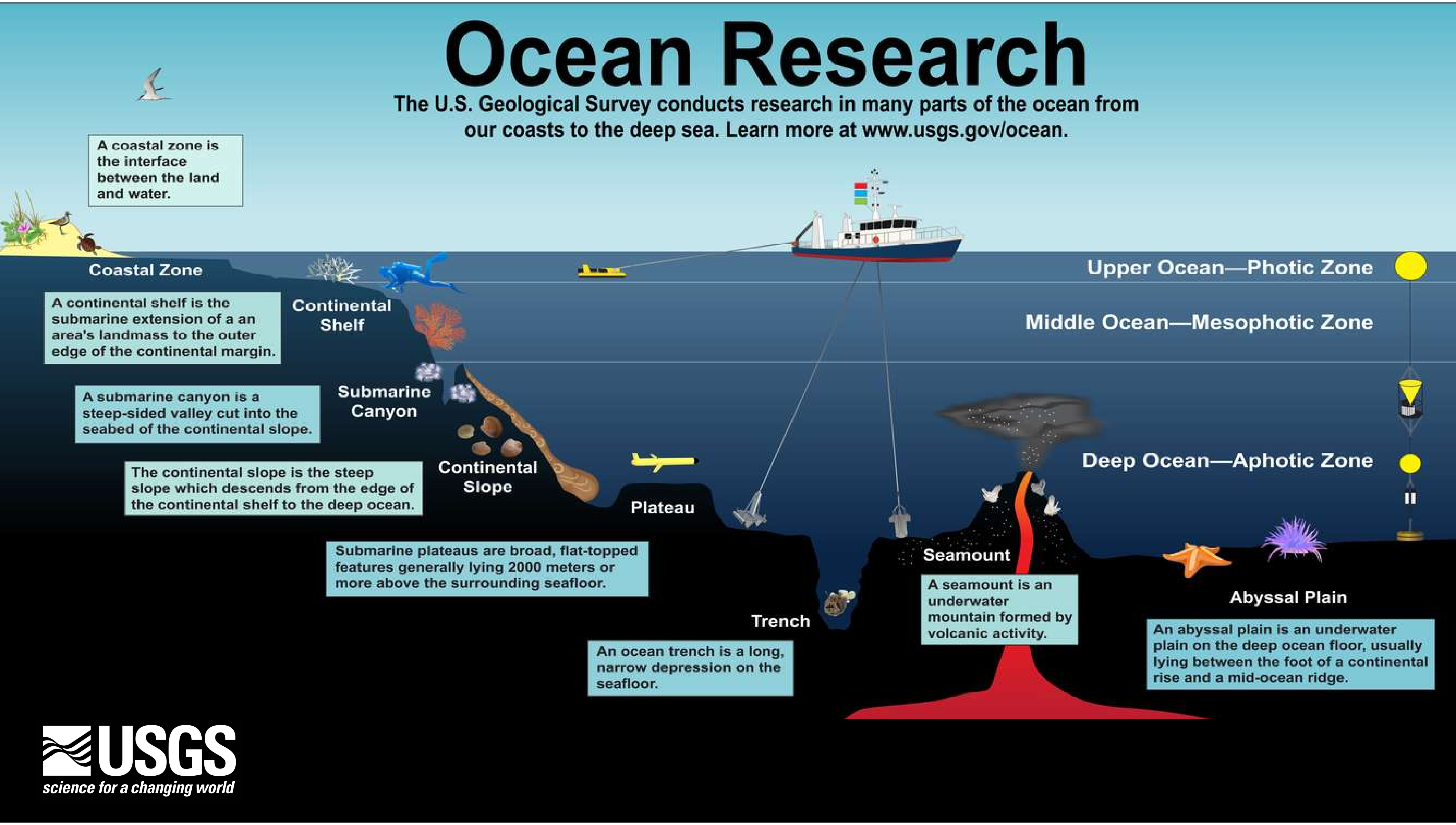


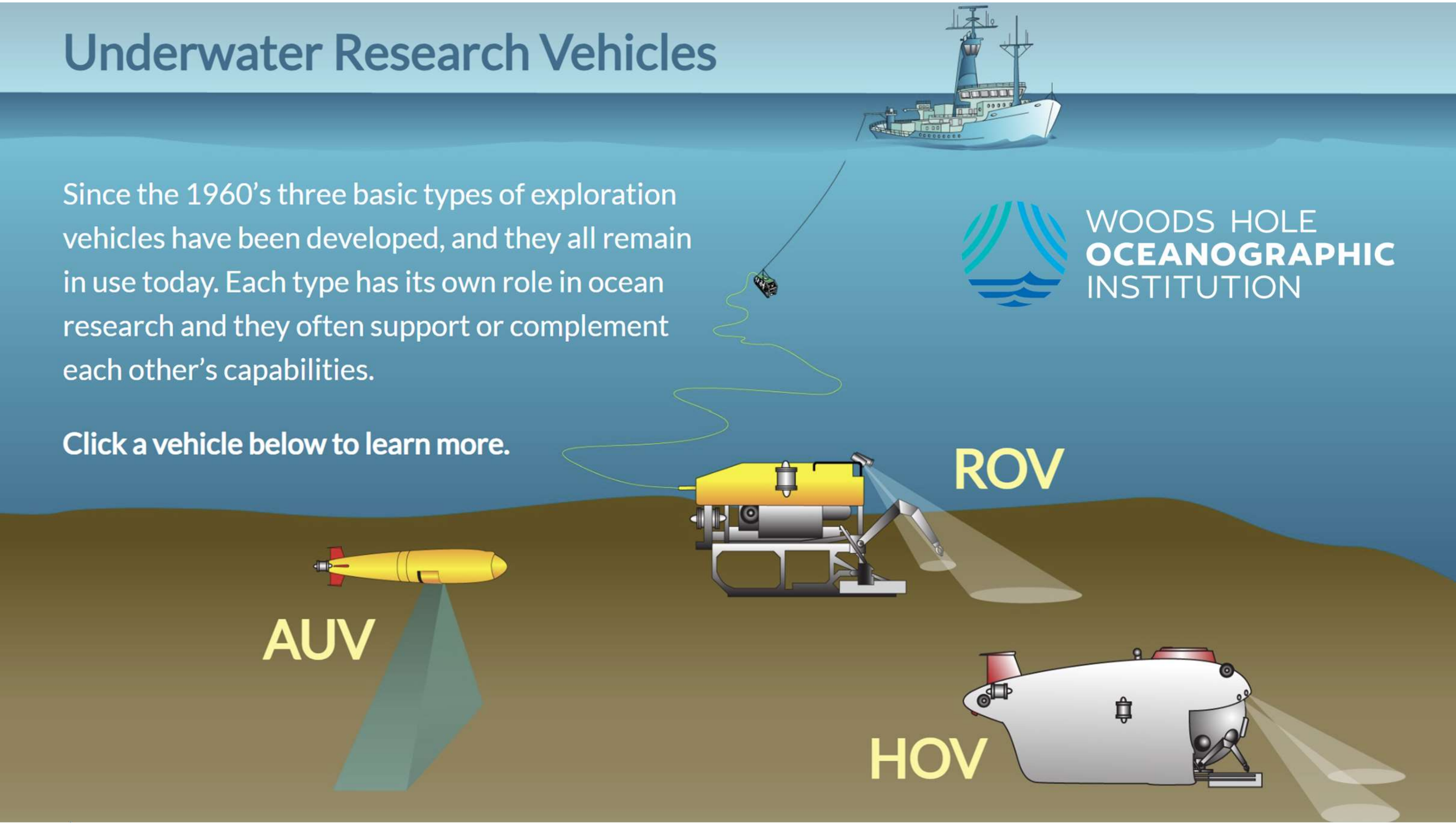
Damage to Ecosystems



The Stakes Are High

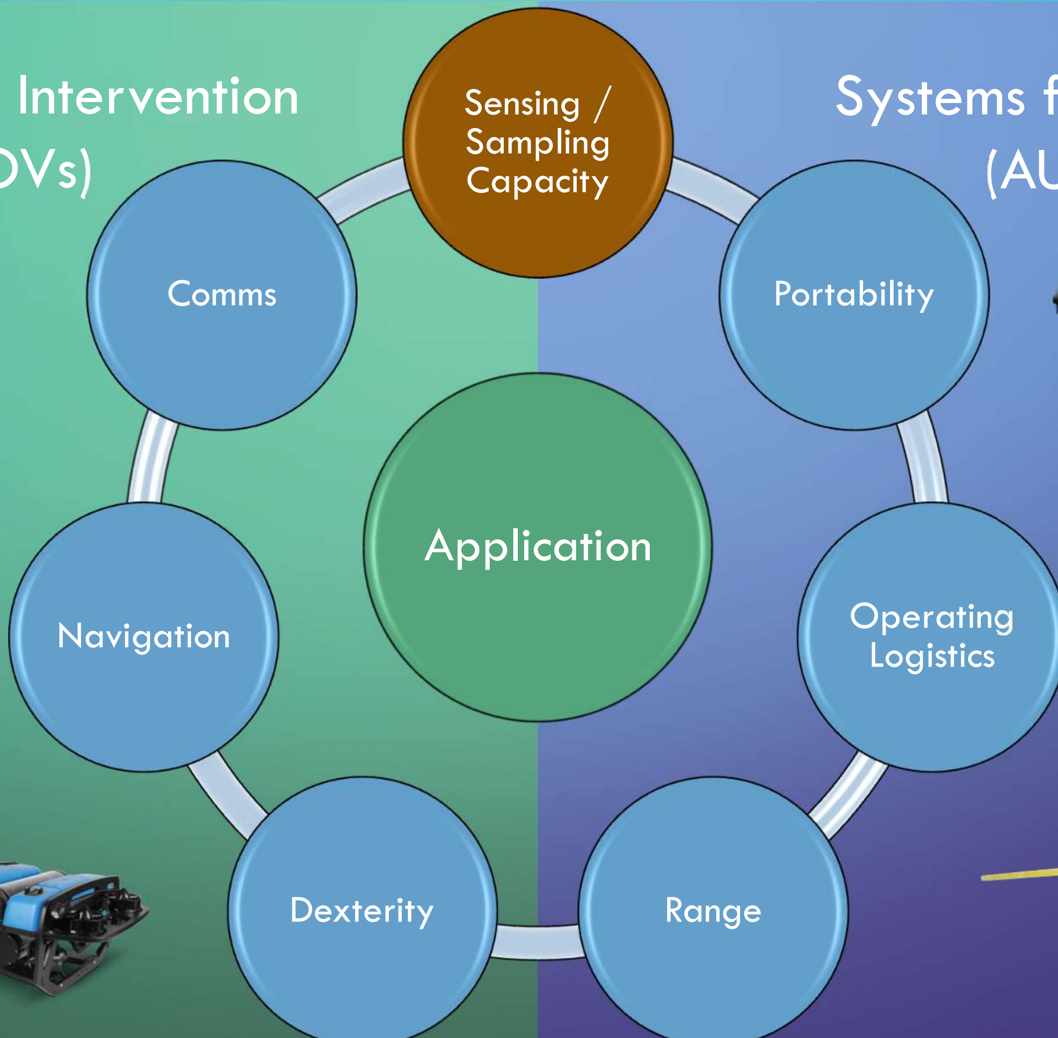



Ocean Research
The U.S. Geological Survey conducts research in many parts of the ocean from our coasts to the deep sea. Learn more at www.usgs.gov/ocean.
A coastal zone is the interface between the land and water.
Coastal Zone
Continental Shelf
A continental shelf is the submarine extension of a an area's landmass to the outer edge of the continental margin.
Upper Ocean—Photic Zone
Middle Ocean—Mesophotic Zone
Submarine Canyon
A submarine canyon is a steep-sided valley cut into the seabed of the continental slope.
Continental Slope
The continental slope is the steep slope which descends from the edge of the continental shelf to the deep ocean.
Deep Ocean—Aphotic Zone
Plateau
Submarine plateaus are broad, flat-topped features generally lying 2000 meters or more above the surrounding seafloor.
Trench
An ocean trench is a long, narrow depression on the seafloor.
Seamount
A seamount is an underwater mountain formed by volcanic activity.
Abyssal Plain
An abyssal plain is an underwater plain on the deep ocean floor, usually lying between the foot of a continental rise and a mid-ocean ridge.
USGS
science for a changing world


Underwater Research Vehicles
Since the 1960's three basic types of exploration vehicles have been developed, and they all remain in use today. Each type has its own role in ocean research and they often support or complement each other's capabilities.
Click a vehicle below to learn more.
WOODS HOLE OCEANOGRAPHIC INSTITUTION
ROV
AUV
HOV

Underwater Vehicles Design Space

Systems for Intervention (ROVs)



Systems for Survey (AUVs)

Risks of Underwater Deployment

Environmental Disturbance

Vehicle Survivability

Mission Completion

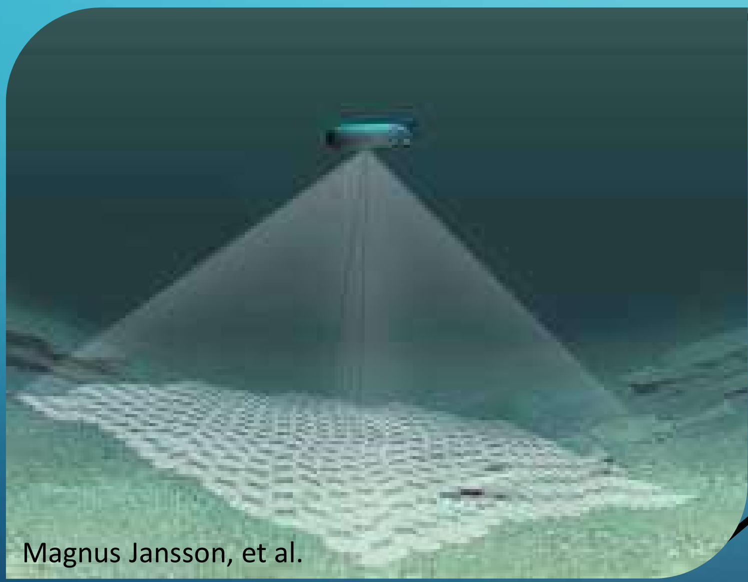
Underwater vs Terrestrial

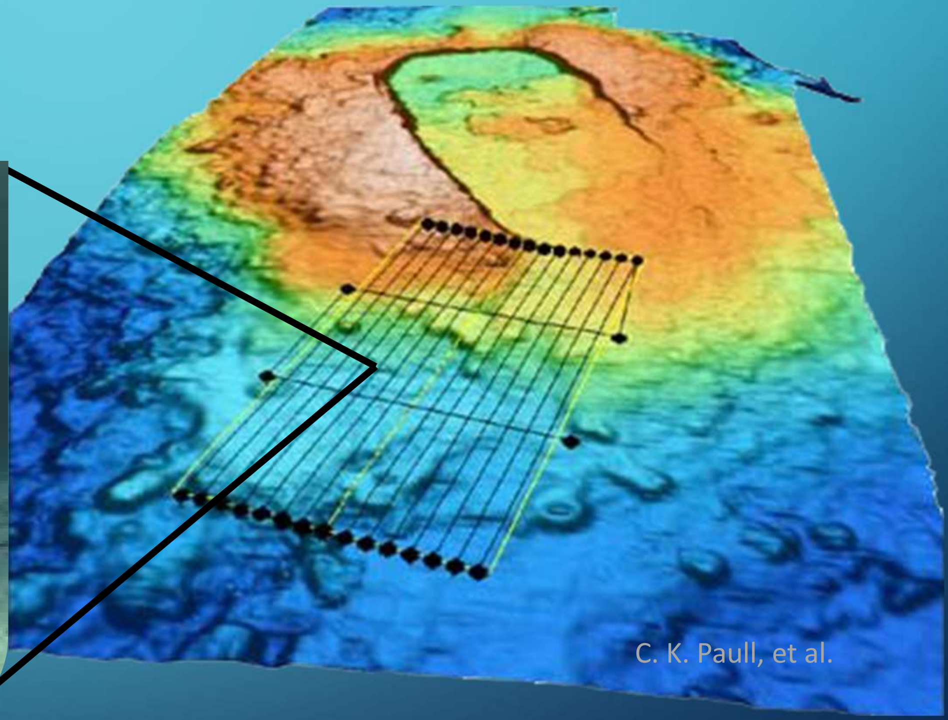
- Hardware and operations are expensive
- System observation is limited (high risk)
- Hardware is prone to failure
- Human intervention is limited

Teleoperated ROV Missions

https://www.whoi.edu/multimedia/inside-the-control-room/

Pre-Scripted AUV Missions





The Golden Rule of Underwater Field Robotics

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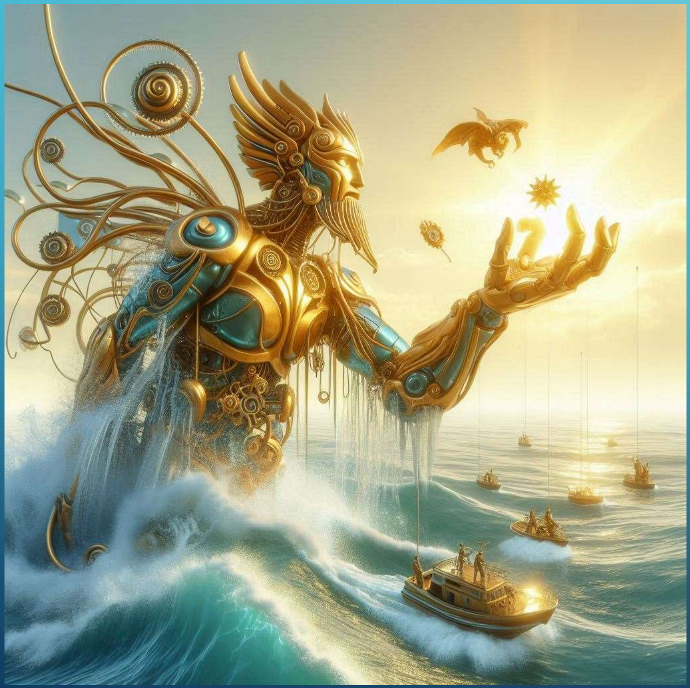
The Golden Rule of Underwater Field Robotics

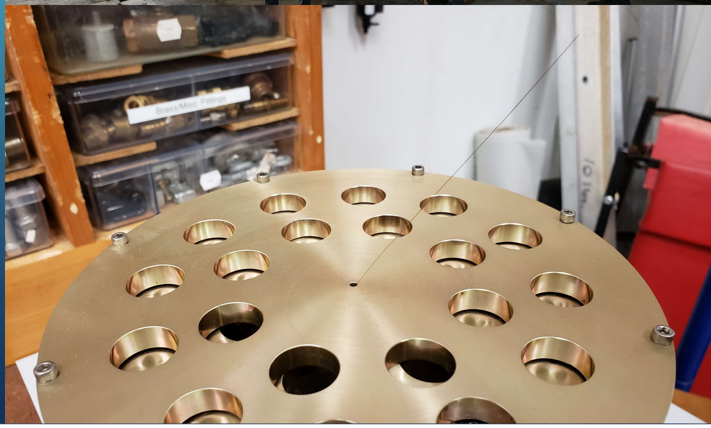
Deployments = # Recoveries



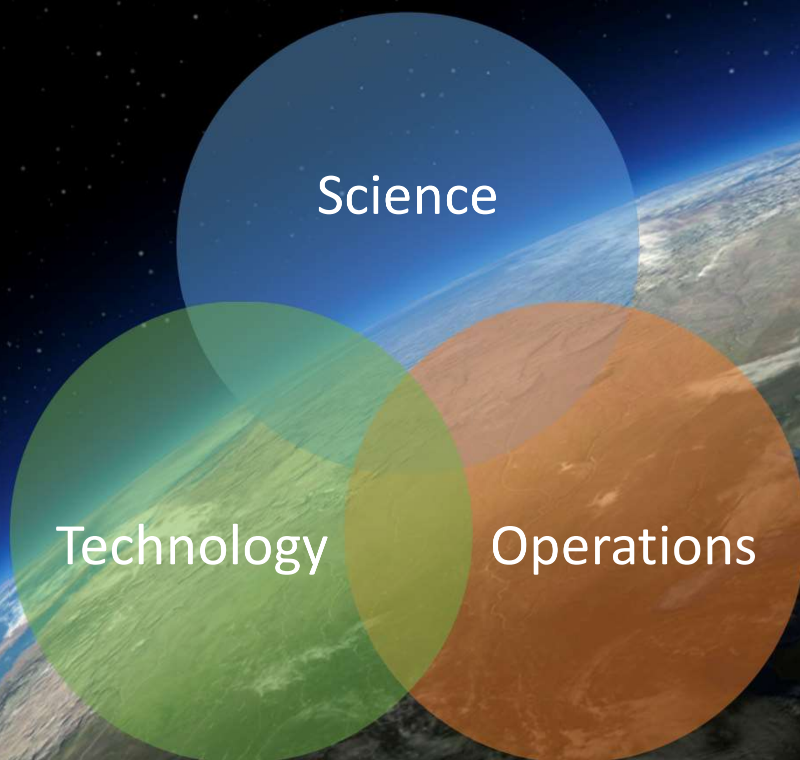
Sampling in Extreme Environments

Nereid Under Ice Hybrid ROV

- Tether is hair-thin fiber optic
- Can operate in AUV mode if tether breaks
- Tethered operation kilometers away from vessel



Planetary Science and Technology through Analog Research Program

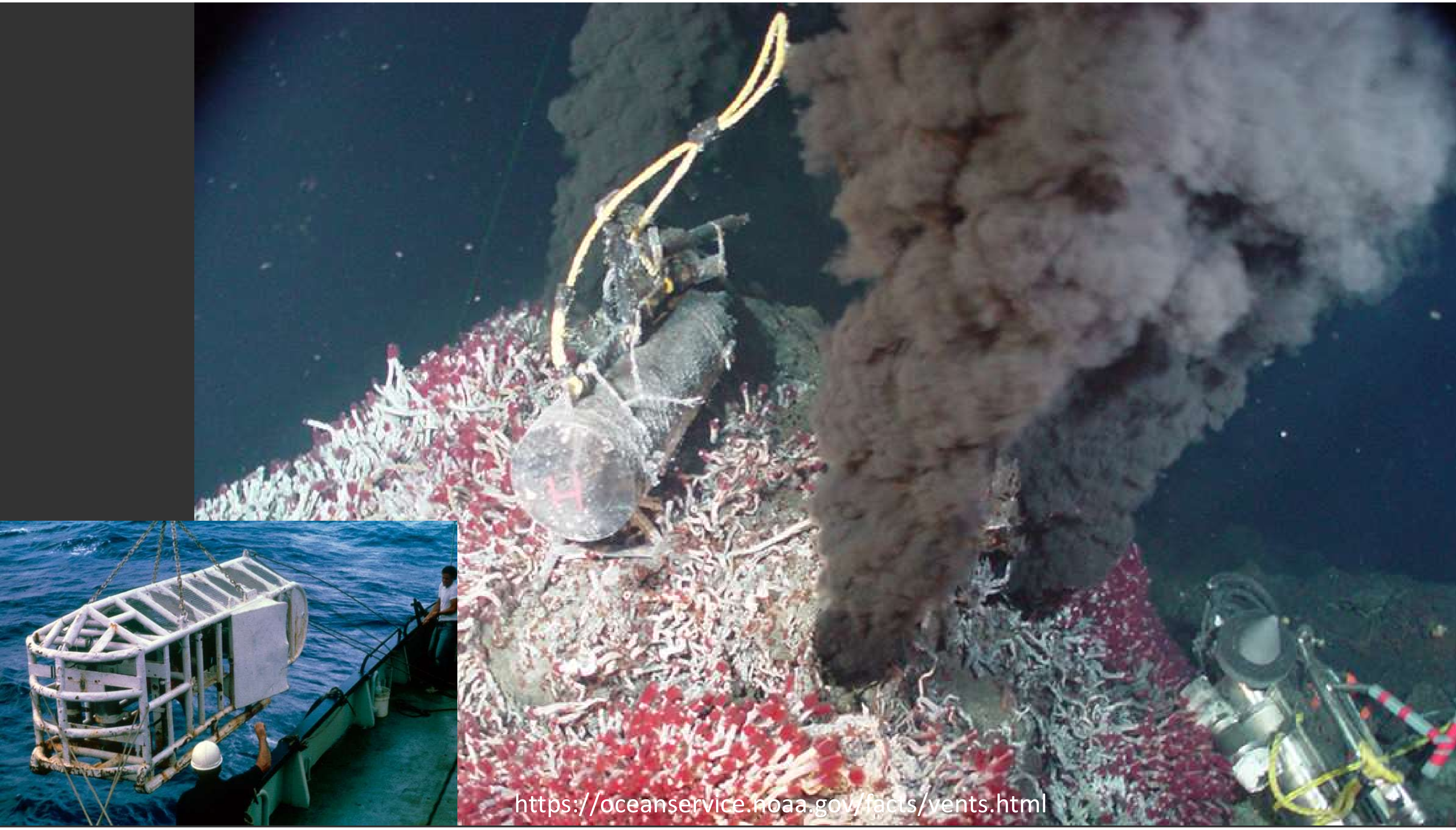


Woods Hole Oceanographic Institution 1930

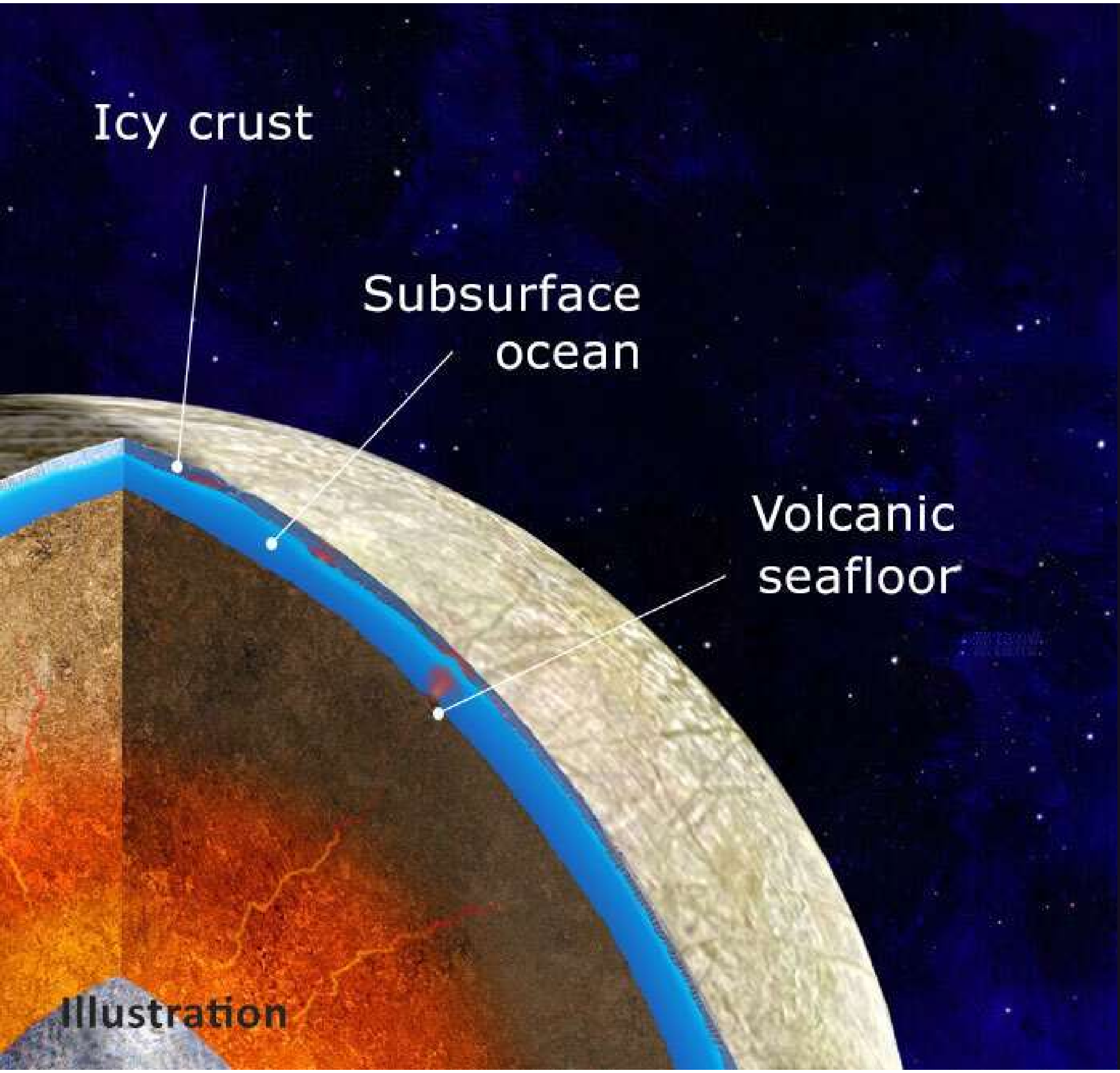
Massachusetts Institute of Technology

ACFR Australian Centre for Field Robotics

University of Michigan



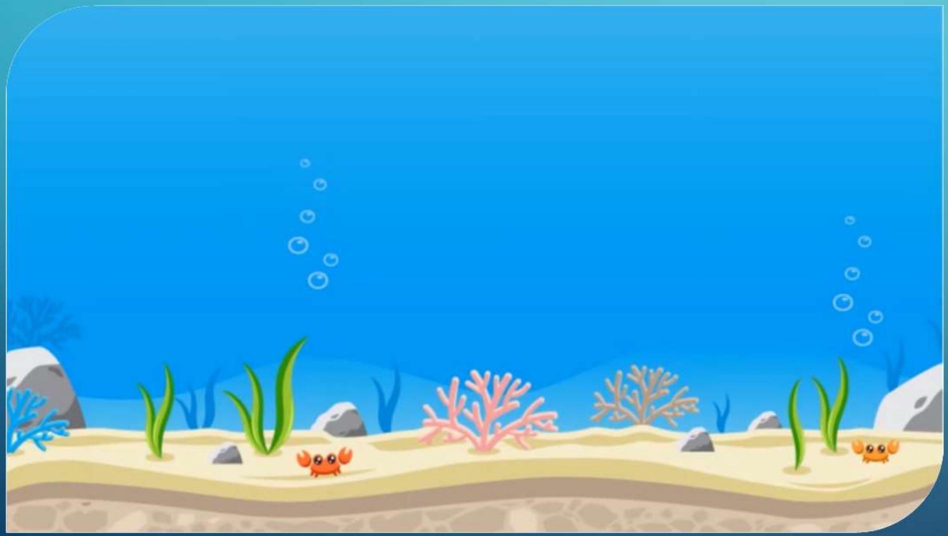
https://oceanservice.noaa.gov/facts/vents.html


Icy crust
Subsurface ocean
Volcanic seafloor
Illustration

Europa

“Real-World” Underwater Environments Pose Visual Challenges

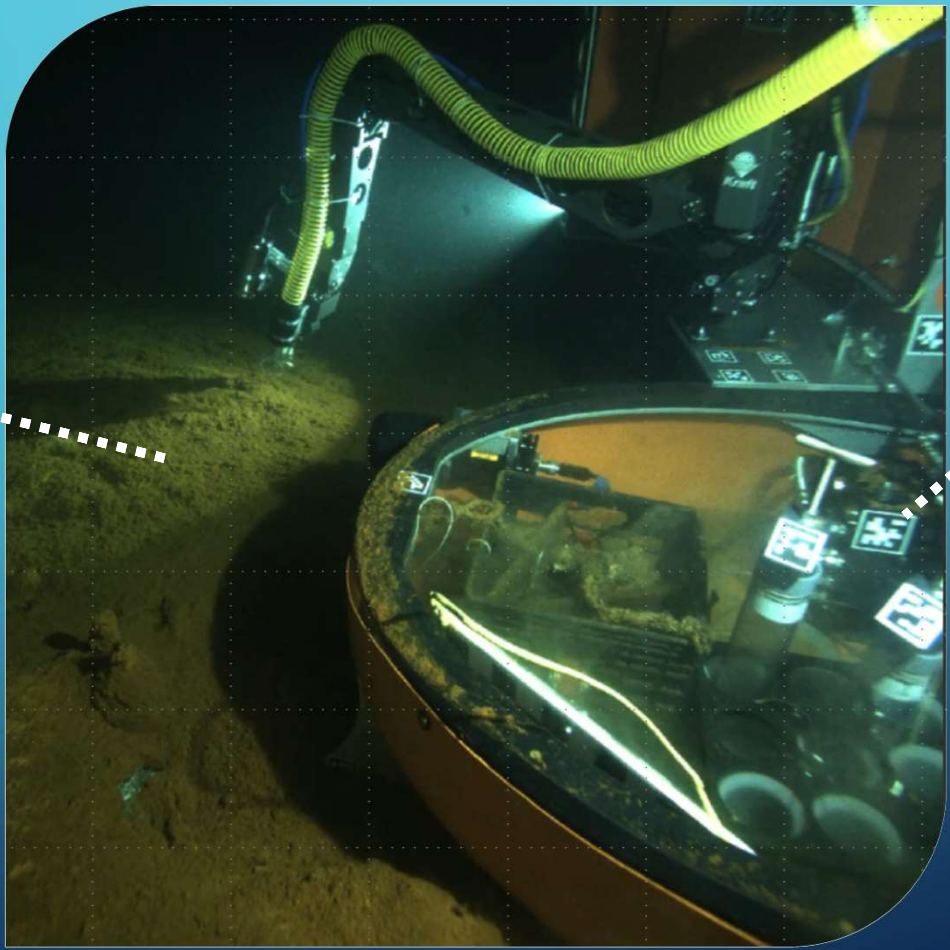
- Inconsistent lighting
- Nonlinear light attenuation effects
- Color and contrast inconsistency
- Haze and backscatter



Dealing With Visual Challenges

The vehicle workspace can be divided into two perceptual environments

Natural, unstructured, uncontrolled

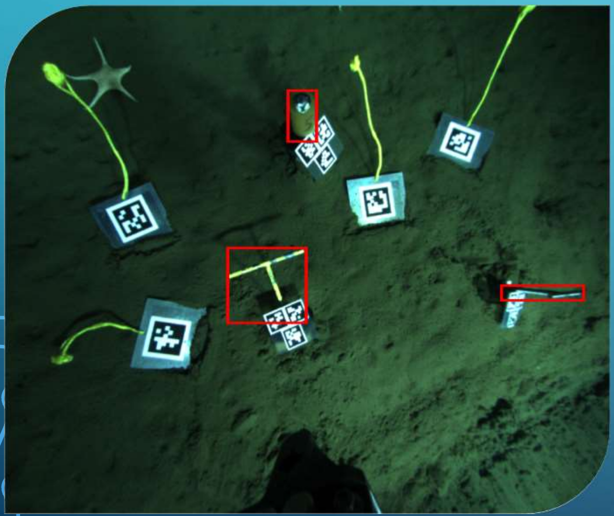


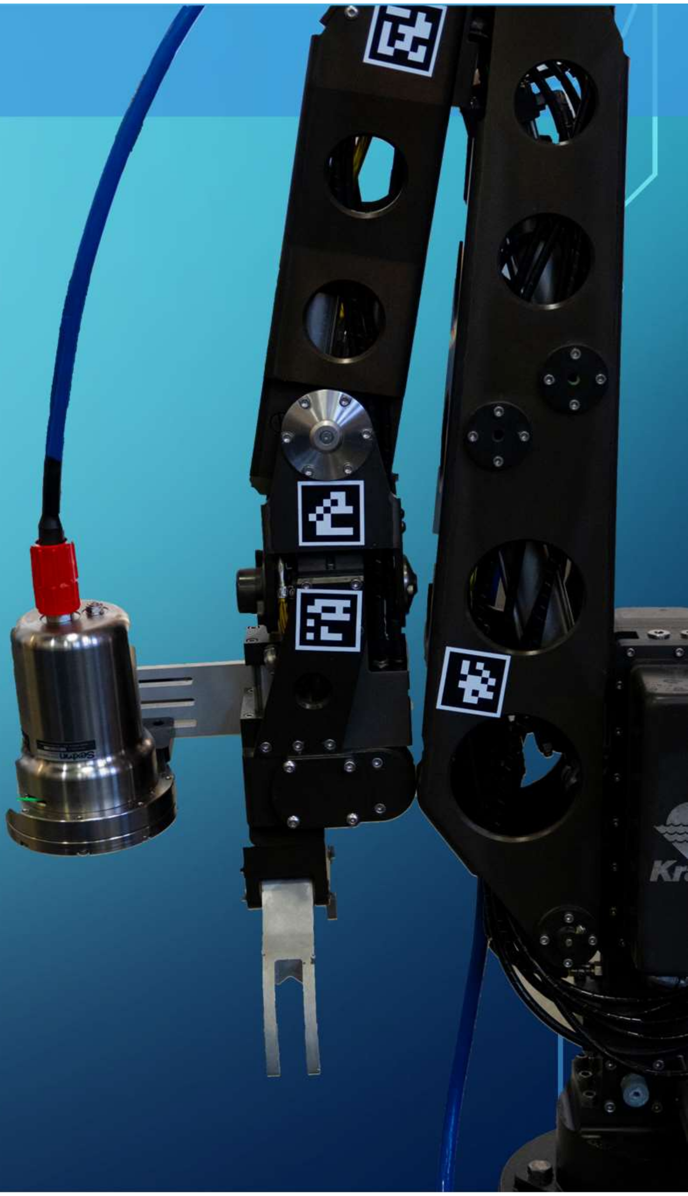
Built, structured, controlled

Dealing With Visual Challenges

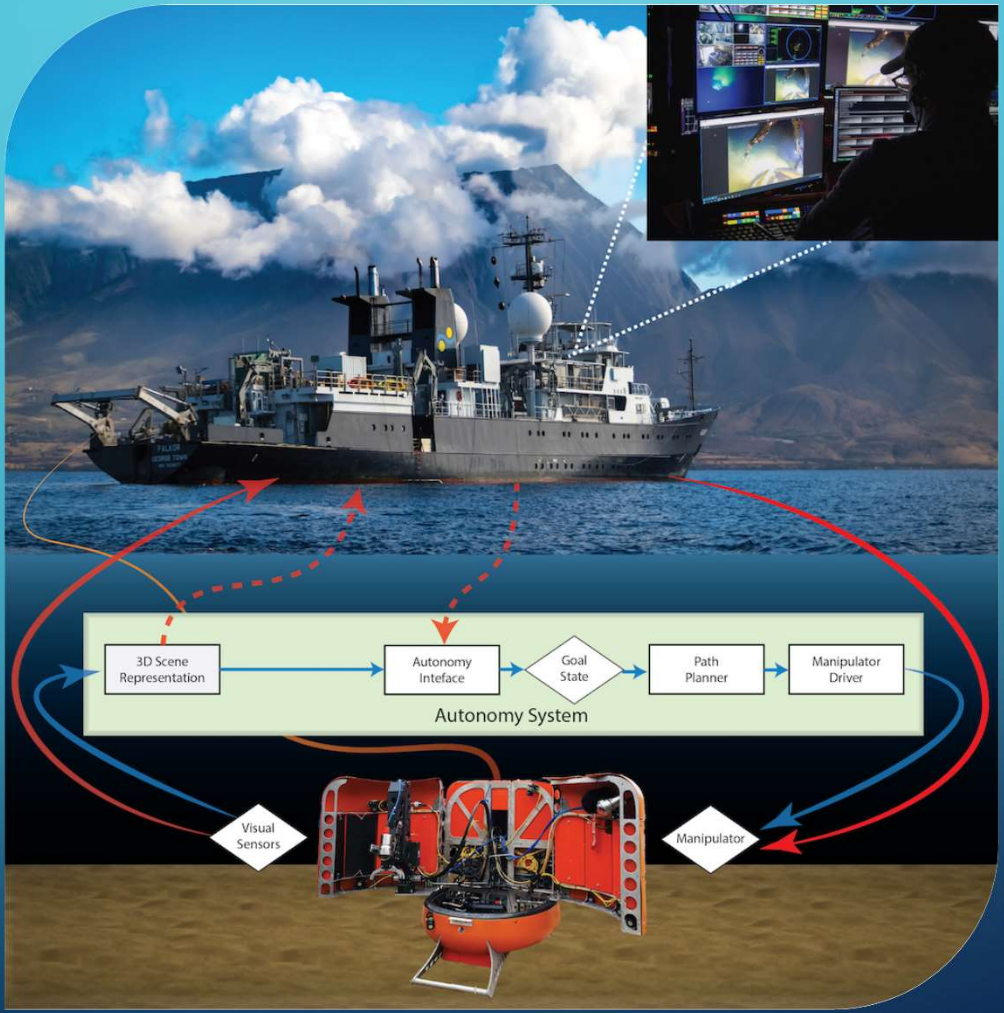
Utility of manipulator mounted cameras

- Dynamic viewpoints without disturbing environment
- Observe occluded parts of scene and complex structure
- Improve viewpoints of tool-tray

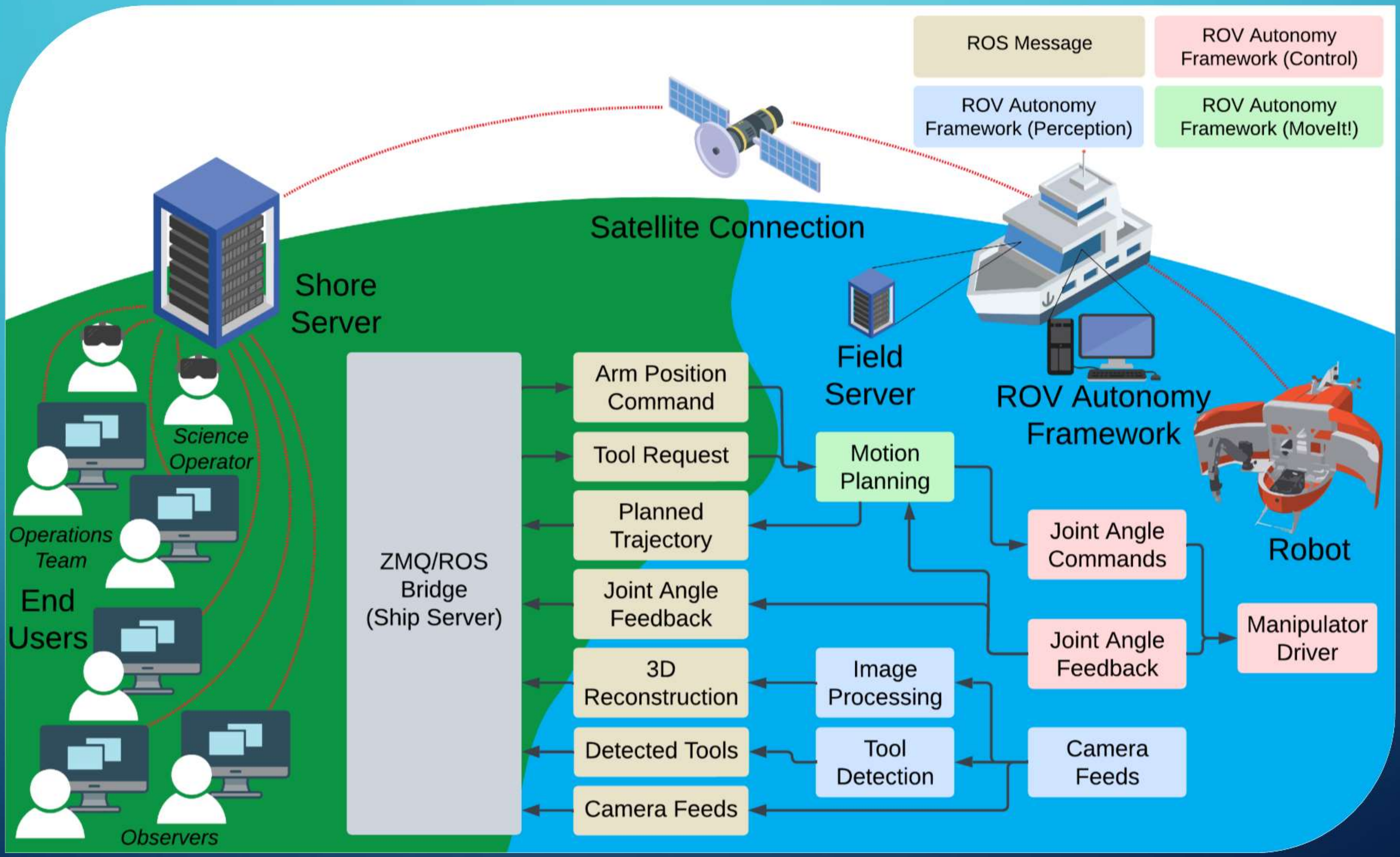




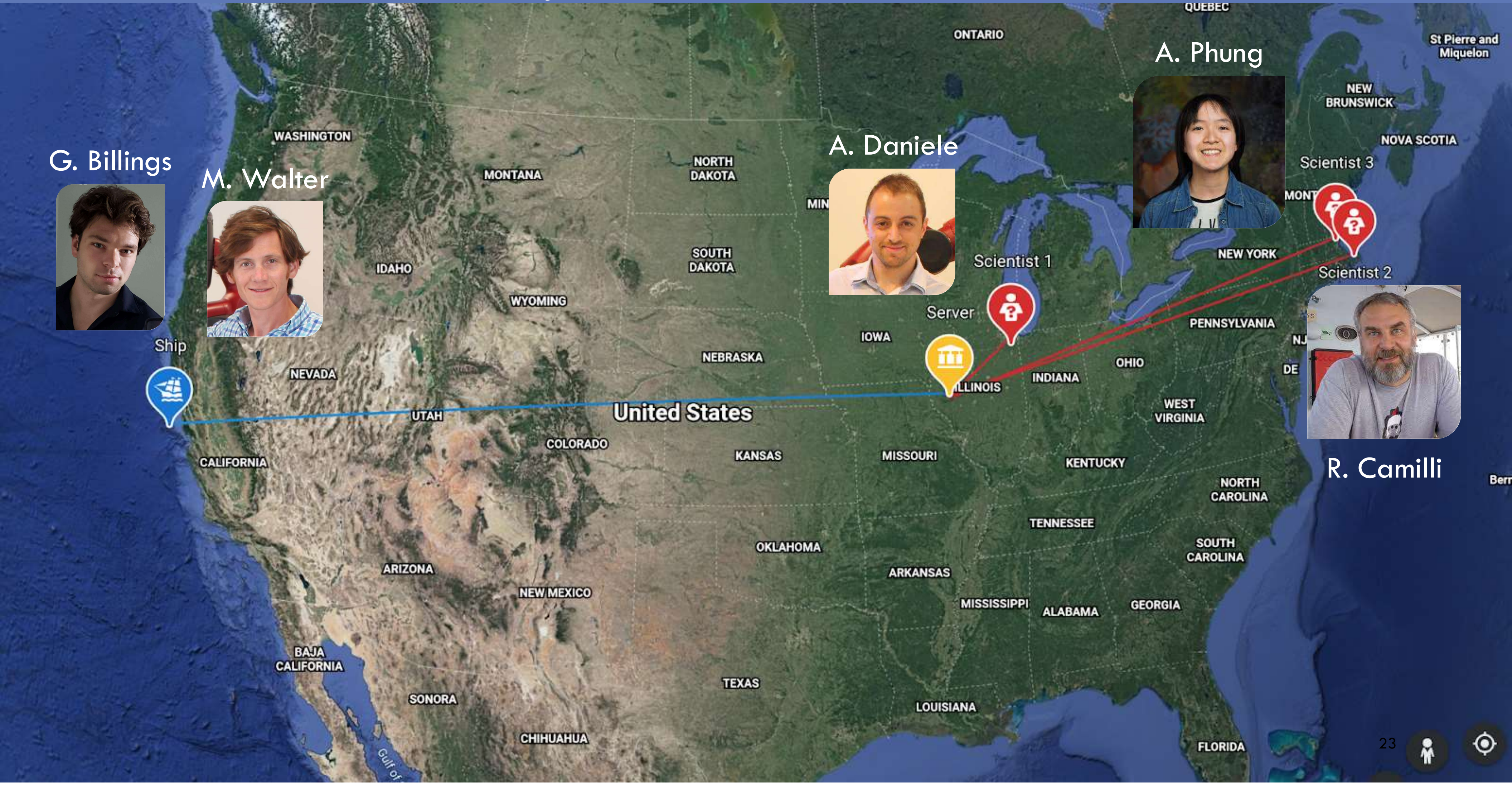
Shared Autonomy for Remote Collaboration



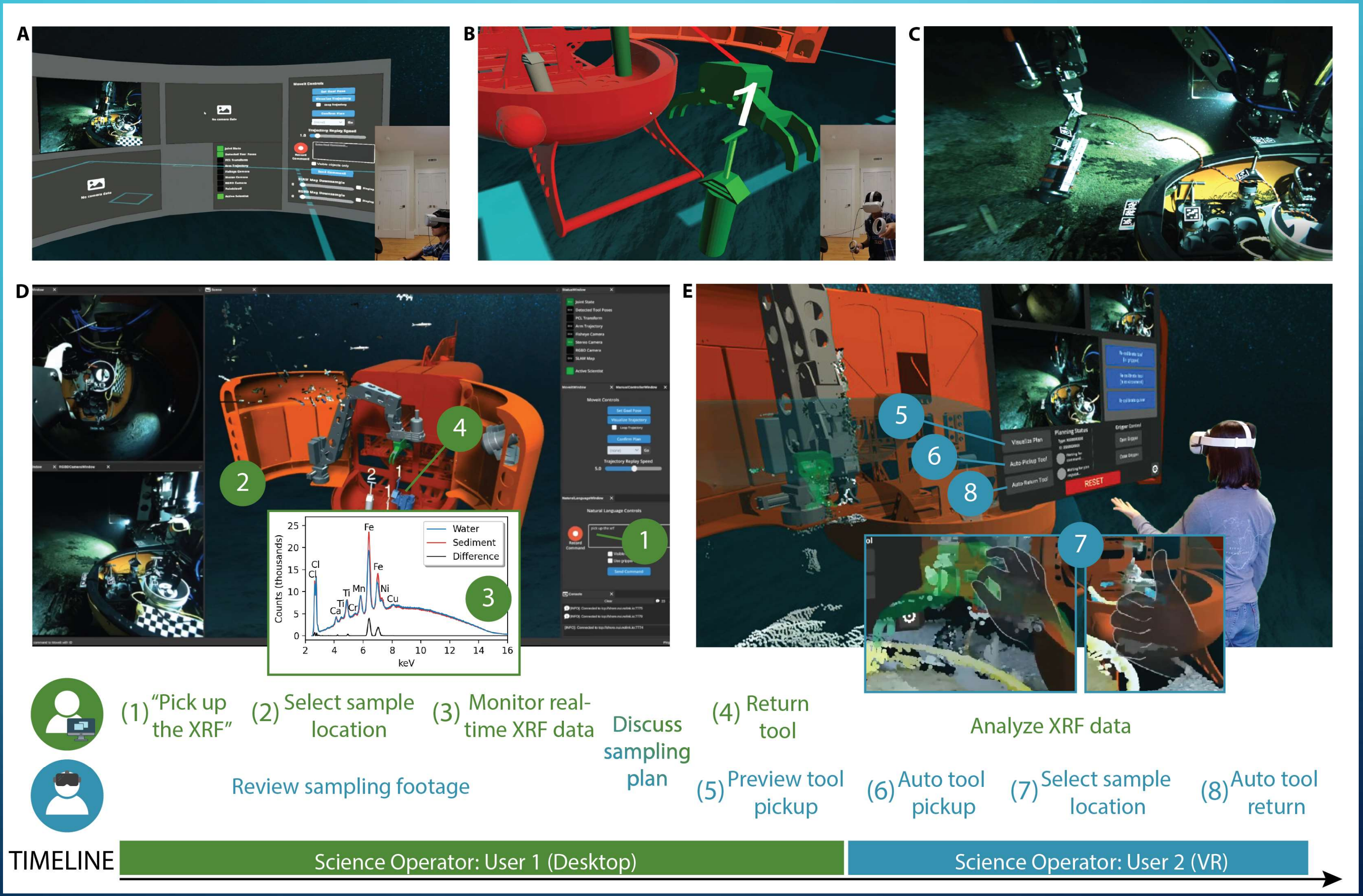
Shared Autonomy for Remote Collaboration

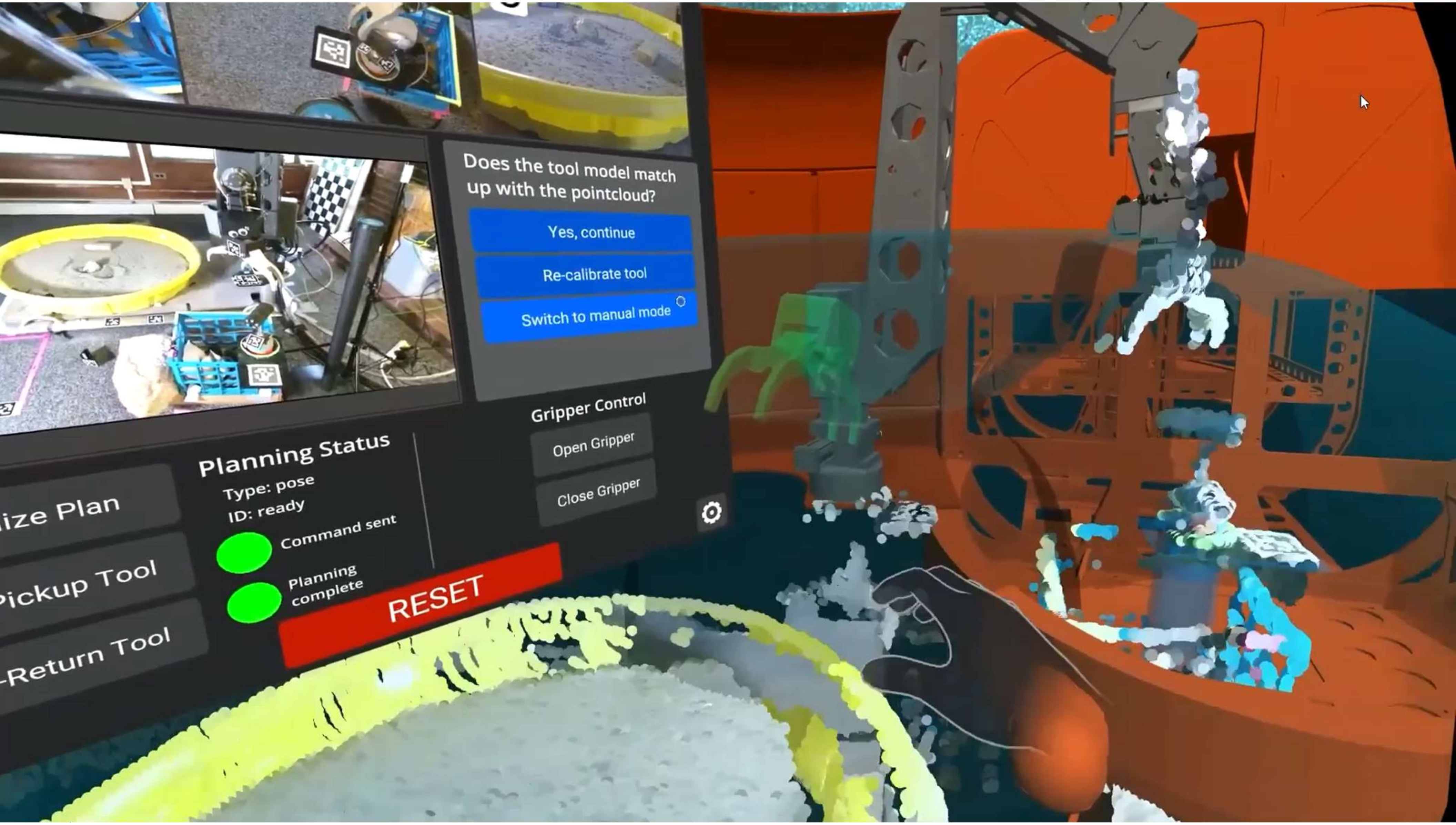


Shared Autonomy for Remote Collaboration (2021)



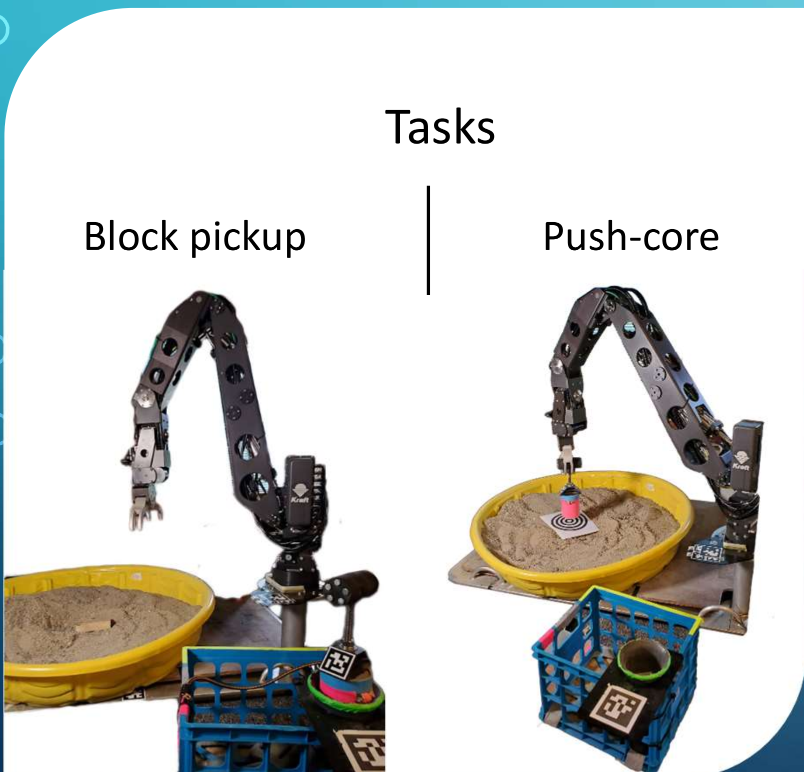
Shared Autonomy for Remote Collaboration

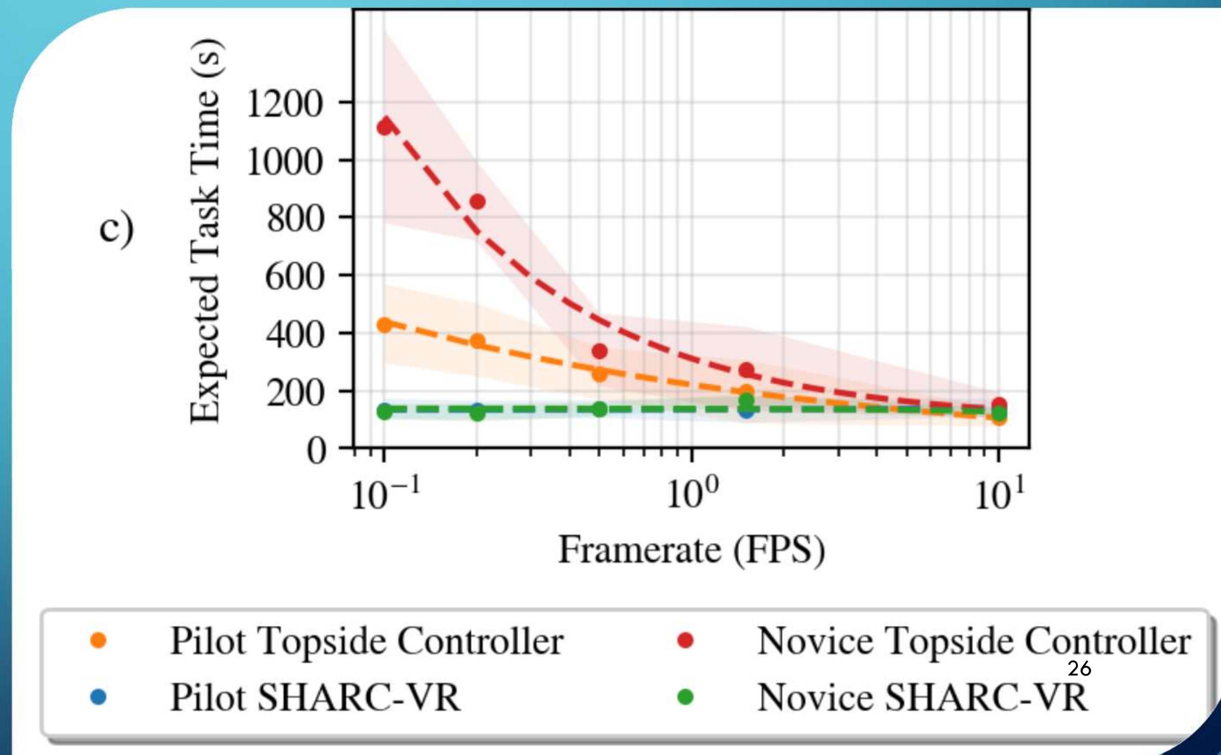



Does the tool model match up with the pointcloud?
Yes, continue
Re-calibrate tool
Switch to manual mode
Gripper Control
Open Gripper
Close Gripper
Planning Status
Type: pose
ID: ready
Command sent
Planning complete
RESET
ize Plan
Pickup Tool
Return Tool

Shared Autonomy for Remote Collaboration

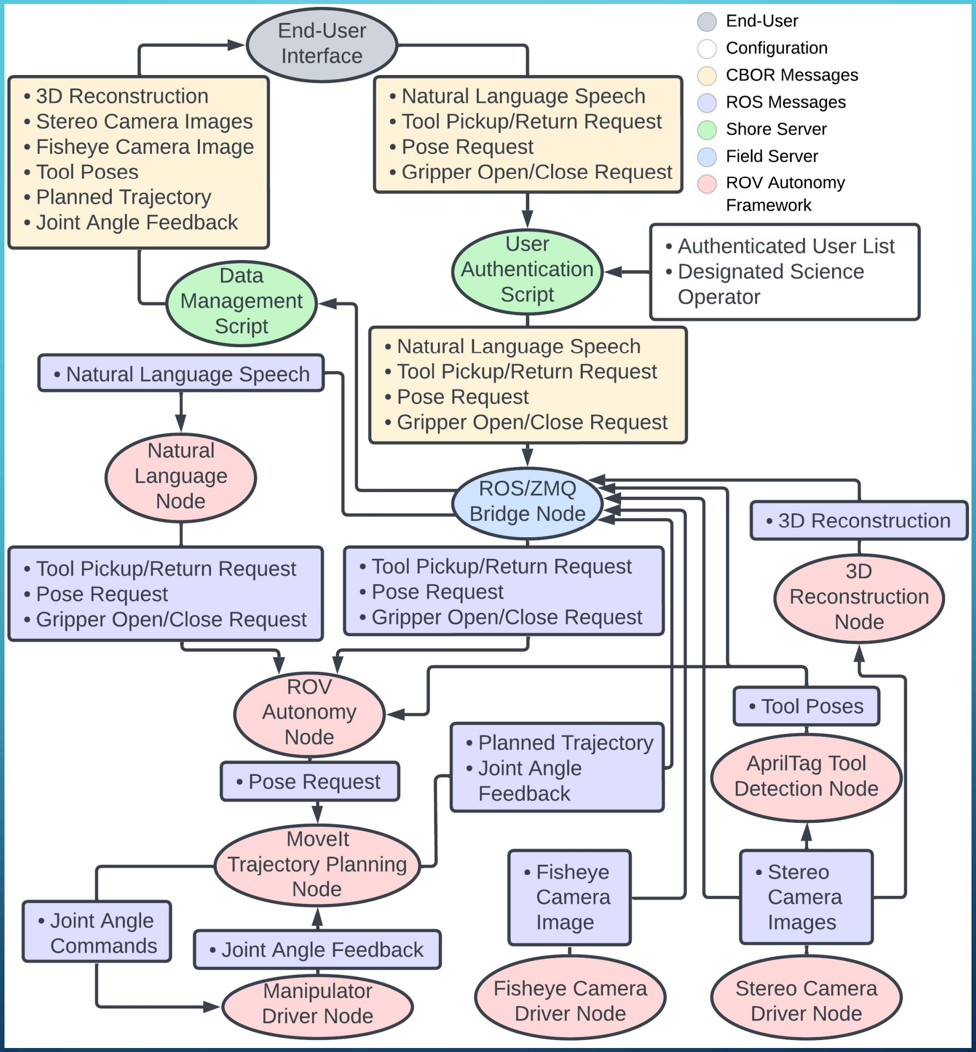
User study trials on testbed comparing novices and trained ROV pilots





It’s Aunt Proof!

Shared Autonomy for Remote Collaboration



Design Space for Polar Survey Vehicles

- Critical to understanding global climate dynamics
- High risk of loss deep under sea-ice
- Paradigm shifting from few high-cost assets to more "dispensable" low-cost systems

$$$

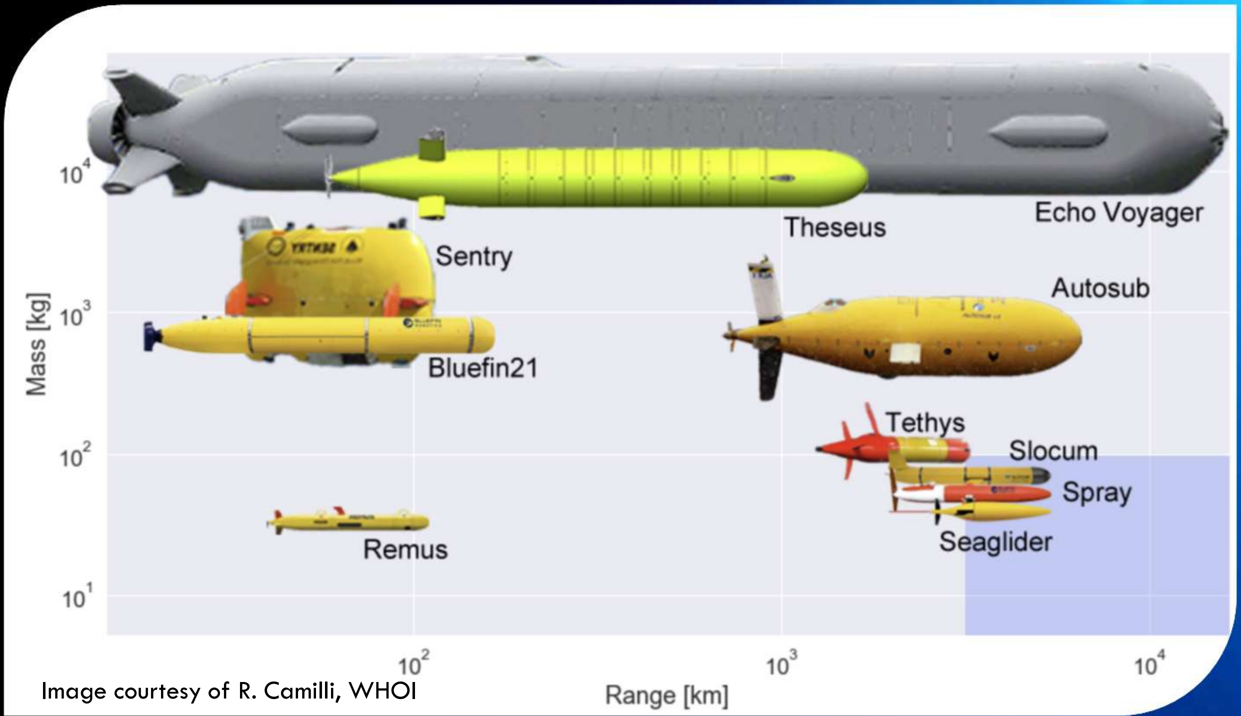
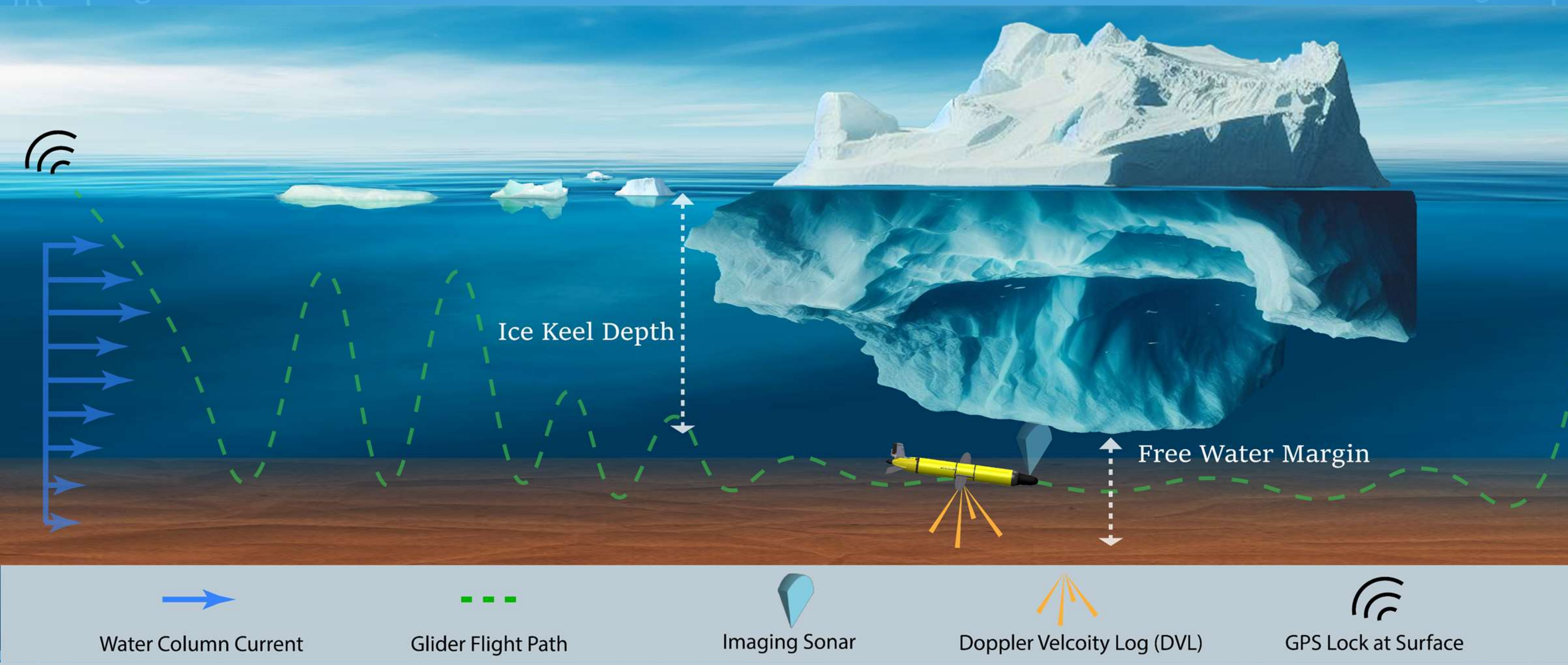


Image courtesy of R. Camilli, WHOI

Image Credit: K. Meiners, et al

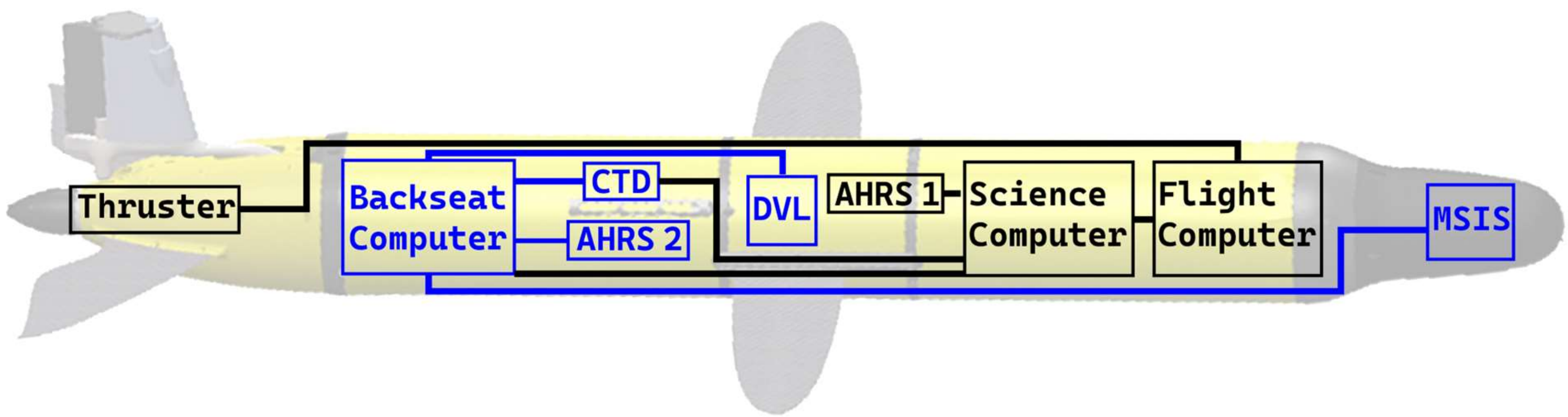
Autonomous Underwater Gliders for Long-Range Survey



Autonomous Underwater Gliders for Long-Range Survey

Modified G3 Slocum Glider

- Modified wings for improved lift/drag
- High power custom thruster
- Operates efficiently in open ocean and depth constrained bands
- Backseat system architecture



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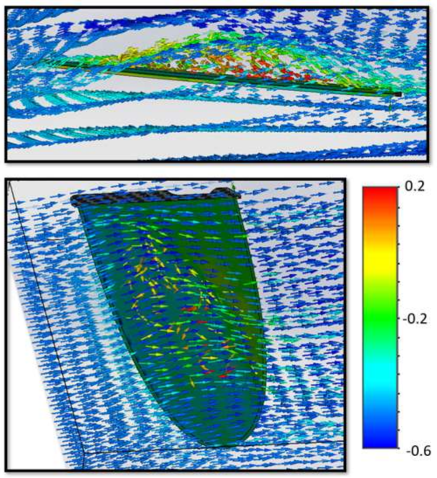

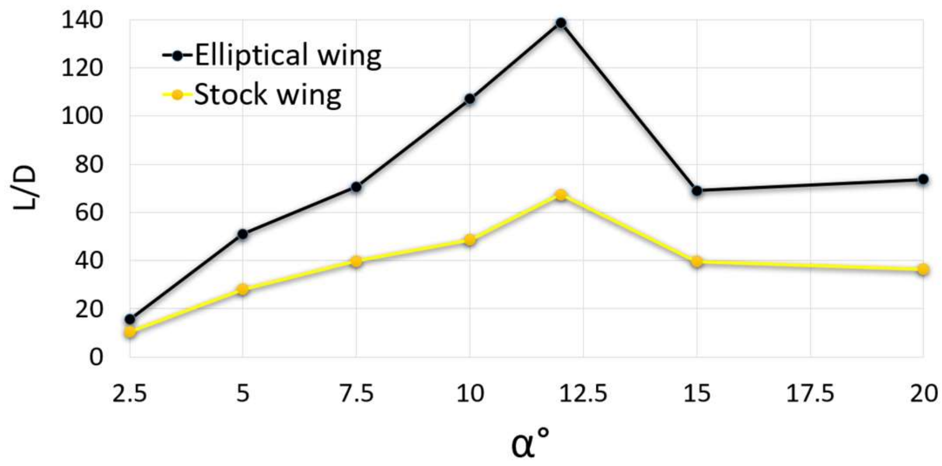

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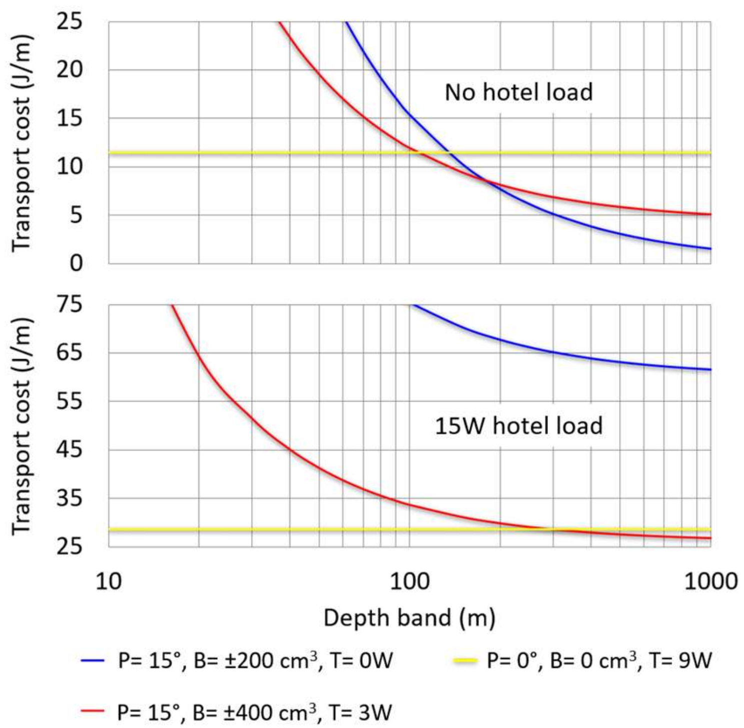

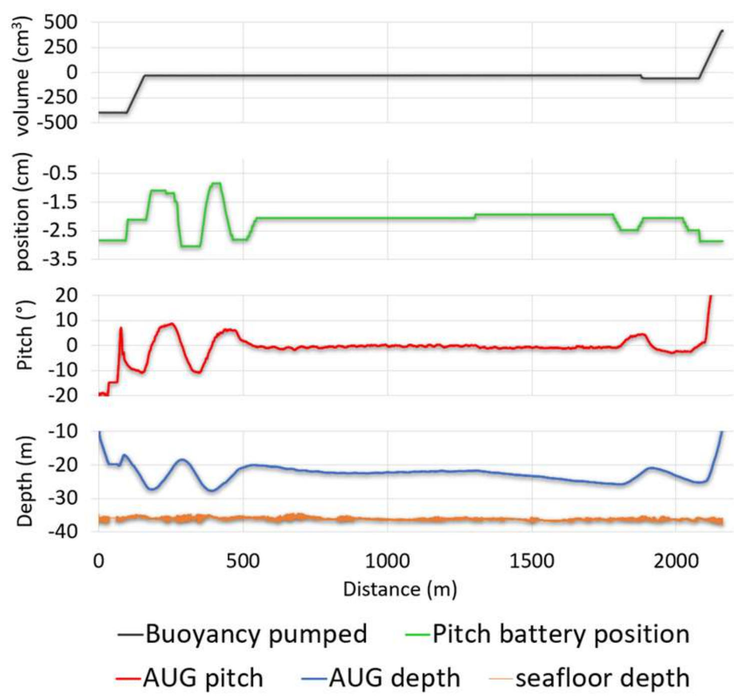

Autonomous Underwater Gliders for Long-Range Survey

Modified G3 Slocum Glider

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- Operates efficiently in open ocean and depth constrained bands

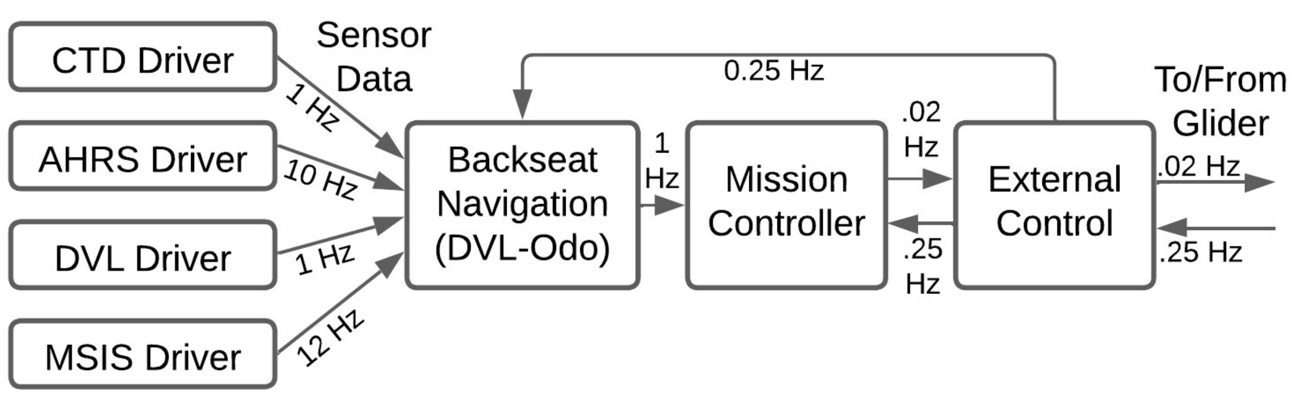
	Deep Transit	Coastal Transit	Survey Mode
Depth Band	1000 m	200 m	10 m
Transport Cost (Joules/m)	3 J/m	10 J/m	29 J/m
Velocity	0.25 m/s	0.69 m/s	0.9 m/s
Endurance [3.2 kWh]	4300 h	460 h	120 h
Range [3.2 kWh]	3800 km	1200 km	400 km
Endurance [12 kWh]	16000 h	1700 h	460 h
Range [12 kWh]	14000 km	4300 km	1500 km

Autonomous Underwater Gliders for Long-Range Survey

Modified G3 Slocum Glider

- Backseat system architecture

Backseat ROS Architecture



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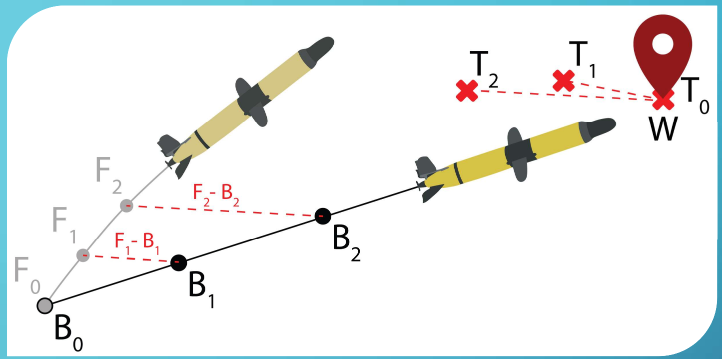
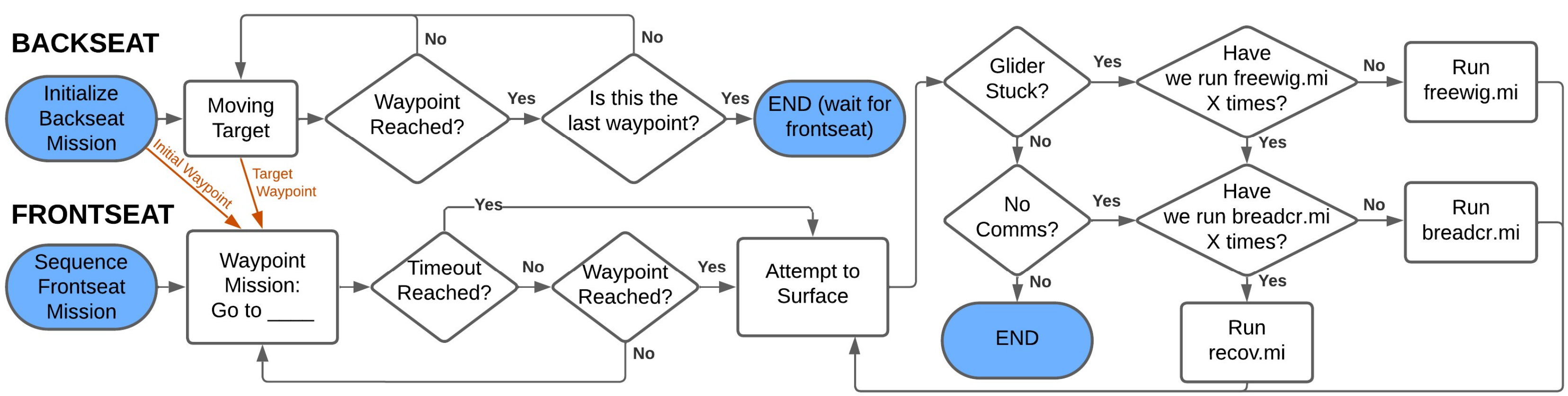


Backseat Carrot Following Mission Controller



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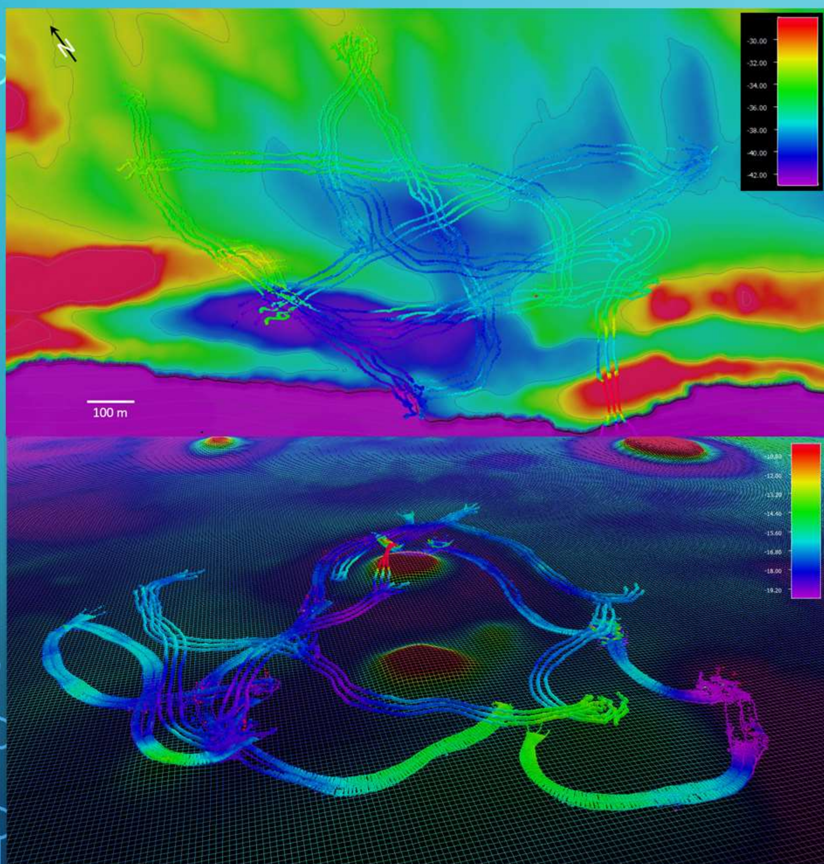
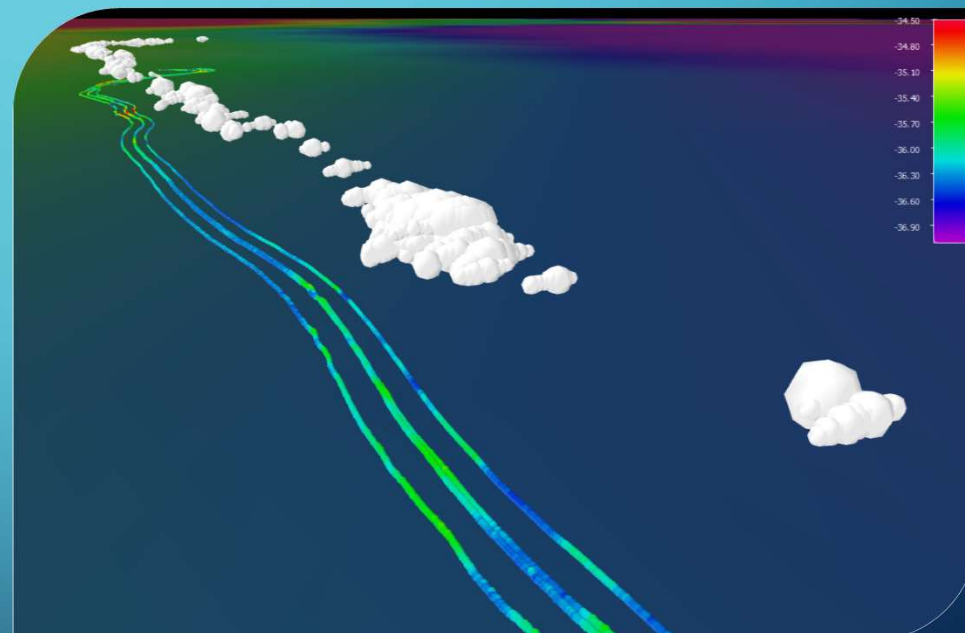




Exploring in The Twilight Zone

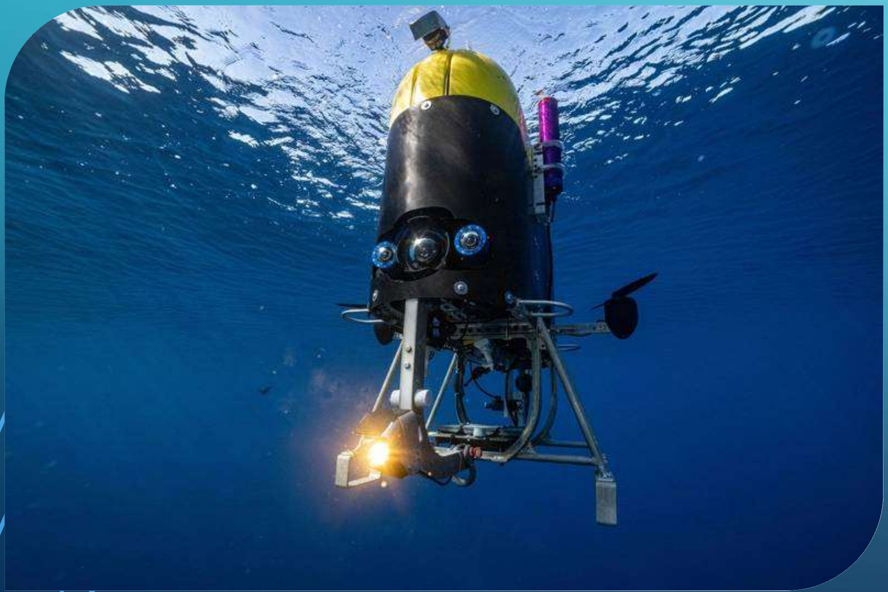
Twilight Zone

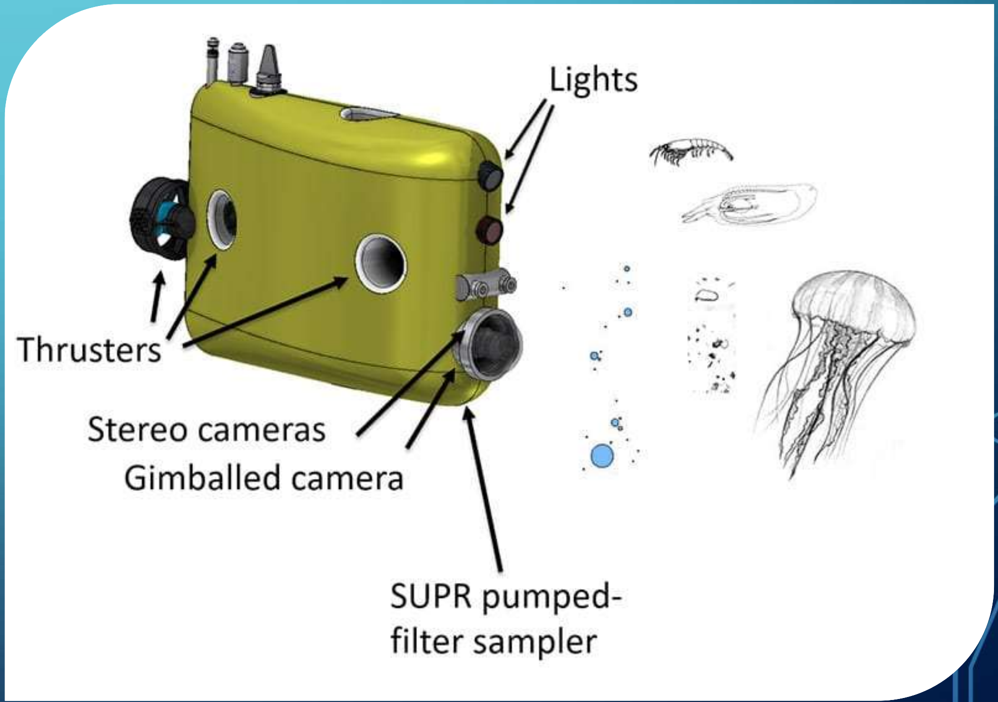
- 200 – 1000m water depth (fringes of sunlight)
- Daily sees the largest migration of animals on the planet to feed at night
- Animals support global food web
- & transport huge amounts of CO_2 from surface waters into the deep ocean
- Remains largely unexplored with rich biodiversity
- Poised to begin biological resource harvesting with unknown consequences

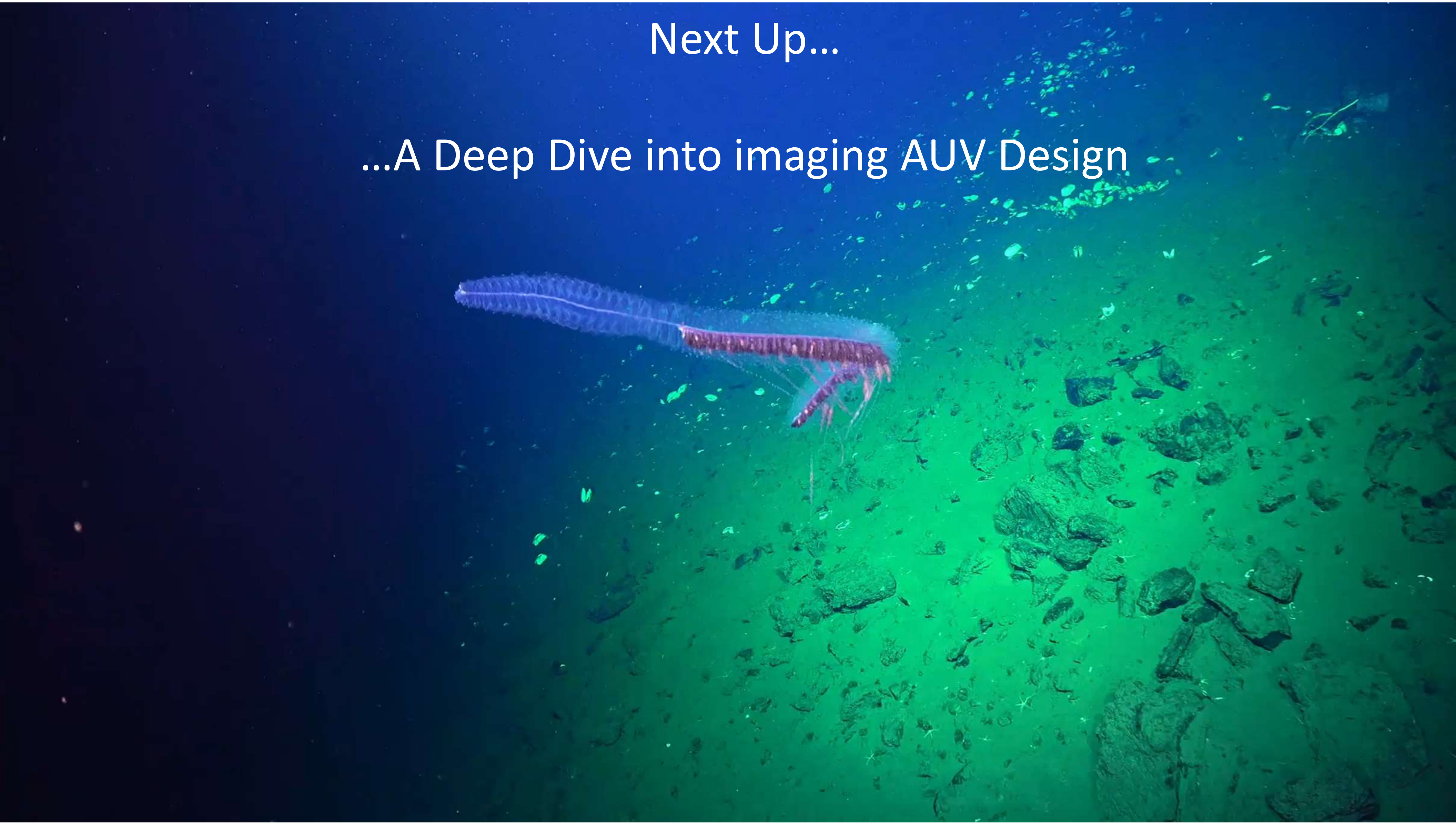
Exploring in The Twilight Zone

Mesobot - Dana R. Yoerger, et al

- $35M Audacious Project to study Twilight Zone
- No sense of global location
- Track and image creatures in the twilight zone
- Collect environmental DNA samples



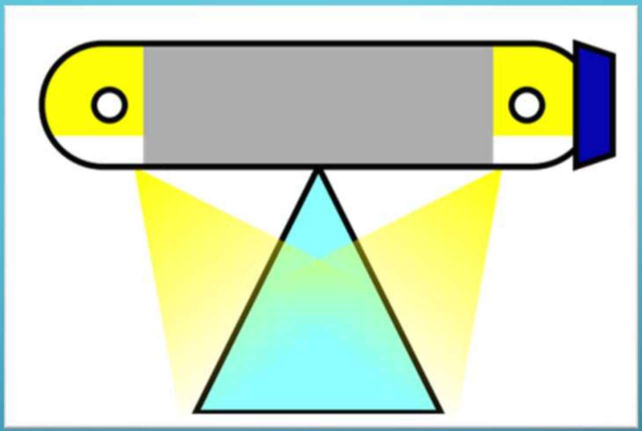



Next Up…
…A Deep Dive into imaging AUV Design

DESIGNING AN AUV

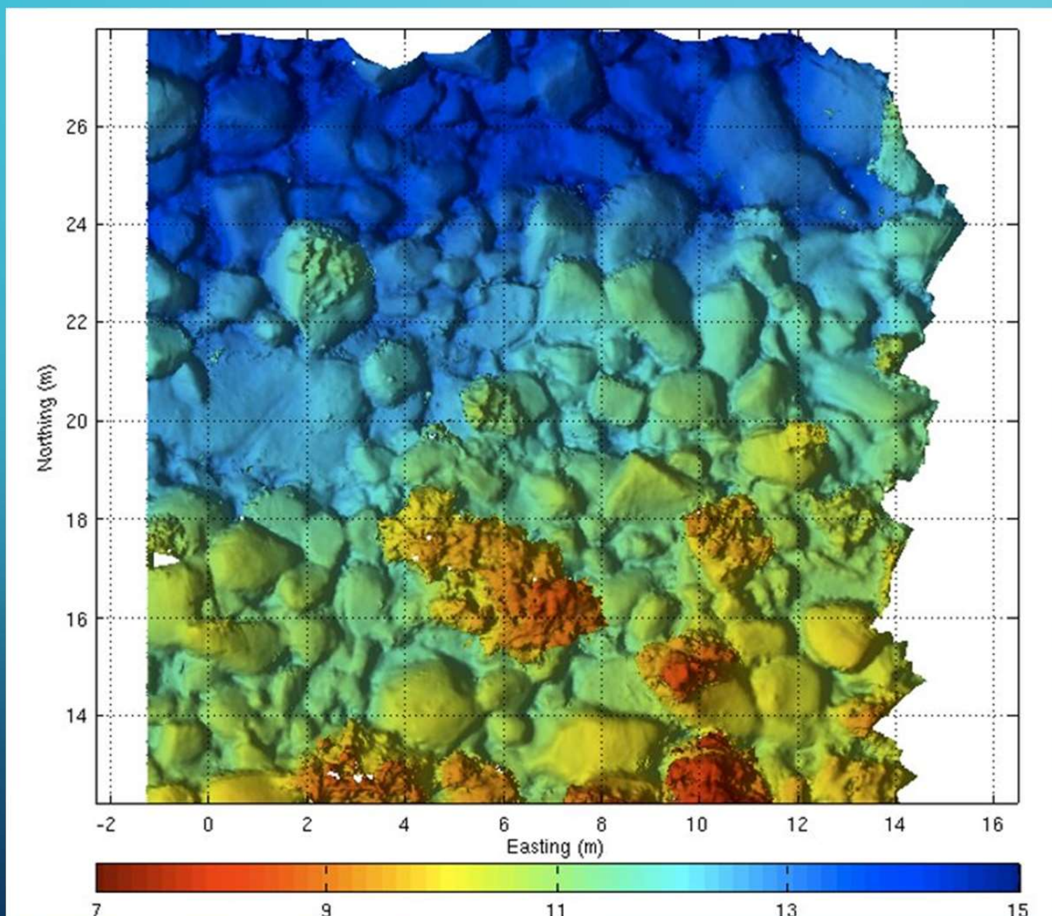
SEAFLOOR IMAGING AND SURVEY

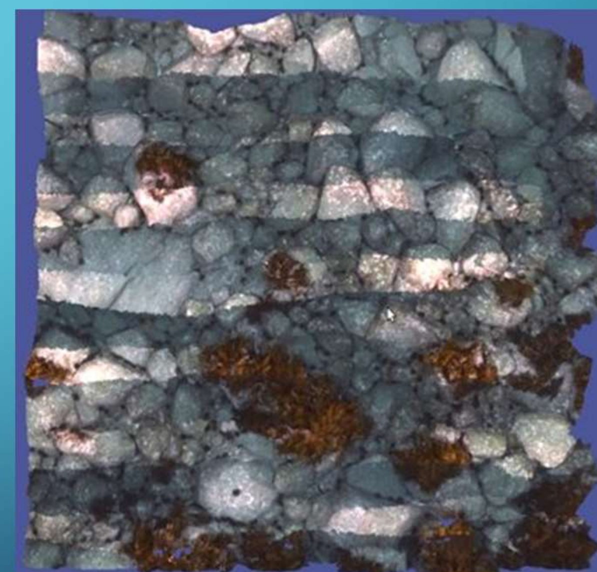
THE TASK



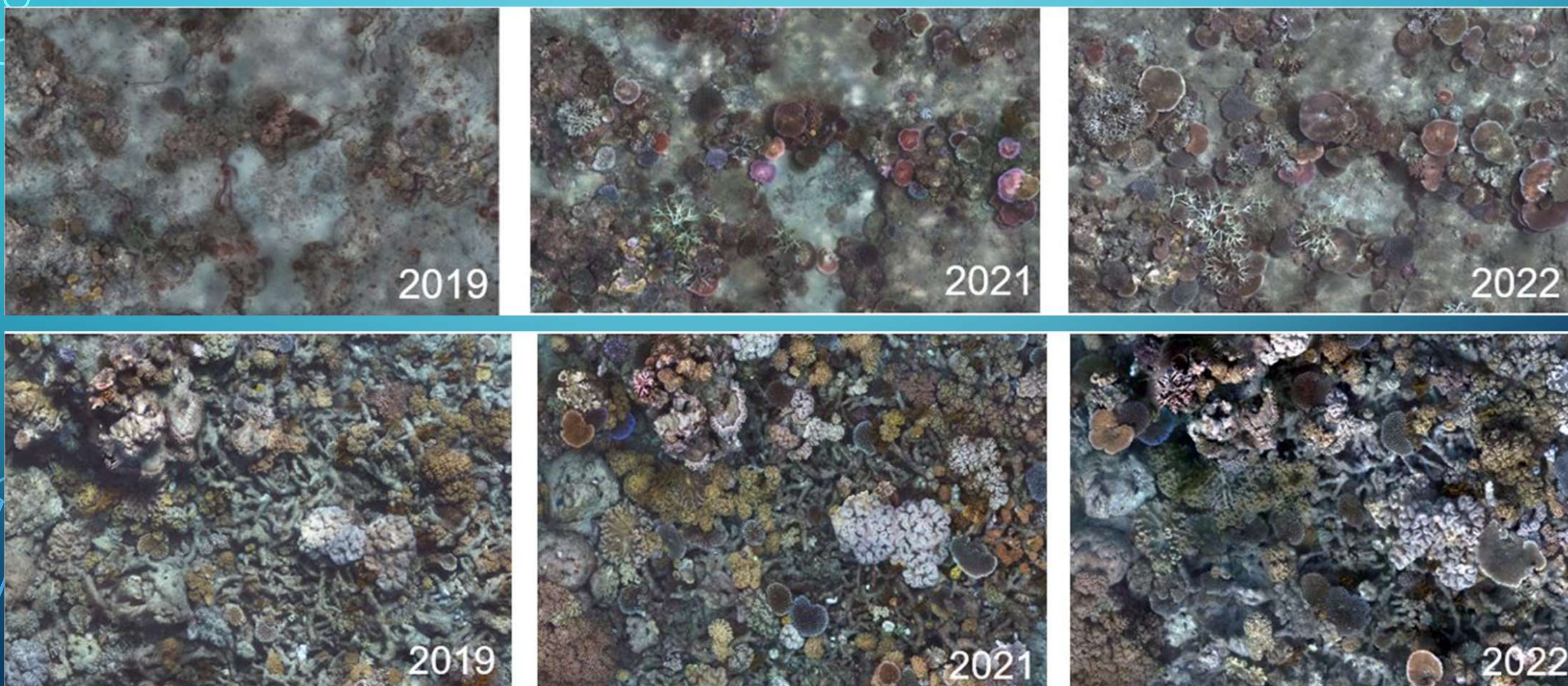
SEAFLOOR IMAGING

BATHYMETRY FROM STEREO





REPEAT SURVEYS - ACROSS YEARS



OUR EXISTING AUVS

SIRIUS & IVER2 DESIGN REVIEW

SIRIUS

- Roll & Pitch Stable
- Hover capable, slow & high(ish) power.
- Good over rough subsea terrain
- Dives easily
- Not super sensitive to ballast
- Requires crane for deployment

IVER

- Less roll stable, travels pitched.
- Can't hover, runs faster, more efficient.
- Struggles over uneven depth/step changes
- Dives with difficulty.
- Difficult to ballast – 250g is too far
- Shore deployable, can be craned.

SIRIUS & IVER2 DESIGN REVIEW

SIRIUS

- Flooded Hull:
  - A lot of added mass
  - Many (expensive!) connectors
- Assembled on arrival
- Easy to modify

IVER

- Single Hull:
  - Payload added by extending platform
  - Minimal connectors (data + power)
- Travels in two pieces!
- Harder to modify

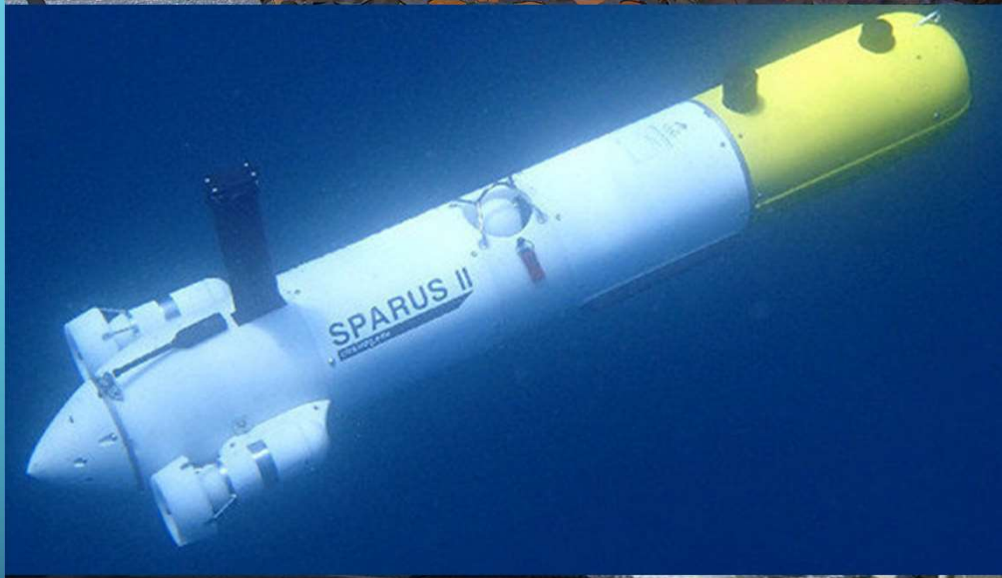
COMMERCIALLY AVAILABLE

Pro:

- Minimal design time & focus on payload
- No FTE to build
- Proven design
- Control/Nav provided
- Shared platform

Con:

- High altitude
- Limited customisation
- Many Large/Heavy
- Supply chain reliant
- Iver2 experience wasn't great
- MILSPEC/Oil and Gas typical market - $$$$



IN-HOUSE DESIGN

- Complete knowledge of internals
- Task specific
- Common software with existing platforms

IMAGING SYSTEM DESIGN TRADEOFFS

	Motion Blur - good	Image Overlap + good	Seafloor Pixel Size - good	Power Usage - good
Vehicle Speed	+	-		mixed
Frame Rate		+		+
Field of View (lens)	-	+	+	
Camera Resolution	+		-	
Exposure Time	+			
Strobe Brightness	-			+

VESSELS FOR MARINE FIELDWORK

No cranes

Relatively cheap - $1k/day
Partners may own the boat!
Book a week to months out
Flexibility in case of weather/delays
Complete control over vessel location
Many boats available

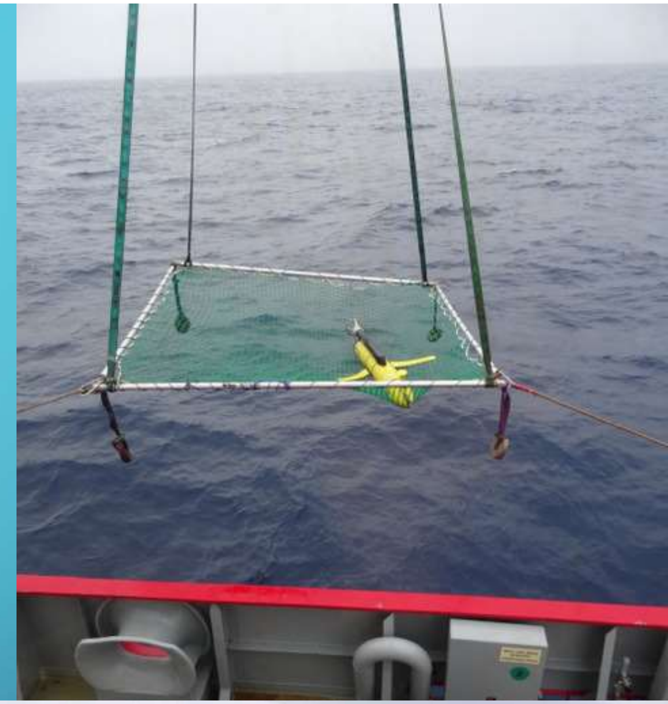
Cranes for deployment

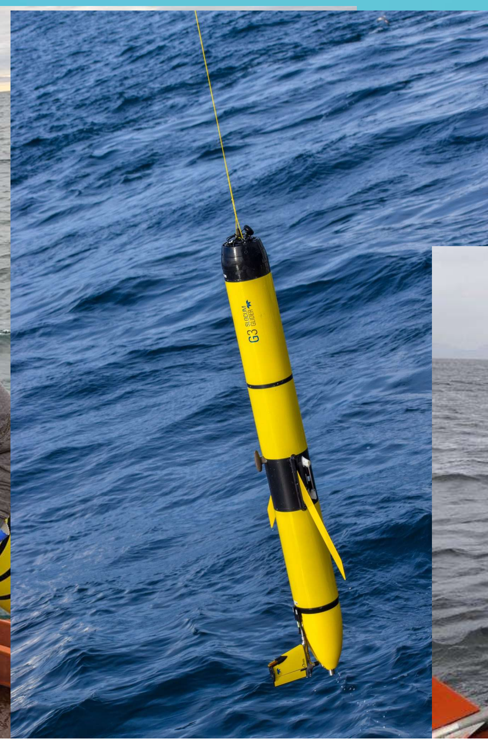
Expensive - $50k+/day
Grants required, can't repeat annually
Book over a year ahead
Can't adjust if bad weather/pandemics
Part of a larger program, reduced control
Few ships available

SAFE DEPLOYMENT AND RECOVERY

SAFE DEPLOYMENT AND RECOVERY


LAUNCH AND RECOVERY SYSTEM





AUV DESIGN CATEGORIES

Hover

Torpedo

Glider

Hybrid?

ACTUATOR CONFIGURATION

OTHER DESIGN CONSIDERATIONS

- Design/Manufacture:
  - Time & capacity to manufacture/build
  - Expertise available – existing in team, hiring staff, outsourcing elements
- Operations:
  - Setup requirements (time, equipment, personnel & skills)
  - Cost of sparing, tools
  - Data transfer rates, charging speed
  - Number & skills of people to operate.

DESIRED IMPROVEMENTS

NIMBUS (2013)

- Smaller than Sirius, easier to deploy
- Ready to deploy on arrival
- Improved navigation/calibration setup
  - Co-locate key navigation sensors in single rigid mount
- Less underwater connectors

SEEKER (2021)

- Two person portable (<50kg)
- Affordable enough to take spare AUV on deployments
- Modular for easier payloads, variants, field 'servicing'
- Internal Antennae to avoid 10dB loss

DESIGN PROCESS

NIMBUS (2013)

- First in house AUV
- Design work spread across multiple team members also working on other projects with higher priority
- Smaller team

SEEKER (2021)

- Second time around
- Tight turn around – 1 year to operational & increased budget
- Slightly larger team, some members focused on the design

EXTERNAL CHANGES

NIMBUS (2013)

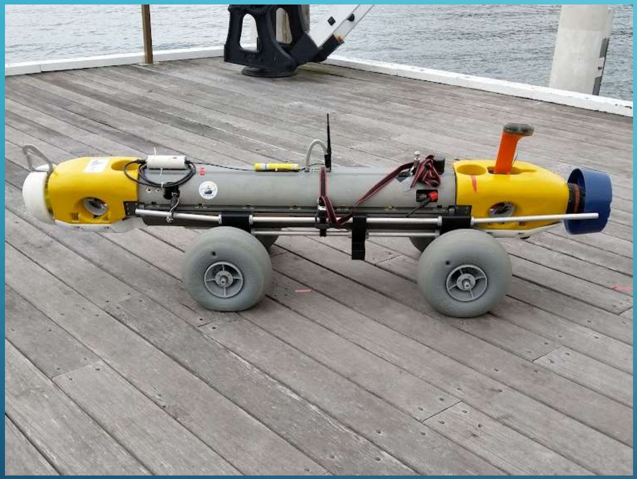
- Larger, Expensive Sensors
  - RDI/Nortek DVL
  - KVH INS, PAROSCI Depth
- Expensive Connectors
  - SUBCONN Micro-Circular
  - Teledyne DGO
- Metal Prototyping

SEEKER (2021)

- Smaller, Cheaper Sensors
  - Puck DVL – Nortek & Waterlinked
  - XSENS INS or Nortek Nucleus
- Cheaper Connectors
  - Bluetrail Cobalt
  - Alternate Microcircular
- 3D Printing Structural Components

MANUFACTURING

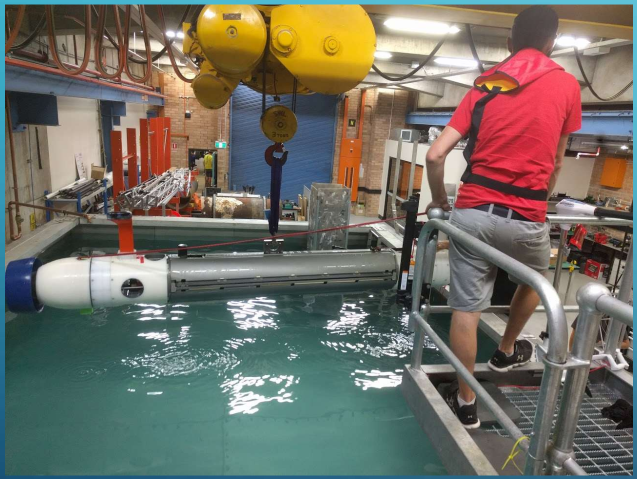
NIMBUS (2013)



SEEKER (2021)

GETTING IN THE WATER

NIMBUS (2013)



SEEKER (2021)

TRIALS AND TRIBULATIONS

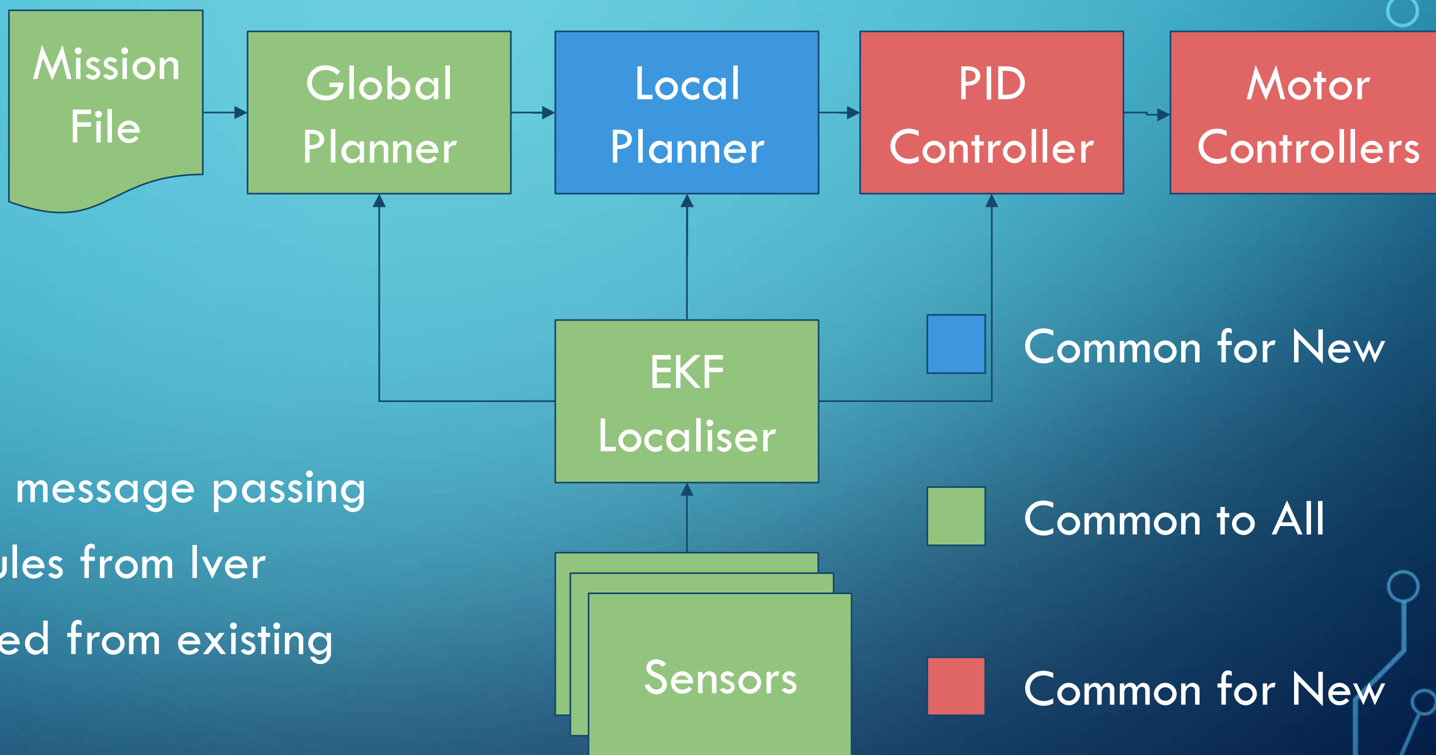
NIMBUS (2013)

- Fresh Water December 2017
- First sea water tests January 2018
  - Needed extra buoyancy
- First serious trials Oct18-Apr19
  - Slow progress designing controllers
  - Damage to Bluefin Tail
- Resumed after repair June '19
  - Ironing out submerged turns
  - Exploring LRS options
- First Deployments January '20

SEEKER (2021)

- Fresh Water August '22
  - Tank buoyancy and dive tests
- Salt water Sep '22
  - Forward & Lateral Control Tuning
  - New USBL system
  - New sensors & different units!
- First Deployments Nov '22
- Imaging system build Jun '23
  - Three weeks from complete to operational.

SOFTWARE - CONTROL AND LOCALISATION



- LCM middleware for message passing
- Inherited many modules from Iver
- New modules adapted from existing

LESSONS LEARNT

- Document everything!
  - This includes what you're making – but also why you did it that way and when you changed/fixed something!
  - Pictures, records of trials enable retrospectives and learning from the past.
- Keep each team involved
  - Hardware decisions can make life very difficult for software later on.
  - Software can workaround some troubles in hardware design.
- Replication is the fastest form of reliability
  - Cheaper components mean less critical points of failure
  - Swapping a watertight vessel is faster than opening to diagnose a PCB
- Build early and iterate