

There are also numberless earths circling around their suns...



# Agenda

Brief review of results

History of exoplanets exploration

Methods of detection

Transit photometry

Doppler spectroscopy

Summary

References

Exoplanets  
detection methods  
and results

Brief review of  
results

History of  
exoplanets  
exploration

Methods of  
detection

Transit photometry

Doppler  
spectroscopy

Summary

References

# Exoplanets: brief review of results

Exoplanets  
detection methods  
and results

Brief review of  
results

History of  
exoplanets  
exploration

Methods of  
detection

Transit photometry

Doppler  
spectroscopy

Summary

References

## Exoplanet

Extrasolar planet is a planet located outside the Solar system

- ▶  $\approx 4050$  confirmed planets as of April 2019 [1]
- ▶  $\approx 50$  **potentially** habitable planets
- ▶ Known parameters: orbital period, distance to the star, mass
- ▶ Only a handful of direct observations

# History of exoplanets exploration

Exoplanets  
detection methods  
and results

Brief review of  
results

History of  
exoplanets  
exploration

Methods of  
detection

Transit photometry

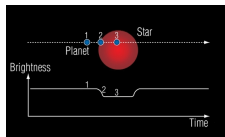
Doppler  
spectroscopy

Summary

References

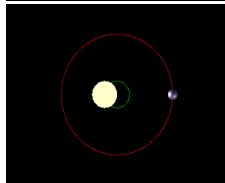
- ▶ 1584 "Innumerable suns and earths" hypothesis by Giordano Bruno
- ▶ 1992  $M_{\oplus}$  planet orbiting PSR B1257+12 pulsar
- ▶ 1995 Planet orbiting a main sequence star detected by ELODIE spectrograph
- ▶ 2008 30+ planets discovered by HARPS spectrograph
- ▶ 2014 Discovery of 715 planets around 305 stars by Kepler Space Telescope

# Methods of detection



## Transit photometry

As the planet moves in front of its star the star luminosity dips, and then returns to its former level



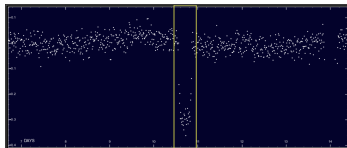
## Doppler spectroscopy

Star moves in a small circle when it is orbited by a planet. These movements causes a tiny periodic Doppler shift

## Others

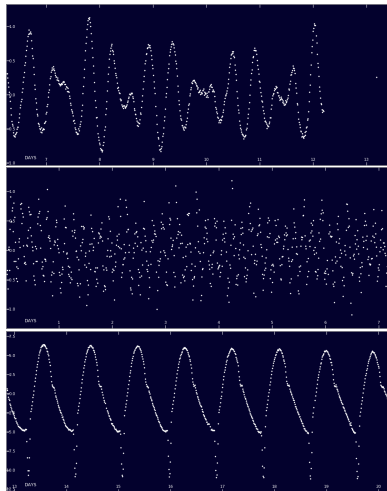
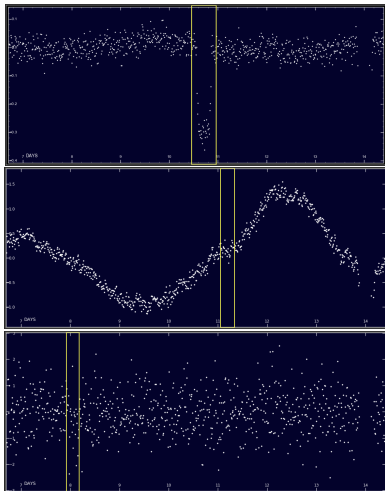
- ▶ Direct infrared imaging (young hot heavy planets)
- ▶ Gravitational microlensing
- ▶ Precision measurement of stars' location

# Transit photometry



- + Planet size estimates (not available with other methods)
- + Atmosphere composition (due to absorption spectrum)
- + Massively scalable ( $\sim 10^5$  stars at a time)
  - Planet must pass directly between its star and Earth
  - Transits are very short (last hours or days)
  - False positives due to eclipsing binaries, stellar variability

# Examples of transits



Exoplanets  
detection methods  
and results

Brief review of  
results

History of  
exoplanets  
exploration

Methods of  
detection

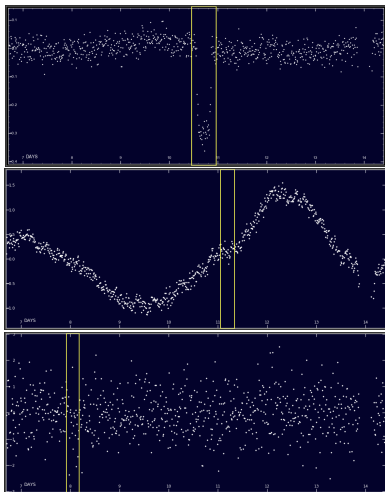
Transit photometry

Doppler  
spectroscopy

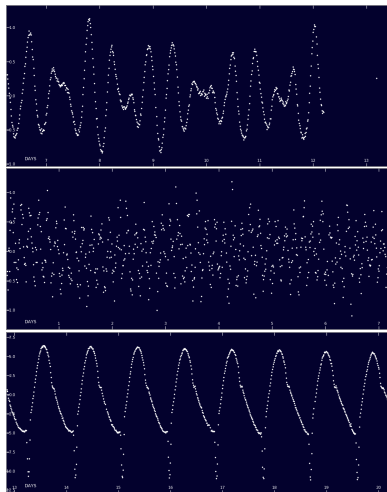
Summary

References

# Examples of transits



Genuine transits



Star spots, eclipsing binaries



# Transit photometry: instruments

Exoplanets  
detection methods  
and results

Brief review of  
results

History of  
exoplanets  
exploration

Methods of  
detection

Transit photometry

Doppler  
spectroscopy

Summary

References

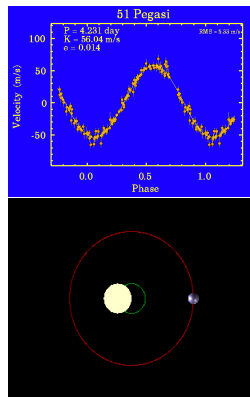
- ▶ Kepler Space Telescope, April 2009 – October 2018
  - ▶ 530000+ stars observed
  - ▶ 2600+ exoplanets detected
- ▶ Transiting Exoplanet Survey Satellite (TESS), April 2018 – now
  - ▶ Study 500000 stars across the whole sky, including 1000 closest red dwarfs
  - ▶ Discover  $\sim 20000$  exoplanets, including 500 – 100 Earth-sized ones
  - ▶ At least 5 exoplanets discovered as of April 15, 2019

# Doppler spectroscopy

Sun: orbital speed:  $V_{orb} \approx 200 \text{ km/s}$

Radial velocity of Sun due to Jupiter:  $\approx 12.7 \text{ m/s}$

- + 1st method that worked with main sequence stars
- + Good at detecting "hot Jupiter" planets
  - Earth like planets undetectable with current instruments
  - Only the lower bound of mass can be estimated
  - False positives due to intrinsic variability of stars
  - No Doppler shift if the orbital plane is "edge-on"



# Doppler spectroscopy: instruments

## ELODIE Spectrograph (1993 – 2006)

Discovered 1st exoplanet orbiting an ordinary star.

Resolution:  $\sim 10$  m/s

## HARPS Spectrograph (2003 – now)

Discovered 130+ exoplanets.

Resolution:  $\sim 1$  m/s

## ESPRESSO Spectrograph (under construction)

Capable of detecting Earth-like planets.

Resolution (planned):  $\sim 0.1$  m/s

Brief review of  
results

History of  
exoplanets  
exploration

Methods of  
detection

Transit photometry

Doppler  
spectroscopy

Summary

References

# Summary

Exoplanets  
detection methods  
and results

Brief review of  
results

History of  
exoplanets  
exploration

Methods of  
detection

Transit photometry

Doppler  
spectroscopy

Summary

References

- ▶ ~ 4000 confirmed exoplanets as of April 2019
- ▶ Planets outnumber stars
- ▶ Small planets are common (around 20 – 50% of stars)
- ▶ Several atmospheres of "hot Jupiters" have been detected
- ▶ 1st atmosphere of Earth-sized planet discovered in 2016 [2]

# Any aliens?

- ▶ 49 potentially habitable planets discovered
  - ▶ **Likely** to have a rocky composition
  - ▶ **Likely** to maintain surface liquid water
- ▶ Atmospheres' composition haven't been measured yet
- ▶ No estimates of the surface temperature
- ▶ No artificial structures have been detected

## What about Tabby's star?

Unusual dimming (up to 21%) is caused by dust [3]

