Exoplanets search

Note some methods can be used for binary stars search as well.
But for planets it is hard to do visual since planets are dim (we see reflected light) and they are near superbright light source (star) which out shine them.

Doppler effect \((1842)\)

\[ f_{obs} = f_{source} \left(1 \pm \frac{v}{c}\right) \]

For the \(+\) \(f_{obs} > f_{source}\) \(\Rightarrow\) blue shift

So if we have an orbit like

\[ \text{we can detect the motion by observing Doppler effect} \]
So what kind of speeds we are talking:

recall \[ v_a^2 = \frac{GM_1}{a} \frac{1}{1+e} \] apoapsis

\[ v_p^2 = \frac{GM_1}{a} \frac{1+e}{1-e} \] periapsis

speed of vector connecting 2 bodies,

\[ \vec{v}_1 = \vec{v} \frac{M}{m_1} \]
\[ \vec{v}_1 - \vec{v}_2 = \vec{v}_0 \]
\[ \vec{v}_2 = -\vec{v} \frac{M}{m_2} \]

\[ m_1 = m_{\text{planet}} \ll m_2 = m_{\text{star}} \]

\[ \Rightarrow M \approx m_1 \]

\[ \Rightarrow \vec{v}_1 \approx \vec{v} \]

\[ v_2 = v_{\text{star}} = \frac{m_{\text{planet}}}{m_{\text{star}}} \vec{v} \]

\[ v_{\text{P star}} = \frac{m_{\text{planet}}}{m_{\text{star}}} \frac{GM_{\text{total}}}{a} \frac{\sqrt{1+e}}{1-e} \]

\[ = \frac{m_p}{m_s} \frac{\sqrt{GM_1}}{a} \frac{\sqrt{1+e}}{\sqrt{1-e}} = \frac{1}{M_1 \approx M_s} \]

\[ = m_p \sqrt{\frac{GM}{a m_s}} \sqrt{\frac{1+e}{1-e}} \]
\[ m_p = \sqrt[3]{\frac{a \text{ m}^3 s^{-2}}{G}} \sqrt{\frac{1-e}{1+e}} \]

\[ \log (M_p) \]

\[ \log (a) \]

\[ \text{for current sensitivity} \quad v \approx 60 \text{ cm/s} \]

the smallest mass we can detect at 1 au around sun like star at e=0

\[ M_p = 0.6 \sqrt{\frac{1 \text{ au} \cdot 2 \times 10^{30} \text{ kg}}{6.67 \times 10^{-11}}} \]

\[ = 0.6 \sqrt{\frac{1.5 \times 10^{11} \cdot 2 \times 10^{30}}{6.67 \times 10^{-11}}} \]

\[ \approx 0.6 \sqrt{\frac{3 \times 10^{52}}{6.67}} = 4 \times 10^{25} \text{ kg} \]

Note

\[ \text{Jupiter} \approx 318 \text{ ME} \]

So to detect Earth like planet we need to move speed sensitivity to \[ 0.6 \text{ m/s} \approx 9 \text{ cm/s} \]
Problems with radial method.

\[ V_{\text{obs}} = V_{\text{star}} \cdot \sin(i) \]

so we always see this combo

So we always know mass times unknown factor \( \sin(i) \).

\( e' \) is also unknown.

But if we can track \( V_{\text{obs}}(t) \)
we can learn something.

**Ex 1** Circular orbit

\[ \theta = \omega t \]

\[ V_{\text{obs}} = \sqrt{r} \sin(\theta) = r \cdot \sin(\omega t) \]

**Ex 2**

fast  \( V_{\text{obs}} \)

slow
Ex 3

[Diagram with labels: Fast, slow, Vobs, Fast, slow]
Other method: transits

So we should see periodic change in flux.

Let's estimate Earth transit across Sun disk.

\[ R_\oplus = 4.0 \times 10^8 \text{ m} \quad A_\oplus = \pi R_\oplus^2 \]
\[ R_\odot = 6.4 \times 10^6 \text{ m} \quad A_\odot = \pi R_\odot^2 \]

\[ \frac{\Delta F}{F} = \frac{\pi R_\oplus^2}{\pi R_\odot^2} = \frac{(6.4 \times 10^6)^2}{(4.0 \times 10^8)^2} = 8 \times 10^{-5} \]

No way to do it on Earth due to atmospheric disturbances.

The method also favors giant planets search.
Direct observation with telescopes.

About 50 star systems by 2015
There is Also gravitational lensing

Far star flux

Masses behave like lenses

Overall by February 2015, about 1889 planets are known.