Spaceflight since Apollo

Astronomy 101
Syracuse University, Fall 2022
Walter Freeman

December 6, 2022

Announcements: makeups/retakes

See email/Blackboard for announcements about lab makeups and quiz retakes.

Turn your homework (due today) in when you leave class today.

Please write your name and your TA's name at the top.

Announcements: final project submissions

You may submit your final projects:

- **At the final exam (Tuesday, December 13, 3pm-5pm)**

Announcements: final project submissions

You may submit your final projects:

- **At the final exam (Tuesday, December 13, 3pm-5pm)**
- To me in my office, on December 9 (morning)
- To me in Holden Observatory, on December 9 (afternoon, 2pm-4pm)
- By email to `suast101projects@gmail.com`

Announcements: final project submissions

You may submit your final projects:

- **At the final exam (Tuesday, December 13, 3pm-5pm)**
- To me in my office, on December 9 (morning)
- To me in Holden Observatory, on December 9 (afternoon, 2pm-4pm)
- By email to `suast101projects@gmail.com`

We want to accommodate your creativity. If you have something unusual in mind, let us know and we will work with you.

Announcements: final project submissions

You may submit your final projects:

- **At the final exam (Tuesday, December 13, 3pm-5pm)**
- To me in my office, on December 9 (morning)
- To me in Holden Observatory, on December 9 (afternoon, 2pm-4pm)
- By email to `suast101projects@gmail.com`

We want to accommodate your creativity. If you have something unusual in mind, let us know and we will work with you.

If you are doing something ambitious and realize you need more time, please ask!

Announcements: final project submissions

You may submit your final projects:

- **At the final exam (Tuesday, December 13, 3pm-5pm)**
- To me in my office, on December 9 (morning)
- To me in Holden Observatory, on December 9 (afternoon, 2pm-4pm)
- By email to `suast101projects@gmail.com`

We want to accommodate your creativity. If you have something unusual in mind, let us know and we will work with you.

If you are doing something ambitious and realize you need more time, please ask!

Please send files as attachments. If you must send links to cloud storage sites, make sure the permissions are set to "anyone with the link".

Announcements: final project submissions

You may submit your final projects:

- **At the final exam (Tuesday, December 13, 3pm-5pm)**
- To me in my office, on December 9 (morning)
- To me in Holden Observatory, on December 9 (afternoon, 2pm-4pm)
- By email to `suast101projects@gmail.com`

We want to accommodate your creativity. If you have something unusual in mind, let us know and we will work with you.

If you are doing something ambitious and realize you need more time, please ask!

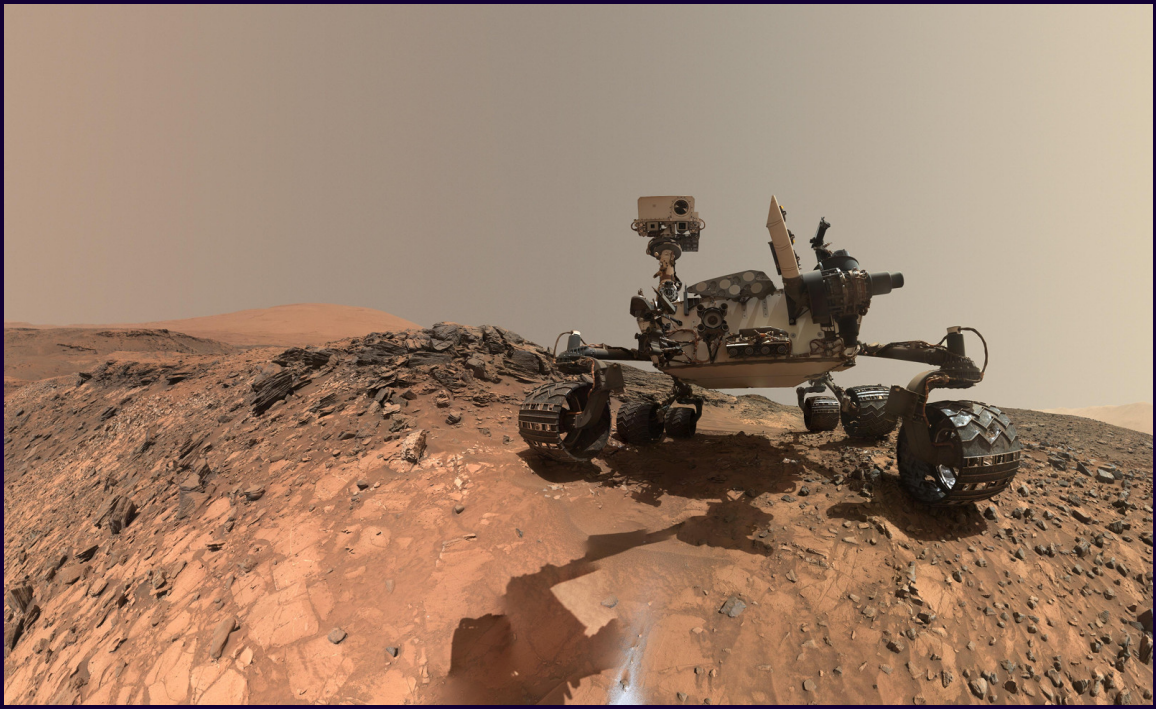
Please send files as attachments. If you must send links to cloud storage sites, make sure the permissions are set to "anyone with the link".

Remember that creative projects should include a brief artist's statement linking your creative work to the stuff of astronomy or science.

Spaceflight since Apollo

Astronomy 101
Syracuse University, Fall 2022
Walter Freeman

December 6, 2022



Selfie by the Curiosity *rover, on the Martian surface*

Announcements: final projects

- I've heard a lot of fantastic ideas for final projects already (and seen a few completed ones)
- Remember, your projects are due on the day of the final
  - We'll have a box there for you to submit things
  - If your project is something best submitted electronically, email it to suast101projects@gmail.com
  - If your project is something complicated (artwork, etc.), come talk to me; we'll make arrangements
  - If you take your exams at CDR, get your project to me before/after (I'll be around, and will be in the Physics Clinic after the exam)

Announcements: final project submissions

You may submit your final projects:

- **At the final exam (Tuesday, December 14, 3pm-5pm)**

Announcements: final project submissions

You may submit your final projects:

- **At the final exam (Tuesday, December 14, 3pm-5pm)**
- To the TA's at Holden Observatory on Friday morning, December 10, from 9:30am-2pm
- To a box in front of my office, Physics Building 215, on December 10
- To your TA's mailbox (for papers and things that will fit)
- By email to `suast101projects@gmail.com`

Announcements: final project submissions

You may submit your final projects:

- **At the final exam (Tuesday, December 14, 3pm-5pm)**
- To the TA's at Holden Observatory on Friday morning, December 10, from 9:30am-2pm
- To a box in front of my office, Physics Building 215, on December 10
- To your TA's mailbox (for papers and things that will fit)
- By email to `suast101projects@gmail.com`

We want to accommodate your creativity. If you have something unusual in mind, let us know and we will work with you.

Announcements: final project submissions

You may submit your final projects:

- **At the final exam (Tuesday, December 14, 3pm-5pm)**
- To the TA's at Holden Observatory on Friday morning, December 10, from 9:30am-2pm
- To a box in front of my office, Physics Building 215, on December 10
- To your TA's mailbox (for papers and things that will fit)
- By email to `suast101projects@gmail.com`

We want to accommodate your creativity. If you have something unusual in mind, let us know and we will work with you.

Doing something creative and awesome and running out of time? Contact me for an extension; we will grant these for ambitious and creative projects depending on what you're doing and what you need.

Announcements: take-home lab

The take-home lab is due this Friday, 9 December.

I accidentally wrote "10 December" in one place, which is of course a Saturday. So, if you turn it in Monday morning, that's okay too. Put it in your TA's mailbox in the Physics Building.

If you didn't do it, it is far too late to do it now. It requires actual measurements of the real Sun or Moon; you cannot do it with simulated or borrowed data.

Announcements: take-home lab

The take-home lab is due this Friday, 9 December.

I accidentally wrote "10 December" in one place, which is of course a Saturday. So, if you turn it in Monday morning, that's okay too. Put it in your TA's mailbox in the Physics Building.

If you didn't do it, it is far too late to do it now. It requires actual measurements of the real Sun or Moon; you cannot do it with simulated or borrowed data.

If you didn't do it, we will make a correction so that missing it doesn't affect your grade too badly.

Preparing for the final exam

- The final exam is next Tuesday, 3PM - 5PM, 13 December
- Section 1 (12:30): Stolkin Auditorium (here)
- Section 2 (2:00): (not here)
- Bring your final projects to the final to submit them

Preparing for the final exam: review sessions

- I'll be holding usual office hours tomorrow and extra help Friday in Holden or the Physics Clinic (12-4 pm).
- The best things to study and how to use them:
  - Previous exercises and homework

Preparing for the final exam: review sessions

- I'll be holding usual office hours tomorrow and extra help Friday in Holden or the Physics Clinic (12-4 pm).
- The best things to study and how to use them:
  - Previous exercises and homework – as the tutorials where you gained your skills

Preparing for the final exam: review sessions

- I'll be holding usual office hours tomorrow and extra help Friday in Holden or the Physics Clinic (12-4 pm).
- The best things to study and how to use them:
  - Previous exercises and homework – as the tutorials where you gained your skills
  - Previous exams

Preparing for the final exam: review sessions

- I'll be holding usual office hours tomorrow and extra help Friday in Holden or the Physics Clinic (12-4 pm).
- The best things to study and how to use them:
  - Previous exercises and homework – as the tutorials where you gained your skills
  - Previous exams – as the sorts of ways we evaluated you on these things

Preparing for the final exam: review sessions

- I'll be holding usual office hours tomorrow and extra help Friday in Holden or the Physics Clinic (12-4 pm).
- The best things to study and how to use them:
  - Previous exercises and homework – as the tutorials where you gained your skills
  - Previous exams – as the sorts of ways we evaluated you on these things
  - The study guides

Preparing for the final exam: review sessions

- I'll be holding usual office hours tomorrow and extra help Friday in Holden or the Physics Clinic (12-4 pm).
- The best things to study and how to use them:
  - Previous exercises and homework – as the tutorials where you gained your skills
  - Previous exams – as the sorts of ways we evaluated you on these things
  - The study guides – as a narration of all the course content in one place

Preparing for the final exam: review sessions

- I'll be holding usual office hours tomorrow and extra help Friday in Holden or the Physics Clinic (12-4 pm).
- The best things to study and how to use them:
  - Previous exercises and homework – as the tutorials where you gained your skills
  - Previous exams – as the sorts of ways we evaluated you on these things
  - The study guides – as a narration of all the course content in one place
  - Your labs

Preparing for the final exam: review sessions

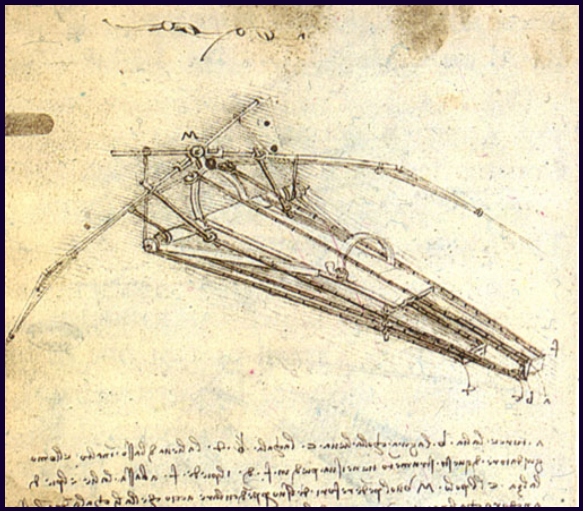
- I'll be holding usual office hours tomorrow and extra help Friday in Holden or the Physics Clinic (12-4 pm).
- The best things to study and how to use them:
  - Previous exercises and homework – as the tutorials where you gained your skills
  - Previous exams – as the sorts of ways we evaluated you on these things
  - The study guides – as a narration of all the course content in one place
  - Your labs – the high points from them will also be on the final, but *there will not be detailed math*
- Next Monday: I'll be in the Physics Clinic as often as I can; so will Clinic TA's
  - I'll send out a note Monday morning/Sunday night with the expected schedule
- Next Tuesday: will be in and out of the Physics Clinic from 10AM until your exam starts

300 BCE: The dream of flight

The ancients; flight as hubris...

1450 CE: The dream of flight

Humanism and the Renaissance: flight as a dream...

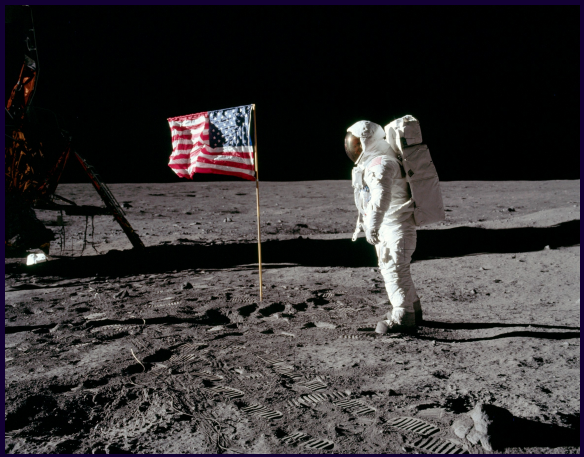


1850-1900: The reality of flight

The Industrial Revolution: fly like the birds, dream of the Moon

1960's: to the Moon!

The space age: one small step for Armstrong...



Today: what next?

- What did we do on the Moon?
- What else have humans done in space?

Today: what next?

- What did we do on the Moon?
- What else have humans done in space?
- Getting to the planets
- Getting us to the planets
- Getting to the stars

Today: what next?

- What did we do on the Moon?
- What else have humans done in space?
- Getting to the planets
- Getting us to the planets
- Getting to the stars

The most important topic today, though, is your questions.

Spaceflight is inspiring; what would you like to talk about?

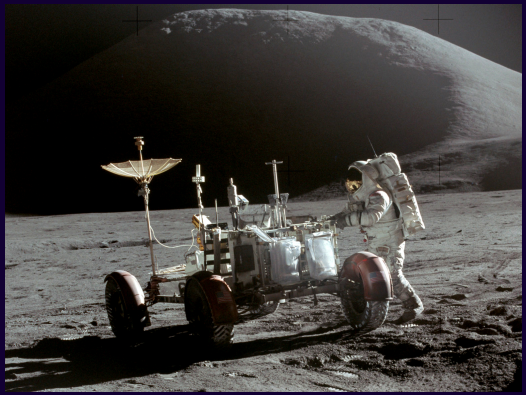
Apollo 11: the Moon, at last!

On 20 July, 1969, humanity walked on another world for the first time.

- Neil Armstrong and Buzz Aldrin descended to the lunar surface
- Michael Collins stayed in lunar orbit in the Command Module
- They stayed on the Moon for nearly a day, walking on the surface for two and a half hours
- They brought back around fifty pounds of moon-rocks
- Gallery of images:
  `http://www.hq.nasa.gov/alsj/a11/a11_eva_thumbs.html`

The remainder of Apollo

- The USA launched seven more *Apollo* missions to the Moon.
- Six of them made it; one, *Apollo 13*, suffered from an explosion en route.
  - Its story was made into a wonderful film of the same name
- 800+ pounds of moon rocks returned to Earth
- Dozens of hours spent on the lunar surface



Apollo 13

- Oxygen is nasty stuff...
  https://youtu.be/C3J1AO9z0tA?t=10

Apollo 13

- Oxygen is nasty stuff...
  `https://youtu.be/C3J1AO9zOtA?t=10`
  - If you've not watched the film, you really should.

Apollo 13

- Oxygen is nasty stuff...
  `https://youtu.be/C3J1AO9zOtA?t=10`
  - If you've not watched the film, you really should.
- The explosion happened while moving away from Earth
- They had to survive long enough to use the Moon's gravity to turn around
- Only cleverness and improvisation got the astronauts home
- `https://www.youtube.com/watch?v=1cYzkyXp0jg`

Apollo 13

- Oxygen is nasty stuff...
  `https://youtu.be/C3J1AO9z0tA?t=10`
  - If you've not watched the film, you really should.
- The explosion happened while moving away from Earth
- They had to survive long enough to use the Moon's gravity to turn around
- Only cleverness and improvisation got the astronauts home
- `https://www.youtube.com/watch?v=1cYzkyXp0jg`
- Humans aren't a successful species because we're good at what we're prepared for
- ... human intelligence lets us survive things we're *not* prepared for


HERE MEN FROM THE PLANET EARTH
FIRST SET FOOT UPON THE MOON
JULY 1969, A. D.
WE CAME IN PEACE FOR ALL MANKIND
NEIL A. ARMSTRONG
ASTRONAUT
MICHAEL COLLINS
ASTRONAUT
EDWIN E. ALDRIN, JR.
ASTRONAUT
RICHARD NIXON
PRESIDENT, UNITED STATES OF AMERICA


HERE MAN COMPLETED HIS FIRST
EXPLORATIONS OF THE MOON
DECEMBER 1972, A.D.
MAY THE SPIRIT OF PEACE IN WHICH WE CAME
BE REFLECTED IN THE LIVES OF ALL MANKIND
EUGENE A. CERNAN
ASTRONAUT
RONALD E EVANS
ASTRONAUT
HARRISON H. SCHMITT
ASTRONAUT
RICHARD NIXON
PRESIDENT, UNITED STATES OF AMERICA

Not just the Moon

Kennedy called for the USA to go to the Moon in 1961. The last Apollo mission to the Moon was in 1972.

Meanwhile...

- 1961: Soviets launch first Venera mission to Venus (it broke before arriving)
- 1962: TV satellite (USA); spy satellite (USSR)
- 1962: Americans launch Mariner 2, which flies by Venus (Mariner 1 failed)
- 1965: France launches a satellite
- 1965: Mariner 5 makes close pass by Mars

Not just the Moon

Kennedy called for the USA to go to the Moon in 1961. The last Apollo mission to the Moon was in 1972.

Meanwhile...

- 1961: Soviets launch first Venera mission to Venus (it broke before arriving)
- 1962: TV satellite (USA); spy satellite (USSR)
- 1962: Americans launch Mariner 2, which flies by Venus (Mariner 1 failed)
- 1965: France launches a satellite
- 1965: Mariner 5 makes close pass by Mars
- late 1960's: US sends Pioneer craft in solar orbit (some survived for 30+ years)
- 1970: Japan and China launch satellites

Not just the Moon

Kennedy called for the USA to go to the Moon in 1961. The last Apollo mission to the Moon was in 1972.

Meanwhile...

- 1961: Soviets launch first Venera mission to Venus (it broke before arriving)
- 1962: TV satellite (USA); spy satellite (USSR)
- 1962: Americans launch Mariner 2, which flies by Venus (Mariner 1 failed)
- 1965: France launches a satellite
- 1965: Mariner 5 makes close pass by Mars
- late 1960's: US sends Pioneer craft in solar orbit (some survived for 30+ years)
- 1970: Japan and China launch satellites
- 2019: 9000 satellites launched, 5000 still up there, 2000 still working

Not just the Moon

Kennedy called for the USA to go to the Moon in 1961. The last Apollo mission to the Moon was in 1972.

Meanwhile...

- 1961: Soviets launch first Venera mission to Venus (it broke before arriving)
- 1962: TV satellite (USA); spy satellite (USSR)
- 1962: Americans launch Mariner 2, which flies by Venus (Mariner 1 failed)
- 1965: France launches a satellite
- 1965: Mariner 5 makes close pass by Mars
- late 1960's: US sends Pioneer craft in solar orbit (some survived for 30+ years)
- 1970: Japan and China launch satellites
- 2019: 9000 satellites launched, 5000 still up there, 2000 still working
- ... we've gotten so good at this that "space pollution" is now an issue!

Not just the Moon

Kennedy called for the USA to go to the Moon in 1961. The last Apollo mission to the Moon was in 1972.

Meanwhile...

- 1961: Soviets launch first Venera mission to Venus (it broke before arriving)
- 1962: TV satellite (USA); spy satellite (USSR)
- 1962: Americans launch Mariner 2, which flies by Venus (Mariner 1 failed)
- 1965: France launches a satellite
- 1965: Mariner 5 makes close pass by Mars
- late 1960's: US sends Pioneer craft in solar orbit (some survived for 30+ years)
- 1970: Japan and China launch satellites
- 2019: 9000 satellites launched, 5000 still up there, 2000 still working
- ... we've gotten so good at this that "space pollution" is now an issue!
- Satellite constellations (like Starlink) new source of light pollution
- "Anti-satellite" weapons could set off a chain reaction making orbit very dangerous

Robotic missions and the planets

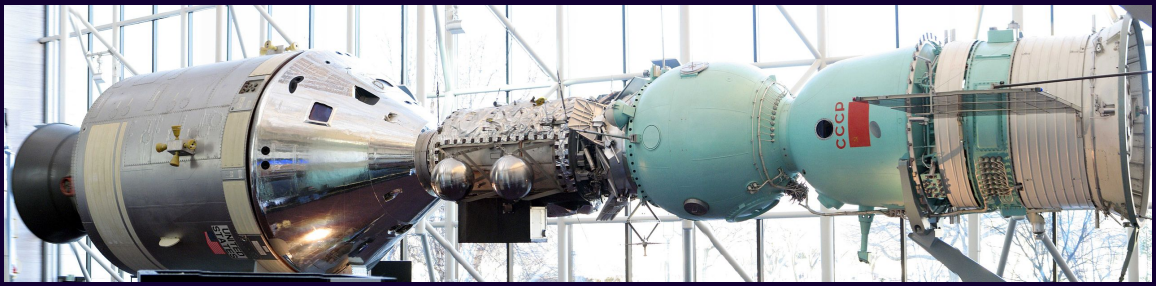
- 1971: Mariner 9 enters Martian orbit
- 1972: US launches Pioneer 10-11, which exited the Solar System
- 1973: USA launches Skylab, which didn't hit anyone on the way down (sorry, kangaroos)
- 1974: Mariner 10 waves to Mercury

Robotic missions and the planets

- 1971: Mariner 9 enters Martian orbit
- 1972: US launches Pioneer 10-11, which exited the Solar System
- 1973: USA launches Skylab, which didn't hit anyone on the way down (sorry, kangaroos)
- 1974: Mariner 10 waves to Mercury
- 1975: Docking between Soyuz-19 and Apollo 18

Robotic missions and the planets

- 1971: Mariner 9 enters Martian orbit
- 1972: US launches Pioneer 10-11, which exited the Solar System
- 1973: USA launches Skylab, which didn't hit anyone on the way down (sorry, kangaroos)
- 1974: Mariner 10 waves to Mercury
- 1975: Docking between Soyuz-19 and Apollo 18



Robotic missions and the planets

- 1976: Viking 1 (USA) lands on Mars
- 1977: Voyagers 1 and 2 launched, passing by outer planets and leaving the Solar System
- 1981: Space Shuttle program begins
- 1986: USSR launches Space Station Mir ("Peace" or "World"); it crashes in 2001
- ... and more

Voyager 1: a history

- 1977 (27): Launch (470 W power)

Voyager 1: a history

- 1977 (27): Launch (470 W power)
- 1979 (29): Jupiter observations

Voyager 1: a history

- 1977 (27): Launch (470 W power)
- 1979 (29): Jupiter observations
- 1980 (30): Saturn observations

Voyager 1: a history

- 1977 (27): Launch (470 W power)
- 1979 (29): Jupiter observations
- 1980 (30): Saturn observations
- 1990 (40): “Pale Blue Dot” portrait of Earth

Voyager 1: a history

- 1977 (27): Launch (470 W power)
- 1979 (29): Jupiter observations
- 1980 (30): Saturn observations
- 1990 (40): “Pale Blue Dot” portrait of Earth
- 1998 (48): Passes *Pioneer 10* at 69 AU; furthest Earth object

Voyager 1: a history

- 1977 (27): Launch (470 W power)
- 1979 (29): Jupiter observations
- 1980 (30): Saturn observations
- 1990 (40): “Pale Blue Dot” portrait of Earth
- 1998 (48): Passes *Pioneer 10* at 69 AU; furthest Earth object
- 2004 (54): 94 AU; enters termination shock (edge of “heliosheath”)
- 2012 (62): 121 AU; exits solar-wind bubble (“heliopause”)

Voyager 1: a history

- 1977 (27): Launch (470 W power)
- 1979 (29): Jupiter observations
- 1980 (30): Saturn observations
- 1990 (40): “Pale Blue Dot” portrait of Earth
- 1998 (48): Passes *Pioneer 10* at 69 AU; furthest Earth object
- 2004 (54): 94 AU; enters termination shock (edge of “heliosheath”)
- 2012 (62): 121 AU; exits solar-wind bubble (“heliopause”)
- 2017 (67): 141 AU; (19 light-hours) backup thrusters used for first time in 37 years; power down to 250 W

Voyager 1: a history

- 1977 (27): Launch (470 W power)
- 1979 (29): Jupiter observations
- 1980 (30): Saturn observations
- 1990 (40): “Pale Blue Dot” portrait of Earth
- 1998 (48): Passes *Pioneer 10* at 69 AU; furthest Earth object
- 2004 (54): 94 AU; enters termination shock (edge of “heliosheath”)
- 2012 (62): 121 AU; exits solar-wind bubble (“heliopause”)
- 2017 (67): 141 AU; (19 light-hours) backup thrusters used for first time in 37 years; power down to 250 W
- 2022 (72): 158 AU; 22 light-hours away

Voyager 1: a history

- 1977 (27): Launch (470 W power)
- 1979 (29): Jupiter observations
- 1980 (30): Saturn observations
- 1990 (40): “Pale Blue Dot” portrait of Earth
- 1998 (48): Passes *Pioneer 10* at 69 AU; furthest Earth object
- 2004 (54): 94 AU; enters termination shock (edge of “heliosheath”)
- 2012 (62): 121 AU; exits solar-wind bubble (“heliopause”)
- 2017 (67): 141 AU; (19 light-hours) backup thrusters used for first time in 37 years; power down to 250 W
- 2022 (72): 158 AU; 22 light-hours away
- 2025 (75): 166 AU; Not enough power to run scientific instruments; science mission ends

Voyager 1: a history

- 1977 (27): Launch (470 W power)
- 1979 (29): Jupiter observations
- 1980 (30): Saturn observations
- 1990 (40): “Pale Blue Dot” portrait of Earth
- 1998 (48): Passes *Pioneer 10* at 69 AU; furthest Earth object
- 2004 (54): 94 AU; enters termination shock (edge of “heliosheath”)
- 2012 (62): 121 AU; exits solar-wind bubble (“heliopause”)
- 2017 (67): 141 AU; (19 light-hours) backup thrusters used for first time in 37 years; power down to 250 W
- 2022 (72): 158 AU; 22 light-hours away
- 2025 (75): 166 AU; Not enough power to run scientific instruments; science mission ends
- Around 2035 (85): Power insufficient to communicate with Earth

Voyager 1: a history

- 1977 (27): Launch (470 W power)
- 1979 (29): Jupiter observations
- 1980 (30): Saturn observations
- 1990 (40): “Pale Blue Dot” portrait of Earth
- 1998 (48): Passes *Pioneer 10* at 69 AU; furthest Earth object
- 2004 (54): 94 AU; enters termination shock (edge of “heliosheath”)
- 2012 (62): 121 AU; exits solar-wind bubble (“heliopause”)
- 2017 (67): 141 AU; (19 light-hours) backup thrusters used for first time in 37 years; power down to 250 W
- 2022 (72): 158 AU; 22 light-hours away
- 2025 (75): 166 AU; Not enough power to run scientific instruments; science mission ends
- Around 2035 (85): Power insufficient to communicate with Earth

The Space Shuttle

- Designed as a “truck” to low-earth orbit
- Great for human development (and spy satellites); not exciting for spaceflight
- Many, many flights – most but not all successful
- `https://www.youtube.com/watch?v=AfnvFnzs91s`

The Space Shuttle

- Designed as a “truck” to low-earth orbit
- Great for human development (and spy satellites); not exciting for spaceflight
- Many, many flights – most but not all successful
- `https://www.youtube.com/watch?v=AfnvFnzs91s`
- `https://youtu.be/MWZs8l2AMps?t=8`
- Management science: big enterprises are *hard* when you must catch all mistakes

The Space Shuttle

- Designed as a “truck” to low-earth orbit
- Great for human development (and spy satellites); not exciting for spaceflight
- Many, many flights – most but not all successful
- `https://www.youtube.com/watch?v=AfnvFnzs91s`
- `https://youtu.be/MWZs8l2AMps?t=8`
- Management science: big enterprises are *hard* when you must catch all mistakes
- How can we go beyond LEO?

Why the Space Shuttle is not exciting

https://upload.wikimedia.org/wikipedia/commons/8/82/Orbitalaltitudes.jpg

Going beyond

- Good news: the hard part is just getting off of Earth; after that it's much easier
- `http://i.imgur.com/AAGJvD1.png`
- Can use planets' atmospheres as a brake to slow down once we get there (no need for another huge rocket burn)
- What about getting people to Mars?

Humans to Mars?

- We've got one-ton robots on Mars; why are humans so much harder?

Humans to Mars?

- We've got one-ton robots on Mars; why are humans so much harder?
- They're squishy
- They don't like radiation
- They want to come back (how much more Δv is that?)

Humans to Mars?

- We've got one-ton robots on Mars; why are humans so much harder?
- They're squishy
- They don't like radiation
- They want to come back (how much more Δv is that?)
- Possible solution: "Mars Direct"-type plans
  - Send a robotic mission ahead of time
  - The robotic mission prepares living space and sets up a nuclear reactor
  - The energy from that reactor makes rocket fuel for the return trip out of Mars' atmosphere

The bigger obstacle: cost

- Cost of Apollo program: $200B
- Cost of one Shuttle launch: $450M (or $1.4B)
- Cost of *Curiosity* rover mission: $2.5B
- Cost of crewed Mars mission: $500B - $1000B (?)

The bigger obstacle: cost

- Cost of Apollo program: $200B
- Cost of one Shuttle launch: $450M (or $1.4B)
- Cost of *Curiosity* rover mission: $2.5B
- Cost of crewed Mars mission: $500B - $1000B (?)
- Cost of US wars in Iraq: $2500B-$5000B
- Cost of Manhattan Project: $25B
- US military budget per year: $800B

The bigger obstacle: cost

- Cost of Apollo program: $200B
- Cost of one Shuttle launch: $450M (or $1.4B)
- Cost of *Curiosity* rover mission: $2.5B
- Cost of crewed Mars mission: $500B - $1000B (?)
- Cost of US wars in Iraq: $2500B-$5000B
- Cost of Manhattan Project: $25B
- US military budget per year: $800B
- Revenue lost from 2017 tax changes: $1000-1500B (Senate Joint Committee on Taxation / Office of Management and Budget)

The bigger obstacle: cost

- Cost of Apollo program: $200B
- Cost of one Shuttle launch: $450M (or $1.4B)
- Cost of *Curiosity* rover mission: $2.5B
- Cost of crewed Mars mission: $500B - $1000B (?)
- Cost of US wars in Iraq: $2500B-$5000B
- Cost of Manhattan Project: $25B
- US military budget per year: $800B
- Revenue lost from 2017 tax changes: $1000-1500B (Senate Joint Committee on Taxation / Office of Management and Budget)
- US spending on healthcare (public and private) per year: $4000B
- US spending on COVID response: $4400B
- US gross domestic product per year: $25,000B
- World GDP per year: $96,000B

There is a very real debate here about priorities!

Is it important for humans to go to Mars?

A: No; resources are limited and we have more important things to do on Earth

B: No; we can explore just as well with robotic probes for a fraction of the cost

C: Yes; science aside, sending humans to Mars advances the scope of human capability, in the same spirit as Kennedy's call for a moon mission

D: Yes; there are things that only humans can do, and the extra cost is worth it in what we'll learn

Is it important for humans to go to Mars?

A: No; resources are limited and we have more important things to do on Earth

B: No; we can explore just as well with robotic probes for a fraction of the cost

C: Yes; science aside, sending humans to Mars advances the scope of human capability, in the same spirit as Kennedy's call for a moon mission

D: Yes; there are things that only humans can do, and the extra cost is worth it in what we'll learn

E: Beam me up, Scotty; there's no intelligent life down here!

Tsiolkovsky: we just need better fuel!

Fuel exhaust speed	Fuel needed
1000 km/hr	300 million billion tons
2000 km/hr	5.5 million tons
3000 km/hr	680,000 tons
5000 km/hr	3100 tons
9000 km/hr (solid rockets)	87 tons
15400 km/hr (hydrogen/oxygen)	13 tons
104000 km/hr (ion thrusters)	470 kilograms

If we could just do better than hydrogen/oxygen rockets, we'd be in business...

Solutions to go beyond...

- Higher exhaust-velocity rockets: nuclear propulsion?
- Dealing with human lifespans

Solutions to go beyond...

- Higher exhaust-velocity rockets: nuclear propulsion?
- Dealing with human lifespans
- Sudden vs. gradual advancement – what's happened in a century?

Solutions to go beyond...

- Higher exhaust-velocity rockets: nuclear propulsion?
- Dealing with human lifespans
- Sudden vs. gradual advancement – what's happened in a century?
- More next time!

Solutions to go beyond...

- Higher exhaust-velocity rockets: nuclear propulsion?
- Dealing with human lifespans
- Sudden vs. gradual advancement – what's happened in a century?
- More next time!

https://www.youtube.com/watch?v=S-WRKeSerUE