Other Worlds and Life Elsewhere

Placing the Solar System in Context

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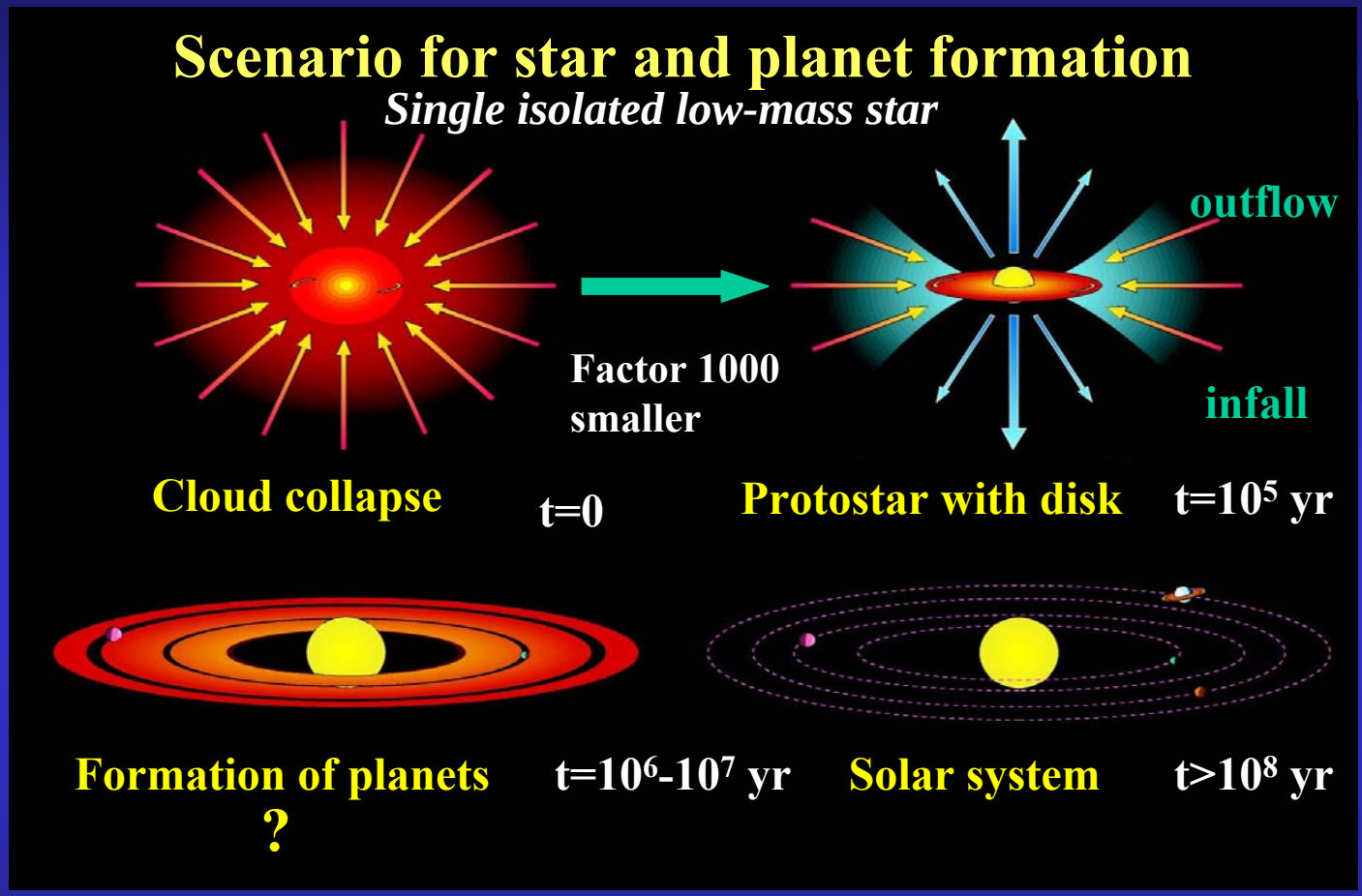
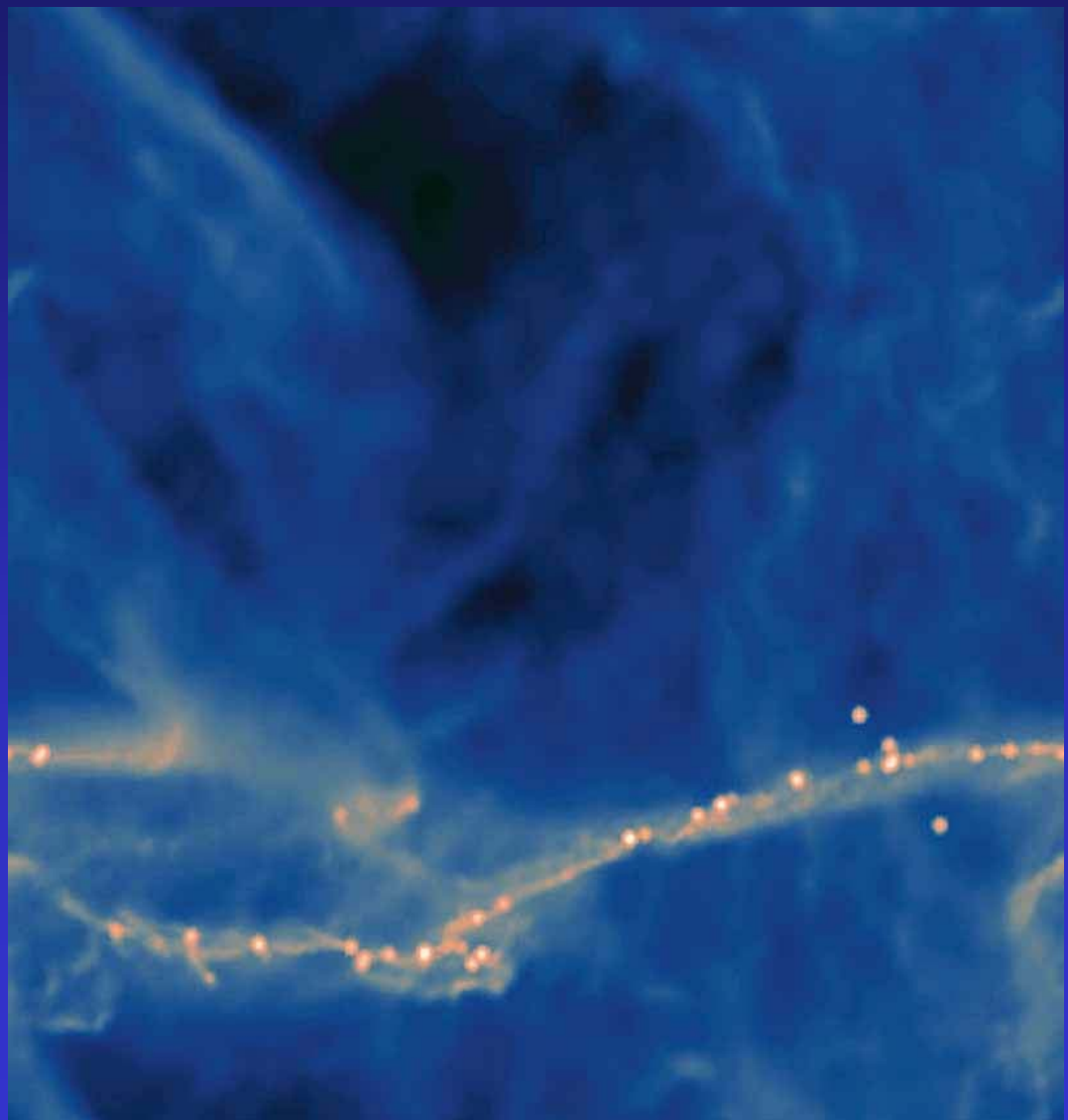
How do stars and planetary systems form?



- Formation of planetary systems – Necessary consequence of the birth process of solar-type stars or lucky coincidence
- Star formation – Near and far (IMF(environment, z))

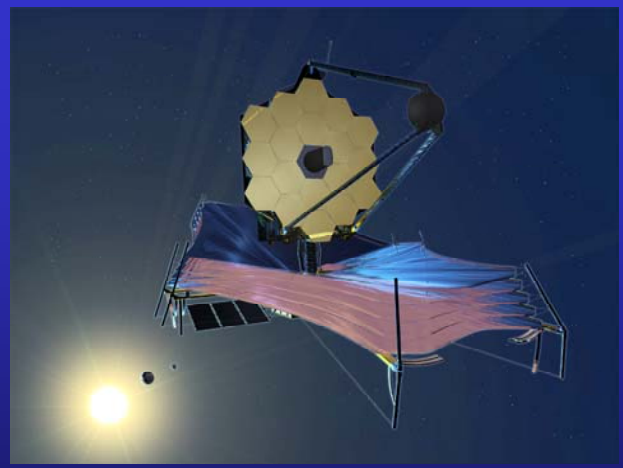
Great Debate I
"Turbulent" or magnetically controlled star formation



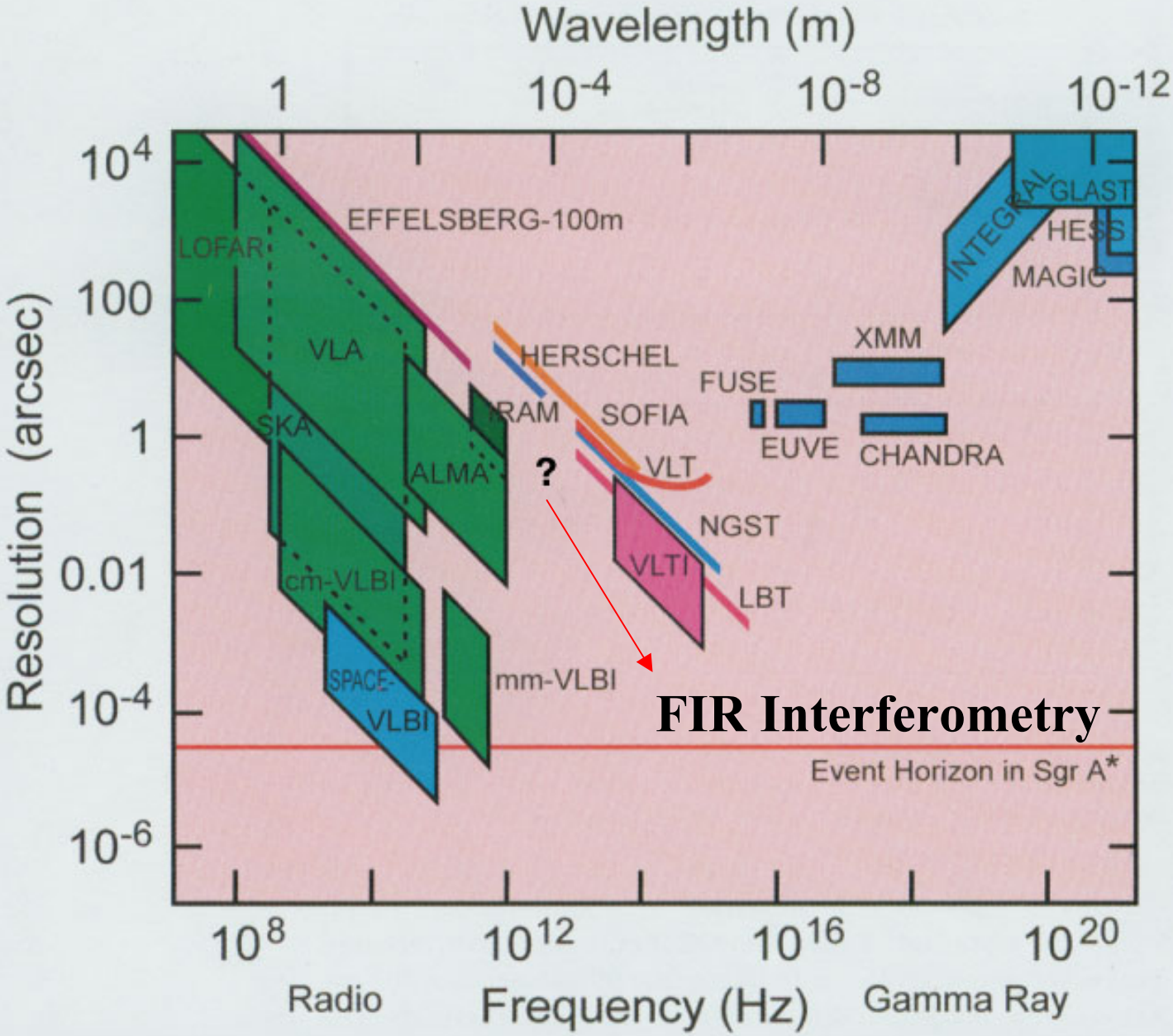
Observational requirements

- High-resolution molecular line spectroscopy (chemical and dynamical evolution: H_2O, HD, light hydrides, OH, H_3O^+, CH^+, ...)
- FIR/Submm polarimetric studies with high spatial resolution (B field)
- Sensitive continuum surveys (IMF, substellar objects)

The road map

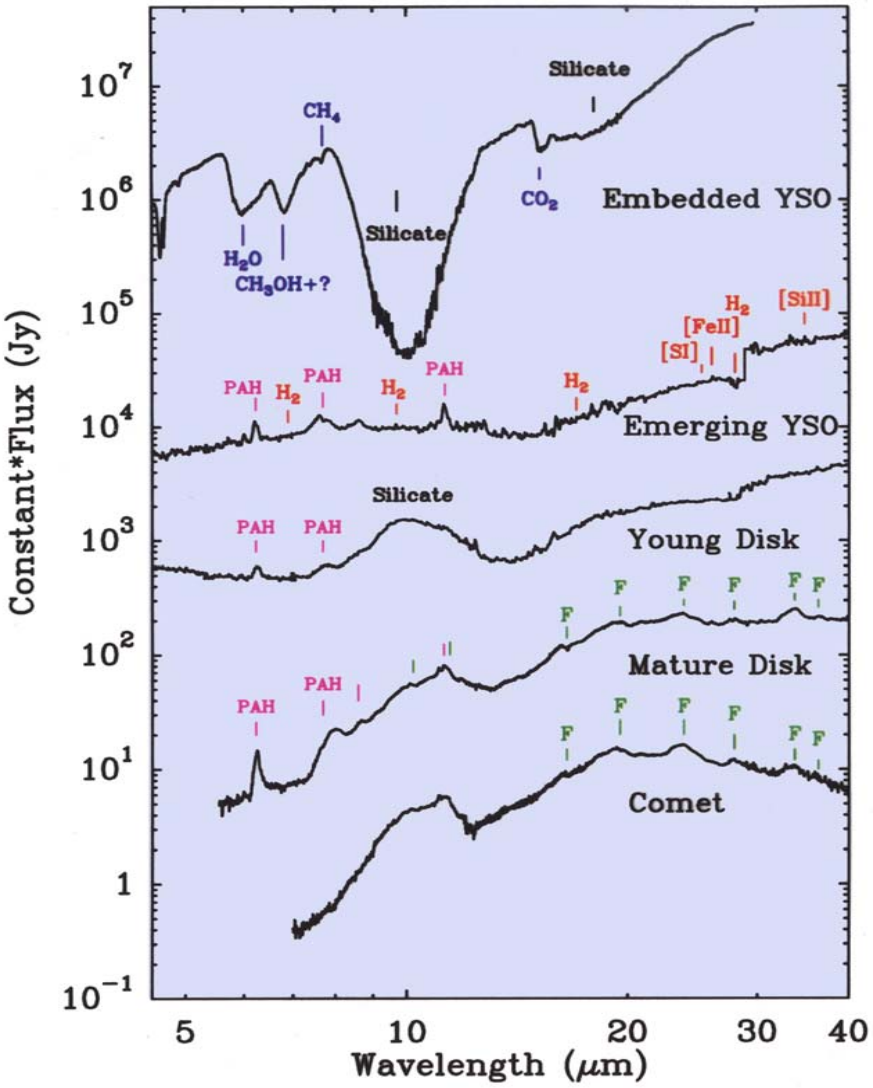


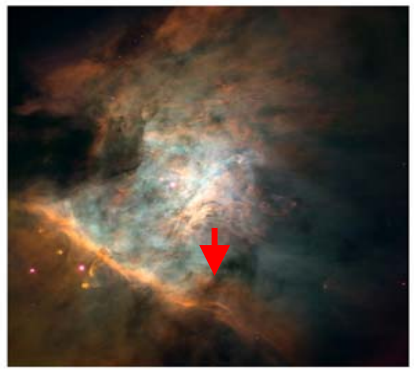
ISO → Herschel → JWST → FIR interferometry

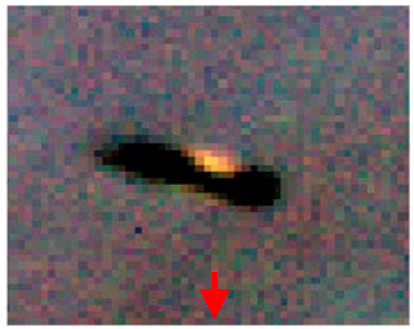

Wavelength (m)
1
10-4
10-8
10-12
Resolution (arcsec)
10^4
100
1
0.01
10-4
10-6
EFFELSBERG-100m
LOFAR
VLA
SKA
ALMA
cm-VLBI
SPACE-VLBI
mm-VLBI
?
HERSCHEL
SOFIA
VLT
NGST
VLTI
LBT
FUSE
EUVE
XMM
CHANDRA
INTEGRAL
GLAST
HESS
MAGIC
Event Horizon in Sgr A*
FIR Interferometry
10^8
10^12
10^16
10^20
Radio
Frequency (Hz)
Gamma Ray

From protoplanetary disks to planets

Understand birthplaces and their evolution







Great Debate II
Core Accretion vs. Gravitational Instability

Great Debate III
Origin of Water (Asteroids or Shift of Snow line)

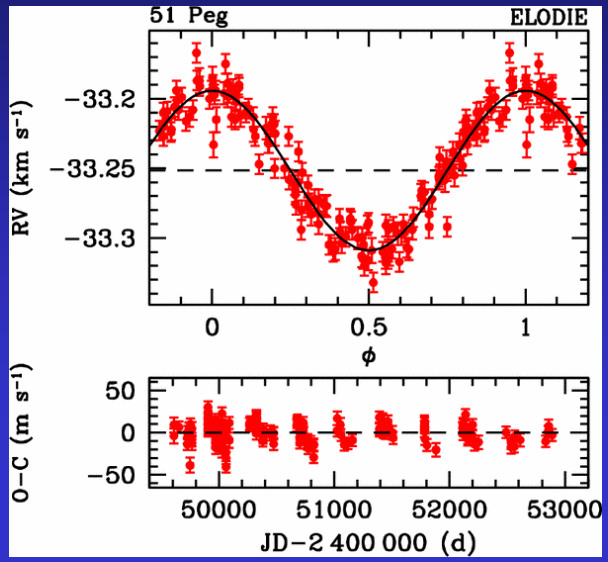
Observational requirements

- **Imaging with very high angular resolution, sensitivity, and dynamic range (e.g. 10mas → 1 AU at 100pc)**
- **Molecular line spectroscopy with high sensitivity and spectral res. (~ 10^5) plus dust spectroscopy with medium resolution**

The Road Map

ISO → Herschel → JWST → FIR interferometry

From detection of giant extrasolar planets to imaging of exo-planets and the search for biomarkers



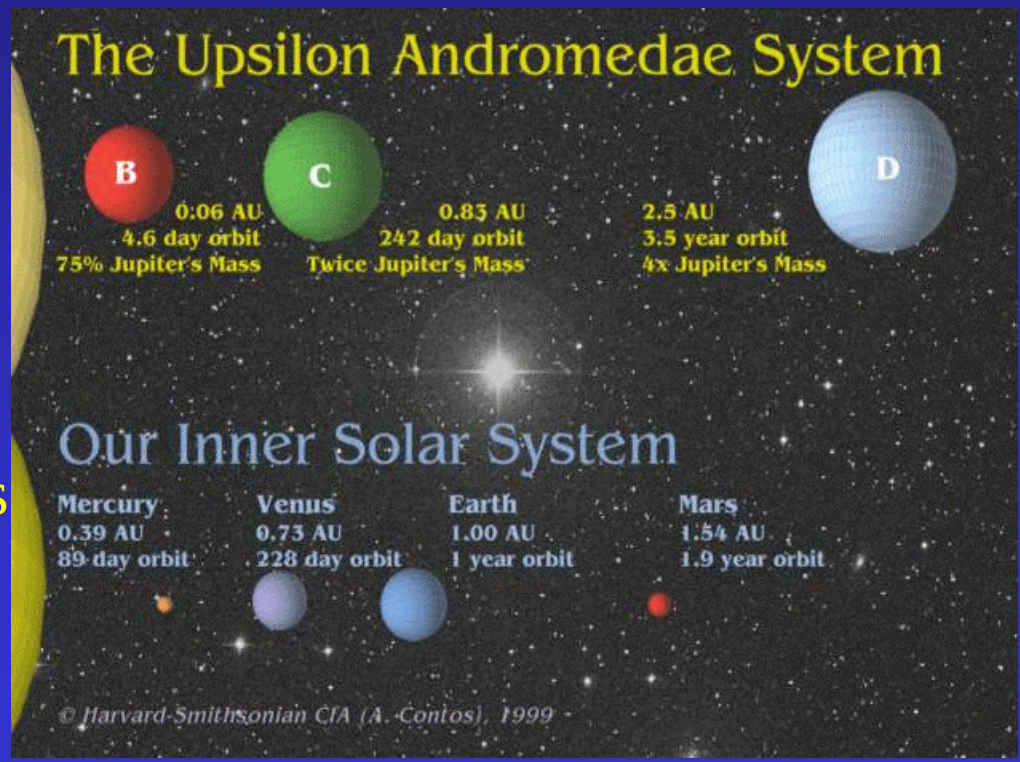
Apollo 11

- Pulsar timing ✓ (3)
- RV techniques ✓ (>100, including Uranus- and Neptun-mass planets)
- Transits ✓ (4)
- Microlensing ✓ (1)
- Astrometry -- (HST observation of Gl 876)
- Direct detection -- (atmosphere of HD 209458b)

Complementarity between ground-based facilities and space projects

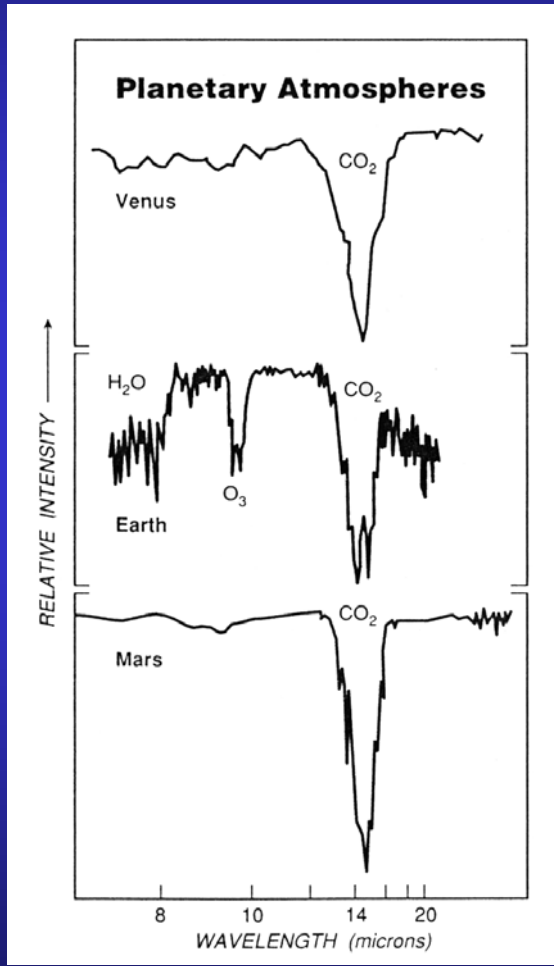
The Questions

- Frequency of Earth-size rocky planets
- Planetary systems' final properties determined by formation or evolution?
- What are the architectures of planetary systems?
- Environmental effects
- Physical properties of planets
- Evidence for Life/Evolution of Life

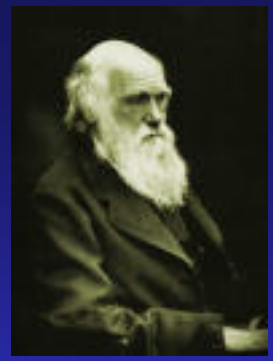


Detection and characterization of extrasolar planets
The road map

- Are there other terrestrial planets?
  (Corot, Eddington, Kepler)
- First statistical census of extrasolar giant planets
  (GAIA, SIM)
- Direct detection plus spectroscopy of terrestrial planets – search for biomarkers
  (Darwin)
- Complete census of terrestrial planets within 100 pc using high-precision astrometry
  (Super-GAIA; 10 nano-arcseconds accuracy at 12 mag)
- Direct detection with larger telescopes and high-resolution spectroscopy (IR and UV)
- Imaging exo-planets (long-term goal)

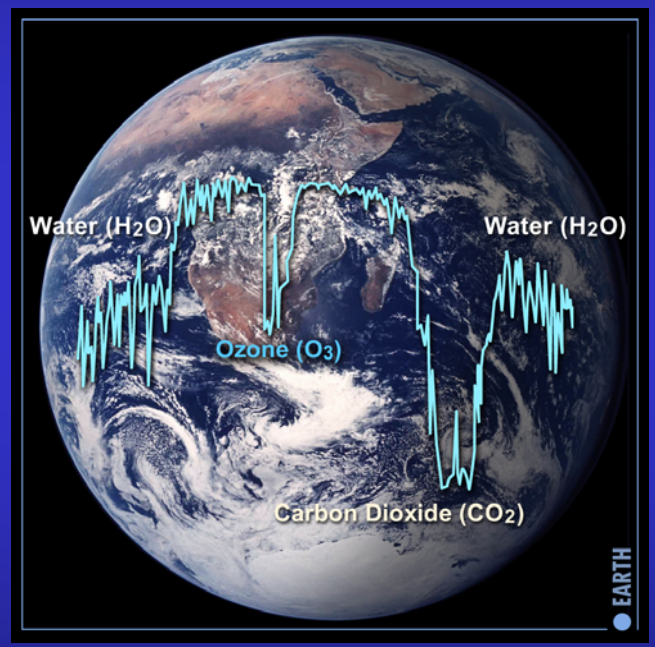


The Search for the „Origin of Species“



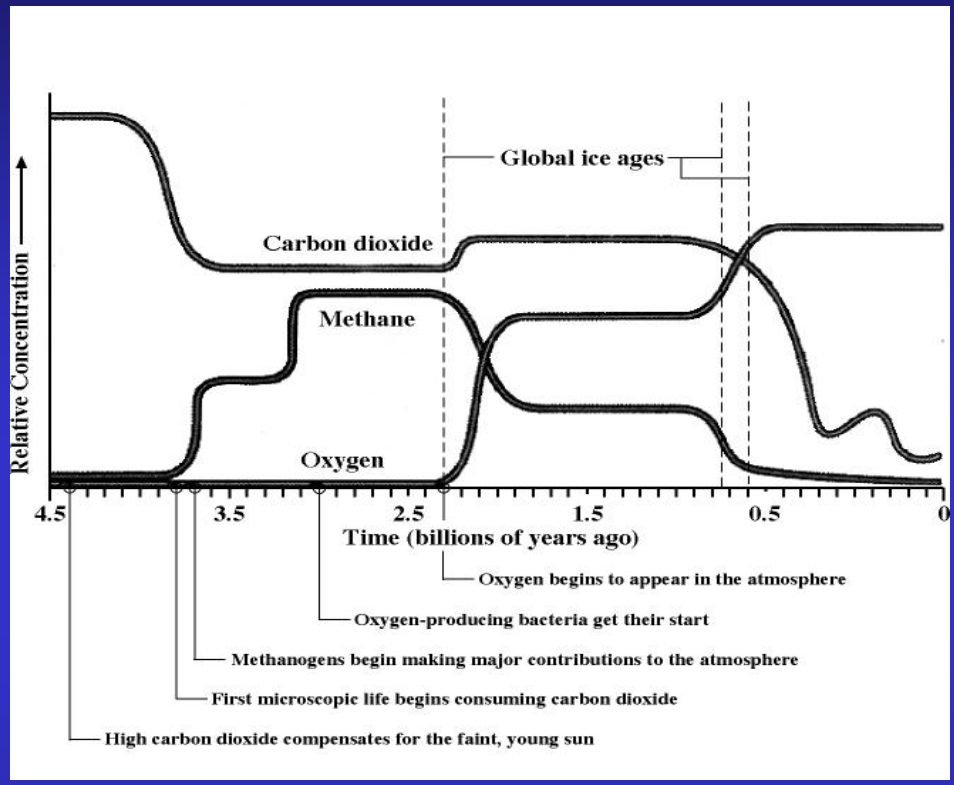
Requirements:

- **High stellar light rejection ratio (10^5-10^6) and sensitivity for detecting light from Exo-Earths (nulling interferometry)**
- **Mid-infrared wavelength range (6 to 18 microns) for detecting evidence for life (ozone, carbon dioxide, water, methane)**



Do not forget …

- Strong complementarity between ground-based facilities and space
- Keep technology balance between "more glass" and "more spatial/ spectral" resolution
- Strong preparatory programme needed and presently realized (technology, target characterization, theory)
- Detection of a variety of biomarkers will revolutionize our view of what "(exo) life" is and how it evolves – Exobiology becomes reality



Kasting (2004)

- Multidisciplinary approach (Astronomy, Biogeochemistry, Planetary Sciences …)

Large impact on the public – Completing the Copernican Revolution

EUROPE IS STRONG IN THIS FIELD
LET US KEEP OUR LEADERSHIP

So many worlds, so little time!

ESA Press Release (~ 2017):

We report evidence for biological activity on another Earth .....