Planets Beyond the Solar System

The New Astronomical Revolution

by Cheryl Harper

A lesson based on information from:

UC Santa Barbara Kavli Institute Conference - March 27, 2010

- Alan Boss - Carnegie Inst. Of WA
  - author - The Crowded Universe: The Search for Living Planets
- Adam Burgasser – UC San Diego
- Debra Fischer – Yale University
- James Kasting – Penn State University
  - author - How to Find a Habitable Planet

An exoplanet is...

★a planet that orbits a star in a solar system other than ours.

★sometimes called an extrasolar planet.

According to **The Extrasolar Planets Encyclopaedia (August 2010)** there are 474 currently detected exoplanets.

So how difficult is it to locate an exoplanet?

Not easy, but there are many ways. Here are a few…

- Direct Imaging
- Astrometry
- Radial velocity (Doppler method)
- Transit Method
- Gravitational Microlensing

Direct Imaging:

observing visible or infrared light produced by or reflected from the exoplanet

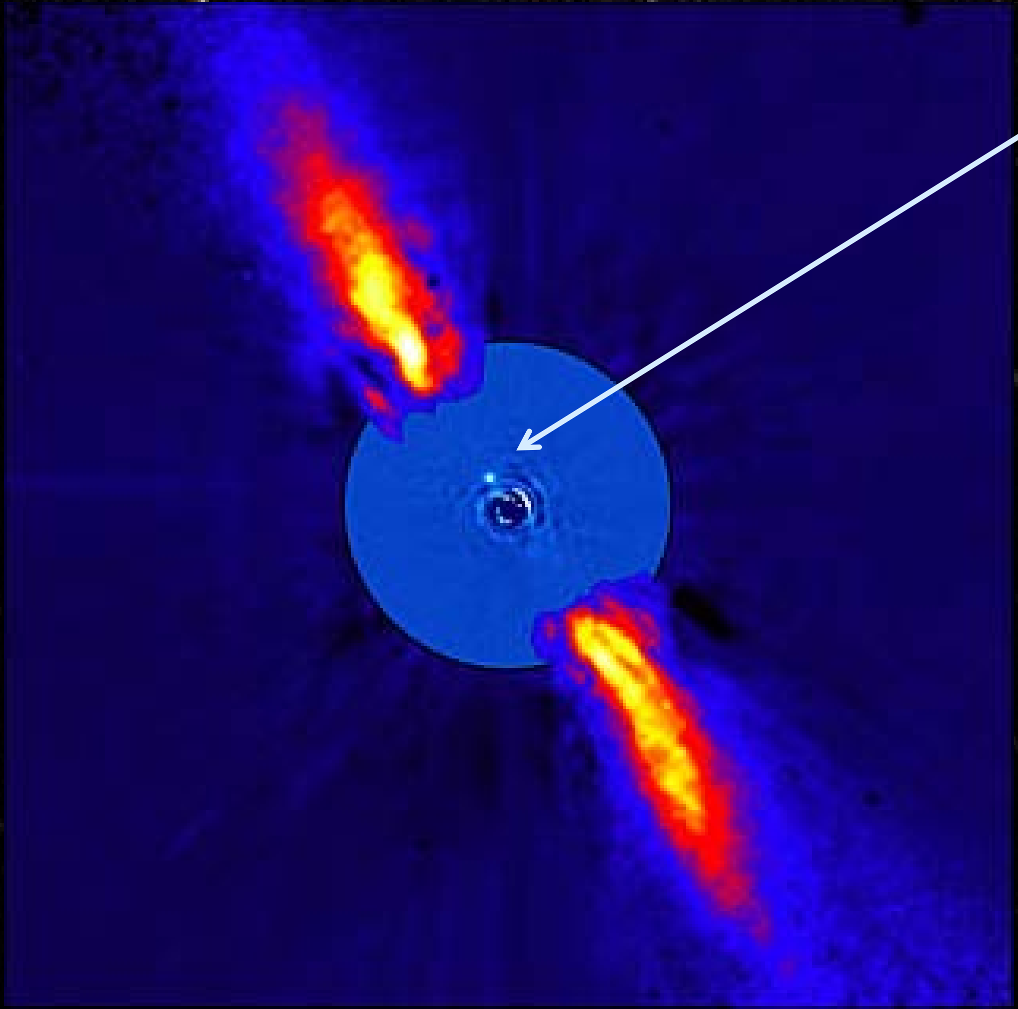
Direct Imaging Info

★Planets reflect visible light and give off some of their own in the infrared range.

★However, they are much dimmer than the stars that they orbit, making them difficult to see.

Direct Imaging continued...

Finding a planet...



http://www.eso.org/public/images/eso0842a/

Planet near Beta Pictoris imaged in 2008 (with direct imaging) by a group of French astronomers using ESO's Very Large Telescope.

Direct Imaging continued…

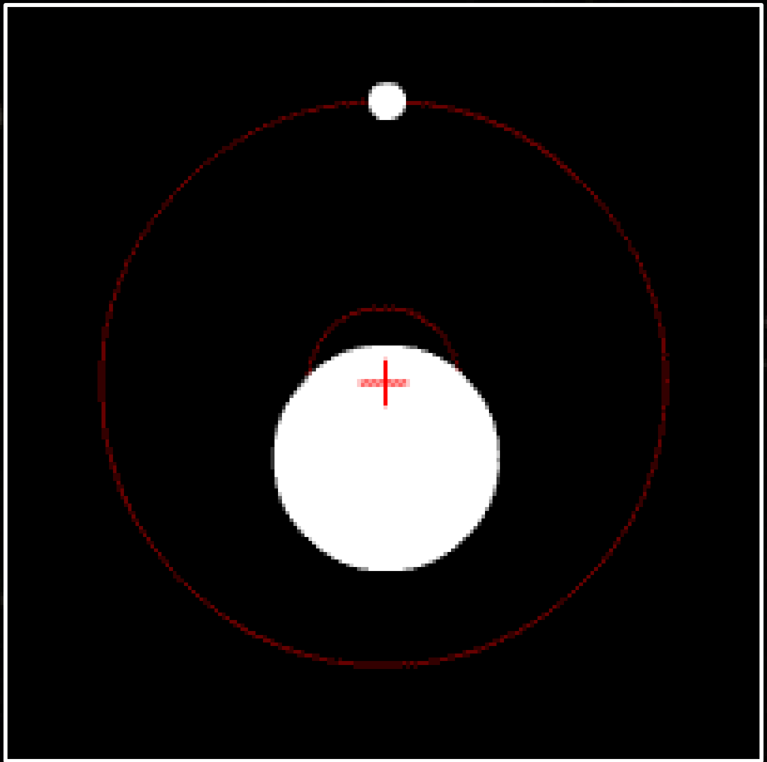
As of July 2010 13 planets have been detected using direct imaging

Astrometry:

Measuring a star's change in position.

The gravitational pull of an orbiting planet will cause the star to "wobble" in its orbit.

Astrometry info



Wikimedia commons

- ★Planets don't actually orbit their sun.
- ★Instead, they orbit the center of mass of the sun-planet system.
- ★A star will "wobble" due to orbiting planets.
- ★Astrometry requires precise measurements over long time spans.

The wobble is more pronounced for...

- ★Closer stars
- ★Lower mass stars
- ★Because Barnard's Star is the second closest star to our Sun and is fairly small, it is a perfect one to study using this method.

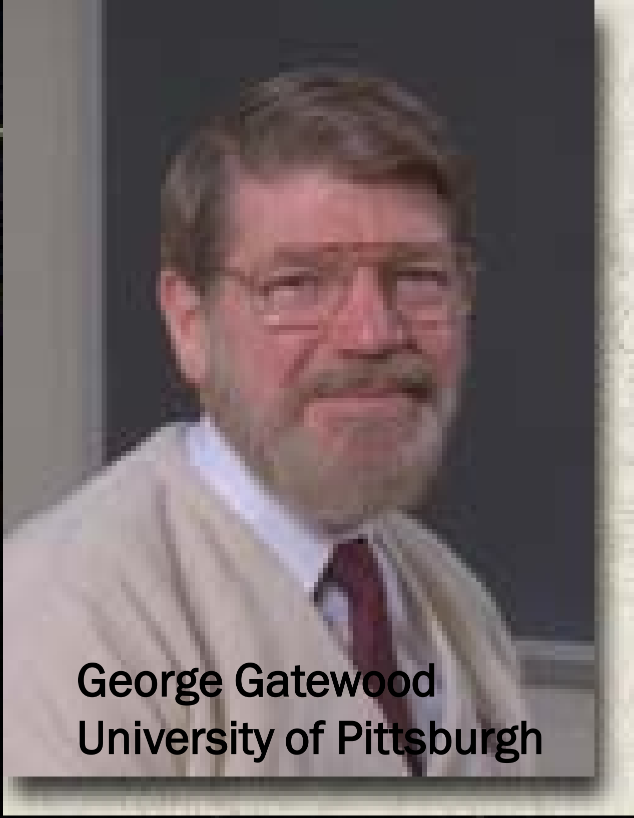
Peter van de Kamp (1901-1995)…

- Was a pioneer in the search for extrasolar planets
- Starting in 1938, he led a group from Sproul Observatory
- In 1963 they claimed evidence for a planet around Barnard's Star

Astrometry continued…

Gatewood and Eichhorn

- ★Studied photographic plates from Allegheny Observatory in Pittsburgh and Van Vleck Observatory in Connecticut
- ★They found no wobbling of Barnard's Star and published these results in 1973.



George Gatewood
University of Pittsburgh

Allegheny Observatory
Pittsburgh, PA

Finding a planet…

- ★Van de Kamp's planet finding was overturned, but, after years of searching, NASA astronomers at Palomar Observatory identified an exoplanet using astrometry in 2009.
- ★It is a gas giant (about 6x Jupiter's mass) called VB 10b and is about 20 light-years away in the constellation Aquila.
- ★It is orbiting a star about 1/12 the mass of our Sun. It is about as far from its star as Mercury is from the Sun.

Radial Velocity (Doppler Effect): Measuring a star's changes in radial velocity using the Doppler effect.

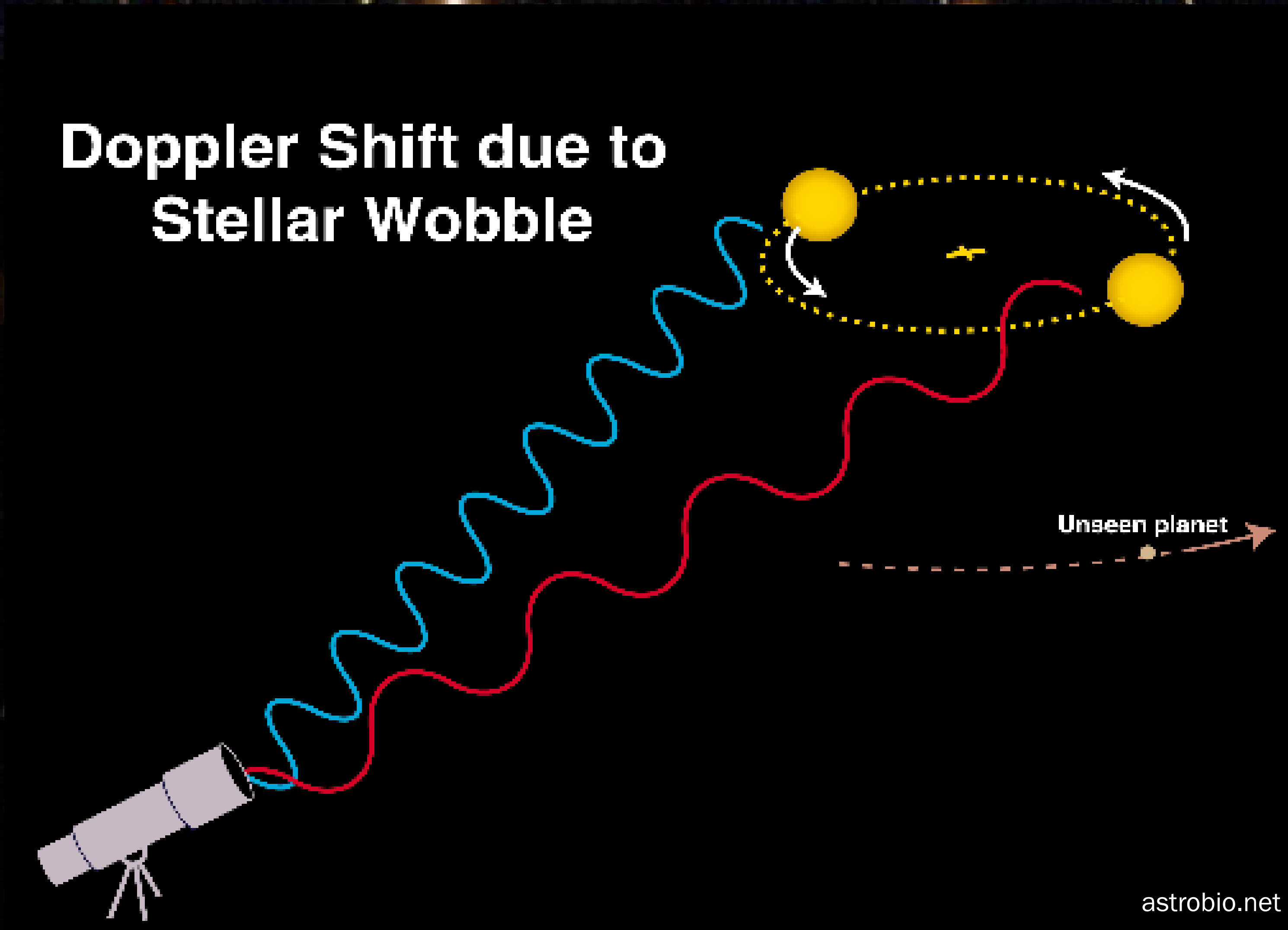
Radial velocity continued...

Radial velocity info

- ★Remember that a star will "wobble" due to orbiting planets.
- ★If a star is wobbling, then it is moving away from us sometimes and toward us at others.
- ★When it is moving away, the wavelength of the light it emits is lengthened – red-shifted
- ★When it is moving toward, the wavelength of the light it emits is shortened – blue-shifted

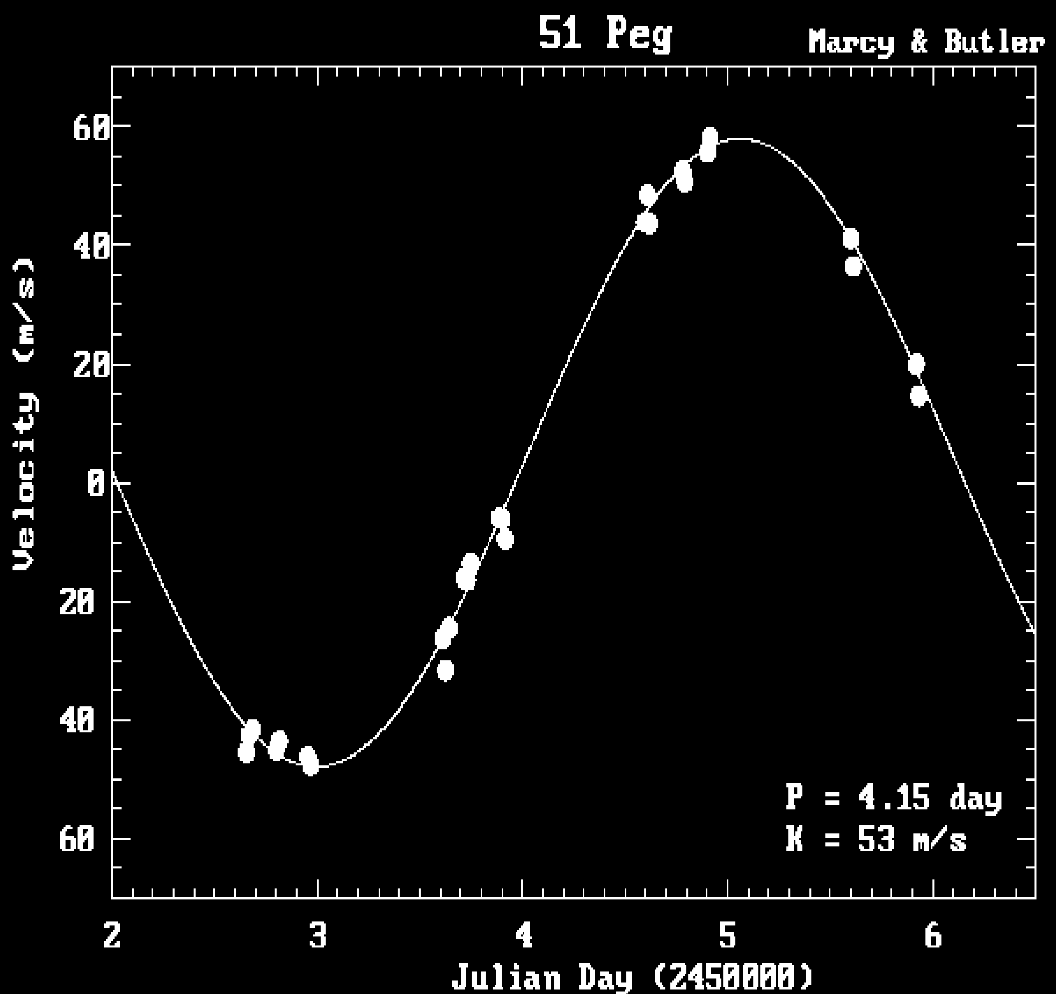
Radial velocity continued...

Radial velocity info



Radial velocity continued…

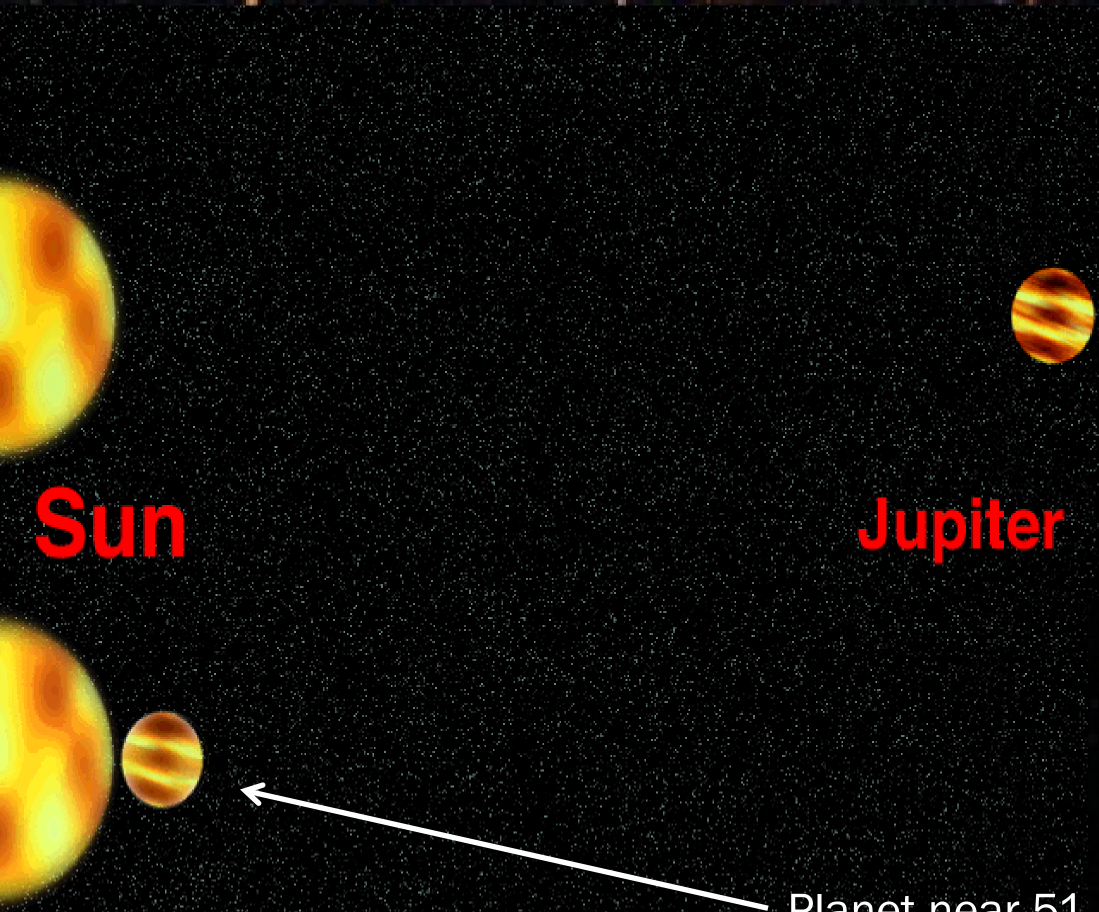
Finding a planet…



Radial velocity methods were used by Mayor and Queloz in 1995 to find the first extrasolar planet around a sun-type star.

Radial velocity continued…

About 51 Pegasi…



- orbital period of only 4.23 days
- mass of about ½ that of Jupiter
- 100 times closer to its sun than Jupiter is.

http://zebu.uoregon.edu/51peg.html

Astrometry and Radial velocity continued…

As of August 2010
443 planets have been
detected using radial
velocity or astrometry

Planetary Transits:
the planet eclipses some of the star’s light as it passes in front of it.

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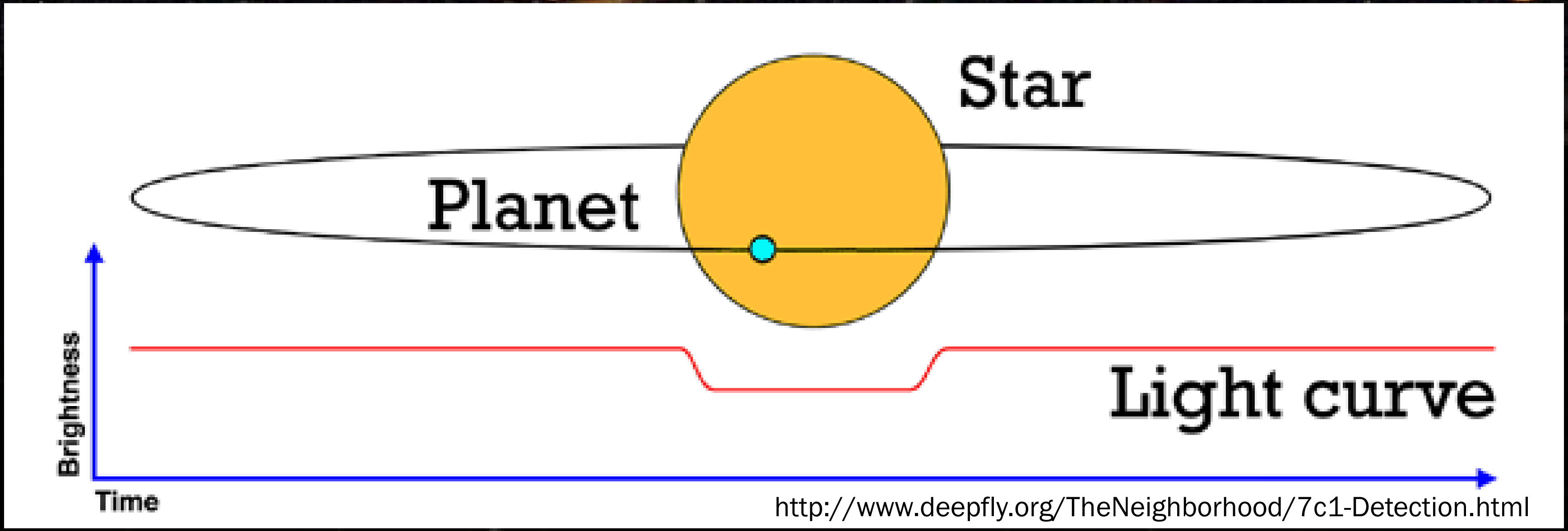
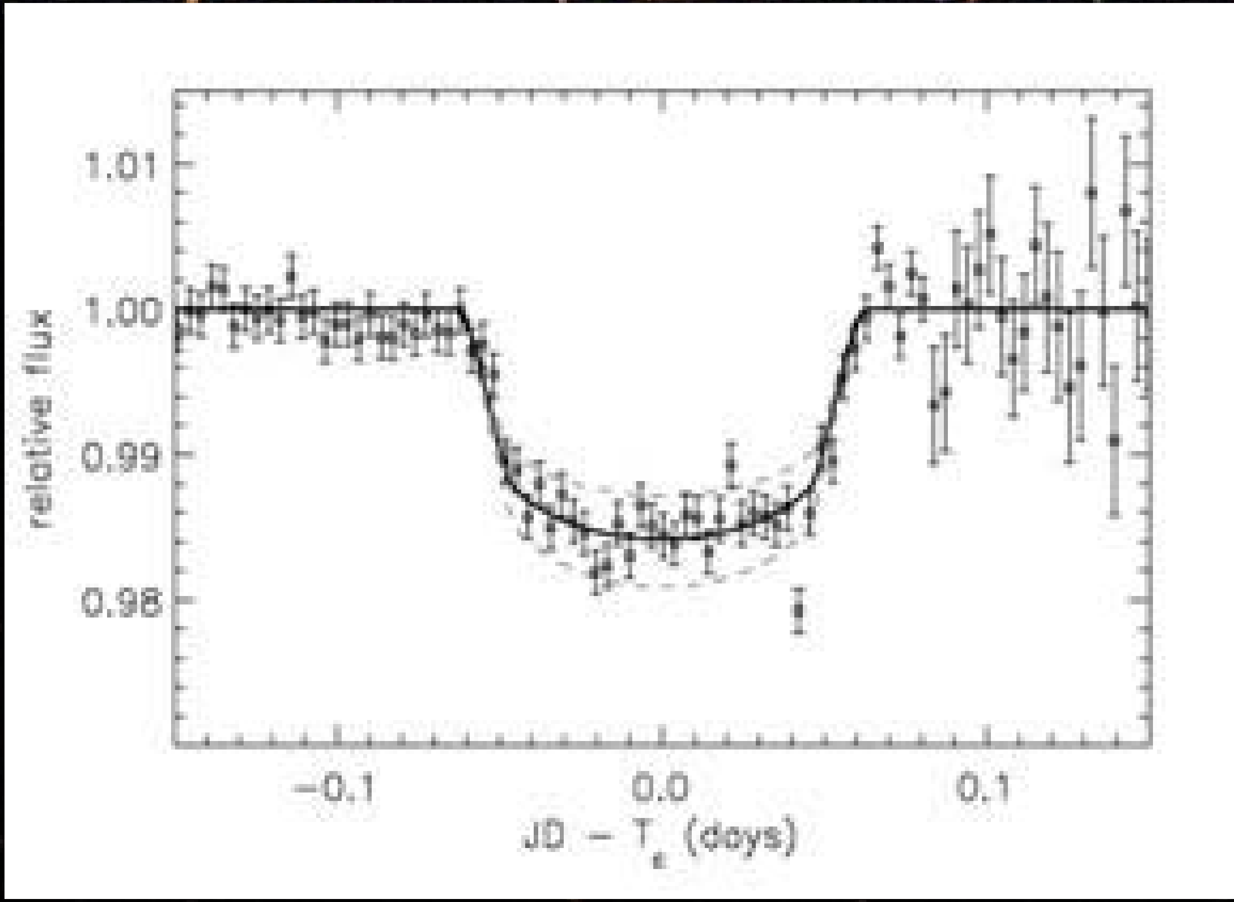
Planetary transits continued…

Planetary transit info…



- ★Can measure radius and mass, and then determine the average density of the planet
- ★Planet must pass at the correct angle
- ★Jupiter can block about 1% of the Sun's light

Finding a planet that transits…



http://astronomyonline.org/Exoplanets/Exoplanets.asp#Charbonneau

Planet transiting HD 209458b in 1999.

Planetary transits continued…

As of July 2010 91 planets have been detected using planetary transits

Gravitational Microlensing: The gravitational field of one star bends the light coming from a more distant star. Orbiting planets can cause variations in the curvature of the light.

Gravitational microlensing continued…

Gravitational Microlensing info…

- ★Can detect small planets at far distances
- ★Microlensing events are not very common
- ★It is also difficult to get a repeat observation
- ★This method does not work well for planets that are very close to their stars.

http://planetquest.jpl.nasa.gov/images/microlensing3-400.jpg

Gravitational microlensing continued…

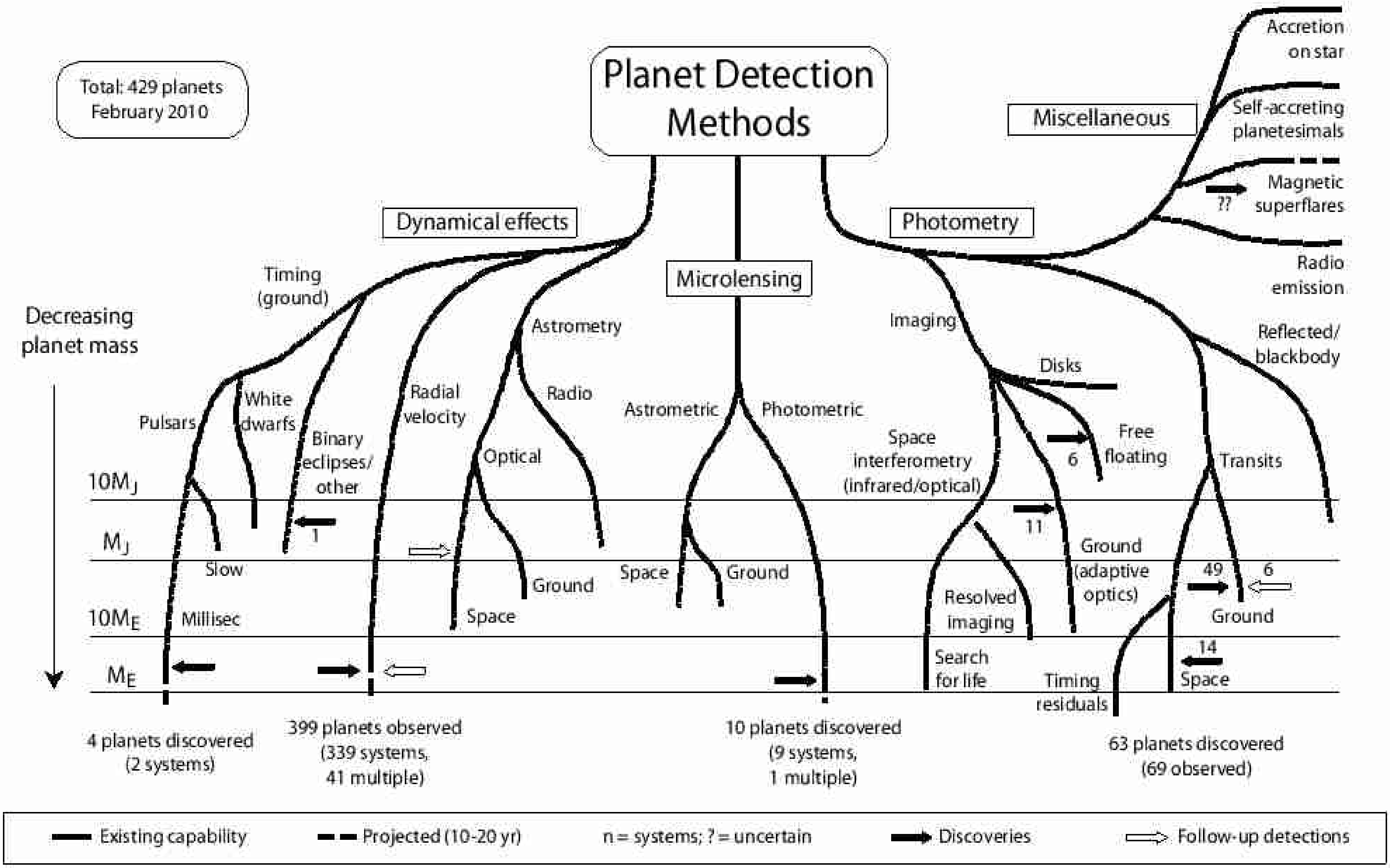
Finding a planet using microlensing…

In 2004, two cooperating international research teams: Microlensing Observations in Astrophysics (Moa) and Optical Gravitational Lensing Experiment (Ogle), located a star-planet system which is 17,000 light years away in the constellation Sagittarius. The planet is about 1.5 times the size of Jupiter and is orbiting a red dwarf star at about three times the distance that the Earth orbits our Sun. They magnify another star which is about 24,000 light years away.

Gravitational microlensing continued…

As of July 2010
10 planets have been detected using microlensing

As of August 2010
a total of 474 planets have been found
(some have been detected using multiple methods)



http://exoplanet.eu/papers/macp-detection-methods.pdf

Who is looking?

Some of the most recent studies to find exoplanets include the COROT and the Kepler missions.

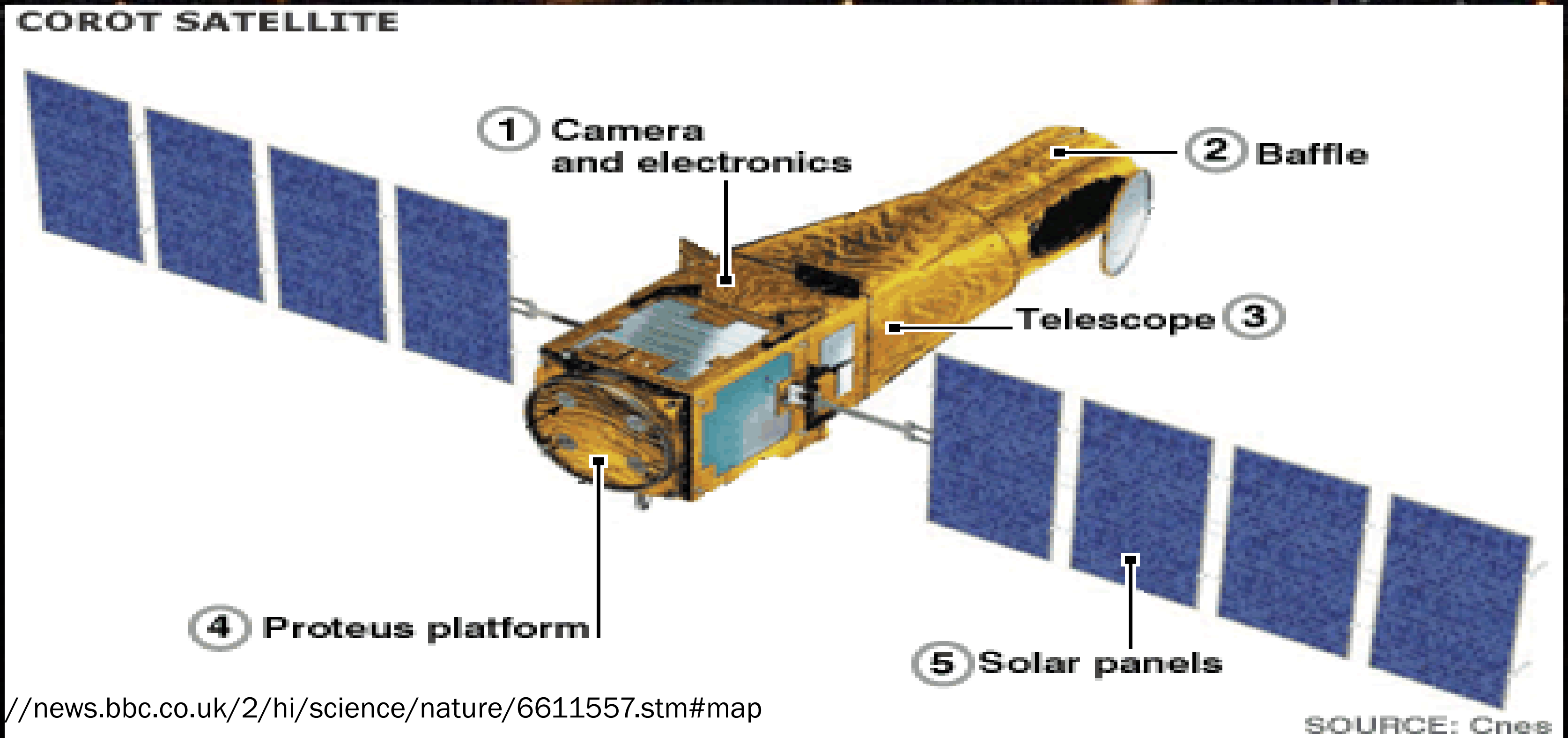
COROT

COnvection, ROtation & planetary Transits

- ★Launched in December 2006
- ★A collaboration of the French space agency CNES and ESA (European Space Agency), Austria, Belgium, Brazil, Germany and Spain
- ★Monitors stars for a decrease in brightness that results from transiting planets.

Searching for exoplanets...

COROT

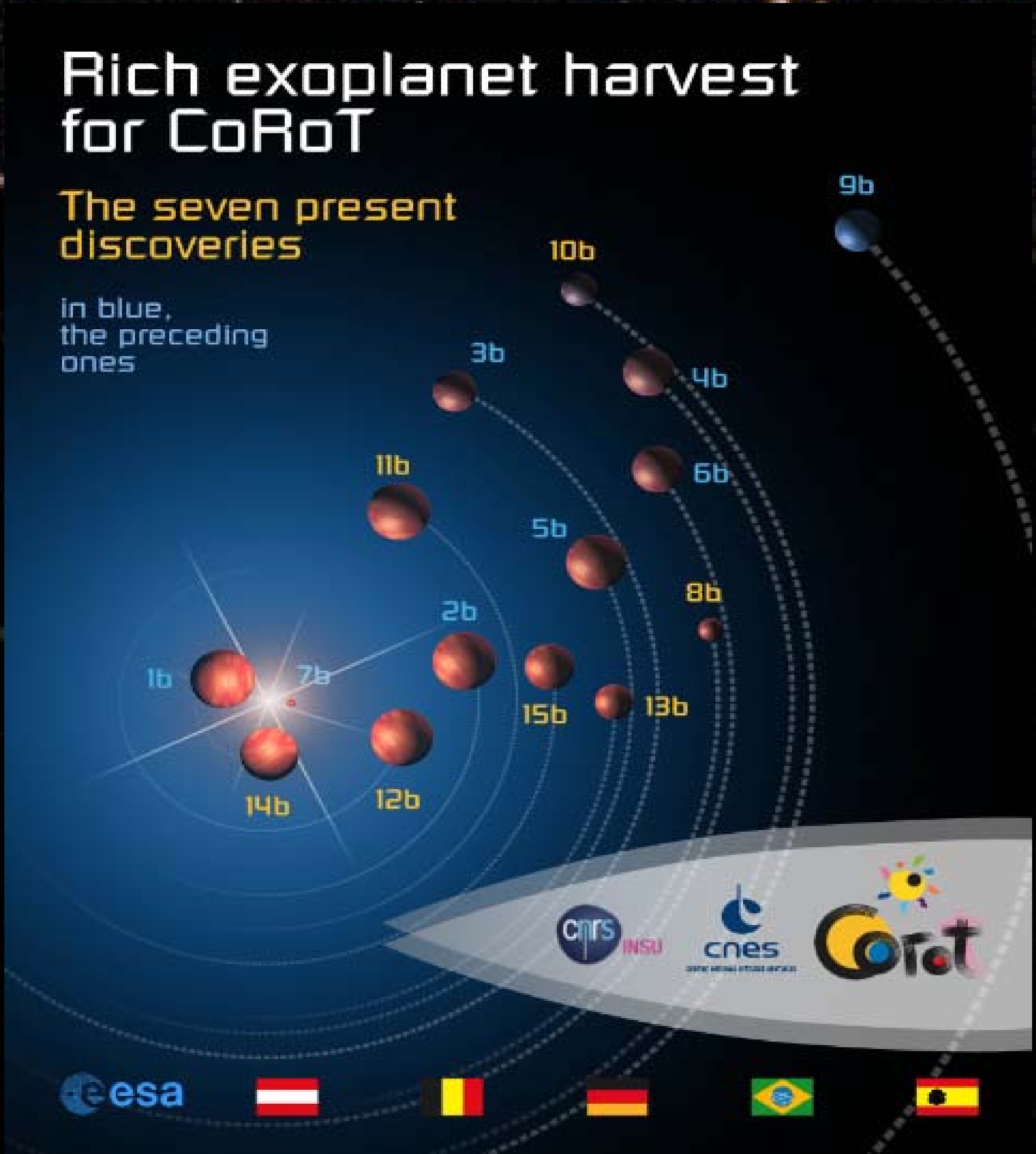


//news.bbc.co.uk/2/hi/science/nature/6611557.stm#map

1. **4CCD camera and electronics:** Captures and analyses starlight
2. **Baffle:** Works to shield the telescope from extraneous light
3. **Telescope:** A 30cm mirror; it views the star fields
4. **Proteus platform:** Contains communication equipment, temperature controls and direction controls
5. **Solar panel:** Uses the Sun's radiation to power the satellite

Searching for exoplanets…

As of July 2010, COROT had located 14 exoplanets.



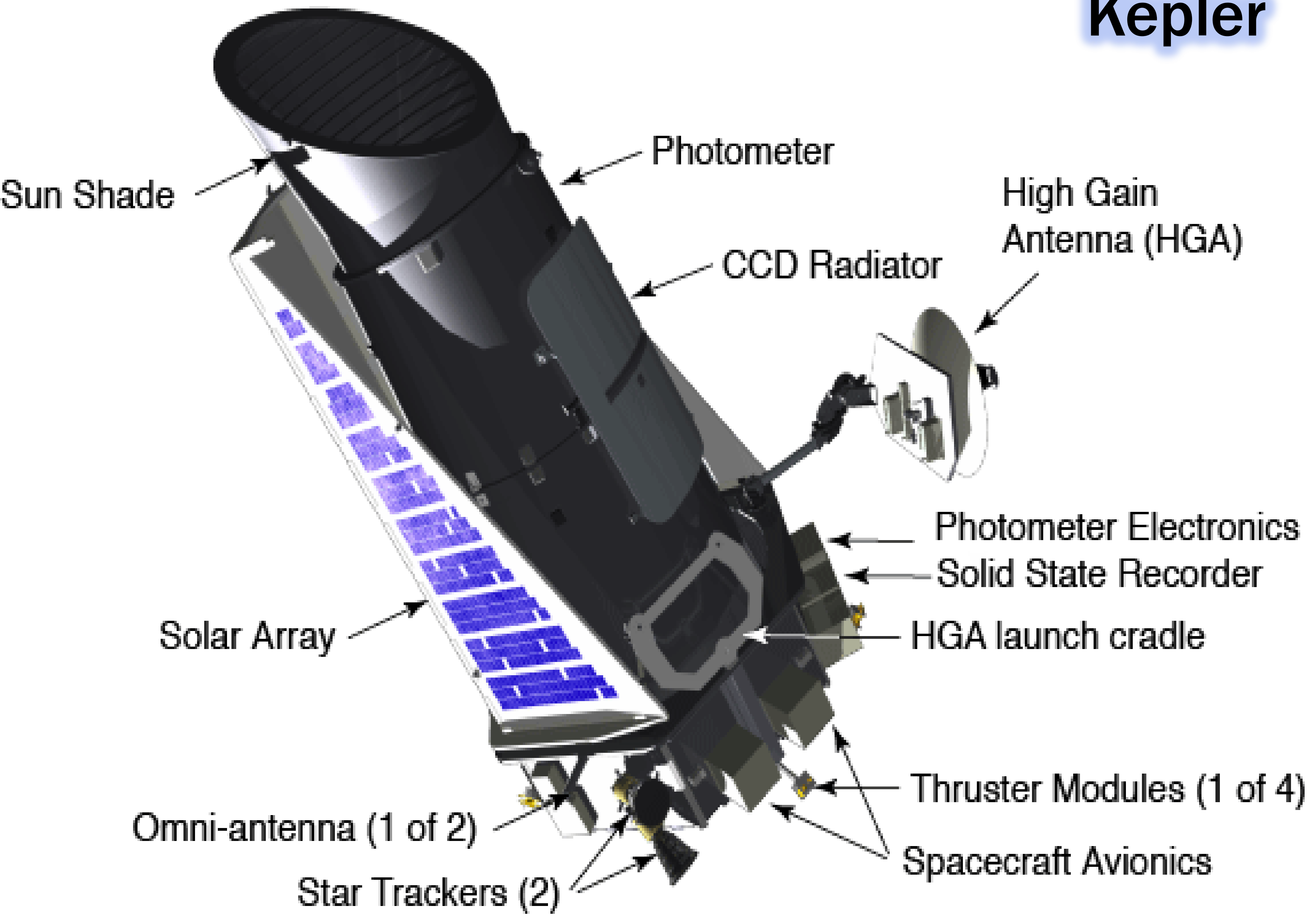
Kepler

- ★Launched in December 2006

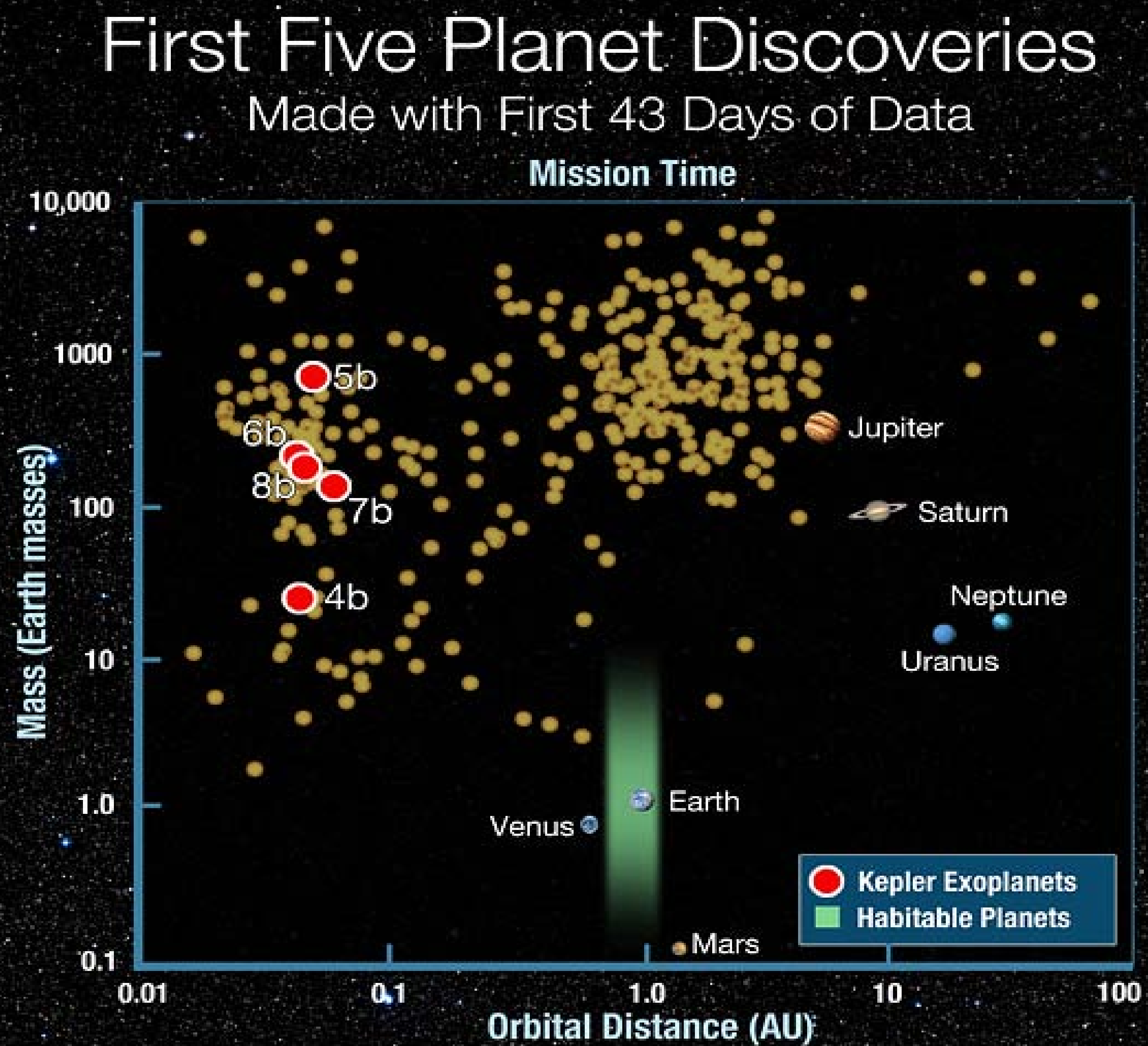
- ★A collaboration of the French space agency CNES and ESA (European Space Agency), Austria, Belgium, Brazil, Germany and Spain

- ★Monitors stars for a decrease in brightness that results from transiting planets.

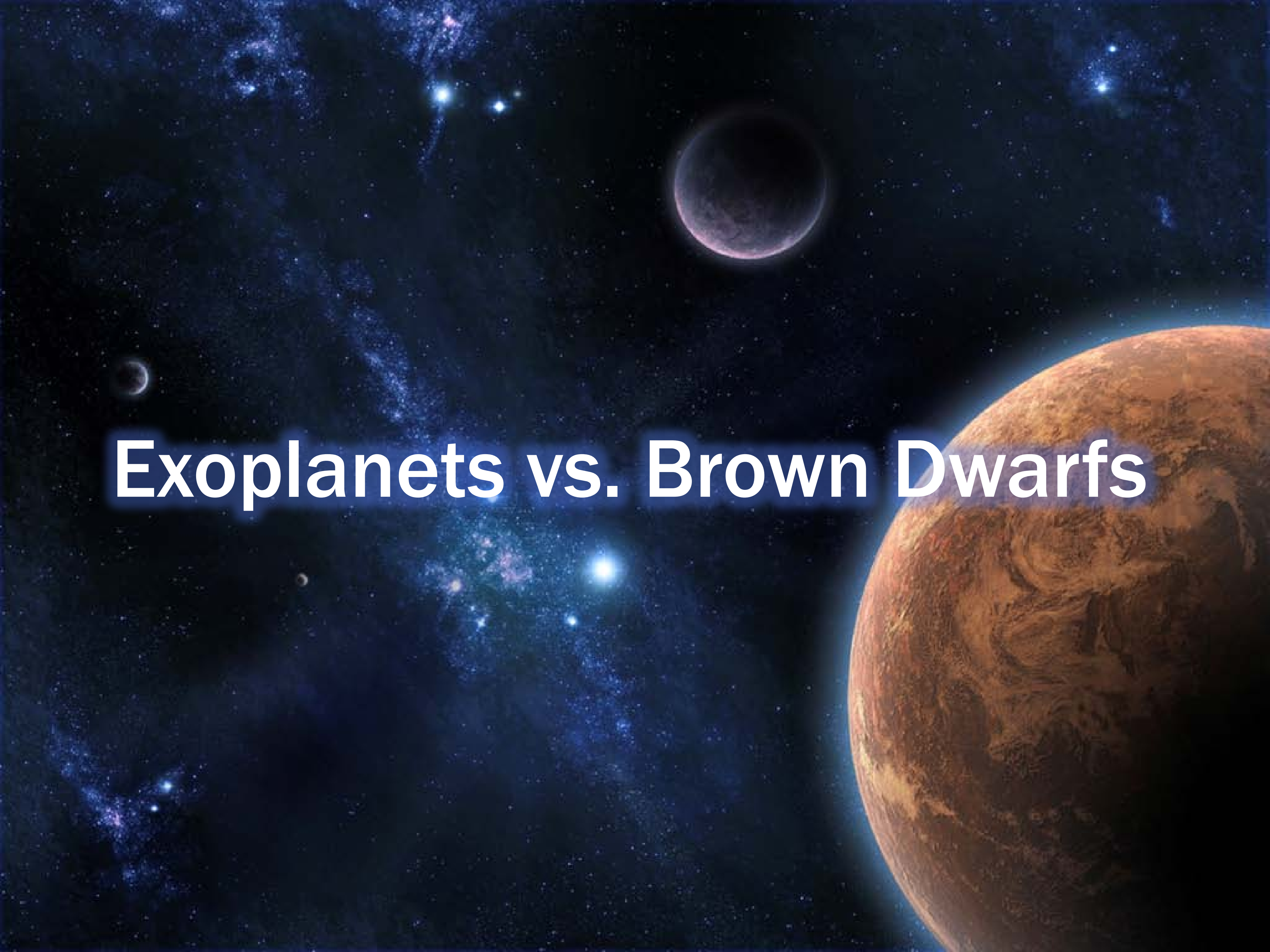
Kepler


Photometer
Sun Shade
High Gain
Antenna (HGA)
CCD Radiator
Photometer Electronics
Solid State Recorder
Solar Array
HGA launch cradle
Thruster Modules (1 of 4)
Omni-antenna (1 of 2)
Spacecraft Avionics
Star Trackers (2)

Searching for exoplanets...



http://onorbit.com/Astronomy?page=14


Exoplanets vs. Brown Dwarfs

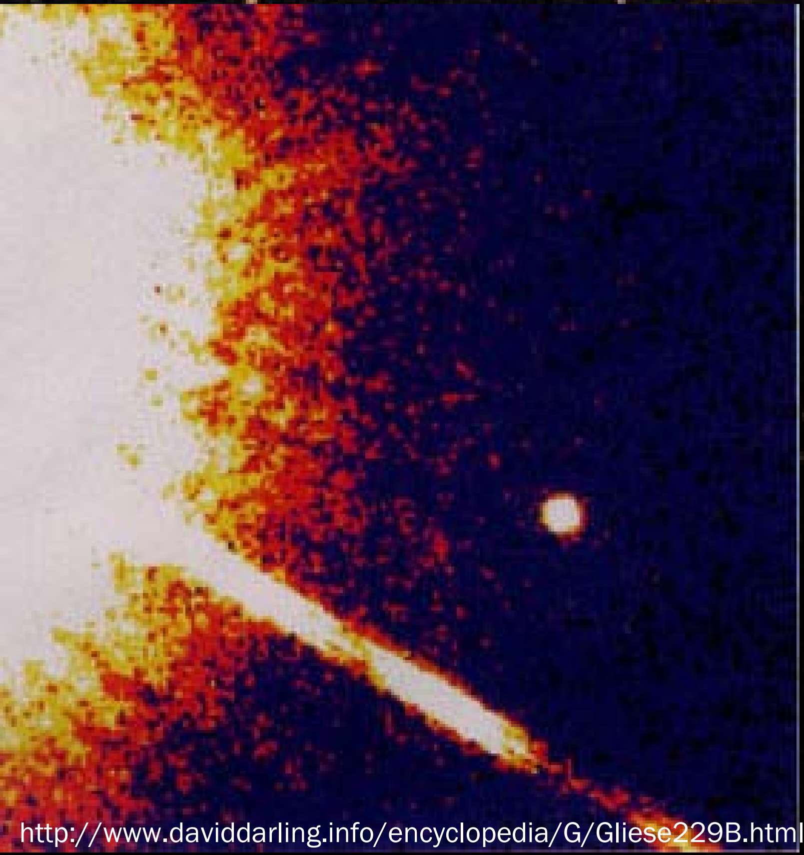
About Brown Dwarfs…

- ★In order to sustain hydrogen fusion, a star's mass must be approximately 0.08 solar masses or above.
- ★The mass of a Brown dwarf is below this limit.
- ★In fact, Brown dwarf sizes are comparable to the size of Jupiter.

Are Brown Dwarfs stars or planets?

According to the IAU
(International Astronomical Union)
a brown dwarf has a mass above that
needed for fusion of deuterium
(approximately 13 Jupiter masses).
An object lower than that mass and orbiting
a star (or star remnant) is said to be a
planet.

Finding Brown Dwarfs...



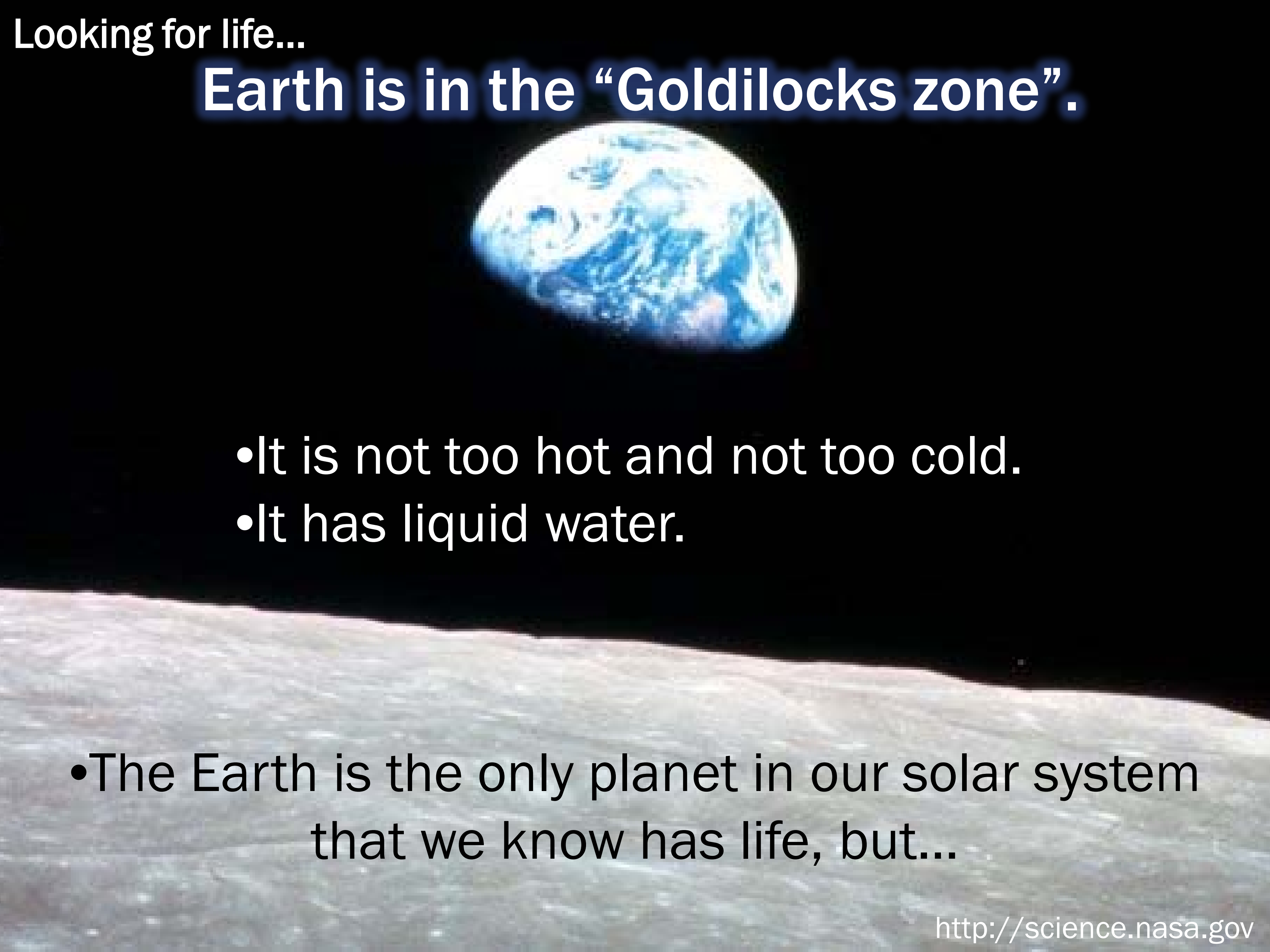
The brown dwarf, Gliese 229B, is the small dot next to the red dwarf, Gliese 229A.

- ★Gliese 229B, the first brown dwarf discovered orbiting a star, was discovered in 1995.
- ★2M1207, the first brown dwarf found to have a planet, was discovered in 2004.
- ★As of August 2010, over 1300 brown dwarfs have been found.

Why search for Brown Dwarfs?

- ★They have characteristics of both stars and planets.
- ★They provide the chance to study planet-like atmospheres which are hot.
- ★There are most likely as many brown dwarfs as there are stars.


The goal?
To find an exoplanet in a
habitable zone.

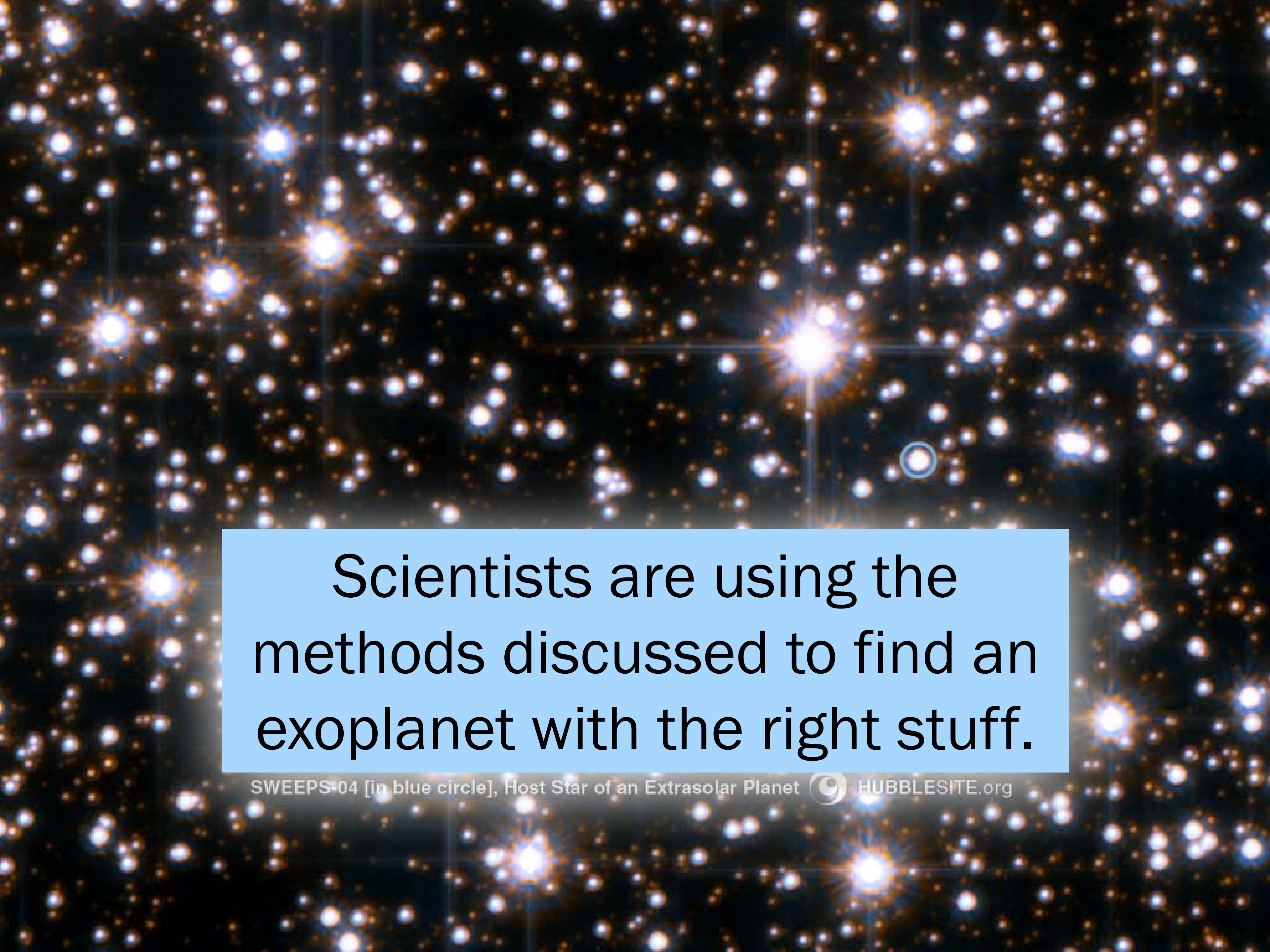

Looking for life…
Earth is in the "Goldilocks zone".
•It is not too hot and not too cold.
•It has liquid water.
•The Earth is the only planet in our solar system that we know has life, but…
http://science.nasa.gov

What is our definition of life?

As we know it here on Earth...

- ★ Liquid water is needed for life
  - ▪ Might be subsurface
- ★ Life is carbon-based


Looking for life…


Scientists are using the methods discussed to find an exoplanet with the right stuff.
SWEEPS-04 [in blue circle], Host Star of an Extrasolar Planet
HUBBLESITE.org

And they are searching elsewhere in our Solar System.

- Eight planets (and five dwarf planets)

Looking for life…

Jupiter's moon Europa?

- ★Evidence for liquid water ocean under ice
- ★The water may be in contact with rocks
- ★The Voyager and Galileo spacecrafts have given some information about Europa, but NASA is hoping to launch the Europa orbiter in 2020.

Looking for life…

How about Mars?

- ★On the surface, it is a frozen desert
- ★There may be subsurface water
- ★There is evidence of methane in the atmosphere

http://science.nasa.gov

★For centuries, people have been searching for other worlds like our own.

We now know that there are many exoplanets. Also, life (extremophiles) can withstand very harsh conditions.

★The challenge now is to find terrestrial planets, similar in size and conditions to our Earth, where liquid water and life might exist.

Current exoplanets counts...

Extrasolar Planets Encyclopedia

http://exoplanet.eu/catalog.php

New Worlds Atlas

http://planetquest.jpl.nasa.gov/atlas/atlas_index.cfm

Current Planet Count Widget

http://planetquest.jpl.nasa.gov/widget.cfm

Questions to consider…

- One of Jupiter's moons, Callisto, orbits Jupiter in a path of radius 1,880,000 km. Given that Callisto has an orbital period of 16.7 days, what is Jupiter's mass?

Questions to consider…

- A typical comet contains about 1×10^{13} kg of ice (water). There are approximately 2×10^{21} kg of water on Earth. Assuming this water came from asteroid impacts with the Earth, how many comets would have to hit the Earth in a time of 500 million years in order to account for this water.

Questions to consider…

- When using the radial velocity method, it is easier to detect planets around low mass stars. Explain why.

- When using the radial velocity method, planets with smaller orbits are easier to detect. Explain why.

Questions to consider…

- A planet transits in front of a star. As it does, the observed brightness of the star dims by a factor of 0.002. Approximating the planet and the star as circles, and given that the radius of the star is 400,000 km, what is the radius of the planet (in km)? Compare this to the diameter of the Earth. Compare this to the diameter of Jupiter.

Questions to consider…

- Do you believe that extraterrestrial life exists?
- Why?

- Now poll at least ten people outside of class and find out their answers to these questions. We will have a class discussion based on the results of the survey.

Questions to consider…

- What effect it might have on Earth if life was found elsewhere in the Universe? Write down at least three answers. Now, discuss this with a small group and compile your answers.

Questions to consider…

- Also, refer to http://spacemath.gsfc.nasa.gov for additional related problems.