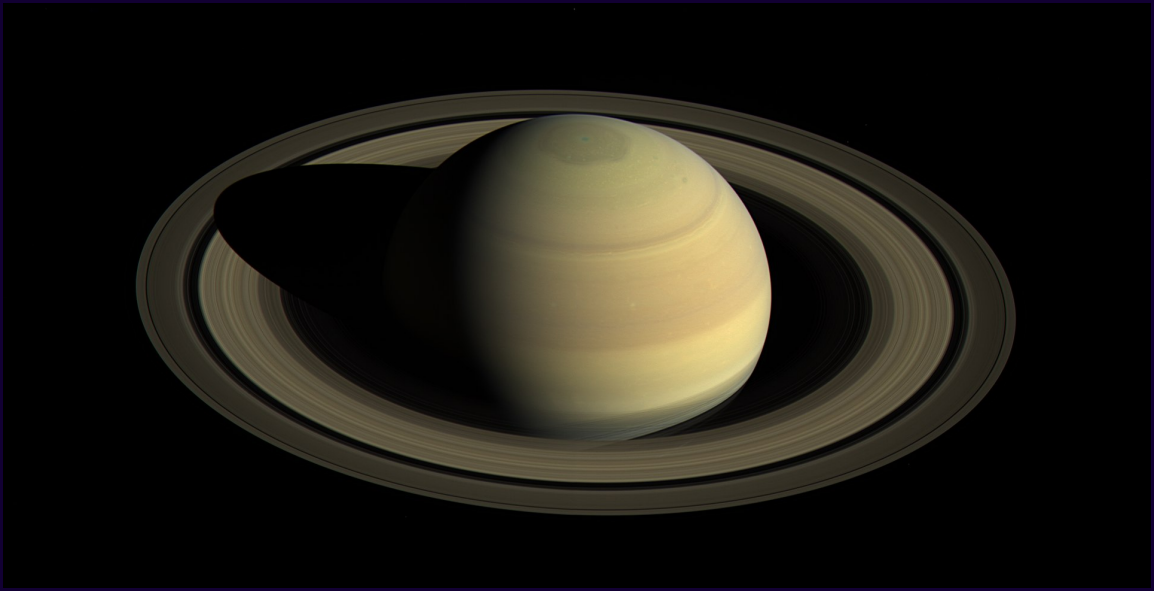
Ad astra per aspera, II

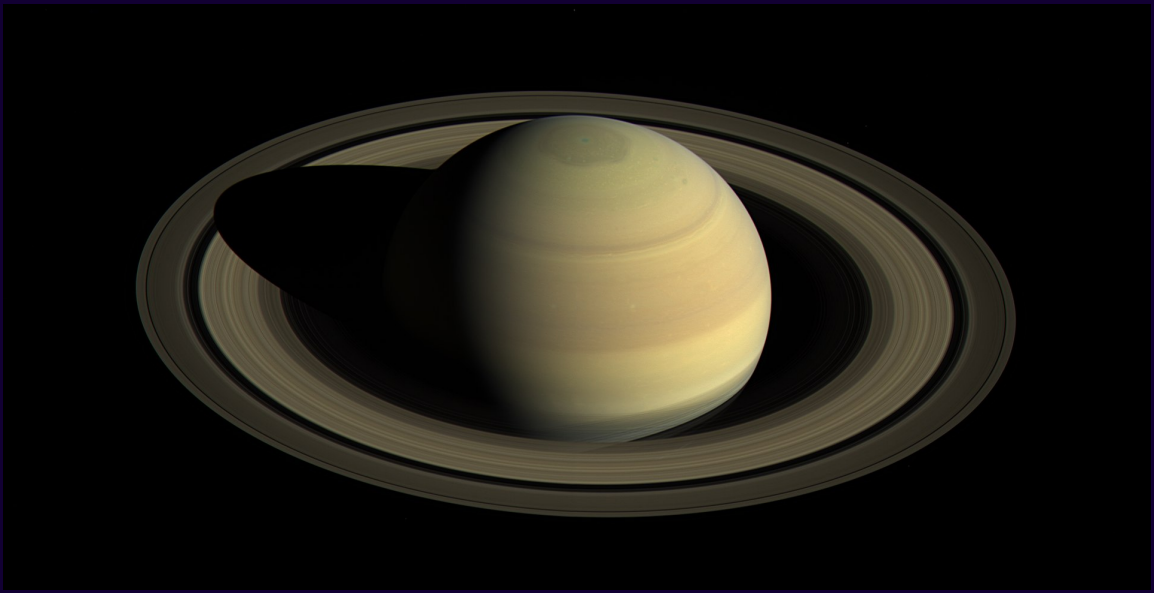
Astronomy 101
Syracuse University, Fall 2020
Walter Freeman

November 24, 2020



I still remember when the first time I pointed the telescope at the sky and I saw Saturn with the rings. It was a beautiful image. And that really made my mind to become a scientist. And that was the first step in order to become an astronaut, of course.

–Umberto Guidoni, Italian astronaut, to NASA (2001)



It's amazing to me that not only can we put a probe around Saturn and get images of its moons, but our math and physics are so freaking accurate we can say, "Hey, you know what? On this date at this time if we turn Cassini that way we'll see a moon over 2 million kilometers away pass in front of another one nearly 3 million kilometers away." Every morning, I have a 50/50 chance of finding my keys. That kinda puts things in perspective.

–Phil Plait, American astronomer (2010)

Announcements

Remaining parts of the semester:

- I'll have discussion hours after class 4PM-6PM on Zoom. Please stop by and say hello, goodbye, or leave me feedback!
- Labs will be held today as planned – you can make up work then
- Project 6 will be posted late tonight
- December 4 is the "final make-up day"
- I'll be in contact very soon about finalizing grades and how you can help us correct errors
- Final projects due December 5
- Blackboard survey on group members posted next week, due December 10

Summary

Last time:

- **Since the end of human flight to the Moon in 1972, we've not been there or anywhere else interesting**

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- **... what now?**

The possibility of life on other worlds...

- What it might look like
- Where it might be hiding, and how we might find it
- How likely this is

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The possibility of extraterrestrial civilizations...

- How we might talk to them
- What *they* might look like
- How likely *they* are: the Drake equation

Summary

...How humans might travel throughout the Solar System...

- More time (“work longer”)
- More effort (“work harder”)
- Better rockets (“work smarter”)

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- The possibility of sending probes to Alpha Centauri
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How we might get to the stars

- The possibility of sending probes to Alpha Centauri
- What we might find there
- How such a mission might look: patience...

Ad astra per aspera: how *we* might become a spacefaring civilization!

- Can we travel to Alpha Centauri?
- ... the technical challenges
- ... the social challenges
- ... the philosophical challenges
- ... and how they would change our humanity

Evan Lewis, BS in Physics, 2019

College of Arts and Sciences Scholar

Member of the SU Marching Band

Member of the SU Homecoming Court

AST 101 (and PHY 307 and PHY 211) coach

Evan is now working toward his PhD in astrophysics.

Evan Lewis, BS in Physics, 2019

"Ad astra per aspera"

Evan Lewis, BS in Physics, 2019

"Ad astra per aspera"

"Through hardship, to the stars!"

Evan Lewis, BS in Physics, 2019
"Ad astra per aspera"

"Through hardship, to the stars!"

(Evan will require less hardship than the rest of us, since he is already so tall.)

Exobiology: life on other worlds

If we're looking for life elsewhere, we should start by looking for Earth-like life:

- Chains of carbon atoms as structural building blocks: `http://bit.ly/2hitrhM`
- Many different chemical pathways to harnessing energy
  - Oxygen: very reactive, very handy, not necessary
  - Light: a great primary energy source, but not necessary!
  - Can also metabolize other things: sulfur, iron, manganese...

Life on Earth is much more resilient than we think!

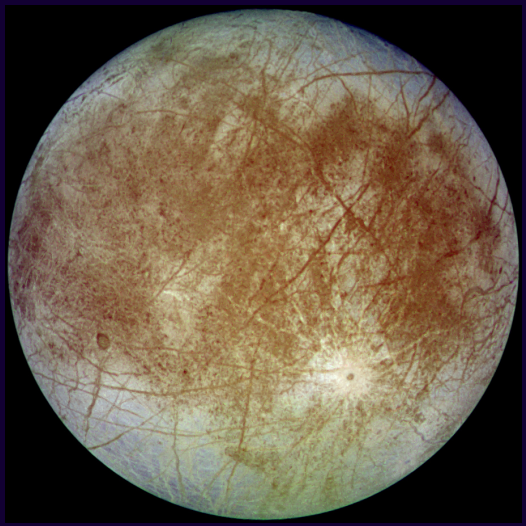
- Above 200F
- Below 0F
- In acid as strong as lemon juice
- Inside the reactors at Chernobyl (!)
- Below the deepest oceans
- On the slopes of Everest

Exobiology: the search for water

Life on Earth needs liquid water; it allows molecules to float around and find each other

Liquid water in the Solar System:

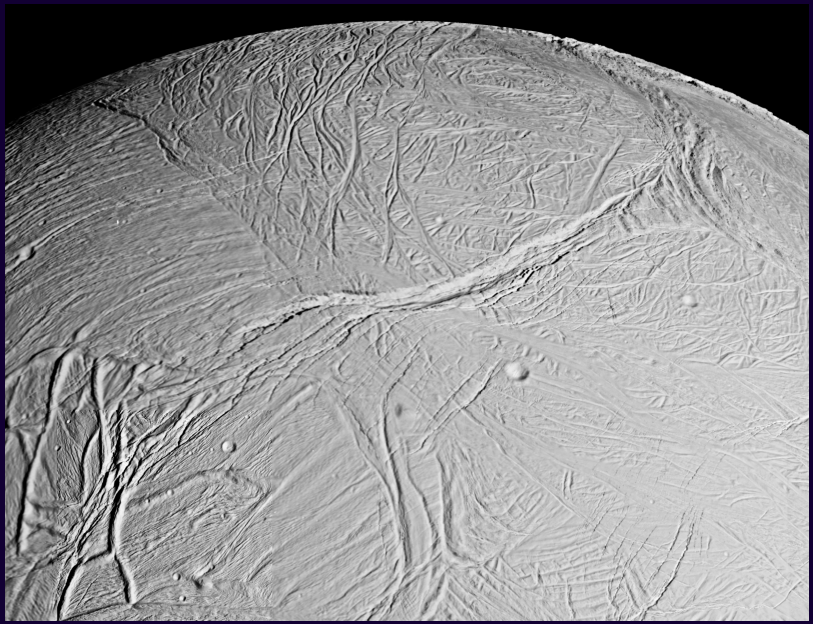
- Need temperatures from 0-c. 100 C
- Earth is perfect (we knew that)
- Young Mars?
- The moons of Jupiter and Saturn...



Europa, from the Galileo *craft (1996)*

Enceladus

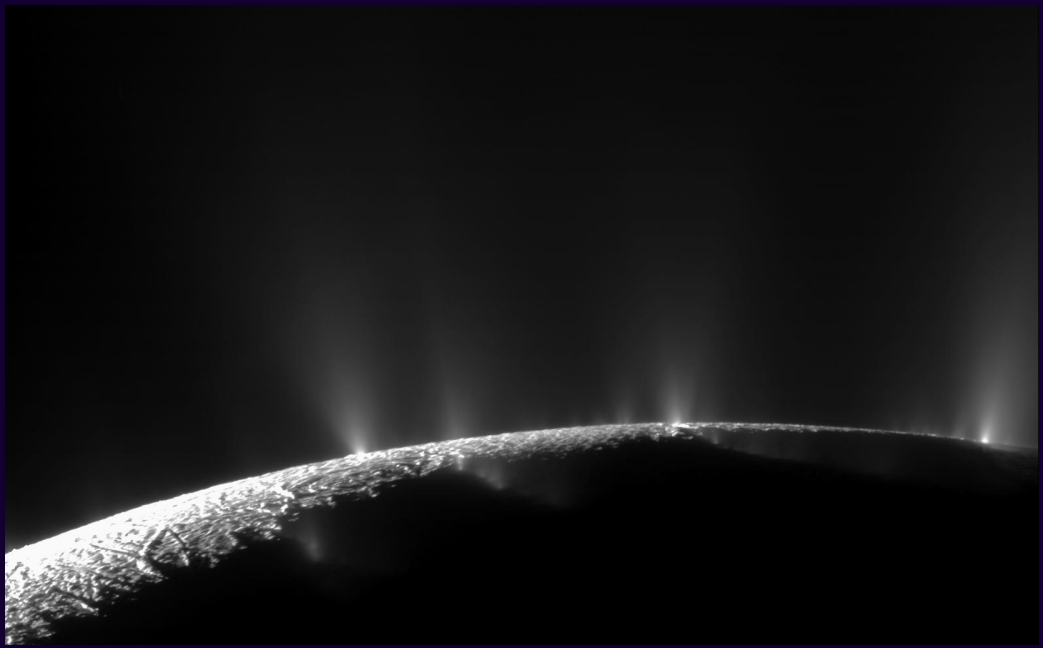
There are saltwater oceans under the ice – and plumes of gas coming out of it!



(From Cassini, *2005)*

Enceladus

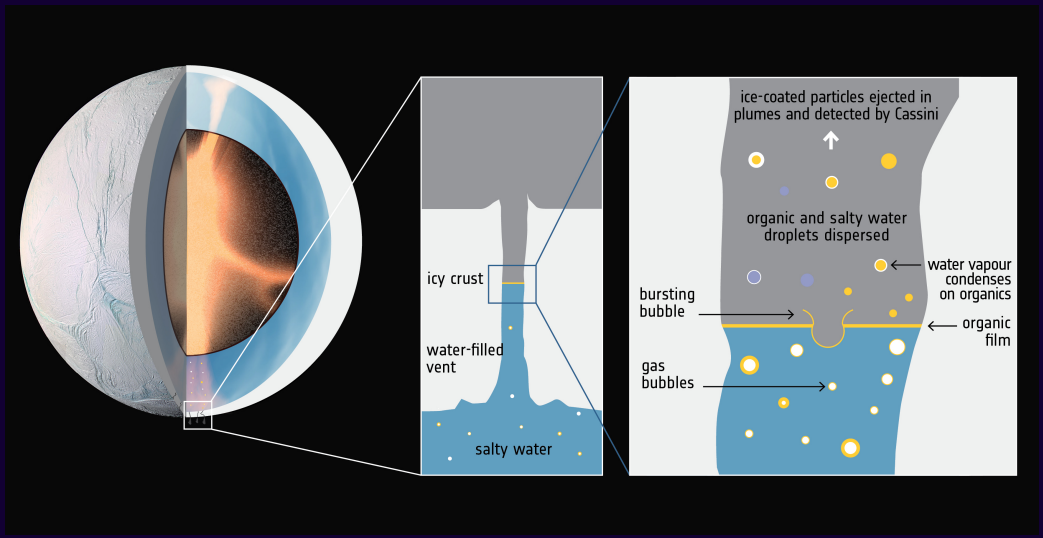
What's in them?



(From Cassini*, 2009)*

Enceladus

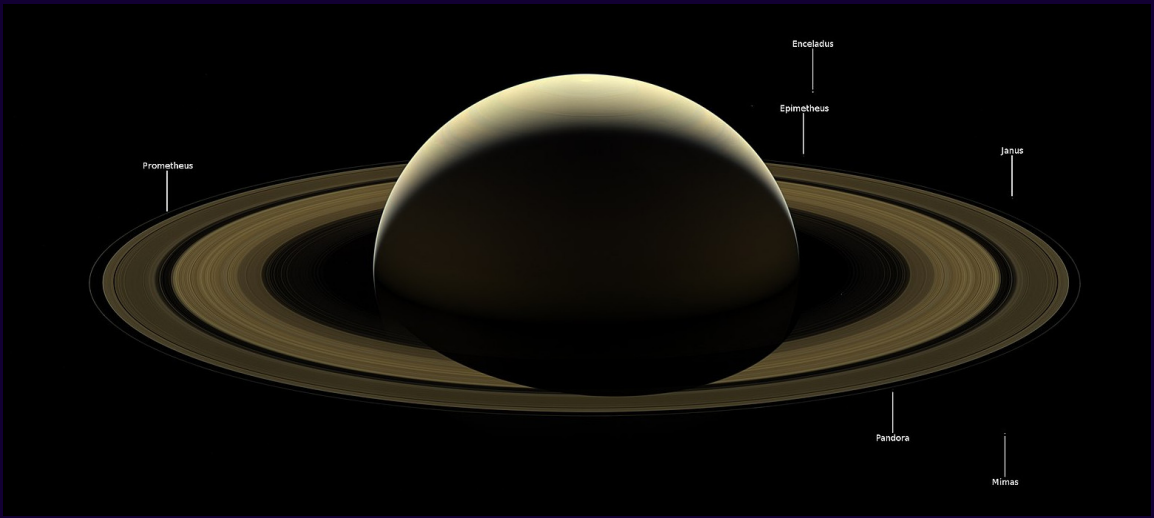
June, 2018: large organic molecules in these plumes!



F. Postberg et al / the European Space Agency

Saturn from Cassini

Saturn has always been an emblem of the fascination of space...



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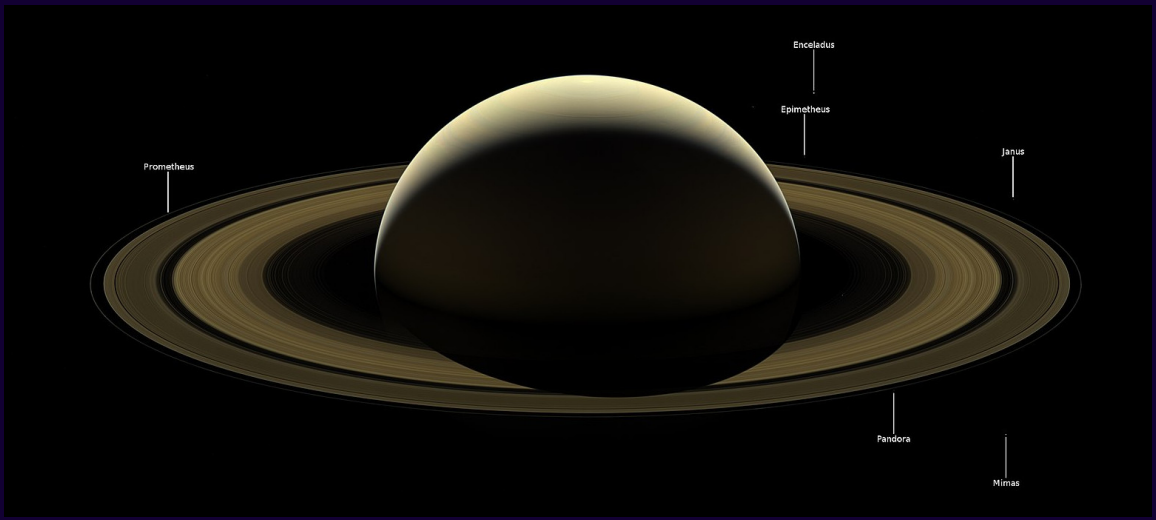


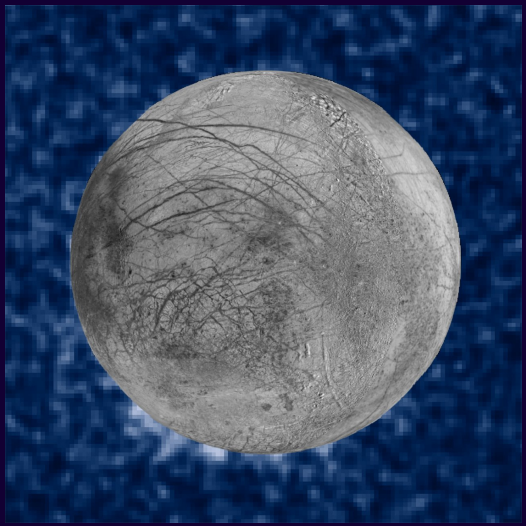
... but now that we know more ...

Exobiology: the search for water

Life on Earth needs liquid water; it allows molecules to float around and find each other

Liquid water in the Solar System:

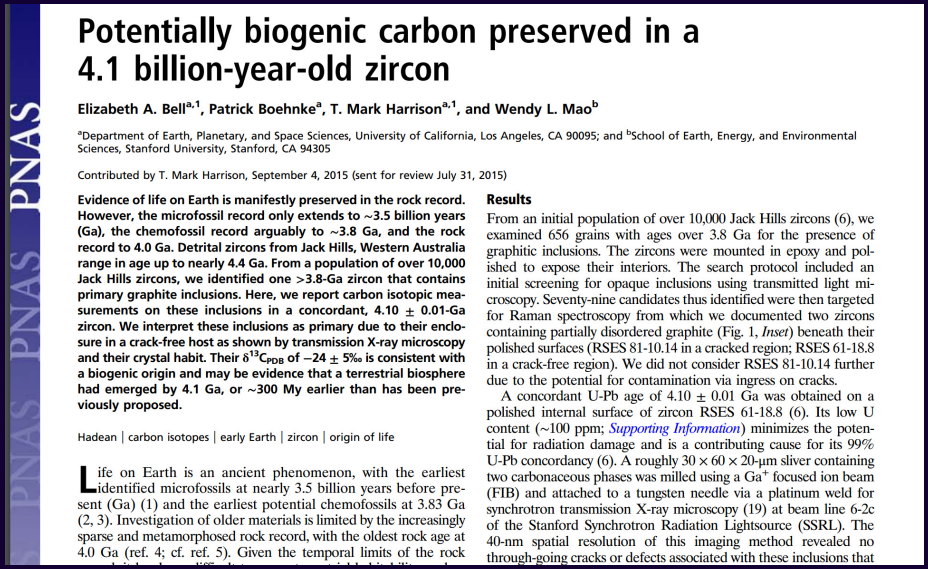
- Need temperatures from 0-c. 100 C
- Earth is perfect (we knew that)
- Young Mars?
- The moons of Jupiter and Saturn...
- Most exciting near-term astrobiology experiment: send a probe to explore the oceans on one of these moons!



Galileo/Voyager/Hubble: ESA (2014)

Exobiology: encouraging signs from Earth

Life evolved on Earth very, very early in its history...



PNAS PNAS PNAS

Potentially biogenic carbon preserved in a 4.1 billion-year-old zircon

Elizabeth A. Bell[a,1], Patrick Boehnke[a], T. Mark Harrison[a,1], and Wendy L. Mao[b]

[a]Department of Earth, Planetary, and Space Sciences, University of California, Los Angeles, CA 90095; and [b]School of Earth, Energy, and Environmental Sciences, Stanford University, Stanford, CA 94305

Contributed by T. Mark Harrison, September 4, 2015 (sent for review July 31, 2015)

Evidence of life on Earth is manifestly preserved in the rock record. However, the microfossil record only extends to ∼3.5 billion years (Ga), the chemofossil record arguably to ∼3.8 Ga, and the rock record to 4.0 Ga. Detrital zircons from Jack Hills, Western Australia range in age up to nearly 4.4 Ga. From a population of over 10,000 Jack Hills zircons, we identified one >3.8-Ga zircon that contains primary graphite inclusions. Here, we report carbon isotopic measurements on these inclusions in a concordant, 4.10 ± 0.01-Ga zircon. We interpret these inclusions as primary due to their enclosure in a crack-free host as shown by transmission X-ray microscopy and their crystal habit. Their $\delta^{13}C_{PDB}$ of −24 ± 5‰ is consistent with a biogenic origin and may be evidence that a terrestrial biosphere had emerged by 4.1 Ga, or ∼300 My earlier than has been previously proposed.

Hadean | carbon isotopes | early Earth | zircon | origin of life

Life on Earth is an ancient phenomenon, with the earliest identified microfossils at nearly 3.5 billion years before present (Ga) (1) and the earliest potential chemofossils at 3.83 Ga (2, 3). Investigation of older materials is limited by the increasingly sparse and metamorphosed rock record, with the oldest rock age at 4.0 Ga (ref. 4; cf. ref. 5). Given the temporal limits of the rock

Results

From an initial population of over 10,000 Jack Hills zircons (6), we examined 656 grains with ages over 3.8 Ga for the presence of graphitic inclusions. The zircons were mounted in epoxy and polished to expose their interiors. The search protocol included an initial screening for opaque inclusions using transmitted light microscopy. Seventy-nine candidates thus identified were then targeted for Raman spectroscopy from which we documented two zircons containing partially disordered graphite (Fig. 1, *Inset*) beneath their polished surfaces (RSES 81-10.14 in a cracked region; RSES 61-18.8 in a crack-free region). We did not consider RSES 81-10.14 further due to the potential for contamination via ingress on cracks.

A concordant U-Pb age of 4.10 ± 0.01 Ga was obtained on a polished internal surface of zircon RSES 61-18.8 (6). Its low U content (∼100 ppm; *Supporting Information*) minimizes the potential for radiation damage and is a contributing cause for its 99% U-Pb concordancy (6). A roughly 30 × 60 × 20-μm sliver containing two carbonaceous phases was milled using a Ga^+ focused ion beam (FIB) and attached to a tungsten needle via a platinum weld for synchrotron transmission X-ray microscopy (19) at beam line 6-2c of the Stanford Synchrotron Radiation Lightsource (SSRL). The 40-nm spatial resolution of this imaging method revealed no through-going cracks or defects associated with these inclusions that

... this suggests that wherever life *can* develop, it will!

Extraterrestrial civilizations: different, but alike

Intelligent life elsewhere has the same resources we do – the same chemical elements and the same physics.

Any intelligent beings in the Universe will come to many of same conclusions we have about Nature.

We'd probably see them in the same way we see everything else: light (radio signals).

Extraterrestrial civilizations: the Fermi paradox

"It's likely they're out there, and that they're older than us. Then where are they?"

Lots of answers, all of them speculative, some of them depressing...

- Civilizations tend not to last very long...
- Civilizations are actually pretty rare
- They're there, but aren't very advanced: humans are uniquely intelligent
- They're there, but are *very* advanced and can hide from us
- Nobody thinks we're worth talking to
- ...

Human travel to Mars and beyond

The problem with human travel: humans are fragile. Humans require life-support baggage and want to come home; robots don't.

Going to Mars is just within the reach of current technology (it's an economics problem, not a science one)

- Mission of several years (there and back)
- Providing for food, life support, and radiation shielding would be an engineering challenge, but we can do that
- Would need rockets larger than Saturn V, but not impossibly so
- Several clever ways to use robotics to reduce the size of the rockets needed (Mars Direct)

Going beyond would likely require substantial improvements in rockets.

Project 5: A small improvement in exhaust velocity gives an exponential increase in how fast a rocket can make you go (and where you can go with it)

Robots to the stars (that survive the trip)

Voyagers 1 and 2 are headed for the stars, but won't make it near any for tens of thousands of years.

→ Can we send a probe to the stars, like *Viking* or *Spirit*?

The problem here is *time*. We could send a probe to Alpha Centauri now – 4.3 ly (270,000 AU away). Should we?

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Two options:

- A slow probe and patience: centuries or millennia
- Higher exhaust-velocity rockets

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- Higher exhaust-velocity rockets
- This would still take 100-1000 years at best – even with nuclear pulse propulsion!
- **The round-trip communication time would be eight years!** (and we can't change that)

Improving rockets

Lots of ideas here – some speculative, some tested (ask if you're curious!):

- Scramjets
  - Harvest oxygen from Earth's atmosphere during initial escape-from-Earth rocket burn; it's much heavier than the hydrogen that goes with it
  - Precursor idea already used for Eurofighter's air-to-air missiles (*Meteor*)
- Nuclear-thermal rockets
  - A nuclear reactor can heat propellant to a higher temperature than its own chemical energy
- Nuclear pulse propulsion (Project 5's example)
  - Set off nuclear explosives behind a durable plate at the rear of a spacecraft
  - Only usable for large craft, and not near Earth for obvious reasons!
- Ion engines
  - Low thrust per weight, but high exhaust velocity
  - Can't use to escape from Earth, but maybe on a space probe?
- Solar sails
  - Sail on the solar wind, or on a laser from Earth or Earth orbit?

Improving humans and changing our outlook

With only a little improvement in rockets, we can conquer space.

Science-fiction authors dream of "faster-than-light travel", but this is likely not possible.

If we take to the stars, humans will be possibly be born, grow, live, love, and die in space. If we stay there long, we will no doubt evolve to match our new surroundings...

There are ways to cheat: cryogenics, freezing embryos and trusting robots to teach babies how to be human...

Even then, a mission to Alpha Centauri will outlive those that send it.

The greatest challenge in spacefaring won't be engineering, science, or even economics – it will be *philosophy*.

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We are a young civilization.

Imagine that the distance from San Francisco to Syracuse was the history of Earth: 4500 km to 4.5 billion years.

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- Modern humans evolved at the Hall of Languages (200 m)

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- Barack Obama was president half of the width of a pencil ago
- You started this class only the thickness of a fingernail ago

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We can conquer space; to become a spacefaring civilization, we will likely need to conquer time as well.

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"I want to build a clock that ticks once a year. The century hand advances once every one hundred years, and the cuckoo comes out on the millennium. I want the cuckoo to come out every millennium for the next 10,000 years. If I hurry I should finish the clock in time to see the cuckoo come out for the first time."

–Danny Hillis, of the Long Now Foundation, 01995

“The existential crisis”

The universe is large and old, and we are small and young.

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A hundred years ago, this inspired an entirely new genre of cosmic horror:

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“The oldest and strongest emotion of mankind is fear, and the oldest and strongest kind of fear is fear of the unknown.”

-H. P. Lovecraft, 1927

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-H. P. Lovecraft, 1927

"We live on a placid island of ignorance in the midst of black seas of infinity, and it was not meant that we should voyage far. The sciences, each straining in its own direction, have hitherto harmed us little; but some day the piecing together of dissociated knowledge will open up such terrifying vistas of reality, and of our frightful position therein, that we shall either go mad from the revelation or flee from the deadly light into the peace and safety of a new dark age."

-H. P. Lovecraft, 1926, from *The Call of Cthulhu*

Do you agree with Lovecraft? How have views changed since then?

We end where we begun: humility and empowerment

“Consider again that dot. That’s here. That’s home. That’s us. On it everyone you love, everyone you know, everyone you ever heard of, every human being who ever was, lived out their lives. The aggregate of our joy and suffering, thousands of confident religions, ideologies, and economic doctrines, every hunter and forager, every hero and coward, every creator and destroyer of civilization, every king and peasant, every young couple in love, every mother and father, hopeful child, inventor and explorer, every teacher of morals, every corrupt politician, every "superstar", every "supreme leader", every saint and sinner in the history of our species lived there – on a mote of dust suspended in a sunbeam.

The Earth is a very small stage in a vast cosmic arena. Think of the rivers of blood spilled by all those generals and emperors so that, in glory and triumph, they could become the momentary masters of a fraction of a dot. Think of the endless cruelties visited by the inhabitants of one corner of this pixel on the scarcely distinguishable inhabitants of some other corner, how frequent their misunderstandings, how eager they are to kill one another, how fervent their hatreds.

We end where we begun: humility and empowerment

Our posturings, our imagined self-importance, the delusion that we have some privileged position in the Universe, are challenged by this point of pale light. Our planet is a lonely speck in the great enveloping cosmic dark....

The Earth is the only world known so far to harbor life. There is nowhere else, at least in the near future, to which our species could migrate. Visit, yes. Settle, not yet. Like it or not, for the moment the Earth is where we make our stand.

It has been said that astronomy is a humbling and character-building experience. There is perhaps no better demonstration of the folly of human conceits than this distant image of our tiny world. To me, it underscores our responsibility to deal more kindly with one another, and to preserve and cherish the pale blue dot, the only home we've ever known."

–Carl Sagan, *Pale Blue Dot (1994)*

We end where we begun: humility and empowerment

But...

We can look at all of this, here from our little mote of dust...

... we can understand how it works – we, our little carbon-and-water brains, can comprehend the steps in the dance that the Universe is dancing.

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... and it's the same everywhere. We – our star, our planet, and our bodies – are part of it, and we can fathom how it works.

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... and it's the same everywhere. We – our star, our planet, and our bodies – are part of it, and we can fathom how it works.

So, if our bodies and our planet are very small – think what our minds can accomplish!

Course evaluations

You have gotten an email regarding course evaluations for the University.

We take this feedback seriously; we are trying new things to bring you this class in a radical new format, and want to improve what we do for the Spring.

Thank you for your patience as I've tried different things, seen what you all like, and what you don't.

Please tell me and my supervisors what you think of this course!

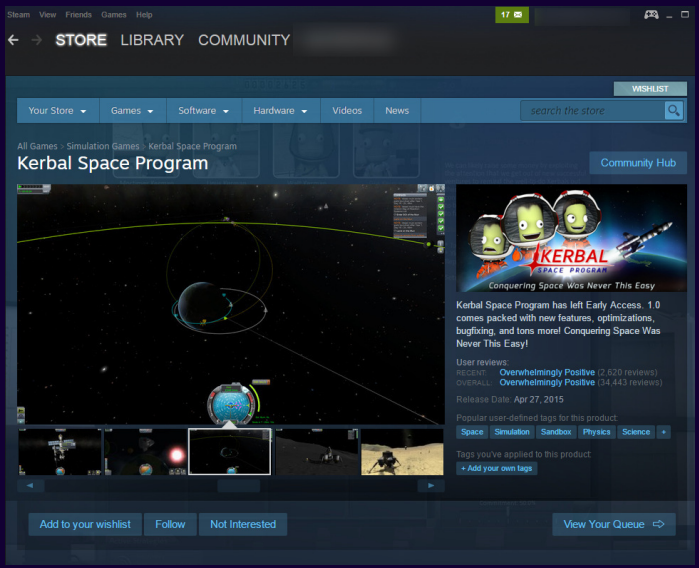
Three last things (1/3): the challenge from Day 1

"With more knowledge comes deeper, more wonderful mystery... with pleasure and confidence we turn over each new stone to find unimagined strangeness leading on to more wonderful questions and mysteries–certainly a grand adventure!

Our poets do not write about [this]; our artists do not try to portray [it]. I don't know why. **Is nobody inspired by our present picture of the universe?** [Science] remains unsung by singers, so you are reduced to hearing not a song or poem, but an evening lecture about it. Is no one inspired by our present picture of the universe? **This is not yet a scientific age.**"

–Richard Feynman, from *The Value of Science* (1955)

A scientific age? You bet.



... you can buy a very physically accurate simulation of spaceflight and rocketry on Steam!

Going beyond (2/3)

This has been a pretty broad survey of astronomy – and much of physics!

What comes next, if you want more of this sort of thing?

Going beyond (2/3): Astronomy 104

Our class covered astronomy inside the Solar System.

AST104 covers the rest of the Universe:

- The life and death of stars
- Galaxies
- Neutron stars
- Black holes
- Gravitational waves (in more depth)
- The origin and fate of the Universe

... the really awesome stuff!

It'll be taught next semester by Prof. Denver Whittington, who is an entertaining teacher and a great fellow. (Ask him about the time we melted a credit card trying to work on the telescope in Holden!)

Going beyond (2/3): ... and more

We have an (astro)physics major/minor!

Courses in...

- Astrophysics and the lives of stars
- The things stars leave behind when they die, like black holes and neutron stars
- Relativity and cosmology – where the universe came from and where it is going
- Waves, vibrations, and optics – a musician's paradise!
- Quantum mechanics
- Computer modeling and simulation
- The physics of heat
- Teaching physics
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A degree in physics is a highly-valued thing in industry – you can study the stars and the natural world, and then have a great shot at a good job.

If you're interested in pursuing this, come speak to me!

Inspiration (3/3)

When I was asked to teach this class, Patty Whitmore (then academic coordinator) told me: "These folks aren't here to learn mathematics. They're not here to learn only the laws of physics; they're here to learn what science is about."

In this class I've aimed to both teach you a little astronomy, and how to think scientifically ... but, also, to connect astronomy to the broader story of human thought.

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In this class I've aimed to both teach you a little astronomy, and how to think scientifically ... but, also, to connect astronomy to the broader story of human thought.

In the end, we look at the sky because it's beautiful – and because it's inspiring.

In 2018, I ended this class with a poem by James Agee about the beauty of the night sky, which was set to music by Morton Lauridsen.

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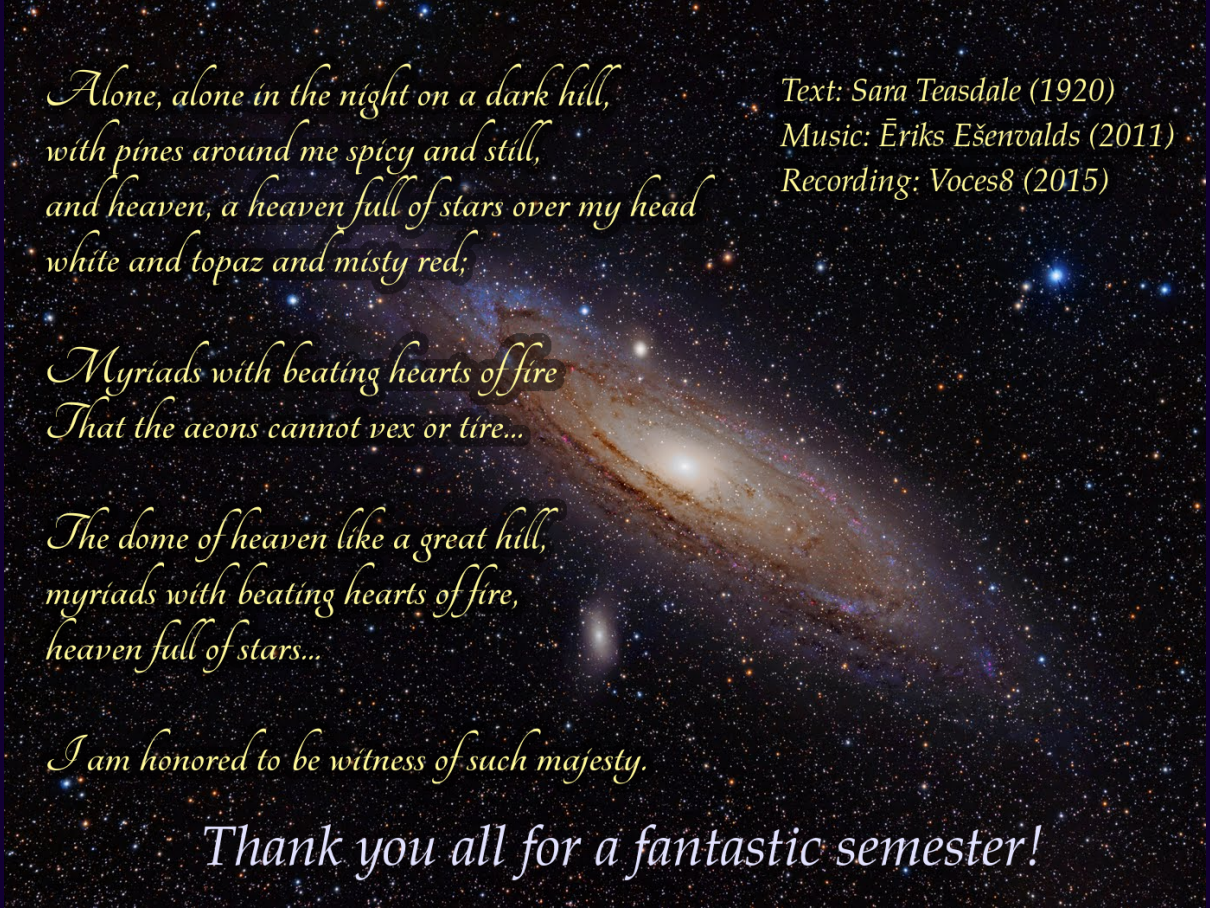
Thank you, Annie. `<3`



Alone, alone in the night on a dark hill,
with pines around me spicy and still,
and heaven, a heaven full of stars over my head
white and topaz and misty red;

Myriads with beating hearts of fire
That the aeons cannot vex or tire...

The dome of heaven like a great hill,
myriads with beating hearts of fire,
heaven full of stars...

I am honored to be witness of such majesty.

Text: Sara Teasdale (1920)
Music: Ēriks Ešenvalds (2011)
Recording: Voces8 (2015)

Thank you all for a fantastic semester!