Extra-solar Planets
Space-based studies

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A historical ‘debate’….

- *There are infinite worlds both like and unlike this world of ours…*

Epicurus (341–270 BC)

- *There cannot be more worlds than one…*

Aristotle (384–322 BC)

Courtesy M.A.C. Perryman

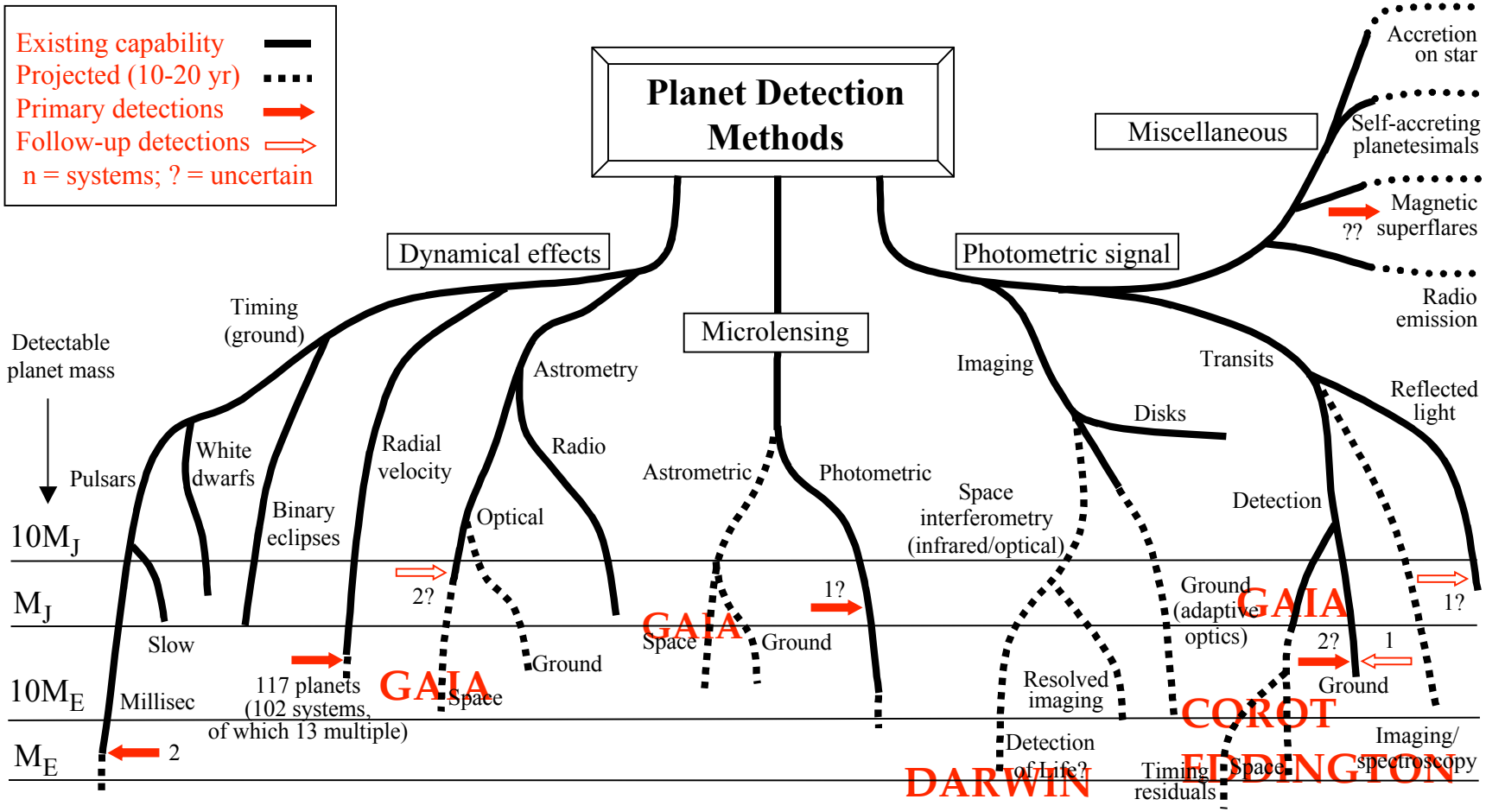
Extra-solar Planets
Questions and Objectives

- **Questions**
  - How common is the formation of planetary systems ?
  - What are their diverse characteristics ?
  - What are the conditions for formation of planets around stars ?
  - What are the characteristics of stars hosting planets ?

- **Objectives**
  - Inventory and characterise extra-solar planets in the solar neighbourhood
  - Detect exo-planetary systems similar to our own
  - Detect planets in the “habitability zone”
  - Detect their atmosphere, detect bio signatures

Planet Detection Methods

Michael Perryman, Rep. Prog. Phys., 2000, 63, 1209 (updated September 2003)



Astrometric detection (1)

$$\alpha = \frac{M_p}{M_s}\frac{a_p}{d}$$

α in arcsec
if a in AU and d in pc

At 10 pc:
Jupiter: 500 μarcsec
10 Earth: 3 μarcsec
Earth: 0.3 μarcsec

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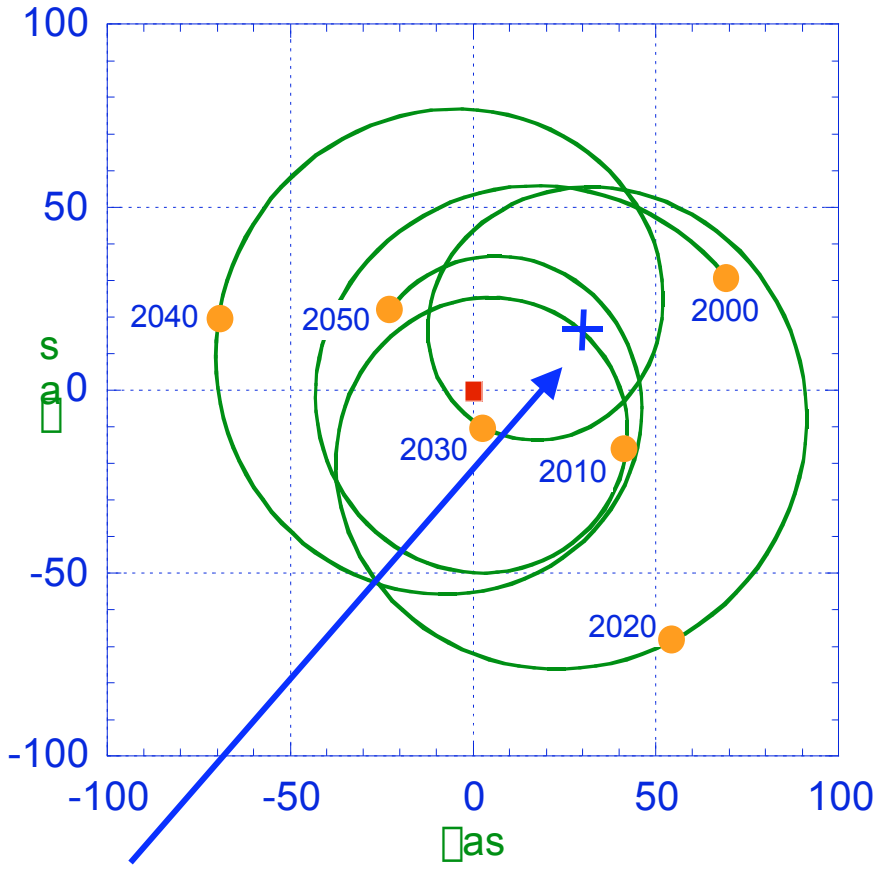
Particularly sensitive to relatively long period, P > 1 yr

Astrometric detection (2)

GAIA will monitor hundreds of thousands of stars of all spectral types for P = 2 - 10 years. F-G-K stars to ~ 200 pc for 1 M_J planets.

- **20-30 000 planets expected**
- **masses**
- **identification of Jupiter-like systems**
- **orbits for ~ 30 % to 100 pc**

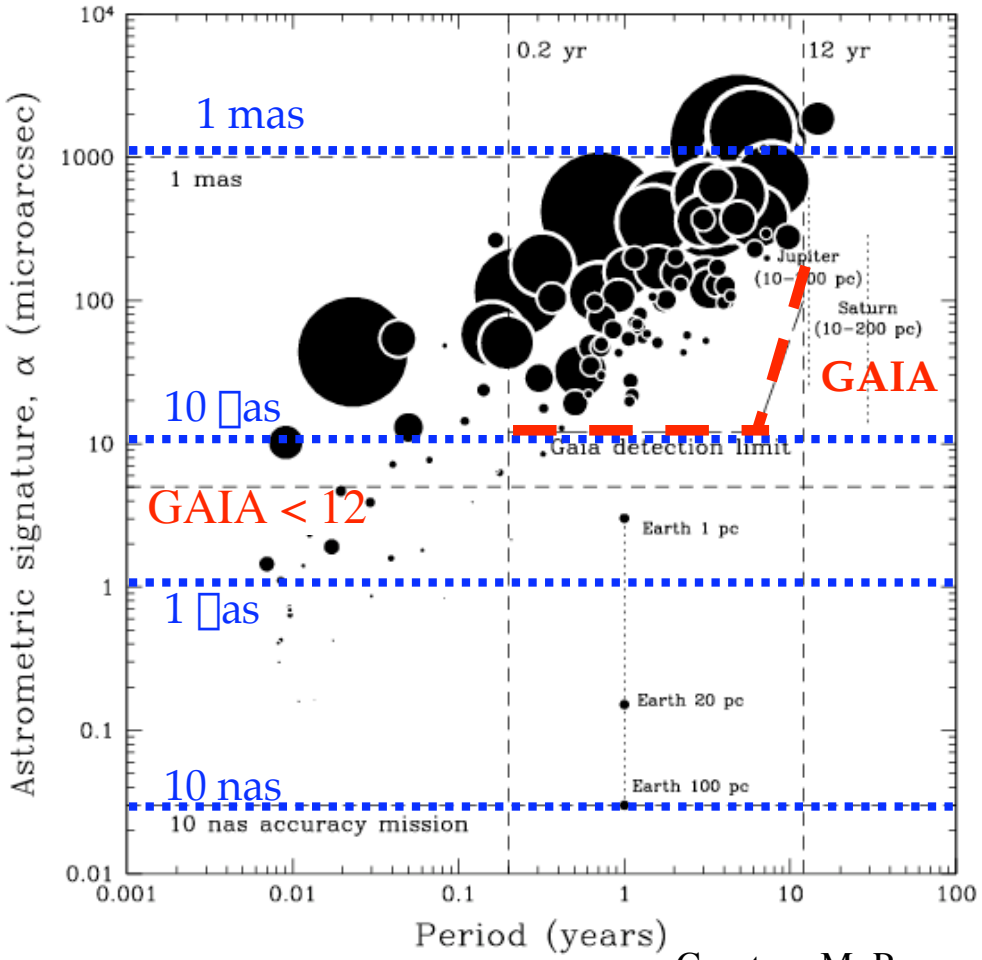
Motion of the Sun, as seen from 100 pc



GAIA accuracy at V = 15 mag

Astrometric detection (3)
complementarity to other projects

- Masses and orbits of nearly all already known planets
- Relative inclinations for multi-planet systems
- Target list for Darwin, VLTI
- Distances, ages, masses, physical characteristics
  - of stars hosting planets
  - of stars with proto-planetary disks
- Pointing
- astrometric and photometric calibration



Courtesy M. Perryman

Photometric detection: transits (1)

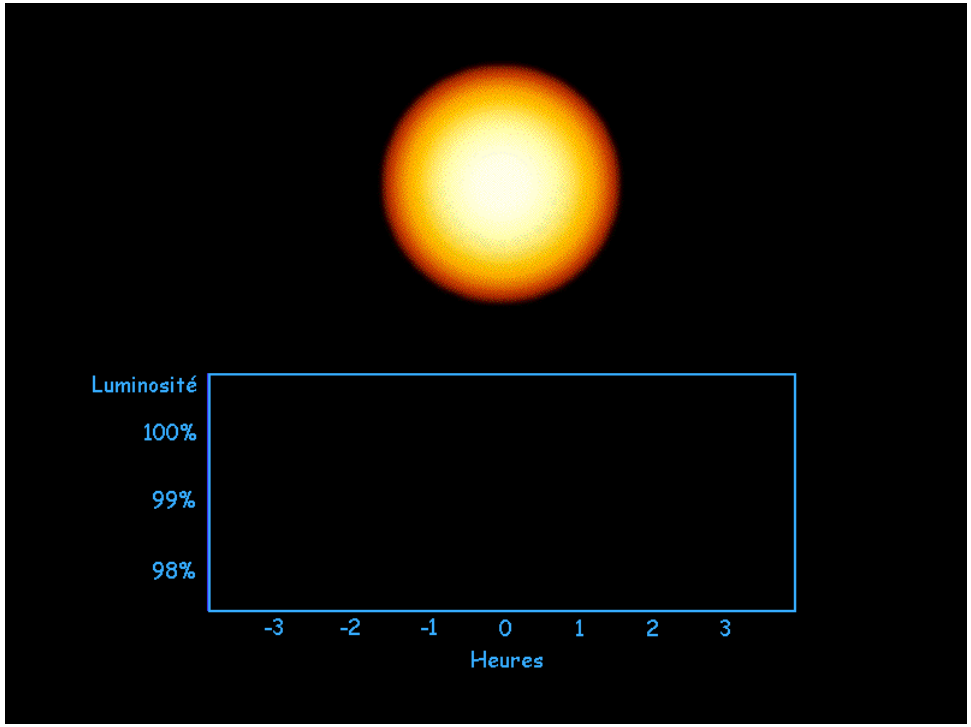
$\Delta m \approx \Delta F / F = (R_P / R_*)^2$

$R_{Earth} = 0.1\ R_{Jup}$
$= 0.01\ R_{Sun}$

Earth : $\Delta m = 10^{-4}$

Jupiter : $\Delta m = 10^{-2}$

HD 209458 : $\Delta m = 1.7\ 10^{-2}$



Courtesy F. Arenou

---> size of planet, period, inclination, detection of rings and moons

Photometric detection: transits (2)

Corot

- Precision 10^{-3} - 10^{-4} at V= 14 over 1h
- Field: 3 degree^2, 120 000 observed stars, 5 x 150 days over 2.5 years

→ **~ several hundreds hot Jupiter**

→ **~ several tens of telluric planets (several x Earth)**

Eddington

- Precision a few 10^{-5} at V= 14 over 1h
- 21 fields of 19 degree^2, ~ 100 000 observed stars, 3 years

→ **~ 20 000 planets with R < 15 R_{Earth}**

→ **~ 2000 terrestrial planets**

→ **~ a dozen Earth-like planets in the habitable zone**

Gaia

- Precision 10^{-3} for V < 14, 10^{-2} at V= 18, irregular time sampling

→ **~ 5000 Jupiter-size objects**

→ **short periods : P 3-10 days**

Transits (3): ground - space cooperation

Pre-mission: multicolour photometry mandatory ! + astrometry to < 0.1 " (E)

- Definition of the instrumental configuration (E)
- Optimisation of target/field choice
- Observation of target neighbourhood

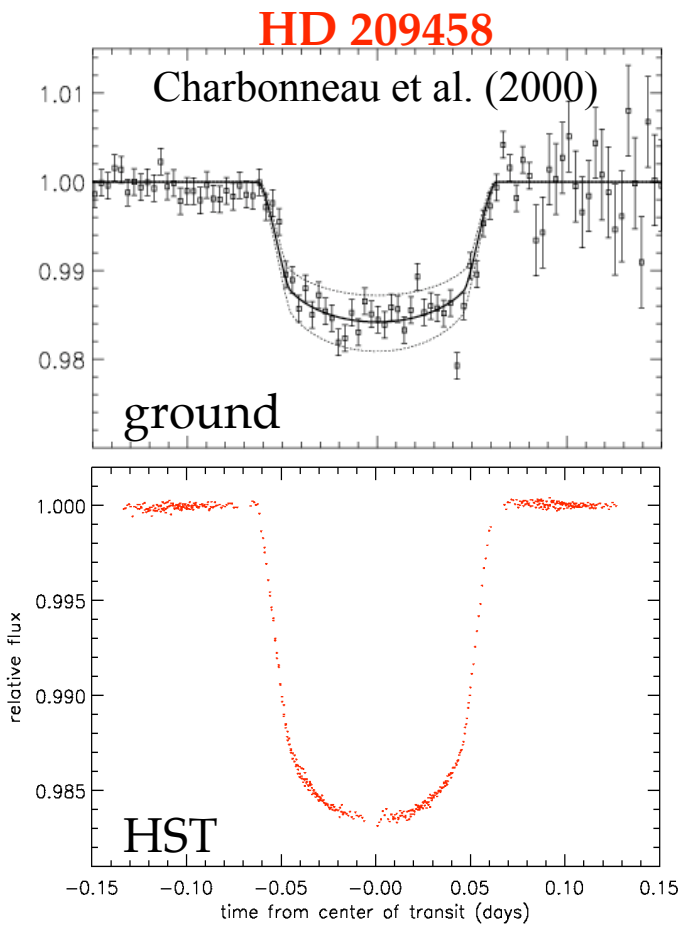
➢ **Corot**: ~ 20 nights, 2m telescopes

➢ **Eddington**: ~ 120 nights, 2m telescopes

During and after the mission

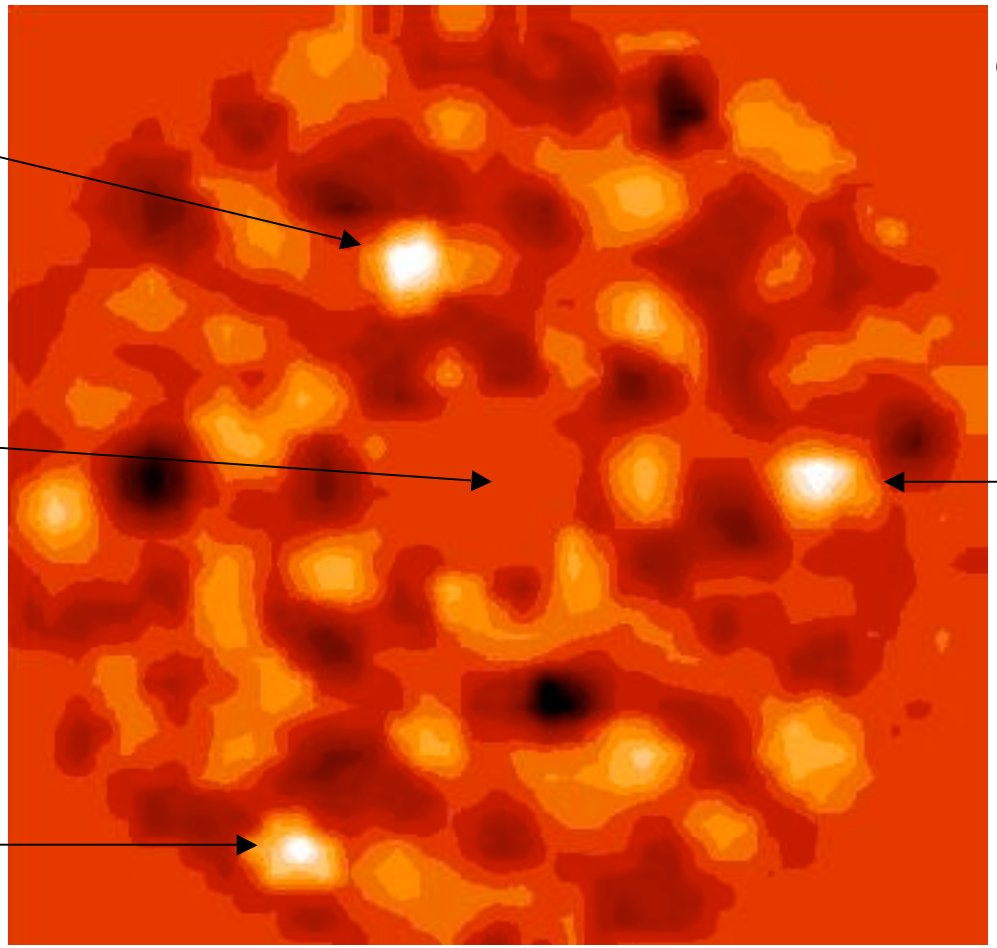
- Determination of stellar diameter
  --> planetary diameter
- **spectroscopic + RV follow-up** --> mass
  --> planet internal structure
- spectroscopy and imaging --> stellar characteristics, presence of a disk, etc.

➢ **Corot**: HARPS ~ 100 nights, UVES ~ 25 nights, SOPHIE ~ 100 nights over several years



Imaging (1)

Darwin imaging (Mennesson & Marrioti 1997)



Imaging + biomarkers detection (2)

Darwin

- **Objectives**
  - detect and study “Earth-like” exo-planets orbiting nearby stars
  - characterize their properties and atmosphere
  - investigate if Earth-like planets are common
  - detect tracers of life
  - investigate Earth-like planet formation
- **Instrument**
  - 50–250 m baseline mid-infrared (5-30 □m) nulling interferometer
  - 6 □ 1.5 m telescopes
  - unprecedented spatial resolution

star/planet intensity: 10^6–10^9

Imaging (3): ground - space cooperation

Preparatory activities

- **Observations**
  - physical parameters, age, variability, dust properties, etc. of each target star
  - as much data as possible about exo-planets
  - places of star and planetary formation
- **Theory**
  - star and planetary formation
  - origin and evolution of planetary systems

Started

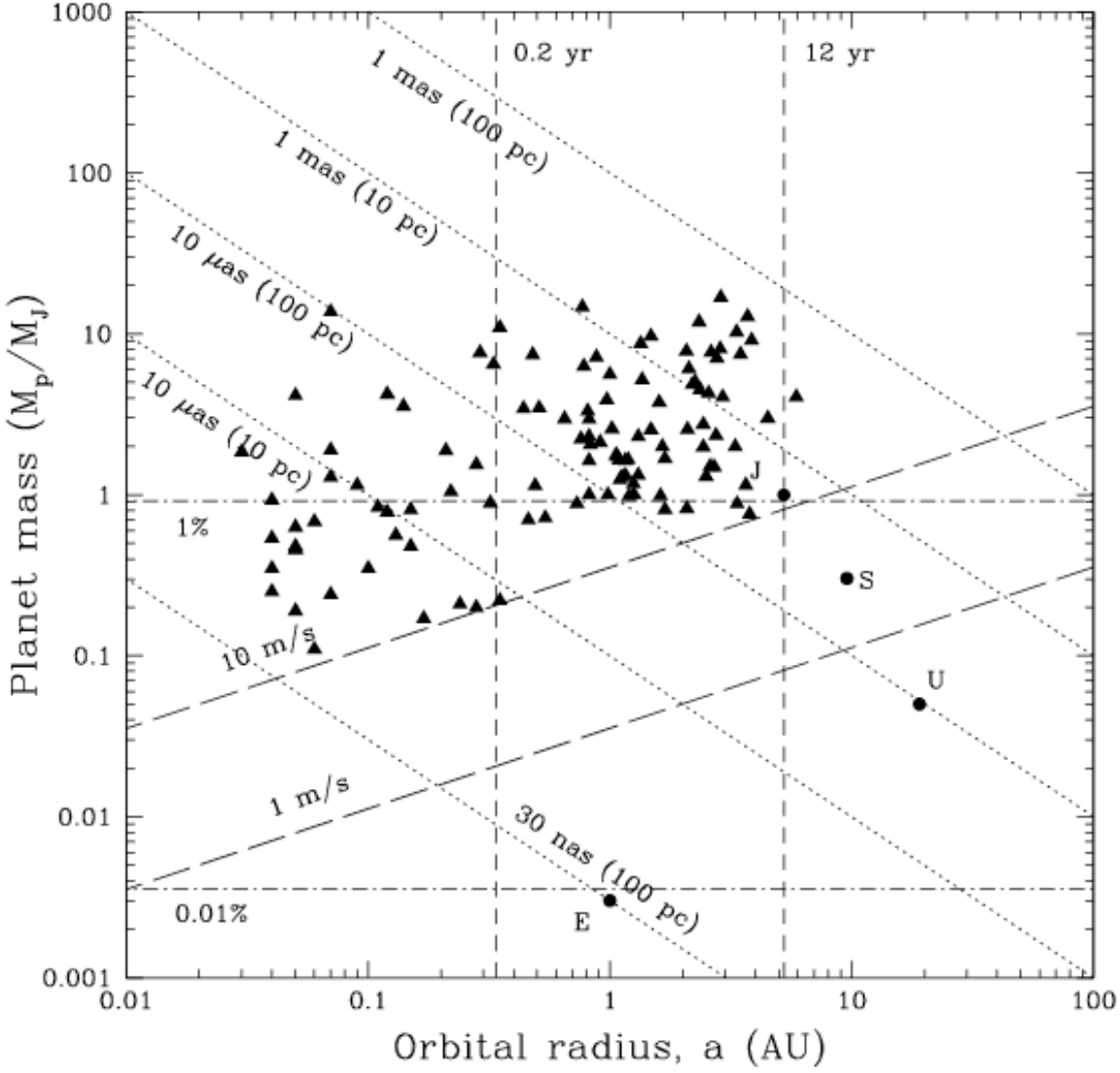
- **GENIE** = Ground-based European Nulling Interferometry Experiment: nulling interferometer at 3.6 - 10 microns for the VLTI
  - verify technology
  - investigate dust and possible brown dwarfs in target systems

Capabilities of the different methods

astrometry

radial velocity

photometry



Courtesy M. Perryman

Formation of planetary systems
Observation of protoplanetary disks

- Detected through their IR, sub-mm or radio emission
- Imaged using HST, ISO, VLT, …

HST Nicmos: HR 4796A
(Schneider et al 1999)

Observation of protoplanetary disks and debris rings:

Herschel, JWST (MIRI), …

Summary and conclusion

- **ESA space missions**
  - **astrometry**: **Gaia** large statistical survey
    over ~ 20 000 planets (P~years, down to a few 10 x Earth)
    + physical characterisation of all objects
  - **transits**: **Corot** (down to a few Earth), **Eddington** (down to Earth-like planets), **Gaia** (Jupiters, P~days)
  - **imaging + search for life**: **Darwin**
  - **protoplanetary disks**: **Herschel, JWST**
- **much complementarity with ground-based experiments**
  - already organised in common ESO/ESA: **GENIE**
  - already some observing programmes
  - **a lot more to coordinate !**

Thanks to European organisations, projects can be developed, which are beyond the capacity of individual countries !