Planetary Science Division Status Report

James L. Green
NASA, Planetary Science Division
October 5, 2015

Presentation at PSS
Europa

BepiColombo (ESA)

Cassini (NASA/ESA)

Juno

Lunar Reconnaissance Orbiter

New Horizons

Rosetta (ESA)

Dawn

JUICE (ESA)

OSIRIS-REx

NEOWISE

Mars Express (ESA)

Mars Odyssey (ESA)

Mars Rover 2020

MRO

MAVEN

ExoMars 2016 (ESA)

ExoMars 2018 (ESA)

Opportunity Rover

Curiosity Rover

InSight
Outline

• Mission Events Overview
• Discovery, New Frontiers & Mars Exploration Programs
• Europa Mission Status
• New Cubesat Selections
• New Studies Initiated
Planetary Science Missions Events

2014
July – Mars 2020 Rover instrument selection announcement
August 6 – 2nd Year Anniversary of Curiosity Landing on Mars
September 21 – MAVEN inserted in Mars orbit
October 19 – Comet Siding Spring encountered Mars
September – Curiosity arrives at Mt. Sharp
November 12 – ESA’s Rosetta mission lands on Comet Churyumov–Gerasimenko
December 2/3 – Launch of Hayabusa-2 to asteroid 1999 JU₃

* Completed

2015
March 6 – Dawn inserted into orbit around dwarf planet Ceres
April 30 – MESSENGER spacecraft impacted Mercury
May 26 – Europa instrument Step 1 selection
July 14 – New Horizons flies through the Pluto system
September – Discovery 2014 Step 1 selection
December 7 – Akatsuki inserted into orbit around Venus

2016
January – Launch of ESA’s ExoMars Trace Gas Orbiter
March 4 – Launch of InSight
July 4 – Juno inserted in Jupiter orbit
September – Discovery 2014 Step 2 selection
September – InSight Mars landing
September – Launch of Asteroid mission OSIRIS – REx to asteroid Bennu
September – Cassini begins to orbit between Saturn’s rings & planet
MESSENGER: BY THE NUMBERS

- 8.73 BILLION miles traveled
- 32.5 TRIPS around the Sun
- 291,008 IMAGES returned to Earth
- 41.25 MILLION SHOTS by the Mercury Laser Altimeter
- 10 TERABYTES of science data released to public
- 91,730 MPH average speed (relative to the Sun)
- 4,100 ORBITS of Mercury completed
- 1,504 EARTH DAYS in orbit
- 8 MERCURY SOLAR DAYS and
- 0 MILES lowest altitude above Mercury
- 6 FLYBYS of the inner planets

APL JOHNS HOPKINS APPLIED PHYSICS LABORATORY

Carnegie Institution for Science
MESSENGER

The graph shows the minimum altitude above terrain (in km) and latitude over time. Key events include OCM-13, OCM-14, OCM-15, OCM-16, and OCM-17. The graph also highlights periods with limited spacecraft communication due to solar conjunction. The probable impact date is marked as April 30, 2015.
EOM for MESSENGER

Impact ~03:26 EDT
Near: 54.4° lat; 210.1° long

Last MESSENGER Image
Dawn’s Approach

Ceres
Size: ~952 km diameter
Rotation: ~9 hours

Capture (March 6)
1st science orbit
Rotation Characterization (RC) 3
13,500 km; April 23, 2015

Tick marks every 2 days

Approach Trajectory

Sun
Ceres Science Orbits

- **Survey Orbit** – started June 5th
  - Duration 7 orbits (22 days)
- **High Altitude Mapping Orbit (HAMO)**
  - Duration ~70 orbits (67 days)
- **Low Altitude Mapping Orbit (LAMO)**
  - Duration 404 orbits (92 days)

Total of ~400 days of operations are planned at Ceres
Ceres Topography (+/- 7 km)

Mapping completed during the Survey Orbit sequence
Ceres Topography (+/- 7 km)

Active Water Vapor Regions Observed by ESA's Herschel Space Telescope
Dawn at Ceres: Bright Spots Crater (Ogmios)

Animation by P. Schenk, LPI
Initial HAMO Observations
New Horizons Flyby of the Pluto System
Closest Approach On July 14, 2015

- Charon-Earth Occultation 14:20:09
- Pluto-Earth Occultation 12:52:30
- Charon-Sun Occultation 14:17:50
- Pluto-Sun Occultation 12:51:28
- Charon C/A 12:04:00 29,432 km 13.87 km/s
- Pluto C/A 11:50:00 13,695 km 13.78 km/s
- Orbit Period: Charon 6.4 d 19,571 km
  Nix 24.9 d 48,675 km
  Hydra 38.2 d 64,780 km
Methane Snow
Nitrogen Snow
Carbon Monoxide Snow
Pluto’s Atmosphere

Pluto's temperature is about 43 K (−230 °C)

Main N₂

Other Volatiles (trace gas) CH₄, CO

Light Photochemical Products H, H₂, N

Hydrocarbons C₂H₂, C₂H₄, C₂H₆, C₄H₂

Nitriles HCN, C₂N₂

Ions N₂⁺, N⁺, CO⁺, C₂H₅⁺

HAZE

Exchange with Surface
Haze region where complex hydrocarbons (Tholins) are created?
Pluto's Majestic Mountains, Frozen Plains and Foggy Hazes
Majestic Mountains and Frozen Plains
Near-Surface Haze or Fog on Pluto
Discovery and New Frontiers Status
Discovery and New Frontiers

- Address high-priority science objectives in solar system exploration
- Opportunities for the science community to propose full investigations
- Fixed-price cost cap full and open competition missions
- Principal Investigator-led project

- Established in 1992
- **$450M cap** per mission excluding launch vehicle and operations phase (FY15$)
- Open science competition for all solar system objects, except for the Earth and Sun

- Established in 2003
- **$850M cap** per mission excluding launch vehicle and operations phase (FY15$)
- Addresses high-priority investigations identified by the National Academy of Sciences
Discovery Program

NEO characteristics: NEAR (1996-1999)

Comet internal structure: Deep Impact (2005-2012)
Lunar Internal Structure GRAIL (2011-2012)

Main-belt asteroids: Dawn (2007-2016)
Lunar surface: LRO (2009-TBD)
ESA/Mercury Surface: Strofio (2016-TBD)
Mars Interior: InSight (2016-TBD)
Status of Discovery Program

Discovery 2014 – Selections announced September 30
- About 3-year mission cadence for future opportunities

Missions in Development
- *InSight*: Launch window opens March 4, 2016 (Vandenberg)
- *Strofio*: Delivered to SERENA Suite (ASI) for BepiColombo

Missions in Operation
- *Dawn*: Science observations now in HAMO

Missions in Extended Operations
- *MESSENGER*: Completed low altitude science operations before impact with Mercury
- *LRO*: In stable elliptical orbit, passing low over the lunar south pole
Discovery Selections

Psyche: Journey to a Metal World  
PI: Linda Elkins-Tanton, ASU  
Deep-Space Optical Comm (DSOC)

Lucy: Surveying the Diversity of Trojan Asteroids  
PI: Harold Levison, Southwest Research Institute (SwRI)  
Advanced Solar Arrays

NEOCam: Near-Earth Object Camera  
PI: Amy Mainzer, JPL  
Deep-Space Optical Comm (DSOC)

VERITAS: Venus Emissivity, Radio Science, InSAR, Topography, and Spectroscopy  
PI: Suzanne Smrekar, JPL  
Deep-Space Optical Comm (DSOC)

DAVINCI: Deep Atmosphere Venus Investigations of Noble gases, Chemistry, and Imaging  
PI: Lori Glaze, GSFC
New Frontiers Program

1st NF mission
New Horizons:
Pluto-Kuiper Belt

2nd NF mission
Juno:
Jupiter Polar Orbiter

3rd NF mission
OSIRIS-REx:
Asteroid Sample Return

Launched January 2006
Flyby July 14, 2015
PI: Alan Stern (SwRI-CO)

Launched August 2011
Arrives July 2016
PI: Scott Bolton (SwRI-TX)

To be launched: Sept. 2016
PI: Dante Lauretta (UA)
Status of New Frontiers Program

Next New Frontiers AO - to be released by end of Fiscal Year 2016
  – New ROSES call for instrument/technology investments released

Missions in Development - OSIRIS REx
  • Operate at Bennu for over 400 days.
  • Returns a sample in 2023 that scientists will study for decades with ever more capable instruments and techniques.

Missions in Operation
  – New Horizons:
    • Pluto system encounter July 14, 2015
    • HST identified 2 KBO’s beyond Pluto for potential extended mission
    • NH approved to target small Kuiper Belt object 2014 MU69
  – Juno:
    • Spacecraft is 5.01 AU from the sun and 1.02 AU from Jupiter
    • Orbit insertion is July 4, 2016
Homesteader Program Overview

- The goal of the Homesteader program is to mature technologies such that they can be included as part of a selectable, low risk mission concept proposal submitted in response to the NF AO.
  - The program supports the advanced development of technology relevant to mission concepts for the next two New Frontiers (NF) AOs.
  - 134 Step 1 and 84 Step 2 proposals were received; 8 proposals **totaling $7.9M** were selected

<table>
<thead>
<tr>
<th>PI</th>
<th>Institution</th>
<th>Title</th>
<th>Technology</th>
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<tbody>
<tr>
<td>Steve Squyres</td>
<td>Cornell Univ.</td>
<td>Sample Acquisition, Containment, and Thermal Control Technology for Comet Surface Sample Return</td>
<td>Sample Acquisition</td>
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<tr>
<td>Lori Glaze</td>
<td>GSFC</td>
<td>Venus Entry Probe Prototype</td>
<td>Extreme Environ.</td>
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<td>Ryan Park</td>
<td>JPL</td>
<td>Advanced Pointing Imaging Camera (APIC)</td>
<td>Instrument</td>
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<tr>
<td>Farzin Amzajerdian</td>
<td>LaRC</td>
<td>Navigation Doppler Lidar Sensor for Reliable and Precise Vector Velocity and Altitude Measurements</td>
<td>EDL</td>
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<tr>
<td>Elena Adams</td>
<td>APL</td>
<td>A small low-cost hopping lander (POGO) for asteroid exploration</td>
<td>Probe</td>
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<tr>
<td>Stojan Madzunkov</td>
<td>JPL</td>
<td>Atmospheric Constituent Explorer System for Planetary Probe Missions</td>
<td>Instruments</td>
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<td>Scott Singer</td>
<td>SpectroLab</td>
<td>Active-tracking MEMS Micro-Concentrator for LILT Missions</td>
<td>Power</td>
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<td>Chris Webster</td>
<td>JPL</td>
<td>Tunable Laser Spectrometer Risk Reduction for Saturn Probe and Venus In Situ Explorer NF Missions</td>
<td>Instrument</td>
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</table>
New Frontiers #4 Focused Missions

- Comet Surface Sample Return
- Lunar South Pole Aitken Basin Sample Return
- Trojan Tour & Rendezvous
- Saturn Probes
- Venus In-Situ Explorer
New Frontiers #5 Focused Missions

• Added to the remaining list of candidates:

  Lunar Geophysical Network

  Io Observer
### RPS Mission Planning

<table>
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<th>Mission</th>
<th>Type</th>
<th>Launch Year</th>
<th>Power Reqmnt ($W_e$)</th>
<th>RPS Type</th>
<th>Pu-238 Availability</th>
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<tr>
<td>Mars Science Lab</td>
<td>Operational</td>
<td>2011</td>
<td>100</td>
<td>1 MMRTG</td>
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<tr>
<td>Mars 2020</td>
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<td>2020</td>
<td>120</td>
<td>1 MMRTG + Spare</td>
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<td>New Frontiers 4</td>
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<td>300</td>
<td>3 MMRTG or 2 eMMRTG</td>
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<td>New Frontiers 5</td>
<td>Notional</td>
<td>2030</td>
<td>300</td>
<td>TBD</td>
<td>Requires new</td>
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</table>

- **Potential 5-6 year-cadence for New Frontier mission opportunities**
  - RPS not required for all mission concepts
- **Radioisotope heater units may be used on missions that do not require RPS**
- **Strategic missions often require RPS; 2 highest priority strategic missions in current decadal (Mars 2020 and Europa) are already in work**
  - Mars 2020 will use an MMRTG
  - Europa mission will be solar powered
FY 14 Budget reflects Congressional change to NASA funding of DOE infrastructure

<table>
<thead>
<tr>
<th></th>
<th>FY12</th>
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<td>Thermoelectric Tech Dev</td>
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<td>$3.3</td>
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<td>MMRTG</td>
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<td>$4.7</td>
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<td>Multi-Mission Launch</td>
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<td>$5.4</td>
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<td>Studies/Sys Eng/Safety</td>
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<td>$4.6</td>
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<td>Program Mgmt/E&amp;PO/Misc</td>
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<td>Pu-238 Supply Project</td>
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<td>DOE Operations &amp; Analysis</td>
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<td>$57.4</td>
<td>$57.3</td>
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<td><strong>Total</strong></td>
<td>$92.7</td>
<td>$96.6</td>
<td>$102.8</td>
<td>$100.6</td>
<td>$102.1</td>
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</table>

**Follow the Water**

**Explore Habitability**

**Seek Signs of Life**

**Prepare for Future Human Explorers**
Potential Exploration Zones

1st Human Landing Site Workshop
October 27-30 at LPI
Europa Activities

Now in Formulation (Phase A)
Europa Multi-Flyby Mission Science Goal & Objectives

- **Goal:** Explore Europa to investigate its habitability

- **Objectives:**
  - **Ice Shell & Ocean:** Characterize the ice shell and any subsurface water, including their heterogeneity, ocean properties, and the nature of surface-ice-ocean exchange
  - **Composition:** Understand the habitability of Europa's ocean through composition and chemistry
  - **Geology:** Understand the formation of surface features, including sites of recent or current activity, and characterize high science interest localities
  - **Reconnaissance:** Characterize scientifically compelling sites, and hazards, for a potential future landed mission to Europa
Overview of Selected Proposals

<table>
<thead>
<tr>
<th>Instrument Type</th>
<th>Name</th>
<th>PI</th>
<th>Institution</th>
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<tbody>
<tr>
<td>Plasma</td>
<td>PIMS</td>
<td>Joseph Westlake</td>
<td>APL</td>
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<tr>
<td>Magnetometer</td>
<td>ICEMAG</td>
<td>Carol Raymond</td>
<td>JPL</td>
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<tr>
<td>Shortwave IR Spectrometer</td>
<td>MISE</td>
<td>Diana Blaney</td>
<td>JPL</td>
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<tr>
<td>Camera</td>
<td>EIS</td>
<td>Elizabeth Turtle</td>
<td>APL</td>
</tr>
<tr>
<td>Ice Penetrating Radar</td>
<td>REASON</td>
<td>Don Blankenship</td>
<td>Univ. Texas/JPL</td>
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<tr>
<td>Thermal Imager</td>
<td>E-THEMIS</td>
<td>Phil Christensen</td>
<td>ASU/Ball</td>
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<tr>
<td>Neutral Mass Spectrometer</td>
<td>MASPEX</td>
<td>Hunter Waite</td>
<td>SWRI</td>
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<tr>
<td>UV Spectrograph</td>
<td>E-UVS</td>
<td>Kurt Retherford</td>
<td>SWRI</td>
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<tr>
<td>Dust Analyzer</td>
<td>SUDA</td>
<td>Sascha Kempf</td>
<td>Univ. Colorado</td>
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</table>
Europa Multi-Flyby Mission Concept Overview

### Science

<table>
<thead>
<tr>
<th>Objective</th>
<th>Description</th>
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<tbody>
<tr>
<td>Ice Shell &amp; Ocean</td>
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<td>Geology</td>
<td>Understand the formation of surface features, including sites of recent or current activity, and characterize high science interest localities.</td>
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<tr>
<td>Recon</td>
<td>Characterize scientifically compelling sites, and hazards for a potential future landed mission to Europa</td>
</tr>
</tbody>
</table>

- Conduct 45 low altitude flybys with lowest 25 km (less than the ice crust) and a vast majority below 100 km to obtain global regional coverage
- Traded enormous amounts of fuel used to get into Europa orbit for shielding (lower total dose)
- Simpler operations strategy
- No need for real time down link

### Key Technical Margins

<table>
<thead>
<tr>
<th>*37 - 41%</th>
<th>40%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass</td>
<td>Power</td>
</tr>
</tbody>
</table>

* Depends on Launch Opportunity and Launch Vehicle
Small Innovative Missions for Planetary Exploration (SIMPLEx-2014)
New Awards in FY15
LunaH-Map: Lunar Polar Hydrogen Mapper  
PI: Craig Hardgrove, ASU School of Earth and Space Exploration

(LunaH-Map) is a 6U CubeSat that will enter a polar orbit around the Moon with a low altitude (5-12km) perilune centered on the lunar South Pole. LunaH-Map carries two neutron spectrometers that will produce maps of near-surface hydrogen (H). LunaH-Map will map H within permanently shadowed craters to determine its spatial distribution, map H distributions with depth (< 1 meter), and map the distribution of H in other permanently shadowed regions (PSRs) throughout the South Pole.

Orbit ground track shown for entire 60 (Earth) day science phase: 141 passes over target area initially (and periodically) centered on Shackleton Crater with close-approach of 5 km at each perilune crossing. Yellow circle denotes LunaH-Map altitude of 8 km; green circle denotes LunaH-Map altitude of 12 km.
**Q-PACE**: CubeSat Particle Aggregation and Collision Experiment  
**PI**: Josh Colwell, University of Central Florida

**Q-PACE** is a thermos sized, LEO CubeSat, that will explore the fundamental properties of low-velocity (< 10 m/s) particle collision in a microgravity environment in an effort to better understand the mechanics of early planetoid development.

Q-PACE is a 2U CubeSat with a collision test cell and several particle reservoirs that contain meteoritic chondrules, dust particles, dust aggregates, and larger spherical monomers. Particles will be introduced into the test cell for a series of separate zero gravity experimental runs. The test cell will be mechanically agitated to induce collisions, which will be recorded by on-board video for later downlink and analysis.

Q-PACE has been accepted by the NASA CubeSat Launch Initiative program in the 2015 round of selections.
Simplex Cubesats
Approved for Tech Development (1 year) Study ONLY
The **Mars Micro Orbiter (MMO)** mission uses a 6U-class Cubesat to measure the Mars atmosphere in visible and infrared wavelengths from Mars orbit.

These science measurements will:

1. Extend the temporal coverage of the global synoptic meteorological record of Mars, which includes atmospheric thermal structure, dust and condensate clouds, and seasonal and perennial polar cap behavior,
2. Characterize the dynamics and energy budget of the current Mars atmosphere,
3. Support present and future Mars missions
4. Characterize present-day habitability

The CubeSat can also act as an orbital communication relay for Mars surface-based missions.
HALO: Hydrogen Albedo Lunar Orbiter  
PI: Michael Collier, NASA GSFC

HALO is a propulsion-driven 6U CubeSat with an ion spectrometer that simultaneously observes the impinging solar wind and the reflected ion component with a nadir-facing low-energy neutral atom imager that observes the upward moving neutral hydrogen.

The HALO mission will survey the surface of the Moon for a minimum of 3 months, allowing it to measure multiple trajectories of the solar wind, follow the moon into the wake region of the Earth’s magnetosphere, and sample meteoric impact.

The goal is to measure the flux as a function of location, solar phase angle, subsurface mineralogy, magnetic anomaly condition, and under meteor shower conditions in order to map the potential for the formation of water and OH in the lunar regolith.
DAVID: Diminutive Asteroid Visitor using Ion Drive
PI: Geoffrey Landis, NASA Glenn Research Center

**DAVID** is a 6U CubeSat mission that will investigate an asteroid much smaller than any investigated by previous spacecraft missions and will be the first NASA mission to investigate an Earth-crossing asteroid.

Despite its small size, the DAVID CubeSat will have three primary instruments that would operate for a short-duration flyby, including a wide-field camera, a narrow-field camera and a point VNIR spectrometer.

DAVID will provide critical first-order data on 2001–GP2’s size, shape, composition, and source region in the main belt, while scouting its rotational state and physical properties.
Initiate New Studies
Objective: Examine the program elements of the PSD R&A programs, as they currently exist following restructuring, for their consistency with past NRC advice.

The committee will address the following questions:

1. Are the PSD R&A program elements appropriately linked to, and do they encompass the range and scope of activities needed to support, the NASA Strategic Objective for Planetary Science and the PSD Science Goals, as articulated in the 2014 NASA Science Plan?

2. Are the PSD R&A program elements appropriately structured to develop the broad base of knowledge and broad range of activities needed both to enable new spaceflight missions and to interpret and maximize the scientific return from existing missions?
Ice Giants Study

• Initiate an Ice Giants Study assigned to JPL

• Goal: Assess science priorities and affordable mission concepts & options in preparation for the next Decadal Survey

• Objectives:
  – Identify mission concepts that can address science priorities based on what has been learned since the 2013-2022 Decadal
  – Identify potential concepts across a spectrum of price points
  – Identify enabling/enhancing technologies
  – Assess capabilities afforded by SLS
Study Ground-Rules

- Address both Uranus and Neptune Orbiters
- Target cost range NTE $2B (FY15$) per mission
- Technical aspects to investigate:
  - Determine pros/cons in using one spacecraft design for both missions (possibility of joint development of two copies)
  - Evaluate use of realistic emerging enabling technologies: distinguish mission specific vs. broad applicability
  - Constrain missions to fit on a commercial LV
  - Identify benefits/cost savings if SLS were available (e.g., time, trajectory…)
- Identify clean-interface roles for potential international partnerships
- Establish a Science Definition Team (SDT)
  - ESA has been invited to provide team members
Joint SDT for a Venus Mission

- A Science Definition Team (SDT) was established by NASA and the Russian Academy of Sciences’ Space Research Institute (IKI) to examine potential future Venus mission scenarios that could prove of interest to both of our science communities.

- The SDT held its first meeting in Moscow earlier this month to begin the exchange of ideas and will hold a second meeting in February 2016.

- NASA will await the findings of this team before deciding on a next course of action.
New Communications Policy
The role of science missions in NASA communications has evolved since missions were directed to propose and spend 1% of their total budget on education and public outreach (EPO). In 2014:

– NASA’s policy documents established new definitions for communications.
  • Traditional news and social media, multimedia and public outreach and engagement were consolidated.

– EPO funding was removed from mission budgets.

– Education activities and funding were consolidated within SMD, under the Director for Science Engagement and Partnerships (see K. Erickson presentation)
  • Activities and funding were restructured along science disciplines, not missions.
  • The Director for Science Engagement and Partnerships has responsibility for integrated education strategies within SMD.
NASA’s Definition of Communications

NASA has defined communications as follows:

• A comprehensive set of activities to effectively convey, and provide an understanding and inspiration about NASA's work, its objectives and benefits to target audiences, the public and other stakeholders, including NASA employees.

• These activities are intended to promote interest and foster participation in NASA's endeavors, and to develop exposure to, and appreciation for, Science, Technology, Engineering, and Math (STEM).

NOTE: This SMD policy does not cover technical communications directed at the scientific and technical community including scientific papers, technical reports, and web sites serving mission data and other technical information.
Roles and Responsibilities

NASA Center or JPL Office of Communications

• Missions must use the communications office of a NASA center or JPL to manage the communications plan and activities.

• These communications offices will be responsible for leading, coordinating, and executing mission communications activities -- in coordination with the mission’s Principal Investigator (PI) for PI-led missions -- and with approval of Headquarters SMD and Office of Communications.

• The communications office develops the communications plan with the project and PI during Phase B of the mission.

• Mission-related communications are funded from the project budget (not within the PI’s mission cost cap).
Roles and Responsibilities

Principal Investigators

• The PI is a key spokesperson for the mission – along with NASA officials -- and is integral in communicating mission updates, science, and new discoveries.

• The PI provides content, analysis, and context for communications activities to convey an understanding of the mission, its objectives and benefits to target audiences, the public, and other stakeholders.

• The PI coordinates with the designated NASA center communications office for all mission-related communications activities.
  – All mission news releases are reviewed by the PI (or designee).
  – In the case of incompatible views, NASA has final decision on release of public products, while ensuring that scientific and technical information remains accurate and unfiltered.
Conference Summary & Initial Findings

- Approximately 100 participants gathered for 3.5 days at CCTP2!
- Cross-disciplinary theme: “Understanding How Climate Systems Work”
- Lots of group discussions after all 14 sub-theme sessions
- An official NASA Conference Proceeding (CP) will be the product from the CCTP2 (ext. abstracts (4 pp.); Executive Summary; Key Findings; etc)
- The complete oral program is archived and available for re-streaming at cctp2.arc.nasa.gov
- Formal AGU/Eos Meeting Report is being formulated

Community interest for a new ROSES element on comparative planetary climates or an embellishment within the re-structured PSD R&A elements

- Formal planetary climate models inter-comparison project is desired: benchmarking and assessment of climate model biases
- Ad hoc SOC (early-career volunteers) for CCTP3 (July 2017) has been formulated
Acknowledgements

The Science Organizing Committee (SOC)
Patricia Beauchamp (Caltech/JPL)
David Brain (University of Colorado, Boulder)
Mark Bullock (SWRI)
Anthony Del Genio (NASA GISS)
Lindy Elkins-Tanton (ASU)
Kelly Fast (NASA HQ/PSD)
Francois Forget (CNRS/LMD)
Jonathan Mitchell (University of California, Los Angeles)
Yvonne Pendleton (NASA ARC)
Douglas Rabin (NASA GSFC)
Adam Showman (University of Arizona)
Timothy Titus (USGS)
Robin Wordsworth (Harvard University)

The Local Organizing Committee (LOC)
Jennifer Baer (SSERVI)
Shirley Berthold (SSERVI), Co-Chair
Amanda Brecht (NASA ARC/BAER)
Carrie Chavez (NASA ARC/SETI)
Ricky Guest (SSERVI)
Maria Leus (SSERVI)
Ashcon Nejad (SSERVI)
Sandra Owen (NASA ARC), Co-Chair
Greg Schmidt (SSERVI)

The Ex Officio Program Participants
Richard Eckman (NASA HQ/ESD)
Madhulika Guhathakurta (NASA HQ/HPD)
Adriana Ocampo (NASA HQ/PSD)
Jonathan Rall (NASA HQ/PSD)
Martin Still (NASA HQ/APD)
Thomas Thompson (Caltech/JPL)
Questions?

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