Roadmaps to Ocean Worlds

OPAG Update
February 2017

Amanda Hendrix (PSI), Terry Hurford (GSFC)
co-chairs

Congressional Direction

- From the Commerce, Justice, Science, and Related Agencies Appropriations Bill, 2016
  - **"…The Committee directs NASA to create an Ocean World Exploration Program whose primary goal is to discover extant life on another world using a mix of Discovery, New Frontiers and flagship class missions consistent with the recommendations of current and future Planetary Decadal surveys**."
- Connected to the view of Ocean Worlds as perhaps habitable and potentially inhabited worlds

OPAG Charge to ROW

- *OPAG chartered ROW; we are coordinating with SBAG since some "SBAG-owned" bodies could be ocean worlds*
- Identify and prioritize science objectives for Ocean Worlds
  - tied to the Decadal Survey
- Design roadmap to explore these worlds to address science objectives
  - Mission sequences, sustained exploration effort
- Assess where each Ocean World fits into the overall roadmap
- Summarize broad mission concepts
  - Considering mission dependences & international cooperation
- Recommend technology development and detailed mission studies in support of the next decadal survey
- Place exploration of Ocean Worlds into the larger context of Solar System exploration

Philosophy on Ocean Worlds

What is an Ocean World?

- We want to be inclusive!
- All bodies which plausibly can have or are known to have an ocean will be considered as part of this study
- A goal is to study the entire spectrum of Ocean Worlds... to understand life in the context of all Ocean Worlds.
  - If we focus on one target and find life, we won't be done!
  - Why would life evolve at one world at not another?
  - Why would life take a particular form at one world and a different one at another?
- It's important to consider ties to the Earth and Earth's ocean here too
- For each of these worlds, after we carefully consider overall/general science objectives, we will subdivide into groups to consider what questions need to be addressed at a target level, and potential mission plans
  - So we'll get into target-based discussions a bit later in the process

Team members

Amend, Jan
Aye, Michael
Bannister, Michele
Barge, Laurie
Beauchamp, Patricia
Beddingfeld, Chloe
Bland, Michael
Bowman, Jeff
Braun, Bobby
Brinckerhoff, William
Buratti, Bonnie

Byrne, Paul
Cable, Morgan
Cabrol, Nathalie
Cartwright, Richard
Castillo-Rogez, Julie
Collins, Geoffrey
Cooper, John
Crary, Frank
Dhingra, Rajani
Diniega, Serina
Elder, Catherine

Emerson, Dave
Eubanks, Marshall
Furfaro, Roberto
German, Chris
Glein, Chris
Goodman, Jason
Hand, Kevin
Hayes, Alex
Hibbard, Kenneth
Hibbitts, Karl
Hoehler, Tori

Holler, Bryan
Hosseini, Sona
Howett, Carly
Kargel, Jeffrey
Lindensmith, Chris
Lopes, Rosaly
MacKenzie, Shannon
Malaska, Michael
Martin, Emily
McKay, Chris
Metzger, Philip

Moore, Jeff,
Neish, Catherine
Neveu, Marc
Nordheim, Tom
Olkin, Cathy
Pappalardo, Robert
Patterson, Wes
Patthoff, Alex
Phillips, Cynthia
Pontefract, Alexandra
Portyankina, Ganna

Poston, Michael
Quick, Lynnae
Rhoden, Alyssa
Ricco, Antonio
Schaible, Micah
Schaible, George
Schenk, Paul
Schmidt, Britney
Scully, Jennifer
Sherwood, Brent
Shock, Everett

Singer, Kelsi
Soderblom, Jason
Sotin, Christophe
Such, Pamela
Turtle, Elizabeth
Vance, Steve
Verbiscer, Anne
Walker, Catherine
Westlake, Joseph
Wray, James

Target teams

- We formed target teams for the following (groups of) targets
  - Enceladus
  - Europa
  - Pluto, Charon & KBOs
  - Ceres & small bodies
  - Ganymede and Callisto
  - Triton
  - Titan
  - Other satellites (“up and coming”)
- Target teams assessed the status of each target: how well are each of the Theme science questions known, what do we know about them, what is their level of their “ocean-worldness”

GOI Document

Table of Contents

Goals, Objectives, Investigations report

- Almost done!
  - Thanks to all for inputs
- Target Teams and Theme/Goal teams provided text covering what is known, and what still needs to be learned about each body, for the GOI document

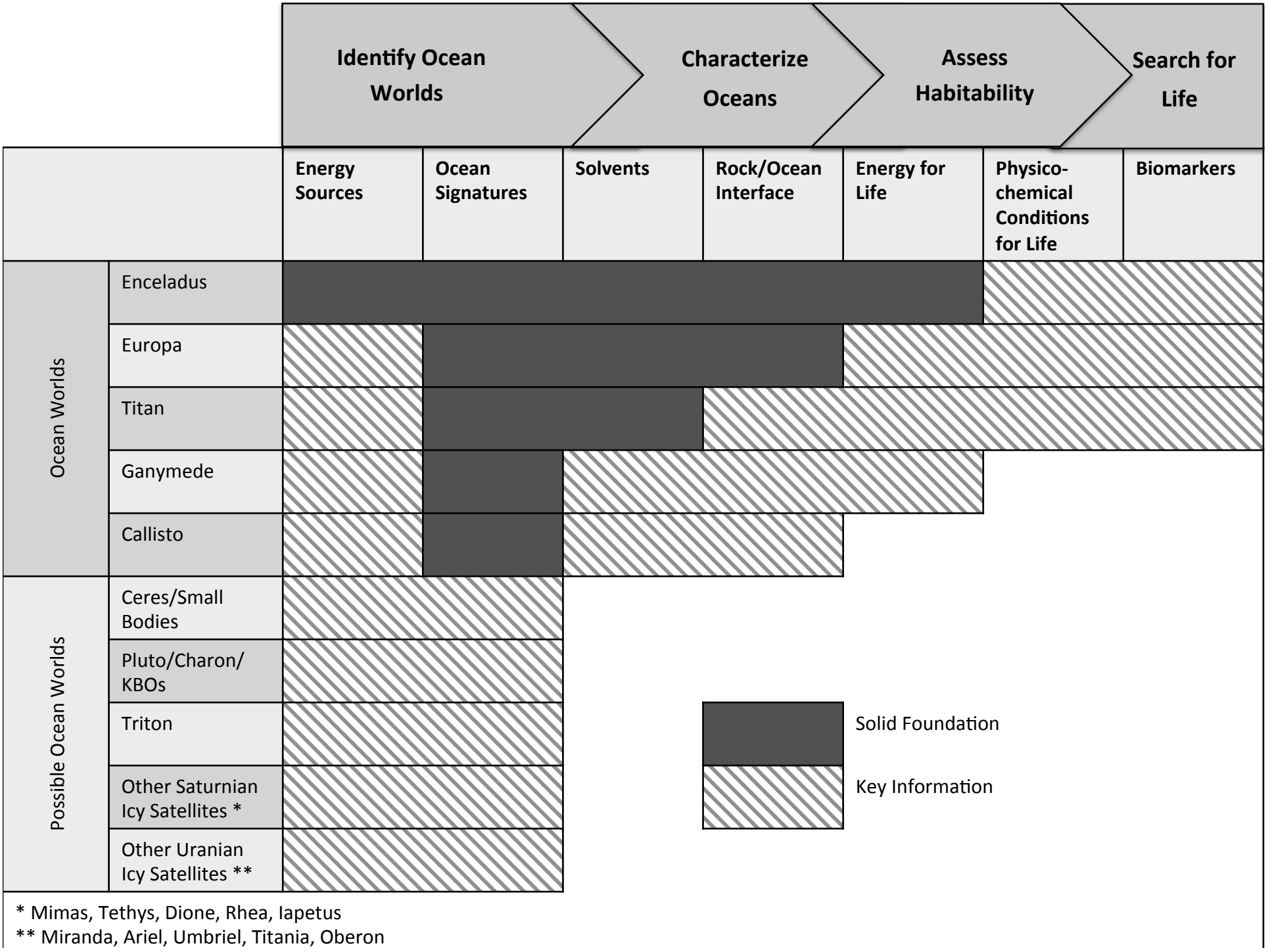
Overarching Goal

- The ROW team has focused on a draft for the main goal for Ocean Worlds in order to start formulating driving science questions:

Identify ocean worlds, evaluate their habitability, and search for life

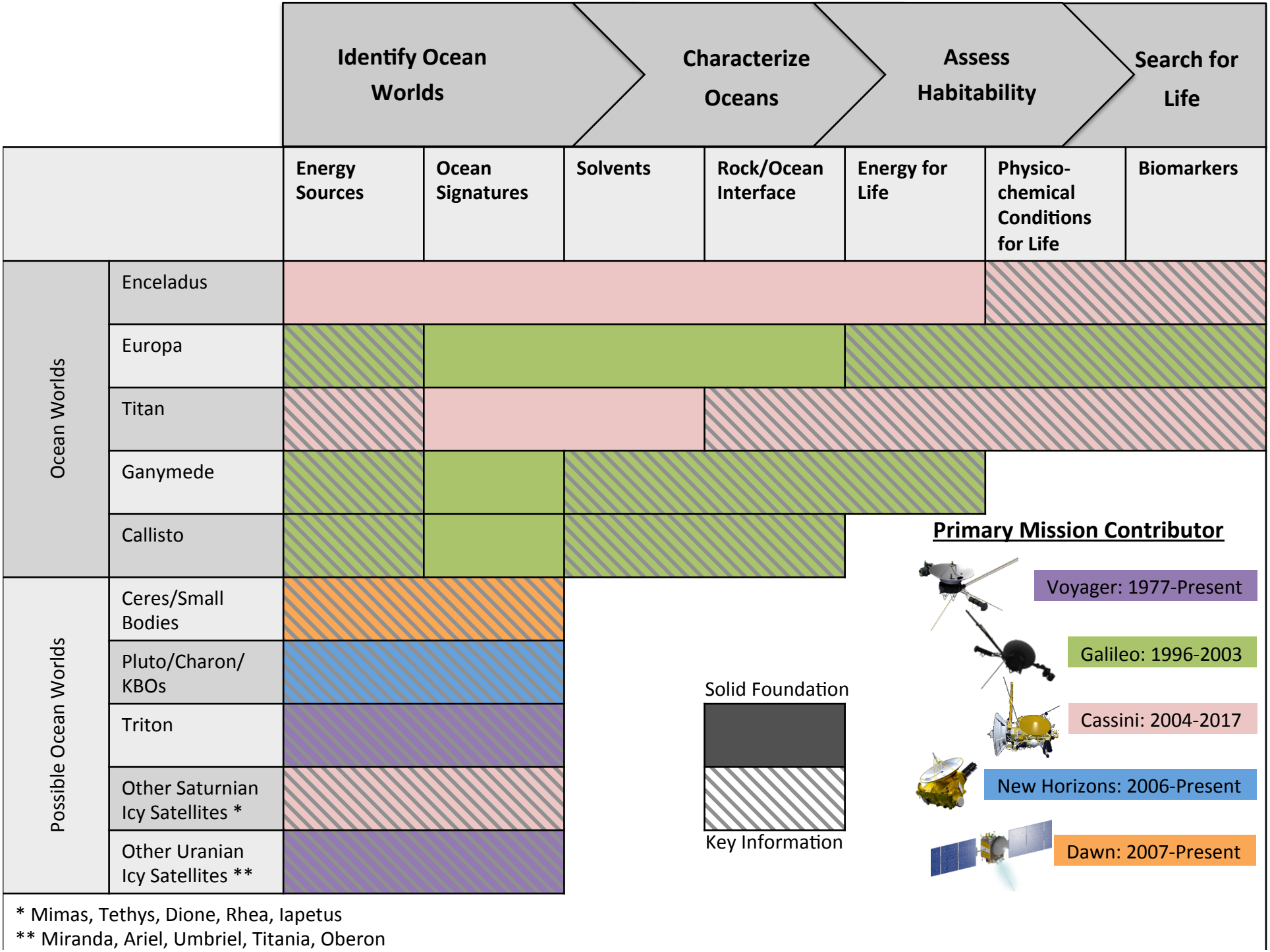
Ocean World Themes

- Four themes
  - Identify ocean worlds
  - Characterize Oceans
  - Assess Habitability
  - Search for Life
- Theme groups came up with an initial set of science questions for each theme
  - Ranging from high level to very detailed



* Mimas, Tethys, Dione, Rhea, Iapetus

** Miranda, Ariel, Umbriel, Titania, Oberon


Identify Ocean Worlds
Characterize Oceans
Assess Habitability
Search for Life
Energy Sources
Ocean Signatures
Solvents
Rock/Ocean Interface
Energy for Life
Physico-chemical Conditions for Life
Biomarkers
Ocean Worlds
Enceladus
Europa
Titan
Ganymede
Callisto
Possible Ocean Worlds
Ceres/Small Bodies
Pluto/Charon/ KBOs
Triton
Other Saturnian Icy Satellites *
Other Uranian Icy Satellites **
Solid Foundation
Key Information
Primary Mission Contributor
Voyager: 1977-Present
Galileo: 1996-2003
Cassini: 2004-2017
New Horizons: 2006-Present
Dawn: 2007-Present
* Mimas, Tethys, Dione, Rhea, Iapetus
** Miranda, Ariel, Umbriel, Titania, Oberon

Theme 1: Identify ocean worlds in the solar system

- Is there a sufficient energy source to support a persistent ocean?
  - Is there remnant radiogenic heating?
  - Is there gravitational energy from a parent planet or satellite?
  - Can the planet or satellite convert available tidal energy into heat?
  - Are the planet's or satellite's orbital or rotational properties favorable to tidal dissipation?
- Are signatures of ongoing geologic activity (or liquids) detected?
  - Do signatures of geologic activity indicate the possible presence of a subsurface ocean? (surface hotspots, plumes, crater-free areas, volcanoes, tectonics)
  - Does the body exhibit tidal and/or rotational evidence indicating the presence of a sub-surface ocean?
  - Does the gravity and topography of the body indicate the presence of a sub-surface ocean?
  - Are temporal changes observed at the body that would indicate the presence of a sub-surface ocean?
  - Is there an atmosphere or exosphere that could be linked with the presence of a sub-surface ocean?
  - Does the electromagnetic response of the body indicate the presence of a sub-surface ocean?
  - Can the surface composition be linked with the presence of a sub-surface ocean?
  - Is the signature of a surface liquid observed (e.g. specular reflection)?
- How do materials behave under conditions relevant to any particular target body? (*R&A*)
  - What are the phase relations of material composing ocean worlds at relevant pressures and temperatures?
  - What is the composition and chemical behavior of materials composing ocean worlds?
  - What are the rheologic mechanisms by which material deforms under conditions relevant to ocean worlds?
  - How does energy attenuation/dissipation occur under conditions relevant to ocean worlds?
  - What are the thermophysical properties of material under conditions relevant to ocean worlds?

Theme 2: Characterize the ocean of each ocean world

- Characterize the ocean's physical properties
  - What is the thickness, composition, and porosity of the ice shell (crust) and how do these properties vary spatially and /or temporally?
  - What is the thickness, salinity, density and composition of the ocean? How do these properties vary spatially and /or temporally?
  - What are the drivers for, and pattern of, fluid motion within the ocean?
- Characterize the ocean interfaces
  - Characterize the seafloor, including the high-pressure ocean – silicate interaction
  - Characterize the ice-ocean interface

Theme 3: Characterize the habitability of each ocean world

- What is the availability (type and magnitude/flux) of energy sources suitable for life, how does it vary throughout the ocean and time, and what processes control that distribution?
  - What environments possess redox disequilibria, in what forms, in what magnitude, how rapidly dissipated by abiotic reactions, and how rapidly replenished by local processes?
  - (Where) is electromagnetic (or other energetic) radiation available? In what wavelengths (or energy) and intensity?
- What is the availability (chemical form and abundance) of the biogenic elements, how does it vary throughout the ocean and time, and what processes control that distribution?
  - What is the inventory of organic compounds, what are their sources and sinks, and what is their stability with respect to the local environment?
  - What is the abundance and chemical form of nitrogen, oxygen, phosphorus, sulfur, and inorganic carbon, what are their sources and sinks, and are there processes of irreversible loss or sequestration relative to the liquid environment?

Theme 4: Understand how life might exist at each ocean world and search for life

- What are the potential biomarkers in each habitable niche? (determine what we're looking for)
  - What can we learn about life on ocean worlds from studying Earth?
  - What niches for life are possible on ocean worlds?
  - What can we learn about life by understanding the history of ocean worlds from their formation to the present?
  - What should be our target indicators? (Life Detection Ladder)
  - How do we distinguish extant from extinct life in environments in which life might develop, and which timescales (e.g., for metabolism, reproduction, dormancy) matter?
- How to search for and analyze data in different environments?
  - How can we look for extant life on an ocean world remotely (from orbit or during a flyby)?
  - How can we look for extant life on an ocean world in situ (landed, underwater, plume) investigations?
  - How can we look for extant life on an ocean world with sample return science?
  - Which science operational strategies should be used to detect life on ocean worlds?

Ocean Worlds Missions Scenarios, Roadmaps & Technologies

- Target Teams have provided
  - input on key measurements needed to move our understanding of each target forward
  - input on future mission types needed
- Technology sub-group (P. Beauchamp) has provided
  - Input on needed technologies

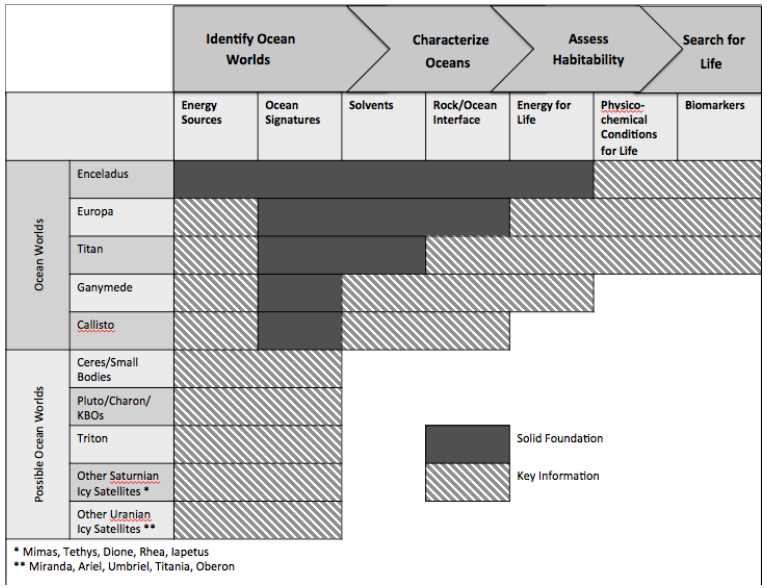
needed technologies

(general, not specific to a mission scenario)

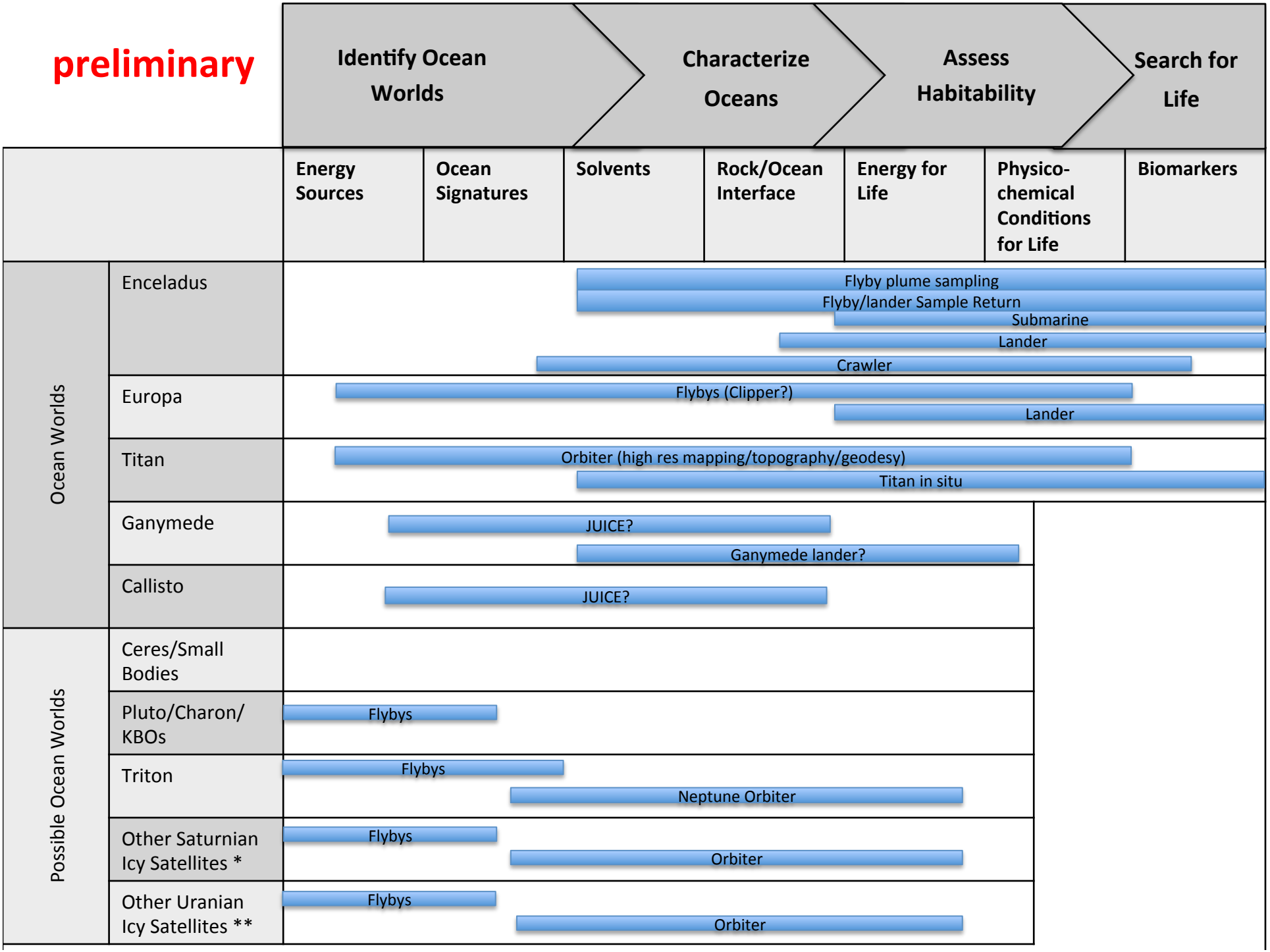
- Instruments
  - Life detection instruments for Ocean Worlds
  - Low mass, low power instruments (e.g., mass spectrometers, imagers) designed for cold, high-radiation ocean world environments
  - Low mass, low power instruments for small spacecraft
- Spacecraft
  - Pin-point landing on Europa/Enceladus (no atm) and Titan (atm)
  - Landing hazard avoidance
  - Surface cryogenic ice sample acquisition and handling
  - Sub-surface (> 0.2m) ice acquisition and handling
  - Low temp-compatible batteries
  - Low temp-compatible, low power, rad-hard electronics
  - Low temp-compatible actuators/mechanisms
  - Planetary Protection techniques/component and material compatibility
  - Ice sample return technologies
  - System and Sub-system Autonomy
  - High Performance computing
  - Small spacecraft technologies (miniaturizing is good….)

Mission strategies & roadmaps - considerations

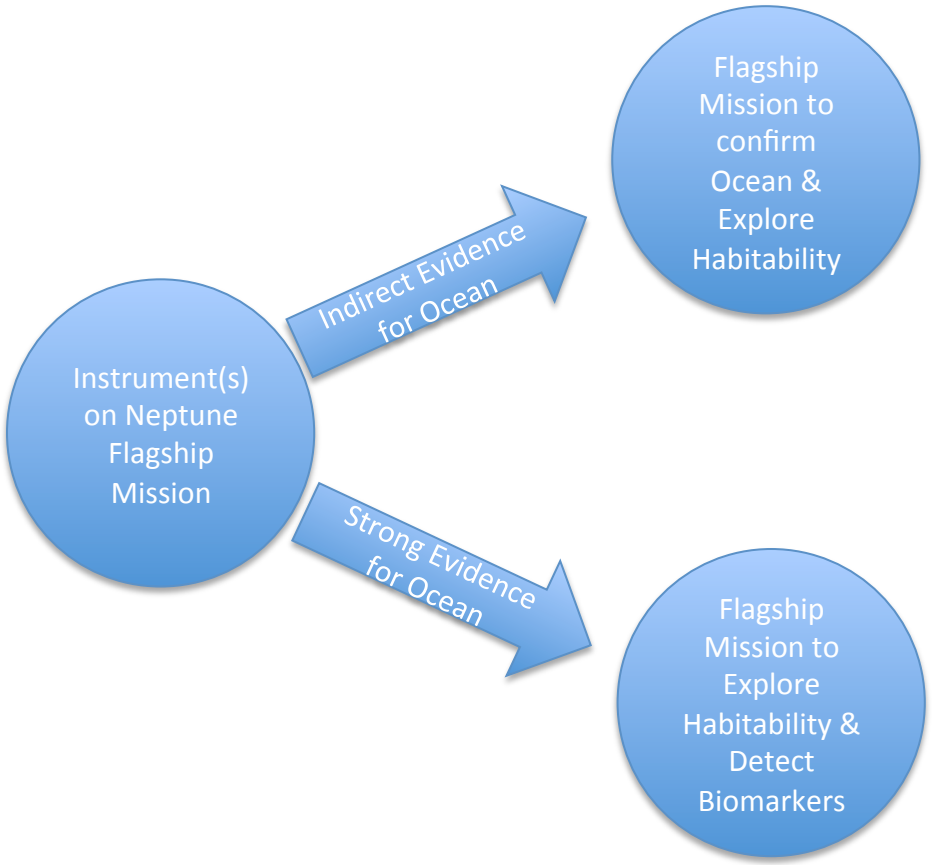
- Want to put together a long-term plan to study ocean worlds and look for life
- The philosophy is to tackle all OWs ~simultaneously, to extend the "knowledge bars" in the Investigations Roadmap (below)
  - Using different mission classes (e.g. small, medium, large)
  - Highest priority for initial mission(s) might be to go after detecting/searching for life at known/accessible oceans
    - But also want to keep as a high priority (maybe a different mission class?) looking for oceans
- Considering that we might expect ~3 SLS launches per decade
- Some OW missions may not require SLS launch
- Some OW missions are already in the
  - Europa Clipper
  - Europa lander
  - JUICE
  - New Frontiers – could be Enceladus
- The assembly of an OW roadmap(s) is complicated and in progress



preliminary



We can also consider a roadmap for each OW: Triton Example



preliminary

Current & Future Activities

- In the future:
  - Vision 2050 workshop
  - Townhall at LPSC
  - Within ROW, collate and vet mission concepts and measurements needed to address science questions
    - Put into Ocean Worlds Missions Scenarios, Roadmaps & Technologies document
  - Provide draft GOI document to OPAG/SBAG (and larger community?) for initial feedback (Feb 2017)
- Ultimately the ROW documents will be provided to the Decadal mid-term review committee and to the next Decadal Survey group
  - To hopefully influence them to create an Ocean Worlds program