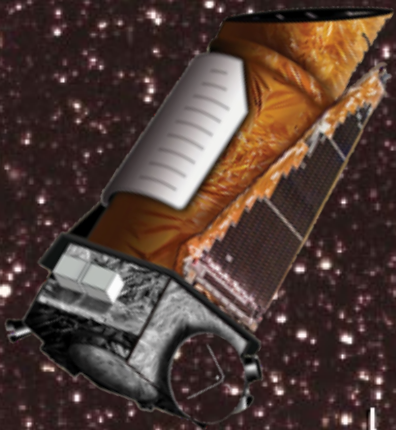


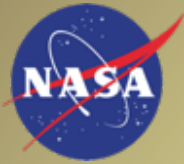
# ***Chasing Exoplanets***

**Jon M. Jenkins**  
**NASA Ames Research Center**

**Friday June 9, 2017**

**Galerija Kapelica / Kapelica Gallery**  
**Earth without humans II / Zemlja brez ljudi II**  
**Ljubljana, Slovenia**

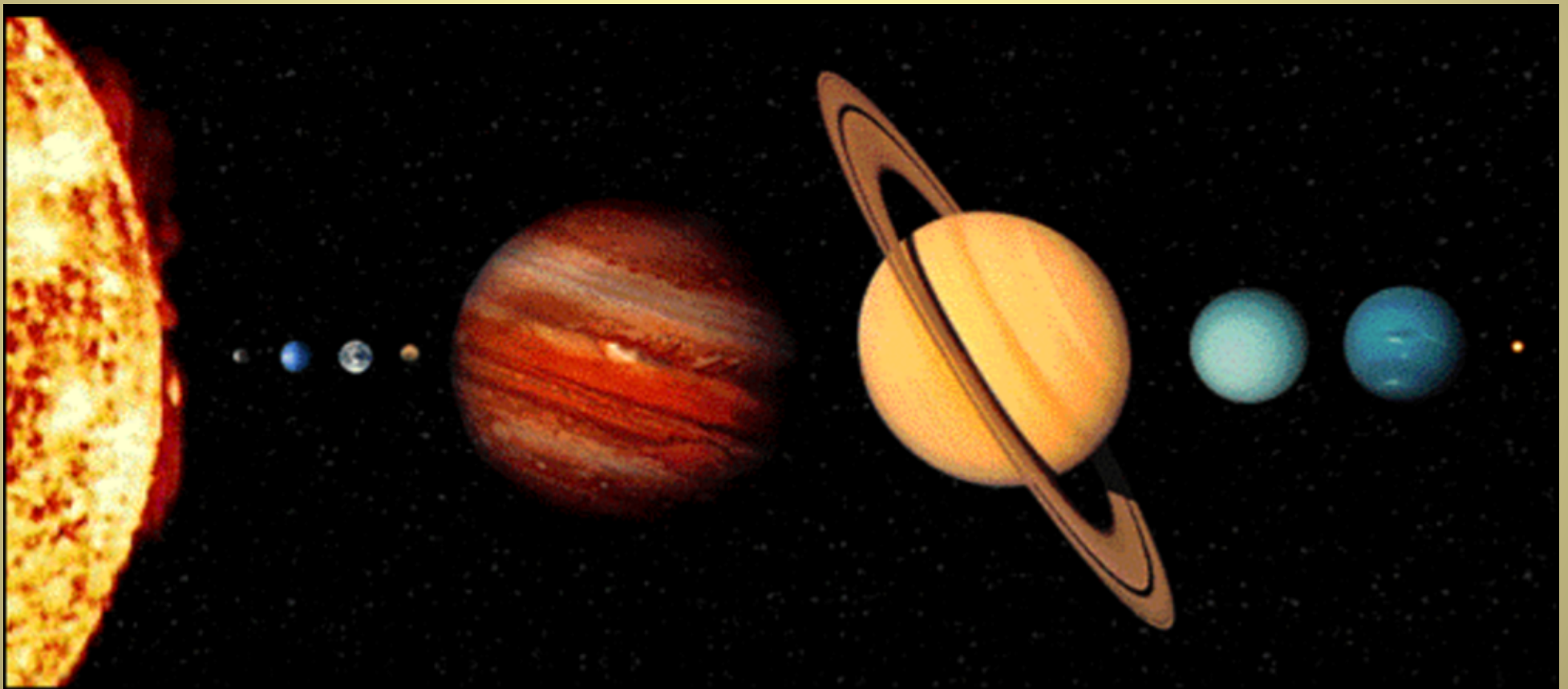


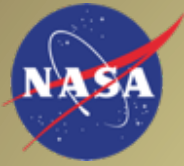


## All the Known Planets In 1994

*Kepler*

*A Search for Earth-size  
Planets*

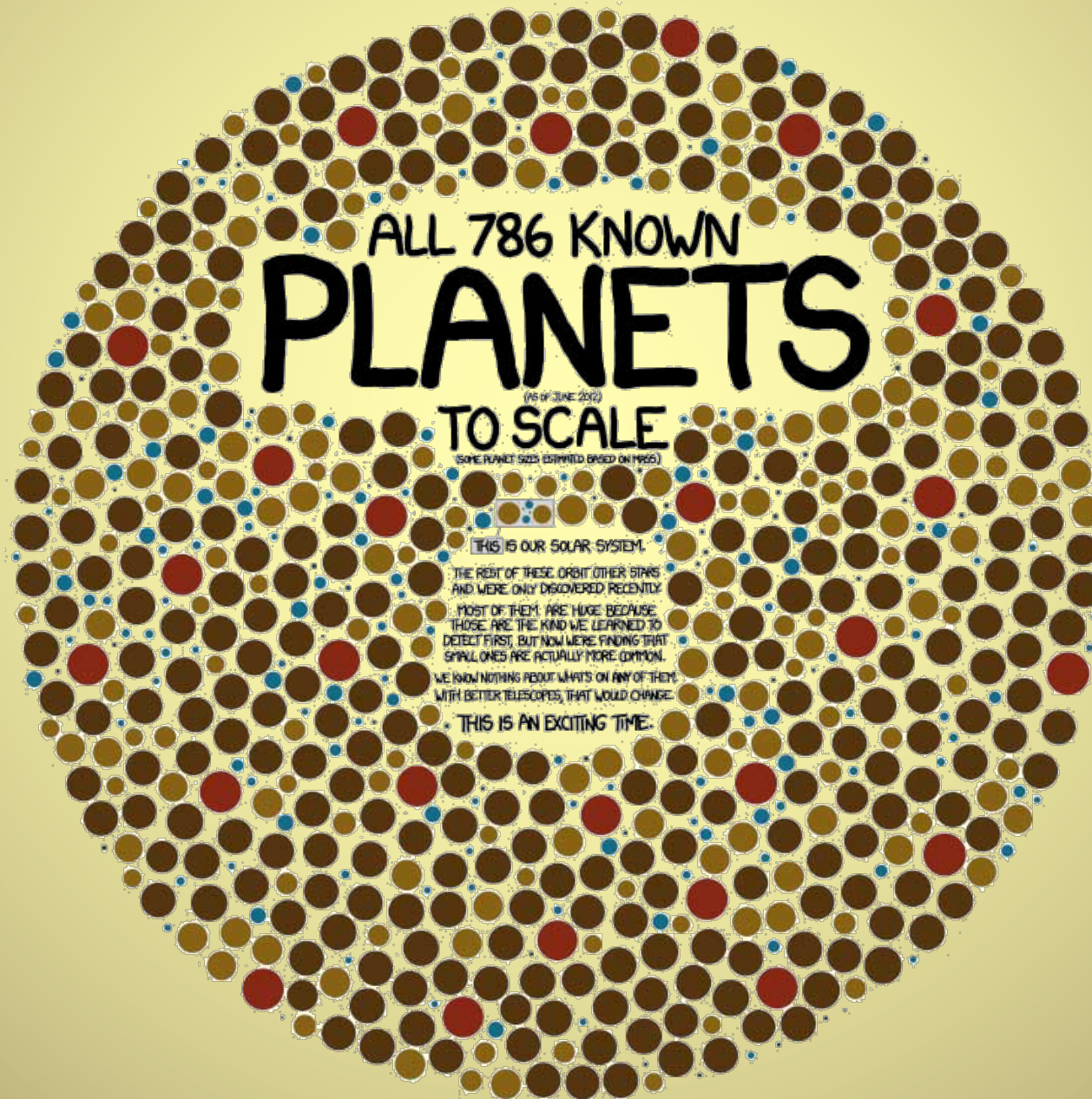




# A More Recent Pictures of Planets

*Kepler*

*A Search for Earth-size  
Planets*



ALL 786 KNOWN

*Kepler*

*A Search for Earth-size*

# PLANETS

(AS OF JUNE 2012)

## TO SCALE

(SOME PLANET SIZES ESTIMATED BASED ON MASS)



THIS IS OUR SOLAR SYSTEM.

THE REST OF THESE ORBIT OTHER STARS AND WERE ONLY DISCOVERED RECENTLY.

MOST OF THEM ARE HUGE BECAUSE THOSE ARE THE KIND WE LEARNED TO DETECT FIRST, BUT NOW WE'RE FINDING THAT SMALL ONES ARE ACTUALLY MORE COMMON.

WE KNOW NOTHING ABOUT WHAT'S ON ANY OF THEM.



# The Kepler Mission

*Kepler*

*A Search for Earth-size  
Planets*

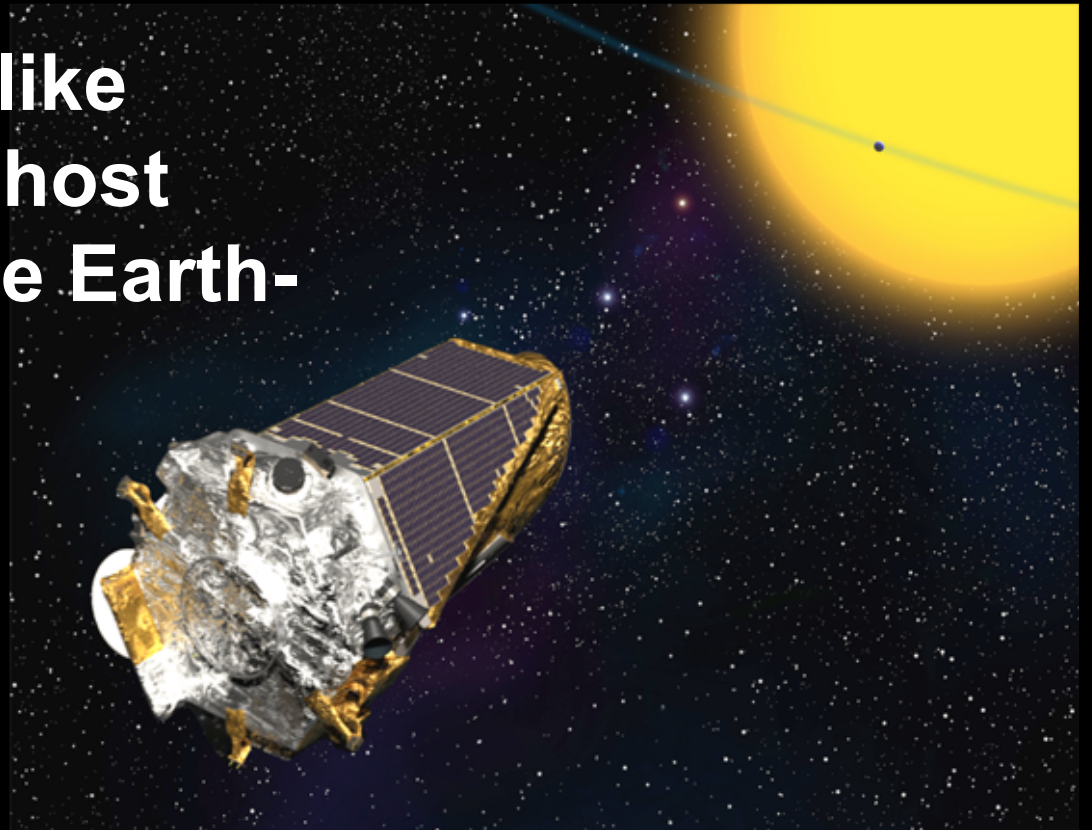
**What fraction of sun-like stars in our galaxy host potentially habitable Earth-size planets?**

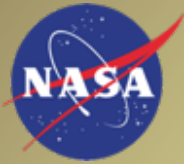


BRIGHTNESS



TIME IN HOURS

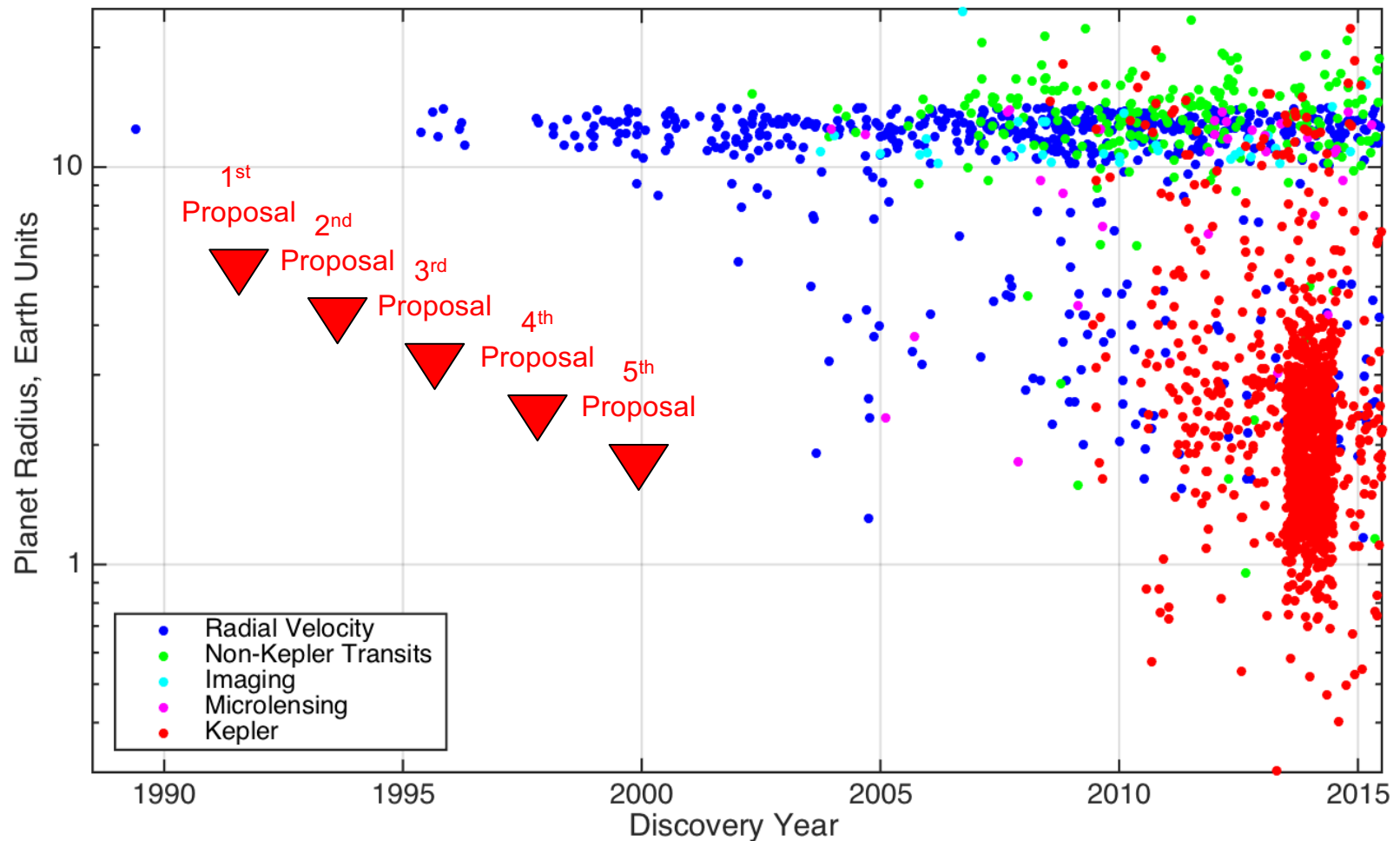




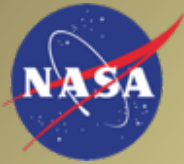
# Exoplanet Discoveries Over Time

Kepler

A Search for Earth-size Planets



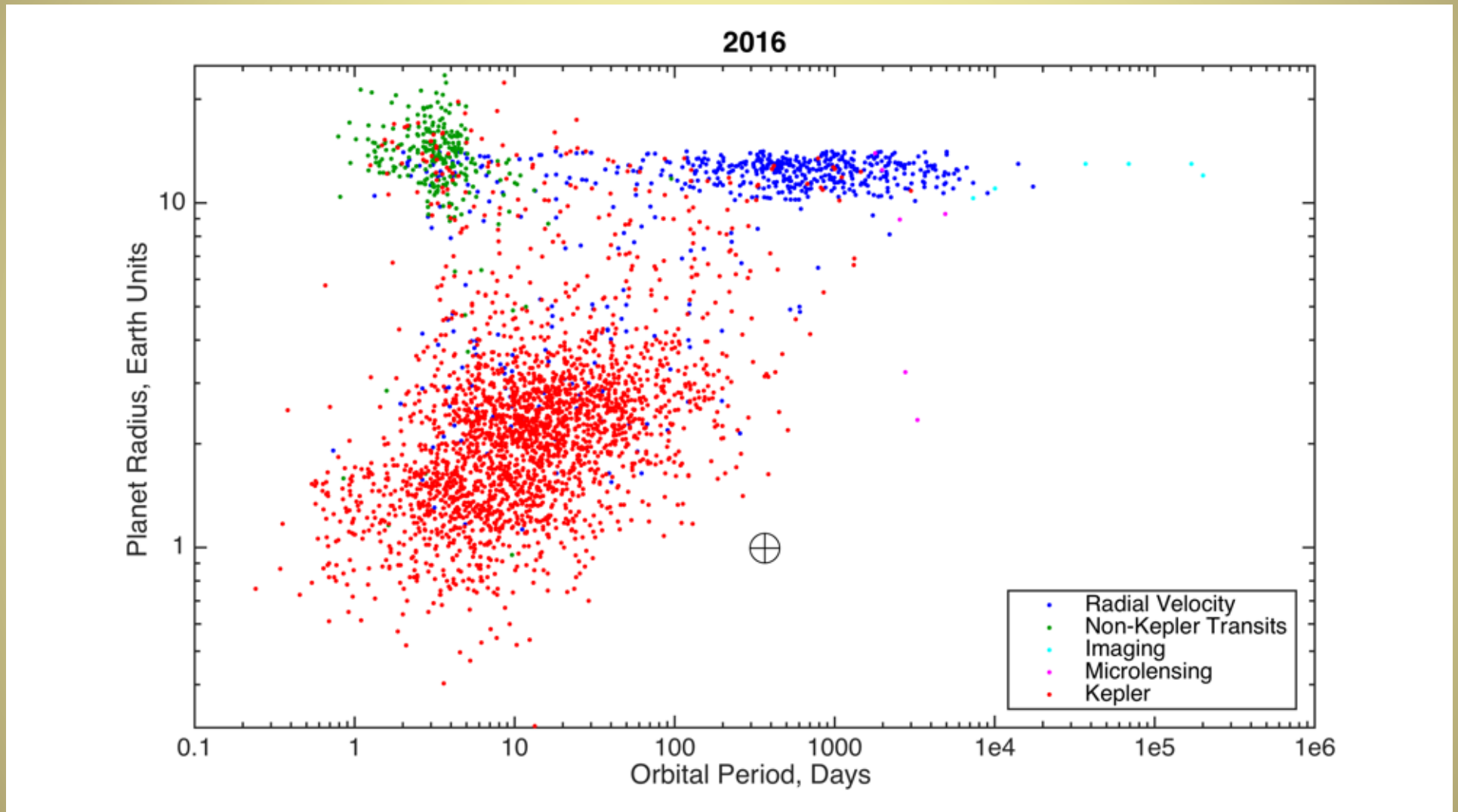
Radii estimated for non-transiting exoplanets  
Discovery data dithered randomly within discovery year

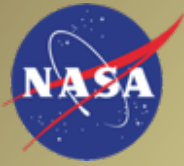


# Exoplanet Discoveries

Kepler

A Search for Earth-size Planets



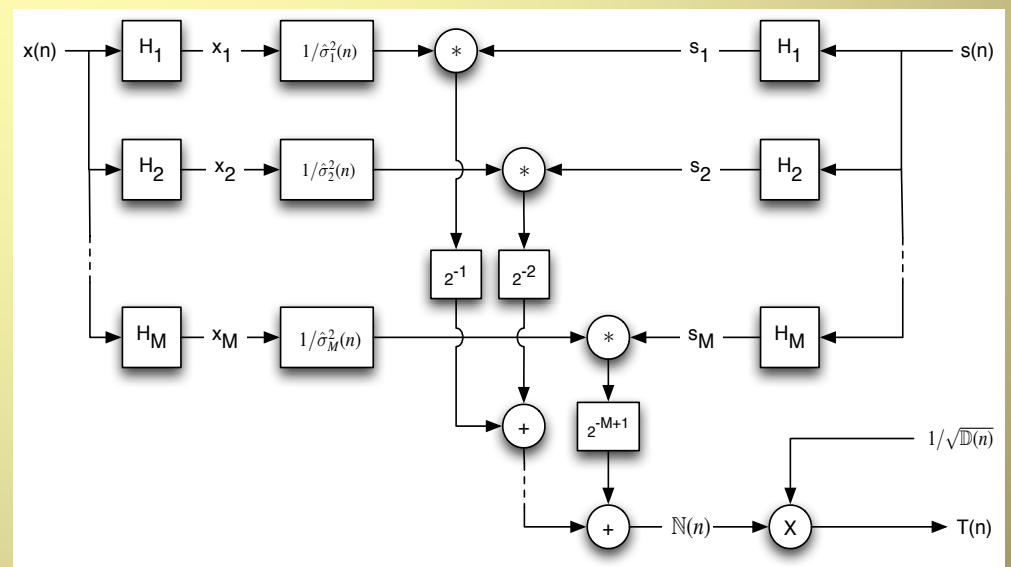


# Enabling Kepler

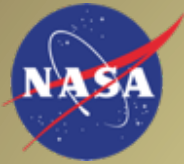
Kepler

A Search for Earth-size Planets

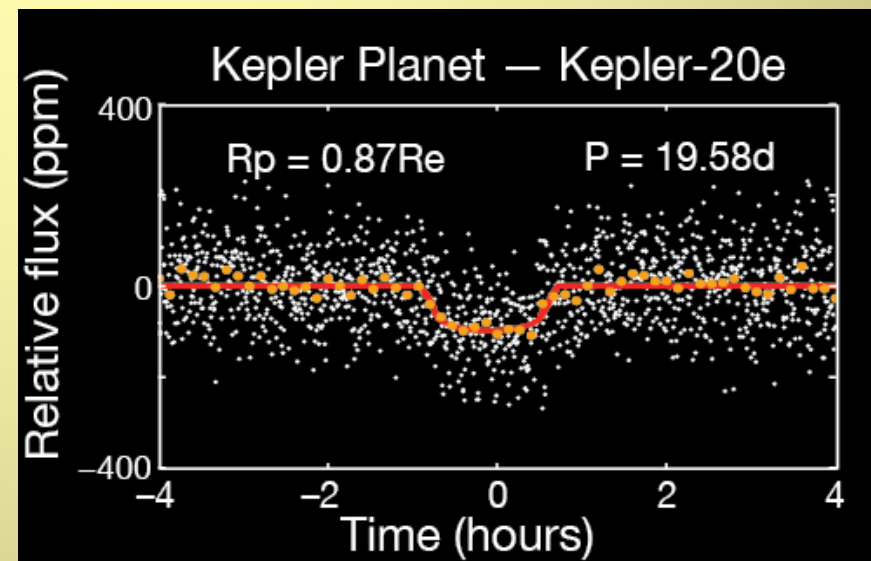
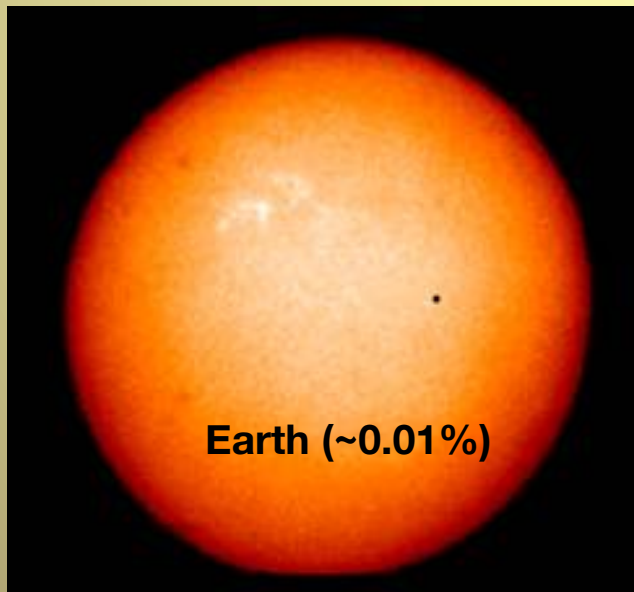
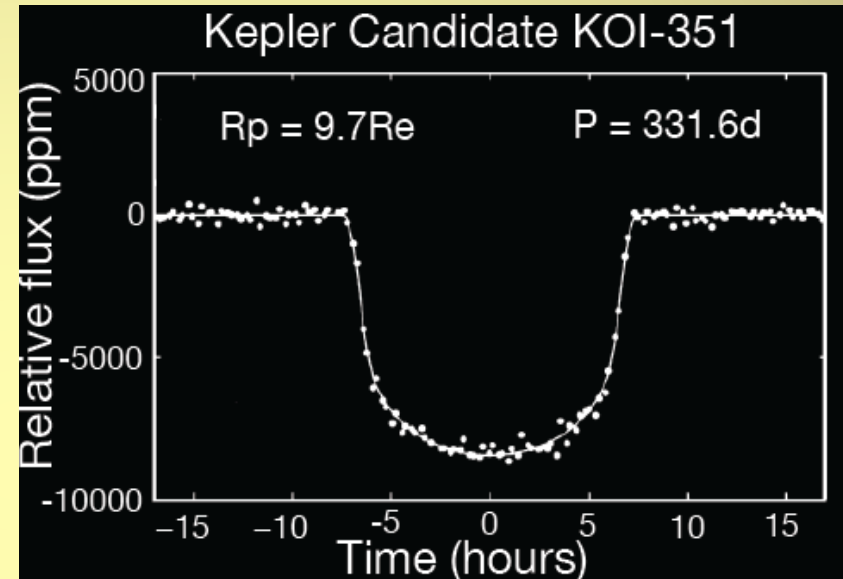
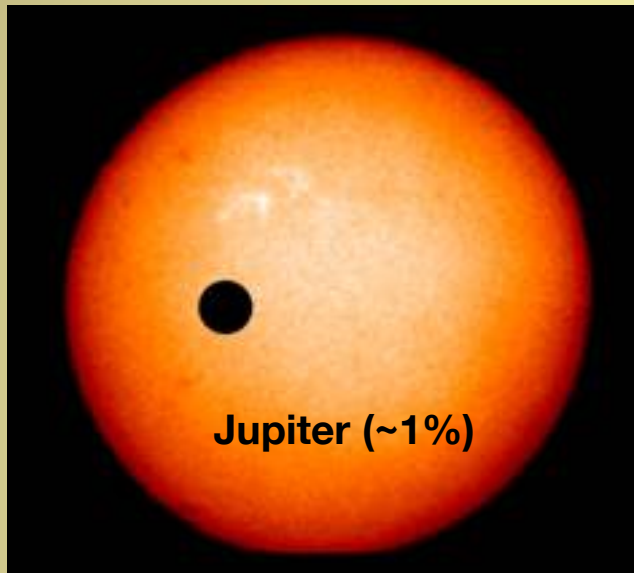
- Back illuminated CCDs (20 ppm photometric precision)
- Sophisticated algorithms
- Computational infrastructure

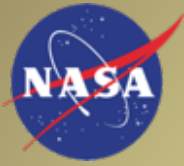






# How Hard is it to Find Good Planets?





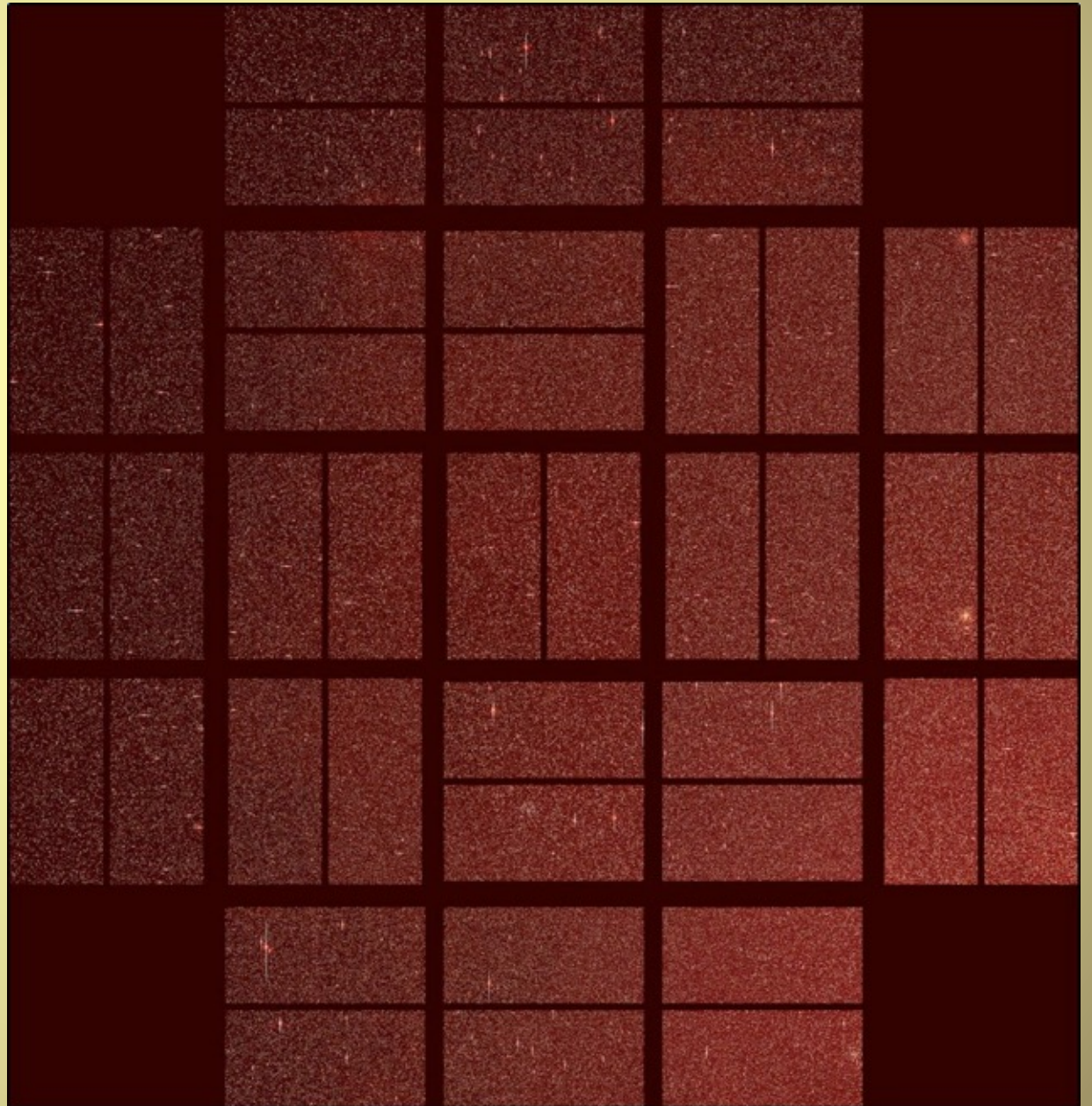
# First Light Image

*Kepler*

*A Search for Earth-size  
Planets*



Launched March 7 2009





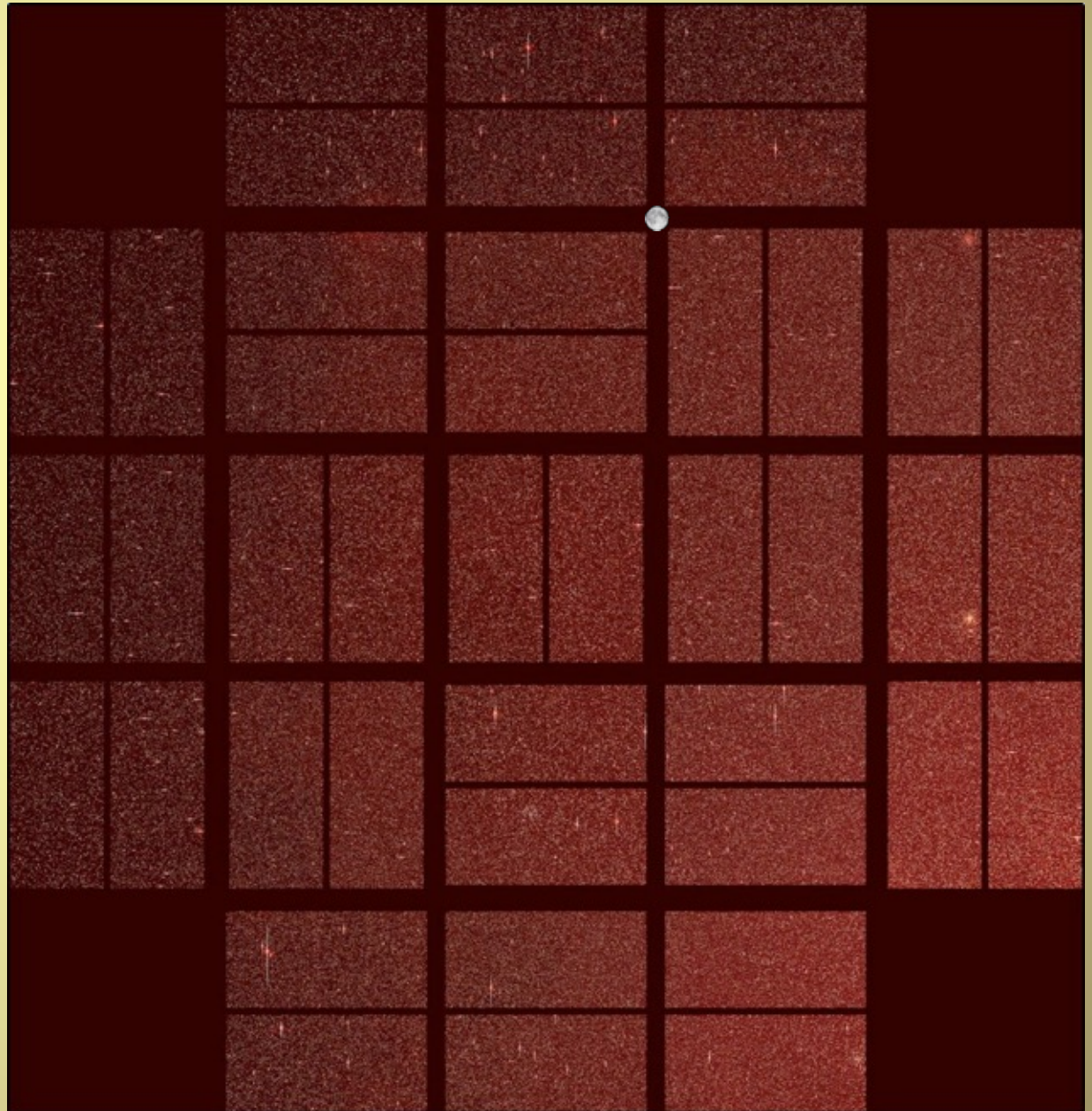
# First Light Image

*Kepler*

*A Search for Earth-size  
Planets*



Launched March 7 2009



# Key Science Results

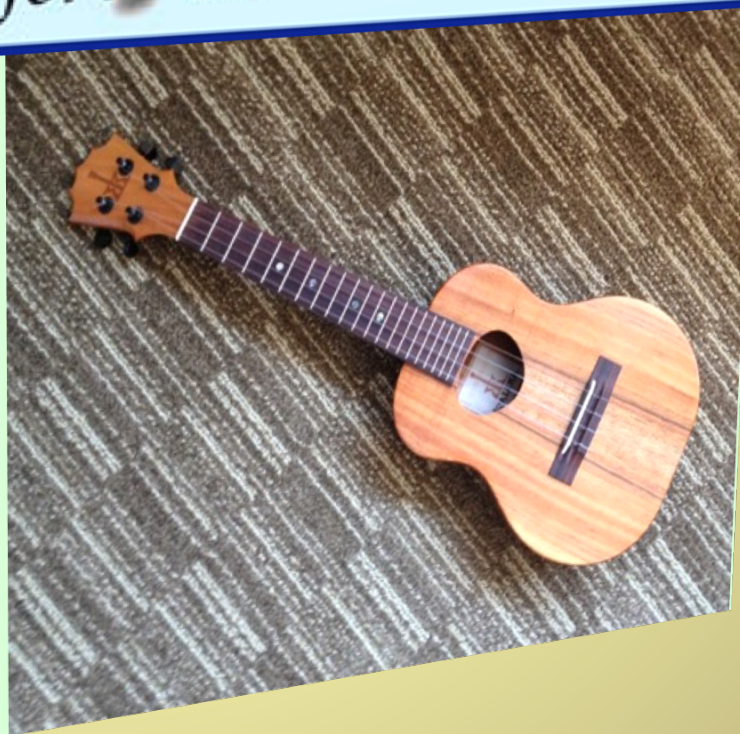


## Kepler

A Search for Terrestrial Planets

### Kepler's Greatest Hits

- Kepler-10b,c
  - Kepler-11b,c,d,e,f,g
  - Kepler-16b
  - Kepler-47c
  - Kepler-22b
  - Kepler-62e,f
  - KIC-12557548
- And Many Others!



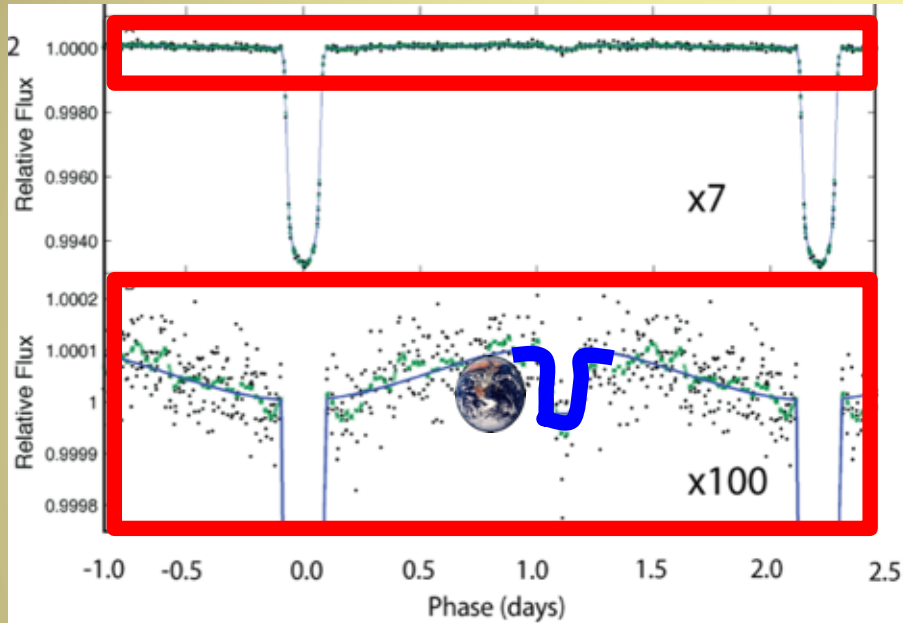


# Kepler's First Science Result

Kepler

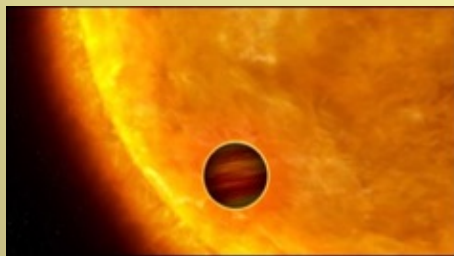
A Search for Earth-size Planets

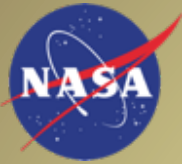
## HAT-P-7B



Kepler Commissioning data (10 days)  
W. Borucki et al., 2009

## Another Star



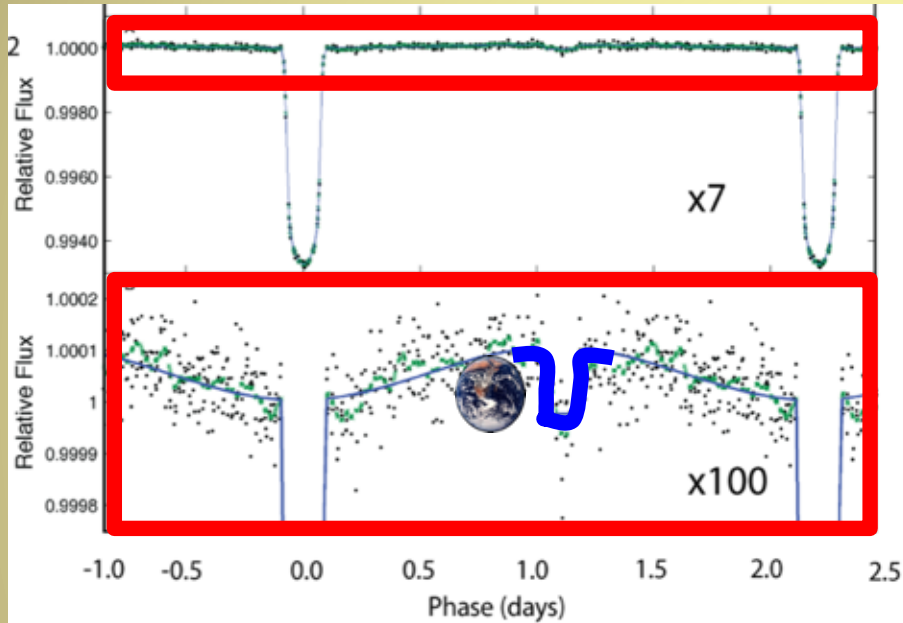


# Kepler's First Science Result

Kepler

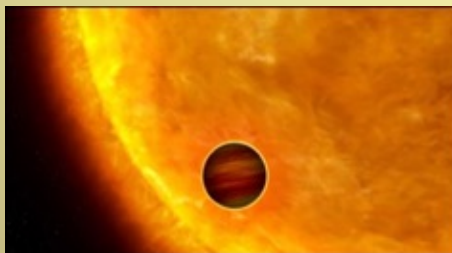
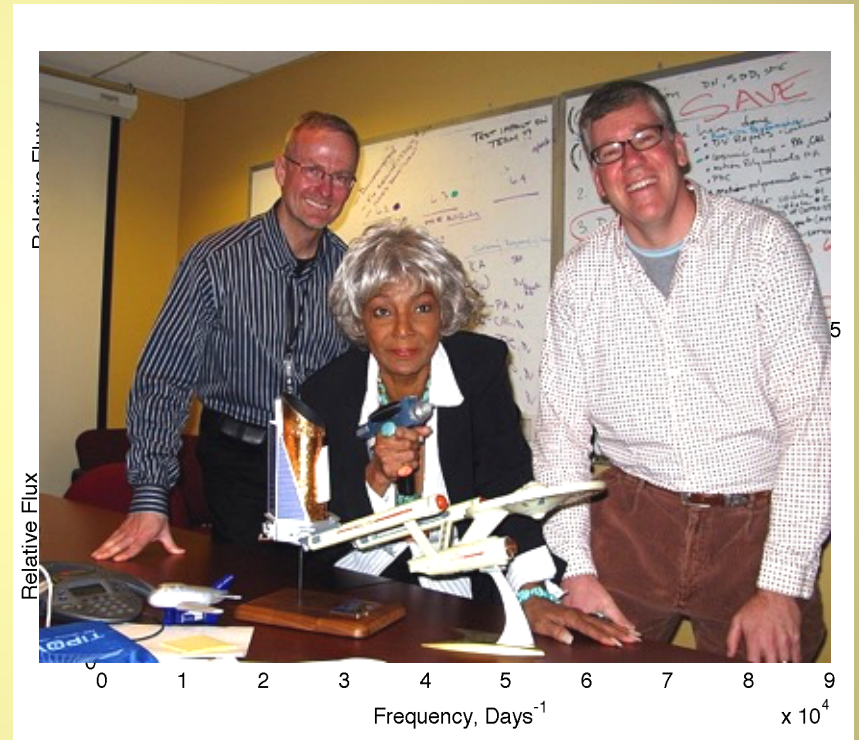
A Search for Earth-size Planets

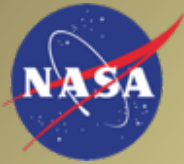
## HAT-P-7B



Kepler Commissioning data (10 days)  
W. Borucki et al., 2009

## Another Star





# Kepler and Asteroseismology

Kepler

A Search for Earth-size Planets

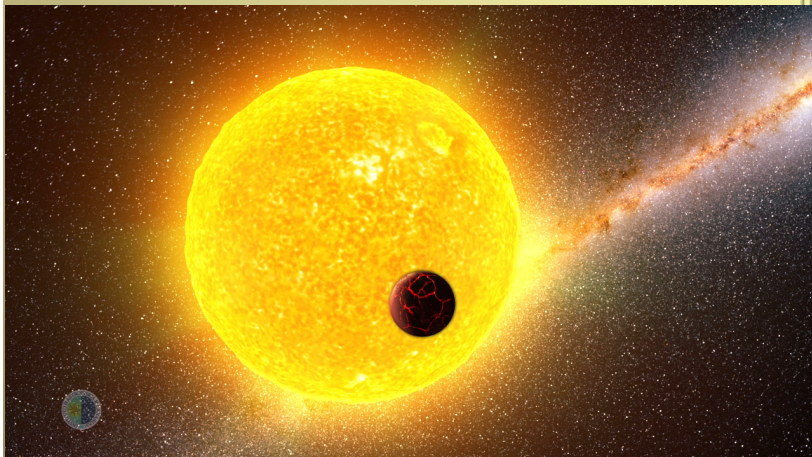
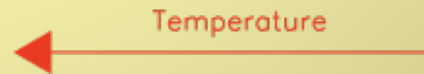
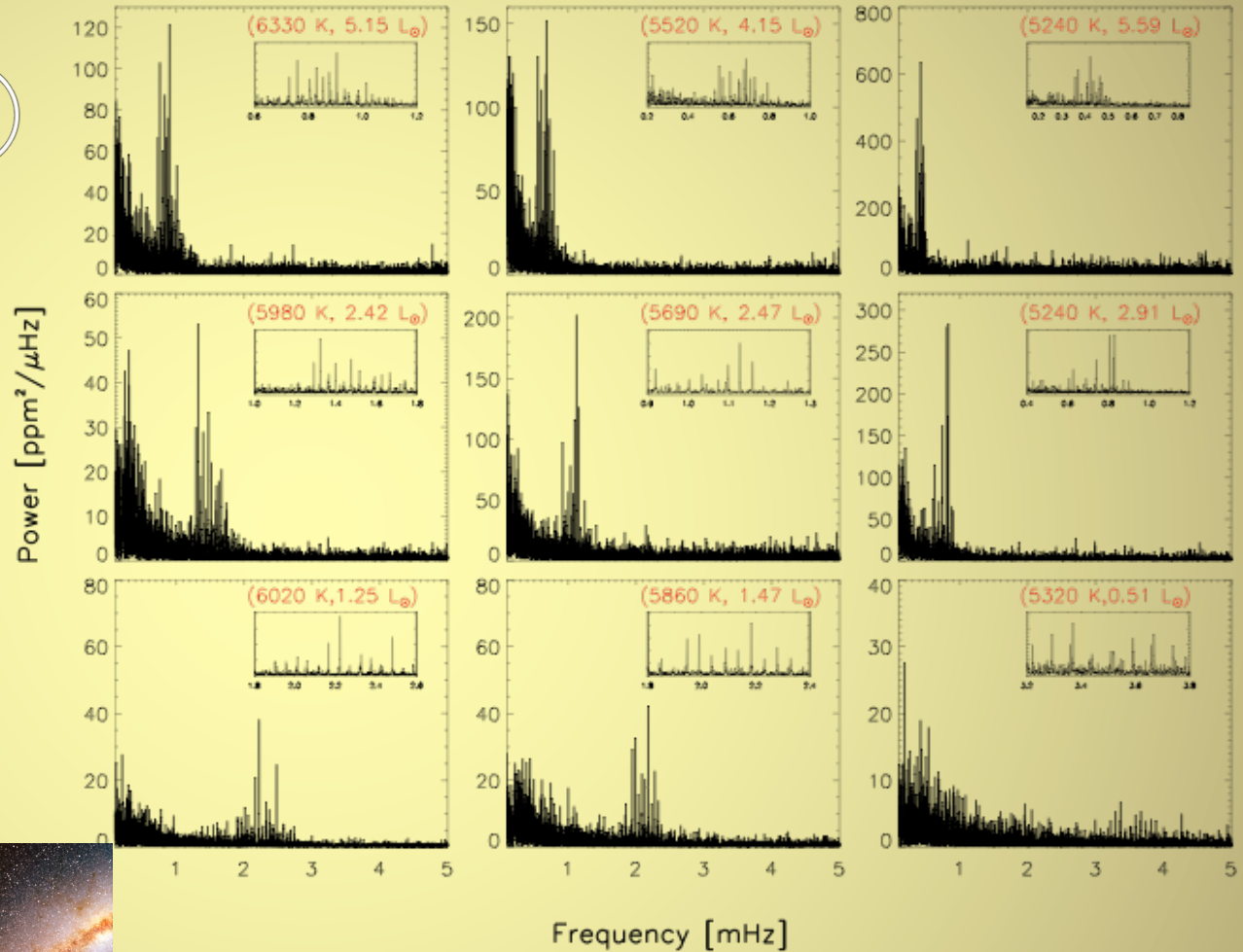
Stars are large resonant cavities that ring like bells



We've measured acoustic modes for >15,000 solar-like stars



Asteroseismology gives unprecedented precision in size, mass of stars



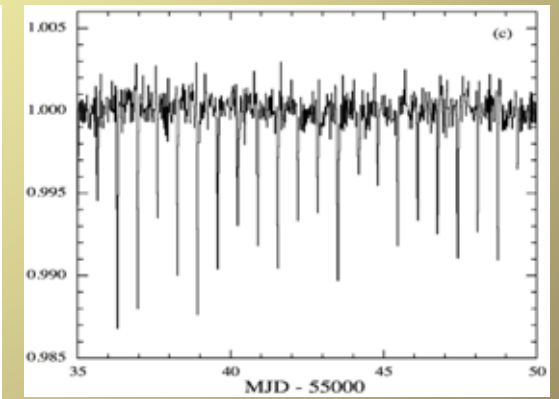
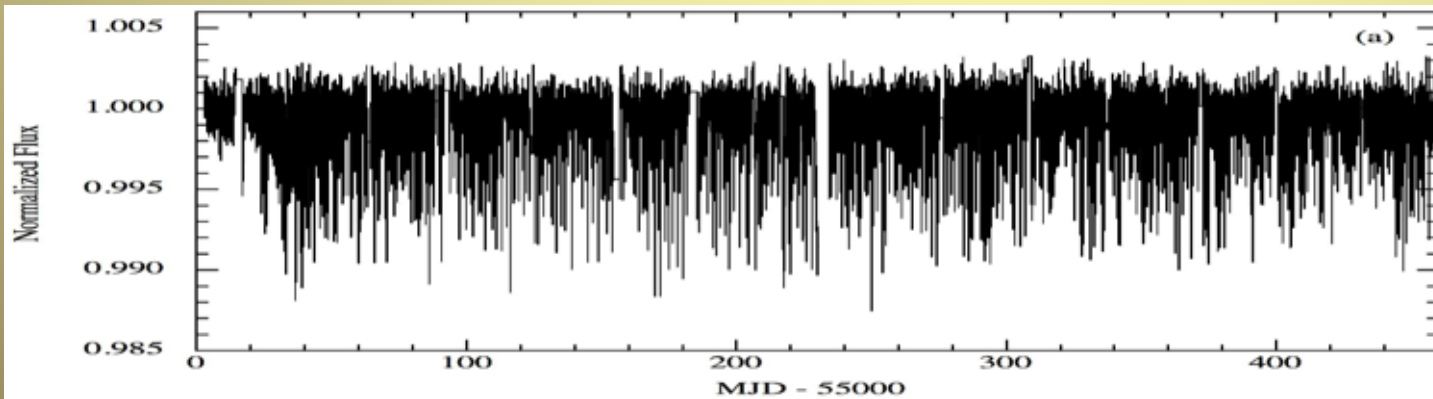
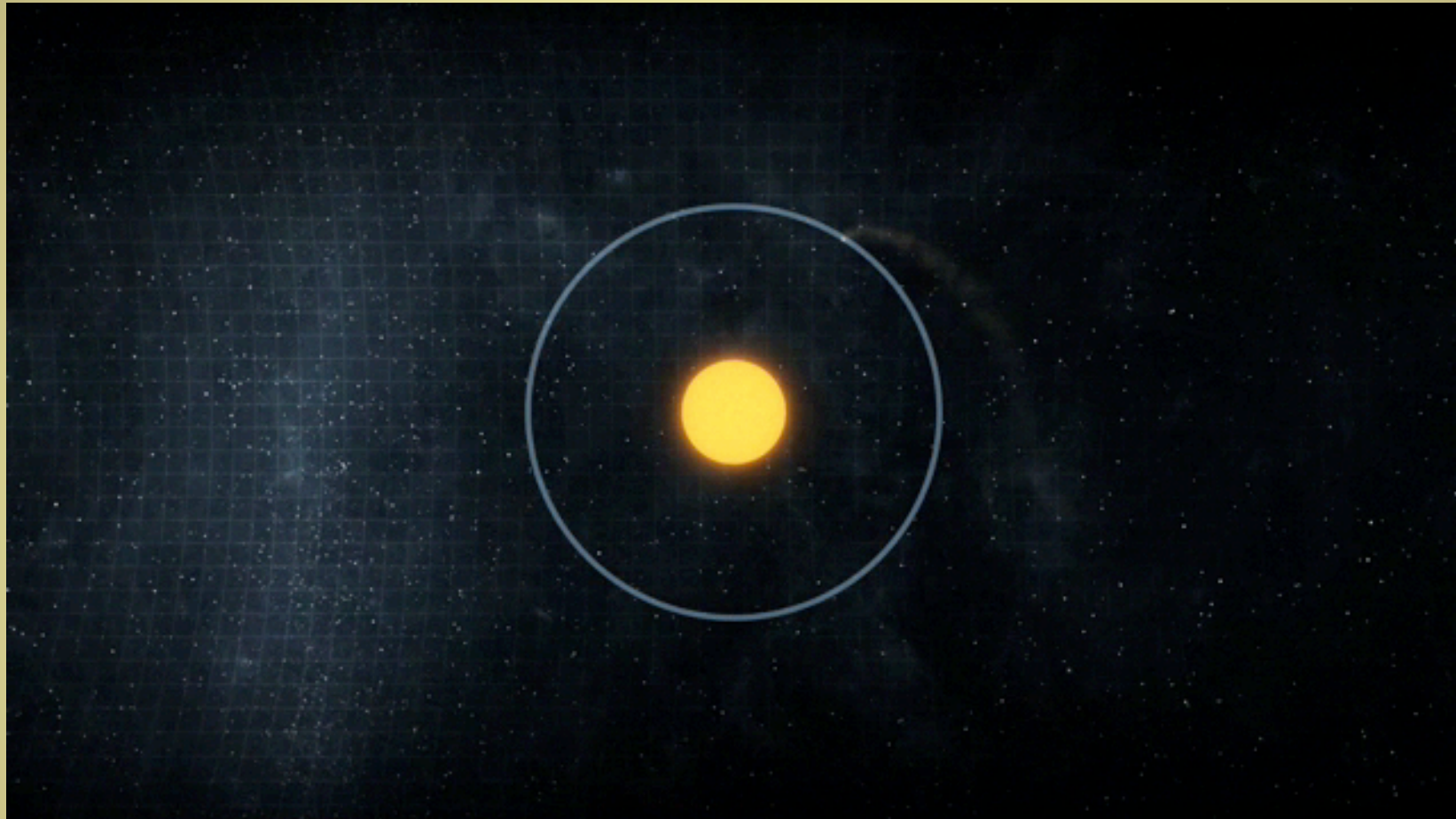
Chaplin et al 2011, Science



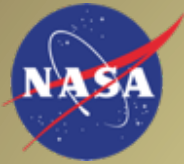
# A Disintegrating Planet: KIC-12557548

*Kepler*

*A Search for Earth-size Planets*







# Multiple Transiting Planets

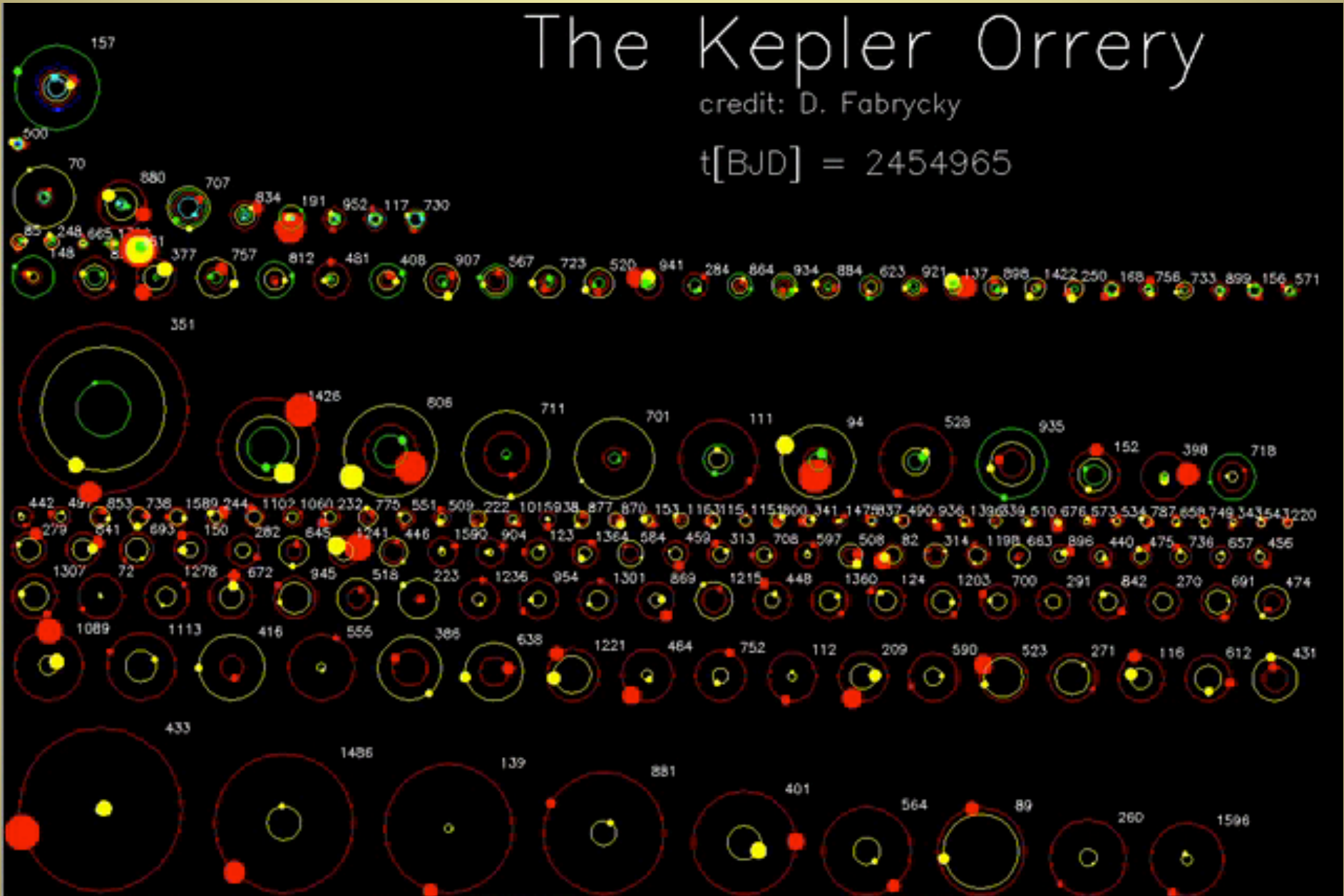
*Kepler*

*A Search for Earth-size Planets*

## The Kepler Orrery

credit: D. Fabrycky

$t[\text{BJD}] = 2454965$



# Searching for Habitable Worlds

KEPLER-20e  
DECEMBER 2011



KEPLER-22b  
DECEMBER 2011



KEPLER-452b  
JULY 2015



KEPLER-186f  
APRIL 2014



ARTISTIC CONCEPT

Kepler-452 System

Kepler-186 System

Solar System

Kepler-186f

Mercury

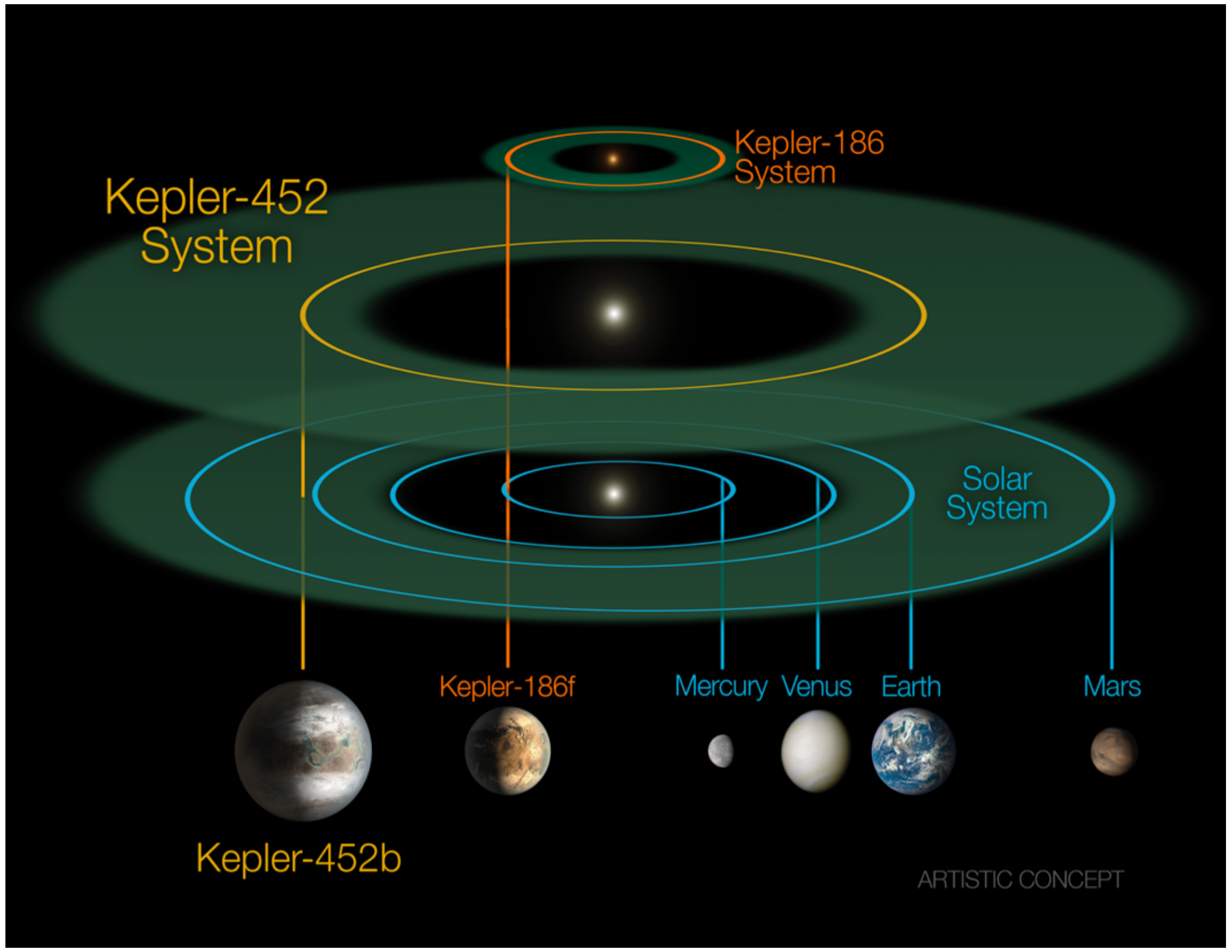
Venus

Earth

Mars

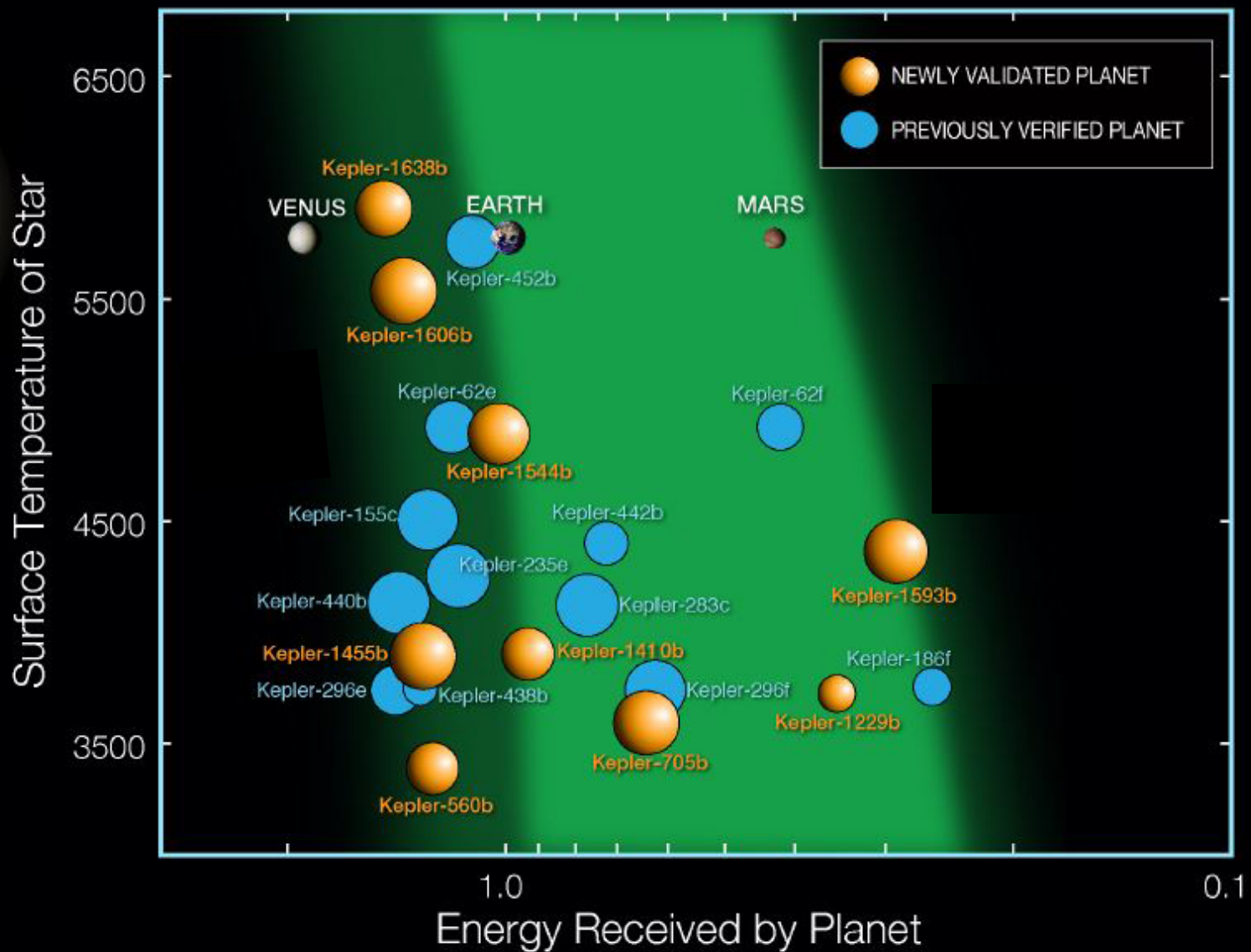
Kepler-452b

ARTISTIC CONCEPT



# Kepler's Small Habitable Zone Planets

As of May 10, 2016

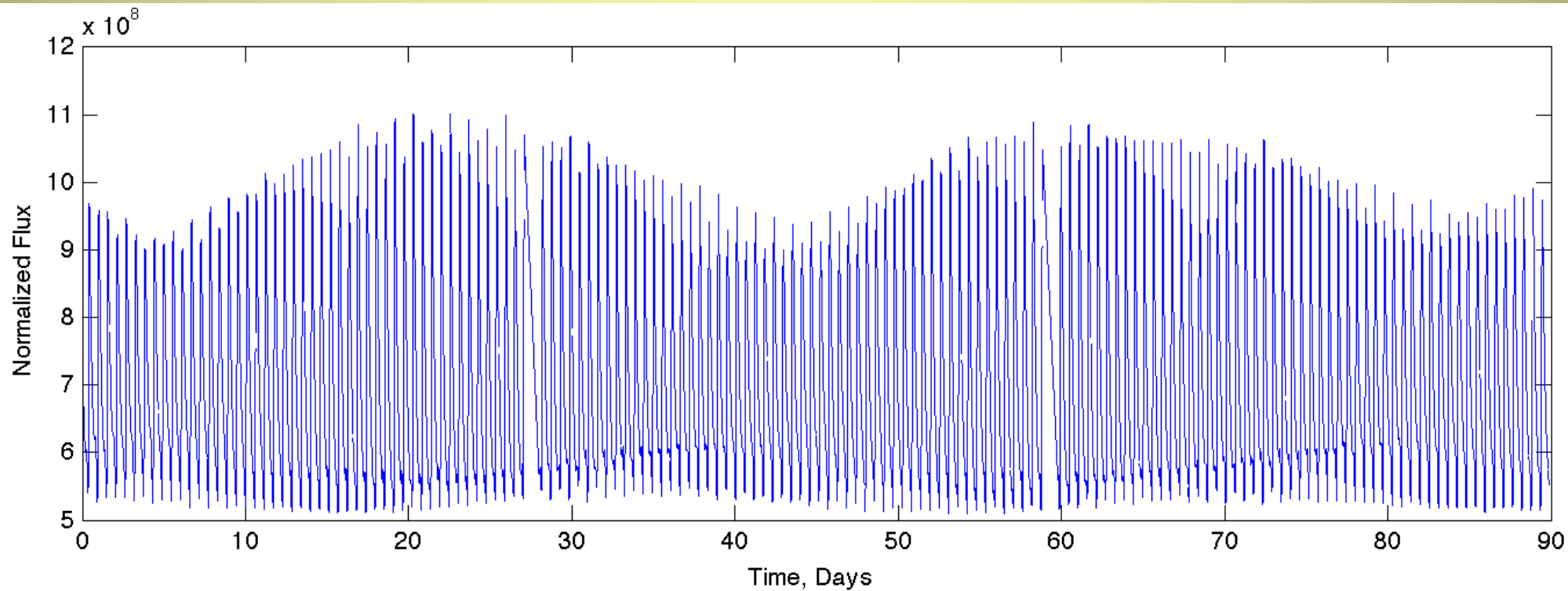


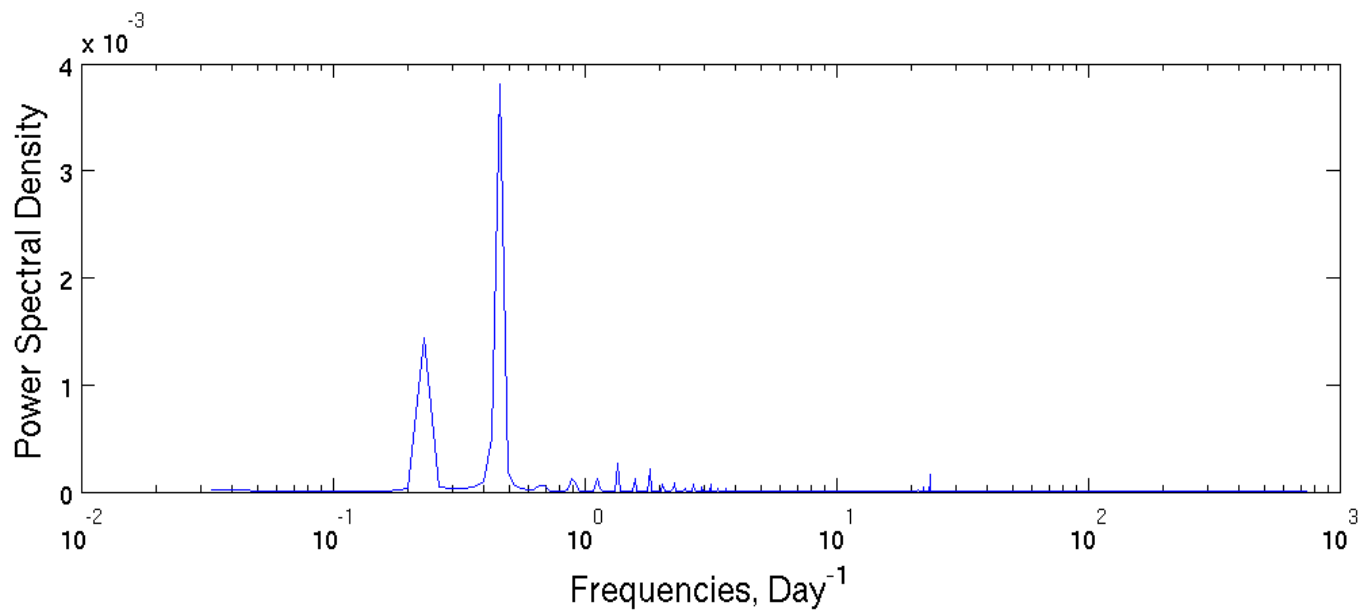
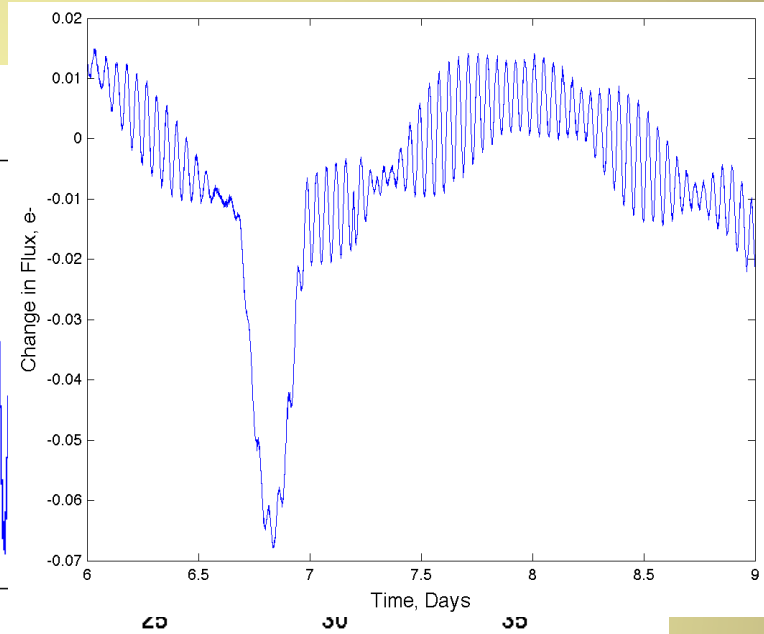
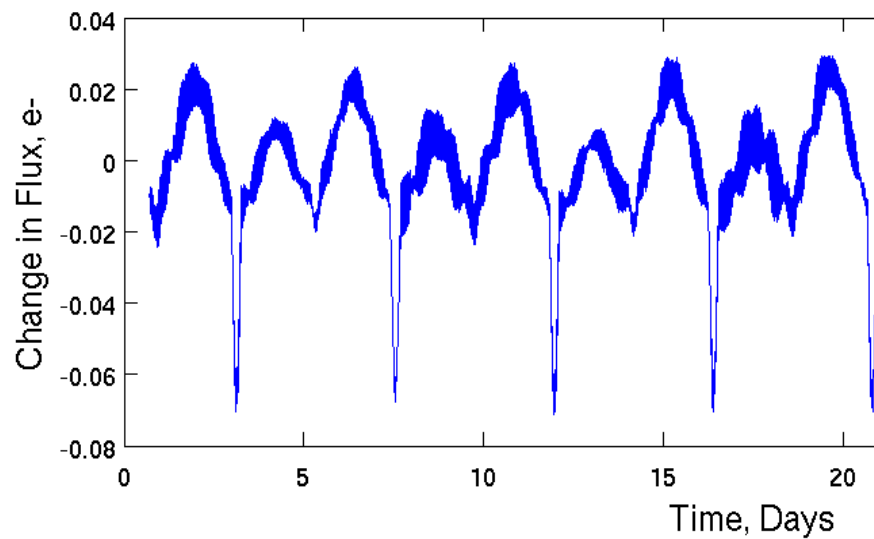


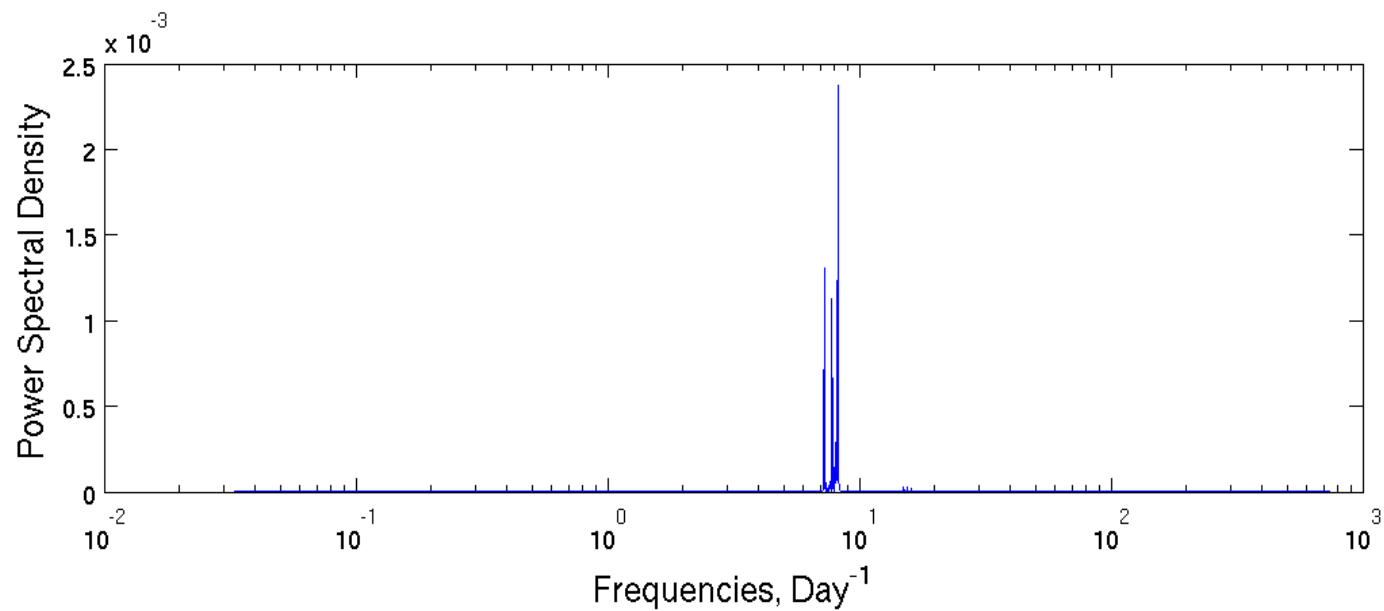
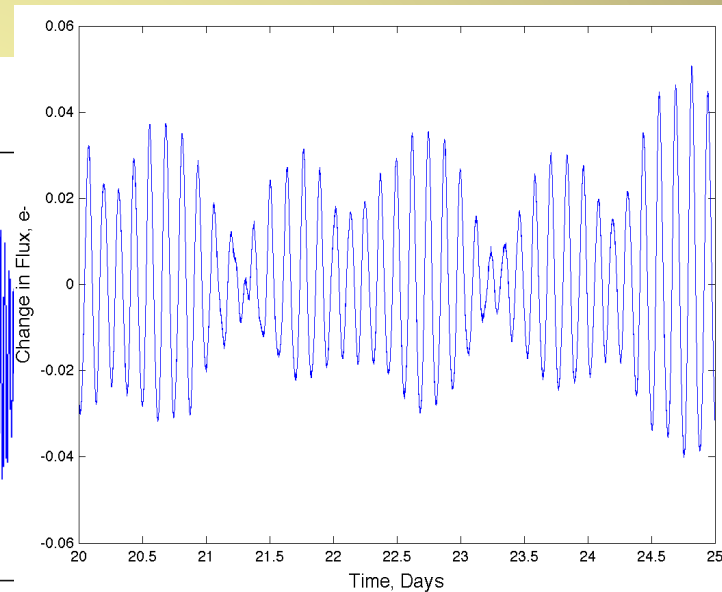
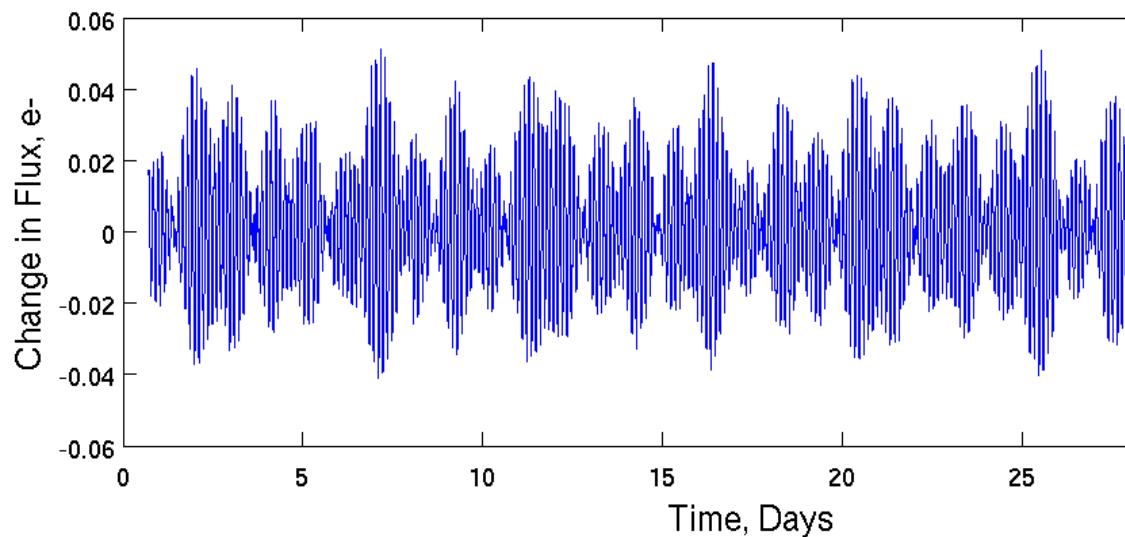
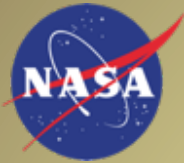
# RR Lyr

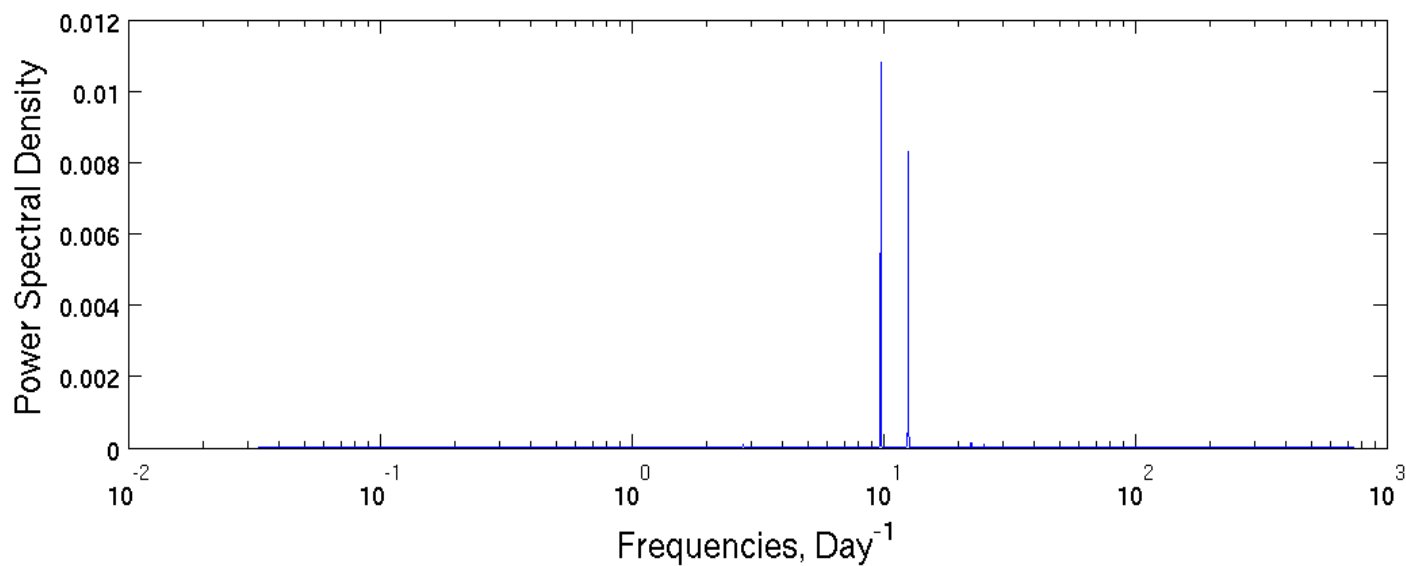
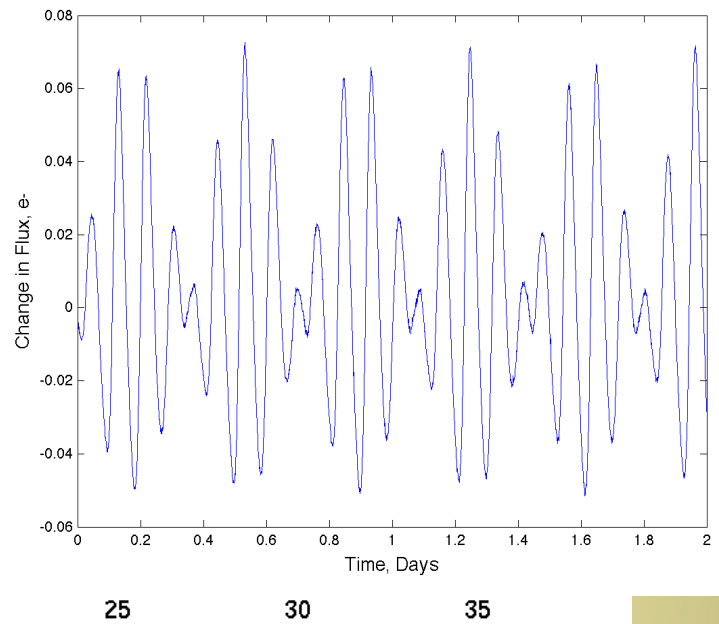
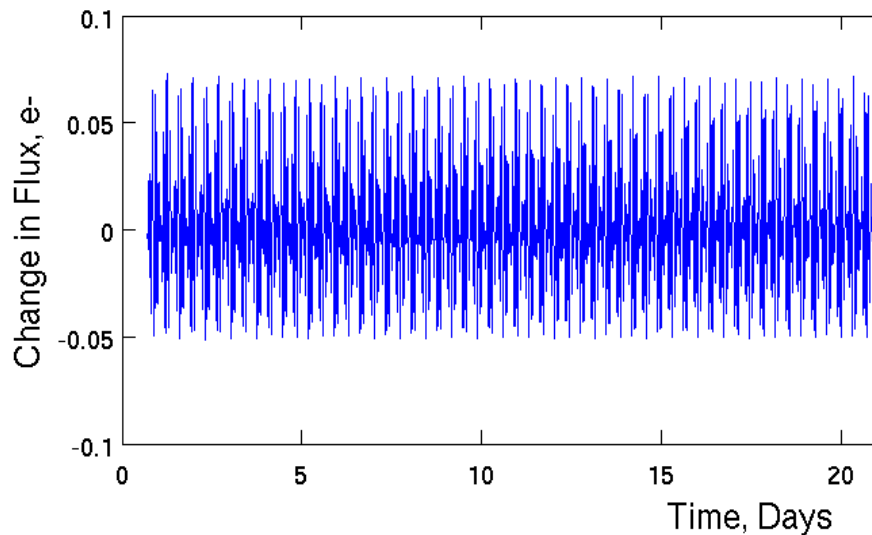
*Kepler*

*A Search for Earth-size  
Planets*



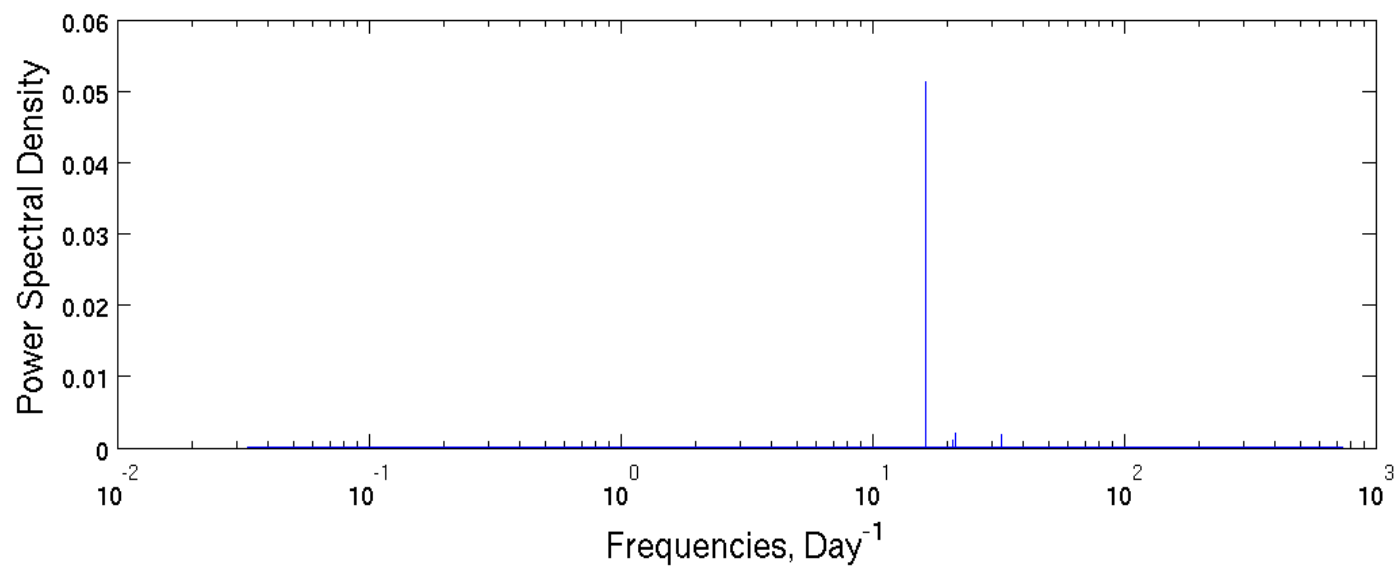
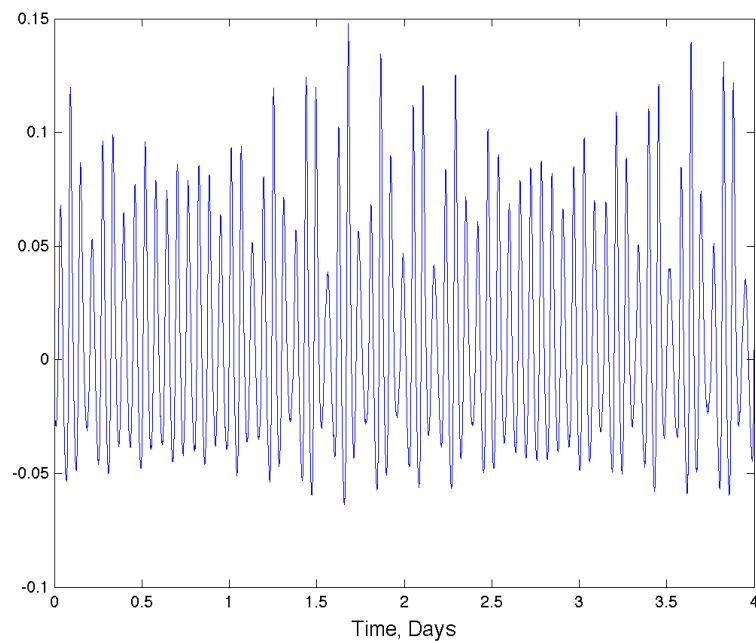
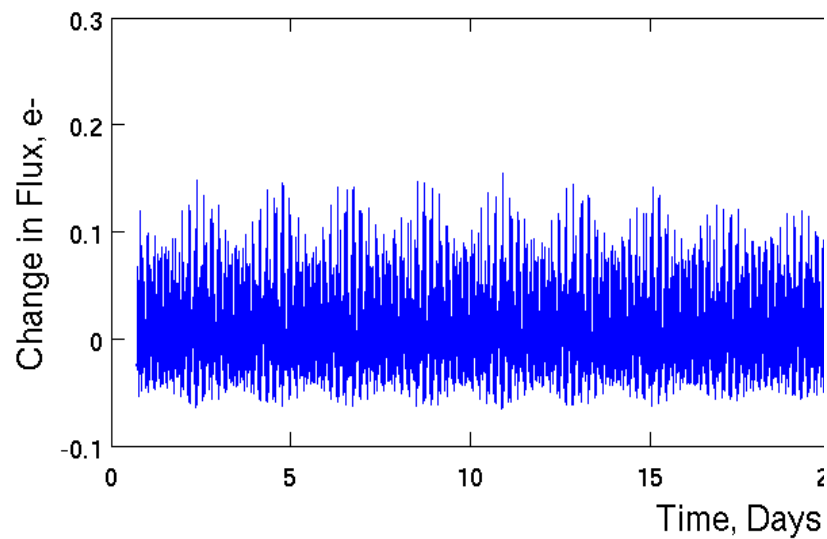
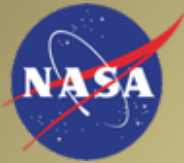




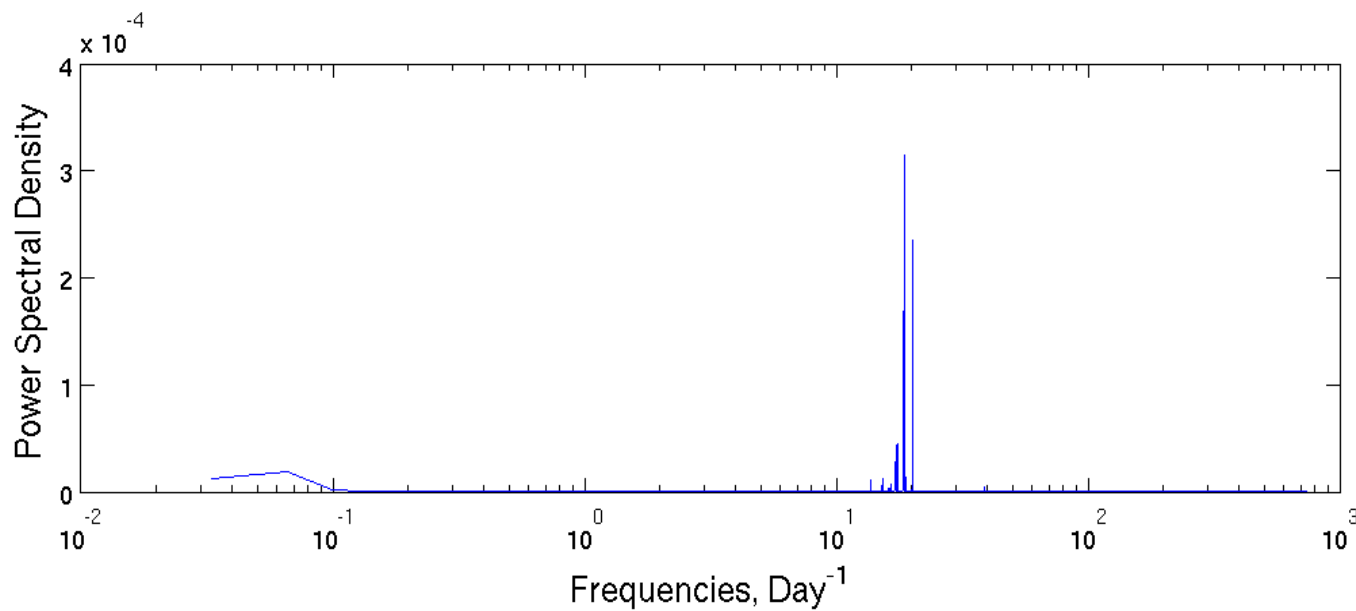
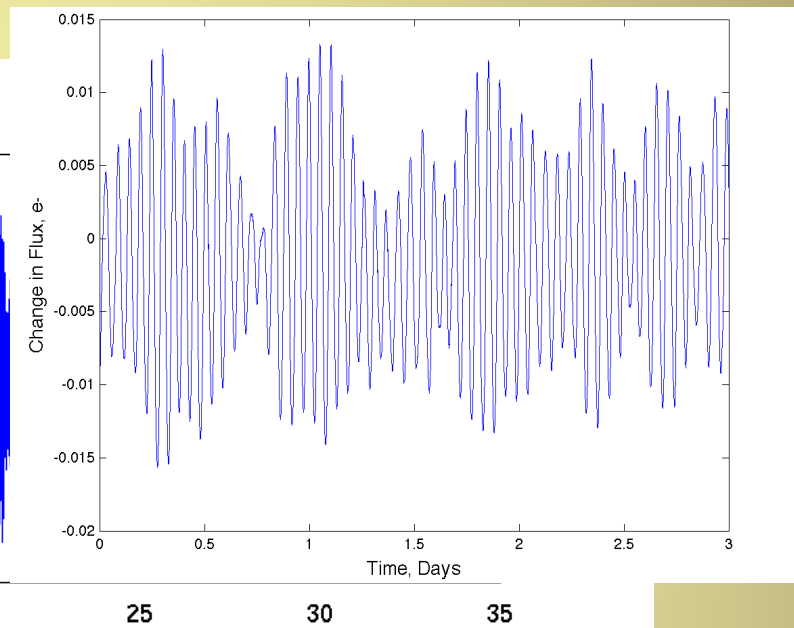
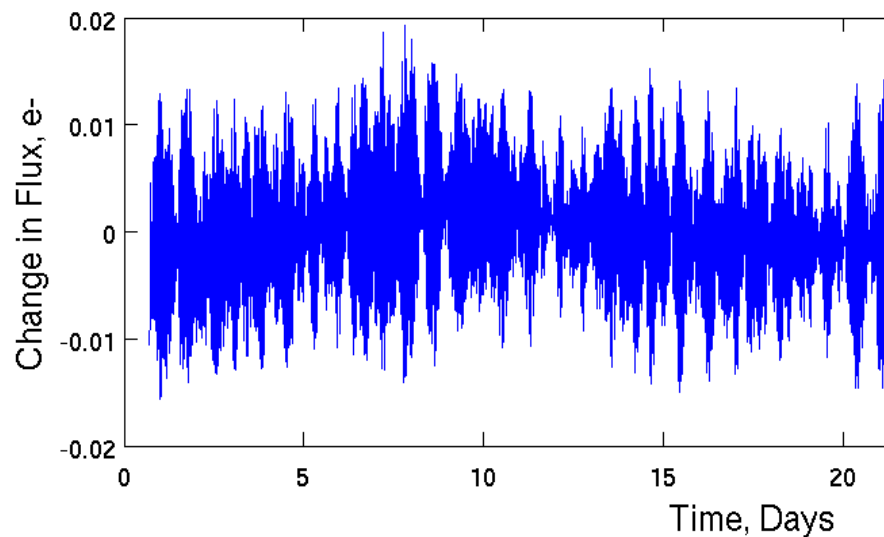
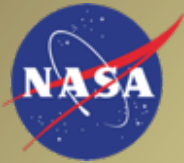


8)

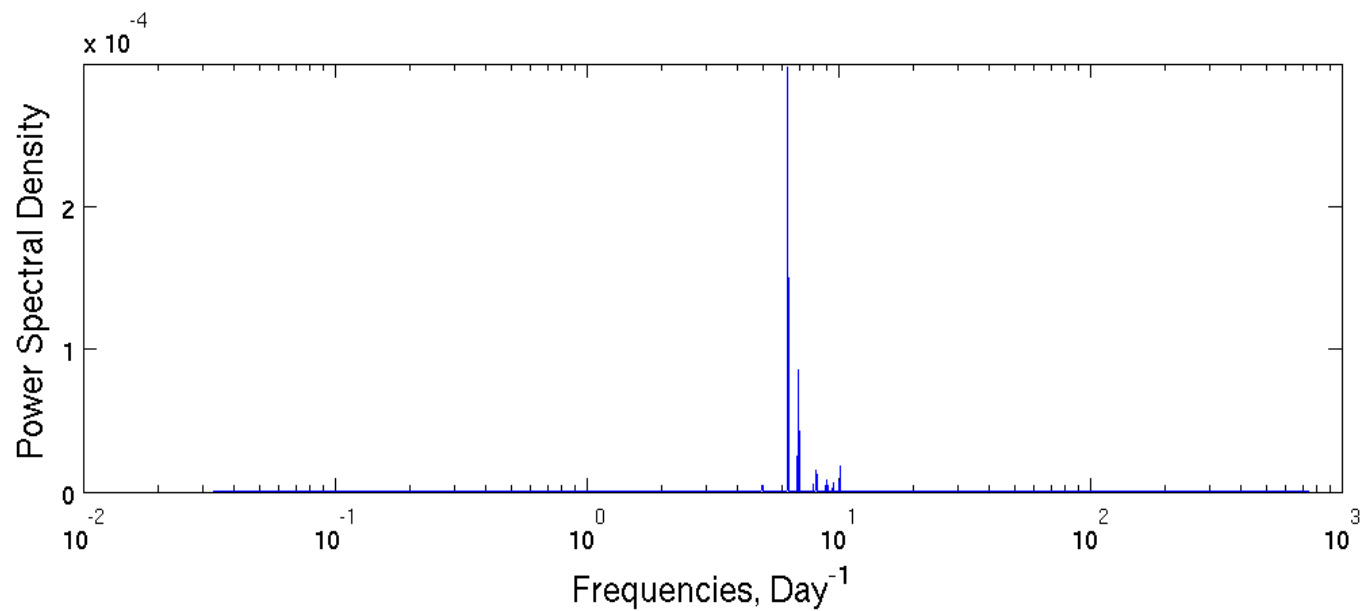
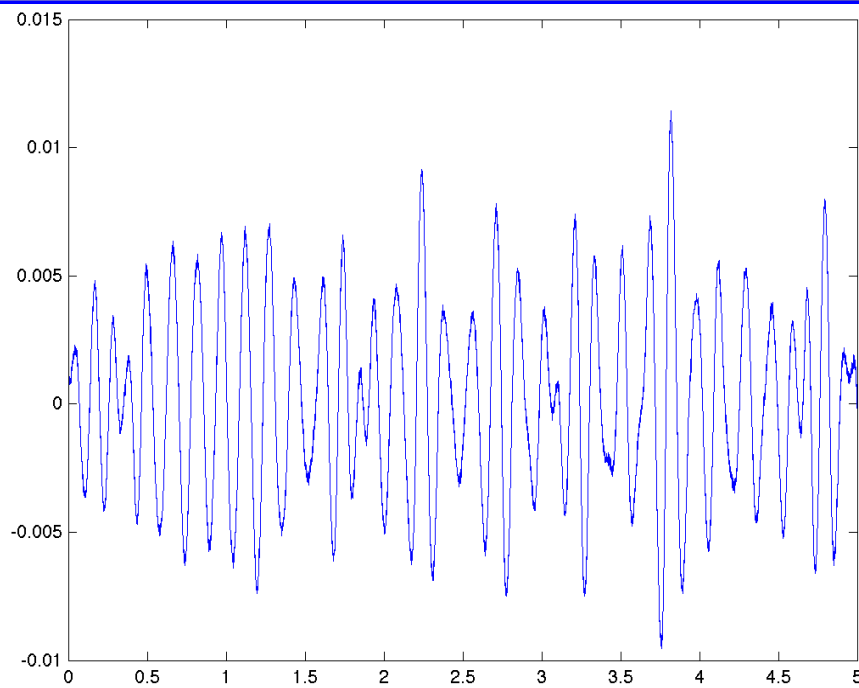
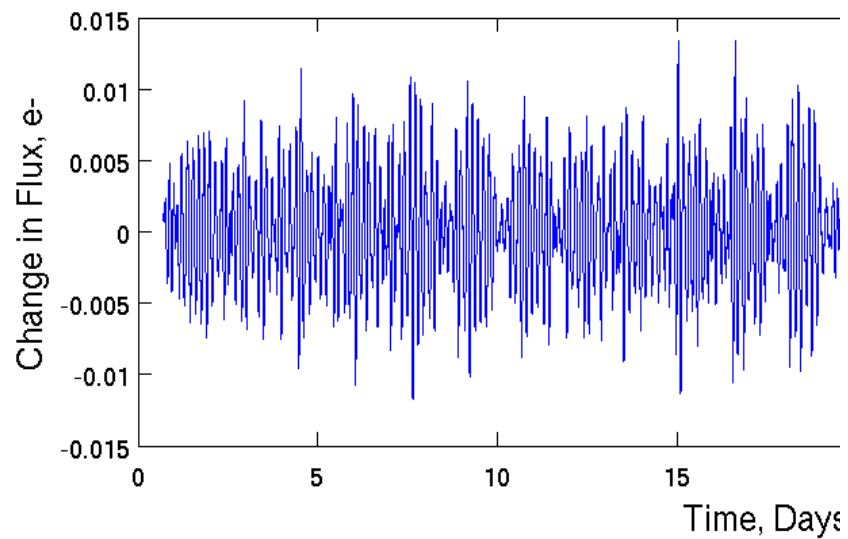




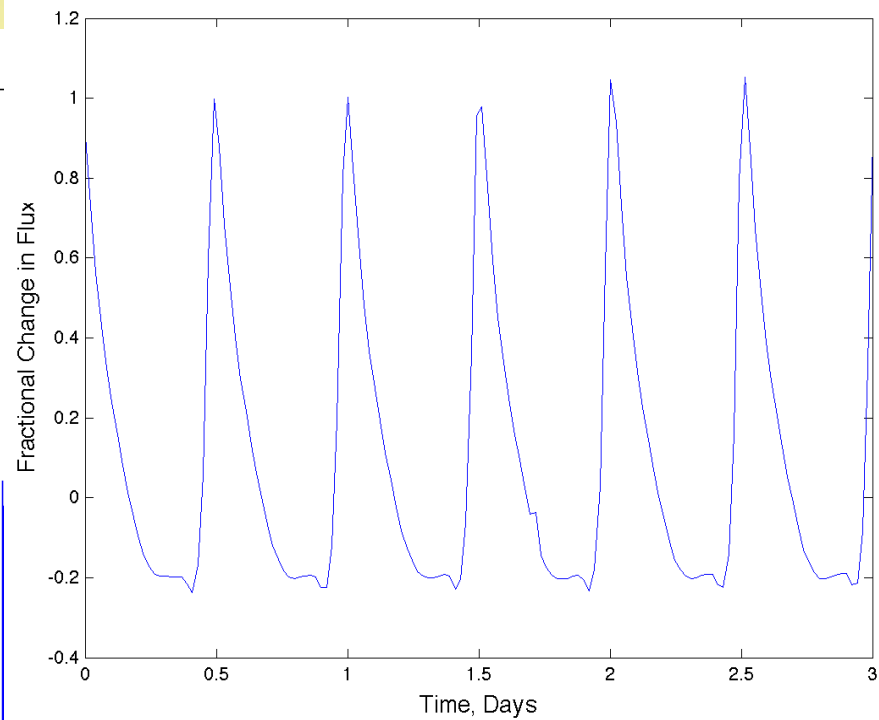
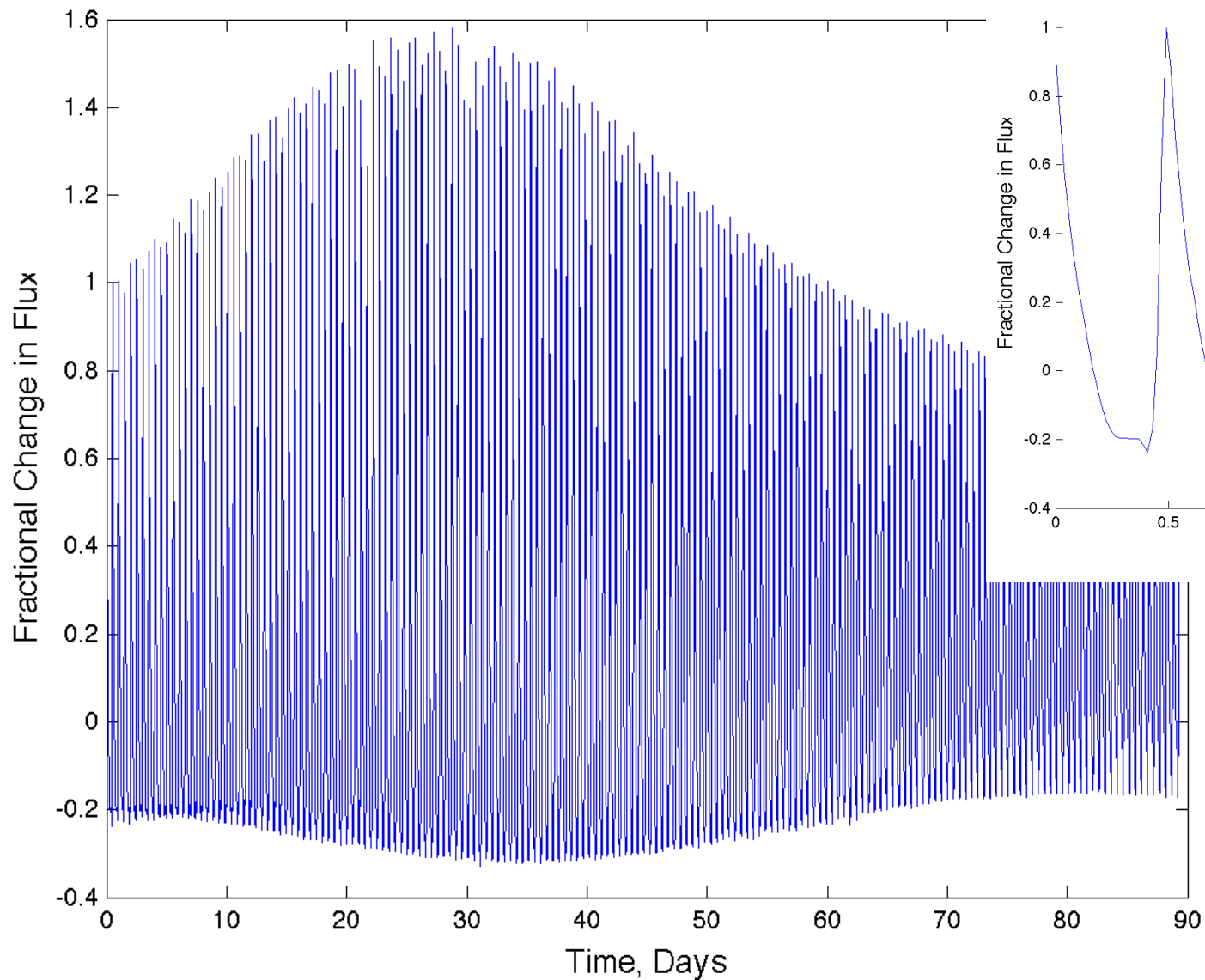
8)



8)



8)



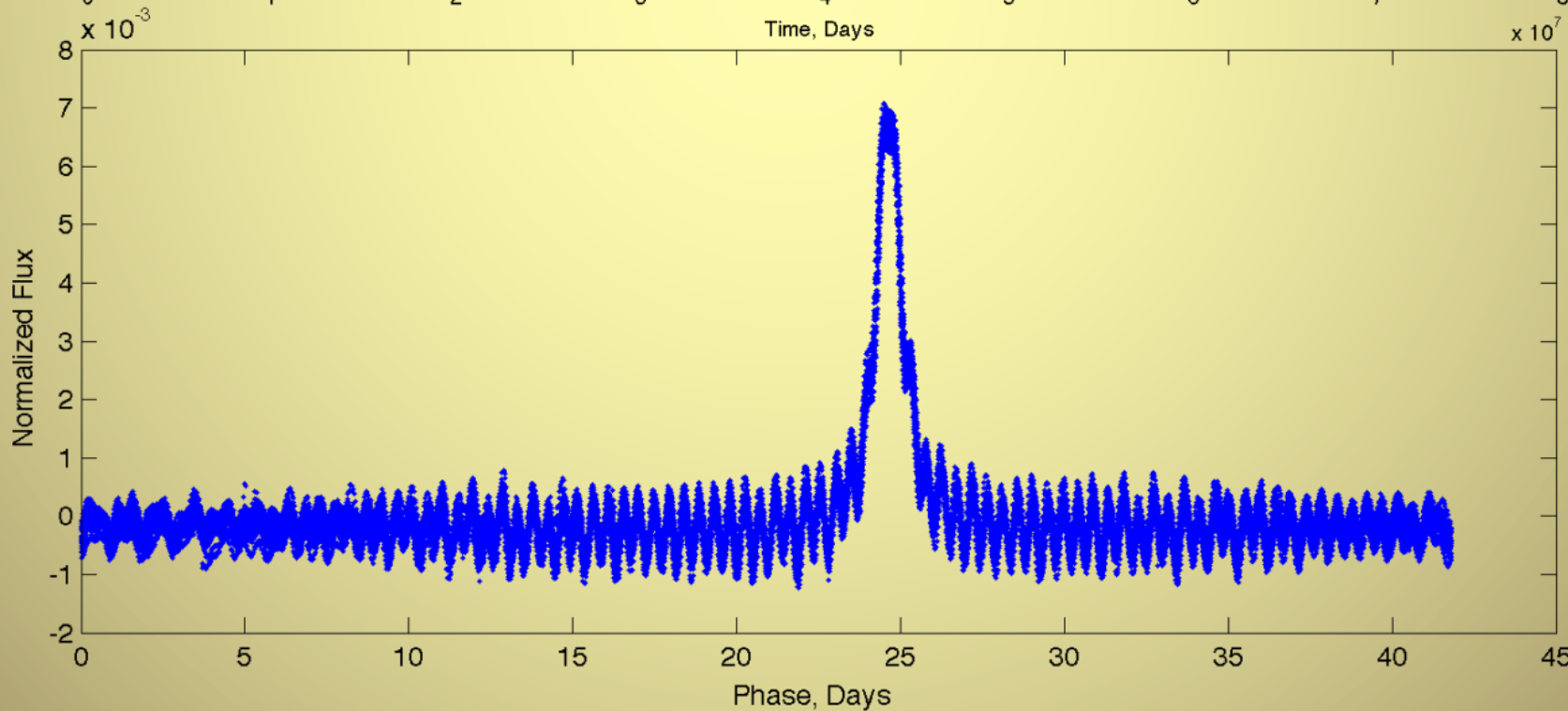
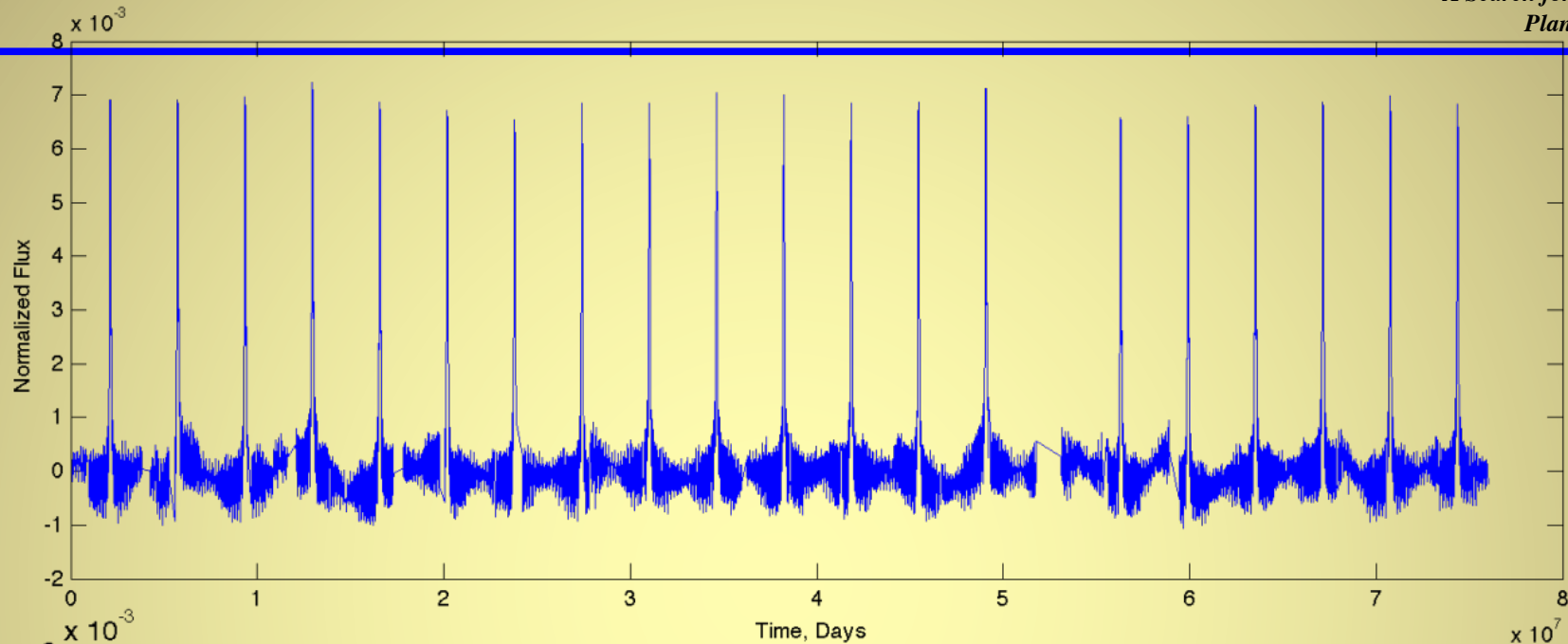
ter Roberts (1946-2008)



# Heartbeat Stars: KOI-54

*Kepler*

*A Search for Earth-size Planets*

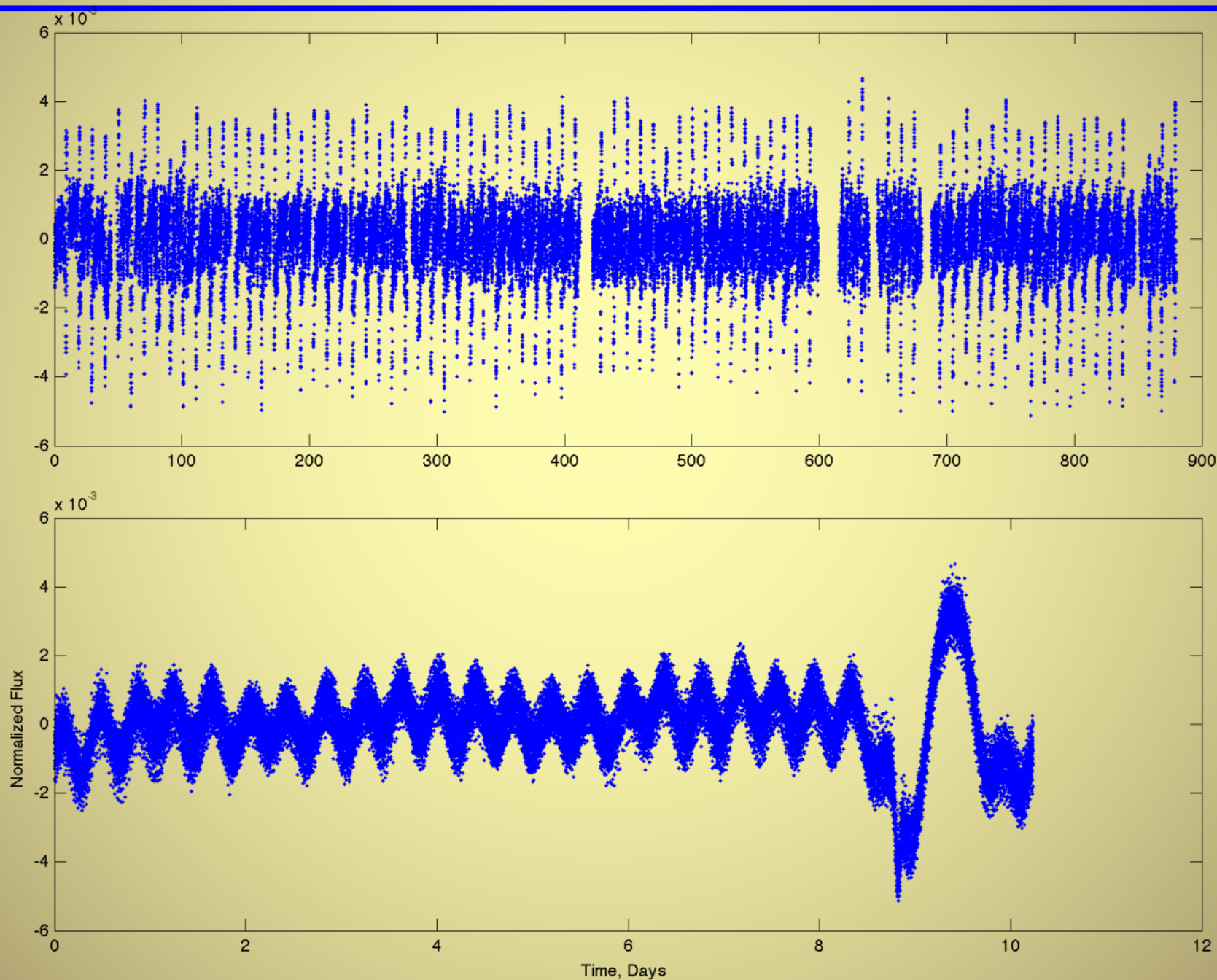




# Heartbeat Stars: Carl

*Kepler*

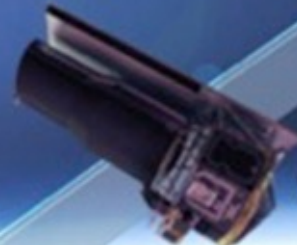
*A Search for Earth-size Planets*



# Exoplanet Missions



Hubble



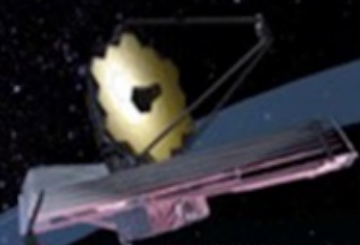
Spitzer



Kepler



TESS



JWST



New Worlds Telescope



WFIRST-AFTA

Ground-based Observatories



2001  
Decadal  
Survey



2010  
Decadal  
Survey