Darwin

...and why it was the right project in 1996....

But maybe not the right one now

At the dawn of time

- In 1996....
- It was decided (by a number of committees related to ESA and NASA) that the time was rapidly approaching when we would be able to search for life elsewhere....
- ....and it would have to be from Space

At the dawn of time

- But it was not taken 100% serious at the beginning, so the job was given to one of the most junior of the staff scientists
- me
- ....and it would be a life and career changer for me
- ....and to the agencies which would never be the same

Darwin

- Darwin is one of the most challenging space projects ever considered by the European Space Agency.
- Its principal objectives were:
  - to detect Earth-like planets around nearby stars,
  - to analyze the composition of any atmospheres
  - to assess their ability to sustain life as we know it
  - To search for “biomarkers”
- The Darwin mission was conceived as a nulling interferometer operating in L2 which makes use of on-axis destructive interferences to extinguish the stellar light while keeping the off-axis signal of the orbiting planet.

Darwin

- Objectives of Darwin:
- 1. To find exoplanets! (in 1996 only two had been identified and many doubted this result)
- 2. To find 1 M_{Earth}, 1 R_{earth}, located 1AU from a G2V star
- 3. To detect, spectroscopically, any possible atmospheres around any detected bodies
- 4. To detect, measure any “biomarkers” in these atmospheres

What did Darwin have to do with SETI?

- ....Nothing and....
- everything
- Darwin was defined as the search for life in the Universe – any life
- Darwin´s origins were in studies from the 80:ties showing that there may be passive signatures of biological activity that could be studied at interstellar distances

A brief history of life

- All life on Earth is probably related and goes back to a “first cell” ~ 4 Gyrs ago
- The oldest fossils are probably (the stromatolites) simple one-cellular with no nucleus (~ 3.5 Gyr). Procaryotes
- 2 Gyrs cells with a nucleus evolved. Eucaryotes, producing Oxygen
- Multicellular life are known from 650 – 542 Myrs ago. The first signs are fossilised tracks of wormlike life
- 542 Myr Cambrian explosion (The Burgess shale)
- Organisms with shells and (exo-)skeletons appear
- First Vertebrates (488-416 Myr ago Ordovicium), Jawless fish

A brief history of life

- First plants on land not later than 444-416 Myr ago (Silur)
- First frogs 416-359 Myr ago (Devon)
- First mammals 251-200 Myr ago (Trias)
- First primates (end of Cretaceus) 66 Myr ago
- Separating from our cousins (Chimpanzees) 7-6 Myr ago
- Homo Erectus ~ 1 Myr – 143Kyr ago
- Homo Heidelbergiensis (the brightest of the lot), Neanderthalensis, Denisovans 800Kyr – 40 Kyr
- Homo Sapiens 200 Kyr - .....
- Radio 140 yrs, Lasers 55 yrs

What did Darwin have to do with SETI?

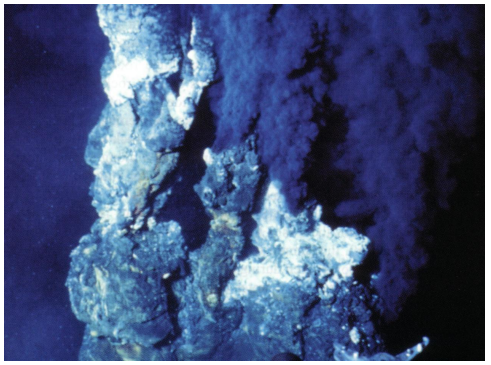
- Sot Darwin should not looking for *intelligent* life!
- The Darwin science team recognized that life has exist on Earth > 3.5 Gyr
- Multicellular, complex life > 500 Myrs
- Hominids for > 6 Myrs
- *Intelligent* life > 1 Myrs
- And intelligent life that can build starships and transmit signals that will reach the stars < 100 yrs
- ➔ ***Darwin would have to look for all of the above!***

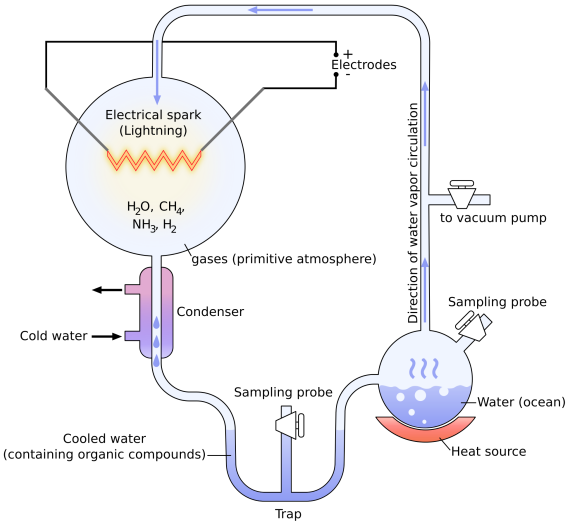
What did Darwin have to do with SETI?

- ....Suggestions by among others Ron Bracewell, Roger Angel, Nick Wolfe, Toby Owen, Bernie Burke....
- Telescope design, spectroscopic biomarkers, etc was identified....
- Based on this work, Legér and co workersin France proposed a study of an interferometric telescope sensitive enough to detect the oxygen, water and CO_2 in Earth´s atmosphere at a minimum of 10pc
- ESA picked this up – maybe for historical reasons
- Since ESA had generated workshops and technical studies (e.g. The SIST,The Lunar study, LIST) since early 80:ties

Darwin was also going to search for life because we want to understand ourselves

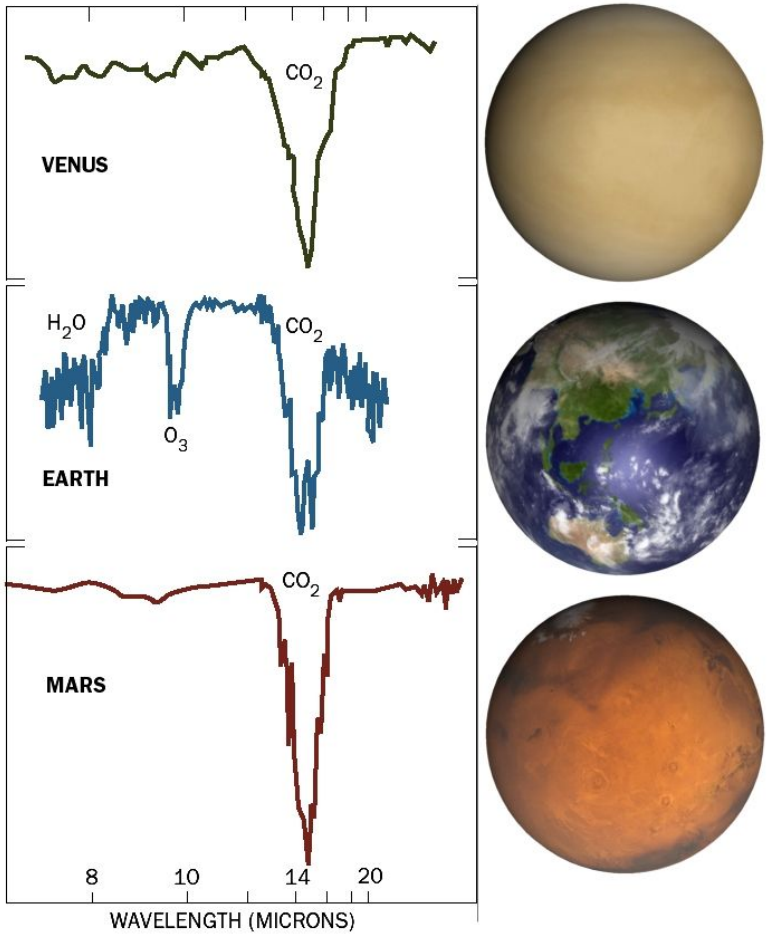
- We don´t know when and how life arose on Earth
- So, how fast did life arise on the Earth? (10^7 → 10^8 → few x 10^8 years?)
- If origin of life is a simple process – Maybe it happened several times on the Earth?
- Are there governing principles for the origin of life– on the Earth, in the Solar System and in the Universe?
- If simple unicellular life formed quickly and multi-cellular complex life takes longer (Cambrian explosion took place 3-3.5 x 10^9 yrs after origin of first life) - What does this imply?

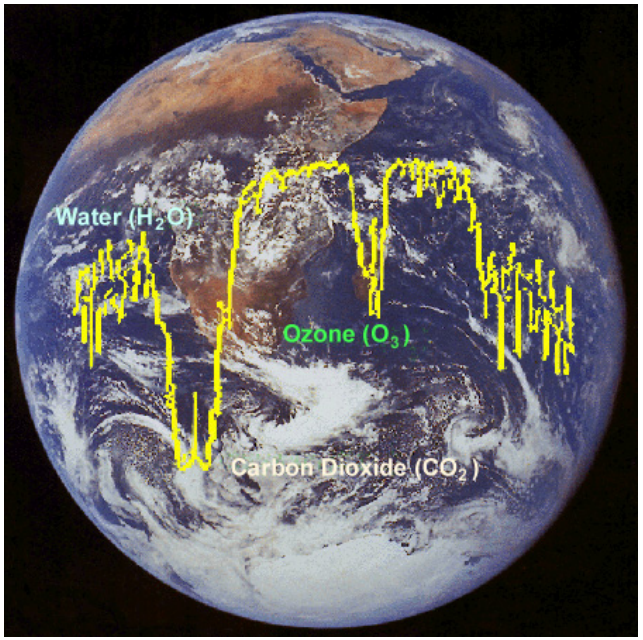




It looks like we can not answer these questions on the Earth – so we need to look elsewhere and make chronologies of life

Darwin Bio markers





The goal is to find rocky planets with an atmosphere out of photo-chemical balance.

(cf. Lederberg, 1965 and Lovelock, 1965)

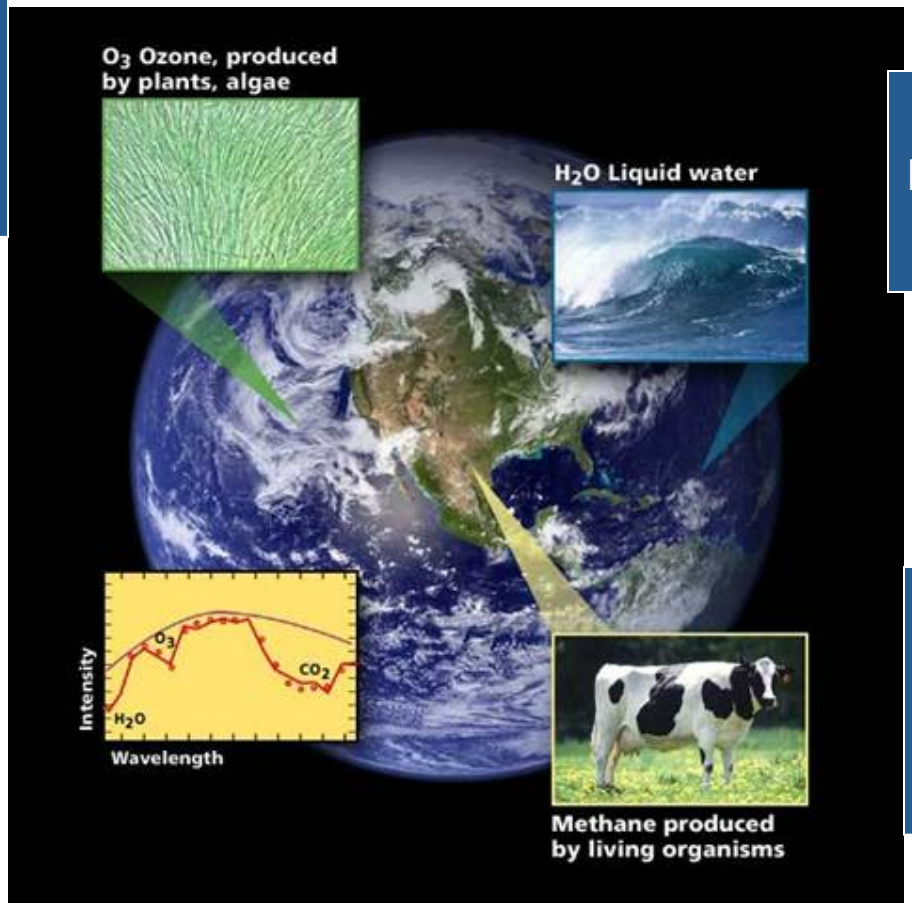
Working definition:

Life ≡ O_3 + H_2O + CO_2

Ideally, detect reduced molecules (CH_4, N_2O) as well

The Darwin plan simplified

For each planet found, analyze the reflected light from the planet to see if the planet has an atmosphere



Look for liquid water

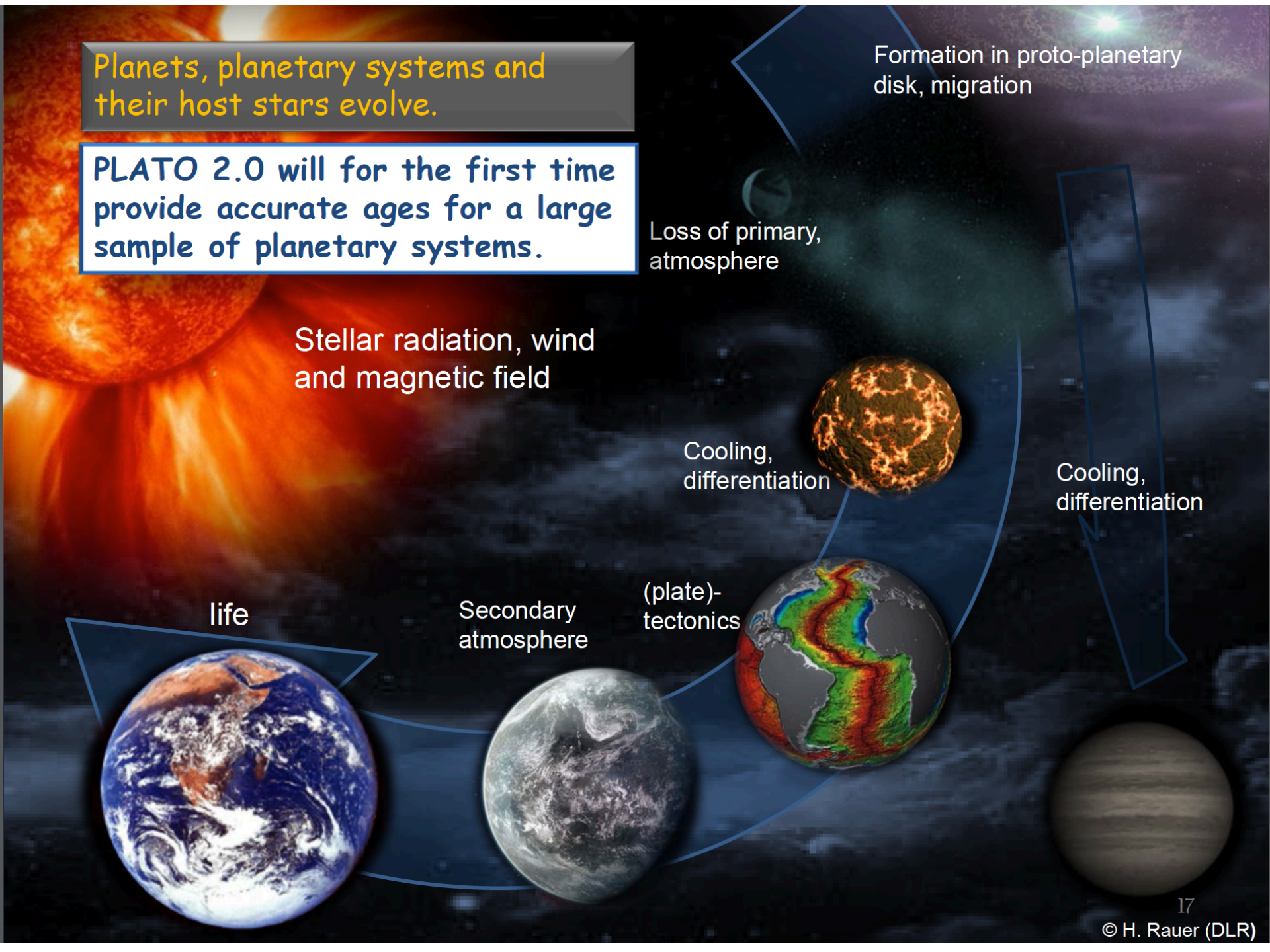
Look for oxygen

Look for other signs of biological activity (methane)

and rule out all other explanations.

Planets, planetary systems and their host stars evolve.

PLATO 2.0 will for the first time provide accurate ages for a large sample of planetary systems.



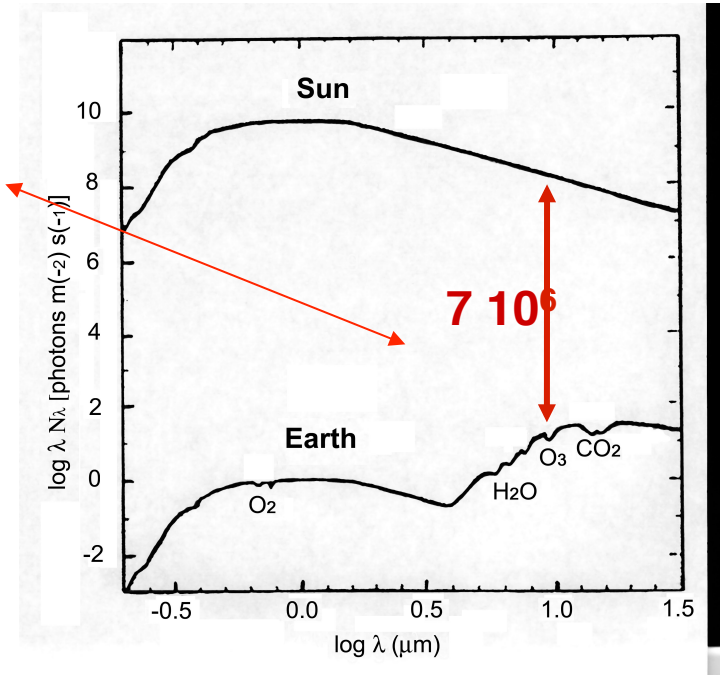
Direct detection of nearby Earth analogues

Three major difficulties:

1. **Contrast: 10^7 in the infrared for a Sun-Earth system; > 10^9 in the visual**
2. **Angular Separation: 0.1 arcsec for a Sun-Earth system at 10pc**
3. **Spectrum: 1 photon m^{-2} μ^{-1} s^{-1}**

We can also see why the Infrared has advantages

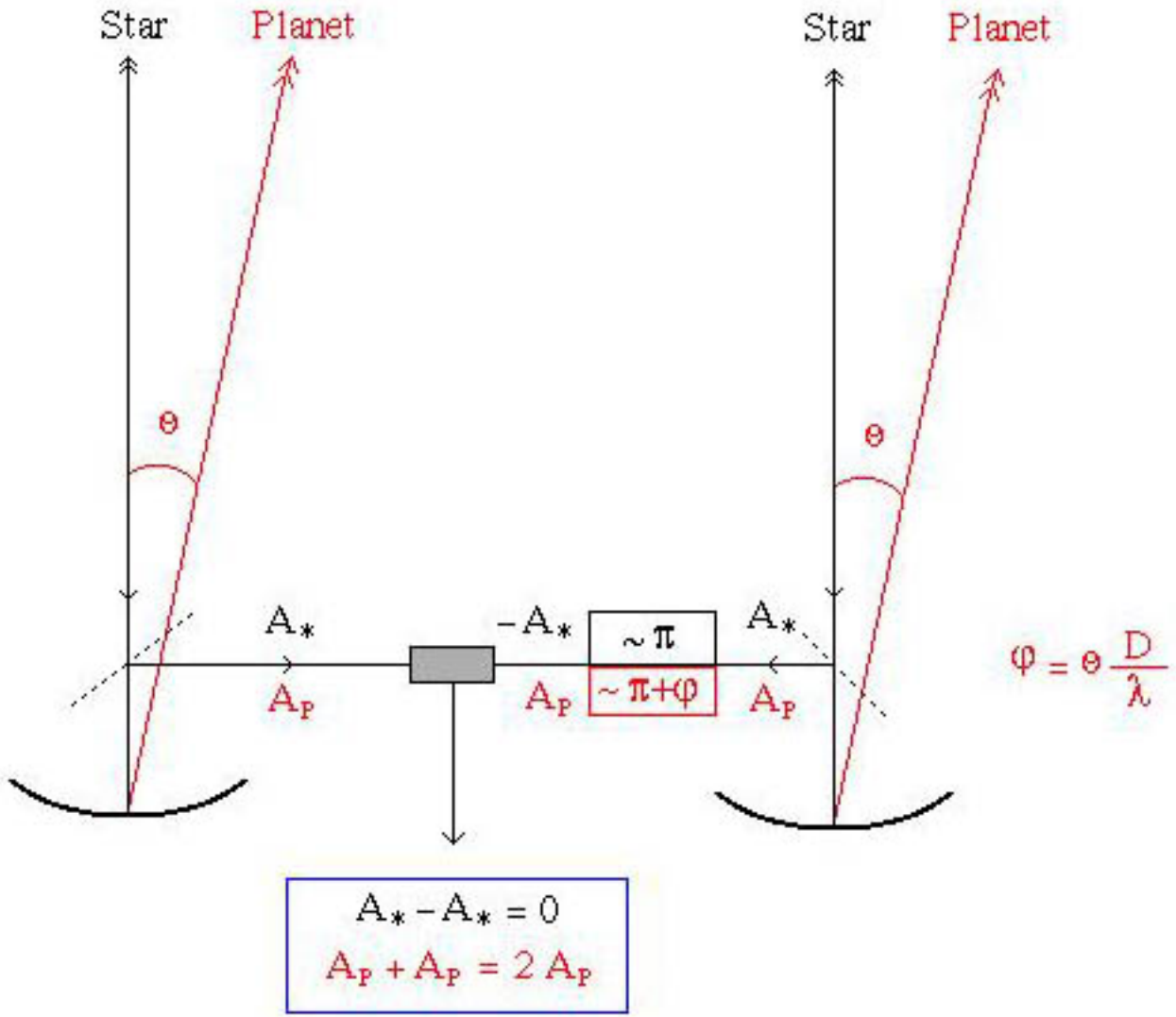
Dynamic range and resolution



The star is billions times brighter…


… than the planet
… hiding in the glare…

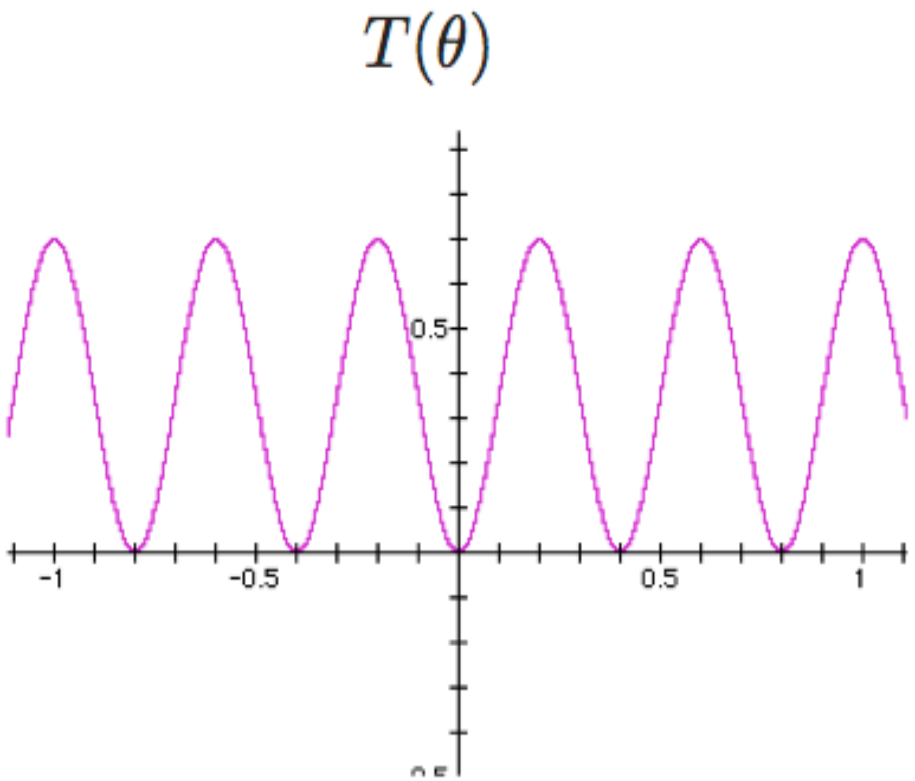

Find the ‘firefly’….


Star
Planet
Star
Planet
θ
θ
A*
A_P
−A*
~π
A_P
~π+φ
A*
A_P
φ = θ D/λ
A* − A* = 0
A_P + A_P = 2 A_P

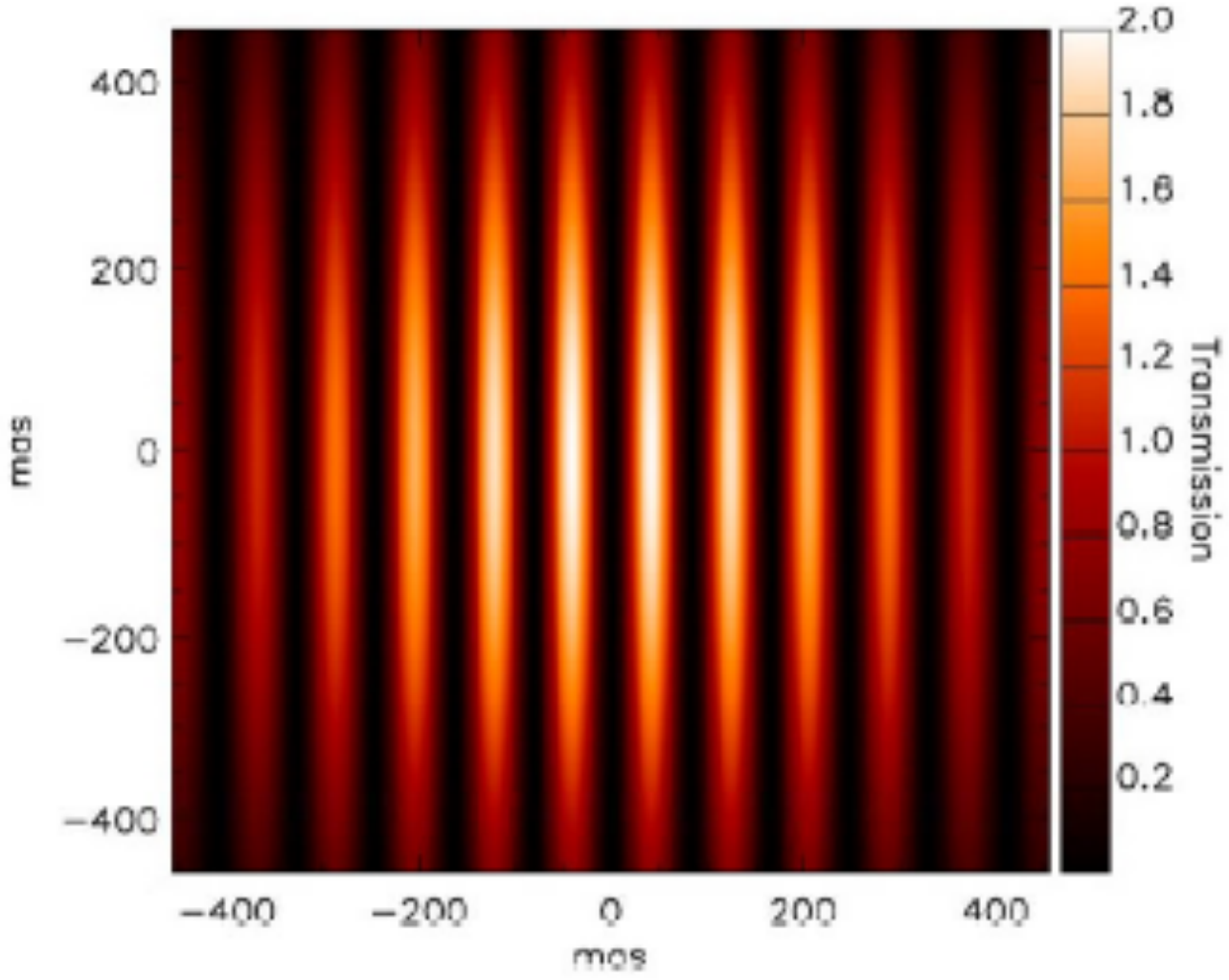
Transmission for monochromatic light

$$T(\theta) = \sin^2 \frac{\pi \theta d}{\lambda}$$

where d is the separation between the telescope mirrors



θ (arcsec) $\rightarrow$
(parallel to baseline)


400
200
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mas
−400
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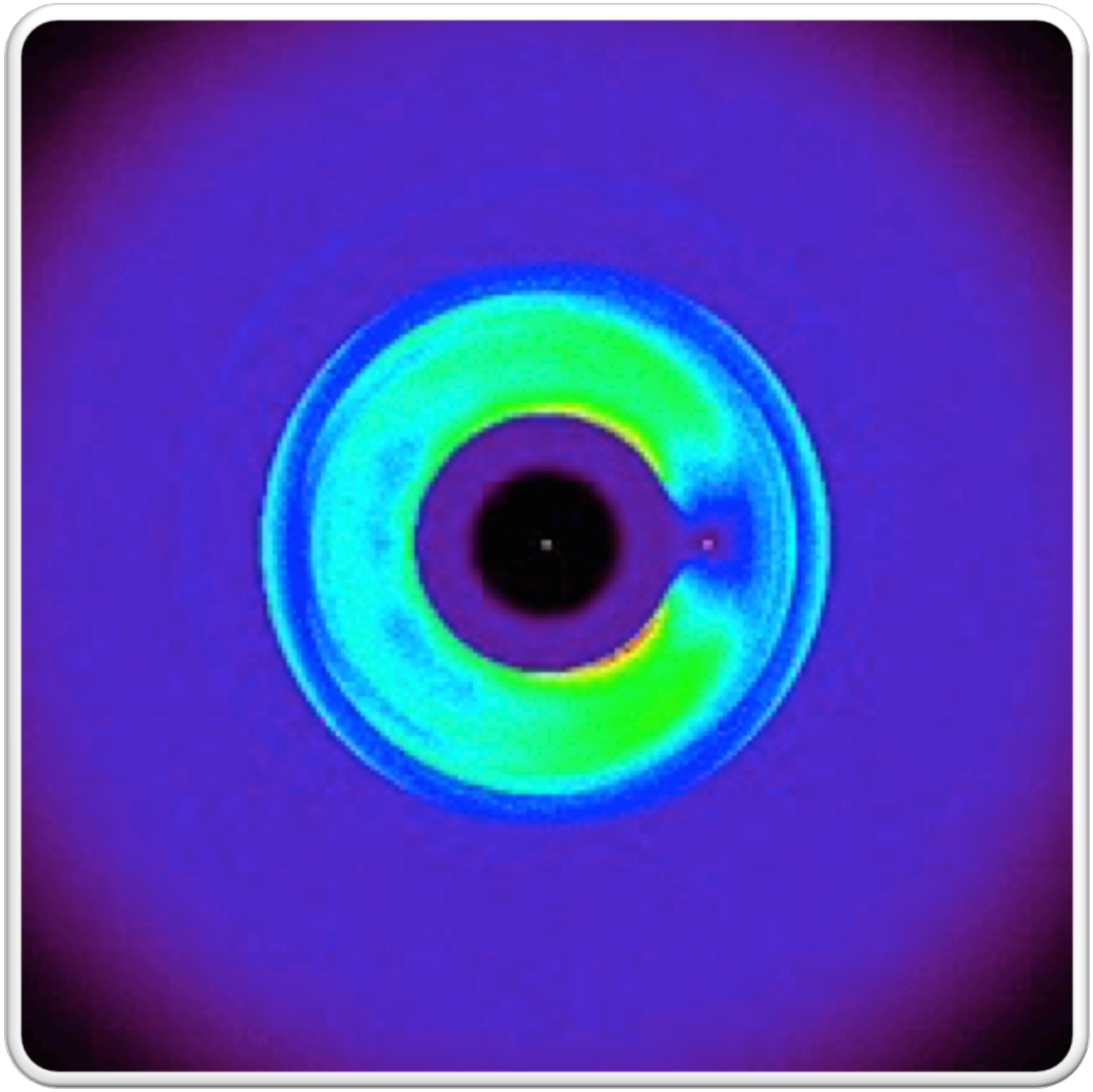
0
200
400
mas
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
Transmission



Pattern of interferometer with 3 or 4 telescopes after one rotation

DARWIN

Science Across Disciplines

A Proposal for the Cosmic Vision 2015-2025 ESA Plan

So why is Darwin not flying?

- There was a lot of new technology
  - Free flying large satellites with cm precision
  - Achromatic phase shifters, etc
- Not the problem
- Collaboration with NASA required
  - Worked fine for 8 years then they jumped off because of JWST
- Cost
  - Not a problem in the beginning (1 ½ Cornerstone)
  - Did not scare anyone
  - Then JWST went from 1M$ to 9M$
- *And that did it*
- In 2007 NASA closed down the collaboration
- ➔ ***And Darwin was put on hold***

Should it be resurrected?

- A lot has happened
- We now have > 4000 exoplanetary candidates
- Essentially not a single system that look like ours
- Could that be due to biases? Yes it could but the point is that the obvious (i.e. Brightest) targets have been observed and are out of the question
- ➔ *So the scientific driver of Darwin is out*
- We need to address different systems than trying for a 1 M_{Earth}, 1 R_{earth}, located 1AU from a G2V star

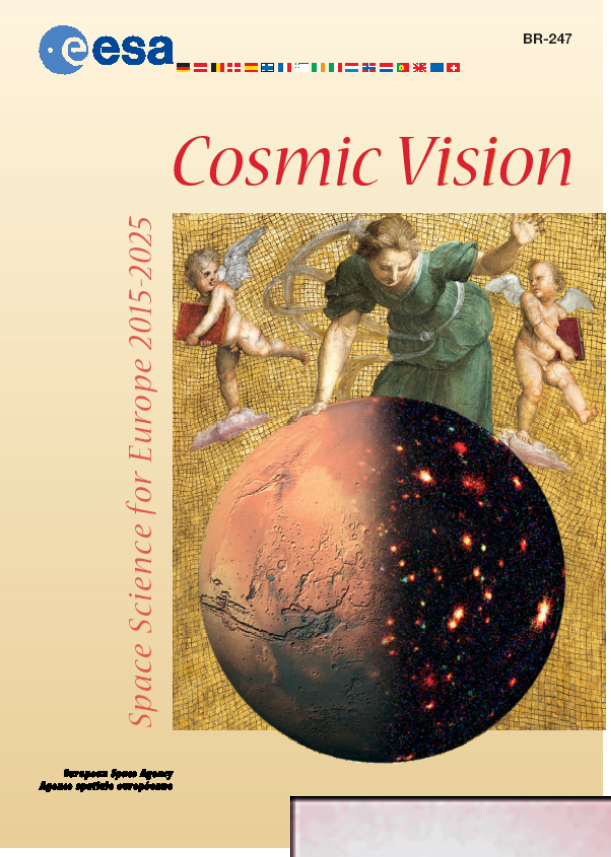
- ➔ But is Darwin the right thing for a 5M_{Earth}, 1.6R_{earth}, located 0.15AU from a M2V star – a red dwarf?
- ***Well, Superman comes from Krypton orbiting GJ3707 so it surely looks like it***

Should it be resurrected?

- But the point is that we need to know more about the planets out there
- Distribution, geology, even atmospheres can actually be characterised with the space missions TESS, CHEOPS, JWST and PLATO
- And then and only then we can start again on something like Darwin
- ....and it is in the ESA Cosmic Vision plan

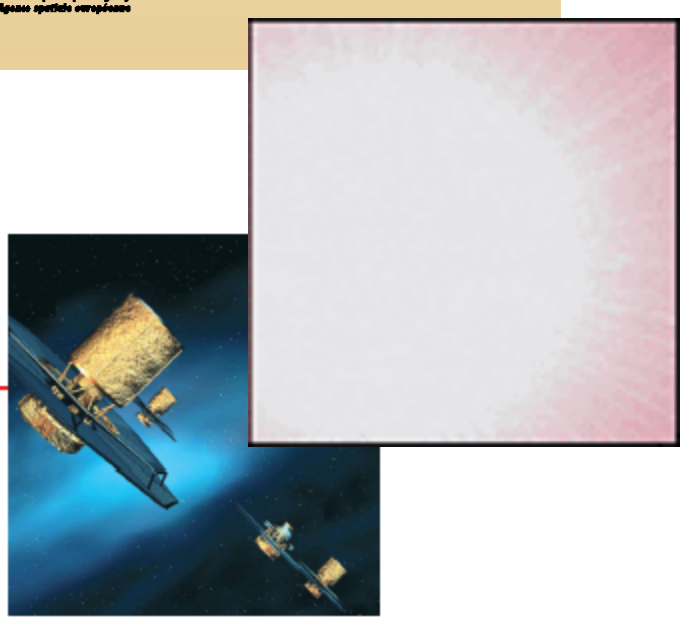
Conclusion

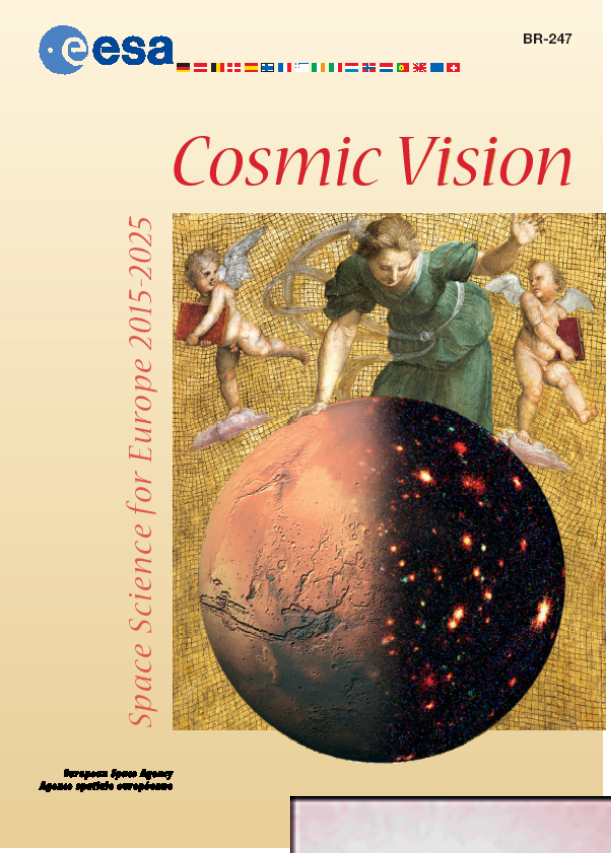
- The Darwin study showed that there is no fundamental “show stopper” in a nulling interferometer
- Parallell studies of coronographic space telescopes show they are also viable
- But they can not observe the same targets
- So we need to know clearly waht targets are we going after



Cosmic Vision is centered around four Grand Themes:

1. **What are the conditions for planet formation and the emergence of life?**
   - **From gas and dust to stars and planets**
   - **From exo-planets to biomarkers**
   - **Life and habitability in the Solar System**
2. **How does the Solar system work?**
3. **What are the Fundamental Physical Laws of the Universe?**
4. **How did the Universe originate and what is it made of?**





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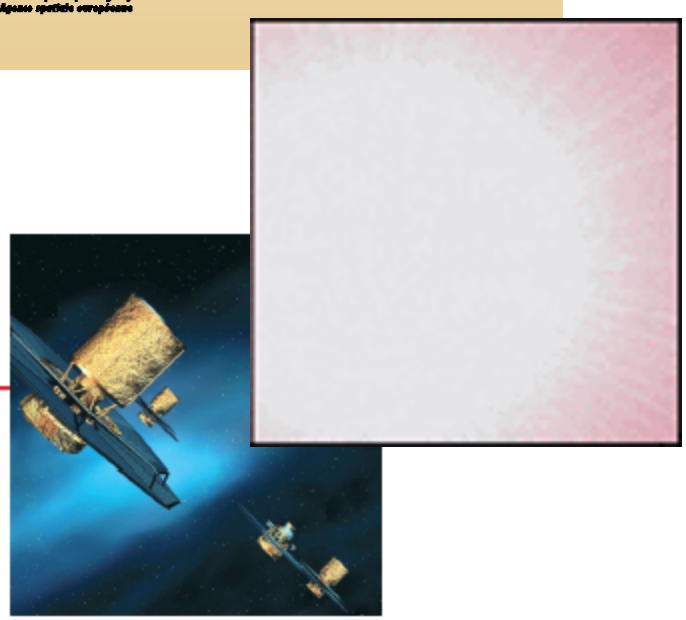

First: *In-depth analysis of terrestrial planets.*
Next: *Understanding the conditions for star & planet formation, and the origin of life.*
Later: *Census of Earth-sized planets, exploration of Jupiter's moon Europa.*
Finally: *Image terrestrial exoplanet.*