SEARCHING FOR INTERSTELLAR COMMUNICATIONS

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NO theories yet exist which enable a reliable estimate of the probabilities of (1) planet formation; (2) origin of life; (3) evolution of societies possessing advanced scientific capabilities. In the absence of such theories, our environment suggests that stars of the main sequence with a lifetime of many billions of years can possess planets, that of a small set of such planets two (Earth and very probably Mars) support life, that life on one such planet includes a society recently capable of considerable scientific investigations. The lifetime of such societies is not known; but it seems unwarranted to deny that among such societies some might maintain themselves for times very long compared to the time of human history, perhaps for times comparable with

To the beings of such a society, our Sun must appear as a likely site for the evolution of a new society. It is highly probable that for a long time they will have been expecting the development of science near the Sun. We shall assume that long ago they established a channel of communication that would one day become known to us, and that they look forward patiently to the answering signals from the Sun which would make known to them that a new society has entered the community of intelligences. What sort of a channel would it be?

The Optimum Channel

Interstellar communication across the galactic



The reader may seek to consign these speculations wholly to the domain of science-fiction. We submit, rather, that the foregoing line of argument demonstrates that the presence of interstellar signals is entirely consistent with all we now know, and that if signals represent the means of detecting them is now at hand. . . The probability of success is difficult to estimate; but if we never search, the chance of success is zero.

The Drake Equation

parameterizing our ignorance

$$N = R_s \times f_p \times n_p \times f_L \times fi \times f_c \times L$$

N is the number of communicating civilizations in the Galaxy today

Astronomical factors	= R x f x n
Biological factors	x f x
Sociological factors	x f x L (# of years communication continues)

Sun-like Stars

R_s – how many "useful" stars of 200,000,000,000 in our galaxy form each year?

- long lasting - to allow complex life to develop
  - 3.5 - 4.0 billion years for the Earth
- quiet and steady energy production
  - few big flares or other 'stellar flares'
  - no binary companion
- about 1/3 of all stars are "useful"

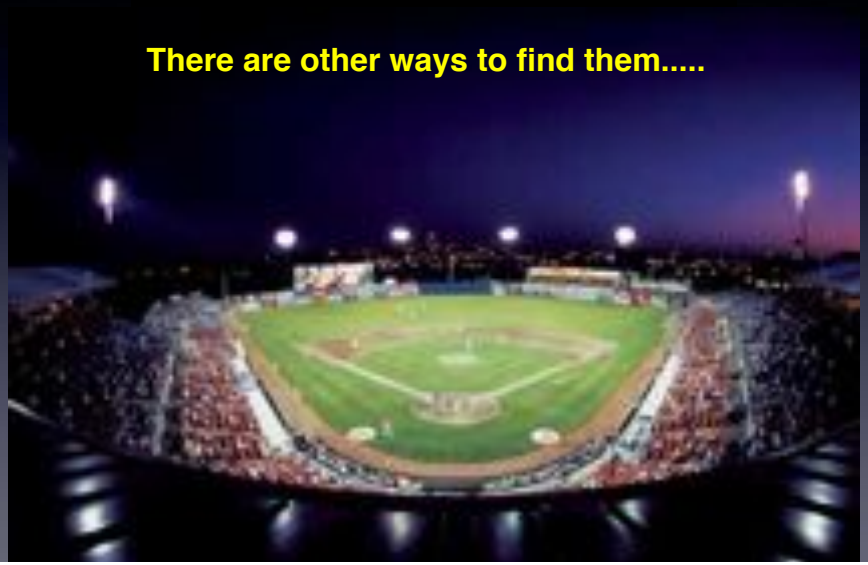
R_s ~ 8 stars / year

Searching for planets around other stars

- Jupiter and the Sun
  - the Sun has a luminosity of 4×10^{33} erg/s
  - Jupiter emits at most 8×10^{24} erg/s
  - the Sun emits 500,000,000 times more light than Jupiter
  - viewed from 10 pc, they are separated by 5 arc sec
- equivalent to
  - 1 candle,
  - 10 feet away from a stadium light bank,
  - viewed from 80 miles away!

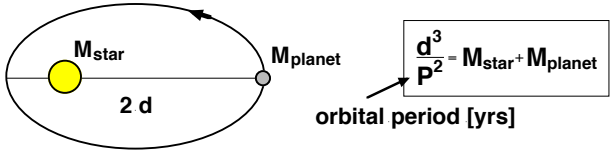
Searching for planets around other stars

There are other ways to find them.....



Wobbles of stars from reflex motion:

- **Kepler's 3rd Law**



- **The "See-Saw" Law**

$$\frac{M_{planet}}{M_{star}} = \frac{d_{star}}{d_{planet}}$$

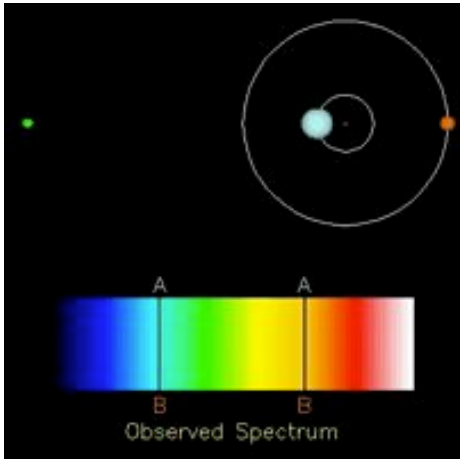


- **$M_{planet} << M_{star}$**
  - star moves in a small orbit
  - measure d_{star} and you know M_{planet}

Reflex Orbital Motion



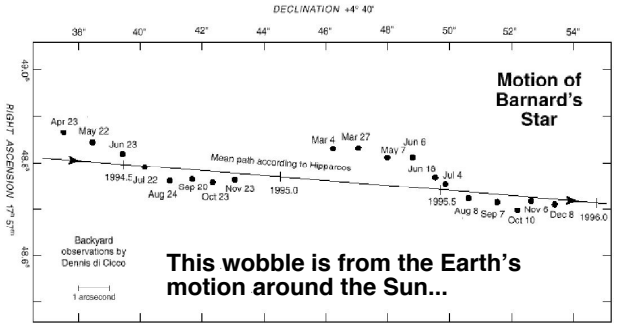
Reflex Orbital Motion



Credit: R. Pogge, OSU

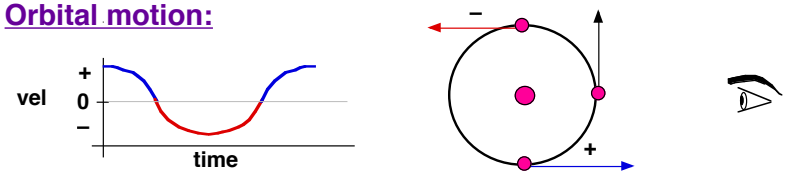
Reflex Orbital Motion

- Jupiter is 1/1000 M_{sun}
- Sun orbits 5au/1000 = 1/200 a.u. around CM
- A 'Jupiter' around Barnard's star would cause a wobble 1/200 the size of the wobble below



Spectroscopy - look for the velocity wobble

Orbital motion:



- Improved chances for detection (V_{star} bigger):

if planet is massive

$$V_{star} = 30\,m/s \times \frac{2\pi}{\sqrt{M_{star}}} \times \frac{1}{\sqrt{d}} \times \frac{M_{planet}}{M_{Jupiter}}$$

also - shorter period = faster detection

- Biggest effect if orbit viewed EDGE ON
- Tilt of orbit to line-of-sight reduces observed velocity

Jupiter as an example:

- V_{Sun} around CM of Solar System = 13 m/s (= 30 mph)
- Doppler effect of 13 m/s is 1 part in 23,000,000 (!)
- varies cyclically over a 12 year cycle
- very difficult (but not impossible) to measure
- need stable spectroscope over long time
- **Earth? 9 cm/s!**

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if planet is massive

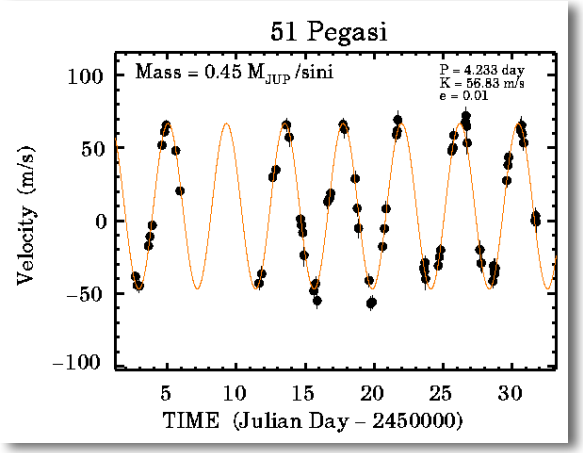
$$V_{star} = 30\,m/s \times \frac{2\pi}{\sqrt{M_{star}}} \times \frac{1}{\sqrt{d}} \times \frac{M_{planet}}{M_{Jupiter}}$$

if planet is close to star

also - shorter period = faster detection

1990-1995 Searches

- precision needed finally achieved
- first searches looked for orbit periods of months
- first discovery: 1995: Mayor & Queloz:



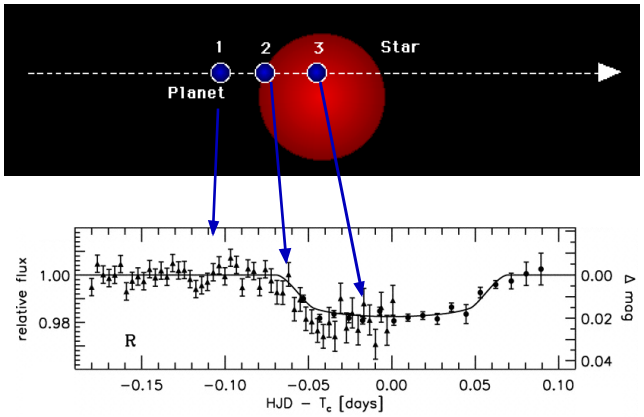
P_{orb} = 4.233 days

M_{planet} = 0.45 $M_{Jupiter}$

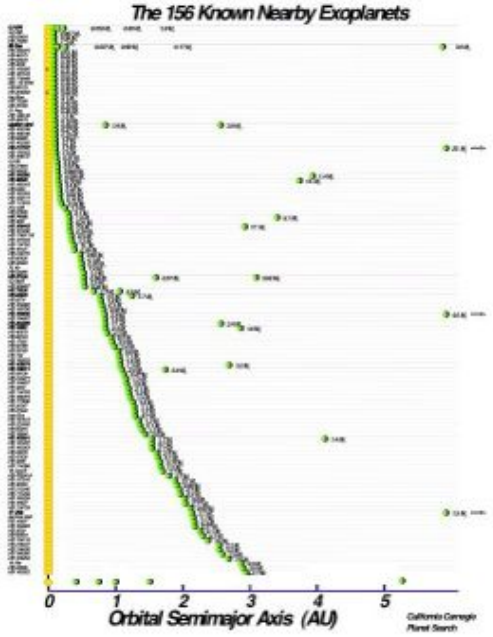
They are Planets:
proof from HD 209458 (1999)

Radial Velocity variable:
$M = 0.69 \pm 0.05\ M_J$
$P = 3.524738 \pm 0.000015$ d.

and
orbits along our line-of-sight
so --> planet transits across the star!

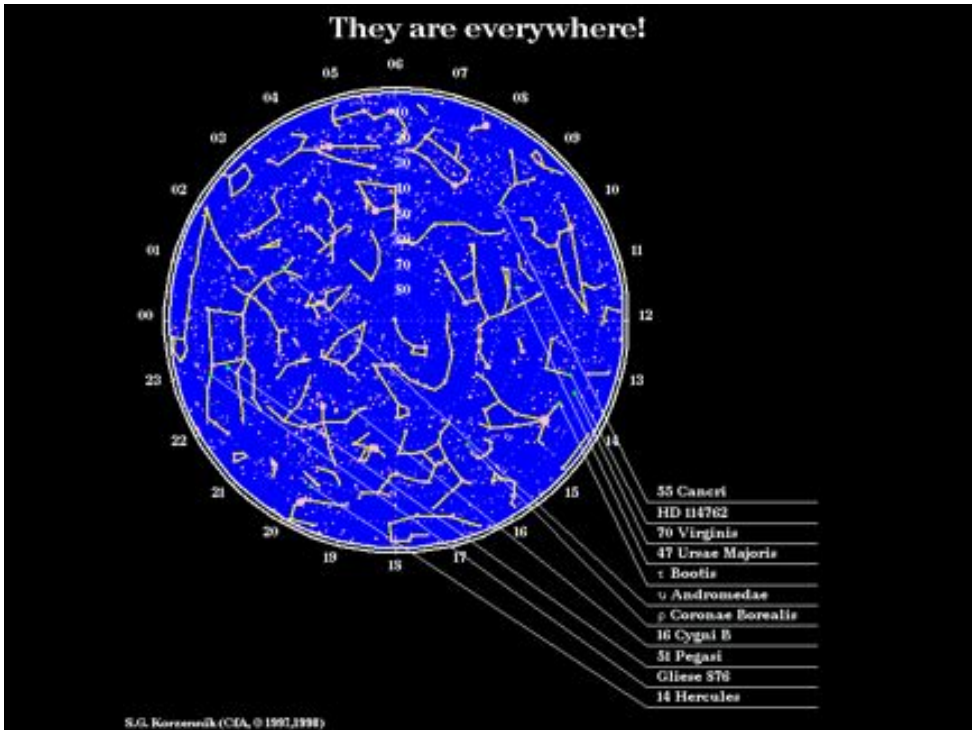


1995 - 2014 Huge strides

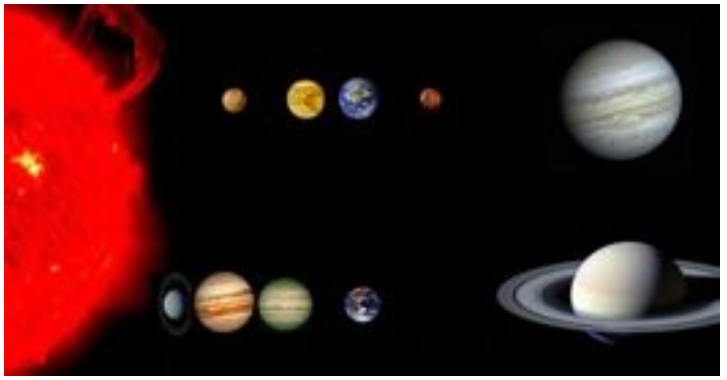


- now over 419 known extrasolar planetary systems found by RV
- many found by Geoff Marcy, Paul Butler, & Friends
- Most are **massive planets**
- Most have **small orbits**
- Many are multiple-planet systems
- one system looks like our own solar system in 5 billion years

$f_p \sim 0.3$

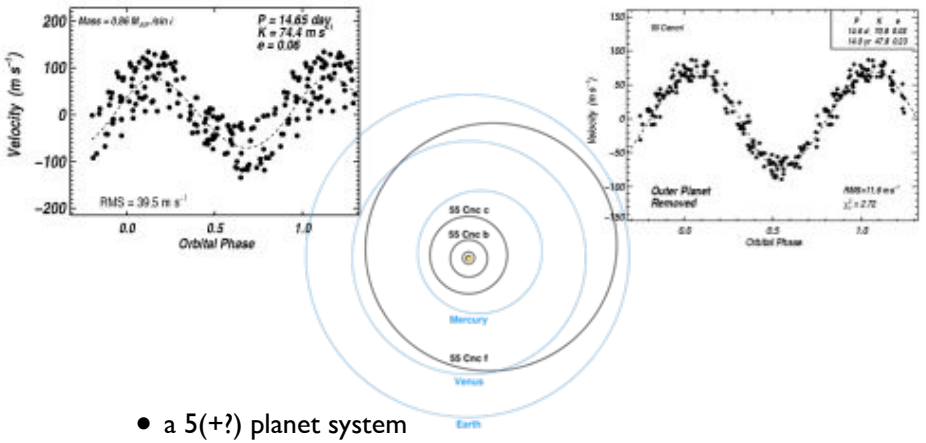


Two interesting systems:
55 Cancri and V391 Pegasi



- a 5(+?) planet system
- planet distribution similar to our own solar system
- room in between for stable earthlike planets

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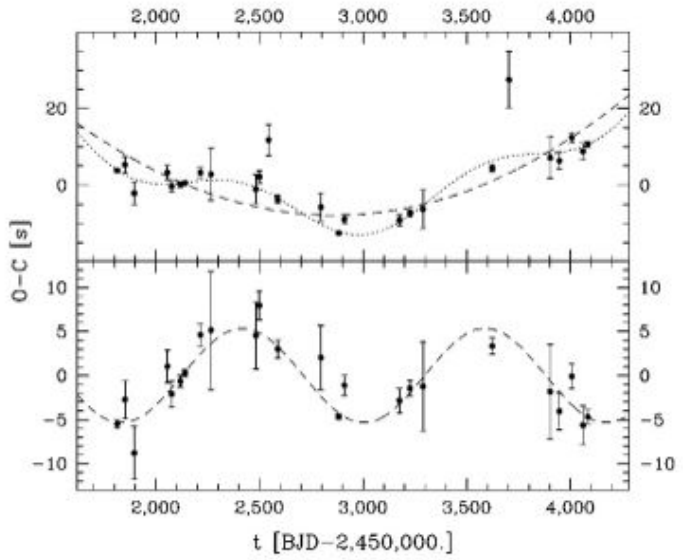
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2001-2002

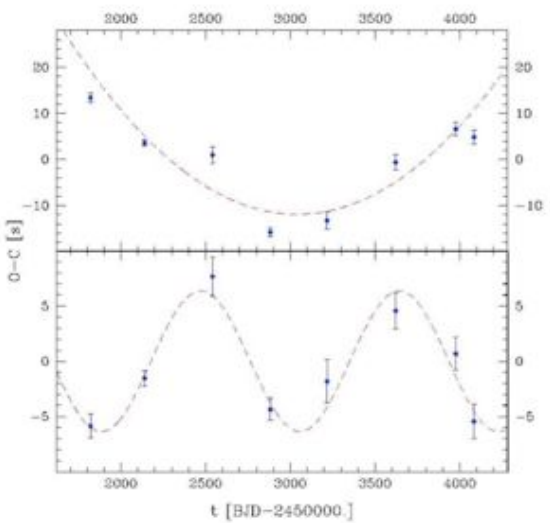
2007 - 6 more years

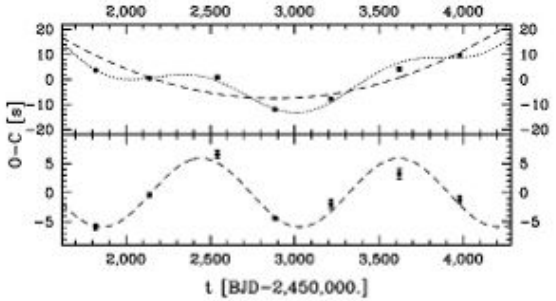
- f1 and f2 remained stable
- (O-C) analysis yields
  - secular change in frequencies (parabola)
  - reflex orbital effects (sinusoid)

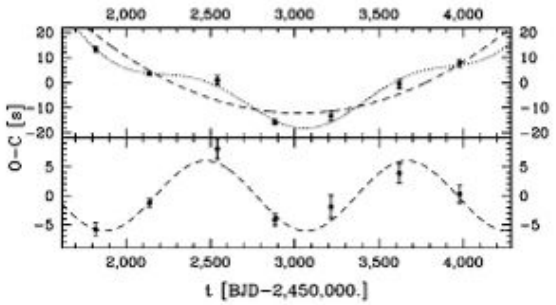
2006



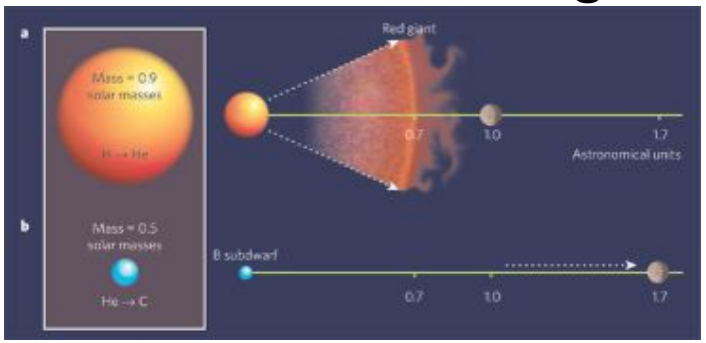
f2



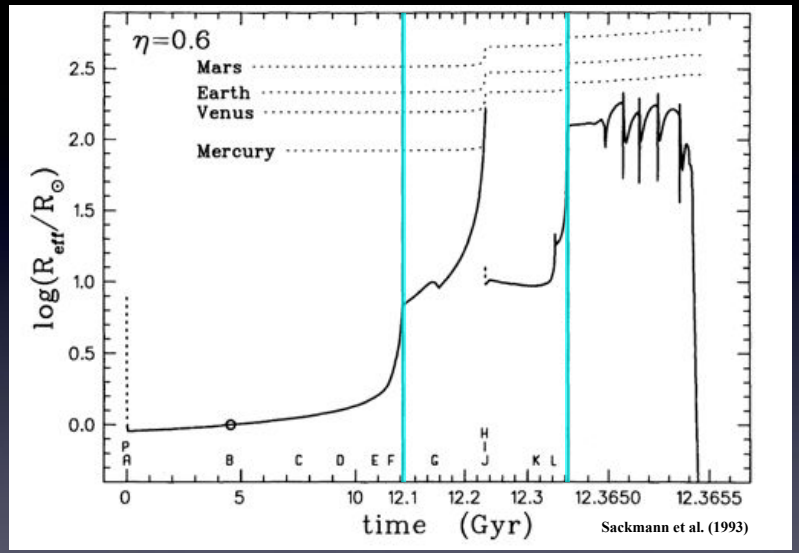


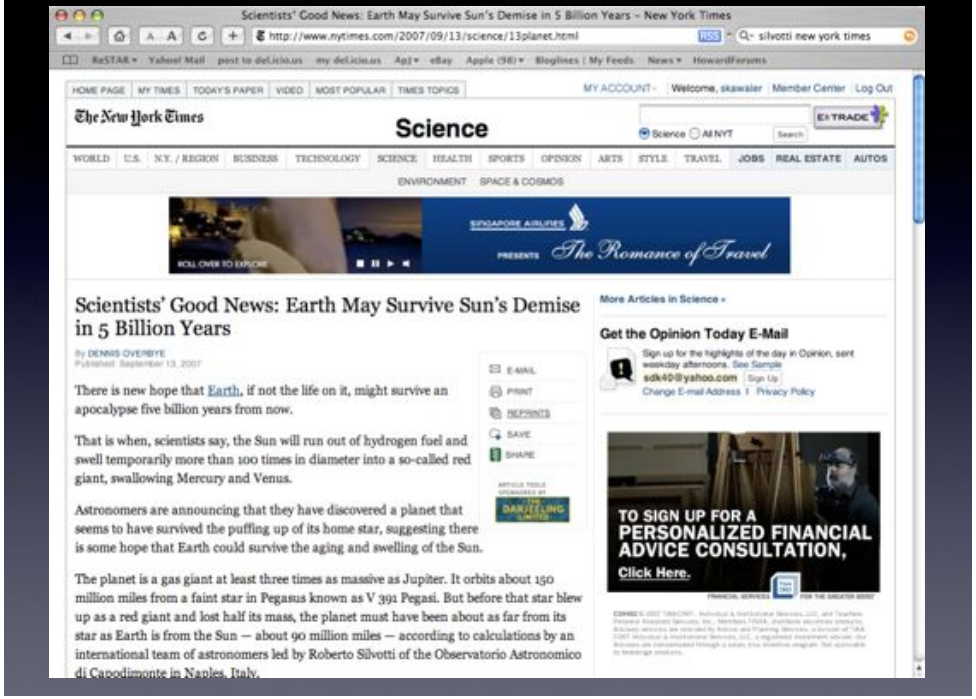


Two interesting systems: 55 Cancri and **V391 Pegasi**



- planetary system that has survived first death of the parent star
- discovered by pulsation phase drift in the remnant stellar core
- work done (in part) with the Whole Earth Telescope
- Roberto Silvotti (Naples) and a bunch of us!





n_p The Habitable Zone

- **water essential to life** (as we know it)
- liquid water has to exist on (or in) the planet
- must be right distance from star
  - heat from star ~ maintain $32^oF < T < 212^o$
  - **too close** - runaway greenhouse (Venus)
  - **too far** - CO_2 ice - no greenhouse (Mars)
  - **BUT**
    - life exists in extreme environments on Earth
    - liquid water a constraint for "normal" life only



Planet Size and Habitability

- Planets form by accretion from a disk of gas and dust
- Too small (about <0.5 $M_\oplus$):
  - Can't hold onto a life sustaining atmosphere (Mercury, Mars)
  - no tectonics - no carbon regulation
  - surface gravity g < 0.8 G
- Too big (about >10 $M_\oplus$):
  - Can hold onto the very abundant light gases (H_2 and He)
  - turns into a giant (Jupiter, Saturn) or ice giant(Uranus, Neptune)
  - surface gravity g > 2.2 G

