The first extrasolar planet discovered is around a neutron due to irregularities in pulsar timing.

Radial Velocity

* Discovered the first planet around a main sequence star in 1995
* Requires high resolution spectrograph
  + Measures blue and redshift emission changes in the star due to perturbations of a planet
  + Inclination is unknown, so planetary mass can only be narrowed to lower possible mass

Transits

* First transit discovered in 1999
* Planets pass in front of the star, causing a periodic dimming that can be observable
* Can reveal rough atmospheric composition of planet due to molecular absorption
* Requires high photometric precision that usually cannot be found in ground telescopes

Microlensing

* First used approximately around the same time as first transit
* Strong Lensing:
  + Extremely large objects (galaxies/clusters) can bend light behind them to induce multiple images to the observer
* Microlensing involves a smaller object (planet in front of a star) where images are barely separated but can be detected through an increase in brightness
  + Microlensing events don’t last long: need long term and high frequency measurements
  + Only ever occur once

Direct Imaging

* First used in 2008
* Requires ground-based observations and high-contrast technology (limited to bright stars due to atmospheric turbulence)
* Allows for determining atmospheric makeup of planets
* Requires a planet to be very far away from the host star

Exoplanet Properties

* Two distinct populations:
  + Super-Earths (1.3 Earth radii)
  + sub-Neptunes (2.4 Earth radii)
* Transitions:
  + Terrestrial to Neptunian (2 Earth masses)
  + Neptunian to Jovian (0.41 Jupiter masses)
* In Situ Planet Formation
  + Core Accretion: smaller particles collide and form “embryos” that then accumulate surrounding gases – mostly explains large planets near stars
    - Core accretion is more efficient with high metallicity: most exoplanets are formed via this
  + Disk instability: turbulence due to cooling of causes irregular gas clumps that gas giants
* Exoplanet Migration
  + Planetary Scattering: Two exoplanets form and one is ejected to a wide orbit and the other comes close to the star
  + Cloud Fragmentation: low mass body forms in the molecular cloud similar to that of a binary/multiple star formation
  + Differentiation:
    - Eccentricities (planetary scattering will have very high eccentricity
    - Orbits will be coplanar during planetary scattering and not in cloud fragmentation
    - Cloud fragmentation results in exoplanets that form much more quickly that that of planetary convergence
* Free floating exoplanets are mainly observed through microlensing due to the lack of light
* Formation of exoplanets are mainly observed through direct imaging of protoplanetary disks but require high telescopic precision