Hot Science Cool Talks

UT Environmental Science Institute

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Better Living Through Microbes

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May 1, 2015

Better Living Through Microbes

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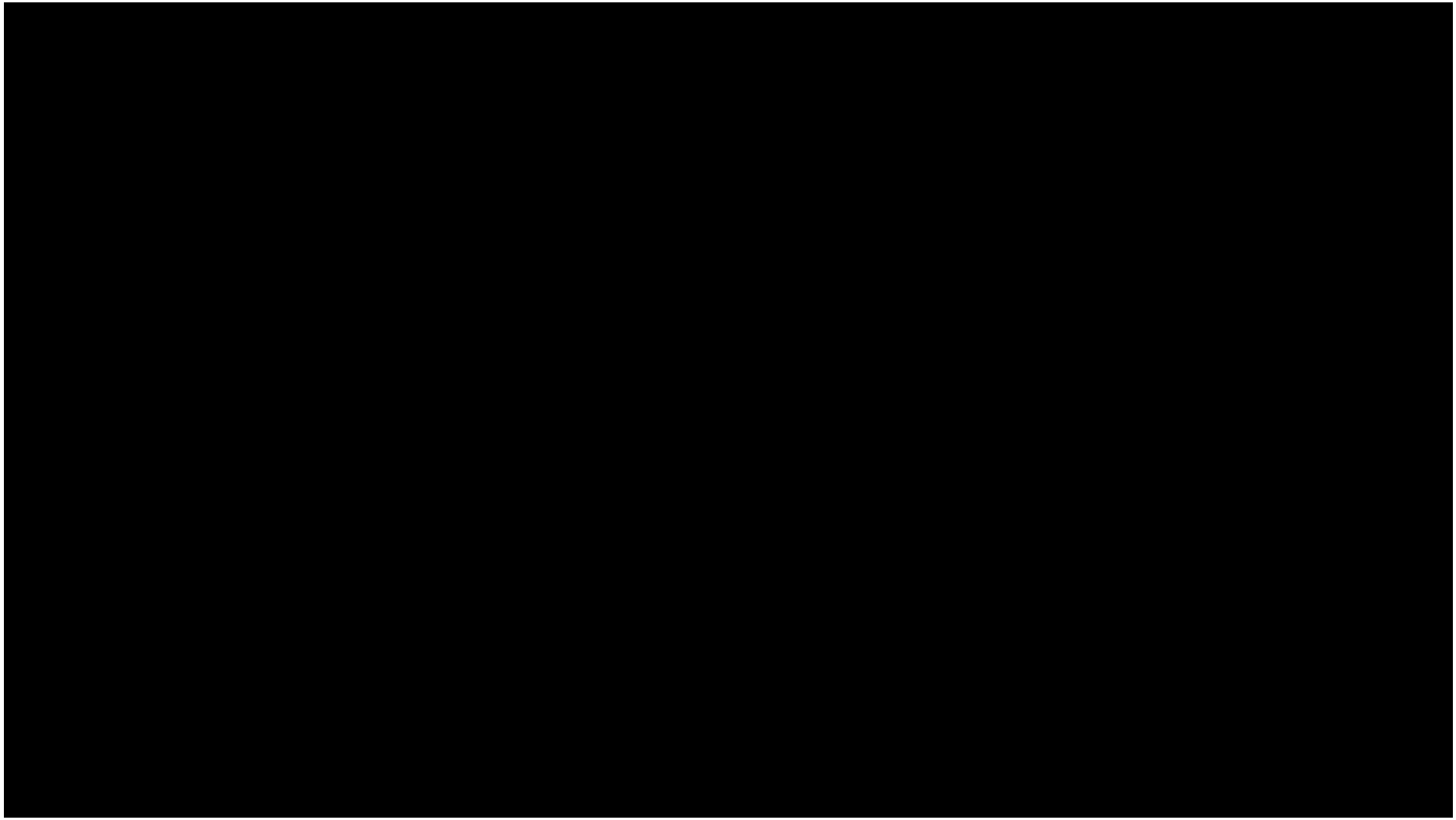
Popular perspectives of microbes



Popular perspectives of microbes

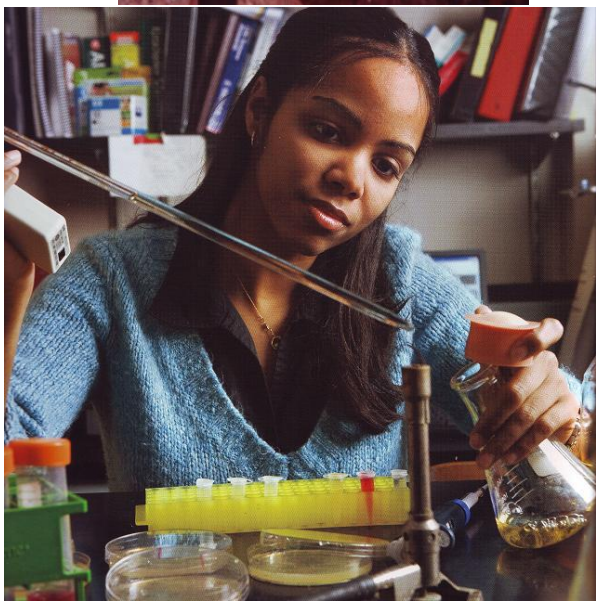
Overall, 58 percent of voters are worried about bacterial contamination of the food supply – with about a third of those saying they worry "a great deal." (2009)

77 percent of American voters worry "a great deal" about infections and antibiotics (2013)

A different story from a microbe fan's perspective

- **Fortune to have great *additional* encounters with microbes**
  - As a middle school student on science field trips
  - Through science fair participations

- **An ongoing "falling in love" moment**
  - Fascination that such small organisms can be fully alive and perform such extraordinary functions.



Tonight's Talk

- **When did we discover microbes?**
- **What are bacterial microbes?**
- **How many families of bacterial microbes are there and what do they do for us?**
- **What conditions can some microbes survive that most organisms cannot?**
- **Who is *D.rad* and what are his special powers?**

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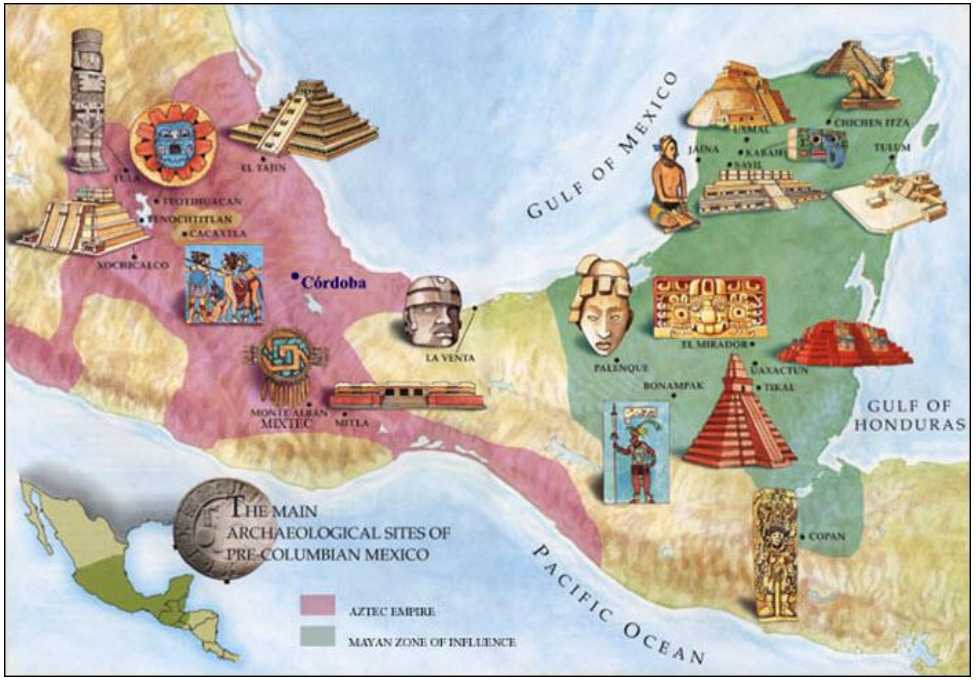
Ancient cultures: great at feeding their people



The Ancient Mayans (Central America)

- ~4,000 years ago (2500 BC to AD 1697)
- Parts of now-Northern Mexico and Honduras
- **Sophisticated agricultural systems**

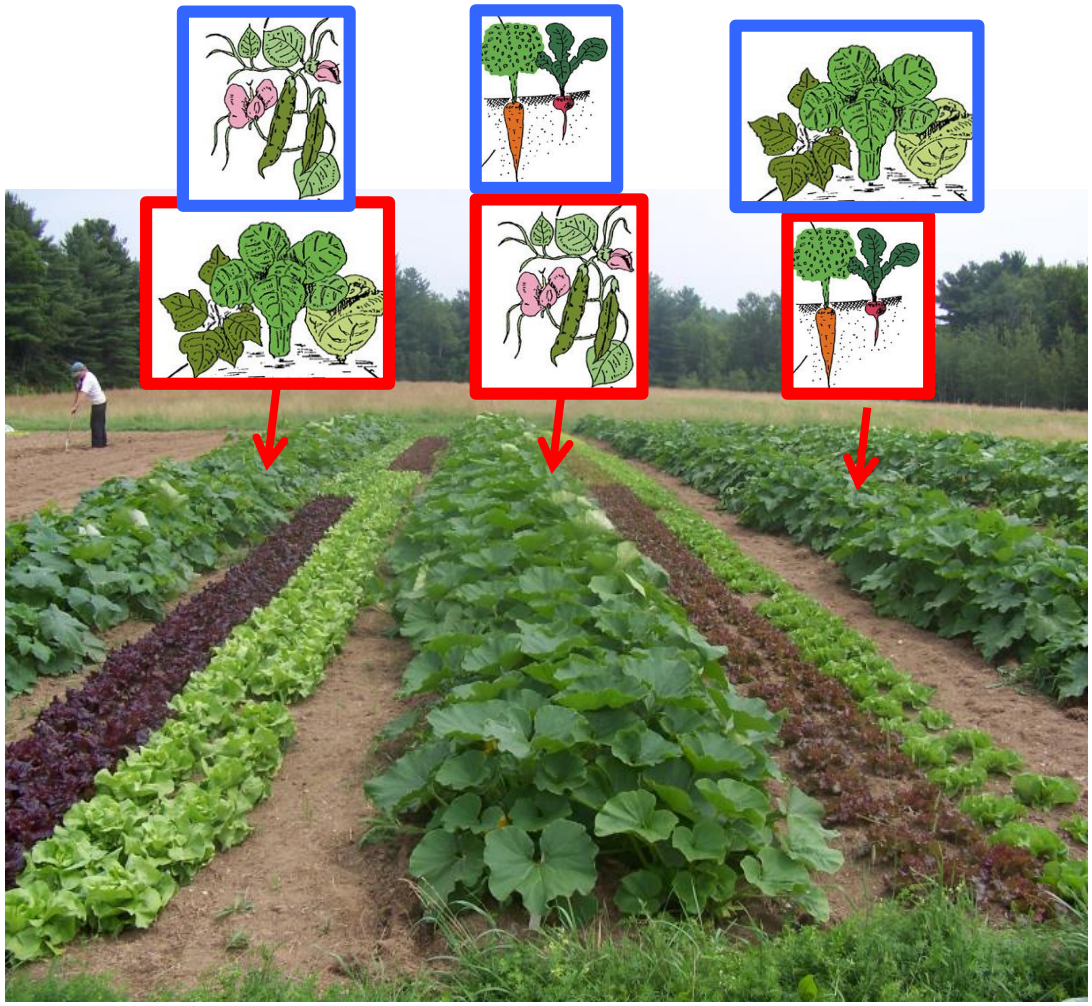
Observation that *crop rotations* led to better yields

What did they do with crop rotations?

- ***Redistribute*** crops in the soil
- “Not to plant the same crop into the same soil location every year”

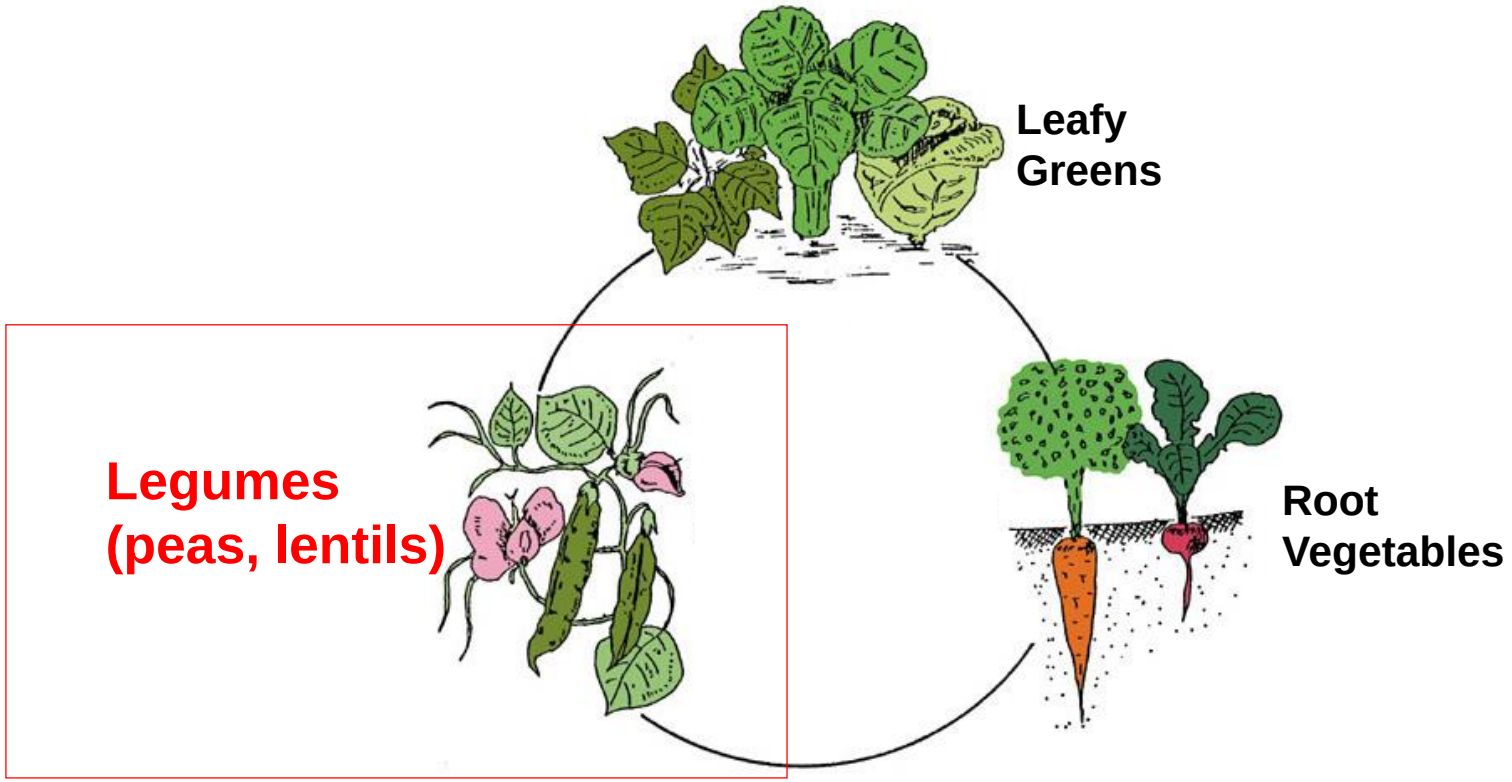
Year 2

Year 1



What is special about crop rotations?

- ***First clue***: something special about the plants like peas, lentils, and clover in restoring ground fertility.

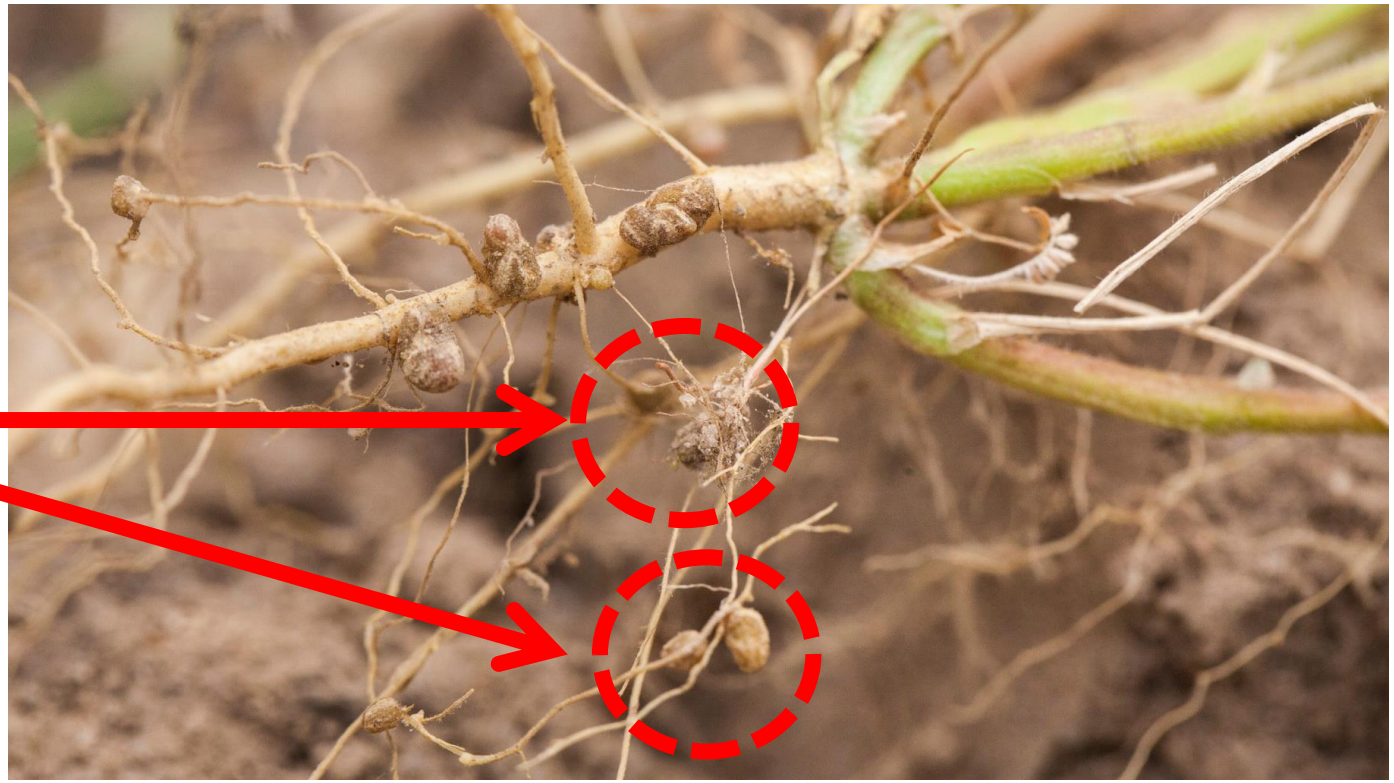


What is special about these plants?

- The microscope: a major invention by Anthony Leeuwenhoek in1683
- We could see things **300 times smaller** than before
- Discovery of “pockets” unique to some plant roots

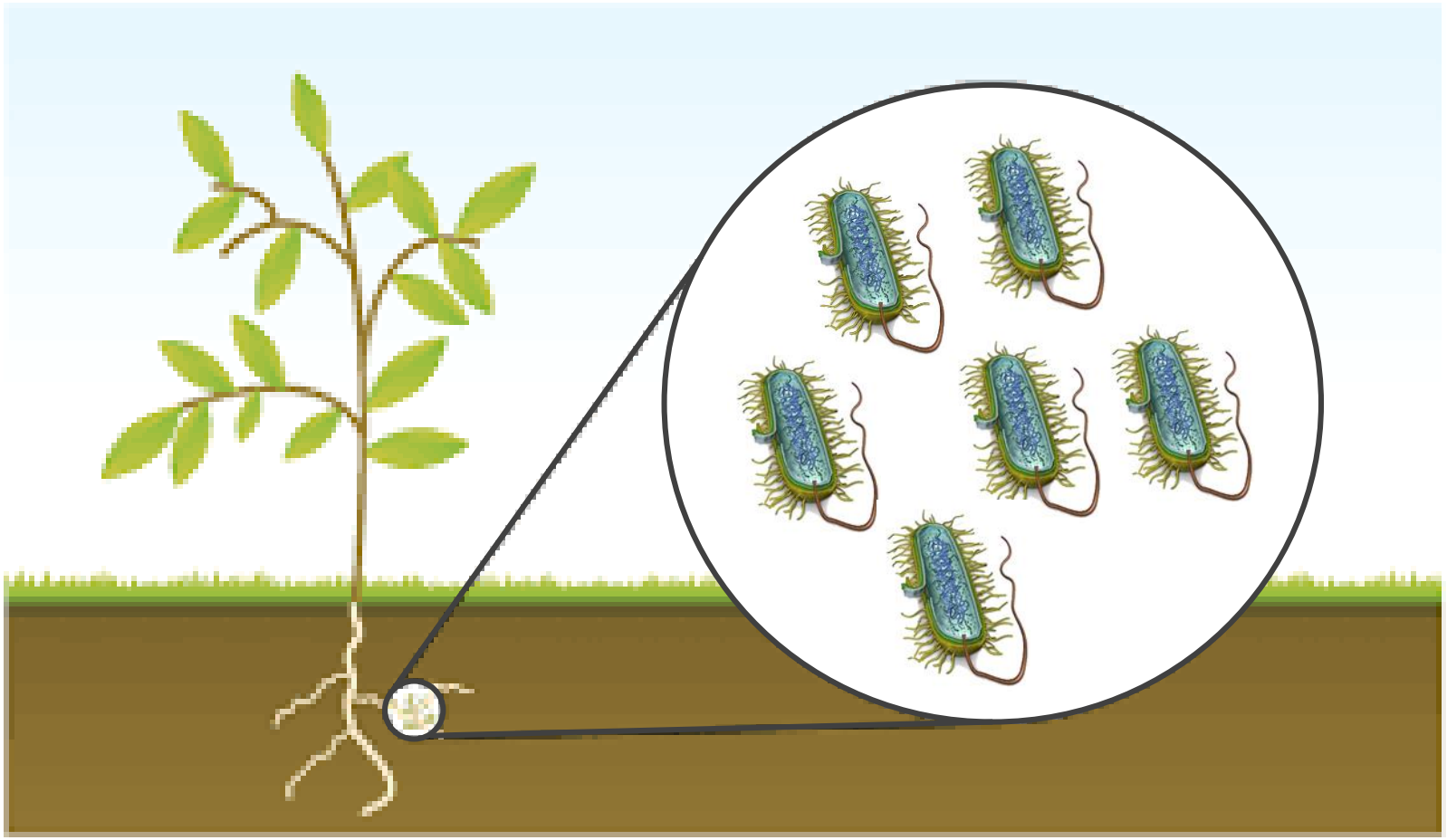
Soy beans, many legumes

nodules



What is inside those pockets?

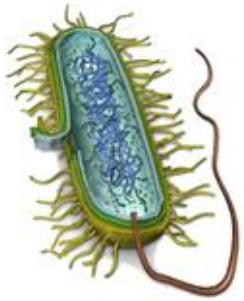
- It was tiny **bacterial organisms inside** that let to more fertile soils when peas, lentils and legumes were planted!



What do these bacterial microbes do?

- ~ 200 years later (1889) bacteria grown in laboratory by Martinus Beijerinck and found that they take **N_2 from air** and convert it to **ammonia** through "nitrogen (N_2) fixation."

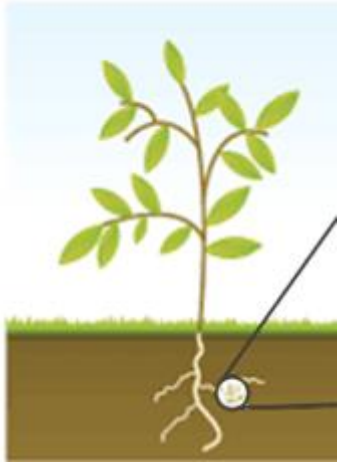
- Even though 80% of the earth is made of **N_2**, plants and animals can't use it in this form.



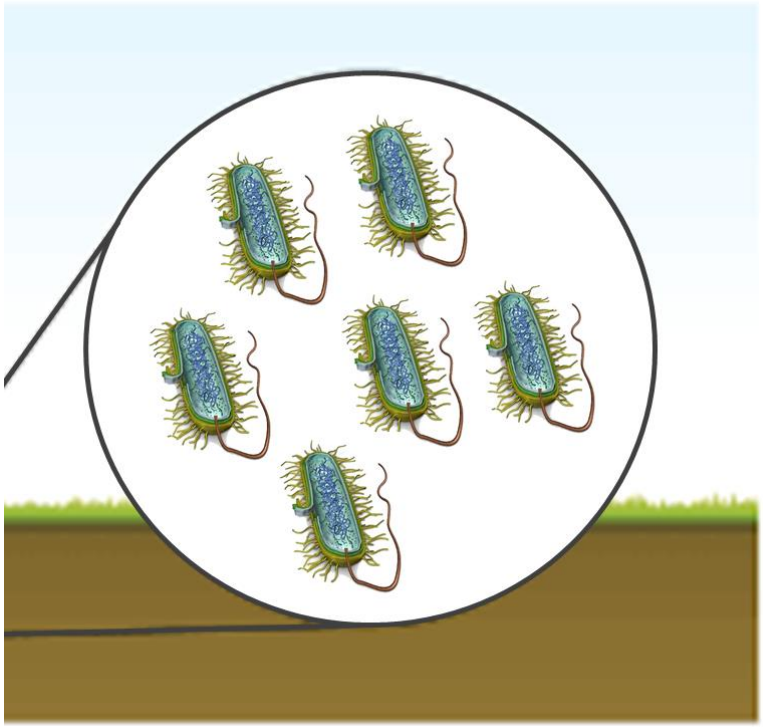
N_2 (Air) → **Ammonia**

The secret of plants that help soil during rotations

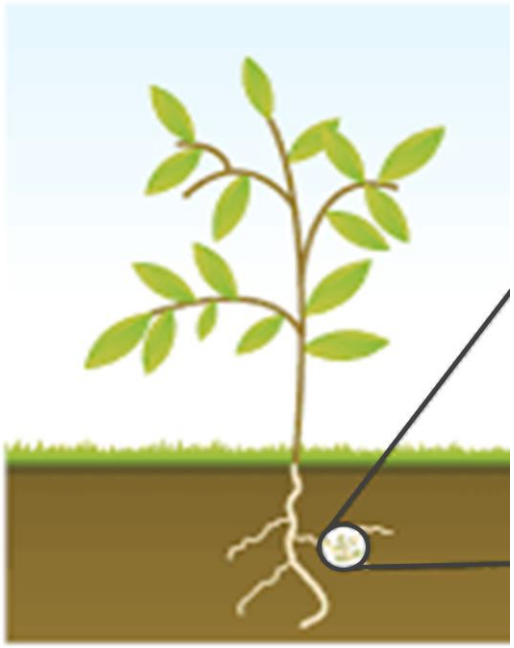
1. Small plant with nodules that contain bacteria.



2. Microbes in the nodules make ammonia, used by plants to grow!

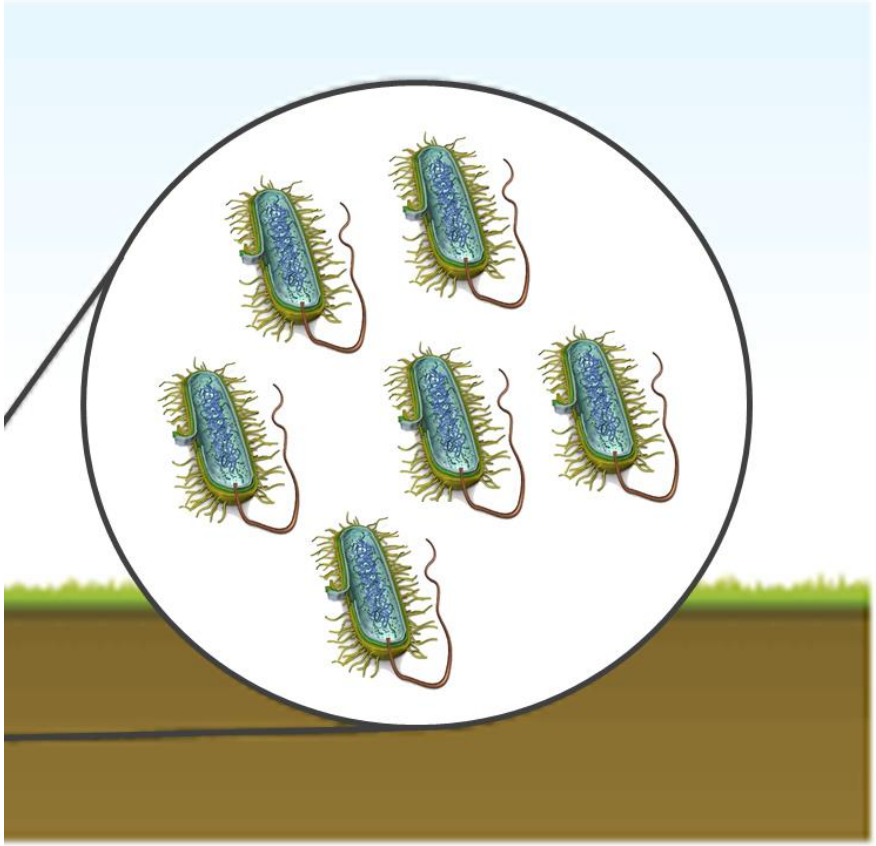


3. Small **plant grows into a big plant,** with the help of ammonia.



Without knowing it… Mayans discovered that microbes are hugely beneficial for plants and soil

- We continue to use ammonia, found in fertilizers, to help plants grow!
- We continue to use crop rotations.



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Ammonia

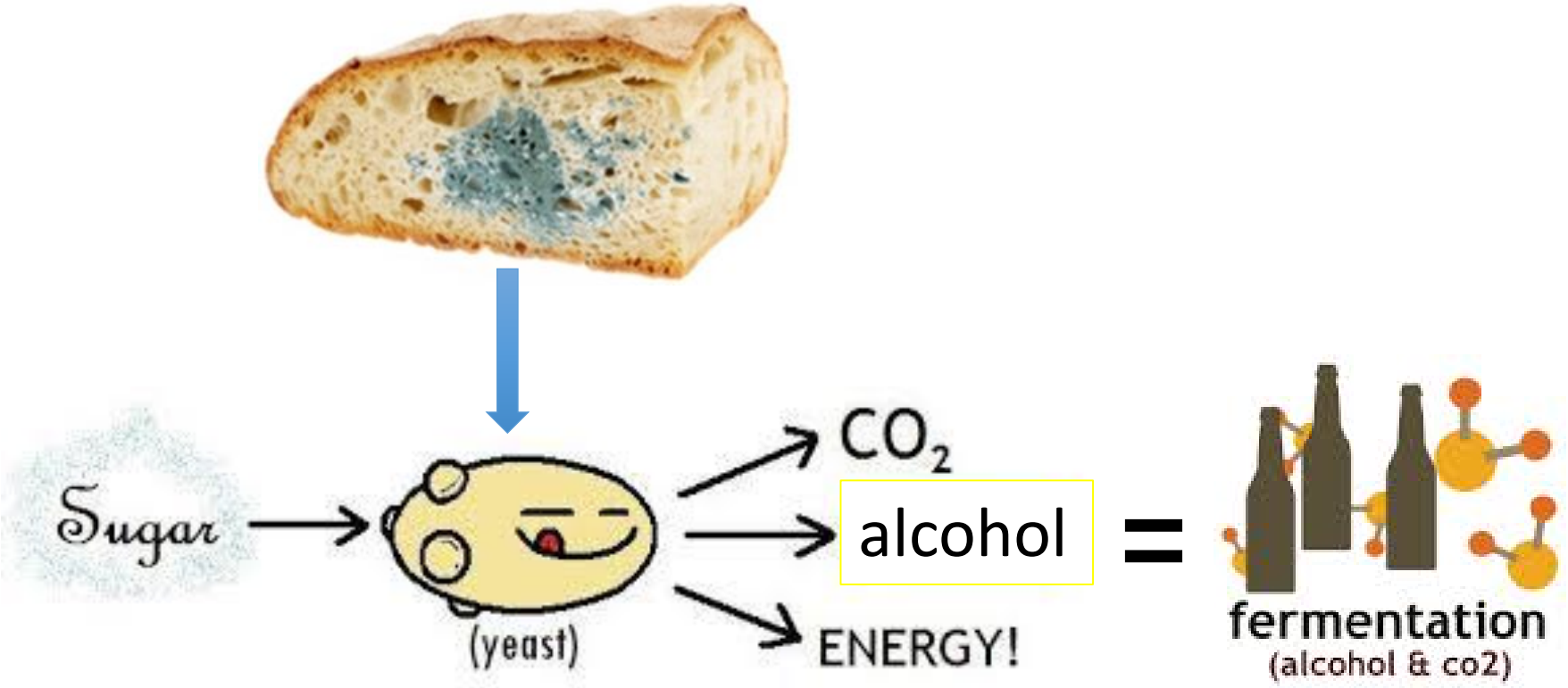
Without knowing it, the Egyptians also put microbes to work to entertain their guests!

- Hieroglyphs with recipes of *exquisite* beer date back to ~ 8000 years ago.

Moldy Bread + Water = the “joy bringer” drink.

What is it about the bread?

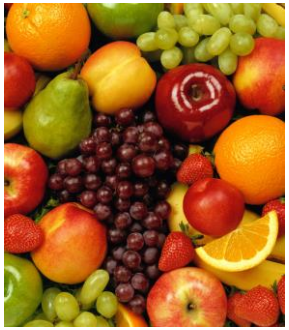
- Bread contained ***yeast microbes*** that produced alcohol in a process of **"fermentation"**



Today…yeast microbes remain critical ingredients for wine and beer

Different combinations of:

fruits & spices



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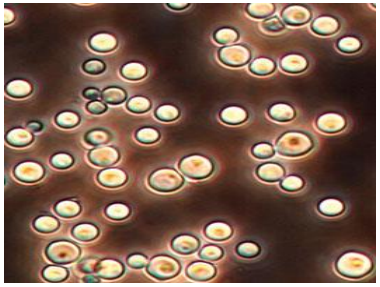
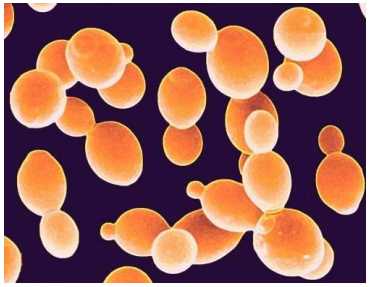
Different types of yeast microbes





Lesson learned from ancient cultures

Without knowing it, societies became **dependent** on microbes **to feed** and **even entertain** their populations.

Tonight's Talk

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- How many families of bacterial microbes are there and what do they do for us?
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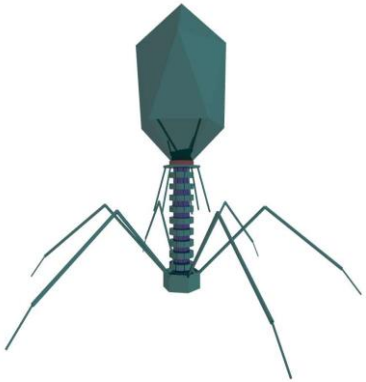
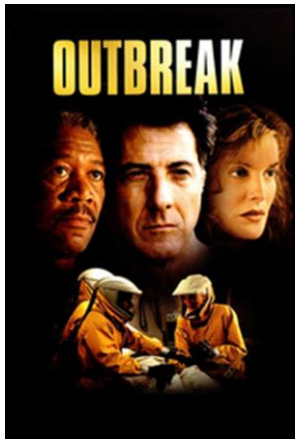
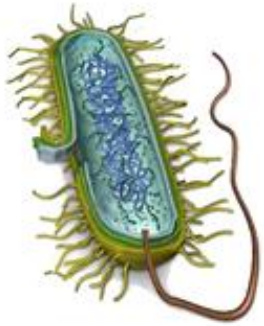
Three types of commonly talked about microbes

Virus
0.02 microns

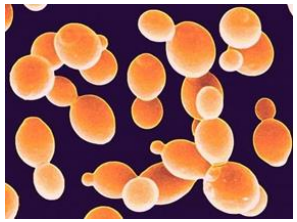




Bacteria
1 micron



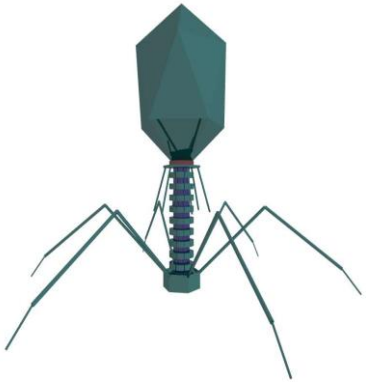
Yeast
40 microns

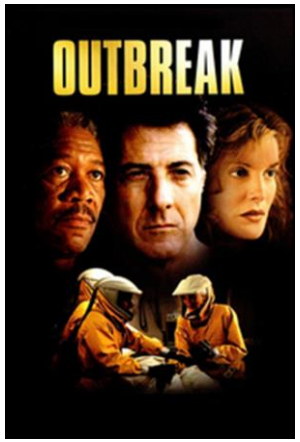


Very different organisms…can’t kill the “flu” virus with antibacterials !

Our focus today: Bacteria

Virus
0.02 microns





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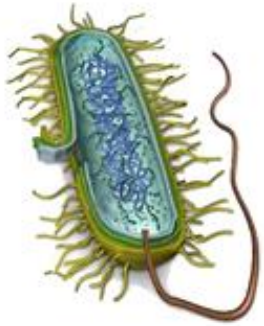

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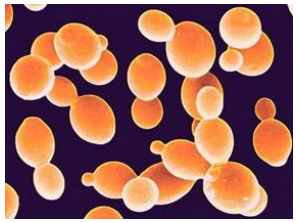


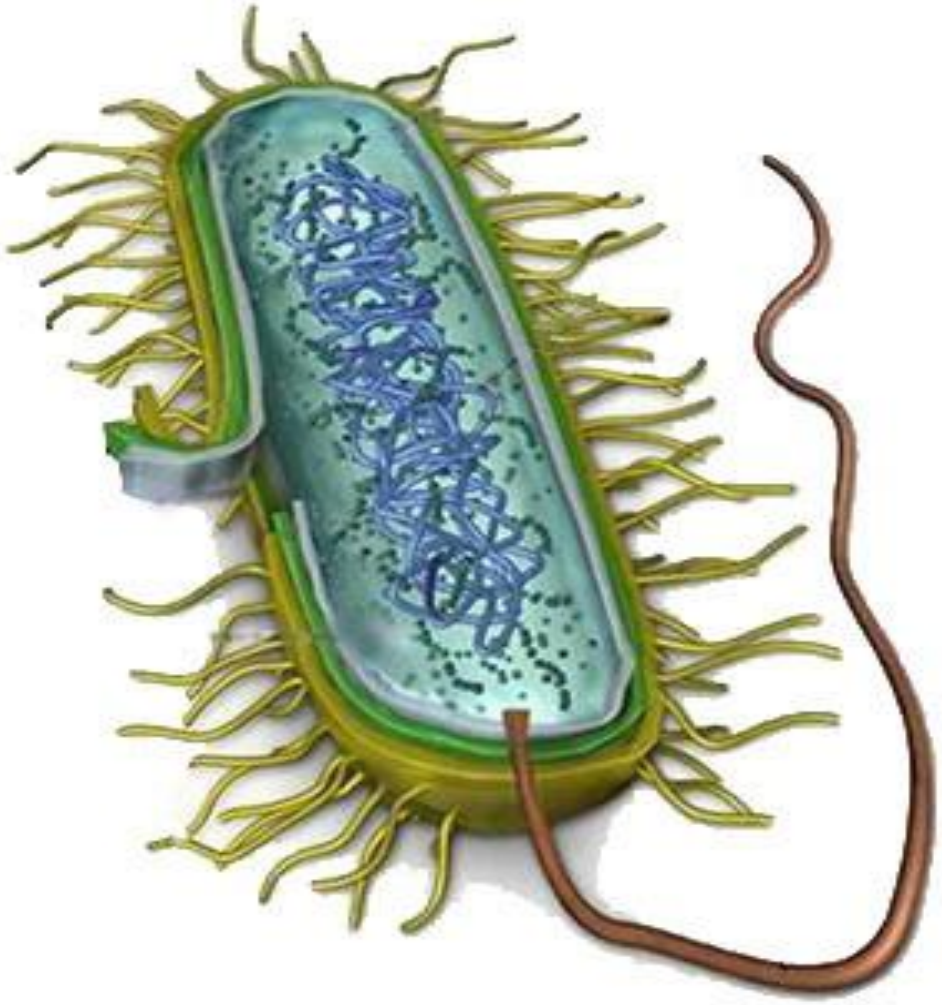
What are bacterial microbes?

- Tiny **single cell** organisms
- Many different families
- They are very, very, very **tiny!**

Tip of your hair can fit
~100 bacteria!

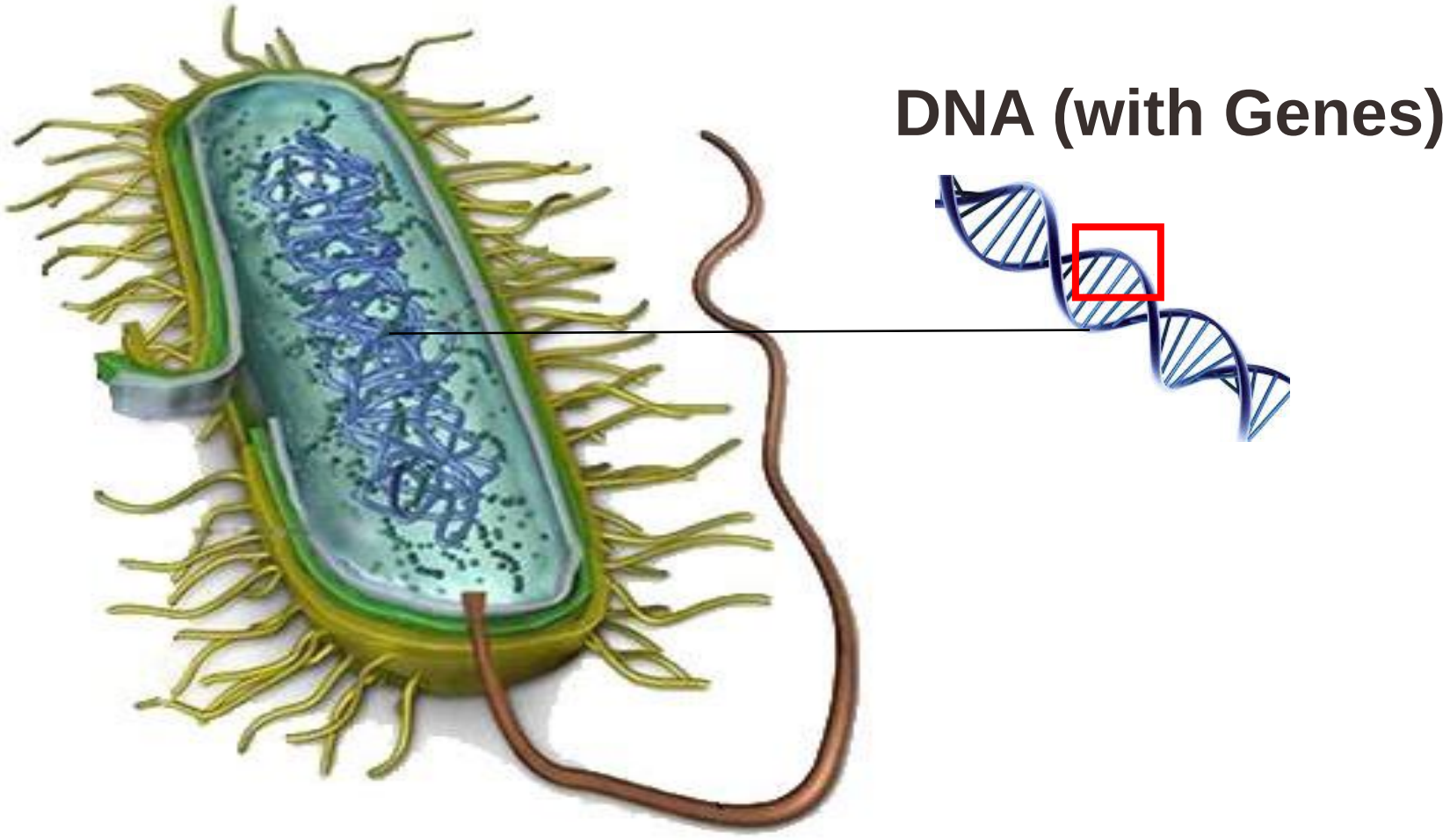
How do these tiny organisms stay alive?

- A bacterial microbe performs all the **same basic functions** that a human cell has to stay alive.

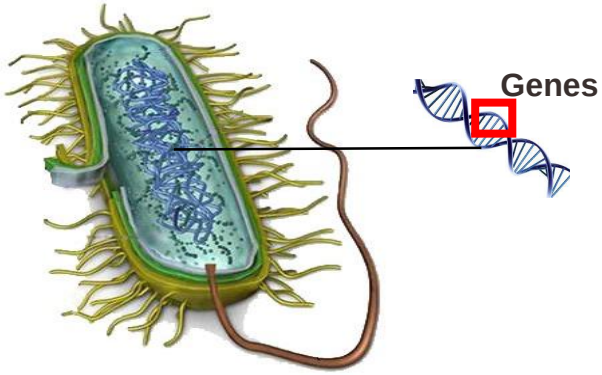


- Membrane “skin” around them, protects them
- Flagella and pilli to move around
- Eat nutrients from their environment (i.e., sugars)
- Reproduce fast

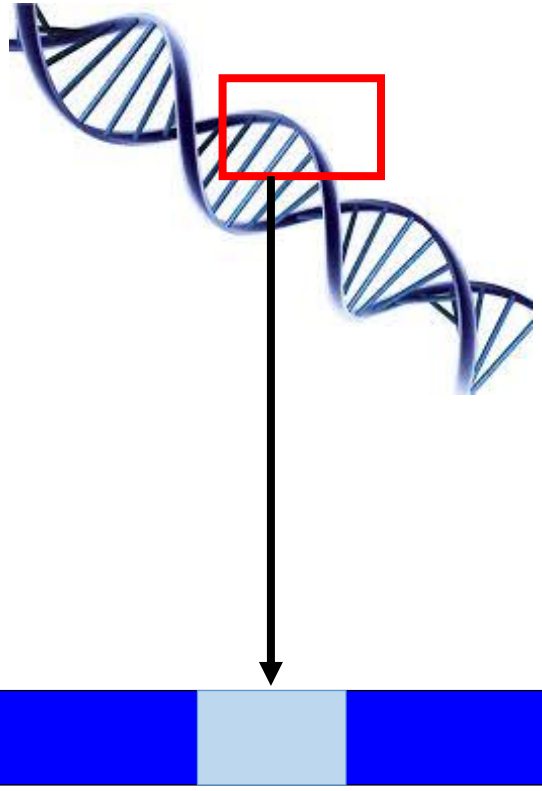
What they do and how they do it are defined by their DNA



Genes encode information as DNA

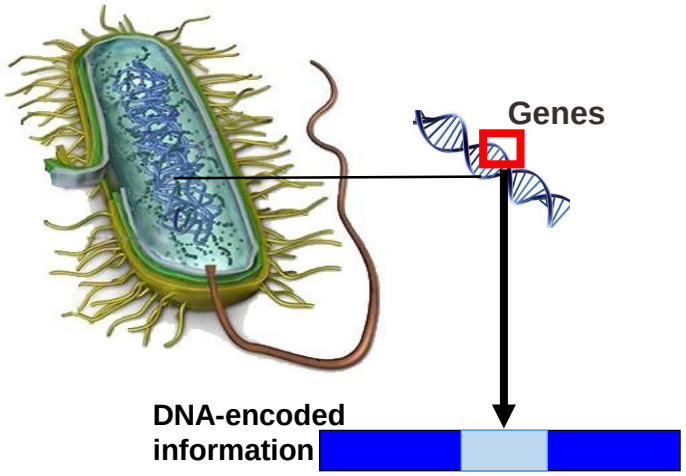


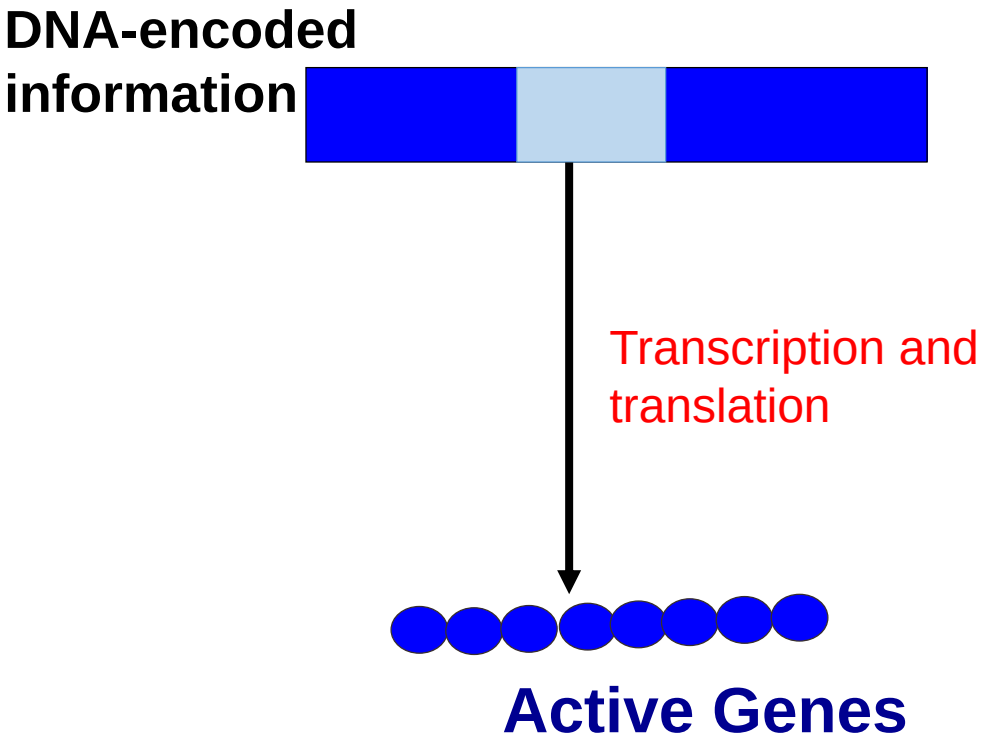
Genes = specific segment of the DNA



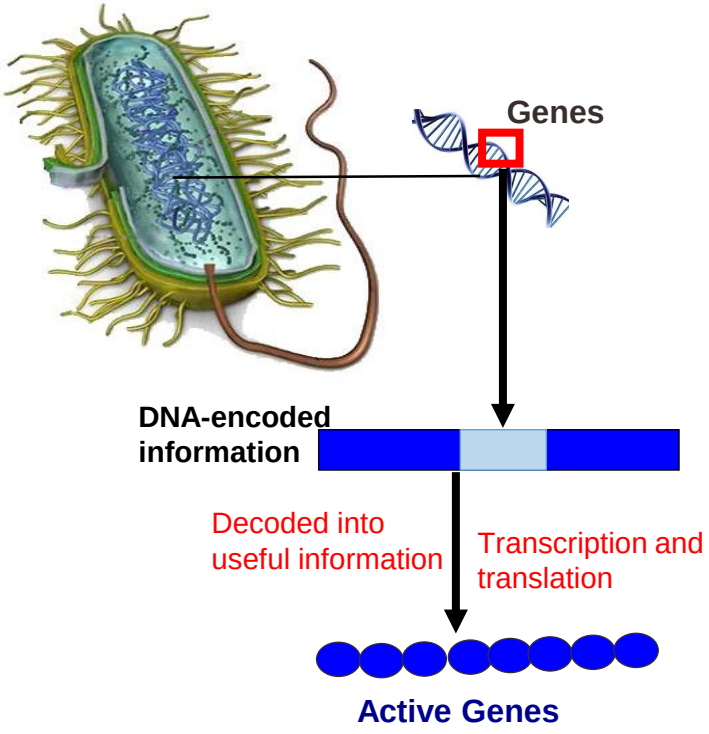
DNA encodes information

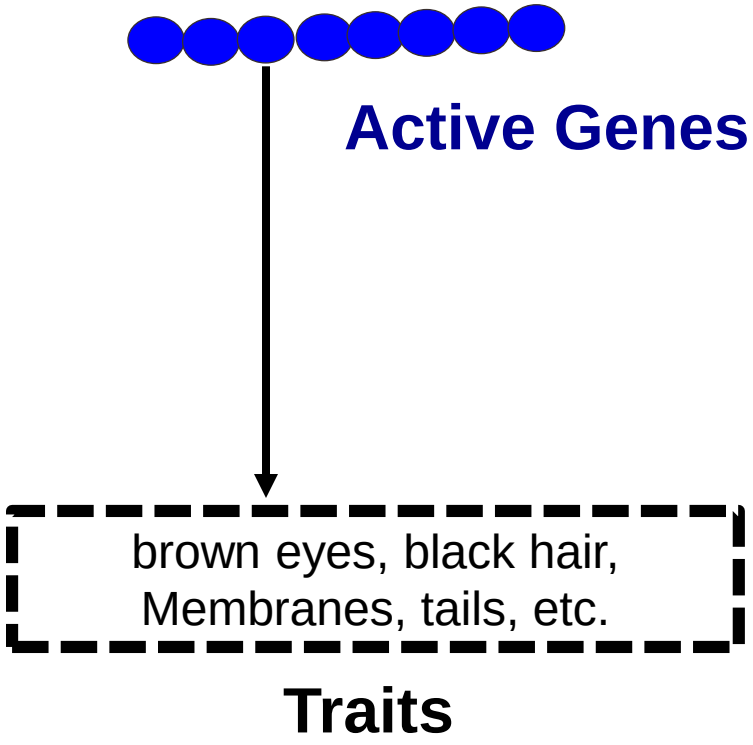
To be useful, genes need to be processed and activated.



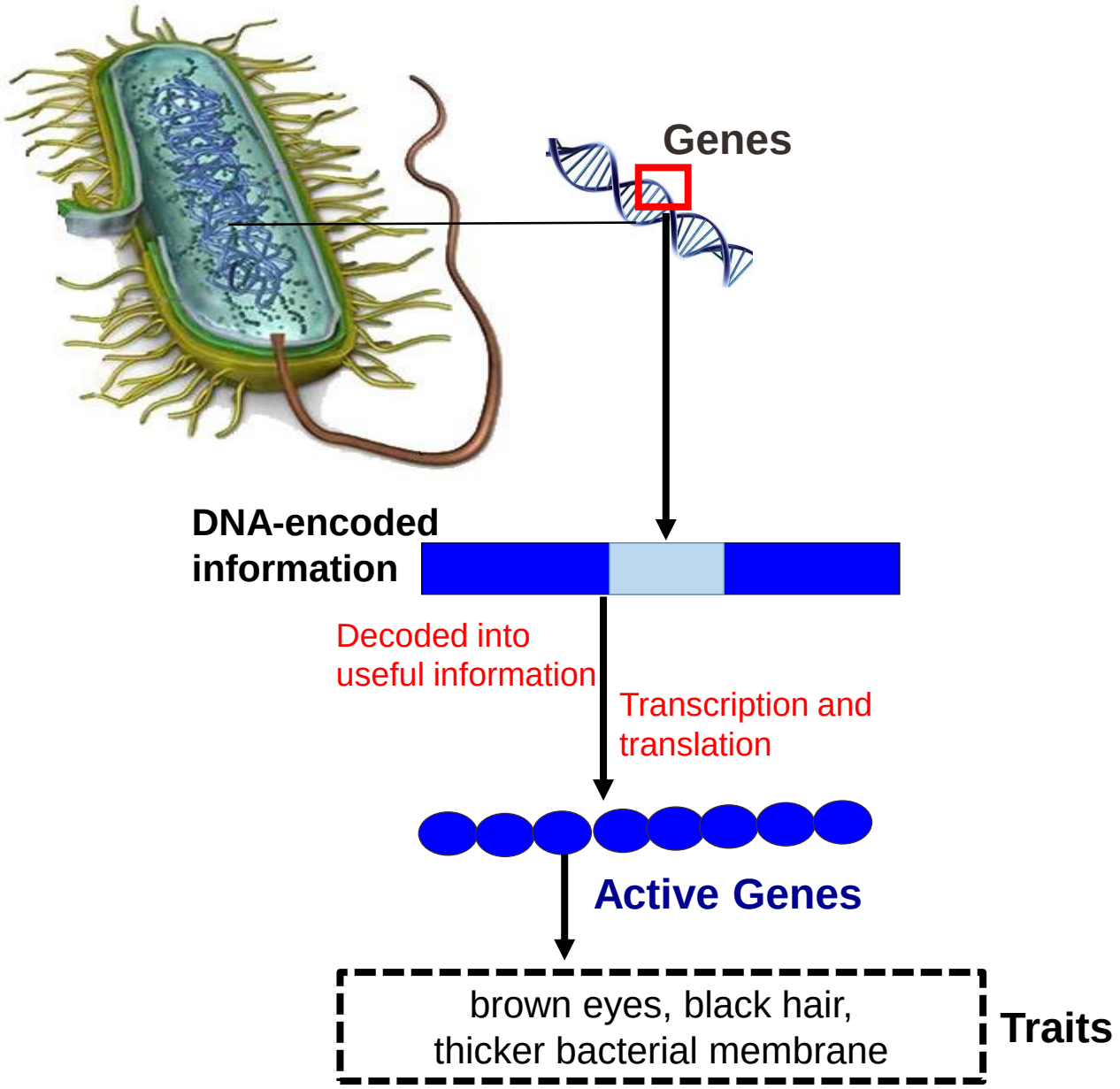


Active genes *actually* lead to all observable traits



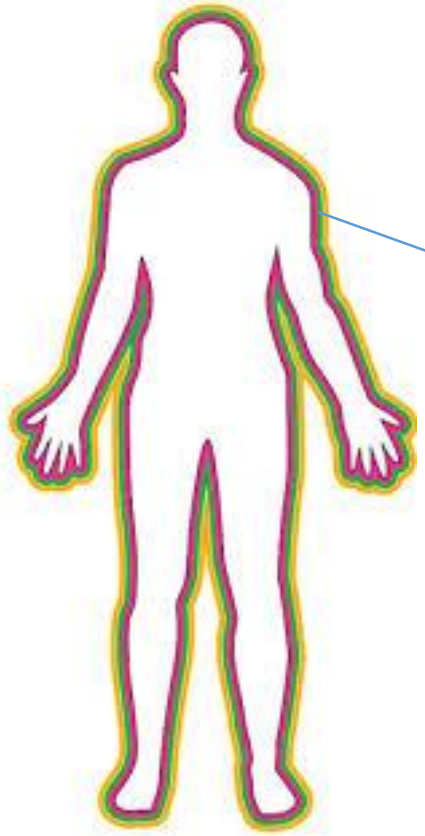


DNA processing leads to specific features



Complex processes similar to human cells!

- A bacterial microbe has all the **same basic functions** that a human cell has to stay alive.
- Great thing! A lot of what we learn about bacteria is **relevant to ALL our cells**.



Human = 100,000,000,000,000
Trillions of human cells

Tonight's Talk

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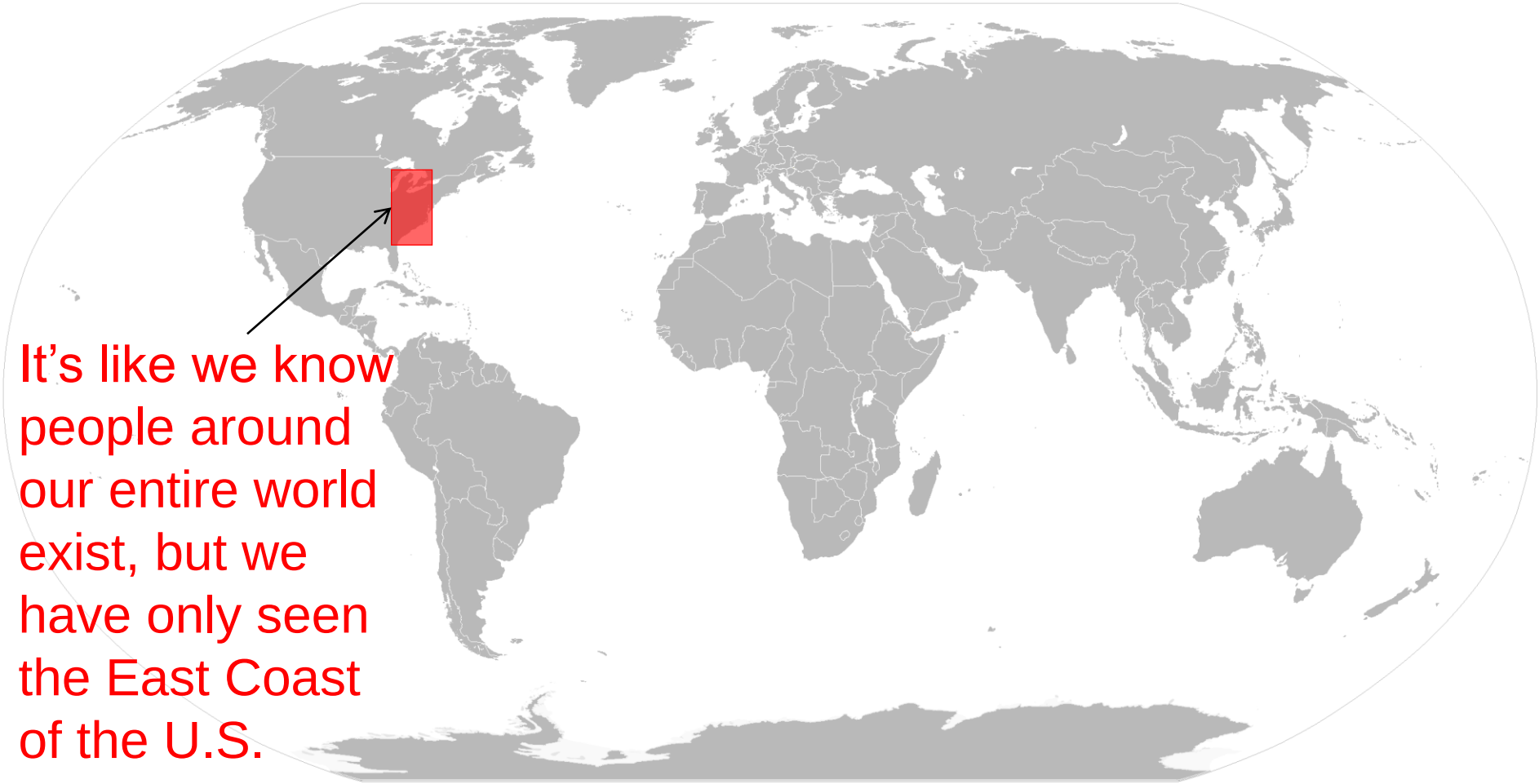
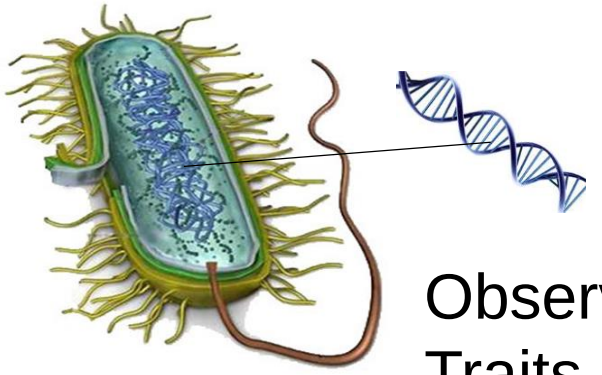
Huge diversity of microbes

- ~ 2,000,000,000 microbial families estimated
- Most cannot grow in the laboratory
- Less than 1% known (most might never know!)

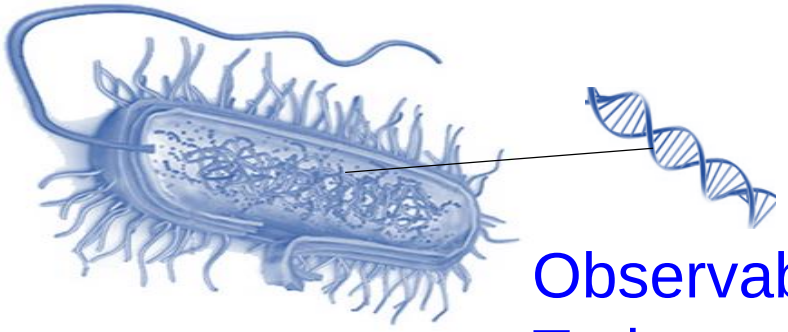


It's like we know people around our entire world exist, but we have only seen the East Coast of the U.S.

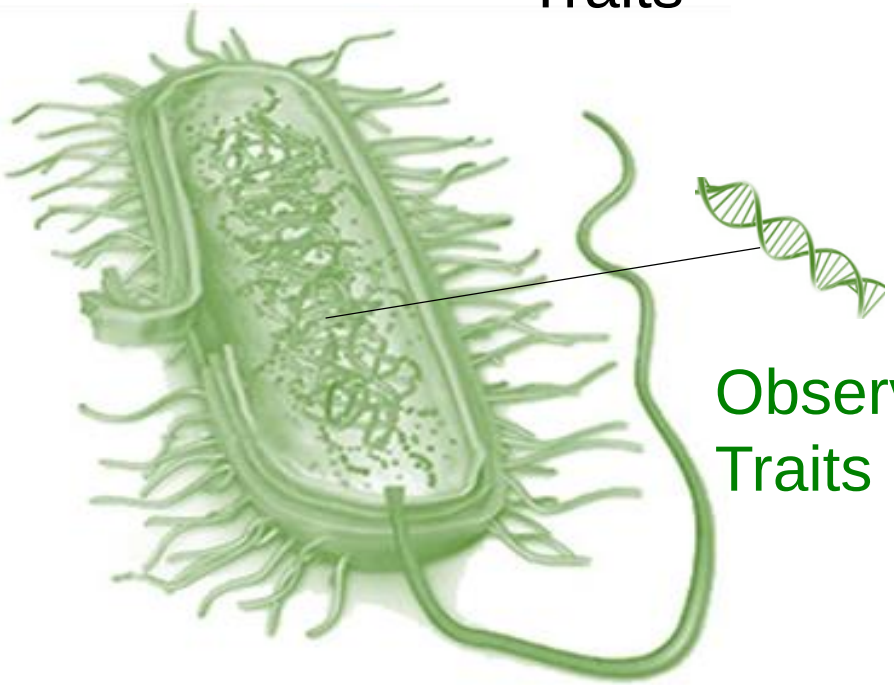
Many different classes of families that have *distinct traits* defined by their different DNA



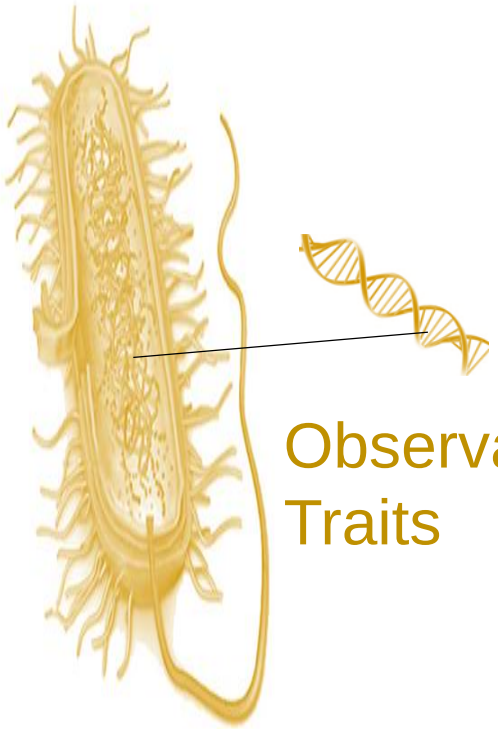
Observable Traits



Observable Traits



Observable Traits



Observable Traits

Even among the few we know, diversity makes for many “good microbes” critically important in sustaining life today.

Vinegar

Insulin
(for diabetes)

Cottage cheese

Buttermilk

Yogurt

Biofuels

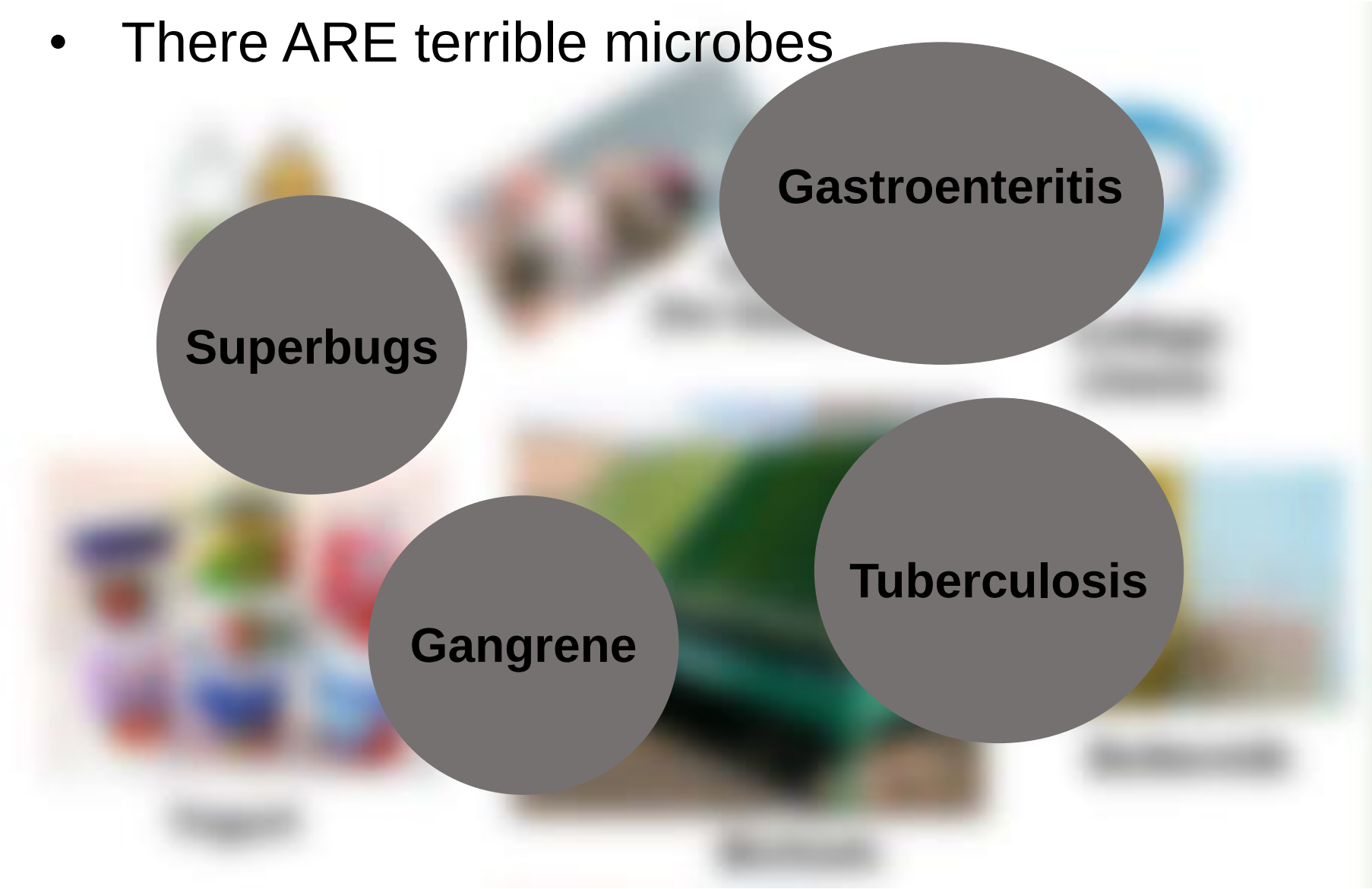
Clean our environment

Make plastics

But… Still highly negative encounter with microbes on the Big Screen

…Bad press not totally unjustified

- There ARE terrible microbes



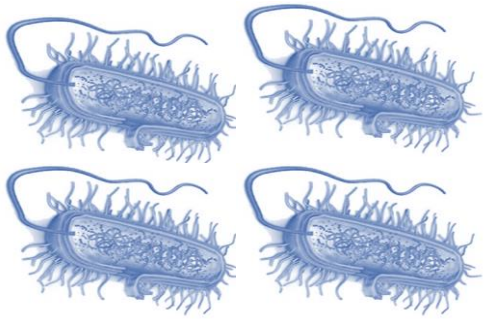
Powerful enemies… the “Black Plague”

- Worst disease in human history
- Spread during trade routes, killing 1/3 of Europe’s population

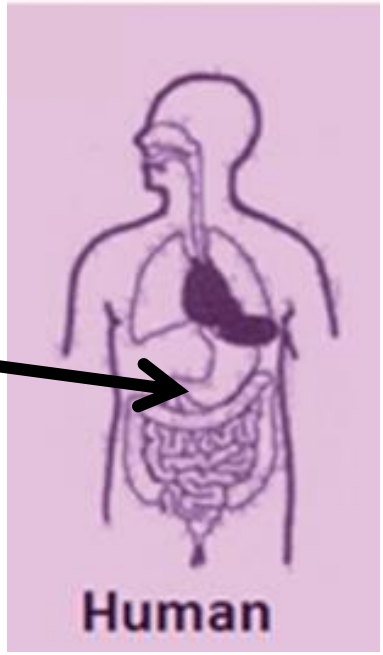
Greatly affected Shakespeare’s life and writings (example: *Romeo & Juliet)*

Not known at the time but caused by a bacterium

- Microbe gets into human through fleas and paralyzes the immune system



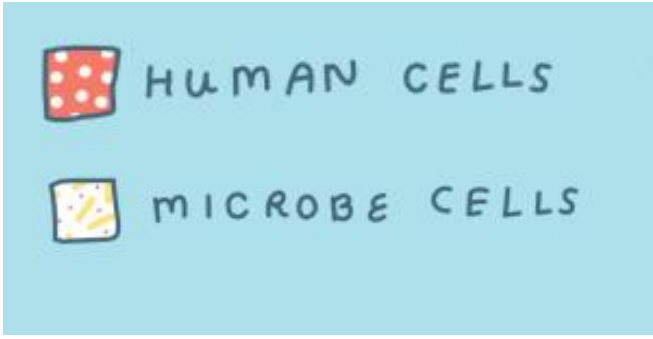
Yersenia pestis



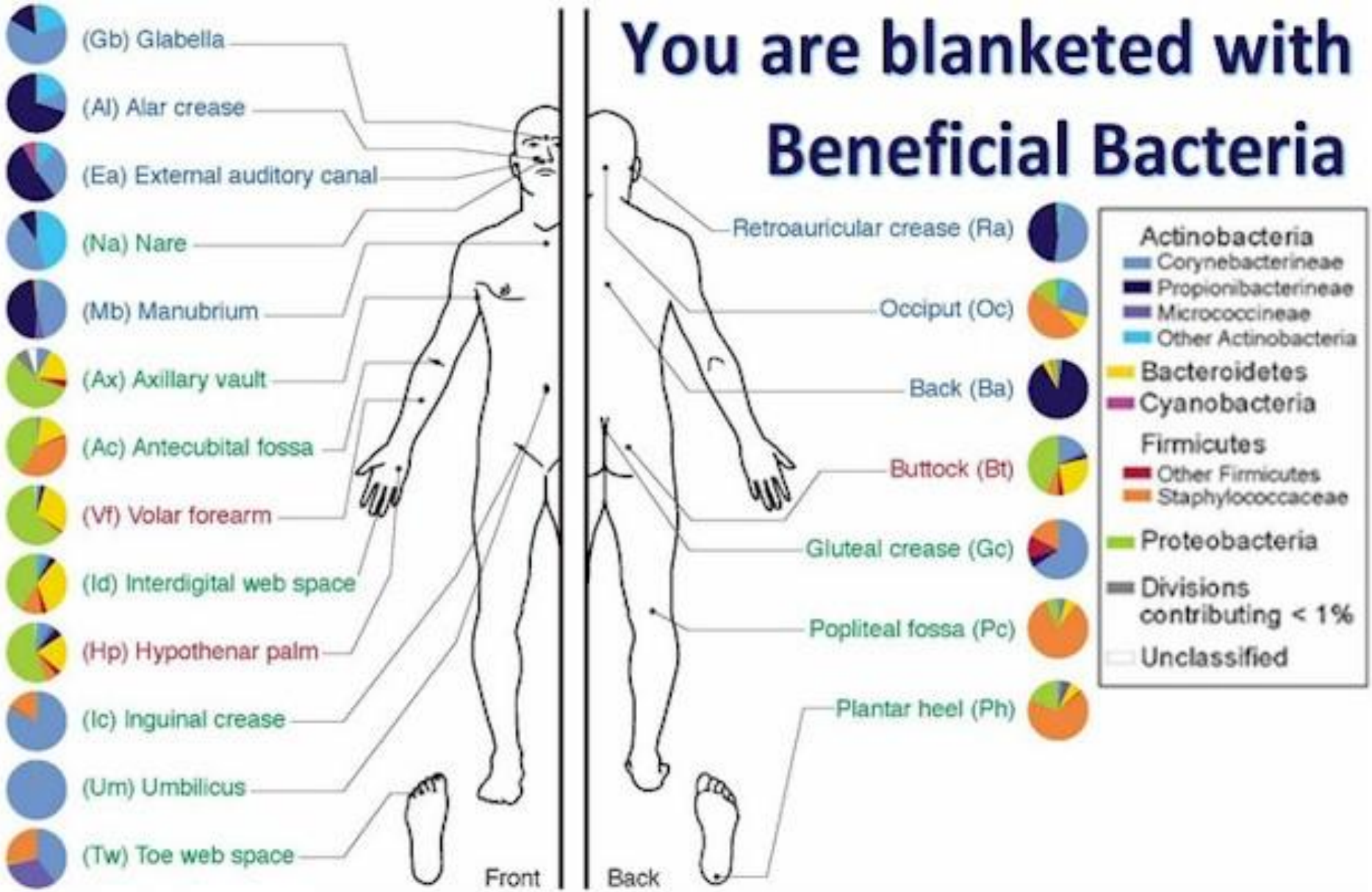
Microbes make up most of the human body

In humans:

- Most microbes in our gut and skin
- Most kept in check by our immune system



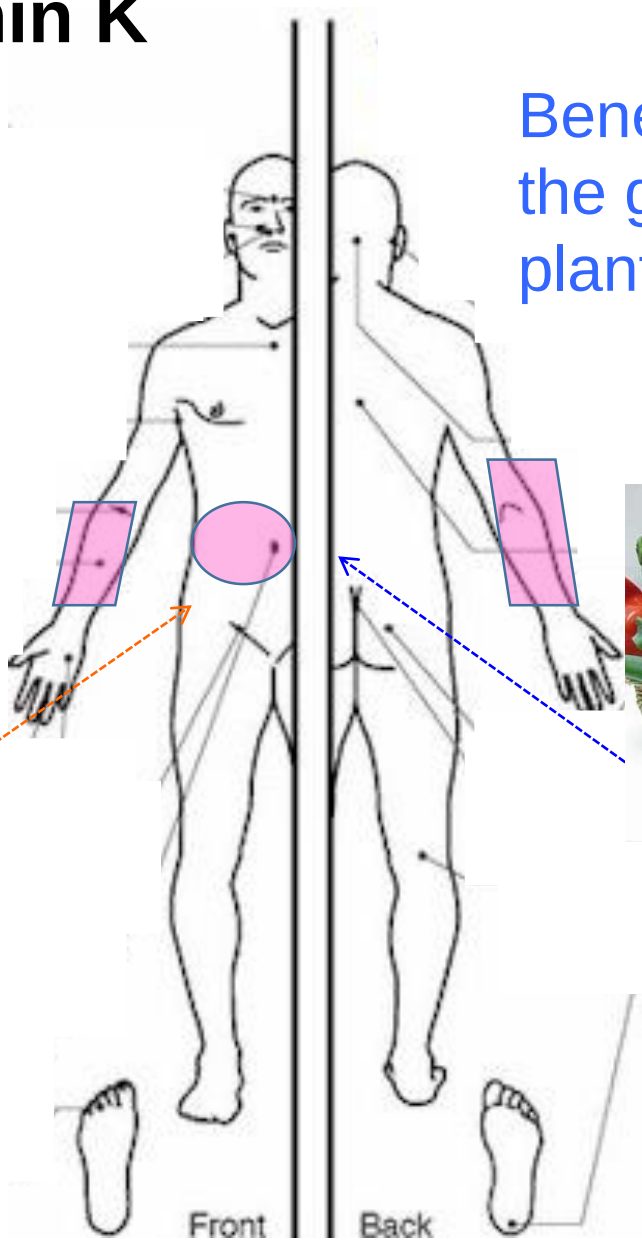
How do bacteria keep us healthy?



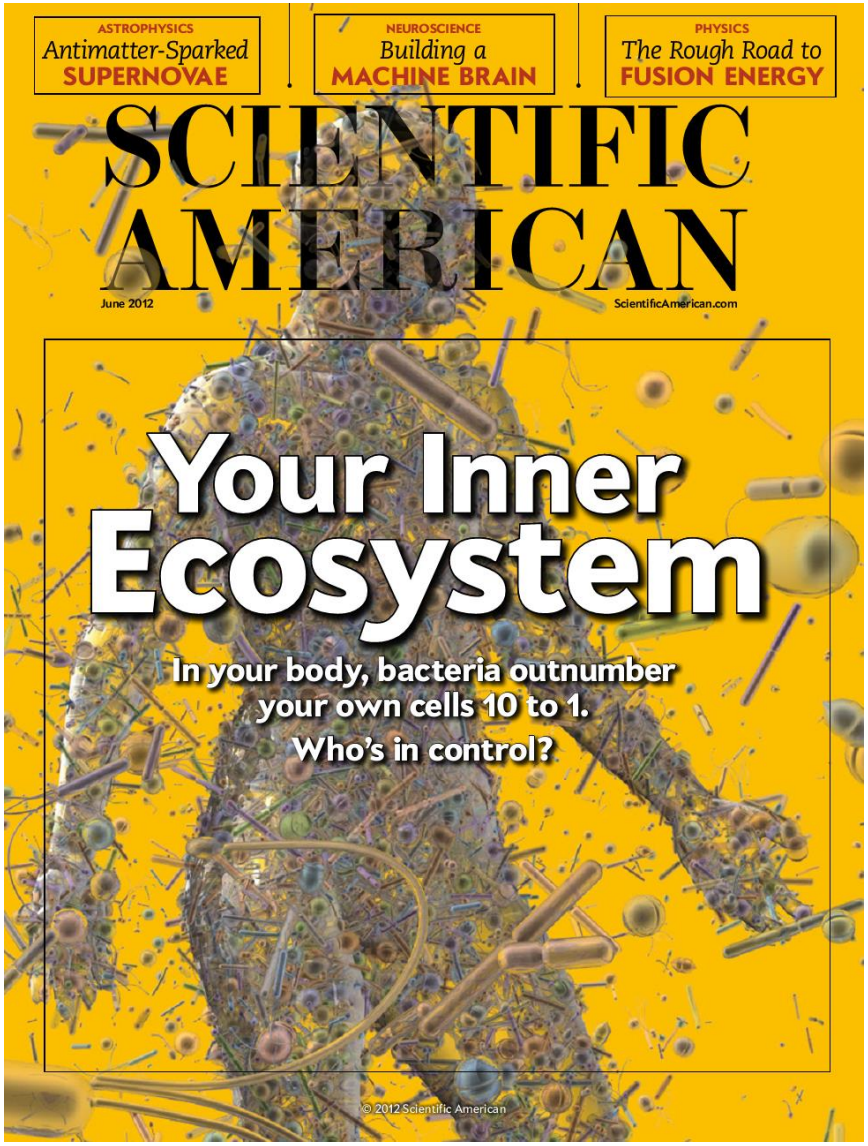
Examples: digestion of vegetables and production of vitamin K

Beneficial bacteria in the gut help digest plants (vegetables)

Beneficial bacteria in the human intestine make ~75% of vitamin K

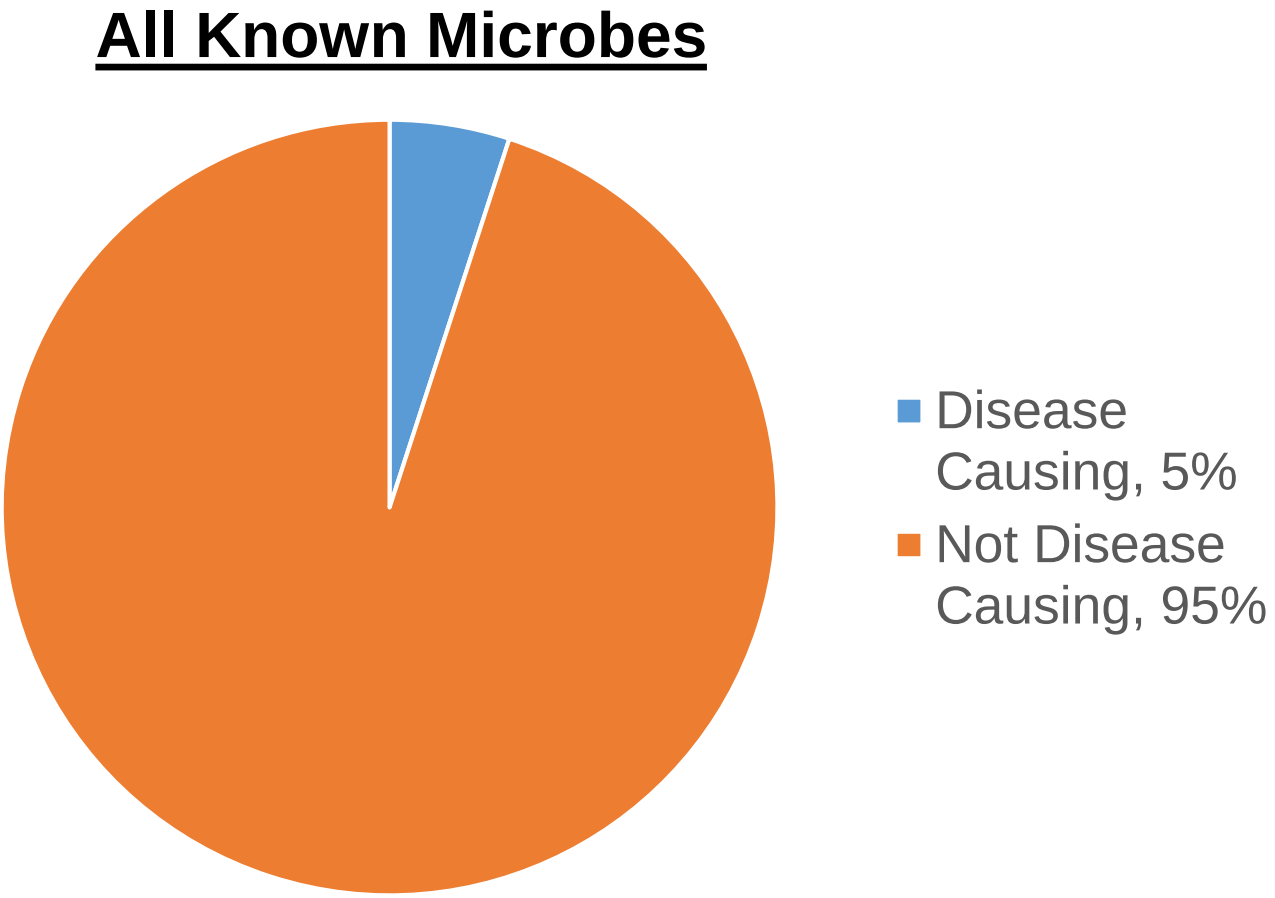


Many ongoing studies on the bacteria we need to survive



A very small number of bad players that get all the press!

- Most of us learn about bacteria in the context of diseases
- Less than 5% of all known microbes cause disease



Still a lot of effort spent to fight microbes

1. **Antibiotics**

2. **Antibacterial cleansers**

3. **Food preservatives**:
   - icing
   - salting
   - drying
   - boiling
   - refrigerating
   - fermentation

→ Kills bacteria or slows down growth if bacteria land on food

Tonight's Talk

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- What are bacterial microbes?
- How many families of bacterial microbes are there and what do they do for us?
- **What conditions can some microbes survive that most organisms cannot?**
- Who is *D.rad* and what are his special powers?

Frequent news guests:

Microbes that survive antibiotics and antibacterials

Deadly 'superbug' is spreading in US hospitals

Mark Koba | @MarkKobaCNBC
Thursday, 24 Jul 2014 | 2:03 PM ET

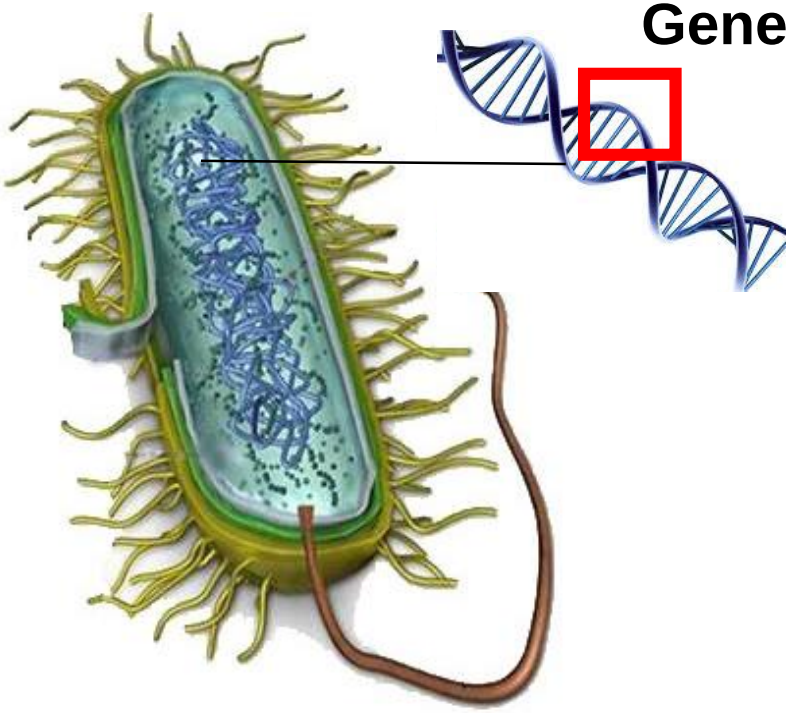
CNBC

Cases of the contagious and deadly "superbug" known as CRE increased five-fold in community hospitals from 2008 to 2012 in the Southeastern U.S., **according to a new study**.

avid Sacks | Stone | Getty Images

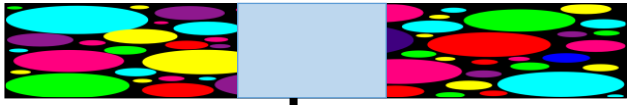
How do they survive chemical and environmental conditions that kill most other organisms?

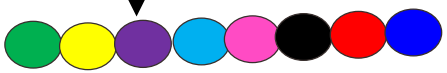
Changes in their DNA information make them less likely to die when we try to kill them



Gene changes = Different, unexpected abilities

Unexpected changes in DNA-encoded information





Unexpected changes in traits

Extremophiles: special group of microbes that survive extreme environments

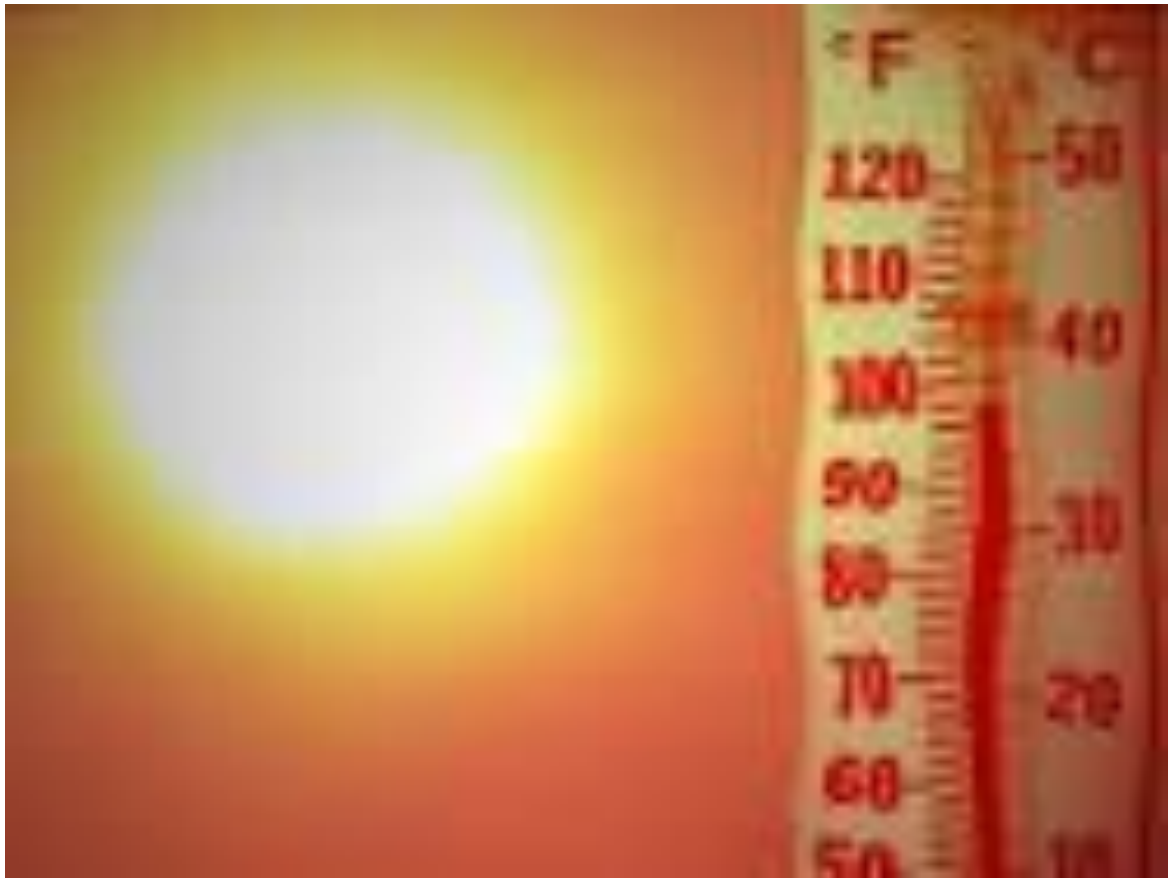
Extremophiles: So what's the fuss?

- Could be a great thing to survive drastic threats!
- Nature's ultimate survivors
- Thrive in an extraordinary range of conditions *where no other life can exist.*

Extreme Cold (refrigerator and freezer)

- … if in food, refrigerating won't kill them!

Extreme Heat (boiling water)



- … if in water, boiling won't kill them!

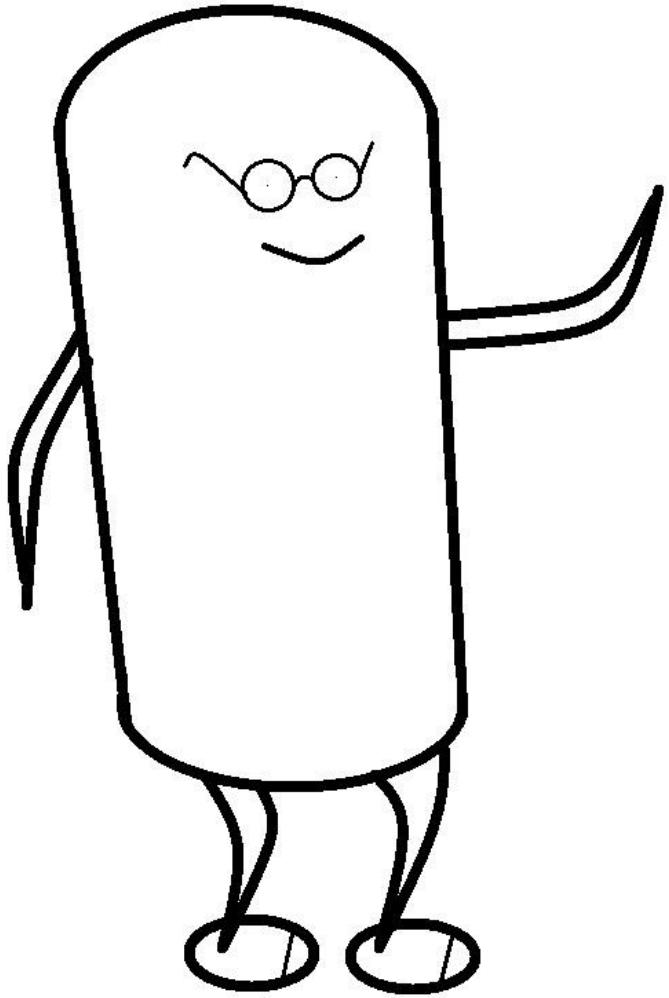
Extreme Dry (deserts)

- … if in food, drying process won't kill them!

Extreme Acid (vinegar and lemon)

- … if in meat or fish, cleaning with vinegar and lemon won't kill them!

An example we feature today…



His official scientific name:

Deinococcus radiodurans

aka

Our nickname:

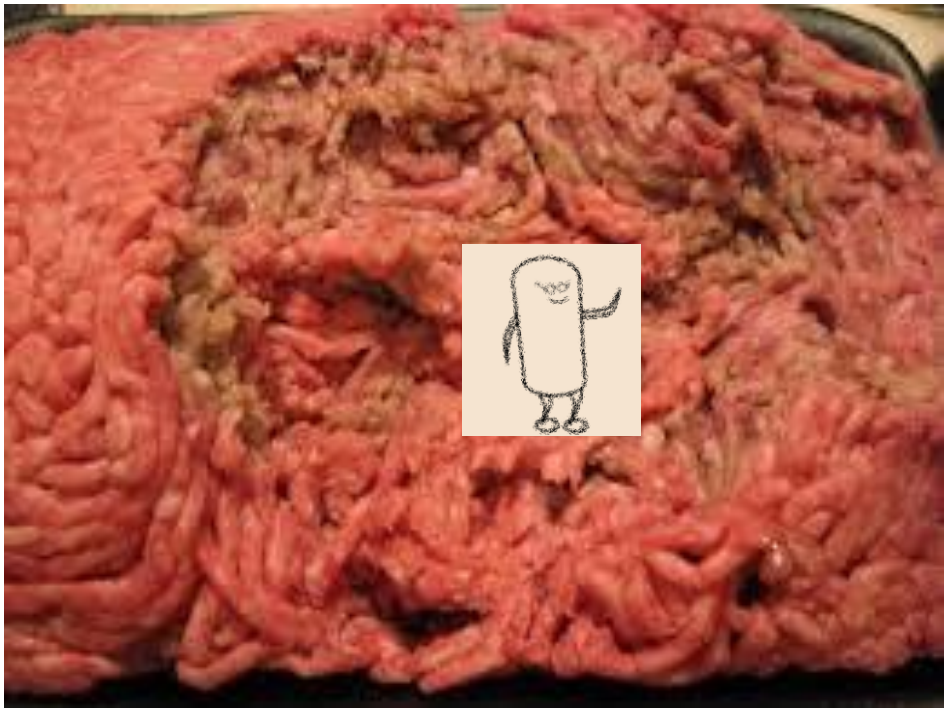
D.rad

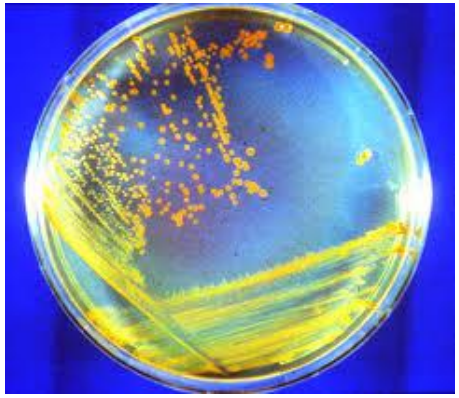
Tonight's Talk

- When did we discover microbes?
- What are bacterial microbes?
- How many families of bacterial microbes are there and what do they do for us?
- What conditions can some microbes survive that most organisms cannot?
- **Who is *D.rad* and what are his special powers?**

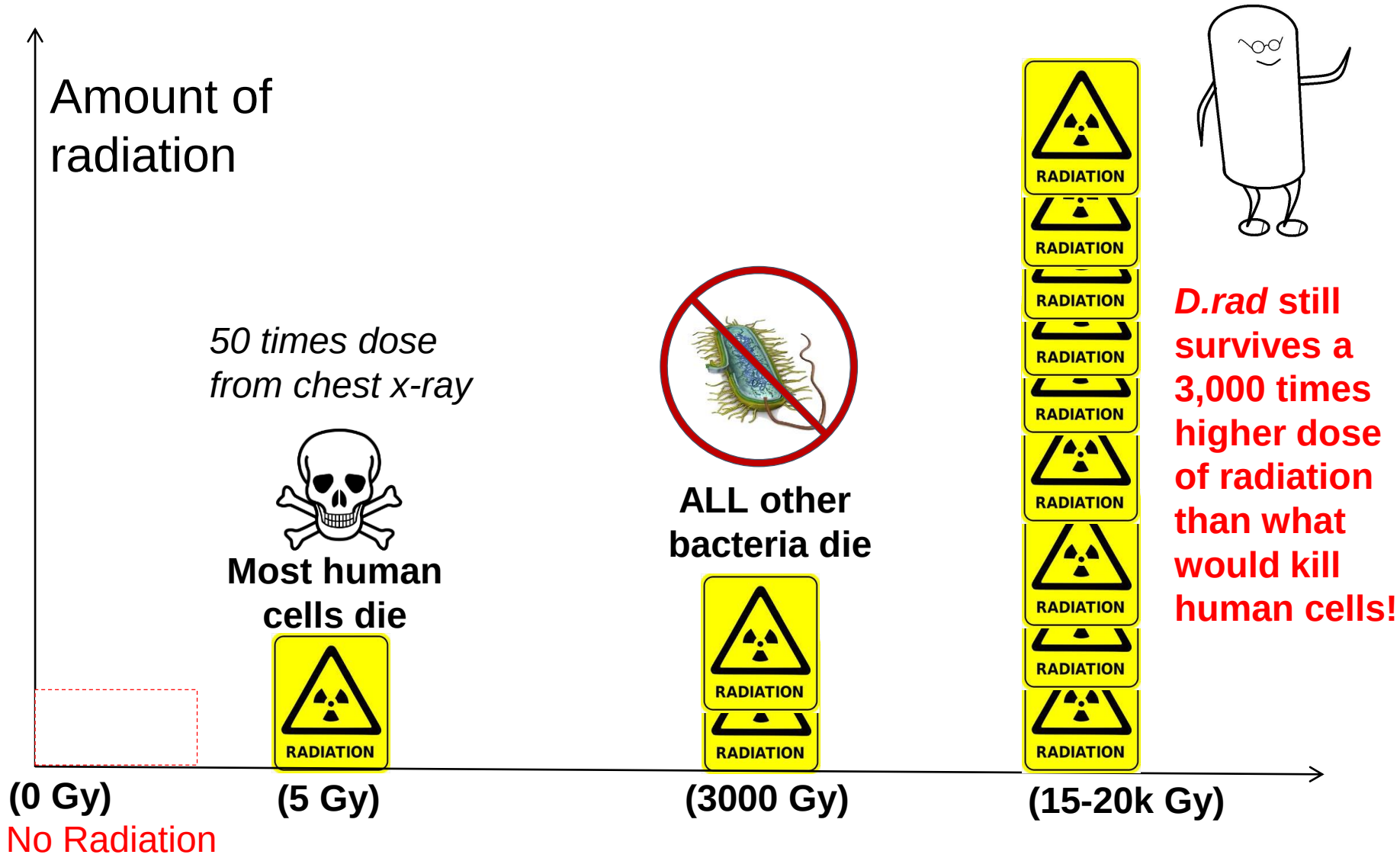
The story of *D.rad begins in Oregon 60 years ago*

Was discovered when ground meat was observed to be spoiled by bacteria **after sterilization with radiation**!

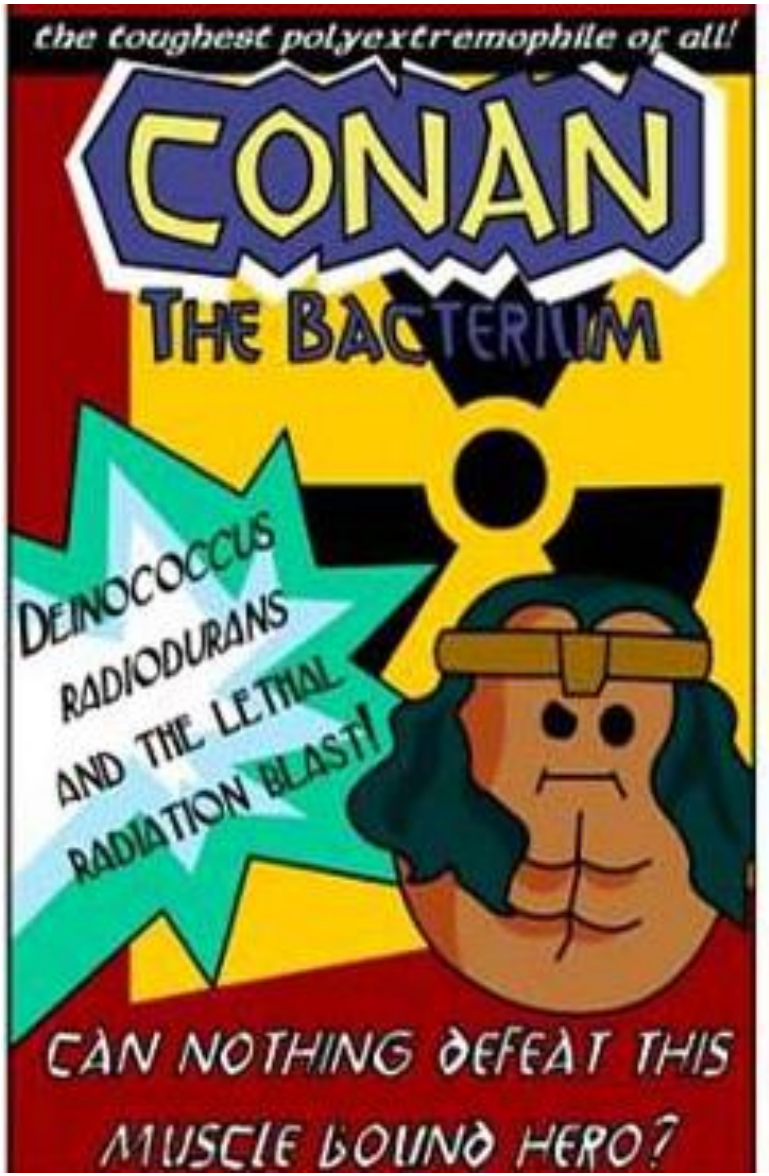




D. rad survives unusually high levels of radiation



… Not just able to survive high doses of radiation



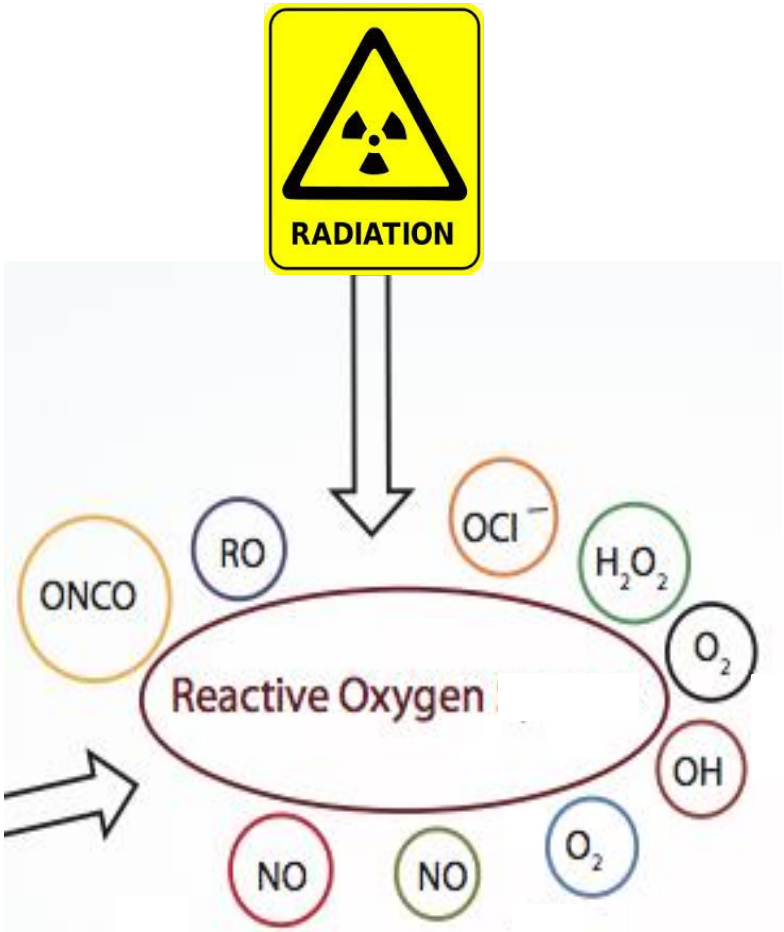
- Extreme dryness
- Extreme oxidative stresses
- Extreme exposure to UV light

Remarkable!

- ***High radiation levels cause a lot of damage to microbes and humans***

- ***Only low amounts used in hospital exams***

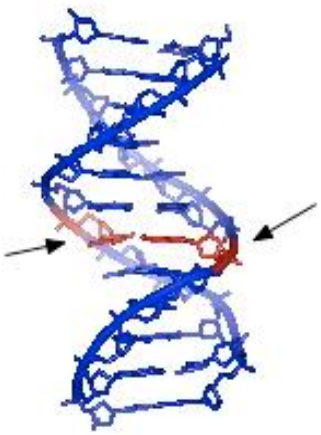
Radiation = Oxidative Stress

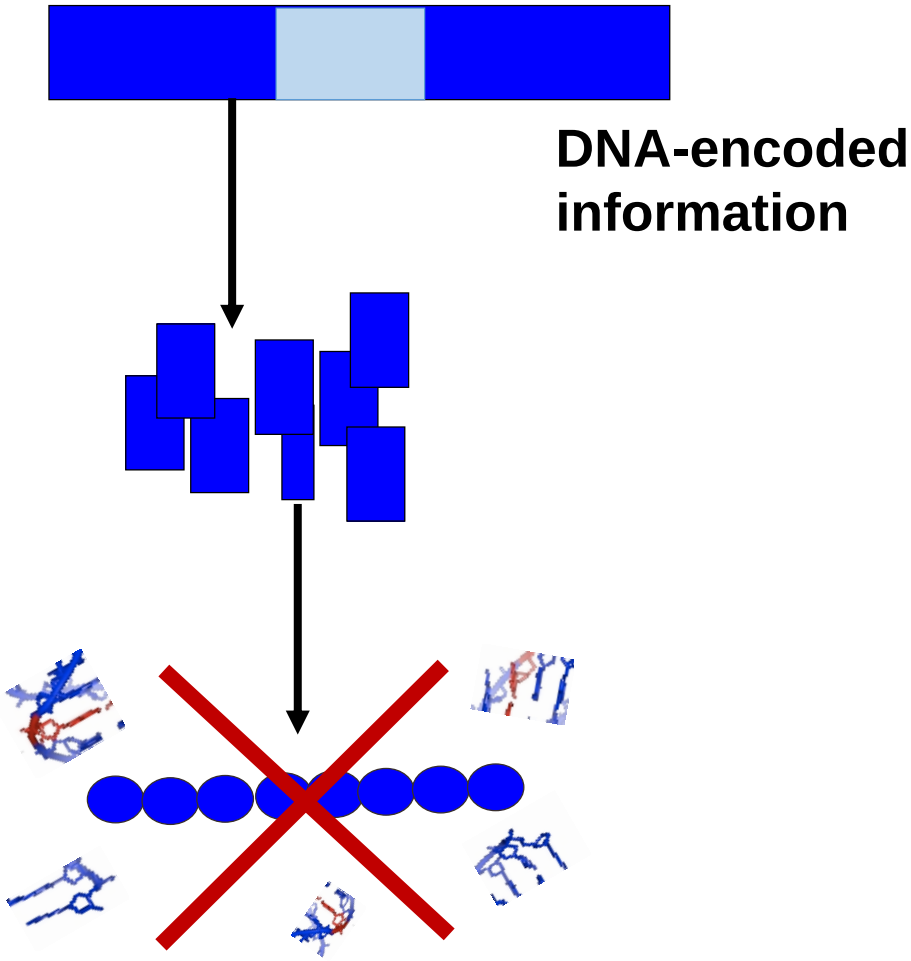


Higher levels of reactive oxygen is created in cells

OXIDATIVE STRESS = Damaged DNA

- High levels of reactive oxygen damage DNA.
- DNA cannot be activated to produce needed traits



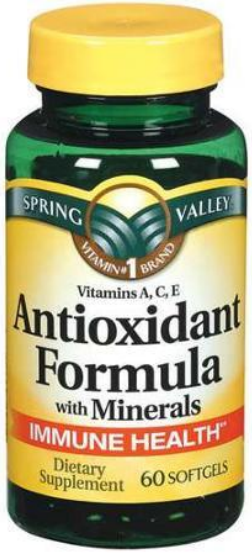


= Unhealthy Cells

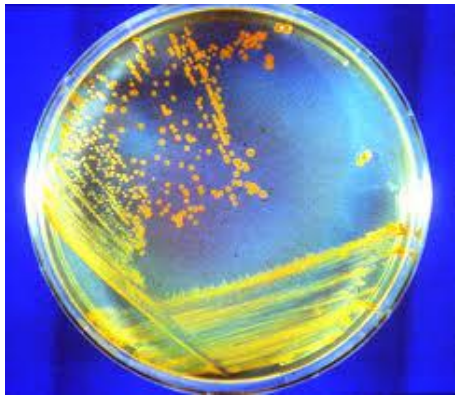
Most living organisms cannot survive high levels of radiation.

Radiation = oxidative stress

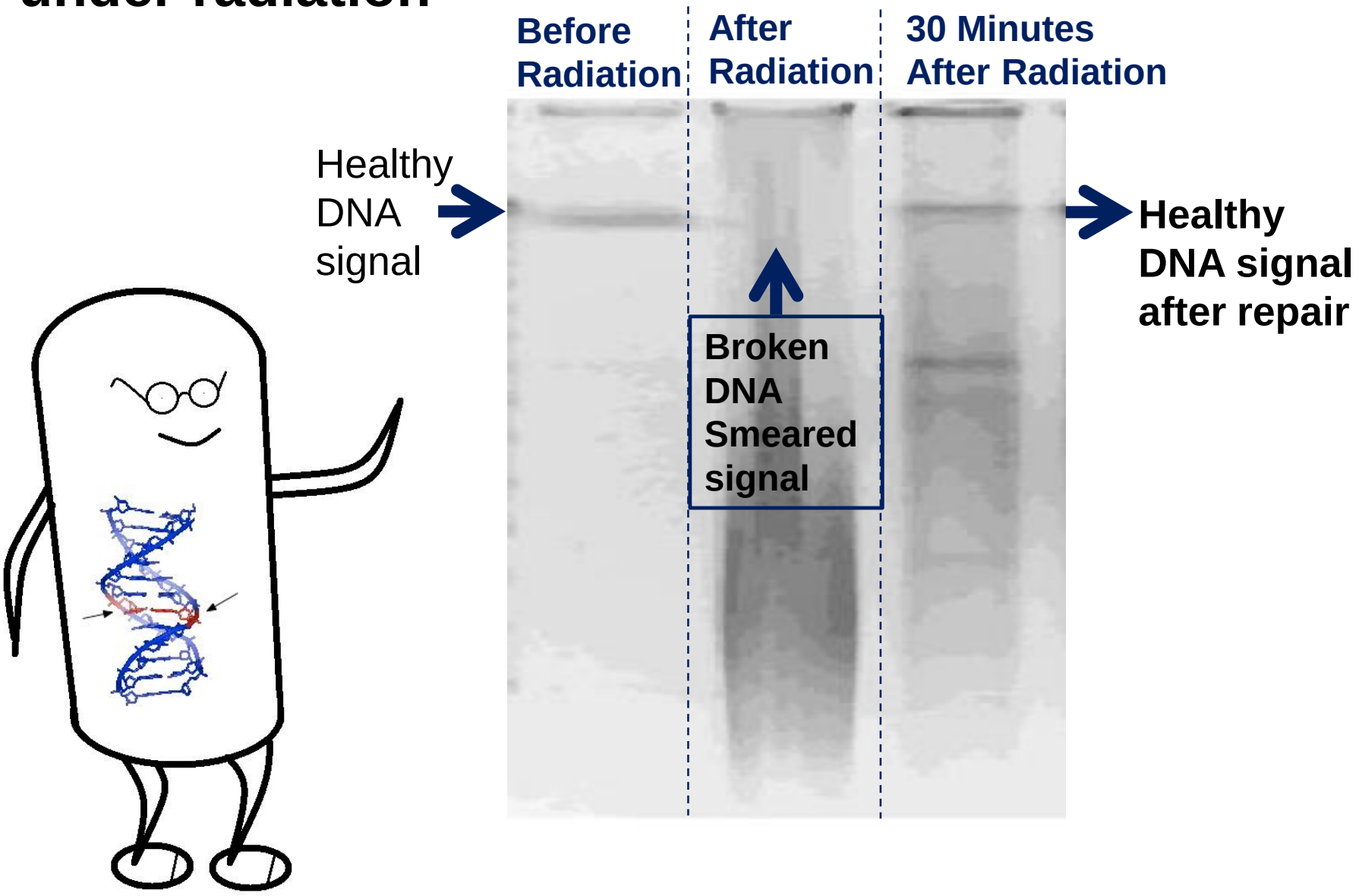
Oxidative stress = damaged DNA



So what is so special about *D.rad*?

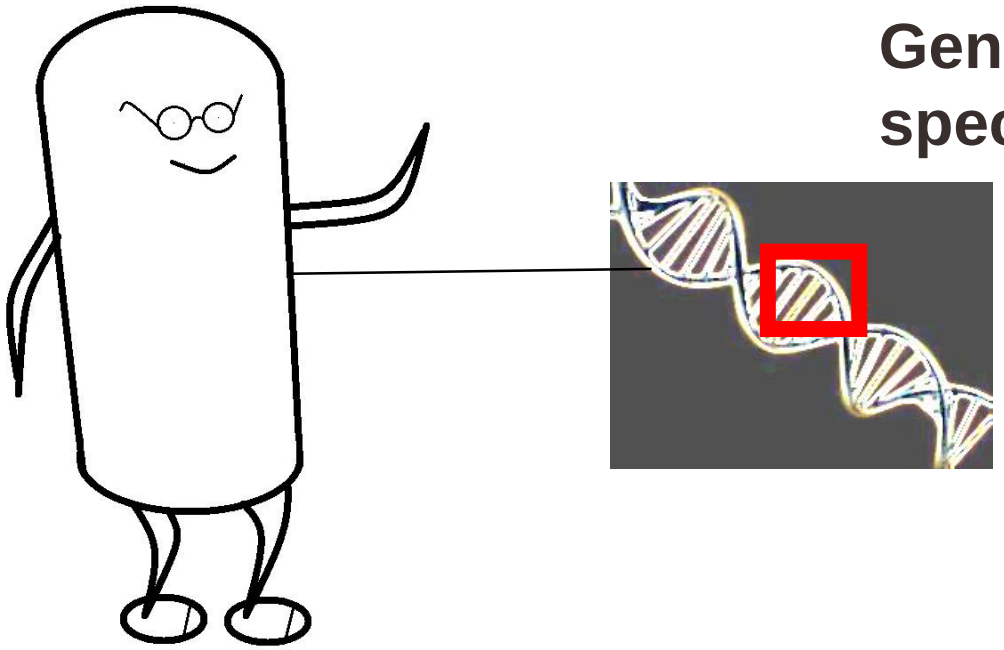


Past scientists noticed *DNA repair capabilities* under radiation



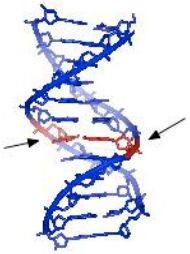
Their hypothesis for next ~ 30 years:

There is something about the DNA in *D.rad* that gives it "special powers" to survive radiation.



Genes with special powers???

All the information for ALL the thousands of genes in the DNA of *D.rad* was obtained by sequencing

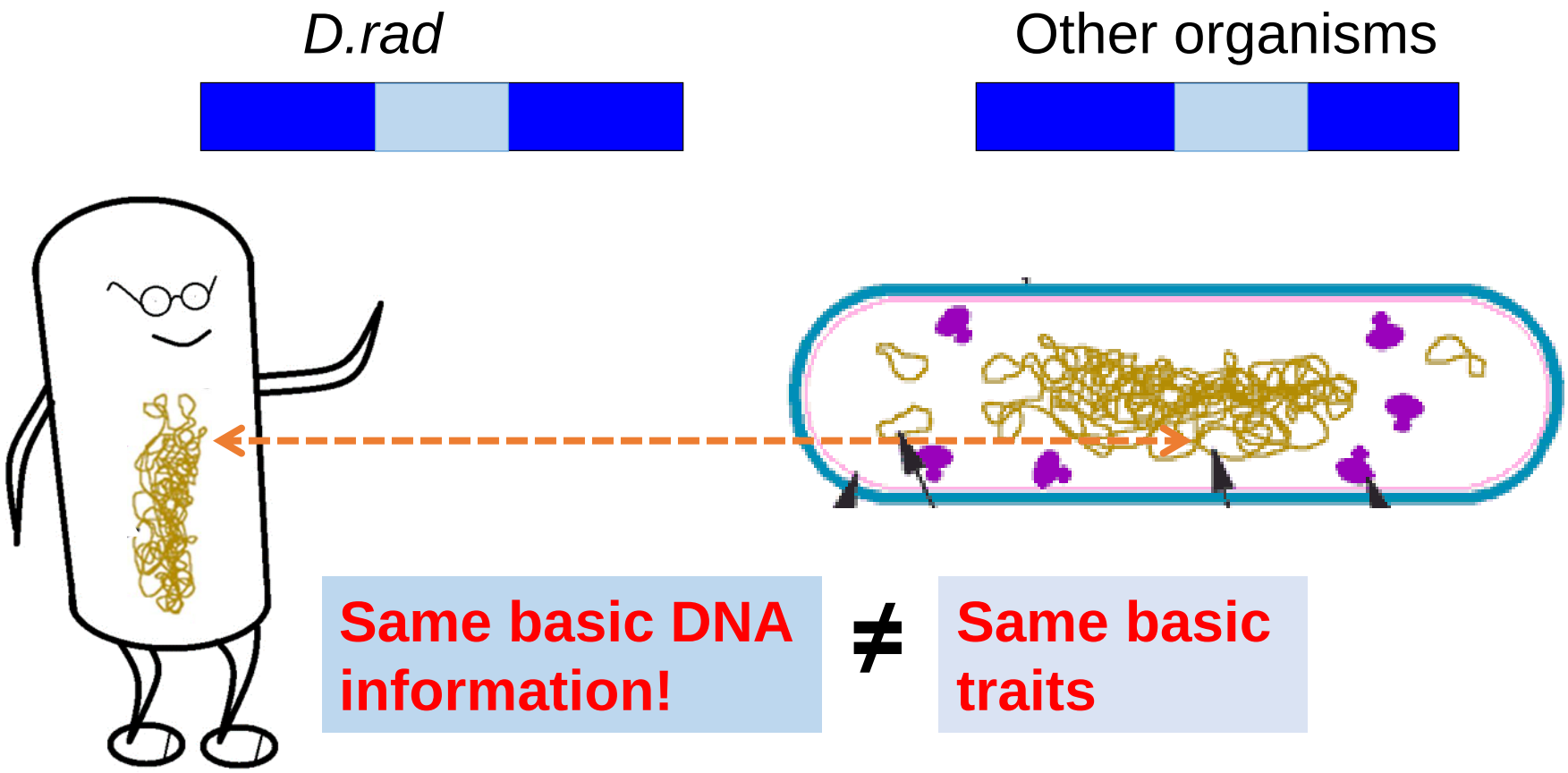


x 10

A great birthday present:
Anyone can sequence their own genes now for only $1000!

Special powers DNA idea disputed by analyzing all the DNA information in *D.rad.*

- Very disappointing results: no special DNA information!



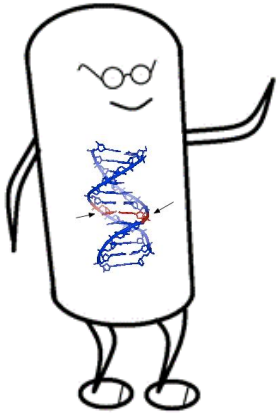
Slade et al, 2011, MMBR, Mar. p133-191

Our hypothesis:

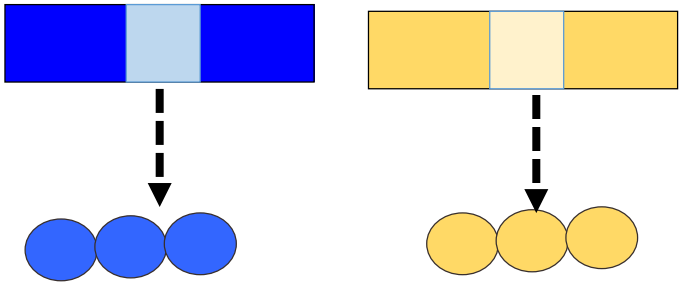
***D.rad* is better at managing how it uses its DNA information when stressed by radiation**

DNA sequencing only tells DNA information: just because is there does not mean is being used !

D.rad



ALL DNA-encoded information:
Not all being actively used!



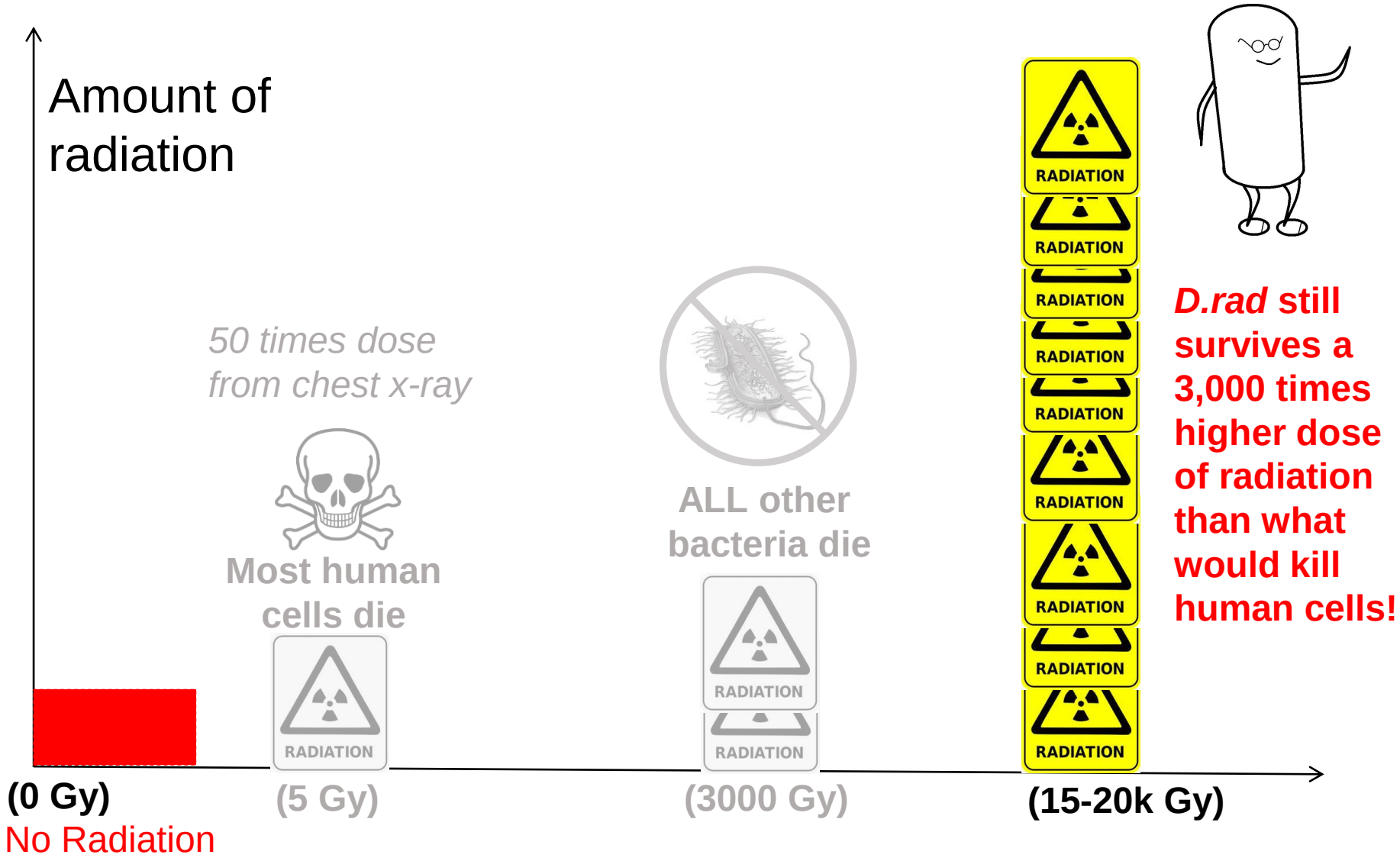
Active Genes

Inactive Genes

Information ACTIVELY being used to make useful traits

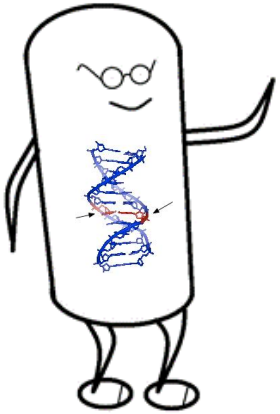
Our work:

Studies in the presence and absence of high levels of radiation



What genes are being actively used during radiation?

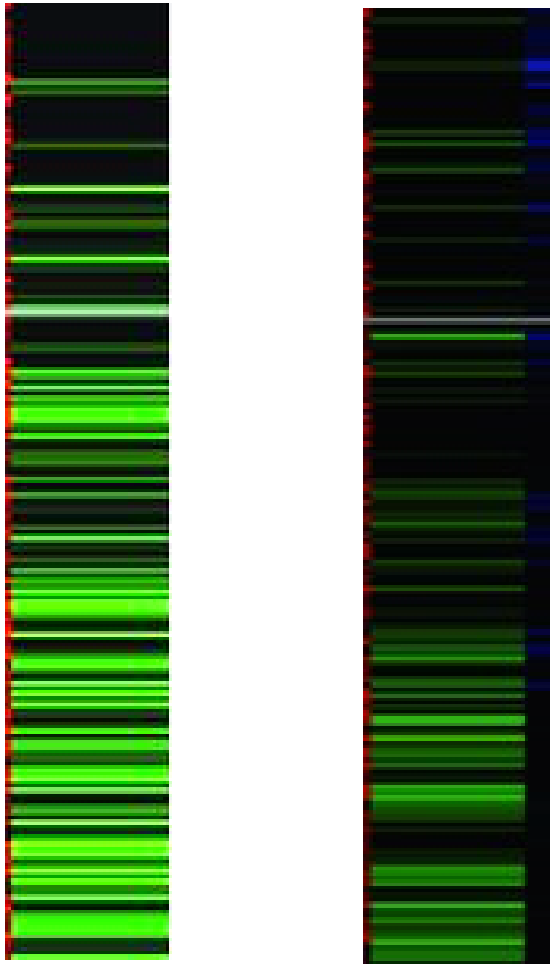
D.rad



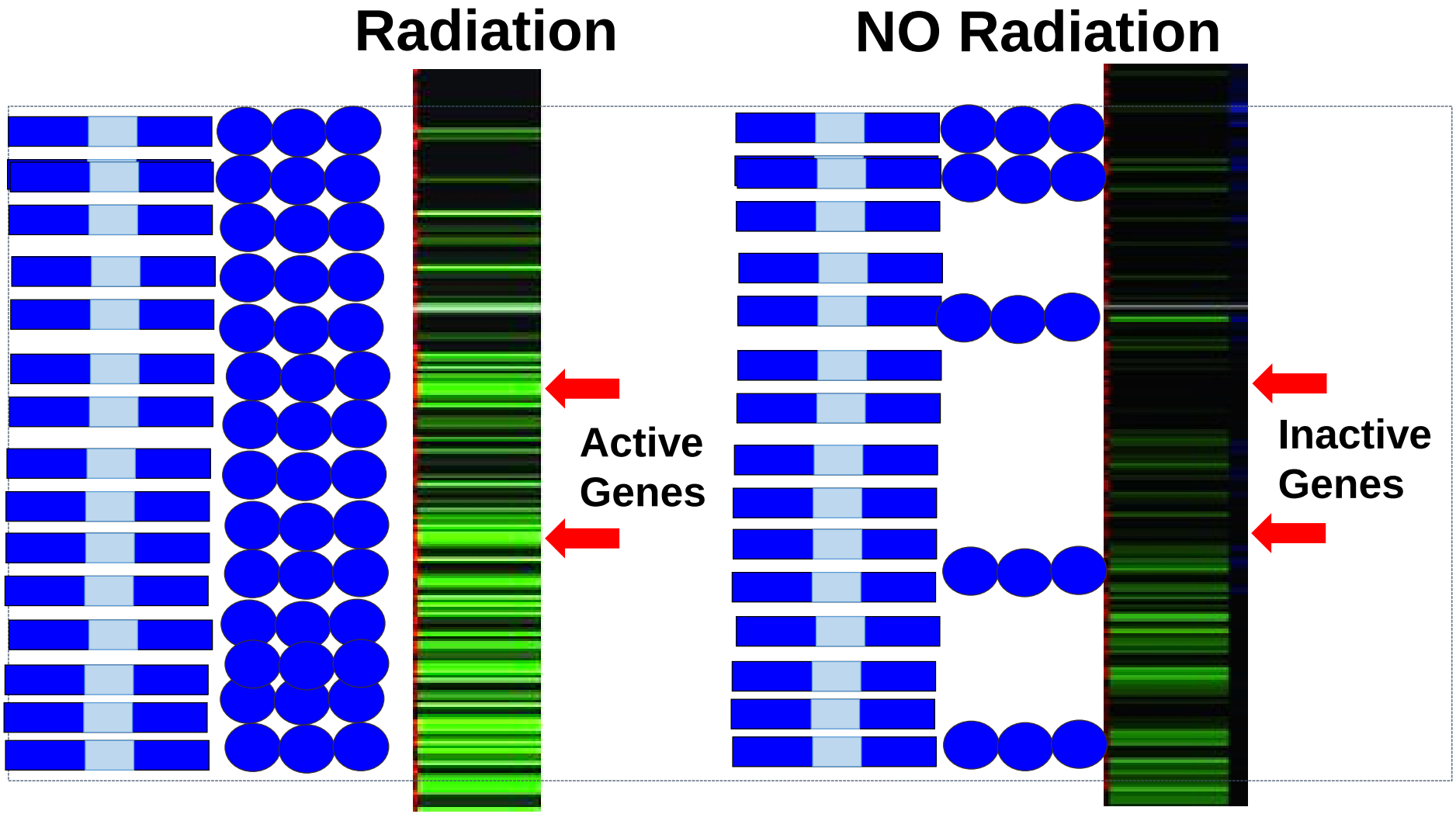
New technological capabilities now allow us to look at *all* of the DNA information actively used

Radiation

NO Radiation



Differences in *specific* genes that are activated with radiation



***D.rad* senses radiation**

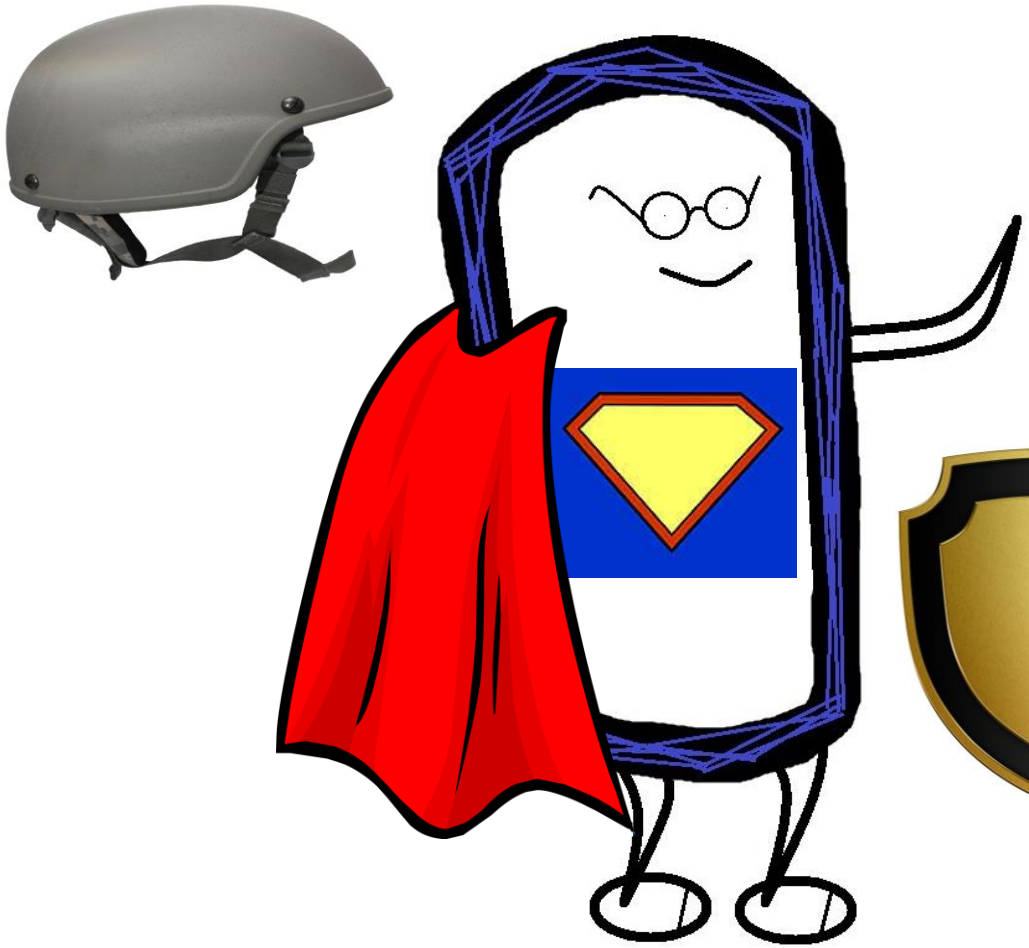
=

Activates specific genes for use under radiation

=

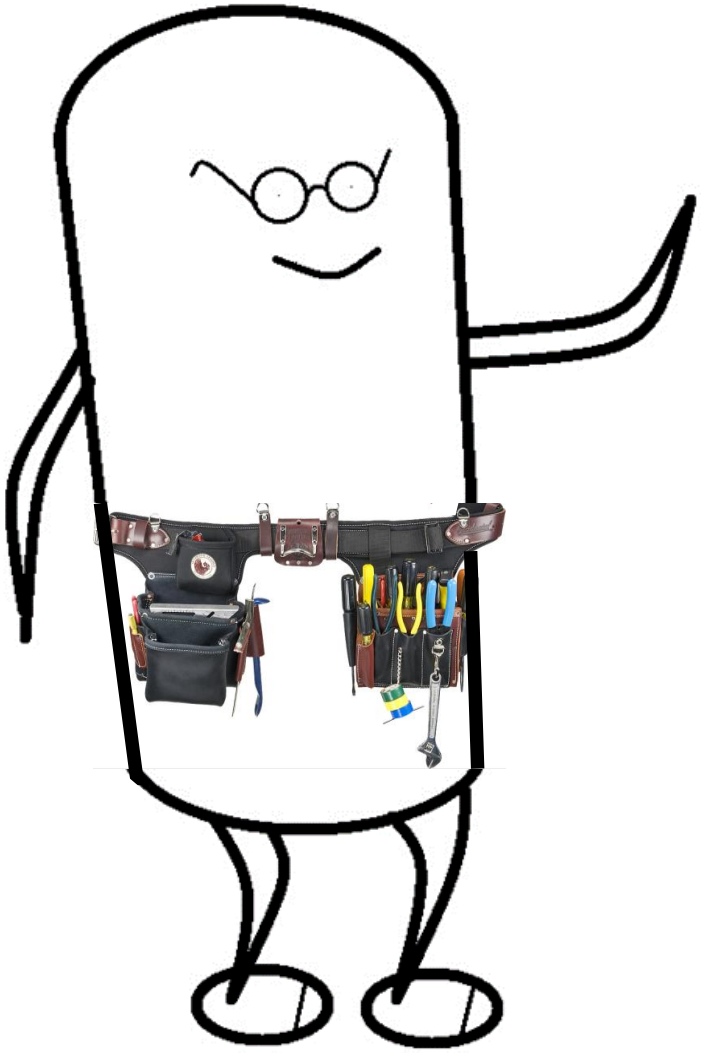
Acquires special traits under radiation

Can easily imagine potential useful traits to help survive radiation



Thicker, **protective membrane** gets made during radiation

Some potential useful traits to help survive radiation

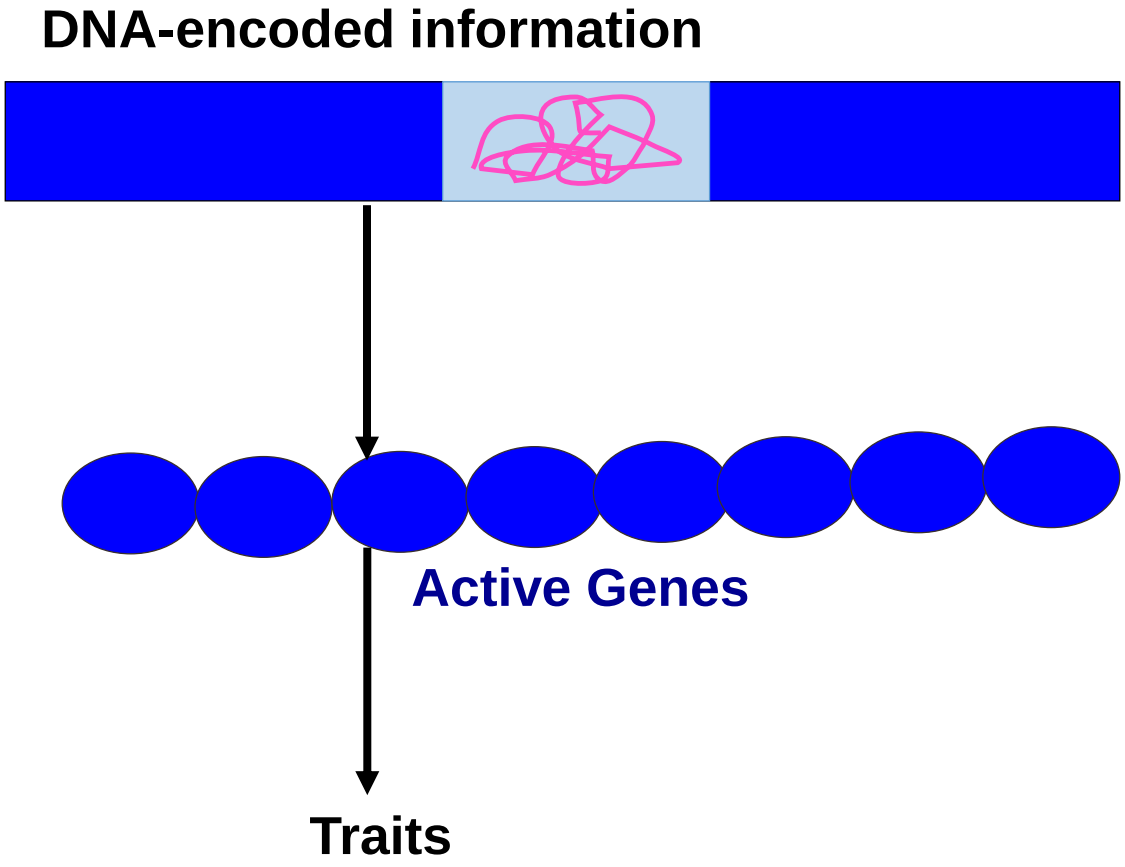


Additional
DNA repair tools
get made during
radiation

How does *D.rad* ensure these traits are active only after radiation?

What does *D.rad* have in its genes?

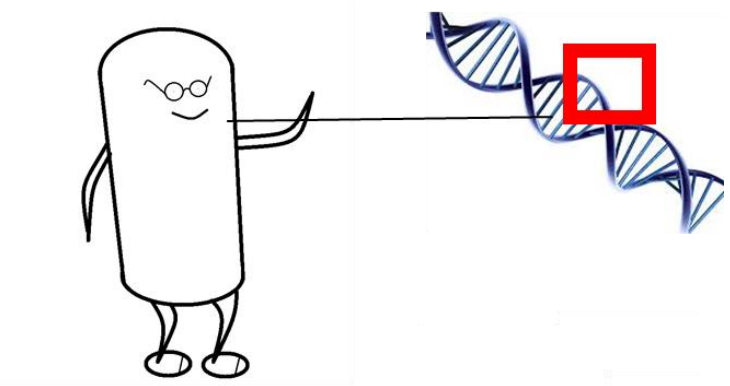
Conventional DNA theory: most of it is useful, but there is also a lot of "junk"

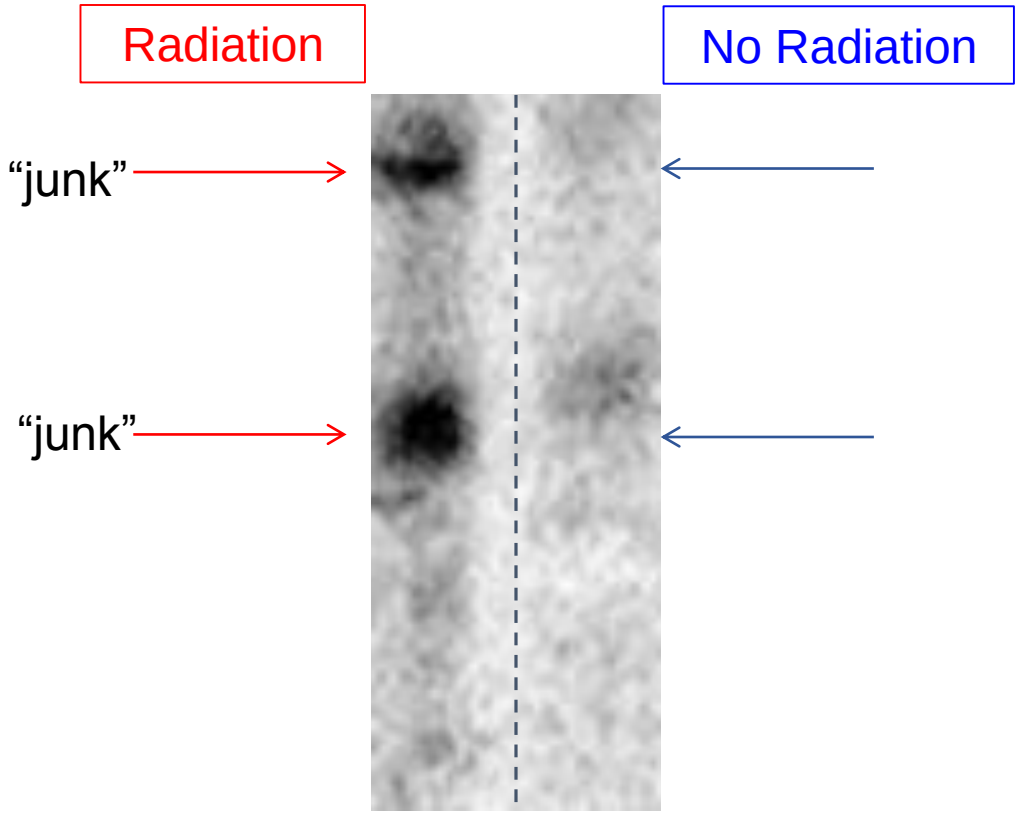


"Junk DNA" has no contribution to traits, *that we can see*.

Observation:
"Junk DNA" accumulate *only after radiation*

- Stained "junk" molecules for visualization
- Hidden under no radiation, only seen after radiation

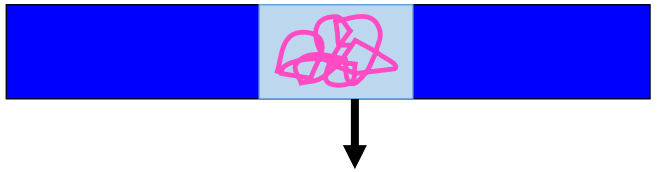


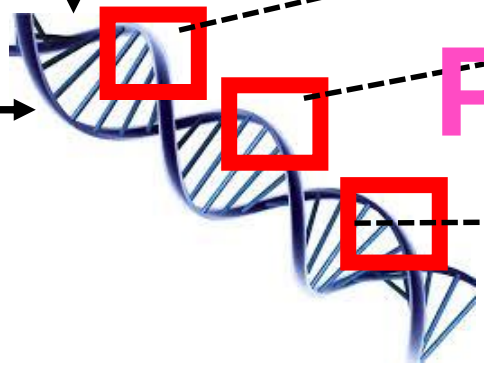


Tsai, Contreras et al. *Applied Environmental Microbiology*, 2015

What do these junk molecules do help survival under radiation?

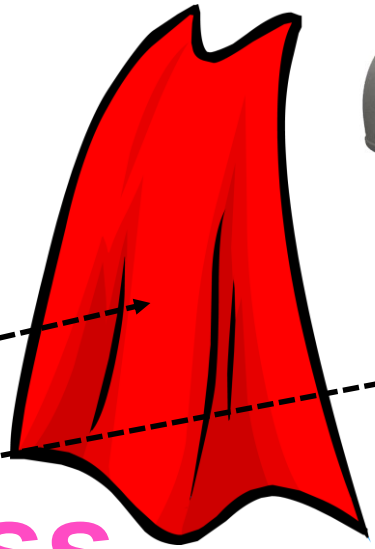
Based on evidence:
Hidden long-distance global controllers that help activate useful traits during radiation





Process

Traits



Breakthrough molecules in science

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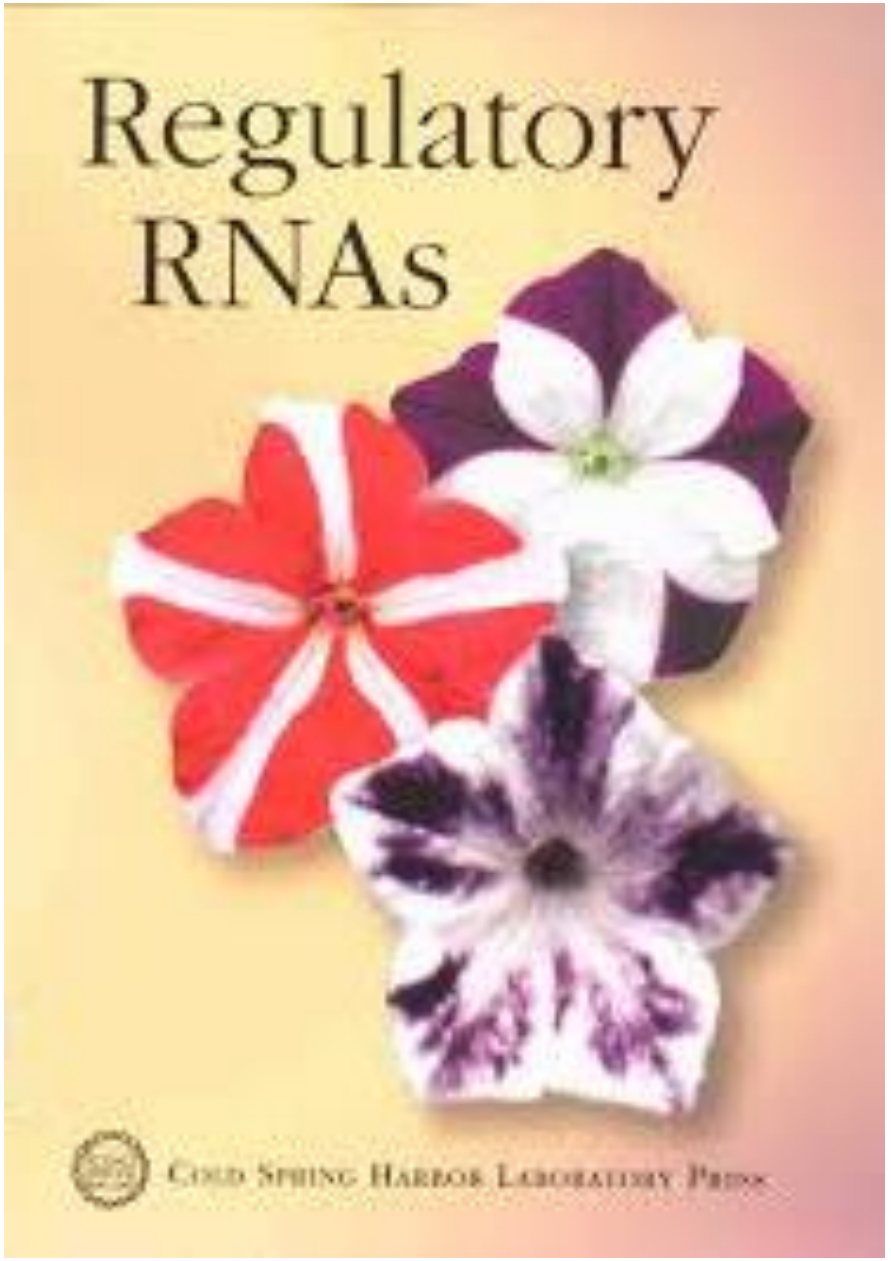


Deep lesson learned:

- Not enough to know DNA information but to understand **how is actively used.**
- ***When*** will traits be visible?
- ***What*** will activate them?
- ***Possibilities:*** stresses, factors sensed in the environment, nutrition, etc.

From *D.rad* we have learned… about surviving extreme radiation

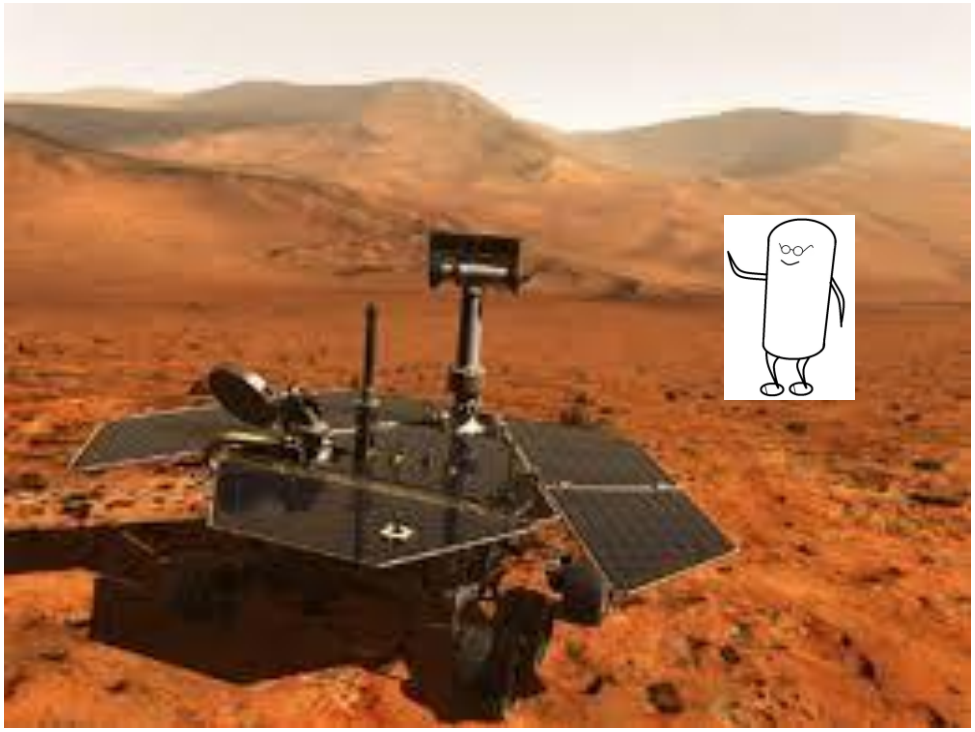
- Secret *superpower traits are* only visible during times of radiation stress.
- The so-called “junk” in the DNA helps to **activate** these traits.

Looking up to *D.rad* for answers to some of the largest challenges we face!

… Imagine life in the unimaginable

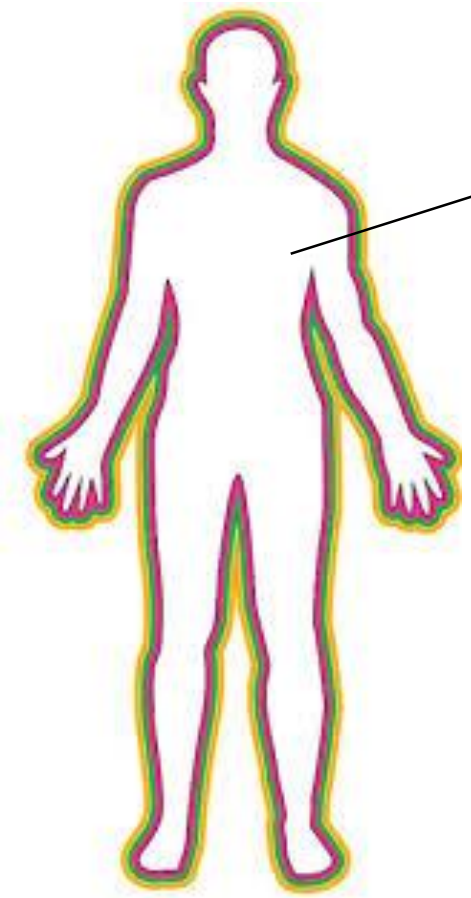
Is there life on other planets?
What might life look like on Mars?

"Selfie" from Rover: Thinner atmosphere, surface much more exposed to radiation



Potential implications to human health

Can we equip humans to survive increasing levels of environmental stress on their cells without leading to disease?



Human =100,000,000,000,000 human cells

Learn from *D.rad* how to shield our cells

Potential implications to human health

Can we see more protection of our cells during radiation treatment from cancer?

General Conclusions: So what is the fuss?

- Microbes are hugely diverse and are the most abundant life form.
- There are many *good microbes,* but a few bad players.
- Our life **depends on them** for food (agriculture), digestion, and many tastes we like.
- ***D.rad* is an example of an extremophile with many attributes that we would like to give humans some day.**
- **Some of *D.rad*'s shielding capacities are currently being tested in mouse models that are undergoing chemotherapy.**

Other Microbe Fans: Contreras Lab

Graduate Students

- **Justin Janovski**
- Grant Gelderman
- Jorge Vazquez
- **Chen-Hsun Tsai**
- Kevin Vasquez
- **Kevin Baldridge**
- Seung Hee Cho
- Bianca Williams
- Steve Sowa
- Katie Haning
- Paul Amador

Undergraduates

* **Respina Vaezian**
*

HS Students

* **Nicholas Curtis**

Funding for this work: NSF CAREER AWARD
AFSOR Young Investigator Award,
Defense Threat Reduction Agency

Chen-Hsun Tsai

- 4th yr, Chemical Engineering PhD prog
- National Taiwan University, 2009, BS in chemical engineering
- “The simpleness of microbes as creatures makes them easy to manipulate, and their complexity gives them abilities beyond imagination. This gives them **great potential for engineering** and that’s why I am interested.”

Justin Janovsky

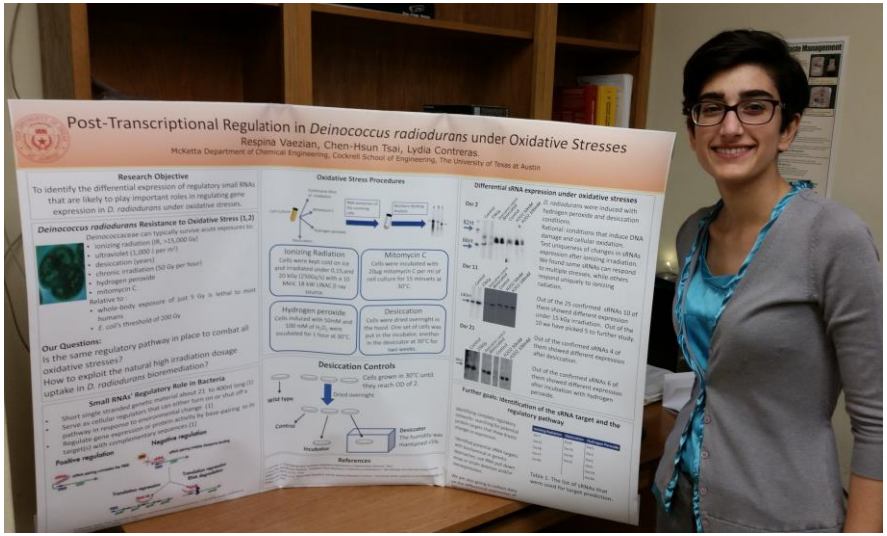
- Master's student in Biochemistry
- "I've always been interested in microorganisms, seeing them as little factories that use molecular machines to make chemicals. I'm fascinated by the idea of learning how they work in order to **engineer them to make industrial and medical products**."

Kevin Baldridge

- PhD student in Chemical Engineering
- Through the lens of biology, I've marveled at the complexity of living things and how life happens to exist.
- As model organisms, microbes allow us to grasp at the straws of how we came to be, and give a glimpse into the machinery of life.
- 'Education is not the filling of a pail, but the lighting of a fire'

  – William Butler Yeats
- **Science fuels the fire.**

Respina Vaezian

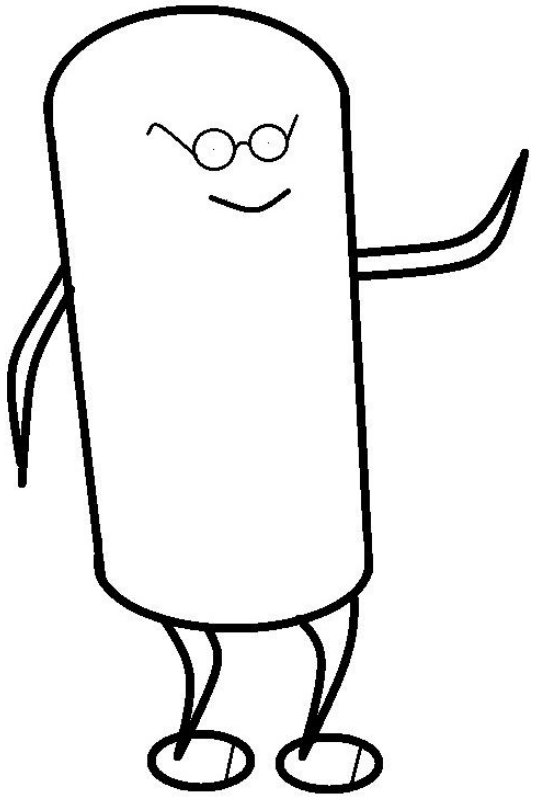


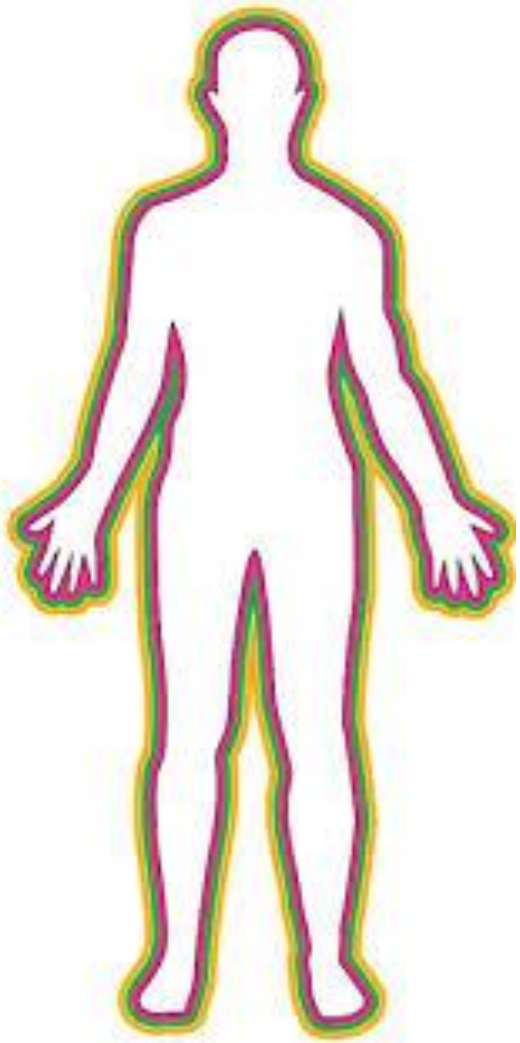
- 3rd yr chemical engineering student
- “As a bedtime story, my mom told me about how Jenner used cowpox to vaccinate for smallpox right before I had to get my **vaccines** for elementary school.”

Nicholas Curtis

- Westwood HS student
- “I'm most excited by the idea that bacteria can be used for a **wide variety of biological applications**, keeping humans alive and well.”

High fives to our microbe friend, *D. rad*!





Dr. Lydia Contreras

Lydia Contreras is an assistant professor of chemical engineering at the University of Texas at Austin. She is a Chevron Centennial Teaching Fellow, and has been recently honored as a Health and Environmental Institute Walter E. Rosenblith New Investigator, with a Norman Hackerman Advanced Research Program Early Career Program award, and a National Science Foundation Career award. The Contreras Lab combines biomolecular engineering, genetic studies and computational modeling, to develop novel applications that could beneficially impact human health. The Contreras Lab has been actively involved STEM outreach to underrepresented communities through the Equal Opportunity in Engineering Program of the Cockrell School of Engineering, Breakthrough Austin, and the John L. Warfield Center for African and African American Studies.