Are We Alone in the Universe?

An Introduction to Astrobiology

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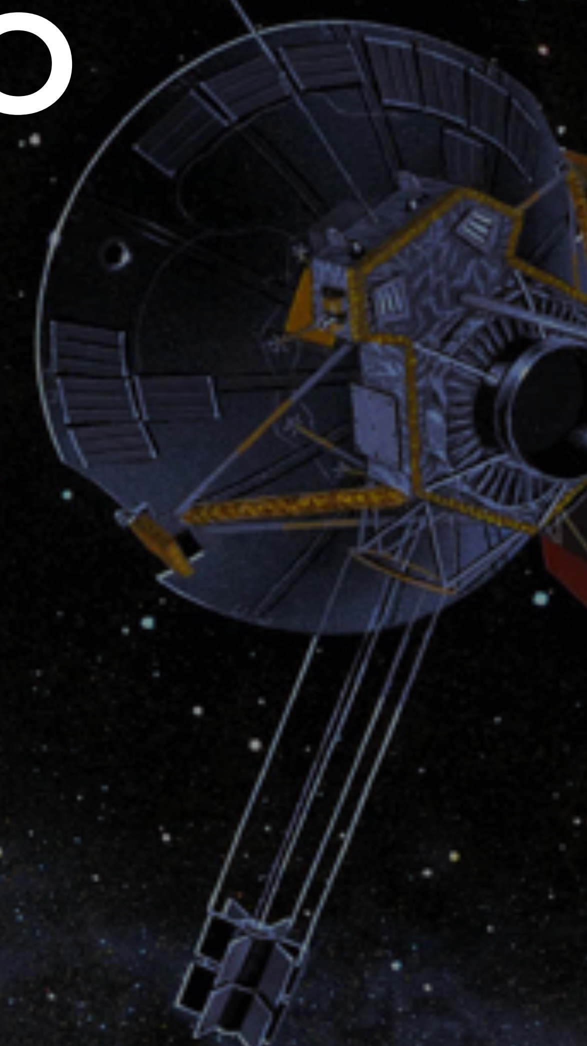


Planetary Science Institute

SciFest Africa, March 2013

The biggest question facing astronomers today...

Are we alone in the Universe?

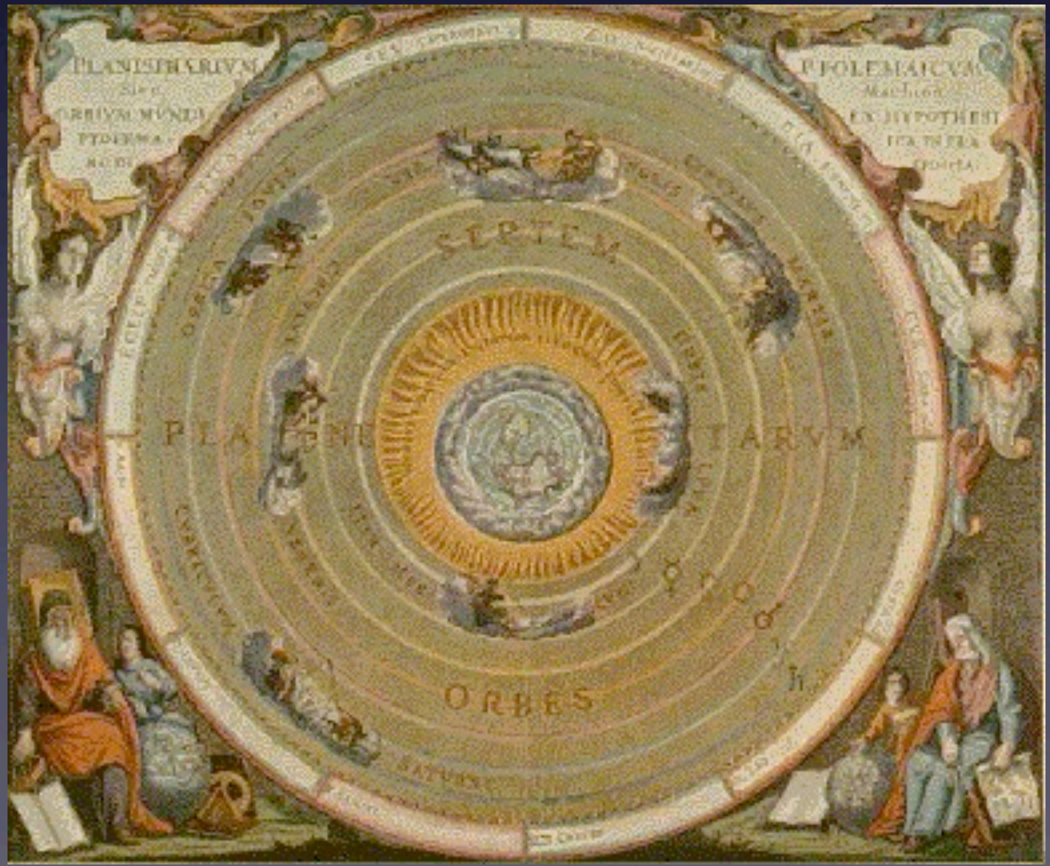
Are We Alone?

- Is our Solar System unique?
- Is the Earth unique?
- Is life on Earth unique?
- Are our laws of physics unique?

1500’s view of our Uniqueness

Earth was believed to be the center of the universe, and the Sun, Moon, planets, and stars circled around it.

“We are special... it’s just us here!”

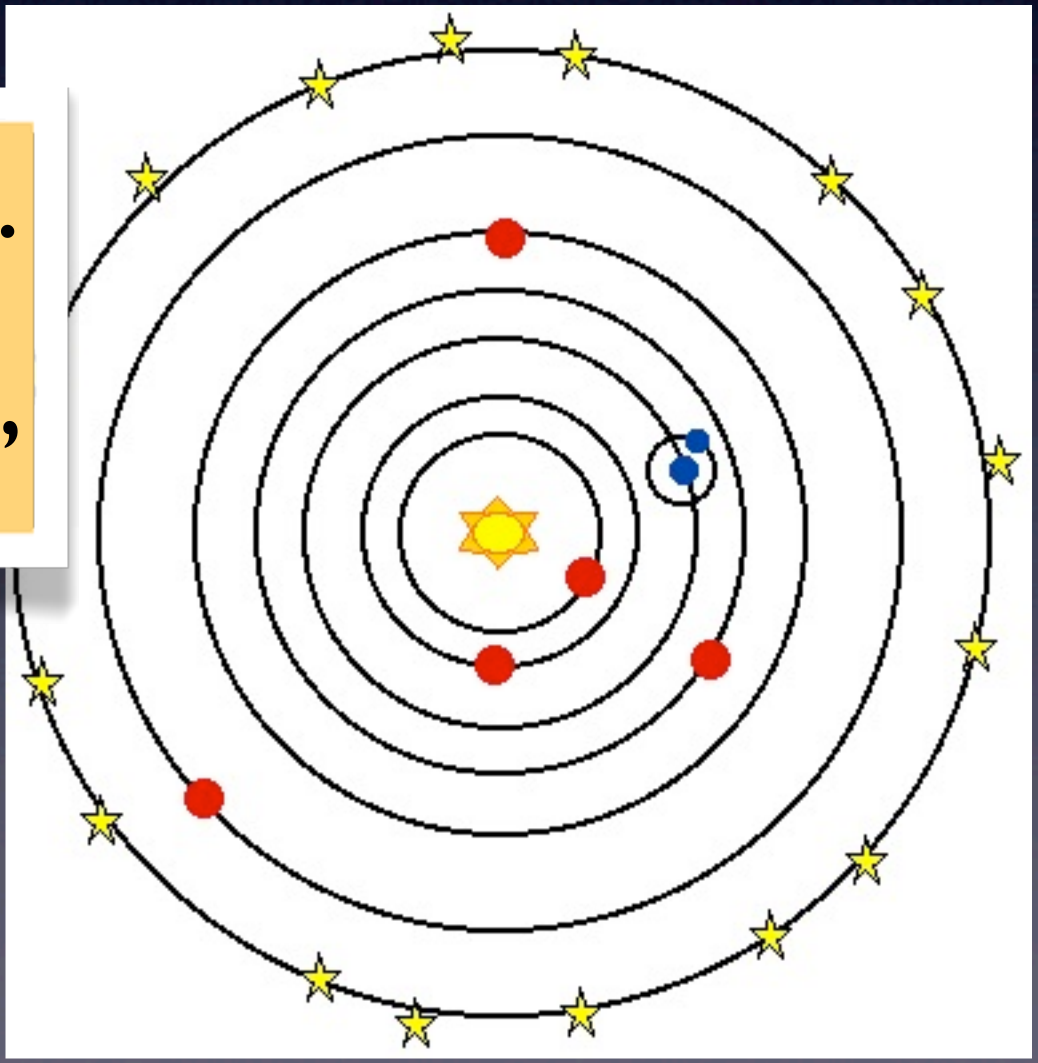


1600 view, post-Copernicus

The Sun was at the center of the Universe, orbited by the Earth and the other planets.

"We are special... it's just us here...

... and four other planets!"

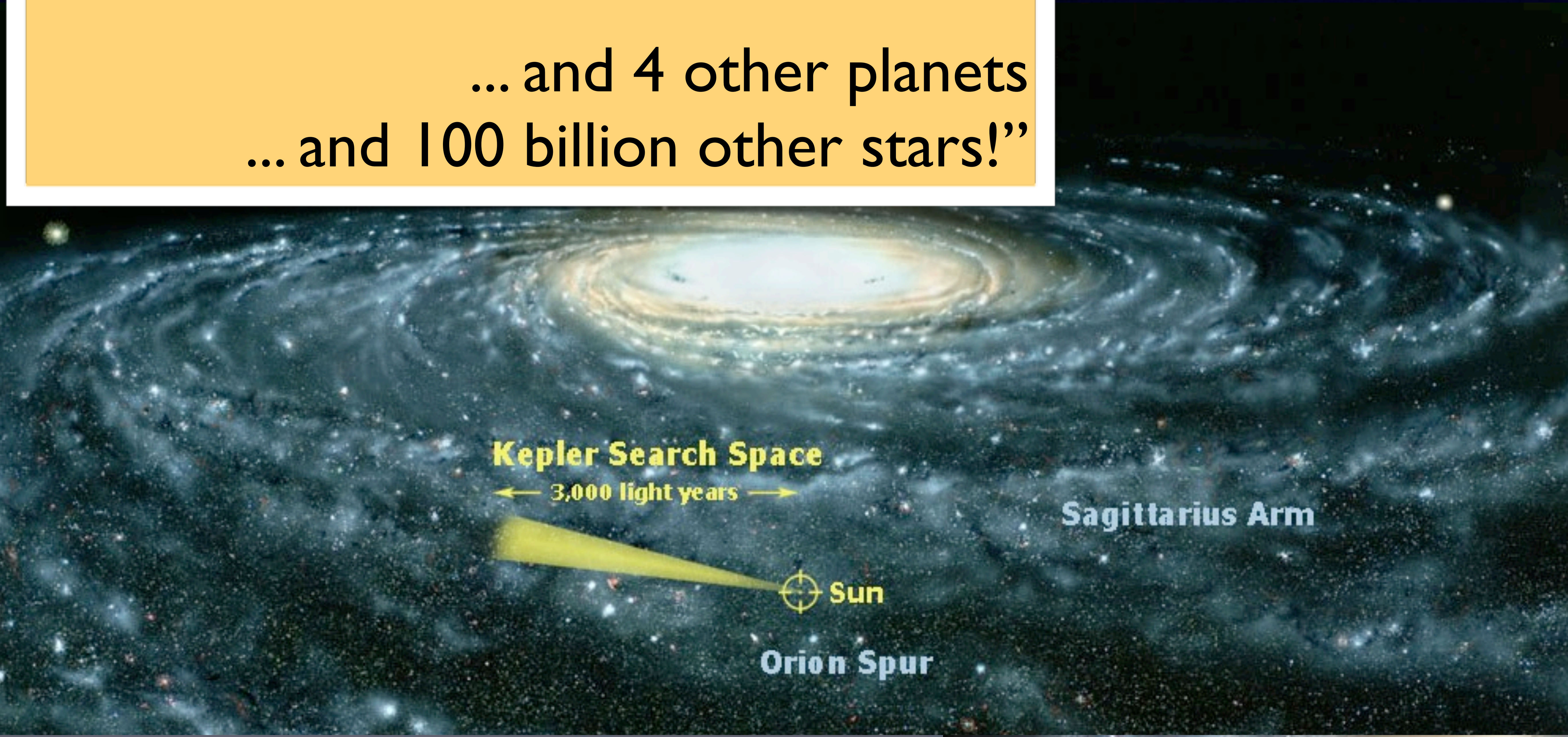


1700 view (post-Huygens)

The points of light in the Milky Way galaxy are recognized as stars that could be like our own.

"We are special... it's just us here...

... and 4 other planets
... and 100 billion other stars!"



1930 view (post-Edwin Hubble)

Spiral clouds in the sky are recognized as individual galaxies like the Milky Way

"We are special... it's just us here...

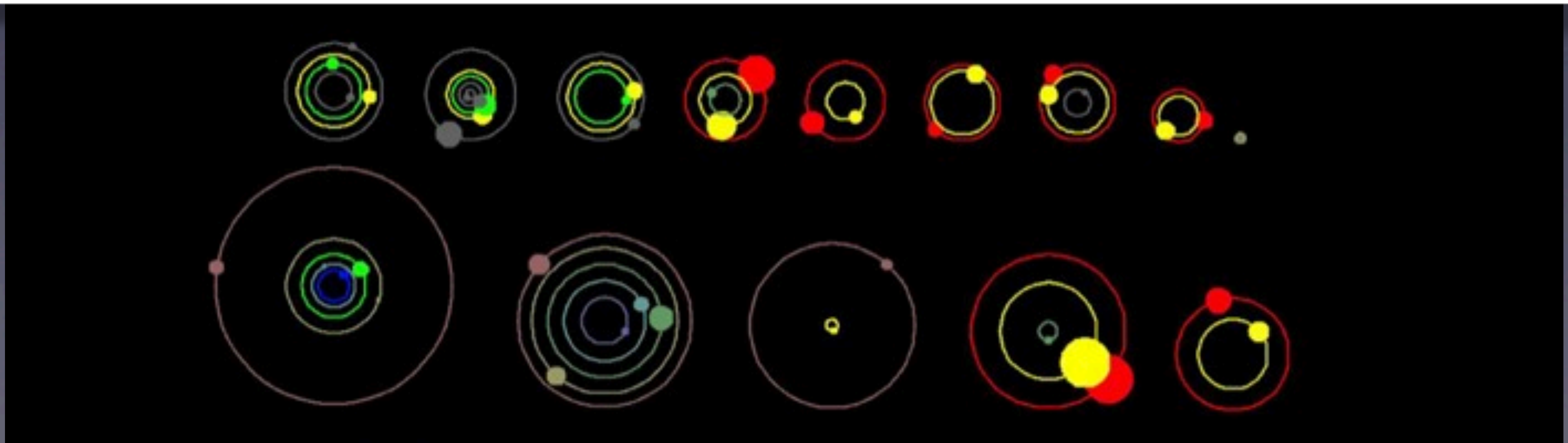
... plus the other 8 planets,
... plus 100 billion other stars in the Milky Way
... plus 100 billion other galaxies, each with
their own 100 billion stars!"

1990's - Present View

Astronomers have found planets around thousands of stars...
there may be more planets than stars in the Universe.

"We are special... it's just us here...

... plus the other 8 planets,
... plus 100 billion other stars in the Milky Way
... plus 100 billion other galaxies, each with their own 100 billion stars
... and each of these 10^{22} stars might have their own planets, so...
... us and 10^{23} other planets!"



Are We Alone?

- Is our Solar System unique? (Probably not)
- Is the Earth unique? (Probably not)
- Is life on Earth unique?

In order to search for life in the Universe, we need to know where to search.

What environmental requirements are there for life on Earth?

What Does Life on Earth Need?

- Not too hot (< 100 C)
- Not too cold (> 0 C)
- pH not too acidic (pH > 3)
- Not too saline
- Not too high pressure
- Not too much radiation
- Not too much ultraviolet light
- Based on C, H, O, N, K (potassium)
- Uses liquid water

Thermophilic (heat-loving) bacteria in Yellowstone at > 95 C
Sea-floor bacteria at > 150 C

What Does Life on Earth Need?

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Cryophilic (cold-loving) bacteria frozen in Antarctic ice at -50 C

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Acidophilic (acid-loving) bacteria such as in mine runoff at Rio Tinto mine, Spain: pH < 2.0

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Halophilic (salt-loving) bacteria,
Makgadikgadi Pans, Botswana

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Piezophilic (pressure-loving) Xenophyophores, at 10 km below the surface in the deepest ocean trenches.

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UV photolysis, organic molecules in young disks, and the origin of meteoritic amino acids

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A B S T R A C T

The origin of complex organic molecules such as amino acids and their precursors found in meteorites and comets is unknown. Previous studies have accounted for the complex organic inventory of the Solar System by aqueous chemistry on warm meteoritic parent bodies, or by accretion of organics formed in the interstellar medium. This paper proposes a third possibility: that complex organics were created *in situ* by ultraviolet light from nearby O/B stars irradiating ices already in the Sun's protoplanetary disk. If the Sun was born in a dense cluster near UV-bright stars, the flux hitting the disk from external stars could be many orders of magnitude higher than that from the Sun alone. Such photolysis of ices in the laboratory can rapidly produce amino acid precursors and other complex organic molecules. I present a simple model coupling grain growth and UV exposure in a young circumstellar disk. It is shown that the production may be sufficient to create the Solar System's entire complex organic inventory within 10^6 yr. Subsequent aqueous alteration on meteoritic parent bodies is not ruled out.

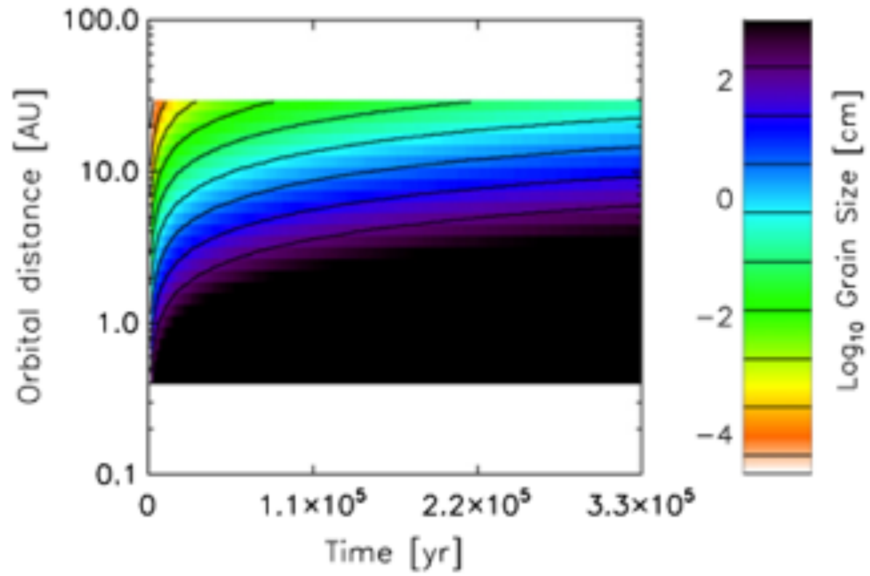

Fig. 1. Grain size, `Nominal`. Grains grow to almost cm sizes throughout the disk within 3×10^5 yr. Growth is stopped at 5 m (black) as other growth mechanisms begin to take over.

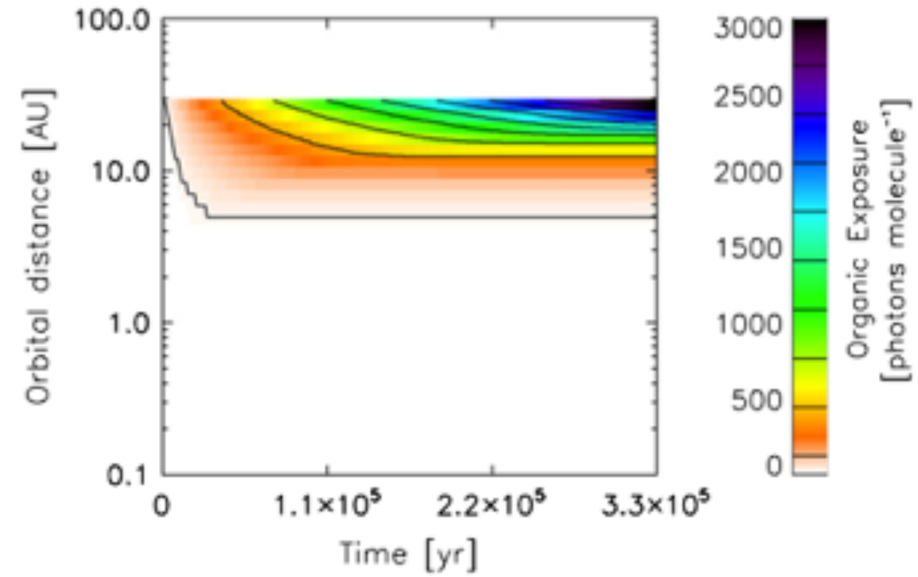

Fig. 4. Photons per molecule, `Nominal`. This shows the net exposure of each original ice molecule in the disk to UV flux. Grains at the outer edge receive the highest flux because of their slow growth and the low surface density.

My own research finds that the UV radiation that might kill life today, in young solar systems can rapidly jumpstart the creation of life's ingredients.

What Does Life on Earth Need?

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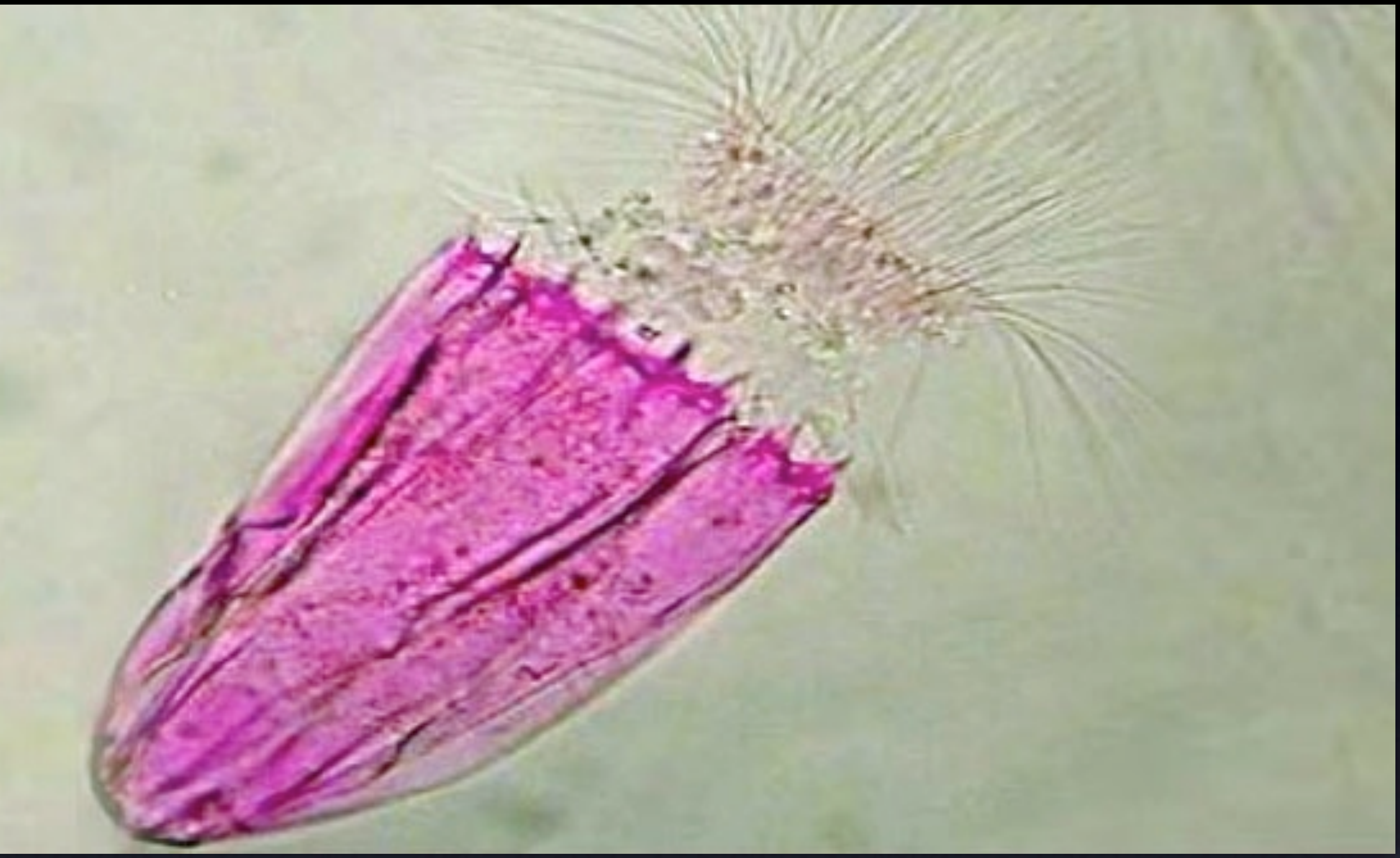
- Uses liquid water



Anoxic (oxygen-free) Spinoloricus animals, discovered in deep trenches on the Mediterranean sea floor, 2011

Evidence for bacteria using As (arsenic) instead of K (potassium) in Mono Lake, USA, 2012

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What Does Life on Earth Need?

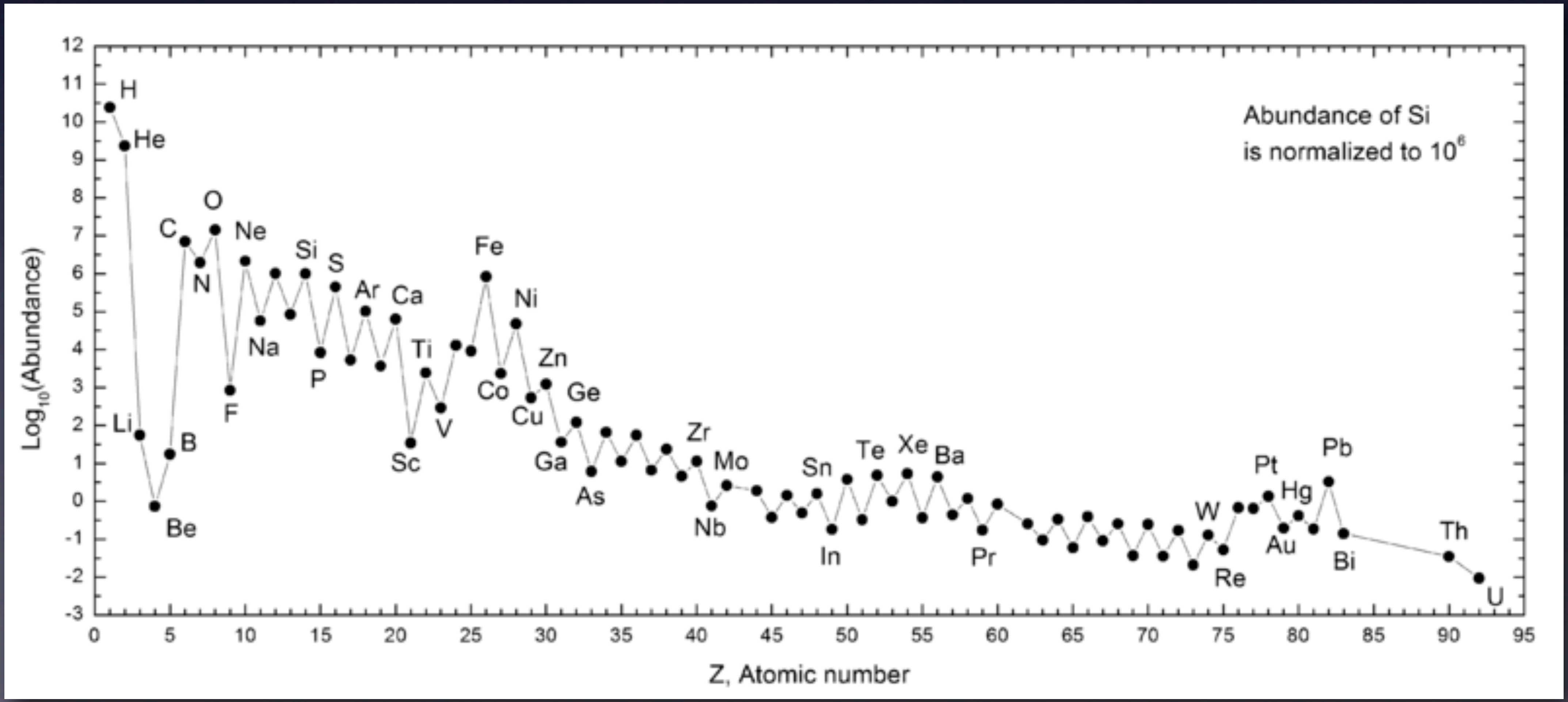
Liquid water

The search for life is largely the search for liquid water.

Liquid Water

Water (H_2O) is very common throughout the Solar System and Universe.

But it is almost always found as a gas (e.g., Venus' clouds) or a solid (e.g., Pluto) -- not a liquid!



Three Best Places to Search for Liquid Water in Solar System

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#1: Mars

- Mars used to have massive water oceans and lakes. They either froze into tundra, or evaporated.

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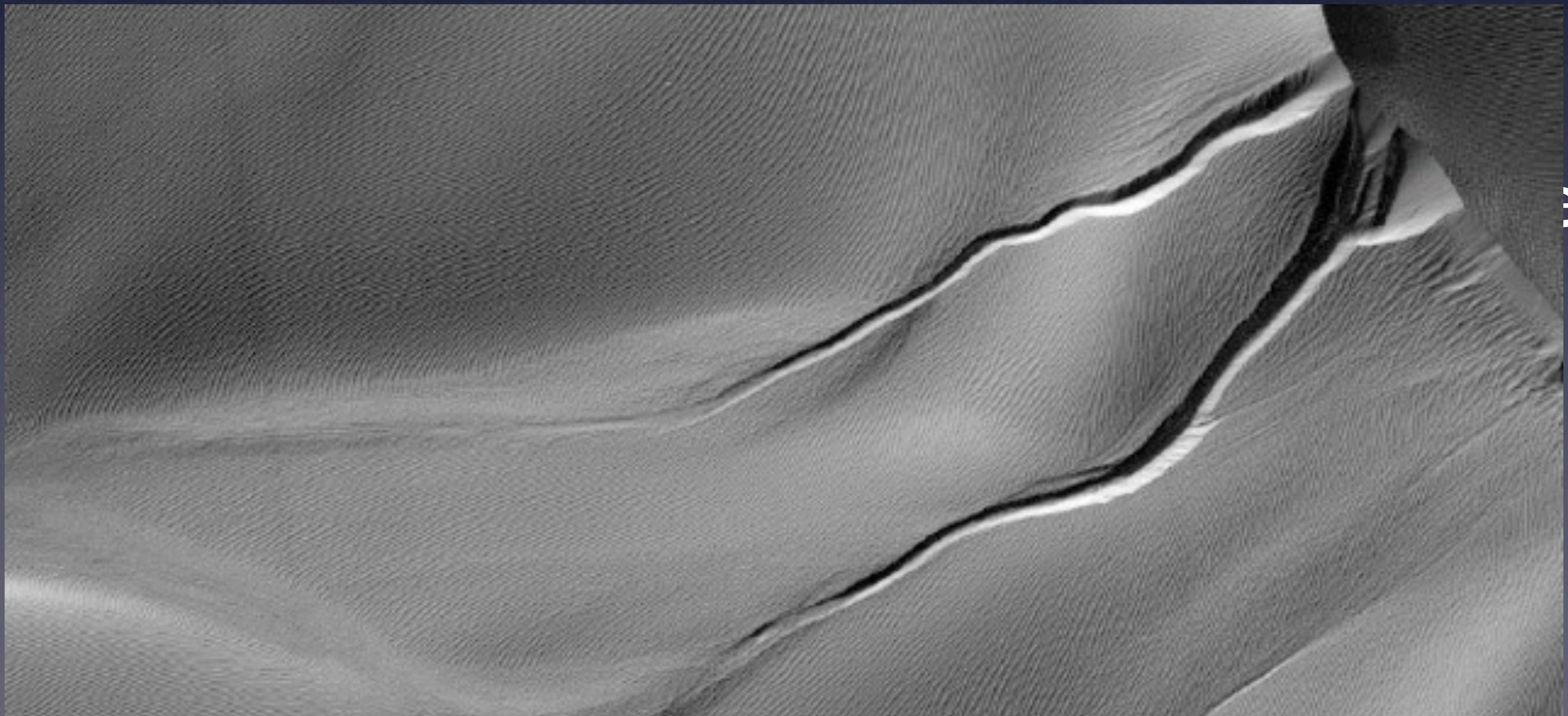


Three Best Places to Search for Liquid Water in Solar System

#1: Mars

- Mars used to have massive water oceans and lakes. They either froze into tundra, or evaporated.
- There's some evidence for occasional water flow on the surface now.
- Mars has some (debated) evidence for fossilized life found in a Martian meteorite that landed in Antarctica.

Three Best Places to Search for Liquid Water in Solar System

#1: Mars

NASA's *Curiosity* rover is currently exploring Mars' surface and looking for signs of past life and habitability.

On-board chemistry experiments measure composition, search for clues such as carbon isotopic ratios.

Three Best Places to Search for Liquid Water in Solar System

#1: Mars

NASA's *Curiosity* update from press conference 12 March 2013:

"Several billions years ago, Mars may well have been a pleasant place for tiny microbes to live, with plenty of water as well as minerals that could have served as food. [*Curiosity*] has not found signs that actual microbes did live in that oasis.

'We have found a habitable environment that is so benign and supportive of life that probably if this water was around and you had been on the planet, you would have been able to drink it,' said John P. Grotzinger, the California Institute of Technology geology professor who is the principal investigator for the NASA mission.

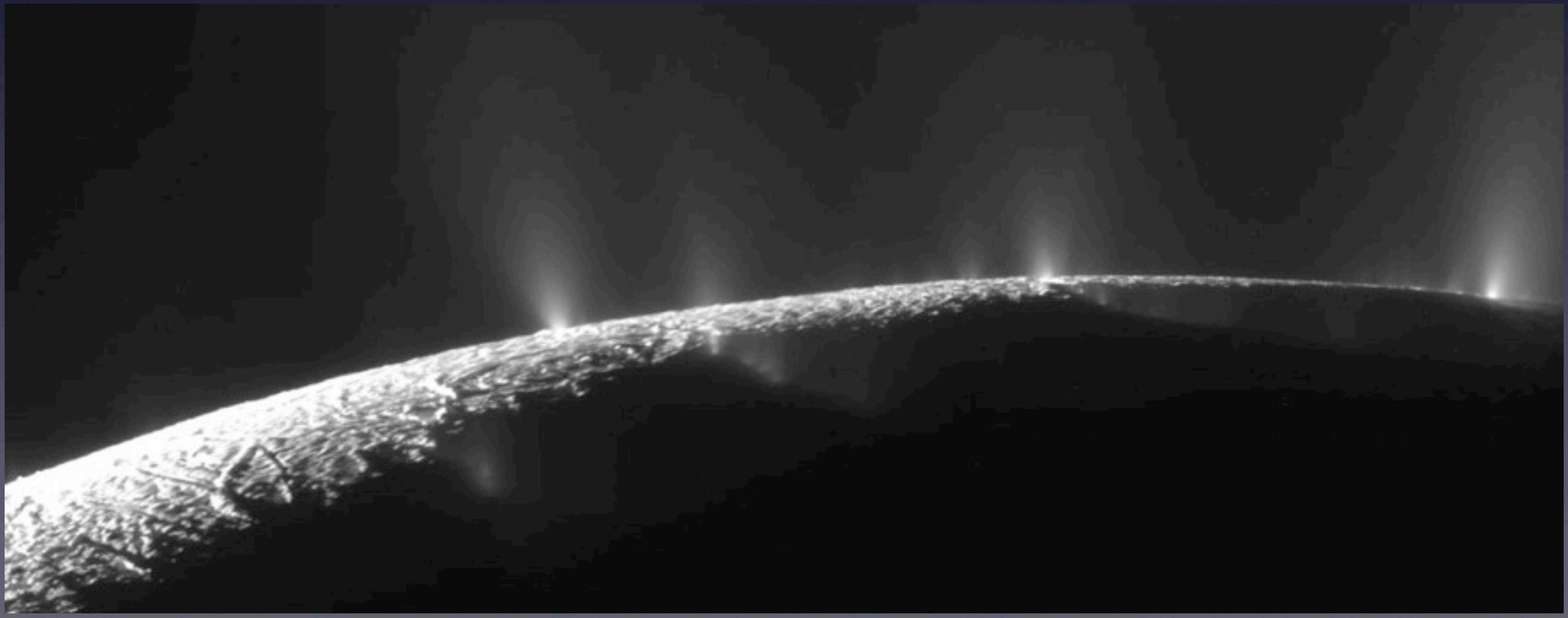
Curiosity scientists identified elements in the rocks - sulphur, N, O, K, C - that are key ingredients of life, as well as minerals like sulfates that primitive microbes could eat for food.

Curiosity has not yet found the carbon building blocks needed to come together to give rise to living organisms."

Three Best Places to Search for Liquid Water in Solar System

#2: Saturn’s moon Enceladus

- Enceladus has massive plumes of erupting water, the size of Yellowstone’s ‘Old Faithful.’



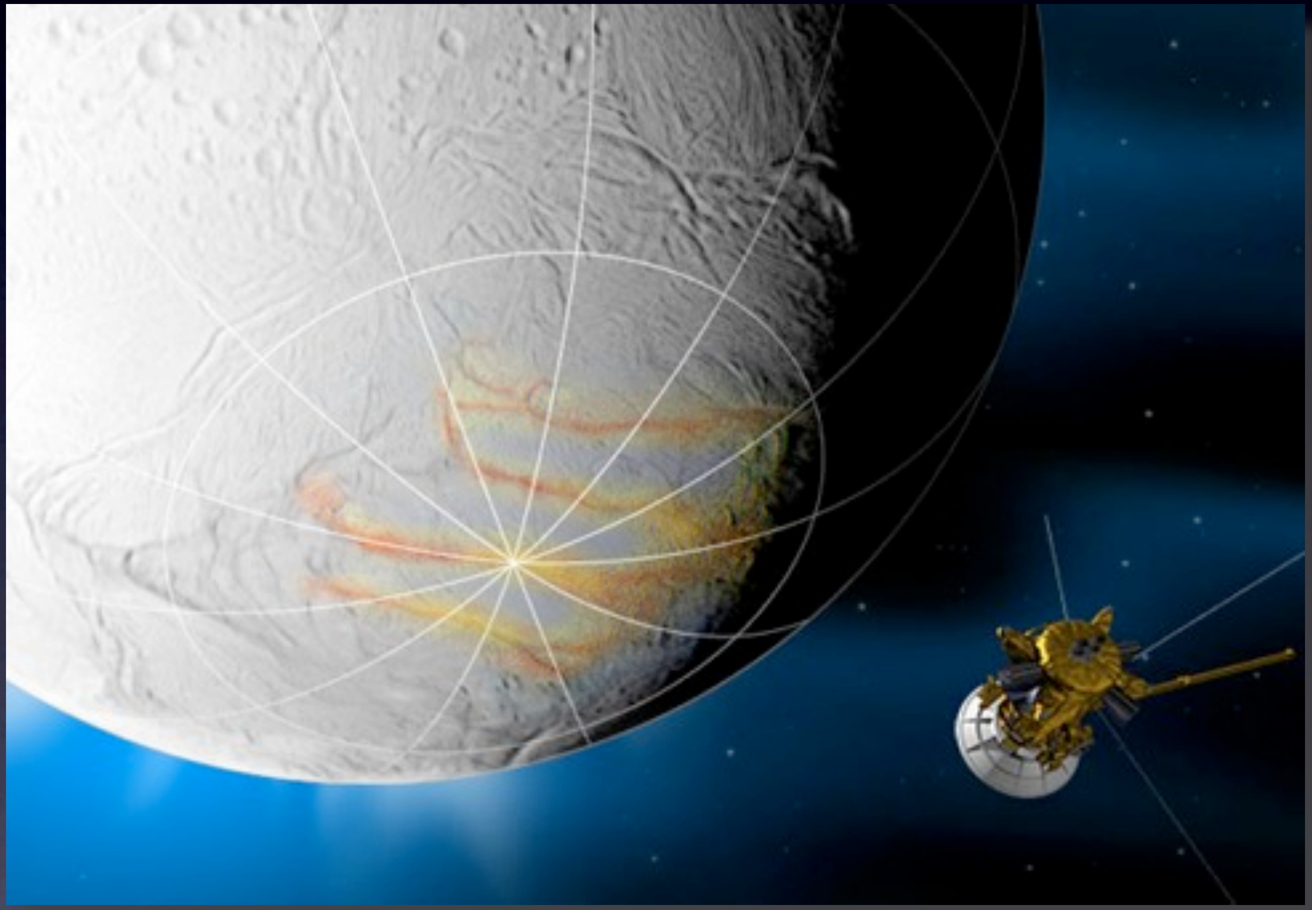
Three Best Places to Search for Liquid Water in Solar System

#2: Saturn’s moon Enceladus

- Enceladus has massive plumes of erupting water, the size of Yellowstone’s ‘Old Faithful.’
- These plumes come out as liquid droplets -- meaning that something must be heating Enceladus, which would otherwise be a cold icy rock.

Three Best Places to Search for Liquid Water in Solar System

#2: Saturn’s moon Enceladus

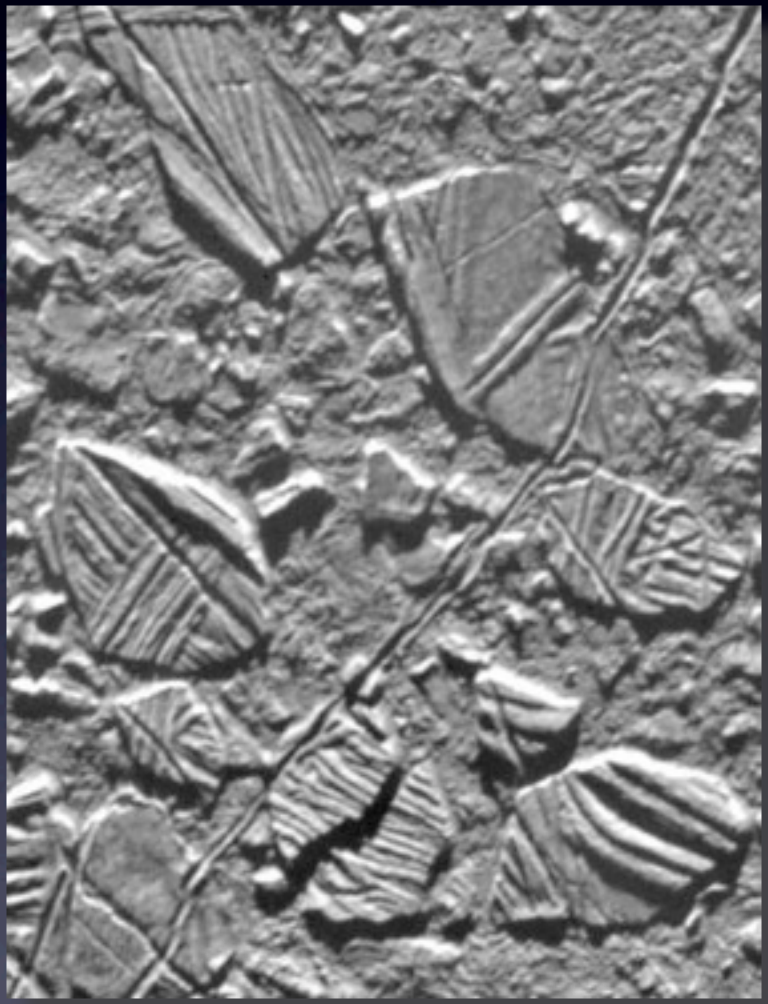


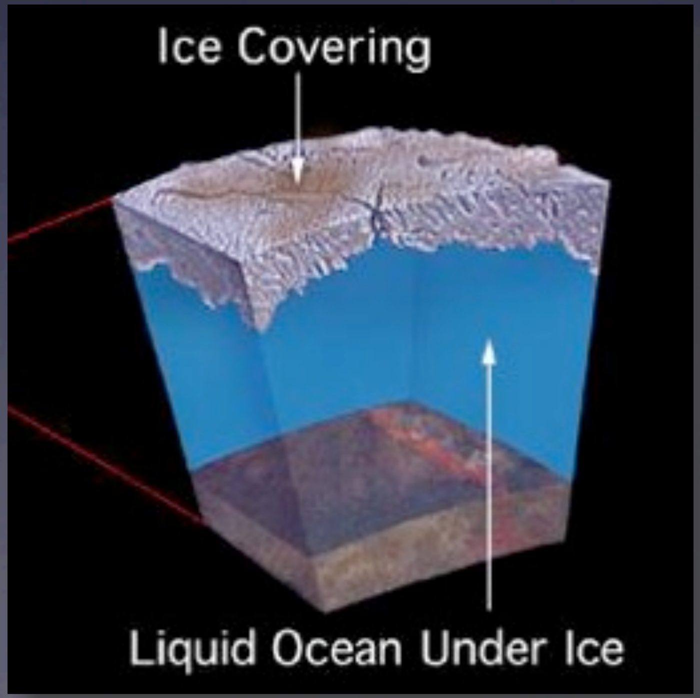
NASA’s Cassini spacecraft is currently orbiting Saturn and has flown directly through Enceladus’ plumes several times, ‘tasting’ them for salts and other clues.

Three Best Places to Search for Liquid Water in Solar System

#3: Jupiter's moon Europa

- Photos show that the surface was recently liquid, with icy 'rafts' floating on a fresh, smooth surface.
- Europa may have a warm ocean underneath an icy shell.





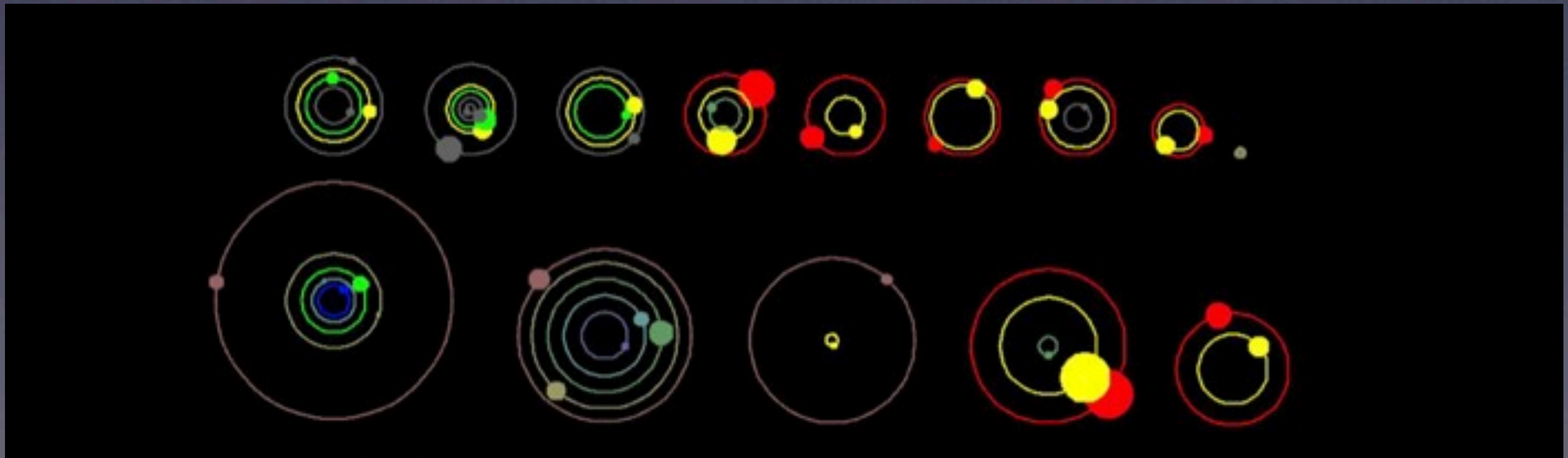
Three Best Places to Search for Liquid Water in Solar System

#3: Jupiter's moon Europa

Europe is planning a mission to Jupiter and Europa, to be launched ~ 2022. Mission will search for warm ocean and organic molecules that could support life.

Three Best Places to Search for Liquid Water in Solar System

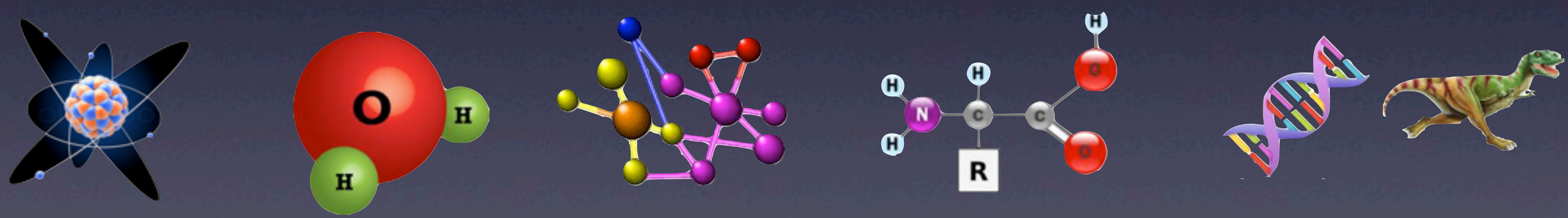
Outside our solar system? For now, every other solar system is too far away for us to be able to make useful detections of liquid water, much less life. We can only crudely guess at the odds.



Once you have a planet, how do you make life?

Method #1: Build it from scratch

Atoms ⇒ Molecules ⇒ Organics ⇒ Amino Acids ⇒ DNA ⇒ Life



Some of these steps are very easy; some are very hard.

Once you have a planet, how do you make life?

Method #2: Bring it in from somewhere else ('Panspermia')

The Earth gets hit by 40 tons of material from asteroids, comets, other planets, and other solar systems every day. Organic molecules and microbes riding along could 'seed' life from one planet to another.

Once you have a planet, how do you make life?

Method #1: Build it from scratch

Method #2: Bring it in from somewhere else

Which of these very different models describes how life on Earth started?

It's a huge question....

And one that we have no idea what the answer is.

A few closing thoughts...

- The Earth is 4.5 billion years old. Life on Earth is about 3.5 billion years old -- that is, life took over almost as soon as it could have.
- The laws of physics, and thus the laws for life, appear to be the same everywhere in the Universe.
- Over the centuries, we have learned a great deal about Earth's place in the Universe, and we know it is not unique. But in the same centuries, we have discovered almost nothing about the specifics of life beyond the Earth, and whether we ourselves are unique. Future centuries hold many discoveries...