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

Agenda

Exoplanet

Extrasolar planet is a planet located outside the Solar system

History of exoplanets exploration

Brief review of results

Methods of detection

Transit photometry

Doppler spectroscopy

Summary

About myself

- 1995 – 2001: studied at the department of physics and technology of Kharkov State University
- 2001 – 2008: worked at Bogoliubov laboratory of theoretical physics (part of Joint Institute for Nuclear Research)
- Research topics:
  - Phenomenology of supersymmetric extensions of the Standard Model (of elementary particles)
  - Calculation of Feynman integrals with several mass scales
  - Nature of Dark Matter

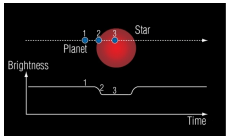
History of exoplanets exploration

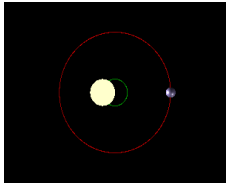
- 1584 "Innumerable suns and earths" hypothesis by Giordano Bruno
- 1992 $M_{\oplus}$ planet orbiting PSR B1257+12 pulsar
- 1995 Planet orbiting a main sequence star detected by ELODIE spectrograph
- 2008 30+ planets discovered by HARPS spectrograph
- 2014 Discovery of 715 planets around 305 stars by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

Exoplanets: brief review of results

- $\approx$ 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

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

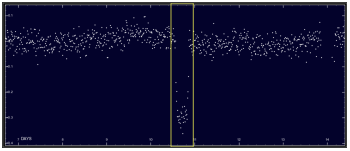
Doppler spectroscopy

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

Others

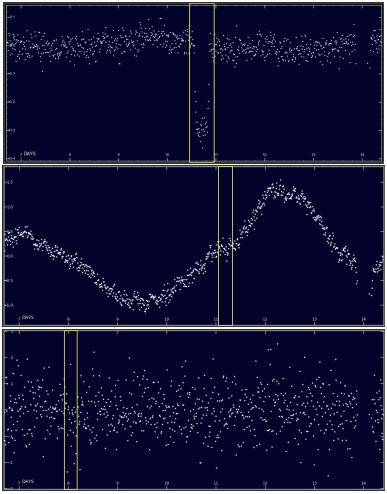
- Direct infrared imaging (young hot heavy planets)
- Gravitational microlensing
- Precise measurement of stars' location

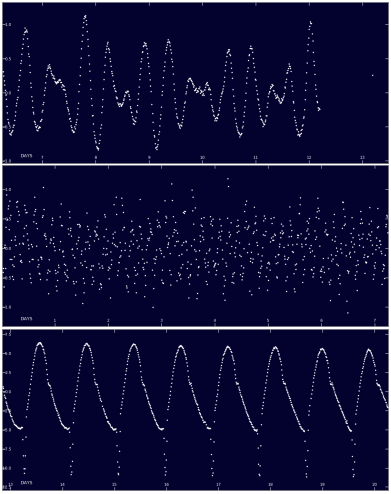
Transit photometry



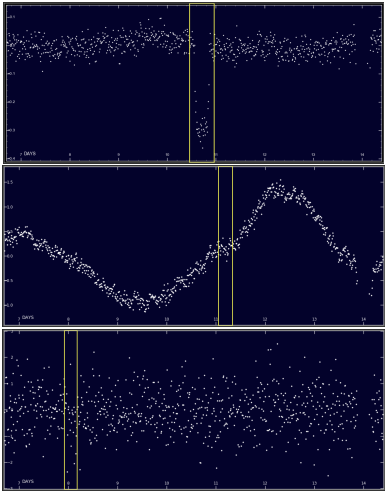
+ Planet size estimates (not available with other methods)
+ Atmosphere composition (due to absorption spectrum)
+ Massively scalable ($\sim 10^5$ stars at a time)
- Planet must pass directly between its star and Earth
- Transits are very short (last hours or days)
- False positives due to eclipsing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

Examples of transits

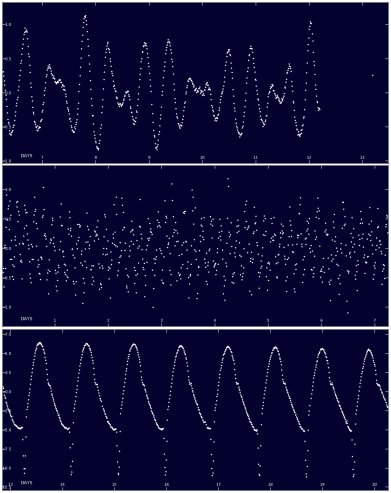




Examples of transits



Genuine transits

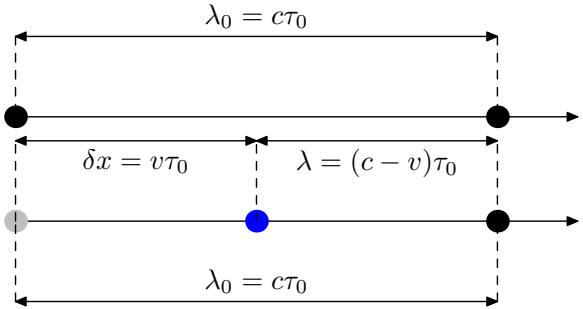


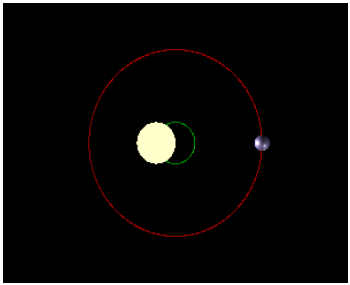
Star spots, eclipsing binaries

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

Classical Doppler effect



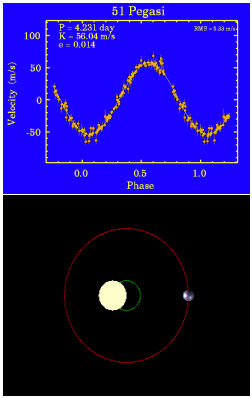


$$\lambda = \left(1 - \frac{v}{c}\right) \lambda_0$$

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]

References I

The Extrasolar Planets Encyclopaedia

exoplanet.eu

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

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

arXiv:1809.00693