Yet another Kepler update

How are planets confirmed?

http://kepler.nasa.gov/

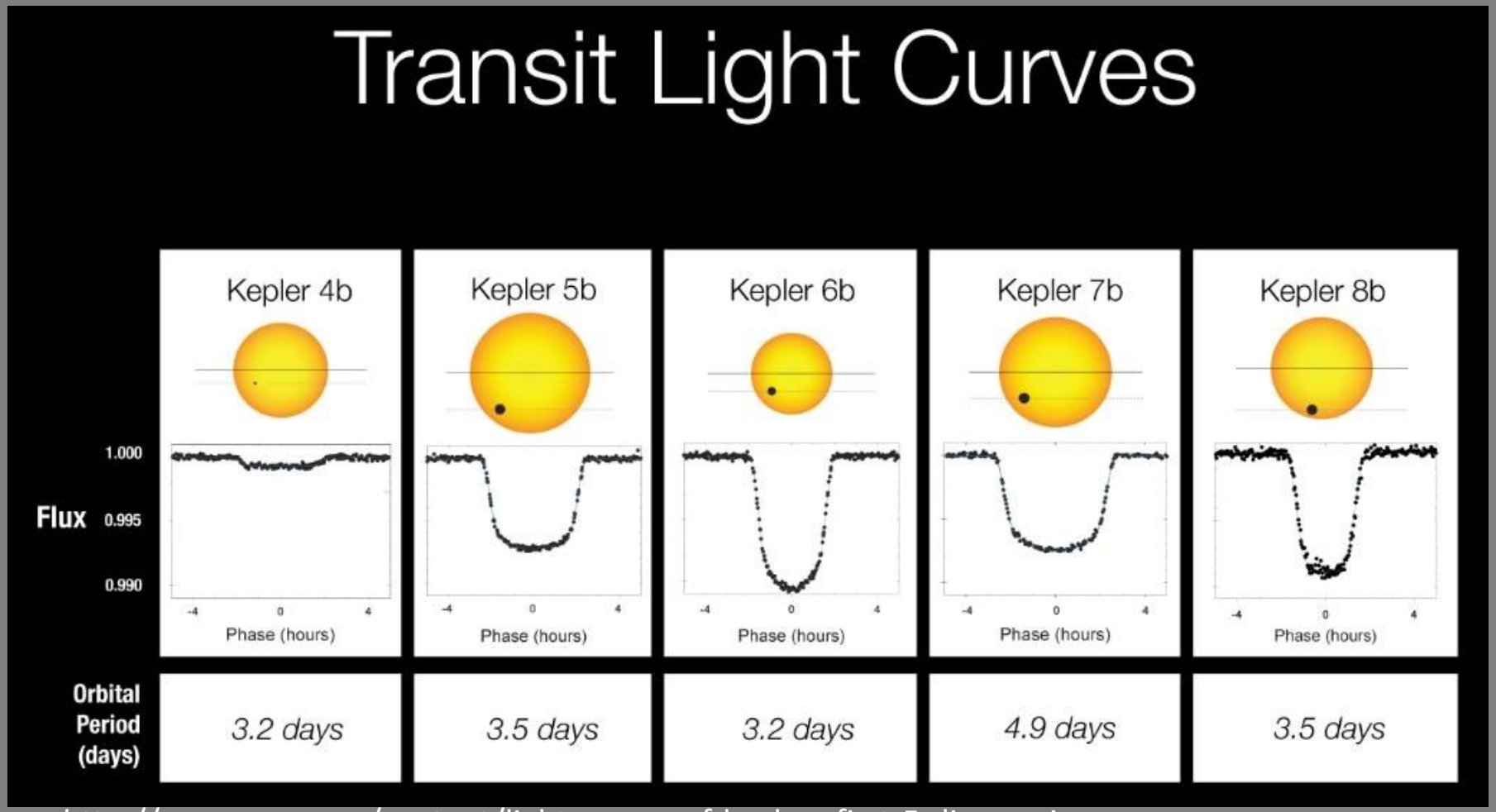
The Kepler Mission

http://www.nasa.gov/content/keplers-launch

NASA Discovery Mission # 10 “Are there other planets, orbiting other stars, with characteristics similar to Earth?”

“The Kepler mission will challenge thousands of stars to a staring contest, you know, like the ones you used to have with your siblings when you were younger, and that you have with the cat every once in awhile?”
— Davin Flateau, 365 Days of Astronomy podcast, March 1, 2009

Detecting Transits with Photometry

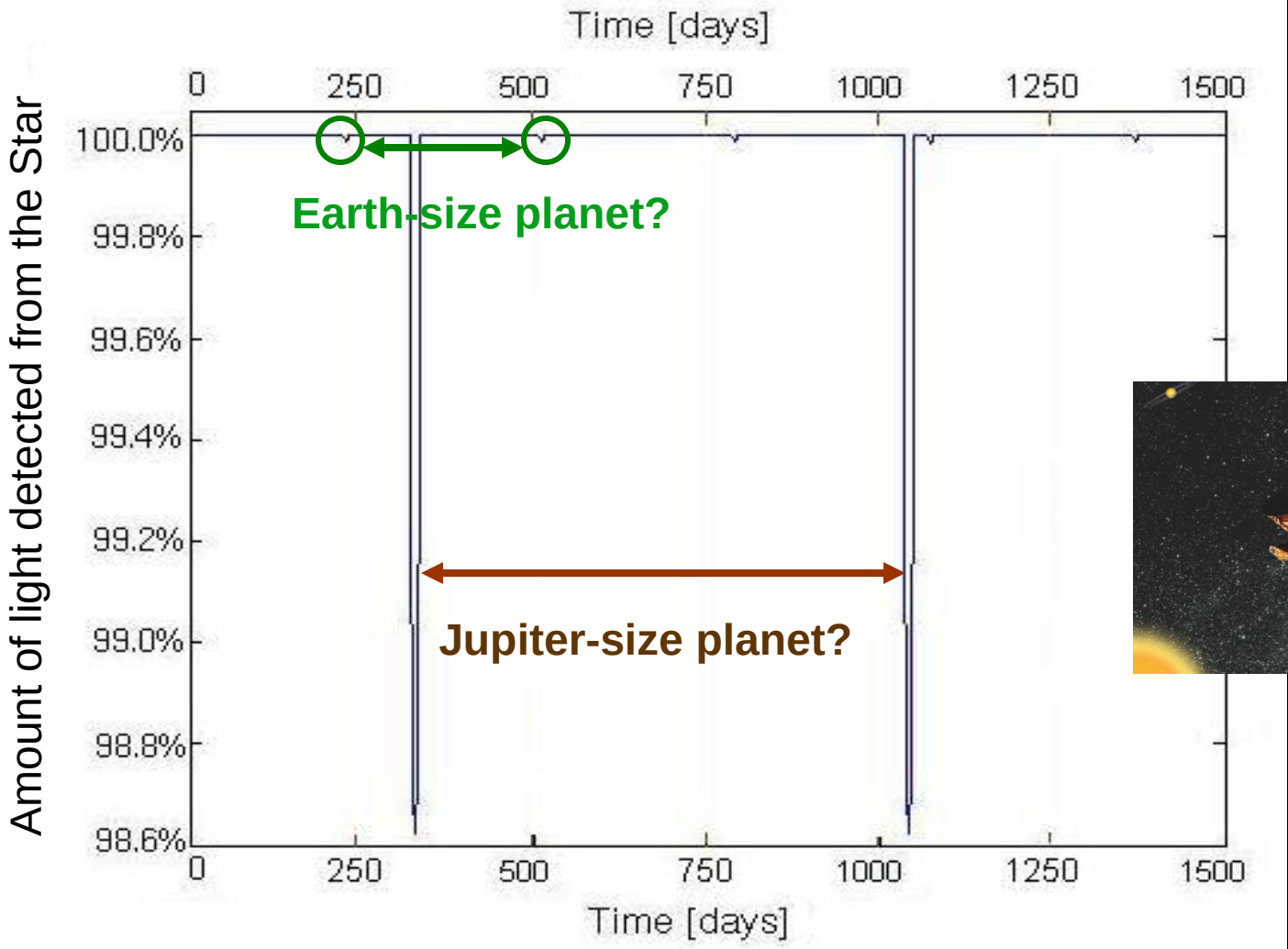


http://www.nasa.gov/content/light-curves-of-keplers-first-5-discoveries

Detecting Planets by Transits

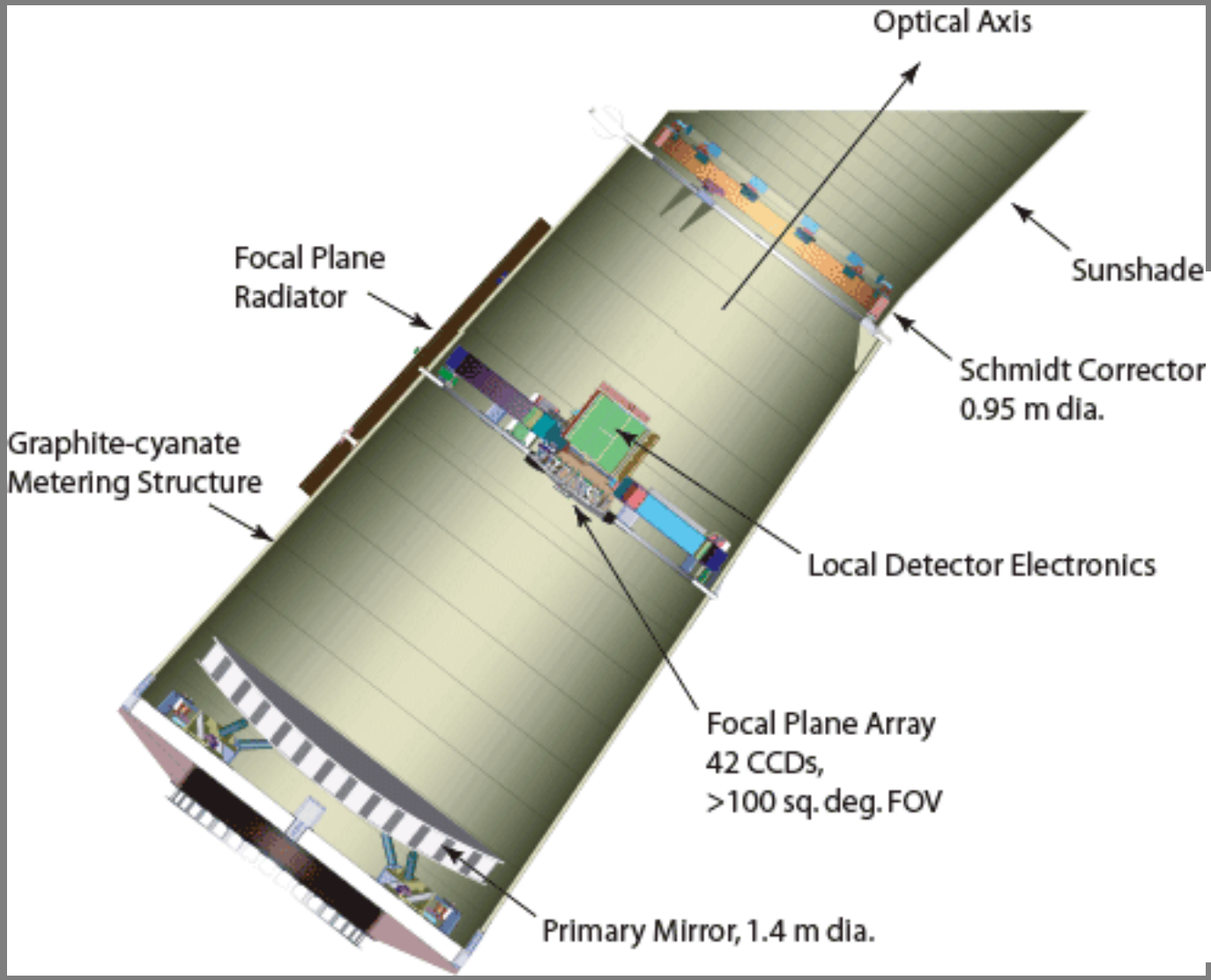
Kepler

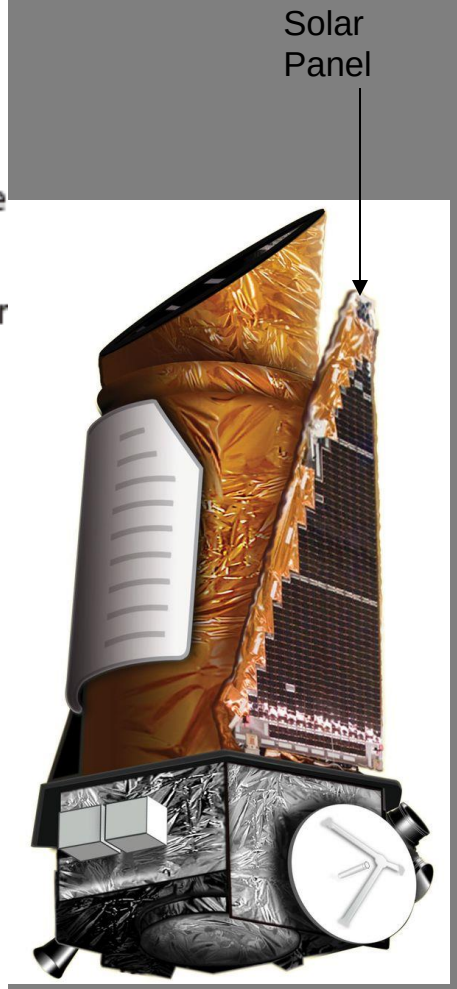
A Search for Habitable



http://nightsky.jpl.nasa.gov/download-redirect.cfm?Doc_ID=180&Doc_Filename=Kepler13%2Eppt

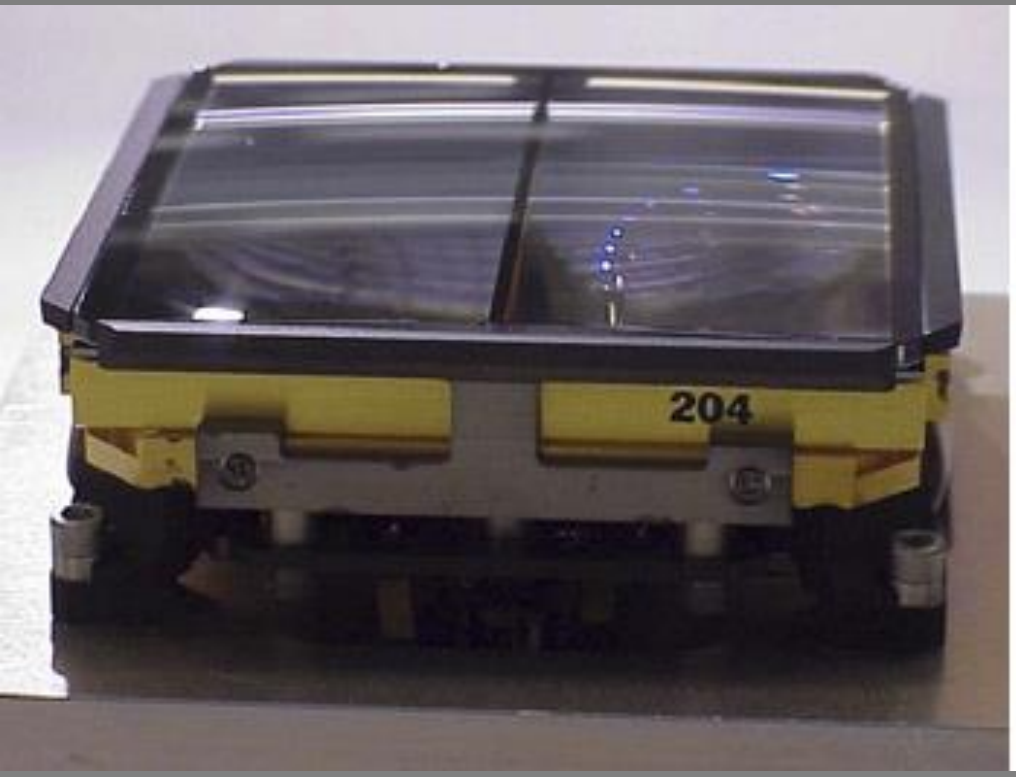
Kepler Photometer

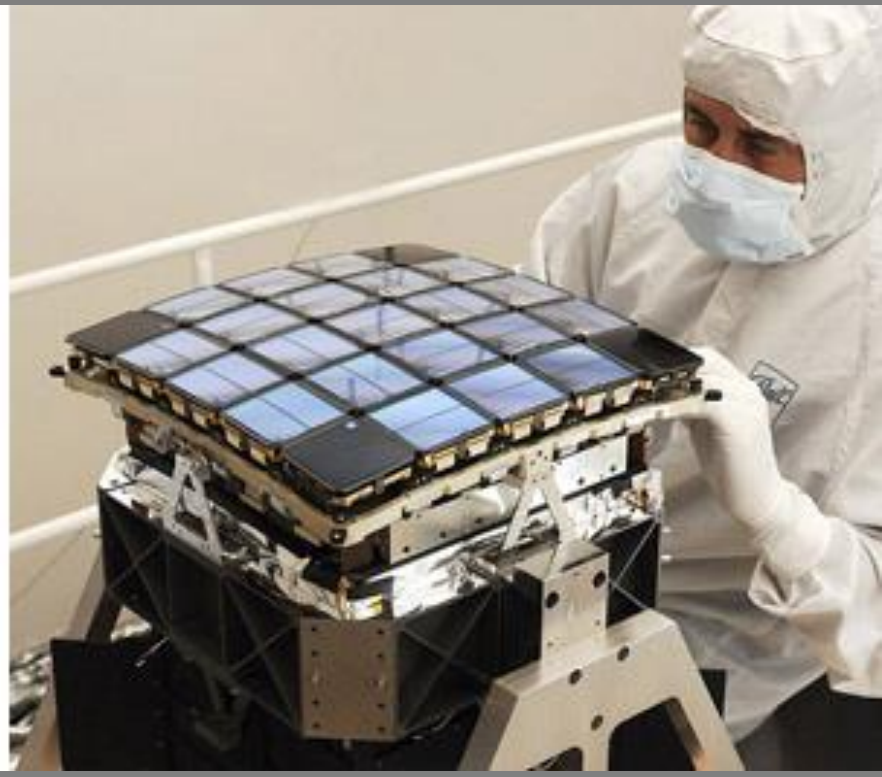




http://kepler.nasa.gov/multimedia/Images/

Kepler CCD Array



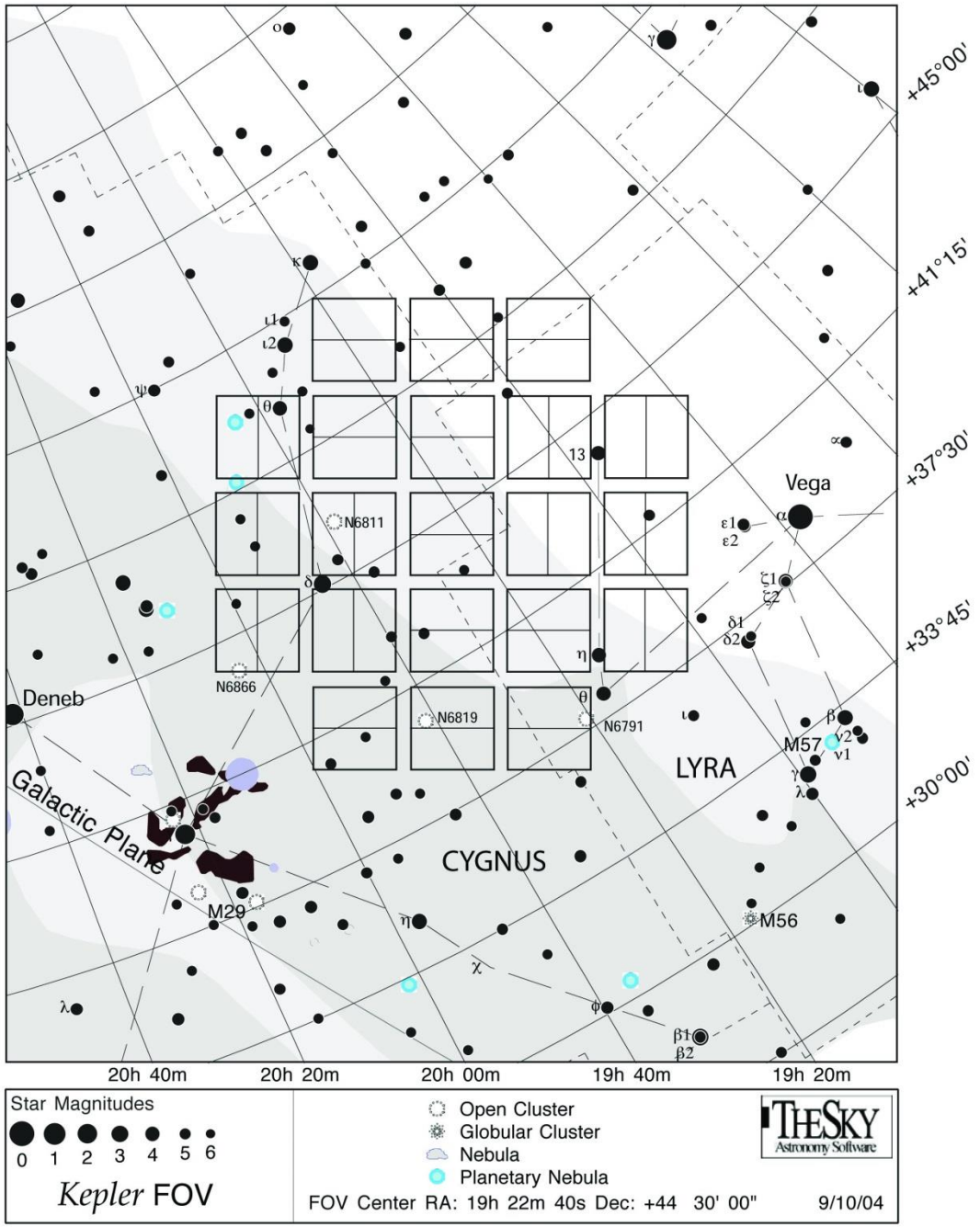


24 pairs of CCD elements, each 2,200 By 1,024 pixels, for 95 megapixels total —30 pixels for each target star

Covers 15-degree wide field of view in Cygnus and Lyra

Square arrangement can turn 90 degrees each quarter

http://kepler.nasa.gov/multimedia/Images/



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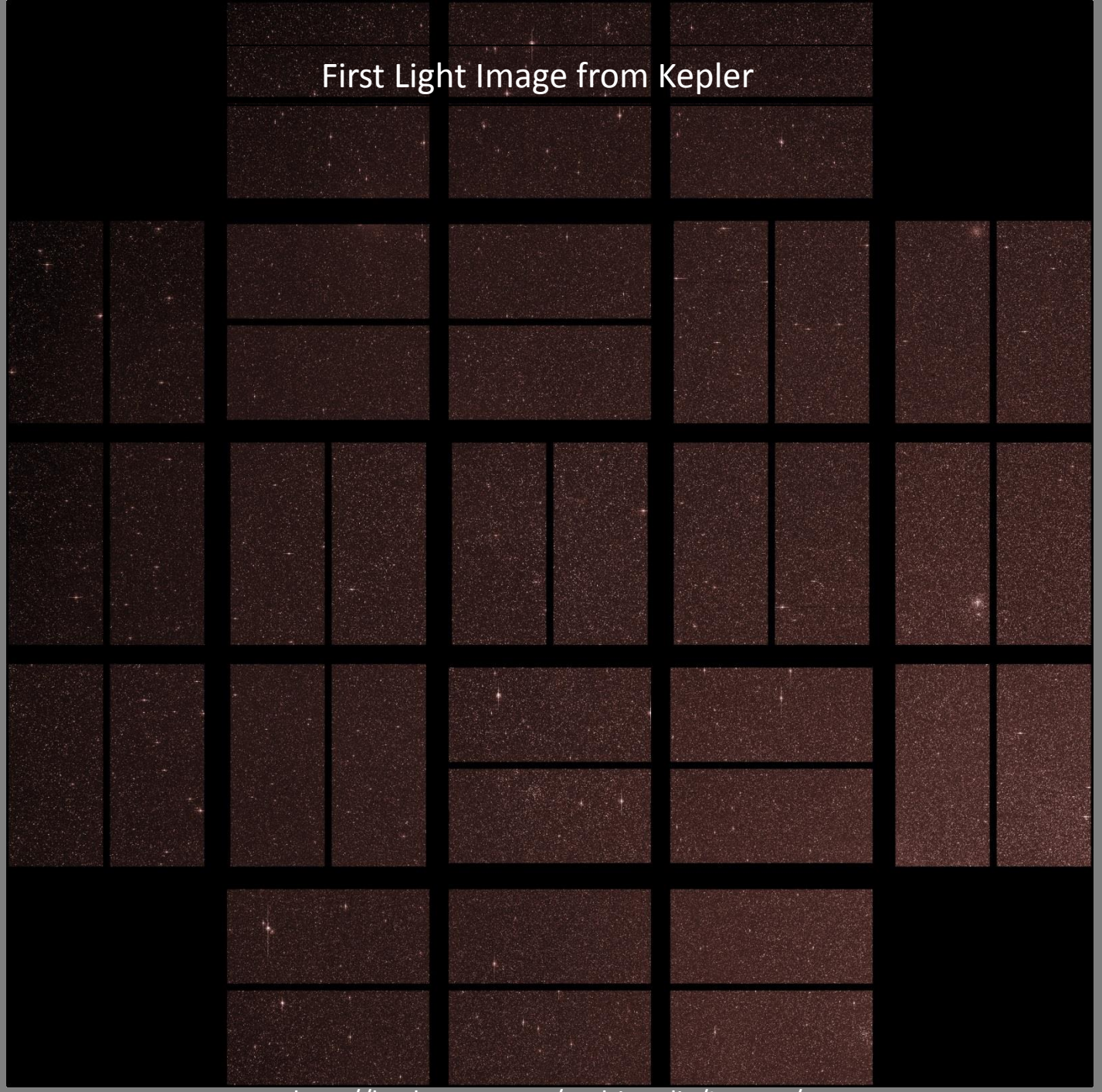

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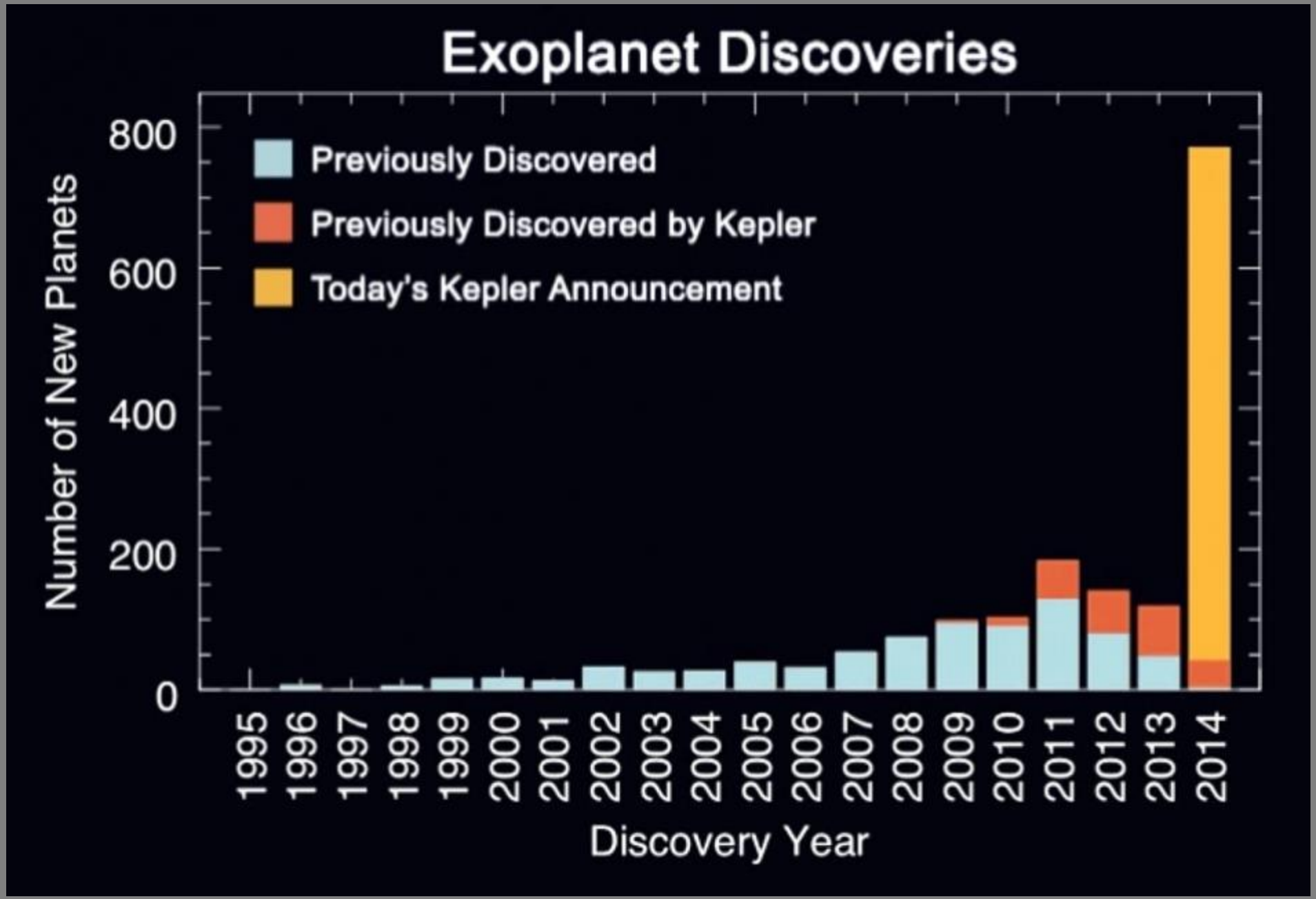
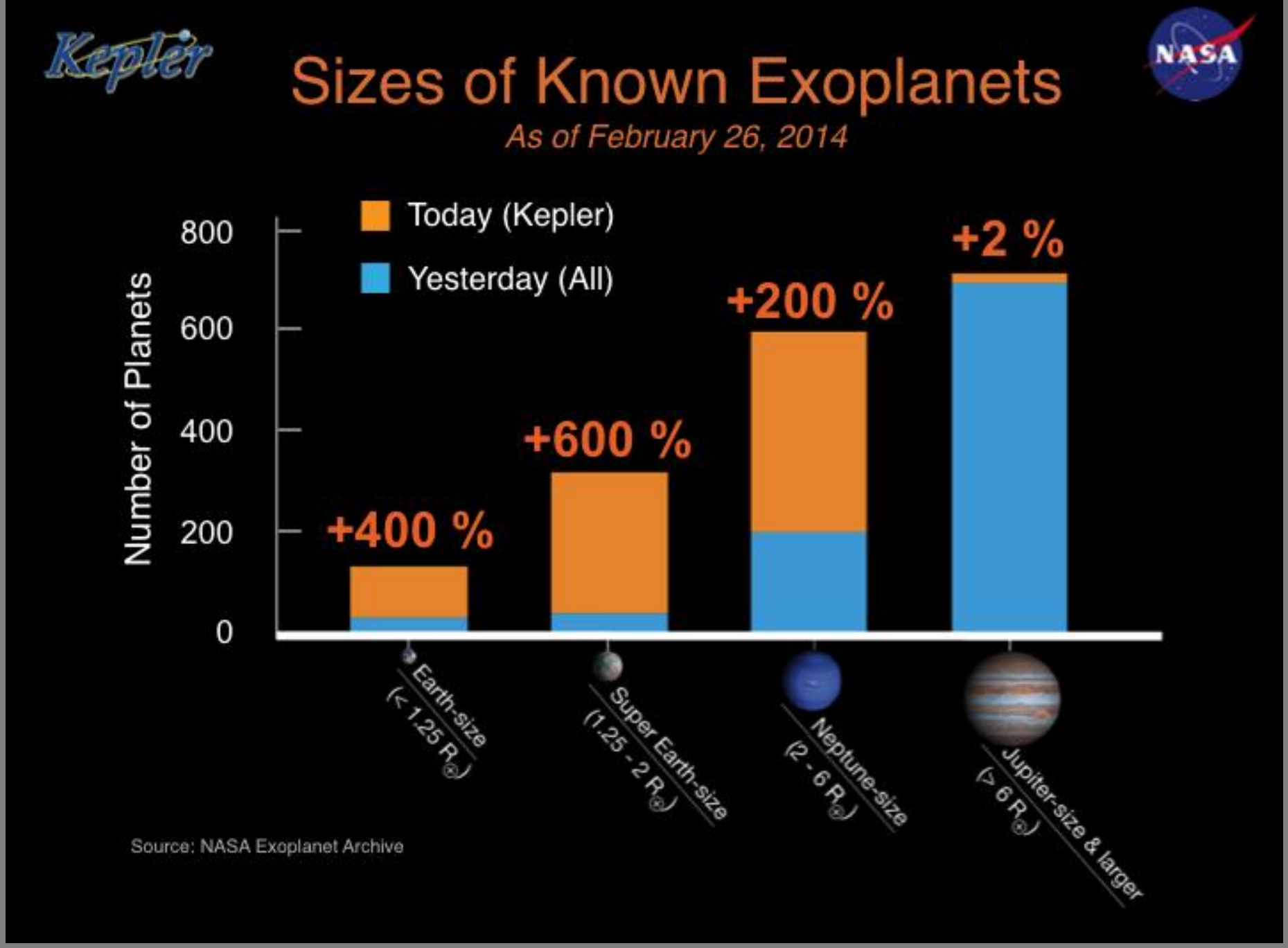
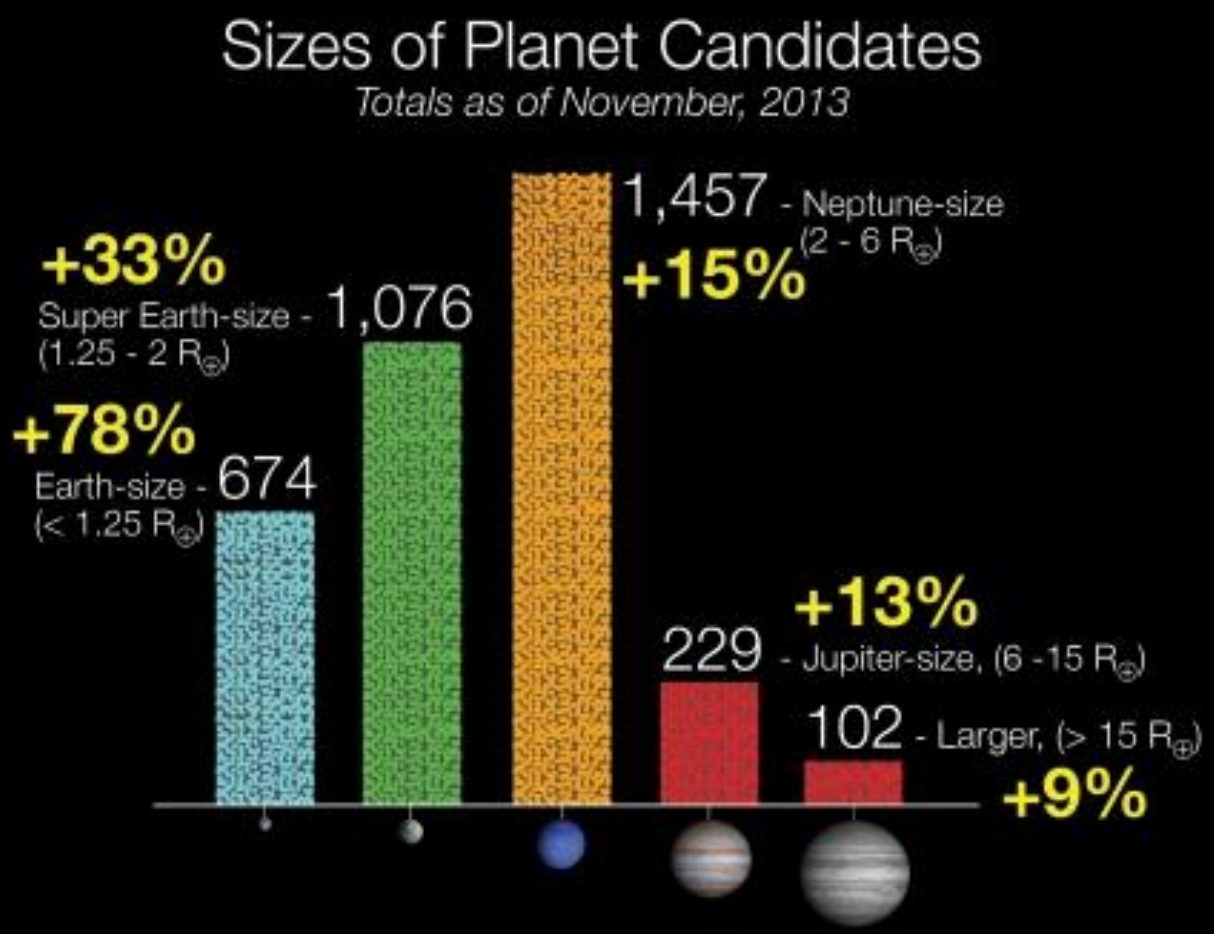


http://www.nasa.gov/sites/default/files/styles/430x323/public/exoplanet-disc.jpg?itok=6-Z_oJ4A



http://www.nasa.gov/sites/default/files/knownexoplanets.jpg

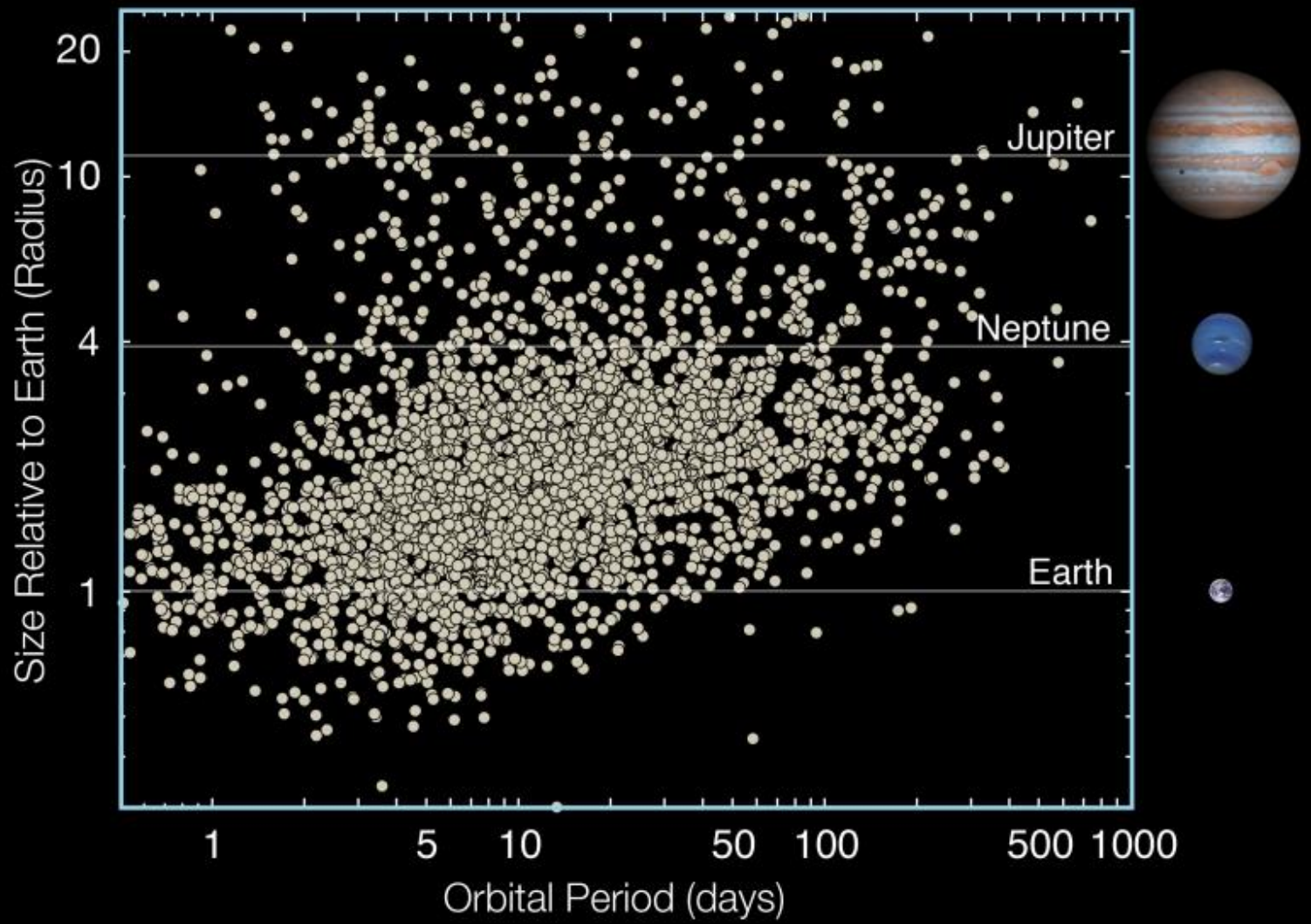
Candidate Planet Sizes



http://www.nasa.gov/sites/default/files/styles/673xvariable_height/public/candidate-sizes-histo_2013-wide_0.jpg?itok=yj_7BivK

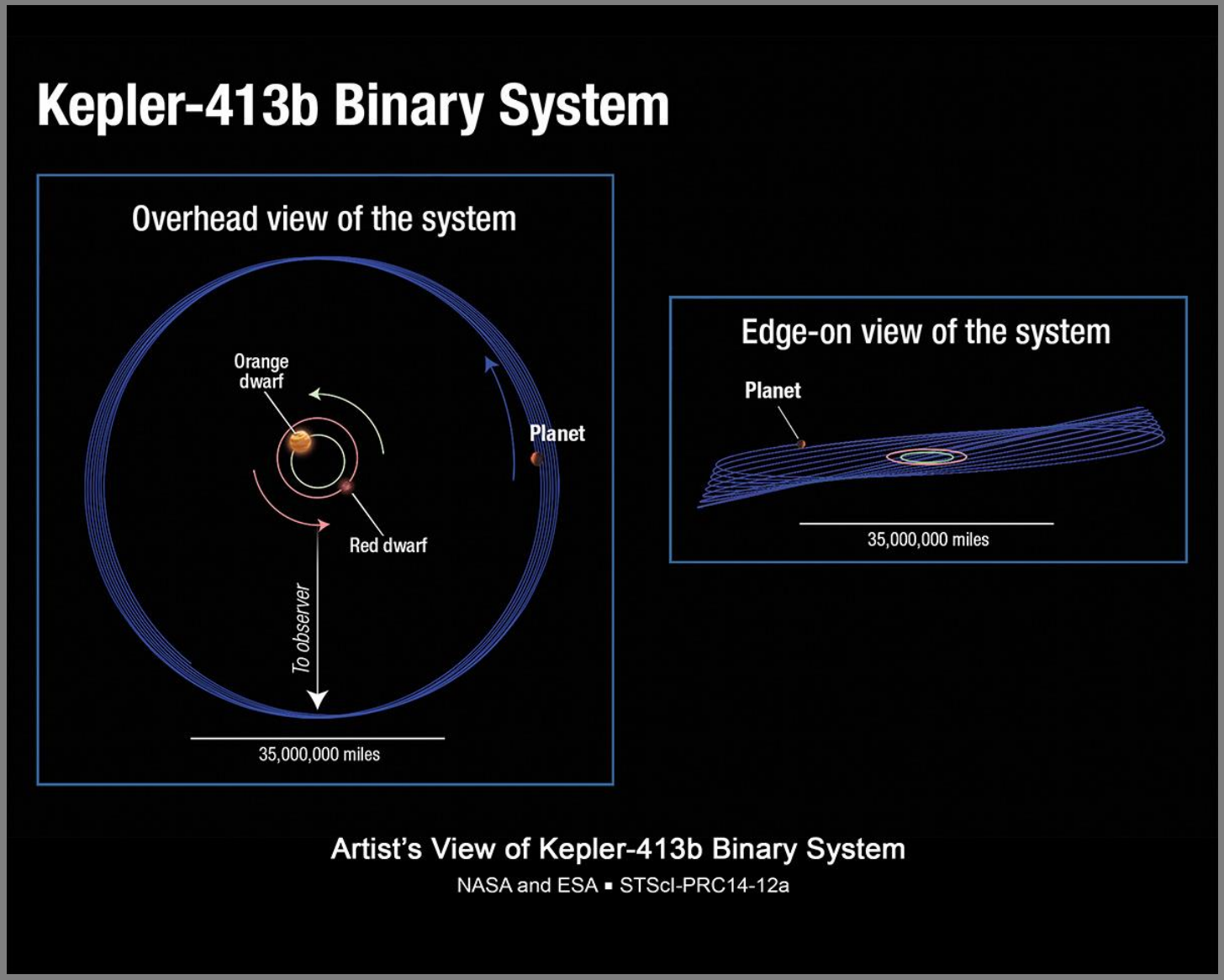
Planet Candidates

As of November 4, 2013



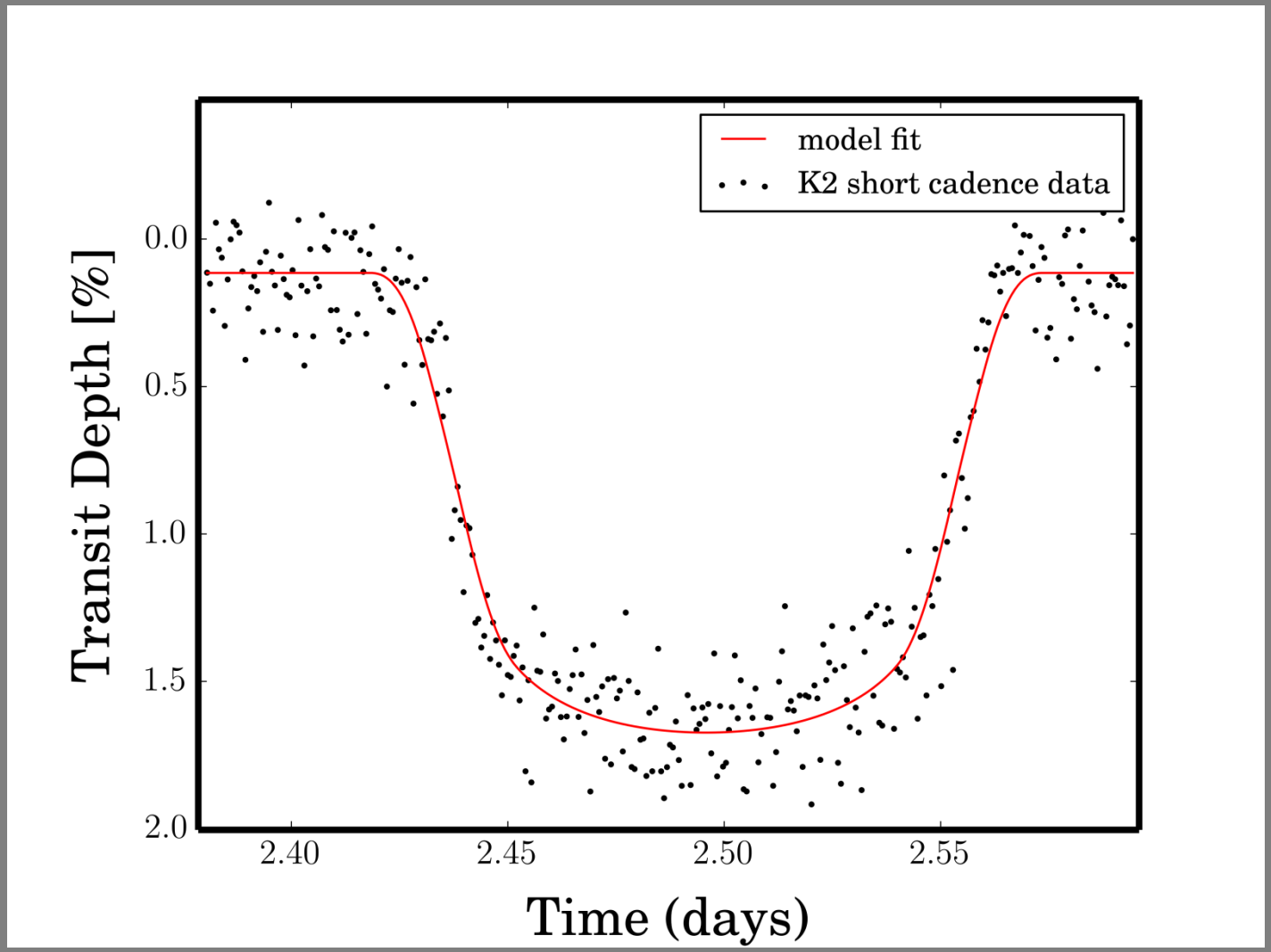
http://www.nasa.gov/sites/default/files/styles/430x323/public/scatter-gram_nov2013_radoper_monochrom.jpg?itok=YXLsgEZ4

Wobbly Circumbinary Planet



http://www.nasa.gov/sites/default/files/p1412aw_0.jpg

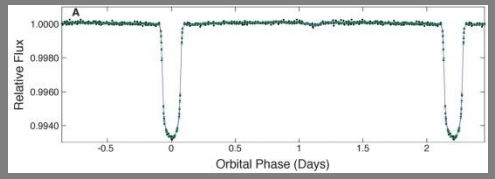
K2 Mission Proposal Status



http://www.nasa.gov/sites/default/files/wasp-28b3-hi-res.png

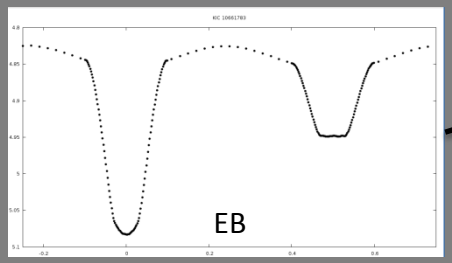
What are…?

Candidate Planets? When analysis of the Kepler data reveals a signal *consistent with* a transiting planet, the target is assigned a Kepler Object of Interest number, e.g., KOI-133, and the candidate becomes KOI-133.01 if it's the first one. Some candidates could be…

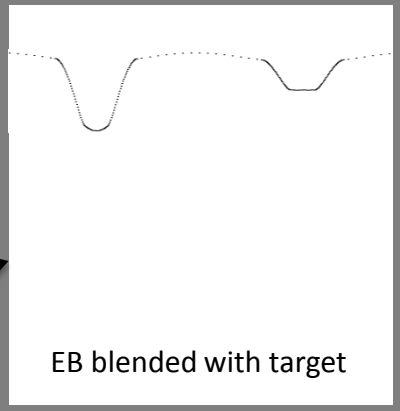


http://exoplanetmusings.files.wordpress.com/2011/12/00009a.jpg

False Positives (FPs)? Signals that look like a transiting planet but are from another cause, usually an eclipsing binary system so close that its light blends with that of the target star. If such sources of confusion can be discounted as very unlikely for some cases, those candidates could be accepted as…



http://www.astro.keele.ac.uk/jkt/codes/kic10661783.png



Confirmed Planets? Signals accepted as almost certainly caused by transiting planets. The KOI then gets a new designation and becomes Kepler-67b, for example.

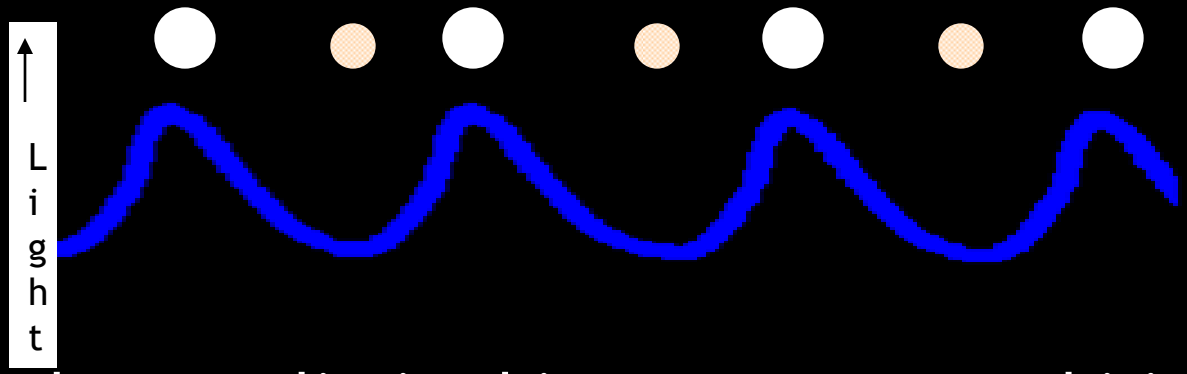
What else causes starlight to dim?

Kepler

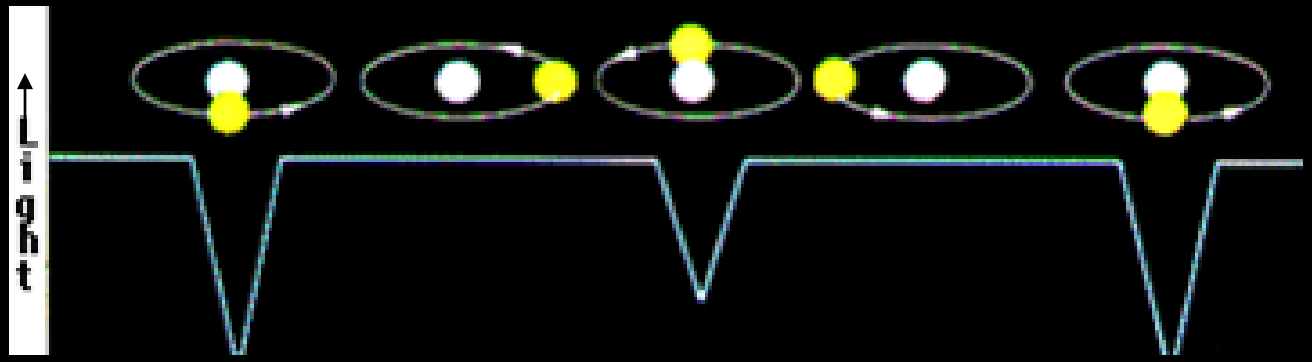
A Search for Habitable Planets

Is it a planet that's causing the star to dim?

It might be a variable star that, for various reasons, normally gets brighter, then dimmer.

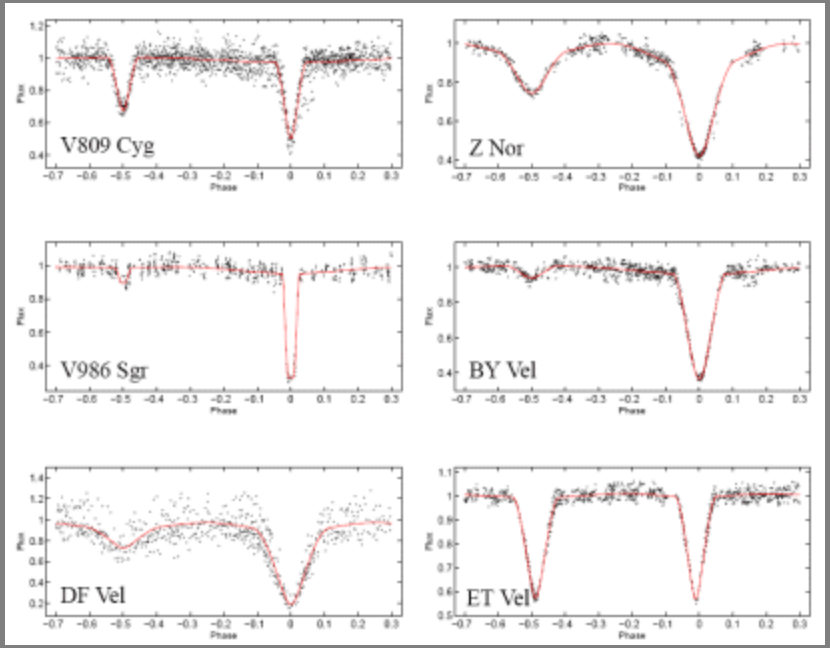


It might be an eclipsing binary: two stars orbiting each other, one passing in front of the other one.



http://nightsky.jpl.nasa.gov/download-redirect.cfm?Doc_ID=180&Doc_Filename=Kepler13%2Eppt

Eclipsing Binaries as Sources of Confusion



- A distant red giant/dwarf star pair could look like a Jupiter-like planet transiting a Sun-like star.
- A distant eclipsing binary blended with the light of the target star would have a light curve diluted by the target's light. The transit depth would then look shallower, like a planet instead of a star.
- The target star could be part of a triple system with two stars eclipsing and the blend of the three stars' light making the depth comparable to a planet transit.

Mitigation Strategies:

- Red giants have elevated levels of stellar variability compared with dwarf stars.
- The secondary transit could be detected if it is not diluted enough.
- Ignoring V-shaped transits would screen many false positives and fewer true planets.
- Blends with distant binaries are more concentrated in the galactic plane than target stars.
- Many blended binaries can be identified from a shift in the center of light during the transit.

http://sci.esa.int/science-e-media/img/d2/OMC-eclipsing-binaries-lightcurves_410.gif

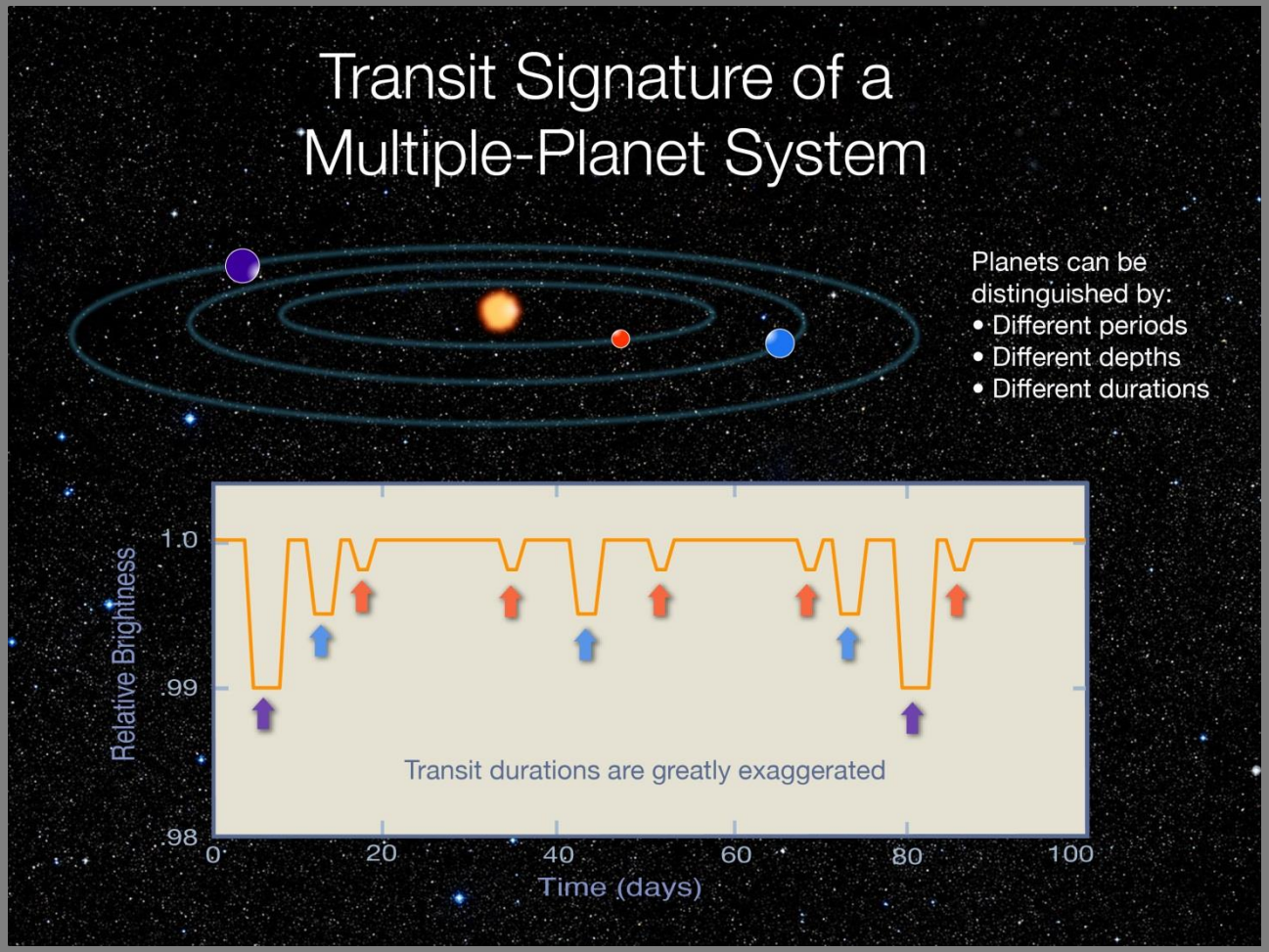
Validation with Follow-up Ground-Based Observations

- Higher resolution images from ground-based observations can rule out many possible blend scenarios if no potential nearby blend stars are found. Kepler's images are deliberately blurred to detect more photons without saturated pixels.
- Adaptive optics and speckle imagery can increase resolution further and restrict the blend possibilities further.
- Spectroscopy can reduce uncertainties about stellar parameters and thus narrow down the potential planet's size and orbital parameters.
- Spectroscopy can rule out the red giant/dwarf star eclipsing binary false positive scenarios.
- High-resolution spectroscopy can provide radial velocity information on the target system.
    - Massive enough planets can be detected independently this way.
    - Eclipsing binaries' radial velocity signatures can be detected.

http://ast.noao.edu/img/keck-domes.jpg

It is difficult to get observing time for a lot of candidate confirmations, so ground-based validation will take years. Still—it could mean a trip to Hawaii.

Confirming Candidates in Multiple Systems *en Masse*



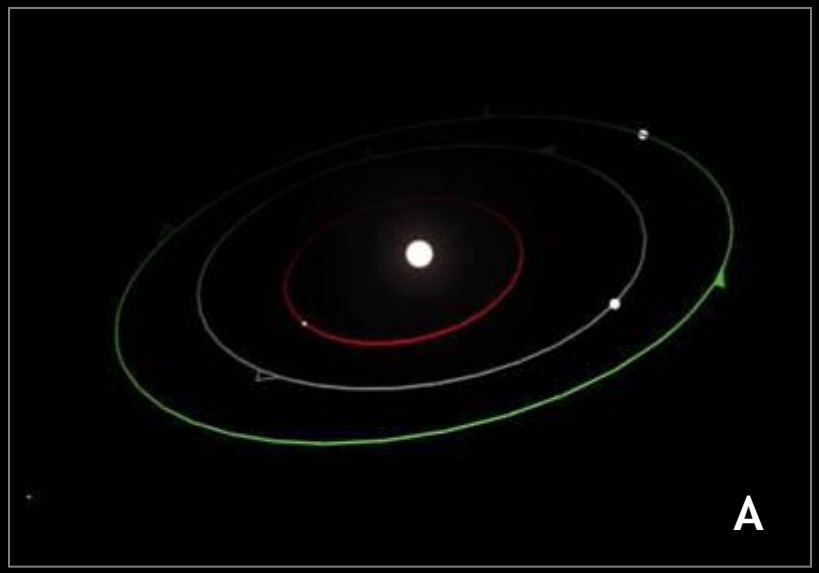
http://kepler.nasa.gov/images/TransitSignature_Mu10D0C0C1-br.jpg

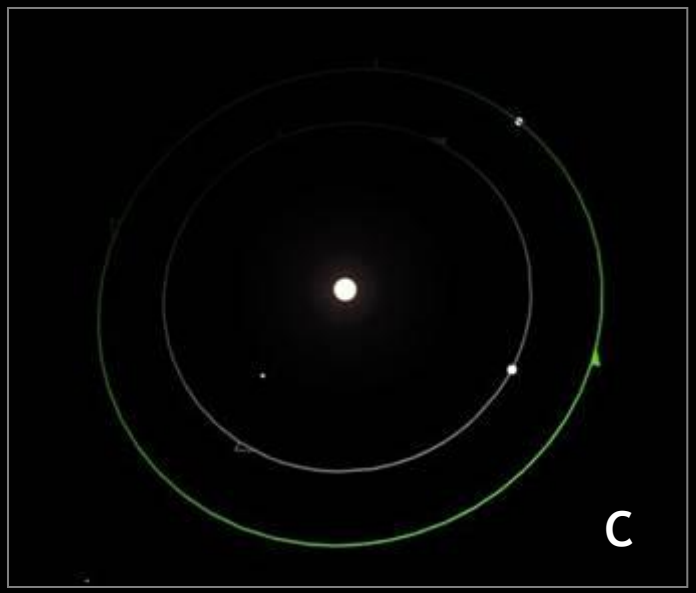
System Orientation

Kepler

A Search for Habitable Planets

For which of these star(s) will Kepler be able to detect transiting planets?





B.

The star's planets must orbit the star edge-on from our viewpoint. Not all planetary orbits are aligned this way . . . .So we must watch thousands of stars to find several that are correctly oriented.

http://nightsky.jpl.nasa.gov/download-redirect.cfm?Doc_ID=180&Doc_Filename=Kepler13%2Eppt

Experiment

- We have a bag of tiles ("Kepler targets") with numbers 1 to 13 and colors **b**lue, blac**k**, **r**ed, and **o**range, plus 2 **J**okers: 54 in all.
- We draw a pair of tiles and record them like this: 6R-12, or 10B-J.
- The first one drawn is a randomly chosen target that has a "planet candidate." If the second one chosen is a 13 or a Joker, that candidate is a "false positive." Otherwise it's "real."
- We put the tiles back and draw and record the next pair. We repeat the process to get a list.
- When we have a list of 12 candidates, we look for any targets that were drawn twice. Those candidates are "multis." Are any of the "multis" false positives?
- We expect about a 2/9 chance for any single target to appear on the list and a 1/9 chance of it being a false positive. We might expect to find 1-1/3 false positives but only about 1/4 of a false positive in multis.

6k-4, 6r-12, 2k-6, 1o-10, 5r-3, 3b-8,
6o-7, 7o-6, 8o-J, 1k-10, 9b-10, 1r-9

8r-7, 9b-10, 4o-10, 3o-1, 6b-13, 6k-13,
10-5, 2k-3, 11r-4, 7k-10, 6k-8, 6o-1

11b-2, 12o-4, 7o-7, Jr-2, 3b-2, 5k-6,
1b-8, 10r-6, 10o-4, Jr-5, 10r-7, 10b-4

Key: false positive
member of a multi

More Information

Kepler

A Search for Habitable Planets

NASA's Kepler Mission:
Using transits
to detect
Earth-size planets
orbiting in the
habitable zone
.
of Sun-like stars.

Kepler web site: http://Kepler.NASA.gov/