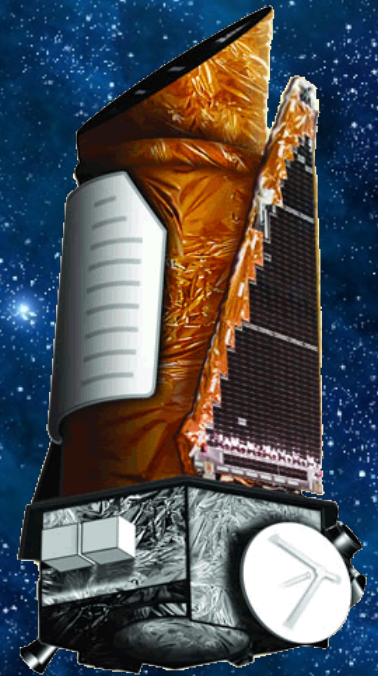


ARE WE ALONE?

Kepler

ON A QUEST

NASA



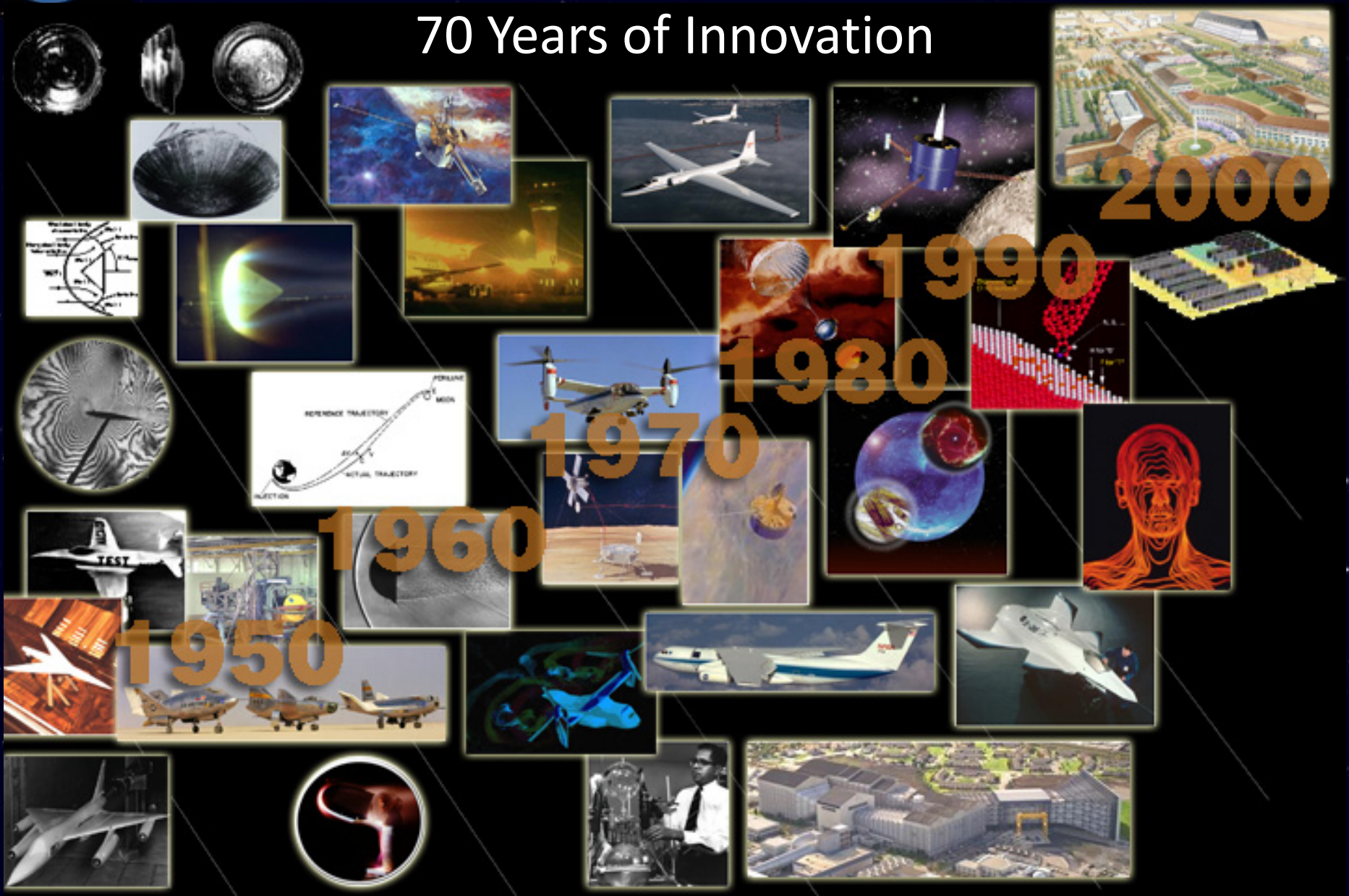
Anima Patil-Sabale,
NASA Ames Research Center
anima.sabale@nasa.gov



What is NASA?

Kepler

70 Years of Innovation



1950

1960

1970

1980

1990

2000



NASA

Kepler





NASA In Movies !?!

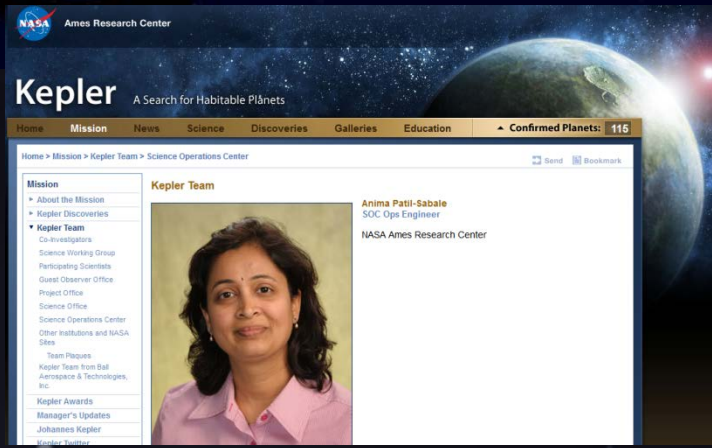
Kepler



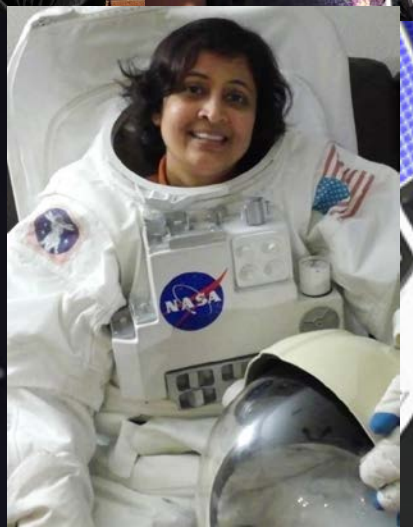


About Me!

Kepler



BS Physics
MS Computer Applications
MS Aerospace Engineering



Sr. Principal Software Engineer
Mission Title: SOCOPS Engineer

My Dream Job!!! →





Johannes Kepler

Kepler





Men Behind the Mission!

William Borucki



David Koch

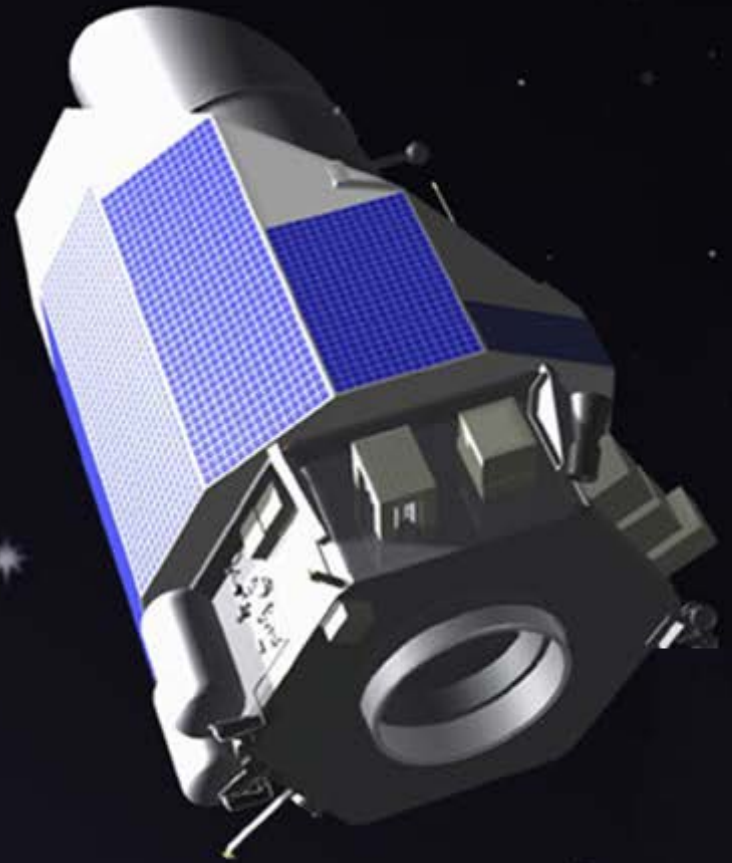




Kepler: The Telescope

Kepler

Kepler's Mission:
Search for Earth-size and
smaller planets in
habitable zone around
sun-like stars in our
galactic neighborhood





Our Habitable Earth!



Air



Water



Land



Life





The Habitable Zone

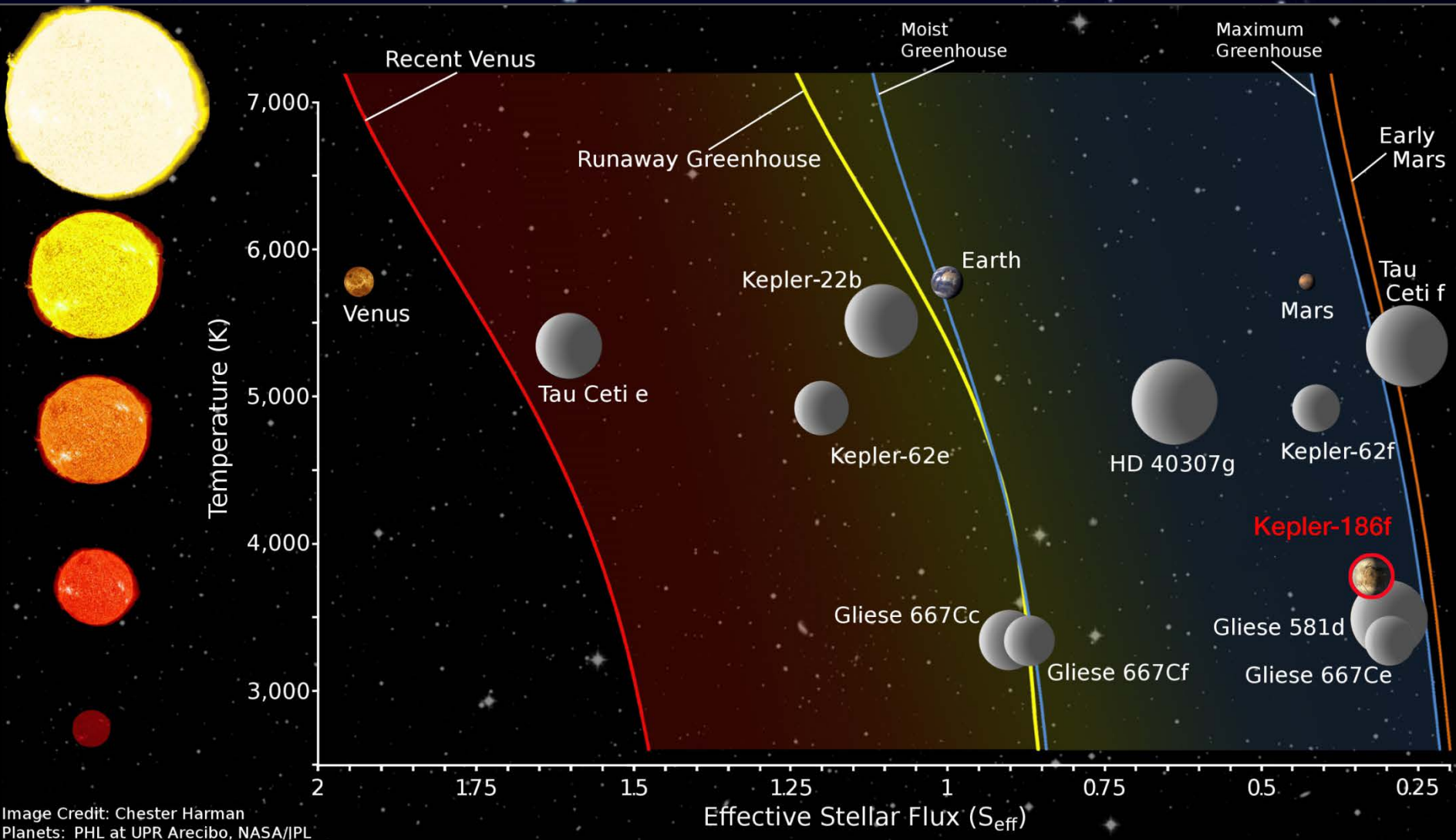


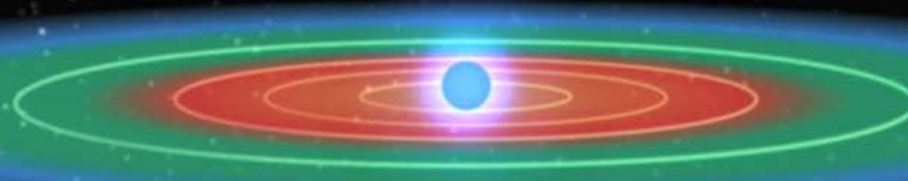
Image Credit: Chester Harman
Planets: PHL at UPR Arcibo, NASA/IPL



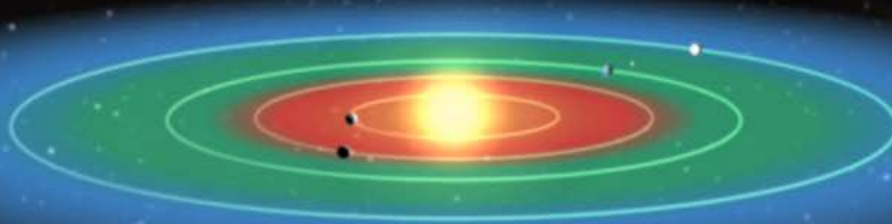
Kepler

Habitable Zone

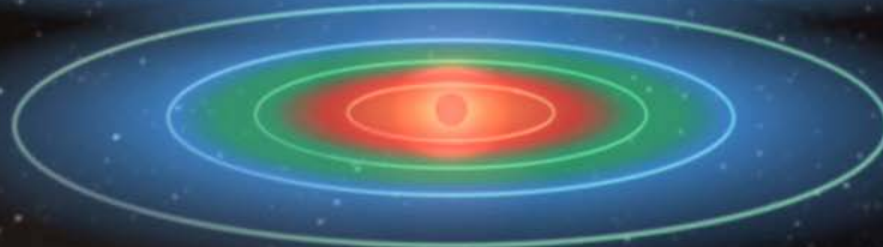
Hotter Stars



Sun-like Stars



Cooler Stars





Searching for Habitable Worlds

The right size but hotter than Earth



Kepler-20e



Artist's concept

MORE DENSE

LESS DENSE



Searching for Habitable Worlds

The right distance from its star but larger than Earth



MORE DENSE

LESS DENSE



Searching for Habitable Worlds

The right size and distance from the star!



Artist's concept

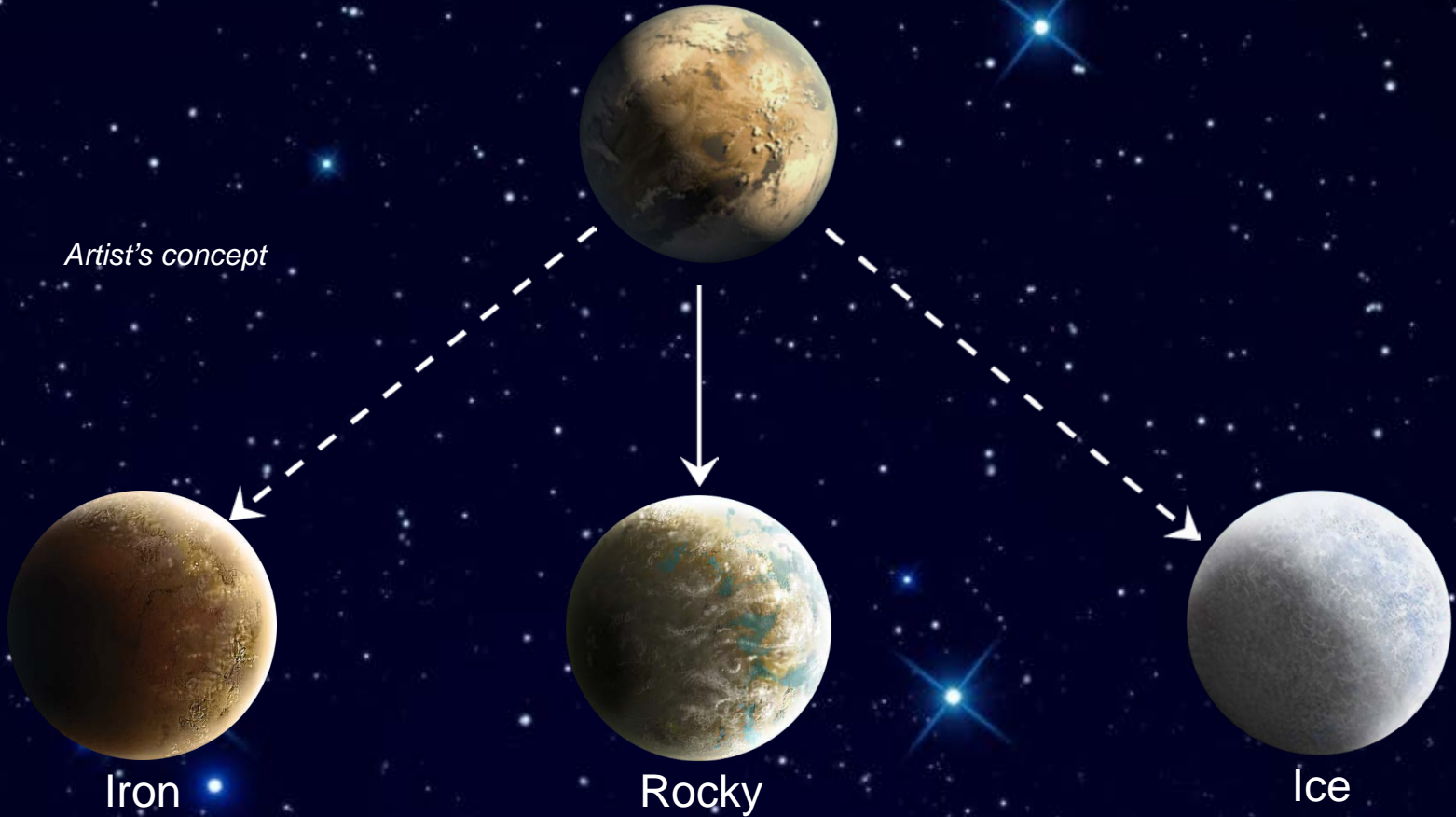
MORE DENSE

LESS DENSE



Composition

Artist's concept

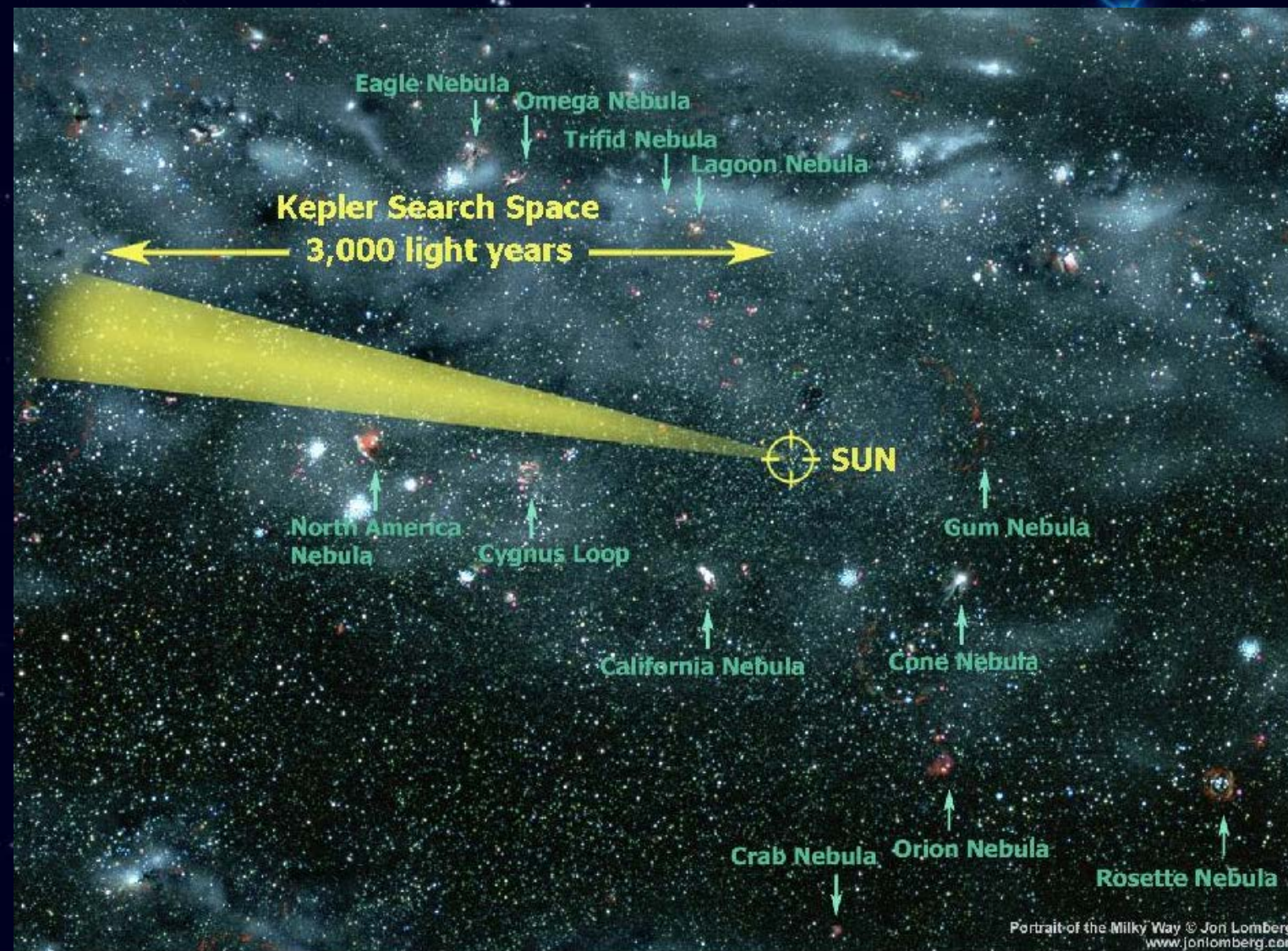


MORE DENSE

LESS DENSE



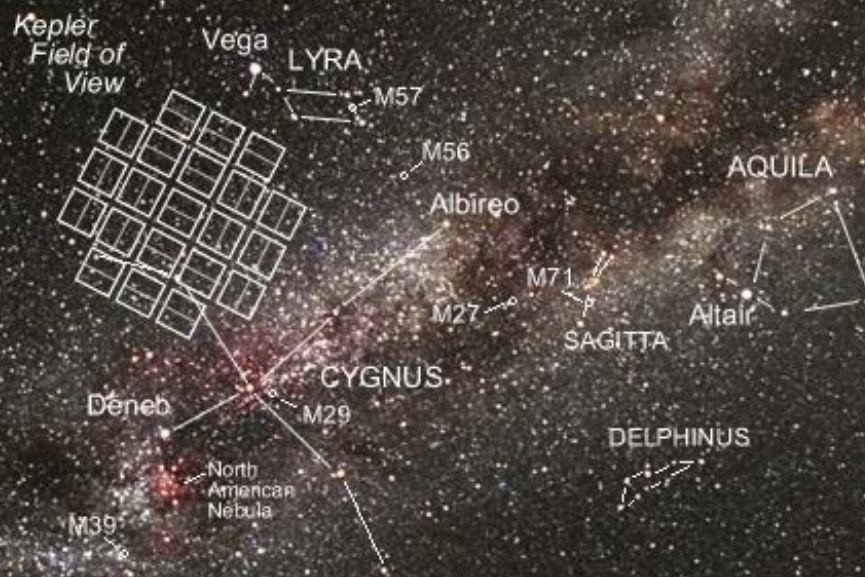
Which Galactic Neighbourhood?



Kepler monitors
100,000+ stars
in Cygnus Lyra
Constellations

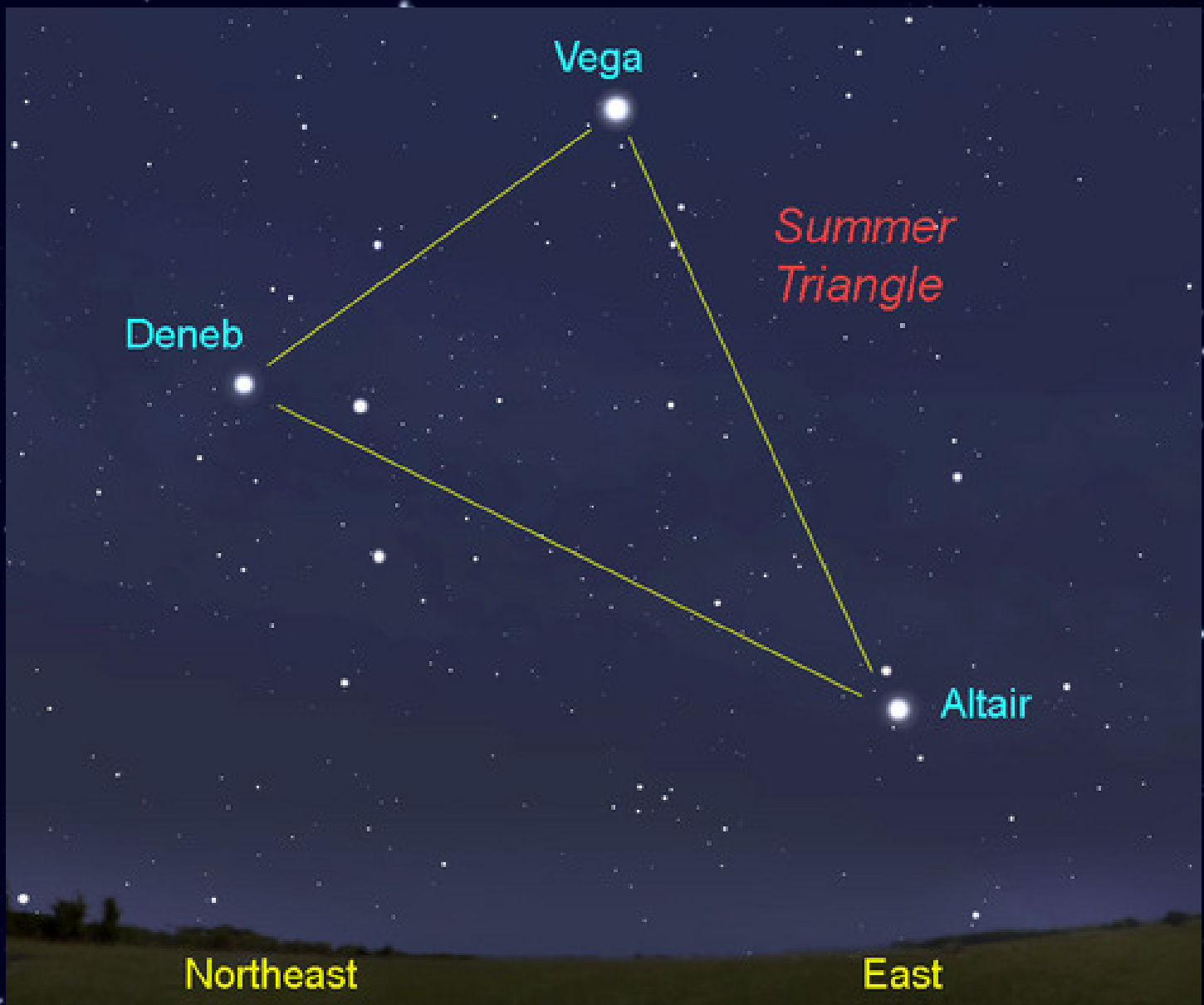


Kepler's Field of View





Kepler's FOV in Summer!



Deneb

Vega

Summer
Triangle

Altair

Northeast

East



The Making of Kepler

Kepler



Schmidt Corrector



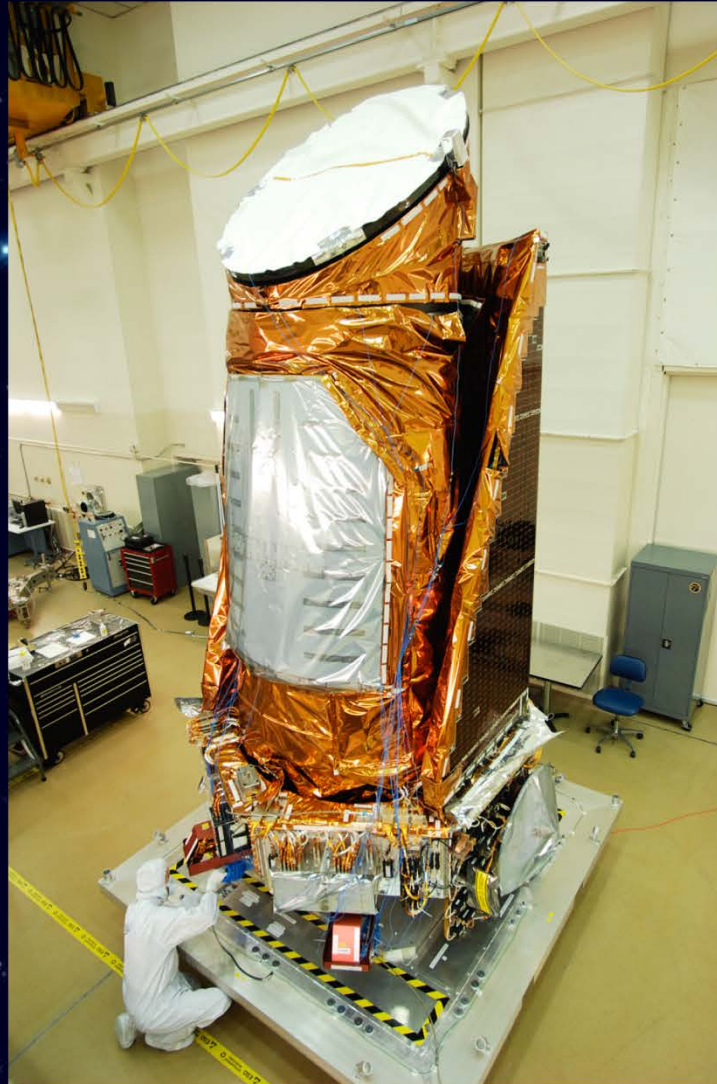
Spider with Focal Plane
and Local Detector Electronics



Focal Plane
95 Mega pixels, 42 CCDs



Primary Mirror.



Fully assembled Kepler photometer
Mounted on the spacecraft



Sunshade



Upper Telescope Housing



Lower Telescope Housing



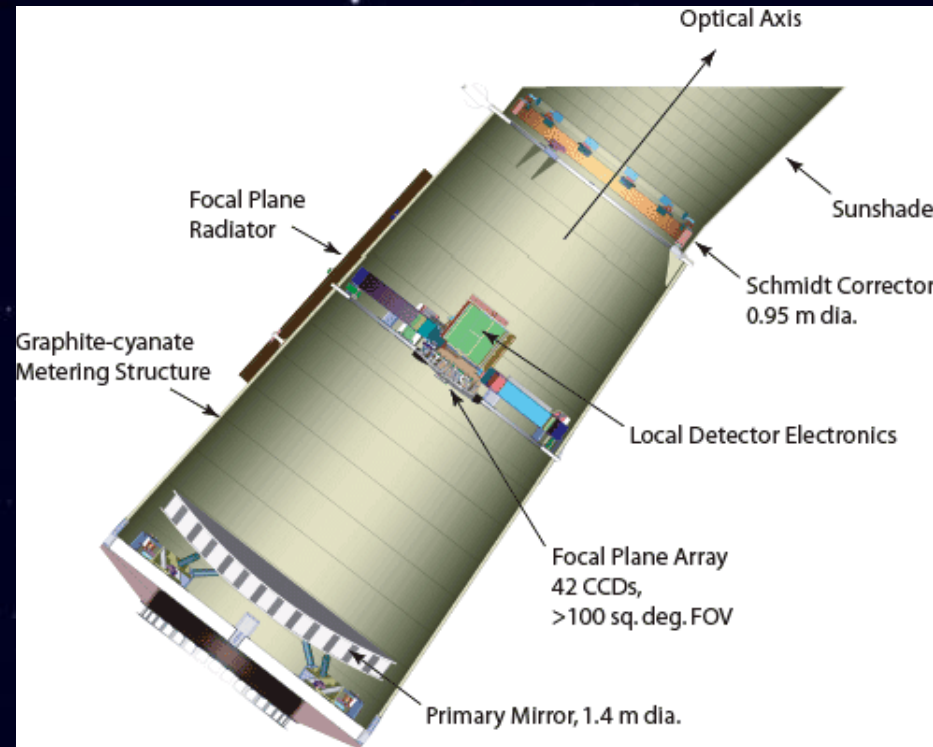
Spacecraft bus integration



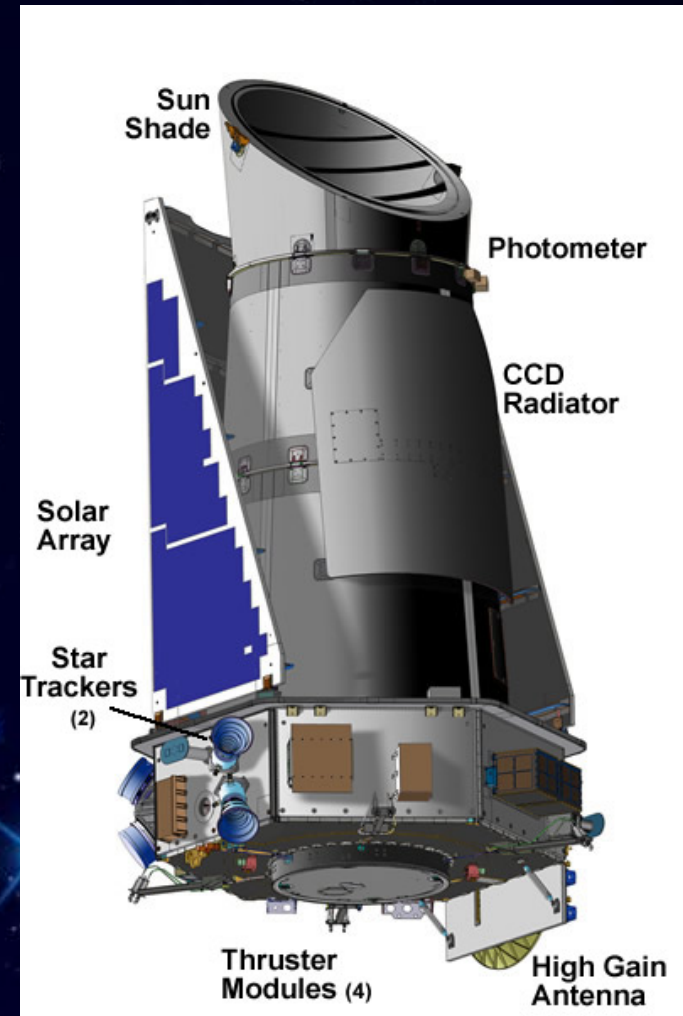
The Making of Kepler



Cross-section



- Schmidt Telescope
- F /1.473
- Focal length 1399.22 mm
- 105 sq. deg. Field (10 x 10)
- 1.4 m primary (ULE glass)
- 0.85 m corrector
- 214,100 photoelectrons per second for m=12 star



The spacecraft →



Kepler

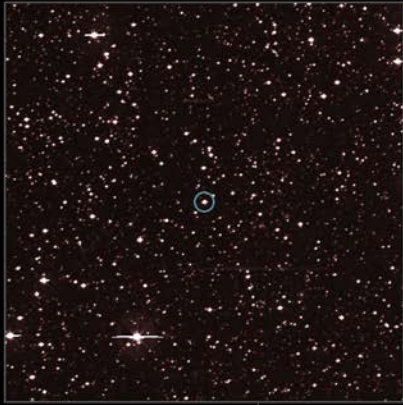
Kepler Launches!





1st Light: 4/8/09

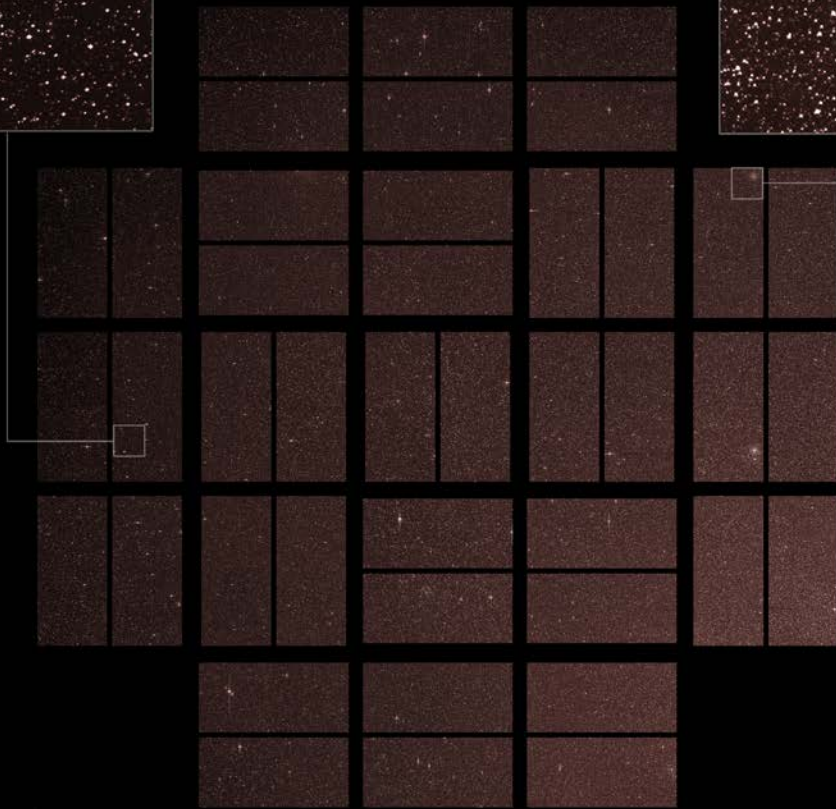
Kepler



TrES-2

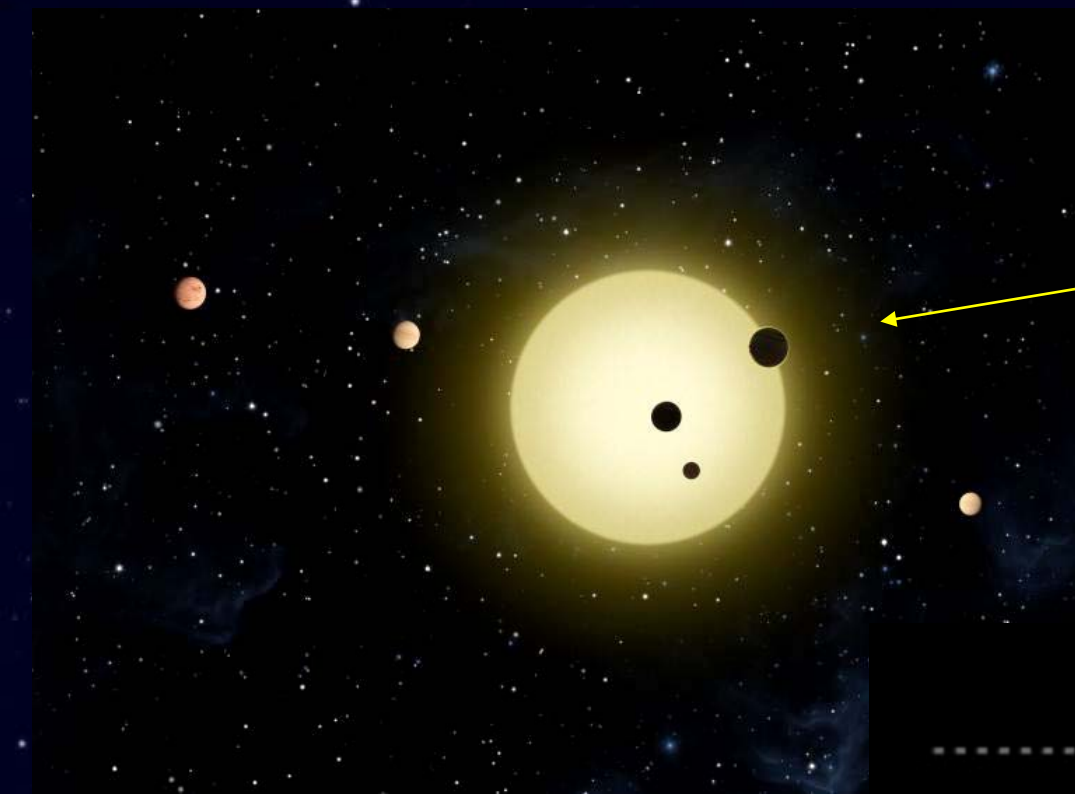


NGC 6791

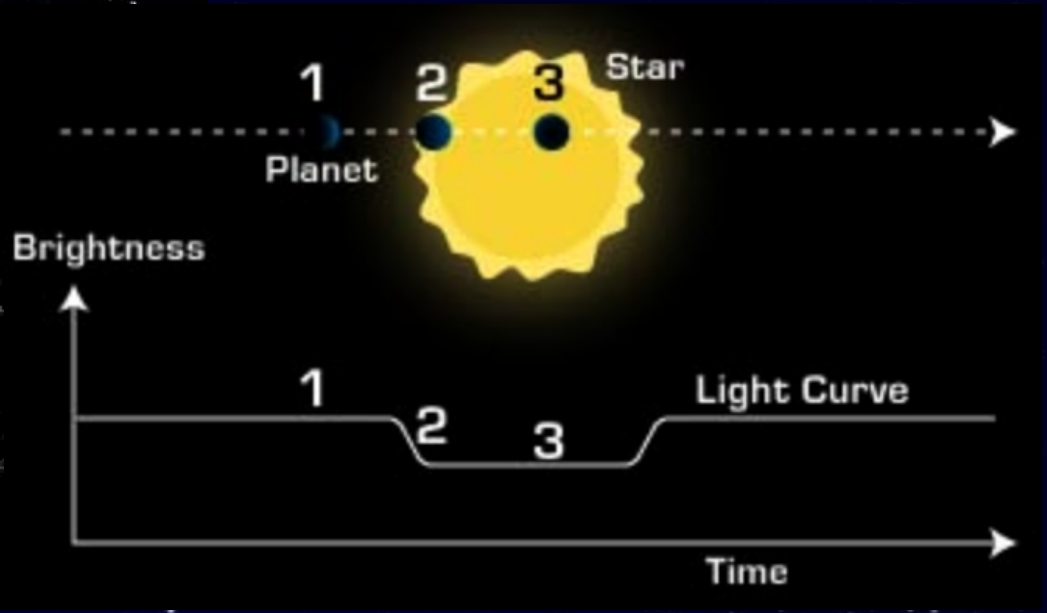
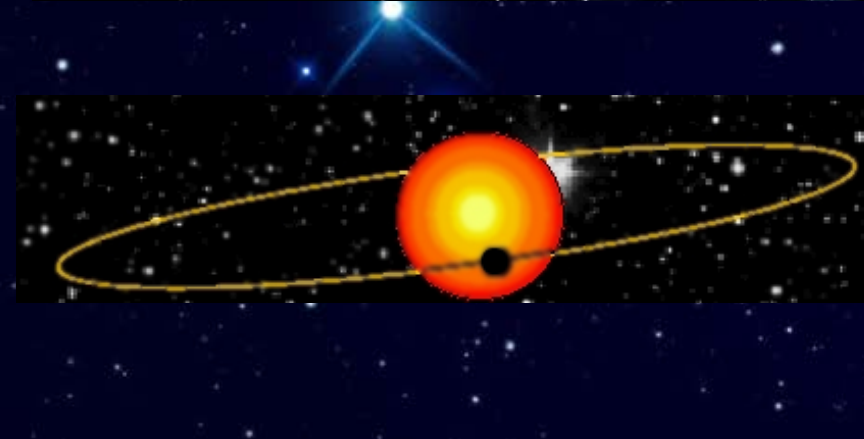




How Does It Work?

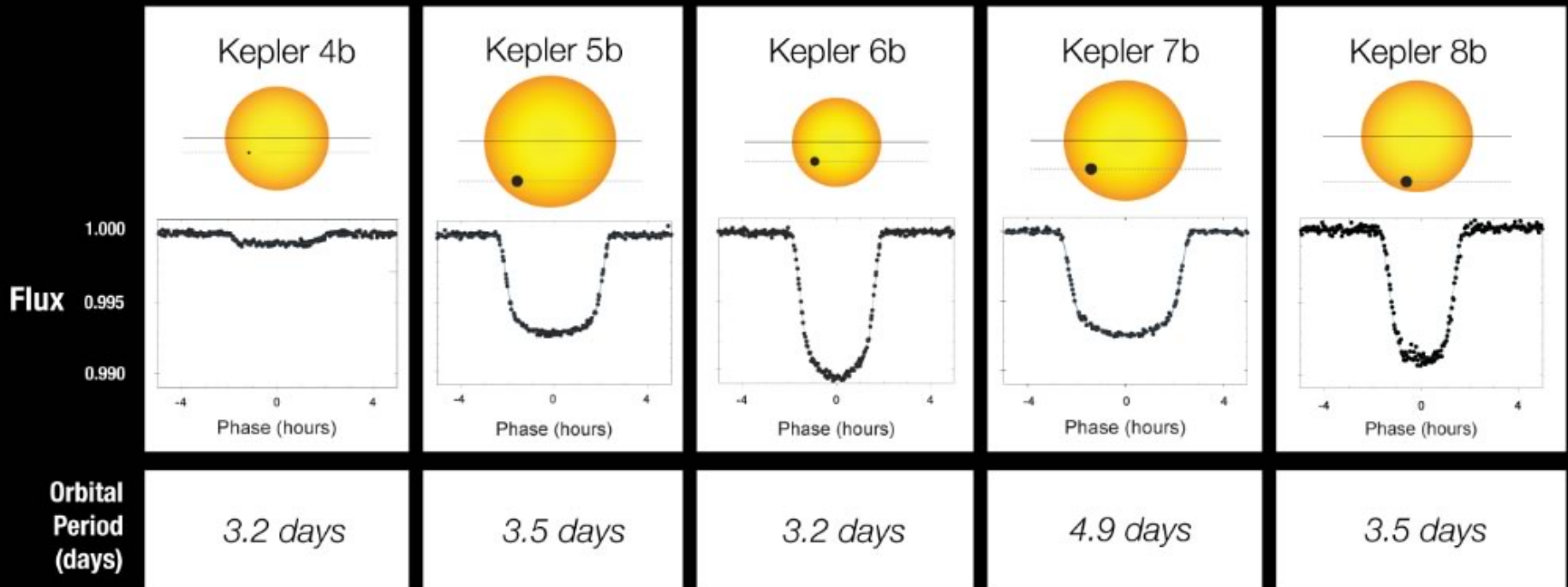


Planets transiting in front of their star

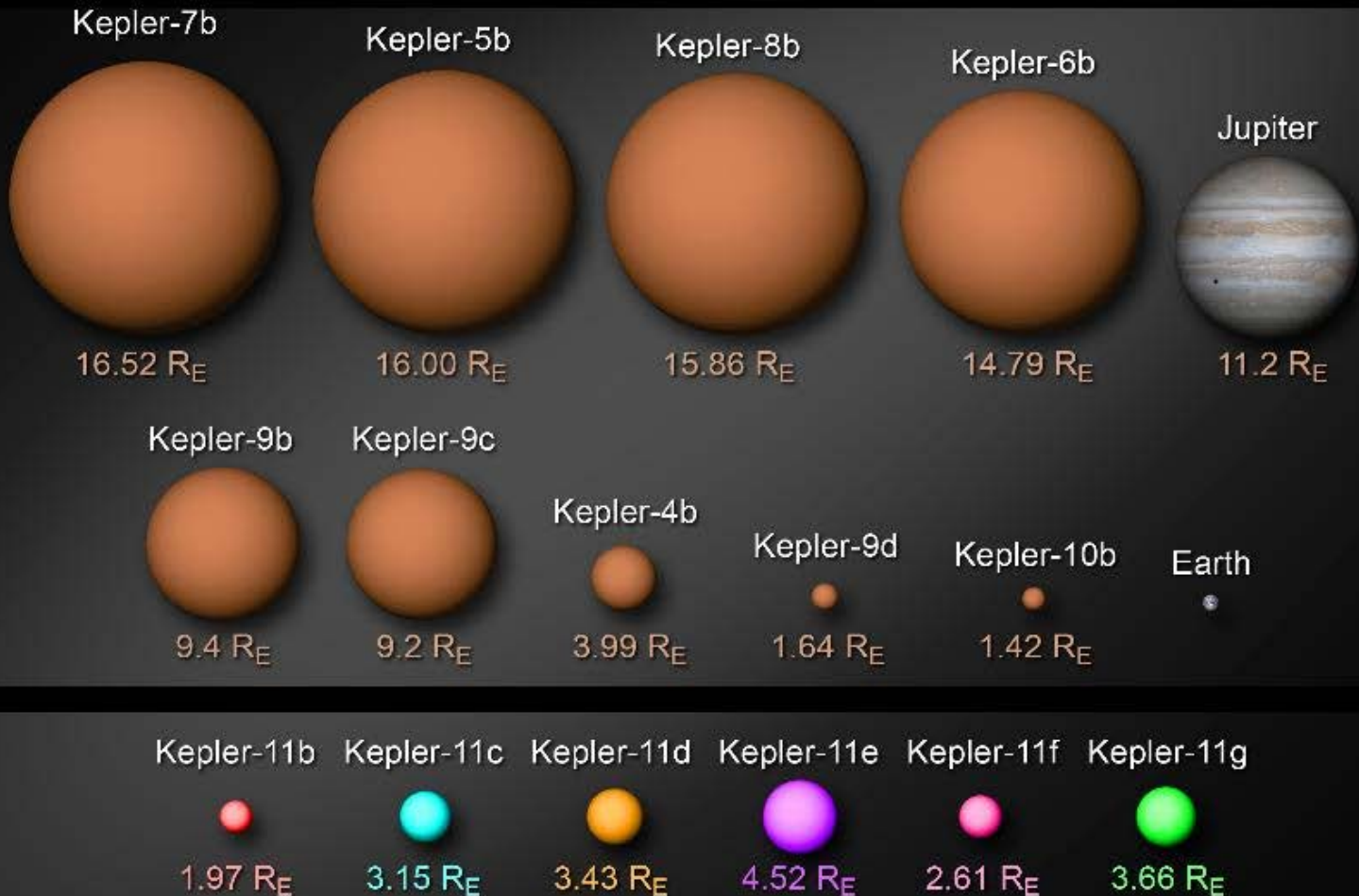




Transit Light Curves



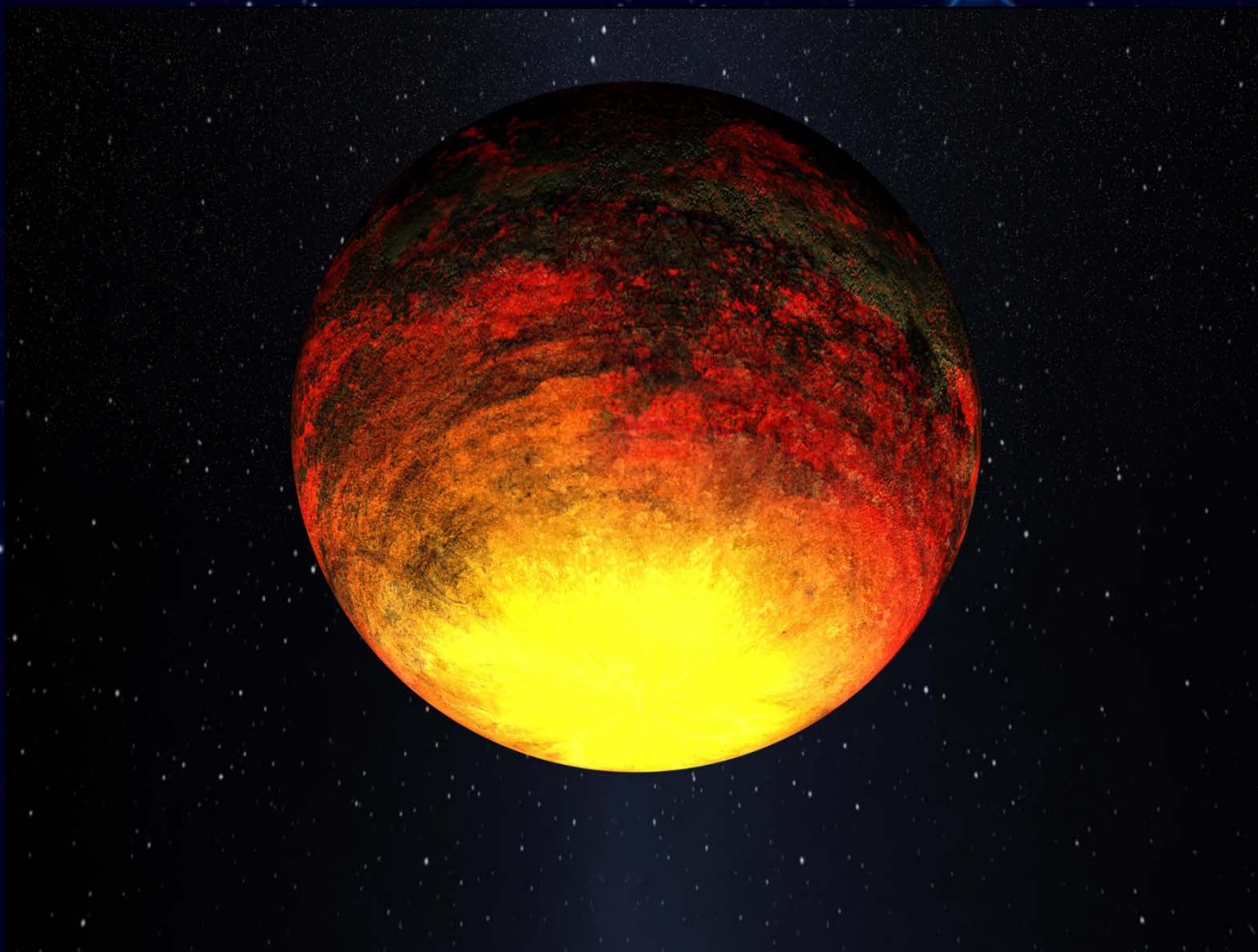
Planet Sizes





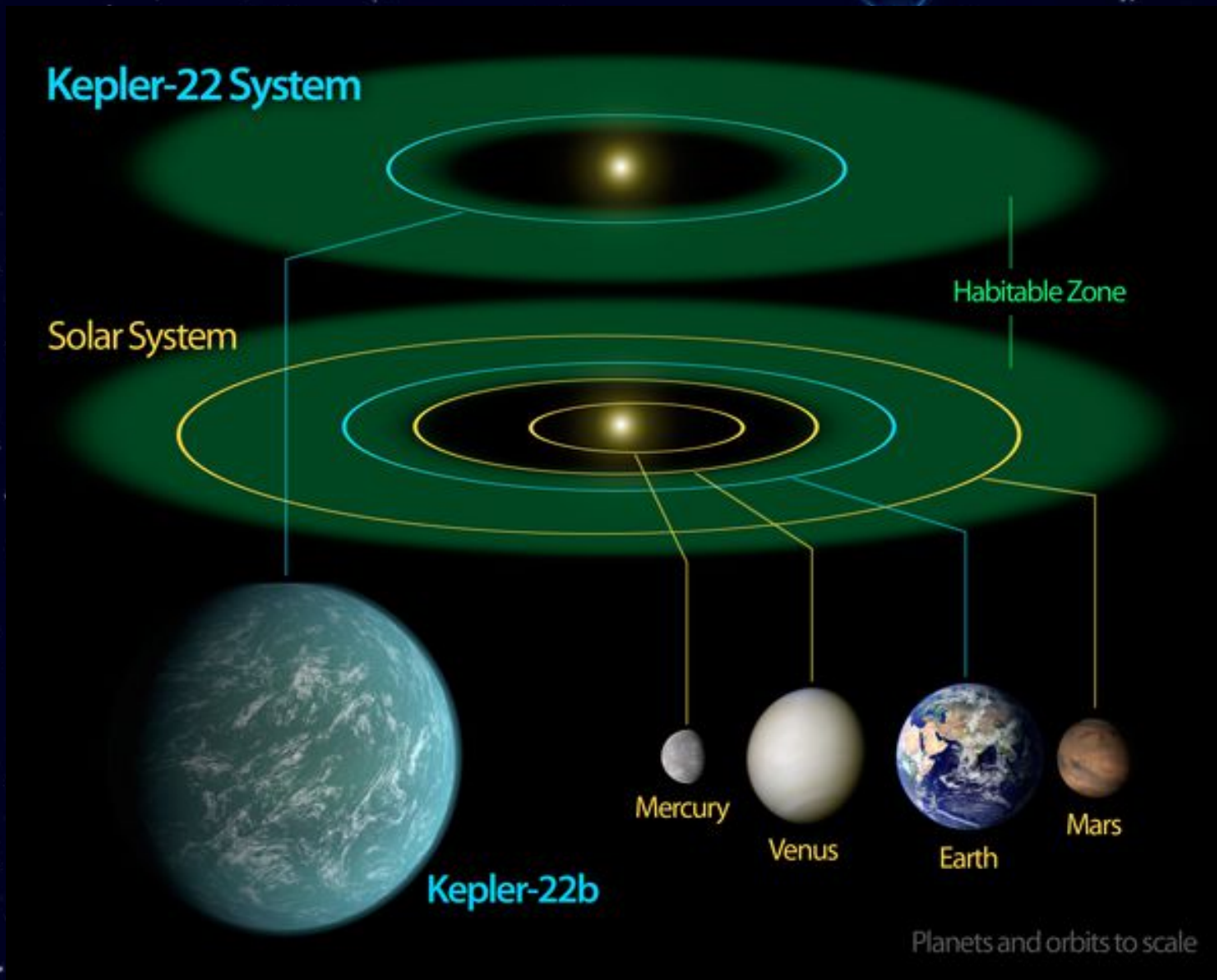
Kepler

Kepler's First Rocky Planet: Kepler-10b





Kepler's First Habitable Zone Planet: Kepler-22b

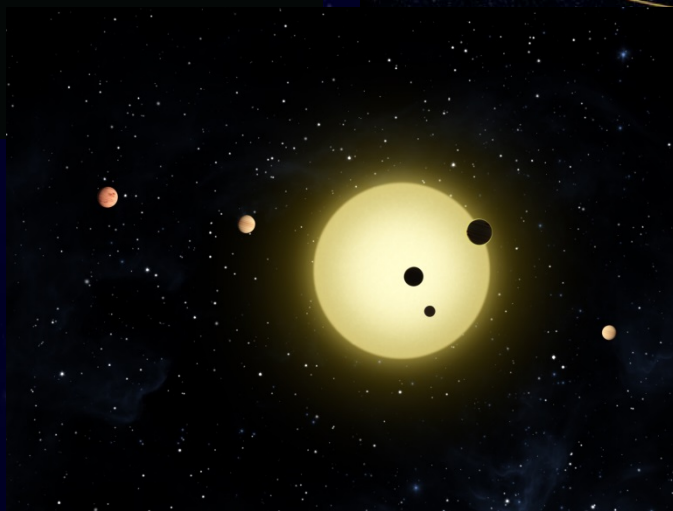
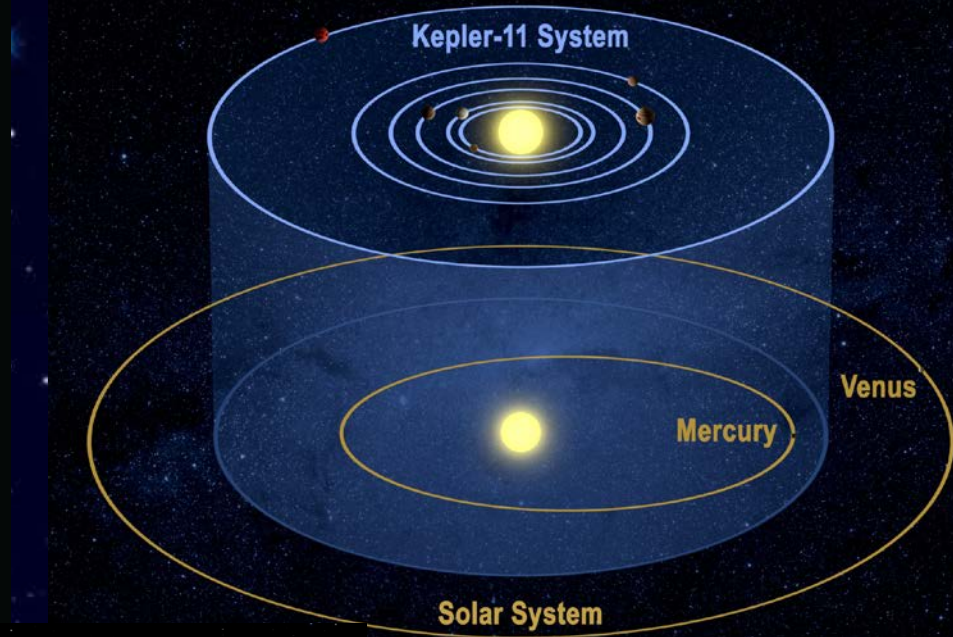
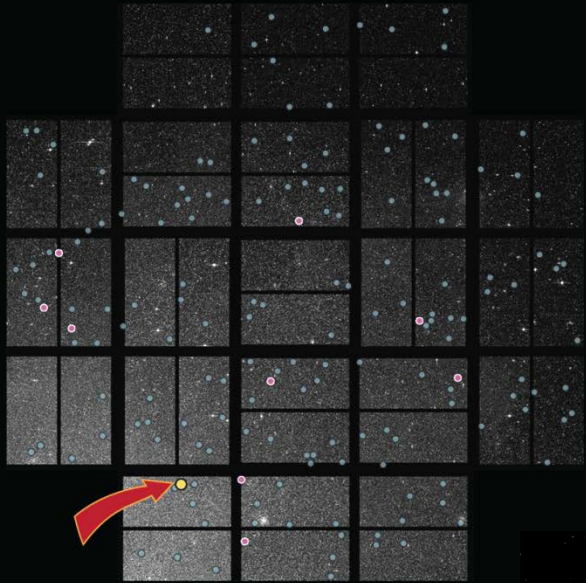




Kepler

Kepler's First Multi-Planetary System

Kepler-11: Six Planets

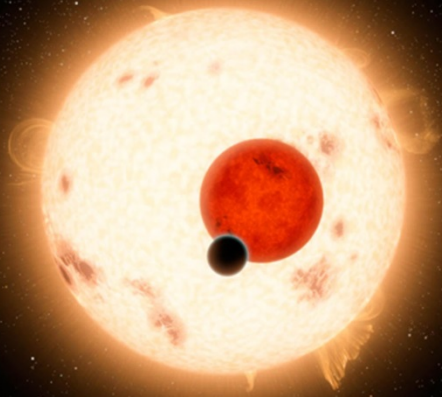




Kepler-16b



A Planet In A Two Star System! Tatooine?!!





Kepler

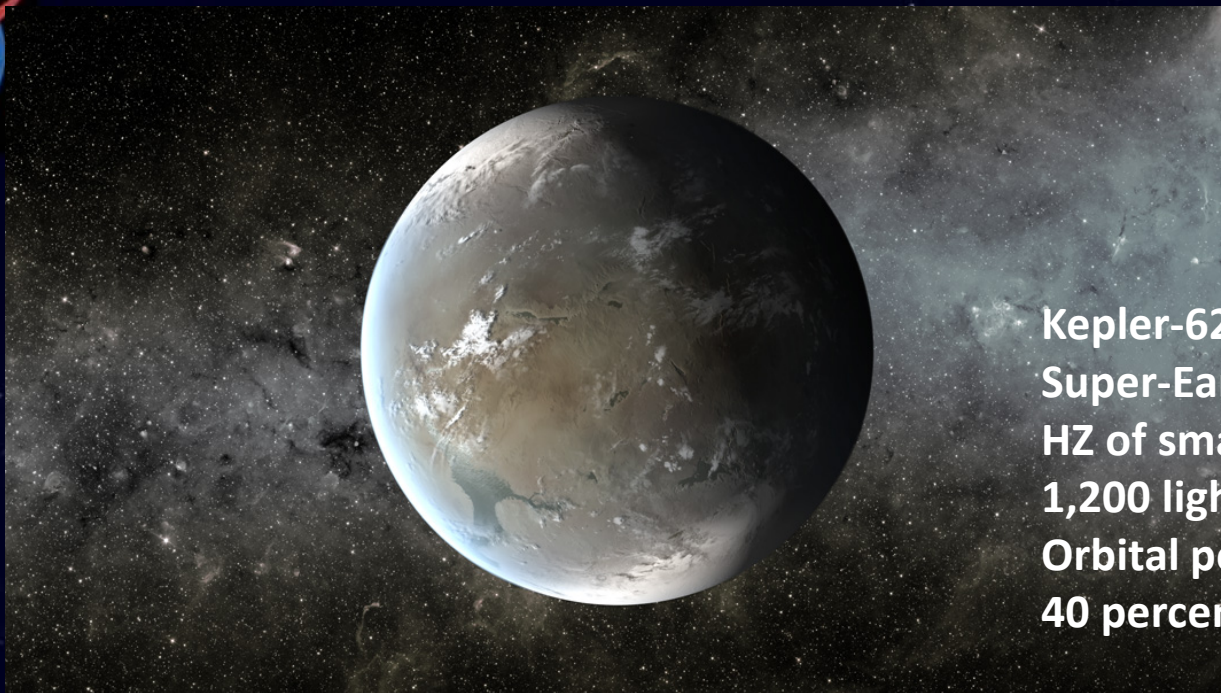


■ ■ ■
TATOOINE

Far from the Bright Center



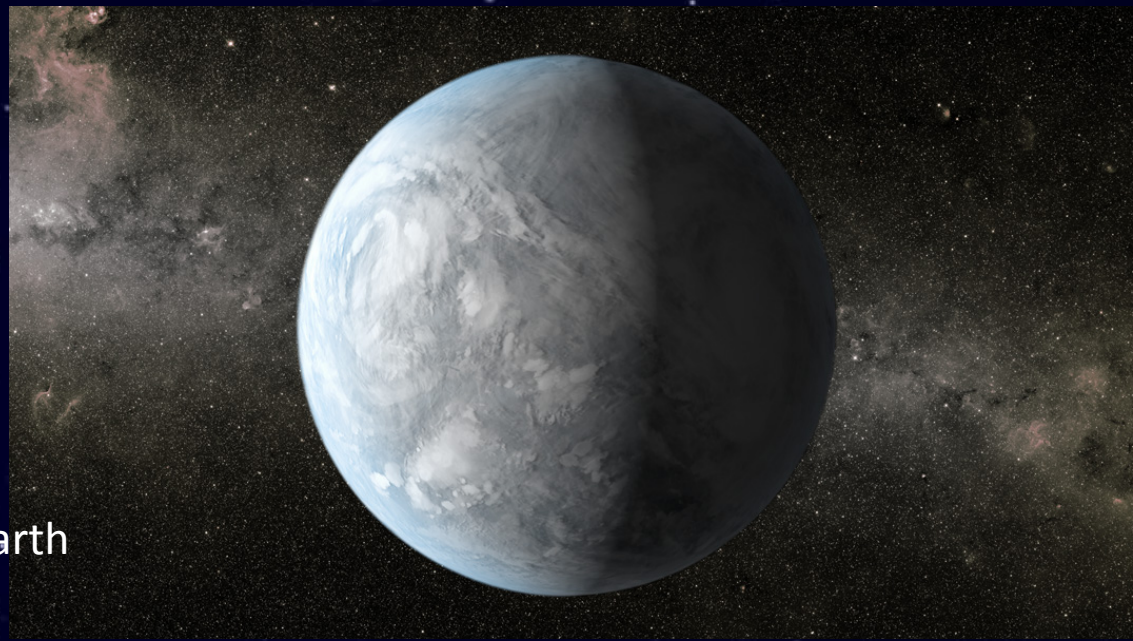
Kepler



**Kepler-62f:
Super-Earth
HZ of smaller, cooler star
1,200 light-years
Orbital period 267 days
40 percent larger than Earth**

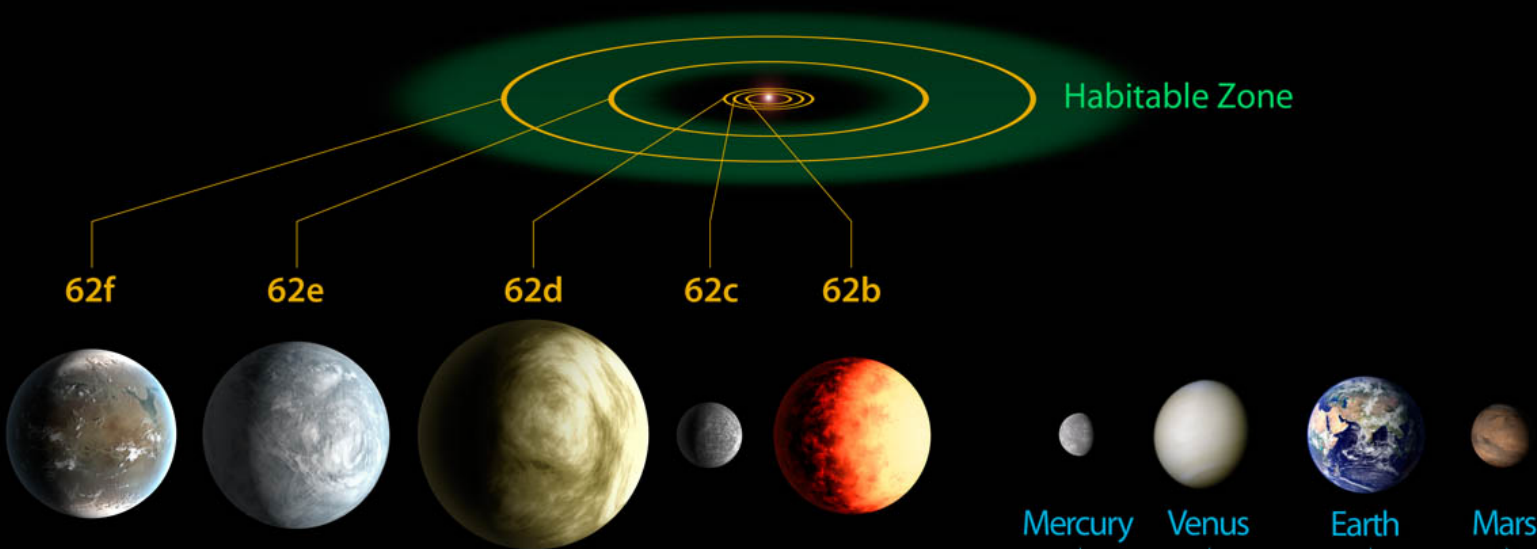


**Kepler-62e:
Super-Earth
HZ of same star
Orbital period 122 days
60 percent larger than Earth**





Kepler-62 System

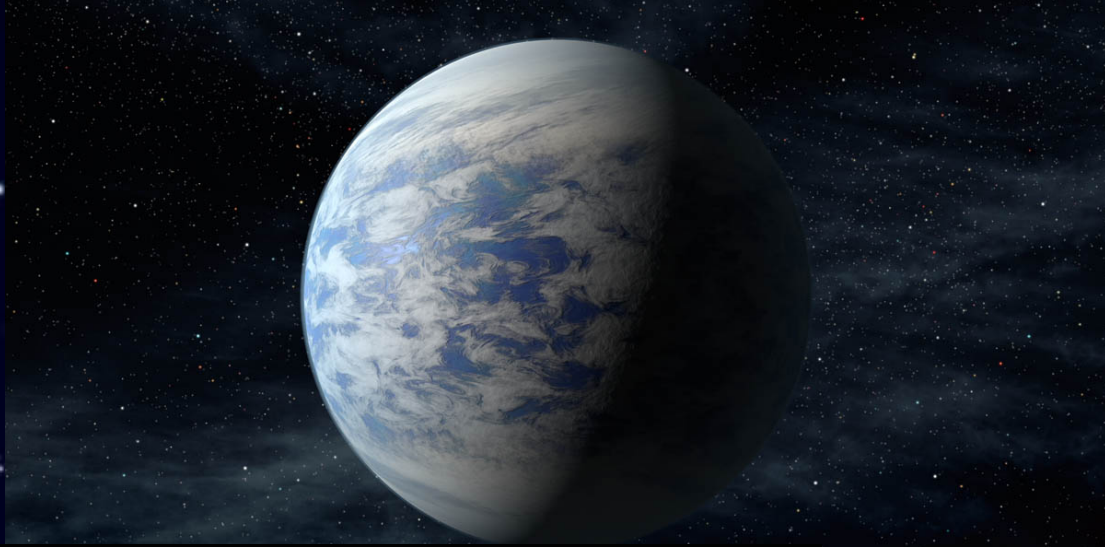


Planets and orbits to scale

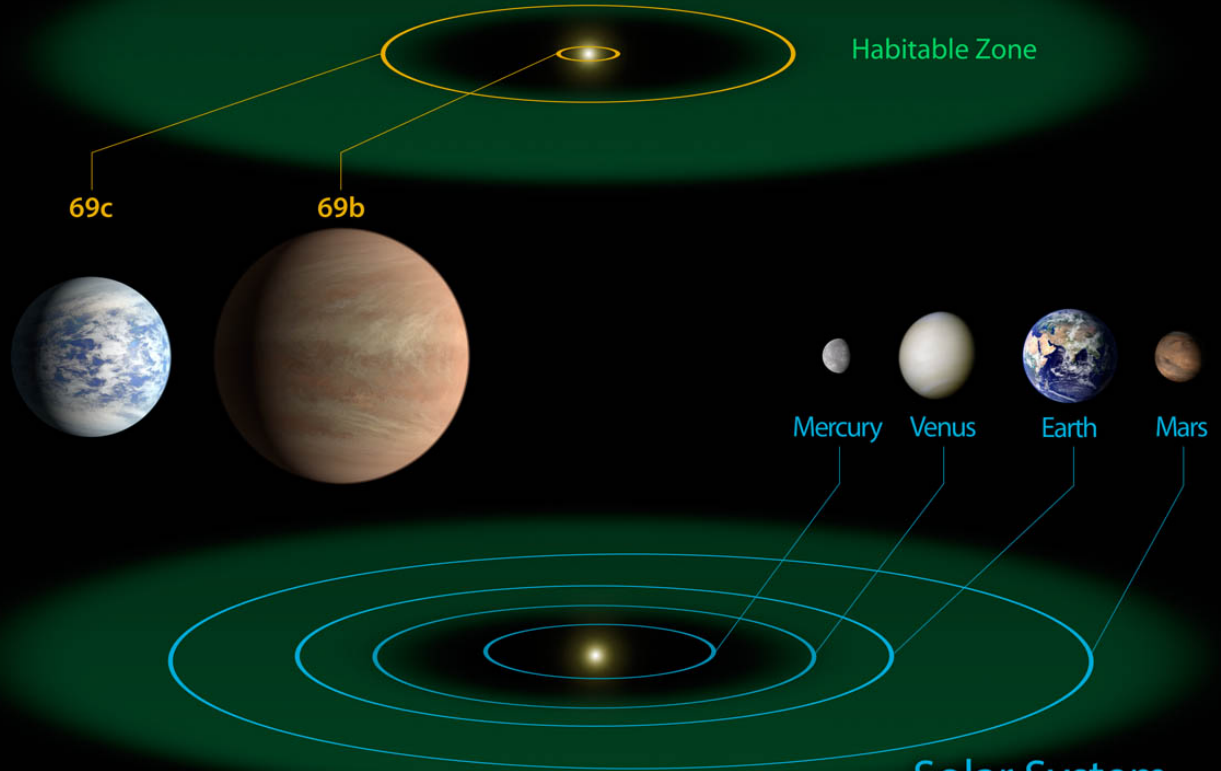
Solar System



Kepler



Kepler-69 System



Kepler-69c:
 Super-Earth
 HZ of sunlike star
 2,700 light-years
 Orbital period 242 days
 70 percent larger than Earth

Planets and orbits to scale



Kepler

Kepler 186-b : Earth Cousin!

The first validated
Earth-size planet
in the habitable zone
of another star!!

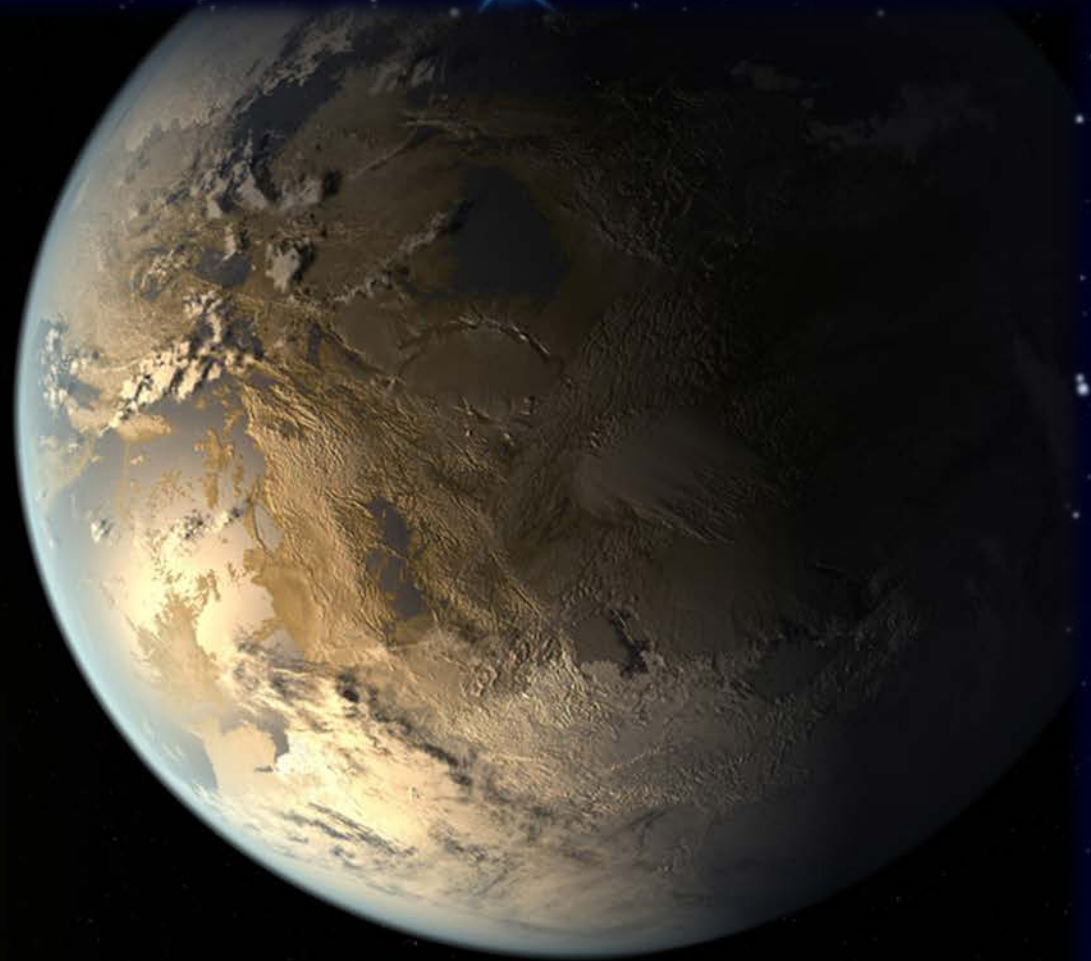
Kepler-69c:

Only 10% larger

HZ of M-dwarf

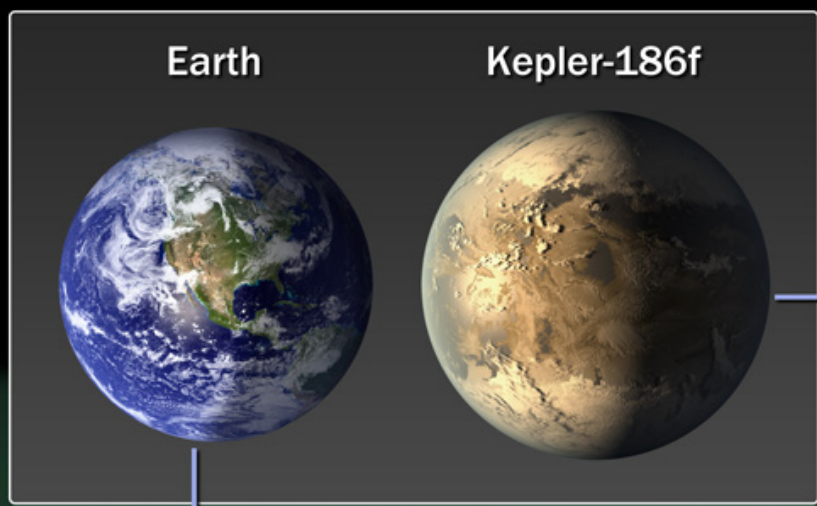
490 light-years

Orbital period 130 days

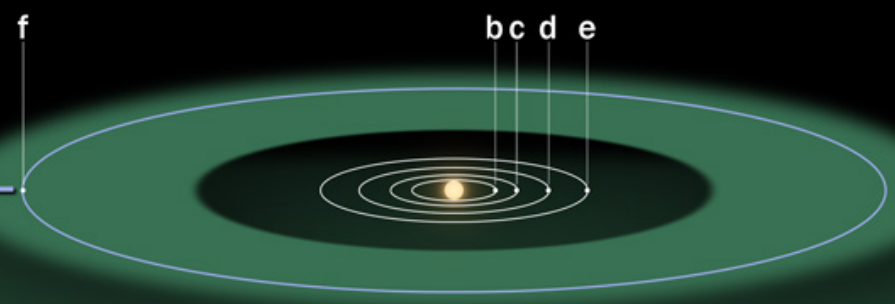




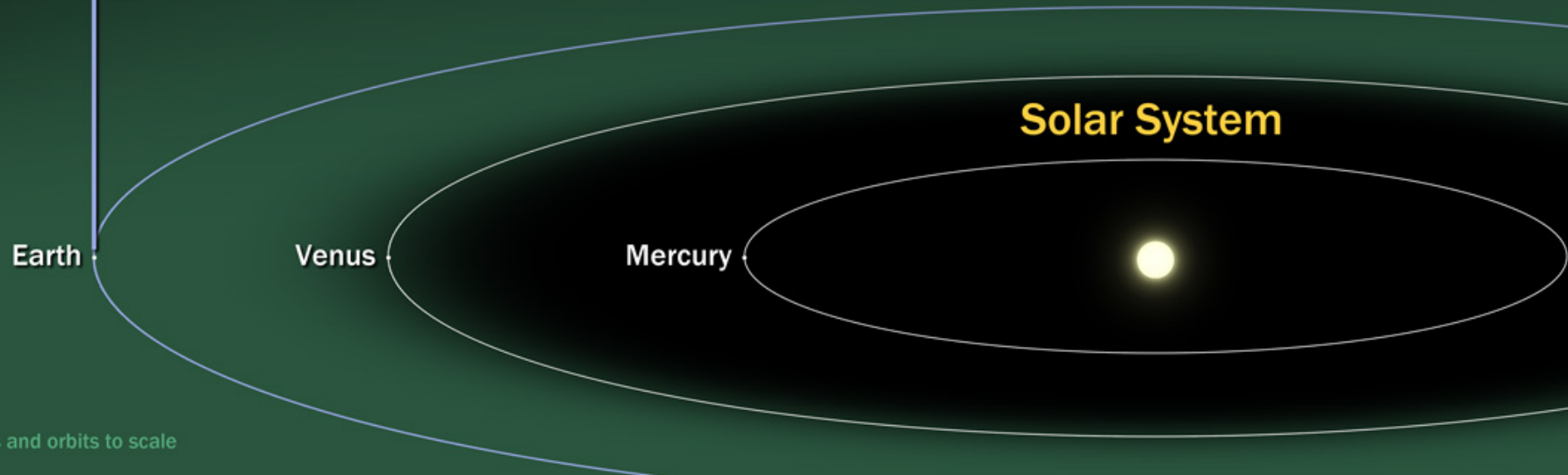
Kepler 186 System



Kepler-186 System



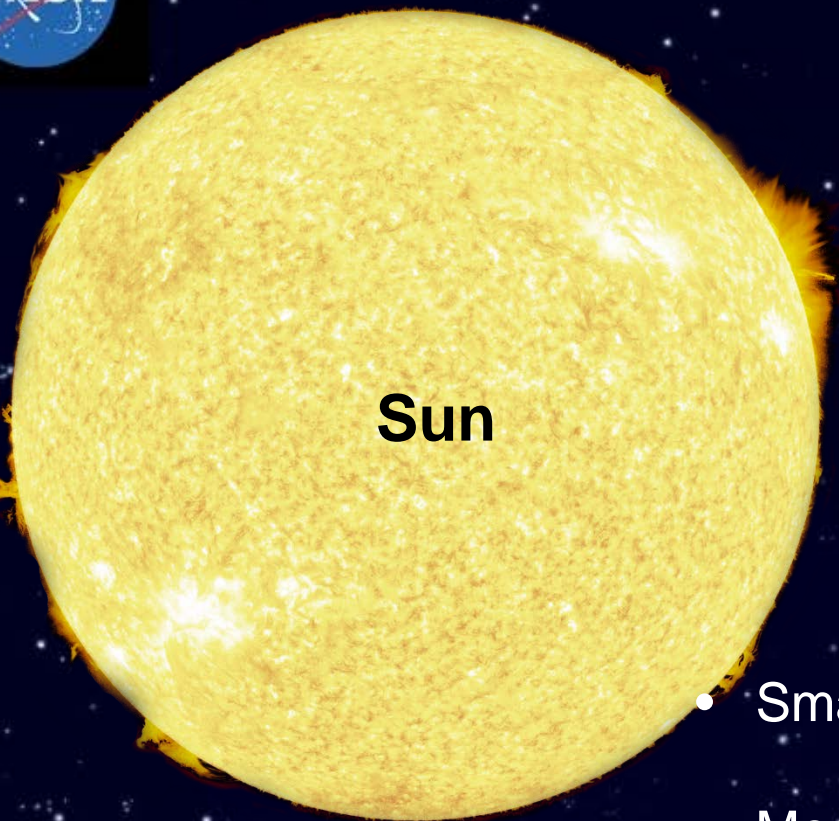
Solar System



Planets and orbits to scale



M Dwarfs



Sun

G dwarf



M dwarf

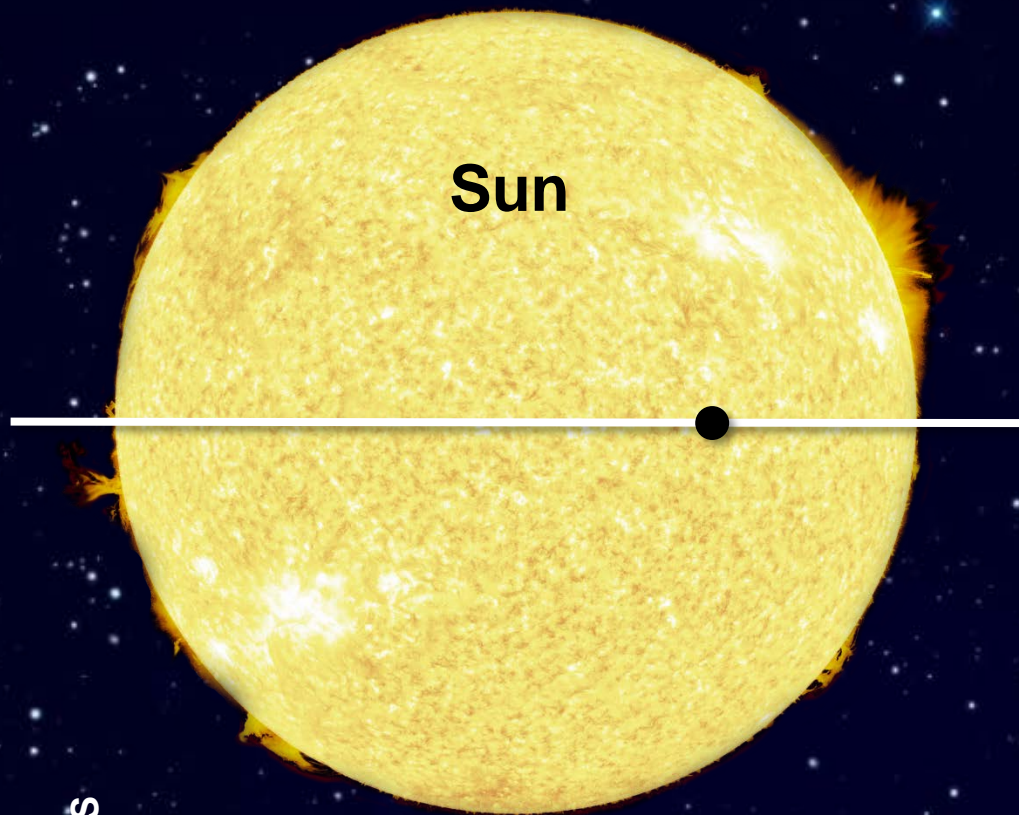
Kepler-186

- Smaller, Cooler, Dimmer
- Most Abundant and Nearest Stars, 7 out of 10 stars in our galaxy are M dwarfs
- The Sun's nearest neighbors are M dwarfs
- M dwarf planets interact differently with their parent star: effect of changed Gravity and Radiation

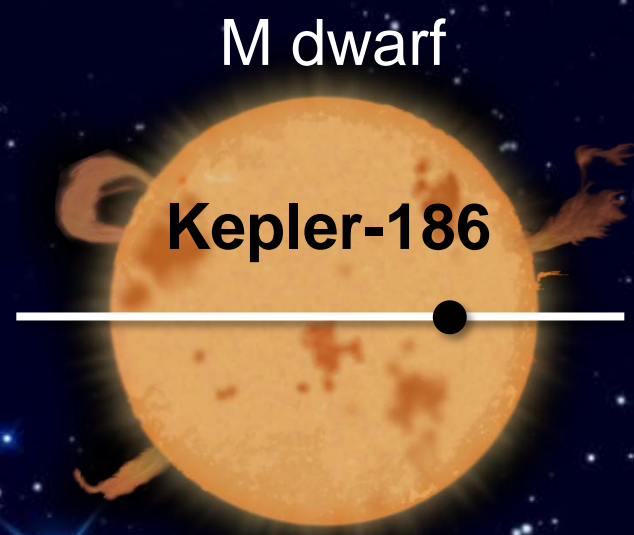


Detecting Planets around M dwarfs Easier

G dwarf

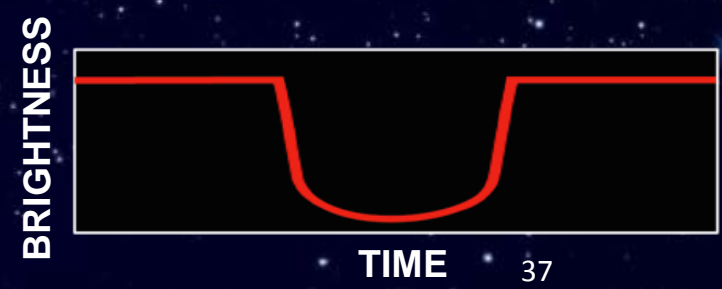
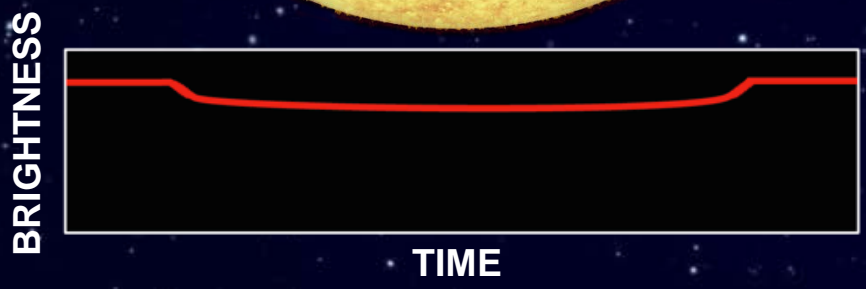


Sun



M dwarf

Kepler-186

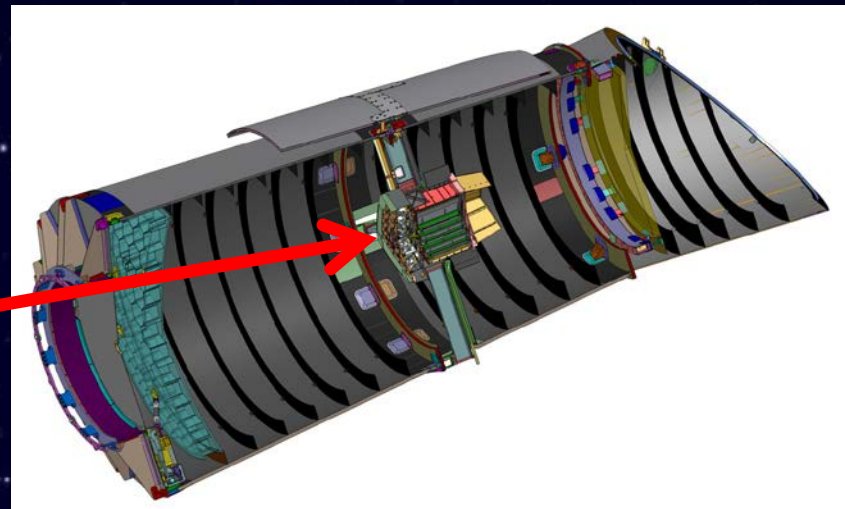
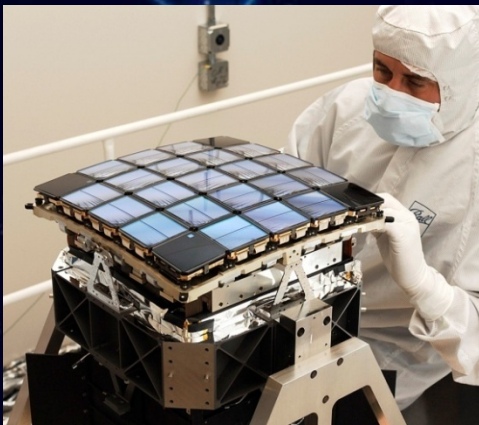




Instrument

KEPLER: A Wide Field-of-View Photometer that Monitors 100,000 Stars for 3.5 yrs with Enough Precision to Find Earth-size Planets in the Habitable Zone

- 0.95 meter aperture provides enough photons
- Observe for several years to detect transit patterns
- Monitor a single large area on the sky continuously to avoid missing transits
- Use heliocentric orbit
- Get statistically valid results by monitoring 170,000 stars
- Random probability of detecting a Sun-Earth analog is about 0.5%
- Wide Field-of-view telescope
- Large array of CCD detectors





Managing the Data Volume

Kepler

Reduction Method	Volume	
Total imaged on board	3.35 TB/day	
After selecting pixels to be downlinked	195.53 GB/day	5.4M pixels of 95M total per frame
After co-adding	741.58 MB/day	Stacks of 270 exposures
After requantization	494.38 MB/day	3 bytes per pixel -> 2 bytes per pixel
After Huffman encoding	139.05 MB/day	4.5 bits per pixel

- 95M pixels
- ~6 second exposures, one after another, around the clock (93% of the time)
- Monthly downlink: ~4 GB
- Ka-band maximum rate: 4.331 Mb/sec (USB 1.1 maximum rate: 12 Mb/sec)
- Kepler downlink speed (pixels/sec): 1,009,196 pixels/sec



Data Flow

Kepler



Raw
Data



Deep Space Network
Canberra/Madrid/Goldstone



Mission Operations Center
Laboratory for Atm. & Space Physics
Boulder, CO

Raw
Pixels

Photo # NH 85748 USS Macon leaving the Moffett Field airship hangar, 26 October 1933



TECHAFFAIR

Science Operations Center
NASA ARC--Moffett Field, CA



Data Management Center
Space Telescope Science Institute
Baltimore, MD

Calibrated Pixels
Calibrated Light Curves



SOC Pipeline Architecture

Kepler

- 64 hosts
- 512 CPUs
- 2.3 terabytes of RAM
- 200 terabytes of raw disk storage
- Infrastructure code is Java, algorithms are MATLAB



- Distributed – scalable architecture for parallel processing of large data sets
- Pluggable Architecture – custom unit of work defined for each module
- Data Accountability and Parameter Management
- Deployment Scalability – from desktop to 128 CPU cluster
- Java/MATLAB Integration – lightning quick debugging/rapid evolution of science code
- Other Features – Graphical console, logging, alerts, real-time monitoring



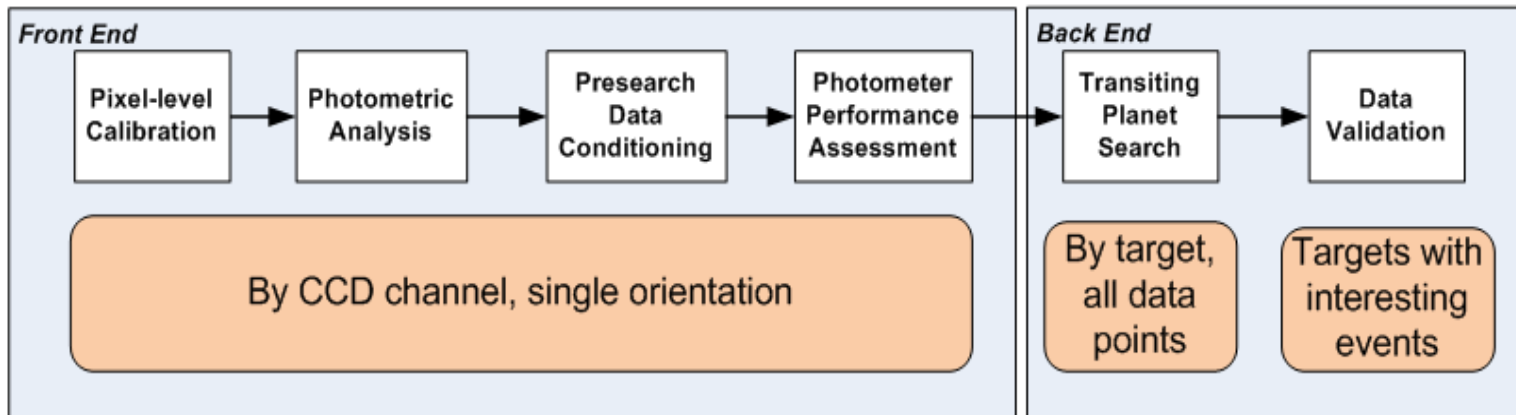
SOC Pipeline Architecture

Kepler



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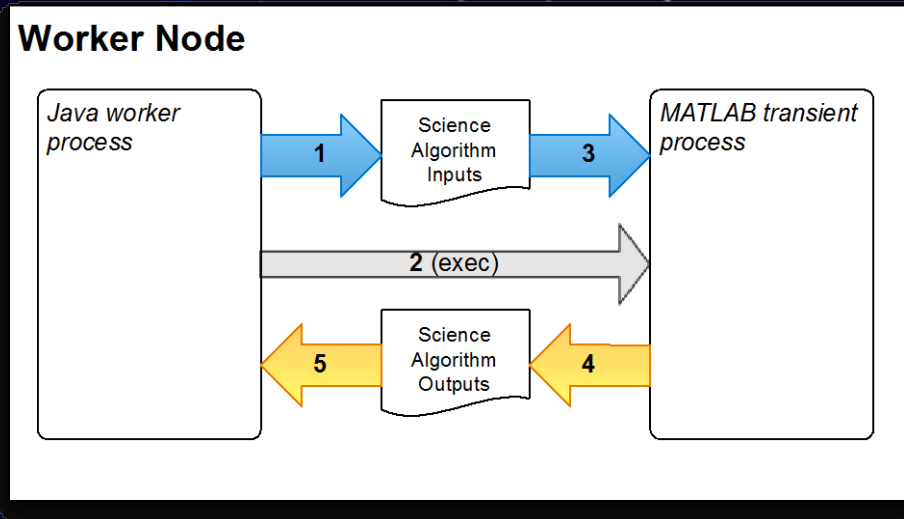
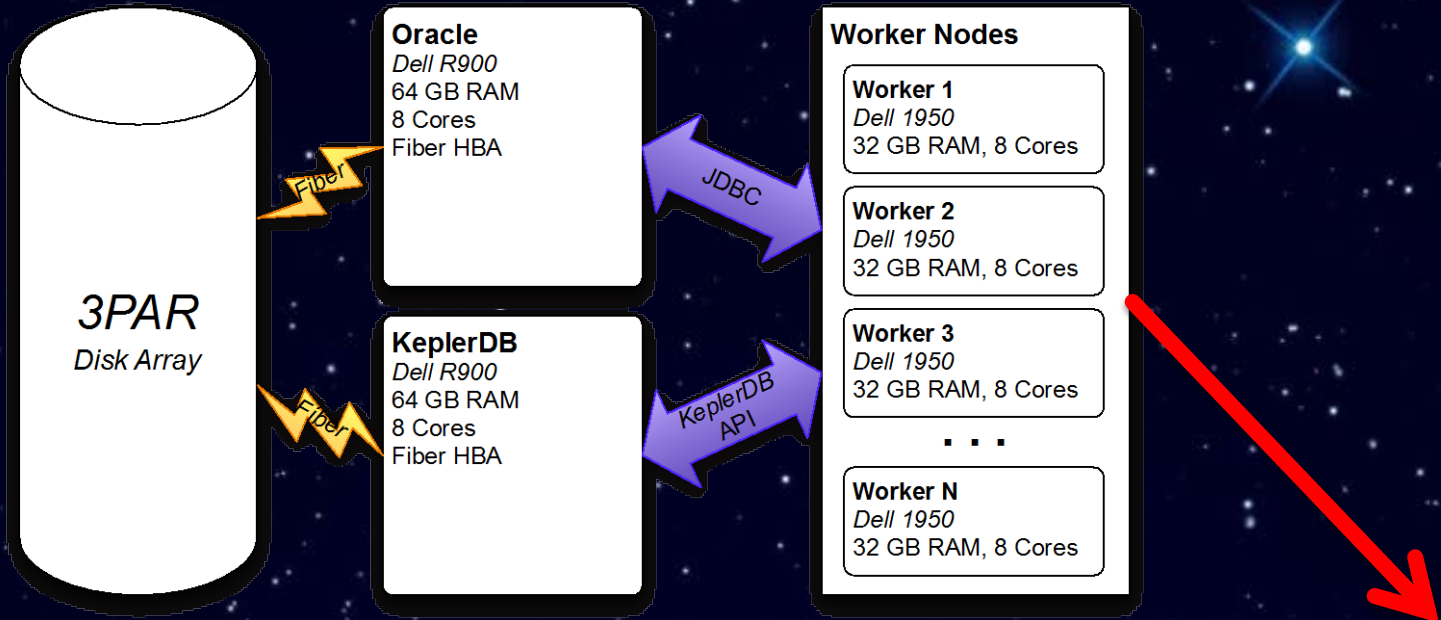
Kepler Science Processing Pipeline



~100 hours to run for 1 quarter's worth of data

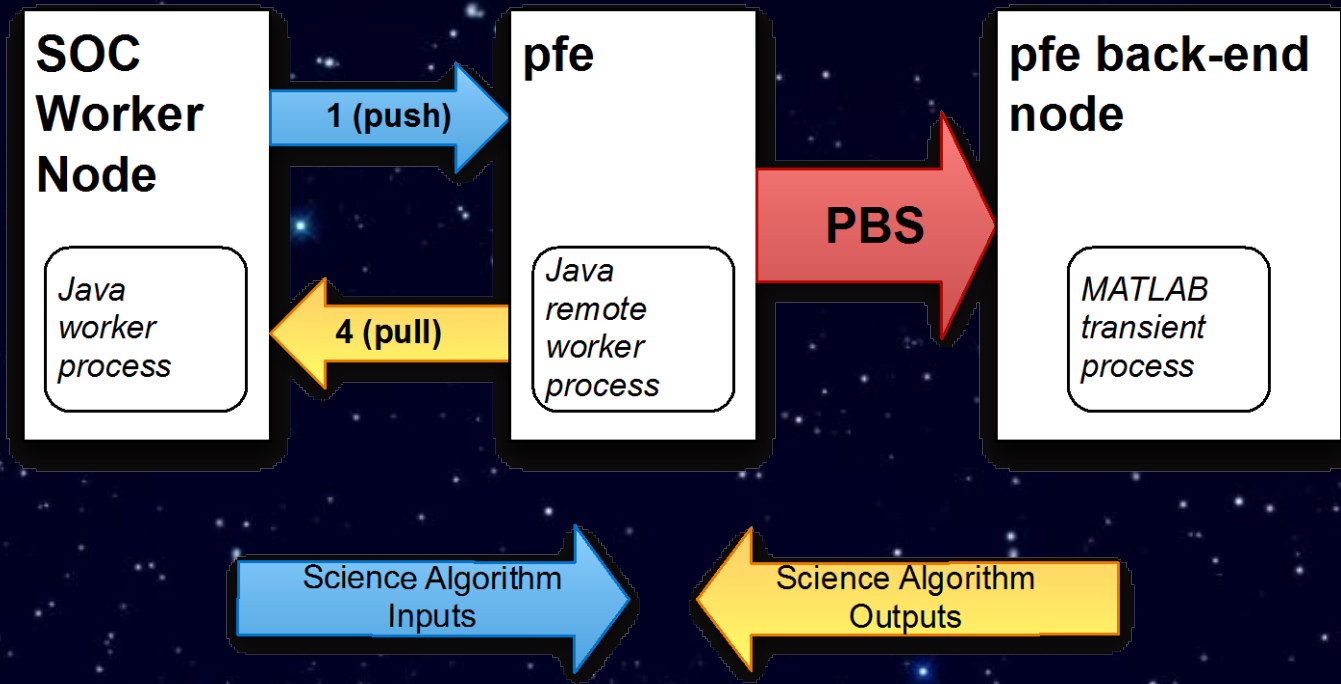


SOC Baseline Architecture





Extending the Pipeline to Pleiades



Module	# Tasks	# PBS jobs	# Sub-tasks
PDC	84 * # of Quarters / 8 cores	84 * # of Quarters / 8 cores	84 * # of Quarters
TPS	84	84	1000-4000 (per task)
DV	84	84	20-300 (per task)



The NAS Pleiades Cluster





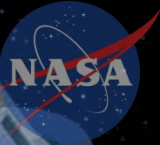
Kepler

Kepler

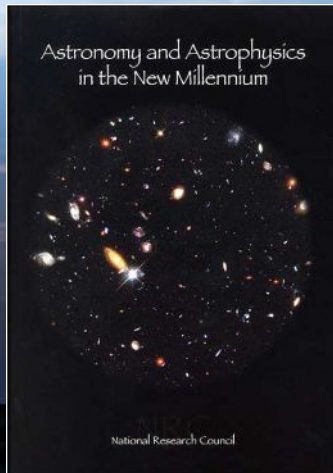
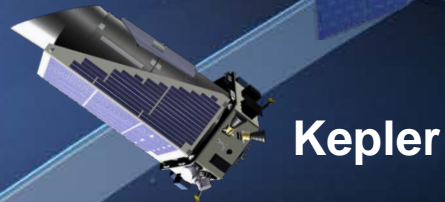
A MOVIE!



Exoplanet Missions



**Ground-based
Observatories**



**2001
Decadal
Survey**

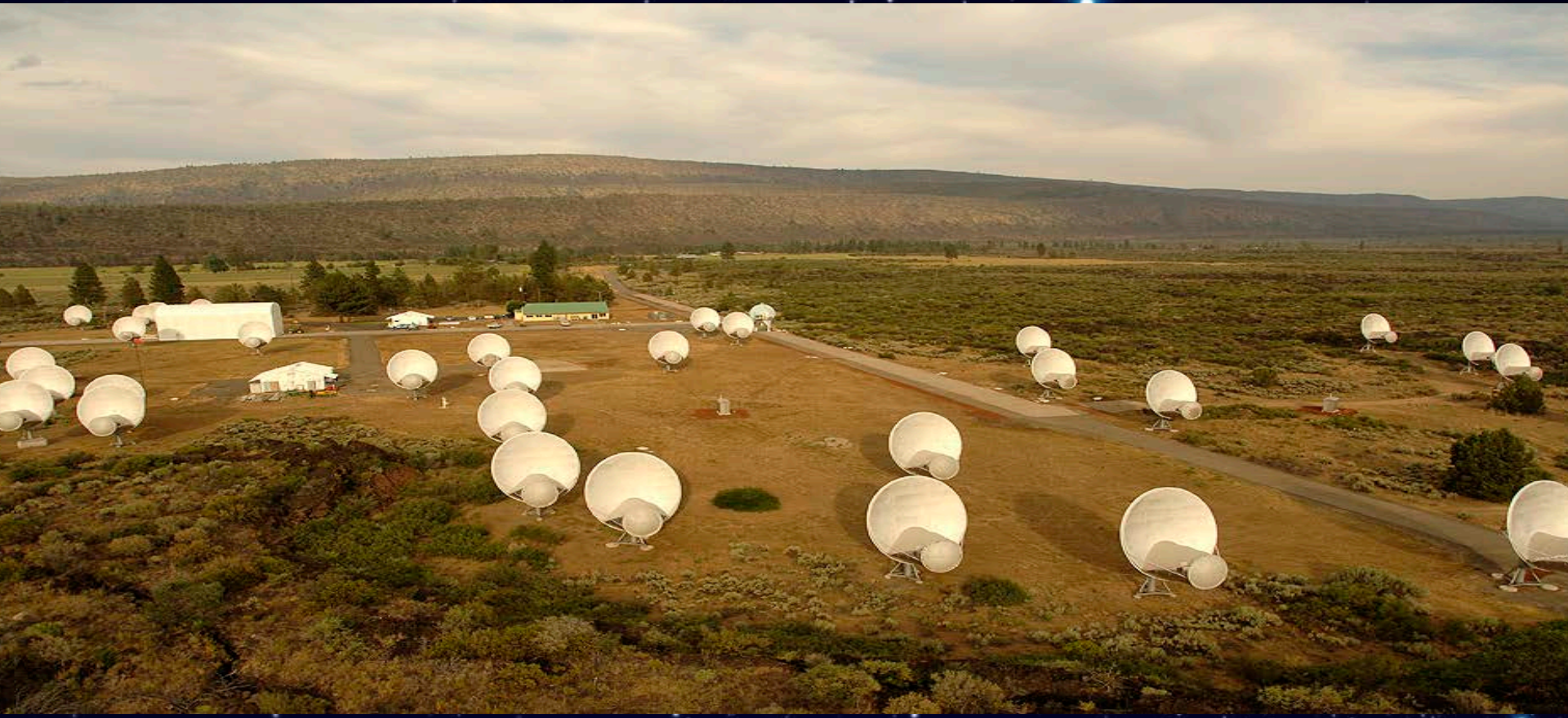


**2010
Decadal
Survey**



Kepler

SETI is Listening...





Kepler

So
Are We Alone??



Kepler Mission: *A search for habitable planets.*



Questions/Comments?



<http://kepler.nasa.gov>

Watch NASA TV Tomorrow!! <http://www.nasa.gov/ntv>

Contact Me : anima.sabale@nasa.gov