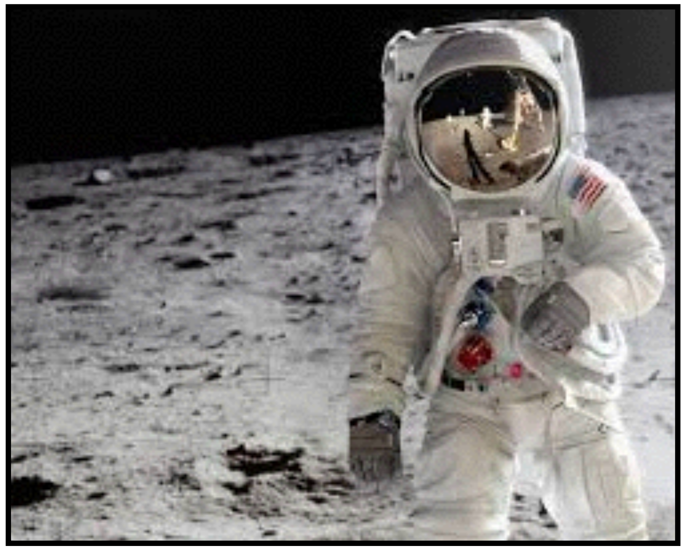
How big is a bacterium?

Is life already on Mars?

UNIVERSITY OF EXETER



How many microbes have been to the moon?

...assuming humans have

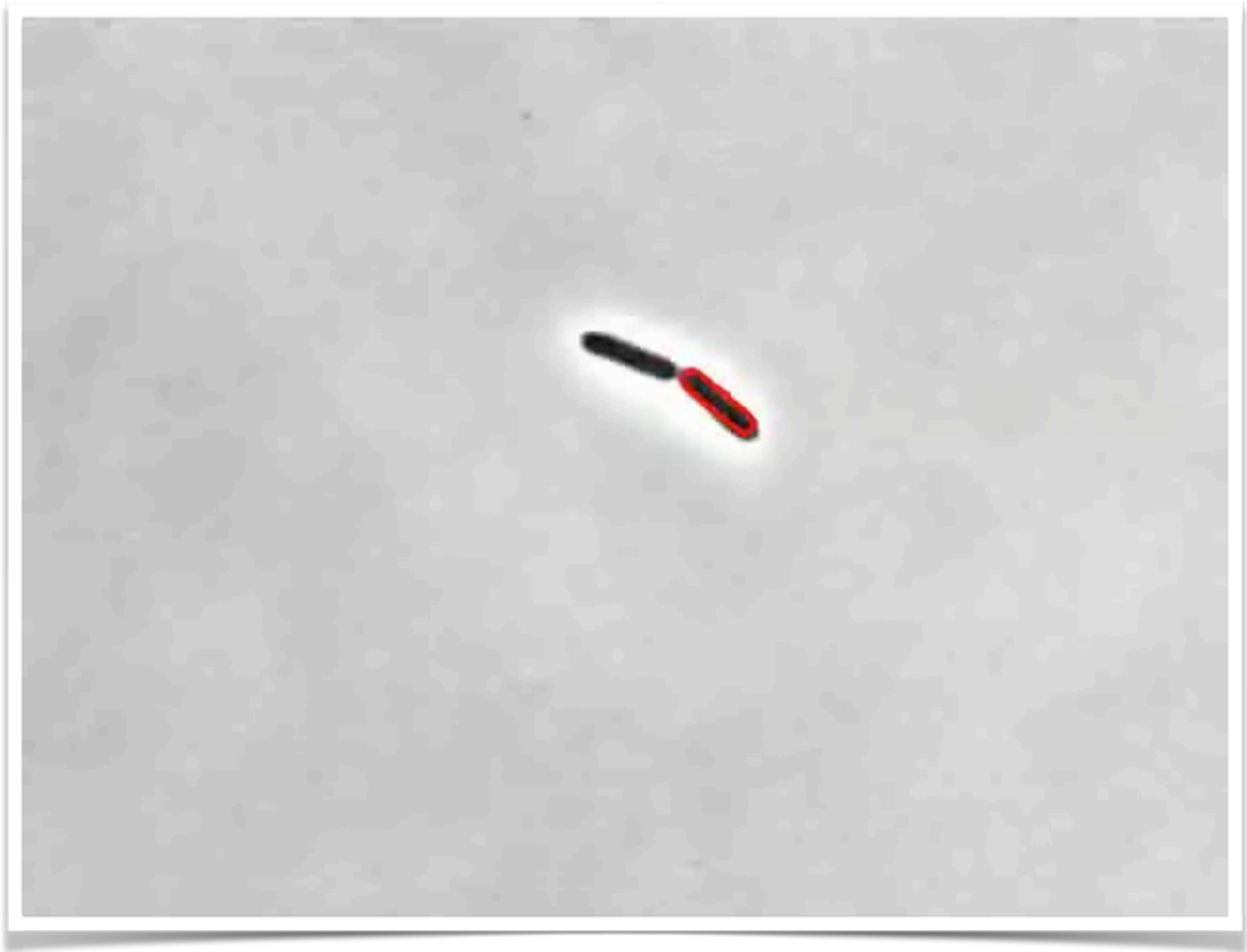
How many bacteria are there, hidden away, in this picture of an astronaut?

The beginning: how big is a bacterial cell?

Eh?

Is this the right question?

Q) How big is a bacterial cell? **A**) Let's follow 'one'.



zombie cells: membrane, but no DNA!

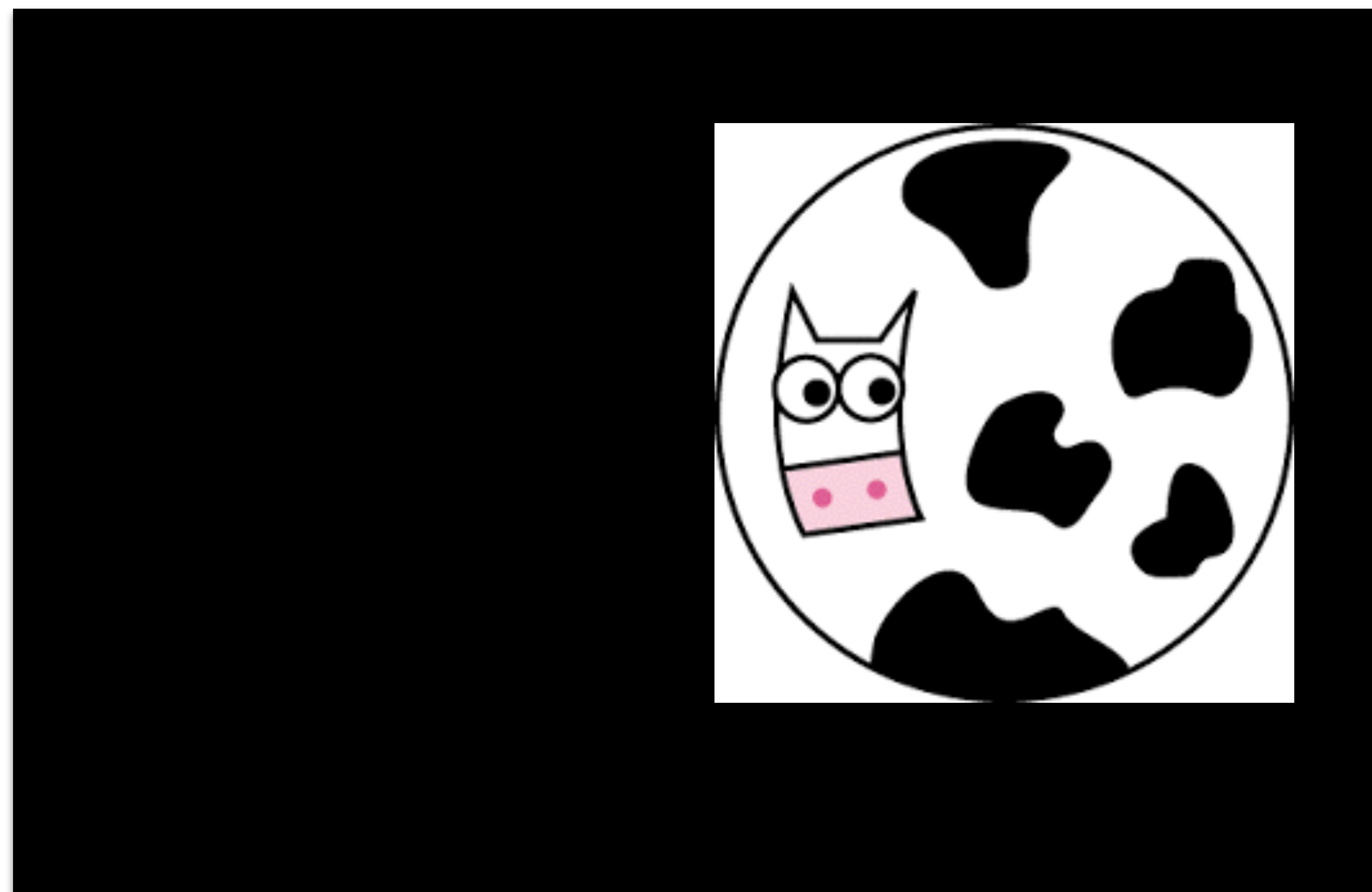
no DNA

- We can speak of the size of a zombie cell.
- We cannot easily speak of the size of a live cell: the size changes on a regular basis.
- Size is known to be related to growth rate…let’s ignore that.

Mathematicians, physicists & chemists use ‘**models**’ to understand phenomena around us:

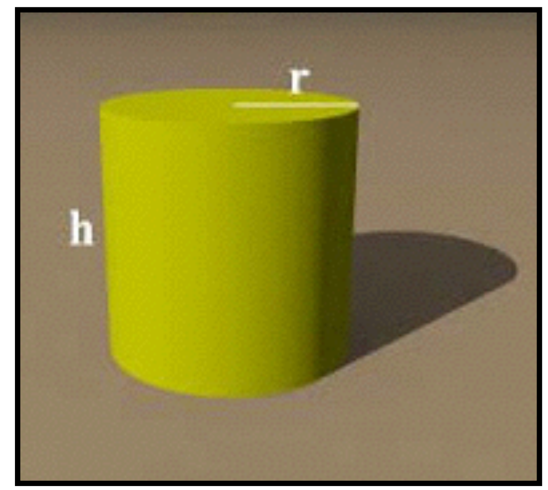
Models make simplifying assumptions,
often distilled into the scientists’ ‘joke’:

“Let us begin by assuming a spherical cow in a vacuum…”

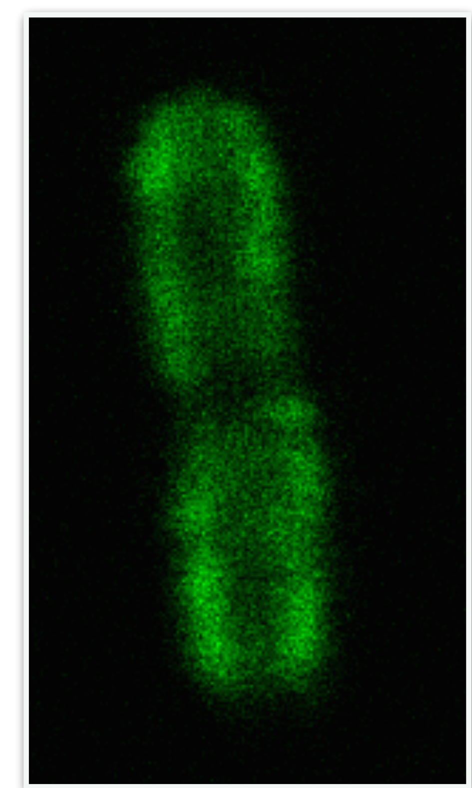


Our spherical cow:

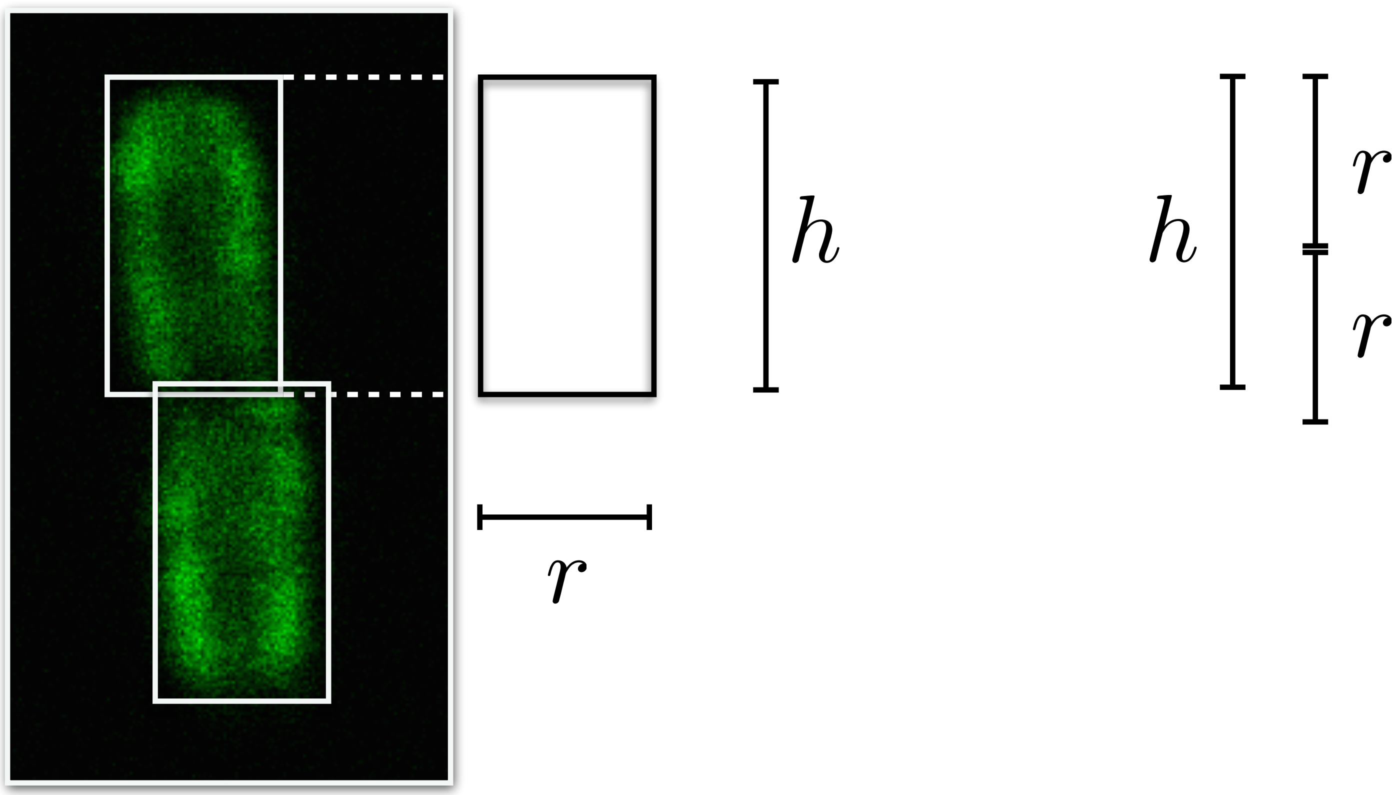
A model bacterial cell:
a cylinder (a rod)



A real image with green protein in the cell's outer membrane:



- Just after the moment of division:



$$h < 2r$$

$$\downarrow$$

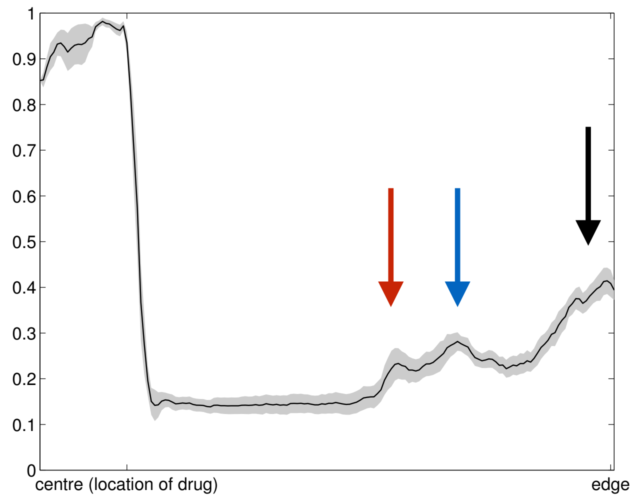
$$h \approx 2r$$

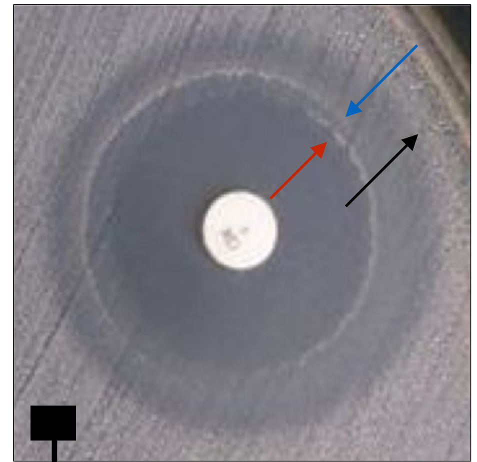
Volume $\approx \pi r^2 h$

- Just before division: $h \approx 4r$

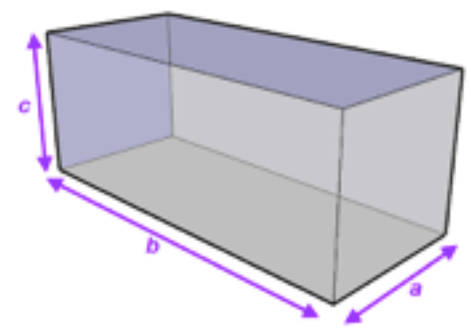
$$2\pi r^3 < \text{Volume} < 4\pi r^3$$

So what is $r\ldots$?



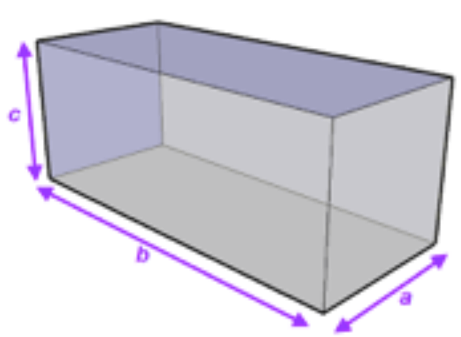


agar
with cells



let's **assume** it's **totally** full of cells, we need to count them…

$$a = b = 1cm \quad c = 0.1cm \quad \} \, 0.1cm^3$$



$10ml$

$\approx 5 \times 10^8$ cells per ml,

$= 5 \times 10^9$ cells per 0.1cm^3,

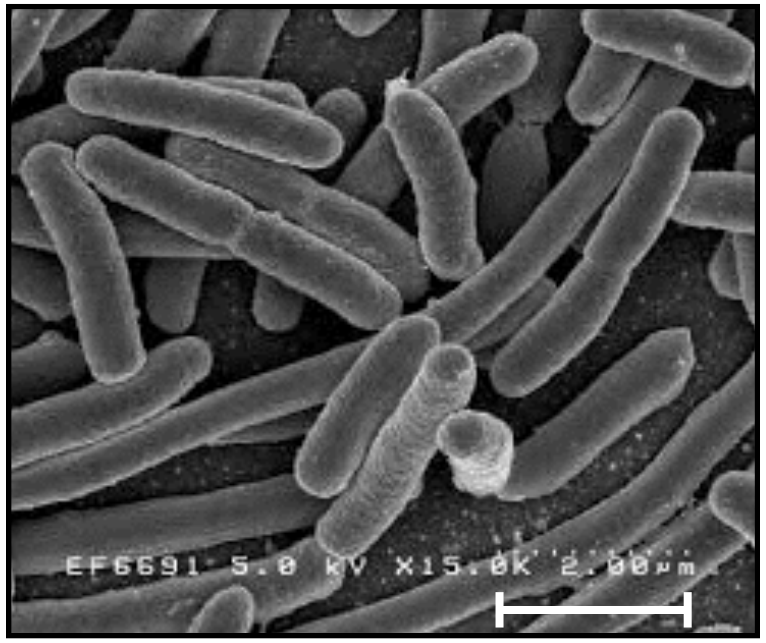
$= 5 \times 10^{10}$ cells per cm^3

$$\boxed{5 \times 10^{10} \text{cells per cm}^3} =$$

$$1 \times \text{cm}^3 \text{ per } \frac{1}{5} \times 10^{-10} \text{cells} =$$

$$\frac{1}{5} \times 10^{-10} \text{cm}^3 \text{ per 1 cell} \Longrightarrow$$

$$\begin{aligned} r &\approx \left(\frac{1}{5} \times 10^{-10} \text{cm}^3 \right)^{1/3} \\ &= \left(\frac{1}{5} \times 10^{-10} \right)^{1/3} \text{cm} \\ &= \frac{1}{5^{1/3}} \times 10^{-10/3} \text{cm} \\ &\approx \frac{1}{1.71} \times 10^{-1/3} 10^{-3} \text{cm} \\ &\approx 0.5848 \times 0.4642 \times 10^{-3} \text{cm} \\ &\approx 10 \times 0.2715 \times 10^{-3} 10^{-3} \text{m} \\ &\approx 2.7 \mu\text{m} \end{aligned}$$



$2\mu m$

Notes:

$$5 \times 10^{10} \frac{\text{cells}}{\text{cm}^3} \Rightarrow \frac{1}{5 \times 10^{10}} \frac{\text{cm}^3}{\text{cells}}$$

$$2\pi r^3 < \text{Volume} < 4\pi r^3$$

The human gut contains about **2L** of microbes:
this includes all NASA employees

$$5 \times 10^8 \text{cells per ml} = 5 \times 10^8 \frac{\text{cells}}{\text{ml}}$$

$$= 5 \times 10^8 \frac{\text{cells}}{10^{-3}\text{L}}$$

$$= 5 \times 10^{11} \frac{\text{cells}}{\text{L}}$$

$$= 10^{12} \frac{\text{cells}}{\text{astronaut gut}}$$

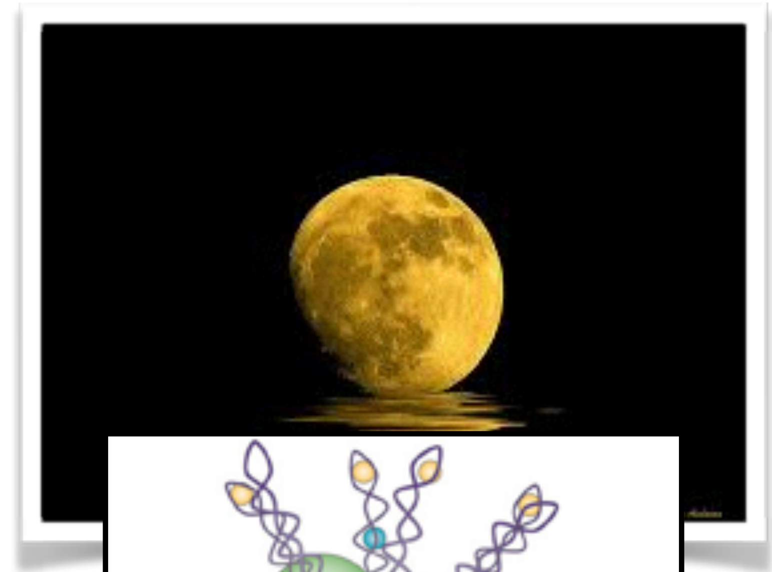
$1\text{ml} = 10^{-3} L$

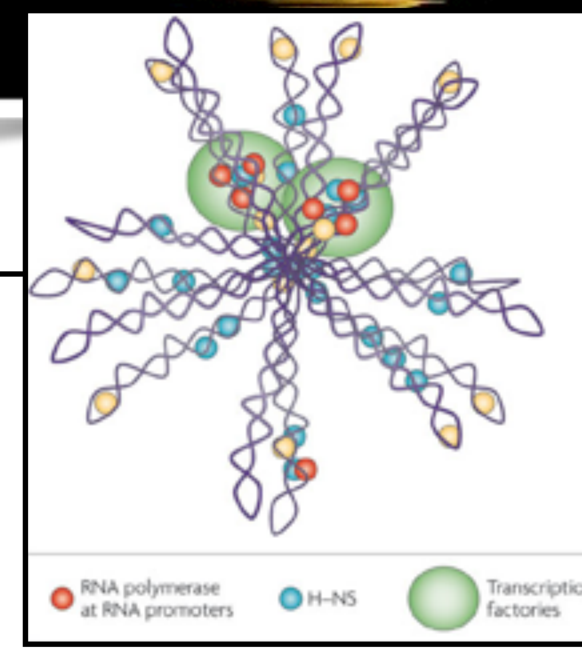
2L

$\approx 24 \times 10^{12}$ bacterial cells have been on the moon

"Bacterial chromosomes are generally ~1000 times longer than the cells in which they reside…"

http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2828278/



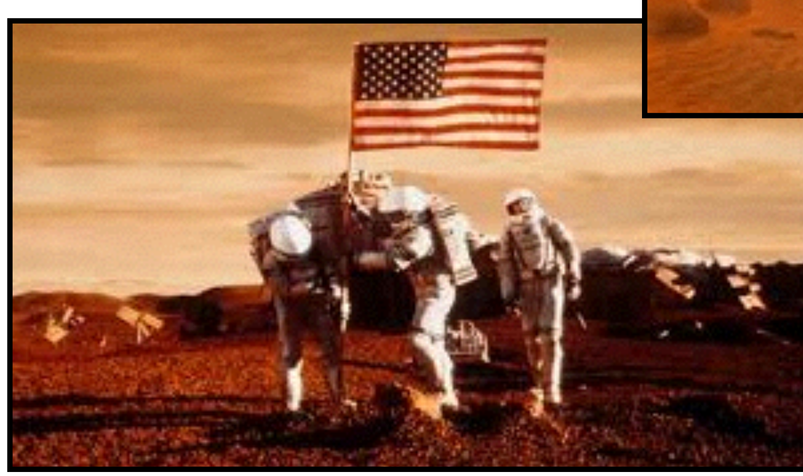


$$r \approx 2.7\mu m$$

$$\text{total DNA length} \approx 2.7\mu m \times 1000 \times 24 \times 10^{12}$$
$$\approx 64,800\mu m \times 10^{12}$$
$$\approx 64,800 \times 10^{-6} m \times 10^{12}$$
$$\approx 64,800 \times 10^{6} m = 64,800 \times 10^{3} km$$
$$= \frac{64,800 \times 10^{3} km}{384,400 km} \text{ Earth-Moon Distances}$$
$$= 168.57 \text{ Earth-Moon Distances}$$

of bacteria that have been to the moon

Who will get here first?



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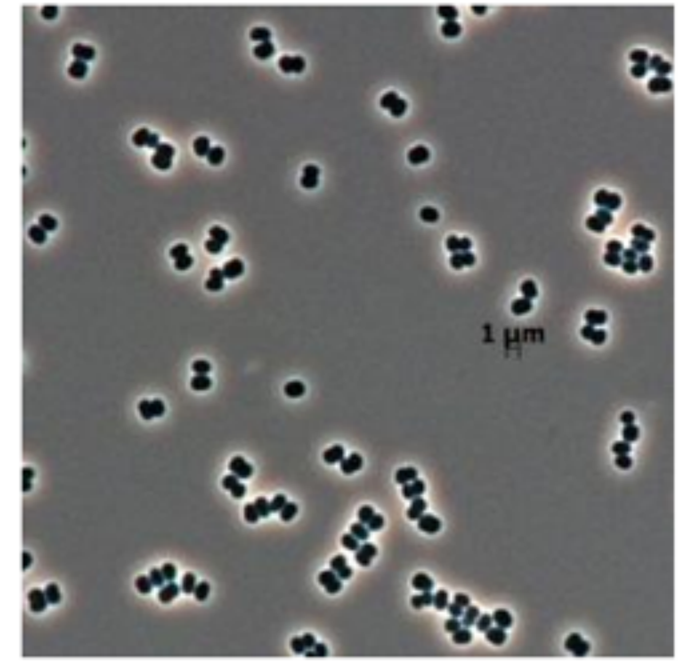
New Bacterial Life-Form Discovered in NASA and ESA Spacecraft Clean Rooms

The previously unknown microbe was tough enough to survive stringent sterilization at two locations. Might it survive a trip to Mars?

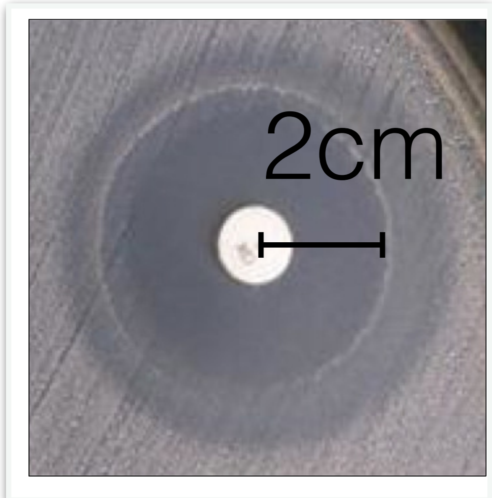
November 20, 2013 | By Clara Moskowitz

High atop a platform inside a clean room at the European Space Agency's (ESA) launch site in South America, scientists painstakingly searched for microbes near the Ariane 5 rocket due to launch the Herschel space telescope in May 2009. Only very unusual organisms can survive the repeated sterilization procedures in clean rooms, not to mention the severe lack of nutrients available. But the scientists' careful inspection was fruitful, turning up a type of bacteria that had been seen only



There is no proof that *T. phoenicis* actually accompanied Phoenix to Mars, but it is possible. "This genus has surely traveled to Mars already, recently in one or more of our spacecraft—they live comfortably in the clean rooms where we build the craft, right?—and maybe even onboard meteorites millions or billions of years ago," Fairén says. "Therefore, if these bugs can actually survive on Mars, they must be there already." Ultimately, the discovery of bacteria as resilient as *T. phoenicis* just goes to show how robust life is. The finding suggests that "once life originates on a planet, it has great adaptive power and can survive a great variety of environmental stresses," says Dirk Schulze-Makuch of Washington State University, who wasn't involved in the study of the new genus. "The $1-million question, of course, is: Under which conditions life can originate in the first place?"

http://www.scientificamerican.com/article/bacteria-discovered-spacecraft-clean-rooms/



Q) How many bacteria died in the making of this document?

Arithmetic rules for units:

$$x \sim [A], y \sim [B] \implies x \cdot y \sim [AB],$$

$$\implies x/y \sim [A/B],$$ read: "x per y"

$$x \sim [A], y \sim [A] \implies x \pm y \sim [A],$$

$$\implies x/y \text{ is unitless},$$

$$x \sim [A], y \sim [B] \implies x \pm y \text{ is not allowed}$$

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egs.

$Q1.$ $5\text{miles} + 6\text{km} = \ ?$

$Q2.$ $\dfrac{S}{K+S}$ has which units, exactly; what about K?

$Q3.$ $2.7\mu m$ is how many nm if $\mu m = 10^{-6}m$ and $nm = 10^{-9}m$?

$$A3.\ 2.7\mu m = \ 2.7\frac{\mu m}{nm}nm = \ 2.7\frac{10^{-6}m}{10^{-9}m}nm = 2.7 \times 1000nm$$