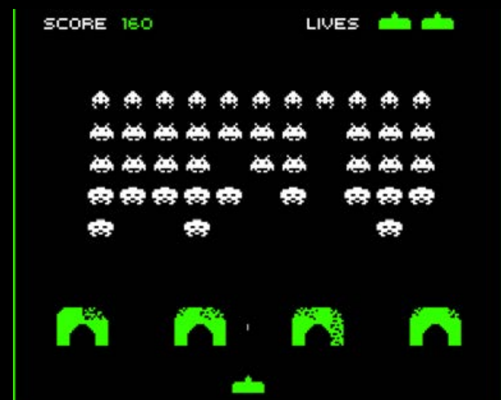


Planetary Protection

ASTR5835 Human Missions to the Moon and Mars Seminar

Noora Alsaeed, Jordan Dixon, Young-Young Shen, Andrew Wilcoski

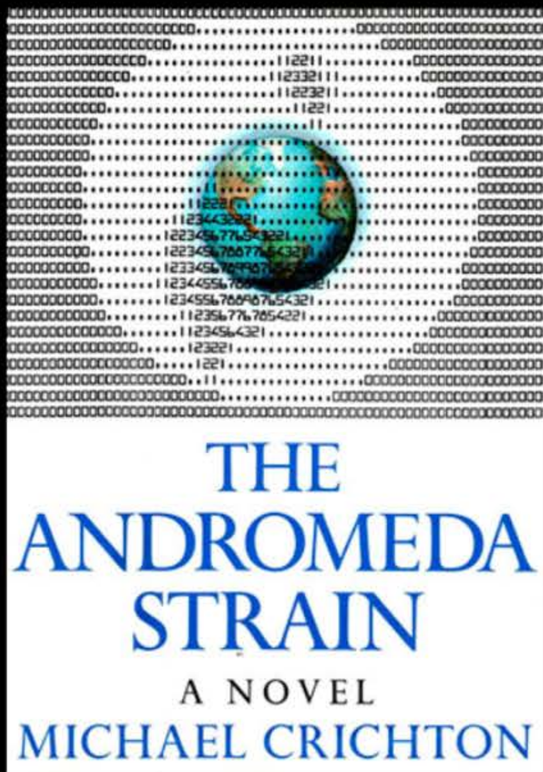
12 November 2019

What is **planetary protection**?

Managing contact between terrestrial life and organic material from celestial bodies in order to:

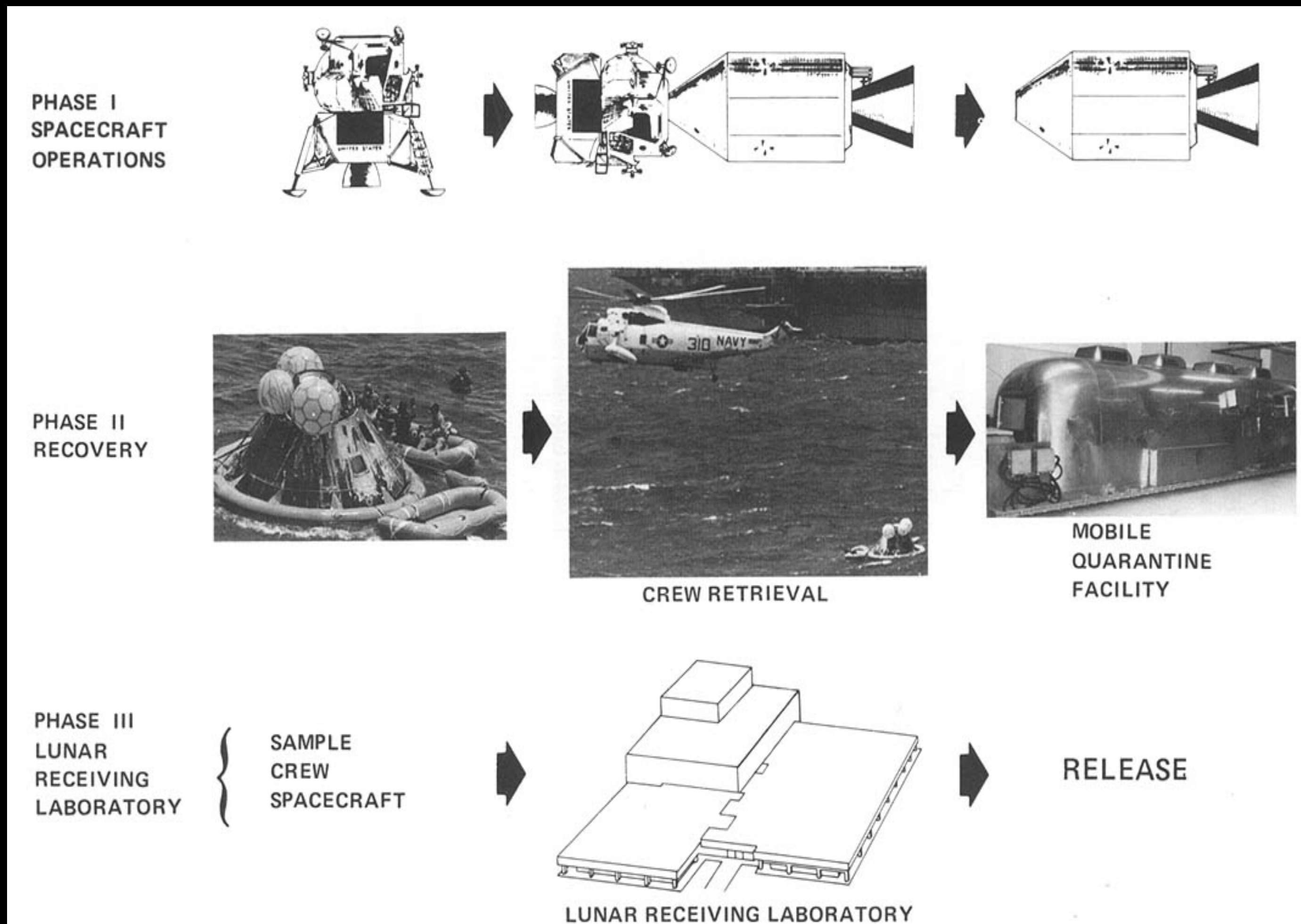
1) Prevent disruption of the scientific study of these bodies
Forward contamination

2) Mitigate harmful contact between pathogens or irritants to terrestrial life **Backward contamination**



Chock-full of microbes?

1. Feed mice moon-dust
2. Wait and hope mice don't die
3. ???
4. Planet successfully protected


PHASE I
SPACECRAFT
OPERATIONS
PHASE II
RECOVERY
CREW RETRIEVAL
MOBILE
QUARANTINE
FACILITY
PHASE III
LUNAR
RECEIVING
LABORATORY
SAMPLE
CREW
SPACECRAFT
RELEASE
LUNAR RECEIVING LABORATORY

Timeline

1956:
Maybe let's talk about this?

1958:
No really, let's talk about this

Committee on Space Research established

Meanwhile

is a thing now

And they care too, so they're only sending sterilized stuff

1963: Planetary Quarantine Program

1976: Office of Planetary Protection

Planetary Protection Officer (PPO)

Timeline

1956:
Maybe let's talk about this?

1958:
No really, let's talk about this

Committee on Space Research established

They make the rules

Meanwhile

is a thing now

And they care too, so they're only sending sterilized stuff

They implement them

1963: Planetary Quarantine Program

1976: Office of Planetary Protection

Planetary Protection Officer (PPO)

They oversee compliance of them

What is **life**?

????

What is **life**?

????

What are the geological conditions where we might find life?

- Heat
- Water
- Complex soup of stuff
- Shielding from "harsh" environment

For the purpose of categorization: Places that are of interest in term of chemical evolution and/or the origin of life

Category	Type	Priority	Example
I	any	No need to protect	undiff/metamorphosed asteroids, Io
II	any	Remote chance of contamination	V, J, U, N and most their satellites, Moon, non Category I asteroids, TNOs < ½ Pluto size
II*			* Icy satellites, Pluto and Charon
III	Flyby, orbiter	Significant chance of contamination	Mars, Europa, Enceladus
IV	Lander, probe	Significant chance of contamination	Mars, Europa, Enceladus
V	All Earth return	Any solar system mission	Unrestricted: Venus, Moon Restricted: Mars Europa, Enceladus

Planetary Protection Categorization Examples

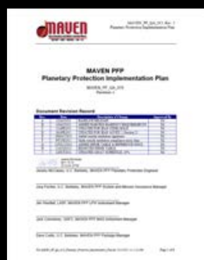




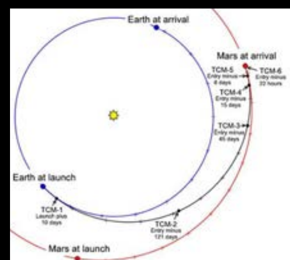

Category	Example Missions
I	*None to date*
II	LRO, LADEE, New Horizons, Cassini-Huygens
III	Europa Clipper, MAVEN, MRO, Dawn
IVa	MSL, MERs,
IVb	Viking, ExoMars 2020 (ESA)
IVc	Phoenix
V unrestricted	Apollo 15, 16, 17, Hayabusa, OSIRIS-Rex
V restricted	Apollo 11, 12, 14, Mars 2020, Mars Sample Return

Current Practices – Robotic Missions

Phase A: Concept Exploration **Phase B: Preliminary Design**



Documentation
All Phases



Trajectory Biasing
Phase A,B

Microbial Reduction
Phase C, D

Sterilization
Phase C, D

Phase C: Critical Design

Biohazard Testing
Post-Flight

Sample Containment
Phase E

Cleanroom Assembly
Phase D

Phase F: Disposal **Phase E: Operations** **Phase D: Assembly, Integration, and Testing**

Current Practices – Robotic Missions

	Category	Required Practices
	I	Documentation
	II	Documentation
	III	Documentation, Cleanroom Assembly, Microbial Reduction, Trajectory Biasing
	IVa	Documentation, Cleanroom Assembly, Microbial Reduction, Trajectory Biasing, Sterilization (as needed)
	IVb	
	IVc	
	V unrestricted	As appropriate for PP Category of outbound mission (usually I or II)
	V restricted	Class IV requirements plus sample containment and biohazard testing

Current Practices – Robotic Missions

<u>Bioburden:</u> Total number of spores in or on an item of interest (NPR 8020.12D)

- Measured using microbiological assays of the item of interest
- NPR 8020.12D prescribes specific bioburden limits for Mars missions only at various stages of the mission
    - For most other missions, it is simply required that "the probability of that a planetary body will be contaminated during the period of biological exploration shall be no more than $1{\times}10^{-3}$" (NPR 8020.12D, p. 29)
    - For Category II*, III, and IV missions to icy bodies, the probability of contamination is further restricted to less than $1{\times}10^{-4}$ (NPR 8020.12D, p. 33)
    - No format for probability of contamination calculations is specified, but the methodology used for the calculation must be included in the documentation for each mission
    - One common way to calculate this is the *Coleman-Sagan Equation*

Current Practices – Robotic Missions

Coleman-Sagan Equation (Sagan and Coleman, 1966)

$$P_c = N_0 R P_s P_t P_R P_g$$

P_c: *Expected* number of spores introduced to planet by a spacecraft or, alternatively, probability that one spore will colonize the planet

N_0: Initial spacecraft bioburden

R: Reduction due to conditions on spacecraft before and after launch

P_S: Probability that microorganisms on the spacecraft reach planet surface

P_t: Probability that spacecraft hits (or lands) on the planet

P_R: Probability that microorganisms will be released from spacecraft

P_g: Probability of growth

Per NPR 8020.12D, $P_c < 10^{-3}$ is desired in general

Current Practices – Human Missions

?

Current Practices – Human Missions

"There is presently ***insufficient scientific and technological knowledge*** *to establish detailed requirements and specifications to enable NASA to incorporate planetary protection into the development of crewed spacecraft and missions."* – NASA Policy Instruction 8020.7

"NASA's current policies for robotic Category V Restricted Earth Return from Mars appear to be unachievable for human missions returning from Mars." – NASA Planetary Protection Independent Review Board (2019)

NASA's Position

"…requires Agency compliance with COSPAR policy regarding biological contamination control for outbound and inbound planetary spacecraft, covering ***all space flight missions****"* – Ibid

Current Practices – Human Missions

The Path Forward

1. Develop capabilities to monitor microbial communities associated with human systems
2. Develop technologies for minimizing contamination release, e.g. closed-loop systems, cleaning/re-cleaning
3. Better understand environmental processes on exploration targets

Future Issues – Backward Contamination

Protection of Earth's biosphere and human explorers from extra-terrestrial life and harmful extra-terrestrial materials.

- Applies to both sample return and human missions
- Relevant to category V, restricted misions (Mars, Europa, Enceladus)
- Primary goal of **all** PP is the protection of Earth's biosphere

Primary Challenge of Backward Contamination

Problem:

The effect of alien materials/life on terrestrial life is unknown.

Primary Challenge of Backward Contamination

Problem:

The effect of alien materials/life on terrestrial life is unknown.

Solution:

Break the chain of contact between alien material and terrestrial life. (i.e. don't let them touch)

Break Chain of Contact – Human Missions

- Virtually impossible, as demonstrated by Apollo
- In situ quarantine procedures and terrestrial quarantine facilities
- May necessitate robotic sample return as a precursor

(NASA/Eugene A. Cernan)

Break Chain of Contact – Robotic Sample Return

- Difficult, but possible
- Terrestrial biosphere protection must be priority of mission
- Complicates technological and logistical design of mission
- Requires existence of Earth-based containment/processing facilities
  - Cleanroom and biosaftey level 4 (the highest level) laboratory, in addition to scientific equipment

Mars Sample Return

- Containment of Mars 2020 samples is responsibility of future missions
- No proposal has been approved by NASA
- Terrestrial receiving facilities do not exist
- NASA has not yet addressed major legal hurdles

Mars Sample Return Legal/Logistical Hurdles

- First Apollo sample returns occurred before many agencies existed or enforced relevant restrictions (EPA, CDC, APHIS)
- NEPA (1970) requires full Environmental Impact Statement (EIS) - typically 6-7 years to complete
- NASA must comply with numerous other government agencies
  - Interagency Committee on Back Contamination (ICBC) must be reformed

Mars Sample Return Legal/Logistical Timeline

Table 2
Summary of necessary activities for safe return of Mars samples.

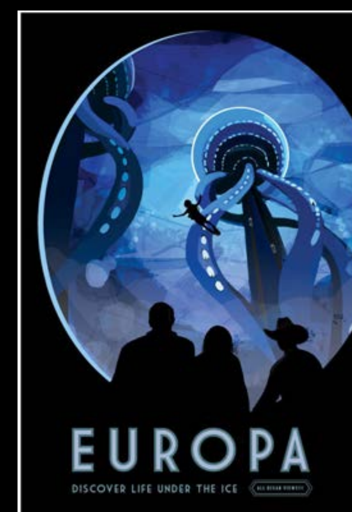
Milestone	Explanation	Key challenges	Timeline
Create oversight organization (Interagency Committee on Back Contamination, or analog)	Bring together representatives from NASA and other specified federal and state government agencies with scientists to determine what is required.	Develop consensus position with regard to containment margin of safety, in given technical, time. and budget constraints.	2 years before Quarantine Regulations are needed
Develop governing Quarantine Regulations	Regulations are necessary to protect the biosphere and ensure any staff accidently exposed to the sample may be quarantined.	Legislation may be necessary to authorize NASA to promulgate these regulations.	Ahead of facility design
File Environmental Impact Statement (EIS)	The National Environmental Policy Act requires an EIS be conducted prior to government actions that may impact the environment.	EIS takes time to develop; NASA may be challenged in court based on the information in the EIS.	Approximately 6–7 years for a typical mission, may be significantly longer.
Build or repurpose containment facility	A facility must be constructed with a cleanroom/bio-containment laboratory to protect samples and the environment.	Requirements must be determined to protect sample/Earth and allow rigorous scientific study.	9 Years, based on iMARS report. Establish facility requirements 2yrs; facility design 2yrs; construction 3yrs; and commissioning 2yrs.
Train scientists and lab technicians	All personnel working in the lab must be trained to avoid accidents and exposure, as well as trained on the equipment.	Training requirements must be determine; training requires time and money.	Estimated 2 years

(Uhran et al., 2019)

Future Issues – Forward Contamination

From ‘NASA PPIRB Final Report, 2019’

- Official view
  - In its essence, Planetary Protection (PP) refers to: (i) managing contact between terrestrial life forms and organic material from celestial bodies **as it relates to adversely affecting the scientific study** of these bodies, called forward contamination.
- Side note
  - Neither COSPAR PP guidelines nor PP as implemented by NASA directly addresses or attempts to mitigate the **ethical issues of forward contamination** that could threaten the biota of other celestial bodies.



Near Future Mars Exploration

Fairén A.G., et al. (2019) *Planetary Protection and the astrobiological exploration of Mars: Proactive steps in moving forward.*

"Future efforts towards Mars exploration should include a discussion about the effects that the strict application of Planetary Protection policies is having on the astrobiological exploration of Mars, which is resulting in a continued delay in the search for Martian life."

"implementing these changes…[will result in an] exploration approach much less risky to the potential Mars biosphere, while also being much more scientifically rigorous about the exploration of the "life on Mars" question"

Two main components of argument:

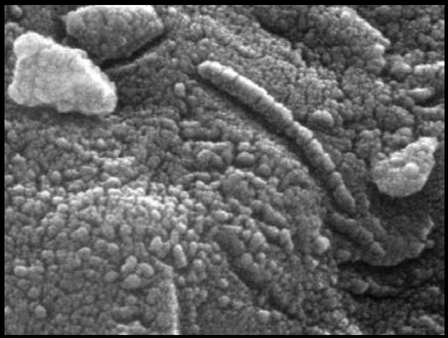
1. Justification for needed changes based on historical context
2. Suggestions of changes moving forward

Near Future Mars Exploration

Fairén A.G., et al. (2019) *Planetary Protection and the astrobiological exploration of Mars: Proactive steps in moving forward.*

Justification for needed changes based on historical context

1. Earth life likely cannot survive on Mars surface, but if it could we can presume there are already active microbial ecosystems
2. Indigenous life would be much better adapted to Mars stressors, so we shouldn't worry about Earth contamination out-competing
3. Bioburden controls already flawed – (i) cleaning procedures rely on similar environmental stressors of Martian surface, and (ii) the "inadvertent finding" argument doesn't hold since current procedures don't neutralize the biochemicals.
4. We can differentiate Earth vs. Martian organisms both by building blocks (if DNA-based) and diversity of cultures
5. Human missions will inevitably introduce more contamination that robotic missions. "One-time only chance for humanity [to explore special regions with robots and classify potential extant biota]"

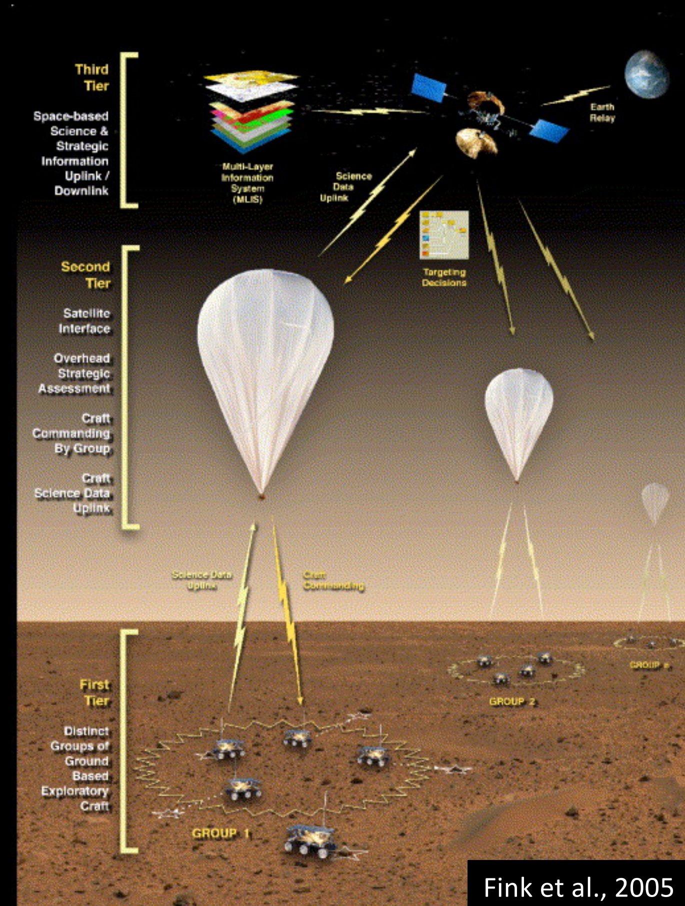


Near Future Mars Exploration

Fairén A.G., et al. (2019) *Planetary Protection and the astrobiological exploration of Mars: Proactive steps in moving forward.*

Suggestions of changes moving forward

1. **Need new rules for PP and SRs**: More realistic to find extant life in Special Regions repairing radiation damage, than finding extinct life degraded by radiation in top layers of soil. Differentiate cleanliness requirements between PP and biological reconnaissance spacecrafts
2. **Focus tech development on advanced biosignature detection methods**: focus on basic building blocks to determine biological vs. abiotic organics in SRs – e.g. Gas Chromatograph Mass Spectromoter, nucleic acid sequencing, powerful microscopes
3. **New mission architectures**: multiple, miniature spacecraft/rovers purpose-built to act as team. Redundancy, easier cleaned, 'personalized' requirements E.g. Tier-Scalable Reconnaissance mission architecture



Fink et al., 2005

Looking beyond Mars

Other notes from PPIRB report:

- **Major Finding:** The late addition of PP requirements to some projects has been costly and inefficient to implement.
  - **Major Recommendation:** PP requirements on missions should be written to define PP intent, rather than detailed implementation methods, thereby allowing projects to select and/or develop implementations most suitable to meet their PP requirements from a systems standpoint**.**
- **Major Finding:** For planetary missions involving locations of high astrobiological potential, it is essential that forward and backward contamination consideration be integral to mission implementation. This applies to both government and private sector missions.
  - **Major Recommendation:** Owing to the changing PP context and the rapid advancement of scientific, technological, and private sector planetary mission capabilities, NASA should reassess its PP guidelines at least twice per decade with an IRB-like body that includes representatives of all major stakeholder communities. The PPIRB findings and recommendations presented in this report apply to the current era and generally are made with a 3-5 year horizon in mind.

Looking beyond Mars

Other notes from PPIRB report:

- **Major Finding:** Although NASA is not a regulatory agency, the Agency can likely affect control over non-NASA U.S. missions by linking PP compliance to eligibility for current or future NASA business or NASA support…
- **Supporting Finding:** COSPAR PP guidelines have evolved to be an internationally recognized, voluntary standard for protection of scientific interests in celestial bodies. Adherence to the COSPAR guidelines has been considered an acceptable mechanism for establishing a State party's compliance with the harmful contamination aspects in Article IX of the OST.
  - **Supporting Recommendation:** For forward contamination, NASA PP policy should move beyond exclusive adherence to spore counts…PP policy should encourage…monitoring and characterization of bioburden of cleanroom facilities and flight hardware. NASA should also encourage the broader use of probabilistic models of the risk of "harmful" forward contamination based on likely scenarios and acceptable risk outcomes.

Setting precedents for future exploration

NASA PPIRB Report - 2019

Supporting Finding: It is impractical for launch providers or satellite hosts to definitively determine the biological content of every payload... The recent experience in which a launch customer placed tardigrades and other biological samples on the SpaceIL Beresheet lunar lander is illustrative. By the Moon's Category II PP designation, it is likely that a payload license would have been readily granted had the bioload been self-reported; however, the lack of such reporting created new issues relating to launch licensing.


Nova Spivack
@novaspivack
Follow

FYI - some perspective: a tiny speck of dehydrated Tardigrades, too small to see, hit an area the size of North America at 1 km/second. The chances of contamination are & were zero. Even if no crash, they would never be able to live, reproduce, spread or do any harm on the Moon.

4:02 AM - 14 Aug 2019

ARCH MISSION FOUNDATION


Why should humans go instead of robots?


Because it's there

What matters to you?

- Should the Moon now be considered of greater importance given PSR water ice?
- How much information do we need to conclude that there is no life on a given planet?
  - Do we understand enough to know whether there could be or if we could detect fundamentally different forms of life?
  - With respect to resource mining, terraforming/colonization, etc., should there be high likelihood of NO life? Simple microbial life?
- How complex is complex enough?
  - If life is found, how complex does it have to be before we decide we should avoid disrupting the ecosystem, if at all?
  - Where do we draw the line for intended mass extinction/genocide?
- Should there be international policy regulating ethical implications of PP? ("one-time only" acts of humanity that cannot be undone)

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Backup Slides

Approaches to Settlement

SID MEIER'S CIVILIZATION BEYOND EARTH

The Martian (2015)

Purity

- Keep everything the same as Earth
- Minimize interaction with planetary environment

Supremacy

- Exert full control over planet
- Full exploitation of planet's resources
- Reshape local environment and ecosystem (if any) to humanity's advantage

Star Trek II: The Wrath of Kahn (1982) Genesis Effect

Harmony

- Integrate with local planet
- Change humanity to be compatible with local ecosystem or environment

The Titan (2018)

Current Practices – Robotic Missions

Documentation

- **Planetary Protection Plan**: Outlines intended or potential impact targets
- **Planetary Protection Implementation Plan**: Details project's implementation of PPP
- **Pre-Launch Planetary Protection Report**: Details impact avoidance strategies, achievement of requirements, values of microbial burden
- **Post-Launch Planetary Protection Report**: Details actual trajectory and updates previous documentation
- **End-of-Mission Report**: Provides final disposition of launched hardware and impact location
- **Inventory of Bulk Constituent Organics**: Quantities, types, and final locations of all organic materials contained on spacecraft to enable analysis of the spread of organic materials

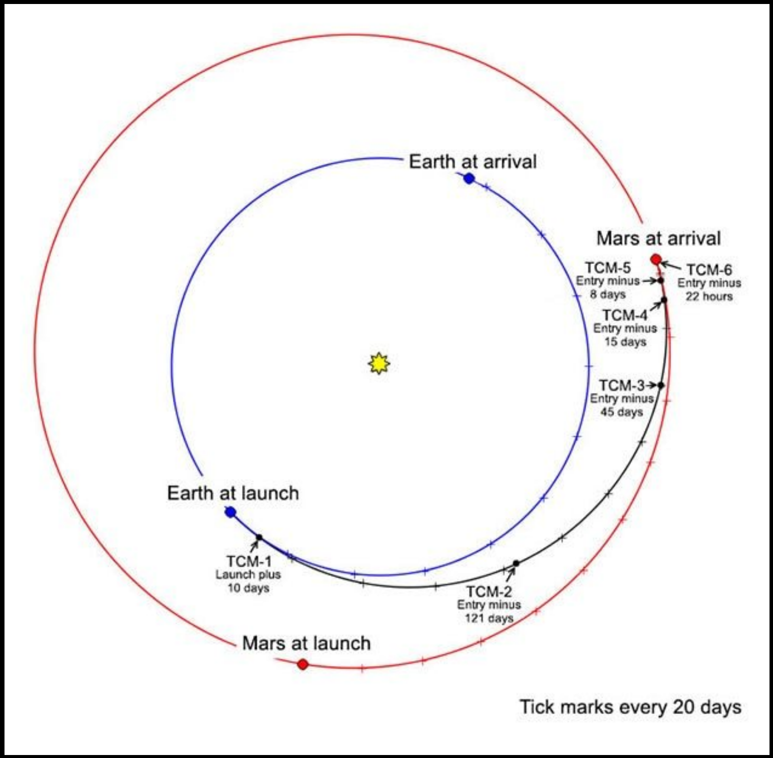
Current Practices – Robotic Missions

Documentation

- **Earth Pre-Launch Report**: Similar to Pre-Launch Report, but for inbound phase of Class V mission
- **Earth Pre-Entry Report**: Demonstrates readiness to enter Earth's atmosphere in compliance with PP requirements
- **Sample Pre-Release Report**: Details sample analysis procedures following end of mission and demonstrates that any planned sample release does not endanger Earth biosphere

Current Practices – Robotic Missions

Trajectory Biasing



Category	Example	Implementation required
I	undiff/metamorphosed asteroids, Io	Documentation only
II	V, J, U, N and most their satellites, Moon, non Category I asteroids, TNOs < ½ Pluto size	Documentation only
II*	* Icy satellites, Pluto and Charon	
III	Mars, Europa, Enceladus	Impact avoidance and/or contamination control including: cleanroom assembly, microbial reduction, and trajectory biasing.
IV	Mars, Europa, Enceladus	Same as above + organics archiving.
V	Unrestricted: Venus, Moon Restricted: Mars Europa enceladus	Same as above + microbial containment of sample, breaking chain of contact with target planet, sample containment and biohazard testing in receiving laboratory etc.