A System of Mesoscale Biomimetic Roboswimmers for Exploration and Search for Life on Europa

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Are There Europans?

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- **Origin of Life on Earth**
  - shallow water – photosynthesis?
  - deep-ocean – chemosynthesis?
- **If Europa has conditions similar to those found near Earth's hydrothermal vents – could life exist there?**

- **Over 300 species have been found to thrive near these vents.**

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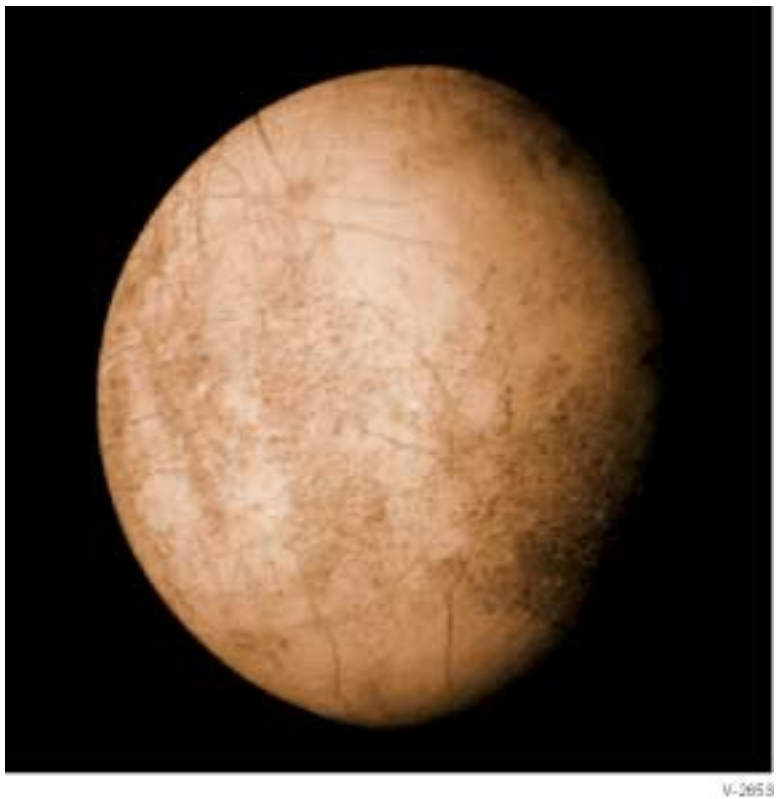
Europa

Europa



- **Second moon of Jupiter (5.2 AU), with radius 1569 km and orbital period about 3.5 days**

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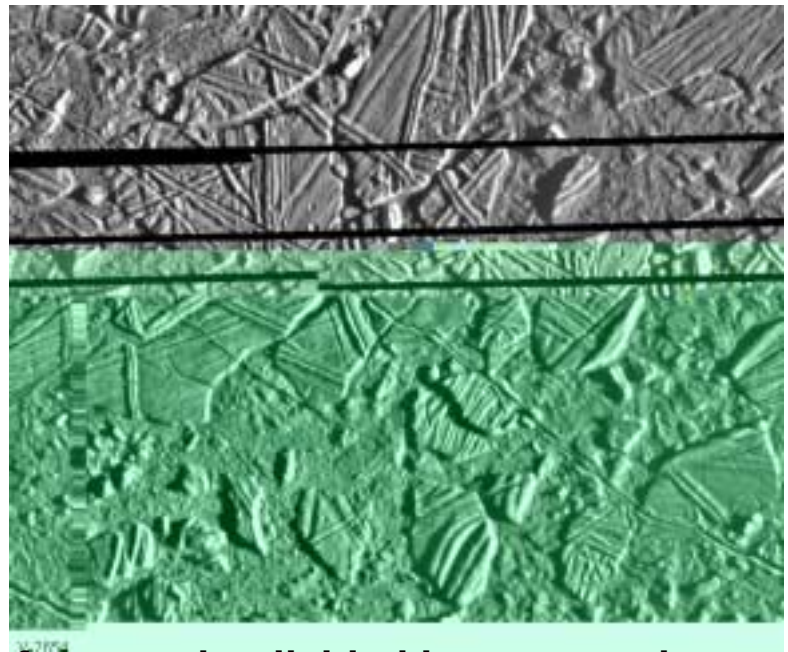

- **Surface can be divided into two major subdivisions:**
  - lineated plains
  - dark mottled terrain
- **Both radiogenic and tidal heating present**
- **Surface exhibits little cratering, indicative of either a youthful surface or a surface regeneration process**

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Problems with Searching for Life on Europa

- **Far away - 5.2 AU (778,330,000 km)**
- **Liquid ocean is below a thick (?) ice crust**
- **Ocean may be many km deep (high pressure)**
- **Life will probably only exist in small zones – how plentiful are they?**
- **What will be the characteristics of the Europans?**

Our Concept of Europa Exploration

- **We believe that teams of many small roboswimmers are required to efficiently explore Europa's ocean**
- **We are focusing on technologies that will become available over the next few decades**
- **We want to capitalize on Nature's experience – biomimetic**
- **While our concept's infrastructure is invariant, the form and function of our proposed roboswimmers is tied to the geophysical character of Europa's ocean**

Europa Ocean Exploration System

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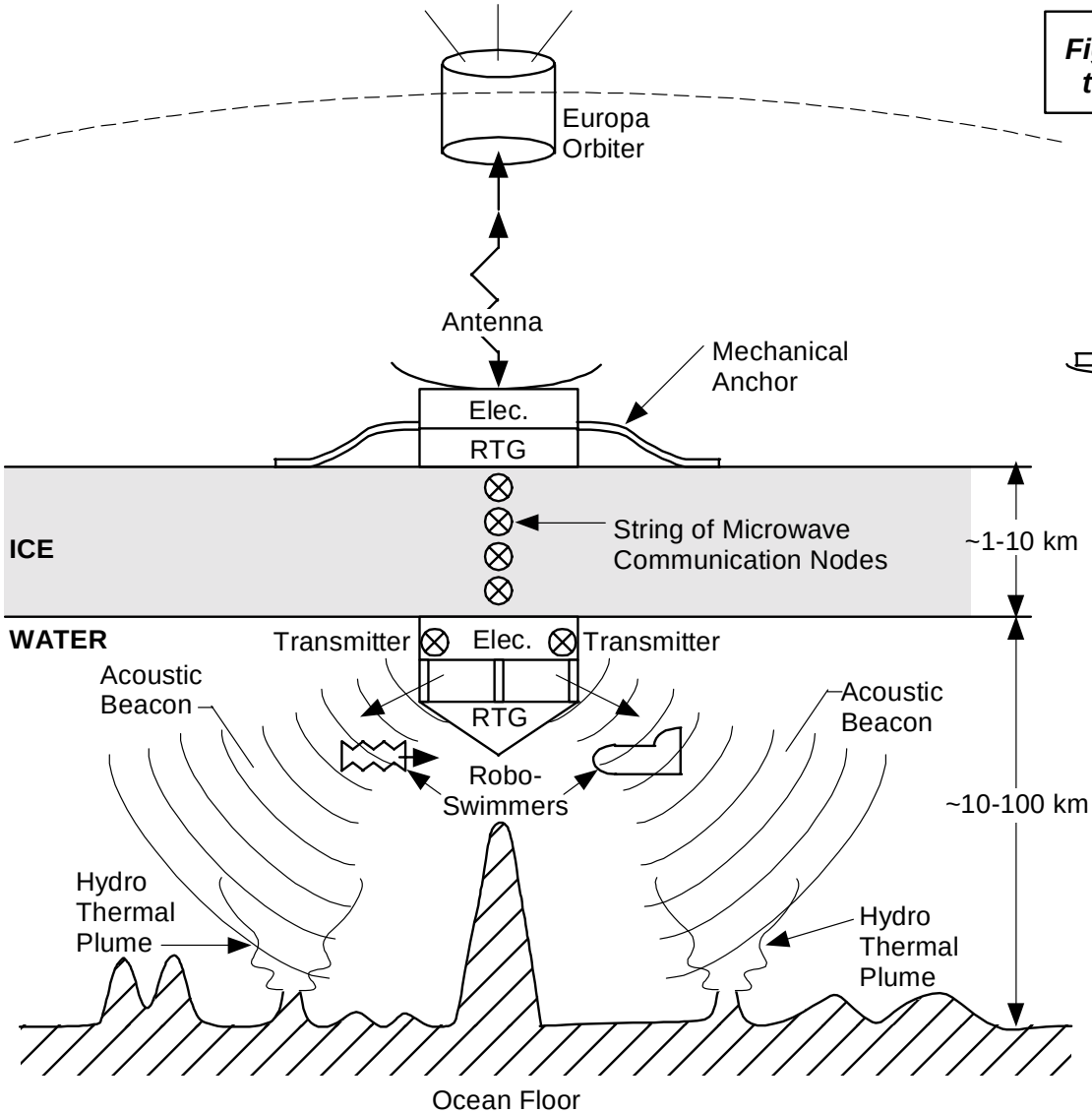
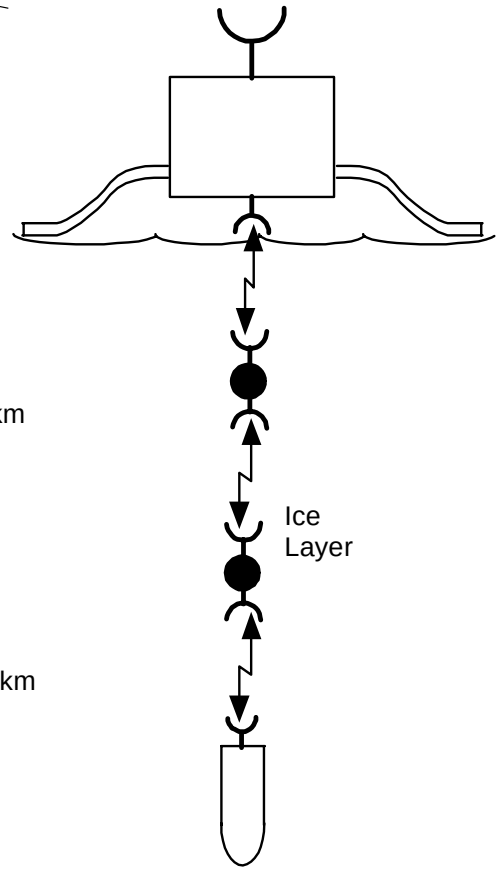


Figure Not to Scale



Phase I Technical Objectives

- **Define the objectives of a robotic exploration mission to Europa. Define specific physicochemical measurements (parameters and ranges) which characterize the ice/ocean environment and the existence of primitive ecosystems on Europa.**

- **Develop the functional attributes for autonomous robots necessary to perform the above measurements. For these attributes, define the classes or types of biomimetic robots and the sensing, actuation, and locomotion capabilities needed for individual robots.**

- **Define how the different classes of autonomous roboswimmers will self-organize and cooperate.**

- **Identify the technological infrastructures necessary to develop the system of self-organizing roboswimmers and their delivery into oceans underneath Europa's ice layers.**

Define Robotic Exploration Mission Objectives

- **Answer these questions…**
  - What are the physical and chemical characteristics of Europa's ocean environment?
  - What are the characteristics of the ice sheet?
  - What in situ data should/could be collected?
  - Where might life exist – near ice, mid-water column, sea floor, in sediments?
  - What will prove the existence of Europans?
  - If life exists how should we study it?

Develop Functional Attributes and Design Concepts for Autonomous Roboswimmers

- **Efficient ocean characterization and search for life requires the use of multiple cooperating autonomous vehicles – *teams***
- **Biomimetic systems design – modest sensors, limited computational power, colony behaviors**
- **Vehicle design driven by environment**
- **Limited knowledge will lead to morphing vehicle concepts**

Hydrothermal Vent Exploration Concept

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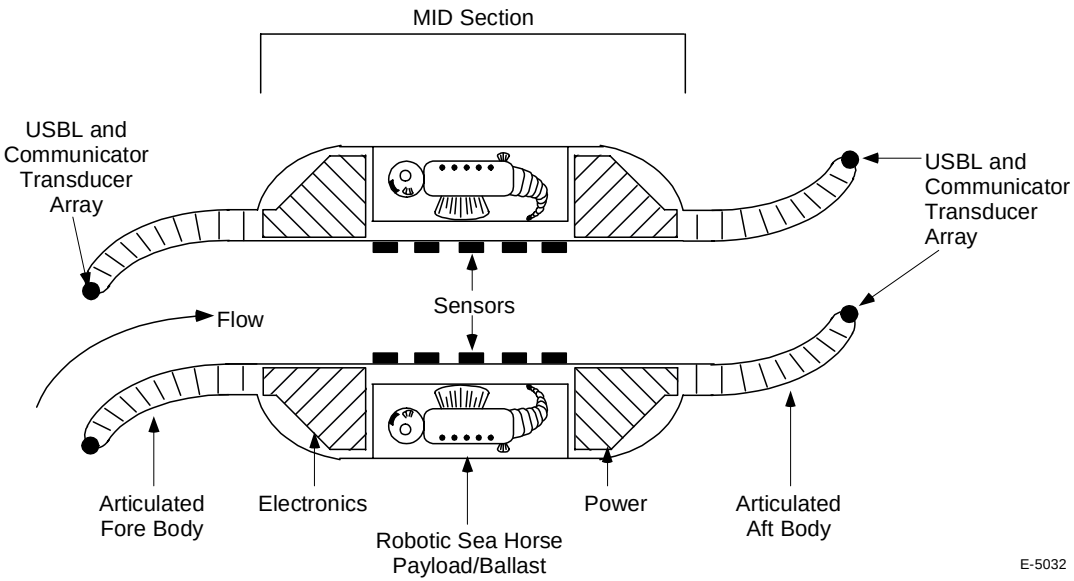
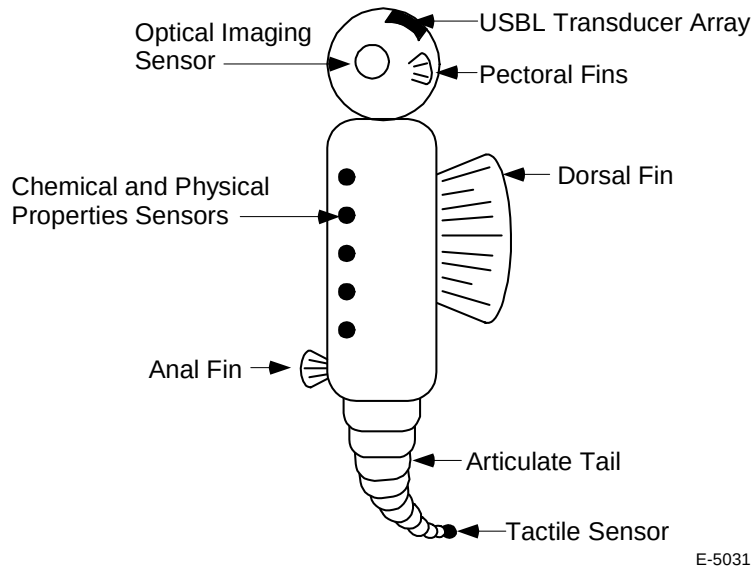
- **Robotic eels**



- **Robotic seahorses**



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Define Functional Attributes of Self-Organizing, Cooperating Group of Autonomous Roboswimmers

- **Limited energy requires coordinated, cooperating team of autonomous vehicles.**
- **Goal Setting and Global Control - A layered coordinated, cooperating autonomous vehicle architecture will be developed. Swarm → Group → Individual.**
- **Interaction Dynamics - Architectures will be defined that control inter-vehicle interactions. This includes eel-to-eel, eel-to-seahorse, and seahorse-to-seahorse coordination.**
- **Vehicle Control – Architectures that allow for fine control of individual vehicles.**

Identify technological infrastructures

- **We will identify the infrastructures necessary for the development of a system of intelligent, biomimetic swimmers for making measurements that characterize the existence of life and the ice/ocean environment on Europa.**

- **Address the issue of delivery of the system to Europa and its penetration through the ice layers on its way to the ocean.**

Europa Missions

- **Europa Orbiter, 2007 launch, Phase B funded**
  - instruments: 300 m resolution visible imaging, ground penetrating radar (~ few km), altimetry (gravity and tides)
  - penetrator possible, but unlikely
- **Europa Lander**
  - short and deep penetrators
  - materials composition measurements
- **Europa Ocean Observer**
  - verify presence of liquid layer, measure ice thickness, image surface
  - identify potential landing regions
- **Europa Ice Clipper**
  - JPL Discovery proposal (not funded)
  - sample return mission
    - impactor ejects material, intercepted by clipper at 50 km above Europa
    - Europa samples analyzed during return trip, re-entry vehicle brings sample back to earth
- **Proposed roboswimmer mission ~ 2020-2025**
  - turbidity, temperature stratification, chemical composition, acoustic propagations, currents, . . .

Phase II Approach

Phase II: 24 months

- **Demonstrate feasibility of key engineering challenges**
  - penetration through ice, deployment of communication nodes along path, and release of payload under water, inter-robot communication, tracking simulated “swimmers” . . .
  - US Army Cold Regions Research and Engineering Laboratory facilities

- **Demonstrate feasibility of key roboswimmer technologies**
  - collective behavior (simulation/analysis)
  - inter/intra species communication and collaboration

Phase III Approach

Phase III: 36 months

- **Demonstrate the penetration and hardware deployment implementation in field and communication through ice**
  - Antarctic subglacial lakes (Vostok) or
  - Resolute Bay, Northwest Territories (Canada)
    - Navy penetration experiments 1993
    - several feet thick ice over several hundred feet deep water
    - support facilities
    - relatively inexpensive

- **Develop roboswimmer prototype(s) and demonstrate measurements, and communications and control capabilities, collaborative operations**
  - functional devices, not necessarily highly compact

NIAC 22nd Annual Meeting
Europa Explorer Update

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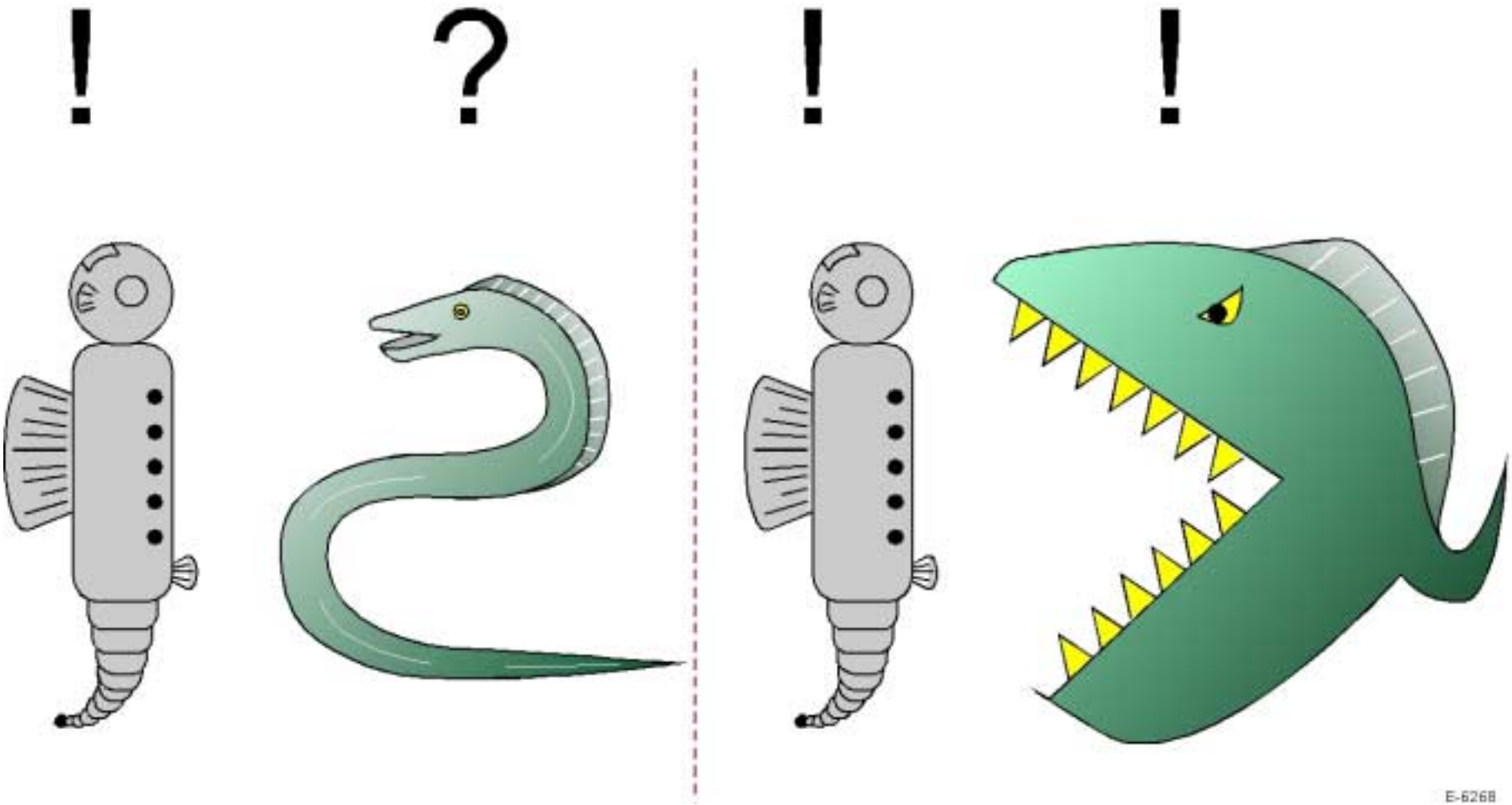

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