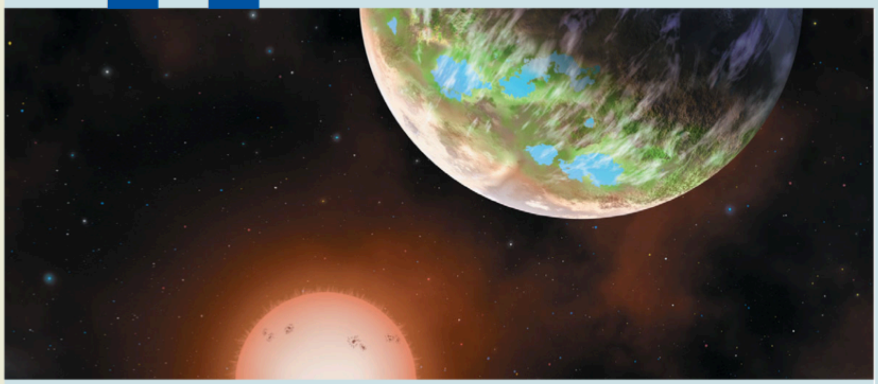
11



Habitability Outside the Solar System

Habitability Outside the Solar System

LEARNING GOALS

11.1 DISTANT SUNS

- How do stellar life cycles affect the possibility of habitable planets?
- How do we categorize stars?
- Which stars would make good suns?

11.2 EXTRASOLAR PLANETS: DISCOVERIES AND IMPLICATIONS

- How do we detect planets around other stars?
- What have we learned about extrasolar planets?
- How could we detect life on extrasolar planets?

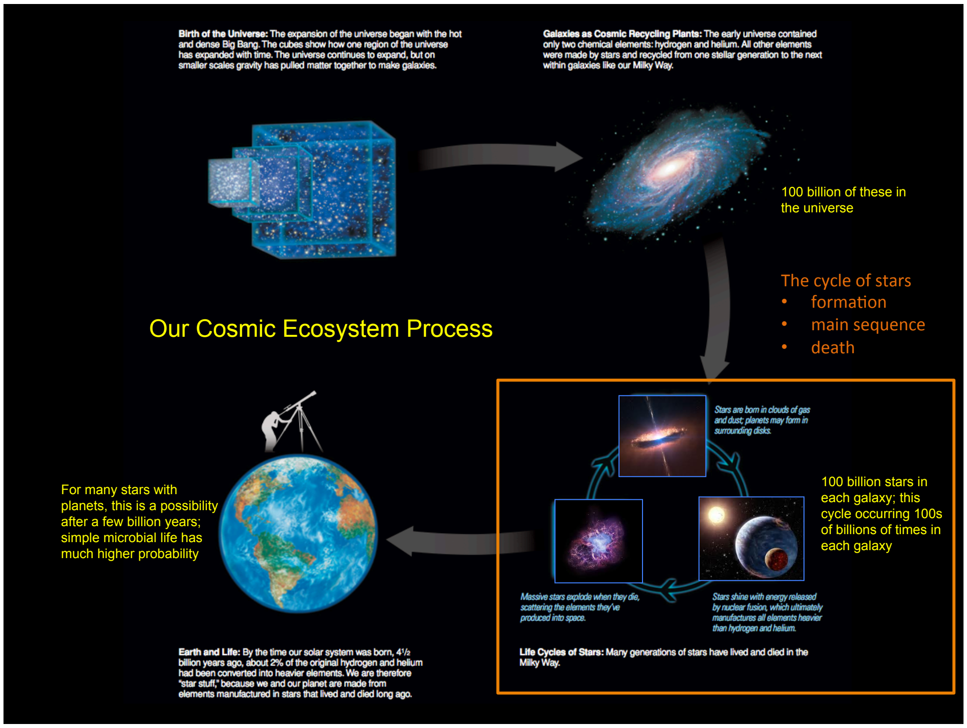
11.3 THE POSSIBILITY THAT EARTH IS RARE

- Are Earth-like planets rare or common?

THE PROCESS OF SCIENCE IN ACTION

11.4 CLASSIFYING STARS

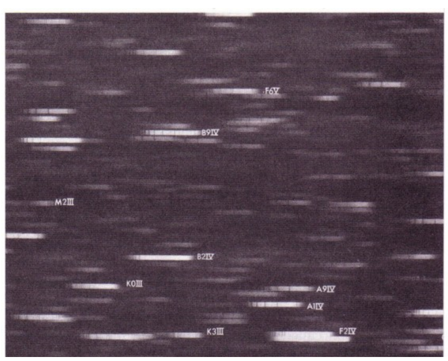
- How and why did the Hertzsprung–Russell diagram develop?
- What can we learn from the Hertzsprung–Russell diagram?



How do We Classify Stars?

Need to classify them, then learn their physical properties….

A, B, C, D, E, … O based upon strength of hydrogen absorption lines
Created a Spectral Sequence O, B, A, F , G, K, M (from hottest to coolest)

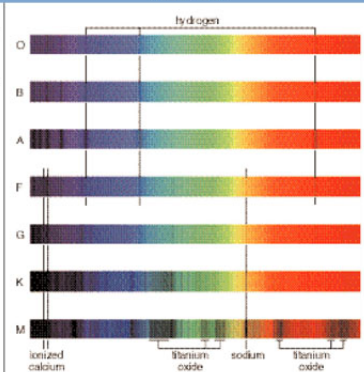


The Harvard Computers of William Pickering. These women PhDs measured, analyzed, and categorized 10s of thousands of stars for the first time in 1900-1910.

How do We Classify Stars?

Table 16.1 The Spectral Sequence

	Spectral Type	Example(s)	Temperature Range	Key Absorption Line Features	Brightest Wavelength (color)	Typical Spectrum
Hottest →	O	Stars of Orion's Belt	>30,000 K	Lines of ionized helium, weak hydrogen lines	<97 nm (ultraviolet)*	
	B	Rigel	30,000 K–10,000 K	Lines of neutral helium, moderate hydrogen lines	97–290 nm (ultraviolet)*	
	A	Sirius	10,000 K–7,500 K	Very strong hydrogen lines	290–390 nm (violet)*	
	F	Polaris	7,500 K–6,000 K	Moderate hydrogen lines, moderate lines of ionized calcium	390–480 nm (blue)*	
Sun →	G	Sun, Alpha Centauri A	6,000 K–5,000 K	Weak hydrogen lines, strong lines of ionized calcium	480–580 nm (yellow)	
	K	Arcturus	5,000 K–3,500 K	Lines of neutral and singly ionized metals, some molecules	580–830 nm (red)	
Coolest →	M	Betelgeuse, Proxima Centauri	<3,500 K	Molecular lines strong	>830 nm (infrared)	



How do We Classify Stars?

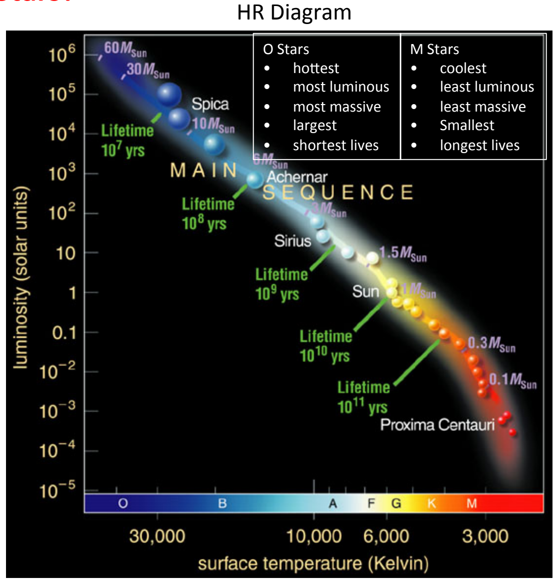
Temperature correlates with all other properties

But the most important property is mass, because this dictates the gravity and hydrostatic equilibrium.

Stars order themselves neatly on a diagram of luminosity versus temperature, called the [Hertzsprung-Russel Diagram]

The Sun is a G-Type star

HR Diagram



What kind of stars are Best?

G and K stars the best?

- There are lots of these stars; nature creates lower mass stars in more abundance
- They have moderate luminosities that peak in the visible part of the spectrum
- They are very long lived; 10s of billions of years, long enough for life to evolve

Spectral Type	Approximate Percentage of Stars in This Class	Surface Temperature (°C)	Luminosity (solar units)	Mass (solar units)	Lifetime (years)
O	0.001%	50,000	1,000,000	60	500 thousand
B	0.1%	15,000	1,000	6	50 million
A	1%	8,000	20	2	1 billion
F	2%	6,500	7	1.5	2 billion
G	7%	5,500	1	1	10 billion
K	15%	4,000	0.3	0.7	20 billion
M	75%	3,000	0.003	0.2	600 billion

UV too intense

Too short lived

Just right?

HZ too small?

M Stars the best?

Habitable zones are narrow and close in; planets would become tidally locked.
Actually, M stars are being looked at with much greater optimism these days….

What kind of stars are Best?

The more luminous the star, the wider the habitable zone; the wider the habitable zone, the higher the probability of finding planets in the zone.

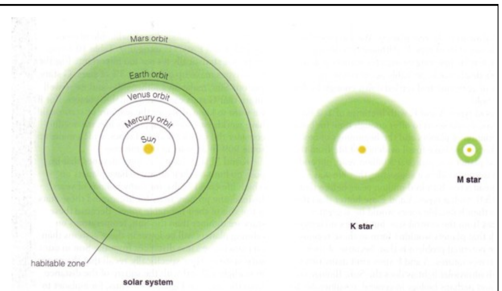
Still, we need to consider how long the star lives, what type of radiation it emits, and how common the type of star is.

G stars have bigger habitable zones than K stars, but K stars are longer lived and more common than G stars. M stars are the longest lived stars.

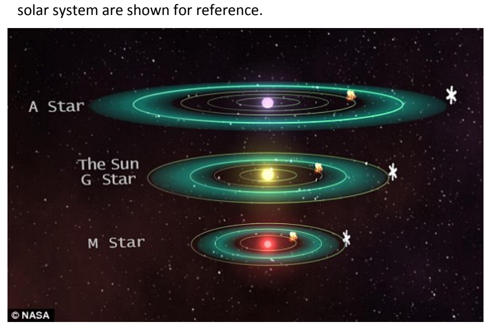
It's a probability calculation problem…
The volume of the habitable zone for stars of a given type times the density distribution of planets around stars of different types, times the abundance of the stars of those types, etc.

M stars win.

G and K stars strong contenders.

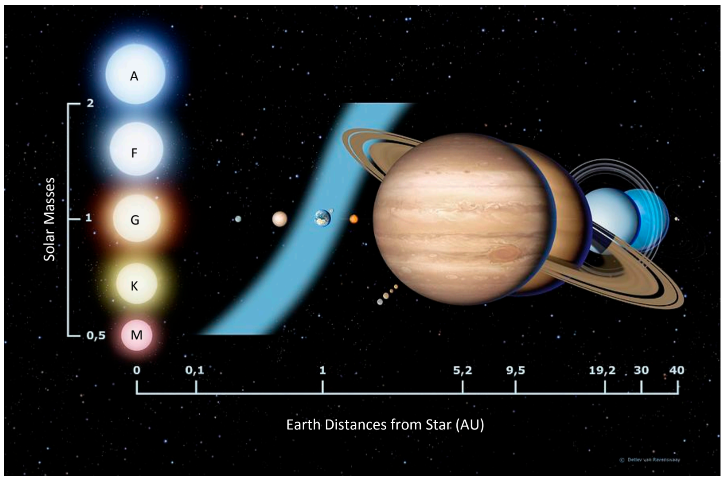


Diagrams of how the habitable zone location is different around stars of different spectral classes. The orbits of the planets in our solar system are shown for reference.



What kind of stars are Best?

Another version of how the habitable zone changes with spectral class



What are the Current Estimates for Habitable Planets?

PHL = Planetary Habitability Laboratory

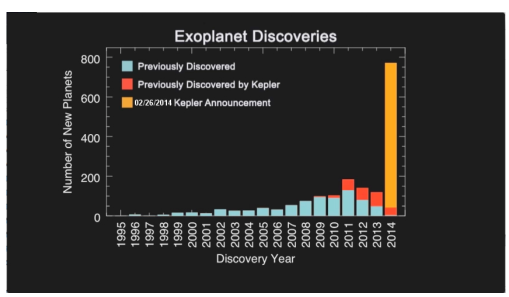
This group uses all the latest data and computes the estimated number of habitable planets!

MAPPING THE HABITABLE UNIVERSE

In stellar neighborhood: (within 33 lightyears)
Total : 132-160
M type stars : 126-151
Solar-like stars : 6-9

In Milky Way Galaxy:
Total : 40-49 billion
M type stars : 38-46 billion
Solar-like stars : 2-3 billion

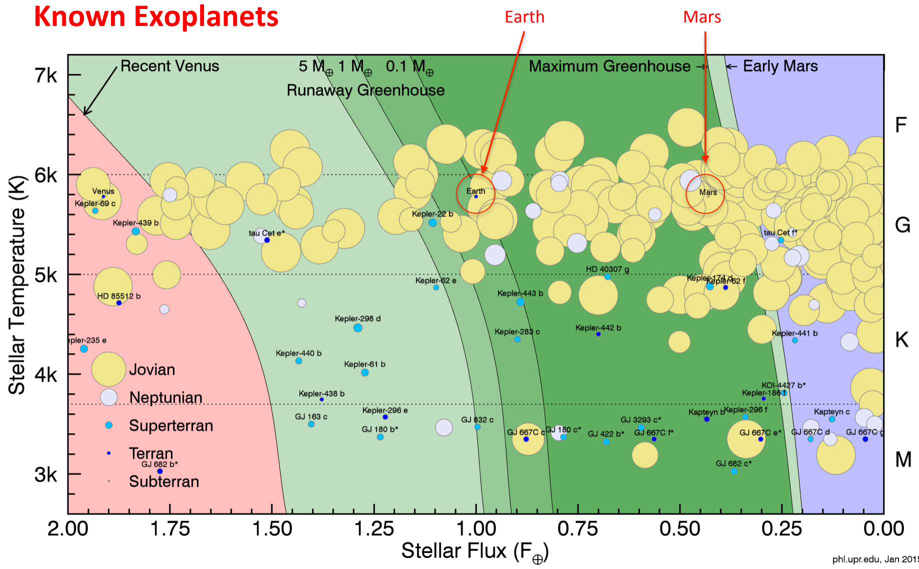
In Observable Universe:
Total : 4.2-5.5 trillion
M type stars : 4.0-5.0 trillion
Solar-like stars : 0.2-0.3 trillion



For reference, here is the number of exoplanets discovered by years.
This includes ALL type of planets, regardless of Earth Similarity Index.

Even with our little neighborhood of the Milky Way, there may be about 150 habitable planets!!!
But they will predominantly be around M type stars!

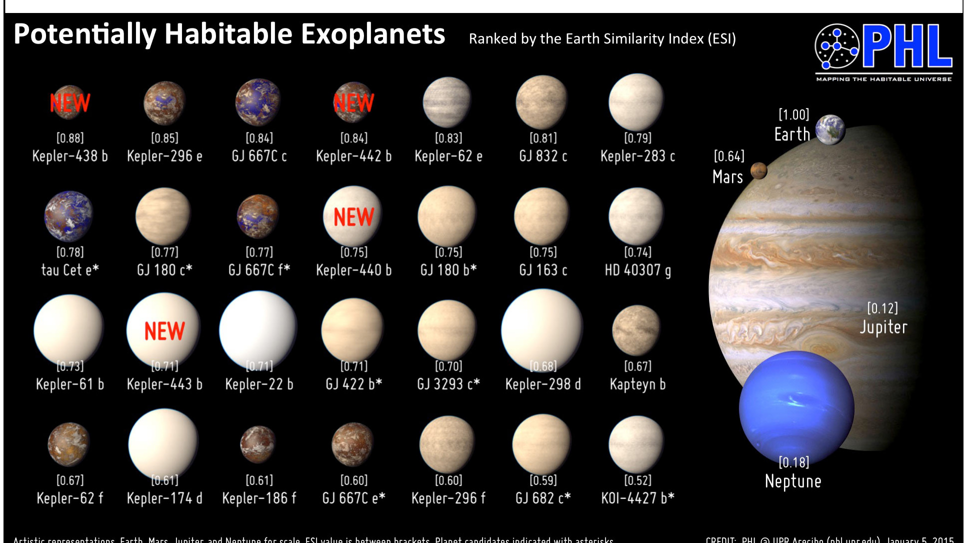
Known Exoplanets



The figure above shows all planets near the habitable zone (green shades). Only those less than 10 Earth masses or 2.5 Earth radii are labeled. Some are still unconfirmed (* = unconfirmed). Size of the circles corresponds to the radius of the planets (estimated from a mass-radius relationship when not available).

Notable Exoplanets

ESI = Earth Similarity Index



As of January 2015

Finding Life on an Exoplanet

Tough Business

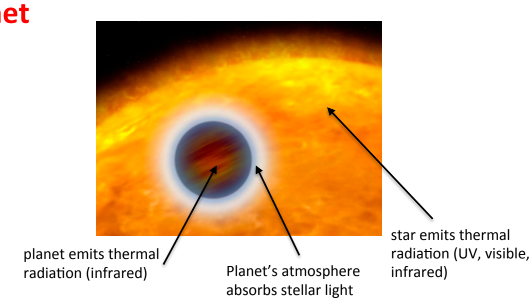
At this stage, we can only make "detailed" observations of the atmospheres of exoplanets

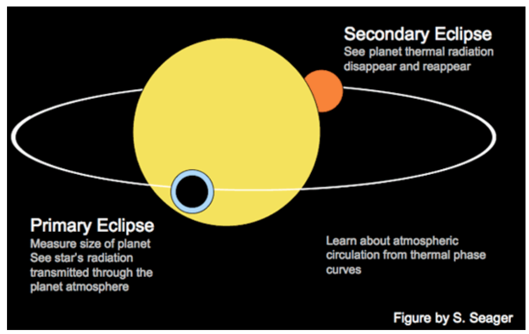
We measure the chemical make up and temperature of the planet using spectroscopy.

We can not resolve the stars or planets, so this spectrum is of both together

We measure the stars spectrum when the planet is behind the star, and then measure the spectrum when it is in front of the star; we "difference" the two spectra and can then measure the spectral signatures from the planet

The spectral signatures provide the chemical make up and temperature of the planet's atmosphere.

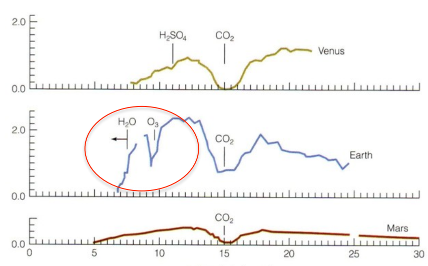




Finding Life on an Exoplanet

Old School: Look for Ozone and Water?

Take a spectrum of the planet in the infrared, where ozone, carbon dioxide, and water absorb and scatter light… (greenhouse window).



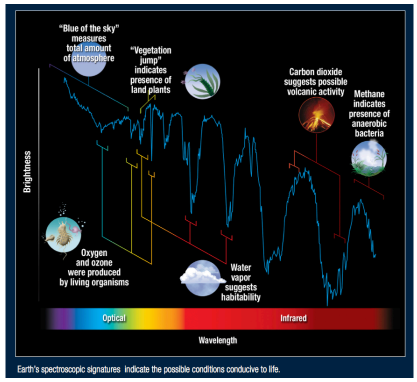
Earth shows water vapor and ozone; oxygen and ozone are products of life on Earth, so we thought this would be a pretty good indirect indication of life on an exoplanet.

Finding Life on an Exoplanet

Today's View

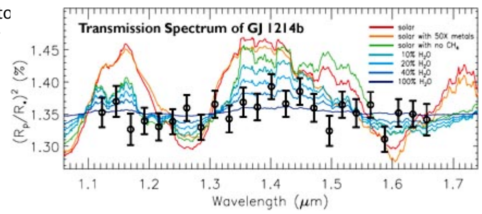
Now we look for a wide variety of much more direct indicators:

- blue of the sky
- ozone + oxygen
- vegetation features
- water vapor
- carbon dioxide
- methane

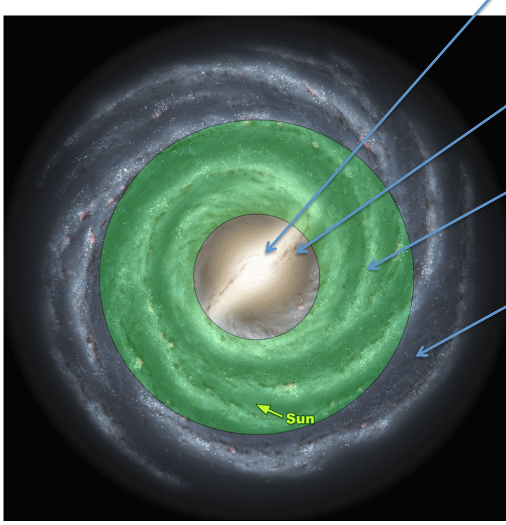


Spectrum of GJ 121 4b compared to models with different water vapor content in the atmosphere

The data are still pretty crude, but come back in 20 years- we'll have this nailed



Galactic Habitability Factors

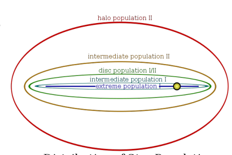


inner region: star density too high; in early times too many supernovae disrupt planet formation; even surviving old M stars would probably not have formed planets; now star formation is too low

bar: instability causes stars to migrate and cross density waves of gas and stars; too much chaos for stable planetary systems

intermediate zone: supernova rates constant with time, rates high enough and stars far enough apart to induce a galactic ecosystem of planets with metals

outer region: stellar density and star formation low, too few supernovae explosion to distribute metals



Distribution of Star Populations in Milky Way

Population 1 stars have the highest metallicity (chemical elements other than hydrogen and helium). Thus the galactic habitable zone is probably confined to the thin disk of the galaxy.