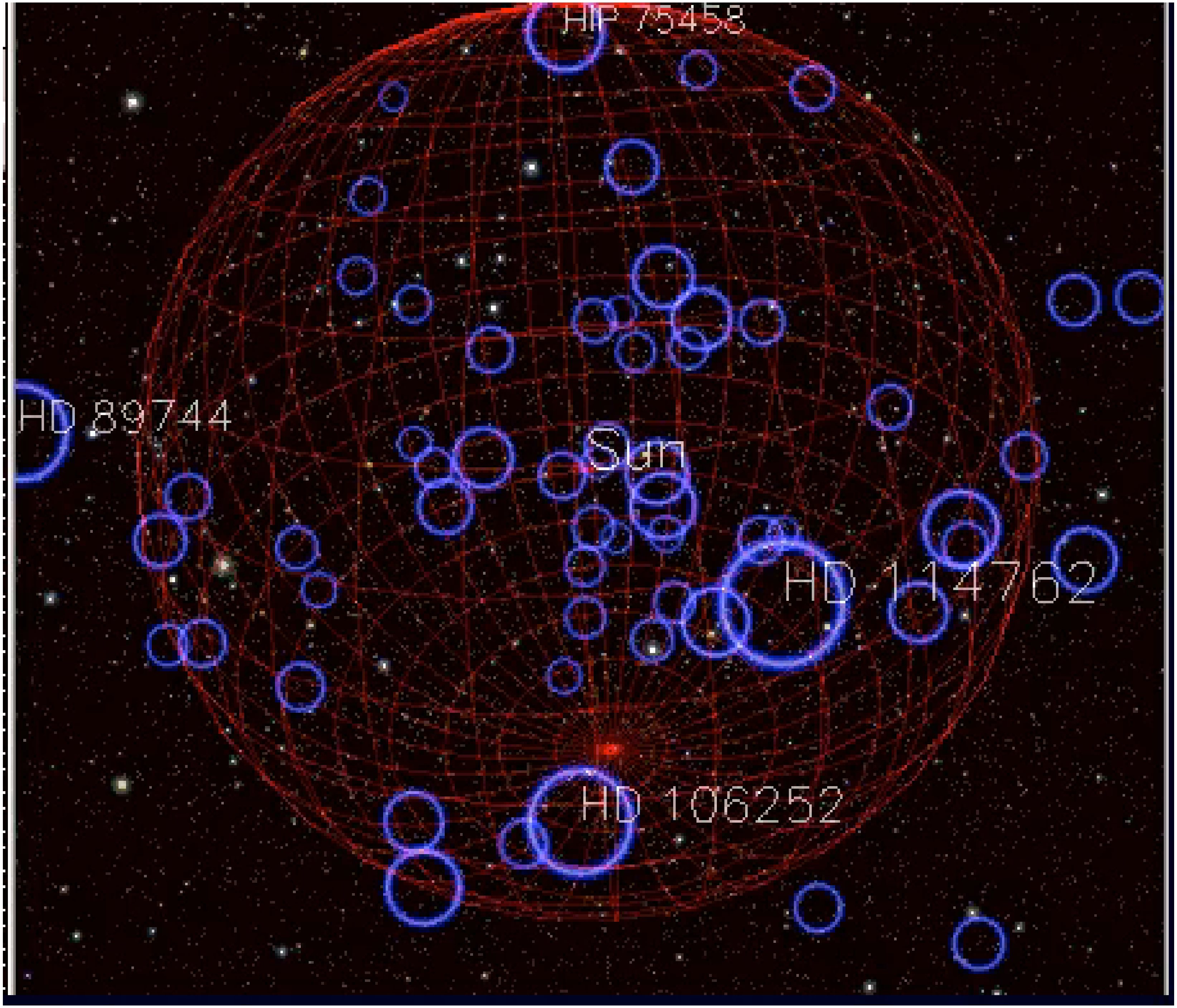
Extrasolar Planets

- Methods of detection
- Characterization
- Theoretical ideas
- Future prospects


HIP 75458
HD 89744
Sun
HD 114762
HD 106252

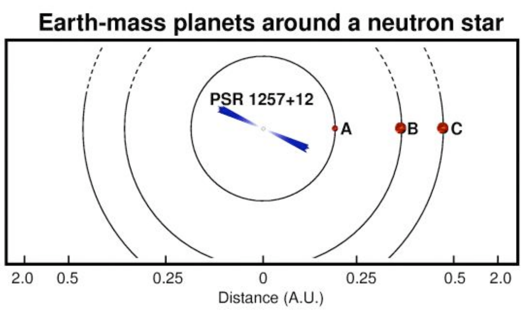
Methods of detection

Methods of detection

Pulsar timing

Planetary motion around pulsar causes periodic pulsar displacement around the center of mass by $\sim a\left(M_p / M_{NS}\right) \sim 10^{-3}$ light-seconds for Earth-like planet ($M_p \sim 10^{28}$ g) at $a = 1$ AU from the neutron star ($M_{NS} \sim 1.4\ M_{Sun}$) – well within current detection capabilities.

m sin i degeneracy **(broken in PSR 1257+12 by planetary interaction)**



First discovered extrasolar system:

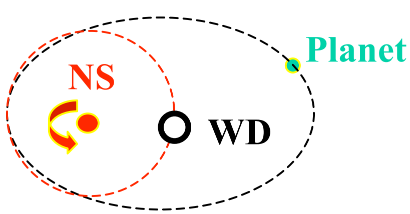
PSR 1257+12 (Wolszczan and Frail 1992)

	A	B	C
Mass, M_Earth	0.015	3.4	2.8
Eccentricity	0.0	0.018	0.026
Period, days	25.3	66.5	98.2
Sem. axis, AU	0.19	0.36	0.47

Similar to Solar System

Second suggested system:

PSR 1620-26 (Backer *et al.* 1993)



Recently confirmed to have a giant planet in a wide eccentric orbit.

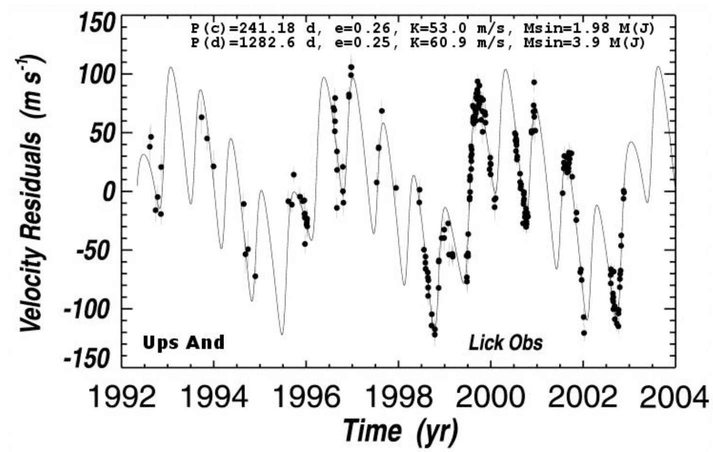
Similar to nearby EGP systems.

__Methods of detection__

Radial Velocity Variations

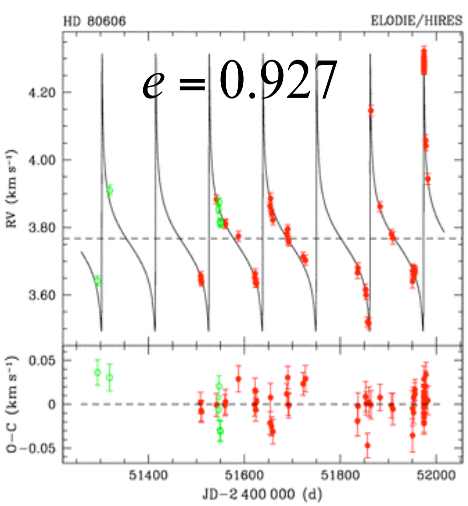
Planetary motion moves star around with velocity $\upsilon_{orb}(M_p / M_*)$ **.**
Jupiter-mass planet at 1 AU causes stellar motion with velocity 30 m/s.

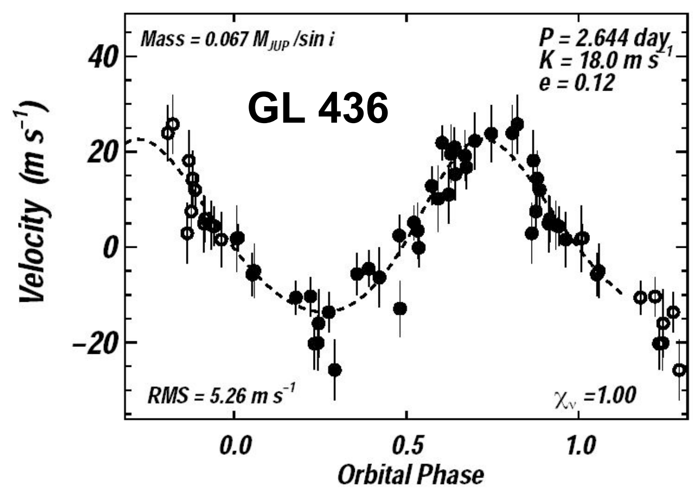
Searching for periodic Doppler shifts can detect planet (like companion in spectroscopic binary).



Butler et al 2004

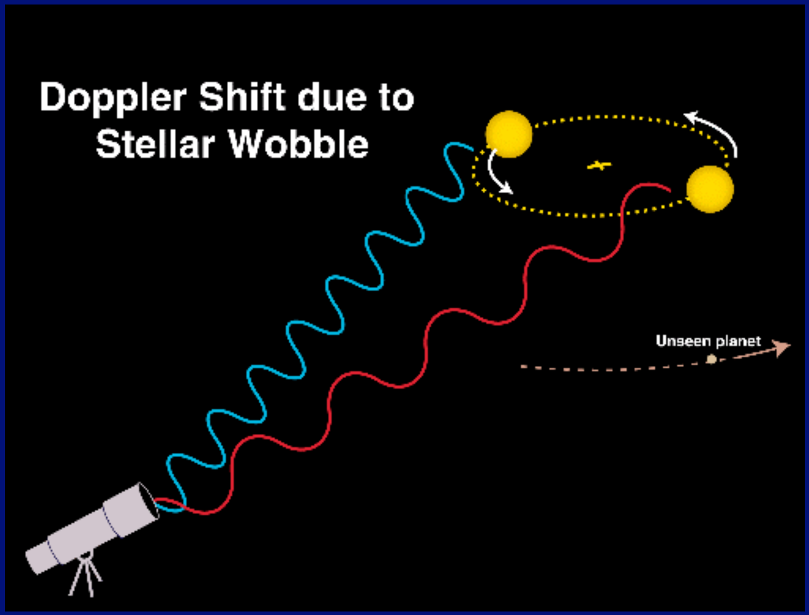
- **Method suffers from m sin i degeneracy**
- **Velocity noise can be pushed down to 1-2 m/s**
- **Up to now the most successful technique – more than 400 planets detected**
- **First detection - 51 Peg** **(Mayor & Queloz 1995)**





Radial velocity

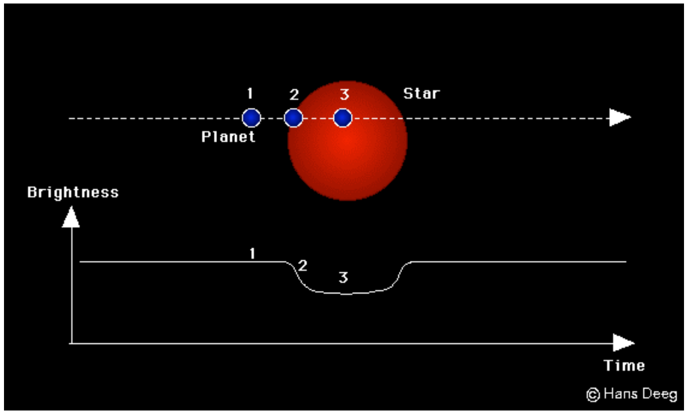
- Stars orbit COM
- Starlight is Doppler shifted
- Shift is tiny: use spectral lines
- Big planets close to the star give biggest RVs
- You measure v sin*i* & P giving M_p sin*i* & a
- Has discovered more than ~400 planets, current precision: ~1 m/s.



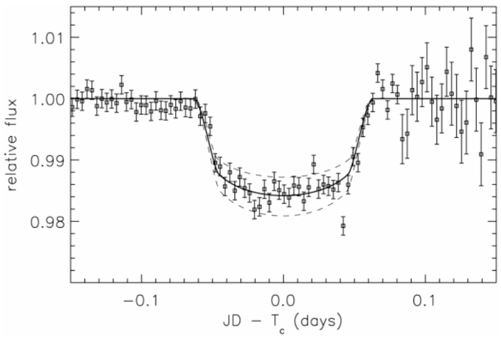
Planetary Transits

Jupiter-size planet passing in front of the star causes stellar flux drop (eclipse) by $\sim (R_p / R_*)^2 \sim 10^{-2}$ for ~ hours.

Transit probability $\sim R_* / a \sim 10^{-2}$ for $a = 1$ AU

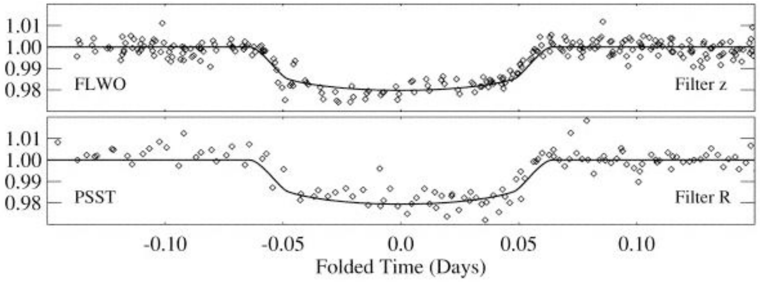


- **Combined with RV data gives mass (sin i =1)**
- **The only method which gives planetary size**
- **Expect signal also in reflected light**



First transit detection in previously known planetary system HD 209458

- **More than 20 transit searches are underway**
- **> 110 planets detected (before Kepler!)**



- **Allow us to measure planetary density**

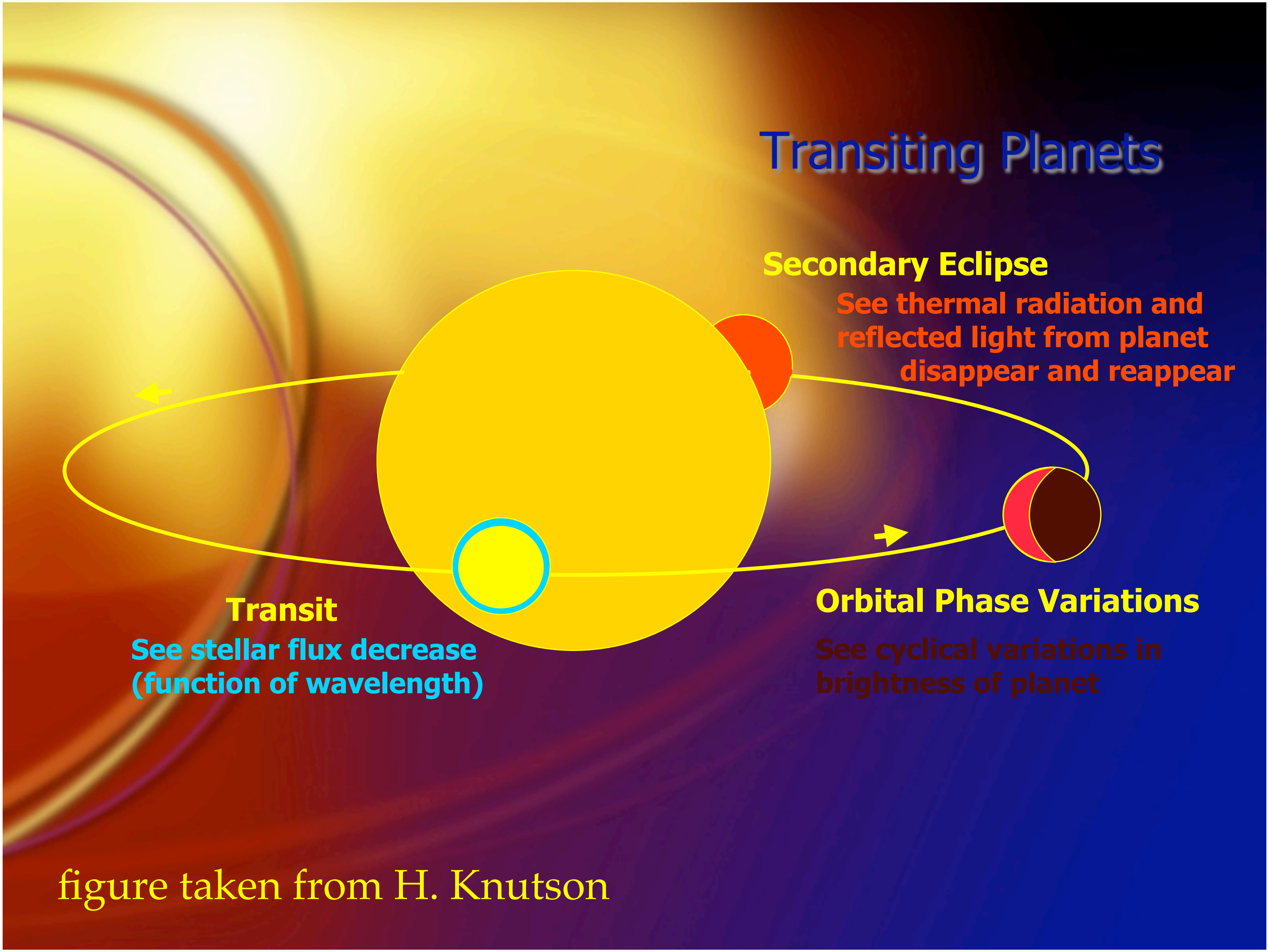
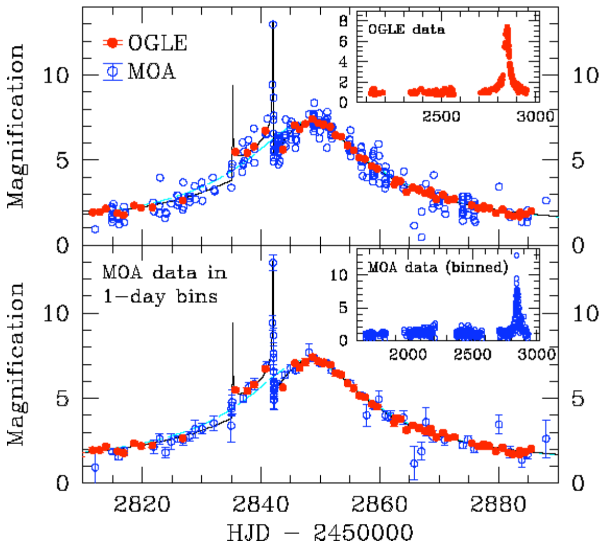


figure taken from H. Knutson

__Methods of detection__

Microlensing



Gravitational lensing by binary systems leads to easily recognizable pattern of magnification.

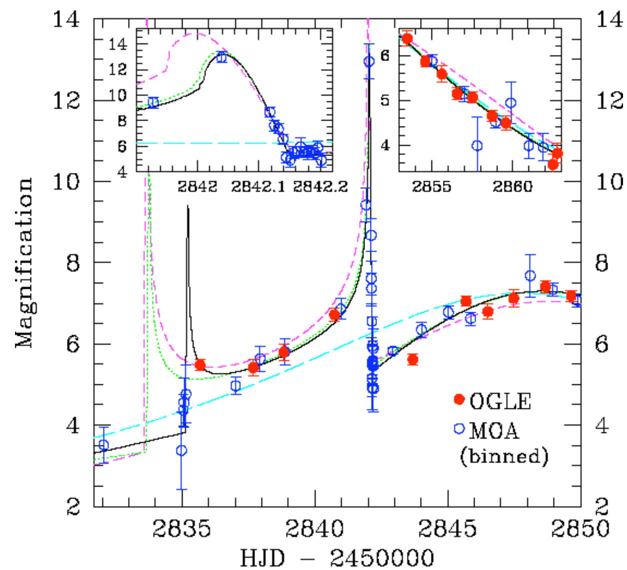
Light curve fitting yields system parameters and may be used for planet searches.

- **Cannot repeat observation**
- **Usually distance is unknown**
- **Stellar brightness unimportant**

OGLE 2003-BLG-235/MOA 2003-BLG-53

(first planet detection by microlensing)

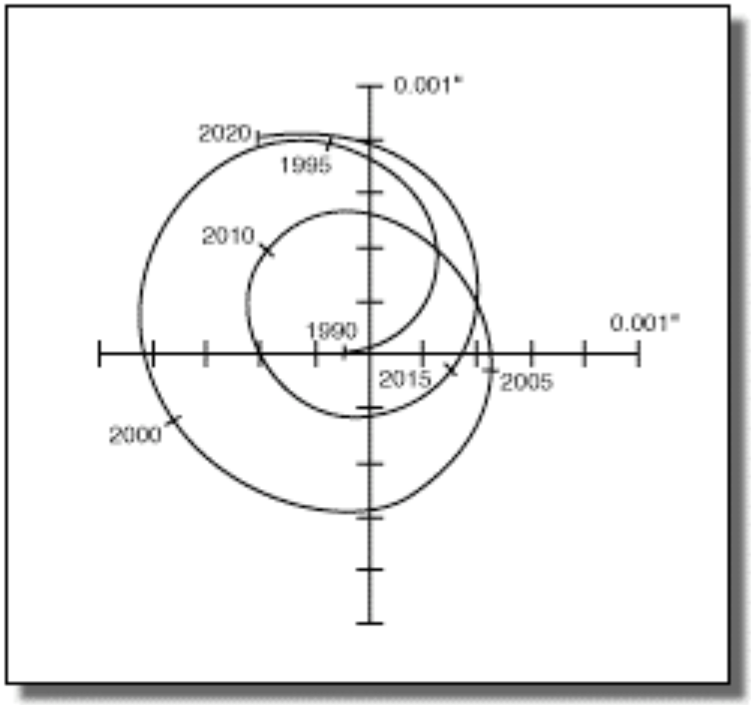
Planetary mass	$M_p \approx 2\ M_J$
Stellar mass	$M_* \approx 0.36\ M_{Sun}$
Semimajor axis	$a \approx 3\ AU$
Distance to the system	$D \approx 5\ kpc$



Astrometry

Jupiter-mass planet at 1 AU moves its star around by $\sim a(M_p / M_*) \sim 10^{-3} a$ **which for** $a = 1$ **AU at 10 pc results in 100 μas displacement on the sky.**

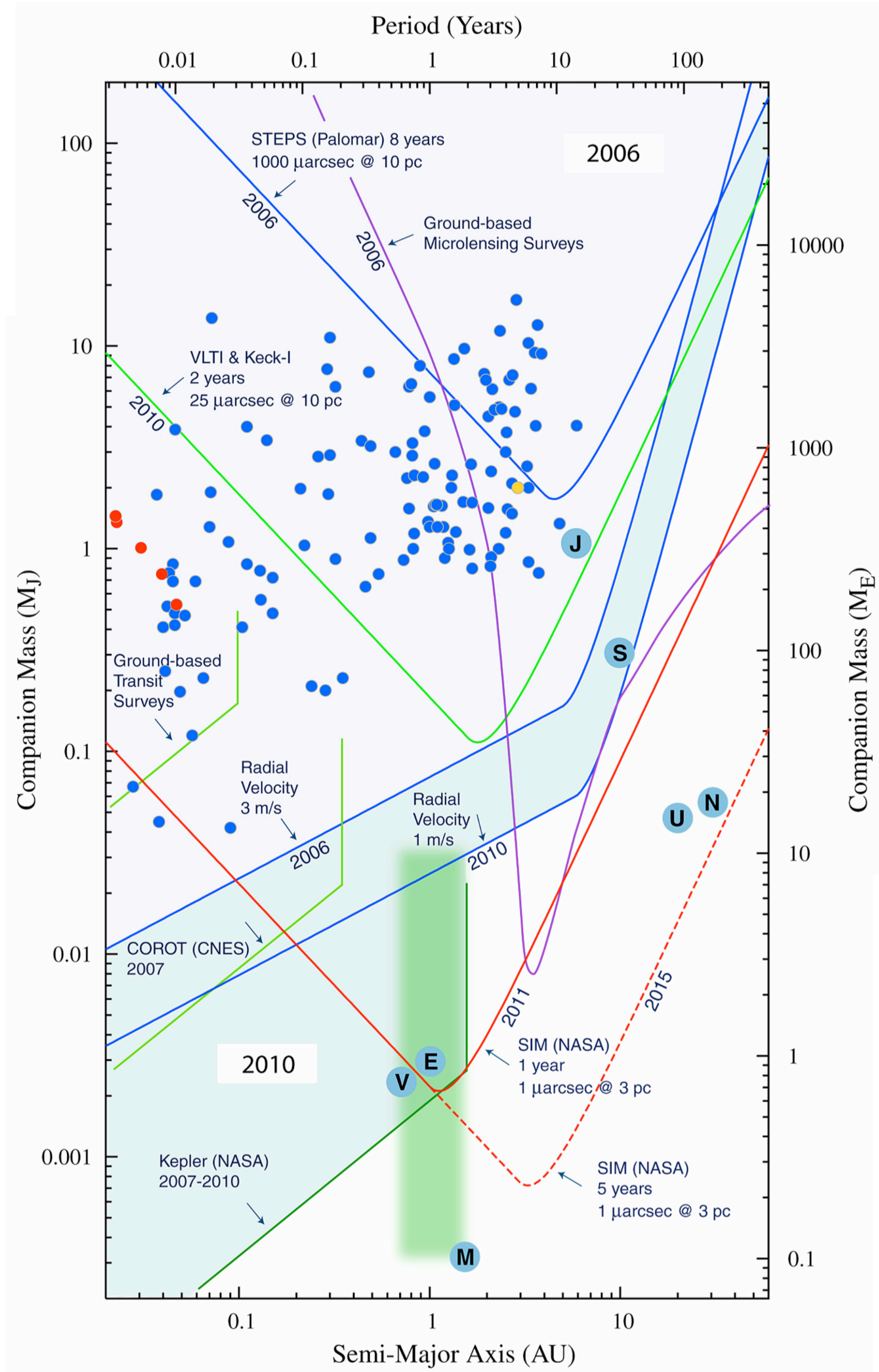
- **Sensitive to massive and distant planets – requires long time baseline**
- **In combination with RV data breaks m sin i degeneracy and determines mass and orbit orientation (similar to observations of stars near the Sgr A*)**
- **Requires exquisite astrometric accuracy.**



Astrometric displacement of the Sun due to Jupiter as seen from 10 parsecs.

Earth-mass Planets?

Radial-velocity and Astrometric techniques

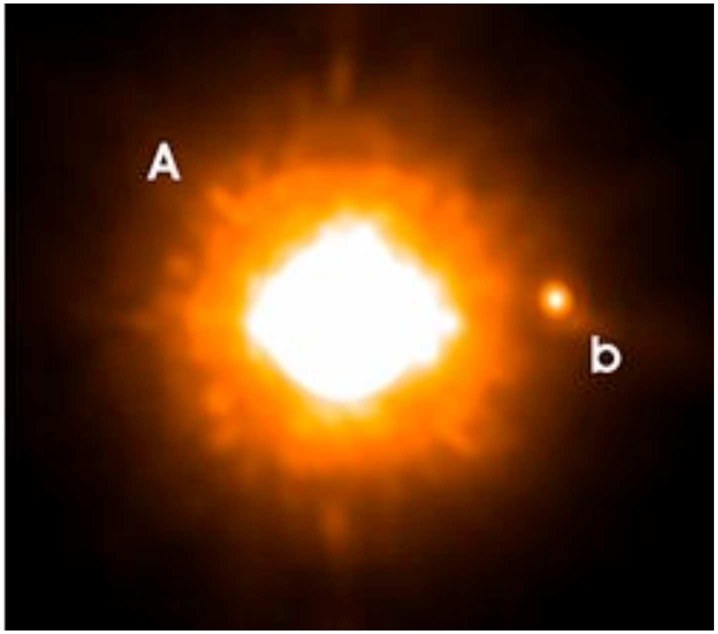


Direct detection

Planets (especially young ones) are rather bright in the infrared. If well-separated from the main star, they can be imaged directly.

Will have common proper motion with the parent star.

GQ Lupi (Neuhauser et al 2005)



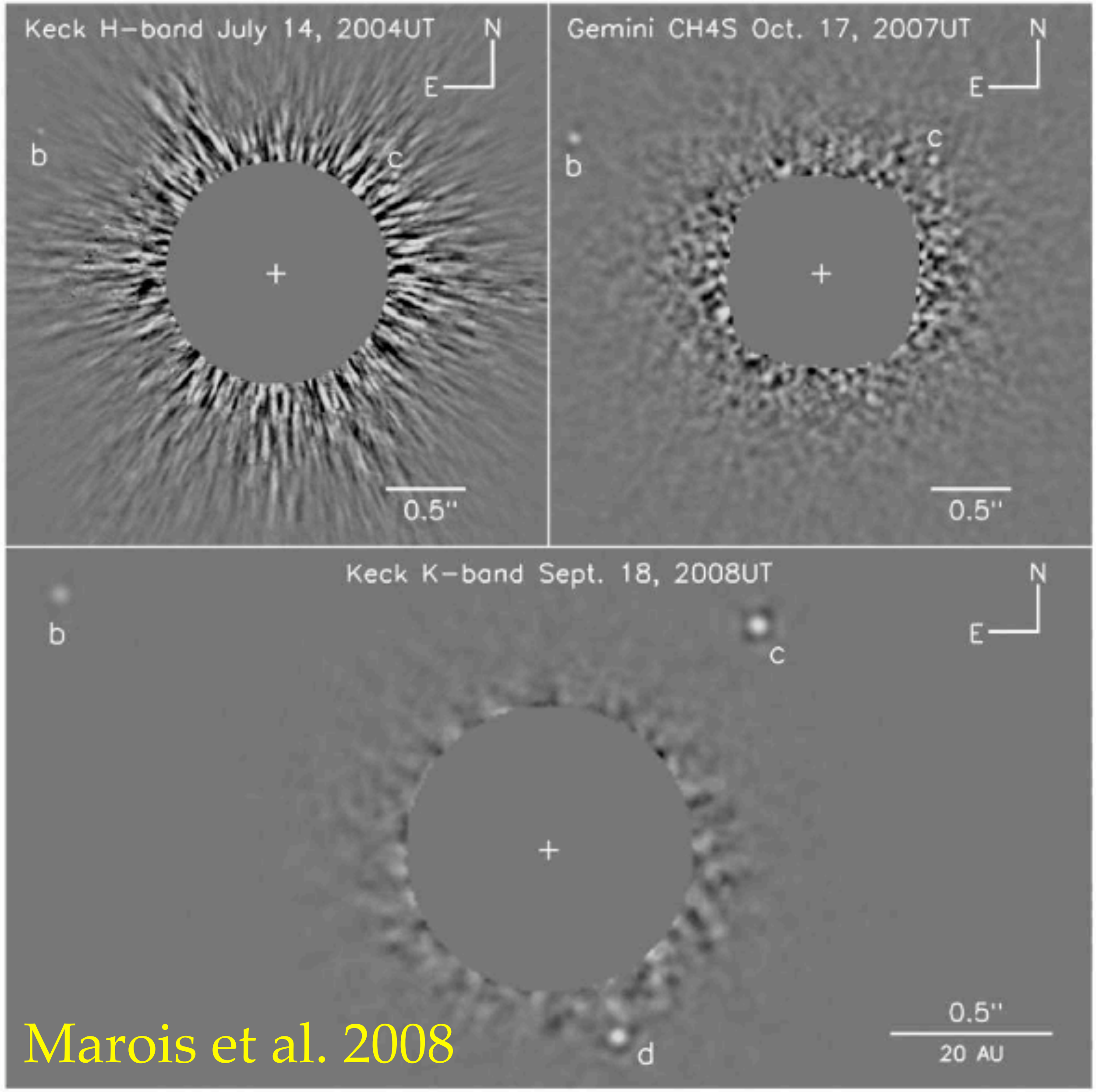
- **Parent star:** **0.7 M_sun, 2 million years old, 140 pc away**
- **Planet:** **has common proper motion, 100 AU away from the star**
- **Properties:** **effective temperature 2000 K, radius of about 1.2 R_Jup**
- **Mass:** **at this age and luminosity can have mass 1 - 42 M_Jup, depending on the model**

Can be a high-mass planet or a brown-dwarf

HR 8799bcd

$M_b \sim 7\ M_J$
$M_c \sim 10\ M_J$
$M_d \sim 10\ M_J$

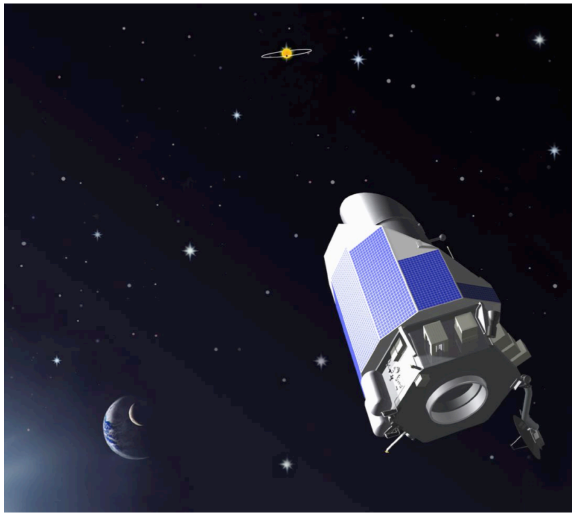
D = 24, 38, 68 AU



Marois et al. 2008

Future Prospects

Kepler



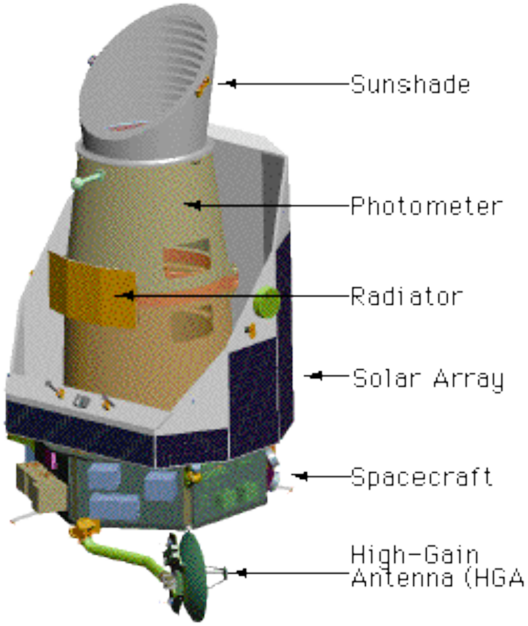
Space-based Photometer (0.95-m aperture)

Photometric One-Sigma Noise <2x10-5

Monitor 150,000 main-sequence stars for planets.

Mission lifetime of ~4 years.

Launched in 2009



Transits of terrestrial planets:

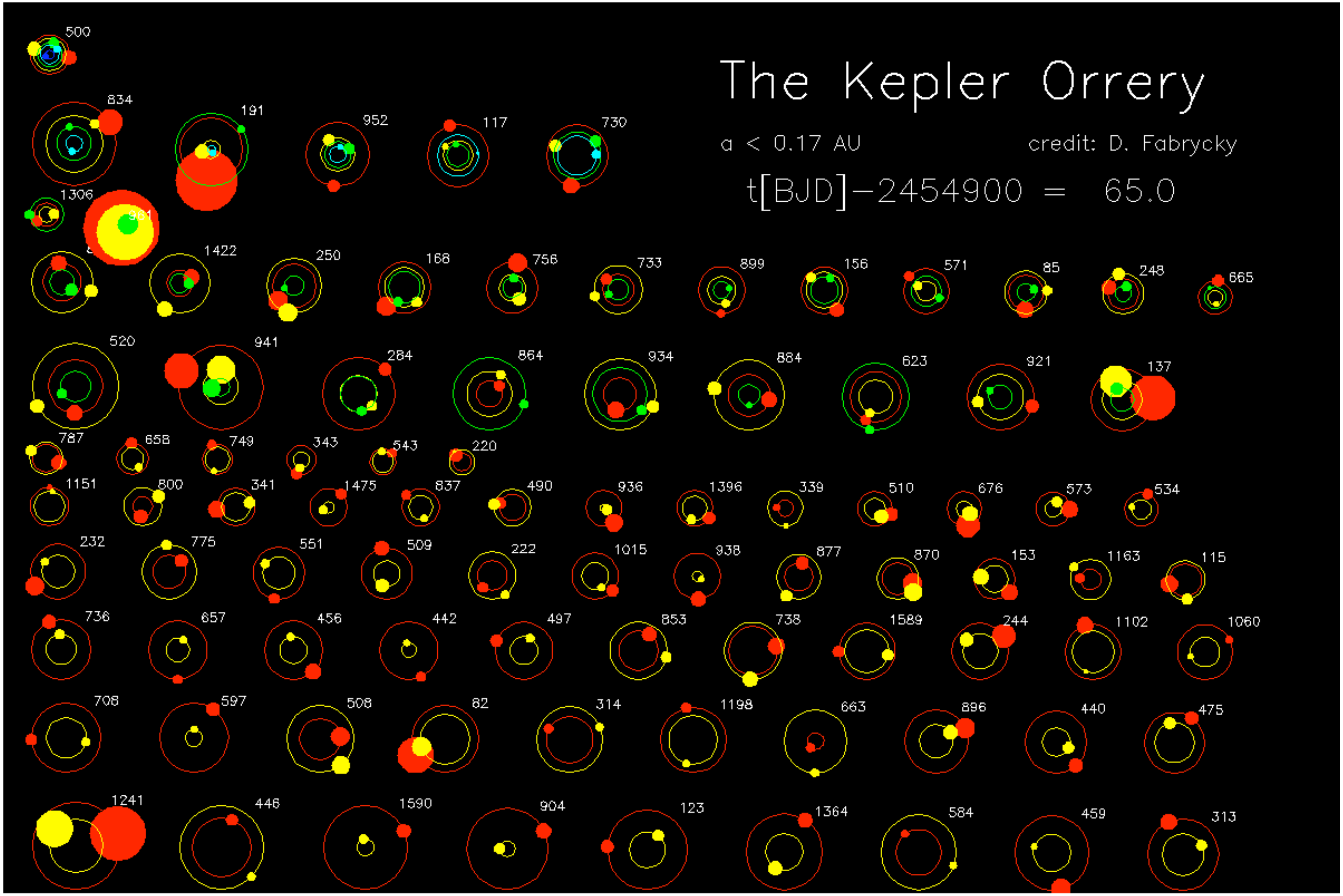
- About 50 planets if most have R~1.0 Re,

Modulation of the reflected light from giant inner planets:

- About 870 planets with periods less than one week.

Transits of giant planets:

- About 135 inner-orbit planet detections along with albedos for about 100 of them.


The Kepler Orrery
a < 0.17 AU
credit: D. Fabrycky
t[BJD]−2454900 = 65.0
500
834
191
952
117
730
1306
1422
250
168
756
733
899
156
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508
82
314
1198
663
896
440
475
1241
446
1590
904
123
1364
584
459
313

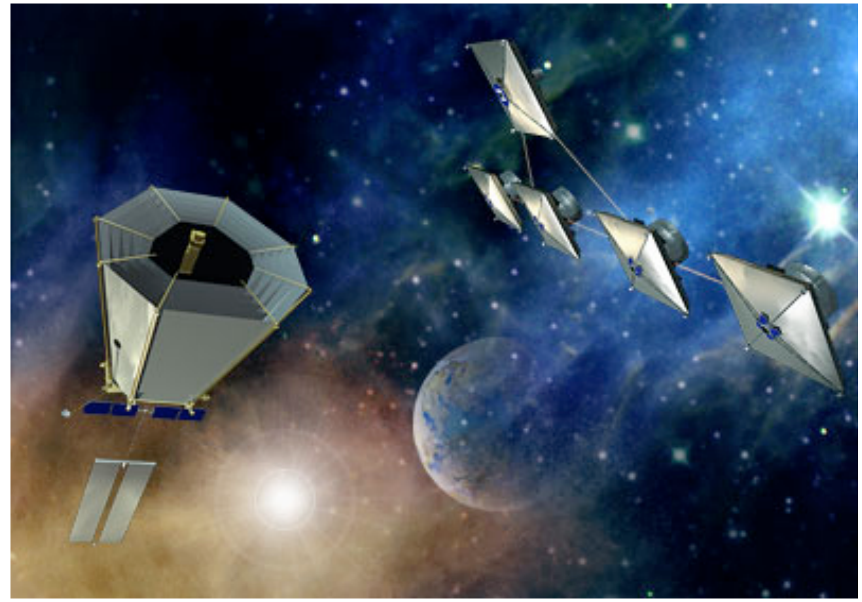
Future prospects

TPF

(Terrestrial Planet Finder)

Two complementary space observatories: a visible-light coronagraph and a mid-infrared formation-flying interferometer.

TPF coronagraph
TPF interferometer



Goals:

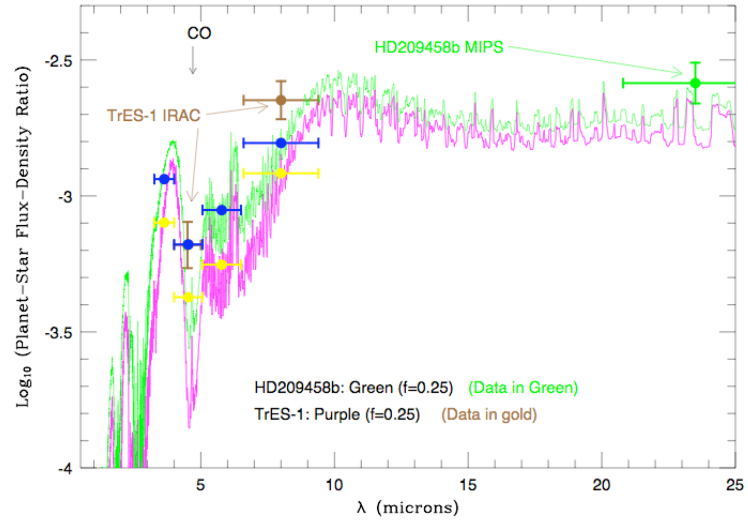
- Survey nearby stars looking for terrestrial-size planets in the "habitable zone“.

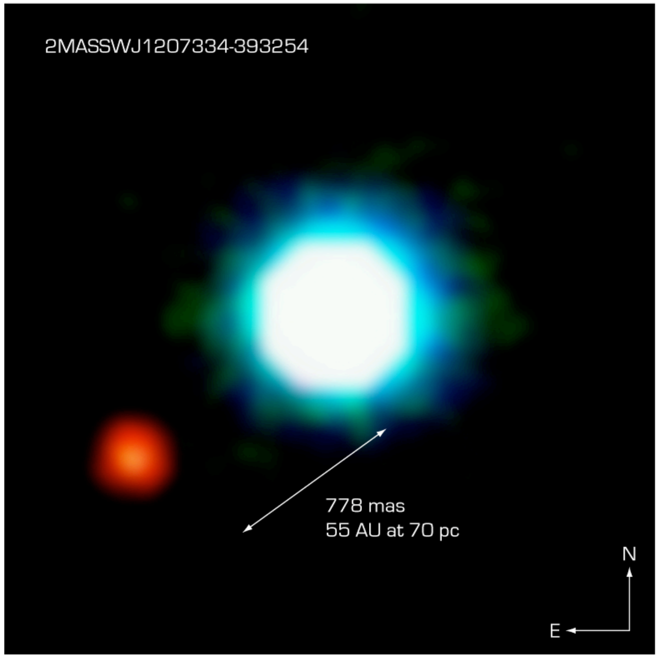
- Follow up brightest candidates with spectroscopy, looking for atmospheric signatures, habitability or life itself.

- Will detect and characterize Earth-like planets around as many as 150 stars up to 15 pc away.

Planetary Prospects

- Increase planetary census
- Direct imaging:
  - Young, massive planets now
  - TPF needed for Earth-like
- Spectra
  - atmospheric abundances
  - biomarkers (O_2, H_2O, O_3)





NACO Image of the Brown Dwarf Object 2M1207 and GPCC

ESO PR Photo 26a/04 (10 September 2004)