Getting Flight Missions to Flight

Karla B. Clark
Jet Propulsion Laboratory
California Institute of Technology
Bring the Universe to You

~5000 Employees
~4000 technical
~30% BS/BA
~35% MS
~35% PhD

~$1.5B annual budget

Images courtesy of NASA/JPL-Caltech unless otherwise stated
Spacecraft and instruments across the solar system (and beyond)

- Spitzer
- ACRIMSAT
- GALEX
- Two Voyagers
- Kepler
- Wide Field Planetary Camera 2
- Mars Reconnaissance Orbiter
- Dawn
- Mars Odyssey
- Opportunity
- Spirit
- Cassini
- Stardust-NExT
- CloudSat
- Deep Impact-Epoxi
- Diviner lunar radiometer instrument
- (Plus ASTER, MISR, TES, MLS, AIRS, M3 and MIRO instruments)
- GRACE
- Kepler
- Herschel/Planc k with JPL instruments
- QuikSCAT
- Jason 1 and Jason 2
The Beginning of the Cycle

Scientific Research

Science Observations Concepts

New Measurement Idea

Mission Concept Formulation

Community Endorsement

Enabling Technology

Images courtesy of NASA/JPL-Caltech unless otherwise stated
The Middle of the Life Cycle

1. Mission Concept Formulation
2. Proposals
3. Mission Design
4. Spacecraft and Instrument Development
5. Integration and Test
6. Environmental Test
The End of the Life Cycle – or is it just the beginning?

Environmental Test → Launch → Real Time Operations → Data Analysis & Science Return → Scientific Research

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Timing

• Alignment of community is crucial
  – Assessment groups and Space Studies Board
  – Presidential and Congressional Science Advisor

• Acceptance of proposals
  – Congressional leanings
  – Budgets - overruns of other missions

• Proposals are often submitted more than once
  – Once accepted – need to be continually re-sold

Getting the go-ahead for a mission often takes longer than actually building and launching it
# Tracing Mission to Science

<table>
<thead>
<tr>
<th>Science Goals</th>
<th>Science Objectives</th>
<th>Observables</th>
<th>Physical parameters</th>
<th>Instrument Functional Requirements</th>
<th>Projected Performance</th>
<th>Mission Functional Requirements (Top Level)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goal 1</td>
<td></td>
<td>Absorption line</td>
<td>Column density of absorber</td>
<td>Alt. Range</td>
<td>XX km</td>
<td>ZZ km</td>
</tr>
<tr>
<td>Goal 2</td>
<td></td>
<td>Emission line</td>
<td>Density and temperature of emitter</td>
<td>Vert. Resol.</td>
<td>XX km</td>
<td>ZZ km</td>
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<tr>
<td>Etc.</td>
<td>Objective 1</td>
<td>Size of features</td>
<td></td>
<td>Horiz. Resol.</td>
<td>XX deg x XX lat x XX long</td>
<td>ZZ deg x ZZ lat x ZZ long</td>
</tr>
<tr>
<td>Objective 2</td>
<td>Objective 2 to N</td>
<td>Rise time of eruptive phenomenon</td>
<td>Temp. Resol.</td>
<td>XX min</td>
<td>ZZ min.</td>
<td>Need AA months of observation to observe variability of phenomena</td>
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<td></td>
<td></td>
<td>Rate of change of observable phenomenon</td>
<td>Precision</td>
<td>XX K</td>
<td>ZZ K</td>
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<td></td>
<td></td>
<td>Repeat above categories</td>
<td>Accuracy</td>
<td>XX K</td>
<td>ZZ K</td>
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</tr>
</tbody>
</table>
### Europa Goal, Objectives, Investigations

<table>
<thead>
<tr>
<th>Goal</th>
<th>Science Objective</th>
<th>Science Investigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>F. Neighbors</td>
<td>Determine how the components of the Jovian system operate and interact, leading to potentially habitable environments in icy moons.</td>
<td>F1. Determine the nature and history of the geological activity and interior evolution of the Galilean satellites. F2. Understand the processes that determine the composition, structure and dynamics of the Jovian atmosphere as a type example of a gas giant planet. F3. Study the interactions between Jupiter's magnetosphere and its satellites.</td>
</tr>
</tbody>
</table>

### Europa Explorer Themes:

- **Origins**
- **Evolution**
- **Processes**
- **Habitability**
- **Life**
# Links between Investigations and Instruments: Europa Science

## Example

<table>
<thead>
<tr>
<th>Objective</th>
<th>Science Investigation</th>
<th>RS</th>
<th>LA</th>
<th>IPR</th>
<th>VIRIS</th>
<th>UVS</th>
<th>INMS</th>
<th>WAC +MAC</th>
<th>NAC</th>
<th>TI</th>
<th>MAG</th>
<th>PPI</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. OCEAN: Characterize the extent of the ocean and its relationship to the deeper interior.</td>
<td>Determine the amplitude and phase of the gravitational tides.</td>
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<td>Characterize the magnetic environment (including plasma), to determine the induction response from the ocean, over multiple frequencies.</td>
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<td>Characterize surface motion over the tidal cycle.</td>
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<td>Determine the satellite's dynamical rotation state.</td>
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<td>Investigate the core, rocky mantle, and rock-ocean interface.</td>
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<td>B. ICE: Characterize the ice shell and any subsurface water, including heterogeneity, and the nature of surface-ice-ocean exchange.</td>
<td>Characterize the distribution of any shallow subsurface water.</td>
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<td></td>
<td>Search for an ice-ocean interface.</td>
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<td>Correlate surface features and subsurface structure to investigate processes governing material exchange among the surface, ice shell, and ocean.</td>
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<td>Characterize regional and global heat flow variations.</td>
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<tr>
<td>C. CHEMISTRY: Determine global surface compositions and chemistry, especially as related to habitability.</td>
<td>Characterize surface organic and inorganic chemistry, including abundances and distributions of materials, with emphasis on indicators of habitability and potential biosignatures.</td>
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<td>Relate compositions to geological processes, especially material exchange with the interior.</td>
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<td>Characterize the global radiation environment and the effects of radiation on surface composition, atmospheric composition, albedo, sputtering, sublimation, and redox chemistry.</td>
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<td>Characterize the nature of exogenic materials.</td>
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<tr>
<td>D. GEOLOGY: Understand the formation of surface features, including sites of recent or current activity, and identify and characterize candidate sites for future in situ exploration.</td>
<td>Determine the formation history and three-dimensional characteristics of magmatic, tectonic, and impact landforms.</td>
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<td>Determine sites of most recent geological activity, and evaluate future landing sites.</td>
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<td></td>
<td>Investigate processes of erosion and deposition and their effects on the physical properties of the surface debris.</td>
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</tbody>
</table>

JEO science investigations are well addressed by the model payload, and instruments are Primary (P) or Secondary (S) in addressing multiple investigations.
Europa Mission Design: Example

• Interplanetary trajectories feature gravity assists to greatly reduce the required specific energy of launch
• Jupiter Orbit Insertion occurs low in Jupiter's gravity well, significantly reducing \( \Delta V \)
• Gravity-assist tour of Jovian satellites greatly reduces size of Europa Orbit Insertion maneuver
### Europa Science Value: Example

<table>
<thead>
<tr>
<th>Objective</th>
<th>Investigation</th>
<th>Instrument</th>
<th>Jupiter System Science</th>
<th>1 GlobFlanck</th>
<th>2 RegionProc</th>
<th>3 TarProc</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1A</td>
<td>1B</td>
<td>2A</td>
</tr>
<tr>
<td>B - Ice</td>
<td></td>
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<td>5</td>
<td>5</td>
<td>4</td>
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</tbody>
</table>

- **B1**: Characterize the phase, size and any subterranean, including their heterogeneity, and the nature of surface ice-ocean exchange.
  - **B1a**: Radar sounding (nominal 50 MHz, with ~10 MHz bandwidth)
  - **B1b**: Wide angle camera (stereo) and laser altimeter
- **B2**: Search for an ice-ocean interface.
  - **B2a**: Radar sounding (nominal 50 MHz, with ~1 MHz bandwidth)
  - **B2b**: Wide angle camera (stereo) and laser altimeter
- **B3**: Correlate surface features, subterranean, structure on the characteristics governing material exchange among ice, surface, and ocean.
  - **B3a**: Radar sounding (dual frequency, nominal ~50 MHz, with 1~50 MHz bandwidth)

Science objectives are mapped to mission design phases.
Looking back …

• Identify your critics and work to make them part of the team
• Small science community – factions can rally together or split the community apart
• Shifting priorities at NASA made advocacy increasingly important
• Importance of precursor science – learn what was essential for previous instrument/mission design
• Invest in enabling technology
• International partnerships essential to mature technology and acquire credibility
• Persistence is the key to successful investigations. They are successful only after the data analysis is complete, and funding for science is always at risk and frequently cut
• Make it fun along the way – celebrate your successes
Why Do I Do This?

- Science knowledge
Why Do I Do This?

- Science knowledge
- Engineering challenge
Why Do I Do This?

- Science knowledge
- Engineering challenge
- People
It’s Worth It

• Timelines can be months to decades
• The challenges are continuous
  – Technical
  – Scientific support
  – Congressional support
• In the end, it comes down to the people you work with
  – Premier scientists, engineers, managers, technicians and business people

A passion to learn unites us all