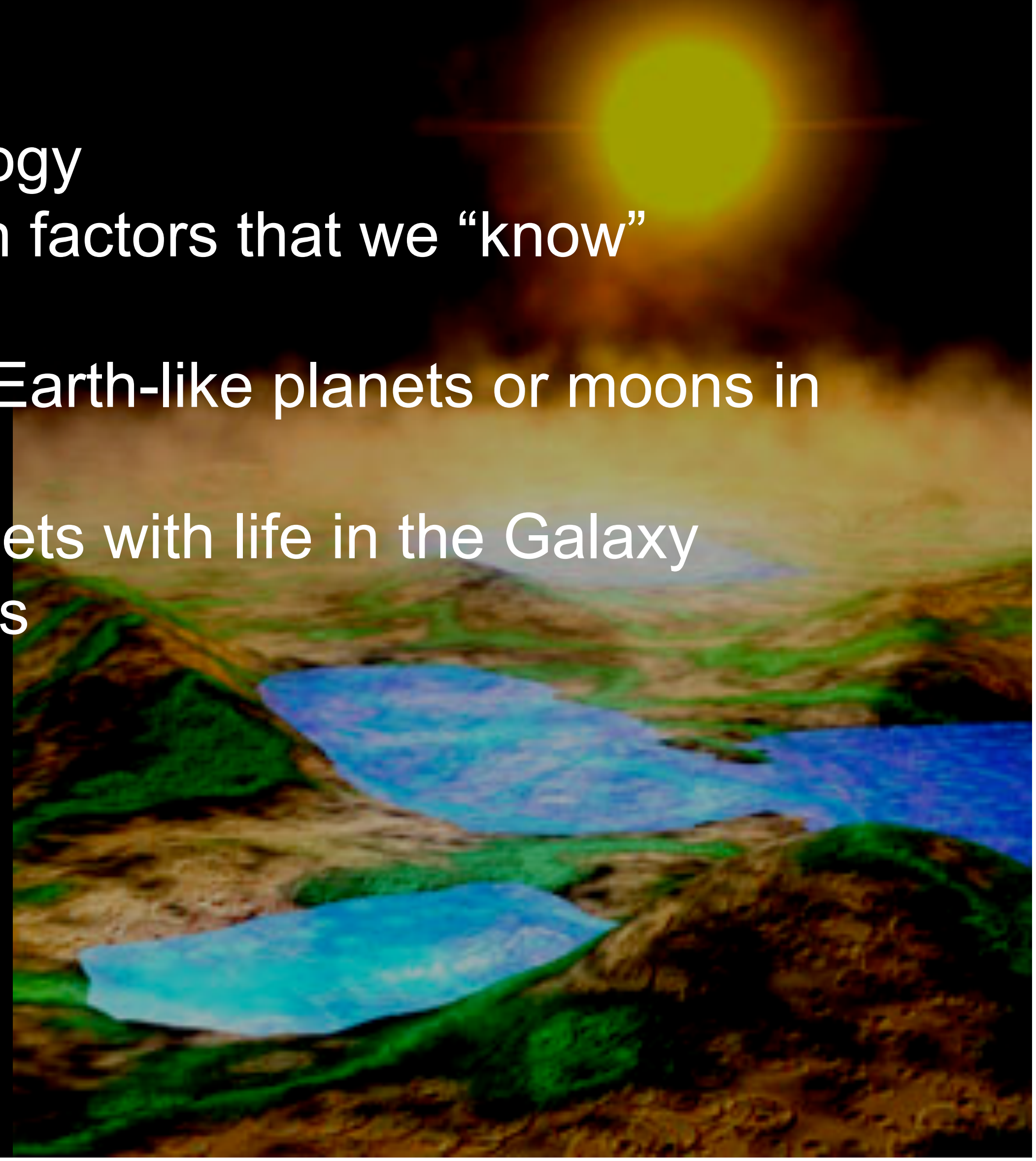
ASTR 380
The Drake Equation

ASTR 380
The Drake Equation

- Drake Equation Methodology
- Reviewing Drake Equation factors that we “know”
- The star formation rate
- Estimating the number of Earth-like planets or moons in the Galaxy
- Estimating number of planets with life in the Galaxy
- The Rare Earth Hypothesis



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The Drake Equation

Drake Equation:

$$N = R^* \times f_p \times n_e \times f_\ell \times f_i \times f_c \times L$$

where:

- N is the number of civilizations in our galaxy for us to talk to today.
- $R*$ is the average rate of star formation in our galaxy
- f_p is the fraction of those stars that have planets
- n_e is the number of planets that can support life per star that has planets
- f_ℓ is the fraction of the above that actually develop life
- f_i is the fraction of the above that develop intelligent life
- f_c is the fraction of civilizations that develop interstellar communication
- L is the length of time such civilizations release detectable signals into space.

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$$N = R^* \times f_p \times n_e \times f_\ell \times f_i \times f_c \times L$$

Underlying Assumptions:

1. By breaking the question into a series of sub-questions you can make a more informed estimate of each factor.

2. Each factor is estimated given that the previous factors in the equation are satisfied.

3. None of the factors are so close to zero as to make the other factors meaningless.

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Drake Equation:

$$N = R^* \times f_p \times n_e \times f_\ell \times f_i \times f_c \times L$$

3. None of the factors are so close to zero as to make the other factors meaningless.

For example, f_i could be 1, or 1/1,000, or 1/1,000,000,000 in your estimate.

Or a better estimate might include the chance of multi-cellular life, the chance of life evolving for a billion years, the chance that intelligent life survived natural selection and so forth.

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Drake Equation:

$$N = R^{*} \times f_p \times n_e \times f_\ell \times f_i \times f_c \times L$$

By formulating the question in terms of a limited number of factors that are between 0 and 1, you are directing people toward a result – unless you are aware of this fact!

In the case of the Drake Equation, the naïve responder's final N is primarily determined by their willingness to use one or more small numbers for the f-factors and the L – lifetime.

You can also arrange an answer by using more or fewer factors! Therefore, this frames the discussion instead of giving a definitive answer

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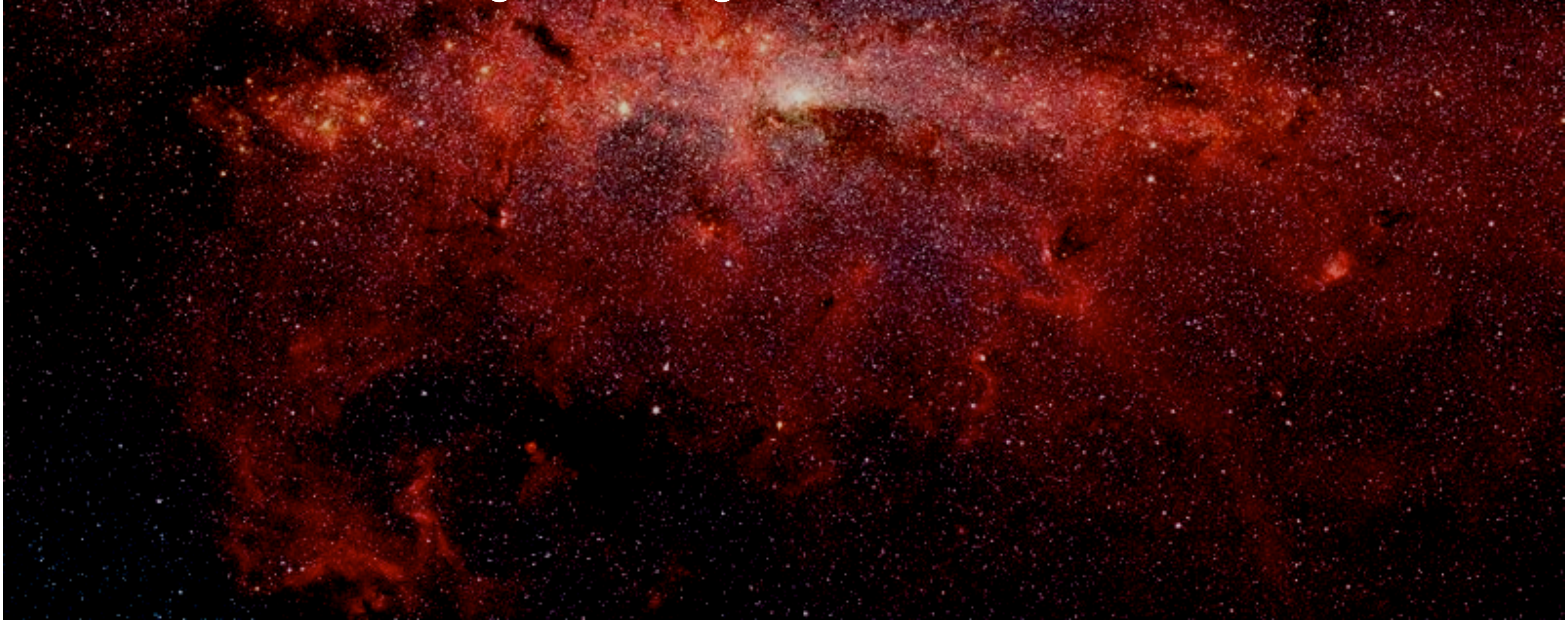
Drake Equation:

$$N = R^* \times f_p \times n_e \times f_\ell \times f_i \times f_c \times L$$

R* is a number that we have not talked about… but astronomers can give us a good estimate of that number…



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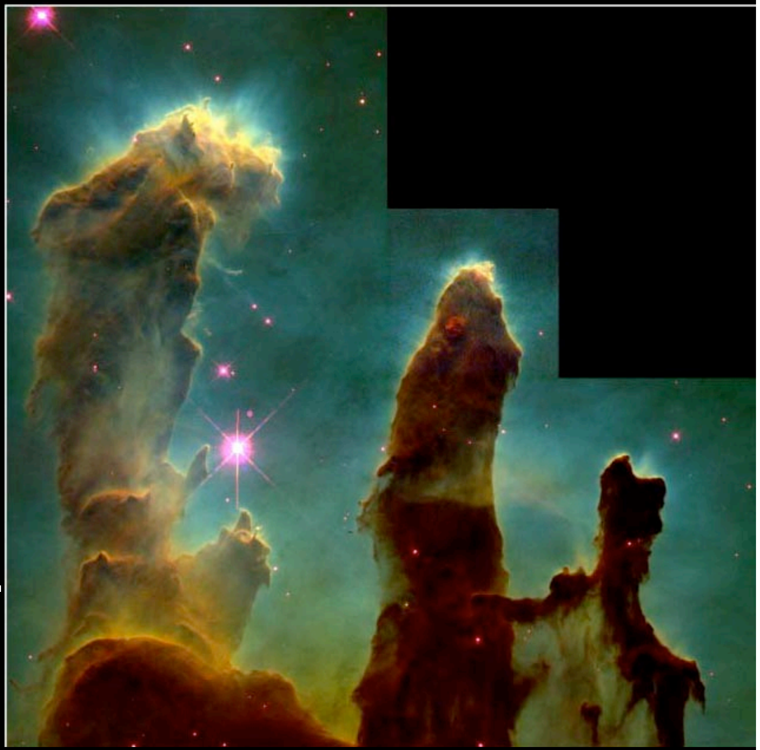
Drake Equation: R* = rate of star formation in our galaxy
Simplest estimate is:
R* = number of stars in the galaxy / age of Galaxy



Number of stars is estimated from the luminosity of the galaxy and the typical luminosity of an individual star.
stars = luminosity of galaxy / luminosity of typical star
The answer is that there are 200-400 billion stars in the galaxy.

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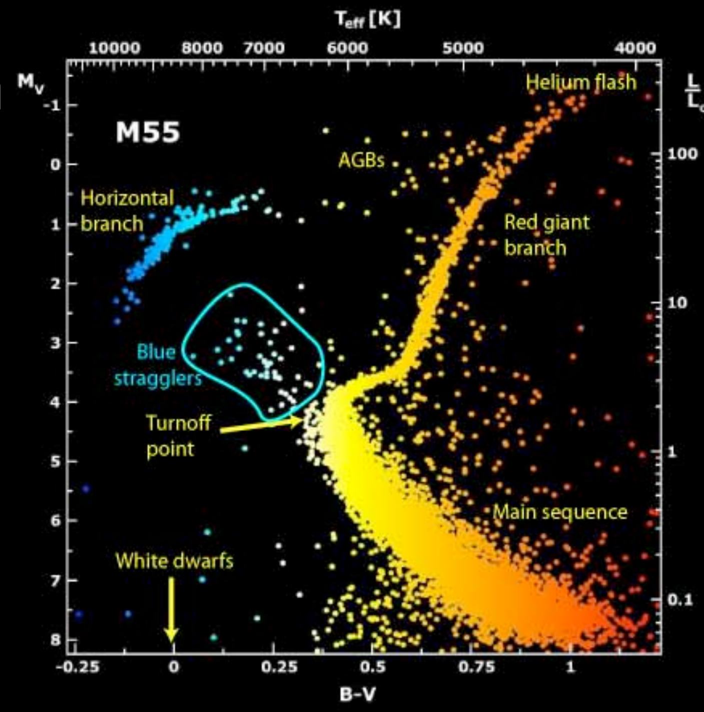
Drake Equation: R* = rate of star formation in our galaxy

Simplest estimate is:

R* = 200-400 billion stars / age of Galaxy

The age of the Galaxy is estimate from the oldest stars in the galaxy.
Answer: 13.6 Billion years.

So our first guess at R* is 15-30 stars per year, right?



But….

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Drake Equation: R* = rate of star formation in our galaxy

But, there are more stars which are older than the Sun than are younger…. So the star formation rate was bigger in the past.

We can estimate the current star formation rate from the massive stars that we see – because they do not live long.

Best estimate of current rate 5-10 stars per year.

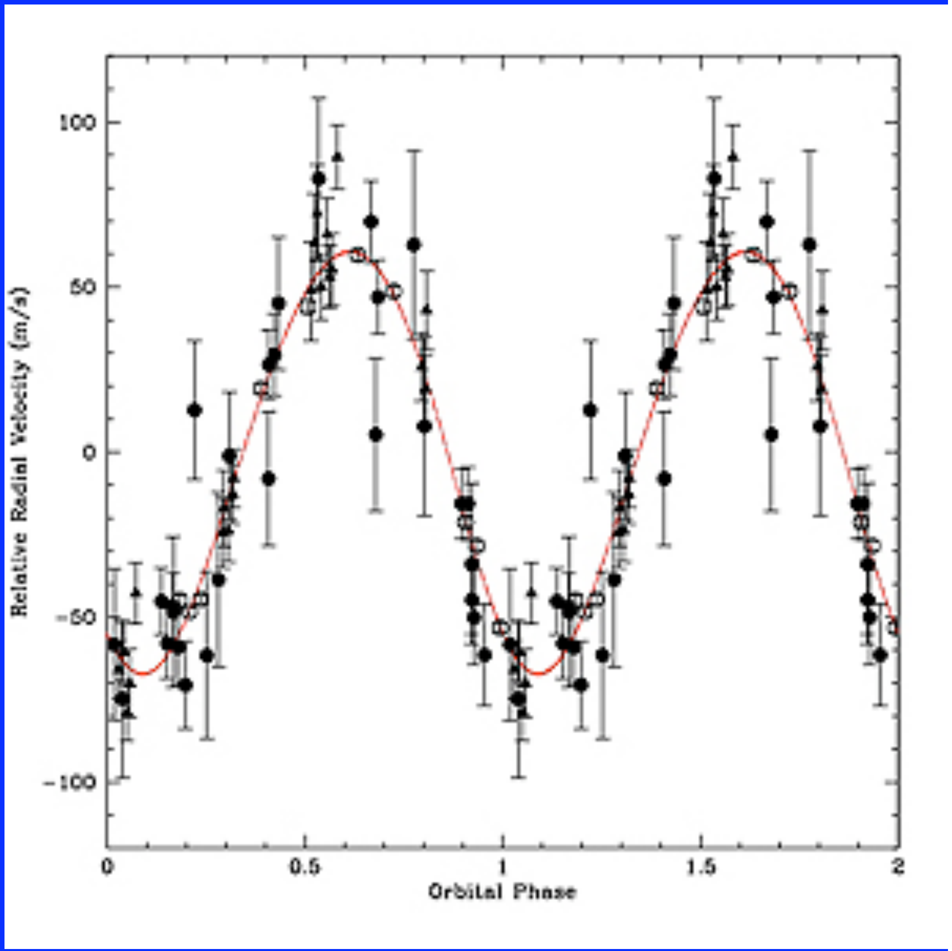
So R* = 5 – 15 stars per year -- is an overall best estimate!

f_p

- Fraction of stars with planets
- Temptation: just take the 5% number that is emerging from surveys
- But we cautioned about selection biases
- What biases exist here, and how might they affect f_p?

First Bias: Undetectable Planets

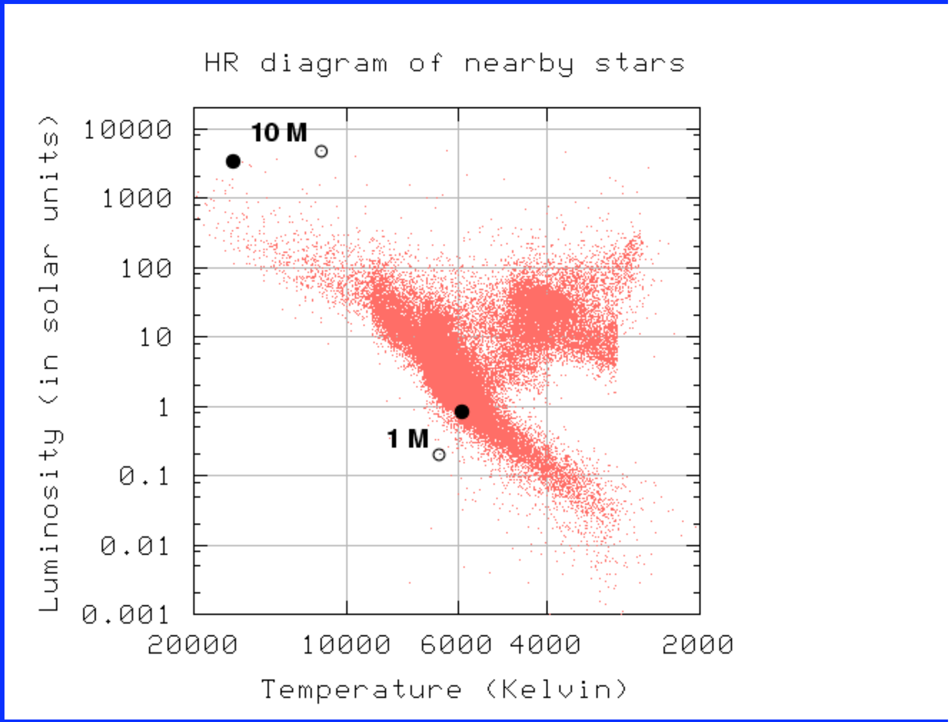
- One problem is that many planets cannot yet be detected
  Low-mass planets
  Planets with long orbital periods
- What fraction would we miss?
- Note that we would see Solar System (just Jupiter), so no problem there



http://www.sdss3.org/images/marvels/radial_velocity.jpg

Second Bias: Star Types

- Most interest has been in stars like our Sun
- But <10% of stars have our Sun's mass or greater
- Planets have been seen around much lower mass stars, but not many have been observed
- Overall fraction depends critically on the fraction around low-mass stars
- What considerations apply?



http://spiff.rit.edu/classes/phys301/lectures/star_death/two_star.gif

Planet Formation vs. Star Mass?

- Not much known
- Star formation takes longer for lower-mass stars
- Might allow planets to form more easily
- No obvious reason they wouldn't

Planets in Binary Star Systems?

- About 2/3 of stars are in binaries/multiples
- Gravity makes nearby orbits unstable
- Reduces locations for planets

Albireo, in Cygnus

http://jumk.de/astronomie/img/albireo.jpg

Class Estimate of f_p?

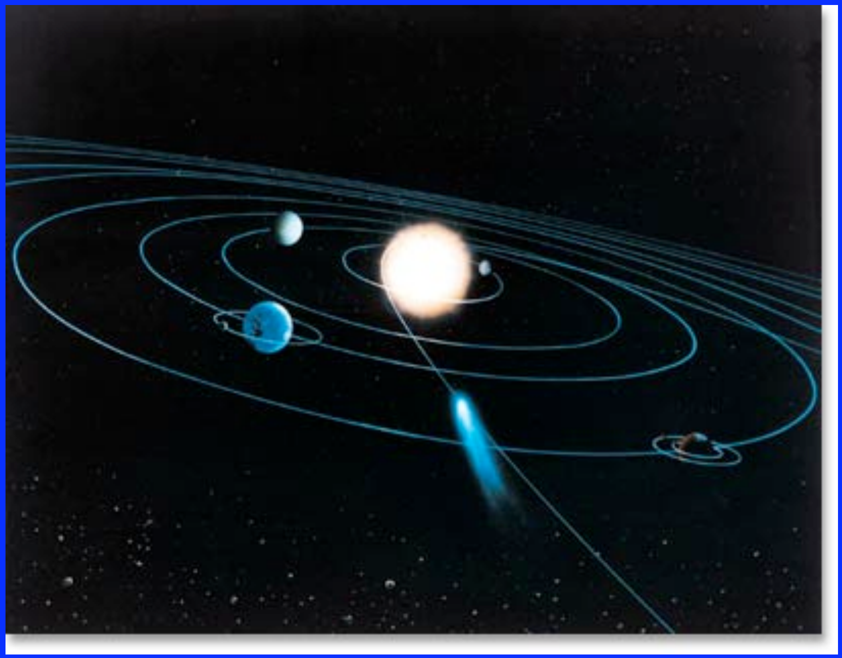
- Minimum 0.005
- Maximum 0.8

n_e

- Number of planets that can support life, per star that has planets
- This is tricky. We have planets, one of which can support life. Is this typical?
- What considerations enter?

Early and Late

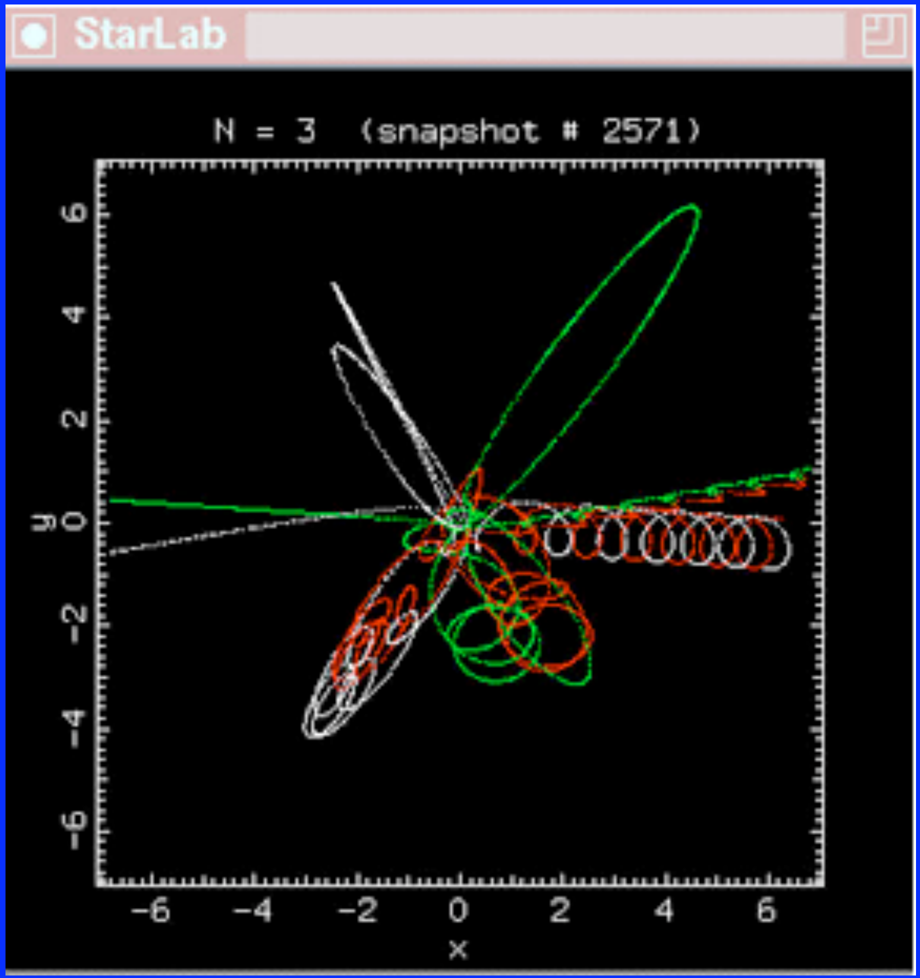
- Early Sun weaker: Venus might have had life
- Late Sun stronger: Mars might get liquid water
- Also, inner planets could be packed closer



http://www.montana.edu/wwwmor/education/NASAtrunks/imagesP/solarSystem.jpg

Eccentricity and Instability

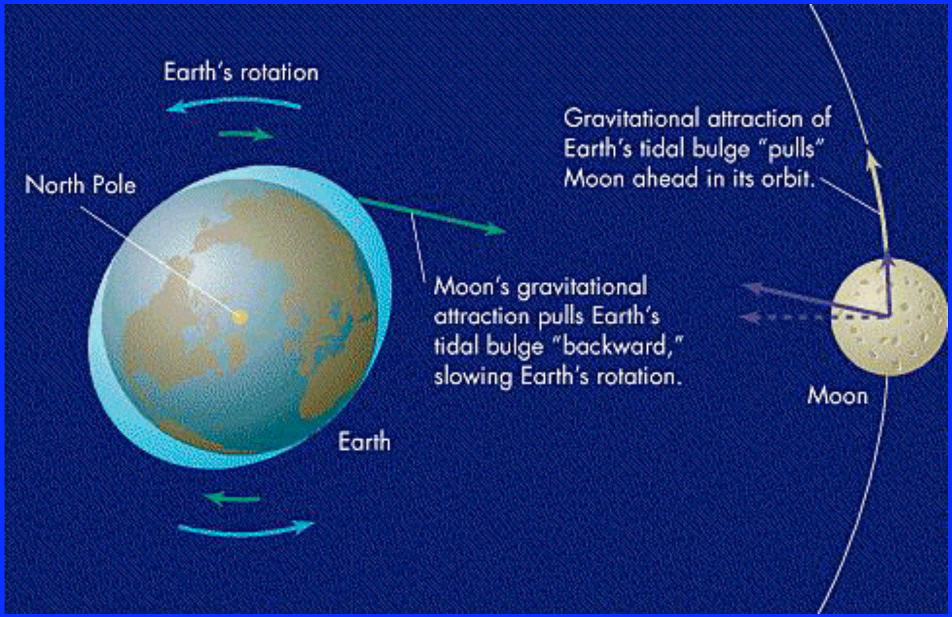
- Most extrasolar orbits are quite elliptical
- And, gas giants move way in
- Both issues mean habitable zone is threatened
- Could n_e be reduced?



Matt Benacquista

Tidal Locking

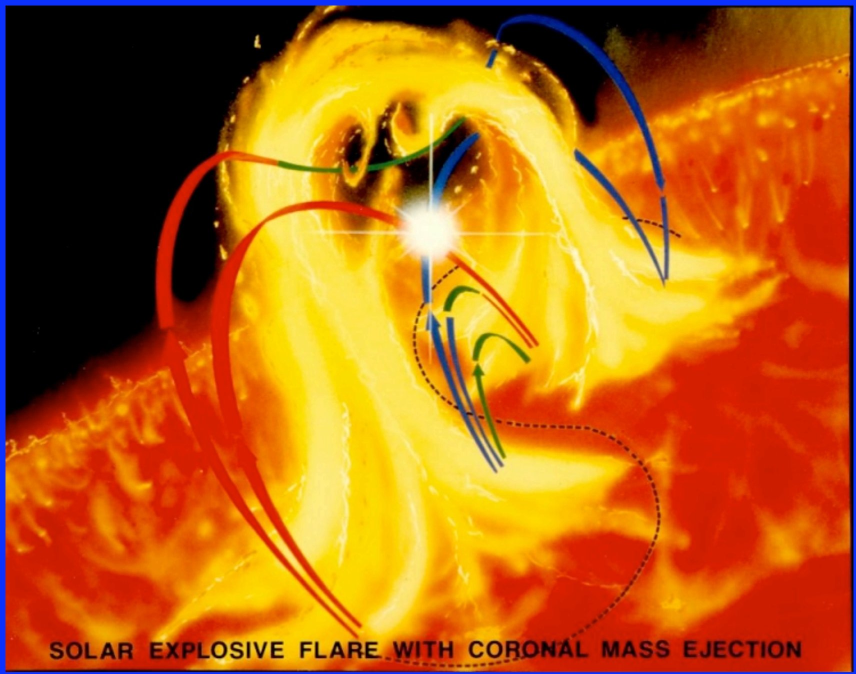
- Gravity creates tidal bulge, tendency is to make one face of planet eventually face star all the time
- For lower-mass stars, happens in the habitable zone
- Reduces fraction of viable planets around low-mass?



http://atropos.as.arizona.edu/aiz/teaching/nats102/images/tidal_locking.gif

Major Flares

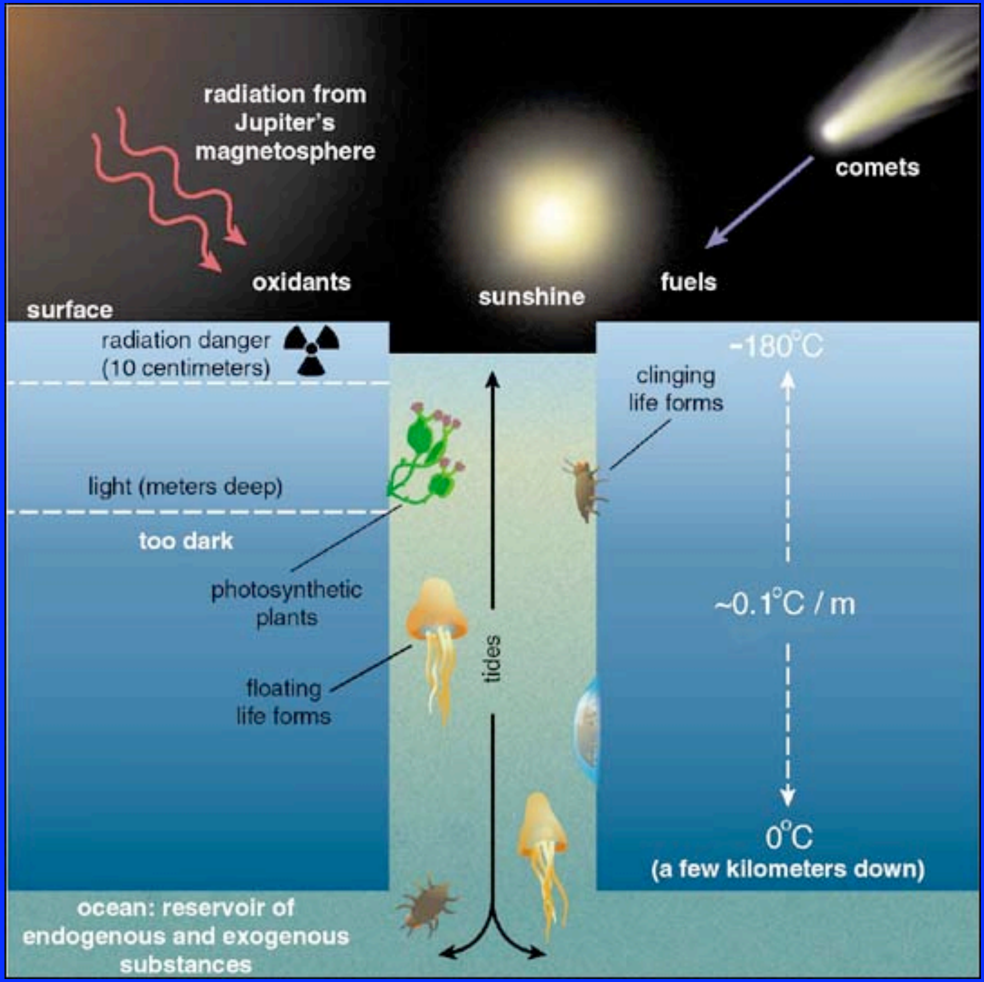
- Our Sun has flares, but these are minor
- Low-mass stars have flares that can double their luminosity or more in a few minutes
- Maybe not stable enough for life?



http://www.aavso.org/images/rons_flare.jpg

Life Outside Habitable Zone?

- Tides, geothermal, moon heated by host planet?



http://www.daviddarling.info/images/Europa_life.jpg

Class Estimate of n_e?

- Minimum 0.01
- Maximum 4

f_l

- Fraction of planets that *could* support life that actually *do* develop life
- Could be microbial
- In our Solar System, we are at 100%!
- Is this typical?

In Favor of High f_l

- Life on Earth dates back as far as it could
- Suggests rapid (<100Myr) formation
- In our case, then, favorable conditions produced life soon
- Common?

Stromatolites

http://imaginationconversion.files.wordpress.com/2008/03/stromatolites_lge.jpg

In Favor of Low f_l

- Giant impacts might keep surface too hot
- Some galactic environments have high radiation
- If planet has weak magnetic field, particles from Sun could sterilize

http://www.hopkins.k12.mn.us/pages/high/courses/online/astro/course_documents/earth_moon/moon/lunar_origin_theori

Do We Need a Big Brother?

- Is it necessary for life to have giant planets to swat away asteroids?
- Or is it better to collect stuff into terrestrial planets?

http://www.ioncmaste.ca/homepage/resources/web_resources/CSA_Astro/files/content/images/unit4/

Special Location in Galaxy?

- Some of the previous fractions might depend on our location
- Close enough for heavy elements, far enough to avoid many supernovae?
- Or do we not have to fine-tune too much?

http://www.terremoto.ca/images/milky_way.jpg

Class Estimate of f_1?

- Minimum 0.0001
- Maximum 1

f_i

- Fraction of planets that, having developed life, develop intelligent life
- Will be the focus of the next class
- But as a preview: here it was 100%; is that typical?

Argument for Low f_i

- Took 3.8 billion years to get species with enough intelligence to communicate
- Needed lucky accidents:
  Animals with backbones?
  Extinction of dinosaurs?
  Maybe many others
- Anything but inevitable

http://www.scienceclarified.com/scitech/images/lsca_0001_0001_0_img0031.j

Argument for High f_i

- Intelligence can be advantage in many environments
  Consider whales/dolphins, not just primates
- Top-end intelligence has tended to increase with time (not in straight line, though)
- Billions of years are available

Class Estimate of f_i?

- Minimum   0.005
- Maximum 0.5

Class Estimate of f_c and L?

- f_c is fraction of intelligent species that can communicate over interstellar distances
- L is the duration that they can do so
- What are your best estimates?
- For the record, the total class answer was between 1.25×10^{-10} and 6×10^{10} in MW!!!
- Are we nearly alone in our galaxy?

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The Drake Equation

Drake Equation: The number of Earth-like locations

$$N = R^* \times f_p \times n_e \times f_\ell \times f_i \times f_c \times L$$

As an intermediate step to N, we now have nearly enough to estimate the number of Earth-like planets in the Galaxy…

N(Earth-like) = R* f_p n_e L(planet)

where L(planet) is the lifetime of a planet– let's say 10 billion years – once formed they do not go away.

R* = 5-15 stars/year
f_p = 0.05 – 0.5 (5% to 50% of stars have planets)

so

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The Drake Equation

Drake Equation: The number of Earth-like locations

$N(\text{Earth-like}) = R^* f_p n_e L(\text{planet})$

n_e #Earths/system	N(earth-like)
1 in a million	2,500 – 75,000
1 in a thousand	2.5 – 75 million
1	2.5 – 75 billion

n_e must be very small (1 in billions) for there to be only a few stars with Earth-like locations in our Galaxy

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The Drake Equation

Drake Equation: The number systems with life!

$$N(\text{planets with life}) = R^* f_p n_e f_l L(\text{life})$$

First, what is L(life)? The length of time that life typically exists on a planet?

For Earth --- about 4 Billion years

Elsewhere?? Perhaps it is wiped out by giant impacts on some fraction of planets. Perhaps it reforms 300 Million years after a sterilizing impact?

As an example….. L(life) = 500 Million years

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Drake Equation: The number of systems with life!

$$N(\text{planets with life}) = R^* \, f_p \, n_e \, f_l \, L(\text{life})$$

What about f_l ? And what exactly is the split of responsibility between life and intelligent life?

If the fraction with life counts the most primitive single cell life, perhaps the fraction is close to 1…. If the requirement is complex animals and plants that perhaps it is close to zero.

For this class we will adopt the simplest form of life as sufficient.

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The Drake Equation

Drake Equation: The number of systems with life!

$$N(\text{planets with life}) = R^* \, f_p \, n_e \, f_l \, L(\text{life})$$

Adopt L(life) = 500 Million years, n_e = 1 in a thousand.
f_p = 0.1 to 0.3, R* = 5-10 stars/year

Fraction with life	N(life)
1 in a million	0.25 – 2
1 in a thousand	250 – 1500
1	250,000 – 1.5 Mil

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Rare Earth Hypothesis:

The emergence of life on Earth was so lucky that it was a one in a billion result.
Even though there are thousands or millions of Earth-like planets in the galaxy, we are likely the only one with life.

Special Circumstances:

1. far from galactic center so stars no too close
2. Terrestrial planet without heavy atmosphere
3. Plate tectonics
4. magnetic field
5.Jupiter in right place cut later bombardment
6. large moon……

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The Drake Equation

Rare Earth Hypothesis:

The argument is that life on Earth required such a large number of finely tuned conditions that it is extremely rare.

$$N(\text{Earths}) = N^* \, n_e \, f_g \, f_p \, f_{rocky} \, f_{mic} \, f_c \, f_l \, f_m \, f_{jup} \, f_{me}$$

Where:

N^* is the number of stars in the Milky Way.
n_e is the average # of planets in a star's habitable zone.
f_g is the fraction of stars in the galactic habitable zone
f_p is the fraction of stars with planets.
f_{rocky} is the fraction of planets that are rocky
f_{mic} is the fraction of habitable planets with microbial life.
f_c is the fraction of planets where complex life evolves
f_l is the fraction of the time when complex life is present.
f_m is the fraction of habitable planets with a large moon.
f_{jup} is the fraction of systems with large Jovian planets.
f_{me} is the fraction of planets with few extinction events

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Rare Earth Hypothesis:

If we try this out….

N^* is the number of stars in the Milky Way = 200 Billion
n_e is the average # of planets in a star's habitable zone = 0.5
f_g is the fraction of stars in the galactic habitable zone = 0.3
f_p is the fraction of stars with planets = 0.1
f_{pm} is the fraction of planets that are rocky = 0.1
f_{mic} is the fraction of habitable planets with microbial life =0.1
f_c is the fraction of planets where complex life evolves = 0.01
f_l is the fraction of the time when complex life is present = 0.1
f_m is the fraction of habitable planets with a large moon = 0.001
f_j is the fraction of systems with large Jovian planets = 1
f_{me} is the fraction of planets with few extinction events = 0.001

N(Earths with complex life) = 0.3! In the Galaxy currently

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Rare Earth Hypothesis:

N(Earths with complex life) = 0.3!   In the Galaxy currently

Notice that this is the number of Earths with evolved complex life forms…. Not the number of Earth-like worlds that we could inhabit.

If I use the same estimate for all of the factors but do not consider factors beyond the possibility of complex life at some point….. I would get 300,000 planets with Earth-like conditions

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And the point is:

The Drake Equation is a useful way to look at the problem of life on other planets but not the only way.

And the way that you look at a problem can steer you towards a particular answer!

Summary

- We don’t know most of the factors, because we only know of one place with life
- Still, we have a lot of stars in our galaxy
- There are also tens of billions of galaxies in the universe
- Many chances!