# What I know today about the Final

- Tuesday, December 10, 8 – 11 am, same place
- Around 80-90 multiple choice / T-F questions
- Closed book and closed note
- No smartphones allowed
- Calculators of any kind are permitted, but the math can be readily done without them
- Equation Sheet Provided
- Around 40% old stuff, 60% new stuff
- **Bring a #2 pencil!**
- **Know your Student ID**

# What I know today about the Final

- Chris and Emily will proctor the Exam
- It is 35% of your quarter grade
- Review Sessions with Chris and Emily
    - Thursday Night
    - Sunday Night
- TA Discussion Sections and Office Hours will happen as planned
- Study Guide is being created
- We will provide Scantrons....
- I will be at a conference on Monday/Tuesday

# Grades so far

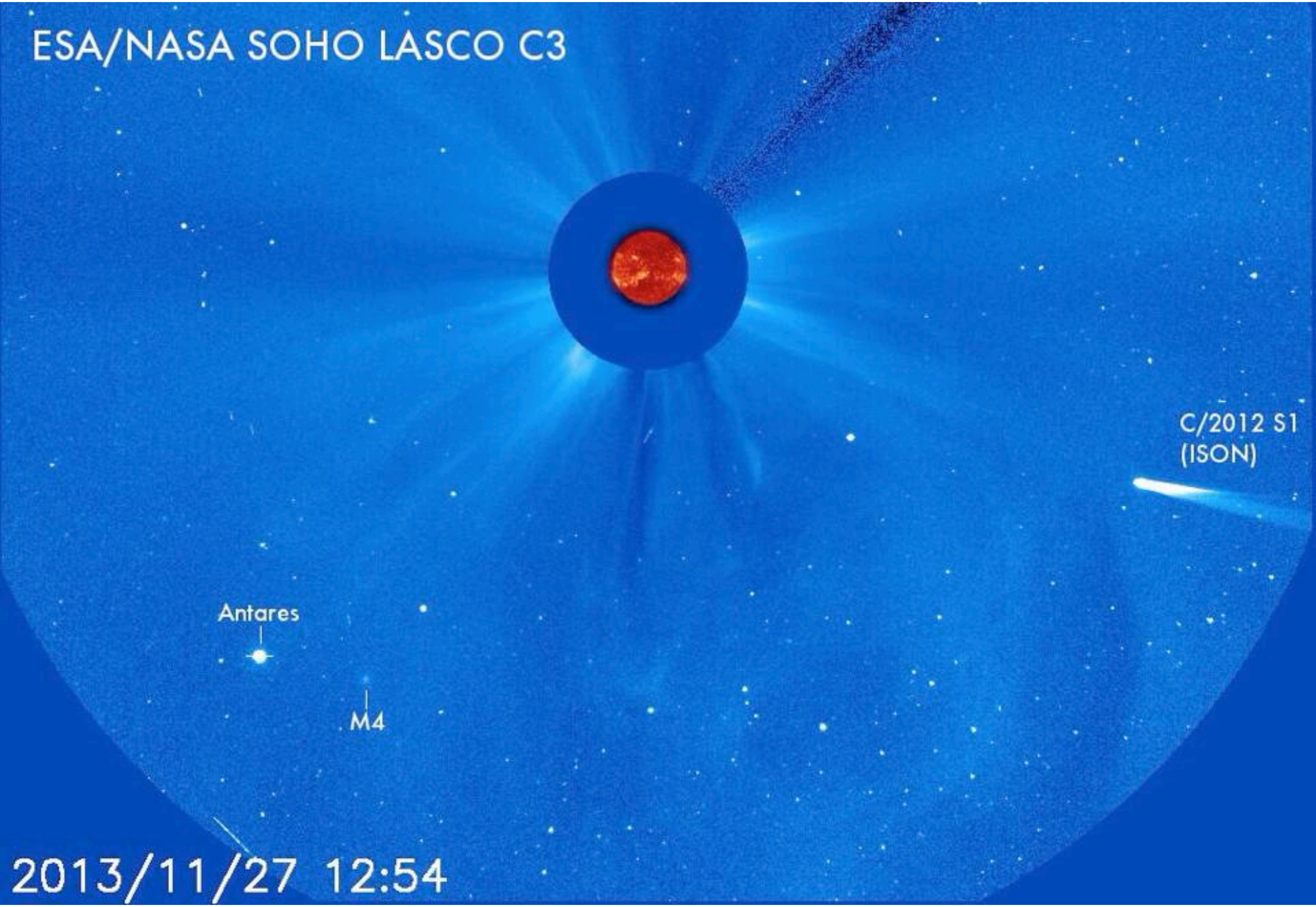
- All HWs have been turned in
- Clicker questions very nearly done
- I will make a tentative grade breakdown based on the HWs, midterms, and clickers, and post that to MA by *Thursday*
    - You'll be able to see where you stand, pre-final

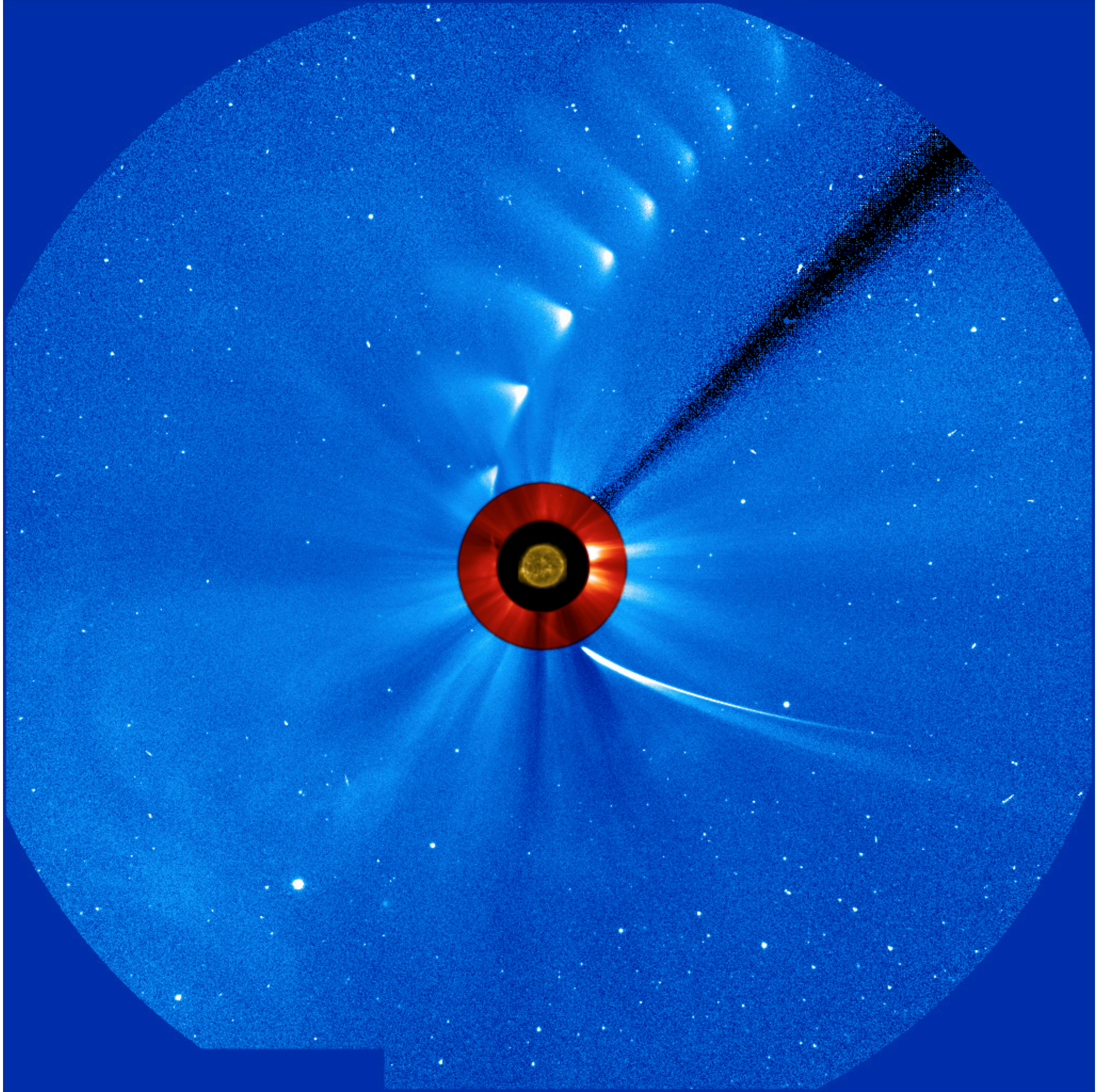
# Online course evaluations

- Please do them before the final exam
- They are important to me, Chris, and Emily for feedback on how the class and discussion sections were run and structured
- Will help to improve the class next time
- When I come up for review, I get judged both on the quality of my teaching (via the evaluations) and the fraction of the evals that actually get filled out

# In the News

- Comet ISON
- Had a very close approach to the Sun
- Was visible in the very early morning before closest approach
- Would have been visible after sunset after closest approach, but…..
- Didn’t make it!


ESA/NASA SOHO LASCO C3
C/2012 S1
(ISON)
Antares
M4
2013/11/27 12:54



# For radial velocity detection: The orbital period of an unseen planet

A. will be the same as period of the star's Doppler shift.
B. will be much longer than the star's.
C. will be much shorter than the star's.

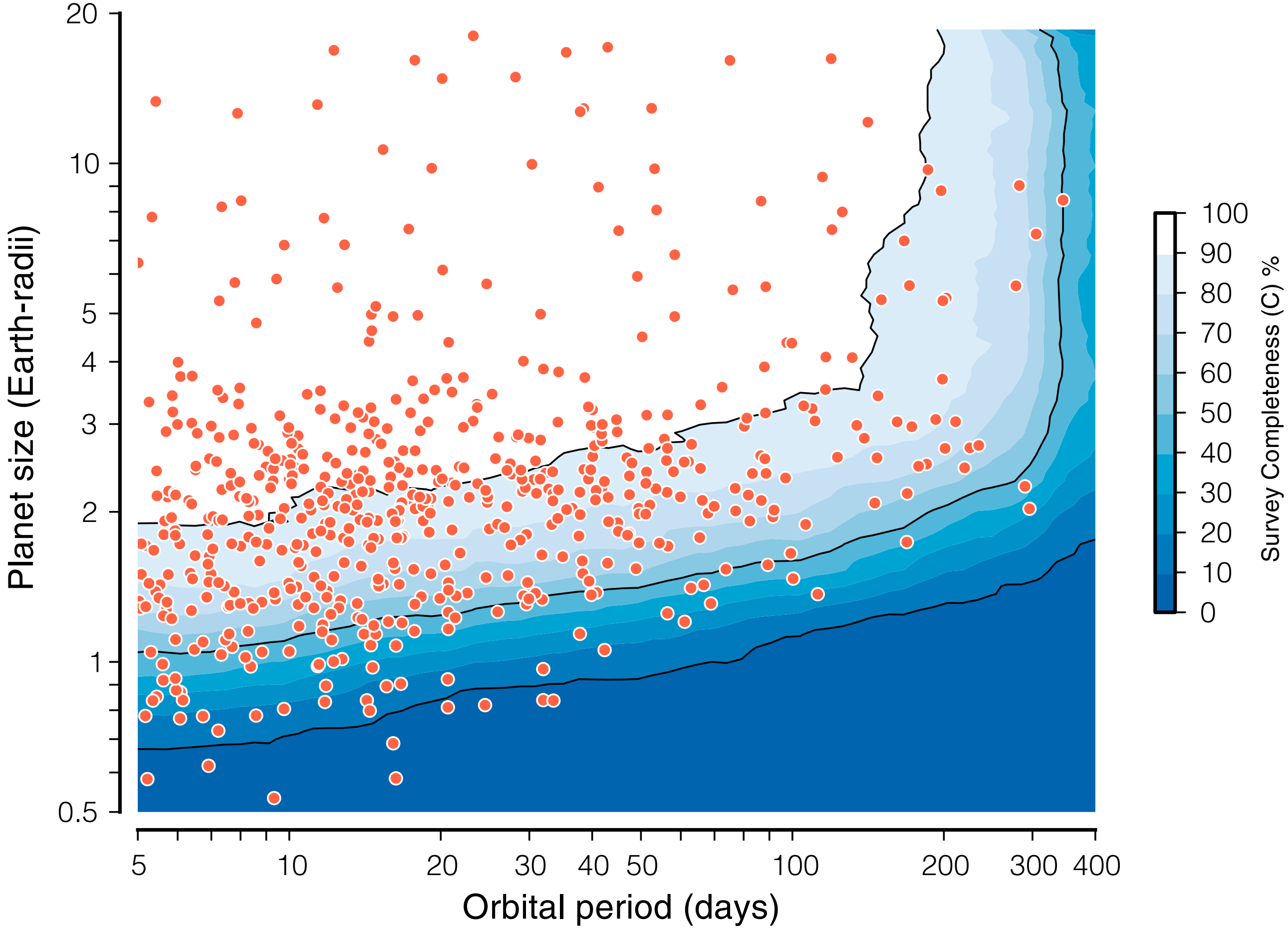
# For radial velocity detection: The orbital period of an unseen planet

***A. will be the same as period of the star's Doppler shift.***

B. will be much longer than the star's.

C. will be much shorter than the star's.

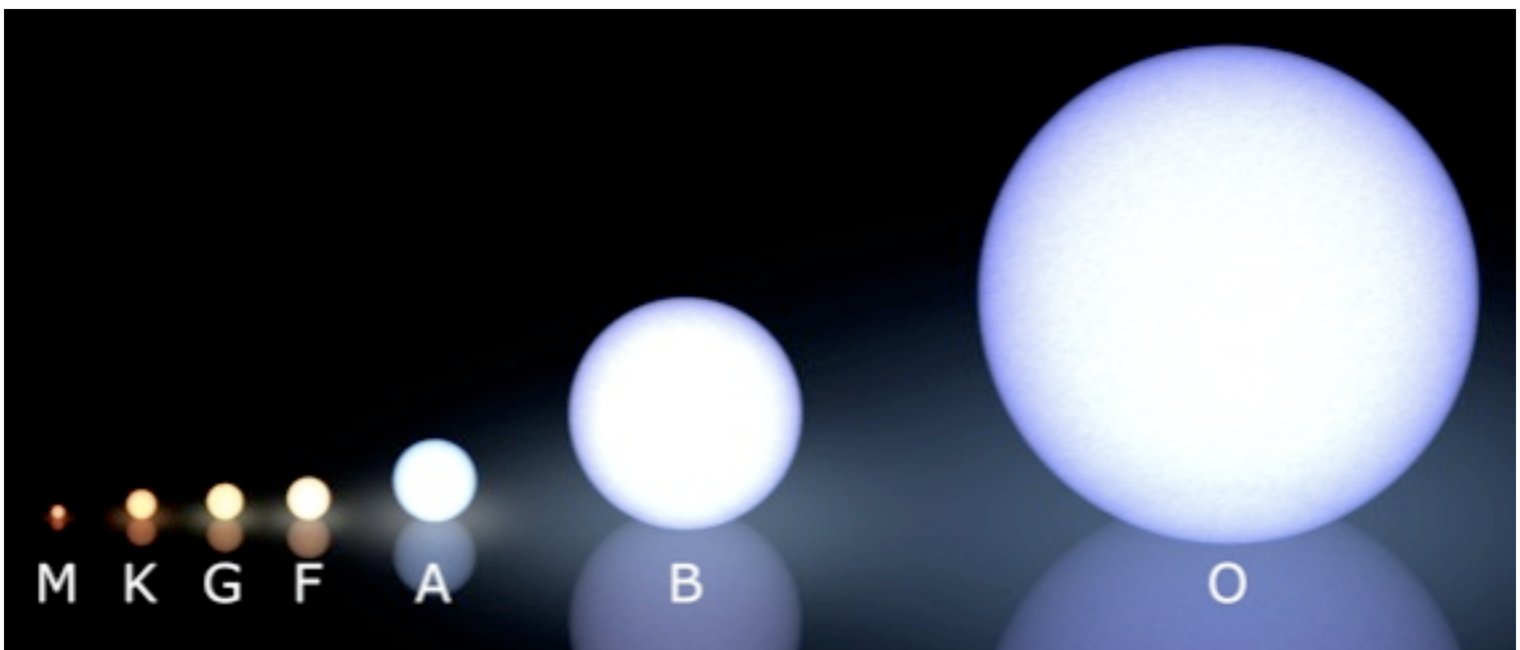
# Real Kepler Planets: How Common Are Planets?




You must determine the properties of the planets that you are seeing, and the planets that you are missing!

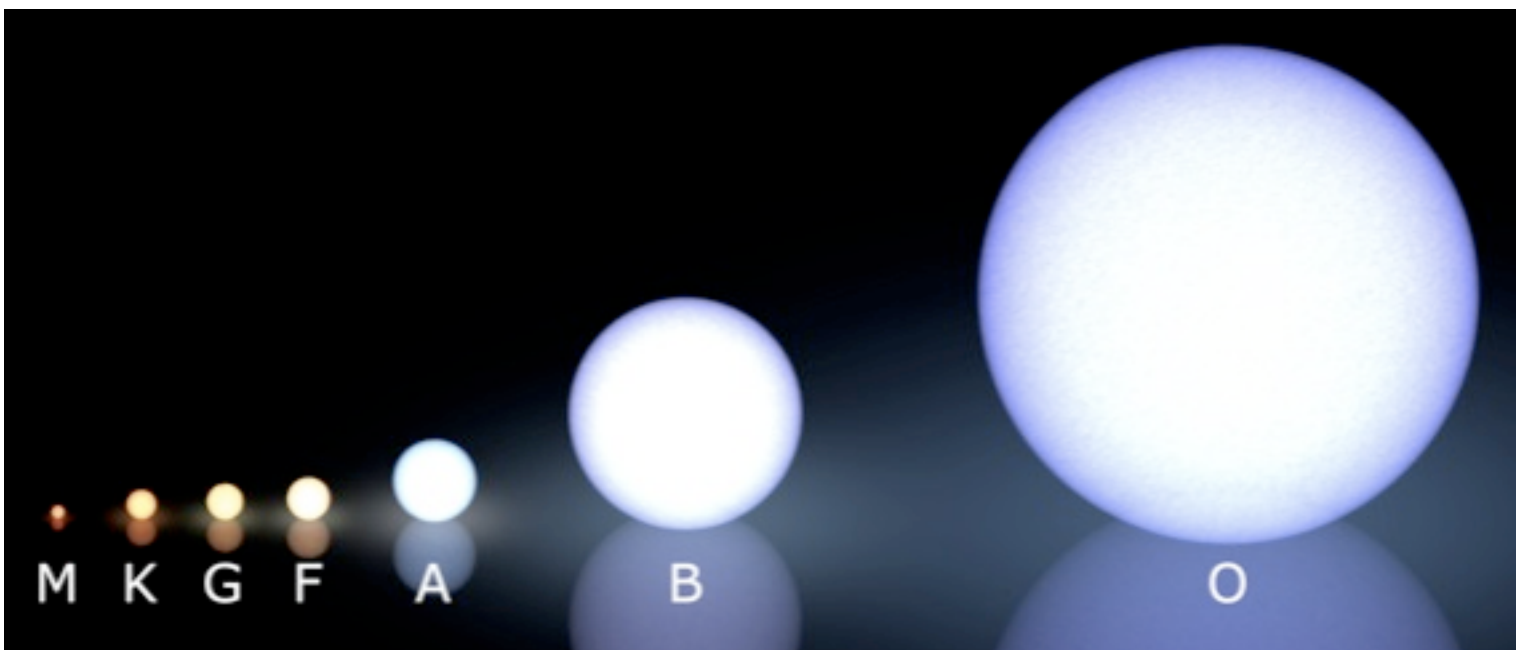
# Planets: Common or Rare?

- Faint M stars, which make up 70% of all stars, have about 1.5 planets with radii > 0.7 $R_{Earth}$, within 80 days of the star
  - Around 20-40% of M stars have have an "Earth-sized" (0.7-1.4 $R_{earth}$) at a temperature range where surface liquid water could be possible



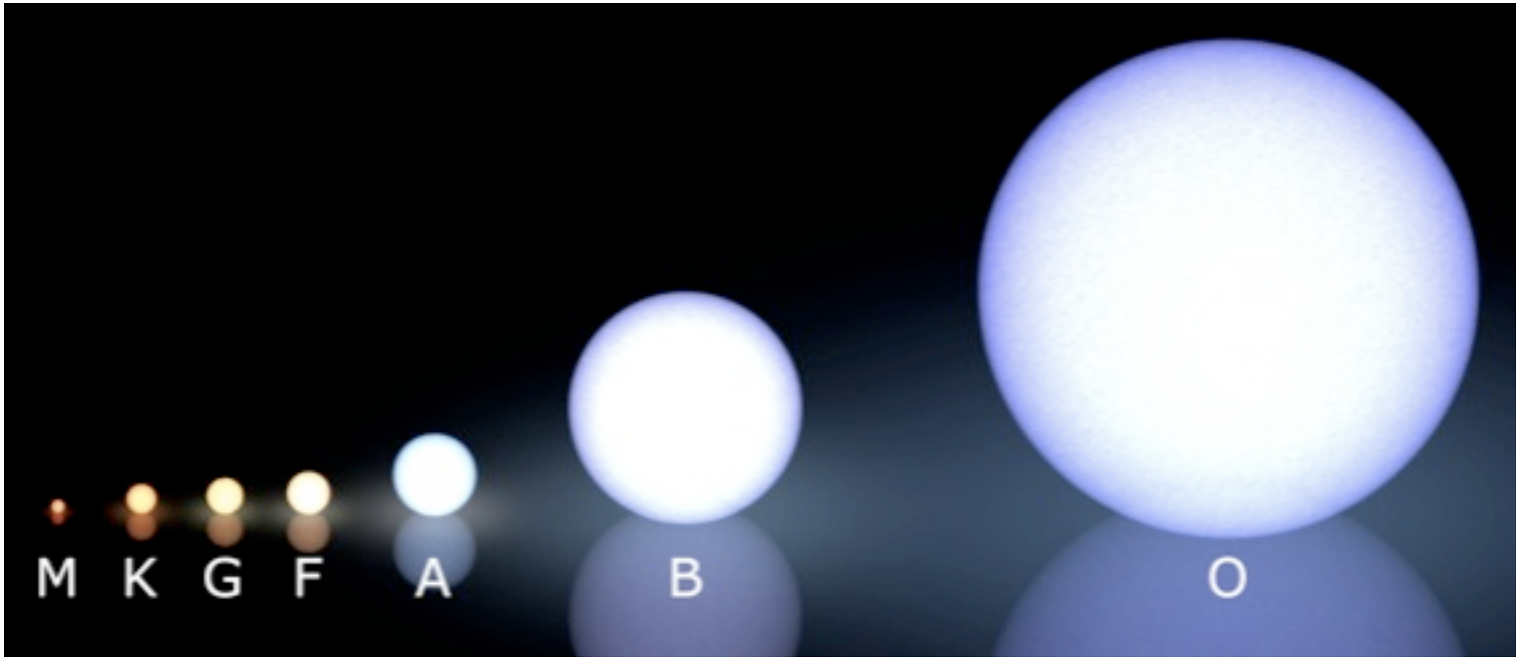
# Planets: Common or Rare?

- For Sun-like stars, about 2/3 of all stars have a planet larger that 1 $R_{Earth}$ within 85 days.
  - Around 5-10% of Sunlike stars have have an "Earth-sized" (1-2 $R_{earth}$) at a temperature range where surface liquid water could be possible



# Planets: Common or Rare?

- For Sun-like stars, about 10-20% of star appear to have a gas giant (Jupiter-like) planet
  - Such planets are mostly on 1-100 AU orbits
- True analogs of our solar system appear to not be the most common outcome of planet formation

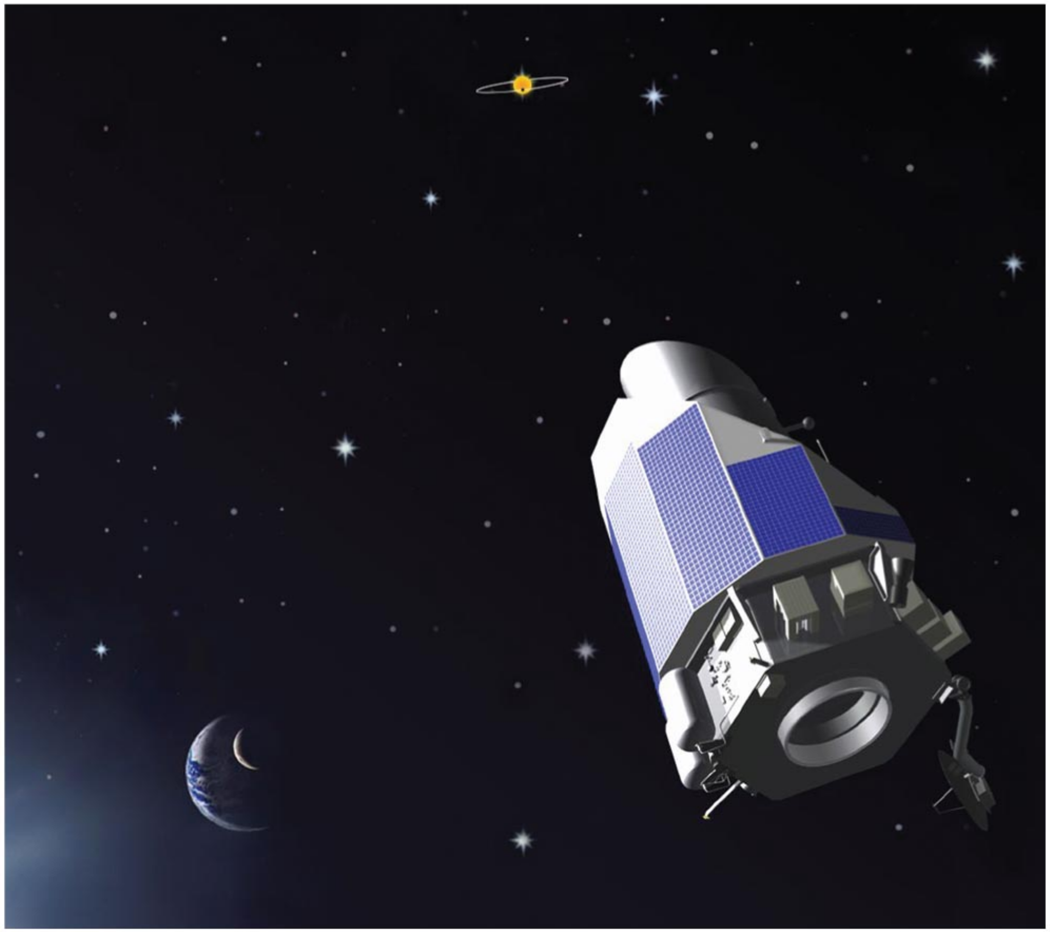


# 13.4 Finding More New Worlds

Our goals for learning:

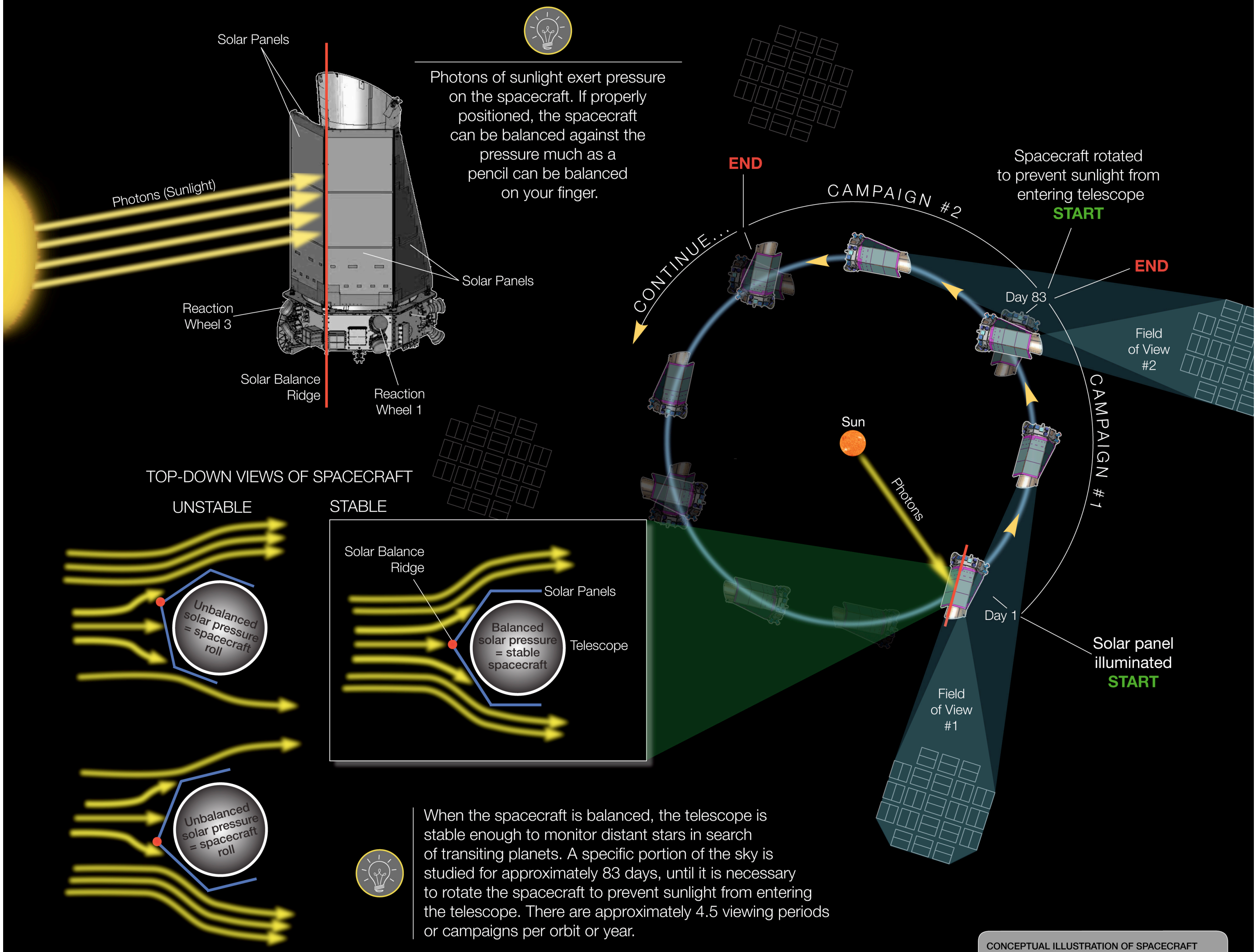
- How will we search for for additional Earth-like planets?
- How will be characterize these planets?

# Transit Missions: What is after Kepler?



- After 4 years, NASA's Kepler Mission was crippled this summer by the loss of a "reaction wheel" (a gyroscope)
- 3 are needed to maintain precise pointing in 3 dimensions
- What can you do with only 2?

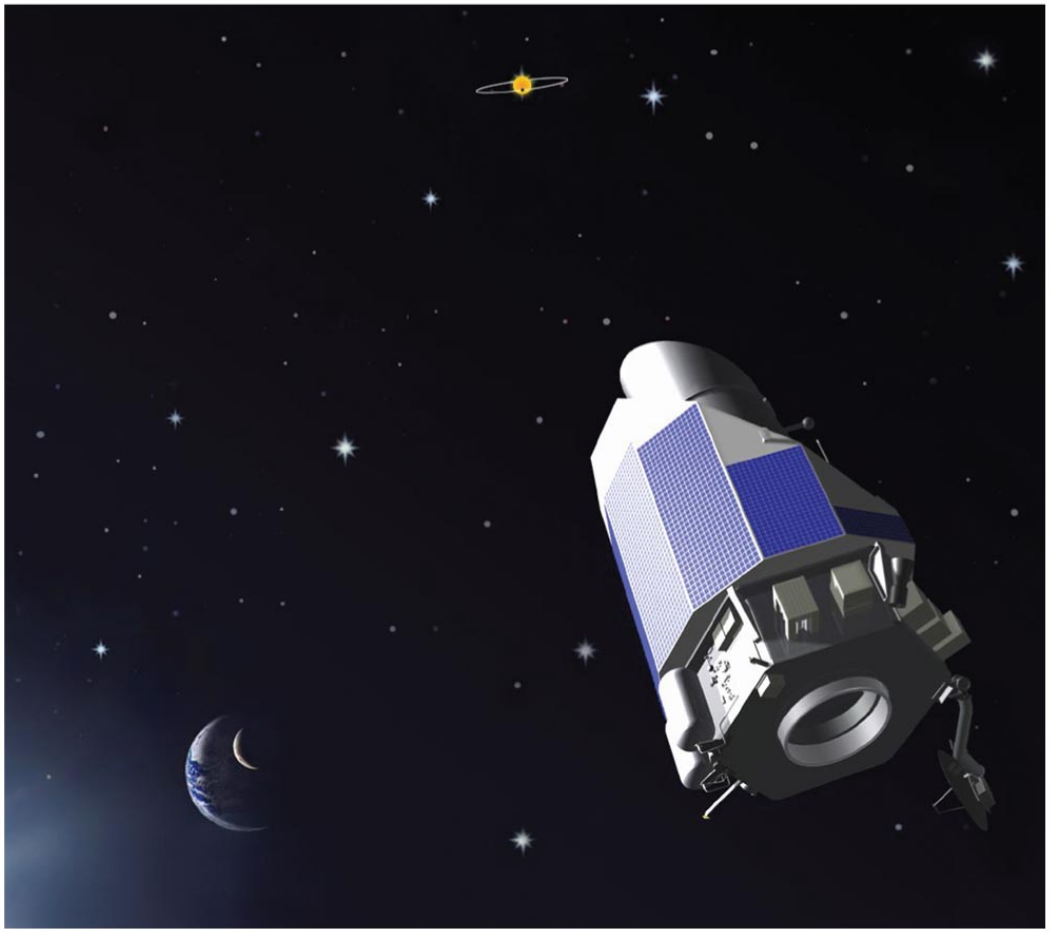
# Kepler's Second Light: How K2 Will Work




When the spacecraft is balanced, the telescope is stable enough to monitor distant stars in search of transiting planets. A specific portion of the sky is studied for approximately 83 days, until it is necessary to rotate the spacecraft to prevent sunlight from entering the telescope. There are approximately 4.5 viewing periods or campaigns per orbit or year.

CONCEPTUAL ILLUSTRATION OF SPACECRAFT SOLAR DISTURBANCE. THE ACTUAL DISTURBANCE IS DUE TO PHOTON PRESSURE, NOT SOLAR WIND.

# Transit Missions: What is after Kepler?



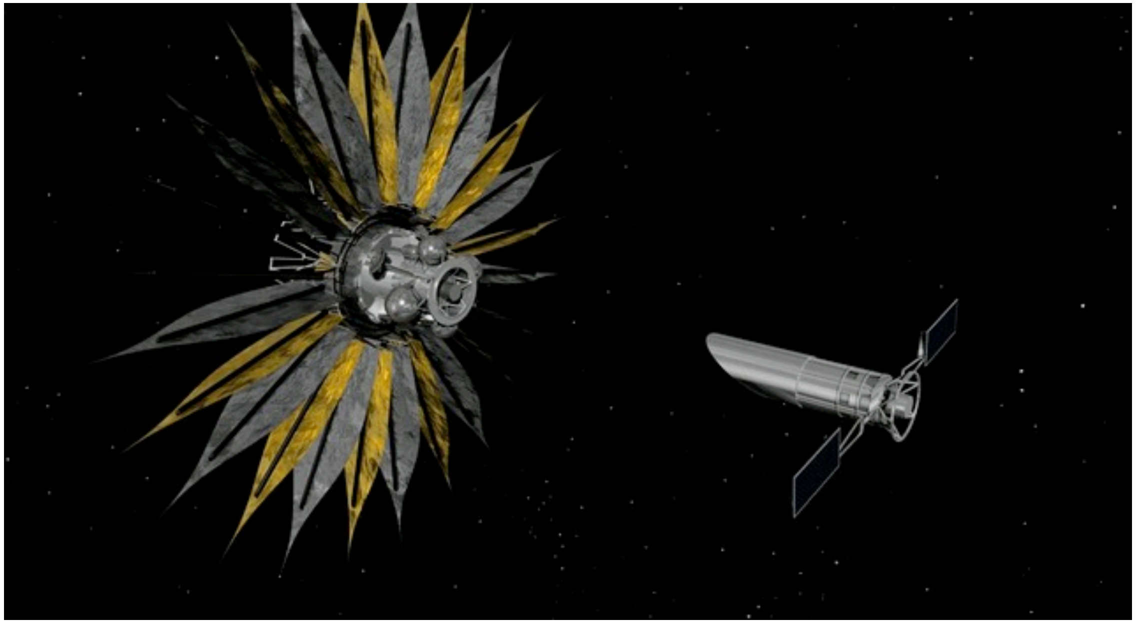
- The proposed “K2” mission would look in the ecliptic to keep constant solar photon pressure
- Could look at a field for about 83 days
- Will likely look at fewer brighter and smaller target stars
- Can find planets in orbits of 27 days, or less

# Future Missions

- *NASA's TESS:* Transiting planets almost as small as Earth, with a focus only on the bright, nearby stars

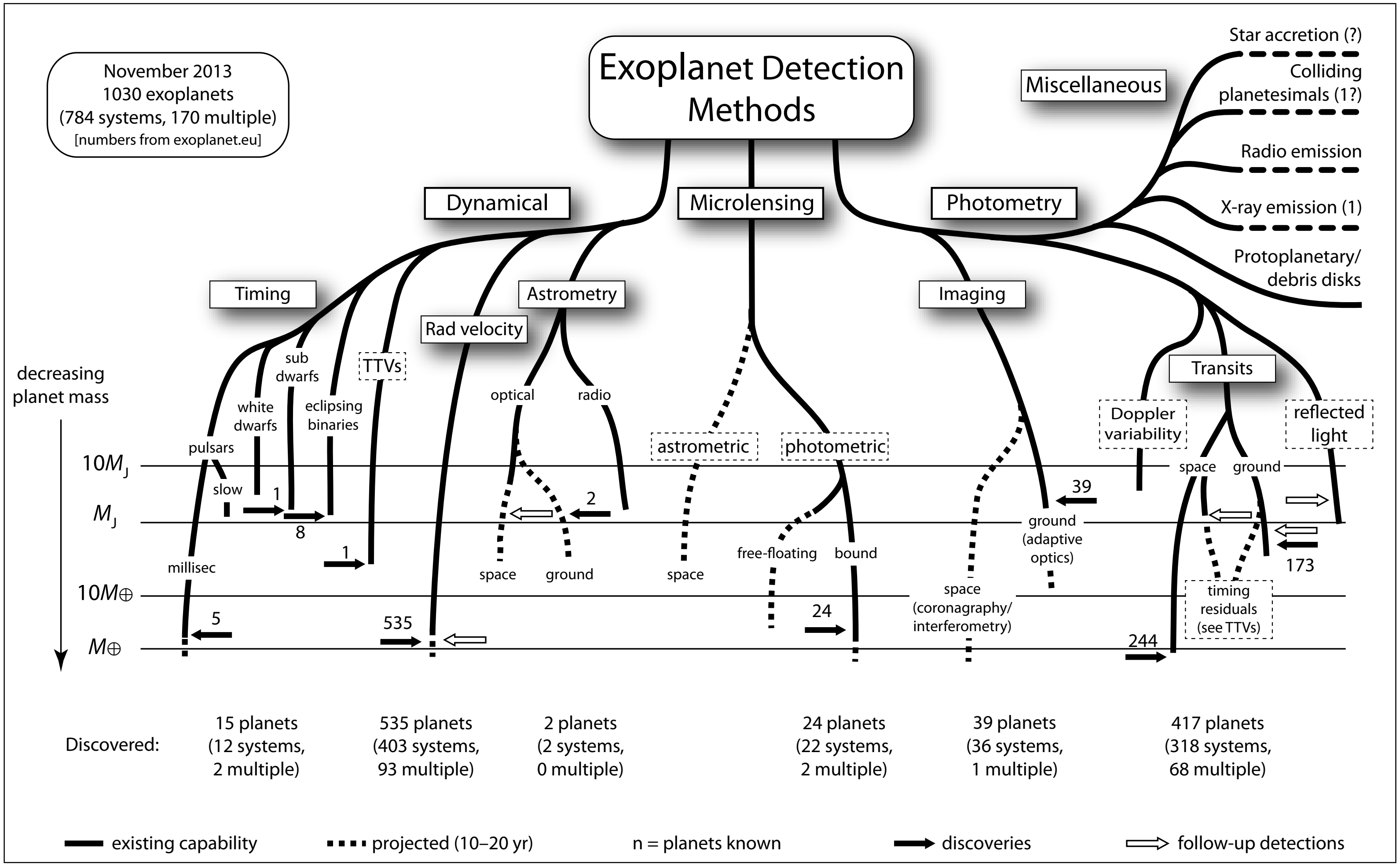
# Future NASA Missions

# Direct Detection



Mission concept for a telescope that could take spectra of Earth-sized planets

- Determining whether Earth-mass planets are really Earth-like requires direct detection.
- Missions capable of blocking enough starlight to measure the spectrum of an Earth-like planet are being planned.



November 2013
1030 exoplanets
(784 systems, 170 multiple)
[numbers from exoplanet.eu]
Exoplanet Detection Methods
Miscellaneous
Star accretion (?)
Colliding planetesimals (1?)
Radio emission
X-ray emission (1)
Protoplanetary/ debris disks
Dynamical
Microlensing
Photometry
Timing
Astrometry
Rad velocity
Imaging
Transits
TTVs
pulsars
white dwarfs
sub dwarfs
eclipsing binaries
slow
millisec
optical
radio
space
ground
astrometric
photometric
free-floating
bound
ground (adaptive optics)
space (coronagraphy/ interferometry)
Doppler variability
reflected light
timing residuals (see TTVs)
decreasing planet mass
10MJ
MJ
10M⊕
M⊕
1
8
1
5
535
2
24
39
173
244
Discovered:
15 planets (12 systems, 2 multiple)
535 planets (403 systems, 93 multiple)
2 planets (2 systems, 0 multiple)
24 planets (22 systems, 2 multiple)
39 planets (36 systems, 1 multiple)
417 planets (318 systems, 68 multiple)
existing capability
projected (10–20 yr)
n = planets known
discoveries
follow-up detections

# What have we learned?

- How will we search for Earth-like planets?
  - Transit missions are capable of finding Earth-like planets that cross in front of their stars.
  - Radial Velocity and Astrometric missions will eventually be capable of measuring the “wobble” of a star caused by an orbiting Earth-like planet.
  - Missions for direct detection of an Earth-like planet will need to use special techniques for blocking starlight.

# 24.3 Life around Other Stars

- Our goals for learning:
  - **What kinds of star might have habitable planets?**
  - **Are Earth-like planets rare or common?**

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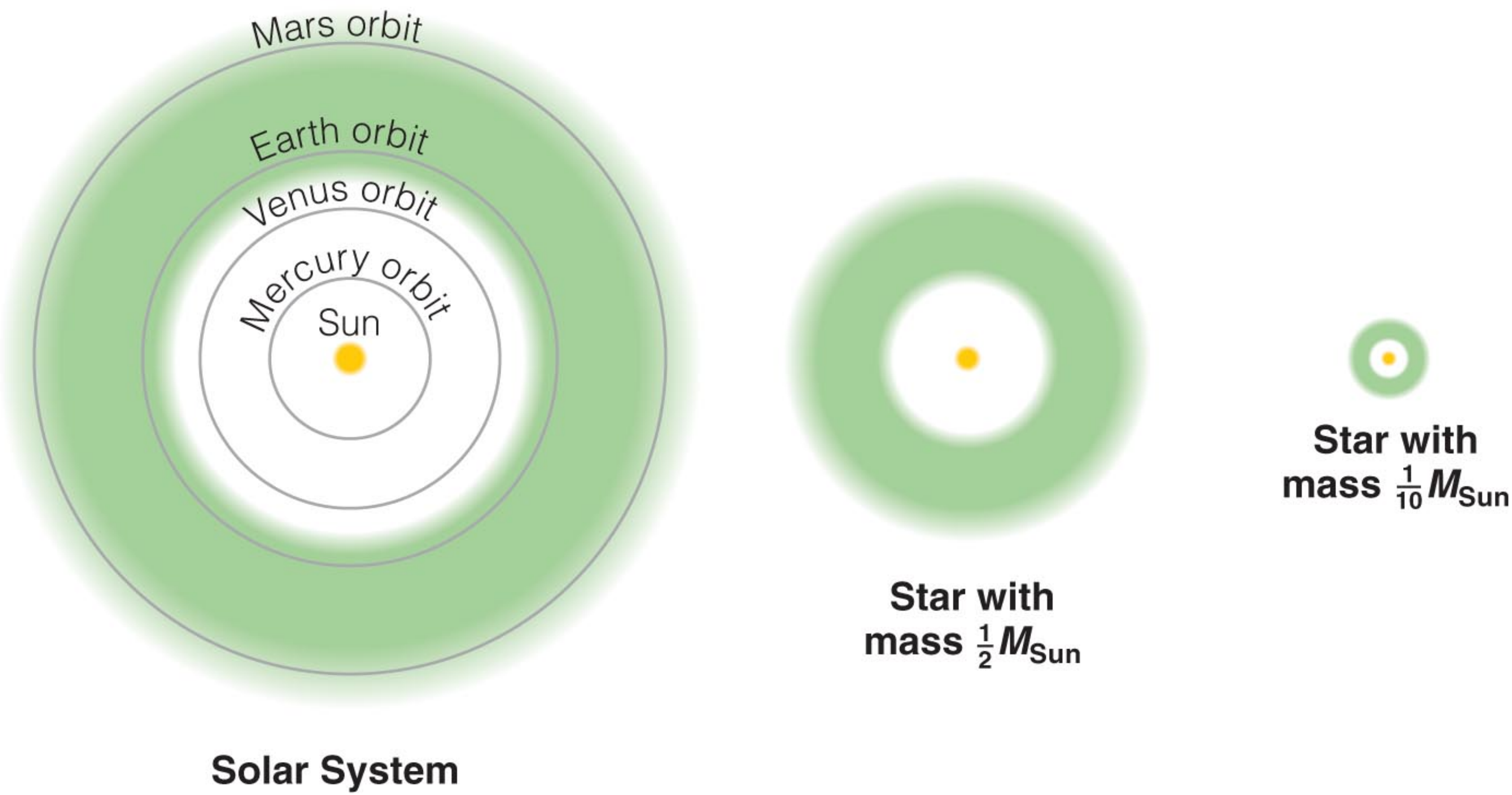
# What kinds of stars might have habitable planets?

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# Habitable Planets

- Definition:
  - A **habitable** world contains the basic necessities for life as we know it, including liquid water.
  - It does *not* necessarily have life.

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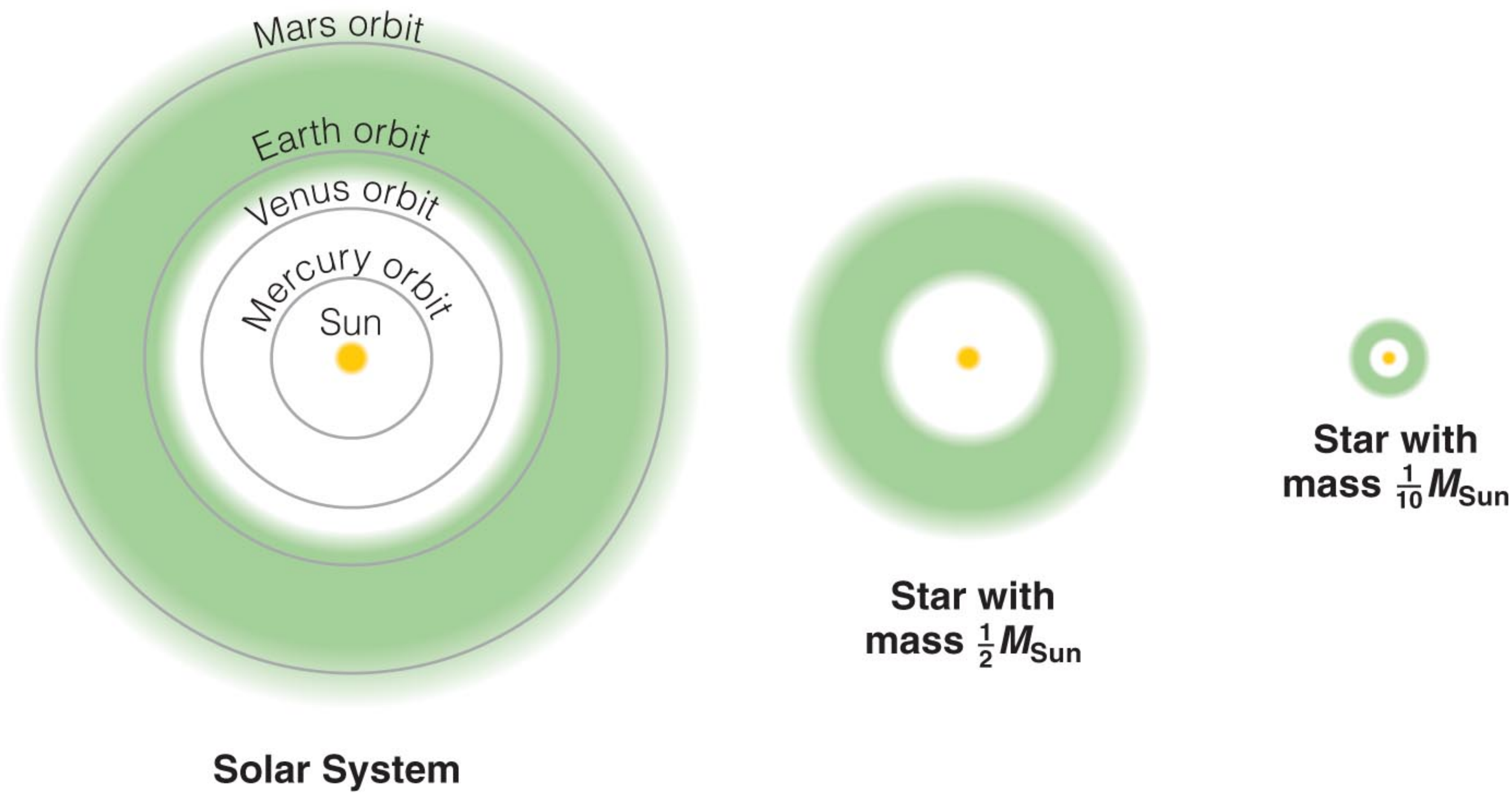
- Star system constraints:
  1) Old enough to allow time for evolution (rules out high-mass stars - 1%)
  2) Need to have stable orbits (*might* rule out binary/multiple star systems - 50%)
  3) Size of "habitable zone": region in which a planet of the *right size* could have liquid water on its surface

- Even with these constraints, billions of stars in the Milky Way could potentially have habitable worlds.



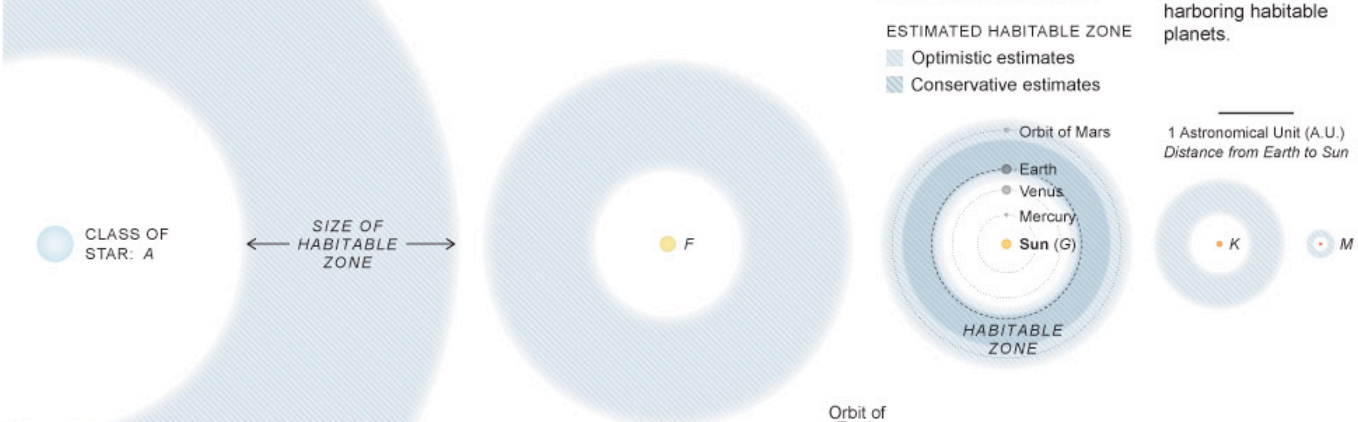

- The more massive the star, the larger its habitable zone— and the higher probability of a planet existing in this zone – <u>all things being equal, which they are not!</u>

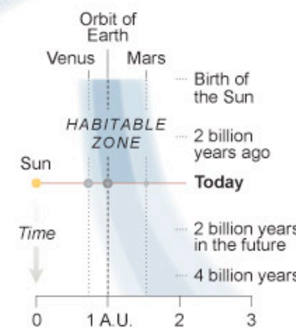
**MASSIVE, CLASS A STARS** are about 20 times brighter than the Sun, with wide habitable zones. But the stars are rare and short-lived, leaving only a billion years for orbiting planets to form and for life to develop.

**LARGE, CLASS F STARS** are also rare, making up only 2 percent of all stars. But with a lifetime of several billion years, the stars could provide ample time for life to form, making them tempting targets for planet hunters.

**THE SUN** is a class G star. Earth orbits near the inner edge of the habitable zone, and Venus and Mars come close, depending on whether researchers use optimistic or conservative estimates for the Sun's habitable zone.

**SMALL, DIM STARS** have relatively small habitable zones but are very numerous and long lived. Class K, G and F stars are thought to be the best candidates for harboring habitable planets.



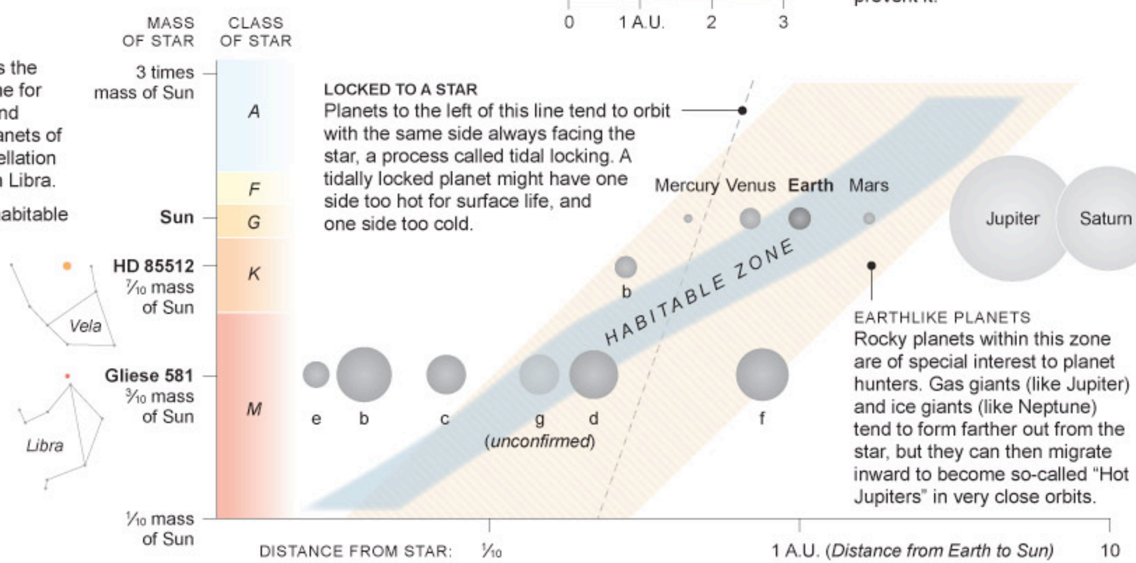

**AN AGING SUN**
Stars brighten with age, and the early Sun was about 30 percent less luminous than it is now.

As the Sun ages, its habitable zone will continue to shift outward. In several billion years Earth's water will evaporate away, unless future inhabitants relocate or use technology to prevent it.

**A SLIDING SCALE**
The chart at right shows the estimated habitable zone for different sizes of star, and highlights known exoplanets of HD 85512, in the constellation Vela, and Gliese 581, in Libra.

An orbit in or near the habitable zone does not ensure surface water. Earth's moon, atmosphere, mass, volcanic and tectonic activity all contributed to habitability.

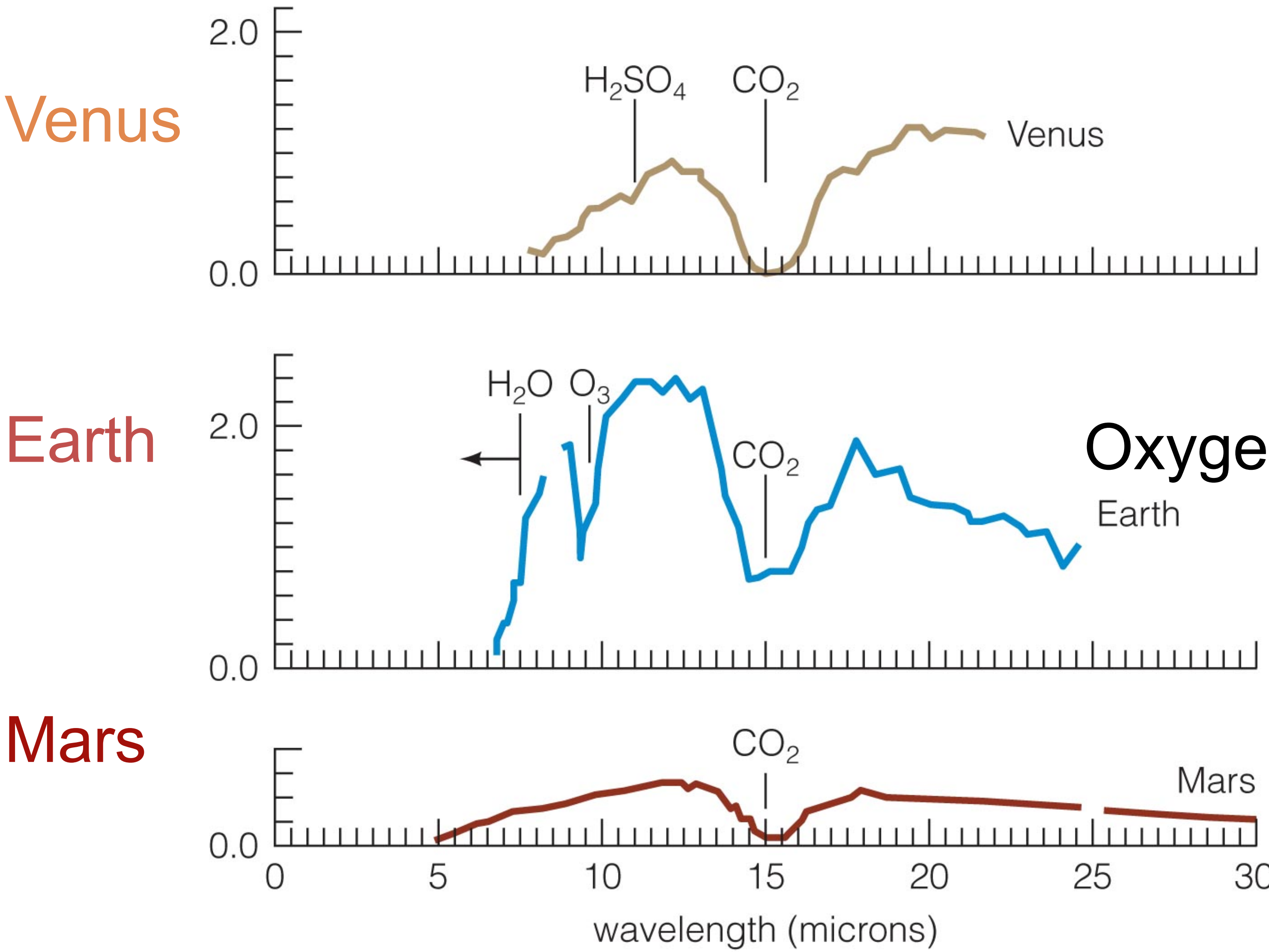
Astronomers stress that distant exoplanets will require more than a good orbit to support surface water and the possibility of life.



# Finding them will be hard

- Recall our scale model solar system:
  - Looking for an Earth-like planet around a nearby star is like standing on the East Coast of the United States and looking for a pinhead on the West Coast—with a VERY bright grapefruit nearby.
  - But new technologies will allow us to search for such planets.

# Spectral Signatures of Life




Oxygen/ozone

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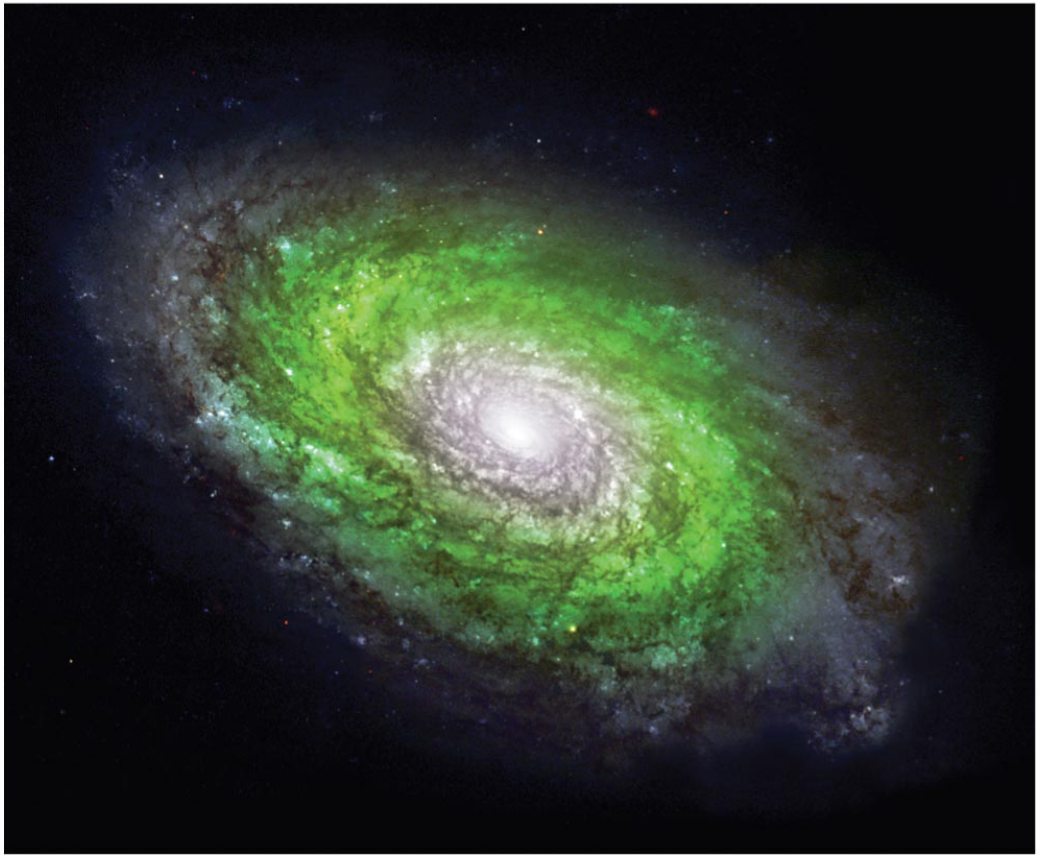
# Elements and Habitability



- Some scientists argue that the proportions of heavy elements need to be just right for the formation of habitable planets.
- If so, then Earth-like planets are restricted to a galactic habitable zone.