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

— Giordano Bruno, Despre infinit univers si lumi, 1584

Agenda

Brief review of results

History of exoplanets exploration

Methods of detection

Transit photometry

Doppler spectroscopy

Summary

References

Exoplanets: brief review of results

Exoplanet

Extrasolar planet is a planet located outside the Solar system

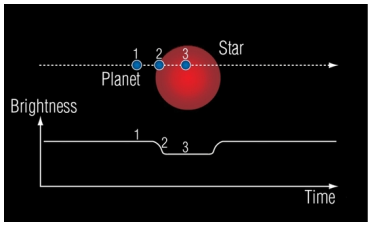
- $\approx$ 4050 confirmed planets as of April 2019 [1]
- $\approx$ 50 **potentially** habitable planets
- Known parameters: orbital period, distance to the star, mass
- Only a handful of direct observations

History of exoplanets exploration

- 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 verified planets around 305 stars by Kepler Space Telescope

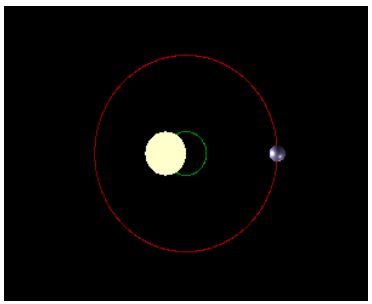
Methods of detection

Transit photometry



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

Doppler spectroscopy

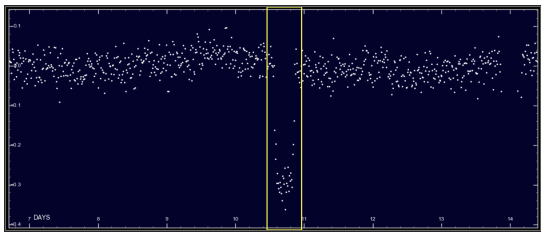


Star moves in a small circle when it is orbited by a planet. These movements causes a tiny periodic Doppler shift

Others

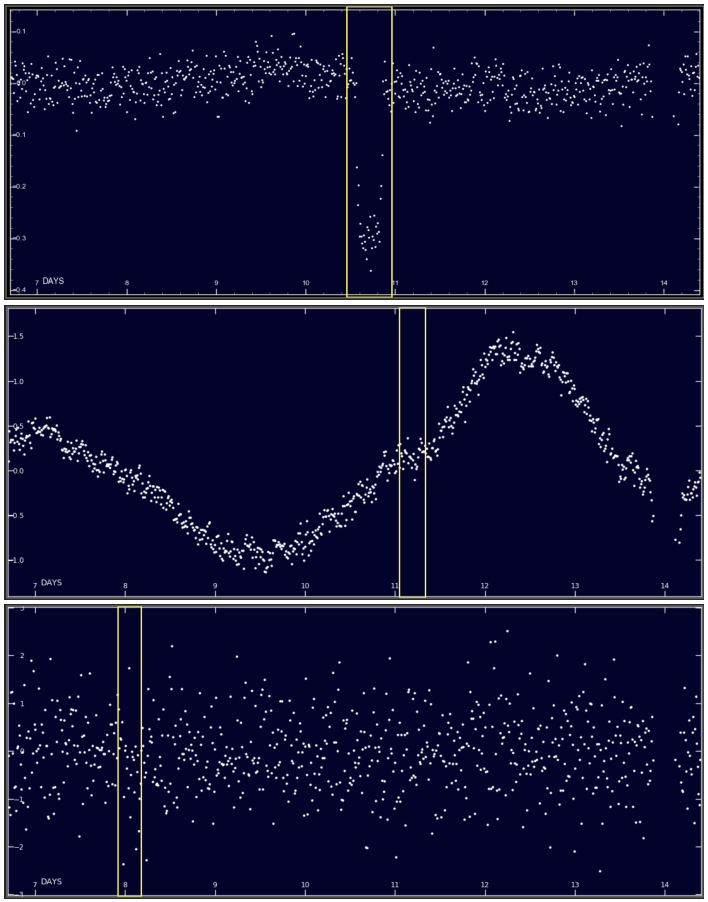
- Direct infrared imaging (young hot heavy planets)
- Gravitational microlensing
- Precision measurement of stars' location

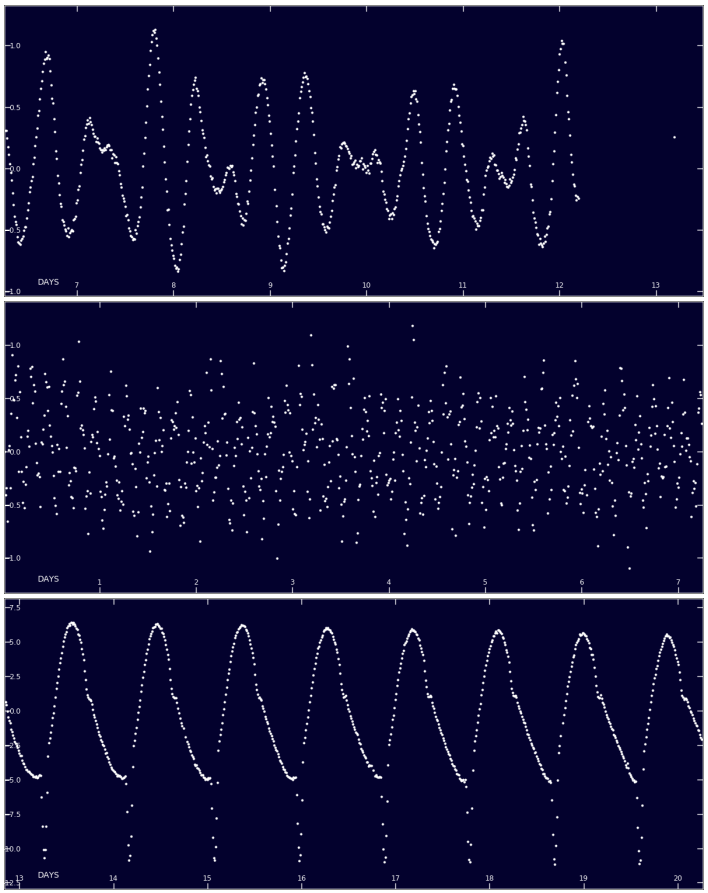
Transit photometry



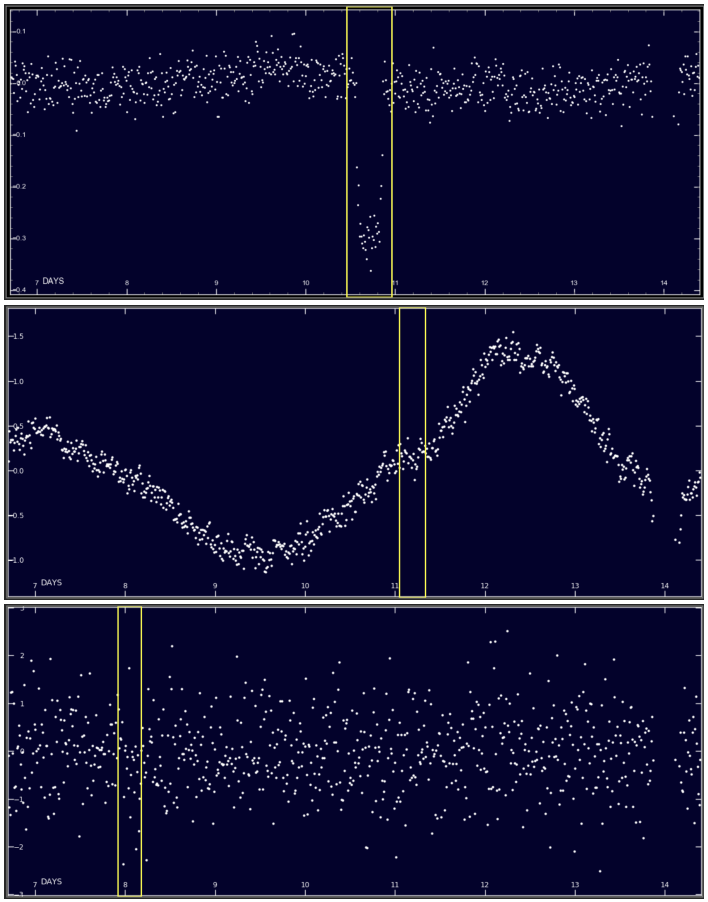
+ Planet size estimates (not available with other methods)
+ Atmosphere composition (due to absorption spectrum)
+ Massively scalable ($\sim 10^5$ stars at a time)
- Planet must pass directly between its star and Earth
- Transits are very short (last hours or days)
- False positives due to eclipsing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

Examples of transits

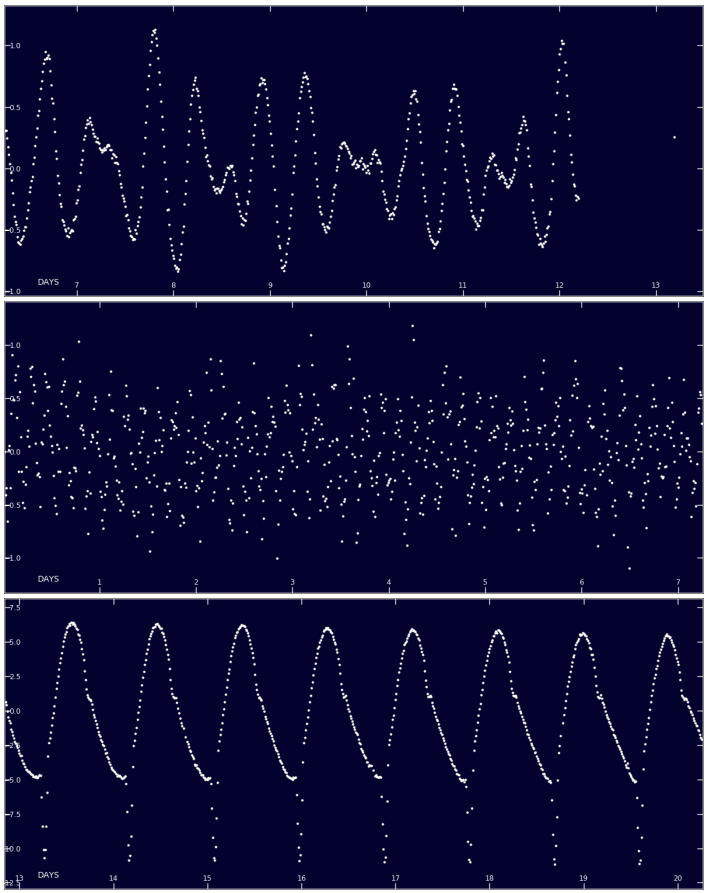




Examples of transits



Genuine transits

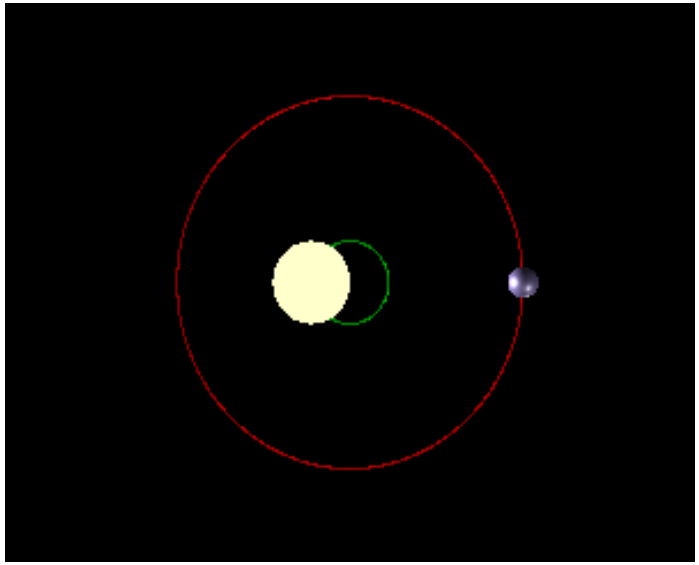


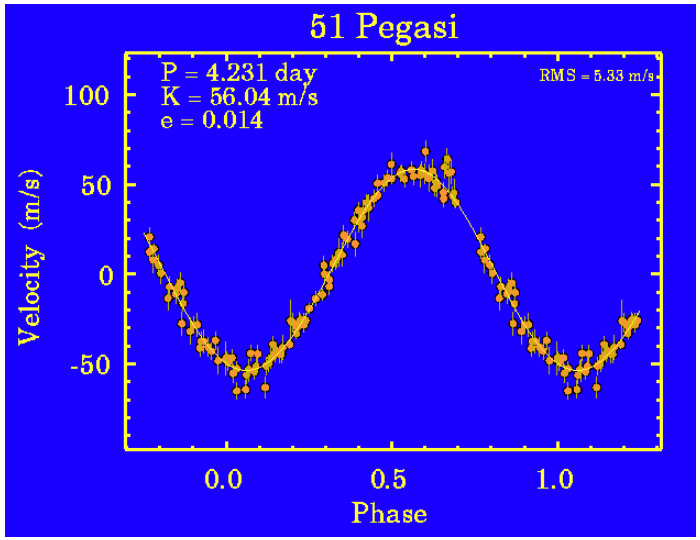
Star spots, eclipsing binaries

Transit photometry: instruments

- 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: $V_{orb} \approx 200\mathrm{km/s}$

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

+ 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: $\sim 10\,\mathrm{m/s}$

HARPS Spectrograph (2003 – now)

Discovered 130+ exoplanets.
Resolution: $\sim 1\,\mathrm{m/s}$

ESPRESSO Spectrograph (under construction)

Capable of detecting Earth-like planets.
Resolution (planned): $\sim 0.1\,\mathrm{m/s}$

Summary

- $\sim$ 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]

The Extrasolar Planets Encyclopaedia

exoplanet.eu

John Southworth, Luigi Mancini, Nikku Madhusudhan, Paul Molliere, Simona Ciceri, Thomas Henning

Detection of the atmosphere of the 1.6 Earth mass exoplanet GJ 1132b

arXiv:1612.02425

Jason T. Wright

A Reassessment of Families of Solutions to the Puzzle of Boyajian's Star

arXiv:1809.00693