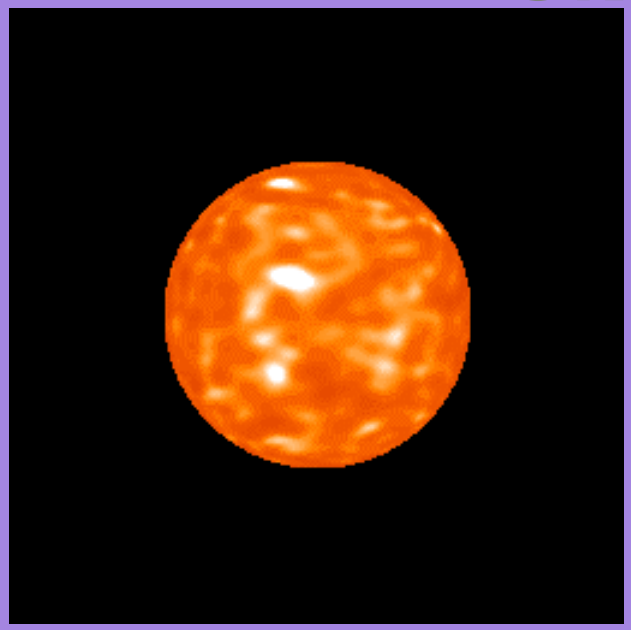
太陽系外惑星探査行

Department of Physics （物理学教室）
University of Tokyo （東京大学）
Yasushi Suto （須藤 靖）



２００１年５月２９日
於 北京大学天文学科

Cosmology in the 20th century

- Rapid progress of cosmology since 1980's
  - existence of dark matter established
  - temperature fluctuations in the microwave background
  - measurement of the Hubble constant within 10 percent accuracy
  - detection of MACHO(Massive Compact Halo objects)
  - possibly non-zero cosmological constant
  - initial conditions of the universe from particle cosmology
- Cosmology is definitely one of the most matured fields in physical sciences at the present time.

What's next, Precision Cosmology ?

--- Since people have been working on the problem for more than sixty years, perhaps the most surprising result would be that in the next decade a consistent and believable picture for the values of the cosmological parameters is at last established. ---

P.J.E.Peebles (1993) ``Principles of Physical Cosmology''

But !

Surprisingly the values of cosmological parameters seem to have been already converged fairly well...

What's next ?

Search for extrasolar planets !

- the goal: ***Are we alone ?***
  - origin of the earth
  - origin of the Solar System
  - habitable planets ⇒ origin of life
  - signature of extra-terrestrial life ?
  - extra-terrestrial intelligence ?

Be careful *not to* join dangerous groups !
Approach the problem *scientifically* !

How to detect extrasolar planets ?

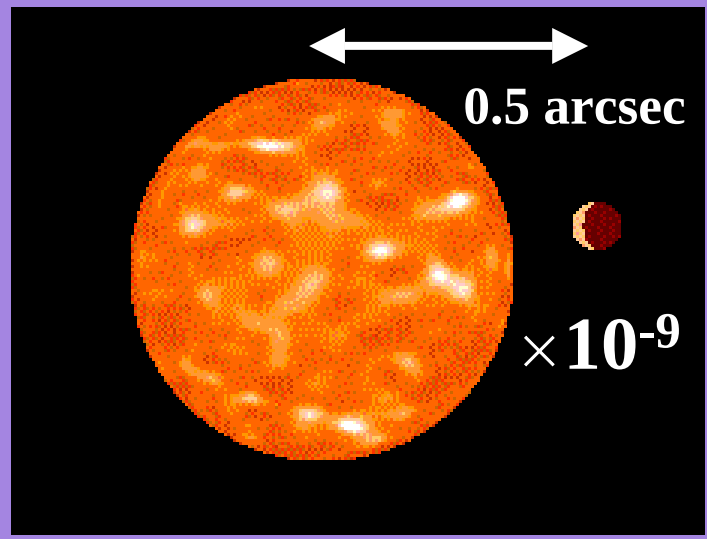
- 直接撮像：高角度分解能
- 主星的速度変動：高精度分光
- 主星的位置変動：高精度位置決定
- 主星的光度変動：高精度測光
- 主星的信号到着時刻変動：
  高時間分解能

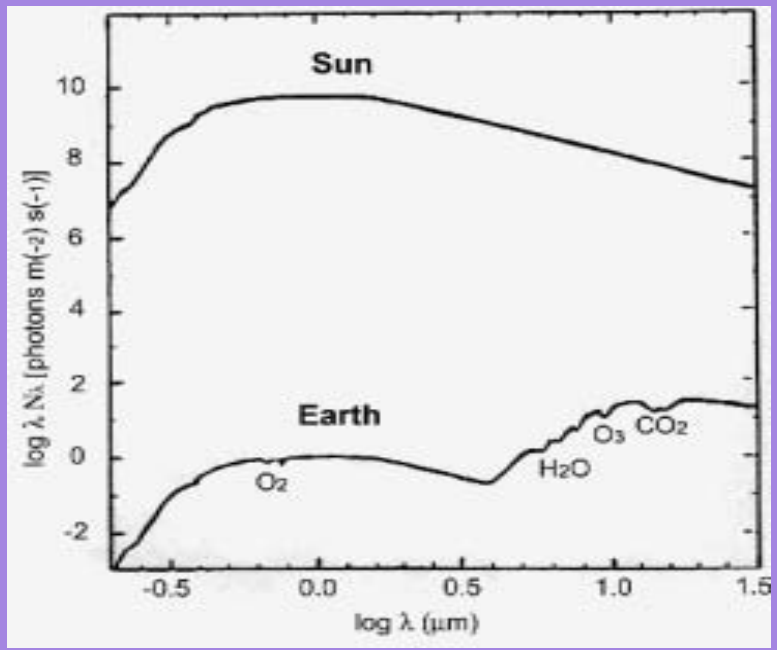
requires the most advanced technology available.
still difficult, but becoming feasible now !

Direct imaging ?

木星 observed at a distance of 10 pc

visual magnitude: 27等級
angular distance from the main star： 0.5秒角

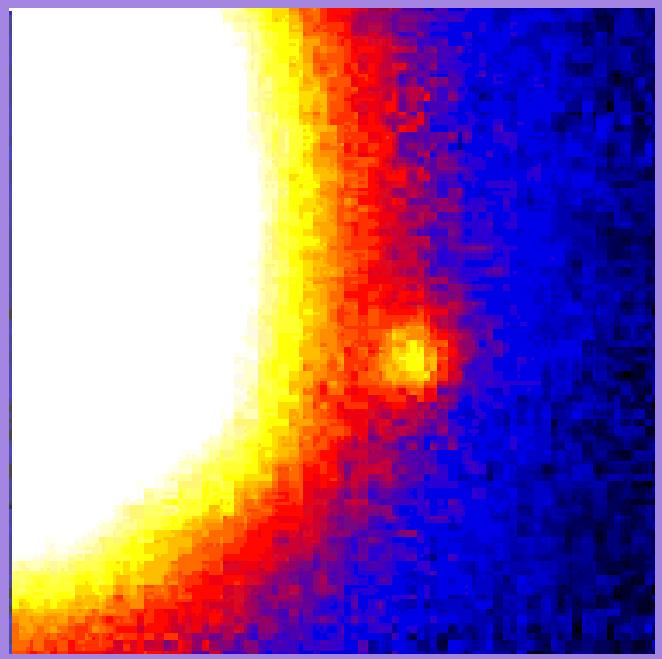


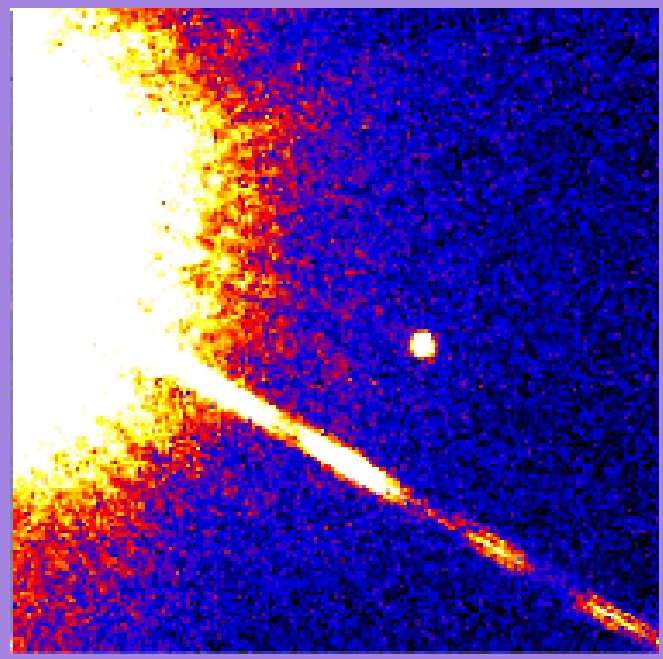


need to detect a 10^{-9} times darker object than the main star which locates within a typical seeing scale of the ground observation !

⇒ Just impossible ！

An observed brown dwarf: Gliese 229b





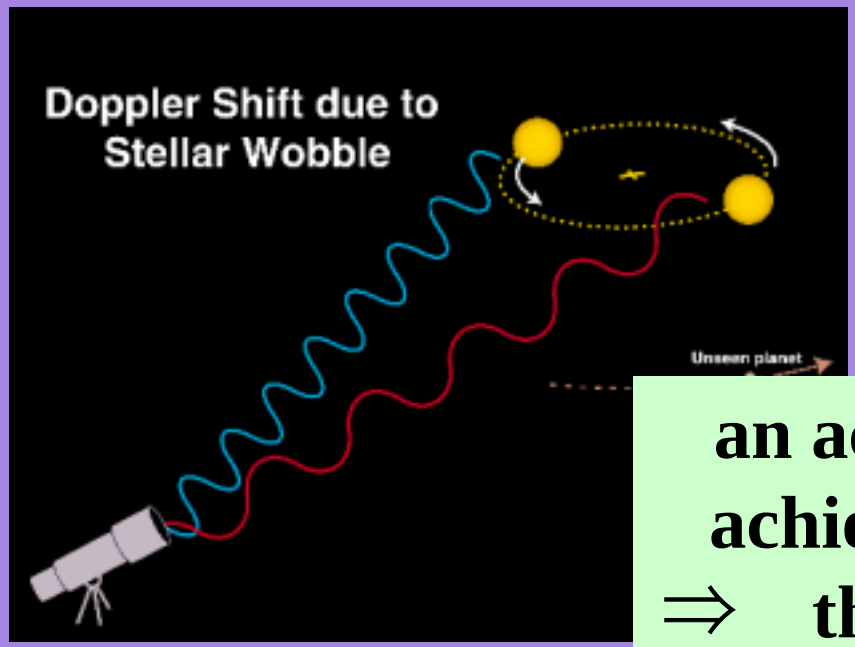
Gliese229 b:
角距離 7arcsec
光度比　5000

左：Palomar
右：HST
(T.Nakajima)

- **木星** seen at a distance of 10pc is 14 times closer to the star and 1/200,000 darker than this example !

Radial velocity of a star perturbed by a planet

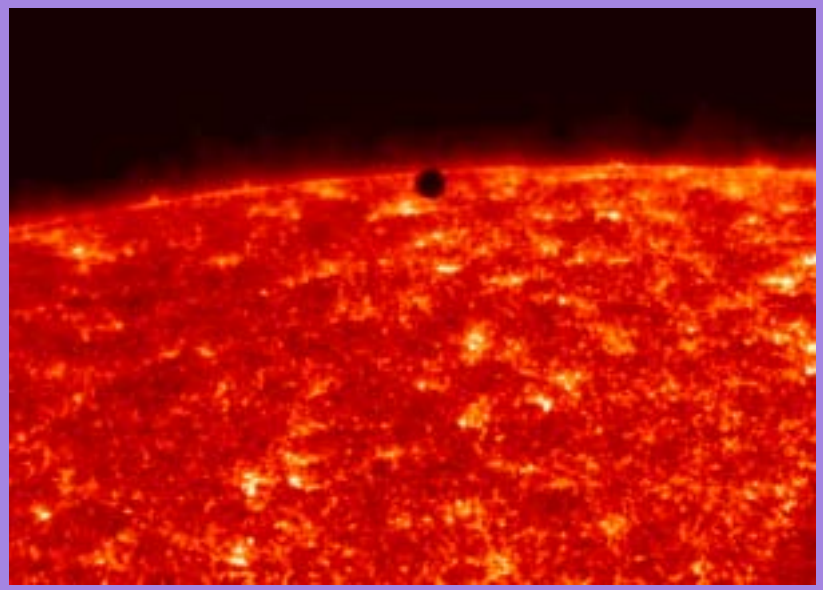
Even if one cannot directly observe a planet, one can infer its presence indirectly from the measurement of the motion of the main star.



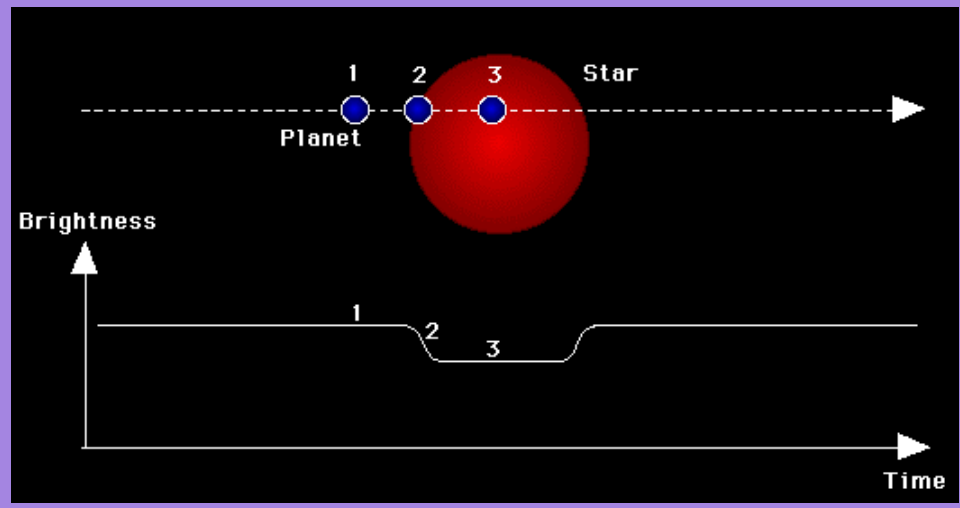
e.g., velocity modulation of the Sun due to a planet
12.5 m/s (木星)
0.1 m/s (地球)

an accuracy of 3m/s is already achieved from the ground obs.
⇒ the current major method in search for Jupiter-sized planets

Occultation of the main star due to the transit of a planet



Mercury across the Sun
(TRACE衛星:1999年11月)



probability of the occultation: 0.3% $(AU/a_{orbit})(R_{star}/R_{Sun})$

flux variation: 1% $(R_{planet}/R_{Jupiter})^2(R_{Sun}/R_{star})^2$

⇔ photometry accuracy in the ground obs. > 0.1%

Arrival time measurement of the pulsar

the perturbed motion of a star due to a planet also produces a periodic change of the arrival time of any signal from the star

$$\Delta t = 0.5\,\text{秒} \left(\frac{M_{planet}}{M_{Jupiter}} \right) \left(\frac{M_{sun}}{M_{star}} \right)^{1/3} \left(\frac{P}{1\,\text{年}} \right)^{2/3}$$

Is there any astronomical object that emits a regular signal and thus enables the accurate monitoring of the arrival time ?

⇒ Yes, pulsars are ideal for that purpose !
(their spin period is stable up to 10^{-19}s/s)

But they are supposed to form after the supernova explosion. Any planets orbiting around the progenitor should have been blown off... Too bad...

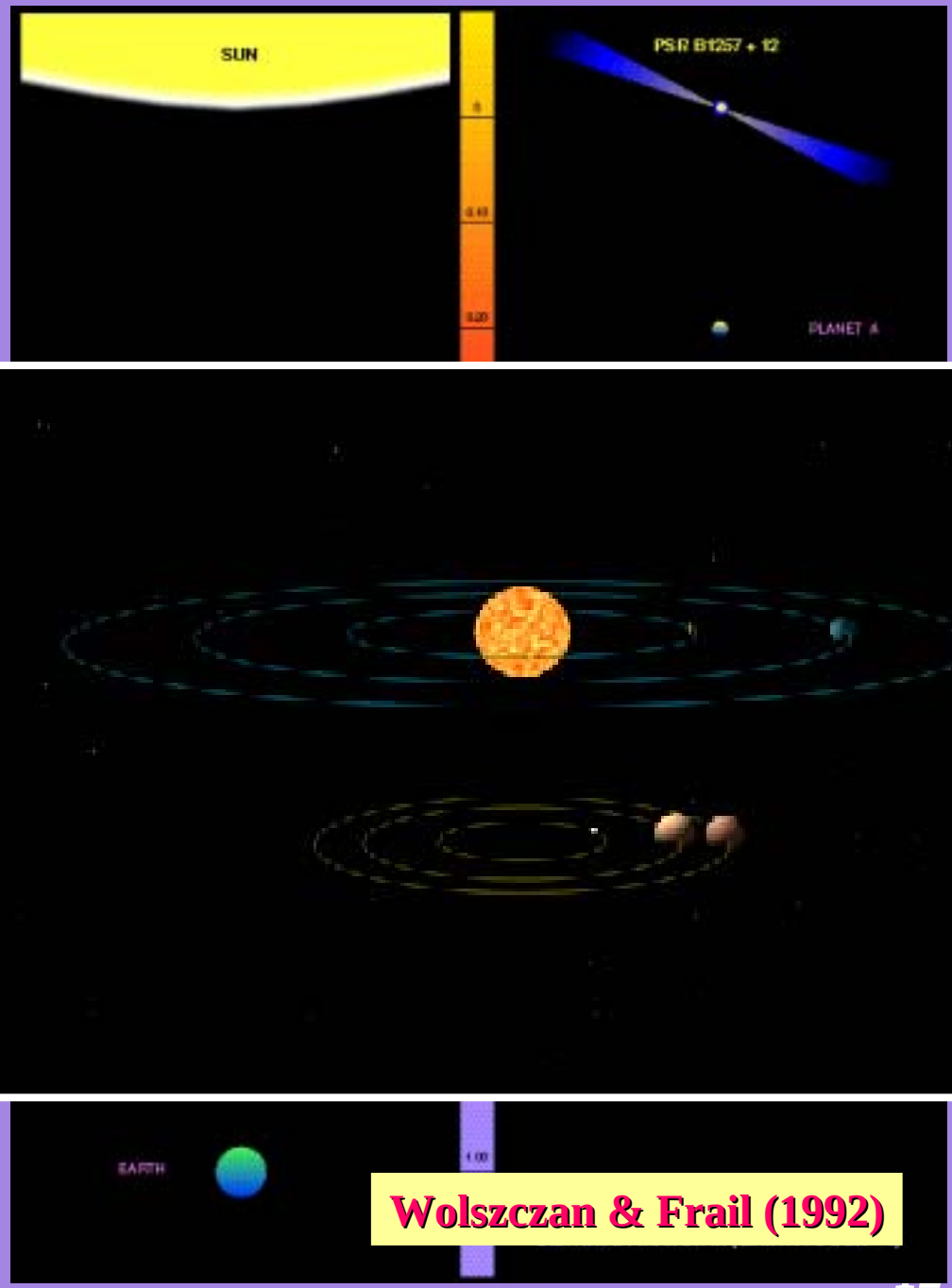
Brief history of the discovery of extrasolar planets

http://exoplanets.org/

- **1992**：three planets around PSR1257-12 (Wolszczan & Frail)
- **1995**：a planet around the main sequence star 51 Pegasi (Mayor & Quelos)
- **1999**：a planetary system (three planets) around the main sequence star υ And (Butler, Marcy & Fisher)
- **1999**：transit of a planet around HD209458 (Charbonneau et al., Henry et al.)
- 67 extrasolar planets are reported as of May, 2001

PSR1257+12: 3 planets around the pulsar

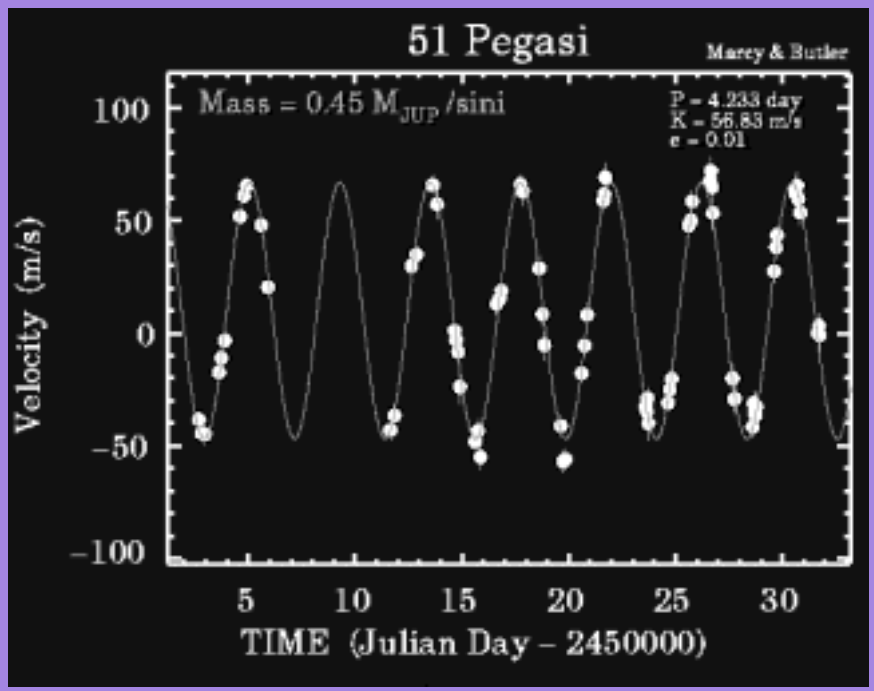
- First discovery of extrasolar planets (most likely 3 !) .
  Just amazing;
  why pulsar ?
  why a planetary system first ?

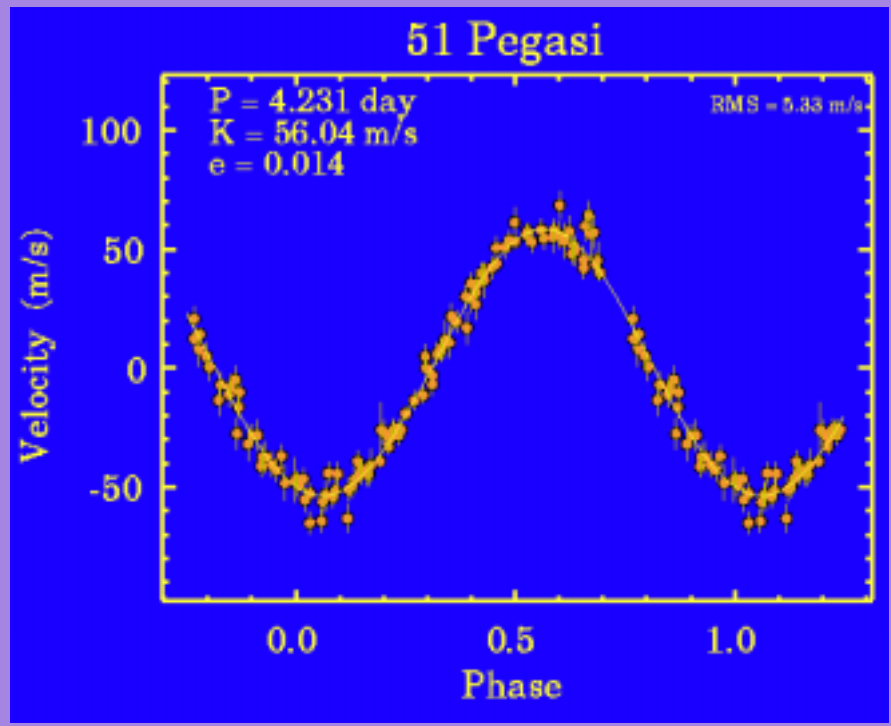


Wolszczan & Frail (1992)

51Pegasi b: a first discovered planet around a main-sequence star

- discovered from the periodic change of the radial velocity of the main star (Mayor & Queloz 1995)

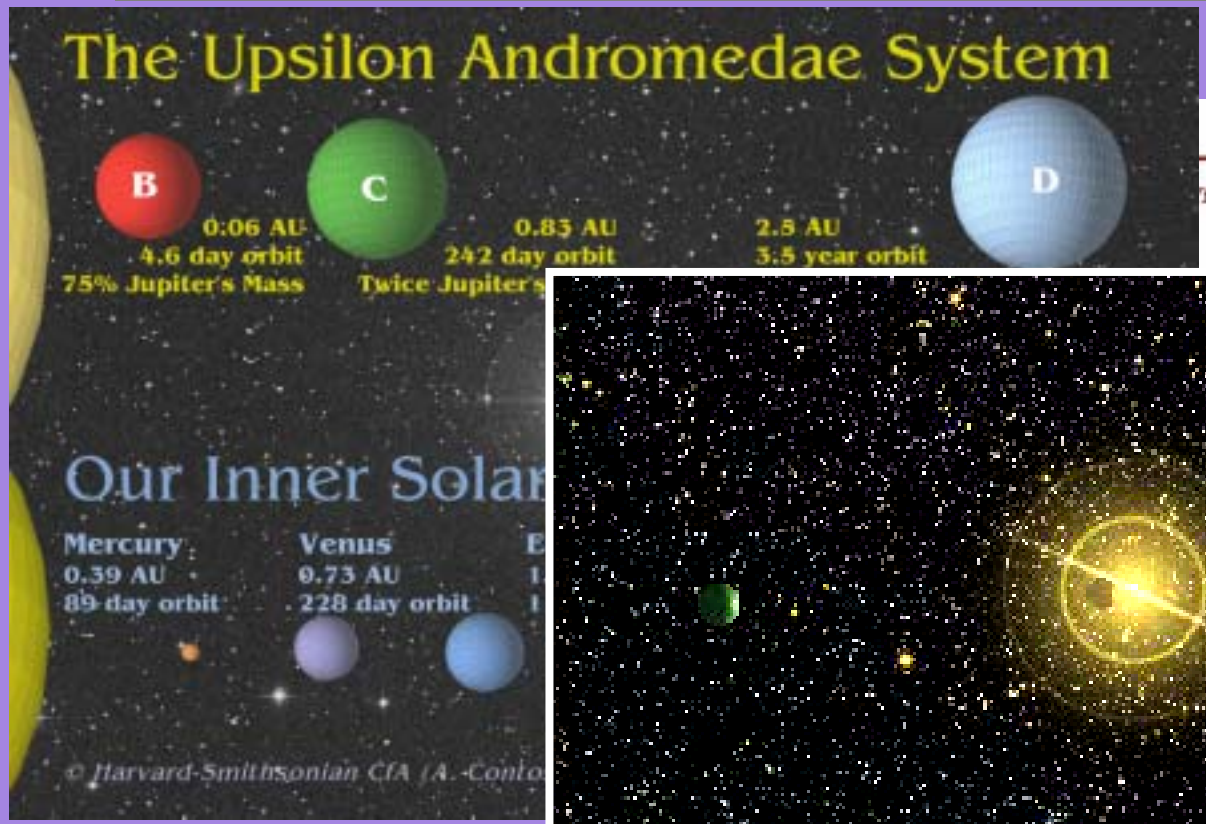


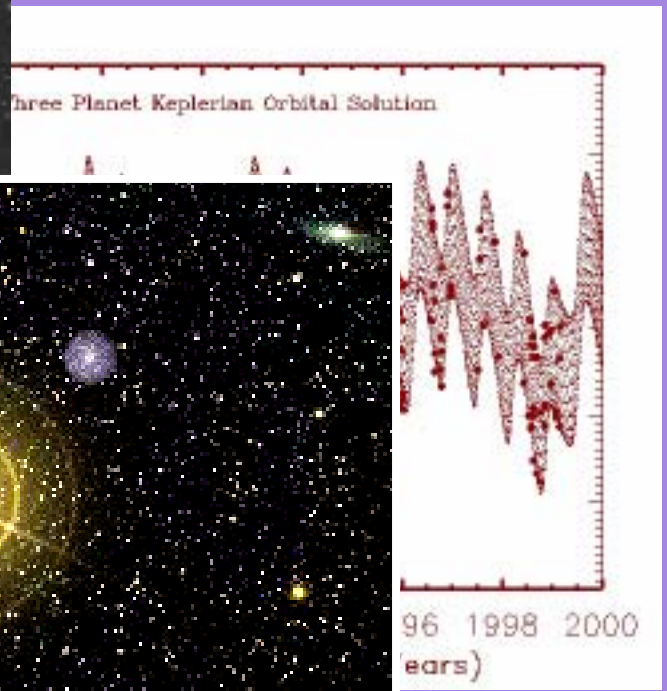


P=4.2 days !

υ And: 3 planets around the star

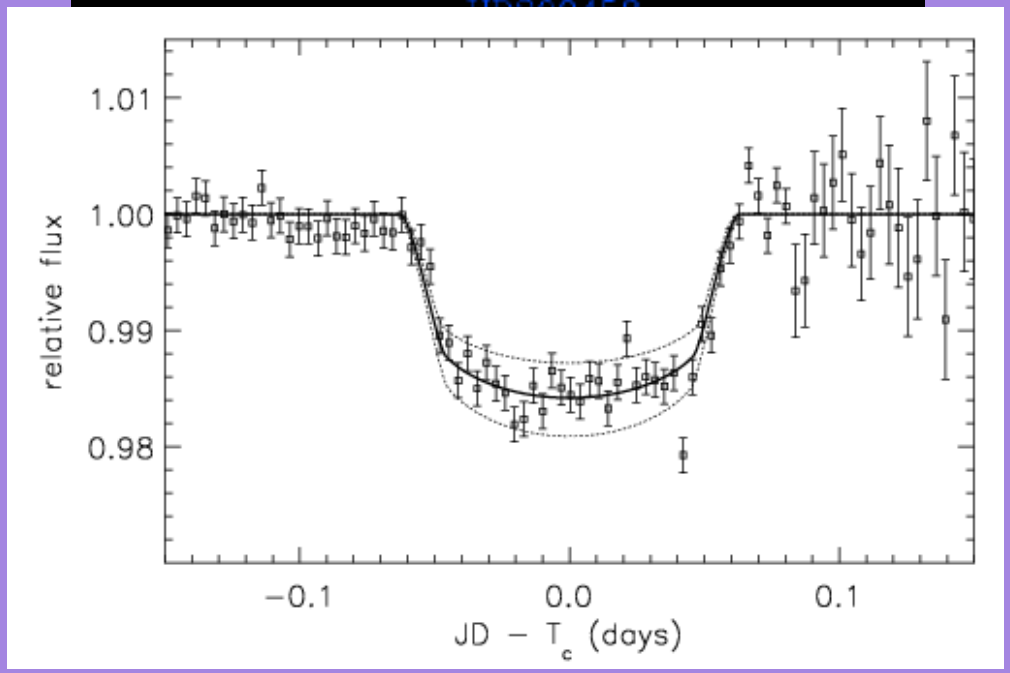
- a first discovered planetary system around a main-sequence star (Butler, Marcy & Fischer 1999)

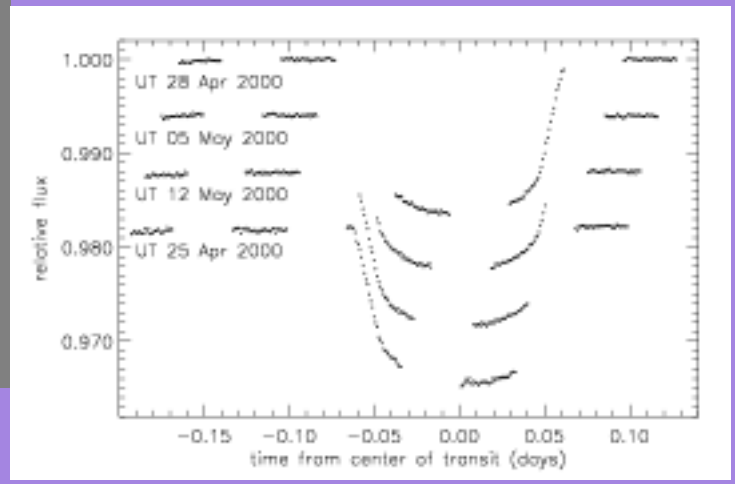


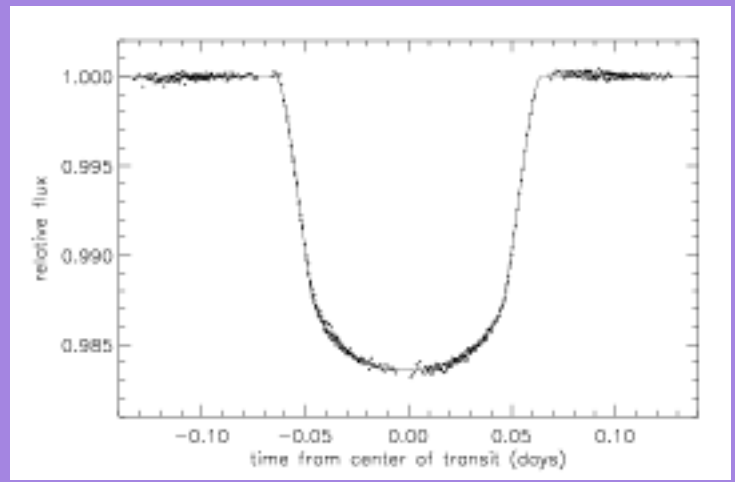


a first discovery of the transit of a planet: occultation in HD209458

- detection of the change of flux of the star at the predicted phase from the velocity measurement (Charbonneau et al. 2000, Henry et al. 2000)



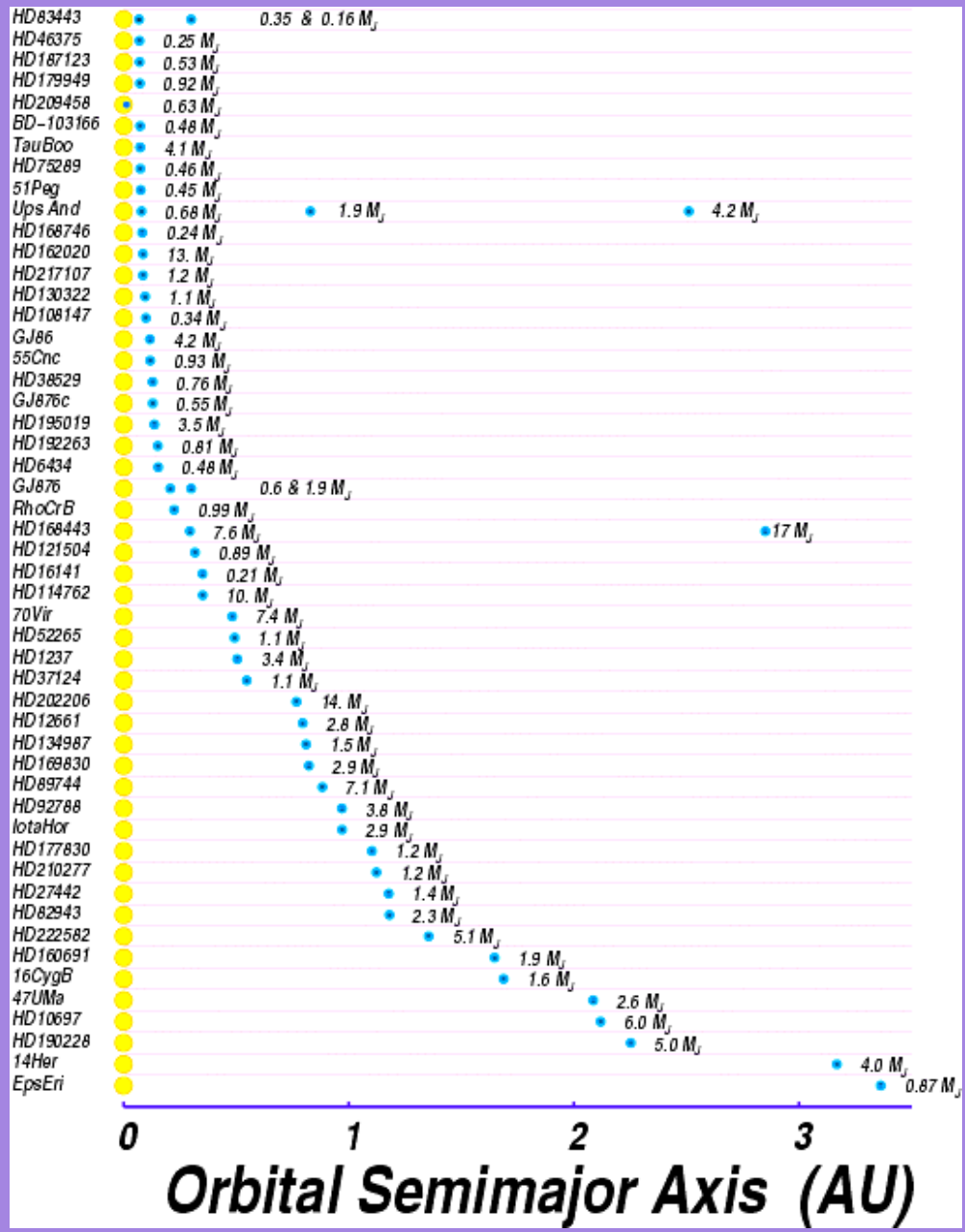




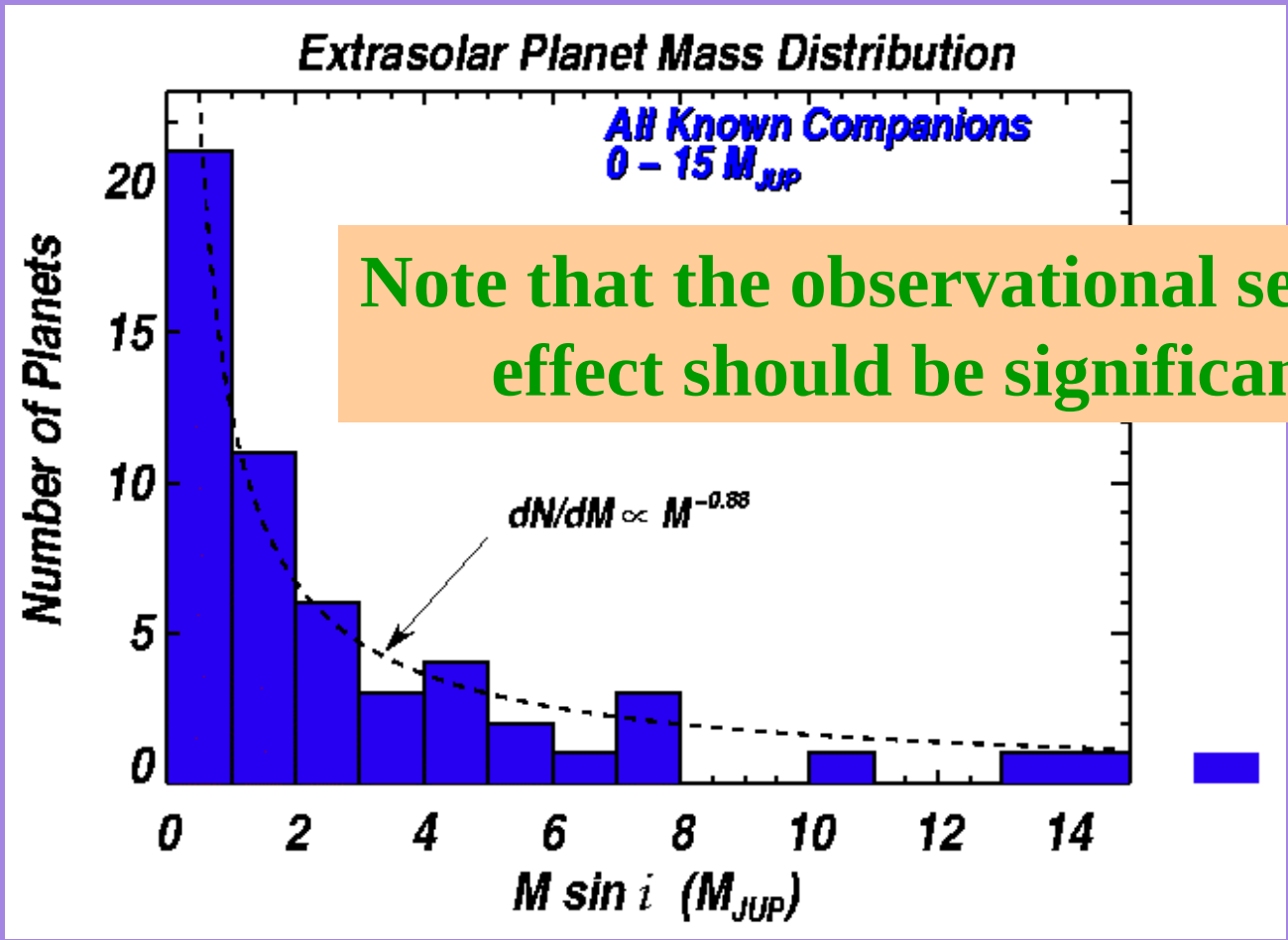
Brown et al. (2001)

A list of discovered extrasolar planets

- many Jupiter-mass extrasolar planets exist !
- their orbital radii are much smaller than predicted before.



mass function of the detected extrasolar planets

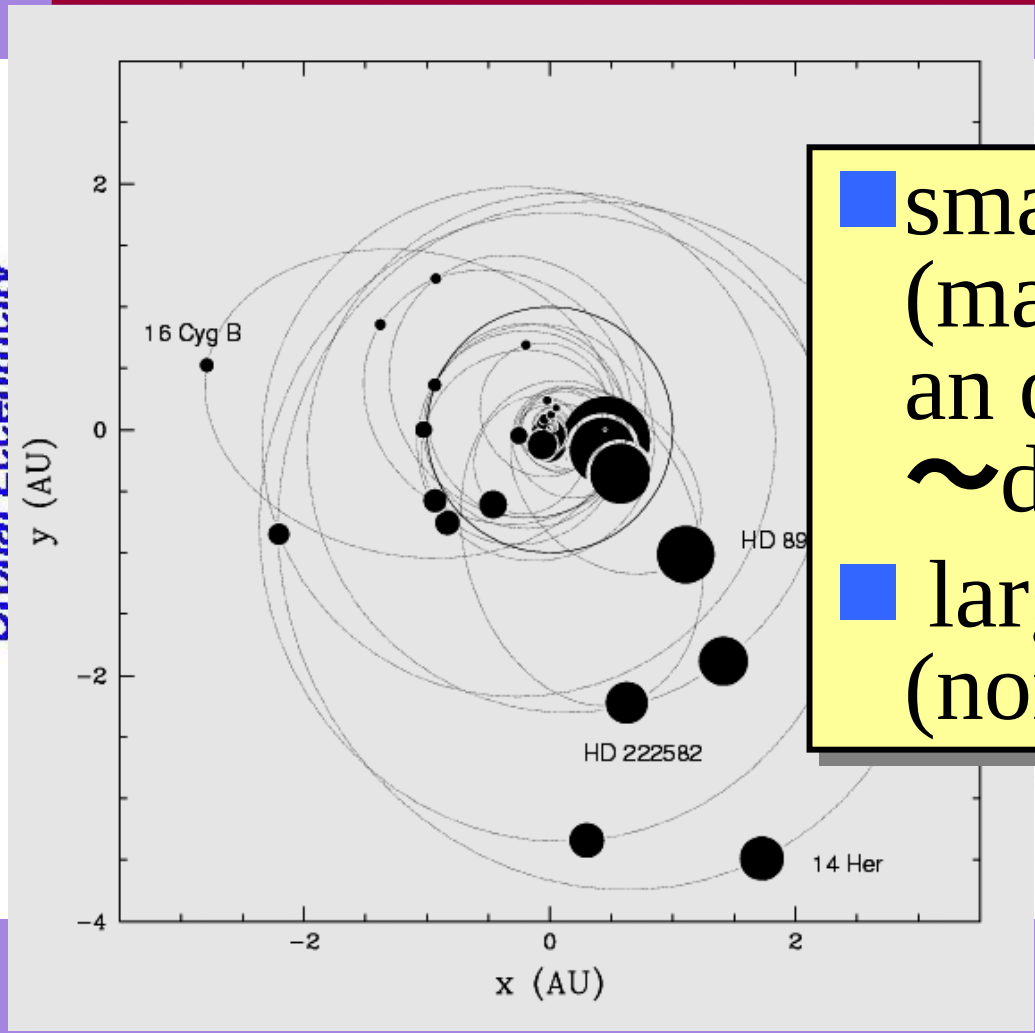


Note that the observational selection effect should be significant !

http://exoplanets.org/

Marcy, Butler, Fischer & Vogt (2000)

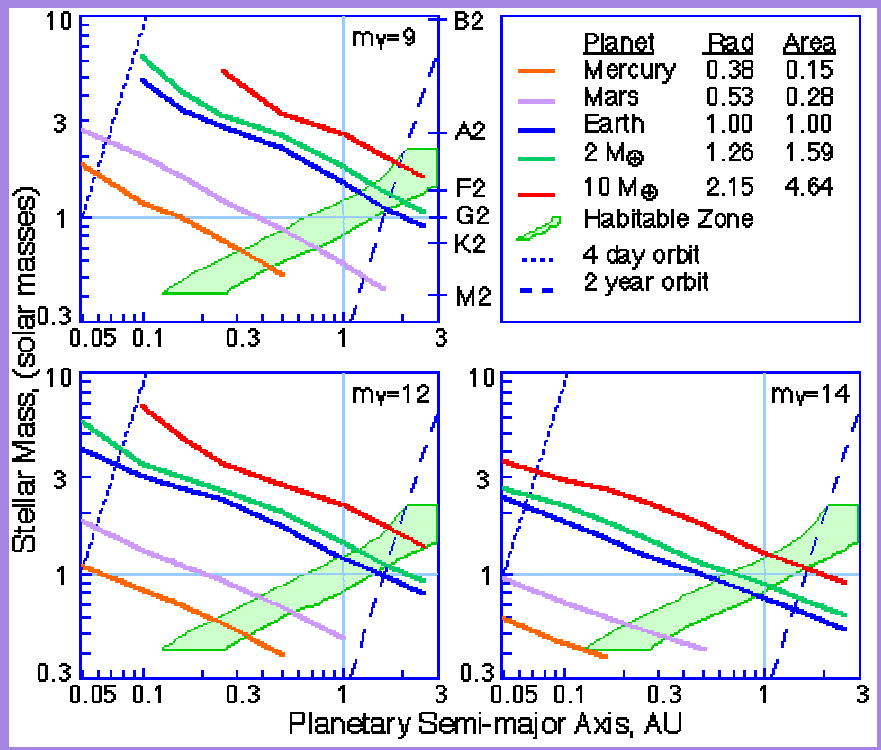
semi-major axis and eccentricity of the planets

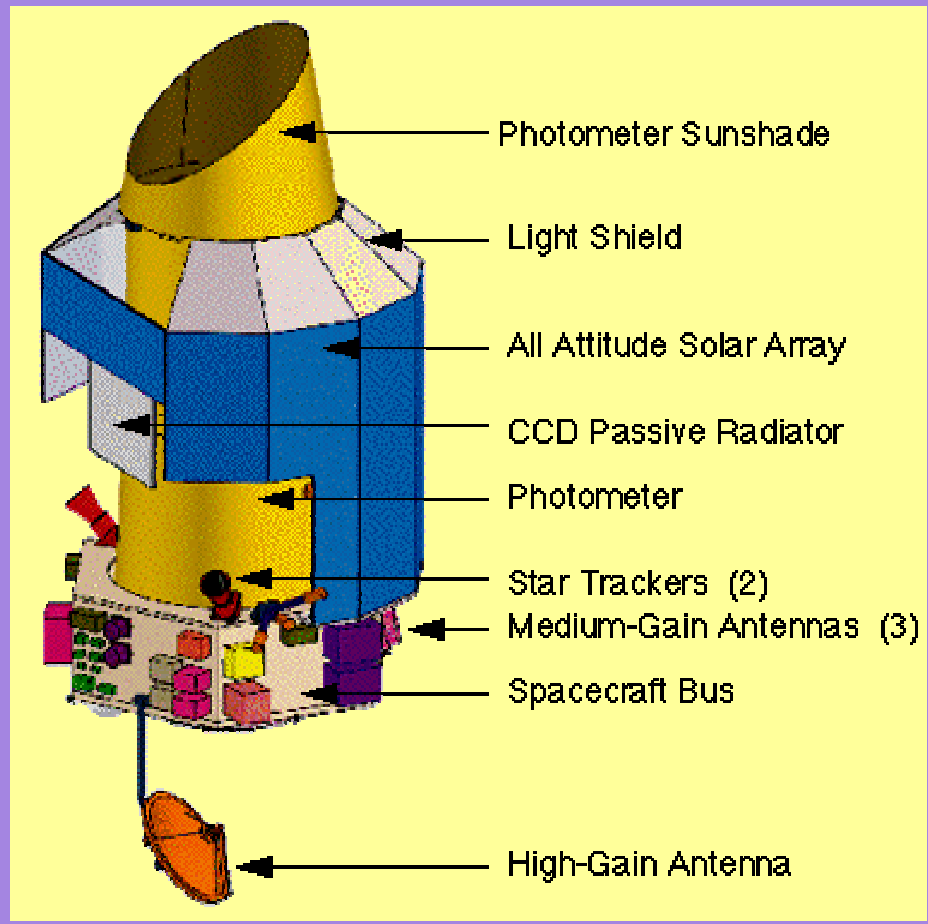


- small orbital radius (many planets with an orbital period of ~days!)
- large eccentricity (non-circular orbit)

Kepler (NASA:launch 2005)

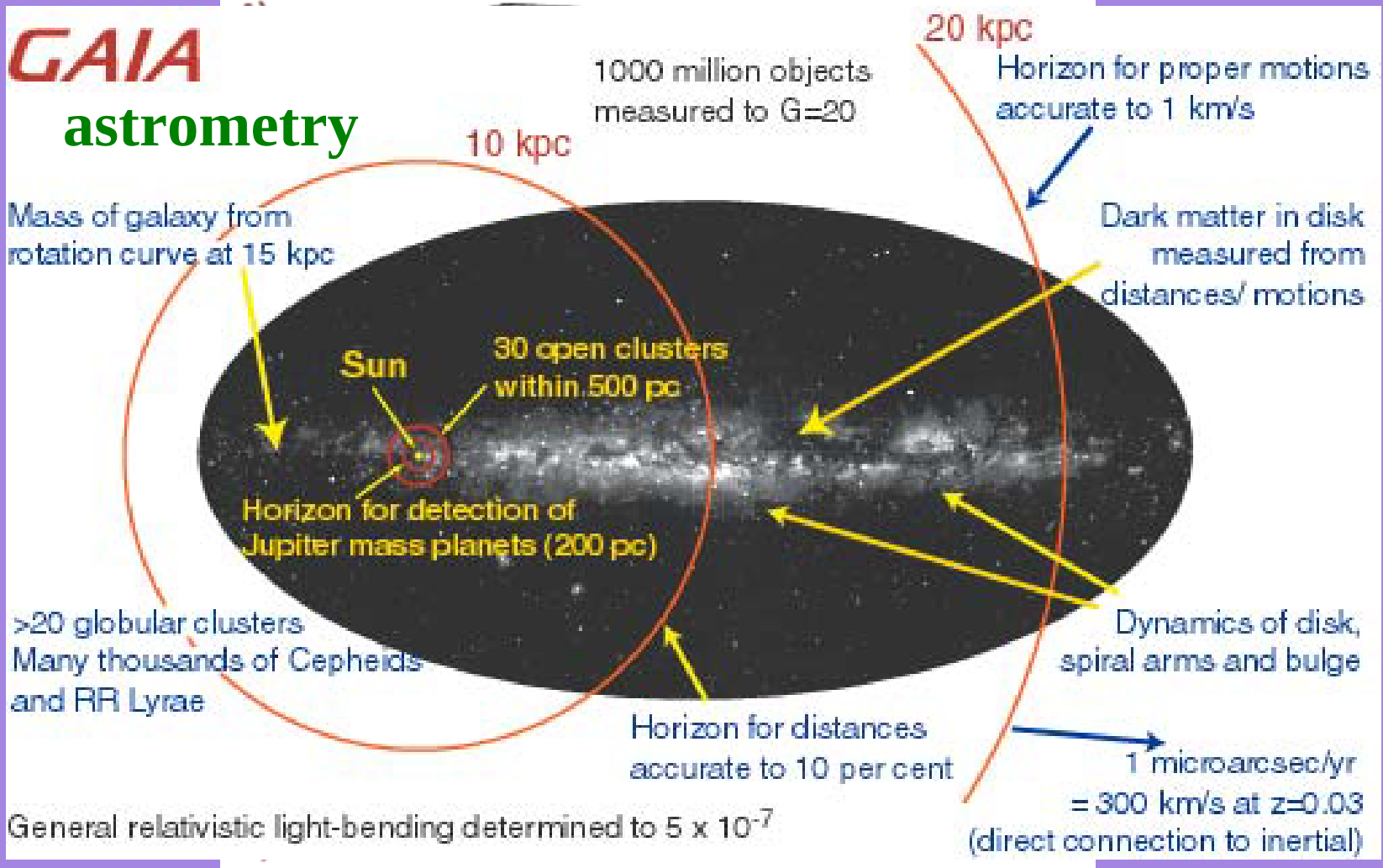
differential photometry





http://www.kepler.arc.nasa.gov/

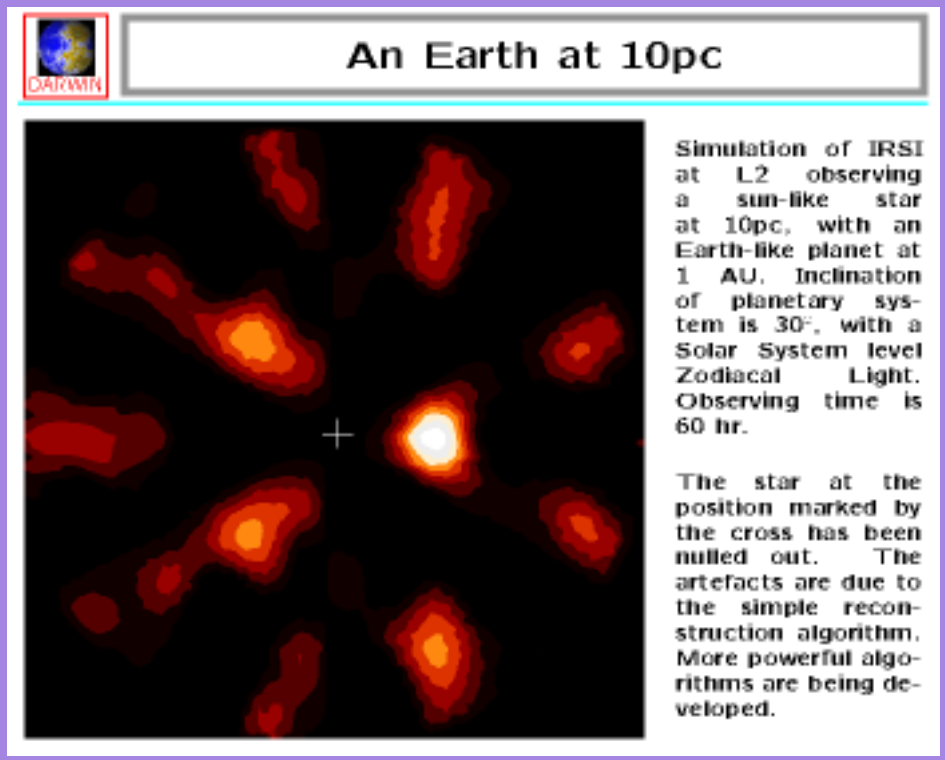
GAIA (ESA: launch 2008-2013)



http://astro.estec.esa.nl/GAIA/

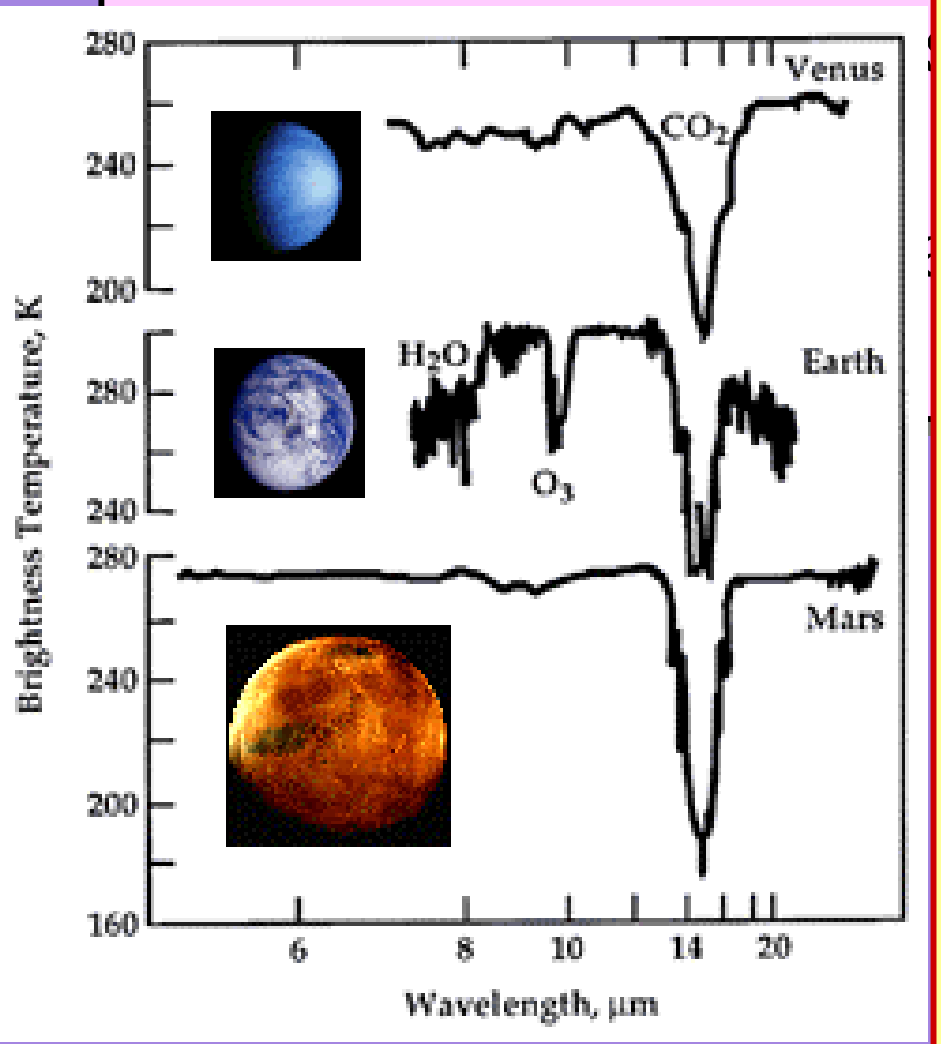
Darwin(ESA:launch after 2015)

infra-red space interferometry: imaging and spectroscopy



http://ast.star.rl.ac.uk/darwin/

Summary and outlook



- Signature of life from the spectroscopic obs.
  - shape of the spectrum
    ⇒ planet's temperature
    ⇒ liquid water ?
  - strong **CO_2** absorption band ⇒ atmosphere ?
  - **O_3** absorption band
    ⇒ abundant oxygen
    ⇒ produced by life ?
  - **H_2O** absorption band
    ⇒ sea in the planet ?

Goal of cosmology in the 21st century

A great Chinese philosopher, Confucius (孔子), was born in 551, B.C. at 中国山東省曲阜.

論語 卷第一 學而第一章 (http://www.confucius.org/)

子曰、學而時習之、不亦說乎、有朋自遠方來、
不亦樂乎、人不知而不慍、不亦君子乎。

孔子说：「不断学习，并且应用出来，不是很值得高兴吗？远方的朋友来访，不是很值得快乐吗？没有人欣赏也不含怒，不是个君子吗？」