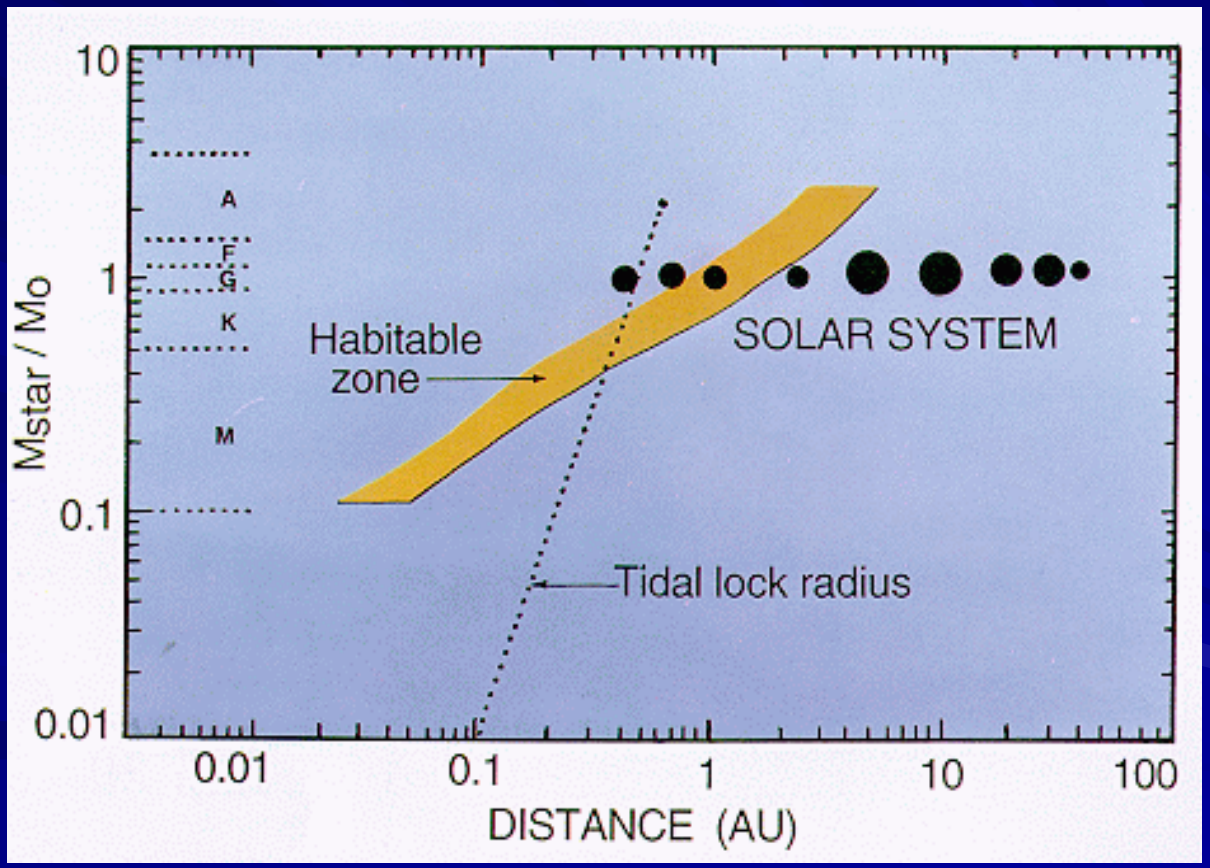
Stability of Planetary Systems

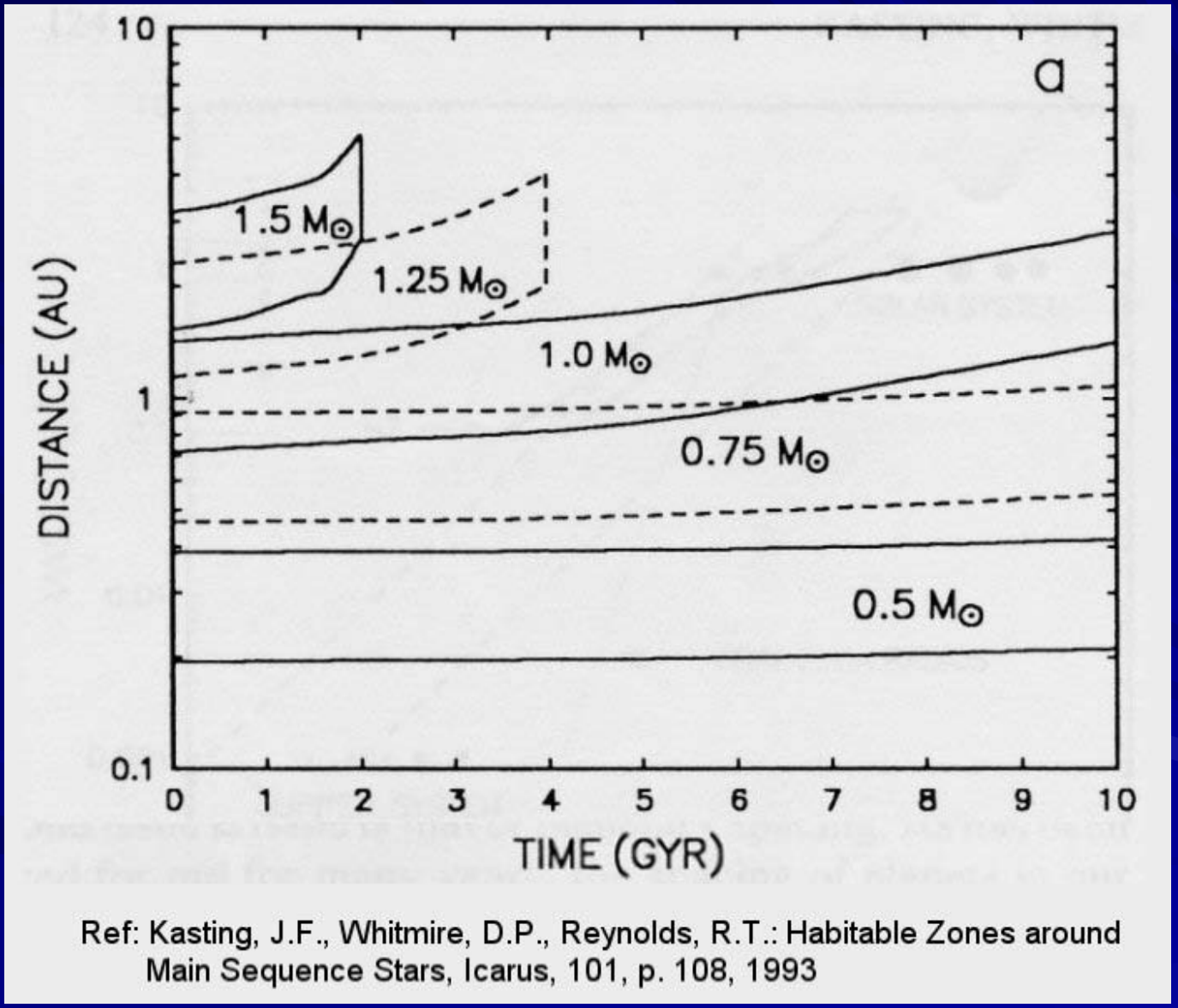
Habitable Zone

- **Zone around a star where liquid water can exist on the surface of a terrestial-like planet**
- **This zone depends on:**
  - **the spectraltype , the mass , the age, …. of the star**
  - **the orbit of the planet**
  - **the mass, the composition, the atmosphere , ……of the planet**
  - **the parameters of other planets in this system (mass, orbit, …)**

Size of the Habitable Zone (HZ)

based on the definition given by Kasting et al. (1993).





Ref: Kasting, J.F., Whitmire, D.P., Reynolds, R.T.: Habitable Zones around Main Sequence Stars, Icarus, 101, p. 108, 1993

exoplanet.eu

website of Jean Schneider (Paris)

Catalog of Extra-Solar Planets

Information of all discovered planets outside the solar system

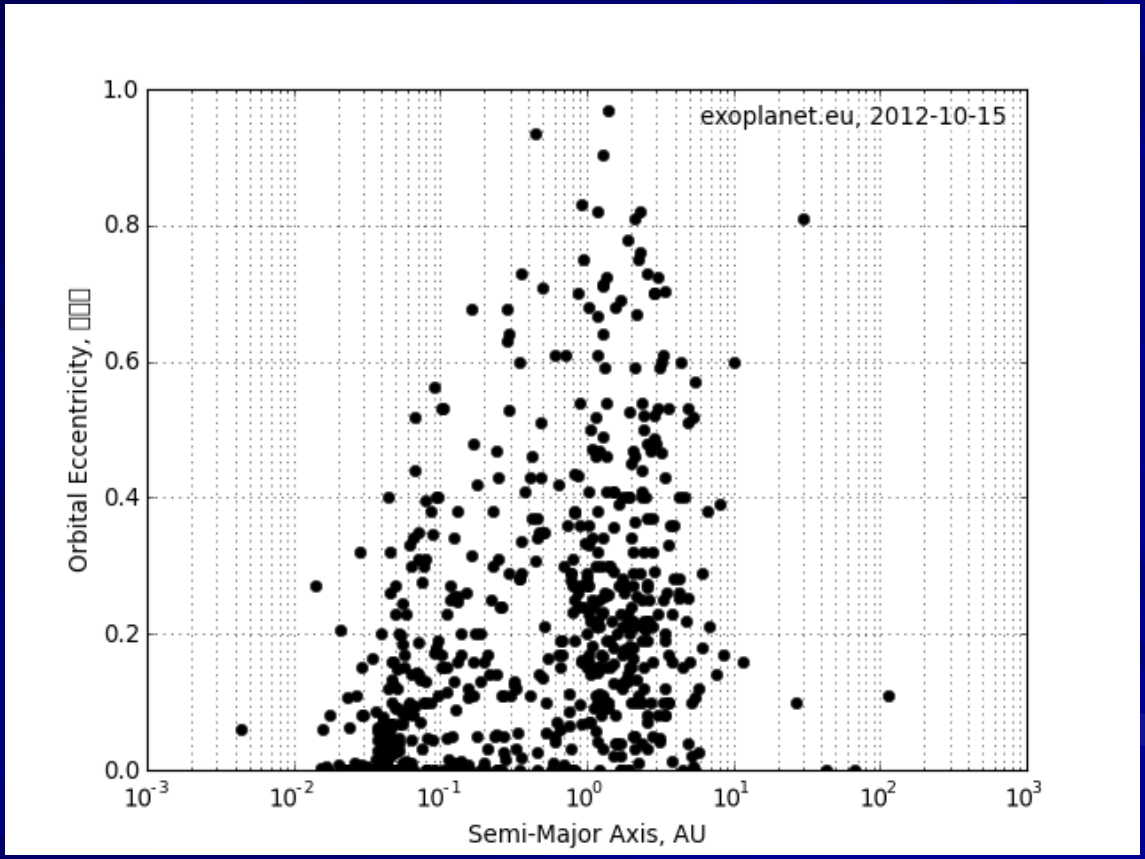
exoplanet.eu

841 Planets

663 Planetary Systems

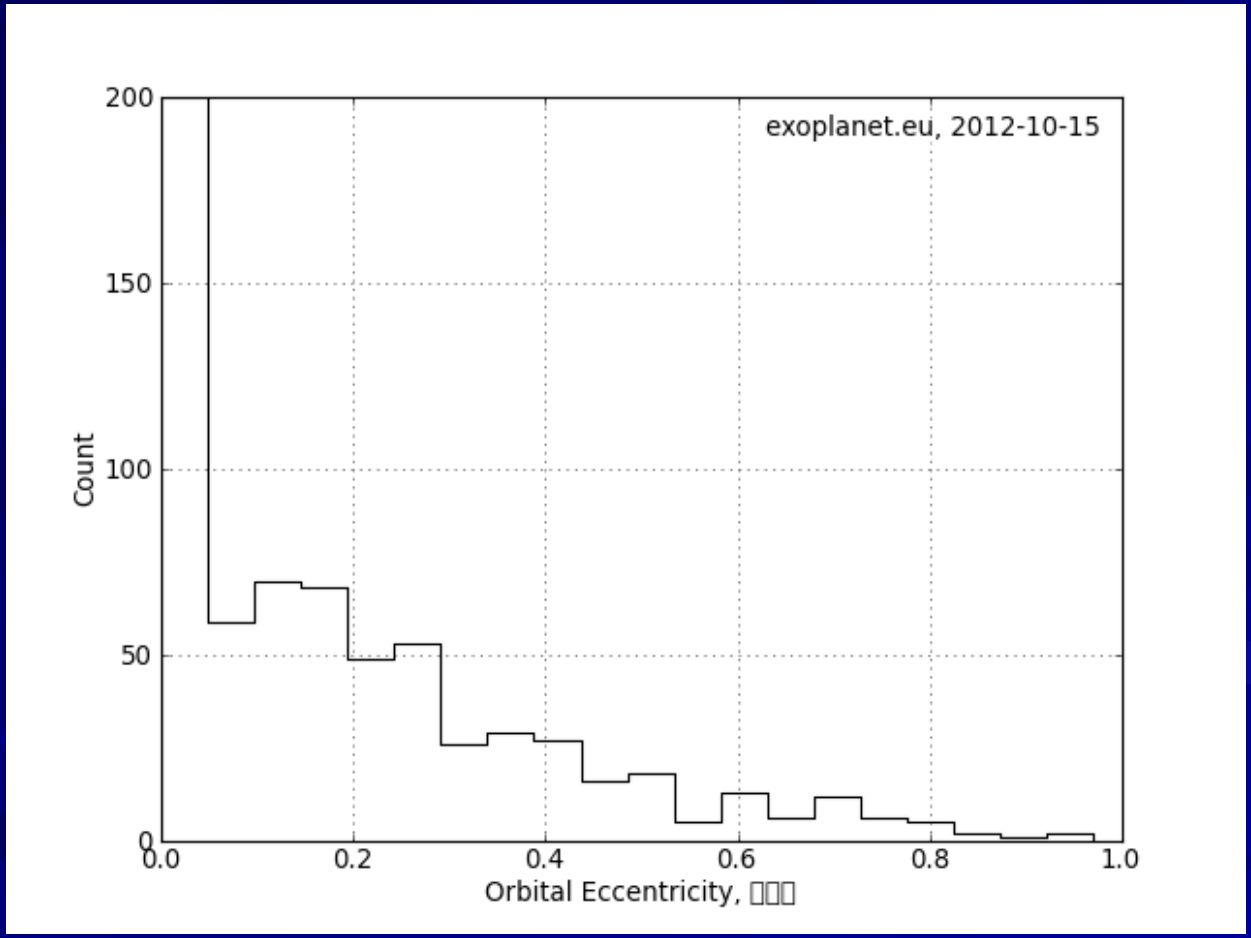
126 Multi-Planet Systems

Semi-major axis – eccentricity diagram of all discovered extra-solar planets



High eccentric planetary motion occurs quite often!

Distribution of the orbital eccentricity

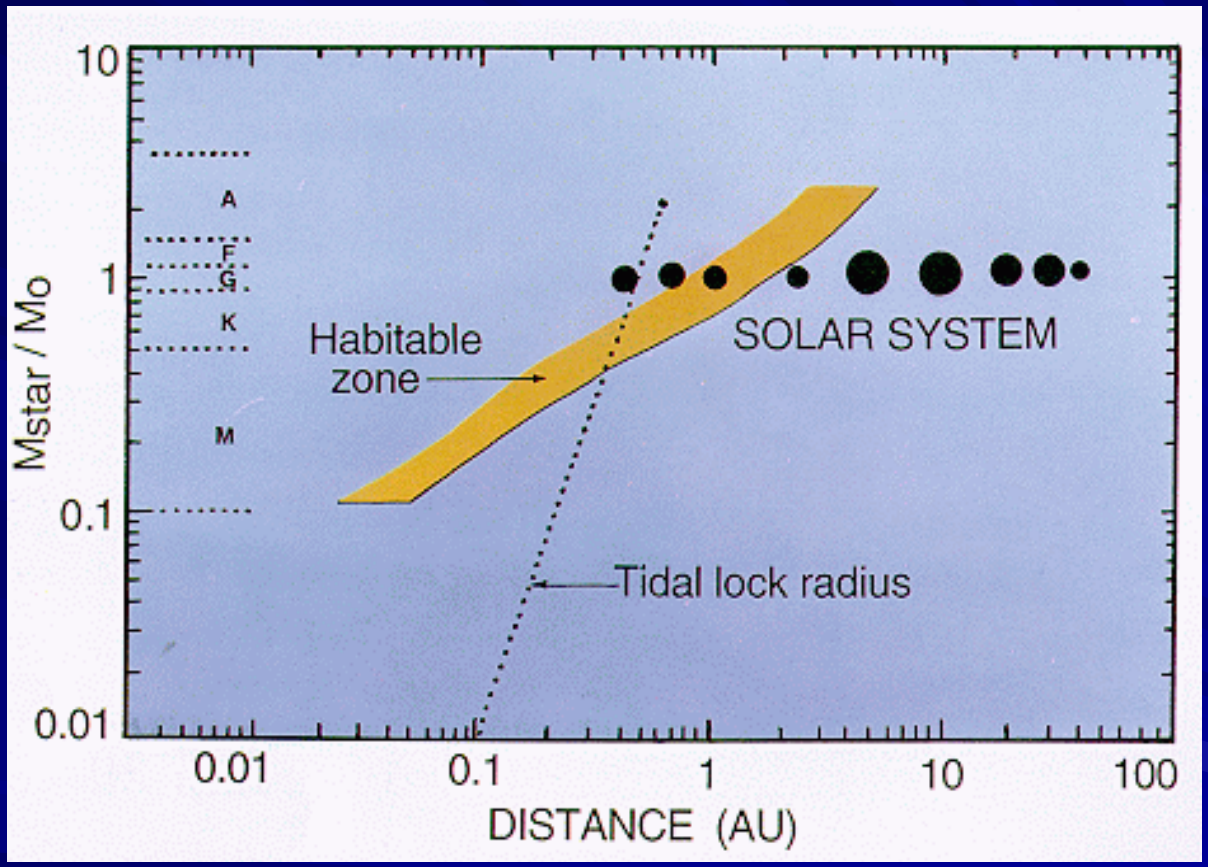


~ 400 planets
e < 0.2

Requirements for the Habitable Zone from the dynamical point of view

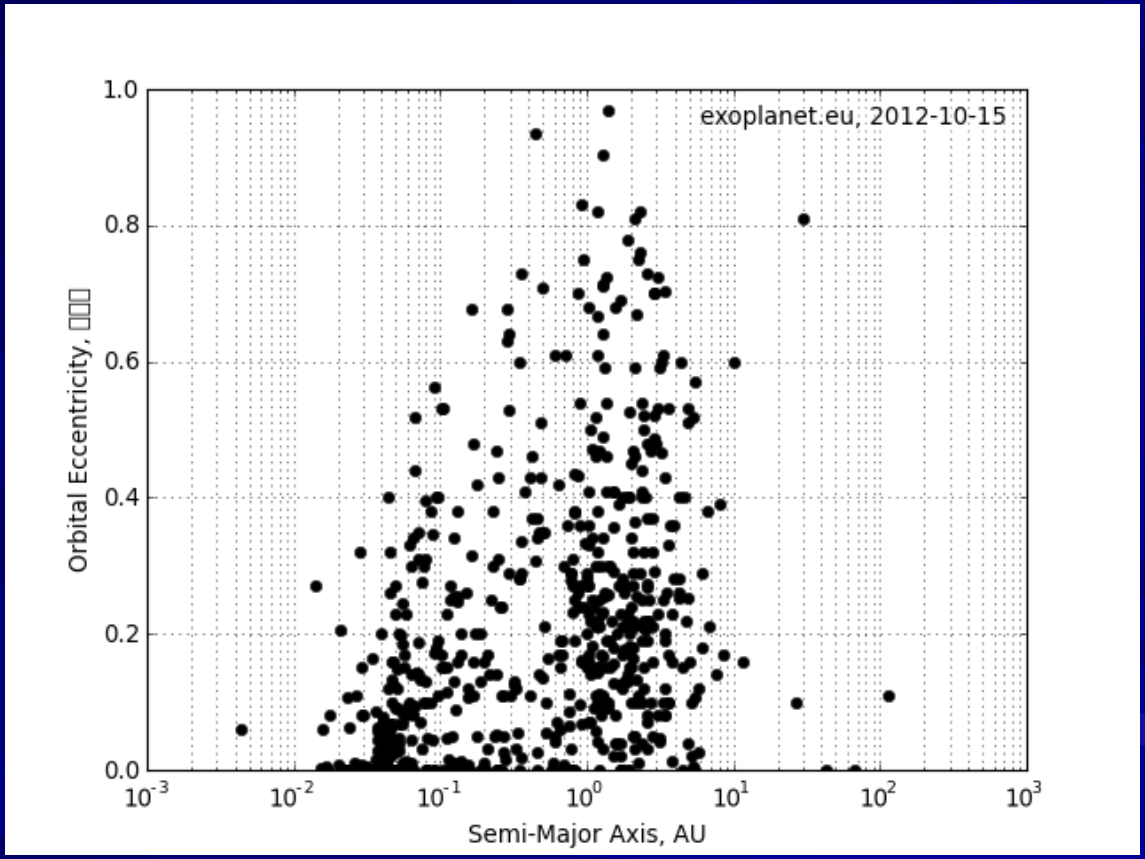
- **Long-term stability of the planetary system**
- **Appropriate distance of the planet to the host-star**
- **Small eccentricity**

HZ is a small area !



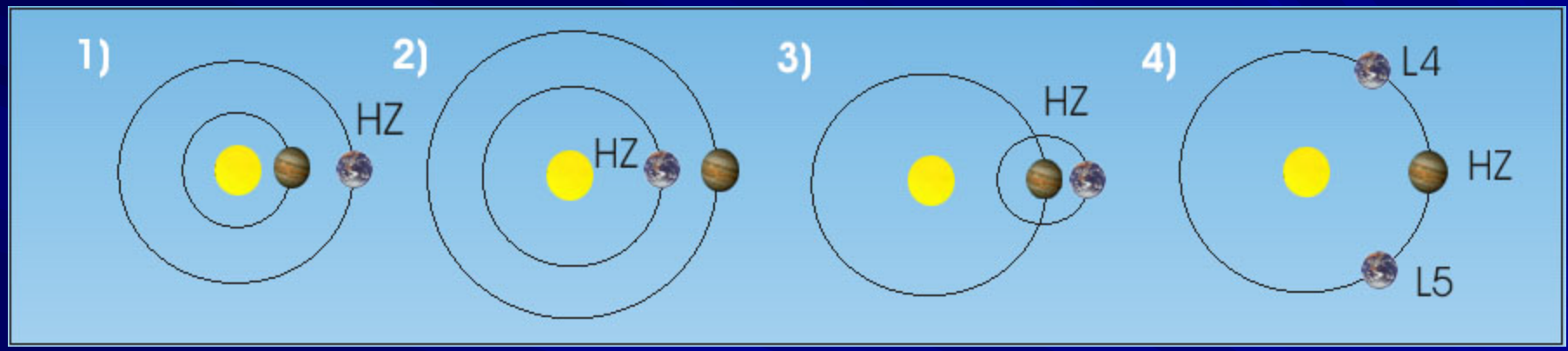
Kasting et al.
(1993).

Semi-major axis – eccentricity diagram of all discovered extra-solar planets



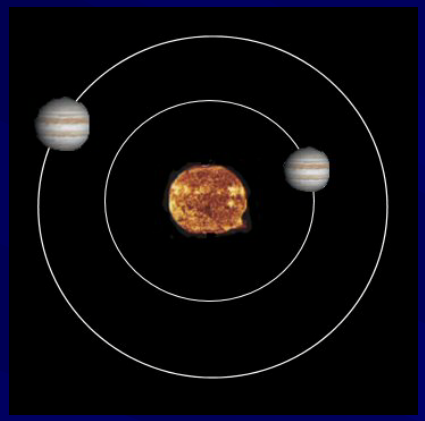
High eccentric planetary motion occurs quite often!

Types of Habitable Zones:

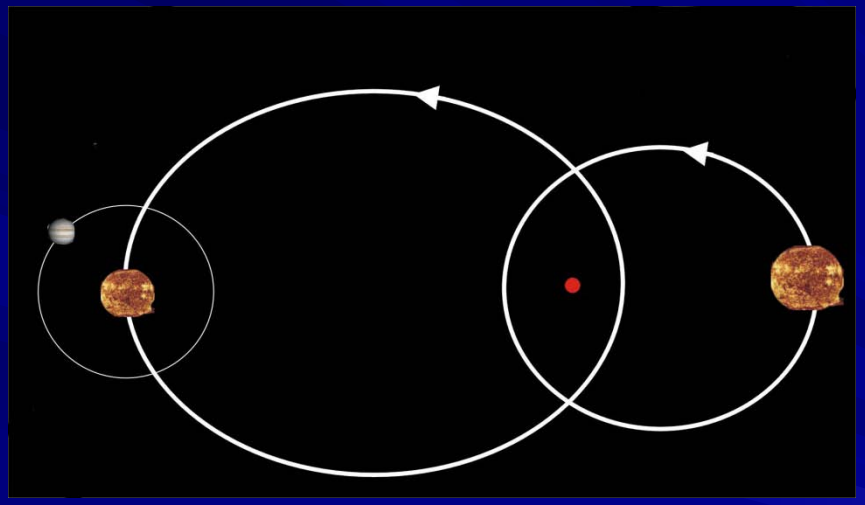


(1)Hot-Jupiter type
(2) Solar system type
(3)+(4) giant planet type: habitable moon or trojan planet

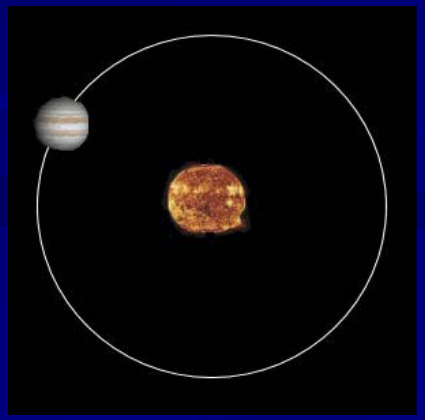
October 2012:
663 planetary systems
841 planets



- **126 Multi-planet systems**
  (http://exoplanet.eu/catalog/)



- **57 planets in binaries**
  (Roell et al., 2012, A&A)



- **Single-Star - Single-Planet**

Two Body Problem

Interaction of two masses moving under the mutual gravitational attraction described by Newton‘s universal law of gravitation:

$$F = G \frac{(m1 \cdot m2)}{d^2}$$

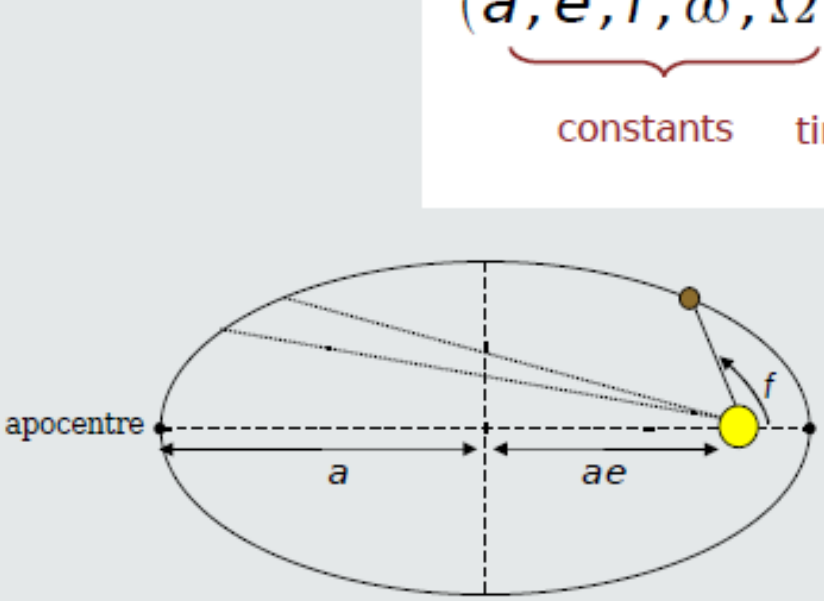
and Kepler‘s empirical laws of planetary motion

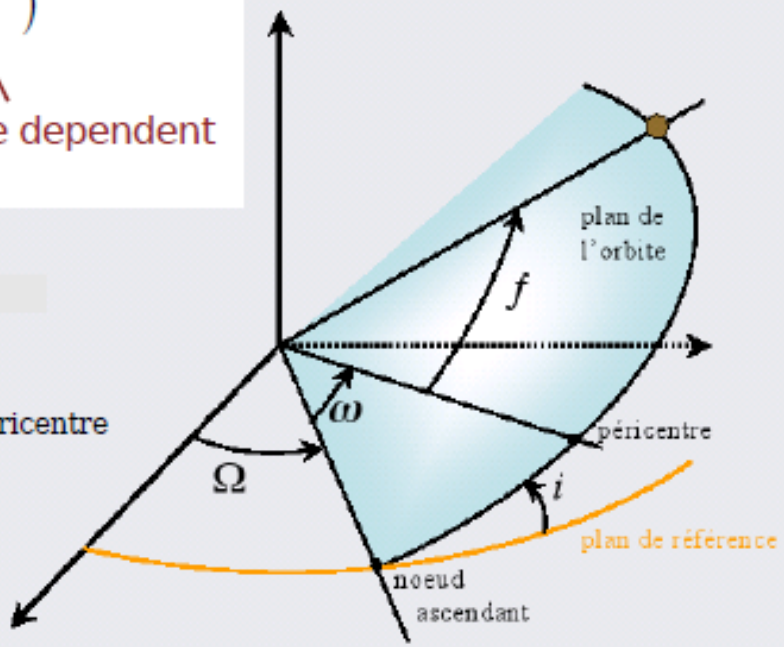
Orbital elements

The planets move in ellipses with the Sun at one focus (first Kepler's law)

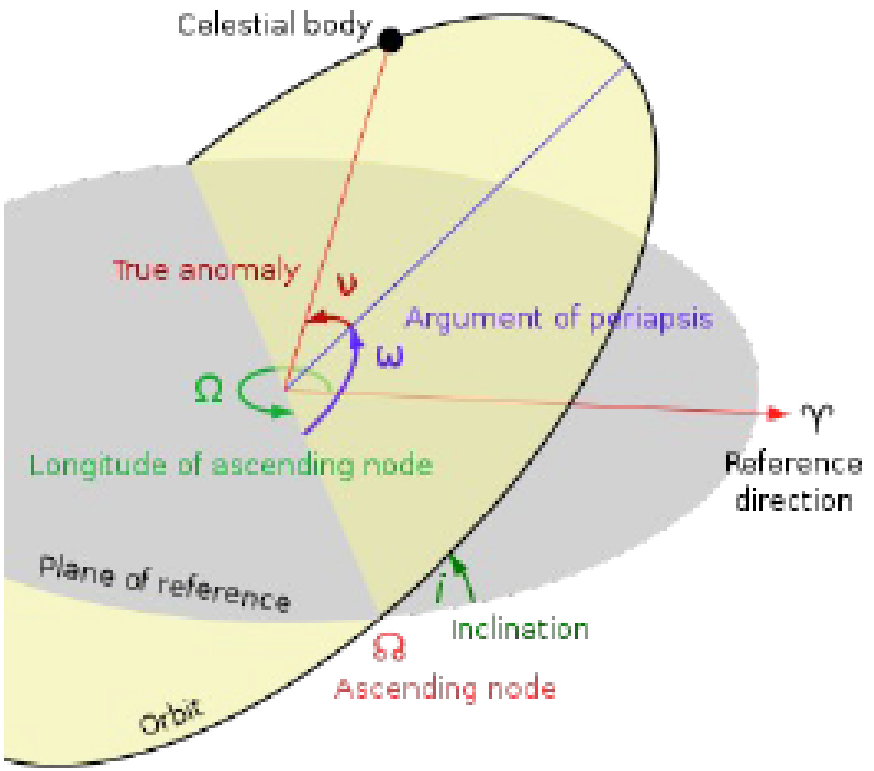
$$(a, e, i, \omega, \Omega, f)$$

constants — time dependent





Osculating elements: $(a,e,i,\Omega,\omega,\nu)$



N-body Systems

The 3-body problem

is the simpliest n-body system

it has no analytical solution ---
18 integrals of motion are needed but only 10 are known the other do not exist (as already shown by Poincare)

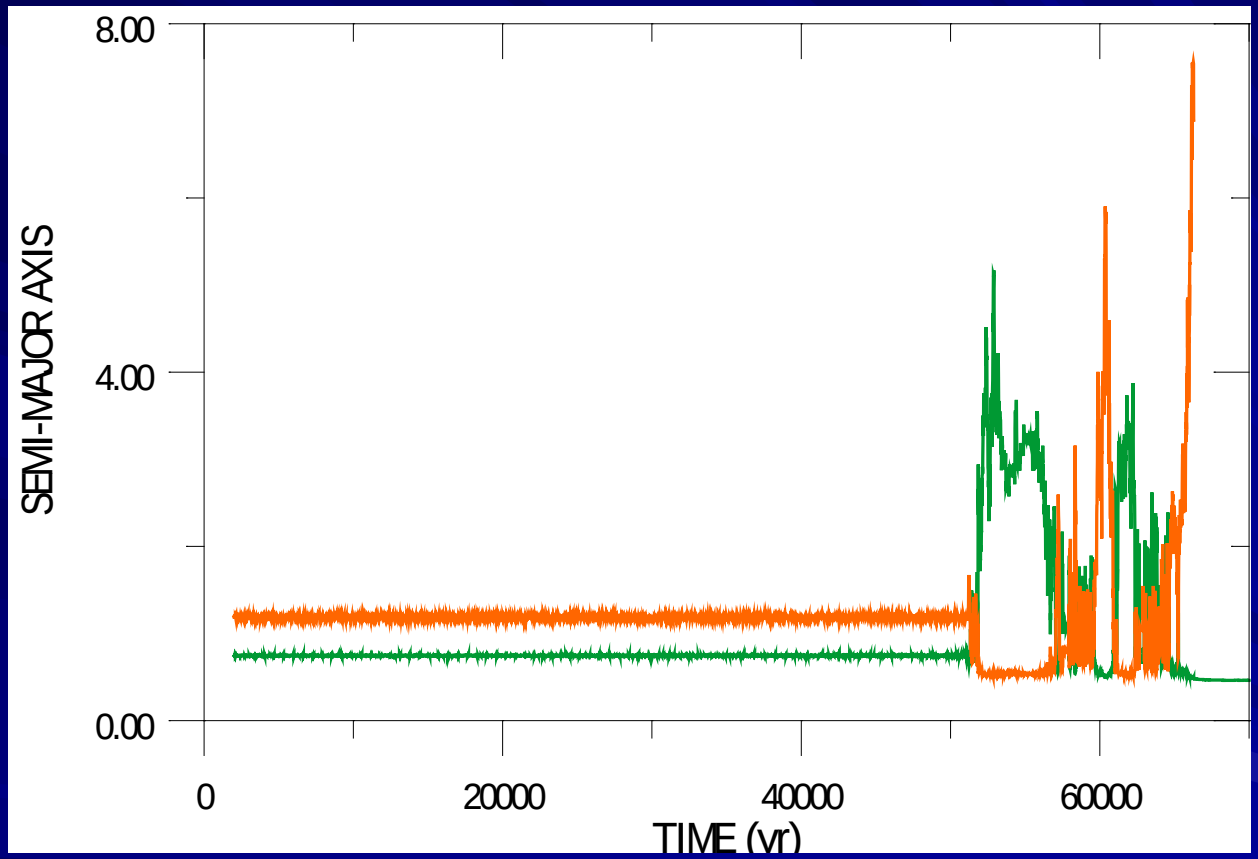
Perturbations in multi-planet systems:

Mean Motion Resonances (MMR):

the orbital periods of two celestial bodies have a ratio of small integers → there is a regular, periodic gravitational influence

Secular Resonance

Major catastrophe in less than 100000 years



(S. Ferraz-Mello, 2004)

Classification of the known multi-planet systems (S.Ferraz-Mello, 2005)

- **Class Ia –>** Planets in mean motion resonance
- **Class Ib →** Low-eccentricity near-resonant planet pairs
- **Class II→** Non-resonant planets with significant secular dynamics
- **Class III→** Hierarchical planet pairs