

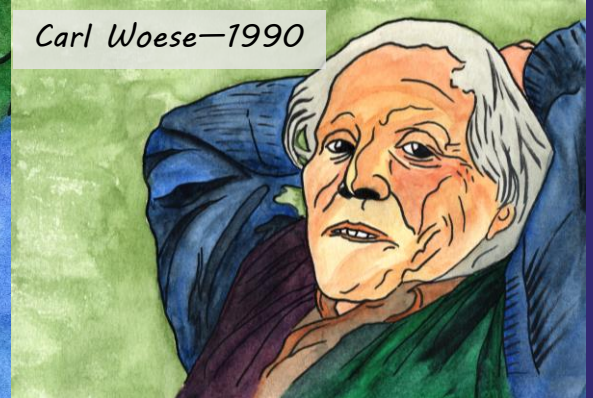
# Adventures in Asgard

A scientific literature review comic by Lilja Strang

In Norse mythology all of life is contained within nine realms. These realms are connected by Yggdrasil, or the World Tree. A similar concept exists in biology. It's called the **tree of life** and it shows the evolutionary connections between all life on earth. These two trees have more in common than most people think.

To begin our story, think back to your earliest biology class. You probably saw either the 1959 tree of life, organized into either 5 kingdoms, or the 1990 tree with 3 domains. The 5 kingdoms tree compared life on the basis of how things looked. Microscopic organisms were too small to see easily, and were excluded.

Carl Woese—1990



Whittaker's 5 Kingdom Tree (1959)

Plantae   Fungi   Animalia

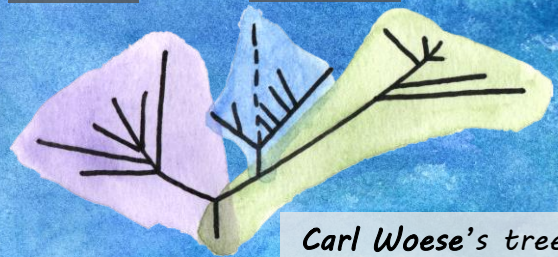


Protista

Monera

Woese's 3 Domain Tree (1990)

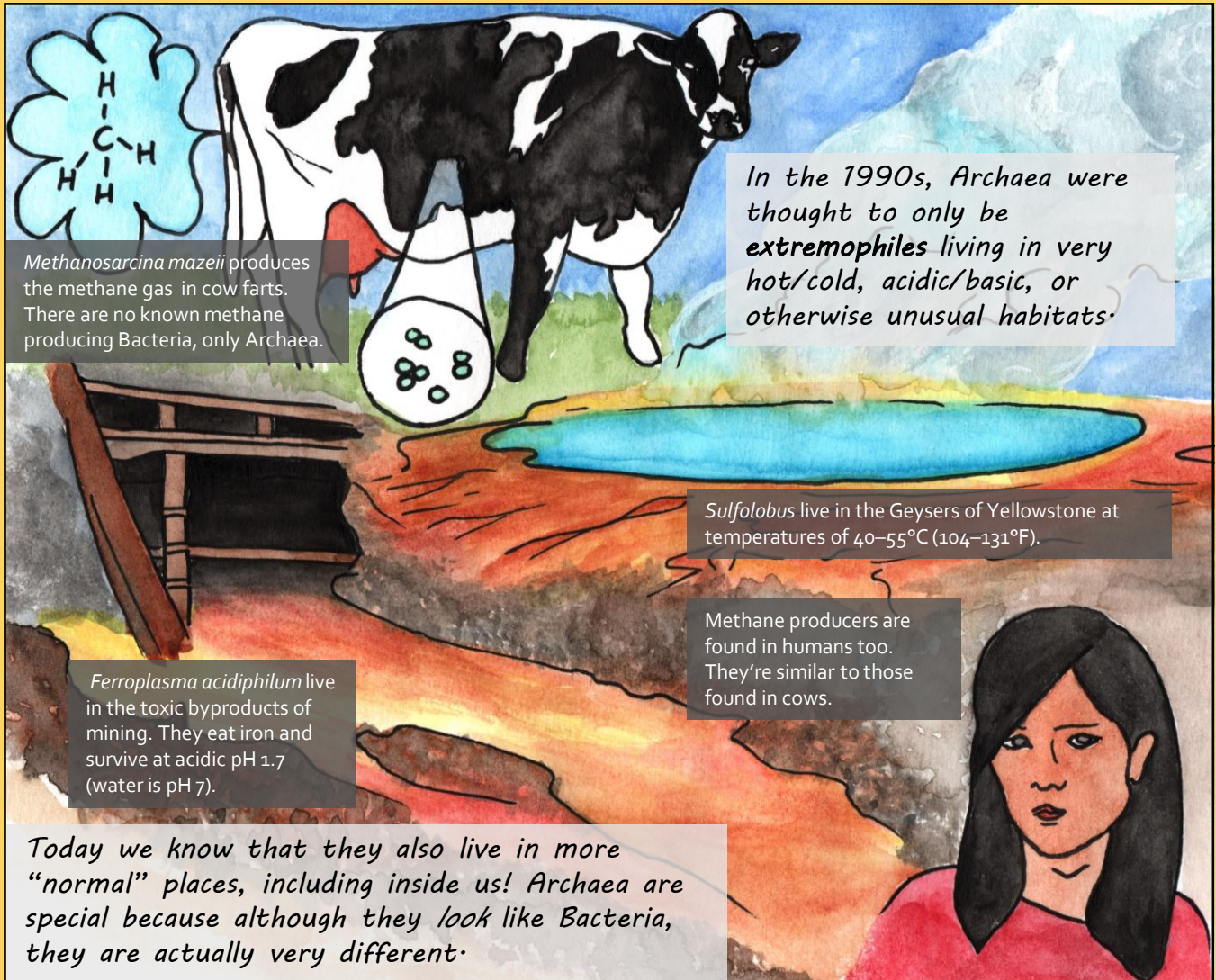
Bacteria   Archaea   Eucarya



Carl Woese's tree was based on the best DNA evidence of his time. Here, the microscopic **Bacteria** and **Archaea** were front and center. In fact, Woese realized that the **Archaea** were very special.

Niðhöggr (Nidhogg) is the dragon that gnaws at the roots of Yggdrasil.





*Methanosarcina mazei* produces the methane gas in cow farts. There are no known methane producing Bacteria, only Archaea.

In the 1990s, Archaea were thought to only be **extremophiles** living in very hot/cold, acidic/basic, or otherwise unusual habitats.

*Sulfolobus* live in the Geysers of Yellowstone at temperatures of 40–55°C (104–131°F).

*Ferroplasma acidiphilum* live in the toxic byproducts of mining. They eat iron and survive at acidic pH 1.7 (water is pH 7).

Methane producers are found in humans too. They're similar to those found in cows.

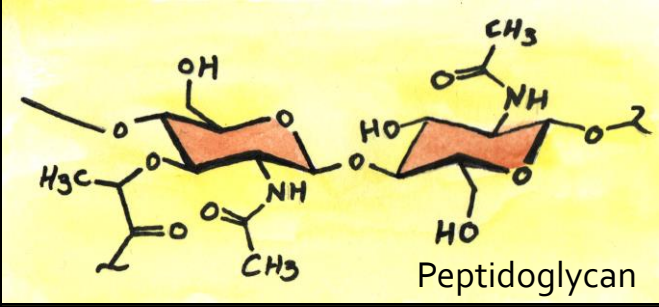
Today we know that they also live in more "normal" places, including inside us! Archaea are special because although they look like Bacteria, they are actually very different.

"These 'bacteria' appear to be no more related to typical bacteria than they are to eukaryotic cytoplasm."

--Woese & Fox (1977)

For example, their Archaeal cell membranes have a different makeup. The chemical peptidoglycan is only found in Bacteria, not Archaea.

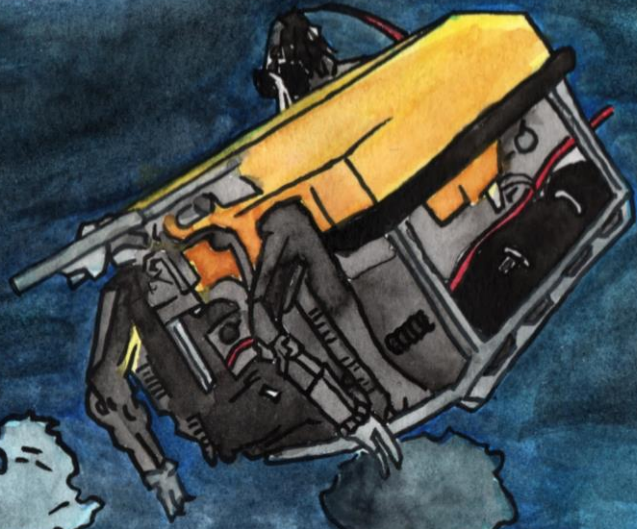
In spite of these differences, Archaea continued to be lumped together with Bacteria as "prokaryotes" for decades because both groups are single-celled.



## 2010 - Arctic Circle



Pedersen (2010)



Deep underwater -  
Loki's Castle Volcanoes

After all this time the discovery of the Loki's Castle volcanoes made scientists more interested in Archaea once again. A Remotely Operated Vehicle (ROV) was taken down to explore the volcanoes and take samples.

## 2015 - Iceland

Metagenomics was used to sequence all of the DNA in the samples from Loki's Castle to show who the microbes are that live in the volcanoes.

What the researchers found surprised them. An entirely new phylum emerged, which they named the **Lokiarchaeota**! No one has ever seen the Lokiarchaeota under a microscope because they haven't been grown in a lab yet. Researchers know about their genomes, but no one knows what they look like!



Spang et al. (2015)

After the discovery of Loki, researchers found others like him...



Thorarchaeota was found in White Oak River, North Carolina... (Seitz et al., 2016)



...and Heimdallarchaeota was found in the same place.

Katarzyna Zaremba-Niedzwiedzka (2017)

Odinarchaeota was discovered on Taketomi Island, Japan.

Kingdom

Super-phylum

Phylum

Proteoarchaeota

Asgard

Lokiarchaeota

Odinarchaeota

Thorarchaeota

Heimdallarchaeota

Eukaryotes

Loki, Thor, Heimdall, and Odin were placed in their own **superphylum** named "Asgard", after the realm in Yggdrasil that is the dwelling place of the Norse Gods. When Asgard was added to the tree of life, something odd emerged... **Eukaryotes**, or multicellular life like us, branch from within the Asgard Archaea!

TACK\*

Korarchaeota

Crenarchaeota

Aigarchaeota

Geoarchaeota

Thaumarchaeota

Bathyarchaeota

\*The TACK superphylum was named when only the phyla in bold were known about (Guy & Ettema, 2011).

How to remember taxonomy:

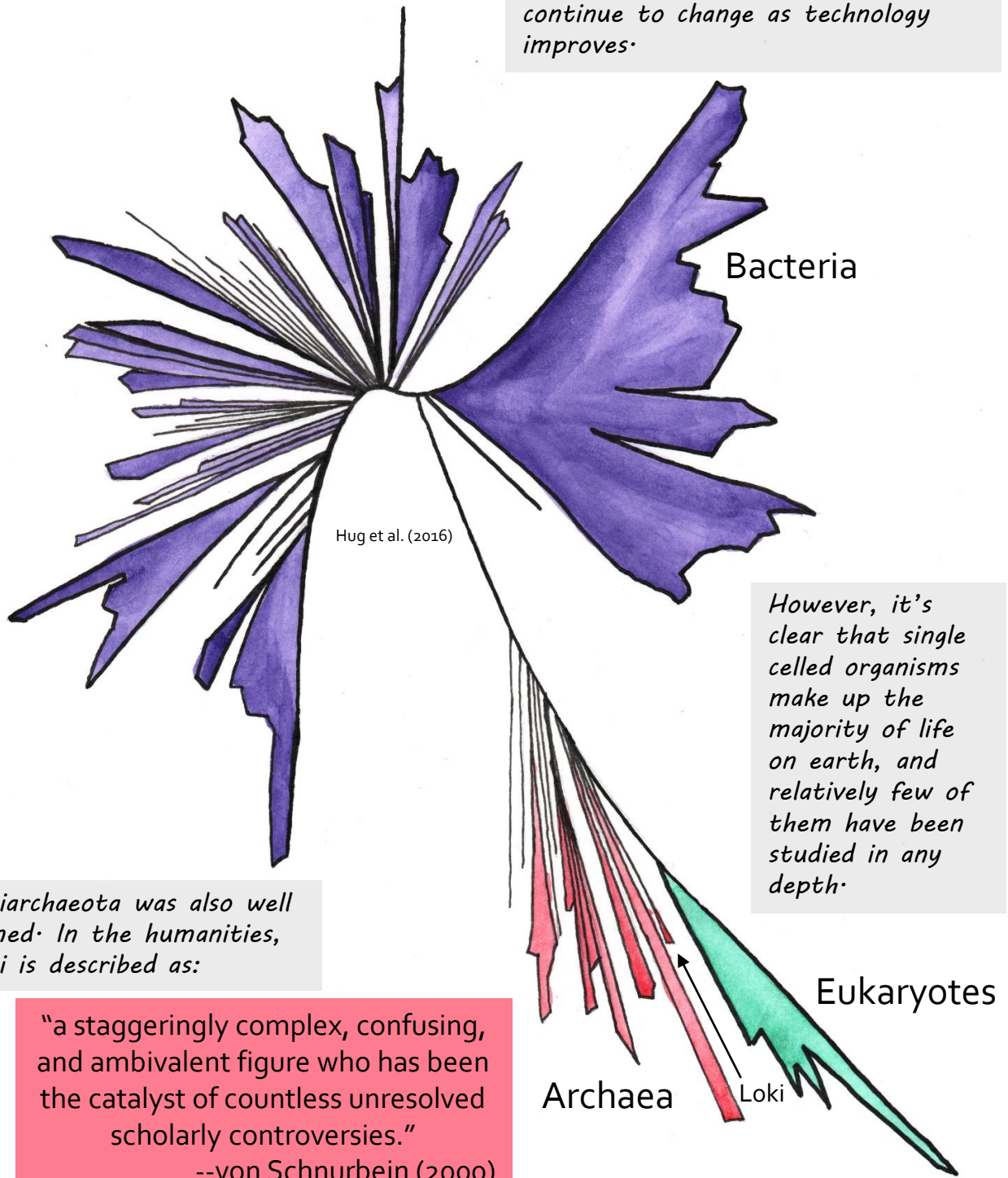
- |         |         |
|---------|---------|
| Do      | Domain  |
| Kings   | Kingdom |
| Play    | Phylum  |
| Cards   | Class   |
| On      | Order   |
| Fuzzy   | Family  |
| Green   | Genus   |
| Stools? | Species |



In other words, humans, plants, animals, fungi, and algae may all technically be Archaea on the new tree of life!

If we zoom out on the new tree of life, this is what it looks like. Microbes take up even more room than they did in Woese's tree!

The assertion that Eukaryotes come from within Archaea is still controversial among scientists, and the tree of life will almost certainly continue to change as technology improves.



However, it's clear that single celled organisms make up the majority of life on earth, and relatively few of them have been studied in any depth.

Lokiarchaeota was also well named. In the humanities, Loki is described as:

"a staggeringly complex, confusing, and ambivalent figure who has been the catalyst of countless unresolved scholarly controversies."  
--von Schnurbein (2000)

...which certainly fits his role on the new tree of life!

# Glossary

- **Archaea** – a classification of life that includes single-celled organisms that are distinct from bacteria in their cell structure and composition. The first Archaea to be discovered were extremophiles, but they are now found in a variety of habitats.
- **Bacteria** – the largest classification of life. It includes single-celled organisms that are distinct from bacteria in their cell structure and composition. Their cell membranes usually contain the chemical “peptidoglycan”. Bacteria can be found in almost all habitats.
- **Cell Membrane** – the lipid (fat) layer that separates the inside of a cell from the outside environment. It often contains proteins and chemicals specific to the type of cell and its function.
- **Cytoplasm** – all of the material inside a cell, except for the nucleus (if the cell is eukaryotic).
- **DNA Sequencing** – the process of finding the exact order of nucleotides (A’s, T’s, G’s, and C’s) in a molecule of DNA. Technology for this process has advanced rapidly in the last decade.
- **Extremophile** – organisms with “extreme” optimal survival conditions, as compared to the conditions of life that are optimal for humans.
- **Eukaryote** – a multi-celled organism whose cells contain a nucleus and other organelles enclosed in membranes.
- **Genome** – The full list of nucleotides in an organism’s genetic material. Sequencing is used to determine an organism’s genome.
- **Metagenomics** – the study of genetic material (DNA, RNA) sampled directly from the environment. It often uses DNA sequencing to answer the question “what lives here?”.
- **Prokaryote** – a single-celled organism that lacks a nucleus, mitochondria, and other organelles.
- **Taxonomy** – the classification of organisms, both living and extinct.
- **Tree of life** – a tool used by biologists to describe the evolutionary relationships between organisms.

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