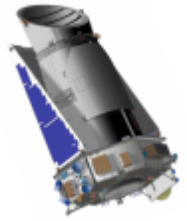
Planet Hunters
www.planethunters.org

or

by Johannes Kepler & Peter Woodward
07.02.11



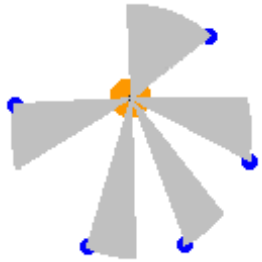
JOHANNES KEPLER

(By permission Sternwarte Kremsmünster)

Kepler's Laws 1609
Astronomia Nova

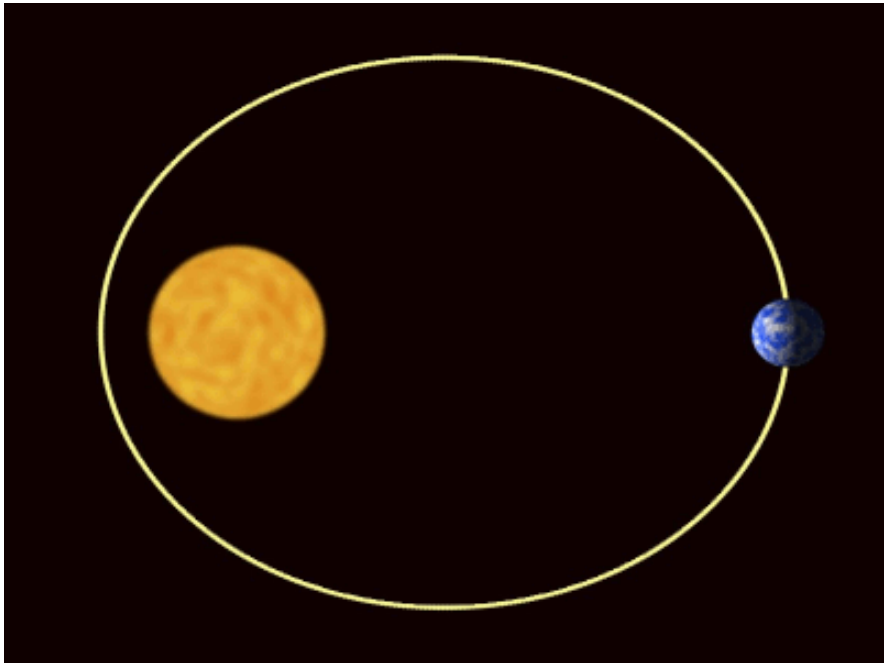
1. Planets move in orbits that are ellipses

2. The line joining a planet with the Sun sweeps equal areas in equal times.



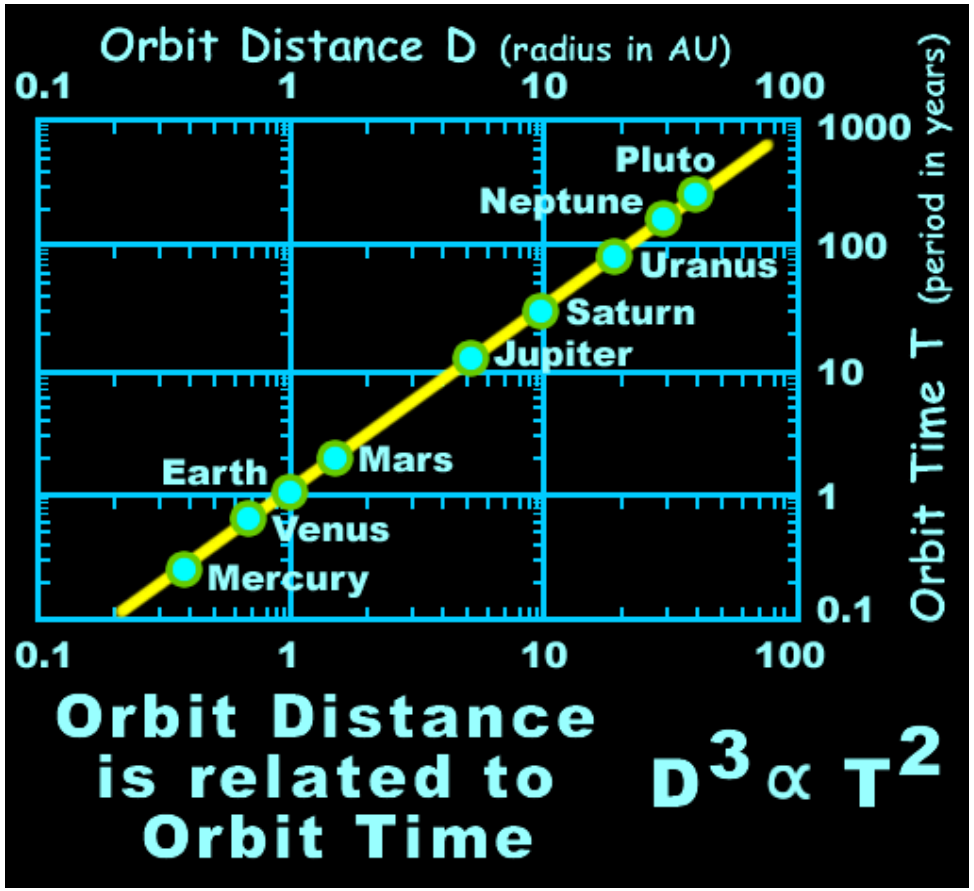
Tom Henderson

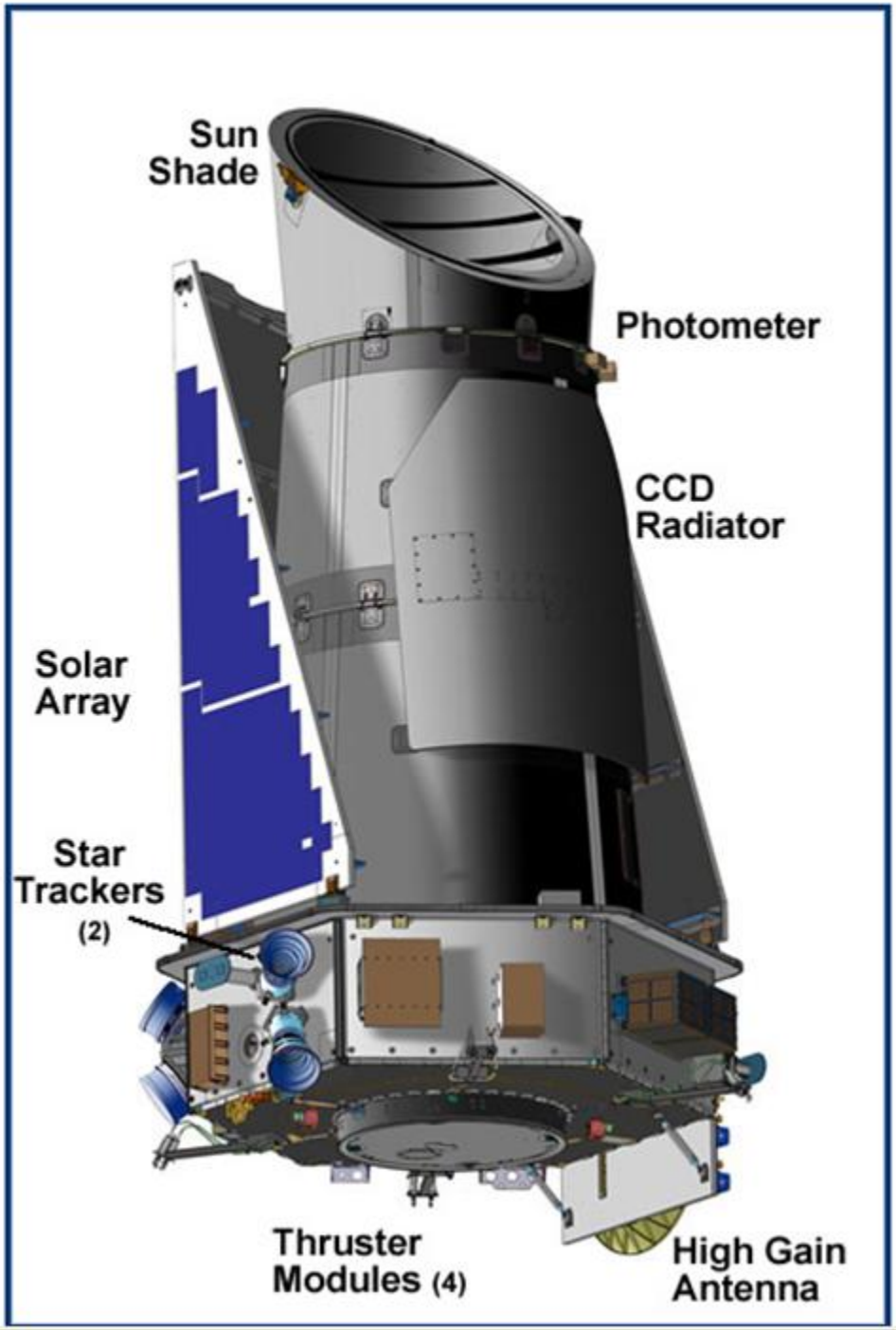
The areas of all triangles are the same size
-Kepler's law of Equal Areas -



Kepler's 3rd Law 1619
Harmonices Mundi

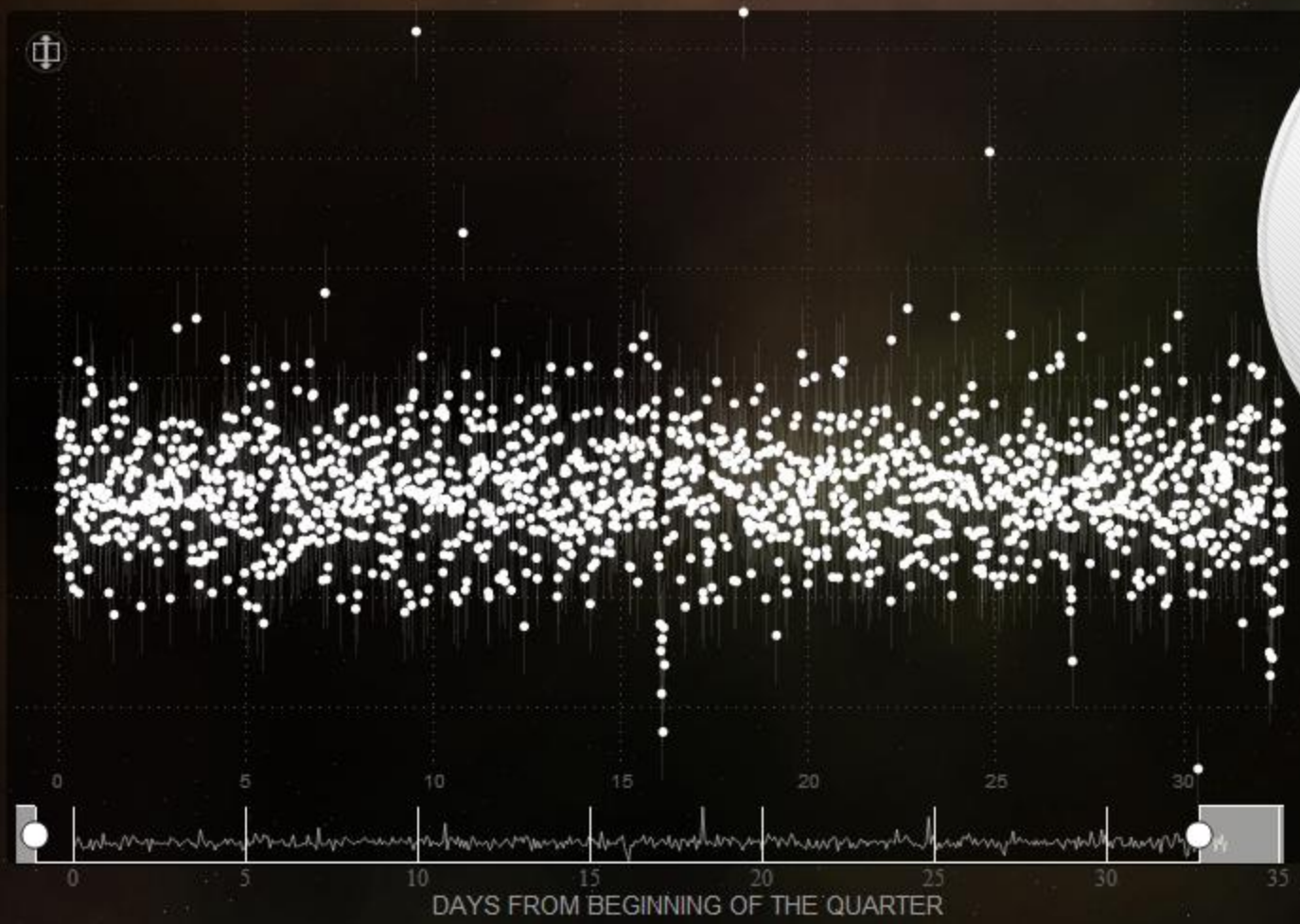
3. The square of the period of the orbit of a planet is proportional to the cube of its mean distance from the Sun.




Sun
Shade
Photometer
CCD
Radiator
Solar
Array
Star
Trackers
(2)
Thruster
Modules (4)
High Gain
Antenna

Kepler Vital Statistics

- In a receding Heliocentric orbit
- Follows the earth rnd. the sun in 371 days
- 4.7 m High (15ft) by 2.7m Wide (9ft)
- Records data for ¼ yr then; downloads
- Each ¼ spacecraft is rolled; solar panel & heat dissipation reasons, spring roll in space!
- Data made public 1yr after download
- 153k stars out of 230k in FOV monitored
- 4.8 to10Mbps highest ever download speed



We find new planets by looking at how the brightness of a star changes over time

NEXT

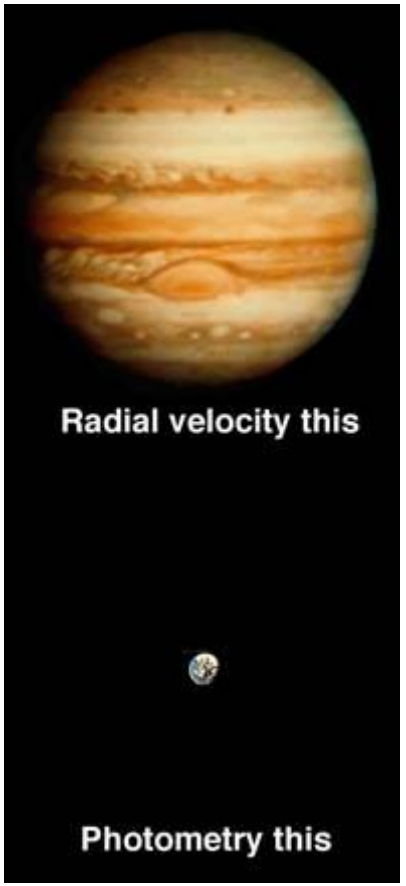
Type of star:	Dwarf
Apparent visual magnitude:	14.2
Temperature	5614 (K)
Radius	0.8x Sol

Why We Need a Different Approach

- Radial velocity (Doppler spectroscopy) method is unable to detect Earth-size planets
- Earth-like planets are about 300 times less massive and about 100 times smaller in area than Jupiter

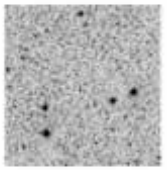
- Need a different approach that can detect smaller planets
- No method exists for detecting **Habitable Zone** planets from ground-based observatories

- The ***Kepler Mission*** uses **photometry** to detect transits and can detect Earth-size planets from space
- **The *Kepler Mission* is optimized to detect habitable planets in the habitable zone of solar-like stars**



Exoplanet encyclopedia http://exoplanet.eu

TECHNIQUES FOR FINDING EXTRASOLAR PLANETS



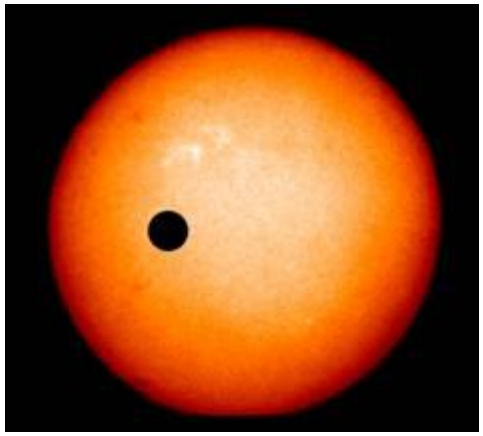
Method	Derive	Mass Limit	Status
Pulsar Timing	τ ; m_p/M_s	Lunar	Successful (4)
Radial Velocity	τ ; $m_p * \sin I$; e	super-Earth	Successful (300+)
Astrometry	τ ; m_p ; a ; D_s		
Ground		sub-Jupiter	In development
Space		super-Earth	Under study
Transit Photometry	τ ; A_p ; a ; I ; D_s ; atm comp.		Successful (20+)
Ground		sub-Jupiter	numerous groups
Space		sub-Jupiter	HST, CoRoT
Space		Earth	***Kepler***
Reflection Photo.	τ ; albedo$*A_p$; a ; atm comp.		
Space		sub-Jupiter	***Kepler***
Microlensing:	f(m,M_s ,r,D_s,D_L)		
Ground		super-Earth	OGLE (4)
Direct Imaging	τ ; albedo$*A_p$; a ; I ; e ; D_s ; atm comp.		
Space		Earth	Under study

(Source: J. Lissauer)

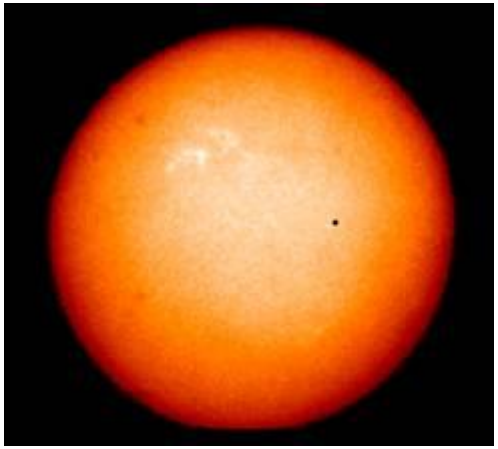
τ=period, a=semi-major axis, mp=planet mass, Ap=planet area, I=orbit inclination, e=eccentricity, Ds=distance to star

USING PHOTOMETRY TO DETECT EARTH-SIZE PLANETS

- The relative change in brightness ($\Delta L/L$) is equal to the relative areas (A_{planet}/A_{star})



Jupiter:
1% area of the Sun (1/100)



Earth or Venus
0.01% area of the Sun (1/10,000)

- To measure 0.01% must get above the Earth's atmosphere
- Method is robust but you must be patient:

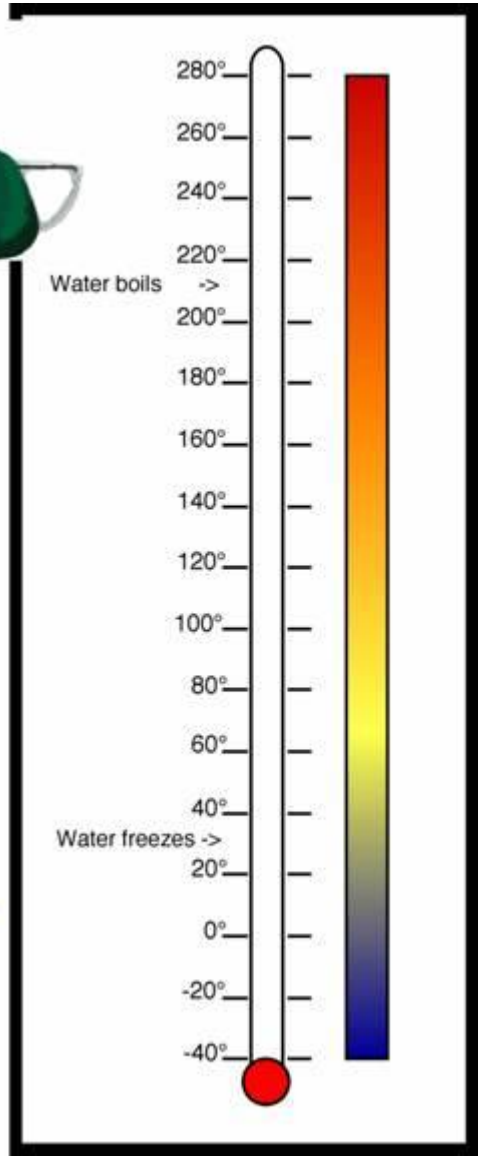
  Require at least 3 transits preferably 4 with same brightness change, duration and temporal separation

Things that affect a Planet's temperature

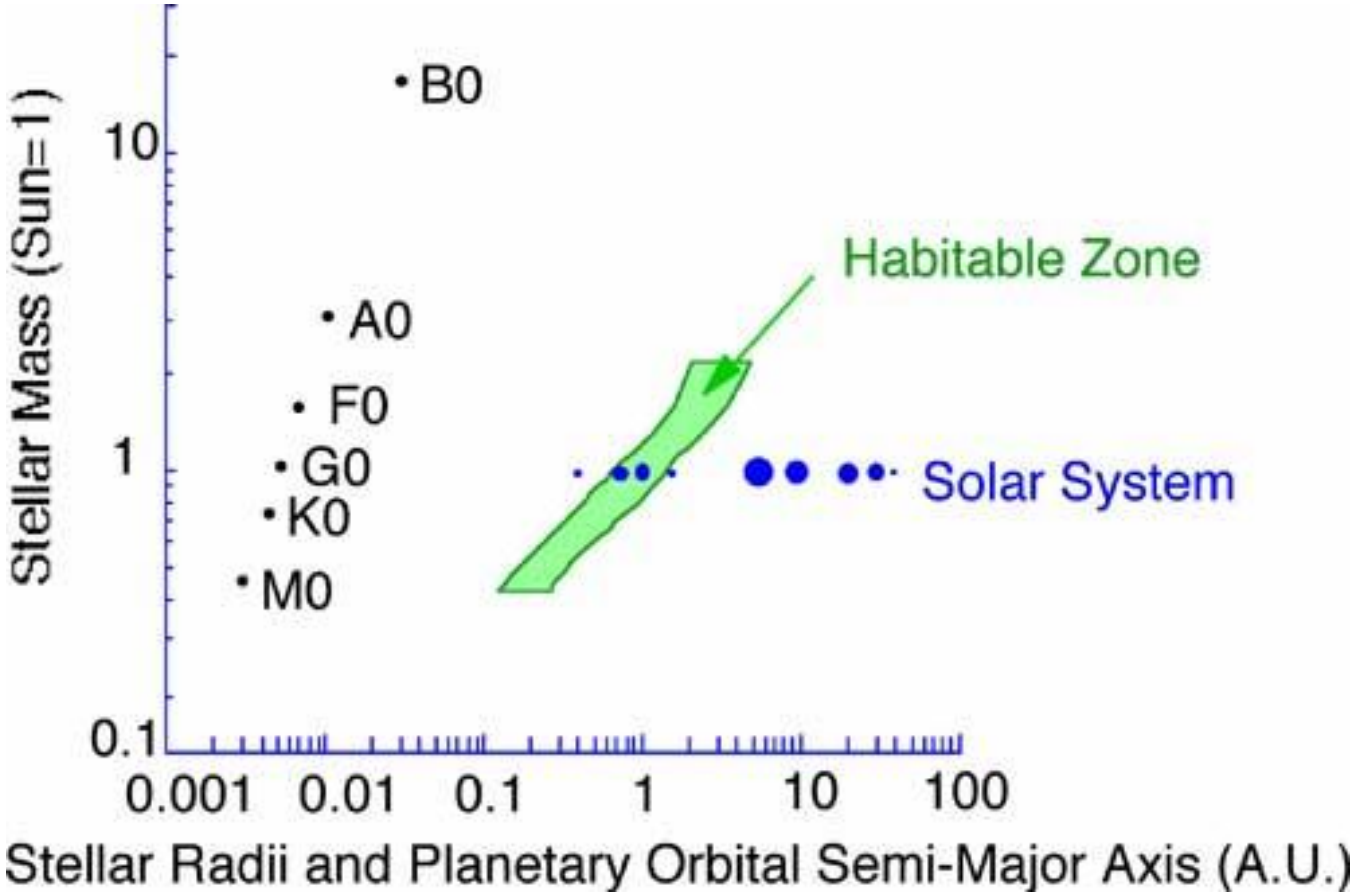
- Want temperature so you can have liquid water on the surface of the planet

1. **Temperature of star**
2. **Distance from the star**
3. **Planet's orbit: circular or elliptical**
4. **Planet's atmos.; greenhouse gases**

- These define the **Habitable Zone (HZ)** for a star

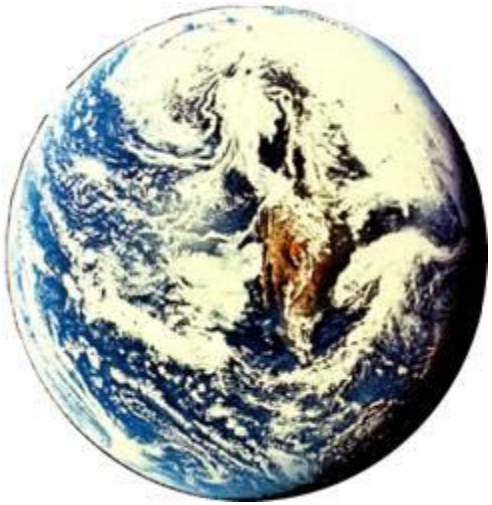


The Habitable Zone for Various Stellar Types



The **Habitable Zone (HZ)** in green is the distance from a star where liquid water is expected to exist on the planets surface. (Kasting, Whitmire and Reynolds, 1993)

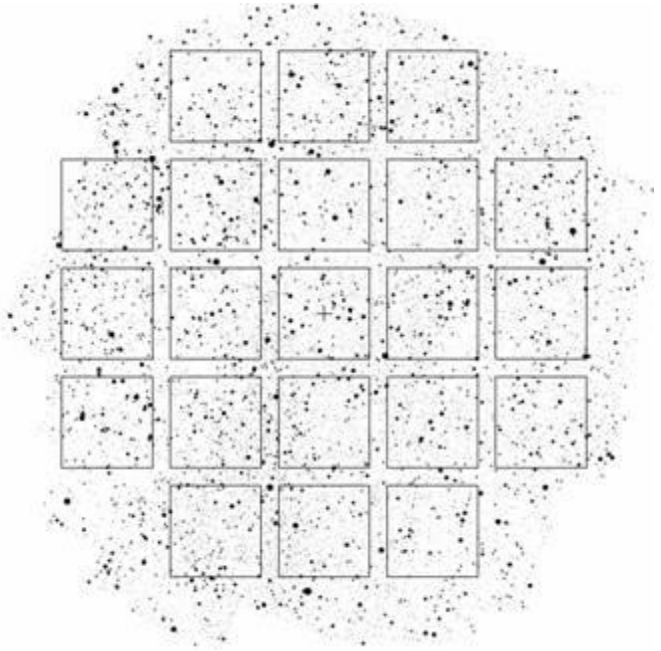
What Is Important About An Atmosphere?



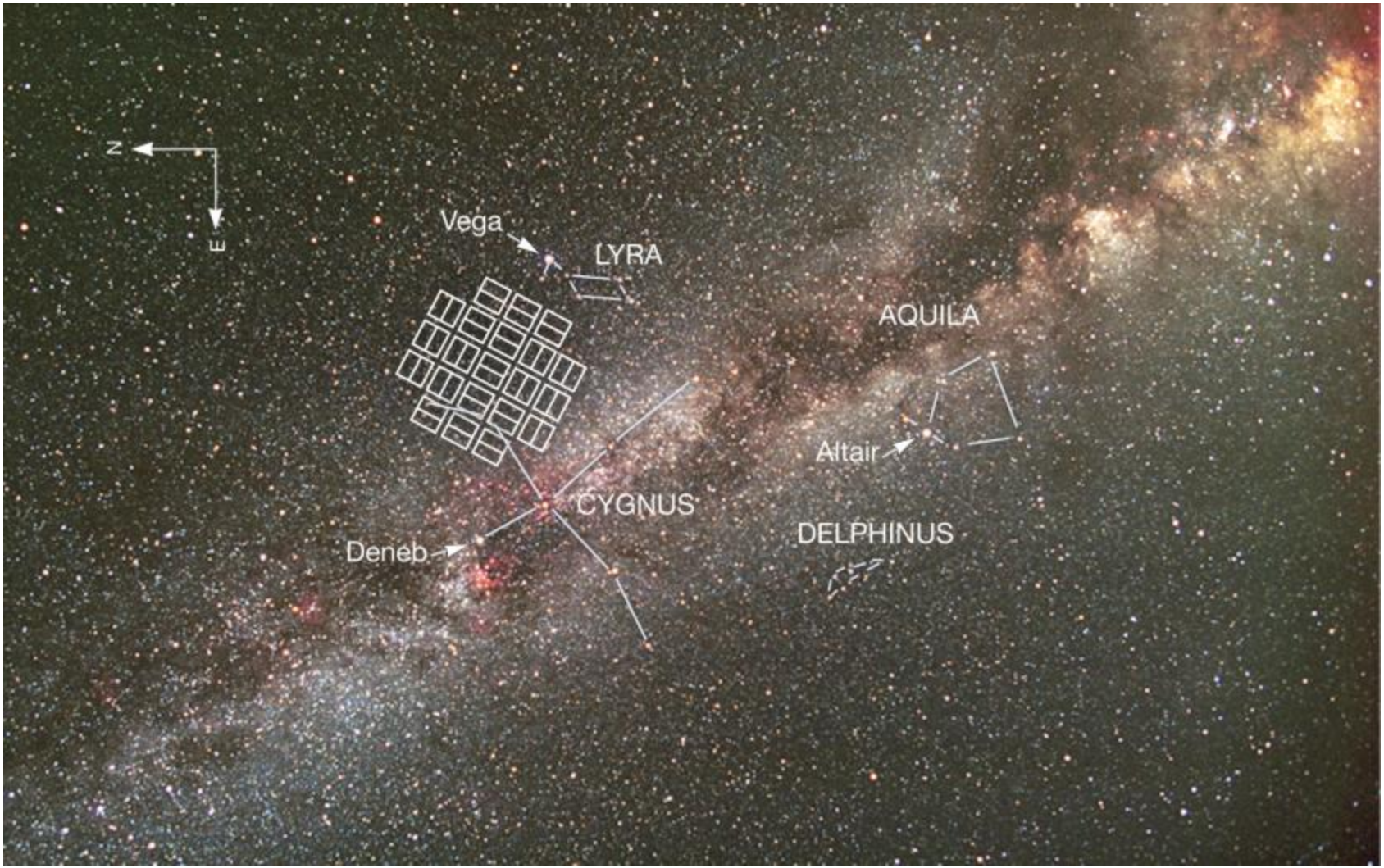
- Composition (Earth)
  - free oxygen (about 23%)
  - mostly inert (about 75% nitrogen)
  - very little toxic gases
- Composition affects temperature
  - Minimize day-night extremes
  - Greenhouse gases (water, CO_2) hold in the heat
- Acts as an invisible protective shield
  - Cosmic rays (high energy gamma-rays, protons, electrons)
  - Solar wind and solar flares (charged particles)
  - UV - ultraviolet
  - Micrometeoroids (e.g., puts holes in Space Shuttle window)
- Transports water **(Personal comment Most important for life)**
  - Rain

Kepler Mission Concept

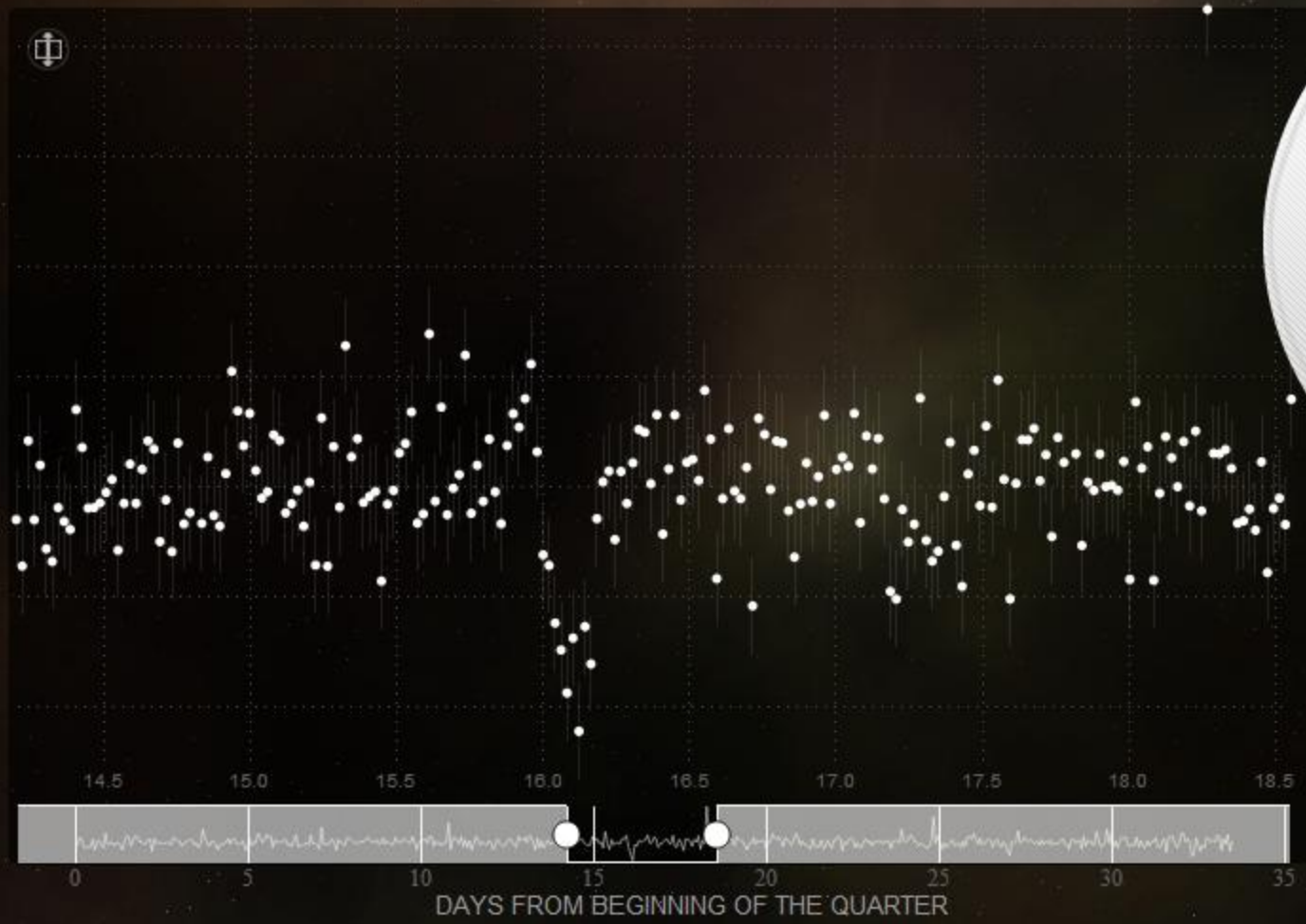
- ***Kepler Mission*** is optimized for finding **Habitable Planets** (0.5 to 10 earth masses) in the **HZ** (near 1 AU) of solar-like stars
- Continuously and simultaneously monitor 100,000 main-sequence stars
- Use a one-meter Schmidt telescope: FOV >100 deg^2 with an array of 42 CCD
- Photometric precision: Noise < 20 ppm in 6.5 hours = 468 ms data loss in 23,400,000 ms= **99.998%**
- Mission: Heliocentric orbit for continuous viewing ≥ 3.5 year duration



FIELD OF VIEW IN CYGNUS



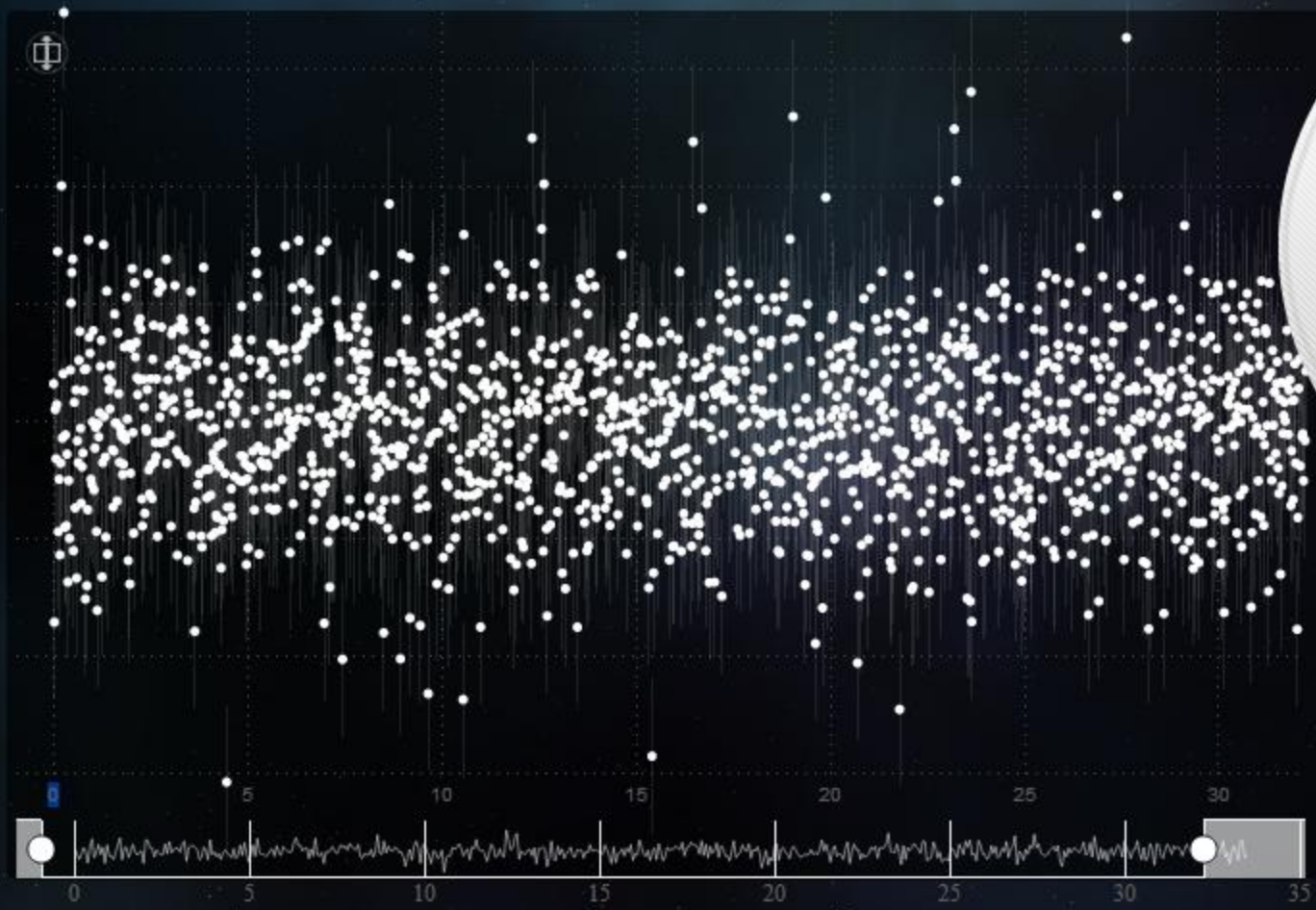
The Kepler star field is a part of the extended solar neighborhood in the Cygnus-Lyra regions along the Orion arm.
It is located on one side of the summer triangle (Deneb-Vega-Altair)



We find new planets by looking at how the brightness of a star changes over time

NEXT

Type of star:	Dwarf
Apparent visual magnitude:	14.2
Temperature	5614 (K)
Radius	0.8x Sol



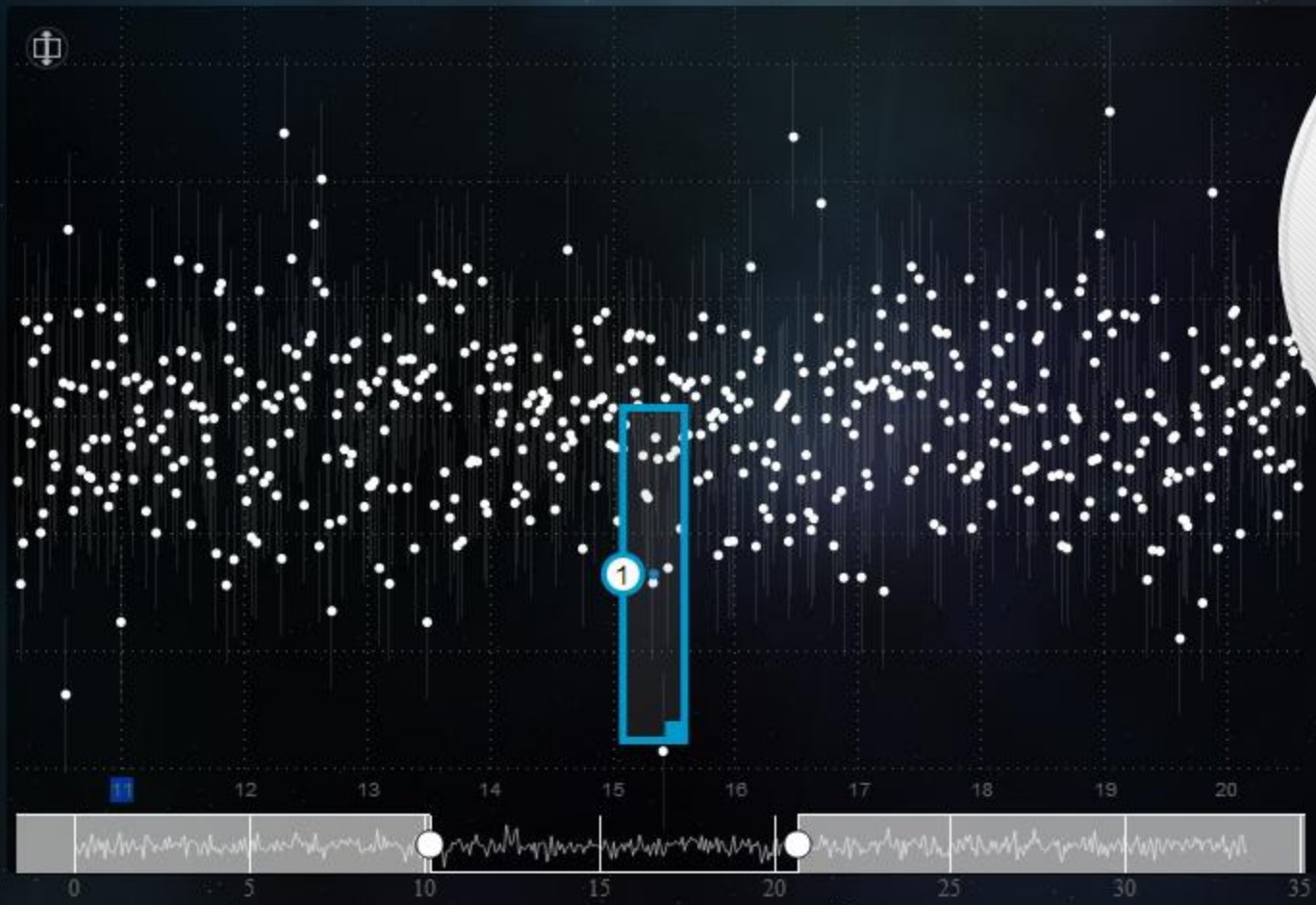
HELP RESTART

Does the star have any transit features?

YES NO

Type of star:	Dwarf
Apparent visual magnitude:	15.9
Temperature	4634 (K)
Radius	0.6x Sol

★ MARK AS FAVORITE



HELP RESTART

Mark a transit on the graph

FINISH

Type of star:	Dwarf
Apparent visual magnitude:	15.9
Temperature	4634 (K)
Radius	0.6x Sol

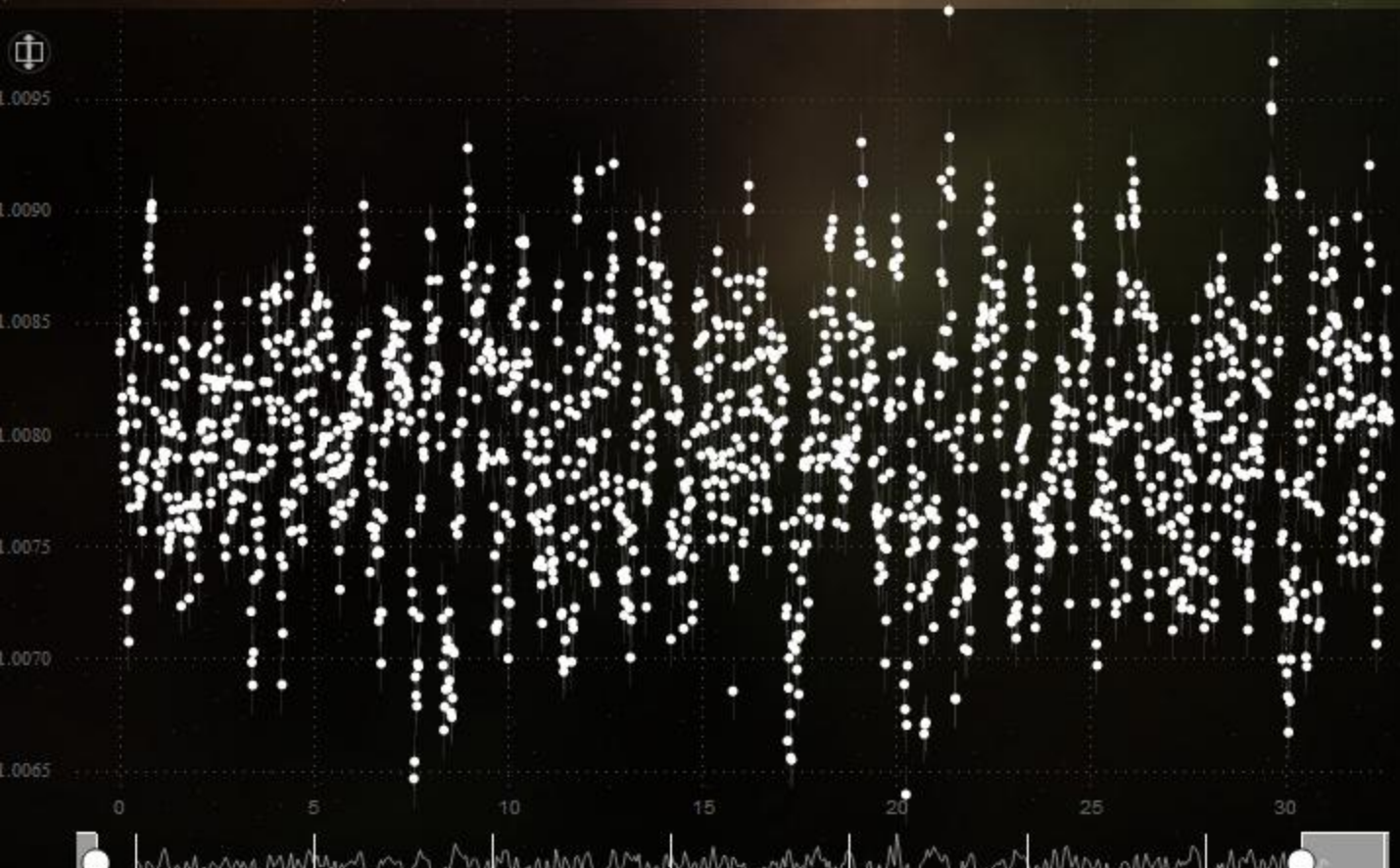
★ MARK AS FAVORITE

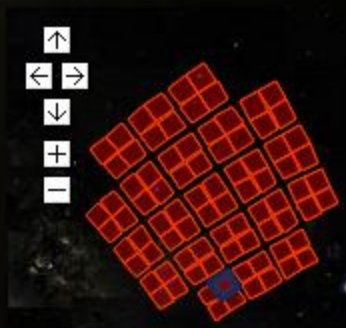
SPH10088328

Giant with a radius 6.2 times that of our Sun. It has a magnitude of 13.3 and is spectral type K

FAVORITED (remove) | DOWNLOAD DATA | VIEW ON KEPLER ARCHIVE | DISCUSS THIS STAR

VIEW STAR





POWERED BY Google

Terms of Use

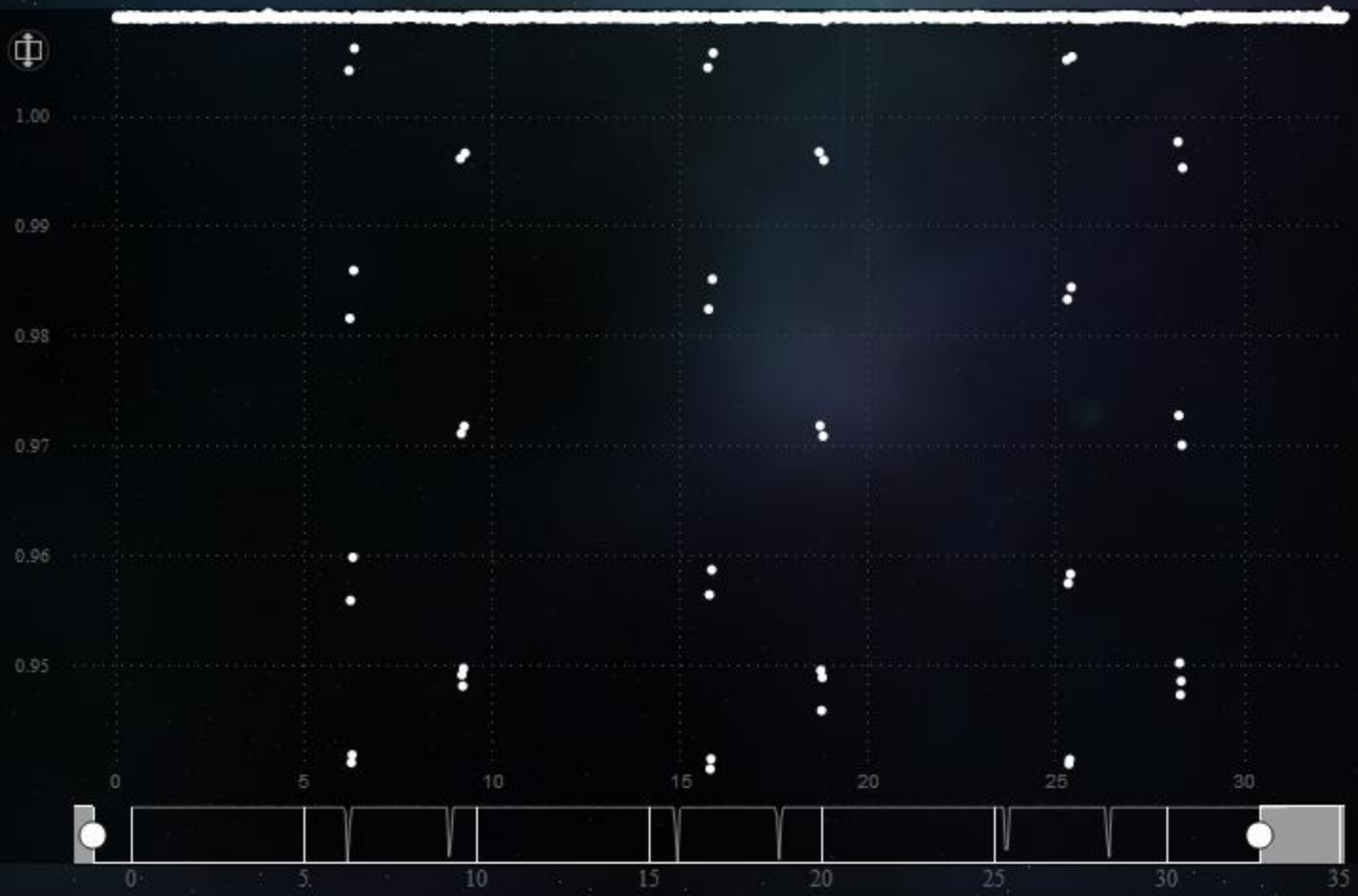
Type of star:	Giant
Apparent visual magnitude:	13.3
Temperature	4734 (K)
Radius	6.2x Sol

SPH10081876

Dwarf with a radius 1.1 times that of our Sun. It has a magnitude of 12.3 and is spectral type G

FAVORITED (remove) | DOWNLOAD DATA | VIEW ON KEPLER ARCHIVE | DISCUSS THIS STAR

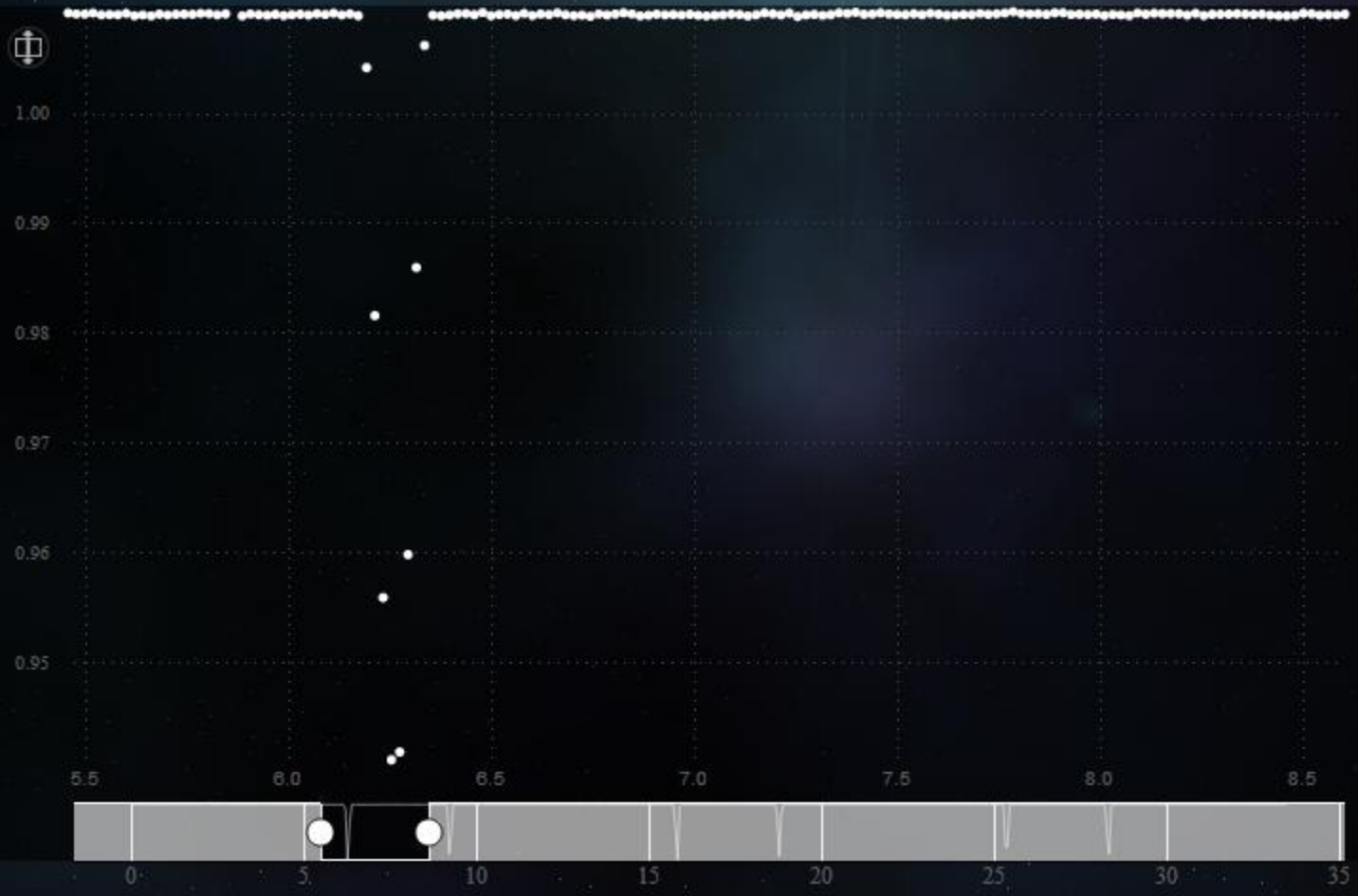
VIEW STAR

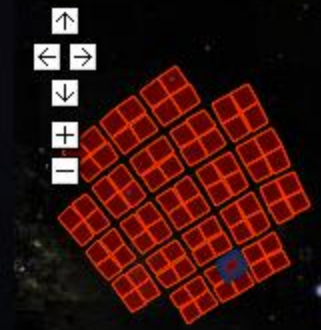


Type of star:	Dwarf
Apparent visual magnitude:	12.3
Temperature	5309 (K)
Radius	1.1x Sol

SPH10081876

Dwarf with a radius 1.1 times that of our Sun. It has a magnitude of 12.3 and is spectral type G





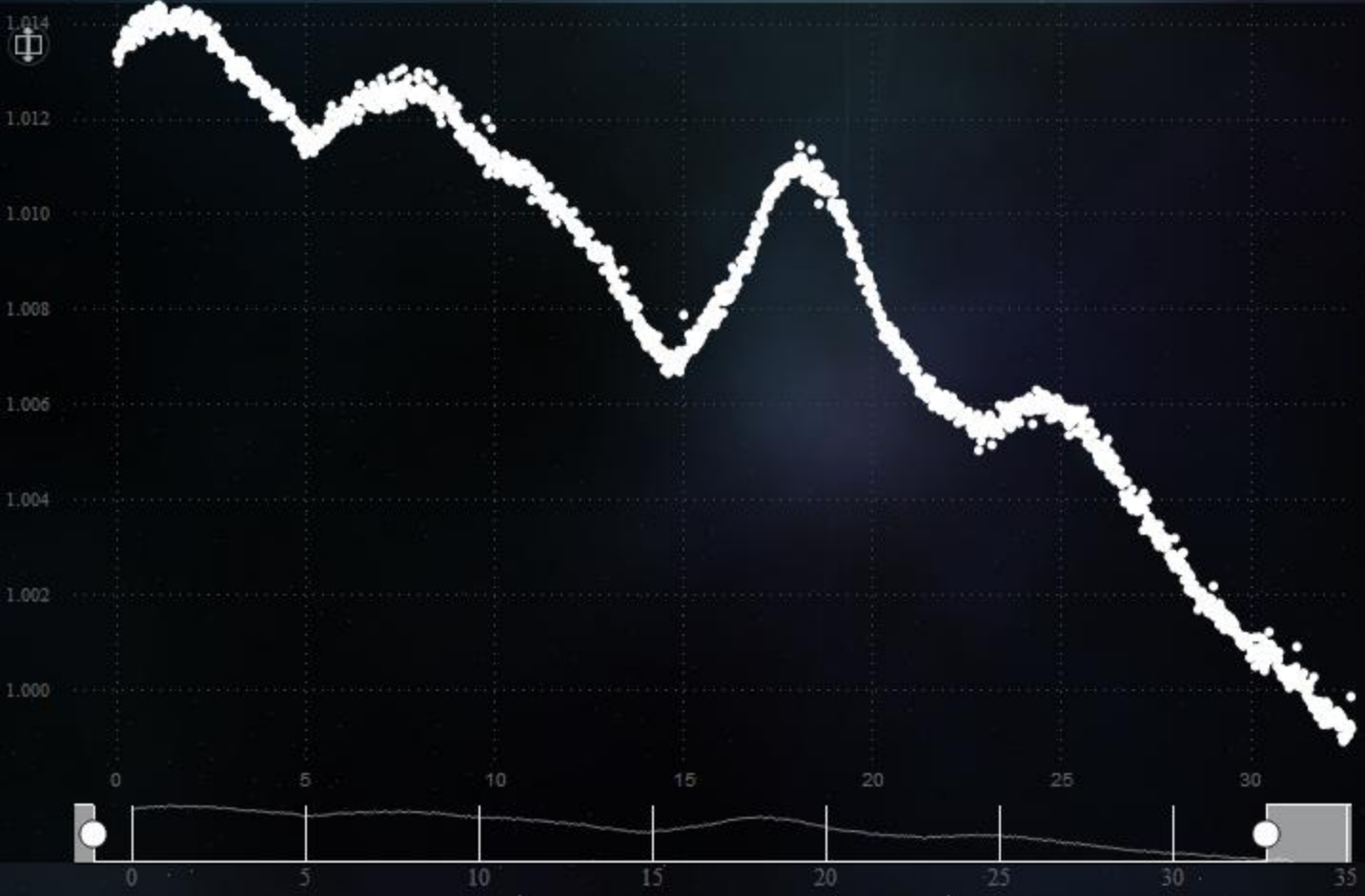
Type of star:	Dwarf
Apparent visual magnitude:	12.3
Temperature	5309 (K)
Radius	1.1x Sol

SPH10082100

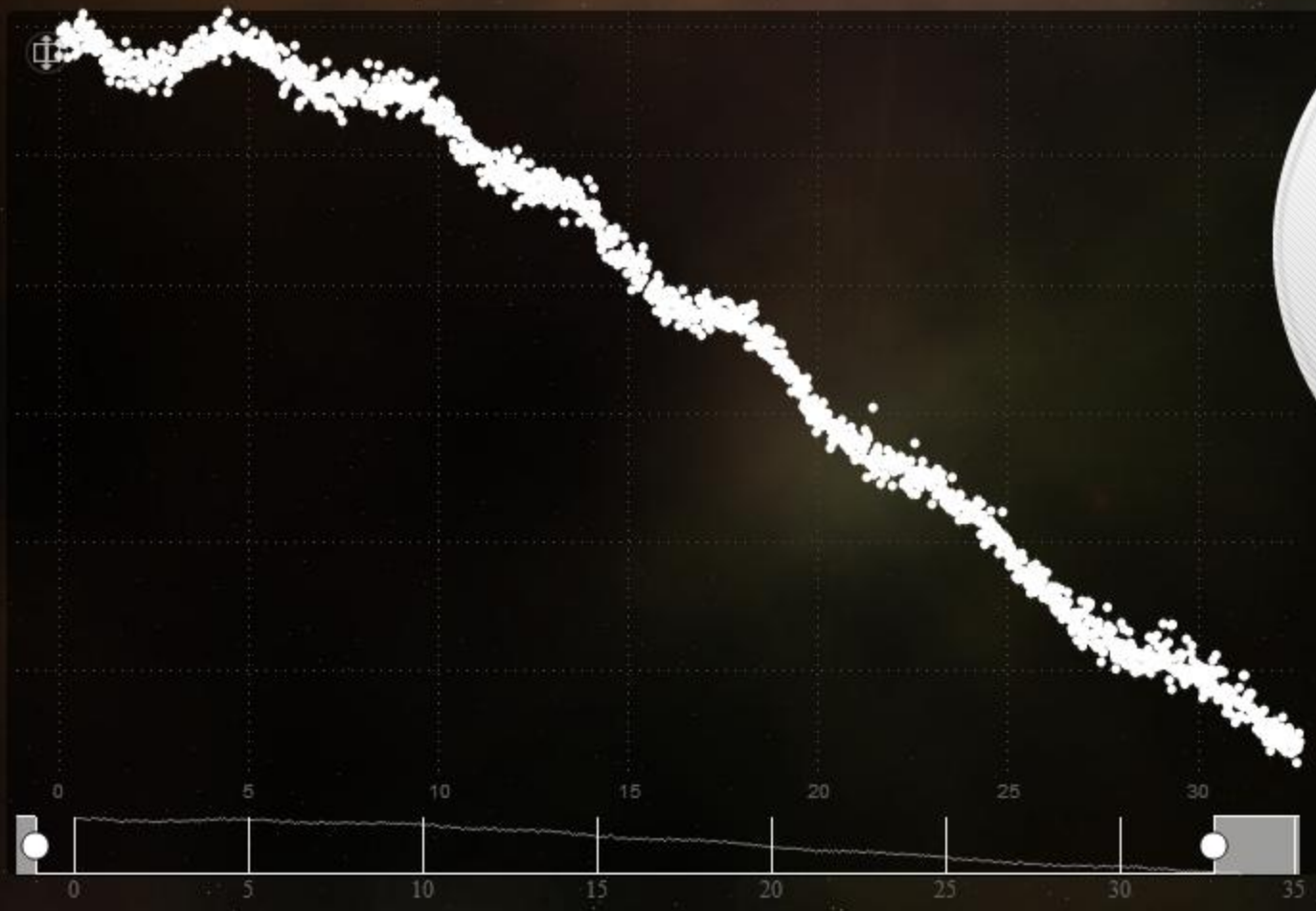
Dwarf with a radius 1.0 times that of our Sun. It has a magnitude of 13.6 and is spectral type G

FAVORITED (remove) | DOWNLOAD DATA | VIEW ON KEPLER ARCHIVE | DISCUSS THIS STAR

VIEW STAR



Type of star:	Dwarf
Apparent visual magnitude:	13.6
Temperature	5489 (K)
Radius	1x Sol



HELP RESTART

Are there any big breaks or gaps in the light curve?

YES NO

Type of star:	Dwarf
Apparent visual magnitude:	14.9
Temperature	5279 (K)
Radius	1.2x Sol

★ MARK AS FAVORITE

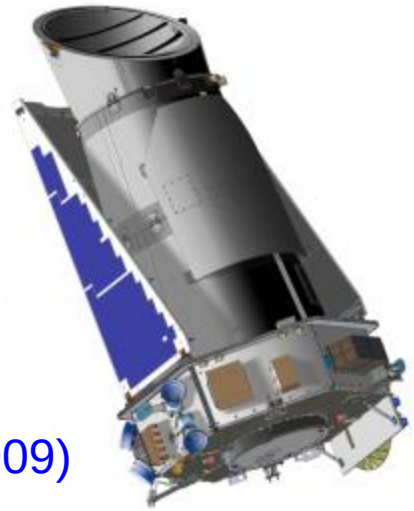
SUMMARY

The ***Kepler Mission*** will:

Observe more than 100,000 dwarf stars
continuously for 3.5 to 6+ years
with a precision capable of detecting Earth's in the **Habitable Zone**

The ***Kepler Mission*** can discover:

Planet sizes from that of Mars to greater than Jupiter
Orbital periods from days up to two years
About 600 terrestrial planetary systems if most have 1 AU orbits
About 1000 inner-orbit giant planets based on
already known frequency
Can expect 100's to 1000's of **???** size planets
depending on frequency **???** and orbit **???**
A NULL result would also be very significant ! ! !



Results on giants expected 9 months after launch (March 2009)
and will continue for 3.5 to 6+ years

http://kepler.nasa.gov

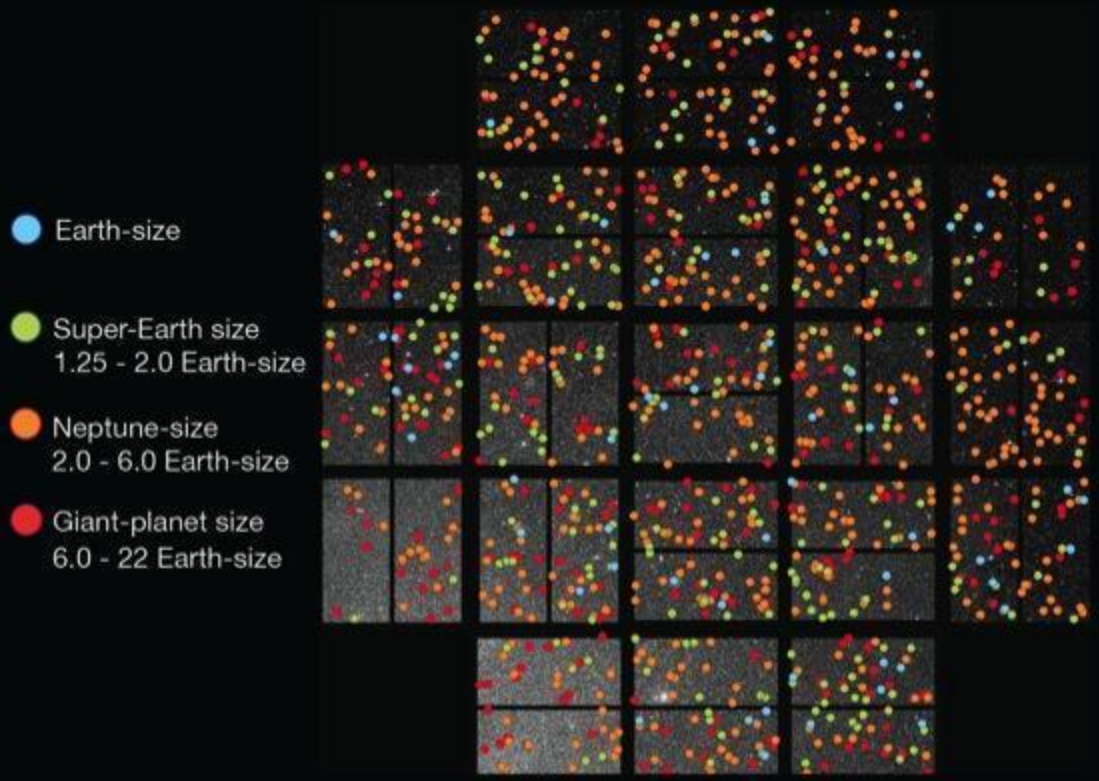
***Kepler* Mission** Progress @ 31.01.11

- Prjct. Team's "Planet Candidates 712"
- Confirmed 9; via rigorous process
- Amateur Planet Candidates 2 **[data released Dec2010]**
- Eclipsing binaries 1879 !
- Remember looking for **HZ** planets
- Project to run for min 3.5 yrs up to 6
- www.exoplanets.eu 520, 440 by Veloc. http://archive.stci.edu

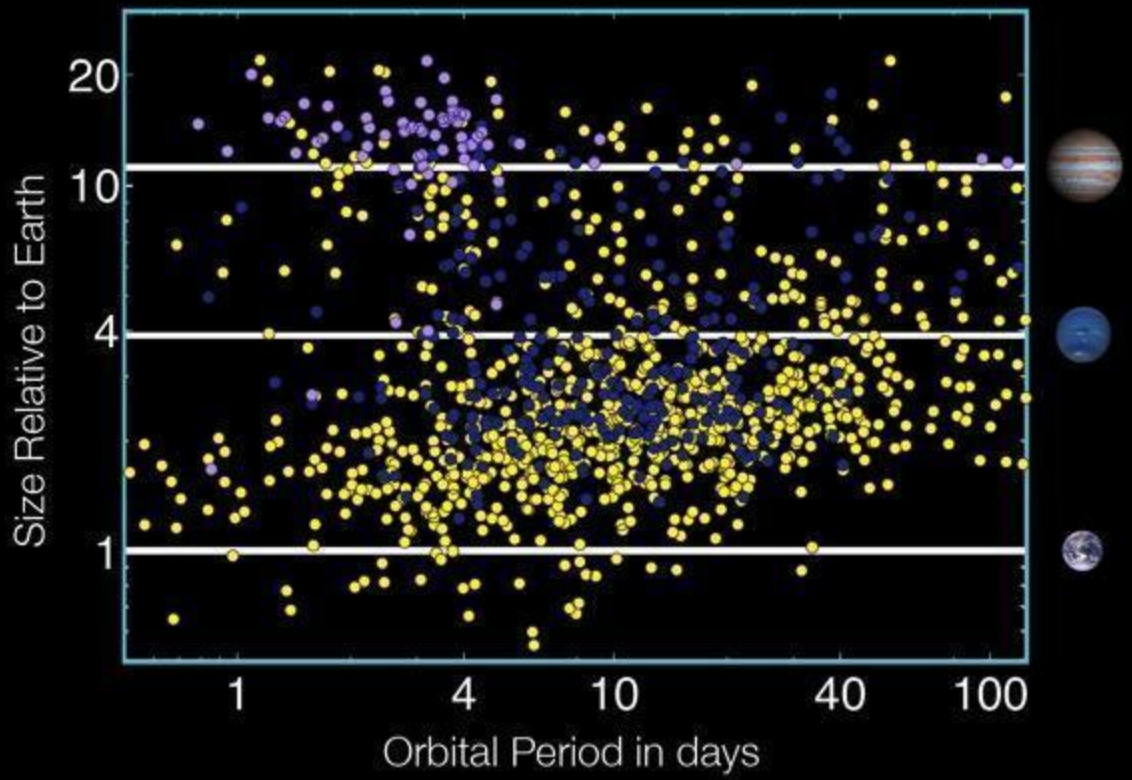
Kepler Mission Progress @ 02.02.11

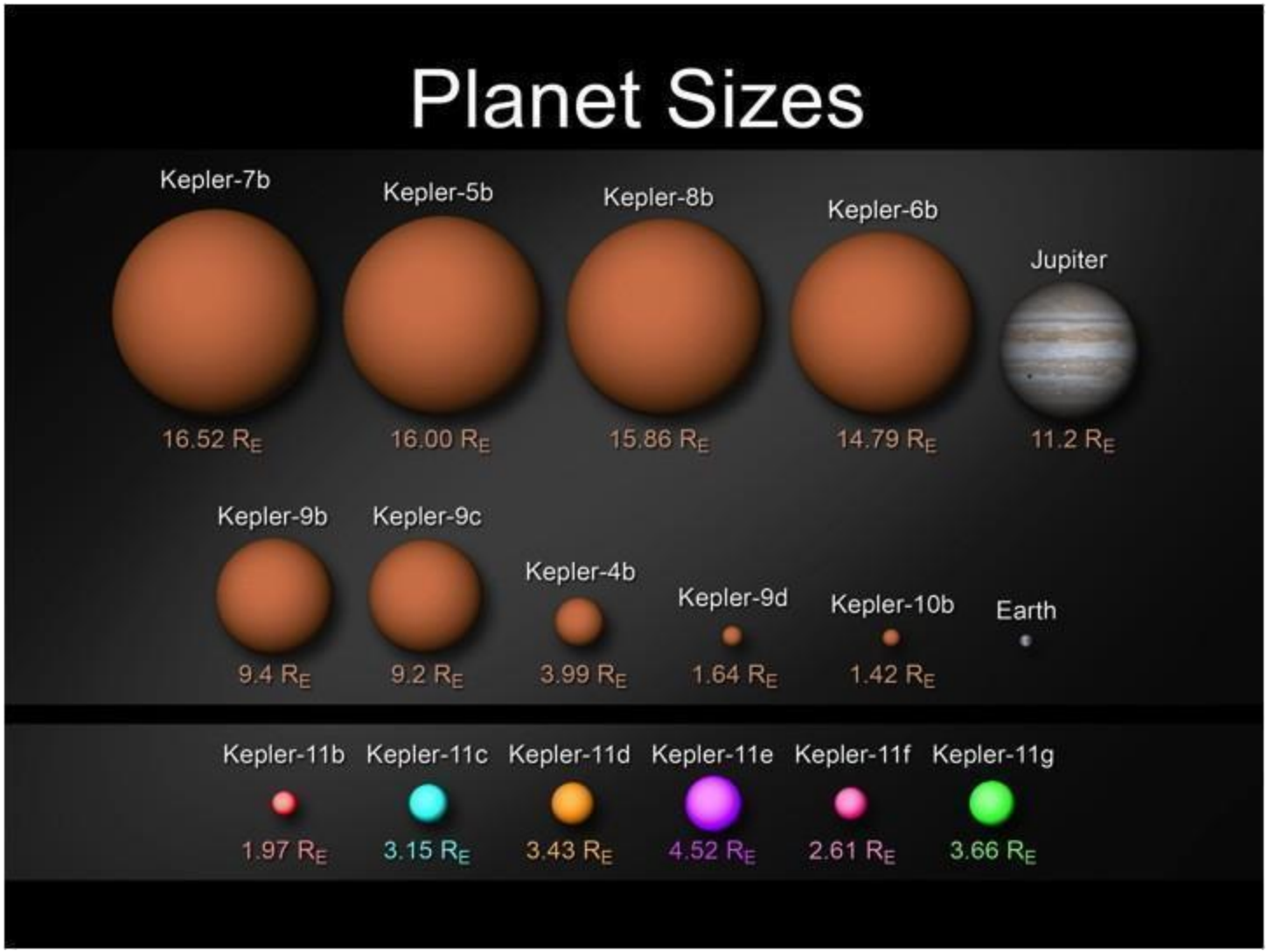
- Data on 1235 candidates
- Data on 155,453 stars from 4 mnths ops
- 68 Earths, 288 Super E, 662 Neptunes 165 Jupiters
- 54 candidates in **HZ**
- 5 smallest 0.9E to 2E
- Many Multi planet
- Only viewing 1/400 of sky

Locations of Kepler Planet Candidates



Kepler Candidates as of February 1, 2011




Planet Sizes
Kepler-7b
16.52 R_E
Kepler-5b
16.00 R_E
Kepler-8b
15.86 R_E
Kepler-6b
14.79 R_E
Jupiter
11.2 R_E
Kepler-9b
9.4 R_E
Kepler-9c
9.2 R_E
Kepler-4b
3.99 R_E
Kepler-9d
1.64 R_E
Kepler-10b
1.42 R_E
Earth
Kepler-11b
1.97 R_E
Kepler-11c
3.15 R_E
Kepler-11d
3.43 R_E
Kepler-11e
4.52 R_E
Kepler-11f
2.61 R_E
Kepler-11g
3.66 R_E