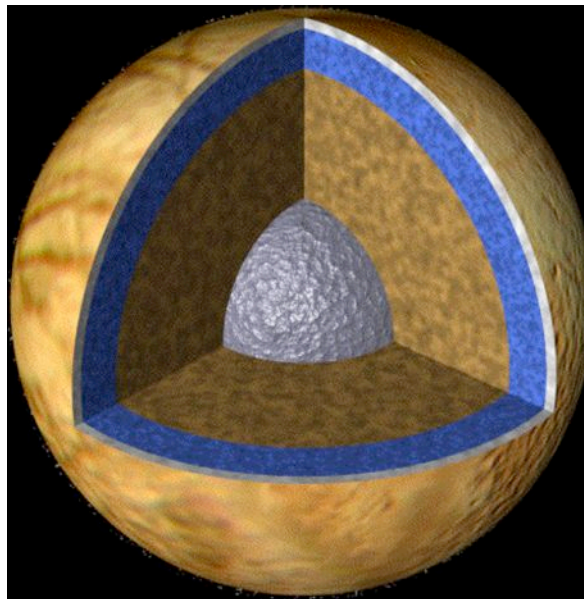


# Protecting Icy Moons:

Planetary Protection



## Implementing Planetary Protection for Outer Planet Satellites



C. Conley, NASA HQ

Information provided by the JUNO project

21 Sept. 2009

# NASA Planetary Protection Policy (NPD 8020.7G): *Protect Science, Protect the Earth*



- “The conduct of scientific investigations of possible extraterrestrial life forms, precursors, and remnants must not be jeopardized.”
  - *avoid forward contamination: don’t “discover” life we brought with us*
- “In addition, the Earth must be protected from the potential hazard posed by extraterrestrial matter carried by a spacecraft returning from another planet or other extraterrestrial sources.”
  - *avoid backward contamination: don’t contaminate the Earth*
- “Therefore, for certain space-mission/target-planet combinations, controls on organic and biological contamination carried by spacecraft shall be imposed in accordance with directives implementing this policy.”
  - *tailor requirements by target location and mission type: don’t require unnecessary measures*
- “This directive applies to NASA Headquarters and NASA Centers, including Component Facilities, and to NASA contractors where specified by contract.”
  - *applies to all NASA missions, human and robotic; referenced in NPR 7120.5*

# Planetary Protection Requirements are based on Scientific Knowledge (NPD 8020.7G, cont.)



- Planetary Protection constraints “will take into account current scientific knowledge about the target bodies through recommendations from both internal and external advisory groups”
  - “Most notably” the Space Studies Board of the NRC
    - *provides recommendations on high-level policy and requirements*
  - Internally, the Planetary Protection Subcommittee of the NASA Advisory Council (formerly the Planetary Protection Advisory Committee)
    - *provides programmatic advice and detailed advice on implementation for individual missions*
    - *includes representatives from other US agencies and international space agencies*
- Specific requirements for robotic missions are detailed in NPR 8020.12, “Planetary Protection Provisions for Robotic Extraterrestrial Missions”
  - signed by SMD AA; applies to all NASA robotic missions
- Additional documents are in preparation to specify requirements for human missions beyond low-Earth orbit
  - to be signed by the SMD AA and ESMD/SOMD AAs for concurrence; top-level requirements under development with ESMD and SOMD, referring to COSPAR



# International Obligations



- The Outer Space Treaty of 1967
  - Proposed to the UN in 1966; Signed in January 1967
  - Ratified by the US Senate on April 25th, 1967
  - Article IX of the Treaty states that:
    - “...parties to the Treaty shall pursue studies of outer space including the Moon and other celestial bodies, and conduct exploration of them so as **to avoid their harmful contamination and also adverse changes in the environment of the Earth resulting from the introduction of extraterrestrial matter** and, where necessary, shall adopt appropriate measures for this purpose...”
- The Committee on Space Research of the International Council for Science maintains an international consensus policy on planetary protection
  - COSPAR policy represents an international scientific consensus, based on advice from national scientific members, including the US Space Studies Board
  - COSPAR is consultative with the UN (through UN COPUOS and the Office of Outer Space Affairs) on measures to avoid contamination and protect the Earth under the Treaty
  - NPR 8020.12 specifies that international robotic missions with NASA participation must follow COSPAR policy, providing a consensus basis for requirements



# The Basic Rationale for Planetary Protection Precautions

(as written by Bart Simpson, Dec. 17, 2000, "Skinner's Sense of Snow")



Science class should not end in tragedy....  
Science class should not end in tragedy....  
Science class should not end in tragedy....  
Science class should not end in tragedy....  
Science class should not

# Planetary Protection Mission Categories



PLANET PRIORITIES	MISSION TYPE	MISSION CATEGORY
A Not of direct interest for understanding the process of chemical evolution. No protection of such planets is warranted.	Any	I
B Of significant interest relative to the process of chemical evolution, but only a remote chance that contamination by spacecraft could jeopardize future exploration. Documentation is required.	Any	II
C Of significant interest relative to the process of chemical evolution and/or the origin of life or for which scientific opinion provides a significant chance of contamination which could jeopardize a future biological experiment. Substantial documentation and mitigation is required.	Flyby, Orbiter	III
	Lander, Probe	IV
All Any Solar System Body	Earth-Return	V <i>“restricted” or “unrestricted”</i>

# Preventing the Forward Contamination of Europa

(Space Studies Board Report released in 2000)

Planetary Protection



- For every mission to Europa, the probability of contaminating a possible european ocean with a viable terrestrial organism at any time in the future should be less than  $10^{-4}$  *per mission*.
- Current cleaning and sterilization techniques are satisfactory to meet the needs of future space missions to Europa.
- Current culture-based method used to determine the bioload on a spacecraft should be supplemented by screening tests for specific types of extremophiles, such as radiation-resistant organisms.
- Modern molecular methods, such as those based on the polymerase chain reaction (PCR), may prove to be quicker and more sensitive to detect and identify biological contamination than NASA's existing culturing protocols.
- Studies should be conducted to improve knowledge of Europa, and define the issues related to minimization of forward contamination, including:
  - Ecology of clean room and spacecraft-assembly areas, with emphasis on extremophiles, such as radiation-resistant microbes
  - Detailed comparisons of bioload assay methods
  - Desiccation- and radiation-resistant microbes that may contaminate spacecraft
  - Autotroph detection techniques; and
  - Europa's surface environment and its hydrologic and tectonic cycles.

# Preventing the Forward Contamination of Europa

## Example Calculation of Probability of Contamination



"The probability of contaminating an European ocean shall be  $\geq 1 \times 10^{-4}$  per mission. The calculation of this probability should include a conservative estimate of poorly known parameters and address the following factors, at a minimum" (COSPAR/NPR 8020.12C)

The number of organisms of type X that could survive on Europa is based on the initial contamination level  $[N_{X0}]$  and various survival factors:

$$N_{Xs} = N_{X0} F_1 F_2 F_3 F_4 F_5 F_6 F_7$$

$F_1$ —Total number of cells relative to cultured cells

$F_2$ —Bioburden Reduction Treatment

$F_3$ —Cruise Survival Fraction

$F_4$ —Radiation Survival Fraction

$F_5$ —Probability of landing at an Active Site

$F_6$ —Burial Fraction

$F_7$ —Probability that an organism survives and proliferates

**N.B.:** This formulation is currently undergoing refinement.

Where the organisms of type X are defined as:

- Type A. Typical, common microorganisms of all types (bacteria, fungi, etc.);
- Type B. Spores of microorganisms, which are known to be resistant to insults (such as desiccation, heat, and radiation);
- Type C. Spores which are especially radiation-resistant; and
- Type D. Rare, but Highly Radiation Resistant non-spore microorganisms (e.g., *Deinococcus radiodurans*).

# Category III/IV Requirements for Europa



Category III and IV. Requirements for Europa flybys, orbiters and landers, including bioburden reduction, shall be applied in order to reduce the probability of inadvertent contamination of an euroman ocean to less than  $1 \times 10^{-4}$  per mission. These requirements will be refined in future years, but the calculation of this probability should include a conservative estimate of poorly known parameters, and address the following factors, at a minimum:

- Bioburden at launch
- Cruise survival for contaminating organisms
- Organism survival in the Jovian radiation environment
- Probability of landing on Europa
- The mechanisms of transport to the euroman subsurface
- Organism survival and proliferation before, during, and after subsurface transfer

# Category III/IV Req.s for Europa (cont.)



- Preliminary calculations of the probability of contamination suggest that bioburden reduction will likely be necessary even for Europa orbiters (Category III) as well as for landers, requiring the use of cleanroom technology and the cleanliness of all parts before assembly, and the monitoring of spacecraft assembly facilities to understand the bioload and its microbial diversity, including specific problematic species.
- Specific methods should be developed to eradicate problematic species. Methods of bioburden reduction should reflect the type of environments found on Europa, focusing on Earth extremophiles most likely to survive on Europa, such as cold and radiation tolerant organisms (SSB 2000).

# Recommendation from the Planetary Protection Subcommittee, 8/7/07



- The Planetary Protection Subcommittee recommends that the standard of a  $10^{-4}$  probability, per mission, of introducing a viable microbe into a liquid water body (e.g., subsurface ocean) be used for Europa and all other icy moons that may have such water bodies, e.g. Ganymede, Callisto, Enceladus, and Titan. (Note: prolonged radiation exposure during flight may be used to help achieve this  $10^{-4}$  standard.) Only when there is convincing evidence that these bodies do not exist at the target, should this standard be relaxed.
- *This defines ‘contamination’ as the introduction of a single viable organism into a liquid water body, therefore removing uncertainties around ‘probability of growth’ (set to 1).*
- *The duration during which contamination is of concern is set by the length of time that organisms remain viable.*

# Preventing Contamination of Icy Moons

## Example Calculation (with some factors revised)



The number of organisms of type X that could survive on an icy body is based on the initial contamination level [ $N_{X0}$ ] and various survival factors:

$$N_{Xs} = N_{X0} F_1 F_2 F_3 F_4 F_5 F_6 F_7 F_8$$

$F_1$ —Total number of cells relative to assayed cells ( $N_{X0}$ )

$F_2$ —Bioburden reduction survival fraction, when/where applied

$F_3$ —Cruise survival fraction

$F_4$ —Radiation survival fraction

$F_5$ —Probability of impacting a protected body

$F_6$ —Probability that an organism survives impact

$F_7$ —Probability of subduction

$F_8$ —Burial survival fraction

Where the organisms of type X are defined as:

- Type A: Typical, common microorganisms of all types (bacteria, fungi, etc.);
- Type B: Spores of microorganisms, which are known to be resistant to insults (e.g., desiccation, heat, radiation);
- Type C: Spores which are especially radiation-resistant; and
- Type D: Rare but highly radiation resistant non-spore microorganisms (e.g., *Deinococcus radiodurans*).



Be prepared for the unexpected...

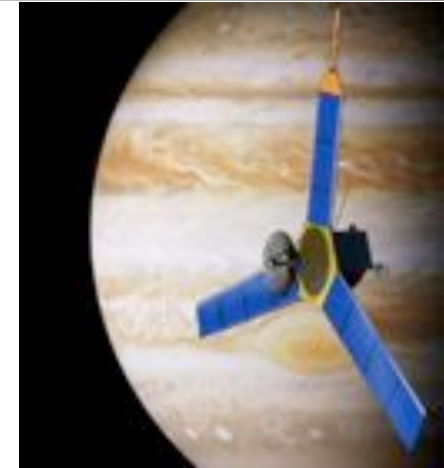
# Juno Implementation Approach



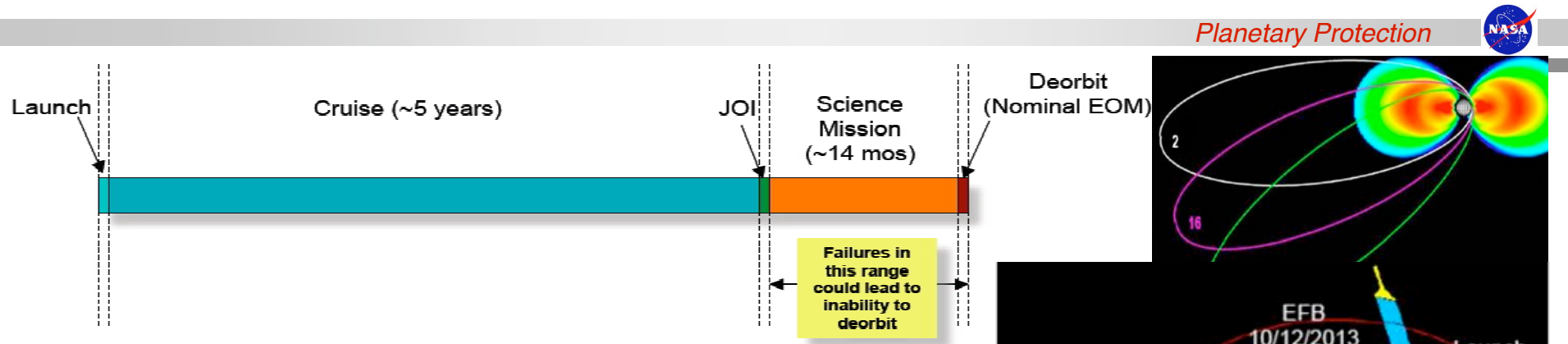
Juno proposed to meet planetary protection requirements by avoiding impact with Europa (and other Galilean satellites) via an End-of-Mission Deorbit Maneuver.

To document a  $1 \times 10^{-4}$  probability of contamination, Juno considered (among others) the following factors:

- How reliable is the spacecraft, over the entire mission phase during which Europa is in jeopardy – i.e., what happens if it stops working by accident?
- How long will organisms survive on the spacecraft – i.e., when does ‘viable’ become moot?
  - Bioburden at launch
  - Survival of contaminating organisms until impact: how lethal is the space environment?
- How likely is an Europa encounter?
- Can organisms survive the impact?
- Mechanisms of transport to the europian subsurface (JUNO didn't need to consider this)

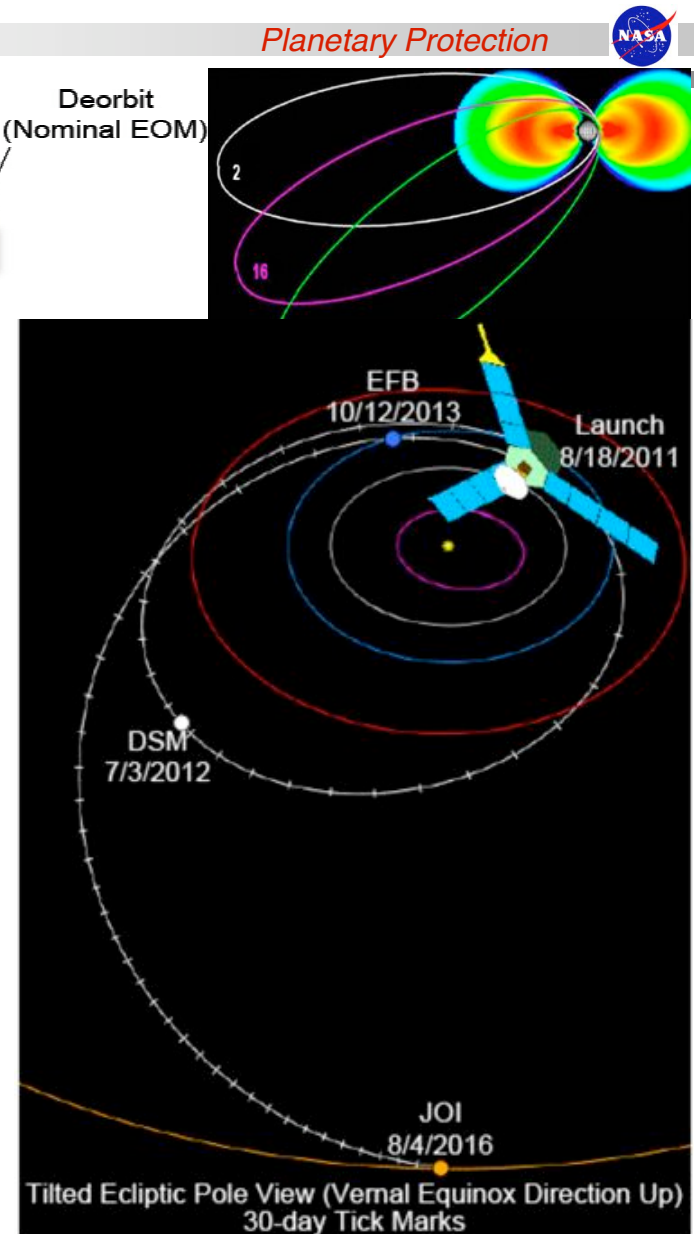


# Spacecraft Reliability



Spacecraft reliability contributes to planetary protection compliance over the period during which a failure might lead to encounters with Europa (or other protected targets). JUNO has allotted a 5% probability of spacecraft failure over the course of the active mission, based on probabilistic risk assessments of hardware and the jovian environment (micrometeoroids, etc.)

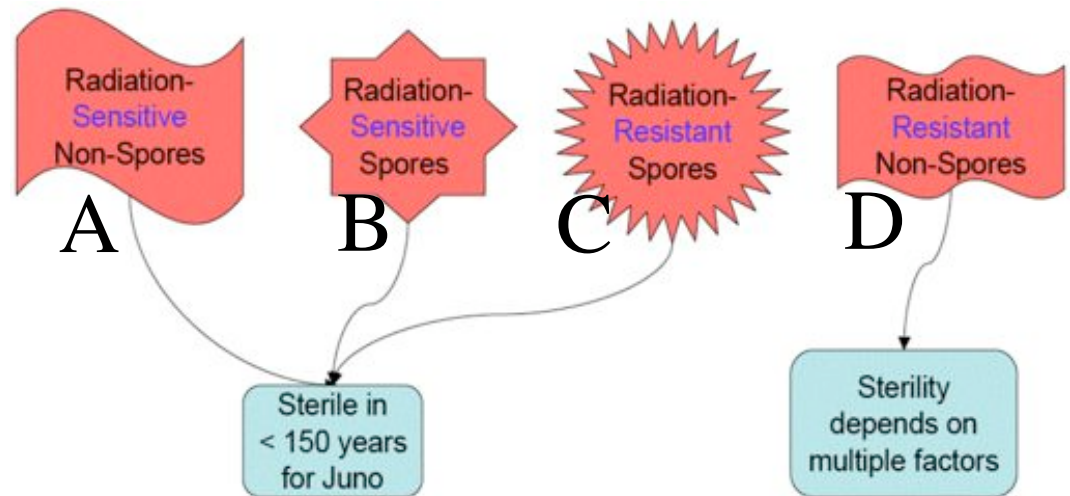
Therefore, JUNO must include additional factors to address the probability of contamination given deorbit burn failure.



# Organism Survival

**JUNO must avoid Europa until all organisms are dead.**

Radiation-sensitive organisms and spores (dormant organisms) that are resistant to radiation are should be dead within 150 years in the radiation environment.



Radiation-resistant non-spores must metabolize to repair radiation damage. Based on the available literature, JUNO was allowed to assume that organisms exposed only to temperatures below  $-80^{\circ}\text{C}$  after spacecraft failure, or in locations where the water activity remained below 0.2, could not metabolize to repair radiation damage. Group D organisms in those conditions were combined with Group A organisms, resulting in spacecraft sterility somewhere between 150 and 300 years.

# Orbital Lifetime



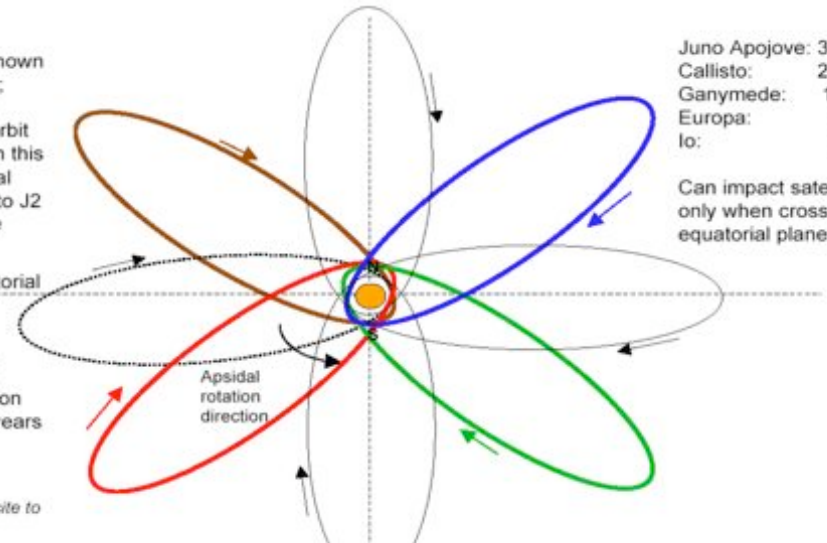
Based on orbital mechanics simulations (Monte Carlo and deterministic), JUNO has less than a 1% chance of impacting Europa in 300 years.

Initial orbit orientation shown in dotted line; arrows show direction of orbit (clockwise on this page); apsidal rotation due to J2 is in opposite direction.

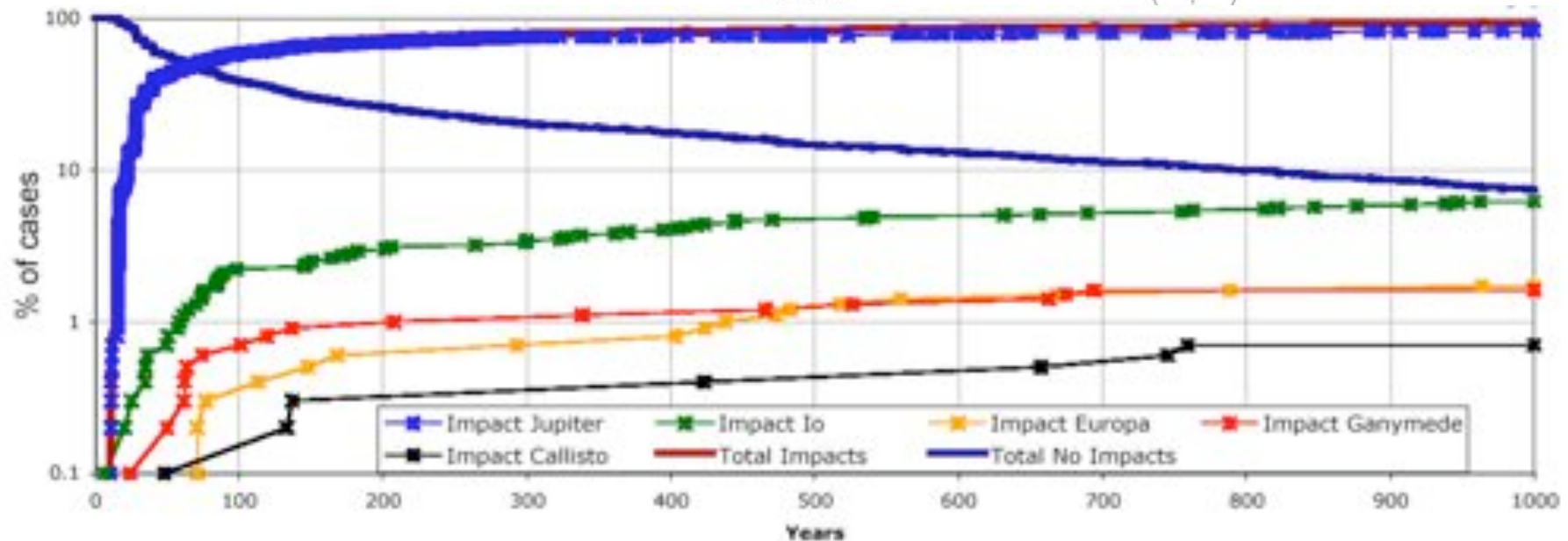
Jupiter equatorial plane

One cycle of apsidal rotation ~11.5 to 13 years

View is from direction opposite to orbit normal.

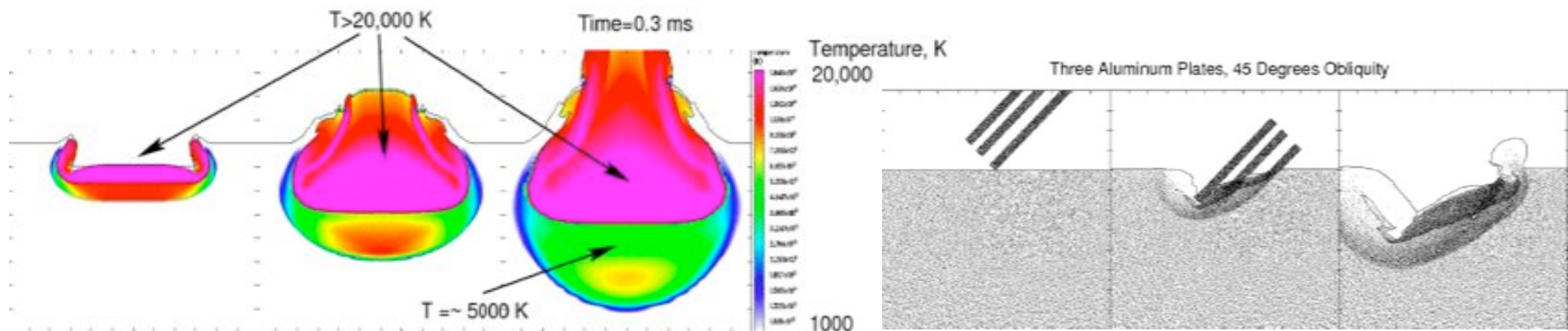


Juno Apojoive: 39 RJ  
 Callisto: 26 RJ  
 Ganymede: 15 RJ  
 Europa: 9 RJ  
 Io: 6 RJ



# Impact Survival

Based on orbital modeling, 99% of JUNO impacts into Europa will be travelling at  $>20$  km/second. 98% of those impacts will be at an obliquity of  $<80^\circ$  that can be modeled using a ‘stacked plate’ approach.



Taking conservative assumptions about ice density and impact heating, and assuming that organisms are killed by 500C for 0.5 sec., only 4% of impacts have a possibility of leaving a viable organism on the european surface: assume this leads to contamination.

# JUNO Allocations and Estimates



Item	Current Best Estimate	Requirement Allocation
<b>Failure Risk Analysis:</b> Probability that spacecraft failure prevents deorbit burn	0.045	$\leq 0.1$
<b>Mission Design:</b> Probability of impact of a non-sterile spacecraft (L3 Mission System)	0.005	$\leq 0.015$
<b>Spacecraft/Europa Impact Analysis:</b> Probability of contamination in the event of an impact	$< 0.04$	0.06
Probability of contamination of the European Ocean	$< 9 \times 10^{-6}$	$9 \times 10^{-5}$
Requirement	$< 1 \times 10^{-4}$	

The ability to include additional factors in the probabilistic calculations based on mission-specific parameters allowed JUNO to determine in the early phases of mission design what would be necessary for compliance with planetary protection requirements.

# Some issues to consider...



- Probability of Contamination calculations are HARD, if useful
  - Estimates of survival during flight may be adequate, but
  - Evaluating contamination given impact involves many poorly-known factors:
    - Impact energy and induced heat
    - Thickness of ice shell
    - Rate of surface turnover
    - Other factors
- The approach used for Mars, setting numerical limits based on measured surface conditions, is more easily evaluated for compliance—but requires MUCH more knowledge of planetary environments than we currently have:
  - Orbiters are very likely to impact after end-of-mission, leading to contact with the subsurface—which will require standards for embedded as well as surface bioburden
  - New biochemical and molecular assays will be available that could form the basis for an icy moons standard, but we do not yet know enough to set that standard
  - Lander spacecraft designed to withstand submersion could tolerate alternative surface sterilization technologies (liquid-based, e.g., bleach)



# **“Workshop on Planetary Protection for Outer Planet Satellites”**



**15 - 17 April 2009 Vienna, Austria**

**John D. Rummel  
Chair, Panel on Planetary Protection  
COSPAR**

# Basic Concept for the OP Workshop

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- Review planetary protection recommendations from the US SSB, and others, in previous work
- Review what is known, or suspected, about the Outer Planets Satellites and other small bodies of the solar system
- Attempt to classify these small bodies with reference to the overall understanding of them, and their potential to support Earth life
- Review the implications of these findings on the Outer Planets Flagship missions, and other potential mission inputs, and then promulgate the final set.

# Future Scientific Studies

## Key Uncertainties in Current Knowledge

There seems to be consensus on the relative ranking of the satellites in the Jupiter and Saturn systems with respect to the degree of concern for planetary protection. This ranking results primarily from a combination of:

1. Evidence for liquid water in their interiors,
2. Probable depth to liquid layer (shallow or deep),
3. Geologic 'youthfulness' and activity

Consensus on 'Concern Scale'



Europa  
Enceladus  
Titan  
Ganymede  
Callisto

- A major difficulty is a lack of agreement in the planetary community regarding the mechanisms and time scales of the geological processes which might result in the exchange of material between the surface and the liquid layers.
- New data and research in several different areas are needed, including spacecraft and telescopic observations, theoretical modeling, laboratory measurements, and related astrobiologic studies.

# Future Scientific Studies (cont.)

## Key Uncertainties in Current Knowledge

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Consideration of models for the interior structures of these objects suggests a rationale for further sub-division of the ranked list, based on the probable nature and location of liquid water layers:

- Titan, Ganymede, and Callisto are close siblings in their bulk properties (radius and density), and models of their interiors based on the complex nature of the water phase diagram suggest that all three may possess deep liquid oceans (more than 150 km below the surface), “perched” or “sandwiched” between a thick crust of low density Ice I and an icy mantle of high density Ice III, with completely or partially differentiated silicate or silicate plus ice below
- Models for Europa and Enceladus on the other hand suggest liquid layers at shallow (tens of kms) depths below an Ice I crust, the liquid being in contact with a primarily silicate mantle or core.

# Future Directions



- Additional workshop to consider specifically Titan and Ganymede
  - Organized by COSPAR with sponsorship by ESA and NASA
  - Scheduled for Dec. 11-12, 2009, at CalTech.
    - Possible methods for inducing heat
    - Thickness of ice shells
    - Rates of surface turnover
    - Other factors
- Future Space Studies Board considerations
- Outcomes taken to COSPAR Bureau by the Panel on Planetary Protection

# Mission needs



- Models of material transfer and means of surface-interior communication
- Methods for evaluating bioburden and modeling reductions in-flight
- **Approaches for sterilizing lander spacecraft at the subsystem and system levels**



Don't spill it!



