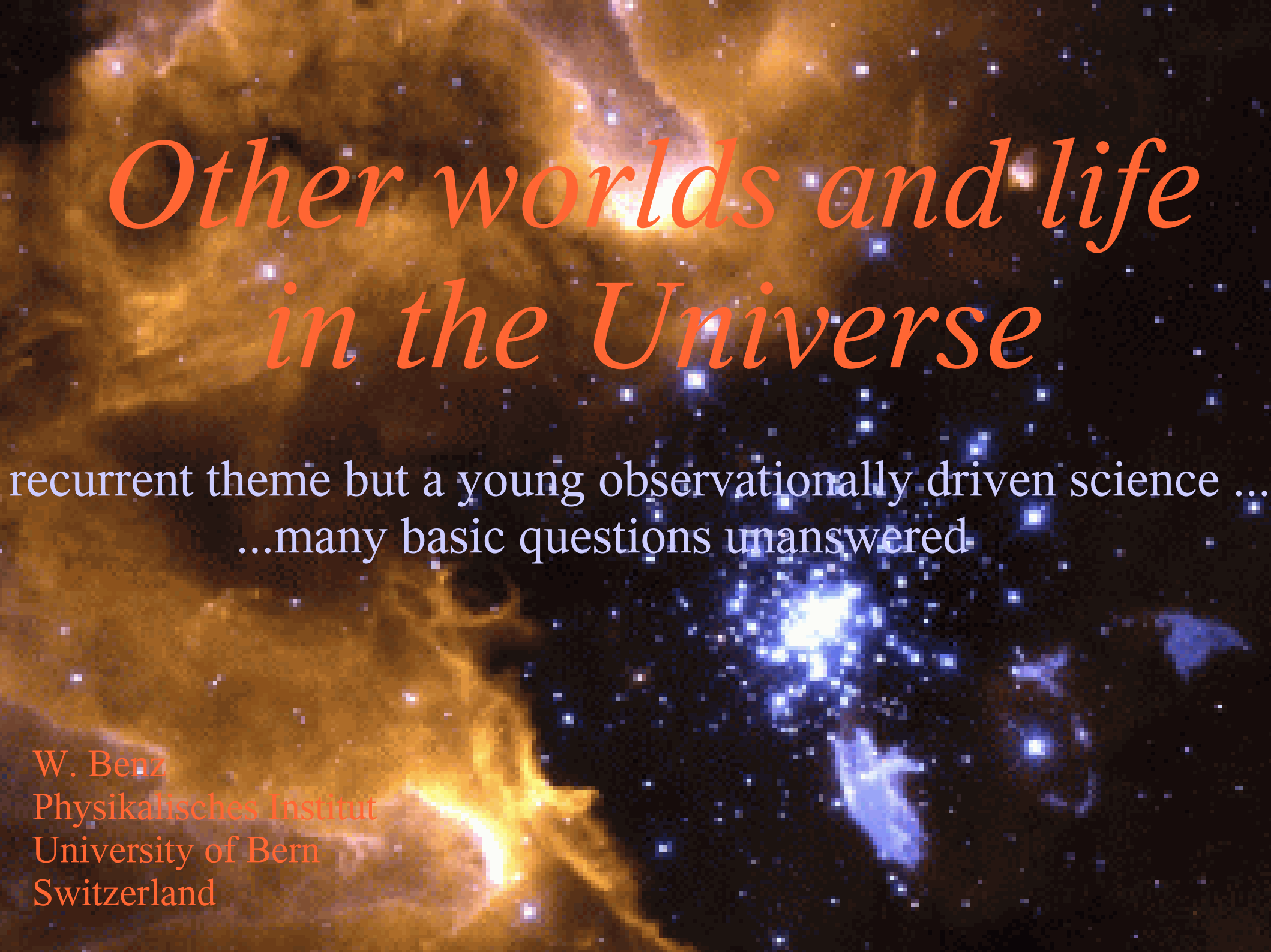


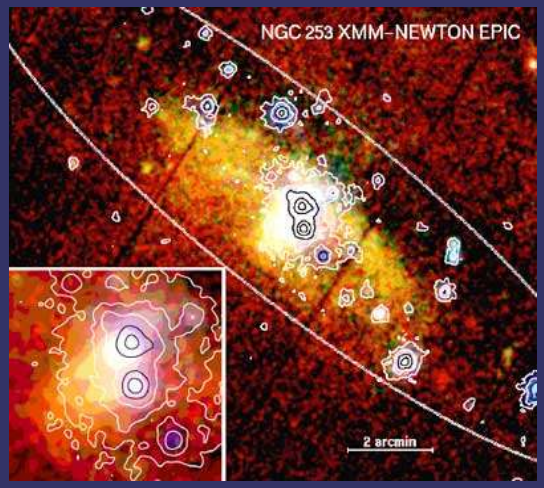
Other worlds and life in the Universe

recurrent theme but a young observationally driven science ...
...many basic questions unanswered

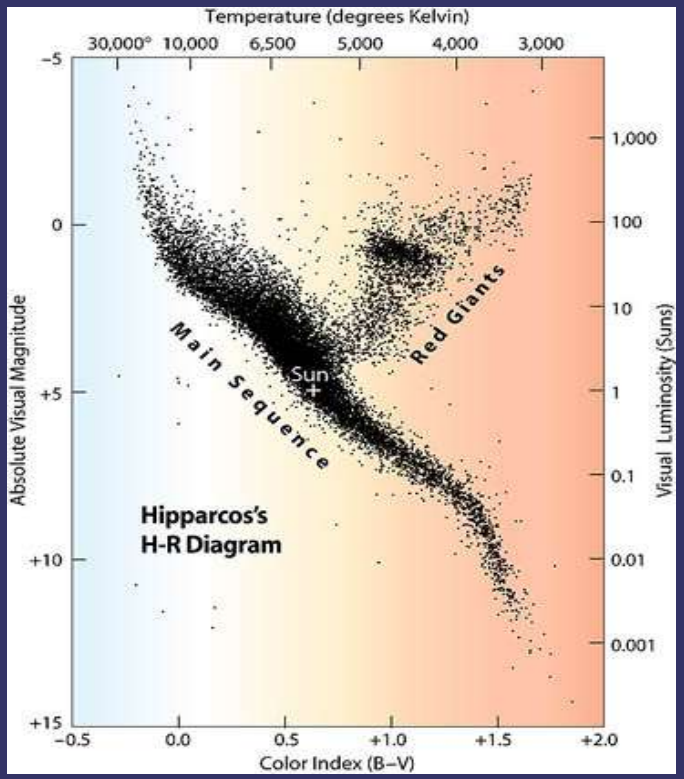
W. Benz
Physikalisches Institut
University of Bern
Switzerland

Stars and star formation

→ *building blocks of the visible universe*



present day →



→ which stars are formed under what circumstances?

- cosmology
- galactic evolution
- ...
- planet formation →

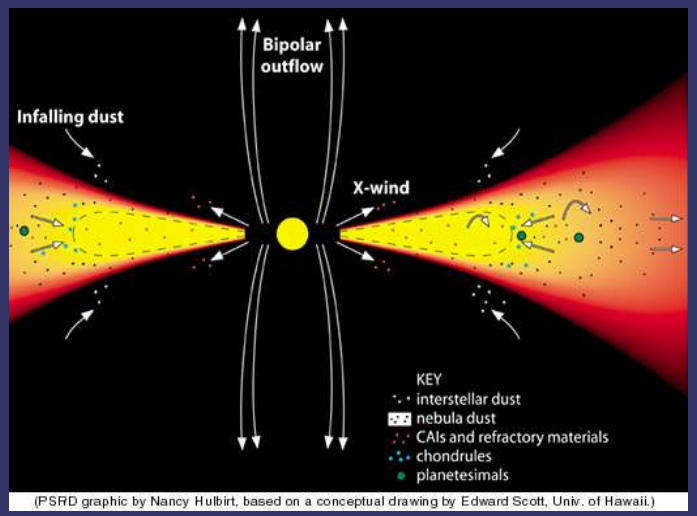
→ *hosts to planetary systems*

→ *We don't have a definitive understanding of:*

- *star formation*
- *very early stages of evolution*

Planets and planet formation

→planets as necessary byproducts of star formation

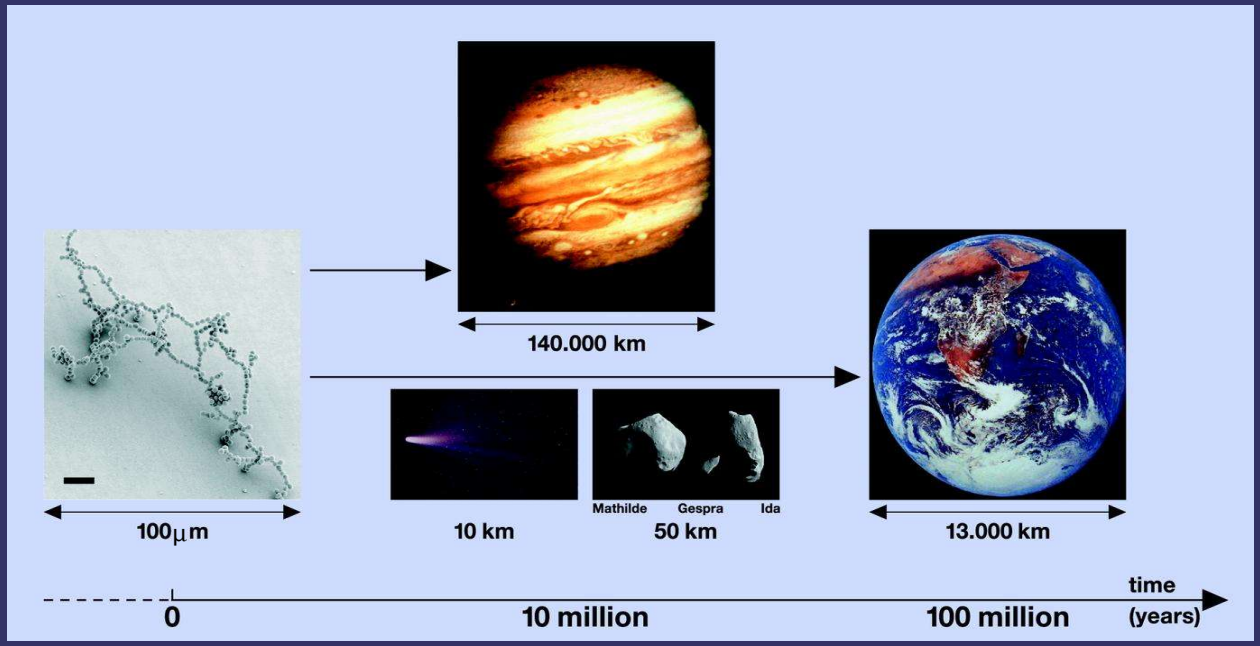


→is the likelihood to host a planet a function of composition and/or environment?

47 Tuc

→no good understanding of planet formation yet!

→from dust to planets



stellar interactions
- disk chemistry
- evaporation of disk
- evaporation of planet

The search for life

1) Searching for life becomes possible

- in our solar system
  - → independent origin?
- on planets orbiting nearby stars
  - → only some forms of life detectable

...but finding life is only one part of the problem!

2) Understanding why, where, and when is equally if not more important

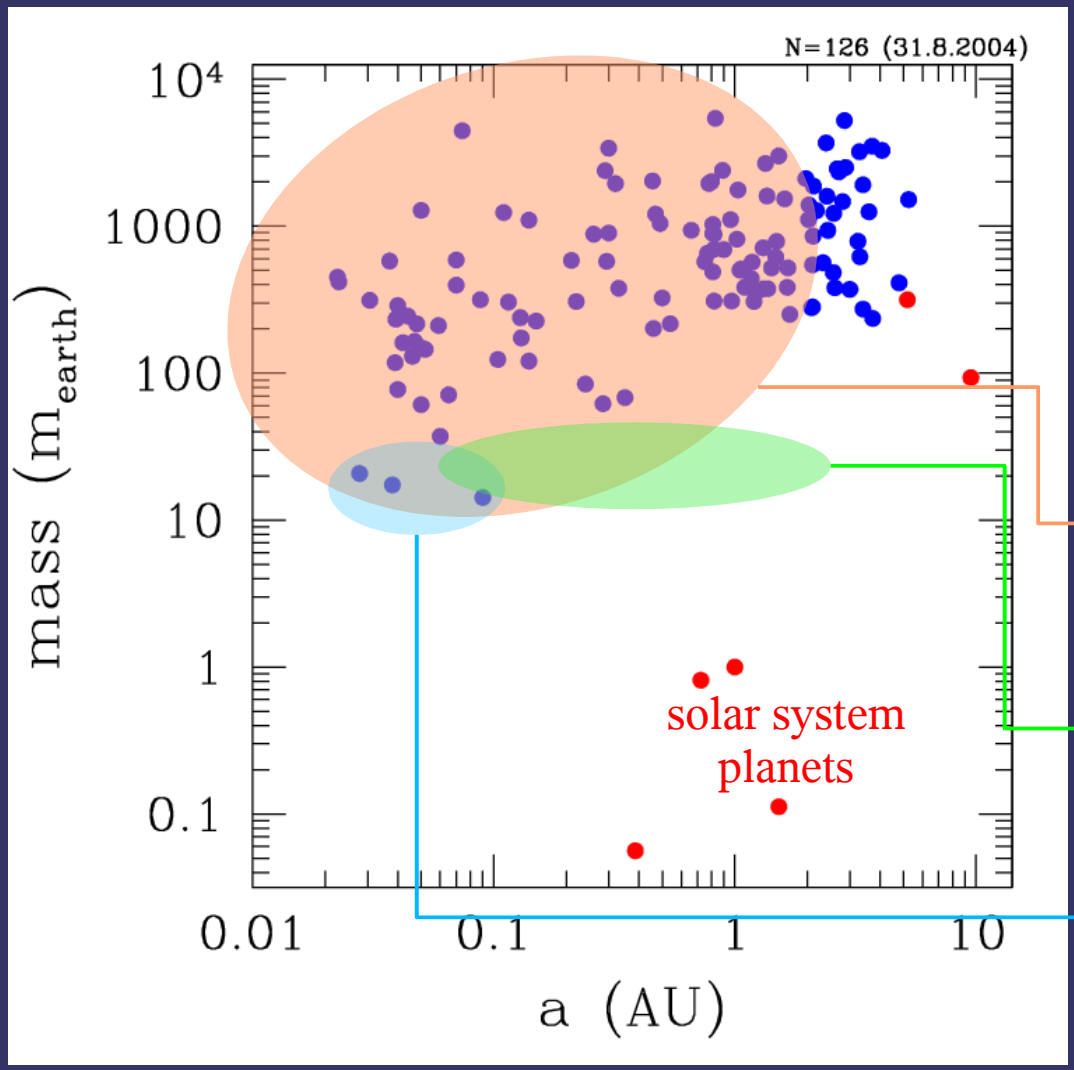
- star formation: setting the initial conditions
- planet formation: building up life support
- origin of life: conditions for developing and surviving

feedback: optimize searches

→ tracing back our own origins

What we know about other worlds (1)

→ diversity!



giant planets can be found orbiting very close to stars

in situ formation or migration?

planet "desert" or obs. bias?

"super-Earth" planets?

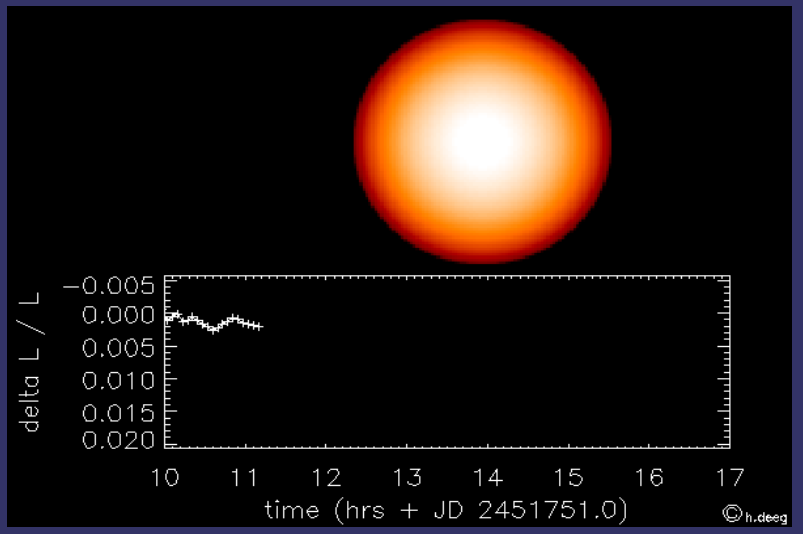
→ these are old systems...

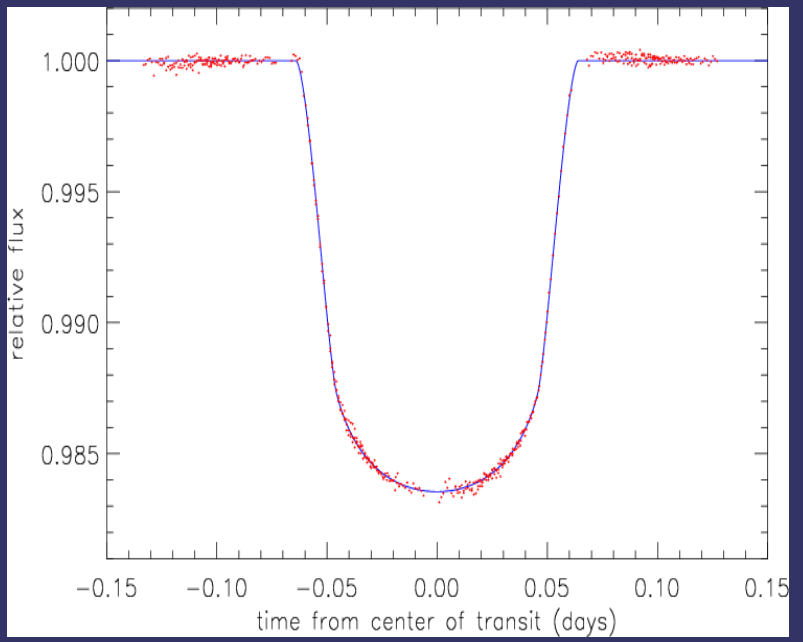
Transit: HD 209458

$R=1.27\ R_J$
$M=0.63\ M_J$ → $\rho = 0.40\ g/cm^3$

↓

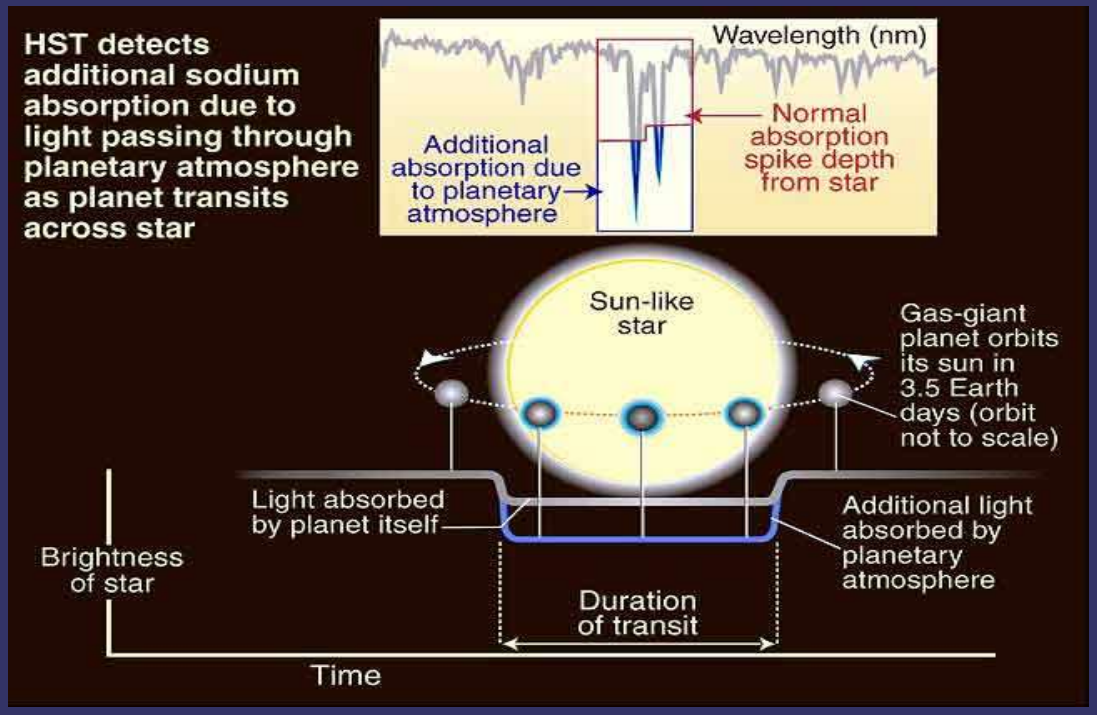
Gaseous planet





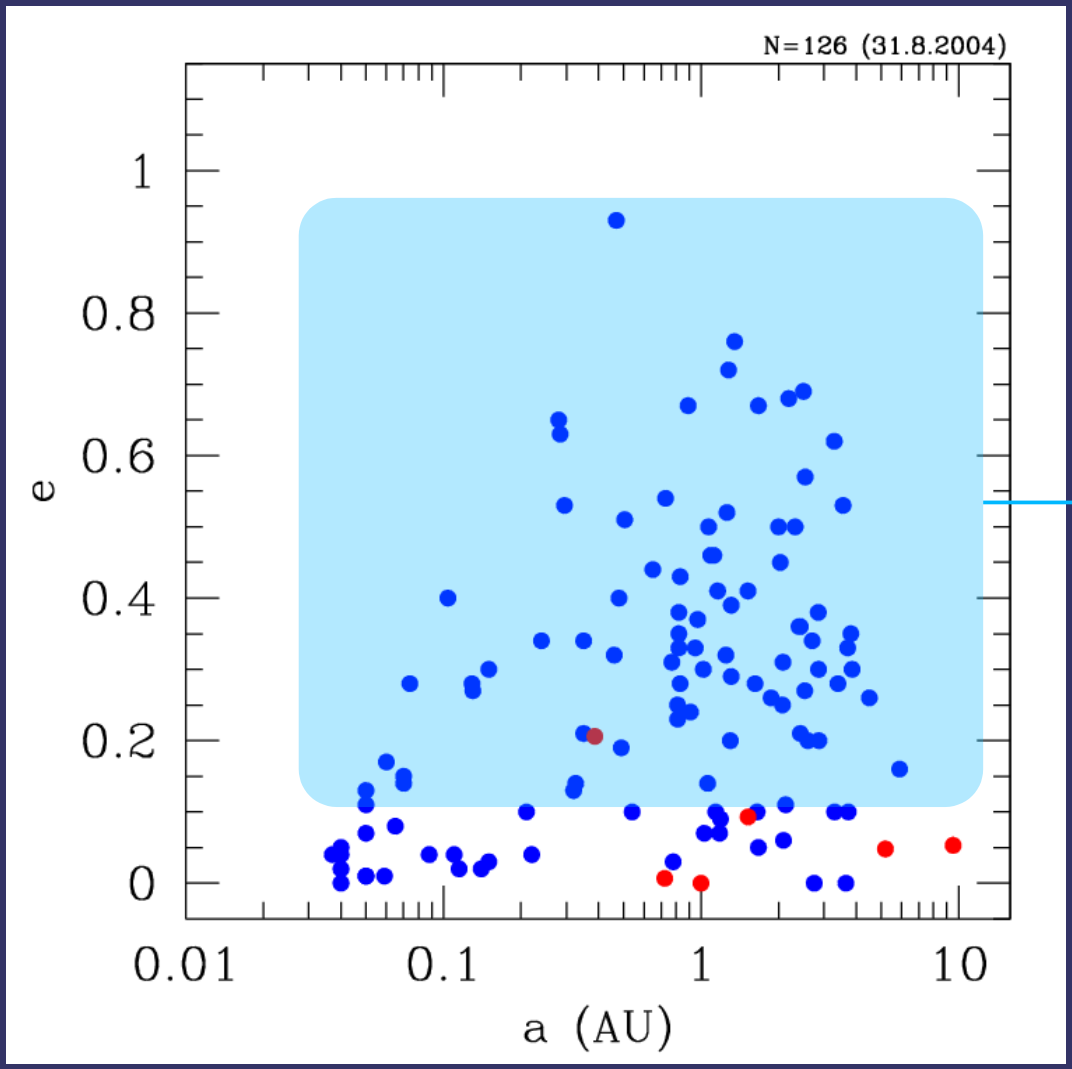
HST (Brown etal)

Charbonneau etal



Information about composition of planetary atmosphere

What we know about other worlds (2)

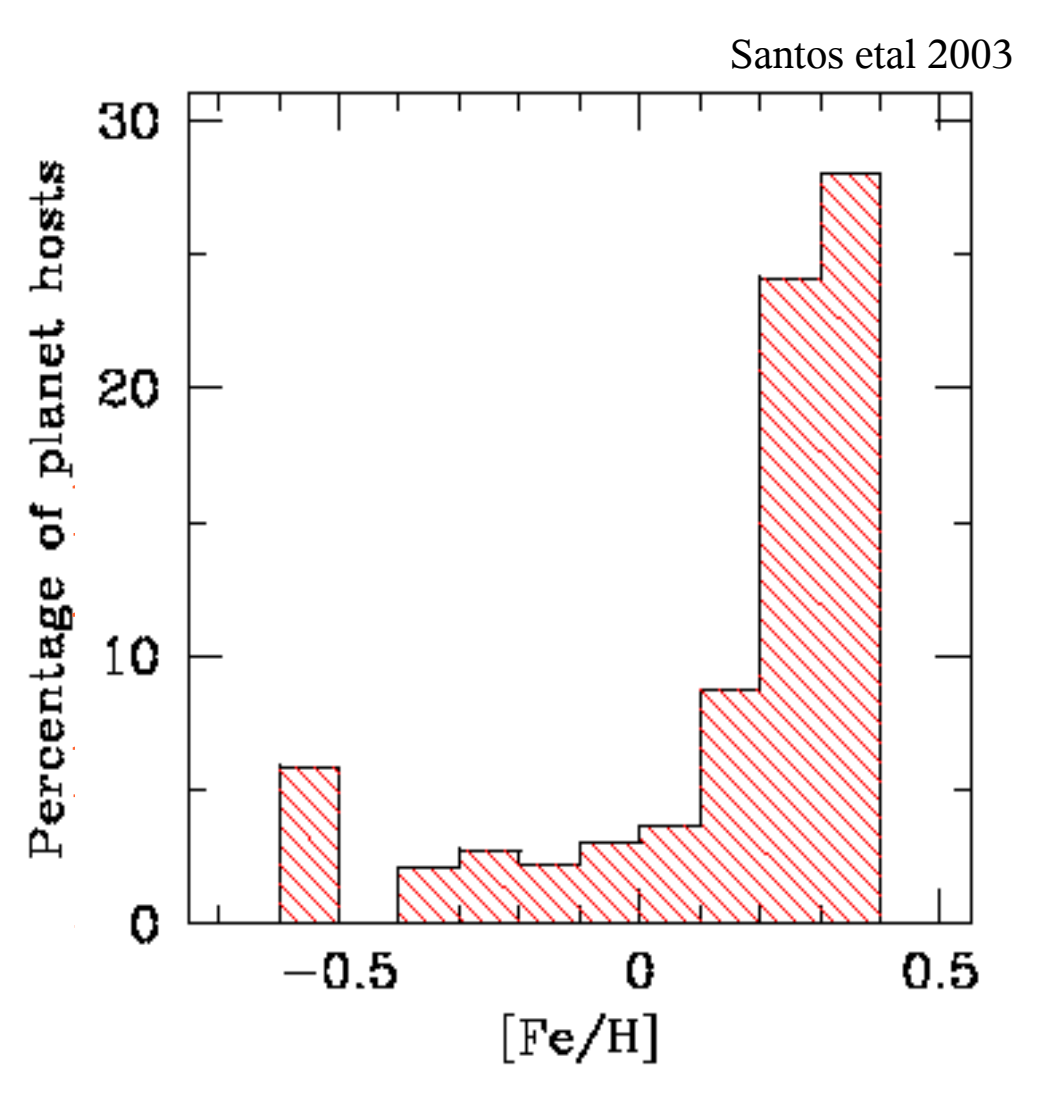


giant planets can be on eccentric orbits

disk evolution or gravitational scattering?

influence on terrestrial planet formation?

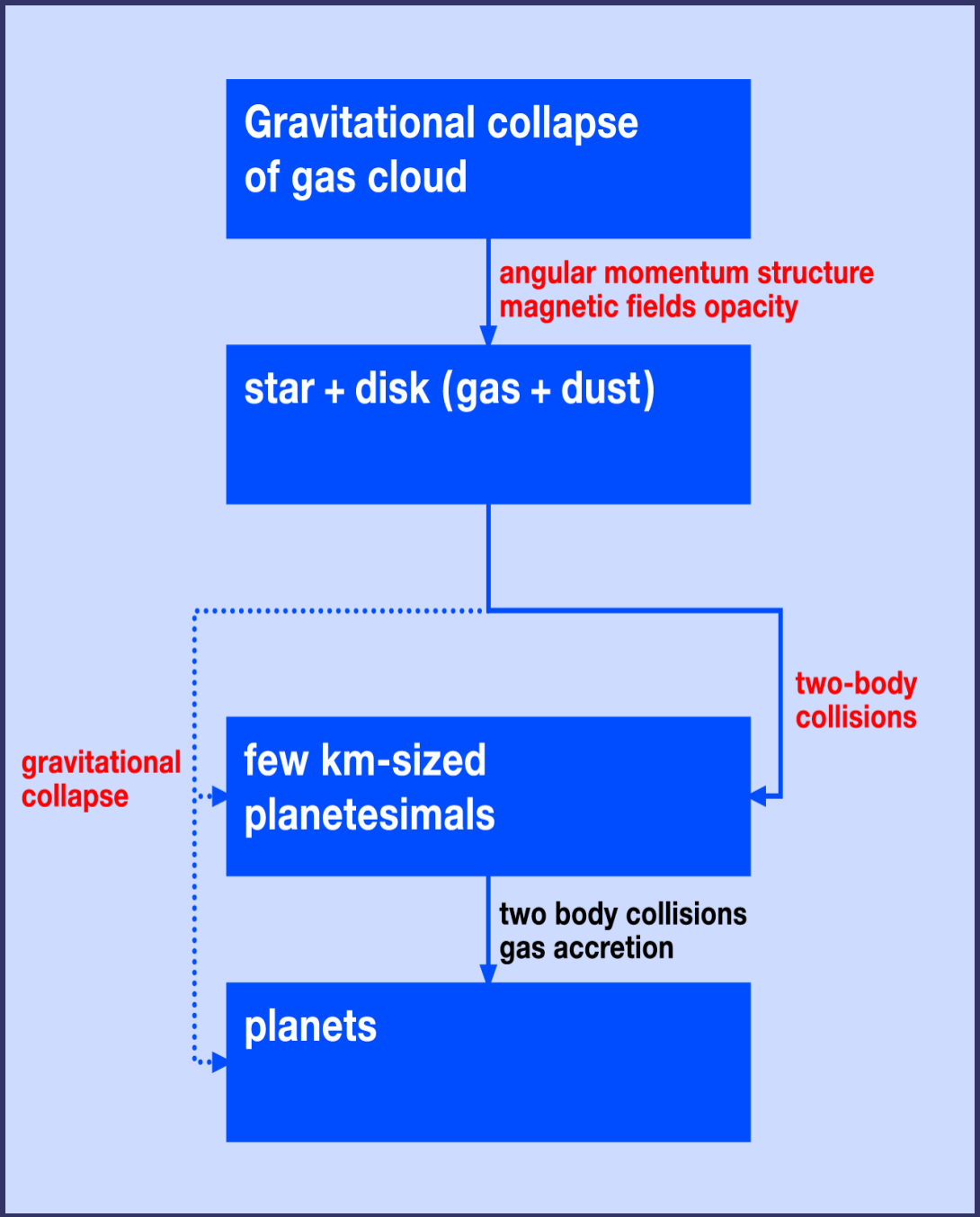
What we know about other worlds (3)



stars with higher metallicity are more likely to host giant planets

- formation or evolution bias?
- earth-like planets around metal rich stars?

Planet formation: The paradigm

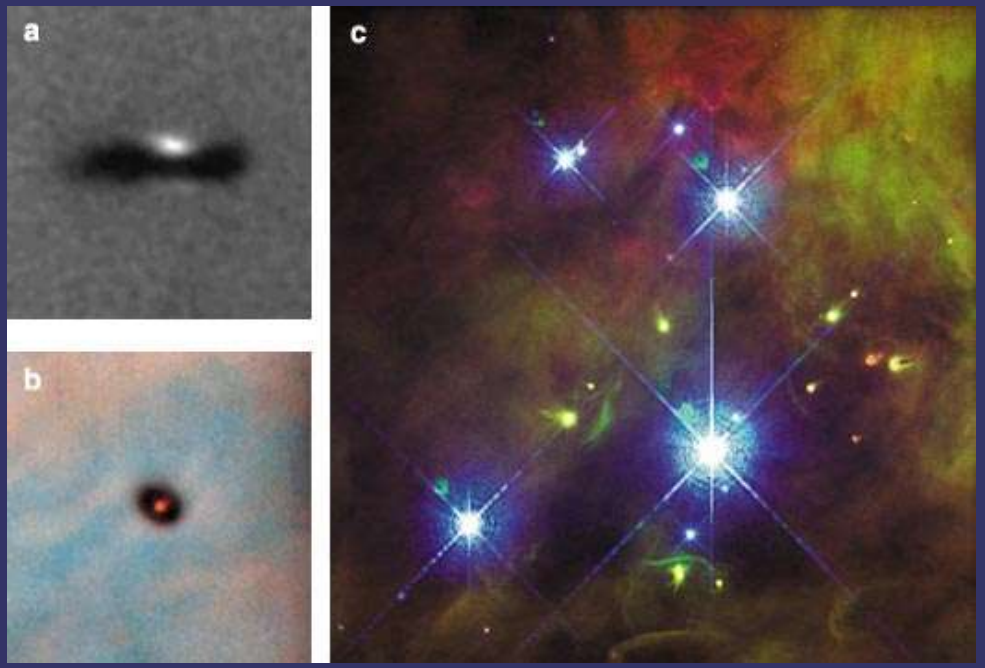


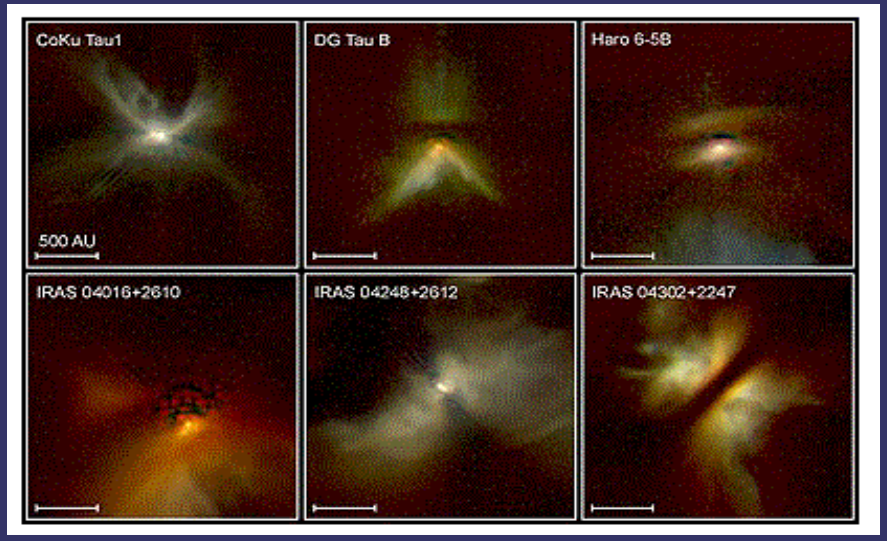
star formation:
- following huge changes in size

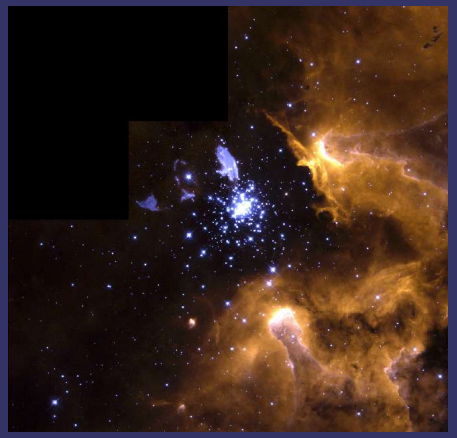
field is observationally driven
... no definitive theory yet...

planet formation:
- following a few ‰ of the mass

Star formation: Setting initial conditions







Formation and structure of young circumstellar disks

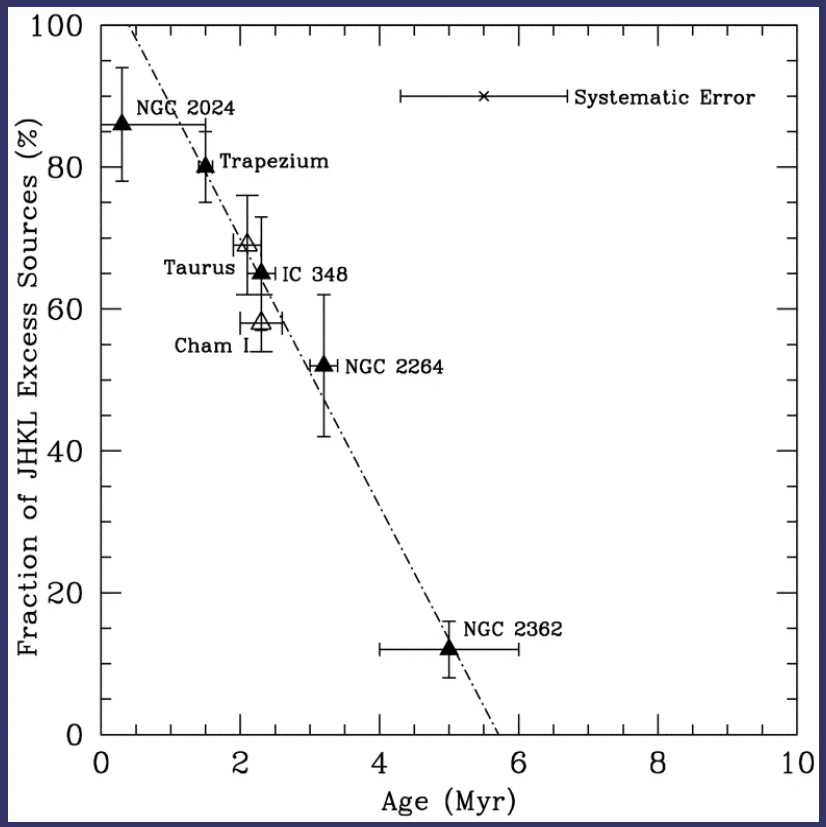
- initial conditions for star formation
- importance of environment (stars are born in clusters)
- mass and size of disks
- detailed structure throughout the disk
  - temperature, density, composition

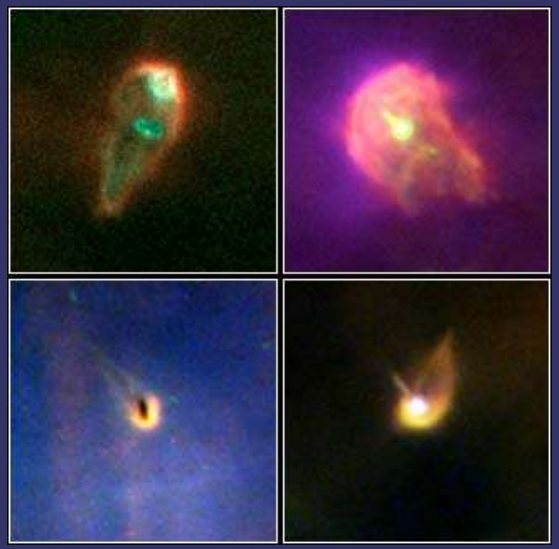
→ *How generic are disk structures?*

Star formation: Limiting the time available

→ *circumstellar disks are relatively short-lived (in clusters $\tau_{1/2} < 3$Myr)*

Haisch etal 2001





→ *Giant gaseous planet formation must be completed within this time frame*

→ *What determines the lifetime of disks ?*

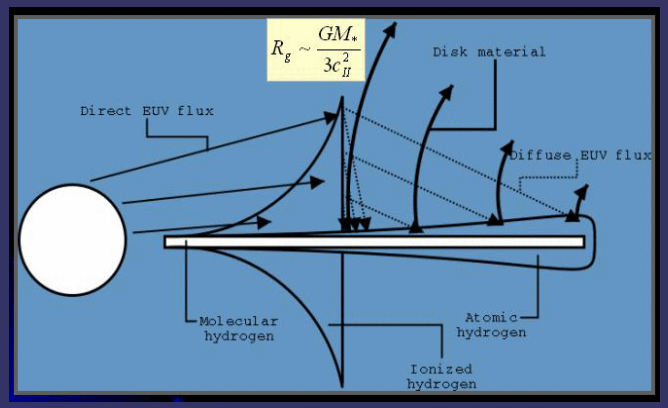
- internal evolution (mass transport, stellar radiation, ...)
- environment (collisions, photoevaporation, ...)

L-band (3.4 μm) photometry:
- excess caused by μ-sized dust @ ~900K
  → inner disk only?

Young stars and disks

→ *coupling between star and gaseous/planetesimal disk?*

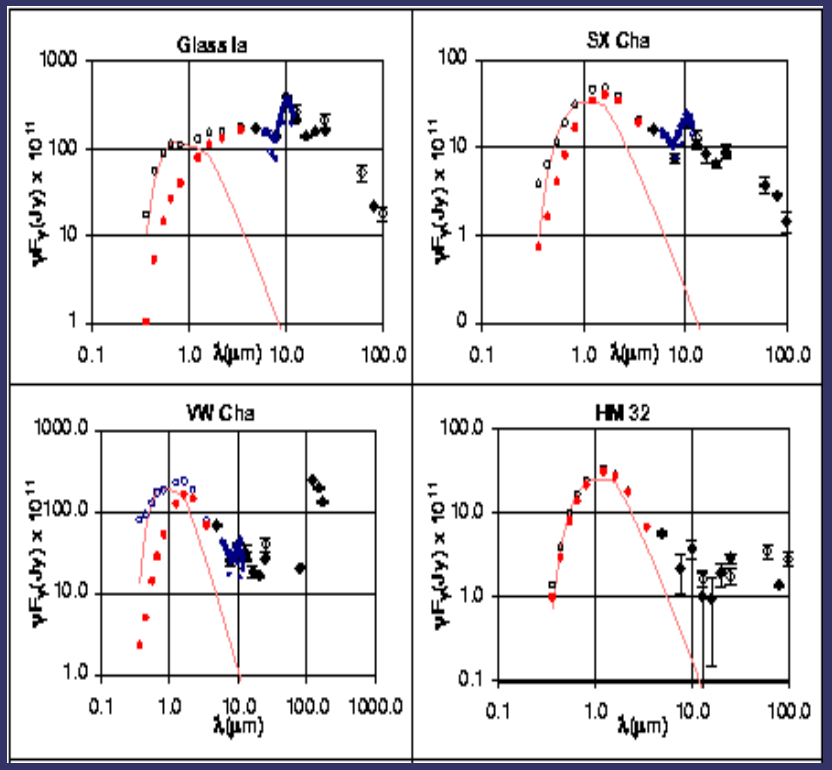
- photoevaporation of the disk:
  → stopping migration



- ionization of the disk:
  → magnetic instabilities
  → active disks

- disk chemistry:
  → coagulation of dust
  → size/composition of dust
  → water, biogenic molecules

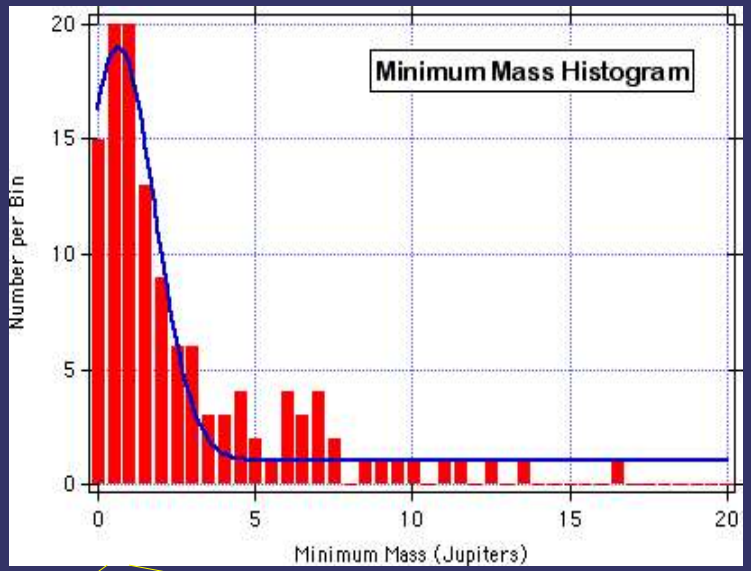
  (→ talk by G. White)



SED of YSOs (Spitzer)

Planet formation: Frequency and diversity

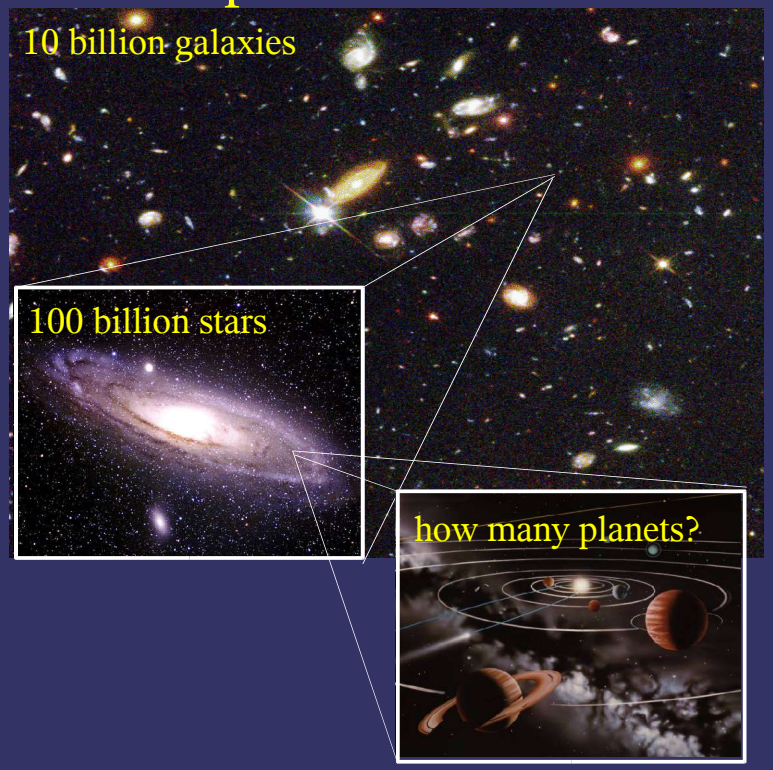
→mass/size distribution



?

small mass, faint, near bright source, far away...

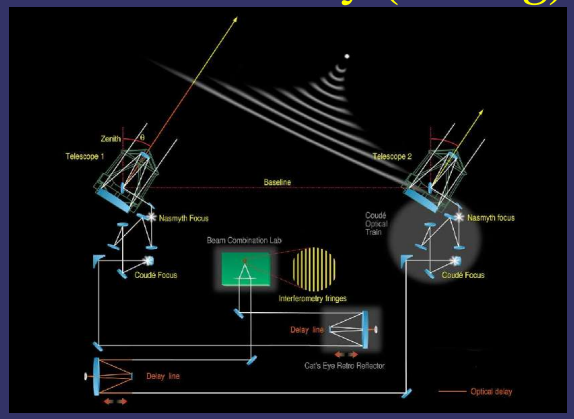
→planet census



→transits

$\Delta F/F \sim 10^{-4}$

→interferometry (nulling)



(→talk by A. Leger)

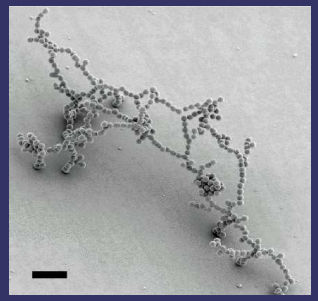
+

→astrometry
→gravitational lensing
→coronograph
→...

→*complete inventory and characterization of what exists...*

Planet formation: Gravitational stability

→formation of cores and/or terrestrial planets: sticking and survival



µm

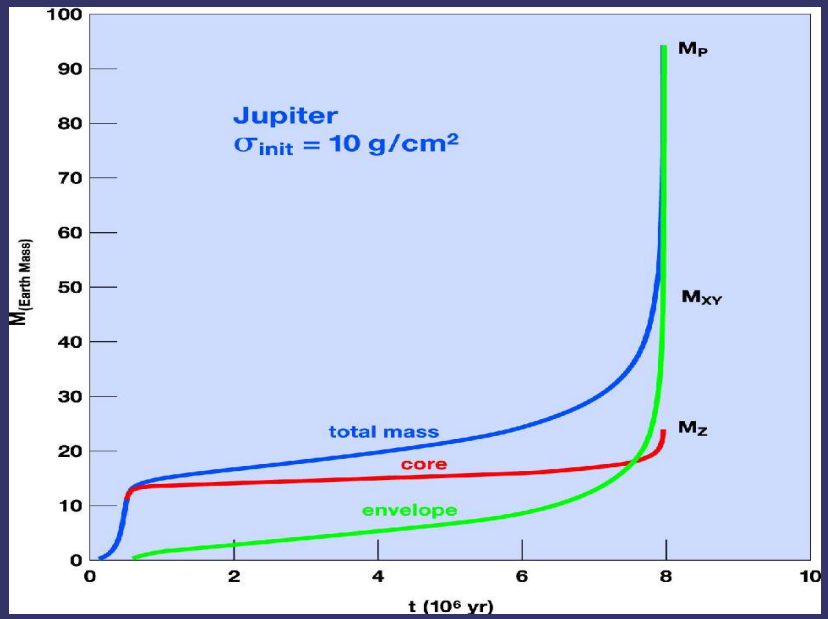
mm

m

km

x 1000 x1000 x1000 x1000

→formation of giant planets: core accretion or direct collapse?



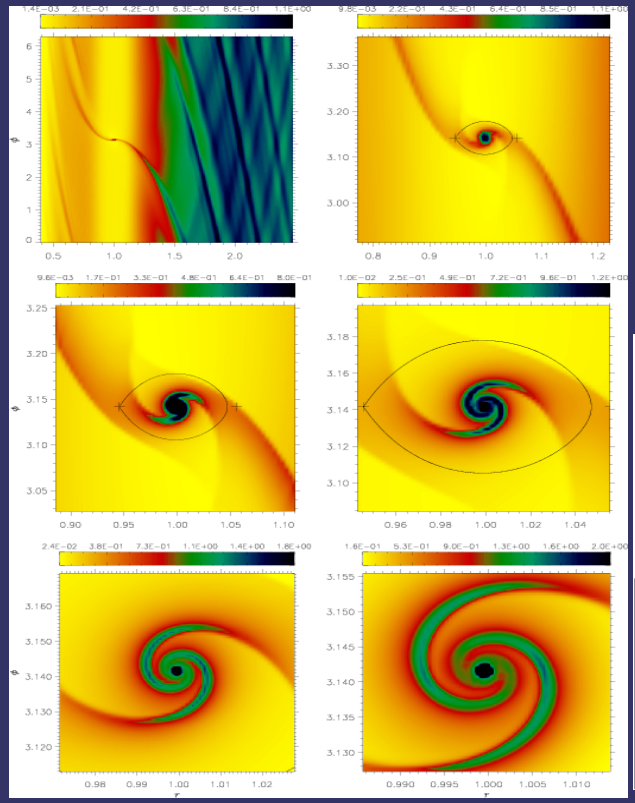
→formation timescale very different
→internal structure and composition differences?

→important constraints from planets in the solar system

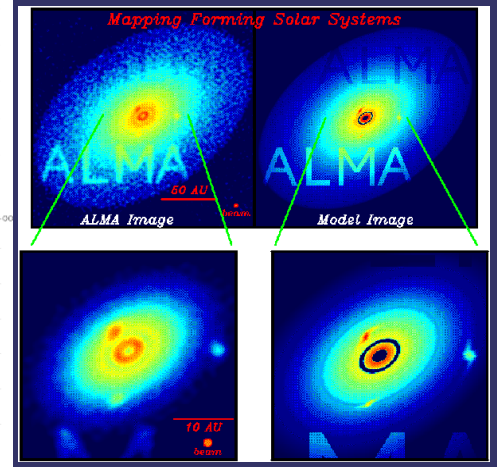
Planet formation: Interactions

→ gaseous disk - planet:
- structures, accretion and migration

D'Angelo etal 2002

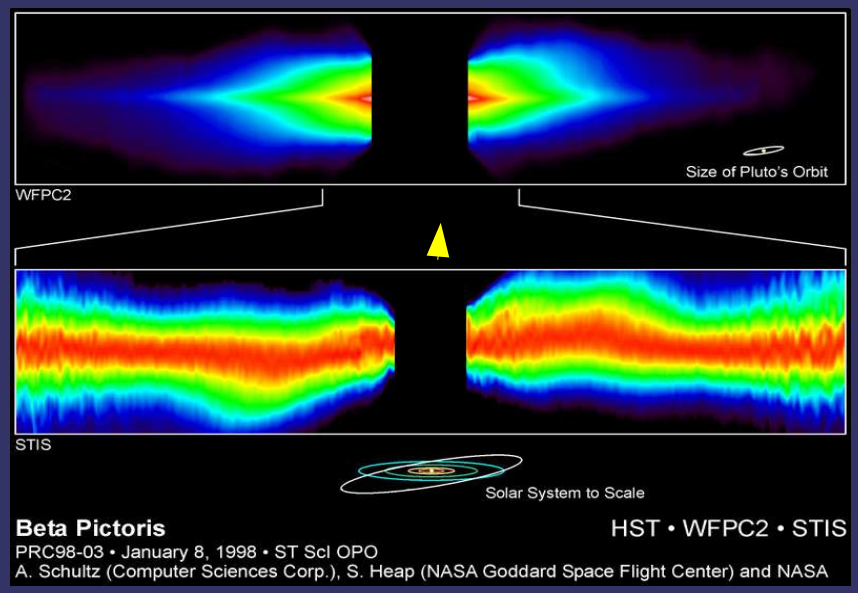


evolution?



→ *migration rates are still inconsistent with the many giant planets detected so far*

→ planetesimal disk - planet:



→ planet- planet:
- eccentricity?

→ *interactions seem to play a key role in the formation of planets!*

Planet formation: Very Important Planets

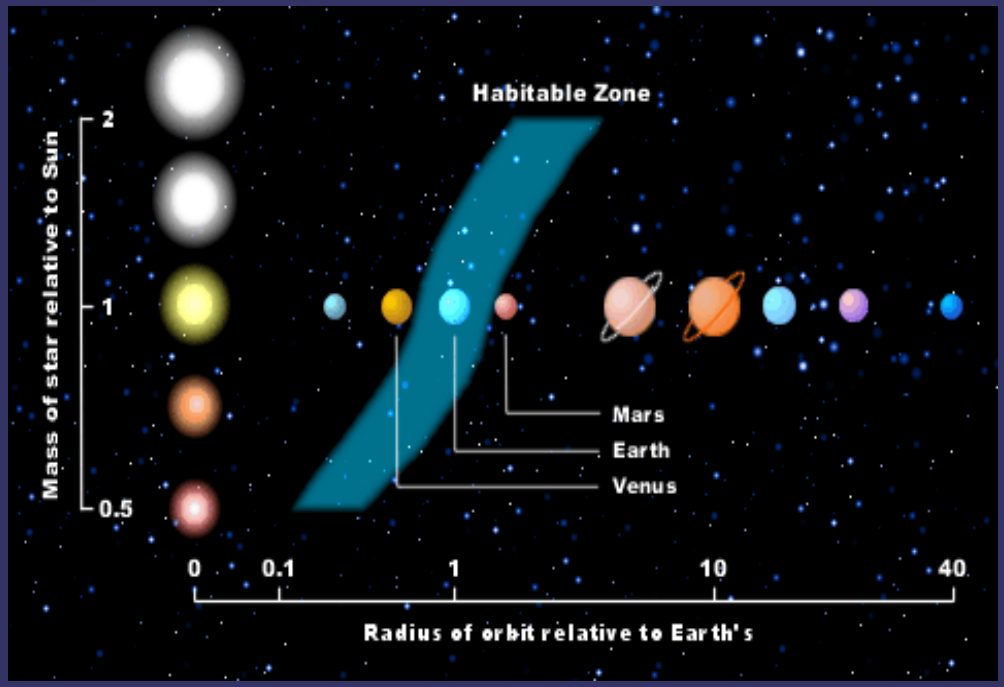
how many planets are suitable for the emergence of life?
Habitable Zone (HZ)

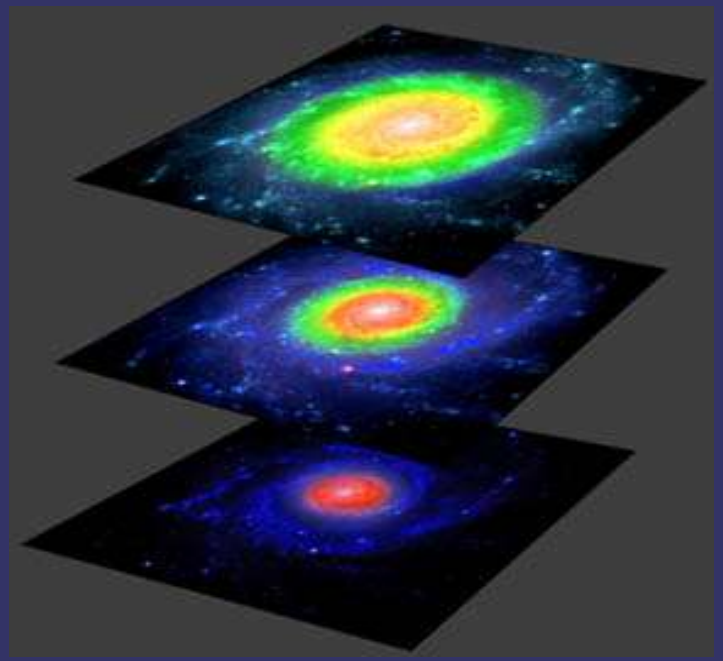
stellar constraints:

- rocky bodies capable of generating and sustaining an atmosphere
  → $0.5\ R_{earth} < R < 2.2\ R_{earth}$
- temperature compatible with liquid water
  → $0 < T < 100$ C

galactic constraints:

- enough heavy elements
- low supernova rate
- no stellar close encounters



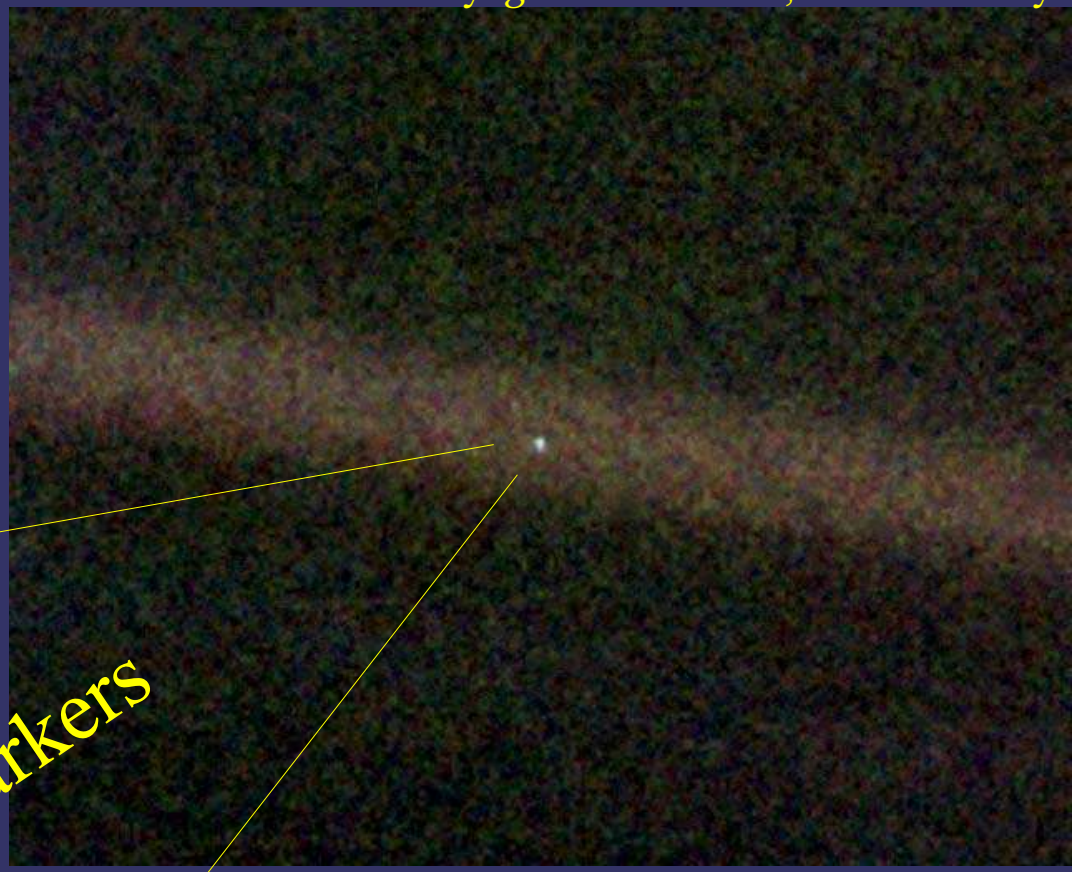


Lineweaver 2004

HZ is also a function of time!

spectroscopic detection of life

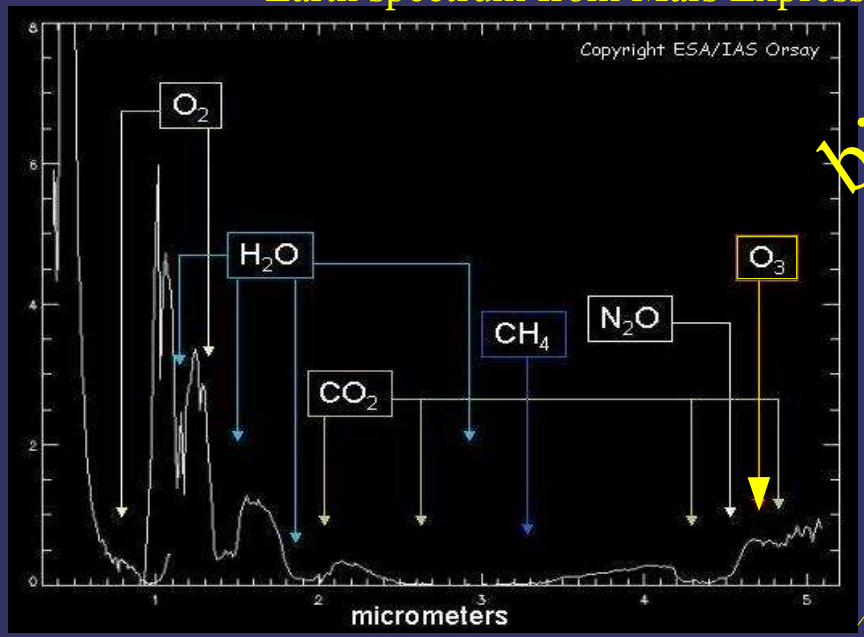
Earth from Voyager 1 on 14.2.90, 42.6 AU away



tasks:

1) image planet
2) take spectrum

Earth spectrum from Mars Express



biomarkers

→ *but not so easy...*

Conclusions

→ ***the search for life must be a global approach in which the path to get there is as important as the final result!***

young systems

- stars and circumstellar disks
- planets in disks

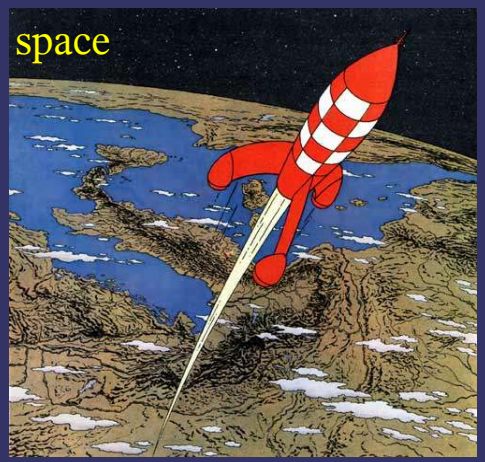
old systems

- detection of earth-sized planets
- imaging of medium and giant planets
- case study: the solar system
- the actual search for life

- hazards to life

all ages

space



ground

→ ***progress hinges on a coherent build-up of knowledge,***

Astronomy/astrophysics and the search for life

1) explore, characterize and explain the diversity amongst existing systems (including the solar system)

2) help define unambiguous markers that allow the detection of life

3) design and build the appropriate tools for detection

→ requires a mixture of:

- development of space missions and large observing facilities
- understanding of the earth: origins and limits of life, climate history, space environment, etc.
- understanding of the underlying physics, chemistry and biology

→ ***multi-disciplinary***