Astrobiología

- INTRODUCCIÓN
  - Kepler
  - Galileo
  - Europa
- PLANETAS EXTRASOLARES
  - Métodos de búsqueda
  - Velocidades radiales
  - Tránsitos
- ESPECTROSCOPÍA
  - De transmisión
  - De reflexión
- BIOMARCADORES
  - Expectativas

Kepler's third law

$$G(\mathcal{M}_* + \mathcal{M}_p)P^2 = 4\pi^2 a^3$$

P = orbital period
a = semimajor axis
M* = Solar mass
Mp = planet mass

KEPLER MISSION: A SEARCH FOR HABITABLE PLANETS

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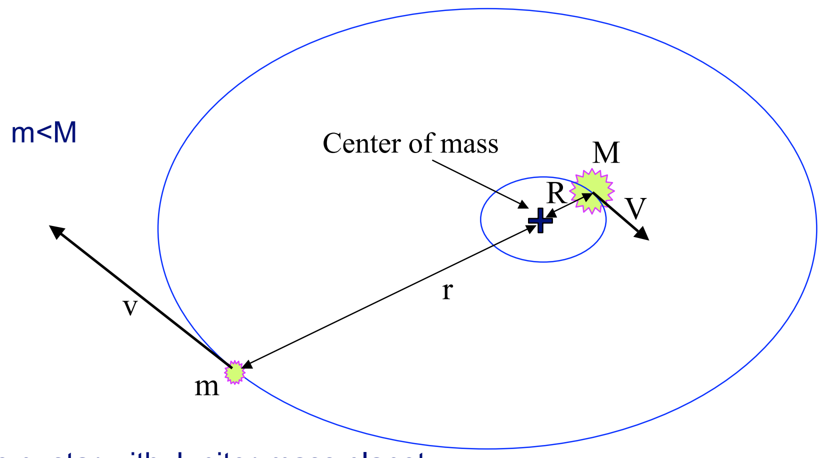
Orbits

m<M

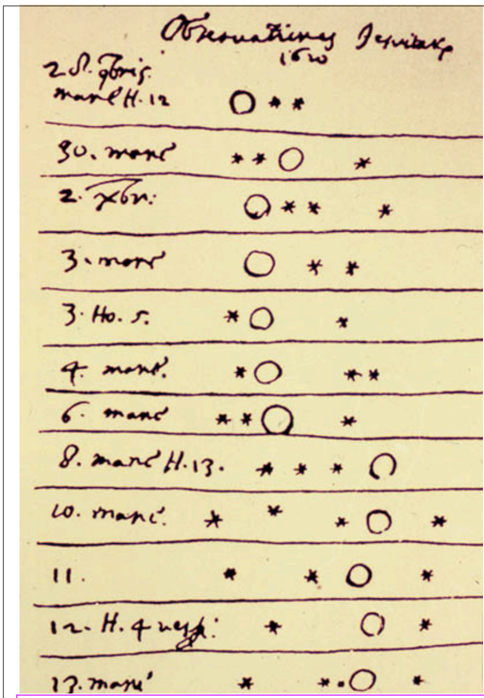


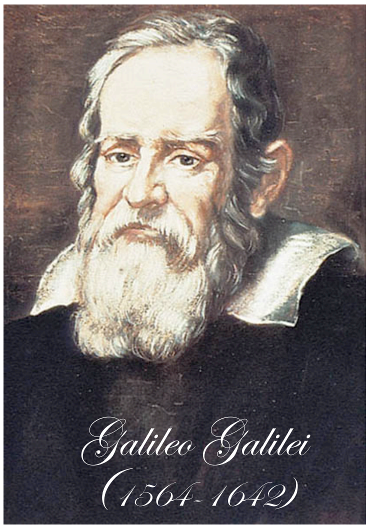
e.g. star with Jupiter-mass planet

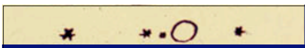
V_J=10km/s, M_J=0.001Mo

→ *Vo=10m/s*

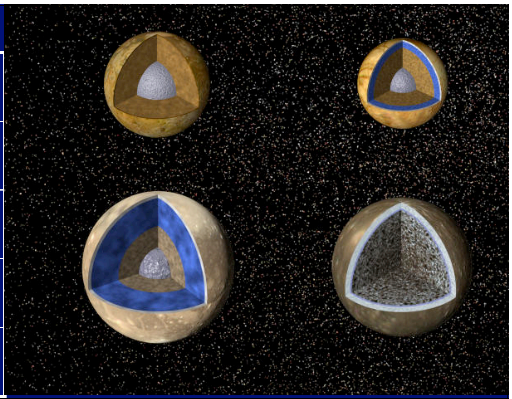
m/M = V/v = R/r

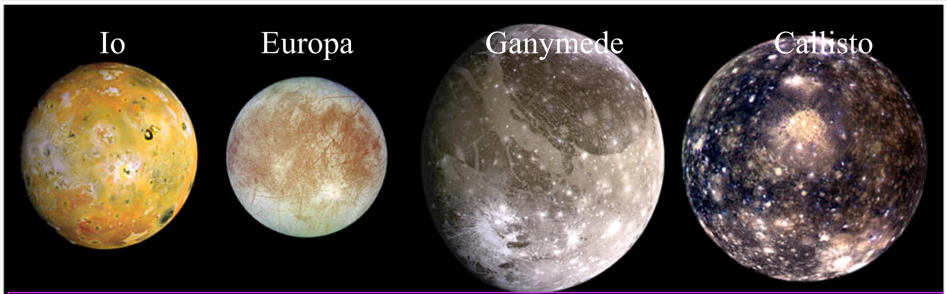






Satélite	Diám.	Densidad	Superf.
Io	3640 km	3.5 g/cm3	Silicatos y sulfuro
Europa	3130 km	3.0 g/cm3	Hielo
Ganímede	5280 km	1.9 g/cm3	Hielo
Callisto	4840 km	1.8 g/cm3	Hielo





Why are exoplanets so difficult to discover?

The distance problem: stars are far far away!

- A problem of brightness:
  planets are intrinsically faint
- A problem of contrast:
  planets live next to shining stars
- A problem of resolution:
  planetas are too close to stars

What is a planet?

The discovery of planets (particularly transits) forced to discuss the issue, because low mass objects have similar sizes.

Planets are opaque bodies that reflect light from their parent stars (except Jupiter decametric emission).

The planet definition depends on the formation mechanism.

A ``planet'' is an object that has a mass between that of Pluto and the Deuterium-burning threshold* and that forms in orbit around an object that can generate energy by nuclear reactions.

(Compare with other IAU definitions)

Here I adopt simple definitions using mass:

- $M/M_{\odot} > 0.080$ is a star
- $0.015 < M/M_{\odot} < 0.080$ is a brown dwarf
- $M/M_{\odot} < 0.015$ is a planet

IAU

Sydney 2003

Search techniques

- Radial velocities
- Transits
- Astrometry
- Microlensing
- Timing
- Direct detections
- Other methods

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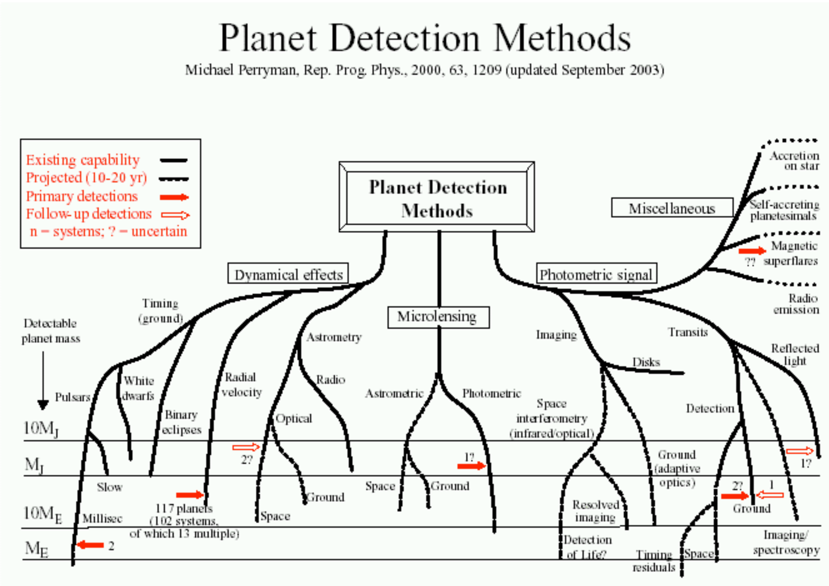
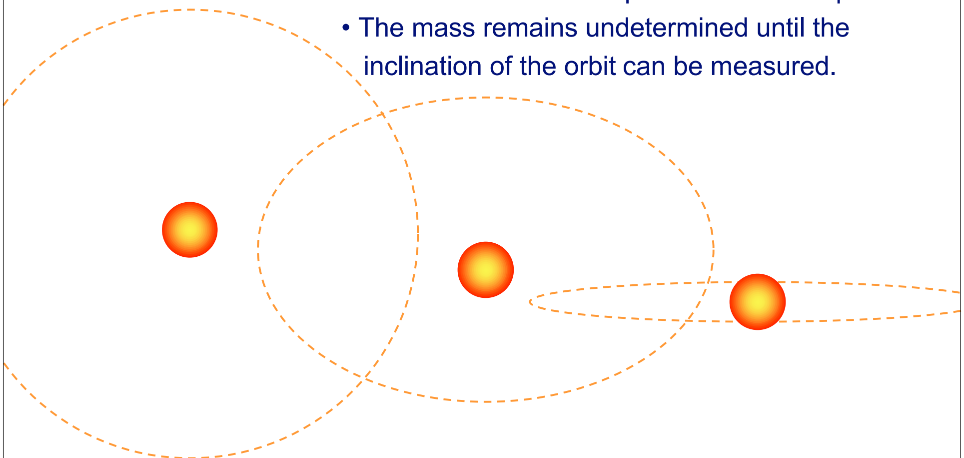
Search techniques



Radial Velocities

Problems:

- Costly in telescope time
- Bias towards massive planets and short periods
- The mass remains undetermined until the inclination of the orbit can be measured.



- Radial velocity (RV) curve: doppler shift vs time
- We measure the period P from the RV curve:
- We get the semimajor orbital axis a from Kepler's 3rd Law:

$G(M_p + M_*)P^2 = 4\pi^2 a^3$

- The velocity of the planet is:

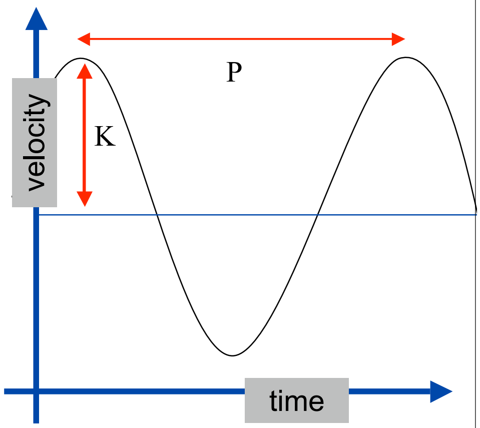
$V_p^2 = GM_*/a$

- From momentum conservation:

$M_p = M_* V_* / V_p$

- We measure the amplitude K of the RV curve: $K = V_* \sin i$

→ we obtain $M_p \sin i$



- Aside from the M sin i and P, the shape of the radial velocity curve gives the orbital eccentricity.

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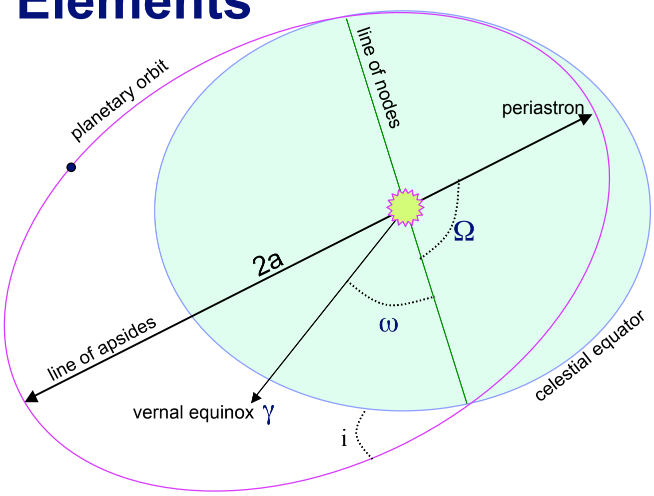
Orbital Elements



- Semimajor axis a
- Period P
- Excentricity e
- Inclination i
- Longitude of the ascending node ω
- Argument of the periastron Ω
- Time of periastron passage τ

RV curves give P, a, e, Ω, τ

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Radial velocities

$M_\odot = 1.989 \times 10^{30}$ kg
$M_{Jup} = M_\odot/1048$
$M_{Sat} = M_\odot/3497$
$M_{Tierra} = M_\odot/332946$

- Planets orbit around the center of mass of the Solar system. This is located close to the center of the Sun because it is by far the most massive body. But the Sun also orbits around this barycenter.
  - Note that Jupiter has contains more than double the mass of all the other planets together.
- Jupiter moves the Sun with an amplitude of *A = 12.5 m/s* and a period of *P = 12 yr*. For Saturn *A = 2.7 m/s*, and *P = 30 yr*.
- Nowadays the search is sensitive to planets with orbits of a < 5 a.u. and planet masses of $M_P > 0.2\ M_J$.
- Current records: a few hot Neptunes with ~10 M_E, and one Super-Earth with ~5 M_E. We cannot detect Earth mass planets using this technique yet.

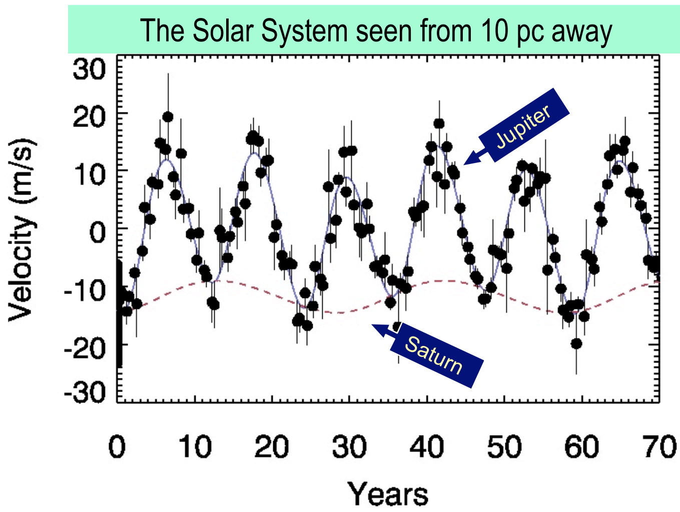
Radial velocities

precision = 10 m/s
→ Jupiter,

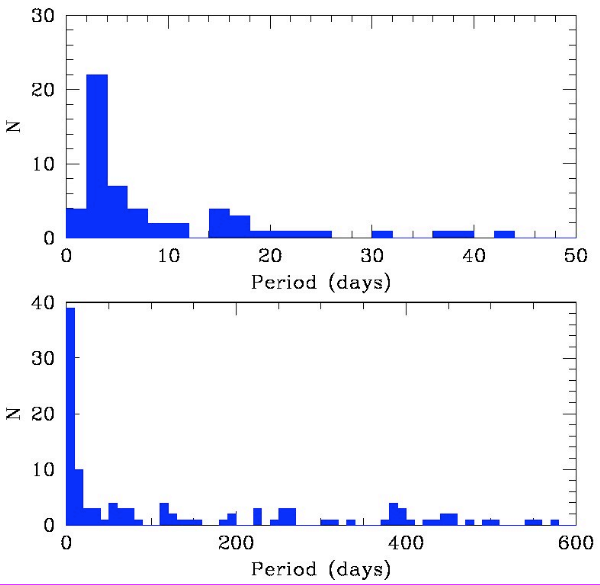
precision = 3 m/s
→ Saturn,

precision = 1 m/s
→ Neptune,

precision = 1 cm/s
→ Earth



Hot Jupiters



Very short period planets are easy to find.

The Roche limit for solar mass stars is:

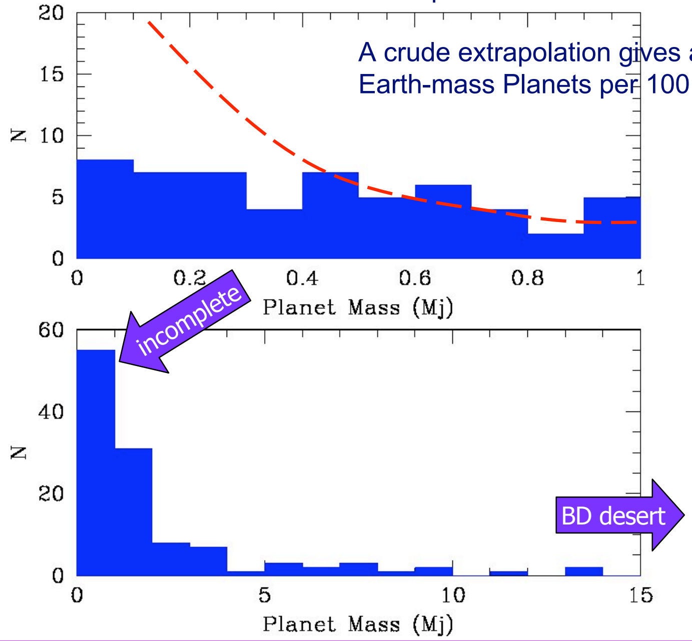
$R_R = 2.44\, R_*\, (r_*/r_p)^{1/3}$

corresponding to

P~1d. There are planets all the way to the Roche limit.

Incompleteness severe for M < 1 Mj

A crude extrapolation gives a few Earth-mass Planets per 100 Stars



Metallicities

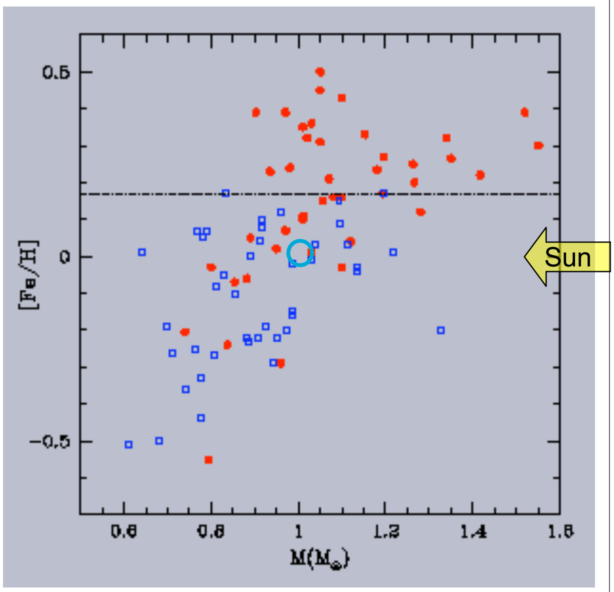
Metallicities vs masses for stars with planets (red circles) and without planets (blue squares).

Conclusion: stars with planets are metal rich.

Change the strategy: select the more metal-rich objects.

N2K program: next 2000 stars with 7<V<9 (Fischer et al. 2005)

Santos et al. 2000

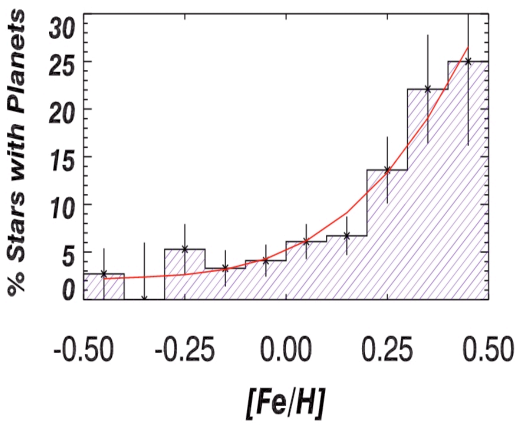


Metallicities

Why are stars with planets more metal-rich?

1. The high metallicities are primordial, and favor the formation of planets simply because there is more heavy material for them.
2. The high metallicities are a result of pollution by the same planetary material.

Normalized metallicity distribution: planets favor metal-rich stars



Fischer & Valenti 2005

The answer may be found by studying different stellar populations across the MW.

The Extrasolar Planets Encyclopaedia

Established in February 1995

Home | **Interactive Catalog** | Bibliography | Research | Meetings | Other Sites

Interactive Extra-solar Planets Catalog

Version: 2.02 Maintained by © 2008 *Jean Schneider* (*CNRS-LUTH, Paris Observatory*)
Technical support : ***Jonathan Normand***

For the use of this catalog README fir

All Catalogs

update : **04 November 2008**

All Candidates detected	**322 planets**
Candidates detected by radial velocity or astrometry *update : 03 November 2008*	261 planetary systems 303 planets 30 multiple planet systems
Transiting planets *update : 28 October 2008*	52 planetary systems 52 planets 0 multiple planet systems
Candidates detected by microlensing *update : 19 September 2008*	8 planets
Candidates detected by imaging *update : 24 September 2008*	6 planets
Candidates detected by timing *update : 14 September 2007*	3 planetary systems 5 planets 1 multiple planet systems

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Jean Schneider *CNRS/LUTH - Paris Observatory*

The URL is exoplanet.eu

Update : 08 November 2008

Latest news :

- **03 November** : Three new planets: HD 143361 b, HD 43848 b and HD 48265 b (Minniti et al)
- **28 October** : Six new planets: BD-17 63 b, HD 131664 b, HD 145377 b, HD 153950 b, HD 17156 b and HD 20868 b (Moutou et al)
- **29 September** : One planet, two names: WASP-11 b/HAT-10 b (West et al. and Bakos et al.)

News Archives

Tutorials
Update : 28 May 2008

Interactive Catalog
readme
Update : 04 November 2008 **322 planets**

Searches for Extrasolar Planets
Update : 05 November 2008

Bibliography
Update : 08 November 2008

Search for Life
Update : 12 July 2004

Illustrations
Update : 29 March 2005

Theory Work
Update : 29 March 2005

Other sites
Update : 24 September 2008

Transits

- Need exquisite measurements of the stellar brightness, sensitive to giant planets.
- Knowing the dependence of R_* with M_* for MS stars, the transit time depends on the orbital period and the star mass as:

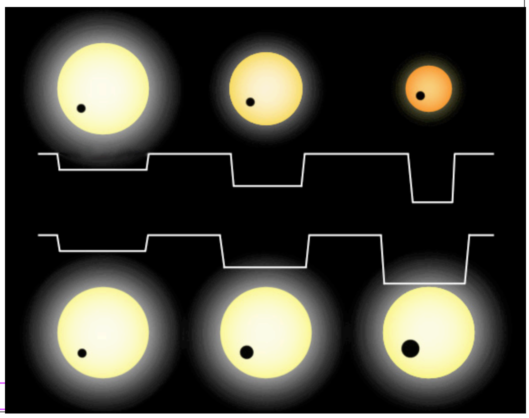
$$t_T = 13(M_*/M_o)^{1/2}(a/1AU)^{1/2} \text{ hours}$$

Need M_*, R_*

- The transit depth depends on the relative planet and star sizes:

$$A = (R_p/R_*)^2$$

- For typical main-sequence stars:
  - Transit durations 2h – 20 h
  - Transit depths 0.0001-0.01 mag



- Examples:

Jupiter transit 0.01 mag, t_T=30h
Earth transit 0.000084 mag, t_T=13h

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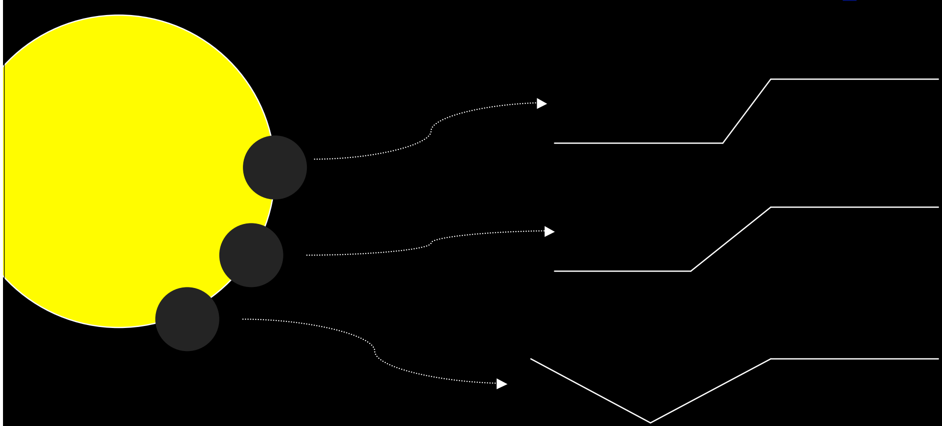
Transit shape



→ Dependence with the orbital inclination: we know the inclination angle i from the shape of the light curve at ingress and egress.

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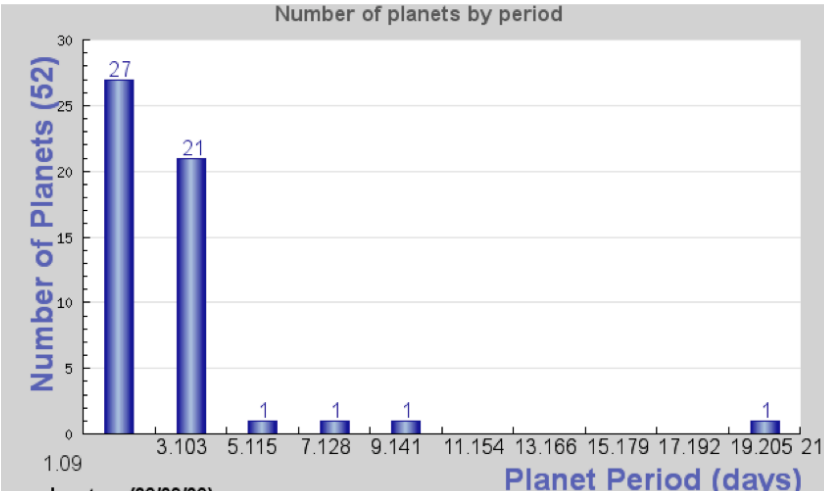
Transiting planets



There is a clear bias towards short period planets

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Extrasolar planets 13 years later

- 322 exoplanets discovered so far (www.exoplanet.eu Nov 2008)
- The majority were found using precise radial velocities, which give ***M sin i***
- A few of them transit in front of their parent stars
- Importance of transiting extrasolar planets: they give ***R, i*** ➔ ρ

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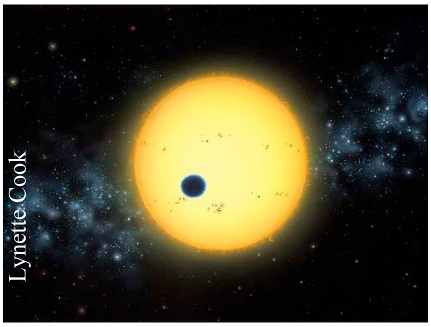
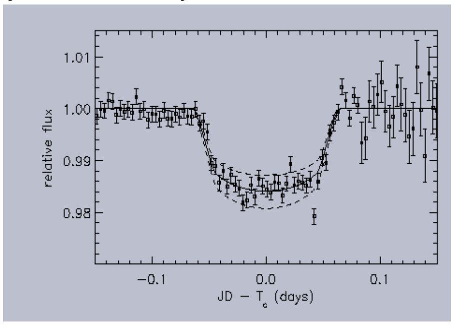
HD209458 transit

- Tested method: Charbonneau et al. (2000) and Henry et al. (2000) found transits in a planet previously discovered by radial velocities.



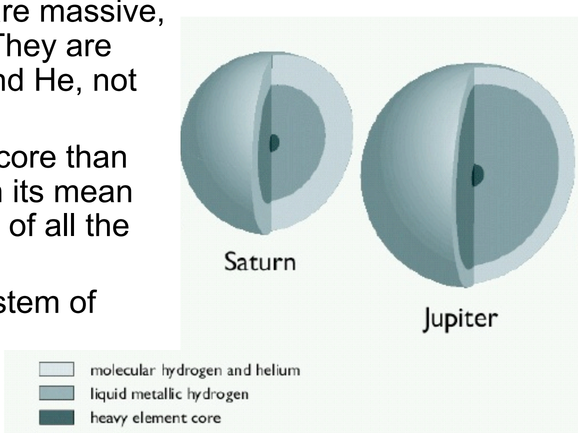


- P = 3.52 d
- M_p = 0.69+/-0.05 M_{jup}
- a = 0.047 UA
- R_s = 1.15+/-0.05 R_o
- R_p = 1.35+/-0.06 R_{jup}
- i = 86.6+/-0.14 deg
- t_T = 184.25 min
- A = 0.015 mag

ρ = 0.4 g/cm^3
➔Gas giant

Gas giant planets

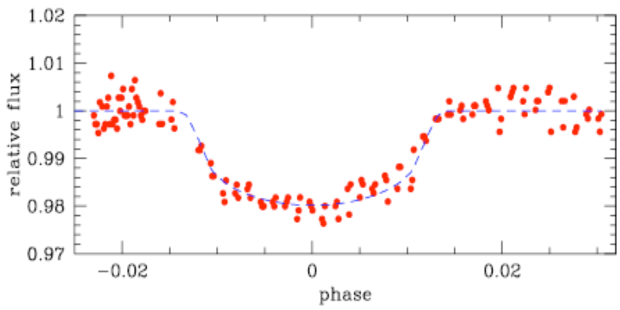
- Jupiter and Saturn are massive, with high gravities. They are made mostly of H and He, not in Solar proportion
- Saturn has a larger core than Jupiter, even though its mean density is the lowest of all the planets
- They have a rich system of satellites.
- They have rings.



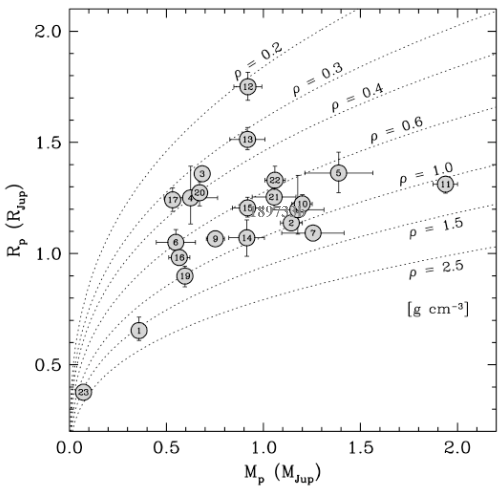
Transits at UC

Example: transit of the hot Jupiter OGLE-TR-111-b, observed with VLT

(J.M. Fernandez, R. Diaz, S. Ramirez, et al. 2007, The Astrophysical Journal)



Radius vs Mass



There are 50 transiting exoplanets known. These are important because we know their mean densities and can test models.

Some of them have radii inflated due to the stellar irradiation:

- Models without irradiation → 1Rj
- Models with irradiation → >1Rj

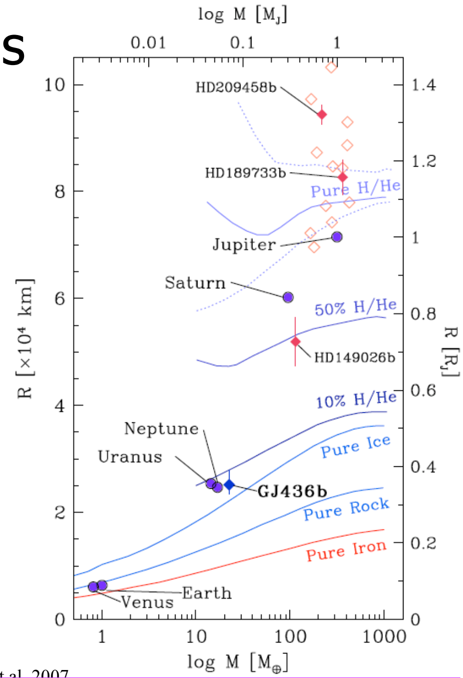
PLANETARY MODELS: Allard et al. 2003, Sudarsky et al. 2003, Baraffe et al. 2003, 2005, Burrows et al 2002, 2003, Chabrier et al. 2004, Bohdenheimer et al. 2005.

The models are complicated because they have several ingredients: composition, albedo, irradiation, atmospheric structure, particle condensation, clouds, rain, snow, solid core, etc.

Extrasolar Neptunes

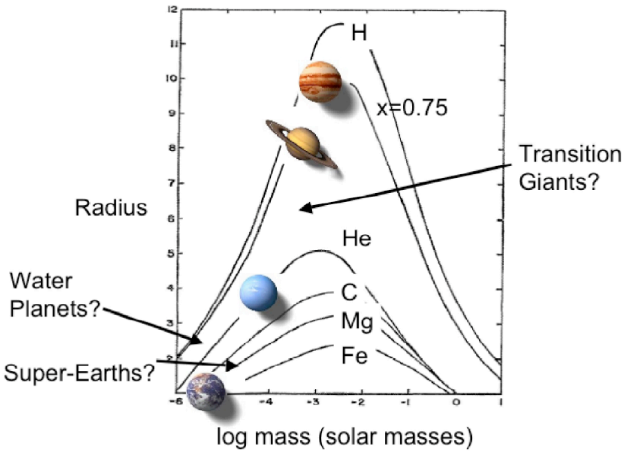
Transit of a Hot Neptune

Detection of the planetary transit in the nearby M-dwarf star GJ 436 using small telescopes. With R = 0.35 R_J, this is the smallest extrasolar planet detected so far. The small size confirms that it is a Neptune-like planet, probably made of ice, and with an atmosphere of light elements (H, He).



Guillon et al. 2007

Other kinds of planets missing?



- ✓ **Transition giants:** with low densities, between Saturn and Neptune
- ✓ **Water Planets:** like Neptune, with low densities
- ✓ **Super Earths:** rocky planets, but more massive than Earth

Some exoplanets… now what?

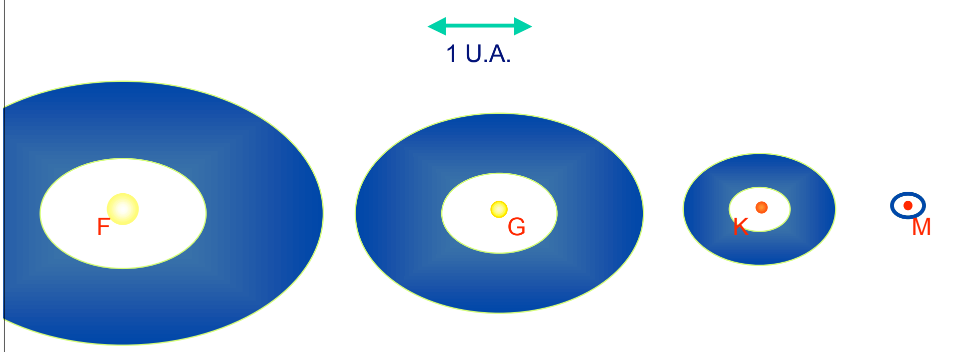
- The looooong road between discovery and real knowledge.
- E.g. Galileo Galilei vs Galileo Mission

Learn more!!!

The stellar habitable zone

Defined as the range of planetary orbits where the water remains liquid. In the Solar system, the HZ is located between the orbits of Venus and Mars. But watch out for exceptions:

- Some eccentric planets can spend most of the time in the HZ.
- Tidal heating of moons not considered, this can provide liquid water all over the Solar system (e.g. Europa)



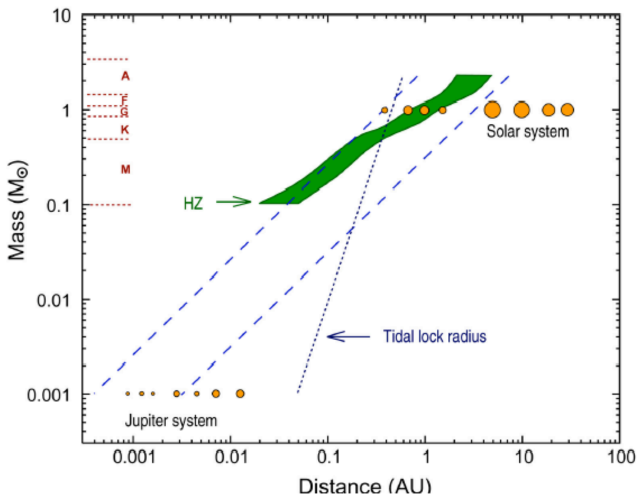
Seas of the Solar System

¿How many worlds with oceans of liquid water in the Solar System?

1. Earth HZ
2. Europa
3. Callisto
4. Ganymede
5. Enceladus
6. Uranus
7. Neptune
8. …

Also: Titan has hydrocarbon seas

The stellar habitable zone

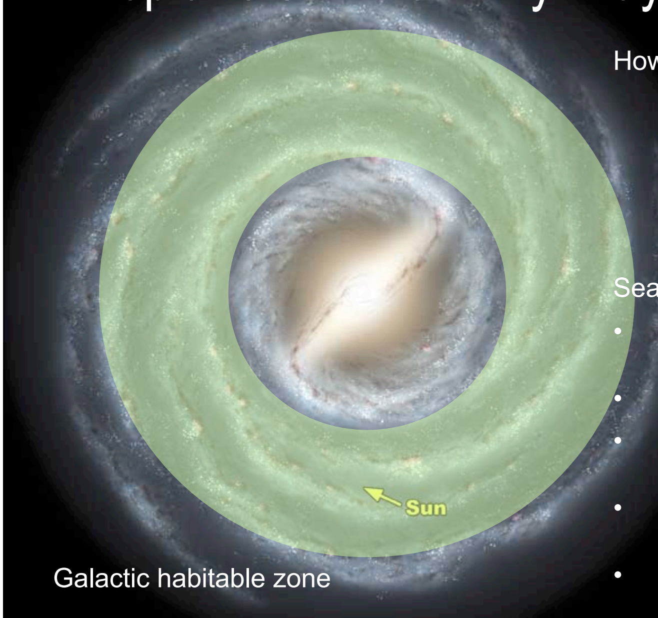


Range of planetary orbits where water remains liquid

Kasting et al. (1993)

For late-type MS stars, if the planets are tidally locked, they rotate very slowly, giving always the same face to the star.
E.g. P_{rot} = 10 hr for Jupiter, P_{rot} = 4 d for HD209458.

Exoplanets in the Milky Way

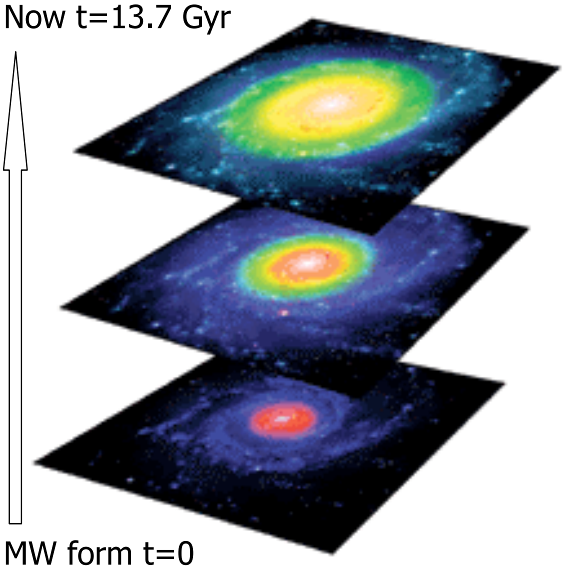


How is the distribution of planets throughout the Galaxy? We do not know, but it must be different according to the metallicity.

Searches in:

- The Solar vicinity (RV searches)
- The disk (OGLE)
- The bulge (Sahu et al. 2006)
- Globular clusters (47 Tuc, Gililland et al. 1997)
- Open clusters

Exoplanets in the Milky Way



How is the distribution of planets throughout the Galaxy?

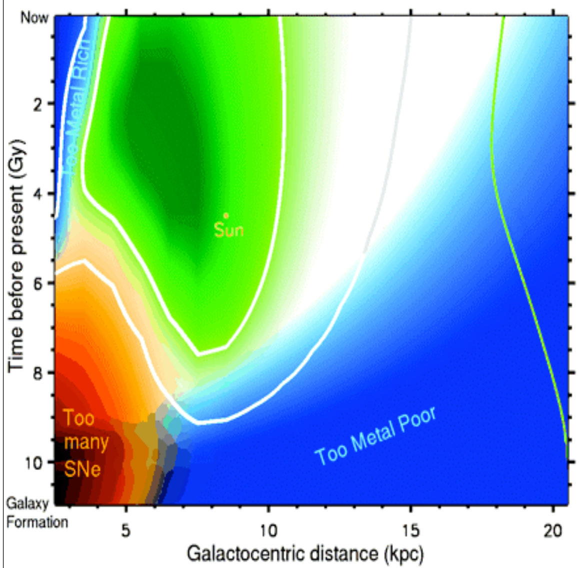
Where is the Galactic habitable zone?

We do not know, but metals are needed to form planets and life.

How does this Galactic habitable zone evolve with time?

Gonzalez 2000, Linewaever et al. 2004

Exoplanets in the Milky Way



Main model assumptions:

No life if [Fe/H] < -1.0, ideal -0.5 < [Fe/H] < 0.3

T = 4 ± 1 Gyr needed for the development of complex life.

No life if SN rates are 20 times larger than the present local value.

~5000000000 stars available, ~70% of them should be older than the Sun.

Linewaever et al. 2004

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Search techniques

- Radial velocities
- Transits
- Astrometry
- Microlensing
- Timing
- Direct detections
- Other methods

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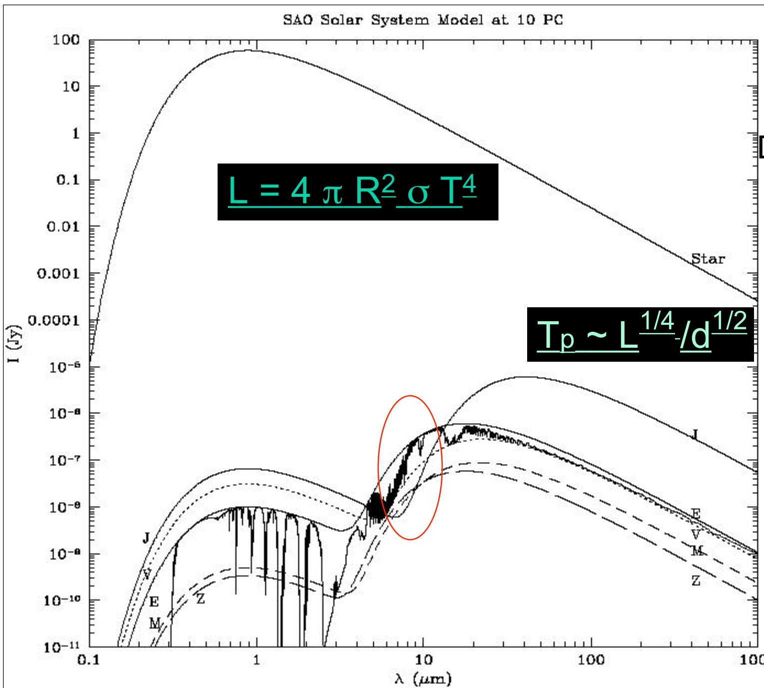
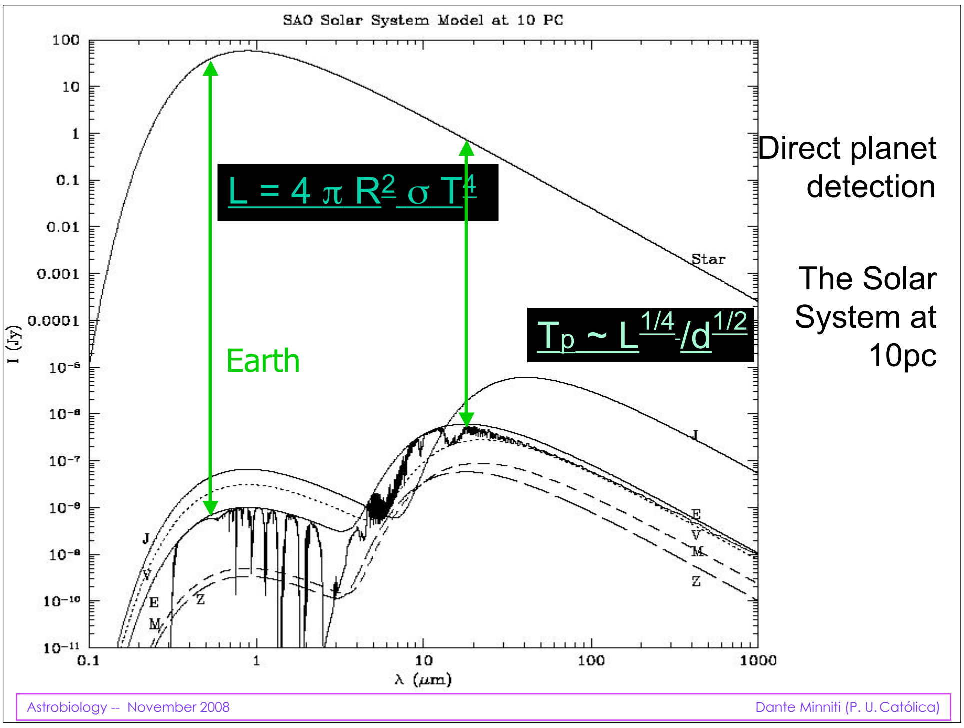
Search for extrasolar planets

- The searches using radial velocities, timing, microlensing, and astrometry depend on the masses of the stars/planets.
- The transit searches depend on the sizes of the stars/planets.
- The direct detections depend on the brightness of the stars/ planets (i.e. sizes, temperatures, albedos, semimajor orbital axis).



Direct planet detection

The Solar System at 10pc


SAO Solar System Model at 10 PC
L = 4 π R2 σ T4
Tp ~ L1/4/d1/2
Earth
Star
Direct planet detection
The Solar System at 10pc
I (Jy)
λ (μm)
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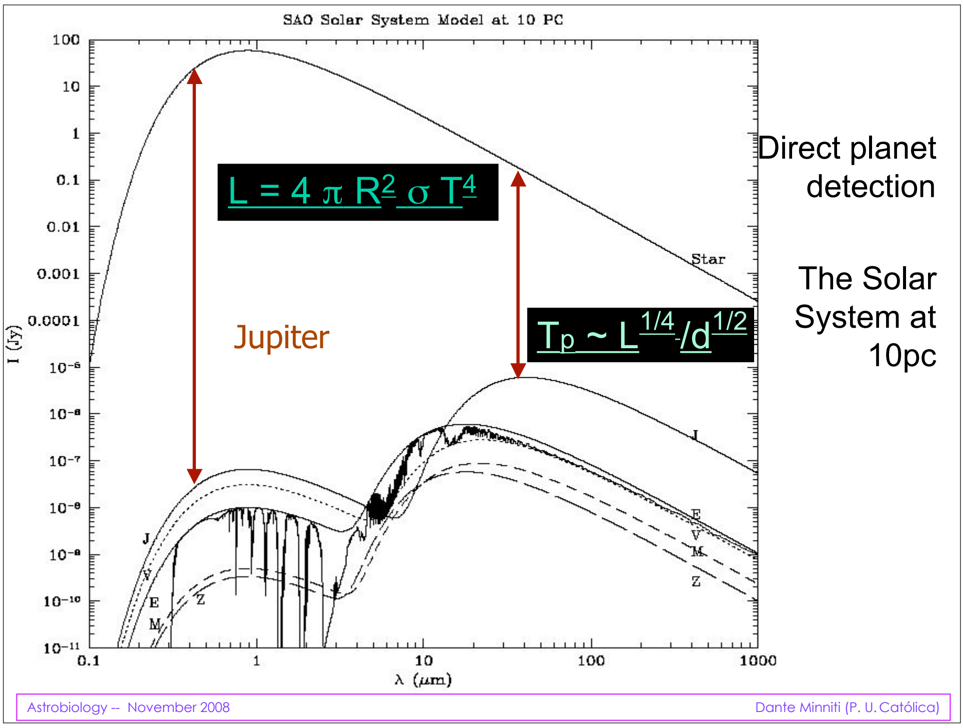
SAO Solar System Model at 10 PC
L = 4 π R2 σ T4
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Jupiter
Star
Direct planet detection
The Solar System at 10pc
I (Jy)
λ (μm)
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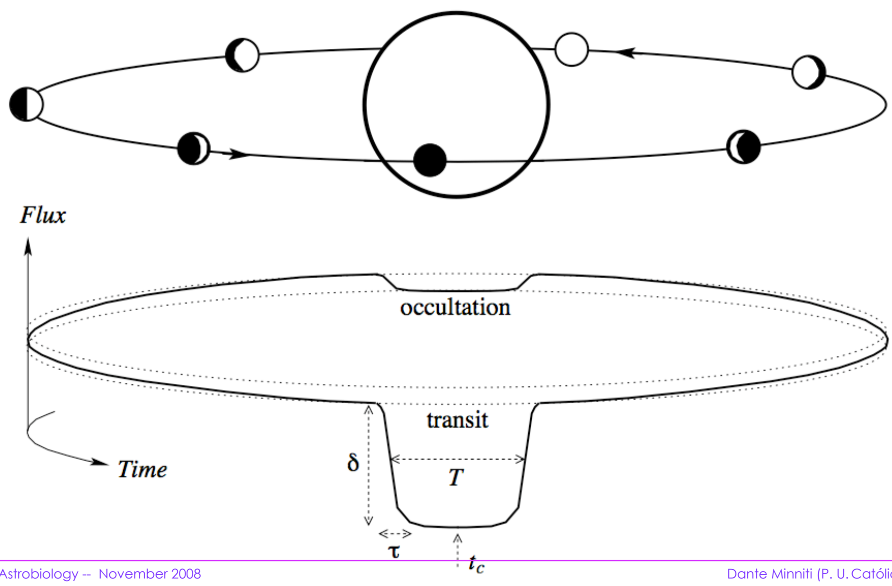
Transits and occultations



Reflected vs instrinsic light

Optical → reflected, attempts with VLT+UVES, HIRES+KECK, satellites MOST, COROT

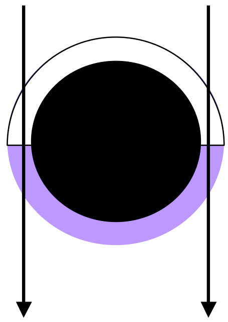
Near-IR → reflected for old objects, intrinsic for young ones

Thermal-IR → intrinsic

Sub-mm → intrinsic

Radio → intrinsic, e.g. Jupiter's decametric radiation

Transmission spectroscopy



The transit time for a hot Jupiter typically is:

t_T ~ 2-3 hr

But if there is a transiting planet at 1AU a longer integration is possible:

t_T ~ 13 hr

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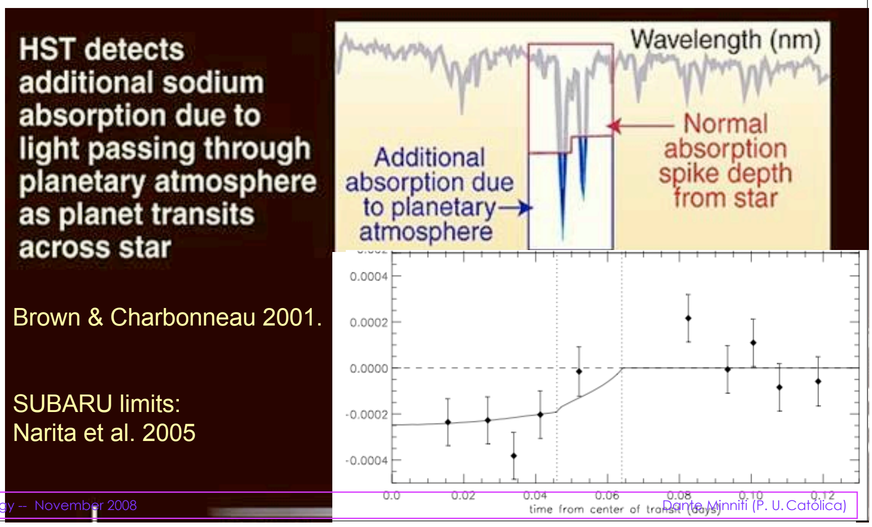
Optical transmission spectroscopy:
Na 5890A doublet with STIS+HST, weak compared to models.

M=0.63 M_{JUP}
R = 1.4 R_{JUP}
ρ = 0.4 g/cm^3
→ **Gas giant**

HD209458 transit



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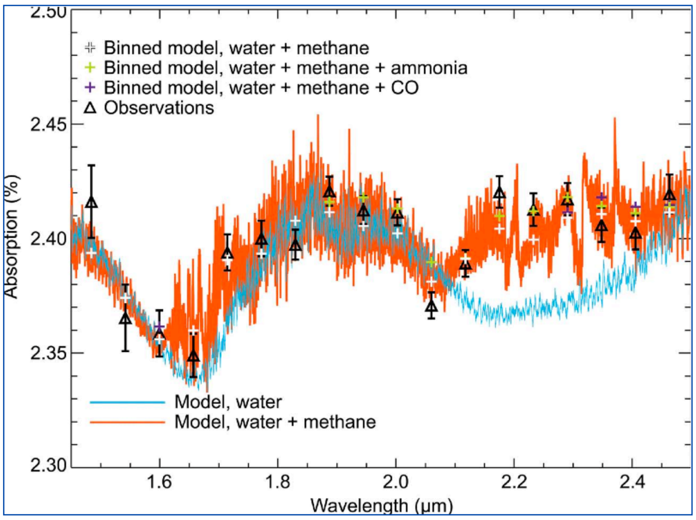
Transmission spectroscopy



Detection of water and methane Tinetti et al. 2007, Swain et al. 2008

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Spectroscopic biomarkers

Can we detect some biomarkers using astronomer's tools?

- UV → O_3 3200A
- Optical → O_2 7600A, O_3 5800A, H_2O,7200A, 8200A, 9400A, CH_4 7900A, 8900A, CO_2 10500A, chlorophyll edge 7200A
  → Earthshine spectrum (Woolf et al. 2002, Arnold et al. 2002): see the signature for the vegetation at 7200A
- IR → O_3 10μm, N_2O, O_2 , CH_4 , CO_2 , H_2O
  → Earthshine spectrum (Turnbull et al. 2005)

Des Marais et al. Astrobiology (2002)

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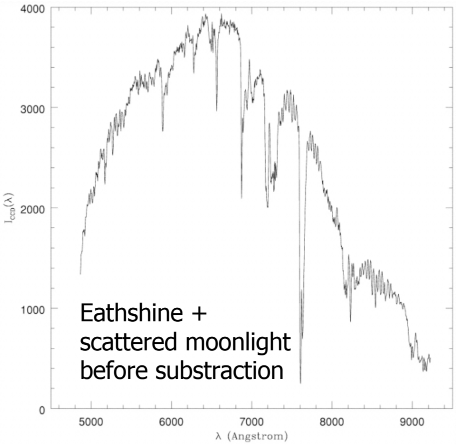
Earthshine spectrum

The Moon as seen from the Earth.

The Earth as seen from the Moon (only18% land).



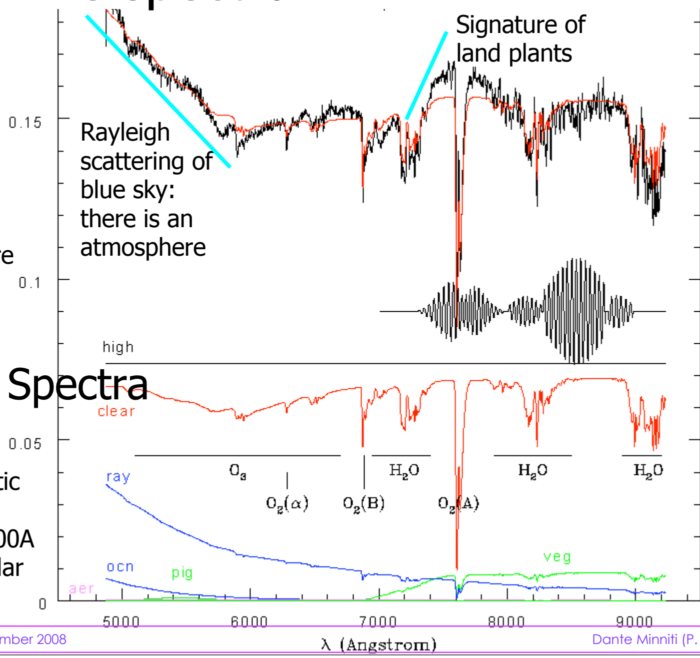
Woolf et al. (2002), Arnold et al. (2002)

Earthshine spectrum

<3000 A atmosphere cut-off, ozone

Optical Spectra

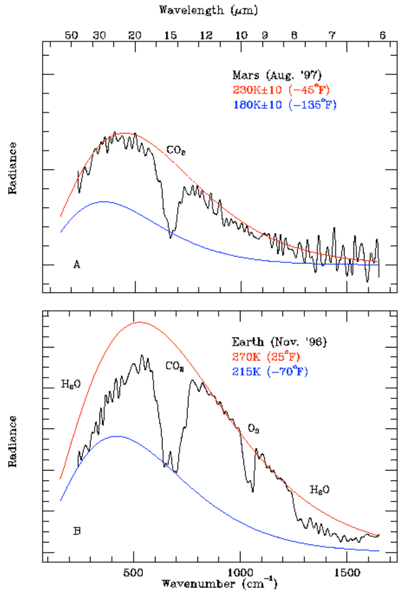
NB: normal photosynthetic range from 4000A to 7000A (tuned to Solar BB peak)



Searching for life

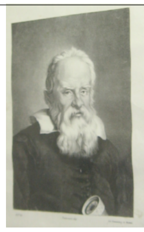
Infrared Spectra:

- The Ozone test
- Earth vs Mars spectrum



NASA/MGS

Searching for life



No way to travel there, we must use telescopes.

Searching for life as we know it:

→ The 1st step is to find a rocky planet in the stellar habitable zone (HZ), although it could also be a satellite of a gas giant.

→ The planet should be in the Galactic habitable zone, not in a globular cluster or close to the Galactic center.

→ The planet should not be tidally locked, ruling out most late-type stars.

→ The system should not be young, so that there are not too many catastrophic comet/asteroid impacts.

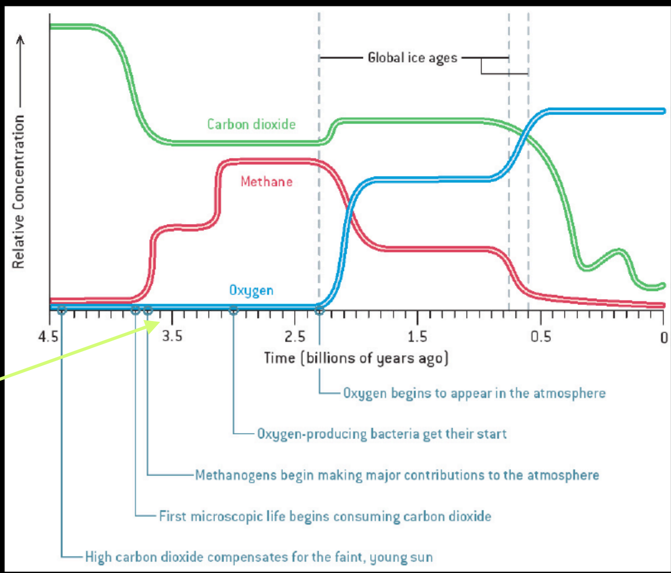
→ Find an atmosphere that shows out of equilibrium composition, containing known biomarkers. (But because our own atmosphere has changed, we have to catch the planet at the right time in evolution in order to see the biomarkers that we expect.)

Evolution of the Earth's atmosphere

Problem:

Time dependence

e.g. Titan today



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N~322 planets, but we do not know…

- The fraction of stars that have planets of any kind
- The real shape of the exoplanet mass distribution function
- The average density of most exoplanets, in order to separate rocky, icy or gas planets
- The fraction of stars that have terrestrial planets in the HZ
- Anything about the colors or spectra for the majority of exoplanets
- Anything about their atmospheres, clouds, surfaces and variability
- Anything about the habitability or signs of life for any exoplanet

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Here is a list of basic web pages to explore:

- Solar System: http://nssdc.gsfc.nasa.gov/planetary
- Astrobiology: http://www.astrobiology.com
- SETI: http://www.seti-inst.edu
- Extrasolar planets: http://exoplanet.eu
- Lick group: http://exoplanets.org
- Geneva group: http://obswww.unige.ch/planet
- Transit Ephemerides: www.transitsearch.org

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