The Elephant in the Room:

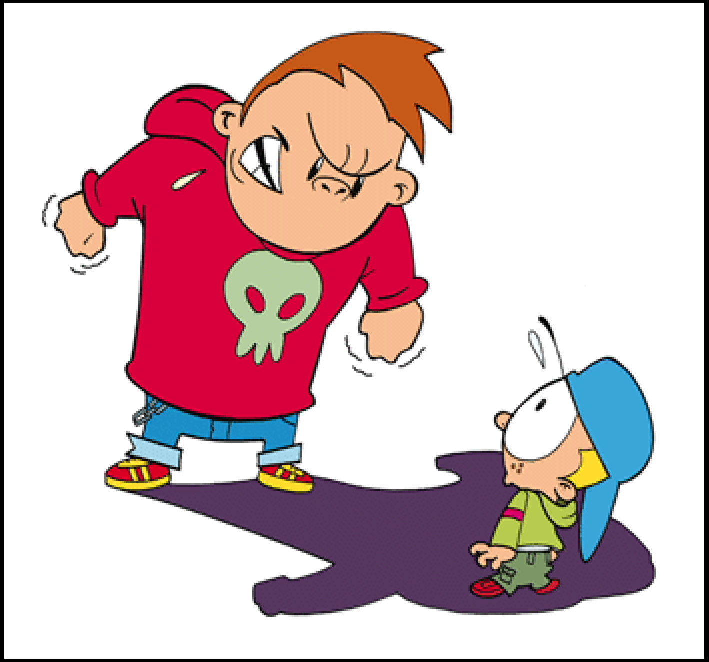
Biomedical Challenges for Long Duration Lunar Habitation

James S. Logan, MD
Clinical Services Branch
NASA Johnson Space Center
james.s.logan@nasa.gov


Hmm…don’t think I’ll mention this to Mission Control… maybe he’ll just go away…

Culture Clash: Engineering and Life Sciences

NASA Version of Culture Clash



Vision for Space Exploration

envisions “permanent human presence” on the moon, first by establishing an “**outpost**” capable of supporting seven-day missions in 2020, then incrementally extending mission duration to as long as six months…

Six reasons for returning to the moon

Reason 1: “Human Civilization:
Extend Human Presence to the Moon
to Enable Eventual Settlement”

First Lunar VSE Mission Milestones

Lunar Elapsed Time	Milestone
0:21:36:21	Exceed Apollo 11 Lunar Surface Time (LST)
2:01:55:12	Exceed Average LST of Entire Apollo Program
3:02:59:40	Exceed Apollo 17 LST
6:04:48:00	First Lunar VSE Crew Exceeds Cumulative Apollo LST in Total Man-Hours

VSE: Assessing Potential Biomedical Threats

1. Are there biomedical ‘showstoppers’ that could potentially threaten the VSE or the current CONOPS?

2. What have science and our operational space experiences taught us that could better qualify or quantify potential threats?

3. What are the implications of the above on the viability and eventual success of the VSE or of permanent human lunar settlement itself?

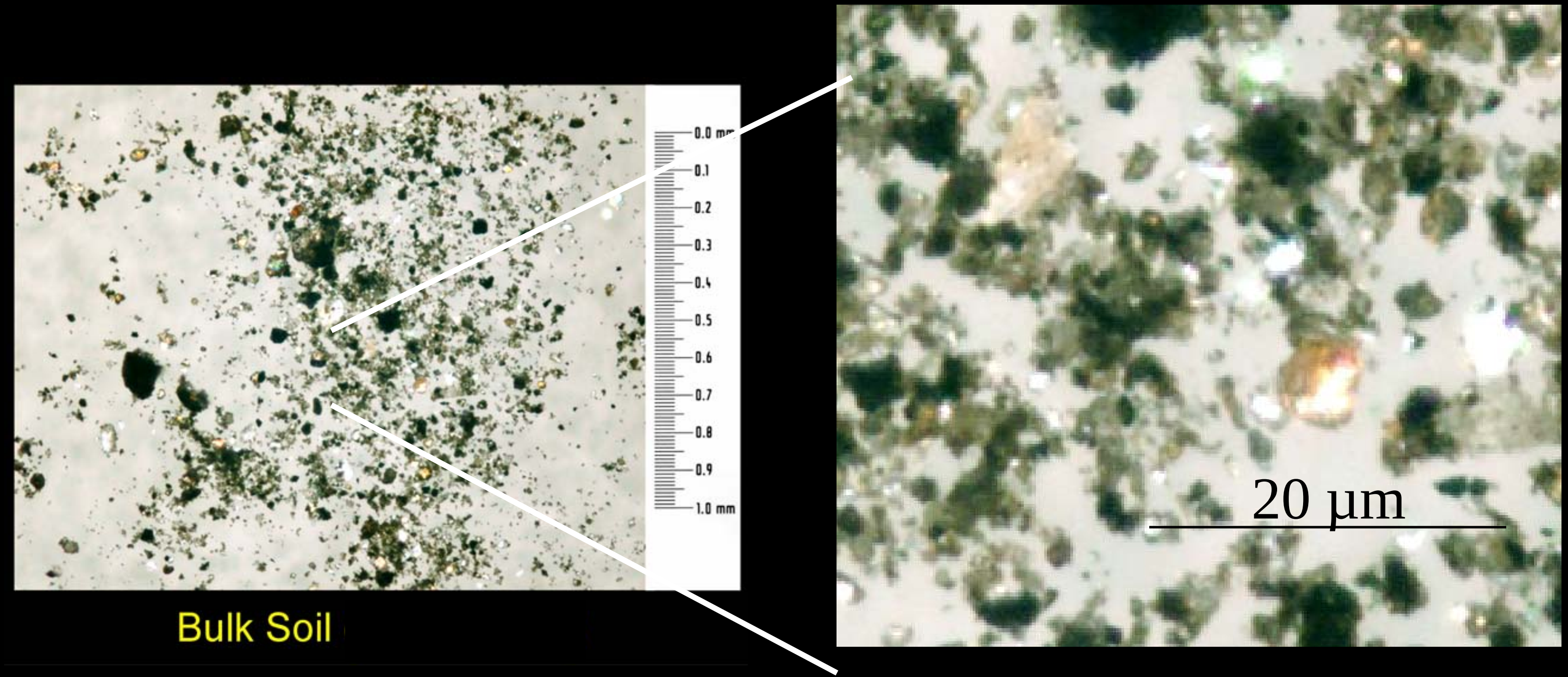
Potential VSE Biomedical Showstoppers

- **Lunar Dust Hazards**
- **Radiation**
- **Hypogravity**
- **Synergistic Effects**

‘Dust was a pain in the #@&% ......we found it everywhere…coatings, seals, gaskets, filters, switches, windows, lens…it got into our nose, eyes and lungs.’

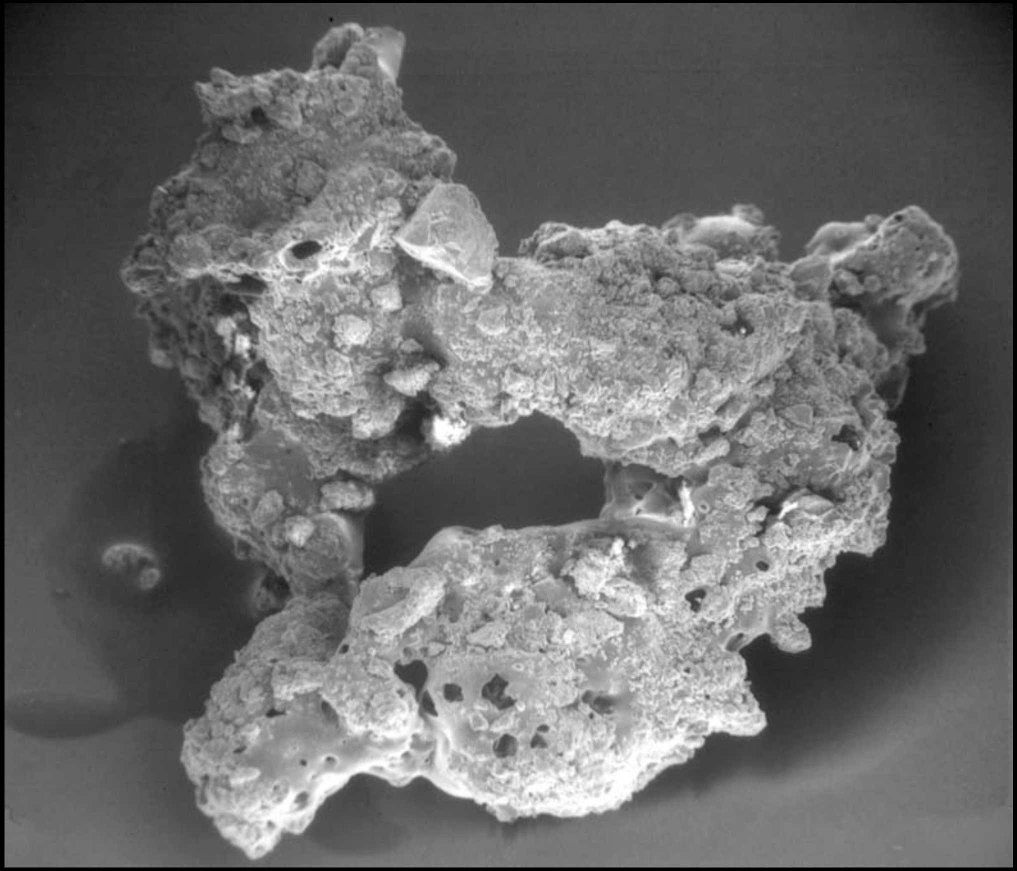
Dust clings to Eugene Cernan's suit after a 1972 moonwalk.

Inhalation Risks



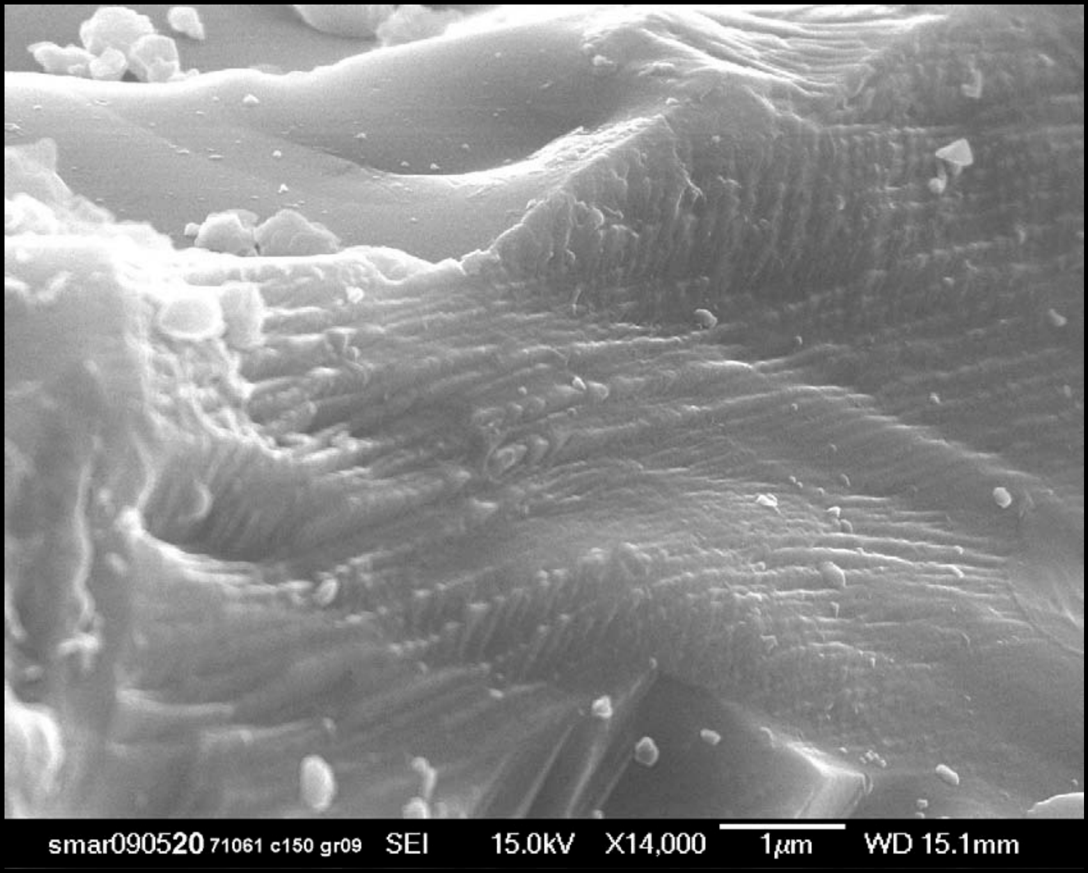
Photos Courtesy of David McKay, NASA JSC

Agglutinate

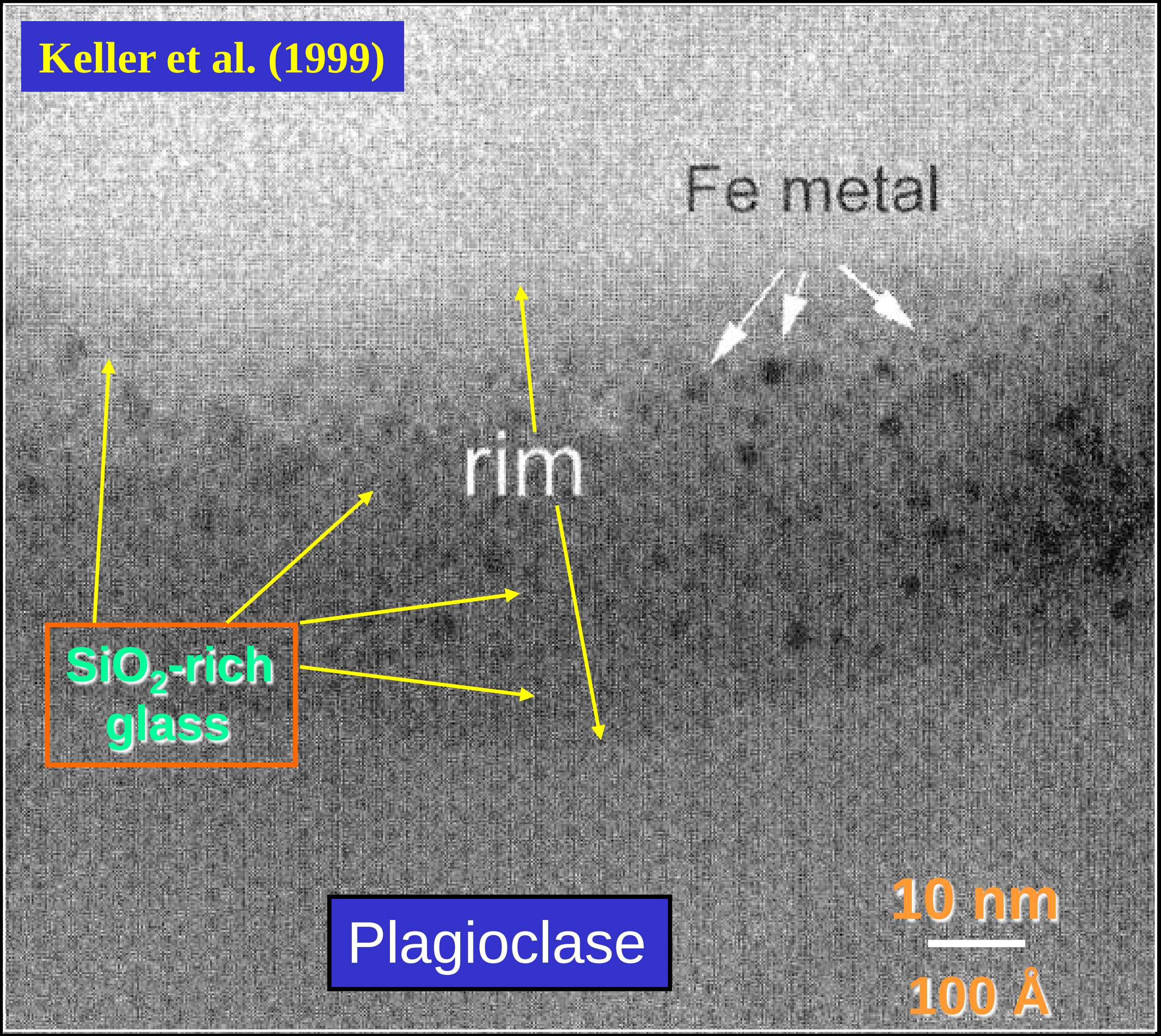


Lunar Grain Surface

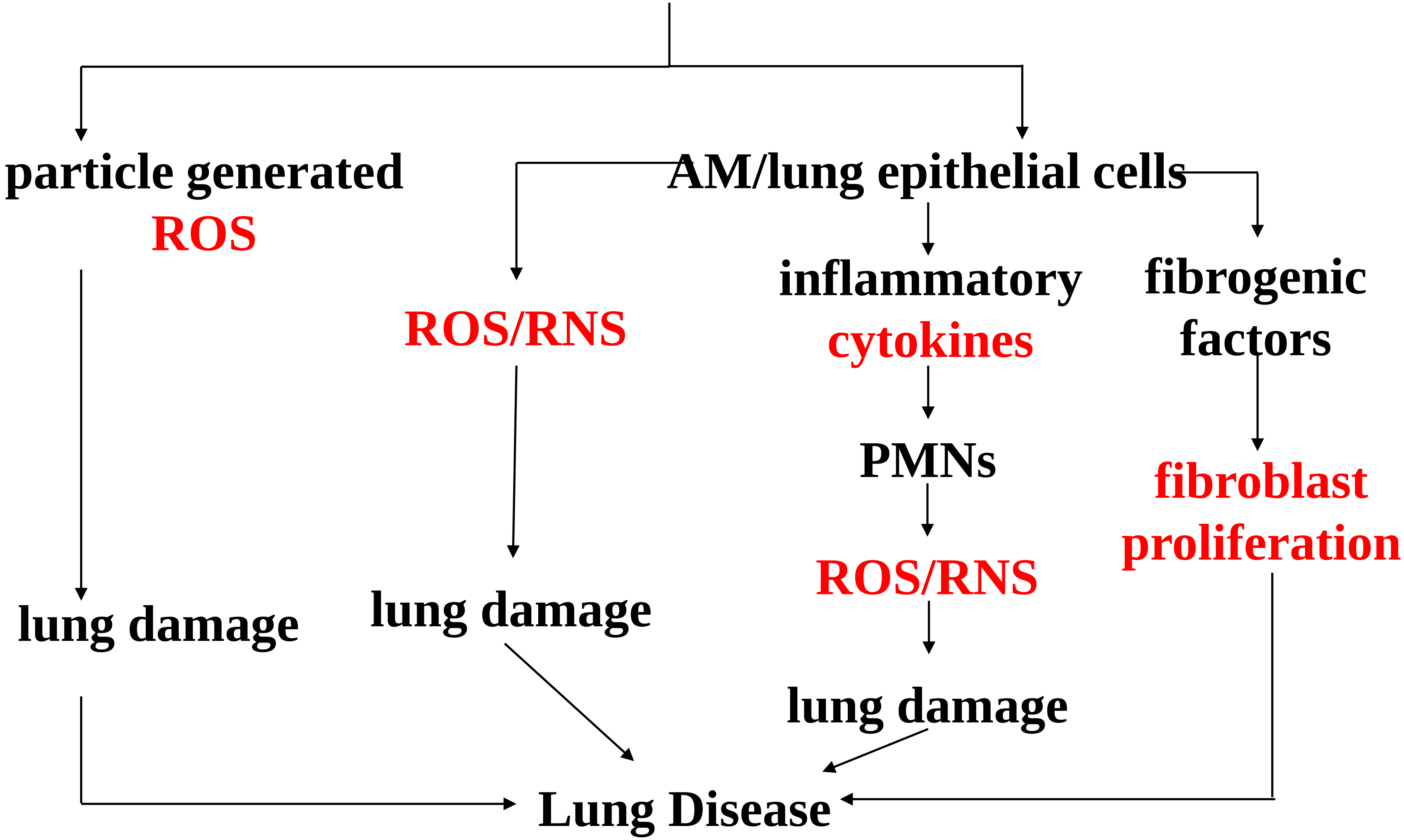
"Etching" by the solar wind generates high density of crystal dislocations which have high biological reactivity



Vapor-Deposited Nanophase Fe° on Plagioclase



Particle Deposition in Alveolar Lung Compartment



Inhalation Toxicity Studies

Lunar Dust = Activated Simulant

?

Toxicity Scale →

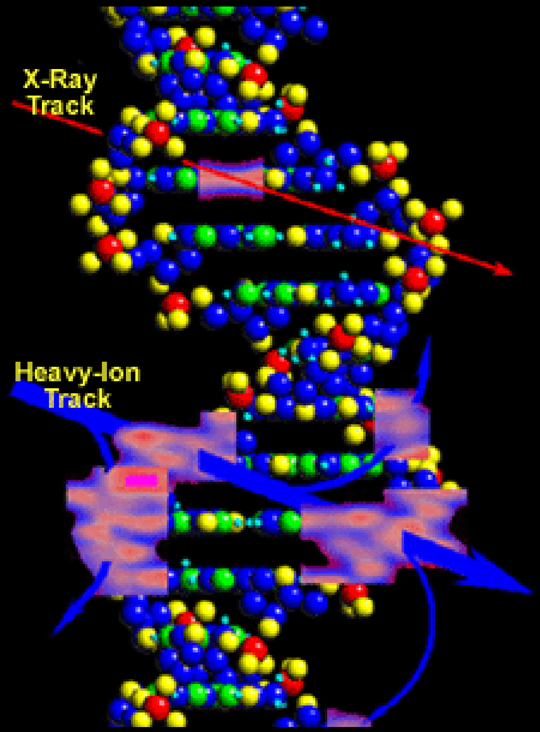
TiO$_2$

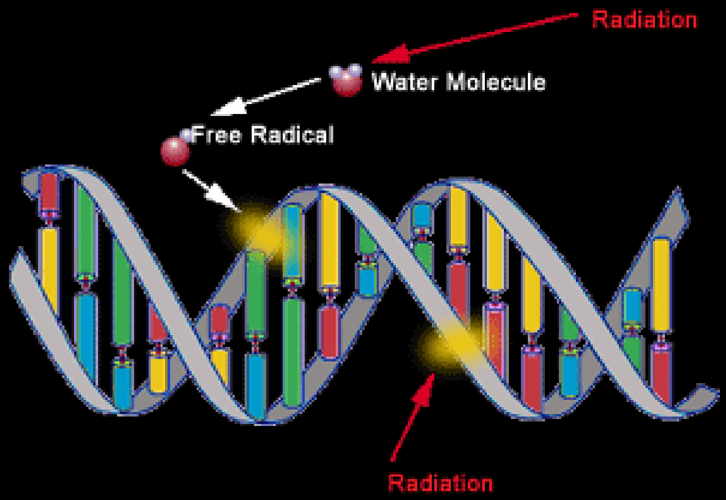
TLV = 10 mg/m^3

Quartz

TLV = 0.025 mg/m^3

Ionizing Radiation





Transfer of linear energy from solar wind and GCR into biological molecules resulting in damage (direct or indirect)

Trends in Radiation Science

Studies indicate radiation effects on human beings are worse than expected

Increasing Relative Biological Effectiveness

[LEO: “Q Factor” ~ 1.3 in 1989; 2.5 in 2000]

Large uncertainties in risk estimates for heavy ions and neutrons due to lack of human and animal data to assess risks

Permissible Exposure Limits (PEL) keep decreasing over time

Radiation Exposure Limits

Career PEL for 45 y.o. radiation worker was **135 rem** in 1989 but only **45 rem** by 2000

Radiation worker exposures have plummeted
(annual limit of 5 rems [50mSv/yr])
(transcontinental pilots ~ 0.5 rem/yr [5 mSv/yr]

In 1976 40,000 workers received average annual dose of 0.82 rem a year
[**350** received more than 5 rem]

By 1999 108,000 workers received average annual dose of 0.29 rem
[**none** received a dose > 5 rem]

Risk of Exposure Induced Death

"REID" is a statistical approach pegged to a single radiation effect: DEATH from cancer directly attributable to the exposure

In 1989 NASA accepted National Committee on Radiation Protection (NCRP) recommendation of career dose limits corresponding to a lifetime **increase of 3% in cancer mortality**

In 2000, NCRP kept that same 3% recommendation but also reduced (almost by half) the dose expected to reach the 3% lifetime risk.

- **45** y.o. male astronaut's 10 year 3% career limit went from **325** rem in 1989 to **150** rem in 2000
- **35** y.o. female astronaut's 10 year 3% career limit went from **175** rem in 1989 to **60** rem in 2000

This is NOT being more conservative, this is a realization that radiation is more harmful than predicted

From "**Apollo Experience Report – Protection Against Radiation**"
NASA TN D-7080 (1973)

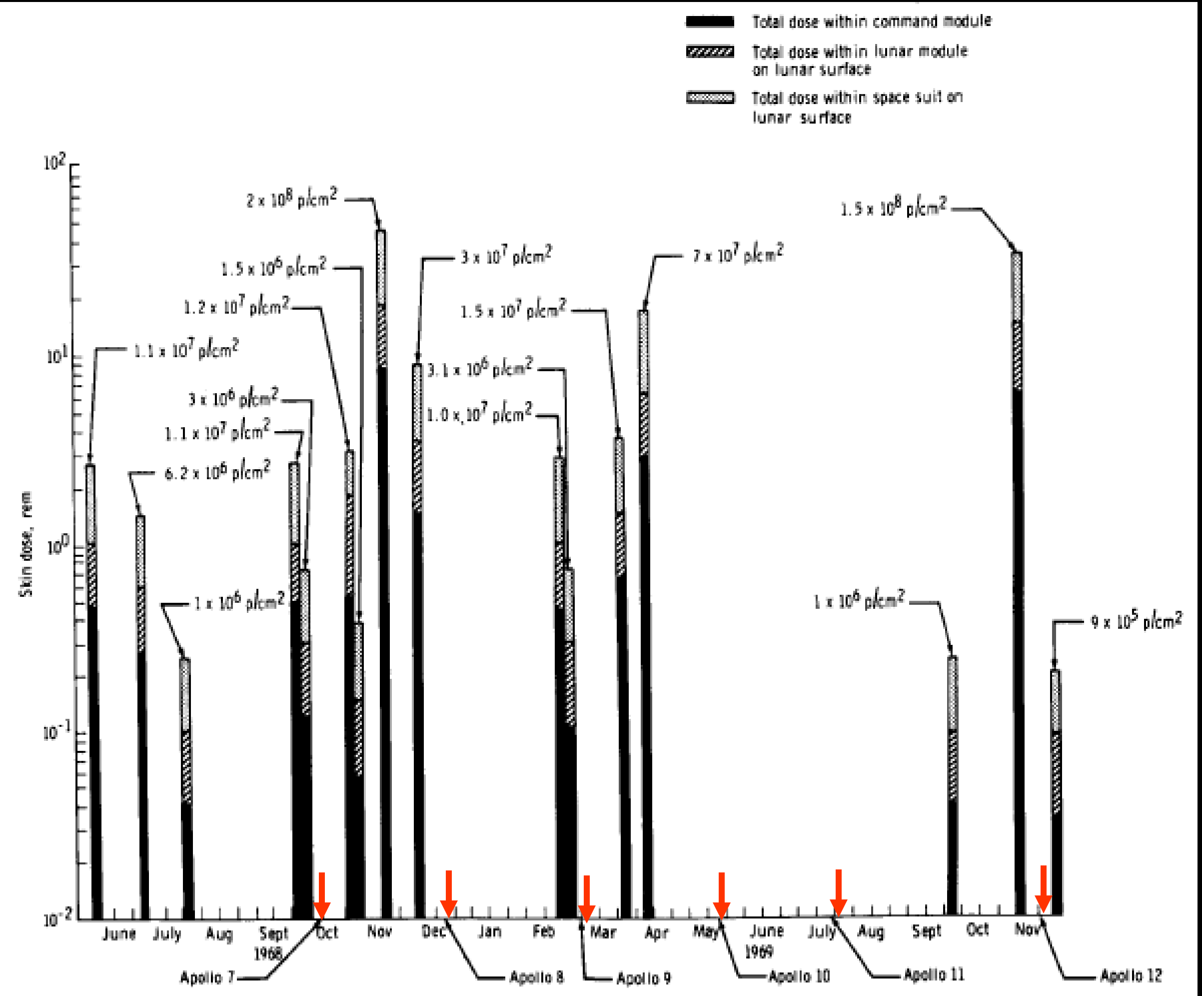


Figure 1. - Radiation-dose estimates for particle events between June 1968 and December 1969.

Radiation Exposures on ISS

ISS is beneath protective magnetosphere of the earth

If you are a 35 year old female when you begin your first six month ISS mission and 40 when you begin your second six month ISS mission (i.e. 5 years between missions), you will have an estimated **2% increased risk** of a fatal cancer

If you are a male (same age and flight schedule), you have a **1% increased risk** of a fatal cancer

Average risk for non-smoker cancer death in the general population is 21% and ~ 41% for a smoker

REID Lunar Mission Profile Variables

Solar Cycle:

Solar Max
Solar Min

Duration:

2 weeks (6 days ‘deep space” + 8 surface days)
3 months (6 days ‘deep space’ + 84 surface days)
6 months (6 days ‘deep space’ + 174 surface days)
9 months (6 days ‘deep space’ + 264 surface days)

Shielding:

5 g/cm2
20 g/cm2*

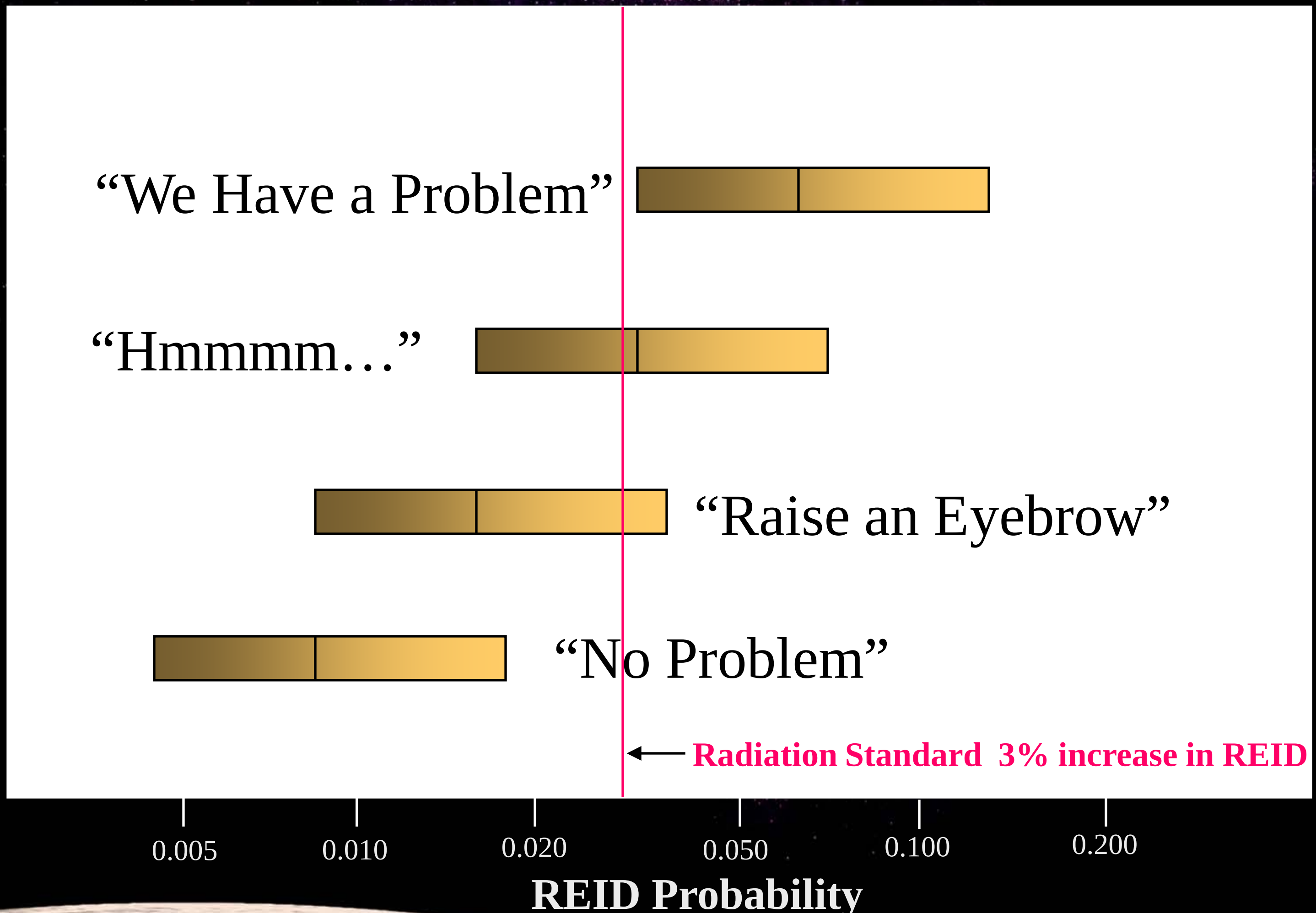
Gender:

Male
Female

*** Can’t fly 20 g/cm2**

REID Categories of Mission Profile Variables

All Data Are Preliminary!!



REID Category Examples*

No Problem:

All sortie missions

Raise an Eyebrow:

Female, Solar Min, 9 months, 20 g/cm2
Female, Solar Max, 9 months, 5g/cm2
Female, Solar Max, 9 months, 20 g/cm2
Male, Solar Min, 9 months, 5 g/cm2
Male, Solar Max, 3 months, 5 g/cm2

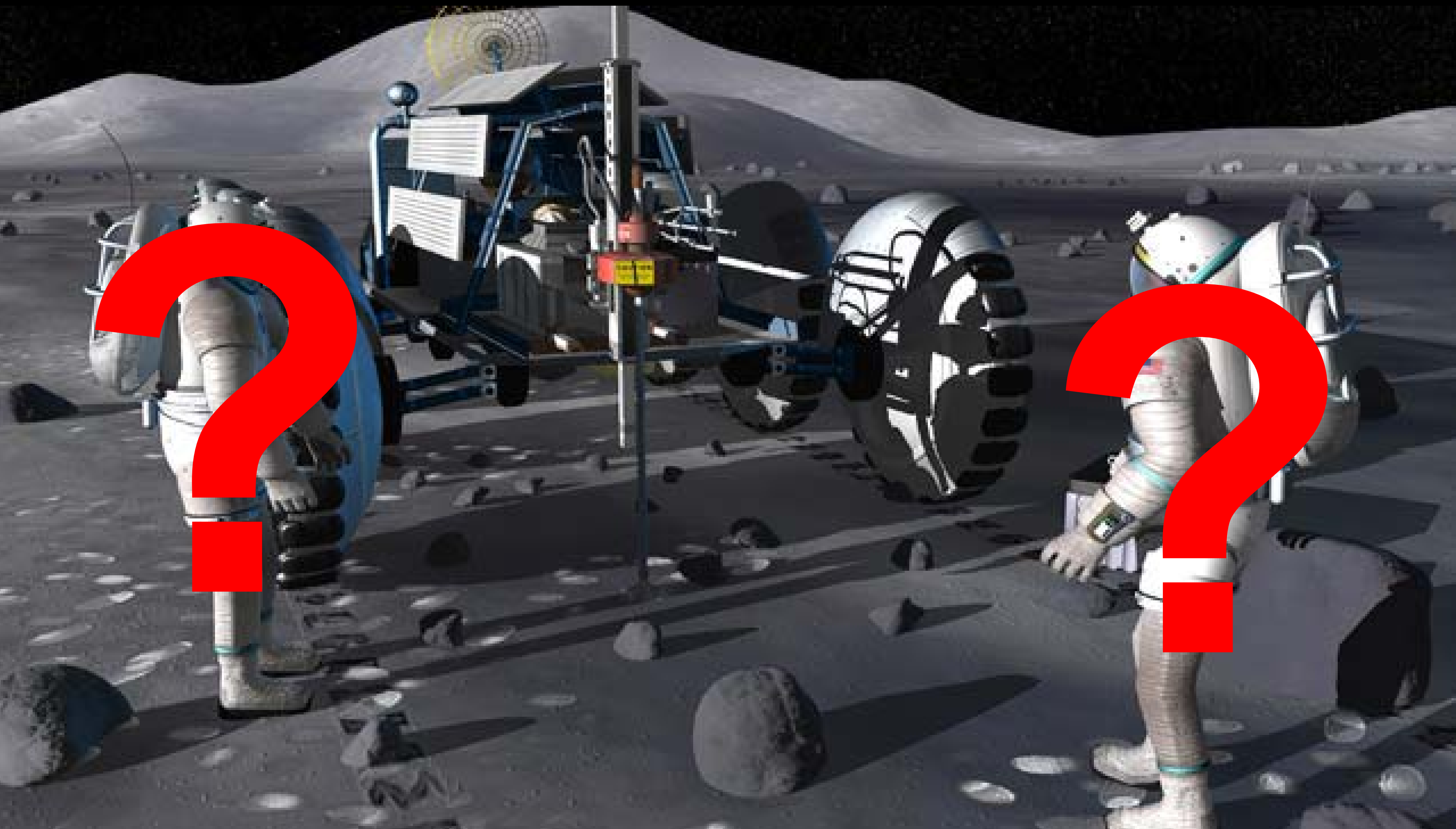
Hmmmm…:

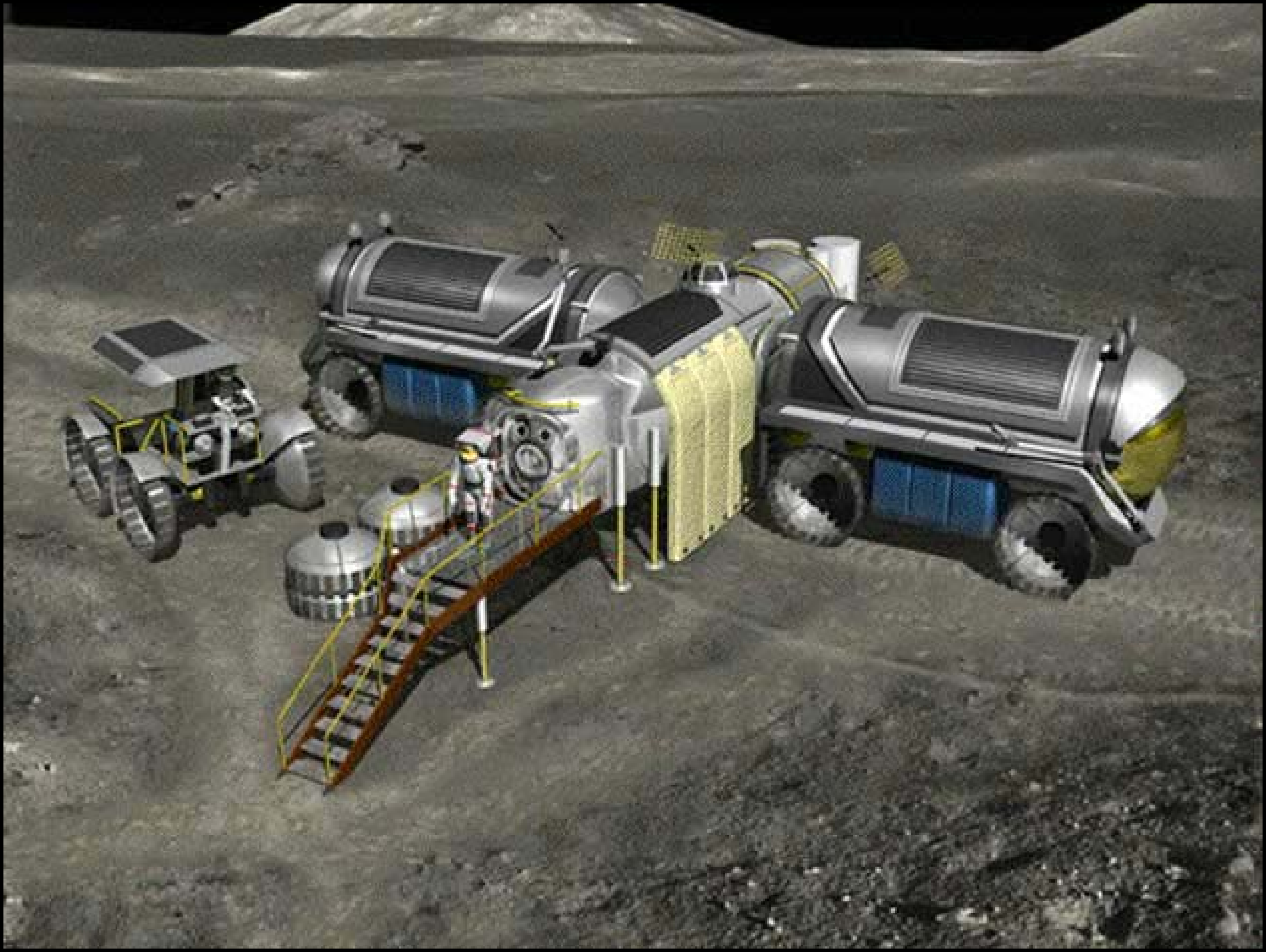
Female, Solar Max, 6 months, 5 g/cm2
Female, Solar Max, 3 months, 5 g/cm2
Male, Solar Max, 6 months, 5 g/cm2

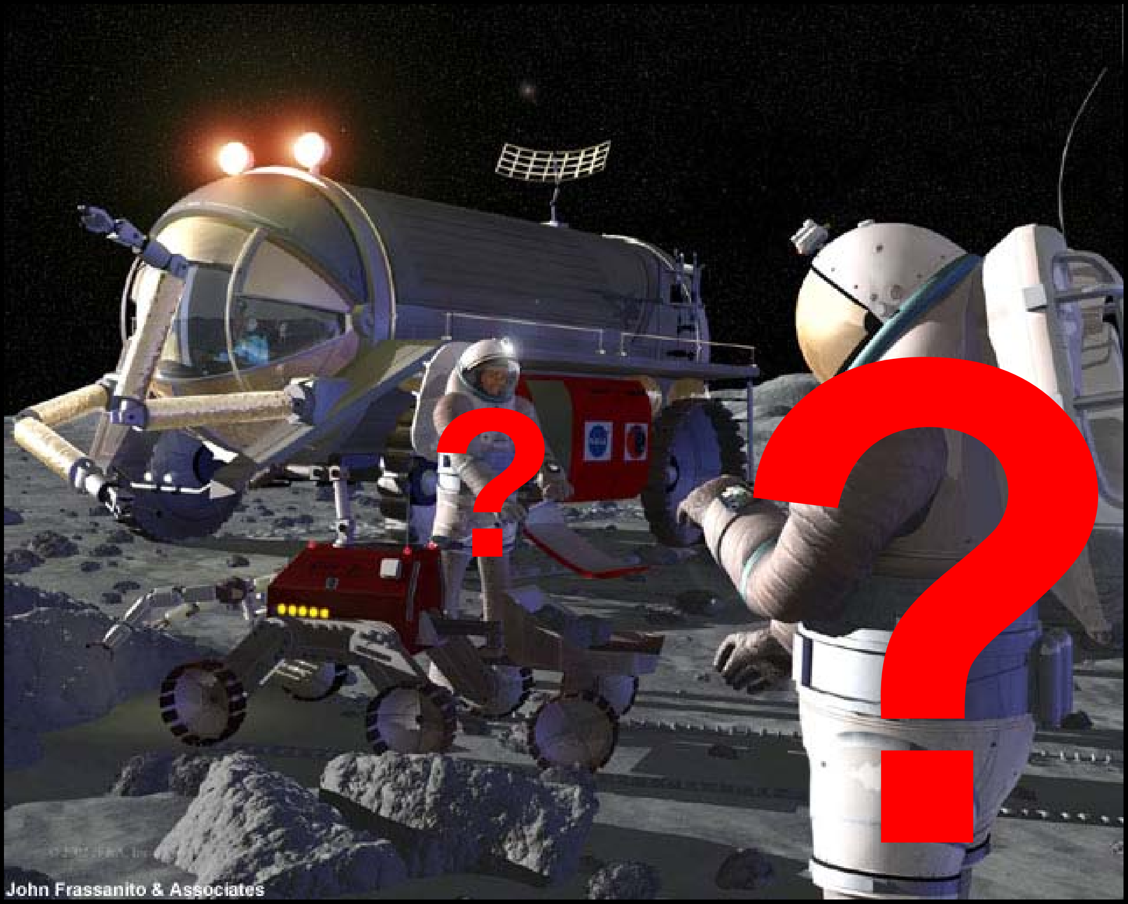
Houston We Have a Problem:

Female, Solar Max, 9 months, 5 g/cm2
Male, Solar Max, 9 months, 5 g/cm2

*** No EVA included!**

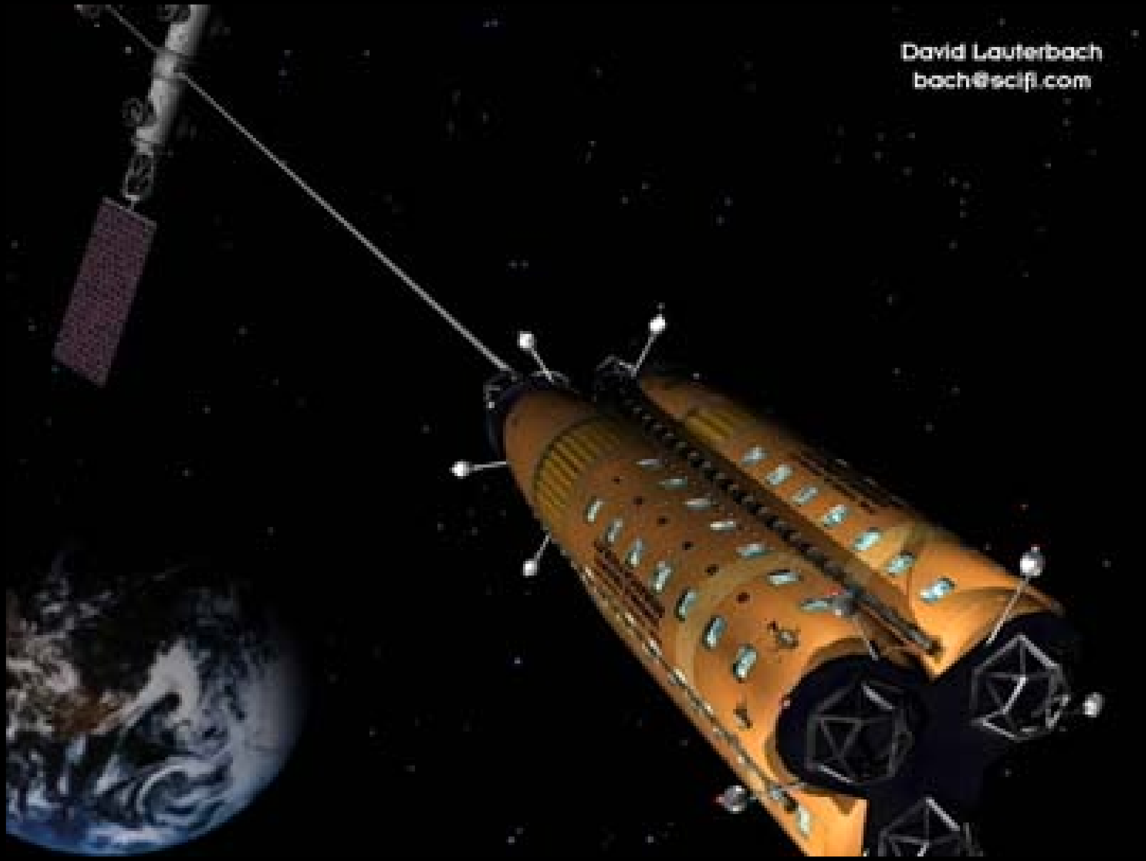





John Frassanito & Associates

Hypogravity

Gravity: It's the Law!



What's the Gravity Prescription?

Dose?

Frequency?

Side Effects?


J.R. Whitesel 2002

Synergistic Effects?

Absolutely!

Are There Biomedical Showstoppers?

It depends …

…on the definition of…

Long Duration?

Outpost?

Settlement?

Frontier?

Civilization?

Potential Lunar Long Duration Showstoppers

Element
Lunar Dust
Radiation
Hypogravity
Synergistic Effects

Potential Lunar Long Duration Showstoppers

Element	Sortie
Lunar Dust	
Radiation	
Hypogravity	
Synergistic Effects	

Potential Lunar Long Duration Showstoppers

Element	Sortie	Outpost
Lunar Dust		
Radiation		**EVA** / **Hab**
Hypogravity		
Synergistic Effects		

Potential Lunar Long Duration Showstoppers*

Element	Sortie	Outpost	Settlement
Lunar Dust			*Wild Card*
Radiation		**EVA** / **Hab**	**Surface (EVA)** / **Depth**
Hypogravity			Nonstarter
Synergistic Effects			

* Assuming current technology and goal of "civilization"

Potential Lunar Long Duration Showstoppers*

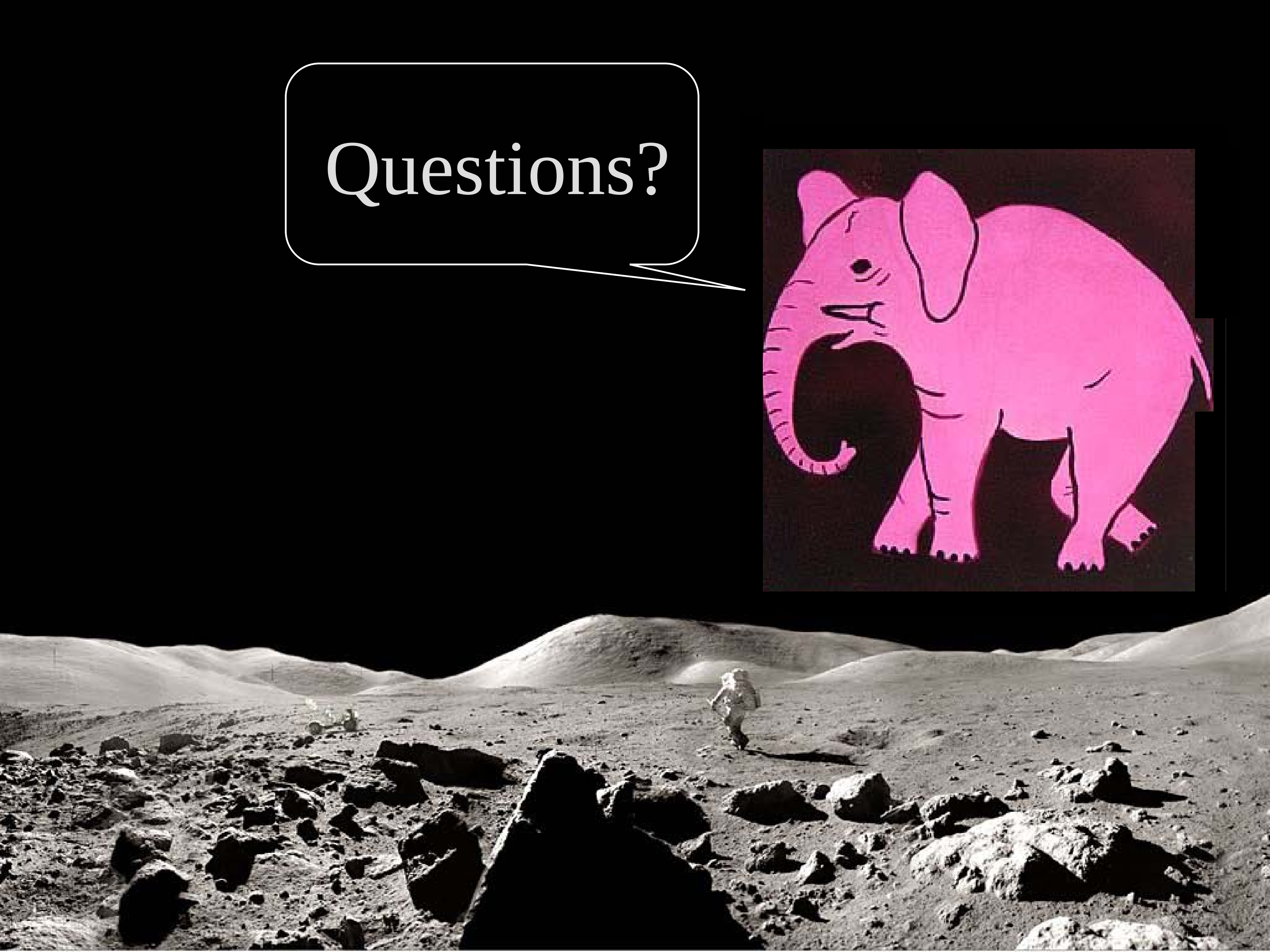
Element	Sortie	Outpost	Settlement	Frontier
Lunar Dust			*Wild Card*	*Wild Card*
Radiation		**EVA** / **Hab**	**Surface (EVA)** / **Depth**	**Surface (EVA)** / **Depth**
Hypogravity			Nonstarter	Nonstarter
Synergistic Effects				

* Assuming current technology and goal of "civilization"

Implications

- Moon *may* only be a sortie site in near term*
- Long-duration habitats will likely be shielded
- Repetitive lunar EVA *may* be constrained
- Optimal combination of robotic and human capabilities to be defined
- Robotic precursor missions advisable for reconnaissance and local site preparation
- Strategic *value* of human lunar activities should be prospectively defined (if "*civilization*" is goal)

*At least not without significant investment in enabling research & technology


Questions?