Logistical notes

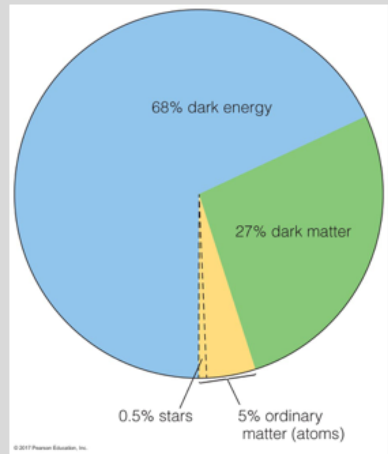
- Please come up and pick up your graded midterm 2 (and/or corrections to midterm 1…) if you haven't already!
  - Srsly pls I don't want to hang on to your tests… you need them to study!

- Tuesday after the break, 11/27, will be a TCO night if clear!

- Happy holiday break! The deadline extension fairy has visited MasteringAstronomy and removed late penalties on Lab 5, Lab 6, and Chapter 20! Rest, eat something tasty, and catch up on homeworks.

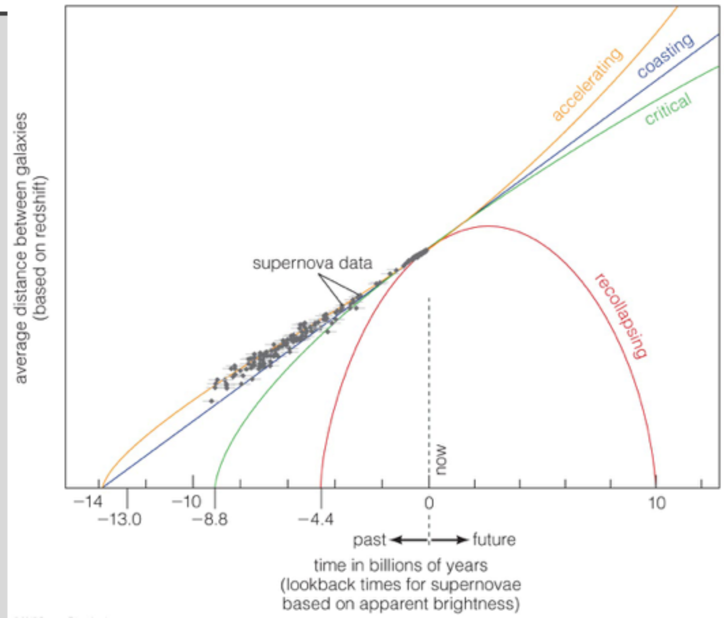
Accelerating universe?

- Acceleration discovered in 1998
- Nobel prize for discovery in 2011
- Acceleration must mean there's some force driving expansion: dark energy!



E=mc^2 shows up again.. The missing mass we haven't been able to account for could be not mass, but rather, energy!

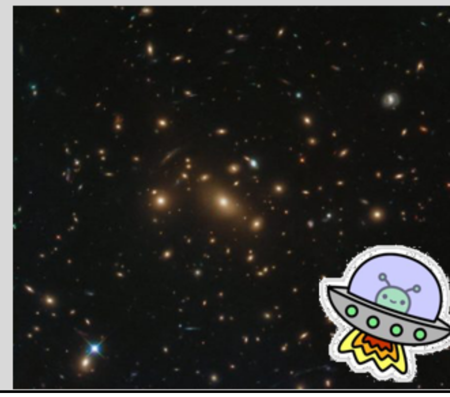
The fate of the universe



https://medium.com/science-uncovered/science-fiction-vs-reality-a-look-at-exoplanets-b5e250bebd95

Life in the Universe

- Switching gears from the heat death of the universe… let's talk about *life*
  - Is there life in the universe, other than us?
  - What are the conditions necessary for life?
  - Where do we look for it?
  - …why haven't we found it yet?



Today's lecture has a lot of question marks. Remember how I said each chapter was getting slimmer because we know less and less about the topics? Yeah, this is the ultimate don't know- life in the universe

Life in our solar system?

- Evidence of extremophiles on Earth expand our view of what "supporting life" might mean
  - Live in extreme heat, acidity, dryness
- Planets in our solar system that may have supported life:
  - Mars:
    - evidence for liquid water in the past
    - current water ice
    - methane gas in its atmosphere that we don't know the origin of
    - potentially liquid water in the interior
    - maybe we'll find Martian fossils someday

Image from https://www.space.com/41329-mars-closest-to-earth-2018.html

Today in science…

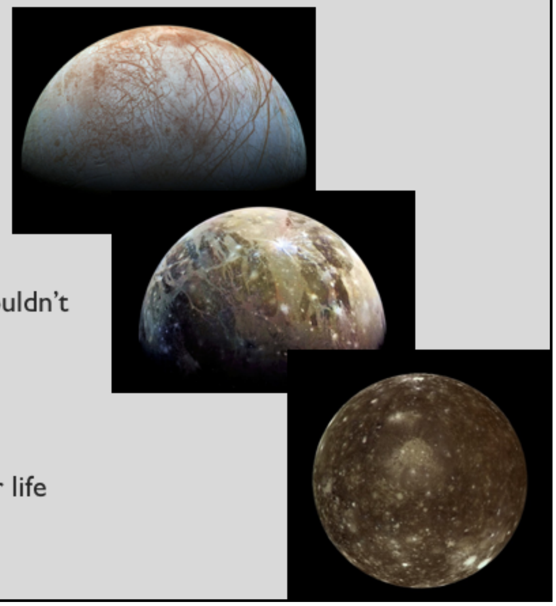
- Chilean Atacama desert thought to have been hyperarid for the past 15 million years
- In places, no rain recorded for past ~500 years
- Microbiome has adapted to arid conditions: about 16 known microbial species in soil
- Until…
  - Rain! ”Freak weather event” left pools of water in normally hyperarid region
  - Only 2-4 microbial species left
- Area thought of as proxy for Mars
- Maybe Mars’ life was wiped out by water, rather than supported
- Must carefully consider what we think is necessary for life in the universe

Theme of class today: life in the universe!

https://www.sciencealert.com/when-rainfall-kissed-the-driest-desert-on-earth-it-was-literally-the-kiss-of-death

Life in our solar system?

- Moons in our solar system that could support life
  - Jupiter:
    - Europa
      - Tidal heating would make interior liquid ocean
      - Hot volcanic vents at bottom of interior sea
      - So promising, scientists wondering why there wouldn't be life after 4.5 billion years
    - Ganymede & Callisto
      - Also have potential for sub-surface liquid oceans
      - But, lower tidal forces; less energy. Maybe smaller life forms

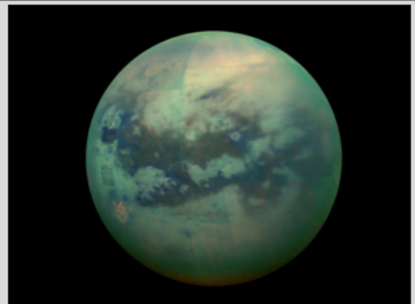


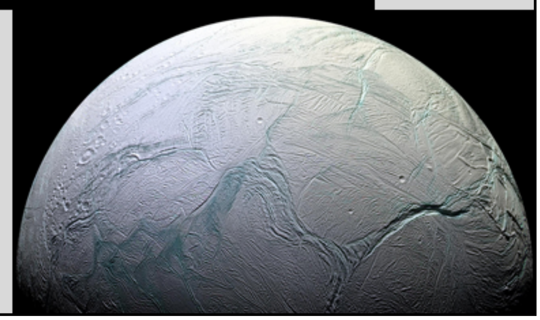
https://phys.org/news/2018-05-evidence-plumes-jupiter-moon-europa.html

https://earthsky.org/space/million-fold-chorus-waves-detected-on-jupiters-moon-Ganymede

Life in our solar system?

- Moons in our solar system that could support life
  - Saturn:
    - Titan
      - Cold, mostly N atmosphere, but atmosphere would protect from radiation/cosmic rays
      - Surface can support liquid methane and ethane lakes, not water
      - Low gravity + atmosphere = we could fly if wearing wings! Spiffy
    - Enceladus
      - Ice fountains and liquid sub-surface water
      - Could possibly live there if we dug down enough





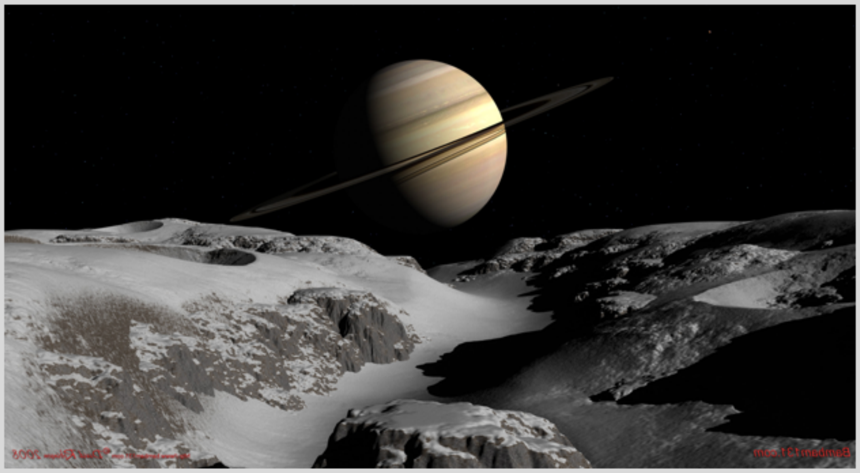
https://www.npr.org/sections/13.7/2017/10/16/555045041/confession-of-a-planetary-scientist-i-do-not-want-to-live-on-mars

http://www.planetary.org/blogs/emily-lakdawalla/2015/04081101-a-moon-with-atmosphere.html

https://solarsystem.nasa.gov/missions/cassini/science/enceladus/

Team Saturn's Moons

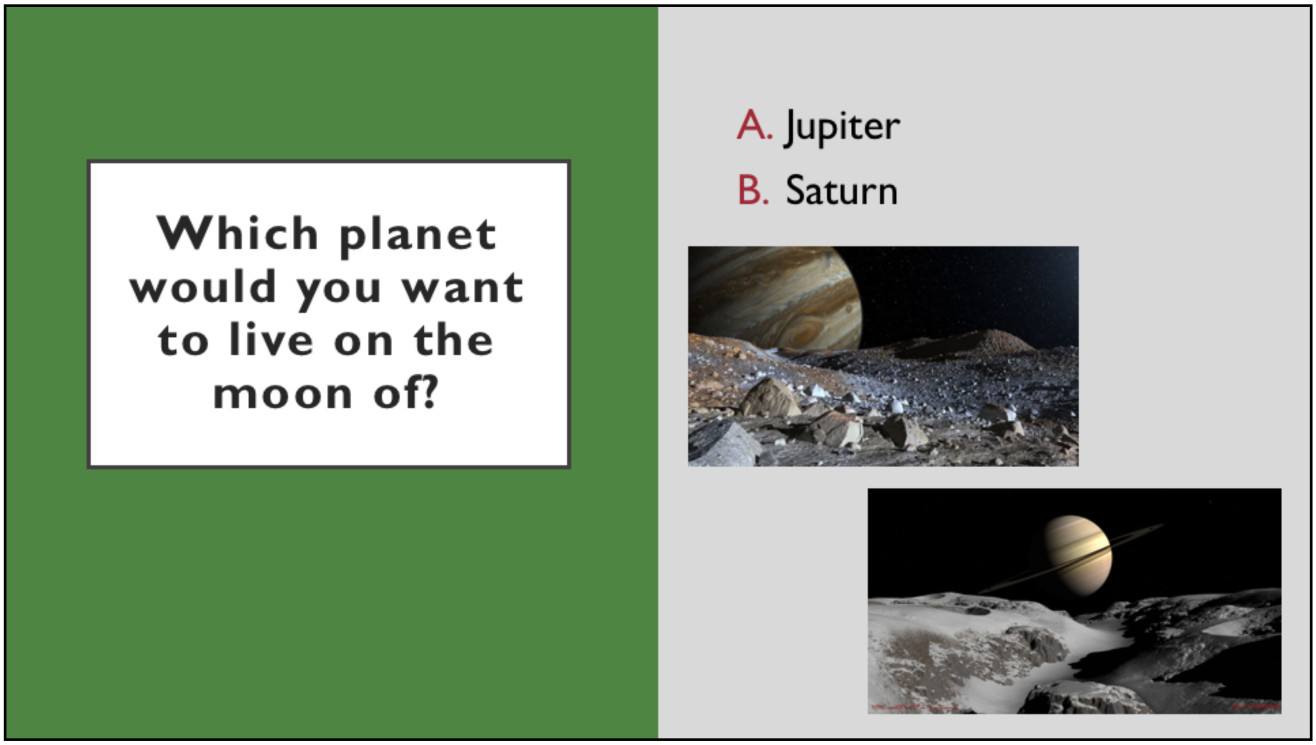
- And that view, right?



https://thewallpaper.co/hd-space-wallpapers-galaxy-high-definition-desktop-images-download-iphone-wallpapers-astro-amazing-2200x1197/

Team Jupiter's Moons

- Hm, or…



Those are the best candidates for life as we know it in our own solar system; they have enough internal energy from tidal forces of their planets/neighboring moons squeezing them to have liquid water under their icy crusts. Or, decent enough pressure and atmospheric blanketing conditions to support life that has sufficient temperature/breathing apparatus

Life outside our solar system?

- SETI: Search for Extra-Terrestrial Intelligence
  - Typically done with radio waves, since that's how we've largely communicated for decades
  - Radio waves from our shows in the 1950s may now be ~60 light years from Earth, though much weaker than our own current technology could detect
  - In 1974, we attempted a high-powered blast of radio into space toward the globular cluster M13
    - 25,000ly from Earth – will take 25,000 years to get there, and another 25,000 ly for any response to get back
  - If we don't know about life in our own solar system, how can we know about other civilizations in the galaxy/universe?

Why might we have picked a globular cluster to beam this signal at?

Life outside our solar system?

- SETI: Search for Extra-Terrestrial Intelligence
  - If we don't know about life in our own solar system, how can we know about other civilizations in the galaxy/universe?
  - Well, let's think about the options/odds… astronomer Frank Drake made an equation for this:

$$\# \text{ Civilizations} = N_{HP} * f_{life} * f_{civ} * f_{now}$$

- N_{HP} = # of Habitable Planets
- f_{life} = fraction of planets that could have life
- f_{civ} = fraction of planets with life where civilization capable of communication could develop
- f_{now} = how many of those planets have civilizations *now*

Right now, we can only figure out with decent accuracy how many habitable planets there might be in the galaxy, and even that one is tough.

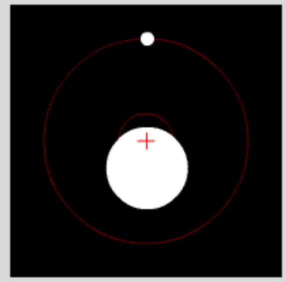
Life outside our solar system?

- Exoplanets seem like a really good place to start looking for extra-solar life! We look for planets that could be habitable. Based on Earth, this requires:
  - A distance far enough from host star for water to be liquid
  - Volcanism to release internal gases to fill planet's atmosphere and oceans
  - Plate tectonics for CO_2 cycle to regulate climate
  - A magnetic field to shield from harmful energetic particles in stellar wind
- Search for exoplanets began around solar-mass stars (or lower) because
  - Massive stars rare
  - Massive stars have shorter lifetimes
  - More observational issues to be discussed…

Exoplanets!

Detecting exoplanets

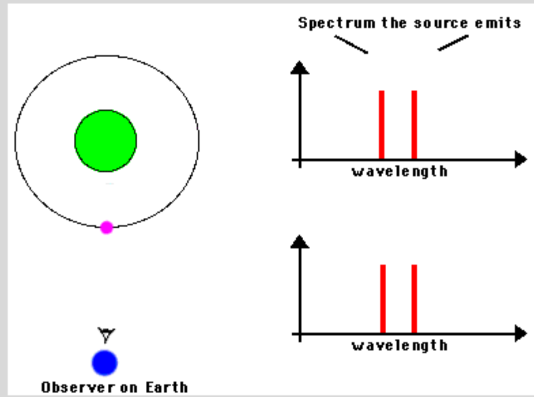
- Many methods for detection
  - Astrometric
    - Star, planet move around system center of mass
    - Can detect motion of star around in the sky
    - Limitations:
      - Star needs to be nearby
      - Planet needs to be massive
      - Inclination of system: optimal orientation is face-on (pole-on)



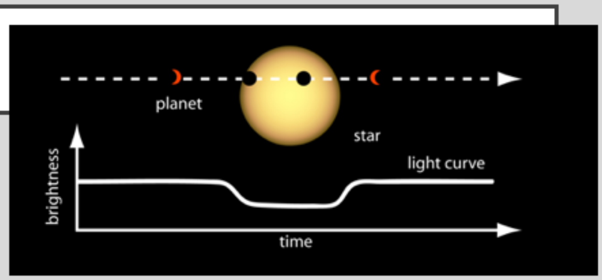
https://earthsky.org/space/how-do-astronomers-discover-exoplanets

Detecting exoplanets

- Many methods for detection
  - Astrometric
  - Doppler
    - Similar to astrometric, but using shift of spectral lines rather than absolute position on the sky
    - Velocity of star at maximal red/blueshift tells us about
      - How massive the planet is
      - Separation of planet and star
    - Limitations:
      - Planet needs to be massive enough, close enough
      - Resolution of spectrograph determines how small a shift can be observed
      - Need to know mass of star well to get planet mass



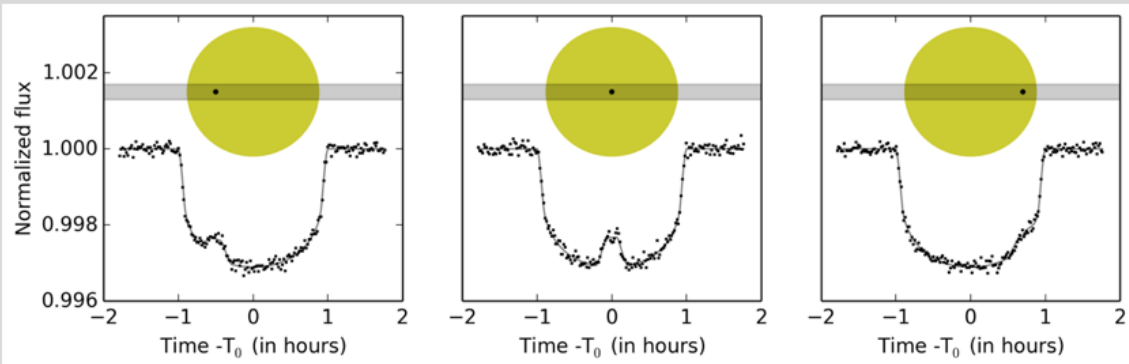
Detecting exoplanets



- Many methods for detection
  - Astrometric
  - Doppler
  - Transit
    - Planet passes between us and star along our line of sight
    - Star+planet (reflected) light, planet blocks some star light, star+planet light, star only
    - Depth of decrease in light related to planet's radius
    - Steepness of light curve shape related to planet radius, sharpness of planet edge (shallower = atmosphere present!)
    - Length of eclipse related to size of star
    - Limitations:
      - Alignment must be such that planet travels into line of sight
      - Planet must be large enough to block sufficient amount of light
      - Can only get radius of planet, no mass information

Aside, re: transits

- Star surfaces aren't perfectly smoothly lit! Have spots and active regions!

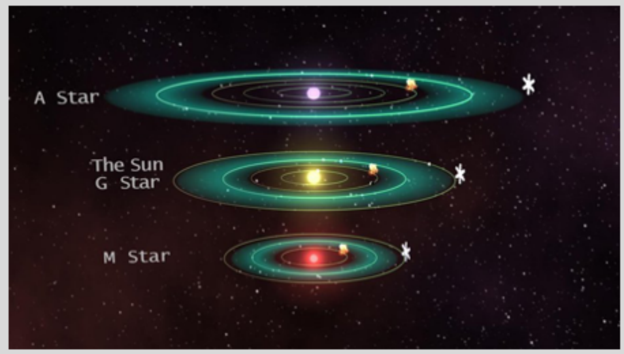


https://wasp-planets.net/2016/09/02/long-lasting-starspots-on-exoplanet-host-qatar-2/

Aside, re: transits

- Which stars are the best to look at for planets?
  - The stars we have the most of
  - Stars with close-in "habitable zones"
  - Stars that are relatively small, so the size of the planet transiting is comparatively large

- M dwarfs!
- Issues:
  - Faint!
  - Active!
    - Flares
    - Spots
    - Effects that make signals confusing



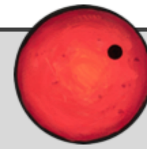
Mearth project

https://www.cfa.harvard.edu/MEarth/Welcome.html

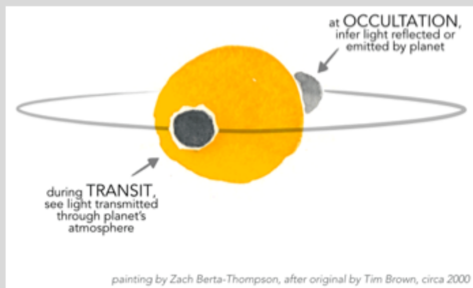
https://www.cfa.harvard.edu/MEarth/Discoveries.html

https://astrobiology.nasa.gov/news/where-is-the-habitable-zone-for-m-dwarf-stars/

M dwarf transits

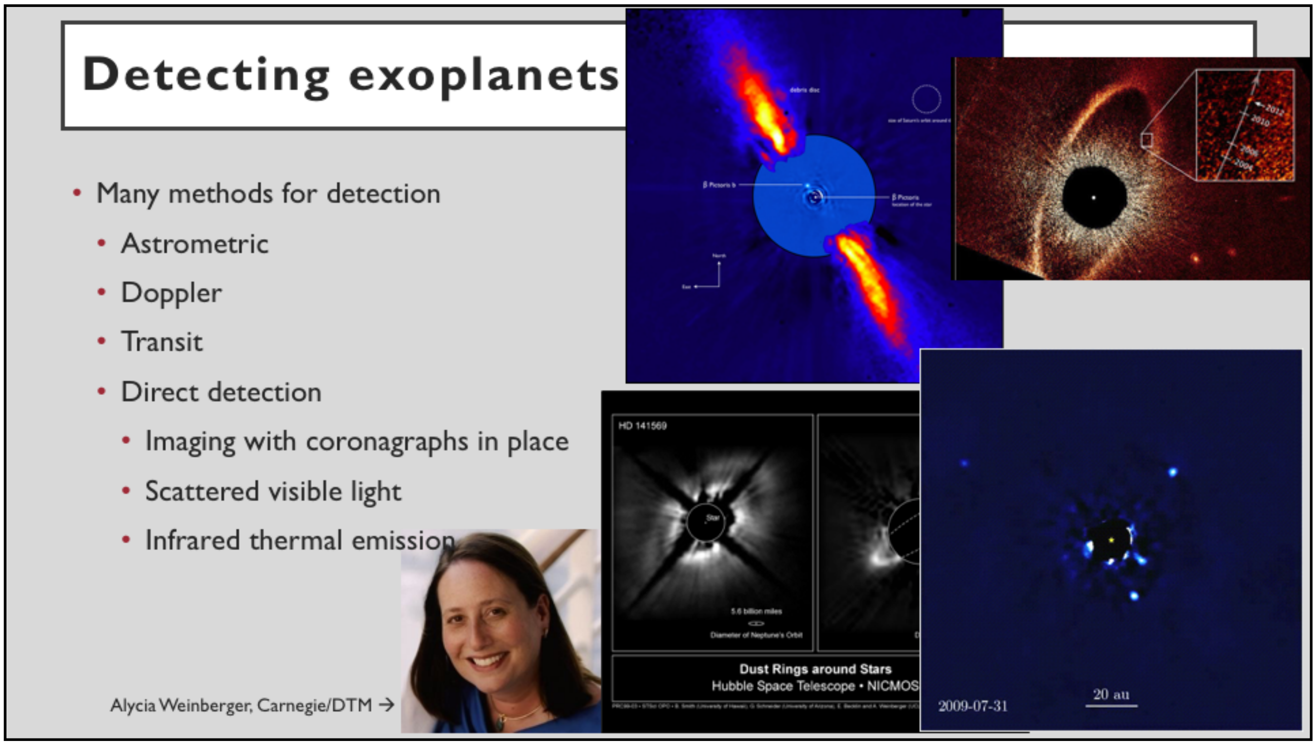


- Proving that astronomers have the coolest footwear…
- Zach Berta-Thompson at CU Boulder is part of the MEarth project
  - Using array of small telescopes to do large survey of nearby M dwarfs looking for Earth-like planets
  - Small budget, big results!



painting by Zach Berta-Thompson, after original by Tim Brown, circa 2000

http://casa.colorado.edu/~bertathompson/



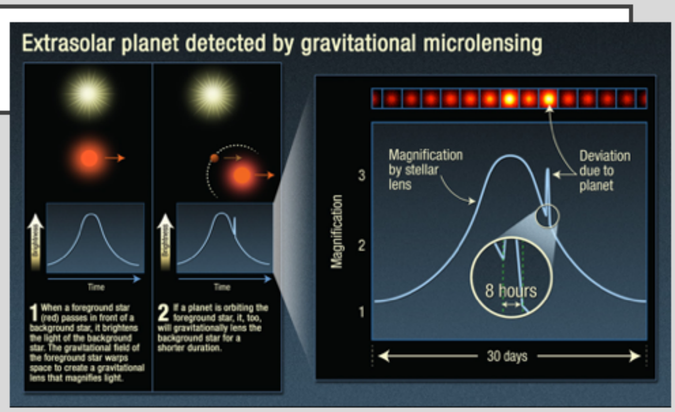
https://en.wikipedia.org/wiki/Beta_Pictoris_b#/media/File:Beta_Pictoris_system_annotated.jpg

https://en.wikipedia.org/wiki/Fomalhaut_b

http://www.planetary.org/explore/space-topics/exoplanets/direct-imaging.html

https://en.wikipedia.org/wiki/Alycia_J._Weinberger

Detecting exoplanets

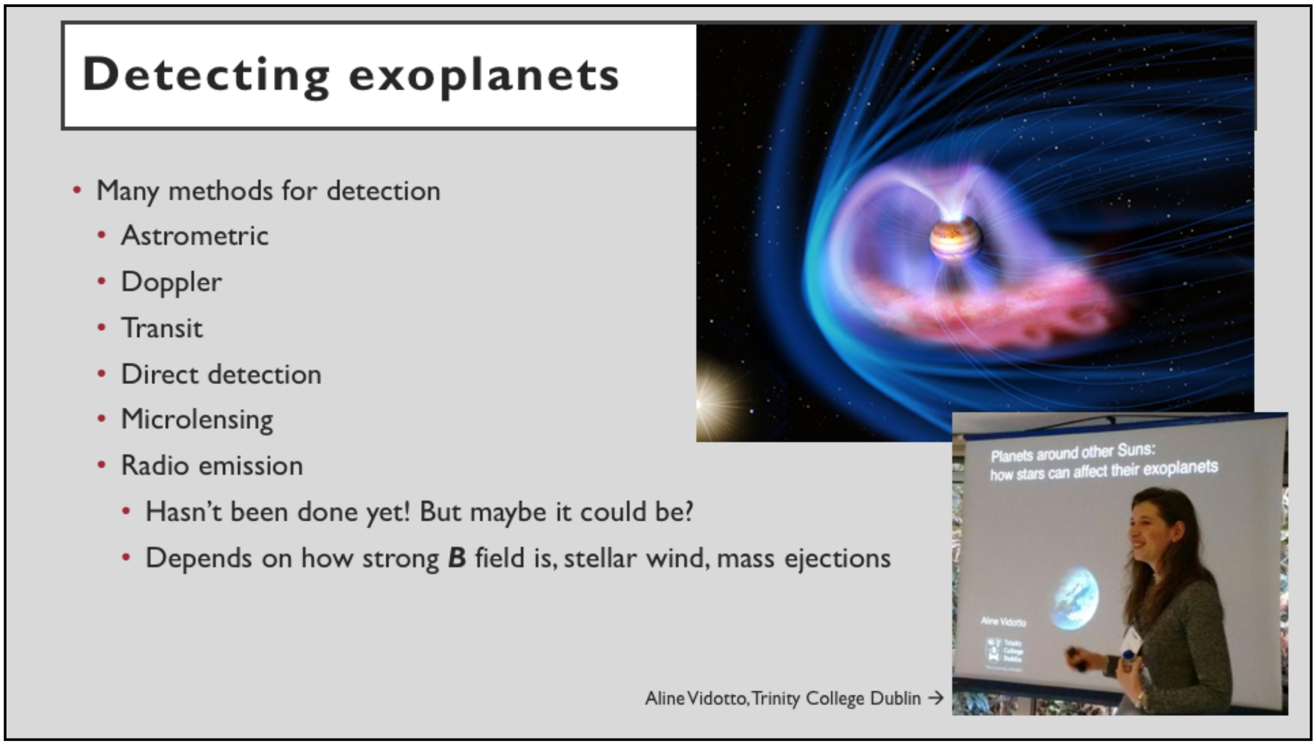


- Many methods for detection
  - Astrometric
  - Doppler
  - Transit
  - Direct detection
  - Microlensing
    - Gravitational lensing, on small scales
    - Mass ratio of planet/star, angular separation of planet/star
    - Allows for detection of low-mass planets
    - Limitations:
      - Difficult to find: perfect alignment needed, timing just right
      - Not repeatable
      - Planet parameters depend on how well we know host stars (often, not well)

http://www.planetary.org/explore/space-topics/exoplanets/microlensing.html

http://hubblesite.org/image/2976

http://www.scholarpedia.org/article/Microlensing_exoplanets



Aline made predictions for what the radio emission would be for a planet called Tau Boo, pioneered work to try to detect exoplanetary radio emission

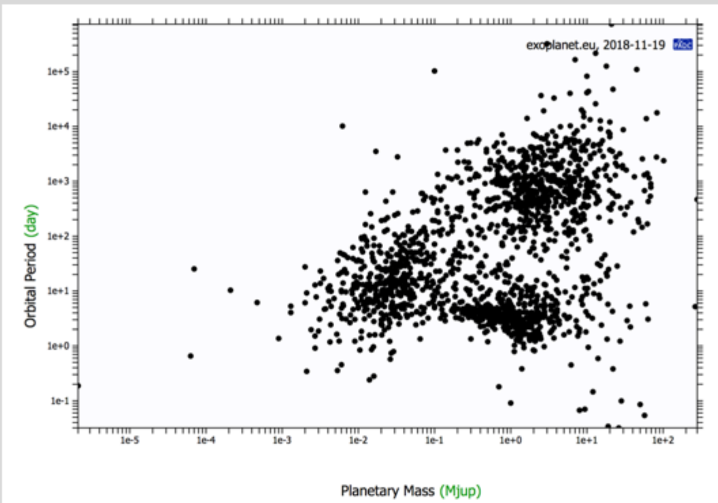
http://herrero-radio-astronomy.blogspot.com/2016/03/coronal-mass-ejection-triggering.html

Exoplanet detections

- With all of these methods, we have detected, to-date, about … 3900 exoplanets!

http://exoplanet.eu

Exoplanets



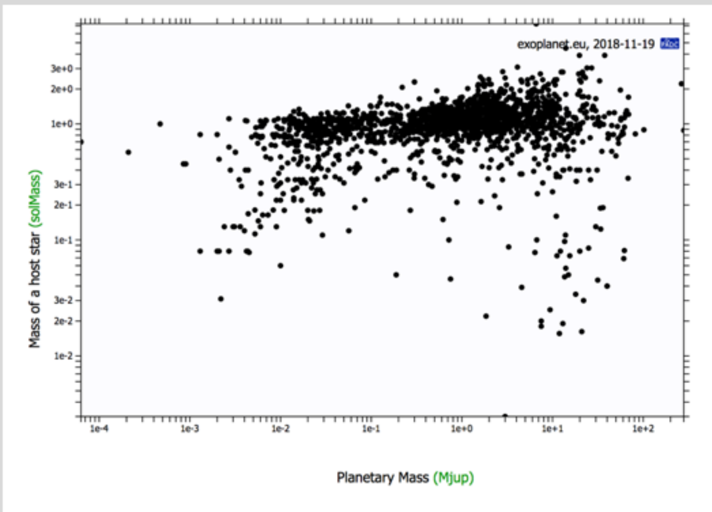
- For reference… masses and orbital periods for our solar system planets:
  - Jupiter
    - 1 M_{Jup}
    - 4,300 d
  - Saturn
    - 0.2 M_{Jup}
    - 11,000 d
  - Neptune
    - 0.05 M_{Jup}
    - 60,200 d
  - Earth
    - 0.003 M_{Jup}
    - 365 d
  - Mars
    - 0.0003 M_{jup}
    - 687 d

exoplanet.eu

http://exoplanet.eu/diagrams/

Our observations are biased toward higher mass planets and shorter orbital periods

Exoplanets



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exoplanet.eu

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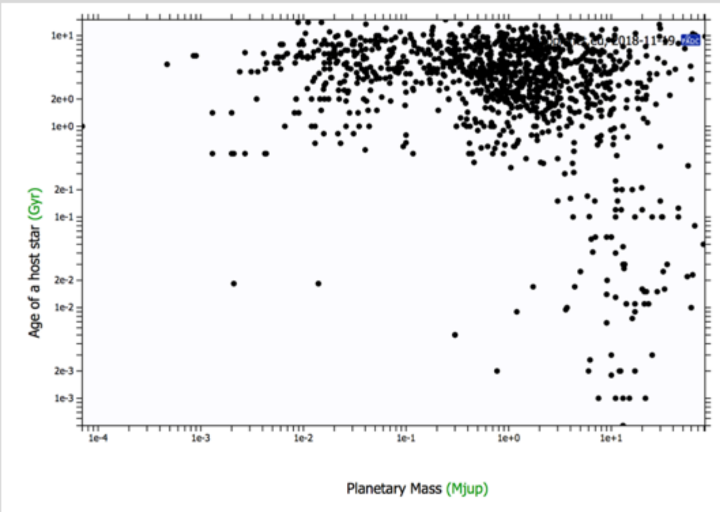
Our observations are biased toward higher mass planets and shorter orbital periods

And also stars ~1 Msun.

Exoplanets



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    - 687 d

exoplanet.eu

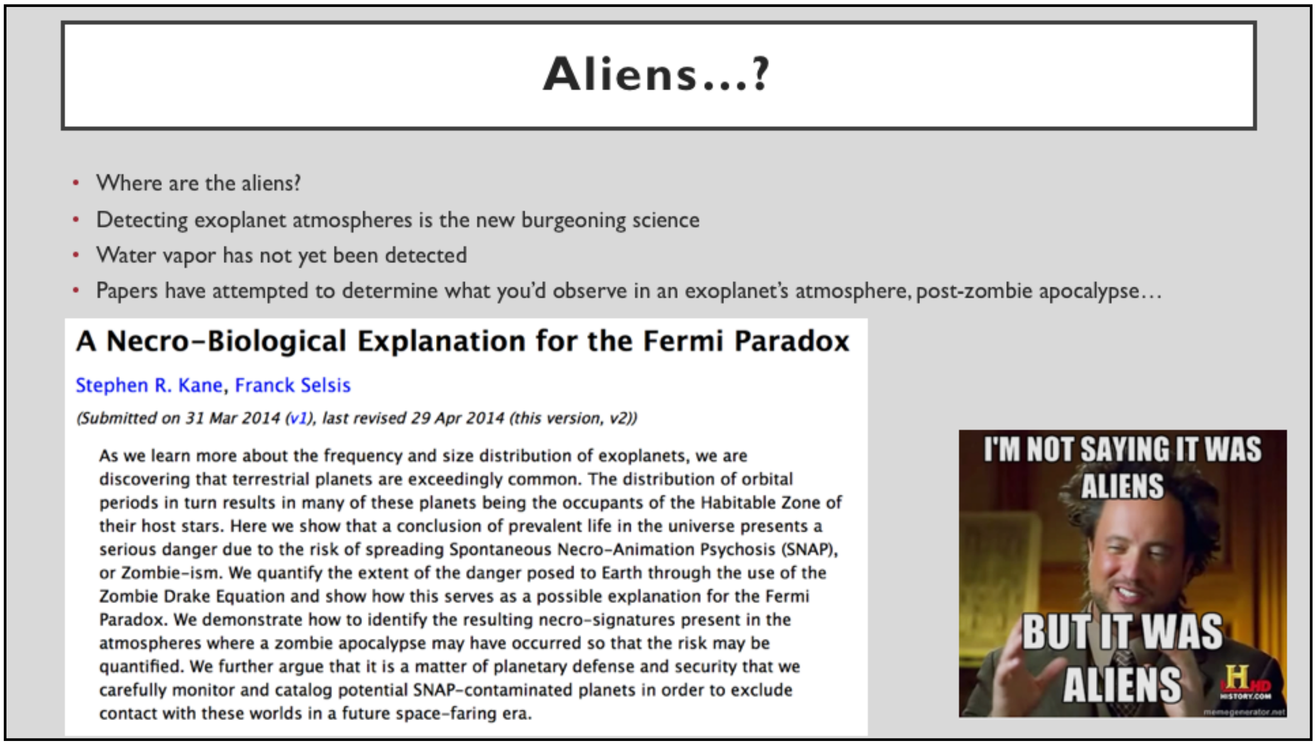
http://exoplanet.eu/diagrams/

Our observations are biased toward higher mass planets and shorter orbital periods

And also stars ~1 Msun.

And also stars >~100Myr, because the gas/dust need to have cleared for us to see the planets. Also, they need to have formed…

Note trappist system planets, GQ Lup system planets



It's a joke.. https://arxiv.org/abs/1403.8146

April fool's day on the arxiv is a good day.

Aliens…?

- The Fermi paradox: Plausible arguments suggest another civilization should exist in our galaxy, but we haven't found it yet. Fermi famously said,
  - "So where is everybody?"
- If we could travel at ~a few percent *c*, within a few centuries, we could have outposts at the nearest stars
- In 10,000 years, we could have many outposts within a few 100 ly of Earth
- Spreading out from those outposts, in 1,000,000 years, we could have a galaxy-spanning civilization
- The Milky Way is about 13.5 billion years old; generations of stars coming before us could have had civilizations that were able to do this already, billions of years before us
  - What if we aren't the only ones?

Aliens…?

- Say the odds of a civilization like ours developing around any given star in the Milky Way is 1 in 1,000,000
- Estimate 100 billion stars in the Milky Way, that means 100,000 civilizations in our Milky Way, one arising roughly every 50,000 years or so
- The next-youngest civilization to ours would be 50,000 years ahead of us, most would be even more, up to billions of years ahead of us
- Recall last slide: to make galactic outposts across entire MW would take ~1,000,000 years
  - "So where is everybody?"

Are we alone?

- Maybe civilizations are extremely rare
  - Maybe our original estimate was really low- instead of 1 in 1,000,000; maybe the odds are more like 1 in 100 billion
  - That could imply we're the first in the MW, maybe the universe
  - No pressure, humans
    - If this is true, our existence is remarkable
    - We would be the first in the universe to be self-aware
    - Humanity's existence would be all the more precious, and…
    - Our self-driven path to demise all the more tragic

Are we alone?

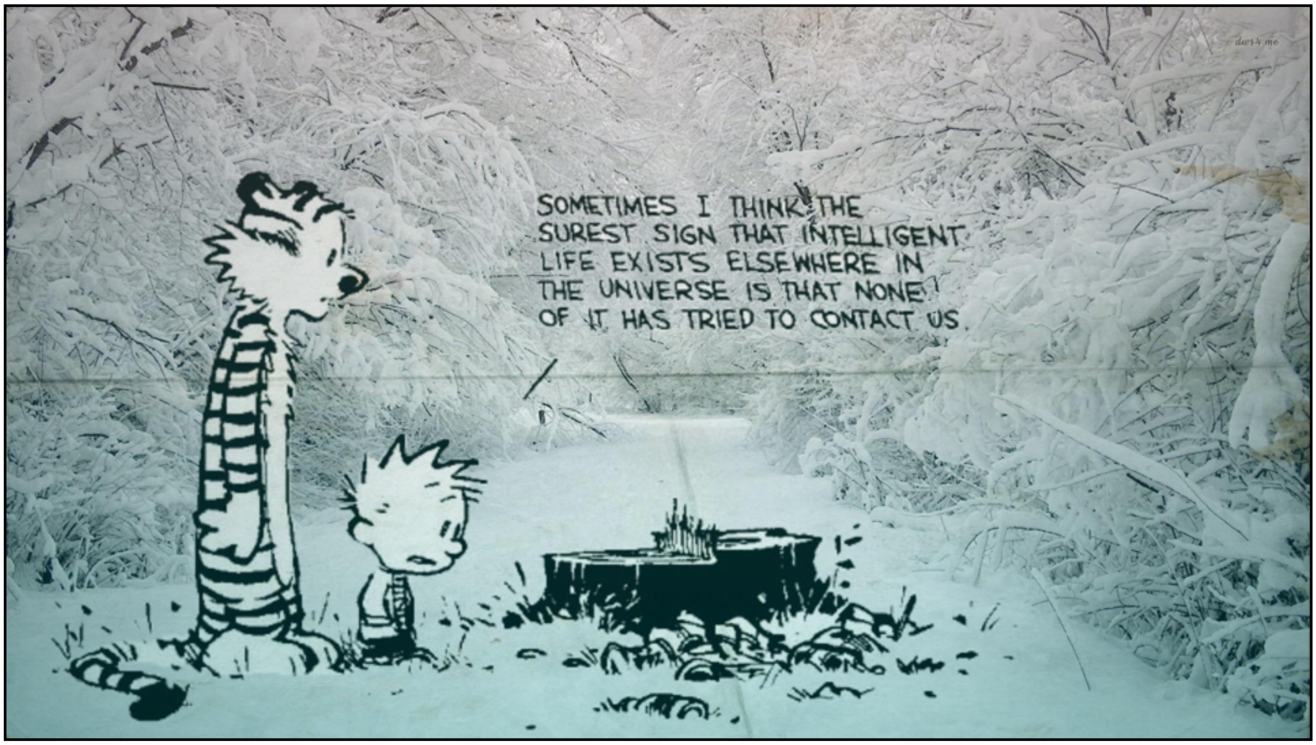
- Ok, scratch that sad one. Let's say civilizations are common, but spreading out throughout the galaxy isn't. Why not?
  - Space travel hard! Expensive!
  - Maybe the urge to travel is unusual and unique to us
  - Orrr maybe civilizations have existed, but .. Um. Destroyed themselves already.
- This option is a bummer for us: if countless other MW civilizations have tried space travel and not succeeded before imploding, it's not a hopeful scenario.

Dang it I was trying to steer toward uplifting…

Are we alone?

- Ok, that was a bummer, too. Option 3: there **IS** a galactic civilization, but it hasn't yet revealed its existence to us.
  - Maybe we're n00bs to the galactic scene and they're deliberately waiting until the time is right to say hey
  - Maybe they're messing with us, like some Earth-sized Truman Show
    - (I mean, it explains the Bermuda Triangle, anyway)
- A large portion of the choice, at this point, appears to be ours:
  - Do we develop technology to take us to the stars, or,
  - Do we self-destruct before we can get there?

Well, ok, not all of us; just some of us.


SOMETIMES I THINK THE SUREST SIGN THAT INTELLIGENT LIFE EXISTS ELSEWHERE IN THE UNIVERSE IS THAT NONE OF IT HAS TRIED TO CONTACT US.

Challenges of space travel

- Our fastest Voyagers (Pioneer 10 & 11, Voyager I & II, New Horizons) are traveling as fast as anything built by humans
  - 0.00001*c*
  - Would take 100,000 years to reach Proxima Cen
- Need to get closer to *c* to make travel to nearby stars feasible
  - Enterprise would need 2000x entirety of Earth's annual energy usage to go 0.5*c*
  - Need new kind of engines
  - Need new kind of shielding from high-energy cosmic rays (due to speed of craft's motion!)
  - Probably need one-way tickets: everyone on Earth would age 50 years for the two years spent traveling 50 light-years near *c*

Clicker free response:

What would you most like me to review next class before the final exam? Which topic this semester was the most challenging for you?

This semester, we studied… →

- History of astronomy
- Scientific method
- Phases of the Moon
- Seasons/the celestial sphere
- Physics
  - Properties of light
  - Properties of matter
  - Kepler's laws
  - Newton's laws
  - Thermal radiation (Wien's law and Planck's law)
- Telescopes
- The Sun
  - Structure
  - Fusion
  - Activity
- Stars
  - Surveying stars (clusters, H-R diagram)
  - Formation
  - evolution
  - after the main sequence
- Galaxies
  - The Milky Way
  - Structure of galaxies
  - evolution
- Cosmology:
  - Hubble's law
  - Evidence of the Big Bang
  - Evolution of the universe
  - Fate of the universe

Movie tiiiime…