Paper(s) Due Tue, Mar 2

Marois et al. 2008. Science 322, 1348.

"Direct Imaging of Multiple Planets Orbiting the Star HR 8799"

Janson et al. 2010 ApJ Letters 710, L35.

"Spatially Resolved Spectroscopy of the Exoplanet HR8799 c"

Detection Methods Covered So Far

(1) Direct methods

(2) Astrometry → position

(3) Radial velocity → velocity

(4) Transits → brightness

(5) Gravitational microlensing → shape and amplitude of lightcurve

Effects of a planet on the parent star

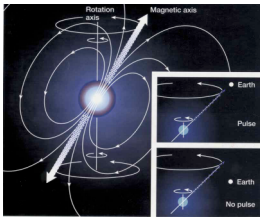
Today:

(6) Pulsar → timing

Pulsar Planets

What is a pulsar?

Rapidly rotating neutron star (born in a supernova explosion), with an extreme gravitational field and a large magnetic field, emitting beamed cyclotron emission.



If Earth is in the beam, we see a pulse during the rotation phase when the beam is pointing at us *(imagine a lighthouse).*

The detected emission :

- is periodic with period of milli-seconds to seconds
- occurs in the radio bands
- has an extremely stable period that does not change or slow down and can be precisely measured

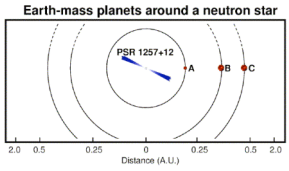
Pulsar Planets

Pulsars have extremely precise spin periods that can be measured against atomic clocks on Earth.

An orbiting planet causes the neutron star to move around its centre of mass.

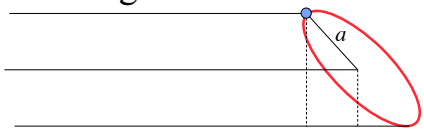
Delay of the pulses from expected arrival time as pulsar orbits the centre of mass, depends on the mass and orbital separation of the planet.

4 planet-mass objects have been detected around 2 different pulsars. PSR 1257+12 is a multiple planet system with 0.02, 4.3 and 3.9 M_E objects on circular orbits with periods of 25, 66, and 98 days.



Extreme radiation from the neutron star makes life (as we know it) very unlikely on these planets. ("Dragon's Egg", by Robert Forward, speculates on possible life forms on neutron stars).

Timing the Star Wobble



$$\Delta t = \frac{a_*}{c}\sin i \cos(2\pi\phi) \qquad \phi \equiv \left(\frac{t - t_0}{P}\right)$$

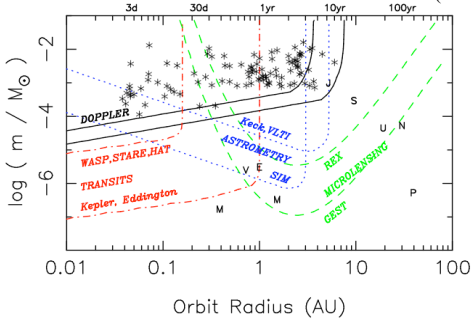
$$a_* = \frac{m_p}{M_* + m_p} a \qquad a^3 = GM_*\left(\frac{P}{2\pi}\right)^2 \qquad M_* \approx 1.4 M_{sun}$$

Pulses arrive earlier/later, due to light travel time, as the star (pulsar) moves around the centre of mass (wobble induced by planet).

Measure P and Δt , hence $m_p \sin(i)$.

Detection limits for different methods

(June 2003)



Data from: The Extrasolar Planet Encyclopaedia http://exoplanet.eu/

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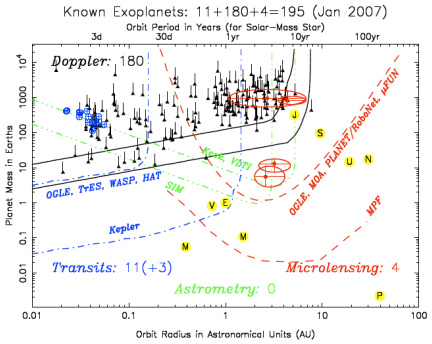

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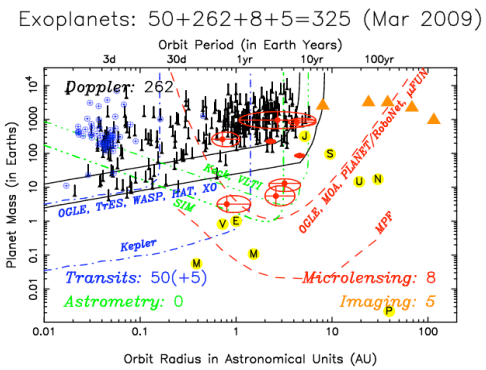

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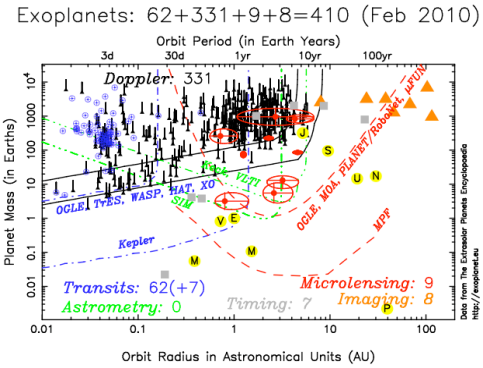

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